# Thexylhaloborane-Methyl Sulfide as Hydroborating and Stereoselective Reducing Agent

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Reactions of alkenes and alkynes with thexylhaloborane-methyl sulfide (ThxBHX·$SMe_2$, $X$=Cl, Br, I) were investigated in detail in order to elucidate the effect of halogen substituent in thexylborane and hence establish their usefulness as hydroborating agent. The reagents readily hydroborated alkenes at 50℃ and alkynes at 25℃ in exceptional regioselectivity. Especially, the selectivity achieved by the bromo and iodo derivative reaches essentially 100%. In addition to that, ThxBHX·$SMe_2$ was applied to the reduction of cyclic ketones to examine its stereoselectivity. The halogen substituent in thexylborane plays an important role in the stereoselective reduction. The stereoselectivity increased dramatically with increasing steric size of the substituent. Finally, the iodo derivative achieved highly stereoselective reduction, such selectivity being comparable to that previously achieved with trialkylborohydrides.

## Introduction

Thexylchloroborane-methyl sulfide (ThxBHCl·$SMe_2$) is a useful reagent for the selective hydroboration of alkenes of different structural types to produce isomerically pure thexylalkylchloroboranes.[1-3] These versatile intermediates have been used effectively in organic synthesis.[3,4]

ThxBHCl·$SMe_2$ and the bromo derivative (ThxBHBr·$SMe_2$) are also attractive selective reducing agent,[5,6] especially for the conversion of carboxylic acids and their derivatives to the corresponding aldehydes.[7,8] In the systematic study to investigate their general reducing characteristics,[5,6] ThxBHBr·$SMe_2$ proved to be weaker in reducing strength but much higher in stereoselectivity than ThxBHCl·$SMe_2$. These results clearly suggest that the halogen substituent in the thexylboranes exerts an additional influence in rate and stereoselectivity in the reduction of organic compounds.

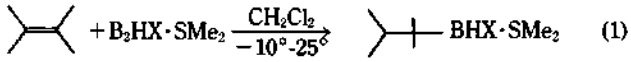
Accordingly, we decided to extend our investigation to the reaction of the iodo derivative (ThxBHI·$SMe_2$). We prepared a series of thexylhaloborane-methyl sulfide (ThxBHX·$SMe_2$, $X$=Cl, Br, I), applied them to the hydroboration of alkenes and alkynes to examine the directive effect, and finally investigate their stereochemistry in the reduction of cyclic ketones, in the hope of better understanding the nature of reagents and of exploring their role in organic synthesis.

A portion of our results has appeared in the form of preliminary communications.[9] We now describe in full the results of our study on the hydroboration and reduction characteristics of thexylhaloborane.

## Results and Discussion

**Preparation of ThxBHX·$SMe_2$.** The reagents were prepared by the monohydroboration of 2,3-dimethyl-2-butene with the corresponding $H_2BX·SMe_2$ ($X$=Cl, Br, I) in $CH_2Cl_2$ Eq. (1). Both $H_2BCl·SMe_2$ and $H_2BBr·SMe_2$ are commercially avalable. $H_2BI·SMe_2$ was prepared from borane-methyl sulfide and iodine.[10]

The $^{11}$B-NMR spectra of the resulting ThxBHX·$SMe_2$ solution in $CH_2Cl_2$ exhibited a clean doublet centered at δ 6.9 ppm ($J_{BH}$=128 Hz) for ThxBHCl·$SMe_2$, δ 5.2 ($J_{BH}$=132 Hz) for ThxBHBr·$SMe_2$ and δ −1.4 ($J_{BH}$=123 Hz) for ThxBHI·$SMe_2$, relative to $BF_3·OEt_2$. In each case a small signal was observed (δ 20.6, ThxBHCl; δ 18.9, ThxBHBr; δ 13.2, ThxBHI), presumably due to the dimer or uncomplexed monomer of ThxBHX. All the reagents were quite stable when kept under a static pressure of dry nitrogen at 0°.




(1)

$X$=Cl, ThxBHCl·$SMe_2$
$X$=Br, ThxBHBr·$SMe_2$
$X$=I, ThxBHI·$SMe_2$

**Hydroboration of Representative Alkenes with ThxBHX·$SMe_2$.** We examined the reaction of ThxBHX·$SMe_2$ with alkenes of different structural types under standard conditions in $CH_2Cl_2$ to determine the time required for complete hydroboration. The rate of hydroboration of alkenes with ThxBHCl·$SMe_2$ and ThxBHBr·$SMe_2$ at 25° was quite satisfactory, whereas the reaction with the iodo derivative was very sluggish. Therefore, a drastic reaction condition was required for a direct comparison: each alkene was hydroborated at 50° with 10% excess quantity of ThxBHCl·$SMe_2$ or ThxBHBr·$SMe_2$ (1.0 M in alkene and 1.1 M in reagent) and with 100% excess quantity of ThxBHI·$SMe_2$. The rate of hydroboration was monitored by hydrolyzing aliquots with a mixture of methanol-glycerine-water (1 : 1 : 1), followed by measurement of hydrogen evolved.

The relative rate of hydroboration with ThxBHX·$SMe_2$ toward alkenes is essentially dependent on steric and electronic nature of the reagents. Thus, the rate is in order of ThxBHCl·$SMe_2$>ThxBHBr·$SMe_2$>ThxBHI·$SMe_2$. The reaction of the iodo derivative in a 100% excess amount at 50° proceeded at a satisfactory rate, showing a complete hydroboration in less than 6h. Consequently, all the alkenes examined undergo the hydroboration readily with these reagents under the experimental conditions. The results are summarized in Table 1.

The directive effects in the hydroboration of alkenes with ThxBHX·$SMe_2$ were next investigated. After standard hydroboration with the reagents under the same conditions

**Table 1.** Reaction of Representative Alkenes with Thexylhaloborane-Methyl Sulfide in Methylene Chloride at 50℃[a]

| Alkene | Time, h | Hydride used for hydroboration[b] | | |
|---|---|---|---|---|
| | | ThxBHCl·$SMe_2$ | ThxBHBr·$SMe_2$ | ThxBHI·$SMe_2$[c] |
| 1-pentene | 1.0 | 0.98 | 0.94 | 0.89 |
| | 3.0 | 1.00 | 1.00 | 1.00 |
| | 6.0 | 1.00 | 1.00 | 1.00 |
| 1-octene | 1.0 | 0.99 | 0.88 | 0.85 |
| | 3.0 | 1.00 | 1.00 | 1.00 |
| | 6.0 | 1.00 | 1.00 | 1.00 |
| 1-decene | 1.0 | 0.97 | 0.74 | 0.72 |
| | 3.0 | 1.00 | 0.98 | 0.89 |
| | 6.0 | 1.00 | 1.00 | 1.00 |
| 3,3-dimethyl-1-butene | 1.0 | 1.00 | 1.00 | 0.92 |
| | 3.0 | 1.00 | 1.00 | 1.00 |
| | 6.0 | | | 1.00 |
| 2,4,4-trimethyl-2 | 1.0 | 1.00 | 1.00 | 0.91 |
| -pentene | 3.0 | 1.00 | 1.00 | 1.00 |
| | 6.0 | | | 1.00 |
| 1-methycyclo- | 1.0 | 0.94 | 0.72 | 0.98 |
| henxene | 3.0 | 1.00 | 0.98 | 1.00 |
| | 6.0 | 1.00 | 1.00 | 1.00 |
| α-methylstyrene | 1.0 | 0.99 | 0.87 | 0.78 |
| | 3.0 | 1.00 | 1.00 | 0.96 |
| | 6.0 | 1.00 | 1.00 | 1.00 |

[a]Reagent : alkene = 1.1 : 1. [b]Molar equivalent determined gasometrically. [c]Reagent : alkene = 2 : 1.

described above, the product in each case was oxidized with alkaline hydrogen peroxide, and the oxygenated products were analyzed by GC. The results are summarized in Table 2.

Essentially quantitative conversions of the alkenes to the corresponding alcohols with an exceptional regioselectivity in placing the boron atom exclusively at the less hindered carbon atom were observed in every case.

The selectivity achieved by all these reagents appears exceptional. This exceptional regioselectivity obtained at such a high temperature (50°) is rather surprising. Inspection of the data for product distribution, however, reveals that the steric size of halogen substitutent in thexylborane influences the regioselectivity in the hydroboration of alkenes. The relative selectivity is in order of ThxBHCl·$SMe_2$<ThxBHBr·$SMe_2$≪ThxBHI·$SMe_2$. Especially, the selectivity achieved by ThxBHBr·$SMe_2$ and ThxBHI·$SMe_2$ reaches essentially 100 %. The selectivity matches that displayed by 9-BBN,[11] the most selective hydroborating agent known.

| | $CH_3(CH_2)_5CH=CH_2$ | | $(CH_3)_3CCH=C(CH_3)_2$ | | $Ph(CH_3)C=CH_2$ | |
|---|---|---|---|---|---|---|
| | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ |
| ThxBHCl·$SMe_2$ | 0.5 | 99.5 | 2 | 98 | 0.5 | 99.5 |
| ThxBHBr·$SMe_2$ | 0.4 | 99.6 | 0.5 | 99.5 | 0.1 | 99.9 |
| ThxBHI·$SMe_2$ | trace | >99.9 | 0.2 | 99.8 | trace | >99.9 |

**Hydroboration of Representative Alkynes with ThxBHX·$SMe_2$.** The monohydroboration of representative terminal and internal alkynes with ThxBHX·$SMe_2$ in a stoichiometric ratio (1 : 1) was examined in $CH_2Cl_2$ at 25° and the results are summarized in Table 3.

Whereas each reagent in rather insensitive to the position of triple bond in alkynes in the hydroboration reaction, the relative reactivity of the reagents toward alkynes is influenced by the steric and electronic nature of halogen substituent. The rate is in order of ThxBHCl·$SMe_2$>ThxBHBr·$SMe_2$≫ThxBHI·$SMe_2$. Nevertheless, thexylhaloboranes have all exhibited satisfactory reactivity toward both the internal and terminal alkynes at 25° in a stoichiometric ratio. Especially noteworthy is the hydroboration of alkynes with excess reagents : only the monohydroboration product was realized in every case under these reaction conditions.

The directive effects of various unsymmetrically substitu-

**Table 2.** Direcive Effects in the Hydroboration of Alkenes with Thexylhaloborane-Methyl Sulfide in Methylene Chloride at 50℃

| Alkene | Products | Product distribution, %[a] | | |
|---|---|---|---|---|
| | | ThxBHCl·$SMe_2$[b] | ThxBHBr·$SMe_2$ | ThxBHI·$SMe_2$[c] |
| 1-pentene | 1-pentanol | 96 | 99.2 | 99.5 |
| | 2-pentanol | 4 | 0.8 | 0.5 |
| 1-octene | 1-octanol | 99.5 | 99.6 | >99.9 |
| | 2-octanol | 0.5 | 0.4 | trace |
| 1-decene | 1-decanol | 99.5 | 99.8 | >99.9 |
| | 2-decanol | 0.5 | 0.2 | trace |
| 3,3-dimethyl-1-butene | 3,3-dimethyl-1-butanol | 99 | 99.2 | 99.5 |
| | 3,3-dimethyl-2-butanol | 1 | 0.8 | 0.5 |
| 2,4,4-trimethyl-2-pentene | 2,4,4-trimethyl-3-pentanol | 98 | 99.5 | 99.8 |
| | 2,4,4-trimethyl-2-pentanol | 2 | 0.5 | 0.2 |
| 1-methylcyclo-hexene | 2-methylcyclohexanol | 99.5 | 99.6 | >99.9 |
| | 1-methylcyclohexanol | 0.5 | 0.4 | trace |
| α-methylstyrene | 2-phenylpropanol | 99.5 | 99.9 | >99.9 |
| | 2-phenyl-2-propanol | 0.5 | 0.1 | trace |

[a]Total yields are 94± 5%. [b]The data listed in ref. (1) are performed at 25°.

**Table 3.** Reaction of Representative Alkynes with Thexylhaloborane-Methyl Sulfide in Methylene Chloride at 25℃[a]

| Alkene | Time, h | Hydride used for hydroboration[b] | | |
|---|---|---|---|---|
| | | ThxBHCl·$SMe_2$[b] | ThxBHBr·$SMe_2$ | ThxBHI·$SMe_2$ |
| 1-hexyne | 0.5 | 0.93 | 0.90 | |
| | 1.0 | 0.97 | 0.95 | 0.64 |
| | 3.0 | 1.00 | 1.00 | 0.84 |
| | 6.0 | 1.00 | 1.00 | 0.94 |
| | 12.0 | | | 1.00 |
| 1-heptyne | 0.5 | 0.90 | 0.87 | |
| | 1.0 | 0.99 | 0.93 | 0.60 |
| | 3.0 | 1.00 | 1.00 | 0.84 |
| | 6.0 | 1.00 | 1.00 | 0.95 |
| | 12.0 | | | 1.00 |
| 2-hexyne | 0.5 | 0.90 | 0.86 | |
| | 1.0 | 0.96 | 0.93 | 0.60 |
| | 3.0 | 1.00 | 1.00 | 0.78 |
| | 6.0 | 1.00 | 1.00 | 0.93 |
| | 12.0 | | | 1.00 |
| 3,3-dimethyl-1-butyne | 0.5 | 0.95 | 0.93 | 0.77 |
| | 1.0 | 0.99 | 0.95 | 0.89 |
| | 3.0 | 1.00 | 1.00 | 0.89 |
| | 6.0 | 1.00 | 1.00 | 1.00 |
| 4,4-dimethyl-2-pentyne | 0.5 | 0.82 | 0.76 | |
| | 1.0 | 0.86 | 0.81 | 0.62 |
| | 3.0 | 0.94 | 0.89 | 0.71 |
| | 6.0 | 1.00 | 0.99 | 0.87 |
| | 12.0 | 1.00 | 1.00 | 0.93 |
| | 24.0 | | | 1.00 |
| phenylethyne | 0.5 | 0.84 | 0.80 | |
| | 1.0 | 0.94 | 0.90 | 0.72 |
| | 3.0 | 1.00 | 1.00 | 0.85 |
| | 6.0 | 1.00 | 1.00 | 0.91 |
| | 12.0 | | | 1.00 |
| 1-phenyl-1-propyne | 0.5 | 0.82 | 0.79 | |
| | 1.0 | 0.89 | 0.85 | 0.69 |
| | 3.0 | 0.95 | 0.91 | 0.75 |
| | 6.0 | 1.00 | 1.00 | 0.80 |
| | 12.0 | 1.00 | 1.00 | 0.90 |
| | 24.0 | | | 1.00 |

[a] Equimolar amount of reagent and alkynes was utilized. [b] Molar equivalent determined gasometrically.

ted acetylenes toward ThxBHX·$SMe_2$ were next investigated. The regioselectivity for the addition of B-H bond was determined by oxidation of the intermediate alkenylthexylhaloboranes with hydrogen peroxide in a buffered solution. The distribution of carbonyl isomers was then quantified by GC analysis. The results are summarized in Table 4.

As is evident from the Table, all the thexylhaloboranes achieve the clean monohydroboration of alkynes examined at 25° with exceptional regioselectivity (>97% purity). Even in the hydroboration of internal alkynes the reagents show an exceptional selectivity. The selectivity is in order of ThxBHI·$SMe_2$>ThxBHBr·$SMe_2$≫ThxBHCl·$SMe_2$, as the case of hydroboration of alkenes. Especially, the selectivity achieved by ThxBHI·$SMe_2$ and ThxBHBr·$SMe_2$ reaches essentially 100%. The selectivity is far superior to that displayed by various prominent hydroborating agents.[11c,12-16] Therefore, regioselective hydroboration of ThxBHX·$SMe_2$ provides a valuable synthetic route to isomerically pure aldehydes and ketones from alkynes.

**Table 4.** Directive Effects in the Monohydroboration of Alkynes with Thexylhaloborane-Methyl Sulfide in Methylene Chloride at 25℃

| Alkyne | Products | Product Distribution, %[a,b,c] | | |
|---|---|---|---|---|
| | | ThxBHCl·$SMe_2$ | ThxBHBr·$SMe_2$ | ThxBHI·$SMe_2$ |
| 1-hexyne | hexanal | 97 | 98 | 99 |
| | 2-hexanone | 3 | 2 | 1 |
| 1-heptyne | heptanal | 98 | 99 | >99.9 |
| | 2-heptanone | 2 | 1 | trace |
| 2-hexyne | 2-hexanone | 98 | 98.5 | 99 |
| | 3-hexanone | 2 | 1.5 | 1 |
| 3,3-dimethyl-1-butyne | 3,3-dimethylbutanal | 99 | >99.9 | >99.9 |
| | 3,3-dimethyl-2-butanone | 1 | trace | trace |
| 4,4-dimethyl-2-pentyne | 4,4-dimethyl-2-pentanone | 99 | 99.5 | >99.9 |
| | 4,4-dimethyl-3-pentanone | 1 | 0.5 | trace |
| phenylethyne | phenylacetaldehyde | 98 | 99 | 99 |
| | acetophenone | 2 | 1 | 1 |
| 1-phenyl-1-propyne | 1-phenyl-2-propanone | 97 | 99 | 99 |
| | 1-phenyl-1-propanone | 3 | 1 | 1 |

[a] The distribution is deduced by GC analysis from the oxygenated products produced following oxidation of the alkenylalkylborane. [b] Total yields are 90±5%, [c] Ref. 9(b).

**Table 5.** Stereoselective Reduction of Cyclic Ketones with Thexylhaloborane-Methyl Sulfide in Methylene Chloride at 0℃ [a-d]

| Ketone | $ThxBH_2$[e] | ThxBHCl·$SMe_2$[f] | ThxBHBr·$SMe_2$[g] | ThxBHI·$SMe_2$ |
|---|---|---|---|---|
| Cyclohexanone | | | | |
| 2-methyl- | 47-50 | 94.5 | 97.5 | 99 |
| 3-methyl- | | 68.5 | 81 | 93 |
| 4-methyl | | 56.5 | 77 | 89 |
| 4-*tert*-butyl- | 11 | 65.5 | 78.5 | 99 |
| 3,3,5-trimethyl- | | 97 | 98 | 99 |
| Norcamphor | 92 | 98.5 | 99 | 99.9 |
| Camphor | 80 | 95 | 97 | 99 |

[a] A 2 : 1 ratio for reagent : ketone was utilized. [b] The yields of alcohols were more than 95%. [c] The figures are percentage of the less stable isomers. [d] Ref. 9(a). [e] Data taken from ref. 12-13. [f] Ref. 5 [g] Ref. 6.

| | $CH_3(CH_2)_4C\equiv CH$ | | $CH_3(CH_2)_2C\equiv CCH_3$ | | $Ph-C\equiv CCH_3$ | |
|---|---|---|---|---|---|---|
| | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ |
| ThxBHCl·$SMe_2$ | 2 | 98 | 2 | 98 | 3 | 97 |
| ThxBHBr·$SMe_2$ | 1 | 99 | 1.5 | 98.5 | 1 | 99 |
| ThxBHI·$SMe_2$ | trace | >99.9 | 1 | 99 | 1 | 99 |

**Stereoselective Reduction of Cyclic Ketones with ThxBHX·$SMe_2$.** The stereoselectivity in the reduction of mono- and bicyclic ketones with ThxBHX·$SMe_2$ was also examined in order to elucidate the halogen effect and hence provide a new class of stereselective reducing agents. The results are summarized in Table 5.

As Table 5 shows, the halogen substituent in thexylborane plays an important role in the stereoselective reduction of typical cyclic ketones as anticipated. The stereoselectivity increased dramatically with increasing steric size of the substituent. For example, in the reduction of 4-*tert*-butylcyclohexanone thexylborane affords only 11% *cis*-4-*tert*-butylcyclohexanol, the less stable isomer. However, the substitution of a chlorine atom for hydrogen in thexylborane exerts a tremendous stereoselectivity enhancement (to 66%). Furthermore, the stereoselectivity increases consistently with increasing size of the halogen substituent, approaching 99%. Finally, the iodo derivative, ThxBHI·$SMe_2$ achieved highly stereoselective reductions with representative cyclic ketnones. Such stereoselectivities are comparable to the results previously achieved at 0° with trialkyl- and alkylalkoxyborohydrides.[17]

## Conclusion

It is evident from this study that ThxBHX·$SMe_2$ ($X$=Cl, Br, I) is a class of highly selective hydroborating and reducing agents. The reagents monohydroborate alkenes and alkynes in exceptional regioselectivity. The exceptional selectivity in the hydroboration of 1-substituted propynes is extraordinary. Furthermore, the reagents reduce cyclic kentones in exceptional stereoselectivity. The selectivity increases consistently with increasing steric size of halogen substituent. Especially, the selectivity achieved by the bromo and iodo derivatives reaches essentially 100%. With alkenes and alkynes, these reagents result in the clean and essentially quantitative formation of isomerically pure alkyl- and alkenylthexylhaloboranes. The rich chemistry associated with the dialkyl- and alkenylalkylhaloboranes must utilize these reagents in organic synthesis.

## Experimental Section

The reaction flasks and other glassware required for the experiments were predried at 140° for several hours, assembled hot and cooled under a stream of dry nitrogen. Syringes were assembled and fitted with needles while hot and then cooled. All reactions were carried out under a static pressure of nitrogen in flasks fitted with septum-covered sidearms, using standard techniques for handling air-sensitive materials.[18]

**Materials**

Commercial grade $CH_2Cl_2$ was pretreated by stirring over concentrated $H_2SO_4$ and distilling from $P_2O_5$. All chemicals were commercial products of the highest purity, which were carefully purified by standard methods before use. Monochloroborane-methyl sulfide ($H_2BCl\cdot SMe_2$) and monobromoborane-methyl sulfide ($H_2BBr\cdot SMe_2$) were used as received from Aldrich. Monoiodoborane-methyl sulfide ($H_2BI\cdot SMe_2$) was prepared from iodine and borane-methyl sulfide (Aldrich), as described previously. Alkenes were distilled from $LiAlH_4$ and stored under nitrogen at ambient temperatures. Alkynes were distilled under nitrogen from a small amount of $NaBH_4$.

**Analyses**

Yields reported in all cases are of analytically pure compounds. $^{11}$B-NMR spectra were recorded on a Bruker WP 80 SY spectrometer. Chemical shifts are with reference to $BF_3OEt_2$. GC analyses were carried out on a Varian 3300 FID chromatograph equipped with a Varian 4400 integrator/plotter using Carbowax 20 M capillary column (50 m).

**Preparation of Thexylhaloborane-Methyl Sulfide (ThxBHX·$SMe_2$) in $CH_2Cl_2$[1-3,19]**

The following reaction is typical of the procedure utilized in the preparation of ThxBHX·$SMe_2$. A 100 m*l* round-bottom flask equipped with a magnetic stirring bar, septum-covered sidearm, and connector tube leading to a mercury bubbler was charged at room temperature with 16.1 m*l* of 6.2 M neat $BH_2I\cdot SMe_2$[13] (100 mmol) and 16.9 m*l* of $CH_2Cl_2$. Then 8.8 g of 2,3-dimethyl-2-butene (105 mmol) was added slowly while stirring at room temperature. The reaction mixture was stirred at room temperature for 48 h. The usual analysis for active hydride showed this solution to be 2.50 M in ThxBHI·$SMe_2$ : $^{11}$B-NMR $\delta$ −1.7 ppm (d, $J_{BH}$=123 Hz).

**General Procedure for the Determination of the Rate of Reaction of Alkenes and Alkynes**

The general procedure was to add 10 mmol of compound to 11 mmol of the reagent (in the reaction of alkynes 10 mmol of the reagent was added) taken in sufficient quantity of the solvent containing a known quantity of a saturated hydrocarbon (generally 5 mmol of *n*-dodecane to serve as internal standard for GC analyses), so that the concentrations were 1 M in the reagent and compound. The reaction mixture was stirred at 50° for alkenes or at 25° for alkynes. The reaction temperature was maintained in a water bath. Aliquots of the reaction mixtures were withdrawn at specific

intervals and hydrolyzed with a mixture of glycerine-water-methanol (1 : 1 : 1) to measure the residual hydride content. From the amount of hydride remaining, the extent of reaction was calculated.

**Regioselectivity of Hydroboration of Alkenes with ThxBHX·SMe$_2$**

The regioselectivity of hydroboration was determined by oxidizing the intermediate alkylboranes to the corresponding alcohols with hydrogen peroxide, followed by GC analysis.

The following reaction is typical of the procedure utilized for determining the directive effect. A dry 10 m*l* round-bottom flask, equipped with a sidearm capped with a rubber septum, a magnetic stirring bar, and a connecting tube attached to a mercury bubbler, was flushed with nitrogen. The flask was immersed in a water bath at 50° and 3.4 m*l* of $CH_2Cl_2$ was injected into the flask, followed by 1.12 g of 1-octene (10 mmol) and 1.70 g of *n*-dodecane (10 mmol). The mixture was stirred, and 4.4 m*l* of a 2.50 M solution of ThxBHBr·SMe$_2$ (11 mmol) in $CH_2Cl_2$ was injected into the flask all at once. Stirring was continued keeping the flask in the water bath for reaction at 50°. The total volume of the mixture was 10 m*l* (1 M in alkene and 1.1 M in ThxBHBr·SMe$_2$). The reaction mixture was stirred for 3 hrs at 50° to complete the hydroboration. The dialkylbromoborane formed in the reaction was oxidized at 0° by adding 6 m*l* of 3 N aqueous NaOH and 3 m*l* of 30% $H_2O_2$. After 2 h of stirring at 25°, the mixture was saturated with $K_2CO_3$. The organic layer was separated, dried with anhydrous $MgSO_4$, and then analyzed by GC for the amounts of 1-octanol and 2-octanol formed in the reaction. The total yield of alcohols was 98%, of which 99.5% was 1-octanol and 0.5% was 2-octanol. The experiment was repeated for other representative alkenes listed in Table 2, and the alcohols produced following oxidation were determined.

**Regioselectivity of Hydroboration of Unsymmetrically Substituted Alkynes with ThxBHX·SMe$_2$**

The regioselectivity of hydroboration was determined by oxidizing the intermediate alkenylboranes to the corresponding carbonyl compounds with hydrogen peroxide, followed by GC analysis.

**Analysis for 1-Alkynes.** To a 25℃ solution of 0.58 m*l* of 1-hexyne (0.415 g, 5.05 mmol), 0.85 g, of dodecane (5.0 mmol) and 1.7 m*l* of $CH_2Cl_2$ were added 2.0 m*l* of 2.50 M ThxBHI·SMe$_2$ solution in $CH_2Cl_2$. After 12 h at 25℃, the reaction mixture was cooled to 0℃, neutralized with 2 m*l* of 2.5 N NaOH, followed by addition of 5 m*l* of buffer solution (pH 7). Then the mixture was oxidized by adding 1.5 m*l* of 30% $H_2O_2$ dropwise at 0℃. The mixture was stirred for 2h at 0℃. Then the aqueous layer was saturated with $K_2CO_3$ and the organic layer was separated. Analysis of the organic layer by GC on a Carbowax 20 M capillary column (15 m) revealed the presence of 99% hexanal and 1% 2-hexanone in a total yield of 91%.

**Analysis for 2-Alkynes.** To a 25℃ solution of 0.62 m*l* of 1-phenyl-1-propyne (0.581 g, 5.0 mmol), 0.85 g of dodecane (5.0 mmol) and 1.7 m*l* of $CH_2Cl_2$ was added 2.0 m*l* of a 2.50 M ThxBHI·SMe$_2$ solution in $CH_2Cl_2$. After 12 h at 25℃, the reaction mixture was cooled to 0℃, quenched with 5 m*l* of 3 N NaOH, and oxidized by adding 2.5 m*l* of 30% $H_2O_2$. The aqueous layer was saturated with $K_2CO_3$ and the organic layer separated. Analysis of the organic layer by GC on a Carbowax 20 M capillary column (15 m) revealed the presence of 99% 1-phenyl-2-propanone and 1% 1-phenyl-1-propanone in a total yield of 93%.

**Conversion of 1-Heptyne to Heptanal with ThxBHI·SMe$_2$.** To a 25℃ solution of 4.81 g of 1-heptyne (50 mmol) in 23 m*l* in $CH_2Cl_2$. After 12 h at 25℃, the reaction mixture was cooled to 0℃, neutralized with 10 m*l* of 3 N NaOH, and followed by addition of 25 m*l* of buffer solution (pH 7). Then the mixture was oxidized by adding 15 m*l* of 30% $H_2O_2$ dropwise. The mixture was syirred for 2 h at 0℃. Then the aqueous layer was saturated with NaCl and the organic layer separated. The aqueous layer was extracted with ether (3×20 m*l*). The combined organic layer was dried over anhydrous $MgSO_4$, followed by removal of the volatile components. Distillation afforded 4.7 g of heptanal; bp. 152-153℃ (lit.[12] 152.8℃), $n_D^{22}$ 1.4120 (lit.[12] $n_D^{20}$ 1.4113). GC analysis showed >99.9% purity and the $^1$H-NMR spectrum agreed with that of an authentic sample.

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# Conformations of the Acyl Esters of *p-Tert*-butylcalix[4]arene and Calix[4]arene

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Tetra acyl esters of *p-tert*-butylcalix[4]arene and calix[4]arene, including acetyl, propionyl, butyryl and isobutyryl, are synthesized and their conformations are inferred from $^1$H-NMR and $^{13}$C-NMR spectra. The conformer distribution is affected by the presence of *t*-butyl group, whereas the acylation products of *p-t*-butylcalix[4]arene are the cone conformers, those of calix[4]arene are mostly partial cone and/or 1,3-alternate conformers. The conformational outcome is also affected by the method of preparation, the NaH-induced reaction is prefered to the acid-induced reaction for cone and partial cone. Interestingly, 1,2-alternate conformer was isolated in 14% yield from the butyrylation of calix[4]arene.

## Introduction

Calixarenes are cavity containing macrocyclic compound made up of phenol and formaldehyde building blocks, and have received a great deal of attention in recent years because of their basket shape and their ability to be functionalized in various ways[1,2]. The cavity of calixarene is conformationally mobile[3] and exists four possible conformational isomers; cone, partial cone, 1,2-alternate and 1,3-alternate as shown on Figure 1.

Shaping the cavity plays a potentially vital role in the design of calixarenes as enzyme mimics, for host-guest interactions depend on complementarity in shape as well as functionality. Upon replacement of the phenolic hydrogens with larger than ethyl group, the calix[4]arenes become conformationally inflexible, existing as discrete entities in one or another of the conformations[4,5]. However, considerable confusion still exists in the conformer distribution on the alkylation or acylation of calixarene. In a study of the aroylation of calix[4]arenes, Gutsche[6] reported that the products partition principally between the cone and 1,3-alternate conformers and the particular conformation in which a calix[4]arene is fixed upon derivatization is dependent on the temperature, the solvent, the para substituent of the calix[4]arene, and the reactivity of the aroylating agent. He also reported that the products of arylmethylation partition principally between the cone and partial cone conformers[7]. The conformation of

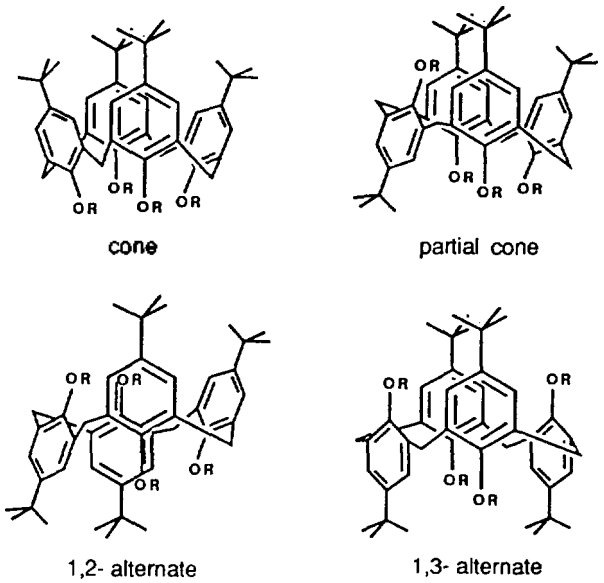


**Figure 1.** Conformations of calix[4]arene.

a derivatized calix[4]arene can be readily established on the bases of it's $^1$H-NMR spectrum, particularly from the patterns arising from the methylene protons joining the aromatic rings of the cyclic array, the cone conformer shows