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Hydrolysis of Malonaldehyde Dianil and β-Arylaminoacrolein Derivatives

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The reversible hydrolysis of β-arylaminoacrolein to form arylamine and malonaldehyde was studied kinetically. The catalytic coefficient of hydronium ions (k^{H^+}) and dissociation constant of the conjugate acid of β-arylaminoacrolein (K^{BH^+}) were evaluated. Hammett plots for k^{H^+} and for K_{BH^+} were linear. The values of log k^{H^+} and pK^{BH^+} were expressed by the equations log $k^{H^+}=1.38\sigma-2.81$ and p$K_{BH^+}=-1.20\sigma+0.90$, respectively. The reversible hydrolysis of malonaldehyde dianil to form β-arylaminoacrolein and arylamine was examined in relation to that of β-arylaminoacrolein. The preparation of β-arylaminoacrolein by hydrolysis of malonaldehyde dianil was achieved under weakly acidic conditions.

Keywords——reversible hydrolysis; kinetic study; dissociation constant; β-arylaminoacrolein; malonaldehyde dianil; malonaldehyde

In the previous paper[2)] we reported a kinetic study of the formation of β-arylaminoacrolein derivatives from β-ethoxyacrolein and aromatic primary amines (equation 1, Chart 1). Neither triethylamine nor acetic acid acted as an efficient catalyst, and the Hammett plot for the second order rate constants gave a ρ value of -2.63 when the reaction was carried out in ethanolic solution at 30°. This indicates that the reaction is markedly affected by the basicity of the arylamine, and that the preparation of β-arylaminoacrolein derivatives from β-ethoxyacrolein and weakly basic arylamine is difficult by this reaction. Actually, β-(*p*-nitroanilino)- and β-(*o*-chloroanilino)acrolein could not be prepared by this method.

The ultraviolet absorption (UV) spectrum of 1-(*p*-methylphenylamino)-3-(*p*-methylphenylimino)-1-propene (malonaldehyde dianil of *p*-toluidine) (I) in 90% aqueous ethanol showed an absorption maximum at 375 nm ($\varepsilon=40000$). On addition of acetic acid (0.1 M), the spectrum showed a bathochromic shift and hyperchromic change; the absorption maximum shifted to 393 nm ($\varepsilon=51800$). These spectra showed no change for 24 hr at room temperature. However, in the presence of acetic acid and sodium acetate (each 0.1 M), the spectrum did change on standing; the optical density at 393 nm decreased while that at 325 nm increased. This implies that I is hydrolyzed to form β-(*p*-toluidino)acrolein (II) in the solution (equation 2, Chart 1). A preparative experiment to obtain II by the hydrolysis of I, however, resulted in recovery of the starting material in aqueous ethanol in the presence of equimolar amounts of acetic acid and sodium acetate. This difference in the results is attributable to the concentration of the reactant. The UV spectrum was measured at 2×10^{-5} M of the substance, while the preparative experiment was attempted at a higher concentration (about 0.2 M). The reaction is presumably reversible,[2)] and the hydrolysis reaction is of pseudo first order while the reverse reaction, *i. e.*, formation of I from II and *p*-toluidine is of second order. Hence the reverse reaction is predominant at higher concentrations. As expected, I was formed in good yield when II and *p*-toluidine were reacted in 90% aqueous ethanol in the presence of equimolar amounts of acetic acid and sodium acetate.

The UV spectrum of II in 90% aqueous ethanol showed no change on standing even in the presence of acetic acid and sodium acetate, while the spectrum of the same compound

1) Location: *2-2-1, Miyama, Funabashi, 274, Japan.*
2) S. Tamura and E. Takeda, *Chem. Pharm. Bull.*, **27**, 403 (1979).

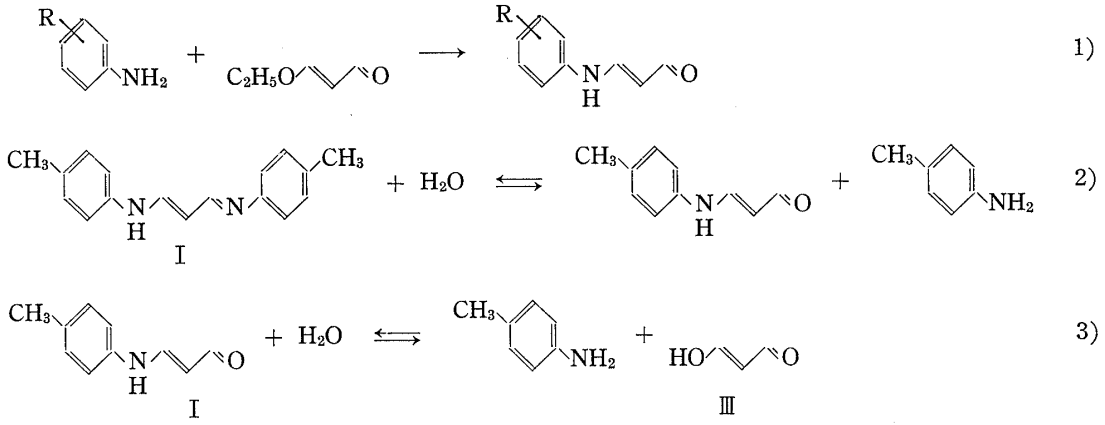

Chart 1

in 1% aqueous ethanol did change on standing in the presence of acetic acid and sodium acetate; the optical density at 325 nm decreased, but increased again on addition of *p*-toluidine to the solution. In contrast, the UV spectrum of I in 1% aqueous ethanol showed no change for 24 hr even in the presence of acetic acid and sodium acetate. The decrease in the optical density at 325 nm of a 1% aqueous ethanol solution of II in the presence of acetic acid and sodium acetate is undoubtedly due to reversible hydrolysis of II to form *p*-toluidine and malonaldehyde (III) (equation 3, Chart 1).

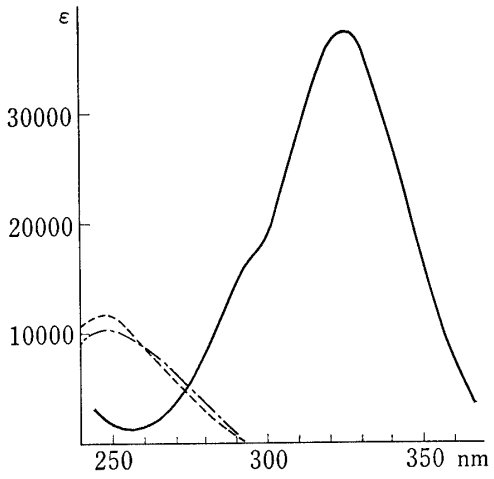

Fig. 1. UV Spectra of II and III in 1% Aqueous Dioxane

——: II, ——: III in the presence of 0.24 M AcOH and 0.12 M AcONa, ------: III in the presence of 0.18 M AcOH and 0.06 M AcONa.

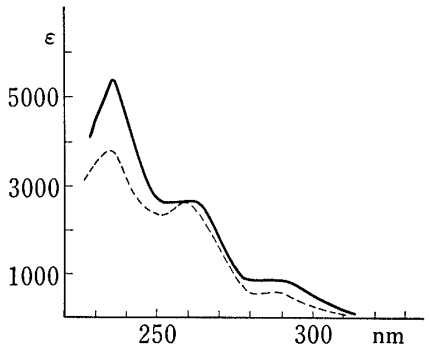

Fig. 2. UV Spectra of *p*-Toluidine in 1% Aqueous Dioxane

——: in the presence of 0.24 M AcOH and 0.12 M AcONa, ------: in the presence of 0.18 M AcOH and 0.06 M AcONa.

Kinetic examination was attempted to elucidate the effects of acid both on the hydrolysis of II and on the reverse reaction. Kinetic runs were carried out at 25° in 1% aqueous dioxane solution instead of in aqueous ethanol solution to avoid any interaction between ethanol and III or other substances. Figs. 1 and 2 show the UV spectra of II in 1% aqueous dioxane and those of *p*-toluidine and III in 1% aqueous dioxane containing acetic acid and sodium acetate. The concentration of II was evaluated from the optical density at 325 nm of the reaction mixture, and the apparent equilibrium constant K' was calculated from the concentration of II 24 hr after the initiation of the reaction. In each measurement, the optical densities of the reaction mixture at 245, 250, 260, 270, 280, 290, 300, 310, 320, 325 and 330 nm were in good agreement with the values calculated from the concentrations of II, III and *p*-toluidine

using the extinction coefficient of each compound at the given wavelength. The reverse runs were carried out by adding *p*-toluidine to the reaction mixture after the reaction had virtually reached equilibrium. The rate equations of hydrolysis and the reverse reaction are represented by equations 4 and 5, respectively,

$$kt = \frac{y_e}{2a-y_e} \ln \frac{ay_e+y(a-y_e)}{a(y_e-y)} \quad 4)$$

$$k_-t = \frac{x_e}{a'b-x_e^2} \ln \frac{(x_e-x_i)(a'b-x_ex)}{(x_e-x)(a'b-x_ex_i)} \quad 5)$$

where a is the initial concentration of II, y and y_e represent the differences between a and the concentration of II at time t and at equilibrium in the hydrolysis reaction, a' is the sum of the concentrations of II and III upon initiation of the reverse reaction, b is the sum of a' and the concentration of newly added *p*-toluidine at the same time, x, x_i, and x_e represent the concentrations of II at time t, at initiation and at equilibrium of the reverse reaction, respectively, and k and k_- are the rate constants of hydrolysis and the reverse reaction.

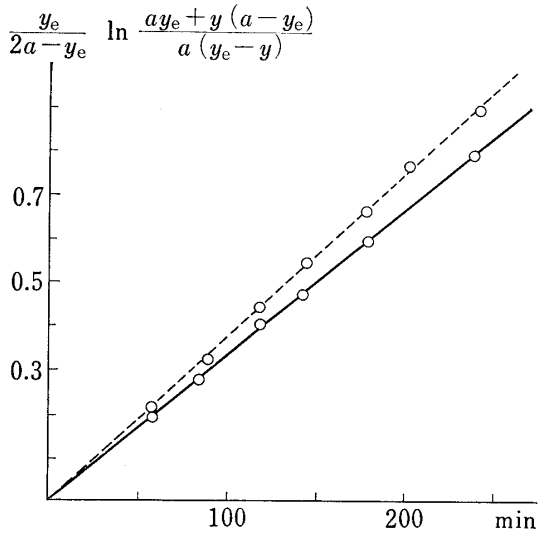

Fig. 3. Plot of the Right-hand Side of Equation 4 against Time

——: in the presence of 0.24 M AcOH and 0.12 M AcONa, ------: in the presence of 0.32 M AcOH and 0.16 M AcONa.

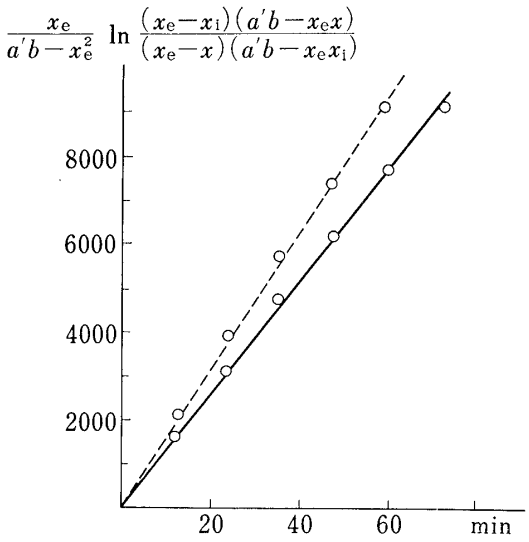

Fig. 4. Plot of the Right-hand Side of Equation 5 against Time

——: in the presence of 0.24 M AcOH and 0.12 M AcONa, ------: in the presence of 0.32 M AcOH and 0.16 M AcONa.

Good linear relationships were obtained by plotting the right-hand sides of equation 4 and equation 5 against time (Figs. 3 and 4), and the results are shown in Table I. A higher buffer concentration produced a larger value of the rate constant for hydrolysis (and naturally for the reverse reaction, Table I, Part A and Part B) when the ratio of acetic acid to sodium acetate was held constant. Each reaction, therefore, suffers general acid catalysis. Comparison of the rate constants at a constant concentration of acetic acid with different ratios of sodium acetate suggests the presence of an appreciable catalytic effect due to hydronium ions.

The apparent equilibrium constant K' is given by equations 6 and 7, for hydrolysis and reverse runs, respectively,

$$K' = \frac{ye^2}{a-y_e} \quad 6)$$

$$K' = \frac{(a'-x_e)(b-x_e)}{x_e} \quad 7)$$

TABLE I.

Part A. Hydrolysis of II in 1% Aqueous Dioxane in the Presence of AcOH and AcONa, Ionic Strength 0.8, at 25°

[AcOH] (M)	[AcONa] (M)	$10^5[H^+]$ (M)	10^5k (sec^{-1})	$10^5K'$ (mol)	k/k_- (mol)	$10^6\alpha K'$ [a] (mol)
0.24	0.12	5.0	5.50	2.46	2.48	2.51
0.32	0.16	5.0	6.20	2.42	2.36	2.47
0.18	0.06	8.0	5.02	3.26	3.32	2.46
0.24	0.08	8.0	6.02	3.31	3.42	2.51

a) To calculate α, the following K_M[3] and K_{AH^+}[4] values were used: $K_M=2.00\times10^{-5}$; $K_{AH^+}=8.31\times10^{-5}$.

Part B. Reverse Reaction

[AcOH] (M)	[AcONa] (M)	k_- (sec^{-1} mol^{-1})	$10^5K'$ (mol)
0.24	0.12	2.22	2.79
0.32	0.16	2.63	2.65
0.18	0.06	1.51	3.71
0.24	0.08	1.76	3.47

Part C. Formation of II from III and *p*-Toluidine

k_- (sec^{-1} mol^{-1})	$10^5K'$ (mol)
1.88	3.47
2.26	3.23
1.35	4.34
1.65	4.24

The value of K' should be equal to k/k_-. The experimental result is in accordance with the above requirement (Table I, Part A). K' values obtained from reverse runs (Table I, Part B) are slightly larger than those obtained from hydrolysis runs (Table I, Part A), presumably owing to the partial degradation of III during the prolonged reaction.

K' is affected by the acidity of the solution because of the dissociation of III and of *p*-toluidine. The true equilibrium constant K is represented by equation 8,

$$K = \alpha K', \quad \alpha = \frac{[H^+]K_{AH^+}}{([H^+]+K_{AH^+})([H^+]+K_M)} \qquad 8)$$

where K_M and K_{AH^+} are the dissociation constants of III and of the conjugate acid of *p*-toluidine, respectively. The $\alpha K'$ values are in good agreement with each other (Table I, Part A).

The formation of II from equimolar amounts of *p*-toluidine and III was also studied from a kinetic viewpoint. The rate equation is represented by equation 9,

$$k_-t = \frac{x_e}{a^2-x_e} \ln \frac{x_e(a^2-xx_e)}{a^2(x_e-x)} \qquad 9)$$

where a is the initial concentration of III and of *p*-toluidine, and x and x_e are the concentrations of II at time t and at equilibrium, respectively. A linear relation was obtained by plotting the right-hand side of equation 9 against time. The results are shown in Table I, Part C. The second-order rate constants k_- thus obtained are slightly smaller than those obtained from the reverse run (Table I, Part B). The apparent equilibrium constants K' are also slightly greater than those obtained from the reverse run (Table I, Part B). III used here was prepared by hydrolysis of malonaldehyde bis(diethyl acetal) in dilute hydrochloric acid, and the resulting reaction mixture was used directly for kinetic runs. Presumably incomplete hydrolysis of malonaldehyde bis(diethyl acetal) caused the above-mentioned differences.

3) F. Masuo and Y. Kimura, *Nippon Kagaku Zasshi*, **81**, 434 (1960).
4) A.I. Biggs and R.A. Robinson, *J. Chem. Soc.*, **1961**, 388.

In a strongly acidic medium ,the value of α (equation 8) can be approximately expressed by equation 10,

$$\alpha = \frac{K_{AH^+}}{[H^+]} \qquad 10)$$

The apparent equilibrium constant K' is equal to K/α, and hence the value of K' increases with increasing acidity of the solution. In aqueous hydrochloric acid solution, therefore, the hydrolysis is a practically irreversible first-order reaction. Kinetic runs were carried out in aqueous hydrochloric acid solution (containing 1% dioxane) at 25°, and a linear relation was obtained by plotting ln a/x against time, where a and x represent the concentrations of II at the initial time and at time t, respectively. The results are shown in Table II. Hydrolysis is clearly accelerated by the catalytic effect of hydronium ions. The hydronium ion-catalyzed reaction includes two steps expressed by equation 11 and equation 12, Chart 2.

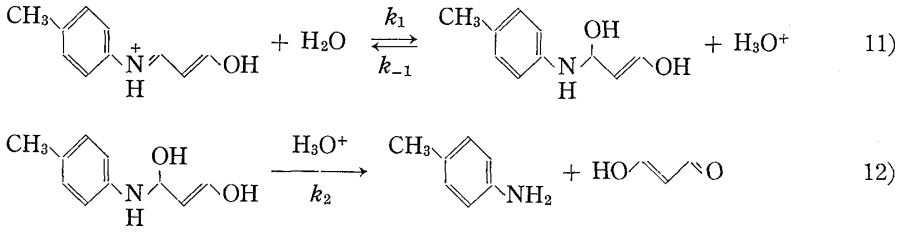

Chart 2

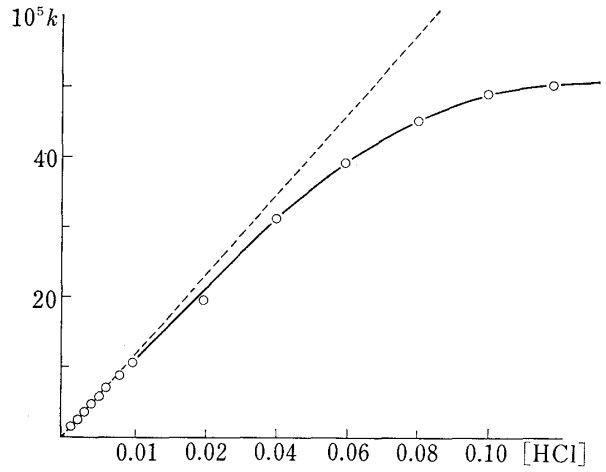

Fig. 5. Rate Constants k of the Hydrolysis of II in Aqueous HCl (containing 1% Dioxane) at 25°

The rate constant k is expressed by equation 13, on a steady-state assumption,

$$k = k^\circ + \frac{k_1 k_2}{k_{-1}+k_2} \frac{[H^+]}{[H^+]+K_{BH^+}} \qquad 13)$$

where k° represents the noncatalyzed or solvent-catalyzed term, and K_{BH^+} is the dissociation constant of the conjugate acid of II. If step 11 is rate-determining ($k_2 \gg k_{-1}$), k is expressed simply by equation 14,

$$k = k^\circ + k_1 \frac{[H^+]}{[H^+]+K_{BH^+}} \qquad 14)$$

In either case, the rate constant k can be expressed by equation 15.

$$k = k^\circ + k^{H^+} \frac{[H^+]}{[H^+]+K_{BH^+}} \qquad 15)$$

If the hydronium ion concentration can be neglected as compared with the value of K_{BH^+}, the rate constant k is expressed simply by equation 16.

$$k = k^\circ + \frac{k^{H^+}}{K_{BH^+}}[H^+] \qquad 16)$$

At a lower concentration (below 0.005 M) of hydrochloric acid, a linear relation was obtained by plotting the experimental rate constant k against hydronium ion concentration, implying that equation 16 is valid under these conditions. The values of k° and k^{H^+}/k_{BH^+} were evaluated by the least-squares method, and the results are shown in Table III. At higher concentrations (above 0.01 M) of hydrochloric acid, the deviation of the experimental rate constants k

Table II. Rate Constants k (sec^{-1}) of Hydrolysis of β-Arylaminoacroleins in Aqueous Hydrochloric Acid (containing 1% Dioxane), Ionic Strength 0.4, at 25°

[HCl] (M)	Substituent on the aromatic ring			
	p-CH_3O	p-CH_3	H	p-Cl
0.001	1.54×10^{-5}	1.57×10^{-5}	1.52×10^{-5}	1.60×10^{-5}
0.002	2.82×10^{-5}	2.61×10^{-5}	2.80×10^{-5}	2.78×10^{-5}
0.003	4.00×10^{-5}	3.84×10^{-5}	4.15×10^{-5}	4.40×10^{-5}
0.004	5.14×10^{-5}	4.92×10^{-5}	5.13×10^{-5}	5.48×10^{-5}
0.005	6.02×10^{-5}	5.92×10^{-5}	6.31×10^{-5}	6.99×10^{-5}
0.006	6.81×10^{-5}	6.78×10^{-5}	7.53×10^{-5}	8.69×10^{-5}
0.008	8.83×10^{-5}	8.89×10^{-5}	9.46×10^{-5}	1.09×10^{-4}
0.01	1.05×10^{-4}	1.06×10^{-4}	1.17×10^{-4}	1.35×10^{-4}
0.02	1.72×10^{-4}	1.95×10^{-4}	2.09×10^{-4}	2.70×10^{-4}
0.04	2.65×10^{-4}	3.15×10^{-4}	3.73×10^{-4}	4.83×10^{-4}
0.06	3.12×10^{-4}	3.98×10^{-4}	5.05×10^{-4}	6.75×10^{-4}
0.08	3.83×10^{-4}	4.55×10^{-4}	6.27×10^{-4}	8.32×10^{-4}
0.10	4.08×10^{-4}	4.92×10^{-4}	6.88×10^{-4}	9.52×10^{-4}
0.12	4.27×10^{-4}	5.32×10^{-4}	7.58×10^{-4}	1.11×10^{-3}
0.16	4.55×10^{-4}	6.17×10^{-4}	8.60×10^{-4}	1.25×10^{-3}
0.20	4.98×10^{-4}	6.30×10^{-4}	9.37×10^{-4}	1.42×10^{-3}
0.40	6.18×10^{-4}	7.63×10^{-4}	1.16×10^{-3}	1.65×10^{-3}

Table III. Hydrolysis of β-Arylaminoacroleins in Aqueous Hydrochloric Acid (containing 1% Dioxane), Ionic Strength 0.4, at 25°

	Substituent on the aromatic ring			
	p-CH_3O	p-CH_3	H	p-Cl
k° (sec^{-1})	5.20×10^{-6}	4.69×10^{-6}	3.99×10^{-6}	2.06×10^{-6}
k^{H^+}/K_{BH^+} (sec^{-1} mol^{-1})	1.13×10^{-2}	1.10×10^{-2}	1.19×10^{-2}	1.35×10^{-2}
K_{BH^+} (mol)	5.50×10^{-2}	8.37×10^{-2}	1.41×10^{-1}	2.20×10^{-1}
pK_{BH^+}	1.26	1.08[a]	0.85	0.66
k^{H^+} (sec^{-1})	6.22×10^{-4}	9.21×10^{-4}	1.68×10^{-3}	2.97×10^{-3}

a) At the 97th Annual Meeting of the Pharmaceutical Society of Japan (Tokyo, April, 1977), we reported the value of pK_{BH^+} of the conjugate acid of II to be 0.96. That value was obtained from kinetic runs made in 1% aqueous ethanol, ionic strength 0.2, at 40°.

from the values corresponding to equation 16 suggests that the concentration of hydronium ions becomes comparable to the value of K_{BH^+} (Fig. 5). K_{BH^+} can be evaluated from equation 15 using the experimental rate constants obtained from the kinetic runs with hydrochloric acid concentrations of 0.04—0.10 M. The results are shown in Table III.

In order to elucidate the aromatic ring substituent effects, kinetic studies of the hydrolysis of p-substituted β-arylaminoacroleins were carried out in aqueous hydrochloric acid solution (containing 1% dioxane) at 25°. The results are shown in Table II and Table III. A Hammett plot for K_{BH^+} gave a linear relation (correlation coefficient=0.9866) (Fig. 6); the pK_{BH^+} values are represented by the equation $pK_{BH^+}=1.20\sigma+0.90$ (the ρ value for K_{BH^+} is 1.20). Biggs and Robinson[4] obtained a ρ value of 2.889 for the dissociation constants of the conjugate acid of arylamines. The electronic effect of substituents on the basicity of β-arylaminoacroleins is in the same direction and much smaller as compared with that on the basicity of arylamines. A Hammett plot for k^{H^+} gave a straight line (correlation coefficient=0.9940) (Fig. 7); the log k^{H^+} values are represented by the equation $\log k^{H^+}=1.38\sigma-2.81$. The significance of the sign and magnitude of the ρ value for k^{H^+} is not clear at present because the rate-determining step is still unknown. The presence of an electron-withdrawing substituent on the

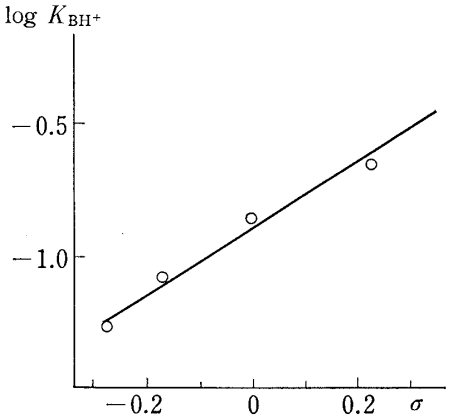

Fig. 6. Hammett Plot for K_{BH^+}

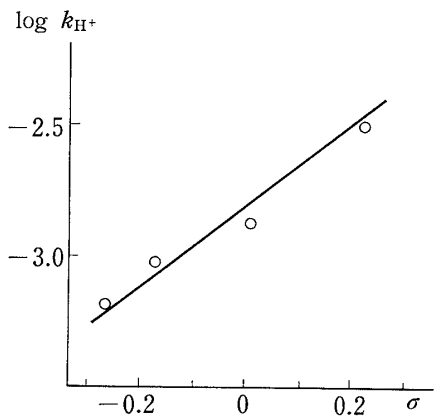

Fig. 7. Hammett Plot for k^{H^+}

TABLE IV. Hydrolysis of 1-Arylamino-3-arylimino-1-propenes (Malonaldehyde Dianils) at 70°. The Amount of Starting Material was 0.01 mol in Each Case

Aryl moiety	Reaction solvent	Reaction time (hr)	Yield of β-aryl-aminoacrolein		Yield of arylamine	Recovered dianil
			Crude product	Pure product		
Phenyl	100 ml 70% EtOH	33	0.92 g (63%)	0.67 g (46%)	0.12 g (13%)	
p-Methylphenyl	100 ml 70% EtOH	8	1.36 g (84%)	0.94 g (58%)	0.30 g (28%)	0.06 g (2%)
p-Methoxyphenyl	120 ml 70% EtOH 20 ml benzene	32	1.36 g (75%)	0.90 g (50%)	0.19 g (15%)	0.01 g (0.4%)
p-Chlorophenyl	100 ml 70% EtOH	21.5	0.97 g (54%)	0.90 g (50%)	1.02 g (80%)	
p-Bromophenyl	100 ml 70% EtOH	10	1.25 g (55%)	1.03 g (46%)	0.69 g (40%)	
p-Iodophenyl[a]	200 ml 70% EtOH 50 ml benzene 30 ml acetcne	49.5	0.74 g (54%)	0.49 g (36%)	0.59 g (55%)	
m-Methylphenyl	100 ml 70% EtOH	25	0.56 g (35%)	0.36 g (22%)	0.52 g (49%)	
m-Methoxyphenyl	100 ml 70% EtOH	36.5	0.85 g (48%)	0.35 g (20%)	0.64 g (52%)	
m-Chlorophenyl	100 ml 70% EtOH	32.5	1.20 g (66%)	0.94 g (52%)	0.87 g (68%)	
m-Bromophenyl	100 ml 70% EtOH	38	0.99 g (44%)	0.68 g (30%)	1.04 g (61%)	
m-Iodophenyl[a]	100 ml 70% EtOH 20 ml benzene	44	0.95 g (70%)	0.62 g (45%)	0.40 g (37%)	
o-Methylphenyl	100 ml 70% EtOH	39.5	0.52 g (32%)	0.14 g (9%)	0.50 g (47%)	
o-Methoxyphenyl	100 ml 70% EtOH	28	1.19 g (67%)	0.49 g (28%)	0.59 g (48%)	
o-Chlorophenyl[b]	100 ml 70% EtOH 20 ml benzene	25	0.36 g	0.08 g	0.13 g	
o-Bromophenyl[c]	100 ml 70% EtOH 20 ml benzene	24.5	0.59 g	0.29 g	0.56 g	
o-Iodophenyl[a]	150 ml 70% EtOH 20 ml benzene	37.5	0.55 g (40%)	0.20 g (15%)	0.79 g (74%)	
α-Naphthyl	200 ml 70% EtOH 40 ml benzene	46	1.53 g (77%)	0.91 g (46%)	0.85 g (59%)	
β-Naphthyl[a]	200 ml 70% EtOH 20 ml benzene	22	0.75 g (76%)	0.53 g (54%)	0.13 g (18%)	

a) The amount of starting material was 0.005 mol.
b) Free dianil could not be crystallized. After neutralization of 2.15 g of the hydrochloride, the resulting oil was hydrolyzed directly.
c) Free dianil could not be crystallized. After neutralization of 3.00 g of the hydrochloride, the resulting oil was hydrolyzed directly.

aromatic ring reduces the basicity of β-arylaminoacroleins, and on the other hand, enhances the catalytic coefficient of hydronium ions (k_{H^+}) by the same order of magnitude. The rate of hydrolysis of β-arylaminoacroleins at lower concentrations of hydrochloric acid, therefore, suffers only a minor electronic effect due to a substituent on the aromatic ring (Table II).

The apparent equilibrium constant K'_D of reversible hydrolysis of malonaldehyde dianil to form β-arylaminoacrolein and arylamine (equation 2, Chart 1) is markedly affected by the acidity of the medium.[5] The value of K'_D is represented approximately by equation 17,

$$K_D' = K_D \frac{K_{DH^+}}{K_{AH^+}+K_{BH^+}} \frac{(K_{AH^+}+a_{H^+})(K_{BH^+}+a_{H^+})}{(K_{DH^+}+a_{H^+})} \qquad 17)$$

where K_D is the true equilibrium constant for equation 2, a_{H^+} is the activity of lyonium ion, and K_{AH^+}, K_{BH^+} and K_{DH^+} are the dissociation constants of the conjugate acids of arylamine, β-arylaminoacrolein and malonaldehyde dianil in the given medium, respectively. Malonaldehyde dianil, a vinylog of amidine, is believed to be a strongly basic substance. Assuming K_{DH^+} to be negligible as compared with a_{H^+}, hydrolysis of malonaldehyde dianil is most unfavorable at the point where a_{H^+} is equal to $\sqrt{K_{BH^+}K_{AH^+}}$.

As described in the beginning of this report, an attempt was made to prepare β-arylaminoacrolein by hydrolysis of malonaldehyde dianil in the presence of equimolar amounts of acetic acid and sodium acetate. These conditions are unfavorable in relation to the K_{BH^+} and K_{AH^+} values, because the acidity of the reaction mixture is too high for the hydrolysis reaction to proceed. When I was heated in 70% aqueous ethanol, II was obtained in good yield in the presence of one-tenth equivalent of acetic acid and nine-tenths equivalent of sodium acetate. The other β-arylaminoacrolein derivatives were prepared from corresponding malonaldehyde dianils by the same method. The results are shown in Table IV. β-(*o*-Chloroanilino)acrolein, which could not be prepared by the customary method, was successfully obtained by this hydrolysis reaction. β-(*p*-Nitroanilino)acrolein could not be obtained even by this method, probably owing to the low solubility of the corresponding malonaldehyde dianil in aqueous ethanol. From the Hammett plot for K_{BH^+}, K_{BH^+} for β-(*p*-nitroanilino)acrolein was calculated to be 3.8. The possibility remains that β-(*p*-nitroanilino)acrolein can be prepared from *p*-nitroaniline and III or its derivatives under more acidic conditions than those used in the hydrolysis of malonaldehyde dianil described in this report.

Experimental

All melting points are uncorrected. The UV spectra were measured on a Hitachi spectrophotometer, model 139, and the nuclear magnetic resonance (NMR) spectra were recorded on a JNM-PMX 60 NMR spectrometer using tetramethylsilane as an internal standard. The following abbreviations are used: singlet (s), doublet (d), double doublet (dd), triplet (t).

Kinetic Experiments

Materials——β-Arylaminoacrolein derivatives used for kinetic studies were prepared according to the previous paper.[6]

Method——The ionic strength of the reaction solutions was maintained at 0.8 for buffer solutions and at 0.4 for HCl solutions by the addition of NaCl. The pH values of buffer solutions were measured with a Toa Dempa glass electrode pH meter, model HA-5A.

Preparation of the Hydrolysis Reaction Solutions——One ml of dioxane solution of II (2×10^{-3} M) was added to aqueous buffer or HCl solution in a 100 ml volumetric flask, and the sample was diluted to the mark with the same aqueous solution.

Preparation of the Reverse Reaction Solutions——At 24 hr after the initiation of the hydrolysis reaction, 1 ml of the same buffer solution of *p*-toluidine (0.004 M, containing 1% dioxane) was added to the reaction solution in a 50 ml volumetric flask, and the sample was diluted to the mark with the reaction solutions.

Preparation of the Reaction Solution of III and *p*-Toluidine——A 2.5 ml aliquot of 1 M HCl was added to 0.2479 g of malonaldehyde bis(diethyl acetal) in a 25 ml volumetric flask, and the mixture was stirred until

5) S. Tamura and M. Ono, *Chem. Pharm. Bull.*, **26**, 3167 (1978).
6) S. Tamura and E. Yabe, *Chem. Pharm. Bull.*, **21**, 2105 (1973).

the solution became clear. The resulting solution was diluted to the mark with H_2O. A portion (1 ml) was diluted to 10 ml with aqueous buffer solution, providing a 0.0045 M solution of III. A dioxane solution (1 ml) of *p*-toluidine (0.0045 M) and 1 ml of 0.0045 M aqueous III solution were added to aqueous buffer solution in a 100 ml volumetric flask and the mixture was diluted to the mark with the aqueous buffer solution.

Preparative Experiments

Preparation of 1-Arylamino-3-arylimino-1-propene (Malonaldehyde Dianil)——First, 4 ml of conc. HCl and 0.04 mol of primary arylamine in 20 ml of EtOH were added to a stirred solution of 8.8 g (0.04 mol) of malonaldehyde bis (diethyl acetal) in 20 ml of EtOH, then the reaction mixture was allowed to stand overnight. Malonaldehyde dianil hydrochloride that precipitated (if necessary, 40 ml of H_2O was added to the mixture to ensure precipitation of the substance) was collected and added to 1000 ml of benzene and 500 ml of 10% aqueous Na_2CO_3. The mixture was stirred until the solution became clear. The benzene layer was separated and dried over K_2CO_3. The solvent was removed under reduced pressure and the residue was recrystallized from a suitable solvent. Analytical data and physical properties of newly prepared malonaldehyde dianils are listed in Table V and Table VI.

Preparation of β-(*o*-Methoxyphenylamino)- and β-(*m*-Methoxyphenylamino)acrolein from β-Ethoxyacrolein and Corresponding Anisidines——A stirred mixture of 0.32 g (0.0032 mol) of freshly distilled β-ethoxyacrolein[2] and 0.1 g of $NaHCO_3$ in 10 ml of MeOH was treated with a solution of 0.36 g (0.0029 mol) of anisidine in 10 ml of MeOH, and the mixture was allowed to stand overnight. MeOH was evaporated off under reduced pressure.

Ethanolic NaOEt solution prepared from 0.06 g (0.003 mol) of Na and 10 ml of EtOH was added to the residue. The EtOH was evaporated off under reduced pressure and the residue was washed with ether then dissolved in H_2O; 7% aqueous $NaHCO_3$ was added, and the resulting precipitate was extracted with benzene. The benzene layer was dried over Na_2SO_4 and the benzene was removed. The residue was recrystallized from benzene. Yields were as follows: *o*-CH_3O, crude material, 0.26 g (51%); pure material, 0.06 g (12%). *m*-CH_3O, crude material, 0.33 g (65%); pure material, 0.22 g (43%). Analytical data and physical properties are listed in Table VII and Table VIII.

Preparation of β-(*m*-Iodophenylamino)acrolein from β-Ethoxyacrolein and *m*-Iodoaniline——A stirred mixture of 1.50 g (0.015 mol) of freshly distilled β-ethoxyacrolein[2] and 0.1 g of $NaHCO_3$ in 10 ml of MeOH was treated with a solution of 3.23 g (0.015 mol) of *m*-iodoaniline in 20 ml of MeOH. After filtration to remove a small amount of precipitate, the filtrate was concentrated under reduced pressure and the residue was washed with 3 ml of benzene, providing 1.27 g (31%) of crude product. Recrystallization from benzene afforded 0.89 g (22%) of pure product. Analytical data and physical properties are listed in Table VII and Table VIII.

Recovery of I from Aqueous EtOH Solution containing AcOH and AcONa——A solution of 0.30 g (0.005 mol) of AcOH and 0.68 g (0.005 mol) of $AcONa \cdot 3H_2O$ in 2.5 ml of H_2O and 12.5 ml of EtOH was added to a mixture of 1.25 g (0.005 mol) of I and 10 ml of EtOH, and the mixture was heated at 70° for 5 hr. Next,

Table V. 1-Arylamino-3-arylimino-1-propenes

Aryl moiety	mp	Amount of starting material (mol)	Yield of			Recrystallization solvent	Analysis (%) Calcd (Found)		
			Hydrochloride	Crude product	Pure product		C	H	N
o-Methylphenyl	40°	0.04	3.71 g		2.77 g (55.4%)	Petroleum benzin	81.56 (81.87	7.24 7.18	11.15 11.11)
o-Methoxyphenyl	104°	0.04	4.40 g	3.80 g (67.4%)	2.90 g (51.4%)	Petroleum benzin	72.32 (72.47	6.43 6.38	9.92 9.63)
o-Iodophenyl	100°	0.04	4.50 g	3.30 g (69.6%)	2.67 g (56.3%)	Petroleum benzin	38.00 (38.04	2.55 2.52	5.91 6.04)
m-Methylphenyl	82°	0.04	5.37 g	3.19 g (63.7%)			81.56 (81.35	7.24 7.06	11.15 11.16)
m-Methoxyphenyl	97°	0.04	5.60 g	3.51 g (62.2%)	1.65 g (29.3%)	Petroleum benzin	72.32 (72.29	6.43 6.31	9.92 9.93)
m-Chlorophenyl	137°	0.04	6.12 g	4.62 g (79.4%)	3.63 g (62.4%)	Benzene	61.87 (61.99	4.15 3.91	9.62 9.66)
m-Bromophenyl	145°	0.04	7.95 g	6.12 g (80.5%)	5.48 g (72.1%)	Benzene	47.40 (47.61	3.18 3.36	7.37 6.89)
m-Iodophenyl	165°	0.02	5.23 g	4.13 g (87.1%)	3.30 g (69.6%)	EtOH	38.00 (38.29	2.55 2.67	5.91 5.71)
α-Naphthyl	133°	0.01	1.13 g	0.47 g (29.2%)	0.28 g (17.4%)	EtOH H_2O	85.68 (85.62	5.63 5.58	8.69 8.77)

Table VI. NMR Spectra of 1-Arylamino-3-arylimino-1-propenes

Aryl moiety	Solvent	1- and 3-Position	2-Position	NH	CH_3
m-Methylphenyl	CD_3SOCD_3	7.93 (d, J=10 Hz)	5.70 (t, J=10 Hz)		2.30(s)
m-Methoxyphenyl	CD_3SOCD_3	8.03 (d, J=11 Hz)	5.83 (t, J=11 Hz)		3.80(s)
m-Bromophenyl	CD_3SOCD_3	8.07 (d, J=11 Hz)	5.80 (t, J=11 Hz)		
m-Chlorophenyl	CD_3SOCD_3	8.05 (d, J=11 Hz)	5.83 (t, J=11 Hz)		
m-Iodophenyl	CD_3SOCD_3	8.00 (d, J=11 Hz)	5.83 (t, J=11 Hz)		
α-Naphthyl	CD_3SOCD_3	8.18 (d, J=11 Hz)	6.32 (t, J=11 Hz)		
o-Methylphenyl	$CDCl_3$	7.58 (d, J=6 Hz)	5.12 (t, J=6 Hz)	11.58(s)	2.33(s)
o-Methoxyphenyl	$CDCl_3$	7.80 (d, J=7 Hz)	5.15 (t, J=7 Hz)	12.20(s)	3.87(s)
o-Iodophenyl	$CDCl_3$	7.53 (d, J=7 Hz)	5.18 (t, J=7 Hz)		

Table VII. β-Arylaminoacroleins

Aryl moiety	mp	Recrystallization solvent	Analysis (%) Calcd C	Calcd H	Calcd N	Found C	Found H	Found N
o-Methoxyphenyl	117°	Benzene	67.78	6.26	7.91	68.11	6.26	8.07
o-Chlorophenyl	101°	Petroleum benzin	59.52	4.44	7.71	59.53	4.42	7.45
o-Bromophenyl	90°	Petroleum benzin	47.81	3.57	6.20	48.12	3.54	5.98
o-Iodophenyl	94°	Petroleum benzin	39.58	2.95	5.13	39.46	2.94	4.96
m-Methoxyphenyl	114°	Benzene	67.78	6.26	7.91	67.63	6.10	7.66
m-Iodophenyl	148°	Benzene	39.58	2.95	5.13	39.47	2.96	4.87

Table VIII. NMR Spectra of β-Arylaminoacroleins (ppm)

Aryl moiety	Solvent		Aldehyde	β-Position	α-Position	CH_3
o-Methoxyphenyl	CD_3OD	s-*trans*	9.13 (d, J=9 Hz)	7.97 (d, J=13 Hz)	5.78 (dd, J=9, 13 Hz)	3.90(s)
		s-*cis*	9.22 (d, J=2 Hz)		5.37 (dd, J=2, 7 Hz)	
o-Chlorophenyl	CD_3OD	s-*trans*	9.15 (d, J=9 Hz)	7.87 (d, J=13 Hz)	5.80 (dd, J=9, 13 Hz)	
		s-*cis*	9.28 (d, J=2 Hz)		5.43 (dd, J=2, 7 Hz)	
o-Bromophenyl	CD_3OD	s-*trans*	9.20 (d, J=9 Hz)	7.87 (d, J=13 Hz)	5.82 (dd, J=9, 13 Hz)	
		s-*cis*	9.33 (d, J=2 Hz)		5.47 (dd, J=2, 7 Hz)	
o-Iodophenyl	CD_3OD	s-*trans*	9.20 (d, J=9 Hz)		5.78 (dd, J=9, 13 Hz)	
		s-*cis*	9.30 (d, J=2 Hz)		5.42 (dd, J=2, 8 Hz)	
m-Methoxyphenyl	CD_3OD	s-*trans*	9.13 (d, J=9 Hz)	8.02 (d, J=13 Hz)	5.65 (dd, J=9, 13 Hz)	3.80(s)
m-Iodophenyl	CD_3SOCD_3	s-*trans*	9.32 (d, J=8 Hz)	8.08 (d, J=13 Hz)	5.55 (dd, J=8, 13 Hz)	10.07 (d, J=13 Hz)

10 ml of 7% aqueous $NaHCO_3$ was added and the resulting precipitate was filtered off with suction. The filtrate was concentrated under reduced pressure and then extracted with benzene. The benzene layer was dried over K_2CO_3 and concentrated. The residue and the former precipitate were combined and recrystallized from benzene. 0.74 g (63%) of I was recovered.

Formation of I from II and *p*-Toluidine——A solution of 0.30 g (0.005 mol) of AcOH and 0.68 g (0.005 mol) of $AcONa \cdot 3H_2O$ in 2.5 ml of H_2O and 12.5 ml of EtOH was added to a mixture of 0.80 g (0.005 mol) of II and 0.54 g (0.005 mol) of *p*-toluidine in 10 ml of EtOH, and the mixture was heated at 70° for 5 hr. The reaction mixture was treated as described above, yielding 0.50 g (40%) of I.

Hydrolysis of 1-Arylamino-3-arylimino-1-propene (Malonaldehyde Dianil)——A mixture of 0.06 g (0.001 mol) of AcOH and 1.22 g (0.009 mol) of $AcONa \cdot 3H_2O$ in 30 ml of H_2O was added to a solution of 0.01 mol of dianil in 70 ml of EtOH. The reaction mixture was heated at 70° in a water bath until no dianil could be detected by TLC, then 0.2 g (0.002 mol) of Na_2CO_3 was added and the mixture was concentrated under reduced pressure. The resulting precipitate was extracted with benzene, and the benzene layer was washed with 7% aqueous $NaHCO_3$ then dried over K_2CO_3. The benzene was removed and ethanolic NaOEt solution prepared from 0.23 g (0.01 mol) of Na and 20 ml of EtOH was added to the residue. EtOH was evaporated off under reduced pressure and the residue was extracted with 100 ml of ether. The residue was dissolved in a small amount of H_2O, then 7% aqueous $NaHCO_3$ was added and the mixture was extracted with benzene. The benzene layer was dried over Na_2SO_4 and the benzene was removed. The residue was recrystallized from benzene. Pure β-arylaminoacrolein was obtained and found to be identical with an authentic sample (except in the case of β-(*o*-haloanilino)-acroleins) by mixed melting point measurement and comparison of the IR spectra. The yields are shown in Table IV and analytical data and physical properties of newly prepared β-arylaminoacrolein derivatives are listed in Table VII and Table VIII. The ether extract was concentrated and the residue was steam-distilled. The distillate was extracted with ether and the extract was treated as usual, to yield the arylamine. The results are shown in Table IV. From the non-volatile part after steam distillation, a small amount of dianil was recovered (Table IV).