HBr-Catalyzed C-Si Bond Cleavage of Benzylsilanes and Subsequent Oxidation into Benzoic Acids with Air as Terminal Oxidant

Jing Sun, a,b,c Yu Wang, c,e Liqiong Han, a Dawen Xu, a Yiyong Chen, a Xinhua Peng, b and Hao Guo* a,d

a Department of Chemistry, Fudan University, 220 Handan Road, Shanghai, 200433, P. R. China. Tel: +86-21-55664361, Fax: +86-21-55664361, E-mail: Hao_Guo@fudan.edu.cn

b School of Chemical Engineering, Nanjing University of Science and Technology, Nanjing, 210094, P. R. China

c Department of Head and Neck Surgery, Fudan University Shanghai Cancer Center; Department of Oncology, Shanghai Medical College, Fudan University, Shanghai, P. R. China

d Key Laboratory of Organofluorine Chemistry, Shanghai Institute of Organic Chemistry, Chinese Academy of Sciences

e They contributed equally.

Supplementary Information

<table>
<thead>
<tr>
<th>Experimental Section</th>
<th>S2</th>
</tr>
</thead>
<tbody>
<tr>
<td>NMR Spectra</td>
<td>S14</td>
</tr>
<tr>
<td>References</td>
<td>S29</td>
</tr>
</tbody>
</table>
Experimental Section

General experimental methods
All reactions were carried out using a PLS-SXE300UV reactor with Xe lamp (300 W) as the irradiation source. Melting points were determined on a WRS-2 apparatus. IR spectra were recorded on a Avatar 360 FT-IR spectrometer. $^1$H (400 MHz), $^{13}$C (100 MHz), $^{19}$F (376 MHz), and $^{31}$P (162 MHz) NMR spectra of samples in CDCl$_3$ (unless stated otherwise) were recorded on an AVANCE III 400 spectrometer. MS (EI, 70 eV) determinations were carried out on a HP 5973 spectrometer. HRMS (EI) determinations were carried out on a Water GCT CA176 spectrometer. HRMS (ESI) determinations were carried out on a Bruker Daltonics micrOTOF II spectrometer.

Compound 1f was commercial available. Compounds 1a, 1b, 1c, 1d, 1e, 1g, 1h, 1j, 1k, 1l, 1m, 1n, 1q, 1r, 1s, 1t, 4 and 5 were prepared according to literature procedures.

Synthesis of diphenyl(4-((trimethylsilyl)methyl)phenyl)phosphine

A solution of (4-bromobenzyl)trimethyl silane (187 mg, 0.77 mmol) in anhydrous Et$_2$O (20 mL) was cooled with ice-salt bath. Then TMEDA (0.4 mL, 2.7 mmol) and n-BuLi (1.6 M in hexane, 2.0 mL, 3.2 mmol) were added subsequently. The reaction mixture was stirred for 1.5 hour, then warmed to rt, and stirred for another 1 hour at rt. After which the reaction mixture was cooled with ice-salt bath, and then chlorodiphenylphosphine (0.5 mL, 2.8 mmol) was added dropwise and stirred for 1 hour with ice-salt bath. Then the mixture was allowed to warm to rt and stirred for 13 hours. The solvent was removed under reduced pressure. Purification by silica gel chromatography (eluent: petroleum ether) afforded a white solid (192 mg, 72%); mp 84.2-84.8 °C (n-hexane); $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.41-7.28 (m, 10 H), 7.24-7.17 (m, 2 H), 7.01 (d, $J$ = 7.2 Hz, 2 H), 2.12 (s, 2 H), 0.03 (s, 9 H); $^{13}$C NMR
(100 MHz, CDCl₃) δ 141.8, 137.9 (d, Jₚₛₜ = 10.3 Hz), 133.9 (d, Jₚₛₜ = 19.7 Hz), 133.7 (d, Jₚₛₜ = 19.0 Hz), 131.4 (d, Jₚₛₜ = 8.1 Hz), 128.5 (d, Jₚₛₜ = 5.8 Hz), 128.4, 128.3, 27.2, -1.8; ³¹P NMR (162 MHz, CDCl₃) δ -6.4 ppm; IR (neat) 1595, 1494, 1476, 1436 cm⁻¹; HRMS (ESI) calcd for C₂₂H₂₆PSi 349.1541, found. 349.1532.

**Synthesis of diphenyl(4-((trimethylsilyl)methyl)phenyl)phosphine oxide (1i)**

Diphenyl(4-((trimethylsilyl)methyl)phenyl)phosphine (350 mg, 1.0 mmol) was added to a solution of H₂O₂ (30%) (0.4 mL), methanol (15 mL), and dichloromethane (15 mL). After stirred for 2 hours at rt, it was quenched with saturated Na₂CO₃ solution (10 mL). The resulting mixture was extracted with dichloromethane (20 mL). The organic layer was washed with water (10 mL), dried over MgSO₄, and concentrated to dryness. Purification by silica gel chromatography (eluent: ethyl acetate) afforded 1i as a white solid (300 mg, 82%); mp 152.9-154.4 °C (petroleum ether/ethyl acetate); ¹H NMR (400 MHz, CDCl₃) δ 7.70-7.62 (m, 4 H), 7.56-7.42 (m, 8 H), 7.09-7.04 (m, 2 H), 2.14 (s, 2 H), -0.02 (s, 9 H); ¹³C NMR (100 MHz, CDCl₃) δ 145.7, 133.0 (d, Jₚₛₜ = 103.6 Hz), 132.1 (d, Jₚₛₜ = 9.5 Hz), 131.8, 128.4 (d, Jₚₛₜ = 11.6 Hz), 128.1 (d, Jₚₛₜ = 12.4 Hz), 127.3 (d, Jₚₛₜ = 108.0 Hz), 27.8, -1.9; ³¹P NMR (162 MHz, CDCl₃) δ 29.6 ppm; IR (neat) 1601, 1473, 1433 cm⁻¹; HRMS (ESI) calcd for C₂₂H₂₆OPSi 365.1491, found. 365.1482.

**Synthesis of (3-(trifluoromethyl)benzyl)trimethylsilane (1o)**

Under argon atmosphere, Mg (121 mg, 5.0 mmol), anhydrous THF (3 mL), chlorotrimethylsilane (691 μL, 8.0 mmol), and a drop of I₂ were added into a dry 50...
mL Schlenk flask. The mixture was stirred at rt for 15 min. Then a solution of 1-(bromomethyl)-3-(trifluoromethyl)benzene (611 μL, 4.0 mmol) in anhydrous THF (7 mL) was added dropwise. After stirred at rt for 24 hours, the reaction was quenched by water (10 mL) and HCl (aq., 1 M) (10 mL). The mixture was extracted with ethyl acetate (30 mL x 3). The combined organic layer was dried over MgSO4. Filtration, concentration, and purification by flash chromatography on silica gel (eluent: petroleum ether) afforded 1o as a colorless oil (491 mg, 53%); 1H NMR (400 MHz, CDCl3) δ 7.36-7.29 (m, 2 H), 7.24 (s, 1 H), 7.17 (d, J = 6.0 Hz, 1 H), 2.15 (s, 2 H), 0.00 (s, 9 H); 13C NMR (100 MHz, CDCl3) δ 141.7 (s), 131.3 (s), 130.5 (q, J = 31.5 Hz), 128.5 (q, J = 2.8 Hz), 124.5 (q, J = 3.8 Hz), 124.4 (q, J = 270.8 Hz), 120.8 (q, J = 3.8 Hz), 27.2 (s), -2.12 (s); 19F NMR (376 MHz, CDCl3) δ -62.6 ppm; IR (neat) 1593, 1491, 1445, 1424 cm⁻¹; MS (EI, 70 eV) m/z 232 (M⁺ 6.46), 140 (100); HRMS (EI, 70 eV) calcd for C11H15F3Si 232.0895, found. 232.0892.

Synthesis of (2-(trifluoromethyl)benzyl)trimethylsilane (1p)

Under argon atmosphere, Mg (125 mg, 5.2 mmol), anhydrous THF (3 mL), chlorotrimethylsilane (700 μL, 8.1 mmol), and a drop of I2 were added into a dry 50 mL Schlenk flask. The mixture was stirred at rt for 15 min. Then a solution of 1-(bromomethyl)-2-(trifluoromethyl)benzene (969 mg, 3.9 mmol) in anhydrous THF (6 mL) was added dropwise. After stirred at rt for 24 hours, the reaction was quenched by water (10 mL) and HCl (aq., 1 M) (10 mL). The mixture was extracted with CH2Cl2 (30 mL x 3). The combined organic layer was dried over MgSO4. Filtration, concentration, and purification by flash chromatography on silica gel (eluent: petroleum ether) afforded 1p as a colorless oil (302 mg, 33%); 1H NMR (400 MHz, CDCl3) δ 7.62 (d, J = 8.0 Hz, 1 H), 7.44-7.37 (m, 1 H), 7.22-7.15 (m, 2 H), 2.39 (s, 2 H), 0.07 (s, 9 H); 13C NMR (100 MHz, CDCl3) δ 140.2 (q, J = 2.2 Hz), 131.2 (q, J = 1.5 Hz), 130.5 (s), 127.3 (q, J = 29.2 Hz), 126.1 (q, J = 5.8 Hz), 124.8 (q, J = 272.1
Hz), 124.0 (s), 23.7 (q, $J$ = 1.5 Hz), -1.37 (s); $^{19}$F NMR (376 MHz, CDCl$_3$) $\delta$ -60.1 ppm; IR (neat) 1607, 1577, 1491, 1455 cm$^{-1}$; MS (EI, 70 eV) m/z 232 (M$^+$ 1.32), 140 (100); HRMS (EI, 70 eV) calcd for C$_{11}$H$_{15}$F$_3$Si 232.0895, found. 232.0900.

**Typical Procedure I for the photoreaction.**

**Synthesis of 4-methoxybenzoic acid (3a)$^{15}$**

(4-Methoxybenzyl)trimethylsilane (38 mg, 0.20 mmol), anhydrous acetonitrile (10 mL), and HBr (aq., 40%) (5.9 $\mu$L, 0.04 mmol) were added to a dry quartz reaction flask which was equipped with a magnetic stirrer and a condenser. The mixture was irradiated by a Xe lamp (300 W) at rt in the open air. The photoreaction was completed after 3.5 hours as monitored by TLC (eluent: petroleum ether : ethyl acetate = 10:1). The solvent was removed and the residue was purified by flash chromatography on silica gel (eluent: petroleum ether : ethyl acetate = 3:1 $\rightarrow$ 1:1) to afford 3a as a solid (27 mg, 91%); $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 8.07 (d, $J$ = 8.0 Hz, 2 H), 6.95 (d, $J$ = 8.0 Hz, 2 H), 3.88 (s, 3 H).

The following compounds were prepared according to typical procedure I.

(1) 3-Methoxybenzoic acid (3b)$^{16}$

The reaction of 1b (39 mg, 0.20 mmol) and HBr (aq., 40%) (5.9 $\mu$L, 0.04 mmol) in anhydrous acetonitrile (10 mL) afforded 3b as a solid (14 mg, 46%); $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.73 (d, $J$ = 8.0 Hz, 1 H), 7.65-7.62 (m, 1 H), 7.43-7.35 (m, 1 H), 7.19-7.13 (m, 1 H), 3.88 (s, 3 H).
The reaction of 1c (38 mg, 0.20 mmol) and HBr (aq., 40%) (5.9 μL, 0.04 mmol) in anhydrous acetonitrile (10 mL) afforded 3c as a solid (15 mg, 50%); 1H NMR (400 MHz, CDCl3) δ 10.88 (brs, 1 H), 8.20-8.17 (m, 1 H), 7.61-7.56 (m, 1 H), 7.17-7.05 (m, 2 H), 4.09 (s, 3 H).

The reaction of 1d (43 mg, 0.20 mmol) and HBr (aq., 40%) (5.9 μL, 0.04 mmol) in anhydrous acetonitrile (10 mL) afforded 3d as a solid (23 mg, 66%); 1H NMR (400 MHz, CDCl3) δ 8.05 (d, J = 8.8 Hz, 2 H), 7.49 (d, J = 8.8 Hz, 2 H), 1.35 (s, 9 H).

The reaction of 1e (47 mg, 0.20 mmol) and HBr (aq., 40%) (5.9 μL, 0.04 mmol) in anhydrous acetonitrile (10 mL) afforded 3e as a solid (32 mg, 83%); 1H NMR (400 MHz, DMSO-d6) δ 12.99 (brs, 1 H), 8.03 (d, J = 8.4 Hz, 2 H), 7.80 (d, J = 8.4 Hz, 2 H), 7.74 (d, J = 6.8 Hz, 2 H), 7.54-7.47 (m, 2 H), 7.46-7.40 (m, 1 H).
(5) Benzoic acid (3f)\(^{20}\)

![Reaction scheme for the preparation of 3f](image)

The reaction of 1f (33 mg, 0.20 mmol) and HBr (aq., 40%) (5.9 \(\mu\)L, 0.04 mmol) in anhydrous acetonitrile (10 mL) afforded 3f as a solid (18 mg, 74%); \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 12.26 (brs, 1 H), 8.13 (d, \(J = 8.0\) Hz, 2 H), 7.65-7.55 (m, 1 H), 7.54-7.30 (m, 2 H).

(6) 4-Chlorobenzoic acid (3g)\(^{16}\)

![Reaction scheme for the preparation of 3g](image)

The reaction of 1g (40 mg, 0.20 mmol) and HBr (aq., 40%) (5.9 \(\mu\)L, 0.04 mmol) in anhydrous acetonitrile (10 mL) afforded 3g as a solid (22 mg, 70%); \(^1\)H NMR (400 MHz, DMSO-\(d_6\)) \(\delta\) 13.12 (brs, 1 H), 7.95 (d, \(J = 8.4\) Hz, 2 H), 7.57 (d, \(J = 8.4\) Hz, 2 H).

(7) 4-Fluorobenzoic acid (3h)\(^{15}\)

![Reaction scheme for the preparation of 3h](image)

The reaction of 1h (35 mg, 0.19 mmol) and HBr (aq., 40%) (5.9 \(\mu\)L, 0.04 mmol) in anhydrous acetonitrile (10 mL) afforded 3h as a solid (22 mg, 82%); \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 8.19-8.10 (m, 2 H), 7.20-7.09 (m, 2 H).

(8) 4-(Diphenylphosphoryl)benzoic acid (3i)\(^{21}\)
The reaction of 1i (71 mg, 0.19 mmol) and HBr (aq., 40%) (5.9 μL, 0.04 mmol) in anhydrous acetonitrile (10 mL) afforded 3i as a solid (39 mg, 62%); \(^{1}H\) NMR (400 MHz, DMSO-\(d_6\)) \(\delta\) 8.11-8.05 (m, 2 H), 7.78-7.69 (m, 2 H), 7.68-7.52 (m, 10 H).

(9) 4-Acetylbenzoic acid (3j)

The reaction of 1j (39 mg, 0.19 mmol) and HBr (aq., 40%) (5.9 μL, 0.04 mmol) in anhydrous acetonitrile (10 mL) afforded 3j as a solid (25 mg, 81%); \(^{1}H\) NMR (400 MHz, DMSO-\(d_6\)) \(\delta\) 13.33 (brs, 1 H), 8.06 (s, 4 H), 2.63 (s, 3 H).

(10) 4-(Methoxycarbonyl)benzoic acid (3k)

The reaction of 1k (43 mg, 0.19 mmol) and HBr (aq., 40%) (5.9 μL, 0.04 mmol) in anhydrous acetonitrile (10 mL) afforded 3k as a solid (30 mg, 86%); \(^{1}H\) NMR (400 MHz, DMSO-\(d_6\)) \(\delta\) 8.05 (s, 4 H), 3.88 (s, 3 H).

(11) 4-(Ethoxycarbonyl)benzoic acid (3l)
The reaction of 1l (46 mg, 0.19 mmol) and HBr (aq., 40%) (5.9 μL, 0.04 mmol) in anhydrous acetonitrile (10 mL) afforded 3l as a solid (34 mg, 90%); 1H NMR (400 MHz, CDCl₃) δ 8.22-8.12 (m, 4 H), 4.42 (q, J = 7.2 Hz, 2 H), 1.43 (t, J = 7.2 Hz, 3 H).

(12) 4-(Diisopropylcarbamoyl)benzoic acid (3m)

The reaction of 1m (55 mg, 0.20 mmol) and HBr (aq., 40%) (5.9 μL, 0.04 mmol) in anhydrous acetonitrile (10 mL) afforded 3m as a solid (40 mg, 81%); mp 251.1-252.9 °C (petroleum ether/ethyl acetate); 1H NMR (400 MHz, CDCl₃) δ 8.53 (brs, 1 H), 8.11 (d, J = 8.4 Hz, 2 H), 7.41 (d, J = 8.4 Hz, 2 H), 3.75 (brs, 1 H), 3.56 (brs, 1 H), 1.56 (brs, 6 H), 1.15 (brs, 6 H); 13C NMR (100 MHz, CDCl₃) δ 170.5, 170.2, 143.4, 130.5, 129.8, 125.7, 50.7, 45.8, 20.6; IR (neat) 1705, 1632, 1473, 1439 cm⁻¹; HRMS (ESI) calcd for C₁₄H₂₁NO₃ 250.1443, found. 250.1433.

(13) 4-(Trifluoromethyl)benzoic acid (3n)

The reaction of 1n (46 mg, 0.20 mmol) and HBr (aq., 40%) (5.9 μL, 0.04 mmol) in
anhydrous acetonitrile (10 mL) afforded 3n as a solid (30 mg, 80%); \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 8.23 (d, \(J = 8.0 \text{ Hz}, 2 \text{ H}\)), 7.76 (d, \(J = 8.0 \text{ Hz}, 2 \text{ H}\)).

(14) 3-(Trifluoromethyl)benzoic acid (3o)\(^{23}\)

\[
\text{1o} \quad \begin{array}{c}
\text{CF}_3 \\
\text{Si}
\end{array}
\xrightarrow{\text{air (1 atm)}}
\begin{array}{c}
\text{CF}_3 \\
\text{Si}
\end{array}
\text{COOH}
\text{3o}
\]

The reaction of 1o (46 mg, 0.20 mmol) and HBr (aq., 40%) (5.9 \(\mu\)L, 0.04 mmol) in anhydrous acetonitrile (10 mL) afforded 3o as a solid (28 mg, 74%); \(^1\)HNMR (400 MHz, CDCl\(_3\)): \(\delta\) 8.40 (s, 1 H), 8.31 (d, \(J = 8.0 \text{ Hz}, 1 \text{ H}\)), 7.89 (d, \(J = 7.2 \text{ Hz}, 1 \text{ H}\)), 7.81-7.50 (m, 1 H).

(15) 2-(Trifluoromethyl)benzoic acid (3p)\(^{23}\)

\[
\text{1p} \quad \begin{array}{c}
\text{CF}_3 \\
\text{Si}
\end{array}
\xrightarrow{\text{air (1 atm)}}
\begin{array}{c}
\text{CF}_3 \\
\text{Si}
\end{array}
\text{COOH}
\text{3p}
\]

The reaction of 1p (46 mg, 0.20 mmol) and HBr (aq., 40%) (5.9 \(\mu\)L, 0.04 mmol) in anhydrous acetonitrile (10 mL) afforded 3p as a solid (29 mg, 77%); \(^1\)H NMR (400 MHz, DMSO-\(d_6\)) \(\delta\) 13.58 (brs, 1 H), 7.85-7.69 (m, 4 H).

(16) Synthesis of benzoic acid (3f)\(^{20}\) from 1q

\[
\text{1q} \quad \begin{array}{c}
\text{SiEt}_3
\end{array}
\xrightarrow{\text{air (1 atm)}}
\begin{array}{c}
\text{SiEt}_3
\end{array}
\text{COOH}
\text{3f}
\]

The reaction of 1q (41 mg, 0.20 mmol) and HBr (aq., 40%) (5.9 \(\mu\)L, 0.04 mmol) in anhydrous acetonitrile (10 mL) afforded 3f as a solid (20 mg, 83%).

(17) Synthesis of benzoic acid (3f)\(^{20}\) from 1r
The reaction of $1r$ (41 mg, 0.20 mmol) and HBr (aq., 40%) (5.9 μL, 0.04 mmol) in anhydrous acetonitrile (10 mL) afforded $3f$ as a solid (17 mg, 70%).

(18) Synthesis of benzoic acid ($3f^2$) from $1s$

The reaction of $1s$ (45 mg, 0.20 mmol) and HBr (aq., 40%) (5.9 μL, 0.04 mmol) in anhydrous acetonitrile (10 mL) afforded $3f$ as a solid (20 mg, 82%).

(19) Synthesis of benzoic acid ($3f^2$) from $1t$

The reaction of $1t$ (59 mg, 0.20 mmol) and HBr (aq., 40%) (5.9 μL, 0.04 mmol) in anhydrous acetonitrile (10 mL) afforded $3f$ as a solid (15 mg, 60%).

(20) Synthesis of benzoic acid ($3f^2$) from $4$

The reaction of $4$ (39 mg, 0.21 mmol) and HBr (aq., 40%) (5.9 μL, 0.04 mmol) in anhydrous acetonitrile (10 mL) afforded $3f$ as a solid (20 mg, 80%).

(21) Synthesis of benzoic acid ($3f^2$) from $5$

The reaction of $5$ (42 mg, 0.22 mmol) and HBr (aq., 40%) (5.9 μL, 0.04 mmol) in
anhydrous acetonitrile (10 mL) afforded 3f as a solid (23 mg, 86%).

\[
\begin{align*}
\text{Ph} & \quad \text{TMS} \\
\text{5} & \quad \xrightarrow{\text{air (1 atm)}} \quad \text{PhCOOH} \\
\text{Xe (300 W), quartz, CH}_2\text{CN, rt, 13 h} & \quad 86\%
\end{align*}
\]

**Gram-scale synthesis of 3d**

\[
\begin{align*}
\text{Bu}^+ & \quad \text{Ph} & \quad \text{TMS} \\
\text{1d} & \quad \xrightarrow{\text{air (1 atm)}} \quad \text{Bu}^+\text{PhCOOH} \\
\text{Xe (300 W), quartz, CH}_2\text{CN, rt, 10 h} & \quad 76\%
\end{align*}
\]

The reaction of 1d (1.1 g, 5.0 mmol) and HBr (aq., 40%) (148 μL, 1.0 mmol) in anhydrous acetonitrile (60 mL) afforded 3d as a solid (677 mg, 76%).

**The conversion of 2a to 3a under Conditions A**

\[
\begin{align*}
\text{MeO} & \quad \text{Ph} & \quad \text{CHO} \\
\text{2a} & \quad \xrightarrow{\text{air (1 atm)}} \quad \text{MeO} & \quad \text{PhCOOH} \\
\text{Xe (300 W), quartz, CH}_2\text{CN, rt, 2.5 h} & \quad 99\%
\end{align*}
\]

2a (29 mg, 0.21 mmol), anhydrous acetonitrile (10 mL), and HBr (aq., 40%) (5.9 μL, 0.04 mmol) were added to a dry quartz reaction flask which was equipped with a magnetic stirrer and a condenser. The mixture was irradiated by a Xe lamp (300 W) at rt in the open air. The photoreaction was completed after 2.5 hours as monitored by TLC (eluent: petroleum ether : ethyl acetate = 10:1). The solvent was removed and the residue was purified by flash chromatography on silica gel (eluent: petroleum ether : ethyl acetate = 3:1) to afford 3a as a solid (32 mg, 99%).

**The photooxidation of 1a under the catalysis of Br₂**

\[
\begin{align*}
\text{MeO} & \quad \text{Ph} & \quad \text{TMS} & \quad \text{CHO} \\
\text{1a} & \quad \xrightarrow{\text{air (1 atm), 10 mol% Br}_2} \quad \text{MeO} & \quad \text{PhCHO} + \text{MeO} & \quad \text{PhCOOH} \\
\text{Xe (300 W), quartz, CH}_2\text{CN, rt, 3.5 h} & \quad 26\% & \quad 65\%
\end{align*}
\]

1a (39 mg, 0.20 mmol), anhydrous acetonitrile (10 mL), and Br₂ (6.4 mg/mL in CH₂CN) (0.5 mL, 0.02 mmol) were added to a dry quartz reaction flask which was equipped with a magnetic stirrer and a condenser. The mixture was irradiated by a Xe
lamp (300 W) at rt in the open air. The photoreaction was completed after 3.5 hours as monitored by TLC (eluent: petroleum ether : ethyl acetate = 10:1). The solvent was removed and the residue was purified by flash chromatography on silica gel (eluent: petroleum ether : ethyl acetate = 3:1→ethyl acetate) to afford 2a (7 mg, 26%) and 3a (20 mg, 65%).
3e

3f
COOH

3p

1 H NMR
References


