A Convenient One-Step Synthesis of Stable β-Amino Alcohol *N*-Boranes from α-Amino Acids

Afroditi Pinaka,[a,b] Georgios C. Vougioukalakis,*[a,c] Dimitra Dimotikali,[b] Vassilis Psyharis,[d] Kyriakos Papadopoulos*[a]

[a] Institute of Physical Chemistry, NCSR Demokritos, 15310 Athens, Greece
Fax +30(210)6511766; E-mail: kyriakos@chem.demokritos.gr

[b] Department of Chemical Engineering, NTU Athens, 15780 Athens, Greece

[c] Laboratory of Organic Chemistry, Department of Chemistry, University of Athens, Panepistimiopolis Zografou, 15771 Athens, Greece
Fax +30(210)6511766; E-mail: vougiouk@chem.uoa.gr

[d] Institute of Materials Science, NCSR Demokritos, 15310 Athens, Greece

Received 23 January 2012; revised 3 February 2012

Abstract: Novel, non-cyclic β-amino alcohol *N*-boranes are isolated from the sodium borohydride–sulfuric acid assisted direct reduction of a series of α-amino acids. The reduction takes place in one step under mild conditions and affords the products in good yields.

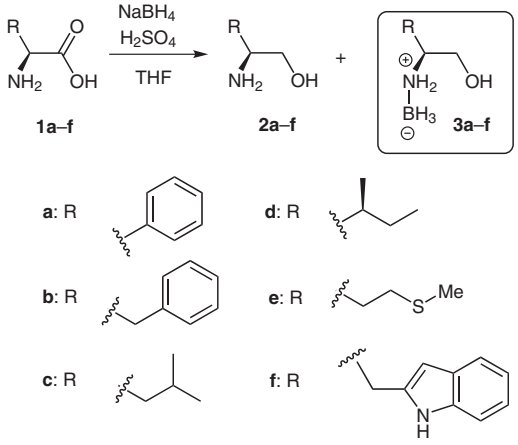
Key words: amino acids, β-amino alcohols, reduction, sodium borohydride, β-amino alcohol *N*-boranes

The importance of amine–borane adducts is profound both in industry and academia. These compounds, characterized by thermal and hydrolytic stability and solubility in a wide variety of solvents,[1] are utilized in a large number of applications including, but not limited to, asymmetric synthesis,[2–5] chemical hydrogen storage,[6–8] the synthesis of cyclic azaboranes and borazines,[9,10] and coordination chemistry.[11,12]

A survey of the literature showed that there are a large number of publications on the synthesis of amine–borane adducts. In sharp contrast, there are only a few reports on the synthesis of β-amino alcohol boranes. The majority of these compounds are obtained through the reaction of β-amino alcohols with borane–etherates or borane–thioetherates.[13–17]

On a different note, β-amino alcohols are usually synthesized either by the direct reduction of free amino acids,[18–26] or indirectly from activated amino acid esters[27–29] and amino acid anhydrides.[30,31] Reagents employed for the reduction of free amino acids are usually metal hydrides, such as lithium aluminum hydride or lithium borohydride, in combination with various organic reagents such as trimethylchlorosilane, borane–methyl sulfide complex activated by trimethylborate, or boron trifluoride–diethyl ether complex. The utilization of sodium borohydride has also been reported in combination with inorganic compounds such as transition metal complexes, iodine, or sulfuric acid.

While implementing a project aimed toward the synthesis of optically pure β-amino alcohols, which were intended for use as organocatalysts in asymmetric reactions, we employed the sodium borohydride–sulfuric acid assisted direct reduction of α-amino acids.[26] Our choice was based on the fact that this was a safe, cheap and reliable synthetic method toward β-amino alcohols. However, during the course of our experiments, we noticed that apart from the targeted β-amino alcohols, unexpected side products were also formed in significant amounts. These side products were observed in all the amino acid reductions we performed. The characterization of these compounds was carried out utilizing a variety of techniques (vide infra) and eventually led to the conclusion that they were the corresponding non-cyclic β-amino alcohol *N*-borane adducts **3a–f** shown in Scheme 1.



Scheme 1 β-Amino alcohol *N*-boranes obtained by the sodium borohydride–sulfuric acid assisted direct reduction of α-amino acids

As mentioned above, amino alcohol–borane adducts are relatively stable compounds which are gaining considerable attention, especially in asymmetric organic reactions where they serve as chiral reducing agents. Considering their increasing importance, we decided to investigate the scope and limitations of their synthesis further, through the direct reduction of α-amino acids using sodium borohydride in the presence of sulfuric acid.

To the best of our knowledge, there are no reports on the direct synthesis of non-cyclic β-amino alcohol *N*-boranes from α-amino acids. β-Amino alcohol–borane adducts are usually synthesized in anhydrous organic solvents from β-

SYNTHESIS 2012, 44, 1057–1062
Advanced online publication: 27.02.2012
DOI: 10.1055/s-0031-1289727; Art ID: T07612SS
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amino alcohols and borane–ether complexes.[13–17] Most of these boranes exist in cyclic form and are known as oxazaborolidines. They are easily hydrolyzed in acidic or alkaline aqueous solutions to afford β-amino alcohols and a mixture of unidentified boron adducts.

At this point, we emphasize the importance of the work-up procedure for this direct reduction of α-amino acids. Following the procedure described by Abiko and Masamune,[26] we obtained the corresponding β-amino alcohols and β-amino alcohol *N*-boranes as 1:1 mixtures. Only after employing acidic followed by alkaline hydrolysis were we able to obtain exclusively the β-amino alcohols in good isolated yields. Nevertheless, our observation suggests that Abiko's procedure is of general applicability, provided that special care is taken during hydrolysis. The use of mild alkaline hydrolysis afforded β-amino alcohol *N*-boranes as the major products. This process might be of industrial importance as these amino alcohol *N*-boranes can be easily synthesized in one step, under mild conditions and in relatively good yields from α-amino acids. They are not flammable and, more importantly, they are relatively stable in air and aqueous solutions.[32]

The sodium borohydride–sulfuric acid assisted reduction procedure was employed initially for the reduction of (*S*)-2-phenylglycine (**1a**). The isolated yield of the expected β-amino alcohol **2a** was lower than that reported by Abiko and Masamune,[26] moreover, an unprecedented product **3a** was also obtained in almost equimolar quantity. The yields of the isolated products **2a** and **3a**, after column chromatography (chloroform–methanol, 1:1), were 33% and 27%, respectively. The same procedure was employed subsequently for the reduction of a series of α-amino acids. In all cases, β-amino alcohols **2** and the corresponding *N*-boranes **3** were obtained in almost equal yields (Table 1).

To improve the yield of *N*-borane adduct **3a**, several optimization attempts were made regarding both the reaction conditions and the quantities of reagents utilized. For example, the reduction was repeated using a large excess of sodium borohydride (10-fold excess). However, no significant differences in the composition or the isolated yields of the reaction products was observed. In another attempt, the reaction mixture was subjected to overnight reflux directly after the addition of the sulfuric acid–diethyl ether solution. After the standard work-up, no product **3a** was isolated at all. The reduction was also carried out in the absence of sulfuric acid, but in this case the yields of both products were negligible. In a final attempt, the work-up procedure was modified; the reaction mixture was hydrolyzed by the addition of aqueous sodium hydroxide solution of low base concentration (4×10^{-2} M) without the addition of methanol. This resulted in formation of the corresponding β-amino alcohol *N*-boranes as the major products in good yields (Table 1). The β-amino alcohol *N*-boranes **3a–f** were characterized by means of NMR spectroscopy (^{1}H, ^{13}C, ^{13}C DEPT, COSY and HSQC experiments), infrared spectroscopy, high-resolution mass spectrometry, elemental analysis and single-crystal X-ray crystallography (see the Supporting Information).

Table 1 Yields and Optical Rotations of β-Amino Alcohols **2a–f** and Novel β-Amino Alcohol *N*-Boranes **3a–f**

α-Amino acid	Product	Yield (%)[a]	Optimized yield (%)[b]	$[\alpha]_D$ (*c* in g/100 mL)
(*S*)-2-phenylglycine (**1a**)	**2a**	33	–	–57.1 (*c* 1.0, $CHCl_3$)
	3a	27	53	–89.3 (*c* 1.0, $CHCl_3$)
(*S*)-phenylalanine (**1b**)	**2b**	26	–	–21.3 (*c* 1.0, $CHCl_3$)
	3b	36	67	–29.5 (*c* 1.0, $CHCl_3$)
(*S*)-leucine (**1c**)	**2c**	29	–	+ 4.6 (*c* 1.3, EtOH)
	3c	28	46	+45.4 (*c* 1.3, EtOH)
(*S*)-isoleucine (**1d**)	**2d**	25	–	+ 5.2 (*c* 1.6, EtOH)
	3d	31	56	+29.4 (*c* 1.6, EtOH)
(*S*)-methionine (**1e**)	**2e**	32	–	–17.2 (*c* 1.4, EtOH)
	3e	44	65	+51.1 (*c* 1.4, EtOH)
(*S*)-tryptophan (**1f**)	**2f**	34	–	–16.5 (*c* 1.0, MeOH)
	3f	27	42	+25.2 (*c* 1.0, MeOH)

[a] Yields obtained using the experimental conditions described in reference 26.
[b] Yields obtained employing the optimized conditions described in this work.

The ^{1}H NMR spectra of β-amino alcohols **2a–f** were in agreement with those reported in the literature,[24–26,28,33–35] and were less complicated than those of the corresponding *N*-boranes **3a–f**. More specifically, in the ^{1}H NMR spectra of β-amino alcohols **2a–f**, three characteristic doublet of doublets were observed at about 3.5, 3.7 and 4.9 ppm, corresponding to the diastereotopic methylene (OCH_2) and methine (NCH) protons of the ABX-system of the aminoethanol moiety. In contrast, the corresponding peaks in the spectra of *N*-boranes **3a–f** appeared closer to each other at about 3.7 ppm, due to the presence of the borane (BH_3) group. The proton signals of the borane group appeared in the region between 1.0 and 2.0 ppm. The ^{13}C NMR spectra of *N*-boranes **3a–f** were analogous to those obtained for β-amino alcohols **2a–f**, with one significant difference: while the two characteristic aliphatic resonances of β-amino alcohols **2a–f** appeared at about 65 (CH_2OH) and 57 ± 2.0 ppm (NCH), in the ^{13}C NMR spectra of *N*-boranes **3a–f** the corresponding carbon signals were much closer to each other (Figure 1), and in some cases overlapped (phenylglycinol borane, **3a**).

The presence of the borane group in compounds **3a–f** was confirmed through the observation of strong absorption bands in the infrared spectra between 2290–2310 cm^{-1}. Such symmetric and asymmetric absorption bands, attributed to B–H hydrogen bonds, have been reported in the literature for various amine–borane adducts.[13,16,36] Positive ion high-resolution mass spectrometry of **3a–f** did not produce valid results since the products undergo hydrolysis under the acidic conditions in which the measurements take place; this observation has previously been reported

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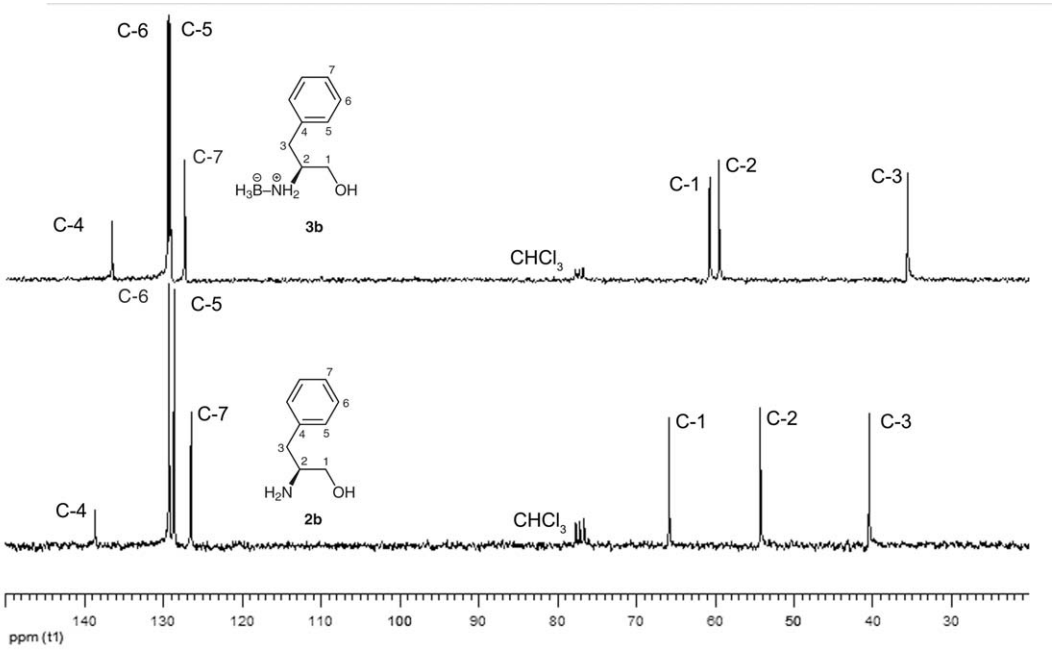

Figure 1 ^{13}C NMR spectra of β-amino alcohol **2b** and the corresponding β-amino alcohol *N*-borane **3b**

in the literature.[37] However, fragments corresponding to $[(2M + H)^+ - 2BH_3 - H_2O]$, observed in the spectra of **3a–d**, strongly suggested that *N*-boranes **3a–f** undergo self-condensation (formation of substituted aminoethyl–aminoethanol adducts) under the conditions employed to record the mass spectra.

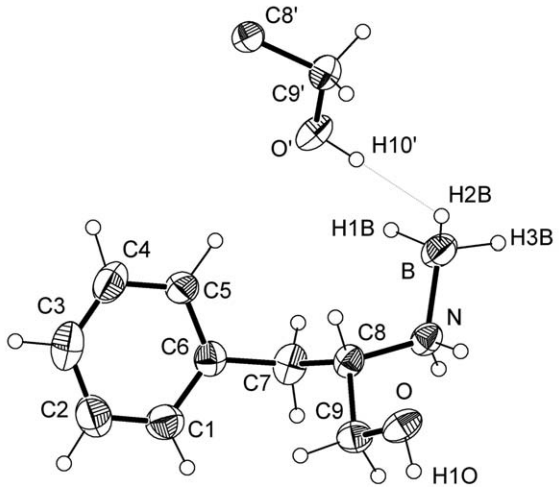

Figure 2 X-ray crystal structure (ORTEP with 30% probability ellipsoids) of phenylalaninol *N*-borane **3b**. The intermolecular dihydrogen bond H2B···H1O′ is shown. Atoms with prime symbols belong to the molecule at the symmetry equivalent site (2 – x, 0.5 + y, 2 – z)

The structures of boranes **3a–f** were further established by elemental analyses, where the measured compositions for all products were in agreement with the calculated values. Unambiguous confirmation of the structures was achieved by X-ray crystallography of borane **3b** (Figure 2). In brief, it is worth mentioning that the B–N bond of 1.610(3) Å is within the observed range of B–N bonds [1.564(6)–1.658(2) Å].[38] The conformation around the boron atom is almost tetrahedral with N–B–H bond angles very close to 109° (see the Supporting Information), and unconventional dihydrogen O–H···H–B [H2B···H1O′: 1.81(3) Å] intermolecular contacts appear in the crystal structure of *N*-borane **3b**.[38,39]

As regards the reaction mechanism for the formation of β-amino alcohol *N*-boranes **3a–f**, we propose that it proceeds in a manner similar to that proposed by Gribble[40] for the reduction of organic acids with sodium borohydride. Thus, sodium borohydride reacts initially with sulfuric acid giving borane (BH_3), which then reacts with the amino acid affording acyloxyborane–amineborane intermediate **A** (Scheme 2). This intermediate undergoes intramolecular transfer of two hydrides from the borane group to the carbonyl group, giving amineborane–borate intermediate **B**, which, under mild work-up conditions [dilute aqueous sodium hydroxide solution, stirring at room temperature, (this work)] or forced work-up conditions (concentrated aqueous hydrochloric acid followed by concentrated alkaline solution) gives amine–boranes **3a–f** or β-amino alcohols **2a–f**, respectively.

In conclusion, the sodium borohydride–sulfuric acid assisted reduction of α-amino acids is an efficient, safe, and relatively cheap one-pot procedure for the preparation of novel, chiral β-amino alcohol *N*-boranes in good yields. Careful work-up involving mild alkaline hydrolysis at room temperature was found to be the most appropriate procedure to obtain the stable β-amino alcohol *N*-borane products.

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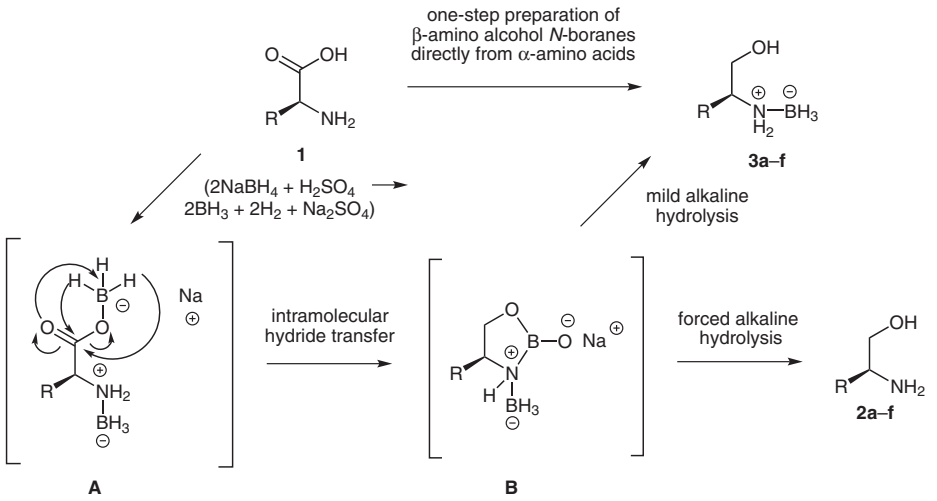

Scheme 2 Proposed mechanism for the sodium borohydride–sulfuric acid assisted reduction of α-amino acids into β-amino alcohol *N*-boranes **3a**–**f**

All solvents were dried and purified according to standard procedures. Reaction products were isolated as chromatographically pure materials. All the amino acids were purchased from commercial suppliers and used without any further purification. TLC was carried out on silica gel plates (Merck Kieselgel F_{254}) and visualization was accomplished by UV light or by spraying with phosphomolybdic acid followed by heating. Flash column chromatography was carried out on SiO_2 (silica gel 60, 70–230 mesh, ASTM). ^{1}H NMR and ^{13}C NMR spectra were recorded on a Bruker Avance 500 MHz (125 MHz for ^{13}C) spectrometer. Chemical shifts are reported in ppm downfield from Me_4Si, using the residual solvent signal as the internal standard. Coupling constants (*J*) are reported in Hz. The assignment of signals in the ^{13}C NMR spectra was verified using DEPT experiments. Infrared spectra were recorded on a Nicolet 6700 Fourier transform spectrometer. Bands are reported in wavenumbers (cm^{-1}) with the following relative intensities: br (broad), s (strong 67–100%), m (medium 33–67%), or w (weak <33%). HRMS spectra were obtained using the electrospray ionization (ESI) method. Absorption spectra were obtained on a JASCO V-560 spectrophotometer. The molar extinction coefficients are given in L mol^{-1} cm^{-1}. Elemental analyses were obtained using a Perkin-Elmer 2400 CHN elemental analyzer. Optical rotation measurements were performed on a Perkin-Elmer 241 polarimeter and calculated from the equation $[\alpha]_D = (\alpha_{measured} \times 100)/c \times l$; where l is the path length of the cell, and *c* the concentration of the solution (g/100 mL). Crystallographic data have been deposited at the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK, and copies can be obtained on request, free of charge, by quoting the publication citation and the deposition number CCDC 857109 (**3b**).

β-Amino Alcohol *N*-Boranes 3a–f; General Procedure

To a three-necked, round-bottomed flask containing $NaBH_4$ (2.28 g, 60 mmol) and anhydrous THF (30 mL) under argon was added the appropriate α-amino acid (15 mmol) with stirring. The flask was immersed in an ice–H_2O bath (0 °C) and a soln of concd H_2SO_4 (1.5 mL, 28.6 mmol) in Et_2O (5.0 mL) was added at such a rate that the temperature was maintained below 20 °C. The mixture was then stirred vigorously at r.t. under an Ar atm for ca. 20 h. After completion of the reaction, the flask was again immersed in an ice-H_2O bath (0 °C) and an aq NaOH soln (100 mL, 4×10^{-2} M) was added slowly, in order to maintain the temperature of the mixture below 40 °C. The resulting mixture was stirred vigorously for 3 h at r.t. **CAUTION:** the full experimental procedure was performed inside a fume-hood in order to safely vent dangerous emissions (H_2). The organic solvents were evaporated under vacuum and the remaining aq soln extracted with $CHCl_3$ (3 × 50 mL). The combined organic extracts were dried over $MgSO_4$ and evaporated to afford novel β-amino alcohol *N*-boranes **3a**–**f** in pure form without the need for further purification.

β-Amino Alcohols 2a–f; General Procedure

To obtain β-amino alcohols **2a**–**f** as the major products, an identical procedure to that described for the synthesis of compounds **3a**–**f** was adopted initially. On completion of the reaction, hydrolysis was achieved by the addition of aq HCl (10 mL, 3 M). The resulting mixture was stirred vigorously for 2 h at r.t. after which, aq NaOH soln (15 mL, 5 M) was added and the work-up procedure described for the synthesis of compounds **3a**–**f** was followed to afford β-amino alcohols **2a**–**f** as the major products in yields of up to 70%.

(2*S*)-(–)-2-Amino-2-phenylethanol *N*-Borane (3a)

The reaction of (*S*)-2-phenylglycine (2.26 g, 15.0 mmol) with $NaBH_4$ (2.28 g, 60 mmol) following the above general procedure furnished **3a** (1.21 g, 53%) as a wax-like product.

$[\alpha]_D^{20}$ –89.3 (*c* 1.0, $CHCl_3$).

IR (neat): 3227 (m, OH), 3143 (w, NH), 2942 (w), 2317 (s, BH), 2274 (s, BH), 1582 (m), 1454 (m), 1162 (s, N→B), 1062 (s), 758 (s), 697 (s) cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.35–7.21 (m, 5 H, phenyl), 4.92 (s, 1 H, NH), 4.03 (dd, J_1 = 11.4 Hz, J_2 = 2.8 Hz, 1 H, OCH_2), 3.91 (br s, 1 H, NH), 3.84 (m, 1 H, NCH), 3.69 (dd, J_1 = 11.4 Hz, J_2 = 2.6 Hz, 1 H, OCH_2), 3.29 (s, 1 H, OH), 1.51 (br s, 3 H, BH_3).

^{13}C NMR (125 MHz, DMSO-d_6): δ = 139.6 (C-3), 128.93 (C-5, C-5′), 128.89 (C-6), 128.4 (C-4, C-4′), 64.6 (C-1), 64.5 (C-2).

HRMS (ESI): *m*/*z* calcd for $C_{16}H_{21}N_2O$ $[(2M + H)^+ - 2BH_3 - H_2O]$: 257.1648; found: 257.1677.

UV/Vis ($CHCl_3$): λ_{max} (ε) = 220 (2560), 258 nm (133).

Anal. Calcd for $C_8H_{14}BNO$: C, 63.63; H, 9.34; N, 9.28. Found: C, 63.44; H, 9.19; N, 9.54.

(2*S*)-(–)-2-Amino-3-phenylpropan-1-ol *N*-Borane (3b)

The reaction of (*S*)-phenylalanine (2.47 g, 15.0 mmol) with $NaBH_4$ (2.28 g, 60 mmol) following the above general procedure furnished **3b** (1.67 g, 67%) as a wax-like product.

$[\alpha]_D^{20}$ –29.5 (*c* 1.0, $CHCl_3$).

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IR (neat): 3273 (m, OH), 3115 (m, NH), 2936 (m), 2353 (s, BH), 2261 (s, BH), 1602 (s), 1299 (s), 1163 (s, N→B), 1044 (s), 699 (s), 747 (s) cm^{-1}.

^1H NMR (500 MHz, $CDCl_3$): δ = 7.37–7.15 (m, 5 H, phenyl), 4.22 (br s, 1 H, NH), 3.87 (dd, J_1 = 11.5 Hz, J_2 = 2.3 Hz, 2 H, OCH, NH), 3.57 (dd, J_1 = 11.5 Hz, J_2 = 5.3 Hz, 1 H, OCH), 3.04 (m, 1 H, CH_2-phenyl), 3.01 (s, 2 H, NCH, OH), 2.79 (m, 1 H, CH_2-phenyl), 1.49 (br s, 3 H, BH_3).

^{13}C NMR (125 MHz, $CDCl_3$): δ = 136.5 (C-7), 129.4 (C-6, C-6′), 129.1 (C-4), 127.3 (C-5, C-5′), 60.7 (C-1), 59.5 (C-2), 35.6 (C-3).

HRMS (ESI): *m*/*z* calcd for $C_{18}H_{25}N_2O$ [(2M + H)$^+$ – 2BH_3 – H_2O]: 285.1961; found 285.1969.

UV/Vis ($CHCl_3$): λ_{max} (ε) = 220 (2032), 258 nm (208).

Anal. Calcd for $C_9H_{16}BNO$: C, 65.50; H, 9.77; N, 8.49. Found: C, 65.31; H, 9.47; N, 8.12.

(2*S*)-(+)-2-Amino-4-methylpentan-1-ol *N*-Borane (3c)

The reaction of (*S*)-leucine (1.96 g, 15.0 mmol) with $NaBH_4$ (2.28 g, 60 mmol) following the above general procedure furnished **3c** (0.91 g, 46%) as a colorless viscous oil.

$[\alpha]_D^{20}$ +45.4 (*c* 1.3, EtOH).

IR (neat): 3231 (m, OH), 3150 (w, NH), 2956 (s), 2871 (m), 2320 (s, BH), 2272 (s, BH), 1586 (m), 1467 (m), 1165 (s, N→B), 1039 (s), 756 (s) cm^{-1}.

^1H NMR (500 MHz, $CDCl_3$): δ = 4.24 (s, 1 H, NH_2), 3.82 (dd, J_1 = 11.3 Hz, J_2 = 3.8 Hz, 2 H, OCH_2), 3.49 (m, 1 H, NCH), 3.23 (br s, 1 H, OH), 2.79 (s, 1 H, NH_2), 1.53 (m, 3 H, CH_2CH), 1.25 (br s, 3 H, BH_3), 0.84 [d, *J* = 5.6 Hz, 6 H, $(CH_3)_2C$].

^{13}C NMR (125 MHz, $CDCl_3$): δ = 61.8 (C-1), 57.1 (C-2), 39.1 (C-3), 25.1 (C-4), 23.2 (C-5), 22.6 (C-5′).

HRMS (ESI): *m*/*z* calcd for $C_{12}H_{29}N_2O$ [(2M + H)$^+$ – 2BH_3 – H_2O]: 217.2274; found: 217.2284.

UV/Vis ($CHCl_3$): λ_{max} (ε) = 226 (287), 258 nm (49).

Anal. Calcd for $C_6H_{18}BNO$: C, 55.00; H, 13.85; N, 10.69. Found C, 55.48; H, 14.00; N, 10.73.

(2*S*,3*S*)-(+)-2-Amino-3-methylpentan-1-ol *N*-Borane (3d)

The reaction of (*S*)-isoleucine (1.96 g, 15.0 mmol) with $NaBH_4$ (2.28 g, 60 mmol) following the above general procedure furnished **3d** (1.09 g, 56%) as a colorless viscous oil.

$[\alpha]_D^{20}$ +29.4 (*c* 1.6, EtOH).

IR (neat): 3238 (m, OH, NH), 2962 (s), 2933 (m), 2877 (w), 2318 (s, BH), 2272 (s, BH), 1586 (m), 1461 (m), 1163 (s, N→B), 1033 (s), 997 (s), 962 (m), 864 (w) cm^{-1}.

^1H NMR (500 MHz, $CDCl_3$): δ = 4.32 and 3.70 (2 × s, 2 H, NH_2), 3.90 (dd, J_1 = 11.6 Hz, J_2 = 3.4 Hz, 1 H, OCH_2), 3.62 (dd, J_1 = 11.6 Hz, J_2 = 3.4 Hz, 1 H, OCH_2), 2.84 (s, 1 H, OH), 2.67 (m, 1 H, NCH), 1.90 (m, 1 H, CH), 1.41 and 1.18 (2 × m, 2 H, CH_2CH_3), 1.63 (br s, 3 H, BH_3), 0.91 (d, *J* = 7.3 Hz, 3 H, CH_3CH), 0.86 (t, *J* = 7.3 Hz, 3 H, CH_3CH_2).

^{13}C NMR (125 MHz, $CDCl_3$): δ = 62.7 (C-1), 59.6 (C-2), 34.1 (C-3), 26.4 (C-4), 14.4 (C-6), 11.6 (C-5).

HRMS (ESI): *m*/*z* calcd for $C_{12}H_{29}N_2O$ [(2M + H)$^+$ – 2BH_3 – H_2O]: 217.2274; found 217.2281.

UV/Vis ($CHCl_3$): λ_{max} (ε) = 226 (280), 252 nm (54).

Anal. Calcd for $C_6H_{18}BNO$: C, 55.00; H, 13.85; N, 10.69. Found: C, 55.16; H, 14.20; N, 10.36.

(2*S*)-(+)-2-Amino-4-methylsulfanylbutan-1-ol *N*-Borane (3e)

The reaction of (*S*)-methionine (2.24 g, 15.0 mmol) with $NaBH_4$ (2.28 g, 60 mmol) following the above general procedure furnished **3e** (1.45 g, 65%) as a colorless viscous oil.

$[\alpha]_D^{20}$ +51.1 (*c* 1.4, EtOH).

IR (neat): 3225 (m, OH), 3142 (w, NH), 2915 (m), 2860 (w), 2316 (s, BH), 2273 (s, BH), 1585 (m), 1427 (m), 1163 (s, N→B), 1077 (s), 1039 (s), 997 (s) cm^{-1}.

^1H NMR (500 MHz, $CDCl_3$): δ = 4.36 and 4.20 (2 × s, 2 H, NH_2), 3.89 (dd, J_1 = 11.5 Hz, J_2 = 4.9 Hz, 1 H, OCH_2), 3.62 (dd, J_1 = 11.5 Hz, J_2 = 6.3 Hz, 1 H, OCH_2), 2.99 (s, 1 H, OH), 2.97 (m, 1 H, NCH), 2.54 (m, 2 H, SCH_2), 2.00 and 1.76 (2 × m, 2 H, CH_2CH_2S), 2.09 (s, 3 H, SCH_3), 1.36 (br s, 3 H, BH_3).

^{13}C NMR (125 MHz, $CDCl_3$): δ = 61.6 (C-1), 57.9 (C-2), 30.9 (C-3), 28.3 (C-4), 15.8 (C-5).

HRMS (ESI): *m*/*z* calcd for $C_5H_{14}NOS$ [(M + H)$^+$ – BH_3]: 136.0791; found 136.0795.

UV/Vis ($CHCl_3$): λ_{max} (ε) = 227 (560), 260 nm (88).

Anal. Calcd for $C_5H_{16}BNOS$: C, 40.28; H, 10.81; N, 9.39. Found: C, 40.40; H, 10.66; N, 9.24.

(2*S*)-(+)-2-Amino-3-(1*H*-indol-2-yl)-propan-1-ol *N*-Borane (3f)

The reaction of (*S*)-tryptophan (3.1 g, 15.0 mmol) with $NaBH_4$ (2.28 g, 60 mmol) following the above general procedure furnished **3f** (1.28 g, 42%) as a colorless viscous oil.

$[\alpha]_D^{20}$ +25.2 (*c* 1.0, MeOH).

IR (neat): 3360 (s, OH), 3252 (s, NH), 3146 (m, NH), 2954 (w), 2332 (s, BH), 2307 (s, BH), 1596 (m), 1454 (m), 1162 (s, N→B), 1027 (s), 749 (s) cm^{-1}.

^1H NMR (500 MHz, CD_3OD): δ = 7.58 (d, *J* = 7.6 Hz, 1 H, ArH), 7.31 (d, *J* = 7.9 Hz, 1 H, ArH), 7.12–6.92 (m, 3 H, ArH), 4.58 (s, 4 H, NH, NH_2, OH), 3.71 (dd, J_1 = 10.7 Hz, J_2 = 4.5 Hz, 1 H, OCH_2), 3.48 (dd, J_1 = 5.8 Hz, J_2 = 14.2 Hz, 1 H, OCH_2), 3.19 (dd, J_1 = 14.2 Hz, J_2 = 7.6 Hz, 1 H, OCH_2), 2.96 (m, 1 H, NCH), 2.95 (m, 2 H, CH_2), 1.52 (br s, 3 H, BH_3).

^{13}C NMR (125 MHz, CD_3OD): δ = 137.2 (C-4), 127.8 (C-11), 123.6 (C-6), 121.6 (C-8), 118.9 (C-7), 118.5 (C-9), 111.4 (C-10), 110.3 (C-5), 61.2 (C-1), 59.5 (C-2), 24.9 (C-3).

HRMS (ESI): *m*/*z* calcd for $C_{11}H_{17}N_2O$ [(M + 3H)$^+$ – BH_3]: 193.1324; found 193.1330.

UV/Vis (MeOH): λ_{max} (ε) = 224 (26580), 280 nm (681).

Anal. Calcd for $C_{11}H_{17}BN_2O$: C, 64.74; H, 8.40; N, 13.73. Found: C, 64.53; H, 8.26; N, 13.58.

Supporting Information for this article is available online at http://www.thieme-connect.com/ejournals/toc/synthesis.

Acknowledgment

We thank NCSR Demokritos and the National Technical University of Athens for financial support. A.P. is grateful to the NCSR Demokritos for a PhD fellowship. The Foundation for Education and European Culture is also acknowledged for providing a scholarship to G.C.V. Mrs. E. Yannakopoulou (Institute of Physical Chemistry, NCSR Demokritos) and Dr. L. Leontiadis (Institute of Radioisotopes & Radiodiagnostic Products, NCSR Demokritos) are gratefully acknowledged for carrying out elemental analysis measurements and for obtaining the HRMS spectra, respectively.

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