742. *The Interaction of* N-*Chloro*-N-*methylbenzamides and of* N-*Chloro*-N-*methylbenzenesulphonamides with* p-*Nitrophenoxide Ion.*

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Kinetic studies of the interaction of *p*-nitrophenol with some *ar*-substituted *N*-chloro-*N*-methylbenzamides and with some *ar*-substituted *N*-chloro-*N*-methylbenzenesulphonamides in alkaline solutions at 25° have been made. With the former compounds in the pH range 9—10, two main reactions are apparently involved: (i) pH-independent chlorination by the *N*-chloro-compound and (ii) pH-dependent hydrolysis of the *N*-chloro-compound to hypochlorous acid, which then rapidly chlorinates the *p*-nitrophenoxide ion. With the latter compounds, however, the chlorination is pH-independent in the pH range 8·5—9·5, suggesting that direct chlorination is the main process involved. Introduction of electron-attracting *ar*-substituents in the *N*-chloro-compounds enhances the rates of these reactions.

Hurst and Soper [1] have shown that *N*-chloroacetanilide reacts with phenols in slightly alkaline solution partly by preliminary hydrolysis to hypochlorous acid and partly by direct attack on the phenoxide ion. The reactions, conducted in the presence of an excess of the phenol (in the pH range 8·7—9·3), were found to be of the first order with respect to *N*-chloroacetanilide, the first-order rate constant (k_1) being related to the concentrations of hydroxyl and phenoxide ions by the equation

$$k_1 = k_h[OH^-] + k_d[OPh^-] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where k_h, k_d are the rate constants for hydrolysis and direct interaction (with phenoxide ion) respectively of *N*-chloroacetanilide.

The interaction of *p*-nitrophenol (K_a, $9{\cdot}6 \times 10^{-8}$ at 25°) [2] with *N*-chloro-*N*-methylbenzamide [3] in the pH range 9—10, in which the phenol is virtually completely ionised, has now been examined. Equation (1) holds quite well, giving values of k_h as 21·4, 21·2, 18·3, 18·4 mole^{-1} min.$^{-1}$ for solutions initially respectively 0·02, 0·03, 0·04, 0·06M in *p*-nitrophenol. The corresponding values of k_d, determined by extrapolating the k_1–$[OH^-]$ graphs to zero $[OH^-]$ and equating the intercepts to $k_d[OPh^-]$ in each case, are 0·011, 0·006, 0·016, 0·013 mole^{-1} min.$^{-1}$ respectively (cf. Fig. 1). The interaction of *N*-chloro-*N*-methyl-*m*-nitrobenzamide [4] and of six hitherto unknown *ar*-substituted *N*-chloro-*N*-methylbenzamides with *p*-nitrophenol (initially 0·02M) in the same pH range was then examined; the results are shown in Fig. 1 and in Table 1.

It is seen that both interaction and hydrolysis reactions are favoured by presence of electron-withdrawing groups in the aromatic ring; some additional experiments also show that the reaction is favoured by electron-releasing groups in the phenol as, indeed, would be expected. An approximately linear relation was noted both between log k_h and log k_d and the Hammett σ value for the substituent. The wide departure of the *m*-nitro-derivative from approximate linearity in both instances causes some doubt as to the accuracy of its determinations.

It may be noted that the preparations of the *N*-chloro-*N*-methylbenzamides described below are the best that have been developed in this work; deviations from these methods frequently result in incomplete *N*-chlorination with consequent low available-chlorine content of the sample. These compounds are generally stable on storage at 0° in absence of light and moisture for a few days, the onset of decomposition being marked by a fall in

[1] Hurst and Soper, *J.*, 1949, 107.
[2] Hantzsch, *Ber.*, 1899, **32**, 3066.
[3] Beilstein's " Handbuch der Organischen Chemie," Vol. IX, p. 268.
[4] Ref. 3, p. 384.

the available-chlorine figure. Methylenebisbenzamide [5] has been identified as the major product of the spontaneous decomposition of *N*-chloro-*N*-methylbenzamide at room temperature (in daylight) after two weeks.

TABLE 1. *Reaction rates of substituted* N-*chloro*-N-*methylbenzamides.*

Subst.	k_1 (10^{-4} min.$^{-1}$)	$t_{\frac{1}{2}}$ (min.)	k_h (mole^{-1} min.$^{-1}$)	k_2 (mole^{-1} min.$^{-1}$)	σ (ref. 6)
H (a)	3·5	2010	19·8	0·011	0·0
p-Me (b)	1·85	3590	15·6	0·005	−0·17
o-Cl (c)	4·15	1660	20·5	0·015	—
m-Cl (d)	7·95	873	52·4	0·023	0·37
p-Cl (e)	5·60	1240	33·6	0·017	0·23
o-NO_2 (f)	18·8	369	38·0	0·082	—
m-NO_2 (g)	32·8	217	58·0	0·145	0·71
p-NO_2 (h)	27·4	253	112·0	0·102	0·78
N-Chloroacetanilide [1] (0·01M)	53	131	454	0·11	—

Initial concentrations were 0·02M-*p*-nitrophenol and 0·005M for (a)—(e), saturated solutions for (f)—(h); pH = 9; temp. 25·1° ± 0·05°.

The interaction of *N*-chloro-*N*-methylbenzenesulphonamide with *p*-nitrophenol in slightly alkaline solutions has also been examined kinetically. In the range of pH 8·5—9·5, the reaction, conducted in the presence of an excess of *p*-nitrophenol, was found to be

FIG. 1.

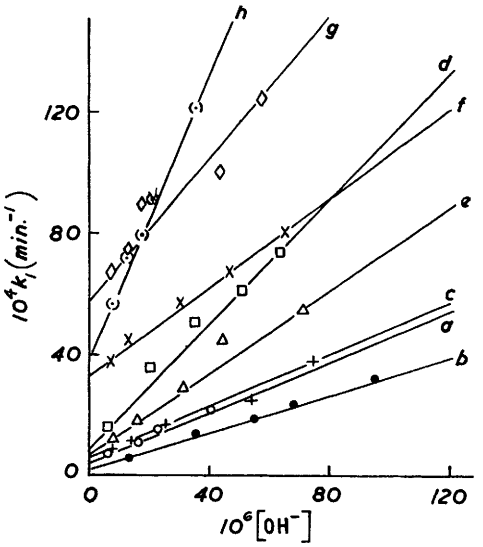


FIG. 2.

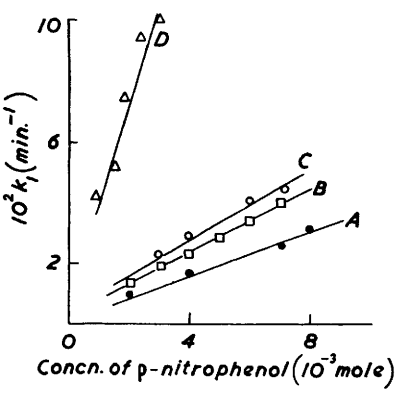


FIG. 1. *Effect of hydroxyl-ion concentration upon rates of reaction of substituted* N-*chloro*-N-*methylbenzamide with* p-*nitrophenol.*

Key	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*
Subst.	H	*p*-Me	*o*-Cl	*m*-Cl	*p*-Cl	*o*-NO_2	*m*-NO_2	*p*-NO_2

FIG. 2. *Effect of* p-*nitrophenol concentration upon rates of reaction of substituted* N-*chloro*-N-*methylbenzenesulphonamides.*

Key	*A*	*B*	*C*	*D*
Subst.	H	*p*-Me	*p*-Br	*m*-NO_2

independent of pH. The reaction was then studied at pH 9 by employing a range of concentrations of *p*-nitrophenol, this compound always being in excess so that the observed removal of active chlorine from the solutions was a first-order reaction. The first-order rate constant (k_1) for the reaction was determined at each concentration of *p*-nitrophenol. The

[5] Pulvermacher, *Ber.*, 1892, **25**, 304.
[6] McDaniel and Brown, *J. Org. Chem.*, 1958, **23**, 420.

plot of k_1 against concentration of *p*-nitrophenol was linear under the experimental conditions, the slope of the line giving the second-order rate constant for the interaction (k).

Extrapolation of the k_1–[OPh^-] graph to zero concentration of *p*-nitrophenol showed a small intercept on the k_1 axis (cf. Fig. 2). The numerical value of the intercept is subject to some experimental error, but separate experiments reveal that a first-order decomposition of the *N*-chloro-compound is occurring in the system, and that this accounts at least partly for the intercept. Since the chlorination reaction is pH-independent, the possibility of a slow hydrolysis of the *N*-chloro-compound by water, with rapid subsequent removal of the hypochlorous acid by *p*-nitrophenol, cannot be rigidly excluded.

The interaction of *N*-chloro-*N*-methyl-*p*-toluenesulphonamide, *N*-chloro-*N*-methyl-*p*-bromobenzenesulphonamide, and *N*-chloro-*N*-methyl-*m*-nitrobenzenesulphonamide with *p*-nitrophenol was also examined, and the same general behaviour noted, though the reaction occurred with markedly increased speed in the case of the *m*-nitro-compound.

TABLE 2. *Reaction rates of substituted* N-*chloro*-N-*methylbenzenesulphonamides.*

Subst.	Initial concentration *N*-Chloro-compound (10^{-4}M)	*p*-Nitrophenol (M)	k_1 (aq.) (10^{-2} min.$^{-1}$)	k_1 (aq. dioxan) (10^{-2} min.$^{-1}$)	k_d (mole^{-1} min.$^{-1}$)
H	5·6	0·003	1·18	1·63	3·54
p-Me	2·25	0·004	2·465	3·153	5·13
p-Br	2·2	0·004	—	2·77	5·78
m-NO_2	1·6	0·002	—	7·2	31·6

pH = 9·06; temp. 25·0° ± 0·05°; $k_{decomp.}$ *ca.* 10^{-4} min.$^{-1}$ (all cases).

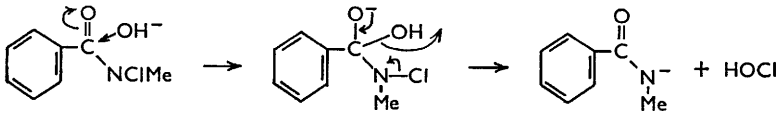
The results (Table 2) refer to aqueous solutions buffered to pH 9·0 in the cases of the parent compound and the *p*-methyl derivative, and to solutions containing 4·5% of dioxan in the cases of the *p*-bromo- and the *m*-nitro-derivative owing to the low solubility of these compounds; separate experiments showed that for the parent compound and the *p*-methyl derivative the reaction was accelerated somewhat in presence of 4·5% of dioxan.

The values of k_d are seen to be all of the same order, that for the *m*-nitro-compound being notably the largest, suggesting that the reaction is favoured by electron-attracting groups in the benzene ring of the *N*-chloro-compound. The most significant feature is the apparent absence of alkaline hydrolysis of the *N*-chloro-compounds.

In considering the reaction of these two series of compounds with *p*-nitrophenol in alkaline solutions, the significant point which emerges is that with *N*-chloro-*N*-methylbenzenesulphonamides (i) no alkaline hydrolysis occurs and (ii) the value of k_d is considerably larger than that for the *N*-chloro-*N*-methylbenzamides. It is quite evident that *N*-chloro-*N*-methylbenzamide and *N*-chloroacetanilide react with *p*-nitrophenol under these conditions by the same mechanism.

The situation is reminiscent of the hydrolysis of carboxylic and sulphonic esters in slightly alkaline solutions.[7] The latter are hydrolysed by a unimolecular process involving alkyl–oxygen fission, and measured hydrolysis rates are practically independent of pH. In contrast, carboxylic esters generally undergo bimolecular hydrolysis, addition of hydroxyl ion to the ester being rate-determining.

Since the values of k_h for the *N*-chloro-*N*-methylbenzamides show an *ortho*-effect,[8] it seems likely that the hydrolysis follows the course:

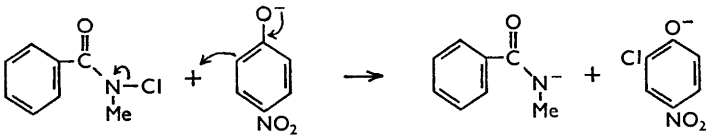


[7] Demeny, *Rec. Trav. chim.*, 1931, **50**, 60; Waters, " Physical Aspects of Organic Chemistry," Routledge and Kegan Paul, London, 1950, Chap. XIII, pp. 327 *et seq.*

[8] Hammett, " Physical Organic Chemistry," McGraw-Hill, New York, 1940, Chap. VII, p. 204.

the first step is rate-determining as for the hydrolysis of carboxylic esters. The inability of the sulphonyl group to add hydroxyl ion virtually precludes a similar alkaline hydrolysis of the *N*-chloro-*N*-methylbenzenesulphonamides.

The k_d values for the *N*-chloro-*N*-methylbenzamides show a much smaller *ortho*-effect, and it is inferred that the direct chlorination does not involve attack at the carbonyl group, *i.e.*:



An analogous mechanism presumably operates for the *N*-chloro-*N*-methylbenzenesulphonamides.

N-Chloro-*N*-methylacetamide was also prepared during this work; its volatility is notable.

Experimental

N-*Chloro*-N-*methylbenzamide*.—*N*-Methylbenzamide (2 g.) was vigorously stirred with 10% aqueous potassium hydrogen carbonate (50 ml.) and 10% aqueous sodium hypochlorite (12 ml.) for 1 hr. The mixture was extracted with chloroform, and the extract washed with 10% aqueous sodium carbonate (50 ml.), dried (Na_2SO_4), and evaporated *in vacuo*. The *N*-chloro-compound remained as a colourless oil [3] (2·4 g., 98%) (Found: available Cl, 41·0. Calc. for C_8H_8ONCl: Cl, 41·9%). Solutions of *N*-chloro-*N*-methylbenzamide in buffer solutions of pH 8, 9, 10 were shown, both spectrophotometrically and by available-chlorine estimation, to be stable under conditions used for the kinetic determinations. At pH 12, the compound slowly decomposed, about 13% of decomposition having occurred after 90 min.

N,o-*Dichloro*-N-*methylbenzamide*.—*o*-Chloro-*N*-methylbenzamide (5 g.) was vigorously stirred with 10% aqueous potassium hydrogen carbonate (250 ml.) and 10% aqueous sodium hypochlorite (50 ml.) for 1½ hr. The oily product was separated by extraction with chloroform. Drying and removal of solvent *in vacuo* gave N,o-*dichloro*-N-*methylbenzamide* (5·46 g., 91%) (Found: available Cl, 34·2. $C_8H_7ONCl_2$ requires 1Cl, 34·8%). At 0°, the compound solidified in rhombic plates, m. p. 32·5—33°.

N,m-*Dichloro*-N-*methylbenzamide*.—*m*-Chloro-*N*-methylbenzamide (1 g.), stirred with one-fifth of the above quantities for 1 hr., gave N,m-*dichloro*-N-*methylbenzamide* (1·05 g., 87%) (Found: available Cl, 34·1%), solidifying (at 0°) as colourless needles, m. p. 15—16°.

N,p-*Dichloro*-N-*methylbenzamide*.—*p*-Chloro-*N*-methylbenzamide (5 g.) gave the N-*chloro-benzamide* (6 g. quantitative), stirring being continued in this case for 4 hr., solidifying at 0° in needles, m. p. 30—30·5° (Found: available Cl, 34·9%).

N-*Chloro*-N-*methyl*-o-*nitrobenzamide*.—Sodium hydroxide (0·6 g. in 7·5 ml. of water) followed by 10% aqueous sodium hypochlorite (7·5 ml.) was added to *N*-methyl-*o*-nitrobenzamide (1 g.), and the mixture was vigorously stirred for 1 hr. The pale solid was filtered off, washed, and dried *in vacuo*. N-*Chloro*-N-*methyl*-o-*nitrobenzamide* (1·14 g., 96%) so formed had m. p. 82—83·5° (Found: available Cl, 32·6. $C_8H_7O_3N_2Cl$ requires Cl, 33·1%). Crystallisation from light petroleum (b. p. 60—80°) gave colourless needles, m. p. 80—81° (Found: Cl, 32·7%).

N-*Chloro*-N-*methyl*-m-*nitrobenzamide*.—A mixture of *N*-methyl-*m*-nitrobenzamide (1 g.), 10% aqueous potassium hydrogen carbonate (50 ml.) and 10% aqueous sodium hypochlorite (10 ml.) was stirred for 2 hr. The nearly colourless product was filtered off, washed, and dried *in vacuo*. The *N*-chloroamide (1·16 g., 97·5%) had m. p. 75—76·5° (lit.,[4] 76—77°) (Found: Cl, 32·5%), and separated as needles [from light petroleum (b. p. 80—100°)] of same m. p. and Cl content.

N-*Chloro*-N-*methyl*-p-*nitrobenzamide*.—Stirring *N*-methyl-*p*-nitrobenzamide (5 g.) with 5 times the quantities given for the *meta*-isomer for 2½ hr. gave N-*chloro*-N-*methyl*-p-*nitrobenzamide* (4·39 g., 72%) as a pale yellow powder, m. p. 85—86° (Found: available Cl, 33·1%). The compound formed hexagonal plates, m. p. 85—86°, from light petroleum (b. p. 40—60°).

N-*Chloro*-N-*methyl*-p-*toluamide*.—*N*-Methyl-*p*-toluamide (1 g.) was stirred with 10% aqueous potassium hydrogen carbonate (50 ml.) and 10% aqueous sodium hypochlorite (10 ml.) for 3 hr. Isolated by means of chloroform as in the first three cases, the N-*chloro-amide* (1·1 g., 89%) was

obtained as a colourless oil (Found: available Cl, 38·3. $C_9H_{10}ONCl$ requires Cl, 38·7%), n_D^{23} 1·5591.

N-*Chloro*-N-*methylacetamide*.—A mixture of *N*-methylacetamide (1 g.), 10% aqueous potassium hydrogen carbonate (50 ml.), and 10% aqueous sodium hypochlorite (10 ml.) was stirred for 1 hr. The resulting colourless solution was extracted with ether, the extract dried, and the solvent cautiously removed *in vacuo*. Distillation then furnished *N*-chloro-*N*-methylacetamide (0·21 g.) as a colourless " volatile " oil, b. p. 34—35°/10 mm. (Found: available Cl, 64·5. C_3H_6ONCl requires available Cl, 66·0%).

Decomposition of N-*Chloro*-N-*methylbenzamide*.—*N*-Chloro-*N*-methylbenzamide was left at room temperature in daylight for approximately 2 weeks. A small amount of solid material separated. The viscous material was chromatographed in chloroform on silica. Elution with chloroform gave *ca.* 25% recovery of liquid products: elution with chloroform containing 5% of ethanol then gave the major fraction (*ca.* 55%) of a solid, purified by crystallisation from benzene, and identified from its infrared spectrum and m. p. and mixed m. p. 223° as methylenebisbenzamide (Pulvermacher [5] gives m. p. 219°).

N-*Chloro*-N-*methylbenzenesulphonamide*.—The sodium derivative of *N*-methylbenzenesulphonamide (11·2 g.) was added to aqueous 50% acetic acid (120 ml.), followed by 5·5 ml. of t-butyl hypochlorite, and the mass was vigorously stirred for 15 min., then diluted with water to 250 ml., and the crystalline precipitate was filtered off and dried *in vacuo* [yield 8·6 g.; m. p. 78° (lit.,[9] 81°) (Found: available Cl, 34·4. Calc. for $C_7H_8SO_2NCl$: Cl, 34·5%).

N-*Chloro*-N-*methyl*-p-*toluenesulphonamide*.—*N*-Methyl-*p*-toluenesulphonamide (2·16 g.), dissolved in glacial acetic acid (20 ml.), was added to t-butyl hypochlorite (1·35 g.), and the mixture stirred for ½ hr. and poured into water (200 ml.). The precipitate was filtered off and dried (yield 1·2 g.; m. p. 81° (lit.,[9] 82°) (Found: available Cl, 30·6. Calc. for $C_8H_{10}ONClS$: Cl, 32·3%).

p-*Bromo*-N-*chloro*-N-*methylbenzenesulphonamide*.—The sodium derivative of *N*-methyl-*p*-bromobenzenesulphonamide (1·5 g.) was stirred for 1½ hr. with t-butyl hypochlorite (0·55 ml.) in glacial acetic acid (10 ml.). Working up as usual and recrystallisation from light petroleum (b. p. 40—60°)–chloroform gave p-*bromo*-N-*chloro*-N-*methylbenzenesulphonamide*, m. p. 86—87° (0·92 g.) (Found: available Cl, 24·8. $C_7H_7SO_2NBrCl$ requires Cl, 25·0%).

N-*Chloro*-N-*methyl*-m-*nitrobenzenesulphonamide*.—*N*-Methyl-*m*-nitrobenzenesulphonamide (5 g.), dissolved in acetic acid (60 ml.), was stirred for 1½ hr. with t-butyl hypochlorite (2·75 ml.). The mixture was poured into ice-water, and the precipitate filtered off, washed, and dried. The product, *N*-chloro-amide (4·8 g.), recrystallised from ether–chloroform at −78°, had m. p. 135—136° (lit.,[9] 136°) (Found: available Cl, 27·0. Calc. for $C_7H_7O_2N_2SCl$: Cl, 28·4%).

Colour Reactions.—When *N*-chloro-*N*-methylbenzamide in dioxan is added to certain phenols dissolved in aqueous sodium hydroxide, a colour develops. Thus blue colours develop immediately with guaiacol, *o*-cresol, *m*-cresol, and *o*-chlorophenol, the first and second becoming green on storage; with *p*-chlorophenol, a green colour develops slowly; transient red and yellow colours appear with α- and β-naphthol respectively; no change is observed with *o*- or *p*-nitrophenol.

Kinetic Measurements.—Buffer solutions were prepared from sodium hydroxide, boric acid (" AnalaR "), and distilled water. *p*-Nitrophenol was recrystallised before use. The *N*-chloro-compounds were freshly prepared as indicated above.

The following experiment is representative for the *N*-chloro-*N*-methylbenzamides.

p-Nitrophenol (6·95 g.) was dissolved in N-sodium hydroxide (50 ml.) and diluted to *ca.* 100 ml. The pH was set to the desired value by using N-sodium hydroxide and 0·1M-boric acid, and the volume was adjusted to 250 ml. by addition of the buffer solution.

N-Chloro-*N*-methyl-*o*-nitrobenzamide (*ca.* 0·6 g.) was shaken for 1 hr. with the selected buffer solution (500 ml.) at 25°. The filtrate (450 ml.) and the *p*-nitrophenol solution were separately equilibrated at the reaction temperature (25·1° ± 0·05°); 50 ml. of the *p*-nitrophenol solution were then added to the solution (450 ml.) of the *N*-chloro-compound, and the mixture was shaken, and replaced in the thermostat bath. The mixture was thus initially 0·02M in *p*-nitrophenol. Periodically aliquot parts (50 ml.) were removed, treated with 10% aqueous potassium iodide (10 ml.) and glacial acetic acid (10 ml.), and the liberated iodine was estimated by titration with 0·025N-sodium thiosulphate; no readings were taken after at most 10% of *p*-nitrophenol had been consumed.

[9] Chattaway, *J.*, 1905, 145.

The experimental procedure for the *N*-chloro-*N*-methylbenzenesulphonamides is a modification of the above. For example, the *m*-nitro-compound (*ca.* 0·2 g.) was dissolved in dioxan (25 ml.), and the buffer solution (570 ml.) was then added. The solution was left (with occasional shaking) for 2 hr., filtered into dioxan (5 ml.), left for ½ hr., and filtered. The filtrate and the standard *p*-nitrophenol solution were separately equilibrated at 25·0° ± 0·05°. To the filtrate (450 ml.) was then added the desired volume of the *p*-nitrophenol solution, and the volume was adjusted to 500 ml. The reaction was followed kinetically by the previous method.

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