Tetrahedron Letters 53 (2012) 6269–6272

Contents lists available at SciVerse ScienceDirect

Tetrahedron Letters

journal homepage: www.elsevier.com/locate/tetlet

Ferrous salt-promoted homocoupling of arenediazonium tetrafluoroborates under mild conditions

Yiyuan Ding[a], Kai Cheng[b], Chenze Qi[b,*], Qingbao Song[a,*]

[a] College of Chemical & Materials Science, Zhejiang University of Technology, Hangzhou 310014, People's Republic of China
[b] Institute of Applied Chemistry and Department of Chemistry, University of Shaoxing, Shaoxing, Zhejiang Province 312000, People's Republic of China

ARTICLE INFO

Article history:
Received 13 April 2012
Revised 10 July 2012
Accepted 7 September 2012
Available online 15 September 2012

Keywords:
Homocoupling
Ferrous salt-promoted
Arenediazonium tetrafluoroborates
Electron transfer reaction

ABSTRACT

A simple and efficient protocol has been developed for the synthesis of various symmetrical biaryls in good to excellent yields from the homocoupling reactions of arenediazonium salts with ferrous salt in carbon tetrachloride solution under mild reaction conditions. Moreover, the novel homocoupling has been demonstrated to proceed via an electron transfer reaction mechanism.

Introduction

Biaryls are not only the key chemical intermediates for a wide range of organic processes, but are also very important structural motif for many natural and synthetic organic compounds.[1] Thus, it is interesting to develop new straightforward and environmentally friendly reactions for the biaryl synthesis. Symmetrical biaryls are traditionally prepared from the reductive homocoupling of aryl halides and the Ullmann reaction is the first practical and efficient process for the synthesis of symmetrical biaryls.[2] However, the Ullmann reaction generally requires a stoichiometric amount of copper and occurs only at a relatively high temperature (~200 °C). The harsh reaction conditions limit its applications for the synthesis of any delicate compounds, which also spawn the development of much milder reactions such as catalyzed by the palladium,[3] rhodium,[4] and gold[5] catalysts for the biaryl synthesis from aryl halides or aryl sulfonates. More recently, much attention has been paid to the developments using catalysts based on relative cheaper transition metals such as nickel,[6] copper,[7] and iron[8] for the carbon–carbon bond formation coupling reactions.

Arenediazonium salts are attractive alternative to the common electrophiles, aryl halides, or triflates,[9] for the carbon–carbon bond formation coupling reactions because of their ready availability from anilines, superior reactivity, and environmental friendliness.[10] Their insensitivity to the substituent electronic and steric effects allows the introduction of various substituents into the biaryl moieties. Also, no additional base is required for these reactions. Thus, it is not surprising that arenediazonium salts have been used as electrophilic partners for the palladium-catalyzed cross-coupling reactions including the Mizoroki–Heck,[11] Suzuki–Miyaura,[12] and Stille reactions.[13]

However, much less attention has been paid to the synthetic utility of the homocoupling of arenediazonium salts for the symmetrical biaryls. Hanna co-workers[14] reported palladium-catalyzed homocoupling of arenediazonium salts for the synthesis of symmetrical biaryls in methanol, but the anisole and benzene by-products were formed in a significant amount. Anisole was believed to be derived from the reaction of arenediazonium salts with methanol. The copper (I)-mediated reductive homocoupling of aryldiazonium salts was first discovered as the side reaction for the Gattermann synthesis of aryl halides from arenediazonium salts. Cepanec et al.[15] reported that copper (I) triflate acts as an efficient stoichiometric reagent for the homocoupling of arenediazonium salt to yield symmetrical biaryl. However, the copper (I) salts are instable, and it require to be in situ prepared for the homocoupling reaction. In the present Letter, we would like to present our results using the much cheaper and environmentally benign ferrous salts to mediate the reductive homocoupling of arenediazonium salts for the synthesis of various symmetrical biaryls under mild reaction conditions.

Results and discussion

No homocoupling biphenyl products were observed for the reaction of benzenediazonium salt with ferrous chloride ($FeCl_2$)

---

* Corresponding authors. Tel./fax: +86 575 88345682.
E-mail addresses: qichenze@usx.edu.cn (C. Qi), qbsong@zjut.edu.cn (Q. Song).

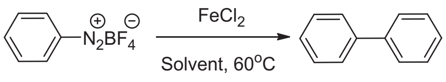
0040-4039/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.tetlet.2012.09.028

in CH_2Cl_2, $CHCl_3$, and acetone (Table 1, entries 3–5). A mixture of anisole (25%) and biphenyl (44%) was obtained when carried out in methanol (Table 1, entry 1). Essentially identical biphenyl yields (54.5 ± 1.5%) were obtained when carried out in THF, 1,4-dioxane, and MTBE (methyl *tert*-butyl ether) (Table 1, entries 6–8). Carbon tetrachloride proved to be the most suitable medium for the homocoupling, leading to a yield of 85% for benzenediazonium salt (Table 1, entry 2). On the other hand, the aromatic solvents such as toluene and xylene seem to be not suitable for the homocoupling of arenediazonium salts (Table 1, entries 9 and 10). Other iron (II) salts such as $Fe(NO_3)_2$, $FeBr_2$, and $Fe(acac)_2$ can afford biphenyl with the yield of 77%, 76%, and 81% in CCl_4, respectively.

The scope of the homocoupling reaction of arenediazonium salts has been examined with respect to the substituents on the aromatic ring (Table 2). The biaryl yields were found to be essentially identical (80 ± 5%) for the seven *p*-substituted (R = H, F, Cl, Br, I, CF_3, and NO_2) arenediazonium salts (Table 2, entries 1–7), suggesting that the polarity of the *p*-substituents has negligible effects on the homocoupling reaction. Most interestingly, the steric effects of the *ortho*- and *meta*-substituents of the arenediazonium salts seem to be also negligible for the homocoupling reaction (Table 2, entries 8–10). It is interesting to note that the homocoupling of 4-bromo and 4-iodobenzenediazonium tetrafluoroborate leads to the exclusive formation 4,4′-dibromo and 4,4′-diiodobiphenyl in 76% and 77%, respectively, (Table 2, entries 4 and 5), indicating the excellent chemoselectivity in contrast to the traditional Ullmann homocoupling of aryl bromides and aryl iodides. Our investigation revealed that depressions of yields were obtained in 52–71% for the alkyl or alkoxy substituent. Some by-product mixtures via radical mechanism have been detected by GC–MS which is in accord with the reaction applied in toluene and xylene. The result maybe gave an explanation for the reductive cross-coupling yields (Table 2, entries 11–15). Notably, the aryl rings structure such as thiophene and benzofuran had also been tested and the desired homocoupling biaryls were synthesized in moderate yield (Table 2, entries 16 and 17).

The ferrous salt-promoted homocoupling of arenediazonium salts could be terminated by the addition of radical scavengers such as hydroquinone or 2,6-di-*tert*-butylphenol, suggesting that the homocoupling reactions proceed via a radical mechanism as shown in Scheme 1. Quantitative analysis by formation of blue potassium ferricyanide $[K_3Fe(CN)_6]$ solution indicates that over 95% Fe^{2+} has been oxidized into Fe^{3+}, indicating that the reductive homocoupling of arenediazonium salt with the oxidation of ferrous ion is stoichiometrically coupled. Reduction of arenediazonium cation by ferrous ion results in the cleavage of the carbon–nitrogen bond, accompanied with the release of nitrogen gas and aryl radical formation. Recombination of the resultant aryl radicals leads to the formation of the desired homocoupling biaryl product (Scheme 1).

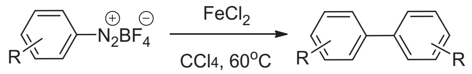
Table 1
Solvent effect on the homocoupling reaction in the presence of iron (II) chloride[a]

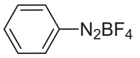
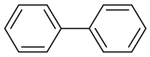
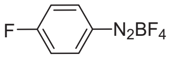
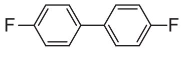
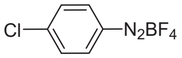
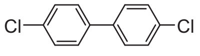
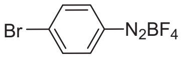
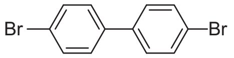
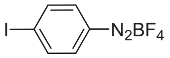
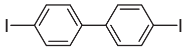
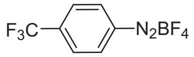
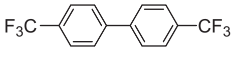
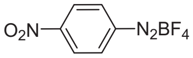
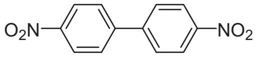
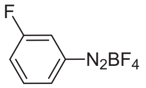
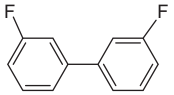
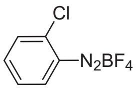
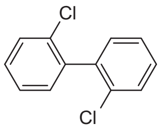
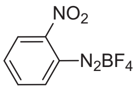
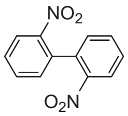
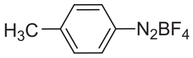
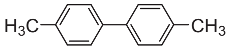
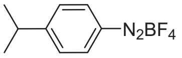
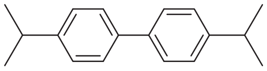
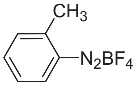
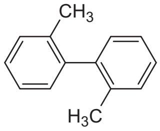
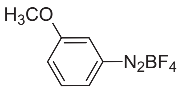
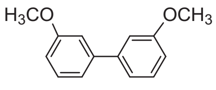
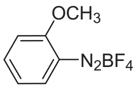
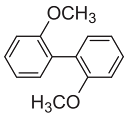
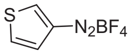
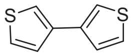
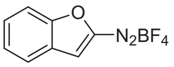
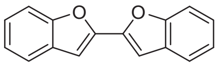


Entry	Solvent	Yield[b] (%)	Entry	Solvent	Yield[b] (%)
1	Methanol	44 (25[c])	6	THF	56
2	CCl_4	85	7	1,4-Dioxane	53
3	CH_2Cl_2	—	8	MTBE	55
4	$CHCl_3$	—	9	Toluene	Complex
5	Acetone	—	10	Xylene	Complex

[a] Reaction conditions: benzenediazonium tetrafluoroborate salt (1 mmol), $FeCl_2$ (1 mmol), solvent (2 mL), 60 °C, 3 h.
[b] Isolated yields.
[c] Yield of anisole is shown in brackets.

Table 2
The screening of various arenediazonium salts[a]



Entry	Arenediazonium salts	Products	Yield[b] (%)
1			85
2			77
3			80
4			76
5			77
6			80
7			82
8			79
9			82
10			86
11			71
12			64
13			70
14			69
15			52
16			56
17			59

[a] Reaction conditions: arenediazonium tetrafluoroborate salt (1 mmol), $FeCl_2$ (1 mmol), CCl_4 (2 mL), 60 °C, 3 h.
[b] Isolated yields.

Obviously, CCl_4 plays an important role in the reaction since it, acting as a good solvent for free radicals reaction, stabilizes the