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Reaction of Trialkylboranes with Sodium Diethyldihydroaluminate in the Presence of 1,4-Diazabicyclo[2.2.2]octane. A Convenient, General Method for Preparation of Sodium Trialkylborohydrides[1]

John L. Hubbard*

Department of Chemistry, Marshall University
Huntington, West Virginia 25755-2520

Joseph C. Fuller, Thomas C. Jackson, Bakthan Singaram*

Department of Chemistry and Biochemistry
University of California, Santa Cruz, California 95064

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Abstract: Trialkylboranes in tetrahydrofuran (THF) or diethyl ether (EE) solutions, including those with exceptionally large steric requirements, react readily with toluene solutions of sodium diethyldihydroaluminate in the presence of 1,4-diazabicyclo[2.2.2]octane (DABCO) to yield the corresponding sodium trialkylborohydrides and diethylaluminum hydride. The diethylaluminum hydride precipitates from solution as its DABCO adduct, with the use of EE as solvent facilitating the separation. This reaction constitutes a convenient, general method for preparing sodium trialkylborohydrides.

The utility of alkali metal trialkylborohydrides as reducing agents[2,3] and in hydride-induced carbonylation reactions[4-6] creates intense interest in methods for their preparation. Since bulk of an alkyl group has a dramatic effect on stereochemistry of reductions,[7,8] it is important to develop preparative reactions which accommodate groups having exceptionally large steric requirements.

The most direct route to trialkylborohydrides is by reaction of trialkylboranes in tetrahydrofuran (THF) with lithium,[9] sodium,[9] or potassium[10] hydrides (eq. 1). However, none of these hydrides in its

$$\mathrm{MH} + \mathrm{R_3B} \xrightarrow{\mathrm{THF}} \mathrm{MR_3BH} \quad (\mathrm{M} = \mathrm{Li, Na, K}) \qquad (1)$$

commercially available form is reactive toward highly hindered trialkylboranes such as tris(3-methyl-2-butyl)borane. This difficulty is circumvented with highly reactive forms of sodium[11] or potassium[12] hydrides, but disadvantages remain due to the requirements for handling air- and water-sensitive solids and for activating the metal hydrides prior to use.

A general and facile synthesis of lithium trialkylborohydrides utilizes reaction between lithium aluminum hydride and trialkylboranes in the presence of 1,4-diazabicyclo[2.2.2]octane (DABCO)[13] (eq. 2). Reagents are manipulated as solutions in THF or diethyl ether (EE), the latter providing a more effective separation of the products. The similarity of sodium diethyldihydroaluminate[14] to lithium aluminum hydride suggested the possibility of an analogous preparation of sodium trialkylborohydrides.

$$LiAlH_4 + R_3B + DABCO \longrightarrow LiR_3BH + DABCO{\cdot}AlH_3\downarrow \qquad (2)$$

Adding a toluene solution of sodium diethyldihydroaluminate to THF solutions of trialkylboranes produced mildly exothermic reactions. For each of the trialkylboranes examined (triethyl, tri-*n*-butyl, tri-*s*-butyl, and tricyclohexyl), the ^{11}B NMR spectrum of the resulting clear, colorless solution showed a mixture of the corresponding dialkylborohydride and trialkylborohydride.

Presumably the initial reaction in the process occurs as shown in eq. 3. Apparently diethylaluminum hydride then instigates a competing reaction in which an alkyl group is transferred from boron to aluminum. Preventing this secondary reaction requires trapping the diethylaluminum hydride as soon as it forms. Since DABCO is effective in removing aluminum hydride[13] (eq. 2), reactions of representative trialkylboranes with sodium diethyldihydroaluminate were carried out in its presence.

$$NaEt_2AlH_2 + R_3B \longrightarrow NaR_3BH + Et_2AlH \qquad (3)$$

Use of THF as solvent for the trialkylboranes resulted in precipitation of DABCO-diethylaluminum hydride as a gel, making quantitative separation from the supernatant trialkylborohydride solution difficult. Use of EE, in contrast, resulted in a crystalline precipitate easily removed by filtration or centrifugation (eq. 4).

$$NaEt_2AlH_2 + R_3B + DABCO \xrightarrow{EE} NaR_3BH + DABCO{\cdot}Et_2AlH\downarrow \qquad (4)$$

Two other tertiary amines, *N,N,N',N'*-tetramethylethylenediamine and *N*-methylpyrrolidine, were evaluated and found to be relatively ineffective for trapping diethylaluminum hydride. In the presence of these amines, most trialkylboranes yielded mixtures of the corresponding di- and trialkylborohydrides.

The reaction was applied to a representative series of trialkylboranes. The sodium trialkylborohydride solutions were characterized by

^{11}B NMR and infrared spectral techniques, as summarized in Table 1. Clean formation of trialkylborohydride is indicated for all examples. The fact that the ^{11}B NMR signals are usually doublets suggests the absence of hydride exchange and is evidence for completeness of reaction.[15,16] The infrared spectra exhibit the characteristic B-H band near 2000 cm^{-1},[9] with no absorptions attributable to the Al-H stretch.[17]

The usefulness of this method depends on ability to use the trialkylborohydride solutions directly for stereoselective reductions. Thus, reduction of 4-*t*-butylcyclohexanone was carried out using sodium tris(3-methyl-2-butyl)borohydride (i.e., sodium trisiamylborohydride) prepared by this procedure. The result was a greater than 99:1 ratio of the *cis*- and *trans*-4-*t*-butylcyclohexanols, essentially identical to the ratio realized with lithium trisiamylborohydride prepared by various procedures.[13,18,19]

Table 1. Infrared and ^{11}B NMR Spectra of the Products from Reaction of Representative Trialkylboranes with Sodium Diethyldihydroaluminate in the Presence of DABCO

Trialkylborane	ν_{B-H}, cm^{-1}	Chemical Shift[a] (multiplicity)	J_{B-H}, Hz
Triethylborane	1961	-12.5 (d)	50
Tri-*n*-butylborane	1968	-14.8 (d)[b]	60
Triisobutylborane	--	-17.8 (d)	50
Tri-*s*-butylborane	1954	- 5.9 (d)	60
Tricyclopentylborane	1970	- 9.9 (d)	63
Tricyclohexylborane	1967	- 6.4 (d)	59
Tri-*exo*-2-norbornylborane	--	- 8.6 (d)	55
Perhydro-9b-boraphenalene[c]	2030	-10.5 (d, 1B)	70
		-11.6 (d, 1B)	60
Tris(3-methyl-2-butyl)borane[d]	1954	-12.0 (d, 3B)	72
		-13.5 (d, 1B)	72
Tris(*trans*-2-methylcyclopentyl)borane[d]	--	-10.6 (s, 3B)	--
		-11.5 (s, 1B)	--

[a] Chemical shifts in δ relative to $BF_3 \cdot Et_2O$ with those upfield assigned as negative. [b] A band for the trialkylborohydride derived from di-*n*-butyl-*s*-butylborane was also observed at δ -12.1. [c] Isomeric pair of borohydrides. [d] Diastereomeric pair of borohydrides.

EXPERIMENTAL

All glassware was dried at least 4 h at 140 °C, assembled hot, and cooled under a stream of nitrogen. The techniques for manipulation of air- and water-sensitive materials are described elsewhere.[20] All materials were stored and manipulated under a nitrogen atmosphere. THF was freshly distilled from lithium aluminum hydride or sodium benzophenone ketyl. Anhydrous EE (Fisher) was used as received. Other materials (Aldrich), including borane-dimethyl sulfide (10.2 M), alkenes, DABCO, 4-*t*-butylcyclohexanone, and sodium diethyldihydroaluminate (2 M), were also used as received. Trialkylboranes were prepared by hydroboration of the corresponding alkenes.[20] IR spectra were obtained for 0.4 M solutions using a Perkin-Elmer 1600 Series FTIR spectrometer with sealed cells and the two-syringe technique.[20] ^{11}B NMR spectra were recorded on a Varian XL-100-15 spectrometer (32.1 MHz) fitted with a Nicolet 1080 data acquisition system, a Varian FT-80A spectrometer (25.517 MHz) fitted with a Hewlett-Packard 3335A synthesizer, or a Bruker ACF Dual Probe spectrometer (250 MHz), using a ^{2}H internal lock, with chemical shifts relative to $BF_3 \cdot Et_2O$ (δ 0).

Reaction of Sodium Diethyldihydroaluminate with Trialkylboranes in THF. The following procedure is representative. A 50-mL flask fitted with magnetic stirring bar and septum inlet was immersed in a water bath and charged with THF (4 mL) and triethylborane (5 mmol, 0.71 mL). To the stirred solution was added a toluene solution of sodium diethyldihydroaluminate (1.95 M, 2.6 mL). A moderately exothermic reaction was observed. Allowing the reaction mixture to cool to 25 °C resulted in a clear solution. ^{11}B NMR: δ -12.2 (s), -17.5 (t, J = 70 Hz). The fact that the former band, due to sodium triethylborohydride, is not a doublet is attributed to rapid hydride exchange.[15,16]

A similar reaction was carried out using THF (3 mL) and tri-*n*-butylborane (5 mmol, 1.21 mL). ^{11}B NMR: δ -14.5 (s), -16.1 (s), -20.1 (t, J = 70 Hz). The band at δ -16.1 is attributed to a borohydride derived from di-*n*-butyl-*s*-butylborane.

A similar reaction was carried out using THF (3 mL) and tri-*s*-butylborane (5 mmol, 1.21 mL). ^{11}B NMR: δ -6.1 (d, J = 65 Hz), -12.1 (t, J = 73 Hz).

A similar reaction was carried out with a THF solution of tricyclohexylborane (0.47 M, 10.6 mL). ^{11}B NMR: δ -6.6 (s), -11.9 (t, J = 68 Hz).

Reaction of Sodium Diethyldihydroaluminate with Trialkylboranes in the Presence of DABCO. The following procedure in EE is representative. A 50-mL centrifuge tube was charged with EE solutions of tris(3-methyl-2-butyl)borane (1.0 M, 10 mL) and DABCO (1.0 M, 10 mL). This clear solution was cooled to 0 °C and a toluene solution of sodium diethyldihydroaluminate (2.0 M, 5 mL) was added slowly with vigorous stirring. A precipitate of DABCO-diethylaluminum hydride formed. After 1.0 h at 25 °C, the reaction mixture was centrifuged. A 1.0-mL aliquot of the clear supernatant liquid gave on hydrolysis 0.40 mmol of hydrogen (100%). The supernatant liquid (24 mL, 96%) was transferred via a double-ended needle to another 50-mL vial for further examination. ^{11}B NMR: δ -12.0 (d, 3B, J = 72 Hz); -13.5 (d, 1B, J = 72 Hz). IR: 1954 cm^{-1}, B-H.

Reduction of 4-*t*-Butylcyclohexanone. A 100-mL flask fitted with a septum inlet and stirring bar and connected to a mercury bubbler was charged with a solution of sodium tris(3-methyl-2-butyl)borohydride (30 mL, 10 mmol). The flask was cooled to -78 °C and 9 mL of a 4-*t*-butylcyclohexanone solution in EE (1.0 M, 9 mmol) was added. The reaction mixture was stirred at -78 °C for 1 h, allowed to warm to 25 °C (6 h), and oxidized using 4 mL of 30% hydrogen peroxide (8.0 M, 32 mmol) in the presence of 3 N sodium hydroxide (4 mL, 12 mmol). (**CAUTION:** exothermic!) The product was extracted with EE (30 mL), washed with water (2 x 10 mL), and dried over anhydrous magnesium sulfate. The solvent was removed under reduced pressure (12 torr) and the crude material was collected: 1.24 g, 89%. Capillary GLC analysis using a 25-m methyl silicate column showed the product to be >99% pure *cis*-*t*-butylcyclohexanol.[13,18]

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