390. *Some Observations Relating to Substituent Effects in Halogenation. Part I*

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The rate of chlorination of biphenyl by chlorine acetate has been measured at 25° in 98% acetic acid as solvent, catalysed by various amounts of perchloric acid. The proportions of isomeric chlorobiphenyls produced under these conditions have been determined by means of isotopic dilution and vapour-phase chromatography. The results show that the phenyl group activates the 2- and 4-positions, whereas the 3-position is deactivated. The $\frac{1}{2}o:p$ ratio is significantly lower in the absence of perchloric acid. The significance of these results is discussed.

Chlorine acetate and bromine acetate are known to act as halogenating species in aqueous acetic acid.[1-5] Under these conditions, equilibria of the following type have been established:

$$XOH + HOAc \rightleftharpoons XOAc + H_2O \quad (X = Cl \text{ or } Br) \tag{1}$$

For very reactive aromatic compounds, *e.g.*, anisole, the rate of reaction with these electrophiles was found to be independent of the concentration of the aromatic compound. For relatively unreactive compounds, *e.g.*, toluene, the rate is slower, and is dependent on the concentration of the aromatic compound.

Furthermore, the rate of the reaction was found to depend on the concentration of the added mineral acid, and on the proportion of water in the solvent. In solutions of hypohalous acids in aqueous acetic acid containing perchloric acid, the dominant electrophilic species were found to be protonated ones, probably those formed according to eqn. (2):

$$XOAc + H^+ \rightleftharpoons XOAcH^+ \quad (X = Cl \text{ or } Br) \tag{2}$$

The phenyl group, with its variable power of electron-release, might well be expected to react differently, depending on whether a positive or a neutral species was concerned. We have, therefore, examined biphenyl under these conditions, in the hope of furthering our knowledge of the effectiveness and behaviour of these electrophiles.

Experimental

Preparation and Purification of Materials.—Acetic acid, m. p. 16·6°, was obtained by standard procedures.[2,6,7] Chlorine gas containing chlorine-36 was generated by reaction of hydrochloric acid, partially labelled with chlorine-36, with potassium permanganate. Chlorine acetate was prepared as described elsewhere.[2,8] Biphenyl had m. p. 70°. Benzene (AnalaR reagent) was dried with sodium, and fractionated; the middle fraction was collected, and had n_D^{25} 1·5023. The 2- and 3-chlorobiphenyls were prepared by the Gomberg reaction from the corresponding chloroanilines.[9] Silver perchlorate was prepared from equivalent amounts of silver oxide and perchloric acid, and its purity was determined gravimetrically.

Kinetics of Chlorination by Chlorine Acetate.—All results refer to a temperature of 25°, and (except where otherwise stated) to 98% (v/v) acetic acid as solvent. Silver perchlorate was added to ensure that no reaction occurred with molecular chlorine. The reactions, carried in blackened bottles to exclude light, were started by addition of the aromatic compound dissolved

[1] G. Stanley and J. Shorter, *J.*, 1958, 246, 256.

[2] P. B. D. de la Mare, I. C. Hilton, and C. A. Vernon, *J.*, 1960, 4039.

[3] P. B. D. de la Mare, I. C. Hilton, and S. Varma, *J.*, 1960, 4044.

[4] P. B. D. de la Mare and J. L. Maxwell, *Chem. and Ind.*, 1961, 553.

[5] P. B. D. de la Mare and J. L. Maxwell, *J.*, 1962, 4829.

[6] P. B. D. de la Mare and M. Hassan, *J.*, 1958, 1519.

[7] K. J. P. Orton and H. King, *J.*, 1911, 99, 1369; K. J. P. Orton and A. E. Bradfield, *J.*, 1927, 986; A. E. Bradfield and B. Jones, *J.*, 1928, 3080; B. Jones, *J.*, 1934, 210; P. W. Robertson, P. B. D. de la Mare, and W. T. Johnston, *J.*, 1943, 276.

[8] P. B. D. de la Mare, A. D. Ketley, and C. A. Vernon, *Research*, 1953, 125.

[9] G. M. Beaven, P. B. D. de la Mare, M. Hassan, E. A. Johnson, and N. V. Klassen, *J.*, 1961, 2749.

in acetic acid, and were followed iodometrically. Blank determinations were carried out for each run. Readings were taken over 50% of the reaction range.

Table 1 lists examples of typical kinetic runs; the second-order rate coefficients were calculated by using the usual formula:

$$k_2 = \frac{2{\cdot}303}{t(a - b)} \log_{10} \left[\frac{b(a - x)}{a(b - x)}\right]$$

TABLE 1

(*a*) Biphenyl (0·0400M); chlorine acetate (0·024M), perchloric acid (0·00M); silver perchlorate (0·0289M).

Time (min.)	0·00	2·33	5·20	8·50	11·80	14·77
Titre (ml.)	18·55	15·30	12·35	9·90	8·15	7·15
k_2 (l. mole^{-1} min.$^{-1}$)...	—	2·19	2·21	2·21	2·19	2·09

(*b*) Biphenyl (0·0300M); chlorine acetate (0·0097M); perchloric acid (0·0228M); silver perchlorate (0·0300M).

Time (min.)	0·00	1·27	1·67	2·25	2·70	4·35	6·30
Titre (ml.)	9·34	7·35	6·85	6·20	5·70	4·35	3·85
k_2 (l. mole^{-1} min.$^{-1}$)...	—	6·60	6·51	6·48	6·56	6·51	6·40

(*c*) Benzene (0·0301M); chlorine acetate (0·0110M); perchloric acid (0·00M); silver perchlorate (0·0300M).

Time (min.)	0·00	60·10	105·18	220·70	287·10	358·20	419	489
Titre (ml.)	10·65	9·75	9·25	7·85	7·35	6·75	6·45	4·95
k_2 (l. mole^{-1} min.$^{-1}$)...	—	0·072	0·069	0·072	0·071	0·071	0·070	0·075

(*d*) Benzene (0·0300M); chlorine acetate (0·0108M); perchloric acid (0·0228M); silver perchlorate (0·0300M).

Time (min.)	0·00	3·85	15·56	30·33	46·90	62·00	98·00
Titre (ml.)	10·40	10·05	9·60	9·00	8·20	7·45	6·30
k_2 (l. mole^{-1} min.$^{-1}$)...	—	0·304	0·300	0·302	0·300	0·302	0·298

Table 2 shows the variation of the rate with the concentration of perchloric acid.

TABLE 2

Biphenyl (M)	Chlorine acetate (M)	Perchloric acid (M)	Silver perchlorate (M)	k_2 (l. mole^{-1} min.$^{-1}$)
0·0400	0·0242	0·00	0·0298	2·18
0·0404	0·0123	0·0013	0·0298	2·44
0·0303	0·01551	0·0032	0·0300	2·79
0·0300	0·01186	0·0068	0·0289	3·37
0·0300	0·0097	0·02280	0·0300	6·51
0·0348	0·0194	0·0464	0·0289	14·6
0·0300	0·0115	0·0740	0·0289	23·8
Benzene	Chlorine acetate (M)	Perchloric acid (M)	Silver perchlorate (M)	k_2 (l. mole^{-1} min.$^{-1}$)
0·03015	0·0110	0·00	0·0300	0·071
0·0300	0·01099	0·00678	0·0289	0·147
0·0300	0·01078	0·0228	0·0289	0·304
0·0300	0·01195	0·0739	0·0289	1·15

Table 3 shows the effect of varying the solvent composition.

TABLE 3

Biphenyl (0·0300M); chlorine acetate (0·009—0·01200M); silver perchlorate (0·0300M).

H_2O (% v/v)	2·1	5·1	10·1	15·1	20·1	30·1
k_2 (l. mole^{-1} min.$^{-1}$)...	2·2	1·67	1·44	1·54	1·55	1·66

Analysis of Products.—The proportions of isomers obtained in the chlorination of biphenyl by chlorine acetate were determined by the method of isotopic dilution, using chlorine acetate partially labelled with chlorine-36. Biphenyl (0·05209M), chlorine acetate (0·02051M), and silver perchlorate (0·0289M), in 98% acetic acid, were allowed to react to completion, thereby producing a solution containing 3·868 g. of mixed chlorobiphenyls.

para-*Substitution.* To a portion of the reaction mixture (250 ml., containing 0·9670 g. of mixed chlorobiphenyls) was added 6·1661 g. of inactive 4-chlorobiphenyl. The chlorobiphenyls and unchanged starting material were recovered and nitrated, as described elsewhere.[10] The product of nitration was precipitated by addition of crushed ice, filtered off, and dissolved in benzene. The dried benzene solution was chromatographed several times on alumina, and the benzene was evaporated from the main fraction. The resulting 4-chloro-4′-nitrobiphenyl was crystallised from ethanol–acetone. It then had m. p. 144° (lit.,[9] 144°) (Found: C, 61·7; H, 3·65; Cl, 14·5; N, 5·9. Calc. for $C_{12}H_8ClNO_2$: C, 61·6; H, 3·4; Cl, 15·2; N, 6·0%). The ethanol–acetone solution (0·1582M) had an activity of 1·409 counts/sec., as compared with the activity of the original chlorine acetate, converted to lithium chloride (0·00982M) for counting, of 1·488 counts/sec. Hence, 0·3850 g. (39·81%) of 4-chlorobiphenyl had been produced in the reaction.

ortho-*Substitution.* A similar procedure was used. The 2-chlorobiphenyl was estimated by converting it into 2-chloro-4,5′-dinitrobiphenyl, which had m. p. 161° (lit.,[9] 159—160°). After several recrystallisations, the specific activity was constant, and, from this value, it was calculated that 0·5620 g. (60·19%) of 2-chlorobiphenyl had been formed.

Analysis by means of vapour-phase chromatography gave 59% of 2-, 0·4% of 3-, and 41% of 4-chlorobiphenyl. Analysis, by isotopic dilution, of the products of reaction of biphenyl with chlorine acetate, in the presence of perchloric acid (0·074M), gave 65·3% of 2- and 34·4% of 4-chlorobiphenyl.

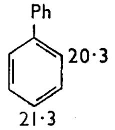
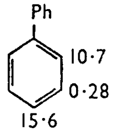
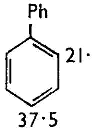
DISCUSSION

From the ultraviolet absorption spectra of solutions of chlorine acetate, it has been shown [2] that, except in high concentrations of acetic acid, the major source of active chlorine is hypochlorous acid.

The chlorination of biphenyl, in 98% acetic acid, with chlorine acetate is generally similar to that found for toluene.[2] The rate is proportional to the first power of the concentration of the aromatic compound, as shown by the constancy of the rate coefficient in the course of a single kinetic run. Addition of perchloric acid catalyses the reaction. The rate of the reaction increased approximately linearly with concentration of added perchloric acid.

In the presence of acid, therefore, it is concluded that a positive chlorinating species is involved. This could be $ClOAcH^+$, $ClOH_2^+$, or Cl^+; by analogy with similar reactions of toluene, it is thought most likely that the effective species is the protonated derivative of chlorine acetate, $ClOAcH^+$.

Polar Effect of the Phenyl Group.—The rate ratio, $k_{\text{biphenyl}}/k_{\text{benzene}}$, of 20·7 for the reaction in the presence of perchloric acid (0·074M), together with the product composition, allows the calculation of the following partial rate factors; values for bromination by the protonated derivative of bromine acetate in aqueous acetic acid [5] and by acidified hypobromous acid in 50% dioxan [10] are included for comparison.

Partial rate factors:			
Reagent and conditions:	ClOAc, $HClO_4$ (0·074M) 98% HOAc, 25°	HOBr, $HClO_4$ 50% dioxan, 25°	$BrOAcH^+$ 75% HOAc, 0·9°
Rel. rate (PhH = 1):	20·7	12·6	26·9

The ½*o* : *p* ratio of the reaction of protonated chlorine acetate is considerably higher than both the limiting value (0·59) for bromination by bromine acetate in the presence of perchloric acid, and that (0·68) for bromination in 50% dioxan. It is conluded, therefore, that steric interference with *ortho*-substitution is less for positive chlorine than for positive bromine. Similar observations have also been made for the halogenation of toluene.[11]

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[10] P. B. D. de la Mare and M. A. Hassan, *J.*, 1957, 3004.

[11] P. B. D. de la Mare and J. H. Ridd, "Aromatic Substitution—Nitration and Halogenation," Butterworths, London, 1959, p. 142; P. B. D. de la Mare and J. T. Harvey, *J.*, 1956, 36; P. B. D. de la Mare, J. T. Harvey, M. Hassan, and S. Varma, *J.*, 1958, 2756.

In the absence of catalytic amounts of perchloric acid, the $\frac{1}{2}o : p$ ratio for chlorination by chlorine acetate in acetic acid at 25° is 0·75, as compared with 0·94 for chlorination by the same reagent in the presence of perchloric acid (0·074M). This change clearly reflects some change in the chlorinating agent, and probably indicates the incursion of reaction through molecular chlorine acetate. The results can be expressed as partial rate factors: $f_o = 27{\cdot}6$; $f_p = 36{\cdot}7$; $f_m = 0{\cdot}18$. Although these values are probably composite, they indicate that the *meta*-position is deactivated, whereas the *ortho*- and *para*-positions are activated. This is in agreement with the results for other electrophilic reactions of biphenyl.[12] Deactivation of the *meta*-position is to be associated with the inductive effect of the phenyl group; activation is to be associated with its conjugative effect.

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