yield, 700 mg (57%); mp 140–145°. The infrared spectrum (in KBr) of XIII exhibited quinolid bands at 1645 and 1665 cm^{-1}.

Anal. Calcd for $C_{28}H_{42}O_2$ (mol wt, 410.62): C, 81.90; H, 10.31. Found: C, 82.04; H, 10.15.

2,4,6-Tri-*t*-butyl-4-(4-diphenylmethyl-2-phenylphenoxy)-2,5-cyclohexadien-1-one (XIV).—4-Hydroxy-3-phenyltriphenylmethane (673 mg, 2 mmoles) was added in four portions under nitrogen to a suspension of active manganese dioxide (5.3 g) in a solution of 2,4,6-tri-*t*-butylphenol (524 mg, 2 mmoles) in benzene (80 ml) which was shaken between each addition. Filtration and evaporation *in vacuo* gave a yellow oily residue which crystallized upon treatment with methanol. It was recrystallized by dissolving in a little ether (under N_2) and adding methanol: yield, 900 mg (75%) of light green to colorless crystals, mp 116–117°.

Anal. Calcd for $C_{43}H_{48}O_2$: C, 86.52; H, 8.11; mol wt, 596.86. Found: C, 86.69; H, 8.23; mol wt (chloroform), 554.

2,4,6-Tri-*t*-butyl-4-(2,6-diphenyl-4-diphenylmethylphenoxy)-2,5-cyclohexadien-1-one (XV).—3,5-Diphenyl-4-hydroxytriphenylmethane (412 mg, 1 mmole) was added over a period of 1 min to a suspension of active manganese dioxide (2.6 g) in a solution of 2,4,6-tri-*t*-butylphenol (262 mg, 1 mmole) which was agitated by a stream of nitrogen. Filtration and evaporation of the light yellow filtrate gave a yellow oily residue which crystallized upon treatment with methanol. It was filtered through a sintered-glass frit, dissolved on the frit in few milliliters of ether (which left a few milligrams of yellow substance undissolved), and filtered into about 50 ml of methanol. The methanol filtrate was agitated by a stream of nitrogen and the very light yellow crystalline precipitate thus formed was removed by filtration: yield, 415 mg (62%). The substance turned yellow above 100° and melted around 275°. During the process of heating, 3,5-diphenylfuchsone is probably formed.

Anal. Calcd for $C_{49}H_{52}O_2$: C, 87.72; H, 7.51; mol wt, 670.45. Found: C, 87.27; H, 7.95; mol wt (chloroform, very yellow solution), 562.

Decomposition of XV.—The deep green solution of the quinol ether derived from 2,4,6-tri-*t*-butylphenol and 3,5-diphenyl-4-hydroxytriphenylmethane (671 mg, 1 mmole) in benzene (25 ml) was refluxed under nitrogen for 3 hr. The solution was then deep brown. Upon cooling to room temperature, 330 mg (80%) of 3,5-diphenylfuchsone crystallized and was removed by filtration: mp 297–298°. The mixture melting point with authentic sample was not depressed.

Spectra.[14]—The infrared spectra were taken on a Perkin-Elmer grating infrared spectrophotometer, Model 521. Ultraviolet spectra were obtained with a Cary recording spectrophotometer, Model 14. Proton magnetic resonance spectra were taken on a Varian A-60 in deuteriochloroform with tetramethylsilane as internal standard.

Registry No.—IIIa, 13391-79-2; IIIb, 13391-80-5; IIIc, 13391-81-6; IIId, 13391-82-7; IIIe, 13391-83-8; IIIf, 13391-84-9; IVa, 13135-13-2; IVb, 11135-10-9; IVc, 13127-43-0; IVd, 13391-88-3; IVe, 13391-89-4; IVf, 13391-90-7; IVg, 13131-76-5; V, 13391-91-8; VI, 13391-92-9; VII, 13391-93-0; VIII, 13391-94-1; X, 13391-95-2; XI, 13428-17-6; XII, 13391-96-3; XIII, 13391-97-4; XIV, 13391-98-5; XV, 13428-16-5.

[14] Thanks are due to Miss Dorothy McClung and Miss Mary Ann Olivier for their prompt collaboration in recording the spectra.

Kinetics of Reactions of Amines with Ethers of 2,4-Dinitrophenol in 10% Dioxane–90% Water. Dependence of Base Catalysis on the Entering Amine and on the Leaving Group

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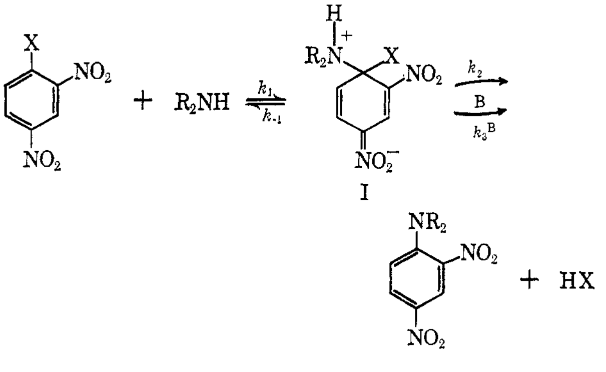
Rates of reactions of 2,4-dinitrophenyl phenyl ether with benzylamine and N-methylbenzylamine have been measured as a function of sodium hydroxide and of amine concentration. The reaction of N-methylbenzylamine is strongly catalyzed by sodium hydroxide and moderately by the amine itself. The second-order rate coefficient k_A is curvilinearly related to hydroxide ion concentration but is an approximately linear function of N-methylbenzylamine concentration. The reaction of benzylamine with 2,4-dinitrophenyl phenyl ether is independent of the hydroxide ion concentration; k_A is slightly decreased with increasing amine concentration. The dependence on piperidine concentration has been determined for the reactions of 2,4-dinitroanisole and of 2,4-dinitrophenyl phenyl sulfide. The second-order rate coefficient of the former reaction is a linear function of piperidine concentration, whereas the latter reaction is not catalyzed by piperidine. In the search for a relation between sensitivity to base catalysis of nucleophilic aromatic substitutions by primary and secondary amines and the acid–base properties of entering amine and leaving group, the partial rate coefficient k_1 and ratios k_2/k_{-1}, k_3^B/k_{-1}, and k_3^B/k_2 were calculated and compared with those previously obtained for similar reactions. The ratio k_3^{OH}/k_2, *i.e.*, the relative catalytic effectiveness of hydroxide ion to water, increases considerably with increasing basicity of the leaving group, but decreases only slightly with increasing basicity of the reacting amine.

Recently Bunnett and Bernasconi[2] investigated the reactions of piperidine with ethers of 2,4-dinitrophenol, in 10% dioxane–90% water, leading to 2,4-dinitrophenylpiperidine. They were able to show that the occurrence of base catalysis depends on the group displaced. Reactions with "good" leaving groups were little or not at all sensitive to catalysis by bases, whereas base catalysis was found to be strong for "poor" leaving groups. This characteristic dependence on the group displaced could easily be rationalized in terms of eq 1,

$$k_A = \frac{k_1k_2 + k_1\Sigma k_3^B[B]}{k_{-1} + k_2 + \Sigma k_3^B[B]} \qquad (1)$$

which is the appropriate kinetic expression for the two-step intermediate complex mechanism for nucleophilic aromatic substitution (eq 2), initially proposed by



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[2] J. F. Bunnett and C. F. Bernasconi, *J. Am. Chem. Soc.*, **87**, 5209 (1965).

Bunnett.[3,4] k_A stands for the second-order rate coefficient of the aminolysis. Depending on the relative magnitudes of k_{-1}, k_2, and $k_3^B[B]$, three types of k_A *vs.* base concentration plots may occur. When $k_2 >> k_{-1}$ or $(k_2 + \Sigma k_3^B[B]) >> k_{-1}$, eq 2 simplifies to eq 3.

$$k_A = k_1 \tag{3}$$

k_A is then independent on base concentration. When $k_{-1} >> (k_2 + \Sigma k_3^B[B])$, eq 2 becomes eq 4, and

$$k_A = \frac{k_1 k_2}{k_{-1}} + \frac{k_1 \Sigma k_3^B[B]}{k_{-1}} \tag{4}$$

k_A is a linear function of base concentration. When k_{-1} and $k_3^B[B]$ are of the same order of magnitude, eq 1 cannot be simplified and a nonlinear response to base concentration will result, as has been discussed at length before.[2]

In this and the following papers[5,6] we wish to focus our attention on two main points: (1) on the dependence of base catalysis upon the group displaced in its quantitative aspect and, in mathematical terms, on the ratio k_3^B/k_2 as a function of leaving group mobility (lacking a more adequate criterion for the leaving group mobility we take its basicity as a measure thereof); (2) on the susceptibility to base catalysis as a function of the entering amine, also in its quantitative aspect, *i.e.*, on the ratio k_3^B/k_2 in relation to amine basicity (from such structure–reactivity relationships a deeper insight into the mechanistic details of the base catalysis should be gained).

In this paper the kinetics of the reactions of benzyl- and N-methylbenzylamine with 2,4-dinitrophenyl phenyl ether and some complementary results on the reaction of piperidine with 2,4-dinitroanisole and 2,4-dinitrophenyl phenyl sulfide in 10% dioxane–90% water are reported.

Experimental Section

Materials.—1,4-Dioxane was purified by the method of Fieser[7] and was stored over lithium aluminium hydride, from which it was distilled as needed; "10% dioxane–90% water" was prepared by diluting one volume of dioxane to a total of ten volumes with distilled water. Commercial piperidine, reagent grade benzylamine (Fluka), and N-methylbenzylamine were heated for 12 hr at reflux with sodium metal and then distilled with piperidine at ordinary pressure and with the other amines under reduced pressure. Middle fractions were taken and stored in the dark. N-Methylbenzylamine was shown by vpc to contain 1% benzylamine after this procedure. As could be shown with a pure sample of N-methylbenzylamine purified by preparative vpc, the small quantity of benzylamine did not interfere with our measurements because the rate of the benzylamine reaction was only slightly larger than the rate of the reaction of N-methylbenzylamine. The hydrochlorides of the amines were prepared by standard methods and recrystallized from ethanol; melting points were 250, 245, and 170–172°, respectively, for piperidine, benzylamine, and N-methylbenzylamine hydrochloride. 2,4-Dinitrophenyl phenyl ether was prepared by the method of Raiford and Colbert[8] and thrice recrystallized from ethanol: mp 69°. 2,4-Dinitroanisole, prepared by the method of Holleman,[9] had mp 88° after four recrystallizations from ethanol. 2,4-Dinitrophenyl phenyl sulfide was prepared by the method of Bogert and Evans[10] and was thrice recrystallized from ethanol: mp 121°. N-(2,4-Dinitrophenyl)piperidine, mp 92°, N-(2,4-dinitrophenyl)benzylamine, mp 146°, and N-(2,4-dinitrophenyl)-N-methylbenzylamine, mp 126°, were prepared by the method of Bunnett and Randall[11] used for N-(2,4-dinitrophenyl)-N-methylaniline.

Rate Measurements.—The general photometric procedure described earlier[2,11] was employed. Measurements were performed on a Beckman DU spectrophotometer at 390 mμ.

The hydrolysis of the 2,4-dinitrophenyl ethers, as a side reaction of the same order, does not complicate the kinetic treatment in a principal way.[11] The hydrolysis of the reaction products however, introduces a consecutive reaction that renders the evaluation of rate constants much more intricate, unless the aminolysis is much faster than the consecutive hydrolysis. Owing to the reduced nucleophilic reactivity of the weakly basic benzylamines, the ratio of aminolysis to hydrolysis rates is markedly reduced compared with piperidine. This ratio could be increased by choosing a relatively high amine concentration (0.2 *M*). Indeed, infinity values (A_∞) of absorbance were only slightly lower than anticipated for quantitative aminolysis; they could easily be corrected by extrapolation.[12]

The equilibrium reaction of the amines with water increases the hydroxide ion concentration but reduces the concentration of free amine. Effective concentrations were calculated by means of K_b values estimated from pK_a values by a procedure described elsewhere:[2] piperidine, $K_b = 1.3 \times 10^{-3}$ ($pK_a = 11.06$[13]); benzylamine, $K_b = 2.65 \times 10^{-5}$ ($pK_a = 9.34$[14]); N-methylbenzylamine, $K_b = 4.28 \times 10^{-5}$ ($pK_a = 9.58$[14]). Other pK_a values are given in the literature.[15-18]

The symbols for the different rate coefficients used in this work are defined as follows: k_ψ is the pseudo-first-order coefficient for the disappearance of the substrate, as determined graphically from a log $(A_\infty - A)$ *vs.* time plot;[19] k_A^*, pseudo-first-order coefficient for formation of 2,4-dinitrophenylpiperidine, -benzylamine, and -N-methylbenzylamine, equals (fractional yield of the aminolysis product) × k_ψ; k_A, second-order coefficient for formation of aminolysis product, equals $k_A^*/[\text{amine}]_{\text{eff}}$, where $[\text{amine}]_{\text{eff}}$ is the corrected concentration of the amine; $k_{OH}^* = k_\psi - k_A^*$; k_{OH}, second-order coefficient for formation of 2,4-dinitrophenol, equals $k_{OH}^*/[OH]_{\text{eff}}$.

k_ψ, k_A^*, and k_A are estimated to be precise within ±2.5%, whereas the experimental error for k_{OH}^* and k_{OH} is larger, depending very much on the yield of the aminolysis reaction. For very high yields (≥96%) the uncertainty can amount to ±50%; for lower yields (usually between 70 and 90%) it is ±15%.

Results

The results of our kinetic investigation are presented in Tables I–III, where for each run the observed pseudo-first-order coefficient (k_ψ), the per cent yield of the aminolysis product (as determined photometrically), and various rate coefficients, as they are defined in the Experimental Section, are listed.

Reaction of N-Methylbenzylamine with 2,4-Dinitrophenyl Phenyl Ether.—Similarly to the reaction of piperidine,[2,20] the reaction of N-methylbenzylamine is

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(3) J. F. Bunnett and R. E. Zahler, *Chem. Rev.*, **49**, 297 (1951).

(4) Equation 1 is derived by means of the steady-state approximation. One assumes that only the second step can be catalyzed by bases, not the first. The summation term $\Sigma k_3^B[B]$ means that any base present in the system may act as a catalyst. k_2 is the uncatalyzed (or solvent catalyzed) component of the second step.

(5) C. F. Bernasconi and P. Schmid, *J. Org. Chem.*, **32**, 2953 (1967).

(6) C. F. Bernasconi, in preparation.

(7) L. F. Fieser, "Experiments in Organic Chemistry," 3rd ed, D. C. Heath and Co., Boston, Mass., 1957, p 284.

(8) L. C. Raiford and J. C. Colbert, *J. Am. Chem. Soc.*, **48**, 2652 (1926).

(9) A. F. Holleman, *Rec. Trav. Chim.*, **35**, 50 (1915).

(10) M. T. Bogert and R. L. Evans, *Ind. Eng. Chem.*, **18**, 301 (1926).

(11) J. F. Bunnett and J. J. Randall, *J. Am. Chem. Soc.*, **80**, 6020 (1958).

(12) See, however, the reaction of morpholine with 2,4-dinitrophenyl phenyl ether.[5]

(13) W. F. K. Wynne-Jones and G. Salomon, *Trans. Faraday Soc.*, **34**, 1321 (1938).

(14) W. H. Carothers, C. F. Bickford, and G. J. Hurwitz, *J. Am. Chem. Soc.*, **49**, 2908 (1927).

(15) R. P. Bell, "The Proton in Chemistry," Cornell University Press, Ithaca, N. Y., 1959, p 43.

(16) A. J. Briggs, *Trans. Faraday Soc.*, **52**, 35 (1956).

(17) M. M. Kreevoy, E. T. Harper, R. E. Duvall, H. S. Wilgus, and L. T. Ditsch, *J. Am. Chem. Soc.*, **82**, 4899 (1960).

(18) H. K. Hall, Jr., *ibid.*, **78**, 2570 (1956).

(19) These plots were linear throughout, assuring that pseudo-first-order kinetics were obeyed.

(20) J. F. Bunnett and R. H. Garst, *J. Am. Chem. Soc.*, **87**, 3879 (1965).

TABLE I

REACTIONS OF N-METHYLBENZYLAMINE, BENZYLAMINE, AND SODIUM HYDROXIDE WITH 2,4-DINITROPHENYL PHENYL ETHER IN 10% DIOXANE–90% WATER AT 29.4°. DEPENDENCE ON HYDROXIDE ION CONCENTRATION[a]

$[NaOH]_{st}$, M	$[OH^-]_{eff}$, M	$[Amine]_{eff}$, M	10^4k_ψ, sec^{-1}	% yield	10^4k_A*, sec^{-1}	10^3k_A, l. mole^{-1} sec^{-1}	10^5k_{OH},* sec^{-1}	10^4k_{OH}, l. mole^{-1} sec^{-1}
A. Reaction of N-Methylbenzylamine[b] with 2,4-Dinitrophenyl Phenyl Ether[c]								
d	0.00004	0.200	2.10	100	2.10	1.05		
0.005	0.0063	0.198	3.10	100	3.10	1.57		
0.010	0.0108	0.199	3.83	100	3.83	1.93		
0.020	0.0204	0.200	4.68	100	4.68	2.34		
0.050	0.050	0.200	6.66	100	6.66	3.33		
0.100	0.100	0.200	8.12	100	8.12	4.06		
0.150	0.150	0.200	9.57	97.8	9.40	4.70	1.70	1.13
0.200	0.200	0.200	10.70	96.0	10.25	5.12	5.50	2.75
B. Reaction of Benzylamine[b] with 2,4-Dinitrophenyl Phenyl Ether[e]								
d	0.00003	0.200	1.46	100	1.46	0.730		
0.005	0.0059	0.199	1.30	98.5	1.28	0.644		
0.020	0.0202	0.200	1.35	97.3	1.31	0.655		
0.050	0.050	0.200	1.35	93.0	1.26	0.630		
0.100	0.100	0.200	1.50	86.0	1.29	0.645	2.10	2.10
0.200	0.200	0.200	1.67	72.2	1.21	0.605	4.65	2.33

[a] Total electrolyte concentration maintained at 0.2 M by addition of sodium chloride as required. [b] $[Amine]_{st} = 0.2\ M$. [c] $[Substrate]_0 = 2.50 \times 10^{-5}\ M$. [d] N-methylbenzylaminehydrochloride = 0.2 M added instead of NaOH. [e] $[Substrate]_0 = 10^{-4}\ M$.

TABLE II

REACTIONS OF PIPERIDINE AND SODIUM HYDROXIDE WITH 2,4-DINITROANISOLE AND 2,4-DINITROPHENYL PHENYL SULFIDE IN 10% DIOXANE–90% WATER AT 29.4°. DEPENDENCE ON PIPERIDINE CONCENTRATION[a]

$[Pip]_{st}$, M	$[Pip \cdot HCl]_{st}$, M	$[Pip]_{eff}$, M	10^5k_ψ, sec^{-1}	% yield	10^5k_A*, sec^{-1}	10^4k_A, l. mole^{-1} sec^{-1}	10^6k_{OH}*, sec^{-1}	10^4k_{OH}, l. mole^{-1} sec^{-1}
A. Reaction of 2,4-Dinitroanisole[b]								
0.05	0.0027	0.0437	2.50	77.8	1.94	4.44	5.60	8.90
0.10	0.0131	0.0937	4.95	89.5	4.43	4.73	5.20	8.20
0.15	0.0233	0.1437	7.82	91.9	7.19	5.00	6.30	10.00
0.20	0.0336	0.1937	11.10	93.8	10.40	5.35	7.00	11.10
0.25	0.0441	0.2437	14.30	95.0	13.60	5.57	7.00	11.10
0.30	0.0544	0.2937	17.80	96.6	17.20	5.86	6.00	9.50
B. Reaction of 2,4-Dinitrophenyl Phenyl Sulfide[c]								
0.0375	Nil	0.0312	0.583	83.8	0.489	1.57	0.94	1.49
0.050	0.0027	0.0437	0.709	87.5	0.620	1.42	0.89	1.42
0.075	0.0079	0.0687	1.11	91.2	1.01	1.48	1.00	1.59
0.100	0.0131	0.0937	1.69	92.9	1.57	1.67	1.20	1.91
0.150	0.0233	0.1437	2.45	95.0	2.33	1.62	1.20	1.91
0.200	0.0336	0.1937	3.37	97.5	3.28	1.69	0.90	1.42
0.250	0.0441	0.2437	4.21	97.5	4.11	1.68	1.00	1.59

[a] Total electrolyte concentration maintained at 0.2 M by addition of sodium chloride as required; $[OH]_{eff}$ maintained constant = $6.30 \times 10^{-3}\ M$ by addition of appropriate amounts of piperidine hydrochloride (column [pip·HCl]). [b] $[Substrate]_0 = 2.50 \times 10^{-4}\ M$. [c] $[Substrate]_0 = 1.25 \times 10^{-5}\ M$ (low substrate solubility).

strongly catalyzed by hydroxide ions. Results are listed in Table IA. In Figure 1 k_A values are plotted against hydroxide ion concentration. The curved plot of Figure 1 resembles the corresponding plot of the reaction of piperidine with the same substrate[2,20] and with 2,4-dinitroanisole[2] and of the reaction of dimethyl amine with 4-nitrophenyl phosphate observed by Kirby and Jencks.[21] In terms of the intermediate complex mechanism this is an example where k_{-1} and k_3^{OH} [OH] have the same order of magnitude. The partial rate coefficient k_1 and the ratio k_3^{OH}/k_{-1} were calculated from the experimental data by nonlinear regression analysis[22] and are tabulated in Table IV, p 2952.

The reaction is also catalyzed by N-methylbenzylamine, as can be seen from the data set forth in Table IIIA. This constitutes the second case[24] in the series of nucleophilic aromatic substitutions with amines in which general base catalysis is demonstrated the classical way.[25,27]

A plot of k_A *vs.* the amine concentration is almost linear (Figure 2). From eq 5, which is a rearranged form

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[21] A. J. Kirby and W. P. Jencks, *J. Am. Chem. Soc.*, **87**, 3217 (1965).

[22] A modified computer program for nonlinear regression analysis developed by Kaiser[23] was used. The calculations were performed in the computer center of ETH.

[23] A. Kaiser, Ph.D. Thesis, ETH, Zürich, 1966.

[24] The reaction of piperidine with 2,4-dinitrophenyl phenyl ether was the first example.[2]

[25] In the classical experiment one determines the rates (k_A in the present case) as a function of buffer concentration, keeping the buffer ratio and the ionic strength constant.[26] For examples, where general base catalysis was demonstrated by a "nonclassical" way, see Bunnett, *et al.*[11,20] That the acceleration of this type of aminolyses is not due to general acid catalysis by the acidic buffer constituent has already been shown in several instances.[2,5,11,20]

[26] L. P. Hammett, "Physical Organic Chemistry," McGraw-Hill Book Co., Inc., New York, N. Y., 1940, p 215.

[27] It might not be unnecessary to stress here that one should carefully differentiate between amine catalysis shown to be of the general base type as found in the present and previous investigations[2,11,20] and the slight accelerations of such reactions brought about by addition of relatively large amounts of amines, as described by Ross.[28] The mechanism of these latter accelerations is still unclear but very probably does not simply involve ordinary base catalysis.[2,29]

[28] S. D. Ross, *Progr. Phys. Org. Chem.*, **1**, 31 (1963).

[29] J. F. Bunnett and R. H. Garst, *J. Am. Chem. Soc.*, **87**, 3875 (1965).

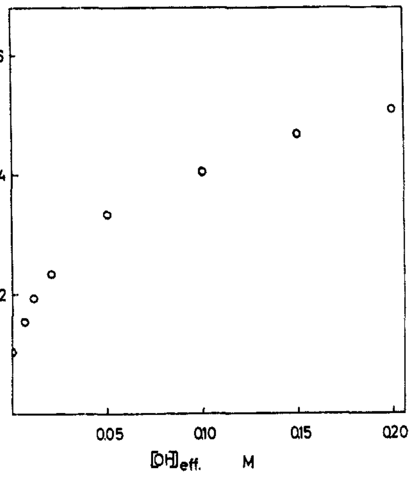

Figure 1.—Reaction of 2,4-dinitrophenyl phenyl ether with N-methylbenzylamine, catalyzed by sodium hydroxide. Data are from Table IA.

TABLE III

REACTIONS OF N-METHYLBENZYLAMINE AND BENZYLAMINE WITH 2,4-DINITROPHENYL PHENYL ETHER IN 10% DIOXANE–90% WATER AT 29.4°. DEPENDENCE ON THE AMINE CONCENTRATION[a]

$[\text{Amine}]_{st}$, M	$[\text{Amine}\cdot\text{HCl}]_{st}$, M	$10^5 k_A{}^*$, sec^{-1}	$10^4 k_A$, l. mole^{-1} sec^{-1}
A. Reaction of N-Methylbenzylamine[b]			
0.050	0.050	1.58	3.16
0.075	0.075	3.37	4.50
0.100	0.100	5.80	5.80
0.125	0.125	8.73	6.98
0.150	0.150	12.40	8.29
0.200	0.200	21.00	10.50
B. Reaction of Benzylamine[c]			
0.050	0.050	4.45	8.90
0.100	0.100	7.67	7.67
0.150	0.150	11.50	7.68
0.200	0.200	14.60	7.30

[a] Total electrolyte concentration maintained at 0.2 *M* by addition of sodium chloride as required; $[\text{substrate}]_0 = 10^{-4}$ *M*; all reactions formed 2,4-dinitrophenylbenzylamine and 2,4-dinitrophenyl-N-methylbenzylamine quantitatively; $[\text{amine}]_{st} = [\text{amine}]_{eff}$. [b] $[OH]_{eff}$ maintained at 4.30×10^{-5} *M* by addition of N-methylbenzylamine hydrochloride. [c] $[OH]_{eff}$ maintained at 2.65×10^{-5} *M* by addition of benzylamine hydrochloride.

$$\frac{k_A}{k_1 - k_A} - \frac{k_3^{OH}[OH]}{k_{-1}} = \frac{k_2}{k_{-1}} + \frac{k_3^{MBA}[MBA]}{k_{-1}} \quad (5)$$

of eq 1, the ratios k_2/k_{-1} and k_3^{MBA}/k_{-1} could easily be determined by linear regression analysis (k_1 and $k_3^{OH}[OH]/k_{-1}$ were known from the [OH] dependence); their numerical values are listed in Table IV. Values of k_{OH} for the reaction of hydroxide ion with 2,4-dinitrophenyl phenyl ether are not tabulated because the yields of 2,4-dinitrophenyl-N-methylbenzylamine were very high throughout. At high yields k_{OH} represents a small difference between two large numbers and is therefore not very precise. k_{OH} for the runs at 0.15 and 0.2 *M* sodium hydroxide concentration is 1.13×10^{-4} and 2.75×10^{-4} l. mole^{-1} sec^{-1}.[30]

Reaction of Benzylamine with 2,4-Dinitrophenyl Phenyl Ether.—Neither a fourfold increase in amine concentration nor the addition of sodium hydroxide at concentrations from 0.005 to 0.2 *M* has an accelerating effect on this reaction, as is evident from the results displayed in Table IB and IIIB. On the contrary, the second-order coefficient k_A is found to decrease by about 20% as the benzylamine concentration is increased from 0.05 to 0.2 *M*. Similar effects have been observed by Ross and Kuntz[31] in the reaction of 2,4-dinitrochlorobenzene with aniline in ethanol and in 50% ethanol–50% ethyl acetate and by Bunnett and Garst[29] in the reaction of 2,4-dinitrofluorobenzene with aniline in methanol. They held charge-transfer complex formation to be responsible; we suggest the same interpretation for the present case.[32]

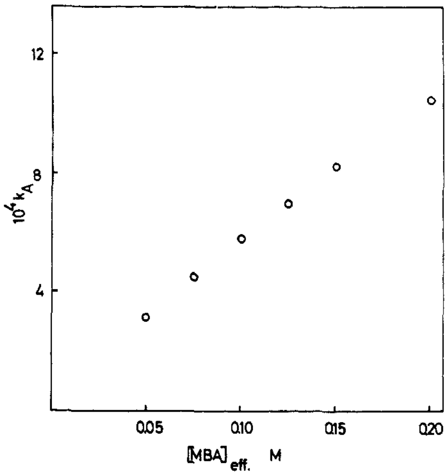

Figure 2.—Reaction of 2,4-dinitrophenyl phenyl ether with N-methylbenzylamine, catalyzed by N-methylbenzylamine. Data are from Table IA.

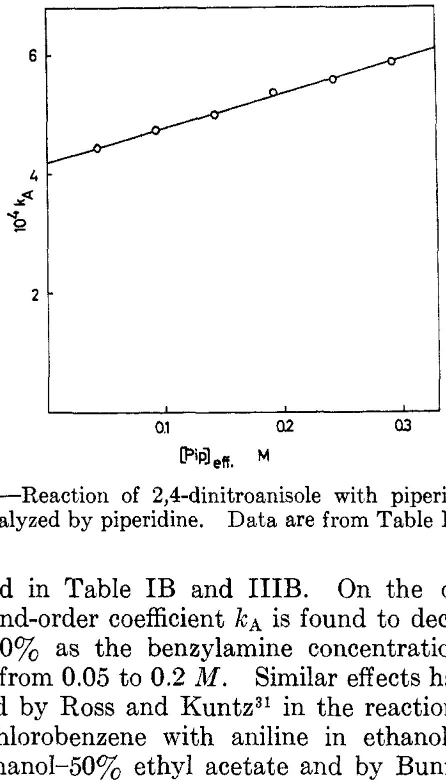

Figure 3.—Reaction of 2,4-dinitroanisole with piperidine, catalyzed by piperidine. Data are from Table IIA.

In terms of the kinetic expression 1 the reaction of benzylamine belongs to the case where $k_2 >> k_{-1}$, and therefore $k_A = k_1$. Although the second step may well be base catalyzed, such catalysis is not kinetically detectable.

k_{OH} for the reaction of hydroxide ion with 2,4-dinitrophenyl phenyl ether is tabulated for the experiments where the yield was less than 90%. The average value is 2.21×10^{-4} l. mole^{-1} sec^{-1}.[30]

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[30] Compare with 4.6×10^{-4} l. mole^{-1} sec^{-1} determined by Bunnett and Bernasconi.[2]

(31) S. D. Ross and I. Kuntz, *J. Am. Chem. Soc.*, **76**, 3000 (1954).

(32) In the system of N-methylaniline and 2,4-dinitrophenyl phenyl ether in 60% dioxane–40% water the solution shows a new broad absorption band roughly between 350 and 500 mμ immediately after mixing the compounds, although the substitution reaction to form 2,4-dinitrophenyl-N-methylaniline does not take place at a measurable rate. This behavior strongly suggests a charge-transfer complex formation: C. F. Bernasconi, unpublished observations.

Reaction of Piperidine with 2,4-Dinitroanisole. Dependence on Piperidine Concentration.—Results are displayed in Table IIA. The reaction of piperidine with 2,4-dinitroanisole is catalyzed by piperidine.[27] The second-order coefficient, k_A, is linearly dependent on piperidine concentration, as can be seen from Figure 3. By means of eq 6, which is the appropriate one to

$$k_A = k_1\frac{k_2}{k_{-1}} + k_1\frac{k_3^{OH}}{k_{-1}}[OH] + k_1\frac{k_3^{pip}}{k_{-1}}[pip] \tag{6}$$

use when k_A is linearly dependent on base concentration, k_2/k_{-1} and k_3^{pip}/k_{-1} can, in principle, be dissected (k_1 and k_3^{OH}/k_{-1} are known from determinations by Bunnett and Bernasconi[2]). In practice only k_3^{pip}/k_{-1} could be determined accurately. k_1k_2/k_{-1} is the intercept of a regression line minus $k_1k_3^{OH}[OH]/k_{-1}$ and represents a very small difference between very large numbers; its value is much smaller than the standard deviation of the regression line (eq 6) and therefore cannot be computed by this method. However, the values of k_2/k_{-1} may be estimated assuming that relation 7 approximately holds.[33] The values of

$$\left(\frac{k_3^{OH}}{k_3^{pip}}\right)_{OPh} : \left(\frac{k_3^{pip}}{k_2}\right)_{OPh} = \left(\frac{k_3^{OH}}{k_3^{pip}}\right)_{OMe} : \left(\frac{k_3^{pip}}{k_2}\right)_{OMe} \tag{7}$$

k_2/k_{-1} and k_3^{OH}/k_2 given in Table IV are calculated from eq 7.

The values of k_{OH}, for the reaction of hydroxide ion with 2,4-dinitroanisole, are in good agreement with the average value of 8.2×10^{-4} l. mole^{-1} sec^{-1} determined by Bunnett and Bernasconi.[2]

Reaction of Piperidine with 2,4-Dinitrophenyl Phenyl Sulfide. Dependence on Piperidine Concentration.—The second-order coefficient, k_A, turned out to be independent of piperidine concentration, as is evident from Table IIB. Bunnett and Bernasconi[2] have shown the reaction to be moderately sensitive to hydroxide ion catalysis when the piperidine concentration was 0.3 *M*. There was some uncertainty about the significance of this catalysis, and two possible explanations were proposed: (1) the reaction is indeed only slightly sensitive to base catalysis, or (2) the sensitivity to base catalysis is strong but the high piperidine concentration has made the expression $k_2 + \Sigma k_3^B[B] > k_{-1}$ by a large contribution of the term $k_3^{pip}[pip]$; in that case the plot of k_A as a function of hydroxide ion concentration would already have passed over the region of steep rise even at low concentrations and would only show the slight, nonlinear dependence on hydroxide ion concentration actually observed. The present results settle the question in favor of the first alternative.[34]

The agreement between values of k_{OH}, the rate coefficient of the hydrolysis of 2,4-dinitrophenyl phenyl sulfide determined in this investigation, with the average of 3.1×10^{-4} l. mole^{-1} sec^{-1} from a previous study[2] is only fair.

Discussion

In Table IV several quantities interesting from a mechanistic point of view are assembled. It is a well-known fact that nucleophilicity toward aromatic carbon is somewhat related to basicity of the nucleophile.[36] In the series of the secondary amines, piperidine, N-methylbenzylamine, and morpholine,[37] k_1 decreases monotonically with decreasing basicity, but a plot (not shown) of log k_1 *vs.* pK is not quite linear. Although we did not *a priori* expect a linear relation between log k_1 and pK, it is interesting to draw a straight line between the points of piperidine and morpholine and calculate a hypothetical value of k_1 for the N-methylbenzylamine reaction from this line. The value for k_1 so estimated is 9.2×10^{-3} l. mole^{-1} sec^{-1} and might well be closer to the true value if one assumes charge-transfer complex formation to be similarly important as in the benzylamine case.

The point for benzylamine does not even approximately conform to the above plot; benzylamine is less nucleophilic than morpholine although the latter is less basic. This compares well with results of Suhr and Grube,[38] who found morpholine to react about eleven times faster with 4-nitrofluorobenzene than benzylamine in dimethyl sulfoxide.

Also the reaction of 2,4-dinitrochlorobenzene[39] and of 4-nitrophenylphosphate[21] with dimethylamine is much faster than with methylamine, whereas the pK's are very similar. Other things being equal, secondary amines seem to be more nucleophilic toward aromatic carbon than primary amines.

The ratio k_2/k_{-1} increases from 10^{-4} to 0.15 by changing the leaving group from methoxy to thiophenoxy (reactions with piperidine). This change reflects mainly the influence of leaving group mobility on k_2. The same ratio also increases considerably with increasing basicity of the amine in the series morpholine, N-methylbenzylamine, and piperidine (reactions with 2,4-dinitrophenyl phenyl ether). Inasmuch as k_{-1} pertains to the reverse step of a nucleophilic addition, it should decrease with increasing basicity of the amine. Here the variation in k_2/k_{-1} therefore primarily expresses changes in k_{-1}.

It is evident from Table IV that the steric requirements of the amine have also a deep influence on the ratio k_2/k_{-1}; the reaction of 2,4-dinitrophenyl phenyl ether with the primary, sterically more favored benzylamine has $k_2/k_{-1} >> 1$, whereas for the secondary N-methylbenzylamine $k_2/k_{-1} = 0.005$. The leaving group being the same and, therefore, k_2 probably being very similar for both reactions, this drastic change reflects strongly the steric effects on k_{-1}. An analogous observation has been made by studying the reaction of benzyl- and N-methylbenzylamine with 2,4-dinitrofluorobenzene in benzene solution: $k_2/k_{-1} = 0.077$ for the former, and $k_2/k_{-1} << 1$ (linear dependence on base

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[33] The assumption relies upon the fact that the leaving groups methoxy and phenoxy are both oxygen bases and may behave similarly as far as base catalysis is concerned. In the case of 2,4-dinitrophenyl phenyl sulfide this assumption would lead to wrong conclusions.

[34] One is tempted to calculate the ratio k_2/k_{-1} from the present results by inserting the previously determined values[2,35] for k_1 and k_3^{OH}/k_{-1} ($k_3^{pip}/k_{-1} = 0$) into the following equation. As the value of k_3^{OH}/k_{-1} is subject to

$$\frac{k_2}{k_{-1}} = \frac{k_A}{k_1} - \frac{k_{3OH}}{k_{-1}}[OH]$$

a rather high uncertainty due to experimental reasons,[2] a corresponding uncertainty in k_2/k_{-1} will result. The value for k_2/k_{-1} given in Table IV is therefore put in parentheses and should be regarded with some caution, although it is probably in the right order of magnitude.

[35] C. F. Bernasconi, Ph.D. Thesis, ETH, Zürich, 1965.

[36] J. F. Bunnett, *Ann. Rev. Phys. Chem.*, **14**, 271 (1963), and references cited therein.

[37] See following paper.[5]

[38] H. Suhr and H. Grube, *Ber. Bunsenges. Physik. Chem.*, **70**, 544 (1966).

[39] O. L. Brady and R. F. Cropper, *J. Chem. Soc.*, 507 (1950).

TABLE IV

REACTIONS OF 1-SUBSTITUTED-2,4-DINITROBENZENES WITH AMINES IN 10% DIOXANE–90% WATER AT 29.4°. DISSECTION OF RATE COEFFICIENTS[a]

Amine	pK_a	Leaving group	pK_a	10^3k_1, l. mole^{-1} sec^{-1}	k_2/k_{-1}	k_3^{am}/k_{-1}, l. mole^{-1}	k_3^{OH}/k_{-1}, l. mole^{-1}	k_3^{OH}/k_2, l. mole^{-1}
Piperidine	11.06	Methoxy	≈16.7[b]	3.77[c]	≈0.0001[d]	0.15	25.7[c]	≈250000
Piperidine	11.06	Phenoxy	9.99[e]	31.1[c]	0.069[f]	7.86[f]	121[f]	1750
Piperidine	11.06	Thiophenoxy	6.52[g]	0.84[c]	(0.15)[h]	≈0	(6.55)[h,i]	(43)[h]
N-Methylbenzylamine	9.58	Phenoxy	9.99[e]	6.40	0.005	0.96	17.2	3500
Morpholine	8.36[j]	Phenoxy	9.99[e]	3.33	0.0015	0.13	11.9	7900
Benzylamine	9.37	Phenoxy	9.99[e]	0.89	≫1			

[a] The uncertainty in k_1, k_2/k_{-1}, k_3^{am}/k_{-1}, k_3^{OH}/k_{-1}, and k_3^{OH}/k_2 lies within ±10% where not otherwise stated (see text). [b] See ref 15. [c] Values taken from ref 2. [d] Estimated value from eq 7; see text. [e] See ref 16. [f] Recalculated values from data of ref 2 by means of a computer program. [g] See ref 17. [h] See footnote 34. [i] See ref 35. [j] See ref 18.

concentration) for the latter reaction.[40] Bunnett and Randall[11] have found that $k_2/k_{-1} = 0.071$ for the reaction of 2,4-dinitrofluorobenzene with N-methylaniline in 60% dioxane–40% water, whereas Bunnett and Garst[29] showed the analogous reaction with aniline not to be base catalyzed ($k_2/k_{-1} >> 1$). Here again steric strain in the intermediate is seen to have a large effect on k_{-1}.

As we have pointed out in the introduction our main interest lies in the ratio k_3^{B}/k_2 (or more specifically in k_3^{OH}/k_2), *i.e.*, in the relative catalytic effectiveness of base B compared with the solvent (which is a measure of sensitivity to base catalysis) and its relation to entering amine and leaving group.

As evident in the last column of Table IV, k_3^{B}/k_2 (here k_3^{OH}/k_2) increases strongly with increasing basicity of the leaving group. This phenomenon seems to be rather general, also appearing in the reactions of *p*-anisidine with 2,4-dinitrofluoro- and 2,4-dinitrochlorobenzene in benzene with the basic catalyst 1,4-diaza[2.2.2]bicyclooctane (DABCO): the ratio $k_3^{\mathrm{DA}}/k_2 \geqslant 5500$ in the case of fluorine, and $k_3^{\mathrm{DA}}/k_2 = 980$ in the case of chlorine as leaving group.[41] Another example is the ratio $k_3^{\mathrm{pip}}/k_{-1}$ for piperidine-catalyzed reactions of piperidine with 1-substituted 2,4-dinitrobenzenes in benzene. When the leaving group is chlorine, $k_3^{\mathrm{pip}}/k_{-1} \cong 0$;[42] when it is fluorine, $k_3^{\mathrm{pip}}/k_{-1} = 1230$;[43] when it is phenoxy, $k_3^{\mathrm{pip}}/k_{-1} \cong \infty$.[44] In the reaction of ammonia with *para*-substituted phenyl acetates, Bruice and Mayahi[45] have found that the ratio $k_{\mathrm{NH_3}}/k_{\mathrm{u}}$ ($k_{\mathrm{NH_3}}$ is the ammonia-catalyzed and k_{u} is the uncatalyzed reaction path) increased with increasing basicity of the leaving group. Base-catalyzed aminolyses of esters are thought to proceed by a very similar mechanism as aminolyses of aromatic substrates;[46] thus the analogy to our results ($k_{\mathrm{NH_3}}/k_{\mathrm{u}}$ corresponds to our k_3^{B}/k_2) is striking.

On the other hand, k_3^{OH}/k_2 is but weakly influenced by the basicity of the amine (Table IV). In contrast to these findings, k_3^{B}/k_2 increases considerably in the reactions of 2,4-dinitrofluorobenzene with the same amines in benzene.[40,47]

The aminolysis of phenyl acetate in aqueous solution is another example where k_3^{OH}/k_2 increases very much going to less basic amines.[48]

There remains the task to interpret all these findings in mechanistic terms. This will be done in the third paper[6] of this series, where the whole problem will be approached in a more general way.

Registry No.—Dioxane, 123-91-1; water, 7732-18-5; piperidine hydrochloride, 6091-44-7; benzylamine hydrochloride, 3287-99-8; N-methylbenzylamine hydrochloride, 13426-94-3; 2,4-dinitrophenyl phenyl ether, 2486-07-9; 2,4-dinitroanisole, 119-27-7; 2,4-dinitrophenyl phenyl sulfide, 2486-09-1; N-(2,4-dinitrophenyl)piperidine, 839-93-0; N-(2,4-dinitrophenyl)benzylamine, 7403-38-5; N-(2,4-dinitrophenyl)-N-methylbenzylamine, 13426-96-5.

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[42] F. Pietra and A. Fava, *Tetrahedron Letters*, 1535 (1963).

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[45] T. C. Bruice and M. F. Mayahi, *J. Am. Chem. Soc.*, **82**, 3067 (1960).

[46] J. F. Bunnett and G. T. Davis, *ibid.*, **82**, 665 (1960).

[47] C. F. Bernasconi, G. Becker, and H. Zollinger, *Helv. Chim. Acta*, **50**, 10 (1967).

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