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# NICKEL-PHOSPHINE COMPLEX-CATALYZED HOMO COUPLING OF ARYL HALIDES IN THE PRESENCE OF ZINC POWDER

Michio Zembayashi, Kohei Tamao, Jun-ichi Yoshida, and Makoto Kumada*

*Department of Synthetic Chemistry, Faculty of Engineering, Kyoto University, Kyoto 606, Japan*

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Homo coupling of aryl and alkenyl halides has been achieved by the Ullmann reaction[1] or by the nickel(0)-complex promoted reaction, recently discovered by Semmelhack et al. (eq. 1).[2] While the former requires rather drastic reaction conditions, the latter occurs under milder conditions, but requires sophisticated air-sensitive nickel(0) complexes such as bis(1,5-cyclooctadiene)nickel(0) or tetrakis(triphenylphosphine)nickel(0), in *stoichiometric amounts*. More recently, Kende et al.[3] reported a modification of the Semmelhack's method, in which the reactive nickel(0) reagent was prepared in situ from easily accessible, air-stable dichlorobis(triphenylphosphine)nickel(II) by reduction with zinc dust (eq. 2).[4] They still used the nickel complex in *stoichiometric amounts*.

$$2\ RX + L_nNi(0) \longrightarrow R\text{-}R + L_2NiX_2 \qquad (1)$$

$$L_2NiX_2 + Zn \xrightarrow{L} L_nNi(0) + ZnX_2 \qquad (2)$$

It can easily be anticipated, however, that this coupling reaction might proceed catalytically in nickel, in the presence of reducing agent such as zinc, since Ni(II) species resulting from the coupling reaction (eq. 1) should be reduced to regenerate Ni(0) active species. In this report we show that the coupling reaction actually proceeds *catalytically in nickel*.

Table I summarizes the results of the homo coupling of bromobenzene under various reaction conditions. These data reveal that the molar ratio PhBr : Zn : $Ph_3P$ : $[Ni(PPh_3)_2Cl_2]$ = 1 : 1 : 0.4 : 0.05 gives the most satisfactory yields of biphenyl. DMF is the most suitable solvent. A relatively large excess of $Ph_3P$ over the nickel catalyst may be needed, because the phosphine

Table I.

$$\mathrm{PhBr} \xrightarrow{\mathrm{Zn},\ [\mathrm{Ni(PPh_3)_2Cl_2}],\ x\ \mathrm{PPh_3}} \mathrm{Ph\text{-}Ph}^{a}$$

| Molar ratio | | | | Solvent | Yield (%)[b] |
|---|---|---|---|---|---|
| PhBr | : Zn | : $PPh_3$ | : $[Ni(PPh_3)_2Cl_2]$ | | |
| 1 | : 1 | : 0.2 | : 0.025 | DMF | 28 |
| 1 | : 1 | : 0.2 | : 0.05 | DMF | 35 |
| 1 | : 1 | : 0.3 | : 0.05 | DMF | 72 |
| 1 | : 1 | : 0.4 | : 0.05 | DMF | 89 |
| 1 | : 1 | : 0.4 | : 0.05 | MeCN | 24 |
| 1 | : 1 | : 0.4 | : 0.05 | THF | 8 |
| 1 | : 1 | : 0.4 | : 0.05 | EtOH | 0 |

[a] Reactions were carried out in a 5 or 10 mmol scale. Heated at 50°C for 20 hr under nitrogen. [b] Determined by GLC.

coordinates also to the zinc salt[5] as it is formed during the course of the reaction. No coupling reaction occurred in the presence of n-$Bu_3P$ in place of $Ph_3P$ as ligand.

Representative results summarized in Table II were obtained under the reaction conditions as above. The reaction can be accomplished even in the presence of certain functional groups such as carbonyl which can not tolerate in similar coupling reactions using organomagnesium reagents.[6] Yields dropped with ortho substituted aryl halides. Thienyl bromide also gave the coupling product in fairly good yield.

A typical procedure is as follows. A mixture of $[Ni(PPh_3)_2Cl_2]$[7] (160 mg; 0.25 mmol), triphenylphosphine (525 mg; 2.00 mmol), zinc powder (325 mg; 4.97 mg atom), and dry DMF (20 ml) was stirred at room temperature for 0.5 hr under nitrogen atmosphere, resulting in the change of the color from green blue to reddish brown. Bromobenzene (843 mg; 5.37 mmol) was added and the mixture heated at 50°C for 20 hr. After hydrolysis the mixture was extracted with ether. The extracts were chromatographed on Silica Gel (eluent: hexane) to give 370 mg (89% yield) of biphenyl.

Although the exact mechanism of the present coupling reaction has not yet been clarified, it seems likely that organozinc intermediates are not involved,[8] but metallic zinc acts as a reducing agent for the Ni(II) species as mentioned above. In connection with this electron-

Table II. Homo Coupling of Organic Bromide[a]

| Organic bromide | Yield (%)[b] | Organic bromide | Yield (%)[b] |
|---|---|---|---|
| PhBr | 89 | *p*-$MeCONHC_6H_4Br$[c] | 37 |
| *p*-$MeC_6H_4Br$ | (73) | *o*-$MeO_2CC_6H_4Br$[c] | (33) |
| *p*-$MeOC_6H_4Br$[c] | (73) | *o*-$MeC_6H_4Br$[c] | (12) |
| *p*-$MeCOC_6H_4Br$ | 58 | α-Thienyl bromide | (41) |
| *p*-$MeO_2CC_6H_4Br$ | 83 | | |

[a] Organic bromide : Zn : $Ph_3P$ : $[Ni(PPh_3)_2Cl_2]$ = 1 : 1 : 0.4 : 0.05 (molar ratio). DMF = 20 ml. Heated at 50°C for 20 hr, unless otherwise noted. [b] Isolated yield. Yields in parentheses were determined by GLC. [c] Heated for 40 hr.

transfer process, we have obtained preliminary results showing that the addition of iodide ions to the reaction mixture greatly accelerates the coupling reaction. Thus, in the presence of an equimolar amount of potassium iodide to the nickel catalyst, the coupling of bromobenzene proceeded *at room temperature* to give biphenyl in 81% yield after 24 hr (or 85% yield after 52 hr), while in the absence of it only 24% yield after 24 hr (or 41% yield after 52 hr) was obtained. This remarkable salt effect suggests that the bridging of a polarizable iodide ion between nickel and zinc species may be involved in the electron transfer processes.[9] We are currently interested in such catalytic reactions based upon redox systems.

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