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THE E2C-E2H MECHANISM. SUBSTITUENT EFFECTS IN TIGHT AND LOOSE S_N2 AND E2 TRANSITION STATES

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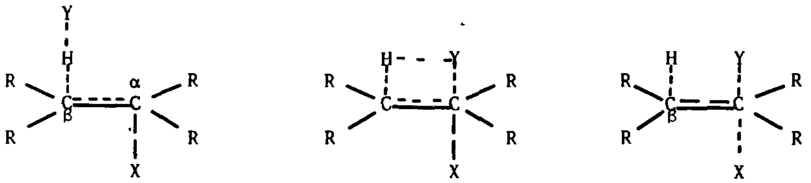
Eck and Bunnett[1] feel that the notion of E2C-like transition states[2] should be discarded. This is because the well known[3] neopentyl steric effect on S_N2 reactions of ethyl and neopentyl halides is not observed in the E2C-like reactions of t-butyl bromide and of 2,3,3-trimethyl-2-bromobutane with chloride ion in acetone[1]. In this paper we show that there is no reason to expect a "neopentyl steric effect" in these E2C-like reactions.

We are not prepared to discard the E2C concept, because all the observations on E2 reactions which we know of can be accommodated by a transition state spectrum II, between the extremes I and III. Typical observations are the nucleophilic tendencies of bases[2], substituent effects at C_β[4], solvation of transition states[5], leaving group tendencies[6], isotope effects[7], Hofmann-Saytzeff products[4,8], and anti versus syn stereochemical requirements[8] in E2 reactions.



I
E2H

II

III
E2C

We feel that S_N2 reactions at a primary carbon atom are not good models for S_N2 reactions at a tertiary carbon atom. They are even worse models for E2C-like reactions at a tertiary carbon atom, especially when dealing with steric effects. This is because solvent effects show[5] that transition states for S_N2 and E2 reactions "loosen", i.e. entering and leaving groups, Y and X are increasingly further from C_α, as C_α changes from a primary, to secondary, to a tertiary alkylated atom[5]. Steric effects fall off dramatically with increasing separation of non-bonded groups, the neopentyl steric effect especially so, as shown by Ingold's calculations[3]. The fall off from a primary to a secondary system is shown in the Table. The S_N2 reaction (1) of ethyl bromide is 16,000 times faster than the S_N2 reaction (2) of neopentyl bromide, but in the S_N2 reactions at secondary carbon, reaction (5) of isopropyl bromide is only 500 times faster than the reaction (6) of 3,3-dimethyl-2-bromobutane. The change of solvent is not significant[9]. We would expect[5] that the "neopentyl" steric effect would continue to decrease for the much looser S_N2 reactions at 3° carbon. Some indication that this might be the case is given by the S_N2 reaction (7) of t-butyl bromide, which is only 3 times faster than the apparent S_N2 reaction (8) of 2,3,3-trimethyl-2-bromobutane. The reaction of NBu_4N_3 in acetone with 2,3,3-trimethyl-2-bromobutane gives acid which is 96.5 ± 1% of the bromide ion produced throughout the reaction. Using procedures outlined in reference 9, we conclude that 3.5 ±1% of the reaction is substitution, but we can only assume that it is a S_N2 substitution, because the reaction rate is less than the solvolysis rate, in acetone. Reasons for the choice of azide ion to detect a S_N2 component are mentioned in reference 2. The rate difference of 3, which we allocate to the S_N2 reactions (7) and (8) of tertiary alkyl bromides, is not unreasonable, in view of the decrease in neopentyl steric effect from the primary (1) and (2) to the secondary (5) and (6) S_N2 reactions. Although the data from reactions (7) and (8) is only suggestive, rather than conclusive, the other data in the Table show that Eck and Bunnett are not justified in using the neopentyl steric effect in S_N2 reactions at a primary or secondary carbon atom to predict behaviour in the much looser[5] E2C-like reactions at tertiary carbon.

Even the neopentyl steric effect for a S_N2 reaction at 3° carbon would not be a good model for the E2C-like reactions at 3° carbon, for the following reasons. Reactions (9) - (14) in the Table are not necessarily[2,4,5,8] E2C-extreme reactions, but rather proceed through transition states II like III. E2C-like reactions will always have a looser C_α--Y bond in the transition state than will the S_N2 reactions of the same reactants[8]. If the C_α---Y bond is tight enough in the transition state, substitution products result, as for reactions of 1° alkyl halides with chloride ion, if the C_α---Y bond is forced to be very loose, olefins predominate, as for reactions of 3° alkyl halides. The steric requirements of an E2C-like transition state will always be different from the corresponding S_N2 transition state, because in the former, C_β is virtually sp^2 hybridised and there is a well developed double bond between C_α and C_β[2,4,5,8]. These features are absent from the S_N2 transition state[3]. The effect of alkyl substituents, at sp^2 hydridised C_α or C_β, on the stability of the well developed double bond in the transition state must also be considered for E2C-like but not for S_N2 reactions[4,8]. Thus methyl groups relative to hydrogen at C_α or C_β stabilize an E2C-like transition state by interacting with the well developed double bond, this effect is absent in the S_N2 reactions.

In view of the points raised here, the comparisons made by Eck and Bunnett[1] are not "evidence against the putative E2C mechanism".

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TABLE

E2 and SN2 Reactions of Alkyl Bromides

No.	SN2 reactions	Solvent	T°	log k^S	Δ log k^S [e]
(1)	$MeCH_2Br + Cl^{-a}$	DMF	100.0	+0.95	4.21
(2)	$\underline{t}$-$BuCH_2Br + Cl^{-a}$	DMF	100.0	-3.26	
(3)	$MeCH_2Br + N_3^{-a}$	DMF	100.0	+1.0	3.22
(4)	$\underline{t}$-$BuCH_2Br + N_3^{-a}$	DMF	100.0	-2.22	
(5)	$MeCBrHMe + Cl^{-a,b}$	Me_2CO	100.0	-1.0	2.4
(6)	$\underline{t}$-$BuCBrHMe + Cl^{-b,c}$	Me_2CO	100.0	-3.4	
(7)	$CH_3CBrMe_2 + N_3^{-a,b}$	Me_2CO	75.0	-2.77	0.4
(8)	$\underline{t}$-$BuCBrMe_2 + N_3^{-b,d}$	Me_2CO	75.0	-3.18	
	E2 reactions			log k^E	Δ log k^E
(9)	$MeCBrHMe + Cl^{-a,b}$	Me_2CO	100.0	$<-3^f$	<1
(10)	$\underline{t}$-$BuCBrHMe + Cl^{-b}$	Me_2CO	100.0	-4.1	
(11)	$MeCBrMe_2 + Cl^{-a,g}$	Me_2CO	69.9	-2.26	-0.2
(12)	$\underline{t}$-$BuCBrMe_2 + Cl^{-g}$	Me_2CO	69.9	-2.07	
(13)	$MeCBrMe_2 + N_3^{-a,b}$	Me_2CO	75.0	-2.17	-0.41
(14)	$\underline{t}$-$BuCBrMe_2 + N_3^{-b}$	Me_2CO	75.0	-1.76	

(a) Reference 9. (b) This work using 0.04-0.05M NBu_4Cl or NBu_4N_3, 0.02M alkyl bromide and 0.05M 2:6 - lutidine. (c) Minor corrections have been made to allow for decomposition of NBu_4Cl at 100°. (d) Total bromide was 3.5 ± 1% greater than acid produced throughout reactions, and this was attributed to a SN2 reaction. cf. text and reference 9. (e) log K (MeRBr) - log k ($\underline{t}$-BuRBr). (f) Propene could not be detected by v.p.c. (g) Reference 1.