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D-Glucosamine based-phosphine for Suzuki-Miyaura cross-coupling reactions in the supported aqueous phase catalysis system

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ABSTRACT

A D-glucosamine-based phosphine/Pd(OAc)$_2$ complex has been applied to the Suzuki-Miyaura coupling reaction of aryl bromides with arylboronic acids using the supported aqueous phase catalysis, SAPC, concept. The recyclability of the catalyst was investigated and revealed a very high activity during the 4 runs.

Due to the importance of the biaryl compounds in a wide range of industrial applications including the preparation of pharmaceuticals, herbicides, polymers, the Suzuki-Miyaura cross-coupling reaction[1] is probably one of the most studied Pd-catalyzed reactions by the organic chemistry community. Its catalytic system provides simple and practical method for creating carbon–carbon and carbon-nitrogen bonds under sustainable conditions with excellent yields. Due to the mild conditions, the reactions are highly tolerant for many functional groups.

Because of its excellent performance, economic and environmental concerns, numerous efforts have been devoted to the development of Suzuki-Miyaura reaction under benign conditions. Among them, the use of water as solvent is one possibility.[2] Water is an attractive solvent for performing chemical reactions, because of its low cost, non-flammability, non-toxicity, and environmental concerns. Except in the case of ligand-free methodology,[3] the use of water as solvent requires the preparation of water soluble ligand,[4] introducing a polar group such as carboxylate, sulfonate, ammonium. Many protocols using water as solvent require an excessive amount of toxic organic solvents for workup (e.g., product extraction from water medium), and therefore become uneconomic and less environmentally. For this reason, the immobilization of the catalyst has been also considerably developed.[5] In the case of Pd catalysts derived from mono- or diphosphine ligands used in the Suzuki-Miyaura reaction, numerous uses of organic[6,7] or inorganic[7,8] supports have been described. An elegant immobilization method is the supported aqueous phase catalysis (SAPC),[9] where the catalyst system is in a liquid phase and not at the solid-liquid interface as for other supported catalysts. Although, rhodium complexes are the most extensively used in SAPC, mainly for the hydroformylation reaction, the first reaction using this system.[10] A few SAPC examples involving Pd-complexes were described mainly in allylic substitution of allyl acetates[11] and in alkoxycarbonylation of alkenes.[12] To the best of our knowledge, no example of Suzuki-Miyaura cross-coupling reaction using SAPC methodology has been described in the literature so far.

In 2002, two of us described the synthesis of a D-glucosamine-based phosphine, called 2-deoxy-2-{[4-(diphenylphosphino) benzoyl]amino}-D-glucopyranose (Fig. 1) and its use in the cross-coupling reaction of aryl iodides or bromides with arylboronic acids.[13] It has been demonstrated that a medium conversion is obtained when water is used as solvent. Conversely, when a mixture of toluene/ethanol/water (3/2/2) is used as solvent, where ethanol plays the role of transfer agent, excellent yields were obtained, with TON up to 97,000. Unfortunately, no catalyst recovery has been possible. In this context, we decided to immobilize the Pd-complex obtained from the same D-glucosamine-based phosphine, L, and Pd(OAc)$_2$ in aqueous layer of the SAPC system in order to recycle the catalyst.

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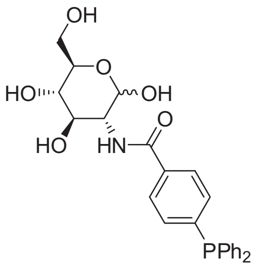
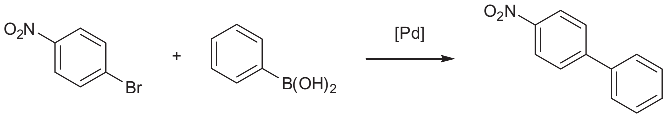


Figure 1. D-Glucosamine-based phosphine.

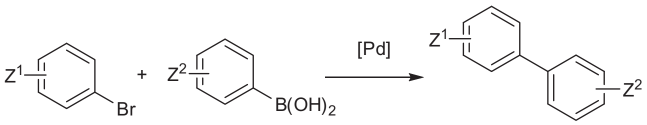
Table 1
Suzuki-Miyaura cross-coupling of 4-bromonitrobenzene and phenylboronic acid[16]



N°	Pd (%mol)	L (%mol)	Run	Yield[a] (%)
1	0.0	0.0	1	0
2	1.0	0.0	1	74
3			2	15
4	1.0	3.0	1	99
5			2	95
6			3	91
7			4	85
8			5	40
9			6	22
10	0.1	0.3	1	93
11			2	86
12			3	44
13			4	32
14			5	18

[a] Isolated chemical yield after column chromatography.

Table 2
Suzuki-Miyaura cross-coupling of arylbromides and arylboronic acids[16]



N°	ArBr	Ar′B(OH)$_2$	Conv.[a] (%)	Yield[b] (%)
1	4-$NO_2C_6H_4$	C_6H_5	100	99
2		3-$MeCOC_6H_4$	92	75
3		3-MeC_6H_4	97	95
4		2,6-$Me_2C_6H_3$	50	45
5	4-$MeCOC_6H_4$	C_6H_5	99	88
6	4-$MeCO_2C_6H_4$		96	95
7	4-VinylC_6H_4		76	65
8	4-$MeOC_6H_4$		30	/
9	2-MeC_6H_4		100	96
10	4-MeC_6H_4		93	85
11	2-Bromonaphtalene		85	83
12	2-Bromopyridine		100	75

[a] Conversion determined by GC.
[b] Isolated chemical yield after column chromatography.

Before evaluating our SAPC system, we tested first the effect of bare silica, dried before use under vacuum at 150 °C during 4 h. The reaction was carried out in toluene in the presence of SiO_2,[14] Na_2CO_3 (3 equiv) as the base, with a 4-bromonitrobenzene/phenylboronic acid ratio of 1–1.1, for 24 h at 80 °C (Table 1, entry 1). No reaction took place. Similarly to explain the role of our ligand in the SAPC, a catalyst (Pd SAPC) was prepared by impregnating dried silica[14] with a solution of $Pd(OAc)_2$ in a mixture of ethanol and water (ratio 2/1), followed by concentration and drying under vacuum at room temperature for 16 h. Indeed, it is well known that ligand-free $Pd(OAc)_2$ is able to catalyze the coupling reaction of aryl iodides and activated or deactivated aryl bromides.[1b,1e,15] Using the conditions reported before and changing SiO_2 alone by Pd SAPC (1% molar of Pd loading), after the first run, the Pd SAPC was filtered off, washed with toluene, and dried under vacuum at room temperature for 16 h, before being used in a second run without any addition of $Pd(OAc)_2$ (Table 1, entries 2 and 3). The yield of the coupling product of 4-bromonitrobenzene and phenylboronic acid decreased from 74% to 15%. This drop in performance was explained by the leaching of the metal when the catalyst was filtered and washed with toluene between the two cycles of reaction.

Then, we evaluated the recycling of the catalyst (L/Pd SAPC) prepared by impregnating dried silica[14] with a solution of D-glucosamine-based phosphine and $Pd(OAc)_2$ (ratio L/Pd = 3/1) in a mixture of ethanol and water (ratio 2/1), followed by concentration and drying under vacuum at room temperature for 16 h. Under the same conditions, with the same Pd loading (1% molar) and without any addition of catalyst, the chemical yield remained stable (99–91%) during three runs, and decreased slightly in the fourth run (85%), before decreasing in the fifth and sixth runs to 40% and 20%, respectively (Table 1, entries 4–9). We also tried to reduce the Pd loading to 0.1% molar (Table 1, entries 10–14). The yields of the two first runs (93% and 86%) were almost similar to the two first runs with a Pd loading ten times higher. However from the third cycle, the yield decreased drastically from 88% to 44%, 32%, and 18%. These decreases of yields from the fifth and the third runs, for 1.0% or 0.1% molar Pd loading respectively, could be due to some accumulation of salts in the mixture, saturating aqueous film. However, the excellent yields obtained in the first runs for the two Pd loadings, demonstrated the positive effect of the D-glucosamine-based phosphine to prevent leaching of the catalyst.

After showing the efficiency of the SAPC in the cross-coupling of 4-bromonitrobenzene with phenylboronic acid, we studied its efficacy in the coupling reaction of activated or deactivated aryl bromides with various arylboronic acids (Table 2). The reactions were carried out under the same conditions as described above with 1% molar of Pd. The yields of coupling of aryl bromides bearing electron withdrawing group with phenylboronic acid were good, lying between 88% and 99% (Table 2, entries 1, 5 and 6), except in the case of 4-vinylbromobenzene where the yield was 65% with a conversion of 76% (Table 2, entry 7).

In the case of coupling of aryl bromides bearing electron donating group with phenylboronic acid, the conversions exceeded 90% (Table 2, entries 9 and 10), except in the case of 4-bromomethoxybenzene where a poor conversion of 30% was observed (Table 2, entry 8). Biaryl coupling of 4-bromonitrobenzene with 4 arylboronic acids was also studied (Table 2, entries 1–4). 4-Bromonitrobenzene reacted efficiently with phenylboronic-, 3-acetylphenylboronic-, or 4-tolylboronic acids giving the corresponding biaryl compounds in good yields (Table 2, entries 1–3). The sterically hindered 2,6-dimethylphenylboronic acid reacted also (Table 2, entry 4) and afforded the coupling product in 45% yield.

While 2-bromonaphthalene gave very low conversion (20%) of coupling product with phenylboronic acid with the same Pd loading in a mixture of toluene/ethanol/water as solvent,[13b] the same cross-coupling reaction performed under SAPC conditions gave the biaryl compound with a conversion of 85% (Table 2, entry 11). Finally, the condensation of the heterocyclic 2-bromopyridine with phenylboronic acid occurred with a total conversion and 75% isolated chemical yield (Table 2, entry 12).

In conclusion, the complexes obtained from palladium acetate and D-glucosamine-based phosphines have been already known to be efficient catalysts for the Suzuki-Miyaura cross-coupling reaction of arylboronic acids and a wide range of aryl iodines, bromides, and chlorides.[13,17] However no efficient recycling has been proposed. In this article, we demonstrated that one of these organometallic species could be easily immobilized in a film of water of SAPC system, and reused four times without loss of activity, indicating no leaching of the metal. In addition, by comparing some coupling reactions performed with the same Pd-complex in a mixture of toluene/ethanol/water as solvent with and without use of SAPC conditions, we observed in some cases a positive effect of silica support.

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References and notes

1. (a) Miyaura, N.; Suzuki, A. *Chem. Rev.* **1995**, *95*, 2457–2483; (b) Littke, A. F.; Fu, G. C. *Angew. Chem., Int. Ed.* **2002**, *41*, 4176–4211; (c)*Topics in Current Chemistry*; Miyaura, N., Ed.; Springer Verlag: Berlin, 2002; (d) Farina, V. *Adv. Synth. Catal.* **2004**, *346*, 1553–1582; (e) Bellina, F.; Carpita, A.; Rossi, R. *Synthesis* **2004**, 2419–2440; (f) Phan, N. T. S.; Van Der Sluys, M.; Jones, C. W. *Adv. Synth. Catal.* **2006**, *348*, 609–679; (g) Torborg, C.; Beller, M. *Adv. Synth. Catal.* **2009**, *351*, 3027–3043.
2. (a) Franzen, R.; Xu, Y. *Can. J. Chem.* **2005**, *83*, 266–272; (b) Shaughnessy, K. H. *Eur. J. Org. Chem.* **2006**, 1827–1835; (c) Shaughnessy, K. H. *Chem. Rev.* **2009**, *109*, 643–710; (d) Lamblin, M.; Nassar-Hardy, L.; Hierso, J.-C.; Fouquet, E.; Felpin, F.-X. *Adv. Synth. Catal.* **2010**, *352*, 33–79; (e) Weeden, J. A.; Huang, R.; Galloway, K. D.; Gingrich, P. W.; Frost, B. J. *Molecules* **2011**, *16*, 6215–6231.
3. (a) Leadbeater, N. E.; Marco, M. *Org. Lett.* **2002**, *4*, 2973–2976; (b) Maegawa, T.; Kitamura, Y.; Sako, S.; Udzu, T.; Sakurai, A.; Tanaka, A.; Kobayashi, Y.; Endo, K.; Bora, U.; Kurita, T.; Kozaki, A.; Monguchi, Y.; Sajiki, H. *Chem. Eur. J.* **2007**, *13*, 5937–5943; (c) Shi, S.; Zhang, Y. *Green Chem.* **2008**, *10*, 868–872; (d) Basu, B.; Biswas, K.; Kundu, S.; Ghosh, S. *Green Chem.* **2010**, *12*, 1734–1738.
4. (a) Bergbreiter, D. E. *Chem. Rev.* **2002**, *102*, 3345–3384; (b) Shaughnessy, K. H. *Chem. Rev.* **2009**, *109*, 643–710; (c) Polshettiwar, V.; Decottignies, A.; Len, C.; Fihri, A. *ChemSusChem* **2010**, *3*, 502–522.
5. (a)De Vos, D. E., Vankelecom, I. F. J., Jacobs, P. A., Eds.Chiral Catalyst Immobilization and Recycling; Wiley-VCH: Weinheim, 2000; (b) Haag, R.; Roller, S. *Top. Curr. Chem.* **2004**, *242*, 1–42; (c) Uozumi, Y. *Top. Curr. Chem.* **2004**, *242*, 77–112; (d) End, N.; Schöning, K.-U. *Top. Curr. Chem.* **2004**, *242*, 241–271.
6. (a) Jang, S.-B. *Tetrahedron Lett.* **1997**, *38*, 1793–1796; (b) Fenger, I.; Le Drian, C. *Tetrahedron Lett.* **1998**, *39*, 4287–4290; (c) Uozumi, Y.; Danjo, H.; Hayashi, T. *J. Org. Chem.* **1999**, *64*, 3384–3388; (d) Inada, K.; Miyaura, N. *Tetrahedron* **2000**, *56*, 8661–8664; (e) Cammidge, A. N.; Baines, N. J.; Bellingham, R. K. *Chem. Commun.* **2001**, 2588–2589; (f) Parrish, C. A.; Buchwald, S. L. *J. Org. Chem.* **2001**, *66*, 3820–3827; (g) Uozumi, Y.; Nakai, Y. *Org. Lett.* **2002**, *4*, 2997–3000; (h) Datta, A.; Ebert, F.; Plenio, H. *Organometallics* **2003**, *22*, 4685–4691; (i) Yamada, Y. M. A.; Takeda, K.; Takahashi, H.; Ikegami, S. *J. Org. Chem.* **2003**, *68*, 7733–7741; (j) van der Heiden, M.; Plenio, H. *Chem. Eur. J.* **2004**, *10*, 1789–1797; (k) Glegola, K.; Framery, E.; Pietrusiewicz, K. M.; Sinou, D. *Adv. Synth. Catal.* **2006**, *348*, 1728–1733.
7. Leyva, A.; Garcia, H.; Corma, A. *Tetrahedron* **2007**, *63*, 7097–7111.
8. (a) Bedford, R. B.; Cazin, C. S. J.; Hursthouse, M. B.; Light, M. E.; Pike, K. J.; Wimperis, S. *J. Organomet. Chem.* **2001**, *633*, 173–181; (b) Tzschucke, C. C.; Markert, C.; Glatz, H.; Bannwarth, W. *Angew. Chem., Int. Ed.* **2002**, *41*, 4500–4503; (c) Paetzold, E.; Jovel, I.; Oehme, G. *J. Mol. Catal. A: Chem.* **2004**, *214*, 241–247; (d) Tzschucke, C. C.; Andrushko, V.; Bannwarth, W. *Eur. J. Org. Chem.* **2005**, 5248–5261; (e) Sayah, R.; Glegola, K.; Framery, E.; Dufaud, V. *Adv. Synth. Catal.* **2007**, *349*, 373–381; (f) Shylesh, S.; Wang, L.; Thiel, W. R. *Adv. Synth. Catal.* **2010**, *352*, 425–432; (g) Costa, N. J. S.; Kiyohara, P. K.; Monteiro, A. L.; Coppel, Y.; Philippot, K.; Rossi, L. M. *J. Catal.* **2010**, *276*, 382–389; (h) Chen, W.; Li, P.; Wang, L. *Tetrahedron* **2011**, *67*, 318–325.
9. Delmas, H.; Jauregui-Haza, U.; Wilhelm, A.-M. In *Multiphase Homogeneous Catalysis*; Cornils, B., Herrmann, W. A., Horvath, I. T., Leitner, W., Mecking, S., Olivier-Bourbigou, H., Vogt, D., Eds.; Wiley-VCH: Weinheim, 2005; pp 297–304.
10. Arhancet, J. P.; Davis, M. E.; Merola, J. S.; Hanson, B. E. *Nature* **1989**, *339*, 454–455.
11. (a) Schneider, P.; Quignard, F.; Choplin, A.; Sinou, D. *New J. Chem.* **1996**, *20*, 545–547; (b) Dos Santos, S.; Tong, Y.; Quignard, F.; Choplin, A.; Sinou, D.; Dutatsta, J. P. *Organometallics* **1998**, *17*, 78–89; (c) Choplin, A.; Dos Santos, S.; Quignard, F.; Sigismondi, S.; Sinou, D. *Catal. Today* **1998**, *42*, 471–478; (d) Dos Santos, S.; Quignard, F.; Sinou, D.; Choplin, A. *Top. Catal.* **2000**, *13*, 311–318.
12. Seayed, J.; Seayed, A. M.; Sarkar, B. R.; Chaudhari, R. V. US 6,479,693, 2002.
13. (a) Parisot, S.; Kolodziuk, R.; Goux-Henry, C.; Iourtchenko, A.; Sinou, D. *Tetrahedron Lett.* **2002**, *43*, 7397–7400; (b) Kolodziuk, R.; Penciu, A.; Tollabi, M.; Framery, E.; Goux-Henry, C.; Iourtchenko, A.; Sinou, D. *J. Organomet. Chem.* **2003**, *687*, 384–391.
14. Silica for the preparation of Pd SAPC and L Pd SAPC was a commercial silica gel 60 (230–240 mesh, Merck).
15. (a) Campi, E. M.; Jackson, W. R.; Maruccio, S. M.; Naeslund, C. G. M. *J. Chem. Soc., Chem. Commun.* **1994**, *1*, 2395; (b) Badone, D.; Baroni, M.; Cardamone, R.; Ielmini, A.; Guzzi, U. *J. Org. Chem.* **1997**, *62*, 7170–7173; (c) Bumagin, N. A.; Bykov, V. V. *Tetrahedron* **1997**, *53*, 14437–14450; (d) Bussolari, J. C.; Rehborn, D. C. *Org. Lett.* **1999**, *1*, 965–967; (e) Klingensmith, L. M.; Leadbeater, N. E. *Tetrahedron Lett.* **2003**, *44*, 765–768; (f) Tao, X.; Zhao, Y.; Shen, D. *Synlett* **2004**, 359–361.
16. *General procedure for the Suzuki-Miyaura reaction with 1% molar of Pd catalyst:* Silica (500.0 mg) was dried in a Schlenck tube under vacuum for 4 h at 150 °C. In another Schlenk tube, Pd(OAc)$_2$ (1.1 mg, 5.0 μmol), D-glucosamine based phosphine (6.6 mg, 15.0 μmol), ethanol (2 mL), water (1 mL) were added. The mixture was stirred for 1 hour at room temperature, and then using canula, was transferred to silica. After stirring for 2 h at room temperature, solvents were evaporated under vacuum and the solid was dried under vacuum for 16 h at room temperature, and then kept under Argon atmosphere prior to be used. Na$_2$CO$_3$ (156.0 mg, 1.5 mmol), aryl bromide (0.5 mmol), and arylboronic acid (0.55 mmol) were placed in the Schlenk tube containing the L/Pd SAPC catalyst prepared as described above. After the addition of ethanol (1 mL) and toluene (7.5 mL), the mixture was stirred at 80 °C for 24 h. After subsequent cooling down and filtration, silica support was washed with toluene (2 × 8 mL). The combined organic phases were concentrated and filtrated through a thin pad of silica before to be analyzed in GC. Purification of the crude product by flash chromatography on silica gel gave the coupling product.
    Recycling cross-coupling reaction of 4-bromonitrobenzene with phenylboronic acid: In the case of 1% molar of Pd catalyst: for the first run, the experimental conditions described above were used. After decantation and filtration, the L/Pd SAPC system was washed with toluene (5 mL), and was dried under vacuum for 16 h. Then, a mixture of 4-bromonitrobenzene (0.5 mmol), phenylboronic acid (0.55 mmol), and Na$_2$CO$_3$ (156.0 mg, 1.5 mmol) were added to the solid. After that, the new cycle was performed following the general procedure for the Suzuki-Miyaura reaction.
17. (a) Beller, M.; Krauter, J. G. E.; Zapf, A. *Angew. Chem., Int. Ed.* **1997**, *36*, 772–774; (b) Nishimura, M.; Ueda, M.; Miyaura, N. *Tetrahedron* **2002**, *58*, 5779–5787; (c) Konovets, A.; Penciu, A.; Framery, E.; Percina, N.; Goux-Henry, C.; Sinou, D. *Tetrahedron Lett.* **2005**, *46*, 3205–3208.