gas chromatographic comparisons. Its infrared spectrum showed N–H absorption at 3.11 μ and no carbonyl or imine absorption.

1,1-Diphenylethylamine.—1,1-Diphenylethyl azide was reduced with lithium aluminum hydride by the procedure of Boyer.[19] The crude product was used as such in gas chromatographic comparisons. Its infrared spectrum showed N–H absorption at 3.10 μ and slight absorption at 11.2 μ (probably from a trace of 1,1-diphenylethylene, whose terminal methylene absorbs at this wave length).

Photolysis of Azides.—A solution (*ca.* 3% by weight) of the azide in hexane was placed in a cylindrical cell with quartz windows of *ca.* 12-ml. capacity. The solution was irradiated with light from a Hanovia SC 2537 low-pressure mercury vapor lamp (Hanovia Chemical and Manufacturing Co., Newark, N. J.). No filters were used, but *ca.* 96.5% of the ultraviolet light emitted by the lamp is claimed to be at 2537 Å. Times of reaction and work-up procedures are described below or tabulated for specific cases. A phenomenon common to all the photolyses was the collection on the quartz window near the light source of a small amount of amorphous, red-brown solid. In one case this was investigated. It constituted only 0.2% of the starting material by weight, and showed no distinct peaks in its infrared spectrum. It did seem to slow the photolyses in their later stages by absorbing part of the light.

Isolation of Products in Photolysis of Triphenylmethyl Azide.—Photolysis of 202.9 mg. of triphenylmethyl azide in 12 ml. of hexane for 2.5 hr. was followed by chromatography on alumina. Elution with 19:1 hexane–benzene gave 129.1 mg. (64%) of unreacted azide. Elution with benzene gave 55.1 mg. (83% of unrecovered azide) of benzophenone phenylimine. Further elution with benzene and finally with chloroform gave only 5 mg. of a red solid and 1.8 mg. of an orange-red oil. Recovered azide plus imine accounted for 93% of the starting material.

Products from Photolysis of 1,1-Diphenylethyl Azide.—The reaction mixture (12 ml. containing *ca.* 0.06 g. of product and 0.2 g. of azide) was diluted with 20 ml. of ether and added slowly to 0.2 g. of lithium aluminum hydride in ether. The solution was refluxed for 4 hr. and treated cautiously with water until the solid salts had precipitated. The clear solution was decanted, combined with ether washings of the residue, and dried over potassium hydroxide. After partial concentration, the solution was analyzed by gas chromatography on a column of 20% Apiezon L on Chromosorb P at 211°. Results are given in Table II.

A control reduction was performed on a simulated reaction mixture. The calculated ratio of the two imines was 1.13:1, found 1.07:1. The calculated ratio of imines to azides was 0.58:1, found 0.36:1.

Products from Photolysis of 2 Phenyl-2-propyl Azide.—The hexane solution containing the product imines and unreacted

azide was kept carefully protected from atmospheric moisture until it was analyzed. Samples of the solution were analyzed directly by gas chromatography on a column of 20% Ucon Polar on Chromosorb P at 140°. These conditions were shown to result in no thermal rearrangement of the azide. Peak positions were established by comparison of retention times with those of authentic samples.

Products from Photolysis of Triarylmethyl Azides.—A 2-neck flask equipped with a pressure-equalizing dropping funnel and containing 5 ml. of concentrated sulfuric acid was heated in an oil bath to 150°. A nitrogen atmosphere was maintained by using the funnel top as a nitrogen inlet and the other neck as outlet. The hexane solution of photolysis products was added rapidly through the dropping funnel with stirring. The flask was then removed from the oil bath, and crushed ice was added with stirring. The hydrolysis products were extracted with three 20-ml. portions of ether and the extracts dried over magnesium sulfate. The solution was analyzed by gas chromatography on a column of 20% Apiezon L on Chromosorb P at temperatures of 205–230°.

Various control experiments were performed. The hydrolysis under the above conditions of a weighed sample of pure benzophenone phenylimine dissolved in hexane gave 97% of benzophenone. Triphenylmethyl azide was subjected to the hydrolysis procedure and gave 1.6% of benzophenone. The same treatment applied to (*p*-nitrophenyl)-diphenylmethyl azide gave less than 4% of benzophenone plus *p*-nitrobenzophenone. In calculating migration aptitudes given in Table I, it was assumed that 4% of the unreacted azide underwent acid-catalyzed rearrangements in all cases. Migration aptitudes obtained by McEwen for benzhydryl azide[20] were assumed to apply, and the amounts of benzophenone and substituted benzophenone formed in the acid-catalyzed reaction calculated as percentages of total reaction (photolytic plus acid catalyzed). These percentages were then subtracted from the observed percentages of the two ketones. The correction to the migration aptitudes was less than 0.10 in all but one case, the photolysis of *p*-chlorophenyldiphenylmethyl azide for 9.5 hr., where it was +0.16.

Thermal rearrangements of 1,1-diphenylethyl and 2-phenyl-2-propyl azides were performed by injecting the azide directly into the gas chromatograph, the reaction apparently occurring mainly on the column as the extent of conversion paralleled the column temperature. Peaks were identified by comparison with authentic samples of the expected imines. For 1,1-diphenylethyl azide a 10-ft. column of 20% silicone on Fluoropak 80 was used with the injector at 230°, the column at 223°, and the detector at 252°. For 2-phenyl-2-propyl azide a 12-ft. column of 20% Ucon Polar on Chromosorb P was used with the injector at 216°, the column at 192°, and the detector at 226°.

(19) J. H. Boyer, *J. Am. Chem. Soc.*, **73**, 5865 (1951).

(20) R. F. Tietz and W. E. McEwen, *ibid.*, **77**, 4007 (1955).

Kinetics of Hydrolysis of N,N'-Diarylformamidines in Alkaline Dioxane Solutions
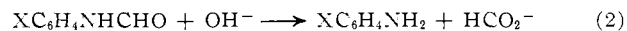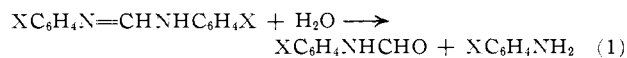
BY ROBERT H. DeWOLFE

The effects of aryl substituents, temperature, solvent polarity, and hydroxide ion concentration on the rate of hydrolysis of N,N'-diarylformamidines were studied. Amidines having electron-releasing aryl substituents hydrolyze in alkaline solutions at a rate which is almost independent of the hydroxide ion concentration and of the structure of the aryl group. Amidines having electron-withdrawing substituents undergo hydrolysis by two processes, one of which appears to be independent of hydroxide ion concentration, and another whose rate is a nonlinear function of hydroxide ion concentration. The nonlinear concentration dependence of the hydroxide ion-catalyzed reaction is shown to be a result of partial conversion of the amidines to unreactive conjugate bases in alkaline solutions. The mechanisms of the hydrolysis reactions are discussed.

The kinetics of hydrolysis of N,N'-diarylformamidines in buffer solutions and solutions of strong acids have been studied previously.[1,2] In acidic solutions, the kinetic data for hydrolysis of the diarylformamidines and N,N'-diarylacetamidines[3] are rationalized equally well by a mechanism involving nucleophilic attack by water or other bases on the hydrated amidinium ion, or by a general base-catalyzed attack by water on the amidinium ion.[4]

Diarylformamidines also hydrolyze under alkaline conditions, yielding arylamines and formanilides as the initial reaction products. The formanilides may, depending on reaction conditions and the structure of the aryl group, hydrolyze at a rate comparable to that of the amidine

$$XC_6H_4N=CHNHC_6H_4X + H_2O \longrightarrow$$
$$XC_6H_4NHCHO + XC_6H_4NH_2 \quad (1)$$

$$XC_6H_4NHCHO + OH^- \longrightarrow XC_6H_4NH_2 + HCO_2^- \quad (2)$$

The present study was undertaken to obtain information on the effect of structure and reaction conditions

(1) R. H. DeWolfe, *J. Am. Chem. Soc.*, **82**, 1585 (1960).

(2) R. H. DeWolfe and R. M. Roberts, *ibid.*, **75**, 2942 (1953).

(3) R. H. DeWolfe and J. R. Keefe, *J. Org. Chem.*, **27**, 493 (1962).

(4) J. F. Bunnett, *J. Am. Chem. Soc.*, **83**, 4971 (1961).

on the kinetics of alkaline hydrolysis of diarylformamidines.

Experimental

The dioxane used in the reaction mixtures was purified by the procedure of Fieser,[5] or by prolonged refluxing over sodium metal. The symmetrically substituted N,N′-diarylformamidines were prepared from ethyl orthoformate and aromatic primary amines by the method of Claisen,[6] and are known compounds. Reagent grade inorganic chemicals were used throughout. Heavy water, of 99.8% purity, was obtained from Bio-Rad Laboratories.

Aqueous dioxane was used as the reaction solvent for kinetic runs because of the very low solubility of most of the amidines in aqueous alkali. Reaction solutions were usually prepared by pipetting the desired volume of a very dilute solution (10^{-3}–10^{-4} M) of the amidine in dioxane into a 25-ml. volumetric flask, adding the sodium hydroxide and salt solutions, and filling the flask to the calibration mark with water. Solutions for comparison of the rate of hydrolysis of N,N′-di-p-nitrophenylformamidine in light and heavy water were prepared by weighing 4.000 g. of H₂O or 4.428 g. (4.00 ml.) of D₂O into a 10-ml. volumetric flask, adding 0.0525 ml. of 50% sodium hydroxide solution from a microburet, and then adding 1.00 ml. of the amidine in dioxane solution. The resulting solutions were approximately 0.20 N in NaOH, and the water in the D₂O solution consisted of 99+% D₂O.

Reaction rates were determined spectrophotometrically, using a Beckman DU spectrophotometer equipped with thermospacers or a Cary Model 14 spectrophotometer equipped with a thermostated cell holder.

The hydrolysis reactions are first order, and rates were determined by measuring the disappearance of the amidine, which absorbs at longer wave lengths than the hydrolysis products. Rate constants were evaluated as described previously.[1] Energies of activation were calculated using the Arrhenius equation, and entropies of activation were calculated for 25°, using the equation

$$\Delta S^{\ddagger} = 2.303 R(\log k - 10.753 - \log T + E_a/4.576T)^7$$

p-Nitroformanilide (m.p. 187–194°) and m-chloroformanilide (m.p. 53–55°) were prepared by the procedure of Huffman.[8] The absorption spectrum of a 20% dioxane–0.1 N NaOH solution of N,N′-di-p-nitrophenylformamidine was determined after ten half-lives for hydrolysis of the amidine, and found to be identical with that of p-nitroaniline. The spectrum of a similar solution of p-nitroformanilide, determined less than 5 min. from mixing, was also identical with that of p-nitroaniline, but quite different from that of a neutral 20% dioxane solution of the anilide (p-nitroaniline: λ_{max} 3830 Å., λ_{min} 2870 Å. in 0.1 N NaOH–20% dioxane; p-nitroformanilide: λ_{max} 3150 Å., λ_{min} 2510 Å. in neutral 20% dioxane). m-Chloroformanilide was found to hydrolyze only very slowly at room temperature in 0.1 N NaOH–20% dioxane. A 20% dioxane–0.1 N NaOH solution of N,N′-di-m-chlorophenylformamidine was heated at 75° for 1.5 hr. (about five half-lives for hydrolysis of the amidine), after which the absorption spectrum of the solution was found to differ from those of solutions of either m-chloroaniline or m-chloroformanilide. The spectrum of the reaction solution was quite similar to the spectrum obtained by graphically adding the spectra of m-chloroaniline and m-chloroformanilide (m-chloroaniline: λ_{max} 2890 Å., λ_{min} 2640 Å.; m-chloroformanilide, λ_{max} 2470 Å., λ_{min} 2300 Å.).

The equilibrium constants for the conversion of N,N′-di-p-nitrophenylformamidine, N,N′-di-m-nitrophenylformamidine, and N,N′-bis-(3,4-dichlorophenyl)-formamidine into their conjugate bases in alkaline aqueous dioxane solutions were determined by the spectrophotometric method of Walba and Isensee.[9] In the case of the two nitrosubstituted amidines, the absorbancies in alkaline solution were extrapolated to the time of mixing the solutions, to correct for hydrolysis of the amidines.

Results and Discussion

As mentioned in the Introduction, the initial products of diarylformamidine hydrolysis are formanilides and arylamines.[10] Because of low solubility of the amidines in the reaction solutions, it was not possible to isolate reaction products under the conditions of the kinetic experiments. In the cases of the di-p-nitrophenyl-

(5) L. F. Fieser, "Experiments in Organic Chemistry," Third Ed., D. C. Heath and Co., New York, N. Y., 1955, p. 284.

(6) L. Claisen, Ann., **287**, 366 (1895).

(7) J. F. Bunnett in "Rates and Mechanisms of Reactions. Part I," Second Ed., A. Weissberger, Ed., Interscience Publishers, Inc., New York, N. Y., 1961, p. 201.

(8) C. W. Huffman, J. Org. Chem., **23**, 727 (1958).

(9) H. Walba and R. W. Isensee, J. Am. Chem. Soc., **77**, 5488 (1955).
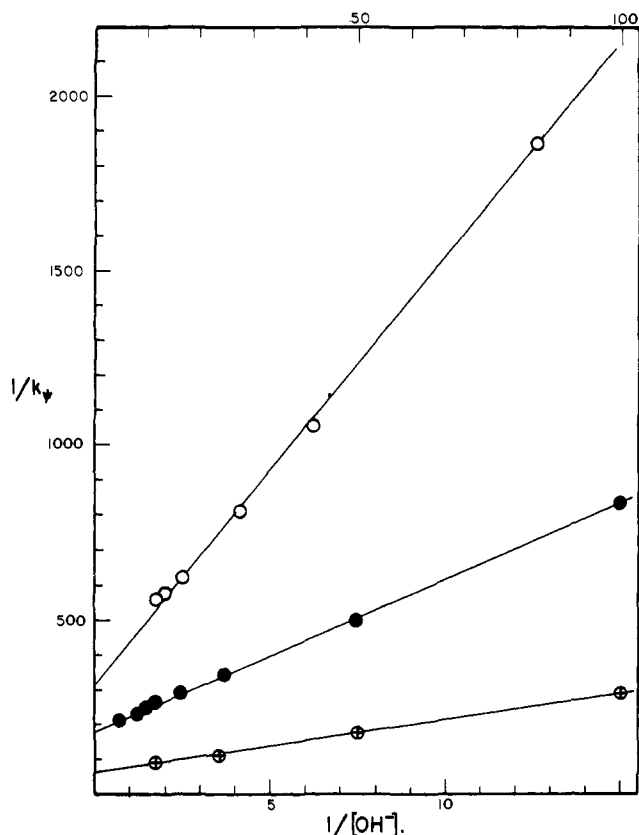
(10) G. Tobias, Ber., **15**, 2442 (1882).

and di-m-chlorophenylformamidines, the reaction products were qualitatively identified from their ultraviolet absorption spectra. The only identifiable product in the case of the nitro derivative was p-nitroaniline, and an independent experiment showed that p-nitroformanilide hydrolyzes very rapidly to p-nitroaniline under the conditions of the kinetic experiments. N,N′-Di-m-chlorophenylformamidine, on the other hand, yields a mixture of m-chloroaniline and m-chloroformanilide, indicating that the anilide is relatively stable under the reaction conditions. Although the kinetics of alkaline hydrolysis of formanilides appear not to have been studied in detail, Holleck and Malkonian found that p-nitroformanilide undergoes alkaline hydrolysis very rapidly.[11]

The results of a preliminary series of kinetic experiments in 20% dioxane solutions of three different hydroxide ion concentrations are reported in Table I. It is apparent that the amidines, $XC_6H_4N{=}CH{-}NHC_6H_4X$, fall into two groups. For one group (X = H, m-CH₃, p-CH₃, p-CH₃O, and p-NO₂) the rate of hydrolysis is practically independent of the hydroxide ion concentration, while for the other group (X = m-Cl, p-Cl, p-Br, and m-NO₂) there is a pronounced increase in hydrolysis rate with increasing hydroxide ion concentration. With the exception of the p-nitro compound, the members of the first group have electron-releasing substituents, while the members of the second group all have electron-attracting substituents.

Table I

Hydrolysis of $XC_6H_4N{=}CH{-}NHC_6H_4X$ in Alkaline 20% Dioxane[a]

	$10^5 k_\psi$					
	—25°, (OH⁻) =			—45°, (OH⁻) =		
X	0.637	0.424[b]	0.212[b]	0.637	0.424[b]	0.212[b]
p-CH₃O				21.0	23.3	23.0
p-CH₃				27.8	30.8	31.5
m-CH₃				30.8	32.9	36.6
H	6.54			32.1	33.2	33.8
p-Cl	6.87	5.60	4.78	38.1	31.4	21.1
p-Br	7.50	6.14	4.73	46.5	32.4	25.8
m-Cl	10.3	7.45	4.68	57.4	42.0	25.6
m-NO₂				236	193	117
p-NO₂	285	292	277			

[a] 1 volume of dioxane per 5 volumes of solution. [b] The ionic strength was maintained at 0.637 by addition of NaCl or KNO₃.

A second series of rate determinations, carried out in 40% dioxane solutions, yields further information on the nature of the hydroxide ion-dependent reaction. The data of Table II show that the hydrolysis of the halo- and m-ethoxy-substituted diarylformamidines involves two competing reactions, one which does not require hydroxide ion, and one whose rate increases with increasing hydroxide ion concentration. Further, the rate of the hydroxide ion-catalyzed reaction is not a linear function of catalyst concentration. Plots of k_ψ vs. (OH⁻) (k_ψ = experimental first-order rate constant) are concave downward in the case of the halo-substituted amidines—that is, the reaction rate tends to level off at high hydroxide ion concentrations. The slopes of k_ψ vs. (OH⁻) graphs at (OH⁻) = 0, which are a measure of the sensitivity of the amidines to hydroxide ion-catalyzed hydrolysis, increase in the order X = m-C₂H₅O < p-Cl < p-Br < o-Cl < m-Cl.

The rates (k_0) of hydrolysis of several diarylformamidines in 40% dioxane at 60.5°, extrapolated to (OH⁻) = 0, are given in Table III. The compounds which do not undergo appreciable hydroxide-ion catalyzed hydrolysis (X = H, p-C₂H₅O, p-CH₃, and m-CH₃) react with water at practically the same rate, while k_0 for

(11) L. Holleck and G. A. Malkonian, Z. Elektrochem., **58**, 867 (1954).

Fig. 1.—Lower scale refers to N,N'-di-*m*-chlorophenylformami-
dine (open circles); upper scale refers to N,N'-di-*p*-nitrophenyl-
formamidine, solid circles for 30° runs, crossed circles for 45°
runs.

the other amidines diminishes steadily as the electron-
withdrawing power of the substituent X increases.
A plot of log k_0 vs. Hammett's σ-constants for the var-
ious substituents[12] consists of two segments rather than

TABLE II
HYDROLYSIS OF XC₆H₄N=CH—NHC₆H₄X IN ALKALINE 40%
DIOXANE[a]

X	T, °C.	(OH⁻) 0.628	0.419[b]	0.210[b]	0.0105[b]
			10⁵k_ψ		
p-C₂H₅O	60.5				16.4
p-CH₃	60.5				19.4
m-CH₃	60.5				16.2
	76.0				51.6
H	60.5				19.1
	76.0				55.3
m-C₂H₅O	45.0	5.33	4.77	4.11	
	60.5	18.8	16.3	14.7	11.3
	76.0	58.1	51.5	44.0	33.7
p-Cl	45.0	14.8	11.0	6.82	
	60.5	51.3	39.0	24.4	8.51
	76.0	153	116	73.8	24.8
p-Br	45.0	17.2	12.7	7.70	
	60.5	60.7	45.8	27.7	8.10
	76.0	176	134	83.0	23.4
m-Cl	45.0	20.5	15.0	9.05	
	60.5	71.5	55.0	32.0	4.94
	76.0	214	162	98.4	16.5
o-Cl	45.0	17.5	12.8	7.05	
	60.5	56.6	41.6	23.4	
	76.0	168	124	69.4	8.85

[a] 2 volumes of dioxane per 5 volumes of solution. [b] Ionic
strength was brought to 0.628 by addition of NaCl.

(12) L. P. Hammett, "Physical Organic Chemistry," McGraw-Hill Book
Co., New York, N. Y., 1940, p. 188.

a single line. The points for X = *p*-C₂H₅O, *p*-CH₃,
m-CH₃, and H yield $\rho \cong 0$, while those for *m*-C₂H₅O,
p-Cl, *p*-Br, and *m*-Cl fall on a line with $\rho \cong -3$.

TABLE III
RATES OF UNCATALYZED HYDROLYSES OF
XC₆H₄N=CH—NHC₆H₄X IN ALKALINE 40% DIOXANE AT 60.5°

X	10⁵k_0	X	10⁵k_0
p-C₂H₅O	16.0	*m*-C₂H₅O	11.0
p-CH₃	19.4	*p*-Cl	7
m-CH₃	16.2	*p*-Br	6
H	19.1	*m*-Cl	2

The Hydroxide Ion-Catalyzed Hydrolysis Reaction.—
The curvature of k_ψ vs. (OH⁻) plots for the amidines
which undergo hydroxide ion-catalyzed hydrolysis,
together with the fact that the curvature is most
pronounced for the amidines having the strongest elec-
tron-withdrawing substituents, suggested that these
amidines are partially converted to unreactive salts in
alkaline solutions

$$ArN=CH—NHAr + OH^- \overset{K_c}{\underset{}{\rightleftharpoons}}$$
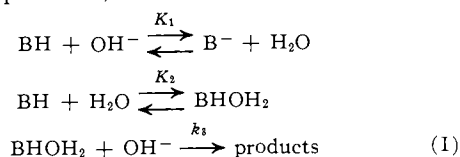$$[ArN{\cdots}CH{\cdots}NAr]^- + H_2O \quad (3)$$
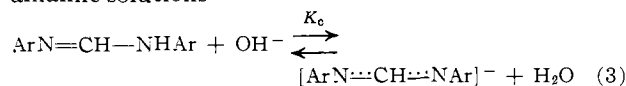
Partial conversion of diarylformamidines to their con-
jugate bases in alkaline solutions is not surprising.
Benzimidazole and a number of substituted imidazoles,
whose resonance-stabilized conjugate bases are similar
in structure to the conjugate bases of diarylformami-
dines, are partially or completely converted to salts
by aqueous alkali.[9,13]
Further evidence that diarylformamidines are parti-
ally converted to salts in dilute hydroxide solutions
was the observation that N,N'-di-*p*-nitrophenylform-
amidine, which is pale yellow in neutral solutions,
is deep red-orange in alkaline solutions. Confirmation
was obtained by determining the equilibrium constants
for reaction 3 for N,N'-di-*p*-nitrophenylformamidine,
N,N'-di-*m*-nitrophenylformamidine, and N,N'-bis-(3,4-
dichlorophenyl)-formamidine by the spectrophoto-
metric procedure of Walba and Isensee.[9] In 40%
dioxane at 25°, $K_c = 65$ for the *p*-nitrophenylamidine,
1.48 for the *m*-nitrophenylamidine, and 3.02 for the
dichlorophenylamidine (ionic strength = 1.0 in all
cases). For the di-*p*-nitrophenylformamidine in 20%
dioxane at 30°, $\mu = 0.2$, $K_c = 25.5$.
Conversion of trifluoroacetanilide and di- and tri-
chloroacetamide into unreactive conjugate bases has
been offered as an explanation for the anomalous saponi-
fication kinetics of these compounds.[14,15] For these
reactions also, plots of reaction rate vs. (OH⁻) are con-
cave downward.
A mechanism involving pre-equilibrium conversion of
the amidine to an unreactive conjugate base and re-
action of the free amidine or, as seems more likely, an
uncharged tetrahedral intermediate (ArNH–CH(OH)–
NHAr) in equilibrium with it with hydroxide ion to
form reaction products, *i.e.*

$$BH + OH^- \overset{K_1}{\rightleftharpoons} B^- + H_2O$$

$$BH + H_2O \overset{K_2}{\rightleftharpoons} BHOH_2$$

$$BHOH_2 + OH^- \overset{k_3}{\longrightarrow} \text{products} \quad (I)$$

has the rate equation

$$k_\psi = k_3K_2[OH^-]/(1 + K_1[OH^-]) \quad (4)$$

if products are formed from hydrated amidine. It
follows from eq. 4 that $1/k_\psi = 1/k_3K_2[OH^-] + K_1/$

(13) D. O. Jordan and H. F. W. Taylor, *J. Chem. Soc.*, 994 (1946).
(14) S. S. Biechler and R. W. Taft, *J. Am. Chem. Soc.*, **79**, 4929 (1957).
(15) A. Bruylants and F. Kezdy, *Record Chem. Progr.*, **21**, 226 (1960).

k_3K_2. Therefore, a plot of $1/k_\psi$ vs. $1/[OH^-]$ should be linear if the hydroxide ion-catalyzed reaction occurs by this mechanism. Such plots are indeed linear for the hydrolysis of N,N'-di-m-chlorophenylformamidine in 40% dioxane at 76°, and for the hydrolysis of N,N'-di-p-nitrophenylformamidine in 20% dioxane at 30° and 45°. (Table IV and Fig. 1; strictly speaking, the observed rate constants should be corrected for the uncatalyzed part of the reaction. This correction is negligible for the reactions in question, however.)

TABLE IV

HYDROXIDE ION CONCENTRATION DEPENDENCE OF THE RATE OF HYDROLYSIS OF $XC_6H_4N=CH-NHC_6H_4X$ IN AQUEOUS DIOXANE SOLUTIONS

X = p-NO$_2$, 20% dioxane at 30°, μ = 0.20		X = p-NO$_2$, 20% dioxane at 45°, μ = 0.20		X = m-Cl, 40% dioxane at 76°, μ = 0.596	
(OH$^-$)	10^4k_ψ	(OH$^-$)	10^4k_ψ	(OH$^-$)	10^4k_ψ
0.20	48.3	0.08	113	0.596	18.0
.12	44.2	.04	94.8	.516	17.3
.10	41.2	.02	58.8	.437	16.3
.08	38.3	.01	34.7	.357	14.7
.06	34.9			.278	12.4
.04	29.4			.198	9.5
.02	20.1			.119	5.4
.01	12.0				

At sufficiently high hydroxide ion concentrations, the rate of hydrolysis approaches the limiting value $k_\psi = k_3K_2/K_1$. This is probably the explanation for the apparent absence of hydroxide ion-catalyzed hydrolysis in the case of N,N'-di-p-nitrophenylformamidine in 20% dioxane solutions above about 0.2 N NaOH (Table I).

The experimental data are therefore compatible with a mechanism involving pre-equilibrium conversion of the amidine to an unreactive conjugate base. At least two other mechanisms account for the data equally well, however. The first involves rate-determining reaction of the conjugate base of the amidine with water

$$BH + OH^- \overset{K_1}{\underset{}{\rightleftarrows}} B^- + H_2O$$

$$B^- + H_2O \overset{k_2}{\longrightarrow} products \qquad (II)$$
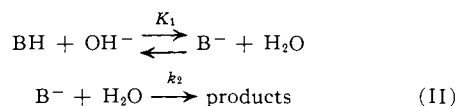
The rate equation required by this mechanism is

$$k_\psi = k_2K_1[OH^-]/(1 + K_1[OH^-]) \qquad (5)$$

The reciprocal of this equation is $1/k_\psi = 1/k_2K_1[OH^-] + 1/k_2$, so that again a plot of $1/k_\psi$ vs. $1/[OH^-]$ should be linear. The third mechanism involves reversible addition of hydroxide ion to the amidine to form an anionic tetrahedral intermediate (ArNH–CH(OH)–$\overline{N}$Ar), followed by rate-determining conversion of the intermediate to reaction products. The rate equation for this mechanism (III) is identical with (5), except that K_1 refers to the equilibrium $BH + OH^- \rightleftarrows BHOH^-$.

Mechanism III can be excluded with considerable confidence on the basis of the spectroscopic and other evidence that the amidines form resonance-stabilized conjugate bases, $ArN\!=\!C\!=\!NAr^-$, rather than addition products in the pre-equilibrium reaction with hydroxide ion.

According to both mechanisms I and II, the quotient obtained by dividing the intercept by the slope of a $1/k_\psi$ vs. $1/[OH^-]$ plot equals K_1, the equilibrium constant for reaction 3. In the case of N,N'-di-p-nitrophenylformamidine in 20% dioxane at 30°, the spectrophotometrically determined equilibrium constant is 25.5, while that determined from the $1/k_\psi$ vs. $1/[OH^-]$ plot is 27.5.

The kinetic data permit no choice between mechanisms I and II. Mechanism I, involving rate-determining reaction of the hydrated amidine with hydroxide ion, seems much more reasonable than mechanism II, which involves rate-determining nucleophilic attack by water on the negatively charged, resonance-stabilized conjugate base of the amidine.

The proposed mechanism of the hydroxide ion-catalyzed hydrolysis reaction is similar to that proposed for alkaline hydrolysis of amides.[14,16] This mechanism is not only compatible with the observed substituent effects, but also with the observed negative entropy of activation (−15 e.u.) for hydroxide ion-catalyzed hydrolysis of N,N'-di-p-nitrophenylformamidine.

The solvent isotope effect, k_{H_2O}/k_{D_2O}, is 1.33 for hydrolysis of di-p-nitrophenylformamidine in 0.2 N NaOH–20% dioxane at 25°. According to (4), $k_{H_2O}/k_{D_2O} \cong k_3{}^{H_2O}K_2{}^{H_2O}K_1{}^{D_2O}/k_3{}^{D_2O}K_2{}^{D_2O}K_1{}^{H_2O}$, since the amidine is nearly completely converted to the conjugate base at this hydroxide ion concentration (i.e., $k_\psi \cong k_3K_2/K_1$). $K_1 = K_a/K_w$, where K_a is the acidity constant of the amidine and K_w is the autoprotolysis constant of water. If it is assumed that the amidine is about one pK unit more acidic than water, it can be estimated from the data of Bell[17] that $K_a{}^{H_2O}K_w{}^{D_2O}/K_a{}^{D_2O}K_w{}^{H_2O} \cong K_1{}^{H_2O}/K_1{}^{D_2O} \cong 0.8$. The solvent isotope effect on k_3K_2 is approximately 1.33 × 0.8 $\cong$ 1.1. This value is only approximate; the true value falls somewhere in the range 0.9 to 1.1. According to the proposed mechanism, the solvent isotope effect is a secondary isotope effect, for which a value less than unity is predicted by the approximate method of Bunton and Shiner.[18]

The dangers inherent in using solvent isotope effects as a criterion of mechanism in base-catalyzed reactions is illustrated by the fact that ethyl acetate saponification and acetamide saponification, which presumably occur by similar mechanisms, have k_{H_2O}/k_{D_2O} ratios of 0.75 and 1.1, respectively.[19,20]

The Hydroxide Ion-Independent Hydrolysis Reaction.—The data of Table I indicate that, for diarylformamidines having electron-releasing aryl substituents, the rate of hydrolysis decreases slightly with increasing hydroxide ion concentration. The decrease is small, but probably is too large to be attributable to experimental errors. This apparent inverse concentration dependence may be due to a secondary salt effect; however, it was found that no detectable change in hydrolysis rate was caused by substitution of KNO$_3$ for NaCl as the salt used to maintain constant ionic strength.

The rate of the uncatalyzed hydrolysis is almost independent of the structure of the aryl group when the aryl substituent is H, m-CH$_3$, p-CH$_3$, and p-C$_2$H$_5$O, but diminishes sharply when H is replaced by electron-withdrawing substituents (Table III).

Two general mechanisms would account for the uncatalyzed hydrolysis reaction: rate-determining attack by hydroxide ion on the conjugate acid of the amidine, or a protonated hydrate in equilibrium with it; or rate-determining attack by water on the free amidine or a hydrate in equilibrium with it. The second of these mechanisms, which could involve either nucleophilic attack on the amidine carbon atom or proton abstraction from the oxygen atom of the hydrated amidine in the rate-determining step, can be dismissed as unlikely on the basis of substituent effects on re-

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(20) O. Reitz, Z. Elektrochem., **44**, 693 (1938).

activity. Whether or not pre-equilibrium hydration of the amidine is involved, reaction by this mechanism should have a positive Hammett ρ-constant. Actually, the observed slope of a log k vs. σ plot varies from 0 to −3. The curvature of the Hammett plot may be due to a change in the rate-limiting step of the reaction when the structure of the aryl group is changed. It cannot be due to hydrolysis by two competing mechanisms, since in this case the plot would be concave upward rather than downward.

The small inverse variation of hydrolysis rate with hydroxide ion concentration for amidines with elec-

tron-releasing substituents (Table I) may be due to rate-determining reaction of protonated amidine or protonated amidine hydrate with water, or to a rate-determining unimolecular reaction of either of these species. A more detailed pH profile for the reaction should show whether a reaction of this nature actually occurs, or whether the small rate changes observed are the result of salt effects.

Syntheses of the Three Isomeric Diethyl- and Dineopentyltetramethylbenzenes[1]

By Melvin S. Newman, John R. LeBlanc,[2] Harold A. Karnes,[2] and George Axelrad[1]

The syntheses of the three isomeric diethyl- and dineopentyltetramethylbenzenes has been accomplished. Differences in the tendencies of the o-isomers as compared to the m- and p-isomers to complex with tetracyanoethylene and 2,4,7-trinitrofluorenone have been observed and briefly discussed. New syntheses of compounds containing cyclopropyl rings have been noted in the lithium aluminum hydride, sodium in liquid ammonia, and Raney nickel reductions of bis-[2,2-bis-(iodomethyl)-propyl]-durene (VIIa) to yield bis-[1-methylcyclopropyl)-methyl]-durene (VIIIa).

Marked differences in the equilibrium constants for the interaction of hexamethylbenzene and hexaethylbenzene with iodine and iodine monochloride have been determined.[3] The low values for hexaethylbenzene were explained in terms of steric effects.[3] To understand these effects better we have prepared the three isomeric diethyltetramethylbenzenes and dineopentyltetramethylbenzenes so that equilibrium constant determinations could be made not only with iodine but also with other reagents which form complexes with aromatic systems.

The thinking behind the choice of these hydrocarbons for study is as follows. Examination of molecular models shows that in the m- and p-isomers the larger groups can readily exist in structures in which the bulky groups (methyl in case of the ethyl derivatives and t-butyl in case of the neopentyl derivatives) lie on the same side of the ring. However, in the o-isomers the tendency should be greater (particularly in the case of the neopentyl compound) to have these groups on opposite sides of the plane of the benzene ring. For this reason measurement of the equilibrium constants for several types of Lewis acid π-complexing reagents would be of interest as one might be able thus to define more accurately the geometrical requirements for complex formation. For example, in o-dineopentyltetramethylbenzene no π-complex would be likely to form if the π-complexing reagent needs to be fairly symmetrically oriented with regard to the six aromatic carbon atoms because one neopentyl group would be shielding each side of the benzene ring.[4] However, if less symmetrical orientation is required by the π-complexing reagent, then complexing should still be possible if the Lewis acid in question were itself not too bulky. Similar effects, to a lesser degree, would be expected with the diethyl (or other alkyl) analog. The structures of the p-, m-, and o-dineopentyltetra-

methylbenzenes VIa, VIb, and VIc, respectively, are shown (not to scale) in the drawings. Only the features essential to the argument are shown.

VIa (para)[5]   VIb (meta)[5]

Faces only partly free for complexing

VIc (ortho)[5]
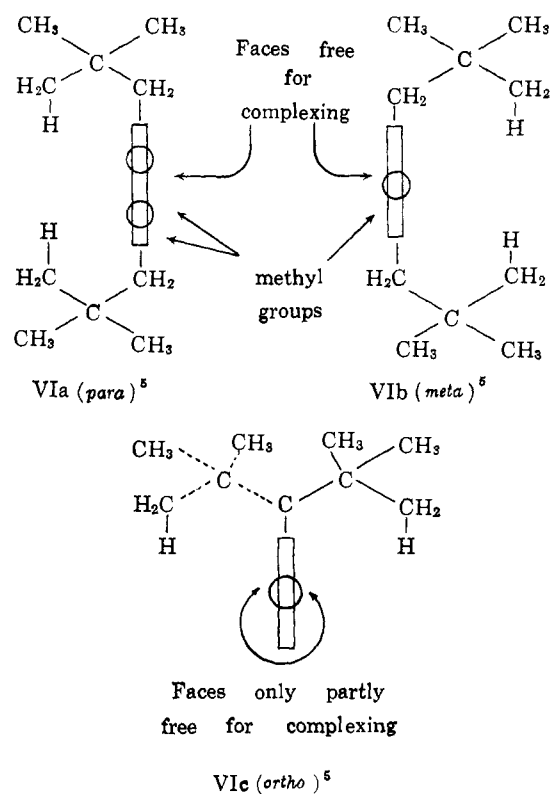
When chloroform solutions containing the same molar concentrations of hydrocarbon and 2,4,7-trinitro-

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(3) L. J. Andrews and R. M. Keefer, J. Am. Chem. Soc., **74**, 4500 (1952).