

Palladium bis(phosphinite) 'PCP'-pincer complexes and their application as catalysts in the Suzuki reaction

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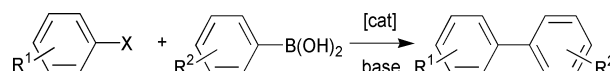
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Palladium complexes of inexpensive, easily synthesised bis(phosphinite) 'PCP'-pincer ligands show good activity in the Suzuki coupling of deactivated and sterically hindered aryl bromides.

Palladium catalysed Suzuki coupling reactions (Scheme 1) generally require fairly high catalyst concentrations, limiting their attractiveness to large-scale commercial applications. This is due to technical problems and costs associated with removal of the spent palladium from the products. Consequently, there has recently been an interest in developing high-activity catalysts that can be used in very low concentrations. Beller and co-workers reported the use of the palladacyclic complex **1**,¹ formed by the metallation of tri(2-tolyl) phosphine, as an efficient catalyst for the Suzuki reaction.² We recently investigated the possibility of using related palladated triarylphosphite complexes and found that the complex **2**



Scheme 1 The Suzuki biaryl coupling reaction

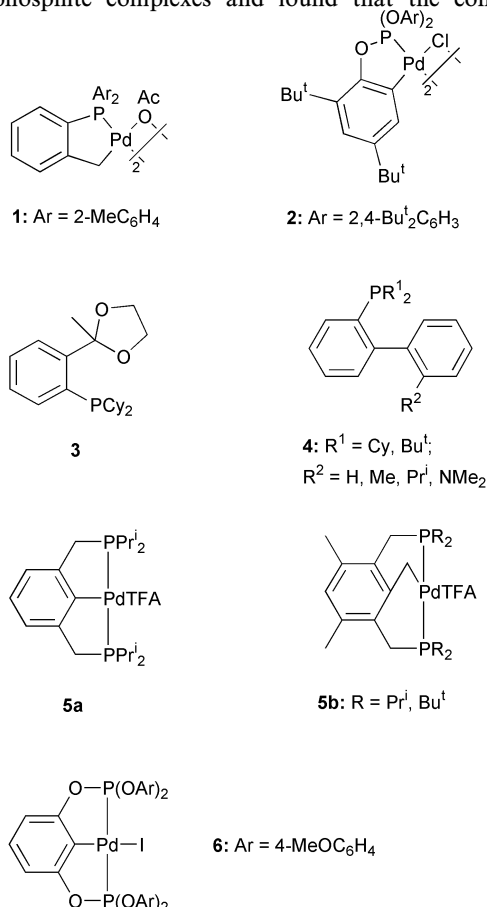
shows extremely high activity with both electronically activated and deactivated aryl bromides—considerably higher than the activity reported for **1**.³

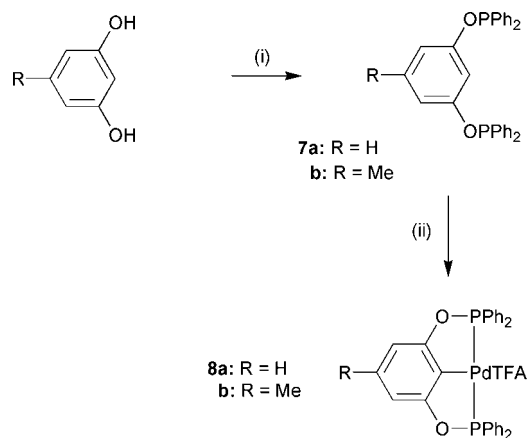
Since then Fu and coworkers,⁴ as well as Guram *et al.*,⁵ have reported good, and Buchwald *et al.*⁶ excellent, activity in the Suzuki reaction using palladium catalysts with the phosphine ligands PBu₃, **3** and **4**, respectively. However, the major drawbacks of these catalyst systems is that the phosphine ligands are comparatively difficult to make or are rather expensive—considerably more expensive than the palladium precursors.⁷ We were therefore interested in continuing our studies on high activity catalysts derived from inexpensive, easily synthesised ligand sets. Inspired by the observations of Milstein *et al.*⁸ and Shibasaki *et al.*⁹ that palladated bis(phosphine) 'PCP'-complexes of type **5** and bis(phosphite) 'PCP'-complexes of type **6** show very high activity in the Heck reaction, we wished to see whether related bis(phosphinite) 'PCP'-pincer complexes would show high activity in the Suzuki reaction.

The ligands **7a** and **7b** are easily synthesised in good yields by the reaction of the appropriate aromatic diol with chlorodiphenylphosphine in toluene in the presence of triethylamine (Scheme 2). The reactions of these ligands with palladium tri-fluoroacetate in THF at room temperature gives the 'PCP'-pincer complexes **8a** and **8b** in good yields. The complexes show excellent air and moisture stability; for instance **8a** shows no sign of decomposition in aerobic solution in the presence of water after 10 days.

The crystal structure of one of the catalysts (**8a**) has been determined¹⁰ and the molecular structure and relevant data are given in Fig. 1. The geometry of the palladium centre is distorted square planar and is grossly similar to that of the complex **6**.⁹ The X-ray analysis confirms that palladation of the pincer ligand has occurred and that the two P-donor groups are in a distorted *trans* configuration. The tri-fluoroacetate ligand coordinates in a unidentate, non-symmetrical fashion, giving greater steric repulsion between the non-coordinated oxygen and the phenyl residues on P1 than those on P2. This is reflected in the considerably larger angle between O3–Pd1–P1 than between O3–Pd1–P2.

To the best of our knowledge no one has reported the application of palladium 'PCP'-pincer complexes as catalysts in the Suzuki reaction. Initially, the complexes were tested for activity in the coupling of phenylboronic acid with the 'easy-

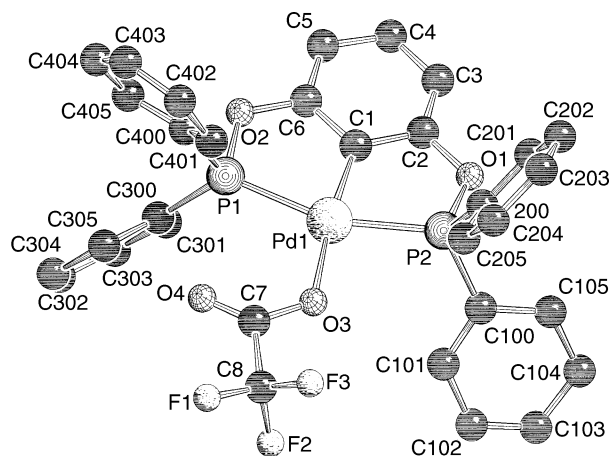




Scheme 2 (i) 2 ClPPh₂, 2.2 Et₃N, toluene, reflux. (ii) Pd(TFA)₂, THF.

to-couple' substrate 4-bromoacetophenone. The results were encouraging with the catalysts showing good activity at 130 °C (Table 1), although not as high as obtained previously with **2**.³

Next we examined the activity of the complexes with the



investigating the use of a range of palladium 'PCP'-pincer complexes with phosphinite, phosphite and phosphine residues in order to elucidate which will make the optimum catalyst for a given substrate in the Suzuki and related reactions.

Experimental

Syntheses

Resorcinolbis(diphenyl)phosphinite, 7a. To a solution of resorcinol (2.5 g, 23.0 mmol) and chlorodiphenylphosphine (8.4 ml, 46.0 mmol) in toluene (40 ml) was added triethylamine (7.0 ml, 50.0 mmol) dropwise. The resultant mixture was then heated at reflux for 18 h. After cooling, the volatiles were removed *in vacuo*, the residue was extracted with THF (20 ml) and the resultant solution was filtered through celite. The celite was washed with THF (2 × 20 ml), the extracts were combined and the solvent was removed *in vacuo* to yield the title product as a yellow–orange solid that was not purified further (8.2 g, 75%). NMR (CDCl₃): ³¹P: δ 114.0; ¹H: δ 6.84 (d, 2H, ³J_{HH} = 8.0 Hz, 3,5-Hs of resorcinol ring); 7.02 (s, 1H, 1-H of resorcinol ring); 7.14 (t, 1H, ³J_{HH} = 8.0 Hz, 4-H of resorcinol ring); 7.44 (m, 12H, PPh₂); 7.63 (m, 8H, PPh₂).

Orcinolbis(diphenyl)phosphinite, 7b. The ligand was obtained as a yellow oil using a method analogous to that for **7a** with 3,5-dihydroxytoluene (orcinol; 2.18 g, 17.6 mmol), chlorodiphenylphosphine (7.2 ml, 39.4 mmol) and triethylamine (7.0 ml, 50 mmol) in toluene (40 ml). Yield 8.5 g, 98%. NMR (CDCl₃): ³¹P: δ 111.3; ¹H: δ 2.29 (s, 3H, CH₃); 6.71 (s, 2H, 4,6-H of orcinol ring); 6.84 (s, 1H, 2-H of orcinol ring); 7.41 (m, 12H, PPh₂); 7.60 (m, 8H, PPh₂).

Complexes 8a and 8b. A solution of palladium trifluoroacetate (0.100 g, 0.302 mmol) and the appropriate bis(diphenyl)phosphinite (0.302 mmol) in THF (5.0 ml) was stirred under nitrogen at room temperature for 2 h. The solvent was then removed *in vacuo*. The residue was washed with ethanol and then recrystallised from dichloromethane–ethanol. Complex **8a** was obtained as a colourless solid (0.175 g, 85%). Crystals suitable for single crystal X-ray analysis were obtained by layering a solution of **8a** in dichloromethane with

hexane. Anal. calc. for C₃₂H₂₃F₃O₄P₂Pd: C 55.15; H 3.3. Found: C 54.85; H 3.55%. NMR (CDCl₃): ³¹P: δ 146.2; ¹H: δ 6.74 (d, 2H, ²J_{HH} = 8.0 Hz, 3,5-Hs of resorcinol ring); 7.12 (t, 1H, ³J_{HH} = 8.0 Hz, 4-H of resorcinol ring); 7.57 (m, 12H, PPh₂); 7.90 (m, 8H, PPh₂).

Complex **8b** was obtained as a colourless solid (0.166 g, 78%). Anal. calc. for C₃₃H₂₅F₃O₄P₂Pd: C 55.75; H 3.5. Found: C 55.1; H 3.3%. NMR (CDCl₃): ³¹P: δ 145.6; ¹H: δ 2.28 (s, 3H, CH₃); 6.57 (s, 2H, 4,6-Hs of orcinol ring); 7.49 (m, 12H, PPh₂); 7.86 (m, 8H, PPh₂).

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