Tetrahedron Letters No. 28, pp 2479 - 2482. 0040-4039/78/0708-2479$02.00/0

CYCLOPROPANE AS A NEIGHBORING GROUP IN SOLVOLYSES OF 2-(1-METHYLCYCLOPROPYL)ETHYL ARENESULFONATES

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(Received in USA 17 February 1978; received in UK for publication 16 May 1978)

The preceding paper[2], which reports trifluoroethanolyses of the conformationally mobile 2-cyclopropylethyl tosylate (1-OTs) and its sterically related acyclic analogue, isoamyl tosylate (2-OTs), shows that cyclopropane is an effective β-neighboring group, in contrast to previous conclusions for solvolyses in less ionizing, more nucleophilic solvents[3].

To probe for possible charge delocalization to the 1-position of the cyclopropane ring and to ascertain the effects of methyl substitution on rates and products and thus the nature of potential intermediates which may be involved in the reactions, we have investigated solvolyses of 2-(1-methylcyclopropyl)ethyl tosylate (3-OTs) in conjunction with an acyclic steric model, 3,3-dimethylbutyl tosylate (4-OTs), in anhydrous acetic acid, formic acid and trifluoroethanol (TFE)[4,5]. Rate constants, measured titrimetrically for acetolyses and spectrophotometrically[2] for trifluoroethanolyses, are listed in Table 1. Product distributions are given below for acetic acid and formic acid and in the scheme for trifluoroethanol.

Table 1. Acetolysis[a] and Trifluoroethanolysis[b] First Order Rate Constants

T(°C)	$k_{3\text{-OBs}}^{HOAc}$ (X10^5) sec^{-1}[c]	$k_{3\text{-OTs}}^{TFE}$ (X10^5) sec^{-1}[d]	$k_{4\text{-OTs}}^{TFE}$ (X10^5) sec^{-1}[e,f]
110.02	---	0.948 ± 0.023	0.381 ± 0.009
120.01	6.69 ± 0.09	1.90 ± 0.14	0.860 ± 0.016
130.01	13.2 ± 0.15	4.10 ± 0.10	1.85 ± 0.07
139.90	26.7 ± 0.2	---	---
75.00	0.102 ± 0.003	0.0459[g]	0.0157[g]

[a] [ROBs] = 0.02 M, solutions buffered with 1.1 equiv. sodium acetate. [b] [ROTs] = 0.9-1.16 mM, [urea] = 1.2-1.3 mM. [c] $\Delta H^{\neq}$ = 21.70 ± 0.90 kcal/mole, $\Delta S^{\neq}$ = -23.01 ± 2.2 eu. [d] $\Delta H^{\neq}$ = 21.98 ± 1.03, $\Delta S^{\neq}$ = -24.70 ± 2.6. [e] $\Delta H^{\neq}$ = 23.43 ± 0.09, $\Delta S^{\neq}$ = -22.55 ± 0.24. [f] $k_{4\text{-OBs}}$(HOAc) at 75.00° is 7.96 X 10^{-7}sec^{-1}, activation parameters recalculated from Ref. 7 as $\Delta H^{\neq}$ = 23.62, $\Delta S^{\neq}$ = -18.90. $k_{4\text{-OBs}}$ (HOAc) was determined independently in this work and agreed with that reported to within 2.5%. [g] extrapolated.

Trifluoroethyl ether products 3-OTFE and 7-OTFE were shown to be stable under solvolysis conditions. Control experiments showed interconversion of 5-OTFE and 6 to yield a 23:77 equilibrium mixture of 5:6. These must equilibrate via a methylcyclopentyl carbenium ion and are probably formed from the same ion in trifluoroethanolysis, analogous to 2-cyclopropylethyl

tosylate[2]. The total fraction of the reaction proceeding by this process, $k_{\Delta}^{c\text{-}C_3H_5}$, is thus at least 39%. For comparison, formolysis products of 3-OTs were also determined (75°, 13.5 hrs., 2.99 equiv. sodium formate[4]). Although formolysis of 3-OTs occurred measurably faster than addition of formic acid to 3-OCHO, definitive product analyses were hampered by the acid-catalyzed ring opening of the initially formed 3-OCHO to give a thermodynamically determined product mixture of E- and Z-9-OCHO (E/Z = 1.80). In a control experiment, 3-OCHO gave starting 3-OCHO (44%) and E- and Z-9-OCHO in 34% and 19% yields, respectively (E/Z = 1.79); an unidentified product was obtained in 3.0% yield. Formolysis of 3-OTs to less than 3% tosylate conversion gave 3-OCHO (87%), E-9-OCHO (8.2%) and Z-9-OCHO (4.5%) (E/Z = 1.82). Rate constants were not determined in formic acid, but absence of any cyclopentyl product from 3-OTs suggests that cyclopropyl participation is greatly reduced in this solvent, if present at all. Acetolysis of the brosylate ester 3-OBs (117°, 10 $t_{1/2}$, 1.13 equiv. sodium acetate) gave 3-OAc (84%), 9-OAc (11%), and two unidentified products (3.2% and 1.8%).

Methyl substitution at the 2- and 3- positions of the cyclopropane ring have been reported to enhance formolysis rates relative to unsubstituted 1-OBs[8], but multiple methyl group substitution fits neither an additive nor a multiplicative relationship. Although also small in magnitude, these rate enhancements are evidence for cyclopropyl participation and delocalization of charge to the β-positions of the cyclopropane ring, probably unsymmetrically. Products were not identified. Accordingly, it was anticipated that methyl substitution at the 1-ring carbon might also increase the reaction rate relative to both the unsubstituted derivative (1-X) and the acyclic model compound (4-X). Pertinent acetolysis and trifluoroethanolysis rate ratios calculated from this work and elsewhere[2,7] are shown in Table 2.

Table 2. Acetolysis and Trifluoroethanolysis Rate Ratios at 75°.

		$k_{3\text{-}X}/k_{4\text{-}X}$	$k_{3\text{-}X}/k_{1\text{-}X}$	$k_{4\text{-}X}/k_{2\text{-}X}$	$k_{1\text{-}X}/k_{2\text{-}X}$
HOAc	(X = OBs)	1.3	0.58	0.43	0.95
TFE	(X = OTs)	2.5	0.73	0.77	3.1

Methyl substitution at the 1-cyclopropyl position shows a small increase (1.3) in the rate of 3-X relative to the acyclic model 4-X in acetolysis and is enhanced by a factor of 2.5 in trifluoroethanolysis. The latter value is comparable to the value $k_{1\text{-}X}/k_{2\text{-}X}$ previously determined[2], and is also indicative of cyclopropyl participation in 3-OTs. However, the observed rate constant of the substituted 3-X is less than that of the unsubstituted 1-X in both solvents. Since the methyl group may be anticipated to enhance the rate of 3-X *via* cyclopropane

participation and as it is too far from the reactive site to exert any inductive effect, other effects may be operative. The methyl group may sterically hinder the solvent-assisted (k_s) process or the anchimerically-assisted process (k_Δ), or both, and may thus retard the observed rate of 3-X relative to 1-X. However, examination of the trifluoroethanolysis products of 3-OTs indicates that the k_Δ processes are in fact more efficient in 3-OTs, since a greater amount of rearranged products (80%) was obtained compared to 1-OTs (59%). Indeed, cyclopentyl products are increased from 25% for 1-OTs to 39% for 3-OTs. This suggests that the methyl group of 3-OTs decreases the k_s process to a greater extent than the k_Δ processes. This is further corroborated by the decreased rate of 4-OTs relative to 2-OTs and by the partial rate factor analysis presented below.

The mechanism may be represented in terms of discrete k_s, $k_\Delta^{c\text{-}C_3H_5}$, and k_Δ^{H} processes analogous to those proposed for solvolysis of 1-OTs[2]; differences between the two primary systems are of degree rather than kind. The unprecedented cyclobutyl products may arise via the k_Δ^{H} route. Hydrogen participation-migration may lead to a 1-methylcyclopropylcarbinyl cation (12), which rearranges to a more stable tertiary dimethylcyclobutyl cation (13). The role of the 1-methylcyclopropyl group may be seen more clearly using the partial rate factor analysis given in Table 3 using the appropriate values from Table 1 and the reaction scheme below.

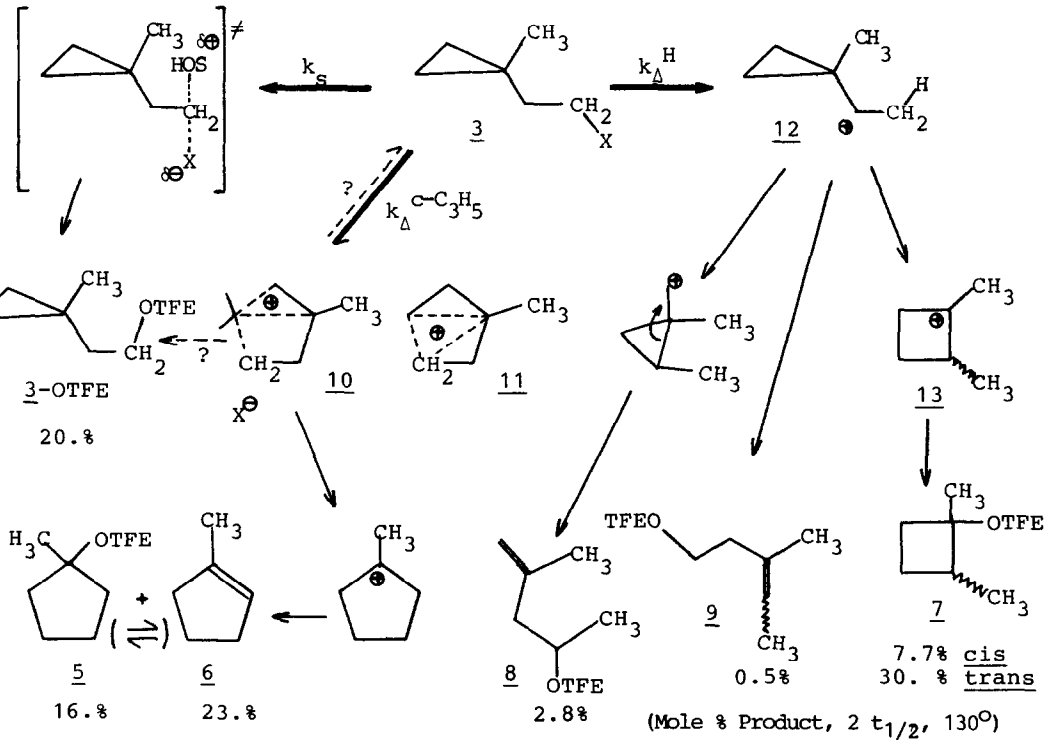

Table 3. Partial Rate Factors for Trifluoroethanolysis of 3-OTs at 130°.

	$k_{obs'd}$	$= k_{\Delta}^{H}$	$+ k_{\Delta}^{c\text{-}C_3H_5}$(cyclopentyl)	$+ [k_s + k_{\Delta}^{c\text{-}C_3H_5}$(cyclopropyl)]
1-OTs	5.51	1.86	1.37	2.28
3-OTs	4.10	1.69	1.58	0.821
$k_{3\text{-OTs}}/k_{1\text{-OTs}}$	0.74	0.91	1.2	0.36

The terms $k_{\Delta}^{c\text{-}C_3H_5}$(cyclopentyl) and $k_{\Delta}^{c\text{-}C_3H_5}$(cyclopropyl) represent cyclopropyl participation leading to cyclopentyl products and to cyclopropylethyl products, respectively; present experimental data do not permit further dissection of k_s and the possible $k_{\Delta}^{c\text{-}C_3H_5}$(cyclopropyl) Thus the values in the right-hand column of Table 3 represent an upper limit for k_s. The ratios of the partial rate factors of 3-OTs and 1-OTs indicate that the k_{Δ} processes are of similar magnitude in both substrates and only slightly increased for $k_{\Delta}^{c\text{-}C_3H_5}$ in 3-OTs. However, k_s is strongly retarded in 3-X indicating that steric hindrance to nucleophilic solvent assistance accounts for the greater part of the observed solvolytic difference between 3-X and 1-X. Cyclopropane participation is thus significantly more efficient than k_s for 3-OTs in TFE (with k_{Δ}^{H} equally competitive) and is enhanced by 20% over cyclopropane participation in 1-OTs. This conclusion requires slight partial charge delocalization to the 1-position of the cyclopropane ring. Furthermore, there is no steric effect of the 1-methyl group on the $k_{\Delta}^{c\text{-}C_3H_5}$ process suggesting that participation and alkylation of the cyclopropane ring occurs not at the 1-ring carbon, which would lead to severe crowding at the pentacoordinate carbon in the transition state or intermediate, but at the far corners of the cyclopropane ring, as in 10, as also proposed in the preceding paper[2].

References and Notes

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