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Insertion of Carboryne into Aromatic Rings: Formation of Cyclooctatetraenocarboranes

Sunewang R. Wang, Zaozao Qiu, and Zuowei Xie*

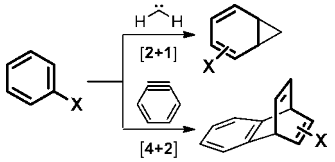
Department of Chemistry and Center of Novel Functional Molecules, The Chinese University of Hong Kong, Shatin, New Territories, Hong Kong, China

Received May 23, 2010; E-mail: zxie@cuhk.edu.hk

Abstract: 1-Iodo-2-lithiocarborane is an efficient precursor to carboryne. It can react with arenes to give different types of dearomatization products, [4+2] cycloaddition and/or cycloinsertion products, dependent upon the substituents on the aromatic rings. The formal cycloinsertion products, cyclooctatetraenocarboranes, is generated from the [2+2] cycloaddition intermediates followed by thermal [3,3] sigmatropic rearrangement. This novel dearomatization of arenes with carboryne also serves as an important method for the synthesis of cyclooctatetraenocarboranes.

Arenes predominantly undergo aromatic substitution reactions although dearomatization of the rings has been documented.[1−4] Generally, cycloaddition reactions involving the benzene ring have proven to be a powerful dearomatization strategy.[3] Two typical cycloaddition patterns have been reported between extremely reactive intermediates and arenes, namely [2+1] cycloaddition of carbenes with aromatic π bonds[3b,5] and [4+2] cycloaddition of benzyne with arenes (Scheme 1).[3d] Carboryne (1,2-dehydro-*o*-carborane) (**2**), a very reactive intermediate reported first in 1990,[6] is known to undergo [4+2] cycloaddition reaction with both benzene[7a] and polycyclic aromatics,[7] resembling that of benzyne.[3d] This reactive species can be generated from either 1-Br-2-Li-1,2-$C_2B_{10}H_{10}$[6] or 1-Me_3Si-2-[IPh(OAc)]-1,2-$C_2B_{10}H_{10}$.[8] Very recently, we reported a more efficient precursor 1-I-2-Li-1,2-$C_2B_{10}H_{10}$ (**1**) for the production of **2**.[9] Heating a solution of **1** in benzene at 80 °C overnight afforded the [4+2] cycloadduct **4a** in 25% isolated yield, much higher than the 8% yield that is afforded from the precursor 1-Br-2-Li-1,2-$C_2B_{10}H_{10}$ (Scheme 2).[7a] Replacement of benzene by toluene gave two [4+2] cycloaddition isomers **4b** and **4b′** in a total yield of 44% with a molar ratio of 26/74. Unprecedentedly, cyclooctatetraenocarboranes **3c**/**3c′** were isolated as major products if benzene was substituted by anisole (Scheme 2). These ring expansion compounds can be viewed as products generated by a formal insertion of the carboryne into an aromatic ring. This new finding is reported in the Communication.

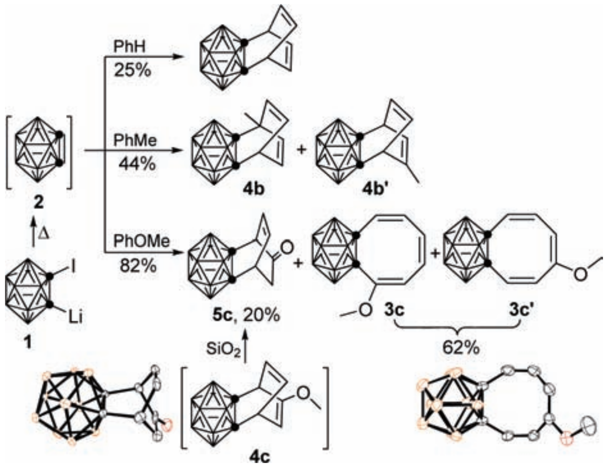
Scheme 1. Dearomatization Reaction of Arenes with Reactive Intermediates



An anisole solution of **1** was heated at 110 °C for 20 h to give, after flash column chromatography on silica gel, the [4+2] cycloadduct **5c** in 20% isolated yield and two cycloinsertion isomers **3c**/**3c′** in 62% isolated yield with a molar ratio of 13/87 (Scheme 2).[10] Compound **5c** should result from the hydrolysis of the corresponding expected methoxy species **4c** during flash column chromatography. The same results were obtained if the reaction was carried out in the dark. Molecular structures of **5c** and **3c′** have been further confirmed by single-crystal X-ray analyses. The unprecedented isolation of cycloinsertion products **3c**/**3c′** prompts us to examine anisole derivatives for understanding the reaction mechanism.

Various substituted anisoles and ethoxybenzene can undergo both cycloinsertion and cycloaddition reactions with carboryne (**2**) to afford cyclooctatetraenocarboranes (**3**) and 1,2-(2,5-cyclohexadiene-1,4-diyl)-*o*-carboranes (**4**), respectively.[10] The results are summarized in Table 1. It seems that the positions of substituents on aromatic rings control the chemoselectivity of the reactions as indicated by the product ratio of **3**:**4**. This ratio is ca. 3:1 for anisole, ethoxybenzene, *ortho*- and *meta*-substituted anisoles (entries 1−4); ca. 1:3 for *para*-substituted ones (entries 5 and 6); and ca. 1:1 for 2,6-disubstituted anisoles (entry 7). Two regioisomers of **4** were observed for **6e**,**f**,**g**,**i** whereas a single product was obtained for **6c**,**d**,**h**, in which the two cage carbons are bonded to the 2,5-positions of anisoles (entries 1, 2, and 6). It is noted that steric factors play a very important role in the regioselectivity of [4+2] cycloaddition reactions in view of the results from entries 5 and 6. Such selectivity is consistent with that observed in the reaction of carboryne with toluene as previously mentioned and reactions of benzyne with arenes.[11]

Scheme 2. Dearomatization Reaction of Arenes with Carboryne



Steric factors also dominate the regioselectivity of cycloinsertion reactions. Only single isomers were observed for **6h**,**i** (entries 6 and 7), in which carboryne inserted into the 1,2- and 3,4-positions of **6h**,**i**, respectively. For anisole (**6c**) and ethoxybenzene (**6d**), two regioisomers were obtained with the 3,4-cycloinsertion product as the major one (entries 1 and 2). No 2,3- or 5,6-cycloinsertion products were observed in all reactions.

The regioisomers of **3** and **4** were isolated in the pure form by flash column chromatography (except for **3f**, **4f**, and **4f′**, entry 4) and fully

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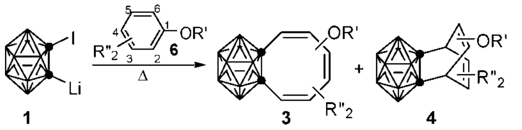
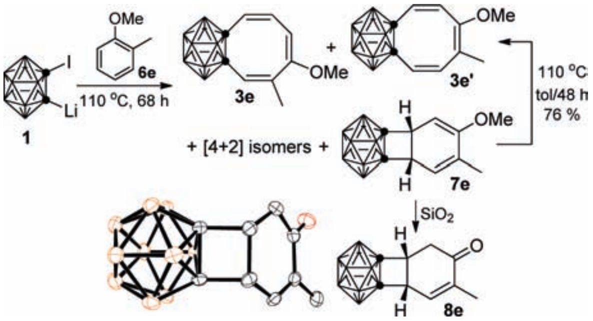
Table 1. Reaction of Anisoles with Carboryne



entry	R′/R″ (**6**)	Product Distribution (%)[a] **3**:**4**	**3** (*site*)	**4** (*site*)	**3**+**4** (%)[b]
1	Me/H (**6c**)	72:28	17 (*1,2*) 83 (*3,4*)	>95 (*2,5*)	82
2	Et/H (**6d**)	75:25	19 (*1,2*) 81 (*3,4*)	>95 (*2,5*)	89
3	Me/2-Me (**6e**)	86:14	33 (*3,4*) 52 (*4,5*)[c]	74 (*2,5*) 26 (*3,6*)	75(12)
4	Me/3-Me (**6f**)	72:28	72 (*4,5*)[c] 10 (*1,6*)[d]	42 (*2,5*) 58 (*3,6*)	65(12)
5	Me/4-Me (**6g**)	24:76	58 (*1,2*) 42 (*3,4*)	21 (*1,4*) 79 (*2,5*)	70
6	Me/4-^{t}Bu (**6h**)	25:75	>95 (*1,2*)	>95 (*2,5*)	75
7	Me/2,6-Me$_2$ (**6i**)	52:48	>95 (*3,4*)	69 (*1,4*) 31 (*2,5*)	77

[a] Determined by ^{1}H NMR of the crude product mixture. *Site* refers to the reactive sites in **6**; e.g. *1,2* means that carboryne inserts into the 1,2-position of anisoles; *2,5* means that two cage carbons are bonded to the 2,5-position of anisoles, respectively. [b] Isolated yield. Most of compounds **4** were isolated in the ketone form **5**. Yields in parentheses refer to a [2+2] cycloaddition product. [c] [2+2] cycloaddition products **7e**,**f** were observed. [d] <5% of 3,4-cycloinsertion product was observed.

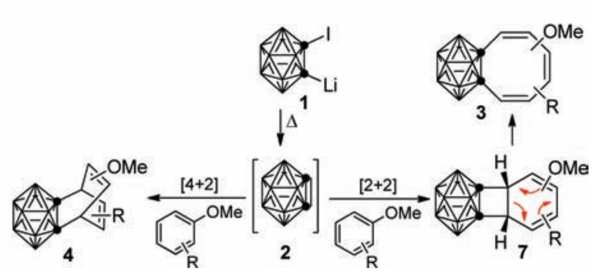
Scheme 3. Reaction of Carboryne with 2-Methylanisole **6e**



characterized.[10a] Molecular structures of **3c′**, **3f**, **3g**, **3h**, **4b′**, **4i**, **5c**, and **8e** were further confirmed by single-crystal X-ray analyses.

The formation of **3** is totally unexpected. Thus, it is important to understand the possible mechanism by which they are formed. From the reaction of **1** with **6e** or **6f** (entries 3 and 4), the [2+2] cycloaddition products **8e** and **8f** were isolated in 12% yield, respectively, in addition to the [4+2] cycloadducts **4** and cycloinsertion products **3**.[10,12] During the isolation of **7e** by flash column chromatography on silica gel, its hydrolysis product **8e** was isolated as colorless crystals, which was characterized by X-ray analyses. Heating a toluene solution of **7e** at 110 °C for 48 h gave **3e′** in 76% yield (Scheme 3). It is noteworthy that under the same reaction conditions, the [4+2] cycloaddition products **4** are thermally stable and cannot be converted into **3** or [2+2] cycloadducts. These experimental data suggest that cycloinsertion products **3** should result from a [3,3] sigmatropic rearrangement of the [2+2] cycloaddition products **7**.[13] A plausible mechanism is thus proposed in Scheme 4. Elimination of LiI from **1** gives the reactive intermediate carboryne **2**,[9] which can undergo [4+2] and [2+2] cycloaddition reactions with anisoles to afford **4** and **7**, respectively.[10b] Thermal rearrangement of **7** generates the formal cycloinsertion products **3**. Steric factors play a role in both regio- and chemoselectivity, and electronic factors may also play a role in the chemoselectivity as only the [4+2] cycloaddition reaction proceeds in toluene.

Scheme 4. Possible Pathways for Reaction of Anisoles with Carboryne



In summary, a [2+2] dearomatization reaction of arenes with carboryne is observed, leading to the formal cycloinsertion products. These ring expansion products, cyclooctatetraenocarboranes, cannot be prepared by other known methods. Reactions of carboryne with arenes bearing other functional groups are under investigation.

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Supporting Information Available: Detailed experimental procedures, complete characterization data, and X-ray data in CIF format for **3c′**, **3f**, **3g**, **3h**, **4b′**, **4i**, **5c**, and **8e**. This material is available free of charge via the Internet at http://pubs.acs.org.

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