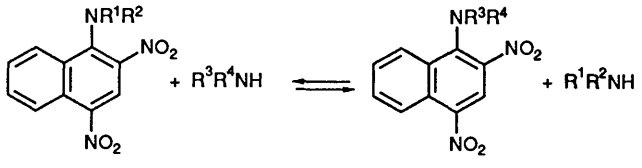
Kinetic Studies of the Reaction of 1-Dialkylamino-2,4-dinitronaphthalenes with Butylamine in Dimethyl Sulfoxide[1]

Shizen Sekiguchi,*† Masaru Hosokawa, Tohru Suzuki and Mitsuo Sato
Department of Applied Chemistry, Gunma University Kiryu, Gunma 376, Japan

The nucleophilic substitution reaction of butylamine with 1-pyrrolidino-2,4-dinitronaphthalene (**1a**) in dimethyl sulfoxide is subject to general base catalysis, whereas the reaction of the same amine with 1-piperidino- (**1b**) or 1-dimethylamino-2,4-dinitronaphthalene (**1c**) is not. General base catalysis is shown to be a consequence of rate-limiting deprotonation of the zwitterionic intermediate complex. The structures of **1a** and **1b** analysed by X-ray crystallography fairly tie in with the great difference in behaviour between **1a** and **1b**.

Although kinetic studies on nucleophilic substitution reactions of activated aromatic substrates with amines (S_NAr) have been the subject of many excellent reviews and reference books,[2-8] those on S_NAr reactions of activated dialkylamino(nucleofuge)-substituted aromatic ones with amines have been scarcely investigated. This can be partly ascribed to the preconception that aminodeamination (transamination) is impossible in S_NAr reactions: Berliner and Monack[9] measured the reaction rate of *N*,*N*-dimethyl-4-bromo-2-nitroaniline with excess piperidine at 25 °C and found it to be very slow, from which dialkylamino groups have been regarded as poor leaving groups.[2,10] In contrast, much kinetic and spectral evidence has been accumulated in nucleophilic addition reactions of activated dialkylamino-substituted aromatic substrates with dialkylamines (called ADD_NAr hereafter), where no substitution occurs.[11-14]

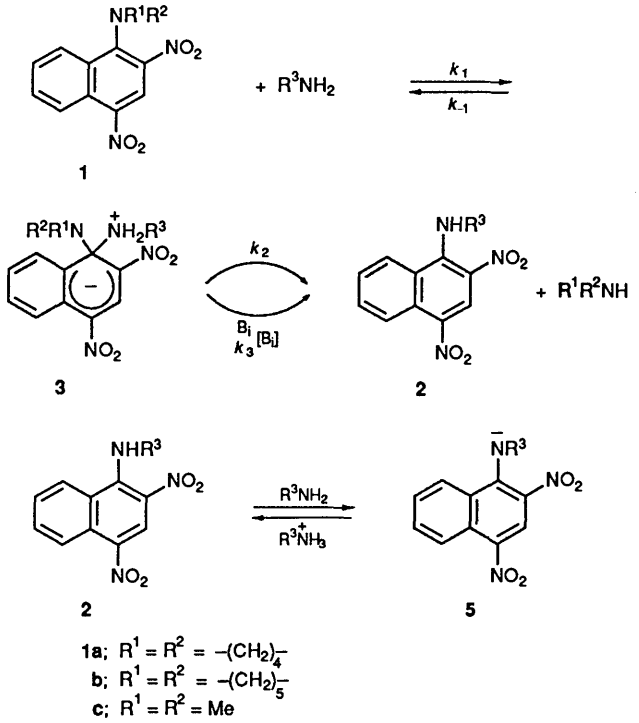


Scheme 1

We have recently found that the dialkylamino groups, such as dimethyl-, diethyl-, *N*-methylbutylamino, piperidino, and pyrrolidino, of 1-substituted 2,4-dinitronaphthalenes (**1**) are very easily replaced by primary amines and pyrrolidine at room temperature in dimethyl sulfoxide (DMSO), as shown in Scheme 1.[15-17] Interestingly nucleophilic secondary amines other than pyrrolidine, *e.g.* dimethyl-, diethyl-, diisopropylamine, and piperidine, showed extremely low reactivity. Such discrepancy in reactivity between pyrrolidine and piperidine has often been observed in S_NAr and ADD_NAr reactions.[6-8,18-20] The combination of the substrate and the amine in the reaction done by Berliner and Monack[9] is found to be inadequate for substitution to occur from our findings. Further, the more bulky 1-alkylamino group of **1**, such as ethylamino, is easily replaced with another less bulky alkylamine, such as methylamine, in a higher yield, whereas the substitution of methylamino group of **1** with ethylamine occurs in a lower yield.[17]

These interesting results prompted us to work on the kinetic studies of the present reactions, since the reaction processes shown in previous work[16,17] are only speculative.

† *Present address:* Tomoegawa Paper Co., Ltd., Technical Research Laboratory, 3-1 Mochimune-tomoe, Shizuoka, Shizuoka 421-01, Japan.



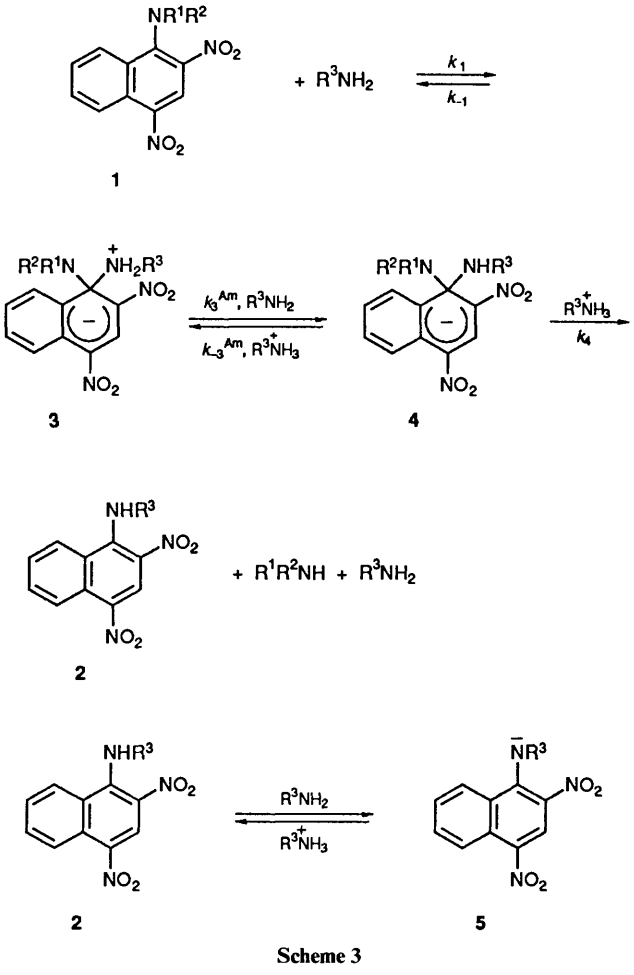
Scheme 2

The generally accepted mechanism of S_NAr reactions involving nucleophilic amines is shown in Scheme 2, where the zwitterionic intermediate (**3**) can proceed to products either spontaneously (k_2) or through base catalysis ($k_3^{B_i}$). In Scheme 2 B_i with a catalytic constant ($k_3^{B_i}$) could be a nucleophilic amine itself or an added base.

If the reaction proceeds to products *via* the $k_3^{B_i}[B_i]$ step (Scheme 3), two mechanistic possibilities exists: (i) rate-limiting proton transfer from **3** to base followed by fast detachment of the R^2R^1N group from the anionic σ intermediate (**4**) ($k_4 \gg k_{-3}^{Am}$) and (ii) rapid proton transfer equilibrium between **3** and **4** followed by rate-limiting R^1R^2N group departure ($k_4 \ll k_{-3}^{Am}$, called SB-GA mechanism).[18-30]

We have found from the kinetic measurements that the reaction for **1a** is catalysed by both butylamine and 1,4-diazabicyclo[2.2.2]octane (DAB), added especially, whereas the reactions for **1b** and **1c** proceed *via* the k_2 step (uncatalysed step).

This paper discusses the origin of occurrence or non-occurrence of base catalysis in the present reactions with the X-ray structural analysis of **1a** and **1b**.



Scheme 3

Results

Time-dependent Absorption Spectra of Reaction Systems.—The time-dependent absorption spectra of **1a** with butylamine were measured in DMSO, where curve (a) is attributed to **1a** (Fig. 1).

Upon addition of excess butylamine to a DMSO solution of **1a**, the mixture gradually turned red [curve (*b*) → (*c*) → (*d*)]. The absorption [curve (*d*)] obtained 20 min after mixing did not change for a long time. The final absorptions obtained for **1b** and **1c** were the same as curve (*d*) in Fig. 1 (not shown). On the other hand, curve (*d*) completely coincided with the absorption obtained just after addition of excess trimethylamine to a DMSO solution of **2** (R^3 = butyl, Scheme 2), where no substitution but deprotonation of the butylamino hydrogen occurred, under the same conditions as for **1a**. From these results curve (*d*) could be attributed to **5** (R^3 = butyl, Schemes 2 and 3).

Kinetic Measurements.—From Scheme 2 the appropriate kinetic expression of eqn. (1) follows, if **3** does not accumulate to an appreciable extent,[6,18,21] where k_A is a second-order rate constant, obtained by dividing a first-order rate constant (k_ψ) by amine concentration.

$$k_A = \frac{k_1k_2 + k_1k_3^{B_i}[B_i]}{k_{-1} + k_2 + k_3^{B_i}[B_i]} \quad (1)$$

As in the present reaction butylamine and 1,4-diazabicyclo-[2.2.2]octane (DAB) are used as a nucleophile and an added base, eqn. (1) can be rewritten as eqn. (2), where Am and B are

$$k_A = \frac{k_1k_2 + k_1k_3^{Am}[Am] + k_1k_3^{B}[B]}{k_{-1} + k_2 + k_3^{Am}[Am] + k_3^{B}[B]} \quad (2)$$

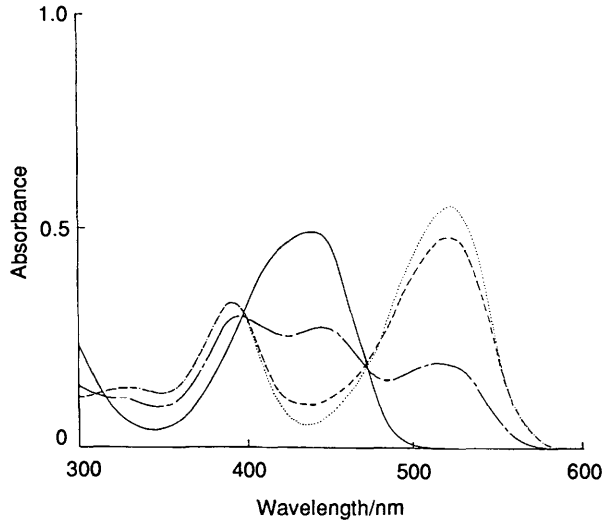


Fig. 1 Spectra relevant to the reaction of **1a** (2.19×10^{-5} mol dm^{-3}) with butylamine (8.92×10^{-3} mol dm^{-3}) at 25 °C in DMSO: curve (*a*) (——), **1a** before addition of amine; curves (*b*) (— — —), (*c*) (– – – –) and (*d*) (· · · ·), just, 10 and 20 min respectively after addition of amine

butylamine and DAB, and k_3^{Am} or k_3^B are the respective catalytic constants. If $k_2 \gg k_{-1}$ or ($k_2 + k_3^{Am}[Am] + k_3^B[B] \gg k_{-1}$) eqn. (1) simplifies to eqn. (3), indicating that k_A is independent of base concentration.

$$k_A = k_1 \quad (3)$$

The results are summarized in Tables 1–3. For **1a** a plot of k_A *vs.* [$BuNH_2$] is curvilinear, tending to reach a limiting value at high [$BuNH_2$] (not shown, Table 1, part A), and then butylammonium chloride scarcely affects the k_A values (Table 1, part B). Further, a plot of $1/k_A$ *vs.* [$BuNH_2$]$^{-1}$ is linear (Fig. 2), which corresponds to eqn. (4) obtained from inversion of eqn. (2) if [B] = 0 and $k_3^{Am}[am] \gg k_2$. The reaction for **1a**, therefore, could be considered to be subject to general base catalysis by butylamine (see Discussion), which is seen in the reaction of 1,3,5-trinitrobenzene with butylamine in DMSO[29] (ADD_NAr). All the S_NAr reactions where base catalysis by butylamine was observed were carried out in aqueous aprotic, *e.g.* dioxane–H_2O or DMSO–H_2O[6,23,30] or aprotic non-polar media, such as benzene.[6] Such reactions in pure DMSO have never been found. From the slope $k_{-1}/k_1k_3^{Am}$ and intercept $1/k_1$ (Fig. 2) k_1 and k_3^{Am}/k_{-1} were estimated to be 3.3 ± 0.1 dm^3 mol^{-1} s^{-1} and 32 ± 1 dm^3 mol^{-1} respectively.

$$\frac{1}{k_A} = \frac{k_{-1}}{k_1k_3^{Am}[Am]} + \frac{1}{k_1} \quad (4)$$

If base catalysis by DAB is observed and the reaction conditions are adjusted so that $k_3^B[B] \gg k_2 + k_3^{Am}[Am]$, eqn. (2) simplifies to eqn. (5), where k_3^D stands for catalytic constant by DAB, and DAB is written for B. From eqn. (5) a curvilinear dependence of k_A on [DAB] should be expected (Fig. 3, Table 1, part C). Inversion of both sides of eqn. (5) gives eqn. (6). From the linear plot of $1/k_A$ *vs.* 1/[DAB], k_1 and k_3^D/k_{-1} can be

$$k_A = \frac{k_1k_3^D[DAB]}{k_{-1} + k_3^D[DAB]} \quad (5)$$

$$\frac{1}{k_A} = \frac{k_{-1}}{k_1k_3^D}\frac{1}{[DAB]} + \frac{1}{k_1} \quad (6)$$

Table 1 Rate data for the reaction of 1-pyrrolidino-2,4-dinitronaphthalene (**1a**) with butylamine in DMSO at 25 °C[a]

$[BuNH_2]/10^{-3}$ mol dm^{-3}	$[DAB]^b/10^{-1}$ mol dm^{-3}	$[BuNH_3Cl]/10^{-3}$ mol dm^{-3}	$k_\psi{}^c/10^{-3}$ s^{-1}	$k_A{}^d/10^{-1}$ dm^3 mol^{-1} s^{-1}	$k_\psi^{calc\,e}/10^{-3}$ s^{-1}
Part A					
1.88		5.00	0.36	1.9	0.36
2.83		5.00	0.80	2.8	0.78
3.71		5.00	1.30	3.5	1.29
4.71		5.00	2.21	4.7	2.03
7.42		5.00	4.98	6.7	4.20
11.1		5.00	10.7	9.6	9.59
14.8		5.00	17.8	12.0	16.0
Part B[f]					
6.63		1.25	3.91	5.90	
6.63		2.50	4.07	6.13	
6.63		3.75	4.15	6.25	
6.63		5.00	4.11	6.19	
6.63		6.25	4.08	6.15	
6.63		7.50	4.05	6.11	
6.63		8.75	4.09	6.16	
Part C					
2.02	0.56		1.70	8.40	1.71
2.02	1.12		2.63	13.0	2.72
2.02	1.68		3.34	16.5	3.39
2.02	2.24		3.75	18.5	3.85
2.02	3.35		4.53	22.4	4.48
2.02	5.03		5.00	24.7	5.02

[a] $[\mathbf{1a}]_0$ 2.01 × 10^{-5} mol dm^{-3}. [b] DAB stands for diazabicyclo[2.2.2]octane. [c] All k_ψ are the averages of duplicate determinations with their accuracies of ± 1.2%. [d] k_A is obtained from k_ψ divided by $[BuNH_2]$. [e] k_ψ^{calc} is calculated from eqn. (4) ([B] = 0) with k_1, 3.3 dm^3 mol^{-1} s^{-1} and k_3^D/k_{-1}, 3.3 dm^3 mol^{-1} s^{-1} and k_3^D/k_{-1}, 6.2 dm^3 mol^{-1} (Part C). [f] Ionic strength 0.01 mol dm^{-3} with tetrapropylammonium iodide.

Table 2 Rate data for the reaction of 1-piperidino-2,4-dinitronaphthalene (**1b**) with butylamine in DMSO at 25 °C[a]

$[BuNH_2]/10^{-3}$ mol dm^{-3}	$[DAB]^b/10^{-1}$ mol dm^{-3}	$[BuNH_3Cl]/10^{-3}$ mol dm^{-3}	$k_\psi{}^c/10^{-4}$ s^{-1}	$k_A{}^d/10^{-2}$ dm^3 mol^{-1} s^{-1}
Part A				
4.71		5.00	1.05	2.22
9.42		5.00	2.17	2.30
14.1		5.00	3.28	2.32
17.4		5.00	4.13	2.37
18.8		5.00	4.44	2.36
23.2		5.00	5.47	2.35
37.7		5.00	8.91	2.36
42.4		5.00	10.1	2.38
52.1		5.00	12.4	2.38
Part B				
6.30	0.56		1.49	2.36
6.30	1.11		1.55	2.46
6.30	1.67		1.44	2.28
6.30	2.22		1.56	2.47
6.30	2.79		1.51	2.39
6.30	3.89		1.46	2.31

[a] $[\mathbf{1b}]_0$ 2.64 × 10^{-5} mol dm^{-3}. [b] DAB stands for diazabicyclo[2.2.2]octane. [c] All k_ψ are the averages of duplicate determinations with their accuracies of ± 1.2%. [d] k_A is obtained from k_ψ divided by $[BuNH_2]$.

calculated in the same way as eqn. (4) (Fig. 4): k_1 is 3.2 ± 0.1 dm^3 mol^{-1} s^{-1} and k_3^D/k_{-1} 6.2 ± 0.2 dm^3 mol^{-1}. Agreement between k_1 values obtained by the two methods is quite good, suggesting the validity of the assumptions that $k_3^{Am}[Am] \gg k_2$ and $k_3^D[DAB] \gg k_3^{Am}[Am] + k_2$.

From the values of k_3^{Am}/k_{-1} and k_3^D/k_{-1} obtained, k_3^{Am}/k_3^D was estimated to be 5.1, which is comparable to the value (2.6) obtained in the DAB-catalysed reaction of 1,3,5-trinitrobenzene with butylamine in DMSO[29] (ADD_NAr), whereas it is markedly large compared with the values (*ca.* 0.01–0.1) ($= k_3^{Am}/k_3^{OH^-}$) obtained in the OH^--catalysed reactions of butylamine with 1-methoxy-4,7-dinitronaphthalene in 60% aqueous dioxane.[23] As a result it follows that k_3^{Am}/k_3^{Bi} greatly depends on base strength and solvent identity.

In the case of **1b** and **1c** the data (Tables 2 and 3) show that the reactions are not accelerated by DAB, and k_A does not change appreciably over the range of amine concentrations. These results are consistent with eqn. (3): the reactions proceed *via* the k_2 step (uncatalysed step) with the k_1 step being rate-determining. All the rate constants and rate ratios are summarized in Table 4.

The results that base catalysis depends on substituent identity at C-1 of the naphthalene moiety in the present reactions considerably attracted our interest from the following fact: in the S_NAr reactions studied so far nucleophilic pyrrolidine has not been used so much as piperidine, partly because of the failure of the former to give rise to base catalysis, for which no reasonable interpretation has been given,[6] whereas when

Table 3 Rate data for the reaction of 1-dimethylamino-2,4-dinitronaphthalene (**1c**) with butylamine in DMSO at 25 °C[a]

$[BuNH_2]$/ 10^{-3} mol dm^{-3}	[DAB][b]/ 10^{-1} mol dm^{-3}	$[BuNH_3Cl]$/ 10^{-3} mol dm^{-3}	k_ψ[c]/10^{-3} s^{-1}	k_A[d]/10^{-1} dm^3 mol^{-1} s^{-1}
Part A				
3.50		6.70	1.98	5.65
7.91		6.70	4.59	5.80
11.9		6.70	6.65	5.58
15.8		6.70	9.36	5.92
19.8		6.70	11.6	5.85
23.5		6.70	13.5	5.74
Part B				
3.60	0.50		2.05	5.72
3.60	1.12		2.07	5.77
3.60	2.58		2.09	5.81
3.60	3.76		2.07	5.76
3.60	4.01		2.08	5.79
3.60	4.32		2.08	5.80

[a] $[\mathbf{1b}]_0$ 2.30×10^{-5} mol dm^{-3}. [b] DAB stands for diazabicyclo[2.2.2]octane. [c] All k_ψ are the averages of duplicate determinations with their accuracies of ± 1.2%. [d] k_A is obtained from k_ψ divided by $[BuNH_2]$.

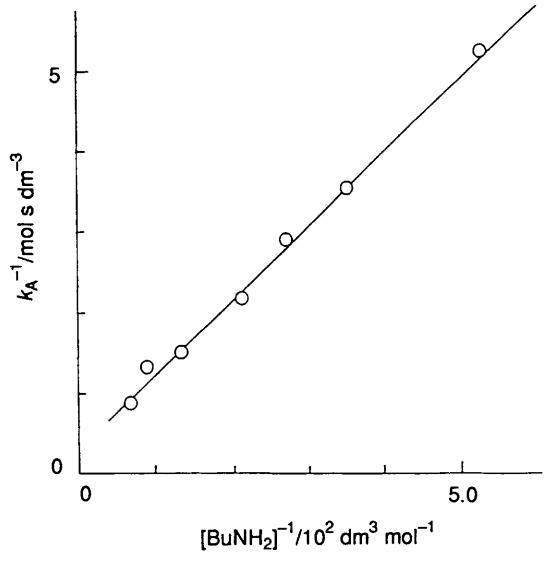


Fig. 2 Plot of $1/k_A$ *vs* $1/[BuNH_2]$ for the reaction of **1a** with butylamine in DMSO

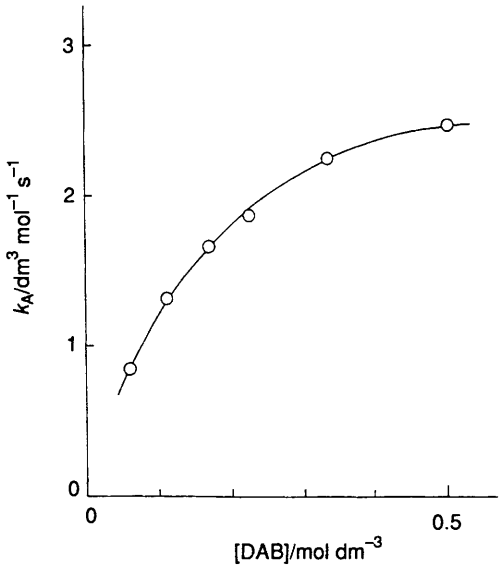


Fig. 3 Relationship between k_A and diazabicyclo[2.2.2]octane (DAB) concentration for the reaction of **1a** with butylamine in the presence of DAB

pyrrolidine is used as a substituent, the present reaction is subject to base catalysis even with butylamine and even in aprotic polar media.

In order to elucidate the difference in behaviour, especially between **1a** and **1b**, we attempted to analyse their structures by X-ray crystallography.

X-Ray Structural Analysis.—The results are summarized in Table 5 and Figs. 5 and 6, indicating great difference between the configurations of **1a** and **1b**. For **1a** C-1 (C6)* is a little deviated from the naphthalene plane [consisting of C5, C1, C2, C4, C9, C13, C10, C7 and C3, Fig. 5(*a*)], where the dihedral angle between the naphthalene plane and the plane consisting of C3, C5 and C6 is 152° [Fig. 5(*b*)]. Accordingly large stabilization by the following resonance interaction (hereafter called coplanarity ability) should be possible for **1a**. The form $\mathbf{1a}^{\pm}$ was previously speculated by Bunnett and co-workers,[19] and we found this resonance to be an important clue to elucidate the reaction mechanism as discussed later. This resonance certainly happens, which is reflected on the wave lengths of maximal absorption (λ_{max}) and molecular extinction coefficients (ε): 438 (21 000), 419 (10 000) and 416 (8000) for **1a**, **1b** and **1c** respectively.[16] Such deformation in benzene rings has been found for paracyclophanes[31] and heptasilaparacyclophane.[32] As a result, the plane of the 2-nitro group is correspondingly deviated upward from the naphthalene plane, keeping a partial resonance interaction with the latter plane: its dihedral angle with the naphthalene plane is 154°. It is worth noting that the C6–N1 bond length is shorter (1.313 Å) compared with the N2–C5 and N3–C2 bond lengths (Table 5), being almost equal to usual C=N bond lengths (1.29–1.31 Å).[33] As usual C–N bond lengths are assumed to be 1.47 Å,[33,34] the resonance ($\mathbf{1a} \longleftrightarrow \mathbf{1a}^{\pm}$) clearly responds to a reduction in the C6–N1 bond length.

On the other hand, **1b** has a conspicuously different configuration, where the average piperidine plane tilts at *ca.* 45° to the naphthalene plane and correspondingly the plane of the 2-nitro group [N30103, Fig. 6(*a*)] does at *ca.* 42° to the naphthalene plane to relieve repulsion against the piperidino group. Both α-methylene groups (C11H2H9 and C13H5H7), therefore, would be expected to interfere with approaching

* Six in C6 represents the number used in X-ray analysis and one in C-1 the number used in usual nomenclature, and so on.

Table 4 Dissection of rate constants of elementary steps

Substrate	k_1 [a]/ $dm^3\ mol^{-1}\ s^{-1}$	(k_3^{Am}/k_{-1}) [b]/ $dm^3\ mol^{-1}$	(k_3^D/k_{-1}) [c]/ $dm^3\ mol^{-1}$	(k_3^D/k_2) [d]/ $dm^3\ mol^{-1}$	(k_3^{Am}/k_2) [e]/ $dm^3\ mol^{-1}$	k_2/k_{-1} [f]	k_3^{Am}/k_3^D [g]
1a	3.3	32	6.2	77	400	0.08	5.1
1b	2.35×10^{-2}						
1c	5.76×10^{-1}						

[a] Derived from eqn. (4). [b] Derived from the slope in the k_A^{-1} *vs* $[Am]^{-1}$ plot of eqn. (4) and k_1. [c] Derived from the slope in the k_A^{-1} *vs* $[DAB]^{-1}$ plot of eqn. (6) and k_1. [d] Derived from k_3^D/k_{-1} and k_2/k_{-1}. [e] Derived from k_3^{Am}/k_{-1} and k_2/k_{-1}. [f] Estimated by averaging the values obtained from eqn. (2) ([B] = 0) by use of two k_A values at 0.011 and 0.0148 mol dm^{-3} butylamine concentrations (Table 1, Part A). [g] Derived from k_3^{Am}/k_{-1} and k_3^D/k_{-1}.

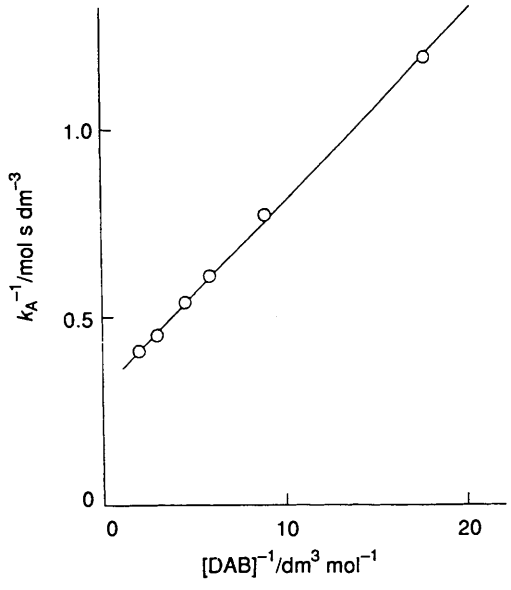
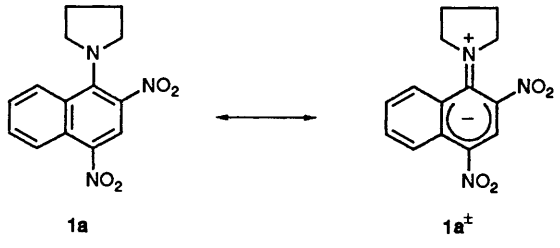


Fig. 4 Plot of $1/k_A$ *vs.* 1/[DAB] for the reaction of **1a** with butylamine in the presence of diazabicyclo[2.2.2]octane (DAB)



nucleophiles. In this configuration too, the incomplete resonance interaction between the naphthalene plane and piperidino group appears to result in reduction in the N2–C8 bond length (1.373 Å). The configuration for **1c** is probably similar to that for **1b**.

Discussion

Base Catalysis.—In the reaction of butylamine with **1a** the increase in k_A occurs not only at low amine concentrations but amounts to a 6.2-fold acceleration between the lowest and highest concentration (Table 1, Part A), and k_A triples between the lowest and highest DAB concentration (Table 1, Part C). Clearly the reaction seems to be catalysed even by 0.01 mol dm^{-3} DAB (Fig. 3). These results definitely indicate general base catalysis, *i.e.* rate-limiting proton transfer.[23,24]

Bernasconi and co-workers[23] conducted detailed kinetic studies on the reactions of butylamine with 1-methoxy-4,7-dinitronaphthalene in 60% aqueous dioxane, with dinitroanisole in the same solvent, and of piperidine with 2-cyano-4-nitrophenyl phenyl ether in 10% aqueous dioxane, which proceed as shown in Scheme 2 (without the process **2** + $R^3NH_2 \rightleftarrows$ **5** + $R^3NH_3^+$) and where NaOH was used as a specifically added base, and showed, based on the increase in k_A with the amine and NaOH concentrations, that these reactions are subject to general base catalysis, *i.e.* rate-limiting proton transfer. Although the increase in k_A at the lowest and highest amine or DAB concentration in the reaction of butylamine with **1a** is similar to their findings,[23] the k_3^{Am}/k_3^D value (5.1) is conspicuously different from their corresponding values (k_3^{Am}/k_3^{OH}) ($\ll 1$), which, as already described in the preceding section, is thought to be a consequence of the identity of solvent (DMSO) and added bulky, weak base (DAB).

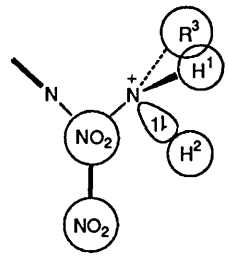
The k_2/k_{-1} *Rate.*—Whether or not base catalysis is observed depends on the identity of amine, nucleofuge, base, and solvent, *i.e.* in all on the k_2/k_{-1} value (< 1 or $\geqslant 1$). Accordingly its cause should be ascribed to the structures of substrates, because the other conditions are identical.

From the configuration of **1a** (Fig. 5) **2** (R^3 = butyl) certainly could assume the similar configuration. In the reaction of butylamine with **1a**, therefore, butylamine could easily approach C-1 of **1a** to keep coplanarity of the H^1–N–C(R^3) plane with the naphthalene plane upon deprotonation of H^2 by the amine, and form **3** with the configuration shown, where deviation of the plane of the 2-nitro group in **1a** would be recovered, resulting in large stabilization of **3**. As a result the free energy of activation for the transition state (TS) in the k_1 step would be remarkably reduced, where the C–N (pyrrolidino nitrogen) bond is shorter and the C–N (methylamino nitrogen) bond is longer. Therefore, the coplanarity ability of pyrrolidino group in the TS would be larger than in **3**. From the viewpoint of the principle of microscopic reversibility these effects in the TS of the k_{-1} step, which is the same as for the k_1 step, would bring about an increase in k_{-1}, rendering k_2/k_{-1} less than one. With **1b** and **1c** butylamine could approach C-1 less easily than with **1a** because of steric interference of the α-CH_2 groups of the piperidino ring or CH_3 groups of dimethylamino one (Fig. 6). These effects could render the free energy of activation for the TS in the k_1 step remarkably high, resulting in a great reduction in k_{-1}, and in turn a k_2/k_{-1} value larger than one (refer to the energy profile in ref. 35).

Mechanism of Base Catalysis.—Based on the kinetic measurements of the reactions described above[23] and other S_NAr and ADD_NAr reactions,[36–38] Bernasconi and co-workers logically concluded that general base catalysis in their reactions is a consequence of rate-limiting deprotonation of the zwitterionic intermediate complex **3**, followed by spontaneous leaving-group expulsion. On the other hand the SB–GA mechanism has been accepted, particularly since Orvik and Bunnett[25] studied the reaction of 1-ethoxy-2,4-dinitronaphthalene with butylamine and *tert*-butylamine in DMSO, corresponding to the reaction with an ethoxy group substituted for the R^2R^1N group

Table 5 Selected bond distances (Å) and bond angles (°) for **1a** and **1b**

1a			
N(1)–C(6)	1.330(3)	C(3)–C(7)	1.405(4)
N(1)–C(8)	1.476(4)	C(4)–C(9)	1.404(4)
N(1)–C(11)	1.486(3)	C(5)–C(6)	1.430(3)
N(2)–C(5)	1.427(3)	C(7)–C(10)	1.371(4)
N(3)–C(2)	1.446(3)	C(8)–C(12)	1.505(5)
C(1)–C(2)	1.364(4)	C(9)–C(13)	1.367(5)
C(1)–C(5)	1.338(4)	C(10)–C(13)	1.377(5)
C(2)–C(4)	1.443(4)	C(11)–C(14)	1.520(6)
C(3)–C(4)	1.431(3)	C(12)–C(14)	1.496(6)
C(3)–C(6)	1.466(3)		
N(1)–C(6)–C(3)	123.6(2)	C(2)–C(1)–C(5)	120.6(2)
N(1)–C(6)–C(5)	122.0(2)	C(3)–C(4)–C(2)	117.2(2)
N(2)–C(5)–C(1)	117.4(2)	C(3)–C(6)–C(5)	114.1(2)
N(2)–C(5)–C(6)	122.9(2)	C(4)–C(3)–C(6)	119.1(2)
N(3)–C(2)–C(1)	116.6(2)	C(6)–N(1)–C(8)	122.7(2)
N(3)–C(2)–C(4)	123.1(2)	C(6)–N(1)–C(11)	125.8(2)
C(1)–C(2)–C(4)	120.3(2)	C(8)–N(1)–C(11)	109.4(2)
C(1)–C(5)–C(6)	119.7(2)		
1b			
N(1)–C(1)	1.473(10)	C(3)–C(4)	1.414(6)
N(2)–C(8)	1.373(8)	C(5)–C(7)	1.406(11)
N(2)–C(11)	1.483(10)	C(5)–C(10)	1.339(14)
N(2)–C(13)	1.489(9)	C(6)–C(9)	1.516(13)
N(3)–C(2)	1.478(12)	C(6)–C(13)	1.516(10)
C(1)–C(3)	1.423(12)	C(7)–C(8)	1.451(11)
C(1)–C(4)	1.338(15)	C(9)–C(12)	1.528(12)
C(2)–C(4)	1.396(11)	C(10)–C(15)	1.372(14)
C(2)–C(8)	1.374(9)	C(11)–C(12)	1.516(11)
C(3)–C(7)	1.421(10)	C(14)–C(15)	1.384(15)
N(1)–C(1)–C(3)	122.3(9)	C(2)–C(8)–C(7)	115.5(6)
N(1)–C(1)–C(4)	115.5(8)	C(3)–C(1)–C(4)	122.2(7)
N(2)–C(8)–C(2)	124.4(7)	C(3)–C(7)–C(8)	121.2(7)
N(2)–C(8)–C(7)	119.9(6)	C(4)–C(2)–C(8)	124.2(8)
N(3)–C(2)–C(4)	113.5(7)	C(8)–N(2)–C(11)	122.3(5)
N(3)–C(2)–C(8)	121.8(7)	C(8)–N(2)–C(13)	120.6(6)
C(1)–C(3)–C(7)	117.2(8)	C(11)–N(2)–C(13)	112.6(6)
C(1)–C(4)–C(2)	119.3(8)		



3

(R^3 = butyl; viewed from the naphthalene ring with 2- and 4-nitro groups)

(Scheme 3). They showed that the reaction consists of two stages, *i.e.* rapid formation of **4** (stage 1) and rate-determining butylammonium ion-catalysed ethoxy group expulsion from **4** (stage 2).

However, we conclude that the reaction for **1a** proceeds *via* general base catalysis with the rate-limiting deprotonation of **3** by a base and spontaneous detachment of the pyrrolidino group (proton transfer mechanism). Immediately after deprotonation of the $\overset{+}{N}H_2R^3$ group of **3** by butylamine, the NHR^3 group could be in conjugation with the naphthalene ring, because of its larger coplanarity ability than that of the pyrrolidino group (Scheme 2). This conjugation could render the C_1–N (pyrrolidino) bond much longer, with the negative charge on the pyrrolidino nitrogen being much larger. Consequently, although lastly the pyrrolidino group leaves taking a proton

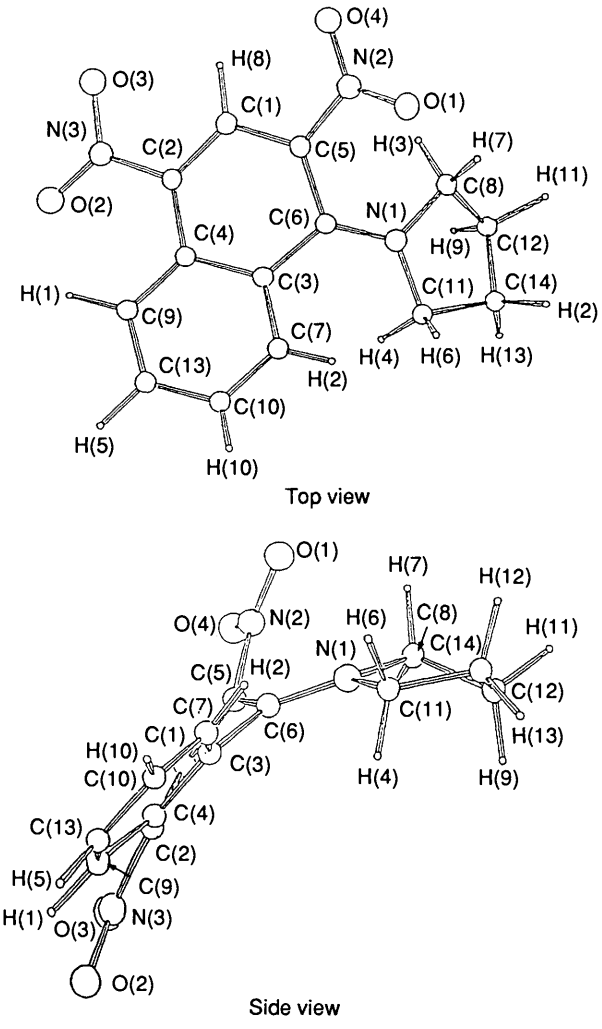


Fig. 5 Structure of **1a** by X-ray analysis

from the butylammonium ion ($BuNH_3Cl$), no acid-catalytic leaving group detachment could be observed.

Although Bernasconi[6,23] concluded, about the S_NAr reactions involving nucleophilic amines in protic solvents, that for a good nucleofuge, *e.g.* phenoxy group, its departure from **4** is fast with the deprotonation of **3** as the rate-limiting step, whereas for a poor one, *e.g.* methoxy group, its departure from **4** is slow and rate-limiting, the present reaction for **1a** can be said to correspond to his former case in spite of the poorer nucleofuge (pyrrolidino) than methoxy group and the use of an aprotic solvent (DMSO). We estimate therefore that this reaction might be the first such case in aprotic solvents.

In conclusion we would propose that in the S_NAr reactions of amines with moderately sterically hindered substrates, such as 1-substituted 2,4-dinitronaphthalenes, the coplanarity ability of amines or 1-substituent, when it is a secondary amino group, to aromatic rings in the TS should be taken into account.

Experimental

Materials.—The preparation and physical and chemical properties of the substrates and products were described elsewhere.[16] G.P.R. grade DAB, butylammonium chloride, and tetrapropylammonium iodide were used as supplied. Butylamine (G.P.R.) was fractionated, the fraction boiling at 77.5 °C being collected. G.P.R. grade DMSO was dried by refluxing over calcium hydride, fractionally distilled under reduced pressure and subsequently protected from moisture.

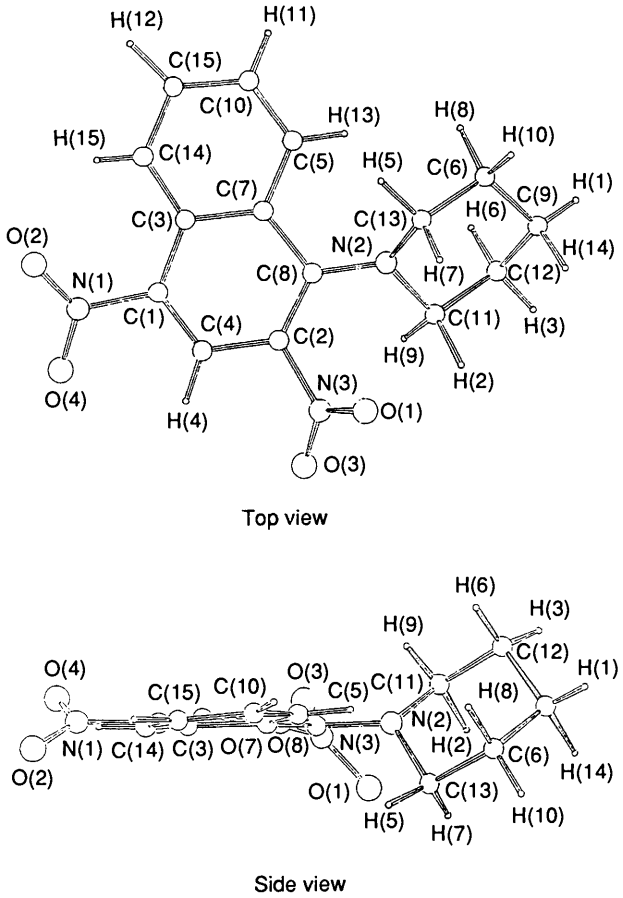


Fig. 6 Structure of **1b** by X-ray analysis

Determination of Equilibrium Constant.—The equilibrium constant (K) for the reaction **2** + R^3NH_2⇌**5** + $R^3NH_3^+$ (Scheme 2, R^3 = butyl) and the molecular extinction coefficient (ε), necessary to calculate k_ψ, were determined as follows: the absorbances at 524 nm were measured at the 23 point butylamine concentrations between 7.46×10^{-3} and 7.40×10^{-2} mol dm^{-3} at 25 °C in DMSO under conditions such that $[\mathbf{2}]_0$ was 1.85×10^{-5} mol dm^{-3} and $[BuNH_3Cl]$ 5.0×10^{-2} mol dm^{-3}, and then K and ε were estimated from the slope and intercept of the linear plot of $[\mathbf{2}]_0/A$ *vs.* $1/[BuNH_2]$ (Benesi–Hildebrand plot) according to eqn. (10), where A

$$\frac{[\mathbf{2}]_0}{A} = \frac{[BuNH_3^+]}{K\varepsilon(BuNH_2]} + \frac{1}{\varepsilon} \qquad (10)$$

represented the absorbance at each amine concentration. The K and ε values were estimated to be 1.61 ± 0.32 and $(2.38 \pm 0.02) \times 10^4$ dm^3 mol^{-1} cm^{-1}.

Rate Measurements.—The same photometric procedure as described elsewhere[39] was used. Good pseudo-first-order kinetic plots were obtained over several half-lives, from which k_ψ, pseudo-first-order rate constant, was calculated by using the Guggenheim method. Then k_A, second-order rate constant, was obtained by dividing k_ψ by the amine concentration.

X-Ray Crystal Structure Analysis of 1-*Pyrrolidino*-2,4-*dinitronaphthalene* (**1a**).—*Crystal data.* $C_{14}H_{13}N_3O_4$, M = 287.0. Monoclinic, a = 16.054(7), b = 15.019(5), c = 10.705(4) Å, β = 93.55(3)°, U = 2576.1 Å^3 (by least-squares refinement on diffractometer angles for 20 centred reflections using graphite monochromated Mo-Kα radiation, λ = 0.710 73 Å), space group $A2/a$, Z = 8, D_c = 1.479 g cm^{-3}. Crystal dimensions were 0.5 × 0.35 × 0.30 mm, and μ(Mo-Kα) is 1.22 cm^{-1}.

Data collection and processing. Data were collected on a Rigaku RASA-6 diffractometer with graphite monochromated Mo-Kα radiation (λ = 0.710 73 Å). A ω–2θ technique with a scan speed of 0.25° min^{-1} was used to measure 5103 reflections. The intensities of three check reflections were measured after every 100 reflections. A total of 1596 unique reflections with $F_{obs} > 3\sigma(F_{obs})$ were used in the analysis.

Structure solution and refinement. All non-hydrogen atoms were found by using the results of SHELXS86. After several cycles of refinements, a difference Fourier synthesis was used to locate all the hydrogen atoms. The final discrepancy indices, R and R_w were 0.0487 and 0.0501 respectively. The final difference electron-density map had maximum and minimum peak heights of 0.22 and −0.23 e Å^{-3} respectively.

X-Ray Crystal Structure Analysis of 1-*Piperidino*-2,4-*dinitronaphthalene* (**1b**).—*Crystal data.* $C_{15}H_{15}N_3O_4$, M = 301.0. Monoclinic, a = 16.83(1), b = 7.233(6), c = 11.770(7) Å, β = 99.46(5)°, U = 1413 Å^3 (by least-squares refinement on diffractometer angles for 20 centred reflections using graphite monochromated Mo-Kα radiation, λ = 0.710 73 Å), space group $P2_1/n$, Z = 4, D_c = 1.414 g cm^{-3}. Crystal dimensions were 0.30 × 0.35 × 0.30 mm.

Data collection and processing. Data were collected on a Rigaku RASA-6 diffractometer with graphite monochromated Mo-Kα radiation (λ = 0.710 73 Å). A ω–2θ technique with a scan speed of 0.25° min^{-1} was used to measure 4407 reflections. The intensities of three check reflections were measured after every 100 reflections. A total of 1176 unique reflections with $F_{obs} > 3\sigma(F_{obs})$ were used in the analysis.

Structure solution and refinement. All non-hydrogen atoms were found by using the results of the SHELXS86. After several cycles of refinements, a difference Fourier synthesis was used to locate all the hydrogen atoms. The final discrepancy indices, R and R_w were 0.0839 and 0.0801 respectively. The final difference electron-density map had maximum and minimum peak heights of 0.12 and −0.14 e Å^{-3} respectively.

All computations were performed on a HITAC M660H (Computer Center of Tokyo University) with the SHELXS system of programs. Complete listings of the atomic coordinates, bond lengths and bond angles together with the thermal parameters are available on request from the Cambridge Crystallographic Data Centre.*

* For details of the deposition scheme, see 'Instructions for Authors,' *J. Chem. Soc., Perkin Trans. 2*, 1993, issue 1.

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