The Substituent Effect. VII. Substituent Chemical Shifts of NH Proton of Acetanilides[1a)]

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NMR chemical shifts of the NH proton of fifty-three *m*- and *p*-substituted acetanilides were determined in dilute DMSO solutions. The substituent chemical shifts were correlated with σ^0 constants with considerable scatter. Deviations were particularly significant for $-R$ groups having α-hydrogen. Improved correlation was found for $-R$ substituents with $(\sigma^0)_{DMSO}$ values which had been derived from the phenol hydroxyl chemical shifts in DMSO. Application of the LArSR equation using the DMSO-modified substituent parameters gave a good linear correlation for all substituents; $\Delta\delta^{NHAc}=0.686\ [(\sigma^0)_{DMSO}+0.277\ (\Delta\bar{\sigma}_R^-)_{DMSO}]$. These results indicate that the deviations are caused primarily by solvent-modification of substituents, the modification being essentially the same for both the acetanilide and the phenol systems in DMSO. The lower r^- value 0.277 in the chemical shifts for the acetanilides than for the phenols suggests that the π-electronic contribution of $+R$ *para* substituents is less important in the acetanilide system than in the phenol one. The resonance substituent parameter for these solvent-modified substituents was found to be proportional to both $(\bar{\sigma}_p^{OH}-\bar{\sigma}_p^{NH})$, the difference between the apparent $\bar{\sigma}_p$ constants of the two systems, and to $\bar{\sigma}_p-0.85\ \bar{\sigma}_m$ of each series. Estimation of a practical set of inductive and resonance substituent parameters for DMSO-modified substituents is attempted.

Foregoing investigations[2—4)] have indicated the following: The hydroxyl chemical shift of *m*- and *p*-substituted phenols in DMF or DMSO is closely related to the chemical reactivities; the substituent effect can be described successfully in terms of the LArSR and LSFE relationships;[5)] the solvent-modification of substituents is of considerable importance in these aprotic solvents. The effect of solvent on the substituent effect in chemical reactivities and physical properties has received considerable attention.[6)] However, hardly any studies have been carried out to elucidate quantitatively such solvent effect on the basis of the linear free energy relationship. The solvent-modification of the nature of substituents can be measured by the deviations in the LArSR or LSFE correlation by means of the sets of substituent parameters which were determined from the reactivity data in aqueous media.

From our interest in the substituent effect in aromatic derivatives, we attempted to estimate the practical measure of inductive and π-electronic effects of "the solvent-modified substituents" in DMF and DMSO solutions.[2,3)] Evaluation of the resonance parameters $(\sigma_\pi)_M$ for the solvent-modified substituents in medium M was carried out by means of the following relation derived from the LSFE equation.[5)]

$$(\sigma_\pi)_M = (\bar{\sigma}_p-0.85\bar{\sigma}_m)_M/C_M \qquad (1)$$

where $\bar{\sigma}_p$ and $\bar{\sigma}_m$ are the apparent substituent constants obtained from the above system in medium M. The characteristic coefficient 0.85 corresponds to the ratio of inductive contributions of the substituent from *para* and *meta* positions in the LSFE relationship. C_M was determined by employing the standard σ_π in place of $(\sigma_\pi)_M$ parameters. The σ_i and $\sigma_p{}^0$ parmeters for solvent-modified substituents in DMF and DMSO were also derived.

This approach stands essentially upon the generality of the unique ratio 0.85 of *para/meta* inductive effects. It will be possible to establish significance of the inductive ratio by confirming its validity in chemical and physical properties whose requirements of resonance widely differ. For one of such systems, the substituent chemical shifts of the NH proton of *m*- and *p*- substituted acetanilides in DMSO have been chosen. The NH chemical shift in this system was found to follow the σ^0 parameters. The resonance exaltation for $+R$ class substituents does not appear to be so important as in the case of phenol hydroxyl chemical shift. Accordingly the comparison of the apparent $\bar{\sigma}_p$ values for both systems should provide interesting information on the resonance (π-electronic) and the inductive effects of the DMSO-modified substituent groups. Such a study would confirm generality of the LArSR and LSFE relationships.

Results and Discussion

The NH proton signal of acetanilides in DMSO is considerably more broadened than the hydroxyl proton signal of phenols in DMSO. However, the DMSO solution seems to give the sharpest and most stable signals of the NH proton, no significant dilution shift being observed. The experimental uncertainty appears to be slightly larger in the NH chemical shifts than the phenol OH chemical shift values. It is estimated that in most cases the error involved in the infinite dilution values does not exceed ±0.5 Hz, although in a few cases the uncertainty may be as high as ±1 Hz. The chemical shifts of NH proton of acetanilides are given in Table 1. Bennett *et al.*[7a)] and Rae *et al.*[7b)] have reported the chemical shift data of several acetanilides in the same solvent, their data being only of *p*-substituted derivatives. The chemical shift values reported were in good agreement with the present results.

Niwa reported the chemical shifts of NH protons of *meta* and *para* substituted formanilides in DMSO.[8)] His data can be compared with the present data to give a good linear relation; correlation coefficient 0.996 and standard deviation ±0.025.

$$\Delta\delta^{NHAc} = 1.003\Delta\delta^{NHCHO}$$

This suggests that there is no significant difference in the substituent effects on the shifts in both systems.

Asabe and Tsuzuki reported on α-NH protons of sub-

Table 1. Chemical shifts of NH protons of *m*- and *p*-substituted acetanilides in DMSO

No.	Subst.	$\Delta\delta_p^{\mathrm{TMS}}$	$\Delta\delta_m^{\mathrm{TMS}}$
1	NO_2	10.485	10.357
2	CN	10.302	10.218
3	CHO	10.308	
4	SO_2CH_3	10.335	10.288
5	SO_2NH_2	10.215	10.185
6	SCN	10.178	
7	COC_6H_5	10.282	10.138
8	$COCH_3$	10.217	10.082
9	$COOCH_3$	10.222	10.110
10	COOEt	10.218	10.110
11	$CONH_2$	10.090	10.005
12	CF_3	10.245	10.222
13	$N{=}NC_6H_5$	10.260	
14	C_6H_5	9.987	
15	H	9.872	
16	I	9.975	9.970
17	Br	10.018	10.047
18	Cl	10.003	10.058
19	F	9.927	10.030
20	SCH_3	9.887	
21	OC_6H_5	9.920	9.968
22	NHAc	9.790	9.863
23	NHC_6H_5	9.725	
24	*t*-Bu	9.795	
25	CH_3	9.775	9.788
26	OCH_3	9.728	9.850
27	OH	9.597	9.732
28	NMe_2	9.562	
29	NH_2	9.435	9.552
30	OAc	9.948	10.032
31	Me_2		9.702
32	Cl_2		10.200

stituted phenylureas in DMSO.[9] Although no *meta* substituents were included, *para* substituents can be correlated linearly with our data by

$$\Delta\delta^{\mathrm{urea}} = 1.282\Delta\delta^{\mathrm{NHAc}}$$

with excellent precision, $R=0.998$ and $s=\pm 0.023$, suggesting that essentially the same interaction mechanism is operating for both systems. The analysis we have made in the present study will be applied in the same way for these systems. The α-NH chemical shift in urea is significantly more susceptible to substituent changes than those in the other NH chemical shifts.

Relative NH chemical shifts of the substituted acetanilides (Table 1) are plotted against the standard σ^0 constants in Fig. 1. The general trends that electron attracting groups tend to shift the NH-resonance position toward low field and the chemical shifts appear to reflect the charge density at the NH-site are borne out, while substantial scatter does not permit us to draw any quantitative conclusion. However, following facts are obvious. No significant exaltation in the resonance contributions of conjugatively electron attracting ($+R$) substituents relative to σ_p^0 scale is observed, employment of σ^- values not improving the fit. This indicates that the present data belong to the so called σ^0 class reactivity. Deviations of higher halogens are attributed to the substituent anisotropy effect. Deviations of the $-R$ substituents with acidic α-hydrogens are all large but similar to the behavior observed in the phenol chemical shift in DMSO. It is most plausible to ascribe these deviations mainly to the substantial substituent-solvent interactions.

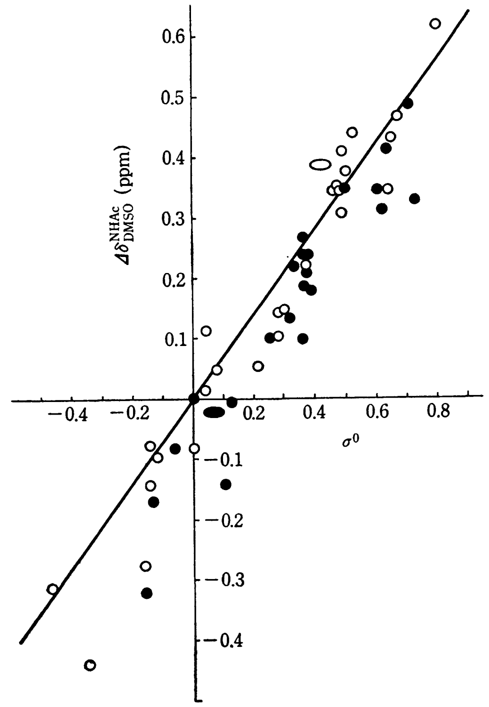

Fig. 1. The plot of $\Delta\delta^{\mathrm{NHAc}}_{\mathrm{DMSO}}$ against standard σ^0: open circles p-substituted and closed circles m-substituted acetanilides.

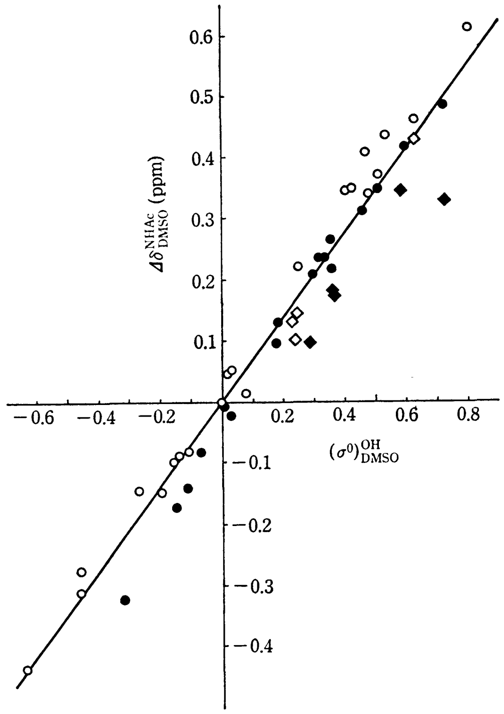

Fig. 2. The plot of $\Delta\delta^{\mathrm{NHAc}}_{\mathrm{DMSO}}$ against $(\sigma^0)^{\mathrm{OH}}_{\mathrm{DMSO}}$: open circles *para*, closed circles *meta*, and squares anisotropic substituents.

The substituent effect is appreciably modified by DMSO.[3] The solvent-modified substituents in DMSO may be assumed to be essentially the same in the acetanilide as in the phenol system. We could thus expect a good correlation between the present data and the $(\sigma^0)_{\mathrm{DMSO}}$ derived from the phenol hydroxyl chemical shifts in DMSO.[3] The good correlation obtained is shown in Fig. 2. $-R$ *para* substituents fall on a straight line determined by *meta* substituents, whereas all the $+R$ *para* substituents deviate slightly but systematically to the direction of enhancing resonance. No improved correlation was observed for the anisotropic halogen groups.

Although the exaltation of resonance contribution of $+R$ class *para* substituents does not appear very significant, the effect may be described by

$$\Delta\delta = \rho(\sigma^0 + r^- \Delta\bar{\sigma}_R^-) \qquad (2)$$

The following equation should be employed in place of Eq. (2) utilizing the modified substituent constants $(\sigma^0)_{\mathrm{DMSO}}$ and $(\Delta\bar{\sigma}_R^-)_{\mathrm{DMSO}}$.[5]

$$\Delta\delta^X = \rho[(\sigma^0)_{\mathrm{DMSO}} + r^-(\Delta\bar{\sigma}_R^-)_{\mathrm{DMSO}}] \qquad (3)$$

The equation agreed excellently with the chemical shift data excluding halogen groups, giving ρ value of 0.686 and r^- of 0.277 with a correlation coefficient 0.994 and a standard deviation ±0.030.[10] The ρ value obtained is, within experimental uncertainty, identical with the value derived from the correlation (Fig. 2). Using this ρ value, the apparent substituent constants $\bar{\sigma}^{\mathrm{NH}}$ can be determined (Table 2). The small r^- value indicates that the through-conjugation interaction between conjugatively electron attracting ($+R$) *para* substituents and the NHAc site is not important in the present system in contrast to the phenol system. This can be explained by the deviation from coplanarity of the NHAc site with the benzene ring. Since an insignificant degree of through-conjugation operates for $+R$ *para* substituents, no significant exaltation of resonance with the $-R$ detection site would be expected for $-R$ *para* substituents. The substituent effect observed in the present system can be regarded as the effect of nearly unexalted σ^0 class. Hence, the excellent fit of $-R$ class substituents to the above correlation, to the first approximation, indicates the validity of $(\sigma_p^0)_{\mathrm{DMSO}}$ values of $-R$ groups derived from the hydroxyl chemical shift of phenols.

TABLE 2. APPARENT SUBSTITUENT CONSTANTS IN DMSO

No.	Subst.	$\bar{\sigma}_p$	$\bar{\sigma}_m$
1	NO_2	0.903	0.717
2	CN	0.637	0.516
3	CHO	0.647	
4	SO_2CH_3	0.685	0.618
5	SO_2NH_2	0.510	0.466
6	SCN	0.457	
7	COC_6H_5	0.607	0.399
8	$COCH_3$	0.513	0.316
9	$COOCH_3$	0.520	0.357
10	COOEt	0.516	0.357
11	$CONH_2$	0.328	0.204
12	CF_3	0.554	0.520
13	$N{=}NC_6H_5$	0.575	
14	C_6H_5	0.178	
15	H	0.010	
16	I	0.160	0.153
17	Br	0.224	0.265
18	Cl	0.202	0.283
19	F	0.090	0.328
20	SCH_3	0.032	
21	OC_6H_5	0.080	0.151
22	NHAc	−0.109	−0.001
23	NHC_6H_5	−0.204	
24	*t*-Bu	−0.102	
25	CH_3	−0.131	−0.111
26	OCH_3	−0.198	−0.022
27	OH	−0.390	−0.194
28	NMe_2	−0.441	
29	NH_2	−0.626	−0.456
30	OAc	0.122	0.243
31	Me_2		−0.237
32	Cl_2		0.468

On the basis of this correlation, we can determine a set of $(\sigma^0)_{\mathrm{DMSO}}$. Because of the small r^- value of 0.277, possible errors involved in the $(\Delta\bar{\sigma}_R^-)_{\mathrm{DMSO}}$ values do not significantly affect the resulting set of $(\sigma^0)_{\mathrm{DMSO}}$ values. This suggests that the new set of $(\sigma^0)_{\mathrm{DMSO}}$ values might be more reliable than the previous one at least for the $+R$ groups (*cf.* Table 3). The solvent-modified parameters $(\sigma^0)_{\mathrm{DMSO}}$ as well as apparent substituent constants $\bar{\sigma}^{\mathrm{NH}}$ are composed of the inductive and the π-electronic effects of the solvent-modified substituents in DMSO.

Solvent-Modified Substituent Parameters

The substituent effects in benzene systems are generally described by the LSFE relationship, to the first approximation, in terms of the combination of mutually independent inductive and π-electronic contributions:[5]

$$\log (k/k_0)_p = \rho(\sigma_i + q_r^+ \sigma_\pi^+ + q_r^- \sigma_\pi^-)$$
$$\log (k/k_0)_m = \rho(1.17\sigma_i + 0.50\sigma_\pi^\pm) \qquad (4)$$

where σ_i is the inductive substituent constant, which is independent of q_r's, a measure of reaction-dependent contributions of its resonance effect. σ_π^+ and σ_π^- are the substituent constants measuring the capability of $-R$ and $+R$ class substituents respectively to donate and withdraw electron through π-electronic delocalization. σ_π^+ corresponds numerically to $0.42\,\Delta\bar{\sigma}_R^+$ and σ_π^- to $0.73\,\Delta\bar{\sigma}_R^-$. By the aid of the characteristic ratio 0.85 or 1/1.17 of the inductive contributions from *para* and *meta* substituents in Eq. (4), a linear π-electronic free energy relationship can be derived which should be free from any inductive contributions:

$$\log (k/k_0)_p - 0.85 \log (k/k_0)_m = \rho C^- \sigma_\pi^- \text{ or } = \rho C^+ \sigma_\pi^+ \qquad (5)$$

where C^- and C^+ are parameters measuring the susceptibility to the π-electronic effects of $+R$ and $-R$ substituents respectively in a given reaction. A convenient modification to accommodate effects of the $+R$ groups in the present system gives Eq. (1).

We have demonstrated the utility of the quantities $\bar{\sigma}_p - 0.85\,\bar{\sigma}_m$ or $\Delta\delta_p - 0.85\,\Delta\delta_m$ for the hydroxyl chemical shifts of phenols in DMSO, as a measure of relative resonance capabilities of the solvent-modified substituents.[2,4] The resonance substituent constants of the DMSO-modified substituents denoted by $(\sigma_\pi^{\pm})_{\rm DMSO}$ or by $(\Delta\bar{\sigma}_{\rm R}^{\pm})_{\rm DMSO}$ were determined by Eq. (1) providing 0.73 $C^-=1.12$ and $0.42C^+=0.24$.[4] The inductive and normal substituent constants denoted by $(\sigma_i)_{\rm DMSO}$ and $(\sigma^0)_{\rm DMSO}$ for the DMSO-modified substituents were subsequently determined from $(\sigma_\pi)_{\rm DMSO}$. The same sort of treatment is expected to be applicable also to the present system. The most important feature of the LSFE treatment, Eq. (4), is the introduction of dual reaction constants for the π-electronic effect, q_r^+ and q_r^-, each for $-R$ and $+R$ substituents. The subsequent treatment has therefore to be applied separately for $+R$ and $-R$ substituent effects. Since our purpose has been to establish the general applicability of our treatment for conjugatively electron attracting $(+R)$ groups, we have chosen the present acetanilide system where the effects of $+R$ *para* substituents significantly differ from those in the phenol chemical shifts.[3,4] Thus, Eq. (5) will be applied first to the analysis of $+R$ substituent effects.

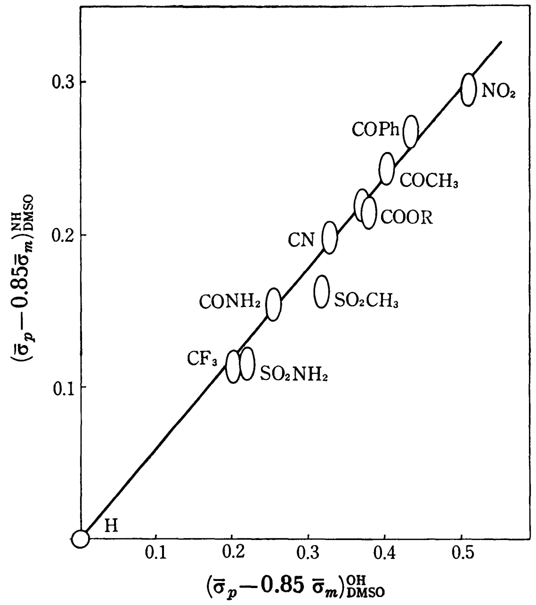

Fig. 3. The plot of $(\bar{\sigma}_p-0\bar{\sigma}.85_m)^{\rm NH}_{\rm DMSO}$ against $(\bar{\sigma}_p-0.85\ \bar{\sigma}_m)^{\rm OH}_{\rm DMSO}$ for $+R$ substituents.

Treatment of +R Substituents. If the assumption of the solvent-modified substituent holds generally, Eq. (1) could be applied to the acetanilide system as well as to the phenol system in the same solvent. Equation (6) would hold provided that $(\Delta\bar{\sigma}_{\rm R}^-)_{\rm DMSO}$ for a series of $+R$ substituents are essentially independent of systems.

$$(\bar{\sigma}_p-0.85\bar{\sigma}_m)^{\rm NH}=\alpha(\bar{\sigma}_p-0.85\bar{\sigma}_m)^{\rm OH} \tag{6}$$

It follows that a plot of the quantities $(\bar{\sigma}_p-0.85\ \bar{\sigma}_m)^{\rm NH}_{\rm DMSO}$ against $(\bar{\sigma}_p-0.85\ \bar{\sigma}_m)^{\rm OH}_{\rm DMSO}$ for various $+R$ substituents should be a straight line of slope α. Figure 3 shows such a straight line with a correlation coefficient 0.997 and a standard deviation ±0.010. Using $\alpha=0.603$ in Eq.(6), $(\Delta\bar{\sigma}_{\rm R}^-)_{\rm DMSO}$ for $+R$ substituents can be derived from the apparent $\bar{\sigma}$ values from the acetanilides, and $(\sigma_\pi^-)_{\rm DMSO}$ by $(\sigma_\pi^-)_{\rm DMSO}=0.73\ (\Delta\bar{\sigma}_{\rm R}^-)_{\rm DMSO}$. The values are in precise agreement with those obtained from the phenol system, no serious corrections being required for the parameter values previously obtained. In this treatment, we have assumed that the *para/meta* inductive contribution ratio is a constant, 0.85, for all substituents irrespective of reactions. The good agreement thus may offer confirmation of the generality of 0.85 for the inductive contribution ratio.

We can apply the LArSR equation[5b] which is modified to (3) to accommodate the effect of DMSO-modified substituents on the chemical shift. If Eq. (3) is applicable to both the phenol and acetanilide systems, it follows that

$$\begin{aligned}(\Delta\bar{\sigma}_{\rm R}^-)_{\rm DMSO}&=(\bar{\sigma}_p{}^{\rm OH}-\bar{\sigma}_p{}^{\rm NH})_{\rm DMSO}/(r^{\rm OH}-r^{\rm NH})\\&=(1/\Delta r)(\bar{\sigma}_p{}^{\rm OH}-\bar{\sigma}_p{}^{\rm NH})_{\rm DMSO}\end{aligned} \tag{7}$$

The coefficient Δr can be determined from the slope of the correlation of $(\bar{\sigma}_p^{\rm OH}-\bar{\sigma}_p^{\rm NH})_{\rm DMSO}$ against $(\Delta\bar{\sigma}_{\rm R}^-)_{\rm DMSO}$. Equation (7) is just the same expression as the basic one of the LArSR theory, indicating that the set of the differences between two sets of apparent $\bar{\sigma}_p$ in any two independent systems with different r's should be equivalent to the relative measure of resonance capabilities of the substituent.[5b] If Eqs. (3) and (4) are valid, the set of resonance quantities in Eq. (6) is proportional to another set of relative resonance capacities of substituents, namely,

$$(\bar{\sigma}_p-0.85\bar{\sigma}_m)^{\rm OH}_{\rm DMSO}=\beta(\bar{\sigma}_p{}^{\rm OH}-\bar{\sigma}_p{}^{\rm NH})_{\rm DMSO} \tag{8}$$

A reasonably good linear correlation (Fig. 4) verifies the equivalency of these two sets of resonance measures.[11] An exceptionally large deviation indicated by the CN group is attributable to the anisotropy effect which appears to be considerably effective only in the acetanilide but not in the phenol chemical shifts.

The correlation could be applied for estimating the $(\Delta\bar{\sigma}_{\rm R}^-)_{\rm DMSO}$ parameter. However, because of the smallness of $(\bar{\sigma}_p^{\rm OH}-\bar{\sigma}_p^{\rm NH})$ quantities, the uncertainty would be larger for the parameter values derived from this set of quantities than those from the $(\bar{\sigma}_p^{\rm NH}-0.85\ \bar{\sigma}_m^{\rm NH})$ quantities. The former evaluation depends on the uncertainty of two independent ρ values, whereas in the latter based upon Eq. (6) any error involved in ρ values is practically unimportant for the evaluation of $(\Delta\bar{\sigma}_{\rm R}^-)_{\rm DMSO}$ parameters, since we can utilize directly two sets of experimental quantities $(\Delta\delta_p-0.85\,\Delta\delta_m)_{\rm DMSO}$ instead of $(\bar{\sigma}_p-0.85\ \bar{\sigma}_m)_{\rm DMSO}$. It is therefore more reasonable to evaluate a set of $(\Delta\bar{\sigma}_{\rm R}^-)_{\rm DMSO}$ parameters by Eq. (6), in comparison with the previous values derived from the phenol hydroxyl chemical shift (Table 3). $(\sigma_i)_{\rm DMSO}$ and then $(\sigma^0)_{\rm DMSO}$ parameters can be determined from $(\Delta\sigma_{\rm R}^-)_{\rm DMSO}$ or $(\sigma_\pi^-)_{\rm DMSO}$ (Table 3). As anticipated, these sets of parameters derived from NH chemical shifts are identical within experimental uncertainty with the corresponding parameters derived from the phenol hydroxyl chemical shift. The identity between the corresponding sets from two independent sources with reasonable precision is a strong evidence for the generality of the LArSR and LSFE relationships. This proves also the validity of the assumption that the substituent effect in a given solvent can be treated as the effect of the solvent-modified substituents, independent of reactions or systems, at least for conjugatively electron

Table 3. Modified substituent parameters in DMSO for $+R$ groups

No.	Subst.	Acetanilides			Phenols		
		$(\sigma_\pi^-)_{DMSO}$	$(\sigma_i)_{DMSO}$	$(\sigma_p^0)_{DMSO}$	$(\sigma_\pi^-)_{DMSO}^{OH}$	$(\sigma_i)_{DMSO}^{OH}$	$(\sigma_p^0)_{DMSO}^{OH}$
1	NO_2	0.326	0.470	0.796	0.331	0.473	0.804
2	CN	0.220	(0.345)	(0.565)	0.227	0.400	0.627
3	CF_3	0.124	0.389	0.513	0.133	0.375	0.508
4	$COCH_3$	0.271	0.154	0.425	0.264	0.140	0.404
5	COC_6H_5	0.297	0.213	0.510	0.283	0.183	0.466
6	$COOCH_3$	0.240	0.201	0.441	0.243	0.183	0.426
7	COOEt	0.237	0.202	0.439	0.246	0.166	0.412
8	SO_2CH_3	0.177	0.450	0.627	0.208	0.418	0.626
9	$CONH_2$	0.172	0.099	0.271	0.166	0.086	0.252
10	SO_2NH_2	0.126	0.342	0.468	0.144	0.332	0.476

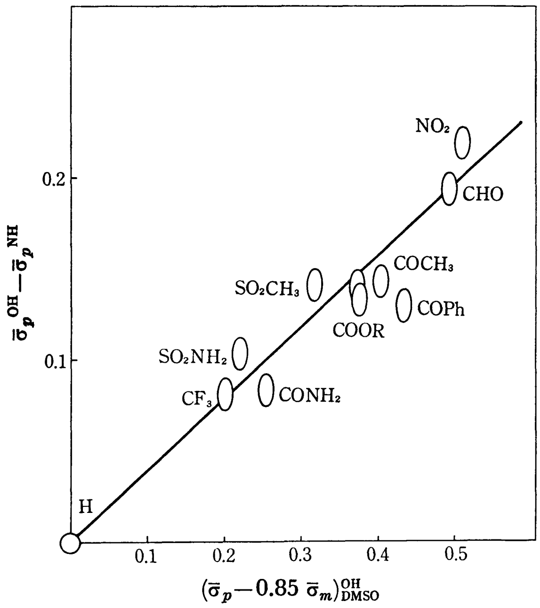

Fig. 4. The plot of $\bar{\sigma}_p{}^{OH}-\bar{\sigma}_p{}^{NH}$ against $(\bar{\sigma}_p-0.85\ \bar{\sigma}_m)_{DMSO}^{OH}$.

attracting substituents.

In order to rationalize the results, it is necessary to compare them with the results of the corresponding analysis of the present shift data according to Taft's equation.[12] Taft's treatment is based on the assumption of i) the equal inductive contributions from a given substituent at *meta* and *para* positions, and ii) the view that the σ_I parameters of any substituent essentially are invariant irrespective of the nature of reaction. Of course, the solvent-variation of these parameters may be imposed. From his theory, the apparent resonance parameters $\bar{\sigma}_R$ of the solvent-modified substituents in DMSO can be given by

$$(\bar{\sigma}_R)_{DMSO} = (\bar{\sigma}_p)_{DMSO} - (\bar{\sigma}_I)_{DMSO}$$

The equal inductive contribution from *meta* and *para* positions implies that the π-electronic effect (or resonance) parameters should be proportional to the difference between *meta* and *para* apparent substituent constants, $\bar{\sigma}_p-\bar{\sigma}_m$, in a given system, namely,

$$(\bar{\sigma}_R)_{DMSO} = \alpha'(\bar{\sigma}_p-\bar{\sigma}_m)_{DMSO} \qquad (9)$$

where α' is a proportionality constant. If Eq. (9) were valid for various systems, $(\bar{\sigma}_p-\bar{\sigma}_m)_{DMSO}$ quantities for two systems may be expected to be linearly related.

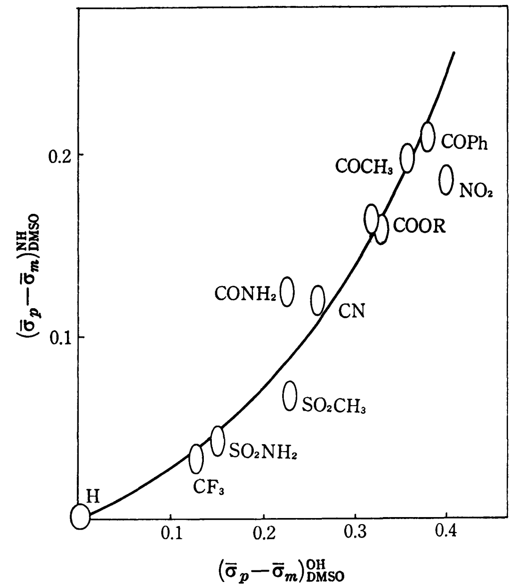

Fig. 5. The relation between Taft's apparent resonance quantities, $(\bar{\sigma}_p-\bar{\sigma}_m)_{DMSO}^{NH}$ and $(\bar{\sigma}_p-\bar{\sigma}_m)_{DMSO}^{OH}$.

Figure 5 shows the correlation of the two sets of Taft's resonance quantities derived from phenol and acetanilide systems in DMSO solution. The correlation is less satisfactorily linear (R=0.961 and $s=\pm0.021$) than that given by Eq. (6). The plot appears to be better described by a smooth curve; otherwise, the deviation of the unsubstituted derivative is significant. Such non-linearity between any two sets of Taft's resonance parameters $\bar{\sigma}_R$ derived from various classes of $\bar{\sigma}$ values is generally observed even in chemical reactivities. For instance, similar resonance quantities $\bar{\sigma}_p-\bar{\sigma}_m$ for $+R$ substituents from the standard σ^- constants are not reasonably linear against the corresponding quantities from the other references σ^0 or σ parameters.[13] This is in contrast to the present results based on our LArSR and LSFE treatment. Taft has concluded that there are no general or universal parameters of resonance effects of substituents.[12] Generalized treatment of the same kind as we have employed could not be possible with Taft's equation based on the equal *meta* and *para* inductive contribution model.

Treatment of —R *Substituents.* In contrast to the remarkable success in correlating effects of conjugatively electron attracting substituents, the analysis of conjugatively electron releasing substituent effects does not appear to be so simple. The same sort of difficulty was observed in the analysis of phenol chemical shifts.[2,4] Neither σ_π nor σ_i parameters obtained were linear against the ordinary sets of corresponding parameters. Thus we can not attain ultimate accuracy in the evaluation of parameters of the solvent-modified substituents from the present data. Nevertheless, it appears of value to estimate somewhat rough but still useful measures of the apparent inductive and π-electronic effects of the so-called solvent-modified substituents.

Since the *para*/*meta* inductive contribution ratio of 0.85 is believed to be valid for $-R$ as well as $+R$ substituents, the quantities $(\bar{\sigma}_p - 0.85\,\bar{\sigma}_m)_{\text{DMSO}}$ for $-R$ groups in either the phenol or the acetanilide system should give a relative measure of the resonance capability of DMSO-modified substituents. Thus, even though they might not be proportional to the standard σ_π^+ or $\Delta\bar{\sigma}_R^+$ parameters, it is anticipated that both sets of quantities are correlated linearly with each other; that is, Eq. (6) holds for $-R$ substituents. Since the apparent substituent constants $\bar{\sigma}_p$ for $-R$ *para* substituents in both systems are identical within their uncertainty and appear both to be of the σ^0 class, the slope α of the correlation should be close to unity. However, the result is not in line with anticipation. The fit does not appear to be satisfactory and the slope α corresponds to roughly 2/3. This implies that the C_M scale in Eq. (1) is not the same for the two apparent stes of $(\sigma_\pi)_{\text{DMSO}}$. A similar treatment based upon Taft's assumption, Eq. (9) for $-R$ substituents, gives no reasonable correlation.

Assuming the effect of $-R$ groups to be of the σ^0 class, the conversion coefficient for $-R$ class substituents can be given as follows, provided that the ordinary resonance contribution scale $q_r^+ = 1.0$ for *para* $-R$ substituents and $q_r^m = 0.50$ for *meta* substituents by means of Eq. (4);

$$(\bar{\sigma}_p - 0.85\bar{\sigma}_m) = 0.575(\sigma_\pi^+)_{\text{DMSO}} \qquad (10)$$

An apparent set of inductive parameters $(\sigma_i)_{\text{DMSO}}$ can thus be given by

$$(\sigma_i)_{\text{DMSO}} = \bar{\sigma}_p - (\sigma_\pi^+)_{\text{DMSO}} = 1.48\bar{\sigma}_m - 0.74\bar{\sigma}_p \qquad (11)$$

The inadequacy of the scale of $(\sigma_\pi^+)_{\text{DMSO}}$ parameters should reflect the consistency of the resulting set of $(\sigma_i)_{\text{DMSO}}$ values. The reliability of the former parameters can be judged in turn from the consistency of the $(\sigma_i)_{\text{DMSO}}$ values. The best practical way of critical examination of both parameters is to compare the $(\sigma_i)_{\text{DMSO}}$ values with a certain reliable measure of the inductive effects of substituents obtained from a completely independent source in the same solvent. As such a reference measure, we have chosen the relative ^{19}F NMR chemical shifts of *m*-substituted fluorobenzenes, correlating with the inductive substituent constants alone.[14] We assume, to a first approximation, that the solvent-modified substituents remain essentially the same in the same solvent regardless of change of the system from acetanilides to *m*-substituted fluorobenzenes. In Fig. 6 the inductive quantities, $(\sigma_i)_{\text{DMSO}}$ for $+R$ groups (Table 3) and those derived from Eq. (11) for $-R$ groups, are plotted against $\Delta\delta^{\text{F}}_{m\text{-X}}$ in DMSO. The $+R$ groups satisfy a linear correlation, while almost all $-R$ substituents deviate considerably from the correlation line. The fit of $+R$ substituents is excellent (correlation coefficient 0.986 and standard deviation ± 0.024) so that the correlation can give rise to a set of the inductive measure $(\sigma_i)^{\text{F}}$, by

$$(\sigma_i)^{\text{F}} = 0.118\Delta\delta^{\text{F}}_{m\text{-X}} + 0.066$$

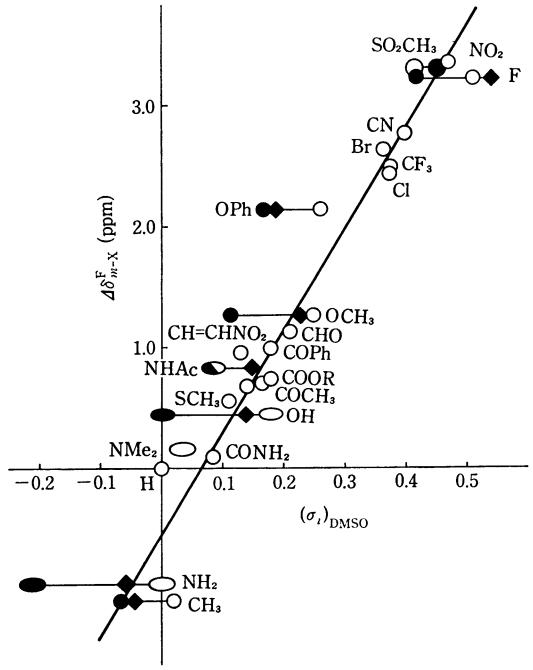

Fig. 6. The plot of ^{19}F substituent chemical shifts of *m*-substituted fluorobenzenes against DMSO-modified inductive substituent parameters, σ_i: open circles $(\sigma_i)^{\text{OH}}_{\text{DMSO}}$, closed circles $(\sigma_i)^{\text{NH}}_{\text{DMSO}}$, and squares $(\sigma_i)^{\text{Corr}}_{\text{DMSO}}$.

As 0.85 for the *para*/*meta* inductive ratio is presumed to be valid for $-R$ groups in this system, the relative π-electronic contribution should be proportional to the quantities $(\bar{\sigma}_p - 0.85\,\bar{\sigma}_m)$. This gives the following equation concerning the π-electronic effect of $-R$ class substituent.

$$\bar{\sigma}_p^{\text{NH}} - (\sigma_i)^{\text{F}} = \gamma(\bar{\sigma}_p - 0.85\bar{\sigma}_m)^{\text{NH}} \qquad (12)$$

The best-fit gave γ value of 2.36 for $-R$ groups in the acetanilide system. The $(\sigma_\pi^+)^{\text{Corr}}_{\text{DMSO}}$ values derived on this basis and $(\sigma_i)^{\text{Corr}}_{\text{DMSO}}$ values given by $\sigma_p - (\sigma_\pi^+)^{\text{Corr}}_{\text{DMSO}}$ are given in Table 4 in comparison with those from the phenol chemical shifts. $(\sigma_i)^{\text{Corr}}_{\text{DMSO}}$ for $-R$ substituents satisfy the correlation determined by $+R$ groups with an excellent precision (Fig. 6); especially, the sub-

TABLE 4. MODIFIED SUBSTITUENT PARAMETERS IN DMSO FOR $-R$ GROUPS

No.	Subst.	Acetanilides		Phenols	
		$(\sigma_\pi^+)^{\text{Corr}}_{\text{DMSO}}$	$(\sigma_i)^{\text{Corr}}_{\text{DMSO}}$	$(\sigma_\pi^+)^{\text{OH}}_{\text{DMSO}}$	$(\sigma_i)^{\text{OH}}_{\text{DMSO}}$
1	F	−0.45	0.54	−0.49	0.51
2	OC_6H_5	−0.11	0.19	−0.25	0.26
3	NHAc	−0.26	0.15	−0.21	0.10
4	CH_3	−0.09	−0.04	−0.18	0.02
5	OCH_3	−0.42	0.23	−0.52	0.25
6	OH	−0.53	0.14	−0.64	0.18
7	NH_2	−0.56	−0.06	−0.64	0.00

stituents carrying acidic hydrogen at the α-position are brought closer to the line. The excellent fit of $-R$ substituents suggests that the quantity $(\bar{\sigma}_p - 0.85\,\bar{\sigma}_m)$ measures the relative capabilities of the π-electronic contributions of solvent-modified substituents, even though the γ value is not 1/0.575 expected for the system of the σ^0 class. On the other hand, the phenol system gives a correlation for $-R$ groups using $(\sigma_i)^{\mathrm{F}}$ values;

$$\bar{\sigma}_p{}^{\mathrm{OH}} - (\sigma_i)^{\mathrm{F}} = (1.00+0.08)(\sigma_\pi{}^+)_{\mathrm{DMSO}}.$$

The unit slope indicates that the scale of the π-electronic effect parameters estimated from the phenol system is reasonable, while deviations of $-R$ groups are considerably large.

The best correspondence to $\Delta\delta^{\mathrm{F}}_{m-\mathrm{X}}$ is observed with $(\sigma_i)^{\mathrm{Corr}}_{\mathrm{DMSO}}$ parameters (Fig. 6). Accordingly, $(\sigma_\pi{}^+)^{\mathrm{Corr}}_{\mathrm{DMSO}}$ derived from acetanilides seems to give a better measure of the π-electronic effect of solvent-modified substituents in DMSO than the other, while it is necessary to justify the higher γ value for the acetanilides before one may draw any conclusion. The identity of the apparent $\bar{\sigma}_p$ values of $-R$ groups in acetanilides and phenols indicates that the resonance contribution scale of $-R$ *para* groups, $q_r{}^+$ or r^+, should be essentially the same in both systems. The ambiguity of the contribution scale of π-electronic effect of *p*-substituents in either system, even if they differ from the σ^0-scale, does not theoretically cause any serious deviation in the γ-value. The contradiction has to be ascribed only an inadequate estimation of the contribution scale of resonance from *meta* substituents. The high γ-value requires the enhanced resonance contribution from *meta* substituents. The $-R$ *meta* groups exert more enhanced electron release in the NHAc than in the phenol chemical shifts. The apparent *meta* substituent constants $\bar{\sigma}^{\mathrm{NH}}_m$ can be correlated with $\bar{\sigma}^{\mathrm{OH}}_m$, taking into account the resonance exaltation in terms of modified LArSR equation:

$$\bar{\sigma}_m{}^{\mathrm{NH}} = 1.03\bar{\sigma}_m{}^{\mathrm{OH}} + 0.14(\sigma_\pi{}^+)$$

This means that the relative resonance effect of $-R$ *meta* substituents in the acetanilides is some 20% more effective than that in the phenol system. The resonance exaltation of *meta* substituents is unusual in general chemical reactivities in which the *meta* resonance remains constant $0.50\,\sigma_\pi{}^\pm$ regardless of the nature of substituents and independent of the type of reactions,[5] as evidenced by general reaction-independency of σ_m constants.

On the other hand, it has been pointed out that NMR chemical shifts of the proton attached to the *meta*-position relative to substituents do not precisely correlate with σ_m but rather with $\sigma_p{}^0$ values.[15] A plausible explanation for this behavior, based on the ring-current model, was proposed by Yukawa and co-workers:[16] The benzene ring current should be disrupted by the disturbance of π-electron distribution with the exo-delocalization with conjugative (either $-R$ or $+R$) substituents. Such an effect may be parallel to the capability of substituents to alter the π-electronic distribution; that is, parallel to $\sigma_\pi{}^\pm$ values. It would follow from this concept that the $-R$ substituents give the apparent resonance exaltation in the *meta* proton chemical shifts. The enhanced π-electronic contribution from *meta*-substituents in the present system can be explained if such an effect is effective in the chemical shifts of hydrogen-bonded NH proton of the acetanilides.

Experimental

Almost all *m*- and *p*-substituted acetanilides were prepared by the acetylation of substituted anilines with acetic anhydride sometimes with addition of pyridine. Anilines made available from other studies of substituent effects were used. The melting points and other physical constants agreed with established values.

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