Registry No.—I, 24705-21-3; malachite green, 14426-28-9; trifluoroethanol, 75-89-8; propargyl alcohol, 107-19-7; choline, 62-49-7; tri-*p*-anisylmethyl cation, 14039-13-5.

References and Notes

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Influence of the *o*-Nitro Group on Base Catalysis in Nucleophilic Aromatic Substitution. Reactions in Benzene Solution[1]

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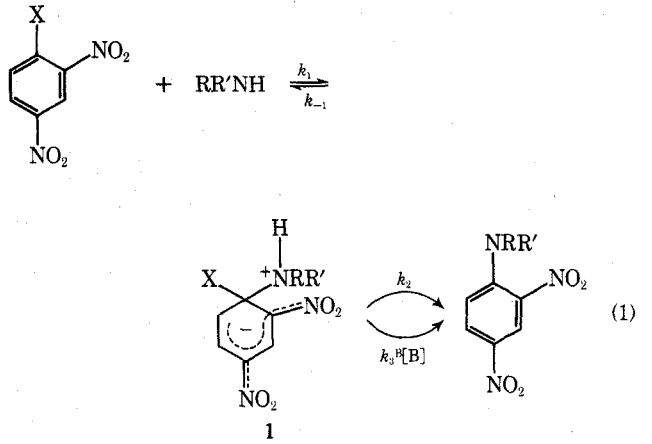
There exist two explanations why nucleophilic aromatic substitutions by secondary amines are frequently more prone to base catalysis than analogous reactions with a primary amine of comparable pK_a. Both are based on the intermediate complex mechanism of eq 1. The first invokes a steric acceleration of the k_{-1} step in the case of secondary amines which reduces k_2/k_{-1} (and k_3^B/k_{-1}) compared to primary amines. The second explanation, initially based on the observation that practically all known examples involved *o*-nitro substituted substrates, invokes intramolecular hydrogen bonding to the *o*-nitro group. Its effect is to lower k_{-1} about equally for primary and secondary amines, but to lower k_2 more for secondary than for primary amines, thus making k_2/k_{-1} larger for primary amines than for secondary amines. Kinetic data on reactions of *n*-butylamine and of piperidine with 1-fluoro-2,4-dinitrobenzene, 1-fluoro-4-nitronaphthalene, and 1-fluoro-4,5-dinitronaphthalene in benzene are presented which support the hydrogen bonding theory. The data are also shown to be most consistent with the SB–GA mechanism of base catalysis in this solvent.

It is well known that some nucleophilic aromatic substitution reactions involving amines as nucleophiles are subject to base catalysis whereas others are insensitive to the addition of base.[3] This has been rationalized in terms of the intermediate complex mechanism where the intermediate may be transformed into products either directly (k_2) or by a base-catalyzed route (k_3^B); eq 1 is representative for the most frequently studied type of substrates, viz., 1-substituted 2,4-dinitrobenzene derivatives. When the product-forming steps are much faster than the reversion of the intermediate to reactants ($k_2 + k_3^B[B] \gg k_{-1}$), intermediate formation (k_1) is rate determining and no base catalysis can be observed. When the rate of the product-forming steps is slower or at least does not greatly exceed the rate of reversion ($k_2 + k_3^B[B] \lesssim k_{-1}$), the net reaction is susceptible to base catalysis.



(1)

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The same conclusions follow from eq 2 which is derived for system 1 on the basis of the steady state assumption.

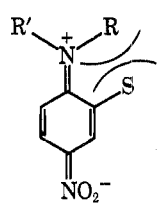
$$\frac{\text{rate}}{[\text{ArX}][\text{RR'NH}]} = k_A = \frac{k_1k_2 + k_1k_3^B[B]}{k_{-1} + k_2 + k_3^B[B]} \quad (2)$$

Whether in a given reaction $k_2 + k_3^B[B] \gg k_{-1}$, or $k_2 + k_3^B[B] \lesssim k_{-1}$, depends on a variety of factors which have been discussed recently.[3a] From the manner in which k_A depends on base concentration one may be able either to evaluate the ratios k_2/k_{-1}, k_3^B/k_{-1} and k_3^B/k_2, or at least to set low or high limits on these ratios.[3a]

The phenomenon of present concern is the frequent observation that the ratios k_2/k_{-1} and k_3^B/k_{-1} are considerably higher for primary amines than for secondary amines of comparable basicity in otherwise identical reactions. Experimentally this manifests itself in two ways. First a number of reactions with secondary amines are base catalyzed ($k_2/k_{-1} < 1$)[3a] whereas the same reaction with a primary amine is not ($k_2/k_{-1} \gg 1$).[3a] Second, reactions involving primary amines sometimes show a curvilinear dependence on base concentration ($k_3^B[B]/k_{-1} < 1$ at low [B], $k_3^B[B]/k_{-1} > 1$ at high [B])[3a] whereas the response is linear when the reaction is with a secondary amine ($k_3^B[B]/k_{-1} \ll 1$ over the entire range of [B]).[3a]

In principle, the smaller k_2/k_{-1} and k_3^B/k_{-1} ratios for secondary amines could be the consequence of smaller k_2 and k_3^B, or of larger k_{-1}, or a combination of both. An attractive explanation, offered by Bunnett and Garst,[4] invokes a steric compression (between amine and aromatic ring plus ortho substituents) in the intermediate in the case of secondary amines. Release of the steric strain enhances k_{-1} and thereby reduces k_2/k_{-1} and k_3^B/k_{-1} for secondary amines.

Another possible steric factor which has the effect of reducing k_2 and k_3^B is the hindrance, by an ortho substituent, of the developing resonance in the product (2). Which



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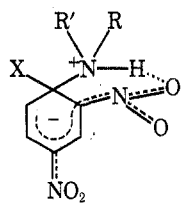

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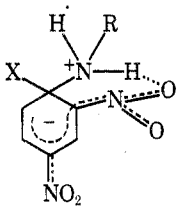

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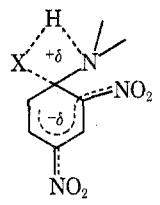
of these steric effects are potentially more important greatly depends on how close the respective transition states are to the intermediate, a question which is difficult to answer. Since both types of steric effects lead to a lowering in k_2/k_{-1} and k_3^B/k_{-1}, we shall not distinguish between them in the following discussions but simply refer to them as "the steric effect".[5]

It appears to us that the steric effect almost certainly plays a role in discriminating between primary and secondary amines, but it may not be the only factor. In a recent review[3a] we pointed out that practically all rate data which permit a comparison of k_2/k_{-1} and k_3^B/k_{-1} ratios for primary and secondary amines involve substrates with an *o-nitro group*. This fact and a number of other observations[3a] led us to suggest that intramolecular hydrogen bonding in the zwitterionic form of the intermediate, as shown in 3 and 4, might be an additional significant factor in this discrimination, particularly in nonpolar solvents.

The argument, briefly restated, runs as follows. Intramolecular hydrogen bonding stabilizes the intermediate with the following consequences. (1) There is a decrease in k_{-1} because breaking the C–N bond requires also breaking of the hydrogen bond, and therefore some extra activation energy. This effect is presumably about equal for primary or secondary amines of equal basicity.

(2) The mechanism of the k_2 step involves a transfer of an ammonio proton to the leaving group in concert with leaving group departure (transition state 5).[3a] In the case of



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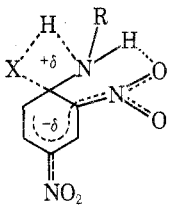

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secondary amines there is only one such proton available and it is tied up in the hydrogen bond to the o-nitro group in the intermediate (3). To make it available for catalysis in 5 the hydrogen bond has first to be broken which adds to the activation energy of the k_2 step and thus reduces k_2 in a similar way as it reduces k_{-1}. In the case of *primary* amines there is a nonhydrogen bonded proton available (4) and thus, in a first approximation no hydrogen bond needs to be broken in going to 5, and k_2 remains unaffected. This is of course not exactly true since transferring the *available* proton to the incipient anion X^- reduces the acidity of the *bonded* hydrogen in 4 and thus reduces the stabilization through hydrogen bonding. However this is in turn partially compensated by an increase in acidity due to transformation from an aliphatic to an aromatic amine. To put it another way, the transition state of the k_2 step for primary amines (6) would benefit somewhat from intramolecular hydrogen bonding but not as much as the intermediate 4. However, since there is absolutely no such stabilization in the transition state of the k_2 step for *secondary* amines, the net effect of introducing an o-nitro group is to make k_2/k_{-1} larger for primary than for secondary amines.

(3) The effect on k_3^B and thus on k_3^B/k_{-1} is more difficult to predict because the details of the mechanism of the k_3^B step in nonpolar solvents are not settled.[3a,6] Though it is obvious that the acidic proton in the zwitterion is removed during the reaction this could happen in different ways, such as (a) rate-limiting proton transfer to the base followed by rapid leaving group expulsion, (b) rapid equilibrium deprotonation followed by slow leaving group expulsion, catalyzed by the conjugate acid of the catalyst (SB–GA mechanism[3a]), (c) concerted proton transfer and leaving group expulsion, perhaps with a cyclic transition state where the amine acts as a bifunctional catalyst. In mechanisms a and c deprotonation of the intermediate is the, or part of the, rate-limiting process. Hence k_3^B should be similarly affected by an o-nitro group as k_2. For the SB–GA mechanism the situation is different; here the proton is removed in a rapid equilibrium step which for both types of amines involves a conversion of a zwitterion, stabilized by an intramolecular hydrogen bond, into a nonstabilized anionic intermediate (this implies that intramolecular hydrogen bonding to the ortho group is minimal in the anionic form of the intermediate in the case of a primary amine). Hence the o-nitro group should not have a discriminating influence on k_3^B (and with it on k_3^B/k_{-1}) between primary and secondary amines if the SB–GA mechanism prevails.[7]

It should be pointed out that the idea of intramolecular bonding to the o-nitro group is not new. For example, Bunnett and Morath[8] explained the stronger activation of an o-nitro group compared to a p-nitro group in reactions with amines by a stabilizing effect on the transition state of the k_1 step; they called the effect "built-in solvation" which

Table I
Reactions of 1-Fluoro-2,4-dinitrobenzene with Piperidine in Benzene at 25°[a]

10^3 [piperidine], M	k_ψ, sec^{-1}	k_A,[b] M^{-1} sec^{-1}
0.306	0.00026	0.85
1.02	0.00152	1.49
2.04	0.00388	1.90
3.06	0.00770	2.52
5.10	0.0175	3.44
10.2	0.067	6.57
20.4	0.259	12.7
50.0	1.13	22.6
100	3.60	36.0
200	10.26	51.3
300	18.6	62.1
400	27.7	69.2
500	38.1	76.1

[a] $[Substrate]_0 = 1.5–4.0 \times 10^{-5}$ M; runs at $[pip] \leq 3.06 \times 10^{-3}$ M measured on conventional spectrophotometer, runs at $[pip] \geq 5.10 \times 10^{-3}$ M measured by the stopped-flow technique. [b] $k_A = k_\psi/[amine]$ where k_ψ is the pseudo-first-order rate coefficient.

was visualized as either electrostatic or as a hydrogen bonding interaction. Bernasconi et al.[9] found that the rate of deprotonation by OH^- of certain zwitterionic σ complexes is slower than expected for a diffusion controlled process, indicating intramolecular hydrogen bonding.

More relevant to the present paper are recent suggestions by Pietra et al.,[10] by Kavalek et al.,[11] and by Chapman et al.[12] Pietra et al.[10] point out that plots of k_A vs. amine concentration have finite intercepts (k_1k_2/k_{-1}) in reactions of primary and secondary amines with 1-fluoro-2,4-dinitrobenzene, but zero intercepts in the reactions of n-butylamine with 1-fluoro-4,7-dinitronaphthalene and of imidazole with 1-fluoro-2,4-dinitrobenzene (attack by the tertiary nitrogen atom of imidazole is assumed). Since the reactions for which there is a possibility of intramolecular hydrogen bonding are also the ones which lead to a finite intercept, while those where hydrogen bonding is impossible were the ones with a zero intercept, Pietra et al.[10] believe that hydrogen bonding *enhances* k_2, thus making k_1k_2/k_{-1} more comparable to $k_1k_3^B/k_{-1}$ and thus more easily detectable.

Kavalek et al.[11a] also suggest that intramolecular hydrogen bonding may be particularly effective in stabilizing the transition state of the k_2 step, thereby increasing the contribution of the noncatalyzed pathway in the reactions of piperidine with 4-substituted 2-nitrofluorobenzenes. Chapman et al.[12] believe that the relatively small k_3^B/k_2 ratios in reactions with o-nitro-substituted substrates can be explained by a reduction in k_3^B and an increase in k_2 due to hydrogen bonding.

We note that all these suggestions are contrary to our own theory; they call for an *increase* in k_2 while ours calls for a *decrease* in k_2 due to hydrogen bonding.

In an earlier paper, Kavalek et al.[11a] attempted to explain why the reaction of 1-fluoro-2,4-dinitrobenzene with N-methylaniline is not catalyzed by N-methylaniline, despite evidence which suggests that $k_2/k_{-1} \ll 1$, whereas the reaction of the same substrate with aniline *is* catalyzed by aniline. Their rationalization was that in **3** there is only one acidic hydrogen which is not easily available to the base catalyst due to the hydrogen bond, thus making $k_3^B[B] \ll k_2$, while in **4** the base can attack the easily available nonbonded proton, thus making $k_3^B[B] > k_2$. This interpretation, which includes some ingredients of our own theory, fails to take into consideration that k_2 should also be re-

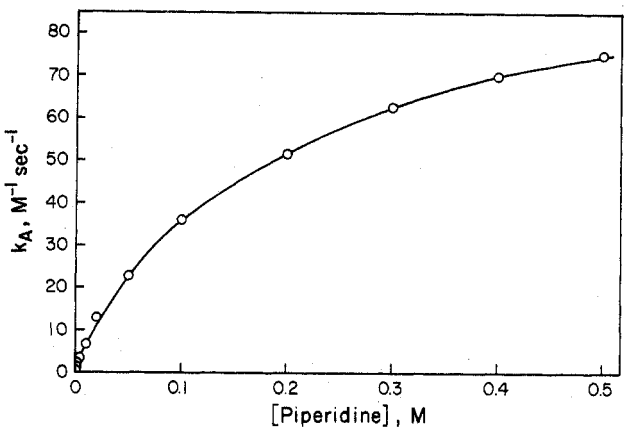


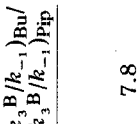
Figure 1. Dependence of k_A on amine concentration in reaction of piperidine with 1-fluoro-2,4-dinitrobenzene.

Table II
Reactions of Fluoronitronaphthalenes with n-Butylamine and Piperidine in Benzene at 25°[a]

[Amine], M	10^7 k_ψ,[b] sec^{-1}	10^6 k_A,[b] M^{-1} sec^{-1}
A. Reaction of 1-Fluoro-4-nitronaphthalene with n-Butylamine		
0.024	0.0838	0.35
0.049	0.361	0.74
0.099	1.50	1.52
0.158	3.96	2.50
0.198	6.44	3.25
0.238	9.52	4.00
0.317	17.4	5.50
0.396	29.9	7.54
B. Reaction of 1-Fluoro-4-nitronaphthalene with Piperidine		
0.01	0.281	2.81
0.02	1.06	5.30
0.03	2.46	8.20
0.04	4.38	10.9
0.05	6.77	13.5
0.06	10.1	16.8
0.10	25.8	25.8
C. Reaction of 1-Fluoro-4,5-dinitronaphthalene with n-Butylamine		
0.01004	0.237	2.36
0.0151	0.460	3.05
0.020	0.875	4.38
0.040	3.34	8.35
0.079	14.6	18.4
0.099	22.6	22.8
0.129	37.7	29.2
0.158	56.9	36.0
0.198	103	52.0
0.238	144	60.7
D. Reaction of 1-Fluoro-4,5-dinitronaphthalene with Piperidine		
0.00196	0.57	29.0
0.00304	1.10	36.1
0.00402	1.76	43.7
0.0059	2.91	49.3
0.00812	5.20	64.1
0.010	7.77	76.9
0.020	26.3	132
0.030	58.3	194
0.040	111	276
0.050	151	303
0.060	224	374
0.080	395	494
0.100	627	627

[a] $[Substrate]_0 = 1.3–5 \times 10^{-4}$ M. [b] $k_A = k_\psi/[amine]$.

Table III
Dissection of Rate Coefficients

Substrate	Amine	k_1k_2/k_{-1}, M^{-1} sec^{-1}	$k_1k_3^B/k_{-1}$, M^{-2} sec^{-1}	k_1, M^{-1} sec^{-1}	k_2/k_{-1}	k_3^B/k_{-1}, M^{-1}	k_3^B/k_2, M^{-1}	$(k_2/k_{-1})_{Bu}/(k_2/k_{-1})_{Pip}$	$(k_3^B/k_{-1})_{Bu}/(k_3^B/k_{-1})_{Pip}$
	n-BuNH$_2$[a]	0.17[a]	35.5[a]	0.71[a,b]	0.24[a,b]	50[a,b]	210[a]	32	7.8
	Piperidine	0.72[c]	609[c]	95	0.0075	6.4	850		
	*n*-BuNH$_2$	$\leqslant 3 \times 10^{-7}$	2.28×10^{-4}		$\ll 0.005$	$\ll 4$	$\geqslant 760$	$\leqslant 2.1$[c]	5.33
	Piperidine	1.9×10^{-5}	6.16×10^{-3}		$\ll 0.02$	$\ll 10$	325		
	*n*-BuNH$_2$	$\leqslant 5 \times 10^{-8}$	1.62×10^{-5}		$\ll 0.015$	$\ll 5$	< 324		
	Piperidine	$\leqslant 2 \times 10^{-7}$	2.74×10^{-4}		$\ll 0.007$	$\ll 10$	< 1360		

[a] Reference 15. [b] Calculated from rate data of ref 15 by Bernasconi.[3a] [c] $k_1k_2/k_{-1} = 0.5$ and $k_1k_3^B/k_1 = 615$ in ref 14.

duced by hydrogen bonding. *In fact our theory predicts that k_2 should be affected by hydrogen bonding about as much as k_3^B if mechanisms a or c for base catalysis prevail, but be reduced more than k_3^B if the SB–GA mechanism prevails.*

We now report data on reactions of some fluoronitroaromatics with piperidine and with *n*-butylamine, in benzene solution. They lend support to our hydrogen bonding theory and to the SB–GA mechanism for base catalysis. We shall also show that the above phenomena[10-12] are easily fitted into the present framework.

Results and Discussion

The reactions of 1-fluoro-2,4-dinitrobenzene both with piperidine[13,14] and with *n*-butylamine[15] have long been known to be base catalyzed by the respective amine nucleophile. Dependence on amine concentration was found to be linear in the case of piperidine[13,14] ($k_2 + k_3^B[B] \ll k_{-1}$ and thus $k_A = k_1k_2/k_{-1} + k_1k_3^B[B]/k_{-1}$) whereas it is curvilinear in the case of *n*-butylamine[15] ($k_2/k_{-1} = 0.24$,[3a] $k_3^B/k_{-1} = 50$[3a]). These two reactions thus epitomize the general findings discussed in the introduction.

Owing to the high rate, the piperidine reaction had only been investigated at piperidine concentrations $\leq 1.43 \times 10^{-2}$ M.[13] It was conceivable that curvature in the plot of k_A vs. piperidine concentration would be obtained at higher concentrations, thus enabling one to calculate the values for k_2/k_{-1} and k_3^B/k_{-1}. Employing the stopped-flow method we have now measured k_A at piperidine concentrations up to 0.5 M. The results are summarized in Table I. A plot of k_A vs. concentration is in fact curvilinear as shown in Figure 1; using standard procedures[4,16] we calculate $k_1 = 95$ M^{-1} sec^{-1}, $k_2/k_{-1} = 0.0075$, $k_3^B/k_{-1} = 6.4$ M^{-1}. Comparing these values with those of the *n*-butylamine reaction (Table III) we note that k_2/k_{-1} is 32-fold larger for *n*-butylamine whereas k_3^B/k_{-1} (B = *n*-butylamine) is 7.8-fold larger than k_3^B/k_{-1} (B = piperidine).

In order to check whether the ratios $(k_2/k_{-1})_{Bu}/(k_2/k_{-1})_{pip}$ and $(k_3^B/k_{-1})_{Bu}/(k_3^B/k_{-1})_{pip}$ would change in the absence of an *o*-nitro group, the reactions of the two amines with 1-fluoro-4-nitronaphthalene and with 1-fluoro-4,5-dinitronaphthalene were investigated. In these substrates the steric requirements of the second benzene ring (peri hydrogen) are only slightly smaller than those of an *o*-nitro group and thus the steric effect should be nearly constant for our purposes.

The results are summarized in Table II. All plots of k_A are linear up to at least 0.1 M amine[17] and thus conform to eq 3.

$$k_A = \frac{k_1k_2}{k_{-1}} + \frac{k_1k_3^B[B]}{k_{-1}} \qquad (3)$$

The intercept (k_1k_2/k_{-1}) in the reaction of piperidine with 1-fluoro-4,5-dinitronaphthalene is appreciable and easily determined. In the other reactions it is very small and cannot be distinguished from zero because the rates become too slow at the amine concentrations which would be low enough for measurements close to the intercept. We have nevertheless estimated an upper limit for k_1k_2/k_{-1} by setting the standard deviation of the intercept equal to this upper limit. They are summarized in Table III, along with the slopes ($k_1^Bk_3/k_{-1}$). By taking the ratios of slope/intercept, k_3^B/k_2 or lower limits thereof can also be calculated.

Furthermore, our data allow upper limits for k_2/k_{-1} and k_3^B/k_{-1} to be estimated as follows. Since the plots of k_A vs. amine concentration do not curve down even at the highest amine concentration ($[B]_{max}$), one can infer $k_3^B[B]_{max}/k_{-1} \ll 1$ or $k_3^B/k_{-1} \ll 1/[B]_{max}$. From $k_2/k_{-1} = (k_3^B/k_{-1})/(k_3^B/k_2)$ one then finds the upper limits of k_2/k_{-1}.

Let us now first focus on the change in k_2/k_{-1} when going from 1-fluoro-2,4-dinitrobenzene to the naphthalene derivatives. We note that k_2/k_{-1} is strongly reduced for both amines. Since, compared to 1-fluoro-2,4-dinitrobenzene, the naphthalenes are (1) slightly less hindered, (2) less activated electronically, and (3) lack the *o*-nitro group, the change in k_2/k_{-1} could in principle be due to any one or a combination of these factors.

Steric Effect. If there is a steric effect at all, it would lead to an *increase* in k_2/k_{-1} for the reaction of piperidine with the naphthalene derivatives. The data show that k_2/k_{-1} decreases, indicating that other, much more important factors, overcompensate whatever steric effect there is.

Electronic Effects. One has to distinguish two electronic effects. The first is the well-known "activating effect" of electron-withdrawing substituents in nucleophilic aromatic substitution, which enhances k_1 but reduces k_{-1} and k_2. The second results in a greater acidity of the ammonio proton in the intermediate, thereby making it a better acid catalyst for leaving group departure, i.e. stabilizing the transition state (**5**) of the k_2 step. Since the two effects on k_2 are in opposite directions, and thus tend to make the net effect on k_2 rather small, it is conceivable that the reduced electronic activation in the naphthalene derivatives enhances k_{-1} much more than it does k_2 (Hammett ρ value larger for k_{-1} than for k_2) leading to very small k_2/k_{-1} ratios for both amines.

This, however, would be in contradiction to the recent findings by Kavalek and Štěrba[11a] that k_2/k_{-1} is relatively insensitive to changes in the 4 substituent in reactions of piperidine with 4-substituted 2-nitrofluorobenzenes in benzene solution. Extrapolating their data to our situation, a reduction of k_2/k_{-1} by a factor of 20–50 is the most to be expected (it is probably less) from the smaller electronic activation in the 1-fluoro-4,5-dinitronaphthalene compared to the 1-fluoro-2,4-dinitrobenzene reactions. This contrasts with our *n*-butylamine reactions where k_2/k_{-1} is reduced from 0.24 to $\ll$ 0.005, i.e., probably at least 10^3-fold and possibly more.

Hydrogen Bonding to *o*-Nitro Group. The hydrogen bonding theory, in the case of *n*-butylamine, easily accounts for that part in the reduction of k_2/k_{-1} which cannot be explained by the electronic effects. Thus the first prediction of the hydrogen bonding theory is verified, viz., that the *o*-nitro group significantly reduces k_{-1}. The second prediction, viz., that hydrogen bonding also reduces k_2, but more so for secondary amines, remains to be proven.

Support for this second assertion comes from a somewhat different analysis of the data in Table III. One may estimate the ratio $(k_2/k_{-1})_{Bu}/(k_2/k_{-1})_{pip}$ for 1-fluoro-4,5-dinitronaphthalene by assuming that the relative nucleophilic reactivities of the two amines toward 1-fluoro-4,5-dinitronaphthalene are about the same as toward 1-fluoro-2,4-dinitrobenzene, i.e., $(k_1)_{Bu}/(k_1)_{pip} \approx 0.0075$. This provides $(k_2/k_{-1})_{Bu}/(k_2/k_{-1})_{pip} \leq 2.1$, which is ≥ 15 times lower than with 1-fluoro-2,4-dinitrobenzene. This shows that removal of the *o*-nitro group indeed reduces $(k_2/k_{-1})_{Bu}$ more (large increase in k_{-1} *not* compensated by equivalent increase in k_2) than it reduces $(k_2/k_{-1})_{pip}$ (large increase in k_{-1} partially compensated by comparable increase in k_2), as predicted.

Strictly speaking the above considerations still do not constitute an absolute proof of the hydrogen bonding theory because the steric theory also predicts that $(k_2/k_{-1})_{Bu}$ and $(k_2/k_{-1})_{pip}$ become more similar to each other the less steric hindrance there is. However, it is doubtful whether the small reduction of steric crowding in the naphthalene derivative could account for a ≥ 15-fold change. More compelling evidence on this point comes from a comparison of the k_3^B/k_{-1} ratios.

The steric theory predicts that $(k_3^B/k_{-1})_{Bu}$ and $(k_3^B/k_{-1})_{pip}$ should become more similar to each other in the less crowded compound, by a similar amount as the k_2/k_{-1} ratios. Incidentally, the hydrogen bonding theory, coupled with mechanism a or c for base catalysis, leads to the same prediction. However, if the SB–GA mechanism is assumed to prevail instead, the hydrogen bonding theory predicts that $(k_3^B/k_{-1})_{Bu}$ and $(k_3^B/k_{-1})_{pip}$ should not change *relative* to one another.[18] Our data bear this out: the ratio $(k_3^B/k_{-1})_{Bu}/(k_3^B/k_{-1})_{pip}$ is practically independent of substrate.

Thus the combined data on k_2/k_{-1} and on k_3^B/k_{-1} support the hydrogen bonding theory as well as the SB–GA mechanism for base catalysis.

Interpretation of Phenomena Reported by Other Investigators. The phenomena, mentioned in the introduction, which led other investigators[10–12] to propose hydrogen bonding theories different from ours, can either be fitted into the framework presented here or explained by other well-known effects. For example, the negligible intercept in the k_A vs. amine concentration plot for the reaction of *n*-butylamine with 1-fluoro-4,7-dinitronaphthalene[10b] is similar to our findings with 1-fluoro4-nitronaphthalene and 1-fluoro-4,5-dinitronaphthalene and thus can be explained similarly. Or, the negligible intercept in the reaction of imidazole (attack by tertiary nitrogen atom) with 1-fluoro-2,4-dinitrobenzene probably arises from the fact that no proton whatever (hydrogen bonded or not) is available to assist fluoride ion expulsion in the k_2 step.

Or, the greater increase in k_3^B/k_{-1} compared to k_2/k_{-1} with increasing electronic activation in reactions of piperidine with 4-substituted 2-nitrofluorobenzenes[11a] is consistent with the SB–GA mechanism for the k_3^B step. This is because in the k_3^B step the intermediate is deprotonated in an equilibrium reaction and thus the full acidifying effect of electron-withdrawing 4 substituents on the proton is felt in k_3^B, while in the k_2 step the same proton is only partially transferred in the transition state and thus k_2 is less sensitive to the acidifying effect of an electron-withdrawing substituent. Or, the absence of catalysis by *N*-methylaniline in the reaction of *N*-methylaniline with 1-fluoro-2,4-dinitrobenzene[11b] (which contrasts with the observation of catalysis by aniline of the reaction of aniline with the same substrate) is probably most easily rationalized by a steric hindrance to the access of the catalyst, a well-known phenomenon with bulky bases.[3a]

Experimental Section

Materials. 1-Fluoro-2,4-dinitrobenzene (Aldrich) and 1-fluoro-4-nitronaphthalene (Aldrich) were recrystallized from ethanol, mp 25–26 and 79–80°, respectively. 1-Fluoro-4,5-dinitronaphthalene was prepared from 1-chloro-4,5-dinitronaphthalene[19] by the method of Pietra et al.[20] used for 1-fluoro-4,7-dinitronaphthalene, yield 20%, mp 192–193°.

Anal. Calcd for $C_{10}H_5N_2O_4F$: C, 50.86; H, 2.13; N, 11.86. Found: C, 50.72, H, 2.13; N, 11.76.

N-(4-Nitronaphthyl)piperidine [mp 74–75°, λ_{max} in benzene 395 nm (ϵ 8900)], *N*-(4-nitronaphthyl)-*n*-butylamine [mp 158–159°, λ_{max} in benzene 409 nm (ϵ 15700)], *N*-(4,5-dinitronaphthyl)piperidine [mp 159–160°, λ_{max} in benzene 390 nm (ϵ 7550)], and *N*-(4,5-dinitronaphthyl)-*n*-butylamine [mp 197°, λ_{max} in benzene 420 nm (ϵ 10500)] were prepared by adapting the method of Bunnett and Randall[21] used for *N*-methyl-2,4-dinitroaniline; the elementary analyses were all excellent. Reagent grade benzene was refluxed over Na–K alloy for 24 hr and distilled immediately before use. Piperidine and *n*-butylamine (both Mallinckrodt) were refluxed over sodium for 12 hr and distilled under nitrogen.

Rate Measurements. The general photometric procedure of Bernasconi and Zollinger[14] was used for the slow reactions. All re-

actions were run in the dark. The reactions with the naphthalene compounds gave only good first-order plots and quantitative yields when run under a nitrogen atmosphere. The reaction of 1-fluoro-4-nitronaphthalene with *n*-butylamine was extremely slow at low amine concentrations and the determination of an infinity value or even an evaluation by the Guggenheim method became impractical. In these runs the reaction was only followed during the first few percent and the infinity value calculated under the assumption of a quantitative yield. The stopped-flow experiments for the reaction of 1-fluoro-2,4-dinitrobenzene with piperidine were carried out on a Durrum[22] stopped-flow spectrophotometer.[23]

The evaluation of the curvilinear plot of k_A vs. amine concentration, to provide k_1, k_2/k_{-1}, and k_3^B/k_{-1}, was according to standard procedures[4,16] in the reaction of piperidine with 1-fluoro-2,4-dinitrobenzene.

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Registry No.—1-Fluoro-2,4-dinitrobenzene, 70-34-8; 1-fluoro-4-nitronaphthalene, 341-92-4; 1-fluoro-4,5-dinitronaphthalene, 52385-37-2; *N*-(4-nitronaphthyl)piperidine, 34599-45-6; *N*-(4-nitronaphthyl)-*n*-butylamine, 57091-55-1; *N*-(4,5-dinitronaphthyl)-piperidine, 57091-56-2; *N*-(4,5-dinitronaphthyl)-*n*-butylamine, 57091-57-3; piperidine, 110-89-4; *n*-butylamine, 109-73-9.

References and Notes

(1) Presented, in part, at the 163rd National Meeting of the American Chemical Society, Boston, Mass., April 1972, Abstracts, No. ORGN-55.
(2) (a) Alfred P. Sloan Fellow, 1971–1973; (b) Facultad de Ciencias Quimicas, Universidad Nacional de Córdoba, Córdoba, Argentina; part of this work was carried out at Córdoba.
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Electronegativity, Hybridization, and Properties of the Carbonyl Group. I. Lewis Basicity

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The basicity of a series of lactams, $\underline{C(O)N(CH_3)(CH_2)_n}$, lactones, $\underline{C(O)O(CH_2)_n}$, cyclic ureas, $\underline{CH_3NC(O)N(CH_3)(CH_2)_n}$, and cyclic carbonates, $\underline{OC(O)O(CH_2)_n}$, $n = 2$ to $n = 5$, was studied with respect to the acids phenol and 1,1,1,3,3,3-hexafluoro-2-propanol. The enthalpies of reaction (measured by infrared spectroscopy, $\Delta\nu_{CO}$) increased in every case: four-membered rings < five-membered rings < six-membered rings ≤ seven-membered rings. The results are explained in terms of the charge capacity of the methylene groups (inductive effect), the effect of ring size upon hybridization and electronegativity, and steric inhibition of resonance from ring strain in small rings.

Although the Lewis basicity of the carbonyl group has been widely studied,[2-5] the factors contributing to the base strength have never been adequately clarified. In this paper we report experiments which indicate that previous workers may have overemphasized certain contributions and minimized other, equally important ones.

It has long been known that the carbonyl group in amides is more basic than that in ketones[2f,6] when measured in nonpolar solvents. Furthermore, the basicity of esters is only slightly less than that of ketones[2f] despite the inductive effect of the electronegative amido and alkoxy groups in the carboxylic acid derivatives. More recently, a limited number of gas-phase proton affinities have been determined. The proton affinity of acetamide is about 37 kcal/mol more exothermic than that of acetone and esters are at least as basic as acetone.[7]

We have undertaken the study of the basicity of a series of cyclic bases in nonpolar solvents. We here report the basicities of several lactones, cyclic carbonates, lactams, and cyclic ureas toward phenol and 1,1,1,3,3,3-hexafluoro-2-propanol (HFIP) as measured by infrared spectroscopy ($\Delta\nu$ of the OH band[4]). We use the term *basicity* in its broadest sense, the ability of an electron donor to donate electron density to an electron acceptor,[8a] which is conveniently measured operationally by the enthalpy of reaction. Ideally, of course, the gas-phase proton affinities are desirable,[8b] but in view of the interesting effects and some controversy arising from hard–soft interactions[8c,9] or, alternatively, electrostatic–covalent effects,[8d,10] we feel that restricting the definition of basicity to proton affinities is undesirable and will simply require that a neologism be invented to replace the old term.