α -Effect in Menschutkin Alkylations

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The Menschutkin-type alkylation of substituted N-methylanilines with methyl arenesulfonates is compared to the same reaction with substituted N-phenylhydroxylamines. The α -effects are small but measurable. The Hammett ρ parameters are not useful in this reaction series as an index of transition-state character. The use of β_{1g}^{Me} parameters along with β_{nuc} values allows the transition states to be placed on the energy surface. The pattern is that the α -nucleophiles form tighter transition states than the normal nucleophiles. The size of the α -effect is related to the ionization potentials (IPs) computed by the AM1 Hamiltonian for a wide variety of reactions showing the α -effect. The larger α -effects depend more greatly on the IP.

Introduction

The α -effect at methyl groups has recently been shown to have small but measurable values with phenylsulfonate and phenylsulfate leaving groups.^{1,2} (A typical α -nucleophile has a pair of electrons on the atom neighboring the reacting site, such as in hydrazine, 1.) The principal

:NH₂-NH₂: 1a typical α -nucleophile

features of these reactions include the following: 1. The slope (β_{nuc}) of a plot of p K_{H^+} vs log k_{nuc} (Brönsted plot) was larger for the α -nucleophiles than for normal nucleophiles. The bond order between the C atom and the nucleophiles at the transition state was thus putatively larger than for a normal nucleophile without the neighboring pair of electrons.

2. The α -effect, as measured by the ratio of rate constants, $k_{\alpha}/k_{\text{normal}}$, was small, of the magnitude of 2–10.

3. The α -effect depended on the nucleofugacity of the leaving group, for HOO- and hydrazine displacing 4-nitrophenylsulfate anions.

4. The $\beta_{1g}^{CH_3}$ (1g = leaving group) of arenesulfonate anions with N-methylbenzohydroxamate anions was 0.45, typical of a normal $S_N 2$ reaction. β_{1g} for the substituted phenoxides was 0.43, also typical of an ordinary $S_N 2$ reaction.³

5. The Hammett ρ_{1g} constants for the reactivity of the α -nucleophiles were lower than for the normal nucleophiles.

These features were interpreted to indicate that α -nucleophiles reacting to displace these kinds of leaving groups from methyl carbons involved tighter transition states than normal nucleophiles did. In two of these reactivity studies charge was dispersed in the transition states (TS). In the case of hydrazine a Menschutkin type of alkylation, creating charge separation, was observed.

The Menschutkin-type alkylations of amines, shown in reaction 1, are reported to involve variable transition states.⁴

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$$G_{1}C_{6}H_{4}NR_{1}R_{2} + CH_{3}OSO_{2}C_{6}H_{4}G_{2} \xrightarrow{\text{methanol-}d_{4}} 2$$

$$(a)R_{1} = Me; R_{2} = H$$

$$(b)R_{1} = OH; R_{2} = H$$

$$G_{1}C_{6}H_{4}NR_{1}R_{2}^{+}CH_{3} + G_{2}C_{6}H_{4}SO_{3}^{-} (1)$$

$$4 \qquad 5$$

Analysis of the reaction mixture from (1b) (with $G_1 =$ H; $G_2 = 4$ -Br) showed that recovery of the mass was quantitative. Analysis by ¹H NMR and GCMS showed that >95% of the products were formed by methylation, following reaction 2 to give substituted methoxy N-me-



thylanilines. Such rearrangements are known from the reactions of N-phenylhydroxylamines with acids in benzene.25

Reaction 1 is thus appropriate because it allows comparison of the effects of a CH₃ group with the effects of a sterically similar OH group that gives rise to an α -nucleophile. Any effect is thus due to the difference the OH makes in the reactivity and by implication any α -effect. The rearrangements in (2) occur after methylation is completed.

Results

The synthesis and characterization of the N-phenylhydroxylamines has previously been reported for all the compounds in this study.⁵ The 4-nitro-N-phenylhydroxylamine was made from an ascorbic acid reduction of 1,4dinitrobenzene.⁶

[†] This author previously published under the name Debbie C. Buss.
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Figure 1. Hammett plot for the reaction of G₁-N-methylanilines with methyl 3-nitrobenzenesulfonate in methanol-d₄ at 29.5 °C.



Figure 2. Hammett plot for the reaction of G_1 -N-phenylhydroxylamines with methyl 3-nitrobenzenesulfonate at 29.5 °C in methanol d_4 .

Synthesis of N-methylanilines and their characterizations followed standard procedures when the desired compounds were not commercially available. Typically, the synthesis of N-methylanilines from the lithium aluminum hydride reduction of their formanilides was achieved, or by alkylation of the formanilide in the case of 4-nitro-N-methylaniline and 3-nitro-N-methylaniline, followed by acid-catalyzed hydrolysis.^{7,8}

The pK_{H^+} values of the N-methylanilines in water⁹ and methanol are reported in Table VI. The pK_{H^+} values of the N-phenylhydroxylamines in both water and methanol are given in Table VII.

The kinetics of reactions 1 were followed by measuring the rate of disappearance of the CH_3O ¹H NMR signals of the methylarenesulfonates under pseudo-first-order conditions, as previously reported¹ (when the solubility of the nucleophiles allowed this; otherwise, the second-order kinetics were followed). All reactions were followed to at

 Table I.
 Alkylations of G₁-N-methylanilines (Reaction 1) at 29.5 °C in Methanol-d₄^a

	at ave O III	meenanor-ut	
G1	G ₂	k (s ⁻¹ M ⁻¹)	-log k
2a			
3-Cl	4-NO2	10.2	3.990
3-Cl	4-Br	2.77	4.556
3-Cl	4-F	1.79	4.745
3-Cl	4-Me	1.08	4.926
3-C1	4-MeO	0.68	5.132
н	3-NO2	55.8	3.253
4-Cl	3-NO ₂	28.2	3.550
4-NO ₂	3-NO2	7.2	4.144
3-NO2	3-NO2	9.3	4.032

 $a - \log k_{nuc} = \sum \sigma 1.08 + 3.3174 \ (n = 5, r = 0.99).$ Average error = $\pm 5\%$.

least 2 half-lives. The data are summarized in Tables I and II and Figures 1 and 2 and give the Hammett plots.

The ρ_{nuc} values vs $G_2 = 3$ -nitro were as follows: for 2a $\rho = -1.13$ (n = 4; R = 0.999); for 2b $\rho = -1.09$ (n = 6; R = 0.995). The parameters were thus nearly the same values for both reactions.

The rate constants were related to pK_{H^+} values in Figure 3. Such plots are necessary to establish the size of the α -effect.²⁸ Figures 4 and 5 relate the rate constants to pK^{Me}_{1g} . These Brönsted plots gave β_{nuc} and β_{1g}^{Me} values summarized in Table III. A statistical evaluation of these slopes showed no statistical difference²⁶ (confidence

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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-d₄ at 29.5 °C.

Table II.	Alkylations	of G ₁ -N-Phenylhydroxylamin	165
(1	leaction 1) at	29.5 °C in Methanol-d.*	

(40			6
Gı	G ₂	$k (s^{-1} M^{-1}) * 10^3$	-log k
2(b)			
4-CH ₈ O	3-NO2	2.06	2.686
н	3-NO2	1.13	2.947
4-CF ₃	3-NO2	0.275	3.561
4-Br	3-NO2	0.759	3.120
4-NO2	3-NO2	0.146	3.836
4-Me	3-NO2	1.56	2.807
н	4-NO2	0.771	2.812
н	4-Br	0.239	3.622
н	4-MeO	0.0541	4.267
н	4-Me	0.0695	4.158
н	4-Me	0.0695	4.15

Table III	A Values for Peastic	n 1

system	β_{nuc}	β _{lg} Me
2a	0.15ª	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 G₂ = 3-NO₂

			_	
$G-\alpha$ -nucleophile	pK _{H⁺}	G-nucleophile	pK _{H⁺}	a-effect
н	5.05	3-Cl	3.75	11.3
4-Br	4.31	3-C1	3.75	7.44
Н	5.05	Н	5.79	2.06
4-Me	6.59	4-Me	6.43	2.12

^a Average error = $\pm 6.3\%$.

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. 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 $k_{\alpha-nuc}$



Figure 5. Plot of pK_{1g}^{Me} vs reactivity of N-phenylhydroxylamine in methanol- d_4 at 29.5 °C.

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

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

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. ($\rho_{a-effect}$ 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 G₁ and G₂. Note that the better leaving group, G₂ = 4-NO₂, does not give an increased α -effect in the case where the nucleophile is held constant (G₁ = 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_{1g} values are reported^{2,11} for the phenylsulfates with normal nucleophiles than for the α -nucleophiles HOOand 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_{1g}^{Me} for reaction 1a (0.52) is higher than these values for methyl transfers from arenesulfonates to anilines in methanol (0.36–0.40) re-

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TADIC V. C-LINCLE VE LICCTION WITHURAWA	Table V	V.	α -Effects	VS	Electron	Withdrawa
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G on 2b	G ₃ on 3	computed α -effect
Н	3-NO2	2.35
4-MeO	3-NO2	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
Hª	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

	•	
2	8	
	pK _{H+} ª	
н	5.79	
4-Me	6.43	
3-C1	3.75	
3-NO2	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
4-OH	4.17	
4-OCH ₃	4.00	6.88
4-Me	3.63	6.59
Н	3.32	5.05
4-Cl	2.58	
4-NO ₂	0.65	0.96
4-CF3		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).

ported 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-

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Table VIII. Comparison of Reactivity Parameters for Methyl Transfers to Several Negatively Charged and Neutral a-Nucleophiles in Methanol or Methanol-d4 29.5 °C

nucleophile	leaving group	$\rho_{ m nuc}$	$\rho_{lg}{}^a$	$\beta_{ m nuc}$	$m{eta}_{lg}^{Me}$	α -effect	ref
H00-	phenylsulfate		0.61	0.16		5.7-11	2
HO-	phenylsulfate		0.92	0.07			2
NH ₂ NH ₂	phenylsulfate		0.70	0.20		3.00-5.2	2
ethylglycine	phenylsulfate		1.00	0.12			2
GPhCON(Me)O-	arenesulfonate	~0.92°	1.29	0.84	0.44	2.5 - 3.5	1
GPhO-		-3.32d	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%	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 report²⁹ 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 groups³² allows calibration of β values for other reactions of benzenesulfonates by dividing ρ_{nuc} (ρ_{1g}) by 2.94, that is, ρ_{eq} for the transference between arenesulfonates. (Presumably the solvent effects on ρ are cancelled out by determining both ρ s in the same solvent.) Our ρ values give $\beta^{\text{calc}}_{\text{nuc}} = 0.38$ 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_{1g}^{Me} values used to obtain β_{1g}^{Me} values are calibrated directly from the Lewis equilibration experiment³² 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 $1.00 - \beta_{1g}^{Me}$). The bond order sum is not the same for the two species, 0.67, for the normal nucleophile species, G-C₆H₄NHMe, but 0.72 for the G-C₆H₄NHOH 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 Bruice¹⁵ 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 cations¹⁹ and the transfer of methyl groups to G-PhCO(NMe)O^{-,1} We have also shown that the AM1 IPs correlate guite 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_{α -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 = $0.93 (\log k)/\text{IP}$ (eV), Figure 8) and the N-methylbenzohydroxamic anions (slope = $-1.55 (\log k)/\text{IP} (eV)$)¹ show the substrate series giving the larger α -effects at CH₃ 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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log knuc

4.50

4.24

3.98

3.72

3.46

3.20 -8.30

8.48



IP (ev)

8.84

9.02

9.20

Figure 6. AM1 ionization potentials vs log k_{nuc} for reactions of G₁-N-phenylhydroxylamines in methanol- d_4 at 29.5 °C with methyl 3-nitrobenzenesulfonate.

8.66



Figure 7. AM1 ionization potentials vs log k_{nuc} for reactions of G₁-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 <i>p</i> -nitrophenyl acetate	water	0.38	77	-0.33	20
3. NMBH	water-dioxane	0.86	4.81	-1.55	1
4. NMBH vs benzvl bromide	water	0.31	13	na	22
5. NMBH	water	0.23	45		23
6. N-phenylhydroxylamines	methanol- d_4	0.19	2.354	-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 groundstate 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 **GN-MeAniline** Δ **G-PhenylNHOH**



Figure 8. Hammett plots for G-N-methylanilines and G-N-phenylhydroxylamines reacting with methyl 3-nitrobenzenesulfonate in methanol-d₄ at 29.5 °C.



at CH₃ 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 reactivityselectivity principle is followed with methylarenesulfonates. (Reactivity increases in the order GPhNHOH > GPh-NHMe but ρ_{nuc} is the same value.) The ρ_{1g} 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 CH₃ 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-NO₂ 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 $\nu_{\rm NH}$ and $\nu_{\rm OH}$ (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 etherpetroleum 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 OCH₃ 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 method²⁷ 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-NO₂ and 4-CF₃ 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_4 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 method¹ 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 (pseudofirst-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 halflives. 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.

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