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HYDROGEN PARTICIPATION, AND NON-CHAIR TRANSITION STATES, IN THE SOLVOLYSIS OF 2-ALKYLCYCLOHEXYL TOSYLATES : EVIDENCE FROM KINETIC DEUTERIUM ISOTOPE EFFECTS

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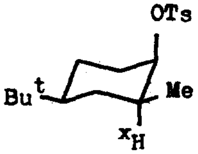
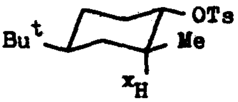
Recently we reported rate and product studies on the solvolysis of the four stereoisomeric 4-tert-butyl-2-methylcyclohexyl tosylates (I - IV, x = 1) (1). As in some previous studies (2) it was found that the solvolytic behaviour of compounds I - IV does not depend on the axial or equatorial character of the tosyloxy group but rather on whether this group is cis or trans to the vicinal methyl. In the former case (compounds I and II) high rates and a greater amount of products which could have arisen by rearrangement, and in the latter (compounds III and IV) lower rates and less rearrangement were found. The results were rationalized by postulating participation of the hydrogen on $C_{(2)}$ in the reaction of both the "cis"-isomers I and II but no such participation in that of the "trans"-isomers (III and IV) (1). This hypothesis, which follows that proposed by Winstein to account for the high ratio of the solvolysis rates of cis- to trans-2-methylcyclohexyl tosylates (3), is directly applicable to the reaction of I; not so to the reaction of the isomer II, for, if hydrogen participation

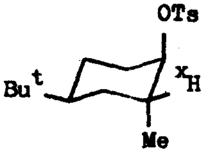


I

II



III



IV

requires an anti-periplanar arrangement of the C-H and C-OTs bonds, it is here necessary to postulate a transition state in which the six-membered ring exists in a non-chair conformation.

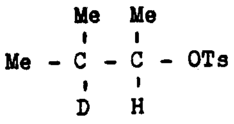
Further evidence on the course of the solvolysis of I - IV was now sought from rate data on the deuterium labelled derivatives I - IV (x = 2). These compounds were synthesised starting from 2-methyl-4-tert-butylcyclohexene (4); this compound with B_2D_6 afforded a mixture of the two "trans" alcohols, which could be separated by chromatography, and after tosylation gave compounds III and IV (x = 2). These were converted, individually, into the corresponding "cis" isomers I and II (x = 2), respectively, by fusion with tetrabutylammonium acetate (5), subsequent reduction of the cyclohexyl acetates with lithium aluminium hydride and tosylation. All alcohols had a deuterium content greater than 90%; the rate data, as given in Table 1, are corrected for incomplete deuteration. The rates were measured in 70% ethanol, using a conductometric procedure (6).

TABLE 1 Rates of Solvolysis (40.0°C, 70% ethanol) and k_H/k_D Values for the Tosylates I - IV

Tosylate		k_1 (sec^{-1})	k_H/k_D
I	^1H	$2.775 \pm 0.006 \cdot 10^{-4}$	2.08
	^2H	$1.333 \pm 0.003 \cdot 10^{-4}$	
II	^1H	$2.636 \pm 0.002 \cdot 10^{-4}$	1.96
	^2H	$1.343 \pm 0.003 \cdot 10^{-4}$	
III	^1H	$1.690 \pm 0.017 \cdot 10^{-6}$	1.19
	^2H	$1.418 \pm 0.030 \cdot 10^{-6}$	
IV	^1H	$1.804 \pm 0.005 \cdot 10^{-5}$	1.15
	^2H	$1.567 \pm 0.001 \cdot 10^{-5}$	

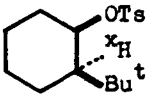
The values of k_H/k_D for the two "trans" isomers do not differ greatly from unity, being 1.19 for III and 1.15 for IV; by contrast, the values for I and II are 2.08 and 1.96, respectively, corresponding closely to values found previously (7) for compounds of the type V. These data confirm our previous assumption of a different mode of hydrogen involvement, in the rate determining step of the reaction, for the compounds I and II on the one hand and the compounds III and IV on the other.

It is assumed that retardation through replacement of hydrogen by deuterium is greatest when the C_β-D bond is anti-parallel to the developing vacant p-orbital. For the isomers III and IV such an arrangement is not attainable. In the isomer I the C-O vs C-D anti-periplanar arrangement exists in the ground state chair form; in isomer II it is attainable only if the molecule reacts by way of a non-chair transition state. The values of k_H/k_D now determined for the compounds I - IV are thus entirely compatible with the conclusions previously drawn (1) regarding their mechanism of solvolysis.

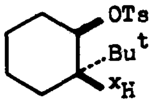


$$\mathrm{Me}-\underset{\mathrm{D}}{\overset{\mathrm{Me}}{\mathrm{C}}}-\underset{\mathrm{H}}{\overset{\mathrm{Me}}{\mathrm{C}}}-\mathrm{OTs}$$

V



VI



VII

An objection against this interpretation has to be dealt with. Goering and Reeves (8) investigated the solvolysis of cis- and trans-2-tert-butylcyclohexyl tosylate (VI and VII, x = 1) and found (a) that the reaction of both isomers is fast relative to that of other 2-alkylcyclohexyl tosylates and (b) that the solvolysis of the cis-isomer VI proceeds only two to three times as fast as that of the trans-isomer VII whereas the k_{cis}/k_{trans} ratio for the corresponding 2-methyl, 2-isopropyl and 2-cyclohexyl cyclohexyl tosylates varies from 60 to 90. They concluded from (b) that there is no acceleration through hydrogen participation in the reaction of cis-2-tert-butylcyclohexyl tosylate (VI) and considered that, consequently, there should not be any in other cis-2-alkylcyclohexyl tosylates, either, it being "difficult to see why hydrogen participation should result in increased reactivity with an adjacent equatorial (cis-placed) methyl or isopropyl but not tertiary butyl group". We suggest that this argument is not valid and propose the following alternative interpretation for the rates of VI and VII.

The relatively high solvolysis rates of both cis- and trans-2-tert-butylcyclohexyl tosylate result from the fact that in both VI as well as VII the C-O and $C-CH_3$ bonds are "syn-axial" with respect to one another; from data on cholestane derivatives (9) this may be estimated to raise solvolysis rates by a factor greater than 5. As for the second point, we think that the unusually small value of the ratio k_{cis}/k_{trans} for the tert-butyl pair VI, VII does not indicate absence of hydrogen participation in the cis-isomer VI but rather is a consequence of an unusually large acceleration of the solvolysis of the trans-isomer VII. This acceleration - relative to the other trans-2-alkylcyclohexyl tosylates - arises as follows. If, as has been suggested, equatorial tosylates react by way of a boat transition state (1,10), then structural features which lower the energy required for converting the chair into a boat will accelerate solvolysis. The syn-clinal interaction between the vicinal equatorial tert-butyl and the tosyloxy group clearly is a feature of this kind (11). Evidence that such interactions do destabilize the chair relative to a boat form is available (12).

The above arguments may be tested through rate measurements on C_β-deuterated substrates. The two compounds VI and VII (x = 2) have therefore been synthesised; B_2D_6 addition to tert-butylcyclohexene (13) afforded the appropriately deuterated trans-2-tert-butylcyclohexanol from which the cis-isomer was obtained by oxidation and subsequent reduction of the ketone by lithium aluminium hydride, followed by chromatographic separation of the isomers. The rate data (Table 2) show that the values of k_H/k_D (1.24 for

TABLE 2 Rates of Solvolysis (25.0°C, 70% ethanol) and k_H/k_D Values for the Tosylates VI and VII

Tosylate		k_1 (sec^{-1})	k_H/k_D
VI	^1H	$3.242 \pm 0.004 \cdot 10^{-4}$	2.20
	^2H	$1.474 \pm 0.002 \cdot 10^{-4}$	
VII	^1H	$8.170 \pm 0.016 \cdot 10^{-5}$	1.24
	^2H	$6.598 \pm 0.010 \cdot 10^{-5}$	

trans-isomer VII and 2.20 for the cis-isomer VI) indeed follow the pattern believed to be indicative of hydrogen participation in the cis-isomer (14).

The present results thus lend further support to the view (1,10) that equatorial tosylates undergo solvolysis via a non-chair transition state and that solvolysis of cis-2-alkylcyclohexyl tosylates is accelerated by hydrogen participation (1,3).

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(14) The somewhat higher values of k_H/k_D found for VI and VII when compared with I - IV are probably a consequence of the lower temperatures employed in the solvolysis of the former compounds.