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EFFECT OF TEMPERATURE ON AMINE CATALYZED AROMATIC NUCLEOPHILIC SUBSTITUTION

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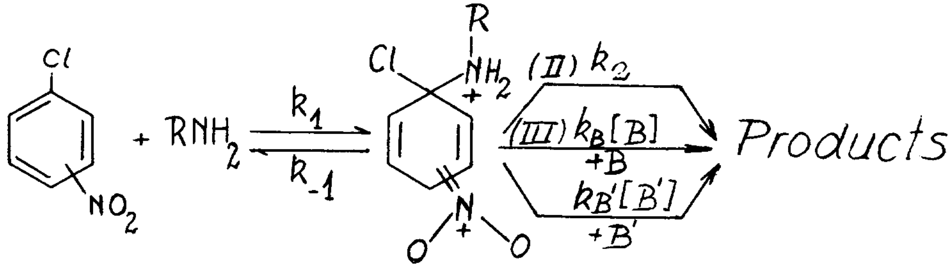
THE base catalyzed mechanism of aromatic nucleophilic substitution by amines, represented by scheme I, has been studied by many investigators since it was first proposed by Brady and Cropper(1). Nevertheless some aspects of it, as for example temperature effect, about which we report here, are not completely understood. The bases B, B', etc. can be the nucleophile itself or other bases present.



(I)

By applying steady state theory

$$k_T = (k_1 \cdot k_2 + k_1 \sum k_{Bi}\ [Bi])/(k_{-1} + k_2 + \sum k_{Bi}\ [Bi]) \qquad (II)$$

is obtained, where k_T is the experimentally measured rate.

When the nucleophile is the only base which participates and assuming that $k_{-1} \gg k_2 + k_B\ [B]$ this equation takes the form

$$k_T = k_1 \cdot k_2/k_{-1} + k_1 \cdot k_B\ [B]\ /k_{-1} = k_o + k_3\ [B]\ . \qquad (III)$$

Then a linear relation between k_T and $[B]$ must be observed.

If the conditions of the reaction lead to a relation $k_{-1} \approx k_2 + k_B\ [B]$ the only valid kinetic equation will be (II) and a graph of k_T vs. $[B]$ will be a curve whose

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slope gradually diminishes as [B] increases, until it becomes almost zero.

The cause and significance of the k_T increments as [B] increases are a source of disagreement between different authors(2)(3). In this communication we wish to contribute to the understanding of the influence of temperature on these k_T increments and hence of the above disagreements.

In the reaction of ortho-chloronitrobenzene with piperidine in benzene at 75º a linear increase of k_T with the nucleophile concentration is observed; by linear regression of k_T over [B] , the values:

$k_o = 25.7 \times 10^{-6}$ l.mol^{-1}.sec.$^{-1}$ and $k_3 = 2.6 \times 10^{-5}$l^2.mol^2.sec.$^{-1}$ were obtained.

Variations of k_T similar to ours, on increasing the nucleophile concentration, have been considered to be relatively small and were attributed to a solvent effect(2). The increments observed, however, in the reaction of o-chloronitrobenzene with piperidine studied here are, in our opinion, a genuine base catalysis effect which obviously is also influenced by the reaction medium, for the following reasons:

a) The addition of piperidine to benzene increases the polarity of the medium; however, k_T increases with the quantity of piperidine in benzene, in spite of which it has been observed in our Laboratory that this reaction, at the same nucleophile concentration, is slower in more polar media:

   k_T in methanol = 8.9×10^{-6}l.mol^{-1}sec.$^{-1}$; k_T in benzene = 27.7×10^{-6}l.mol^{-1}.sec.$^{-1}$.

b) An increase in the piperidine concentration always causes an increase in k_T whether the solvent be more polar (methanol) or less polar (benzene) than piperidine(4).

c) On measuring k_T at increasing concentrations of piperidine added to benzene at 45º, 60º and 75º, the specific rates k_o and k_3 each comply separately with Arrhenius' equation, $\ln k = \ln A - E/RT$, which would hardly be the case if the k_T increase were only due to a solvent effect.

   The differences between the values of the thermodynamic parameters of the catalyzed (k_B) and non-catalyzed (k_2) steps are: $E^*_B - E^*_2 = -5.2$ Kcal/mol and $\Delta S^*_B - \Delta S^*_2 = 11.3$ e.u. which shows that the catalyzed step has a lower activation energy and requires more arranging.

d) It was also seen that on keeping constant the ratio o-$(NO_2)C_6H_4Cl/C_5H_{10}NH$ =

0.07M/0.7M, k_T increases linearly with the addition of increasing quantities of pyridine, an amine that in the reaction conditions used does not have nucleophilic action, whether the reaction takes place in methanol (more polar than pyridine) or in benzene (less polar)$^{(4)}$.

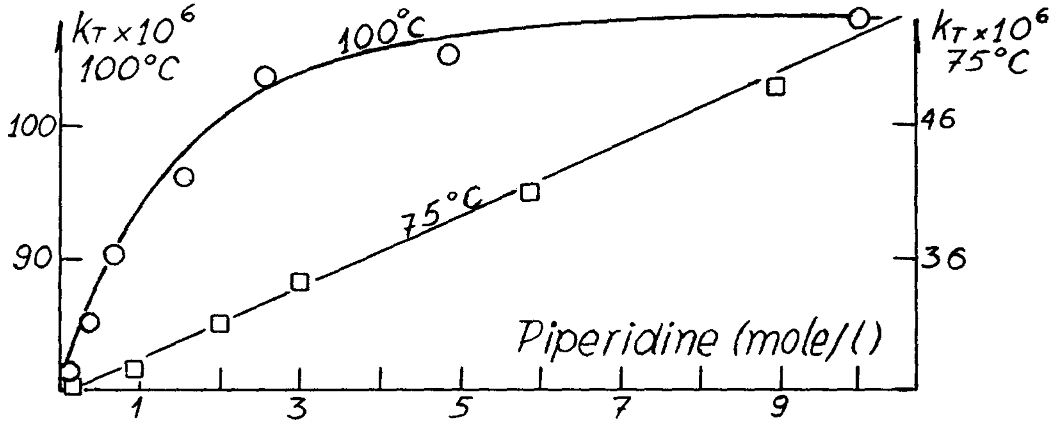
We would now like to draw attention to an effect of temperature on the variation of the k_T constant with the concentration of amine in the reaction of o-chloronitrobenzene with piperidine in benzene. While the variation at 75º C is linear, at 100º C it is not so (Table I and Graph I) which shows that $k_{-1} \gg k_2 + k_B$ [B] no longer holds good but rather $k_{-1} \approx k_2 + k_B$ [B] and consequently equation II applies instead of equation III.

TABLE I

k_T values for the reaction of o-chloronitrobenzene with piperidine, in benzene, at different initial concentrations of this amine, at 75ºC and 100º C

75º C			100º C		
ArCl mole.l^{-1}	Piperidine mole.l^{-1}	$k_T \times 10^6$ l.mole^{-1}.sec^{-1}	ArCl mole.l^{-1}	Piperidine mole.l^{-1}	$k_T \times 10^6$ l.mole^{-1}.sec^{-1}
0.1103	0.2662	26.1	0.0732	0.160	80.9
0.1099	0.9824	27.7	0.0756	0.393	85.0
0.1099	2.0347	31.3	0.0750	0.720	90.3
0.1101	3.0349	34.1	0.0751	1.610	96.0
0.1099	5.8841	40.9	0.0698	2.540	104.1
0.1101	8.9975	48.6	0.0728	4.890	105.0
			0.0767	10.000	108.0

Graph I. Plots of TABLE I data.



The values k_1 = 1104 x 10^{-7} $l.mole^{-1}sec.^{-1}$, k_B/k_{-3} = 4.12 $l.mole^{-1}$ and k_2/k_{-1} = 1.92 were calculated for this case by Bunnett's method(5). We agree with this author's view that this kinetic behavior supports the proposed base catalyzed mechanism.

Recently Pietra reported (6) that at 25º there is a linear relation between k_T and piperidine concentration in the reaction of 4-chloro-3-nitrobenzotrifluoride with piperidine in benzene, while we had observed in a previous work(7) a relation at 35º between these two parameters similar to that presented now by o-chloronitrobenzene at 100º C.

These results(6)(7) are of a similar pattern to those reported above and would appear to indicate that in the reactions studied not only do the concentration of the nucleophile, the catalyst and the polarity of the medium influence the mechanism, but also the temperature. This may not allow a strict comparison of studies made at different temperatures, even though the same reaction is formally involved, simply because there may have been a change in the relative rates of the straightforward and base catalyzed decomposition pathways of the intermediate. (II vs. III in scheme I).

The temperature effect would then be the reason why Pietra did not find an isotope effect at 25º(6) while we did at 35º in the reaction of 4-chloro-3-nitrobenzotrifluoride with piperidine in benzene(7).

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