The association of tetraoxo[24]aneN$_8$ (**6**) with carboxylates and nucleotides was also investigated (see Table II). At neutral pH, **6** takes on two protons and then goes on to form 1:1 complexes **9** with the above anions. The association constants for these complexes are greater than each of those for the doubly protonated, propylene-bridged bisdioxo[16]aneN$_5$ (**4b**), indicating that **6** is a more suitable receptor than **3b**, especially for the nucleotide anions. In fact, Dreiding models suggest that the flexible nucleotide can easily be positioned so as to interact efficiently with diprotonated **6**, through its phosphate and adenine sites.

The bis(macromonocyclic polyamine) and the tetraamide-containing macrocyclic polyamine ligands presented in this study may serve as a new class of efficient receptor molecules. Variations in ring size, donor atom number, and substituent may provide a number of novel, versatile derivatives that could simultaneously expand our knowledge of biological anion transport.

Acknowledgment. We are grateful for financial support from the Ministry of Education, Science and Culture, Japan (Grant-in-Aid for Scientific Research on Priority Area of "Macromolecular Complexes", No. 63612511).

Registry No. **4a**, 113423-16-8; **4b**, 123963-00-8; **5a**, 113450-03-6; **5b**, 123963-01-9; **6**, 123963-02-0; AMP, 61-19-8; ATP, 56-65-5; HPO_4^{2-}, 14066-19-4; $[Fe(CN)_6]^{4-}$, 13408-63-4; $[Fe(CN)_6]^{3-}$, 13408-62-3; citrate^{3-}, 126-44-3; 2,2′-[1,8-(3,6-dioxaoctanediyl)]-bis(dimethyl malonate), 104883-36-5; 1,1-diamino-3,6,9-triazaundecane, 112-57-2; 2,2′-(1,3-propanediyl)bis(diethyl malonate), 82031-49-0; iminodiacetic acid diethyl ester, 6290-05-7; 1,5-diamino-3-azapentane, 111-40-0.

Nitration of Phenylboron Dichloride with Nitronium Tetrafluoroborate. Attempted Nitration of Iodobenzene Dichloride and Phenylphosphorus Dichloride[1a]

George A. Olah,* Mark Piteau,[1b] Khosrow Laali, Chandra B. Rao, and Omar Farooq

Donald P. and Katherine B. Loker Hydrocarbon Research Institute and Department of Chemistry, University of Southern California, Los Angeles, California 90089-1661

Received April 11, 1989

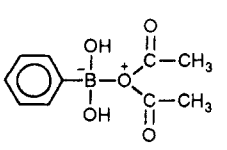
Electrophilic nitration of phenylboron dichloride with nitronium tetrafluoroborate and *N*-nitro-2,4,6-collidinium tetrafluoroborate was investigated in nitromethane solution. The reactions give 10–18% ortho, 67–69% meta, and 15–21% para isomer. NMR studies of the systems also show the formation of PhBFCl and $PhBF_2$ by fluoride exchange as well as their intermediate complexes with the BF_4^- anion. The high meta content is attributed to the nitration of uncomplexed phenylboron dihalides with the $-BX_2$ group exhibiting an –I effect which directs the nitration significantly to the meta position. High para isomer content was obtained when the phenylboron dihalides were mostly complexed by the BF_4^- anion, thereby reducing the –I effect of $-BX_2$ group. The nitration of iodobenzene dichloride gave essentially only nitroiodobenzenes due to the dissociation of $PhICl_2$ and the much faster nitration of PhI as compared to $PhICl_2$. Attempted nitration of $PhPCl_2$ with $NO_2^+BF_4^-$ in CH_3NO_2 led only to oxidation. The oxidation could not be prevented even when trimethyl phosphate was used as solvent or the milder nitrating agent $MeONO_2/BF_3$.

Introduction

Aromatic nitration reactions have been studied extensively with regard to their mechanism, directive effects of various substituents, and synthetic applications.[2] There is substantial interest in electrophilic nitration of organometallic compounds, and this area is comparatively less studied. We have been interested in the Friedel–Crafts chemistry of $PhBCl_2$ and $PhPCl_2$ and their electrophilic substitution as well as in determining the directive effects in these reactions. Combined with continued interest in aromatic nitration, we report here results of the nitration of $PhBCl_2$ and attempted nitration of $PhPCl_2$ with $NO_2^+BF_4^-$ and *N*-nitro-2,4,6-collidinium tetrafluoroborate. A related study of nitration of $PhICl_2$ was also carried out.

Nitration of Phenylboron Dichloride

Among nitrations of boron-substituted aromatics, only that of benzeneboronic acid has been studied. Ainley and Challenger[3] reported that nitration of $PhB(OH)_2$ with mixed acid at –20 °C gave 70% meta substitution, but with nitric acid in acetic anhydride 60% of the ortho isomer was formed. Harvey and Norman[4] reinvestigated these reactions and in agreement with the previous workers found predominant meta substitution in mixed acid (22% ortho, 73% meta, and 5% para) and predominant ortho substitution in HNO_3/acetic anhydride (63% ortho, 23% meta, and 14% para). Predominant meta substitution was attributed to the –K effect of $-B(OH)_2$, and predominant ortho substitution to an anionc complex formation with acetic anhydride, activating ortho:para positions due to the +I effect of boron anion.[4] Nitration in protic acids is



usually accompanied by some nitrodeboronation, and nitrobenzene is often detected in the product mixture. Analogous to $-B(OH)_2$, the presence of a $-BCl_2$ moiety is expected to direct the substitution to the meta position.

(1) (a) Aromatic Substitution. 57. For part 56, see: Olah, G. A.; Bach, T.; Prakash, G. K. S. *J. Am. Chem. Soc.*, submitted. (b) Visiting scientist from Société Nationale des Poudres et Explosifs LeBouchet, France.
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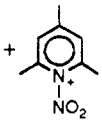
0022-3263/90/1955-0046$02.50/0

Table I. Nitration of $PhBCl_2$ in CH_3NO_2

reagent	reaction time, h	isomer distribution, % ortho	meta	para
$PhBCl_2 + NO_2^+BF_4^-$ (4:1)	4	18	67	15
(1:1)	4	13	69	18
 (4:1)	3	10	69	21
$PhBCl_2 + Me_4N^+BF_4^- + NO_2^+BF_4^-$ (4:4:1)	4	10	40	50
$PhBCl_2 + NaBF_4^- + NO_2^+BF_4^-$ (4:4:1)	4	7	80	13

Bromination of $PhBCl_2$ was briefly studied,[5] and the product was reported after hydrolysis to be *B,B,B*-tris(*m*-bromophenyl)boroxine.

We report now that $PhBCl_2$ can be nitrated with $NO_2^+BF_4^-$ or with *N*-nitro-2,4,6-collidinium tetrafluoroborate[6] in nitromethane solution. The reactions are relatively slow, and yields are only 10–20%. The nitrated products were reacted with $CuCl_2$ and analyzed as isomeric chloronitrobenzenes. Competing nitrodeboronation giving nitrobenzene was also observed.

Predominant meta nitration takes place with excess $PhBCl_2$ as well as by using a 1:1 molar ratio of $NO_2^+BF_4^-$:$PhBCl_2$ (Table I). In the latter case, however, the nitro products are those of PhBFCl and $PhBF_2$ due to fluoride exchange of $PhBCl_2$ in the system (vide infra). Substantially increased para substitution was observed only under those conditions where interaction of $-BF_4^-$ ion with $PhBX_2$ had resulted in formation of anionic borato complexes (vide infra).

^{11}B NMR Studies of $PhBCl_2/NO_2^+BF_4^-$ System

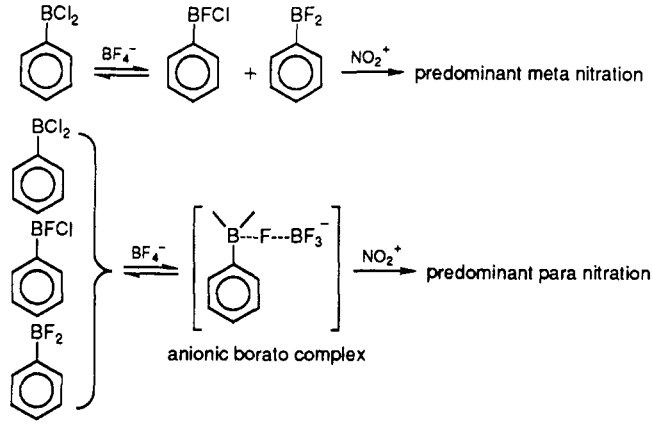
Prior to nitration of $PhBCl_2$ with $NO_2^+BF_4^-$, its behavior with BF_4^- anion derived from other salts was studied. ^{11}B NMR spectra of a 15% solution of $PhBCl_2$ in CH_3NO_2 showed a singlet absorption at δ ^{11}B 52.2 ($\Delta\nu_{1/2}$) 116 Hz). Addition of 0.25 equiv of $Me_4N^+BF_4^-$ through vortex mixing gave five new signals in the ^{11}B NMR spectra. The absorptions at δ ^{11}B 40.2 (d, 88 Hz) and 24.7 (t, 60 Hz) were due to PhBFCl and $PhBF_2$ as confirmed from the ^{11}B NMR spectra of the authentic compounds.[7,8] The NMR singlet absorptions at δ ^{11}B 2.7 ($\Delta\nu_{1/2}$ 40 Hz) and 6.4 ($\Delta\nu_{1/2}$ 58 Hz) were identified as due to the anionic borato complexes $PhBF_3^-$ and $PhBF_2Cl^-$ and that at δ ^{11}B 10.4 ($\Delta\nu_{1/2}$ 48 Hz) was assigned to the $PhBCl_2F^-$ complex. An increase in the ratio of $Me_4N^+BF_4^-$:$PhBCl_2$ resulted in an increase in signal intensities of borato complexes, $PhBX_2F^-$, especially that of $PhBF_3^-$, at the expense of all the phenylboron dihalides, particularly, that of $PhBCl_2$. At 1:1 molar ratio of $Me_4N^+BF_4^-$:$PhBCl_2$, (based on ^{11}B NMR spectra) ~ 30% $PhBF_2$ and 70% $PhBF_3^-$ borato complex were formed. Thus interaction of $PhBCl_2$ with BF_4^- results in (1) fluoride exchange giving PhBClF and $PhBF_2$ and (2) conversion of all the phenylboron dihalides, available in the system, into the corresponding anionic borato complexes, $PhBX_2F^-$ (X = Cl and/or F).

When 0.25 equiv of $NO_2^+BF_4^-$ was added to $PhBCl_2$ in nitromethane solution with vortex mixing, the same five boron signals corresponding to the five boron compounds discussed in the preceding paragraph were observed. The formation of the same five boron compounds in both the absence and presence of NO_2^+ ion shows that in situ nitration of the aromatic moiety in all the boron components does not affect the boron center to a significant enough degree to be reflected in a change in ^{11}B NMR chemical shifts of the nitrated products. In this experiment, based on ^{11}B NMR, about 62% $PhBCl_2$ together with about 10% PhBFCl and $PhBF_2$ were found to remain unreacted. In the isomer distribution of the obtained nitro compounds the high meta ratio is attributed to the nitration of the uncomplexed phenylboron dihalides in which the $-BX_2$ groups are, due to their –I effect, meta-directing. At 1:1 molar ratio of $NO_2^+BF_4^-$:$PhBCl_2$, no $PhBCl_2$ was found to remain unreacted and about 20% phenylboron dihalides consisting mainly of $PhBF_2$ remained uncomplexed. The high meta ratio in the nitrated product obtained by using the above ratio of reagents is again attributed to the nitration of these uncomplexed phenylboron dihalides.

When to the reaction mixture of 1:1 $Me_4N^+BF_4^-$:$PhBCl_2$ 0.25 equiv of $NO_2^+BF_4^-$ was added, the signals due to phenylboron dihalides (mainly $PhBF_2$) disappeared and a $PhBF_3^-$ complex was formed. Formation of this complex reduces the –I effect of $-BX_2$ group and therefore, nitration of this complex gives a high para isomer ratio compared to that of the uncomplexed phenylboron dihalides.

The fluoride exchange reaction of $PhBCl_2$ with $NaBF_4$ was also investigated. Owing to the low solubility of $NaBF_4$ in CH_3NO_2 use of 1:1 molar $NaBF_4$:$PhBCl_2$ (or even excess of $NaBF_4$) resulted only in 30% conversion of $PhBCl_2$ to fluorinated boron compounds. Nitration of this reaction mixture with 0.25 equiv of $NO_2^+BF_4^-$ gives again high meta isomer ratio attributable to the uncomplexed phenylboron dihalides (Scheme I).

Scheme I



Nitration of Iodobenzene Dichloride

It has been shown that iodobenzene dichloride and some of its substituted derivatives are in equilibrium with chlorine and the corresponding iodobenzene.[7]

On the basis of a kinetic study, the dissociation constant for this process was shown to be much smaller in CCl_4 than in CH_3NO_2.[9] The presence of an ortho nitro group was also shown to promote the dissociation by participation of the ortho NO_2 substituent as an internal nucleophile.[10] Accordingly, we studied the nitration of $PhICl_2$ in CCl_4 solvent using a short reaction time (1 h). The reaction was

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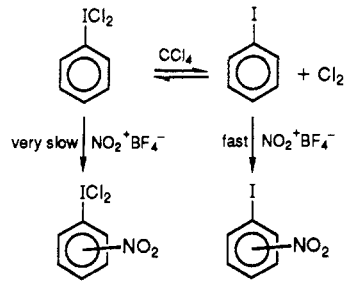
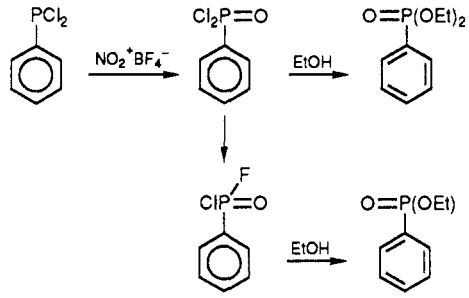
Scheme II



Scheme III



stopped by addition of benzene to the reaction mixture to remove unreacted $NO_2^+BF_4^-$. For GC analysis the $-ICl_2$ substituents were converted to iodo derivatives by addition of *p*-xylene to the reaction mixture, which reacts readily with Cl_2 and displaces the equilibrium completely to the right. GC analysis of the reaction mixture showed the presence of iodobenzene, *p*-xylene, nitrobenzene, chloro-*p*-xylene, and iodonitrobenzene isomers (Scheme II). The isomer distribution of iodonitrobenzene isomers was 36.5% ortho and 63.4% para (no meta isomer was detected). A comparison of the isomer distribution observed with that of nitration of iodobenzene with $NO_2^+BF_4^-$ in sulfolane solution[11] giving 36.3% ortho and 63.7% para isomer clearly indicates that the products arise by nitration of iodobenzene itself, since $NO_2^+BF_4^-$ reacts much faster with iodobenzene as compared to $PhICl_2$.

Attempted Nitration of Phenylphosphorous Dichloride

Directive effect of phosphorus containing groups in aromatic substitution is also of substantial interest. Protic and aprotic nitrations of *N*-arylphosphoramidates and phosphorthioamidates have been studied.[12] Previous work from our laboratory showed that triphenylphosphine is oxidized when treated with $NO_2^+BF_4^-$ in CH_2Cl_2 to triphenylphosphine oxide and C-nitration was not observed.[13]

In the present study we attempted to nitrate $PhPCl_2$ with $NO_2^+BF_4^-$ in dry CH_2Cl_2 solvent at room temperature. Again oxidation to dichlorophenylphosphorus oxide was observed. After treatment with EtOH two products were separated (GC) and identified (by ^1H NMR and GC MS) as $PhP(=O)(OEt)_2$ (60%) and $PhP(=O)(F)(OEt)$ (40%), the latter indicating chlorine to fluorine exchange (Scheme III).

In an attempt to avoid oxidation, nitration of $PhPCl_2$ was carried out in $(MeO)_3PO$ solvent. However, once again the ^{31}P NMR spectrum of the reaction mixture indicated oxidation to $PhPOCl_2$. Attempted nitration using the mild nitration agent $MeONO_2/BF_3$[14] in CH_3NO_2 solvent also led to oxidation. The ^{31}P NMR chemical shift of $PhPOCl_2$ is shielded (from that in the neat compound) by complexation with $NO_2^+BF_4^-$. In control experiments the equilibrium could be reversed by addition of excess $PhPOCl_2$. The ^{31}P NMR data are shown in Table II.

Table II. ^{31}P NMR Chemical Shifts[a] of the Nitration Reaction Mixtures and the Starting Substrates

compd	nitration agent	solvt	δ ^{31}P
$PhPCl_2$		$(MeO)_3P=O$	−162.3
$PhPOCl_2$		neat	−34.2
$PhPOCl_2$		BF_3/CH_3NO_2	−56[b]
$PhPCl_2$	$NO_2^+BF_4^-$	CH_2Cl_2	−50.3
$PhPCl_2$	$NO_2^+BF_4$	$(MeO)_3P=O$	−35.1
$PhPCl_2$	$MeONO_2/BF_3$	CH_3NO_2	−56

[a] From external phosphoric acid [b] Further addition of $PhPOCl_2$ to the reaction mixture shifted the signal to δ ^{31}P −46.1.

Experimental Section

$PhBCl_2$ (Alfa) was transferred under dry nitrogen from the sealed tube to a 25-mL brown bottle with a stopper that was protected by Teflon tape. The flask was flushed with nitrogen and kept in the dark under refrigeration. $PhICl_2$ was freshly prepared according to the literature[11] from PhI and Cl_2. $PhPCl_2$ and $PhPOCl_2$ were commercially available (both from Aldrich) samples of highest purity and were used as received. $Na^+BF_4^-$, $Me_4N^+BF_4^-$, and isomeric chloronitrobenzenes were available from Aldrich. $NO_2^+BF_4^-$ was freshly prepared by reaction of HNO_3 with HF/BF_3 in CH_2Cl_2 solvent.

Gas chromatographic analysis was carried out on a Varian GC (Model 3700) equipped with a quartz silica column (DB-1) and an automated integrator, and GC/MS analysis was performed on a Finnigan Mat Incos-50 instrument. ^{11}B and ^{31}P NMR studies were accomplished on a Varian FT-80 instrument using $BF_3{:}OEt_2$ and H_3PO_4 as external reference respectively.

Authentic $PhBF_2$ and PhBFCl were prepared according to literature procedures.[7,8]

General Procedure for Nitration of $PhBCl_2$. To $PhBCl_2$ (1 mmol) diluted in dry CH_3NO_2 (20 mL) was added under dry nitrogen $NO_2^+BF_4^-$ (1 mmol or 0.25 mmol) in CH_3NO_2 at 0 °C with efficient mixing. The reaction mixture was allowed to warm to room temperature. After 4 h it was quenched with water and extracted in CH_2Cl_2 separately, and the solvent was removed. To the reaction mixture was added an aqueous solution of cupric chloride, and the mixture was heated at 100 °C for 3 h. After cooling, the organic material was twice extracted with CH_2Cl_2, separated, and dried ($MgSO_4$), solvents were evaporated, and the residue was chromatographed. Elution with hexanes provided a mixture, containing among other products the isomeric chloronitrobenzenes, which was analyzed by GC MS. The nitrochlorobenzene isomers were identified by co-injection with authentic samples.

For nitration with *N*-nitro-2,4,6-collidinium salt, the salt was in situ generated by reacting collidine with $NO_2^+BF_4^-$ in CH_3NO_2 and was injected with efficient magnetic stirring into a solution of $PhBCl_2$ in CH_3NO_2 under nitrogen.

General Procedure for Nitration of $PhICl_2$. To a solution of $PhICl_2$ (0.7 g, 2.5 mmol) in $(MeO)_3PO$ (5 mL) was added dropwise at 20 °C a solution of $NO_2^+BF_4^-$ (0.35 g, 2.5 mmol) in $(MeO)_3PO$ with efficient magnetic stirring. After 1 h, unreacted $NO_2^+BF_4^-$ was removed by adding 5 mL of benzene to the reaction mixture. After a further 30 min, *p*-xylene (1 mL) was added to the reaction mixture at 50 °C over 30 min. The reaction mixture was then quenched in aqueous bicarbonate, extracted in ether, dried ($MgSO_4$), and concentrated on rotary evaporator prior to GC analysis.

Acknowledgment. Support of our work by the Office of Naval Research is gratefully acknowledged.

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