Polyhalogenoaromatic Compounds. Part 46[1]. Circumstantial Evidence for the Intermediacy of Radical Anions during the Reaction of Magnesium with ω-Bromoalkoxypolychloro-arenes and -heteroarenes

By **Basil J. Wakefield* Jeffrey P. Whitten,** and, in part, **Paul S. Farley,** The Ramage Laboratories, Department of Chemistry and Applied Chemistry, University of Salford, Salford M5 4WT

4-(ω-Bromoalkoxy)tetrachloropyridines, 4-(ω-bromoalkoxy)-3,5-dichloro-2,6-difluoropyridines, and (ω-bromoalkoxy)-pentachlorobenzenes have been prepared by reaction of the appropriate aryl and heteroaryl oxides with 1,ω-dibromoalkanes. The main products from the reactions of the bromoethoxy- or bromopropoxy-tetrachloropyridines with magnesium were the furopyridine (9a) and pyranopyridine (9b), respectively. Elimination of other possible reaction pathways leads to the hypothesis that the cyclisations proceed by electron transfer from magnesium to the tetrachloropyridyl group, followed by nucleophilic displacement of bromide from the side chain. In the absence of a leaving group in the side chain, the radical-anion intermediate leads to a Grignard reagent.

THE principal starting materials for the investigation described here, and some other studies, were the (ω-bromoalkoxy)polyhalogeno-arene and -heteroarenes (1), (2), and (3). They were prepared by the reaction between the appropriate polyhalogenoaryl oxide anion and dibromoalkane, as summarised in Table 1. With potassium carbonate in acetone (method A) the reactions were extremely slow, requiring *ca.* 10 days for acceptable conversions, but they were quicker in acetonitrile in the presence of 18-crown-6 (method B). Some reactions of pentachlorophenoxide in boiling dimethylformamide (method C) gave erratic results. In each case the required compound was accompanied by the disubstitution product (4), (5), or (6). A curious feature of some of these reactions, notably the uncatalysed reaction of tetrachloropyridine 4-oxide with 1,2-dibromoethane, was that the proportion of the disubstituted product was much higher than expected. It is difficult to find a convincing explanation why compound (1a), but not (2a) or (3a), is apparently more reactive towards the anion than is 1,2-dibromoethane. Models show that *all* the polyhalogenoaryl groups would probably present less steric hindrance than bromine to an S_N2 reaction. The electronic effects of the tetrachloropyridyl group and pentachlorophenyl group at the $-CH_2Br$ group also appear to be similar, since the relevant $^{13}C-^1H$ coupling constants are the same (153.1 Hz) for compounds (1a) and (3a).

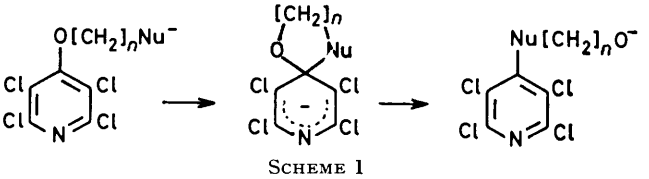
Some earlier observations[2] had suggested that tetrachloropyridyloxy-derivatives would readily undergo Smiles rearrangements[3] as shown in Scheme 1. Very few examples of Smiles or related rearrangements involving organometallic or carbanionic intermediates have been reported.[3,4] We therefore tried the reactions of compound (1) and related compounds with magnesium, expecting that we might observe a novel type of Smiles rearrangement involving the Grignard reagent (7), leading to the alcohol (8).

TABLE 1

Reactions of polyhalogenoaryl oxides with 1,ω-dibromoalkanes, $Br[CH_2]_nBr$

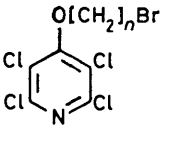
Anion	Method[a]	Yields of products (%)					
		$n = 2$		$n = 3$		$n = 6$	
		(1a)	(4a)	(1b)	(4b)	(1c)	(4c)
CCl:CCl·N:CCl·CCl:C–O⁻	A	14	26[b]	64	26	75	17
	B	31	12[b]	83	16	66	14
		(2a)	(5a)	(2b)	(5b)	(2c)	(5c)
CCl:CF·N:CF·CCl:C–O⁻[c]	B	29	10	64	27	70	17
		(3a)	(6a)	(3b)	(6b)	(3c)	(6c)
$C_6Cl_5O^-$	A	55	18				
	B	55	36	66	22	55	24
	C	61	14	22—56	0	*d*	10—13

[a] A, potassium carbonate, acetone, 10 d; B, pre-formed potassium salt, 18-crown-6, acetonitrile, 20 h; C, pre-formed potassium salt, DMF, 3 h. In each case the molar ratio of oxide to dibromoalkane was 1 : 2. [b] Pyridinol (*ca.* 35%) recovered. [c] An analogous reaction with 1,10-dibromodecane gave 1-bromo-10-(3,5-dichloro-2,6-difluoro-4-pyridyloxy)decane. [d] Tended to decompose on distillation, giving 1-pentachlorophenoxyhex-5-ene.

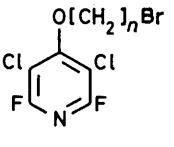


SCHEME 1

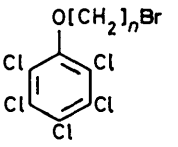
After an induction period, magnesium reacted with 1-bromo-3-tetrachloro-4-pyridyloxypropane (1b) in THF



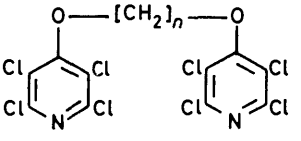
(1) a; $n = 2$
b; $n = 3$
c; $n = 6$



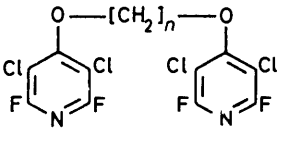
(2) a; $n = 2$
b; $n = 3$
c; $n = 6$



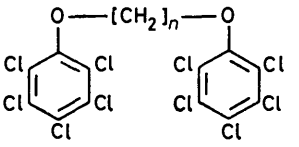
(3) a; $n = 2$
b; $n = 3$
c; $n = 6$



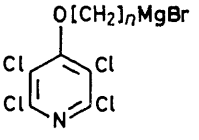
(4) a; $n = 2$
b; $n = 3$
c; $n = 6$



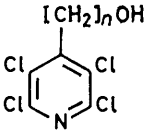
(5) a; $n = 2$
b; $n = 3$
c; $n = 6$



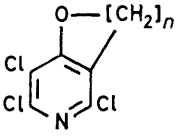
(6) a; $n = 2$
b; $n = 3$
c; $n = 6$



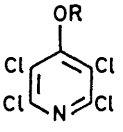
(7)



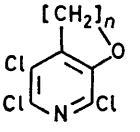
(8) a; $n = 2$
b; $n = 3$



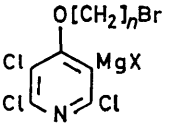
(9) a; $n = 2$
b; $n = 3$



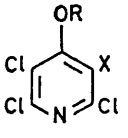
(10) a; R = Pr^n
b; R = Et
c; R = $CH_2CH{=}CH_2$



(11)



(12)



(13)

a; R = Et, X = H
b; R = Pr^n, X = H
c; R = Et, X = MgX
d; R = Pr^n, X = MgX
e; R = $CH_2CH{=}CH_2$, X = H
f; R = $[CH_2]_3Br$, X = H

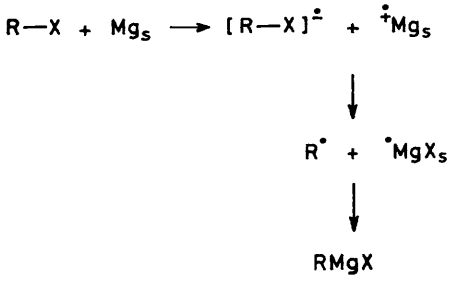
at room temperature. When the reaction started an intense dark red-purple colour developed, and heat was evolved. When water was added to quench the reaction, the intense colour was discharged. The products were tetrachloropyridin-4-ol and a compound (72%) whose spectra and elemental analysis (see Experimental section) were in accordance with the unexpected pyranopyridine structure (9b). The reaction was very clean, and no tetrachloro-4-propoxypyridine (10a) from hydrolysis of a Grignard reagent (7), or 3-tetrachloro-4-pyridylpropan-1-ol (8a), from its Smiles rearrangement, were detected. A similar reaction with 4-(2-bromoethoxy)tetrachloropyridine (1a) gave tetrachloropyridin-4-ol (54%) and the furopyridine (9a) (45%). Analogous reactions with lithium in place of magnesium took longer to initiate, and gave lower yields.

The spectroscopic evidence did not totally exclude the isomeric structures (11), which could have arisen *via* intramolecular attack at the 3-position of the anion of the rearranged product (8). However, we had already found that the anions (8), prepared by another route, did not cyclise even under much more vigorous conditions.[5] This reluctance of 4-substituted tetrachloropyridines to cyclise *via* intramolecular nucleophilic substitution at the 3-position (see also ref. 6) caused us to doubt that the compounds (9) were formed by the, at first sight, most likely route, *i.e.* by cyclisation of the Grignard reagent (7). We therefore examined the reaction in more detail. A conceivable alternative pathway was the formation of the Grignard reagent (12), which then cyclised to (9) by displacement of bromide from the side chain. This seemed unlikely, since it

would involve reaction of magnesium with an aryl chloride in preference to an alkyl bromide (*cf.* ref. 7). To test whether reaction could occur at the ring, the 4-alkoxytetrachloropyridines (10) were used. Reaction with magnesium in THF followed by hydrolysis gave, besides starting material and tetrachloropyridin-4-ol, the 4-alkoxy-2,3,6-trichloropyridines (13a, b). The position of the ring hydrogen was shown by its chemical shift (δ *ca.* 6.9 p.p.m., whereas for an α-H δ would have been *ca.* 8 p.p.m.[8]). The inference was that the Grignard reagents (13c, d) had been formed. On the other hand, when deuterium oxide was added to the product from a reaction with tetrachloro-4-ethoxypyridine (10b), only *ca.* 50% deuterium incorporation in the product was observed, indicating that some of the product (13a) was formed before the addition of deuterium oxide.

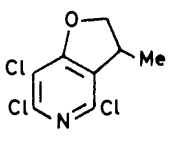
As a test of whether a Grignard reagent (12), or for that matter (7) was an intermediate in the formation of compounds (9), a reaction of the bromopropoxy-compound (1b) with magnesium was carried out in the presence of ethyl acetate, which has been shown to trap Grignard reagents efficiently in Barbier-type reactions.[9] The products formed were the same as those obtained in the absence of ethyl acetate, and no products involving reaction of a Grignard reagent with ethyl acetate were detected. Although a very rapid cyclisation of (12) could not be entirely excluded, we inferred that this Grignard reagent was probably not an intermediate.

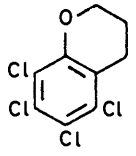
We next considered the possibility that the cyclisation involved a *precursor* of a Grignard reagent. Many studies have been made on the mechanism of formation of Grignard reagents. Following the key studies of the Amsterdam school, in which CIDNP effects clearly implicated radical pair precursors, the most widely accepted mechanism is that shown in simplified form (omitting side reactions) in Scheme 2.[10,11] This pathway

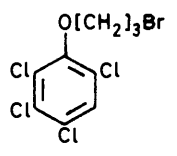


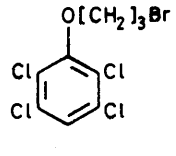
SCHEME 2

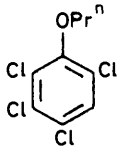
involves an initial electron transfer from the magnesium surface to the organic halide, followed by transfer of halide ion, and finally coupling of the resulting alkyl radical with surface-bound 'magnesium(I) halide'. Since the lifetime of radical anions of alkyl halides is, in general, very short,[12] we believed the most likely intermediate to be involved in the cyclisation was a radical. We have shown that photolysis of pentachloropyridine and tetrachloro-4-pyridyl derivatives results in loss of β-chlorines to give 3-pyridyl radicals.[13] Photolysis of 4-allyloxytetrachloropyridine (10c) gave the dihydrofuropyridine (14),* together with tetrachloropyridin-4-ol, thus showing that a 3-pyridyl radical could be trapped

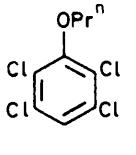

(14)

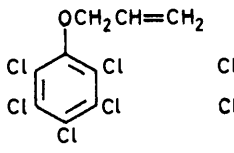

(16)

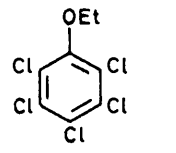

(17)

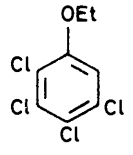

(18)

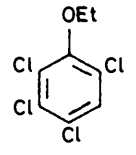

(19)

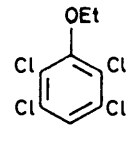

(20)


(21)


(22)


(23)

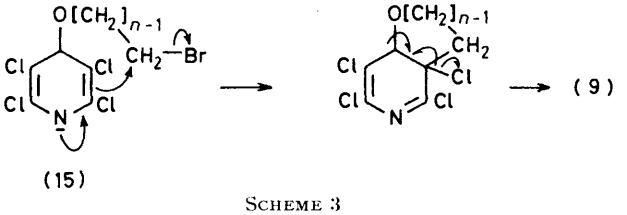

(24)


(25)

* It is of interest that *thermolysis* of 4-allyloxytetrachloropyridine gives the isomeric 4,6,7-trichloro-2,3-dihydro-2-methylfuro[3,2-*c*]pyridine *via* a Claisen rearrangement.[14]

by the allyloxy group.[15] However, a reaction of 4-allyloxytetrachloropyridine (10c) with magnesium gave the dechlorinated product (13e) and tetrachloropyridin-4-ol, but no dihydrofuropyridine (14). Conversely, photolysis of the 3-bromopropoxypyridine (1b) gave the dechlorinated product (13f), but none of the cyclised product (9b). We concluded that the magnesium-induced cyclisations did not proceed *via* free radicals.

Having obtained evidence against all the other possibilities, we were left with the hypothesis that the key intermediate was a radical anion. Although the evidence in favour of this hypothesis was entirely circumstantial, there were some theoretical considerations in its favour. (*a*) The electron-deficient nature of the polychloropyridyl ring would favour electron transfer to it. (*b*) There is some evidence that polyhalogenoaromatic radical anions may be more stable than alkyl or simple aryl analogues.[16] (*c*) A major contribution to the overall structure of the radical anion could be represented by the formula (15), and nucleophilic character might well be exhibited at its 3-position, leading to cyclisation as shown in Scheme 3.



SCHEME 3

In Scheme 3 a homolytic loss of the β-chlorine is depicted but this might well take place at the metal surface.

Attempts to detect CIDNP effects which might provide evidence of radical or radical-anion intermediates were unsuccessful. E.s.r. signals were observed, but were poorly resolved. A few further experiments were carried out which gave results consistent with a radical-anion intermediate. (*a*) A reaction of the bis(tetrachloro-4-pyridyloxy)propane (4b) with magnesium gave the cyclised product (9b) in almost quantitative yield. In this case reaction of magnesium at the side-chain could almost certainly be excluded.[17] (*b*) Reactions of magnesium with the pentachlorophenoxy-derivative (3b) gave a complex mixture comprising, besides the cyclised product (16), compounds (17) to (21). Not all of these could be isolated, but fractions containing mixtures of isomeric or closely related compounds were analysed by g.l.c., using authentic compounds for peak-enhancement. In this system, some reaction did occur at the side-chain, leading to products (19) to (21). However, we suggest that the main reaction again occurred *via* electron transfer to the ring. In this case, the resulting radical anion had a less localised structure, so that some formation of the *m*- and *p*-Grignard reagents occurred, leading to products (17) and (18); but cyclisation to (16) took precedence over formation of the *o*-Grignard reagent.

The reaction of magnesium with pentachloro(ethoxy)-benzene (22) where cyclisation was not possible, gave all three isomeric tetrachloro(ethoxy)benzenes.

EXPERIMENTAL

I.r. spectra were recorded for Nujol mulls or liquid films. ^{1}H N.m.r. spectra (60 MHz or 90 MHz) and ^{13}C n.m.r. spectra (20 MHz) were recorded for solutions in $CDCl_3$ unless otherwise stated, with Me_4Si as internal standard. G.l.c. analyses used a 3 m × 5 mm glass column packed with 1% OV210 on Chromosorb WW 100/120 mesh, nitrogen carrier gas, and flame ionisation detector. Calculated *m/e* values for mass spectra are for ions containing ^{35}Cl only; the appropriate patterns of isotope peaks were observed. Light petroleum refers to the fraction of b.p. 60—80 °C, unless otherwise stated.

3,5-Dichloro-2,6-difluoropyridin-4-ol was a gift from I.C.I. Ltd. Tetrachloropyridin-4-ol,[18] tetrachloro-4-ethoxypyridine,[19] 4-allyloxytetrachloropyridine and allyloxypentachlorobenzene,[14] and pentachloro(ethoxy)benzene [19] were prepared according to the references cited or with appropriate modifications.

Tetrachloro-4-propoxypyridine.—Potassium tetrachloropyridin-4-olate (5.5 g, 0.02 mol), 1-bromopropane (2.6 g, 0.022 mol), 18-crown-6 (0.01 g), and dry acetonitrile (40 ml) were stirred under reflux during 12 h. Conventional work-up gave *tetrachloro-4-propoxypyridine* (1.1 g, 20%), m.p. 28—29 °C, δ 1.0 (3 H, t), 1.8 (2 H, m), and 4.1 (2 H, t) (Found: C, 34.7; H, 2.6; N, 5.1. $C_8H_7Cl_4NO$ requires C, 34.9; H, 2.6; N, 5.1%).

Tetrachloro(propoxy)benzenes.—(*a*) Sodium (0.6 g) was added to a solution of 2,3,5,6-tetrachloronitrobenzene (2.6 g) in propan-1-ol (50 ml), and the mixture was stirred under reflux during 4 h. Water (100 ml) was added. Conventional work-up, *via* chloroform extraction, gave 2,3,5,6-*tetrachloro(propoxy)benzene* (2.0 g, 65%), m.p. 38 °C (from ethanol), δ 1.2 (3 H, t, Me), 1.9 (2 H, m, CH_2Me), 4.1 (2 H, t, OCH_2), and 7.55 (1 H, s, ArH) (Found: C, 39.5; H, 2.9%; M^+, 272. $C_9H_8Cl_4O$ requires C, 39.5; H, 2.9%; M^+, 272).

(*b*) A mixture of 2,3,4,5-tetrachlorophenol (1.0 g), anhydrous potassium carbonate (1.0 g), 1-iodopropane (2.0 g), 18-crown-6 (trace), and acetonitrile (20 ml) was stirred under reflux during 12 h. Evaporation of the solvent and conventional work-up gave 2,3,4,5-*tetrachloro(propoxy)benzene* (0.6 g, 50%), m.p. 47—48 °C (from ethanol), δ 1.1 (3 H, t, Me), 1.9 (2 H, m, CH_2Me), 4.1 (2 H, t, OCH_2), and 7.05 (1 H, s, ArH) (Found: C, 39.5; H, 3.0%; M^+, 272. $C_9H_8Cl_4O$ requires C, 39.5; H, 2.9%; M^+, 272).

Reactions of Polyhalogenoarene Oxides with Dibromoalkanes.—*Method A*. The polyhalogenophenol or pyridinol (0.02 mol), the dibromoalkane (0.042 mol) anhydrous potassium carbonate (4.0 g), and dry acetone (40 ml) were stirred under reflux during 10 days. The solvent was evaporated and ether (100 ml) and 2M-sodium hydroxide (50 ml) were added and the layers were separated. Acidification of the aqueous layer gave recovered phenol (pyridinol). The ether layer was dried ($MgSO_4$) and evaporated to dryness. The products from the pyridinols were separated by column chromatography (silica, gradient elution with light petroleum and chloroform; in each case the monosubstituted compound was eluted first) and purified by conventional methods. In the case of the pentachlorophenoxy-derivatives, the disubstituted compound crystallised from the reaction mixture and was isolated by filtration. Yields are given in Table 1. Physical and analytical data are listed in Table 2.

Method B. The phenol (pyridinol) (0.02 mol), anhydrous potassium carbonate (0.02 mol), and acetone (100 ml)

TABLE 2

ω-Bromoalkoxypolyhalogenoarenes and 1,ω-di(polyhalogenoaryloxy)alkanes

Compound [a]	M.p. (°C)	Recryst. solvent [g]	^{1}H N.m.r. (δ)	Formula	Found (required) [b] C, %	H, %	N, %
1-Bromo-2-tetrachloro-4-pyridyloxyethane (1a)	60—63	LP + C	3.7 (2 H, t, CH_2Br), 4.4 (2 H, t, OCH_2)	$C_7H_4BrCl_4NO$	24.75 (24.7)	1.1 (1.2)	4.25 (4.1)
1-Bromo-3-tetrachloro-4-pyridyloxypropane (1b)	56—57	LP + C	2.4 (2 H, m), 3.7 (2 H, t), 4.4 (2 H, t)	$C_8H_6BrCl_4NO$	27.25 (27.15)	1.75 (1.7)	4.0 (4.0)
1-Bromo-6-tetrachloro-4-pyridyloxyhexane (1c)	122 [c] (2.5 mmHg)	—	1.7 (8 H, m), 3.4 (2 H, t), 4.2 (2 H, t)	$C_{11}H_{12}BrCl_4NO$	33.3 (33.4)	3.1 (3.1)	3.9 (3.5)
1-Bromo-2-(3,5-dichloro-2,6-difluoro-4-pyridyloxy)ethane (2a)	75 [c] (1 mmHg)	—	3.7 (2 H, t), 4.6 (2 H, t)	$C_7H_4BrCl_2F_2NO$		*d*	
1-Bromo-3-(3,5-dichloro-2,6-difluoro-4-pyridyloxy)propane (2b)	73 [c] (1 mmHg)	—	2.4 (2 H, m), 3.75 (2 H, t), 4.5 (2 H, t)	$C_8H_6BrCl_2F_2NO$	30.4 (29.9)	1.9 (1.9)	4.6 (4.4)
1-Bromo-6-(3,5-dichloro-2,6-difluoro-4-pyridyloxy)hexane (2c)	78 [c] (1 mmHg)	—	1.7 (8 H, m), 3.45 (2 H, t), 4.4 (2H, t)	$C_{11}H_{12}BrCl_2F_2NO$	36.4 (36.4)	3.3 (3.3)	3.9 (3.9)
1-Bromo-10-(3,5-dichloro-2,6-difluoro-4-pyridyloxy)decane	103—105 [c] (0.1 mmHg)	—	1.2 (16 H, m), 3.55 (2 H, t), 4.3 (2 H, t)	$C_{15}H_{26}BrCl_2F_2NO$	42.9 (43.0)	4.9 (4.8)	3.5 (3.3)
1-Bromo-2-pentachlorophenoxyethane (3a)	77—78	C and LP	3.7 (2 H, t), 4.35 (2 H, t)	$C_8H_4BrCl_5O$	26.1 (25.7)	1.1 (1.1)	— —
1-Bromo-3-pentachlorophenoxypropane (3b)	64—65	H	2.4 (2 H, m), 3.7 (2 H, t), 4.2 (2 H, m)	$C_9H_6BrCl_5O$	28.2 (27.9)	1.5 (1.5)	— —
1-Bromo-6-pentachlorophenoxyhexane (3c)	36—37 [e]	H	1.9 (8 H, m), 3.7 (2 H, t), 4.2 (2 H, t)	$C_{12}H_{12}BrCl_5O$	33.9 (33.6)	2.8 (2.8)	—
1-Bromo-3-(2,3,4,5-tetrachlorophenoxy)propane	85 [c] (0.5 mmHg)	—	2.4 (2 H, quint), 3.65 (2 H, t), 4.2 (2 H, t), 7.0 (1 H, s)	$C_9H_7BrCl_4O$	30.8 (30.6)	2.1 (2.0)	— —
1-Bromo-3-(2,3,4,6-tetrachlorophenoxy)propane (17)	85 [c] (0.5 mmHg)	—	2.4 (2 H, quint), 3.65 (2 H, t), 4.2 (2 H, t), 7.55 (1 H, s)	$C_9H_7BrCl_4O$	31.1 (30.6)	2.3 (2.0)	— —
1-Bromo-3-(2,3,5,6-tetrachlorophenoxy)propane (18)	110 [c] at 0.7 mmHg	—	2.4 (2 H, quint), 3.65 (2 H, t), 4.2 (2 H, t), 7.45 (1 H, s) 4.2 (2 H, t), 7.45 (1 H, s)	$C_9H_7BrCl_4O$		*f*	
1,2-Bis(tetrachloro-4-pyridyloxy)ethane (4a)	158—159	LP + C	4.6 (s)	$C_{12}H_4Cl_8N_2O_2$	29.4 (29.3)	0.95 (0.8)	5.5 (5.7)
1,3-Bis(tetrachloro-4-pyridyloxy)propane (4b)	140—142	LP + C	2.4 (2 H, quint), 4.35 (4 H, t)	$C_{13}H_6Cl_8N_2O_2$	31.0 (30.9)	1.2 (1.2)	5.6 (5.5)
1,6-Bis(tetrachloro-4-pyridyloxy)hexane (4c)	125—126	LP + C	1.7 (8 H, m), 4.25 (4 H, t)	$C_{16}H_{12}Cl_8N_2O_2$	35.1 (35.1)	2.2 (2.2)	5.1 (5.1)
1,2-Bis(3,5-dichloro-2,6-difluoro-4-pyridyloxy)ethane (5a)	94—95	E + W	4.8 (s)	$C_{12}H_4Cl_4F_4N_2O_2$	33.8 (33.8)	0.8 (0.9)	6.5 (6.6)
1,3-Bis(3,5-dichloro-2,6-difluoro-4-pyridyloxy)propane (5b)	54—55	H + C	2.5 (2 H, quint.), 4.7 (4 H, t)	$C_{13}H_6Cl_4F_4N_2O_2$	35.5 (35.5)	1.3 (1.4)	6.4 (6.4)
1,6-Bis(3,5-dichloro-2,6-difluoro-4-pyridyloxy)hexane (5c)	72—73	E + W	1.7 (8 H, m), 4.3 (4 H, t)	$C_{16}H_{12}Cl_4F_4N_2O_2$	39.8 (39.9)	2.5 (2.5)	5.7 (5.8)
1,2-Di(pentachlorophenoxy)ethane (6a)	213—214	C	3.1 (s)	$C_{14}H_4Cl_{10}O_2$	30.1 (30.1)	0.7 (0.8)	— —
1,3-Di(pentachlorophenoxy)propane (6b)	170—171	C	2.4 (2 H, quint), 4.3 (4 H, t)	$C_{15}H_6Cl_{10}O_2$	31.3 (31.4)	1.0 (1.0)	— —
1,6-Di(pentachlorophenoxy)hexane (6c)	134—135	H	1.7 (8 H, m), 4.0 (4 H, t)	$C_{18}H_{12}Cl_{10}O_2$	35.1 (35.1)	1.9 (1.9)	— —

[a] All new compounds. [b] Mass spectra of all compounds showed molecular ions at required *m/e*, with appropriate isotope peaks. [c] B.p. (Kugelrohr). [d] M^+ 304.8822 (304.8822). [e] B.p. (Kugelrohr) 75 °C at 3 × 10^{-3} mmHg. [f] M^+, 349.8433 (349.8433). [g] LP = Light petroleum, C = chloroform, H = hexane, E = ethanol, W = water.

were stirred under reflux during 2 h. The mixture was filtered whilst hot and the filtrate was evaporated to dryness. To the residue was added dry acetonitrile (40 ml), the dibromoalkane (0.042 mol), and 18-crown-6 (*ca.* 10 mg), and the mixture was stirred under reflux during 10 h. The products were obtained as described for Method A, in the yields recorded in Table 1.

Method C. Potassium pentachlorophenoxide (0.02 mol), the dibromoalkane (0.042 mol), and dry, redistilled DMF (40 ml) were stirred under reflux during 3 h. The mixture was cooled, and the 1,ω-di(pentachlorophenoxy)alkane was filtered off and washed with water. The filtrate was evaporated to dryness under reduced pressure, and the ω-bromoalkoxypentachlorobenzene was isolated by chromatography (silica, light petroleum, and chloroform). Distillation of 1-bromo-6-pentachlorophenoxyhexane, especially at pressures above 0.1 mmHg, tended to give 1-pentachlorophenoxyhex-5-ene, b.p. (Kugelrohr) 120 °C at 1 mmHg, $\nu_{max.}$ 3 075 and 1 649 cm^{-1}; δ 1.8 (4 H, m), 2.1 (2 H, t), 4.05 (2 H, t), 4.85 (1 H, m), 5.2 (1 H, m), and 5.8 (1 H, m) (Found: C, 41.4; H, 3.2%; M^+, 346. $C_{11}H_{12}Cl_5O$ requires C, 41.4; H, 3.2; M^+, 346).

Method D. A tetrachlorophenol (1.0 g), anhydrous potassium carbonate (1.0 g), 18-crown-6 (trace), and 1,3-dibromopropane (20 ml) were stirred under reflux during 8 h. Evaporation of the excess of dibromopropane and chromatography of the residue gave the 1-*bromo*-3-(*tetrachlorophenoxy*)*propane*: for b.p.s. and spectroscopic data see Table 2.

Reactions with Magnesium.—General procedure. All reactions were carried out in an atmosphere of dry, oxygen-free nitrogen.

Sodium (2 g) was added to a solution of benzophenone (10 g) in tetrahydrofuran (THF) (500 ml) and the mixture was heated under reflux until a permanent blue colour was obtained. The THF was distilled onto magnesium turnings (8 g). Bromoethane (20 g) was added dropwise, and when formation of the Grignard reagent had occurred the mixture was heated under reflux for *ca.* 4 h. THF was distilled from the resulting solution directly into a dry flask with a side-arm which could function as an air condenser in case of an exothermic reaction, containing the magnesium * and organic substrate to be used for the reaction. When the reaction started (red-purple colour) the mixture was left for 24 h; 2M-HCl (20 ml) was added. The mixture was extracted with chloroform, and the organic layer was extracted with aqueous potassium carbonate. The aqueous layer was acidified and the phenol or pyridinol precipitated was dried, weighed, and identified by comparison with an authentic specimen. The organic layer was dried ($MgSO_4$) and evaporated to a small volume. Products were isolated from the residue by chromatography on silica (gradient elution with light petroleum and chloroform).

(*a*) A reaction of 1-bromo-3-tetrachloro-4-pyridyloxypropane (3.3 g, 0.01 mol) and magnesium (0.26 g, 0.011 g-atom) in THF (50 ml) gave tetrachloropyridin-4-ol (0.7 g, 31%) and 5,7,8-*trichloro*-3,4-*dihydro*-2H-*pyrano*[3.2-c]*pyridine* (9b) (1.6 g, 72%), m.p. 123—124 °C (from chloroform and hexane); ^1H δ 2.1 (2 H, m, 4-H), 2.7 (2 H, t, 3-H), and 4.4 (2 H, t, 5-H); ^{13}C δ [$(CD_3)_2SO$] 20.0 (C-4) 22.0 (C-3), 68.2 (C-5), 116.4 and 118.4 (C-2a, 7), 144.1 and 146.8 (C-2,8), and 160.1 (C-6a) p.p.m. (Found: C, 40.2; H, 2.5; N, 6.0%; M^+, 237. $C_8H_6Cl_3NO$ requires C, 40.3; H, 2.5; N, 5.9%; M^+, 237).

* Singly sublimed magnesium was used. 'Grignard grade' magnesium turnings gave inferior results. Triply sublimed magnesium gave results similar to singly sublimed magnesium.

(*b*) A reaction of 1-bromo-3-tetrachloro-4-pyridyloxypropane (4.0 g, 0.012 mol) and magnesium (0.5 g, 0.021 g-atom) in THF (20 ml) and ethyl acetate (2 ml) gave tetrachloropyridin-4-ol (0.32 g, 12%) and the pyranopyridine (9b) (1.5 g, 67%).

(*c*) A reaction of 1-bromo-2-tetrachloro-4-pyridyloxyethane (4.0 g, 0.011 mol) and magnesium (0.5 g, 0.021 g-atom) in THF gave tetrachloropyridin-4-ol (1.5 g, 54%) and 4,6,7-*trichloro*-2,3-*dihydrofuro*[3.2-c]*pyridine* (9a) (1.15 g, 45%), m.p. 129 °C (from chloroform–hexane), δ 3.3 (2 H, t) and 4.9 (2 H, t) (Found: C, 37.2; H, 1.9; N, 6.4%, M^+, 223. $C_7H_4Cl_3NO$ requires C, 37.45; H, 1.8; N, 6.2%; M^+, 223).

(*d*) A reaction of tetrachloro-4-propoxypyridine (4.0 g, 0.014 mol) and magnesium (0.5 g, 0.021 g-atom) in THF (20 ml) gave tetrachloropyridin-4-ol (0.1 g, 16%), starting material (1.6 g, 25%), and 2,3,6-*trichloro*-4-*propoxypyridine* (1.76 g, 51%), b.p. (Kugelrohr) 163 °C/1 mmHg, δ 1.05 (3 H, t), 1.8 (2 H, m), 4.0 (2 H, t), and 6.9 (1 H, s) (Found: C, 39.7; H, 3.2; N, 5.8%; M^+, 239. $C_8H_8Cl_3NO$ requires C, 39.9; H, 3.4; N, 5.8%; M^+, 239).

(*e*) A similar reaction of tetrachloro-4-ethoxypyridine (4.0 g, 0.015 mol) gave tetrachloropyridin-4-ol (0.4 g, 22%), impure starting material (0.6 g), and 2,3,6-*trichloro*-4-*ethoxypyridine* (0.6 g, 23%), b.p. (Kugelrohr) 160 °C at 0.15 mmHg; δ 1.6 (3 H, t), 4.2, (2 H, q), and 6.85 (1 H, s) p.p.m. (Found: C, 37.4; H, 2.6; N, 6.0%; M^+, 225. $C_7H_6Cl_3NO$ requires C, 37.1; H, 2.7; N, 6.2%; M^+, 225).

The reaction was repeated, but was quenched with deuterium oxide (5 ml) before further work-up. Integration of the ^1H n.m.r. spectrum and the ratio of the peaks in the mass spectrum at *m/e* 225 and 226 showed that the trichloropyridine product (0.4 g, 23%) comprised 2,3,6-trichloro-4-ethoxypyridine and 2,3,6-trichloro-5-deuterio-4-ethoxypyridine in a ratio of 1 : 1.

(*f*) A reaction of 4-allyloxytetrachloropyridine (4.0 g, 0.15 mol) and magnesium (0.5 g, 0.021 g-atom) in THF (20 ml) gave tetrachloropyridin-4-ol (0.45 g, 14%), starting material (1.5 g, 38%) and 4-*allyloxy*-2,3,6-*trichloropyridine* (0.4 g, 11%), b.p. (Kugelrohr) 160 °C at 1 mmHg, δ 4.75 (2 H, d), 5.4 (2 H, m), 6.2 (1 H, m), and 6.7 (1 H, s) (Found: C, 40.7; H, 2.8; N, 5.9%; M^+, 239. $C_8H_8Cl_3NO$ requires C, 40.3; H, 2.5; N, 5.9%; M^+, 239).

(*g*) A reaction of 1-bromo-3-pentachlorophenoxypropane (5.0 g, 0.012 mol) and magnesium (0.32 g, 0.013 g-atom) in THF required stirring after initiation. On work-up the aqueous phase yielded a multicomponent mixture of phenols (1.1 g). Chromatography of the mixture of products from the organic phase gave the following fractions; for each fraction except the last the i.r. and ^1H n.m.r. spectra and g.l.c. retention times were measured and compared with those of authentic specimens.

(i) Mixture (0.05 g, 1.5%) of 2,3,4,6-tetrachloro(propoxy)-benzene (19) and 2,3,5,6-tetrachloro(propoxy)benzene (20); (ii) allyloxypentachlorobenzene (21) (0.05 g, 1.2%); (iii) starting material (0.10 g, 2%); (iv) mixture (0.35 g, 7.7%) of 1-bromo-3-(2,3,4,6-tetrachlorophenoxy)propane (17) and 1-bromo-3-(2,3,5,6-tetrachlorophenoxy)propane (18); (v) 5,6,7,8-*tetrachlorochroman* (16) (1.0 g, 31%), m.p. 103—104 °C (from light petroleum), δ 2.1 (2 H, tt), 2.9 (2 H, t), and 4.4 (2 H, t) (Found: C, 39.6; H, 2.3%; M^+, 270. $C_9H_6Cl_4O$ requires C, 39.7; H, 2.2%; M^+, 270).

(*h*) A reaction of pentachloro(ethoxy)benzene (2.0 g, 0.0086 mol) and magnesium (0.5 g, 0.021 g-atom) in THF (20 ml) gave a mixture (1.6 g) of tetrachloro(ethoxy)-

benzenes. The aromatic region of the ^1H n.m.r. spectrum showed signals at δ 6.95 (23), 7.4 (24), and 7.5 (25) in the proportions 7 : 6 : 9.

(i) A reaction of 1,3-bis(tetrachloro-4-pyridyloxy)propane (4b) (3.0 g, 0.0055 mol) and magnesium (0.5 g) in THF gave tetrachloropyridin-4-ol (1.0 g, 83%) and the pyranopyridine (9b) (1.4 g, 98%).

Photolyses.—General procedure. A solution of the compound (*ca.* 1% w/v) was irradiated by a medium-pressure mercury lamp using a Pyrex filter, the progress of the reaction being monitored by t.l.c. The solvent was evaporated and the residue subjected to column chromatography on silica.

(*a*) 1-Bromo-3-tetrachloro-4-pyridyloxypropane in THF gave starting material (65%) and 1-*bromo*-3-(2,3,6-*trichloro*-4-*pyridyloxypropane* (13f) (24%), b.p. (Kugelrohr) 174 °C at 3 mmHg, δ 2.3 (2 H, m), 3.6 (2 H, t), 4.25 (2 H, t), and 6.85 (1 H, s) (Found: M^+, 316.8776. $C_8H_7BrCl_3NO$ requires M^+, 316.8776).

A similar reaction in diethyl ether gave starting material (25%) and the same product (47%).

(*b*) 4-Allyloxytetrachloropyridine in THF gave tetrachloropyridin-4-ol (17%), starting material (48%), and 4,6,7-*trichloro*-3-*methyl*-2,3-*dihydrofuro*[3,2-c]*pyridine* (14) (24%), m.p. 77 °C (from hexane), δ 1.5 (3 H, d, *J* 8 Hz, CH_3), 3.7 (1 H, m, H-3), 4.6 (1 H, dd, *J* 5 Hz and 10 Hz, 2-H), and 5.0 (1 H, t, *J* 10 Hz, other 2-H) (Found: C, 40.6; H, 2.5; N, 5.7%; M^+, 237. $C_8H_6Cl_3NO$ requires C, 40.3; H, 2.5; N, 5.9%, M^+, 237).

A similar reaction in diethyl ether gave tetrachloropyridin-4-ol (47%), starting material (34%), and the furopyridine (14) (10%).

We thank S.R.C. for Studentships (J. P. W., P. S. F.); the Organic Chemistry Group of the Free University, Amsterdam, for gifts of magnesium, facilities for CIDNP observations, advice, and hospitality; Professor H. Suschitzky for helpful discussions; and I.C.I. Ltd. for gifts of chemicals.

[1/899 *Received*, 4*th June*, 1981]

REFERENCES

[1] Part **45**, B. J. Wakefield and D. J. Wright, *J. Chem. Research*, 1981, (*S*) 129; (*M*) 1832.

[2] B. Iddon, H. Suschitzky, and A. W. Thompson, *J. Chem. Soc., Perkin Trans. 1*, 1973, 2971; M. N. Patel and B. J. Wakefield, unpublished work; C. Steele and H. Suschitzky, unpublished work.

[3] W. E. Truce, E. M. Kreider, and W. W. Brand, *Org. React.*, 1970, **18**, 99.

[4] E. Grovenstein, jun., *Adv. Organomet. Chem.*, 1977, **16**, 167; E. Grovenstein jun., *Angew. Chem., Int. Ed. Engl.*, 1978, **17**, 713; J. J. Eisch and D. A. Russo, *J. Organomet. Chem.*, 1968, **14**, 13. Some of the experiments reported in the last reference may have some analogy to those described here.

[5] N. J. Foulger and B. J. Wakefield, *J. Chem. Soc., Perkin Trans.* 1, 1974, 871.

[6] D. Moran, N. N. Patel, N. A. Tahir, and B. J. Wakefield, *J. Chem. Soc., Perkin Trans. 1*, 1974, 2310.

[7] M. S. Kharasch and O. Reinmuth, 'Grignard Reactions of Nonmetallic Substances,' Constable, London, 1954.

[8] J. D. Cook and B. J. Wakefield, *J. Organomet. Chem.*, 1968, **13**, 15; R. A. Fernandez, H. Heaney, J. M. Jablonski, K. G. Mason, and T. J. Ward, *J. Chem. Soc. C*, 1969, 1908.

[9] F. A. Hartog, Ph.D. Thesis, Free University, Amsterdam, 1978; C. Blomberg and F. A. Hartog, *Synthesis*, 1977, 18.

[10] H. W. H. J. Bodewitz, C. Blomberg, and F. Bickelhaupt, *Tetrahedron*, 1973, **29**, 719; 1975, **31**, 1053.

[11] For other recent studies see for example H. R. Rogers, C. L. Hill, Y. Fujiwara, R. J. Rogers, H. L. Mitchell, and G. M. Whitesides, *J. Am. Chem. Soc.*, 1980, **102**, 217; J. E. Dubois, G. Molle, G. Tourillon and P. Bauer, *Tetrahedron Lett.*, 1979, 5069; B. J. Schaart, C. Blomberg, O. S. Akkerman, and F. Bickelhaupt, *Can. J. Chem.*, 1980, **58**, 932; H. M. Walborsky and R. B. Banks, *Bull. Soc. Chim. Belg.*, 1980, **89**, 849, and references therein.

[12] C. P. Andrieux, C. Bloeman, J. M. Dumas-Bouchiat, F. M'Halla and J. M. Savéant, *J. Am. Chem. Soc.*, 1980, **102**, 3806; J. Lichtscheidl and N. Getoff, *Monatsh. Chem.*, 1979, **110**, 1367; see also J. T. Wang and F. Williams, *J. Am. Chem. Soc.*, 1980, **102**, 2860; J. T. Wang and F. Williams, *Chem. Phys. Lett.*, 1980, **71**, 557; M. C. R. Symons, *Chem. Phys. Lett.*, 1980, **72**, 559.

[13] E. Ager, G. E. Chivers, and H. Suschitzky, *J. Chem. Soc., Perkin Trans. 1*, 1973, 1125; J. Bratt, B. Iddon, A. G. Mack, H. Suschitzky, J. A. Taylor, and B. J. Wakefield, *J. Chem. Soc., Perkin Trans. 1*, 1980, 648.

[14] B. Iddon, H. Suschitzky, and J. A. Taylor, *J. Chem. Soc., Perkin Trans. 1*, 1979, 2756.

[15] *cf.* S.-K. Chung and F.-F. Chung, *Tetrahedron Lett.*, 1979, 2473.

[16] M. B. Yim, S. DiGregorio, and D. E. Wood, *J. Am. Chem. Soc.*, 1977, **99**, 4260; R. D. Chambers, W. K. R. Musgrave, C. R. Sargent, and F. G. Drakesmith, *Tetrahedron*, 1981, **37**, 591; M. C. R. Symons, *J. Chem. Soc., Faraday Trans. 1*, 1981, 783.

[17] Examples of insertion of magnesium into a carbon–oxygen bond are known, however: A. Maercker, *J. Organomet. Chem.*, 1969, **18**, 249; C. Blomberg, G. Schat, H. Grootveld, and F. Bickelhaupt, *Liebigs Ann. Chem.*, 1972, **763**, 148.

[18] J. Bratt and H. Suschitzky, *J. Chem. Soc., Perkin Trans. 1*, 1973, 1689.

[19] D. J. Berry, Ph.D. Thesis, Salford, 1970.