second recrystallization from the same solvent raised the m.p. to 168–169°; λ_{max} at *p*H of 1, 254 mμ. *Anal.* Calcd. for $C_7H_8N_4O$: C, 51.2; H, 4.9. Found: C, 50.9; H, 4.9.

Preparation of 6-Methylmercaptopyrazolo(3,4-*d*)pyrimidine (IV).—To 150 ml. of ethanol was added 10 ml. of concentrated ammonium hydroxide, 7.0 g. of 4-chloro-6-methylmercaptopyrazolo(3,4-*d*)pyrimidine (VIII) and 2.7 g. of 10% palladium-on-carbon. The solution was shaken on the low pressure hydrogenator at a hydrogen pressure of 20 lb./sq. in. for 24 hours, after which time the uptake of hydrogen had ceased. The solution was filtered and the filtrate evaporated to dryness on the steam-bath. The residue was recrystallized from an 80% ethanol–water mixture to yield 1.7 g. of white crystals, m.p. 201–204°. A second recrystallization from the same solvent raised the m.p. to 210–212°; λ_{max} at *p*H of 1, 240 and 300 mμ. *Anal.* Calcd. for $C_6H_6N_4S$: C, 43.4; H, 3.6; N, 33.7. Found: C, 43.0; H, 3.5; N, 33.1.

Preparation of 4-Methoxy-6-methylmercaptopyrazolo(3,4-*d*)pyrimidine.—To a solution of 1.0 g. of sodium in 75 ml. of absolute methanol was added 4.0 g. of 4-chloro-6-methylmercaptopyrazolo(3,4-*d*)pyrimidine (VIII). The solution was heated for four hours on the steam-bath and then neutralized with glacial acetic acid. The cooled solution yielded 3.1 g. of white needles, m.p. 190–192°. Recrystallization from a methanol and water mixture raised the m.p. to 193–194°; λ_{max} at *p*H of 1, 240 and 282 mμ. *Anal.* Calcd. for $C_7H_8N_4OS$: C, 42.9; H, 4.1; N, 28.6. Found: C, 43.0; H, 3.9; N, 29.0.

Preparation of 4-Substituted-aminopyrazolo(3,4-*d*)pyrimidines (XVI) (see Table I). General Method 1.—Five to ten grams of 4-chloropyrazolo(3,4-*d*)pyrimidine (XV) was added to 50 to 100 ml. of a 25–40% aqueous solution of the primary or secondary amine. The solution was heated for four hours on the steam-bath and then allowed to cool in the refrigerator overnight. The filtered precipitate was then washed with a little ice-water, dried and recrystallized from the solvent indicated.

General Method 2.—Five to ten grams of XV was added to approximately 0.15 mole of primary or secondary amine dissolved in 150 ml. of absolute ethanol. The solution was heated for four hours on the steam-bath at which time the volume had been reduced to approximately 50 ml. The solution was cooled overnight and filtered. The crude product was then recrystallized from the indicated solvents.

Preparation of 4-Substituted-amino-6-methylmercaptopyrazolo(3,4-*d*)pyrimidines (III) (see Table II).—The preparation of these compounds was carried out by treating 4-chloro-6-methylmercaptopyrazolo(3,4-*d*)pyrimidine (VIII) according to general method 1 or general method 2 for the preparation of 4-substituted-aminopyrazolo(3,4-*d*)pyrimidines (XVI).

LAS VEGAS, NEW MEXICO

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY OF THE UNIVERSITY OF CALIFORNIA AT LOS ANGELES]

Studies in Stereochemistry. XXV. Eclipsing Effects in the E_2 Reaction[1]

BY DONALD J. CRAM, FREDERICK D. GREENE AND C. H. DEPUY

RECEIVED NOVEMBER 23, 1954

Eclipsing effects in the E_2 reactions of the diastereomers of the 1,2-diphenyl-1-propyl-X system have been studied as a function of the leaving group [X = Cl, Br and $^+N(CH_3)_3$], of the solvent [C_2H_5OH, *n*-$C_6H_{13}CHOHCH_3$, $(CH_3)_3COH$, *n*-$C_8H_{17}OH$, $C_2H_5(CH_3)_2COH$, C_6H_6], and of the base [C_2H_5ONa, *n*-$C_6H_{13}CHOKCH_3$, $(CH_3)_3COK$, *n*-$C_8H_{17}ONa$, $C_2H_5(CH_3)_2COK$]. The ratio of rates k_{E_2} *threo*/k_{E_2} *erythro* varied from 1–11 with X = Cl, the value of the ratio increasing with increasing base strength and decreasing solvating ability of the medium. With X = Br, the rate ratio varied between 0.7 and 5.4, the solvent and base strength effects being similar to those found when X = Cl. With X = $^+N(CH_3)_3$, the rate ratio was 57 in C_2H_5OH with C_2H_5ONa as base. In $(CH_3)_3COH$ with $(CH_3)_3COK$ as base, the rate ratio was about 1, but in this case *trans*-olefin was obtained from both diastereomers. In all other cases a *trans* elimination occurred, the *threo* isomer giving *trans* and the *erythro* isomer giving *cis*-α-methylstilbene. Equilibration of the olefins with acid gave *trans*/*cis* ~50. The variation in rate ratios is interpreted in terms of the variation of the transition state from a geometry similar to that of the starting material (no groups eclipsed) to one similar to the product (four groups eclipsed).

Differences in reactivity of diastereomeric compounds have been recognized for about seventy-five years, as has the fact that *cis–trans*-olefin pairs possess different thermodynamic stability.[2] Eclipsing effects have been invoked only relatively recently to explain these phenomena and have been discussed in connection with both the relative thermodynamic stability of isomeric substances and the relative stability of isomeric transition states arising from either the same compound or diastereomerically related compounds.[3] Two distinct problems arise with respect to the magnitude of eclipsing effects in transition states, the first involving the bulk of the groups, and the second concerning the degree to which these groups are actually eclipsed.[4]

The bimolecular elimination reaction as applied to diastereomerically related starting materials pos-

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(1) This work was sponsored by the Office of Ordnance Research, U. S. Army.

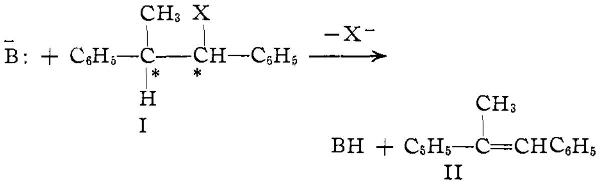
(2) For summary articles of the earliest literature, see: (a) P. Pfeiffer, *Z. physik. Chem.*, **48**, 40 (1904); (b) P. F. Frankland, *J. Chem. Soc.*, 654 (1912).

(3) With respect to the thermodynamic stability of isomeric olefins see: (a) G. B. Kistiakowsky, J. R. Ruhoff, H. A. Smith and W. E. Vaughan, THIS JOURNAL, **57**, 876 (1935); (b) R. B. Williams, *ibid.*, **64**, 1395 (1942); (c) D. J. Cram, *ibid.*, **71**, 3883 (1949); (d) D. Y. Curtin and B. Luberoff, Abstracts of Thirteenth National Organic Symposium of the American Chemical Society, Ann Arbor, Mich., June, 1953, p. 40; (e) R. Y. Mixer, R. F. Heck, S. Winstein and W. G. Young, THIS JOURNAL, **75**, 4094 (1953). Regarding differences in thermodynamic stability of diastereomeric 1,2-dimethylcyclopentanes, see: (f) W. Beckett, K. S. Pitzer and R. Spitzer, *ibid.*, **69**, 2488 (1947). With respect to reactivity differences in closing five-membered rings, see: (g) H. Hermans, *Z. physik. Chem.*, **113**, 338 (1924). For examples of reactivity differences in 1,2-molecular rearrangements, see: (h) D. Y. Curtin, P. I. Pollak, E. E. Harris and E. K. Meislich, THIS JOURNAL, **72**, 961 (1950), **73**, 992 (1951), and **74**, 2901, 5518, 5905 (1952); (i) D. J. Cram and F. A. Abd Elhafez, *ibid.*, **76**, 28 (1954). Examples of the phenomena as applied to acyl migrations are: (j) L. H. Welsh, *ibid*, **69**, 128 (1947), and **71**, 3500 (1949); (k) V. Bruckner, G. Fodor, J. Kiss and C. Kovacs, *J. Chem. Soc.*, 885 (1948), and subsequent papers. Reactivity differences as applied to the 1,2-elimination reaction are: (l) W. G. Young, D. Pressman and C. D. Coryell, THIS JOURNAL, **61**, 1640 (1939); ref. 3d; (m) R. E. Lutz, D. F. Hinkley and R. H. Jordan, *ibid.*, **73**, 4649 (1951); (n) S. Winstein, E. Grunwald, K. C. Schreiber and J. Corse, *ibid.*, **74**, 1118 (1952), and quoted references; ref. 6; (o) D. Y. Curtin and D. B. Kellom, *ibid.*, **75**, 6011 (1953); (p) D. J. Cram and J. D. McCarty, *ibid.*, **76**, 5740 (1954). For an example of eclipsing effects in the reverse aldol condensation, see: (q) H. E. Zimmerman and J. English, Jr., *ibid.*, **76**, 2285, 2291, 2294 (1954). For an example of a reactivity difference in the formation of a chloronium ion, see: (r) S. Winstein and D. Seymour, *ibid.*, **68**, 121 (1946).

(4) D. Y. Curtin, *et al.*, (ref. 3d, 3o and *Record Chem. Progress*, **15**, 111 (1954)) have introduced the term "*cis* effect" in connection with their extensive correlation of differences in reactivity (or stability) of isomers with the differences in bulk of groups becoming eclipsed.

sesses certain advantages for the study of particularly the latter problem. The mechanism of the transformation is known,[5] and the great energetic preference of the reaction for assuming a *trans* steric course has been thoroughly established.[6] The relative thermodynamic stability of the starting materials (diastereomers) can be estimated and that of the products (geometric isomers) can be determined. Thus, the relative rates of the E_2 reaction as applied to diastereomers allow the geometry of the transition state to be identified as being more like that of the starting material or of the product with regard to steric effects.[7]

The 1,2-diphenyl-1-propyl-X system (I) was chosen for this investigation for the following reasons: (1) the diastereomeric starting materials are crystalline and can be prepared with X as a number of different leaving groups[8]; (2) the *cis–trans*-olefinic products (II) are easily identified since they are crystalline and possess different ultraviolet absorption spectra[8a]; (3) the elimination can go in only one direction, and the transformation occurs with the virtual exclusion of substitution reaction.



$$\bar{B}: + C_6H_5-\underset{\underset{H}{|}}{\overset{\overset{CH_3}{|}}{\overset{*}{C}}}-\overset{\overset{X}{|}}{\overset{*}{C}H}-C_6H_5 \xrightarrow{-X^-} BH + C_6H_5-\overset{\overset{CH_3}{|}}{C}=CHC_6H_5$$

I II

The effects of four factors on the reaction rates have been studied: the nature of the leaving group, the solvent, the strength of the base, and the size of the base.

Thermodynamic Stability of Products and Starting Materials.—Pure samples of *cis*- and *trans*-α-methylstilbene (II) were prepared,[8b] equilibrated under acid conditions, and each resulting mixture was analyzed, making use of the differences in ultraviolet absorption spectra of the two olefins[8a] (see Experimental). The *trans* isomer (two phenyl groups *trans*) predominated in the product by a factor of at least 50/1. Unfortunately, means are not available for equilibrating the diastereomeric starting materials themselves [I with X = Cl, Br and $^+N(CH_3)_3$]. However, the diastereomeric formates (I with X = OCHO) have been equilibrated in formic acid[8c] and have been found to be of about equal energy (*threo/erythro* = 0.82). Since the bulk of a chlorine or bromine atom does not differ much from that of a formate group, one might expect these diastereomeric halides to be of approximately the same energy, with possibly the *erythro* isomer being the more stable of the two. On the other hand, with X = $^+N(CH_3)_3$, the *threo* isomer can be expected to be more stable than the *erythro* since $^+N(CH_3)_3$ is probably effectively more bulky than a phenyl group.[9] Since the groups attached to the $>C=C<$ in the olefins are eclipsed and those groups attached to the $>\overset{*}{C}-\overset{*}{C}<$ in the diastereomers are not, the differences in stability of the former compounds should be markedly greater than those of the latter.

Kinetics of the Elimination Reaction.—Table I records the kinetic data for the reactions of *threo*- and *erythro*-1,2-diphenyl-1-propyl-X in which X = Cl, Br and $^+N(CH_3)_3$. In those runs where X = Cl and Br, the reaction rates were followed by titrating the liberated halide ion by the Volhard method. Where X = $^+N(CH_3)_3$, the reactions were followed spectrophotometrically, making use of the intense absorption in the ultraviolet of the two olefins. Since with the concentrations of base and alkyl halide employed the pseudo first-order and second-order rate constants do not differ within experimental error from one another, only the former are employed, except in runs 26 and 27, conducted in benzene, where the concentration of base and alkyl halide are of the same order of magnitude. In these two runs, true second-order rate constants are used. In all cases, a minimum of five points are taken, the average being seven.

The k_{E_2}'s (measured as pseudo first-order rate constants) of Table I are corrected by the yields of olefin obtained in each run (Table I) in those reactions followed by the titrimetric method. In those reactions followed spectrophotometrically, k_{E_2} was measured directly. Outside of the two runs (26 and 27) made in pure benzene, no drifts in rate constant with time were observed.

In ethanol with X = Cl, a change in base concentration from 1 to 2 *N* represents a change in medium which is not reflected in a variation of k_{E_2}'s for the diastereomers. In the other solvents the small amount of data available suggests that over the range of base concentrations employed, the k_{E_2}'s vary approximately linearly with base concentration, and that the rate of change of k_{E_2} with base concentration is independent of which diastereomer is involved.

Products of the Elimination Reaction.—The stereospecific character of the base-induced elimination reaction of the *threo*- and *erythro*-1,2-diphenyl-1-propyl chlorides and bromides with potassium ethylate in ethanol and with potassium 2-octylate in benzene was established previously through product isolation experiments.[8b] In the present study the olefin produced in all but runs 26 to 29 (benzene present in the solvent) was examined spectrophotometrically. Since *cis*-α-methylstilbene possesses λ_{max} 262 mμ (ϵ 11,700) and *trans*-α-methylstilbene

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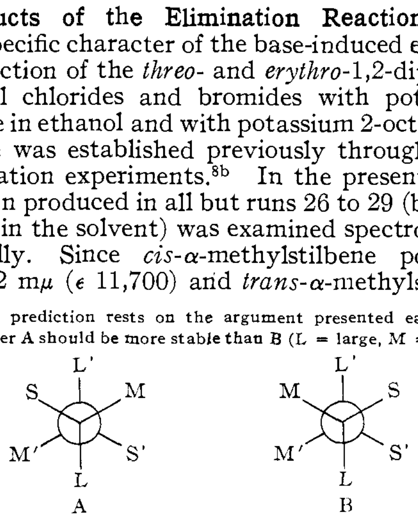
[5] M. L. Dhar, E. D. Hughes, C. K. Ingold, A. M. Mandour, G. A. Maw and L. I. Woolf, *J. Chem. Soc.*, 2093 (1948).

[6] (a) Ref. 2a and 2b; (b) P. Pfeiffer, *Ber.*, **45**, 1816 (1912); (c) S. Winstein, D. Pressman and W. G. Young, THIS JOURNAL, **61**, 1645 (1939); (d) S. J. Cristol, *ibid.*, **69**, 338 (1947).

[7] G. S. Hammond [*ibid.*, **77**, 334 (1955)] has recently made a qualitative correlation between the rate, the thermodynamics and the geometry of transition states of reactions.

[8] (a) D. J. Cram and F. A. Abd Elhafez, *ibid.*, **74**, 5828 (1952); (b) **74**, 5851 (1952); (c) **75**, 339 (1953).

[9] This prediction rests on the argument presented earlier that diastereomer A should be more stable than B (L = large, M = medium



and S = small groups in a relative sense). Three experimental tests of the argument have been consistent with this generalization [see ref. 8c and D. J. Cram and F. D. Greene, THIS JOURNAL, **75**, 6005 (1953)].

TABLE I

RATES OF ELIMINATION REACTION OF 1,2-DIPHENYL-1-PROPYL-X

Run	Temp., °C. ±0.02	Solvent	Base[a] concn., moles/l.	Alkyl-X			% yld. olefin	k_{E_2},[b] liters moles^{-1} sec.$^{-1}$
				X	Config.	Concn., mole/l.		
1	74.94	C_2H_5OH	1.282	Cl	*threo*	0.0643	96	4.47 ± 0.06 × 10^{-5}
2	74.94	C_2H_5OH	1.915	Cl	*threo*	.0688	98	4.50 ± .08 × 10^{-5}
3	49.87	C_2H_5OH	1.915	Cl	*threo*	.0688	98	3.29 ± .04 × 10^{-6}
4	74.94	C_2H_5OH	1.143	Cl	*erythro*	.0348	100	4.32 ± .03 × 10^{-5}
5	74.94	C_2H_5OH	2.325	Cl	*erythro*	.0675	100	4.32 ± .04 × 10^{-5}
6	49.73	C_2H_5OH	2.016	Cl	*erythro*	.0677	100	2.96 ± .03 × 10^{-6}
7	75.07	*n*-$C_8H_{17}OH$	0.4966	Cl	*threo*	.0685	90	2.83 ± .04 × 10^{-6}
8	75.07	*n*-$C_8H_{17}OH$	.849	Cl	*threo*	.0690	90	1.41 ± .01 × 10^{-6}
9	75.07	*n*-$C_8H_{17}OH$	.927	Cl	*threo*	.0708	89	1.14 ± .02 × 10^{-6}
10	75.07	*n*-$C_8H_{17}OH$	.849	Cl	*erythro*	.0672	99	1.51 ± .03 × 10^{-6}
11	75.07	*n*-$C_8H_{17}OH$	.927	Cl	*erythro*	.0381	98	1.25 ± .02 × 10^{-6}
12	75.02	*n*-$C_6H_{13}CHOHCH_3$	1.082	Cl	*threo*	.07504	96	1.80 ± .03 × 10^{-5}
13[c]	75.02	*n*-$C_6H_{13}CHOHCH_3$	1.082	Cl	*erythro*	.07504	100	5.10 ± .05 × 10^{-6}
14[d]	75.00	$(CH_3)_3COH$	0.604	Cl	*threo*	.0674	94	3.76 ± .20 × 10^{-5}
15[d]	75.00	$(CH_3)_3COH$	.865	Cl	*threo*	.0543	92	4.50 ± .04 × 10^{-5}
16[d]	49.60	$(CH_3)_3COH$	.865	Cl	*threo*	.0544	93	2.93 ± .03 × 10^{-6}
17[d]	75.00	$(CH_3)_3COH$	.7704	Cl	*erythro*	.0688	90	4.04 ± .09 × 10^{-6}
18[d]	75.00	$(CH_3)_3COH$	.9232	Cl	*erythro*	.0686	91	4.37 ± .07 × 10^{-6}
19[d]	75.00	$(CH_3)_3COH$	1.280	Cl	*erythro*	.0683	90	5.55 ± .07 × 10^{-6}
20[d]	99.50	$(CH_3)_3COH$	0.9232	Cl	*erythro*	.0685	90	5.14 ± .04 × 10^{-5}
21[d]	100.80	$(CH_3)_3COH$	1.280	Cl	*erythro*	.0686	90	7.45 ± .25 × 10^{-5}
22[e]	75.00	$(CH_3)_3COH$	0.8866	Cl	*threo*	.06925	94	3.10 ± .03 × 10^{-5}
23[e]	75.00	$(CH_3)_3COH$	1.130	Cl	*erythro*	.07337	87	8.57 ± .10 × 10^{-6}
24[d]	75.08	$C_2H_5(CH_3)_2COH$	0.7002	Cl	*threo*	.06934	83	4.95 ± .09 × 10^{-5}
25[d]	75.08	$C_2H_5(CH_3)_2COH$	.7002	Cl	*erythro*	.06934	82	4.60 ± .08 × 10^{-6}
26[f]	74.96	C_6H_6	.1236	Cl	*threo*	.0679	..[g,i]	3.33 ± .42 × 10^{-4}
27[f]	74.96	C_6H_6	.1236	Cl	*erythro*	.0679	..[g,j]	6.34 ± 1.10 × 10^{-5}
28	50.01	$C_2H_5OH-C_6H_6$	.612	Br	*threo*	.0369	..[g,k]	2.10 ± 0.04 × 10^{-4}
29	50.01	$C_2H_5OH-C_6H_6$	.612	Br	*erythro*	.0369	..[g,l]	3.03 ± .10 × 10^{-4}
30	50.00	$(CH_3)_3COH$	.5673	Br	*threo*	.0369	94	6.58 ± .14 × 10^{-5}
31	50.00	$(CH_3)_3COH$	.5673	Br	*erythro*	.0369	93	1.22 ± .04 × 10^{-5}
32[h]	74.84	C_2H_5OH	1.220	$^+N(CH_3)_3$	*threo*	.00507	93	1.07 ± .02 × 10^{-3}
33[h]	74.84	C_2H_5OH	1.220	$^+N(CH_3)_3$	*erythro*	.0262	89	1.88 ± .13 × 10^{-5}
34[d,h]	30.00	$(CH_3)_3COH$	0.5070	$^+N(CH_3)_3$	*threo*	.528 × 10^{-3}	100	4.26 ± .23 × 10^{-4}
35[d,h]	30.00	$(CH_3)_3COH$	0.5070	$^+N(CH_3)_3$	*erythro*	.418 × 10^{-3}	98	3.91 ± .21 × 10^{-4}

[a] Runs 1-11, 28, 29, 32 and 33, sodium alcoholate (see solvent) employed; runs 12-21, 24, 25, 30, 31, 34 and 35, potassium alcoholate (see solvent) used; runs 22 and 23, C_2H_5OK and runs 26 and 27, *n*-$C_6H_{13}CHOKCH_3$ used; concn. at 25°. [b] Pseudo first-order rate constant followed by Volhard method except where indicated. Corrected for solvent expansion (see Experimental) except in runs 26 and 27 and those conducted at 30° (runs 34 and 35). Also corrected to the amount of olefin produced. [c] k_{E_2} based on 111% of olefin. Results from a small amount of *cis* → *trans*. [d] *trans*-Olefin was main product. All other reactions stereospecific, *threo* → *trans*, *erythro* → *cis*. [e] Equivalent amount of absolute ethanol added to $(CH_3)_3COH[(CH_3)_3COK = 1$ equivalent]. [f] True second-order rate constants are reported. Rate constants decrease in value with time and are between second and third order. [g] Benzene prevented ultraviolet analysis of olefins. Olefins were isolated, *threo* → *trans* and *erythro* → *cis*. In runs 28 and 29, benzene had to be added to solubilize the bromides; proportions employed: 30 ml. of ethanol to 20 ml. of benzene. [h] Runs followed spectrophotometrically. [i] Yield *trans*-olefin, 93%. [j] Yield *cis*-olefin, 87%. [k] Yield *trans*-olefin, 100%. [l] Yield *trans*-olefin, 98%.

λ_{max} 273 mμ (ε 19,900),[10] the amount of olefin produced as well as its character could be determined. Product isolation experiments were carried out in experiments duplicating the conditions of runs 15, 18, 26, 27, 28, 29, 32 and 33 (Table I). The poorest yield of olefin indicated spectrophotometrically was 86%, and the average was 96%. The poorest yield of olefin isolated was 85%.

Those reactions involving a primary or secondary alkoxide as base clearly assumed a *trans* steric course, the *threo* isomer giving *trans*- and the *erythro* the *cis*-olefin. The two runs (30 and 31) conducted at 50° with potassium *t*-butylate and the alkyl bromides were also stereospecific in the same sense. However, in those runs conducted at 75° (or above) in *t*-butyl alcohol with potassium *t*-butylate as base, the *erythro*-chloride gave predominantly *trans*-olefin (runs 17-21). Under the conditions of the experiment *cis*-olefin was found to isomerize largely to the *trans*. In an experiment with *erythro*-chloride, *t*-butyl alcohol and potassium *t*-butylate (88°) which was interrupted after one half-life, at least 20% of the olefin possessed the *cis* configuration. In view of these results, it is highly probable that the *erythro*-alkyl chloride gave *cis*-olefin which was subsequently isomerized to the *trans*. In contrast, the *erythro* quaternary ammonium salt in *t*-butyl alcohol with potassium *t*-butylate (run 35) gave only *trans* olefin at a temperature (30°) at which *cis* olefin was demonstrated to persist.

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[10] The ultraviolet spectrum of each olefin is recorded in ref. 8a. The differences in the shapes of the curves allow the two olefins to be easily differentiated.

TABLE II

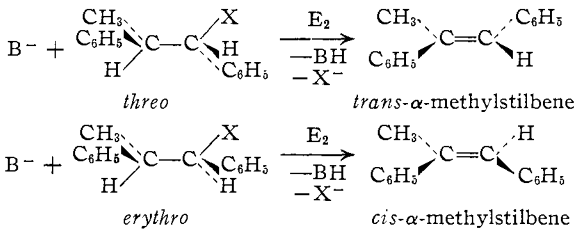
RATIOS OF ELIMINATION RATES OF DIASTEREOMERIC 1,2-DIPHENYL-1-PROPYL-X

Runs comp.	X	Temp., °C.	Solvent	Base	k_{E_2} *threo*/ k_{E_2} *erythro*
28 + 29	Br	50	$C_2H_5OH-C_6H_6$[a]	C_2H_5ONa	0.7[b]
3 + 6	Cl	50	C_2H_5OH	C_2H_5ONa	1.1
30 + 31	Br	50	$(CH_3)_3COH$	$(CH_3)_3COK$	5.4
16 − 21	Cl	50	$(CH_3)_3COH$	$(CH_3)_3COK$	15[c]
32 + 33	$^+N(CH_3)_3$	75	C_2H_5OH	C_2H_5ONa	57
2 + 5	Cl	75	C_2H_5OH	C_2H_5ONa	1.0
8 + 10	Cl	75	n-$C_8H_{17}OH$	n-$C_8H_{17}ONa$	0.9
12 + 13	Cl	75	n-$C_6H_{13}CHOHCH_3$	n-$C_6H_{13}CHOKCH_3$	3.5
26 + 27	Cl	75	C_6H_6	n-$C_6H_{13}CHOKCH_3$	~5[d]
15 + 17 - 19	Cl	75	$(CH_3)_3COH$	$(CH_3)_3COK$	10.6[e]
22 + 23	Cl	75	$(CH_3)_3COH$	C_2H_5OK	~4[f]
24 + 25	Cl	75	$C_2H_5(CH_3)_2COH$	$C_2H_5(CH_3)_2COK$	10.7
34 + 35	$^+N(CH_3)_3$	30	$(CH_3)_3COH$	$(CH_3)_3COK$	1.1[g]

[a] Benzene employed (40% by volume) to solubilize the bromides. [b] Ratio based on pseudo first-order rates, not corrected for amount of olefin produced. Isolation experiments indicated at least 85% yield in each case. [c] k_{E_2} *threo* for run 16 is employed. k_{E_2} *erythro* is calculated for 49.60° and a base concentration the same as for run 16 (0.865 M) as follows. A plot of k_{E_2} *erythro vs.* base concentration at 75° is virtually linear, and a rate of 4.26×10^{-6} l. mole^{-1} sec.$^{-1}$ can be inferred for k_{E_2} *erythro* at 0.865 M base at 75°. Utilizing runs 18 and 20 (base = 0.9232 M), ΔH can be calculated, and using these values, k_{E_2} *erythro* at 0.865 M base at 49.60° is 2.24×10^{-7} l. mole^{-1} sec.$^{-1}$. [d] Ratio only approximate since rates are of higher than second order but are calculated as second order. The qualitative results (yields) obtained previously (ref. 8b) pointed to a larger value for this ratio. The present results are the more reliable. [e] k_{E_2} *erythro* = 4.26×10^{-6} l. mole^{-1} sec.$^{-1}$ at base concentration of 0.865 M is used (see footnote *c*). [f] Ratio only approximate since rates were not determined at the same base concentration. [g] Ratio of rates of appearance of *trans*-olefin, not k_{E_2}, *threo*/k_{E_2} *erythro*. Both diastereomers give the same olefin.

Discussion

The above results strongly suggest that except where both X = $^+N(CH_3)_3$ and the base is a tertiary alcoholate (runs 34 and 35),[11] the E_2 mechanism applies to the reactions of both diastereomers. This contention is supported by: (1) the high yields and stereospecificity in the production of olefin; (2) the virtual absence of solvolysis products; (3) the very low yields of elimination as compared to substitution product obtained in experiments where the system was deliberately solvolyzed.[8c] Table II records the rate ratios k_{E_2} *threo*/k_{E_2} *erythro* obtained for the various diastereomeric pairs under the conditions employed for reaction.



threo *trans*-α-methylstilbene

erythro *cis*-α-methylstilbene

Comparisons of the rate ratios (k_{E_2} *threo*/k_{E_2} *erythro*) are far more significant than comparison of k_{E_2} *threo*'s for several reasons. The rate ratios were calculated from two rates determined under the same conditions, or corrected to the same conditions. These ratios are relatively insensitive to medium effects. For instance, runs 12 and 13 conducted in 2-octanol with 2-octylate anion as base give a ratio of 3.5, whereas runs 26 and 27 conducted in benzene give a ratio of ~5, although the absolute rates differ by a factor of 18. As long as k_{E_2} *threo* and k_{E_2} *erythro* are determined at the same temperature and base concentration, the rate ratios are also insensitive to base concentration (runs 14, 15, 17, 18 and 19). This constancy of rate ratios reflects the fact that in comparisons of diastereomers the *same bonds are being made and broken*. The molecular environments for the two reactions differ only in respect to the *arrangement of groups about the two asymmetric carbon atoms*, and to effects arising out of this difference.[12] Comparisons of k_{E_2} *threo* are more difficult to interpret because factors affecting these rates do not cancel in the same sense.

Three of the eleven ratios of Table II representing two different leaving groups (X = Cl and Br) and two different bases and solvents (C_2H_5ONa in C_2H_5OH and n-$C_8H_{17}ONa$ in n-$C_8H_{17}OH$) give k_{E_2} *threo*/k_{E_2} *erythro* ratios of about 1, even though K_{E_2} *threo* rates, had they all been compared at the same temperature, would have ranged by factors up to 1000 from one another.[13] This fact points to the conclusion that the diastereomeric transition states for these particular reactions possess geometries similar to the starting materials with respect to eclipsing effects. Since the diastereomeric starting materials are probably of comparable thermodynamic stability (see previous section), the ratios of greater than 1 must reflect mainly differences

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[11] The fact that the rate of appearance of *trans*-olefin from *both* diastereomers is the same suggests that (a) the rate-determining step is proton abstraction to give carbanion, and (b) the difference in the energies of the diastereomeric transition states is about the same as the difference in energies of the diastereomeric starting states. Regarding the reverse reaction of proton uptake by diastereometric carbanions, D. H. R. Barton and C. H. Robinson [*J. Chem. Soc.*, 3045 (1954)] have found some experimental support for the idea that the equilibrium constant for the diastereomeric carbanions is about the same as the equilibrium constant for the diastereomeric products.

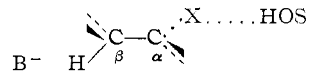
[12] Three effects are probably important: differences in nonbonded interactions of substituents at Cα and Cβ; differences in steric inhibition of resonance; differences in degrees of solvation. These three effects are gathered together in the term "eclipsing effect."

[13] The rate at which *threo*-bromide would be consumed by sodium ethylate in ethanol at 75° can be estimated to be at least 2×10^{-3}, whereas *threo*-chloride reacted with sodium n-octylate in n-octyl alcohol (75°) at a rate of about 1.4×10^{-6} l. mole^{-1} sec.$^{-1}$.

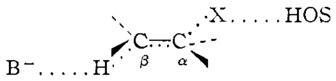
in stability of the diastereomeric transition states, the *threo* transition state leading to *trans*-olefin being more stable than the *erythro*. Thus eclipsing effects[12] have in a sense been isolated.

The ratio k_{E_2} *threo*/k_{E_2} *erythro* appears to be insensitive to small changes in base size. With X = Cl, the ratio obtained for potassium *t*-amylate and potassium *t*-butylate are almost identical (10.7 and 10.6),[14] as are the ratios obtained for sodium ethylate and sodium octylate (1.0 and 0.9, respectively). That variations in base size cannot be correlated with variations in rate ratios is demonstrated by the fact that although sodium ethylate is the base common to runs 2 + 5 and 32 + 33, the ratio obtained from runs 2 + 5 is 1 and from 32 + 33 is 57. On the other hand, k_{E_2} *threo* itself is undoubtedly sensitive to base size.

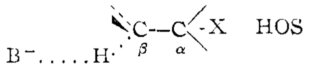
The geometry of the transition state can be best correlated with three factors, the nature of the leaving group, the base strength and the solvating ability of the solvent. These factors can be discussed most conveniently in terms of the relative importance of the three types of contributions to the structure of the transition state, III, IV and V. Structures III and V possess geometries similar to that of the starting material, the substituents attached to C_α and C_β being uneclipsed. On the other hand, structure IV possesses a geometry more like that of the olefinic product with the double bond rather thoroughly developed, and the substituents at C_α and C_β being relatively eclipsed. Thus the greater the value of k_{E_2} *threo*/k_{E_2} *erythro*, the greater the importance of structure IV.



III



IV



V

As base strength increases from ethylate to 2-octylate to *t*-butylate the value of the above ratio for the diastereomeric *chlorides* increases from 1 to 3.5 to 10.7. This trend probably reflects the amount of assistance that the electron pair of the C–H bond gives to the breaking of the C–X bond, the stronger the base the greater the assistance and the more important structure IV becomes. Solvation effects in passing from ethanol to *t*-butyl alcohol would reinforce the effect of base strength. In passing from ethanol to 2-octanol to *t*-butyl alcohol the solvating ability of the solvent for the base and leaving groups (Cl^-) would decrease. Structure III would be favored over IV in an efficient anion-solvating solvent (such as ethanol) because only in III has Cl become solvated more than B^- has become desolvated. In a less efficient anion-solvating solvent such as *t*-butyl alcohol, structure IV would become more important because charge would become more dispersed and less solvation energy would have to be overcome.[15]

In the runs involving potassium ethylate in *t*-butyl alcohol, k_E *threo*/k_E *erythro* = 4.[16] The acidities of ethanol and *t*-butyl alcohol have been estimated to differ by only one *pK* unit.[17] Therefore, the basic species actually responsible for the elimination in these runs cannot be identified, and a separation of solvation and base strength effects is unfortunately impossible.[18] Probably both effects operate to place the ratio between that found in primary alcohol with primary alkoxide and that in tertiary alcohol with tertiary alkoxide.

Variation in the nature of the leaving group has an even more serious effect on k_{E_2} *threo*/k_{E_2} *erythro*. Thus in ethanol with sodium ethylate as base, in passing from X = Br to Cl to $^+N(CH_3)_3$, the ratio changes from 0.7 to 1.1 to 57. Apparently with the quaternary ammonium group the transition state possesses more the character of IV, the electron pair in the C_β–H bond providing considerable assistance to the breaking of the C_α–$^+N(CH_3)_3$ bond. This result is probably a consequence of the enhanced acidity of the hydrogen attached to C_β, which derives from the positive charge on the nitrogen. A second factor that probably contributes to the variation in the ratios as X is changed relates to the relative ease of breaking the C_α–X bond. In the SN1 and SN2 reactions, Br > Cl > $^+N(CH_3)_3$ in ease of substitution.[19] The more difficult X is to displace, the more assistance would be needed from the C_β–H electron pair, and the greater becomes the contribution of the eclipsed structure IV to the transition state. The fact that k_{E_2} *threo* where X = $^+N(CH_3)_3$ is greater than when X = Cl is undoubtedly a consequence of the greater acidity of C_β–H in the quaternary ammonium compound.[20]

The result obtained in *t*-butyl alcohol with potassium *t*-butylate is also consistent with the above interpretation. With both halides, this stronger base increases the amount of double bond character in the transition state (structure IV) because the C_β–H bond is more broken, and k_{E_2} *threo*/k_{E_2} *erythro* becomes 5.4 and 15 (50°) for the bromide and chloride, respectively. Again the better leav-

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[14] In the E_2 reaction of these two bases with *tert*-amyl bromide, H. C. Brown and I. Moritani [This Journal, **75**, 4112 (1953)] observed that the ratio of 2-methyl-1-butene to 2-methyl-2-butene changed from 2.5 to 3.5 in passing to the larger base.

[15] C. K. Ingold, "Structure and Mechanism in Organic Chemistry," Cornell University Press, Ithaca, N. Y., 1953, p. 457.

[16] This is the only ratio obtained from rate constants determined at different base concentrations (runs 22 and 23 of Table I). If the changes in rate with base concentration follow those observed with potassium *t*-butoxide in *t*-butyl alcohol (runs 14–21 of Table I), and runs 22 and 23 are corrected accordingly, the ratio becomes 4.8.

[17] W. K. McEwen, This Journal, **58**, 1124 (1936). See also A. A. Morton, *Chem. Revs.*, **35**, 1 (1944); E. F. Pratt and K. Matsuda, This Journal, **75**, 3739 (1953); A. R. Pinder and H. Smith, *J. Chem. Soc.*, 113 (1954).

[18] Even if the ethylate anion is the base, the base strength would vary from ethanol to *t*-butyl alcohol, probably becoming stronger in the more basic (latter) solvent.

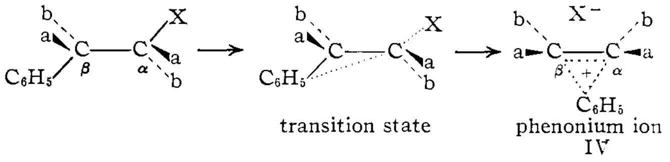
[19] C. K. Ingold, ref. 15, p. 339.

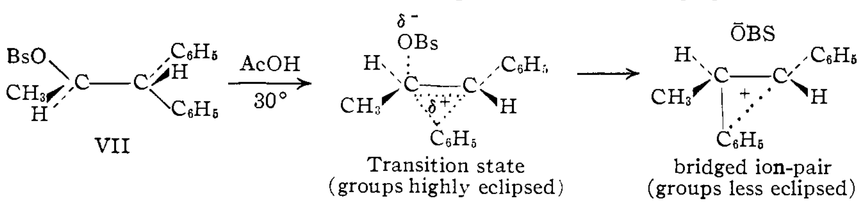
[20] Actually in ethanol with sodium ethylate at 75° k_{E_2} *threo* for X = $^+N(CH_3)_3$ is about twenty times k_{E_2} *threo* for X = Cl^-. This factor would probably be larger if the transition states were eclipsed to about the same extent. (Even in the *threo* series, a phenyl and methyl on the one hand and phenyl and hydrogen on the other are becoming eclipsed.)

ing group (Br^-) produces a less eclipsed transition state.[21]

As might be expected, with $X = {}^+N(CH_3)_3$, the strong base and the relatively acidic hydrogen at C_β combine to drive the reaction into another mechanistic channel in which the rate-determining transition state might be similar to structure V, a carbanion being produced which subsequently passes to olefin in a second stage. Since V possesses a geometry similar to that of the starting material (in the sense that the substituents at C_α and C_β are uneclipsed) it is not surprising that $k_{threo}/k_{erythro} = 1.1$. An alternate explanation would involve rapid epimerization at C_α followed by elimination reaction.

These results demonstrate that by appropriately varying the structural and environmental features of a system defined by a single carbon skeleton, the transition state can be varied from a geometry resembling starting material to one resembling product. Many of the same principles can be applied to other systems and other reactions. Thus in the Wagner–Meerwein rearrangement in acyclic systems involving phenyl as the migrating group, the importance of eclipsing effects depends largely on the relative position of the transition state between the geometry of the starting uneclipsed state and the phenonium ion intermediate[22] in which the substituents at C_α and C_β are eclipsed. In these systems in which the phenonium ion is potentially symmetrical (VI) with the substituents at C_α and C_β eclipsed, the partial rates of solvolysis leading to phenonium ion are approximately the same for each diastereomer.[23] Thus the transition states appear to be close to starting material in their geometry, and the eclipsing of groups (*e.g.*, two isopropyl groups)[23] occurs after the transition state has been passed. In contrast, in the acetolytic rearrangement of 1,1-diphenyl-2-propyl *p*-bromobenzenesulfonate(VII),[3i] only that phenyl migrated in detectable amounts which involved a transition state in which the bulky non-migrating groups (methyl and phenyl) are *trans* to one another. Thus in this system the phenyl group is more nearly half-way between C_α and C_β in the transition state, and the substituents are more eclipsed. This geometry follows from the probability that in the phenonium ion produced, the phenyl is more bonded to C_α than C_β (charge is distributed in the non-migrating benzene ring), and the point of maximum eclipsing was passed on the way to the bridged ion. A similar explanation can be applied to the pronounced importance of eclipsing effects observed in the pinacol and allied rearrangements,[3h] the OH on C_β playing the same type of role as C_6H_5 on C_β plays in the rearrangement of VII.





Experimental

Preparation of 1,2-Diphenyl-1-propyl Trimethylammonium Iodides.—The procedure is recorded for the *threo* isomer. A solution of 6 g. (0.016 mole) of *erythro*-1,2-diphenyl-1-propyl *p*-toluenesulfonate[8b] and 10 ml. of anhydrous dimethylamine in 60 ml. of dry benzene was heated at 75° in a sealed tube for 48 hours. The resulting mixture was cooled and shaken with a mixture of ether and 3 *N* sulfuric acid. The acidic layer was washed with ether, made basic with 3 *N* sodium hydroxide solution and extracted with ether. The ether layer was washed with water, dried, evaporated, and the residual oil was distilled at 2 mm. and 140° (pot temperature) to give 1.4 g. (40% yield) of *threo*-1,2-diphenyl-1-propyldimethylamine.

Anal. Calcd. for $C_{17}H_{21}N$: C, 85.30; H, 8.84; N, 5.85. Found: C, 85.31; H, 9.13; N, 5.81.

The *erythro*-amine was prepared in the same way to give a 35% yield, distilled at a pot temperature of 130° and 2 mm.

Anal. Calcd. for $C_{17}H_{21}N$: C, 85.30; H, 8.84. Found: C, 85.40; H, 8.73.

A solution of 1.0 g. of the *threo*-amine in 3 ml. of methyl iodide was allowed to stand at 0° for 12 hours. The crystalline salt that separated was recrystallized three times to give the quaternary ammonium salt. Reworking of the filtrates provided a total of 1.3 g. of *threo*-quaternary ammonium salt, m.p. 174–176° dec.

Anal. Calcd. for $C_{18}H_{24}NI$: C, 56.69; H, 6.34; N, 3.67; I, 33.29. Found: C, 56.28; H, 6.37; N, 3.57; I, 33.12.

The *erythro*-quaternary ammonium salt was prepared in the same way in 85% yield, m.p. 212–213° dec.

Anal. Calcd. for $C_{18}H_{24}NI$: C, 56.69; H, 6.34; N, 3.67. Found: C, 56.58; H, 6.32; N, 3.64.

Preparation of 1,2-Diphenyl-1-propyl Chlorides and Bromides.—The diastereomeric chlorides were prepared as described previously,[8b] *threo* isomer, m.p. 51–52.5°; *erythro* isomer, m.p. 139–140°. The diastereomeric bromides were also prepared as reported,[8b] *threo* isomer, m.p. 60–61°; *erythro* isomer, m.p. 149–152°.

Equilibration *cis*- and *trans*-α-Methylstilbenes.—A solution of 1.0 g. of *cis*-α-methylstilbene (m.p. 47–48°, prepared as before[8b]) and 0.05 g. of *p*-toluenesulfonic acid in 15 ml. of glacial acetic acid was heated at 75° for 8 hours. The solution was cooled, shaken with a mixture of pure pentane and water, and the organic layer was dried and evaporated. The crystalline residue was flash distilled at a pot temperature of 140° at 0.5 mm. to give 1.0 g. of material, ε 19,700 at λ 273 mμ in the ultraviolet in 95% ethanol (Beckman quartz spectrophotometer, model DU); authentic *trans*-olefin run at the same time, ε 19,900 at λ 273; authentic *cis*-olefin, ε 10,000 at λ 273. Calculations based on Beer's law indicate the product to be 98% *trans*-olefin, 2% *cis*.

A similar treatment of 1.0 g. of the *trans*-olefin (m.p. 81–82°[8b]) provided 1.0 g. of equilibrated material, ε 19,600 at λ 273 mμ, the product being 97% *trans*-olefin, 3% *cis*.

Stability of *cis*-α-Methylstilbene in Base.—A solution of 67 mg. of *cis*-α-methylstilbene in 5 ml. of 0.785 *N* potassium

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[21] Had the bulk of the leaving group had an important effect on how well developed the double bond was in the transition state [see H. C. Brown and H. L. Berneis, THIS JOURNAL, **75**, 10 (1953)], eclipsing effects might be expected to be greater for the bulkier leaving group (Br^-). The results are in the opposite direction.

[22] D. J. Cram, THIS JOURNAL, **71**, 3863 (1949), and subsequent papers.

[23] D. J. Cram, F. A. Abd Elhafez, and H. LeRoy Nyquist, unpublished results, and S. W. Winstein and K. Schreiber, *ibid.*, **74**, 2165 (1952).

t-butylate in *t*-butyl alcohol was heated at 75° for two weeks in a sealed test-tube under nitrogen. The tube was broken into 95% ethanol and the product was analyzed by ultraviolet spectral analysis (see later section), and was found to be greater than 98% *trans*-α-methylstilbene (ϵ 19,750 at λ 273 mμ). In a second experiment the same amount of *cis*-olefin was heated in 1.2 *N* potassium *t*-butylate in *t*-butyl alcohol under nitrogen at 30° for 24 hours. Ultraviolet spectral analysis demonstrated the olefin to be unchanged (ϵ 11,700 at λ 262 mμ).

Product Isolation Experiments.—A solution of 2.30 g. of *erythro*-1,2-diphenyl-1-propyl chloride was heated at reflux for 15 hours in a 1.9 *M* solution (70 ml.) of sodium ethylate in ethanol. The mixture was cooled and shaken with a mixture of water and pure pentane. The pentane layer was washed well with water, dried, evaporated to a small volume, and cooled. The material that separated (1.75 g., 90% yield) gave m.p. 47–48°, undepressed by admixture with an authentic sample of *cis*-α-methylstilbene. A similar experiment with *threo*-chloride provided *trans*-α-methylstilbene in 87% yield, m.p. 81–82°, undepressed by admixture with an authentic sample.

A solution of 1 g. of *erythro*-1,2-diphenyl-1-propyl chloride in 30 ml. of 0.9 *N* potassium *t*-butylate in *t*-butyl alcohol was held at reflux (88°) for 66 hours (estimated one half-life of chloride). The resulting mixture was cooled, shaken with water and pure pentane, and the pentane layer was washed well with water, dried and evaporated to a small volume. When cooled three separate crops of crystals separated: 1st crop, wt. 0.25 g., m.p. 80–81°, undepressed by admixture with an authentic sample of *trans*-olefin; 2nd crop, 0.075 g., m.p. 77–79°, m.m.p. with *trans*-olefin, 79–81°; 3rd crop, 0.110 g., m.p. 40–45°, m.m.p. with *cis*-olefin, 42–46°. The filtrates were not further examined.

A solution of 1.0 g. of *erythro*-1,2-diphenyl-1-propyl bromide in 0.70 *N* potassium *t*-butylate in *t*-butyl alcohol (30 ml.) was held at 50° for 12 hours. The mixture was cooled, and the olefin isolated as in the above experiments in 85% yield, m.p. 46–48°, undepressed by admixture with an authentic sample of *cis*-olefin.

A solution of 0.200 g. of *threo*-1,2-diphenyl-1-propyl trimethylammonium iodide in 10 ml. of 2 *N* sodium ethylate in ethanol was held at reflux for 40 hours. From the mixture was isolated (see above) 0.085 g. (90% yield) of material, m.p. 81–82°, undepressed by admixture with an authentic sample of *trans*-olefin. In a similar experiment 0.200 g. of *erythro* material gave 0.080 g. (85% yield) of *cis*-olefin, m.p. 46–47°, undepressed by admixture with an authentic sample.

Spectroscopic Analysis.—All measurements for runs 1–25, 30 and 31 were made with a Cary recording ultraviolet spectrophotometer (model 11 MPS). In each case the products of an infinity ampoule were diluted with 95% ethanol to the desired concentration (one that gave an observed optical density of 1.02 to 1.60). The analysis for *trans*-α-methylstilbene was made at $\lambda_{\max}$ 273 mμ (ϵ 19,960 and for *cis*-α-methylstilbene at $\lambda_{\max}$ 262 mμ (ϵ 11,780). In cases where the identity of olefin was in question the spectrum from 220 to 280 mμ was examined. To minimize errors: (1) all samples were examined immediately after ampoules were opened; (2) the same volumetric flasks and the same order of operations were used throughout; (3) the same cells were used; (4) a sample of pure olefin was diluted to a comparable concentration and analyzed at the same time as were the products.

Preparation of Basic Solutions.—In all cases the solvents were purified by distillation through a 35-plate (bubble plate) column from a pot to which had been added sodium. For runs 24 and 25, *t*-amyl alcohol was synthesized (methylmagnesium iodide and methylethylacetone). The basic solutions were prepared as follows. Dry oxygen-free nitrogen was bubbled through the solvent for two hours, and the desired amount of carefully cleaned metal added quickly. Nitrogen was bubbled through the solution until the metal had reacted. Short exposure of the alkoxide solutions to air produced coloration, and accordingly the solutions were stored and transferred under nitrogen. In runs 22 and 23 an equivalent amount of absolute ethanol (equivalent to amount of base) was added to a solution of potassium *t*-butoxide in *t*-butyl alcohol.

Kinetics Followed Titrimetrically (Runs 1–31).—Due to the gross differences in solubility of the *threo*- and *erythro*-halides, the ampoules (5-inch Pyrex test-tubes drawn out at both ends) were filled in different ways. The procedure for the *threo*-chlorides is outlined below. To a solution of sodium (or potassium) alkoxide was added a concentrated solution of *threo*-chloride in the same alcohol, and the ampoules were filled with aliquots of the solution (4.98 ml.). "Zero" time was taken as one minute after the ampoules had been introduced (with shaking) into the thermostat. The determination of chloride ion was carried out by breaking an ampoule (vigorous shaking) immersed in a mixture of 50 ml. of 2.5 *N* nitric acid and 25 ml. of ether in a heavy walled Pyrex separatory funnel. In each case the ampoule broke at both ends. The aqueous phase was drawn off into a 500-ml. glass stoppered erlenmeyer flask containing 5 ml. of 0.1 *N* silver nitrate solution. The ethereal layer was washed with a 25-ml. portion of water, and the aqueous phase was added to the erlenmeyer flask. The excess of silver ion was titrated by the Volhard method. After the calculated average pseudo first-order rate constants were corrected for solvent expansion,[24] the k_{E_2}'s were calculated by multiplying the corrected average rate constants by the ratio of the observed olefin concentration to the theoretical amount of olefin.

The procedure for runs involving the *erythro*-chloride was slightly different. Because of the insufficient solubility of this substance in the alcohols at room temperature, approximately 80-mg. samples of material were weighed (tolerance of ±0.2 mg.) into broken-off bottoms of small vials. These caps were then dropped into ampoules, and an aliquot of alkoxide solution was introduced. Each ampoule was given a 2-minute warm-up time (shaking) prior to "zero" time. From this point on the procedure was the same as for the *threo*-chloride.

The slow rate of solution of the chloride in run 6 (ethanol, sodium ethoxide at 50°) necessitated the ampoules to be shaken at 75° for one minute, and then at 50° for one minute before "zero" time.

The diastereomeric bromides were run in exactly the same way as the chlorides. The benzene had to be added to runs 28 and 29 to effect solution, the *erythro*-bromide being particularly insoluble.

In most of the runs the inorganic salt formed crystallized from the solution as the reaction proceeded. No drifts in the rate constants were observed that could be associated with this phenomenon. Addition of the salt at the beginning of a run had no observable effect on the rate.

Kinetics Followed Spectrophotometrically (Runs 32–37).—The *threo*-quaternary ammonium salt was run in ethanol (run 32) utilizing the ampoule technique described for the *threo*-halides, 2-ml. aliquots of stock solution being taken for each ampoule. The ampoules for the *erythro*-quaternary ammonium salt (run 33) were made by weighing into each ampoule 50 ± 0.2 mg. of the salt and adding aliquots of basic solution. The ampoules were broken under 95% ethanol. The appearance of olefin was followed by the change in ϵ of the resulting solutions diluted with 95% ethanol to give optical densities of from 0.05 to 1.07 in matched 1-cm. quartz cells (Beckman ultraviolet spectrophotometer, model DU). The *trans*-olefin from *threo*-salt was measured at λ 273 mμ, and the *cis*-olefin from *erythro*-salt at λ 262 mμ.

For runs 35 and 36 a saturated solution of *erythro*-salt in *t*-butyl alcohol at 30° was prepared, and the concentration of salt was determined (Volhard method). A 10-ml. aliquot of this solution was mixed with 10 ml. of standard potassium *t*-butoxide in *t*-butyl alcohol. At appropriate intervals 2-ml. aliquots were taken and analyzed as described above for olefin. The run involving *threo*-salt was conducted the same way except that the saturated solution of salt of known concentration was diluted with *t*-butyl alcohol to make the concentration of salt the same as with the run involving *erythro* material. The spectra of the infinity tubes of runs 36 and 37 from λ 220 to 300 mμ were taken, and in both cases the spectrum proved to be that of *trans*-olefin.

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(24) The densities of approximately 0.5 *N* alkoxide solutions were determined at 20°, 25°, 50°, 75°, giving rise to the following values for the expansion coefficients: for ethanol, $d^{25°}/d^{75°}$ 1.061, $d^{25°}/d^{50°}$ 1.029, $d^{20°}/d^{75°}$ 1.066; for 1-octanol, $d^{25°}/d^{75°}$ 1.048; for *t*-butyl alcohol, $d^{25°}/d^{50°}$ 1.04, $d^{25°}/d^{75°}$ 1.072, $d^{25°}/d^{100°}$ 1.11.