

Catalytic dechlorination of aromatic chlorides using Grignard reagents in the presence of $(C_5H_5)_2TiCl_2$

Ryuichiro Hara, Kimihiko Sato, Wen-Hua Sun and Tamotsu Takahashi*

Catalysis Research Center and Graduate School of Pharmaceutical Sciences, Hokkaido University, Sapporo 060-0811, Japan and CREST, Science and Technology Corporation (JST), Sapporo 060-0811, Japan.

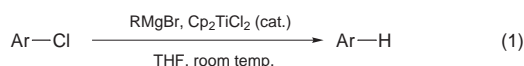
E-mail: tamotsu@cat.hokudai.ac.jp

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Dechlorination of aromatic chlorides was efficiently performed with alkyl Grignard reagents in the presence of a catalytic amount of $(C_5H_5)_2TiCl_2$.

Dehalogenation of organic halides is a fundamental subject in organic chemistry.¹ Therefore, diverse methods and a variety of reagents have been developed. The reactivity order of halogens is, in most cases, $I > Br > Cl \gg F$, and that of halogen-containing substrates is allylic \approx benzylic $>$ aliphatic $>$ aromatic. It is thus suggested that dechlorination of aromatic chlorides cannot readily be achieved,² and the development of methodology for such remains to be studied. In addition to the synthetic usefulness of the reaction, recently evolving ecological demands for dechlorination of pollutant perchlorinated compounds³ strongly motivated us toward this subject.⁴

We have recently published a report that $(C_5H_5)_2ZrCl_2$ catalyzed the efficient and selective debromination or deiodination reactions of aromatic halides using alkylmagnesium reagents.⁵ However, this reaction did not proceed at a significant level for chloro derivatives. During the course of our study on the dechlorination reactions of aromatic chlorides, we found that titanocene dichloride catalyzed the reduction of aromatic chlorides when used with appropriate alkylmagnesium reagents [eqn. (1)].



Colomer and Corriu reported early in 1974 that $Pr^iMgBr-(C_5H_5)_2TiCl_2$ reacted with various organic bromides and iodides in Et_2O to give the dehalogenated products.⁶ They suggested, however, that their system was not applicable to aromatic chlorides.

The use of THF as a solvent was found to dramatically improve the reactivity of the titanium-catalyzed dehalogenation reaction. A typical reaction procedure is as follows: To a solution of an aromatic chloride (1.0 mmol) and $(C_5H_5)_2TiCl_2$ (0.1 mmol, 0.1 equiv. with respect to the substrate) in THF (2.5 ml) was added BuMgCl (1.0 M solution in THF, 3.0 mmol, 3 equiv. at $-78^\circ C$). The reaction mixture was stirred at ambient temperature for several hours and the products were detected by GC and NMR.

Dechlorination of 4-chloroanisole was carried out using various Grignard reagents (Table 1). As expected, MeMgBr did not reduce 4-chloroanisole. The reaction with PhMgBr, which has an aromatic β -hydrogen, did not proceed. Bu^iCH_2MgBr which has γ - rather than β -hydrogens, gave a yield which did not exceed the amount of catalyst used. The reaction with Bu^iMgBr or EtMgBr gave moderate yields while the reactions with PrMgBr, Pr^iMgBr , Bu^iMgBr or BuMgCl gave high yields. Thus, the difference in reactivity may be due to both the β - and γ -hydrogens and their steric factors.

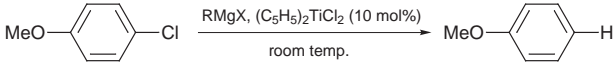
Table 2 shows the results of dechlorination of various aromatic chlorides. Chloroanisoles were reduced to anisole over varied reaction times (entries 2–4). Chloronaphthalenes were reduced within 30 min (entries 5 and 6). The hydroxy group of

4-chlorophenol was deprotonated by an additional equimolar amount of Grignard reagent and the reaction then proceeded (entry 7).

When 2,4-dichloroanisole was treated with a catalytic amount of $(C_5H_5)_2TiCl_2$ (0.2 mmol) and 6 equiv. of BuMgCl, the 2,4-dichloroanisole was completely consumed within 1 h. Anisole was obtained in 66% yield after 24 h, and 24% of 4-chloroanisole and 10% of 2-chloroanisole remained. Addition of 9 equiv. of BuMgCl did not significantly improve this situation.

Interestingly, when a combination of 1.0 equiv. of $(C_5H_5)_2TiCl_2$ and 2.0 equiv. of BuMgCl was used for the

Table 1 Assessment of Grignard reagents and solvents in the $(C_5H_5)_2TiCl_2$ -catalyzed dechlorination of 4-chloroanisole^a



Entry	RMgX	Solvent	Yield (%) ^b	Recovered <i>p</i> -chloroanisole (%) ^b
1	MeMgBr	THF	0	100
2	EtMgBr	THF	59	34
3	PrMgBr	THF	91	5
4	Pr^iMgBr	THF	93	0
5	BuMgCl	THF	95	0
6	BuMgCl	Et_2O	59	35
7	BuMgCl	hexane	53	38
8	Bu^iMgBr	THF	42	52
9	Bu^tMgBr	THF	81	17
10	Isopentyl MgBr	THF	83	15
11	Neopentyl MgBr	THF	5	90

^a The typical reaction conditions: 4-chloroanisole (1 mmol), alkylmagnesium reagent (3 mmol), $(C_5H_5)_2TiCl_2$ (0.1 mmol), room temperature, 48 h.
^b Yields were determined by GC.

Table 2 Results of $(C_5H_5)_2TiCl_2$ -catalyzed dechlorination reaction^a

Entry	Aromatic chloride	t/h	Yield (%) ^b	Recovered aromatic chlorides (%) ^b
1	PhCl	48	74 ^c	12
2	2-Chloroanisole	6	99	0
3	3-Chloroanisole	48	80	12
4	4-Chloroanisole	48	95	0
5	1-Chloronaphthalene	0.5	>99	0
6	2-Chloronaphthalene	0.5	>99	0
7 ^d	4-Chlorophenol	3	>99 ^c	0
8 ^e	2,4-Dichloroanisole	24	<i>f</i>	<i>f</i>

^a The typical reaction conditions: BuMgCl (3 equiv.), $(C_5H_5)_2TiCl_2$ (0.1 equiv.), room temperature. ^b Unless otherwise noted, yields were determined by GC. ^c Yield was determined by NMR. ^d BuMgCl (4 equiv.). ^e BuMgCl (6 equiv.), $(C_5H_5)_2TiCl_2$ (0.2 equiv.). ^f Yield of anisole: 66%; 2-ClC₆H₄OMe: 10%; 4-ClC₆H₄OMe: 24%; 2,4-Cl₂C₆H₃OMe: 0%.

stoichiometric reaction of 1-chloronaphthalene, we obtained only 10% of naphthalene after 1 h and 11% after 3 h. This is in sharp contrast to the fast reaction under catalytic conditions (see Table 2, entry 5) and the stoichiometric reduction of bromobenzene by $(C_5H_5)_2ZrBu_2$.⁵ Addition of an additional 1.0 equiv. of $BuMgCl$ promoted the reaction to afford 43% of the reduction product after 1 h. This suggests that the actual catalyst in the reaction is formed only when an excess of Grignard reagent is present, and the species is not solely $(C_5H_5)_2TiBu$ or $(C_5H_5)_2Ti-H$, which are thought to be formed in various hydrogenation reactions.⁷

The reduction of alkyl chlorides was also attempted under similar conditions. However, for example, 1-chlorooctane was reduced to octane in a moderate yield of 64% where isomers of octenes as by-products were detected. This may be due to the formation of an octyltitanium species followed by β -hydrogen elimination.

The reaction mechanism is not clear yet for our specific case although several possibilities in similar reactions have been discussed.⁶ The plausible intermediates are (i) $(C_5H_5)_2Ti^{III}-H$,⁸ which may transfer hydride through a four-membered transition state, (ii) a hydridomagnesium species,⁹ and (iii) direct β -hydride transfer from an alkyl substituent on titanium metal.

In conclusion, aromatic chlorides were successfully dechlorinated by alkylmagnesium reagents in the presence of a catalytic amount of $(C_5H_5)_2TiCl_2$, where the corresponding bromides and iodides were also dehalogenated. The choice of solvent was found to be important. Our investigation on this subject is still progressing to widen the scope and to clarify the mechanism.

Notes and references

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