# Conjugate Additions of $\alpha$ , $\beta$ -Unsaturated Ketones with Arylzinc Species That Form in situ from Diethylzinc and Arylboronic Acids

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**Abstract:** Conjugate addition of  $\alpha$ , $\beta$ -unsaturated ketones with arylzinc species that form in situ from diethylzinc and a series of arylboronic acids by boron-zinc exchange reactions were investigated. 1,4-Addition products were formed in yields of 34–93%.

**Keywords:** conjugate addition,  $\alpha$ , $\beta$ -unsaturated ketone, arylboronic acid, boron-zinc exchange reaction

Conjugate addition of organometallic reagents to electron-deficient olefins is one of the most versatile methods for forming carbon-carbon bonds.<sup>1</sup> Due to the importance of the resulting  $\beta$ -substituted carbonyl compounds in organic synthesis, many conjugate additions of organometallic reagents, such as those of lithium, magnesium, zinc, and boron, to enones have been extensively studied.<sup>2</sup> Recently, important advances have been made regarding asymmetric conjugate additions of arylboronic acids and the corresponding esters, and related reactions with alkylzincs.<sup>3</sup> These reactions generally require the use of transition-metal complexes as catalysts. Since arylzinc species can be formed by boron-zinc exchange reactions,<sup>4,5</sup> we started a project to prepare  $\beta$ -aryl carbonyl compounds via the conjugate addition of arylzinc, generated in situ from arylboronic acids and diethylzinc, to  $\alpha$ , $\beta$ -unsaturated ketones.5

We first studied the reaction of chalcone (1a) with the combination of phenylboronic acid and diethylzinc. The phenylzinc species was prepared by stirring a mixture of phenylboronic acid and a 3-fold excess of  $Et_2Zn$  in toluene at 60 °C under argon for 12 hours. It was then reacted with chalcone (1a) at 0 °C to give 3a in 92% yield (Table 1, entry 1).<sup>6</sup> The use of several commercial arylboronic acids 2a–f and an ester 2g in the 1,4-addition of chalcone (1a) under the above reaction conditions was then investigated. The results are summarized in Table 1.

As shown in Table 1, 1,4-additions are highly dependent on the structures of the arylboronic acids. Boronic acid with two strongly electron-withdrawing trifluoromethyl groups was not good for 1,4-addition (entry 6). This is probably due to an incomplete boron-zinc exchange.<sup>5</sup> 2-Chlorophenylboronic acid also gave a low yield of 34% for 1,4-addition, which might be the result of steric hin-

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 Table 1
 1,4-Addition to Chalcone 1a by the Combination of Aromatic Boronic Acids and Diethylzinc



drance by the 2-chlorophenyl group (entry 5). Arylzincs formed from other arylboronic acids, such as phenylboronic acid and 4-substituted phenylboronic acids, reacted well with chalcone (1a) to furnish 1,4-adducts 3a–d in high yields (entries 1–4). Pinacol phenylboronate (2g, entry 7) gave a lower yield than its analogue 2a.



Scheme 1 Reactions of 1a with Ph<sub>2</sub>Zn and Ph<sub>2</sub>Zn–Et<sub>2</sub>Zn



Scheme 2 Reactions of 1a with  $Ph_2Zn$  promoted by a mixture of  $MeB(OH)_2$  and  $Et_2Zn$ 

To understand whether the EtB(OZnEt)<sub>2</sub> generated in situ from diethylzinc and arylboronic acid acts as a catalyst to promote the 1,4-addition of EtZnAr to  $\alpha$ , $\beta$ -unsaturated ketone, chalcone (**1a**) was treated with Ph<sub>2</sub>Zn and an organozinc species formed in situ from Et<sub>2</sub>Zn–Ph<sub>2</sub>Zn.<sup>7</sup> No 1,4addition adduct **3a** was produced in either reaction (Scheme 1). However, the combination of Et<sub>2</sub>Zn and phenylboronic acid reacted smoothly with chalcone (**1a**) to give **3a** in 92% yield (Table 1, entry 1). In addition, reactions of **1a** with Ph<sub>2</sub>Zn in the presence of a mixture of MeB(OH)<sub>2</sub> and Et<sub>2</sub>Zn proceeded well to give **3a** in 77% yield (Scheme 2). These results demonstrated that EtB(OZnEt)<sub>2</sub> might catalyze the 1,4-addition.



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1,4-Additions of several unsaturated ketones in the presence of Et<sub>2</sub>Zn and phenylboronic acid were examined. The results are listed in Table 2. Most of the tested ketones underwent 1,4-addition to give the expected product in good yields, except for ketone 1j and 1m. The 1,4-addition of 1j produced 4j in only 38% yield (entry 9). Only trace amount of product was observed with unsaturated ketone 1m (entry 12), which implied that the unsaturated ketone with an aliphatic substituted carbonyl group was less reactive. Compound 1f bearing a 2,6-dichlorophenyl group showed relatively low yield for 1,4-addition (63% yield), probably due to its steric bulk (entry 5). Reactions of  $\alpha,\beta$ -unsaturated ketones containing a nitro group always gave worse results than those of their structural analogues bearing other electron-withdrawing groups (entries 6 and 9).

In summary, conjugated additions of  $\alpha$ , $\beta$ -unsaturated ketones with the arylzinc species formed in situ from diethylzinc and arylboronic acids were studied. 1,4-Addition products were formed in yields of 34–93%. The observed 1,4-addition of the  $\alpha$ , $\beta$ -unsaturated ketones is useful since it does not require transition-metal catalysts for the aryl transfer reactions.<sup>2</sup>

NMR spectra were recorded on a Brucker-300 MHz spectrometer. EI Mass spectra were recorded on a VG-7010E spectrometer. IR spectra were recorded on NicroLab 200SXV spectrometer. Elemental analysis was performed on Italy CARCOERBA 1106 apparatus. All reactions that are air and moisture sensitive were carried out under an anhyd argon atmosphere using standard Schlenk line techniques. Toluene was dried with Na–benzophenone. Petroleum ether (bp 60–90 °C) and EtOAc for column chromatography were distilled before use.

#### 1,4-Addition to Generate 3a-e and 4b-m; General Procedure

Under an argon atmosphere, a solution of diethylzinc in hexane (1.0 M, 2.25 mL, 2.25 mmol) was added to a solution of PhB(OH)<sub>2</sub> (91.3 mg, 0.75 mmol) in anhyd toluene (6 mL) in a flame-dried Schlenk flask (25 mL). After being stirred at 60 °C for 12 h, the reaction mixture was cooled to 0 °C and a solution of **1a** (62.4 mg, 0.3 mmol) in anhyd toluene (1.5 mL) was added. After stirring at 0 °C for 10 h, the reaction was quenched with sat. aq NH<sub>4</sub>Cl (10 mL). The resulting mixture was extracted with EtOAc ( $3 \times 10$  mL). The combined organic layers were washed with brine and dried over anhyd Na<sub>2</sub>SO<sub>4</sub>. The solvent was removed under vacuum. The residue was purified by flash chromatography on silica gel (hexane–EtOAc, 35:1) to give **3a** as white crystals (79 mg, 92% yield); mp 94.4–95.8 °C.

IR (KBr): 3026, 1677, 1596, 1494, 1450, 1264, 1213, 750, 702  $\rm cm^{-1}.$ 

<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>): δ = 3.64 (d, J = 7.3 Hz, 2 H), 4.72 (t, J = 7.3 Hz, 1 H), 7.06–7.11 (m, 5 H), 7.16–7.19 (m, 8 H), 7.32–7.37 (m, 2 H), 7.44–7.46 (m, 1 H), 7.83–7.86 (m, 2 H).

 $^{13}\text{C}$  NMR (75 MHz, CDCl<sub>3</sub>):  $\delta$  = 44.6, 45.8, 126.3, 127.8, 128.0, 128.5, 128.5, 133.0, 137.0, 144.1, 197.9.

MS (EI, 70 eV): m/z (%) = 286 [M<sup>+</sup>], 167 (36), 105 (100).

#### 3b

Yield: 78%; colorless solid; mp 95.4-96.4 °C.

IR (KBr): 3027, 1679, 1492, 1451, 1260, 1208, 757, 746, 701, 685 cm<sup>-1</sup>.

<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>):  $\delta$  = 3.71 (d, *J* = 7.0 Hz, 2 H), 4.79 (t, *J* = 7.0 Hz, 1 H), 7.19–7.29 (m, 9 H), 7.45–7.56 (m, 3 H), 7.92–7.95 (m, 2 H).

<sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>): δ = 44.5, 45.2, 126.5, 127.7, 128.0, 128.6, 129.1, 132.1, 133.2, 136.8, 142.5, 143.6, 197.6.

MS (EI, 70 eV): m/z (%) = 320 [M<sup>+</sup>], 201 (26), 105 (100).

Anal. Calcd for  $C_{21}H_{17}$ ClO: C, 78.62; H, 5.34. Found: C, 78.67; H, 5.41.

#### 3c

Yield: 73%; colorless solid; mp 94.6–95.8 °C.

IR (KBr): 3006, 1675, 1514, 1268, 1213, 1037, 702 cm<sup>-1</sup>.

<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>):  $\delta$  = 3.69 (d, *J* = 7.3 Hz, 2 H), 3.75 (s, 3 H), 4.76 (t, *J* = 7.3 Hz, 1 H), 6.79–6.82 (m, 2 H), 7.16–7.19 (m, 3 H), 7.25–7.27 (m, 4 H), 7.41–7.46 (m, 2 H), 7.52–7.54 (m, 1 H), 7.91–7.94 (m, 2 H).

 $^{13}\text{C}$  NMR (75 MHz, CDCl<sub>3</sub>):  $\delta$  = 44.8, 45.1, 55.1, 113.9, 126.2, 127.7, 128.0, 128.5, 128.5, 128.7, 133.0, 136.2, 137.0, 144.5, 158.0, 198.1.

MS (EI, 70 eV): m/z (%) = 316 [M<sup>+</sup>], 197 (100).

Anal. Calcd for  $C_{22}H_{20}O_2$ : C, 83.51; H, 6.37. Found: C, 83.35; H, 6.57.

# 3d

Yield: 88%; colorless solid; mp 98.2-99.8 °C.

IR (KBr): 3058, 1671, 1510, 1215, 747, 700, 685 cm<sup>-1</sup>.

<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>):  $\delta$  = 3.71 (d, *J* = 7.3 Hz, 2 H), 4.80 (t, *J* = 7.3 Hz, 1 H), 6.93–6.98 (m, 2 H), 7.19–7.29 (m, 7 H), 7.42–7.47 (m, 2 H), 7.53–7.58 (m, 1 H), 7.92–7.95 (m, 2 H).

 $^{13}\text{C}$  NMR (75 MHz, CDCl<sub>3</sub>):  $\delta$  = 44.8, 45.1, 115.1, 115.4, 126.5, 127.7, 128.0, 128.6, 129.2, 129.3, 133.1, 136.9, 144.0, 159.7, 163.0, 197.8.

MS (EI, 70 eV): m/z (%) = 304 [M<sup>+</sup>], 185 (38), 105 (100).

Anal. Calcd for  $C_{21}H_{17}FO$ : C, 82.87; H, 5.63. Found: C, 82.72; H, 5.73.

# 3e

Yield: 34%; colorless oil.

IR (neat): 3060, 1687, 1447, 750, 693 cm<sup>-1</sup>.

<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>):  $\delta$  = 3.76 (d, *J* = 7.3 Hz, 2 H), 5.29 (t, *J* = 7.3 Hz, 1 H), 7.12–7.29 (m, 8 H), 7.36–7.39 (m, 1 H), 7.41–7.47 (m, 2 H), 7.52–7.59 (m, 1 H), 7.94–7.99 (m, 2 H).

 $^{13}$ C NMR (75 MHz, CDCl<sub>3</sub>):  $\delta$  = 42.2, 43.9,126.4, 126.8, 127.6, 128.0, 128.0, 128.4, 128.4, 128.5, 129.9, 133.1, 136.8, 141.3, 142.4, 197.3.

MS (EI, 70 eV): m/z (%) = 320 [M<sup>+</sup>], 105 (100).

Anal. Calcd for  $C_{21}H_{17}$ ClO: C, 78.62; H, 5.34. Found: C, 78.93; H, 5.44.

#### 4b

Yield: 83%; colorless solid; mp 97.4-99.2 °C.

IR (KBr): 3023, 2962, 1677, 1513, 1450, 1261, 1097, 1079, 1026, 801  $\rm cm^{-1}.$ 

<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>):  $\delta$  = 2.29 (s, 1 H), 3.72 (d, *J* = 7.3 Hz, 2 H), 4.77 (t, *J* = 7.3 Hz, 1 H), 7.07–7.10 (m, 2 H), 7.15–7.26 (m, 3 H), 7.26–7.27 (m, 4 H), 7.42–7.47 (m, 2 H), 7.53–7.55 (m, 1 H), 7.92–7.95 (m, 2 H).

<sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>): δ = 20.9, 44.7, 45.5, 126.2, 127.6, 127.7, 128.0, 128.5, 128.5, 129.2, 133.0, 135.8, 137.0, 141.1, 144.3, 198.0.

MS (EI, 70 eV): m/z (%) = 300 [M<sup>+</sup>], 181 (95), 105 (100).

Anal. Calcd for  $C_{22}H_{20}O$ : C, 87.96; H, 6.71. Found: C, 88.18; H, 6.75.

# 4e

Yield: 85%; colorless solid; mp 108.9–109.6 °C.

IR (KBr): 3025, 1678, 1488, 1450, 1259, 1207, 754, 743, 700, 686 cm<sup>-1</sup>.

<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>):  $\delta$  = 3.68 (d, *J* = 1.0 Hz, 1 H), 3.70 (d, *J* = 1.0 Hz, 1 H), 4.74 (t, *J* = 7.2 Hz, 1 H), 7.11–7.14 (m, 2 H), 7.17–7.27 (m, 5 H), 7.35–7.45 (m, 4 H), 7.52–7.57 (m, 1 H), 7.89–7.93 (m, 2 H).

 $^{13}\text{C}$  NMR (75 MHz, CDCl<sub>3</sub>):  $\delta$  = 44.4, 45.2, 120.1, 126.6, 127.6, 127.9, 128.6, 128.6, 129.5, 131.5, 133.1, 136.8, 143.1, 143.5, 197.5.

MS (EI, 70 eV): m/z (%) = 364 [M<sup>+</sup>], 247 (57), 165 (67), 105 (100), 77 (76).

Anal. Calcd for  $C_{21}H_{17}BrO: C$ , 69.05; H, 4.69. Found: C, 69.13; H, 4.48.

# 4f

Yield: 63%; colorless oil.

IR (neat): 3059, 3027, 1691, 1448, 1432, 780, 752, 692 cm<sup>-1</sup>.

<sup>1</sup>H NMR (300 MHz,  $CDCl_3$ ):  $\delta = 3.86$  (q, J = 17.6 Hz, 1 H), 4.17 (q, J = 17.6 Hz, 1 H), 5.85 (t, J = 6.8 Hz, 1 H), 7.05–7.29 (m, 8 H), 7.42–7.7.48 (m, 2 H), 7.56–7.66 (m, 1 H), 7.99–8.02 (m, 2 H).

<sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>): δ = 40.5, 40.5, 126.1, 127.2, 127.8, 128.1, 128.3, 128.6, 133.1, 139.4, 140.7, 197.8.

MS (EI, 70 eV): m/z (%) = 354 [M<sup>+</sup>], 105 (100), 77 (51).

Anal. Calcd for C<sub>21</sub>H<sub>16</sub>Cl<sub>2</sub>O: C, 71.00; H, 4.54. Found: C, 71.02; H, 4.72.

# 4g

Yield: 53%; yellow oil.

IR (neat): 3060, 3028, 1686, 1597, 1517, 1345, 747, 700 cm<sup>-1</sup>.

<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>):  $\delta$  = 3.77 (t, *J* = 6.0 Hz, 2 H), 4.91 (t, *J* = 7.3 Hz, 1 H), 7.22–7.32 (m, 5 H), 7.42–7.48 (m, 4 H), 7.55–7.60 (m, 1 H), 7.93–7.96 (m, 2 H), 8.10–8.14 (m, 2 H).

<sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>):  $\delta$  = 44.1, 45.7, 123.8, 127.0, 127.7, 128.0, 128.7, 128.9, 129.1, 133.4, 136.5, 142.5, 146.4, 151.7, 197.1.

MS (EI, 70 eV): m/z (%) = 331 [M<sup>+</sup>], 105 (100).

Anal. Calcd for C<sub>21</sub>H<sub>17</sub>NO<sub>3</sub>: C, 76.12; H, 5.17; N, 4.23. Found: C, 76.19; H, 5.45; N, 4.36.

# 4h

Yield: 89%; colorless solid; mp 124.1-125.5 °C.

IR (KBr): 3056, 1677, 1596, 1448, 1200, 779, 759, 699 cm<sup>-1</sup>.

<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>):  $\delta$  = 3.82 (q, *J* = 7.3 Hz, 2 H), 5.63 (t, *J* = 7.3 Hz, 1 H), 7.13–7.58 (m, 12 H), 7.70–7.73 (m, 1 H), 7.76–7.83 (m, 1 H), 7.91–7.94 (m, 2 H), 8.15–8.18 (m, 1 H).

 $^{13}\text{C}$  NMR (75 MHz, CDCl<sub>3</sub>):  $\delta$  = 41.3, 45.0, 123.7, 124.3, 125.1, 125.4, 126.1, 126.3, 127.2, 127.9, 128.0, 128.4, 128.5, 128.7, 131.5, 133.0, 134.0, 136.9, 139.6, 143.8, 197.8.

MS (EI, 70 eV): m/z (%) = 336 [M<sup>+</sup>], 217 (100), 105 (87).

Anal. Calcd for  $C_{25}H_{20}O$ : C, 89.25; H, 5.99. Found: C, 89.34; H, 6.00.

# 4i

Yield: 85%; colorless solid; mp 81.1–81.8 °C.

 $IR(KBr): 3059, \, 3027, \, 1681, \, 1395, \, 1507, \, 1493, \, 789, \, 778, \, 700 \ cm^{-1}.$ 

<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>):  $\delta$  = 3.86 (d, *J* = 7.5 Hz, 2 H), 4.73 (t, *J* = 7.5 Hz, 1 H), 7.01–7.33 (m, 10 H), 7.47–7.51 (m, 3 H), 7.76–8.23 (m, 4 H).

<sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>): δ = 46.5, 48.3, 124.2, 125.6, 126.3, 126.4, 126.7, 127.6, 127.8, 128.2, 128.5, 129.9, 132.3, 133.8, 136.5, 143.8, 202.5.

MS (EI, 70 eV): m/z (%) = 336 [M<sup>+</sup>], 155 (100).

Anal. Calcd for  $C_{25}H_{20}O$ : C, 89.25; H, 5.99. Found: C, 89.05; H, 5.99.

# 4j

Yield: 38%; colorless solid; mp 137.9-139.5 °C.

IR (KBr): 3109, 3022, 1693, 1599, 1516, 1345, 750, 700 cm<sup>-1</sup>.

<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>):  $\delta$  = 3.76 (d, *J* = 7.3 Hz, 2 H), 4.77 (t, *J* = 7.3 Hz, 1 H), 7.18–7.29 (m, 10 H), 8.03–8.06 (m, 2 H), 8.26–8.29 (m, 2 H).

 $^{13}\text{C}$  NMR (75 MHz, CDCl<sub>3</sub>):  $\delta$  = 45.2, 45.9,123.8, 126.6, 127.6, 128.4, 129.0, 141.3, 143.4, 196.7.

MS (EI, 70 eV): m/z (%) = 331 [M<sup>+</sup>], 167 (100).

Anal. Calcd for  $C_{21}H_{17}NO_3$ : C, 76.12; H, 5.17; N, 4.23. Found: C, 76.20; H, 5.30; N, 4.32.

### 4k

Yield: 80%; colorless solid; mp 71.2–72.8 °C.

IR (neat): 3059, 3026, 1685, 1596, 1593, 1490, 1451, 1429, 1263, 700  $\rm cm^{-1}$ 

<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>):  $\delta$  = 3.61 (d, *J* = 7.3 Hz, 2 H), 3.70 (s, 3 H), 4.70 (t, *J* = 7.3 Hz, 1 H), 6.99–7.00 (m, 1 H), 7.03–7.11 (m, 2 H), 7.13–7.16 (m, 8 H), 7.19–7.26 (m, 1 H), 7.33–7.35 (m, 1 H), 7.41–7.45 (m, 1 H).

<sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>): δ = 44.7, 45.9, 55.3, 112.2, 119.6, 120.6, 126.3, 127.8, 128.5, 129.5, 138.3, 144.0, 159.7, 197.7.

MS (EI, 70 eV): m/z (%) = 316 [M<sup>+</sup>], 167 (50), 135 (100).

Anal. Calcd for  $C_{22}H_{20}O_2$ : C, 83.51; H, 6.37. Found: C, 83.83; H, 6.21.

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Yield: 93%; colorless oil.

IR (neat): 3083, 3059, 2958, 2928, 2870, 1684, 1596, 1493, 1447, 749, 700, 689  $\rm cm^{-1}.$ 

<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>):  $\delta$  = 0.80 (d, *J* = 6.6 Hz, 3 H), 0.99 (d, *J* = 6.6 Hz, 3 H), 1.91 (m, 1 H), 3.15 (q, *J* = 6.9 Hz, 1 H), 3.36 (d, *J* = 6.7 Hz, 2 H), 7.16–7.29 (m, 5 H), 7.39–7.44 (m, 2 H), 7.50–7.52 (m, 1 H), 7.88–7.90 (m, 2 H).

 $^{13}\text{C}$  NMR (75 MHz, CDCl<sub>3</sub>):  $\delta$  = 20.4, 21.0, 33.3, 42.6, 47.9, 126.1, 128.0, 128.1, 128.4, 128.5, 132.8, 137.4, 143.6, 199.5.

MS (EI, 70 eV): m/z (%) = 252 [M<sup>+</sup>], 132 (74), 105 (100).

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#### References

- (a) Pertter, P. Conjugate Addition Reactions in Organic Synthesis; Pergamon Press: Oxford, **1992**. (b) Rossiter, B. E.; Swingle, N. M. Chem. Rev. **1992**, 92, 771.
- (2) (a) For leading references on organolithium: Cooke, M. P. J. Org. Chem. 1984, 49, 1144. (b) Organomagnesium: Modi, S. P.; Gardner, J. O.; Milowsky, A.; Wierzba, M.; Forgione, L.; Mazur, P.; Solo, A. J.; Duax, W. L.; Galdecki, Z.; Grochulski, P.; Wawrzak, Z. J. Org. Chem. 1989, 54, 2317. (c) Also see: Maruoka, K.; Imoto, H.; Saito, S.; Yamamoto, H. J. Am. Chem. Soc. 1994, 116, 4131. (d) Organozinc: Knochel, P.; Singer, R. D. Chem. Rev. 1993, 93, 2117. (e) Also see: Hanson, M. V.; Rieke, R. D. J. Am. Chem. Soc. 1995, 117, 10775. (f) Organoboronic acid and esters: Sakai, M.; Hayasagi, H.; Miyaura, N. Organometallics 1997, 16, 4229. (g) Also see: Nishikata, T.; Yamamoto, Y.; Miyaura, N. Angew. Chem. Int. Ed. 2003, 42, 2768.
- (3) For reviews of asymmetric catalysis: (a) Tomioka, K.; Nagaoka, Y. In *Comprehensive Asymmetric Catalysis*; Jacobsen, E. N.; Pfaltz, A.; Yamamoto, H., Eds.; Springer: Berlin, **1999**. (b) Kanai, M.; Shibasaki, M. In *Catalytic Asymmetric Synthesis*; Ojima, I., Ed.; Wiley: New York, **2000**, 569–592. (c) Hayashi, T.; Yamasaki, K. *Chem. Rev.* **2003**, *103*, 2829.

- (4) (a) Srebnik, M. *Tetrahedron Lett.* **1991**, *32*, 2449.
  (b) Oppolzer, W.; Radinov, R. N. *J. Am. Chem. Soc.* **1993**, *115*, 1593. (c) Langer, F.; Schwink, L.; Devasagayaraj, A.; Chavant, P.-Y.; Knochel, P. *J. Org. Chem.* **1996**, *61*, 8229.
  (d) Boudier, A.; Bromm, L. O.; Lotz, M.; Knochel, P. *Angew. Chem. Int. Ed.* **2000**, *39*, 4414. (e) Dahmen, S.; Bräse, S. *Org. Lett.* **2001**, *3*, 4119.
- (5) Bolm, C.; Rudolph, J. J. Am. Chem. Soc. 2002, 124, 14850.
- (6) Decreasing the amount of  $Et_2Zn$  led to an incomplete reaction.
- (7) (a) Bolm, C.; Kesselgruber, M.; Hermanns, N.; Hildebrand, J. P.; Raabe, G. *Angew. Chem. Int. Ed.* **2001**, *40*, 1488.
  (b) Bolm, C.; Hermanns, N.; Hildebrand, J. P.; Muñiz, K. *Angew. Chem. Int. Ed.* **2000**, *39*, 3465.