

BH₃·Me₂S: An Alternative Hydride Source for NiH-Catalyzed Reductive Migratory Hydroarylation and Hydroalkenylation of Alkenes

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Borane dimethylsulfide (BMS) was found to be an efficient hydride source for nickel-hydride catalyzed reductive migratory hydrofunctionalization reactions. Catalytic reductive migratory hydroarylation and migratory hydroalkenylation were achieved with BMS in high yields and with excellent regioselectivity. A large-scale experiment employing as little as 0.5 equivalents of BH₃·Me₂S as the hydride source delivered the desired migratory hydroarylation product in high yield and selectivity.

Starting from stable and easily available feedstock alkenes and electrophilic cross-coupling partners, metal-hydride^[1,2] catalyzed reductive (migratory) hydrofunctionalization has been reported recently to enable the synthesis of a range of structurally complex molecules under mild conditions.^[1–6] In these reactions, a stoichiometric amount of hydrosilane is commonly used as an efficient hydride source. For example, polymethylhydrosiloxane (PMHS), a byproduct of the silicone industry is useful in this context. Other silanes were shown to be optimal but are more expensive than PMHS and hydrosilanes such as (MeO)₃SiH and (EtO)₃SiH present a fire hazard.^[7] Nickel hydride has enabled a series of reductive migratory hydrofunctionalizations, including arylation, alkylation, amination, and thiolation along the hydrocarbon chain of alkenes (Figure 1a).^[6] Owing to the low molecular weight, fewer waste products, and low cost associated with borane (Figure 1b, 1 equivalent of BH₃ is associated with 3 equivalents of R₃Si–H), we recently questioned whether commercially available borane could be used as a mild, inexpensive and safe hydride source in NiH chemistry. Here we report the successful implementation of this possibility and describe the use of borane dimethylsulfide (BMS) as a hydride

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a NiH-catalyzed reductive migratory hydrofunctionalization





Figure 1. Borane dimethylsufide (BMS) as hydride source in nickel-hydride catalyzed reductive migratory hydrofunctionalization reactions. FG = functional group.

source in NiH-catalyzed reductive migratory hydroarylation and migratory hydroalkenylation (Figure 1b).

The feasibility of using borane dimethylsulfide (BMS) as hydride source was first examined with the migratory hydroarvlation of 4-phenyl-1-butene (1 a) with methyl 4-iodobenzoate (2a) (Table 1).^[6d] After extensive examination of the reaction parameters, the desired migratory hydroarylation product (3 a) was found to be produced in 91% isolated yield as a single benzylic isomer (>99:1 regioisomeric ratio) at -19° C (Table 1, entry 1). Other nickel catalysts such as NiCl₂·dmbpy (dmbpy= 6,6'-dimethyl-2,2'-bipyridine) led to a lower yield (entry 2). Reduction of the catalyst loading to 10 mol% also led to diminished yield (entry 3). Inferior results were achieved with other borane sources (entries 4-6). THF was found to be unsuitable as the solvent (entry 7). An inferior result was obtained when the reaction was conducted at 0°C (entry 8). Comparable results were obtained when 1 equiv. of the aryl iodide (2 a) was used (entry 9) or when 0.5 equiv. of $BH_3 \cdot Me_2S$ was used (entry 10), further highlighting the superiority of BH₃·Me₂S as the hydride source. Replacement of aryl iodide (2a) by the relatively less reactive aryl bromide led to diminished yield (entry 11). The reaction proceeded fast and was complete within 4 h (entry 12).

Under the optimal reaction conditions, a fairly broad scope of aryl iodides was suitable as coupling partners, delivering aryl (3b-3l) or heteroaryl (3m-3p) products (Table 2). Both electron-withdrawing (3b-3e, 3g) and electron-rich (3f, 3j-3l) aryl

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Table 1. Variation of reaction parameters.			
Ph 1a Entry	$\label{eq:constraint} \begin{array}{c} 12 \text{ mol}\% \text{ NiBr}_2 \text{ dmbpy} \\ 1.0 \text{ equiv } BH_3 Me_2 S \\ \hline 1.0 \text{ equiv LiOMe} \\ DMA (0.075 \text{ M}) \\ -19 \ ^\circ C, \ 12 \text{ h} \\ \end{array} \\ \begin{array}{c} \text{Vertication from standard conditions} \end{array}$	CO ₂ Me dml Ph 3a Yield [%] ^[a]	N N rr ^(b)
1	none	93 (91)	>99:1
2	NiCl ₂ ·dmbpy instead of NiBr ₂ ·dmbpy	70	99:1
3	10 mol% NiBr₂ dmbpy	73	98:2
4	BH ₂ ·N ['] Pr ₂ instead of BH ₃ ·Me ₂ S	80	>99:1
5	BH ₃ ·THF instead of BH ₃ ·Me ₂ S	28	99:1
6	HBpin instead of BH ₃ ·Me ₂ S	79	>99:1
7	THF instead of DMA	0	-
8	0°C	50	>99:1
9	1.0 equiv. 2 a	82	>99:1
10	0.5 equiv. BH₃·Me₂S	92	>99:1
11	aryl bromide used	45	>99:1
12	4 h	92	>99:1
[a] Yields determined by crude ¹ H NMR using 2,5-dimethylfuran as the			

[a] Yields determined by crude 'H NMR using 2,5-dimethylfuran as the internal standard. The yield in parentheses is the isolated yield. [b] Regioselectivity (rr) determined by GC and GCMS analysis. dmbpy=6,6'-dimethyl-2,2'-bipyridine.

iodides underwent migratory hydroarylation smoothly. A variety of functional groups were well-tolerated, including esters (**3b**), a nitrile (**3c**), ethers (**3f–3k**), and a Boc-protected amino (**3l**). Notably, both an easily reduced ketone (**3d**) and a boronic acid pinacol ester potentially used for further coupling (**3e**) were all left intact. In general, the substituents could be placed at *para*, *meta*, or *ortho* position (**3b–3p**). However, a moderate yield was obtained from an aryl iodide with an *ortho*-substituent (**3h**), presumably due for steric reasons. Heterocycles such as benzofuran (**3m**) and thiophene (**3n**, **3o**) were also shown to be competent coupling partners.

The coupling partners could include a variety of alkenyl bromides which produce the corresponding migratory hydroalkenylation products (**4a**–**4i**) smoothly.^[6aa,8] β -Aryl-conjugated (*E*)-alkenyl bromides with various substituents are suitable



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substrates (4a–4d). Good migratory coupling results were also observed for heterocycles such as furyl- and thienyl-conjugated alkenyl bromides (4f, 4g). Both β -alkyl-decorated alkenyl



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bromide (4h) and $\alpha\text{-alkyl}$ substituted alkenyl bromides (4i, 4e) were suitable substrates.

We next explored the scope of the alkenes (Table 3). Both terminal alkenes (5b-5f) and internal alkene (5g) underwent this migratory hydroarylation smoothly. The reaction is insensitive to the chain length between the C=C double bond and the aryl group ($5b \ vs \ 5c$). Both electron-donating (5d) and electron-withdrawing ($5e, \ 5f$) substituents on the remote aromatic ring were likewise suitable for this reaction, even when there was a substituent at the *ortho*-position (5f). A variety of styrenes were also shown to be competent substrates (5h-5p), regardless of the *E/Z* configuration. Notably, a structurally complex glucoside derivative (5n), as well as heterocyclic thiophene (5p), were all competent coupling partners.

The robustness of this reaction was further demonstrated by a gram-scale experiment that used a reduced amount of hydride source. As shown in Scheme 1, only 0.5 equivalent of borane dimethylsulfide (BMS) as hydride source proved to be sufficient for reaction performed on a 5 mmol scale.

In summary, we report that the low-cost borane dimethylsulfide (BMS) is an efficient hydride source for nickel-hydride catalyzed migratory hydrofunctionalization reactions. With this newly identified hydride source, migratory hydroarylation and migratory hydroalkenylation proceed with broad substrate scope under mild conditions. The application of borane dimeth-



Scheme 1. Gram-scale experiment with 0.5 equivalent borane dimethylsulfide (BMS).

ylsulfide (BMS) in other NiH-catalyzed reactions is currently in progress in our laboratory.

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Conflict of Interest

The authors declare no conflict of interest.

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[8] Due to the formation of styrene product with a more steric hindered secondary alkyl group at β -position, no further isomerization product or subsequent alkenylation product was obtained.

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