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SOLVATION EFFECTS IN THE BECKMANN REARRANGEMENT
THE PROBLEM OF STERIC HINDRANCE TO SOLVATION

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Steric hindrance to solvation (the shielding effect of bulky groups to solvation at a reaction center) has been quoted as influencing acid and base dissociation constants (1,2), relative rate constants in solvolyses reactions (3,4,5) and certain electronic transitions (6). A quantitative evaluation of this effect is difficult, because of the problem of separating the contributions of polar from steric effects in a reaction. The Beckmann rearrangement of oxime picryl ethers 1 seems to be a suitable model reaction for studying the influence of steric inhibition of solvation in solvolysis for the following reasons:

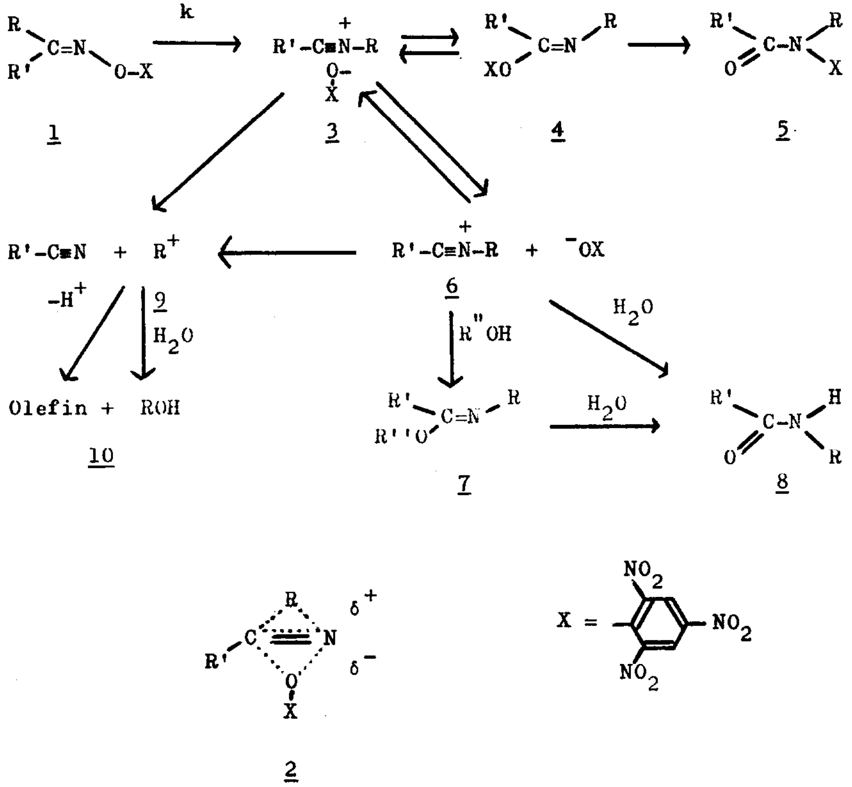
1: Compounds 1a - 1k bearing stationary and migrating substituents R and R', respectively, with different effective volumes, can easily be synthesized from the corresponding ketones by making the alkali salts of their oximes (7) with strong bases (NaH in ether, $KOC(CH_3)_3$ in ether) and treating them with picrylchloride (8).

2: The rearrangement can be carried out in a wide range of solvents with different polarities (9), in principle from mixtures of water with organic solvents to hydrocarbons.

3: The kinetics of the reactions in transmitting solvents can be measured UV-spectrophotometrically (10) by a continuous method at the absorption maximum of picryl ethers between 290-295 nm.

4: The mechanism of the Beckmann rearrangement and fragmentation of ketoxime derivatives has been studied extensively (10,11,12) and is visualized as in FIG.I.

FIG. I



Oxime picryl ethers 1 rearrange in the rate determining step to nitrilium ions 3 or imino-picryl ethers 4 (10). The transition state can be formulated as a highly polar, crypto-ionic, ion-pair-like complex 2 (11). Reaction path 1→4→5 (Chapman rearrangement (13)) is observed in non nucleophilic solvents (10). If R is a good electrofugic (11) group, 3 or 6 solvolyzes to a nitrile and a carbonium ion 9. The product ratio 5:10:8 and the relative reaction rates are influenced by the nature of R (migratory aptitude); R' (polar effects), the steric interaction of R with R' in the ground state, the solvent polarity and the reaction temperature (11).

The first order rate constants k at 77.6 °C, of oxime picryl ethers 1a - 1k in 50 %, 70 %, 90 % dioxane/water mixtures (D/W), in 1,4-dichlorobutane (DCB) and in pure dioxane (D) (1g also in isooctane) have been measured or determined by extrapolations from data at lower temperatures. From simple electrostatic considerations (14) it was expected that the rates of highly substituted substrates 1 (hindrance to solvation by hydrophobic groups in the ground, and mainly the transition state, lower effective dielectric constant near the reaction center) would be less sensitive to solvent change than the rates of models with substituents R and R' having smaller effective size (less shielding to solvation). This is based on the assumption that both the polar and strain effects, as well as the geometry of the transition state 2 are not drastically altered by solvent polarity change more for one particular picryl ether than for another (15). Plots of log k of 1a - 1k vs. a polarity scale (either E_T (9), Y (9, 16) or internal scale for the Beckmann rearrangement) for the chosen solvents and a comparison of the slopes m should indicate whether or not steric hindrance to solvation is an effective factor contributing to relative rearrangement rates (3).

The results are summarized in FIG. II and TABLE III.

FIG. II

Plot of log k vs. E_T (Kcal/mole) for the Beckmann Rearrangement of 1a - 1k in Different Solvents

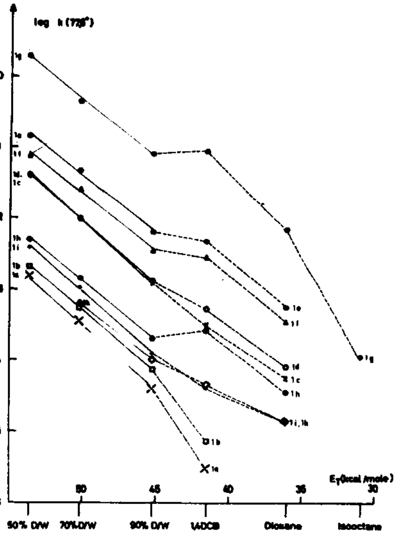


TABLE III

Oxime Picryl Ethers

Oxime Picryl Ethers Nr.	R	R'	Sign in FIG.II	m_Y a)	m_{E_T} b)	$S = \frac{k_{70\%D/W}}{k_{DCB}}$ c)	log S	ΣE_s d)
1a	C_2H_5-	CH_3-	✕	0.45	0.18	118.2	2.07	-0.07
1b	$n-C_4H_9$	CH_3-	□	0.43	0.17	80.2	1.90	-0.39
1c	$CH_3(C_2H_5)C-$	CH_3-	×	0.45	0.18	32.0	1.50	-1.13
1d	$(CH_3)_3C-$	CH_3-	○	0.44	0.18	19.6	1.29	-1.54
1e	$(C_2H_5)_3C-$	CH_3-	◒	0.40	0.16	9.92	0.996	-3.80
1f	$(CH_3)_3C-$	$n-C_4H_9-$	△	0.40	0.16	8.86	0.947	-1.93
1g	$(CH_3)_3C-$	cyclo-$C_6H_{11}-$	⊙	0.40	0.16	5.09	0.706	-2.33
1h	$(CH_3)_3C-$	C_6H_5-	●	0.41	0.17	5.48	0.738	e)
1i	$n-C_4H_9-$	$n-C_4H_9-$	+	0.44	0.17	26.0	1.413	-0.78
1k	$n-C_{17}H_{35}-$	$n-C_{17}H_{35}-$	◇	0.36 f)	0.14 f)	13.8	1.140	e)

a) Slope of log k vs. Y for dioxane/water mixtures. b) Slope of log k vs. E_T for dioxane/water mixtures. c) Ratio of k in 70 % dioxane/water (D/W) to k in 1,4-dichlorobutane (DCB). d) Sum of Taft's steric parameters E_S for R and R'. e) E_S values were not available. f) Only from measurements in 70 % and 90 % dioxane/water.

In dioxane/water mixtures m_{E_T} and m_Y are not significantly structure dependent*. Thus steric hindrance to solvation does not show up as an effect on relative rate constants for polar solvent mixtures. This is probably due to cancelling effects on $\Delta\Delta F^{\neq}$ in the ground and transition states (15). This will be better discussed, when all the activation parameters $\Delta H^{\neq}$ and $\Delta S^{\neq}$ are available (17).

In contrast to the foregoing results when reaction rates in non-hydroxylic solvents (1,4-dichlorobutane or dioxane) are compared with those in dioxane/

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* A similar structural independence (18) of differential rates in protic solvents has been observed in the solvolysis of substituted bromoadamantanes (18,19) and substituted cyclohexyltosylates (19). A negligible structural dependence of relative rates on solvent mixtures has been found in S_N1 reactions (3). In one case (5) this is probably due to a change in mechanism with solvent polarity.

water mixtures, there seems to be a characteristic relationship between the relative rates in two solvents and the bulk of R and R'. This can be shown by comparison of log $[k_{70\,\%\,D/W}/k_{DCB}]$ with the sum of Taft's E_S values (20) for the substituents R and R' (TABLE III). Although it is clear that large groups exhibit a different shielding effect to attack of water at the carbonyl center in acid catalyzed ester hydrolysis than to solvation in the Beckmann rearrangement, the linear relationship between log S and ΣE_S is remarkably good. This result suggests that with the model reaction <u>1</u>→<u>3</u> it might be possible to separate steric inhibition to solvation (log S might be a quantitative value) from other effects. However, further kinetic measurements in other solvents (e.g. alcohol/water mixtures), work currently being carried out in this laboratory are needed to support this speculation. The interpretation of the activation parameters for the 1,2-migrations of <u>1a</u> - <u>1k</u> in the employed and new solvent systems will be discussed on the basis of Arnett's (21) hypothesis of ground state and transition state solvation and the structuredness of water in binary solvent mixtures (22) in a future paper to appear in Helvetica Chimica Acta (17).

The observed structural dependence of relative rates of oxime picryl ethers in different solvents also throws some doubt on the usefulness of linear free energy relationships for extended polarity scales (9) (i.e. for protic <u>and</u> aprotic solvents) based on solvolyses reactions (23).

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