



Palladium β -diketonate complex catalyzed synthesis of monosubstituted arylferrocenes

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ABSTRACT

Palladium β -diketonate complexes are reported as efficient catalysts for the selective synthesis of monosubstituted arylferrocenes by a cross-coupling reaction of bis(ferrocenyl)mercury with aryl halides. The present protocol was applicable to aryl halides providing good to excellent yields of the desired products.

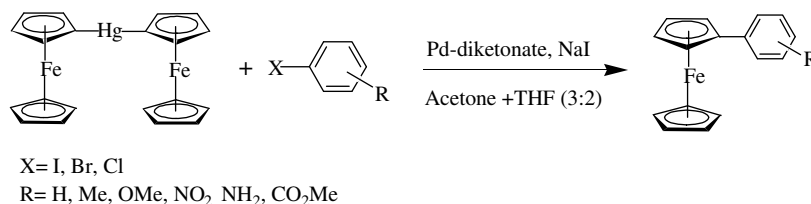
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Recently, there has been a resurgence of interest in the chemistry of ferrocene and its derivatives due to their increasing applications in many fields of chemistry¹ such as material science,² asymmetric catalysis³ and biologically active compounds.⁴ The synthesis of arylsubstituted ferrocenes has attracted considerable attention due to their use in the design of liquid crystal materials.⁵

Several methods have been reported in the literature for the synthesis of arylsubstituted ferrocenes.⁶ The typical method involves the reaction of ferrocene with aryl diazonium salts.⁷ However, in this case the yield of monoarylferrocene was in the range of 5–40%. Another method relies on a two-step procedure. The first step is the metalation of ferrocene, which involves the use of toxic and expensive *n*-BuLi. The second step involves the cross-coupling of the metal derivative of ferrocene with aryl halides.^{7,8} The major drawbacks of these methods are that they provide moderate yields of coupling products and require preliminary laborious preparation techniques.

Beletskaya and co-workers⁹ have reported the Pd(PPh₃)₄- and PdCl₂(PPh₃)₄-catalyzed cross-coupling of bis(ferrocenyl)mercury with aryl halides. The advantage of this method is that bis(ferrocenyl)mercury is air and moisture stable, and is easily obtained by direct mercuriation of ferrocene without the requirement of *n*-BuLi. However, despite their potential utility, the protocol requires the use of toxic and expensive phosphine-containing ligands and was applicable only to aryl iodides. Thus, there is a need to develop an efficient protocol, which could directly catalyze the arylation of bis(ferrocenyl)mercury with a wide range of aryl halides (preferably aryl chlorides since they are cheap and many are commercially available) employing a single-component Pd-complex as catalyst.

In continuation of our work on the synthesis of ferrocene derivatives and 2,2,6,6-tetramethyl-3,5-heptanedionate (TMHD)-catalyzed organic transformations,¹⁰ we herein report on the arylation of bis(ferrocenyl)mercury with aryl halides catalyzed by



Scheme 1. Synthesis of substituted monoarylferrocenes.

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Table 1Effect of the catalyst and solvent on the arylation of bis(ferrocenyl) mercury with *p*-iodonitrobenzene^a

Entry	Catalyst	Solvent	Yield (%)
1	Pd(TMHD) ₂	Acetone–THF ^b	98
2	Pd(acac) ₂	Acetone–THF ^b	90
3	Pd(OAc) ₂	Acetone–THF ^b	58
4	Cu(TMHD) ₂	Acetone–THF ^b	54
5	Ni(TMHD) ₂	Acetone–THF ^b	12
6	Pd(TMHD) ₂	Acetone	22
7	Pd(TMHD) ₂	THF	60
8	Pd(TMHD) ₂	DMF	52
9	Pd(TMHD) ₂	NMP	44
10	Pd(TMHD) ₂	Toluene	18
11	Pd(TMHD) ₂	Chloroform	10
12	Pd(TMHD) ₂	DMSO	8

^a Reaction conditions: bis(ferrocenyl)mercury (1 mmol), *p*-iodonitrobenzene (2 mmol), NaI (4 mmol), catalyst (2 mol %), solvent (10 ml), time 1.5 h at 80 °C.^b Acetone–THF 3:2.**Table 2**Synthesis of monoarylferrocenes using Pd(TMHD)₂ and Pd(acac)₂^a

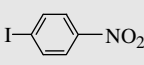
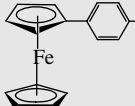

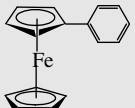

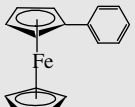

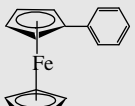
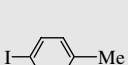
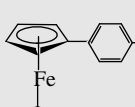
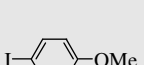
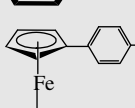

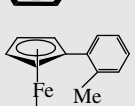
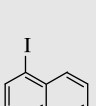
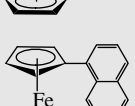

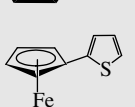
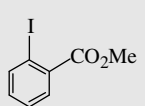
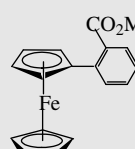
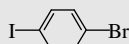
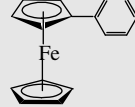
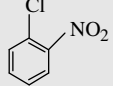
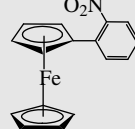
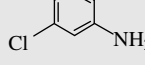
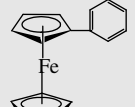
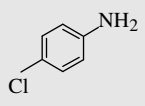
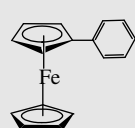
Entry ^{ref.}	Aryl Halide	Product	Yield ^{b,d} (%)	Yield ^{c,d} (%)
1 ^{6b}			98	90
2 ^{6a}			72	68
3 ^{6a}			82	75
4 ^{6a}			88	80
5 ^{6a}			83	71
6 ^{6a}			73	60
7 ^{6b}			78	67
8 ^{6a}			85	70
9 ^{6a}			90	82

Table 2 (continued)

Entry ^{ref.}	Aryl Halide	Product	Yield ^{b,d} (%)	Yield ^{c,d} (%)
10 ^{6b}			86	66
11 ^{6a}			84	75
12 ^{6b}			80	71
13 ^{6b}			65	43
14 ^{6b}			71	62

^a Reaction conditions: bis(ferrocenyl)mercury (1 mmol), aryl halide (2 mmol), NaI (4 mmol), catalyst (2 mol %), Ac–THF (10 ml), time 1.5 h at 80 °C.^b Pd(TMHD)₂ (2 mol %).^c Pd(acac)₂ (2 mol %).^d Isolated yield.

well-defined and stable O-containing palladium β-diketonate complexes, viz Pd bis(2,2,6,6-tetramethyl-3,5-heptanedionate) [Pd(TMHD)₂] and Pd bis(acetylacetonate) [Pd(acac)₂]. The ease of preparation of these complexes,¹¹ their high solubility in organic solvents, indefinite shelf life, stability towards air and compatibility with a wide variety of aryl halides make them ideal complexes for the synthesis of monosubstituted arylferrocenes (Scheme 1).

In order to evaluate the effect of catalysts and solvents, the coupling of *p*-iodonitrobenzene with bis(ferrocenyl) mercury was selected as a model reaction. Initially, the catalytic activity of various complexes such as Pd(TMHD)₂, Pd(acac)₂, Pd(OAc)₂, copper bis(2,2,6,6-tetramethyl-3,5-heptanedionate) [Cu(TMHD)₂] and nickel bis(2,2,6,6-tetramethyl-3,5-heptanedionate) [Ni(TMHD)₂] were investigated (Table 1). Of the various complexes screened Pd(TMHD)₂ and Pd(acac)₂ were found to be the best catalysts with the possible reason being that a better balance exists between the electronic and steric effects in these complexes. The effect of various solvents such as acetone, THF, DMF, NMP, toluene, chloroform and DMSO on the reaction system were investigated and the combination of acetone and THF at reflux was found to be the best solvent and was used for further studies.

Thus, using Pd(TMHD)₂ or Pd(acac)₂ as the catalyst and a mixture of acetone–THF(3:2) as solvent, a wide variety of aryl halides having different steric and electronic properties were coupled with bis(ferrocenyl)mercury in the presence of NaI (Table 2, entries 1–14).¹² It was found that coupling of *p*-iodonitrobenzene with bis(ferrocenyl) mercury provided an excellent yield of 98% with Pd(TMHD)₂ and a 90% yield with Pd(acac)₂ (entry 1). Less reactive bromo- and chlorobenzene also reacted under the present catalytic

system (entries 3 and 4). Also, electron-donating groups such as methyl, methoxy, bromo and amine, and electron-withdrawing groups such as methyl ester and nitro were viable partners under the present conditions (entries 5–7 and 10–14). Sterically hindered 1-iodonaphthalene also reacted smoothly under the present conditions providing an excellent yield of the desired product (entry 8). The heteroaryl halide 2-iodothiophene was also coupled efficiently under the present conditions (entry 9). No electronic and steric effects were observed for *ortho*, *meta* and *para* substituents.

In summary, the synthesis of monoarylferrocenes in good to excellent yields using cheap and air stable Pd(TMHD)₂ and Pd(acac)₂ complexes has been developed. This system works equally well for a wide variety of aryl halides and tolerates a variety of functional groups.

References and notes

1. Togni, A.; Hayashi, T. In *Ferrocenes*; VCH: New York, 1995.
2. (a) Long, N. J. *Metalloenes*; Blackwell: London, 1995; (b) Hale, P. D.; Inagaki, T.; Karan, H. I.; Okamoto, Y.; Skotheim, T. A. *J. Am. Chem. Soc.* **1989**, *111*, 3482–3484.
3. (a) Jary, W. G.; Baumgartner, J. *Tetrahedron: Asymmetry* **1998**, *9*, 2081–2085; (b) Richards, C. J.; Locke, A. J. *Tetrahedron: Asymmetry* **1998**, *9*, 2377–2407; (c) Togni, A. *Angew. Chem., Int. Ed.* **1996**, *35*, 1475–1477; (d) Togni, A.; Dorta, R.; Koelner, C.; Poida, G. *Pure Appl. Chem.* **1998**, *70*, 1477–1485.
4. Balvioine, G. G. A.; Delaire, J. C.; Maltery-Fanton, I.; Nakatani, K.; Bella, S. D. *Organometallics* **1999**, *18*, 21–29.
5. (a) Imrie, C.; Loubser, C. *Chem. Commun.* **1994**, 2159–2160; (b) Imrie, C.; Loubser, C. *J. Chem. Soc., Perkin Trans. 2* **1997**, 399–410; (c) Galyametdinov, Yu. G.; Kadkin, O. N.; Prosvirin, A. V. *Izv. Acad. Nauk SSSR, Ser. Khim.* **1994**, 941; (d) Galyametdinov, Yu. G.; Kadkin, O. N.; Ovchinnikov, I. V. *Izv. Acad. Nauk SSSR, Ser. Khim.* **1990**, 2462.
6. (a) Imrie, C.; Loubser, C.; Engelbrecht, P.; McClelland, C. W. *J. Chem. Soc., Perkin Trans. 1* **1999**, 2513–2523; (b) Little, W. F.; Reilley, C. N.; Johnson, J. D.; Lynn, K. N.; Sanders, A. P. *J. Am. Chem. Soc.* **1964**, *86*, 1376–1381.
7. (a) Nesmeyanov, A. N.; Perevalova, E. G.; Golovnya, R. V.; Nesmeyanov, O. A. *Dokl. Akad. Nauk SSSR* **1954**, *97*, 459; (b) Nesmeyanov, A. N.; Perevalova, E. G.; Golovnya, R. V. *Dokl. Akad. Nauk SSSR* **1954**, *99*, 539; (c) Weinmayr, V. *J. Am. Chem. Soc.* **1954**, *77*, 3012–3014; (d) Broadhead, G. D.; Pauson, P. L. *J. Chem. Soc.* **1955**, 367–370; (e) Little, W. F.; Clark, A. K. *J. Org. Chem.* **1960**, *25*, 1979–1982; (f) Rosenblum, M.; Howells, W. G.; Banerjee, A. K.; Bennett, C. *J. Am. Chem. Soc.* **1962**, *84*, 2726–2732; (g) Little, W. F.; Nielsen, B.; Williams, R. *Chem. Ind.* **1964**, 195–197; (h) Beckwith, A. L. J.; Jackson, R. A.; Longmore, R. W. *Aust. J. Chem.* **1992**, *45*, 857.
8. (a) Knapp, R.; Rehahn, M. *J. Organomet. Chem.* **1993**, *452*, 235; (b) Guillaeneux, D.; Kagan, H. B. *J. Org. Chem.* **1995**, *60*, 2502–2505; (c) Iyoda, M.; Okabe, T.; Katada, M.; Kuwatani, Y. *J. Organomet. Chem.* **1996**, *569*, 225; (d) Foxman, B. M.; Rosenblum, M. *Organometallics* **1993**, *12*, 4805.
9. (a) Tsvetov, A. V.; Latyshev, G. V.; Lukashev, N. V.; Beletskaya, I. P. *Tetrahedron Lett.* **2000**, *41*, 3987–3990; (b) Tsvetov, A. V.; Latyshev, G. V.; Lukashev, N. V.; Beletskaya, I. P. *J. Organomet. Chem.* **2001**, *637–639*, 653–663.
10. (a) Purecha, V. H.; Nandurkar, N. S.; Bhanage, B. M.; Nagarkar, J. M. *J. Chem. Res.* **2007**, *7*, 426–428; (b) Purecha, V. H.; Nandurkar, N. S.; Bhanage, B. M.; Nagarkar, J. M. *Tetrahedron Lett.* **2008**, *49*, 1384–1387; (c) Nandurkar, N. S.; Bhanage, B. M. *Tetrahedron* **2008**, *64*, 3655; (d) Nandurkar, N. S.; Bhanushali, M. J.; Bhor, M. D.; Bhanage, B. M. *Tetrahedron Lett.* **2008**, *49*, 1045; (e) Nandurkar, N. S.; Bhanushali, M. J.; Bhor, M. D.; Bhanage, B. M. *Tetrahedron Lett.* **2007**, *48*, 6573–6576.
11. Typical procedure for the preparation of Pd(TMHD)₂: Palladium chloride (1.8 g, 10 mmol) and sodium chloride (0.59 g, 10 mmol) were dissolved in methanol (50 mL) and stirred at room temperature overnight. The solution was filtered into a 100 mL volumetric flask and diluted with methanol to give a 0.1 M palladium(II) concentration. A mixture of this solution (100 mL), 2,2,6,6-tetramethyl-3,5-heptanedione (4.6 g, 25 mmol) and sodium carbonate (1.06 g, 10 mmol) was stirred overnight. The resulting yellow precipitate (4.03 g, 85% yield) was filtered and dried. Mp 238–240 °C.
12. General procedure: Under a nitrogen atmosphere, a mixture of bis(ferrocenyl)mercury (1 mmol), aryl halide (2 mmol), Pd(TMHD)₂ (2 mol %) and NaI (4 mmol) in Ac-THF (3:2, 10 ml) was stirred at room temperature for 5 min. The reaction mixture was then heated in an oil bath at 80 °C for 1.5 h. The reaction mixture was cooled to room temperature and the solvent was removed under reduced pressure. The residue was purified by column chromatography (Silica Gel 60–120 mesh) using petroleum ether (60/80)/ethyl acetate as eluent to afford the pure product. All the products are known compounds and were characterized by GCMS and ¹H NMR.