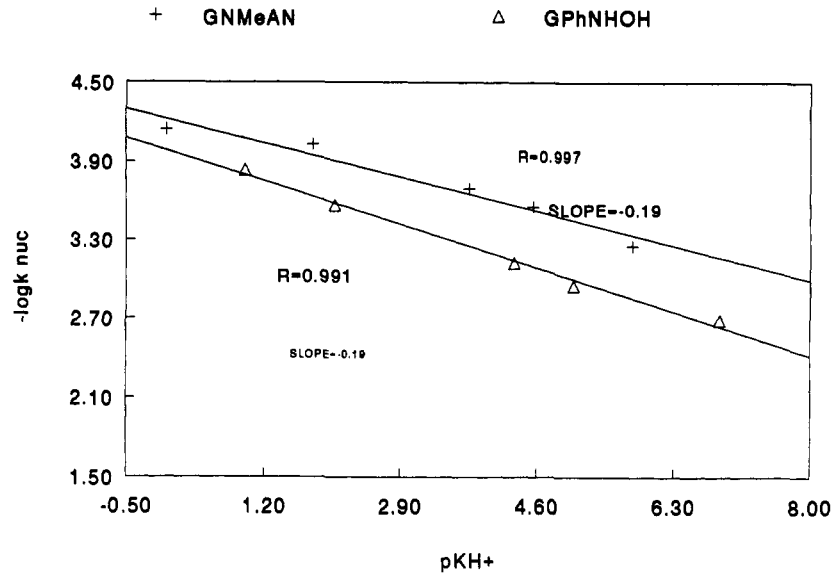

Figure 3. Brönsted plot for reaction of G_1-*N*-methylanilines with methyl 3-nitrobenzenesulfonate in methanol-d_4 at 29.5 °C and for reaction of G_1-*N*-phenylhydroxylamines with methyl 3-nitrobenzenesulfonate at 29.5 °C in methanol-d_4.

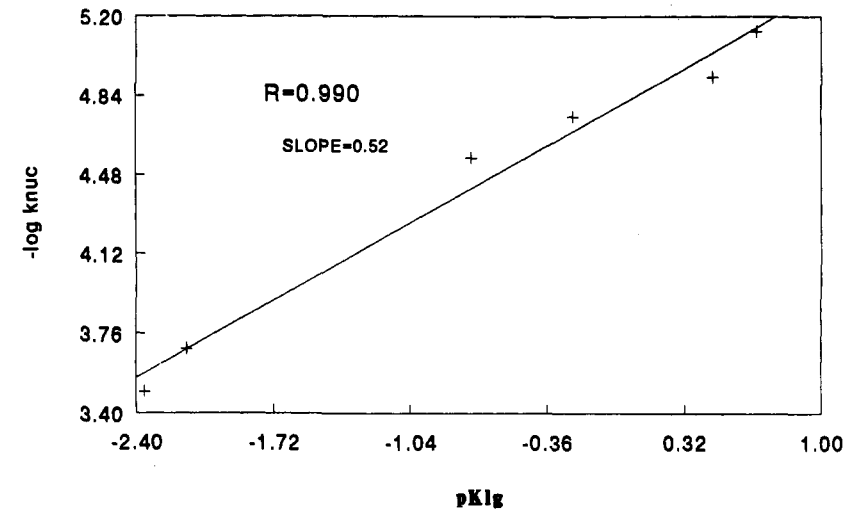

Figure 4. Plot of pK_{1g}^{Me} vs reactivity for 3-chloro-*N*-methylaniline in methanol-d_4 at 29.5 °C.

Table II. Alkylations of G_1-*N*-Phenylhydroxylamines (Reaction 1) at 29.5 °C in Methanol-d_4[a]

G_1	G_2	k (s^{-1} M^{-1}) * 10^3	-log k
2(b)			
4-CH_3O	3-NO_2	2.06	2.686
H	3-NO_2	1.13	2.947
4-CF_3	3-NO_2	0.275	3.561
4-Br	3-NO_2	0.759	3.120
4-NO_2	3-NO_2	0.146	3.836
4-Me	3-NO_2	1.56	2.807
H	4-NO_2	0.771	2.812
H	4-Br	0.239	3.622
H	4-MeO	0.0541	4.267
H	4-Me	0.0695	4.158

[a] Average error = ±6.3%.

interval test) for the β_{nuc} values. When the worst point (for 4-nitro-*N*-methylaniline, the hardest pK_{H^+} to determine) was omitted the slope for the plot became 0.19. In Figure 3 the isolated point is for 4-nitro-*N*-methylaniline. Also on this plot is the point for 3-nitro-*N*-methylaniline (circled) that was obtained from a Hammett plot. This β_{nuc} value was the same as for the *N*-phenylhydroxylamines. The statistical treatment for the β_{1g}^{Me} values showed they were different at a 95% confidence level.

Table III. β Values for Reaction 1

system	β_{nuc}	β_{lg}^{Me}
2a	0.15[a]	0.36
2b	0.19	0.47

[a] This value was not statistically different from 0.19.

Table IV. α-Effects for Reaction 1 vs G_2 = 3-NO_2

G-α-nucleophile	pK_{H^+}	G-nucleophile	pK_{H^+}	α-effect
H	5.05	3-Cl	3.75	11.3
4-Br	4.31	3-Cl	3.75	7.44
H	5.05	H	5.79	2.06
4-Me	6.59	4-Me	6.43	2.12

Several measured values of the α-effect are summarized in Table IV using the definition k_α-nuc/k_{nuc}. They are all in the range of 2–11. They did not plot well vs σ or σ⁻ for the α-nucleophile.

It is important to compare α-nucleophiles with normal nucleophiles of the same pK_a values. The Brönsted plots of reactions 1a and b allowed comparison of rate constant ratios from the prediction equations 3a and b, respectively.[17] Comparing the k_{nuc} for the hypothetical normal nucleophile of pK_{H^+} value identical to the measured $k_{\alpha\text{-nuc}}$

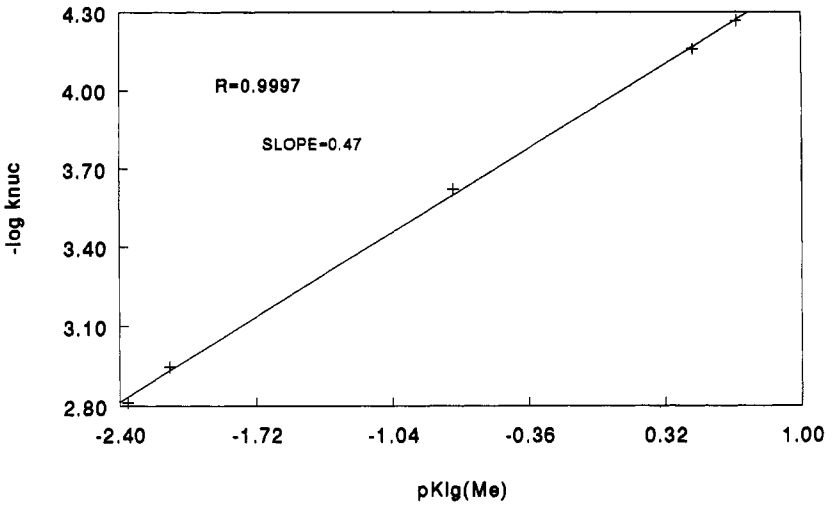

Figure 5. Plot of pK_{lg}^{Me} vs reactivity of *N*-phenylhydroxylamine in methanol-d_4 at 29.5 °C.

$$\log k_{nuc} = pK_{H^+}(0.1464) - 4.1726 \quad (3a)$$

$$\log k_{\alpha\text{-nuc}} = pK_{H^+}(0.1867) - 3.9865 \quad (3b)$$

we can obtain an indication of the effect of electron withdrawal on the α-effect at methyl groups.

Table V summarizes the computed α-effects. A mild dependence on electron withdrawal is observed. ($\rho_{\alpha\text{-effect}}$ from a poorly fitting (0.92) Hammett plot (not shown) was −1.10.) The dependence of the α-effect on the nucleofugacity, noted by Buncel with HOO^- and hydrazine, is found in the present system to be a complex dependence on both substituents G_1 and G_2. Note that the better leaving group, G_2 = 4-NO_2, does not give an increased α-effect in the case where the nucleophile is held constant (G_1 = H). For the mildly electron-donating group, Me, the order is reversed.

Discussion

An overall summary of the Menschutkin alkylations of this study with two types of negatively charged α-nucleophiles previously reported[1,2] appears in Table VIII.

The ρ_{nuc} values for both the normal and α-nucleophiles are nearly the same. β_{nuc} values for the normal species are only slightly larger. The same observation was made for the NMBHA anions in our previous work.[1] These anions gave ρ_{nuc} values for the normal nucleophiles that were larger than for the α-nucleophiles.

Larger ρ_{lg} values are reported[2,11] for the phenylsulfates with normal nucleophiles than for the α-nucleophiles HOO^- and hydrazine. This is reversed for the G-*N*-phenylhydroxylamines and arenesulfonates. The β_{nuc} values for the negatively charged α-nucleophiles and hydrazine are larger, indicating more bonding with the C atom in the TS than for the normal nucleophiles phenoxide, and ethylglycine. The conclusion was the TS for α-nucleophile attack was displaced in a direction perpendicular to the trajectory of a normal S_N2 reaction (an anti-Hammond effect).

Different patterns for Menschutkin-type alkylations, using *N*-phenylhydroxylamines (charge created) are apparent in Table VIII. The value of β_{lg}^{Me} for reaction 1a (0.52) is higher than these values for methyl transfers from arenesulfonates to anilines in methanol (0.36–0.40) reported by Lee et al.[12] The β_{nuc} values are much smaller (0.15–0.19) for the *N*-methylanilines than for the anilines also reported by Lee et al.[12] (0.52–0.63) in methanol. This effect can be ascribed to the increased steric demand introduced by the methyl group (or OH group). Such variations of the TS structure are reported for several Menschutkin systems.[13,14] The β_{nuc} for the *N*-phenylhy-

Table V. α-Effects vs Electron Withdrawal

G on **2b**	G_3 on **3**	computed α-effect
H	3-NO_2	2.35
4-MeO	3-NO_2	3.06
4-CF_3	3-NO_2	2.04
4-NO_2	3-NO_2	1.51
4-Me[a]	3-NO_2	2.38[b]
H[a]	4-NO_2	2.26
4-Me[a]	4-NO_2	2.04

[a] From computations based on rate constants from Hammett and Brönsted plots. [b] Measured value 2.12 (Table IV).

Table VI. pK_{H^+} Values for *N*-Methylanilines in MeOH at 25 °C

	2a
	pK_{H^+}[a]
H	5.79
4-Me	6.43
3-Cl	3.75
3-NO_2	1.81
4-NO_2	−0.018

[a] Average deviation (±0.06). pK_{H^+}(water) = 4.79 − 3.52$\Sigma\sigma$(or σ^-).[8] pK_{H^+}(MeOH) = 5.59 − 4.71$\Sigma\sigma$(or σ^-).

Table VII. pK_{H^+} Values for *N*-Phenylhydroxylamines in Water and Methanol (MeOH) at 25 °C

compd **2b**, G =	pK_{H^+} water[a]	MeOH[b]
4-OH	4.17	
4-OCH_3	4.00	6.88
4-Me	3.63	6.59
H	3.32	5.05
4-Cl	2.58	
4-NO_2	0.65	0.96
4-CF_3		2.08

[a] Average deviation ±0.05. [b] Average deviation ±0.09. pK_{H^+} = 3.30 − 2.18$\Sigma\sigma(\sigma^-)$ (r = 0.996; n = 5 (water). pK_{H^+} = 5.33 − 5.78$\Sigma\sigma$ (r = 0.997; n = 5) (MeOH).

(11) Buncel, E.; Chauqui, C. *J. Org. Chem.* **1980**, *45*, 3621.

(12) Lee, I.; Choi, Y. H.; Rhyu, K. W.; Shin, C. S. *J. Chem. Soc., Perkin Trans. 2* **1989**, 1881.

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Table VIII. Comparison of Reactivity Parameters for Methyl Transfers to Several Negatively Charged and Neutral α-Nucleophiles in Methanol or Methanol-d_4 29.5 °C

nucleophile	leaving group	ρ_{nuc}	ρ_{lg}[a]	β_{nuc}	β_{lg}^{Me}	α-effect	ref
HOO⁻	phenylsulfate		0.61	0.16		5.7–11	2
HO⁻	phenylsulfate		0.92	0.07			2
NH_2NH_2	phenylsulfate		0.70	0.20		3.00–5.2	2
ethylglycine	phenylsulfate		1.00	0.12			2
GPhCON(Me)O⁻	arenesulfonate	−0.92[c]	1.29	0.84	0.44	2.5–3.5	1
GPhO⁻		−3.32[d]	1.24	0.31	0.43		1
GPhNHOH		−1.09	1.39	0.19	0.47	1.5–3.0	1
GPhNHMe	arenesulfonate	−1.13	1.06	0.15[b]	0.52		1

[a] This ρ value refers to the leaving group, substituted phenylsulfate, or arenesulfonate. [b] This number is not statistically different than the 0.19 for *N*-phenylhydroxylamines.

droxylamines is nominally larger by 0.04 units but is not statistically different.

Calibration of β parameters is desirable for their use as TS indicators. One at least needs to know that the reactions studied are well behaved. A recent report[29] shows that even within a reaction series β values (computed from ratios of ρ values) can change sign. These authors concluded that negative β values, for Menschutkin reactions with phenyl ethyl chloride substrates, interpreted as negative bond making (breaking) was absurd. These workers, however, noted that the arenesulfonate substrates, similar to those in the present paper *are* well behaved (no $\rho_x > 0$). They interpreted this fact to indicate that a well-behaved mechanism occurs with arenesulfonates in Menschutkin reactions.[30] Our ρ_{nuc} values are likewise well behaved for both species of nucleophiles and are close to 1.00. Lee has shown,[33] in an analysis of cross interaction between identical groups, that the defining equilibrium for methyl transfer between arenesulfonate groups[32] allows calibration of β values for other reactions of benzenesulfonates by dividing ρ_{nuc} (ρ_{lg}) by 2.94, that is, ρ_{eq} for the transference between arenesulfonates. (Presumably the solvent effects on ρ are cancelled out by determining both ρs in the same solvent.) Our ρ values give $\beta^{calc}_{nuc} = 0.38$ for reaction 1a and 0.37 for reaction 1b. The difference between the computed values and the measured values may reflect steric hindrance as mentioned above. At least our system is not giving ill-behaved parameters. The pK_{lg}^{Me} values used to obtain β_{lg}^{Me} values are calibrated directly from the Lewis equilibration experiment[32] and are reported to range from 0 to 1.0.[3a] It is reasonable to conclude that these values give reasonable probes of the TS in the present work. Note that the magnitude of the computed values of β_{nuc} are essentially the same for both species, similar to the conclusion from the measured values.

The total bond order to C in the TS for the two types of nucleophiles can be computed as the sum of the β_{nuc} values plus the bond order to the leaving group (given by $1.00 - \beta_{lg}^{Me}$). The bond order sum is not the same for the two species, 0.67, for the normal nucleophile species, G-C_6H_4NHMe, but 0.72 for the G-C_6H_4NHOH species. This difference implies that the Menschutkin-type reactions, using α-nucleophiles, follow the trend of an anti-Hammond effect toward tighter transition states, just as with negatively charged nucleophiles.

Smaller α-effects follow from smaller β_{nuc} values in Menschutkin systems relative to negatively charged nucleophiles. This is also in agreement with the much earlier work of Dixon and Bruice[15] who found that larger α-effects always occurred with a larger β_{nuc}.

Our group has pointed to the stability of the radicals resulting from oxidation of the G-PhCO(NMe)O⁻ anions.[1,18] The mixing of radical character into the S_N2 TS is the principle idea of one model of the α-effect.[10] AM1 ionization potentials (IPs) correlate the capture of a wide variety of α-nucleophiles by triphenylmethyl cations[19] and the transfer of methyl groups to G-PhCO(NMe)O⁻.[1] We have also shown that the AM1 IPs correlate quite well with IPs obtained by high-level ab initio computations.[19a] The present work supplies an additional example of such a correlation of the rates of nucleophilic attack by α-nucleophiles; Figures 6 and 7 show linear correlations for the IPs of substituted *N*-methylanilines and *N*-phenylhydroxylamines and log k_{nuc} for reaction 1a and b.

Literature data allow the correlation of the AM1 IPs with log k_{nuc} values. (For example, substituted perbenzoate anions vs *p*-nitrophenylacetate in carbonate buffer at pH = 10 in water at 25 °C.[20]) The log $k_{\alpha\text{-nuc}}$ values correlate fairly well with AM1 IPs ($n = 6$; $R = 0.96$) (plot not shown), slope = −0.20. The α-effect in this system was 77 (Table IX).

These correlations may indicate that mixture of radical character into the TSs may occur in these systems. This argument supports Hoz's ideas of mixing single electron transfer character into the TSs of α-nucleophiles attacking at C=O groups. The present data indicate this may also occur even at methyl groups.[10]

Plots of log k_{nuc} vs AM1 IPs for GPhNHOH (slope = 0.93 (log *k*)/IP (eV), Figure 8) and the *N*-methylbenzohydroxamic anions (slope = −1.55 (log *k*)/IP (eV))[1] show the substrate series giving the larger α-effects at CH_3 depends more on the IPs. Table IX summarizes the results of these types of studies for several systems. In each case the greater α-effects correlate with a greater dependence on the IPs of the α-nucleophiles.

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(17) A similar treatment was followed in ref 14, Table 1, footnote j.

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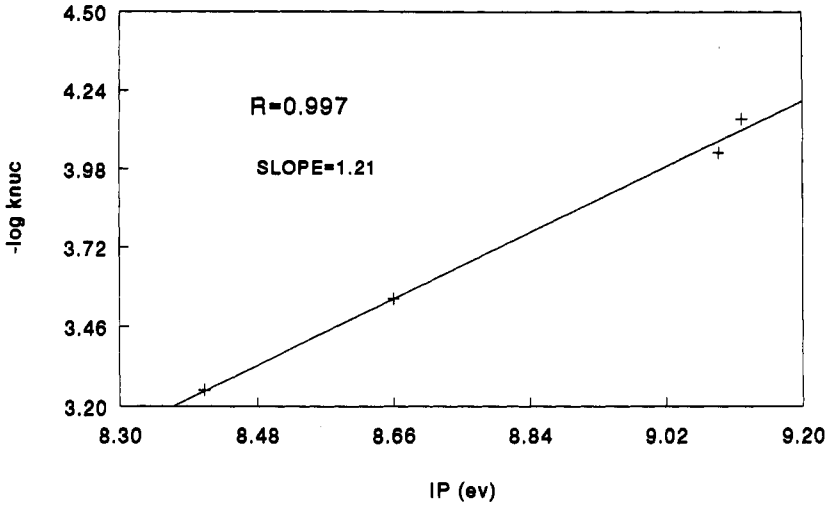


Figure 6. AM1 ionization potentials vs log k_{nuc} for reactions of G_1-*N*-phenylhydroxylamines in methanol-d_4 at 29.5 °C with methyl 3-nitrobenzenesulfonate.

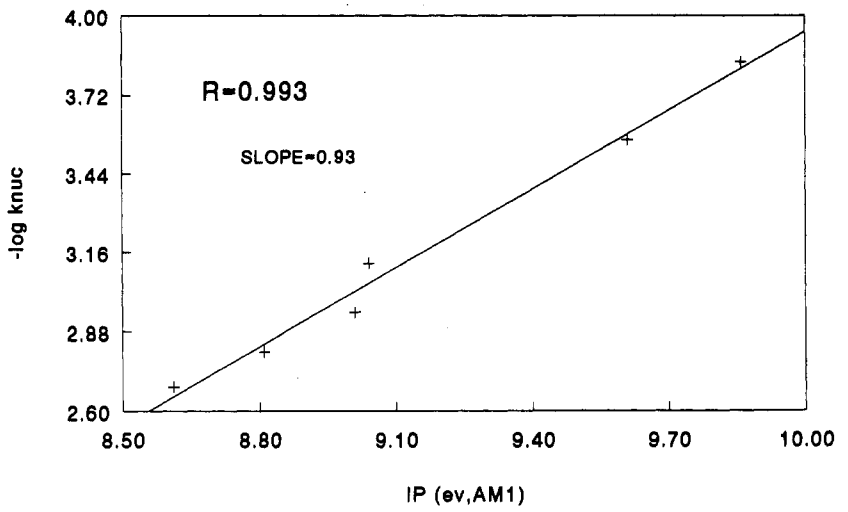


Figure 7. AM1 ionization potentials vs log k_{nuc} for reactions of G_1-*N*-phenylhydroxylamines with methyl 3-nitrobenzenesulfonate at 29.5 °C in methanol-*d*.

Table IX. Comparison of the AM1 IP Dependence vs k_{nuc} for Several Systems

system	solvent	β_{nuc}	α-effect	slope of IP vs log k_{nuc}	ref
1. perbenzoic anions vs α-bromotoluic acid pH = 10, 25 °C	water	0.08	13	−0.20	19
2. ditto vs *p*-nitrophenyl acetate	water	0.38	77	−0.33	20
3. NMBH	water–dioxane	0.86	4.81	−1.55	1
4. NMBH vs benzyl bromide	water	0.31	13	na	22
5. NMBH	water	0.23	45		23
6. *N*-phenylhydroxylamines	methanol-d_4	0.19	2.35[a]	−0.93	this work

[a] Computed from Hammett plots of log k_{nuc} for the normal nucleophile. The comparison was for a normal nucleophile of the same pK_{H^+} vs the α-nucleophile.

A reviewer suggested that the present AM1 IP correlations do not necessarily indicate admixture of SET character in the TS because at least one origin of the α-effect is ground-state destabilization of the α-nucleophile, due to interactions between the unshared pairs of electrons which result in raising the HOMO level. However, Hoz and Buncel have carefully analyzed ground-state destabilization as a source of the α-effect and rejected it because it leads to the conclusion that the α-effect should be greatest when $\beta_{nuc} = 0.0$.[28a] This is contrary to fact. Their conclusion was that the α-effect is due to some intrinsic feature of the TS. The Hoz model, Scheme I, indicates that this additional stability is due to the character of the three-electron radical admixed in the TS.

α-Nucleophiles should show greater dependence on IPs in a plot of log k_{nuc} vs IP than a closely related normal nucleophilic series if Scheme I represents an important aspect of the α-effect. Hoz has noted that two-electron transfer from an α-nucleophile would not retain the splitting of the three-electron diagram in Scheme I and would thus supply no special stability, contrary to the Hoz–Buncel analysis.

In conclusion, the α-effects in these varied systems all show a greater dependence on IP than for normal nucleophilic attack. This is an observation unreported until the present paper. It is consistent with the Hoz model of the α-effect. Such consistency may indicate that even

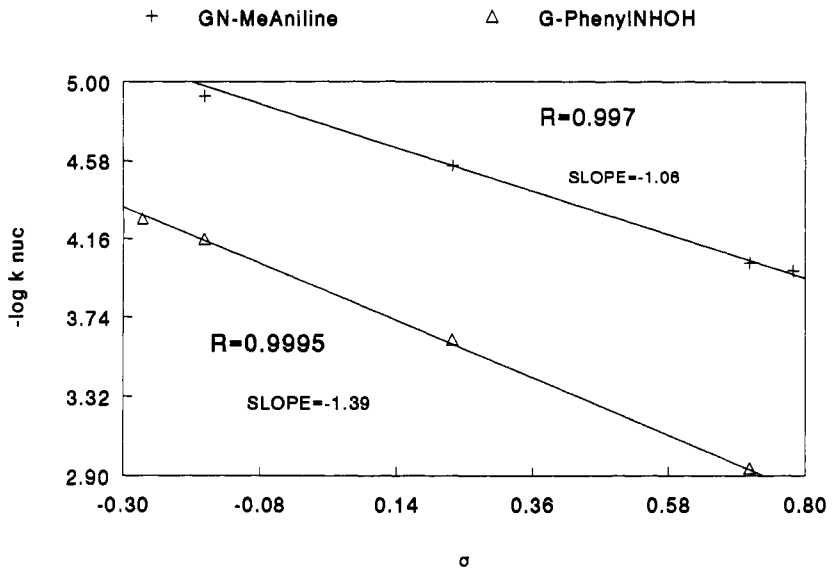
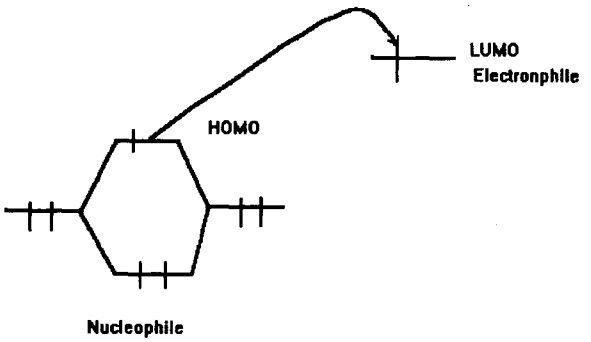


Figure 8. Hammett plots for G-*N*-methylanilines and G-*N*-phenylhydroxylamines reacting with methyl 3-nitrobenzenesulfonate in methanol-d_4 at 29.5 °C.

Scheme I. Hoz Model for the α-Effect



at CH_3 groups some admixture of SET character occurs. Further information is needed to establish this point.

Similar values of ρ_{nuc} for the G-*N*-phenylhydroxylamines and the G-*N*-methylanilines shows this parameter does not serve well to probe the TS even though the reactivity–selectivity principle is followed with methylarenesulfonates. (Reactivity increases in the order GPhNHOH > GPhNHMe but ρ_{nuc} is the same value.) The ρ_{lg} values for GPhNHOH and GPhNHMe are in the reverse order from the previous work on NMBHA anions. These observations agree with Buncel that the use of ρ as a selectivity parameter is questionable especially in cases where anti-Hammond behavior is possible.[2,11] McLennan has likewise expressed strong reservation about dependence on ρ values as an index of TS character.[24]

Conclusions

In every case presented in this work α-nucleophilic reactivity in several series of a wide variety of α-nucleophiles log k_{nuc} correlated with AM1 ionization potentials. These correlations are consistent with the Hoz model of the α-effect. This consistency may indicate a substantial amount of SET character may be mixed into the TS even at CH_3 groups. Larger β_{nuc} values are associated with larger α-effects regardless of development or dispersal of charge. *N*-Phenylhydroxylamines display a small α-effect at methylarenesulfonates but display small anti-Hammond shifts of the TS toward tighter TSs, with an increased total bond order than *N*-methylanilines.

Experimental Section

Synthesis of *N*-Phenylhydroxylamines. All syntheses of substituted *N*-phenylhydroxylamines were performed by the method of Crumbliss et al.[5] except for the 4-MeO and 4-NO_2 derivatives. For the known materials the physical constants of their benzohydroxamic acid derivatives agreed with the literature values.

4-Nitro-*N*-phenylhydroxylamine was made by reducing *p*-dinitrobenzene with ascorbic acid in a 2.0 N sodium carbonate solution.[6] Recrystallization from hot benzene gave sharp melting (106–7 °C) material in ca. 60% yield.

4-Methoxy-*N*-phenylhydroxylamine was synthesized by a slight modification of the Crumbliss method. Initial attempts to make this compound by this method, heating with powdered zinc, gave tarry materials. Synthesis by Raney nickel and hydrazine hydrate lead to mixtures with the anisidine that were hard to separate.[16] The 4-methoxy-*N*-phenylhydroxylamine was found to be easily made by omitting the heating step in the Crumbliss procedure.

Typically, 5.00 g (32.7 mmol) of 4-nitroanisole was suspended in 50 mL of water containing 2.0 g (37.4 mmol) of ammonium chloride at 25 °C. The solution was magnetically stirred, and the temperature was monitored. Finely powdered zinc metal 4.27 g (65.3 mmol) was added slowly, keeping the temperature below 40 °C. The organic layer progressively disappeared. The mixture was allowed to stir until the temperature fell to 30 °C. After filtration of the precipitate and saturating the solution with salt, the mixture was cooled to 0 °C with an ice–salt water bath. Filtration of a precipitate gave a yellow solution. This solution was treated with 2 mL of concd HCl to give a purple

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solution and extracted with ether. The remaining aqueous layer was neutralized with sodium carbonate and extracted with 3 × 100 mL of ether. After drying and solvent removal a red oil remained that formed yellow crystals on standing. This material had two bands in the 3300-3400 cm^{-1} region, due to ν_{NH} and ν_{OH} (Nujol). On standing in air these bands became the twin bands of *p*-anisidine.

Reaction of *N*-Phenylhydroxylamine with Methyl 4-Brosylate. A typical reaction is described. To a methanol solution of 590 mg (5.41 mmol) of *N*-phenylhydroxylamine, stirred magnetically at room temperature (25 °C) was added 1360 mg (5.42 mmol) of methyl 4-brosylate. The reaction was allowed to stir at room temperature for 72 h and worked up by evaporation of the methanol. The mass recovered was 2054 mg (theory 1950) representing quantitative recovery. The reaction mixture was picked up in methylene chloride and washed with saturated sodium bicarbonate solution and 6 M HCl and the HCl solution neutralized with dilute sodium hydroxide. This latter solution was extracted with methylene chloride, dried over sodium sulfate, and evaporated. Examination of the ^1H NMR of the reaction mixture and comparison with authentic materials assured us that all of the starting material was consumed. Analysis of the mixture by TLC (silica gel-G plates; Analtech, Inc.) using 50:50 ether–petroleum ether showed six major components. The mixture was separated on tapered silica gel-G plates (Analtech Taper Plate) using 50:50 ether–petroleum ether. Recovery of the R_f zones at 0.39–0.57, 0.29–0.39, and 0.22–0.29 gave ca. 90% of the product mass. The ^1H NMR analysis of these fractions showed signals due to OCH_3 groups near 3.7–3.8 ppm. The GCMS showed only masses of 123 or 137 for these products. These masses correspond to the rearranged products in reaction 2, including those from rearrangement of the starting *N*-phenylhydroxylamine, catalyzed by the 4-brosic acid produced in reaction 1. The major product was 4-*N*-methylanisidine, as shown by a clean ^1H NMR comparable to known spectra.

pK_{H^+}. The pK_{H^+} values for the *N*-phenylhydroxylamines in water were obtained by the standard half neutralization of the compounds in water or water/MeOH (less than 5% MeOH was used to solubilize) with standard hydrochloric acid and a Jenco Electronic, Ltd pH meter (Model 671P) at 25 °C in a jacketed beaker. Temperature was maintained by a Polyscience Model 9100 refrigerated constant temperature circulator.

The MeOH pK_{H^+} values were determined by either a buffer method[27] or by direct measurement of both the protonated forms in strongly acidic solutions, in the free base form, and then in solutions of known H^+ ion concentration. All solutions were ca. 10^{-4} M. In the cases of very weak *N*-phenylhydroxylamines and 4-NO_2 and 4-CF_3 substituents the absorbance of the protonated species occurred at a wavelength of 355 nm. In these case the protonated form absorbed more strongly than the free base so the difference made in the absorbance value on protonation was used to determine the K_a value. The fact that the Hammett plot was not changed by this different method justifies its use.

Kinetics. The kinetics for reaction 1a,b were determined using a modification of the previously published ^1H NMR method[1] in methanol-d_4 at 29.5 °C in a Varian XL200 NMR equipped with a variable-temperature probe. The *N*-methylanilines or *N*-phenylhydroxylamines were present in at least 10-fold excess (pseudo-first-order conditions) except for the nitro-substituted compounds, which had limited solubility. The kinetics for these compound were performed under second-order conditions. All plots gave good straight lines. They were analyzed by least squares, and those having regression coefficients of 0.99 or better were accepted. All reactions were followed to at least 2 half-lives. The second-order rate constants were found from the pseudo-first-order rate constants by dividing by the known concentrations of the reagents in 10-fold excess.

Acknowledgment is made to the donors of the Petroleum Research Fund, administered by the American Chemical Society, for partial support of this research. We also thank the National Science Foundation for a RUI grant to study the reactivity of *N*-phenylhydroxylamines.

Solvolysis of [3-^{13}C]-4-Homoadamantyl Tosylate. Limited Degeneracy of 4-Homoadamantyl Cation via Multiple Wagner–Meerwein Rearrangement and Vicinal Hydride Shifts under Solvolytic Conditions

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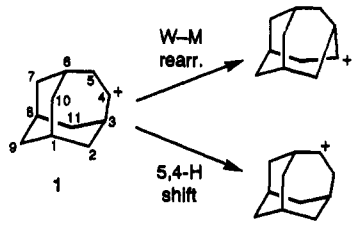
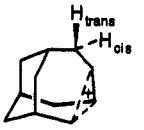
The solvolysis of 4-homoadamantyl tosylate in methanol, acetic acid, and 2,2,2-trifluoroethanol yielded 4-substituted homoadamantane and 4-homoadamantene as major products, together with *exo*-2-substituted homoadamantane and 2,4-dehydrohomoadamantane. The analysis of carbon-13 label distribution in the products from the [3-^{13}C]-labeled reactant, which provided results complementary to those of Nordlander's deuterium label experiments, showed that the 4-homoadamantyl cation is a classical ion that is rapidly rearranging via the degenerate Wagner–Meerwein process (k_w). This equilibrium was more nearly complete in less nucleophilic solvents. Another possible degenerate rearrangement, 5,4-hydride shift (k_h), was shown to be much slower (k_w/k_h = 140–760): most of the 4-substituted product is formed with no more than a single hydride shift. Thus, the potential 11-fold degeneracy of the 4-homoadamantyl cation through the two types of rearrangements is partially restricted by competing solvent attack (k_p). The analysis of the label distribution for the recovered reactant revealed involvement of appreciable ion pair return (k_{-i}). The relative rates of the four possible processes concerning the fate of 4-homoadamantyl cation were determined in acetic acid at 40 °C to be k_p:k_{-i}:k_w:k_h = 1:3.0:9.7:0.068.

Introduction

Multiple degenerate rearrangements of secondary alicyclic carbenium ions often construct systems with complete degeneracy over their entire structures.[1] The 4-homoadamantyl cation (1) potentially undergoes two types of degenerate rearrangements, Wagner–Meerwein rearrangement and 5,4-hydride shift. If both processes take place repeatedly, all 11 carbons of the tricyclic framework become equivalent. Operation of each type of rearrangement can be detected independently by the analysis of the label distribution in the products from an isotopically labeled precursor.

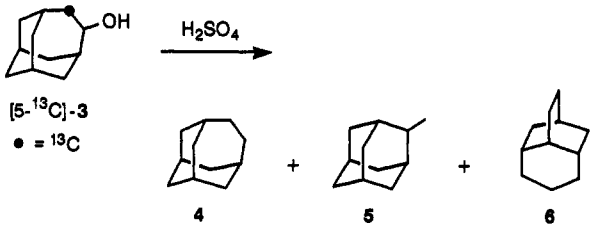


1



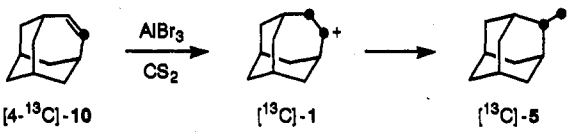
2

Majerski et al. have reported the ^{13}C label scrambling of the 4-homoadamantyl cation under two contrasting conditions.[2,3] Treatment of [5-^{13}C]-4-homoadamantanol ([5-^{13}C]-3) with sulfuric acid gave homoadamantane (4), 2-methyladamantane (5), and 4-homoisotwistane (6) in a ratio 1:1:2. The label had scrambled over all carbons in each product.[2] On the other hand, $AlBr_3$ in carbon disulfide converted [4-^{13}C]homoadamantene to [^{13}C]-5 as



4 5 6

a single major product, in which the majority (~90%) of the label equally distributed at only C-2 and CH_3.[3] This marked difference in the degree of label scrambling was explained in terms of extended lifetime of the 4-homoadamantyl cation in sulfuric acid and its tight ion pairing in carbon disulfide.



[4-^{13}C]-10 [^{13}C]-1 [^{13}C]-5

In addition, the 4-homoadamantyl cation generated under solvolytic conditions was anticipated to show partial degeneracy, since the rearrangements occur in competition with solvent capture.[4,5] Nordlander[4] analyzed the label distribution in the acetolysis products, 4-homoadamantyl acetate (8b) and 4-homoadamantene (10), from deuterium-labeled 4-homoadamantyl tosylates [^{2}H]-7 and showed that the substitution process is accompanied by essentially full Wagner–Meerwein rearrangement of 1 together with its limited rearrangement by 5,4-hydride shift. On the basis of the absence of cis–trans stereoselectivity in the hydride shift, involvement of σ-bridged intermediate 2

• Abstract published in *Advance ACS Abstracts*, December 1, 1993.

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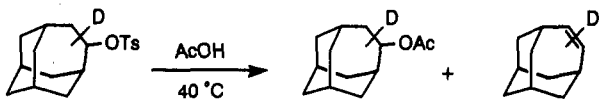
Table I. Rate Constants for the Solvolyses of 4-Homoadamantyl Tosylate 7

solvent	$Y_{2\text{-AdOTs}}$[a]	N_{OTs}[a]	temp (°C)	k_1 (s^{-1})	$\Delta H^{\ddagger}$ (kcal mol^{-1})	$\Delta S^{\ddagger}$ (eu)
EtOH[b]	−1.75	0.00	25.0	1.68×10^{-6} [c]		
MeOH[b]	−0.92	−0.04	25.0	1.05×10^{-5} [c]	24.9	2.1
			40.0	8.23×10^{-5} [c]		
AcOH[d]	−0.61	−2.35	25.0	1.35×10^{-5} [e]	22.7	−4.9
			40.0	8.17×10^{-5} [c]		
80% EtOH[b]	0.00	0.00	25.0	4.50×10^{-5} [c]		
60% EtOH[b]	0.92	−0.08	25.0	3.10×10^{-4} [f]		
50% EtOH[b]	1.29	−0.09	25.0	8.70×10^{-4} [f]		
TFE[b]	1.80	−3.0	25.0	1.74×10^{-3} [f]	19.0	−7.6
			40.0	8.45×10^{-3} [f]		
TFA[g]	4.57	−5.56	25.0	2.26×10^{-1} [e]	10.3	−27.0

[a] Schadt, F. L.; Bentley, T. W.; Schleyer, P. v. R. *J. Am. Chem. Soc.* **1976**, *98*, 7667. [b] Buffered with 2,6-lutidine. [c] Determined titrimetrically within an experimental error of ±2%. [d] Buffered with sodium acetate. [e] Calculated from data at other temperatures, ref 4. [f] Determined conductimetrically within an experimental error ±0.5%. [g] Buffered with sodium trifluoroacetate.



[^{2}H]-7 [^{2}H]-8b [^{2}H]-10

was ruled out. However, large kinetic and equilibrium isotope effects by deuterium left the question of how extensively vicinal hydride shifts take place and how rapidly the 4-homoadamantyl cation undergoes Wagner–Meerwein rearrangement relative to hydride shift and to product formation.

In order to answer these questions, we carried out the solvolysis of [3-^{13}C]-4-homoadamantyl tosylate ([3-^{13}C]-7). Carbon-13 was used as an isotopic label instead of deuterium to minimize the influence of isotope effect. The lifetime of the cationic intermediate was varied by using solvents with different nucleophilicities. This paper describes the results of the label distribution analyses over all ring carbons of the products and the recovered reactant by quantitative ^{13}C NMR measurements.

Results

Synthesis. Lithium aluminum hydride reduction of 4-homoadamantanone, obtained by acylative ring expansion[6] of 1-adamantanecarbaldehyde, gave 4-homoadamantanol. The alcohol was converted to tosylate **7** in the usual manner.[7] Carbon-13 label was introduced by following the same procedure starting with 1-adamantane-[^{13}C]carbaldehyde.[6] ^{13}C NMR analysis of the [3-^{13}C]-4-homoadamantanol obtained in this way indicated that the label was located exclusively at C-3 with a ^{13}C content of 96.8 ± 0.1%.

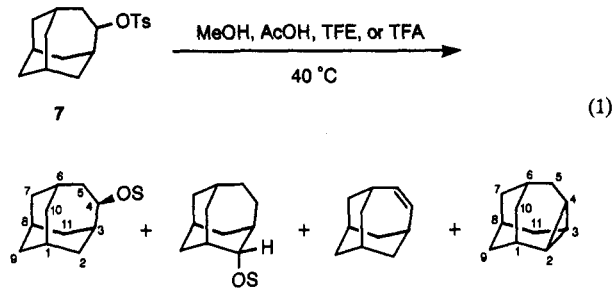
Solvolysis Rates. The rates of solvolysis of unlabeled 4-homoadamantyl tosylate (**7**) were determined by titrimetric or conductimetric methods in MeOH, 2,2,2-trifluoroethanol (TFE), EtOH, and aqueous EtOH in the presence of excess 2,6-lutidine. Good first-order plots (r > 0.9997) were obtained in all cases. The rate data are summarized in Table I, together with those reported[4] for acetolysis and trifluoroacetolysis of **7**.

Table II. Products of Solvolyses of 4-Homoadamantyl Tosylate 7[a]

substrate	solvent	temp (°C)	product distribution (%) 8a-d	9a-d	10	11
7	MeOH[b]	25.0	70	1	25	4
	AcOH[c]	25.0	61	2	33	4
	TFE[b]	25.0	75	6	17	2
	TFA[d]	25.0	72	28	0	
[3-^{13}C]-7	MeOH[b]	40.0	69	1	26	4
	AcOH[c]	40.0	63	3	31	3
	TFE[b]	40.0	73	7	18	2

[a] Relative yields determined by GC. [b] Buffered with 2,6-lutidine. [c] Buffered with sodium acetate. [d] Buffered with sodium trifluoroacetate, ref 4.

Product Studies. For the product study the buffered solvolysis of labeled and unlabeled **7** was carried out in MeOH, AcOH, and TFE at 25 °C (10 half-lives) and at 40 °C (20 half-lives). Analysis of the reaction mixture by GC indicated the presence of four compounds, which were identified as 4-substituted homoadamantanes (**8a-c**), *exo*-2-substituted homoadamantanes (**9a-c**), 4-homoadamantene (**10**), and 2,4-dehydrohomoadamantane (**11**, tetracyclo[5.3.1.0^{3,5}0^{4,9}]undecane). Compounds **8a**, **8b**, **9a**, **9b**, **10**, and **11** were synthesized via independent routes for the comparison purposes. Trifluoroethyl ethers **8c** and **9c** were identified by the NMR spectra of the trifluoroethanolysis products. Control experiments showed that each product was stable under the solvolysis conditions. The product distributions were determined by GC and listed in Table II.[8]



7 (1)

8a-d 9a-d 10 11

a: S = Me
b: S = Ac
c: S = CF_3CH_2
d: S = CF_3CO

^{13}C Label Distribution in Solvolysis Products. The chemical shifts of some homoadamantane derivatives are summarized in Table III. Signals were assigned based on chemical shifts, signal intensities, and off-resonance decoupling or the DEPT measurements. Additional information about assignment was obtained on the basis of the ^{13}C–^{13}C coupling observed for labeled products. All the products and the recovered tosylate were found to contain more than 90% of the label at two adjacent positions, which were assigned to C-3 and C-4, in approximately 1:1 ratios. C-2, -5, and -11 were readily distinguished from other carbons by the line splitting caused by C-3 and C-4.

C-2 and C-10 were differentiated from C-11 and C-7, respectively, with the assumption that these carbons are

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(8) It was shown by Nordlander that the addition of TFA to 4-homoadamantene (**10**) is not involved in the trifluoroacetolysis of **7**.[4] However, **8d** and **9d** may have been formed partly through 2,4-dehydrohomoadamantane (**11**), since rapid addition of TFA was observed to this compound at 25 °C to yield **8d** and **9d** in a ratio of 75:25.