

NUCLEAR MAGNETIC RESONANCE
SPECTRA OF PHENOXIDES AND
RELATIONSHIP TO RATES OF ALKYLATION

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We wish to report a remarkable correlation between the nuclear magnetic resonance spectra of alkali metal phenoxides and their rates of alkylation in a number of aprotic solvents.

The reactivity of synthetic intermediates such as enolates and alkoxides is influenced to a great degree by the solvent.² The high reactivity of these anions in dipolar aprotic solvents has frequently been attributed primarily to the solvation of the metal counterion by the dipolar aprotic solvent,^{2c,d,e,3} while the possibility of additional transition state solvation has received little emphasis.⁴ In order to provide direct information on the nature of these solvent effects, we have examined the proton NMR spectra of alkali metal phenoxides in a number of solvents. Some of our data for sodium and potassium phenoxide are listed in the Table.⁵

Since the chemical shift of an aromatic hydrogen is related to the electron density at that position of the ring,⁶ the upfield shift of the phenoxide hydrogens⁷ should reflect the ionic character of the metal-oxygen bond (in aprotic solvents), and hence the solvating ability of the medium.⁸ In principle, the NMR spectra of metal enolates⁹ should provide similar information; however, phenoxides have the advantage of having hydrogens (para) farther removed from the metal cation and the associated solvation shell.^{10,11}

Other workers¹³ have shown that the UV spectra of phenoxides are also dependent on solvent, and their values are included in the Table. The UV and NMR data are compared in Figure 1. It can be seen that the order of solvating ability determined by the two methods is quite similar.

We were particularly interested to see if the chemical reactivity of phenoxides could be correlated with this apparent solvating ability. Ugelstad and co-workers have measured the rates of alkylation of sodium and potassium phenoxides with n-butyl chloride and with n-butyl bromide in a number of solvents,¹⁴ and more recently Reichle¹⁵ has measured the reactivity of phenoxides toward several aryl halides in a number of solvents. In Figure 2 the kinetic data for the reaction of potassium phenoxide with n-butyl bromide¹⁴ and with 4-chlorodiphenylsulfone¹⁵ are compared to the chemical shifts.

This comparison clearly distinguishes between the two types of solvents involved, the ethers (dioxane, THF, and the glymes), and the dipolar aprotic solvents (acetone, acetonitrile, DMF, and DMSO).¹⁶ The close correlation between the reaction rates and the NMR shifts in the ethers is consistent with the view that the primary interaction of these solvents is with the metal cation, in both the ground state and the transition state.^{14,17} It is perhaps premature to speculate on the reasons for the departure of the dipolar aprotic solvents from this

Table

no.	solvent	Sodium phenoxide				Potassium phenoxide			
		NMR ^a			UV ^b	NMR ^a			UV ^b
		ortho	meta	para	$\lambda_{\max}(E_T)$	ortho	meta	para	$\lambda_{\max}(E_T)$
1	D ₂ O	6.64	7.16	~6.59	287 (99.6) ^c	-	-	-	-
2	n-butylamine	6.39	6.86	6.17	308 (92.8)	6.46	6.92	6.23 ^d	-
3	dioxane	6.38	6.96	6.28	299.7 (95.4)	6.27	6.91	6.15 ^d	306.8 (93.2)
4	acetone	6.42	6.85	6.16	-	6.41	6.85	6.11	-
5	acetonitrile	6.37	6.93	6.21	-	6.29	6.86	6.06	-
6	THF	6.40	6.88	6.18	300.6 (95.1)	6.31	6.85	6.06	-
7	glyme	6.48	6.88	6.18	302 (94.7)	6.30	6.84	6.04	314 (91.1)
8	diglyme	6.41	6.85	6.13	-	6.27	6.81	5.99	-
9	triglyme	6.39	6.83	6.10 ^d	-	6.23	6.75	5.91	-
10	tetraglyme	6.36	6.81	6.07	-	6.20	6.73	5.87	-
11	DMF	6.33	6.80	6.00	323 (88.5) ^e	6.20	6.73	5.85	-
12	DMSO	6.03	6.68	5.82 ^d	-	5.97	6.65	5.75	-
13	HMPA	6.23	6.63	5.78	-	6.16	6.61	5.74	-

^aProton chemical shifts in ppm relative to TMS ($\delta = 0$) (relative to DSS in D₂O), all at ca. 35°. ^bWavelength of secondary band in m μ ; transition energy in kcal/mole; from ref. 13c unless otherwise indicated. ^cIn water; see ref. 13a. ^dPartly insoluble. ^eRef. 13 b; see also ref. 13d.

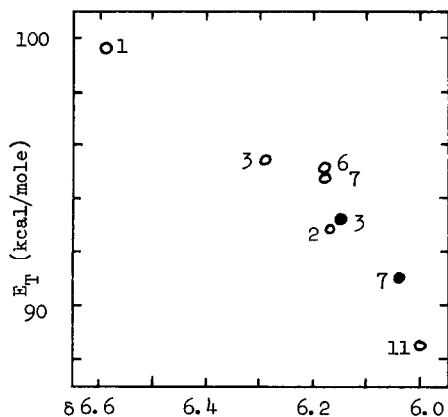


Figure 1. Correlation of UV data (from ref. 13) with NMR data (chemical shift of para hydrogen): (o) sodium phenoxide; (●) potassium phenoxide.

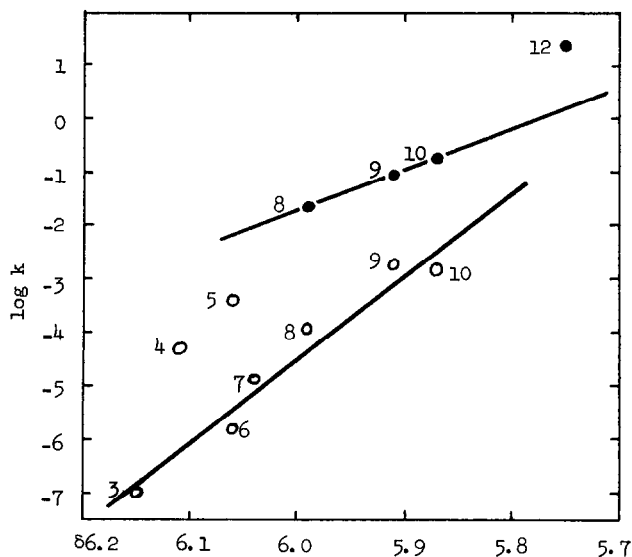


Figure 2. Comparison of rate data with chemical shift (para) of potassium phenoxide: (o) reaction with n-butyl bromide at 25° (ref. 14); (●) reaction with p-chlorodiphenylsulfone at 160° (ref. 15).

correlation.

Despite the synthetic importance of metal enolates and alkoxides, the influence of solvent and cation on the nature of the metal-oxygen bond and the type of ion-pairing involved in these systems is still not well understood. By studying the ground state properties of phenoxides and other systems, we hope to learn more about the nature of cation-solvent interactions, and the influence of solvent on the reactivity of synthetic intermediates.¹⁸

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5. The phenoxides were prepared by a method similar to that of N. Kornblum and A.P. Lurie, J. Amer. Chem. Soc., 81, 2705 (1959). All spectra were taken on a JEOL MH-100 spectrometer using 0.1 M solutions with TMS as an internal standard (except in D₂O, where DSS was used), at ambient temperature (about 35°). In one case that was examined (sodium phenoxide in glyme), the chemical shift was essentially invariant with concentration (from 0.03 M to 1.0 M); see also ref 3g.
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we find that the chemical shifts of 0.1 M solutions of benzene or anisole change very little with solvent. A more detailed discussion of this point will be given in our full paper. See also P. Diehl, *J. Chim. Phys.*, 61, 199 (1964), and G.W. Smith, *J. Mol. Spect.*, 12, 146 (1964).

11. Phenoxides have a number of other advantages over simple enolates: they are more easily prepared, they are stable in a wider variety of solvents (including water), and their NMR absorptions are downfield from those of nearly all commonly employed solvents. The upfield shift in the NMR of metal phenoxides in DMSO was first noted by Brown,^{7a} and since then has been used several times as an aid to the structural elucidation of phenolic natural products (for example, see refs. 7b-d). Solvent effects on the NMR of metal enclates^{8a,d,h,i} and carbanion salts¹² have also been observed.
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16. Comparison of the NMR shifts with the other kinetic data from ref. 14 clearly indicates that DMF is in this group. Alkylation rates in other dipolar aprotic solvents were not reported.
17. Although measurements of ground state solvation have been compared in some cases with reaction rates in a qualitative sense (for example, ref. 13c), we are not aware of any previous examples of a direct numerical comparison.
18. We thank Research Corporation and the National Science Foundation for their support of this work.