Inhibition of Reductive Elimination of Diorganopalladium Species by Formation of Tetraorganopalladates

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Reductive elimination of $(^tBuC{\equiv}C)_2Pd(PPh_3)_2$ to give $^tBuC{\equiv}CC{\equiv}CBu^t$ (**4**) is strongly inhibited by an excess of $LiC{\equiv}CBu^t$ through the formation of $Li_2Pd(C{\equiv}CBu^t)_4$, which does not readily decompose to produce (**4**); these results provide, for the first time, a mechanistic interpretation of the hitherto puzzling inhibitory action of highly electropositive metals, such as Li, in Pd-promoted coupling reactions.

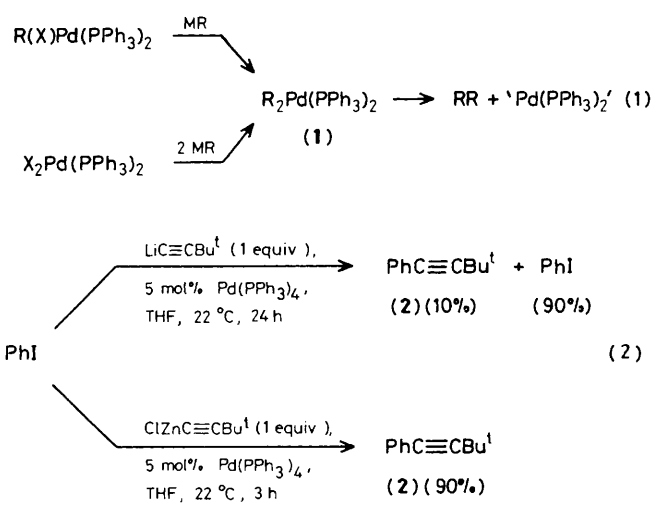
Carbon–carbon bond formation *via* reductive elimination of diorganopalladium species (**1**) has proved to be a selective and versatile synthetic methodology.[1] The required intermediate (**1**) is usually generated *in situ* by transmetallation, and the method has been shown to be highly general with respect to M in equation (1). At the same time, however, it also displays a marked countercation (M) dependence.[2] For example a striking contrast between Li, a highly electropositive metal, and Zn, a metal of intermediate electronegativity, is clearly seen in the results for the formation of $PhC{\equiv}CBu^t$, equation (2).

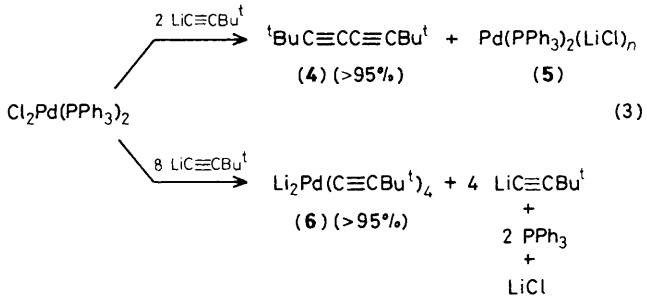
$$PhPd(PPh_3)_2I$$
(**3**)

In this communication we report that reductive elimination of diorganopalladium species (**1**) is strongly inhibited by an excess of organolithium reagent, *e.g.*, $LiC{\equiv}CBu^t$, through the formation of tetraorganopalladates, *e.g.*, $Li_2Pd(C{\equiv}CBu^t)_4$. Although some similar palladate complexes have been reported,[3] their inhibitory role in the Pd-promoted coupling reaction has not been reported.

The first clue to understanding the adverse and puzzling effect of organolithium reagents was found in two stoicheiometric reactions of preformed $PhPd(PPh_3)_2I$, (**3**), with $LiC{\equiv}CBu^t$ and $ClZnC{\equiv}CBu^t$. In sharp contrast with the catalytic reactions shown in equation (2), both of these reactions gave (**2**) in >95% yields within 1 h. Since these results indicated that the intrinsic reactivity of $LiC{\equiv}CBu^t$ towards (**3**) might not be lower than that of $ClZnC{\equiv}CBu^t$, an inhibitory effect of $LiC{\equiv}CBu^t$ was suspected.

A dramatic and clearcut inhibitory effect was observed in the reaction of $Cl_2Pd(PPh_3)_2$ with $LiC{\equiv}CBu^t$, equation (3). Thus, the 1:2 reaction of these two reagents in tetrahydrofuran (THF) at 22 °C gave $^tBuC{\equiv}CC{\equiv}CBu^t$ (**4**) in >95% yield with no indication of dissociation of PPh_3 from Pd. The ^{31}P n.m.r. spectrum of the reaction mixture showed only one relatively broad signal at 23.1 p.p.m. attributable to $Pd(PPh_3)_2(LiCl)_n$, (**5**), where $n = 1$ or 2.[4] Addition of 1 equiv. of PhI converted (**5**) into (**3**) in >90% yield within 30 min. On the other hand, the use of 8 equiv. of $LiC{\equiv}CBu^t$ gave only a trace of (**4**). ^{31}P N.m.r. examination indicated quantitative liberation of PPh_3 (−4.48 p.p.m.). Although the ^1H n.m.r. spectrum of the reaction mixture showed only one Bu^t signal at 1.04 p.p.m., its ^{13}C n.m.r. spectrum indicated that there were two discrete $C{\equiv}CBu^t$ groups in an essentially 1:1 ratio; The one that shows the ^{13}C n.m.r. signals at δ 28.94, 33.19, 114.54, and 123.86 belongs to $LiC{\equiv}CBu^t$. The other set of ^{13}C n.m.r. signals at δ 29.81, 33.42, 95.92, and 115.36 is





attributable to $Li_2Pd(C{\equiv}CBu^t)_4$ (**6**). Treatment of the 1:8 reaction mixture with 8 equiv. of cyclohexanone induced a rapid disappearance of LiC≡CBu^t (4 equiv.) with concomitant formation of 1-(3′,3′-dimethylbutynyl)cylohexanol followed by a much slower disappearance of (**6**), the rate ratio of the two processes being >50:1.

The 1:4 reaction of $Cl_2Pd(PPh_3)_2$ with LiC≡CBu^t led to competitive formation of (**4**) and (**6**). However, treatment of Li_2PdCl_4 with 4 equiv. of LiC≡CBu^t cleanly and quantitatively yielded (**6**) free of PPh_3 and LiC≡CBu^t [i.r. (THF) 2067 (m, $\nu_{C\equiv C}$) cm^{-1}; ^{1}H n.m.r. (THF) δ 1.04 (s); ^{13}C n.m.r. (THF) δ 29.45, 33.36, 99.89, and 115.51]. The ^{13}C n.m.r. signals of this sample did not show any splitting upon addition of a mixture obtained by the reaction of $Cl_2Pd(PPh_3)_2$ with 8 equiv. of LiC≡CBu^t. The rate of the reaction of (**6**) prepared from Li_2PdCl_4 with cyclohexanone is essentially the same as that of the slow section of the corresponding reaction of the 1:8 reaction product. It is important to note that, in the reaction of $Cl_2Pd(PPh_3)_2$ with ClZnC≡CBu^t, both the 1:2 and 1:8 reactant ratios did not show any sign of inhibition and led to the formation of (**4**) in essentially quantitative yields within 1 h at 22 °C.

In summary, the inhibitory effect of LiC≡CBu^t in the reductive elimination of $(^tBuC{\equiv}C)_2Pd(PPh_3)_2$ is attributable to the excessively high reactivity of LiC≡CBu^t, which induces competitive or preferential formation of $Li_2Pd(C{\equiv}CBu^t)_4$. This provides, for the first time, a clear mechanistic interpretation for the hitherto puzzling inhibitory effect of organolithium reagents in Pd-promoted coupling reactions.

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