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EFFECT OF POLAR SUBSTITUENTS ON HINDERED ROTATION ABOUT SULFUR-NITROGEN AND CARBONYL-NITROGEN BONDS IN METHYL N-ARENESULFENYL-N-BENZYLURETHANES

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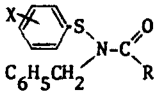
The substantial effect of polar substituents on barriers to rotation about S-N bonds in substituted arenesulfenamides, $X\text{-}C_6H_4SNR'R''$, has been attributed to (p-d)π conjugation between nitrogen and sulfur.[1] However, no such effect has been observed on barriers to *syn, anti* interconversion in N-alkylidenearenesulfenamides, RR'C=NSAr, and consequently the importance of (p-d)π bonding has been questioned.[2] The absence of a polar substituent effect on nitrogen inversion barriers in a series of N-arenesulfenylaziridines, $X\text{-}C_6H_4S\overset{\frown}{N\text{-}C}(CH_3)_2$, has been interpreted as evidence for the absence of acceleration of the rate of nitrogen inversion as a result of d-orbital conjugation.[3] This interpretation requires that the extent of (p-d)π bonding in the ground state for pyramidal inversion be equal to the extent of such bonding in the planar transition state, thus producing no net effect on the barrier to inversion. Alternatively, these results can be viewed as evidence suggesting that (p-d)π bonding is unimportant in sulfenamides and that another explanation should be sought for the substituent effects on sulfenamide rotational barriers.

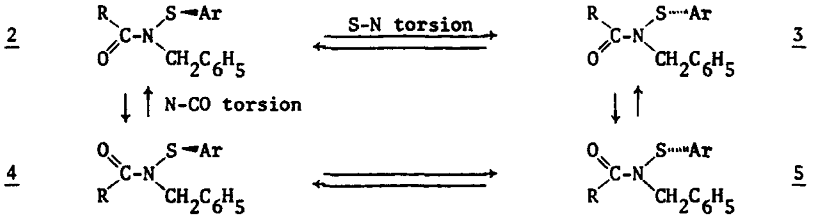
We now report a new approach toward determining the importance of d-orbital conjugation, in an attempt to find which of the two alternatives correctly explains these results. Barriers to amide bond rotation as well as barriers to S-N bond rotation have been examined in a series of substituted N-arenesulfenyl-N-benzylamides, (1).[4]



1a, R = H; X = *p*-Cl
b, R = C_6H_5; X = *p*-Cl
c, R = OCH_3; X = *p*-OCH_3
d, R = OCH_3; X = *p*-CH_3
e, R = OCH_3; X = H
f, R = OCH_3; X = *p*-Cl
g, R = OCH_3; X = *m*-NO_2
h, R = OCH_3; X = *p*-NO_2
i, R = OCH_3; X = 2,4$(NO_2)_2$

In 1, like in the sulfenylaziridine series, an arenesulfenamide structure is directly attached to a second functional group, which, likewise, undergoes a slow exchange process, observable by dnmr spectroscopy. Slow rotation about the nitrogen-carbonyl bond in amides is a well documented phenomenon.[5] If the extent to which the lone pair of electrons on nitrogen overlaps with a d-orbital on sulfur (*i.e.*, the extent of (p-d)π conjugation) depends on substitution of the benzenesulfenyl ring in 1, it follows that the extent of conjugation between nitrogen and the carbonyl bond also depends on this substitution. An increase in the electron density along the S-N bond caused by an electron withdrawing substituent X, should be accompanied by a simultaneous decrease in the electron density between nitrogen and carbon, as the same lone pair of electrons is involved in both of these bonds. Consequently, an increase of S-N and a decrease of N-CO torsional barriers would be expected if (p-d)π bonding were responsible for substituent dependence of the barriers. The barrier to amide rotation in formanilides has been shown recently to decrease markedly when an electron withdrawing group is attached to the phenyl ring, and this has been similarly interpreted as a result of a decrease in electron density along the N-C bond.[6]

The dynamic processes that could be followed by dnmr spectroscopy of 1 are shown in the Scheme. This structure constitutes a unique system in which each of two different barriers can be measured separately and an unequivocal assignment made on symmetry grounds. The prochiral benzyl group serves as a probe for this assignment. Slow exchange of enantiomers ($2 \rightleftarrows 3$, $4 \rightleftarrows 5$) while amide rotation is fast on the nmr time scale, results in an AB quartet due to the diastereotopic methylene protons. Upon cooling the sample, exchange of diastereomers ($2 \rightleftarrows 4$, $3 \rightleftarrows 5$) becomes slow, and eventually splitting of the quartet occurs into two unequally populated AB patterns. A typical set of spectra featuring these changes is shown in Figure 1. In this example the high field portions of the two quartets accidentally overlap. In the reverse situation, when amide rotation is slow relative to sulfenamide rotation, the singlet observed at high temperatures first splits upon cooling into two unequal singlets due to *syn* (4,5) and *anti* (2,3) isomers, and at lower temperature further splitting into two AB quartets occurs.



The choice of R = OCH_3 in 1c - i was necessary in order to enable the measurement of $\Delta G^{\neq}$

Table 1. 100 MHz dnmr data.[a]

Compd	Amide Barrier K^b	$\Delta\nu$ Hz	T^oC^e	$\Delta G^{\neq}$ kcal/mole	Sulfenamide Barrier $\Delta\nu_1^f$	$\Delta\nu_2^f$	$T\ ^oC^e$	$\Delta G^{\neq}$ kcal/mole
1a					159^d	-	-46	10.5
1b					155^d	-	-63	9.7
1c	4.7	16^c	-36	12.1	136^d	58^d	-85	8.7
1d	4.6	16^c	-36	12.1	156^d	50^d	-76	9.1
1e	5.0	20^d	-35	12.1	156^d	50^d	-69.5	9.4
1f	6.5	19^c	-36	12.0	154^d	50^d	-68	9.5
1g	4.5	19^d	-38.5	12.0	100^d	42^d	-63	9.9
1h	8.0	20^d	-40.5	12.0	122^d	40^d	-40.5	10.9
1i	4.0	22^d	-21.5	12.3	47^g		58	16.2

a. Measured in *ca.* 10-15% solutions in toluene-d_8.
b. Equilibrium constant of *syn, anti* interconversion.
c. $\Delta\nu$ extrapolated from slow exchange spectra. d. Value used in line shape analysis. e. Spectrum taken at this temperature was used for simulation. Exact coalescence could not always be observed. f. $\Delta\nu_1$ and $\Delta\nu_2$ are the chemical shift differences between benzyl methylene protons of the major and minor amide isomers, respectively. J_{AB} in all compounds was 14 Hz. g. At this temperature a single AB pattern was observed.

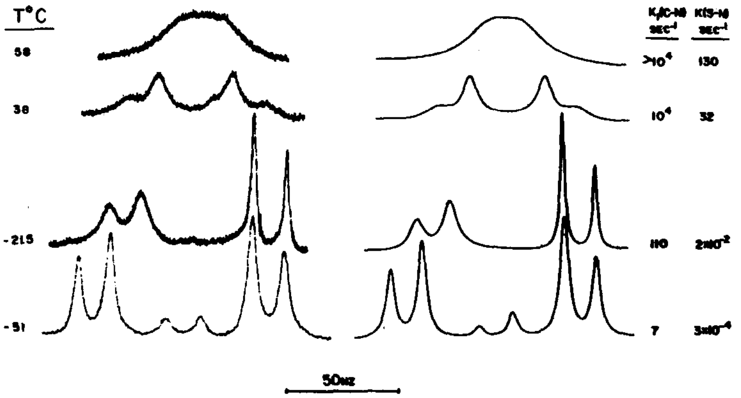


Figure 1. PMR spectra of 1i; left: experimental; right: computed

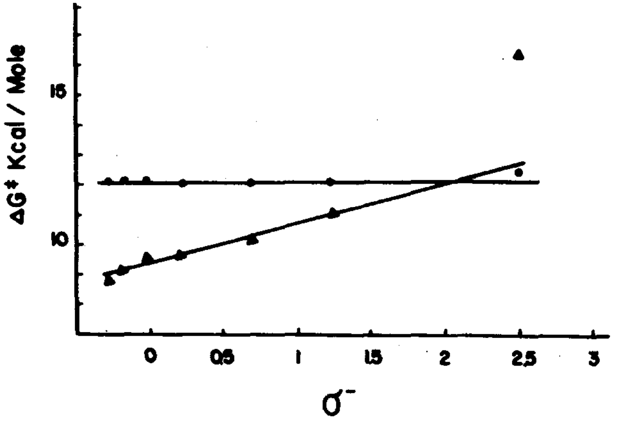


Figure 2. Plot of $\Delta G^{\neq}$ for N-C (●) and N-S (▲) rotation in 1c-i *vs.* σ^- substituent constant.

values for amide rotation, since 1a and 1b showed single amide resonances at temperatures down to -85°C. This could be a result of unfavorable equilibrium populations of the *syn* and *anti* isomers. In 1c - i the equilibrium constants are well within the measurable range (Table 1), apparently as a result of similar S-O interactions in the *syn* and *anti* isomers.

Rate constants at or near the two coalescence temperatures of each compound were obtained by line shape analysis,[7] and free energies of activation were calculated using the Eyring equation (Table 1). A plot of $\Delta G^{\neq}$ *vs.* σ^- substituent constant (Figure 2) clearly indicates a substantial substituent dependence of sulfenamide barriers, in contrast to the total absence of substituent effect on barriers to N-C rotation (using Raban's[1a] modification of the Hammett analysis, we obtain for the S-N barrier: $\rho' = -275 \pm 29$, $\rho_{300} = -.9 \pm .1$, correlation coefficient = .978; for the C-N barrier: $\rho' = -12 \pm 9$, $\rho_{300} = -.04 \pm .03$, correlation coefficient =.54).[8]

The assumption that (p-d)π conjugation equally stabilizes both the ground and transition states is inapplicable in this case, as conjugation between nitrogen and the carbonyl group cannot exist in the transition state for amide rotation. Hence it may be concluded that the effect of (p-d)π bonding on substituent dependence of sulfenamide barriers is insignificant, and an additional or alternative mechanism is required. A possible alternative may involve "gauche" type effects,[9] whereby alteration of X results in changes in C-S bond polarity, which can effect the balance between repulsive and attractive potentials in the ground and transition state conformations. MO calculations are being undertaken in an effort to test this hypothesis.[10]

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8. Not surprisingly, the point for the *ortho* substituted compound 1i deviates from the line, and it has therefore been omitted from the least squares analysis for the S-N barriers.
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10. We thank Professor M. Raban and Dr. A. Pross for helpful discussions.