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METHYLBORANE - A REMARKABLE UNHINDERED MONOALKYLBORANE WHICH ACHIEVES THE CONTROLLED SEQUENTIAL HYDROBORATION OF REPRESENTATIVE ALKENES

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Abstract: Methylborane, $MeBH_2$, the simplest of the monoalkylboranes, possesses extraordinary hydroboration characteristics in tetrahydrofuran. In this solvent, methylborane is capable of monohydroborating the usual classes of alkenes, hindered and unhindered, to provide the simple alkylmethylboranes, RMeBH. The addition of a second equivalent of another alkene to the alkylmethylborane formed initially produces the sequential hydroboration product, RR'MeB. In all cases there is no evidence of redistributed products.

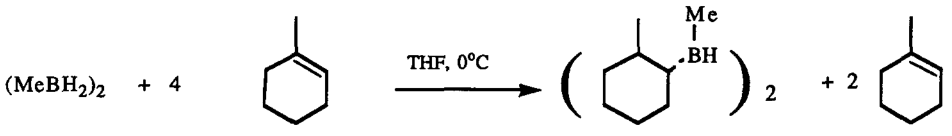
The discovery of hydroboration[1] has made a great number of symmetrical trialkylboranes readily available. These organoboranes are very versatile. It is possible to transfer the alkyl group from boron to virtually all elements of interest to organic chemistry, including carbon, to achieve the synthesis of essentially all compounds significant to organic chemistry.[2] However, symmetrical triorganylboranes have certain limitations. To overcome these problems, a number of routes have been developed for the preparation of organoboranes other than the simple trialkylboranes, R_3B.[3] As part of our efforts to prepare monoorganylboron and diorganylboron compounds which cannot be prepared by direct hydroboration,[4] we have recently prepared pure methylborane in high yield and purity from the corresponding lithium methylborohydride (eq 1).[5]

$$2\ LiMeBH_3 + 2\ HCl \longrightarrow (MeBH_2)_2 + 2\ H_2 + 2\ LiCl \qquad (1)$$

The reaction of methylborane, $MeBH_2$, in pentane or ethyl ether (EE) with two equivalents of various alkenes proceeds routinely to yield the corresponding dialkylmethylboranes (eq 2)[5].

$$(MeBH_2)_2 + 4\ \text{alkene} \xrightarrow[\text{pentane}]{\text{EE or}} 2\ R_2MeB \qquad (2)$$

However, $MeBH_2$, liberated in tetrahydrofuran, THF, behaves very differently. Thus the hydroboration of 1-methylcyclohexene in THF at 0°C stops at the first stage of hydroboration to yield clearly (*trans*-2-methylcyclohexyl)methylborane even in the presence of 100% excess 1-methylcyclohexene (eq 3).



(3)

The clean formation of the alkylmethylborane was totally unexpected and with only two exceptions without precedent in the reaction of monoalkylboranes with alkenes. Previously monohydroboration had been achieved only in the reaction of highly hindered hydroboration reagents, such as thexylborane ($ThxBH_2$)[6] and monoisopinocampheylborane ($IpcBH_2$)[7], with relatively hindered alkenes. The present report describes the result of our investigations to achieve the successful sequential hydroboration of all classes of alkenes with methylborane in THF.

The formation of the initial hydroboration product was studied by treating representative alkenes with methylborane in THF at 0°C. In most cases the hydroboration is complete within 5 min, essentially independant of the structure of the alkene (Table I).

Table I. Hydroboration in a 1:1 Molar Ratio of Representative Alkenes with $MeBH_2$ in THF[a]

			product distribution, %[b]		
alkene	time min.	temp °C	$MeBH_2$	RMeBH	R_2MeB
1-hexene	1	-25	5	95	0
styrene	20	0	5	95	0
2-methyl-1-pentene	1	-25	2	96	2
trans-4-methyl-2-pentene	5	0	2	98	0
2-methyl-2-butene	5	0	2	98	0
2,3-dimethyl-2-butene	10	0	2	98	0
cyclopentene	5	0	2	98	0
norbornene	5	-25	6	94	0
1-phenylcyclopentene	90	0	3	97	0
1-methylcyclohexene	5	0	5	95	0

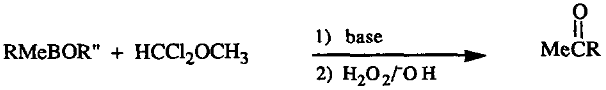
[a] 5-10% excess of alkene was used. [b] Analyzed by ^{11}B NMR of peak heights of methanolyzed products. [4,13]

The much slower hydroborating alkenes, styrene and phenylcyclopentene, require longer reaction times, 20 and 90 minutes respectively. In the case of the more reactive alkenes, reaction at 0°C leads to mixtures of mono- and dihydroboration products. However, selective monohydroboration can be achieved for 1-hexene and 2-methylpentene by lowering the reaction temperature to -25°C and decreasing the reaction time to 1 min. In contrast, hydroboration of 1-hexene by thexylborane, $ThxBH_2$, provides a mixture of mono- and dihydroborated products.[8]

These sterically nonhindered dialkylboranes can undergo relatively rapid disproportionation. However, treatment with methanol or 2-propanol gives the corresponding alkylmethylborinic esters, relatively stable toward redistribution (eq 4).

$$(RMeBH)_2 + 2\ R''OH \longrightarrow 2\ RMeBOR'' + 2\ H_2 \qquad (4)$$

The structure of these borinic esters was confirmed by mass spectroscopy and ^1H NMR or by conversion to the corresponding ketone via the DCME reaction,[9] followed by analysis utilizing gas chromatography (eq 5). These results are summarized in Table II.



$$RMeBOR'' + HCCl_2OCH_3 \xrightarrow[2)\ H_2O_2/^-OH]{1)\ base} MeCR \text{ (with O above C: } Me\overset{\overset{O}{\|}}{C}R) \qquad (5)$$

In all cases examined, we obtained cleanly either the borinic ester or the expected methyl ketone product in excellent yield. There was no indication of significant redistribution products.

The ability to control and stop the hydroboration at the first stage makes possible the addition of another alkene to the alkylmethylborane to give the desired mixed dialkylmethylborane in high purity (eq 6).

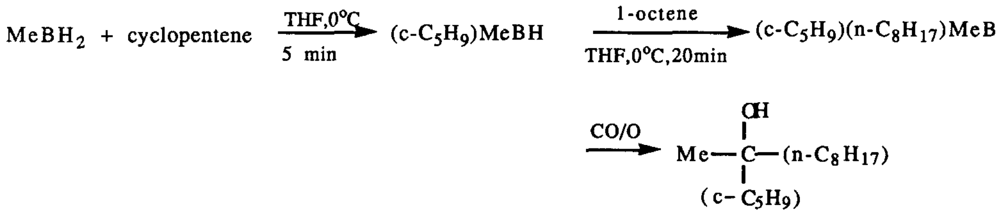
$$(RMeBH)_2 + 2\ \text{alkene} \longrightarrow 2\ RR'MeB \qquad (6)$$

Table II. Preparation of Methyl Ketones and *tertiary* Alcohols from the Organoboranes Produced by the Hydroboration of Various Alkenes with Methylborane in THF

alkene A	temp °C	time min	alkene B	temp °C	time min	^{11}B NMR[a,b]	methyl ketone[c] (%)[d]	tertiary alcohol[e],%[f]
1-hexene	-25	1				52.6	2-octanone (96)	
2-methyl-1-pentene	0					52.5[g]		
cyclopentene	0	5	1-octene	0	60	86.0		(±)-2-cyclopentyl 2-decanol, 71
norbornene	-25	5				51.4	(±)-2-exo-norbornyl methyl ketone (96)	
phenylcyclopentene	0	90				52.0	(±)-trans-2-phenylcyclopentyl methyl ketone (89)	
phenylcyclopentene	0	90	2-methyl-1-heptene	0	20	83.0		(±)-2-(trans-2-phenylcyclopentyl 1)-4-methyl-2-nonanol, 72
(+)-α-pinene	0	20				52.1	isopinocampheyl methyl ketone, (86)	

[a] In ppm relative to BF_3 etherate. [b] Borinic esters were obtained by quenching the reaction mixture with either methanol or isopropanol at the reaction temperature. [c] For preparation of methyl ketone see text. [d] GC yields were calculated in the presence of an internal standard. [e] Tertiary alcohols obtained after carbonylation-oxidation, see text. [f] Isolated yield after column chromatography. [g] Isolated as the isopropoxy ester. Yield: 75%, bp 86-88°C (25 mmHg); $n^{20}D$ 1.4048; mass spectrum (CI): m/e (%) 169 (M^+ + H).

For example, the hydroboration of cyclopentene with methylborane in THF at 0°C is complete within 5 minutes, forming cyclopentylmethylborane. The reaction of 1-octene with this dialkylborane is somewhat slower, requiring approximately 1h at 0°C, to yield the desired trialkylborane (^{11}B NMR δ + 86). The structure of this product was confirmed by carbonylation-oxidation[2a] of the trialkylborane to give a 71% isolated yield of pure product (eq 7).[10]



$$MeBH_2 + \text{cyclopentene} \xrightarrow[5\ \text{min}]{THF,0^\circ C} (c\text{-}C_5H_9)MeBH \xrightarrow[THF,0^\circ C,20min]{1\text{-octene}} (c\text{-}C_5H_9)(n\text{-}C_8H_{17})MeB \xrightarrow{CO/O} Me\text{—}\overset{OH}{\underset{(c\text{-}C_5H_9)}{C}}\text{—}(n\text{-}C_8H_{17}) \qquad (7)$$

The relative lack of sensitivity to the steric demands of the alkene in the initial hydroboration with methylborane in THF (Table I) indicates that the rate determining step must be a fast equilibrium formation of methylborane monomer, followed by a more rapid monohydroboration, similar to the behavior of 9-BBN in the hydroboration of reactive alkenes. On the other hand, the slowness of the second hydroboration must be attributed either to a slow formation of the RMeBH monomer, or to a relatively slow reaction of this monomer with alkenes, or to both (eq 8).[11]

$$(MeBH)_2 \xrightleftharpoons{\text{fast}} 2\ MeBH_2 \xrightarrow[\text{alkene}]{\text{very fast}} (RMeBH)_2 \xrightarrow[\text{alkene}]{\text{slow}} 2\ R_2MeB \qquad (8)$$

THF is critical in achieving controlled monohydroboration. Although in EE or THF the overall rate of hydroboration to the trialkylborane is essentially the same, in THF the alkylmethylborane is selectively formed from methylborane, while in EE, mono- and dihydroborated products are formed competitively.

Methylborane, the simplest of the monoalkylboranes, is the first example of a sterically unhindered monoalkylborane capable of stepwise hydroboration. In THF methylborane selectively monohydroborates all classes of alkenes, hindered and nonhindered, to yield the alkylmethylboranes. The addition of a second equivalent of another alkene to the alkylmethylborane gives a sequential hydroboration product, RR"MeB, free of redistribution products. This development makes readily available hitherto inaccessible mixed organoboranes which can be further transformed to a myriad of products via the rich chemistry of organoboranes. Such mixed organoboranes were available previously only through indirect hydroboration procedures.[12]

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(10) The preparation of 2-cyclopentyl-2-decanol is illustrative. Methylborane 15mmol, is liberated from 1.0M lithium methylborohydride in THF and an equivalent of 3.11M hydrogen chloride in diethyl ether at 0°C. Cyclopentene, 1.0 equivalent, is hydroborated to the dialkylborane within 5 min at 0°C. Addition of 1.0 equivalent of the second alkene, 1-octene, yields the mixed trialkylborane within 1h at 0°C. Carbonylation is carried out in a Parr "mini" reactor, in the presence of 22.5 mmol ethylene glycol at 700 psi, 150°C for 24h. After oxidation with alkaline hydrogen peroxide, the product is extracted from the aqueous solution with pentane, providing a 90% yield of the product. The material is purified by column chromatography (silica gel, hexane-EE 98:2): 2.4g, 71% pure material. IR$_{\nu OH}$4357; ^{13}C NMR 74.1, 49.6, 41.9, 32.1, 30.6, 29.9, 29.5, 27.3, 26.8, 26.1, 25.9, 24.1, 22.9, 14.3.

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