Substituent Effects in NHC–Boranes: Reactivity Switch in the Nucleophilic Fluorination of NHC–Boranes

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Abstract: Substituents on the boron atom of NHC–boranes direct the reactivity of the ligated boreniums obtained through hydride abstraction. Depending on the electronics of the substituent, the reaction is selectively steered toward either B-substitution or Lewis base exchange.

Key words: boron, carbene complexes, fluorine, cations, Lewis acids

Boreniums $[LBR_2]^+$ are tricoordinate boron cations formally obtained from complexation of the highly unstable borinium cations $[BR_2]^+$ and Lewis bases L. They are gaining increased attention because of their original structures and reactivities.[1]

N-Heterocyclic carbenes (NHC) have proved especially good at stabilizing the $[BR_2]^+$ moiety, including rarely observed structures, such as the dihydroxyborenium.[2] NHC–borenium cations have also been used to functionalize NHC–boranes with different nucleophiles,[3] and most recently they have been introduced as catalysts for main-group catalytic hydrogenation.[4]

Because of their promise, the elucidation of the factors governing how substituents at boron influence the ligated boreniums and/or electrophilic NHC–boranes is an important task. In the present paper we examine how aryl substituents in NHC–monofluoroboranes can selectively direct reactivity either toward bis-B-fluorination or toward Lewis base exchange.

We recently showed that *B*-aryl-substituted NHC–boryl radicals are delocalized.[5] If this were the case for NHC–boreniums as well, then this feature could be used to influence the reactivity at boron toward new boreniums or electrophilic NHC–boranes usable for hydrogenations.[6] We decided to probe this issue by studying a new method to make NHC–fluoroboranes from NHC–hydridoboranes. The current process is two steps (introduction of a leaving group and displacement) and is limited in scope (Scheme 1, a).[3]

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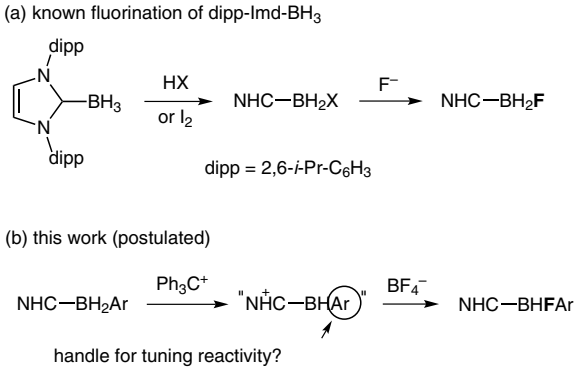
We hypothesized that boreniums would abstract a fluoride from the tetrafluoroborate ion (BF_4^-). In turn, we selected $Ph_3C^+ \cdot BF_4^-$ as reagent envisioning that the tritylium cation would serve for borenium generation (Scheme 1, b).[7] Fluoride transfer from BF_4^- would generate the neutral and highly Lewis acidic BF_3. To side-step the possible boron exchange at the NHC, we added phenol to trap the BF_3 generated.



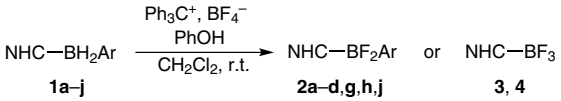
Scheme 1 General scheme for NHC–borane fluorinations

In a typical experiment,[8] triphenylcarbenium tetrafluoroborate[7a] (1 equiv) was added to NHC–borane **1a** in dichloromethane at room temperature, then phenol (1 equiv) was immediately added. After five minutes at room temperature, the solvent was evaporated in vacuo and the product was purified by flash chromatography. NHC–difluoroborane **2a** was isolated in 68% yield as the sole NHC-containing product of the reaction (Scheme 2 and Table 1, entry 1). Interestingly, the reaction did not stop after the first fluorination. A second fluorine was introduced on the boron, as shown by ^{19}F ($\delta = -153.2$ ppm), ^{11}B NMR analysis (broad singlet at $\delta = 4.8$ ppm), and mass spectrometry.

The difluorination was also observed with *B*-aryl IPr–boranes bearing electron-withdrawing groups on the aryl ring (Table 1, entries 2–4, IPr = 2,6-diisopropylphenyl imidazolydinene). On the contrary, aryl rings with electron-rich substituents or the electron-rich heteroaryl thio-

phene led to IPr–BF_3 **3** as the only product of the reaction (entries 5 and 6).

Difluorination was again observed with the less sterically demanding IMe–BH_2Ph (**1g**, IMe = 2,6-dimethyl imidazolydinene) as well as with the corresponding *B*-EWG-substituted aryl borane **1h** (Ar = *p*-trifluoromethylphenyl, Table 1, entry 8). Conversely, the BF_3 adduct **4** was isolated from the *p*-methoxy derivative **1i** (Table 1, entry 9).



Scheme 2 Fluorination of *B*-aryl NHC–boranes

Table 1 Fluorination of *B*-Aryl NHC–Boranes

Entry	Starting material	NHC	Ar	Product, yield (%)
1	**1a**	IPr	Ph	**2a** 68
2	**1b**	IPr	4-$MeO_2CC_6H_4$	**2b** 100
3	**1c**	IPr	4-$F_3CC_6H_4$	**2c** 83
4	**1d**	IPr	3-BrC_6H_4	**2d** 86
5	**1e**	IPr	4-$MeOC_6H_4$	**3** 80
6	**1f**	IPr	2-thiophenyl	**3** 59
7	**1g**	IMe	Ph	**2g** 51
8	**1h**	IMe	4-$F_3CC_6H_4$	**2h** 81
9	**1i**	IMe	4-$MeOC_6H_4$	**4** 80

A crystal of suitable for X-ray diffraction was obtained upon slow evaporation of a hexane solution of difluoroborane **2g**, and its structure was solved (Figure 1). The crystal structure confirmed the bisfluorination, as well as the presence of a tetrahedral boron atom.

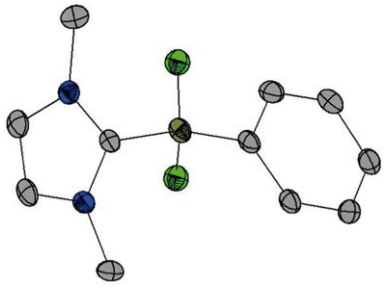
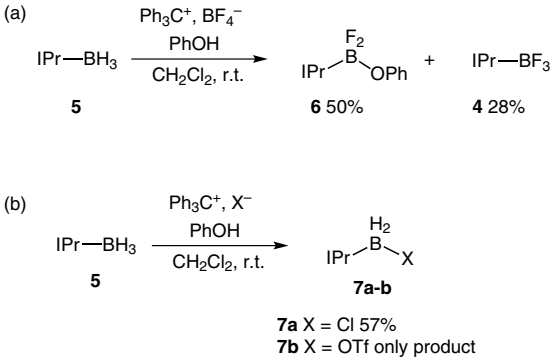


Figure 1 X-ray structure of compound **2g**

The results show that the reaction outcome is influenced by the nature of the substituent on the aryl group at boron, giving either NHC–BF_2Ar **2** or NHC–BF_3 **3** and **4** products exclusively.

The BF_3 adducts **3** and **4** could derive from NHC migration to the BF_3 formed during fluoride abstraction or from electrophilic deboration of the *B*-aryl group followed by perfluorination. In the cases where the NHC–BF_3 complexes **3** and **4** were isolated, we observed the formation of the boronic acids derived from the arylboranes (large singlets around δ = 30 ppm in ^{11}B NMR). This tends to favor the first hypothesis (boron exchange, see Scheme 4, b).

The unsubstituted IPr–BH_3 (**5**) cannot undergo deboration because it does not have an aryl group (Scheme 3). This delivered an approximately 1:2 mixture of IPr–BF_3 (**4**) and difluoroborane adduct **6** (78% overall yield), in which one molecule of phenol has been incorporated in the final complex (Scheme 2, a). Alternatively, with triphenylcarbeniums with counterions that do not release fluorine (Cl^-, TfO^-), monosubstituted chloro (**7a**, 57%), or trifluoromethanesulfonyl (**7b**) adducts were observed (Scheme 3, b). Compound **7a** was isolated, but not **7b** which is not stable to column chromatography.[2d,3]



Scheme 3 Reaction of the unsubstituted NHC–borane **5**

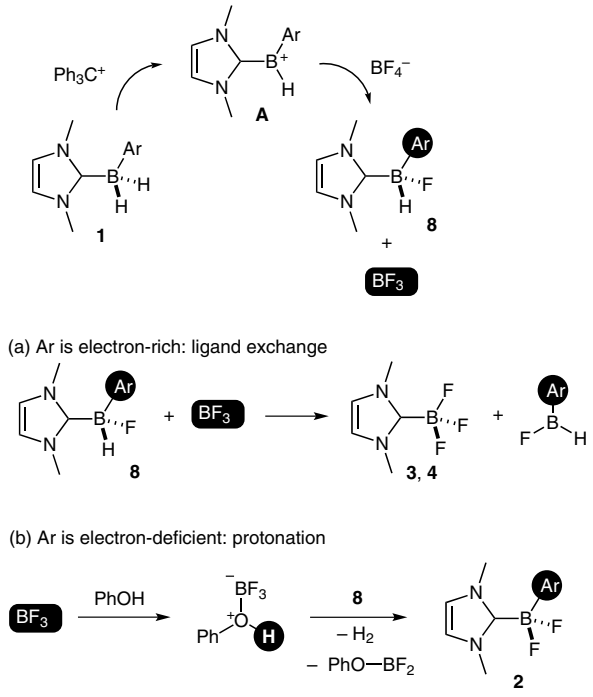
With these data, we propose the following mechanistic hypothesis to explain the reactivity pattern exhibited by the NHC–boranes in the borenium-mediated fluorination (Scheme 4).

Initial hydride abstraction from **1** or **5** by the triphenylcarbenium ion delivers boreniums such as **A**, which captures a fluoride to deliver NHC–monofluoroboranes like **8** and BF_3.

When the carbenium counterion is Cl^- or TfO^-, there is no byproduct of the nucleophilic addition to the borenium and the reaction delivers the corresponding NHC–BH_2–Nu derivatives (Scheme 3, b).

With the tetrafluoroborate salt, the reaction continues because of the BF_3 generated after the nucleophilic addition to the boreniums, and the products depend on the aryl group. When the aromatic group is electron-deficient, BF_3 is trapped by phenol quickly. However, this generates one equivalent of HF, which is the source of the second fluorination, through an acid–base reaction.[3] The yields in difluorinated compounds are generally high.

When the aryl is electron-rich, however, the Lewis basic carbene liberates BArHF and complexes the more Lewis



Scheme 4 Proposed mechanism

acidic BF_3. This certainly also reduces the steric strain in the case of the more sterically demanding IPr carbene.

When there is no substituent, as is the case with **5** (Scheme 3, a), the reaction paths compete as we isolated compounds from NHC exchange with both BF_3 and PhO–BF_2.

To conclude, we have expanded the understanding of NHC–borane and electronic borenium chemistries. The subtituents at boron provide a handle to steer the reactivity through electronic effects beside steric effects. This latter possibility has been demonstrated for fluorine introduction, but it also opens perspectives for controlling other borenium-based reactions, such hydroborations, electrophilic borylations, as well as catalytic hydrogenations.

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Supporting Information for this article is available online at http://www.thieme-connect.com/ejournals/toc/synlett.

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(8) **General Procedure**
To a solution of NHC–borane complex (1 equiv) in CH_2Cl_2 (0.07 M) was added the triphenylcarbenium derivative (1 equiv), then phenol (1 equiv). The reaction mixture was stirred at r.t. for 5 min. The solvent was then evaporated in vacuo, and the residue was purified by flash chromatography.
Typical Characterization Data for Compound 2a
Mp 222–227 °C. IR (diamond): ν = 2960, 2930, 2870, 2360 (B–F), 1460, 1260, 1060, 1015, 930, 800, 760, 735 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 7.50 (t, *J* = 7.8 Hz, 2 H, *p*-H of IPr), 7.28 (d, *J* = 7.8 Hz, 4 H, *m*-H of IPr), 7.04 (s, 2 H, NCH), 6.94 (t, *J* = 6.9 Hz, 1 H, *p*-H of Ph), 6.88 (t, *J* = 6.8 Hz, 2 H, *m*-H of Ph), 6.77 (d, *J* = 6.6 Hz, 2 H, *o*-H of Ph), 2.61–2.55 [m, 4 H, C*H*(CH_3)$_2$], 1.20 [d, *J* = 6.8 Hz, 12 H, CH(C*H*$_3$)$_2$], 1.13 [d, *J* = 6.8 Hz, 12 H, CH(C*H*$_3$)$_2$]. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 145.5 (C arom.), 134.2 (C arom.), 131.7 (CH arom.), 130.4 (CH arom.), 126.6 (CH arom.), 125.9 (CH arom.), 123.8 (NCH), 123.8 (CH arom.), 29.0 [*CH*(CH_3)$_2$], 25.9 (CH*CH*$_3$CH$_3$), 22.3 (CHCH$_3$*CH*$_3$). ^{11}B NMR (133 MHz, BF_3·OEt_2): δ = 4.8 (br s). ^{19}F NMR (376 MHz, $CFCl_3$): δ = –153.2 (br s). HRMS: *m/z* calcd. for $C_{33}H_{41}N_2{}^{11}BF_2Na$ $[M + Na]^+$: 537.3223; found: 537.3224.

