^1H NMR Study of the Substituent Transmission Effects through SO_2 and CO Groups in *p,p'*-Disubstituted Derivatives of Phenyl Phenacyl Sulphones (β-Keto Sulphones)

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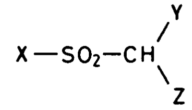
The NMR proton chemical shifts of the CH_2 group in phenyl phenacyl sulphones (β-keto sulphones) *p*-X-$C_6H_4SO_2CH_2COC_6H_4$-Y-*p*, measured in $(CD_3)_2$ are used to study transmission of the substituent effect through SO_2 and CO groups. Contrary to the estimation of this effect from CH_2-acidities [$\rho(SO_2) < \rho(CO)$][4] the results were that $\rho(SO_2) > \rho(CO)$, and it was shown that application of σ_p^+ gives a significantly better correlation than that with σ_p. These findings have been interpreted on the basis of structural data.

The transmission of substituent effects through sulphone and carbonyl groups has been studied for a long time. It has been demonstrated that in a series of compounds of general formula (**1**) the acidity constants and chemical shifts of the SO_2–CH group clearly depend upon the electron-donating and -accepting properties of the substituents.[1–7] At present it is still not certain how far the dπ–pπ conjugation between SO_2 and the adjacent carbon atom should be taken into account.

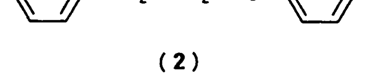


$$X{-}SO_2{-}CH\begin{matrix}Y\\ \\ Z\end{matrix}$$

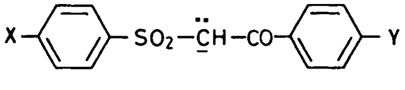
(**1**)

Bordwell and co-workers[3] reported that the differences in the values of σ_p constants for the $-SO_2CH_3$ group in systems of various delocalization ability provided strong evidence for the involvement of the d-orbitals of sulphur in dπ–pπ conjugation with a substituent, *via* the benzene ring. For example, the $\sigma_p(SO_2CH_3)$ value obtained from ionization of phenol substituted by this group in the *para* position was higher than that obtained from the dissociation of benzoic acid, *i.e.* +0.98 and +0.72, respectively.

Amel and Marek[4] postulated that such differences were as a result of the electronegativity of sulphur in the sulphonyl group varying with the nature of the other substituent. Indeed Huheey's electronegativity value[8] for the SO_2CH_3 group is 3.1 (in Pauling's scale) in comparison with 2.69 for $COCH_3$, and for SO_2Ph and COPh the electronegativity should be rather lower.[8] Thus it seems correct to accept directly the inductive character of these substituents, particularly that of SO_2. Correlation pK_a values of β-keto sulphones (**2**) with σ^+ constants puts in doubt the occurrence of strong through-resonance in this case, as Amel and Marek[4] obtained a much better linear dependence with σ than with σ^+ constants. Comparison of reaction constants $\rho(SO_2)$ and ρ(CO) showed a significantly better transmission of the substituent effect through the CO group than through the SO_2 one; ρ-values were found to be equal to 2.35 and 2.01, respectively. Amel and Marek have not excluded the possibility of participation of the d-orbitals of sulphur in the stabilization of carbanion (**3**) formed after ionization of the β-keto sulphones (**2**), which was suggested by the high positive value of $\rho(SO_2)$ *i.e.* +2.01. According to these workers, the magnitude of the stabilization of the carbanion depends upon the electronegativity of sulphur in the SO_2 group, which in turn depends upon the electronic effect caused by the X-substituent.[4]



(**2**)



(**3**)

Conversely, theoretical calculations by Wolfe *et al.*[5,6] seemed to refute the concept of sulphur d-orbital participation in the stabilization of the carbanion (**3**), the latter being explained by the operation of the simple inductive effect.

The aim of this paper is to study the transmission of substituent effects *via* the SO_2 and CO groups, estimated by application of the Hammett-like equation to methylene group ^1H NMR chemical shifts measured in a series of compounds (**2**). Comparison of our results which concern neutral species (**2**) with those of Amel and Marek which were measured for equilibrium (4): *i.e.* involving both neutral and ionic species,

$$\underset{\textbf{(4a)}}{XPhSO_2{-}CH_2{-}COPhY} \rightleftharpoons \underset{\textbf{(4b)}}{XPhSO_2\underset{\cdot\cdot}{C}H{-}COPhY} + H^+ \quad (4)$$

may be valuable in discussing the nature of the transmission effect.

Results and Discussion

Chemical shifts of methylene protons in *p*-Y-phenyl *p'*-X-phenacyl sulphones (**2**) were measured in two solvents: $CDCl_3$ and $(CD_3)_2SO$. All the measurements in $(CD_3)_2SO$ are collected in Table 1.

The signals measured were sharp and well defined in the range $4.97 \leqslant \delta \leqslant 5.96$ ppm, *i.e.* at lower field values than the

Table 1. ^{1}H NMR chemical shifts [δ_{XY}(ppm)] of methylene protons in (**2**) measured in $(CD_3)_2SO$ (the substituents X are arranged in order of their σ_p^+ values[12]).

X-Substituent	Y-Substituent NH_2	NHAc	Me	H	Cl	Br	NO_2
NH_2	4.97	5.17[a]	5.18	5.24	5.25	5.26	5.35
OMe	5.13	5.37	5.40	5.46	5.47	5.48	5.60
NHAc	5.13[a]	5.38	5.40	5.45	5.45	5.47	5.57
OPh	5.18	5.43	5.47	5.50	5.52	5.53	5.65
Me	5.17	5.42	5.44	5.51	5.52	5.52	5.64
Ph	5.30	5.53	5.55	5.61	5.62	5.64	5.75
H	5.24	5.48	5.51	5.56	5.58	5.58	5.70
Cl	5.32	5.58	5.59	5.64	5.65	5.66	5.76
I	5.28	5.54	5.57	5.60	5.64	5.64	5.74
Br	5.31	5.56	5.59	5.61	5.64	5.66	5.74
NO_2	5.49	5.75	5.76	5.78	5.84	5.84	5.96

[a] For X = NH_2, Y = NHAc and X = NHAc, Y = NH_2, δ-values were calculated using a variance-method analysis.

Table 2. C–C(O) and C–$S(O_2)$ bond lengths/Å in CH_3COCH_3, $CH_3SO_2CH_3$ and in $PhSO_2CH_2COPh$.[13,14]

Compound	C–C(O)	C–$S(O_2)$
CH_3COCH_3	1.517 (±0.003)	—
$CH_3SO_2CH_3$	—	1.771 (±0.003)
$PhSO_2CH_2COPh$	1.521 (±0.005)	1.742 (±0.004)

typical values for the methylene group (2 to 4 ppm). This is obviously the result of the strong electron-accepting properties of both adjacent substituents SO_2 and CO, and hence the greater deshielding of the CH_2 hydrogen atoms.

In order to study how far substituents X and Y in (**2**) may interact by mutual conjugation and affect the CH_2 ^{1}H NMR signals in a complex way, the data of Table 1 were subjected to a principal component analysis.[9–11] The result was that the first principal component accounted for 99.6% of the total variance of the data in Table 1 and hence we could conclude that there is no significant mutual conjugation between X and Y in (**2**). Additionally, when we applied the values of this component calculated for two cases by using (i) columns and then (ii) rows of the data matrix to obtain the principal components, we found that their values correlated better with the σ^+ constants (r = 0.974 and 0.973, respectively) than with σ (r = 0.937 and 0.942, respectively).

Thus, knowing that there is no mutual conjugation between the X and Y substituents in (**2**) we applied a two-parameter Hammett-like equation, assuming an independent substituent effect of X and Y on the CH_2 ^{1}H NMR signals δ_{XY} [equation (5)] where $\hat{\delta}_{XY}$ denotes chemical shifts in question, δ_0 is

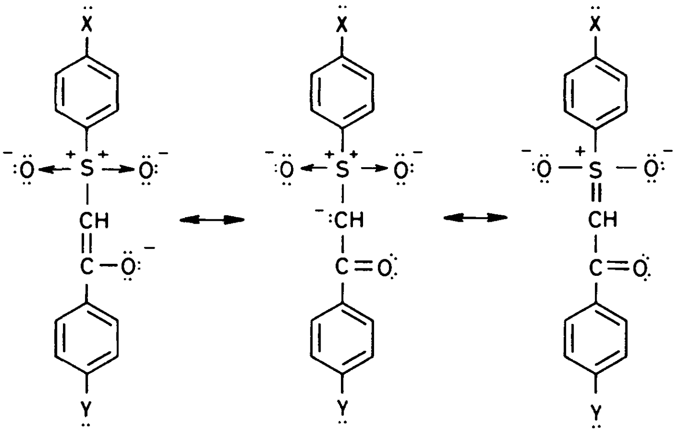
$$\hat{\delta}_{XY} = \delta_0 + [\rho(SO_2).\sigma_X^+] + [\rho(CO).\sigma_Y^+] \qquad (5)$$

an intercept of the regression (approximately the value for X=Y=H), σ_X^+ and σ_Y^+ are the Brown–Okamoto[12] σ^+ constants applied to the X and Y substituents in (**2**); $\rho(SO_2)$ and ρ(CO) stand for reaction constants describing in this case the transmission of effect of the substituent through the SO_2 and CO groups in (**2**). Application of equation (5) to the data of Table 1 gives the following results $\rho(SO_2)$ = 0.251 (±0.010); ρ(CO) = 0.204 (±0.009), δ_0 = 5.599 (±0.006); r = 0.969 (where figures in parentheses are the standard errors).

The difference between $\rho(SO_2)$ and ρ(CO) is significant and hence it should be interpreted. Moreover, these results are in the reverse order to those obtained by Amel and Marek[4] [$\rho(SO_2)$ = 2.01 and ρ(CO) = 2.35].

An additional difference is that in our case we have used σ_p^+, whereas Amel and Marek applied σ_p. Formally it may be clearly stated that in our case interaction must be more like those observed in solvolysis of *p*-cumyl chloride with a strong positively charged reaction site, whereas in Amel and Marek's case interactions have to resemble those in *para*-substituted benzoic acids. We shall attempt to rationalize these conclusions by use of the simple resonance theory.

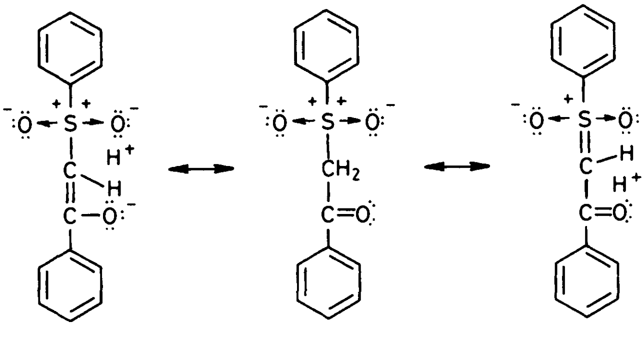
Initially, it must be remembered that equilibrium (4) was set up in a strongly polarizing medium in which strong solvent effects may affect the electronic structure of both substrates and products of equilibrium (4). Then, the quantity measured, pK_a depends on the difference in free energy between (**4a**) and (**4b**) and the resultant effect is to favour the substituent which best stabilizes the most polar resonance canonical. The overall result[4] of $\rho(SO_2) < \rho(CO)$ may be summarized schematically if we accept a greater contribution of (**6a**) than that of (**6c**) in the description of the β-keto sulphone carbanion.



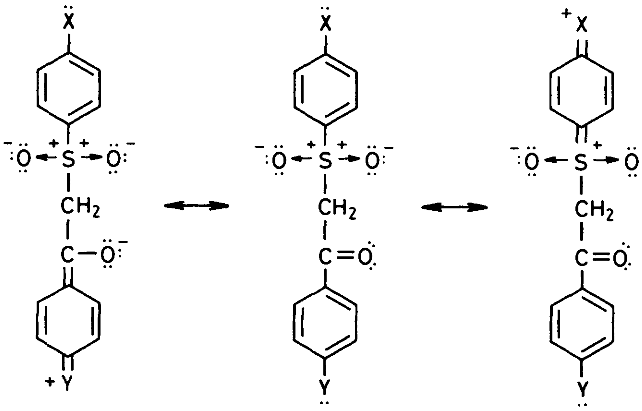
(6a) (6b) (6c)

The situation seems to be much clearer in the case of the interpretation of ^{1}H NMR data. A recent X-ray structural analysis[13] of (**2**) with X = Y = H gave the results shown in Table 2, where the bond lengths of $S(O_2)$–CH_3 and CH_2–C(O) are compared with the respective $S(O_2)$–CH_3 and C(O)–CH_3 in $CH_3SO_2CH_3$ and CH_3COCH_3.[14]

Comparison of these data suggests a greater contribution of (**7c**) than of (**7a**) to the description of the geometry of the unsubstituted system (**2**), since the $S(O_2)$–C bond length in (**2**) is significantly smaller than that in $CH_3SO_2CH_3$ whereas

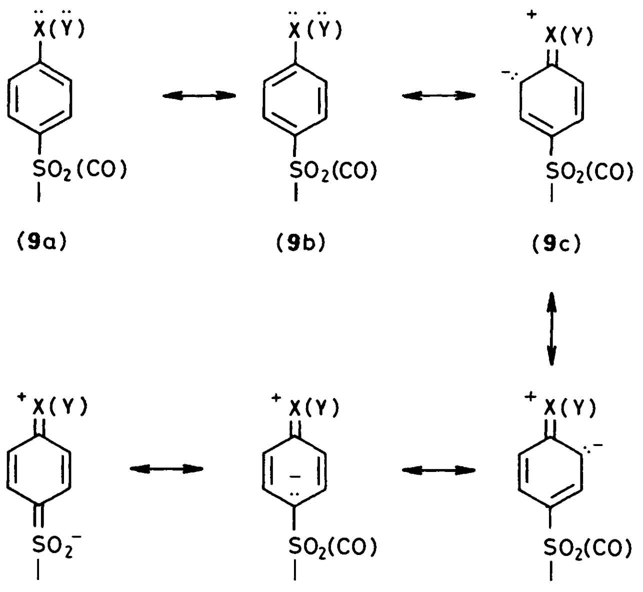


(7a) (7b) (7c)



(8a) (8b) (8c)

C–CO bond lengths are of almost equal value for both systems. From this point of view the substituents attached to the $PhSO_2$ part of (**2**) should affect the methylene group more strongly than those attached to the PhCO part of (**2**). Moreover, in both cases this argument seems to preclude, or at least to diminish the participation of a resonance structure such as (**8c**). Thus it seems reasonable to accept that electron-donating substituents polarize the ring as illustrated in the Scheme with a very small contribution from structure (**8c**) [≡ (**9f**)] to the resonance canonicals.



(9a) (9b) (9c) (9f) (9e) (9d)

Scheme.

Our suggestion may be supported by quantum-chemical calculations for *p*-nitroaniline and *p*-nitrophenol[15] as well by structural studies of *N*,*N*-diethyl-*p*-nitroaniline[16] for which the weight of canonical (**9f**) estimated by the HOSE-model[17] was the lowest for all the canonicals (**9a–f**) taken into account. The same conclusion was reached for other *p*-X-$PhNO_2$ systems with a great variety of electron-donating X-substituents.[18] We may summarize the results obtained as follows. Electron-donating substituents polarize the ring following the Scheme in a way corresponding to the σ^+ values on both sides of (**2**). Then further transmission through the SO_2 and CO groups is easier for the C–S(O_2) bond because of its stronger double-bond character and hence $\rho(SO_2) > \rho(CO)$ in equation (5).

Experimental

Proton magnetic resonance (^1H NMR) spectra were measured with a 60 MHz Tesla BS–467B apparatus in $CDCl_3$ and $(CD_3)_2SO$. The signal position was recorded with reference to the external standard 1,1,1,3,3,3-hexamethyldisilazane (HMDS) with an accuracy ±0.5 Hz (*ca.* 0.01 ppm). The results obtained in $CDCl_3$ were inadequate for this study because of the poor solubility of some β-keto sulphones. Owing to the use of $(CD_3)_2SO$ as the solvent, the system was sensitive to variations of substituents (the range of the observed chemical shifts of the methylene group was wider than in $CDCl_3$).

Preparation of β-*Keto Sulphones* (**2**).—*p*-Substituted phenacyl bromide (0.02 mol) and tetrabutylammonium bromide (0.4 g, *ca.* 0.0012 mol) were added to the solution of *p*-substituted sodium benzenesulphinate (0.022 mol) in anhydrous tetrahydrofuran (25 cm^3). The mixture was boiled for 1 h and after being cooled it was poured into water (250 cm^3). The precipitate of β-keto sulphone was filtered, washed with water, and recrystallized from ethanol. Approximate yields of 73–93% were obtained. The methods of synthesis as well as physicochemical properties and β-keto sulphones' identification are given elsewhere.[19]

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