Synthesis, Characterization, and Bromine Substitution of Diamine Complexes of Carboxyborane and Methoxycarbonylborane. Diazabora Rings Containing B-Carboxyl and B-Carboxylato Groups

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DA·2BH_2CN (**1**) [DA = *N*,*N*,*N*′,*N*′-tetramethylethanediamine (TMEDA, **a**), *N*,*N*,*N*′,*N*′-tetramethylpropanediamine (TMPDA, **b**), and *N*,*N*,*N*′,*N*′-tetramethylbutanediamine (TMBDA, **c**)], (DA·2BH_2CNEt)$(BF_4)_2$ (**2**), and DA·2BH_2COOH (**3**) complexes were prepared from Me_2S solution of $(BH_2CN)_n$ (→ **1** → **2** → **3**) in fast procedures, differently from those usually applied, in good yields. Dimethyl esters (**4**) were prepared from **3** with methanol in very fast reactions catalyzed by HBr. **3** and **4** were transformed into DA·BH_2COOH (**5a**,**b**) and DA·BH_2COOMe (**6**) with DA in THF. Bromination of **3** in aqueous HBr yielded diamine-bis(monobromocarboxyboranes) (**7**), in vigorous conditions diamine-bis(dibromocarboxyboranes) (**9**) were produced. *N*-Bromosuccinimide in methanol transformed **3a**,**b** directly into diamine-bis(bromomethoxycarbonylboranes) (**8a**,**b**). BrH·DA·BH(Br)COOH (**10a**,**b**) could be prepared from **5a**,**b** with bromine in strongly acidic medium. N-Deprotonated **10a** quickly transformed into a five-membered cyclic cation $[TMEDA·BHCOOH]^+$ (cation in **12a**) in both water and methanol. Thus, this ion was formed by dissolution of **10a** in water, bromination of **5a** or destroying one of the borane moieties in **7a** by a base. N-Deprotonated **10b** in water decomposed with a pH-dependent rate, but in methanol, in the presence of base, it transformed into a six-membered cyclic cation $[TMPDA·BHCOOH]^+$ (cation in **12b**). **8a**,**b** could also be transformed into cyclic cations by destroying one of their borane moieties in methanol, (**8b** in absence of acids only). All cations were prepared as bromide, hexafluorophosphate and tetraphenylborate salts. pK_a values of **12a**,**b** (pK_a = 5.5−5.6) are 3 units lower than those of amine-carboxyboranes. Zwitterions (**18a**,**b**) formed by their deprotonation were prepared. Cyclic cation $[TMEDA·B(Br)COOH]^+$ (cation in **19a**) formed on destroying one dibromocarboxyborane of **9a**. This cation, quite a strong acid (p$K_a \approx 4.2$), was prepared as hexafluorophosphate and tetraphenylborate salt. The latter was transformed with aqueous KOH into the corresponding zwitterion (**21a**).

Introduction

A large number of amine carboxyboranes and their derivatives substituted on the carbon atom (amine·BH_2X, where X = COOH,[1−5] COOR,[5−7] $CONR_2$,[1,2,5] C(O)NHOH,[8] CSNHR,[4] C(OR)═NR,[5] C(CN)═NR,[4] etc.) have been synthesized in the past twenty years. Extensive biological and pharmacological studies revealed remarkable hypolipidemic,[9] anticancer,[9,10] antiosteoporotic,[11] and antiinflammatory[9,12] activities of amine carboxyboranes and their ester, amide, and peptide derivatives. The biological role of these complexes is still being explored.[3,13,14] With respect to these biological and pharmacological activities we focused our efforts on the synthesis and characterization of boron-substituted derivatives, a type of compounds, which have attracted less attention so far. To date only few derivatives of the type amine·BH(R)COX (R = alkyl, X = OR, NR_2)[15,16] and a couple of carboxylated diazadiborinanes and diazadiborolidines[17,18] have been prepared. We planned to attach different substituents to boron via the brominated derivatives of carboxyboron compounds, as intermediates, taking advantage of the good leaving character of the

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bromine. Our earlier paper[19] reported the synthesis of many amine complexes of bromocarboxyborane and bromomethoxycarbonylborane. Through a $Br^- \rightarrow$ amine exchange, similarly to the method discovered by Nöth,[20] these complexes afforded the previously unknown bis(amine)carboxyboronium cations $[AA'B(H)COOR]^+$.[21,22] Furthermore, our preliminary studies showed that bromination of TMEDA·BH_2COOR (R = H, Me) yields $[TMEDA{\cdot}B(H)COOR]^+$ cyclic cation directly.[21] Relying upon these findings we have investigated the bromination of diamine complexes of carboxyborane and methoxycarbonylborane. These studies yielded numerous bromocarboxyboron complexes and several carboxyboronium cations, which represent a new type of amine-borane complexes. The biological screening of these compounds is planned. Our observations showing that amines readily expel bromide encourage us to attempt the synthesis of A·BH(X)COOR (X = R′, OR′, SR′, NR'_2) complexes from bromocarboxy compounds for further (including biological) studies.

Experimental Section

Methods and Materials. All reactions, except those involving water or noted otherwise, were performed under an oxygen- and water-free N_2 atmosphere using the general Schlenk techniques in flamed or oven-dried glassware with absolutized solvents freshly distilled prior to use.

Methyl sulfide was dried over sodium, then fractionally distilled. Dichloromethane was distilled from CaH_2 and then refluxed with $NaBH_4$/diglyme and fractionally distilled. Methanol was distilled from $Mg(OCH_3)_2$. THF and ether were distilled from sodium benzophenone. Chloroform was distilled from P_2O_5 after shaking with concd H_2SO_4 and drying with $CaCl_2$. Acetonitrile and DMSO were distilled from CaH_2. Acetone was distilled from a 1.5 m Raschig packed column.

TMEDA was distilled from KOH. TMPDA and TMBDA (Aldrich) were kept over 4 Å molecular sieves (Aldrich), which were activated by keeping at 320 °C for 12 h, and stored under dry N_2. NBS was recrystallized from water and dried in an N_2 stream before use. Bromine (Ferak), 48% aq HBr solution, KPF_6 (Fluka), $KBrO_3$, KBr, and $NaBPh_4$ (Reanal) were used as received.

Methyl sulfide solution of cyanodihydroborane oligomer was prepared by known procedure.[23] Et_3OBF_4 was synthesized by the Meerwein protocol.[24] Methanolic HBr solution was prepared by absorbing gaseous HBr (liberated from 48% aq HBr solution by P_2O_5 and dried by Granusic A (J. T. Baker)) in methanol under N_2.

Compounds **1a**, **2a**, **3a**, **5a**,[4] and **4a**[7] were prepared as previously described.

NMR spectra were recorded on a Bruker AM 360 instrument in 5 mm o.d. tubes at room temperature. ^{1}H spectra were referred to DSS in D_2O and TMS in other solvents. ^{13}C (90.5 MHz) spectra were referred to deuterated solvent signals ($CDCl_3$, 77.0 ppm; acetone-d_6, 29.9 ppm; DMSO-d_6, 39.5 ppm), and DSS in D_2O as external reference. Ambiguities in assigning ^{1}H and ^{13}C signals were cleared with homonuclear decoupling and shift correlation (^{1}H−^{1}H and ^{13}C−^{1}H) experiments. Carbons directly attached to boron could not be observed. ^{11}B (115.5 MHz) spectra were referred to $Et_2O{\cdot}BF_3$ in a capillary inserted into the tube. In cases when multiplicities could only be revealed by applying Gaussian multiplication, multiplets are marked "broad" and coupling constants are not given.

IR spectra were recorded on a Perkin-Elmer Paragon PC 1000 FT-IR spectrometer.

Acidity constants of **5a** and **14a** were determined pH-metrically at 25 ± 0.1 °C at 0.2 M KCl ionic strength using a Radiometer PH M 52 pH-meter referenced to a saturated calomel electrode, and the data were evaluated by PSEQUAD.[25] Approximate acidity constants of **14b** and **19a** were estimated from the half-neutralization pH.

The boron and bromine content of the samples was determined with acid−base titration in the presence of mannitol, or by using the Volhard method, respectively, after fusion with NaOH and KOH. Analyses of BF_4 and PF_6 salts were performed in the presence of large excess of $CaCl_2$.

Safety Note. *Dihydrocyanoborane oligomer was always handled in methyl sulfide solution because explosions were experienced with neat* $(BH_2CN)_n$.[26]

Syntheses. TMPDA·2BH_2CN (1b). A methyl sulfide solution of cyanodihydroborane (33.5 mL, 2.29 M; 76.8 mmol BH_2CN) was added dropwise to an ice-cooled and stirred methyl sulfide solution (35 mL) of TMPDA (5.00 g, 38.4 mmol) over 30 min, and the mixture was stirred for a further 20 min at room temperature. The precipitate was filtered off, washed with methyl sulfide (3 × 10 mL) and dried in a N_2 stream. Yield: 7.86 g (98%). Anal. Calcd (found) for $C_9H_{22}B_2N_4$: B, 10.40 (10.31). ^{1}H NMR (DMSO-d_6, δ): 2.83 (m, 4H, NCH_2), 2.61 (s, 12H, NCH_3), 2.01 (m, 2H, $CH_2CH_2CH_2$). ^{13}C{^{1}H} NMR (DMSO-d_6, δ): 59.56 (NCH_2), 49.23 (NCH_3), 17.34 ($CH_2CH_2CH_2$). ^{11}B NMR (DMSO-d_6, δ): −14.6 (br t). IR (KBr, cm^{-1}): ν(B−H), 2431, 2417; ν(C≡N), 2194.

TMBDA·2BH_2CN (1c). A methyl sulfide solution of cyanodihydroborane (21.8 mL, 2.29 M; 49.8 mmol BH_2CN) was added dropwise to an ice-cooled and stirred methyl sulfide solution (12 mL) of TMBDA (3.59 g, 24.9 mmol) over 20 min and the mixture was stirred at room temperature for a further 20 min. The precipitate was filtered off, washed with methyl sulfide (4 × 5 mL), and dried in a N_2 stream. Yield: 5.12 g (93%). Anal. Calcd (found) for $C_{10}H_{24}B_2N_4$: B, 9.74 (9.60). ^{1}H NMR ($CDCl_3$, δ): 2.93 (m, 4H, NCH_2), 2.69 (s, 12H, NCH_3), 1.75 (m, 4H, $CH_2(CH_2)_2CH_2$). ^{13}C{^{1}H} NMR ($CDCl_3$, δ): 62.63 (NCH_2), 50.26 (NCH_3), 21.04 ($CH_2(CH_2)_2CH_2$). ^{11}B NMR ($CDCl_3$, δ): −15.4 (br t). IR (KBr, cm^{-1}): ν(B−H), 2429, 2395; ν(C≡N), 2196.

[TMPDA·2BH_2CNEt](BF_4)$_2$ (2b). Et_3OBF_4 (5.46 g, 28.7 mmol) was added to the stirred suspension of **1b** (2.90 g, 14.0 mmol) in dichloromethane (30 mL), and the mixture was refluxed for 3 h. The solvent was distilled off, the residual oil—which slowly transformed into crystals—was kept under vacuum to reach a constant weight. It was then stirred with ether (40 mL) for 20 min, then filtered, washed with ether (3 × 20 mL), and dried in a N_2 stream. Yield: 6.05 g (99%). Anal. Calcd (found) for $C_{13}H_{32}B_4F_8N_4$: B, 9.84 (9.76). ^{1}H NMR (CH_2Cl_2, δ(TMS)): 4.11 (q, 4H, NCH_2CH_3), 3.12 (m, 4H, $(CH_3)_2NCH_2$), 2.81 (s, 12H, NCH_3), 2.13 (m, 2H, $CH_2CH_2CH_2$), 1.54 (t, 6H, NCH_2CH_3). ^{13}C{^{1}H} NMR (CH_2Cl_2, δ(TMS)): 60.28 ($(CH_3)_2NCH_2$), 50.52 (NCH_3), 41.60 (NCH_2CH_3), 17.87 ($CH_2CH_2CH_2$), 13.32 (NCH_2CH_3). ^{11}B NMR (CH_2Cl_2, δ): −0.1 (s, BF_4^-), −14.1 (br, complex). IR (KBr, cm^{-1}): ν(B−H), 2476, 2436; ν(C≡N), 2317.

[TMBDA·2BH_2CNEt](BF_4)$_2$ (2c). A dichloromethane solution (20 mL) of Et_3OBF_4 (7.07 g, 37.2 mmol) was added to the stirred solution of **1c** (3.93 g, 17.7 mmol) in dichloromethane (30 mL), and the mixture was refluxed for 2 h and then left at room temperature for an hour. The gelly precipitate was filtered off, compressed with a glass rod, washed with dichloromethane (4 × 10 mL), and dried in a N_2 stream. Yield: 5.68 g (71%). Anal. Calcd (found) for $C_{14}H_{34}B_4F_8N_4$: B, 9.53 (9.37). ^{1}H NMR (CH_2Cl_2, δ(TMS)): 4.13 (q, 4H, NCH_2CH_3), 3.15 (m, 4H, $(CH_3)_2NCH_2$), 2.77 (s, 12H, NCH_3), 1.82 (m, 4H, NCH_2CH_2), 1.54 (t, 6H, NCH_2CH_3). ^{13}C{^{1}H} NMR (CH_2Cl_2, δ(TMS)): 61.12 ($(CH_3)_2NCH_2$), 50.93 (NCH_3), 41.57 (NCH_2CH_3), 20.65 (NCH_2CH_2), 13.37 (NCH_2CH_3). ^{11}B NMR (CH_2Cl_2, δ): −0.1 (s, BF_4^-), −14.5 (br, complex). IR (KBr, cm^{-1}): ν(B−H), 2462, 2434; ν(C(N) 2317.

TMPDA·2BH_2COOH (3b). **2b** (5.85 g, 13.3 mmol) was dissolved in water (25 mL) and the solution was gently shaken at 55, 70, and 80 °C for consecutive 5 min periods. The solution was then quickly cooled

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to 60 °C left to cool to room temperature, and allowed to stand for an hour, while a large amount of white needles appeared. The mixture was then cooled in an ice−water bath for 30 min, the crystals were collected on a filter, washed with 0 °C water (3 × 10 mL), and dried in a N_2 stream. Yield: 2.87 g (88%). Anal. Calcd (found) for $C_9H_{24}B_2N_2O_4$: B, 8.79 (8.77). ^{1}H NMR (DMSO-d_6, δ): 10.16 (s, 2H, COOH), 2.89 (m, 4H, NCH_2), 2.63 (s, 12H, NCH_3), 1.95 (m, 2H, $CH_2CH_2CH_2$). ^{13}C{^{1}H} NMR (DMSO-d_6, δ): 58.94 (NCH_2), 48.56 (NCH_3), 17.06 ($CH_2CH_2CH_2$). ^{11}B NMR (DMSO-d_6, δ): −14.6 (br). IR (KBr, cm^{-1}): ν_{assoc}(O−H), 2720, 2630, 2574; ν(B−H), 2406; ν_{as}(C═O), 1648.

TMBDA·2BH$_2$COOH (3c). 2c (4.89 g, 10.8 mmol) was dissolved in water (20 mL), and the solution was heated to 85 °C in 2 min, then kept and gently shaken at 85 °C for 10 min. The solution was then cooled to room temperature and slowly stirred with a magnetic stir bar for 15 min. The crystals were filtered off, washed with water (3 × 7 mL), and dried in a N_2 stream. Yield: 2.71 g (97%). Anal. Calcd (found) for $C_{10}H_{26}B_2N_2O_4$: B, 8.32 (8.43). ^{1}H NMR (DMSO-d_6, δ): 10.11 (s, 2H, COOH), 2.93 (m, 4H, NCH_2), 2.58 (s, 12H, NCH_3), 1.53 (m, 4H, $CH_2(CH_2)_2CH_2$). ^{13}C{^{1}H} NMR (DMSO-d_6, δ): 60.91 (NCH_2), 48.61 (NCH_3), 20.39 ($CH_2(CH_2)_2CH_2$). ^{11}B NMR (DMSO-d_6, δ): −11.4 (br). IR (KBr, cm^{-1}): ν_{assoc}(O−H), 2720, 2630, 2568; ν(B−H), 2430, 2380; ν_{as}(C═O), 1644.

TMPDA·2BH$_2$COOMe (4b). Methanolic solution of HBr (0.90 mL, 0.276 M, 0.248 mmol) was added to the stirred suspension of **3b** (1.02 g, 4.15 mmol) in methanol (25 mL), and the clear solution, formed immediately upon the addition of HBr, was stirred for 10 min. The 4 Å molecular sieves (1.85 g) were added to the solution, which was allowed to stand for several hours. The molecular sieves were filtered off, and the filtrate was evaporated to dryness in vacuo. The residue was collected on a filter with ether (30 mL) and extracted into ether to a point when only a small amount of noncrystalline material remained on the filter (ca. 45 times). The precipitate was filtered from the extract, washed with ether (2 × 3 mL) and dried in a N_2 stream. Yield: 1.01 g (89%). Anal. Calcd (found) for $C_{11}H_{28}B_2N_2O_4$: B, 7.89 (7.89). ^{1}H NMR ($CDCl_3$, δ): 3.54 (s, 6H, OCH_3), 2.98 (m, 4H, NCH_2), 2.72 (s, 12H, NCH_3), 2.08 (m, 2H, $CH_2CH_2CH_2$). ^{13}C{^{1}H} NMR ($CDCl_3$, δ): 59.69 (NCH_2), 49.93 (OMe), 47.99 (NMe), 18.17 ($CH_2CH_2CH_2$). ^{11}B NMR ($CDCl_3$, δ): −11.2 (br t). IR (KBr, cm^{-1}): ν(B−H), 2403; ν_{as}(C═O), 1670.

TMBDA·2BH$_2$COOMe (4c). Methanolic solution of HBr (1.14 mL, 0.276 M, 0.314 mmol) was added to the stirred suspension of **3c** (0.68 g, 2.62 mmol) in methanol (15.5 mL), and the stirred mixture was then placed into a 65 °C water bath for 6 h, while the slurry transformed into a clear solution. On standing at room-temperature large plates precipitated. The product was filtered at 0 °C, washed with methanol (3 × 2 mL), and dried in a N_2 stream. Yield: 0.61 g (81%). Anal. Calcd (found) for $C_{12}H_{30}B_2N_2O_4$: B, 7.51 (7.63). ^{1}H NMR ($CDCl_3$, δ): 3.54 (s, 6H, OCH_3), 3.03 (m, 4H, NCH_2), 2.69 (s, 12H, NCH_3), 1.65 (m, 2H, $CH_2(CH_2)CH_2$). ^{13}C{^{1}H} NMR ($CDCl_3$, δ): 61.66 (NCH_2), 49.66 (OCH_3), 47.91 (NCH_3), 21.09 ($CH_2(CH_2)CH_2$). ^{11}B NMR ($CDCl_3$, δ): −11.1 (t, ^1J(B,H) = 101 Hz). IR (KBr, cm^{-1}): ν(B−H), 2406; ν_{as}(C═O), 1674.

TMPDA·BH$_2$COOH (5b). TMPDA (3.02 g, 23.2 mmol) was added to a supension of **3b** (1.90 g, 7.73 mmol) in THF (15 mL), and the mixture was refluxed for 6 h. TMPDA and THF were then removed in vacuo, and the solid residue was kept in a vacuum to reach a constant weight. It was then suspended in ether (25 mL) and the suspension was filtered. The filtered solid was extracted with the filtrate to a point when only a flimsy gel remains (ca. 45−50 times). The crystals were filtered from the extract, washed with ether (5 mL), and dried in a N_2 stream. Yield: 2.03 g (70%). Anal. Calcd (found) for $C_8H_{21}BN_2O_2$: B, 5.75 (5.80). ^{1}H NMR ($CDCl_3$, δ): 3.02 (m, 2H, $BNCH_2$), 2.70 (s, 6H, $BNCH_3$), 2.29 (m, 2H, $CH_2CH_2CH_2$), 2.22 (s, 6H,:NCH_3), 1.84 (m, 2H,:NCH_2). ^{13}C{^{1}H} NMR ($CDCl_3$, δ): 60.83 ($BNCH_2$), 56.78 (:NCH_2), 49.48 ($BNCH_3$), 45.11 (:NCH_3), 21.33 ($CH_2CH_2CH_2$). ^{11}B NMR ($CDCl_3$, δ): −11.3 (br). IR (KBr, cm^{-1}): ν_{assoc}(O−H), 2682, 2560; ν(B−H), 2380; ν_{assoc}(N−H), 1944 br; ν_{as}(C═O), 1654.

TMEDA·BH$_2$COOMe (6a). TMEDA (0.92 g, 7.92 mmol) was added to the solution of **4a** (1.03 g, 3.96 mmol) in THF (8 mL). The mixture was refluxed for 1 h, cooled to 0 °C, and the solvent was immediately evaporated in vacuo and kept in a vacuum until a microcrystalline material (**4a**) appeared in the oil (**6a**). In a typical experiment the product consisted of 85 mol % **6a**, 12 mol % TMEDA, and 3 mol % **4a**. This composition remained constant for a few hours in a refrigerator (4 °C). Yield: 1.53 g (contains 7.18 mmol **6a**). ^{1}H NMR ($CDCl_3$, δ): 3.54 (s, 3H, OCH_3), 3.13 (m, 2H, $BNCH_2$), 2.76 (s, 6H, $BNCH_3$), 2.60 (m, 2H,:NCH_2), 2.24 (s, 6H,:NCH_3). ^{13}C{^{1}H} NMR ($CDCl_3$, δ): 59.13 ($BNCH_2$), 53.52 (:NCH_2), 49.63 ($BNCH_3$), 47.62 (OCH_3), 45.27 (:NCH_3). ^{11}B NMR ($CDCl_3$, δ): −10.7 (br t). IR (neat, cm^{-1}): ν(B−H), 2394, 2302 sh; ν_{as}(C═O), 1672.

TMPDA·BH$_2$COOMe (6b). TMPDA (0.96 g, 7.4 mmol) was added to the solution of **4b** (0.81 g, 2.96 mmol) in THF (5.7 mL). The mixture was refluxed for 1.5 h and then cooled to room temperature. The solvent was evaporated in vacuo and the residue was kept in a vacuum (<0.1 mmHg) to reach a constant weight. The product is a clear oil consisting of **6b** (97 mol %) and **4b** (3 mol %). This composition remains constant for ca. 1 day in refrigerator (4 °C). The increase of the amount of **4b** is indicated by appearance of white crystals. Yield: 1.15 g (96%). Anal. Calcd (found) for $C_9H_{23}BN_2O_2$: B, 5.35 (5.50). ^{1}H NMR ($CDCl_3$, δ): 3.54 (s, 3H, OCH_3), 3.02 (m, 2H, $BNCH_2$), 2.71 (s, 6H, $BNCH_3$), 2.27 (m, 2H,:NCH_2), 2.21 (s, 6H,:NCH_3), 1.83 (m, 2H, $CH_2CH_2CH_2$). ^{13}C{^{1}H} NMR ($CDCl_3$, δ): 60.69 ($BNCH_2$), 56.56 (:NCH_2), 49.18 ($BNCH_3$), 47.48 (OCH_3), 44.95 (:NCH_3), 21.17 ($CH_2CH_2CH_2$). ^{11}B NMR ($CDCl_3$, δ): −11.0 (br t). IR (neat, cm^{-1}): ν(B−H), 2393, 2300 sh; ν_{as}(C═O), 1673.

TMBDA·BH$_2$COOMe (6c). THF (4 mL) and TMBDA (0.887 g, 6.15 mmol) were added to **4c** (0.354 g, 1.229 mmol), and the mixture was refluxed for 11 h, then allowed to cool to room temperature and to stand overnight. The precipitated crystals (**4c**) were collected on filter, and the filtrate was evaporated to dryness in vacuo and kept at 0.1 mmHg to give a dense, slightly opalescent oil of constant weight. In a typical experiment the product was contaminated with 8 mol % TMBDA. This composition remained constant for a few days in a refrigerator. Yield: 0.540 g (contains 2.36 mmol **6c**). ^{1}H NMR ($CDCl_3$, δ): 3.54 (s, 3H, OCH_3), 3.01 (m, 2H, $BNCH_2$), 2.69 (s, 6H, $BNCH_3$), 2.31 (m, 2H, BCH_2CH_2), 2.24 (s, 6H,:NCH_3), 1.67 (m, 2H, $BNCH_2CH_2$), 1.45 (m, 2H,:NCH_2CH_2). ^{13}C{^{1}H} NMR ($CDCl_3$, δ): 62.31 ($BNCH_2$), 59.04 (:NCH_2), 49.18 ($BNCH_3$), 47.96 (OCH_3), 45.32 (:NCH_3), 25.10 (:NCH_2CH_2), 21.03 ($BNCH_2CH_2$). ^{11}B NMR ($CDCl_3$, δ): −10.7 (br t). IR (KBr, cm^{-1}): ν(B−H), 2393; ν_{as}(C═O), 1672.

TMEDA·2BH(Br)COOH (7a). 3a (1.00 g, 4.31 mmol) was suspended in water (5 mL), then dissolved by addition of NaOH solution (15.3 mL, 0.295 M, 4.51 mmol). To this solution was added a mixture of bromine (1.43 g, 8.96 mmol), 48% aq HBr (10 mL), and water (20 mL) in seconds, under extremely vigorous stirring. After 20 min 48% aq HBr (6 mL) was added, and the resulting mixture was heated to 60 °C over 10 min. The mixture was then allowed to cool to room temperature, and the precipitate was filtered, washed with 2 M HBr (3 × 6 mL) then water (5 × 5 mL), predried in a fast N_2 stream, washed with ether (3 × 10 mL), and dried in a N_2 stream. Yield: 1.35 g (80%). Anal. Calcd (found) for $C_8H_{20}B_2Br_2N_2O_4$: B, 5.55 (5.74); Br, 41.01 (40.17). ^{1}H NMR (DMSO-d_6, δ): 11.16 (s, 2H, COOH), 3.49 (m, 4H, CH_2), 2.86, 2.85 (2 × s, 2 × 6H, NCH_3). ^{13}C{^{1}H} NMR (DMSO-d_6, δ): 53.73, 53.65 (NCH_2), 47.10, 46.35, 46.21 (NCH_3). ^{11}B NMR (DMSO-d_6, δ): −4.5 (br). IR (KBr, cm^{-1}): ν_{assoc}(O−H), 2744, 2598; ν(B−H), 2474; ν_{as}(C═O), 1659.

TMPDA·2BH(Br)COOH (7b). 3b (0.82 g, 3.33 mmol) was dissolved in a mixture of acetone (17 mL), water (8 mL), and 48% aq HBr (0.4 mL). The solution was cooled in an ice−water bath and, prior to the precipitation of a solid, a solution of bromine (1.21 g, 7.57 mmol) in aq HBr (18 mL, 5 m/m %) was added over 10−15 min at steadily decreasing speed under stirring. Acetone was removed in vacuo, and the precipitated crystals were collected on a filter, washed with water (4 × 6 mL), and dried in a N_2 stream. Yield: 1.10 g (82%). Anal. Calcd (found) for $C_9H_{22}B_2Br_2N_2O_4$: B, 5.36 (5.48); Br, 39.59 (39.12). ^{1}H NMR (DMSO-d_6, δ): 11.12 (s, 2H, COOH) 3.05 (m, 4H, NCH_2), 2.79 (s, 12H, NCH_3), 2.05 (m, 2H, $CH_2CH_2CH_2$). ^{13}C{^{1}H} NMR (DMSO-d_6, δ): 57.54 (NCH_2), 46.29, 46.24, 45.81 (NCH_3), 15.83 ($CH_2CH_2CH_2$). ^{11}B NMR (DMSO-d_6, δ): −4.4 (br). IR (KBr, cm^{-1}): ν_{assoc}(O−H), 2751, 2658, 2598; ν(B−H), 2470; ν_{as}(C═O), 1653.

TMBDA·2BH(Br)COOH (7c). 3c (0.80 g, 3.08 mmol) was

suspended in water (8 mL) and dissolved by addition of aq NaOH solution (6.52 mL, 1.00 M, 6.52 mmol). This solution was cooled in an ice−water bath, and before precipitation of any solid a bromine solution (prepared by adding 48% aq HBr (5.4 mL) to a 0 °C solution of $KBrO_3$ (0.353 g, 2.11 mmol) in water (10 mL)) was added in a second under extremely vigorous stirring. The mixture was warmed to ca. 30 °C and filtered after the disappearance of the light yellow color. The microcrystalline product (which contains 4 mol % **3c** and 5 mol % TMBDA·BH(Br)COOH·BBr_2COOH and TMBDA·2BBr_2COOH) was washed with water (4 × 6 mL), predried with air suction, washed with ether (4 × 5 mL), and dried with air suction. Yield: 1.22 g (95%). Anal. Calcd (found) for $C_{10}H_{24}B_2Br_2N_2O_4$: B, 5.18 (5.30); Br, 38.26 (39.06). ^{1}H NMR (DMSO-d_6, δ): 11.08 (br s, COOH), 3.09 (m, 4H, NCH_2), 2.76, 2.77 (2 × s, 2 × 6H, NCH_3), 1.61 (m, 4H, $CH_2CH_2CH_2$-CH_2). ^{13}C{^{1}H} NMR (DMSO-d_6, δ): 59.88 (NCH_2), 46.32, 45.75 (NCH_3), 19.63 ($CH_2(CH_2)_2CH_2$). ^{11}B NMR (DMSO-d_6, δ): −4.5 (br). IR (KBr, cm^{-1}): ν_{assoc}(O−H), 2740, 2657, 2591; ν(B−H), 2464; ν_{as}(C═O), 1654.

TMEDA·2BH(Br)COOMe (8a). To a suspension of **3a** (0.62 g, 2.67 mmol) in methanol (10 mL) was added NBS (0.96 g, 5.39 mmol) over 30 min in small portions. After 30 min the precipitated crystals were separated on a filter, washed with methanol (3 × 4 mL), and dried in a N_2 stream. Yield: 0.83 (74%). Anal. Calcd (found) for $C_{10}H_{24}B_2Br_2N_2O_4$: B, 5.18 (5.15); Br, 38.26 (38.57). ^{1}H NMR ($CDCl_3$, δ): 3.63 (s, 6H, OCH_3), 3.63, 3.45 (2 × m, 3+1H, NCH_2) 3.02, 2.98, 2.97, 2.96 (4(s, 4(3H, NCH_3). ^{13}C{^{1}H} NMR ($CDCl_3$, δ): 55.97, 55.19 (NCH_2), 49.50 (OCH_3), 49.10, 48.77, 48.69, 47.72 (NCH_3). ^{11}B NMR ($CDCl_3$, δ): −7.0 (br d). IR (KBr, cm^{-1}): ν(B−H), 2501 sh, 2484; ν_{as}(C═O), 1676.

TMPDA·2BH(Br)COOMe (8b). To a solution of **3b** (0.63 g, 2.56 mmol) in methanol (12 mL) was added solid NBS (0.91 g, 5.12 mmol) in small portions over 30 min. The solution was evaporated to dryness, and the residue was kept under high vacuum (<0.1 mmHg) to afford a semisolid. It was then dissolved in dichloromethane (10 mL) and the succinimide was removed by extraction with aq HBr solution (7 × 3 mL, 0.005 M). The CH_2Cl_2 layer was dried with Na_2SO_4, the solvent was evaporated with a N_2 stream, and the residue was kept in a vacuum to give a colorless oil of constant weight. Yield: 0.87 g (79%). Anal. Calcd (found) for $C_{11}H_{26}B_2Br_2N_2O_4$: B, 5.01 (4.86); Br, 37.01 (36.10). ^{1}H NMR ($CDCl_3$, δ): 3.62 (s, 6H, OCH_3), 3.25, 3.15, 2.99 (3 × m, 1+2+1H, NCH_2), 2.95, 2.92 (2 × s, 3+9H, NCH_3), 2.28, 2.19, 2.05 (3 × m, 0.5+1+0.5H, $CH_2CH_2CH_2$). ^{13}C{^{1}H} NMR ($CDCl_3$, δ): 59.53, 59.13 (NCH_2), 49.39 (OCH_3), 47.99, 47.72, 47.48, 47.13 (NCH_3), 17.15 ($CH_2CH_2CH_2$). ^{11}B NMR ($CDCl_3$, δ): −6.4 (br). IR (neat, cm^{-1}): ν(B−H), 2473; ν_{as}(C═O), 1674.

TMEDA·2BBr_2COOH (9a). To a stirred suspension of **3a** (0.94 g, 4.05 mmol) in aq HBr solution (9.0 mL, 3.5 m/m%) was added a solution of bromine in 48% aq HBr (4.32 mL, 4.5 M, 19.44 mmol Br_2) over 4−5 min at 0 °C. The flask was equipped with a reflux condenser, and the bath temperature was raised to 40 °C over 10 min, then to 70 °C over 40 min, then to 80 °C over 20 min for 2 h, and then to 95 °C over 1.5 h for 2.5 h. After cooling to room temperature the crude product was filtered, washed with water (5 × 5 mL), and dried with air suction. Crude **9a** was dissolved in DMSO (8.0 mL) and kept at 50−55 °C for 5 h. The solution was concentrated to ca. 2 mL in vacuo employing a 60 °C bath and 0.1 M aq HBr solution was slowly added. The precipitate was collected on a filter, washed with water (4 × 5 mL), dried with air suction, washed with ether (3 × 6−8 mL) in the course of drying. Yield: 1.24 g (56%). Anal. Calcd (found) for $C_8H_{18}B_2Br_4N_2O_4$: B, 3.95 (4.06); Br, 58.38 (56.77). ^{1}H NMR (DMSO-d_6, δ): 11.85 (s, 2H, COOH), 3.95 (s, 4H, NCH_2), 3.08 (s, 12H, NCH_3). ^{13}C{^{1}H} NMR (DMSO-d_6, δ): 53.79 (NCH_2), 46.97 (NCH_3). ^{11}B NMR (DMSO-d_6, δ): −0.6 (br). IR (KBr, cm^{-1}): ν_{assoc}(O−H), 2786, 2676, 2618; ν_{as}(C═O), 1654.

TMPDA·2BBr_2COOH (9b). To a stirred suspension of **3b** (1.01 g, 4.11 mmol) in water (8.0 mL) was added a solution of bromine in 48% aq HBr (7.20 mL, 4.5 M, 32.4 mmol Br_2) over 4−5 min at 0 °C. The flask was equipped with a reflux condenser. The bath was warmed to 45 °C over 10 min, then to 80 °C over 30 min for 1 h, then to 95 °C for 10 h. After cooling to room temperature the crude product was filtered, washed with water (ca. 6 × 10−15 mL) until the filtrate was colorless. The permeability of the precipitate against water was constantly decreasing as the filtration advanced. The filtered material was dried with air suction, washed with ether (3 × 6−8 mL) in the course of drying. Yield: 1.33 g (58%). Anal. Calcd (found) for $C_9H_{20}B_2Br_4N_2O_4$: B, 3.85 (3.89); Br, 56.92 (55.16). ^{1}H NMR (DMSO-d_6, δ): 11.80 (s, 2H, COOH), 3.39 (m, 4H, NCH_2), 3.02 (s, 12H, NCH_3), 2.22 (m, 2H, $CH_2CH_2CH_2$). ^{13}C{^{1}H} NMR (DMSO-d_6, δ): 56.16 (NCH_2), 45.70 (NCH_3), 15.83 ($CH_2CH_2CH_2$). ^{11}B NMR (DMSO-d_6, δ): −0.2 (br). IR (KBr, cm^{-1}): ν_{assoc}(O−H), 2790, 2683, 2621; ν_{as}(C═O), 1667.

TMBDA·2BBr_2COOH (9c). 2c (0.80 g, 3.08 mmol) was dissolved in aq NaOH solution (6.34 mL, 1.00 M, 6.34 mmol), and aq HBr (2.8 mL, 30 m/m%) and then bromine solution in 48% aq HBr (8.0 mL, 6.0 M, 48.0 mmol Br_2) were added at 0 °C and under vigorous stirring. The mixture was then placed into a 35 °C water bath. The bath was warmed to 70 °C over 30 min, then to 85 °C over 40 min for 8 h. After cooling to room temperature, the precipitate was collected on a filter, washed with water (5 × 10 mL), 1% aq $NaHSO_3$ (3 × 5 mL), and then with water (3 × 6 mL), and dried with air suction while being washed with ether (3 × 5 mL) in the course of drying. The product is contaminated with TMBDA·(BBr_2COOH)·(BHBrCOOH) and TMBDA·2BH(Br)COOH (7−8 mol % altogether). Yield: 0.40 g (23%). Anal. Calcd (found) for $C_{10}H_{22}B_2Br_4N_2O_4$: B, 3.76 (3.84); Br, 55.54 (54.09). ^{1}H NMR (DMSO-d_6, δ): 11.70 (s, 2H, COOH), 3.43 (m, 4H, NCH_2), 2.97 (s, 12H, NCH_3), 1.73 (m, 4H, $CH_2(CH_2)_2CH_2$). ^{13}C{^{1}H} NMR (DMSO-d_6, δ): 58.61 (NCH_2), 45.51 (NCH_3), 19.52 ($CH_2(CH_2)_2CH_2$). ^{11}B NMR (DMSO-d_6, δ): − 0.4 (br). IR (KBr, cm^{-1}): ν_{assoc}(O−H), 2770, 2664, 2596; ν_{as}(C═O), 1655.

TMEDA·BH(Br)COOH·HBr (10a). Aq HBr (15 mL, 30 m/m%) was added to **5a** (0.90 g, 5.17 mmol) in an ice−water bath. To the vigorously stirred suspension a solution of bromine in 30 m/m% aq HBr (1.72, mL 3.00 M, 5.16 mmol) was added dropwise, while the mixture turned into a clear solution. When a microcrystalline precipitate appeared, the addition of the bromine was interrupted (at ca. 1.15 mL), and aq HBr (1.5 mL, 30 m/m%) was added. The addition of the bromine solution was then continued. After stirring at 0 °C for 30 min the product was collected on a filter, washed with acetone (3 × 6 mL) and dried in a N_2 stream. Yield: 1.26 g (73%). Anal. Calcd (found) for $C_7H_{19}BBr_2N_2O_2$: B, 3.24 (3.38); Br, 47.87 (47.55). ^{1}H NMR (20% DCl, δ): 3.75−3.50 (m, 4H, NCH_2), 3.02, 3.01, 2.99, 2.97 (4 × s, 12H, NCH_3). ^{11}B NMR (20% DCl, δ): −5.7 (br).

The filtrate combined with the washing liquor was evaporated in vacuo, and aq KPF_6 (0.320 g, 1.74 mmol in 4.0 mL) was added. **14a** was obtained as described in method B for **14a**. Yield: 0.32 g (17%).

TMPDA·BH(Br)COOH·HBr (10b). To a stirred 0 °C suspension of **5b** (0.83 g, 4.41 mmol) in acetone (5 mL) was added aq HBr (0.66 mL, 30 m/m%), then bromine dissolved in 30 m/m% aq HBr (1.60 mL, 3.0 M, 4.80 mmol). After 5 min the solution was diluted with acetone (15 mL), and then it was concentrated in vacuo to a viscous oil. Addition of acetone (15 mL) and evaporation were repeated three times and increasing amount of solid was obtained. The product was filtered off, washed with acetone (3 × 5 mL) and dried in a N_2 stream. Yield: 1.13 g (74%). Anal. Calcd (found) for $C_8H_{21}BBr_2N_2O_2$: B, 3.11 (3.15); Br, 45.94 (44.86). ^{1}H NMR (1 M DCl, δ): 3.21 (m, 4H, NCH_2), 2.94, 2.89 (2 × s, 12H, NCH_3), 2.22 (m, 2H, $CH_2CH_2CH_2$). ^{11}B NMR (1 M DCl, δ): −5.3 (br).

2-Carboxy-1,1,3,3-tetramethyl-1,3,2λ^4-diazaborolidinium Bromide (12a). 10a (0.81 g, 2.43 mmol) was dissolved in water (6 mL), and then the solvent was removed in vacuo. Acetone (10 mL) was added to the residue, and then the solvent was evaporated; acetone (5 mL) was added again, and the product was filtered off, washed with acetone (2 × 2 mL), and dried in a N_2 stream. Yield: 0.48 g (78%). Anal. Calcd (found) for $C_7H_{18}BBrN_2O_2$: B, 4.27 (4.26); Br, 31.59 (31.83). ^{1}H NMR (D_2O, δ): 3.64 (m, 4H, NCH_2), 3.04, 3.03 (2 × s, 2 × 6H, NCH_3). ^{13}C{^{1}H} NMR (D_2O, δ): 62.12 (NCH_2), 56.56, 51.15 (NCH_3). ^{11}B NMR (D_2O, δ): 0.9 (d, ^1J(B,H) = 110 Hz). IR (KBr, cm^{-1}): ν_{assoc}(O−H), 2710, 2584; ν(B−H), 2454; ν_{as}(C═O) 1684.

2-Carboxy-1,1,3,3-tetramethyl-1,3,2λ^4-diazaborinanium Bromide (12b). To a suspension of **10b** (0.88 g, 2.53 mmol) in methanol (8 mL) was added methanolic KOH solution (7.76 mL, 0.342 M, 2.65 mmol). The solution was evaporated to a constant weight. Acetonitrile

(80 mL) was added to the residue and the suspension stirred for 20 min in a 40 °C water bath. The insoluble parts (KBr) were filtered off and washed with 40 °C acetonitrile (3 × 4 mL). The filtrate was evaporated in vacuo, and ether (20 mL) and methanol (8 mL) were slowly added to the stirred residue until only a small amount of jelly material remained undissolved. The mixture was then filtered, the filtrate was evaporated with a N_2 stream, and the residue was kept in a vacuum for 15 min. The residue was suspended in ether (15 mL) and filtered, and the product was dried in a N_2 stream. Yield: 0.62 g (92%). Anal. Calcd (found) for $C_8H_{20}BBrN_2O_2$: B, 4.05 (4.00); Br, 29.93 (31.13). ^{1}H NMR (D_2O, δ): 3.23, 3.19 (overlapping multiplets, 4H, NCH_2), 2.97, 2.87 (2 × s, 2 × 6H, NCH_3), 2.37 (m, 1H, axial CH_2CHHCH_2), 2.02 (m, 1H, equatorial CH_2CHHCH_2). ^{13}C{^{1}H} NMR (D_2O, δ): 63.52 (NCH_2), 56.37, 48.12 (NCH_3), 21.46 ($CH_2CH_2CH_2$). ^{11}B NMR (D_2O, δ): −1.9 (d, ^1J(B,H) = 113 Hz). IR (KBr, cm^{-1}): ν(B−H), 2464; ν_{as}(C═O), 1680.

2-Methoxycarbonyl-1,1,3,3-tetramethyl-1,3,2λ^4-diazaborolidinium Bromide (13a). To the solution of **6a** (7.24 mmol, freshly prepared from **4a** (0.97 g, 3.73 mmol)) in methanol (8 mL) was added dropwise a freshly prepared solution of bromine (1.17 g, 7.32 mmol) in methanol (13 mL). The first 5 mL portion was added in 5 min, the second 5 mL over 30 min, and the remaining bromine solution was added over 80 min as the rate of discoloration decreased. The addition of bromine was accompanied by the appearance of a precipitate, and the color of the mixture turned permanently pale yellow. The mixture was then stirred at room temperature. After 1 h methanolic NaOH solution (3.03 mL, 2.42 M, 7.33 mmol) was added dropwise over 5 min. The slightly opalescent solution was evaporated at room temperature in vacuo to give a solid residue of constant weight. It was moved onto a filter and was extracted (ca. 20−22 times) into acetone (20 mL). The crystals precipitated from the extract were collected on a filter, washed with acetone (2 × 2 mL), and dried in a N_2 stream. The product was washed off from the filter using chloroform (10 mL in 4 decreasing portions) and the filtrate was then evaporated to dryness employing a N_2 stream. The solid residue was suspended in ether (4 mL) and then the suspension was evaporated to dryness. The residue was suspended in ether (8 mL), and the product was filtered, washed with ether (2 × 5 mL), and dried in a N_2 stream. Yield: 1.29 g (67%). Anal. Calcd (found) for $C_8H_{20}BBrN_2O_2$: B, 4.05 (3.97); Br, 29.93 (30.54). ^{1}H NMR ($CDCl_3$, δ): 4.21, 3.99 (2 × m, 2 × 2H, NCH_2), 3.68 (s, 3H, OCH_3), 3.21, 3.15 (2 × s, 2 × 6H, NCH_3). ^{13}C{^{1}H} NMR ($CDCl_3$, δ): 60.12 (NCH_2), 54.62, 49.39 (NCH_3), 49.23 (OCH_3). ^{11}B NMR ($CDCl_3$, δ): 1.1 (d, ^1J(B,H) = 115 Hz). IR (KBr, cm^{-1}): ν(B−H), 2517; ν_{as}(C═O), 1692.

2-Methoxycarbonyl-1,1,3,3-tetramethyl-1,3,2λ^4-diazaborinanium Bromide (13b). To a stirred solution of freshly prepared **6b** (0.67 g, 3.32 mmol) in methanol (4 mL) was added a freshly prepared solution of bromine (0.58 g, 3.63 mmol) in methanol (7 mL) over 25 min at 0 °C. After 10 min methanolic NaOH solution (1.50 mL, 2.42 M, 3.63 mmol) was added dropwise over 20 min. The solution was then evaporated to give an oil that solidified. The residue was moved to a filter with acetone (10 mL) and extracted into the filtrate (10 times). The solid that precipitated from the extract was filtered off, washed with acetone (2 × 1 mL), and dried in a N_2 stream. Yield: 0.60 g (64%). Anal. Calcd (found) for $C_9H_{22}BBrN_2O_2$: B, 3.85 (3.78); Br, 28.44 (28.81). ^{1}H NMR ($CDCl_3$, δ): 3.68 (s, 3H, OCH_3), 3.60 (m, 2H, equatorial NCH*H*), 3.27 (m, 2H, axial NC*H*H), 3.18, 3.04 (2 × s, 2 × 6H, NCH_3), 2.89 (m, 1H, axial CH_2CHHCH_2), 2.24 (m, 1H, equatorial CH_2CHHCH_2). ^{13}C{^{1}H} NMR ($CDCl_3$, δ): 62.17 (NCH_2), 54.95 (NCH_3), 49.34 (OCH_3), 46.29 (NCH_3), 19.28 ($CH_2CH_2CH_2$). ^{11}B NMR ($CDCl_3$, δ): −1.6 (d, ^1J(B,H) = 113 Hz). IR (KBr, cm^{-1}): ν(B−H), 2479; ν_{as}(C═O), 1683.

2-Carboxy-1,1,3,3-tetramethyl-1,3,2λ^4-diazaborolidinium Hexafluorophosphate−Potassium Hexafluorophosphate (4/1) (14a). 5a (0.70 g, 4.02 mmol) and KPF_6 (1.01 g, 5.50 mmol) were dissolved in water (12 mL). To this solution was addded over 2−3 min an aq bromine solution (4.14 mmol Br_2) prepared by the reaction of $KBrO_3$ (0.230 g, 1.38 mmol), KBr (0.980 g, 8.23 mmol) and aq HBr (1.52 mL, 48 m/m%) in water (6.5 mL) at 0 °C. After addition of bromine was complete, the precipitate was redissolved by warming the mixture to 65 °C, then the solution was allowed to cool to room temperature, then it was cooled to 0 °C in an ice−water bath. After 20 min the crystals were collected on a filter, washed with cold water (4 × 1.5 mL), and dried by air suction. Yield: 1.16 g (79%). Anal. Calcd (found) for $C_{28}H_{72}B_4F_{30}KN_8O_8P_5$: C, 23.10 (23.13), H, 4.98 (4.96); B, 2.97 (2.94); K, 2.69 (2.62); N, 7.70 (7.70). ^{1}H NMR (acetone-d_6, δ): 10.74 (s, 1H, COOH), 3.84 (m, 4H, NCH_2), 3.20, 3.15 (2 × s, 2 × 6H, NCH_3). ^{13}C{^{1}H} NMR (acetone-d_6, δ): 60.37 (NCH_2), 54.68, 49.20 (NCH_3). ^{11}B NMR (acetone-d_6, δ): 1.9 (d, ^1J(B,H) = 113 Hz). IR (KBr, cm^{-1}): ν_{assoc}(O−H), 2757, 2664, 2532; ν(B−H), 2464; ν_{as}(C═O), 1664.

2-Carboxy-1,1,3,3-tetramethyl-1,3,2λ^4-diazaborinanium Hexafluorophosphate (14b). To a suspension of **10b** (0.55 g, 1.58 mmol) in methanol (5 mL) was added methanolic KOH solution (4.85 mL, 0.342 M, 1.66 mmol KOH), and the solution was evaporated to dryness in vacuo. Aqueous KPF_6 (0.44 g, 2.39 mmol in 5.5 mL) was added to the residue, and the mixture was acidified with H_2SO_4 (0.5 mL, 2 M). The precipitate was redissolved by warming and the clear solution was allowed to cool to room temperature for a day. After shaking and leaving the mixture for 1 h in an ice−water bath, the crystals were collected on a filter, washed with cold water (4 × 1 mL), and dried by air suction. Yield: 0.34 g (65%). Anal. Calcd (found) for $C_8H_{20}BF_6N_2O_2P$: B, 3.26 (3.19). ^{1}H NMR (acetone-d_6, δ): 10.82 (s, 1H, COOH), 3.47 (m, 2H, equatorial NCH*H*), 3.34 (m, 2H, axial NC*H*H), 3.14, 3.08 (2 × m, 2 × 6H, NCH_3), 2.59 (m, 1H, axial CH_2CHHCH_2), 2.12 (m, 1H, equatorial CH_2CHHCH_2). ^{13}C{^{1}H} NMR (acetone-d_6, δ): 62.95 (NCH_2), 55.48, 45.99 (NCH_3), 19.47 ($CH_2CH_2CH_2$). ^{11}B NMR (acetone-d_6, δ): −0.8 (d, ^1J(B,H) = 112 Hz). IR (KBr, cm^{-1}): ν(O−H), 3430; ν(B−H), 2477; ν_{as}(C═O), 1713.

2-Carboxy-1,1,3,3-tetramethyl-1,3,2λ^4-diazaborolidinium Tetraphenylborate (15a). To a 0 °C solution of **3a** (0.405 g, 2.33 mmol) in water (5 mL) was added bromine water (11.45 mL, 0.210 M, 2.40 mmol Br_2) dropwise over a few minutes. The solution was warmed to room temperature, and aq $NaBPh_4$ solution (19.0 mL, 0.128 M, 2.43 mmol) was added. After 30 min stirring the precipitate was filtered and washed with water (3 × 5 mL). The wet crude **15a** was dissolved off the filter with acetone, water (10 mL) was added to the solution, and then the acetone was removed by gently warming and bubbling N_2 through the solution. The precipitated crystals were filtered, washed with water (2 × 3 mL), and dried by air suction. Yield: 1.05 g (91%). Anal. Calcd (found) for $C_{31}H_{38}B_2N_2O_2$: B, 4.39 (4.37). ^{1}H NMR (acetone-d_6, δ): 7.34 (m, 8H, *o*-CH), 6.94 (m, 8H, *m*-CH), 6.82 (m, 4H, *p*-CH), 3.71 (m, 4H, NCH_2), 3.13, 3.08 (2 × s, 2 × 6H, NCH_3). ^{13}C{^{1}H} NMR (acetone-d_6, δ): 164.97 (q, B-C(phenyl), ^1J(C,^{11}B) = 48.8 Hz), 137.04 (*o*-phenyl), 126.07 (*m*-phenyl), 122.29 (*p*-phenyl), 60.31 (NCH_2), 54.68, 49.17 (NCH_3). ^{11}B NMR (acetone-d_6, δ): 1.9 (d, cation, ^1J(B,H) = 114 Hz), −5.7 (s, BPh_4). IR (KBr, cm^{-1}): ν_{assoc}(O−H), 2880, 2750, 2622; ν(B−H), 2474; ν_{as}(C═O), 1668.

2-Carboxy-1,1,3,3-tetramethyl-1,3,2λ^4-diazaborinanium Tetraphenylborate (15b). To a solution of **12b** (0.258 g, 0.966 mmol) in water (6 mL) was added acetone (12 mL) and aq $NaBPh_4$ solution (8.4 mL, 0.128 M, 1.08 mmol). The precipitate was redissolved by addition of acetone (ca. 20 mL). Acetone was removed in vacuo. The crystals of **15b** were collected on a filter, washed with water (5 × 5 mL), and dried by air suction. Yield: 0.463 g (95%). Anal. Calcd (found) for $C_{32}H_{40}B_2N_2O_2$: B, 4.27 (4.26). ^{1}H NMR (acetone-d_6, δ): 7.34 (m, 8H, *o*-CH), 6.93 (m, 8H, *m*-CH), 6.79 (m, 4H, *p*-CH), 3.32 (m, 2H, equatorial NCH*H*), 3.23 (m, 2H, axial NC*H*H), 3.07 and 3.02 (2 × s, 2 × 6H, NCH_3), 2.49 (m, 1H, axial CH_2CHHCH_2), 2.01 (m, 1H, equatorial CH_2CHHCH_2). ^{13}C{^{1}H} NMR (acetone-d_6, δ): 164.94 (q, B−C(phenyl), ^1J(C,^{11}B) = 48.8 Hz), 137.01 (*o*-phenyl), 126.01 (*m*-phenyl), 122.26 (*p*-phenyl), 62.87 (NCH_2), 55.54, 45.89 (NCH_3), 19.47 ($CH_2CH_2CH_2$). ^{11}B NMR (acetone-d_6, δ): −0.8 (d, complex, ^1J(B,H) = 117 Hz); −5.7 (s, BPh_4). IR (KBr, cm^{-1}): ν_{assoc}(O−H), 2736, 2610; ν(B−H), 2484; ν_{as}(C═O), 1666.

2-Methoxycarbonyl-1,1,3,3-tetramethyl-1,3,2λ^4-diazaborolidinium Hexafluorophosphate (16a). To the suspension of **8a** (0.412 g, 0.956 mmol) in methanol (6.0 mL) was added TMEDA (0.57 g, 4.91 mmol), and the mixture was refluxed for 6 h during which period a clear solution was obtained. It was evaporated to dryness in vacuo. The residue was dissolved in water (2.0 mL), and aq KPF_6 (0.144 g, 0.78 mmol in 1.80 mL) was added. The crystalline precipitate was

redissolved by heating to 60 °C, and the clear solution was allowed to cool to room temperature. It was kept in an ice−water bath for 30 min and the colorless needles were collected on a filter, washed with cold water (3 × 1 mL), and dried by air suction. Yield: 0.279 g (44%). Anal. Calcd (found) for $C_8H_{20}BF_6N_2O_2P$: B, 3.26 (3.21). ^{1}H NMR (acetone-d_6, δ): 3.87 (m, 4H, NCH_2), 3.68 (s, 3H, OCH_3), 3.19 and 3.16 (2s, 2 × 6H, NCH_3). $^{13}C\{^1H\}$ NMR (acetone-d_6, δ): 60.39 (NCH_2), 54.65 (NCH_3), 49.23 (NCH_3 and OCH_3). ^{11}B NMR (acetone-d_6, δ): 2.1 (d, ^1J(B,H) = 113 Hz). IR (KBr, cm^{-1}): ν(B−H), 2521; ν_{as}(C═O), 1699.

2-Methoxycarbonyl-1,1,3,3-tetramethyl-1,3,2λ^4-diazaborinanium Hexafluorophosphate (16b). To a solution of **8b** (0.45 g, 1.11 mmol) in methanol (6.0 mL) was added TMPDA (0.72 g, 5.53 mmol). The mixture was refluxed for 3 h, and then evaporated to dryness in vacuo. The residue was dissolved in water (2 mL), filtered, and H_2SO_4 (0.10 mL, 2 M) and aq KPF_6 (0.22 g, 1.20 mmol in 2.6 mL) were added to the filtrate. The precipitate was redissolved by warming the mixture to 70−80 °C, and the clear solution was allowed to cool to room temperature. It was kept in an ice−water bath for 30 min, and the crystals were collected on a filter, washed with cold water (3 × 1.5 mL), and dried by air suction. Yield: 0.33 g (86%). Anal. Calcd (found) for $C_9H_{22}BF_6N_2O_2P$: B, 3.12 (3.20). ^{1}H NMR (acetone-d_6, δ): 3.68 (s, 3H, OCH_3), 3.43 (m, 2H, equatorial NCH*H*), 3.34 (m, 2H, axial NC*H*H), 3.13, 3.03 (2 × s, 2 × 6H, NCH_3), 2.58 (m, 1H, axial CH_2CHHCH_2), 2.15 (m, 1H, equatorial CH_2CHHCH_2). $^{13}C\{^1H\}$ NMR (acetone-d_6, δ): 62.71 (NCH_2), 55.24 (NCH_3), 49.53 (OCH_3), 46.07 (NCH_3), 19.47 ($CH_2CH_2CH_2$). ^{11}B NMR (acetone-d_6, δ): −0.7 (d, ^1J(B,H) = 113 Hz). IR (KBr, cm^{-1}): ν(B−H), 2479, ν_{as}(C═O), 1673.

2-Methoxycarbonyl-1,1,3,3-tetramethyl-1,3,2λ^4-diazaborolidinium Tetraphenylborate (17a). To a solution of **13a** (0.223 g, 0.835 mmol) in water (12 mL) was added aq $NaBPh_4$ solution (6.5 mL, 0.140 M, 0.91 mmol). Acetone was added to the slurry to obtain a clear solution. The acetone was then removed in vacuo, when the product separated from the aqueous solution as small plates. It was filtered, washed with water (3 × 2 mL), and dried by air suction. Yield: 0.412 g (97%). Anal. Calcd (found) for $C_{32}H_{40}B_2N_2O_2$: B, 4.27 (4.24). ^{1}H NMR (acetone-d_6, δ): 7.34 (m, 8H, *o*-CH), 6.94 (m, 8H, *m*-CH), 6.79 (m, 4H, *p*-CH), 3.67 (m, 4H, NCH_2), 3.65 (s, 3H, OCH_3), 3.08, 3.05 (2s, 2 × 6H, NCH_3). $^{13}C\{^1H\}$ NMR (acetone-d_6, δ): 164.89 (q, B−Ph, ^1J(B,H) = 48.8 Hz); 136.96, 125.98, 122.21 (Ph); 60.12 (NCH_2), 54.51 (NCH_3) 49.09 (NCH_3 and OCH_3). ^{11}B NMR (acetone-d_6, δ): 1.9 (d, complex, ^1J(B,H) = 110 Hz); −5.7 (s, BPh_4). IR (KBr, cm^{-1}): ν(B−H), 2445, ν_{as}(C═O), 1695.

2-Methoxycarbonyl-1,1,3,3-tetramethyl-1,3,2λ^4-diazaborinanium Tetraphenylborate (17b). To a solution of **13b** (0.156 g, 0.555 mmol) in water (3 mL) was added aq $NaBPh_4$ solution (4.4 mL, 0.140 M, 0.62 mmol). Acetone was added to the slurry to obtain a clear solution. The acetone was then removed in vacuo, when the product crystallized from the aqueous solution. It was filtered, washed with water (3 × 2 mL) and dried by air suction. Yield: 0.283 g (98%). Anal. Calcd (found) for $C_{33}H_{42}B_2N_2O_2$: B, 4.16 (4.16). ^{1}H NMR (acetone-d_6, δ): 7.34 (m, 8H, *o*-CH), 6.94 (m, 8H, *m*-CH), 6.79 (m, 4H, *p*-CH), 3.65 (s, 3H, OCH_3), 3.25 (m, 2H, equatorial NCH*H*), 3.17 (m, 2H, axial NC*H*H), 3.01, 2.93 (2 × s, 2 × 6H, NCH_3), 2.44 (m, 1H, axial CH_2CHHCH_2), 1.97 (m, 1H, equatorial CH_2CHHCH_2). $^{13}C\{^1H\}$ NMR (acetone-d_6, δ): 164.94 (q, B−Ph_4, ^1J(C,B) = 48.8 Hz), 137.01, 126.04, 122.32 (Ph), 62.63 (NCH_2), 55.21 (NCH_3), 49.55 (OCH_3), 46.07 (NCH_3), 19.44 ($CH_2CH_2CH_2$). ^{11}B NMR (acetone-d_6, δ): −0.8 (d, complex, ^1J(B,H) = 115 Hz); −5.7 (s, BPh_4). IR (KBr, cm^{-1}): ν(B−H), 2465; ν_{as}(C═O), 1684.

1,1,3,3-Tetramethyl-1,3,2λ^4-diazaborolidinium 2-Carboxylate (18a). Methanol (11.5 mL) and TMEDA (0.57 g, 4.91 mmol) were added to **7a** (0.64 g, 1.64 mmol). After stirring at room temperature for 2.5 h a clear solution was obtained. It was evaporated in vacuo to give an oily residue. It was dissolved in methanol (3 mL) which was in turn thoroughly evaporated. Ether (12 mL) was added to the resinous residue to furnish a solid. The mixture was filtered, and the solid was washed with ether (2 × 5 mL) and dried in a N_2 stream. This solid was dissolved in water (1.0 mL), aq KOH solution (3.20 mL, 1.012 M, 3.24 mmol) was added, and the solution was evaporated to dryness. Dichloromethane (10 mL) was added to the resinous residue, and then the solvent was evaporated. The residue was solidified by addition of dichloromethane (10 mL) and, if it was necessary, trituration. The solid was filtered and dried in a N_2 stream. The solid was slurried in acetonitrile (60 mL) and stirring was continued at room temperature for 1 h. The insoluble parts (KBr) were filtered off and the filtrate was evaporated to dryness in vacuo. The residual solid was collected to a filter with ether (10 mL) and dried in a N_2 stream. Yield: 0.34 g (60%).

Anal. Calcd (found) for $C_7H_{17}BN_2O_2$: B, 6.28 (6.06). ^{1}H NMR (D_2O, δ): 3.53 (m, 4H, NCH_2), 2.98, 2.96 (2 × s, 2 × 6H, NCH_3). $^{13}C\{^1H\}$ NMR (D_2O, δ): 61.69 (NCH_2), 56.38, 50.85 (NCH_3). ^{11}B NMR (D_2O, δ): 1.3 (d, ^1J(B,H) = 117 Hz). IR (KBr, cm^{-1}): ν(B−H), 2422; $\nu_{as}(CO_2^-)$, 1502; $\nu_s(CO_2^-)$, 1400.

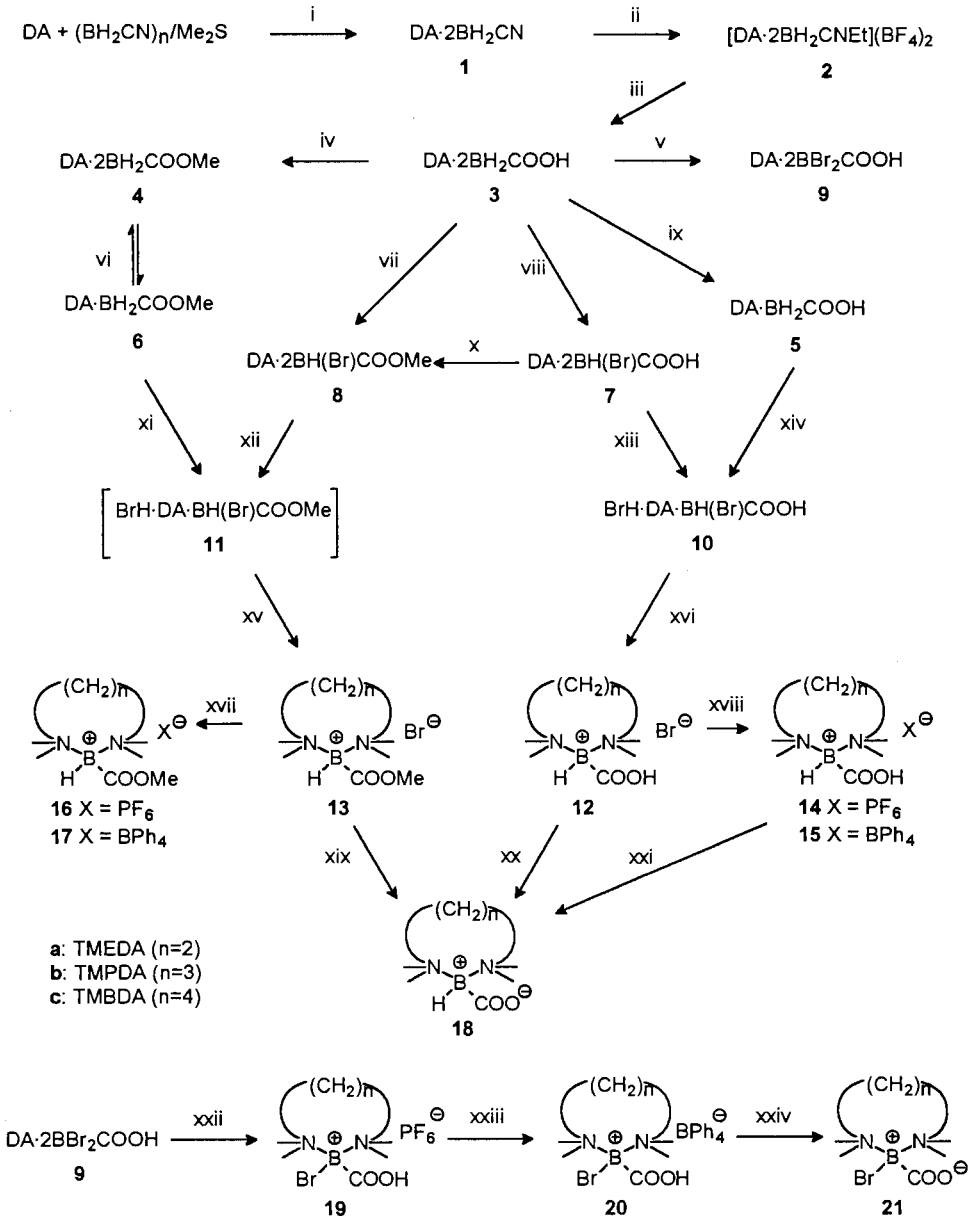
1,1,3,3-Tetramethyl-1,3,2λ^4-diazaborinanium 2-Carboxylate (18b). The pH of a solution of **12b** (0.64 g, 2.40 mmol) in water (10 mL) was adjusted between 9.5 and 9.7 with aq KOH (ca. 2.33 mL, 1.012 M, ca. 2.36 mmol). The solution was evaporated in vacuo, the vitreous residue was suspended in acetonitrile (35 mL) and the slurry was stirred at room temperature until the insoluble parts consisted of white microcrystalline only. The slurry was then filtered, the solid was washed into the filtrate with acetonitrile (2 × 1 mL) and the filtrate was evaporated in vacuo. The solid residue was collected on a filter with ether (10 mL) and dried in a N_2 stream. Yield: 0.378 g (85%). Anal. Calcd (found) for $C_8H_{19}BN_2O_2$: B, 5.81 (5.67). ^{1}H NMR (D_2O, δ): 3.18 (m, 2H, axial NC*H*H), 3.10 (m, 2H, equatorial NCH*H*), 2.95, 2.76 (2 × s, 2 × 6H, NCH_3), 2.33 (m, 1H, axial CH_2CHHCH_2), 1.98 (m, 1H, equatorial CH_2CHHCH_2). $^{13}C\{^1H\}$ NMR (D_2O, δ): 63.51 (NCH_2), 56.34, 48.10 (NCH_3), 21.43 ($CH_2CH_2CH_2$). ^{11}B NMR (D_2O, δ): −1.0 (d, ^1J(B,H) = 96 Hz). IR (KBr, cm^{-1}): ν(B−H), 2442; $\nu(CO_2^-)_{as}$, 1490; $\nu(CO_2^-)_s$, 1406.

2-Bromo-2-carboxy-1,1,3,3-tetramethyl-1,3,2λ^4-diazaborolidinium Hexafluorophosphate (19a). Methanol (3.0 mL) and TMEDA (0.35 g, 3.01 mmol) were added to **9a** (0.63 g, 1.15 mmol) at 0 °C. The suspension was stirred at room temperature for 4 h, then evaporated in vacuo. The residue was dissolved in water (2.80 mL), and the solution was acidified with H_2SO_4 (0.20 mL, 2 M). The insoluble parts were filtered off, washed with water (2 × 0.4 mL), and aq KPF_6 (0.164 g, 0.87 mmol in 2.0 mL) was added to the filtrate. The precipitate was redissolved by warming, and the solution was allowed to cool to room temperature. After 30 min in an ice−water bath the crystals were collected on a filter, washed with 0 °C water (3 × 1 mL), and dried by air suction. Yield: 0.261 g (29%). Anal. Calcd (found) for $C_7H_{17}BBrF_6N_2O_2P$: B, 2.72 (2.67); Br, 20.13 (20.41). ^{1}H NMR (D_2O, δ): 3.86 (m, 4H, NCH_2), 3.22 and 3.19 (2 × s, 2 × 6H, NCH_3). $^{13}C\{^1H\}$ NMR (D_2O, δ): 61.74 (NCH_2), 57.48 and 53.89 (NCH_3). ^{11}B NMR (D_2O, δ): 4.2 (s). IR (KBr, cm^{-1}): $\nu(O-H)_{monomeric}$, 3413; ν_{assoc}(O−H), 2767, 2618; $\nu_{as}(C=O)_{monomeric}$, 1693; $\nu(C=O)_{dimeric}$, 1656.

2-Bromo-2-carboxy-1,1,3,3-tetramethyl-1,3,2λ^4-diazaborolidinium Tetraphenylborate (20a). To an aqueous solution of **19a** (0.316 g, 0.796 mmol in 60 mL) was added dropwise a $NaBPh_4$ solution (0.286 g, 0.836 mmol in 5 mL water) over a few minutes at 36 °C. The mixture was then allowed to cool to room temperature, and the precipitate was collected on a filter, washed with water (4 × 3 mL), and dried with air suction. Yield: 0.435 g (96%). Anal. Calcd (found) for $C_{31}H_{37}B_2BrN_2O_2$: B, 3.79 (3.72); Br, 13.99 (13.68). ^{1}H NMR (acetone-d_6, δ): 7.35 (m, 8H, *o*-CH), 6.94 (m, 8H, *m*-CH), 6.80 (m, 4H, *p*-CH), 3.83 (s, 4H, NCH_2), 3.28, 3.25 (2 × s, 2 × 6H, NCH_3). $^{13}C\{^1H\}$ NMR (acetone-d_6, δ): 165.00 (q, B−C(phenyl), ^1J(C,^{11}B) = 48.8 Hz), 137.07 (*o*-phenyl), 126.12 (*m*-phenyl), 122.37 (*p*-phenyl), 60.10 (NCH_2), 55.78 and 52.17 (NCH_3). ^{11}B NMR (acetone-d_6, δ): 4.8 (br s, cation), −5.7 (s, BPh_4). IR (KBr, cm^{-1}): ν_{assoc}(O−H), 2777, 2624; ν_{as}(C═O), 1668.

2-Bromo-1,1,3,3-tetramethyl-1,3,2λ^4-diazaborolidinium 2-Carboxylate (21a). To a solution of **20a** (0.368 g, 0.644 mmol) in acetone (6.5 mL) was added water (2.0 mL) and over 1 min KOH solution (1.14 mL 0.567 M, 0.646 mmol). Acetone was removed by bubbling N_2 through the solution and the water loss was compensated (2 × 1 mL). $KBPh_4$ was then filtered off and washed with water, and the filtrate combined with the washing liquid was evaporated to dryness in vacuo. The residue was scratched off the wall of the flask in the presence of acetone (5 mL), collected on a filter, washed with acetone

Scheme 1



(2 × 1 mL), and dried in a N_2 stream. Yield: 0.147 g (91%). Anal. Calcd (found) for $C_7H_{16}BBrN_2O_2$: B, 6.28 (6.06). ^{1}H NMR (D_2O, δ): 3.81 (m, 4H, NCH_2), 3.17, 3.13 (2 × s, 2 × 6H, NCH_3). $^{13}C\{^1H\}$ NMR (D_2O, δ): 61.46 (NCH_2), 57.36, 53.86 (NCH_3). ^{11}B NMR (D_2O, δ): 4.9 (s).

Results and Discussion

Diamine-bis(carboxyboranes) and Diamine-bis(methoxycarbonylboranes) (3, 4). Diamine-bis(carboxyboranes) **3a**−**c** were prepared by the usual route for the synthesis of amine carboxyboranes (Scheme 1, i−iii). Diamine-bis(cyanoboranes) (**1**) were synthesized from a Me_2S solution of cyanoborane (Scheme 1, i) in nearly quantitative (ca. 3-fold compared to ether, THF, and glyme[28] solutions) yields, similarly to our synthesis of cyanoborane complexes of monobasic amines.[7,27] This improvement is probably due to the soft character of Me_2S, which renders "BH_2CN" more susceptible to base exchange.

Previous papers in the literature describe the ethylation reactions (Scheme 1, ii) employing 50−100% excess of Et_3OBF_4 and 24−72 h reaction times.[1,2,29−31] In contrast, we have found that diamine-bis(cyanoboranes) **1** could be completely converted into their bis(ethylnitrilium dihydroborane) tetrafluoroborates **2** in 2−3 h using a small (3−5%) excess of Et_3OBF_4.

Diamine-bis(carboxyboranes) **3** were conveniently prepared from the corresponding nitrilium salts **2** (Scheme 1, iii) using a short (5−15 min), high-temperature (80−100 °C) hydrolysis with 85,[4] 88, and 97% yields, respectively. This high-temperature hydrolysis has already been applied in our laboratory for the synthesis of other amine-carboxyboranes.[4,7] It is

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superior to those described in the literature[2,29,30] that afford lower yields in long reaction times (1−3 days) at room temperature.

Diamine-bis(methoxycarbonylboranes) **4** were readily synthesized from the appropriate carboxyborane complexes **3** (Scheme 1, iv) employing an esterification procedure elaborated earlier in our laboratory.[7] Unlike complexes of monofunctional amines, the observed order of reactivities of **3** toward esterification is TMPDA > TMEDA ≫ TMBDA, where the complex of the latter showed orders of magnitude slower esterification.

Diamine-carboxyboranes and Diamine-methoxycarbonylboranes (5, 6). The first mono(carboxyborane) complex of a diamine has been prepared in our laboratory by treating TMEDA·2BH_2COOH with excess TMEDA in acetonitrile.[4] The TMPDA complex **5b** was obtained similarly in THF (Scheme 1, ix). Analogous reactions involving **3c** and TMBDA did not result in formation of significant quantities of the expected mononuclear complex **5c** either in THF, or in TMBDA. Quite surprisingly, the reaction between Me_3N·BH_2COOH and a large excess of TMBDA yielded the binuclear complex **3c** exclusively. It may be due to the much lower solubility of the binuclear derivative **3c** compared to that of the mononuclear complex **5c**. A similar phenomenon, observed for TMEDA·2BH_3 and TMEDA·BH_3, was explained by Nöth[32] as due to lattice stabilization effects.

Reactions between diamine-bis(methoxycarbonylboranes) **4** and the appropriate amines reached nearly complete conversion. All the expected diamine-methoxycarbonylboranes **6** were prepared in good yields. The products were, however, contaminated with some starting material, even when large excess of amine was employed. After removal of the amine the equilibrium (Scheme 1, vi) slowly shifted to reformation of **4**. It should be noted that mononuclear complexes **6** are much more stable in $CDCl_3$ solutions (in which **4** are also highly soluble) than in neat form.

Diamine-bis(bromocarboxyboranes) (7), Diamine-bis(bromomethoxycarbonylboranes) (8), Diamine-bis(dibromocarboxyboranes) (9), and Diamine-bromocarboxyborane-hydrobromides (10). Bromination of diamine-bis(carboxyboranes) **3** takes place in two steps with decreasing rates (eq 1a,b).

$$\mathrm{DA{\cdot}2BH_2COOH} + 2\mathrm{Br_2} \xrightarrow{\text{fast}} \mathrm{DA{\cdot}2BH(Br)COOH} + 2\mathrm{HBr} \quad (1a)$$

$$\mathrm{DA{\cdot}2BH(Br)COOH} + 2\mathrm{Br_2} \xrightarrow{\text{slow}} \mathrm{DA{\cdot}2BBr_2COOH} + 2\mathrm{HBr} \quad (1b)$$

DA = TMEDA, TMPDA, TMBDA

Diamine-bis(bromocarboxyboranes) **7**, which contain two chiral boron atoms, could be obtained in good yields using slightly more than 1 molar equiv of bromine per carboxyborane groups (Scheme 1, viii). Since all brominated derivatives possess very low solubilities in water, the isolated complexes **7** were contaminated with byproducts containing BH_2COOH and BBr_2-COOH groups. The amount of impurities could be minimized by starting from the clear solution of the sodium salt of **3a**, and freshly precipitated **3c** with large specific surface area. Bromination of the TMPDA complex **3b** was more conveniently accomplished in homogeneous phase employing a water−acetone mixture, where the relatively slow reaction between bromine and acetone prevented the formation of overbrominated byproducts containing BBr_2COOH groups. TMEDA complex **7a** was also formed under similar conditions, but its isolated yield was low due to extensive transformation into **12a**.

As with monofunctional amine complexes, diamine-bis-(bromocarboxyboranes) **7** undergo decomposition in aqueous media, which is accompanied by partial formation of the cyclic cation in the case of **7a** (see next section). The decomposition was instantaneous in alkaline and fast in neutral media. In acid solution the rate of the decomposition decreased as the concentration of the acid increased, similarly to that observed for Me_3N·BH(Br)COOH.[19] Preparations were therefore performed in media strongly acidified by HBr. In addition, the use of HBr allowed us to prepare more concentrated bromine solutions than in water alone.

Preparation of diamine-bis(bromomethoxycarbonylboranes) **8** was attempted by esterification of the bromocarboxyborane complexes **7** (Scheme 1, x). The rates of these reactions showed the same order as seen for esterification of nonbrominated carboxyborane complexes **3**, but appeared much lower even in the presence of 10 mol % HBr per carboxylic groups. A similar difference has been reported for monofunctional amine complexes of bromocarboxyborane compared to corresponding amine-carboxyboranes.[7] Formation of TMEDA·2BH(Br)-COOMe (**8a**) was accompanied by extensive transformation into the cyclic cation **13a** (see below). In contrast, esterification of **7b** took place without observable formation of cyclic cation **13b**, thereby making this route synthetically useful. Slow esterification of TMBDA·2BH(Br)COOH (**7c**) was accompanied by extensive decomposition to TMBDA·2HBr.

The diamine-bis(carboxyboranes) **3a** and **3b** could conveniently be converted into the corresponding brominated esters **8a** and **8b** in one step with NBS in methanol (Scheme 1, vii), (NBS was added as solid in small portions, since it slowly reacts with methanol). After introduction of the first portion (ca. 5 mol %), the starting materials dissolved in minutes forming of the corresponding esters (**4a**,**b**). A study of the effect of NBS as esterification catalyst is currently under way in our laboratory. A possible explanation may be the generation of acyl hypobromites,[33] which would react with methanol affording the corresponding esters and HOBr and the latter may be able to maintain the catalytic cycle. The bromination reactions were very fast at room temperature.. Formation of cyclic cations **13a**,**b** was negligible, and the products were less contaminated than those obtained from **7a**,**b** by esterification.

Further bromination of all studied BH(Br)COOH complexes (**7**) could be carried out only in heterogeneous phase owing to their low solubility in each studied solvent, and required vigorous conditions. Formation of **9c** was accompanied by extensive decomposition and an impure product was obtained in low yield.

Bromination of diamine-carboxyboranes **5a**,**b** in strongly acidic medium afforded diamine-bromocarboxyborane-hydrobromides **10a**,**b** (Scheme 1, xiv) in a fast reaction. In the reaction of the TMEDA complex **5a**, a considerable amount of cyclic cation **12a** formed as a byproduct. These *N*-protonated mononuclear complexes (**10a**,**b**) proved to be valuable intermediates in the syntheses of cyclic cations **12a**,**b**.

2-Carboxyl, 2-Methoxycarbonyl, and 2-Carboxylate Derivatives of 1,1,3,3-Tetramethyl-1,3,2λ^4-diazaborolidine, 1,1,3,3-Tetramethyl-1,3,2λ^4-diazaborinane and 2-Bromo-1,1,3,3-tetramethyl-1,3,2λ^4-diazaborolidine Rings (12−21). BrH·TMEDA·BH(Br)COOH (**10a**) on dissolution in water or in dilute acids transformed into cyclic cation **12a** in a fast reaction

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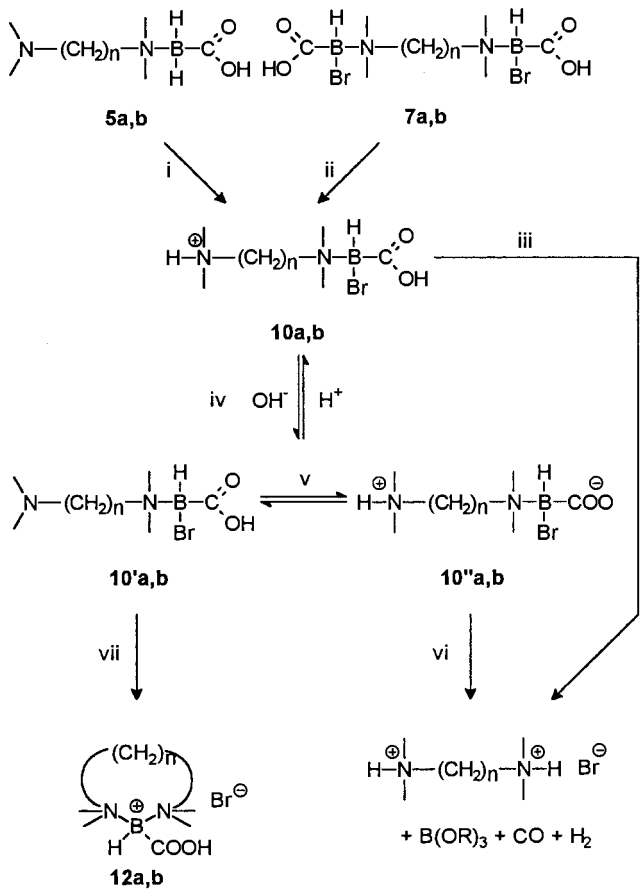
Scheme 2



(Scheme 1, xvi). This reaction was accompanied by decomposition affording TMEDA·2HBr, $B(OH)_3$, CO, and H_2, to a small extent depending on reaction conditions. In case of BrH·TMPDA·BH(Br)COOH (**10b**) in water, exclusively this slow decomposition took place and formation of the cyclic cation **12b** was not observed by ^{1}H NMR. On the other hand, in methanol the decomposition of **10b** and the ring closure took place concurrently, while reaction between **10b** and NaOH afforded **12b** instantaneously and in good yield.

Apparently, ring closure took place whenever **10a** was in water, or **10b** was in methanol, i.e., bromination of **5a** in water (Scheme 1, xiv and xvi) and thermal or alkaline decomposition of one of the borane moieties in **7a** or **7b** in water or methanol, respectively (Scheme 1, xiii and xvi).

The rate of the decomposition of **7a**,**b** in water increased with pH, similarly to that established for Me_3N·BH(Br)COOH in our earlier paper.[19] The hydrolysis of this complex was explained by the combination of fast decarbonylation of the deprotonated $B-COO^-$ group and slow decomposition of Me_3N·BH(Br)-COOH via a bromide → water exchange on the boron. The rate-determining step of the transformations of **7a**,**b** into either **12a**,**b** or DA·2HBr, appears to be the formation of intermediates **10a**,**b** as they could not be detected during monitoring of the reactions by ^{1}H NMR.

10a,**b** in both water and methanol are in equilibrium with their N-deprotonated **10′a**,**b** and O-deprotonated **10″a**,**b** forms (Scheme 2, iv and v). It seems certain, that of the three species, only **10′a**,**b** is capable of forming a ring, while the other two undergo decomposition (Scheme 2, iii and vi) in the manner described in the previous paragraph. The state of the equilibrium is governed by the magnitude and the proportion of acidity constants of the ammonium group (pK_a^N) and the carboxylic group (pK_a^O). Based on the pK_a values determined for TMEDA·BH_2COOH ($pK_a^O = 7.0$, $pK_a^N = 8.9$)[34] and considering that H·Br exchange caused ca. 2.5 units decrease in pK_a value of Me_3N·BH_2COOH,[19] the equilibrium concentrations of the corresponding species are expected as follows: [**10a**] > [**10″a**] > [**10′a**]. However, our experiments leading to **10a** yielded **12a** almost exclusively. Consequently, the ring closure of **10′a** must be extremely fast in comparison with the decomposition of **10a** and **10″a**. The state of the protonation equilibrium for analogous **10b** is expectably similar. Therefore, the failure to form ring **12b** in water is caused mainly by the sloth of the ring closure step, which can be explained by the general trend established for intramolecular nucleophilic substitutions. Namely, five-membered rings are formed two or 3 orders of magnitude faster than six-membered rings.[35] Ryschkewitsch has also found the formation of C_nN_2B rings much more favored for $n = 2$, compared to $n = 3$.[36]

The pK_a values in methanol of protonated amines and acetic acid, respectively are about 1 and 5 log units higher compared to water.[37] Assuming similar changes for pK_a^N and pK_a^O values of **10b**, the proportion [**10′b**]/[**10″b**] becomes much larger in methanol than in water. This can explain the predominant ring formation (**12b**) on deprotonation of **10b** by NaOH in methanol.

Processes taking place in the course of the bromination of diamine-methoxycarbonylboranes **6a**,**b**, as well as the decomposition of **8a**,**b** in methanol, are probably analogous to those shown in Scheme 2, i.e., the first step of these processes is the formation of HBr·DA·BH(Br)COOMe (**11a**,**b**) (though complexes of this composition were not prepared). However, there is one essential difference: species containing $BH(Br)COO^-$ groups obviously do not form, so the equilibria (iv) and (v) can be simplified to the equilibrium between ester derivatives of **10a**,**b** and **10′a**,**b**, where N-protonated species slowly decompose via Br·MeOH/OH^- exchange and N-deprotonated species yield cyclic cations **13a**,**b**. Bromination of **6a** and **6b** afforded cyclic cations **13a** and **13b**, after neutralization by methanolic NaOH solution. The decomposition of one of the borane moieties in **8a** in methanol was fairly slow, yielding cyclic cation **13a** (Scheme 1, xii and xv), similar to the decomposition of **7a** described above. The process attained ≥95% conversion, despite the presence of HBr evolved from the decomposed borane moiety, which once more demonstrates the rapidity of the formation of the five membered ring. On the other hand, decomposition of one of the borane moieties in **8b** cannot result in ring closure unless the evolved HBr was continuously removed by 4 Å molecular sieves or NaOH. In the case of 4 Å molecular sieves the reaction took 12 h at 50 °C, after removal of the molecular sieves the decomposition went on at a similar rate, but the ring formation was not prolonged. In the presence of one molar equivalent of NaOH the decomposition was 3−4 times faster (probably owing to the $Br^- \rightarrow OH^-$ exchange).

In all previously mentioned reactions, one of the two borane moieties in **7a**,**b** and **8a**,**b** was destroyed. This loss inspired us to find a more economical path to **12a,b** and **13a,b**. Base exchange reactions of DA·2BH(Br)COOR + DA·2DA·BH(Br)-COOR type would result in the cyclic cations in 2-fold yield. However, the yields were found close to those attained by the simple decomposition of **7a**,**8a** or that of **7b**,**8b** effected by

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NaOH, ruling out taking place of considerable base exchange. This consequence was unequivocally checked in reactions of **7a** and **8a** with TMPDA, and conversely, of **7b** and **8b** with TMEDA, where the base exchange should be indicated by the appearance of the cyclic cation formed with the added amine. ^{1}H NMR monitoring of these reactions showed noticeable base exchange only in the reaction of **8a** and TMPDA (26−28%).

12a,**b** and **13a**,**b** are hygroscopic crystalline solids and very soluble in either water or methanol. **13a**,**b** possess considerable solubility also in acetone and chloroform. All cyclic cations are quite stable in acidic aqueous media. **12a**,**b** undergo deprotonation with bases and transform into **18a**,**b** (Scheme 1, xx). The protonation constants (pK_a) are 5.59 for the five-membered cyclic cation and approximately 5.55 for the six-membered cyclic cation. These values are 3 units lower than those of amine-carboxyboranes.[38,39] **13a**,**b** in alkaline media also transform into **18a**,**b** via the hydrolysis of the ester group (Scheme 1, xix). In the presence of equimolar NaOH the half-lives were 4 h for **13a** and 72 days for **13b**, so the difference between the reaction rates was a few 100-fold. Hydrolysis experiments with **13a** in the presence of 5−20 mol % NaOH showed that NaOH did not act as a catalyst.

Both cyclic cations form poorly water soluble salts with PF_6^- and BPh_4^- anions (Scheme 1, xvii and xviii). The hexafluorophosphates appeared valuable from preparative aspect as they could be precipitated in pure form from reaction mixtures, even when considerable amounts of the corresponding ammonium ions were present. The hexafluorophosphate salt of [TMEDA·B(H)COOH]$^+$ ion crystallized as a double salt with potassium hexafluorophosphate, [TMEDA·B(H)COOH]PF_6·KPF_6 (4/1), while no precipitate fell out on addition of $NaPF_6$ solution. The tetraphenylborates could be obtained in pure form only from reaction mixtures containing no ammonium ions.

Zwitterionic species **18a**,**b**, formed from cyclic cations of **12a**,**b** and **13a**,**b** with KOH, could be prepared in pure form after separation from KBr. Moreover, pure aqueous solution of **18a**,**b** could be obtained in the reactions between the appropriate tetraphenylborate salts (**15a**,**b**) and KOH (Scheme 1, xxi). Both zwitterions are hygroscopic and possess extremely high solubility in water.

TMEDA-bis(dibromocarboxyborane) (**9a**) could be transformed into a cyclic cation containing the >B(Br)COOH group (Scheme 1, xxii), which was prepared as a hexafluorophosphate salt (**19a**), in two different ways. These were the reactions of **9a** with TMEDA in methanol and with NaOH in water. These reactions showed rates similar to those affording **12a** from **7a**, but the yields were much lower. The cyclic cation [TMEDA·B(Br)COOH]$^+$ was found to be the strongest known acid in the area of carboxyboron compounds with an approximate pK_a value of 4.17. The zwitterionic species **21a** formed upon deprotonation of **19a** undergoes slow decomposition in water (with a half-life of ca. 40 h), but is stable in solid form. **21a** was prepared with equimolar KOH from [TMEDA·B(Br)-COOH]BPh_4 (**20a**) (Scheme 1, xxiv), which was in turn produced from **19a** (Scheme 1, xxiii). The formation of the analogous six-membered ring could not be observed in similar reactions.

Analogy between Amine-carboxyboranes and α-Amino Acids or Carboxylic Acids. Spielvogel, the pioneer of the area, regarded amine-carboxyboranes as the protonated boron analogues of α-amino acids, or often named them simply the boron analogues of amino acids.[1,3,15,29,40,41] This concept has been widely accepted in the literature.[6,16,38,42,43] This analogy inspired wide-ranging studies of the biological and pharmacological activities of these compounds. However, this analogy, which is based on the $C^+ \leftrightarrow B$ isoelectronic relationship, obviously does not denote chemical similarity between amine-carboxyboranes and α-amino acids, since the charges, which naturally have a major influence on chemical properties, of the isoelectronic analogue species are different.

In contrast to protonated glycine ($NH_3^+-CH_2COOH$), ammonia-carboxyborane NH_3·BH_2COOH, regarded as its isoelectronic analogue, could not be deprotonated on the nitrogen atom.[39] All metal complexes prepared so far have been carboxylato complexes, and chelate formation characteristic to α-amino acids has not been observed.[39,42] Another important difference between protonated glycine and NH_3·BH_2COOH is that peptide bond could be formed only on the carboxyl group of NH_3·BH_2COOH; amine carboxyboranes are in the N-terminal position in all dipeptides and a tripeptide[41] known so far. Ab initio calculations investigating the amine-carboxyborane ↔ α-amino acid analogy revealed considerable differences in the geometry, charge distribution, dipole moment and electrostatic potential, which, according to the authors, were due, at least partly, to the presence of an additional hydrogen attached to nitrogen.[44] The difference of 6 units between the pK_a value of NH_3·BH_2COOH (8.33)[39] and pK_{a1} value of glycine (2.35),[45] which is assigned to the deprotonation of the isoelectronic protonated glycine, does not refer to strict analogy between the two species. When regarding amine-carboxyboranes as the boron analogues of α-amino acids in general, one should consider that the former, except ammonia-carboxyborane, are complexes of alkyl or aromatic amines. Alkylamine complexes are analogues of *N*-alkylamino acids, while amino acid analogy for aromatic amine complexes cannot be interpreted.

In the chemistry of boron−nitrogen compounds, analogies are sought based on not only $C^+ \leftrightarrow B$ isoelectronic relationship, but more frequently on the $B-N \leftrightarrow C-C$ relationship, where isoelectronic species possess the same charge (see for example: borazine-benzene, hexagonal BN-graphite, cubic BN-diamond). The latter relationship was called isoelectronic and isosteric by Wiberg.[46] There has been some confusion about these two terms in the literature since the classical paper of Langmuir.[47] We use the term "isoelectronic" as recommended by IUPAC,[48] and ignore the term "isosteric", as to our knowledge IUPAC has not yet defined. Considering the isoelectronic relationship between BN and CC groups, ammonia-carboxyborane is isoelectronic with propionic acid, and amine-carboxyboranes are isoelectronic with carboxylic acids. Using this approach an isoelectronic boron analogue of glycine does not exist, while isoelectronic boron analogue of alanine would be H_3N·$BH(NH_2)COOH$.

The compounds DA·$2BH_2COOH$ (DA = TMEDA, TMPDA,

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TMBDA) reported in this paper are isoelectronic analogues of methylated α,ω-dicarboxylic acids (namely adipic, pimelic, and suberic acid, respectively). Compounds DA·BH_2COOH are isoelectronic analogues of methylated derivatives of ω-amino acids. **18a** is isoelectronic with 1,1,3,3-tetramethylproline-betaine, and such relationship can be established between **18b** and 1,1,3,3-tetramethylpipecolinate betaine, as well as between **12a**,**b** and the protonated forms of the corresponding betaines.

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Supporting Information Available: Description of further synthetic methods for **8b**, **13a**, **13b**, **14a**, **14b**, **16a**, **16b**, **18a**, **19a**, and textual presentation of IR and NMR data (4 pages). Ordering information is given on any current masthead page.

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