THE EFFECT OF STERIC SIZE OF LEAVING GROUP ON RATES OF THE COMPETING *syn*- AND *anti*-PATHWAYS IN BIMOLECULAR ELIMINATION*

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Approximate rates of the competing *syn*- and *anti*-pathways have been determined in t-C_4H_9OK–t-C_4H_9OH promoted elimination from two homologous series of tosylates: *I*-OTs→*trans-III* (R = H, CH_3, C_2H_5, n-C_3H_7, i-C_3H_7, t-C_4H_9) and *II*-OTs→*trans-IV* (R = CH_3, C_2H_5, n-C_3H_7, i-C_3H_7, t-C_4H_9). A comparison has been made with rates of the same processes in the elimination of the corresponding trimethylammonium salts: $I\text{-}\overset{(+)}{N}(CH_3)_3$→*trans-III* and $II\text{-}\overset{(+)}{N}(CH_3)_3$→*trans-IV*. The title effect is demonstrated by a comparative analysis of the rate patterns obtained for the two leaving groups.

Although frequently invoked in mechanistic discussions[1–10], the effect of steric size of leaving group has been never demonstrated unambiguously[2,10] in bimolecular elimination, at least in open-chain systems. Considering possible modes of operation of the elusive effect, Brown suggested[3]: "Although steric acceleration has been demonstrated in many cases of unimolecular reactions, we know of no authentic case where steric acceleration has been demonstrated in a bimolecular reaction. Steric hindrance (retardation) is the recognized pattern of behavior for such reactions".

The determination of the dissected rates of *anti*- and *syn*-elimination which we recently performed[11,12] in two homologous series of alkyltrimethylammonium salts *I* and *II* (Scheme 1; $X = \overset{(+)}{N}(CH_3)_3$) disagreed, however, considerably with this suggestion. No substantial steric retardation has been found in the *anti*-elimination. Instead, a very pronounced steric acceleration has been observed in the *syn*-elimination. Extreme steric requirements of the trimethylammonium group have been proposed to account for the unexpected pattern of behavior in the dichotomous reaction.

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In order to demonstrate that steric size of leaving group is indeed the responsible factor, we now report an analogous set of dissected rates for *anti*- and *syn*-elimination of a sterically less demanding *p*-toluenesulphonyloxy group. A comparison of the rate patterns obtained for t-C_4H_9OK–t-C_4H_9OH promoted elimination in the *p*-toluenesulfonyloxy and trimethylammonium series *I* and *II* (Scheme 1) is the subject of the present discussion.

$$\underset{I}{RCH_2CHXn\text{-}C_5H_{11}} \xrightarrow{k^{anti}+k^{syn}} \underset{trans\text{-}III}{RCH_2CH{=}CHn\text{-}C_4H_9}$$

$$\underset{II}{RCHXCH_2n\text{-}C_5H_{11}} \xrightarrow{k^{anti}+k^{syn}} \underset{trans\text{-}IV}{RCH{=}CHn\text{-}C_5H_{11}}$$

X: $N^{(+)}(CH_3)_3$ or OTs
R in *I*: H, CH_3, C_2H_5, n-C_3H_7, i-C_3H_7, t-C_4H_9
R in *II*: CH_3,C_2H_5, n-C_3H_7, i-C_3H_7, t-C_4H_9

SCHEME 1

RESULTS

The overall (*anti*- plus *syn*-) rate constants of *trans-III* and *trans-IV* alkene formation from t-C_4H_9OK–t-C_4H_9OH promoted reaction of tosylates *I* and *II*, respectively, were reported previously[13]. Now we have dissected the overall rate constants of the *trans*-alkene formation, k^{tot}, into the *anti* and *syn* components using the Eqs (*1*) and (*2*):

$$k^{anti} = (\%\ anti)\ k^{tot}/100 \qquad (1)$$

$$k^{syn} = (\%\ syn)\ k^{tot}/100\,, \qquad (2)$$

where % *anti* and % *syn* are the contributions of the *anti* and the *syn*-pathways, respectively, in the overall olefin-forming reaction. In most instances, direct experimental values of % *anti* and % *syn* were not available. As an approximation, we have therefore employed the values determined by Chiao and Saunders[14] and by us[6,15,16] in related situations (Table I). The dissected rate constants resulting from this approximate calculation are presented in Table II. For the branched homologues (R = i-C_3H_7 and R = t-C_4H_9) in both the tosylate series *I* and *II* the dissection has been accomplished already in the previous work[13,16].

DISCUSSION

Approximate rates of the *syn*→*trans-II* and *anti*→*trans-II* pathways in the t-C_4H_9OK–t-C_4H_9OH promoted elimination of the tosylates *I* (X = OTs) are graphically presented in Fig. 1*a* and compared with the rates of the corresponding pathways

in the elimination of the trimethylammonium salts *I* ($X = \overset{(+)}{N}(CH_3)_3\overset{(-)}{Cl}$)in Fig. 1*b*.

It is apparent that the rate patterns for *syn*-elimination are in the two compared series different. In the trimethylammonium series *I* ($X = \overset{(+)}{N}(CH_3)_3$), rates of the *syn*--pathway rise very pronouncedly with increasing size of the alkyl substituent R

TABLE I

Estimated Contributions of the *syn*- and *anti*-Pathways to the *trans-III* and *trans-IV* Alkene Formation in the t-C_4H_9OK–t-C_4H_9OH Promoted Reaction of the Tosylates *I*-OTs and *II*-OTs Respectively

R	% *syn*-Pathway[a]	
	I-OTs→*trans-III*	*II*-OTs→*trans-IV*
H	12[b]	—
CH_3	20[c]	12[b]
C_2H_5	20[c]	20[c]
n-C_3H_7	15[d]	15[d]
i-C_3H_7	30[e]	30[e]
t-C_4H_9	50[e]	50[e]

[a] % *syn* + % *anti* = 100. [b] Experimental value for *trans*-2-hexene formation in t-C_4H_9ONa–t-C_4H_9OH promoted elimination of 2-hexyl *p*-toluenesulphonate; ref.[14]. [c] Experimental value for *trans*-3-hexene formation in t-C_4H_9OK–t-C_4H_9OH promoted elimination of 3-hexyl *p*-toluenesulphonate; ref.[14]. [d] Experimental value for *trans*-5-decene formation in t-C_4H_9OK–t-C_4H_9OH promoted elimination of 5-decyl *p*-toluenesulphonate; ref.[6]. [e] Estimated values from ref.[16].

TABLE II

Approximate Rate Constants of the *syn*- and *anti*-Pathways Participating in the t-C_4H_9OK–t-C_4H_9OH Promoted Alkene-Forming Processes *I*-OTs→*trans-III* and *II*-OTs→*trans-IV* at 80·7°C (in l mol^{-1} s^{-1})

R	*I*-OTs→*trans-III*		*II*-OTs→*trans-IV*	
	10^5k^{syn}	10^5k^{anti}	10^5k^{syn}	10^5k^{anti}
H	0·8	5·5	—	—
CH_3	1·1	4·5	1·0	7·2
C_2H_5	1·2	4·8	1·2	4·6
n-C_3H_7	1·0	5·7	0·7	3·9
i-C_3H_7	1·4	3·3	0·8	1·8
t-C_4H_9	2·8	2·8	0·27	0·27

in the order H < CH_3 < C_2H_5 < n-C_3H_5 < i-C_3H_7 < t-C_4H_9, the overall rate spread in the series being about 400. In the tosylate series *I* (X = OTs), on the other hand, the same structural variation induces only minor changes in rates of the *syn*-pathway, the rate spread between the extremes R = H and R = t-C_4H_9 being now less than 4.

This difference between the two leaving groups agrees well with the conformational explanation we advanced[12] earlier for the elimination of the alkyltrimethylammonium salts. According to our proposal, the sterically outsized trimethylammonium group repels the alkyls on C_α and C_β as far away from itself as possible, enforcing thus arrangement where the alkyls R and n-C_4H_9 sterically interfere (Scheme 2, *A*). The alkyltrimethylammonium salts are therefore assumed to be strained in the ground state, with the extent of strain increasing as the steric size of R is enhanced. On going from the staggered conformation *A* to the eclipsed* arrangement *B* which is required for the *syn*→*trans-III* pathway, the repulsion between the alkyl substituents is relieved, which provides the driving force for the observed acceleration.

In the *syn*-elimination of the corresponding tosylates the situation is presumably different because the less bulky and unsymmetrical *p*-toluenesulphonyloxy group does not suffice to enforce a strained ground-state conformation which would correspond to *A*. Examination of models suggests that for a majority of the homologues *I*

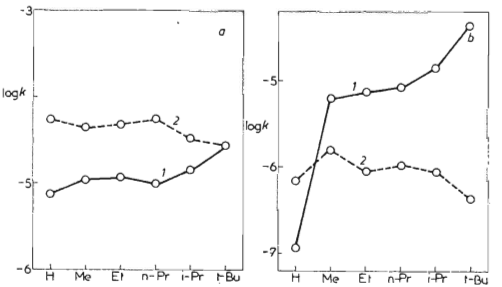


FIG. 1

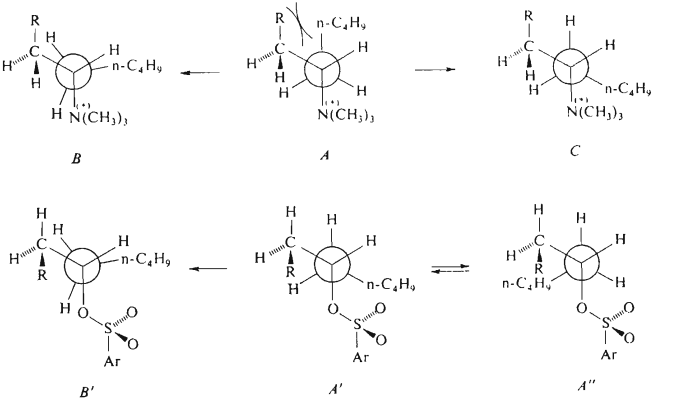
Effect of the Substituent R and Leaving Group on Rates of the Competing *syn*- and *anti*-Pathways (full and dotted lines, respectively) in Elimination Series *I* (+)

a *I*-OTs→*trans-III*; 0·43M t-C_4H_9OK–t-C_4H_9OH at 80·7°C, *b* *I*-$N(CH_3)_3$→*trans-III*; 0·43M t-C_4H_9OK–t-C_4H_9OH at 35°C (taken from ref.[12]).

1 *syn*, *2* *anti*.

* Conceivably, the eclipsed conformation *B* exists, in part, already in the ground state; *cf.* ref.[17].

the *p*-toluenesulphonyloxy group can be placed between ends of the *transoid* carbon-chain skeleton in such a manner (Scheme 2, *A'*) that it does not introduce any substantial strain. Only when R = t-C_4H_9, steric compression in *A'* would be significant. However, as we have pointed out earlier, ground-state strain in this particular case is reduced by preferring the alternative conformation *A''* (*cf.* "neohexyl anomaly" in ref.[16]). Irrespective of R, no marked relief of strain therefore occurs in the tosyloxy series *I* on going to the eclipsed conformation *B'*, which explains why the observed steric acceleration in the *syn*-elimination is so small.

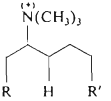


SCHEME 2

In a contrast to the clear-cut effect of leaving group in the *syn*-elimination, the rate patterns for the *anti*-elimination of *p*-toluenesulphonyloxy and trimethylammonium group are very similar (Fig. 1*a* and 1*b*, respectively). A very small variation of rates with R is found in both the two compared series *I* suggesting absence of steric effects in the reaction.

However, the conformational analysis of the *anti*-elimination leads[12] in the trimethylammonium series *I* to another conclusions. On going from the ground state *A* (Scheme 2) to the conformation *C*, which is required for the *anti*-elimination, the repulsion between the alkyl groups R and n-C_4H_9 is replaced by a gauche interaction between n-C_4H_9 and $\overset{(+)}{N}(CH_3)_3$ groups. Since the gauche interaction is constant in the homologous series *I*, a gradual rise of rates with increasing size of R, such as it was observed in the *syn*-elimination, should occur also in the *anti*→*trans-III* pathway, in apparent discord with Fig. 1*b*.

As a resolution for this disagreement we have suggested[11,12] that steric hindrance to base approach must be also taken into account in the *anti*-elimination. Some time ago, Bailey and Saunders[4] and in a modified version Felkin[6] predicted that a strong, leaving-group induced, hindrance of base operates in the reaction. According to their proposal[4], the very bulky trimethylammonium group forces ends of alkyl chains into a position where they interfere with the approaching base in *anti*-elimination (Scheme 3).



SCHEME 3

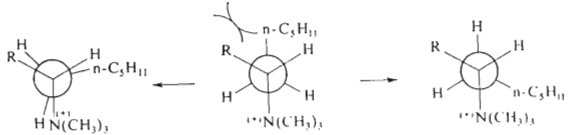
In the homologous series of alkyltrimethylammonium salts *I*, both the base approach hindrance as well as the relief of ground-state repulsion between the alkyl groups (Scheme 2, *C*) vary with steric size of R. A superposition of the two factors which individually are large but operate in opposite direction can therefore lead to kinetic results in the *anti*-elimination that are insensitive to the variation of R.

In the *anti*-elimination of the corresponding tosylates the conformational situation is evidently different. Since the *p*-toluenesulphonyloxy group does not repel the neighbouring alkyls away from itself, no marked relief of strain as well as no marked hindrance to base approach will arise. Absence rather than balance of steric effects thus probably accounts for the leveling of rates in the *anti*-elimination of tosylates *I*.

A Structural Threshold Where Steric Hindrance Becomes Predominant in the Reaction

In order to assess steric influence of leaving group in a wider spectrum of structural variation, we have examined the corresponding positionally isomeric series *II* (Scheme 1; X = OTs and $\overset{(+)}{N}(CH_3)_3$). Although polar influence of the alkyl group R cannot be ignored[12,13,16] entirely in the two subsidiary series, it is nonetheless expected that the main influence is steric. The approximate rates of the competing *syn*→*trans-IV* and *anti*→*trans-IV* pathways determined in the t-C_4H_9OK – t-C_4H_9OH promoted elimination of the tosylates and trimethylammonium salts *II* are graphically presented in Fig. 2. A close resemblance between the rate patterns for *syn*→*trans-III* and *syn*→*trans-IV* and also between those for *anti*→*trans-III* and *anti*→*trans-IV* pathways is apparent from a comparison of the trimethylammonium series *I* and *II* in Figs 1*b* and 2*b*. It strongly suggests that steric effects in the two isomeric series of quaternary salts are nearly the same.

On the other hand, the corresponding rate patterns in the isomeric tosylate series *I* and *II* (X = OTs) are markedly different (Fig. 1*a* and 2*a*, respectively). In particular, a sharp decrease of rates of *anti*-elimination is induced by a stepwise branching of the substituent R (R = i-C_3H_7, t-C_4H_9) in the tosylate series *II*. This is taken to indicate the threshold of structural complexity where steric hindrance to base approach becomes prevalent in the reaction. Modest steric requirements of *p*-toluenesulphonyloxy group are proposed to be requisite for the predominance of the steric hindrance. In the elimination from trimethylammonium series *II*, the steric hindrance assumedly continues to be submerged by the accompanying relief of the ground-state compression (Scheme 4).



SCHEME 4

It is known[18] that ion-paired t-C_4H_9OK is the active base species in the elimination of the tosylates whereas the dissociated base is involved in the elimination of the trimethylammonium salts. Accordingly, different steric resuirements of the alternative base species might be argued[19,20] to be responsible for the differences observed in the

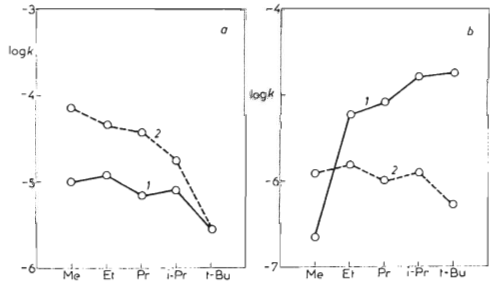


FIG. 2

Effect of the Substituent R and Leaving Group on Rates of the Competing *syn*- and *anti*-Pathways (full and dotted lines, respectively) in Elimination Series *II*

a *II*-OTs→*trans-IV*; 0·43M t-C_4H_9OH at 80·7°C, *b* *II*-$\overset{(+)}{N}(CH_3)_3$→*trans-IV*; 0·43M t-C_4H_9OK–t-C_4H_9OH at 35°C (taken from ref.[12]).

1 *syn*, *2* *anti*.

elimination of the tosylates and the trimethylammonium salts. However, it will be shown in the following paper[21] that steric requirements of the ion-paired and dissociated alkoxide species are almost identical in t-C_4H_9OK – t-C_4H_9OH system.

A Comparison with the Results Reported by Chiao and Saunders

In a recent study, Chiao and Saunders[14] examined partial rates of *syn*- and *anti*-elimination in the t-C_4H_9ONa – t-C_4H_9OH promoted reaction of 2-hexyl and 3-hexyl *p*-toluenesulphonates and compared the results with those reported for structurally related quaternary salts $(I-\overset{(+)}{N}(CH_3)_3$; R = H and R = CH_3, respectively) by us[11]. While no definite conclusions have been drawn from this limited comparison, the trends established by the American authors are in a very good accord with the present evidence. As a sole discrepancy[22], replacement of 2-hexyl by 3-hexyl residue causes[14] a much stronger decrease of rate in *anti*-elimination than it does an analogous structural change in the tosylate series *I* (2-heptyl→3-octyl) or *II* (2-octyl→3-nonyl); *cf.* Table II. At present, we have no satisfactory explanation for this difference.

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