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NMR and X-ray diffraction studies of two bicyclic borates containing chiral boron and nitrogen atoms

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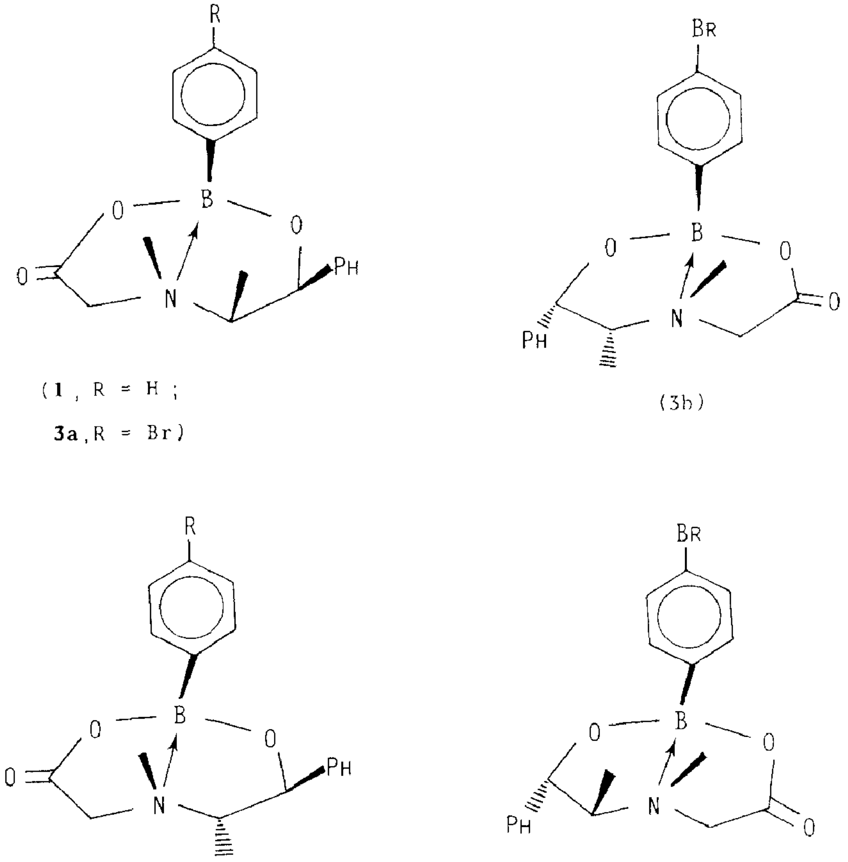
Abstract

Ring closure between the nitrogen and boron atoms during the syntheses of bicyclic organoboron compounds occurs under asymmetric induction, since reactions of optically active *N*-methyl-*N*-(1-methyl-2-phenyl-2-hydroxyethyl)glycines with 4-bromophenylboronic acid or with 1,4-phenylenediboronic acid provides the corresponding bicyclic boron derivatives ($N \rightarrow B$)-4-bromophenyl[*N*-methyl-*N*-(1-(*S*)-methyl-2-(*R*)-phenyl-2-oxyethyl)aminoacetate-*O*,*O*′,*N*]boron (**3a–3b**), ($N \rightarrow B$)-4-bromophenyl[*N*-methyl-*N*-(1-(*S*)-methyl-2-(*S*)-phenyl-2-oxyethyl)aminoacetate-*O*,*O*′,*N*]boron (**4a–4b**), ($N \rightarrow B$)($N' \rightarrow B'$)-1,4-phenylenebis[*N*-methyl-*N*-(1-(*S*)-methyl-2-(*R*)-phenyl-2-oxyethyl)aminoacetate-*O*,*O*′,*N*]bis-boron (**5**) and ($N \rightarrow B$)($N' \rightarrow B'$)-1,4-phenylenebis[*N*-methyl-*N*-(1-(*S*)-methyl-2-(*S*)-phenyl-2-oxyethyl)aminoacetate-*O*,*O*′,*N*]bisboron (**6**) in high stereochemical yields. The configuration of the nitrogen and boron atoms in **6** and in ($N \rightarrow B$) phenyl[*N*-methyl-*N*-(1-(*S*)-methyl-2-(*S*)-phenyl-2-oxyethyl)aminoacetate-*O*,*O*′,*N*]boron (**2**) is established by single crystal X-ray diffraction studies.

Introduction

In recent years we have been interested in the syntheses of bicyclic boron compounds derived from diethanolamines [1], phenolamines [2,3], iminodiacetic acid [4] and *N*-alkyl-*N*-(2-hydroxyethyl)glycine [5], as well as in studying the intramolecular $N \rightarrow B$ coordination. At present, there is considerable interest in bicyclic boron compounds that present cytotoxic activity [6–8] and that also have found application in a technique known as boron neutron therapy used for the treatment of certain brain tumors [9].

Two interesting features in the compounds reported herein are: (a) the carboxylic function which guarantees good stability, as has been observed in organyl boronic



(**1**, R = H;
3a, R = Br)

(**3b**)

(**2**, R = H;
4a, R = Br)

(**4b**)

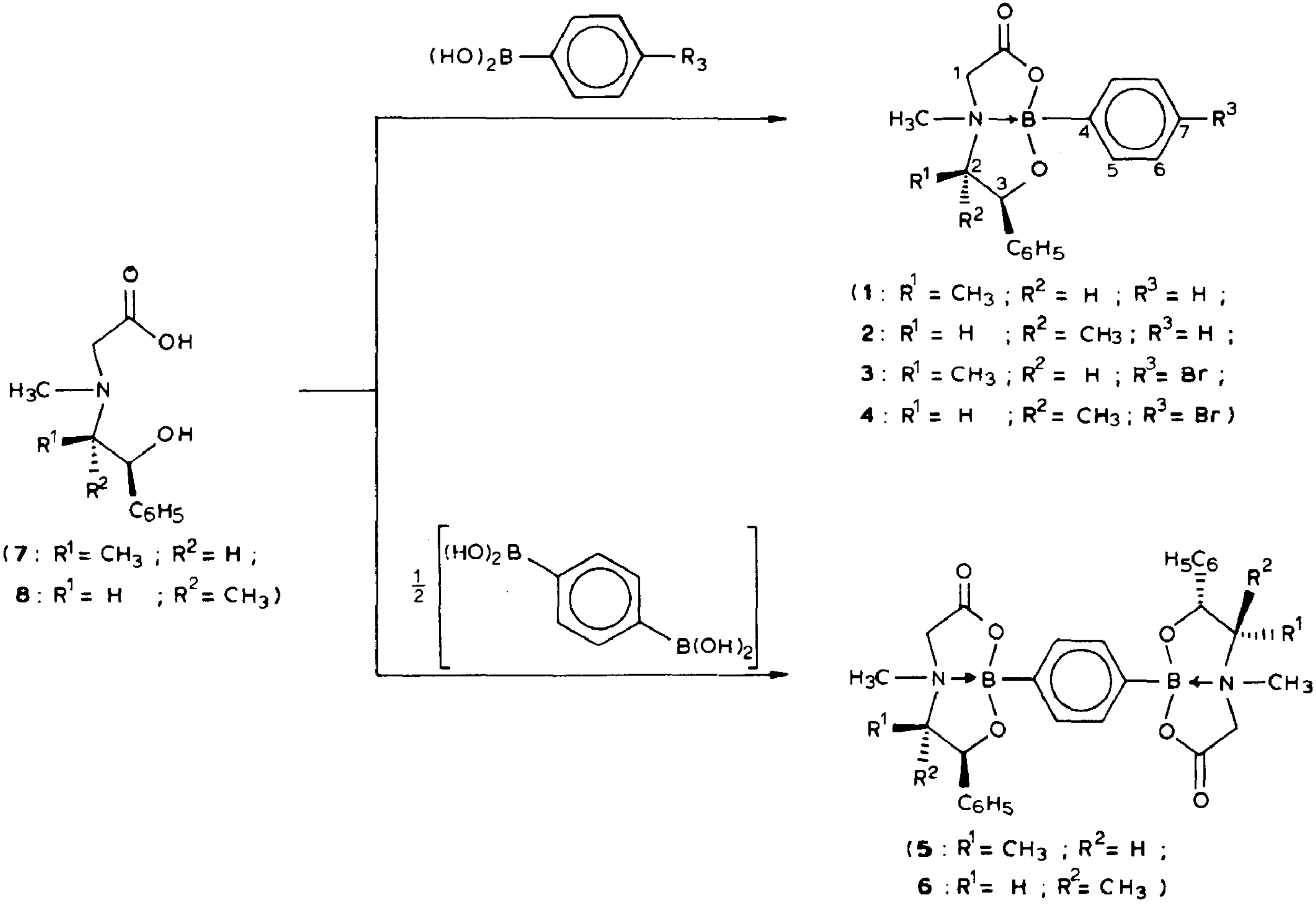
Scheme 1

esters derived from iminodiacetic acid [4,5,10], this stability being of interest for biological application, and (b) the presence of two different groups (a chiral alkoxide and a carboxide) which lead to two configurationally stable chiral centers, boron and nitrogen, as has been reported [2,11,15] in molecules containing such chiral atoms.

We recently established the configuration of the boron and nitrogen atoms in **1** (Scheme 1) by NMR analysis including NOE experiments [5]. In the present work, we report the syntheses and stereochemistry of the four polycyclic compounds **3a**–**3b**, **4a**–**4b**, **5** and **6**, wherein the boron and nitrogen atoms are chiral. We established their configuration by single crystal X-ray diffraction studies of **2** and **6**.

Discussion and results

From the reaction of optically active *N*-methyl-*N*-(1-methyl-2-phenyl-2-hydroxyethyl)glycines (**7** and **8**) with 4-bromophenylboronic and 1,4-phenylenediboronic acids, four and eight diastereoisomers, respectively, may be expected. However, those having a *trans* ring junction are very unprobable due to severe ring strain. In



($\mathbf{7}$: $R^1 = CH_3$; $R^2 = H$;
$\mathbf{8}$: $R^1 = H$; $R^2 = CH_3$)

($\mathbf{1}$: $R^1 = CH_3$; $R^2 = H$; $R^3 = H$;
$\mathbf{2}$: $R^1 = H$; $R^2 = CH_3$; $R^3 = H$;
$\mathbf{3}$: $R^1 = CH_3$; $R^2 = H$; $R^3 = Br$;
$\mathbf{4}$: $R^1 = H$; $R^2 = CH_3$; $R^3 = Br$)

($\mathbf{5}$: $R^1 = CH_3$; $R^2 = H$;
$\mathbf{6}$: $R^1 = H$; $R^2 = CH_3$)

Scheme 2

Table 1

^{13}C and ^{11}B NMR chemical shifts (in ppm) for compounds **3** to **6** in DMSO-d_6

C atom	**3a**	**4a**	**4b**	**5**	**6**
CO	170.2	169.9	168.5	171.0	170.1
1	63.1	53.3	58.8	62.0	52.8
2	71.1	72.7	70.8	69.8	71.7
3	76.0	79.5	82.4	74.6	78.2
4	138.0	–	–	139.9	140.4
5	134.8	134.6	134.6	131.9	132.0
6	131.0	130.9	130.9	–	–
7	123.6	123.3	123.3	–	–
N–Me	44.2	48.0	37.4	42.3	47.0
C–Me	11.6	9.4	8.8	10.9	8.6
ipso	138.1	138.0	139.6	139.4	139.5
ortho	126.0	126.6	126.6	125.8	126.9
meta	128.6	128.7	128.7	129.2	128.4
para	127.8	126.6	126.6	127.1	128.1
B atom	+11.2	+11.2	+11.2	+5.0	+6.0

fact, the ring closure at the boron and nitrogen atoms seems to be originated by asymmetric induction. Thus, ^1H NMR analyses of the reaction products show that ligands **7** and **8** react with 4-bromophenylboronic acid leading to two diastereoisomers (**3a**/**3b** and **4a**/**4b**) in 95/5 and 70/30 ratios, respectively, while after treating with 1,4-phenylenediboronic acid they yield the single isomer **5** or **6**, respectively (Scheme 2).

Formation of bicyclic structures can easily be demonstrated by spectroscopic methods since the $\delta(^{11}B)$ values (Table 1) lie in the range [2–6] corresponding to N → B coordination compounds (δ +11 to +5 ppm), while the ^1H NMR spectra show the diastereotopic protons α to the carbonyl function as an AB pattern owing to a rigid structure (Table 2). Also, the IR absorption of the carbonyl groups are

Table 2

^1H NMR chemical shifts (in ppm, J in Hz) for compounds **3** to **6** in DMSO-d_6

^1H atom	**3a**	**4a**	**4b**	**5**	**6**
1	3.72 4.12 J_{AB} 18	3.30 4.10 J_{AB} 18	3.20 3.62 J_{AB} 16	4.10 4.55 J_{AB} 18	3.55 4.32 J_{AB} 17
2	3.50(m)	2.87(m)	2.87(m)	3.75(m)	3.10(m)
3	5.42(d) J 4	4.67(d) J 9	4.85(d) J 9	5.45(d) J 4	4.65(d) J 9
5	7.50–7.60(m)	7.50–7.60(m)		7.65(s)	7.65(s)
6				–	–
N–Me	2.27(s)	2.28(s)	2.15(s)	2.35(s)	2.30(s)
C–Me	0.70(d) J 6	1.10(d) J 6	1.12(d) J 6	0.75(d) J 6	1.10(d) J 6
C_6H_5	7.30–7.60 (m)	7.20–7.75 (m)		7.40–7.60 (m)	7.30–7.60 (m)

Table 3

Crystal data, collection and refinement parameters for (*N* → *B*)-phenyl[*N*-methyl-*N*-(1-(*S*)-methyl-2-(*S*)-phenyl-2-oxyethyl)aminoacetate-*O*,*O*′,*N*]boron (**2**) and for (*N* → *B*)(*N*′ → *B*′)-1,4-phenylenebis[*N*-methyl-*N*-(1-(*S*)-methyl-2-(*S*)-phenyl-2-oxyethyl)aminoacetate-*O*,*O*′,*N*]bis-boron (**6**)

A. Crystal parameters		
chemical formula	$C_{18}H_{20}O_3NB$	$C_{30}H_{34}O_6N_2B_2$
molecular weight	309.176	540.237
crystal system	tetragonal	orthorhombic
space group	$P4_12_12$	$P2_12_12_1$
crystal size, mm	0.68 × 0.50 × 0.08	0.2 × 0.2 × 0.1
crystal color	white	white
cell constants		
a, Å	7.5524(21)	10.8938(28)
b, Å	7.5524(21)	12.8960(42)
c, Å	59.2007(240)	20.6721(74)
cell volume, $Å^3$	3376.73(23)	2904.130(155)
ρ(calc), g/cm^3	1.21	1.23
Z	8	4
F(000),e^-	1304	1240
B. Data collection parameters		
μ, cm^{-1}	6.6	6.96
scan width, below $K_{\alpha1}$, above $K_{\alpha2}$, deg	0.9, 1.1	1.0, 1.2
2θ limits, deg	3.0–110.0	3.0, 110.0
scan speed(variable), deg min^{-1}	(4.0, 29.3)	(4.0, 29.3)
exposure time, h	51.63	47.87
total no, reflections collected	2544	2114
no. unique reflections	1820	1307
C. Structure refinement		
reflections for final refinement	1793	1300
parameters refined	216	375
R(F), %	5.76	6.27
R_w(F), %	6.26	6.41
goodness of fit for the last cycle	1.010	1.106
final *G*	0.00218	0.00201
residual electron density, ($e^-/Å^3$)	0.2685	0.1854

indicative of cyclic compounds (ν_{max} 1742–1749 cm^{-1}), while the mass spectra of compounds **3** and **4** show the presence of bromine and boron in the molecular ions.

The ^1H and ^{13}C NMR data for **3**–**6** (Tables 1 and 2) are in agreement with the configuration of compounds **1** and **2** [5].

Compounds **2** and **6** were crystallized from dichloromethane/hexane and from acetone/dimethylsulfoxide, respectively, to provide suitable crystals that establish the configuration of the boron (*S*) and nitrogen (*R*) atoms by single crystal X-ray diffraction studies (Tables 3–7).

The carbonyl ring (A) (Fig. 1 and 2) is planar (torsion angles: O(1)–B–N–C(3) for **2** is 8.2°, O(1)–B(1)–N(4)–C(3) for **6** is 5.9° and O(21)–B(21)–N(24)–C(23) for **6** is 0°) and the pseudoephedrine ring (B) has an envelope form in both structures. The B–Ar and N–CH_3 groups are eclipsed, the torsion angles are: 5° for **2**; 6.4° and 4.3° for **6**; the N–CH_3 and C–CH_3 dihedral angles are: 77.2° for **2**; 81.4° and 81.2° for **6** and the C–CH_3 and C–C_6H_5 dihedral angles are 68.9° for **2**; 71.1° and

Table 4

Atom coordinates ($\times 10^4$) and temperature factors (Å^2 $\times 10^3$) for ($N \rightarrow B$)-phenyl[*N*-methyl-*N*-(1-(*S*)-methyl-2-(*S*)-phenyl-2-oxyethyl)aminoacetate-*O*,*O*′,*N*]boron (**2**)

Atom	*x*	*y*	*z*	U_{eq} [a]
B	7531(6)	8179(6)	572(1)	64(2)
O(1)	9517(3)	8149(4)	549(1)	74(1)
C(2)	10240(5)	6561(7)	547(1)	75(2)
O(2)	11831(4)	6293(5)	545(1)	106(2)
C(3)	8907(5)	5106(6)	544(1)	75(2)
N	7110(4)	5962(4)	542(1)	62(1)
C(4)	6109(6)	5450(6)	339(1)	82(2)
C(5)	6054(4)	5578(5)	757(1)	61(1)
C(6)	6816(5)	6917(5)	923(1)	60(1)
C(7)	6026(6)	3643(6)	829(1)	83(2)
O(8)	6958(3)	8505(3)	797(1)	69(1)
C(9)	5683(4)	7197(5)	1134(1)	57(1)
C(10)	5836(5)	6041(6)	1315(1)	69(1)
C(11)	4809(5)	6256(6)	1508(1)	78(2)
C(12)	3628(5)	7655(7)	1522(1)	82(2)
C(13)	3507(6)	8834(7)	1343(1)	87(2)
C(14)	4523(5)	8581(6)	1148(1)	71(1)
C(15)	6646(5)	9402(5)	386(1)	65(1)
C(16)	7570(6)	10105(6)	204(1)	74(2)
C(17)	6752(7)	11086(6)	32(1)	88(2)
C(18)	4963(7)	11367(6)	42(1)	89(2)
C(19)	3987(7)	10719(6)	219(1)	89(2)
C(20)	4819(6)	9754(6)	393(1)	83(2)
H(3a)	9079	4296	393	112(11)
H(3b)	9053	4279	694	112(11)
H(4a)	6737	6022	190	128(10)
H(4b)	4756	5940	352	128(10)
H(4c)	6092	4012	323	128(10)
H(5)	4630	5748	736	111(15)
H(6)	8075	6446	990	56(9)
H(7a)	5390	2848	698	144(10)
H(7b)	5289	3516	986	144(10)
H(7c)	7379	3181	854	144(10)
H(10)	6774	4946	1306	99(6)
H(11)	4934	5327	1648	99(6)
H(12)	2802	7825	1671	99(6)
H(13)	2619	9968	1355	99(6)
H(14)	4385	9492	1006	99(6)
H(16)	8994	9884	194	118(7)
H(17)	7530	11618	−107	118(7)
H(18)	4309	12108	−93	118(7)
H(19)	2563	10952	225	118(7)
H(20)	4035	9275	535	118(7)

[a] Equivalent isotropic *U* defined as one third of the trace of the orthogonalised U_{ij} tensor (except for the H atoms).

63.4° for **6**. The groups are staggered since the boron aryl and N–CH_3 are bent further away, as indicated by the bond angle values (CH_3–N–B of 115.0° for **2** and **6** and N–B–C of 115.0° for **2** and **6**). The structure determination of **2** and **6**

Table 5

Bond lengths (Å) and angles (deg.) for (*N* → *B*)-phenyl[*N*-methyl-*N*-(1-(*S*)-methyl-2-(*S*)-phenyl-2-oxyethyl)aminoacetate-*O*,*O*′,*N*]boron (**2**)

B-O(1)	1.506(5)	B-N	1.713(6)
B-O(8)	1.422(5)	B-C(15)	1.584(6)
O(1)-C(2)	1.318(6)	C(2)-O(2)	1.219(5)
C(2)-C(3)	1.490(6)	C(3)-N	1.503(5)
N-C(4)	1.474(5)	N-C(5)	1.527(5)
C(5)-C(6)	1.526(5)	C(5)-C(7)	1.523(6)
C(6)-O(8)	1.418(4)	C(6)-C(9)	1.527(5)
C(9)-C(10)	1.388(5)	C(9)-C(14)	1.367(5)
C(10)-C(11)	1.390(5)	C(11)-C(12)	1.385(7)
C(12)-C(13)	1.385(6)	C(13)-C(14)	1.401(6)
C(15)-C(16)	1.391(5)	C(15)-C(20)	1.406(6)
C(16)-C(17)	1.402(6)	C(17)-C(18)	1.369(7)
C(18)-C(19)	1.373(7)	C(19)-C(20)	1.411(7)
O(1)-B-N	99.3(3)	O(1)-B-O(8)	112.9(3)
N-B-O(8)	102.1(3)	O(1)-B-C(15)	111.5(3)
N-B-C(15)	114.8(3)	O(8)-B-C(15)	114.9(3)
B-O(1)-C(2)	115.3(3)	O(1)-C(2)-O(2)	124.0(5)
O(1)-C(2)-C(3)	113.1(3)	O(2)-C(2)-C(3)	122.9(5)
C(2)-C(3)-N	107.0(3)	B-N-C(3)	104.6(3)
B-N-C(4)	115.9(3)	C(3)-N-C(4)	110.9(3)
B-N-C(5)	101.3(3)	C(3)-N-C(5)	112.5(3)
C(4)-N-C(5)	111.2(3)	N-C(5)-C(6)	102.5(3)
N-C(5)-C(7)	115.1(3)	C(6)-C(5)-C(7)	117.3(3)
C(5)-C(6)-O(8)	104.3(3)	C(5)-C(6)-C(9)	114.2(3)
O(8)-C(6)-C(9)	110.8(3)	B-O(8)-C(6)	111.7(3)
C(6)-C(9)-C(10)	119.8(3)	C(6)-C(9)-C(14)	121.0(3)
C(10)-C(9)-C(14)	119.2(3)	C(9)-C(10)-C(11)	121.0(4)
C(10)-C(11)-C(12)	119.7(4)	C(11)-C(12)-C(13)	119.2(4)
C(12)-C(13)-C(14)	120.5(4)	C(9)-C(14)-C(13)	120.3(4)
B-C(15)-C(16)	123.4(4)	B-C(15)-C(20)	120.3(3)
C(16)-C(15)-C(20)	116.3(4)	C(15)-C(16)-C(17)	123.0(4)
C(16)-C(17)-C(18)	119.1(4)	C(17)-C(18)-C(19)	120.4(4)
C(18)-C(19)-C(20)	120.3(5)	C(15)-C(20)-C(19)	120.9(4)

establishes the central bicyclic structure showing a N → B bond length of 1.71 Å for **2** and **6**, the values being comparable to the N → B bond length in analogous compounds [3,16]. In contrast the boron oxygen bond lengths are different, since the B-OCO (1.50 Å) is longer than the B-OCH (1.42 Å).

Experimental

NMR spectra were recorded with Jeol FX90Q (^{11}B and ^{13}C NMR) and Varian Associates EM-390 (^{1}H NMR) spectrometers. Chemical shifts are relative to $F_3B \cdot OEt_2$ or TMS. Mass spectra were obtained with a Hewlett-Packard 5985-A spectrometer and infrared spectra were determined on a Nicolet MX-1 FT spectrophotometer. The single crystal X-ray studies were performed on a Nicolet R3m four-circle diffractometer using monochromated Cu-K_α radiation. Substituted

(*continued on p. 11*)

Table 6

Atom coordinates ($\times 10^4$) and temperature factors ($\text{Å}^2 \times 10^3$) for ($N \rightarrow B$), ($N' \rightarrow B'$)-1,4-phenylene-bis[*N*-methyl-*N*-(1-(*S*)-methyl-2-(*S*)-phenyl-2-oxyethyl)aminoacetate-*O*,*O*′,*N*]bisboron (**6**)

Atom	*x*	*y*	*z*	U_{eq} [a]
B(1)	102(8)	8612(7)	10251(4)	54(3)
O(1)	388(4)	7874(4)	9724(2)	65(2)
C(2)	−478(7)	7209(5)	9568(4)	64(3)
O(2)	−401(5)	6598(4)	9136(3)	80(2)
C(3)	−1618(7)	7313(6)	10004(4)	64(3)
N(4)	−1387(5)	8261(4)	10419(3)	58(2)
C(4)	−2329(7)	9055(6)	10271(4)	73(3)
C(5)	−1342(7)	8037(5)	11136(3)	55(3)
C(6)	6(7)	7692(6)	11257(3)	67(3)
C(7)	−2319(8)	7278(6)	11401(4)	81(4)
O(8)	700(5)	8386(4)	10856(2)	72(2)
C(9)	369(8)	7778(6)	11959(3)	66(3)
C(10)	686(10)	8743(8)	12203(4)	100(4)
C(11)	1062(12)	8861(10)	12861(5)	134(6)
C(12)	1187(12)	7956(13)	13233(6)	153(7)
C(13)	812(14)	7022(13)	13013(6)	156(8)
C(14)	437(11)	6914(8)	12360(4)	117(5)
C(15)	276(7)	9787(5)	10033(4)	61(3)
C(16)	117(8)	10598(5)	10465(4)	73(3)
C(17)	201(7)	11628(6)	10279(4)	68(3)
C(18)	460(7)	11906(5)	9645(3)	66(3)
C(19)	702(8)	11103(6)	9212(4)	68(3)
C(20)	571(7)	10067(6)	9400(3)	65(3)
B(21)	394(9)	13081(6)	9407(4)	64(4)
O(21)	579(5)	13834(4)	9970(3)	78(2)
C(22)	−370(8)	14454(5)	10089(4)	72(3)
O(22)	−367(6)	15110(4)	10519(3)	99(3)
C(23)	−1409(8)	14277(6)	9636(4)	77(3)
N(24)	−1060(6)	13431(4)	9178(3)	75(2)
C(24)	−1987(8)	12572(7)	9192(5)	110(5)
C(25)	−836(9)	13786(6)	8488(4)	86(4)
C(26)	501(8)	14158(6)	8514(4)	75(3)
C(27)	−1774(10)	14531(8)	8219(5)	126(5)
O(28)	1103(5)	13361(4)	8864(2)	72(2)
C(29)	1083(9)	14385(7)	7864(4)	85(4)
C(30)	1187(11)	13549(8)	7426(4)	116(5)
C(31)	1765(13)	13707(9)	6827(5)	142(6)
C(32)	2248(14)	14685(12)	6685(6)	158(7)
C(33)	2194(15)	15466(12)	7116(6)	160(7)
C(34)	1598(10)	15333(7)	7702(4)	109(5)
H(3a)	−1718	6626	10307	137(24)
H(3b)	−2443	7414	9712	137(24)
H(4a)	−2134	9757	10546	77(13)
H(4b)	−3234	8762	10403	77(13)
H(4c)	−2309	9230	9755	77(13)
H(5)	−1582	8728	11412	113(30)
H(6)	161	6878	11141	77(22)
H(7a)	−2200	7190	11922	108(16)
H(7b)	−2219	6526	11167	108(16)
H(7c)	−3230	7588	11301	108(16)
H(10)	658	9419	11887	293(31)
H(11)	1241	9625	13066	293(31)
H(12)	1593	8011	13714	293(31)

Table 6 (continued)

Atom	x	y	z	U_{eq}[a]
H(13)	809	6352	13334	293(31)
H(14)	190	6152	12172	293(31)
H(16)	−81	10419	10970	80(11)
H(17)	55	12233	10639	80(11)
H(19)	995	11284	8720	80(11)
H(20)	702	9458	9040	80(11)
H(23a)	−2222	14047	9908	102(19)
H(23b)	−1602	14986	9368	102(19)
H(24a)	−1690	11950	8871	90(14)
H(24b)	−2873	12867	9030	90(14)
H(24c)	−2073	12274	9683	90(14)
H(25)	−952	13167	8134	60(19)
H(26)	583	14920	8739	74(22)
H(27a)	−1538	14720	7720	225(33)
H(27b)	−1784	15238	8508	225(33)
H(27c)	−2679	14170	8233	225(33)
H(30)	824	12788	7551	150(16)
H(31)	1831	13077	6477	150(16)
H(32)	2682	14819	6217	150(16)
H(33)	2620	16210	7004	150(16)
H(34)	1530	15980	8039	150(16)

[a] Equivalent isotropic U defined as one third of the trace of the orthogonalised U_{ij} tensor (except for the H atoms).

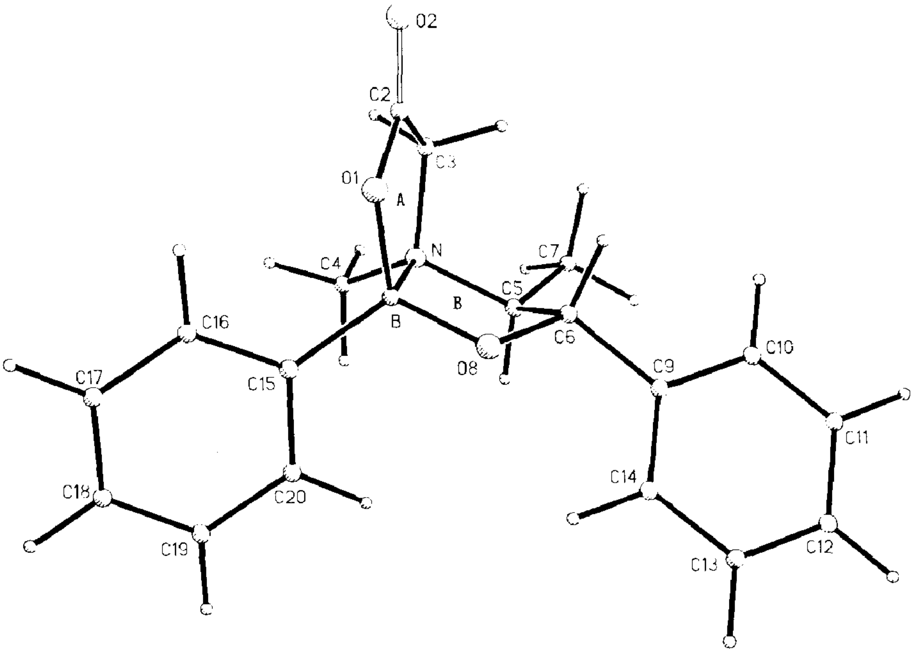


Fig. 1. Molecular structure of **2**.

Table 7

Bond lengths (Å) and angles (deg.) for $(N \rightarrow B),(N' \rightarrow B')$-1,4-phenylenebis[*N*-methyl-*N*-(1-(*S*)-methyl-2-(*S*)-phenyl-2-oxyethyl)aminoacetate-*O*,*O*′,*N*]bisboron (**6**)

B(1)–O(1)	1.480(10)	B(1)–N(4)	1.718(10)
B(1)–O(8)	1.441(10)	B(1)–C(15)	1.592(11)
O(1)–C(2)	1.314(9)	C(2)–O(2)	1.194(9)
C(2)–C(3)	1.541(11)	C(3)–N(4)	1.514(10)
N(4)–C(4)	1.480(10)	N(4)–C(5)	1.511(9)
C(5)–C(6)	1.555(11)	C(5)–C(7)	1.546(11)
C(6)–O(8)	1.434(9)	C(6)–C(9)	1.508(10)
C(9)–C(10)	1.386(13)	C(9)–C(14)	1.391(13)
C(10)–C(11)	1.428(13)	C(11)–C(12)	1.405(20)
C(12)–C(13)	1.352(23)	C(13)–C(14)	1.417(16)
C(15)–C(16)	1.387(11)	C(15)–C(20)	1.396(10)
C(16)–C(17)	1.385(10)	C(17)–C(18)	1.387(10)
C(18)–C(19)	1.395(10)	C(18)–B(21)	1.594(11)
C(19)–C(20)	1.398(10)	B(21)–O(21)	1.530(10)
B(21)–N(24)	1.714(12)	B(21)–O(28)	1.409(10)
O(21)–C(22)	1.330(10)	C(22)–O(22)	1.226(9)
C(22)–C(23)	1.487(12)	C(23)–N(24)	1.494(10)
N(24)–C(24)	1.499(10)	N(24)–C(25)	1.518(11)
C(25)–C(26)	1.534(13)	C(25)–C(27)	1.509(14)
C(26)–O(28)	1.418(9)	C(26)–C(29)	1.515(11)
C(29)–C(30)	1.411(13)	C(29)–C(34)	1.387(13)
C(30)–C(31)	1.404(15)	C(31)–C(32)	1.398(19)
C(32)–C(33)	1.346(19)	C(33)–C(34)	1.385(16)

O(1)–B(1)–N(4)	100.2(5)	O(1)–B(1)–O(8)	114.4(6)
N(4)–B(1)–O(8)	101.5(6)	O(1)–B(1)–C(15)	112.3(6)
N(4)–B(1)–C(15)	114.9(6)	O(8)–B(1)–C(15)	112.6(6)
B(1)–O(1)–C(2)	116.6(6)	O(1)–C(2)–O(2)	124.3(7)
O(1)–C(2)–C(3)	112.3(6)	O(2)–C(2)–C(3)	123.4(7)
C(2)–C(3)–N(4)	105.4(6)	B(1)–N(4)–C(3)	104.8(5)
B(1)–N(4)–C(4)	115.5(5)	C(3)–N(4)–C(4)	109.0(6)
B(1)–N(4)–C(5)	102.6(5)	C(3)–N(4)–C(5)	113.9(5)
C(4)–N(4)–C(5)	110.9(5)	N(4)–C(5)–C(6)	104.0(5)
N(4)–C(5)–C(7)	116.6(6)	C(6)–C(5)–C(7)	114.3(6)
C(5)–C(6)–O(8)	103.1(5)	C(5)–C(6)–C(9)	112.4(6)
O(8)–C(6)–C(9)	111.8(6)	B(1)–O(8)–C(6)	112.9(6)
C(6)–C(9)–C(10)	118.8(7)	C(6)–C(9)–C(14)	121.9(7)
C(10)–C(9)–C(14)	119.3(7)	C(9)–C(10)–C(11)	120.9(9)
C(10)–C(11)–C(12)	117.5(11)	C(11)–C(12)–C(13)	121.7(12)
C(12)–C(13)–C(14)	119.8(13)	C(9)–C(14)–C(13)	120.2(10)
B(1)–C(15)–C(16)	121.4(7)	B(1)–C(15)–C(20)	122.6(6)
C(16)–C(15)–C(20)	116.0(7)	C(15)–C(16)–C(17)	122.4(8)
C(16)–C(17)–C(18)	121.6(7)	C(17)–C(18)–C(19)	116.9(7)
C(17)–C(18)–B(21)	121.9(7)	C(19)–C(18)–B(21)	121.1(6)
C(18)–C(19)–C(20)	120.8(7)	C(15)–C(20)–C(19)	122.1(7)
C(18)–B(21)–O(21)	111.3(6)	C(18)–B(21)–N(24)	112.2(6)
O(21)–B(21)–N(24)	99.5(6)	C(18)–B(21)–O(28)	117.7(7)
O(21)–B(21)–O(28)	111.8(6)	N(24)–B(21)–O(28)	102.7(6)
B(21)–O(21)–C(22)	114.8(6)	O(21)–C(22)–O(22)	123.1(8)
O(21)–C(22)–C(23)	112.5(6)	O(22)–C(22)–C(23)	124.3(8)
C(22)–C(23)–N(24)	108.5(7)	B(21)–N(24)–C(23)	104.6(6)
B(21)–N(24)–C(24)	115.0(6)	C(23)–N(24)–C(24)	110.9(6)
B(21)–N(24)–C(25)	101.0(6)	C(23)–N(24)–C(25)	114.6(6)
C(24)–N(24)–C(25)	110.4(7)	N(24)–C(25)–C(26)	102.3(6)

Table 7 (continued)

N(24)–C(25)–C(27)	115.4(8)	C(26)–C(25)–C(27)	117.2(7)
C(25)–C(26)–O(28)	103.3(6)	C(25)–C(26)–C(29)	115.3(7)
O(28)–C(26)–C(29)	113.5(7)	B(21)–O(28)–C(26)	109.8(6)
C(26)–C(29)–C(30)	117.1(8)	C(26)–C(29)–C(34)	123.6(7)
C(30)–C(29)–C(34)	119.1(8)	C(29)–C(30)–C(31)	119.4(9)
C(30)–C(31)–C(32)	119.0(10)	C(31)–C(32)–C(33)	121.3(12)
C(32)–C(33)–C(34)	120.4(13)	C(29)–C(34)–C(33)	120.7(10)

glycines [17], *p*-bromophenylboronic acid and 1,4-phenylenediboronic acid [18] were prepared following reported syntheses.

*(N → B)(N′ → B′)-1,4-Phenylenebis[N-methyl-N-(1-(S)-methyl-2-(R)-phenyl-2-oxyethyl)aminoacetate-O,O′,N]bisboron (**5**); ((+)-ephedrine derivative)*

The following procedure is representative of all reactions performed in this study. A solution of *N*-methyl-*N*-(1-(*S*)-methyl-2-(*R*)-phenyl-2-hydroxyethyl)glycine (**7**) (0.69 g, 3.0 mmol) in 100 ml of a 1/1 ethanol/benzene mixture was placed in a 250 ml flask equipped with a magnetic stirrer and a Dean-Stark trap. 1,4-Phenylenediboronic acid (0.25 g, 1.5 mmol) was added and the mixture was kept under reflux for 8 h. Removal of the solvents in vacuo afforded 0.80 g (98%) of compound **5**, m.p. 310–312°, IR: ν(CO) 1745 cm^{-1}.

*(N → B)-4-Bromophenyl[N-methyl-N-(1-(S)-methyl-2-(R)-phenyl-2-oxyethyl)aminoacetate-O,O′,N]boron (**3**) ((+)-ephedrine derivative)*

Reaction of *N*-methyl-*N*-(1-(*S*)-methyl-2-(*R*)-phenyl-2-hydroxyethyl)glycine (**7**) (0.44 g, 2.0 mmol) and 4-bromophenylboronic acid (0.40 g, 2.0 mmol) gave 0.23 g (38%) of **3**, m.p. 89–91°C, IR: ν(CO) 1749 cm^{-1}, MS: $m/z = 387$ ($M^+ + 2$, 14%), 390 ($M^+ + 3$, 3%), 71 (42%), 70 (100%), 56 (69%), 42 (57%).

*(N → B)-4-Bromophenyl[N-methyl-N-(1-(S)-methyl-2-(S)-phenyl-2-oxyethyl)aminoacetate-O,O′,N]boron (**4**) ((+)-pseudoephredrine derivative)*

Reaction of *N*-methyl-*N*-(1-(*S*)-methyl-2-(*S*)-phenyl-2-hydroxyethyl)glycine (**8**) (0.44 g, 2 mmol) and 4-bromophenylboronic acid (0.40 g, 2.0 mmol) gave 0.23 g (38%) of a mixture of compound **4a** and **4b** (70/30), m.p. 115–116°C, IR: ν(CO) 1748 cm^{-1}, MS: $m/z = 387$ (M^+, 17%), 388 ($M^+ + 1$, 4%), 389 ($M^+ + 2$, 17%), 390 ($M^+ + 3$, 2.5%), 71 (42%), 70 (100%), 56 (51%), 42 (43%).

*(N → B)(N′ → B′)-1,4-Phenylenebis[N-methyl-N-(1-(S)-methyl-2-(S)-phenyl-2-oxyethyl)aminoacetate-O,O′,N]bisboron (**6**) ((+)-pseudoephedrine derivative)*

Reaction of *N*-methyl-*N*-(1-(*S*)-methyl-2-(*S*)-phenyl-2-hydroxyethyl)glycine (**8**) (0.89 g, 4 mmol) and 1,4-phenylenediboronic acid (0.33 g, 2.0 mmol) gave 0.90 g of **6** (83%) m.p. 330–333°C. IR: ν(CO) 1742 cm^{-1}. Compound **6** was crystallized from acetone/dimethylsulfoxide.

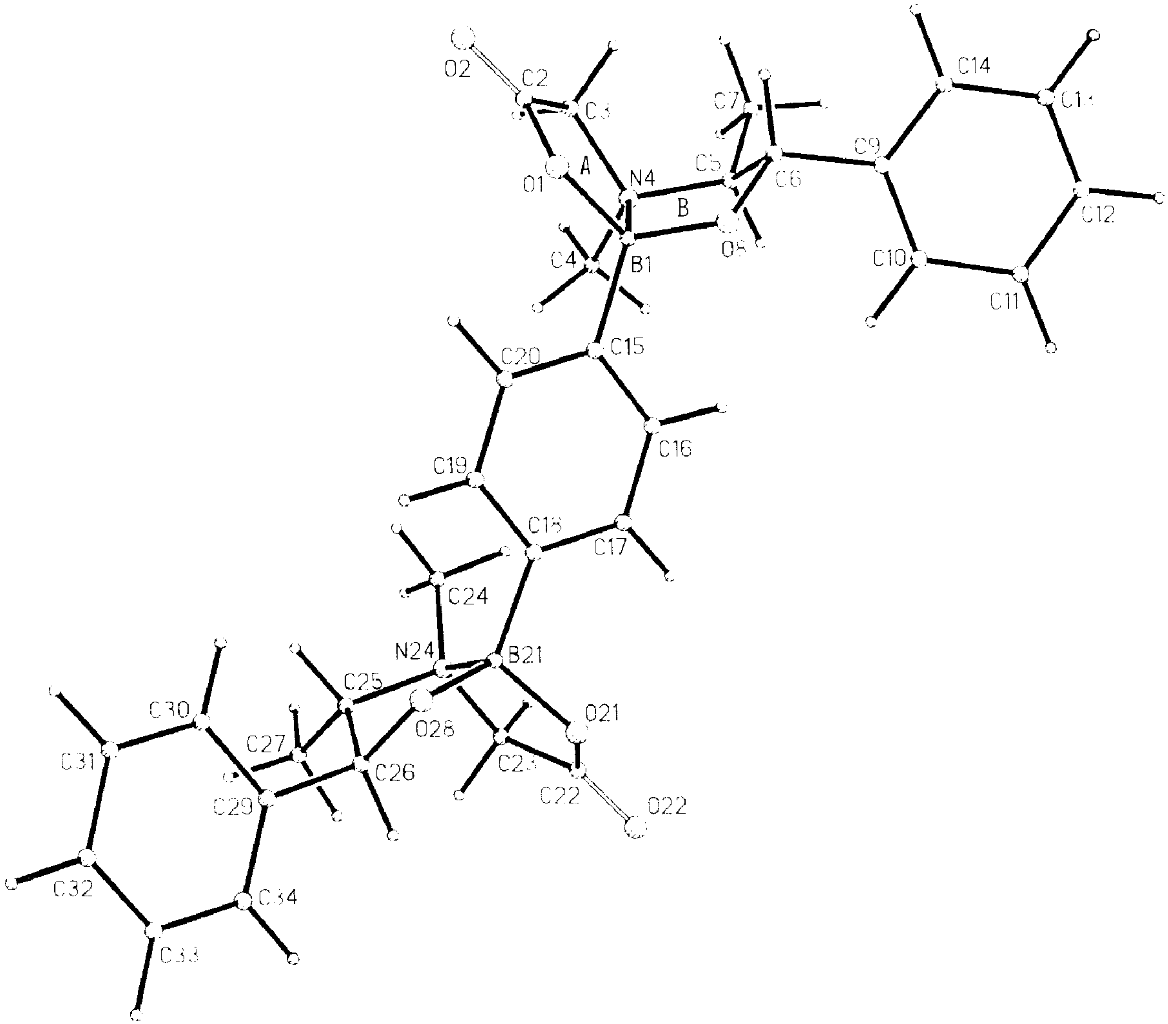


Fig. 2. Molecular structure of **6**.

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