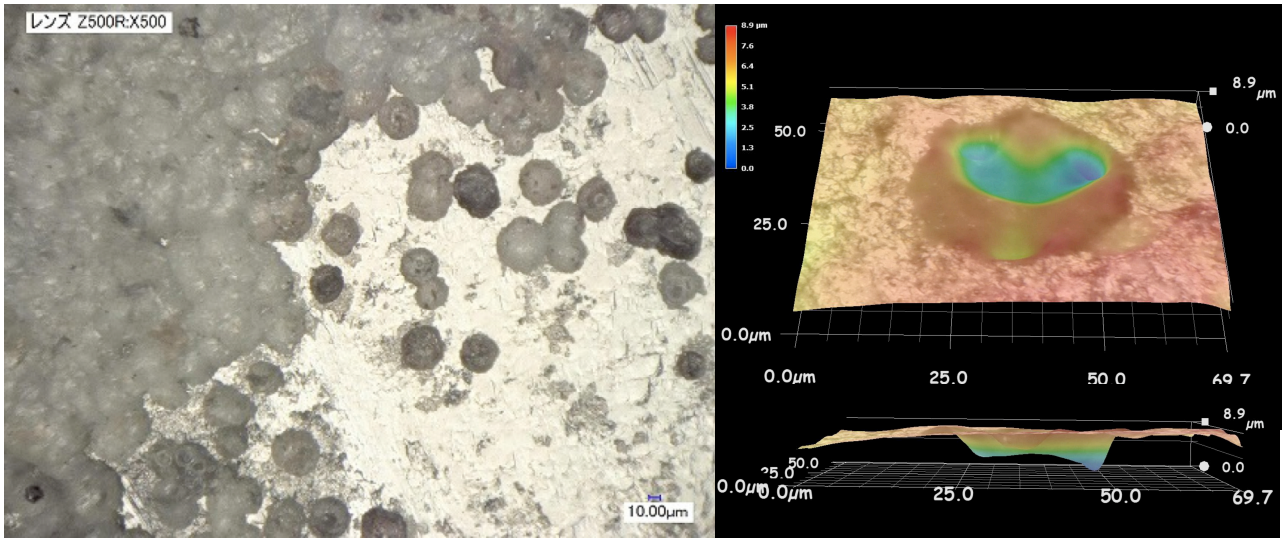


Figure 3-8. The photograph of the left side is a surface of metallic Mg after the reaction of **1a** in DMPU (conv. of **1a** = 24%). The photographes of the right side are one of the observed pits and its cross-sectional view.

The surface of the Cu-deposited Mg metal prepared from Mg ribbon and CuCl salt in the presence of Me_3Si-Cl in THF, is shown in **Figure 3-9**. As expected, several micrometer-sized Cu metal-deposits were observed on the Mg surface. Most surface of the Cu-deposited Mg metal retained metallic luster.

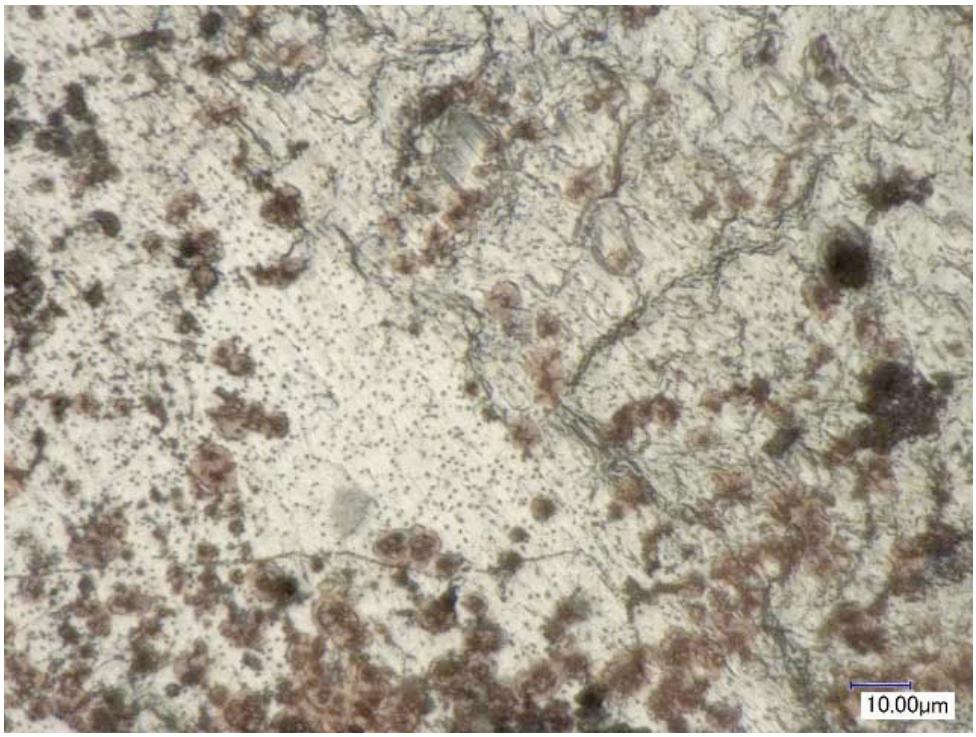
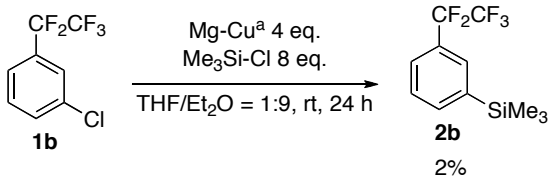


Figure 3-9. The surface of Cu-deposited Mg metal prepared from Mg ribbon and CuCl (molar ratio = 1:0.001) in THF and Me_3Si-Cl.

The surfaces of Cu-deposited Mg metal after the reaction of **1b** in THF/Et_2O (1:9) (conversion of **1b** = 3%, **Scheme 3-7**) were shown in **Figure 3-10**. No deep pit was observed on the surface. However, Cu-colored metal deposits were observed in black-colored region. The Cu-colored region (illustrated as green region in bottom photographs in **Figure 3-10**) was more frequently appeared in the black region than in the region having metallic luster. These observations suggest that the consumption of the Mg metal proceeded nearby the Cu-deposits.

The surface of further consumed Cu-deposited Mg metal (after the reaction shown in **Scheme 3-8**) was shown in **Figure 3-11**. Cu-colored metal was found on the border of the black pits and in the pits of the rough metallic Mg surface. Meanwhile, the metallic Mg surface distal to the Cu-deposits retained its metallic luster. These observations also suggest that the reaction proceed nearby the Cu-deposits.

The shapes of pits on Cu-deposited Mg metal shown in **Figure 3-11** were compared with those on metallic Mg after the reaction of **1b** in DMPU solvent shown in **Figure 3-8**. Deep (approximately 40 μm depth) noncircular black pits were observed on the surface of Cu-deposited Mg metal (the bottom photographs in **Figure 3-11**). Meanwhile, shallow (approximately 1-7 μm depth), uniformed circular black pits were observed in case of metallic Mg without Cu deposits, as reported by Bowyer and his coworkers [9b-c]. These results suggested that the consumption of Mg(0) atoms near the Cu deposits proceeds toward vertically rather than horizontally. In the case of metallic Mg without Cu, the consumption of metallic Mg proceed horizontally as proposed by Whitesides and his coworkers [9a]. This result also suggested that the reaction proceed nearby the Cu-deposits.



Scheme 3-7. The reaction for observation of surfaces of Mg-Cu. [a] Mg-Cu was prepared in advance in THF.

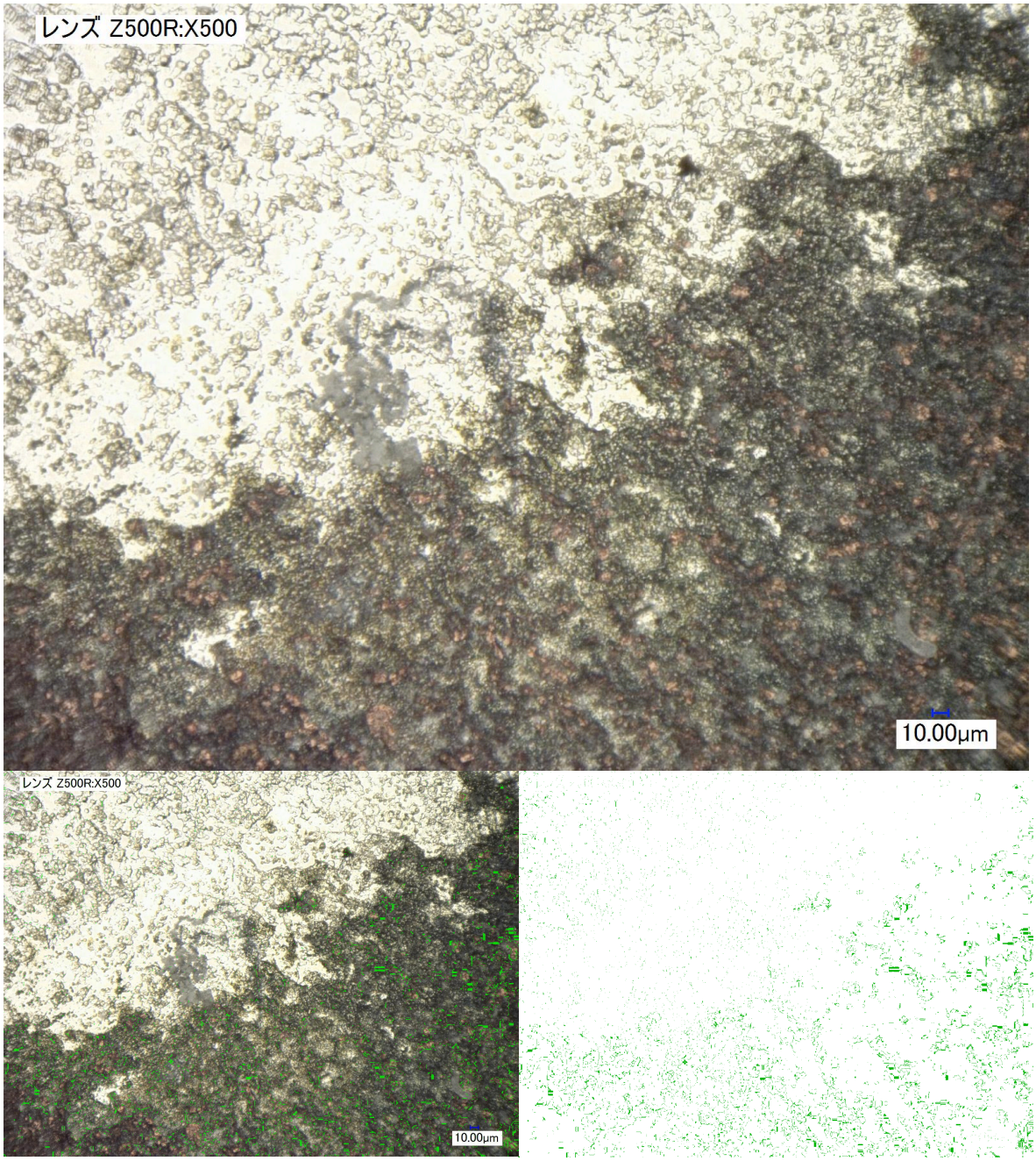
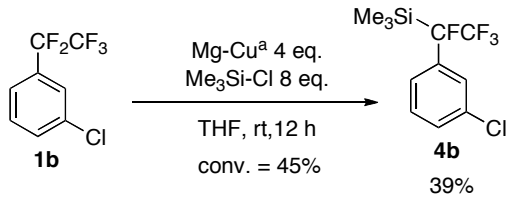


Figure 3-10. The top photograph shows a surface of Cu-deposited Mg metal after the reaction of **1b** in THF/Et_2O = 1:9 for 24 hours (**Scheme 3-7**). The bottom left figure shows a photograph after Cu-colored region was daubed with green. The bottom right figure shows only the Cu-colored region after being daubed with green in the picture.



Scheme 3-8. The reaction for observation of surfaces of Cu-deposited Mg metal. [a]Mg-Cu was prepared in advance in THF.

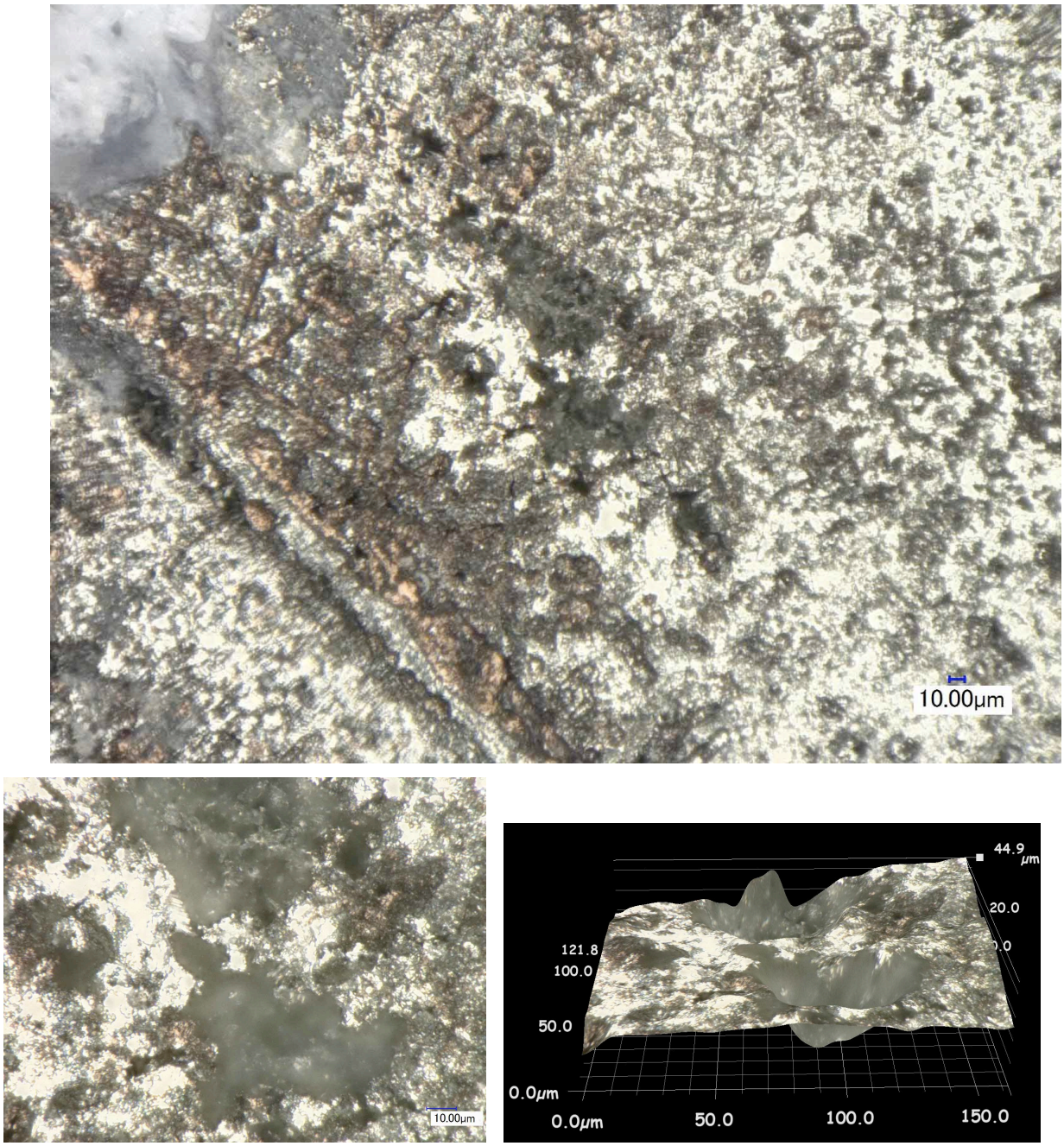


Figure 3-11. Photographs of the surfaces of Cu-deposited Mg metal after the reaction of **1b** in THF (**Scheme 3-8**). The bottom photographs show a deep black pit observed on the surface of Cu-deposited Mg metal after the reaction of **1b** in THF.

These observations of the surfaces of metallic Mg surfaces are consistent with the hypothetical scheme in **Figure 3-1**. The Cu metal on the surface attracts some free electrons from the metallic Mg, because Cu is a nobler metal than Mg. As a consequence, the surface of the metallic Mg gains some positive charge, which would promote interactions with the negatively charged halogen atoms of the substrates. This interaction between the metallic Mg surface and the halogen atoms would promote C-halogen bond cleavage with an initial outer-sphere electron transfer from the Cu-deposits.

3-3. Conclusions

The regioselective reductive dechloro-silylations of chloro-(pentafluoroethyl)benzenes (**1**) into trimethylsilyl-(pentafluoroethyl)benzenes (**2**) were performed. Reductive trimethylsilylation of compounds **1**s with Mg powder and Me_3Si-Cl (Mg/Me_3Si-Cl) in DMPU gave corresponding defluorinated (1,2,2,2-tetrafluoro-1-trimethylsilyl)-chlorobenzenes (**4**s) as the major product. While, the reactions of compounds **1** by Cu-deposited Mg and Me_3Si-Cl (Mg-Cu/ Me_3Si-Cl) in THF-Et_2O (1:9) gave corresponding Grignard reagent formation-type compounds **2**s as the sole products. The selectivity was explainable on the basis of conventional “diffusion mechanism of Grignard reagent formation”. The use of Cu-deposited Mg metal and a less polar solvent would allow concerted processes without formation of unstable anion radical species, to give Grignard-type compound selectively.

Microscope observations of Cu-deposited Mg metal suggested the magnesium around Cu(0) deposit was selectively consumed after the reactions. This observation indicate the reactions occurred only around the Cu-deposit, and is consistent with proposed mechanism of the effect of Cu, which is Cu(0) on magnesium forms “micro-sized electrode” to promote electron transfer from the magnesium.

3-4. Experimental section

3-4-1. General

All NMR spectra were recorded as $CDCl_3$ solutions. ^1H NMR (600 MHz) was recorded with Varian Unity INOVA AS600. ^1H NMR (400 MHz), ^{13}C NMR (100 MHz), ^{19}F NMR (376 MHz) spectra were recorded with Varian VNMRS-400 instrument. ^1H NMR (300 MHz), ^{13}C NMR (75 MHz), spectra were recorded with Varian-Mercury-300 instrument. ^{13}C NMR (50 MHz) spectra were recorded with Varian GEMINI-200 instrument. The chemical shifts are reported in δ (ppm) related to the $CHCl_3$ (7.26 ppm for ^1H NMR), $CDCl_3$ (77 ppm for ^{13}C NMR) and C_6F_6 (0 ppm for ^{19}F NMR: The relative chemical shift of C_6F_6 to $CFCl_3$ is –162.2 ppm). Coupling constants (*J*) are reported in hertz (Hz). Infrared spectra were recorded on a Hitachi 270-30 spectrometer. Only selected absorbances are reported (ν in cm^{-1}). MS analyses were performed on a Shimadzu GCMS-QP5050A. Elemental analyses were performed on a Perkin Elmer series II CHNS/O Analyzer 2400. Microscope observations were performed on KEYENCE VHX-1000. Mg powder was purchased from Merck (particle size 0.1 mm, 97% pure, synthetic grade. catalog # 8.18506.0100). Magnesium ribbon for microscope-observations was purchased from Aldrich (≧99.5% Mg basis, catalog# 13103-25G). Copper(I) chloride was purchased from Wako pure chemicals (99.9% purity, catalog# 033-12482).

3-4-2. Typical procedure for preparations of (pentafluoroethyl)benzenes (1a-c)

Copper(I) iodide (9.62 g, 50 mmol) was heated with a heating gun until it becomes greenish in vacuo. Sodium pentafluoropropionate (12.3 g, 65 mmol) was added and dried in vacuo for 60 minutes. Substituted iodobenzene (50 mmol) and NMP (72 ml) was added and stirred for 5 h under argon at 170 °C. Direct distillation of the crude reaction mixture afforded mixture of NMP and **1**. The crude product was washed with water for 3 times. Then, organic phase was separated and dried with Molecular Sieves 3Å. Compound **1** was obtained as colorless oil.

1-Chloro-4-(pentafluoroethyl)benzene (**1a**). 79% Yield. Colorless oil. bp 67 °C/50 mmHg. ^1H NMR (300 MHz, $CDCl_3$) δ 7.54 (d, *J* = 8 Hz), 7.49 (d, *J* = 8 Hz). ^{19}F NMR (283 MHz, $CDCl_3$) δ 76.9 (s, 3F), 46.8 (s, 2F).

1-Pentafluoroethyl-4-(trifluoroethyl)benzene (**1c**). ^1H NMR (400 MHz, $CDCl_3$) δ 7.75 (d, *J* = 8 Hz, 2H), 7.79 (d, *J* = 8 Hz, 2H). ^{19}F NMR (376 MHz, $CDCl_3$) δ 46.3 (s, 2F), 77.1 (s, 3F), 98.5 (s, 3F). EI MS *m/z* (% relative intensity) 264 (M+, 17), 195 (100), 145 (48).

3-4-3. Typical procedure for preparations of bromo(pentafluoroethyl)benzenes (1d and 1e)

Copper(I) bromide (14.35 g, 100 mmol) and sodium pentafluoropropionate (12.3 g, 65 mmol) were dried in vacuo for 2 hours. Then, bromo-iodobenzene (14.15 g, 50 mmol) was added. Then, NMP (72 ml) was added and stirred for 6 hours under argon gas at 170 °C. Direct distillation of the crude reaction mixture (70 °C/40 mmHg) afforded mixture of **1**, several by-products, and NMP. The crude product was washed with water for 3 times to remove NMP. Then, organic phase was separated and dried over Molecular Sieves 3Å. Mixture of **1** was obtained as colorless oil. The product was found 80-90% pure, which contains a few by-products.

Solution of nickel bromide (4.4 g, 20 mmol) in anhydrous NMP (72 ml) was heated at 170 ℃ under an argon atmosphere. The mixture of bromo(pentafluoroethyl)benzene (10 mmol, containing 6% of iodo(pentafluoroethyl)benzene) was added dropwise and the mixture was stirred for 6 hours at 170 ℃. After allowing mixture to cool to room temperature, the reaction mixture was poured into 60 ml of water in a separating funnel. Organic phase was extracted with diethyl ether (5 ml×5) from water. Ether solution was washed with water for 4 times to remove NMP. Then, organic phase was washed with brine. The solution was dried over $MgSO_4$. Purification by a short column on silica gel and distillation afforded bromo(pentafluoroethyl)benzenes **1d** and **1e**, respectively.

1-Bromo-4-(pentafluoroethyl)benzene (**1d**). 20% yield. Colorless oil. bp 70 °C/40 mmHg. IR ν_{max}(neat)/cm^{-1} 1650, 1490, 1340, 1210. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.47 (d, *J* = 8 Hz, 1H), 7.65 (d, *J* = 8 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 113.2 (tq, *J* = 253, 38 Hz), 119.4 (qt, *J* = 286, 39 Hz), 126.9 (br), 127.8 (t, *J* = 25 Hz), 128.1 (br), 132.1 (s). ^{19}F NMR (283 MHz, $CDCl_3$) δ 46.6 (s, 2F), 76.9 (s, 3F). EI MS *m/z* (relative intensity) 276 (M^+, 46), 274 (28), 207 (100), 205 (97), 126 (8), 75 (15). Elemental Anal. Calc for $C_{11}H_{13}F_5Si$: C, 34.94; H, 1.47; N, 0.00. Found: C, 34.95; H, 1.46; N, 0.00.

1-Bromo-3-(pentafluoroethyl)benzene (**1e**). 20% yield. Colorless oil. bp 70 °C/40 mmHg**.** IR ν_{max}(neat)/cm^{-1} 1580, 1430. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.39 (t, *J* = 8 Hz, 1H), 7.54 (d, *J* = 8 Hz, 1H), 7.72 (d, *J* = 8 Hz, 1H), 7.75 (s, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 112.6 (tq, *J* = 254, 39 Hz), 118.9 (qt, *J* = 286, 39 Hz), 122.8 (s), 125.1 (br), 129.6 (br), 130.3 (br), 130.8 (t, *J* = 24 Hz), 135.1 (s). ^{19}F NMR (283 MHz, $CDCl_3$) δ 46.7 (s, 2F), 77.0 (s, 3F). EI MS *m/z* (relative intensity) 276 (M^+, 65), 274 (41), 207 (97), 205 (100), 126 (48), 75 (18). Elemental Anal. Calc for $C_{11}H_{13}F_5Si$: C, 34.94; H, 1.47; N, 0.00. Found: C, 34.93; H, 1.47; N, 0.00.

3-4-4. Typical procedure for selective reductive dechloro-silylation from Chloro(pentafluoroethyl)-benzenes (1) with use of Cu-deposited Mg/Me_3Si-Cl.

Mg powder (0.486 g, 20 mmol) and copper(I) chloride (0.248 g, 2.5 mmol) were stirred in THF (2.0 ml) for 5 minutes under an argon atmosphere. The solution became dark suspension. Then, Et_2O (18.0 ml) and Me_3Si-Cl (40 mmol, 5.0 ml) was added to the solution and stirred for 10 minutes at 40 °C (bath temperature). 1-Chloro-3-(perfluoroethyl)benzene (**1b**) (1.1578 g, 5 mmol) was added dropwise over 10 minutes into the stirred suspension. The suspension was stirred for additional 10 hours at 40 °C (bath temperature, reflux). After evaporation of the solvent, residual Mg and Cu were filtrated through celite with hexane. The mixture of the products was purified by column chromatography on silica gel (hexane eluent), and provided compound **2b** as colorless oil (1.07 g, 80%). Additional distillation gave the product of higher purity.

1-(Pentafluoroethyl)-4-(trimethylsilyl)benzene (**2a**). Colorless oil. 69% Yield (determined on ^{19}F NMR). bp 95 °C/40 mmHg. IR ν_{max} (neat) 2960 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ 0.35 (s, 9H), 7.62 (d, *J* = 8 Hz, 2H), 7.71 (d, *J* = 8 Hz, 2H). ^{13}C NMR (50 MHz, $CDCl_3$) δ −1.4 (s), 113.6 (tq, *J* = 251, 37 Hz), 119.3 (qt, *J* = 284, 39 Hz), 125.5 (t, *J* = 7 Hz), 129.1 (t, *J* = 24 Hz), 133.6 (s), 145.7 (s). ^{19}F NMR (283 MHz, $CDCl_3$) δ 46.6 (s, 2F), 77.0 (s, 3F). EI MS *m/z* (% relative intensity) 268 (M^+, 3), 253 (100), 92 (21), 77 (11). Elemental Anal. Calc for $C_{11}H_{13}F_5Si$: C, 49.24; H, 4.88. Found: C, 49.07; H, 5.01.

1-(Pentafluoroethyl)-3-(trimethylsilyl)benzene (**2b**). Colorless oil. 80% Yield. bp 95 °C/40 mmHg. IR ν_{max} (neat) 2970 cm^{-1}. ^1H NMR (600 MHz, $CDCl_3$) δ 0.30 (s, 9H), 7.48 (t, *J* = 8 Hz, 1H), 7.57 (d, *J* = 8 Hz, 1H), 7.71 (partially overlapping d, *J* = 8 Hz, 1H), 7.69 (partially overlapping s, 1H). ^{13}C NMR (150 MHz, $CDCl_3$) δ −1.42 (s), 113.7 (tq, *J* = 254, 39 Hz), 119.2 (qt, *J* = 286, 40 Hz), 126.7 (t, *J* = 6.3 Hz), 127.9 (s), 128.1 (t, *J* = 24 Hz), 130.8 (t, *J* = 6 Hz), 136.8 (s), 141.8 (s). ^{19}F NMR (283 MHz, $CDCl_3$) δ 46.8 (s, 2F), 76.9 (s, 3F). EI MS *m/z* (% relative intensity) 268 (M^+, 2), 253 (100), 203 (25), 92 (28), 77 (16). Elemental Anal. Calc for $C_{11}H_{13}F_5Si$: C, 49.24; H, 4.88. Found: C, 49.18; H, 5.11.

(Pentafluoroethyl)benzene (**3**). Volatile colorless oil (the authentic sample). ^1H NMR (600 MHz, $CDCl_3$) δ 7.51 (t, *J* = 7.2 Hz, 2H), 7.58 (t, *J* = 7.2 Hz, 1H), 7.60 (d, *J* = 7.2 Hz, 2H). ^{19}F NMR (283 MHz, $CDCl_3$) δ 46.8 (s, 2F), 77.0 (s, 3F). EI MS *m/z* (relative intensity) 196 ($[M]^+$, 25), 127 (100), 77 (15).

1-[1',2',2',2'-Tetrafluoro-1'-(trimethylsilyl)ethyl]-4-chlorobenzene (**4a**). Colorless oil. 32% Yield (determined by ^{19}F NMR). bp 40 °C/0.1 mmHg. IR ν_{max} (neat) 2970 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.16 (s, 9H), 7.28 (d, *J* = 8.4 Hz, 2H), 7.38 (d, *J* = 8.4 Hz, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ –3.7 (s), 95.4 (dq, *J* = 185, 34 Hz), 124.9 (qd, *J* = 282, 25 Hz), 125.4 (d, *J* = 11 Hz), 128.7 (d, *J* = 3 Hz), 133.6 (d, *J* = 18 Hz), 134.0 (s). ^{19}F NMR (283 MHz, $CDCl_3$) δ –36.3 (q, *J* = 12 Hz, 1F), 89.9 (d, *J* = 12 Hz, 3F). EI MS *m/z* (% relative intensity) 194 (M^+ – Me_3SiF, 26), 192 (78), 157 (8), 73 (100). Elemental Anal. Calc for $C_{11}H_{13}ClF_4Si$: C, 46.40; H, 4.60. Found: C, 46.62; H, 4.53.

1-[1',2',2',2'-Tetrafluoro-1'-(trimethylsilyl)ethyl]-4-(trifluoromethyl)benzene (**4c**). 66% Yield. Colorless oil. bp 120 °C/ 15 mmHg. IR ν_{max} (neat) 2980 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.48 (d, *J* = 8 Hz, 2H), 7.67 (dd, J = 8, 2 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ –3.8 (s), 95.6 (dq, *J* = 184, 34 Hz), 124.0 (q, *J* = 270 Hz), 124.4 (dd, *J* = 12, 1 Hz), 125.4 (t, *J* = 3 Hz), 125.0 (dq, *J* = 280, 25 Hz), 130.0 (q, *J* = 33 Hz), 139.2 (d, *J* = 18 Hz). ^{19}F NMR (376 MHz, $CDCl_3$) δ –36.3 (q, *J* = 11 Hz, 1F), 90.3 (d, *J* = 11 Hz, 3F), 99.1 (s, 3F). EI MS *m/z* (% relative intensity) 226 (M^+ – Me_3SiF, 100), 73 (49). Elemental Anal. Calc for $C_{12}H_{13}F_7Si$: C, 45.28; H, 4.12. Found: C, 45.26; H, 3.82.

1-[1',2',2',2'-Tetrafluoro-1'-(trimethylsilyl)ethyl]-4-(trimethylsilyl)benzene (**5a**). Colorless oil. 78% yield (determined by ^{19}F NMR). bp 50 °C/0.1 mmHg. IR ν_{max} (neat) 2960 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$) δ 0.16 (s, 9H), 0.27 (s, 9H), 7.31 (d, *J* = 8 Hz, 2H), 7.52 (d, *J* = 8 Hz, 2H). ^{19}F NMR (283 MHz, $CDCl_3$) δ –37.5 (q, *J* = 12 Hz, 1F), 90.1 (d, *J* = 12 Hz, 3F). EI MS *m/z* (% relative intensity) 230 (M^+ – Me_3SiF, 19), 215 (100), 77 (26), 73 (82). Elemental Anal. Calc for $C_{14}H_{22}F_4Si_2$: C, 52.14; H, 6.88. Found: C, 51.88; H, 6.85.

1-[1',2',2',2'-Tetrafluoro-1'-(trimethylsilyl)ethyl]-3-(trimethylsilyl)benzene (**5b**). Colorless oil. 68% Yield (determined by ^{19}F NMR). bp 50 °C/0.1 mmHg. IR ν_{max} (neat) 2970 cm^{-1}. ^{1}H NMR (600 MHz, $CDCl_3$) δ 0.15 (s, 9H), 0.27 (s, 9H), 7.33 (d, *J* = 8 Hz, 1H), 7.37 (tt, *J* = 8, 1 Hz, 1H), 7.46 (partially overlapping d, *J* = 1 Hz, 1H), 7.48 (partially overlapping dt, *J* = 8, 1 Hz, 1H). ^{13}C NMR (50 MHz, $CDCl_3$) δ –3.5 (s), –1.2 (s), 95.7 (dq, *J* = 184, 33 Hz), 125.4 (dq, *J* = 281, 25 Hz), 124.2 (d, *J* = 12 Hz), 127.6 (s), 128.5 (d, *J* = 10 Hz), 132.7 (s), 134.0 (d, *J* = 19 Hz), 140.5 (s). ^{19}F NMR (283 MHz, $CDCl_3$) δ –37.4 (q, *J* = 9 Hz, 1F), 90.1 (d, *J* = 9 Hz, 3F). EI MS *m/z* (% relative intensity) 230 (M^+ – Me_3SiF, 31), 215 (94), 77 (28), 73 (100). Elemental Anal. Calc for $C_{14}H_{22}F_4Si_2$: C, 52.14; H, 6.88. Found: C, 52.03; H, 6.71.

3-4-5. Grignard reactions from bromo(trifluoromethyl)benzenes

Conventional method (Table 3-7, entries 1 and 3)

Mg turnings (0.0875 g, 3.6 mmol) were heated with a heating gun in vacuo for 1 hour. After cooling, THF 3 ml was added. Then, THF solution of bromo(trifluoromethyl)benzene (0.675 g, 3.0 mmol, 5 M solution) was added dropwise over 15 minutes and stirred for additional 30 minutes at room temperature. The solution of Grignard reagent was cannulated into the solution of benzophenone (0.547 g, 3.0 mmol) in Et_2O (3 ml) over 15 minutes under an argon atmosphere at room temperature. The reaction mixture was stirred for 12 hours (over night) at room temperature. The reaction mixture was quenched with saturated NH_4Cl aq. (5 ml). Then, extracted with Et_2O (5 ml × 5) and washed with brine. Obtained pale yellow solution was dried over $MgSO_4$ and evaporated. The purification by silica gel column chromatography (hexane : Et_2O = 20 : 1, R*f* = 0.04) gave the adduct **6**. The yellow viscous oil **6** was weighed after removal of solvents in vacuo.

Improved method (Table 3-7, entries 2 and 4)

Mg powder (0.0875 g, 3.6 mmol) was heated with a heating gun in vacuo over 1 hour. After cooling, CuCl was added and dried in vacuo for 15 minutes again. Anhydrous THF (3 ml) was added and stirred for 30 minutes under an argon atmosphere. The magnesium powder got dark and greenish color of CuCl disappeared. Then, Et_2O (9 ml) was added. A bromobenzotrifluoride (0.675 g, 3.0 mmol) was cannulated into Mg-Cu suspension. The color change of solution into brown was immediately observed. The reaction mixture was stirred for 30 minutes at room temperature. The solution of the Grignard reagent was cannulated into the solution of benzophenone (0.5467 g, 3.0 mmol) in Et_2O (3 ml) over 15 minutes under an argon atmosphere at room temperature. The reaction mixture was stirred for 12 hours (over night) at room temperature. The reaction mixture was quenched with saturated NH_4Cl aq. (5 ml). Then, extracted with Et_2O (5 ml × 5) and washed with brine. Obtained pale yellow solution was dried over $MgSO_4$ and evaporated. The purification by silica gel column chromatography (hexane : Et_2O = 20 : 1, R*f* = 0.04) gave the adduct **6**. The yellow viscous oil **6** was weighed after removal of solvents in vacuo.

Diphenyl(4-(trifluoromethyl)phenyl)methanol (**6a**) [ref. 10]. 74% yield (Conventional method). 79% yield (Improved method). Pale yellow viscous oil. IR ν_{max} (neat)/cm^{-1} 3490 (broad), 3070, 1620. ^1H NMR (600 MHz, $CDCl_3$) δ 2.82 (s, 1H), 7.24-7.26 (m, 4H), 7.30-7.35 (m, 6H), 7.46 (d, *J* = 8.4 Hz, 2H), 7.57 (d, *J* = 8.4 Hz, 2H). ^{19}F NMR (564 MHz, $CDCl_3$) δ 99.2 (s). EI-MS *m/z* (relative intensity) 328 $[M]^+$ (10), 251 (34), 183 (44), 173 (46), 105 (100), 77 (30).

Diphenyl(3-(trifluoromethyl)phenyl)methanol (**6b**) [ref. 10]. 83% yield (Conventional method). 82% yield (Improved method). Pale yellow viscous oil. IR ν_{max} (neat)/cm^{-1} 3490 (broad), 1600. ^1H NMR (600 MHz, $CDCl_3$) δ 2.83 (s, 1H), 7.24-7.25 (m, 4H), 7.29-7.35 (m, 6H), 7.42 (t, *J* = 7.8 Hz, 1H), 7.45 (d, *J* = 7.2 Hz, 1H), 7.54 (d, *J* = 7.2 Hz, 1H), 7.69 (br, 1H). ^{19}F NMR (564 MHz, $CDCl_3$) δ 99.3 (s). EI-MS *m/z* (relative intensity) 328 $[M]^+$ (16), 251 (48), 183 (54), 173(54), 105 (100), 77 (32).

3-4-6. Preparations of Cu-deposited Mg and metallic Mg for microscope-observations

3-4-6-1. Preparation of metallic Mg after the reaction of compound 1a in DMPU

Cut Mg ribbon (0.0486 g, 2 mmol) was stood still in DMPU (2 ml), Me_3Si-Cl (0.5 ml, 4 mmol) and substrate **1a** (0.1158 g, 0.5 mmol) under an argon atmosphere for 12 hours (from 0 °C to room temperature). The supernatant liquid was analyzed by ^{19}F NMR and GC-MS. The conversion of **1a** was 24% (determined by ^{19}F NMR based on α,α,α-trifluorotoluene as an internal standard). Then, residual Mg ribbon was filtered and washed by 30 ml of anhydrous THF quickly and gently. Observation of Mg-Cu surface was carried out immediately after drying by N_2 gas. The photographs were shown in **Figure 3-8**.

3-4-6-2. Preparation of Cu-deposited Mg

Cut magnesium ribbon (ca. 10 mm × 3 mm × 0.2 mm, 0.2431 g, 10 mmol) and CuCl (0.0010 g, 0.01 mmol) were stood still in THF (5 ml), Me_3Si-Cl (2.5 ml, 20 mmol) at room temperature for 12 hours. Yellow color was disappeared. Then, Cu-deposited Mg was filtered and washed by 30 ml of anhydrous THF gently. Observation of Mg-Cu was carried out immediately after drying by N_2 gas. A picture was shown in **Figure 3-9**.

3-4-6-3. Preparation of Cu-deposited Mg after the reaction of compound 1b (conv. = 3%)

Cu-deposited Mg prepared in THF shown above (0.0486 g, 2 mmol) was stood still in THF/Et_2O (1:9) (1 ml), Me_3Si-Cl (0.5 ml, 4 mmol) and substrate **1b** (0.1158 g, 0.5 mmol) at room temperature under an argon atmosphere for 24 hours. The supernatant liquid was analyzed by ^{19}F NMR and GC-MS. The result was shown in **Scheme 3-7** (determined by ^{19}F NMR based on α,α,α-trifluorotoluene as an internal standard). Then, Cu-deposited Mg was filtered and washed by 10 ml of anhydrous THF quickly and gently. Observation of Mg-Cu surface was carried out immediately after drying by N_2 gas. The pictures were shown in **Figure 3-10**.

3-4-6-4. Preparation of Cu-deposited Mg after the reaction of compound 1b (conv. = 45%)

Cu-deposited Mg prepared in THF shown above (0.0486 g, 2 mmol) was stood still in THF (1 ml), Me_3Si-Cl (0.5 ml, 4 mmol) and substrate **1b** (0.1158 g, 0.5 mmol) at room temperature under an argon atmosphere for 12 hours. The supernatant liquid was analyzed by ^{19}F NMR and GC-MS. The result was shown in **Scheme 3-8**. The conversion of substrate **1b** was 45% (determined by ^{19}F NMR based on α,α,α-trifluorotoluene as an internal standard). Then, Cu-deposited Mg was filtered and washed by 10 ml of anhydrous THF quickly and gently. Observation of Mg-Cu surface was carried out immediately after drying by N_2 gas. The pictures were shown in **Figure 3-11**.

3-5. References

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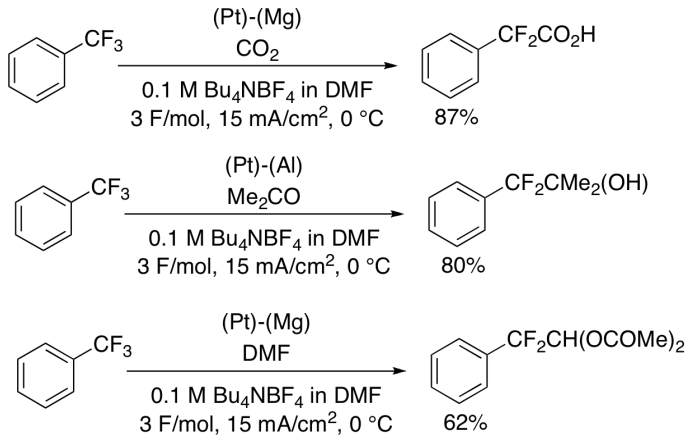
Chapter 4. Reductive reactions of benzotrifluoride derivatives by Cu-deposited Mg and chlorotrimethylsilane

4-1. Introduction

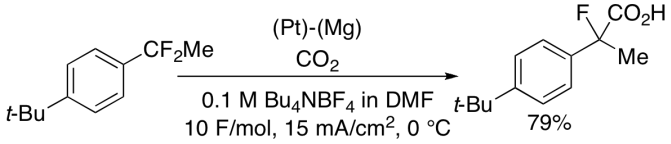
4-1-1. Conventional reductions of benzotrifluoride derivatives

Reductive defluorination of benzotrifluoride derivatives has been studied by several groups [1,2,3]. Electrochemical reductive defluorinations of benzotrifluoride using electrophiles such as CO_2 [2a], acetone [2a], DMF [2a], and Me_3Si-Cl [3] had been reported (**Scheme 4-1**). This transformation was successfully applied to the syntheses of various fluorinated nonsteroidal anti-inflammatory drugs (NSAIDs) (**Scheme 4-2**) [2b].



Saboureau, C.; Troupel, C.; Sibille, S.; Perichon, S. *Chem. Commun.* **1989**. 1138-1139.

Scheme 4-1. Examples of electroreductive benzylic defluorinations

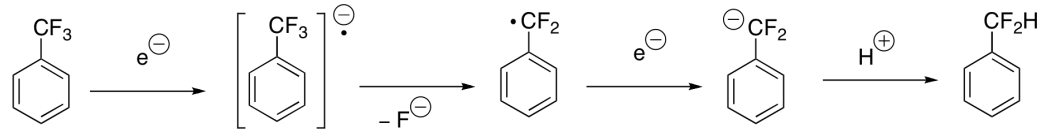


Yamauchi, Y.; Fukuhara, T.; Hara, S.; Senboku, H. *Synlett* **2008**, 438-442.

Scheme 4-2. An example for the electrochemical syntheses of various fluorinated nonsteroidal anti-inflammatory drugs (NSAIDs)

Electrochemical benzylic defluorination of benzotrifluoride derivatives have been studied [1] by

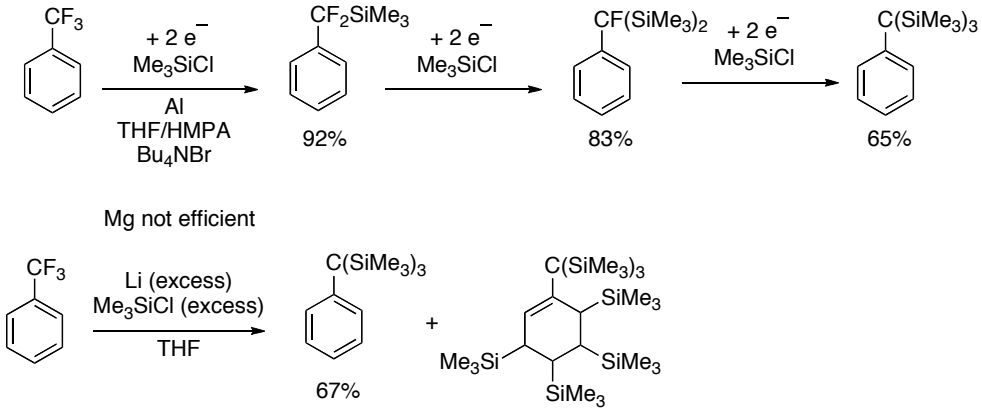
several groups since the first report on electrochemical benzylic defluorination-hydration by Lund in 1959 [1a]. A plausible mechanism without passing thorough carbene species was suggested by Audrieux et al. (**Scheme 4-3**) [1e]. In their report, anion radical species was considered to be an intermediate of C-F bond cleavage.



Andrieux,C.-P.; Combellas, C.; Kanoufi, F.; Savéant, J.-M.; Thiébault, A. *J. Am. Chem. Soc.* **1997**, *119,* 9527-9540.

Scheme 4-3. A proposed mechanism for electroreductive defluorinations of benzotrifluoride

Meanwhile, Mg metal-promoted reductive defluorination-silylation was reported to be "not efficient" by Clavel et al., in their report of electrochemical benzylic defluorination-silylation of benzotrifluoride (**Scheme 4-4**) [3a]. The reductive reaction by Li metal results in formation of completely defluorinated-silylated compounds. This would be caused by high reducing ability of lithium metal for removal of just one fluorine atom of benzotrifluoride. Meanwhile, the reducing ability of metallic Mg would be low for defluorination of benzotrifluoride.



Clavel, P.; Léger-Lambert, M-P.; Biran, C.; Serein-Spirau, F.; Bordeau, M.; Roques, N.; Marzouk, H. *Synthesis* **1999**, 829-834.

Scheme 4-4. Reductive defluorinations of benzotrifluoride by electrochemical reduction or Li metal

The results shown in chapter 2 and chapter 3 prompted us to evaluate the effect of Cu-deposits on metallic Mg surface. The reductive defluorinations of benzotrifluoride derivatives by Cu-deposited Mg metal for evaluation of the reducing ability of it were performed. The reasons for selection of reductive defluorinations of benzotrifluoride derivatives are as follows. (1) We can verify the LUMO energy level of the substrates by simple change of the substituents on the aromatic rings. (2) Benzotrifluoride is difficult to be reductively defluorinated by metallic Mg, as reported. From the reasons shown above, the reductive defluorinations of benzotrifluoride derivatives were performed to evaluate the reducing ability of Cu-deposited Mg metal.

4-2. Results and discussion

The Cu(0) on Mg accelerated reductive defluorination of benzotrifluoride **1f**. The effects of activation methods of powdered metallic Mg were summarized in **Table 4-1**. Conventional and popular activation method (annealing of metallic Mg surface, addition of catalytic amount of I_2, and ultrasonic irradiation) resulted in insufficient conversion of the substrates (entries 1-3). While use of Cu-deposited Mg prepared from powdered metallic Mg (4 eq.) and CuCl (0.1 eq.) gave compound **2f** in 26% yield with large standard deviation. Use of Cu-deposited Mg metal prepared from powdered metallic Mg (4 eq.) and CuCl (0.5 eq.) gave compound **2f** and **3f** in 67% yield and 3% yield, respectively (entry 5). Addition of Cu(0) powder (0.5 eq.) to suspension of powdered metallic Mg also gave compound **2f** in better yield than the conventional activation methods (entry 6). Here, the use of the Cu(0) powder in the absence of metallic Mg resulted in complete recovery of the substrate **1f**. These results are consistent with the working hypothetical shown in chapter 2 and chapter 3, and imply that “Cu(0) deposits on metallic Mg surface” promote the reductive defluorination of

benzotrifluoride **1f**.

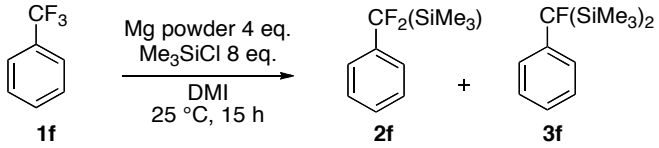
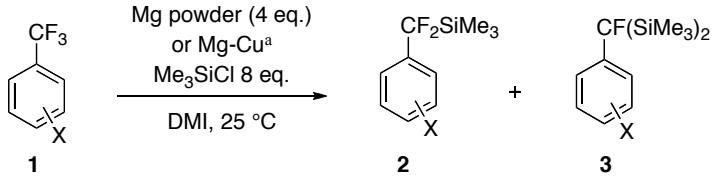


Table 4-1. Effects of activations of powdered metallic Mg

entry	Activation of Mg	Temp. [°C]	Conv. [%][a]	Yield of **2f** [%][a]	Yield of **3f** [%][a]
1	Annealing[b]	25	2±1	2±1	0±0
2	Annealing[b]	50	9±1	9±1	0±0
3	Annealing[b] + I_2 (cat.) + sonication [c]	around 50	10±6	10±6	0±0
4	CuCl (0.1 eq.) [d]	25	26±17	26±17	0±0
5	CuCl (0.5 eq.) [d]	25	70±14	67±13 (90)	3±2 (6)
6	Cu(0) powder (0.5 eq.)[e]	25	25±2	25±2	0±0
7	Cu(0) powder (0.5 eq.)[e] without Mg(0)	25	0±0	0±0	0±0

[a] The reactions were performed on 0.5 mmol scale for 5 times. Product distributions were determined by ^{19}F NMR. Values are mean values of 5 experiments. Standard deviations were calculated from results of 5 experiments. The values in parentheses are isolated yields on 5 mmol scale. [b] Powdered metallic Mg was annealed in vacuo by a heating gun at around 200 °C. [c] Ultrasonic was irradiated during the reaction. [d] Powdered Mg and CuCl were mixed in DMI for 15 minutes just prior to the reaction. [e] Grain diameter of Cu(0) powder is approximately 3 μm.

The results of the reductive defluorinations of compound **1** by both metallic Mg and Cu-deposited Mg metal in DMI are summarized in **Table 4-2**. The LUMO energy levels of the substrates were calculated by Hartree-Fock (HF) with 6-31G** basis set in MacSpartan plus package program. The reaction of chloro-substituted benzotrifluorides (**1a** and **1c**) led to the formation of Grignard-type dechloro-silylation products and defluoro-silylated products in the DMI solvent (**Scheme 4-5**).

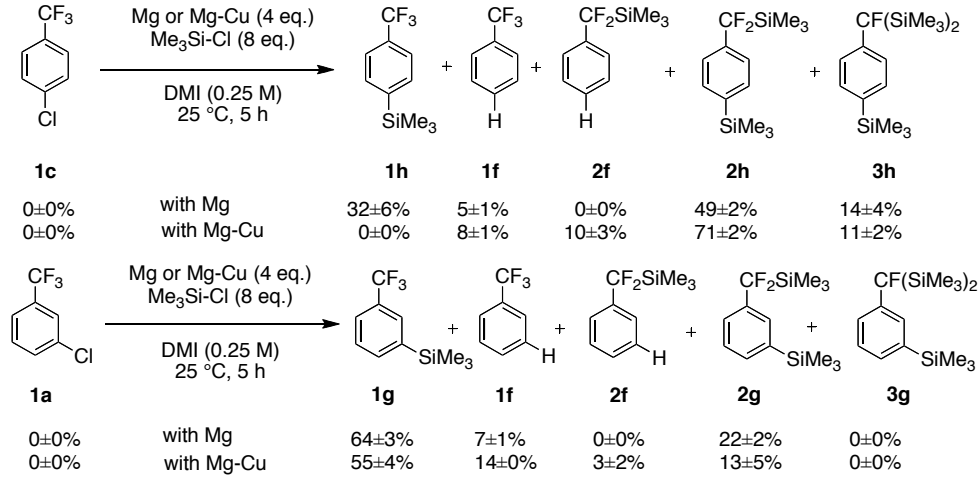


1 **2** **3**

Table 4-2. The effects of substituent on benzotrifluoride derivatives in reductive defluorination with use of Mg/Me_3Si-Cl system

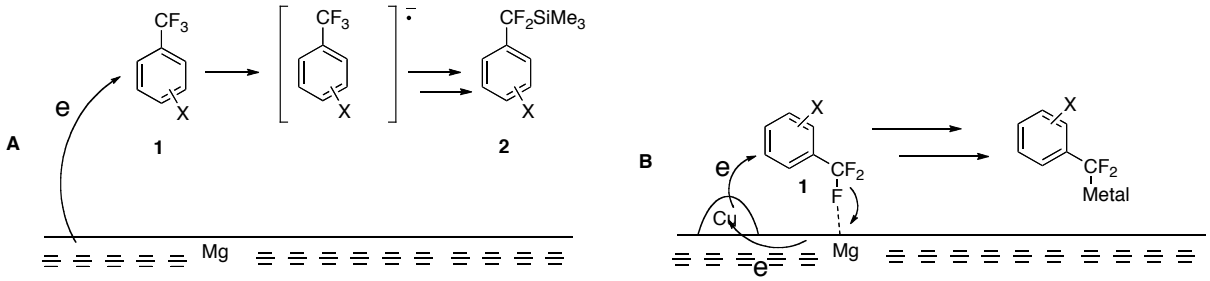
entry	X (compound)	σ_m or σ_p	LUMO level [eV] [d]	time [h]	Results in cases Mg was used [%] [b]			Results in cases Mg-Cu was used [%] [b]		
					conv.	**2**	**3**	conv.	**2**	**3**
1	3-Cl (**a**)	0.37	2.776	5	100±0	See **Scheme 4-5**		100±0	See **Scheme 4-5**	
2	3-F (**b**)	0.34	2.602	5	98±2	93±2 (86)	5±2	100±0	2±3	97±3 (96)
3	4-Cl (**c**)	0.23	2.769	5	100±0	See **Scheme 4-5**		100±0	See **Scheme 4-5**	
4	3-OMe (**d**)	0.12	2.945	15	2±1	2±1	0±0	46±24	45±22 (91)	1±2 (2)
5	4-F (**e**)	0.06	2.908	15	0±1	0±1	0±0	57±12	57±12 (85)	0±0
6	H (**f**)	0	3.049	15	2±1	2±1	0±0	70±14	67±13 (90)	3±2 (6)
7	3-$SiMe_3$ (**g**)	–0.04	2.881	5	1±0	1±0	0±0	95±2	53±5 (82)	42±6 (16)
8	4-$SiMe_3$ (**h**)	–0.07	2.657	15	17±16	17±16 (78)	0±0	99±2	35±15	63±16 (94)
9	3,5-Me_2 (**i**)	–0.14	3.070	15	0±0	0±0	0±0	16±4	16±4 (57 [c])	0±0
10	3-NMe_2 (**j**)	–0.16	3.063	15	0±0	0±0	0±0	5±2	5±2 (32 [c])	0±0
11	4-Me (**k**)	–0.17	3.300	15	0±0	0±0	0±0	8±2	8±2 (68 [c])	0±0
12	4-OMe (**l**)	–0.27	3.053	15	0±0	0±0	0±0	0±0	0±0 (0 [c])	0±0
13	4-NMe_2 (**m**)	–0.83	3.422	15	0±0	0±0	0±0	0±0	0±0 (0 [c])	0±0

[a] Mg-Cu was in situ prepared from Mg powder (4 eq.) and CuCl (0.5 eq.) in DMI just before the reaction. [b] Product distributions were determined by ^{19}F NMR. Other products were not detected by ^{19}F NMR and GC. Numbers in parentheses are isolated yields on 5 mmol scale. [c] The reaction condition for isolation of products is 50 °C, 0.5 M (substrate/DMI). [d] The LUMO energy levels of the substrates were calculated by Hartree-Fock (HF) with 6-31G** basis set in MacSpartan plus package program.



Scheme 4-5.

Here, we should note that the σ values showed the limitations of the reaction of the Cu-deposited metallic Mg, although the LUMO level showed the limitations of the reaction of metallic Mg. **Table 4-2** is arranged according to the σ values of the substrates and clearly shows the limitations of the reaction on Cu-deposited Mg metal between $-0.27 < \sigma_{limit} < -0.17$. Meanwhile, the order of the substrates does not show the limitations of the reaction of Mg without Cu-deposits. The limitation of the reaction by Mg metal without Cu-deposits was shown by the arrangement according to the LUMOs instead of that according to the σ values. This alteration of the scale of the limitations is consistent with the hypothetical **Scheme 4-6**. That is, the extent of the concerted electron transfer reactions involving outer-sphere and inner-sphere electron transfers on the surface of Cu-deposited metallic Mg would be determined by the stability of the possible metal anionoid species of **Scheme 4-6B**. Meanwhile, the stepwise outer-sphere electron transfer(s) on the metallic Mg without Cu-deposits would be determined by the LUMO levels of the substrates (**Scheme 4-6A**). These hypothetical mechanisms were consistent with those suggested in chapter 3 (**Figure 3-1**).



Scheme 4-6. A plausible mechanism of reductive defluorinations of benzotrifluoride derivatives using metallic Mg (A) or Cu-deposited Mg metal (B).

4-3. Conclusions

As conclusions, Cu-deposited Mg metal could reduce benzotrifluoride derivatives which have 0.1-0.3 eV higher LUMO energy level than did Mg. The order of the reactivities of substrates was

consistent with Hammett σ values rather than calculated LUMO energy level. This result implied that rate-determining step includes C-F bond cleavage process, which shows Cu activates C-F bond cleavage process. Results of reductive defluorinations of benzotrifluoride derivatives are also consistent with this hypothesis.

4-4. Experimental section

4-4-1. Procedures for preparations of benzotrifluoride derivatives (1)

3,5-Dimethylbenzotrifluoride and 4-methylbenzotrifluoride (**1i** and **1k**): Anhydrous sodium trifluoroacetate (4.0 eq.) and copper(I) iodide (2.0 eq.) was stirred in NMP under an argon atmosphere at room temperature. 1-Iodo-3,5-dimethylbenzene (30 mmol) or 1-iodo-4-methylbenzene (30 mmol) was added to the suspension. The suspension was stirred for additional 5 hours at 160 °C. Direct distillation gave the mixture of the product and NMP. The mixture was washed by cold water for 3 times. The upper layer was dried over MS 3A.

4-(Trifluoromethyl)anisole (**1l**): Compound **1l** was prepared according to ref. 4. 4-(trifluoromethyl)phenol (4.05 g, 25 mmol) was stirred with methyl iodide (5.0 g, 35 mmol) and $CaCO_3$ (3.51 g , 25.4 mmol) in refluxing acetone (50 ml) for 12 hours. After removal of white solid by filtration and subsequent evaporation, the resulting solution and white solid was extracted by ether from water (5 ml×6) and was washed with brine. After drying over Na_2SO_4 and evaporation, 4-(trifluoromethyl)anisole was obtained in 95% yield.

4-(Dimethylamino)benzotrifluoride (**1m**): Compound **1m** was prepared according to the ref. 5. A slurry of 4.35 g (0.027 mol) of 4-(trifluoromethyl)aniline, 6 g (0.16 mol) of sodium borohydride, and 50 mL of tetrahydrofuran (THF) was made in a beaker. A solution was prepared by adding first 8.3 mL of 35% aqueous formaldehyde and then 7 ml of 3 M sulfuric acid to 50 mL of THF in a 500 mL round-bottom flask equipped with a stirrer and condenser and sitting in a water bath. The slurry was then added dropwise to the flask, allowing the reaction mixture to cool between each addition. After half the slurry had been added, another 7 mL of 3 M sulfuric acid was added. On completion of the reaction, solid KOH was added to raise the pH to 1**.** The organic layer was separated, combined with ether extracts of the aqueous layer, washed with brine, dried over magnesium sulfate, and rotary evaporated to yield a crude product consisting of white crystals. The crude product was recrystallized twice from ethanol/water and dried under vacuum to yield 2 g of the pure amine. ^{1}H NMR (300 MHz,

$CDCl_3$) δ 3.02 (s, 6H), 6.71 (d, J = 8.4 Hz, 2H), 7.45 (d, J = 8.7 Hz, 2H). ^{19}F NMR (283 MHz, $CDCl_3$) δ 100.9 (s, 3F).

3-(Dimethylamino)benzotrifluoride (**1j**): A mixture of 4-(trifluoromethyl)aniline (4.83 g, 30 mmol) and trimethyl phosphate (4.29 g, 30.6 mmol) was stirred under an argon atmosphere at 150 °C for 1 hour and at 186 °C for 2 hours. After addition of 10 ml of NaOH aq. (3 M), the solution was extracted with ether from water (5 ml × 6) and was washed with brine. After drying over Na_2SO_4 and evaporation, distillation (130 °C/15 mmHg) gave 3.5 g of product in 61% yield as colorless liquid.

4-4-2. Representative Procedure for Reductive defluorination from benzotrifluoride derivatives with use of Mg-Cu/Me_3Si-Cl.

a) For **Table 4-2**, copper(I) chloride (0.025 g, 0.25 mmol) and Mg powder (0.049 g, 2 mmol) were stirred in DMI (2 ml) and Me_3Si-Cl (0.5 ml, 4 mmol) for 15 minutes under an argon atmosphere. Then, a benzotrifluoride derivative **1** (0.5 mmol) was added dropwise into the dark suspension. The solution was stirred for additional time (see **Table 4-2**), keeping the temperature at 25 °C (bath temperature). After decantation, supernatant liquid was analyzed by ^{19}F NMR and GC with 4-(trifluoromethyl)anisole as an internal standard.

b) For isolations of the major products, copper(I) chloride (0.248 g, 2.5 mmol) and Mg powder (0.486 g, 20 mmol) were stirred in DMI (20 ml, 10 ml for **2i**, **2j**, **2k**) and Me_3Si-Cl (5 ml, 40 mmol) for 15 minutes under an argon atmosphere. Then, a benzotrifluoride derivative **1** (5 mmol) was added dropwise over 5 minutes into the dark suspension. The solution was stirred for additional time (see **Table 4-2**), keeping the temperature 25 °C (bath temperature, 50 °C for **2i**, **2j**, **2k**). After addition of 5 ml of hexane, Mg-Cu was removed by decantation and the suspension was simultaneously extracted with hexane (5 ml × 5). Then, the combined hexane layer was washed with 10 wt% HCl aq. and brine. After drying over sodium sulfate, purification by column chromatography on silica gel (hexane eluent) and distillation afforded the product.

Difluoro(trimethylsilyl)methylbenzene (**2f**). Colorless oil. 90% Yield (5 mmol scale). bp 100 °C/15 mmHg. IR ν_{max} (neat) 2970 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$) δ 0.14 (s, 9H), 7.3–7.4 (m, 5H). [δ 0.21 (s, 9H), 7.26–7.45 (m, 5H) (ref 3a)] ^{13}C NMR (50 MHz, $CDCl_3$) δ –4.8 (s), 124.6 (t, J = 7 Hz), 128.2 (s), 128.2 (t, J = 263 Hz), 128.7 (s), 138.2 (t, J = 20 Hz). [δ –4.9 (s), 128.3 (s), 124.7 (t, J = 8 Hz), 128.8 (t, J = 2.6 Hz), 134.5 (t, J = 265 Hz), 138.3 (t, J = 20.4 Hz). (ref 3a)] ^{19}F NMR (376 MHz, $CDCl_3$) δ 49.4 (s). [δ 49.7 (s) (ref 3a)] EI MS *m/z* (% relative intensity) 127 (M^+ – Me_3Si, 3). 108 (M^+ – Me_3SiF, 100), 81 (19), 77 (15), 73 (44). Elemental Anal. Calcd for $C_{10}H_{14}F_2Si$: C, 59.96; H, 7.04.

Found: C, 59.99; H, 7.23.

[Fluoro-bis(trimethylsilyl)]methylbenzene (**3f**). Colorless oil. 6% Yield (5 mmol scale). ^{1}H NMR (600 MHz, $CDCl_3$) δ 0.08 (s, 18H), 7.04 (br, 2H), 7.09 (dt, *J* = 7, 1 Hz, 1H), 7.29 (t, *J* = 8 Hz, 2H). [δ 0.23 (s, 18H), 7.08–7.40 (m, 5H) (ref 3a)] ^{19}F NMR (376 MHz, $CDCl_3$) δ −56.2 (s). [δ −56.7 (s) (ref 3a)] EI MS *m/z* (% relative intensity) 162 (M^+ – Me_3SiF, 41), 147 (100), 135 (43), 77 (22), 73 (53).

1-Fluoro-3-[difluoro(trimethylsilyl)methyl]benzene (**2b**). Colorless oil. 86% Yield (5 mmol scale). bp 110 °C/20 mmHg. IR ν_{max} (neat) 2970 cm^{-1}. ^{1}H NMR (600 MHz, $CDCl_3$) δ 0.14 (s, 9H), 7.04 (partially overlapping dq, *J* = 11, 1 Hz, 1H), 7.07 (partially overlapping tq, *J* = 8, 1 Hz, 1H), 7.11 (tq, *J* = 8, 1 Hz, 1H), 7.38 (q, *J* = 8 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ –4.9 (s), 111.9 (dt, *J* = 24, 8 Hz), 115.8 (dt, *J* = 19, 2 Hz), 120.4 (td, *J* = 7, 3 Hz), 127.5 (t, *J* = 265 Hz), 130.0 (d, *J* = 7 Hz), 140.7 (td, *J* = 21, 7 Hz), 162.6 (d, *J* = 245 Hz). ^{19}F NMR (376 MHz, $CDCl_3$) δ 49.4 (td, *J* = 9, 6 Hz, 1F), 49.5 (s, 2F). EI MS *m/z* (% relative intensity) 145 (M^+ – Me_3Si, 5), 126 (M^+– Me_3SiF, 100), 77 (16), 73 (61). Elemental Anal. Calcd for $C_{10}H_{13}F_3Si$: C, 55.02; H, 6.00. Found: C, 54.87; H, 6.30.

1-Fluoro-3-[bis(trimethylsilyl)fluoromethyl]benzene (**3b**). Colorless oil. 96% Yield (5 mmol scale). bp 110 °C/20 mmHg. IR ν_{max} (neat) 2970 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.07 (d, *J* = 1 Hz, 18H), 6.76 (br, 2H), 6.77 (tdd, *J* = 8, 2, 1 Hz 1H), 7.23 (q, *J* = 7 Hz, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ –2.46 (d, *J* = 44 Hz), 99.6 (d, *J* = 158 Hz), 108.4 (t, *J* = 29 Hz), 110.8 (d, *J* = 21 Hz), 116.6 (d, *J* = 12 Hz), 129.3 (d, *J* = 7 Hz), 147.6 (dd, *J* = 14, 7 Hz), 163.2 (d, *J* = 245 Hz). ^{19}F NMR (376 MHz, $CDCl_3$) δ –54.0 (s, 1F), 48.6 (br, 1F). EI MS *m/z* (% relative intensity) 180 (M^+ – Me_3SiF, 53), 165 (100), 153 (43), 139 (38), 77 (72), 73 (87). Elemental Anal. Calcd for $C_{13}H_{22}F_2Si_2$: C, 57.30; H, 8.14. Found: C, 57.67; H, 8.23.

1-[Difluoro(trimethylsilyl)methyl]-3-methoxybenzene (**2d**). Colorless oil. 91% Yield (5 mmol scale). bp 110 °C/3 mmHg. IR ν_{max} (neat) 2970 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.15 (s, 9H), 3.82 (s, 3H), 6.87 (q, *J* = 1 Hz, 1H), 6.90 (dq, 8, 1 Hz, 1H), 6.92 (dq, 8, 1 Hz, 1H), 7.32 (t, *J* = 8 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ –4.9 (s), 55.1 (s), 110.2 (t, *J* = 8.2 Hz), 114.3 (t, *J* = 2 Hz), 117.0 (t, *J* = 7 Hz), 128.0 (t, *J* = 263 Hz), 129.4 (s), 139.7 (t, *J* = 20 Hz). ^{19}F NMR (376 MHz, $CDCl_3$) δ 49.6 (s). EI MS *m/z* (% relative intensity) 230 (M^+, 12) 138 (M^+ – Me_3SiF, 70), 109 (58), 77 (26), 73 (100). Elemental Anal. Calcd for $C_{11}H_{16}F_2OSi$: C, 57.36; H, 7.00. Found: C, 57.42; H, 7.26.

1-[Fluoro-bis(trimethylsilyl)methyl]-3-methoxybenzene (**3d**). Colorless oil. 2% Yield (5 mmol scale). bp 150 °C/3 mmHg. IR ν_{max} (neat) 2960 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.07 (d, *J* = 1 Hz, 18H), 3.79 (s, 3H), 6.58 (br m, 2H), 6.61 (ddd, *J* = 8, 3, 1 Hz, 1H), 7.19 (t, *J* = 8 Hz). ^{13}C NMR (100 MHz, $CDCl_3$) δ –2.39 (d, *J* = 4 Hz), 55.0 (s), 99.9 (d, *J* = 156 Hz), 107.1 (d, *J* = 16 Hz), 109.2 (s), 113.6 (d, *J* = 12 Hz), 128.7 (s), 146.2 (d, *J* = 13 Hz), 159.5 (br). ^{19}F NMR (376 MHz, $CDCl_3$) δ –55.0 (s). EI MS *m/z* (% relative intensity) 285 (M^+, 11), 192 (M^+ – Me_3SiF, 25), 177 (65), 165 (36), 89 (37), 77 (46), 73 (100).

1-[Difluoro(trimethylsilyl)methyl]-3-(dimethylamino)benzene (**2j**). Colorless oil. 32% Yield (5 mmol scale). bp 110 °C/0.8 mmHg. IR ν_{max} (neat) 2970 cm^{-1}. ^{1}H NMR (600 MHz, $CDCl_3$) δ 0.15 (s, 9H), 2.96 (s, 6H), 6.66 (s, 1H), 6.68 (d, *J* = 8 Hz, 1H), 6.73 (d, *J* = 8 Hz, 1H), 7.25 (t, *J* = 8 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ –4.78 (s), 40.4 (s), 108.5 (t, *J* = 8 Hz), 112.8 (partially overlapping t, *J* = 2 Hz), 112.8 (partially overlapping t, *J* = 8 Hz), 128.5 (t, *J* = 263 Hz), 128.9 (s), 138.8 (t, *J* = 20 Hz), 150.3 (s). ^{19}F NMR (376 MHz, $CDCl_3$) δ 49.5 (s). EI MS *m/z* (% relative intensity) 243 (M^+, 60), 150 (M^+ – Me_3SiF, 100), 136 (42), 77 (13), 73 (60). Elemental Anal. Calcd for $C_{12}H_{19}F_2NSi$: C, 59.22; H, 7.87; N, 5.76. Found: C, 59.35; H, 8.02. N, 5.87.

1-[Difluoro(trimethylsilyl)methyl]-3,5-dimethylbenzene (**2i**). Colorless oil. 57% Yield (5 mmol scale). bp 60 °C/0.8 mmHg. IR ν_{max} (neat) 2980 cm^{-1}. ^{1}H NMR (600 MHz, $CDCl_3$) δ 0.13 (s, 9H), 2.34 (s, 6H), 6.93 (s, 2H), 7.00 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ –4.82 (s), 21.3 (s), 122.4 (t, *J* = 8 Hz), 128.4 (t, *J* = 263 Hz), 130.4 (t, *J* = 2 Hz), 137.8 (s), 138.1 (t, *J* = 39 Hz). ^{19}F NMR (376 MHz, $CDCl_3$) δ 50.0 (s). EI MS *m/z* (% relative intensity) 228 (M^+, 1), 136 (M^+ – Me_3SiF, 100), 77 (11), 73 (53). Elemental Anal. Calcd for $C_{12}H_{18}F_2Si$: C, 63.12; H, 7.95. Found: C, 63.15; H, 7.56.

1-[Difluoro(trimethylsilyl)methyl]-3-(trimethylsilyl)benzene (**2g**). Colorless oil. 82% Yield (5 mmol scale). bp 70 °C/0.6 mmHg. IR ν_{max} (neat) 2970 cm^{-1}. ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.14 (s, 9H), 0.28 (s, 9H), 7.32 (d, *J* = 8 Hz, 1H), 7.39 (t, *J* = 8 Hz, 1H), 7.46 (s, 1H), 7.53 (d, *J* = 7 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ –4.89 (s), –1.23 (s), 125.0 (t, *J* = 8 Hz), 127.5 (s), 128.5 (t, *J* = 264 Hz), 129.4 (t, *J* = 8 Hz), 133.7 (t, *J* = 3 Hz), 137.2 (t, *J* = 39 Hz), 140.6 (s). ^{19}F NMR (376 MHz, $CDCl_3$) δ 49.2 (s). EI MS *m/z* (% relative intensity) 257 (M^+ – CH_3, 5), 180 (M^+ – Me_3SiF, 67), 165 (28), 73 (100). Elemental Anal. Calcd for $C_{13}H_{22}F_2Si_2$: C, 57.30; H, 8.14. Found: C, 57.42; H, 8.41.

1-[Fluoro-bis(trimethylsilyl)methyl]-3-(trimethylsilyl)benzene (**3g**). Colorless oil (a mixture with isomer **8h**). 16% Yield (5 mmol scale). bp 110 °C/0.6 mmHg. IR ν_{max} (neat) 2960 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 0.08 (s, 18H), 0.26 (s, 9H), 7.09 (br, 1H), 7.13 (br, 1H), 7.23 (dt, *J* = 7, 1 Hz, 1H), 7.28 (t, *J* = 7 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ −2.38 (d, *J* = 4 Hz), −1.14 (s), 100.0 (d, *J* = 155 Hz), 121.8 (d, *J* = 15 Hz), 126.0 (d, *J* = 11 Hz), 127.3 (s), 128.9 (s), 139.2 (s), 143.3 (d, *J* = 7 Hz). ^{19}F NMR (376 MHz, $CDCl_3$) δ −57.0 (s). EI MS *m/z* (% relative intensity) 311 ($M^+ - CH_3$, 1), 234 ($M^+ - Me_3SiF$, 3). 146 (53), 73 (100).

1-[Difluoro(trimethylsilyl)methyl]-4-flourobenzene (**2e**). Colorless oil. 85% Yield (5 mmol scale). bp 100 °C/15 mmHg. IR ν_{max} (neat) 2980 cm^{-1}. ^1H NMR (600 MHz, $CDCl_3$) δ 0.13 (s, 9H), 7.09 (t, *J* = 8 Hz, 2H), 7.31 (dd, *J* = 8, 6 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.04 (s), 115.3 (d, *J* = 22 Hz), 126.7 (q, *J* = 24 Hz), 128.0 (t, *J* = 264 Hz), 134.3 (dt, *J* = 21, 3 Hz), 163.0 (dt, *J* = 246, 3 Hz). ^{19}F NMR (376 MHz, $CDCl_3$) δ 48.8 (tt, *J* = 8, 6 Hz, 1F), 50.4 (d, *J* = 3 Hz, 2F), EI MS *m/z* (% relative intensity) 145 ($M^+ - Me_3SiF$, 7), 126 ($M^+ - Me_3SiF$, 100), 73 (44). Elemental Anal. Calcd for $C_{10}H_{13}F_3Si$: C, 55.02; H, 6.00. Found: C, 55.07; H, 6.06.

1-[Fluoro-bis(trimethylsilyl)methyl]-4-fluorobenzene (**3e**). Colorless oil. 2% Yield (5 mmol scale). bp 70 °C/0.6 mmHg. ^1H NMR (400 MHz, $CDCl_3$) δ 0.06 (s, 18H), 6.9−7.0 (m, 4H). ^{19}F NMR (376 MHz, $CDCl_3$) δ −55.1 (s, 1F), 41.5 (quint, *J* = 7 Hz, 1F). EI MS *m/z* (% relative intensity) 180 ($M^+ - Me_3SiF$, 47), 165 (100), 153 (50), 77 (67), 73 (90).

1-[Difluoro(trimethylsilyl)methyl]-4-toluene (**2k**). Colorless oil. 68% Yield (5 mmol scale). bp 110 °C/15 mmHg. IR ν_{max} (neat) 2970 cm^{-1}. ^1H NMR (600 MHz, $CDCl_3$) δ 0.13 (s, 9H), 2.37 (s, 3H), 7.20 (d, *J* = 8 Hz, 2H), 7.22 (d, *J* = 8 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ −4.90 (s), 21.1 (s), 124.6 (t, *J* = 8 Hz), 128.5 (t, *J* = 263 Hz), 128.9 (s), 135.4 (t, *J* = 20 Hz), 138.6 (t, *J* = 3 Hz). ^{19}F NMR (376 MHz, $CDCl_3$) δ 50.1 (s). EI MS *m/z* (% relative intensity) 122 ($M^+ - Me_3SiF$, 100), 73 (35). Elemental Anal. Calcd for $C_{11}H_{16}F_2Si$: C, 61.64; H, 7.52. Found: C, 61.42; H, 7.64.

1-[Difluoro(trimethylsilyl)methyl]-4-(trimethylsilyl)benzene (**2h**). White solid. 78% Yield (5 mmol scale). Mp 42−43 °C. bp 70 °C/0.6 mmHg. IR ν_{max} (KBr) 2970 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 0.14 (s, 9H), 0.28 (s, 9H), 7.30 (d, *J* = 8 Hz, 2H), 7.55 (d, *J* = 8 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ −4.83 (s), −1.20 (s), 123.9 (t, *J* = 8 Hz), 128.3 (t, *J* = 263 Hz), 133.2 (s), 138.5 (t, *J* = 20 Hz), 141.3 (t, *J* = 2 Hz). ^{19}F NMR (376 MHz, $CDCl_3$) δ 49.4 (s). EI MS *m/z* (% relative intensity) 257 ($M^+ - CH_3$,

8). 180 (M^+ – Me_3SiF, 68), 165 (29), 73 (100). Elemental Anal. Calcd for $C_{13}H_{22}F_2Si_2$: C, 57.30; H, 8.14. Found: C, 57.46; H, 8.29.

1-[Fluoro-bis(trimethylsilyl)methyl]-4-(trimethylsilyl)benzene (**3h**). White solid. 94% Yield (5 mmol scale). Mp 55–56 °C. bp 110 °C/0.6 mmHg. IR ν_{max} (KBr) 2960 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 0.07 (s, 18H), 0.24 (s, 9H), 6.99 (br d, *J* = 7 Hz, 2H), 7.40 (d, *J* = 7 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ –2.32 (d, *J* = 4 Hz), –0.94 (s), 100.0 (d, *J* = 155 Hz), 120.5 (d, *J* = 13 Hz), 132.8 (s), 135.0 (s), 144.9 (d, *J* = 13 Hz). ^{19}F NMR (376 MHz, $CDCl_3$) δ –56.6 (s, 1F). EI MS *m/z* (% relative intensity) 311 (M^+ – CH_3, 2), 234 (M^+ – Me_3SiF, 10), 146 (44), 73 (100). Elemental Anal. Calcd for $C_{16}H_{31}FSi_3$: C, 58.83; H, 9.56. Found: C, 58.71; H, 9.58.

4-5. References

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Appendix A (the work performed with co-workers, Mr. Ohno and Mr. Takeda)

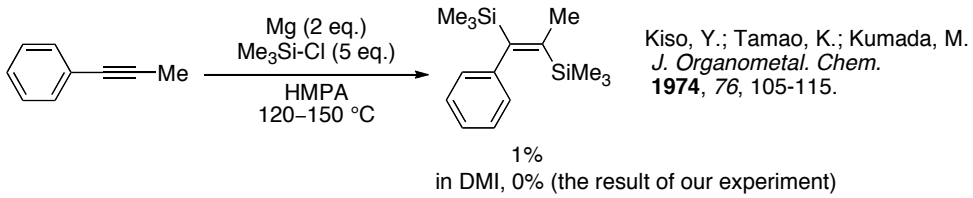
Reductive bissilylations of arylacetylenes by Cu-deposited Mg metal and chlorotrimethylsilane

A-1. Introduction

Hexamethylphosphoramide (HMPA) had been used as a polar aprotic solvent having a high polarity (DN = 38.8, AN = 10.6). The HMPA has been used as a solvent or an additive for a lot of Mg metal-reductions to proceed the reduction efficiently [1, 2a]. This effect would be attributed to its high DN and high affinity to metal cations [1a]. However, the HMPA is highly toxic and cancer suspect agent. This disadvantage of the HMPA makes the solvent incapable of using.

Meanwhile, DMI does not have such carcinogenic nature and toxicity. From that reason, DMI is used in some organometallic reactions, as an alternative to HMPA [3]. This would be attributed to ureal (diamide) structure similar to that of HMPA (triamide).

However, DMI is not superior to HMPA as a polar aprotic solvent. For example, Mg(0)-promoted reductive bissilylation of methylphenylacetylene in DMI solvent resulted in lower conversion than that in HMPA (**Scheme A-1**) [2a]. This would be attributed to lower DN of DMI (DN = 27, measured according to ref. 5) than that of HMPA. The inefficiency of some reactions using the DMI compared to that using the HMPA has hampered its use as an alternative to the HMPA.



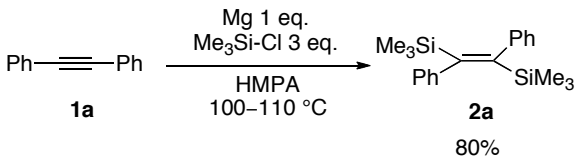
Scheme A-1. The conventional bissilylation of methylphenylacetylene

Cu-deposited Mg metal has found to have a higher reducing ability than the Mg metal itself in the present studies in this thesis. This would make the reactions by Cu-deposited Mg metal in DMI solvent more efficient. The reactions by Cu-deposited Mg metal in DMI solvent may be an alternative of reactions by metallic Mg in HMPA solvent. Other new reactions using Cu-deposited Mg metal were explored in order to extend the utility of Cu-deposited Mg metal. In this appendix A, reductive bissilylations of arylacetylenes by Cu-deposited Mg metal are described [4].

A-2. Results and discussion

The bissilylation of diphenylacetylene by Cu-deposited Mg metal was performed (**Table A-1**). French chemists reported that the reduction of diphenylacetylene **1a** by Mg(0)/Me_3Si-Cl in hexamethylphosphoramide (HMPA) at 100–110 °C gave (*E*)-1,2-bis(trimethylsilyl)-1,2-diphenylethylene **2a** in 80% isolated yield (**Scheme A-2**) [1b]. Meanwhile, the reaction using Mg(0) powder without Cu in DMI solvent resulted in recovery of **1a** (**Table A-1**, entry 1). The reaction using Cu-deposited Mg metal gave compound **2a** in 92% isolated yield (entry 2). However, the reaction under the same conditions on larger (3.0 mmol) scale gave complex mixture of products (entry 3, determined by GC). The reacting solution appeared to be blue-black colored under an argon atmosphere, which probably indicated formation of stable π*-anion-radical species of **1a**. The reaction in mixed solvent of DMI and THF (1:1) gave compound **2a** in 90% yield (entry 4), which

was probably because of destabilization of π*-anion radical species by less polar THF solvent like the solvent effects shown in **Figure 3-1** in chapter 3. These results would show the utility of reactions by Cu-deposited Mg metal in DMI solvent as an alternative to the reactions using Mg/HMPA.



Dunogues, J.; Calas, R.; Duffaut N. Lapouyade, P.; Gerval, J. *J. Organomet. Chem.* **1969**, *20*, P20-P21.

Scheme A-2. Conventional reductive bissilylation of diphenylacetylene

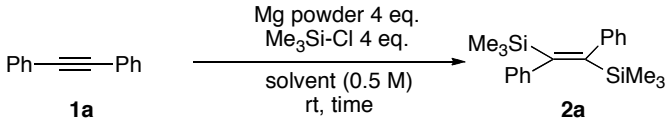
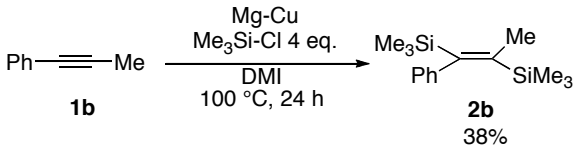


Table A-1. Bissilylaions of diphenylacetylene **1a** using Cu-deposited Mg

entry	scale [mmol]	activation of Mg	solvent	time [h]	Results	
					Isolated yield of **2a** [%]	The color of crude solution
1	0.5	none	DMI	6	0	none
2	0.5	CuCl (0.3 eq.)[a]	DMI	6	92	none
3	3.0	CuCl (0.3 eq.)[a]	DMI	6	tr. (complex mixture)[b]	dark blue
4	3.0	CuCl (0.3 eq.)[a]	DMI/THF (1:1)	10	90	none

[a] CuCl was mixed with Mg powder in DMI solvent for 15 minutes just before the reaction. [b] Determined by GC.

Another reaction by Cu-deposited Mg/Me_3Si-Cl in DMI solvent was performed. The reductive bissilylation reaction of methylphenylacetylene by Cu-deposited Mg and chlorotrimethylsilane at 100 °C was performed (**Scheme A-3**). As the result, compound **2b** was obtained in 38% of isolated yield. The reaction in HMPA solvent has reported to result in formation of **2b** in 1% yield (**Scheme A-1**) [2a]. This result suggested that Cu-deposited Mg in DMI solvent could be a better reducing agent and solvent than the Mg/HMPA.



Scheme A-3. The reductive bissilylation of methylphenylacetylene **1b**. Here, Mg-Cu was prepared in situ from Mg powder (4 eq.) and CuCl (0.3 eq.).

A-3. Conclusion

The reaction by Cu-deposited Mg metal in DMI solvent can be used as an alternative reaction conditions to those of metallic Mg in HMPA solvent.

A-4. Experimental section

(*E*)-1,2-diphenyl-1,2-bis(trimethylsilyl)ethylene (**2a**): Metallic Mg powder (0.292 g, 12 mmol) and CuCl (0.089 g, 0.9 mmol) was placed in 20 ml two-necked flask. The suspension of Mg and CuCl was stirred in DMI (2 ml), THF (2 ml) and Me_3Si-Cl (1.5 ml, 12 mmol) under an argon atmosphere for 15 minutes. After addition of diphenylacetylene **1a** (0.535 g, 3 mmol) solution (1.5 M, THF:DMI = 1:1, 2 ml), the suspension was stirred at room temperature for 10 hours. After confirmation of complete consumption of the substrate **1a** by TLC, Cu-deposited Mg metal was removed by decantation with *n*-hexane. After repeated decantation and extractions from the suspension, the combined hexane layer was washed by water and brine. After drying over magnesium sulfate, solvent was removed under a reduced pressure. Purification by silica gel chromatography with *n*-hexane eluent, the bissilylated product was obtained as a white solid in 90% yield.

White solid. 90% yield. ^{1}H NMR (400 MHz, $CDCl_3$) δ −0.4 (s, 18H), 7.04 (dt, J = 7.2, 2 Hz, 4H), 7.19 (tt, J = 7.4, 1 Hz, 2H), 7.28 (t, J = 7.4 Hz, 4H) [these data are consistent with those reported in ref. 2a, δ −0.38 (s, 18H), 7.10 (m, 10H). Those of the *cis*-isomer are reported to be as follows, δ 0.13 (s, 18H), 6.70 (m, 10H).]. EI MS *m/z* (% relative intensity) 324 (M^+, 2), 309 (7), 221 (16), 73 (100).

(*E*)-1-methyl-2-phenyl-1,2-bis(trimethylsilyl)ethylene (**2b**): Mg powder (0.292 g, 12 mmol) and CuCl (0.089 g, 0.9 mmol) was placed in a 10 ml two-necked flask with a condenser. The mixture of Mg and CuCl was stirred in DMI (6 ml) and Me_3Si-Cl (1.5 ml, 12 mmol) under an argon atmosphere for 10 minutes. After addition of methylphenylacetylene (0.345 g, 3 mmol), the suspension was stirred at 100 °C for 24 hours. After confirmation of complete consumption of the substrate by TLC, Cu-deposited Mg was removed by decantation with *n*-hexane. Simultaneously with decantation, the

products were extracted with *n*-hexane from DMI solution. The combined hexane layer was washed by water and brine. After drying over magnesium sulfate, solvent was removed under a reduced pressure. Purification by silica gel chromatography with *n*-hexane eluent (R*f* = 0.64), the bissilylated product was obtained as colorless oil in 38% yield.

Colorless oil. 38% yield. IR ν_{max} (neat) 2964 cm^{-1}. ^1H NMR δ −0.3 (s, 9H), 0.0 (s, 9H), 2.0 (s, 3H), 6.8−6.9 (m, 2H), 7.0−7.4 (m, 3H) [ref. 2a, δ −0.29 (s, 9H), 0.02 (s, 9H), 2.0 (s, 3H), 6.99 (m, 5H)]. EI MS *m/z* (% relative intensity) 262 (M^+, 8), 247 (7), 189 (8), 73 (100).

A-5. References and notes

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Appendix B (the work performed with co-worker, Mr. Katayama)

Donor numbers and acceptor numbers of LiCl/DMI solvent system

B-1. Introduction

In chapter 2, the addition of Li salts into the reaction media (Me_3SiCl/DMI solution) resulted in higher selectivity for formation of ethyl 2,2-difluoro-2-(trimethylsilyl)acetate over corresponding silyl ketal by-product. However, the reason why the addition of LiCl gave higher selectivity for ethyl 2,2-difluoro-2-(trimethylsilyl)acetate remains unsolved. Being considered from our plausible mechanism shown in **Scheme 2-26**, LiCl was considered to stabilize anion species and/or to hinder the attack of the anion species to Me_3SiCl, which is the same to effect of high polarity of the solvent. Thus, the polarity (DN and AN) of the LiCl/DMI solution was estimated under this hypothesis.

B-2. Results and discussion

The method reported by Sone and Soukup [1b] was selected as the method to measure DNs (**Table B-1**). Sone et al. have reported the method to estimate the DNs of solvents by the addition of $[Cu(acac)(tmen)]^+[BPh_4]^-$ as an indicator [1b]. The results in their report seem consistent with reported Gutmann's DNs. Thus, this method was selected as the method to estimate the DNs of the DMI-LiCl solutions. The maximum adsorption λ_{max} of the UV-vis. spectra were measured and DNs were estimated from the equation (1) and the equation (2). As the results, DN was increased by the addition of LiCl up to 84 from 28 (entry 5 and/or entry 6). These results suggested some anion species interacted to metal cation center of the Cu-complex. The same effect would work to some Mg cations, as the result, anion species would be stabilized by separation of some Mg cations and some anion intermediates.

$$k\nu\ [cm^{-1}] = 10000 / \lambda_{max} \qquad (1)$$

$$DN = -0.0688k\nu + 18.55 \qquad (2)$$

Table B-1. Relationship between DNs of Li salts/DMI solutions

Entry	Li salt (eq.)	λ_{max} (nm)	$k\nu$ (cm^{-1})	DN[a]
1	none	602	16.6	28
2	LiCl (0.01)	730	13.7	71
3	LiCl (0.025)	735	13.6	72
4	LiCl (0.05)	754	13.3	77
5	LiCl (0.1)	782	12.8	84
6	LiCl (0.3)	782	12.8	84
7	LiBr (0.05)	695	14.4	61
8	LiI (0.05)	635	15.7	41

[a] DNs of DMI solutions were calculated from equations (1) and (2) from λ_{max}.

The method reported by Reichardt et al. [1c] was selected as the method to measure ANs (**Table B-2**). Reichardt's dye (**Figure B-1**) can be used as an indicator for ANs. ANs of Li salts/DMI solution were calculated from the maximum absorbances λ_{max} according to equation (3) and equation (4) [1c]. Equation (4) was introduced from results reported by Reichardt's et al. Here, the maximum absorbances λ_{max} were observed by UV-vis spectra with 4×10^{-4} M amount of Reichardt's dye. As the results, the ANs of the DMI solutions were increased by the addition of LiCl up to 35 from 19 (entry 5). This result also suggested that the addition of LiCl to DMI stabilizes anion species, which probably hindered attacks of anion species to Me_3Si-Cl. The better selectivity for ethyl 2,2-difluoro-2-(trimethylsilyl)acetate over silyl ketal would be attributed to this increase of AN as well as the increase of DN, by the addition of LiCl.

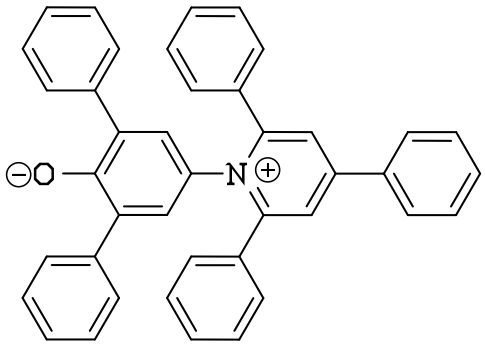

Figure B-1. The structure of Reichardt's dye

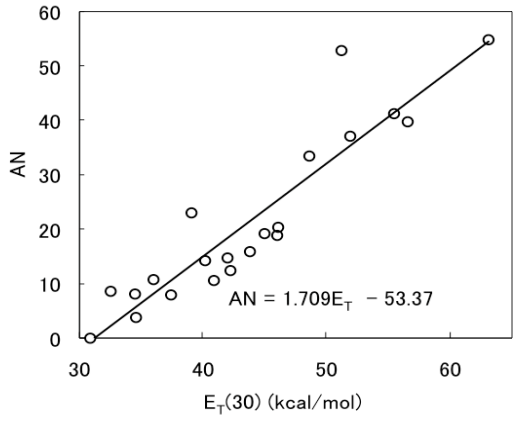

Figure B-2. The prots reported by Reichardt et al.

$$E_T(30)\ [\text{kcal/mol}] = 28591 / \lambda_{max}\ [\text{nm}] \quad (3)$$

$$AN = 1.71E_T - 53 \quad (4)$$

Table B-2. Relationships between ANs of lithium salts/DMI solution and equivalence of lithium salts

Entry	Lithium salt (eq.)	λ_{max} (nm)[a]	E_T (kcal/mol)	AN[b]
1	none	671	42.6	19
2	LiCl (0.01)	634	45.1	24
3	LiCl (0.05)	567	50.4	33
4	LiCl (0.1)	559	51.1	34
5	LiCl (0.3)	554	51.6	35
6	LiBr (0.05)	571	50.1	32
7	LiI (0.05)	574	49.8	32

[a]λ_{max}s were measured with Reichardt's dye (4×10^{-4} M). [b]ANs were calculated from E_T values according to eq. (4).

B-3. Conclusions

Addition of LiCl into DMI solvent increased its DNs and ANs. These results suggested that the addition of LiCl into DMI stabilizes anion species, which probably hindered attacks of anion species to Me_3Si-Cl. The better selectivity for ethyl 2,2-difluoro-2-(trimethylsilyl)acetate over silyl ketal would be attributed to these observed increase of AN and the increase of DN.

B-4. Experimental section

UV-Vis spectroscopy was measured by HITACHI U-3210 spectrophotometer.

Procedure for preparation of [Cu(tmen)(acac)]ClO_4

1.118 g (3.0 mmol) of copper (II) perchlorate hexahydrate dissolved in aqueous methanol (1:1) and solutions of TMEDA (0.45 ml, 3.0 mmol) and acetylacetone (0.31 ml, 3.2 mmol) in the same solvent were mixed together, and 0.1537 g (1.5 mmol) of anhydrous sodium carbonate was added to neutralize acetylacetone. The mixed solution was concentrated under a reduced pressure at 30 °C, and the crude product separated out was twice recrystallized from methanol. [Cu(tmen)(acac)]ClO_4 was obtained as violet crystals.

Procedure for preparation of [Cu(tmen)(acac)] BPh_4

3.89 g (10.3 mmol) of [Cu(tmen)(acac)]ClO_4 was dissolved in 50 ml of water, and 100 ml of warm aqueous solution containing 4.485 g (13.11 mmol) of $NaBPh_4$ was added with stirring. The obtained pink precipitate was filtered off, washed with warm water, and dried under a reduced pressure. Pink powder was obtained.

Typical procedures for preparation of solutions

Excess amount of a lithium salt was placed in a 50 mL flame-dried flask and dried under a reduced pressure at 200 °C by a heating gun. After addition of 10 ml of the solvent, the solution was stirred at 30 °C for over 12 hours under an argon atmosphere. If the residual salt was not observed by naked eyes, additional salt was added, and stirred for over 12 hour. After cooling to 20 °C (in the case of DMF, cooling to 30 °C) for over 4 hours, the solution was filtrated. 1 mL of the filtrate was dried under a reduced pressure at 100-150 °C to remove the solvent. Residual salt was weighed and solubility was measured [g/dL].

Typical procedure for measurement of DNs and ANs.

For measurement of DNs, Reichardt's dye (0.5 mg) was added to the 2.5 ml of the solution. Then, UV-vis spectroscopy was measured. For measurement of ANs, [Cu(acac)(tmen)]$^+B^-Ph_4$ (1.5 mg) was added to the solution. Then, UV-vis spectroscopy was measured.

B-5. References

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Chapter 2

Defluorination–silylation of alkyl trifluoroacetates to 2,2-difluoro-2-(trimethylsilyl)acetates by copper-deposited magnesium and trimethylsilyl chloride

Shinya Utsumi, Toshimasa Katagiri, and Kenji Uneyama

Tetrahedron **2012**, *68*, 580–583.

Chapter 3 and Chapter 4

Cu-deposits on Mg metal surfaces promote electron transfer reactions

Shinya Utsumi, Toshimasa Katagiri, and Kenji Uneyama

Tetrahedron **2012**, *68*, 1085–1091.

List of presentations

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・ 19th International Symposium on Fluorine Chemistry (19th ISFC) 2009.8.23-28 (poster)

Shinya Utsumi, Toshimasa Katagiri, Kenji Uneyama

Prevention of Defluorination in Grignard Reagent Preparation from 4-Bromobenzotrifluoride

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Toshimasa Katagiri, Shinya Utsumi

Preparation of Fluoroalkyl-substituted Aryl Silanes from Corresponding Halides via Grignard Reagent Formation

Presentations in domestic conferences

・ 日本化学会第 88 春期年会 2008.3.29 (口頭発表)

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Mg による *p*-chloro-(perfluoroethyl)benzene の脱フッ素化反応の制御

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○内海 慎也・片桐 利真・宇根山 健治

還元的脱フッ素化反応と Grignard 試薬形成型反応の Cu を用いた反応経路制御

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・学術振興会フッ素化学第 155 委員会 2011.1.20

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Mg-Cu/TMSCl によるトリフルオロ酢酸エチルからの 2, 2-ジフルオロ-2-トリメチルシリル酢酸エチルの調製

・ 第 91 回日本化学会春季年会 (2011)

◯内海慎也・片桐利真

Mg/TMSCl 系を用いた還元的脱フッ素化による ethyl 2,2-difluoro-2-(trimethylsilyl)acetate の合成

・ 第 38 回有機典型元素化学討論会 (2011.12.08)

○ 内海慎也・片桐利真・宇根山健治

還元的脱フッ素-シリル化反応における Cu(0)による Mg 金属の還元能力の強化

Acknowledgement

Studies presented in this thesis have been carried out under the direction of Associated Professor Toshimasa Katagiri.

I am particularly indebted to Dr. Toshimasa Katagiri, Associated Professor of Department of Applied chemistry, Okayama University, for his patient and continuous direction throughout the course of the presented study.

I express appreciation to Mr. Katsuya Seki, Keyence, Co. Ltd., for lending a VHX-1000, a microscope.

I express appreciation to Dr. Kenji Uneyama, Professor Emeritus, Okayama University, for his helpful suggestions.

I express appreciation to Dr. Yutaka Nakamura, Kanto Denka Kogyo Co., Ltd, for his accurate advices. I really respect his excellent works from which studies of chapter 3 in this thesis were derived.

I express deep appreciations to Mr. Yuji Tsuchikura and Mr. Koji Fujitani, for many discussions. I also wish to express appreciation to Mr. Akira Isobe, Mr. Yasuhiro Tanaka, Mr. Takashi Nomura, Mr. Akinori Harada, Mr. Masato Yanagi, Mr. Hiroyuki Asano, Mr. Keisuke Kataoka, and Miss Mayuko Taeda for warm directions during my master's course and undergraduate course.

I also make acknowledgements for active discussions to all members of Molecular Design Laboratory, Okayama University, Mr. Ken-ichi Ohno Mr. Fumiya Ozaki, Mr. Takayuki Seiki, Mr. Yousuke Katayama, Mr. Akira Fukuda, Mr. Yuuto Nakanishi, Mr. Daisuke Mori, Mr. Shinji Hiramatsu, Mr. Daisuke Takeda.

Finally, I deeply appreciate the financial support and encouragement of my family, Yoshitake Utsumi, Yoshiko Utsumi, Yoshitaka Utsumi, Kasumi Utsumi and Shohhei Utsumi.

Shinya Utsumi

The Graduate School of
Natural Science and Technology
Okayama University

March, 2012