(3) C. G. Swain and E. C. Lupton, *J. Am. Chem. Soc.*, **90**, 4328 (1968).
(4) W. S. Matthews, J. E. Bares, J. E. Bartmess, F. G. Bordwell, F. J. Cornforth, G. Drucker, Z. Margolin, R. J. McCallum, G. J. McCollum, and N. R. Vanier, *J. Am. Chem. Soc.*, **97**, 7006 (1975).
(5) This is an average of the values of 0.855 for σ_I calculated from Taft's $\sigma^*_{CH_2NMe_3^+}$ of 1.90 (obtained from hydrolysis data)[6] and 0.765 calculated from the $\sigma^*_{CH_2NMe_3^+}$ of 1.70 obtained from the p*K* of $Me_3N^+CH_2CO_2H$,[7] Charton's σ_I of 0.73,[8] and Taft's σ_I of 0.92 obtained from aromatic reactivities (and from ^{19}F NMR chemical shifts).[9,10]
(6) R. W. Taft, "Steric Effects in Organic Chemistry", M. S. Newman, Ed., Wiley, New York, N.Y., 1956, p 619.
(7) H. C. Brown, D. H. McDaniel, and O. Häfliger, "Determination of Organic Structures by Physical Methods", E. A. Braude and F. C. Nachod, Ed., Academic Press, New York, N.Y., 1955, Chapter 14.
(8) M. Charton, *J. Org. Chem.*, **29**, 1222 (1964).
(9) R. W. Taft, E. Price, I. R. Fox, I. C. Lewis, K. K. Andersen, and G. T. Davis, *J. Am. Chem. Soc.*, **85**, 709 (1963).
(10) J. Hine, "Structural Effects on Equilibria in Organic Chemistry", Wiley-Interscience, New York, N.Y., 1975, Chapter 3.
(11) The Me_3C group is a better model sterically than Me, but, since the differences in acidities between Me_3CCH_2EWG and $MeCH_2EWG$ are small, compared to $Me_3N^+CH_2EWG$, it makes but little difference which model is used.
(12) Polar contributions are clearly dominant according to the Swain–Lupton analysis.[3] Judging from the relative size of σ_I and σ_R^-, polar contributions are dominant according to the Ehrenson, Brownlee, and Taft dual parameter analysis, except for CH_3CO type substituents.[13] These analyses are based on oxygen and nitrogen acid systems. For carbon acid systems, *p*-$G_6H_4CH_2EWG$ our results to date suggest that polar and resonance contributions are more nearly equal.
(13) S. Ehrenson, R. T. C. Brownlee, and R. W. Taft, *Progr. Phys. Org. Chem.*, **10**, 1 (1973).
(14) This is caused primarily by a resonance saturation effect.[15]
(15) F. G. Bordwell and G. J. McCollum, *J. Org. Chem.*, in press.
(16) F. G. Bordwell, N. R. Vanier, W. S. Matthews, J. B. Hendrickson, and P. L. Skipper, *J. Am. Chem. Soc.*, **97**, 7160 (1975).
(17) F. G. Bordwell, J. E. Bartmess, G. E. Drucker, Z. Margolin, and W. S. Matthews, *J. Am. Chem. Soc.*, **97**, 3226 (1975).

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Carbon Acids. 9. The Effects of Divalent Sulfur and Divalent Oxygen on Carbanion Stabilities

Summary: Using the trimethylammonio group, Me_3N^+, as a model to calculate the polar effect, the carbanion stabilizing effects of MeO and PhO groups have been found to be smaller than calculated, and the carbanion stabilizing effects of MeS and PhS groups have been found to be much larger than calculated.

Sir: There is long-standing and abundant evidence in the literature to indicate that divalent sulfur causes an adjacent C–H bond to be much more susceptible to cleavage by base than does divalent oxygen.[1] The greater kinetic acidity produced by α-RS (or α-PhS) than α-RO (or α-PhO) groups has been assumed by most experimentalists to be associated with a greater ability of divalent sulfur to stabilize an incipient carbanion in the transition state of the deprotonation reactions by a conjugative effect involving 3d orbitals.[1] On the other hand, theoreticians have generally been skeptical of the need to invoke such conjugative interactions.[2] For example, recent ab initio calculations have failed to reveal any role for 3d orbital conjugation in stabilizing the $HSCH_2^-$ anion, and the conclusion has been drawn that sulfur stabilizes carbanions by polarization, rather than by d-orbital conjugation.[3]

In the previous paper in this series[4] we used the difference in acidities (Δp*K*) of $Me_3N^+CH_2EWG$ and $MeCH_2EWG$ (EWG = CN, $PhSO_2$, or PhCO) as a measure of the sensitivities of these carbon acids to polar effects, $\Delta pK = \sigma_I\rho_I$. The ρ_I values were then used in conjunction with σ_I to estimate the polar effect anticipated for a group, G, in the GCH_2CN, GCH_2SO_2Ph, and GCH_2COPh carbon acid systems. When G is a π acceptor it should stabilize the $GCHEWG^-$ anion by conjugation, as well as by a polar effect, and the increase in acidity observed should be larger than that calculated from the $\sigma_I\rho_I$ relationship. This was found to be true when G is a strong π-acceptor group (CH_3CO, PhCO, NO_2, $PhSO_2$, CN), the $\Delta\Delta pK$'s ranging from 6.2 to 18.0 p*K* units.[4] If RS or PhS groups have π-acceptor capacity, we would then expect to find that the acidities are enhanced to an extent greater than expected on the basis of their polar effects; no enhancement is expected, of course, for RO and PhO groups. The results are summarized in Table I for four carbon acid systems.

Table I. Comparison of the Acidifying Effects of MeO, PhO, MeS, and PhO Groups with the ir Polar Acidifying Effects

G	$\sigma_I{}^a$	$\Delta pK_{calcd}{}^b$	$\Delta pK_{obsd}{}^c$	$\Delta\Delta pK^d$
	A. GCH_2CN Carbon Acids; $\rho_I = 14.5$			
Me	-0.04^e	(0.0)	(0.0)	
Me_3N^+	0.82^f	(11.9)	11.9	
PhO	0.38	5.2	4.4	−0.8
PhS	0.30^g	4.4	11.7	7.3
	B. GCH_2SO_2Ph Carbon Acids; $\rho_I = 14.1$			
Me	-0.04^e	(0.00)	(0.0)	
Me_3N^+	0.82^f	(11.6)	11.6	
MeO	0.27	3.8	0.3	−3.5
PhO	0.38	5.3	3.1	−2.2
MeS	0.23	3.2	7.6	4.4
PhS	0.30^g	4.2	10.5	6.3
	C. GCH_2COPh Carbon Acids; $\rho_I = 11.9$			
Me	-0.04^e	(0.0)	(0.0)	
Me_3N^+	0.82^f	(9.8)	9.8	
MeO	0.27	3.2	1.5	−1.7
PhO	0.38	4.5	3.3	−1.2
PhS	0.30^g	3.6	7.3	3.7
PhSe	0.24^h	2.9	5.8	2.9
	D. 9-G-Fluorene Carbon Acids; $\rho_I = 8.1$			
Me	-0.04^e		(0.0)	
Me_3C	-0.07^e	(0.0)		
Me_3N^+	0.82^f	(6.55)	6.55^i	
MeO	0.27	2.2	0.2	−2.0
PhO	0.38	3.1	2.4	−0.7
MeS	0.23	1.9	4.3	2.4
PhS	0.30^g	2.4	6.9	4.5

[a] From ref 9 unless otherwise noted. [b] From $\Delta pK = \sigma_I\rho_I$. [c] Relative to the p*K* of $MeCH_2CN$ (32.5, series A), or $MeCH_2SO_2Ph$ (31.0, series B), or $MeCH_2COPh$ (24.4, series C), or 9-methylfluorene (22.3, series D). [d] $\Delta\Delta pK = \Delta pK_{obsd} - \Delta pK_{calcd}$. [e] Taken as (0.0). [f] An average value; see footnote 5 of ref 4. [g] See ref 10. [h] Calculated from 0.45 $\sigma^*_{CH_2SePh}$ using the data of L. D. Pettit, A. Royston, C. Sherrington, and R. J. Whewell, *J. Chem. Soc.* B, 588 (1968). [i] Relative to 9-*tert*-butylfluorene (p*K* = 24.55).

For reasons given earlier,[4] we do not expect the Me group in $MeCH_2EWG$ to be a good model sterically or electronically for the Me_3N^+ group in $Me_3N^+CH_2EWG$. In addition, the steric relationships between G and the site of electron charge density changes for the various $GCHEWG^-$ anions.[4] Steric effects for 9-substituted fluorenes are more severe than in the GCH_2EWG carbon acids. In fluorene, substitution of Me_3C for H at the 9 position causes a 1.7 p*K* unit decrease in acidity, whereas substitution of Me for H causes a 0.5 p*K* unit *increase* in acidity. In the fluorene system 9-*tert*-butylfluorene has been used as a model for 9-trimethylammoniofluorene, but 9-methylfluorene has been used as a model to calculate Δp*K*'s for 9-MeO-, 9-PhO-, 9-MeS-, and 9-PhS-fluorenes. Although the difficulties in choosing proper models are such as to make the calculations of polar effects of an approximate nature, the results obtained for the various carbon acid systems are consistent and we believe that the $\Delta\Delta pK$'s are significant.

Note first that the $\Delta\Delta pK$'s for MeO and PhO groups are negative in every instance, i.e., the observed ΔpK's are *smaller* than those expected on the basis of the polar effect. This is a pattern that has been observed previously for the effect of α-MeO substituents on the base-catalyzed exchange rates for deprotonation of acetates, GCH_2CO_2Me, and their cyclic analogs.[5] It has been suggested that, when G = MeO, the incipient carbanion produced in the transition state for these deprotonations is destabilized by an electronegativity effect and by lone pair–lone pair interactions.[5] Such destabilizing effects by MeO or PhO in the carbanions, $MeOCHEWG^-$ and $PhOCHEWG^-$ would account for the negative $\Delta\Delta pK$ values in Table I.

In sharp contrast to the negative $\Delta\Delta pK$'s observed for PhO, the $\Delta\Delta pK$'s for PhS are all positive and large, ranging from 3.7 to 7.3 p*K* units. This suggests stabilization of the anions over and above that expected from a polar effect of the order of 6 to 10 kcal/mol. These effects are similar to those observed with strong π-acceptor groups,[4] although they are somewhat smaller in magnitude.

The strikingly large acidifying effect of the PhS group can be brought out further by some direct comparisons of the p*K* data. Despite the much smaller polar effect of PhS ($\sigma_I = 0.30$) than Me_3N^+ ($\sigma_I = 0.82$), $PhSCH_2SO_2Ph$ is only 0.9 p*K* unit less acidic than $Me_3N^+CH_2SO_2Ph$, $PhSCH_2CN$ is only 0.2 p*K* unit less acidic than $Me_3N^+CH_2CN$, and 9-PhS-fluorene (p*K* = 15.4) is 2.4 p*K* units *more* acidic than 9-Me_3N^+-fluorene (p*K* = 17.8).

It is difficult to decide whether these large effects are caused solely by the high degree of polarizability of sulfur, as the ab initio calculations suggest,[3] or whether a conjugative effect is also operative. Several results from our p*K* data lead us to believe that more than polarizability is involved. Note, for example, that $\Delta\Delta pK$ is greater for $PhSCH_2COPh$ (3.7) than for $PhSeCH_2COPh$ (2.9), despite the greater polarizability of selenium. In addition, Hammett correlations for equilibrium acidities in Me_2SO in both the meta- and para-substituted phenylacetonitrile system[6] and the 3-substituted fluorene system,[7] require σ_p^- for PhS, rather than σ_p, despite the fact that resonance effects are greatly attenuated when operating across a benzene ring.[4] Finally, there is strong evidence that the F_3CSO_2 and $PhSO_2$ groups enter into conjugation based on their strong acidifying effect on methane and the diminution of this effect when the substituent is placed on a cyclopropane ring.[8] Since tetravalent sulfur can exert strong conjugative effects, it seems likely that divalent sulfur can also enter into electron acceptor conjugation with α carbanions.

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References and Notes

(1) For a review see C. C. Price and S. Oae, "Sulfur Bonding", Ronald Press Co., New York, N.Y., 1962, pp 55–60.

(2) C. A. Coulson, *Nature (London)*, **221**, 1106 (1969); J. I. Musher, *Angew. Chem., Int. Ed. Engl.*, **8**, 54 (1969); J. I. Musher, *J. Am. Chem. Soc.*, **95**, 1320 (1972); J. B. Florey and L. C. Cusachs, *ibid.*, **94**, 3040 (1972).

(3) A. Streitwieser and J. E. Williams, *J. Am. Chem. Soc.*, **97**, 191 (1975); F. Bernardi, I. G. Csizmadia, A. Mangini, H. B. Schlegel, M.-H. Whangbo, and S. Wolfe, *ibid.*, **97**, 2209 (1975).

(4) F. G. Bordwell, M. Van Der Puy, and N. R. Vanier, *J. Org. Chem.*, preceding paper in this issue.

(5) J. Hine, L. G. Mahone, and C. L. Liotta, *J. Am. Chem. Soc.*, **89**, 5911 (1967); J. Hine and P. D. Dalsin, *ibid.*, **94**, 6998 (1972).

(6) J. E. Bares, unpublished results.

(7) J. Branca, unpublished results.

(8) F. G. Bordwell, N. R. Vanier, W. S. Matthews, J. B. Hendrickson, and P. L. Skipper, *J. Am. Chem. Soc.*, **97**, 7160 (1975).

(9) J. Hine, "Structural Effects on Equilibria in Organic Chemistry", Wiley-Interscience, New York, N.Y., Chapter 3.

(10) M. Charton, *J. Org. Chem.*, **29**, 1222 (1964).

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Nucleic Acid Related Compounds. 19. Concerning the Mechanism of Formation of "2,3′-Imino-1-(β-D-lyxofuranosyl)uracil" [2-Amino-1-(3-deoxy-β-D-lyxofuranosyl)-4-pyrimidinone-$N^2 \rightarrow 3'$-anhydronucleoside] from $O^2 \rightarrow 2'$ Cyclonucleosides and "Ammonium Azide"[1]

Summary: Postulated attack of azide anion (from "ammonium azide") at C^2 of the pyrimidine ring of $O^2 \rightarrow 2'$ cyclonucleoside **1** followed by intramolecular cyclization with accompanying loss of nitrogen gas to give $N^2 \rightarrow 3'$ cyclonucleoside **3** does not occur, as was demonstrated by incorporation of ^{15}N from labeled ammonium chloride and verified by analogous formation of **3** using "ammonium acetate".

Sir: In a very recent issue of this journal, the conversion of $O^2 \rightarrow 2'$-anhydro-1-(5-*O*-benzoyl-3-*O*-methanesulfonyl-β-D-arabinofuranosyl)uracil (**1**) and related $O^2 \rightarrow 2'$ cyclonucleosides to the corresponding $N^2 \rightarrow 3'$-anhydro-2-amino-1-(5-*O*-benzoyl-3-deoxy-β-D-lyxofuranosyl)-4-pyrimidinone (**3**) and related derivatives using "ammonium azide" in hot *N,N*-dimethylformamide (DMF) was described.[2] This transformation was postulated to proceed via azide attack at C^2 of the pyrimidine ring followed by an unusual intramolecular attack by the geminal electrons of N^1 of the azide moiety (intermediate **2**) to give **3** by an unexplained (necessarily reductive) process. Treatment of 5′-*O*-trityl-$O^2 \rightarrow 2'$-anhydro-1-(β-D-arabinofuranosyl)uracil with "ammonium azide" in DMF at 110° was reported[2] to give 59% 1-(5-*O*-trityl-2-azido-2-deoxy-β-D-ribofuranosyl)uracil, plus 33% starting material, which is in agreement with previous studies of Moffatt and coworkers[3] involving SN2-type displacement of O^2 from $C^{2'}$ of an $O^2 \rightarrow 2'$ anhydronucleoside using lithium azide. An "unprecedented" "introduction of an azide group into pyrimidine bases through O^2 anhydronucleosides"[2] was proposed to explain the formation of **3**. A 'striking "through bond" electronegative influence to $C^{2'}$ was attributed[2] to the leaving group (mesylate) at $C^{3'}$ to rationalize azide attack at $C^{2'}$ in the 5′-*O*-trityl-3′-hydroxy compound (i.e., absence of the 3′-*O*-mesyl function).

Fox and coworkers[4] have reported that treatment of 3′-*O*-mesyl-$O^2 \rightarrow 5'$-anhydrothymidine with ammonia at room temperature in a sealed vessel gave the $N^2 \rightarrow 3'$-anhydro-2′,3′-dideoxy compound (corresponding to **3**). Attack of ammonia at C^2 of the pyrimidine ring with displacement of alkoxide ($OH_2C^{5'}$ or OCH_3, from reaction with $MeOH/Et_3N$) was postulated with subsequent intramolecular displacement of mesylate by the exocyclic amino function of the isocytosine system to give the $N^2 \rightarrow 3'$ cyclonucleoside.[4]

In the present reaction, ammonium azide was assumed to be generated in situ from a sixfold molar excess of ammonium chloride and sodium azide.[2] This more soluble azide salt was the presumed nucleophile. However, the following acid–base equilibrium (eq 1) would be expected to provide a finite [pK_a