Tri-tert-butylphosphine [P(t-Bu)₃]: An Electron-Rich Ligand for Palladium in Cross-Coupling Reactions

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Introduction

Transition-metal-catalyzed cross-couplings are recognized to be the most powerful carbon–carbon bond forming reactions.¹ The palladium-catalyzed coupling of aryl halides, arylsulfonates with aryl/alkyl metals (such as M = B, Sn, Zn, Si, Mg) are very often employed in the synthesis of compounds, the skeletons of which are found in a wide range of important natural products and analogues of biological interest.² Before 1990, the insertion of palladium into C–Br and C–I bonds was well exploited. However, the same reaction with C–Cl bonds proved to be very difficult. Organochloride compounds are less expensive than the other organohalides, and would thus be most interesting partners in cross-coupling reactions. Fu and co-workers have shown that electron-rich ligands such as tri-tert-butylphosphine [P(t-Bu)₃] allow the metal insertion into C–Cl bonds at or above room temperature. Subsequent transmetalations with organoboron, organotin, organozinc, organocopper and organosilicon reagents and final reductive elimination give the corresponding products of C–C cross-couplings.² Littke and Fu showed that arylation of olefins can be catalyzed by the same Pd/P(t-Bu)₃ system.

Other convenient ligands have been proposed to promote the palladium oxidative addition of aryl chlorides. Most common today are bulky, electron-rich chelating bisphosphines as those proposed by Milstein,³ bulky and electron-rich phosphines proposed by Buchwald,⁴ the palladacycles and N-heterocyclic carbene proposed by Herrmann,⁷ as well as the phosphites proposed by Beller.⁸

Preparation

P(t-Bu)₃ 1 can be easily prepared by a two-step sequence starting with addition of tert-butylmagnesium chloride to PCl₃ (Scheme 1). Chloro-di-tert-butylphosphine thus obtained is then reacted with 1.2 equiv of tert-butyl lithium to produce desired product 1.⁴c The pKₐ of P(t-Bu)₃ was found to be 11.4. Thus, P(t-Bu)₃ appears to be one of the most basic phosphines, leading to a particular behaviour as ligand in numerous catalyzed reactions.⁴a,b

Scheme 1

This ligand is available from Strem company as a 10% solution (w/w) in hexane or in dioxane. Although it is also available in pure form from other commercial sources, it is conveniently used as a solution, since only a small amount of ligand is usually needed and also because it is most air sensitive in its pure form. The reagent can be stored at low temperature and must be manipulated in a glove box or under a nitrogen flow.

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Abstracts

(A) The Buchwald–Hartwig amination of aryl halides was realized for the first time in 1998 using P(η5-C5H5)2, as ligand to the palladium catalyst.9 Fu and co-workers extended the scope of P(η5-C5H5)2, as ligand for other types of palladium-catalyzed coupling reactions of aryl chlorides. These authors reported the reactions of triflates and aryl chlorides in Suzuki–Miyaura,10 Stille,11 Negishi,12b Hiyama12b and other C–C cross-coupling reactions. Recently, we found that arenesulfonyl chlorides can be used in the desulfitative Suzuki–Miyaura13 and Stille,11 Negishi,12a Hiyama12b cross-coupling of terminal acetylenes and aryl bromides require high temperatures and CuI as a co-catalyst. Using P(dba)3 as ligand to the palladium catalyst,14 we have shown the Heck–Mizoroki reactions can act already at room temperature.15a Herrmann and co-workers,15b showed that the use of P(dba)3 as base.17 The Pd/P(dba)3 catalytical system: (a) Dubbaka, S. R.; Vogel, P. Angew. Chem.–Eur. J. 2003, 12, 1529. (b) Dubbaka, S. R.; Vogel, P. Synlett 2004, 1235.

(B) Typical reaction conditions for the Sonogashira–Hagihara cross-coupling of terminal acetylenes and aryl bromides require high temperatures and CuI as a co-catalyst. Using P(η5-C5H5)2, ligand, Fu and Buchwald showed that electron-rich aryl bromides can react already at room temperature.15a Herrmann and co-workers,15b as well as chemists of Merck company,15c showed that the use of aryl chlorides can be reacted at higher temperature using the same ligand.15d We have shown that the desulfitative Sonogashira–Hagihara reactions with arenesulfonyl chlorides can be carried out in the presence of CuI, with 3 mol% Pd(dba)3 and 10 mol% P(η5-C5H5)2.16

(C) Littke and Fu have shown the Heck–Mizoroki reactions can couple aryl chlorides with mono- or disubstituted olefins giving the corresponding arylated products with high stereoselectivity. This requires the use of P(η5-C5H5)2 ligand to the palladium and Cy3NMe as base.17 The Pd/P(η5-C5H5)2 system is also a good catalyst in the desulfitative Heck–Mizoroki arylation reactions with arenesulfonyl chlorides.18

(D) Recently, Sakei and co-workers have used 1-aryltriazenes as electrophilic partners in cross-coupling reactions. For instance, the reaction of aryltriazenes and areneboronic acids in the presence of electron-rich aryl bromides can react already at room temperature.16b We have shown that the desulfitative Sonogashira–Hagihara reactions with arenesulfonyl chlorides can be carried out in the presence of CuI, with 3 mol% Pd(dba)3 and 10 mol% P(η5-C5H5)2.16b

References