Solid-state Suzuki reaction catalyzed by ferrocene palladacycles without solvent

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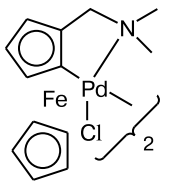
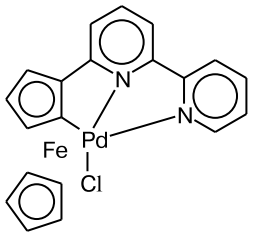
The possibility to carry out the Suzuki reaction without solvent using two ferrocene palladacycles with bi- and tridentate (C,N) and (C,N,N) ligands was studied.

Key words: Suzuki reaction, ferrocene palladacycles, catalysts, solid-state reaction.

When studying catalytic possibilities of ferrocene palladacycles **1** and **2**, we found that the Suzuki reaction occurred successfully in the presence of these complexes.[1] Heating is needed for catalysis by palladacycle **2**, whereas compound **1** acts as a catalysts at ~20 °C as well and even, as shown by our colleagues,[2] on cooling.



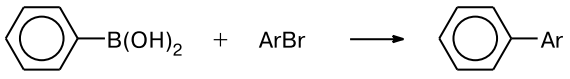
1



2

Earlier we carried out the reaction of aryl bromides with phenylboric acid (**3**) in aqueous methanol in the presence of K_2CO_3 and the catalyst. In this work, we performed a series of experiments to reveal the possibility of interaction of acid **3** with aryl halides without any solvent in the presence of palladium complex **1** and K_2CO_3 (Scheme 1, Table 1). This approach is a methodological continuation of our studies of solid-state organic synthesis.[3—8]

Scheme 1



3 **4, 6—9** **5, 10—13**

Ar = 4-$MeCOC_6H_4$ (**4**, **5**), 4-$MeOC_6H_4$ (**6**, **10**), 4-MeC_6H_4 (**7**, **11**), Ph (**8**, **12**), 1-naphthyl (**9**, **13**)

Reagents and conditions: **1** or **2**, K_2CO_3, 20 or 50 (100) °C.

In the first experiment, the same ratios of components were used as in the reaction in solution: 1 equiv. of 4-bromoacetophenone (**4**) was mixed with 1.5 equiv. of

Table 1. Reactions of phenylboric acid (**3**) with aryl bromides **4** and **6—9** in the presence of catalyst **1** or **2** without solvent*

Entry	ArBr	Catalyst	τ/h**	*T*/°C	Product	Yield (%)
1	4-$MeCOC_6H_4Br$ (**4**)	**1**	5	50	**5**	82
2	**4**	**1**	72	20	**5**	90
3	4-$MeOC_6H_4Br$ (**6**)	**1**	72	20	**10**	59
4	4-MeC_6H_4Br (**7**)	**1**	72	20	**11**	90
5	PhBr (**8**)	**1**	72	20	**12**	74
6	1-Bromonaphthalene (**9**)	**1**	72	20	**13**	61***
7	**4**	**2**	14	100	**5**	40

* Conditions: 3 mmoles of $PhB(OH)_2$, 2 mmoles of ArBr, 20 mmoles of K_2CO_3, and 0.5 mol.% catalyst **1** or **2**.
** Duration of the reaction.
*** The starting 1-bromonaphthalene remained.

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acid **3** and 2 equiv. of K_2CO_3, catalyst **1** (0.5 mol.%) was added, and the mixture was stirred and placed in an oily bath heated to 50 °C. On mixing the components, the reaction mixture transformed into a sticky oily state; however, after heating for 1 h, it turned out to be a solid sintered mass, which was difficult to stir. According to the TLC data, the reaction mixture contained a minor amount of the desired product. Similar behavior of the solid-state reaction mixture was observed in our previous studies[7,8] and, therefore, we decided to change the reaction conditions by increasing the fraction of K_2CO_3.

In the next experiment, the amount of K_2CO_3 was increased by 5 times and the rest ratio of the reactants was remained unchanged. The reaction mixture remained solid upon stirring and heating at 50 °C for 1 h. The TLC study of the sample taken at this moment showed that the reaction completed to a considerable extent, but the starting 4-bromoacetophenone remained unreacted. The reaction mixture was heated for 4 h more with periodical stirring until the starting aryl halide disappeared. After the reaction mixture was treated and chromatographed, the yield of the product was rather high (see Table 1, entry *1*).

However, the interaction with phenylboric acid with 4-bromoacetophenone without solvent on heating cannot be called the truly solid-state reaction, because the temperature of the reaction mixture coincides with the melting point of aryl halide. In addition, aryl halides, which were planned to use in further experiments, are rather volatile compounds and, hence, are inappropriate for heating under the experimental conditions indicated. Therefore, we studied the possibility to carry out the Suzuki reaction without both solvent and heating. In the next experiment, we used the same amounts and ratios of components as in the previous experiment, but the reaction mixture was stored at ~20 °C in the closed flask with periodical stirring. A noticeable amount of the product was observed in 1 day, and the reaction was completed for 3 days (see Table 1, entry *2*).

Then we carried out the reaction of acid **3** with other aryl halides in the presence of catalyst **1** and excess K_2CO_3 without solvent. The reaction mixtures were stored at ~20 °C in closed flasks with periodical stirring. According to the TLC data, under these conditions. the reactions of 4-bromoanisole (**6**), 4-bromotoluene (**7**), and bromobenzene (**8**) with acid **3** were almost completed for 1 day, while the reaction of 1-bromonaphthalene (**9**) was not completed even for 3 days. All reaction mixtures were treated 3 days after, and the yields of the obtained biaryls are listed in Table 1.

Thus, it is shown that dimeric palladacycle **1** of the (C,N) type successfully catalyzes the Suzuki reaction not only in a solvent under very mild conditions but also without solvent.

Since in the previous work another ferrocene palladacycle with the tridentate ligand of the (C,N,N) type **2** was used as a catalyst of this reaction, we checked the catalytic properties of this compound in the reaction without solvent of acid **3** with 4-bromoacetophenone in the presence of excess K_2CO_3, using the ratio of components usual for our experiments. The well stirred reaction mixture was stored for 12 h at ~20 °C and then heated for 6 h at 50 °C in an open flask. However, no product formed at either ~20 °C or 50 °C. Biaryl was obtained only when the reaction temperature was increased to 100 °C, but after heating for 14 h at this temperature the yield of compound **5** was low (see Table 1, entry *7*) probably due to the sublimation of aryl bromide under the experimental conditions. Nevertheless, this experiment showed that palladacycle **2** can also catalyze the Suzuki reaction without solvent but under more drastic conditions than those for compound **1**, which agrees with our previous experiments in solution.[1]

Experimental

^{1}H NMR spectra were recorded on a Bruker instrument (300 MHz). Catalysts **1** (see Ref. 9) and **2** (Ref. 10) and phenylboric acid (**3**)[11] were synthesized according to the procedures described earlier. To carry out experiments without solvent, K_2CO_3 was milled for 15 min in an ML-1 laboratory ball mill.

Reaction of aryl bromides 4 and 6—9 with phenylboric acid 3 (general procedure). Dichloromethane (5 mL) was added to a mixture of milled K_2CO_3 (20 mmol) and 0.5 mol.% catalyst **1** or **2**, the mixture was stirred, the solvent was distilled off *in vacuo*, and acid **3** was added. The mixture was stirred, aryl halide **4** or **6—9** (2 mmol) was added, and the reaction mixture was stirred with a glass stick until a homogeneous mixture was formed. The mixture was stored for 3 days in a closed flask with periodical stirring or heated in an open flask. Then CH_2Cl_2 was added to the mixture and filtered through zeolite, CH_2Cl_2 was washed off, the solvent was evaporated, and the mixture was chromatographed on SiO_2 (hexane—$CHCl_3$). The yields of obtained biaryls **5** and **10—13** are given in Table 1. All compounds synthesized were described earlier and characterized by the comparison of the ^{1}H NMR spectra with the spectra presented in literature.

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