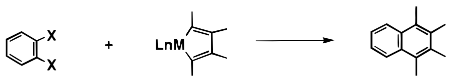
Copper-Mediated Coupling of Zirconacyclopentadienes with Dihalo Aromatic Compounds. Formation of Fused Aromatic Rings

Tamotsu Takahashi,*[,†] Ryuichiro Hara,[‡]
Yasushi Nishihara,[†] and Martin Kotora[‡]

Catalysis Research Center and
Graduate School of Pharmaceutical Sciences
Hokkaido University
Kita-ku, Sapporo 060, Japan
Coordination Chemistry Laboratories
Institute for Molecular Science
Myodaiji, Okazaki 444, Japan

Received February 7, 1996

Coupling reactions between sp^2 carbon centers such as alkenyl−aryl coupling reactions have been very attractive for organic synthesis since alkenylmetals can be readily prepared from alkynes.[1] Metallacyclopentadienes are also conveniently prepared from two alkynes and low-valent metal species.[2] However, there is no precedent for the intermolecular coupling of metallacyclopentadienes with dihalo aromatic compounds to form fused aromatic rings (eq 1), to the best of our knowledge.



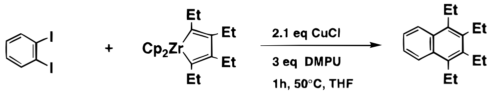
(1)

Symmetrical or unsymmetrical zirconacyclopentadienes have been easily prepared from alkynes or diynes in high yields with high selectivities.[3−5] In order to use these useful zirconacyclopentadienes,[6] we have developed novel carbon−carbon bond formation reactions such as double allylation reaction[7] and cycloaddition reaction of zirconacyclopentadienes.[8] During the course of our study on carbon−carbon bond formation reactions of zirconacyclopentadienes, we found a novel type of coupling reaction. In this paper we report a copper-mediated intermolecular coupling of zirconacyclopentadienes with dihalo aromatic rings. This reaction can provide a novel preparative method of fused aromatic ring compounds.

The typical procedure is as follows. To a mixture of zirconacyclopentadiene **1a** which was prepared from Cp_2ZrBu_2 (Negishi reagent)[4a] and 2 equiv of 3-hexyne in THF were added 2.1 equiv of copper chloride, 3 equiv of DMPU (*N,N′*-(dimethylpropylene)urea) and 1 equiv of diiodobenzene at room temperature. The mixture was stirred at 50 °C for 2 h. Naphthalene derivative **2a** was formed in 89% yield. Zirconacyclopentadiene **1a** was completely consumed. After hydrolysis 4,5-diethyl-3,5-octadiene was not obtained. At room temperature, a long reaction time was required.

Yields were dependent on the amount of DMPU. Without DMPU, **2a** was not formed. When 1.0 equiv of DMPU was used, the yields were 50−60%. The best yields were obtained when 2.5−3.0 equiv of DMPU was used. The use of HMPA instead of DMPU gave the same result.

Recently we have reported copper-catalyzed or -mediated double allylation reaction[7] and cycloaddition reaction[8] of zirconacyclopentadienes. For these reactions the use of DMPU was not necessary. In this coupling reaction to form fused aromatic compounds, the effect of addition of DMPU was remarkable. Addition of CuCl to a THF solution of **1a** prepared *in situ* led to the gradual formation of insoluble yellow precipitates. When DMPU was added to the mixture, the yellow powder was dissolved in THF to form a dark brown solution. When 1,2-diiodobenzene was added to this solution, **2a** was formed. However, in the absence of 1,2-diiodobenzene, diene derivatives containing metals such as Cu and Zr in the mixture gradually decomposed to afford undefined compounds. When iodobenzene was used instead of 1,2-diiodobenzene in the reaction of **1a**, 3-phenyl-4,5-diethyl-3,5-octadiene was obtained in 75% yield.



1a **2a: 89%**

(2)

The results are shown in Table 1. For various zirconacyclopentadienes, the corresponding fused aromatic compounds were obtained in good to high yields. Zirconacyclopentadiene **1b** prepared from 2 equiv of 5-decyne gave a high yield of 1,2,3,4-tetrabutylnaphthalene (**2b**) (88% yield). Unsymmetrical zirconacyclopentadiene **1c** afforded the corresponding unsymmetrical **2c** in 53% yield. When the starting zirconacyclopentadiene **1d** was a mixture of regioisomers, the product **2d** was also a mixture of two regioisomers. Zirconacyclopentadienes **1e** and **1f** prepared from diynes provided tetrahydroanthracenes **2e** and **2f**, respectively. The structure of **2e** was characterized by X-ray analysis and is shown in Figure 1. This structure clearly showed the formation of fused aromatic compound **2e** by the reaction of **1e** with 1,2-diiodobenzene. Zirconacyclopentadienes with trimethylsilyl substituents in the α-position did not react with 1,2-diiodobenzene. When 1,2,4,5-tetraiodobenzene was used, a double coupling reaction proceeded to give anthracene derivative **2h** in 62% isolated yield.

[†] Hokkaido University.

[‡] Institute for Molecular Science.

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(5) For unsymmetrical zirconacyclopentadienes, see: (a) Takahashi, T.; Swanson, D. R.; Negishi, E. *Chem. Lett.* **1987**, 623−626. (b) Buchwald, S. L.; Watson, B. T.; Huffman, J. C. *J. Am. Chem. Soc.* **1987**, *109*, 2544−2546. (c) Buchwald, S. L.; Nielsen, R. B. *J. Am. Chem. Soc.* **1989**, *111*, 2870−2874. (d)Van Wagenen, B. C.; Livinghouse, T. *Tetrahedron Lett.* **1989**, *30*, 3495−3498. (e) Takahashi, T.; Kageyama, M.; Denisov, V.; Hara, R.; Negishi, E. *Tetrahedron Lett.* **1993**, *34*, 687−690. (f) Xi, Z.; Hara, R.; Takahashi, T. *J. Org. Chem.* **1995**, *60*, 4444−4448.

(6) Alkyne insertion of zirocnacyclopentadienes has been reported; see: (a) Famili, A.; Farona, M. F. Thanedar, S. *J. Chem. Soc., Chem. Commun.* **1983**, 435−436. It was reported that the reaction of $Cp_2Zr(CO)_2$ with an excess of diphenylacetylene gave cyclopentadienone as a minor product. See: (b) Sikora, D. J. ; Rausch, M. P. *J. Organomet. Chem.* **1984**, *276*, 21−37. For main group heterocycle formation from zirconacyclopentadienes, see: (c) Fagan, P. J.; Nugent, W. A. *J. Am. Chem. Soc.* **1988**, *110*, 2310−2312. (d) Fagan, P. J.; Nugent, W. A.; Calabrese, J. C. *J. Am. Chem. Soc.* **1994**, *116*, 1880−1889.

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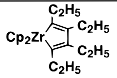
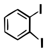
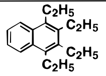
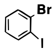
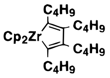
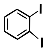
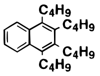
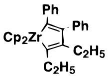
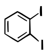
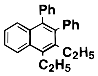
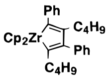
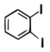
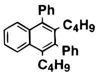
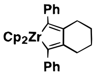
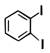
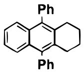
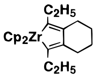
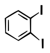
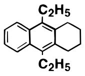
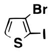
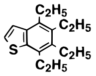
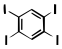
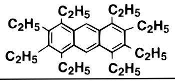
(8) Takahashi, T.; Kotora, M.; Xi, Z. *J. Chem. Soc., Chem. Commun.* **1995**, 361−362.

(9) For transmetalation of other zirconacycles to Cu, see: (a) Kasai, K.; Kotora, M.; Suzuki, N.; Takahashi, T. *J. Chem. Soc., Chem. Commun.* **1995**, 109−110. (b) Lipshutz, B. H.; Segi, M. *Tetrahedron* **1995**, *51*, 4407−4420.

S0002-7863(96)00407-6 CCC: $12.00

Table 1. Reactions of Zirconacyclopentadienes with Dihalo or Tetrahalo Aromatic Compounds[a]

Run	Zirconacyclopentadiene	Halo Aromatic Compounds	Product	Yield/%[b]
1	 **1a**		 **2a**	89(70)
2	**1a**		**2a**	89
3	 **1b**		 **2b**	88 (59)
4	 **1c**		 **2c**	53
5	 **1d**		 **2d**	77 (59)[c]
6	 **1e**		 **2e**	61 (48)
7	 **1f**		 **2f**	58
8	**1a**		 **2g**	32 (29)
9	**1a**		 **2h**	(62)[d]

[a] All reactions were carried out at 50 °C. Reaction time 3 h unless otherwise noted. [b] Isolated yields are shown in parentheses. [c] A mixture of regioisomers were obtained in a ratio of 5.6:1. The minor isomer was 1,4-diphenyl-2,3-dibutylnaphthalene. [d] Reaction time 6 h.

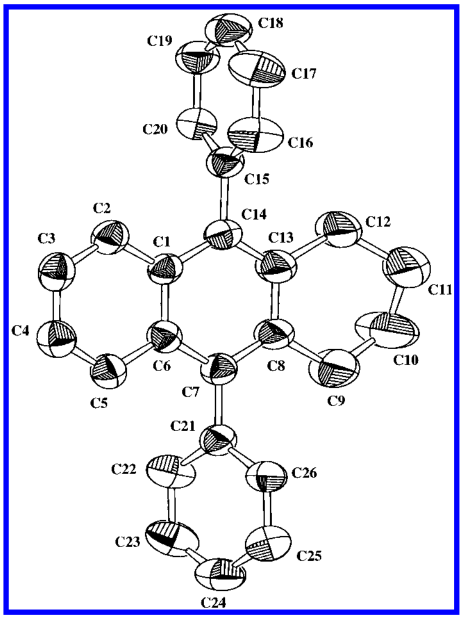
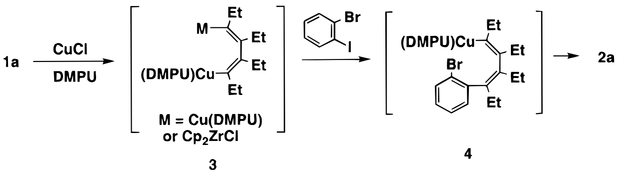


Figure 1. Structure of **2e**.

1,2-Dibromobenzene was not reactive in this reaction. Only 4% of **2a** was formed at 50 °C even after 12 h. Most of the 1,2-dibromobenzene remained unreacted. However, reaction of **1a** with 1-bromo-2-iodobenzene instead of 1,2-dibromobenzene gave **2a** in 89% yield. Similarly, 2,3-dibromothiophene did not afford the coupling product on treatment with **1a**. However, 2-iodo-3-bromothiophene reacted with **1a** to give **2g** in 32% yield. This suggested that a plausible mechanism of this coupling reaction involves a stepwise coupling. The high reactivity of iodide is required for the first intermolecular coupling step. When zirconacyclopentadiene **1a** is treated with CuCl, transmetalation of the diene moiety from zirconium to copper proceeded to form **3** as usually observed.[7-10] 1-Bromo-2-iodobenzene reacts with **3** to give **4.** For the second step which is intramolecular coupling, bromide is reactive enough.



Further investigations are now in progress in this area.

Supporting Information Available: Details of the experimental procedure and analytical data for compounds **2a**−**2h** and X-ray analysis data of **2e** (12 pages). Ordering information is given on any current masthead page.

JA960407X

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(10) Transmetalation of alkenyl carbons from zirconium to copper has been reported. See: (a) Yoshifuji, M.; Loots, M.; Schwartz, J. *Tetrahedron Lett.* **1977**, 1303−1306. (b) Lipshutz, B. H.; Ellsworth, E. L. *J. Am. Chem. Soc.* **1990**, *112*, 7440−7441. (c) Babiak, K. A.; Behling, J. R.; Dygos, J. H.; McLanghlin, K. T.; Ng, J. S.; Kalish, V. J.; Kramer, S. W.; Shone, R. L. *J. Am. Chem. Soc.* **1990**, *112*, 7441−7442. (d) Lipshutz, B. H.; Hato, K. *Tetrahedron Lett.,* **1991**, *32*, 5647−5650. (e) Lipshutz, B. H.; Fatheree, P.; Hagan, W.; Stevens, K. L. *Tetrahedron Lett.* **1992**, *33*, 1041−1044. (f) Lipshutz, B. H.; Keil, R. *J. Am. Chem. Soc.* **1992**, *114*, 7919−7920. (g) Lipshutz, B. H.; Wood, M. R. *J. Am. Chem. Soc.* **1993**, *115*, 12625−12626. (h) Takahashi, T.; Kotora, M.; Kasai, K.; Suzuki, N. *Tetrahedron Lett.* **1994**, *35*, 5685−5688. (i) Takahashi, T.; Kotora, M.; Fischer, R.; Nishihara, Y.; Nakajima, K. *J. Am. Chem. Soc.* **1995**, *117*, 11039−11040.