Organoboranes. 48. Improved Procedures for the Preparation of Boronic and Borinic Esters

Herbert C. Brown,* Morris Srebnik,[1a] and Thomas E. Cole[1b]

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

Received April 9, 1986

Two improved procedures for liberating boronic, $RB(O\text{-}i\text{-}Pr)_2$, and borinic, $RR'BO\text{-}i\text{-}Pr$, esters from their "ate" complexes, free of isopropyl alcohol, have been developed. Pyrolysis of lithium organylborates, $LiRB(O\text{-}i\text{-}Pr)_3$ and $LiRR'B(O\text{-}i\text{-}Pr)$, directly yields the relatively volatile boronic and borinic esters in high purity, leaving behind a residue of lithium isopropoxide. Treatment of the lithium organylborates with appropriate acid chlorides, usually acetyl or benzoyl, cleanly liberates either volatile or nonvolatile boronic or borinic esters, readily separated from the isopropyl ester produced as a byproduct. These developments greatly facilitate the preparation of boronic and borinic esters in high purity.

This last decade has witnessed an increased interest in the chemistry and synthetic utility of boronic and borinic acids and esters.[2] Although numerous methods are available for the preparation of boronic and borinic acids and esters, the yields are frequently quite unsatisfactory. For example, the addition of Grignard reagents to trialkoxyboranes at low temperatures, followed by dilute acid hydrolysis, yields the boronic acids.[3] However, low yields are generally obtained for smaller alkyl groups and a tedious isolation procedure is necessary to isolate the esters. The redistribution of triorganylboranes with trialkoxyboranes and trihaloboranes has also been employed.[4,5] Other less direct routes utilizing haloboranes,[6] catecholborane[7] and thexylborane[8] have been described. Boronic acids and esters have been prepared by the reaction of trialkylboranes with alcohols[9] and aldehydes[10] and the thermal redistribution with boron trichloride or trialkoxyboranes. Alternatively, the preparation of symmetrical borinic acids and esters can be obtained via hydroboration using haloboranes, BH_2Cl or BH_2Br, followed by hydrolysis or alcoholysis[11] or by the stepwise hydridation–hydroboration of alkyldihaloboranes.[12] As part of our ongoing research efforts to develop new methodologies for the preparation of organoboranes, we have recently reported a simple and rational approach to boronic[13] and borinic[14] esters via the stepwise addition of an organolithium reagent to triisopropoxyborane (eq 1) and to organyldiisopropoxyborane (eq 2), followed by addition of hydrogen chloride in ethyl ether, to yield the corresponding boronic and borinic esters.

$$LiR + B(O\text{-}i\text{-}Pr)_3 \rightarrow LiRB(O\text{-}i\text{-}Pr)_3 \xrightarrow{HCl/EE} RB(O\text{-}i\text{-}Pr)_2 + LiCl + i\text{-}PrOH \quad (1)$$

$$LiR' + RB(O\text{-}i\text{-}Pr)_2 \rightarrow LiRR'B(O\text{-}i\text{-}Pr)_2 \xrightarrow{HCl/EE} RR'BO\text{-}i\text{-}Pr + LiCl + i\text{-}PrOH \quad (2)$$

While the above procedure is applicable in most cases, the 2-propanol formed as the byproduct can form azeotropes with the boronic and borinic esters and thus complicate their isolation from the reaction mixture. Additionally, the isolation of the more volatile boronic and boronic esters, i.e., methyldiisopropoxyborane (bp 105–107 °C) and dimethylisopropoxyborane (bp 52–54 °C) is hampered by the presence of 2-propanol (bp 82 °C) of comparable volatility. A more direct approach to these important intermediates, avoiding the coformation of 2-propanol, would offer major advantages.

In this paper we describe two improved procedures for the high-yield preparation of relatively volatile boronic and borinic esters. One route involves the thermal dissociation of the corresponding lithium "ate" complexes (eq 3 and 4).

$$LiRB(O\text{-}i\text{-}Pr)_3 \xrightarrow{\Delta} RB(O\text{-}i\text{-}Pr)_2 + LiO\text{-}i\text{-}Pr \quad (3)$$

$$LiRR'B(O\text{-}i\text{-}Pr)_2 \xrightarrow{\Delta} RR'BO\text{-}i\text{-}Pr + LiO\text{-}i\text{-}Pr \quad (4)$$

In the second route, the "ate" complex is treated with an acid chloride selected so that the isopropyl ester produced can be readily separated by distillation from the desired boronic or borinic ester (eq 5 and 6). This procedure is more general than the thermal dissociation me-

$$LiRB(O\text{-}i\text{-}Pr)_3 + R''C(O)Cl \rightarrow RB(O\text{-}i\text{-}Pr)_2 + R''C(O)O\text{-}i\text{-}Pr + LiCl \quad (5)$$

$$LiRR'B(O\text{-}i\text{-}Pr)_2 + R''C(O)Cl \rightarrow RR'BO\text{-}i\text{-}Pr + R''C(O)O\text{-}i\text{-}Pr + LiCl \quad (6)$$

(1) (a) Lady Davis Fellow, 1984–1985, Hebrew University in Jerusalem. (b) Purdue University Research Associate.

(2) (a) For the preparation of (α-bromoalkyl)boronate, see: Pasto, D. J.; McReynolds, K. *Tetrahedron Lett.* **1971**, 801. Pasto, D. J.; Chow, J.; Arora, S. K. *Tetrahedron* **1969**, *25*, 1557. (b) For aryl halides from arylboronic acids, see: Mikhailov, B. M.; Bubnov, Yu. N. *Organoborane Compounds in Organic Synthesis*; Harwood: London, 1984; Chapter 8, p 303 and references cited therein. (c) Carbon–carbon bond formation: Matteson, D. S.; Majumdar, D. J. *J. Am. Chem. Soc.* **1980**, *102*, 7588. Brown, H. C.; Imai, T. *Ibid.* **1983**, *105*, 6285. (d) Unsymmetrical biaryls: Sharp, M. J.; Sniekus, V. *Tetrahedron Lett.* **1985**, *26*, 5997. (e) Optically active compounds: Brown, H. C.; Singaram, B. *J. Am. Chem. Soc.* **1984**, *106*, 1797. Matteson, D. S.; Sadhu, K. M.; Ray, R.; Peterson, M. J.; Majumdar, D.; Hurst, G. D.; Jesthi, P. K.; Tsai, D. J. S.; Erdik, E. *Pure Appl. Chem.* **1985**, *57*, 1741. (f) Biologically active compounds: Kinder, D. H.; Katzenellbogen, J. A. *J. Med. Chem.* **1985**, *28*, 1917.

(3) (a) Washburn, R. M.; Levens, E.; Albright, C. F.; Billig, F. A.; Cernak, E. S. *Adv. Chem. Ser.* **1959**, *No. 23*, 102. (b) McCusker, P. A.; Ashby, E. C.; Makowski, H. S. *J. Am. Chem. Soc.* **1957**, *79*, 5179. (c) Snyder, H. R.; Kuck, J. A.; Johnson, J. R. *Ibid.* **1938**, *60*, 105. (d) Mattraw, H. C.; Erickson, C. E.; Laubengayer, A. W. *Ibid.* **1956**, *78*, 4901.

(4) Köster, R.; Grassberger, M. A. *Liebigs Ann. Chem.* **1968**, *719*, 169.

(5) (a) Brown, H. C.; Gupta, S. K. *J. Am. Chem. Soc.* **1970**, *92*, 6983. (b) Brown, H. C.; Levy, A. B. *J. Organomet. Chem.* **1972**, *44*, 233. (c) Brown, H. C.; Basavaiah, D.; Bhat, N. G. *Organometallics* **1983**, *2*, 1309.

(6) Brown, H. C.; Ravindran, N. *J. Am. Chem. Soc.* **1976**, *98*, 1785.

(7) Brown, H. C.; Ravindran, N.; Kulkarni, S. U. *J. Org. Chem.* **1980**, *45*, 384.

(8) (a) Lane, C. F.; Kabalka, G. W. *Tetrahedron* **1976**, *32*, 981. (b) Kabalka, G. W. *Org. Prep. Proced. Int.* **1977**, *9*, 133.

(9) Johnson, J. R.; Van Campen, M. G. *J. Chem. Soc.* **1938**, *60*, 121.

(10) Meerwein, H.; Hinz, G.; Majert, H.; Sonke, H. *J. Prakt. Chem.* **1937**, *147*, 226.

(11) Brown, H. C.; Ravindran, N. *J. Am. Chem. Soc.* **1972**, *94*, 2112.

(12) Kulkarni, S. U.; Basavaiah, D.; Zaidlewicz, M.; Brown, H. C. *Organometallics* **1982**, *1*, 212.

(13) Brown, H. C.; Cole, T. E. *Organometallics* **1983**, *2*, 1316.

(14) Brown, H. C.; Cole, T. E.; Srebnik, M. *Organometallics* **1985**, *4*, 1788.

0276-7333/86/2305-2300$01.50/0

Table I. Thermal Decomposition of Lithium Organyltriisopropoxyborates and Lithium Diorganyldiisopropoxyborates

lithium borate	temp for thermal decomp, °C	borane	scale, mmol	isolated yield, %
lithium methyltriisopropoxyborate	120	methyldiisopropoxyborane	50–500	91–96
lithium isopropyltriisopropoxyborate	≤25	isopropyldiisopropoxyborane	100	95
lithium *n*-butyltriisopropoxyborate	120	*n*-butyldiisopropoxyborane	218–250	92–95
lithium *sec*-butyltriisopropoxyborate	≤25	*sec*-butyldiisopropoxyborane	50–250	90–96
lithium *tert*-butyltriisopropoxyborate	≤25	*tert*-butyldiisopropoxyborane	50	89
lithium phenyltriisopropoxyborate	120	phenyldiisopropoxyborane	100	86
lithium dimethyldiisopropoxyborate	50	dimethylisopropoxyborane	38	92
lithium *tert*-butylmethyldiisopropoxyborate	≤25	*tert*-butylmethylisopropoxyborane	50	73

thod. It can be used to prepare either volatile or nonvolatile boronic or borinic esters. In practice, acetyl chloride can be used for the less volatile derivatives and benzoyl chloride for the more volatile derivatives.

Results and Discussion

The preparation of boronic and borinic esters by pyrolysis of metal "ate" complexes has received little attention. Generally magnesium salts (and less so, sodium salts) have been employed.[15] The yields of boronic and borinic esters have been variable and very low. This is not surprising as it has been observed that dilute acid hydrolysis of magnesium "ate" complexes is essential in order to obtain respectable yields of complex-free esters.[16] The pyrolysis of the corresponding lithium complexes has not been reported.

When the "ate" complexes obtained from methyllithium and triisopropoxyborane or methyllithium and methyldiisopropoxyborane were heated under vacuum in the absence of solvent, pure methyldiisopropoxyborane and dimethylisopropoxyborane were readily obtained in yields of 96% and 93%, respectively. The purity, as determined by ^{11}B NMR, was ≥99%. Solid lithium isopropoxide was recovered quantitatively from the pyrolysis flask.

Similarly, the pyrolysis of various lithium organyltriisopropoxyborates and lithium diorganyldiisopropoxyborates derived from readily available organolithium reagents furnished excellent isolated yields of boronic and borinic esters. The results are summarized in Table I.

^{11}B NMR analysis of the products indicated clean formation of boronic and borinic esters with only trace quantities of starting material detectable. Importantly, there is no observable isomerization of *tert*-butylboronic or -borinic ester, as detected by oxidation to the alcohol or by ^{1}H NMR, which has been reported by others.[3b,17] To minimize possible redistribution reactions, thermolysis was restricted to temperatures below 170 °C. This proved adequate even for the phenylboronic esters.

The stability of the lithium organyltriisopropoxyborates and lithium diorganyldiisopropoxyborates depends on both steric and electronic factors. For example, lithium methyl-, *n*-butyl-, and phenyltriisopropoxyborates are white solids at room temperature, as is lithium dimethyldiisopropoxyborate.[18] Substitution by a branched alkyl group decreases the stability of the addition complex. Elimination of lithium isopropoxide occurs at or below room temperature, as indicated by ^{11}B NMR analysis of the reaction mixture (Table II). A phenyl group stabilizes the "ate" complex relative to an alkyl group. For example, lithium phenylisopropyldiisopropoxyborate is stable at 25 °C (δ 7.00), while lithium cyclohexylisopropylborate is essentially completely dissociated to borinic ester (δ 51.3).

Table II. ^{11}B NMR Chemical Shifts of Lithium Organyl- and Diorganylborates at 25 °C in Diethyl Ether

lithium borate	δ
lithium dimethyldiisopropoxyborate	5.8
lithium methylphenyldiisopropoxyborate	6.6
lithium isopropylphenyldiisopropoxyborate	7.0
lithium diphenyldiisopropoxyborate	6.41
lithium *tert*-butylmethyldiisopropoxyborate	52.9
lithium di-*tert*-butyldiisopropoxyborate	49.9
lithium cyclohexylisopropyldiisopropoxyborate	51.3
lithium *tert*-butylphenyldiisopropoxyborate	49.9
lithium methyltriisopropoxyborate	7.4
lithium *n*-butyltriisopropoxyborate	6.6
lithium phenyltriisopropoxyborate	4.5
lithium isopropyltriisopropoxyborate	30.5
lithium *sec*-butyltriisopropoxyborate	29.5
lithium *tert*-butyltriisopropoxyborate	29.5

On the other hand, increasing steric congestion around the boron can offset the influence of a phenyl group: lithium phenyl-*tert*-butyldiisopropoxyborate exists entirely as the borinate (δ 49.9) at room temperature. The relative stability of the lithium "ate" complexes is reflected in the temperature required for thermal diisociation (Table I).

Protonation of lithium "ate" complexes derived from isopropyl esters with hydrogen chloride in ethyl ether liberates 2-propanol (eq 1 and 2). The latter may form azeotropes with certain organoboranes and thus interferes with their isolation. In addition, the presence of 2-propanol can necessitate tedious fractional distillation of more volatile boronic and borinic esters (vide infra). These problems can be avoided by treating the lithium "ate" complexes with an appropriate acid chloride. Thus addition of benzoyl chloride to lithium dimethyldiisopropoxyborane (eq 7) yields isopropyl benzoate (bp 218 °C) as a byproduct, easily separated from dimethylisopropoxyborane (bp 52–54 °C).

$$LiMe_2B(O\text{-}i\text{-}Pr)_2 + PhCOCl \rightarrow Me_2BO\text{-}i\text{-}Pr + PhCO_2\text{-}i\text{-}Pr + LiCl \quad (7)$$

Conversely, less volatile boronic and borinic esters, i.e., 2-furyldiisopropoxyborane or diphenylisopropoxyborane can be conveniently isolated by addition of acetyl chloride to the lithium complexes. Using these acid chlorides, we have obtained excellent isolated yields of boronic and borinic esters. The volatile byproduct, isopropyl acetate, bp 86 °C, is readily separated from higher boiling boronic and borinic esters, and we have not encountered azeotrope formation between the boronic or borinic esters and the carboxylic ester byproducts. The results are tabulated in Table III. A further advantage of the acid chloride procedure is the convenience of using neat reagent instead of a standardized solution of hydrogen chloride in ethyl ether.

(15) (a) Woods, W. G.; Strong, P. L. *J. Organomet. Chem.* **1967**, *7*, 371. (b) Woods, W. G.; Bengelsdorf, I. S.; Hunter, D. L. *J. Org. Chem.* **1966**, *31*, 7766.

(16) Köster, R. in *Houben-Weyl: Methoden der Organischen Chemie*; Georg Thieme Verlag: Stuttgart, 1982; Vol. 1, Chapter 4, p 755.

(17) (a) Kramer, G. W.; Brown, H. C. *J. Organomet. Chem.* **1974**, *73*, 1. (b) McCusker, P. A.; Marra, J. V.; Hennion, G. F. *J. Am. Chem. Soc.* **1961**, *83*, 1924.

(18) Generally lithium diorganyldiisopropoxyborates are soluble in diethyl ether. The solids are obtained after removal of solvents.

Table III. Decomposition of Lithium Organyl- and Diorganylborates with Acid Chlorides

lithium borate	acid chloride	borane	^{11}B NMR δ	bp, °C (mmHg)	isolated yield, %
lithium phenyltriisopropoxyborate	acetyl chloride	phenyldiisopropoxyborane	28.0	98–100 (8)	84
lithium 2-furyltriisopropoxyborate	acetyl chloride	2-furyldiisopropoxyborane	23.3	76–78 (15)	74
lithium dimethyldiisopropoxyborate	benzoyl chloride	dimethylisopropoxyborane	52.0	52–54 (758)	82
lithium phenylisopropyldiisopropoxyborate	acetyl chloride	phenylisopropylisopropoxyborane	48.6	106–108 (15)	84
lithium diphenyldiisopropoxyborate	acetyl chloride	diphenylisopropoxyborane	44.8	88 (0.1)	87

Conclusion

We have demonstrated the practical utility of thermal dissociation of lithium organyldiisopropoxyborates as a means of obtaining boronic and borinic esters in high purity and high yields on a preparative scale. Nonvolatile boronic and borinic esters can be obtained cleanly by treatment of their respective lithium "ate" complexes with acetyl chloride. Volatile boronic and borinic esters can be similarly isolated with benzoyl chloride. The above procedures offer distinct advantages in the ease of isolation for a large variety of these important boronic and borinic ester derivatives.

Experimental Section

Methods and Materials. All glassware was dried at 140 °C for at least 3 h and assembled hot under a stream of nitrogen.[19] Reactions were carried out under a static pressure of nitrogen. Anhydrous ethyl ether (Mallinckrodt) was stored over 4-Å molecular sieves under nitrogen and used without further purification. The organolithium reagents are commercial materials (Aldrich or Alfa), except for isopropyllithium, which was prepared according to the method of Gilman.[20] The concentrations were standardized prior to use, but the reagents were not purified further. Triisopropoxyborane, acetyl chloride, and benzoyl chloride (Aldrich) were distilled from calcium hydride and stored under nitrogen. ^{1}H NMR spectra were recorded on a Varian T-60 spectrometer relative to tetramethylsilane; ^{11}B NMR spectra were obtained on a Varian FT-80 spectrometer (25.517 MHz) relative to boron trifluoride etherate. Mass spectra were obtained on a Finnigan Model 4000 gas chromatographic mass spectrometer. Microanalyses were performed in house.

General Procedure for the Thermal Dissociation of Lithium Organyltriisopropoxyborates and Lithium Diorganyldiisopropoxyborates. The preparation of methyl diisopropoxyborane is typical. A 150-mL round-bottom flask containing a magnetic stirring bar and connected to a cold trap fitted with two stopcocks (closed) into which were placed loose wads of glass wool (to filter out lithium isopropoxide fines), and a side arm capped with a rubber septum was charged with triisopropoxyborane (9.81 g, 52.2 mmol) and 52 mL of ethyl ether. The flask was colled to −78 °C (acetone, dry ice), and methyllithium (37.3 mL, 52.2 mmol) was slowly added via a double-ended needle. During the addition, a white precipitate formed. Stirring was continued for an additional hour at −78 °C and then for 2 hours at ambient temperature. The outlet of the cold trap was connected to a water aspirator, the stopcocks were opened, and the vacuum was applied slowly so as to prevent frothing. After 2 h, the aspirator was replaced by a high vacuum pump (0.2 mmHg) and residual ethyl ether removed. The reaction flask was immersed in an oil bath and the cold trap cooled to −78 °C. The reaction mixture was heated (110–120 °C oil bath temperature) under vacuum (0.1–0.2 mmHg) for 3 h. During this time the flask was occasionally shaken to ensure proper stirring and heat transfer. The oil bath was removed, the stopcocks were closed, and the cold trap was filled with nitrogen. After the mixture was warmed to room temperature, the methyl diisopropoxyborane collected in the cold trap was transferred via a double-ended needle to a vial. Yield: 6.8 g (47.2 mmol, 90%). Proton NMR (neat): δ 4.30 (septet, J = 18 Hz, 2 H), 1.05 (d, J = 18 Hz, 12 H), 0.08 (b s, 3 H). Boron NMR (neat): +30.3 ppm (s). Methyl diisopropoxyborane has been prepared in 500-mmol runs in the same proportions as described above, with yields up to 96%.

Preparation of Isopropyldiisopropoxyborane. The reaction was conducted as described above with isopropyllithium (177 mL, 101 mmol) and triisopropoxyborane (19.0 g, 101 mmol). Solvent was removed at 0 °C and 15 mmHg. The oil bath was heated to 80 °C. Yield: 16.3 g (94.2 mmol, 93%), bp 138 °C (749 mmHg); n^{20}_D 1.3853. Proton NMR ($CDCl_3$): δ 4.40 (septet, J = 18 Hz, 2 H); 1.13 (d, J = 18 Hz, 12 H), 0.93 (b s, 7 H). Boron NMR (neat): +30.5 ppm (s). Anal. Calcd for $C_9H_{21}BO_2$: C, 62.80; H, 12.22; B, 6.29. Found: C, 62.59; H, 12.59; B, 5.93.

***n*-Butyldiisopropoxyborane.** Reaction performed as described above utilizing *n*-butyllithium (115 mL, 218 mmol) and triisopropoxyborane (41 g, 218 mmol) yielded *n*-butyldiisopropoxyborane: 37.3 g (291 mmol, 93%); proton NMR (neat) δ 4.20 (septet, J = 18 Hz, 2 H), 1.23–0.63 (m, 9 H) overlapped with isopropyl doublet at 0.98 (d, J = 18 Hz, 12 H); boron NMR (neat) +30.2 ppm (s).

***sec*-Butyldiisopropoxyborane.** The reaction was run as above with *sec*-butyllithium (208 mL, 250 mmol) and triisopropoxyborane (47.0 mL, 250 mmol). Solvents were removed at 0 °C and 15 mmHg. Oil bath temperature was maintained at 50 °C to furnish *sec*-butyldiisopropoxyborane: 42.0 g (206 mmol, 90%); bp 138–140 °C (754 mmHg); proton NMR (neat) δ 4.35 (septet, J = 18 Hz, 2 H), 1.09 (d, J = 18 Hz, 12 H), 0.8 (b m, 9 H); boron NMR (neat) +29.5 ppm (s).

***tert*-Butyldiisopropoxyborane.** The reaction was conducted as described above with *tert*-butyllithium (30.9 mL, 51 mmol) which was added to triisopropoxyborane (9.59 g, 51 mmol) in 51 mL of ethyl ether cooled to *−100 °C* instead of *−78 °C*. Solvents were removed at 0 °C and 15 mmHg. The oil bath was maintained at 50 °C to furnish *tert*-butyldiisopropoxyborane: 8.44 g (45.3 mmol, 89%); bp 136–138 °C (754 mmHg); proton NMR (neat) δ 4.50 (septet, J = 18 Hz, 2 H), 1.12 (d, J = 18 Hz, 12 H), 0.95 (s, 9 H); boron NMR (neat) δ +29.5 ppm (s).

Phenyldiisopropoxyborane. The reaction was conducted as described under the general procedure using phenyllithium (57 mL, 102 mmol) to yield phenyldiisopropoxyborane: 18.0 g (97.3 mmol, 86%); proton NMR (neat) δ 7.93 (m, 2 H), 7.57 (m, 3 H), 4.6 (septet, 2 H), 1.10 (d, 12 H); boron NMR (neat) δ +28 ppm (s).

***tert*-Butylmethylisopropoxyborane.** The reaction was run as described above utilizing methyllithium (38.4 mmol, 24.6 mL) and *tert*-butyldiosopropoxyborane (7.15 g, 38.4 mmol). Volatiles were removed at atmospheric pressure, and the product was distilled; yield 3.9 g (27.5 mmol, 73%); bp 90–92 °C (741 mmHg); proton NMR ($CDCl_3$) δ 4.30 (septet, J = 18 Hz, 1 H), 1.15 (d, J = 18 Hz, 6 H), 0.83 (s, 9 H), 0.30 (b s, 3 H); boron NMR (neat) +52.9 ppm (s).

Dimethylisopropoxyborane. The reaction was conducted as described above with methyllithium (50 mmol, 42 mL) and methyldiisopropoxyborane (7.1 g, 50 mmol). Workup as described in the general procedure (oil bath temperature, 80 °C) yielded dimethylisopropoxyborane: 4.6 g (46 mmol, 92%); proton NMR ($CDCl_3$) δ 4.40 (septet, J = 18 Hz, 1 H), 1.19 (d, J = 18 Hz, 6 H), 0.37 (b s, 6 H); boron NMR (neat) +52.1 ppm (s).

General Procedure for the Decomposition of Lithium Organyl- and Diorganylborates with Acid Chlorides. The preparation of diphenylisopropoxyborane is typical. To a solution of phenyldiisopropoxyborane (9.0 g, 43.9 mmol) in 44 mL of ethyl ether cooled to −78 °C was slowly added phenyllithium (22 mL, 44 mmol). The reaction was stirred at −78 °C for 2 h and then warmed to 0 °C. Neat acetyl chloride (3.43 mL, 48.4 mmol) was added via syringe and the ice bath removed. After the mixture was stirred for 15 min at room temperature, the precipitated

(19) For handling air-sensitive compounds, see: Brown, H. C.; Kramer, G. W.; Levy, A. B.; Midland, M. M. *Organic Synthesis via Boranes*; Wiley-Interscience: New York, 1975.

(20) Gilman, H.; Moore, F. W.; Baine, O. *J. Am. Chem. Soc.* **1941**, *63*, 2479.

lithium chloride was allowed to settle. The clear liquid phase and washings (2 × 15 mL of ethyl ether) were transferred to a distillation flask. Volatiles were removed in vacuo. Distillation furnished pure diphenylisopropoxyborane: yield 8.56 g (38.3 mmol, 87%); bp 88–90 °C (0.1 mmHg); proton NMR ($CDCl_3$) δ 7.57 (m, 2 H), 7.37 (m, 3 H), 4.57 (septet, J = 18 Hz, 1 H), 1.25 (d, J = 18 Hz, 6 H); boron NMR (neat) +44.8 ppm (s).

2-Furyldiisopropoxyborane. The reaction was run as described above with 2-furyllithium,[21] prepared from furan (200 mmol, 15 mL), n-butyllithium (200 mmol, 77 mL), and triisopropoxyborane (17.5 g, 93 mmol).[22] The "ate" complex was treated with acetyl chloride (7.85 g, 100 mL). Isolation yielded 2-furyldiisopropoxyborane: yield 13.5 g (69 mmol, 74%); bp 76–78 °C (15 mmHg); n^{20}_D 1.4306; proton NMR ($CDCl_3$) δ 7.60 (m, 1 H), 6.97 (m, 1 H), 6.40 (m, 1 H), 4.83 (septet, J = 18 Hz, 2 H), 1.33 (d, J = 18 Hz, 12 H); boron (neat) +23.3 ppm (s).

Phenylisopropylisopropoxyborane. The reaction was conducted as described under the general procedure using isopropyllithium (22.8 mmol, 40 mL) and triisopropoxyborane (4.64 g, 22.5 mmol). Workup with acetyl chloride (1.96 g, 25 mmol) and isolation yielded 3.60 g (18.9 mmol, 84%): bp 106–108 °C (15 mmHg); proton NMR ($CDCl_3$) δ 7.27 (m, 5 H), 4.47 (septet, J = 18 Hz, 1 H), 1.22 (d, J = 18 Hz, 6 H), 1.02 (b d, J = 15 Hz, 6 H); boron NMR (neat) +48.6 ppm (s).

Dimethylisopropoxyborane. The reaction was conducted as described under the general procedure using methyldiisopropoxyborane (15.3 g, 106 mmol) and methyllithium (66.3 mL, 106 mmol). The reaction was quenched with benzoyl chloride (14.9 g, 106 mmol) to yield, after careful distillation, 8.7 g (87 mmol, 82%): bp 52–54 °C (7.58 mmHg); proton NMR ($CDCl_3$) δ 4.40 (septet, J = 18 Hz, 1 H), 1.19 (d, J = 18 Hz, 6 H), 0.37 (b s, 6 H); boron NMR (neat) +52.1 ppm (s).

Phenyldiisopropoxyborane. The reaction was run as described under the general procedure using phenyllithium (17 mL, 30.6 mmol) and triisopropoxyborane (5.6 g, 30 mmol). The reaction was quenched with acetyl chloride (2.1 mL, 30 mmol) to yield after distillation 5.2 g (25.2 mmol, 84%).

Acknowledgment. We thank the Lady Davis Fellowship from the Hebrew University in Jerusalem, Israel, for the grant of a fellowship which made this study possible.

Registry No. $MeB(O\text{-}i\text{-}Pr)_2$, 86595-27-9; $i\text{-}PrB(O\text{-}i\text{-}Pr)_2$, 103885-29-6; $BuB(O\text{-}i\text{-}Pr)_2$, 86595-32-6; $s\text{-}BuB(O\text{-}i\text{-}Pr)_2$, 86595-33-7; $t\text{-}BuB(O\text{-}i\text{-}Pr)_2$, 86595-34-8; $PhB(O\text{-}i\text{-}Pr)_2$, 1692-26-8; t-BuMeB(O-i-Pr), 97782-73-5; $Me_2B(O\text{-}i\text{-}Pr)$, 95407-90-2; $Ph_2B(O\text{-}i\text{-}Pr)$, 69737-51-5; $RB(O\text{-}i\text{-}Pr)_2$ (R = 2-Furyl), 103885-30-9; i-PrPhB(O-i-Pr), 97782-97-3; $LiMeB(O\text{-}i\text{-}Pr)_3$, 103885-14-9; $Li\text{-}i\text{-}PrB(O\text{-}i\text{-}Pr)_3$, 103885-15-0; $LiBuB(O\text{-}i\text{-}Pr)_3$, 103885-16-1; $Li\text{-}s\text{-}BuB(O\text{-}i\text{-}\infty Pr)_3$, 103885-17-2; $Li\text{-}t\text{-}BuB(O\text{-}i\text{-}Pr)_3$, 103885-18-3; $LiPhB(O\text{-}i\text{-}Pr)_3$, 103885-19-4; $LiMe_2B(O\text{-}i\text{-}Pr)_2$, 103885-20-7; Li-$t$-BuMeB(O-≤$i$-Pr)$_2$, 103885-21-8; $LiRB(O\text{-}i\text{-}Pr)_3$ (R = 2-furyl), 103885-22-9; $Li\text{-}i\text{-}PrPhB(O\text{-}i\text{-}Pr)_2$, 103885-23-0; $LiPh_2B(O\text{-}i\text{-}Pr)_2$, 103885-24-1; $LiPhMeB(O\text{-}i\text{-}Pr)_2$, 103885-25-2; $Li(t\text{-}Bu)_2(B(O\text{-}i\text{-}Pr)_2$, 103885-26-3; $LiRB(O\text{-}i\text{-}Pr)_3$ (R = cyclohexyl), 103885-27-4; $Li\text{-}t\text{-}BuPhB(O\text{-}i\text{-}Pr)_2$, 103885-28-5; $BnO\text{-}i\text{-}Pr)_3$, 5419-55-6; *LiMe*, 917-54-4; Li-i-Ph, 1888-75-1; LiBu, 109-72-8; Li-s-Bu, 598-30-1; Li-t-Bu, 594-19-4; LiPh, 591-51-5; 2-furyllithium, 2786-02-9; acetyl chloride, 75-36-5; benzoyl chloride, 98-88-4.

(21) Ramanathan, V.; Levine, R. *J. Org. Chem.* **1962**, *27*, 1216.

(22) Possibly because of its low solubility, it was necessary to reflux 2-furyllithium with triisopropoxyborane 8 h to obtain good yields of the lithium borate. More soluble organolithium compounds reacted rapidly at −78 °C (compare ref 13).

Organoboranes. 49. An Examination of Convenient Procedures for the Generation of Borane and Monoalkyl- and Dialkylboranes from Lithium Borohydride and Monoalkyl- and Dialkylborohydrides

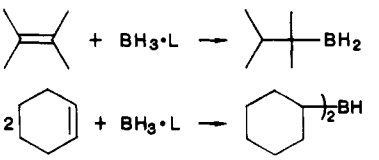
Thomas E. Cole, Raman K. Bakshi,[1a] Morris Srebnik,[1b] Bakthan Singaram,[1a] and Herbert C. Brown*

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

Received May 20, 1986

The simple preparation of monoalkyl- and dialkylboranes previously developed by the addition of methyl iodide to lithium monoalkyl- and dialkylborohydrides in tetrahydrofuran solution has been expanded to alternative procedures involving other solvents, such as diethyl ether (EE) and n-pentane, and other reagents, such as phenol, acetic acid, methanesulfonic acid, ethereal hydrogen chloride, trimethylsilyl chloride, and trimethylsilyl methanesulfonate. The practicality of generating monoalkyl- and dialkylboranes from the corresponding borohydrides has been demonstrated in representative solvents utilizing appropriate reagents. The reaction of lithium borohydride with the above reagents was also studied. The reaction of lithium borohydride with 1 equiv of acetic acid produces a mixture of lithium tetraacetoxyborohydride and unreacted lithium borohydride instead of the expected lithium monoacetoxyborohydride. Because of discrepancies with the reported results for sodium borohydride, the study was extended to this reagent.

Hydroboration of olefins with BH_3·THF or BH_3·Me_2S generally proceeds rapidly past the monoalkylborane stage to the dialkyl- and trialkylborane stages.[2] Consequently it is generally not possible to synthesize monoalkyl- or dialkylboranes by the direct reaction of most olefins with borane. Only in the case of certain hindered and highly hindered olefins is is possible to control the hydroboration so as to achieve the synthesis of pure monoalkyl and dialkylboranes (eq 1 and 2).[2] Additionally, these monoalkyl- and dialkylboranes possess limited stability upon storage, so they must be freshly prepared before use.



(1) (a) Postdoctoral research associate on Grant GM 10937-23 of the National Institutes of Health. (b) Lady Davis Fellow from the Hebrew University, Israel.

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

0276-7333/86/2305-2303$01.50/0