Use of Correlation of ^{1}H and ^{13}C Chemical Shifts of *N*-Arylsuccinanilic Acids, *N*-Arylsuccinimides, *N*-Arylmaleanilic Acids, and *N*-Arylmaleimides with the Hammett Substituent Constants for the Studies of Electronic Effects

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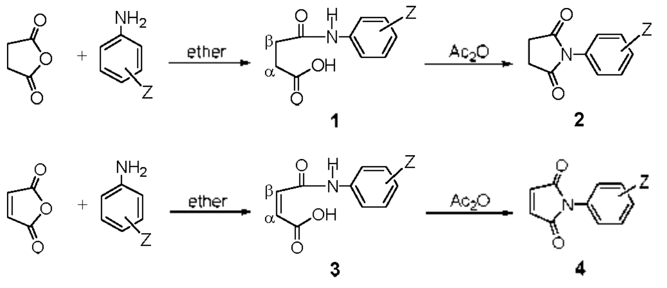
A series of *N*-arylsuccinanilic acids, *N*-arylsuccinimides, *N*-arylmaleanilic acids, and *N*-arylmaleimides was prepared and their NMR spectra were examined by correlating the ^{1}H and ^{13}C chemical shift values with the corresponding Hammett σ values. The carbonyl carbons of the amides show a normal correlation with σ but those of the imides show an inverse correlation.

Key Words: Correlation of chemical shifts, Succinanilic acid, Succinimide, Maleanilic acid, Maleimide

Introduction

In the course of our investigation on the effect of the substituent in benzene ring on the chemical shift of ^{1}H and ^{13}C in the side chain,[1] we were interested in systems of which only the hybridization of the C atoms are different. Succinimides (**2**) and maleimides (**4**) are structurally related with the difference of the -CH_2-CH_2- and -CH=CH-, respectively, as the components of the five-membered rings. Both are cyclic imides with the ring-forming atoms in planar arrangement. Unlike *N*-arylpropanamides or *N*-arylacrylamides which should have conformational isomers, the *N*-arylsuccinimides and -maleimides should have only one conformation unless there is a substituent at the *ortho*-position of the benzene ring.



Z: **a**, *m*-NO_2; **b**, *m*-Br; **c**, *m*-Cl; **d**, *m*-F; **e**, *m*-OCH_3; **f**, *m*-CH_3; **g**, *p*-NO_2; **h**, *p*-Br; **i**, *p*-Cl; **j**, *p*-F; **k**, p-OCH_3; **l**, *p*-CH_3; **m**, H

Maleimides are commonly used as dienophiles in Diels-Alder reactions and the products are succinimide derivatives.[2] Both of the *N*-phenyl derivatives of succinimides (**2**) and maleimides (**4**) are easily prepared from succinic anhydride and maleic anhydride, respectively. The intermediates that are *N*-phenylsuccinanilic acids (**1**) and *N*-phenylmaleanilic acids (**3**) may have different conformation, that may cause remarkable characteristics of the NMR chemical shifts in both series as well as for the intermediates. Here we report our NMR studies on these four series.

Results and Discussions

The succinanilic acids **1**[3] and the maleanilic acids **3**[4] were prepared by reacting succinic anhydride and maleic anhydride, respectively, with *m*- and *p*-substituted anilines in diethyl ether at room temperature. The crude **1** and **3** could be converted to the *N*-phenylimides **2** and **4** by heating with acetic anhydride.[3,4]

Table 1. Chemical Shift Values (Hz)[a] of 0.1 *M* Succinanilic Acides (**1**) in DMSO-d_6 Obtained at 400 MHz for ^{1}H and 100 MHz for ^{13}C.

	OH	NH	α-H	β-H	COOH	CONH	α-CH_2	β-CH_2
a	33.8	212.3	10.6	20.9	−5.5	92.7	10.7	−14.0
b	9.9	76.9	−0.1	2.4	−7.8	46.6	2.7	−13.2
c	6.8	81.5	1.0	3.9	−10.1	46.2	2.7	−13.8
d	9.7	91.3	1.4	4.6	−8.0	45.3	3.9	−13.6
e	0.5	−2.8	−2.9	−3.9	−0.5	7.5	3.9	−5.0
f	−0.3	−30.5	−2.0	−3.7	0.4	−6.2	−0.5	2.4
g	24.6	259.5	10.9	32.0	−13.7	116.9	24.7	−25.0
h	10.0	60.8	−1.3	−0.9	−5.2	23.2	2.4	−8.8
i	6.9	60.5	−0.4	0.0	−3.2	21.6	0.4	−7.1
j	1.5	24.9	−0.6	−5.3	−2.0	−8.2	−9.7	0.0
k	−3.0	−58.7	−0.6	−16.3	5.3	−53.6	−14.9	11.1
l	−3.0	−35.4	−2.6	−7.4	3.0	−26.1	−5.9	4.4
m	4851.4	3977.2	1006.5	1022.2	17434.7	17055.9	3152.1	2927.6

[a] Positive value indicates downfield shift and the negative value indicates upfield shift from the chemical shift value of **1m**.

All of the crude products **1-4** were purified by recrystallization from various solvents in order to obtain analytically pure compounds for the NMR studies. The NMR spectra of **1-4** were obtained with a 0.1 *M* solution in DMSO-d_6. A uniform concentration of 0.1 *M* is essential for the correlation study. Unambiguous assignments for the signals were made by ^1H-^1H COSY and ^1H-^{13}C HETCOR spectroscopy.[5] The chemical shift values for ^1H and ^{13}C signals are listed in Tables 1-3.

As one of the attempts to analyze the effects of substituents quantitatively, the correlation of the chemical shift values vs. the Hammett σ values has been widely investigated.[6] The analysis is typically carried out by the single substituent parameter (SSP) approach and dual substituent parameter (DSP) approach, which are represented by equations 1 and 2, respectively.[7]

Table 2. Chemical Shift Values (Hz)[a] of 0.1 *M* *N*-Phenylsuccinimides (**2**) and 0.1 *M* *N*-Phenylmaleimides (**4**) in DMSO-d_6 Obtained at 400 MHz for ^1H and 100 MHz for ^{13}C.

	2			4		
	CH_2CH_2	C=O	CH_2CH_2	CH=CH	C=O	CH=CH
a	12.6	-34.7	10.1	35.5	-60.2	21.2
b	-3.4	-25.1	4.6	13.5	-44.5	8.2
c	-1.3	-28.3	3.2	15.3	-43.8	10.0
d	0.5	-30.8		15.3	-51.7	4.7
e	-5.9	-9.3	0.3	2.5	-16.8	-5.3
f	-4.7	4.1	0.2	0.9	-5.1	-7.7
g	14.2	-48.2	13.8	33.2	-70.5	39.3
h	-5.7	-23.6	3.0	13.5	-39.9	6.2
i	-2.8	-19.1	2.0	12.5	-34.5	5.4
j	-4.3	3.2	0.4	5.9	-10.1	-0.3
k	-11.2	19.4	-9.2	-8.2	17.0	-14.7
l	-7.5	6.7	-0.43	-4.8	1.3	-10.5
m	1112.74	17742.0	2895.6	2868.2	17051.7	13521.6

[a] Positive value indicates downfield shift and the negative value indicates upfield shift from the chemical shift value of **2m** and **4m**.

$$\delta = \rho\sigma + \delta o \tag{1}$$

$$\delta = \rho_I\sigma_I + \rho_R\sigma_R + \delta o \tag{2}$$

We have found that the correlations of the ^1H and ^{13}C chemical shifts against the Hammett σ values[8] using SSP analysis are fair to good, as shown in Figure 1.

The slopes (ρ) and the correlation coefficients from the similar plots are listed in Table 4. But the correlations with **3** merely show trends except for the protons and carbons of the amido group. One of the contrasting observations is that the carbonyl carbons of the imides **2** and **4** show inverse correlations whereas the amide carbons of **1** and **3** show normal correlations. The absolute magnitude of the slope for the amidyl C of **1** is about 2.4 times of that of **2**. Similarly, the slope for the amidyl C of **3** is about 1.3 times of that of **4**.

Cyclization to an imide changes both the sign and the magnitude of the slope. The positive slope (normal correlation) of the carbonyl carbon against σ may be understood as a result

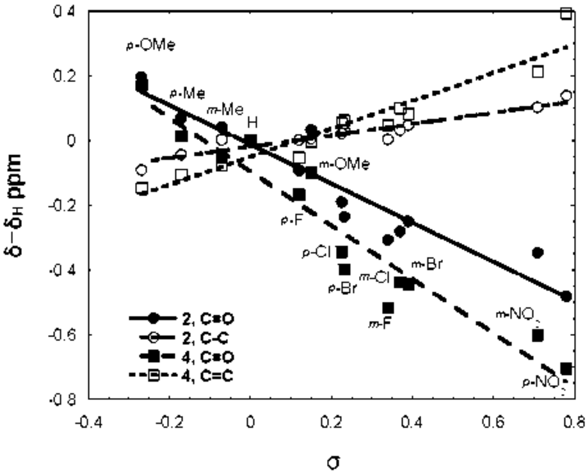


Figure 1. Correlation between σ and ^{13}C chemical shifts of **2** and **4** in DMSO-d_6.

Table 3. Chemical Shift Values (Hz)[a] of 0.1 *M* Maleanilic Acides (**3**) in DMSO-d_6 Obtained at 400 MHz for ^1H and 100 MHz for ^{13}C.

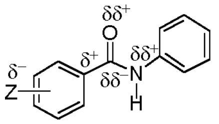
	OH	NH	α-H	β-H	COOH	CONH	α-C	β-C
a	−85.8	149.6	18.0	10.6	4.5	69.1	−15.0	−11.5
b	−80.0	31.4	0.6	−6.5	2.3	31.1	−3.7	40.6
c	−102.8	40.4	2.5	−3.6	5.4	36.6	−1.5	13.4
d		49.6	4.3	−5.3	12.6	36.7	−7.6	−14.1
e	−23.8	−12.4	1.0	−10.9	9.8	−2.2	−26.3	10.2
f	−6.3	−22.8	−0.9	−5.5	2.0	−7.7	−12.6	16.6
g	−87.9	189.0	18.7	21.0	−1.8	88.1	4.6	−20.8
h	−74.8	29.5	−0.5	−6.7	4.7	15.7	−2.2	−21.0
i	−56.0	30.1	−0.3	−5.0	0.8	11.2	−0.8	−24.1
j	−98.0	14.4	−2.7	−5.3	−2.0	−4.4	6.6	−14.2
k	124.6	−1.2	−3.3	−5.7	−22.1	−40.3	−25.5	49.7
l	49.3	−8.0	−2.3	−6.2	−8.1	−20.5	−9.9	31.2
m	5248.5	4155.7	2523.3	2590.0	16737.3	16372.5	13217.6	13091.3

[a] Positive value indicates downfield shift and the negative value indicates upfield shift from the chemical shift value of **3m**.

Table 4. Best Fit of the Single Substituent Parameter Equation for the ^1H and ^{13}C Chemical Shifts of **1-4** in DMSO-d_6 in Hz.

	1		**2**		**3**		**4**	
	ρ	r	ρ	r	ρ	r	ρ	r
HOCO	32.13	0.925			−164.25	0.772		
HNCO	290.46	0.977			180.00	0.899		
HOCOCH	11.83	0.830			20.14	0.874		
HNCOCH	36.47	0.929			19.52	0.712		
CHCH			20.47	0.880			41.09	0.981
HOCO	−15.43	0.896			14.09	0.513		
HNCO	146.72	0.988			111.45	0.984		
HOCOCH	−29.77	0.956			−42.68	0.542		
HNCOCH	26.61	0.875			11.86	0.359		
CHCH			17.16	0.938			42.94	0.950
C=O			−60.53	0.960			−83.85	0.964

of π polarization.[9] Yuzuri, *et al.* observed a normal correlation of *N*-benzoylanilines when the substituents are on the aniline ring. On the other hand, an inverse correlation results if the substituents are on the benzoyl ring.[9] The phenomena were explained by a mechanism of π polarization as shown in **I** and **II**.



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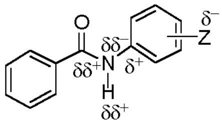


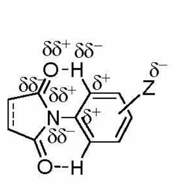
II

We also observed a normal correlation for the ^{13}C chemical shifts of the carbonyl carbons in the series of benzanilides, thiophene-2-carboxanilides, and furan-2-carboxanilides.[1f] The normal correlation of the carbonyl carbon signals observed for **1** and **3** may be explained as a result of π polarization because they are all secondary amides like benzanilides.

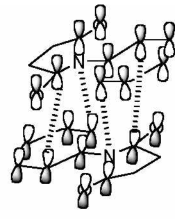
However, the inverse correlation observed for the series of **2** and **4** is not apparently related to the π polarization. Instead, it may be the result of coplanarity of the benzene and the imide rings. Because of the favorable intramolecular hydrogen bonding between the carbonyl O atoms and the *ortho*-H atoms, the *p* orbitals are all perpendicular to the plane. As a result of coplanarity of the two rings, the electronic effect of the substituent Z may cause an induced polarization through *ipso*-C-N bond and *ortho*-H---O bond. The former polarization causes the carbonyl atom to be positive whereas the latter one causes it to be negative, as shown in **III**.

The two effects may offset one another and the result may be a smaller magnitude for the ρ values compared to those of **1** and **3**. Although the absolute ρ values for **2** and **4** are smaller than those of **1** and **3**, the negative sign of the ρ value cannot be explained by the rationale.

One plausible rationale is the transmission of the substituent effect through space by stacking, as shown in **IV**. Such stacking should be possible because of the coplanarity of the five- and six-membered rings. The result of the induced polarization through stacking is the partial negative charge in the carbonyl carbon, which leads the inverse correlation. Furthermore, the carbon atom adjacent to the carbonyl carbon would show a normal correlation, according to the rationale. This is the case as shown in Table 4.



III



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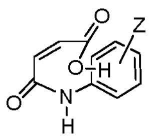

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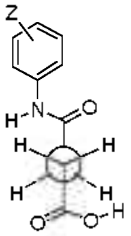
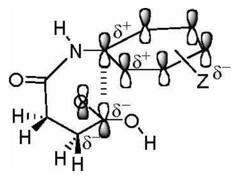


VI



VII

The ρ values for the α-C and α-H are very close with same sign for **2** and **4**. This is also evidence that the electronic effect of the substituent Z is transmitted through space by stacking. If the effect is transmitted merely through bonds, the value should become smaller as the distance from the substituent increases.

Although the ρ values of smaller than 20 Hz may be considered as an indication of the insignificant effect of the substituents, there are ρ values whose magnitude and signs are worth pointing out. The ρ value for the proton in COOH of **3** is one of them. Despite the distance between the proton and the substituent Z the magnitude (−164.25 Hz) is comparable to that of NH (180.00 Hz) which is very close to the benzene ring. The fact that the absolute values are close between NH and OH may be an indication that both protons are close to the substituent Z. This may be possible if the OH proton lies on the top of the benzene ring, as shown in **V**.

On the other hand, the most likely conformation of **1** may be an *anti* form, as shown in **VI**. However, such a conformation

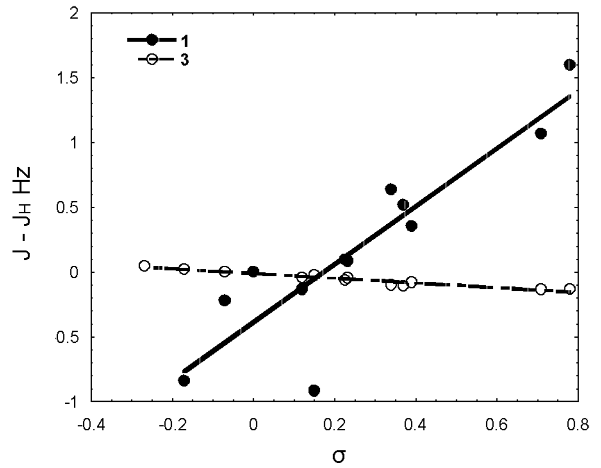


Figure 2. Correlations of the coupling constants of **1** and **3** *vs*. σ.

cannot explain the inverse correlation of ^{13}COOH and α-$^{13}CH_2$ although their ρ values are small (−15.43 and −29.77, respectively). A possible explanation is a *syn* conformation which leads to *p* orbital overlapping, as shown in **VII**. The *ipso*-C and the carbon atom of the COOH could be components of a six-membered ring. It is conceivable that the *p* orbitals of an *ipso*-C and that of a C=O may overlap so that induced polarization is possible. Such polarization should result in an inverse correlation for the carbon of the COOH group, and the observation is consistent with such a rationale. The *syn* conformation should also lead to an induced polarization of the α-CH_2 because the α-C and *ortho*-C may be parts of a six-membered ring.

The favorable *syn* conformation that leads to an inverse correlation of COOH and α-CH_2 is supported by the correlation of the coupling constants of α-CH_2-H_2C-β with the Hammett σ values. As shown in Figure 2, the coupling constants ^3J of **1**, ranging 4.15 - 6.74 Hz show a fairly good correlation with a slope of 2.25 Hz (r = 0.917).

Similar correlation is possible with **3**, but shows an inverse correlation, although the absolute magnitude of the slope is less that 8% of that of **1** ($\rho = -0.18$ Hz, r = 0.969). Considering the magnitude of the *cis*-coupling constant of **3** (about 12 Hz)[10] which is 2 - 3 times larger than that of **1**, the effect of the substituent Z which is linearly transmitted to the coupling constant may be considered as evidence of the *syn* conformation which allows the through-space transmission of the effect.

In conclusion, we report that the correlation of the chemical shift with the Hammett σ values may be a useful tool in understanding the conformation and stacking phenomena of conjugated systems. Through-space transmission of the electronic effect is as important as through-bond transmission in conjugated systems.

Experimental

Nuclear magnetic resonance (NMR) spectra were recorded on a Bruker DPX-400 FT NMR spectrometer in the Central Lab of Kangwon National University at 400 MHz for ^{1}H and 100 MHz for ^{13}C and were referenced to tetramethylsilane. The solutions were 0.10 *M* in DMSO-d_6. Each solution was prepared in a 1 mL cylindrical volumetric flask by weighing the compound into the flask and filling with solvent containing 1%-TMS. A portion (0.6 mL) of the solution was transferred into a 5 mm NMR tube and the spectrum was obtained at 20 °C. The chemical shift values that are relevant to the correlation are listed in Tables 1-3.

All the derivatives of **1**, **2**, **3** and **4** are known compounds, and they were prepared by following literature procedures.[3,4]

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