1-Pyrrolylborane-Tetrahydrofuran Complex; A New Bifunctional Hydroborating Agent

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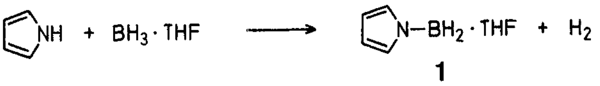
We report on the use of a new bifunctional hydride as reducing agent: 1-pyrrolylborane-tetrahydrofuran complex (**1**). This molecule is an exceptional example of a highly reactive aminoborane. The synthesis of **1** has been reported[1,2], but to our knowledge there is no mention in the literature concerning the use of **1** as a hydroborating agent. We thought that further study of this reagent was warranted, because:

- it is a bifunctional hydride compound and this kind of compound is very useful in the cyclic hydroboration of dienes;
- it is a strong Lewis acid[3] and this property makes it more reactive;
- pyrrole can be removed easily from the initial product by hydrolysis or alcoholysis to give the corresponding acids or esters;
- compound **1** is readily prepared under mild conditions from pyrrole and borane-tetrahydrofuran ($BH_3\cdot THF$).



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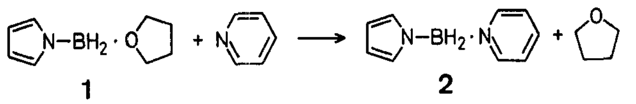
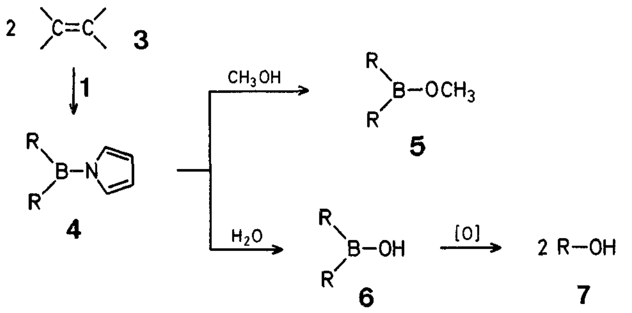
During syntheses of **1** following some of the reported methods[2], we observed loss of hydride when high temperatures, long reaction times, or an excess of pyrrole were used, probably due to hydroboration of the pyrrole ring. We therefore tried to find better conditions for the preparation of **1**. We have now found that 1-pyrrolylborane-tetrahydrofuran complex (**1**) can be conveniently prepared in 80–83% yield (in solution) by the reaction of pyrrole with borane-tetrahydrofuran at 20 °C (1 h). The yield was determined from the amount of hydrogen evolved and by titration of pyrrole and hydride in the tetrahydrofuran solution of **1**. Complex **1** cannot be isolated; it decomposes on evaporation of solvent. However, addition of pyridine to the solution of **1** affords the sufficiently stable, isolable complex 1-pyrrolylborane-pyridine (**2**) in 80–83% yield (based on the initially used borane-tetrahydrofuran and pyrrole).



1 **2**

We investigated the reactions of complex **1** with representative alkenes, with an alkyne, and with carbonyl compounds. We found that 1-pyrrolylborane-tetrahydrofuran (**1**) is an effective hydroborating agent, the regioselectivity obtained in the hydroboration of alkenes usually being better than that of borane-tetrahydrofuran (Table 1) and comparable to that of thexylborane[4] and of chloroborane[5].

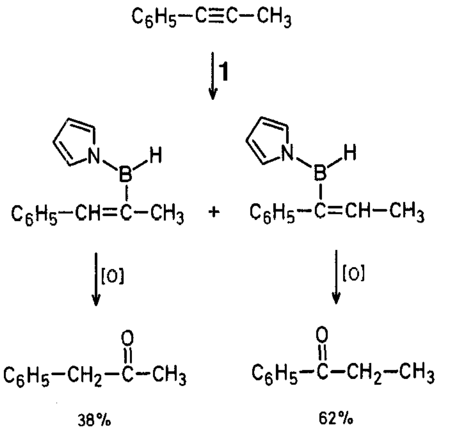
Hydroboration of alkenes (**3**) such as 1-octene, 2-methyl-2-butene, and cyclohexene with **1** leads to the formation of dialkyl-(1-pyrrolyl)-boranes (**4**). Methanolysis of **4** affords methyl dialkylborinates (**5**). Addition of water to the solution containing **4** followed by evaporation at reduced pressure gives the dialkylborinic acids **6** which can be oxidized to the alcohols **7** with alkaline hydrogen peroxide.



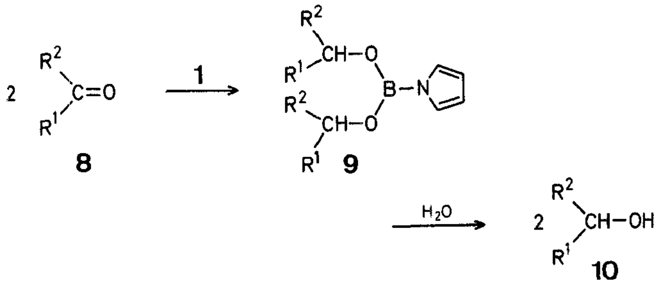
For comparison it should be noted that in the hydrogen peroxide oxidation of the hydroboration products obtained from alkenes and thexylborane (an extensively used hydroborating agent) the product alcohols may be contaminated with 2,3-dimethyl-2-butanol.

Hydroboration of less reactive alkenes with an equimolar amount of **1** proceeds only to the stage of the monoalkyl-(1-pyrrolyl)-borane, an excess of **1** being required for complete hydroboration.

Hydroboration of 1-phenylpropyne with 1-pyrrolylborane-tetrahydrofuran (**1**) leads to the formation of two isomeric 1-alkenylboranes which can be oxidized to 1-phenyl-2-propanone and 1-phenyl-1-propanone, respectively.



Aldehydes and ketones (**8**) can be reduced with 1-pyrrolylborane-tetrahydrofuran (**1**) to give, after hydrolysis of the intermediate 1-pyrrolylboronic esters **9**, the corresponding primary or secondary alcohols (**10**), respectively. The intermediacy of **9** was proven by N.M.R. spectrometry upon addition of acetone (**8**, $R^1 = R^2 = CH_3$) to a solution of **2** in an N.M.R. tube.



The ratios of the two stereoisomers obtained from the reductions of 2-methylcyclohexanone and 5α-cholestan-3-one, respectively, are different from the corresponding ratios observed with disiamylborane or borane-tetrahydrofuran as reducing agents (Table 2).

0039-7881/81/0332-0214$03.00

Table 1. Hydroboration-Oxidation of Unsaturated Hydrocarbons

Substrate	Total Yield [%][a] of Products obtained with Ratio **2:1** and **1:1**		Products	Isomer Ratios obtained with				b.p./torr [°C]	
	2:1	1:1		1-Pyrrolyl-borane (**1**)	$BH_3\cdot THF$	Thexyl-borane[4]	Cl—BH_2 etherate[5]	found	reported[12]
1-octene	96 (100)	(100)	1-octanol	99	[b]	94.95	95.5	100°/20	98°/19
			2-octanol	1	[b]	5.6	0.5		
2-methyl-2-butene	(89)	(98)	3-methyl-2-butanol	100	98[6]		97.7		
			2-methyl-2-butanol	0			0.3		
styrene	(46)	88 (96)	2-phenylethanol	86.4	81[6]	94	96	95°/10	97.4°/10
			1-phenylethanol	13.5	19	6	4		
2-phenylpropene	(56)	(90)	2-phenylpropanol	100	100[6]	100			
3-phenylpropene	(55)	(87)	1-phenyl-2-propanol	3.4	10[6]				
			3-phenylpropanol	96.6	90				
1-phenylpropene	(49)	(92)	1-phenylpropanol	90.4	85[6]				
			1-phenyl-2-propanol	9.6	15				
cyclohexene	(100)	(100)	cyclohexanol						
methylcyclohexene	(46)	(80)	1-methylcyclohexanol	0	1.5[7]				
			trans-2-methylcyclohexanol	100	97.7				
			cis-2-methylcyclohexanol	0	0.8				
cyclooctene	85	(90)	cyclooctanol					100°/20	106–108°/22
1-phenylpropyne		(90)	1-phenyl-1-propanone	62	74[8]	43[8]			
			1-phenyl-2-propanone	38	26	57			

[a] Yields of isolated pure products. Yields in parentheses were determined by G.L.C. analysis (Carbowax 20M, 20% on chromosorb W, 80–100 mesh and using alkanes as internal standards).

[b] Hydroboration of 1-hexene with $BH_3\cdot THF$ proceeds with 94% of boron attack at C-1[6].

Table 2. Reduction of Aldehydes and Ketones (**8, 11**) to the Corresponding Alcohols (**10, 12**) via Hydroboration-Hydrolysis

Aldehydes or Ketones **8**		Yield [%] of Alcohol[a]	Products	Isomer Ratios obtained with			m.p. or b.p./torr [°C]	
R^1	R^2			1-Pyrrolyl-borane (**1**)	Disiamyl-borane	$BH_3\cdot THF$	found	reported[12]
CH_3	CH_3	(88)	2-propanol					
C_2H_5	CH_3	(98)	2-butanol					
—$(CH_2)_5$—		(91)	cyclohexanol					
—$CH(CH_3)$—$(CH_2)_4$—		(100)	*cis*-2-methylcyclohexanol	54[b]	79[9]	26[9]		
			trans-2-methylcyclohexanol	46	21	74		
5α-cholestan-3-one		90	5α-cholestan-3β-ol	62[c]	93[11]	90[11]		
			5α-cholestan-3α-ol	38	7	10		
C_6H_5	CH_3	93	1-phenylethanol				b.p. 95°/15	b.p. 93°/14
C_6H_5	C_6H_5	(96)	benzhydrol					
n-C_3H_7	H	(100)	butanol					
C_6H_5	H	(98)	benzyl alcohol					

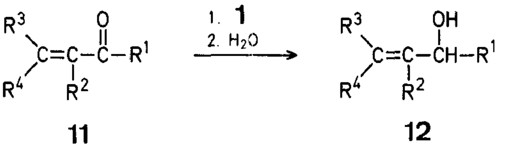
Aldehydes or Ketones **11**										
R^2	R^1	R^3	R^4							
H	—$(CH_2)_3$—		H	(90)	2-cyclohexenol	100		100[10]		
H	—$(CH_2)_4$—		H	(92)	2-cycloheptenol					
H	H	CH_3	H	(92)	2-butenol					
H	H	C_6H_5	H	88 (93)	3-phenyl-2-propenol (cinnamyl alcohol)				m.p. 31°	m.p. 34°

[a] Yields of isolated pure products. Yields in parentheses were determined by G.L.C. analysis (the columns used in all cases were carbowax 20M, 20%, chromosorb W, 80/100 mesh or OV-17 10%, Gas-chrom Q, 80/100 mesh and using alkanes as internal standards).

[b] The isomer ratio was determined by G.L.C. analysis (Diglycerol, 5% on chromosorb W 80–100 mesh).

[c] The isomer ratio was determined by G.L.C. analysis of silylated alcohols (SE 30, 2% on chromosorb W[AW-DMCS] 100/120 mesh), isomers were not separated.

The selective reduction of 2-alkenals and 1-alkenyl ketones (**11**) to give the corresponding allylic alcohols (**12**) is generally difficult to achieve. The use of borane-tetrahydrofuran complex leads to the formation of the saturated alcohols[10]. Contrary to this, the pyrrolyl group in complex **1** modifies the selectivity of borane in such a manner that allylic alcohols (**12**) are obtained exclusively.



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1-Pyrrolylborane-Tetrahydrofuran Complex (1; in Solution):

A dry 250 ml three-necked, round-bottomed flask equipped with stirrer, pressure-equalizing dropping funnel, and nitrogen inlet and outlet (the latter is connected to a mercury gasimeter) is flushed with dry nitrogen and maintained under a static pressure of nitrogen. The flask is maintained at 20 °C by means of a thermostat bath and is charged with a 1.3 molar solution (100 ml, 0.13 mol) of borane (BH_3) in tetrahydrofuran. To this solution, freshly distilled pyrrole (9 ml, 0.13 mol) is added dropwise with stirring. The clear mixture is then stirred at 20 °C for 1 h to complete the reaction. [During the reaction, 0.105 mol of hydrogen were evolved. Hydrolysis of 10 ml of the reaction solution afforded 0.021 mol of hydrogen and 0.011 mol of pyrrole].

In all hydroborations, the solution of complex **1** as prepared above is used without further treatment. The hydride content is determined prior to use by hydrolysis of a small aliquot of the solution and determination of the hydrogen evolved.

1-Pyrrolylborane-Pyridine Complex (2):

Pyridine (3.165 g, 40 mmol) is added, under nitrogen, to the solution of 1-pyrrolylborane-tetrahydrofuran complex (**1**; 10 mmol) in the reaction vessel of its preparation. The solvents are removed under reduced pressure at room temperature to leave complex **2** as a white solid; yield: 80% (as determined by titration of hydride content, pyrrole, and pyridine; yield based on borane-tetrahydrofuran initially used).

^{1}H-N.M.R. ($CDCl_3/TMS_{int}$): $\delta=6.1$ (m, 2H, 3-H,4-$H_{pyrrole}$); 6.7 (m, 2H, 2-H,5-$H_{pyrrole}$); 7.25 (m, 2H, 3-H,5-$H_{pyridine}$); 7.75 (m, 1H, 4-$H_{pyridine}$); 8.1 ppm (m, 2H, 2-H,6-$H_{pyridine}$). B—H could only be detected by indirect means, i.e., after addition of acetone to give *diisopropyl 1-pyrrolylboronate* (**9**, $R^1=R^2=CH_3$); $\delta=1.05$ (d, 12H, $J=6$ Hz, 4 CH_3); 3.85 ppm (h, 2H, $J=6$ Hz, 2 O—CH).

2-Phenylethanol from Styrene; Typical Hydroboration-Oxidation Procedure:

A dry 250 ml three-necked, round-bottomed flask equipped with stirrer, pressure-equalizing dropping funnel, and nitrogen inlet and outlet (the latter is connected to a mercury gasimeter) is flushed with dry nitrogen and maintained under a static pressure of nitrogen. The flask is charged with a 1.3 molar solution (69 ml, 0.09 mol) of 1-pyrrolylborane (**1**) in tetrahydrofuran and cooled to 0 °C. Then, styrene (11 ml, 0.096 mol) is added and the mixture is stirred for 15 h at room temperature. Water (25 ml) is added with stirring and tetrahydrofuran and water are removed under reduced pressure at 25 °C. The residual product is dissolved in tetrahydrofuran (30 ml) and aqueous 3 molar sodium hydroxide (15 ml) is added rapidly with stirring, followed by the dropwise addition of 30% hydrogen peroxide (15 ml) (exothermic reaction) while maintaining the temperature of the mixture at a maximum of 40–50 °C. Stirring is then continued for 1 h at 40–50 °C to ensure complete oxidation. Sodium chloride is added to saturate the aqueous phase, the organic phase is separated, and the aqueous phase is extracted with dichloromethane (3 × 200 ml). The organic phases are combined and dried with sodium sulfate. The solvent is evaporated to give a mixture of the pure phenylethanols: *1-phenylethanol* (13.5%) and *2-phenylethanol* (86.4%), as determined by G.L.C. analysis (carbowax 20M, 20% on chromosorb W, 80–100 mesh); yield: 10.4 g (89%); b.p. 95 °C/10 torr.

3-Phenyl-2-propenol (Cinnamyl Alcohol) from Cinnamaldehyde; Typical Reduction (Hydroboration-Hydrolysis) Procedure:

A dry 100 ml flask equipped with stirrer, septum inlet, and nitrogen inlet and outlet (the latter is connected to a mercury gasimeter) is flushed with dry nitrogen and maintained under a static pressure of nitrogen. The flask is charged with a 1.3 molar solution (15.4 ml, 0.02 mol) of 1-pyrrolylborane (**1**) in tetrahydrofuran, and cooled to 0 °C. Then, cinnamaldehyde (4.62 g, 0.035 mol) is added and stirring is continued for 3 h at 0 °C. 2 Normal hydrochloric acid (10 ml) is then added with stirring. The aqueous phase is saturated with potassium carbonate, the organic phase is separated, and the aqueous phase is extracted with dichloromethane (3 × 200 ml). The organic phases are combined and dried with sodium sulfate. The solvent is evaporated to give crystalline *3-phenyl-2-propenol*; yield: 4.05 g (88%); m.p. 31 °C (Ref.[12], m.p. 34 °C); m.p. after one recrystallization from ethyl ether/pentane: 33 °C.The product is pure according to G.L.C. analysis (OV-17, 10% on gaschrom Q, 80–100 mesh).

Received: December 28, 1979
(Revised form: May 13, 1980)

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