

217. *The Kinetics of Aromatic Halogen Substitution. Part III.* *Iodination by Iodine Chloride.*

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Iodination by iodine chloride of, *e.g.*, acetanilide and anisole, like the corresponding brominations by bromine, shows third-order kinetics in acetic acid solution. When there is steric hindrance to the entry of the iodine atom into the benzene ring, as in pentamethylbenzene and *p*-tolyl methyl ether, there is concomitant iodine chloride-catalysed chlorination, and this has an inducing effect on the iodination. In chlorobenzene solution this side reaction becomes more prominent, occurring with a compound like anisole, for which steric hindrance is not to be expected.

THE use of iodine chloride as an iodinating agent has long been known, but its applicability is limited. Chattaway and Constable (*J.*, 1914, 105, 124) showed that in acetic acid solution, a 90% yield of the *p*-iodo-derivative is obtained from acetanilide. In iodination with iodine chloride the liberated hydrogen chloride combines with the reagent to form HICl_2 , with the result that the rate falls off rapidly during the course of the reaction, just as in the corresponding brominations owing to HBr_3 formation. This complicates the kinetic interpretation, necessitating measurements of the initial rates for the evaluation of the reaction order. The general conditions of such measurements have been discussed in Part I of this series (*J.*, 1943, 276). The following results were obtained for acetanilide, times (mins.) being shown for 10% iodine chloride absorption in acetic acid.

Temp.	M/20.		M/40.
24°	160	($n = 3.3$)	780
50	36	($n = 2.6$)	105

The order is approximately 3 at 24° and is less at 50°, an effect similar to that found in the bromination of this compound, for which orders, $n = 3.0$ (24°) and $n = 2.5$ (50°), were obtained at the same concentrations.

The iodination of anisole in acetic acid is accompanied by a certain amount of simultaneous chlorination. Equimolecular amounts of reactants, M/20, at 24°, ceased to react at 78% halogen absorption owing to the formation of HICl_2 . To such a solution a slight excess of anisole was added, and dry nitrogen passed through for 15 minutes. This procedure removed hydrogen chloride, but no chlorine, permitting a further gradual 8% halogen absorption, after which only iodine was left. The ratio of iodination to chlorination is therefore approximately 5 : 1, and on adding water to the solution, *p*-iodoanisole, m. p. 50—52°, was precipitated. The contribution of this concurrent chlorination is not sufficient seriously to affect the order of the iodination reaction, and the times, in acetic acid at 24°, indicate third-order kinetics :

	M/20.		M/40.		M/80.
Time ($x = 20$) at 24°	11.8	($n = 3.0$)	46.5	($n = 3.1$)	216
Time ($x = 20$) at 40°	4.8	($n = 3.0$)	19.0	($n = 3.0$)	77

Experiments with anisole in relative excess revealed that the reaction was unimolecular with reference to anisole and bimolecular with reference to iodine chloride.

Pentamethylbenzene, which was found to undergo bromination in acetic acid at a rapid rate approximately the same as that for anisole, reacts moderately rapidly with iodine chloride. With this compound a steric effect is to be expected, as the approach of the large iodine atom is hindered by the *ortho*-methyl groups. This reveals itself in the sense that the alternative chlorine substitution makes a greater contribution than in the reaction with anisole, where there is no steric hindrance. In M/20-solution in acetic acid at 24° there is 80% halogen absorption, corresponding with the relative contributions, iodination : chlorination = 3 : 1. Rate measurements show predominantly third-order kinetics in the experimental concentration range :

	M/40.		M/80.
Time ($x = 10$)	26	($n = 2.9$)	95

In *p*-tolyl methyl ether steric hindrance to the entry of the large iodine atom into the *o*-position is also to be expected, and with M/20-reactants in acetic acid at 24° the iodine chloride substitution stops at ~67% halogen absorption, corresponding with equal contributions of iodination and chlorination; disturbed third-order kinetics are observed :

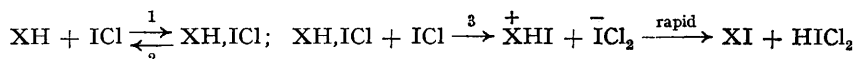
	M/20.		M/40.		M/80.
Time ($x = 20$)	86	($n = 3.3$)	420	($n = 2.7$)	1390

A summary of these iodine chloride reactions is now given :

	Acetanilide.	Anisole.	Pentamethylbenzene.	<i>p</i> -Tolyl methyl ether.
Concurrent chlorination ...	10%	20%	30%	50%
Relative rates, Br ₂ /ICl	950 : 1	350 : 1	150 : 1	70 : 1

Instead of the total rate of halogenation with iodine chloride becoming less (as compared with bromination) when there is steric hindrance, the reverse effect is observed. The alternative chlorine substitution, which is catalysed by iodine chloride, apparently exerts an inducing effect on the iodination by this reagent, and this becomes more considerable as the relative contribution of the chlorination increases. Other examples of induction in halogenation reactions have been reported (cf. *J.*, 1945, 509). On changing to chlorobenzene as solvent, the tendency for iodine chloride halogenation to proceed by the chlorination route becomes more pronounced, even when there is no steric hindrance; e.g., for anisole the contribution of the chlorination is 50%. Correspondingly, there is an increase in the velocity of the reaction, the relative rates, Br₂ to ICl, for anisole in chlorobenzene being 5 : 1 (in acetic acid solution the ratio is 350 : 1). This concurrent halogenation observed with iodine chloride should be still more pronounced with iodine bromide, as this compound is more dissociated than the chloride. According to Militzer (*J. Amer. Chem. Soc.*, 1938, 60, 256), phenol in carbon tetrachloride solution is exclusively brominated by iodine bromide. It is not, however, necessary to assume that this reaction proceeds according to the scheme $XH + IBr \rightarrow XBr + HI$; $HI + IBr \rightarrow I_2 + HBr$, for a mechanism involving iodine bromide-catalysed bromination will explain the experimental result.

The iodination of aromatic compounds by iodine chloride is analogous, not only to bromine substitution, but also to iodine chloride and bromine addition to unsaturated compounds. In acetic acid solution in the concentration region $m/40$, all four reactions show third-order kinetics, the order being reduced on rise in temperature owing to the incursion of a bimolecular reaction. It is concluded that the reaction mechanisms are similar (cf. *J.*, 1943, 279), taking place for iodination according to the scheme :



and for third-order kinetics

$$d[XI]/dt = (k_1 k_3 / k_2) [XH][ICl]^2.$$

EXPERIMENTAL.

The compounds used were: anisole, b. p. 154.5°/760 mm.; *p*-tolyl methyl ether, b. p. 179°/760 mm.; acetanilide, m. p. 113.5°; pentamethylbenzene, m. p. 53.5°. The general technique was as previously described, the reactions being carried out with darkened bottles in a room with dim illumination. At 24° the iodine chloride solutions in acetic acid were found to be stable during the time of a reaction, but at higher temperatures there was a slight decrease in titre, necessitating a small correction. Herewith a typical set of measurements :

10 Ml. anisole, $m/40$ + ICl, $m/40$; HOAc, 50°; 1 ml. samples titrated with KI and 0.01N-Na ₂ S ₂ O ₃ .						
Time (mins.)	0	10	15	20	30	50
Titre (ml.)	4.98	4.62	4.46	4.25	3.98	3.62
Zero titre (ml.)	—	4.98	4.97	4.97	4.96	4.95

From the curve, $x = 10$, $t = 15$; second expt., $x = 10$, $t = 14$.

Experiments to determine relative contributions of anisole and iodine chloride in acetic acid at 24°; times (mins.), $x = 10$; A, $m + ICl$, $m/20$, $t = 0.60$; A, $m/2 + ICl$, $m/40$, $t = 3.0$; A, $m/4 + ICl$, $m/40$, $t = 3.5$; A, $m/4 + ICl$, $m/80$, $t = 8.0$: these gave n (anisole) 1.2, n (ICl) 2.2. The remaining measurements have been quoted in the text.