Nickel-Catalyzed Coupling Reaction of Zirconacyclopentadienes with Two Alkynyl Halides: Formation of Multi-Substituted Arylalkynes

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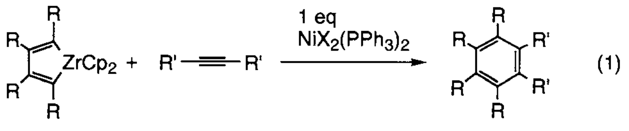
Zirconacyclopentadienes reacted with two equiv of alkynyl halides in the presence of a catalytic amount of $NiCl_2(PPh_3)_2$ to afford multi-substituted arylalkynes.

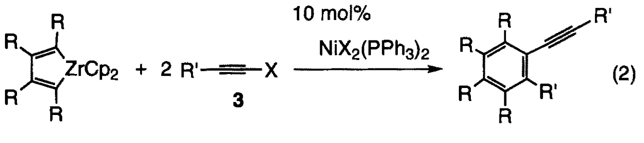
Since the first example of transmetalation of zirconacyclopentadienes **1** to Cu,[1] various carbon–carbon bond formation reactions of zirconacyclopentadienes **1** have been investigated.[2] Recently, we have found that the zirconacyclopentadienes **1** reacted with various kinds of alkynes in the presence of a stoichiometric amount of $NiX_2(PPh_3)_2$ (X = Cl or Br) to give benzene derivatives **2** as shown in eq (1).[3] In particular, a general preparative method of benzene derivatives from three different alkynes was achieved by this procedure.[3,4]



1 **2**

For the transmetalation of zirconacyclopentadienes to Ni, Ni(II) halides are necessary, since the formation of the Zr–halogen bond is the driving force. In the formation of benzene derivatives, formally produced are Ni(0) complexes which do not incorporate in the transmetalation. This is the major reason why Ni does not catalyze the benzene formation from zirconacyclopentadienes and an alkyne. In order to complete a catalytic cycle, re-oxidation of Ni(0) to Ni(II) halides is required. Alkynyl halides were chosen as the organic halides for oxidation of the Ni(0) complexes to Ni(II).

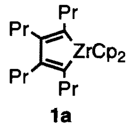
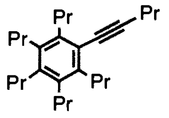
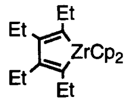
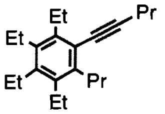
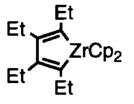
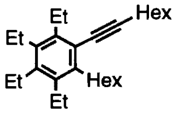
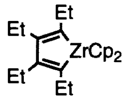
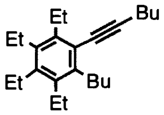
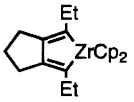
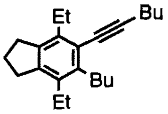
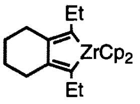
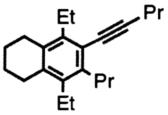
In this paper we would like to report nickel-catalyzed coupling reaction of zirconacyclopentadienes **1** with two equiv of alkynyl halides **3** as shown in eq (2).[5]



1 **4**

Typical procedure is as follows. To a THF solution of zirconacyclopentadiene **1a** (R = Pr), which was in situ prepared by the reaction of Cp_2ZrBu_2 (1 mmol)[6] with two equiv of 4-octyne (2 mmol), was added 10 mol% of $NiCl_2(PPh_3)_2$ (0.1 mmol) and 2 equiv of 1-bromo-1-pentyne (2 mmol) at room temperature. The mixture was stirred at room temperature for 24 h. GC analysis of the reaction mixture using dodecane as an internal standard indicated the formation of 2,3,4,5,6-pentapropyl-1-pentynylbenzene in 55% yield.

Table 1. Nickel catalyzed reaction of zirconacyclopentadienes with alkynyl halides[a]

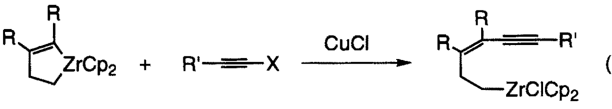
Zirconacyclopentadiene	Alkynyl Halide	Product	Yield/%[b]
 **1a**	Pr—≡—Br **3a**	 **4a**	55 (40)
 **1b**	Pr—≡—Br **3a**	 **4b**	54 (43)
 **1b**	Hex—≡—Cl **3b**	 **4c**	55 (42)
 **1b**	Bu—≡—Br **3c**	 **4d**	55 (41)
 **1c**	Bu—≡—Br **3c**	 **4e**	50 (45)
 **1d**	Pr—≡—Br **3a**	 **4f**	50 (37)

[a] Zirconacyclopentadienes were *in situ* prepared by the reaction of Cp_2ZrBu_2 (1 mmol) and 2 mmol of alkynes or 1 mmol of diyne; Alkynyl halide 2 mmol, $NiCl_2(PPh_3)_2$ 0.1 mmol; Solvent THF. [b] GC yield. Isolated yields are in parentheses.

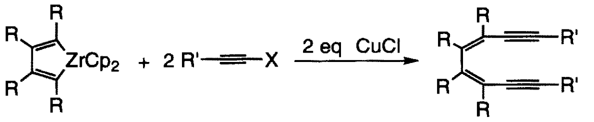
The results obtained here are summarized in Table 1. Not only monocyclic zirconacyclopentadienes but also bicyclic zirconacyclopentadienes gave arylalkynes. $NiCl_2(PPh_3)_2$ and $NiBr_2(PPh_3)_2$ gave similar results. The use of $NiCl_2(PBu_3)_2$ did not give the desired products. When 10 mol% of $NiCl_2$(dppe) and 10 mol% of $NiCl_2$(dppb) were used for the reaction of **1b** with **3c**, the desired product was obtained in 34% (room temperature) and 30% (50 °C) yields, respectively. Palladium complexes such as $PdCl_2(CH_3CN)_2$ and $Pd(OAc)_2/2PPh_3$ were not effective for this reaction.

Other organic halides such as allyl chloride did not give the desired products. The use of 1-chloronon-1-en-3-yne derivative afforded only a β-chlorostyrene derivative (80% yield) in a stoichiometric reaction.

It is interesting to compare these reactions with the reaction of zirconacyclopentadienes or zirconacyclopentenes with alkynyl halides in the presence of CuCl.[7,8] In the case of copper-mediated reactions, the carbon–halogen bond of alkynyl halides always reacted with the sp^2-carbon attached to zirconium.

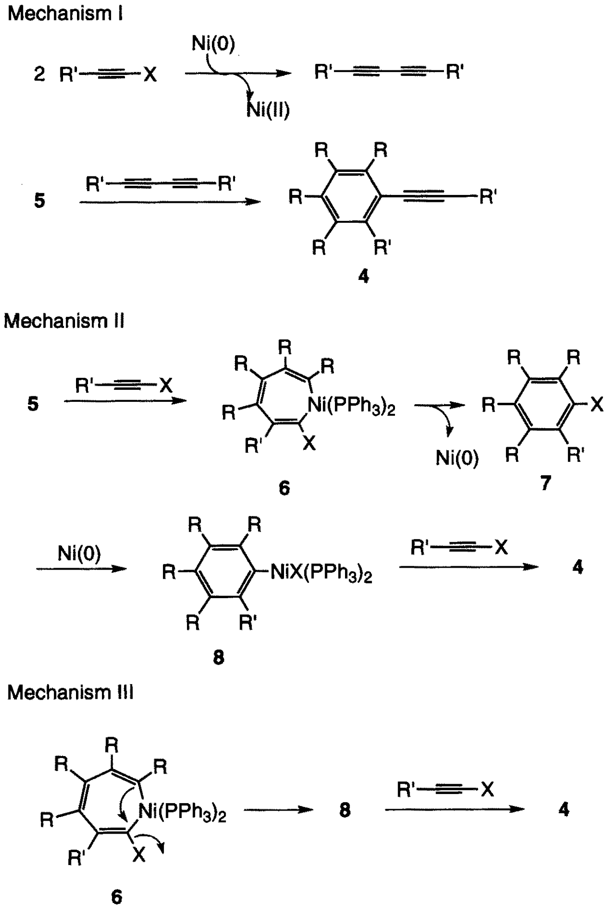


(3)



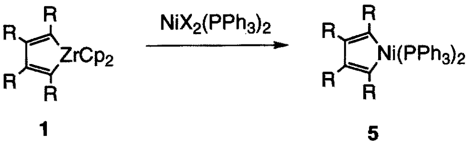
(4)

In the reaction using Ni complexes, GC analysis did not give any alkynylation products of zirconacyclopentadienes. This result suggests that the carbon–carbon triple bond of alkynyl halides reacted first. In other words, the insertion reaction of the carbon–carbon triple bond in the Ni–carbon bond is much more favorable than the coupling of the carbon–halogen bond.



Scheme 1.

It is already demonstrated that transmetalation of zirconacyclopentadienes to Ni with $NiCl_2(dppe)$ proceeded to give a nickelacyclopentadiene.[3,9] Therefore, in this catalytic reaction, the formation of nickelacyclopentadiene **5** from zirconacyclopentadienes **1** is reasonable as shown in eq (5).



(5)

There are three possible mechanisms (I–III) from the nickelacyclopentadienes **5** to **4** as shown in the Scheme 1. The formation of diynes during the reaction of eq (2) was not detected. Therefore, the mechanism (I) is not likely.

Elucidation of the reaction mechanism must await further investigation.

References and Notes

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4 The first benzene formation from zirconacyclopentadienes was achieved using CuCl, see a)T. Takahashi, M. Kotora, and Z. Xi, *J. Chem. Soc., Chem. Commun.*, **1995**, 361. b) T. Takahashi, Z. Xi, A. Yamazaki, Y. Liu, K. Nakajima, and M. Kotora, *J. Am. Chem. Soc.*, **120**, 1672 (1998).

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