Iron-Catalyzed Dechlorination of Aryl Chlorides

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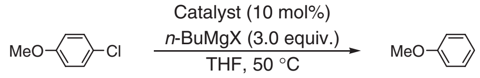
Electron-rich aryl chlorides such as chloroanisole, chloroaniline, and chlorotoluene were dechlorinated by Grignard reagents in the presence of a catalytic amount of iron chlorides. This is in sharp contrast to the cross-coupling reactions of electron-poor aryl chlorides with Grignard reagents.

Dechlorination of aryl chlorides is important target not only in organic chemistry but also in environmental chemistry.[1] Several catalytic systems have been reported using Pd(0)/KOMe, [Rh]/HSiEt$_3$, Ni(0)/i-PrONa, and other systems for dechlorination of aryl chlorides.[2–9]

Our group has reported selective dehalogenation of aryl halides using Cp$_2$ZrCl$_2$ or Cp$_2$TiCl$_2$ as a catalyst with Grignard reagents.[9] In particular, the combination of cat. Cp$_2$TiCl$_2$/RMgX was efficient as a catalyst system for dechlorination of aryl chlorides. During our further investigations, we surveyed the combination of transition metal chlorides and Grignard reagents for dechlorination of aryl chlorides. In this paper we would like to report a new system of iron catalyst/Grignard reagent for dechlorination of aryl chlorides.

Table 1. MCl$_n$-catalyzed dechlorination of 4-chloroanisole with n-BuMgCl

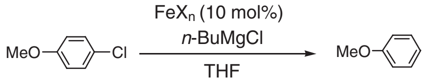


Entry	Catalyst	Time/h	Yield/%[a]
1	VCl$_3$	48	45
2	CrCl$_3$	48	53
3	MnCl$_2$	24	6
4	FeCl$_3$	24	84
5	CoCl$_2$	48	29
6	CuCl$_2$	48	27
7	ZnCl$_2$	24	0
8	MoCl$_5$	24	2
9	CdCl$_2$	24	0
10	LaCl$_3$	24	0

[a]Yields were determined by GC analyses.

A series of transition metal chlorides (10 mol %) were examined for dechlorination reaction of 4-chloroanisole with n-BuMgCl (3 equiv.) in THF at 50 °C. The results are summarized in Table 1. Interestingly, FeCl$_3$ showed the highest catalytic activity among them and anisole was obtained in 84% yield after 24 h (Entry 4). The activities of the other metal chlorides were much lower than that of iron catalyst under these conditions.

Table 2. Iron-catalyzed dechlorination of 4-chloroanisole



Entry	Catalyst	n-BuMgCl /equiv.	Temp /°C	Time /h	Yield[a] /%
1	FeCl$_3$	3.0	50	24	84
2	FeCl$_2$	3.0	50	48	93
3	Fe(acac)$_2$	3.0	50	48	61
4	FeCl$_3$	2.0	50	24	57
5	FeCl$_3$	3.0	rt	24	33

[a]Yields were determined by GC analyses.

In order to optimize the reaction conditions, several types of iron salts, reaction temperature, and the amount of n-BuMgCl were tested as shown in Table 2. Iron chlorides FeCl$_n$ ($n = 2$ or 3) were better than Fe(acac)$_2$ (Entries 1–3). Reducing the amount of the Grignard reagent significantly lowered the product yield (Entry 4). When the reaction was carried out at room temperature, the yield remarkably decreased (Entry 5). In the absence of iron salts, the reaction did not proceed.

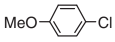
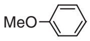
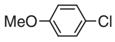
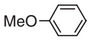
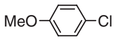
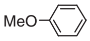
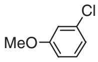
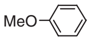
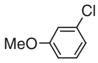
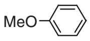
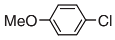
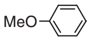
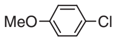
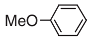
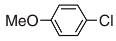
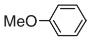
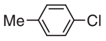
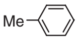
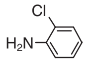
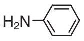
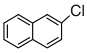
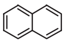
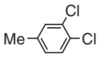
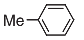
Table 3 summarizes the results of the FeCl$_3$-catalyzed dechlorination reactions of a series of aryl chlorides with several kinds of Grignard reagents. The dechlorination of 3- or 4-chloroanisole with a series of alkyl Grignard reagents gave anisole in high yields (Entries 1–4). When n-C$_{12}$H$_{25}$MgBr was employed for the reaction, 1-dodecene was formed in 107% GC yield based on 3-chloroanisole (Entry 5). On the other hand, in the cases of MeMgCl and PhCH$_2$MgCl without β-hydrogen, anisole was obtained only in 21 and 41% yield, respectively (Entries 6 and 7). It would suggest that the existence of β-hydrogen on the Grignard reagents is necessary for this reaction to proceed efficiently. For dechlorination of 4-chlorotoluene, 2-chloroaniline, and 2-chloronaphthalene, the desired products were formed in good to high yields (Entries 9–11). Double dechlorination of 3,4-dichlorotoluene was also examined with FeCl$_3$ (20 mol %) and n-BuMgCl (6.0 equiv.) to afford toluene in 85% yield (Entry 12).

Recently Fürstner et al. have reported that simple iron salts such as FeCl$_n$, Fe(acac)$_n$ ($n = 2$, 3) were highly efficient catalysts for cross-coupling reactions of alkyl Grignard reagents with aryl chlorides.[10] In sharp contrast, no coupling products were detected in the present reactions. Probably, the reason for such difference can be attributed to the electronic properties of the employed aryl chlorides. For the cross coupling reaction, electron-deficient substituents are required on aryl chlorides, whereas the reduction proceeds efficiently with electron-donating group on aryl chlorides.

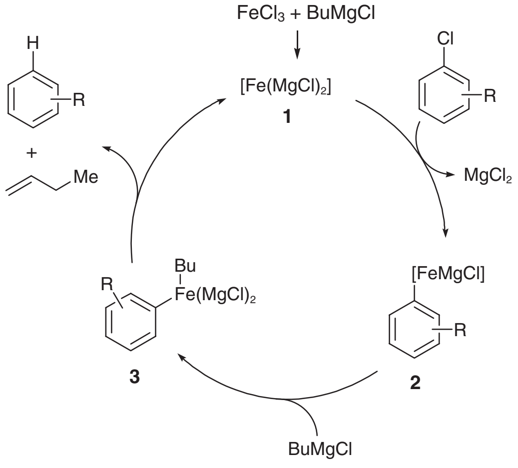
A proposed mechanism for the iron-catalyzed dechlorina-

Table 3. $FeCl_3$-catalyzed dechlorination of aryl chlorides

$$\text{Ar-Cl} \xrightarrow[\text{THF, 50 °C}]{\text{RMgX (3.0 equiv.), FeCl}_3\text{ (10 mol\%)}} \text{Ar-H}$$

Entry	Aryl Chloride	RMgX	Time/h	Product	Yield/%[a]
1		i-PrMgBr	48		94
2		*tert*-BuMgCl	48		90
3		$\text{PhCH}_2\text{CH}_2\text{MgCl}$	24		89
4		n-BuMgCl	24		91
5		n-$\text{C}_{12}\text{H}_{25}$MgBr	24		74
6		PhCH_2MgCl	48		41
7		MeMgCl	24		21
8		VinylMgBr	24		9
9		n-BuMgCl	48		95
10		n-BuMgCl	48		91
11		n-BuMgCl	6		66
12[b]		n-BuMgCl	48		85

[a] Yields were determined by GC analyses. [b] The reaction was carried out with 6 equiv. of BuMgCl and 20 mol % of $FeCl_3$.



Scheme 1.

tion of aryl chloride with Grignard reagent is shown in Scheme 1. This is based on the iron-catalyzed cross-coupling reaction proposed by Fürstner et al.[10a,b] The catalyst, $FeCl_3$, is reduced by BuMgCl to generate an ate complex **1**, which is active enough to react with an aryl chloride to form an aryliron complex **2**. Further reaction of **2** with BuMgCl produces a diorganoiron complex **3**. Finally, β-H elimination followed by reductive elimination affords a reduced arene.

It seems that a key intermediate is the complex **3**. When the aryl group is substituted with electron-withdrawing group, reductive elimination pathway is favored to give the cross coupling product. On the other hand, electron-donating groups on the aryl rings would increase the electron density of the iron atom in the intermediate **3**. It is well known that such electronic effect is unfavorable for reductive elimination.[11] Consequently, β-H elimination of the alkyl group would proceed instead of reductive elimination to afford the corresponding dechlorinated arene in the present reaction.

It is worth noting that the iron-catalyst shows significant reactivity even with MeMgCl or PhCH_2MgCl. It is remarkable contrast to the titanocene-catalyzed reaction, which did not work for the dechlorination at all with such Grignard reagents.[9b] The fact would suggest the existence of another reaction pathway in the present dechlorination, such as radical reaction.[12]

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