SODIUM PERBORATE: A MILD AND CONVENIENT REAGENT FOR EFFICIENTLY OXIDIZING TRIALKYLBORANES

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Abstract: Sodium perborate, a readily available and inexpensive reagent, efficiently oxidizes organoboranes. The reagent permits the oxidation of a wide variety of functionally substituted organoboranes. In nearly every instance, the product yields exceed those obtained using standard oxidation procedures.

Trialkylboranes have proven to be versatile intermediates in a number of synthetic sequences. The utility of the borane reagents is centered on the stereo-defined nature of their reactions and on the fact that they can be prepared containing a wide variety of important functional groups, eg. carboxylic acid esters, nitriles, etc.[1] Interestingly, nearly every synthesis involving organoboranes reagents includes an oxidation reaction to remove organoborane by-products or to generate the target molecule.[2] The most effective method for oxidizing organoboranes involves heating the boron reagent with 30% hydrogen peroxide and 3 N sodium hydroxide at 50°C.[3] The harsh nature of this standard oxidation reaction is often incompatible with the functional groups present in the target molecules.

In an attempted to minimize side reactions of functionally substituted organoboranes, researchers have resorted to modifying the standard oxidation procedure. Successful methods include the simultaneous addition of the base and peroxide [4] and the use of milder bases.[5,6] Other modifications include the use of oxidizing reagents other than hydrogen peroxide; these reagents are often expensive [7], inconvenient to handle [8,9], difficult to prepare [10], or are themselves reactive towards certain functional subtituents.[7-11]

Sodium perborate is an inexpensive, stable and easily handled oxidant which has an excellent shelf life. The reagent has been shown to be a mild oxidizing agent [12], yet the application of this reagent to organoboron compounds has been limited to the oxidation of alkenylboronic acids.[13] We wish to report that sodium perborate efficiently oxidizes a variety of organoboranes to the corresponding alcohols. The product yields are comparable to those obtained using the standard oxidation procedure.[3,7] The results of a comparative study are summarized in Table I.

Since sodium perborate is a mild oxidant, a comparative study was performed in which a series of functionally substituted alkenes were hydroborated and oxidized using both the sodium

Table I

Comparison of the Efficiencies of the Sodium Perborate and Hydrogen Peroxide Oxidation Proceduces [a,b]

| Organoborane [c] | Product [d] | Yield, % [e] | |
		Sodium Perborate	Hydrogen Peroxide
Tri-n-hexylborane	1-hexanol [f]	94	94
Tri-1-(2-methyl)pentylborane	2-methyl-1-hexanol	99	98
Tri-3-hexylborane	3-hexanol	99 [g]	98
Tri-cyclohexylborane	cyclohexanol	98 [g]	98
Tri-norbornylborane	exo-norborneol	98 [g]	98

[a]The sodium perborate procedure was carried out for 2 h at room temperature in water using a stoichiometric quantity of $NaBO_3 \cdot 4H_2O$ (3 equiv). [b]The peroxide oxidations were carried out by adding hydrogen peroxide (3 equiv.) as a 30% aqueous solution and 1 equiv. of sodium hydroxide (3 N) to the organoborane (1 M in tetrahydrofuran) and heating to 50°C for 1 h.[3] [c]The organoborane was prepared via the hydroboration of the corresponding alkene using the standard procedures outlined in ref 3. [d]All products exhibited physical properties and spectral characteristics in accord with literature values.[8] [e]Yields determined via GLC analysis. [f]Conversion based on tri-n-hexylborane. [g]Oxidation was performed using 1 eq of NaOH with heating to 50°C for 30 min.

perborate procedure and the standard procedure.[3] The results are presented in Table II. Only the major product is reported in Table II; isomeric alcohols are also formed due to the mesomeric and inductive effects of the functional substituent during hydroboration.[14] The product yields are comparable to those obtained using trimethylamine N-oxide (a relatively expensive reagent and often exceed those obtained using the standard oxidation procedure because the strong base used in the peroxide method often leads to side reactions such as elimination and cyclization.[15]

The oxidation of tri-(3-chloro-2-methyl)propylborane is representative of the sodium perborate procedure. 3-Chloro-2-methyl-1-propene (0.81 g, 9.0 mmol) was dissolved in 1.5 mL of THF contained in a dry, nitrogen-flushed, 25-mL three-necked flask. Which was equipped with a nitrogen inlet tube, a gas outlet tube connected to a mercury bubbler, a thermometer, a magnetic stirring bar and maintained under a positive pressure of N_2. The flask was cooled to 0°C (ice bath) and hydroboration was initiated by dropwise addition of a 2.0 M solution of dimethyl sulfide-borane complex (1.5 mL, 3 mmol). Alternatively, borane-THF can be used. The mixture was stirred at 0°C for 2 h, and then brought to room temperature. To the resultant tri-(3-chloro-2-methyl)propylborane in THF was added sequentially, water (3 mL) and sodium perborate (1.38 g, 9.0 mmol). The mixture was maintained at room temperature (water bath) for 2 h while vigorously stirring. The two phases were separated, and the aqueous phase extracted with ether (3 x 5 mL). The combined organic phase was washed with saturated NaCl solution (5 mL), dried ($MgSO_4$), and the product was isolated by distillation.

Table II

Comparison of the Sodium Perborate and Hydrogen Peroxide Oxidation Procedures for a Series of Functionally Substituted Organoboranes [a]

Alkene	Product [b,c]	Yield % [d] NaBO$_3$ [e]	H$_2$O$_2$/OH$^-$ [f]
H$_3$C—⟨⟩—SCH$_2$C(CH$_3$)=CH$_2$	H$_3$C—⟨⟩—SCH$_2$CH(CH$_3$)CH$_2$OH	92	85
(methylenedioxyphenyl)-CH$_2$CH=CH$_2$	(methylenedioxyphenyl)-CH$_2$CH$_2$CH$_2$OH	81	77
Ph-C(=O)-O-CH(CH$_3$)(CH$_2$)$_2$CH=CH$_2$	Ph-C(=O)-O-CH(CH$_3$)(CH$_2$)$_4$OH	89	86
ClCH$_2$C(CH$_3$)=CH$_2$	ClCH$_2$CH(CH$_3$)CH$_2$OH	83	35

[a]The organoboranes were formed via the hydroboration of the alkenes listed in the table. [b]Only the major product is indicated. [c]All products exhibited physical properties and spectral characteristics in accord with literature values.[8] [d]By GLC analysis. [e]The sodium perborate procedure was carried out for 2 h at room temperature in water using a stoichiometric quantity of NaBO$_3$·4H$_2$O (3 equiv). [f]The peroxide oxidations were carried out by adding hydrogen peroxide (3 equiv.) as a 30% aqueous solution and 1 equiv. of sodium hydroxide (3 N) to the organoborane (1 M in tetrahydrofuran) and heating to 50°C for 1 h.[3]

The use of sodium perborate as an oxidizing agent for organoboranes is a viable alternative to the standard oxidation procedure. The reagent is inexpensive, more stable and far safer to handle than hydrogen peroxide. The application of the perborate oxidation to a variety organoborane syntheses is currently under investigation.

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