DOI: 10.1002/ejoc.200500915

Rapid Microwave-Promoted Catalyst- and Base-Free Suzuki-Type Coupling Reaction in Water

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Keywords: Suzuki-type reaction / Sodium tetraphenylborate / Iodonium salt / Iodane / Microwave irradiation

Catalyst- and base-free Suzuki coupling of sodium tetraphenylborate with hypervalent iodonium salts and iodanes was achieved with the aid of microwave irradiation in water, providing a convenient method for the formation of carbon–carbon bonds in good yields in short times.

Introduction

The Suzuki reaction is one of the most versatile and widely utilized reactions for the selective construction of carbon–carbon bonds, in particular for the formation of biaryls.[1] In the development of improved conditions for the Suzuki reaction, a wide range of metal complexes have been used as catalysts in these coupling reactions, with attention having been particularly focused on palladium. Leadbeater and Marco recently reported the first catalyst-free Suzuki coupling reaction,[2] investigating the coupling of aryl halides with arylboronic acids, which afforded biaryls in good yields under microwave irradiation conditions in water at 150 °C for 5 min (Figure 1). They also found that sodium tetraphenylborate could be used in place of phenylboronic acid as a phenylating agent in the coupling reaction, though the yields were somewhat low. Because of the generation of pressure in this method and the need for specialized sealed vessels, development of mild and efficient catalyst-free reaction conditions is required in order to extend the scope of catalyst-free Suzuki reaction.

We focused our attention on hypervalent iodonium compounds since these – iodonium salts in particular – have found synthetic application due to their high reactivity toward various nucleophiles.[3] They have been widely used in Suzuki reactions, replacing aryl halides or triflates and affording products in excellent yields under mild reaction conditions.[4] As part of a program to investigate the catalyst-free Suzuki reaction, we first used hypervalent iodanes in place of aryl halides to couple with sodium tetraphenylborate in water at room temperature, and found an efficient catalyst- and base-free Suzuki-type coupling reaction, giving good yields (Figure 2).[5] However, iodonium salts did not couple with phenylboronic acid or sodium tetraphenylborate in water at room temperature or higher temperatures. We then explored the catalyst-free coupling of sodium tetraphenylborate with hypervalent iodine compounds in water under microwave irradiation conditions, due to the fast reaction rates of microwave-assisted organic syntheses in water.[6] Here we would like to report a rapid and efficient catalyst- and base-free microwave-assisted Suzuki-type coupling reaction.

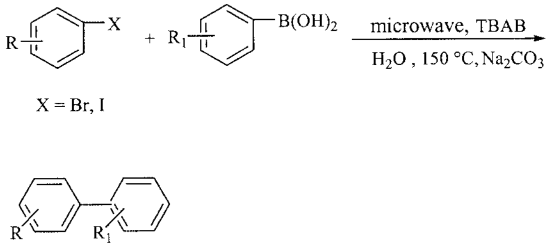

Figure 1. Catalyst-free Suzuki coupling reaction of aryl halides with arylboronic acids.

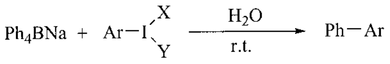

Figure 2. Catalyst-free Suzuki coupling reaction of sodium tetraphenylborate with iodanes.

Results and Discussion

Initially we used diphenyliodonium chloride to investigate the coupling reaction with phenylboronic acid in water under microwave irradiation conditions, but found that the coupling was difficult to effect. Fortunately, though, when

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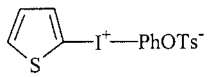
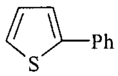
sodium tetraphenylborate was used in place of phenylboronic acid, the biphenyl coupling product was obtained on microwave irradiation for several minutes. Prompted by this result, a series of experiments were performed on the coupling of sodium tetraphenylborate with diphenyliodonium chloride in order to determine suitable reaction conditions. It was found that when the molar ratio of sodium tetraphenylborate to diphenyliodonium chloride reached 2:1, the best result (90% of the biphenyl) was afforded on microwave irradiation for 4 min at 100 °C. This procedure prompted us to investigate further the reactions between sodium tetraphenylborate (**1**) and a series of iodonium salts (**2**): both symmetrical and unsymmetrical biaryls (**3**) were found to be readily available in short times under the optimized conditions (Scheme 1), and the results are summarized in Table 1.

$$\underset{\mathbf{1}}{Ph_4BNa} + \underset{\mathbf{2}}{RI^+R_1X^-} \xrightarrow[H_2O\text{ , }100\text{ °C}]{\text{microwave}} \underset{\mathbf{3}}{Ph\text{-}R}$$

Scheme 1.

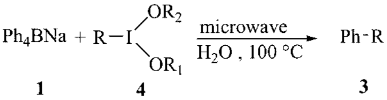
Table 1. The results of the coupling reaction of sodium tetraphenylborate with iodonium salts.

Entry	Iodonium salt	Product	Time (min)	Yield (%)[a]
1	$Ph_2I^+Cl^-$ **2a**	Ph-Ph **3a**	4	90
2	(p-Me-$C_6H_4)_2I^+Br^-$ **2b**	p-Me-C_6H_4-Ph **3b**	3	93
3	(p-Br-$C_6H_4)_2I^+Br^-$ **2c**	p-Br-C_6H_4-Ph **3c**	3	91
4	p-Me-C_6H_4-I^+-$PhBr^-$ **2d**	**3b**	2	74
5	p-MeO-C_6H_4-I^+-$PhBr^-$ **2e**	p-MeO-C_6H_4-Ph **3d**	4	77
6	 **2f**	 **3e**	3	80
7	(m-O_2N-$C_6H_4)_2I^+Br^-$ **2g**	m-O_2N-C_6H_4-Ph **3f**	5	37
8	(p-Me-$C_6H_4)_2I^+BF_4^-$ **2h**	**3b**	15	41

[a] Isolated yield.

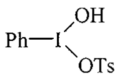
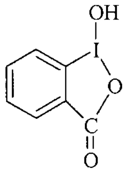
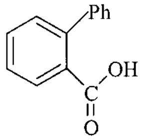
It can be seen in Table 1 that most reactions could be completed in 4 min, affording products in good to excellent yields (Entries 1–6). Iodonium salt **2g**, with the electron-withdrawing substituent on the phenyl group, provided product **3f** in only 37% yield after 5 min (Entry 7). This was quite different from the results reported by Leadbeater and Marco, who found that use of aryl bromides with electron-withdrawing substituents usually gave higher yields. We also found that the anions of the iodonium salts affected the yields strongly: with **2b** the reaction was complete after only 3 min and afforded **3b** in 93% yield (Entry 2), whilst when **2h** was used in place of **2b** under the same reaction conditions, **3b** was obtained in a poor 41% yield even after a prolonged reaction time of 15 min (Entry 8).

Taking advantage of above results, we further investigated coupling between sodium tetraphenylborate and iodanes, which have rarely been used as electrophilic reagents in coupling reactions.[7] Under the optimized reaction conditions, we found that iodanes **4** readily coupled with sodium tetraphenylborate (**1**) in only 2 min, affording products **3** in good yields (Scheme 2, Table 2).



Scheme 2.

Table 2. Results of the coupling reactions between sodium tetraphenylborate and iodanes.

Entry	Iodane	Product	Time (min)	Yield (%)[a]
1	 **4a**	Ph-Ph **3a**	2	83
2	$PhI(OAc)_2$ **4b**	**3a**	2	87
3	$PhI(OCOCF_3)_2$ **4c**	**3a**	1	82
4	Ph-I^+-O-I^+-Ph $2BF_4^-$ **4d**	**3a**	1	80
5	p-$ClC_6H_4I(OAc)_2$ **4f**	p-Cl-C_6H_4-Ph **3g**	2	73
6	 **4g**	 **3h**	1	67

[a] Isolated yield.

In summary, microwave-promoted catalyst- and base-free Suzuki-type coupling reactions between sodium tetraphenylborate and hypervalent iodonium compounds are reported. The mechanism is thought to involve an initial exchange of anion of the iodonium salt or acid radical of iodane with Ph_4B^-, and an intramolecular coupling reaction then follows to furnish the product. This coupling reaction provides a fast and efficient method for preparation of biaryls, and has some advantages such as mild reaction conditions, simple procedure, and good yields. The scope of the catalyst-free Suzuki coupling reactions could also be extended.

Experimental Section

Melting points were determined on a digital melting point apparatus and were not corrected. IR spectra were recorded on a FT-170 SX instrument, ^{1}H NMR spectra were measured on a Bruker AM-400 FT-NMR spectrometer, and mass spectra were determined on an HP5989A mass spectrometer. Microwave reactions were carried out with a single-mode cavity Sanle WHL70S-01 Microwave Synthesizer (Nanjing Sanle Microwave Equipment Corporation). Iodonium salts were prepared by the literature procedures,[8–10] as were iodanes.[11–16] Sodium tetraphenylborate is commercially available.

General Procedure for Reactions between Sodium Tetraphenylborate and Iodonium Salts or Iodanes: Sodium tetraphenylborate (**1**, 513 mg, 1.5 mmol), iodonium salt **2** or iodane **4** (0.75 mmol), and water (5 mL) were placed in a 50 mL flask fitted with a condenser. The vessel was placed in the center of the microwave synthesizer and was then exposed to microwave irradiation (250 W) to heat it at reflux for 1–5 min at 100 °C. After irradiation, the reaction mixture was allowed to cool to room temperature and extracted with diethyl ether (3 × 20 mL). The organic layer was dried with anhydrous $MgSO_4$ and the solvents were removed in vacuo. The crude product was separated on a silica gel plate with hexane as eluent and the pure product **3** was afforded in good yields.

Acknowledgments

Financial support from the Natural Science Foundation of China, Zhejiang Province (Project Y404016) and the Education Foundation of China, Zhejiang Province (Project 20040569) is greatly appreciated.

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Received: November 23, 2005