Synthesis of Highly Iodinated Icosahedral Mono- and Dicarbon Carboranes

Rajiv R. Srivastava, Donald K. Hamlin, and D. Scott Wilbur*

Department of Radiation Oncology, University of Washington, Seattle, Washington 98195

Received August 12, 1996

Highly iodinated molecules have application as X-ray contrast agents due to the opacity of the iodine atoms to low energy X-rays.[1] Current X-ray contrast agents are principally composed of substituted iodinated benzene compounds and their dimers.[2] Most of the iodinated benzene derivatives have three iodine atoms substituted in an alternating fashion with other substituents that are designed to increase water solubility and decrease *in vivo* toxicity.[2,3] Although the current radiographic contrast media have been optimized over many years of development, improvements are still being sought.[4]

One method of improving contrast agents is to increase the iodine content in the molecules. It is known that an increase in the percentage of molecular weight due to iodine in a contrast agent from 28.7 to 37.5% doubles the contrast of the radiographic image at selected X-ray energies.[1] This fact suggests that chemical moieties other than benzene rings, which can be more highly iodinated, might present new alternatives for contrast agents. A novel departure from the conventional iodinated benzene ring compounds can be obtained by application of iodinated borane and carborane cage compounds. Although there are a large number of borane cage compounds of various cage sizes, the *closo*-icosahedral borane and carborane cage compounds are of particular interest.[5] The interest in icosahedral boron cage compounds comes from the fact that they are quite stable to a variety of chemical conditions and have the potential for incorporation of a large number of iodine atoms per molecule. Importantly, boron−iodine bonds are stronger than carbon−iodine bonds,[6] and iodinated borane cage molecules are particularly stable to chemical and biological deiodination.[7] Also, icosahedral borane and carboranes (e.g., **1**−**5**) are aromatic and undergo electrophilic substitution reactions, making this common method of iodination attractive for introducing iodine into the cage molecules.[8] Further, due to the electronic nature of these molecules, the cage containing only boron atoms (i.e., $B_{12}H_{12}^{2-}$, **1**) is dianionic; the cage containing one carbon atom (i.e., $CB_{11}H_{12}^{1-}$, **2**) is anionic; and the cage compounds containing two carbon atoms (i.e., isomeric $C_2B_{10}H_{12}$, **3**−**5**) are neutral (Figure 1). This difference in charge on the cages could lead to significantly different properties in the iodinated compounds and, ultimately, in iodinated contrast agents that contain them.

A critical issue in the application of iodinated boranes and carboranes is the ability to highly iodinate the cage structures. Periodination of the borane cage molecules $B_{10}H_{10}^{2-}$ and $B_{12}H_{12}^{2-}$, **1**, and a few of their substituted derivatives have been previously reported.[7a,9] Halogenation of cage boron atoms in *closo*-dicarbaboranes **3**−**5** has also been studied previously. While perfluorination[10] and perchlorination[11] of dicarbaboranes have been obtained, perhalogenation with bromine or iodine has not been accomplished. Indeed, it has been reported that a maximum of three bromine atoms can be substituted onto *o*-carbaborane, **3**, using $AlCl_3$ catalyst unless the carbons have an electron-donating alkyl substituent (e.g., methyl group) that increases the amount of substitution by 1 to a maximum of 4 bromine atoms.[12] With *m*-dicarbaborane, **4**, and *p*-dicarbaborane, **5**, only the mono- and dibromo or diiodo derivatives could be obtained under the reaction conditions studied.[11b,13] In contrast to the *closo*-dicarbaboranes, it has been reported that *closo*-carbaboranes (monocarbon carboranes, e.g., **2**) do not readily perhalogenate even with chlorine. Indeed, in an early study it was reported that reaction of the unsubstituted anionic monocarbon carborane with chlorine gas at 0 °C caused extensive degradation of the carborane molecule.[14] They further stated that attempts to iodinate C-trialkylamine derivatives, "even with the aid of $AlCl_3$ or a photolamp", were unsuccessful. A later study, however, reported that halogenation reactions could be accomplished under different conditions.[15] In that study the hexachloro derivative was obtained when the unsubstituted monocarbon carborane was chlorinated with excess chlorine in acetic acid at 80 °C. Interestingly, the hexabromo derivative was obtained under the same reaction conditions, whereas only the diiodo derivative was obtained when excess iodine was used.

In a practical sense, any new contrast media containing iodinated boron cage molecules will need to be substituted with a minimum of six iodine atoms (preferably 8−11 iodine atoms), or have greater than 65% iodine by weight, to make them functionally competitive with iodinated phenyl contrast agents. The percentage of iodine by

(1) Peng, C. T. In *Burger's Medicinal Chemistry*, 4th ed.; Wolff, M. E., Ed.; John Wiley & Sons, Inc.: New York, 1981; Part III, Chapter 61, pp 1139−1203.

(2) (a) Hoey, G. B.; Smith, K. R.; El-Antably, S; Murphy, G. P. In *Handbook of Experimental Pharmacology; Radiocontrast Agents*; Sovak M., Ed.; Springer-Verlag: New York, 1984; Chapter 1, pp 23−125. (b) Hoey, G. B.; Wiegert, P. E.; Rands, R. D. In *International Encyclopedia of Pharmacology and Therapeutics; Radiocontrast Agents;* Knoefel, P. K., Ed.; International Union of Pharmacology: Stockholm, Sweden, 1971; Section 76, Volume I, Chapter 2, pp 23−131.

(3) Almen, T. In *International Encyclopedia of Pharmacology and Therapeutics; Radiocontrast Agents;* Knoefel, P. K., Ed.; International Union of Pharmacology: Stockholm, Sweden, 1971; Section 76, Volume II, Chapter 13, pp 443−550.

(4) Sovak, M. *Nucl. Med. Biol.* **1988**, *15*, 3−7.

(5) Rudolph, R. W. *Acc. Chem. Res.* **1976**, *9*, 446−452.

(6) Kerr, J. A. In *Handbook of Chemistry and Physics*, 74th ed.; Lide, D. R., Ed.; CRC Press: Boca Raton, FL, 1993; pp 9−124.

(7) (a) Knoth, W. H.; Miller, H. C.; Sauer, J. C.; Balthis, J. H.; Chia, Y. T.; Muetterties, E. L. *Inorg. Chem.* **1964**, *3*, 159−167. (b) Wilbur, D. S.; Hamlin, D. K.; Buhler, K. R.; Srivastava, R. R.; Stray, J. E.; Daniel, J.; Vessella, R. L. *Quart. J. Nucl. Med.* **1995**, *39*, 51−52.

(8) Grimes, R. N. *Carboranes*; Academic Press: New York, 1970; pp 133−140.

(9) (a) Knoth, W. H. *J. Am. Chem. Soc.* **1966**, *88*, 936−939. (b) Knoth, W. H. *J. Am. Chem. Soc.* **1967**, *89*, 4850−4852. (c) Buhrens, K.-G.; Preetz, W. *Angew. Chem., Int. Ed. Engl.* **1977**, *16*, 173−174.

(10) Kongpricha, S.; Schroeder, H. *Inorg. Chem.* **1969**, *8*, 2449−2452.

(11) (a) Schroeder, H.; Heying, T. L.; Reiner, J. R. *Inorg. Chem.* **1963**, *6*, 1092−1096. (b) Sieckhaus, J. F.; Semenuk, N. S.; Knowles, T. A.; Schroeder, H. *Inorg. Chem.* **1969**, *8*, 2452−2457.

(12) (a) Smith, H. D.; Knowles, T. A.; Schroeder, H. *Inorg. Chem.* **1965**, *4*, 107−111. (b) Potenza, J. A.; Lipscomb, W. N.; Vickers, G. D.; Schroeder, H. *J. Am. Chem. Soc.* **1966**, *88*, 628−629. (c) Potenza, J. A.; Lipscomb, W. N. *Inorg. Chem.* **1966**, *5*, 1478−1482. (d) Potenza, J. A.; Lipscomb, W. N. *Inorg. Chem.* **1966**, *5*, 1483−1488.

(13) (a) Stanko, V. I.; Gol'tyapin *J. Gen. Chem. USSR* **1969**, *39*, 676. (b) Andrews, J. S.; Zayas, J.; Jones, M. *Inorg. Chem.* **1985**, *24*, 3715−3716. (c) Zakharkin, L. I.; Ol'shevskaya, V. A.; Poroshina, T. Y.; Balagurova, E. V. *J. Gen. Chem. USSR* **1987**, *57*, 1800−1803.

(14) Hyatt, D. E.; Scholer, F. R.; Todd, L. J.; Warner, J. L. *Inorg. Chem.* **1967**, *6*, 2229−2233.

(15) Jelinek, T.; Plesek, J.; Hermanek, S.; Stibr, B. *Collect. Czech. Chem. Commun.* **1986**, *51*, 819−829.

S0022-3263(96)01560-5 CCC: $12.00

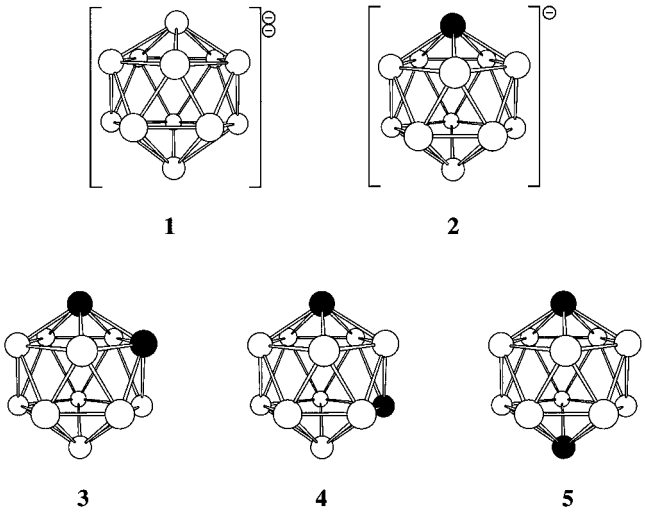


Figure 1. Three-dimensional representations (ball and stick) of icosahedral borane ($B_{12}H_{12}^{2-}$, **1**), monocarbon carborane ($CB_{11}H_{12}^{1-}$, **2**), and regioisomeric dicarbon carboranes ($C_2B_{10}H_{12}$; **3**−**5**). Open circles represent boron atoms; solid circles represent carbon atoms. For simplification the protons on cage atoms have been excluded.

weight for highly iodinated boron cage molecules can be over 90%, making these compounds particularly attractive. Indeed, even when substituents are added to attain water solubilization and/or diminished toxicity of highly iodinated borane cage molecules, high percentages of iodine (e.g., 65−85% of molecular weight) could be obtained. Thus, it was considered important to increase the levels of iodine substitution of the carborane cage molecules over those previously reported in the literature. Since we were interested in application of both anionic and neutral borane cage molecules to prepare new X-ray contrast agents, an investigation of the iodination reactions of these compounds was carried out. Presented herein are the results of that investigation.

Results and Discussion

Previous iodination studies had only obtained two iodine atoms substituted on the *closo*-carbaborane **2** and *closo*-dicarbaboranes **3**−**5**; therefore, it was reasoned that a method of catalysis might be needed to further iodinate these compounds. While many different methods of catalysis have been described for iodination reactions of nonactivated or deactivated compounds,[16] we were particularly interested in strong acid catalysts such as concentrated H_2SO_4[17] and triflic acid[16b,18] on the basis of their reported high catalytic activity in electrophilic substitution reactions. Reports of electrophilic iodinations using triflic acid made this reagent most attractive for our studies.[19]

Although it was thought that catalysis would be required, iodination studies were initially conducted without triflic acid catalyst to determine what the maximum number of iodine atoms might be substituted under the conditions similar to those employed to periodinate **1**.[7a] Thus, reactions of *o*-dicarbaborane, **3**, and *m*-dicarbaborane, **4**, were conducted with a 1:1 mixture of ICl and 1,1,2,2-tetrachloroethane heated to 150 °C. After several days, reaction mixtures were obtained that, by mass spectral analysis, indicated that the highest substitution in each case was six iodine atoms. However, it was found that these reaction conditions could be used to prepare (for the first time) periodinated monocarbon carborane **7** and the corresponding periodinated C-amino monocarbon carborane **8**.[20]

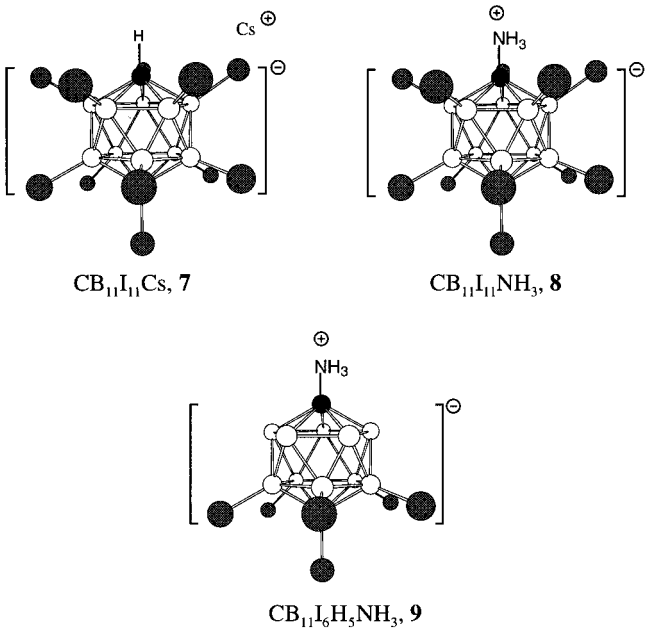


Figure 2. Three-dimensional representations (ball and stick) of B-periodinated 1-carba-*closo*-dodecaboranes (**7** and **8**) and hexaiodinated 1-amino-1-carba-*closo*-dodecaborane (**9**). Open circles represent boron atoms; solid black circle represents the carbon atom; gray circles represent substituted iodine atoms. For simplification the protons on boron atoms in **9** have been excluded.

While triflic acid was not required to prepare periodinated monocarbon carborane **7**, reaction in triflic acid was found to produce another compound of interest. Reactions of 1-amino-1-carbaborane, **6**, in triflic acid/ICl at room temperature yielded the hexaiodo derivative; 1-amino-7,8,9,10,11,12-hexa-B-iodo-1-carba-*closo*-dodecaborane, **9**. It is presumed that protonation of the amino substituent on the carbon deactivates the adjacent boron atoms to electrophilic iodination, resulting in only the hexaiodo product. This hypothesis seems to be upheld by the fact that the unsubstituted monocarbon carborane, **2**, yields a mixture of (more highly) iodinated products under the same reaction conditions. Drawings depicting the three-dimensional structures of the periodinated C-amino monocarbon carboranes **7** and **8**, and the hexaiodinated C-amino monocarbon carborane **9** are shown in Figure 2.

Attempts to periodinate *o*-carborane and *m*-carborane were conducted at elevated reaction temperatures (120

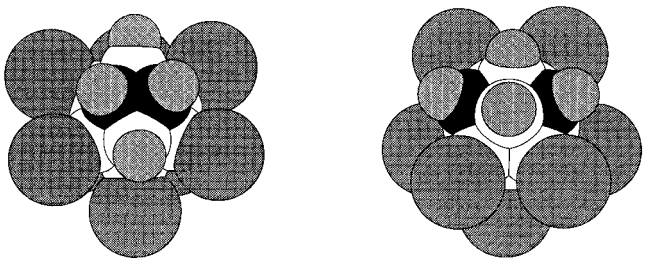
(16) (a) Braendlin, H. P.; McBee, E. T. In *Friedel−Crafts and Related Reactions*; Olah, G. E., Ed.; Interscience: New York, 1964; Vol. III, Part 2, Chapter XLVI, pp 1517−1593. (b) Effenberger, F. *Angew. Chem., Int. Ed. Engl.* **1980**, *19*, 151−230.

(17) (a) Mattern, D. L. *J. Org. Chem.* **1993**, *48*, 4772−4773. (b) Mattern, D. L.; Chen, X. *J. Org. Chem.* **1991**, *56*, 5903−5907.

(18) (a) Howells, R. D.; McCown, J. D. *Chem. Rev.* **1977**, *77*, 69−92. (b) DesMarteau, D. D. *J. Am. Chem. Soc.* **1978**, *100*, 340−341.

(19) (a) Barluenga, J.; Ganzalez, J. M.; Garcia-Martin, M. A.; Campos, P. J.; Asensio, G. *J. Org. Chem.* **1993**, *58*, 2058−2060. (b) Olah, G. A.; Wang, Q.; Sandford, G.; Prakash, G. K. S. *J. Org. Chem.* **1993**, *58*, 3194−3195.

(20) *N,N*-Dimethylamino-1-carbaborane was also periodinated, but a mixture of two compounds was obtained (1:3 ratio by HPLC). Attempts to purify this mixture were unsuccessful. It is likely that the minor product is the monomethyl amine as it is known that demethylation can occur with iodine, and the ^{1}H NMR was consistent with this.



ortho-$C_2B_{10}I_8H_4$, **10** *meta*- $C_2B_{10}I_8H_4$, **11**

Figure 3. Three-dimensional representations (space filling) of the proposed structures for octa-iodinated *ortho*- and *meta*-dicarbon carboranes (**10** and **11**). Large gray spheres represent iodine atoms; colorless spheres represent boron atoms; black spheres represent carbon atoms; small gray spheres represent protons.

°C) with a 1:1 v/v mixture of triflic acid and ICl. The reactions were followed by HPLC analysis showing that over a 10−11 day period many different peaks grew in and disappeared as the iodination progressed. After 11 days very little change was noted in the HPLC chromatograms. The ^{1}H NMR, ^{11}B NMR, and mass spectral data of the isolated products from reactions of **3** and **4** indicated that eight (not 10) iodine atoms had been substituted on cage structures, yielding compounds **10** and **11**. While the structures have not been unequivocally determined, it seems likely that the two boron atoms in each structure that are bonded to two carbon atoms did not undergo iodine substitution. This structural assignment is based on the fact that the boron atoms bonded to two carbon atoms would be the most electron deficient. Drawings depicting the proposed three-dimensional structures of the octa iodo dicarbaborane derivatives **10** and **11** are shown in Figure 3. Reaction of *p*-dicarbaborane, **5**, under the same conditions led to periodination. Conclusive evidence for periodination was obtained from ^{11}B and mass spectral analysis. Mass spectral analysis indicated that there were 10 iodine atoms on the *p*-carborane molecule, and the ^{11}B NMR was a singlet, indicating that only one type of boron present. It is important to note that in *p*-dicarbaborane each of the boron atoms are bonded with only one carbon atom.

In summary, we have found that monocarbon and dicarbon carboranes will undergo electrophilic iodination to yield boron cage compounds containing 6−11 iodine atoms per molecule under the reaction conditions studied. Iodination of anionic monocarbon carboranes is relatively facile, being accomplished with ICl at reflux in tetrachloroethane. In contrast, neutral dicarbon carboranes required reflux in a triflic acid/ICl mixture to obtain maximal iodination.

Experimental Section

All chemicals purchased from commercial sources were analytical grade or better and were used without further purification. 1,2-Carborane (*o*-carborane, **3**), 1,7-carborane (*m*-carborane, **4**), and 1,12-carborane (*p*-carborane, **5**) were purchased either from Aldrich Chemical Co. (Milwaukee, WI) or Astor LTD (Los Angeles, CA). Triflic acid and iodine monochloride (ICl) were obtained from Aldrich Chemical Co. 1-Carba-*closo*-dodecaboranes (**2** and **6**) were prepared as previously described[21] to yield the Cs salt or neutral compounds with the appropriate spectral characteristics. Silica gel chromatography was conducted with 70−230 mesh 60 Å silica gel (Aldrich Chemical Co.). Elemental analyses were obtained from Desert Analytics, Tucson, AZ. Satisfactory elemental analyses were not obtained for the Cs salts of iodinated monocarbon boranes **7** and **8**. The difficulty in obtaining satisfactory elemental analyses is thought to be caused by contamination with other counterions and/or the presence of double salts. The identity of these compounds was confirmed by ^{11}B NMR and MS data, and the purity was confirmed by HPLC analyses (Supporting Information).

^{1}H, ^{13}C, and ^{11}B NMR were obtained on multinuclear instruments (200 MHz for ^{1}H; 50.3 MHz for ^{13}C, 64.2 MHz for ^{11}B; or 500 MHz ^{1}H and 160.47 MHz for ^{11}B). Determination of the extent of iodination was accomplished by evaluation of ^{1}H coupled and decoupled ^{11}B NMR. FAB^+ mass spectral data were obtained at 8 kV using a matrix of sodium salt of 3-nitrobenzyl alcohol. FAB^- mass spectral data were obtained at 8 kV in a matrix of thioglycerol. Partial listing of the boron isotopic envelope peaks is provided to indicate identity and purity of samples. Melting points are uncorrected. Structural drawings were prepared with ChemDraw or ChemDraw 3D computer programs.

HPLC separations were obtained on either a quaternary 1050 gradient pumping system with a variable wavelength UV detector (254 nm) and an evaporative light-scattering detector or an isocratic system consisting of a 1050 pump, variable-wavelength UV detector, and a refractive index detector. HPLC separations were conducted at a flow rate of 1 mL/min on a 5 μm, 125 × 4.6 mm C-18 columns (LiChrospher 100 RP-18). All compounds were evaluated on a gradient system using an initial mixture of 40% MeOH/60% of an aqueous 1% triethylammonium acetate, pH 4.4, solution. The gradient was held at the initial mixture for 2 min, increased to 100% MeOH over a 13 min period, and held at 100% MeOH for 5 min. Retention times (t_R) for compounds are provided with the experimental descriptions.

Cesium Undeca-*B*-iodocarba-*closo*-dodecaborane, 7. A 100 mL round-bottom flask was charged with 0.452 g (1.64 mmol) of Cs 1-carba-*closo*-dodecaborane, **2**. To the flask was added 10 mL of 1,1,2,2-tetrachloroethane and 9.58 g (59 mmol) of ICl. After the reaction mixture was stirred for 30 min at room temperature, it was heated slowly to 150 °C in an oil bath. After 63 h the reaction mixture was removed from the oil bath and allowed to come to room temperature. The solid that formed was collected by gravity filtration and washed with 50 mL CH_2Cl_2. The solid was dissolved in 70 mL of EtOAc and washed with 2 × 20 mL of aqueous $NaHSO_3$, 2 × 10 mL H_2O, and 20 mL saturated aqueous NaCl. The EtOAc solution was dried over $MgSO_4$ and concentrated on a rotary evaporator to give an oily mass. The oily material was placed on a high vacuum to remove residual solvent yielding 1.52 g (56%) of a faint yellow solid.

A 200 mg quantity of the crude product was dissolved in 30 mL of water and was passed through a 2.5 × 15 cm ion-exchange column (Amberlite IR-120 plus). An additional 70 mL of water was passed through the column to assure complete elution. The aqueous eluant was concentrated to approximately 5 mL on a rotary evaporator, and a 1:1 w/v solution of CsCl in H_2O was added. The precipitate was (gravity) filtered and dried at 75 °C/0.2 Torr to yield 214 mg of a faint yellow solid, mp >300 °C (turns brown on heating). HPLC of this solid indicated that the compound (t_R = 17.6 min) was >99% pure (ELSD detection): IR (Nujol, cm^{-1}) 1597 (w), 1093 (m), 915 (m), 720 (w); ^{1}H NMR (acetone-d_6) 2.86; ^{11}B NMR (acetone-d_6, 64.21 MHz, ^{1}H decoupled) −7.9 (1B), −12.2 (5B), −19.2 (5B) [^{1}H-coupled spectrum identical to decoupled]; FAB^- MS (isotopic abundance), calcd for (M − H) $CHB_{11}I_{11}$ 1527 (74), 1528 (100), 1529 (81), found 1527 (74), 1528 (100), 1529 (82).

1-Aminoundeca-*B*-iodo-1-carba-*closo*-dodecaborane, 8. To a 100 mL round-bottom flask containing 1.00 g (6.29 mmol) of 1-aminoundecahydro-1-carba-*closo*-dodecaborane, **6**, were added 40 mL of 1,1,2,2-tetrachloroethane and then 7.2 mL (22.5 g, 138 mmol) of ICl. The mixture was stirred at room temperature for 30 min and then heated to 150−160 °C with stirring for 48 h. The reaction mixture was allowed to cool to room temperature and was (gravity) filtered. The solid obtained was washed with 2 × 50 mL of CH_2Cl_2 and then dissolved in 150 mL of EtOAc. The EtOAc solution was washed with 50 mL of 10% $NaHSO_3$ solution, 2 × 10 mL of H_2O, and then 20 mL of saturated NaCl

(21) (a) Knoth, W. H.; Little, J. L.; Lawrence, J. R.; Scholer, F. R.; Todd, L. J. (1968) *Inorg. Synth.* **1968**, *11*, 33−41. (b) Plesek, J.; Jelinek, T.; Drdakova, E.; Hermanek, S.; Stibr, B. *Collect. Czech. Chem. Commun.* **1984**, *49*, 1559−1562.

solution. The solvent was removed on a rotary evaporator to dryness (an additional 5 mL of H_2O was added and removed) to yield a light yellow viscous material. This material was dissolved in 20 mL of H_2O, and a solution of 1.5 g (8.9 mmol) CsCl in 2 mL of H_2O was added. An additional 10 mL of H_2O was added to the resultant thick white precipitate, which was collected by filtration. The wet mass was dried at 60 °C/0.2 mm overnight to give 8.15 g (77%). HPLC indicated that the compound (t_R = 17.1 min) was >98% pure: mp >300 °C; IR (Nujol, cm^{-1}) 1583 (m), 938, 720 (w); ^{11}B NMR (acetone-d_6, ^1H-decoupled spectra) −11.8 (1 B), −14.8 (10 B) [^1H-coupled spectra same as decoupled spectra]; MS FAB$^-$ (isotopic abundance) calcd for $CH_2B_{11}I_{11}N$ 1542 (74), 1543 (100), 1544 (81), found 1542 (73), 1543 (100), 1544 (78).

1-Amino-7,8,9,10,11,12-hexa-*B*-iodo-1-carba-*closo*-dodecaborane, 9. This compound was prepared as described for compound **8**, except **6** (100 mg, 0.63 mmol) was reacted with 1.98 mL (3.37 g) of triflic acid and 1.06 mL (3.37 g, 20.8 mmol) of ICl. The reaction yielded 0.530 g (92%) of a light yellow solid. HPLC indicated that the compound (t_R = 13.7 min) was >99% pure: mp >300 °C; IR (Nujol, cm^{-1}) 3570 (m), 3500 (m), 3140 (w), 2580 (w), 1575 (w), 1550 (w), 995 (m), 915 (w), 865 (m), 810 (w), 720 (w); ^{11}B NMR (acetone-d_6, ^1H-decoupled spectra) −6.9 (s, 1 B), −12.6 (s, 5 B), −19.0 (s, 5 B); (^1H-coupled spectra) −6.9 (s, 1 B), −12.6 (d, 5 B, J = 171 Hz), −19.0 (s, 5 H); mass calcd for $CB_{11}I_6NH_7$ 913 (74), 914 (100), 915 (81), found 913 (76), 914 (100), 915 (79).

4,5,7,8,9,10,11,12-Octa-*B*-iodo-1,2-dicarba-*closo*-decaborane, 10. A 100 mL three-neck round-bottom flask was charged with 1.0 g (6.93 mmol) of 1,2-dicarbaborane, **3**. The flask was purged with argon, and 11 mL (124 mmol) of triflic acid was added. Following this, 11 mL (40.4 g, 249 mmol) of ICl was carefully added. After the reaction mixture was stirred at room temperature for 10 min, the reaction temperature was elevated to 120 °C for 6 days. The reaction mixture was allowed to cool to room temperature, and 20 mL of ice-cold H_2O was added. A 70 mL quantity of 15% aqueous $NaHSO_3$ was added to quench the excess ICl. The precipitate in the yellow solution was collected by filtration. The solid was dissolved in 200 mL of hot EtOAc (60 °C), and zinc dust was added portionwise until the solution became colorless. The colorless solution was passed through a pad of celite and was concentrated on a rotary evaporator to yield 5.28 g (66%) of a light yellow solid.

A 300 mg quantity of the crude solid was recrystallized from 10 mL of a 1:1 mixture of acetone/MeOH to yield 207 mg (67%) of a colorless solid, mp >300 °C. HPLC indicated that this compound (t_R = 18.9 min) was 99% pure (ELSD detection): IR (Nujol, cm^{-1}) 3033 (m), 2995 (m), 1179 (m), 1108 (m), 953 (m), 911, 890 (w), 860 (m), 798 (m); ^1H NMR (DMSO-d_6) 7.61 (s, 2 H), 6.40 (s, 2 H); ^{13}C NMR (DMSO-d_6) 61.5; ^{11}B NMR (THF-d_8) −4.77 (2 B), −13.47 (4 B), (broad shoulder at −12.36) −21.14 (4B) [shoulder at −9 to −11 ppm splits in ^1H-coupled spectrum]; MS FAB$^-$ (isotope abundance) calcd for $C_2H_4B_{10}I_8$ 1149 (66), 1150 (100), 1151 (90), found 1149 (60), 1150 (100), 1151 (100). Anal. Calcd for $C_2H_4B_{10}I_8$: C, 2.09; H, 0.35; B, 9.39; I, 88.17. Found: C, 2.25; H, 0.23; B, 9.31; I, 88.02.

4,5,6,8,9,10,11,12-Octa-*B*-iodo-1,7-dicarba-*closo*-decaborane, 11. This compound was prepared as described for compound **10**. The reaction of 1.0 g (6.93 mmol) of 1,7-dicarbaborane, **4**, yielded 5.52 g of a light brown solid. The solid was dissolved in 200 mL of hot EtOAc (60 °C), and zinc dust was added portionwise until the solution became colorless. The colorless solution was passed through a pad of Celite and was concentrated on a rotary evaporator to yield 4.9 g (50%) of a colorless solid.

A small portion of the crude compound (84% pure by HPLC) was recrystallized from methanol/acetone to give a colorless solid, mp >300 °C. HPLC indicated that this compound (t_R = 18.9 min) was >98% pure (ELSD detection): IR (Nujol, cm^{-1}) 3000 (m), 1133 (m), 1109 (w), 953 (m), 902, 882 (w), 840 (m), 788 (w); ^1H NMR (DMSO-d_6, ^1H decoupled) 7.67 (s, 2 H), 6.43 (s, 2 H); ^{13}C NMR (DMSO-d_6) 63.95; ^{11}B NMR (THF-d_8) −10.20 (2 B), −11.77 (2 B), −13.49 (2B), −20.63 (4 B) [peak at −13.49 ppm split in ^1H-coupled spectrum]; MS/HRMS (FAB$^-$, isotopes) calcd for $C_2H_4B_{10}I_8$ 1149 (66), 1150 (100), 1151.3560 (90), found 1149 (64), 1150 (100), 1151.3508 (98). Anal. Calcd for $C_2H_4B_{10}I_8$: C, 2.09; H, 0.35; B, 9.39; I, 88.17. Found: C, 2.50; H, 0.32; B, 9.14; I, 88.12.

Deca-*B*-iodo-1,12-dicarba-*closo*-decaborane, 12. This compound was prepared as described for compound **10**. The reaction of 1.0 g (6.93 mmol) of 1,12-dicarbaborane, **5**, yielded 9.12 g (79%) of a light brown solid after drying under vacuum. A 100 mg quantity of the crude solid was purified by washing with 1:1 MeOH/acetone to give 89 mg (89%) of a colorless solid, mp >300 °C. HPLC indicated that this compound (t_R = 19.3 min) was 95% pure (ELSD detection): IR (Nujol, cm^{-1}) 1112, 905 (shoulder at 920), 850 (w), 720 (w); ^{11}B NMR (THF-d_8, $BF_3{\cdot}OEt_2$ in benzene-d_6 external std.) −17.45 (s) [no noticeable difference in ^1H coupled spectrum]; MS (FAB$^-$, M − H, isotopes) calcd for $C_2B_{10}I_{11}$ 1528 (66), 1529 (100), 1530 (90), found 1528 (73), 1529 (100), 1530 (80). Anal. Calcd for $C_2H_2B_{10}I_{10}$: C, 1.71; H, 0.14; B, 7.70; I, 90.44. Found: C, 1.82; H, 0.12; B, 7.39; I, 90.79.

Acknowledgment. We thank Dr. Ross Lawrence (Medicinal Chemistry Department, University of Washington) for his efforts in obtaining mass spectral data on the iodinated boranes and carboranes. We thank Mallinckrodt Medical, St. Louis, MO, for financial support of these studies.

Supporting Information Available: Copies of ^{11}B spectra (^1H coupled and decoupled) for starting materials **2**−**6** and iodinated derivatives **7**−**12** and HPLC chromatograms for purified **7**−**9** (25 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

JO961560C