

Substituent Effects on Carbon-13 Chemical Shifts in 4-Substituted Biphenyls and Benzenes. A Substituent Effect Transmitted through Eight Covalent Bonds

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The ¹³C chemical shifts of 14 monosubstituted benzenes and 14 4-substituted biphenyls have been determined and correlated by various linear free energy relationships. Resonance has been shown to be the dominant factor affecting ¹³C chemical shifts in these systems. A significant substituent effect through eight covalent bonds has been observed.

Linear free energy relationships of the simple Hammett type

$$\ln \frac{k}{k_0} = \sigma \rho$$

based on the effect of substituents on the ionization of 3- and 4-substituted benzoic acids date back to 1937.² Over the ensuing years many other defining reactions have been developed to better represent the transition states of reaction under study.³ These studies have adequately demonstrated for a very restricted scope of transition states that a particular σ constant will give a good linear free energy plot and a corresponding reaction constant with fairly high correlation. Hammett plots have previously been applied to measurements other than chemical reactions, such as ¹⁹F chemical shifts in polynuclear aromatic compounds⁴ and as a probe of π delocalization⁵ and ¹³C chemical shifts in monosubstituted benzenes.⁶

Unfortunately, the number of substituent parameters has proliferated without bounds, and recently various attempts have been made to simplify, consolidate, and better understand these multitudinous sets of constants. It is apparent that the major contributions to any substituent effect must be related in some way to the ability of the substituent to alter the electronic structure at the site involved in the molecule under study. Contributions due to simple electrostatic effects arising from electronegativity differences in the substituent are transferred to the reaction site through simple inductive processes, field effects, and resonance or mesomeric phenomena. Attempts have been made to divide substituent effects into these various contributions and thereby find a common basis for the numerous substituent effects derived from a variety of chemical reactions or physical properties. Swain and Lupton⁷ have, for example, represented any substituent constant as

$$\sigma = fF + rR \quad (1)$$

using a variable combination of field and resonance parameters (F and R) unique to any substituent weighted by the empirical f and r coefficients. The field contributions in this treatment are based on the ionization constants for 4-substituted bicyclo[2.2.2]octane-1-carboxylic acids. The resonance contribution to any substituent effect is determined by removal of the field effect from the corresponding σ_p (Hammett's original parameter). The per cent resonance character of any substituent constant can thus be determined from the relative magnitude of r and f . For example, Swain and Lupton calculate the per cent resonance for σ_p^+ to be 66% whereas σ_m manifests only a 22% resonance contribution.

Dewar has attempted to relate the effect of a substituent

on all positions in a molecule by a combination of three parameters, F , M , and MF (field, mesomeric, and mesomeric field) properly weighted in a given molecule by coefficients which reflect the assumed molecular geometry. In this theory, a given substituent is thus represented by the appropriate admixture of three basic parameters, thus combining into a unified treatment the substituent effect at all points in a molecule. This approach has been applied with success to the pK_a of substituted carboxylic acids and chemical reactions in side chains, but with a marked lack of success in the case of ¹⁹F chemical shifts. This led Dewar⁸ to conclude that "the effects of substituents on chemical properties and on ¹⁹F chemical shifts present entirely different problems and that attempts to combine the two will prove fruitless." A fluorine atom, at the periphery of a molecule and extensively involved in solvent interactions, probably is not a very good probe of a substituent effect, especially when inference is made regarding the nonfluorinated species. On the other hand, all organic molecules are made up of frameworks of carbon atoms, and the fortuitous replacement of a ¹²C nucleus by a ¹³C has little effect on the electronic structure of the molecule being studied and thus could be expected to be an excellent probe of substituent effects. The availability of modern techniques (fast Fourier transform pulse nmr, incoherent noise decoupling, large sample sizes, etc.)⁹ permits the measurement of the nuclear magnetic resonance of the relatively rare (1.1%) and difficult to detect ¹³C nucleus in fairly dilute solutions. Two useful spectroscopic results can be anticipated from such studies. First, the correlation with existing parameter sets would demonstrate the terms important in chemical shift theory. Second, once the dependence of a particular ¹³C shift on substituents is determined, the relationship can be used to predict unknown chemical shifts and aid in the interpretation of complex cmr spectra. For example, a linear free energy relationship was used to good advantage in determining the identity of CIDNP polarizations arising from the induced decomposition of benzoyl peroxide in tetrachloroethylene.¹⁰

Experimental Section

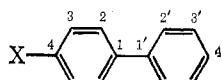
All compounds were commercially available and used as received with the exception of *p*-biphenylcarboxylic acid (Aldrich), which was sublimed and twice recrystallized from glacial acetic acid. The methyl ester was prepared by treatment of the *p*-biphenylcarboxylic acid with ethereal diazomethane,¹¹ followed by evaporation of ether. Whenever possible cmr measurements were made in 12-mm sample tubes on 10% solutions in acetone containing 10% benzene as internal standard. Acetone was selected simply as the only solvent capable of dissolving the majority of the biphenyls in the 10% concentration range. Samples that were not soluble in this solvent system were run in suitable solvents as noted in Table II. All chemical shifts are expressed in δ units relative to

Table I
Carbon-13 Chemical Shifts of Substituted Benzenes^a

Substituent	Registry no.	Position				
		1	2,6	3,5	4	Other
H ^d	71-43-2	0	0	0	0	0
CH ₃ ^e	108-88-3	-9.36	0.10	-0.65	3.00	107.59
F ^c	462-06-6	-34.61	13.19	-1.94	4.07	
Cl ^c	108-90-7	-5.60	-0.18	-1.74	1.55	
Br ^c	108-86-1	6.17	-3.15	-2.07	1.13	
I ^c	591-50-4	34.47	-9.17	-2.19	0.64	
OH ^e	108-95-2	-29.29	13.00	-1.13	8.90	
OCH ₃ ^e	100-66-3	-31.59	14.41	-1.09	7.85	73.77
CN ^f	100-47-0	15.98	-3.78	-1.06	-4.63	-44.28
NO ₂ ^{b,c}	98-95-3	-19.64	5.19	-0.97	-6.31	
CO ₂ H ^f	65-85-0	-2.32	-1.39	-0.18	-4.69	-39.16
CO ₂ CH ₃ ^f	93-58-3	-2.13	-1.08	-0.19	-4.63	-38.10
						76.81
NH ₂ ^c	62-53-3	-20.08	13.87	-0.65	11.51	
CH ₃ CO ^g	98-86-2	-9.13	0.14	-0.25	-4.55	-68.70
						102.44

^a $\delta(^{13}\text{C})$ relative to internal benzene = 0.00; 10% in acetone unless otherwise noted. ^b Neat, 10% added benzene. ^c H. Spiesscke and W. G. Schneider, *J. Chem. Phys.*, **35**, 731 (1961). ^d P. C. Lauterbur, *J. Amer. Chem. Soc.*, **83**, 1846 (1961). ^e T. D. Alger, D. M. Grant, and E. G. Paul, *ibid.*, **88**, 5397 (1966). ^f A. M. Ihrig and J. L. Marshall, *ibid.*, **94**, 1756 (1972). ^g Assigned by proton decoupling using the values of J. S. Martin and B. P. Dailey, *J. Chem. Phys.*, **39**, 1722 (1963).

Table II
Carbon-13 Chemical Shifts of 4-Substituted Biphenyls^a



Substituent	Registry no.	1	2	3	4	1'	2'	3'	4'	Other
H	92-52-4	-12.75	1.39	-0.56	0.99	-12.75	1.39	-0.56	0.99	
CH ₃	644-08-6	-9.90	1.61	-0.50	-8.63	-12.71	1.55	-0.50	1.30	108.05
F	324-74-3	-9.12	-0.44	12.84	-34.34	-11.71	1.47	-0.60	0.99	
Cl ^c	2051-62-9	-11.34	-0.17	-0.66	-4.70	-11.43	1.48	-0.60	0.60	
Br	92-66-0	-11.39	-0.69	-3.59	7.14	-11.87	1.51	-0.54	0.54	
I	1591-31-7	-11.43	-0.70	-9.64	35.66	-12.34	1.59	-0.70	0.50	
OH	92-69-3	-4.09	0.30	12.55	-29.74	-12.74	1.99	-0.45	1.92	
OCH ₃	613-37-6	-5.15	0.37	13.96	-12.46	-12.46	1.85	-0.48	1.68	73.47
CN	2920-38-9	-17.02	0.59	-4.36	17.37	-10.70	1.14	-0.85	-0.37	9.74
NO ₂	92-93-3	-19.13	0.44	4.34	-19.03	-10.35	0.94	-0.91	-0.65	
CO ₂ H	92-92-2	-17.44	1.14	(-1.98) ^d	(0.15) ^d	-11.64	1.33	-0.72	0.06	(-42.47) ^d
CO ₂ CH ₃ ^b	720-75-2	-17.14	1.15	-1.68	-4.57	-11.47	1.32	-0.75	0.04	-38.47
										76.79
NH ₂	92-67-1	-1.15	0.79	13.48	-19.70	-13.16	2.46	-0.37	2.46	
CH ₃ CO ^e	92-91-1	-17.04	1.28	-0.74	-7.97	-11.55	1.16	-0.58	0.04	-29.57
										102.26

^a 10% in acetone with 10% benzene internal reference. ^b 5% in acetone. ^c 20% in acetone. ^d Saturated in HOAc at 85°. ^e 5% in acetone.

internal benzene and were measured in the FFT mode on a Varian XL-100-15 spectrometer equipped with 620f computer and gyrocode decoupler. Field-frequency lock was obtained utilizing a concentric 4-mm tube of acetone-d₆.

Linear regression analyses were obtained using a plot program on a Hewlett-Packard 9810A (500 program steps, 111 data registers) equipped with 9862A plotter and 11210A mathematics ROM. Regression analysis of the equation

$$\Delta\delta = aAF^s + bBM^s + cCM_F^s \quad (2)$$

was accomplished by matrix solution of the following equations.

$$a\Sigma(AF^s)^2 + b\Sigma[(AF^s)(BM^s)] + c\Sigma[(AF^s)(CM_F^s)] = \Sigma[(AF^s)\Delta\delta]$$

$$a\Sigma[(AF^s)(BM^s)] + b\Sigma(BM^s)^2 + c\Sigma[CM_F^s(BM^s)] = \Sigma[(BM^s)\Delta\delta]$$

$$a\Sigma[(AF^s)(CM_F^s)] + b\Sigma[(BM^s)(CM_F^s)] + (CM_F^s)^2 = \Sigma[(CM_F^s)\Delta\delta] \quad (3)$$

Here $\Delta\delta$ is the chemical shift of the substituted compound relative to the parent; A, B, and C are Dewar's weighting factors; and a, b, and c are the regression parameters which measure the relative importance of Dewar's three terms to the carbon-13 shift.

Results and Discussion

Carbon-13 magnetic resonance FFT measurements were made on the 14 monosubstituted benzenes listed in Table I and the 14 4-substituted biphenyls listed in Table II. The tables summarize the chemical shifts observed for each of the positions in each of the compounds relative to benzene internal standard. The chemical shift region covered by the aromatic region in these compounds is about 55 ppm. The measurements on monosubstituted benzenes are in excellent agreement with earlier assignments made on neat samples by continuous wave cmr.

Our first attempts to correlate and in fact to assign the chemical shifts of the various carbons in each compound consisted of linear regression analyses of the shift and individual position vs. various σ parameters available in the literature to determine which gave the best correlation. As expected, the 1 and 2 positions of 1-substituted benzene and the 4 and 3 positions of 4-substituted biphenyls did

Table III
Summary of $\sigma\rho$ Correlations for 12 Substituents
(Acetyl Excluded)

Compd	Position	σ_T	ρ_T	r^c
Biphenyl	1	p^+	-9.5887	-0.9926
Biphenyl	2	m	-0.9853	-0.3256
Biphenyl ^a	2	m^+	-1.3720	-0.4657
Biphenyl	2 ep ^b	m	-2.6408	-0.9322
Biphenyl ^a	2 ep	m^-	-2.1611	-0.9537
Biphenyl	2 no ep	m	-1.5603	-0.9656
Biphenyl	2 no ep	m^+	-1.6222	-0.9725
Biphenyl	1'	m	3.3065	0.9471
Biphenyl	2'	p^+	-0.6397	-0.9520
Biphenyl	3'	m	-0.5088	-0.8483
Biphenyl ^a	3'	m^+	-0.5344	-0.8676
Biphenyl	3'	p	-0.3664	-0.9544
Biphenyl	4'	p^+	-1.5712	-0.9909
Biphenyl	4'	p	-2.1823	-0.9972
Benzene	3	m	-1.2306	-0.4409
Benzene ^a	3	m^+	-1.5621	-0.5148
Benzene	3 ep	m	-2.7123	-0.9441
Benzene ^a	3 ep	m^+	-2.2172	-0.9765
Benzene	3 no ep	m	-1.3898	-0.8371
Benzene	3 no ep	m^+	-1.9431	-0.9018
Benzene	4	p^+	-9.8090	-0.9923

^a OH omitted. ^b ep = electron pairs. ^c Correlation coefficient. Average correlation obtained from σ_p^+ and σ_m (divided) = 0.94 ± 0.02 .

not correlate with any of the parameters, being too subject to local and steric effects of the attached substituents. However, the 3 and 4 positions of benzenes and the 1, 2, 1', 2', 3', and 4' positions of 4-substituted biphenyls did give excellent correlation with appropriate σ constants.

Table III summarizes the results of these linear regression analyses, giving the observed ρ 's (slopes) and correlation coefficients. Theoretically the intercepts of these lines, which are plots of $\Delta\delta$ (chemical shift, substituted-unsubstituted) vs. the appropriate σ constant should be zero. The intercept, however, was allowed to float in these analyses and used as a further check of the validity of fit. In each case the intercept is less than ± 1 ppm and thus give a fairly good check on the reliability of the treatment. The coefficients of correlation for the best fit of each position range between 0.84 and 0.99 providing the correlations with m and m^+ are divided into those substituents with and without free electron pairs. Several points should be made with respect to Table III. First the ρ 's (slopes) reported range from ca. -10 to +3.

The best fits for the 4 position of benzenes and the 1 position of biphenyls were found for σ_p^+ , although σ_p was about as good or even slightly better for 4'-biphenyls. Positions 3 of benzene and 2, 1', and 3' of biphenyls correlate well with σ_m although 3, 2, and 1' are slightly better characterized with σ_m^+ although these correlations are for fewer substituents. An interesting phenomenon is observed in plots of 3-carbons in benzenes and 2-carbons of biphenyls. Figure 1 shows a plot of $\Delta\delta$ vs. σ_m^+ for the 2-carbon of biphenyls. As can be seen, the substituents evenly distribute above and below the best least-squares line. However, excellent correlation is obtained when the two natural lines are treated separately. The result is that every substituent on the lower line (NH_2 , OH , OCH_3 , X) contains a free pair of electrons while all those on the upper line (CH_3 , COOH , COOCH_3 , CN , NO_2) have no such free electrons available. Taken together with the fact that correlation is obtained with σ_p^+ (66% resonance)⁷ rather than σ_p (53% resonance)⁷ this result shows the importance of the contribution of electron pairing to the carbon chemical shift.

Two more points should be made with respect to these correlations. First, if each nonsterically interacting position

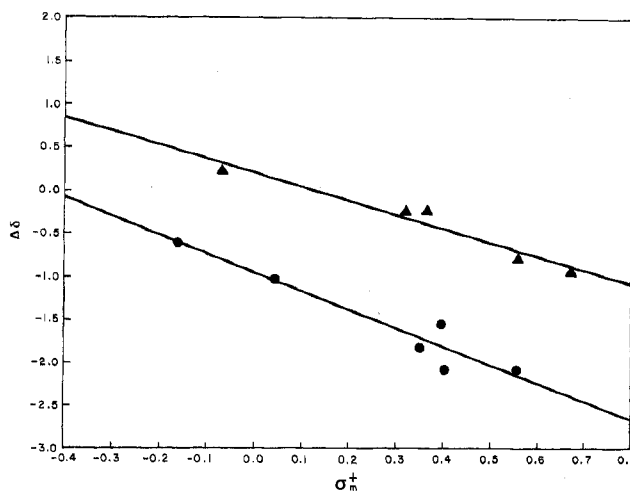


Figure 1. $\Delta\delta$ (ppm) vs. σ_m^+ for the 2-carbon of 4-substituted biphenyls: \blacktriangle , substituents with unshared electron pairs; \bullet , substituents without unshared electron pairs.

in monosubstituted benzenes and 4-monosubstituted biphenyls is plotted against the product of the appropriate σ constant (for simplicity either σ_m or σ_p^+) and the ρ corresponding to that position, an excellent straight line is obtained. Such a composite plot should in theory have a slope of 1 and an intercept of 0. Figure 2 shows that the correlation of $\Delta\delta$ with the appropriate $\sigma\rho$ product has a slope of 1.02, intercept of 0.08, and correlation of 0.97. Second, the substituent effect is transmitted (with about 10% efficiency) all the way from the 4-carbon of biphenyls to the 4'-carbon with a correlation of 0.99 (Figure 3). That is to say, we have observed a substituent effect transmitted through eight covalent bonds.

In order to further investigate the classical contributions of field and resonance to the substituent effect we here report, a linear regression was made using Dewar's FMMF treatment.⁸ The field, mesomeric, and mesomeric field contributions for each position were taken directly from the literature,⁸ while the appropriate geometrical factors were kindly provided by Professor Dewar,¹² and are summarized in Table IV.

Figure 4 shows a plot of $\Delta\delta$ vs. Dewar's σ values. As can be seen, the FMMF treatment does not successfully correlate the chemical shifts of monosubstituted benzenes and 4-monosubstituted biphenyls with a single ρ parameter. However, inspection of the points shows independent correlations for each position in a manner similar to that reported above for classical σ plots. The Dewar treatment prescribes an exact mixture of field, mesomeric, and field due to mesomeric effects which correlate with reaction parameters. To explore the importance of an alternative mix in chemical shifts a new regression analysis was undertaken

Table IV^a
Geometrical Parameters of Dewar Equation for
4-Substituted Biphenyls

$$\sigma = AF^s + BM^s + CM_F^s$$

Position	A	B	C
1	0.500	0.129	0.197
2	0.577	0.000	0.360
3	1.000	0.129	0.176
1'	0.333	0.000	0.178
2'	0.277	0.032	0.192
3'	0.218	0.000	0.191
4'	0.200	0.032	0.137

^a Reference 12.

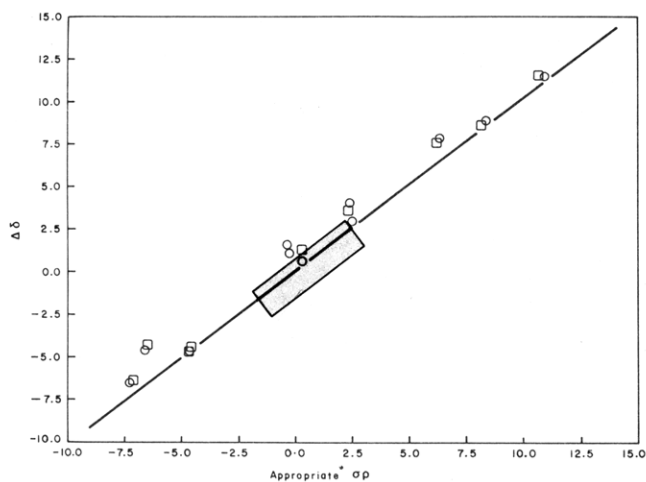


Figure 2. A plot of $\Delta\delta$ vs. the appropriate $\sigma\rho$ product for 3 and 4 positions of benzenes and 1, 2, 1', 2', 3', and 4' positions of biphenyls: O, 4-C benzenes; \square , 1-C biphenyls. The enclosed area comprises the region of extreme overlap of all other positions.

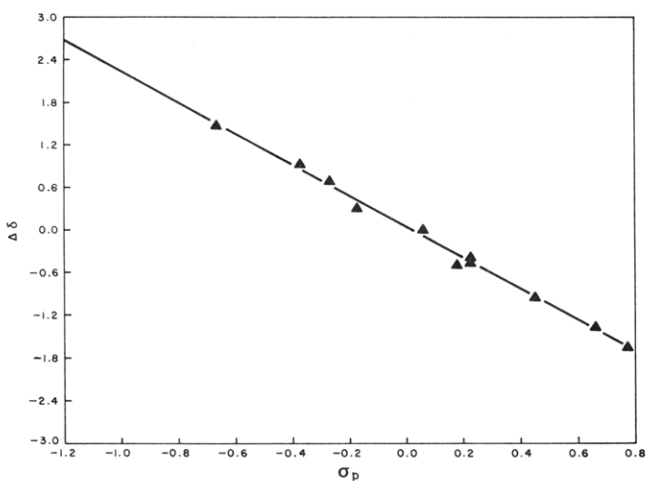


Figure 3. $\Delta\delta$ (ppm) vs. σ_p for the 4'-C of biphenyls.

using eq 2. The success of this fit can be seen from Figure 5, which is quite similar to that presented in Figure 2 for a combined classical $\sigma\rho$ treatment. The coefficients found are $a = -0.4833$, $b = -19.8484$, and $c = +1.9520$ with a correlation coefficient of 0.93, only slightly less than that found for the combined $\sigma\rho$ treatment (0.97) which of course contained many more degrees of freedom. These results show that if the field effect is taken as 1.0, the mesomeric effect is 41 times greater, and the mesomeric field effects are 4 times greater and of opposite sign in their effect on chemical shift.

This analysis when taken along with the effect of free electron pairs on the substituent noted in the meta position (in Figure 1) and the correlation of para positions with σ_p^+ (66% resonance) shows the import of resonance as compared with field effects on the carbon chemical shift. As it has been exhibited that chemical shifts will reflect primarily the charge distributions in aromatic systems,^{6b,13} we must conclude that electronic reorganization in these molecules through resonance structures is of greater significance than that due to electrostatic field effects. It appears from this study that field effects will alter the carbon-13 shifts in only a minimal way, and to the extent that these contribute to σ values which characterize chemical reactions, one might expect a failure in correlating chemical shifts. In Figure 1 there is reasonable correlation of $\Delta\delta$ for each of the two classes of substituents, but as σ_m and σ_m^+ minimize the

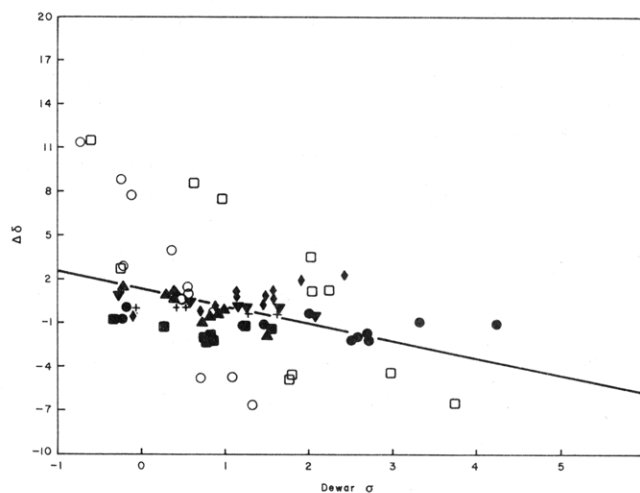


Figure 4. $\Delta\delta$ (ppm) vs. Dewar's calculated σ for 3 and 4 positions of benzenes and 1, 2, 1', 2', 3', and 4' positions of biphenyls. In areas of extreme overlap, representative points have been chosen to demonstrate the data with minimum confusion. The line represents the least-squares "best fit" of the scattered data: ●, biphenyl 2-C; \square , biphenyl 1-C; ◆, biphenyl 1'-C; ▼, biphenyl 2'-C; +, biphenyl 3'-C; ▲, biphenyl 4'-C; ■, benzene 3-C; ○, benzene 4-C.

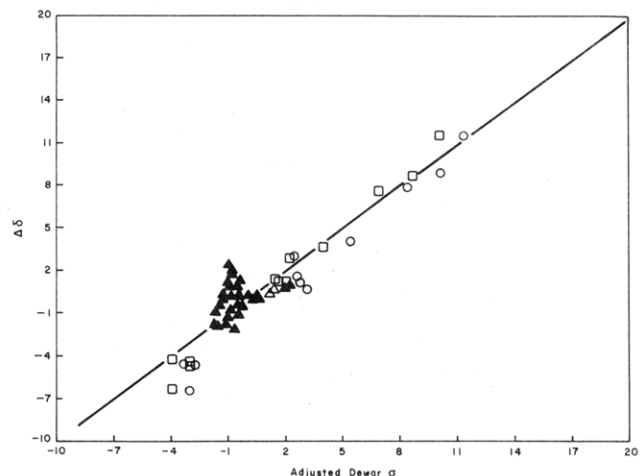


Figure 5. $\Delta\delta$ (ppm) vs. adjusted Dewar σ . The shifts are the same as in Figure 4. In areas of extreme overlap only representative points are shown: ○, benzene 4-C; \square , biphenyl 1-C; ▲, all other positions.

resonance feature so important in carbon shifts, the plot breaks into those substituents with widely different resonance features. Likewise for the other positions and other σ parameters good chemical shift correlations were always obtained whenever a parameter sensitive to resonance effects was employed.

In chemical shift theory, the magnetic field mixes small amounts of intrinsic angular momentum possessed by p electrons into the ground-state description of the molecules. This, to a first approximation, depends on the electronic charge in the immediate vicinity of the carbon nucleus and is less affected by long-range field effects resulting from remote substituents. On the other hand, σ parameters obtained from reaction rates are determined by the electronic structure of the activated complex, where electrons are loosely held and considerably more delocalized. In this condition the electrons would be more polarizable and therefore more sensitive to electrostatic field effects. It is understandable, therefore, that simultaneous correlation of both shifts and reaction rates with a given σ parameter would be fortuitous unless the appropriate dissection of the contributing components is first achieved. It is to be noted,

however, that carbon shift data can be used to characterize the important resonance feature and thereby aid in the separation of these various effects in reaction rate or related equilibrium data. Thus, instead of the σ 's for shifts and other chemical properties being totally unrelated, the information from the two sources is complementary and can be combined to characterize the relative importance of the component parts which affect the various σ 's to differing degrees.

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Aromatic Substitution. XXVI.¹ Kinetics of Nucleophilic Substitution of Some Bromopyridines and -picolines with Methoxide, Thiomethoxide, Phenoxide, and Thiophenoxide Ions

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The rates and activation of parameters were determined for the reactions of KSM_e in methanol with 2-bromo-, 2-bromo-3-methyl-, 2-bromo-5-methyl-, 2,3-dibromo-, and 2,5-dibromopyridine, and of KOMe, KOPh, KSM_e, and KSPh with 2-bromo-, 2-bromo-3-methyl-, and 2-bromo-5-methylpyridine in hexamethylphosphoramide. The results confirm the previous conclusion that a 3-methyl substituent activates the 2 position in the case of attack by thiophenoxide ion (but not with the other three nucleophiles) because of a combination of ion-dipole and dispersion attractive forces between the 3 substituent and the PhS⁻, and not because of a heavy (sulfur) nucleophile effect.

Quantitative studies² of the nucleophilic aromatic substitution of a hydride ion equivalent in the pyridine series by phenyllithium have established that a 3-methyl or a 3-ethyl group *activates* the 2 position of the pyridine nucleus toward this nucleophilic attack, methyl activating it more than ethyl. On the other hand, the 6 position was *deactivated* normally, as expected on the basis of the electron-donating effect of the alkyl group. In the reactions of 3-picoline with methyllithium³ and with sodamide (Tschitschibabin reaction),⁴ however, the 3-methyl substituent did not activate C-2, although attack still occurred predominantly at the 2 rather than at the 6 position. An ion-dipole attractive interaction between the 3-methyl group and the approaching methyllithium³ or amide anion could account for these observations.⁵ Steric acceleration of substitution at C-2 by the 3 substituent was considered but had to be rejected on the basis that a 3-methyl group was found to activate C-2 more than did a 3-ethyl group.² The normal deactivation of C-6, but the much lesser deactivation, or even net activation, of C-2 is not explained, contrary to what is stated,⁶ by simple Hückel calculations of localization energies which do not take into account ortho effects by the substituent at C-3. Two possibilities were discussed to account for the results obtained in the phenyllithium reactions. (a) London dispersion forces⁷ acting between the 3-alkyl substituent and the polarizable attacking nucleophile could lower the activation energy for attack at C-2 but not

at C-6. (b) The formation of an electron-deficient type bond⁸ between the 3-alkyl group and the organolithium compound would facilitate attack at C-2.

In order to decide between these alternatives, kinetic studies on two model systems were carried out. The reaction of 2-bromo-, 2-bromo-3-methyl-, and 2-bromo-5-methylpyridine with methoxide ion was studied under a variety of conditions.⁹ The rates were in the order 2-bromo- > 2-bromo-3-methyl- > 2-bromo-5-methylpyridine and were dependent upon E_a . This order of reactivity parallels that found in the methyllithium and Tschitschibabin reactions but not in the phenyllithium reaction. The lesser deactivation of the ortho than the para position by a 3-methyl group was attributed⁹ to an ion-dipole attraction¹⁰ between the methoxide ion approaching the 2 position and the methyl group which more than compensates for the greater inductive effect of the substituent at the ortho than at the para position, and any steric hindrance by the 3 substituent¹¹ to approach.

In order to find a system that would provide a model for the relative reactivities observed with phenyllithium, the kinetics of the reaction of 2-bromopyridines (1) with phenoxide ion in methanol to give 2 were studied, in the hope that the highly polarizable thiophenoxide would lead to the London attractive forces⁷ discussed above. Indeed, the sought-for order of reactivities was observed: 2-bromo-3-methyl- > 2-bromo- > 2-bromo-5-methylpyridine.¹² The