Copper-Catalyzed Asymmetric N–H Insertion Reactions: Couplings of Diazo Compounds with Carbamates to Generate α-Amino Acids

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Supporting Information

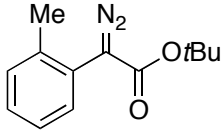
General. All reactions were carried out in oven-dried glassware under an atmosphere of nitrogen. All chemicals were purchased from commercial suppliers and used as received, unless noted otherwise. $BocNH_2$ (Fluka) was recrystallized from dichloromethane and pentane. 1,2-Dichloroethane (anhydrous; Fluka), CuBr (Strem), $AgSbF_6$ (Strem), and $CbzNH_2$ (Aldrich) were used as received. Bpy* was prepared and resolved as previously described.[1]

HPLC analyses were carried out on an Agilent 1100 series system with Daicel Chiralpak® columns in hexane/isopropanol mixtures. GC analysis were carried out on an Agilent 6850 series system with a CP-Chirasil-Dex CB column; 140 °C (5.0 min), 1.0 °C/min to 160 °C; 14.37 psi He or on an Astec G-TA column; 140 °C (1.0 min), 1.0 °C/min to 180 °C; 14.89 psi He. Melting points were measured on a Hoover melting point apparatus and are uncorrected.

I. Preparation of the Diazo Compounds

The syntheses of the following diazo compounds have previously been described: *tert*-butyl α–diazo–α–phenylacetate [72410-67-4] and *tert*-butyl α–diazo–α–4-methoxyphenylacetate [76530-00-2].

The α–aryl-α–diazoesters were prepared via direct diazo transfer to the α–aryl esters, as previously reported, using either tosyl azide or *p*-ABSA.[2] The yields have not been optimized.

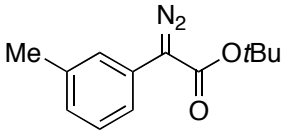


The diazo ester was prepared from the ester (3.10 g, 15.0 mmol), MeCN (53 mL), DBU (4.50 mL, 30.0 mmol), and *p*-ABSA (5.40 g, 22.5 mmol). Product: 1.02 g (29%); orange oil.

^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.51-7.47 (m, 1H), 7.37-7.32 (m, 3H), 2.47 (s, 3H), 1.63 (s, 9H);

^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 165.5, 137.6, 130.93, 130.89, 128.7, 126.5, 124.8, 81.9, 28.6, 20.2; the resonance of the carbon that bears the diazo group was not detected;

IR (film) 2979, 2932, 2084, 1699, 1491, 1368, 1295, 1253, 1149, 1006 cm^{-1}.

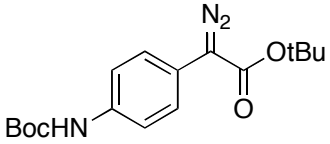


The diazo ester was prepared from the ester (2.44 g, 11.8 mmol), MeCN (42 mL), DBU (2.70 mL, 17.8 mmol), and *p*-ABSA (3.70 g, 15.4 mmol). Product: 1.33 g (47%); orange oil.

^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.38-7.34 (m, 1H), 7.29-7.27 (m, 2H), 7.02-6.99 (m, 1H), 2.38 (s, 3H), 1.58 (s, 9H);

^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 164.9, 138.8, 128.9, 126.6, 126.1, 124.8, 121.2, 82.1, 28.6, 21.8; the resonance of the carbon that bears the diazo group was not detected;

IR (film) 2979, 2931, 2084, 1701, 1605, 1492, 1369, 1344, 1290, 1143, 1055, 779 cm^{-1}.

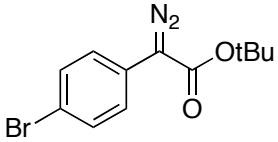


The diazo ester was prepared from the ester (1.87 g, 6.08 mmol), MeCN (32 mL), DBU (1.36 mL, 9.23 mmol), and *p*-ABSA (1.90 g, 7.90 mmol). Product: 681 mg (34%); orange solid.

^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.38 (app s, 4H), 6.46 (s, 1H), 1.55 (s, 9H), 1.52 (s, 9H);

^{13}C NMR ($CDCl_3$, 126 MHz) δ 165.1, 152.9, 136.3, 125.1, 120.3, 119.1, 82.2 (x2), 28.6, 28.5; the resonance of the carbon that bears the diazo group was not detected;

IR (film) 3055, 2987, 2306, 2086, 1693, 1521, 1422, 1266, 1150, 896, 744 cm^{-1}.

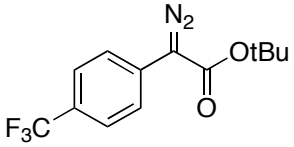


The diazo ester was prepared from the ester (1.67 g, 6.15 mmol), MeCN (28 mL), DBU (1.38 mL, 9.23 mmol), and tosyl azide (1.54 g, 8.00 mmol). Product: 1.40 g (77%); orange solid.

^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.48 (d, J = 9.0 Hz, 2H), 7.35 (d, J = 8.7 Hz, 2H), 1.55 (s, 9H);

^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 164.3, 132.1, 125.53, 125.50, 119.2, 82.6, 28.6; the resonance of the carbon that bears the diazo group was not detected;

IR (film) 3055, 2984, 2088, 1696, 1491, 1347, 1266, 1148, 1003, 740, 705 cm^{-1}.

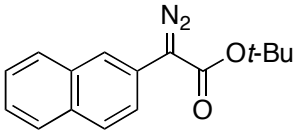


The diazo ester was prepared from the ester (3.46 g, 13.3 mmol), MeCN (60 mL), DBU (2.90 mL, 20.0 mmol), and *p*-ABSA (4.20 g, 17.3 mmol). Product: 1.45 g (38%); orange solid.

^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.60 (app s, 4H), 1.55 (s, 9H);

^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 163.9, 130.9, 127.4 (q, $^2J_{CF}$ = 33.0 Hz), 125.9 (q, $^3J_{CF}$ = 3.8 Hz), 123.6, 122.5, 82.9, 28.5; the resonance of the carbon that bears the diazo group was not detected;

IR (film) 3055, 2987, 2094, 1699, 1422, 1328, 1266, 1148, 896, 740, 705 cm^{-1}.



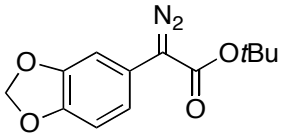
The diazo ester was prepared from the ester (843 mg, 3.48 mmol), MeCN (14 mL), DBU (0.78 mL, 5.22 mmol), and tosyl azide (870 mg, 4.52 mmol). Product: 695 mg (74%); orange solid.

^{1}H NMR ($CDCl_3$, 300 MHz) δ 8.04 (s, 1H), 7.86-7.79 (m, 3H),

7.52-7.43 (m, 3H), 1.60 (s, 9H);

^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 164.9, 133.8, 131.5, 128.7, 127.8, 127.7, 126.7, 125.8, 123.5, 122.6, 122.1, 82.4, 28.6; the resonance of the carbon that bears the diazo group was not detected;

IR (film) 3055, 2987, 2306, 2088, 1696, 1422, 1266, 1148, 896, 739, 705 cm^{-1}.

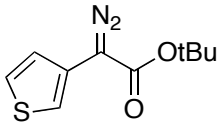


The diazo ester was prepared from the ester (1.64 g, 6.94 mmol), MeCN (28 mL), DBU (1.56 mL, 10.4 mmol), and tosyl azide (1.73 g, 9.02 mmol). Product: 489 mg (27%); orange solid.

^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.06-7.05 (m, 1H), 6.85-6.83 (m, 2H), 5.96 (s, 2H), 1.54 (s, 9H);

^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 165.1, 148.5, 146.0, 127.8, 117.9, 109.0, 105.9, 101.4, 82.2, 28.5); the resonance of the carbon that bears the diazo group was not detected;

IR (film) 3055, 2984, 2087, 1694, 1505, 1493, 1370, 1266, 1235, 1041, 740, 705 cm^{-1}.



The diazo ester was prepared from the ester (4.34 g, 21.9 mmol), MeCN (69 mL), DBU (4.90 mL, 32.8 mmol), and tosyl azide (6.80 g, 28.5 mmol). Product: 829 mg (17%); orange solid.

^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.40-7.36 (m, 2H), 7.03-7.01 (m, 1H), 1.56 (s, 9H);

^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 165.0, 126.4, 124.6, 123.9, 117.6, 82.3, 28.6); the resonance of the carbon that bears the diazo group was not detected;

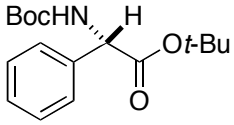
IR (film) 3055, 2986, 2306, 2085, 1695, 1422, 1318, 1266, 1139, 896, 740, 705 cm^{-1}.

II. Catalytic Asymmetric N–H Insertion Reactions

All enantioselectivities and isolated yields that are reported in Tables 2 and 3 are the average of two experiments, one with (–)-bpy* and one with (+)-bpy*.

Typical Procedure for Table 2. Entry 1. In a glovebox, a solution of the catalyst was prepared by adding CuBr (4.7 mg, 33 μmol), (–)-bpy* (24.0 mg, 37.5 μmol), $AgSbF_6$ (9.7 mg, 28 μmol), and 1,2-dichloroethane (4.3 mL) to a vial (#1). The resulting mixture was stirred for 45 min. In a separate vial (#2), the diazo ester (154 mg, 0.704 mmol) and $BocNH_2$ (55.0 mg, 0.469 mmol) were dissolved in 1,2-dichloroethane (3.4 mL), and this solution was added by syringe over 3 min to vial #1 (vial #2 was rinsed with 1,2-dichloroethane (0.1 mL)). The reaction mixture was stirred at room temperature for 30 min, and then the solvent was removed and the product was purified by flash chromatography.

When the reaction was set up outside of a glove box, a lower yield (64%) and ee (81%) were obtained (a single experiment).



After chromatography on silica gel (1% Et_2O in CH_2Cl_2), the desired compound was isolated as a white solid: run 1, 105 mg (73%; 93% ee); run 2, 110 mg (76%; 95% ee). The ee was determined on a CP-Chirasil-Dex CB column with t_r(major) 21.6 min, t_r(minor) 22.0 min.

mp: 115-116 °C;

$[\alpha]^{20}_D$ = –120 (c = 0.95, CH_2Cl_2); 95% ee, from (+)-bpy*;

^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.29-7.21 (m, 5H), 5.53 (d, *J* = 6.5 Hz, 1H), 5.13 (d, *J* = 7.5 Hz, 1H), 1.36 (s, 9H), 1.31 (s, 9H);

^{13}C NMR ($CDCl_3$, 126 MHz) δ 170.4, 155.0, 137.0, 128.8, 128.2, 127.1, 82.5, 78.0, 58.2, 28.5, 27.9;

IR (film) 3055, 2987, 2306, 1422, 1266, 896, 740, 705 cm^{-1};

HRMS (ESI) calcd for $C_{17}H_{25}NNaO_4$ ($M + Na^+$) 330.1676, found 330.1679.

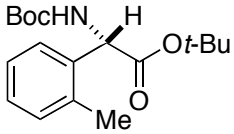


Table 2, entry 2. The compound was prepared with (–)-bpy* from the diazo ester (119 mg, 0.512 mmol) and $BocNH_2$ (40.0 mg, 0.341 mmol). After chromatography on silica gel (1% Et_2O in CH_2Cl_2), the desired compound was isolated as a colorless oil: run 1, 74.0 mg (68%; 80% ee); run 2, 81.0 mg (74%; 81% ee). The ee was determined on an Astec G-TA column with t_r(major) 37.1 min, t_r(minor) 37.6 min.

$[\alpha]^{20}_D$ = +86 (c = 1.25, CH_2Cl_2); 80% ee, from (–)-bpy*;

^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.27-7.16 (m, 4H), 5.52 (d, *J* = 7.0 Hz, 1H), 5.44 (d, *J* = 7.5 Hz, 1H), 1.43 (s, 9H), 1.37 (s, 9H);

^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 170.9, 155.1, 136.8, 136.5, 130.9, 128.1, 126.4, 126.1, 82.3, 79.9, 54.7, 28.5, 28.0, 19.7;

IR (film) 3055, 2985, 2306, 1712, 1492, 1369, 1266, 1154, 896, 740, 705 cm^{-1};

HRMS (ESI) calcd for $C_{18}H_{27}NNaO_4$ ($M + Na^+$) 344.1832, found 344.1838.

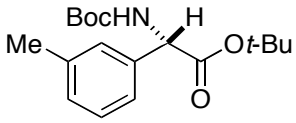


Table 2, entry 3. The compound was prepared with (–)-bpy* from the diazo ester (163 mg, 0.704 mmol) and $BocNH_2$ (55.0 mg, 0.469 mmol). After chromatography on silica gel (1% Et_2O in CH_2Cl_2), the desired compound was isolated as a colorless oil: run 1, 114 mg (76%; 88% ee); run 2 (with 0.427 mmol of $BocNH_2$), 100 mg (73%; 87% ee). The ee was determined on an AD-H column (hexanes/*iso*-propanol 90:10, flow 1.0 mL/min) with t_r(minor) 6.5 min, t_r(major) 10.4 min.

$[\alpha]^{20}_D$ = +88 (c =1.50, CH_2Cl_2); 88% ee, from (–)-bpy*;

^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.22 (dd, *J* = 15, 7.5 Hz, 1H), 7.16-7.09 (m, 3H), 5.55 (d, *J* = 7.5 Hz, 1H), 5.16 (d, *J* = 7.5 Hz, 1H), 2.34 (s, 3H), 1.44 (s, 9H), 1.40 (s, 9H);

^{13}C NMR ($CDCl_3$, 126 MHz) δ 170.5, 155.0, 138.5, 137.7, 129.0, 128.7, 127.9, 124.1, 82.4, 80.0, 58.2, 28.5, 28.0, 21.6;

IR (film) 3055, 2984, 2306, 1712, 1494, 1266, 1155, 1052, 740, 705 cm^{-1};

HRMS (ESI) calcd for $C_{18}H_{27}NNaO_4$ ($M + Na^+$) 344.1832, found 344.1833.

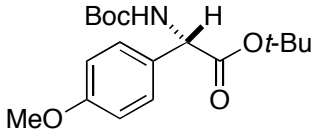


Table 2, entry 4. The compound was prepared with (–)-bpy* from the diazo ester (159 mg, 0.640 mmol) and $BocNH_2$ (50.0 mg, 0.427 mmol). After chromatography on silica gel (1% Et_2O in CH_2Cl_2), the desired compound was isolated as a colorless oil: run 1, 89.0 mg (62%; 94% ee); run 2, 86.0 mg (60%; 95% ee). The ee was determined on an AD-H column (hexanes/*iso*-propanol 90:10, flow 1.0 mL/min) with t_r(minor) 9.4 min, t_r(major) 11.1 min.

$[\alpha]^{20}_D$ = +106 (c = 1.20, CH_2Cl_2); 94% ee, from (–)-bpy*;

^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.28 (d, *J* = 8.0 Hz, 2H), 6.87 (d, *J* = 9.0 Hz, 2H), 5.56 (d, *J* = 7.0 Hz, 1H), 5.14 (d, *J* = 7.5 Hz, 1H), 3.78 (s, 3H), 1.44 (s, 9H), 1.40 (s, 9H);

^{13}C NMR ($CDCl_3$, 126 MHz) δ 170.6, 159.4, 154.9, 130.0, 128.3, 114.3, 82.3, 79.9, 57.6, 55.3, 28.5, 27.9;

IR (film) 3055, 2987, 2306, 1422, 1266, 896, 740, 705 cm^{-1};

HRMS (ESI) calcd for $C_{18}H_{27}NNaO_5$ ($M + Na^+$) 360.1781, found 360.1772.

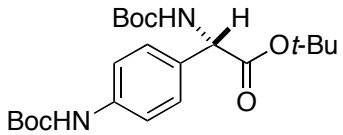


Table 2, entry 5. The compound was prepared with (–)-bpy* from the diazo ester (171 mg, 0.512 mmol) and $BocNH_2$ (40.0 mg, 0.341 mmol). After chromatography on silica gel (5% Et_2O in CH_2Cl_2), the desired compound was isolated as a white solid: run 1, 112 mg (78%; 89% ee); run 2, 109 mg (76%; 92% ee). The ee was

determined on an AS-H column (hexanes/*iso*-propanol 95:5, flow 1.0 mL/min) with t_r(minor) 11.6 min, t_r(major) 15.9 min.

mp: 174-175 °C;

$[\alpha]^{20}_D$ = –80 (c = 1.20, CH_2Cl_2); 92% ee, from (+)-bpy*;

^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.34 (d, *J* = 8.0 Hz, 2H), 7.26 (d, *J* = 8.5 Hz, 2H), 6.69 (s, 1H), 5.57 (d, *J* = 7.0 Hz, 1H), 5.14 (d, *J* = 7.5 Hz, 1H), 1.51 (s, 9H), 1.43 (s, 9H), 1.38 (s, 9H);

^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 170.4, 155.0, 152.9, 138.4, 132.3, 129.1, 127.8, 118.7, 82.5, 80.0, 57.7, 28.5, 28.0;

IR (film) 4453, 4197, 3945, 3055, 2987, 2306, 1728, 1422, 1266, 1156, 896, 740 cm^{-1};

HRMS (ESI) calcd for $C_{22}H_{34}N_2NaO_6$ ($M + Na^+$) 445.2309, found 445.2313.

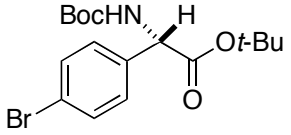


Table 2, entry 6. The compound was prepared with (–)-bpy* from the diazo ester (152 mg, 0.512 mmol) and $BocNH_2$ (40.0 mg, 0.341 mmol). After chromatography on silica gel (2% Et_2O in CH_2Cl_2), the desired compound was isolated as a colorless oil: run 1, 113 mg (86%; 85% ee); run 2, 113 mg (86%; 85% ee). The ee was determined on an AD-H column (hexanes/*iso*-propanol 95:5, flow 1.0 mL/min) with t_r(minor) 15.8 min, t_r(major) 17.0 min.

$[\alpha]^{20}_D$ = +72 (c = 1.65, CH_2Cl_2); 85% ee, from (–)-bpy*;

^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.46 (d, *J* = 8.4 Hz, 2H), 7.24 (d, *J* = 8.4 Hz, 2H), 5.65 (d, *J* = 6.9 Hz, 1H), 5.15 (d, *J* = 7.2 Hz, 1H), 1.42 (s, 9H), 1.38 (s, 9H);

^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 169.8, 154.9, 137.2, 131.9, 128.8, 122.2, 83.0, 80.3, 57.7, 28.5, 27.9;

IR (film) 3055, 2987, 2306, 1712, 1422, 1266, 1156, 896, 706, 736 cm^{-1};

HRMS (ESI) calcd for $C_{17}H_{24}BrNNaO_4$ ($M + Na^+$) 408.0781, found 408.0789.

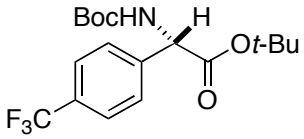


Table 2, entry 7. The compound was prepared with (–)-bpy* from the diazo ester (146 mg, 0.512 mmol) and $BocNH_2$ (40.0 mg, 0.341 mmol). After chromatography on silica gel (1% Et_2O in CH_2Cl_2), the desired compound was isolated as a colorless oil: run 1, 113 mg (88%; 85% ee); run 2, 115 mg (90%; 84% ee). The ee was determined on an AD-H column (hexanes/*iso*-propanol 99:1, flow 1.0 mL/min) with t_r(major) 17.2 min, t_r(minor) 19.1 min.

$[\alpha]^{20}_D$ = +77 (c = 1.25, CH_2Cl_2); 85% ee, from (–)-bpy*;

^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.60 (d, *J* = 8.0 Hz, 2H), 7.49 (d, *J* = 8.0 Hz, 2H), 5.76 (d, *J* = 7.0 Hz, 1H), 5.26 (d, *J* = 7.0 Hz, 1H), 1.42 (s, 9H), 1.39 (s, 9H);

^{13}C NMR ($CDCl_3$, 126 MHz) δ 169.5, 154.9, 142.2, 130.4 (q, $^2J_{CF}$ = 32.2 Hz), 127.4, 125.8 (q, $^3J_{CF}$ = 3.4 Hz), 124.2 (q, J_{CF} = 272 Hz), 83.2, 80.4, 57.9, 28.5, 27.9;

IR (film) 3055, 2987, 2306, 1713, 1422, 1326, 1266, 1156, 896, 736, 706 cm^{-1};

HRMS (ESI) calcd for $C_{18}H_{24}F_3NNaO_4$ ($M + Na^+$) 398.1550, found 398.1559.

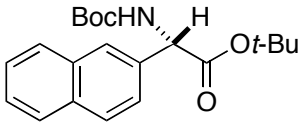


Table 2, entry 8. The compound was prepared with (–)-bpy* from the diazo ester (155 mg, 0.578 mmol) and $BocNH_2$ (45.1 mg, 0.385 mmol). After chromatography on silica gel (1% Et_2O in CH_2Cl_2), the desired compound was isolated as a white solid: run 1, 96.0 mg (70%; 89% ee); run 2, 103 mg (75%; 92% ee). The ee was determined on an AD-H column (hexanes/*iso*-propanol 90:10, flow 1.0 mL/min) with t_r(minor) 7.4 min, t_r(major) 10.3 min.

mp: 172-173 °C;

$[\alpha]^{20}_D$ = +106 (c = 1.20, CH_2Cl_2); 89% ee, from (–)-bpy*;

^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.85-7.83 (m, 4H), 7.50-7.47 (m, 3H), 5.73 (d, *J* = 7.0 Hz, 1H), 5.38 (d, *J* = 7.5 Hz, 1H), 1.45 (s, 9H), 1.39 (s, 9H);

^{13}C NMR ($CDCl_3$, 126 MHz) δ 170.4, 155.0, 135.4, 133.5, 133.2, 128.7, 128.3, 127.9 (x2), 126.4 (x2), 124.9, 82.7, 80.1, 58.4, 28.5, 28.0;

IR (film) 3055, 2986, 2306, 1712, 1422, 1266, 1155, 896, 739, 705 cm^{-1};

HRMS (ESI) calcd for $C_{21}H_{27}NNaO_4$ ($M + Na^+$) 380.1832, found 380.1831.

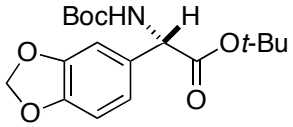


Table 2, entry 9. The compound was prepared with (–)-bpy* from the diazo ester (120 mg, 0.458 mmol) and $BocNH_2$ (35.7 mg, 0.305 mmol). After chromatography on silica gel (2% Et_2O in CH_2Cl_2), the desired compound was isolated as a colorless oil: run 1, 80.0 mg (75%; 89% ee); run 2, 77.0 mg (72%; 91% ee). The ee was determined on an AD-H column (hexanes/*iso*-propanol 90:10, flow 1.0 mL/min) with t_r(minor) 9.2 min, t_r(major) 13.2 min.

$[\alpha]^{20}_D$ = +80 (c = 1.80, CH_2Cl_2); 89% ee, from (–)-bpy*;

^{1}H NMR ($CDCl_3$, 300 MHz) δ 6.83-6.75 (m, 3H), 5.95 (s, 2H), 5.56 (d, *J* = 6.6 Hz, 1H), 5.09 (d, *J* = 7.5 Hz, 1H), 1.43 (s, 9H), 1.40 (s, 9H);

^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 170.4, 154.9, 148.0, 147.6, 131.8, 120.7, 108.6, 107.6, 101.3, 82.6, 80.1, 57.9, 28.5, 27.9;

IR (film) 3055, 2987, 2306, 1715, 1422, 1266, 1155, 896, 740, 705 cm^{-1};

HRMS (ESI) calcd for $C_{18}H_{25}NNaO_6$ ($M + Na^+$) 374.1574, found 374.1572.

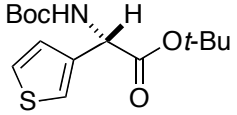


Table 2, entry 10. The compound was prepared with (–)-bpy* from the diazo ester (172 mg, 0.768 mmol) and $BocNH_2$ (60.0 mg, 0.512 mmol). After chromatography on silica gel (1% Et_2O in CH_2Cl_2), the desired compound was isolated as a yellow oil: run 1, 84.0 mg (51%; 82% ee); run 2, 77.0 mg (46%; 77% ee). The ee was determined on an IA column (hexanes/*iso*-propanol 95:5, flow 1.0 mL/min) with t_r(minor) 11.3 min, t_r(major) 14.3 min.

$[\alpha]^{20}_D$ = –52 (c = 1.70, CH_2Cl_2); 77% ee, from (+)-bpy*;

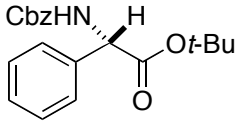
^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.31-7.28 (m, 1H), 7.24-7.23 (m, 1H), 7.08 (dd, *J* = 3.6, 1.2 Hz, 1H), 5.46 (d, *J* = 7.5 Hz, 1H), 5.32 (d, *J* = 8.4 Hz, 1H), 1.45 (s, 9H), 1.44 (s, 9H);

^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 170.1, 153.6, 138.2, 126.5, 126.4, 122.5, 82.7, 80.2, 54.3, 28.5, 28.1;

IR (film) 3430, 3054, 2983, 2306, 1714, 1493, 1369, 1265, 1154, 1055, 744, 705 cm^{-1};

HRMS (ESI) calcd for $C_{15}H_{23}NNaO_4S$ ($M + Na^+$) 336.1240, found 336.1246.

Typical Procedure for Table 3. Entry 1. In a glovebox, a solution of the catalyst was prepared by mixing CuBr (3.8 mg, 27 μmol), (–)-bpy* (19.6 mg, 30.6 μmol), $AgSbF_6$ (7.9 mg, 23 μmol), and 1,2-dichloroethane (26 mL) in a vial (#1). This mixture was stirred for 45 min, and then a portion (8.6 mL) was placed into a separate vial (#2). In another vial (#3), the diazo ester (83.4 mg, 0.382 mmol) and $CbzNH_2$ (60.0 mg, 0.382 mmol) were dissolved in 1,2-dichloroethane (6.0 mL). This solution was added by syringe over 3 min to vial #1 (additional 1,2-dichloroethane (0.1 mL) was used to rinse vial #3, and this was added to vial #1). The reaction mixture was allowed to stir for 5 min, and then the remainder of the catalyst (vial #2) was added in one portion. Finally, the remainder of the diazo ester (41.7 mg, 0.191 mmol) in 1,2-dichloroethane (6.0 mL) was added dropwise over 0.5 min to the reaction mixture. The mixture was stirred at room temperature for 30 min, concentrated to dryness, and purified by flash chromatography.



After chromatography on silica gel (0.5% Et_2O in CH_2Cl_2), the desired compound was isolated as a colorless oil: run 1, 96.0 mg (74%; 94% ee); run 2, 110 mg (77%; 95% ee). The ee was determined on an AD-H column (hexanes/*iso*-propanol 95:5, flow 1.0 mL/min) with t_r(minor) 19.5 min, t_r(major) 25.5 min.

$[\alpha]^{20}_D$ = –71 (c = 2.35, CH_2Cl_2); 94% ee, from (+)-bpy*;

^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.36 (br app s, 10H), 5.89 (d, *J* = 6.9 Hz, 1H), 5.28 (d, *J* = 7.5 Hz, 1H), 5.11 (dt, *J* = 8.7 Hz, 12 Hz, 2H), 1.40 (s, 9H);

^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 175.7, 155.5, 137.5, 136.4, 128.9, 128.7, 128.4, 128.3, 127.1, 82.8, 67.1, 58.5, 27.9;

IR (film) 3424, 3055, 2984, 2306, 1722, 1498, 1266, 1153, 1051, 739, 704 cm^{-1};

HRMS (ESI) calcd for $C_{20}H_{23}NNaO_4$ ($M + Na^+$) 364.1519, found 364.1520.

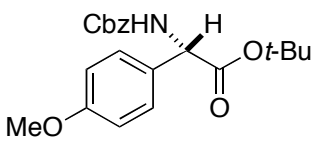


Table 3, entry 2. The compound was prepared with (–)-bpy* from the diazo ester (130 mg, 0.525 mmol) and $CbzNH_2$ (55.0 mg, 0.350 mmol). After chromatography on silica gel (100% CH_2Cl_2), the desired compound was isolated as a colorless oil: run 1, 62 mg (48%; 90% ee); run 2, 110 mg (49%; 90% ee). The ee was determined on an AD-H column (hexanes/*iso*-propanol 90:10, flow 1.0 mL/min) with t_r(minor) 22.1 min, t_r(major) 24.5 min.

$[\alpha]^{20}_{D}$ = –92 (c = 1.30, CH_2Cl_2); 90% ee, from (+)-bpy*;

^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.27 (br app s, 5H), 7.21 (d, *J* = 8.7 Hz, 2H), 6.79 (d, *J* = 8.7 Hz, 2H), 5.76 (d, *J* = 7.2 Hz, 1H), 5.12 (d, *J* = 7.5 Hz, 1H), 5.02 (dt, *J* = 7.8 Hz, 12 Hz, 2H), 3.72 (s, 3H), 1.32 (s, 9H);

^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 170.2, 159.6, 155.5, 136.4, 129.7, 128.7, 128.4, 114.3, 82.6, 67.1, 58.0, 55.4, 28.0;

IR (film) 3055, 2987, 2306, 1719, 1512, 1421, 1266, 1154, 896, 740, 705 cm^{-1};

HRMS (ESI) calcd for $C_{21}H_{25}NNaO_5$ ($M + Na^+$) 394.1625, found 394.1619.

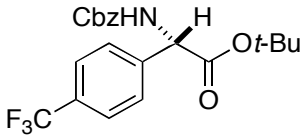


Table 3, entry 3. The compound was prepared with (–)-bpy* from the diazo ester (137 mg, 0.477 mmol) and $CbzNH_2$ (50.0 mg, 0.318 mmol). After chromatography on silica gel (1.0% Et_2O in CH_2Cl_2), the desired compound was isolated as a white solid: run 1, 105 mg (81%; 81% ee); run 2, 96.0 mg (74%; 83% ee). The ee was determined on an AD-H column (hexanes/*iso*-propanol 95:5, flow 1.0 mL/min) with t_r(minor) 16.2 min, t_r(major) 18.0 min.

mp: 103-104 °C;

$[\alpha]^{20}_{D}$ = –93 (c = 1.20, CH_2Cl_2); 83% ee, from (+)-bpy*;

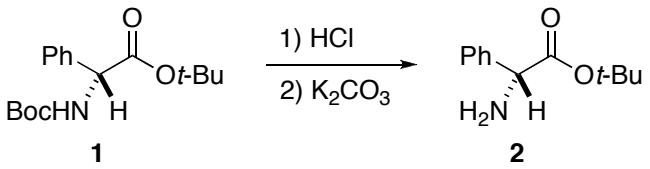
^{1}H NMR ($CDCl_3$, 300 MHz) δ 7.62 (d, *J* = 8.1 Hz, 2H), 7.51 (d, *J* = 8.1 Hz, 2H), 7.36 (br app s, 5H), 6.06 (d, *J* = 6.6 Hz, 1H), 5.33 (d, *J* = 6.9 Hz, 1H), 5.10 (dt, *J* = 11.4 Hz, 12.3 Hz, 2H), 1.40 (s, 9H);

^{13}C NMR ($CDCl_3$, 75.5 MHz) δ 169.1, 155.5, 141.7, 136.2, 130.6 (q, $^2J_{CF}$ = 32.5 Hz), 128.7, 128.5, 128.4, 127.5, 125.9 (q, $^3J_{CF}$ = 3.9 Hz), 122.3, 83.6, 67.3, 58.2, 27.9;

IR (film) 3055, 2987, 2306, 1719, 1422, 1266, 1167, 896, 740, 705 cm^{-1};

HRMS (ESI) calcd for $C_{21}H_{22}F_3NNaO_4$ ($M + Na^+$) 432.1393, found 432.1397.

III. Determination of Absolute Configuration



1 **2**

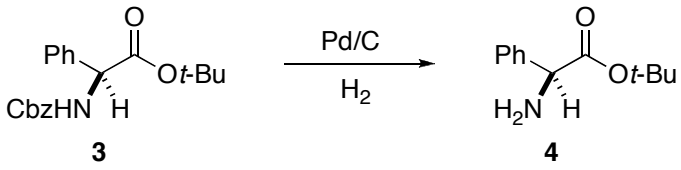
A solution of HCl in dioxane (4.0 M; 0.12 mL) was added to a solution of **1** (53.0 mg, 0.172 mmol; 94% ee; from (+)-bpy*) in ethyl acetate (0.5 mL). The mixture was stirred at room temperature for 2 h, and then the solvent was removed. Diethyl ether (2.0 mL) and 10% K_2CO_3 (1.0 mL) were added to the white residue, and the reaction mixture was stirred until all of the solids had dissolved. The product was extracted with Et_2O (1.0 mL x 2), and the combined organic layers were washed with brine and then dried over $MgSO_4$. After chromatography on silica gel (5% MeOH in EtOAc), product **2** was isolated as a crystalline colorless solid (30.3 mg; 85%).

$[\alpha]^{20}_D = -98$ (c = 1.61, $CHCl_3$);

Literature value for **2**: $[\alpha]^{20}_D = -108$ (c = 1.61, $CHCl_3$);[3]

^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.38-7.27 (m, 5H), 4.49 (s, 1H), 1.92 (s, 2H), 1.40 (s, 9H);

^{13}C NMR ($CDCl_3$, 126 MHz) δ 173.4, 141.1, 128.8, 127.9, 126.8, 81.7, 59.5, 28.1.



3 **4**

Pd/C (50.0 mg) was added to a vial that contained **3** (50.0 mg, 0.146 mmol; 94% ee; from (–)-bpy*) in methanol (0.6 mL), and the resulting mixture was stirred under H_2 (1 atm) for 1 h at r.t. Then, the mixture was filtered through a plug of Celite. Water (1 mL) was added to the filtrate, and the product was extracted with Et_2O (1 mL x 3). The combined organic layers were dried over $MgSO_4$, and the solvent was removed, thereby providing **4** as a colorless crystalline residue (30.0 mg; 99%).

$[\alpha]^{20}_D = +95.5$ (c = 1.61, $CHCl_3$);

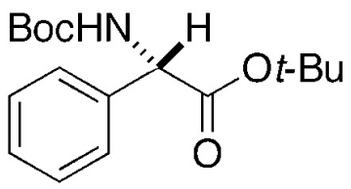
Literature value for the enantiomer of **4**: $[\alpha]^{20}_D = -108$ (c = 1.61, $CHCl_3$).[3]

IV. References

(1) Rios, R.; Liang, J.; Lo, M. M.-C.; Fu, G. C. *Chem. Commun.* **2000**, 377–378.

(2) Maier, T. C.; Fu, G. C. *J. Am. Chem. Soc.* **2006**, *128*, 4594–4595.

(3) Smith, A. B., III; Yager, K. M.; Taylor, C. M. *J. Am. Chem. Soc.* **1995**, *117*, 10879–10888.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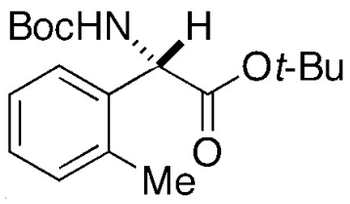
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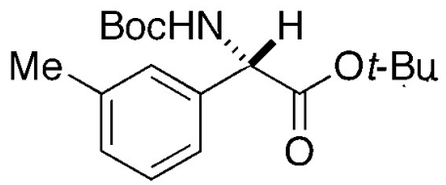
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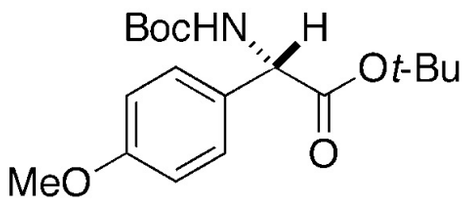
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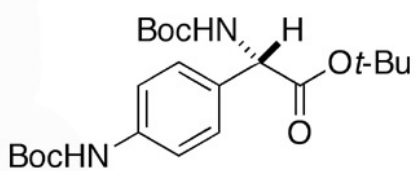
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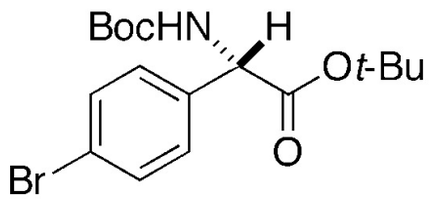
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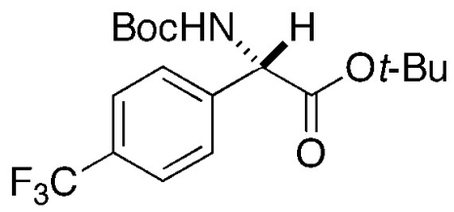
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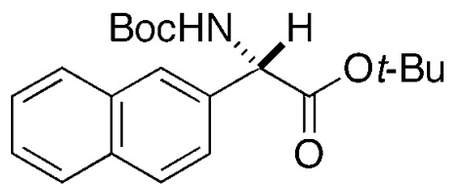
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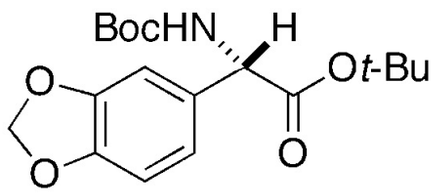
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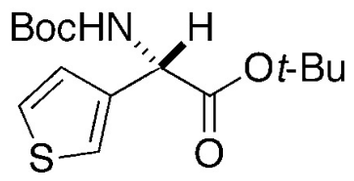
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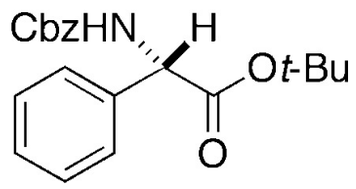
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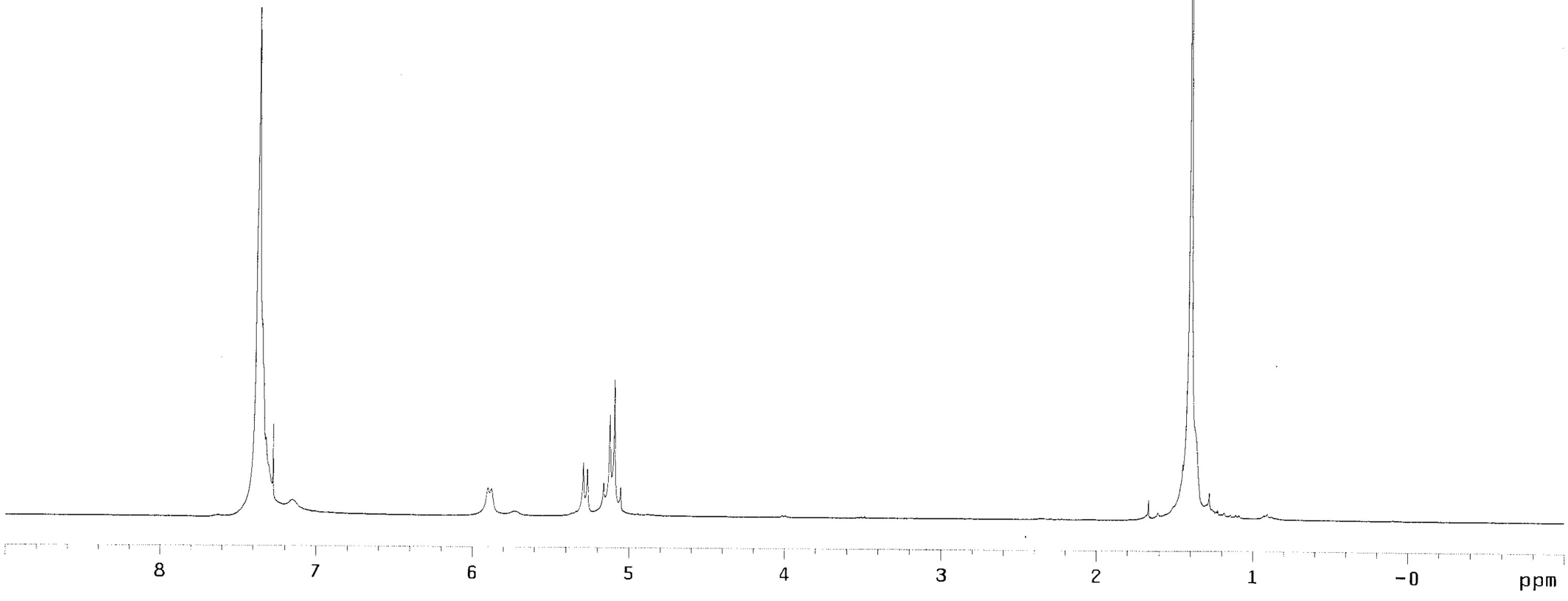
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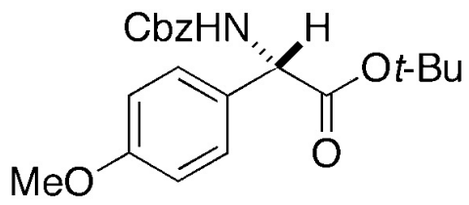
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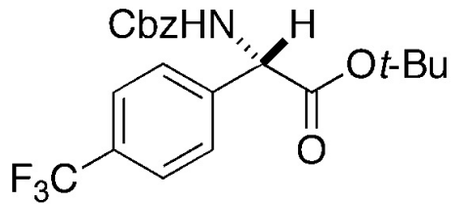
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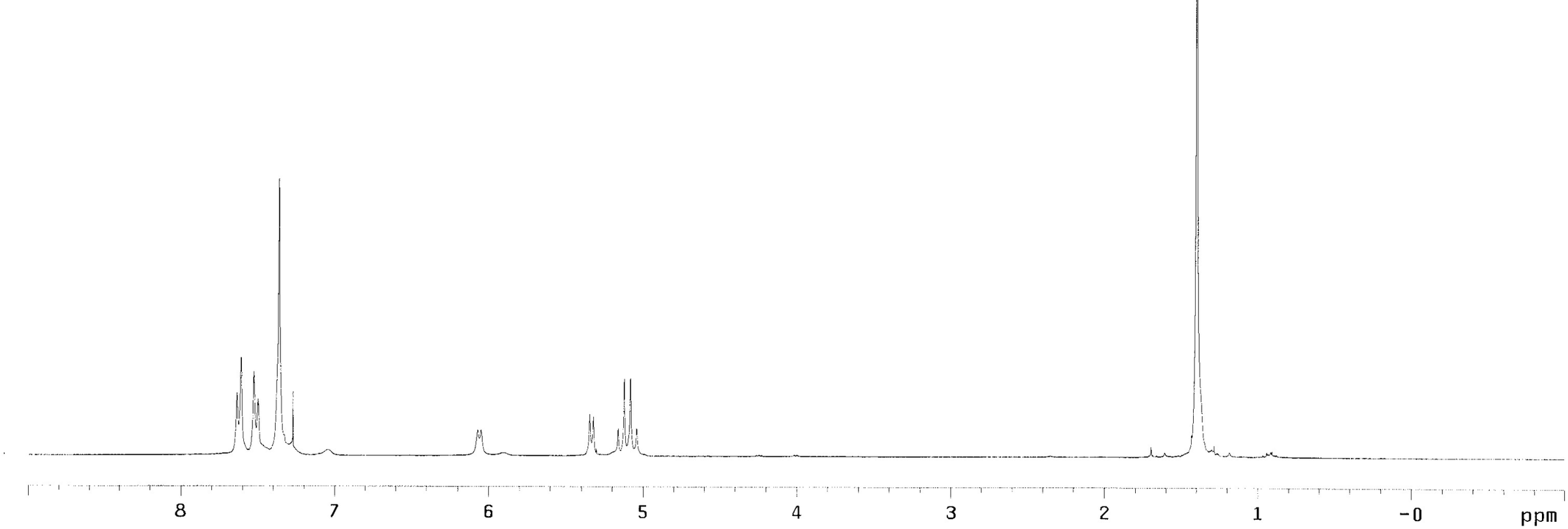
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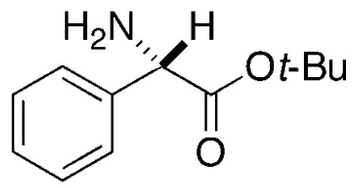
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