withdrawn and transferred to a flask attached to a trap. The volatiles were collected in this trap at −196 °C and then warmed to room temperature and analyzed by infrared spectroscopy. The results are summarized in Table VIII.

Preparation of CH_3CN Solutions of $Fe(CO)_4(NCCH_3)$ Using $(CH_3)_3NO$. Trimethylamine *N*-oxide (40 mg, 0.53 mmol) was placed in a pressure-equalizing dropping funnel atop a standard Schlenk flask. The system was evacuated and purged with N_2 several times. Pentacarbonyliron (0.05 mL, 0.37 mmol) and CH_3CN (10 mL) were added via syringe to the Schlenk flask and CH_3CN (10 mL) to the dropping funnel. The $(CH_3)_3NO$ solution was added dropwise to the $Fe(CO)_5$ solution with stirring. Slow addition results in clean conversion to a product showing ν_{CO} at 2060 (m) and 1955 (s, br) cm^{-1}.

The addition is continued until no $Fe(CO)_5$ remains as monitored by infrared. Attempts to isolate the product by removing the solvent under vacuum resulted in decomposition. Likewise, addition of water yielded a precipitate which also underwent decomposition. Addition of PPh_3 to the CH_3CN solution showed no production of $Fe(CO)_4PPh_3$ after an hour; however, upon standing overnight a mixture of $Fe(CO)_4(PPh_3)$ and $Fe(CO)_3(PPh_3)_2$ resulted. No $Fe(CO)_5$ was observed to form when PPh_3 was present.

Use of $[HFe(CO)_4]^-/CH_3I$ Solutions for Generation of Substituted Iron Carbonyls. To a solution of $[Et_4N][HFe(CO)_4]$ in CH_2Cl_2 (0.10 g in 10 mL) containing added ligand L (L = PPh_3) was added ca. 0.25 mL of MeI. The solutions very quickly changed to yellow, and infrared spectra were taken. A mixture of $Fe(CO)_4L$ and $Fe(CO)_3L_2$ complexes was obtained.

Reaction of $Fe(CO)_5$ with CH_3I in CH_3CN. To an N_2-purged quartz reaction tube was placed in a water-cooled bath and irradiated with a 400-W Ace Hanovia mercury arc lamp for 24 h. At that time an aliquot was withdrawn and analyzed by quantitative infrared spectroscopy to give acetone in yields of 26 and 28% based on $Fe(CO)_5$ for two separate trials. In the absence of CH_3I, new metal carbonyl peaks at 2060 and 1955 cm^{-1} grew in.

Acknowledgment. This work has been supported by the Robert A. Welch Foundation (K.H.W.). The infrared spectrometer used in this work was purchased under a grant from the Atlantic Richfield Foundation under the auspices of the Research Corp. (K.H.W.). T.R.L. also acknowledges the Robert A. Welch Foundation for an undergraduate fellowship. We would also like to thank Professor Marcetta Y. Darensbourg for communication of results prior to publication. We are also indebted to her for the GC analysis of the methylcyclopropane/1-butene product mixture. Professor Jack R. Norton is also to be recognized for insightful discussion. C. B. Lagrone is acknowledged for assisting with the manuscript preparation.

Registry No. $[Et_4N][HFe(CO)_4]$, 25879-01-0; CH_3I, 74-88-4; C_2H_5I, 75-03-6; $(CH_3)_2CHI$, 75-30-9; $(CH_3)_2SO_4$, 77-78-1; $Fe(CO)_5$, 13463-40-6; $NCCH_3$, 75-05-8; $Fe(CO)_4(NCCH_3)$, 14741-66-3; 6-bromo-1-hexene, 2695-47-8; (bromomethyl)cyclopropane, 7051-34-5; 4-bromo-1-butene, 5162-44-7.

Organoboranes. 44. A More Convenient, Practical Route To Achieve the Homologation of Boronic Esters

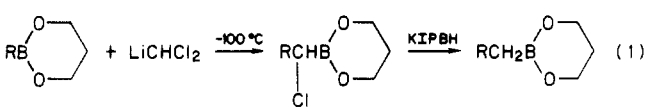
Herbert C. Brown* and Shankar M. Singh

Richard B. Wetherill Laboratory, Purdue University, West Lafayette, Indiana 47907

Received August 20, 1985

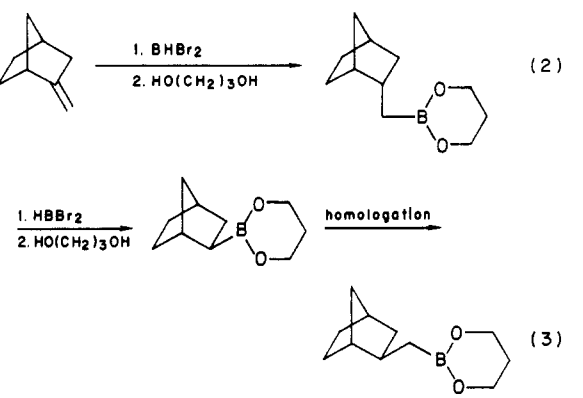
A more practical procedure has been developed for the homologation of boronic esters, utilizing the in situ formation of (dichloromethyl)lithium at −78 °C from dichloromethane and one of the bases, lithium diisopropylamide (LDA) or lithium 2,2′,6,6′-tetramethylpiperidide (LTMP), followed by in situ reduction of the α-chloroboronic ester intermediates with potassium triisopropoxyborohydride (KIPBH). This procedure is relatively more practical for large-scale applications and avoids both the low temperature (−100 °C) and the use of an equivalent of alkyllithium required by the earlier procedure. The reaction is broadly applicable to many of the boronic esters tested with the earlier procedure.

Previously the homologation of organylboronic esters was achieved with (dichloromethyl)lithium[1] (prepared at −100 °C from dichloromethane and *n*-butyllithium), followed by reduction of the intermediate with KIPBH[2] (eq 1).



(1)

This reaction has proven to be of considerable value in permitting the syntheses of boron derivatives not available through hydroboration. Thus, the hydroboration of 2-methylenenorbornane would proceed from the exo direction to yield the endo product, while the homologation of the hydroborated norbornene derivative affords the exo derivative (eq 2 and 3). Similarly, the hydroboration of



2-methylmethylenecyclopentane furnishes a mixture predominating in the cis isomer whereas the homologation of

(1) (a) Matteson, D. S.; Majumdar, D. *J. Am. Chem. Soc.* **1980**, *102*, 7588. (b) *Organometallics* **1983**, *2*, 1529.
(2) Brown, H. C.; Naik, R. G.; Singaram, B.; Pyun, C. *Organometallics*, in press.

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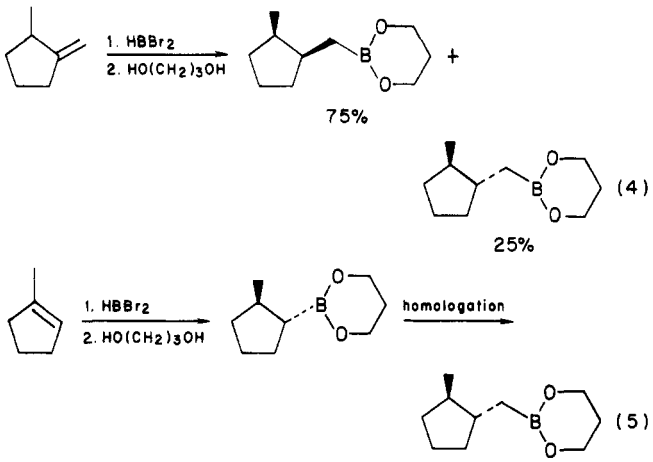
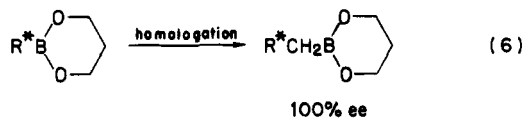
the hydroboration product gives only the trans isomer (eq 4 and 5).

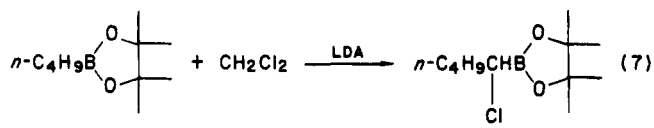


The above homologation method has also proven enormously promising in homologating chiral derivatives. Thus, the homologation of chiral boronic esters gives one-carbon-extended chiral boronic esters in essentially 100% ee[3] (ee = enantiomeric excess) (eq 6).

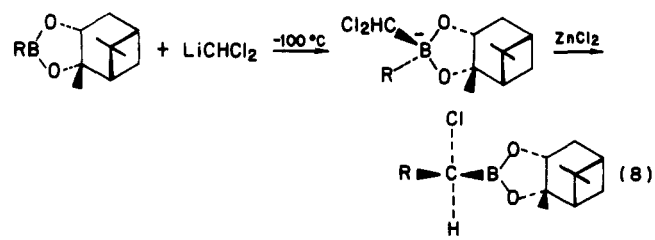


However, the generation of (dichloromethyl)lithium and its subsequent reaction with the organylboronic esters requires a temperature of −100 °C.[4] This rigorous requirement for temperatures of −100 °C or below makes the above method impractical for large-scale preparations.

Matteson and his co-workers[1] reported in their original study that it was possible to synthesize (dichloromethyl)lithium in the presence of a highly hindered boronic ester by the reaction of lithium diisopropylamide with dichloromethane at −78 °C. The reagent thus formed reacted satisfactorily with the boronic ester used in the case reported to yield the α-chloroboronic ester (eq 7).



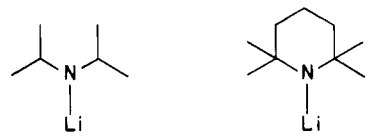
Matteson later reported to us that they had not explored this possible synthesis because the presence of the diisopropylamine in the reaction mixture interfered with an essential reagent. They were primarily interested in applying the chloromethylation reaction to boronic esters containing the chiral auxiliary pinanediol. To achieve the highest possible asymmetric synthesis, zinc chloride was necessary to facilitate the rearrangement of the intermediate borate complex[5] (eq 8). The diisopropylamine,



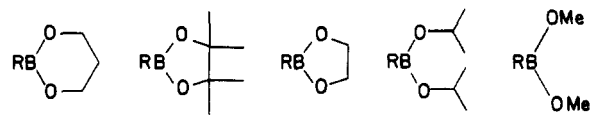
present in the reaction mixture, must coordinate with the zinc chloride and prevent the latter from exerting its catalytic effect[6] (eq 9).

We decided to explore this reaction as a possible solution to the problem of providing a practical procedure for the homologation of organylboronic esters. Since KIPBH does not react with secondary amines,[7] it appeared to us that the presence of secondary amine might not cause any difficulty in our procedure, in contrast to that encountered by the Matteson synthesis.

Accordingly, we decided to test two bases: lithium diisopropylamide (LDA) and lithium 2,2′,6,6′-tetramethylpiperidide (LTMP)



with dichloromethane at −78 °C in the presence of a select group of boronic esters.



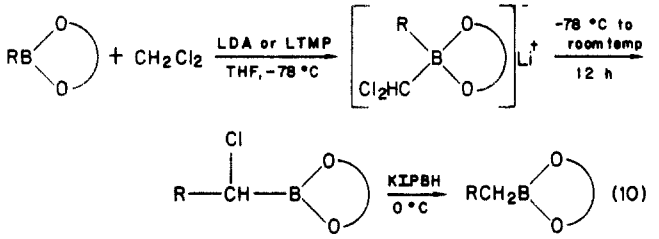
Indeed, it proved possible to develop a much simpler procedure for the homologation reaction than that previously utilized. In addition, it should be noted that LDA and LTMP can be prepared from the more economical reagent lithium,[8] avoiding the use of the more expensive reagent *n*-butyllithium.

Results and Discussion

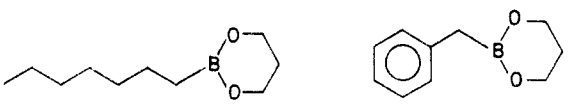
The alkylboronic esters were prepared by the hydroboration of alkenes with dibromoborane–dimethyl sulfide, followed by alcoholysis.[9] Phenyl-1,3-dioxaborinane was prepared by the procedure reported in the literature.[10]

For our preliminary study, 2-(1-hexyl)-1,3-dioxaborinane was chosen. To a mixture of dichloromethane and boronic ester in tetrahydrofuran (THF) was added a freshly prepared solution of lithium diisopropylamide dropwise at −78 °C, and the reaction mixture was subsequently allowed to warm up to room temperature over a period of 12 h. The ^{11}B NMR spectrum of the reaction mixture revealed the formation of 2-(1-chloro-1-heptyl)-1,3-dioxaborinane (δ +27). This also cleanly shows that the diisopropylamine formed in the course of the reaction neither complexes with the product nor reacts with the α-chloro substituent. The intermediate α-chloroboronic ester was reduced in situ in 2 h by adding a slight excess of KIPBH at 0 °C. At that time, the ^{11}B NMR spectrum of an aliquot of the reaction mixture showed the clean formation of 2-(1-heptyl)-1,3-dioxaborinane (δ 30–31) and triisopropoxyborane (δ +18). Evaporation of the solvent yielded the crude one-carbon-homologated boronic ester (eq 10). The crude 2-(1-heptyl)-1,3-dioxaborinane containing triisopropoxyborane

(3) Brown, H. C.; Naik, R. G.; Bakshi, R. K.; Pyun, C.; Singaram, C., submitted for publication.
(4) Dichloromethyllithium is unstable above −100 °C. See ref 1 and the references cited therein.
(5) Matteson, D. S.; Sadhu, K. M. *J. Am. Chem. Soc.* **1983**, *105*, 2077.
(6) Matteson, D. S., personal communication.
(7) Brown, H. C.; Cha, J. S.; Nazer, B.; Kim, S. C.; Krishnamurthy, S. *J. Org. Chem.* **1984**, *49*, 885.
(8) Reetz, M. T.; Maier, W. F. *Justus Liebigs Ann. Chem.* **1980**, 1471.
(9) Brown, H. C.; Bhat, N. G.; Somayaji, V. *Organometallics* **1983**, *2*, 1311.
(10) Brown, H. C.; Cole, T. E. *Organometallics*, **1983**, *2*, 1316.

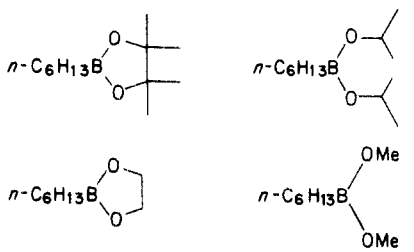


as the byproduct was treated with water to remove the triisopropoxyborane, and the *n*-heptylboronic acid thus obtained was reesterified with 1,3-propanediol.[9] Distillation of the residue gave pure 2-(1-heptyl)-1,3-dioxaborinane in excellent yield. Similarly, 2-benzyl-1,3-dioxaborinane was also prepared in high yield.



Since these organylboronic esters have been isolated and characterized in our laboratory,[2,3] we decided to determine the yields and purities of these homologated boronic esters by oxidation and GC identification and analysis of the alcohols produced. The results are summarized in Tables I and II.

To establish the generality of this homologation reaction, we decided to vary (1) the boronic ester grouping and (2) the organyl moiety on boron. Accordingly, we applied the above procedure to the following boronic esters in which the ester groupings were varied.



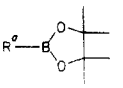
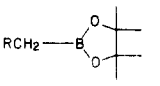
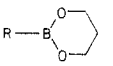
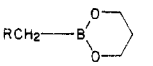
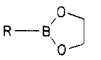
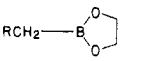
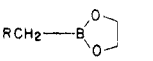
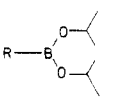
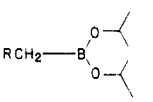
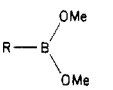
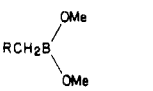
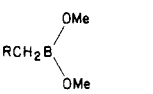
Sterically hindered boronic esters were first examined. Thus, 2-(1-hexyl)-4,4′,5,5′-tetramethyl-1,3-dioxaborolane and diisopropyl *n*-hexylboronate were next homologated with (dichloromethyl)lithium to afford 1-heptanol in excellent yields. However, 2-(1-hexyl)-1,3-dioxaborolane and dimethyl *n*-hexylboronate, sterically less hindered than 2-(1-hexyl)-1,3-dioxaborinane, gave 1-heptanol in only moderate yields. At this point, we thought it might be possible to improve the yield of the homologated boronic ester by using a more hindered base to generate (dichloromethyl)lithium. Indeed, the use of lithium 2,2′,6,6′-tetramethylpiperidide provided one-carbon-homologated alcohols in high yields, even with less hindered boronic esters (Table I).

Next, we varied the organyl moiety on boron. For this study, we chose the 1,3-dioxaborinane grouping for all boronic esters because of its wider accessibility and the high yield of the homologated product with the more accessible base LDA. It was established that all of the 1,3-dioxaborinanes examined with various organic groups attached to boron, including primary, secondary, cyclic, bicyclic, and aryl, can be homologated to the desired boronic esters in reasonable yields (Table II).

Conclusion

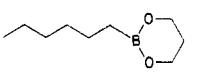
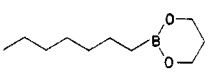
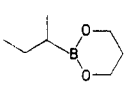
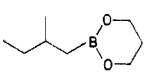
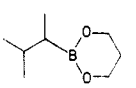
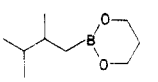
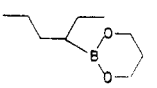
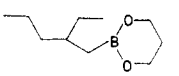
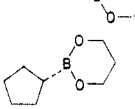
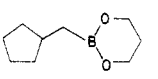
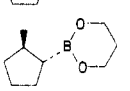
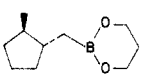
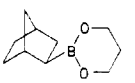
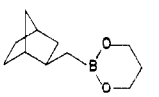
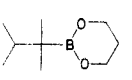
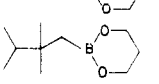
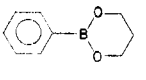
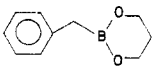
Using the present homologation procedure, it is now possible to achieve one-carbon homologation of organylboronic esters by a simple, convenient, and efficient procedure. Even less hindered boronic esters can be successfully homologated with use of LTMP, a more hindered base than LDA. This sequence is very attractive for the

Table I. Homologation of *n*-Hexylboronic Esters with CH_2Cl_2/Base

boronic ester	base	homologated boronic ester[d]	yield,[e] %
	LDA[b]		81
	LDA		85
	LDA		57
	LTMP[c]		79
	LDA		71
	LDA		45
	LTMP		83

[a] R = *n*-hexyl. [b] LDA = lithium diisopropylamide. [c] LTMP = lithium 2,2′,6,6′-tetramethylpiperidide. [d] Alkaline H_2O_2 oxidation gives 1-heptanol. [e] GC analyses of the alcohols were done on 5% Carbowax 20M on Chromosorb W (12 ft × $^1/_8$ in.) column using *n*-hexadecane as the internal standard.

Table II. Homologation of Organyl-1,3-dioxaborinane with CH_2Cl_2/LDA

RB	RCH_2B	yield,[b] %
		85 (81)
		83
		82
		87
		76
		79
		79
		15
		75[c] (70)

[a] Yield of alcohols after oxidation with alkaline H_2O_2. [b] GC analyses of the alcohols were carried out on 5% Carbowax 20M on Chromosorb W (12 ft × $^1/_8$ in.) column and each alcohol was identified by GC coinjection with an authentic sample. The yield in parentheses refers to isolated yield of boronic ester. [c] Isolated yield.

economical synthesis on a large scale of homologated boronic acids and esters not available by simple, direct hydroboration.

Experimental Section

All operations were carried out under a nitrogen atmosphere with oven-dried glassware.[11] IR spectra were recorded on a Perkin-Elmer 1420 ratio recording spectrophotometer. ^{1}H NMR spectra were recorded on a Varian T-60 (60-MHz) spectrometer. ^{11}B NMR spectra were recorded on a Varian FT-80A instrument. The GC analyses were carried out on a Varian 1200 research chromatograph equipped with a flame ionization detector (columns 12 ft × $^1/_8$ in. packed with 5% Carbowax 20M on Chromosorb W and with 5% SE-30 on Chromosorb W AW DMCS).

Materials. Tetrahydrofuran (THF) was freshly distilled from sodium benzophenone ketyl prior to use. Dichloromethane was distilled over P_2O_5 and stored over 4-Å molecular sieves. Diisopropylamine and 2,2',6,6'-tetramethylpiperidine were distilled over calcium hydride. Potassium triisopropoxyborohydride (KIPBH) in THF was purchased from Aldrich Chemical Co.

Organylboronic Esters. The boronic esters were prepared by the hydroboration of alkenes with dibromoborane–dimethyl sulfide, followed by alcoholysis.[9] Phenyl-1,3-dioxaborinane was prepared by the procedure reported in the literature.[10]

Homologation of 2-(1-Hexyl)-1,3-dioxaborinane. Freshly prepared lithium diisopropylamide (28 mmol) was added dropwise to a mixture of dichloromethane (2 mL, 30 mmol) and 2-(1-hexyl)-1,3-dioxaborinane (3.4 g, 20 mmol) in THF (28 mL) at −78 °C. After the addition, the reaction mixture was allowed to warm up to room temperature over a period of 12 h. The ^{11}B NMR spectrum of the reaction mixture revealed the formation of 2-(1-chloro-1-heptyl)-1,3-dioxaborinane (δ +27). The intermediate α-chloroboronic ester was reduced without isolating with KIPBH (17.5 mL, 22 mmol) at 0 °C in 2 h, as indicated by the ^{11}B NMR analysis (δ 30–31). The solvent was removed at reduced pressure (12 torr), and the residue thus obtained was stirred with water (20 mL) for 1 h to hydrolyze triisopropoxyborane and the product. The reaction mixture was extracted with ether (5 × 25 mL), washed twice with water, and dried ($MgSO_4$). Evaporation of the solvent afforded the crude *n*-heptylboronic acid which was reesterified with 1,3-propanediol[9] and distilled under high vacuum.

2-(1-Heptyl)-1,3-dioxaborinane: 81% yield; bp 75 °C (2 torr); ^{1}H NMR ($CDCl_3$) δ 0.36–1.6 (m, 15 H), 1.9 (q, J = 6 Hz, 2 H), 3.93 (t, J = 6 Hz, 4 H).

Homologation of 2-(Phenyl)-1,3-dioxaborinane. To a mixture of 2-phenyl-1,3-dioxaborinane (2.43 g, 15 mmol) and dichloromethane (1.5 mL, 22.5 mmol) in THF (21 mL) at −78 °C was added freshly prepared lithium diisopropylamide (21 mmol) dropwise over a period of 20 min. After the addition, the contents were stirred for 12 h at −78 °C to room temperature to complete the rearrangement of the borate complex. The intermediate α-chloroboronic ester (δ +27) was reduced with KIPBH (13 mL, 16.5 mmol) at 0 °C in 2 h as revealed by the ^{11}B NMR analysis (δ +30.5). The solvent was removed at reduced pressure, and the products thus obtained were stirred with water (20 mL) for 1 h to hydrolyze triisopropoxyborane. The aqueous solution was extracted with ether (5 × 25 mL), washed with water (2 × 30 mL), and dried ($MgSO_4$). Evaporation of the solvent yielded the crude benzylboronic acid, which was reesterified with 1,3-propanediol and purified by distillation.

2-Benzyl-1,3-dioxaborinane: 70% yield; bp 75 °C (0.3 torr); ^{1}H NMR ($CDCl_3$) δ 1.86 (q, J = 6 Hz, 2 H), 2.2 (s, 2 H), 3.93 (t, J = 6 Hz, 4 H), 7.16 (m, 5 H).

Characterization of the Homologated Products by Oxidation. The other boronic esters homologated (Tables I and II) were not isolated but characterized by oxidation with alkaline hydrogen peroxide. The alcohols produced were characterized by GC examination, and the yield was established by analysis of the alcohols (Tables I and II).

Acknowledgment. We are grateful to the National Science Foundation (Grant CHE 8414171) for their generous support of this work.

Registry No. CH_2Cl_2, 75-09-2; LDA, 4111-54-0; LTMP, 38227-87-1; KIPBH, 42278-67-1; 2-(1-hexyl)-1,3-dioxaborinane, 86290-24-6; 2-(1-methylpropyl)-1,3-dioxaborinane, 30169-72-3; 2-(1,2-dimethylpropyl)-1,3-dioxaborinane, 98303-38-9; 2-(1-ethylbutyl)-1,3-dioxaborinane, 86290-28-0; 2-cyclopentyl-1,2-dioxaborinane, 30169-74-5; *trans*-2-(2-methylcyclopentyl)-1,3-dioxaborinane, 86290-31-5; *exo*-2-(2-bornyl)-1,3-dioxaborinane, 30154-25-7; 2-(1,2,2-trimethylpropyl)-1,3-dioxaborinane, 63689-74-7; 2-phenyl-1,3-dioxaborinane, 4406-77-3; 2-(1-hexyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane, 86308-26-1; 2-(1-hexyl)-1,3,2-dioxaborolane, 86290-25-7; diisopropyl *n*-hexylboronate, 86290-26-8; dimethyl *n*-hexylboronate, 2344-23-2; 2-(1-heptyl)-1,3-dioxaborinane, 101031-41-8; 2-(2-methylbutyl)-1,3-dioxaborinane, 101031-42-9; 2-(2,3-dimethylbutyl)-1,3-dioxaborinane, 98303-39-0; 2-(2-ethylpentyl)-1,3-dioxaborinane, 98303-40-3; 2-(cyclopentylmethyl)-1,3-dioxaborinane, 101031-43-0; *trans*-2-(2-methylcyclopentylmethyl)-1,3-dioxaborinane, 98303-41-4; *exo*-2-(2-bornylmethyl)-1,3-dioxaborinane, 98303-43-6; 2-(2,2,3-trimethylbutyl)-1,3-dioxaborinane, 101031-44-1; 2-benzyl-1,3-dioxaborinane, 62930-28-3; 2-(1-heptyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane, 101031-45-2; 2-(1-heptyl)-1,3,2-dioxaborolane, 101031-46-3; diisopropyl *n*-heptylboronate, 101031-47-4; dimethyl *n*-heptylboronate, 101031-48-5.

(11) Brown, H. C.; Kramer, G. W.; Levy, A. B.; Midland, M. M. "Organic Syntheses via Boranes"; Wiley-Interscience: New York, 1975.