Tetrahedron Letters No.46, pp. 5701-5706, 1966. Pergamon Press Ltd.
Printed in Great Britain.

BIFUNCTIONAL CATALYSIS IN ACTIVATED NUCLEOPHILIC AROMATIC SUBSTITUTION.

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(Received 7 September 1966)

It is known (1,2) that the reaction of fluro-2,4-dinitro-benezene (FDNB) with piperidine (PIP) in benezene follows rate law 1:

$$\text{Rate}/\left[\text{FDNB}\right]\left[\text{PIP}\right] = \underline{k}_u + \underline{k}_{\text{PIP}}\left[\text{PIP}\right] \qquad (1)$$

This reaction has been found to undergo base catalysis (3).

We report here some new kinetic data which show that bifunctional catalysis may be important in such reaction. These data concern the reaction of FDNB or chloro-2,4-dinitrobenezene (CDNB) with piperidine in benezene at 25°C in the presence of such addenda as α-pyridone, N-methyl-α-pyridone or phenol. The yield of N-(2,4-dinitrophenyl) piperidine is quantitative also in the presence of these addenda.

Data of Fig.1 show that at constant piperidine concentration (5.2×10^{-4} M) the second-order rate coefficient for the reaction of FDNB (2.5×10^{-5} M) increases less than linearly with increasing stoichiometric phenol or α-pyridone concentration but well linearly with increasing concentration of monomeric (4) α-pyridone, while N-methyl-α-pyridone does not affect the rate.

These results can be compared with those obtained for the reaction of CDNB which is known (1) to follow a simple second-order rate law. In this case the addition of α-pyridone up to 0.036 M - at constant (5.2×10^{-4} M) piperidine concentration - has no appreciable kinetic effect. Moreover, the addition of phenol - at constant (5.2×10^{-4} M) piperidine concentration -

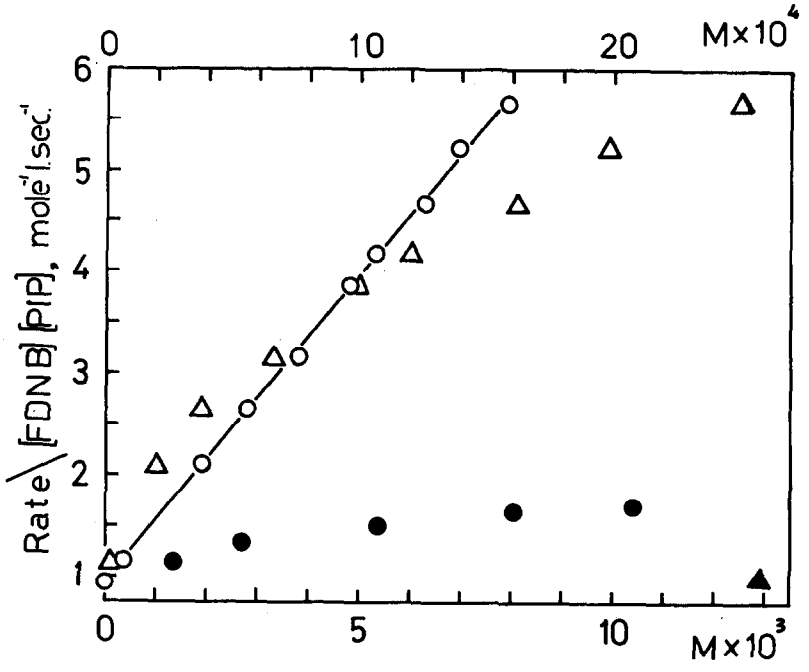


FIG.1. Second-order rate coefficient for reaction of FDNB with piperidine, as a function of the concentration of added: N-methyl-α-pyridone, closed triangles, phenol, closed circles; stoichiometric α-pyridone, open triangles; monomeric -pyridone, open circles (upper scale).

markedly lowers the rate: the second-order rate coefficient changing from 0.0857 mole^{-1}l.sec.$^{-1}$, in the absence of addenda (1) , to 0.0649, 0.0464, and 0.0197 mole^{-1}l.sec.$^{-1}$ in the presence of phenol 0.0027, 0.0081, and 0.027 M, respectively.

Another set of data for the reaction of FDNB (2.5 x 10^{-5} M) shows that (Fig.2) the second-order rate coefficient in the absence of addenda (1) or at constant α-pyridone concentration (stoichiometric 3.3 x 10^{-3}M, monomeric (4) 7.6 x 10^{-4} M) or phenol concentration (2.7 x 10^{-3} M) increases linearly with increasing

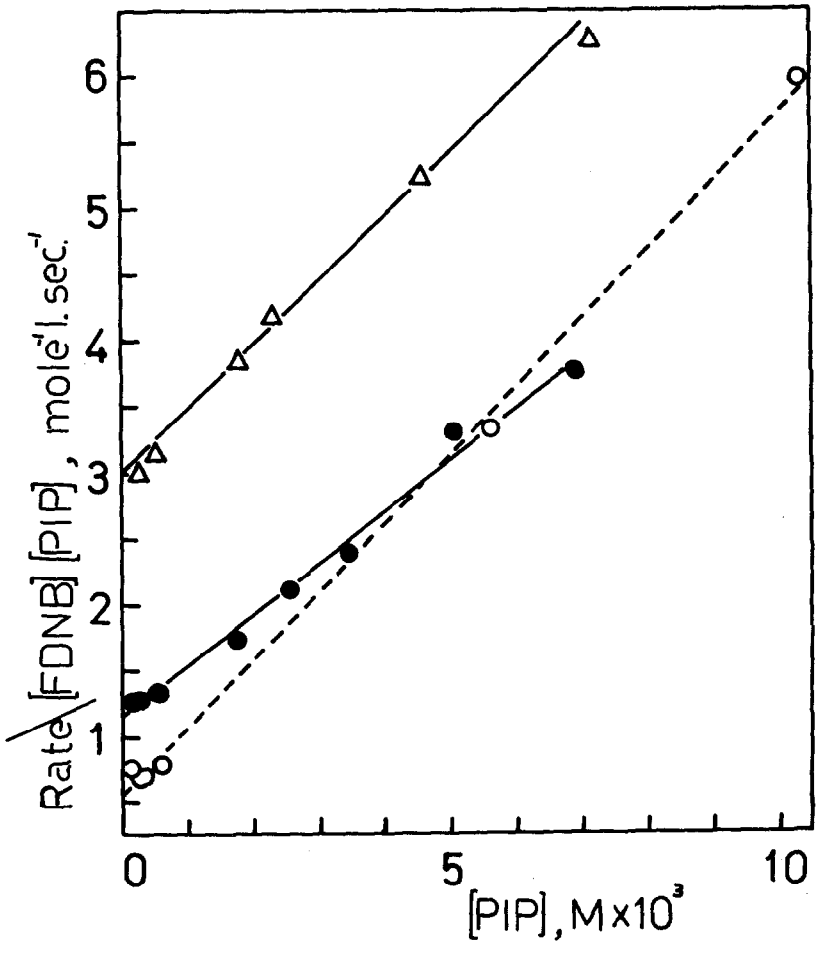


FIG.2. Second-order rate coefficient for reaction of piperidine with FDNB, as a function of piperidine concentration. Open circles, without addenda; closed circles, plus phenol 2.7×10^{-3} M; open triangles, plus α-pyridone 3.3×10^{-3} M.

piperidine concentration.

The catalytic coefficient of ∝-pyridone, $\underline{k}_{\alpha\text{-pyr}}$, calculated as the slope of the straight line of Fig. 1 for monomeric ∝-pyridone, is 3010 mole^{-2}l.^{2}sec.$^{-1}$. This value agrees well with that (3200 mole^{-2}l.^{2}sec.$^{-1}$) extrapolated to zero piperidine concentration from data of Fig.2 fitted into equation 2

$$\text{Rate}/\left[\text{FDNB}\right]\left[\text{PIP}\right] = \underline{k}_{u} + k_{\alpha\text{-pyr}}\left[\alpha\text{-pyr}\right] \qquad (2)$$

where ∝-pyr stands for monomeric ∝-pyridone. This good agreement proves that the catalytic activity of dimeric ∝-pyridone can be neglected - as we have done - and that interaction between piperidine and ∝-pyridone is not of much importance.

In the case of phenol it is seen from Fig. 1 that the rate data can be fitted into an equation akin to 2—in which stoichiometric phenol concentration is substituted for $\left[\alpha\text{-pyr}\right]$ —only up to about 3 x 10^{-3} M phenol. In this range of phenol concentration the catalytic coefficient, $\underline{k}_{\text{PhOH}}$, calculated as above for ∝-pyridone, results 150 or 220 mole^{-2}l.^{2}sec.$^{-1}$ from data of Fig. 1 or 2, respectively. Interaction between phenol and piperidine should be mainly responsible for this disagreement. This is likely in view of the curvature of the phenol plot of Fig. 1 and of the crossing of the lines (Fig. 2) in the presence and in the absence of piperidine.

The catalytic coefficients obtained here and in previous works (1,2,3) are listed in the Table.

These results can be rationalized on the basic of the intermediate complex mechanism (5), with the formation of the intermediate rate determining in the case of CDNB (1). Acidic substances like phenol or methanol lower the rate of reaction of CDNB - the former much more than the latter (3) - most probably because of hydrogen bonding with the nucleophile.

In the case of FDNB, decomposition of intermediate I must be rate limiting. Examination of the Table shows that the reaction of FDNB is catalyzed by substances having either the

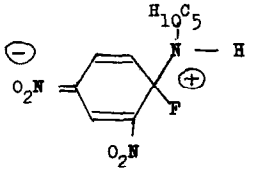
TABLE

Reaction of FDNB with piperidine in benezene at 25°C. Catalytic coefficient of various addenda.

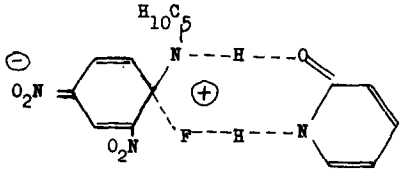
Added substance	Catalytic coefficient (a), mole $^{-2}$l.^{2}sec.$^{-1}$
α-pyridone	3200
Piperidine (b)	600
Phenol	220
Triethylenediamine (c)	32
Methanol (c,b)	21
Pyridine (c)	2
Triethylamine (b)	0
N-methyl-α-pyridone	0

(a) See text; (b) Ref.1,2; (c) Ref.3.

predominant character of bases or that of acids. However, the most efficient catalyst, α-pyridone, is very much weaker as a base (in water) than pyridine (6) and much weaker as an acid (in water) than phenol (6). The only likely explanation is that α-pyridone acts as a bifunctional catalyst assisting the concerted separation of both ammonium proton and fluoride from intermediate I. The rate limited transition state would then be approximated by II



(I)



(II)

This interpretation* is substantiated by the finding that N-methyl-α-pyridone which, compared to α-pyridone lacks the acidic hydrogen, is devoid of any catalytic activity.

Molecular models show that γ-pyridone, contrary to α-pyridone, cannot assume in the transition state the orientation required

* The third-order term, k_{PIP}, of equation 1 above has been suggested to arise from piperidine acting as a bifunctional catalyst (7). However, the present results are not able to support such hypothesis, even if they do not reject it.

for effective bifunctional catalysis. Therefore, our expectation was that γ-pyridone would be a very poor catalyst for the reaction of FDNB. This is a well known test for bifunctional catalysis (8,9). However, in our hands, benzene at 25°C failed to dissolve more than 9×10^{-5} M γ-pyridone. At this concentration γ-pyridone does not affect appreciably the rate while α-pyridone has a miserable effect (Fig. 1). Thus the above test is inconclusive here. These results show that previous conclusion (9), that, in a reaction similar to ours, γ-pyridone cannot be an effective bifunctional catalyst as its acidic and basic functions are too far apart, were not warranted.

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