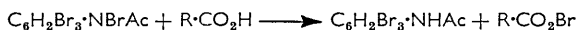


39. Reactions of *N*-Bromoacetanilides in Chlorobenzene and Benzene Solutions in the Presence of Acetic and Propionic Acids.

By S. C. CHAN and G. C. ISRAEL.

The rates at which *N*,2,4,6-tetrabromoacetanilide disappears from solutions containing anisole and acetic or propionic acid have been examined in chlorobenzene and benzene. The first-order rate constants vary with the acid concentration according to an equation of the type $k_1^2 + Ak_1 = Bc$, which is explicable if the reaction between *N*,2,4,6-tetrabromoacetanilide and carboxylic acid giving bromine acylate (the intermediate brominating agent) is of second order, *i.e.*, of first order with respect to each reactant:



and due account is taken of the dimerization of the carboxylic acid in such solutions. It is assumed that only the monomeric form of the acid is active in the reaction.

THE mechanism of the rearrangements of *N*-bromoacylanilides has been controversial. Bell *et al.*¹⁻⁴ studied them in aprotic solvents in presence of a number of different carboxylic acids and phenols, and concluded that the rearrangement involved an intramolecular mechanism.

Soper and his co-workers⁵ examined the rearrangement of *N*-bromoacetanilide and *N*,2,4,6-tetrabromoacetanilide in the presence of anisole (or phenetole) and acetic acid in chloroform and in chlorobenzene, and showed that an intramolecular mechanism was not involved and that a highly reactive intermediate brominating agent, which was not hypobromous acid, was formed. They suggested that this might be bromine acetate (acetyl hypobromite).

They also showed that, in the absence of the acid catalyst, the *N*-bromoacylanilide does not react with anisole (or phenetole) to an extent greater than 2% in either chloroform or chlorobenzene, although Dewar⁶ appears to have overlooked this when he suggested that the *N*-bromoanilide might brominate the added ether directly. Dewar also suggested that, if the rearrangements were intermolecular, they might take place through a π -complex, but later Dewar and Scott⁷ presented evidence in favour of Soper and his co-workers' earlier suggestion. Dewar and Scott⁷ showed that the reaction is of first order with respect to the *N*-bromoacylanilide. They do not say how the rate varies with the acid concentration. Further, Dewar and Scott do not appear to have taken into account the possibility that, when other anilides are present, metathesis may give rise to the presence of other *N*-bromoanilides. Thus, in the rearrangement of *N*-bromoacetanilide, *p*-bromoacetanilide is produced and this may react directly with *N*-bromoacetanilide to form *N*,*p*-dibromoacetanilide which will react at a different rate. We have found evidence of such a direct interchange. However, *N*,2,4,6-tetrabromoacetanilide cannot rearrange in this way in an aprotic solvent in the presence of acids, and the formation of solutions of mixed *N*-bromo-anilides is thus avoided. We have therefore examined the rates at which it reacts with anisole in chlorobenzene and in benzene in the presence of varying concentrations of acetic or propionic acid and have determined how the first-order reaction constants vary with the concentration of the acid present.

¹ Bell, *Proc. Roy. Soc.*, 1934, A, **143**, 377.

² Bell and Levinge, *ibid.*, 1935, A, **151**, 211.

³ Bell, *J.*, 1936, 1154.

⁴ Bell and Lidwell, *J.*, 1939, 1096.

⁵ Israel, Tuck, and Soper, *J.*, 1945, 547.

⁶ Dewar, "Electronic Theory of Organic Chemistry," Oxford Univ. Press, 1949, p. 225.

⁷ Dewar and Scott, *J.*, 1957, 2676.

EXPERIMENTAL

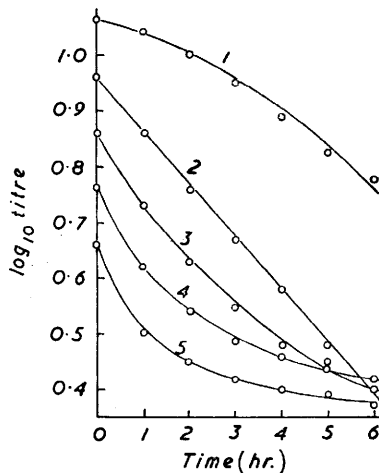
Materials.—Chlorobenzene was dried (K_2CO_3), and then distilled to yield a fraction of constant b. p. 132° ($n_D^{20} = 1.5248$; Beilstein gives $n_D^{20} = 1.52479$).

Benzene ("AnalaR") was shaken several times with concentrated sulphuric acid until no further darkening occurred, then separated, dried (K_2CO_3), refluxed for 24 hr. in the presence of potassium, and finally distilled to yield a fraction of constant b. p. 80° ($n_D^{20} = 1.5014$; Beilstein gives $n_D^{20} = 1.5014, 1.5015$).

Anisole was kept over crystalline ferrous sulphate overnight, then dried ($CaCl_2$, then Na), and fractionally distilled in the presence of sodium in an atmosphere of argon. It was stored in a desiccator in the dark ($n_D^{20} = 1.5175$; Beilstein gives $n_D^{20} = 1.5179$).

FIG. 1. Rearrangement of *N*-bromoacetanilide in chlorobenzene.

- 1, 0.00M-Ph-NHAc; log titre.
- 2, 0.01M-Ph-NHAc; log titre -0.1.
- 3, 0.02M-Ph-NHAc; log titre -0.2.
- 4, 0.03M-Ph-NHAc; log titre -0.3.
- 5, 0.04M-Ph-NHAc; log titre -0.4.



Glacial acetic acid (Merck) was purified by freezing and allowing the frozen acid to melt, the first liquid fractions being rejected. The remaining solid acetic acid was melted and appeared to need no further purification. It was stored in a desiccator.

Propionic acid (B.D.H.) was heated for $\frac{1}{2}$ hr. with an amount of benzoic anhydride equivalent to the amount of water present, chromic oxide being added to catalyse the hydrolysis of the anhydride. The mixture was fractionally distilled and the resulting propionic acid was found by titration to be more than 99.97% pure (b. p. $141.35^\circ/760$ mm. Beilstein gives b. p. $140.9^\circ/760$ mm., $141.05^\circ/760$ mm., $141.35^\circ/760$ mm.).

N-Bromoacetanilide, prepared by the method used by Israel, Tuck, and Soper,⁵ had a purity of 90—95% by titration of the iodine liberated by adding acidified potassium iodide.

N,2,4,6-Tetrabromoacetanilide was prepared by adding 6 g. of bromine in 20 c.c. of chloroform to 200 c.c. of 5% sodium hydrogen carbonate solution. The mixture was cooled with ice and 6 g. of powdered 2,4,6-tribromoacetanilide were added, the resulting mixture being stirred in the dark for 1 hr. The chloroform layer was separated, washed with water, dried ($CaCl_2$), and evaporated in the cold by a current of argon in the dark. The yellow crystals had a purity of 90—95% by titration. Recrystallization did not improve the purity.

Rate Measurements.—A standard thermostat maintained at $25^\circ \pm 0.01^\circ$ was provided with a hood and curtain to exclude light. Stock solutions of the *N*-bromoanilide, anisole, and acetic or propionic acid in the appropriate solvent were stored in the bath. The required volume of the *N*-bromoanilide solution was pipetted into a 50 ml. volumetric flask and diluted to the mark with pure solvent. The required volumes of the acid solution and of anisole solution were added to a second 50 ml. volumetric flask and diluted to the mark with pure solvent. When these solutions had reached temperature equilibrium, the reaction was started by pouring both solutions simultaneously into a 250 ml. conical flask. 10 ml. samples were removed at regular intervals during about 6 hr. and delivered into 10 ml. of 3% sodium iodide solution. The iodine liberated was titrated with standard thiosulphate (starch).

N-Bromoacetanilide.—Two sets of experiments were carried out in chlorobenzene, acetanilide

being present in varying amounts. The results of the first set are in Fig. 1, those of the second set being the same.

These figures show that the rate of reaction is greatly affected by the addition of acetanilide. On the other hand, similar mixtures prepared at the same time but without the acetic acid catalyst remained perfectly stable during the time in which the reactions were followed. Thus the possibility of direct reaction between the *N*-bromoanilide and acetanilide was excluded. In each case, there was a marked deviation from the usual first-order kinetics over the first 4 hr., but thereafter the usual first-order equation appears to hold.

The initial first-order velocity constants were determined by drawing the tangents to the curves at zero time. Their variations with acetanilide concentration are in Tables 1 and 2. In all Tables the concentration quoted is that of the *N*-bromoacetanilide actually in solution, calculated on the purity quoted.

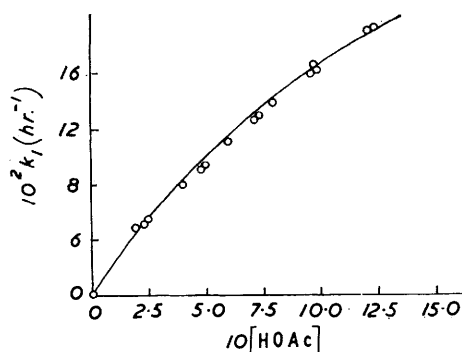
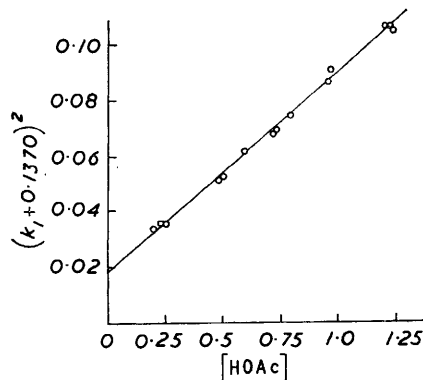
TABLE 1. [HOAc] = 0.511.

$10^2[\text{Ph}\cdot\text{NBrAc}]_i = 1.038$, purity 94.0%					
$10^2[\text{Ph}\cdot\text{NHAc}]$	0	1.045	1.994	2.993	4.070
10^2k_1 (hr. ⁻¹)	6.91	22.5	33.6	40.5	45.1

TABLE 2. [HOAc] = 0.511.

		1.004, purity 90.8%			
	0	1.124	2.065	3.051	4.078
	7.49	24.2	35.9	51.4	66.3

These results suggests strongly that the anilide and the *N*-bromoanilide present are interacting directly in the way mentioned earlier. The difference between the sets of results in these

FIG. 2. Rearrangement of *N*,2,4,6-tetrabromoacetanilide in presence of acetic acid.FIG. 3. Rearrangement of *N*,2,4,6-tetrabromoacetanilide in presence of acetic acid.

two tables is undoubtedly due to difference in the purities of the *N*-bromoacetanilide used. From the method of preparation, it is almost certain that the impurity is *p*-bromoacetanilide.

In view of the uncertainty of the results for *N*-bromoacetanilide, this line of investigation was not pursued further.

N,2,4,6-Tetrabromoacetanilide. Solutions of the tetrabromoacetanilide in chlorobenzene were stable for a long time in the dark. Its solutions in chlorobenzene containing added (a) acetic or propionic acid, or (b) anisole were stable for up to 2 days in the sense that the iodine titre of such solutions was unaltered.

Kinetic experiments were first carried out to determine whether, and under what conditions, the concentration of anisole affects the rate of reaction. The results (Tables 3 and 4) show that, below a concentration of 0.2M-anisole, the reaction rate varies with the concentration of the anisole, but above this value the reaction rate is sensibly independent of that concentration.

TABLE 3. [HOAc] = 0.988.

$10^2[\text{C}_6\text{H}_2\text{Br}_3\cdot\text{NBrAc}] = 1.541$, purity 94.7%					
$10[\text{PhOMe}]$	0.00	0.959	1.918	2.877	3.836
$10k_1$ (hr. ⁻¹)	0.00	1.37	1.50	1.55	1.55

TABLE 4. [HOAc] = 0.988.

		1.114, purity 94.7%		
	0.00	0.371	5.057	6.742
	0.00	1.57	1.58	1.62

The next kinetic experiments were carried out with a concentration of added anisole so high that it did not appear in the kinetic equation. Three sets were conducted (Tables 5—7), the

TABLE 5.
 [PhOMe] = 0.575.

$10^2[\text{C}_6\text{H}_2\text{Br}_3\cdot\text{NBrAc}] = 1.430$, purity 93.7%			
$10[\text{HOAc}]$	0.00	2.43	4.86
10^2k_1 (hr. ⁻¹) ...	0.00	5.15	9.12
$10[\text{HOAc}]$	7.29	9.72	12.15
10^2k_1 (hr. ⁻¹) ...	12.56	15.79	18.83

 TABLE 6.
 [PhOMe] = 0.591.

1.176 , purity 94.0%			
0.00	2.48	4.96	
0.00	5.44	9.29	
7.44	9.92	12.40	
12.78	16.06	18.86	

 TABLE 7.
 [PhOMe] = 0.570.

0.905 , purity 93.0%			
0.00	1.97	3.93	
0.00	4.76	8.04	
5.90	7.86	9.83	
11.10	13.73	16.42	

concentration of the tetrabromoacetanilide being constant in each set and the acetic acid concentration varied. The rate of disappearance of the anilide followed first-order kinetics, confirming the observations of Soper *et al.*⁵ and Dewar and Scott.⁷

The plot of all these values of k_1 against the acetic acid concentration was a single curve passing through the origin (Fig. 2). By the method of least squares, the curve of best fit was found to be given by

$$10^2k_1^2 + 27.40k_1 = 7.9[\text{HOAc}]$$

Whence

$$10^2(k_1 + 0.1370)^2 = 7.9[\text{HOAc}] + 1.88 \quad \dots \quad (A)$$

Values of k_1 calculated by using eqn. (A) were in good agreement with the observed values. Further, from equation (A), the plot of the observed values of $(k_1 + 0.1370)^2$ against $[\text{HOAc}]$ should be linear. Fig. 3, in which all three sets of results are plotted, shows that a single straight line is obtained. The line of best fit, determined by the method of least squares, was given by an equation identical with (A).

Solutions of the tetrabromoacetanilide in purified benzene were also stable, and remained stable when either acetic acid or anisole was added. Kinetic results for benzene solution with the addition of anisole are in Tables 8—10.

 TABLE 8.
 [PhOMe] = 0.599.

$10^2[\text{C}_6\text{H}_2\text{Br}_3\cdot\text{NBrAc}] = 1.461$, purity 92.5%			
$10[\text{HOAc}]$	0.00	2.43	4.86
10^2k_1 (hr. ⁻¹)	0.00	8.55	13.54
$10[\text{HOAc}]$	7.29	9.72	12.15
10^2k_1 (hr. ⁻¹) ...	18.64	22.65	26.5

 TABLE 9.
 [PhOMe] = 0.587.

1.260 , purity 92.8%			
0.00	2.43	4.86	
0.00	8.49	13.57	
7.29	9.72	12.15	
18.59	22.36	26.55	

 TABLE 10.
 [PhOMe] = 0.589.

0.994 , purity 92.8%			
0.00	2.43	4.86	
0.00	8.51	13.57	
7.29	9.72	12.15	
18.63	22.45	26.62	

These results also gave a single curve for which the equation of best fit was

$$10^2k_1^2 + 25.32k_1 = 11.19[\text{HOAc}],$$

Whence

$$10^2(k_1 + 0.1266)^2 = 11.19[\text{HOAc}] + 1.60 \quad \dots \quad (B)$$

The plot of the observed values of $(k_1 + 0.1266)^2$ against $[\text{HOAc}]$ was a single straight line and the line of best fit was given by an equation identical with (B).

A similar set of experiments (Tables 11—13) using chlorobenzene as solvent and propionic acid as the catalyst gave analogous results to those found when acetic acid was used to promote the reaction.

 TABLE 11.
 [PhOMe] = 0.561.

$10^2[\text{C}_6\text{H}_2\text{Br}_3\cdot\text{NBrAc}] = 1.429$, purity 93.6%			
$10[\text{Et}\cdot\text{CO}_2\text{H}]$...	0.00	2.53	5.05
10^2k_1 (hr. ⁻¹)	0.00	4.62	8.72
$10[\text{Et}\cdot\text{CO}_2\text{H}]$...	7.58	10.10	12.63
10^2k_1 (hr. ⁻¹)	12.45	15.80	19.52

 TABLE 12.
 [PhOMe] = 0.566.

1.176 , purity 90.1%			
0.00	2.55	5.10	
0.00	4.87	8.89	
7.64	10.19	12.74	
12.69	16.19	19.72	

 TABLE 13.
 [PhOMe] = 0.566.

0.950 , purity 92.8%			
0.00	2.57	5.14	
0.00	5.09	9.05	
7.71	10.28	12.85	
12.89	16.57	19.83	

The values of k_1 so obtained lie on a single curve, found by the method of least squares to be given by

$$10^2k_1 + 66.58k_1 = 13.24[\text{Et}\cdot\text{CO}_2\text{H}]$$

Whence

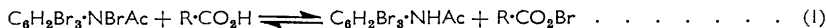
$$10^2(a_1 + 0.3329)^2 = 13.24[\text{Et}\cdot\text{CO}_2\text{H}] + 10.8 \quad \dots \quad (C)$$

As before the plot of the observed values of $(k_1 + 0.3329)^2$ against $[\text{Et}\cdot\text{CO}_2\text{H}]$ gave a straight line, the line of best fit, determined by the method of least squares, being given by an equation identical with (C).

No indications of the double-titre phenomenon observed by Dewar and Scott⁷ were obtained.

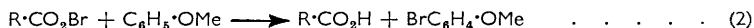
DISCUSSION

According to the Soper mechanism, the reaction between *N*,2,4,6-tetrabromoacetanilide and an easily brominatable substance in the presence of a carboxylic acid in an aprotic solvent occurs in two stages. The first, reaction between the *N*-bromoanilide and the carboxylic acid, is apparently the rate-determining step.



The bromine acylate so formed then reacts with the easily brominatable additive as fast as it is formed.

When the concentration of the added anisole is low, the rate of the reaction:



is lower than that of reaction (1). Above a certain minimum concentration of anisole, reaction (2) is sensibly faster than reaction (1), with the result that the concentration of anisole no longer affects the rate of overall reaction. Under such conditions, the equation and mechanism suggest that the reaction should be of second order, *i.e.*, of first order with respect to *N*-bromoanilide and to carboxylic acid. The fact that the reaction is of first order with respect to the *N*-bromoanilide is well established (refs. 1—7 and present work). The inference that the reaction should also be of first order with respect to carboxylic acid is, at first sight, not confirmed by our results, since the plots of k_1 against the concentrations of carboxylic acids used are not linear but conform to an equation of the

$$k_1^2 + Ak_1 = Bc \quad \dots \quad (D)$$

type (D) where k_1 is the first-order constant for the rate of disappearance of the *N*-bromoanilide and c the concentration of the carboxylic acid in the reaction mixture. A and B are constants dependent not only on the nature of the carboxylic acid but also on that of the aprotic solvent.

Carboxylic acids are associated in solvents such as benzene or chlorobenzene. Investigations⁸ on the equilibrium between non-associated and associated carboxylic acid molecules have shown that, in dilute solutions, the associated molecules are principally dimers, the carboxyl groups being linked by hydrogen bonds to form a ring. It would be expected that such dimers would be inactive in catalysing the reactions studied here, since they can supply protons only after dissociation into monomers.

If the reaction studied is of first order with respect to the carboxylic acid present

$$k_1 = k_2c_m \quad \dots \quad (E)$$

where c_m is the concentration of monomeric carboxylic acid in the reaction mixture, and k_2 is the second-order constant for the reaction given by eqn. (1). Representing the concentration of the dimer by c_d , we have

$$c_m^2/c_d = K \text{ or } c_d = c_m^2/K$$

where K is the equilibrium constant for $(\text{R}\cdot\text{CO}_2\text{H})_2 \rightleftharpoons 2\text{R}\cdot\text{CO}_2\text{H}$. If c is the total concentration of carboxylic acid in the reaction mixture as determined by titration, it follows that

$$c = c_m + 2c_d = c_m + 2c_m^2/K \quad \dots \quad (F)$$

Substitution of eqn. (E) and rearrangement gives

$$k_1^2 + (Kk_2/2)k_1 = (Kk_2^2/2)c \quad \dots \quad (G)$$

⁸ Davies, Jones, Patnaik, and Moelwyn-Hughes, *J.*, 1951, 1249.

Equation (G) is clearly of the same form as equation (D), found experimentally, and these two equations are identical if $A = Kk_2/2$ and $B = Kk_2^2/2$, whence $k_2 = B/A$ and $K = 2A^2/B$ can be determined (Table 14).

TABLE 14.

Acid	Solvent	$10^2 k_2$ (l. mole ⁻¹ hr. ⁻¹)	K (mole l. ⁻¹)
Acetic	C ₆ H ₅ Cl	25.87	2.12
Acetic	C ₆ H ₆	44.19	1.15
Propionic	C ₆ H ₅ Cl	19.88	6.70

The values of K so calculated are about 10^3 times larger than those quoted in the literature.^{8,9} The discrepancy may not however be surprising, since, in the system studied, there are present reasonable concentrations of polar compounds (*N*-bromoanilide and anisole). The presence of such polar compounds would be expected to shift the dimerization equilibrium in favour of the monomer.

We feel that these results demonstrate clearly that, when the concentration of easily brominatable additive is sufficiently high, the reaction between *N*,2,4,6-tetrabromoacetanilide and carboxylic acid is in fact of second order as is required by the Soper mechanism and that the apparent deviation from simple second-order kinetics is explained by the intervention of dimerization of the carboxylic acid.

We thank Professor J. E. Driver for discussions and encouragement, and Drs. P. B. D de la Mare and Y. Pocker for criticisms and suggestions.

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[Received, June 19th, 1959.]

⁹ Pohl, Hobbs, and Gross, *J. Chem. Phys.*, 1941, **9**, 408.