Graphical Abstract

Synthesis of (1-alkynyl)dicarbonylcyclopentadienyliiron complexes by palladium-catalyzed Sonogashira-type carbon–iron bond formation

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Synthesis of (1-alkynyl)dicarbonylcyclopentadienyliiron complexes by palladium-catalyzed Sonogashira-type carbon–iron bond formation

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Abstract—Treatment of \([\text{CpFe(CO)}_2\text{I}]\) with terminal alkynes in the presence of catalytic amounts of dichlorobis(triphenylphosphine)palladium and copper iodide in aliphatic amine/THF results in Sonogashira-type carbon–iron bond formation to yield \([\text{CpFe(CO)}_2(C\equiv CR)]\) in good yields. © 2010 Elsevier Science. All rights reserved

Dicarbonylcyclopentadienyliorganoirons \([\text{CpFe(CO)}_2\text{R}]\) have been attracting considerable attention in the field of coordination chemistry. Among them, the corresponding (1-alkynyl)iron complexes \([\text{CpFe(CO)}_2(C\equiv CR)]\) are interesting not only as fundamental organometallic compounds but also as potentially useful precursors for molecular electronic devices.

The synthesis of the (1-alkynyl)iron complexes often employs the reactions of \([\text{CpFe(CO)}_2X]\) (\(X = \text{halogen}\)) with lithium or magnesium acetylides, which lack generality and functional group compatibility. Although palladium-catalyzed Migita-Kosugi-Stille-type reactions of \([\text{CpFe(CO)}_2\text{I}]\) with (1-alkynyl)stannanes offer an alternative route, preparation of the tin reagents and removal of tin impurities would be troublesome. Copper-catalyzed reactions of \([\text{CpFe(CO)}_2X]\) (\(X = \text{Cl}\) or \(\text{Br}\)) with terminal acetylenes providing \([\text{CpFe(CO)}_2(C\equiv CR)]\) are most useful at present due to their reasonable scope and efficiency. However, the yields heavily depended on the alkynes used and \([\text{CpFe(CO)}_2\text{I}]\) would not react under the copper-catalyzed conditions. More efficient and versatile methods for the synthesis of \([\text{CpFe(CO)}_2(C\equiv CR)]\) are hence awaited.

Recently, we have developed easy and efficient methods for the synthesis of \([\text{CpFe(CO)}_2\text{Ar}]\), the palladium-catalyzed Kumada-Tamao-Corriu-, Negishi-, and Suzuki-Miyaura-type \(^9\) reactions of \([\text{CpFe(CO)}_2\text{I}]\) with arylmetal reagents. Here we report the synthesis of \([\text{CpFe(CO)}_2(C\equiv CR)]\) by palladium-catalyzed Sonogashira-type carbon–iron bond formation. \(10\)

Treatment of \([\text{CpFe(CO)}_2\text{I}]\) with phenylacetylene in the presence of catalytic amounts of \(\text{CuI}\) and \([\text{PdCl}(\text{PPh}_3)_2]\) in a triethylamine/THF mixed solvent afforded \([\text{CpFe(CO)}_2(C\equiv CP)\text{Ph}]\) \(11\) (1a) in 60% yield (Eq 1). The combination of \(\text{CuI}\) and the palladium catalyst is important. The reaction was sluggish when copper iodide (11% yield) or the palladium complex (18%) was omitted. After screening reaction conditions, we found that diisopropylamine is the most effective base (Eq 2). The reaction in a diisopropylamine/THF mixed solvent at 25 °C for 30 min afforded 1a in 81% yield, albeit with a smaller amount, 2.5 mol%, of the palladium catalyst. \(12\)

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The scope of alkynes is summarized in Table 1. A methyl or methoxy group at the 4 position of the arylacetylene had little influence on the reaction (entries 1 and 2). The steric effect of a 2-methyl group was also negligible (entry 3). On the other hand, electron-withdrawing groups retarded the reaction. The reaction with 4-fluorophenylacetylene required a higher temperature and a longer reaction time to attain a satisfactory result (entry 4). More disappointingly, very inefficient conversions were observed in the reactions of 4-trifluoromethyl- and 4-cyanophenylacetylene (entries 5 and 6).

We thus reexamined the conditions for the reactions with electron-deficient arylacetylenes. To our delight, ethylidisopropylamide proved to be effective. In addition, the amounts of [PdCl₂(PPh₃)₂] and CuI were changed from 2.5 mol% and 5 mol% to 5 mol% and 2.5 mol%, respectively. For instance, treatment of [CpFe(CO)₂] with 4-trifluoromethylphenylacetylene under the reoptimized conditions (Conditions B) furnished the corresponding alkynyliron 1f in 86% yield (entry 7). Cyano or halo-substituted arylacetylenes were also transformed efficiently (entries 8–11). Iron complex 1k bearing a carbonyl group was obtained in high yield (entry 12) although 1k was unstable under air and decomposed during chromatographic purification on silica gel.

Table 1. Scope of alkynes

<table>
<thead>
<tr>
<th>entry</th>
<th>R</th>
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<tr>
<td>1</td>
<td>4-MeC₆H₄</td>
<td>A</td>
<td>1b</td>
<td>85</td>
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<tr>
<td>2</td>
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<td>A</td>
<td>1c</td>
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<td>A</td>
<td>1d</td>
<td>88</td>
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<td>A</td>
<td>1e</td>
<td>77ᵇ</td>
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<tr>
<td>5</td>
<td>4-CF₂C₆H₄</td>
<td>A</td>
<td>1f</td>
<td>13</td>
</tr>
<tr>
<td>6</td>
<td>4-NCC₆H₄</td>
<td>A</td>
<td>1g</td>
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<tr>
<td>7</td>
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<td>B</td>
<td>1f</td>
<td>86</td>
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<tr>
<td>8</td>
<td>4-NCC₆H₄</td>
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</tr>
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<td>9</td>
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<td>1b</td>
<td>91</td>
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<td>4-ClC₆H₄</td>
<td>B</td>
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</tr>
<tr>
<td>11</td>
<td>4-BrC₆H₄</td>
<td>B</td>
<td>1j</td>
<td>74</td>
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<tr>
<td>12</td>
<td>4-MeOC(=O)C₆H₄</td>
<td>B</td>
<td>1k</td>
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<tr>
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<td>A</td>
<td>1l</td>
<td>34ᶜ</td>
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<td>14</td>
<td>t-C₆H₅</td>
<td>A</td>
<td>1m</td>
<td>66ᶜ</td>
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<tr>
<td>15</td>
<td>Me₂Si</td>
<td>A</td>
<td>1n</td>
<td>73ᶜ</td>
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</table>

ᵃConditions A: 2.5 mol% [PdCl₂(PPh₃)₂], 5 mol% CuI, Pr₂NH. Conditions B: 5 mol% [PdCl₂(PPh₃)₂], 2.5 mol% CuI, Pr₂EtN.ᵇ At 50 °C for 1 h.ᶜ Based on NMR analysis of a crude mixture.

Although the reaction of [CpFe(CO)₂] with aliphatic terminal acetylene or trimethylsilylacetylene proceeded under Conditions A (entries 13–15), products 1l–1n were not isolated efficiently in our hands due to the instability under air.¹³

The Sonogashira-type reaction is so chemoselective that 4-ethynylbenzyl alcohol underwent smooth carbon–iron bond formation without affecting the hydroxy group (Scheme 1). To verify that the hydroxy group remained intact, the hydroxy group of 1o was acetylated to yield 1p. The benzylic protons of the starting alcohol and 1o appeared around 4.6–4.7 ppm in ¹H NMR analysis, whereas those of 1p appeared at a clearly different chemical shift of 5.04 ppm. These NMR analyses strongly support the inertness of the hydroxy group under the palladium catalysis.

Scheme 1. Chemoselective reaction of 4-ethynylbenzyl alcohol

The reaction of [CpFe(CO)₂] with 1,4-diethynylbenzene afforded dinuclear iron complex 1q in high yield (Eq 3), highlighting the efficiency of the carbon–iron bond formation.

Not only iodoiron complexes but also similar molybdenum and tungsten complexes underwent alkynylation under Conditions A (Eq 4).

The Sonogashira-type reaction was applicable to the alkynylation of [Cp*Fe(CO)₂] (Eq 5). Due to the more bulky and electron-donating Cp* group, [Cp*Fe(CO)₂] was less reactive. The reaction required larger catalyst
loadings and a longer reaction time. Tetrabutylammonium fluoride (TBAF) served as a base more efficiently than ethyldisisopropylamine and disisopropylamine. It is worth noting that the precedent copper-catalyzed alknylation of [Cp*Fe(CO)Br] is low-yielding.

\[
\text{OC-Fe-C} \quad \text{OC-Fe-C} \quad \text{OC-Fe-I} \\
\text{OC-Fe-C} \quad \text{OC-Fe-C} \quad \text{OC-Fe-I}
\]

The TBAF-mediated alknylation conditions were also effective for the alknylation with diynylsilane 3, which represents a model synthesis of oligoynyliron as molecular electronic devices (Eq 6). Diynylsilane 3 reacted with [CpFe(CO)I] in the presence of TBAF and the [PdCl([PPh$_3$)$_2$])CuI catalyst to yield diynyliron complex 1r in 80% yield. It is worth noting that 3 is readily available and stable whereas phenylbutadiyne is difficult to synthesize and to handle.

\[
\text{OC-Fe-C} \quad \text{OC-Fe-C} \quad \text{OC-Fe-I} \\
\text{OC-Fe-C} \quad \text{OC-Fe-C} \quad \text{OC-Fe-I}
\]

In summary, we have applied an important carbon–carbon bond forming reaction, the Sonogashira reaction, to the construction of carbon–iron bonds. We have thus developed a method for the synthesis of 1-alkynyliron complexes [CpFe(CO)$_2$I(C≡CR)]. The iron complexes will find many applications in advanced material sciences as well as coordination chemistry and organic synthesis.

Acknowledgments

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References

10. The palladium-catalyzed Sonogashira carbon–carbon bond formation reactions of [CpFe(dppe)CCl] with aryl halides were reported. See references 3 and 8.
12. Experimental procedure: An iodoiron complex [CpFe(CO)$_2$I] (152 mg, 0.50 mmol), Cul (4.8 mg, 0.025 mmol), and [PdCl([PPh$_3$)$_2$]) (8.8 mg, 0.013 mmol) were placed in a 20-mL reaction flask under argon. THF (1.0 mL), phenylacetylene (82 µL, 0.75 mmol), and disopropylamine (0.50 mL) were sequentially added at 25 °C. The resulting mixture was stirred for 30 min at the same temperature. The mixture was then passed through a pad of silica gel by using ethyl acetate as an eluent. The filtrate was concentrated in vacuo. Chromatographic purification on silica gel (carbon disulfide/chloroform = 1:1) provided 1a (112 mg, 0.40 mmol) in 81% yield.
13. We believe that purification in a glovebox filled with inert gas would allow isolation of these unstable complexes.
14. The reactions of iodoiron complexes with polynyllithium were reported: Sakurai, A.; Akita, M.; Moro-oka, Y.


Supplementary Material

Characterization data of the products. Supplementary data associated with this article can be found in the online version.