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Catecholborane (1,3,2-Benzodioxaborole). A Versatile Reducing Agent[1]

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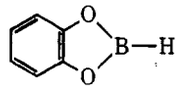
The reaction of 1,3,2-benzodioxaborole [catecholborane (CB)] with representative functional groups was studied to determine the utility of CB as a selective reducing agent. The approximate rates, stoichiometry, and products of the reductions were determined under standard conditions ($CHCl_3$, 25 °C). The results indicate that CB is unique compared to other substituted boranes. The reduction rates appear to be solvent independent with the exception of alkenes. Primary alkenes react very sluggishly, whereas secondary alkenes are unreactive at room temperature; as a result, many selective reductions can be performed in the presence of alkenes.

In the important area of selective reductions, we wish to report on the useful applications of catecholborane (1,3,2-benzodioxaborole, 1). Although borane complexes[2,3] and



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substituted boranes[4,5,6] have been employed as selective reducing agents, catecholborane (CB) has certain unique properties which merit attention. Recently, a review article on some of the chemistry of CB has appeared.[7]

CB has some practical advantages over other, commonly used reducing agents: (1) It is a liquid at room temperature and may be used without solvent.[8] (2) CB is soluble and stable in all common, aprotic solvents (e.g., benzene, toluene, chloroform, ether, hexane, etc.). (3) CB is stable in dry air and reacts only slowly with moist air. (4) CB may be stored unchanged for over a year at 0 °C, in contrast to certain other substituted boranes.[9,10]

Results and Discussion

Since this study was carried out to determine the relative reactivity of CB toward various functional groups, a standard set of conditions was selected. The reactions were conducted at room temperature, generally in $CHCl_3$, with stoichiometric amounts of hydride and substrate (with the initial concentration of substrate at approximately 0.5 M). Faster reaction can be achieved by using excess hydride, raising the temperature, or increasing the concentration of the substrate. The rates of reduction were usually independent of the solvent utilized, although the hydroboration of alkenes was, in fact, solvent dependent[11] (Table I).

The reactivity exhibited by the various functional groups toward CB in $CHCl_3$ can be classified for convenience into three broad categories:

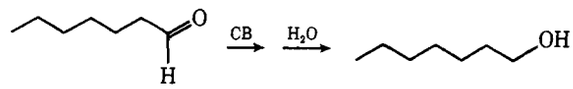
(1) Fast—those functionalities that react in 24 h or less (Table II).

(2) Slow—those functionalities whose reaction times exceed 24 h (Table III).

(3) Inert—those functionalities that exhibit no reactivity toward CB (Table IV).

The data in the tables demonstrate that there is a wide range of reactivity within each category.

Aldehydes, Ketones, and Derivatives. Heptanal and benzaldehyde were investigated as representatives of aliphatic and aromatic aldehydes. Heptanal is rapidly and quantitatively reduced to the corresponding alcohol (eq 1).[12] Likewise, benzaldehyde is reduced rapidly to benzyl alcohol.



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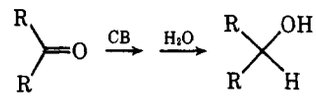
Cyclic and acyclic aliphatic ketones were reduced in high yields (eq 2).[12] 2-Octanone was slowly reduced with 1 or 2



(2)

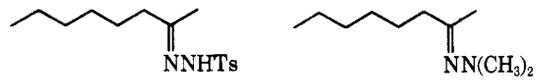
equiv of hydride. On the other hand, cyclopentanone and cyclohexanone exhibited varying degrees of reactivity,[13] as shown in the tables.

Table I. Representative Examples of Reduction Rates in Various Solvents[a]

Substrate	Solvent	Redn time, h	% redn[b]
$C_6H_{13}CH{=}CH_2$	$CHCl_3$	43.2	5
$C_6H_{13}CH{=}CH_2$	THF	46.5	25
Cyclohexene	$CHCl_3$	46	0[c]
Cyclohexene	THF	46	0[c]
Cyclopentanene	$CHCl_3$	72	68
Cyclopentanone	THF	72	71
Cyclohexanone	$CHCl_3$	24.6	84[c]
Cyclohexanone	Tolune	21	96[c]
$C_6H_{13}CHO$	$CHCl_3$	3	94
$C_6H_{13}CHO$	THF	3	87
$C_6H_{13}CHO$	THF	3.5	97

[a] Reductions were carried out using equimolar amounts of substrate and CB (concentration of reactants: ~0.5 M) at room temperature. [b] Reduction followed by GLC. [c] Reduction followed by NMR.

Two imine derivatives, 2-octanone *p*-toluenesulfonylhydrazone (**2**) and 2-octanone *N,N*-dimethylhydrazone (**3**), were



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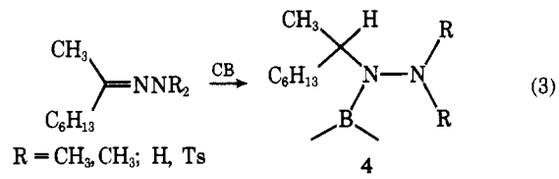
prepared and reduced. These compounds were very reactive with CB and produced the corresponding hydrazinoborane derivatives, **4**, in nearly quantitative yields (eq 3).



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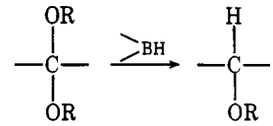
The reduction of acetals and ketals was examined since they are commonly utilized as protecting groups for ketones and aldehydes. CB reacted with the diethyl ketal of cyclohexanone and the diethyl acetal of heptanal to give the corresponding ethers (eq 4). This cleavage with CB is analogous to results with BH_3.[14]



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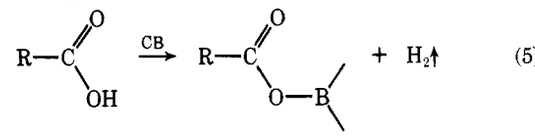
Carboxylic Acids and Derivatives. Propionic and benzoic acids reacted rapidly and quantitatively with 1 equiv of CB, liberating hydrogen gas, to form the corresponding acyloxyborane,[2,15] **5** (eq 5). The acyloxyborane, **5**, reacted further with



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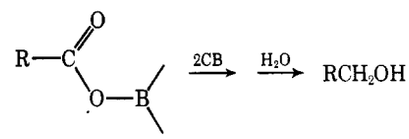
2 additional equiv of CB to give a quantitative yield of the corresponding alcohols (eq 6). Attempts were made, by



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varying reaction conditions to produce the corresponding aldehyde from the acid precursor. However, only trace amounts of aldehyde were detected indicating that reduction of the acyloxyborane, **5**, is slow in comparison to reduction of the aldehyde formed during the reduction.

Propionic acid reacted at a moderate rate whereas benzoic acid was reduced much slower, presumably owing to the weaker Lewis basicity of the carbonyl group in the latter compound.

The sodium salt of stearic acid was reduced rapidly over the period of 6.5 h at room temperature in THF. This is a surprising result when compared to the fact that borane is inert toward the sodium salt of an acid.[16]

Butyric anhydride required 4 equiv of CB for complete reduction. Presumably, the first equivalent of hydride produces the corresponding aldehyde and an acyloxyborane (eq 7). The

Table II. Reduction of Fast Reacting Groups with Catecholborane[a]

Functionality	Substrate	Registry no.	Ratio of H/substrate	Time for 50% redn, min	% overall redn (time, h)[b]
Aldehyde	$C_6H_{13}CHO$	111-71-7	1:1	20	93[c] (4)
	C_6H_5CHO	100-52-7	1:1	35	85 (2)
	C_6H_5CHO		2:1	11	92 (1.5)
Ketone	Cyclohexanone	108-94-1	1:1	75	84 (24.7)
Hydrazone	$C_6H_{13}C(CH_3){=}NNHTs$	54798-76-4	1:1	19	100 (0.92)
	$C_6H_{13}C(CH_3){=}NN(CH_3)_2$	60676-12-2	1:1	16	93 (1)
Acid salt	$C_{17}H_{35}CO_2Na$	822-16-2	3:1[d]		100 (6.5)
Sulfoxide	$(CH_3)_2SO$	67-68-5	2:1	27	93 (23.8)
Amine oxide	$(CH_3)_3NO$	1184-78-7	2:1	3	94 (8.5)
Anhydride	$(C_3H_7CO)_2O$	106-31-0	4:1	30	86 (24)
Epoxide	Propylene oxide	75-56-9	1:1[e]	165	99[c] (27)
	Propylene oxide		2:1[f]	10	100 (1)
	Styrene oxide	96-09-3	1:1[e]		100 (.25)
RC≡CH	$C_4H_9C{\equiv}CH$	693-02-7	1:1	738	79 (25.3)
Acetal	$C_6H_{13}CH(OC_2H_5)_2$	688-82-4	1:1		20 (24)
Ketal	1,1-Diethoxycyclohexane	1670-47-9	1:1		100 (1)

[a] Reactions were carried out using an initial substrate concentration of 0.5 M in $CHCl_3$ at room temperature. [b] Reduction followed by NMR. [c] Reduction followed by GLC. [d] Sodium stearate was reduced in THF because of solubility problems in $CHCl_3$. [e] The epoxides react with 1 equiv of CB to give a mixture of products. [f] Propylene oxide reacts with 2 equiv of CB to give i (79%) and ii (21%).

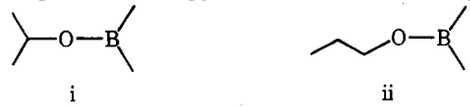

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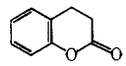
Table III. Reduction of Slow Reacting Groups with Catecholborane[a]

Functionality	Substrate	Registry no.	Ratio of H/substrate	Time for 50% redn, h	% overall redn (time, h)[b]
RCOR	Cyclopentanone	120-12-3	1:1	28	68[c] (72)
	$C_6H_{13}COCH_3$	111-13-7	1:1	40	70 (163)
	$C_6H_{13}COCH_3$		2:1	7.3	91 (71.8)
RCOCl	CH_3COCl[d]	75-36-5	2:1		20 (72)
$RCM{=}CH_2$	$C_6H_{13}CH{=}CH_2$	111-66-0	1:1		5 (44)
$RC{\equiv}N$	$C_2H_5C{\equiv}N$	107-12-0	2:1	48.6	54 (63)
RCO_2H	$C_6H_5CO_2H$	65-85-0	3:1		28[e] (20)
	p-$NO_2C_6H_4CO_2H$	62-23-7	3:1		87 (90)
$RCONR_2$	$CH_3CON(CH_3)_2$	125-19-5	2:1		40 (96)

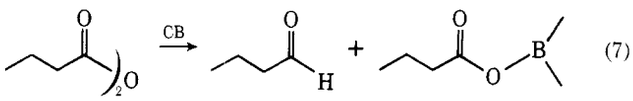
[a] Reductions were carried out using an initial substrate concentration of 0.5 M in $CHCl_3$ at room temperature. [b] Reduction followed by NMR. [c] Reduction followed by GLC. [d] Initial concentration was 1.66 M. [e] This reduction goes to 85% completion in 152 h in refluxing $CHCl_3$.

Table IV. Groups Exhibiting No Reactivity toward Catecholborane[a]

Functionality	Substrate	Registry no.	Ratio of H^-/substrate	Rxn time, h	% redn[b]
RCO_2R	$C_3H_7CO_2C_2H_5$	105-54-4	1	81	0[c]
RSR	$(CH_3S)_2$	624-92-0	1	42.7	0
RNO_2	CH_3NO_2	75-52-5	1	168	0
RSO_2R	Tetramethylenesulfone	126-33-0	1	94	0
RCH=CHR	Cyclohexene	110-83-8	1	46	0
RCO_2R		119-84-6	1	96	0
$(RCO)_2O$	$(CF_3CO)_2O$	407-25-0	4	21	0
	Maleic anhydride	108-31-6	4	50	0
RBr	n-$C_8H_{17}Br$	111-83-1	1	48	0
RI	n-$C_5H_{11}I$	628-17-1	1	48	0

[a] Reductions were carried out using an initial substrate concentration of 0.5 M in $CHCl_3$ at room temperature. [b] Reduction followed by NMR. [c] Reduction followed by GLC.

proposed initial step prompted us to investigate the possibility of aldehyde production under varying reaction conditions.



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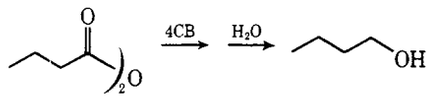
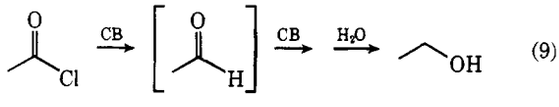
Only trace amounts of aldehyde were detected in all cases. It is apparent that the reduction of the anhydride by CB is slow compared to the reduction of the aldehyde produced from the initial addition of CB to the anhydride.

The reduction of butyric anhydride was fairly rapid; after 20 h an 86% yield of butanol was obtained (eq 8). Trifluoroacetic and maleic anhydride were inert toward CB at room temperature in chloroform; however, trifluoroacetic anhydride reacted slowly in refluxing $CHCl_3$.[17]



(8)

Acetyl chloride reacted very slowly with CB taking 2 equiv to produce the corresponding alcohol. Presumably, the reduction proceeds through initial reduction of the acid chloride to give the corresponding aldehyde which in turn produces the alcohol (eq 9). As would be expected, only a trace of aldehyde was detected in this reduction.



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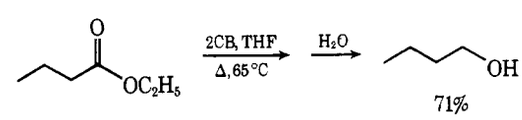
Ethyl butyrate did not react at room temperature in $CHCl_3$ but reacted slowly to produce the alcohol in good yields in refluxing THF or $CHCl_3$ (eq 10).

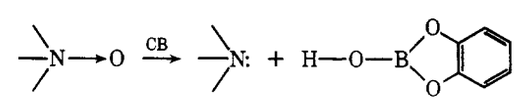


(10)

The lactone, coumarin, was also examined and was found to be inert toward CB at room temperature in $CHCl_3$.

Acetamide liberated less than 1 equiv (62%) of the theoretical amount of hydrogen for the two acidic hydrogens, and a mixture of products was produced. However, benzamide liberated 2 equiv of hydrogen but did not undergo further reaction. The tertiary amide *N,N*-dimethylacetamide underwent reduction at room temperature to give the corresponding amine in 40% yield. It should be noted that *N,N*-dimethylacetamide was cleanly reduced to dimethylethylamine by utilizing a 50% excess of CB and running the reaction in refluxing chloroform solution.

Amine Oxides and Sulfoxides. Both the amine oxide and sulfoxide functionalities are readily reduced by CB. Trimethylamine oxide and dimethyl sulfoxide react rapidly with 2 equiv of CB to liberate 1 equiv of hydrogen gas and to produce trimethylamine and dimethyl sulfide, respectively. By analogy with borane, and from spectral data, the following reactions appeared to occur (eq 11 and 12). The liberation of hydrogen



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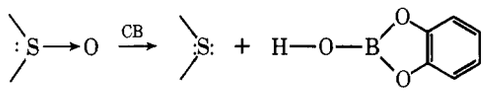

(12)

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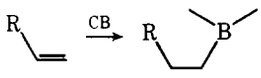
resulted from the reaction of CB with the acidic hydrogen of 6 produced as a common intermediate of the reductions.

Alkenes.[8] Terminal and interanal alkenes were examined. Surprisingly, CB reduces alkenes extremely slowly at room temperature with only 5% reduction of 1-octene over approximately a 2-day period. This should allow many selective reductions to be performed which are not possible with borane. Good yields of the corresponding 2-alkyl-1,3,2-benzodioxaborole 7 (eq 13) were obtained when the reactions were

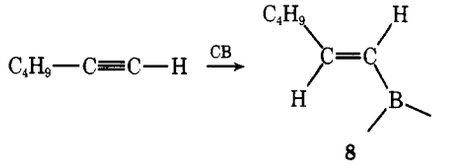


(13)

carried out at 60–70 °C. The rate of hydroboration of alkenes is dependent on the solvent to a certain extent (Table I). For example, 1-octene was hydroborated faster in refluxing THF than in refluxing $CHCl_3$. This might be attributed to two possible factors: (1) the catalytic action of ethers for the reduction of alkenes by boranes[11] and (2) the slightly higher reflux temperature of THF. At these concentrations, the hydroboration of 1-octene proceeded smoothly until it reached a maximum of approximately 81%; beyond this point, isomerization of the 1-octene occurred, producing increasing amounts of internal alkene (presumably via hydroboration–dehydroboration) with a concomitant decrease in yield of the alkylborane.

The secondary alkene, cyclohexene, did not undergo hydroboration at room temperature but slowly reacted in refluxing THF and $CHCl_3$ producing 2-cyclohexyl-1,3,2-benzodioxaboraole.

Alkynes.[8] Terminal alkynes were found to react much faster than alkenes. For example, hydroboration of 1-hexyne with CB was a fast reaction at room temperature producing the corresponding vinylborane in both THF and $CHCl_3$. 1-Hexyne reacted with CB to give cis addition[8] and formation of 2-alkenyl-1,3,2-benzodioxaborole (8, eq 14) which is a useful



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synthetic intermediate. As a result of the increased reactivity of alkynes, they can be selectivel reduced in the presence of alkenes.

Other Functional Groups. Propylene oxide and styrene oxide reacted at a moderate rate with 1 equiv of CB to give a mixture of products. However, propylene oxide reacted rapidly and quantitatively with 2 equiv of CB to give the ring-opened alcohols, 2-propanol (79%) and 1-propanol (21%).

The aliphatic nitro group of nitromethane and the aromatic nitro group of *p*-nitrophenylacetic acid were inert to CB at room temperature.

As noted earlier, dimethyl sulfoxide reacted rapidly with CB. However, tetramethylenesulfone and dimethyl disulfide were found to be inert toward CB at room temperature. The disulfide group is also inert toward CB under refluxing conditions in THF.

Primary alkyl bromides and iodides are inert toward CB at room temperature, as determined using *n*-octyl bromide and *n*-pentyl iodide.

Selective Reductions. Systematic exploration of the reducing characteristics of CB has revealed a broad diversity of reactivity of CB toward various functional groups. This range of reactivity makes possible many selective reductions.

Table V. Selective Reduction of Heptanal in Presence of Various Substrates[a]

Substrate	% unreacted substrate[b]	% heptanol[b,c]
$C_6H_{13}COCH_3$	93	94
$C_8H_{17}CH{=}CH_2$[d]	97	99
Cyclohexene	100	100
$C_2H_5C{\equiv}N$	100	100
CH_3COCl	100	92
$C_3H_7CO_2C_2H_5$	100	100
n-$C_8H_{17}Br$	100	100

[a] Reductions were carried out using an initial substrate concentration of ≃0.5 M. CB was added dropwise to a −5 °C solution. The solution was allowed to sit for 0.5 h at −5 °C, warmed to 0 °C for 0.5 h, and allowed to sit for 6 h at room temperature and then analyzed. [b] Reactions analyzed by GLC. [c] Heptanol is produced by hydrolyzing the reaction product, 2-heptoxy-1,3,2-benzodioxaborole. [d] Registry no., 872-05-9.

Table VI. Selective Reduction of Cyclohexanone in the Presence of Various Substrates[a]

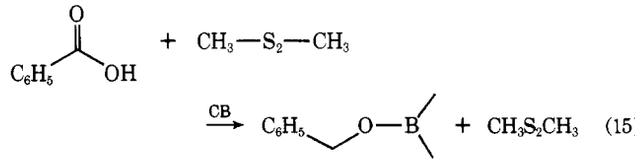
Substrate	Unreacted substrate, %[b]	Cyclohexanol, %[b,c]
$C_8H_{17}CH{=}CH_2$	100	98
Cyclohexene	100	98
$C_2H_5C{\equiv}N$	100	98
CH_3COCl	95	98
$C_3H_{17}CO_2C_2H_5$	100	98
n-C_4H_9Br[d]	100	98

[a] Reductions were carried out using an initial substrate concentration of ≃0.5 M. CB was added to a −5 °C solution. The solution was allowed to sit for 5 h at −5 °C, warmed to 0 °C for 15 h, and allowed to sit for 23 h at room temperature and then analyzed. [b] Reactions analyzed by GLC. [c] Cyclohexanol is produced by hydrolyzing the reaction product, 2-cyclohexoxy-1,3,2-benzodioxaborole. [d] Registry no., 109-65-9

In competitive experiments, various substrates, in equal molar quantities, were allowed to compete for a limited quantity of CB. A number of selective reductions were observed. Table V displays the selective reduction of an aldehyde in the presence of various functional groups. Table VI presents the selective reduction of a given ketone in the presence of various functional groups. These two tables are representative of the utility of CB as a selective reducing agent.

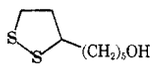
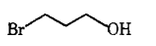
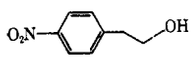
Examination of Tables V and VI reveals that CB will preferentially reduce an aldehyde in the presence of a ketone in quantitative yield (Table V); this reduction is not possible using borane. Also in contrast to borane, CB reacts with terminal alkynes to give the monohydroboration product. For example, CB will readily hydroborate 1-hexyne in the presence of cyclohexene.

CB does not cleave the disulfide linkage even at elevated temperatures; this is in contrast to sodium borohydride[18] and lithium aluminum hydride.[19] Thus, it should be possible to reduce a variety of functional groups in the presence of the disulfide linkage; indeed, two acids were reduced in the presence of the disulfide group in quantitative yields (eq 15 and 16).

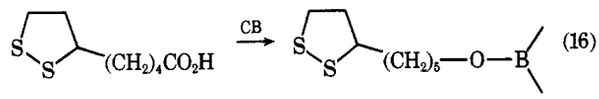


(15)

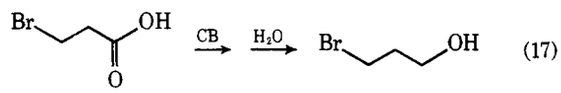
Table VII. Characterization of Products Obtained via Selective Reduction

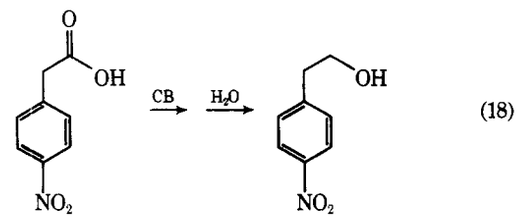
Compd	Registry no.	^{1}H NMR ($CDCl_3$), δ	Obsd bp, °C	Ref bp, °C
	539-55-9	1.5 (broad, 8 H, alkyl), 2.4 (quintet, 2 H, ring CH_2), 3.15 (t, 2 H, $-CH_2S-$), 3.6 (m, 3 H, –CHRS and $-CH_2O-$), 4.9 (s, 1 H, –OH)	*a*	*a*
	627-18-9	2.1 (quintet, 2 H, $-CH_2-$), 3.5 (t, 2 H, $-CH_2Br$), 3.9 (t, 2 H, $-CH_2O-$), 4.2 (s, 1 H, –OH)	75–77 (14 mm)	76 (14 mm)[25]
	100-27-6	3.0 (t, 2 H, $-CH_2Ar$), 3.9 (t, 2 H, $-CH_2O$), 5.2 (s, 1 H, –OH), 7.7 (A_2X_2, 4 H, ArH)	63.5–4.5	64[*b*][26]
	96-48-0	2.5 (complex m, 4 H, $-CH_2CH_2CO-$), 4.4 (t, 2 H, $-CH_2O-$)	250	206 (760 mm)[27]

[a] This alcohol is notoriously unstable and has not been characterized in its pure form. The spectral data and solution characteristics of the product obtained in the CB reduction are in complete agreement with data presented by earlier workers.[24] [b] Melting point.

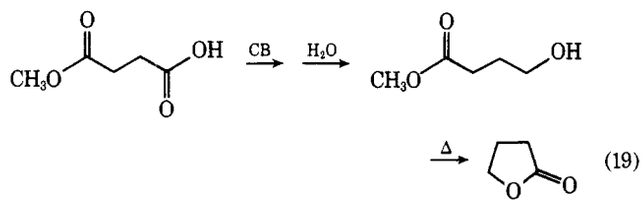

(16)

Unlike lithium aluminum hydride,[20] CB does not reduce alkyl halides or nitro compounds over long periods of time at room temperature; therefore, many functional groups can be reduced in the presence of halides (Tables V and VI) or nitro groups. For example, acids can be quantitatively reduced in the presence of a bromide or a nitro group (eq 17 and 18).

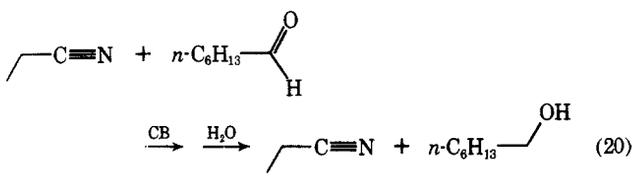

(17)


(18)

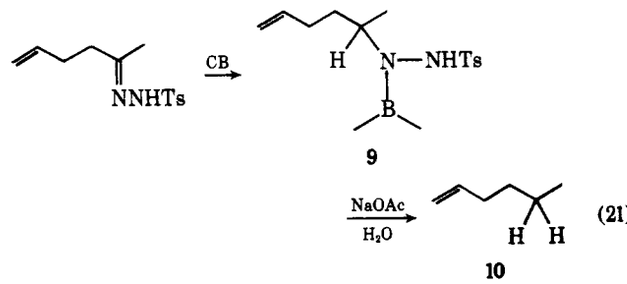
Esters are unreactive at room temperature. Thus, CB and borane will quantitatively reduce aldehydes (Table V), ketones (Table VI), or acids in the presence of an ester (eq 19).


(19)

Unlike borane, CB reduces nitriles extremely slowly and, thus, it is possible to reduce many of the functional groups present in Table II in the presence of nitriles (Tables V and VI) in quantitative yields (eq 20).


(20)

The quantitative reductions of an aldehyde and a ketone by CB in the presence of a terminal and secondary alkene were successfully performed (Tables V and VI). In a similar manner, an imine derivative was selectively reduced in the presence of a terminal alkene and a tosyl group to give the corresponding hydrazinoborane derivative **9** in quantitative yield (eq 21). This valuable synthetic intermediate may be converted to the deoxygenated compound, **10**.[21,22]


(21)

Summary. Catecholborane (1,3,2-benzodioxaborole) has been shown to be an important and versatile reducing agent for many selective reductions. It exhibits some reductive properties which are unique and complementary to other substituted boranes, such as thexylborane, disiamylborane, and 9-borabicyclononane.

Experimental Section

Analysis and Spectra. GLC analysis was carried out on a Varian Aerograph Model 1700 instrument using SE-30 (5% on 60–80 Chromosorb W, 0.25 in. × 6 ft column). The NMR spectra were recorded on a Varian T-60.

Materials. The substrates used for the reductions are all commercially available and were used without further purification. A standard solution of borane in THF was prepared according to published procedures.[23] Catechol (99+% purity) was dried at 25 °C over P_2O_5 under vacuum for 24 h.

Solvent Purification. Both $CHCl_3$ and THF were dried and stored under nitrogen. THF was dried over $LiAlH_4$ and distilled. $CHCl_3$ was washed several times with concentrated sulfuric acid followed by several water washes to remove the ethanol which is added as a stabilizer and then dried with $MgSO_4$. $CHCl_3$ was then distilled from fresh $MgSO_4$ under nitrogen and stored at 0 °C in the dark to prevent decomposition.

Preparation of Catecholborane (1,3,2-Benzodioxaborole). A 2.14 M solution of borane in THF (770 mmol, 396 ml) maintained under nitrogen was placed in a dry 1000-ml flask which was connected to a hood vent through a mercury bubbler. The reaction flask was immersed in an ice bath and catechol (770 mmol, 77 g) in THF (200 ml) was added over a 6-h period to the rapidly stirred borane solution. After addition of catechol, the solution was stirred overnight at room temperature to complete the reaction. Removal of THF and distillation under nitrogen afforded 39.5g (~50%) of catecholborane, bp 40 °C (26 mm).

Reduction Procedure. The substrate (2.5 mmol) was placed into a flame-dried 25-ml flask, fitted with a stirring bar and septum, and connected to a mercury bubbler to maintain a nitrogen atmosphere. $CHCl_3$ was added along with an appropriate internal standard for either GLC or NMR analysis. The flask was maintained at 25 °C via

a water bath. Catecholborane (2.6 mmol, a 5% excess) was added dropwise as a neat liquid to the stirred reaction mixture.

Aliquots were withdrawn at various time intervals, quenched with water, and analyzed by GLC or NMR.

Isolation. Reduction of aldehydes, ketones, acids, acid chlorides, anhydrides, and esters produces the corresponding alkoxy-1,3,2-benzodioxaboroles. The reduction of palmitic anhydride is representative of the general procedure utilized in this study. Palmitic anhydride (2.15 g, 4.32 mmol) was placed in a 25-ml flask which was assembled as described previously. Chloroform (70 ml) was then added and catecholborane (2.03 ml, 18.6 mmol) was added dropwise. The mixture was refluxed until the reduction was complete (3 days, monitored by NMR). The solution was extracted with one 25-ml portion of H_2O followed by six 25-ml extractions using a 1.0 N NaOH solution to remove catechol. The solution was then dried and separated using column chromatography; the column support was silica gel (Sargent-Welch, 60–200 mesch). The hexadecanol was eluted using a ligroin–ether mixture (98 and 2%, respectively). The first material eluted from the column was the hexadecanol (96% isolated, 2.02 g, 8.24 mmol).

Characterization of Products. The spectral data and physical constants of a number of products obtained via selective reduction with CB are summarized in Table VII.

Registry No.—Borane, 13283-31-3; catechol, 154-23-4; CB, 274-07-4.

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(12) The initial product was the 2-alkoxy-1,3,2-benzodioxaborole which was readily hydrolized to the corresponding alcohol. As an example, the initial product in the reduction of heptanal exhibits the following NMR ($CDCl_3$); δ 0.90 (m, 3 H, $-CH_3$), 1.33 (m, 10 H, alkyl), 4.13 (t, 2 H, $-OCH_2-$), 7.1 (s, 4 H, Ar). In general, the hydrogens of the $-OCH_2-$ moiety appear 0.5 δ to lower field in the borole derivatives than they do in the free alcohols.
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(17) After 95 h (refluxing $CHCl_3$), the yield of 2,2,2-trifluorethanol was 52% (NMR in $CDCl_3$ exhibits a quartet at δ 3.93).
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Simple Models of Nucleic Acid Interactions. 1. Base–Base Interactions in 1,2-Di(adenosin-N^6-yl)ethane and 1,4-Di(adenosin-N^6-yl)butane[1a,b]

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Treatment of 6-chloro-9-β-D-ribofuranosylpurine (I) with 1,2-diaminoethane in dimethylformamide at room temperature in the presence of triethylamine gave 1,2-di(adenosin-N^6-yl)ethane (IIIb). Compound IIIb was also prepared by coupling of I with N^6-(2-aminoethyl)adenosine (IVa). Similarly, condensation of 6-chloro-9-(2,3-*O*-isopropylidene-β-D-ribofuranosyl)purine (V) with IVa afforded 2′,3′-*O*-isopropylidene-1,2-di(adenosin-N^6-yl)ethane (VI), a derivative of IIIb with functionally differentiated ribose residues. Coupling of I with 1,4-diaminobutane gave 1,4-di(adenosin-N^6-yl)butane (IIIc) and N^6-(4-aminobutyl)adenosine (IVb). UV and CD spectra of IIIb and IIIc in water are consistent with an intramolecular base–base interaction (stacking). Thus, the hypochromism of IIIb is greater than that of IIIc. Both IIIb and IIIc exhibit an increased molecular ellipticity in CD spectra over the corresponding model compounds VIIa and VIIb. This increase is more pronounced in IIIc than IIIb. In 0.01 N HCl IIIb still exhibits a considerable hypochromism whereas that of IIIc virtually disappeared. By contrast, the CD spectra of IIIb and IIIc show a sharp drop in the molecular ellipticity which in both cases does not substantially differ from that in model compounds VIIa or VIIb. The effect of protonation on stacking, UV and CD spectra of IIIb and IIIc is discussed.

Interactions between the strands of nucleic acids are essential for the biological roles of both DNA and RNA in phenomena such as replication of DNA, transcription of genetic information from DNA to RNA, codon–anticodon interaction of mRNA with tRNA, etc., wherein two molecules (strands) approach one another closely enough to form a complex. The stability of these complexes derives mainly from the formation of specific hydrogen bonds between complementary bases (Watson–Crick or "wobble" pairing). In another type of interaction, the portions of nucleic acid molecules do not form hydrogen-bonded structures but, nevertheless, interact with each other through base stacking: the heterocyclic residues in the DNA or RNA are held in parallel planes in a sandwichlike arrangement. This base stacking is of importance for maintaining the proper secondary structure of DNA and RNA. It may also be of significance in some other cases where portions of DNA or RNA molecules are close enough but cannot form a hydrogen-bonded complex because of lack of the corresponding complementary bases. This situation may arise in the crucial step of protein synthesis where the pepti-