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On the Cleavage Reaction Mechanism of Diphenyl Oxides and Related Compounds by Metallic Sodium in Liquid Ammonia. I.

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The liquid ammonia-metallic sodium cleavage reaction of methoxy substituted diphenyl oxide & dibenzo-*para*-dioxin derivatives have been discussed with respect to the molecular parameters estimated from the modified Hueckel Molecular Orbital treatments, and favorable correspondences have been acknowledged among empirical and theoretical evidences.

Introduction

Formerly, the cleavage reaction of diphenyl oxide derivatives by metallic sodium in liquid ammonia have been widely used in the structural determination of Menispermaceous plant alkaloids.[2] And, this reaction extended by Sartoretto & Sowa[3] showed special interest in the cleavage of diphenyl oxide linkage in an elegant manner, and the phenolic & nonphenolic reaction products afforded reliable parent molecular structure, as is shown below.

$$\text{R–O–R}' \longrightarrow \text{R–H} + \text{R}'\text{–OH} \qquad (1)$$

where $$\text{Na} \xrightarrow[\text{liq.NH}_3]{} \text{Na}^+ + \text{e}$$

But, on the contrary, the reaction mechanism of above fission reaction has some ambiguity in spite of numerous empirical evidence.

Recently, the modified Hueckel molecular orbital calculation —ω technique —has been proved reliable for the estimation of π-electron charge density distribution of substituted aromatics.[4] In this study, several molecular parameters of diphenyl oxide framework with methoxyl groups have been estimated from above treatment, and presented some inspection on the reaction mechanism.

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1) Location: *Toneyama 6–5, Toyonaka, Osaka.*
2) M. Kulka, "The Alkaloids," ed. R.H.F. Manske, H.L. Holmes Academic Press, New York, IV, 1954, p. 199; VII, 1960, p. 439.
3) P.A. Sartoretto and F.J. Sowa, *J. Am. Chem. Soc.*, **59**, 603 (1937); G.W. Watt, *Chem. Rev.*, **46**, 317 (1950).
4) Y. Sasaki and M. Suzuki, *Chem. Pharm. Bull.* (Tokyo), **17**, 1090 (1968).

Experimental

The diphenyl oxide and its related framework is divided into two phenoxyl groups according to the conclusion from dipole moment data.[5] The mathematical treatments have been carried out on an NEAC 2200 Type Electric Computer at Osaka University Computer Center using h_x and k_x proposed in the previous paper.[4]

Results and Discussion

I. Molecular Parameters of Methoxysubstituted Benzenes

Molecular parameters of this series—π-electron charge density distribution, free valence, superdelocalizability, etc.—are in the following.

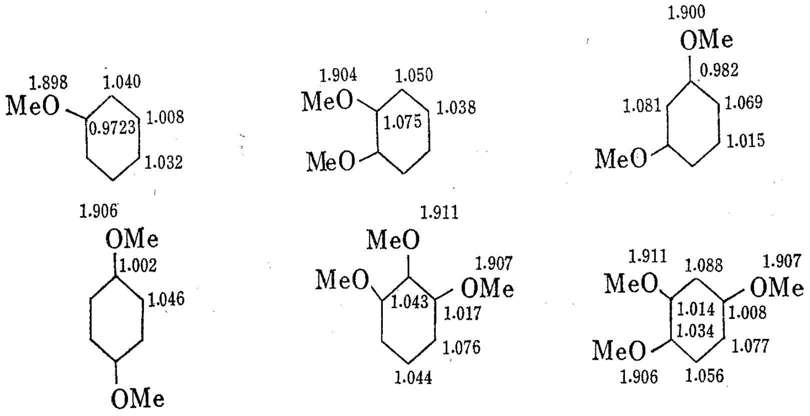

Chart 1. π-Electron Charge Density Distribution

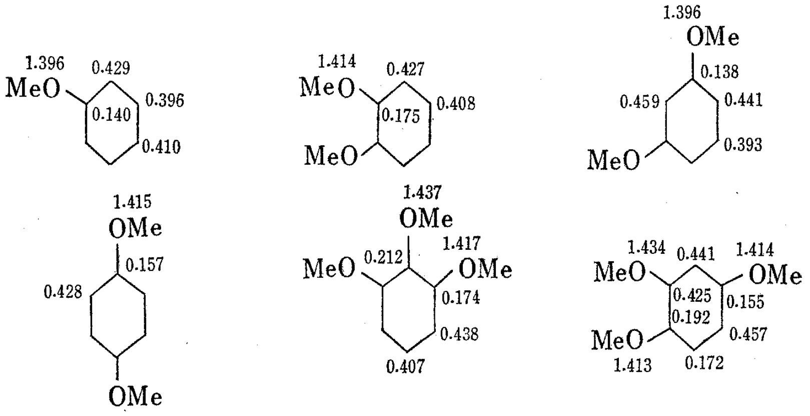

Chart 2. Free Valence

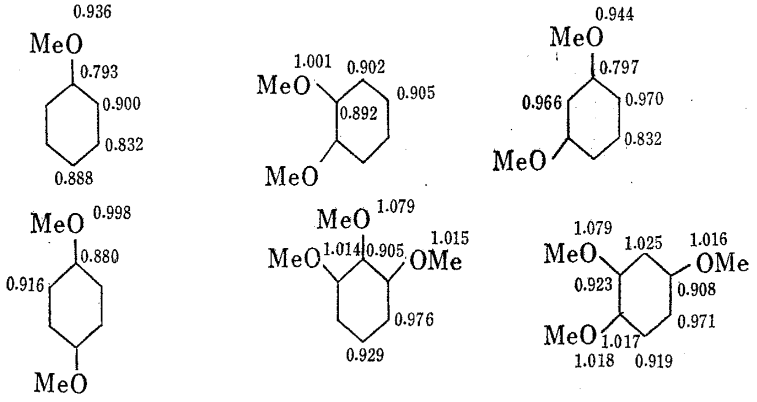

Chart 3. Free Radical Superdelocalizability

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5) K. Higashi and S. Uyeo, *Bull. Chem. Soc. Japan*, **14**, 87 (1939).

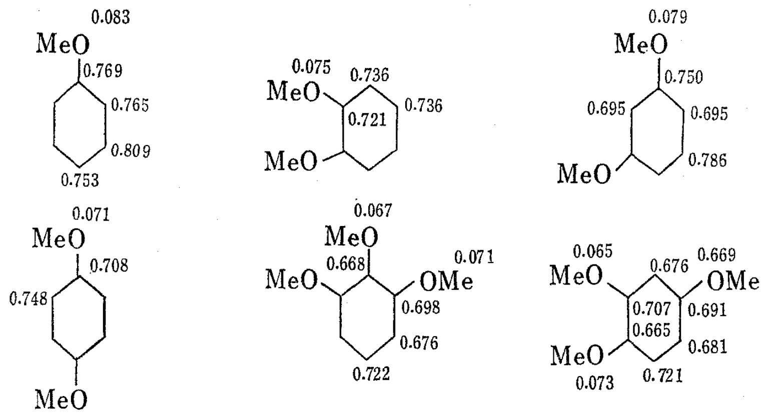


Chart 4. Nucleophilic Superdelocalizability

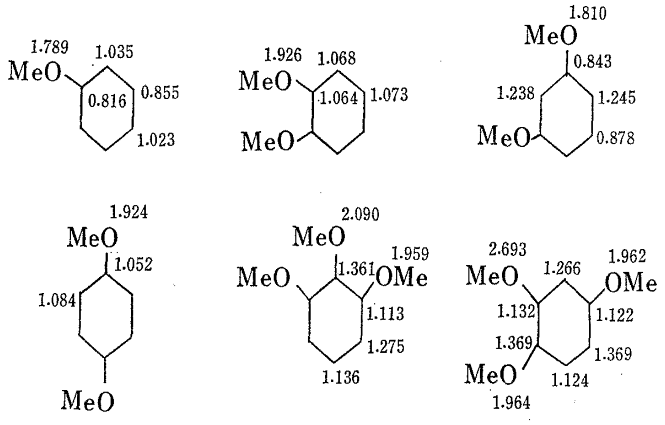


Chart 5. Electrophilic Superdelocalizability

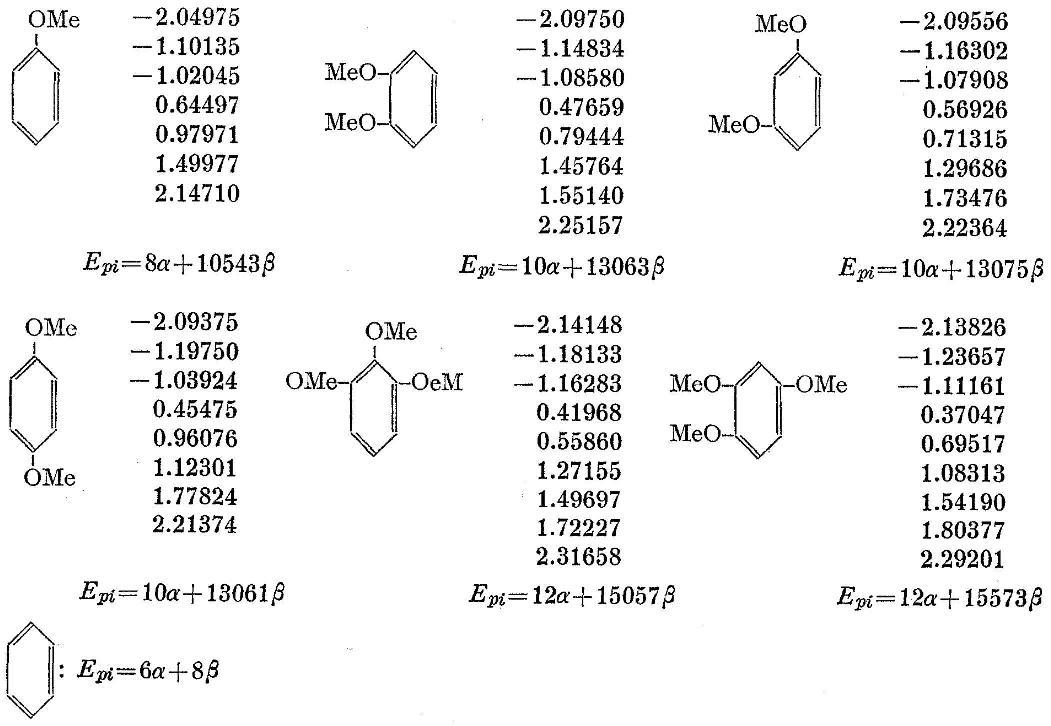


Chart 6. π-Electron Energy E_{pi} and Energy Level

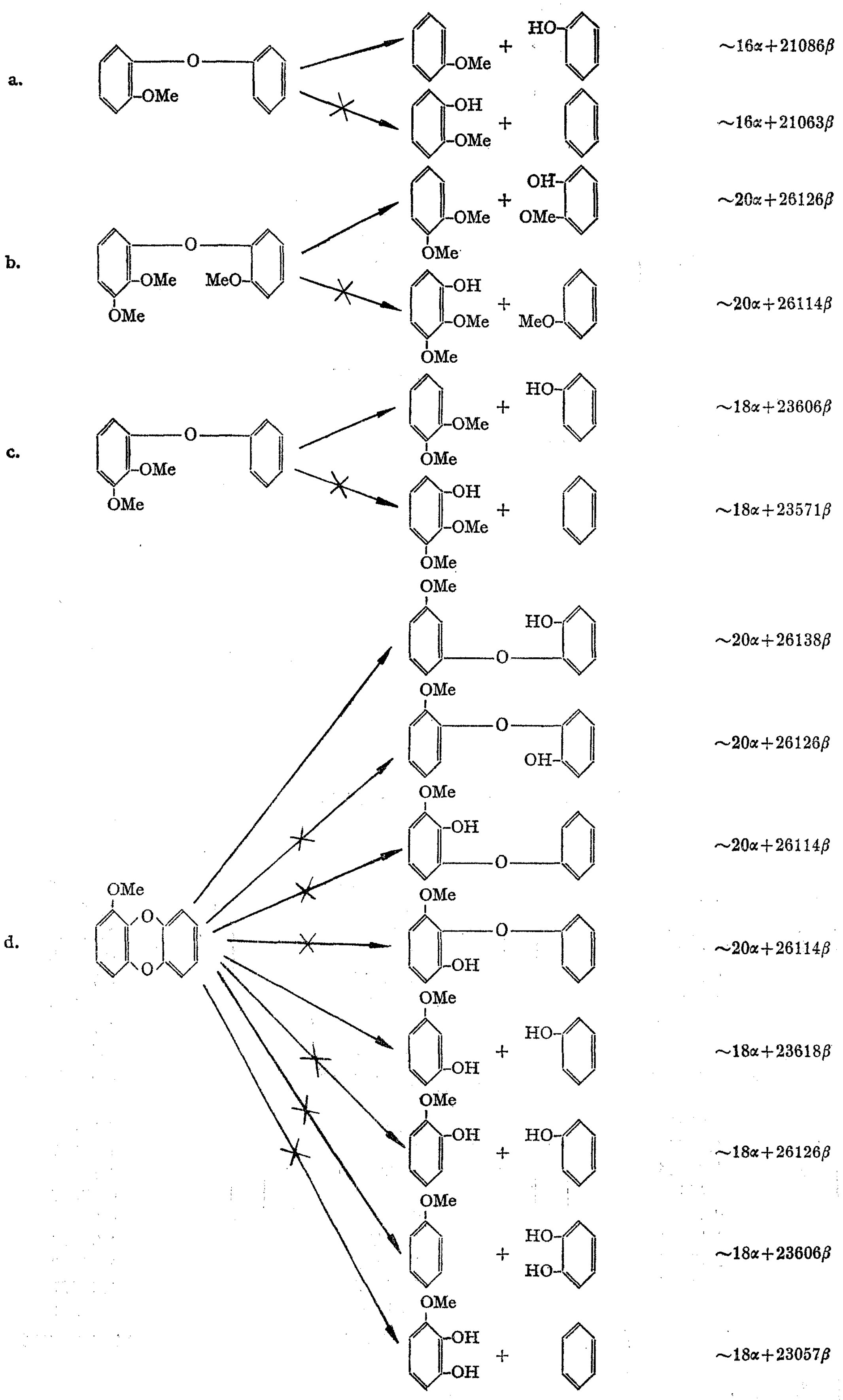


Chart 7. (continue)

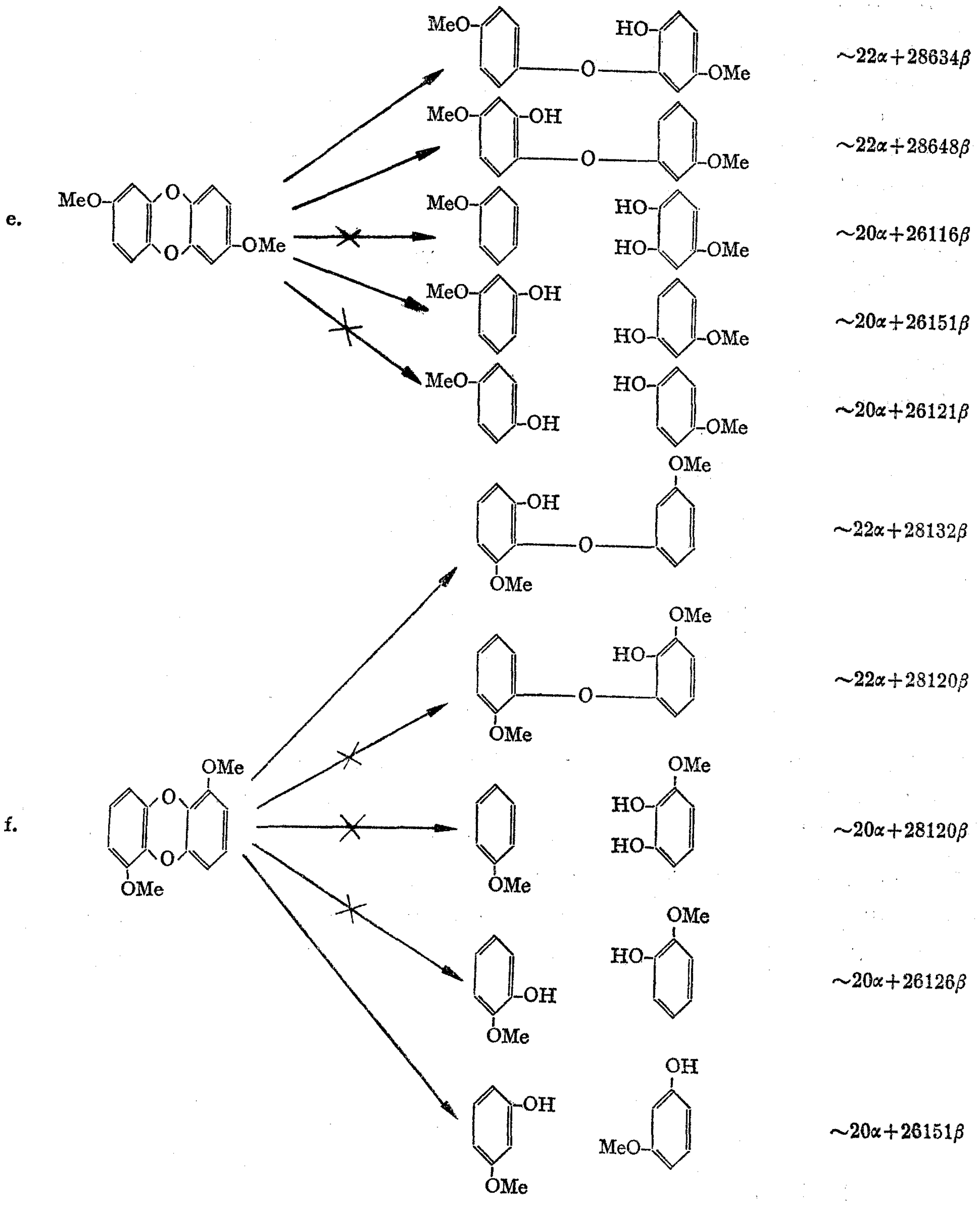


Chart 7. π-Electron Energy E_π and Reaction Mode

From the above results shown in Chart 1,2,3,4 and 5, it is probable that an electrophilic attack of the sodium ion on an ether oxygen in the initial stage of the fission reaction is supported from Chart 1 and 5, whereas the free radical attack of the sodium atom is from Chart 2 and 3, and the ensueing reaction on R·or R^+ should be expected in the second stage (*cf.* equation 2), but there is no possibility of nucleophilic attack (*cf.* Chart 4).

$$\mathrm{R{-}O{-}R'} \begin{array}{l} \xrightarrow{\mathrm{Na}} \mathrm{R\cdot + NaOR'} \\ \xrightarrow[\mathrm{Na^+}]{} \mathrm{R^+ + NaOR'} \end{array} \longrightarrow \mathrm{RH + R'OH} \qquad (2)$$

In the present step, it is impossible to deduce the definite conclusions on the reaction intermediates R·or R^+, and will be examined from both theoretical and experimental view point in the due time.

II. On the Fission Mode of Methoxysubstituted Diphenyl Oxide and Its Related Compounds

In this section, we have tried to present the details of the cleavage reaction mode from estimating the π-electron energy E_π of the reaction products by the simple sum of E_π value of the parent compounds (*cf.* Chart 6), and obtained the conceivable results compatible with the empirical ones (*cf.* Chart 7). One of the above results shown in Chart 7_a is consistent with the empirical rule that the fission reaction is facilitated by the OMe group adjacent to an ether type oxygen linkage.

In general, the calculated E_π supports the favorable fission mode, in other words, the reaction mode prefers the direction of smaller E_π.

III. The Delocalization Energy L_{+}^{ω} of Anisole

In this section, *ortho-*, *meta-* and *para*-delocalization energies of anisole have been estimated as are shown in Chart 8.

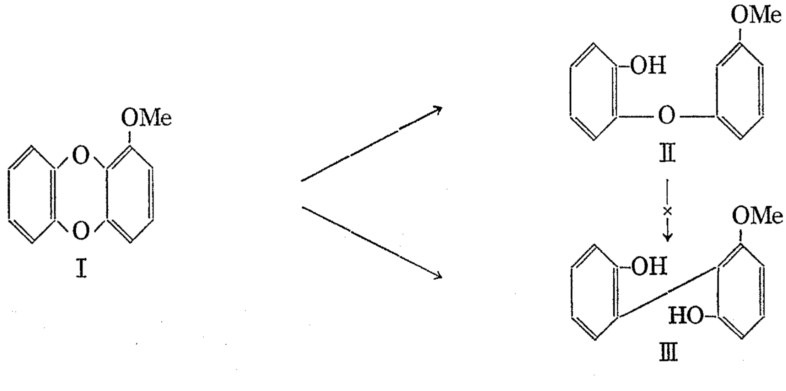
ortho-L_{+}^{ω}	-1.92859	*meta*-L_{+}^{ω}	-1.94986	*para*-L_{+}^{ω}	-1.96369
	-1.23871		-1.22551		-1.17359
	-0.37483		-0.27135		$-0,37910$
	0.64705		0.54718		0.83390
	1.37499		1.23090		1.01716
	1.77008		1.91864		1.91532
	$E_\pi=6\alpha+7.58424\beta$		$E_\pi=6\alpha+7.39344\beta$		$E_\pi=6\alpha+7.53276\beta$
	$\therefore\ -0.42\beta$		$\therefore\ -0.61\beta$		$\therefore\ -0.47\beta$

Chart 8. *ortho, meta, para*-L_{+}^{ω} of Anisole

The above results support the fundamental assumption that the fission reaction initiated by an electrophilic attack of sodium ion on an ether oxygen followed by the formation of anisolium ion must be favorable because of an adjacent OMe group (*cf.* Chart 7_a)

IV. The Formation of Biphenyl Derivatives as Byproducts

Empirically, methoxysubstituted dibenzo-*para*-dioxin derivative-for example (1)-afforded biphenyl derivative (II) as byproduct, and the yield of which is increased when NaH or NH_4Cl are added.⁶⁾



And, it is a well known fact that III is not obtained directly from II. It is assumed, consequently, that II and III are afforded at single stroke from (I), and this assumption is also accepted reasonable from the E_π data in Chart $7_{d,e,f}$.
This is because, by adding NaH or NH_4Cl, the dissociation (3) & (4), which afford Na^+ & NH_4^+ with isoelectric structure, affect the k_1 stage of (5), and facilitate k_2 stage—the addition of sodium atom.

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6) Y. Inubushi and K. Nomura, *Yakugaku Zasshi*, **79**, 838 (1959); **81**, 7 (1961); **82**, 696, 1341 (1962).

$$\mathrm{NaH} \rightleftharpoons \mathrm{Na}^+ + \mathrm{H}^- \qquad (3)$$

$$\mathrm{NH_4Cl} \rightleftharpoons \mathrm{NH_4}^+ + \mathrm{Cl}^- \qquad (4)^{7)}$$

where $k_{\mathrm{diss.}} = 12.8 \times 10^{-4}$ mole/liter

$$\mathrm{Na^+e} \overset{k_1}{\rightleftharpoons} \mathrm{Na}^+ + \mathrm{e}$$

$$2\mathrm{Na^+e} \underset{k_2}{\rightleftharpoons} \mathrm{Na_2} \qquad (5)^{8)}$$

where $k_1 = 9.6 \times 10^{-3}$ mole/liter

$k_2 = 23 \times 10^{-3}$ mole/liter

On the contrary, it is probable that in the absence of NaH or NH_4Cl, the both electrophilic and radical attack occur at the same time. The experimental details will be explored in the near future.

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7) G. Jander, H. Spandau, C.C. Addison, "Anorganische und Allgemeine Chemie in flüssigen Ammoniak," Vol. 1 Friedr. Vieweg & Sohn, Braunschweig 1966 p. 174, 178, 297.

8) J.L. Dyke, R.F. Sankuer and G.E. Smith, *J. Am. Chem. Soc.*, **82**, 4797, 4803 (1960).