Activation of Electrophilic Aromatic Substitution by the Substituent $-CH_2Co(dmgH)_2py$. Products of Reaction of Benzylcobaloximes with Halogens in Acetic Acid

By S. N. Anderson, D. H. Ballard, and M. D. Johnson,* Department of Chemistry, University College, 20 Gordon St., London WC1H 0AJ

Benzyl-, 2-methylbenzyl-, and 4-methylbenzyl-cobaloxime react rapidly with low concentrations of chlorine and bromine in acetic acid to give the corresponding benzyl and methylbenzyl halides. 3-Methylbenzylcobaloxime undergoes a substantial proportion of ring substitution by both bromine and chlorine in competition with the cleavage of the carbon–cobalt bond. 3,5-Dimethylbenzylcobaloxime undergoes ring substitution before carbon–cobalt bond cleavage and at rates greater than those for the comparable substitution reactions of mesitylene, but comparable with those of 3,5-dimethylanisole. The *p*-xylylenedicobaloxime does not undergo ring substitution, but *m*-xylylenedicobaloxime undergoes considerable substitution at both the positions *para*- to the organometallic substituents, before carbon–cobalt bond cleavage occurs. In contrast, iodine causes carbon–cobalt bond cleavage without prior ring substitution in all the cases studied. The results are discussed in terms of the substituent effect of the organometallic group, which is greater than that of the methyl group, but less than that of the methoxy-group.

TRANSITION-METALS are known to have a marked effect on the reactions of organic molecules to which they are π-bonded.[1] However, much less is known about the influence of σ-bonded transition-metals on organic reactivity, both in direction and degree. From a study [2] of the influence of several transition-metal-containing groups on the acidity of pyridinium ions to which they are attached, we concluded that groups such as $-CH_2Mn(CO)_5$, $-CH_2Fe(CO)_2(\pi\text{-}C_5H_5)$, and $-CH_2Co(CN)_5^{3-}$ were not only very strongly electron donating, but also that this electron donation was at least partially conjugative in origin.

Strong electron-donating effects of this kind are not without precedent in organometallic chemistry. Several substituents of the type $-CH_2M$, where M is a non-transition metal and its appendant ligands, have been shown to be electron donating and some, *e.g.* $-CH_2SnMe_3$ and $-CH_2HgCH_2Ph$, are believed to be more effective than the methoxy-group.[3] The origin of these effects has received much attention. Spectroscopic studies [4,5] on charge-transfer complexes of molecules containing these substituents indicate that their origin may lie in σ–π-overlap or ' vertical stabilisation ' [3,5] brought about by overlap of an orbital of the methylene carbon with a filled σ-orbital of the metal of the appropriate symmetry. However, neighbouring-group participation may be an important factor in many reactions of such molecules.

In order to ascertain whether comparable transition-metal containing substituents are as marked in their influence on reactivity, a study of the reactions of the corresponding benzyl compounds seemed appropriate. Whereas the pyridiniomethylmetal ions studied previously are unreactive towards electrophilic substitution in the heteroaromatic ring by virtue of the strong deactivating effect heteroatom group ($-\overset{+}{N}H=$),[6] the aromatic

[1] *E.g.*, J. D. Holmes, D. A. K. Jones, and R. Pettit, *J. Organometallic Chem.*, 1965, **4**, 324; E. O. Fischer and K. Öfele, *Chem. Ber.*, 1958, **91**, 2763.

[2] M. D. Johnson and N. Winterton, *J. Chem. Soc.* (*A*), 1970, 507.

[3] W. Hanstein, H. J. Berwin, and T. G. Traylor, *J. Amer. Chem. Soc.*, 1970, **92**, 829.

[4] H. Bock and H. Alt, *J. Amer. Chem. Soc.*, 1970, **92**, 1569.

[5] W. Hanstein, H. J. Berwin, and T. G. Traylor, *J. Amer. Chem. Soc.*, 1970, **92**, 7476.

[6] H. H. Jaffe, *J. Amer. Chem. Soc.*, 1955, **77**, 4445.

ring of the benzyl group should be appreciably more susceptible to electrophilic attack. However, in multifunctional benzylmetal compounds, complications may arise because of attack at other sites in the molecule.

In this paper are described product studies on the reation of three halogens, chlorine, bromine, and iodine, on a number of benzylcobaloximes in acetic acid, in order to obtain information about the substituent effect of the group $-CH_2Co(dmgH)_2py$, where dmgH is the monoanion of dimethylglyoxime.

RESULTS

Benzylcobaloximes.—The benzylcobaloximes were prepared from the corresponding benzyl halides by reaction with the bis(dimethylglyoximinato)pyridinecobaltate(I) acid, under nitrogen, at room temperature. Within the period of the reactions concerned, the benzylcobaloximes did not undergo any decomposition in the absence of the halogen. The organometallic product was isolated by filtration before and after pouring the reaction mixture into water, and the organic products were obtained by washing the precipitates, and extraction of the filtrates, with light petroleum. The organometallic products were identified mainly from their ^1H n.m.r. spectra, by halogen analysis and by their further reaction with either the same or different halogens. Where mixed organometallic products were formed, these were not separated, but their composition was determined from their spectra. For example, the 3,5-dimethyl-*x*-chlorobenzylcobaloxime obtained from the reaction of 1 mol. of chlorine with

TABLE 1

Benzylcobaloximes: spectra and analysis

			^1H N.m.r. (CDCl$_3$) [a]				Analysis (%)		
Reagent	Product	Yield	dmgH	CH_3	CH_2	aromatic	C	H	N
$PhCH_2Br$	(I) [b]	57%	8·1		7·2	3·05			
2-MeC_6H_4·CH_2Br	(II)		8·05	7·9	7·05	2·9—3·2	53·1 (53·3)	6·2 (5·9)	14·8 (14·8)
3-MeC_6H_4·CH_2Br	(III)		8·05	7·7	7·15	2·9—3·3	52·9 (53·3)	6·0 (5·9)	14·7 (14·8)
4-MeC_6H_4·CH_2Br	(IV)	64%	8·05	7·92	7·10	3·10	51·7 (53·3)	6·0 (5·9)	14·6 (14·8)
3,5-$Me_2C_6H_3$·CH_2Br	(V)	65%	8·05	7·75	7·15	H_2 3·28; H_4 3·15	53·7 (54·2)	5·9 (6·2)	14·2 (14·4)
1,4-$C_6H_4(CH_2Br)_2$	(VI)		8·10		7·25	3·35		*d*	
1,3-$C_6H_4(CH_2Br)_2$	(VII)		8·10		7·25	H_2 3·62; $H_5 = H_4$ = *ca.* 3·18	47·8 (48·6)	5·7 (5·5)	15·8 (16·6)
1,2-$C_6H_4(CH_2Br)_2$	(VIII)	7·3%	8·10		7·00				
					4·9 [e]	2·8—3·4		*f*	
5-Me-1,3-$C_6H_3(CH_2Br)_2$	(IX)	38%	8·05	7·75	7·25	H_2 3·70; H_4 3·30		*d*	
1,3,5-$C_6H_3(CH_2Br)_3$	(X)	20·5%	8·05		7·28				
					5·60	H_2 3·63; H_4 3·10		*f*	
2,4,5-$Me_3C_6H_2$·CH_2Br	(XI)	76%	8·1	7·80 7·95	7·10	H_3 3·29; H_6 3·48	54·7 (55·1)	6·6 (6·4)	14·1 (14·0)

[a] τ-Values. [b] (Co) = $Co(dmgH)_2py$.[c] [c] dmgH = Monoanion of dimethylglyoxime. [d] See text (results section). [e] CH_2Br. [f] Not analysed.

ion in methanolic solution. The ^1H n.m.r. characteristics and analyses of the products are shown in Table 1. Two such preparations were unsuccessful; the displacement of the second halide ion from *ortho*-xylylene dibromide and of the third halide ion from 1,3,5-tris(bromomethyl)benzene could not be achieved. The former failure is almost certainly a result of steric hindrance to the second displacement reaction, and the latter is probably because of a combination of the insolubility of the intermediate 5-bromomethyl-1,3-xylylenedicobaloxime (X), and steric hindrance. Two of the dicobaloximes, (IV) and (IX), though clearly of the structure indicated in the formulae, as shown by the ^1H n.m.r. spectra and the products of their reaction with iodine, repeatedly gave variable analyses in which the C : H : N ratio was correct but the absolute values were low.

Reaction of the Benzylcobaloximes with Halogens.—Each of the benzylcobaloximes was treated with various proportions of chlorine, bromine, or iodine in acetic

1 mol. of 3,5-dimethylbenzylcobaloxime was identified as a mixture of 3,5-dimethyl-4-chloro- and 3,5-dimethyl-2-chloro-benzylcobaloxime from the ^1H n.m.r. spectra, by halogen analysis, and by conversion with an excess of bromine into the corresponding mixture of 3,5-dimethylchlorobenzyl bromides, which were identified by mass spectrometry and ^1H n.m.r. spectroscopy. The organometallic products identified are shown in Table 2, together with the yields quoted as a percentage of the organometallic material isolated, and with footnotes as to the method(s) used in their identification. The ^1H n.m.r. spectra of the products are shown in Table 3.

Similarly, the organic products, which have almost all been prepared previously, were not separated, but the composition of the mixtures was determined by ^1H n.m.r. and mass spectrometry. The organic products identified are shown in Table 2 and their ^1H n.m.r. spectra in Table 3. In all cases the overall recovery of organometallic and organic products was good

(70—90%) and any loss of material does not significantly affect the conclusions reached.

Semiquantitative comparisons of rates of reaction of the substrates with bromine and of selected aromatic compounds with bromine were made in two ways. Either the reactions were carried out separately under comparable conditions and the extent of reaction was measured in each case, or competition reactions were carried out using 1 mol. of halogen with 1 mol. of benzylcobaloxime and 1 mol. of standard substance.

[7] P. B. D. de la Mare and J. H. Ridd, 'Aromatic Substitution; Nitration and Halogenation,' Butterworths, London, 1959.

DISCUSSION

The reaction of halogens with aromatic compounds has been studied in considerable detail.[7] In general, chlorine is more reactive than bromine and iodine is relatively unreactive. Thus, whilst most aromatic compounds may be halogenated by molecular chlorine and molecular bromine, there is no clear cut case of iodination by molecular iodine. Much of the information about the mechanism of these reactions has come from broad comparisons of reactivity and from product studies, despite the fact that the order of reaction with respect to halogen is frequently greater than unity,

TABLE 2

Products of reaction of halogens with benzylcobaloximes (*ca.* 1·5 g.) in acetic acid (*ca.* 40 ml.) under nitrogen

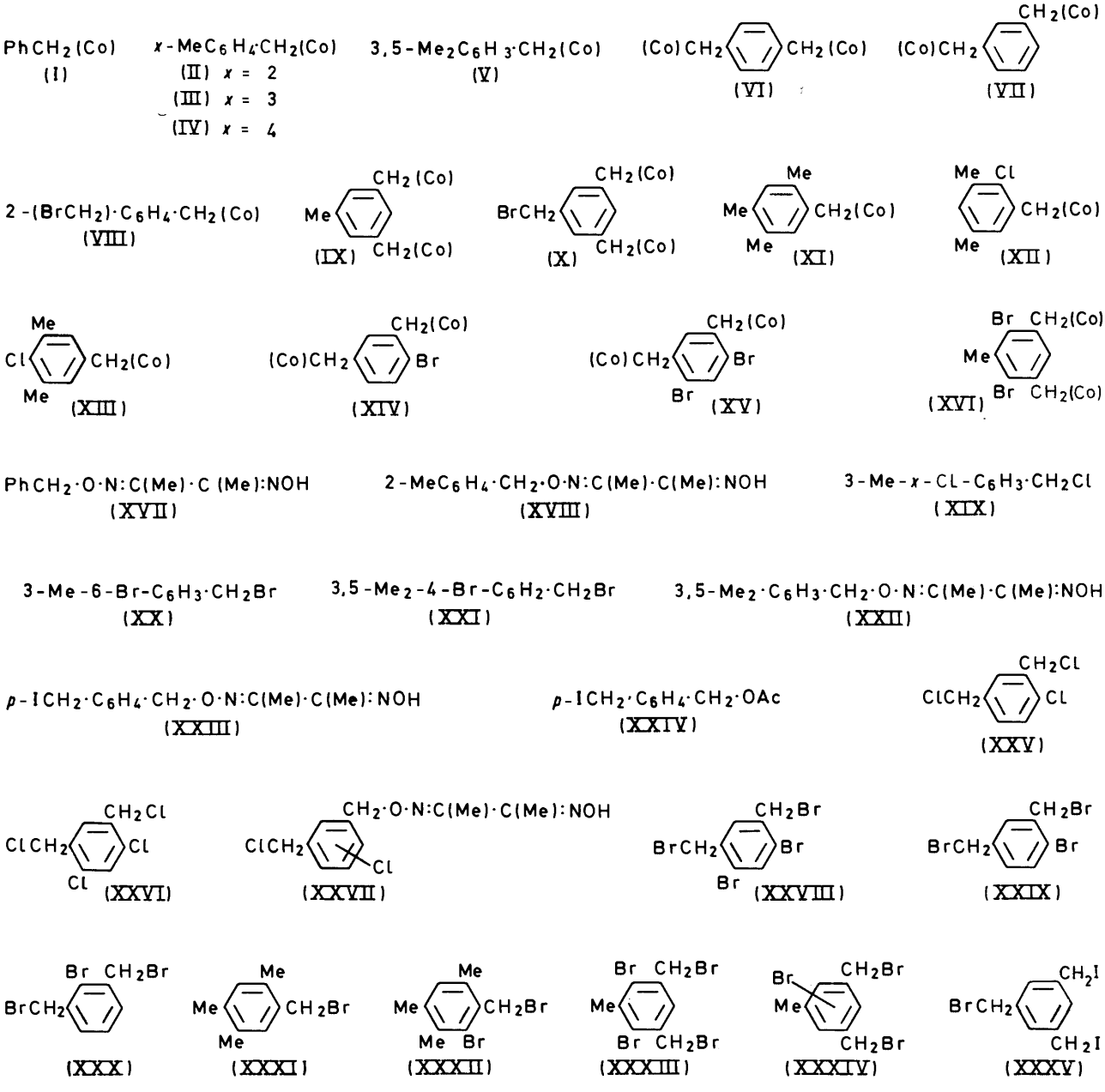


TABLE 2 (*Continued*)

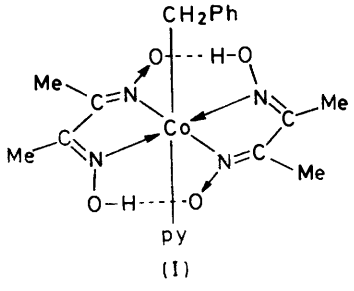
Substrate	Halogen (mole)	Organometallic product [a]	Organic product [b]
(I)	Cl_2 (1)	None	$PhCH_2Cl$ (62%) [c] (XVII) (38%) [c-e]
	Br_2 (1)	None	$PhCH_2Br$ (≥90%) [c] (XVII) (≤1%) [c,d]
	I_2 (1)	None	$PhCH_2I$ (≥90%) (XVII) (≤1%) [c,d]
(II)	Cl_2 (2)	None	2-MeC_6H_4·CH_2Cl (70%) [c] (XVIII) (30%) [c-e]
	Br_2 (2)	None	2-MeC_6H_4·CH_2Br (≥90%) [c]
	I_2 (2)	None	2-MeC_6H_4·CH_2I (70%) [c] (XVIII) (30%) [c,d]
(III)	Cl_2 (2)	None	(XIX) (75%) [c,d,f] 3-MeC_6H_4·CH_2Cl (25%) [c]
	Br_2 (2)	None	(XX) (50%) [c,d] 3-MeC_6H_4·CH_2Br (50%) [c]
	I_2 (2)	None	3-MeC_6H_4·CH_2I (≥90%) [c]
(IV)	Br_2 (2)	None	4-MeC_6H_4·CH_2Br (≥90%) [c]
	I_2 (2)	None	4-MeC_6H_4·CH_2I (≥90%) [c]
(V)	Cl_2 (1)	(XIII) (60%) [c,g,h] (XII) (40%) [c,g,h]	Traces only
	Br_2 (2)	None	(XXI) (≥90%) [c,d,g]
	I_2 (2)	None	3,5-$Me_2C_6H_3$·CH_2I (≥90%) [c,d] (XXIII) (Trace) [f,e]
(VI)	Cl_2 (3)	None	*p*-Xylylene dichloride (≥90%) [c]
	Br_2 (3)	None	*p*-Xylylene dibromide (≥90%)
	I_2 (3)	None	*p*-Xylylene di-iodide (≥70%) [c] (XXIII) (15%) [c,d] (XXIV) (15%) [c,d]
(VII)	Cl_2 (4)	None	(XXV) (80%) [c,d] (XXVI) (10%) [c,d] (XXVII) (Trace) [c,d,f]
	Br_2 (3)	(XIV) (70%) [c] (XV) (*ca.* 10%) [c]	None
	Br_2 (3)	None	(XXVIII) (50%) [c,d] (XXIX) (50%) [c,d] (XXX) (Trace) [c,d]
(XI)	Br_2 (2)	None	(XXXI) (≥90%) [c] (XXXII) (Trace) [c,f]
(IX)	Br_2 (1)	(XVI) (70%) [c,g,i,j]	None
	Br_2 (4)	None	(XXXIII) (≥70%) [c,d] (XXXIV) (≤30%) [c,f]
(X)	I_2 (2)	None	(XXXV) (≥90%) [c,d]

[a] Percentage of organometallic material isolated. [b] Percentage of organic material isolated. [c] Identified from ^1H n.m.r. spectrum. [d] Identified from mass spectrum. [e] Identified by C, H, N analysis after purification (D. H. Ballard and M. D. Johnson, unpublished work). [f] Mixture of isomers. [g] Identified by halogen analysis. [h] Identified by reaction with bromine, see text. [i] Identified by reaction with iodine, see text. [j] Low overall yield.

particularly in the case of reactions of bromine in acetic acid. Only at low bromine concentrations, in acetic acid, are these substitutions first order in the halogen. Therefore, the reactions described in this work were all carried out by the slow addition of the bromine solution to the benzylcobaloxime solution in order to keep the bromine concentration as low as possible. Under these conditions reactions of higher order in bromine should be negligible and the comparison between substitution and carbon–cobalt bond cleavage should be more meaningful. When the reactions are carried out with higher concentrations of bromine than are used here, other products may well be obtained.

In contrast, though many metal to saturated carbon bonds are known to be susceptible to cleavage by halogens, much less is known about the mechanism of these reactions. The order $Br_2 > I_2$ has been established for the cleavage of carbon–tin [8] and carbon–mercury [9] bonds and for other carbon to non-transition-metal bonds, but only qualitative information is available about the cleavage of carbon to transition-metal bonds. For example, a number of organotransition-metal compounds have been characterised by cleavage of the carbon–metal bond with iodine.

The benzylcobaloximes [*e.g.* (I)] therefore provide an interesting system in which to compare the electrophilic substitution in the ring with the cleavage of the carbon–cobalt bond. It is not the purpose of this work to



(I)

determine the mechanism of the cleavage of the carbon–cobalt bond by the halogens. However, as this cleavage would be expected to be very fast with benzylcobaloxime

[8] M. Gielen and J. Nasielski, *Bull. Soc. chem. belges*, 1962, **71**, 601.

[9] I. P. Beletskaya, T. A. Azizyan, and O. A. Reutov, *Izvest. Akad. Nauk, S.S.S.R., Otdel. khim. Nauk*, 1963, 1332.

TABLE 3

^{1}H N.m.r. spectrum [a] of reaction products

Compound	Aromatic protons	$-CH_2X$	CH_3 (aromatic)	CH_3 (other)
(*a*) Organometallic products ($CDCl_3$) X = (Co)				
(XII)	H_2 3·3; H_4 3·15	7·15	7·75, 7·82	8·05 [b]
(XIII)	H_2 3·23; H_6 3·23	7·24	7·68	8·05 [b]
(XIV)	H_2 3·74; [c] H_5 3·12; [d] H_6 3·34	7·16		7·98 [b]
(XV)	H_2 3·62; H_5 obscured	7·34		8·07 [b]
(XVI)	H_2 3·66	7·40	7·60	8·00 [b]
(*b*) Organic products (CCl_4). (i) No halogen in aromatic ring: X = halogen				
$PhCH_2Cl$	2·77	5·53		
$PhCH_2Br$	2·72	5·59		
$PhCH_2I$	2·76—2·96	5·79		
$2\text{-}MeC_6H_4\cdot CH_2Cl$	2·74	5·36	7·56	
$2\text{-}MeC_6H_4\cdot CH_2Br$	2·83	5·57	7·63	
$2\text{-}MeC_6H_4\cdot CH_2I$	2·75—3·00	5·64	7·71	
$3\text{-}MeC_6H_4\cdot CH_2Cl$	2·86	5·56	7·64	
$3\text{-}MeC_6H_4\cdot CH_2Br$	2·92	5·72	7·76	
$3\text{-}MeC_6H_4\cdot CH_2I$	2·90—3·00	5·69	7·73	
$4\text{-}MeC_6H_4\cdot CH_2Br$	2·75, 2·89	5·59	7·68	
$4\text{-}MeC_6H_4\cdot CH_2I$	2·78, 2·96	5·63	7·73	
$3,5\text{-}Me_2C_6H_3\cdot CH_2I$	H_2 2·98; H_4 3·10; H_6 2·98	5·60	7·72	
$p\text{-}C_6H_4(CH_2Cl)_2$	2·66	5·50		
$p\text{-}C_6H_4(CH_2Br)_2$	2·50	5·56		
$p\text{-}C_6H_4(CH_2I)_2$	2·69	5·57		
(XXIV)	*ca.* 2·69	4·96		
		5·61 [e]		8·01
(XXXV)	2·74	5·67 [e]		
		5·57		
(XXXI)	H_3 3·11; H_6 2·99	5·60	7·70	
Organic products (CCl_4). (ii) Containing halogen in the aromatic ring; X = halogen				
(XIX)	2·86	5·53	7·64	
(XX)	H_2 2·90; H_4 3·01; [g] H_5 2·59	5·65	7·71	
(XXI)	H_2 2·91; H_5 2·91	5·69	7·60	
(XXV)	2·45—2·8	5·36, 5·50		
(XXVI)	2·45—2·8	5·48		
(XXVIII)	H_2 2·60; H_5 2·34	5·65		
(XXIX)	H_2 2·66; H_5 2·57; H_6 2·97	5·36, 5·50		
(XXXII)	2·9—3·2	5·60	7·7—7·9	
(XXXIII)	2·52	5·40	7·31	
(XXXIV) [j]	*ca.* 2·7	5·40, 5·55	7·60, 7·58	
Organic products (CCl_4). (iii) Ethers of dimethylglyoxime; X = $-O\cdot N{:}C(Me)\cdot C(Me){:}NOH$				
(XVII)	2·77	4·90		8·05 [h]
(XVIII)	2·85	4·83	7·67	7·99 [h]
(XXII)	*ca.* 2·91	4·87	7·72	7·96 [h]
(XXIII)	*ca.* 2·69	4·86, 5·61 [e]		7·99 [h]
(XXVII)	2·4—2·75	4·86, 5·48 [i]		7·99 [h]

[a] τ-Values. [b] Dimethylglyoxime methyl resonance. [c] $J_{2,6}$ = 2·4 Hz. [d] $J_{5,6}$ = 8·2 Hz. [e] X = I. [f] X = Acetoxy. [g] $J_{4,5}$ = *ca.* 8 Hz. [h] $-O\cdot N{:}C(Me)\cdot C(Me){:}NOH$. [i] X = Cl. [j] More than one product is represented by (XXXIV).

and its derivatives, we would only expect to observe ring substitution if the metal-containing substituent is strongly activating with respect to electrophilic attack.

Our initial studies on benzylcobaloxime showed that cleavage of the carbon–cobalt bond was indeed rapid with molecular chlorine, bromine, and iodine, and the formation of the benzyl halide as the major product in each case was not totally unexpected. However, as ring substitution could not be detected it is apparent that the activating influence of the group $-CH_2Co(dmgH)_2py$ * is insufficient on its own to overcome the high rate of side-chain cleavage.

The side reaction involving the formation of the monobenzyl ether of dimethylglyoxime is novel and is the subject of a separate study to be reported later.

Since bromination and chlorination are among those reactions whose rates are most susceptible to the nature and number of substituents in the benzene ring,[10] the tendency to ring substitution should increase markedly as the number of activating substituents increases. Therefore, it seemed possible that ring substitution might be observed if the metal-containing group were supplemented by other activating substituents such as methyl groups.

In fact, neither *ortho*- nor *para*-methyl groups influence the course of the reaction appreciably, except in so far as the proportion of the monobenzyl ether of dimethylglyoxime is affected. In contrast, the presence of a single *meta*-methyl group [as in (III)] causes an appreciable change towards ring substitution in the reactions with both bromine and chlorine. For example, in the reaction of 3-methylbenzylcobaloxime (III) with an excess of chlorine, some 75% of the reaction involves an initial attack of halogen on the ring followed by carbon–cobalt bond cleavage, and some 25% of the reaction involves direct carbon–cobalt bond cleavage without prior ring substitution. Under comparable conditions, 3-methylbenzyl chloride is inert to substitution by chlorine. Owing to the compact character of the aromatic proton resonances of the products, the position of substitution by chlorine in the ring is not clear, but in the corresponding reaction with bromine, the major product, as indicated by the ^{1}H n.m.r. spectrum, is that with bromine in the 6-position, *ortho*- to the organometallic group and *para*- to the methyl group. In the corresponding reaction of 3-methylbenzylcobaloxime with iodine, no substitution products were apparent.

The introduction of a second *meta*-methyl group changes the course of the reactions with chlorine and with bromine still further towards substitution. Carbon–cobalt bond cleavage of 3,5-dimethylbenzylcobaloxime (V) is only observed in the presence of an excess of halogen after ring substitution has occurred once.

* Some dissociation of the pyridine from the cobalt is known to occur in acetic acid solution and the effects described are in part due to the substituent $-CH_2Co(dmgH)_2$.solvent. Such a change is unlikely to have a major effect on the character of the substituent.

[10] L. M. Stock and H. C. Brown, *Adv. Phys. Org. Chem.*, 1963, **1**, 35.

Thus, with 1 mol. of chlorine a mixture of chlorinated benzylcobaloximes [(XII) and (XIII)] is obtained; the predominant isomer as indicated by the ^1H n.m.r. spectrum is 3,5-dimethyl-4-chlorobenzylcobaloxime. In the comparable reaction with bromine, substitution occurs almost exclusively in the 4-position. It was confirmed that, within the time of these reactions, 3,5-dimethylbenzyl halides do not undergo substitution under comparable conditions. The reaction of 3,5-dimethylbenzylcobaloxime with iodine led to exclusive cleavage of the carbon–cobalt bond.

The competitive bromination of 3,5-dimethylbenzylcobaloxime in the presence of an equivalent amount of mesitylene led exclusively to the brominated 3,5-dimethylbenzylcobaloximes observed above, which indicates that the group $-CH_2Co(dmgH)_2py$ is more activating than the methyl group. The competitive bromination of 3,5-dimethylanisole and 3,5-dimethylbenzylcobaloxime gave almost equal proportions of the brominated derivatives of each substrate. However, this gives no more than an indication that both the methoxy-group and the organometallic group are strongly activating; when the rates of two competing reactions are within several orders of magnitude of the encounter rate, equal proportions of the two products are to be expected, irrespective of the absolute rates of reaction of each species.

Surprisingly, the introduction of a second organocobaloxime group into the *para*-position of benzylcobaloxime does not lead to observable ring substitution by either chlorine or bromine, only to carbon–cobalt bond cleavage with or without ether formation. However, when the second organocobaloxime group is introduced into the position *meta*- to the organometallic group of benzylcobaloxime, the ring substitution is enhanced so much that *two* halogen substitutions may take place in the ring before cleavage of the carbon–cobalt bond is achieved. Thus, in the reaction of the *meta*-xylylenedicobaloxime (VII) with an excess of chlorine, the main product is 1-chloro-2,4-bis(chloromethyl)benzene (XXV) together with an appreciable amount of 1,5-dichloro-2,4-bis(chloromethyl)benzene (XXVI). Little substitution occurs at the position between the two organometallic groups.

Similarly, the bromination of the *meta*-xylylenedicobaloxime with 1 mol. of bromine gives rise to predominantly the monobrominated dicobaloxime (XIV) together with some of the symmetrical dibrominated dicobaloxime (XV). In the presence of an excess of bromine, the mono- and di-brominated products (XXVIII) and (XXIX) were formed in almost equal amounts. Small variations in the yields of these two products were evident when the reaction was carried out under slightly different conditions. We ascribe this to two main factors: (i) the aromatic ring is relatively inert to reaction with halogen atoms which may be formed in low concentration, whereas the carbon–metal bond cleavage is apparently highly susceptible to the presence of free radicals. Any homolysis of bromine would therefore lead to diminished amounts of the desired ring substitution products. (ii) As the reaction of the *meta*-dicobaloxime is very fast and may approach the encounter rate, the exact proportions of mono- and di-substituted products will depend upon the mode of addition of the halogen to the cobaloxime. It is also possible that the reactions of higher order in bromine may intrude to some extent, making the rate of bromine addition to these more reactive substrates more critical.

Clearly, the organometallic substituent is very selective in its activation of the substitution. That two such groups in mutually *para*-positions should give quite a different result from that when the same two groups are in mutually *meta*-positions indicates that their effect is largely conjugative in origin,[11] especially as the preferred position of substitution is apparently exclusively *para*- to one group and *ortho*- to the other. Had the substituent effect been substantially inductive in character, then appreciable substitution would have occurred in the *para*-dicobaloxime (VI).

It is possible that the competitive cleavage of the carbon–cobalt bond is also influenced by the second organometallic substituent. For example, it is possible that the organometallic group in the *para*-position of (VI) enhances the cleavage of the other carbon–cobalt bond more than it does in the *meta*-position of (VII). However, it is generally found that the influence of conjugatively electron-donating substituents on ring substitution reactions is markedly greater than their influence on side-chain reactions, as shown by the much greater negative values of the Brown σ^+-constants than the Hammett σ-constants [12] for such substituents, and by the generally larger values of ρ for substitution reactions. The dominance of carbon–cobalt bond cleavage in the *para*-xylylenedicobaloxime is therefore unlikely to be due to the substituent effect of one cobaloxime group on the other.

The presence of two organocobaloxime groups and one methyl group in positions mutually *meta* to one another would therefore be expected to enhance ring substitution still further. Indeed, with an excess of bromine, the substrate (IX) is readily substituted and the dibrominated product (XXXIII) predominates. With three methyl groups and one organometallic group as in (XI), steric hindrance to substitution would be expected and little substitution is apparent at the one position activated by the single organometallic group.

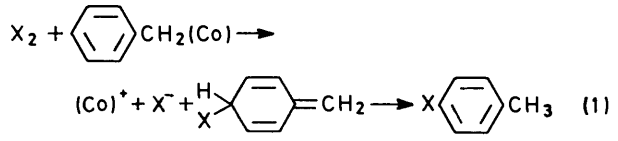
We also investigated the possibility that substituted toluenes might be formed if the attack of the halogen on the ring were to result in a concerted cleavage [13] of the carbon–cobalt bond as in equation (1). However, no toluenes could be detected in any of the products obtained in this work. Similarly, as the *para*-xylylene-

[11] C. K. Ingold, 'Structure and Mechanism in Organic Chemistry,' Cornell University Press, 1969, p. 311.

[12] H. C. Brown and Y. Okamoto, *J. Amer. Chem. Soc.*, 1958, **80**, 4979.

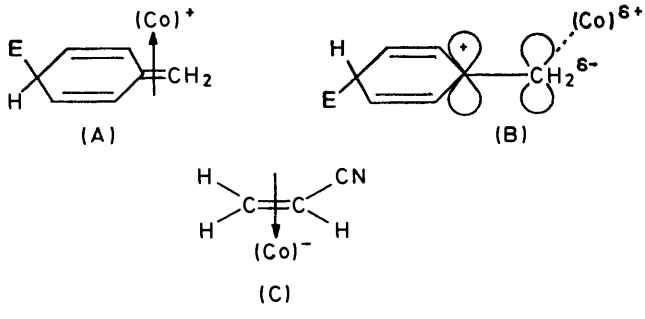
[13] G. Bundel, V. I. Rozenberg, A. L. Kurts, N. D. Antonova, and O. A. Reutov, *J. Organometallic Chem.*, 1969, **18**, 209.

dicobaloximes are relatively stable in acetic acid, the formation of the *para*-xylylene dihalides is not a result of an uncatalysed decomposition followed by capture of an intermediate by halogen.



The strong electron-donating character of the organometallic group is in accord with our observations concerning other transition metal groups such as $-CH_2Fe(CO)_2(\pi\text{-}C_5H_5)$, $-CH_2Mn(CO)_5$, *etc.* The present results do not enable us to determine the exact nature of the electron donation, which may involve π-complex formation as in (A) or σ–π-overlap (vertical stabilisation) as in (B). The former requires the metal-containing group to be in different positions, relative to the ring, in the initial and transition states, whereas the latter has the cobalt atom with its appendant ligands in essentially the same position relative to the benzyl group in the initial and transition states. Precedent for the former comes from the observation of cobaloxime olefin π-complexes [*e.g.* (C)] as intermediates in the addition of cobaloxime(I) species to olefins.[14] However, the formation of such π-complexes with cobalt(III) is less likely than with cobalt(I). The precedent for vertical stabilisation comes from organotin and organosilicon chemistry.[3-5] For those reactions which approach the encounter rate, the activation energy must be low and hence the transition state must closely resemble the initial state. Under these conditions, the σ–π-overlap stabilisation is much more appropriate than π-complex formation.

Further support for the conjugative character of the $-CH_2Co(dmgH)_2py$ group comes from the chemical shifts of the aromatic protons of the various benzylcobaloximes. The τ-values of aromatic protons have been



related to the influence of substituents on the π-electron density at each position of the ring. Whilst some attempts have been made to correlate such chemical shifts with the Hammett σ-constants,[15] these correlations are not generally very satisfactory because of the several different factors controlling chemical shifts. Similar attempts to correlate the present chemical shifts with the Hammett σ-constants for the methyl and organocobaloxime groups are also unsatisfactory, but do show up one interesting feature. With a single $-CH_2Co(dmgH)_2py$ group in the molecule, the chemical shift of the *ortho* and *para* protons is increased relative to benzene by some 0·23 p.p.m. When two such groups are present in the molecule, the shift is *ca.* 0·4 p.p.m. per group. The former is slightly less than that observed when the methoxy-group is the substituent, but the latter is almost the same as that observed when methoxy- is the substituent (0·42 p.p.m. per methoxy-group).[16]

From these product studies it is possible to predict the outcome of a number of reactions of electrophiles with benzyl transition-metal compounds. The main factors to consider are (i) the inherent reactivity of the methylene carbon–metal bond towards the electrophile; (ii) the susceptibility of that reaction to substituents on the benzyl group; (iii) the reactivity of benzene towards the electrophile; and (iv) the susceptibility of the reaction of benzene to substituents, especially to the methylene–metal substituent. *Bromination and chlorination* which have been discussed above form one class of reactions. *Iodination and mercuration* are in a second class; the reactivity of the carbon–metal bond is sufficiently greater than that of the benzene ring, and the susceptibility of the latter to substituents is sufficiently small that ring substitution is not expected even in highly activated molecules. *Protonation* forms part of a third class; the proton is not particularly effective as a reagent in aromatic substitution, but it has a marked aversion to saturated carbon.[17] The aromatic substitution reaction is also rather susceptible to substituents ($\rho = ca. -8$)[18] and aromatic hydrogen exchange should therefore be observed in many benzylmetal compounds even in the absence of additional activating substituents. Where attack of an electrophile may also occur at sites other than the carbon–metal bond or the aromatic ring, then these predictions must necessarily require modification.

EXPERIMENTAL

4-Methylbenzylbromide (Koch–Light), 2-methylbenzyl chloride (Kodak), 1,4-xylylene dibromide (Aldrich) were commercial products used without further purification. The following compounds were prepared by the reaction of appropriate amounts of *N*-bromosuccinimide (in the presence of dibenzoyl peroxide) and *m*-xylene, mesitylene, or 1,2,4,5-tetramethylbenzene in carbon tetrachloride at 76°: 3-methylbenzyl bromide, 1,3-xylylene dibromide, 3,5-dimethylbenzyl bromide, 1,3-bis(bromomethyl)-5-methylbenzene, 1-bromomethyl-2,4,5-trimethylbenzene.[19]

[14] G. N. Schrauzer, J. H. Weber, and T. M. Beckham, *J. Amer. Chem. Soc.*, 1970, **92**, 7078.
[15] J. W. Emsley, J. Feeney, and L. H. Sutcliffe, 'High Resolution Nuclear Magnetic Resonance Spectroscopy,' Pergamon Press, London, 1966, Section 10.12.3.
[16] P. Dichl, *Helv. Chim. Acta*, 1961, **44**, 829.
[17] M. D. Johnson, *Rec. Chem. Progr.*, 1970, **31**, 143.
[18] Based on R. Baker and C. Eaborn, *J. Chem. Soc.*, 1961, 5077.
[19] W. H. Hunter and D. E. Edgar, *J. Amer. Chem. Soc.*, 1932, **54**, 2025.

1,3,5-Tris(bromomethyl)benzene [20,21] was prepared by the method of Reid and Königstein [22] by the two-stage reaction of *N*-bromosuccinimide with mesitylene.

^{1}H N.m.r. spectra were recorded on Perkin-Elmer R10 60 MHz and Varian HA/HR 100 MHz instruments. Mass spectra were recorded using G.E.C. MS 9 and 12 instruments.

Preparation of Cobaloximes.—All compounds were prepared by a similar method and the synthesis of benzylcobaloxime is a typical example. Cobalt chloride hexahydrate (11·8 g., 0·05 mole) was dissolved in methanol (185 ml.) containing dimethylglyoxime (11·6 g., 0·1 mole) under nitrogen. Sodium hydroxide (2 g., 0·1 mole) dissolved in water (20 ml.) was added dropwise followed by pyridine (4 g., 0·05 mole). After being stirred for 20 min. the mixture was cooled to 0°. Sodium hydroxide (2 g., 0·05 mole) in water (10 ml.) and sodium borohydride (0·5 g., 0·013 mole) dissolved in a minimum amount of water were added to it and the product was stirred until the deep blue colour of cobalt(I) was apparent. Benzyl bromide (8·5 g., 0·05 mole) was added dropwise and the mixture was stirred for 40 min. A bright orange precipitate appeared and the mixture was added to water (200 ml.) and the precipitate was filtered off, washed with water, and air dried. The crude product was recrystallised from chloroform–light petroleum (b.p. 40—60°) to give deep orange crystals of benzylcobaloxime (11 g., 4·•%). The yields of substituted benzylcobaloximes varied from 40 to 80%. In some cases recrystallisation was effected by dissolving the material in acetic acid and pouring the solution into water containing several equivalents of pyridine.

Reaction of Benzylcobaloximes with Halogens.—Two examples illustrate the procedures. (1) 4-Methylbenzylcobaloxime (1·57 g., 3·3 mmole) was dissolved in acetic acid (15 ml.) under nitrogen. A solution of bromine (1·1 g., 7 mmole) in acetic acid (10 ml.) was added dropwise to the stirred solution over 5 min. The mixture was stirred for a further 1·5 hr. and the green solid was filtered off. The filtrate was poured into water (50 ml.) and the organic product was extracted with light petroleum (b.p. $\leqslant$40°; 3 × 50 ml.). The extract was washed with sodium hydrogen carbonate solution, with sodium metabisulphite solution, and with water; it was then dried ($MgSO_4$). On removal of the solvent the product was shown to be almost pure 4-methylbenzylbromide by ^{1}H n.m.r. spectroscopy.

(2) A solution of chlorine (0·37 g., 5·2 mmole) in acetic acid (10 ml.) was added dropwise to a stirred solution of 3,5-dimethylbenzylcobaloxime (2·5 g., 5·0 mmole) under nitrogen. After 1·5 hr. a green precipitate (0·3 g.) was filtered off. The filtrate was poured into the water containing 5% pyridine and the bright orange precipitate (2·47 g.) was filtered off, washed with water, and dried in air. The ^{1}H n.m.r. spectrum indicated that the solid product was largely a chlorinated dimethylbenzylcobaloxime (Found: Cl, 5·6%. Calc. for $C_{22}H_{29}ClCoN_5O_4$: Cl, 6·8%). The primary aqueous layer was extracted with light petroleum. The extract was washed with sodium hydrogen carbonate solution, with sodium metabisulphite solution, and with water; it was then dried ($MgSO_4$). On evaporation of the solvent, only traces of 1-chloromethyl-3,5-dimethylbenzene remained.

Reaction of Halogenobenzylcobaloximes with Halogens.—The halogenobenzylcobaloximes isolated from the halogenation of benzylcobaloximes were treated with an excess of iodine in acetic acid. The solution was poured into water and the organic product was extracted with petroleum; it was worked up as described above. The products were identified by mass spectra and ^{1}H n.m.r. spectra (Table 2).

Competitive Bromination.—A solution of bromine (0·8 g., 5 mmole) in acetic acid (15 ml.) was added dropwise (0·5 hr.) to a stirred solution of 3,5-dimethylanisole (0·68 g., 5 mmole) and 3,5-dimethylbenzylcobaloxime (2·45, g. 5 mmole) in acetic acid (45 ml.) at room temperature under nitrogen in the dark. The solution was stirred for 2·25 hr. and then poured into water (100 ml.). The solid which precipitated was washed with 5% aqueous pyridine and dried *in vacuo* to give yellow brown crystals (0·25 g.) which were shown by ^{1}H n.m.r. to be a mixture of almost equal amounts of 2-bromo-3,5-dimethylbenzyl- and unchanged 3,5-dimethylbenzyl-cobaloxime (Found: Br, 6·10%. Calc. for $C_{44}H_{57}Co_2BrN_{10}O_8$: Br, 7·6%). The filtrate was extracted with petroleum (b.p. $<$40°) in the manner described above to give a yellow oil (0·39 g.) the ^{1}H n.m.r. spectrum of which indicated it to be a mixture of 3,5-dimethylanisole and *x*-bromo-3,5-dimethylanisole in 1 : 1 molar ratio. No perceptible bromination of mesitylene was apparent when the above bromination was carried out with mesitylene in place of 3,5-dimethylanisole.

[1/1678 *Received, September 13th,* 1971]

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