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Synthesis and structure of benzoboroxoles: novel organoboron heterocycles

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Abstract

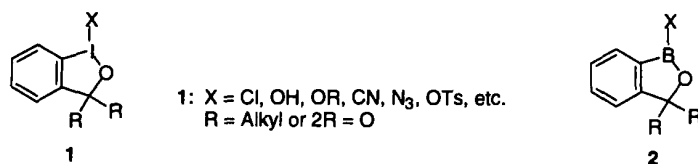
Benzoboroxoles (**5**) can be prepared from the readily available *o*-bromobenzyl alcohols via dilithiation followed by reaction with triisopropylborate. X-Ray structural analysis of 1-hydroxy-3(1*H*)-1,2-benzoboroxole (**5a**) as well as the results of ab initio molecular orbital calculations indicate a planar structure of the boron center with a relatively short C–B bond. Preliminary results regarding the chemistry of benzoboroxoles are also reported. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: boron and compounds; boron heterocycles; X-ray crystal structures.

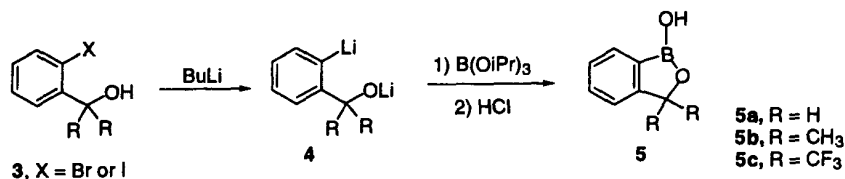
Five-membered cyclic derivatives of main group elements represent a very general and important group of organic compounds. Many of these heterocycles have found wide application as common reagents for organic synthesis. The traditional, well-known examples of such reagents are derivatives of nitrogen heterocycles, such as *N*-bromosuccinimide and potassium phthalimide. More recently, significant research activity has centered on the cyclic derivatives of hypervalent elements,¹ such as benziadoxoles **1**^{1b} and a variety of similar derivatives of hypervalent sulfur, phosphorus, silicon and even penta- and hexacoordinated boron^{1c} as the heteroatom. At the same time, an efficient general approach to the analogous cyclic derivatives of tricoordinated boron, benzoboroxoles **2**, is still unrealized. The simplest derivative, benzoboroxole **5a** has been previously reported by Torssell in 1957 as a by-product.^{2a} Immediately following Torssell's work, Snyder and co-workers improved the procedure, and prepared some simple derivatives.^{2b} However, no attempt was made to formally characterize the structure, or examine its potential utility as a synthetic intermediary. Taking this into account, plus recent literature on the synthetic utility of boronic acids,^{2c} as well as the useful properties of benziadoxoles and similar heterocyclic derivatives of main group elements,¹ we report here the preparation and structural investigation of the similar benzoboroxoles **5**.

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Our general approach to benzoboroxoles **5** allows for variability in the synthetically attractive benzylic position of these cyclic boronic acid esters. We began our study with the preparation of 1-hydroxy-3(1*H*)-1,2-benzoboroxole **5a**. The synthesis started with the generation of dianion **4** from *o*-bromobenzyl alcohol **3** with butyllithium. Dianion **4** was transferred via canula to a solution of triisopropylborate in ether maintained at -78°C .³ After a suitable time period the reaction was worked-up with aqueous acid, and the ether layer was removed and concentrated under reduced pressure to give crude 1-hydroxy-3(1*H*)-1,2-benzoboroxole **5a** as an oil. The crude material was triturated with cold hexane to induce crystallization. This solid material was combined with the solid produced on standing from the concentration of the mother liquor to give a pure white crystalline solid, 86% yield (Scheme 1).⁴ The structure of **5a** was verified by ¹H, ¹³C, and ¹¹B NMR, and unambiguously proven with single crystal X-ray analysis (Fig. 1). Compounds **5b** and **5c** were prepared by a similar procedure.



Scheme 1.

According to the available literature, structure **5a** represents the first X-ray structure of a cyclic boronic acid and one of a few examples of a trigonally coordinated organoboron derivative. Compound **5a** crystallizes as dimers due to hydrogen bonding involving the OH groups (Fig. 1). In comparison, X-ray studies of phenylboronic acid indicate a more elaborate crystal lattice due to an increased hydrogen-bonding network. This brings about a slight deviation from planarity with respect to the COO (plane defined by the *ipso* carbon, and the boronic acid oxygens), and phenyl mean planes. The bond angles at the trigonal boron are also distorted from ideal values in a manner that increases the linearity of the hydrogen bonds. The important bond lengths in phenylboronic acid are B–O (1.378, 1.362 Å), and B–C (1.568 Å), respectively.⁵ This data is in good agreement with ours, relative to the logical changes assumed from the general changes in structure between the two molecules. Our X-ray data suggests a less elaborate hydrogen bonding network, which thereby eliminates the deviations with respect to the COO, and phenyl mean planes. There is also evidence of a slight exaggeration in the distortion of the bond angles around the trigonal planar boron. Compound **5a** exhibits the following bond angles: 118.3° (O(1)–B(1)–O(2)), 110.5° (O(1)–B(1)–C(1)), and 131.2° (O(2)–B(1)–C(1)). The most obvious difference in these data as compared to phenylboronic acid is the relatively large difference in O(2)–B(1)–C(1) bond angles (131.2

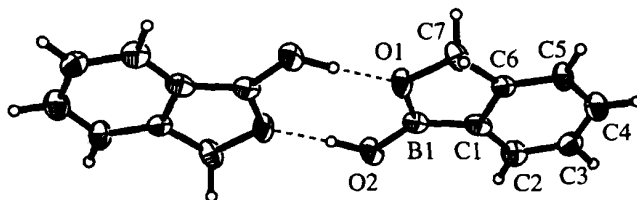
Figure 1. X-Ray crystal structure of compound **5a**

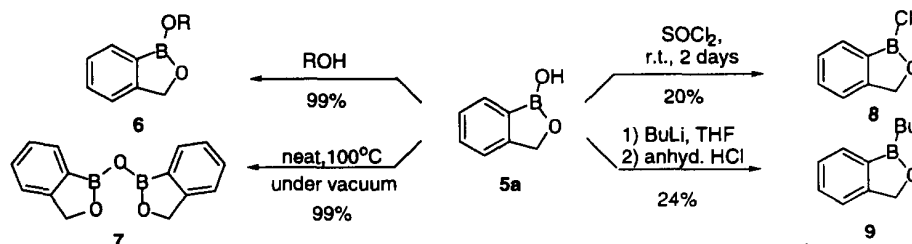
Table 1
Geometrical parameters of benzoboroxole **5a**

Parameter	Observed	HF/6-31G*	MP2/6-31G*	B3LYP/6-31G*
B-C (Å)	1.494	1.560	1.554	1.554
B-O1 (Å)	1.408	1.367	1.386	1.382
B-O2 (Å)	1.372	1.348	1.366	1.361
O1-B-O2 (°)	118.3	122.5	122.5	122.2
O1-B-C1 (°)	110.5	108.3	109.2	109.0
O2-B1-C1 (°)	131.2	129.2	128.2	128.8

versus 125.0). We can account for these changes based on the *true* planarity (the sum of the angles around boron is 360°) of the trigonally coordinated boron in **5a**, and the differences in the Lewis basicity of the neighboring oxygen lone pairs. These differences are due to the geometrical constraints placed on the Lewis basic unshared pair located in the ring, and its inability to form a strong Lewis acid/base association with the boron atom. These constraints are not present with the 'free' OH, and hence we see shorter bond distances. This is in direct accordance with the published data for phenylboronic acid.

Molecular orbital calculations on **5a** are in good agreement with X-ray data. The geometries of all structures were optimized at the Hartree–Fock and MP2 level. In addition, density functional methods (B3LYP) were applied. For all calculations the standard basis set 6-31G* was used. The optimized structures were verified as minima by means of a vibrational analysis. A comparison of important structural data of the observed and calculated structures shows only minor differences (Table 1). The B–C distance is overestimated by all theoretical models, whereas the B–O distances are slightly underestimated. This could be related to the fact that, in the solid state, the compound is seen in hydrogen-bonded dimers, where both oxygen atoms are involved in hydrogen bonding. For all theoretical investigations, the monomeric structure was used.

Preliminary investigations were initiated to study the chemical properties of **5a**. These findings indicate that benzoboroxole **5a** has similar chemistry to most organoboronic acids (Scheme 2).⁶ Compounds **5a** quantitatively forms the boronate ester on reaction with a variety of alcohols to give esters **6**, as expected.⁷ The similar is true for the formation of the anhydride **7**. The nucleophilicity of the 'free' OH group of **5** was investigated by studying the in-situ preparation of the mono-chloro cyclic ester **8**. The low conversion to presumably compound **8** as evidenced by ¹¹B NMR, suggested the assumed poor nucleophilicity of the OH moiety. The in-situ preparation and analysis of the cyclic borinic ester **9**, proceeded through formation of an intermediate ate-complex, which was degraded to **9** by the addition of 1 equivalent of anhydrous HCl. The reaction progress of each of these characteristic transformations of boronic acids were monitored by ¹¹B NMR and are in agreement with ¹¹B NMR data of similar compounds.⁸



Scheme 2.

In conclusion, this study represents the first structural study of the trigonally coordinated benzobor-

oxoles **5**, including single crystal X-ray analysis. In addition, the method of preparation presented here allows for the synthesis of numerous derivatives, with little or no alteration in the synthetic protocol. We continue to evaluate the chemistry of these compounds with regard to their potential synthetic utility as boronic acid analogs.

Acknowledgements

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- 1-Hydroxy-3(1*H*)-1,2-benzoboroxole (**5a**): A solution of 2-bromobenzyl alcohol **3** (3.74 g, 20 mmol) in dry diethyl ether (50 ml) was stirred at 0°C under a nitrogen atmosphere. *n*-Butyllithium (40 mmol, 16 ml, 2.5 M in hexane) was added dropwise over 10 min time period. After stirring for 2 h, the reaction mixture was cooled to –78°C. This solution was transferred via canula to a solution of triisopropyl borate (4.6 ml, 20 mmol, in 10 ml Et₂O) at –78°C. The reaction was maintained at that temperature for 2 h and slowly warmed to room temperature overnight. This produced a heterogeneous white slurry that was carefully acidified to pH=5 with hydrochloric acid (3 M; ca. 35 ml). The resulting clear homogeneous biphasic solution, was diluted with water (50 ml) and the layers were separated. The aqueous was extracted with diethyl ether (4×50 ml) and the combined ether extracts were washed with brine (25 ml), aqueous HCl (3M, 3×25 ml), brine (25 ml), dried (Na₂SO₄), filtered, and concentrated in vacuo. The crude oil was triturated with cold hexane to induce crystallization. This solid material was combined with the solid produced on standing from the concentration of the mother liquor to give a pure white crystalline solid. Drying under reduced pressure gave benzoboroxole **5a** as colorless crystals, 86% yield. The X-ray quality single crystals were obtained as colorless needles by slowly cooling a solution of benzoboroxole **5a** in methylene chloride/hexane at 0°C. For **5a**: mp 87–89°C, IR (KBr): 3300 cm⁻¹; ¹H NMR (CDCl₃): δ=7.83 (d, 1H), 7.54 (t, 1H), 7.44 (t, 2H), 6.15 (s, 1H), 5.19 (d, 3H); ¹³C NMR (CDCl₃): δ=153.6, 131.5, 131.3, 130.9, 127.5, 121.3, 71.8; ¹¹B NMR (CDCl₃): δ=33.2 ppm. Anal: calcd for C₇H₇BO₂: C, 62.74; H, 5.27. Found: C, 62.75; H, 5.27.
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- All preliminary investigations of compound **5a** were verified by ¹¹B NMR. The respective ¹¹B NMR δ values for compounds **6**, **7**, **8**, and **9**, are 29.7, 32.7, 41.6, and 51.2 ppm. Due to the expected reactivity of compounds **8** and **9**, they were prepared, and analyzed in-situ. The yields listed for these compounds are yields derived from the NMR.
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