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Cross-coupling of polychlorobenzenes with phenylboronic acid in the presence of [Pd]—imidazolium salts as catalytic systems

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The reactions of di-, tetra-, and hexachlorobenzenes with phenylboronic acid in the presence of [Pd]—imidazolium salt—base as catalytic systems afford cross-coupling products in moderate yields. The highest conversions are attained when imidazolium salts bearing bulky aromatic substituents are used and the reaction is carried out in the presence of alkali alkoxides containing H_{α} atoms. Cross-coupling is accompanied by hydrodechlorination of aromatic C—Cl bonds.

Key words: cross-coupling, Suzuki reaction, polychloroarenes, biaryls, imidazolium salts.

In our previous studies, we demonstrated that polychloroarenes can be involved into C—C cross-coupling with organozinc compounds[1] and arylboronic acids.[1,2] These transformations open up a one-step route to functionally substituted arenes and polyarylbenzenes from readily available and inexpensive polychloroaromatic

Table 1. Cross-coupling of PCA with $PhB(OH)_2$ (1.5 mol mol^{-1}) involving imidazolium salts (85—90 °C, 7—8 h)

Entry	PCA	Catalytic system[b]	Solvent	Base	PCA conversion (%)	Yields of cross-coupling products (mol. %)[a]			
						I	II	III	IV
1	**1**	**I**—Pd(OAc)$_2$	Dioxane	K_3PO_4	79	75	4	—	—
2	**2**	**I**—Pd(OAc)$_2$	Dioxane	K_3PO_4	~100	~100	—	—	—
3	**2**	**I**—Pd(OAc)$_2$	Dioxane	Cs_2CO_3	31	31	—	—	—
4	**2**	**II**—Pd(OAc)$_2$	Dioxane	K_3PO_4	38	38	—	—	—
5	**3**	**I**—Pd(OAc)$_2$	Dioxane	K_3PO_4	0	—	—	—	—
6	**3**	**I**—Pd(OAc)$_2$	Dioxane	KOH	18	4	4	—	10
7	**3**	**I**—Pd(dba)$_2$	Dioxane	Bu^{t}ONa	81	$\Sigma18^{c}$	35+6	22	—
8	**3**	**II**—Pd(dba)$_2$ [d]	Toluene + MeOH	MeOK	94	$\Sigma39^{c,e}$	$\Sigma43^{c,e}$	$\Sigma12^{c,e}$	—
9	**3**	**II**—Pd(OAc)$_2$	Dioxane + MeOH	KOH	40	$1+5^{c}$	$\Sigma16^{c}$	$3+15^{c}$	—
10	**3**	**II**—Pd(OAc)$_2$	Dioxane + Pr^{i}OH	KOH	80	$3+7^{c}$	$\Sigma60^{c}$	10^{c}	—
11	**3**	**III**—Pd(dba)$_2$ [d]	Toluene + MeOH	MeOK	72	4	—	—	—
12	**4**	**I**—Pd(dba)$_2$ [d]	Toluene + MeOH	MeOK	80	$\Sigma6^{c,f}$	$\Sigma46^{c,f}$	$\Sigma28^{c,f}$	—
13	**4**	**II**—Pd(dba)$_2$ [d]	Toluene + MeOH	MeOK	86	$\Sigma34^{c}$	$\Sigma48^{c}$	—	—

[a] Yields of mono- (**I**), di- (**II**), tri- (**III**), and tetrasubstituted products (**IV**) are given. According to GC/MS data; a 100% balance is completed by unreacted PCA, in some cases, together with its hydrodechlorination product.

[b] Palladium compound (6 mol.%), imidazolium salt (12 mol.%).

[c] Mixtures of compounds with different extents of dechlorination.

[d] Pd(dba)$_2$ and imidazolium salt (each 3 mol.%) and Bu_4NBr (10 mol.%).

[e] Composition of the reaction mixture (the percentages of isomers for each formula are indicated in parentheses): $C_6H_2Cl_4$ (6), PhC_6H_4Cl (9), $PhC_6H_3Cl_2$ (4 + 24), $PhC_6H_2Cl_3$ (2), $Ph_2C_6H_4$ (11 + 8), $Ph_2C_6H_3Cl$ (2 + 10 + 12), $Ph_3C_6H_3$ (8), $Ph_3C_6H_2Cl$ (4).

[f] Composition of the reaction mixture (%): Ph_2 (3), C_6Cl_6 (14), C_6HCl_5 (4), PhC_6H_4Cl (3 + 7 + 4), $PhC_6H_3Cl_2$ (1 + 4 + 6), $PhC_6H_2Cl_3$ (1 + 1 + 1 + 2), PhC_6HCl_4 (3), $Ph_2C_6H_4$ (1 + 8), $Ph_2C_6H_3Cl$ (3 + 4 + 5), $Ph_2C_6H_2Cl_2$ (1 + 1 + 6 + 1 + 1 + 4 + 6), $Ph_2C_6HCl_3$ (1 + 1 + 2 + 1).

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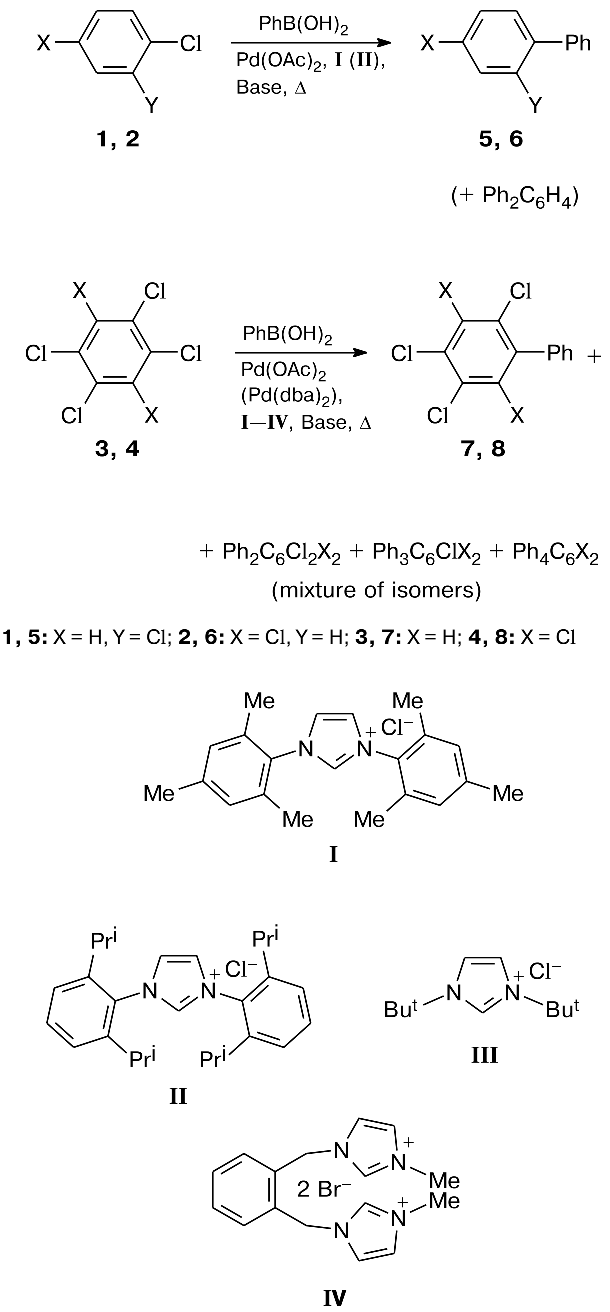
compounds (PCA). In the case of less nucleophilic arylboronic acids, low reactivity of PCA required the use of special catalytic systems comprising electron-enriched sterically hindered phosphine ligands[3] or N-heterocyclic carbene palladium complexes.[4] The advantages of N-heterocyclic carbene complexes or their precursors (imidazolium salts) include air stability and ready accessibility.

This communication presents the results of a more detailed study of the cross-coupling of 1,2-dichlorobenzene (**1**), 1,4-dichlorobenzene (**2**), 1,2,4,5-tetrachlorobenzene (**3**), and hexachlorobenzene (**4**) with phenylboronic acid in the presence of [Pd]—imidazolium salt catalytic systems. Salts **I**—**IV** differing in the electronic and steric properties of substituents at the heterocyclic nitrogen atoms were used as the sources of imidazolium ligands (Scheme 1, Table 1).

It was found that isomeric 1,2- and 1,4-dichlorobenzenes (**1** and **2**) (see Table 1, entries *1*—*4*) are converted into chlorobiphenyls in 75—100% yields in the presence of the $Pd(OAc)_2$—**I**—K_3PO_4 catalytic system. Tetrachlorobenzene **3** is less reactive and virtually does not react with $PhB(OH)_2$ under these conditions (in the presence of this catalytic system) (see Table 1, entries *5* and *6*). However, the use of sodium *tert*-butoxide as the base gave a mixture of cross-coupling products in 81% yield (entry *7*). The use of the $Pd(dba)_2$—**II**—potassium methoxide—toluene system[4d] increases the substrate conversion to 94% (entry *8*); however, in this case, reductive hydrodechlorination occurs in parallel with the cross-coupling. Hydrodechlorination also plays an important role when KOH with methanol (entry *9*) or 2-propanol (entry *10*) is used. It is known[4b,5] that in processes of this type, alcohols containing H_α atoms are converted into carbonyl compounds. The composition of reaction mixtures prompts the conclusion that cross-coupling and hydrodechlorination proceed here at comparable rates. The highest conversions of PCA **3** were observed in the presence of catalytic systems containing imidazolium salts **I** and **II** bearing bulky aryl substituents. The process carried out in the presence of 1,3-di(*tert*-butyl)imidazolium chloride (**III**) afforded the cross-coupling product in a yield of only 4%, together with 1,2,4-trichlorobenzene in 24% yield (entry *11*). Systems containing *N*-methyl-substituted bis-imidazoilium derivative **IV** did not catalyze this reaction.

It was shown for hexachlorobenzene **4** that catalytic systems containing imidazolium salts **I** and **II** do promote cross-coupling and dechlorination of perchloroarenes resulting in C—C and C—H bond formation, respectively. The PCA conversion can be as high as 80—86% (entries *12* and *13*).

Scheme 1



1, 5: X = H, Y = Cl; **2, 6:** X = Cl, Y = H; **3, 7:** X = H; **4, 8:** X = Cl

To conclude, we studied the composition of the dechlorination products of di-, tetra-, and hexachlorobenzenes induced by the $PhB(OH)_2$—base—[Pd]—imidazolium salt systems. The route and efficiency of reaction were found to depend on the number of chlorine atoms in the PCA molecule, the structure of the imidazolium salt used, and the nature of the base. Under the chosen conditions, the process ensures high conversions of PCA but has poor chemo- and regioselectivities.

Experimental

GC/MS analysis was carried out on an Agilent Technologies 85973 Network instrument (EI, 70 eV) attached to an Agilent

Technologies 6890 chromatograph with a HP-5MS capillary column (30000×0.25 mm), injector and flame ionization detector temperature of 280 °C, temperature programming 60→300 °C, 10 deg $\min^{-1}$, then 5 min at 300 °C, and helium as the carrier gas, 2 mL $\min^{-1}$. During GLC analysis, total ionic current and the FID signal were recorded in parallel. The chromatographic peak areas were corrected taking into account the number of carbon atoms in the molecule, and the mole fractions of the components were then calculated. 1,2-Dichlorobenzene (**1**) and 1,4-dichlorobenzene (**2**) (Lancaster), 1,2,4,5-tetrachlorobenzene (**3**) (Acros), hexachlorobenzene (**4**) (Aldrich), and 1,3-dimesitylimidazolium chloride (**I**) (Acros) were used as purchased. 1,3-Di(2,6-diisopropylphenyl)imidazolium chloride (**II**),[6] 1,3-di(*tert*-butyl)imidazolium chloride (**III**),[7] and 3,3´-(*o*-phenylenedimethylene)bis(1-methylimidazolium) dibromide (**IV**)[8] were prepared by known procedures.

Cross-coupling procedure. ***A.*** Palladium acetate (13 mg, 0.06 mmol), imidazolium salt **I—III** (0.135 mmol) or bis-salt **IV** (0.07 mmol), and K_3PO_4 (431 mg, 2.03 mmol) were introduced into a Schlenk vessel. Under argon, dioxane (2 mL) was added, and oxygen was removed by evacuation followed by filling with argon. The mixture was heated at 80 °C for 1 h and cooled to ~20 °C. Polychloroarene (1 mmol) and a solution of phenylboronic acid (185 mg, 1.53 mmol) in dioxane (2 ml) were added. The reaction mixture was stirred for 7 h at 95 °C, and an aliquot sample was taken and concentrated *in vacuo* to remove dioxane. The residue was dissolved in benzene, filtered through a silica gel layer, and analyzed by GC/MS. In some experiments, other bases were used instead of K_3PO_4 (see Table 1).

When Bu^tONa was used as the base, all reactants were added simultaneously and then the reaction mixture was stirred for 7—8 h at 95 °C.

B (with potassium methoxide). A Schlenk tube was charged with $Pd(dba)_2$ (7 mg, 0.012 mmol), imidazolium salt **I** or **II** (0.012 mmol), Bu_4NBr (31.2 mg, 0.041 mmol), PCA (0.41 mmol), and $PhB(OH)_2$ (93 mg, 0.41 mmol). Toluene (2 mL) was added under argon and the mixture was stirred for 5 min. The mixture was cooled to 0 °C and a 25% solution of MeOK (0.35 mL) in MeOH (Merck) was added. The reaction mixture was stirred for 7—8 h at 95 °C and analyzed as described above.

When KOH (90 mg, 1.6 mmol) with addition of alcohols was used as the base (instead of MeOK), dry components were charged to the reaction vessel and then dioxane (2 mL) and MeOH or Pr^iOH (0.6 mL) were added under argon. Then the reaction was carried out as described above.

The reaction products were identified from GC/MS data. For the mass numbers of molecular ion peaks (given for ^{35}Cl isotopes, the isotope clusters corresponded to the number of chlorine atoms in the molecule) of the cross-coupling products, see: **5** and **6**, PhC_6H_4Cl (188); **7**, $PhC_6H_2Cl_3$ (256); **8**, PhC_6Cl_5 (324); $PhC_6H_3Cl_2$ (222); PhC_6HCl_4 (290); $Ph_2C_6H_4$ (230); $Ph_2C_6H_3Cl$ (264); $Ph_2C_6H_2Cl_2$ (298); $Ph_2C_6HCl_3$ (332); $Ph_2C_6Cl_4$ (366); $Ph_3C_6H_3$ (306); $Ph_3C_6H_2Cl$ (340); $Ph_3C_6HCl_2$ (374); $Ph_3C_6Cl_3$ (408); $Ph_4C_6H_4$ (382). The retention times of monosubstituted products **5—8** were also compared with those of authentic samples.

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