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Multiple Substituent Effects on ^{13}C Chemical Shifts of *N*-Benzylideneanilines. Evidence for Substituent-Substituent Interactions and Their Implications of Conformational Changes with Substituents

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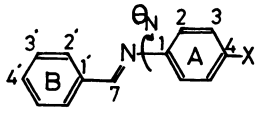
Carbon-13 chemical shifts are reported for series of *N*-benzylideneanilines; 4-$YC_6H_4CH{=}NC_6H_4NMe_2$-4, 4-$NO_2C_6H_4CH{=}NC_6H_4X$-4, 4-$YC_6H_4CH{=}NC_6H_4NO_2$-4, and 4-$YC_6H_4CH{=}NC_6H_3(CH_3)_2$-2,6. Multiple substituent effects on the azomethine carbon chemical shifts were examined, and nonadditivity observed for 4-$YC_6H_4CH{=}NC_6H_4NMe_2$-4 and 4-$NO_2C_6H_4CH{=}NC_6H_4X$-4 is interpreted in terms of substituent-substituent interactions accompanied by conformational changes with substituents in these *N*-benzylideneanilines. Effects of the substituents Y (on the benzylidene benzene ring) on the azomethine carbon chemical shifts were also studied in detail. The results suggest that there are two competetive electronic factors responsible for chemical shift variation, and that the substituent effects should be treated separately between electron-releasing and electron-withdrawing groups. The latter groups always exert inverse (the chemical shifts undergo upfield shifts with increase in the electron-withdrawing properties of the substituents) substituent effects, whereas the former exhibit normal (the chemical shifts undergo upfield shifts with increase in the electron-releasing properties of the substituents) or inverse substituent effects depending on the degree of electron demand developed on the azomethine carbons.

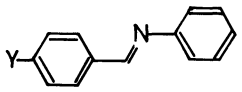
It is well-known that *N*-benzylideneaniline (NBA) takes a conformation in which the benzene ring on the nitrogen atom (ring A) is twisted from the molecular plane containing the C=N bond.[1] However, only a few studies have been made on the role of electronic effects of substituents on the molecular conformations of *N*-benzylideneanilines in solution.[2] We have recently shown that *N*-benzylidene-4-nitroaniline takes a more twisted conformation than NBA itself in solution and in gas phase by UV[1] and photoelectron spectroscopy.[2a] On the other hand, Zollinger[2b] and Kubota[2c] reported that *N*-(4-nitrobenzylidene)-4-dimethylaminoaniline takes a nearly planar conformation in solution. They suggested that the planar conformation of the disubstituted NBA would be ascribed to a through-conjugative interaction of the dimethylamino group with the nitro group. These studies suggest that electronic effects of a 4′-substituent on the benzylidene benzene ring (ring B) as well as those of a 4-substituent on the ring A will play an important role to determine the molecular conformations of NBAs.

In a previous paper, we demonstrated the anomalous substituent effects on the azomethine proton chemical shift of 4-substituted *N*-benzylideneanilines that the



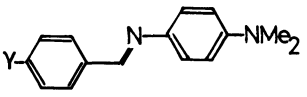
1

1a, X=NMe_2; **1b**, OCH_3; **1c**, CH_3; **1d**, H; **1e**, F; **1f**, Cl; **1h**, CO_2Et; **1j**, NO_2.



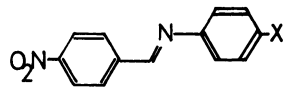
2

2a, Y=NMe_2; **2b**, OCH_3; **2c**, CH_3; **2d**, H; **2f**, Cl; **2g**, Br; **2i**, CN; **2j**, NO_2.



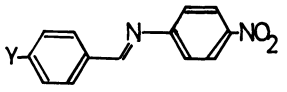
3

3a, Y=NMe_2; **3b**, OCH_3; **3c**, CH_3; **3d**, H; **3f**, Cl; **3g**, Br; **3i**, CN; **3j**, NO_2.



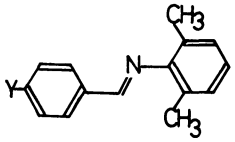
4

4a, X=NMe_2; **4b**, OCH_3; **4c**, CH_3; **4d**, H; **4e**, F; **4f**, Cl; **4h**, CO_2Et; **4j**, NO_2.



5

5a, Y=NMe_2; **5b**, OCH_3; **5c**, CH_3; **5d**, H; **5f**, Cl; **5i**, CN; **5j**, NO_2.



6

6a, Y=NMe_2; **6b**, OCH_3; **6c**, CH_3; **6d**, H; **6f**, Cl; **6g**, Br; **6i**, CN; **6j**, NO_2.

Scheme 1.

azomethine proton of the 4-nitro derivative resonates at a higher field than that of NBA, and interpreted them in terms of the change of molecular conformations induced by the 4-nitro group.[3] In order to get deeper insight into the conformational change with substituents in *N*-benzylideneanilines, we have undertaken a detailed study of multiple substituent effects on carbon-13 chemical shifts in several *N*-benzylideneanilines.

In the present paper, ^{13}C NMR data are presented for series of multiply substituted *N*-benzylideneanilines, **3—6**. Special attention is paid to additivity of the multiple substituent effects on the azomethine carbon chemical shifts in these *N*-benzylideneanilines. Effects of the substituents Y on the ring B are also analyzed and discussed in detail.

Results and Discussion

Assignment of the ^{13}C NMR Spectra. For analysis of the ^{13}C NMR chemical shifts of **3—6** ^{13}C NMR data of the corresponding monosubstituted NBA derivatives, series **1** and **2**, are necessary. The ^{13}C NMR spectra of **1** and **2** are already reported by Inamoto *et al.*[4] Since reinvestigation on the ^{13}C NMR spectra of some of the monosubstituted derivatives was found to give the same chemical shifts as reported within the experimental error, only the derivatives of X=NMe_2, F, and CO_2Et, Y=Br and CN were measured in the present study. The results are summarized in Table 1. The results of the multiply substituted derivatives **3—6** are listed in Table 2.

Assignment of the chemical shifts of some derivatives of **1** and **2** was already described.[4] Assignment of the chemical shifts in **3—6** has been made maily by using substituent-induced chemical shifts (SCS) of **1**, **2**, and substituted benzenes.[5] Consideration of the signal intensities also permitted to distinguish the ortho and meta carbons from the ipso carbons, the carbons attached directly to the substituents. In some cases, off-resonance decoupled spectra were used to differentiate the carbons bearing a hydrogen.

Aromatic Carbons. The SCS values of the aromatic carbons of **1** and **2** are not considered here since they were already analyzed and discussed.[4] For **3—6**, the Hammett relationship was examined. The results are shown in Table 3.

Generally, good correlations were found for the ipso carbons except those attached directly to the variable substituents X or Y. For example, C-1, C-1′, and C-4 in V exhibit a good correlation with Hammett σ constants; however, C-4′, which is directly attached to Y, does not show any good correlation. Furthermore,

Table 1. ^{13}C NMR Chemical shifts (ppm from TMS) of monosubstituted derivatives, **1** and **2** in $CDCl_3$[a]

No.	Substituent Y	Substituent X	C-1	C-2	C-3	C-4	C-1′	C-2′	C-3′	C-4′	C-7
1a[b]	H	NMe_2	141.29	122.03	113.08	149.70	137.29	128.34	128.53	130.20	155.52
			(+10.66)	(−1.27)	(+15.89)	(−23.91)	(−1.18)	(+0.34)	(+0.05)	(+0.88)	(+4.45)
1b[c]	H	OCH_3	144.96			158.55	136.81			131.04	157.95
			(+6.99)			(−32.76)	(−0.70)			(+0.13)	(+2.12)
1c[c]	H	CH_3	149.53			135.41	136.61			130.91	158.81
			(+2.42)			(−9.62)	(−0.50)			(+0.26)	(+1.26)
1d	H	H	152.18[c]			125.94	136.48			131.24	160.01
			151.95[b]	120.76	128.97	125.79	136.11	128.68	128.58	131.17	160.07
1e[b]	H	F	147.89	122.25	115.65	161.07	136.06	128.68*	128.58*	131.17	159.60
			(+4.06)	(−1.49)	(+13.32)	(−35.28)	(+0.05)	(0.00)	(0.00)	(0.00)	(+0.47)
1f[c]	H	Cl	150.59			131.57	136.21			131.57	160.40
			(+1.36)			(−5.78)	(−0.10)			(−0.40)	(−0.33)
1h[b]	H	CO_2Et	156.06	120.56	130.73	127.70	135.82	128.97*	128.73*	131.71	161.34
			(−4.11)	(+0.20)	(−1.76)	(−1.91)	(+0.29)	(−0.29)	(−0.15)	(−0.54)	(−1.27)
1j	H	NO_2	158.08[a]			145.69	135.68			132.56	162.79
			157.82[b]	121.15	124.87	145.50	135.53	129.27	128.88	132.25	162.46
			(−5.87)	(−0.39)	(+4.10)	(−19.71)	(+0.58)	(−0.59)	(−0.30)	(−1.08)	(−2.39)
2a[c]	NMe_2	H	152.65			125.07	124.74			153.24	160.00
			(−0.70)			(+0.72)	(+11.37)			(−22.07)	(+0.07)
2b[c]	OCH_3	H	152.58			125.60	129.52			162.39	159.41
			(−0.63)			(+0.19)	(+6.59)			(−31.22)	(+0.66)
2c[c]	CH_3	H	152.45			125.73	134.02			141.58	159.87
			(−0.50)			(+0.06)	(+2.09)			(−10.41)	(+0.20)
2f[c]	Cl	H	151.65			126.14	134.88			137.20	158.28
			(+0.30)			(−0.35)	(+1.23)			(−6.03)	(+1.79)
2g[b]	Br	H	151.41	120.76	129.07	126.09	135.03	130.00	131.86	125.70	158.55
			(+0.44)	(0.00)	(−0.10)	(−0.30)	(+1.08)	(−1.32)	(−3.28)	(+5.47)	(+1.52)
1i[b]	CN	H	150.87	120.86	128.97*	126.82	139.88	129.17*	132.34	114.26	157.63
			(+1.08)	(−0.10)	(0.00)	(−1.03)	(−3.77)	(−0.49)	(−3.76)	(+16.91)	(+2.44)
2j[c]	NO_2	H	151.06			127.26	141.78			149.40	157.38
			(+0.89)			(−1.47)	(−5.67)			(−18.23)	(+2.69)

a) The asterisk means that the assignment may be reversed. Values in parentheses indicate the SCS. The positive values mean upfield shifts. b) The present work. c) Ref. 4.

Table 2. ^{13}C NMR Chemical shifts (ppm from TMS) of disubstituted derivatives, **3**, **4**, **5**, and **6** in $CDCl_3$[a)]

No.	Substituent		C-1	C-2	C-3	C-4	C-1′	C-2′	C-3′	C-4′	C-7
	Y	X									
3a	NMe_2	NMe_2	142.27	121.88	113.18	148.87	125.21	129.85	111.67	152.00	156.59
			(−0.98)	(+0.15)	(−0.10)	(+0.83)	(+12.08)	(−1.51)	(+16.86)	(−21.71)	(−1.07)
3b	OCH_3	NMe_2	141.59	122.03	113.08	149.36	130.14	129.90	114.11	161.68	155.42
			(−0.30)	(0.00)	(0.00)	(+0.34)	(+7.15)	(−1.56)	(+14.42)	(−31.39)	(+0.10)
3c	CH_3	NMe_2	141.39	122.08	112.98	149.46	134.49	128.29	129.27	140.61	155.81
			(−0.10)	(−0.05)	(+0.10)	(+0.24)	(+2.80)	(+0.05)	(−0.74)	(−10.32)	(−0.29)
3d	H	NMe_2	141.29	122.23	113.08	149.70	137.29	128.34	128.53	130.29	155.52
3f	Cl	NMe_2	140.90	122.32	113.08	149.94	135.82	129.46	128.88	136.36	153.86
			(+0.39)	(−0.09)	(0.00)	(−0.24)	(+1.47)	(−1.12)	(−0.35)	(−6.07)	(+1.66)
3g	Br	NMe_2	140.61	122.32	112.94	149.85	136.11	129.60	131.81	124.62	153.76
			(+0.68)	(−0.29)	(+0.14)	(−0.15)	(+1.18)	(−1.26)	(−3.28)	(+5.67)	(+1.76)
3i	CN	NMe_2	139.68	122.76	112.74	150.39	141.05	128.49	132.30	113.33	152.05
			(+1.61)	(−0.73)	(+0.34)	(−0.69)	(−3.76)	(−0.15)	(−3.77)	(+16.96)	(+3.47)
3j	NO_2	NMe_2	139.56	122.83	112.67	150.46	142.71	128.62	123.84	b)	151.46
			(+1.73)	(−0.80)	(+0.41)	(−0.76)	(−5.42)	(−0.28)	(+4.69)		(+4.06)
4a	NO_2	NMe_2	139.56	122.83	112.67	150.46	142.71	128.62	123.84	b)	151.46
			(+11.50)			(−23.20)	(−0.93)				(+5.92)
4b	NO_2	OCH_3	143.69	122.57	114.62	159.33	142.03	128.99	123.84	149.10	154.52
			(+7.37)			(−32.07)	(−0.25)			(+0.30)	(+2.86)
4c	NO_2	CH_3	148.46	120.98	129.88	137.11	141.95	129.17	123.79	149.38	155.94
			(+2.60)			(−9.85)	(−0.17)			(+0.02)	(+1.44)
4d[c)]	NO_2	H	151.06			127.26	141.78			149.40	157.38
4e	NO_2	F	146.91	122.69	116.04	161.85	141.53	129.31	123.84	149.31	156.81
			(+4.15)			(−34.59)	(+0.25)			(+0.09)	(+0.57)
4f	NO_2	Cl	149.33	122.30	129.36	132.64	141.32	129.36	123.86	149.46	157.43
			(+1.73)			(−5.38)	(+0.46)			(−0.06)	(−0.05)
4h	NO_2	CO_2Et	154.93	120.61	130.88	128.88	141.14	129.60	123.99	149.70	158.65
			(−3.87)			(−1.62)	(+0.64)			(−0.30)	(−1.27)
4j	NO_2	NO_2	156.21	121.20	125.06	146.35	140.58	129.90	124.09	150.09	159.89
			(−5.15)			(−19.09)	(+1.20)			(−0.69)	(−2.51)
5a	NMe_2	NO_2	158.89	121.19	124.84	144.71	123.61	131.09	111.49	153.15	161.81
			(−1.07)	(−0.04)	(+0.03)	(+0.79)	(+11.92)	(−1.82)	(+17.39)	(−20.90)	(+0.65)
5b	OCH_3	NO_2	158.21	121.25	124.91	145.20	128.49	131.90	114.40	163.10	161.73
			(−0.39)	(−0.10)	(−0.04)	(+0.30)	(+7.04)	(−2.63)	(+14.48)	(−30.85)	(+0.73)
5c	CH_3	NO_2	158.02	121.15	124.87	145.30	132.88	129.27*	129.60*	143.05	162.37
			(−0.20)	(0.00)	(0.00)	(+0.20)	(+2.65)	(0.00)	(−0.72)	(−10.80)	(+0.09)
5d	H	NO_2	157.82	121.15	124.87	145.50	135.53	129.27	128.88	132.25	162.46
5f	Cl	NO_2	157.45	121.18	124.97	145.64	133.88	130.36*	129.27*	138.51	161.07
			(+0.37)	(−0.03)	(−0.10)	(−0.14)	(+1.65)	(−1.09)	(−0.39)	(−6.26)	(+1.39)
5i	CN	NO_2	156.74	121.20	125.01	146.20	139.05	128.53	132.62	115.60	160.36
			(+1.08)	(−0.05)	(−0.14)	(−0.70)	(−3.52)	(+0.74)	(−3.74)	(+16.65)	(+2.10)
5j	NO_2	NO_2	156.21	121.20	125.06	146.35	140.58	129.90	124.09	150.09	159.89
			(+1.61)	(−0.05)	(−0.19)	(−0.85)	(−5.05)	(−0.63)	(+4.79)	(−17.84)	(+2.57)
6a	NMe_2		151.85	127.21	127.80	122.86	124.13	129.80	111.37	152.29	161.68
			(−0.73)	(−0.34)	(+0.15)	(+0.74)	(+11.88)	(−1.17)	(+16.97)	(−21.02)	(+0.69)
6b	OCH_3		151.41	127.04	127.95	123.33	129.04	130.00	114.06	162.22	161.46
			(−0.29)	(−0.17)	(0.00)	(+0.27)	(+6.97)	(−1.37)	(+14.28)	(−30.95)	(+0.91)
6c	CH_3		151.31	126.87	127.95*	123.45	133.57	128.34*	129.36	141.53	162.12
			(−0.19)	(0.00)	(0.00)	(+0.15)	(+2.44)	(+0.29)	(+1.02)	(−10.26)	(+0.25)
6d	H		151.12	126.87	127.95	123.60	136.01	128.63	128.34	131.27	162.37
6f	Cl		150.78	126.67	128.00	123.69	134.40	129.41	128.82	137.18	160.80
			(+0.34)	(+0.20)	(−0.05)	(−0.09)	(+1.61)	(−0.78)	(−0.48)	(−5.91)	(+1.57)
6g	Br		150.68	126.58	127.95	123.64	134.69	129.56	131.71	125.65	160.85
			(+0.44)	(+0.29)	(0.00)	(−0.04)	(+1.32)	(−0.93)	(−3.37)	(+5.62)	(+1.52)
6i	CN		150.39	126.67	128.14	124.18	139.58	128.73	132.40	114.50	160.70
			(+0.73)	(+0.20)	(−0.19)	(−0.58)	(−3.57)	(−0.10)	(−4.06)	(+16.77)	(+1.67)
6j	NO_2		150.33	126.67	128.19	124.28	141.20	128.97	123.79	149.31	160.39
			(+0.79)	(+0.20)	(−0.24)	(−0.68)	(−5.19)	(−0.34)	(+4.55)	(−18.04)	(+1.98)

a) Values in parentheses indicate the SCS from the corresponding parent compounds in each series. The asterisk means that the assignment may be reversed. b) Not observed. c) Ref. 4.

among these ipso carbons, C-1′, which is situated at the para position of the carbon bearing Y, is highly sensitive to substituent electronic effects, as indicated by a ρ value exceeding 10 (Table 3). Similar high sensitivity of the substituent effects is also noticed for C-1 in **4**, C-1′ in **3** and **6**. Poor correlations (the results

Table 3. Hammett ρ values and correlation coefficients for aromatic carbons[a,b]

Carbon	Series			
	3	**4**	**5**	**6**
C-1	−1.77	10.70	−1.63	−1.02
	(0.978)	(0.942)	(0.988)	(0.988)
C-4	1.03	−8.84	1.03	0.87
	(0.996)	(0.318)	(0.995)	(0.990)
C-1′	10.54	−1.32	10.28	10.20
	(0.965)	(0.994)	(0.963)	(0.960)
C-4′	−29.20	0.83	−14.40	−15.48
	(0.827)	(0.954)	(0.513)	(0.517)

a) Calculated with σ values. b) Absolute values of the chemical shifts were employed for the regression analyses.

not shown) for C-2, C-3, C-2′, and C-3′ on the rings bearing the substituent X or Y, that is, C-2′ and C-3′ in **3**, **5**, and **6**, and C-2 and C-3 in **4**, may be attributed to predominance of secondary perturbations such as anisotropy and/or neighboring effects over the substituent electronic effects.

Substituent-Substituent Interactions in Disubstituted N-Benzylideneanilines. For disubstituted *N*-benzylideneanilines, 4-$YC_6H_4CH{=}NC_6H_4X$-4, if the effects of both substituents on the chemical shifts are additive as expressed by a simple addition of the effects of the substituents X in **1** and Y in **2**, the chemical shift of the azomethine carbon of a disubstituted NBA can be calculated according to Eq. 1, where ΔX and ΔY are differences in the chemical shifts between the unsubstituted NBA, δH, and the monosubstituted compounds with substituents X, δX, and Y, δY, respectively. The value of 160.07 denotes the chemical shift of the unsubstituted NBA. The $(\Delta X+\Delta Y)$ corresponds to a calculated SCS (Eq. 2), and the observed SCS is given by Eq. 3, where δ C_{obsd} X–Y refers to the chemical shift observed for the disubstituted NBA. For **3** and **4** δ C_{calcd} X–Y and SCS_{calcd} X–Y are obtained according to Eqs. 1 and 2, and are listed in Table 4 together with the corresponding observed values. If the additivity holds for **3** and **4**, SCS_{calcd} X–Y should be the same as SCS_{obsd} X–Y. However, Table 4 shows a large difference between them. This may reflect a strong interaction between the two substituents X and Y. This situation can well be visualized by plotting SCS_{obsd} X–Y against SCS_{calcd} X–Y, as shown

$$\delta C_{calcd}X\text{–}Y = 160.07 + (\Delta X+\Delta Y) \quad (1)$$

$$SCS_{calcd}X\text{–}Y = \Delta X + \Delta Y \quad (2)$$

$$SCS_{obsd}X\text{–}Y = 160.07 - \delta C_{obsd}X\text{–}Y \quad (3)$$

$$\Delta X = \delta H - \delta X$$

$$\Delta Y = \delta H - \delta Y$$

in Figs. 1 and 2 for **3** and **4**, respectively, in which SCS values for the corresponding monosubstituted NBAs are also plotted to provide a scaling for the deviation.[7] As shown in Fig. 1, the discrepancy between SCS_{calcd} X–Y and SCS_{obsd} X–Y is noticed for NBAs with an electron-releasing or an electron-withdrawing substituent. Thus, the actual azomethine carbon chemical shifts deviate to the downfield from the calculated values for **3** with the electron-releasing groups. In a striking contrast, the deviations are to the upfield for **3** with the electron-withdrawing groups. On the other hand, Fig. 2 shows that the observed values accord well with the calculated ones for **4** with the electron-withdrwaing groups whereas significant deviations are noticed for **4** with the electron-releasing groups such as a dimethylamino and a methoxyl.

The Hammett treatment with σ values[6] of these deviations, $\Delta\delta$ (defined by SCS_{obsd} X–Y−SCS_{calcd} X–Y), for **3** gives a fairly good linear relationship with a correlation coefficient of 0.967 as shown in Fig. 3a. A similar plot for **4** gives a relationship with a correlation coefficient of 0.900; however, a plot with σ^+ values[6] affords a better linear relationship with a correlation coefficient of 0.957 (Fig. 3b). No significant trend of $\Delta\delta$ can be found for **5**.

Multiple substituent effects have been extensively studied on reaction rates, thermal and spectroscopic parameters in various organic π-systems.[8] Although nonadditivity has been observed in the multiple substi-

Table 4. Additivity for azomethine carbon chemical shifts of **3** and **4**

No.	Substituent Y	Substituent X	$\delta C_{calcd}X$–Y	$\delta C_{obsd}X$–Y	$SCS_{calcd}X$–Y	$SCS_{obsd}X$–Y	$\Delta\delta$[a]
3a	NMe_2	NMe_2	155.55	156.59	+4.52	+3.48	−1.04
3b	OCH_3	NMe_2	154.96	155.42	+5.11	+4.65	−0.46
3c	CH_3	NMe_2	155.42	155.81	+4.65	+4.26	−0.39
3f	Cl	NMe_2	153.83	153.86	+6.24	+6.21	−0.03
3g	Br	NMe_2	154.10	153.76	+5.97	+6.31	+0.34
3i	CN	NMe_2	153.18	152.05	+6.89	+8.02	+1.13
3j (=**4a**)	NO_2	NMe_2	152.93	151.46	+7.14	+8.61	+1.47
4b	NO_2	OCH_3	155.26	154.52	+4.81	+5.55	+0.74
4c	NO_2	CH_3	156.12	155.94	+3.95	+4.13	+0.18
4e	NO_2	F	156.91	156.81	+3.16	+3.26	+0.10
4f	NO_2	Cl	157.71	157.43	+2.36	+2.64	+0.28
4h	NO_2	CO_4Et	158.65	158.65	+1.42	+1.42	0.00
4j	NO_2	NO_2	159.77	159.89	+0.30	+0.18	−0.12

a) $\Delta\delta = SCS_{obsd}X\text{–}Y - SCS_{calcd}X\text{–}Y$.

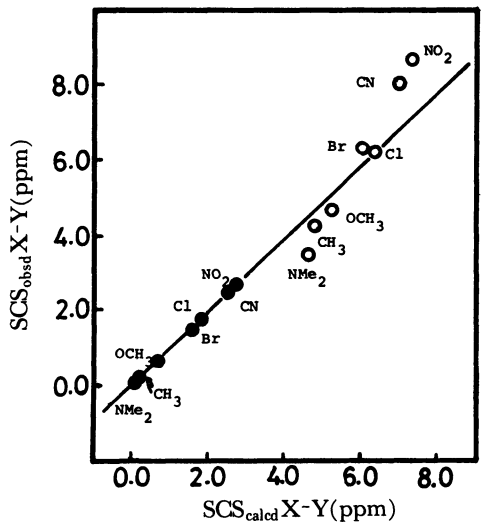


Fig. 1. Nonadditivity of multiple substituent effects on the azomethine carbon chemical shifts in **3**. The open circles denote the SCS in **3** and the closed circles denote the SCS in **2**.

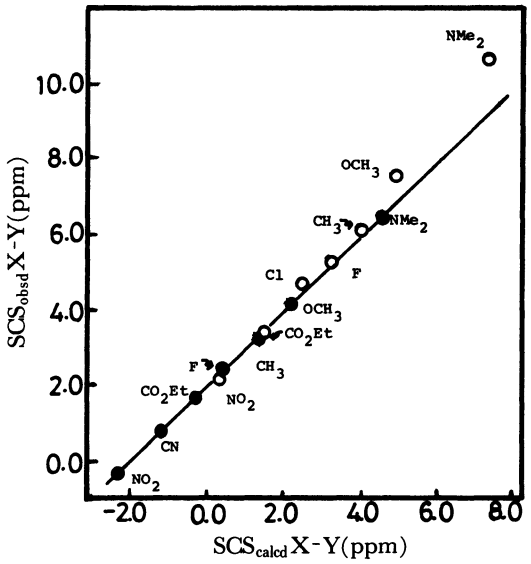


Fig. 2. Nonadditivity of multiple substituent effects on the azomethine carbon chemical shifts in **4**. The open circles denote the SCS in **4** and the closed circles denote the SCS in **1**.

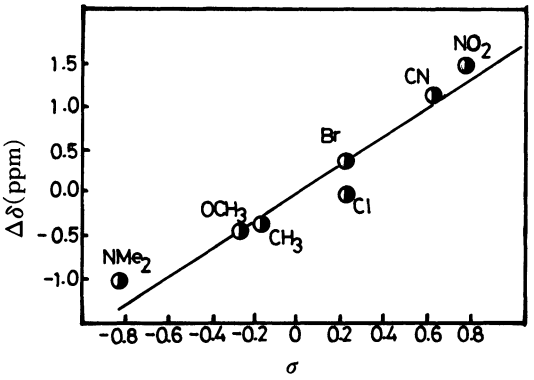


Fig. 3a. Plot of $\Delta\delta$ *vs.* Hammett σ constants in **3**.

tuent effects on bromination rates of 1,1-diphenylethylene,[8h] α-methylstilbenes,[8o] and polysubstituted

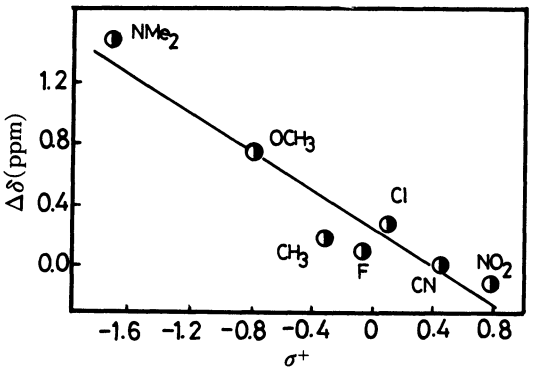


Fig. 3b. Plot of $\Delta\delta$ *vs.* Hammett σ^+ constants in **4**.

benzenes,[8i] on stabilization energies of trityl cations[8c] and anions,[8b] and on proton and carbon chemical shifts of several conjugated π-systems,[8f,g,j,l,m] few reports have appeared on the systems in which substituent–substituent interactions may lead to conformational changes of molecules.

We interpret the nonadditivity of multiple substituent effects on the azomethine carbon chemical shifts in **3** and **4** as a consequence of the substituent–substituent interaction which may be accompanied by conformational changes of the NBA derivatives. The downfield deviation of $\Delta\delta$ for NBAs with the electron-releasing groups in **3** may be reasonably interpreted in terms of suppression of the electron donation from the 4-dimethylamino group on the ring A toward the azomethine carbon by strongly electron-donating groups such as a 4′-dimethylamino and a 4′-methoxyl. In contrast, strongly electron-withdrawing groups such as 4′-cyano and a 4′-nitro enhances the electron donation resulting in an upfield deviation of $\Delta\delta$ as observed for **3** (Fig. 1). Thus, the net electron-releasing ability of the 4-dimethylamino group depends on the electronic properties of the 4′-substituents. Actually, $\Delta\delta$'s for **3** give a good linear elationship with Hammett σ constants with a correlation coefficient of 0.967 as shown above (Fig. 3a). The degree of the variable electronic effect of the 4-dimethylamino group may be evaluated by $\Delta\Delta\delta$ (defined by a difference in $\Delta\delta$'s) among the 4′-substituents. For example, for **3** $\Delta\delta(NMe_2)-\Delta\delta(NO_2)$ gives $\Delta\Delta\delta$ of 2.51 in a chemical shift unit, indicating that the net variation of the electronic effect of the 4-dimethylamino group corresponds to 2.51 ppm. This seems to be significant since the magnitude is as large as SCS of the methoxyl group in **1**. The systematic change in $\Delta\delta$ clearly indicates the interaction between the 4-dimethylamino group and the 4′-substituents. Such substituent–substituent interactions have often been observed by other workers.[8] With respect to the multiple substituent effects on the chemical shifts, Dubois, Doucet and their coworkers undertook a detailed study on electronic structures of diarylcarbenium ions.[8l,j] They observed a clear nonadditivity of the effects of two methoxyl groups on the α-carbon chemical shift. For example, for bis(4-

methoxyphenyl) carbenium ions, the first methoxyl group induces a change of 20.3 ppm in the α-carbon chemical shift whereas the second one induces only a 5.5 ppm change. Apparently, as the authors describe, saturation of the electronic effect occurs. Our own observation that the electron-donating effect of the 4-dimethylamino group is strongly suppressed by the 4′-dimethylamino and 4′-methoxyl groups is consistent with that by Dubois *et al.*, and will represent an example of a neutral system in which the electronic effect of a substituent will depend on another substituent in the molecule.

In the case of **4**, the discrepancy may also be explained similarly in terms of the interactions between the 4′-nitro group and the variable substituents, especially the electron-releasing groups on the ring A. The through-conjugative interaction between the 4′-nitro group and the electron-releasing groups will give the upfield deviations of $\Delta\delta$'s. A better correlation of $\Delta\delta$'s with σ^+ than with σ values also supports this interpretation (Fig. 3b).

We point out here that the substituent–substituent interactions in **3** and **4** may be accompanied by conformational change in these disubstituted NBAs. It is well-known that besides the π-π conjugation throughout the π-systems the n-π conjugation, which involves delocalization of the lone pair electrons on the nitrogen atom to the ring A and thus favors a highly twisted conformation, plays an important role in determining the molecular conformation of NBAs in solution.[2b,9] Since the through-conjugative interaction in the whole π-system will lead to a less twisted conformation,[2] it is reasonable to consider that the decrease in the electron donation from the 4-dimethylamino group in **3** will give rise to a less planar conformation.

Consider first the case of **4**. It is quite reasonable to assume that *N*-(4-nitrobenzylidene)-4-nitroaniline, **4j**, takes a conformation twisted as much as *N*-benzylidene-4-nitroaniline, **1j**, in solution,[1] since it is not likely that the 4′-nitro group may change the twist angle θ_N. If, for example, *N*-(4-nitrobenzylidene)-4-dimethylaminoaniline, **4a**, also adopts a considerably twisted conformation, the enhanced electron donation from the 4-dimethylamino group toward the azomethine carbon should not be observed since such electron donation must be greatly suppressed by the twisting of the conjugated π-system. Therefore, the electron donation from the 4-dimethylamino group in **4a** will be accompanied by a certain decrease in the twist angle θ_N in going from **4j** to **4a** Actually, it is reported by Zollinger[2b] and Kubota[2c] that **4a** will take a nearly planar conformation in solution as revealed by the UV and ESR spectra. A Hammett correlation of the azomethine carbon chemical shifts in **4** may also be supporting evidence. As illustrated in Fig. 4, treatment of SCS_{obsd} of the azomethine carbon chemical shifts with Hammett σ^+ constants shows an excellent linear

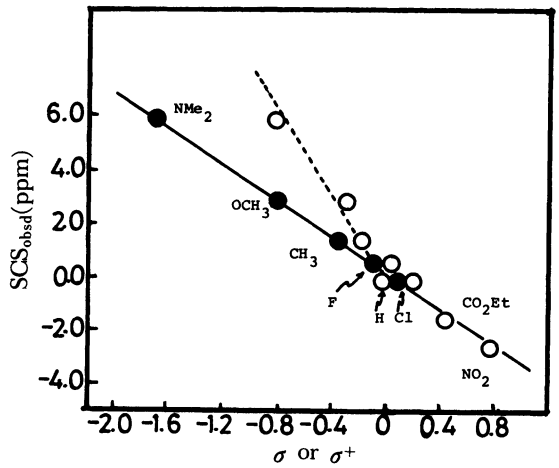
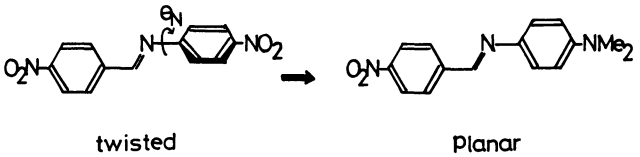
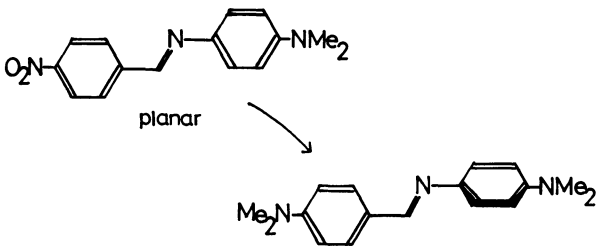


Fig. 4. Plot of SCS_{obsd} *vs.* Hammett σ(○) or σ^+(●) constants in **4**.



Scheme 2.



Scheme 3.

relationship with a correlation coefficient of 0.999 (correlation coefficient with σ values is 0.978). This can be best interpreted in terms of the enhanced electron donation from the electron-donating groups toward the azomethine carbon, and thus, in terms of a certain decrease in the twist angle θ_N in going from **4h** and **4j** to **4b** and **4a** (Scheme 2). A Similar concept can also be advanced to account for $\Delta\delta$'s in **3**. As already pointed out, the *N*-lone pair delocalization may be suppressed by the electron-releasing effect of the 4-substituents resulting in less twisted conformations. In other words, the more electron-donating the 4-substituent, the smaller twist angle θ_N would result. Since the electron donation from the 4-dimethylamino group is considerably suppressed in **3a** and **3b**, as shown by the larger $\Delta\delta$'s, resulting in the decrease in the through-conjugative interaction, it is reasonable to consider that **3a** and **3b** will take less planar conformations compared with a nearly planar conformation of **3j**. A feature of such a conformational change with the substituents based on the above discussion is illustrated in Scheme 3.

It is of interest noting that Freedman and his coworkers[8d] reported a substituent dependence of

rotational barriers of *N*-aryl bonds in 4′-substituted 4-dimethylaminotrityl cations. Our study may represent a new example that the change of molecular conformation can be induced by the substituent–substituent interactions.

Effects of Substituents Y on the Azomethine Carbon Chemical Shifts. Examination of the SCS data of the azomethine carbon chemical shift indicates that the modes of the substituent effects are different between the 4-substitution and 4′-substitution. Thus, in **1** and **4** which carry the variable substituents X on the ring A, the electron-releasing groups cause significant upfield shifts, whereas the electron-attracting groups generate appreciable downfield shifts. Accordingly, the substituent effect is normal in these cases. In contrast, in the series of **2**, **3**, **5**, and **6** in which the variable substituents Y are on the ring B, the electron-withdrawing groups cause upfield shifts, whereas the variation of SCS values remain small (≈1 ppm) with the electron-releasing groups. The overall SCS variation ia smaller (2—5 ppm) in **2**, **3**, **5**, and **6** than in **1** and **4** (7—8 ppm). Thus, the azomethine carbon chemical shift is more sensitive to the electronic effect of the substituents on the ring A than to that on the ring B.

However, careful examination of the SCS values in **2**, **3**, **5**, and **6** reveals that the electron-donating and electron-attracting groups behave in different ways to transmit the electronic effect on the azomethine carbon as illustrated in Figs. 5 to 8 which show plots of the

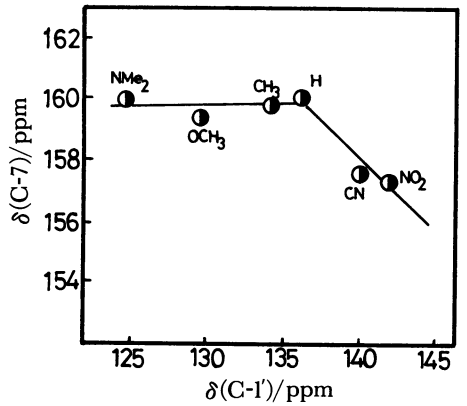


Fig. 5. Plot of δ(C-7) *vs.* δ(C-1′) in **2**.

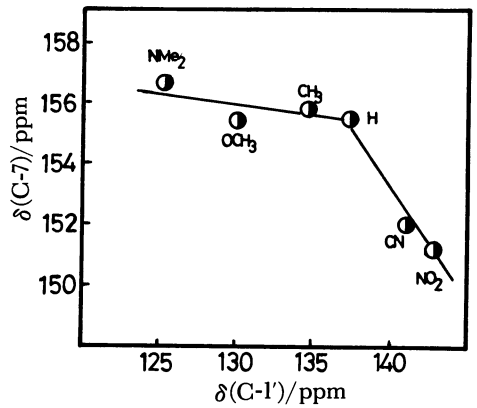


Fig. 6. Plot of δ(C-7) *vs.* δ(C-1′) in **3**.

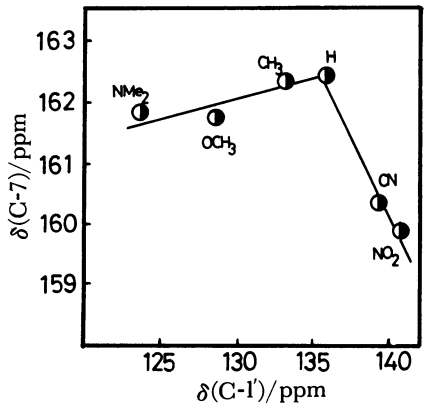


Fig. 7. Plot of δ(C-7) *vs.* δ(C-1′) in **5**.

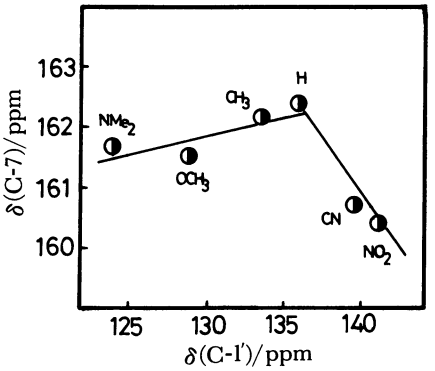
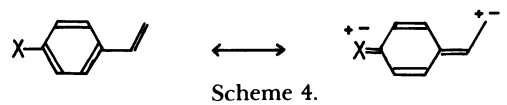


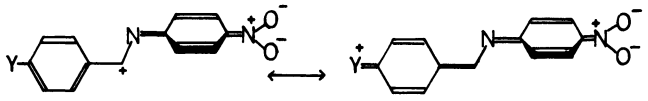
Fig. 8. Plot of δ(C-7) *vs.* δ(C-1′) in **6**.

azomethine carbon chemical shifts against the C-1′ chemical shifts which remarkably suffer the electronic effect of the 4′-substituents as mentioned in a previous section (halogen atoms are omitted from the consideration since they apparently deviate from the lines). Figures 5—8 clearly indicate that in all the series studied the electron-withdrawing groups on the ring B generally cause upfield shifts, whereas the effects of the electron-releasing groups are different from each other, and seem to depend on electron demand on the azomethine carbon induced by the fixed substituent on the ring A. Thus, the chemical shifts are not very sensitive to the electron-releasing groups in **2**. However, the azomethine carbon suffers a roughly inverse substituent effect (the NMe_2 derivative resonates at a lower field than the unsusbtituted derivative) in **3** which carry the 4-dimethylamino group. In a striking contrast, opposite trends can well be seen in **5** and **6**, where the azomethine carbon chemical shift suffers a roughly normal substituent effect with the electron-releasing groups to give rise to the V-shape correlation with the C-1′ chemical shifts (Figs. 7 and 8).

The above finding that 4′-substituents exert a relatively small electronic effect on the azomethine carbon chemical shift seems to be in keeping with reported results on the α-carbon chemical shifts in styrenes,[10,11] acetophenones,[12] and benzaldehydes.[13] These have been interpreted in terms that the 4-substituents do not change significantly the electron densities on the α-carbons as dipicted for 4-substituted



Scheme 4.



Y: electron-releasing groups

Scheme 5.

styrenes in Scheme 4 as an example. However, lack of systematic studies as well as the relatively minor variation of the chemical shifts and their poor correlation with structural parameters such as Hammett constants have made it difficult to get deeper insight into the substituent effects on the α-carbon chemical shifts in benzilidene-type conjugated systems. In this respect, the correlation of the azomethine carbon chemical shifts with the C-1′ chemical shifts is of particular interest. The present study with systematic changes of the substituents on the ring A clearly indicates that 4′-substituent effects should be treated separately between the electron-releasing and the electron-withdrawing groups. Thus, the electron-withdrawing groups cause the inverse substituent effects in all the series, whereas the effects with the electron-releasing groups may be normal, inverse, or even absent depending on the electron demand developed on the azomethine carbons by the structural and/or electronic effects of the substituents on the ring A.

As depicted in Figs. 7 and 8, the effects with the electron-releasing groups is normal in **5** and **6** in which the electron demand on the azomethine carbons seems to increase compared with **2**. In **5**, the 4′-nitro group will generate significant electron deficiency on the azomethine carbons compared with those of **2**. Likewise, the *N*-lone pair delocalization in **6** to the ring A enhanced by twisting of the C–N bond by the 2,6-dimethyl groups will result in the increase in electron demand on the azomethine carbon.[3] Under these circumstances, the electron-releasing groups will donate electrons more efficiently toward the azomethine carbon resulting in the normal upfield shift, as shown in Scheme 5. Actually, the normal substituent effect on the α-carbon chemical shift was observed in methyldiphenylcarbenium and hydroxydiphenylcarbenium ions by Doucet and his coworkers, [81] in which the strong electron demand on the cationic carbons enhances the electron donation from the electron-releasing groups to give rise to the normal upfield shift. The proposed concept can be further supported by examining available data for 4-substituted β,β-dichloro-,[14] **7**, and β,β-dicyanostyrenes,[15] **8**. We treated the results in a similar manner to that employed for the present study, and the correlations for these two series are illustrated in Figs. 9 and 10. In the case of the dichlorostyrenes, the α-carbon chemical shift suffers a inverse substitu-

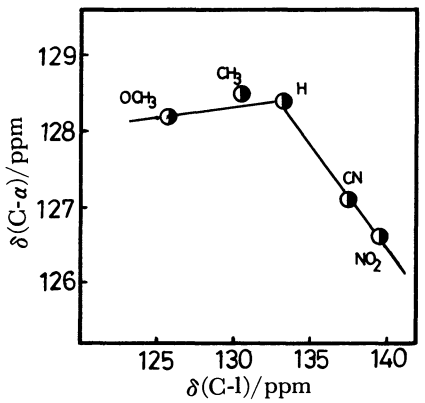


Fig. 9. Plot of δ(C-α) *vs.* δ(C-1) in **7**.

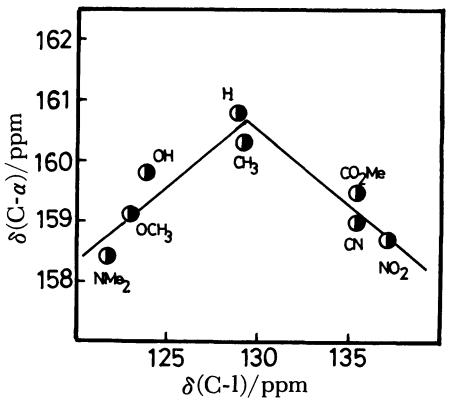
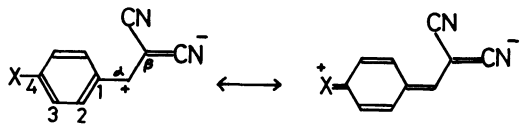


Fig. 10. Plot of δ(C-α) *vs.* δ(C-1) in **8**.



X: electron-releasing groups

Scheme 6.

ent effect with the electron-withdrawing groups, whereas the chemical shifts remain roughly constant with the electron-releasing groups, as found for **2**. This indicates that the substituent effects must also be treated separately between the electron-releasing and electron-withdrawing groups. Such a situation can well be seen in the dicyanostyrenes in which a clear V-shape correlation was observed. The normal substituent effect with the electron-releasing groups can be reasonably interpreted in terms of the proposed concept that the electron demand on the α-carbon plays an important role in determining the mode of the substituent effect (Scheme 6).

The inverse substituent effects on the proton and carbon chemical shifts have been occasionally observed by other workers. For example, Reynolds *et al.*[11] reported that introduction of a 4-nitro group caused an upfield shift of the α-carbon chemical shift in 4-substituted styrenes. Inamoto and his coworkers also reported[4] the inverse substituent effect on the azomethine carbon chemical shifts in **2**, and attributed this phenomenon to the effect of charge alternation

originally proposed by Pople.[16,17] The similar observation in the present study may also be explicable by the same effect. It should be pointed out, however, that this explanation cannot be advanced for the effect of the electron-releasing groups on the azomethine carbons. Even for **2** originally reported by Inamoto *et al.* and for **3** which carry the 4-dimethylamino group on the ring A, it is clear that the correlations cannot be treated in a single line. Whether the substituent effect is normal or inverse must depend on the degree of the electron demand developed on the azomethine carbons.

In summary, the present study revealed importance of two competetive factors responsible for the 4′-substituent effects on the azomethine carbon chemical shifts in *N*-benzylideneanilines. It should be also pointed out that similar mode of the substituent effects may be extended to the α-carbon chemical shifts in other benzylidene-type conjugated systems.

Conclusion

Multiple substituent effects on the azomethine carbon chemical shift were examined for a few series of disubstituted *N*-benzylideneanilines. Nonadditivity of the multiple substituent effects was observed for **3**, 4-$YC_6H_4CH{=}NC_6H_4NMe_2$-4, and **4**, 4-$NO_2C_6H_4CH{=}NC_6H_4X$-4. It is pointed out that the observed nonadditivity can be understood in terms of the substituent–substituent interactions accompanied by the conformational changes with the substituents in these NBAs. The present study also revealed that there are two modes of the 4′-substituent (on the ring B) effects on the azomethine carbon chemical shift. Depending on the degree of the electron demand developed on the azomethine carbons, the effects with the electron-releasing groups may be normal or inverse; the former effects result from the efficient electron donation from the substituents and the latter can be explained in terms of the charge alternation on the carbon frameworks induced by the substituents.

Experimental

Materials. *N*-benzylideneaniline, *N*-benzylidene-4-nitroaniline, and *N*-benzylidene-2,6-dimethylaniline were available from the previous work.[1] All other *N*-benzylideneanilines were similarly prepared, and fully characterized by physical constants, spectral data, and/or elemental analyses. All new compounds gave satisfactory elemental analyses. To our knowledge, the physical constants of the following compounds are not reported previously; **3b**, mp 141.5—143 °C (uncorrected), **3d**, mp 144—145 °C, **3f**, mp 162—163 °C, **3g**, mp 170.5—171 °C, **3i**, mp 194.5—195.5 °C, **4e**, mp 109—110 °C, **4h**, mp 177—178 °C, **5c**, mp 137—138 °C, **5f**, mp 164.5—165.5 °C, **5i**, mp 183—183.5 °C, **6a**, mp 74.5—76 °C, **6b**, mp 40—41 °C, **6c**, mp 162—163 °C, **6f**, mp 157—158 °C, **6g**, mp 152—153 °C, **6i**, mp 68-69 °C, **6j**, mp 98—100 °C.

^{13}C NMR Spectra. ^{13}C NMR spectra were recorded on a JEOL FX-60 spectrometer operating in a Fourier Transform mode with complete proton decoupling as described previously.[3] Off-resonance decoupled spectra were also recorded in some cases. The spectra were usually taken at room temperature; however, samples of **4** were run at *ca.* 40—55 °C of the probe temperature at saturated concentrations. Solvent was $CDCl_3$ in all cases.[18]

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