Sequential Nucleophilic−Electrophilic Reactions Selectively Produce Isomerically Pure Nona-*B*-Substituted *o*-Carborane Derivatives

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Nine equal substituents on the intensively studied *o*-carborane have been obtained for the first time by a combined nucleophilic-electrophilic reaction sequence. Iodine and methyl groups have been introduced to prove the generality of the method.

Introduction

During the last decade there has been a great deal of interest in introducing a large number of substituents on boron in icosahedral boranes and heteroboranes.[1−6] The possibility of generating weakly coordinating anions,[3,6,7] X-ray contrast agents,[8] camouflaged boron clusters,[5] the attainment of molecules comparable in size to C_{60} [9] and the generation of stable radicals[4] are some of the goals that have stimulated this research. Substitutions have been achieved with a good degree of success for cluster anions, but there are few examples for the dicarbaboranes. This is surprising considering that the chemistry of the latter has become one of the most intensively investigated areas in the field of boranes and heteroboranes.[10] The paucity of reported examples is in agreement with the relative rates of halogenation, which decrease in the order $[B_{12}H_{12}]^{2-} > [CB_{11}H_{12}]^{-} > C_2B_{10}H_{12}$.[11] Thus, methods to introduce substituents on the well studied *o*-carborane cluster need to be investigated. The *o*-carborane, 1,2-dicarba-*closo*-dodecaborane, contains four distinct types of boron atoms that may be ordered according to their distance from the C atoms, with B(9,12) being the farthest away, followed by B(8,10), B(4,5,7,11), and B(3,6), which are adjacent to both carbon atoms. Those farthest from the carbon atoms are the more electron-rich and those closest are the more electron-poor. It is generally accepted that icosahedral carboranes are aromatic[12] and undergo electrophilic substitution reactions, making this method attractive for the introduction of iodine into the cage molecules.[10] Whereas perfluorination[13] and perchlorination[14] of dicarbaboranes has been achieved, perbromination has not been accomplished. Indeed, only a maximum of four bromine atoms have been incorporated in dicarboranes to date. Periodination of *o*-carborane has not been achieved. Before 1996 the maximum number of iodines in *o*-carborane was two, occupying the 9- and 12-positions.[1,15] Little information exists on higher substitution although reference has been made to 8,9,10,12-tetraiodo-*o*-carboranes.[16] Major progress was recently achieved with the synthesis of the eight iodine 4,5,7,8,9,10,11,12-octaiodo-1,2-dicarba-*closo*-dodecaborane.[8] The carbons adjacent to the B(3,6) positions are resistant to electrophilic methods, although with the extremely powerful electrophiles F^+ and Cl^+ full substitution has been achieved. However, with the milder electrophiles Br^+ and I^+ this has not been possible.

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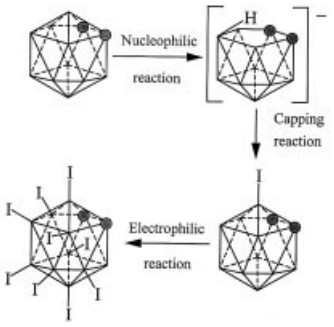
Results and Discussion

We based our work on the hypothesis that the first introduced group in the cluster determines the subsequent reactivity of the cluster towards further substitution causing, in cases such as the reaction of *o*-carborane with mild electrophiles, persubstitution to be impossible. To attain such substitution more than one type of reaction is necessary: an

electrophilic reaction for the electron-rich boron atoms and a nucleophilic reaction for the electron-poor B(3,6) atoms. With this aim, we devised the sequence of reactions shown in Scheme 1.



Scheme 1. Synthesis of 3,4,5,7,8,9,10,11,12-nonaiodo-1,2-dicarba-*closo*-dodecaborane (*closo*-**1**) from *o*-carborane

The first step consists of producing 3-I-1,2-$C_2B_{10}H_{11}$. This is achieved by a nucleophilic reaction to remove one boron adjacent to the two carbon atoms followed by a capping reaction with BI_3 to give 3-I-1,2-$C_2B_{10}H_{11}$.[1] The next step consists of an electrophilic reaction with $AlCl_3$ and CH_3I. The presence of one B(3)−I will provide information on the susceptibility of the second boron, B(6), adjacent to both carbons, to electrophilic attack.

In a typical experiment 3-I-1,2-$C_2B_{10}H_{11}$ (3.7 mmol) was mixed with triflic acid[17] (66.5 mmol) and ICl (6.0 mL, 111 mmol). Following heating at 90 °C for three days, and after workup, a 94% yield of 3,4,5,7,8,9,10,11,12-nonaiodo-1,2-dicarba-*closo*-dodecaborane (*closo*-**1**) was obtained. The $^{11}B\{^1H\}$ NMR shows a 2:1:1:1:2:2:1 pattern spanning from δ = −4.2 to −22.1 ppm. Only the resonance at δ = −11.1 ppm, of intensity 1, shows splitting due to proton coupling in the ^{11}B NMR spectrum, indicating that all of the boron atoms, except B(6), have an exo-cluster iodine substituent. This was confirmed by X-ray diffraction analysis of *closo*-**1**·EtOAc (Figure 1).[18] Consequently, the pre-introduced B(3)−I does not labilize B(6)−H.

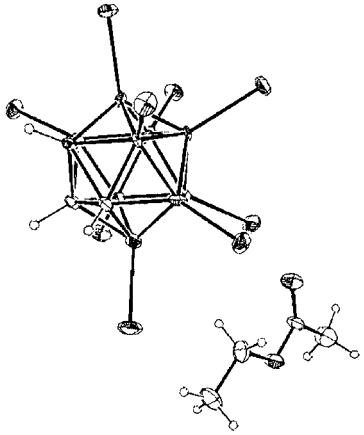


Figure 1. Perspective view of *closo*-**1**·EtOAc with 30% ellipsoids; H atoms have been omitted for clarity; selected bond lengths (Å): C(1)−C(2) 1.637(14), B−I 2.113(6)−2.166(11)

The method is successful for mildly electron-withdrawing elements, posing the question: could it be applicable for the introduction of Me substituents?

A good target was the long sought after 3,4,5,7,8,9,10,11,12-nonamethyl-1,2-dicarba-*closo*-dodecaborane (*closo*-**2**). The strategy for its synthesis was also a combination of nucleophilic and electrophilic attacks, the first producing 3-CH_3–1,2-$C_2B_{10}H_{11}$,[19] followed by reaction with $AlCl_3$ and CH_3I at reflux temperature for two days to produce *closo*-**2** (98%) after subsequent workup. The $^{11}B\{^1H\}$ NMR spectrum shows a 2:1:1:5:1 pattern indicating the geometrical similarity of *closo*-**1** and *closo*-**2**. The B(6) resonance is observed at δ = −17.16 ppm and again shows an exo-terminal proton coupling. As before, the pre-introduced B(3)−CH_3 does not labilize B(6)−H, thus maintaining the *closo* structure.

Conclusion

To summarize, a combined nucleophilic and electrophilic sequential process has allowed for the first time the introduction of nine equal substituents onto the well-studied *o*-carborane species. Iodine and methyl groups have been introduced to prove the generality of the method.

Experimental Section

General Remarks: Elemental analyses were performed using a Carlo Erba EA1108 microanalyser. IR spectra were recorded from KBr pellets on a Shimadzu FTIR-8300 spectrophotometer. ^1H and $^1H\{^{11}B\}$ NMR (300.13 MHz), $^{13}C\{^1H\}$ NMR (75.47 MHz) and ^{11}B NMR (96.29 MHz) spectra were recorded with a Bruker ARX 300 instrument equipped with the appropriate decoupling device. Chemical shift values for ^{11}B NMR spectra were referenced to external $BF_3{\cdot}OEt_2$ and those for ^1H, $^1H\{^{11}B\}$ and $^{13}C\{^1H\}$ NMR spectra were referenced to $SiMe_4$. Chemical shifts are reported in units of parts per million downfield from the reference with all coupling constants in Hz.

Unless otherwise noted, all manipulations were carried out under a dinitrogen atmosphere using standard vacuum line techniques. Iodine monochloride, aluminium trichloride and triflic acid were purchased from Aldrich.

***closo*-1:** Triflic acid (10.0 g, 66.5 mmol) and then ICl (6.0 mL) were added, under nitrogen flow, to 3-iodo-1,2-dicarba-*closo*-dodecaborane (1.0 g, 3.7 mmol). The mixture was heated at 90 °C for three days and then allowed to cool to room temperature. Cold water (10 mL) and then aqueous $NaHSO_3$ were added to the mixture. The resultant precipitate was filtered and then immediately dissolved in 125 mL of hot EtOAc and Zn added until the solution became colourless. The colourless solution was filtered and the solvent evaporated with a water pump. The solid obtained was recrystallized from EtOAc. (4.5 g, 94% yield). $C_2H_3B_{10}I_9$ (1277.1): calcd. C 1.88, H 0.23; found C 1.97, H 0.20. IR: $\tilde{\nu}$ = 3012 ($C_{cluster}$-H), 2650 (B-H) cm^{-1}. ^1H NMR (CD_3COCD_3): δ = 6.98 (br. s, $C_{cluster}$-H, B-H) ppm. ^{11}B NMR (CD_3COCD_3): δ = −4.2 (s, 2B), −9.7 (s, 1B), −11.1 [1B, B(6)], −12.6 (s, 1B), −17.2 (s, 2B), −20.3 (s, 2B), −22.1 (s, 1B) ppm. $^{13}C\{^1H\}$ NMR (CD_3COCD_3): δ = 72.5 (s, $C_{cluster}$) ppm. MALDI-TOF-MS: *m*/*z* = 1277.0 [M^+]. The $^1H\{^{11}B\}$

NMR of crystals of *closo*-**1**·EtOAc was run in CD_3COCD_3: δ = 6.98 (d, $^3J_{H,H}$ = 3.8 Hz, 2 H, $C_{cluster}$-H), 6.98 (br. s, 1 H, B-H), 4.06 (q, $^2J_{H,H}$ = 7.1 Hz, 2 H, CH_2), 3.54 (s, 3 H, CH_3), 1.20 (t, $^2J_{H,H}$ = 7.1 Hz, 3 H, CH_3) ppm.

***closo*-2:** MeI (6.4 mL) was added to a mixture of 3-methyl-1,2-dicarba-*closo*-dodecaborane (0.7 g, 4.4 mmol) and $AlCl_3$ (1.2 g, 8.8 mmol). The mixture was refluxed for 2 days after which the unchanged MeI was distilled off. The residue was hydrolyzed and extracted with pentane. The combined organic phases were treated with $Na_2S_2O_3$ and dried over $MgSO_4$. The final compound was purified by flash silica gel chromatography using pentane as the eluting solvent to give 3,4,5,7,8,9,10,11,12-nonamethyl-1,2-dicarba-*closo*-dodecaborane. (1.2 g, 98% yield). $C_{11}H_{30}B_{10}$ (270): calcd. C 48.89, H 11.11; found C 48.98, H 11.25. IR: $\tilde{\nu}$ = 3056 ($C_{cluster}$-H), 2945, 2905, 2833 (C-H), 2590 (B-H) cm^{-1}. $^1H\{^{11}B\}$ NMR ($CDCl_3$): δ = 0.32 (br. s, 3 H, CH_3), 0.13 (br. s, 6 H, CH_3), 0.05 (br. s, 6 H, CH_3), 0.01 (br. s, 3 H, CH_3), −0.12 (br. s, 3 H, CH_3), −0.23 (br. s, 6 H, CH_3), 2.89 (d, $^3J_{H,H}$ = 43 Hz, 2 H, $C_{cluster}$-H), 1.86 (br. s, 1 H, B-H) ppm. ^{11}B NMR ($CDCl_3$): δ = 5.4 (s, 2B), −2.1 (s, 1B), −4.2 (s, 1B), −8.8 (s, 5B), −17.2 (d, $^1J_{B,H}$ = 161 Hz, 1B) ppm. $^{13}C\{^1H\}$ NMR ($CDCl_3$): δ = −3.02 (br., CH_3), 54.25 (s, $C_{cluster}$) ppm. MALDI-TOF-MS: *m*/*z* = 270.1 [M^+].

X-ray Crystallographic Study: CCDC-185388 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge at www.ccdc.cam.ac.uk/conts/retrieving.html [or from the Cambridge Crystallographic Data Centre, 12, Union Road, Cambridge CB2 1EZ, UK; Fax: (internat.) +44−1223/336−033; E-mail: deposit@ccdc.cam.ac.uk].

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[18] Crystal data for *closo*-**1**·EtOAc. $C_6H_{11}B_{10}I_9O_2$, monoclinic, space group $P2_1/n$ (no. 14), *a* = 11.394(3), *b* = 17.549(3), *c* = 14.237(2) Å, β = 100.537(15)°, *U* = 2798.7(10) $Å^3$, *Z* = 4, D_c = 3.240 g cm^{-3}, μ(Mo-K_a) = 9.973 mm^{-1}, *T* = 294 K. *F*(000) = 2360. 4921 Unique reflections were collected by ω/2θ ($2\theta_{max}$ = 50°). The structure was solved by direct methods and refined on F^2 by the SHELX-97 program to *R*1 = 0.0384 (*wR*2 = 0.0774) with a goodness-of-fit of 1.024.

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