Acknowledgments. We gratefully acknowledge the donors of the Petroleum Research Fund, administered by the American Chemical Society, the Research Corporation, and particularly E. I. DuPont DeNemours and Company for generous financial support, and Matthey Bishop, Inc., and Engelhard Industries for large loans of palladium chloride.

References and Notes

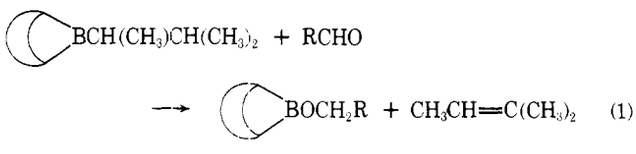
(1) Part 14: R. C. Larock and M. A. Mitchell, *J. Am. Chem. Soc.*, **100**, 180 (1978).
(2) M. Yoshifuji, M. J. Loots, and J. Schwartz, *Tetrahedron Lett.*, 1303 (1977).
(3) G. Zweifel and R. L. Miller, *J. Am. Chem. Soc.*, **92**, 6678 (1970).
(4) G. Zweifel and N. L. Polston, *J. Am. Chem. Soc.*, **92**, 4068 (1970).
(5) G. Zweifel, N. L. Polston, and C. C. Whitney, *J. Am. Chem. Soc.*, **90**, 6243 (1968).
(6) H. C. Brown and N. Ravindran, *J. Org. Chem.*, **38**, 1617 (1973).
(7) E. Negishi, G. Lew, and T. Yoshida, *J. Chem. Soc., Chem. Commun.*, 874 (1973).
(8) E. Negishi and T. Yoshida, *J. Chem. Soc., Chem. Commun.*, 606 (1973).
(9) Y. Yamamoto, H. Yatagai, and I. Moritani, *J. Am. Chem. Soc.*, **97**, 5606 (1975).
(10) R. C. Larock, *J. Org. Chem.*, **41**, 2241 (1976).
(11) R. C. Larock and J. C. Bernhardt, *J. Org. Chem.*, **42**, 1680 (1977).
(12) A. M. Caporusso, G. Giacomelli, and L. Lardicci, *J. Org. Chem.*, **42**, 914 (1977).
(13) R. C. Larock and H. C. Brown, *J. Organomet. Chem.*, **36**, 1 (1972).
(14) R. C. Larock, S. K. Gupta, and H. C. Brown, *J. Am. Chem. Soc.*, **94**, 4371 (1972).
(15) DuPont Young Faculty Scholar, 1975–1976.
(16) A. P. Sloan Foundation Fellow, 1977–1979.

Richard C. Larock,* [15,16] Bernhard Riefling
Department of Chemistry, Iowa State University
Ames, Iowa 50011
Received October 4, 1977

B-Alkyl-9-borabicyclo[3.3.1]nonanes as Mild, Chemoselective Reducing Agents for Aldehydes

Summary: *B*-Siamyl-9-BBN will reduce a variety of functionalized aldehydes to the corresponding alcohols even in the presence of unhindered ketones.

Sir: Certain *B*-alkyl-9-borabicyclo[3.3.1]nonanes (9-BBN) have been shown to be effective reducing agents for benzaldehyde. The efficiency of these compounds as reducing agents is largely dependent on the structure of the alkyl group on 9-BBN.[1] We wish to report that *B*-(3-methyl-2-butyl)-9-borabicyclo[3.3.1]nonane (*B*-siamyl-9-BBN)[2] is an effective reagent for the reduction of a wide variety of aldehydes under mild conditions.[3] The formation of an intermediate alkoxyborane is accompanied by the liberation of 2-methyl-2-butene (eq 1).[4] The boron species is conveniently removed by precipitation as the ethanolamine complex, leaving the alcohol in solution. Several representative examples of successful conversions of aldehydes are presented in Table I, which illustrates a number of attractive features of the reagent system.



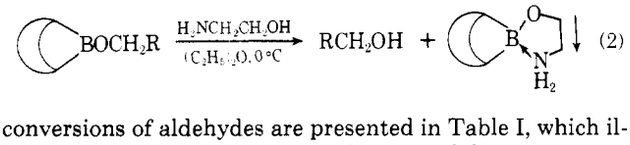


Table I. Reduction of Aldehydes to Alcohols with *B*-Siamyl-9-BBN

Product[a]	% yield[b]
$CH_3(CH_2)_4CH_2OH$	103 (54)
$(CH_3)_3CCH_2OH$	101 (49)
$(CH_3)_2C{=}CH(CH_2)_2C(CH_3){=}CHCH_2OH$[c]	100 (76)
$C_6H_5CH{=}CHCH_2OH$[d]	82 (62)
$C_6H_5CH_2OH$	97 (90)
p-$ClC_6H_4CH_2OH$	92 (80)
p-$CH_3OC_6H_4CH_2OH$	97 (65)
p-$(CH_3)_2NC_6H_4CH_2OH$	(92)
p-$O_2NC_6H_4CH_2OH$	(76)

[a] All compounds exhibited satisfactory spectra in accord with the assigned structure. [b] Determined by GLC using calibrated internal standard, numbers in parentheses indicate isolated yields. [c] A mixture of 61% geranial and 39% neral; the same ratio of geraniol and nerol was obtained. [d] *trans*-Cinnamaldehyde; the product had spectral properties identical with those of *trans*-cinnamyl alcohol.

First, trialkylboranes are exceedingly tolerant of many functional groups.[5] For example, *B*-siamyl-9-BBN reduces α,β-unsaturated aldehydes to allylic alcohols with neither detectable conjugate reduction nor 1,4 addition of the alkylborane in the absence of oxygen.[6] Branched or highly hindered aliphatic aldehydes are reduced almost as rapidly as straight-chain aldehydes; hexanal is reduced only slightly faster than pivalaldehyde. The rate of reduction of para-substituted benzaldehydes is increased by electron-withdrawing groups and decreased by electron-donating groups. Benzaldehyde is reduced about ten times faster than *p*-dimethylaminobenzaldehyde.

Perhaps the most remarkable feature of the *B*-alkyl-9-BBN compounds is their ability to selectively reduce aldehydes in the presence of ketones. While a number of reagents[7] have been devised which show similar discrimination, only diisopropyl carbinol on alumina is reported to be sufficiently selective to reduce an aldehyde in preference to an unhindered cyclohexanone.[7g] We have found that substantial reduction of a wide variety of ketones is attained only after many days at reflux with *B*-siamyl-9-BBN.[8] Cyclohexanone itself is reduced only to the extent of 2–3% under conditions for aldehyde reduction. Indeed, a competition between benzaldehyde and acetophenone for a single equivalent of *B*-siamyl-9-BBN resulted in a >95% reduction of the aldehyde in 2 h with no detectable reduction of the ketone.[9]

Two substrates, *p*-dimethylaminobenzaldehyde and *p*-nitrobenzaldehyde, proved troublesome since the intermediate alkoxyborane could not be subjected to the usual workup conditions without incurring decomposition. Modified procedures for these allowed isolation of the alcohols with no further complications.

A general procedure for aldehyde reduction is as follows. A dry, 200-mL flask with a side arm covered by a rubber septum, containing a magnetic stirring bar, and surmounted by a reflux condensor connected to a mercury bubbler, was flushed with nitrogen. To the flask was added 62 mL of a 0.5 M solution of 9-BBN in THF (31 mmol), followed by 3.4 mL of distilled 2-methyl-2-butene (32 mmol). The mixture was stirred at reflux for 2 h. Then 30 mmol of freshly distilled aldehyde was injected into the flask.[10,11] Solid aldehydes were first dissolved in a small volume of THF and the solution was introduced into the reaction vessel via syringe. At the end of 2 h of reflux the solution was cooled to room temperature. Then ~0.2 mL of acetaldehyde was injected into the flask to destroy excess organoborane and the solution was stirred for 15 min. The solvent and volatile components were removed

0022-3263/78/1943-1470$01.00/0

by water aspirator while stirring vigorously in a 40 °C water bath. The oily residue was dissolved in 30 mL of anhydrous diethyl ether and the solution was cooled in an ice bath. Then 1.85 mL of ethanolamine (31 mmol) was injected with rapid stirring. The precipitate was filtered on a fritted-glass funnel and washed with 5 mL of ether. The filtrate was washed with 60 mL of a saturated sodium chloride solution, dried ($MgSO_4$), and concentrated under vacuum to yield the crude product. The alcohol may be isolated by distillation at reduced pressure or by chromatography and is generally pure by NMR and GLC.

The capacity of *B*-alkyl-9-BBN compounds as chemoselective as well as enantioselective[12] reducing agents for aldehydes has been demonstrated.[13] The reagent is exceptionally mild since the reaction proceeds under essentially neutral conditions. The Meerwein–Pondorf–Verley type of mechanism proposed for this reduction[1] suggests that this reagent should possess unique properties. We are continuing to investigate both the mechanism and scope of these reactions.

Acknowledgment. We gratefully acknowledge support of this work by the Research Corporation.

References and Notes

(1) M. M. Midland, A. Tramontano, and S. A. Zderic, *J. Organomet. Chem.*, **134**, C17 (1977).
(2) H. C. Brown, E. F. Knights, and C. G. Scouten, *J. Am. Chem. Soc.*, **96**, 7765 (1974). 9-BBN is commercially available from the Aldrich Chemical Co.
(3) The reaction may be performed at room temperature. As standard conditions we have used 2 h in refluxing THF.
(4) Reduction via olefin elimination in the cyclooctyl ring has not been observed.
(5) H. C. Brown, G. W. Kramer, A. B. Levy, and M. M. Midland, "Organic Syntheses via Boranes", Wiley-Interscience, New York, N.Y., 1975.
(6) H. C. Brown and G. W. Kabalka, *J. Am. Chem. Soc.*, **92**, 714 (1970).
(7) (a) H. C. Brown, "Boranes in Organic Chemistry", Cornell University Press, Ithaca, N.Y., 1972, p 215; (b) R. O. Hutchins and D. Kandasamy, *J. Am. Chem. Soc.*, **95**, 6131 (1973); (c) G. W. Gribble and D. C. Ferguson, *J. Chem. Soc., Chem. Commun.*, 535 (1975); (d) C. S. Sell, *Aust. J. Chem.*, **28**, 1383 (1975); (e) Y. Yamamoto, H. Toi, A. Sonoda, and S-I. Murahashi, *J. Am. Chem. Soc.*, **98**, 1965 (1976); (f) H. C. Brown, S. Krishnamurthy, and N. M. Yoon, *J. Org. Chem.*, **41**, 1778 (1976); (g) G. H. Posner, A. W. Runquist, and M. J. Chapdelaine, *J. Org. Chem.*, **42**, 1202 (1977); see Table III of this reference for a comparison of aldehyde reducing agents.
(8) Ketones may be reduced in a reasonable time if the concentration of the organoborane is increased.
(9) All ketones tested were reduced at least 100–200 times slower than the aldehydes. *B*-Siamyl-9-BBN is slightly more reactive toward acetophenone than toward cyclohexanone.
(10) When *p*-nitrobenzaldehyde was reduced, the reaction was conducted at room temperature for 3 h. After destroying excess organoborane with acetaldehyde, the solvent was removed under vacuum at room temperature. The residue was dissolved in 200 mL of ether and 1.85 mL of ethanolamine was added. The solution was filtered and the ether was concentrated under vacuum to about 3 mL (a drop or two of methanol will redissolve any precipitate). The product was eluted with ether from a silica gel column then concentrated by rotary evaporator and distilled by Kugelrohr at 0.01 mmHg, 110 °C. The alcohol was obtained as light yellow crystals in 76% yield, mp 67–69 °C.
(11) *p*-Dimethylaminobenzaldehyde was refluxed for 8 h. The solution was cooled to room temperature and treated with 2 mL of water, stirred for 15 min, then extracted with 2 × 30 mL of acidified water (concentrated HCl added dropwise until the solution had a pH of 1). The aqueous extracts were combined, made basic to pH paper (with 3 N sodium hydroxide solution), and extracted with 2 × 20 mL of ether (saturing the water with potassium carbonate after the first extraction). The combined extracts were dried over magnesium sulfate, filtered, and concentrated under vacuum to yield the product (pure by NMR).
(12) M. M. Midland, A. Tramontano, and S. A. Zderic, *J. Am. Chem. Soc.*, **99**, 5211 (1977).
(13) **Note Added in Proof.** It has been reported that 9-BBN-pyridine will selectively reduce aldehydes [H. C. Brown and S. U. Kulkarni, *J. Org. Chem.*, **42**, 4169 (1977)].

M. Mark Midland,* Alfonso Tramontano

Department of Chemistry, University of California Riverside, California 92521

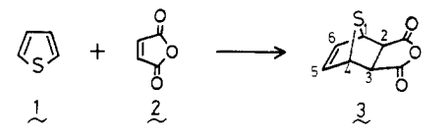
Received October 26, 1977

Diels–Alder Reaction of Thiophene with Maleic Anhydride at Very High Pressure[1,2]

Summary: The Diels–Alder reaction of thiophene with maleic anhydride proceeds under very high pressure conditions, affording the exo adduct.

Sir: There has been current interest in the Diels–Alder reaction of thiophenes. Because of the high aromaticity, it is a well-known fact that thiophene itself is inert to maleic anhydride.[3] The only recorded thiophene derivatives which are able to react with maleic anhydride in a Diels–Alder manner are thiophene 1,1-dioxide[4] and 2,5-dimethoxythiophene.[5] Recently it has been reported that some simple thiophene derivatives can combine with extremely reactive dienophiles such as dicyanoacetylene and dimethyl acetylenedicarboxylate.[6–10]

In this communication we wish to report the successful Diels–Alder reaction of thiophene with maleic anhydride at very high pressure (eq 1). In this way the 7-thiabicyclo[2.2.1]-hept-2-ene skeleton **3** is simply accessible.[11]



1 **2** **3** (1)

Thiophene failed to react with maleic anhydride in methylene chloride at 15 kbar and room temperature for 3 days. The reaction without solvent or with a Lewis acid catalyst (e.g., $MgCl_2$) was also fruitless.[12] These facts show a striking absence of diene character in thiophene, and contrast remarkably with the case of furan.[2] However, when we examined the reaction at higher temperatures at 15 kbar for 3 h in methylene chloride, we found that the reaction does occur (Table I). Inspection of the Table I reveals that the most favorable result is obtained at 100 °C. Thus, from the reaction mixture a highly crystalline compound **3**, mp 159.5–161.5 °C, of molecular formula $C_8H_6O_3S$ (MS, M^+ 182) was obtained in yields of 37–47% after recrystallization from ether or chloroform. On the stereochemistry of the adduct **3**, it is suggested that **3** has exo configuration from spectral data and chemical evidence as follows. In the ^1H NMR spectra, the C_2 and C_3 protons appear at δ 3.63 as a doublet signal (J = 1 Hz). When the dihedral angle between protons at C_1 and C_2 and also at C_3 and C_4 is taken into account, this fact indicates that **3** has exo configuration.[13] In agreement, the half methyl ester derived from **3** did not undergo iodolactonization (I_2–KI).[14]

Subsequently, the effect of solvent in the formation of the adduct **3** was investigated (Table II). The low yield in benzene is presumably due to the freezing of reaction medium at very high pressure.[15]

The following procedure for the Diels–Alder reaction of thiophene with maleic anhydride is representative.[16] A methylene chloride solution (1 mL) of thiophene (3 mmol) and

Table I. Temperature Dependence of the Yield [a] in the Adduct 3 between Thiophene and Maleic Anhydride

Room temp	No reaction	100 °C	37–47%
40 °C	No reaction	120 °C	18%
80 °C	8%	150 °C	Decomp

[a] The yield based on the isolated material.

Table II. Solvent Dependence of the Yield in the Adduct 3 between Thiophene and Maleic Anhydride (100 °C)

CH_2Cl_2	$CHCl_2CHCl_2$	C_6H_6	AcOEt
37–47%	47%	6–7%	15–19%

0022-3263/78/1943-1471$01.00/0