Tetrahedron. Vol 24, pp. 2367 to 2375. Pergamon Press. 1968. Printed in Great Britain

THE KINETICS OF THE TRIETHYLENEDIAMINE-CATALYSED AMINOLYSIS OF PHENYL N-PHENYLCARBAMATES WITH ANILINE IN DIOXAN

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(*Received in Japan* 15 *March* 1967; *accepted for publication* 15 *May* 1967)

Abstract—The rates of aminolysis of *p*-substituted phenyl N-phenylcarbamates with aniline in dioxan forming N,N'-diphenylurea and corresponding phenols were followed by UV spectrophotometry. The rates of the reaction of phenyl, *p*-tolyl and *p*-methoxyphenyl N-phenylcarbamates having an electron-releasing group satisfied the equation: $v = k[\text{TED}][\text{ester}]$. Here, triethylenediamine used as catalyst is abbreviated as TED. Introduction of an electron-releasing group into the ester retarded the reaction with Hammett's ρ value of $+1{\cdot}63$. On the other hand, the electron-attracting groups in the esters accelerated the reactions which satisfy the third-order kinetics. For example, the rate of the reaction of *p*-chlorophenyl N-phenylcarbamate with aniline was illustrated by the following equation.

$$v' = k_3[\text{TED}][\text{ester}][\text{aniline}]$$

p-Nitrophenyl N-phenylcarbamate reacted with aniline in the presence or even in the absence of catalyst.

$$v'' = \{k_2 + k_3[\text{TED}]\}[\text{ester}][\text{aniline}]$$

The above described reactions were catalysed only by tertiary amine. Moreover, the conductive substances and the new absorption bands in UV spectra were obtained only on the reaction of esters and TED. A probable mechanism which involves an ion pair of quaternary ammonium salt as a quasi-stable incipient intermediate, followed by a rapid attack on aniline, has been discussed.

SEVERAL mechanisms for the reaction of aminolysis or amidation have been discussed and in particular, the special base catalysis indicated by Betts and Hammett[1] has been refuted. The mechanisms which have been proposed are: (a) general base-acid catalysis,[2] (b) general base catalysis[3] and (c) concerted mechanism.[4] The difference between mechanisms a and b is only on the rate-determining step, and that between a and c is only on the catalytic step whether consecutive (mechanism a) or simultaneous (mechanism c). In each of the three mechanisms, all of the reactions, performed by Bunnett, Jencks and or Bruice, proceed without difficulty even in the absence of a catalyst. It is therefore, difficult to confirm a catalytic step. Thus, the authors are in doubt whether the N-atom of the amide formed is the N-atom of the amine which has reacted with the carbonyl carbon of the ester in the beginning of the reaction.

In order to determine this point, a reaction which only proceeds with the aid of a catalyst was selected. The reactions of *p*-substituted phenyl N-phenylcarbamates with aniline in the presence of TED satisfy the provision except *p*-nitrophenyl N-phenylcarbamate (NPC).

RESULTS AND DISCUSSIONS

Kinetics

The rate data of TED-catalysed aminolysis of phenyl N-phenylcarbamate (PPC) with aniline in dioxan at 80° are shown in Tables 1 and 2. The rate follows the first-order equation. The plots of the first-order rate constant *vs* the concentration of catalyst gives a straight line passing through the origin as illustrated in Fig. 1. Therefore, the rate is given by the following equation.

$$v = k_1[\text{ester}], \quad k_1 = k[\text{TED}] \tag{1}$$

TABLE 1. THE ORDER OF THE REACTION OF PPC WITH ANILINE IN THE PRESENCE OF TED IN DIOXAN AT 80°

conc of PPC and aniline: both 0·1M conc. of TED: 0·02M

Time (min)	$\log \frac{a}{a-x}$	$k_1{}^a$ 10^{-5} sec^{-1}	$\frac{x}{a(a-x)}$	$k_2{}^b$ 10^{-4} l mole^{-1} sec^{-1}
0				
15	0·032	8·23	0·77	8·55
33	0·072	8·50	1·81	9·13
90	0·200	8·53	5·86	10·85
150	0·316	8·07	10·70	11·88
210	0·460	8·38	18·85	14·95
240	0·519	8·23	23·05	16·01
		Av. 8·32		

[a] These values were calculated as the first-order with PPC.

[b] These values were calculated as the first-order with PPC and aniline, respectively.

TABLE 2. THE CONSTANCY OF APPARENT FIRST-ORDER RATE CONSTANT WITH VARIOUS CONCENTRATION OF PPC AND ANILINE IN THE REACTION MIXTURE WITH 0·02M TED AT 80°

Initial conc. of PPC 10^{-2}M	Initial conc. of Aniline 10^{-2}M	k_1 10^{-5} sec^{-1}
5	10	8·22
10	10	8·32
15	10	8·22
10	5	7·98
10	15	8·32

Here, the rate constant, k, is independent of the concentration of aniline. Therefore, it is assumed that the rate-determining step is the reaction of PPC and TED forming an intermediate, followed by a rapid attack on aniline to form N,N'-diphenylurea (DPU). The energy of activation of this reaction was calculated to be 20·9 kcal/mole from the average values of $k \times 10^3$ l mole^{-1} sec^{-1}: 70°, 1·77; 75°, 2·54; 80°, 4·16.

The ester having an electron-releasing group such as *p*-tolyl and *p*-methoxyphenyl N-phenylcarbamate (abbreviated as TPC and MPC, respectively) satisfied the Eq. 1. The reaction was retarded by the introduction of an electron-releasing group

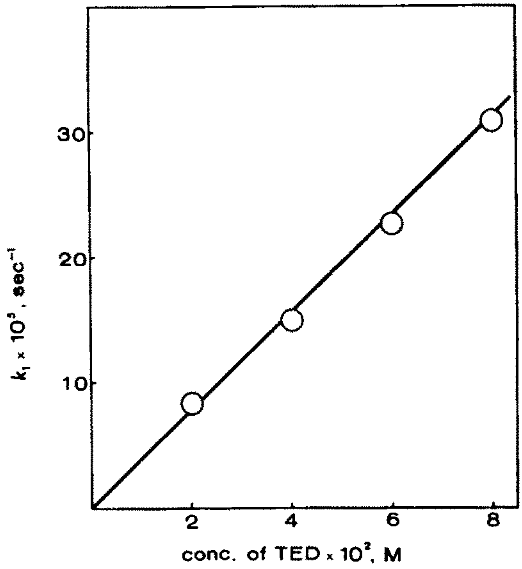

FIG. 1 The plots of the first-order rate constant *vs* the concentration of TED on the reaction of PPC with aniline in dioxan at 80°

conc. of PPC and aniline: each 0·1M

into the Ph group of the ester and the Hammett's plot gave a positive ρ value of $+1{\cdot}63$ as shown in Fig. 2.

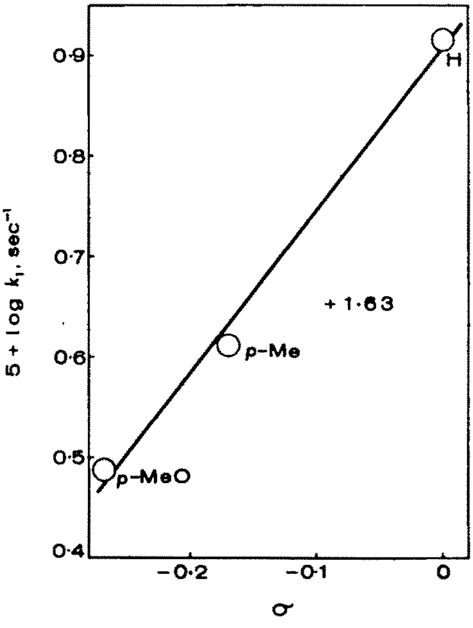

FIG. 2 Hammett plots for the aminolysis of the esters having an electron-releasing group with aniline at 80°

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On the other hand, the ester having an electron-attracting group such as *p*-chlorophenyl or *p*-nitrophenyl N-phenylcarbamate (abbreviated as CPC and NPC, respectively) satisfied the accompanying general equation.

$$v_{gen} = k_{2obs}[\text{ester}][\text{aniline}], \quad k_{2obs} = k_2 + k_3[\text{TED}]$$

The values of $k_2 \times 10^2$ l mole^{-1} sec^{-1} and $k_3 \times 10^2$ l^2 mole^{-2} sec^{-1} of CPC obtained from Fig. 3 were 0 and 0·32, respectively. Therefore, the kinetics for the aminolysis of CPC is given by the following equation:

$$v' = k_3[\text{TED}][\text{ester}][\text{aniline}] \qquad (2)$$

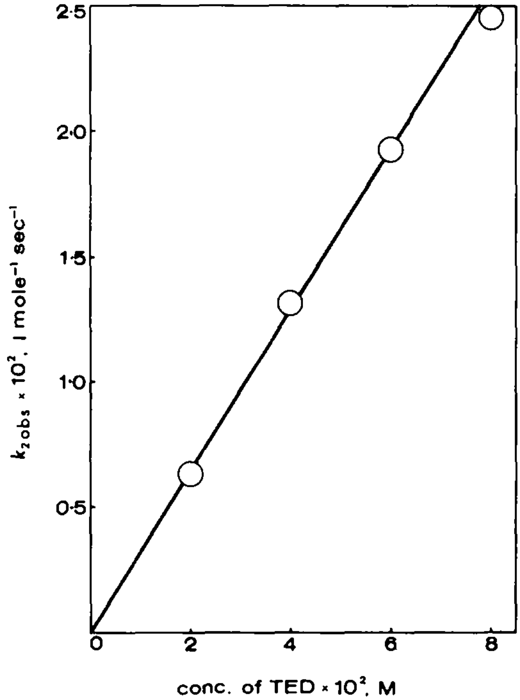


Fig. 3 The plots of the second-order rate constant *vs* concentration of TED on the reaction of CPC with aniline in dioxan at 80°

conc. of CPC and aniline: each 0·1M

Similarly, for the reaction of NPC, the values of $k_2 \times 10^2$ l mole^{-1} sec^{-1} and $k_3 \times 10^2$ l^2 mole^{-2} sec^{-1} are obtained 1·08 and 7·08, respectively, from Fig. 4. The value of the former agrees well with the experimental value of 1·05 obtained by the reaction without TED. Therefore, the rate equation is given by

$$v'' = \{k_2 + k_3[\text{TED}]\}[\text{ester}][\text{aniline}] \qquad (3)$$

Here, the conversion curve of the reaction of NPC alone indicates a state of equilibrium. However, the backward reaction of DPU with *p*-nitrophenol (both 0·01M) in the presence of TED(0·004M) in dioxan does not occur even on heating at 80° for 4 hr. Hence, the phenomenon is not due to the equilibrium, but to the

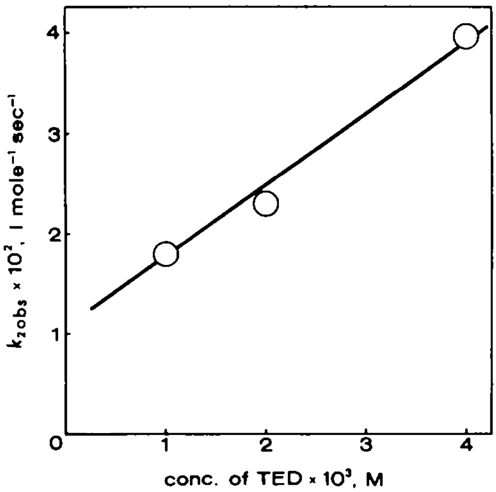


FIG. 4 The plots of the second-order rate constant *vs* concentration of TED on the reaction of NPC with aniline in dioxan at 80°

conc. of NPC and aniline: each 0·1M

activity loss of the catalyst by the strong acidity of *p*-nitrophenol formed by the reaction, and to the long induction period of the reaction of NPC with aniline without catalyst in a low concentration (both 0·0045M). Indeed, the reaction of NPC with aniline (each 0·0045M) in the absence of catalyst at 80° in dioxan has a long induction period (ca. 200 min) as shown in Fig. 5.

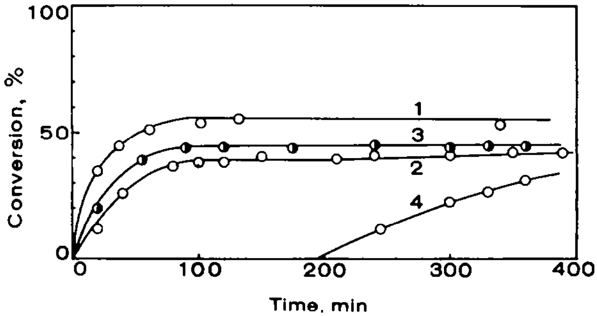


FIG. 5 The conversion curves of the reaction of NPC with aniline in dioxan at 80°

	conc. of NPC in M	conc. of aniline in M	conc. of TED in M
1	0·01	0·01	0·004
2	0·01	0·01	0·002
3	0·0045	0·0045	0·004
4	0·0045	0·0045	none

A discussion of an intermediate

(a) *The measurement of the conductivities.* The conductivities of each member and couple in the reactions of PPC and/or CPC with aniline in the presence of TED were measured by Yokogawa–Hewlett–Packard universal bridge 4255A (BV-Z-13C) as shown in Table 3. The results show that the conductive products, which may exist as an ion pair of the ammonium salt in dioxan, are formed only in the couple of the catalyst and the ester such as PPC or CPC.

TABLE 3. SPECIFIC CONDUCTIVITIES OF THE REACTANTS AND PRODUCTS AT 23 ± 0·5°

Reaction conc. of esters and aniline: both 0·1M
conc. of TED: 0·02M
conc. of phenols: each 0·1M
Measurement conc.: half of the values described above

Substance	Specific conductivity $10^{-6}\Omega^{-1}\text{cm}^{-1}$	Couple of substances	Specific conductivity $10^{-6}\Omega^{-1}\text{cm}^{-1}$
Cond. water	2·2	Aniline + TED	6·7
Dioxan (50% aq.)	1·2	Aniline + PPC	2·1
PPC	2·7	Aniline + CPC	2·0
CPC	3·6	Aniline + NPC	5·9
NPC	2·2	PPC + TED	156·2
Aniline	1·6	CPC + TED	162·6
TED	13·8	NPC + TED	276·9
Phenol	1·0	Phenol + TED	16·8
p-Chlorophenol	1·1	*p*-Chlorophenol + TED	30·8
p-Nitrophenol	2·7	*p*-Nitrophenol + TED	240·4

Reaction mixture	Specific conductivity $10^{-6}\Omega^{-1}\text{cm}^{-1}$
PPC + Aniline + TED	29·9
CPC + Aniline + TED	52·9
NPC + Aniline + TED	231·6

(b) *UV spectra.* The UV spectra of each individual member and couple in the reaction of PPC and or CPC with aniline in the presence of TED was measured, after the solution had been heated at 80° for 3 hr and then filtered by glass filter. The spectra of the mixtures of aniline with ester and with catalyst and or other couples gave additive absorption curves. The mixture of ester with catalyst, however, gave a new absorption maximum and a minimum, for example, the mixtures of TED with PPC and with CPC indicated new absorption maxima at 256–257 and 231·5–233 mμ, and absorption minima at 230 and 255–257 mμ, respectively. These phenomena agree well with the results of conductivity measurements.

(c) *Kinetic examination.* In the second-order reaction, in which the step forming an intermediate by the reaction of PPC with TED determines the rate of the reaction, it is supposed that the reaction which is started by the addition of aniline to the mixture of PPC and TED in dioxan heated previously at 80° for 3 hr will proceed promptly at the initial stage. That is, a curve of log $a/(a - x)$ *vs* time will not pass through the origin. The experimental results indicate that this conclusion is valid as shown in Fig. 6.

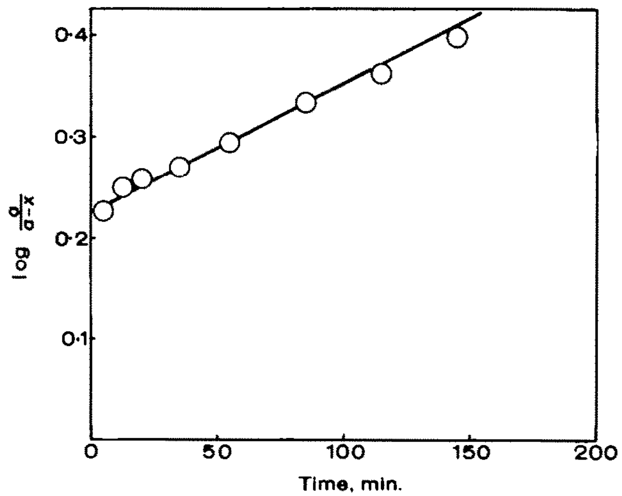
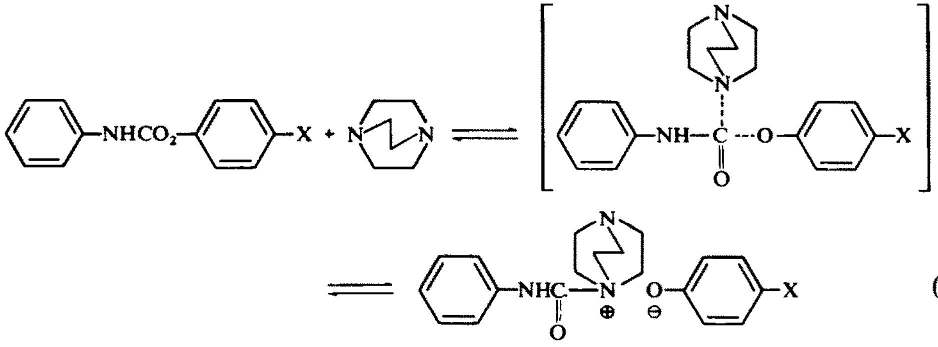


FIG. 6 Reaction started by the addition of aniline to the mixture of PPC and TED heated previously at 80° for 3 hr

conc. of PPC and aniline: both 0·1M
conc. of TED: 0·02M

Over-all mechanism

The above described reactions are not catalysed by primary or secondary amines such as n-butylamine or piperidine, but catalysed by tertiary amines such as methylmorpholine, especially TED. The rate of PPC, TPC and MPC satisfies the Eq. 1, and the Hammett's plot gives a positive ρ value of $+1{\cdot}63$. The mixture of PPC and TED in dioxan heated at 80° for several hr indicated conductivity and its UV spectra gave a new absorption maximum, which does not belong to phenyl isocyanate (λ_{max},



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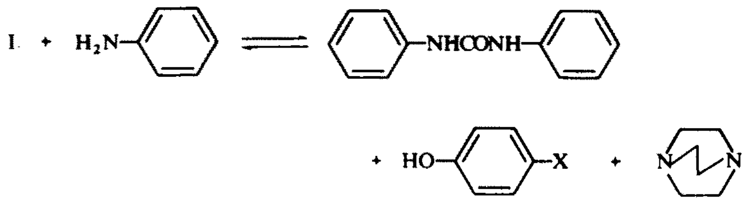
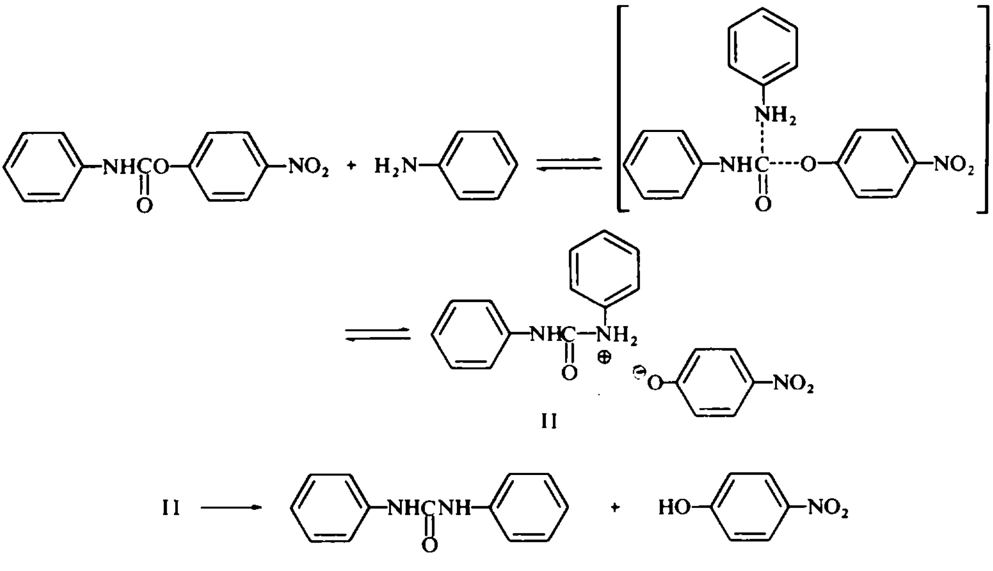


(5)

242·5 mμ in dioxan). A reaction mixture such as PPC, aniline and TED also has a considerable conductivity (Table 3). It is assumed, from these results, that the rate-determining step in the second-order reaction is the formation of quaternary ammonium salt, followed by its rapid attack on aniline. As the facility of quaternary ammonium salt formation depends on the positivity of the carbonyl carbon atom of the esters, it is reasonable that the Hammett's plot gives a positive ρ value in the reaction of the esters having an electron-releasing group. It is presumed that the rate of ammonium salt formation will be accelerated in the reaction of the esters having an electron-attracting group and that the reactions satisfy the third-order equation, when the rate of step 4 is larger than that of step 5. The rate of the reaction of the esters having an electron-attracting group such as CPC and NPC with aniline at 80° satisfies the third-order equation. Therefore, the rate-determining step is the reaction of the ion pair of ammonium salt with aniline (step 5). This phenomenon will be due to the fact that the carbonyl carbon atom tends to take a more positive charge owing to an electron-attracting group in the ester and is attacked easily by the nitrogen atom of TED. Consequently, in the case of NPC having a strong electron-attracting group, the carbonyl carbon is attacked by the nitrogen atom of aniline directly, even in the absence of TED. As the couple of NPC and aniline indicates conductivity, the direct reaction of NPC and aniline maybe passes through ion pair as follows:



EXPERIMENTAL

Materials. Phenyl and *p*-substituted phenyl N-phenylcarbamates were obtained by the reaction of phenyl isocyanate and corresponding phenols and recrystallized from benzene and then from EtOH; phenyl N-phenylcarbamate (m.p. 123°), *p*-tolyl N-phenylcarbamate (m.p. 113°), *p*-methoxyphenyl N-phenylcarbamate (m.p. 135°), *p*-chlorophenyl N-phenylcarbamate (m.p. 139°) and *p*-nitrophenyl N-phenylcarbamate (m.p. 147°). Aniline (b.p. 80–81°/20 mmHg) and MeOH (b.p. 65–66°) were also rectified by distillation. Triethylenediamine (m.p. 112°) obtained from Meisei & Co., Ltd. was purified by sublimation under the reduced press (10 mmHg). N,N'-Diphenylurea was recrystallized from pyridine, m.p. 241°. Phenols were purified by distillation or recrystallization: phenol, b.p. 77–79°/20 mmHg;

p-cresol, b.p. 92–94°/20 mmHg; *p*-methoxyphenol, m.p. 54°; *p*-chlorophenol, m.p. 37°; *p*-nitrophenol, m.p. 113°. Dioxan was refluxed for 7 hr with 10% of its volume of 1N HCl, a slow stream of air being passed in through the condenser to remove the acetaldehyde formed. The organic layer was then separated after treating with KOH. It was then distilled from Na, b.p. 101°.

Reaction products criterion. Dioxan soln (100 ml) containing PPC, aniline (both 0·05 mole) and TED (0·002 mole) was kept at 80° for 4 hr. And then, dioxan was removed to ca. half volume. The residue was poured into water (1000 ml). The ppt was filtered off and identified by mixed m.p. with an authentic sample, yield 80%, m.p. and m.m.p. 239 ~ 241°.

Reaction analysis. The reactions were followed by Hitachi Perkin–Elmer UV-VIS spectrophotometer model 139. The absorption maxima of PPC and DPU were 235, 255 mμ, and minimum of DPU was 225 mμ, respectively. The absorption of aniline, phenol and TED are negligible at these wave lengths. Mixtures of PPC, aniline, DPU and phenol of known concentrations corresponding to 0, 20, 40, 60, 80 and 100% conversions were prepared and a plot of the difference of extinctions $(E_{255} - E_{225})$ *vs* $(E_{255} - E_{235})$ gave a straight line,[5] and the calculated conversion from the values of $(E_{255} - E_{235})$ at 0 and 100% conversion agreed well with the conversions calculated from the composition of the mixture within 1% error.

A typical run for the rate measurements. A soln of 1 ml of 0·2M TED in dioxan was poured into a soln of 9 ml of 0·111M PPC and aniline in dioxan to start the reaction, after both soln had attained temperature equilibrium. Aliquots (each 0·1 ml) were taken out at appropriate time intervals, and diluted with MeOH to a 2×10^{-5}M total concentration of PPC, DPU, aniline and phenol. The conversion percentage was determined graphically.

A typical procedure for the conductivity measurement. A dioxan soln (10 ml) of PPC and TED (0·1M and 0·02M, respectively) was heated at 80° for 3 hr. The soln was diluted by 10 ml of conductivity water. The ppt formed was filtered off on a glass filter. Then, the conductivity of the soln was measured by Yokogawa–Hewlett–Packard universal bridge 4255A(BV-Z-13C) at 23°.

Acknowledgements—The authors are grateful to Mr. U. Ueda and S. Miyazaki for their aids in performing these experiments. We also acknowledge with pleasure the support of this work by Meisei & Co. Ltd. and Yokoo Seiki Co. Ltd.

REFERENCES

[1] R. L. Betts and L. P. Hammett, *J. Am. Chem. Soc.* **59**, 1568 (1937).
[2] J. F. Bunnett and G. T. Davis, *Ibid.* **82**, 665 (1960).
[3] W. P. Jencks and J. Carriuolo, *Ibid.* **82**, 675 (1960).
[4] T. C. Bruice and M. F. Mayahi, *Ibid.* **82**, 3067 (1960); M. F. Menger, *Ibid.* **88**, 3081 (1966).
[5] Y. Ogata, Y. Furuya and M. Ito, *Ibid.* **85**, 3649 (1963).