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Carbon-13 Nuclear Magnetic Resonance Spectroscopy. VII.[1] Studies on Carbon-13 Nuclear Magnetic Resonance Spectra in Aromatic and Heteroaromatic Systems. (3). Carbon-13 Chemical Shifts of Disubstituted Benzene Derivatives

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The ring C-13 nuclear magnetic resonance chemical shifts of 1,4- and 1,3-disubstituted benzene derivatives were compared with those of monosubstituted benzene derivatives and the substituent constants σ_i.

The slopes of C-1 and C-2 chemical shifts of 1,4-disubstituted benzene derivatives and also those of C-1 and C-5 of 1,3-disubstituted series are linear with respect to σ_i. The slopes of other positions have the same characters with those of the corresponding shifts of monosubstituted benzene derivatives.

Introduction

The preceding paper[3] of this series reported the C-13 magnetic resonance chemical shifts of numerous substituted aromatic compounds, and the practical utility of the simple sum rule for the chemical shift was also verified. Formerly, it was thought that neither C-13 nor H-1 chemical shifts at the *meta* positions of monosubstituted benzenes have any definite correlations with the substituent constants or other physical constants. However, Yamada, *et al.*[4] showed that H-1 chemical shifts at the *meta* position of monosubstituted benzene derivatives can be shown by the sum of the contributions of field and ring current effects of the substituent groups. Only, the C-13 and H-1 chemical shifts of the *para* position have been examined in details.[5] Recently, the contributions of the ring current effect of monosubstituted benzene for the ring C-13 chemical shifts have been estimated about +0.5 ppm[6] with reference to

Table I. C-1, C-2, and C-13 Magnetic Resonance Chemical Shifts of 1,4-Disubstituted Benzene Derivatives

	R_1/R_4	NH_2	OH	OMe	Me	F	H
C-1	NH_2		−13.1	−14.3	−18.2	−16.7	−19.3
	OH	−21.5		−23.6	−25.0	−23.1	−27.1
	OMe	−24.1	−25.3	−26.1	−30.5	−27.9	−32.2
	Me	+2.2	−2.3	−1.9	−6.1	−5.4	−9.2
	F	−28.5	−30.0	−29.1	−33.3	−30.9	−35.1
C-2	NH_2		+11.2	+12.7	−2.0	+12.5	−1.5
	OH	+11.2		+12.7	−2.3	+11.9	−1.9
	OMe	+11.7	+11.5	+12.7	−2.3	+12.6	−1.5
	Me	+12.7	+12.5	+14.2	−0.6	+13.1	+0.1
	F	+11.5	+11.3	+13.4	−2.1	+12.4	−1.5

ppm with reference to benzene

1) Part VI: G. Miyajima, Y. Sasaki, and M. Suzuki, *Chem. Pharm. Bull.* (Tokyo), **20**, 429 (1972).
2) Location: *Toneyama 6-1-1, Toyonaka, Osaka.*
3) G. Miyajima, Y. Sasaki, and M. Suzuki, *Chem. Pharm. Bull.* (Tokyo), **19**, 2301 (1971).
4) H. Yamada, Y. Tsuno, and Y. Yukawa, *Bull. Chem. Soc. Japan*, **43**, 1459 (1970).
5) H. Spiesecke and W.G. Schneider, *J. Chem. Phys.*, **35**, 731 (1961).
6) G. Miyajima, Y. Sasaki, and M. Suzuki, Abstracts of 9th NMR Symposium in Japan. Oct. 6, 1970. p. 179.

benzene, and this magnitude is the same or smaller order with the contribution from the solvent effect.[7] In this paper, the C-13 chemical shifts of 1,3- and 1,4-disubstituted benzene derivatives are satisfactorily correlated with those of monosubstituted benzene derivatives.

Experimental

General Treatment——Among the C-13 chemical shifts summarized in the previous paper,[3] those of the 1,4-disubstituted benzene series are classified into five groups, (*i.e.*, *para*-substituted aniline, phenol, anisol, toluene and fluorobenzene series). However, those of the 1,3-disubstituted benzene series are classi-

Table II. C-1, C-5, and C-13 Magnetic Resonance Chemical Shifts of 1,3-Disubstituted Benzene Derivatives

	R_1/R_3	NH_2	OMe	Me	F	H
C-1	NH_2		−21.5	−18.8		−19.3
	OMe	−33.3	−33.5	−33.3		−32.2
	Me	−10.7	−11.7	−9.1	−12.1	−9.2
C-5	NH_2		−2.5	−1.4		−1.5
	OMe	−2.5	−2.1	−1.6		−1.5
	Me	−1.4	−1.6	+0.1	−1.3	+0.1

ppm with reference to benzene

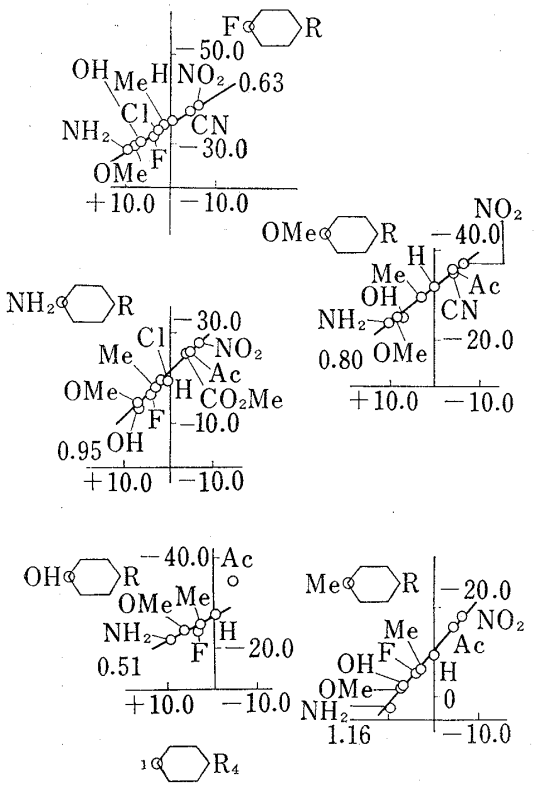

Fig. 1a. Correlations between C-1 Shifts of 1,4-Disubstituted Benzenes and *para* Shifts of Monosubstituted Benzenes

Numbers with + or − signs are chemical shifts, and those without signs are slopes.

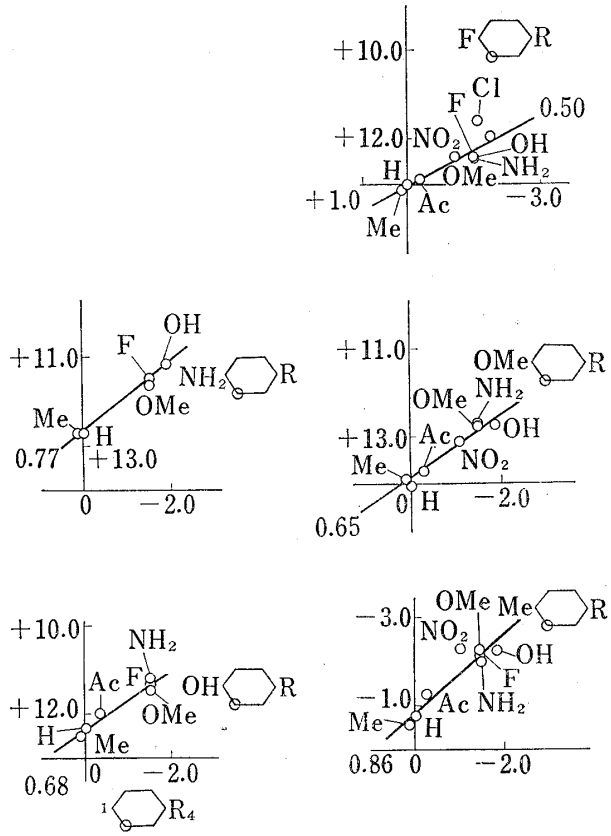

Fig. 1b. Correlations between C-2 Shifts of 1,4-Disubstituted Benzenes and *meta* Shifts of Monosubstituted Benzenes

Numbers with + or − signs are chemical shifts and those without signs are slopes.

7) G. Miyajima, Y. Sasaki, and M. Suzuki, *Chem. Pharm. Bull.* (Tokyo), **19**, 2301 (1971).

fied into three groups (*i.e.*, *meta*-substituted aniline, anisol and toluene series). Because the substituent groups with a small magnetic anisotropy, (*e.g.*, NH_2, OMe[5,8a,b] Me,[9] F[10] and H), in general, afford good linear relation with the substituent constants σ_i or σ_π.[11]

In this paper, the C-13 chemical shifts of the *meta*-, *ortho*- and *para*-carbons and carbon atoms with substituent groups are correlated with those of monosubstituted benzene derivatives and the slopes of the linear relations are compared with respect to substituent constants such as σ_i.

Results and Discussion

The C-13 chemical shifts of *meta* positions of the 1,4-disubstituted aniline, phenol, anisol, toluene and fluorobenzene series (R_1=Me, NH_2, OMe, OH, F: R_4= variable substituent) are summarized in Table I, and those of the 1,3-disubstituted aniline, anisol and toluene series (R_1=Me, OMe, NH_2: R_3=variable substituent) are shown in Table II.

The ring C-13 chemical shifts cited in Tables I and II are compared with those of monosubstituted benzene,[3] and the linear relations obtained are shown in Fig. 1a, b and Fig. 2.

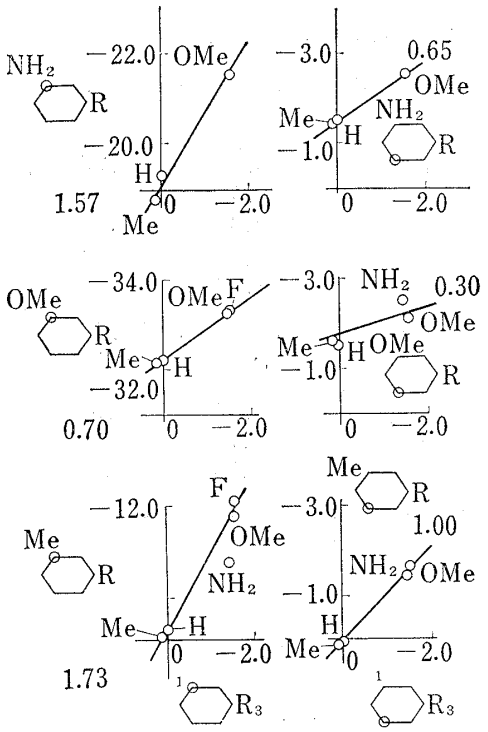

Fig. 2. Correlations between C-1 and C-5 Shifts of 1,3-Disubstituted Benzenes and *meta* Shifts of Monosubstituted Benzenes

Numbers with + or − signs are chemical shifts, and those without signs are slopes.

The observed slopes of the above linear relations are summarized in Table III, and the linear relations of these slopes with regard to the substituent constants σ_i are ahown in Fig. 3a, b.

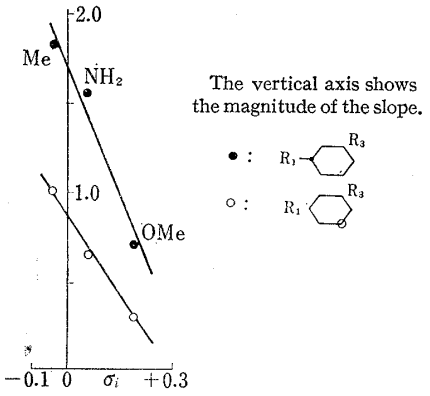

Fig. 3a. Correlations between Slopes and Substituent Constants σ_i

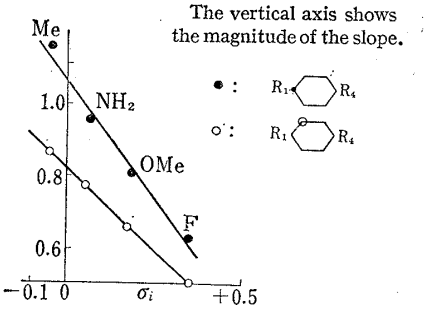

Fig. 3b. Correlations between Slopes and Substituent Constants σ_i

8) *a*) H. Kasiwagi and J. Niwa, *Bull. Chem. Soc. Japan*, **36**, 405 (1963); *b*) G.S. Reddy, J.H. Goldstein, and L. Mandell, *J. Am. Chem. Soc.*, **83**, 1301 (1961).
9) J.A. Pople, *J. Chem. Phys.*, **37**, 60 (1962).
10) G. Miyajima, unpublihed work.
11) Y. Yukawa and Y. Tsuno, *Nippon Kagaku Zasshi*, **86**, 873 (1965).

Table III. Slopes of 1,4- and 1,3-Disubstituted Benzene Derivatives

1,4-Disubstituted benzene derivatives	C-1	C-2
1-NH_2	0.95	0.77
1-OH	0.51	0.68
1-OMe	0.80	0.65
1-F	0.63	0.50
1-Me	1.16	0.86
1,3-Disubstituted benzene derivatives	**C-1**	**C-5**
1-NH_2	1.57	0.65
1-OMe	0.70	0.30
1-Me	1.73	1.00

Ring C-13 chemical shift with reference to mono ubstituted benzene.

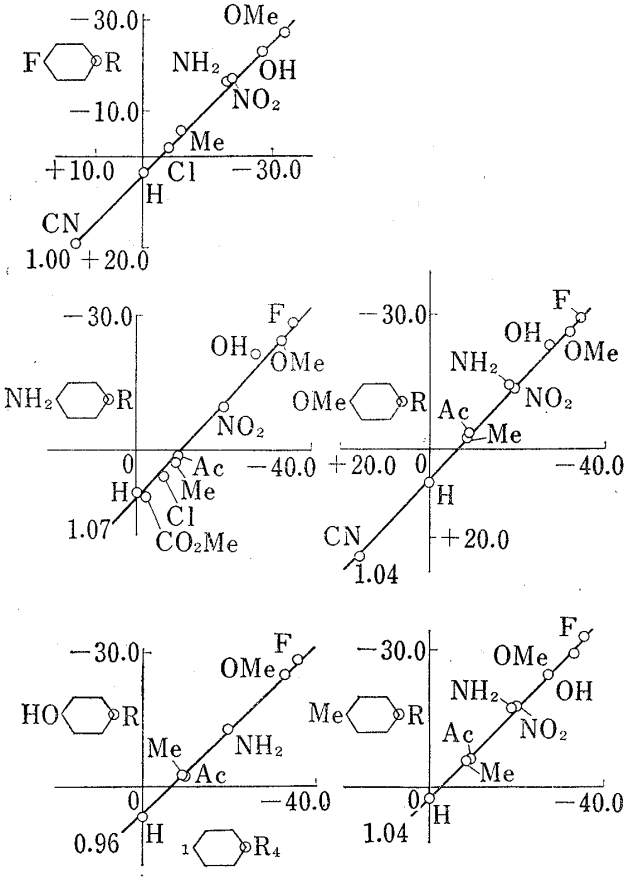

Fig. 4a. Correlations between Chemical Shifts of Carbons with Substituent Groups of 1,4-Disubstituted Benzenes and the Corresponding Shifts of those of Monosubstituted Benzenes

Numbers with + or − signs are chemical shifts and those without signs are slopes.

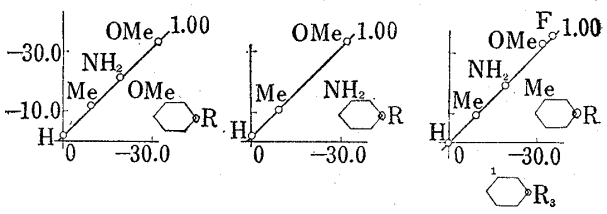

Fig. 4b. Correlations between Chemical Shifts of Carbons with Substituent Groups of 1,3-Disubstituted Benzenes and the Corresponding Shifts of those of Monosubstituted Benzenes

Numbers with + or − signs are chemical shifts and those without signs are slopes.

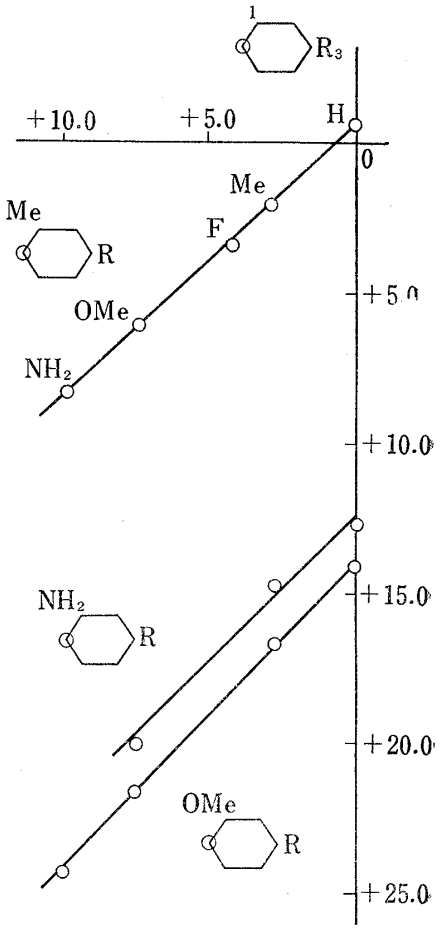

Fig. 4c. Correlations between C-6 Shifts of 1,3-Disubstituted Benzenes and *para* Shifts of Monosubstituted Benzenes

Numbers with + or − signs are chemical shifts.

This result suggests that the introduction of a second substituent on the benzene ring results in an inductive contribution to the *meta* carbon, represented by the substituent constant σ_i. However, unexpectedly, the observed slopes of the correlations between the chemical shifts of C-1 of 1,4-disubstituted benzenes and those of the *para* carbons of monosubstituted benzenes are linear with respect to σ_i. This is probably due to the enhanced field effect from the mesomeric interaction between the *para* substituent groups. The chemical shifts of C-4 of the 1,4-disubstituted series and of C-3 and C-6 of the 1,3-disubstituted series gave linear relations with those of the corresponding shifts of monosubstituted benzenes with slopes of $\sim$1.00. This result suggests that the effects of substituents at these positions are similar to those of substituents of monosubstituted benzene derivatives (*cf.* Fig. 4a—c). Similar relations were also found for the C-2 and C-4 shifts of the 1,3-disubstituted benzene series and those of the C-3 shifts of the 1,4-disubstituted benzene series.

From these results, it is concluded that the contributions of the polar effects to C-13 chemical shifts of the C-2, C-3, C-4, and C-6 positions of the 1,3-disubstituted benzene series, and the C-3 and C-4 positions of the 1,4-disubstituted series are similar to those of the corresponding shifts of the monosubstituted benzene series.