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Stopped-Flow Kinetics of Reactions of 1-Ethoxy-2,4-dinitronaphthalene with Pyrrolidine and Piperidine in Dimethyl Sulfoxide Solution[1)]

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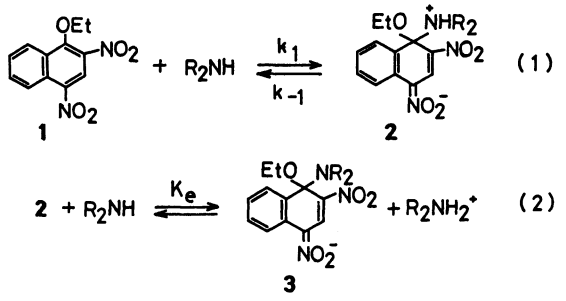
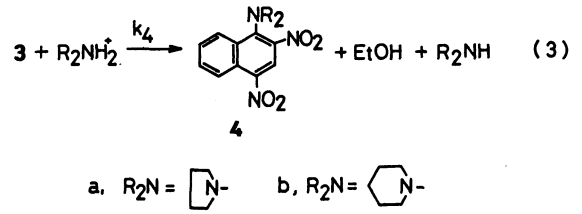
The reaction of 1-ethoxy-2,4-dinitronaphthalene (**1**) with pyrrolidine or piperidine in dimethyl sulfoxide occured in two stages (Stages I and II). In the stage I, a σ-adduct forms at such a rate as is measured by a stopped-flow technique, and in the stage II it decays at a slower and spectrophotometrically measurable rate. The pyrrolidine system is more reactive than the piperidine system in the stages I and II, with the former reactivity in the stage II being ca. 11000 times higher than the latter. This huge difference was found by NMR evidence to stem from the structure of transition state in the stage II. Further, the activation parameters were determined, which corresponded to such difference in reactivity very well.

Previously we carried out the kinetics of the reaction of 1-ethoxy-2,4-dinitronaphthalene (**1**) with pyrrolidine or piperidine in dimethyl sulfoxide (DMSO) and determined the reaction sequence (Scheme 1).[2)] The

Stage I



Stage II



a, R_2N= b, R_2N=

Scheme 1.

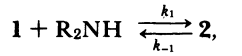
reaction occurs in two distinct stages (Stages I and II), in which the stage I is relatively fast and the stage II is slow. As the k_4 stage is rate-determining as shown in Table 5 and general acid catalyzed,[2)] the present reaction can be considered to proceed via the SB-GA (special base [R_2NH]-general acid [$R_2NH_2^+$] catalysis) mechanism.[3,4)] Several aromatic nucleophilic substitution reactions (S_NAr) via the SB-GA mechanism have been observed[5-8)] since Orvik and Bunnett[9)] confirmed the SB-GA mechanism in the reaction of **1** with butylamine and *t*-butylamine in DMSO. In this paper we determined the activation parameters of the reaction in Scheme 1 and reconsidered such huge difference in the k_4 step between the pyrrolidine and piperidine systems [k_4(pyrrolidine)/k_4(piperidine)= ca. 11000], using ^{1}H NMR evidence.

Results

General Features. Upon addition of excess piperidine to a DMSO solution of in the presence of piperidinium chloride, the solution instantly turned red, indicating the formation of a σ adduct, which corresponded to the first spectral change from curve a, attributable to **1**, to curve b, attributable to **3b** (Fig. 1).[2,9-11)] The second spectral change of curve b→c→d→e was much slower, in which curve e was attributable to **4b** (NR_2=$C_5H_{10}N$).

Therefore, the reaction consists of the I and II stages: the stage I is the fast formation of **3** (Eqs. 1 and 2) and the stage II is the relatively slow decomposition of **3**, giving **4**.

Stage I Kinetics. Let us rewrite Scheme 1 in a fashion more useful for the derivation of rate equations as Scheme 2. Under the conditions studied, the reaction occurs rapidly to establish the equilibrium between **1** and **3** (Fig. 1 and Eqs. 4 and 5).



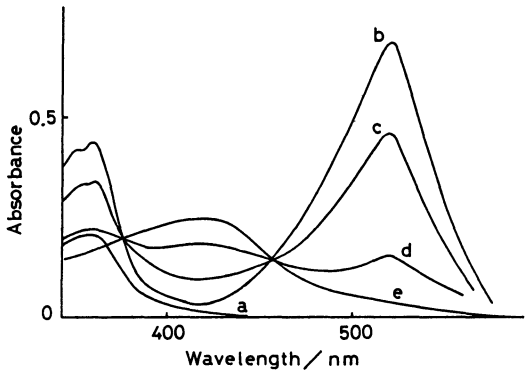


Fig. 1. Time-dependent absorption spectra relevant to the reaction of 1-ethoxy-2,4-dinitronaphthalene (**1**, 2.87×10^{-5}M) with piperidine (1.01 M) in the presence of piperidinium chloride (8.08×10^{-2}) in DMSO at 25 °C: a **1** before addition of piperidine; b, c, d, and e immediately, 60, 240, and 1200 min, respectively, after addition of piperidine.

$$2 + R_2NH \underset{}{\overset{K_e}{\rightleftarrows}} 3 + R_2\overset{+}{N}H_2, \quad (5)$$

$$3 + R_2\overset{+}{N}H_2 \underset{}{\overset{k_4}{\rightleftarrows}} 4 + C_2H_5OH + R_2NH, \quad (6)$$

Scheme 2.

Accordingly the pseudo-first-order rate constant (k_ψ) for attainment of the equilibrium is the sum of those for the foward and reverse reactions, and Eq. 7 holds (see the reference[12] about its derivation).

$$k_\psi = k_1[R_2NH] + \frac{k_{-1}[R_2\overset{+}{N}H_2]}{K_e[R_2NH]} \quad (7)$$

Multiplying each side by $[R_2NH]$,

$$k_\psi[R_2NH] = k_1[R_2NH]^2 + \frac{k_{-1}}{k_e}[R_2\overset{+}{N}H_2]. \quad (8)$$

This kinetic measurements on the stage I were shown in Tables 1 and 2, and a linear plot of $k_\psi[R_2NH]$ against $[R_2NH]^2$, at constant piperidinium chloride concentration, is compatible with Eq. 8 (Fig. 2). From the slope and intercept, k_1 and k_{-1}/K_e can be obtained. The similar relationship was obtained for the pyrrolidine system too (not shown).

As a result, one can evaluate the equilibrium constant, K_i, for the overall stage I by using k_1 and k_{-1}/K_e [$K_i = k_1/(k_{-1}/K_e)$].

The best K_i value, however, was determined as follows: the K_i value derived from the stage I kinetics was put into the rate equation for the stage II (Eq. 9) as an initial value and its best value was evaluated by using a nonlinear least squares method (refer to the next paragraph about the detailed procedure). From the best K_i value and the k_1 values, obtained accurately from the slope in a plot of $k_\psi[R_2NH]$ vs. $[R_2NH]^2$, k_{-1}/K_e was recalculated. These values are summarized in Table 5 together with the activation and thermodynamic parameters obtained from the temperature-dependence of these constants. The calculated k_ψ values, obtained by using these k_1 and k_{-1}/K_e, are in good agreement with the observed k_ψ values (Table 1 and 2).

Table 1. Reaction of **1** with Pyrrolidine in DMSO: Stage I Kinetics[a]

$[C_4H_8NH]$ M	k_ψ s^{-1}	k_ψ(calcd)[b] s^{-1}	$[C_4H_8NH]$ M	k_ψ s^{-1}	k_ψ(calcd)[b] s^{-1}
	35 °C			45 °C	
0.011	236	231	0.015	470	470
0.020	139	138	0.021	345	346
0.031	101	104	0.038	210	216
0.045	90.5	91.1	0.051	177	183
0.058	91.6	89.7	0.069	171	166
0.071	92.3	92.7	0.080	167	163
0.093	110	110	0.091	163	163
0.111	115	113	0.102	165	166
0.121	116	119	0.135	182	182
	50 °C				
0.028	403	404			
0.042	298	295			
0.058	251	244			
0.069	228	277			
0.078	222	219			
0.099	217	214			
0.113	223	217			
0.135	227	226			

a) $[\mathbf{1}]_0$ ca. 5.0×10^{-5} M; $[C_4H_8\overset{+}{N}H_2Cl^-]_0$ 4.27×10^{-3} M; measurement at 522 nm; all k_ψ are average of duplicate runs, differing by <3.5%. b) Calculated by substituting the k_1 and (k_{-1}/K_e) values in Table 5 into Eq. 7.

Table 2. Reaction of **1** with Piperidine in DMSO: Stage I Kinetics[a]

$[C_5H_{10}NH]$ M	k_ψ s^{-1}	k_ψ[b] s^{-1}	$[C_5H_{10}NH]$ M	k_ψ s^{-1}	k_ψ[b] s^{-1}
	35 °C			45 °C	
0.014	182	187	0.013	572	571
0.025	111	111	0.028	276	276
0.032	90.9	91.2	0.049	176	174
0.049	69.5	69.2	0.065	142	145
0.065	60.4	62.2	0.081	127	131
0.082	60.3	60.0	0.095	121	124
0.098	59.5	60.6	0.112	120	121
0.117	61.9	63.0	0.127	121	120
0.130	65.9	65.4			
	50 °C				
0.025	506	507			
0.043	312	311			
0.062	236	234			
0.083	194	195			
0.092	184	186			
0.120	172	170			
0.135	168	167			
0.147	166	167			

a) $[\mathbf{1}]_0$ ca. 5.0×10^{-5} M; $[C_5H_{10}\overset{+}{N}H_2Cl^-]_0$ 5.10×10^{-3} M; measurement at 522 nm; all k_ψ are average of duplicate runs, differing by <2.4%. b) Calculated by substituting the k_1 and (k_{-1}/K_e) values in Table 5 into Eq. 7.

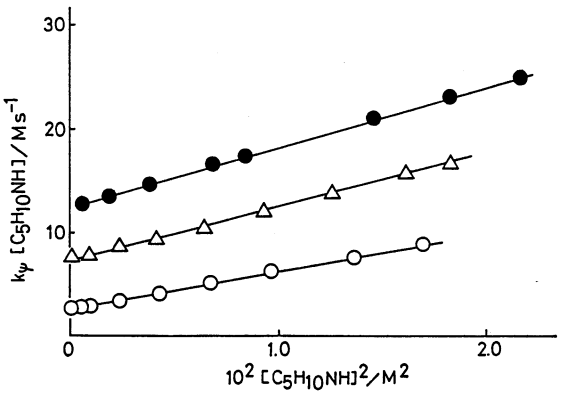


Fig. 2. Relationship between k_ψ $[C_5H_{10}NH]/M\,s^{-1}$ and $[C_5H_{10}NH]^2/M^2$ (Stage I): ○ 35; △ 45; ● 50 °C.

Stage II Kinetics. As the overall stage I is a mobile fast equilibrium (K_i) on the time scale of the stage II under the present conditions, the substrate is considered substantially to be split between **1** and

3. Letting $[\mathbf{1}]_{st}=[\mathbf{1}]+[\mathbf{3}]$, and letting K_i be the equilibrium constant for the overall stage I, one derives Eq. 9 (K_{obsd}; pseudo-first-order rate constant for the stage II,[9]

$$k_{obsd}=\frac{k_4K_i[R_2NH]^2[R_2\overset{+}{N}H_2]}{K_i[R_2NH]^2+[R_2\overset{+}{N}H_2]} \quad (9)$$

in which k_{obsd} depends on amine and amine hydro-

Table 3. Reaction of **1** with Pyrrolidine in DMSO; Stage II Kinetics[a]

$[C_4H_8NH]$	10^2k_{obsd}	10^2k_{obsd}(calcd)[b]	$[C_4H_8NH]$	10^2k_{obsd}	10^2k_{obsd}(calcd)[b]
M	s^{-1}	s^{-1}	M	s^{-1}	s^{-1}
	35 °C			45 °C	
0.011	0.48	0.49	0.010	0.36	0.36
0.016	0.91	0.90	0.021	1.39	1.39
0.027	1.86	1.87	0.034	2.83	2.84
0.032	2.23	2.24	0.041	3.58	3.57
0.036	2.51	2.50	0.052	4.53	4.54
0.041	2.76	2.78	0.060	5.10	5.11
0.054	3.32	3.30	0.071	5.73	5.74
0.064	3.57	3.56	0.083	6.24	6.24
0.082	3.85	3.86	0.103	6.82	6.82
0.102	4.05	4.40	0.114	7.04	7.04
0.123	4.16	4.16	0.123	7.20	7.19
	50 °C				
0.021	1.32	1.34			
0.039	3.55	3.56			
0.049	4.74	4.73			
0.059	5.74	5.76			
0.068	6.56	6.54			
0.078	7.27	7.25			
0.088	7.81	7.83			
0.105	8.59	8.58			
0.117	8.98	8.97			
0.122	9.13	9.11			

a) $[\mathbf{1}]_0$ ca. 2.3×10^{-5} M; $[C_4H_8\overset{+}{N}H_2Cl^-]_0$ 1.45×10^{-3} M; measurement at 522 nm; all k_{obsd} are average of duplicate runs, differing by <2.4%. b) Calculated by substituting the k_4 and K_i values in Table 5 into Eq. 9.

Table 4. Reaction of **1** with Piperidine in DMSO: Stage II Kinetics[a]

$[C_5H_{10}NH]$	10^5k_{obsd}	10^5k_{obsd}(calcd)[b]	$[C_5H_{10}NH]$	10^5k_{obsd}	10^5k_{obsd}(calcd)[b]
M	s^{-1}	s^{-1}	M	s^{-1}	s^{-1}
	35 °C			45 °C	
0.100	2.66	2.67	0.110	4.35	4.38
0.261	12.3	12.2	0.150	7.78	7.81
0.342	16.6	16.6	0.251	18.9	18.8
0.381	18.3	18.4	0.292	23.5	23.5
0.430	20.4	20.3	0.361	31.9	31.8
0.500	22.6	22.6	0.460	42.3	42.4
0.572	24.4	24.3	0.531	48.8	48.7
0.673	26.0	26.1	0.672	58.7	58.7
0.780	27.8	27.7	0.750	63.1	63.2
	50 °C				
0.120	5.94	6.02			
0.201	14.4	15.3			
0.261	24.2	24.5			
0.292	29.5	29.3			
0.350	38.7	39.1			
0.440	53.5	53.4			
0.582	73.2	73.1			
0.671	83.6	83.5			
0.840	98.7	98.8			

a) $[\mathbf{1}]_0$ ca. 5.0×10^{-5} M; $[C_5H_{10}\overset{+}{N}H_2Cl^-]_0$ 8.00×10^{-2} M; measurement at 522 nm; all k_{obsd} are average of duplicate runs, differing by <2%. b) Calculated by substituting the k_4 and K_i values in Table 5 into Eq. 9.

chloride concentrations (Tables 3 and 4), and involves K_i, mentioned in the preceding paragraph.

The best K_i and k_4 values were determined as follows: first, the K_i values, derived from the stage I kinetics, were used to calculate k_4, that is, for pyrrolidine K_i=1.32, 0.53, and 0.35, and for piperidine 0.77, 0.33_8 and 0.35 M^{-1} (M=mol dm^{-3}, and so forth) at 35, 45, and 50 °C, respectively; second, by substituting these K_i values and the experimental values ([R_2NH], k_{obsd}, and [R_2NH_2Cl]) of the top line at each temperature in Tables 3 and 4 into Eq. 9, the following k_4 values were calculated, that is, for pyrrolidine 33.4, 69.6, and 94.6, and for piperidine 4.07×10^{-3}, 11.1×10^{-3}, and 18.1×10^{-3} $M^{-1}s^{-1}$ at 35, 45, and 50 °C, respectively; third, by substituting these K_i and k_4 values into Eq. 9 as initial values and using a nonlinear least squares method (Gauss-Newton method), the best K_i and k_4 values were obtained, which are listed in Table 5. The k_{-1}/K_e values in Table 5 were calculated, therefore, by using these K_i values and the k_1 ones (obtained in the stage I kinetics).

Agreement between observed and calculated k_{obsd}, derived by substituting the K_i and k_4 values into Eq. 9, was found to be fairly good (Tables 3 and 4).

Equation 9 is converted to Eq. 10 by rearranging and taking logarithms. To check the validity of Eq. 10, we plotted the quantity on the left side against that on the right side of Eq. 10 by using the pyrrolidine or piperidine concentrations, and the K_i and k_4 values in Table 5 (Fig. 3). The slopes are 1.99 ± 0.02,

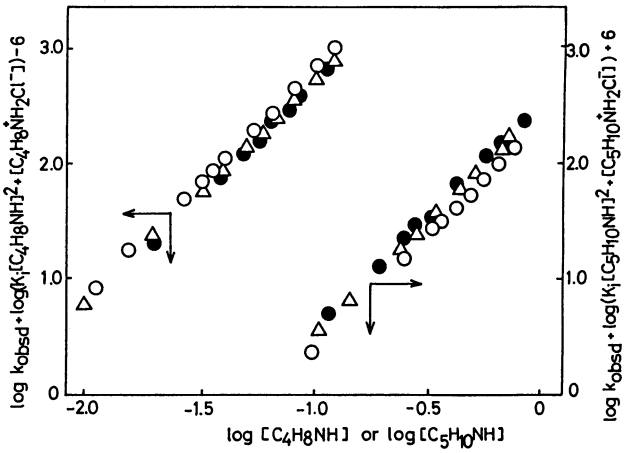
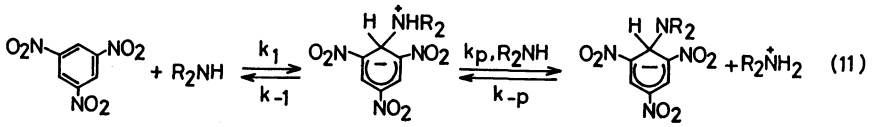


Fig. 3. Relationships between $\log k_{obsd}+\log(K_i[C_4H_8NH]^2+[C_4H_8\dot{N}H_2Cl^-])-6$ and $\log[C_4H_8NH]$, and between $\log k_{obsd}+\log(K_i[C_5H_{10}NH]+[C_5H_{10}\dot{N}H_2Cl^-])+6$ and $\log[C_5H_{10}NH]$ (Stage II).

Table 5. Summary of Rate Constants, Equilibrium Coefficients, Activation and Thermodynamic Parameters

Reaction	Parameter[a]	Temp °C	Reaction with pyrrolidine	Reaction with piperidine
1 → 2	$k_1/M^{-1}s^{-1}$	25[b]	6.5×10^2	2.4×10^2
		35	$8.22\pm0.10\times10^2$	$3.52\pm0.05\times10^2$
		45	$9.77\pm0.16\times10^2$	$4.92\pm0.05\times10^2$
		50	$11.0\pm0.2\times10^2$	$5.67\pm0.06\times10^2$
	$\Delta H^{\ddagger}$		3.3 ±0.4	5.6 ±05
	$\Delta S^{\ddagger}$		−34.5 ±1.5	−27.7 ±1.6
	$\Delta G^{\ddagger}$		13.6 ±0.6	14.2 ±0.7
1 ⇄ 3	K_i/M^{-1}	25[b]	3.44±0.05	1.55±0.02
		35	1.44±0.01	0.70±0.01
		45	0.61±0.01	0.34±0.01
		50	0.44±0.01	0.23±0.01
	ΔH^0		−15.8 ±0.8	−14.4 ±0.6
	ΔS^0		−50.5 ±2.3	−39.6 ±2.1
	ΔG^0		−0.74±1.06	−2.59±2.1
3 → 1	$k_{-1}/K_e/s^{-1}$	25[b]	-1.89 ± 10^2	1.54 ± 10^2
		35	$5.11\pm0.10\times10^2$	$5.02\pm0.13\times10^2$
		45	$1.60\pm0.03\times10^3$	$1.44\pm0.02\times10^3$
		50	$2.54\pm0.05\times10^3$	$2.42\pm0.06\times10^3$
	$\Delta H^{\ddagger}$		8.9 ±1.1	20.3 ±1.1
	$\Delta S^{\ddagger}$		15.4 ±3.8	19.4 ±3.7
	$\Delta G^{\ddagger}$		14.4 ±1.6	14.5 ±1.5
3 → 4	$k_4/M^{-1}s^{-1}$	25[b]	15.7	$1.40\pm0.01\times10^{-3}$
		35	30.6 ±0.3	$4.11\pm0.02\times10^{-3}$
		45	56.8 ±1.1	$1.12\pm0.01\times10^{-2}$
		50	76.6 ±2.0	$1.84\pm0.02\times10^{-2}$
	$\Delta H^{\ddagger}$		11.4 ±0.5	18.9 ±0.7
	$\Delta S^{\ddagger}$		−14.6 ±1.6	−8.2 ±3.1
	$\Delta G^{\ddagger}$		15.8 ±0.7	21.4 ±1.2

a) Units of $\Delta H^{\ddagger}$, ΔH^0, $\Delta G^{\ddagger}$, and ΔG^0(25 °C) are $kcal_{th}$ dm^{-3};units of $\Delta S^{\ddagger}$ and ΔS^0 (25 °C) are cal_{th} K^{-1} dm^{-3}. b) Cited from the Ref. 2. These values are almost the same as those in the present reaction, differing by <3.0%.



Scheme 2.

1.96±0.01, and 2.00±0.01 for pyrrolidine, and 2.00±0.01, 2.01±0.01, and 2.00±0.01 for piperidine at 35, 45, and 50 °C, indicating the validity of Eq. 10.

$$\log k_{obsd} + \log (K_1[R_2NH]^2 + [R_2\overset{+}{N}H_2]) = \log k_4K_i + 2\log[R_2NH] + \log[R_2\overset{+}{N}H_2] \quad (10)$$

Discussion

Stage I. Rate and Equilibrium Constants. The pyrrolidine system is a little more reactive than the piperidine one at the k_1 step, depending on $\Delta H^{\neq}$ rather than on $\Delta S^{\neq}$ (Table 5). Further, much more difference is seen between the $\Delta S^{\neq}$ values than between the $\Delta H^{\neq}$ ones, although difference between the $\Delta G^{\neq}$ values is much less, which could arise from the steric or stereoelectronic origin, as discussed in the later paragraph, by considering similar properties for these two amines, such as their pK_a values.[2,15] For the nucleophilic attack of pyrrolidine on **1**, electron delocalization would be considered to be somewhat larger between the unshared electron on the nitrogen atom of pyrrolidinyl group and the naphthalene moiety (**1**) than that for piperidine,[2] which would increase, to a larger extent, the repulsion between α-methylene group of the pyrrolidinyl ring and 2-nitro group of **1** (refer to later discussion).

The pyrrolidine/piperidine reactivity ratios at the step are 2.7, 2.3, 2.0, and 1.9 at 25, 35, 45, and 50 °C, respectively, which are close to the corresponding ratios in K_i, overall stage I equilibrium constant: 2.2, 2.1, 1.8, and 1.9 at 25, 35, 45, and 50 °C, respectively. These results naturally stems from the similar k_{-1}/K_e values for the two amine systems. The present kinetics can not tell whether these values (k_{-1}/K_e) arise from each almost same k_{-1} and K_e values or from appropriate balance of their different ones for the two amines (see the next paragraph).

Proton Transfer in K_e Step. The results in Tables 1—4 are fairly consistent with the reaction sequence in Scheme 1. It is well-known, however, that whether the K_e step is a fast mobile equilibrium or a proton transfer is sophisticated or controvertial.[3,4,10,11] A relatively slow proton-transfer reaction has been found in the reactions of methyl 4-methoxy-3,5-dinitrobenzoate with pyrrolidine[5] or butylamine[6] in DMSO, of 1-ethoxy-2,4,6-trinitrobenzene with butylamine,[7] and of 1-phenoxy-2,4-dinitro- and 1-phenoxy-6-methyl-2,4-dinitrobenzene with pyrrolidine and piperidine in 60% dioxane-40% water,[8] from which it is evident that in the case of secondary amines a proton transfer is relatively slow on account of steric effects.

In addition, Bernasconi et al.[13] and Crampton and Greenhalgh[14] determined the rate and equilibrium constants for the reactions of 1,3,5-trinitrobenzene (**5**) with pyrrolidine and piperidine in 30% DMSO-70% water[13] (hereafter abbreviated to DMSO-water) or in DMSO[14] (Scheme 2). From these results k_p and k_{-p} are as follows: k_1 (M^{-1} s^{-1}), k_{-1} (M^{-1} s^{-1}), k_p (M^{-1} s^{-1}), k_{-p}, (M^{-1} s^{-1}), K_p and K (M^{-1}, overall equilibrium constant) are 9.00×10^3, 6.2×10^5, 1.7×10^7, 5.1×10^4, 3.3×10^2, and 4.7 for the pyrrolidine system and 4.10×10^3, 1.0×10^6, 1.6×10^7, 3.9×10^4, 4.1×10^2, and 1.2 for the piperidine system at 20 °C in 30% DMSO-70% water, whereas 7.5×10^5, 1.0×10^5, 1.5×10^6, 3.0×10^3, 500, and 3.5×10^3 for the pyrrolidine system and $>2\times10^5$, $>1.44\times10^4$, 1.4×10^5, 2.8×10^2, 500, and 2.14×10^3 for the piperidine system at 25 °C in DMSO.

As a result, k_{-1}/K_p, corresponding to k_{-1}/K_e in the present reaction, is calculated to be 1.9×10^3 and 2.4×10^3 s^{-1} in DMSO-water, and 2×10^2 and $>2.9\times10^{-1}$ s^{-1} in DMSO for pyrrolidine and piperidine respectively, in which $(k_{-1}/K_p)_{pyr}/(k_{-1}/K_p)_{pip}$ is 0.8 in DMSO-water and ca. 6.8 in DMSO. The one thing to be commented at this point is that the K_p values in DMSO are presumed ones (see the reference[14] for the details), and therefore a little uncertain. By considering these results, our ratio, mentioned just above, is 1.2, which can be believed to be similar to their values,[13,14] although their magnitudes are reversed or different, probably depending on solvent compositions and structures of substrates.

In addition, we assumed that K_e step is an equilibrium. In some reactions,[5,7,8,13,14] however, rate-limiting or partly rate-limiting proton transfer has been advocated, which can be estimated from the effect of added bases, such as DABCO (1,4-diazabicyclo-[2.2.2]octane), on k_ψ. In the preliminary experiment, we found that in the presence of **1** (2.46×10^{-5} M) and pyrrolidine (2.15×10^{-2} M) k_ψ changed from 10.3±0.5 to 12.5±0.3 s^{-1} at [DABCO]=1.90×10^{-2} to 1.90×10^{-1} M (10-fold change), whereas in the presence of **1** (2.46×10^{-5} M) and piperidine (3.95×10^{-1} M) k_ψ changed from 3.13±0.61 to 3.62±0.116 s^{-1} at [DABCO]=1.40×10^{-2} to 1.76×10^{-1} M (ca. 17-fold change). An increase in k_ψ is 21% for the former and 15.6% for the latter, which is much less than those found already.[5,7,8,13,14] These results indicates that pK_a of **2** is less than that of **6** partly due to an electron-withdrawing character of the ethoxyl group. It would be reasonable, therefore, that the K_e step is

treated as an equilibrium.

Huge Difference in Reactivities of Stage II. It was already described that pyrrolidinium or piperidinium ion catalyzes the explusion of ethoxide ion from **3** (general acid catalysis).[2] Huge difference in k_4 at 25 °C corresponds to $\Delta\Delta G^{\neq}$ of 5.6 kcal mol^{-1} (1 cal_{th}=4.184 J) (Table 5). In view of the similarity of the two amines in the stage I behavior and their pK_a [11.27 (H_2O)[15] and 11.42% (30% DMSO-70% water)[13] for pyrrolidine; 11.22 (H_2O)[15] and 11.42 (30% DMSO-70% water)[13] for piperidine] this huge difference is very surprising. We concluded by examination of Dreiding models that some steric, stereoelectronic or conformational effect concerning the carbon-bound amino moiety in the transition state for the k_4 step is the source of this huge stage II reactivity difference [about detailed discussion, refer to the reference[2]].

We have recnetly found the NMR evidence supporting the discussion described just above (Fig. 4).

Interestingly the signal pattern of aromatic protons of 1-dimethylamino-2,4-dinitronaphthalene (**4c**), in which the singlet at δ 8.81 and the multiplets centered at ca. δ 8.68 and ca. δ 7.88 are attributed to H^3, $H^{5,8}$, $H^{6,7}$ respectively, was found to be similar to those of 1-diethylamino- (**4d**), 1-(*N*-methylbutylamino)- (**4e**), and **4b** (about numbering of protons see Fig. 5A). The pattern (Fig. 4C) was obtained in 64 days after piperidine (3 equivalents) were added into a DMSO-d_6 solution of **4b** (NR_2; piperidino). The downfield shift of H^3 singlet of **4b** from δ 8.63 to 9.30 is characteristic for its conversion to an adduct.[10] The signal pattern of **4a** is similar, if anything, to 1,1-dipiperidino-substituted 2,4-dinitronaphthalene anionic σ complex, in which the NR_2 (piperidino) group is substituted in place of the ethoxyl group in **3**, that is, two piperidino groups are attached to C_1. These results show that in the case of **4a** such conjugation as **4** (Fig. 5A) is larger than in the case of **4b** and **4c—d**, suggesting comparatively small steric interaction between α-methylene group of the pyrrolidinyl ring and 2-nitro group. This implies that when the ethoxyl group is expelled from **3** (k_4 step), the pyrrolidinyl ring can more easily keep its plane coplanar to the naphthalene moiety at a certain angle and that its unshared electron pair can assume a configuration antiperiplanar to the rupturing C-O bond with respect to the C_1-N (piperidino nitrogen) bond in the transition state (Fig. 5B). Although in this transition state the pyrrolidinyl ring is drawn as a plane, the conformation with C_2 symmetry is greatly preferred for substituted pyrrolidines.[17] Backside assistance of this electron pair to expulsion of the ethoxyl group would cause a huge increase in reactivity at the k_4 step for the pyrrolidine system.[16]

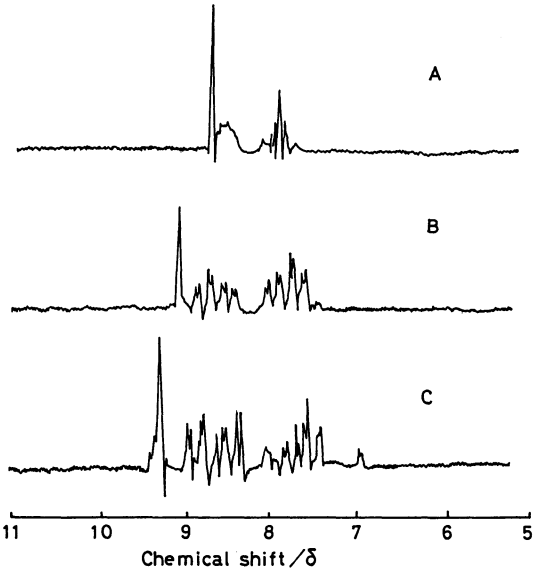


Fig. 4. ^{1}H NMR spectra for 1-dimethylamino- (**4c**, A), 1-pyrrolidino-2,4-dinitronaphthalene (**4a**, B), and 1,1-dipiperidino-substituted 2,4-dinitronaphthalene anionic a complex (C) in DMSO-d_6.

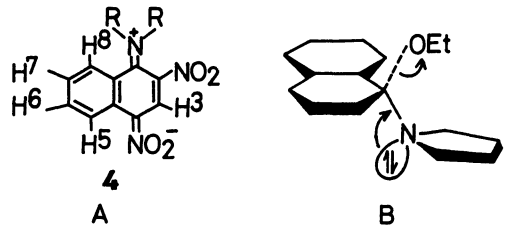


Fig. 5. Canonical structure of 1-(disubstituted amino)-2,4-dinitronaphthalene (A), and transition state at the k_4 step for the pyrrolidine system, in which 2- and 4-nitro groups are omitted for simplicity (B).

Experimental

NMR spectra were recorded on a Varian A-60D spectrometer and UV-VIS absorption spectra on a Hitachi Model 200-10 spectrophotometer. All the melting points were uncorrected.

Materials. Dimethyl sulfoxide, pyrrolidine, piperidine, diethylamine, *N*-methylbutylamine were purified as previously described.[2] Commerical dimethylamine was used without further purification. Pyrrolidinium and piperidinium chloride, and 1-ethoxy-2,4-dinitronaphthalene (**1**) were prepared as previously described.[2]

1-(Disubstituted amino)-2,4-dinitronaphthalene (**4a—e**) were prepared from 1-chloro-2,4-dinitronaphthalenes and corresponding amine as previously described.[18] The yield was higher than 80% and the elemental analysis was within (calculated value ±0.3%) in each case. The physical properties were shown in the following except for **4b**.[18] All mp, λ, ε, and δ were in DMSO.

(1-Pyrrolidinyl)-2,4-dinitronaphthalene (4a): Mp 201.5—202 °C; λ_{438} (ε 2.1×10^4); ^{1}H NMR δ=1.93 [4H, m, NC_4H_8 (2β-CH_2)] and 3.73 [4H, t, NC_4H_8 (2α-CH_2)].

1-Dimethylamino-2,4-dinitronaphthalene (4c): Mp 87—87.5 °C; λ_{419} (ε 8.8×10^3); ^{1}H NMR δ=3.07 [6H, s, $N(CH_3)_2$], 7.87 (2H, m, $H^{6,7}$), 8.67 (1H, s, H^3), and 8.53 (2H, m, $H^{5,8}$).

1-Dimethylamino-2,4-dinitronaphthalene (4d): Mp 87.5—88.5 °C; λ_{430} (ε 1.5×10^4); ^{1}H NMR δ=1.13 [6H, t, $N(CH_2CH_3)_2$], 3.40 [(4H, q, $N(CH_2CH_3)_2$], 7.93 (2H, m, $H^{6,7}$), 8.67 (1H, s, H^3), and 8.53 (2H, m, $H^{5,8}$).

1-(*N*-Methylbutylamino)-2,4-dinitronaphthalene (4e): Mp 66—67 °C; λ_{425} (ε 7.4×10^3); ^{1}H NMR δ=0.80 [3H, t, $N(CH_2)_3CH_3$], 1.50 [4H, m, $N(CH_2)_3CH_3$ (β- and γ-CH_2)], 3.09 (3H, s, NCH_3), 3.21 [2H, t, $N(CH_2)_3CH_3$ (α-CH_2)], 7.95 (2H, M, $H^{6,7}$), 8.53 (2H, m, $H^{5,8}$), and 8.73 (1H, s, H^3).

Rate Measurement. As regards the kinetics of formation of σ adduct (**3**) (Stage I), an increase in the absorbance at 522 nm, due to **3** was followed in order to estimate the apparent first-order rate constant (k_ψ) with a thermostatted stopped-flow spectrophotometer (Otsuka Denshi Co.).[2] In order to estimate k_{obsd} (Stage II) a decrease in the absorbance at 522 nm was followed with a thermostatted Hitachi Model 200-10 spectrophotometer.[2]

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