Tetrahedron Letters,Vol.23,No.9,pp 975-978,1982
Printed in Great Britain 0040-4039/82/090975-04$03.00/0

ION-PAIRING AND AGGREGATION EFFECTS ON REACTIVITY IN AN INTRAMOLECULAR HYDRIDE TRANSFER

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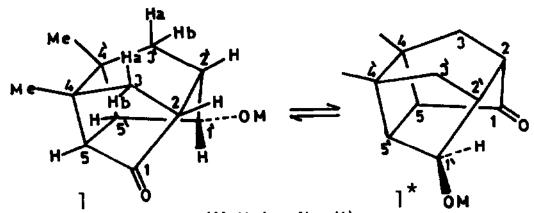
Abstract The concentration and cation dependence of rates of degenerate rearrangement of 1(M=Li, Na, K) in dmso have been examined and are shown to be consistent with dissociation of the salts prior to rearrangement

Alkali metal salts of ketols such as 1(R=H)[1] isomerise by intramolecular hydride transfer in a process apparently related to the familiar Meerwein-Ponndorf-Verley-Oppenauer redox couple However, because of the constraints of the molecular framework, intramolecular O. O distances may be large [4 62Å in 1(R=H)[2]] compared to the size of alkali metal cations,[3] and cyclic transition states involving simultaneous transfer of cation and hydride from alkoxide to carbonyl group[4] are not sterically feasible The role of the cation in these and other anionic rearrangements is of interest,[5] and we now describe relevant experiments with 1(M=Li, Na, and K)



1 (M=H,Li,Na,K) 1*

The ketoxides were prepared by addition of one equivalent of the appropriate metal d_6-dimsyl to d_6-dmso solutions[6] of 1(M=H)[1] The 300 MHz ^1H NMR spectra of 1(M=H) and 1(M=Na) were well resolved and have been assigned with the aid of de-coupling experiments (see Table 1)

Table 1 NMR data for 1(M=H, Li, and Na) in $d_6$dmso

Assignment	Chemical shift (δ) M=H	M=Li	M=Na	pattern and splittings (Hz)
H1'	4.82	4.01	4.07	s, $W_{\frac{1}{2}}$=2.5
H2	2.19	2.09	2.06	dm, 9 5, $W_{\frac{1}{2}}$=6
H2'	2.32	#	1.85	dm, 9.5, $W_{\frac{1}{2}}$=6
H3a	2.08	#	2.15	d, 13 0
H3'a	1.92	#	1.71	d, 13 0
H3b	0.86	0.78	0.80	dd, 13 0, 3.0
H3'b	1.50	#	1.78	dd, 13.0, 3 0
H5 or H5'	2.01	#	1 67	dd, 9.5, 2 5
H5 or H5'	2.15	#	1.85	dd, 9 5, 2 5
Me4 or Me4'	1.15	1.18	1.21	s
Me4 or Me4'	1.01	1.00	1.02	s

#not resolved.

Rates of degenerate re-arrangement in 1(M=Na) were determined by line shape analysis[7] of the region from δ0 4 to 1 5, containing signals from the exchange methyls and H3b (see figure 2) With 1(M=K) static spectra could not be obtained, even at 400 MHz , at temperatures above the freezing point of dmso, and, although a small cation dependence of methyl signal separation was observed in the spectra of 1(M=Li) and 1(M=Na), static parameters from 1(M=Na) were used in its line shape analysis. In stark contrast, only small line broadening could be observed in the spectra of 1(M=Li). Rates for 1(M=Li) and 1(M=K) are therefore less reliable[8] than for 1(M=Na).

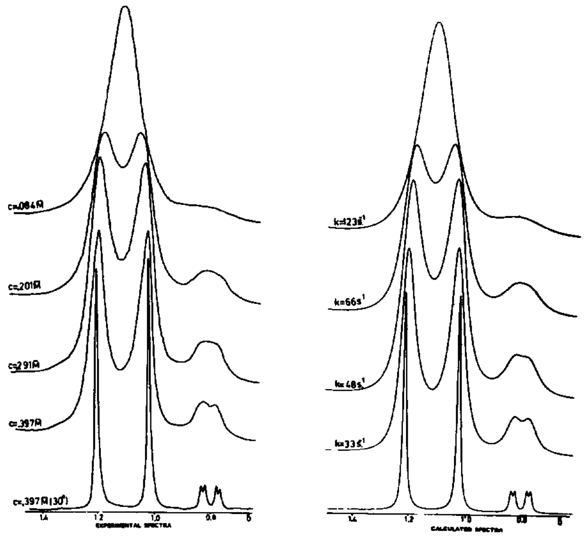


Figure 2 . Concentration dependent ^1H NMR spectra of 1(M=Na) in d_6-dmso at 84^o

The collected rate data (Table 2) shows that for all the cations, rates increase with decreasing metal ketoxide concentration. Extrapolation of the rates for the solutions of ca 045M to 84^o gives an approximate ordering of reactivity of 1 10^2 10^5 for the Li, Na, and K ketoxides, a similar, but more emphatic ordering, to that found by Warnhoff[5] and by Lansbury[9] for related intramolecular processes and the reverse of the cation dependence of the intermolecular counterpart [10]

Both the cation and concentration dependence of the rates are consistent with the solutions containing largely unreactive associated species, $(ROM)_m$ or $(R^*OM)_m$, in equilibrium

Table 2 : NMR* rate data for degenerate rearrangement of 1(M=Li, Na, and K)

cation	concentration(c) of ketoxide, ($\bar{M}$)	Rates (k_{obs} (T)), (sec.$^{-1}$ (^{o}C))					
K^a	.044	—	—	—	—	515(28),	221(22)
K^a	.022	—	—	—	—	778(28),	359(22)
K^a	.011	—	—	—	—	1071(28),	411(22)
K^a	.006	—	—	—	—	1508(28),	699(22)
Na^b	.397	61(95),	33(84)	—	—	—	—
Na^b	.291	81(95),	48(84)	—	—	—	—
Na^b	.201	103(95),	66(84)	36(75)	—	—	—
Na^b	.084	194(95),	123(84),	71(75),	31(68)	—	—
Na^c	.046	—	196(84)	—	65(65)	—	—
Li^d	070	—	1 4(83)	—	—	—	—
Li^d	.046	—	1.7(83)	—	—	—	—
Li^d	.025	—	4 2(83)	—	—	—	—
Li^d	.015	—	8.5(83)	—	—	—	—

*Spectra determined at 400 MHz(a), 220 MHz(b), 300 MHz(c), and 80 MHz(d).

with a much smaller amount of reactive dissociated species. Ab initio GVB and CI calculations[11] show that the $H\text{-}CH_2O^-$ bond is weaker than the $H\text{-}CH_2OK$ and the $H\text{-}CH_2ONa$ bonds by 4.8 and 6 4 $kcal.mol.^{-1}$ respectively and we suggest that the reactive species in solution may be the free ketoxide anion, RO^- or R^*O^-, which is only weakly solvated[12] by dmso. The exchange process may then be represented by equations (1) through (3), where k_{tr} is the rate constant for hydride in RO^- or R^*O^-.

$$(1) \qquad (ROM)_m \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} mRO^- + mM^+$$

$$(2) \qquad RO^- \underset{k_{tr}}{\overset{k_{tr}}{\rightleftharpoons}} R^*O^-$$

$$(3) \qquad mR^*O^- + mM^+ \underset{k_1}{\overset{k_{-1}}{\rightleftharpoons}} (R^*OM)_m$$

The association constant, $K_{ass}=k_{-1}/k_1$, combines equilibria for aggregation (4) and ion-pairing (5) so that $K_{ass}=K_{agg} \cdot K_{ip}^m$. Exner's[12] conductimetric measurements on dmso solutions of Li, Na, and K t-butoxide gave ion-pairing constants of 10^8, 10^6, and 270 M^{-1} respectively so that K_{ass} can reasonably be expected to be large.

$$(4) \qquad m(ROM) \overset{K_{agg}}{\rightleftharpoons} (ROM)_m$$

$$(5) \qquad mM^+ + RO^- \overset{K_{ip}}{\rightleftharpoons} ROM$$

The expression (6) then relates the observed rate constants (k_{obs}) to the stoichiometric metal ketoxide concentration(c).

$$(6) \qquad k_{obs} = \left[k_{tr} \ K_{ass}^{-1/2m} \ m^{-1/2m} \cdot 2^{(\frac{1}{2}-1/2m)}\right] . c^{(1/2m - 1)}$$

The most extensive and reliable data is the set for 1(R=Na) at 84^0 and a least squares fit of this data to equation (7) gave the order of reaction, n = -.77($\pm$ 06),[8] corresponding

$$(7) \qquad k_{obs} = A \ (c)^n$$

to an aggregation number, m = 2.17, suggesting that the aggregates are mainly dimeric. The fit also gave A = 18.2($\pm$3 5)[8], to be identified with the square bracketed factor in (6), and the effect of ion-pairing and aggregation may be gauged by taking Exner's value for $K_{ip} = 10^6$ for Na-t-butoxide,[12] and rearranging to give (8).-

$$(8) \qquad k_{tr} = 1.8 \times 10^4 \times K_{agg}^{23}$$

We have no independent estimate for K_{agg}, but with $K_{agg} \geqslant 1$, 1 8 x 10^4 sec^{-1} represents a crude minimum estimate for the rate constant for hydride transfer within the dissociated alkoxide anion [cf k_{obs} - 1.96 .10^2 sec^{-1} for c=0.046$\bar{M}$ (M=Na)]

While the data for 1(M=Li) and 1(M=K) does not merit a similar treatment, the pattern is clear, reactivity, in dmso at least, is dominated by aggregation and ion-pairing phenomena Attempts to correlate reactivity with ketol structure[6] are therefore perilous. Ion-pairing is, however, suppressed in presence of appropriate cryptands.[13] Rates should then be cation and concentration independent and characteristic of ketoxide structure, and we hope to report on this aspect in a future paper.

Notes and References

1 W. K. Appel, T. J. Greenhough, J. R. Scheffer, J. Trotter and L. Walsh, J. Amer. Chem Soc., 102, 1158 (1980).

2 From empirical force field calculation, using method of N. L. Allinger, M. T Tribble, M. A Miller, and J Tyminski, J Amer. Chem Soc , 93, 1637 (1971)

3 Li^+, Na^+, and K^+ have ionic radii of 0 60, 0.95, and 1.33Å respectively L Pauling, 'The Nature of the Chemical Bond', Cornell U P., Ithaca, (1960)

4 A. Imamura and T. Hirano, J. Amer Chem. Soc , 97, 4192 (1975), and references therein

5 E. W. Warnhoff, P. Reynolds-Warnhoff, M. Y. H. Wong, J Amer Chem Soc , 102, 5956 (1980).

6 G.-A Craze and I Watt, J.C S Perkin II, 175 (1981)

7 The signals from the methyls and H3b and H3'b were modelled as five appropriately scaled AB exchanging pairs. G Binsch in Dynamic NMR Spectroscopy L M Jackmann and F. A. Cotton, Eds , Academic Press. 1975, Ch 3

8 Rates for 1(R=Na) at 84^{o} have 95% confidence limits $\leqslant$5% from curve fitting of the spectra. The quoted errors for A and n are also 95% confidence limits based on the fit.

9 P. T. Lansbury and F. D Saeva, J Amer Chem Soc., 89, 1890 (1967)

10 R. D. Burnett and D. N. Kirk, J.C S Perkin II, 1482 (1976)

11 M L. Steigerwald, W A. Goddard III, and D A Evans, J Amer Chem Soc , 101, 1994 (1979)

12 J H. Exner and E. C. Steiner, J. Amer Chem Soc , 96, 1782 (1974)

13 For example see G A. Russell and C E Osuch, J Org. Chem , 45, 1242 (1980)

Acknowledgement We thank the SERC for financial support and the High Field NMR facility (Sheffield) for the 400 MHz spectra.