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CARBON-13 NMR SUBSTITUENT EFFECTS IN *PARA*-SUBSTITUTED BENZOPHENONES

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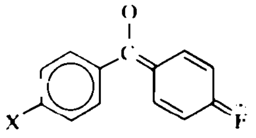
Abstract—The carbon-13 NMR spectra for a series of benzophenones was obtained and analyzed, using the dual substituent parameter (DSP) equation. The DSP analysis indicates that transmission of the substituent effect to the substituted ring is primarily resonance controlled while the transmission to the second phenyl ring involves a π-bond polarization mechanism. The DSP analysis of the C_4' chemical shifts (para carbon in ring B) was found to compare very favorably with the fluorine "tag" data for analogous systems. Data for some *para-para'* benzophenones is also given.

The application of ^{13}C chemical shift data to the study of substituent electronic effects in aromatic systems is currently under investigation in this laboratory.[1] Of particular interest is the transmission of substituent chemical shifts through potentially "insulating" centers. These "insulating" centers can be of three types; fully saturated, i.e. the methylene group in α-substituted toluenes, unsaturated neutral groups such as the carbonyl moiety in benzophenone or completely conjugated as found in *trans*-stilbene.[2] Of present interest is the second type of center, the carbonyl group, which is expected to allow only minor direct conjugation between the phenyl rings. The system chosen for study was para-substituted benzophenones as these compounds are readily available commercially.

A recent report has critically examined some para-substituted benzophenone substituent effects by ^{19}F NMR utilizing a para-fluoro "tag" in the second phenyl ring.[2] However, fluorine is known to be a relatively good electron donor and thus could interact directly with the second phenyl ring. The result of this conjugative interaction is to perturb the electronic ground state of the benzophenone molecule such as in I.



I

This resonance form may allow more facile transmission of the substituent electronic effect as a more completely conjugated system is attained. In accord with this notion, the transmitability of the substituent effect of the fluorine "tagged" benzophenones was found to be equal to that found for *trans*-stilbene.[2] Additionally, the use of ^{19}F chemical shifts for substituent effect studies has come under attack.[3] It has been stated that fluorine chemical shifts are not appropriate for such studies especially when extension to non-fluorinated analogs is attempted.

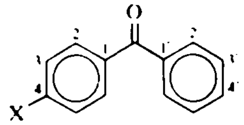
In contrast to the replacement of a hydrogen by a fluorine, the replacement of a ^{12}C by a ^{13}C nucleus should have little effect on the electronic nature of the molecule. Also, the carbon nucleus is not at the periphery of the molecule and thus is less subject to solvent concentration effects.[3] Previous work in this area has established that ^{13}C chemical shift data is suitable for the study of substituent effects.[4]

The purpose of this study is two-fold: (i) to assess the mechanism of the transmission of electronic effects and (ii) to assess the validity of using ^{19}F chemical shifts for substituent effect studies.

RESULTS AND DISCUSSION

Assignments

The ^{13}C NMR chemical shifts and substituent chemical shifts for the *para*-substituted benzophenones are listed in Tables 1 and 2, respectively. The numbering sequence for these compounds is given below.



Data for selected *para*-methoxy-*para'*-substituted benzophenones are given in Table 3.

The assignment of the CO carbon is straightforward; this carbon resonance is at the lowest field position in the spectrum. The remainder of the proton-decoupled spectrum for the monosubstituted benzophenone consists of eight lines (12 lines are observed in the instance of the *para*-fluoro derivative), four of which are significantly more intense than the other resonances. These are readily assigned to the C_2, C_2', C_3 and C_3' carbons on the basis of symmetry considerations. The specific assignments were determined by consideration of previously reported substituent effects in benzene derivatives[4c] and by analogy with the shifts reported for similarly substituted acetophenones.[5] The C_2' and C_3' carbon shifts were found to remain reasonably constant in accord with the published data on Michler's ketone derivatives,[6a] and on some ortho-substituted benzophenones.[6b] The remaining four resonances were assigned using the following rationale: C_4' was the most intense peak as it is the only protonated carbon, C_1 and C_4 on the basis of substituent chemical shifts, and C_1' by default.

The assignments for the disubstituted benzophenones were made on the basis of substituent effects observed in the monosubstituted series. The consistency between the experimental and calculated chemical shifts strongly supports the correctness of the above assignments.

Table 1. ^{13}C chemical shift values for a series of *para*-substituted benzophenones[1]

	CO	C1	C2	C3	C4	C1'	C2'	C3'	C4'
H	196.3	137.6	129.9	128.2	132.3	137.6	129.9	128.2	132.3
Me	196.3	134.9	130.2	128.9	143.1	137.9	129.5	128.2	132.0
Cl	195.0	135.8	131.4	128.5*	138.7	137.2	129.8	128.3*	132.5
OMe	195.4	130.2	132.6	113.6	163.3	138.3	129.7	128.2	131.9
Br	195.3	136.3	131.5	131.5	127.4	137.2	129.9	128.4	132.6
F	195.0	133.8	132.6	115.5	165.5	137.6	129.9	128.3	132.3
NH_2	195.4	127.1	132.9	113.6	151.4	139.0	129.5	128.0	131.4
NO_2	194.7	142.9	130.6	123.6	149.9	136.4	130.1	128.7	133.4
OH	197.0	129.3	133.1	115.4	161.0	138.0	129.4	128.3	132.2

1. In ppm from TMS

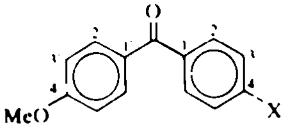
*. Values in same row may be reversed.

Table 2. Substituent chemical shifts for a series of *para*-substituted benzophenones

	CO	C1	C2	C3	C4	C1'	C2'	C3'	C4'
Me	0.0	-2.7[a]	0.3	0.7	10.8	0.3	-0.4	0.0	-0.3
Cl	-1.3	-1.8	1.5	0.3	6.4	-0.4	-0.1	0.1	0.2
OMe	-0.9	-7.4	2.7	-14.6	31.0	0.7	-0.2	0.0	-0.4
Br	-1.0	-1.4	1.6	3.3	4.9	-0.4	0.0	0.2	0.3
F	-1.3	-3.8	2.7	-12.7	33.2	0.0	0.0	0.1	0.0
NH_2	-0.9	-10.5	3.0	-14.6	19.1	1.4	-0.4	-0.2	-0.9
NO_2	-1.6	5.3	0.7	-4.7	17.6	-1.2	0.2	0.5	1.1
OH	0.7	-7.8	3.2	-12.8	27.7	0.4	-0.5	0.1	-0.1

a. Negative values indicate upfield shifts.

Table 3. ^{13}C chemical shift values for the *para*-methoxy *para*-substituted benzophenones



	H	OMe	NO_2	F
CO	195.4[1]	195.5 (194.5)[2]	193.4 (193.8)	193.9 (194.1)
C1	138.3	130.9 (130.9)	143.9 (143.6)	134.6 (134.5)
C2	129.7	132.3 (132.5)	130.3 (130.4)	132.2 (132.4)
C3	128.2	113.5 (113.6)	123.5 (123.5)	115.3 (115.5)
C4	131.9	163.0 (162.9)	149.6 (149.5)	165.1 (165.1)
C1'	130.2	130.9 (130.9)	129.0 (129.0)	130.1 (130.2)
C2'	132.6	132.3 (132.4)	132.7 (132.4)	132.4 (132.6)
C3'	113.6	113.5 (113.6)	114.0 (114.1)	113.7 (113.7)
C4'	163.3	163.0 (162.9)	164.1 (164.1)	163.3 (163.3)

[1] In ppm from TMS.

[2] Values in parentheses are calculated from the substituent shifts given in Table 2.

EXPERIMENTAL

All the monosubstituted benzophenones were commercially available and of high purity. These compounds were used as received. The disubstituted benzophenones were obtained from P. D. Bartlett and C. A. Kingsbury. The ^{13}C magnetic resonance spectra were obtained in the Fourier transform mode on a JEOL FX-60 spectrometer system equipped with a Texas Instruments computer with a 24K memory. The spectra were obtained at an observing frequency of 15.03 MHz. Sample concentrations were *ca.* 20% W/V in deuterochloroform in 10 mm O.D. sample tubes. General NMR spectral and instrumental parameters employed were: internal deuterium lock to solvent; spectral width of 4000 Hz (266 ppm); a pulse width of 4 μs, corresponding to a 36° pulse angle; and a pulse repetition time of 2.1 sec. All shifts reported are estimated to be accurate to ± 0.05 ppm.

Dual substituent parameter correlations (DSP)

In order to obtain useful comparison between the fluorine NMR and the ^{13}C chemical shift data sets, it is particularly instructive to analyze the data via the DSP treatment shown in eqn (1).

$$\delta_{\mathrm{obs}} = \rho_I\sigma_I + \rho_R\sigma_R + \delta_0. \qquad (1)$$

The observed substituent effect (δ_{obs}) is an additive combination of polar (σ_I) and resonance (σ_R) effects. The coefficients ρ_I and ρ_R (obtained from regression analysis) depend primarily upon the position of the substituent relative to the detection center. The relative transmitability of the polar and resonance effects has been defined as the λ-value (ρ_R/ρ_I). The δ_0-value is the intercept of the regression analysis and should be equal to the chemical shift of the parent system (substituent = H). The σ_I scale has been found to be of general utility while the σ_R scale is defined by four different sets of values depending instance correlation using $\sigma_{R(BA)}$ was found to be appropriate.[2,8]

The DSP analysis for the *para*-substituted benzophenones is summarized in Table 4. Data for the *para*-OH substituent was not used in the analysis as suitable σ_I and σ_R values are not available for X = OH. DSP analysis for carbons 4 and 3 gave poor results as these carbons are subject to additional interactions of a steric and compressional nature. Analysis of these shifts are possible if additional parameters are added to eqn (1).[4b] However, the substituent effects at these carbons were not of primary concern. The substituent shifts for carbons 2′ and 3′ are too small to allow correlation with the DSP parameters.

Interpretation of DPS analysis

The behavior of C_1 (*para* to the substituent) is unexceptional. As expected, the most important factor contributing to the observed substituent shift is the transmission of electronic effects via direct resonance interaction. In regard to recent interest concerning π-inductive effects,[9] the benzoyl moiety, by virtue of its ρ_I-value compares with other fixed substituents in the following order: $CN < NH_2 < OMe < \phi CO < F < NO_2$. This order is proposed to reflect the ease of π-bond polarization at the para position by the fixed substituent.

The transmission of the substituent effect to the CO carbon is seen to be primarily inductive in nature. The negative value of the substituent shift is indicative of a slight increase of electron density at this carbon.[4c] Similar albeit qualitative observations (the inaccuracy of the published shift data preclude use of the DSP analysis) have been made for acetophenones.[4] The dominance of inductive interactions at the α-carbon appears to be general as similar effects are seen in *para*-substituted phenyl acetylenes (ρ_I = − 2.83, $\rho_{R(BA)}$ = − 1.19),[10] styrenes (ρ_I = 2.35, $\rho_{R(BA)}$ = 0.52),[1] and biphenyls (ρ_I = 2.95, $\rho_{R(BA)}$ = 1.15).[12] Thus resonance effects are greatly localized to the A ring. Further evidence supporting the minor influence of the *para*-substituent towards the conjugative interaction between phenyl rings in benzophenone, at least in the ground state, comes from recent data obtained on Michler's ketone.[6] It was found that the dihedral angle, here, is virtually the same as in benzophenone itself even though Michler's ketone contains two potentially conjugative interacting *para*-dimethylamino groups.

The substituent effect at C_1', in general, is of opposite sign to that found at C_1 and of much smaller magnitude. The DSP analysis indicated that inductive and resonance effects are equally important; the field effect is most likely due to π-bond polarization. This effect may be due to electron transfer from C_1' to the A phenyl ring and thus may account for some of the electron density increase at the carbonyl carbon. An alternate mechanism may arise from a through space transmission of π-bond polarization from ring A to ring B resulting in the alternating partial charges observed at the C_1 and C_1' carbons. The actual picture is probably a blend of the above two mechanisms.

The transmission of electronic effects at C_4' is of extreme concern and importance for this carbon is where the fluorine "tag" is located. The DSP analysis indeed shows that the relative importance of ρ_I and $\rho_{R(BA)}$ is the same as found in the fluorine "tag" model (ρ_I = 2.77, $\rho_{R(BA)}$ = 2.61).[2] The difference in magnitude of these ρ values is clearly a consequence of the increased sensitivity of fluorine shifts in comparison with ^{13}C

Table 4. Dual substituent parameter analysis of the *para*-substituted benzophenones

Carbon	ρ_I	$\rho_{R'}$	λ	a^2	b^2	i	$\bar{r}$	Avg. Dev.	Range^3
CO	-2.31	0.52	0.22	-0.94	0.11	196.3	0.980	0.09	1.6
C1'	-1.63	-1.83	1.12	-0.66	-0.85	137.6	0.996	0.05	2.6
C4'	1.35	1.28	0.91	0.71	0.81	132.3	0.995	0.04	2.0
C1	5.12	13.37	2.61	0.43	0.96	137.1	0.995	0.40	12.7
C2	1.98	-3.51	1.86	0.25	-0.90	129.9	0.996	0.07	3.0

1. $\sigma_{R(BA)}$ values used.
2. Correlation coefficient of a two parameter equation of σ_I or $\sigma_{R(BA)}$ vs $\delta_{\mathrm{observed}}$.
3. In ppm.

shifts.[13] The alternating sign of the substituent shift (vs C_1') is consistent with the π-bond polarization mechanism. Clearly, if resonance forms such as I contribute significantly to the ground state electronic structure of the benzophenones then enhanced transmission of the ^{13}C substituent effect should be observed in the instance of the disubstituted benzophenones. This enhancement should be reflected in the nonadditive behavior of the substituent shifts. Given in Table 3 are the observed chemical shifts and the chemical shifts calculated from the monosubstituted benzophenone substituent shifts. The extremely good correlation between these two values indicates that no additional participation of the second *para*-substituted phenyl ring occurs.

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REFERENCES

[1a] M. J. Shapiro, *J. Org. Chem.* in press. [b] M. J. Shapiro, *Org. Magn. Reson.* in press.

[2] S. K. Dayal, S. Ehrenson and R. W. Taft, *J. Am. Chem. Soc.* **94**, 9114 (1972).

[3] M. J. S. Dewar, R. Golden and J. M. Harris, *Ibid.* **93**, 4187 (1971).

[4a] R. J. Pugmire and D. M. Grant, *Ibid.* **90**, 687 (1968). [b] W. B. Smith and D. L. Deavenport, *J. Magn. Reson.* 7, 364 (1972). [c] G. L. Nelson, G. C. Levy and J. D. Cargioli, *J. Am. Chem. Soc.* **94**, 3089 (1972).

[5] K. S. Dhami and J. B. Stothers, *Can. J. Chem.* **43**, 479 (1965).

[6a] K. D. Bartle, G. Hallas and J. D. Hepworth, *Org. Magn. Res.* 7, 154 (1975). [b] G. W. Buchanan, G. Montando and P. Rinocchiaro, *Can. J. Chem.* **51**, 1053 (1973).

[7] The dual substituent parameter was introduced by Taft and Lewis, *J. Am. Chem. Soc.* **80**, 2436 (1956). It is believed that the incorporation of an intercept (δ_o) in this equation allows an additional check on the goodness of the data.

[8] R. T. C. Brownlee, S. Ehrenson and R. W. Taft, *Prog. Phys. Org. Chem.*, **51**, 1857 (1973).

[9] J. Bromilow, R. T. C. Brownlee, R. D. Topsom and R. W. Taft, *J. Am. Chem. Soc.* **98**, 2020 (1976).

[10] D. A. Dawson and W. F. Reynolds, *Can. J. Chem.* **53**, 373 (1975).

[11] G. K. Hamer, I. R. Peat and W. F. Reynolds, *Ibid.* **51**, 897 (1973).

[12] E. M. Schulman, K. A. Christensen, D. M. Grant and C. Walling, *J. Org. Chem.* **39**, 2686 (1974).

[13] J. A. Pople, W. G. Schneider and H. J. Bernstein, *High Resolution Nuclear Magnetic Resonance*, pp. 317–345. McGraw-Hill, New York (1959).