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Aromatic iodination with iodine monochloride by using a catalytic amount of ferrocenium tetrakis(3,5-bis(trifluoromethyl)phenyl)borate[†]

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Abstract

Direct iodination reaction of several aromatic compounds with 1.1–2.0 molar amounts of iodine monochloride (ICl) proceeded smoothly to afford the corresponding aromatic iodides in good to excellent yields by using 5 mol% of $Cp_2FeB[3,5\text{-}(CF_3)_2C_6H_3]_4$ (**1**) in the coexistence of DDQ or ZnO. © 2000 Published by Elsevier Science Ltd.

Keywords: catalysis; halogenation; ferrocenes; aryl halides.

Aromatic iodides have widely been used as synthetic intermediates in the formation of new carbon–carbon or carbon–heteroatom bonds via replacement of their iodine atoms with electrophiles.[1] However, synthetic methods leading to aromatic iodides[2] by direct iodination of aromatic compounds are relatively limited compared with those of preparing aromatic chlorides and bromides because of the low electrophilicity of iodine.

Iodination of aromatic compounds was carried out by using molecular iodine together with a strong oxidizing agent such as nitric acid, sulfuric acid, iodic acid, sulfur trioxide or hydrogen peroxide[3] in order to generate a better electrophile by oxidation of molecular iodine. It was also reported that the aromatic iodination with molecular iodine was catalyzed by stoichiometric amounts of metal halides, such as $AlCl_3$–$CuCl_2$[4] or $SbCl_5$,[5] and a direct iodination was carried out by using NH_4I and catalytic amounts of $NOBF_4$ in CF_3COOH/CH_2Cl_2 or CF_3COOH/CH_3COOH with molecular oxygen.[6] In those methods, large amounts of aromatic compounds were needed and the reactions had to be conducted under strongly acidic conditions. Now, we would like to report direct iodination of several aromatic compounds with 1.1–2.0 molar

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[†] Dedicated to Professor H. H. Wasserman on the occasion of his 80th birthday.

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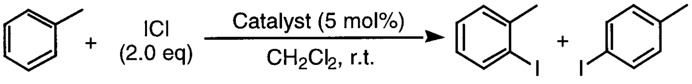
amounts of iodine monochloride (ICl) by using a catalytic amount of $Cp_2FeB[3,5\text{-}(CF_3)_2C_6H_3]_4$ (**1**) in the coexistence of DDQ or ZnO.

In order to carry out the direct iodination reaction under milder conditions, catalytic activation of an iodinating agent with mild Lewis acids having $B(C_6F_5)_4$ or $B[3,5\text{-}(CF_3)_2C_6H_3]_4$[7] anion was considered based on the following evidence. The above anions have been known as low-coordinating anions and were frequently employed as counter ions of several Lewis acid catalysts because they enhanced the Lewis acidities of the counter metals. Then, mild Lewis acids were expected to be obtained by combining those low-coordinating anions with counter metals, which were normally thought to have a low Lewis acidity.

First, lithium was chosen and $LiB(C_6F_5)_4$ (**2**) was used as the mild Lewis acid catalyst in the direct iodination of aromatic compounds. When catalytic iodination of toluene with ICl[8] was tried by using 5 mol% of **2**, the effect of the catalyst was not observed and a similar result to that of non-catalyzed iodination was obtained (Table 1, entries 1 and 3). Next, $LiB[3,5\text{-}(CF_3)_2C_6H_3]_4$ (**3**) was used and the desired products were then obtained in 68% yield (entry 5). The yields of the desired iodinated aromatic compounds were greatly improved in both **2**- and **3**-catalyzed reactions (entries 4 and 6) in the coexistence of DDQ, which might have worked as a radical trapping agent to suppress benzylic iodination.

Table 1
Effect of catalysts and DDQ[a]



Entry	Catalyst	Additive (0.5 equiv.)	Time/h	*o*/*p*[b]	Yield%[b]
1	None	None	8	49/51	48
2	None	DDQ	8	49/51	47
3	$LiB(C_6F_5)_4$ (**2**)	None	8	44/56	50
4	**2**	DDQ	8	48/52	91
5	$LiB(3,5\text{-}C_6H_3(CF_3)_2)_4$ (**3**)	None	10	46/54	68
6	**3**	DDQ	10	48/52	92
7	$Cp_2FeB(3,5\text{-}C_6H_3(CF_3)_2)_4$ (**1**)	None	10	46/54	61
8	**1**	DDQ	0.5	51/49	8
9[c]	**1**	DDQ	8	53/47	Quant.

[a] Diiodo and chlorinated products were not detected.

[b] Determined by GC analyses.

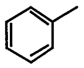
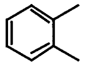
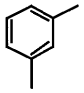
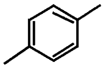
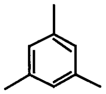
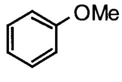
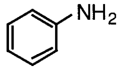
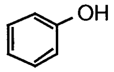
[c] The yields of *o*- and *p*-iodotoluene greatly decreased to 28% in a prolonged reaction time (24 h).

A ferrocenium ion was considered to have interacted with an electron at the outer sphere.[9] It was then figured that the ferrocenium ion would exhibit low Lewis acidity and that **1** would work as a mild Lewis acid in the iodination of aromatic compounds. Recently, Molins and co-workers reported on the preparation of **1**[10] and described that this ferrocenium salt could be purified easily by recrystallization and stored in air for at least one month. The iodination reaction using **1** alone did not give as good a result as **2**- and **3**-catalyzed reactions did, while the addition of DDQ was effective and the iodide was obtained in good yield.

Then, direct iodination of several more reactive aromatic compounds with ICl was tried by using 5 mol% of **1** (Table 2). It was found that **1**-catalyzed iodination effectively took place in the coexistence of zinc oxide (ZnO).[11] It was assumed that ZnO captured hydrogen chloride formed during the iodination reaction and it helped the smooth turnover of the catalyst **1**.

Table 2
Synthesis of aromatic iodides[a]

$$\mathrm{ArH} + \underset{(1.1\ \mathrm{eq})}{\mathrm{ICl}} \xrightarrow[\substack{\mathrm{ZnO}\ (1.0\ \mathrm{eq}) \\ \mathrm{CH_2Cl_2},\ \mathrm{r.t.}}]{\mathbf{1}\ (5\ \mathrm{mol\%})} \mathrm{ArI}$$

Entry	ArH	Time/h	*o*/*p*[b]	Yield/%[b]
1[c]		8	47/53	68
2		2	3-/4-iodo- *o*-xylene 79/21	83
3		3	4-iodo- *m*-xylene	91
4		3	—	70
5		3	—	93
6		3	11/89	95
7		3	5/95	88
8		3	16/84[e]	89[d]

[a] Diiodo and chlorinated products were not detected. [b] Determined by GC analyses. [c] ICl (2 eq) was used. [d] Isolated yield. [e] Determined by ^{1}H NMR spectra.

A typical experimental procedure for the iodination of toluene with ICl is as follows: to a mixture of **1** (0.05×10^{-1} mmol) and DDQ (0.55 mmol) in dichloromethane (2.20 mL), a solution of ICl in dichloromethane (1.0 M, 2.21 mL) was added at room temperature. After stirring for 30 min, toluene (117.6 μL, 1.11 mmol) was added and the reaction mixture was stirred for 8 h at room temperature.

The reaction was quenched by adding saturated aqueous sodium sulfite, and the mixture was extracted with ethyl acetate. The combined organic layer was washed with H_2O and brine, dried over $MgSO_4$, filtered and concentrated in vacuo. The yield and the isomeric ratio of aromatic iodides were determined by GC analysis (SHIMADZU CAPILLARY COLUMN HiCap Series CBP10-M25-0.25) of the resulting residue (quantitative, $o/p = 53/47$) by comparison with those of authentic samples. Neither diiodo nor chlorinated products were detected.

It is noted that the iodination of aromatic compounds with 1.1–2.0 molar amounts of ICl was effectively promoted by a catalytic amount of **1** in the coexistence of DDQ or ZnO at room temperature. The results shown in Table 2 demonstrate that **1** could serve as a mild Lewis acid catalyst in the present iodination reaction. Further investigation on applications of this novel catalyst system to other halogenation reactions is now in progress.

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