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Supporting Information

Organocatalyzed Highly Enantioselective Michael Additions of Malonates to Enones Using Primary-Secondary Chiral Diamines

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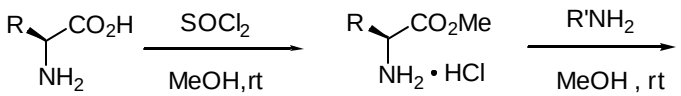
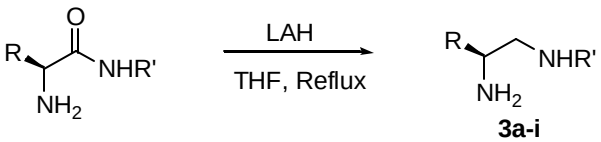
General Information: Unless otherwise indicated, all compounds and reagents were purchased from commercial suppliers and used without further purification. Proton nuclear magnetic resonance spectra are recorded at 300 MHz. All chemical shifts (d) are given in ppm. NMR spectra were recorded on Varian EM-360A, Varian EM90 or Brucker AMX-300 NMR spectrometer. IR spectra were recorded on a Perkin-Elmer 983G instrument. MS or HRMS was recorded on a HP-5989A spectrometer. Melting points were determined on a METTLER-TOLEDO FP62 melting point apparatus and are uncorrected. Elemental analysis was performed on a Carlo-ERBA1106 instrument. HPLC analysis was carried out on WATERS equipment.

General procedure for the synthesis of catalysts 3a-i (**3g** was prepared according to known procedure[1])





3a-i

Typical Procedure for the Esterifation of Amino Acid

To a suspension of L-phenylalanine (10.0 g, 60.0 mmol) in ice-cooled dry methanol (120 mL) was added dropwise thionyl chloride (10.0 g, 85.0 mmol). After the solution was stirred at room temperature overnight, the solvent was removed under reduced pressure to give L-phenylalanine methyl ester hydrochloride as a colorless crystalline solid quantitatively, which was directly used in the next step without further purification.

Typical Procedure for the Preparation of Amino Amide [2]

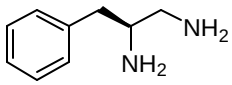
A solution of L-phenylalanine methyl ester hydrochloride (23.3 mmol) and propylamine (233.0 mmol) in anhydrous methanol (50 mL) was stirred at room

temperature for 3 days. The reaction mixture was concentrated, and the residue was purified by column chromatography on silica gel using petroleum ether / ethyl acetate (2:1) as eluant to give the (*S*)-2-amino-3-phenyl-N-propylpropanamide (3.9g).

Typical Procedure for the Reduction of Amino Amide to Diamine[3]

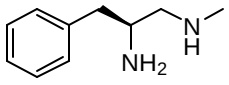
To a solution of (*S*)-2-amino-3-phenyl-N-propylpropanamide (3.4 g, 16.3 mmol), in THF (60 mL) was added lithium aluminum hydride (3.7 g, 97.8 mmol) at 0 ? . After being stirred for 30 min at 0 °C, the reaction was allowed to heat at reflux for 48 h before the reaction was quenched with Na_2SO_4 and water with vigorous stirring at 0 ? . The white-gray suspension was filtered and the filtrate was concentrated. The crude product was purified by column chromatography on silica gel petroleum using petroleum ether / ethyl acetate (1:1) to give the desired product (*S*)-3-phenyl-N^1-propylpropane-1,2-diamine **(3d)** (2.69 g, 86% yield).

(*S*)-3-phenylpropane-1,2-diamine (3a)[4]



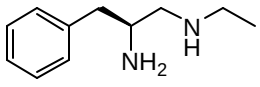
Colorless oil; $[\alpha]_D^{27}$ = -16.2 (*c* = 1.0 in $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) d 1.36 (brs, 4H), 2.45-2.57 (m, 2H), 2.74-2.82 (m, 2H), 2.91-2.99 (m, 1H), 7.18-7.33 (m, 5H) ppm.

(*S*)-N^1-methyl-3-phenylpropane-1,2-diamine (3b)[5]



Colorless oil; $[\alpha]_D^{25}$ = -2.0 (*c* = 1.0 in $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) d 1.51 (brs, 3H), 2.41-2.54 (m, 2H), 2.44 (s, 3H), 2.66 (dd, *J* = 4.9, 11.7 Hz, 1H), 2.79 (dd, *J* = 4.8, 13.5 Hz, 1H), 3.06-3.15 (m, 1H), 7.18-7.30 (m, 5H) ppm.

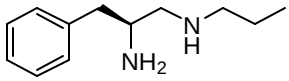
(*S*)-N^1-ethyl-3-phenylpropane-1,2-diamine (3c)



Colorless oil; $[\alpha]_D^{27}$ = -1.9 (*c* = 1.0 in $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) d 1.10 (t, *J* = 7.5 Hz, 3H), 1.28 (brs, 3H), 2.43-2.53 (m, 2H), 2.62-2.82 (m, 4H), 3.06-3.17 (m,

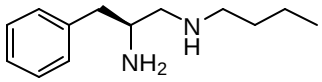
1H), 7.19-7.33 (m, 5H) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) d 15.3, 42.9, 44.2, 52.5, 55.9, 126.1, 128.3, 129.2, 139.2 ppm; IR (neat): 3290, 2965, 2925, 1666, 1601, 1495, 1453, 1377, 1128, 745, 701 cm^{-1}; HRMS calc. $C_{11}H_{18}N_2$ (M^+): 178.1470. Found: 178.1474.

(*S*)-3-phenyl-N^1-propylpropane-1,2-diamine (3d)



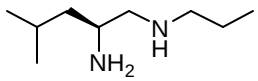
Colorless oil; $[\alpha]_D^{27}$ = 4.3 (*c* = 1.0 in $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) d 0.92 (t, *J* = 6.9 Hz, 3H), 1.51-1.64 (m, 2H), 2.51-2.71 (m, 7H), 2.75-2.83 (m, 2H), 3.15-3.24 (m, 1H), 7.18-7.33 (m, 5H) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) d 11.8, 22.5, 42.6, 51.6, 52.0, 55.1, 126.6, 128.7, 129.5, 138.7 ppm; IR (neat): 3273, 3026, 2929, 1661, 1602, 1495, 1454, 746, 701 cm^{-1}; HRMS calc. $C_{12}H_{20}N_2$ (M^+): 192.1626. Found: 192.1623.

(*S*)-N^1-butyl-3-phenylpropane-1,2-diamine (3e)



Colorless oil; $[\alpha]_D^{27}$ = 3.1 (*c* = 1.0 in $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) d 0.91 (t, *J* = 7.5 Hz, 3H), 1.28-1.40 (m, 2H), 1.44-1.54 (m, 2H), 1.82 (brs, 3H), 2.45-2.55 (m, 2H), 2.58-2.68 (m, 2H), 2.71-2.82 (m, 2H), 3.09-3.18 (m, 1H), 7.19-7.33 (m, 5H) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) d 14.2, 20.6, 32.0, 42.9, 49.8, 52.4, 55.9, 126.5, 128.7, 129.4, 139.1 ppm; IR (neat): 3285, 3026, 2927, 1665, 1602, 1495, 1454, 1377, 1129, 746, 701 cm^{-1}; HRMS calc. $C_{13}H_{22}N_2$ (M^+): 206.1783. Found: 206.1778.

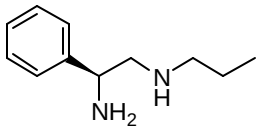
(*S*)-4-methyl-N^1-propylpentane-1,2-diamine (3g)



Colorless oil; $[\alpha]_D^{27}$ = 12.5 (*c* = 1.0 in $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) d 0.88-0.95 (m, 9H), 1.19 (t, *J* = 6.9 Hz, 2H), 1.46-1.58 (m, 5H), 1.65-1.80 (m, 1H), 2.33 (dd, *J* = 8.4, 8.7 Hz, 1H), 2.54-2.65 (m, 3H), 2.84-2.93 (m, 1H) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) d 11.5, 21.7, 23.0, 23.3, 24.4, 45.5, 48.5, 51.7, 56.9 ppm; IR (neat): 3301, 2956, 2929, 2872, 1465, 807 cm^{-1}; HRMS calc. $C_9H_{22}N_2$ (M^+): 158.1783. Found:

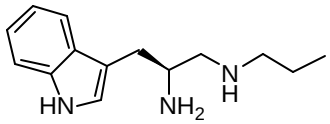
158.1787.

(*S*)-2-phenyl-N^1-propylethane-1,2-diamine (3h)



Colorless oil; $[\alpha]_D^{27}$ = 18.1 (*c* = 1.0 in $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) d 0.86 (t, *J* = 7.2 Hz, 3H), 1.41-1.48 (m, 2H), 1.67 (brs, 3H), 2.51-2.57 (m, 2H), 2.68-2.77 (m, 2H), 3.97-4.02 (m, 1H), 7.22-7.31 (m, 5H) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) d 11.6, 23.0, 51.6, 55.4, 57.6, 126.3, 127.0, 128.3, 144.7 ppm; IR (neat): 3295, 2958, 2931, 2874, 1667, 1602. 1493, 1454, 1379, 760, 701 cm^{-1}; HRMS calc. $C_{11}H_{18}N_2$ (M^+): 178.1470. Found: 178.1467.

(*S*)-3-(1H-indol-3-yl)-N^1-propylpropane-1,2-diamine (3i)

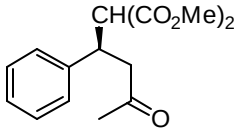


Yellow oil; $[\alpha]_D^{26}$ = -0.8 (*c* = 1.0 in $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) d 0.91 (t, *J* = 7.5 Hz, 3H), 1.45-1.54 (m, 5H), 2.48-2.62 (m, 3H), 2.63-2.71 (m, 1H), 2.79 (dd, *J* = 3.9, 11.7 Hz, 1H), 2.64 (dd, *J* = 4.5, 11.4 Hz, 1H), 3.20-3.28 (m, 1H), 7.03 (d, *J* = 1.8 Hz, 1H), 7.11 (t, *J* = 6.9 Hz, 1H), 7.20 (t, *J* = 7.2 Hz, 1H), 7.36 (d, *J* = 7.8 Hz, 1H), 7.62 (d, *J* = 7.5 Hz, 1H), 8.42 (brs, 1H) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz) d 11.7, 22.7, 31.9, 51.1, 51.6, 55.5, 111.5, 111.6, 118.7, 119.0, 121.6, 123.4, 127.7, 136.6 ppm; IR (neat): 3244, 2928, 1619, 1456, 1340, 1104, 740, 702 cm^{-1}; HRMS calc. for $C_{14}H_{21}N_3$ (M^+): 231.1735. Found: 231.1728.

General procedure for the Michael reaction.

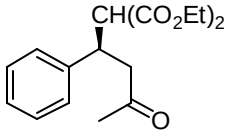
To a mixture of enone **2** (0.5 mmol), catalyst **3** (0.1 mmol) and TFA (0.1 mmol) in $CHCl_3$ (1.0 mL) was added malonate **1** (1.0 mmol) at ambient temperature. After 24 h of stirring, the reaction mixture was quenched with 1 M aqueous HCl solution and extracted with EtOAc. The combined organic layer was dried over Na_2SO_4, filtered, and concentrated to afford the corresponding Michael adduct **4** after flash column chromatography on silica gel (petroleum ether/Et_2O as eluent).

Dimethyl 2-(3-oxo-1-phenylbutyl)malonate (4aa)[6]



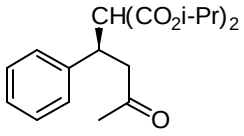
White solid; $[\alpha]_D^{25}$ = -14.1 (*c* = 1.0 in $CHCl_3$); m.p. 43-44 ? ; ^{1}H NMR (300 MHz, $CDCl_3$) d 2.03 (s, 3H), 2.87-3.02 (m, 2H), 3.50 (s , 3H), 3.72 (s, 3H), 3.73 (d, *J* = 9.6 Hz, 1H), 3.94-4.02 (m, 1H), 7.17-7.30 (m, 5H) ppm; enantiometric excess: 97%, determined by HPLC (Chiralpak AD column, hexane/*i*-PrOH 90:10, flow rate 1 mL/min; t_{major} = 13.5 min, t_{minor} = 15.4 min, *?* = 254 nm).

Diethyl 2-(3-oxo-1-phenylbutyl)malonate (4ba)[6]



White solid; $[\alpha]_D^{26}$ = -15.5 (*c* = 1.0 in $CHCl_3$); m.p. 40-42 ? ; ^{1}H NMR (300 MHz, $CDCl_3$) d 1.01 (t, *J* = 7.2 Hz, 3H), 1.26 (t, *J* = 7.2 Hz, 3H), 2.02 (s , 3H), 2.86-3.01 (m, 2H), 3.69 (d, *J* = 9.6 Hz, 1H), 3.91-4.01 (m, 3H), 4.19 (q , *J* = 7.2 Hz, 2H), 7.16-7.30 (m, 5H) ppm; enantiometric excess: 98%, determined by HPLC (Chiralpak AD column, hexane/*i*-PrOH 90:10, flow rate 1 mL/min, t_{major} = 12.5 min, t_{minor} = 18.6 min, *?* = 254 nm).

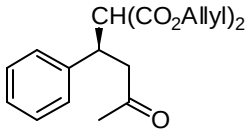
Diisopropyl 2-(3-oxo-1-phenylbutyl)malonate (4ca)[6]



Colorless oil; $[\alpha]_D^{26}$ = -19.4 (*c* = 1.0 in $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) d 0.96 (d, *J* = 6.6 Hz, 3H), 1.03 (d, *J* = 6.9 Hz, 3H), 1.23 (dd, *J* = 1.5, 6.0 Hz, 6H), 2.00 (s, 3H), 2.84-2.99 (m, 2H), 3.64 (d, *J* = 10.2 Hz, 1H), 3.90-3.98 (m, 1H), 4.71-4.83 (m, 1H), 4.99-5.11(m, 1H), 7.15-7.30 (m, 5H) ppm; enantiomeric excess: >99%, determined by HPLC (Chiralpak AD column, hexane/*i*-PrOH 90:10, flow rate 1

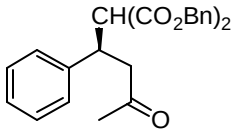
mL/min, t_{major} = 9.6 min, t_{minor} =13.8 min, *?* = 254 nm).

Diallyl 2-(3-oxo-1-phenylbutyl)malonate (4da)[6]



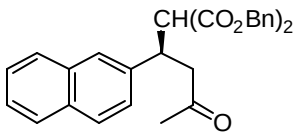
Colorless oil; $[\alpha]_D^{26}$ = -12.1 (*c* = 1.0 in $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) d 2.02 (s, 3H), 2.87-3.02 (m, 2H), 3.78 (d, *J* = 9.6 Hz, 1H), 3.96-4.04 (m, 1H), 4.38 (d, *J* = 5.7 Hz 2H), 4.63 (d, *J* = 5.4 Hz, 2H), 5.10-5.15 (m, 2H), 5.22-5.34 (m, 2H), 5.57-5.70(m, 1H), 5.81-5.94 (m, 1H), 7.17-7.30 (m, 5H) ppm; enantiomeric excess: 98%, determined by HPLC (Chiralpak AD column, hexane/*i*-PrOH 90:10, flow rate 1 mL/min, t_{major} = 13.6 min, t_{minor} = 20.3 min, *?* = 254 nm).

Dibenzyl 2-(3-oxo-1-phenylbutyl)malonate (4ea) [6]



White solid; $[\alpha]_D^{26}$ = -7.1 (*c* = 1.0 in $CHCl_3$); m.p. 85-88 ? ; ^{1}H NMR (300 MHz, $CDCl_3$) d 1.95 (s, 3H), 2.88 (d, *J* = 6.9 Hz, 2H), 3.82 (d, *J* = 9.6 Hz, 1H), 3.96-4.04 (m, 1H), 4.89 (s, 2H), 5.13 (s, 2H), 7.04-7.07 (m, 2H), 7.18-7.38 (m, 13H) ppm; enantiomeric excess: 99%, determined by HPLC (Chiralpak AD column, hexane/*i*-PrOH 90:10, flow rate 1 mL/min, t_{major} =33.0 min, t_{minor} = 46.0 min, *?* = 254 nm).

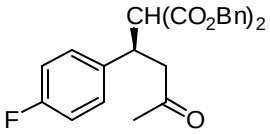
Dibenzyl 2-(1-(naphthalen-2-yl)-3-oxobutyl)malonate (4eb) [6]



White solid; $[\alpha]_D^{25}$ = -7.6 (*c* = 1.0 in $CHCl_3$); m.p. 66-68 ? ; ^{1}H NMR (300 MHz, $CDCl_3$) d 1.94 (s, 3H), 2.89-3.04 (m, 2H), 3.94 (d, *J* = 9.6 Hz, 1H), 4.14-4.22 (m, 1H), 4.84 (s, 2H), 5.15 (s, 2H), 6.90 (d, *J* = 7.5 Hz, 2H), 7.01 (t, *J* = 6.9 Hz, 2H), 7.18 (t, *J*

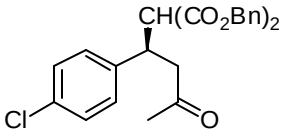
= 7.2 Hz, 1H), 7.25-7.36 (m, 6H), 7.43-7.47 (m, 2H), 7.64 (m, 1H), 7.72-7.78 (m, 3H) ppm; enantiomeric excess: 99%, determined by HPLC (Chiralpak AD column, hexane/*i*-PrOH 80:20, flow rate 0.75 mL/min, t_{major} =35.6 min, t_{minor} = 47.8 min, *?* = 254 nm).

Dibenzyl 2-(1-(4-fluorophenyl)-3-oxobutyl)malonate (4ec)



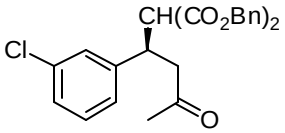
White solid; $[\alpha]_D^{25}$ = -8.5 (*c* = 1.0 in $CHCl_3$); m.p. 105-107 ? ; ^{1}H NMR (300 MHz, $CDCl_3$) d 1.95 (s, 3H), 2.84 (d, *J* = 6.3 Hz, 2H), 3.77 (d, *J* = 9.6 Hz, 1H), 3.94-4.01 (m, 1H), 4.91 (s, 2H), 5.14 (s, 2H), 6.87 (t, *J* = 9.6 Hz, 2H), 7.08-7.16 (m, 4H), 7.26-7.35 (m, 8H) ppm; ^{13}C NMR ($CDCl_3$, 100MHz) d 30.5, 39.9, 47.3, 57.5, 67.4, 67.6, 115.5, 115.7, 128.5, 128.6, 128.7, 128.9, 130.0, 135.2, 135.4, 136.2, 167.5, 168.0, 205.9 ppm; IR (neat): 3068, 1745, 1714, 1603, 1512, 1256, 1153, 757, 700 cm^{-1}; MS (70 ev): *m/z* (%): 357 (0.68) [M^+-Bn], 91 (100); Anal. calcd. for $C_{27}H_{25}FO_5$: C: 72.31; H: 5.62. Found: C: 72.28; H: 5.63. enantiomeric excess: 99%, determined by HPLC (Chiralpak AD column, hexane/*i*-PrOH 80:20, flow rate 0.75 mL/min, t_{major} =27.1 min, t_{minor} = 43.4 min, *?* = 254 nm).

Dibenzyl 2-(1-(4-chlorophenyl)-3-oxobutyl)malonate (4ed) [6]



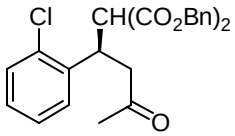
White solid; $[\alpha]_D^{25}$ = -8.7 (*c* = 1.0 in $CHCl_3$); m.p. 82-84 ? ; ^{1}H NMR (300 MHz, $CDCl_3$) d 1.95 (s, 3H), 2.84 (d, *J* = 6.9 Hz, 2H), 3.77 (d, *J* = 9.6 Hz, 1H), 3.91-4.00 (m, 1H), 4.92 (s, 2H), 5.14 (s, 2H), 7.07-7.09 (m, 2H), 7.11-7.16 (m, 4H), 7.26-7.35 (m, 8H) ppm; enantiomeric excess: >99%, determined by HPLC (Chiralpak AD column, hexane/*i*-PrOH 80:20, flow rate 0.75 mL/min, t_{major} =27.6 min, t_{minor} = 44.3 min, *?* = 254 nm).

Dibenzyl 2-(1-(3-chlorophenyl)-3-oxobutyl)malonate (4ee)



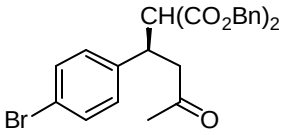
White solid; $[\alpha]_D^{25}$ = -8.3 (*c* = 1.0 in $CHCl_3$); m.p. 66-68 ? ; ^1H NMR (300 MHz, $CDCl_3$) d 1.97 (s, 3H), 2.86 (d, *J* = 7.2 Hz, 2H), 3.79 (d, *J* = 9.9 Hz, 1H), 3.94-4.01 (m, 1H), 4.92 (s, 2H), 5.13 (s, 2H), 7.07-7.34 (m, 14H) ppm; ^{13}C NMR ($CDCl_3$, 100MHz) d 30.2, 39.9, 46.7, 56.9, 67.2, 67.4, 126.5, 127.5, 128.2, 128.3, 128.5, 128.6, 129.7, 134.2, 134.8, 135.0, 142.5, 167.1, 167.6, 205.3 ppm; IR (neat): 3064, 1731, 1597, 1570, 1455, 1259, 1156, 746, 696 cm^{-1}; MS (70 ev): *m/z* (%): 373 (1.06) [M^+-Bn], 91 (100); Anal. calcd. for $C_{27}H_{25}ClO_5$: C: 69.75; H: 5.42. Found: C: 69.70; H: 5.36. enantiomeric excess: 99%, determined by HPLC (Chiralpak AD column, hexane/*i*-PrOH 80:20, flow rate 0.75 mL/min, t_{major} =21.3 min, t_{minor} = 24.9 min, *?* = 254 nm).

Dibenzyl 2-(1-(2-chlorophenyl)-3-oxobutyl)malonate (4ef)



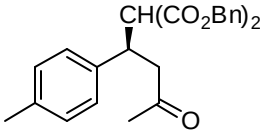
Colorless oil; $[\alpha]_D^{25}$ = -0.2 (*c* = 1.0 in $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) d 1.99 (s, 3H), 2.92-3.10 (m, 2H), 4.10 (d, *J* = 9.0 Hz, 1H), 4.43-4.50 (m, 1H), 4.99 (s, 2H), 5.10 (d, *J* = 1.5 Hz, 2H), 7.09-7.32 (m, 14H) ppm; ^{13}C NMR ($CDCl_3$, 100MHz) d 30.2, 37.3, 45.3, 55.1, 67.4, 67.5, 127.2, 128.4, 128.5, 128.6, 128.7, 128.8, 130.4, 134.2, 135.3, 135.4, 137.8, 167.7, 168.1, 206.1 ppm; IR (neat): 3033, 1730, 1498, 1476, 1455, 1375, 1216, 751, 697 cm^{-1}; MS (70 ev): *m/z* (%): 429 (0.68) [M^+-Cl], 91 (100); Anal. calcd. for $C_{27}H_{25}ClO_5$: C: 69.75; H: 5.42. Found: C: 69.84; H: 5.52. enantiomeric excess: 99%, determined by HPLC (Chiralpak AD column, hexane/*i*-PrOH 80:20, flow rate 0.75 mL/min, t_{major} =22.0min, t_{minor} = 28.0 min, *?* = 254 nm).

Dibenzyl 2-(1-(4-bromophenyl)-3-oxobutyl)malonate (4eg)



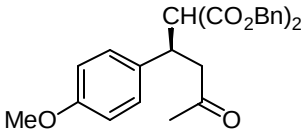
White solid; $[\alpha]_D^{24}$ = -6.9 (*c* = 1.0 in $CHCl_3$); m.p. 77-80 ? ; ^1H NMR (300 MHz, $CDCl_3$) d 1.95 (s, 3H), 2.83 (d, *J* = 6.9 Hz, 2H), 3.77 (d, *J* = 9.6 Hz, 1H), 3.91-3.99 (m, 1H), 4.92 (s, 2H), 5.14 (s, 2H), 7.03-7.07 (m, 4H), 7.26-7.35 (m, 10H) ppm; ^{13}C NMR ($CDCl_3$, 100MHz) d 30.5, 40.0, 47.1, 57.2, 67.5, 67.6, 121.4, 128.6, 128.8,128.9, 130.2, 131.9, 135.1, 135.3, 139.6, 167.5, 167.9, 205.7 ppm; IR (neat): 3034, 1735, 1491, 1456, 1408, 1261, 1133, 755, 699 cm^{-1}; MS (70 ev): *m/z* (%): 417 (0.42) [M^+-Bn], 91 (100); Anal. calcd. for $C_{27}H_{25}BrO_5$: C: 63.66; H: 4.95. Found: C: 63.72; H: 5.05. enantiomeric excess: 99%, determined by HPLC (Chiralpak AD column, hexane/*i*-PrOH 80:20, flow rate 0.75 mL/min, t_{major} =30.0min, t_{minor} = 49.0 min, *?* = 254 nm).

Dibenzyl 2-(3-oxo-1-p-tolylbutyl)malonate (4eh)



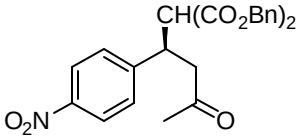
White solid; $[\alpha]_D^{25}$ = -8.1 (*c* = 1.0 in $CHCl_3$); m.p. 86-89 ? ; ^1H NMR (300 MHz, $CDCl_3$) d 1.94 (s, 3H), 2.28 (s, 3H), 2.85 (d, *J* = 6.9 Hz, 2H), 3.79 (d, *J* = 9.9 Hz, 1H), 3.92-4.00 (m, 1H), 4.90 (s, 2H), 5.13 (s, 2H), 7.00-7.09 (m, 6H), 7.25-7.33 (m, 8H) ppm; ^{13}C NMR ($CDCl_3$, 100MHz) d 21.3, 30.5, 40.4, 47.4, 57.7, 67.3, 67.5, 128.2, 128.4, 128.5, 128.7, 128.8, 129.5, 135.4, 135.5, 137.0, 137.4, 167.7, 168.2, 206.3 ppm; IR (neat): 3033, 1739, 1709, 1514, 1496, 1297, 1222, 732, 698 cm^{-1}; MS (70 ev): *m/z* (%): 444 (0.42) [M^+], 91 (100); Anal. calcd. for $C_{28}H_{28}O_5$: C: 75.65; H: 6.35. Found: C: 75.82; H: 6.37. enantiomeric excess: >99%, determined by HPLC (Chiralpak AD column, hexane/*i*-PrOH 80:20, flow rate 0.75 mL/min, t_{major} =23.8min, t_{minor} = 36.5 min, *?* = 254 nm).

Dibenzyl 2-(1-(4-methoxyphenyl)-3-oxobutyl)malonate (4ei)



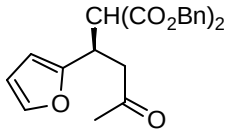
White solid; $[\alpha]_D^{25}$ = -10.2 (*c* = 1.0 in $CHCl_3$); m.p. 54-56 ? ; ^1H NMR (300 MHz, $CDCl_3$) d 1.94 (s, 3H), 2.83 (d, *J* = 6.9 Hz, 2H), 3.75-3.79 (m, 4H), 3.91-4.00 (m, 1H), 4.90 (s, 2H), 5.14 (s, 2H), 6.74 (d, *J* = 8.7 Hz, 2H), 7.07-7.12 (m, 4H), 7.26-7.32 (m, 8H) ppm; ^{13}C NMR ($CDCl_3$, 100MHz) d 30.2, 39.8, 47.2, 55.1, 57.5, 67.0, 67.2, 113.9, 128.1, 128.2, 128.4, 128.5, 129.1, 132.0, 135.0, 135.2, 158.6, 167.4, 167.9, 206.0 ppm; IR (neat): 3066, 2953, 1745, 1715, 1611, 1517, 1456, 1249, 1139, 696 cm^{-1}; MS (70 ev): *m/z* (%): 460 (0.78) [M^+], 91 (100); Anal. calcd. for $C_{28}H_{28}O_6$: C:73.03; H: 6.13. Found: C: 73.28; H: 6.19. enantiomeric excess: >99%, determined by HPLC (Chiralpak AD column, hexane/*i*-PrOH 80:20, flow rate 0.75 mL/min, t_{major} =35.5min, t_{minor} = 60.9 min, *?* = 254 nm).

Dibenzyl 2-(1-(4-nitrophenyl)-3-oxobutyl)malonate (4ej) [6]



Yellow solid; $[\alpha]_D^{25}$ = -9.0 (*c* = 1.0 in $CHCl_3$); m.p. 67-69 ? ; ^1H NMR (300 MHz, $CDCl_3$) d 1.96 (s, 3H), 2.88-2.91 (m, 2H), 3.82 (d, *J* = 9.3 Hz, 1H), 4.03-4.11 (m, 1H), 4.93 (s, 2H), 5.15 (s, 2H), 7.07 (d, *J* = 6.3 Hz, 4H), 7.23-7.35 (m, 10H), 7.96 (d, *J* = 8.7 Hz, 2H) ppm; enantiomeric excess: 99%, determined by HPLC (Chiralpak OD-H column, hexane/*i*-PrOH 80:20, flow rate 0.75 mL/min, t_{major} =43.4min, t_{minor} =39.2 min, *?* = 254 nm).

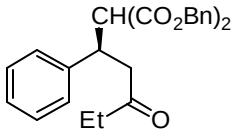
Dibenzyl 2-(1-(furan-2-yl)-3-oxobutyl)malonate (4ek) [6]



Colorless oil; $[\alpha]_D^{25}$ = -3.5 (*c* = 1.0 in $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) d 2.02 (s, 3H), 2.80-3.00 (m, 2H), 3.90 (d, *J* = 7.8 Hz, 1H), 4.10-4.17 (m, 1H), 5.04 (s, 2H), 5.12 (s, 2H), 6.02 (d, *J* = 3.3 Hz, 1H), 6.19 (dd, *J* = 1.5, 3.0 Hz, 1H), 7.21-7.33 (m,

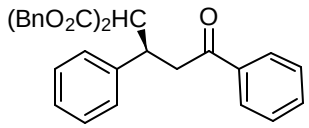
11H) ppm; enantiomeric excess: 99%, determined by HPLC (Chiralpak AD column, hexane/*i*-PrOH 80:20, flow rate 0.75 mL/min, t_{major} =21.5min, t_{minor} = 25.2 min, *?* = 254 nm).

Dibenzyl 2-(3-oxo-1-phenylpentyl)malonate (4el) [6]



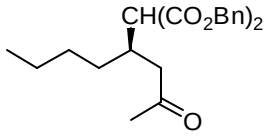
White solid; $[\alpha]_D^{25}$ = -0.9 (*c* = 1.0 in $CHCl_3$); m.p. 69-71 ? ; ^{1}H NMR (300 MHz, $CDCl_3$) d 0.88 (t, *J* = 7.2 Hz, 3H), 2.08-2.32 (m, 2H), 2.78-2.93 (m, 2H), 3.84 (d, *J* = 9.9 Hz, 2H), 3.98-4.06 (m, 1H), 4.88 (s, 2H), 5.13 (d, *J* = 1.5 Hz), 7.04-7.32 (m, 14H) ppm; enantiomeric excess: 99%, determined by HPLC (Chiralpak AD column, hexane/*i*-PrOH 80:20, flow rate 0.75 mL/min, t_{major} =24.4min, t_{minor} = 40.6min, *?* = 254 nm).

Dibenzyl 2-(3-oxo-1,3-diphenylpropyl)malonate (4em)[7]



White solid; $[\alpha]_D^{25}$ = -14.7 (*c* = 1.0 in $CHCl_3$); m.p. 87-89 ? ; ^{1}H NMR (300 MHz, $CDCl_3$) d 3.44 (d, *J* = 6.6 Hz, 2H), 3.95 (d, *J* = 9.6 Hz, 1H), 4.18-4.26 (m, 1H), 4.91 (s, 2H), 5.14 (d, *J* = 4.5 Hz), 7.05-7.08 (m, 2H), 7.18-7.28 (m, 13H), 7.36-7.41 (m, 2H), 7.48-7.54 (m, 1H), 7.81 (d, *J* = 7.8 Hz, 2H) ppm; enantiomeric excess: >99%, determined by HPLC (Chiralpak AD column, hexane/*i*-PrOH 80:20, flow rate 0.75 mL/min, t_{major} = 43.4min, t_{minor} = 89.3min, *?* = 254 nm).

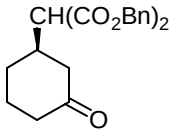
Dibenzyl 2-(2-oxooctan-4-yl)malonate (4en) [6]



Colorless oil; $[\alpha]_D^{27}$ = -5.1 (*c* = 1.0 in $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) d 0.80-0.84 (m, 3H), 1.20-1.33 (m, 6H), 2.03 (s, 3H), 2.41-2.50 (m, 1H), 2.63-2.69 (m, 2H), 3.66 (d, *J* = 5.4 Hz, 1H), 5.12-5.14 (m, 4H), 7.26-7.31 (m, 10H) ppm;

enantiomeric excess: 98%, determined by HPLC (Chiralpak OD-H column, hexane/*i*-PrOH 95:5, flow rate 1.0 mL/min, t_{major} 10.0 min, t_{minor} = 9.3min, *?* = 254 nm).

Dibenzyl 2-(3-oxocyclohexyl)malonate (4eo) [6]



White solid; $[\alpha]_D^{25}$ = -14.7 (*c* = 1.0 in $CHCl_3$); m.p. 62-64 ? ; ^{1}H NMR (300 MHz, $CDCl_3$) d 1.39-1.53 (m, 1H), 1.57-1.71 (m, 1H), 1.88-1.92 (m, 1H), 1.98-2.06 (m, 1H), 2.14-2.28 (m, 2H), 2.35-2.50 (m, 2H), 2.51-5.61 (m, 1H), 3.41 (d, *J* = 7.8 Hz, 1H), 5.15 (d, *J* = 1.8 Hz, 4H), 7.26-7.34 (m, 10H) ppm; enantiomeric excess: 90%, determined by HPLC (Chiralpak AS-H column, hexane/*i*-PrOH 95:5, flow rate 1.0 mL/min, t_{major} 56.4 min, t_{minor} = 47.5 min, *?* = 254 nm).

Reference

[1] [1] J. Christoffers, A. Mann, *Chem. Eur. J.* **2001**, *7*, 1014.

[2] D. Zhang, X. Xing, G. D. Cuny, *J. Org. Chem.* **2006**, *71*, 1750.

[3] H. Brunner, P. Hankofer, U. Holzinger, B. Treittinger, H. Schönenberger, *Eur. J. Med. Chem.* **1990,** *25*, 35.

[4] D. A. Alonso, P. G. Andersson, *J. Org. Chem.* **1998**, *63*, 9455.

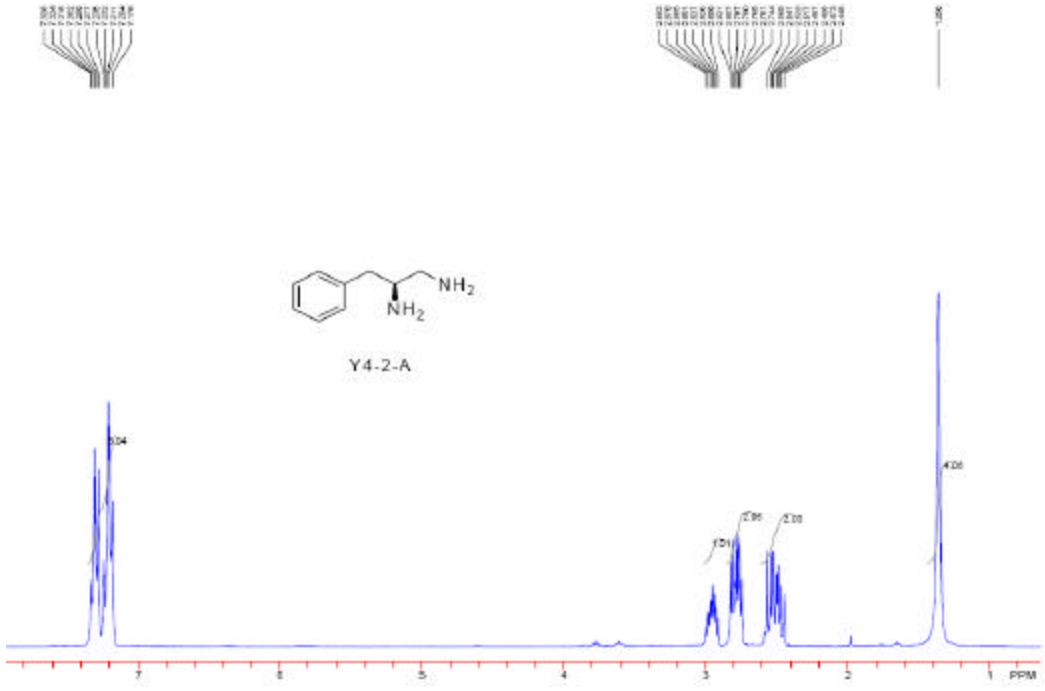
[5] N. Halland, R. G. Hazell, K. A. Jørgensen, *J. Org. Chem.* **2002**, *67*, 8331.

[6] N. Halland, P. S. Aburel, K. A. Jørgensen, *Angew. Chem.* **2003**, *115***,** 685; *Angew. Chem., Int. Ed.* **2003**, *42*, 661.

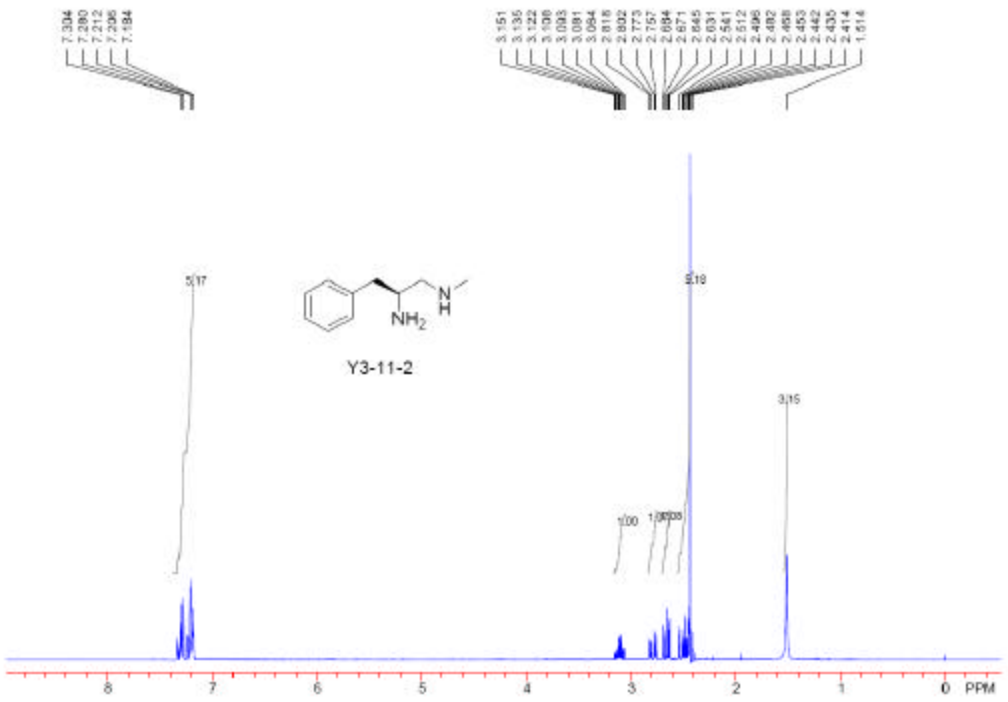
[7] T. Ooi, D. Ohara, K. Fukumoto, K. Maruoka, *Org. Lett.* **2005**, *7*, 3195.

NMR spectra for catalysts 3a-i

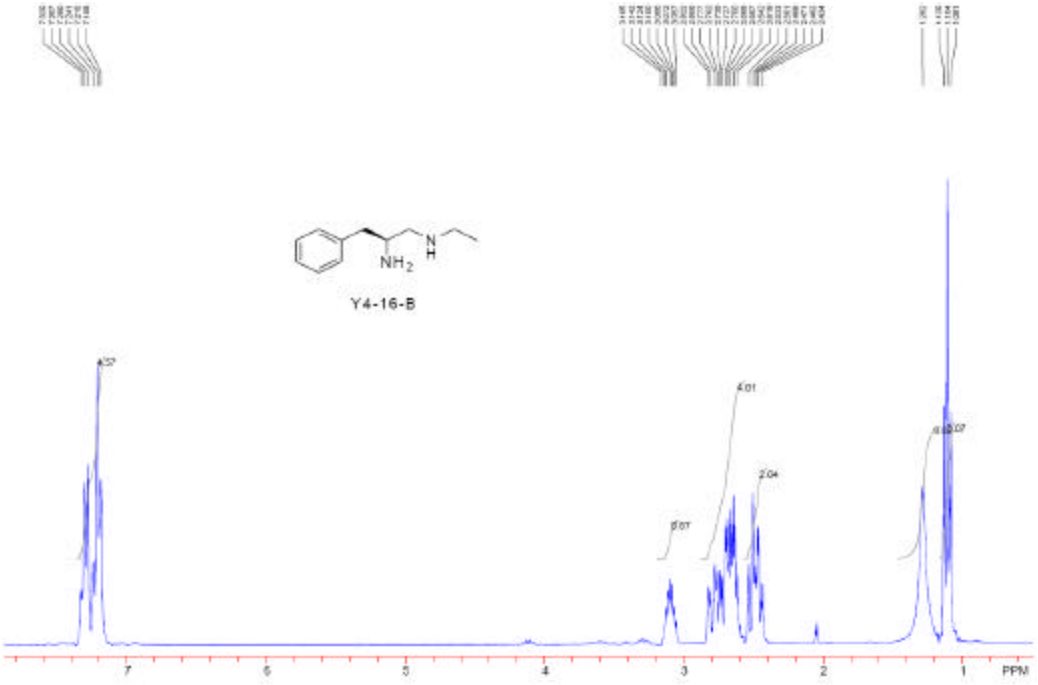
3a (^{1}H NMR)



3b (^{1}H NMR)

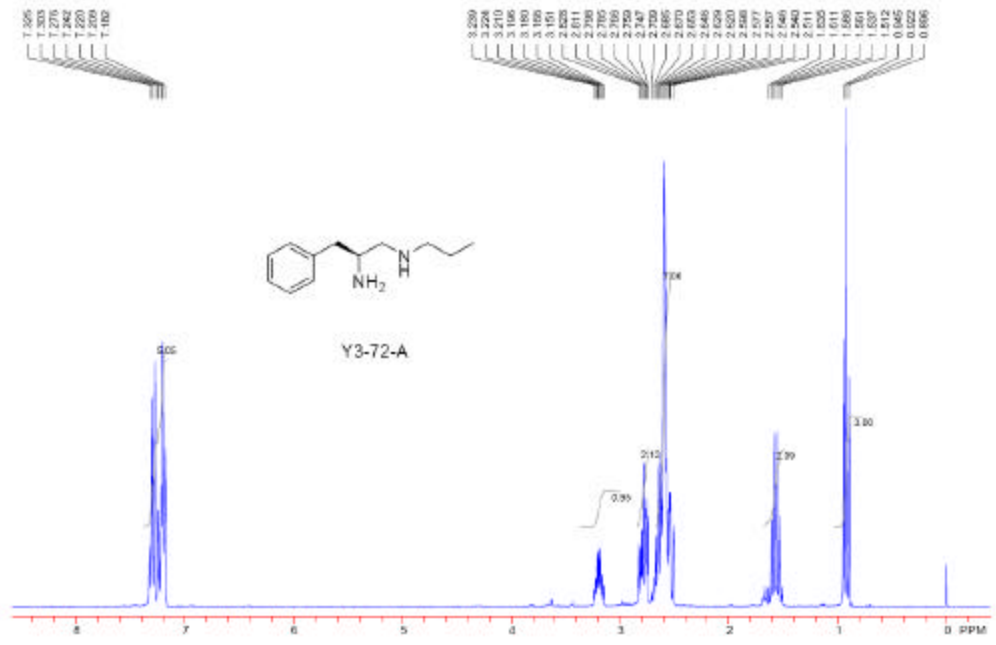


3c (^{1}H NMR)

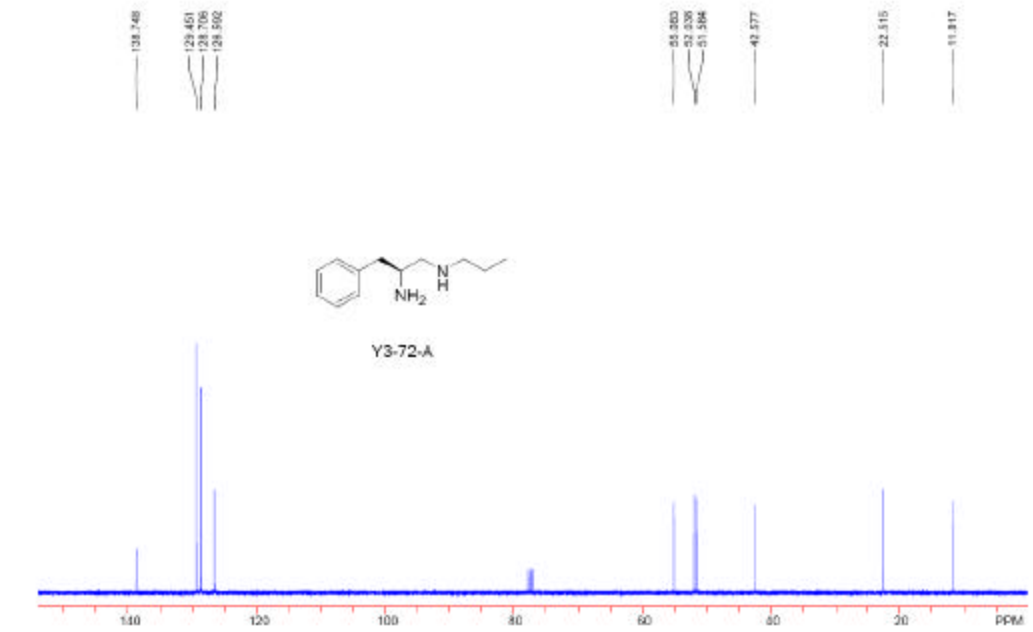


3c (^{13}C NMR)

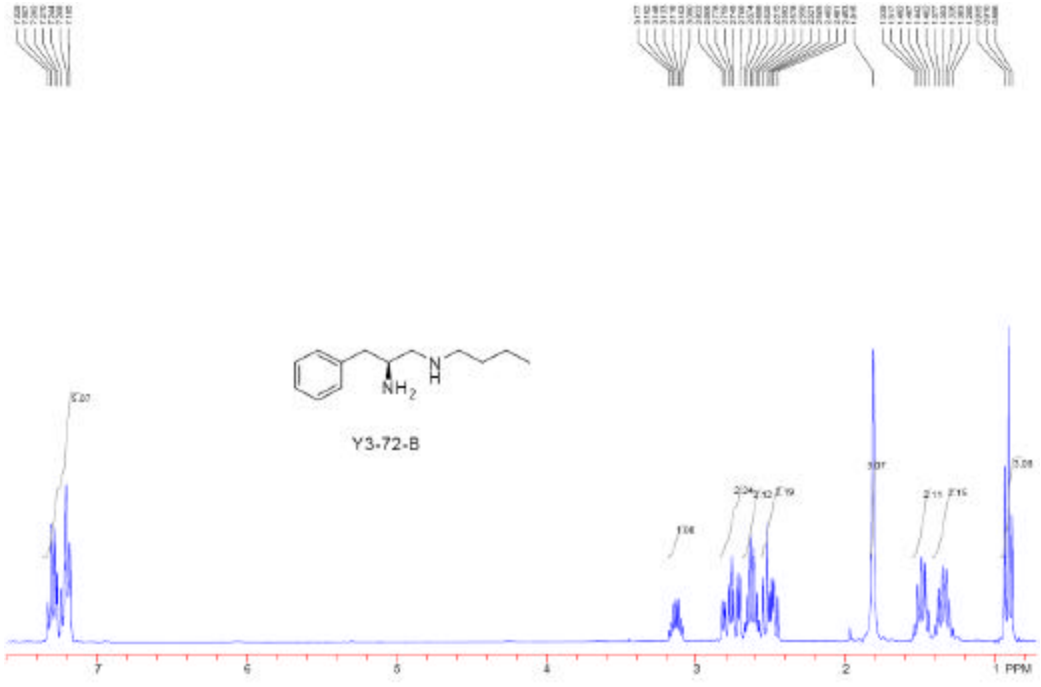
3d (^{1}H NMR)



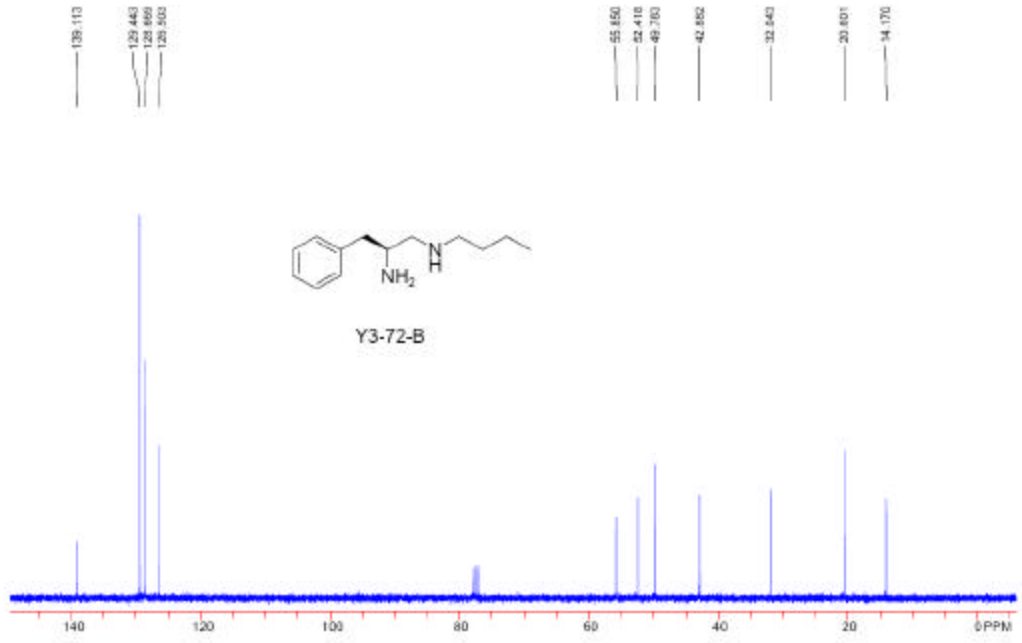
3d (^{13}C NMR)



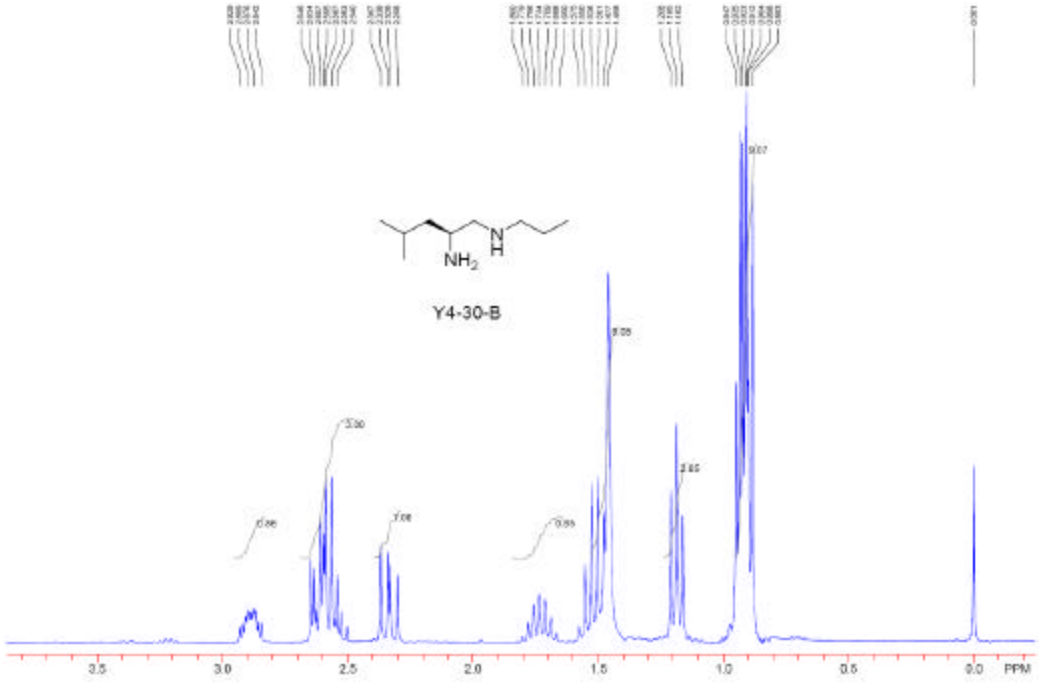
3e (^{1}H NMR)



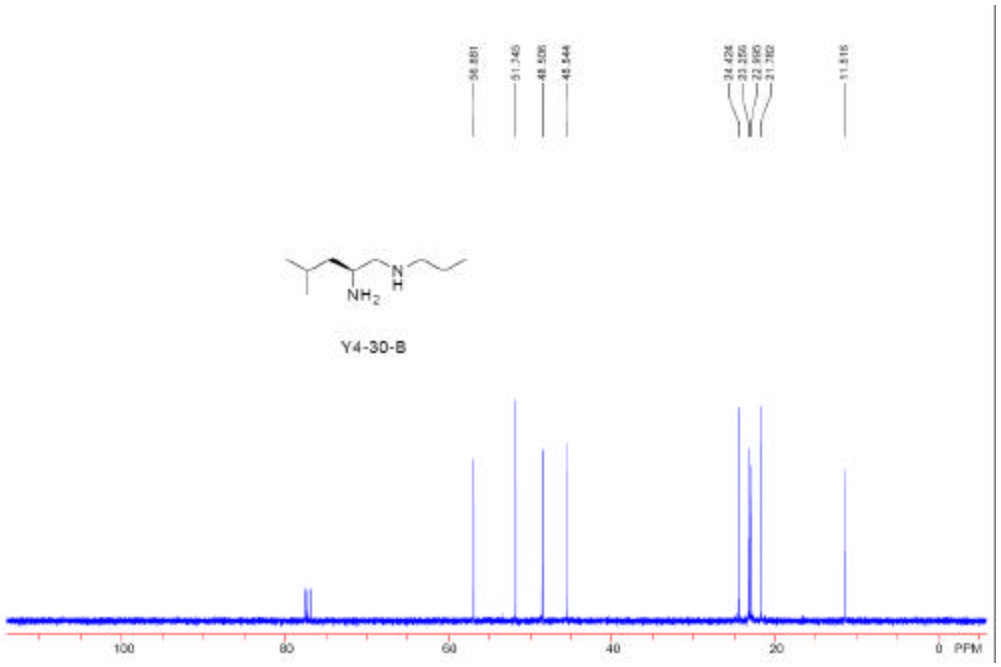
3e (^{13}C NMR)



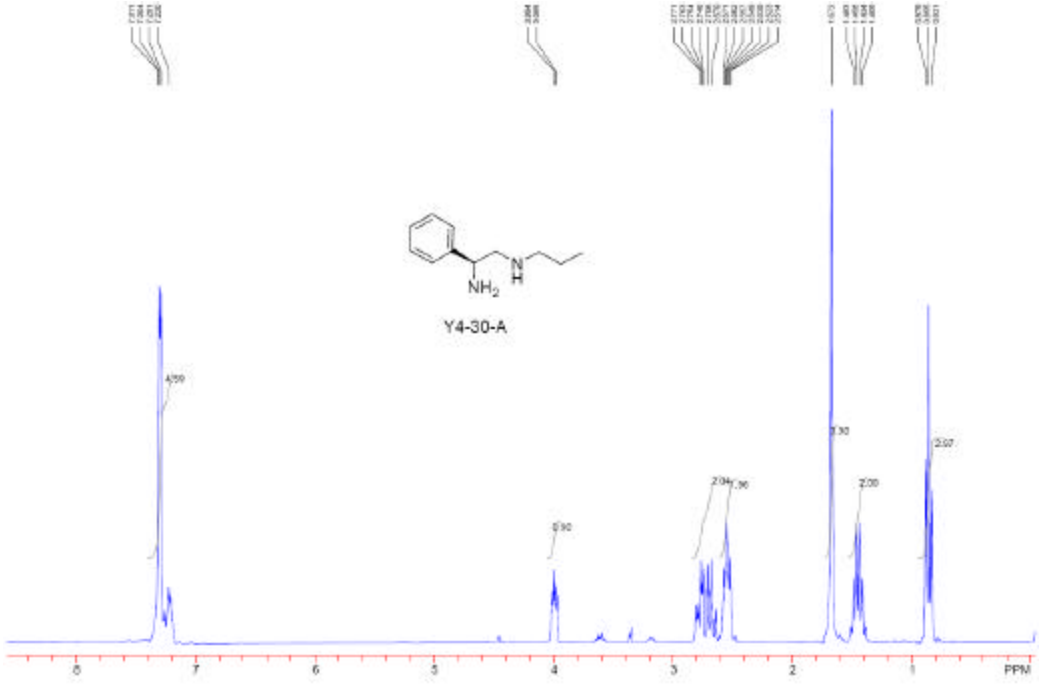
3g (^{1}H NMR)



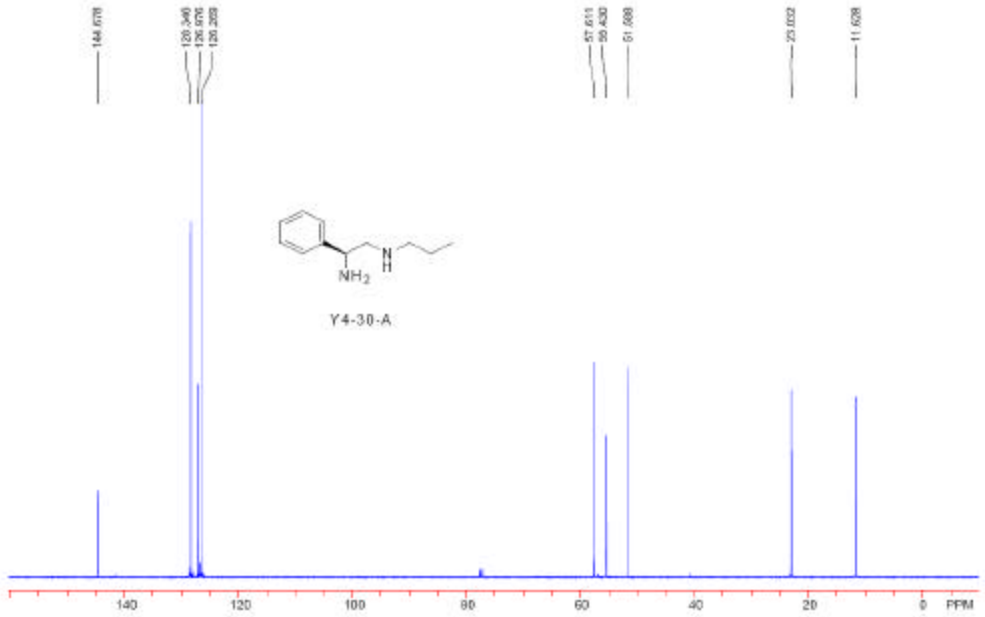
3g (^{13}C NMR)


56.881
51.749
48.506
45.544
34.424
23.255
22.995
21.782
11.515
NH2
N
H
Y4-30-B
100
80
60
40
20
0 PPM

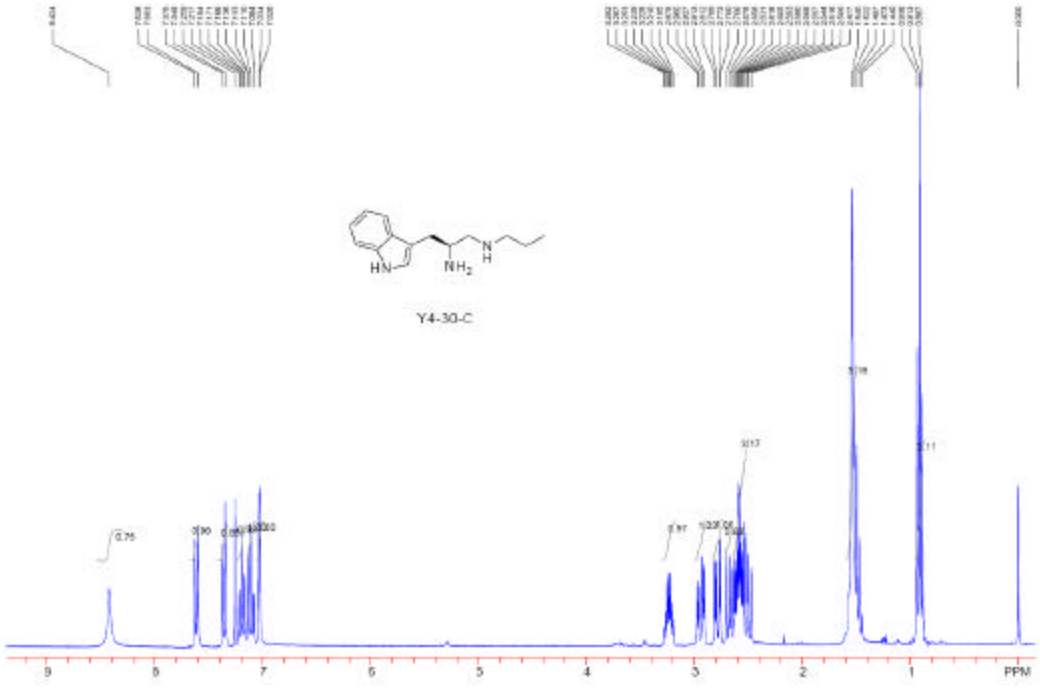
3h (^{1}H NMR)


NH2
N
H
Y4-30-A
4.59
0.90
2.04
1.90
3.00
2.00
2.07
8
7
6
5
4
3
2
1
PPM

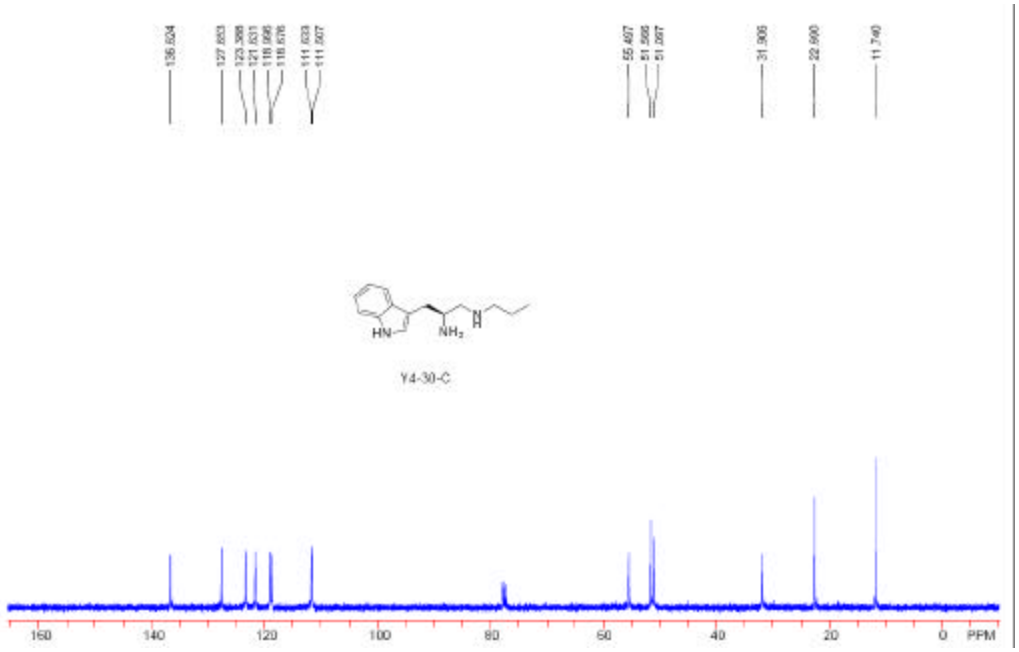
3h (^{13}C NMR)



3i (^{1}H NMR)

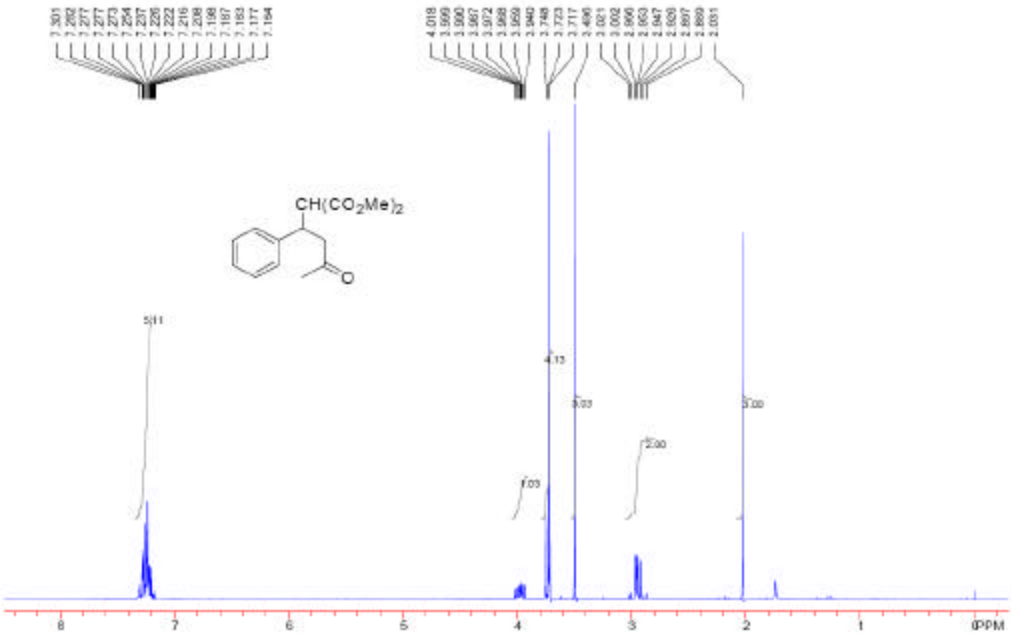


3i (^{13}C NMR)

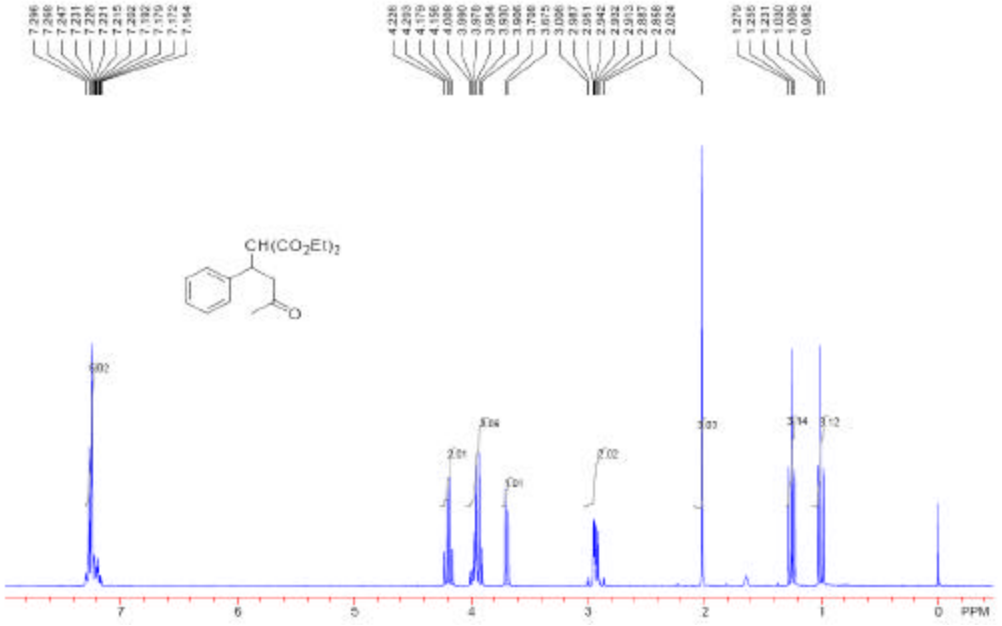


NMR spectra for compounds 4

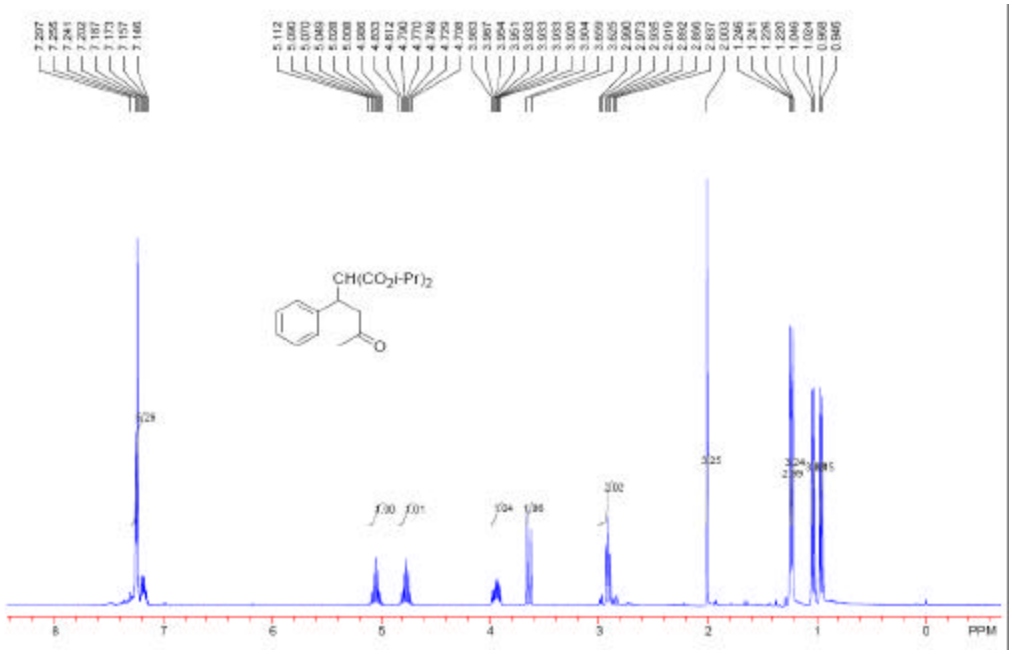
4aa (^{1}H NMR)



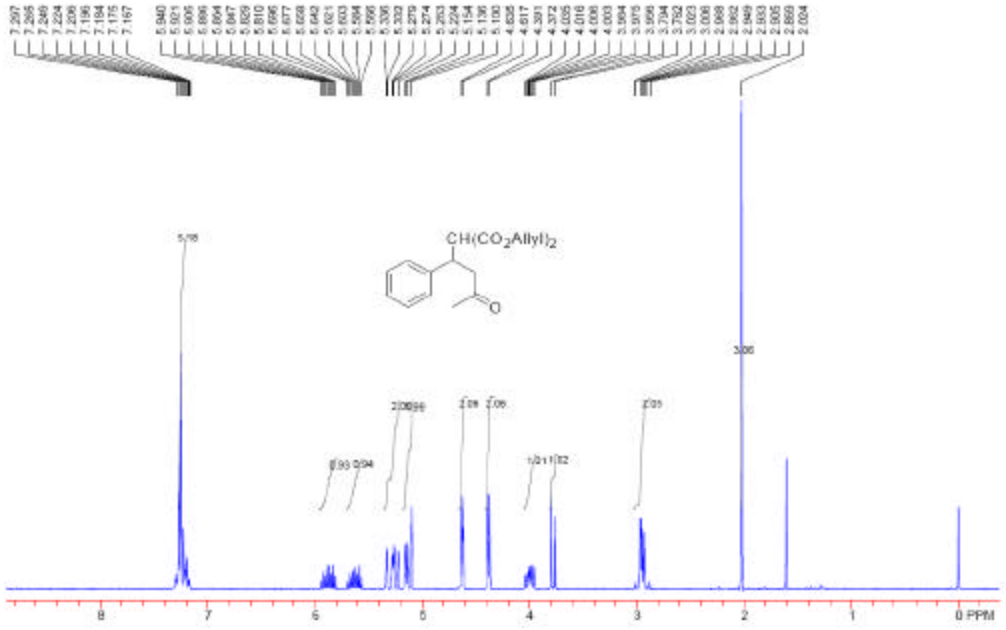
4ba (^{1}H NMR)



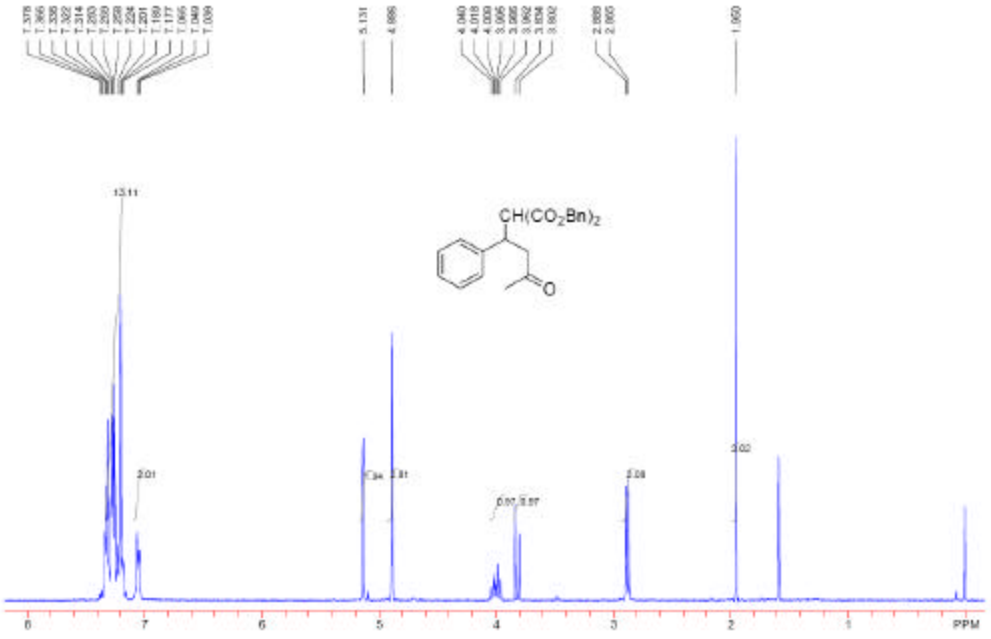
4ca(^{1}H NMR)



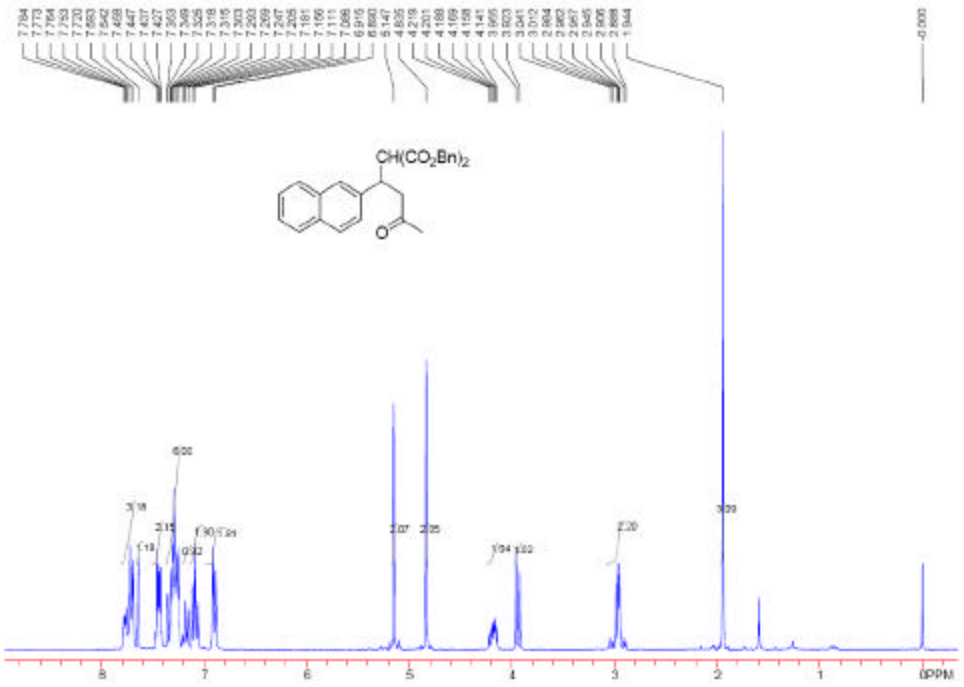
4da(^{1}H NMR)



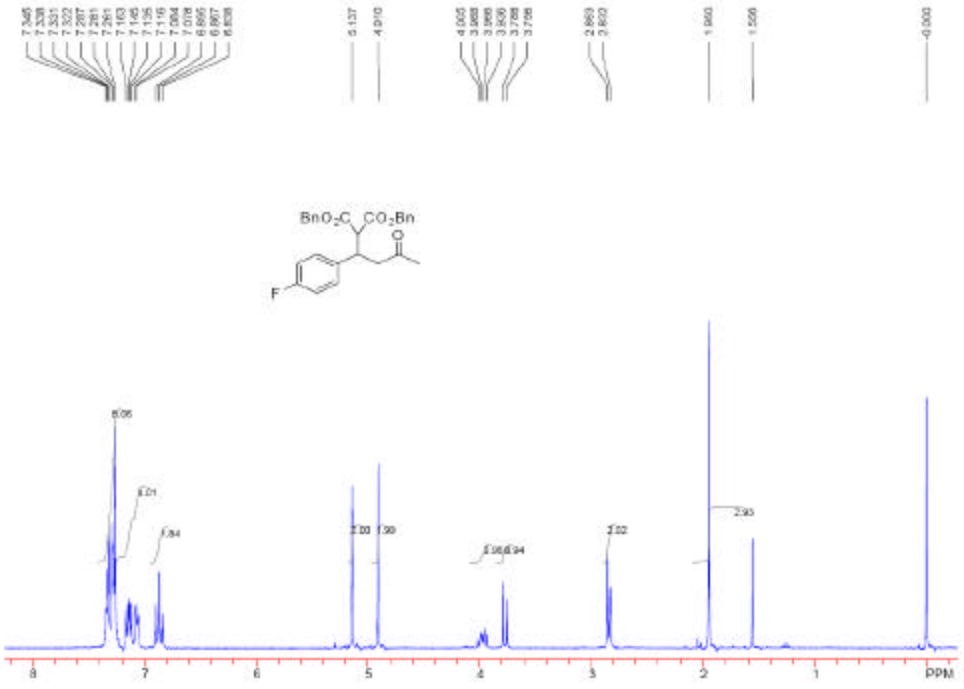
4ea(^{1}H NMR)



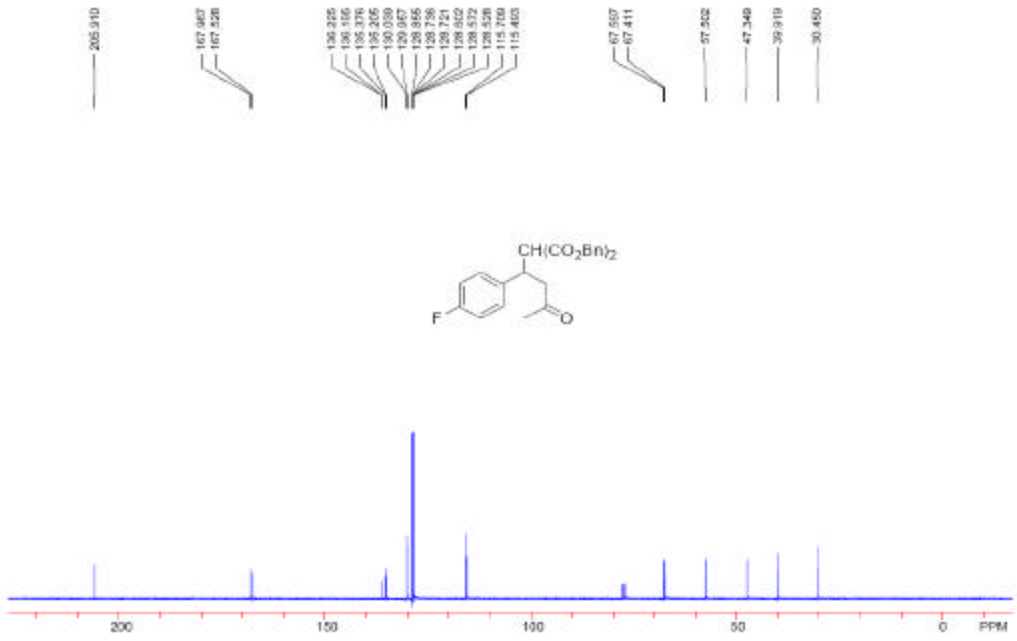
4eb (^{1}H NMR)



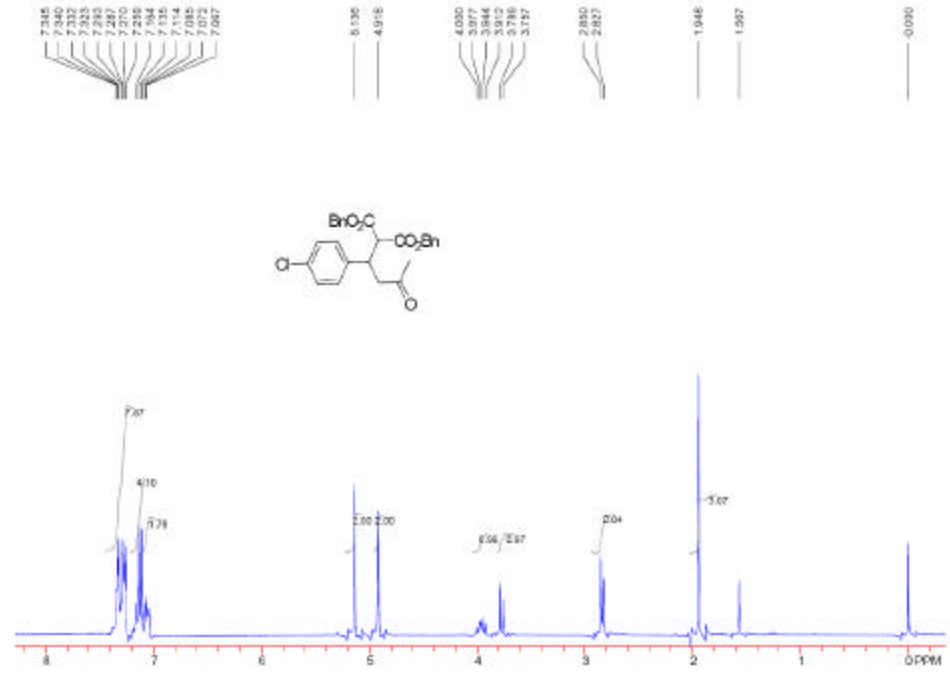
4ec (^{1}H NMR)



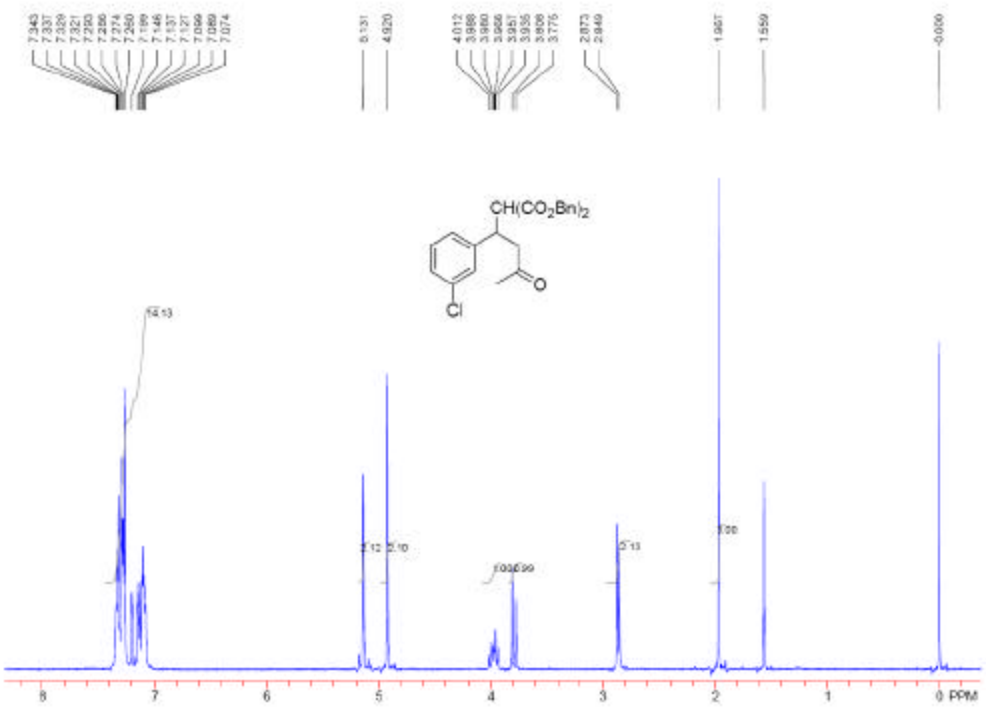
4ec (^{13}C NMR)



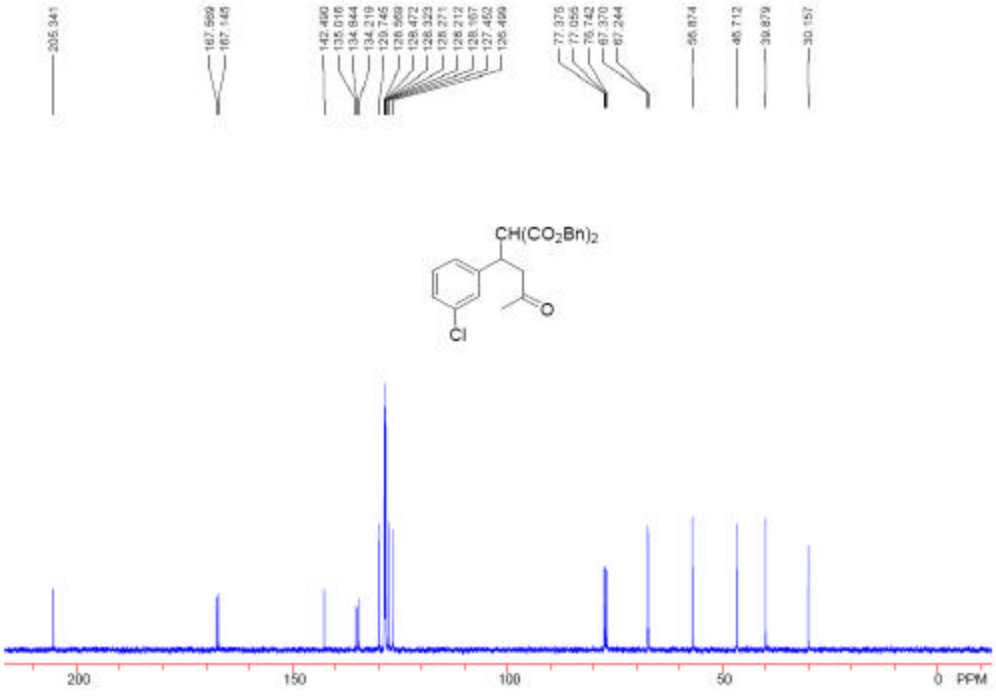
4ed (^{1}H NMR)



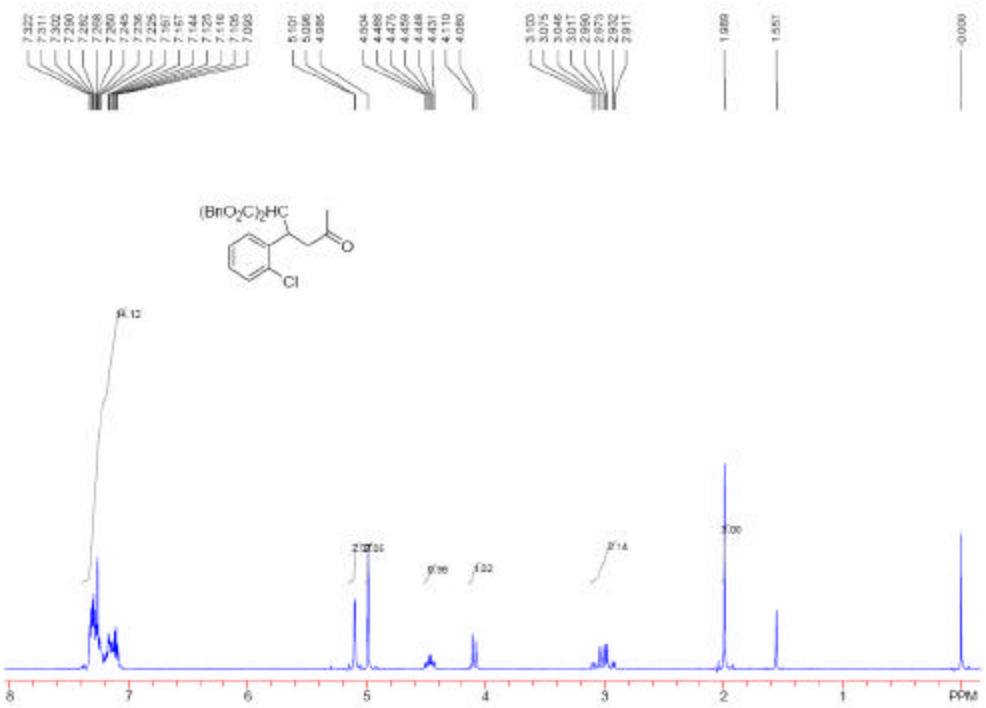
4ee (^{1}H NMR)



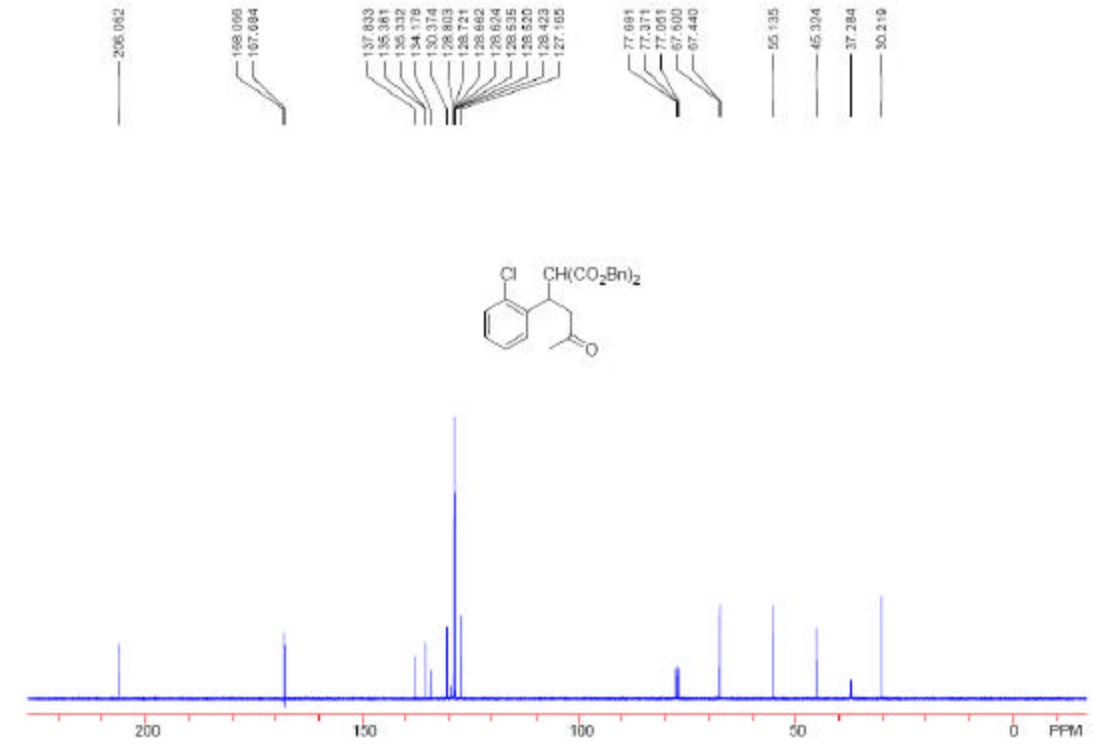
4ee (^{13}C NMR)



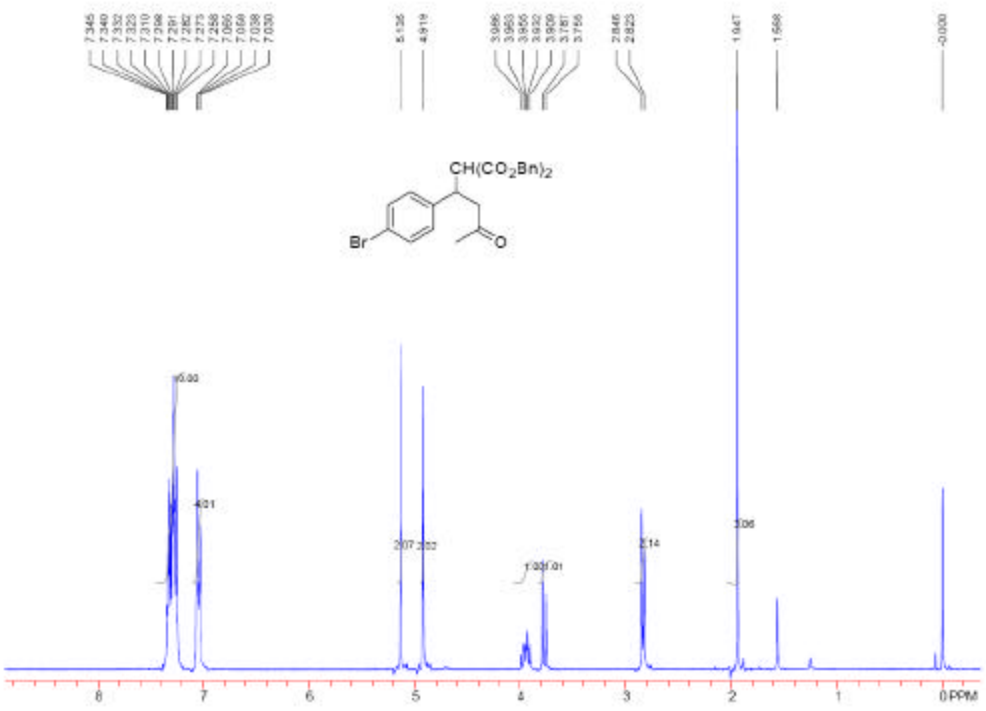
4ef (^{1}H NMR)



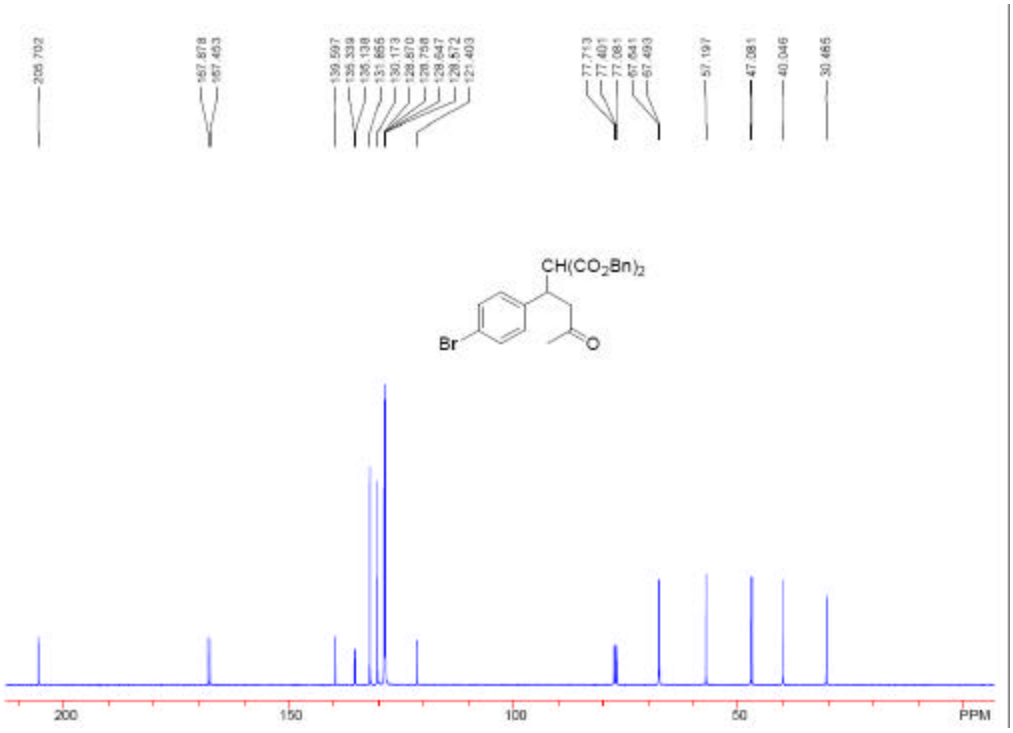
4ef (^{13}C NMR)



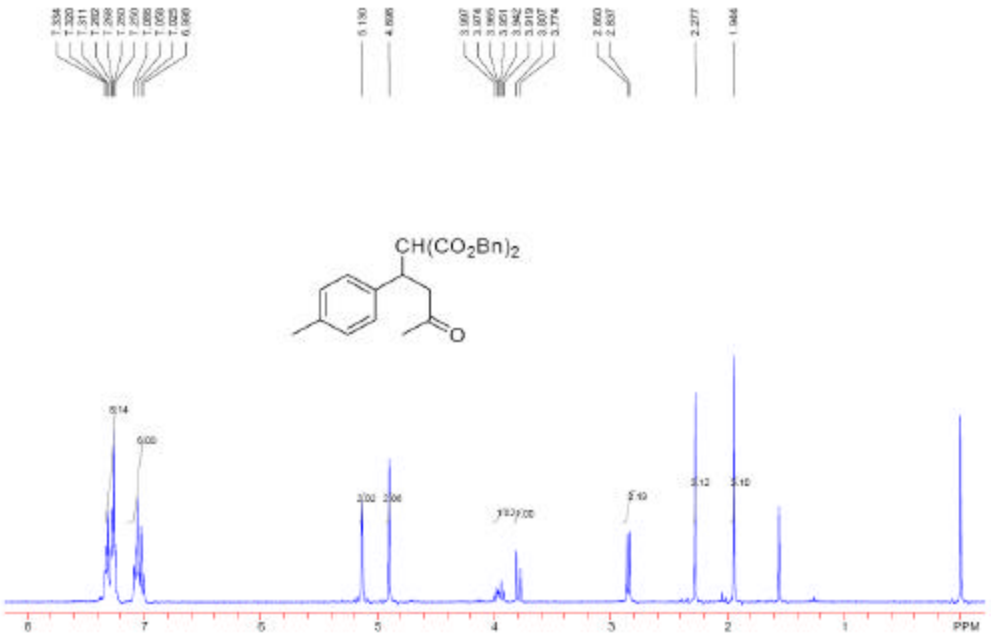
4eg (^{1}H NMR)



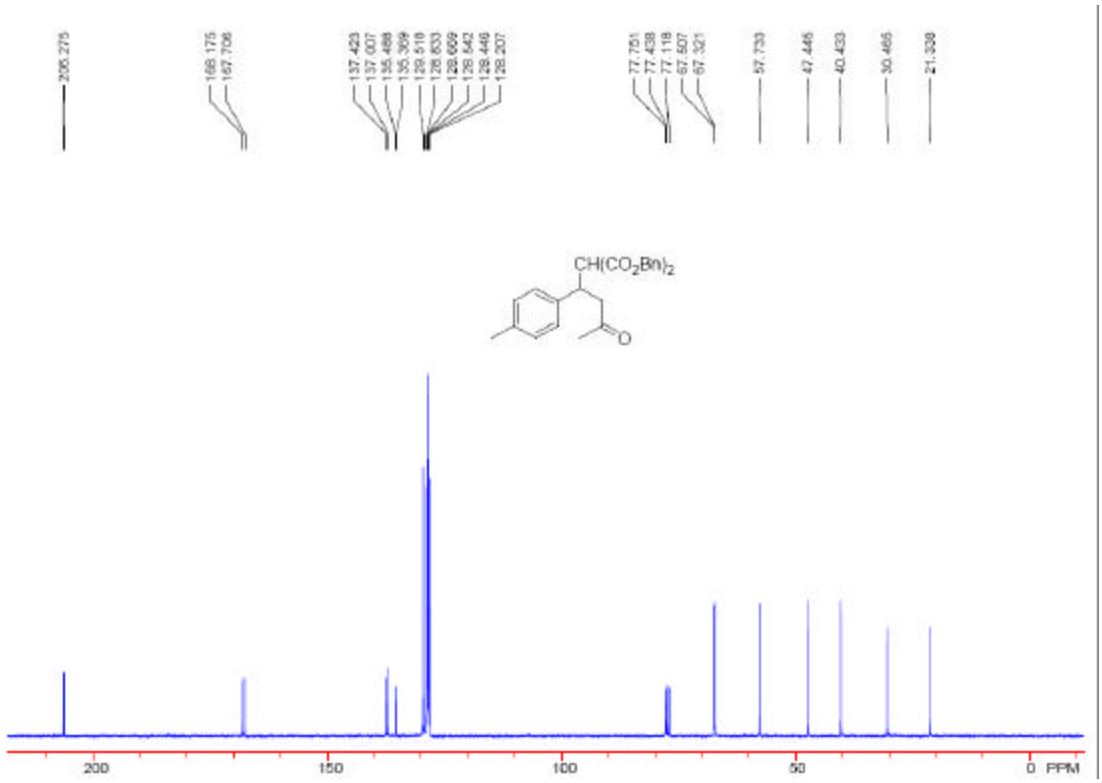
4eg (^{13}C NMR)



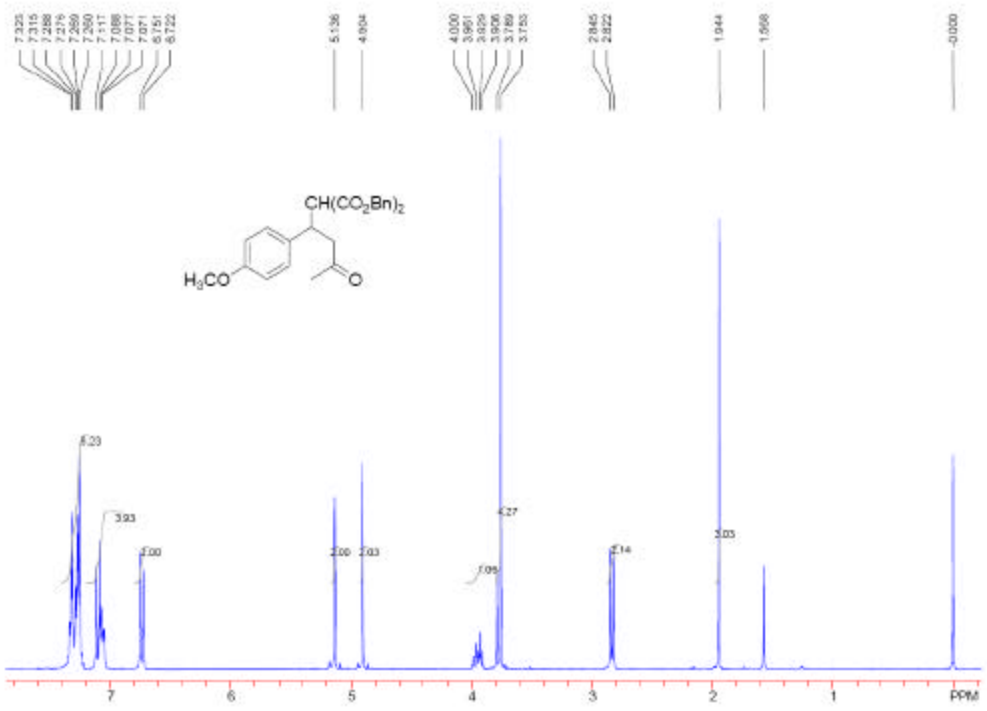
4eh (^{1}H NMR)



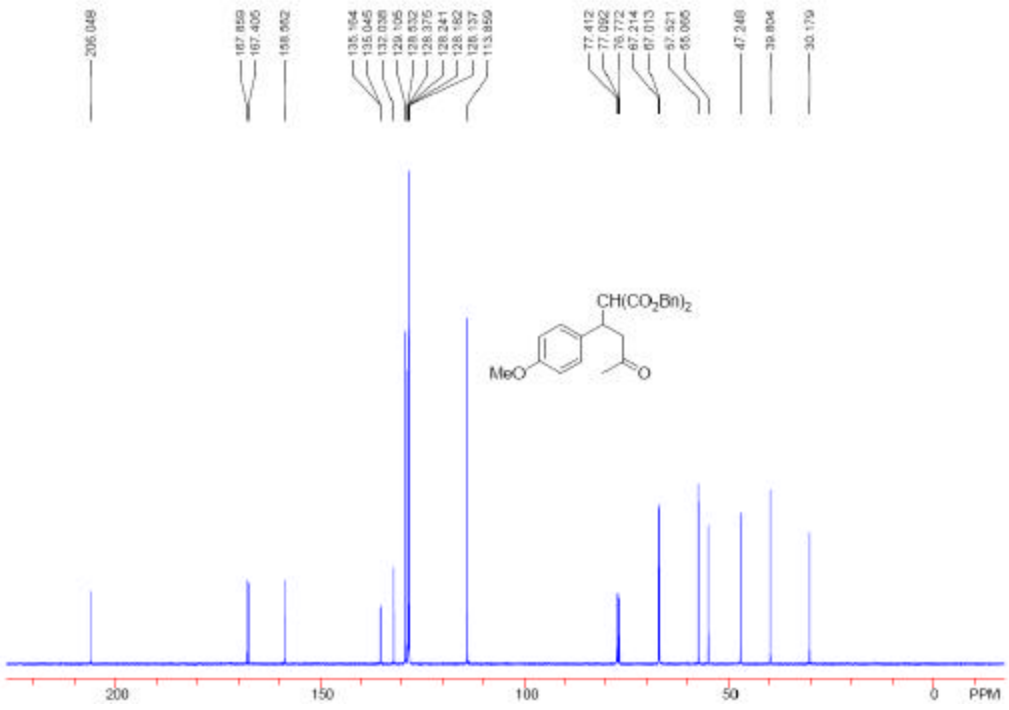
4eh (^{13}C NMR)



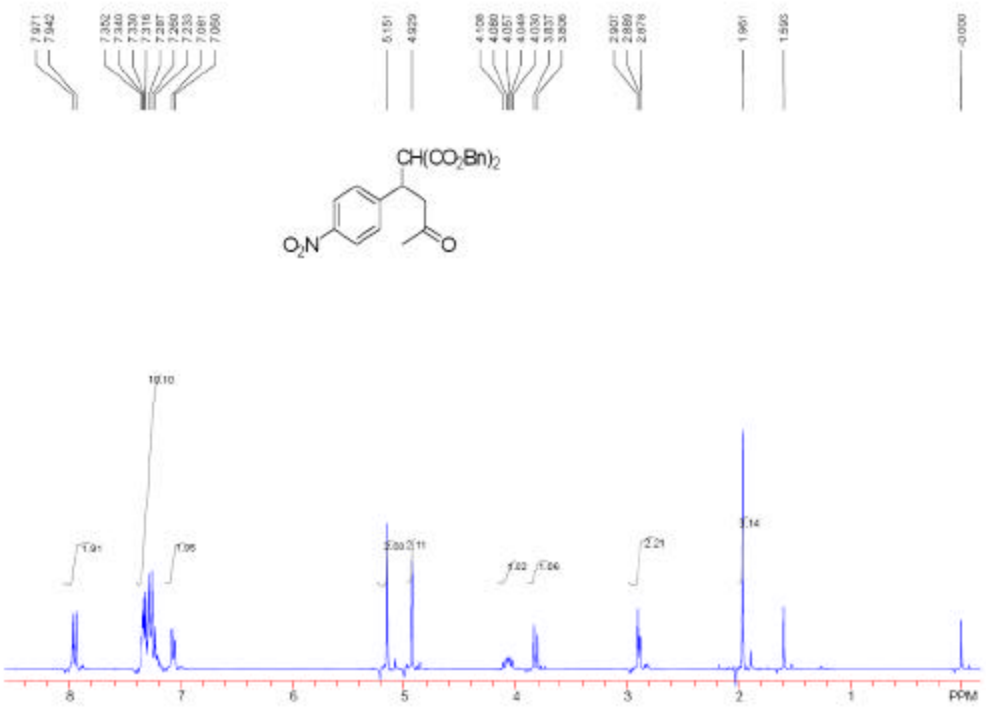
4ei (^{1}H NMR)



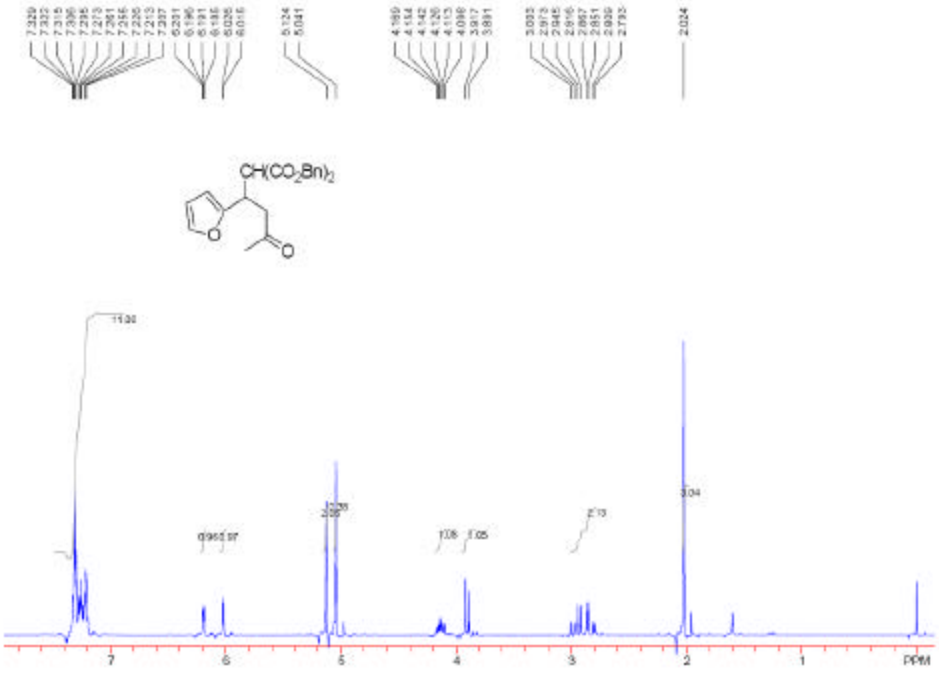
4ei (^{13}C NMR)



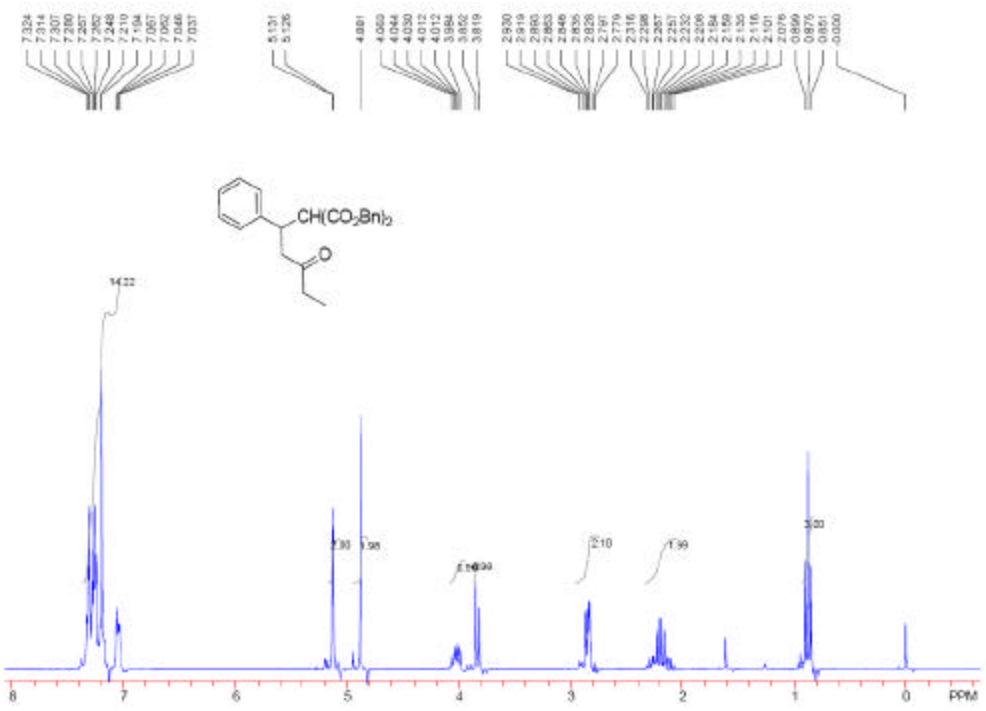
4ej (^{1}H NMR)



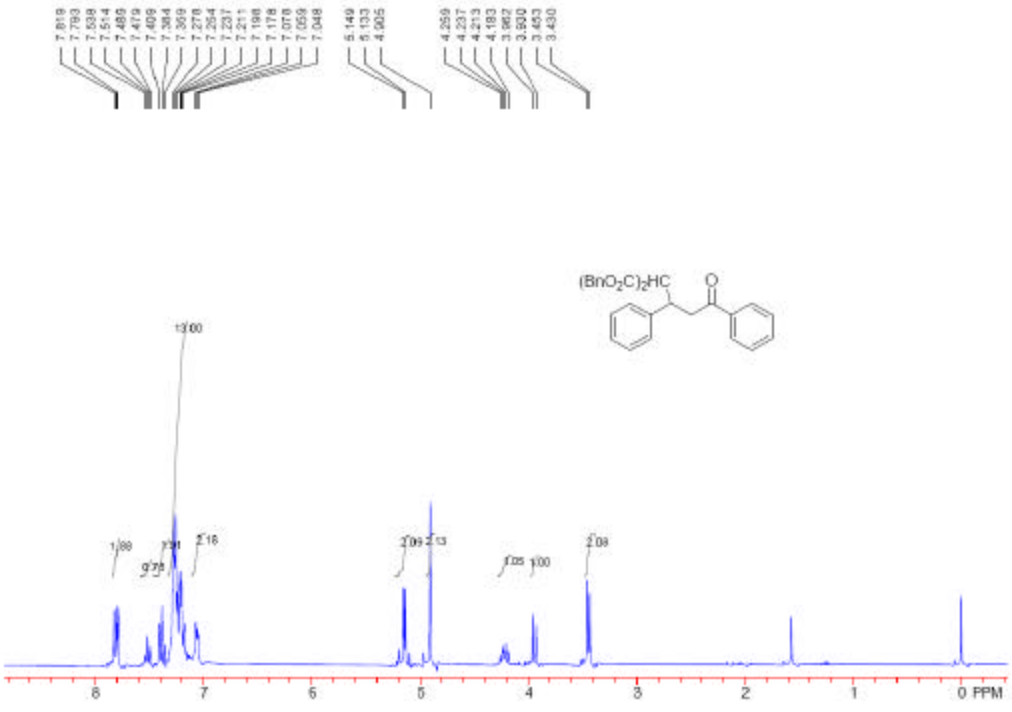
4ek (^{1}H NMR)



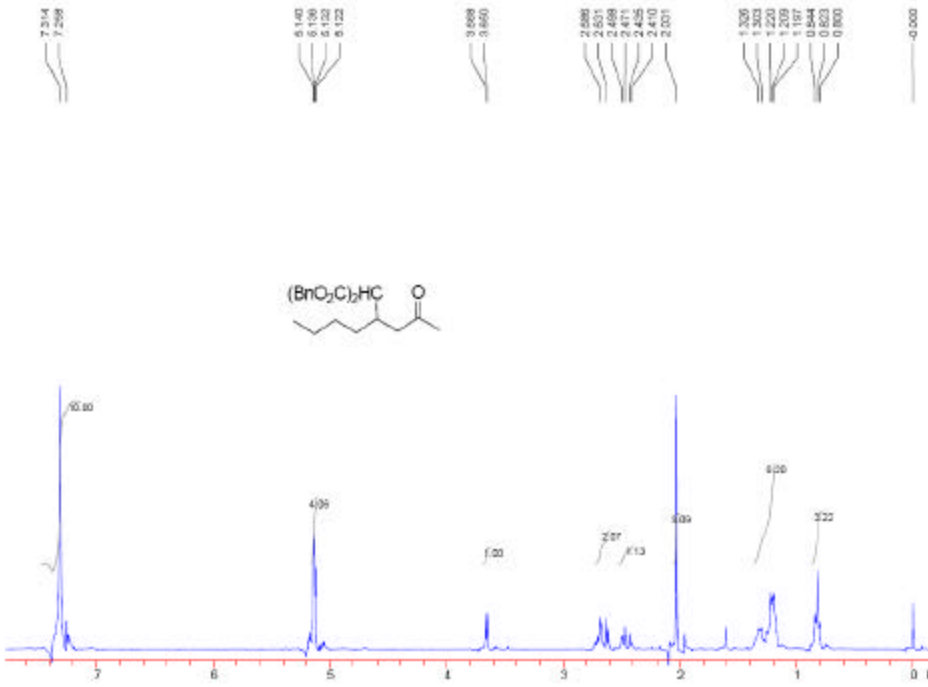
4el (^{1}H NMR)



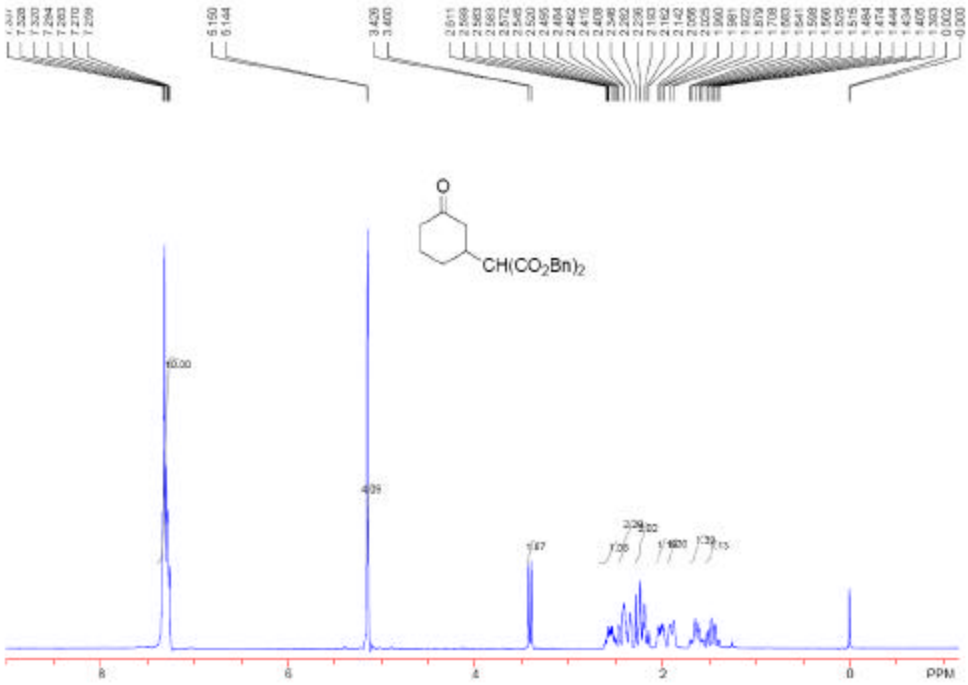
4em (^{1}H NMR)



4en (^{1}H NMR)

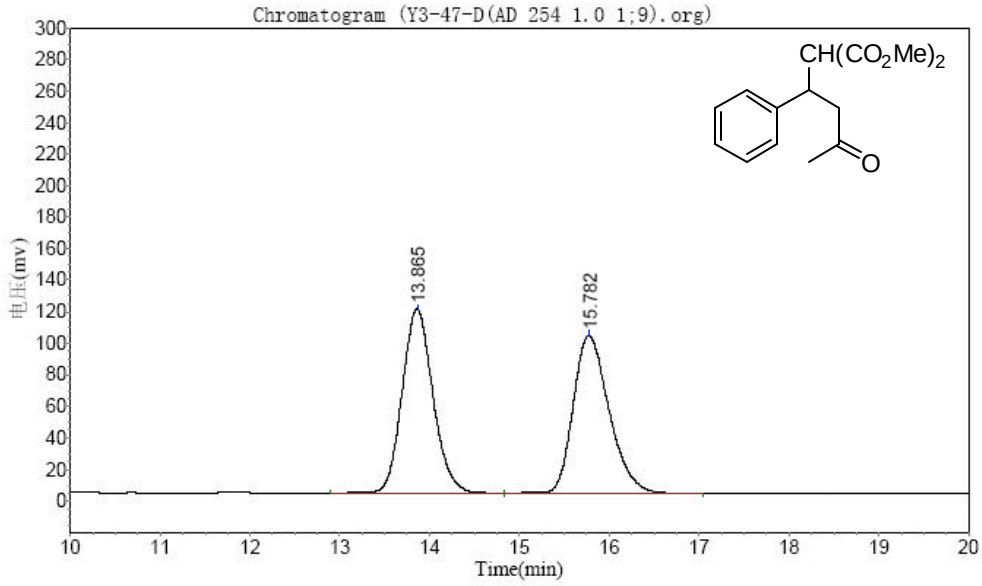


4eo (^{1}H NMR)

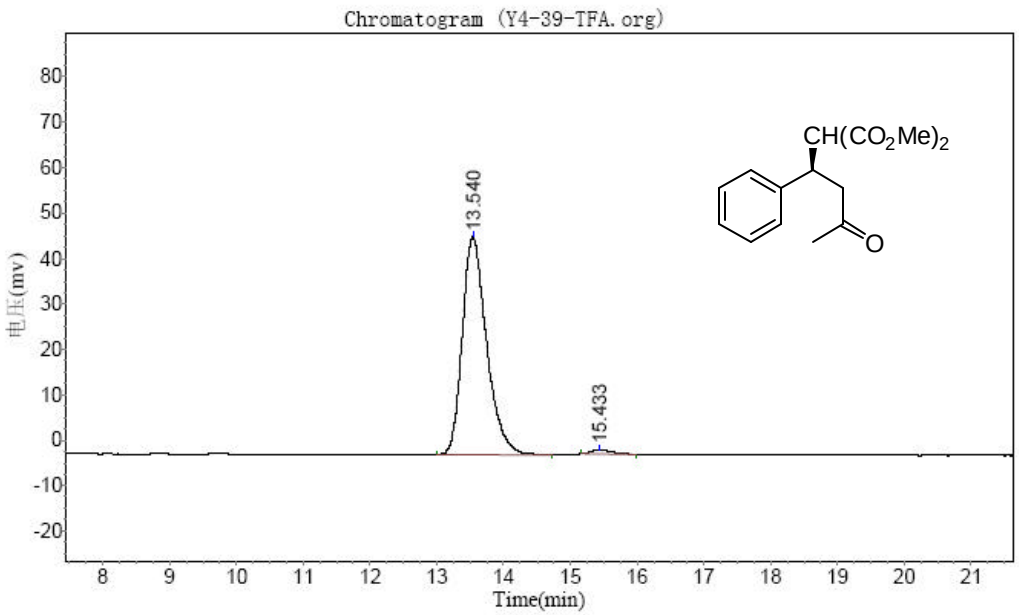


HPLC spectra for compounds 4

HPLC spectra for compound **4 aa**



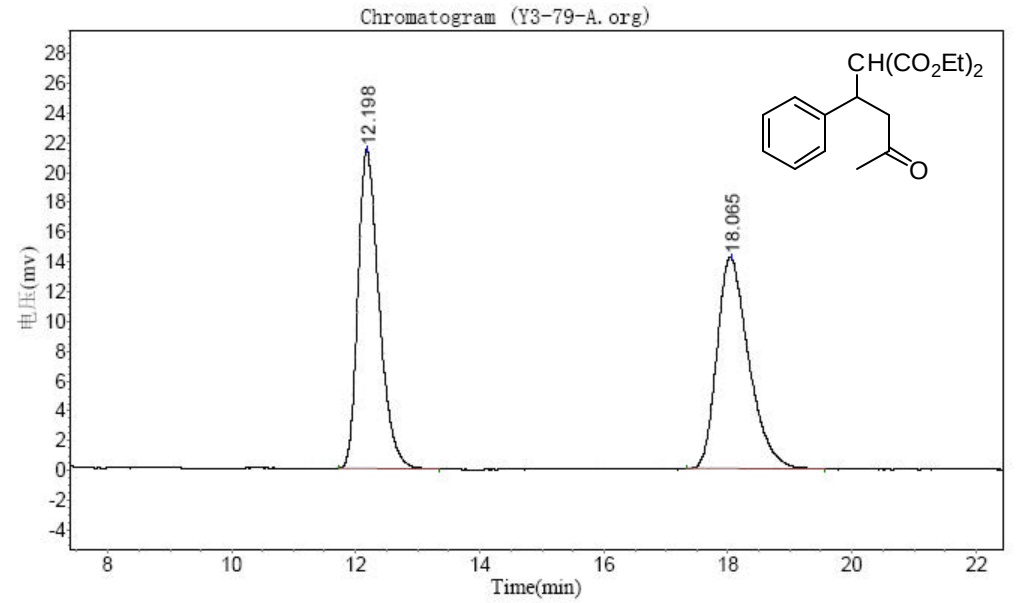
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		13.865	117483.930	2887532.750	50.1616
2		15.782	100745.547	2868930.000	49.8384
Total			218229.477	5756462.750	100.0000



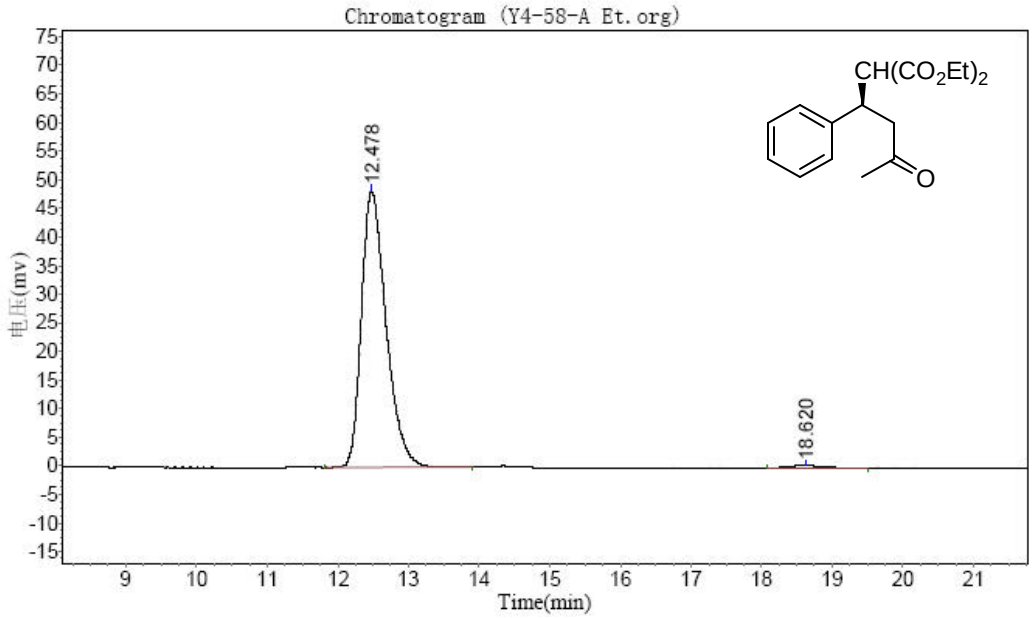
Results

Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		13.540	47943.348	1213163.000	98.4055
2		15.433	839.004	19657.158	1.5945
Total			48782.352	1232820.158	100.0000

HPLC spectra for compound **4ba**



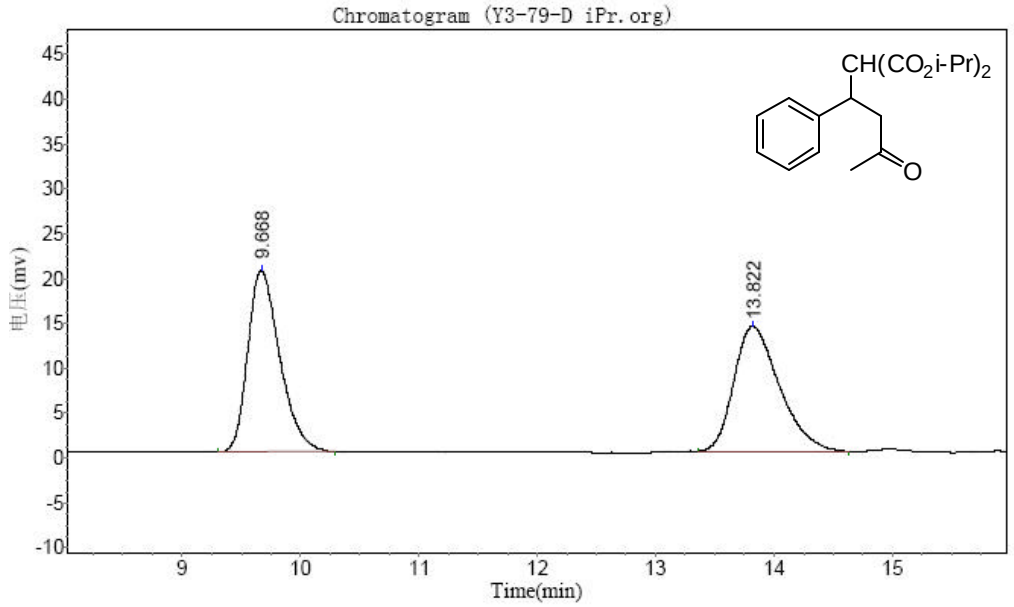
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		12.198	21379.084	506225.000	50.0262
2		18.065	14131.567	505695.688	49.9738
Total			35510.651	1011920.688	100.0000



Results

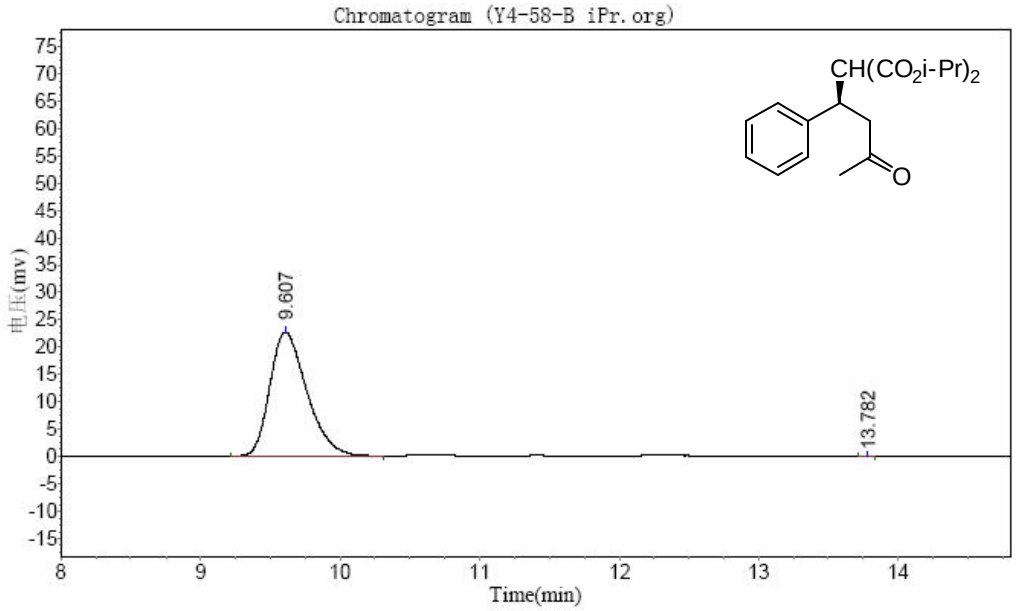
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		12.478	48323.848	1166605.000	98.9230
2		18.620	372.897	12701.200	1.0770
Total			48696.745	1179306.200	100.0000

HPLC spectra for compound **4ca**



Results

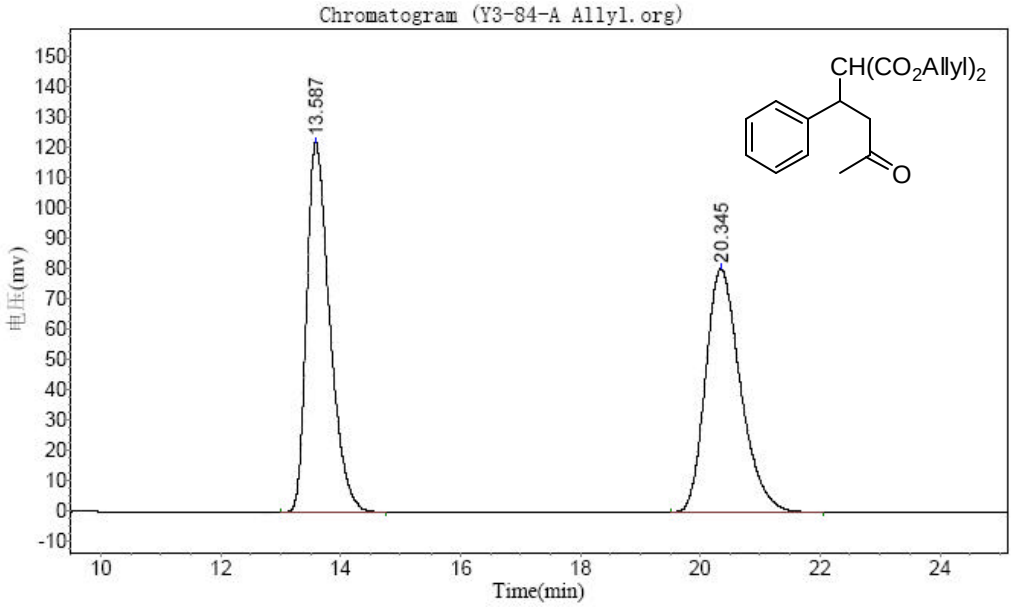
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		9.668	20252.668	379815.688	50.5905
2		13.822	13903.822	370949.344	49.4095
Total			34156.490	750765.031	100.0000



Results

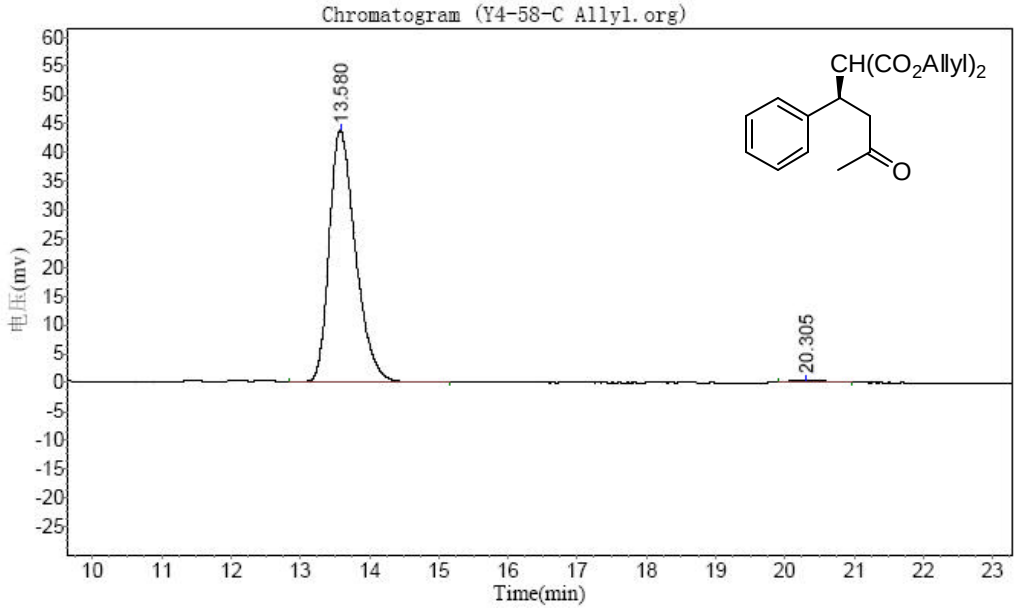
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		9.607	22779.223	420533.438	99.9803
2		13.782	25.055	82.950	0.0197
Total			22804.277	420616.387	100.0000

HPLC spectra for compound **4da**



Results

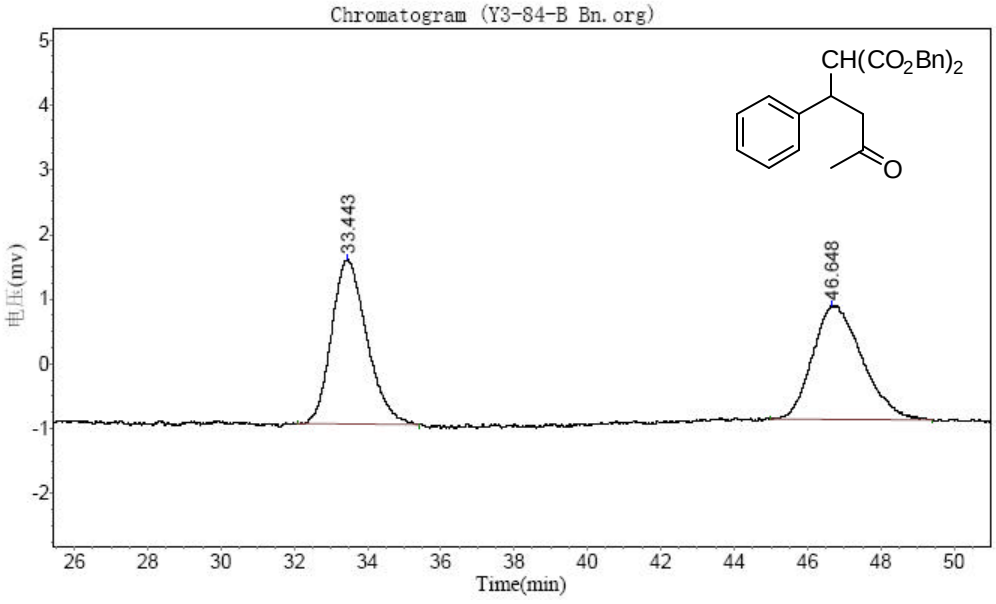
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		13.587	122207.656	3276442.750	50.0067
2		20.345	80572.383	3275570.500	49.9933
Total			202780.039	6552013.250	100.0000



Results

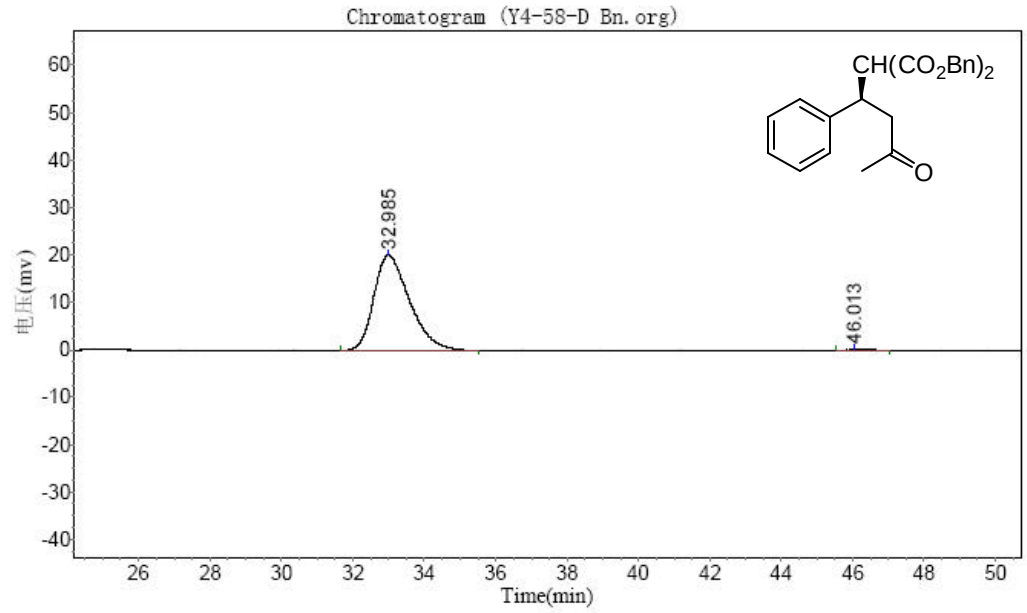
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		13.580	43857.586	1157878.625	99.0593
2		20.305	337.630	10996.000	0.9407
Total			44195.216	1168874.625	100.0000

HPLC spectra for compound **4ea**



Results

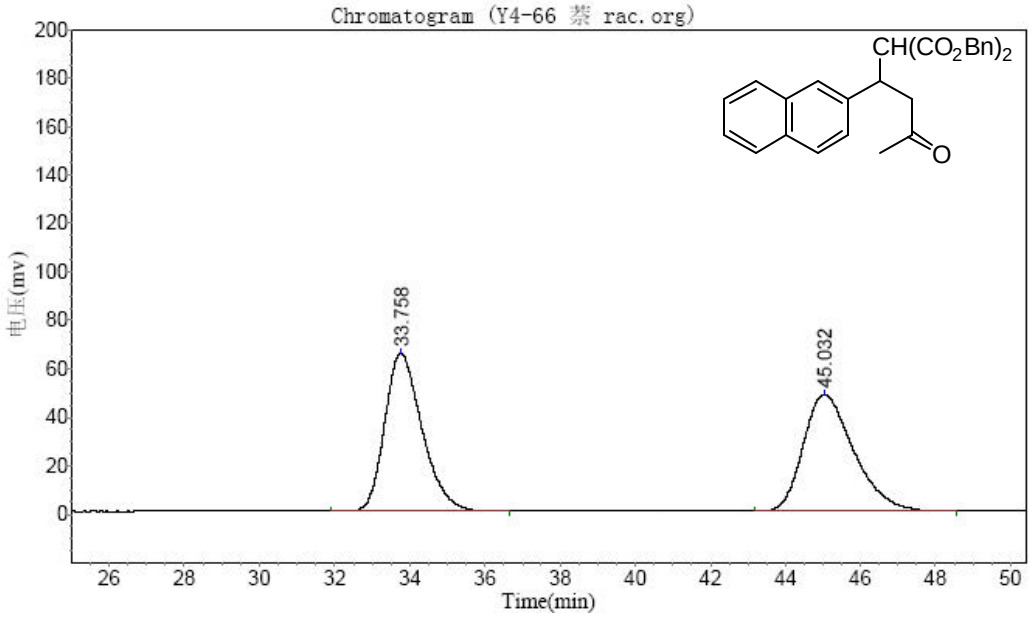
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		33.443	2537.212	168674.406	50.6674
2		46.648	1752.867	164230.703	49.3326
Total			4290.079	332905.109	100.0000



Results

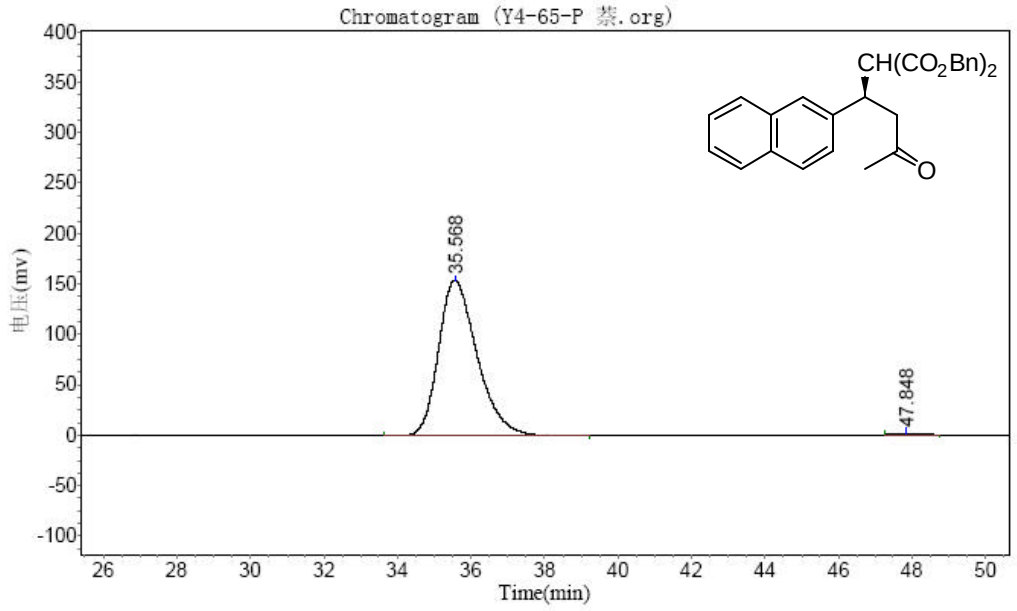
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		32.985	20004.365	1381760.625	99.5969
2		46.013	122.354	5592.500	0.4031
Total			20126.719	1387353.125	100.0000

HPLC spectra for compound **4eb**



Results

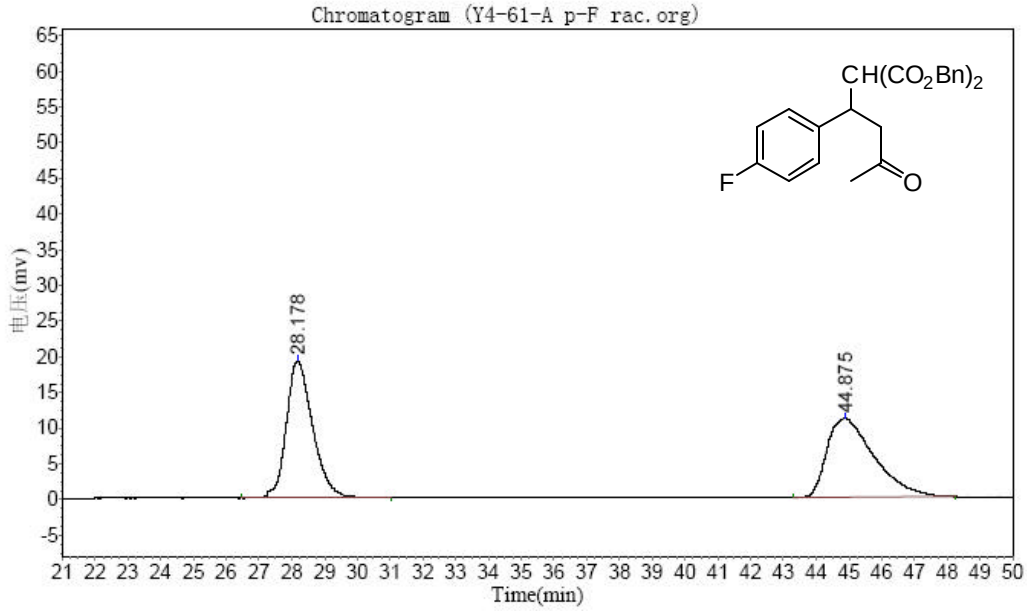
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		33.758	65232.844	4513968.500	50.1079
2		45.032	48158.457	4494533.000	49.8921
Total			113391.301	9008501.500	100.0000



Results

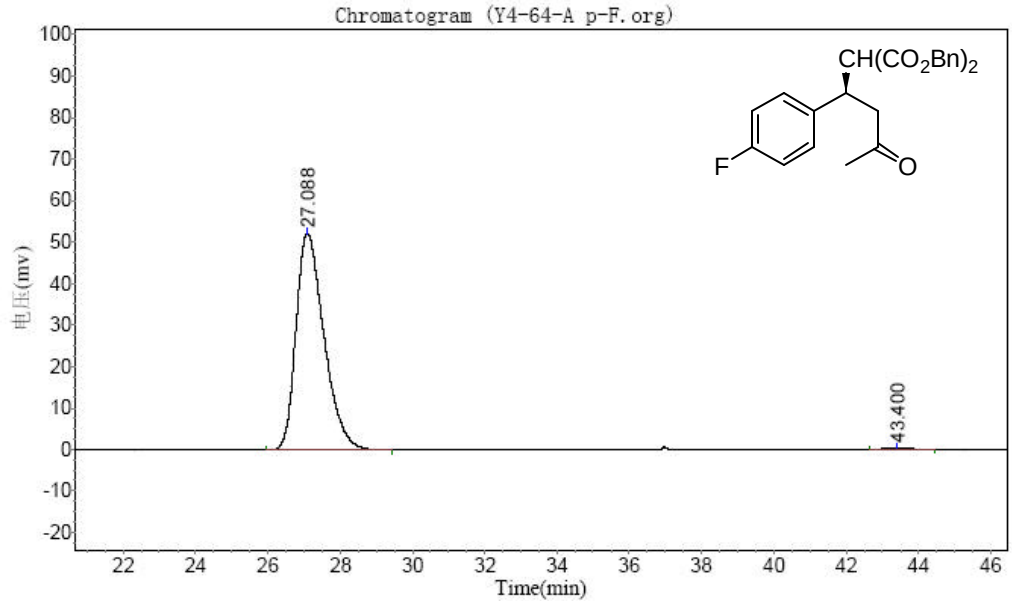
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		35.568	153712.125	11143953.000	99.6139
2		47.848	796.232	43189.699	0.3861
Total			154508.357	11187142.699	100.0000

HPLC spectra for compound **4ec**



Results

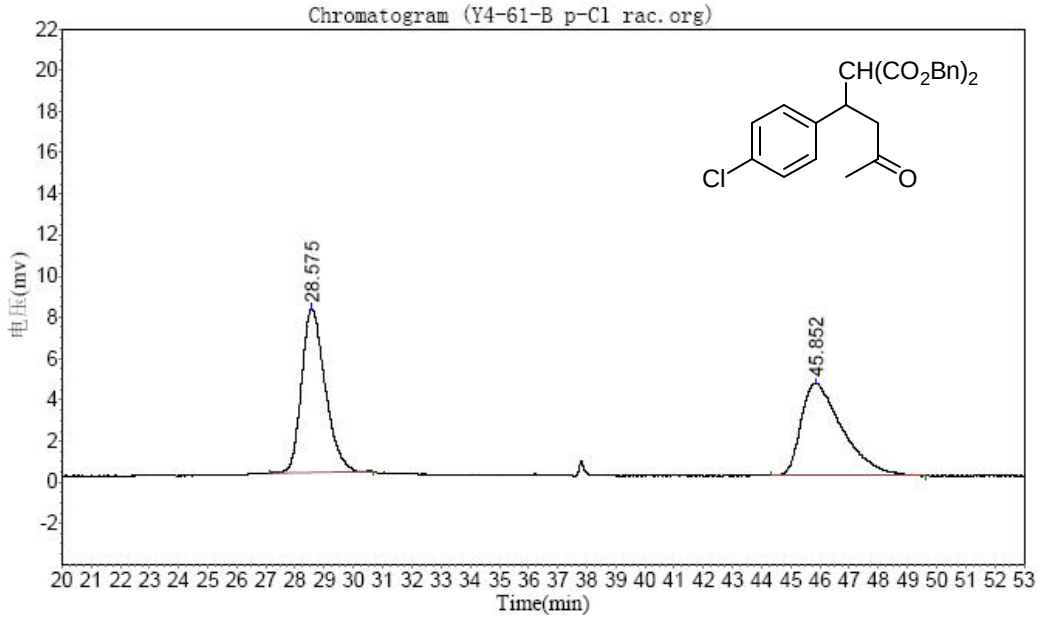
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		28.178	19205.670	1067162.750	49.0956
2		44.875	11025.282	1106481.500	50.9044
Total			30230.952	2173644.250	100.0000



Results

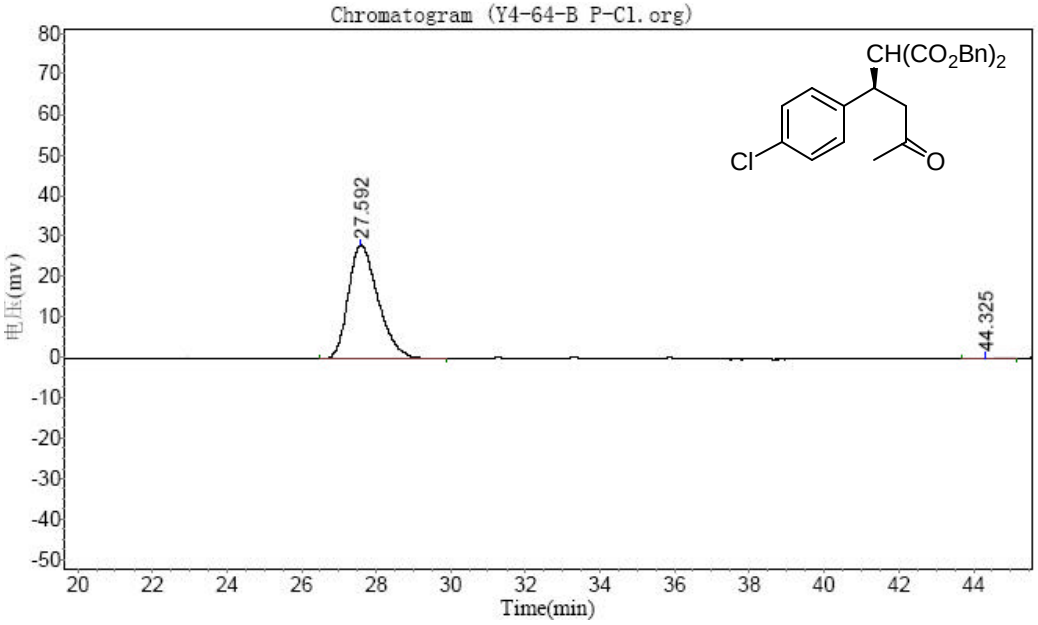
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		27.088	52287.852	2813233.250	99.3208
2		43.400	309.684	19237.299	0.6792
Total			52597.535	2832470.549	100.0000

HPLC spectra for compound **4ed**



Results

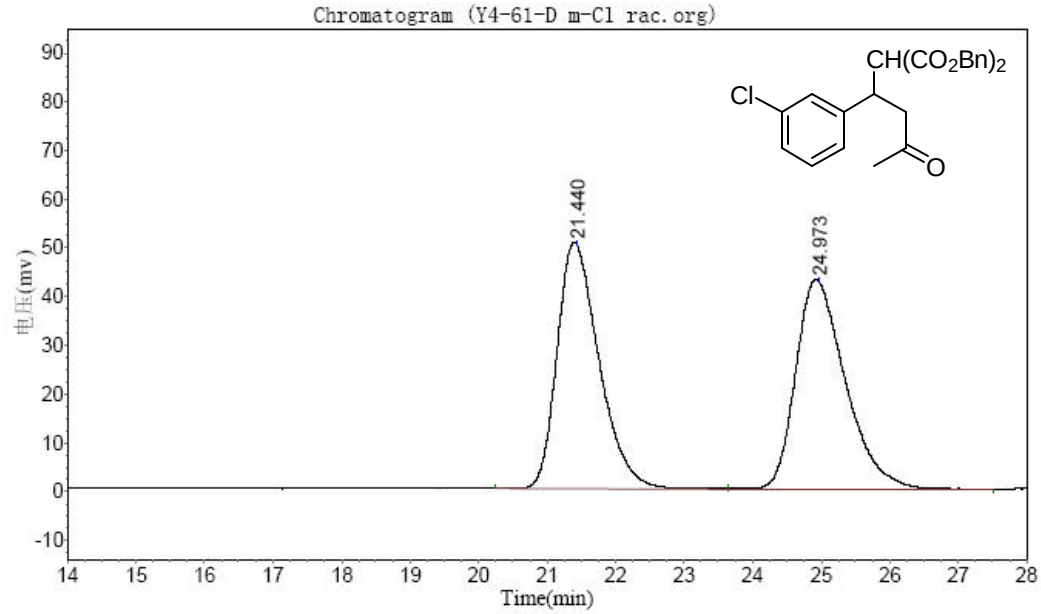
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		28.575	7939.914	445444.313	50.0287
2		45.852	4475.875	444932.563	49.9713
Total			12415.789	890376.875	100.0000



Results

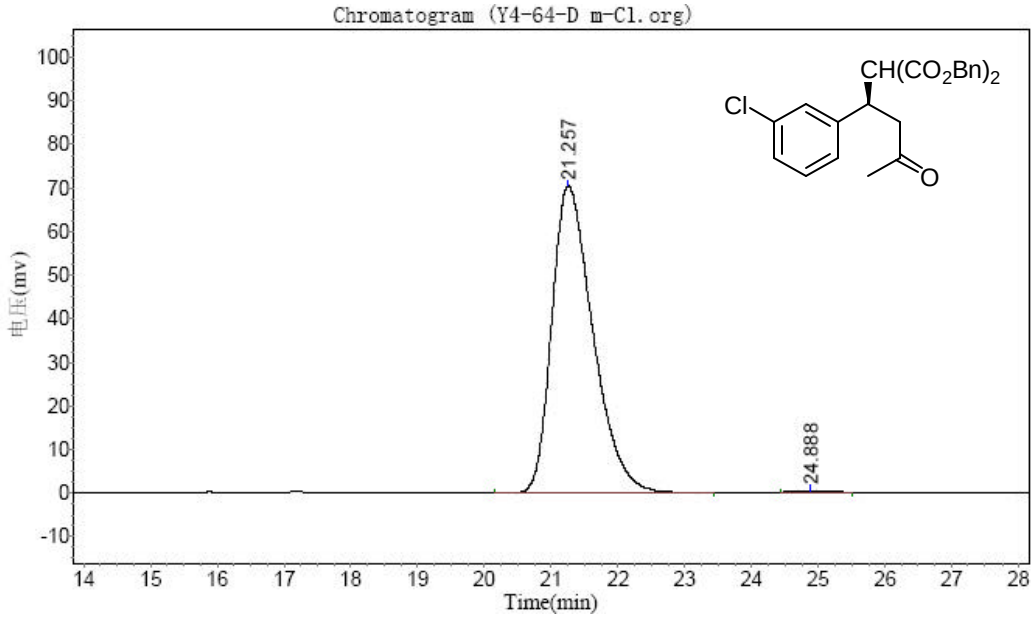
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		27.592	28183.439	1570904.625	99.7189
2		44.325	101.069	4427.900	0.2811
Total			28284.509	1575332.525	100.0000

HPLC spectra for compound **4ee**



Results

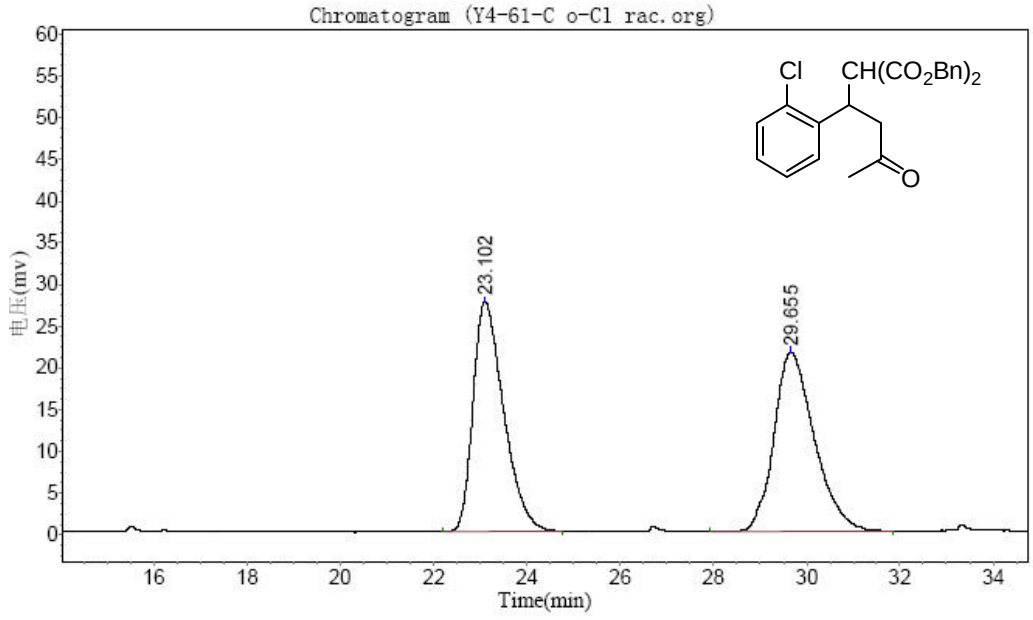
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		21.440	50440.543	2148710.750	49.8632
2		24.973	42825.414	2160501.000	50.1368
Total			93265.957	4309211.750	100.0000



Results

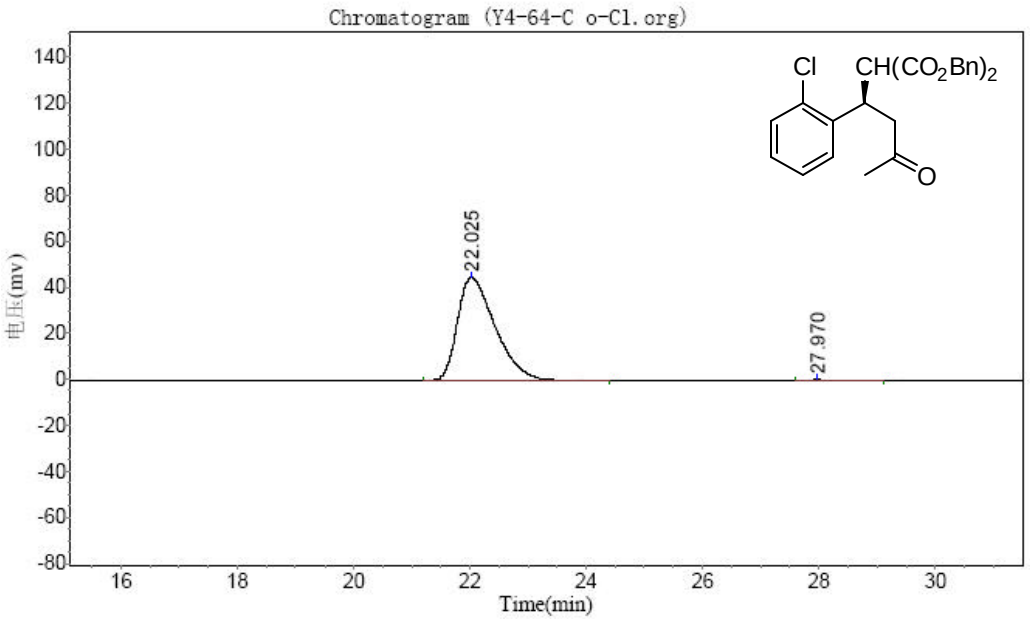
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		21.257	70579.172	3026108.750	99.5267
2		24.888	396.798	14390.699	0.4733
Total			70975.969	3040499.449	100.0000

HPLC spectra for compound **4ef**



Results

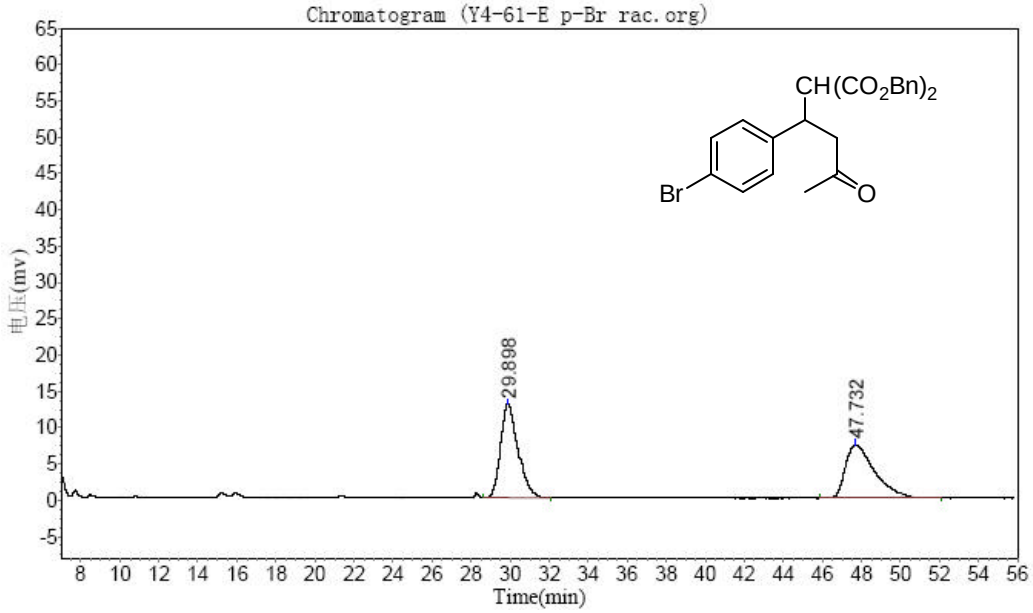
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		23.102	27522.537	1254240.625	49.2164
2		29.655	21466.557	1294180.125	50.7836
Total			48989.094	2548420.750	100.0000



Results

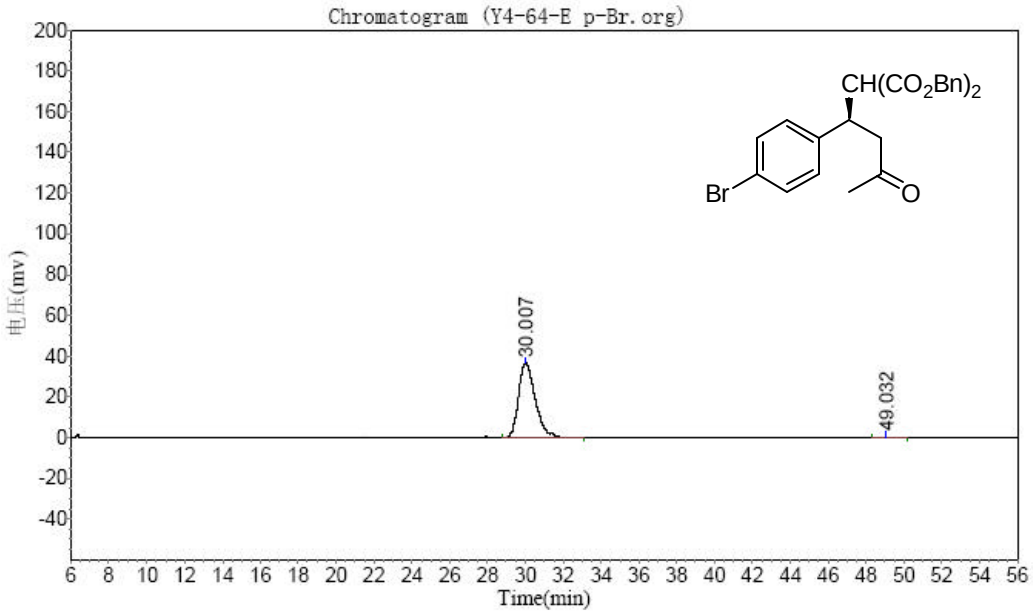
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		22.025	45035.609	2026804.625	99.5333
2		27.970	214.382	9503.047	0.4667
Total			45249.992	2036307.672	100.0000

HPLC spectra for compound **4eg**



Results

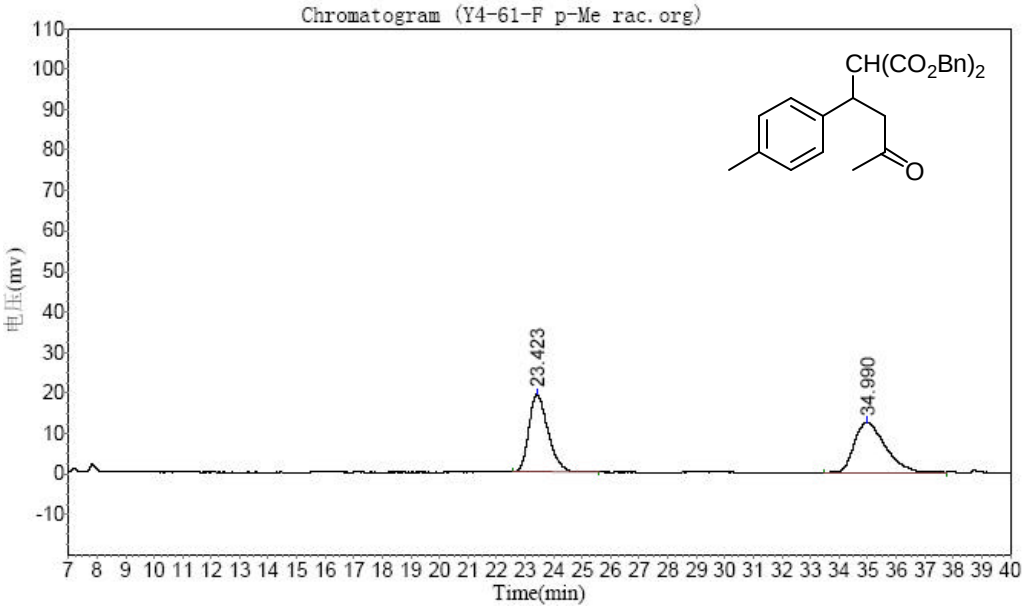
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		29.898	12884.833	802809.438	50.8954
2		47.732	7332.771	774560.688	49.1046
Total			20217.604	1577370.125	100.0000



Results

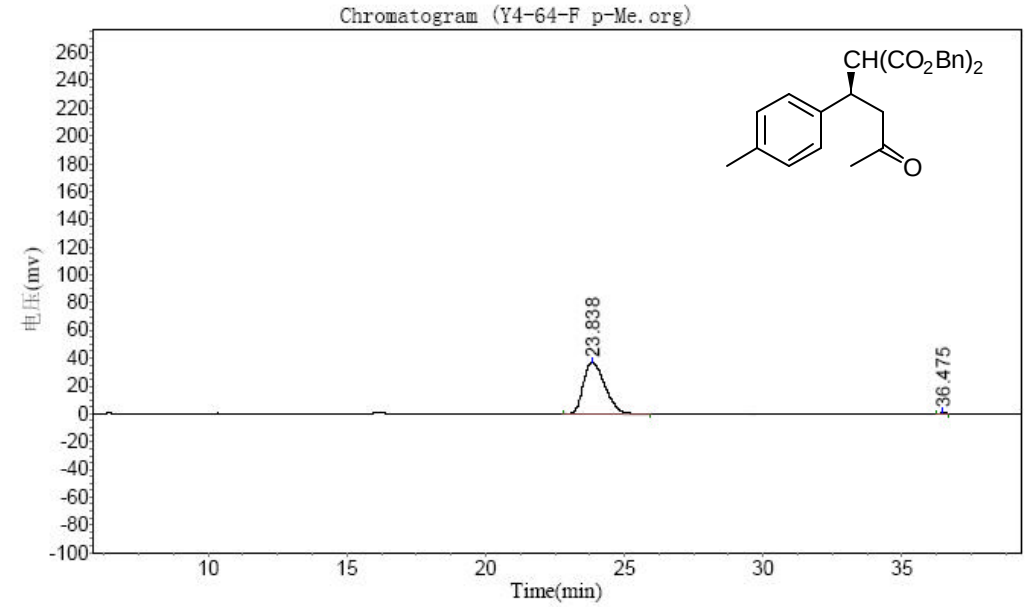
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		30.007	36722.227	2253035.500	99.6931
2		49.032	121.160	6936.849	0.3069
Total			36843.387	2259972.349	100.0000

HPLC spectra for compound **4eh**



Results

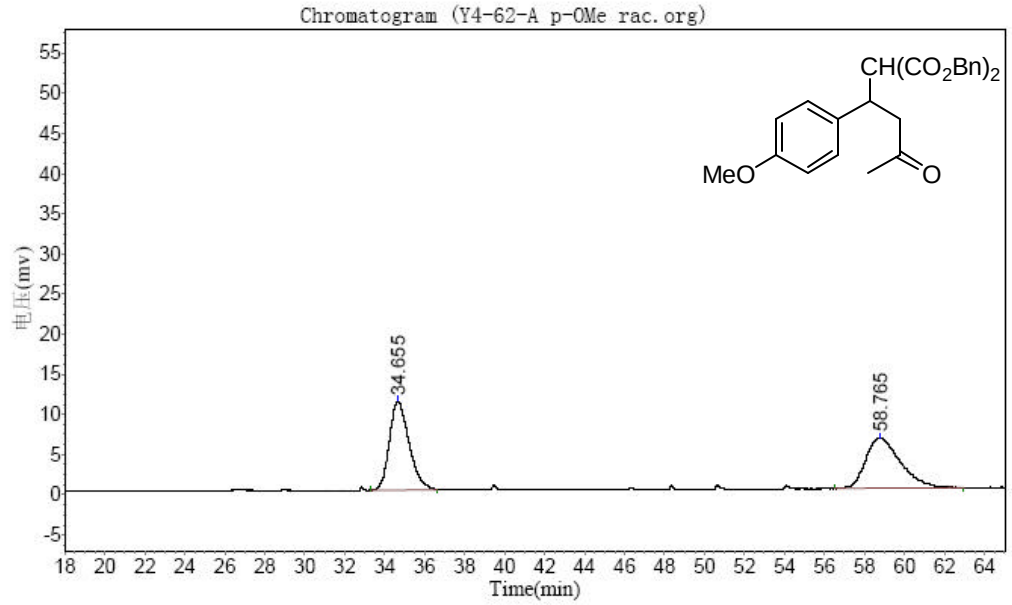
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		23.423	19263.465	905969.313	49.2120
2		34.990	12338.127	934984.250	50.7880
Total			31601.592	1840953.563	100.0000



Results

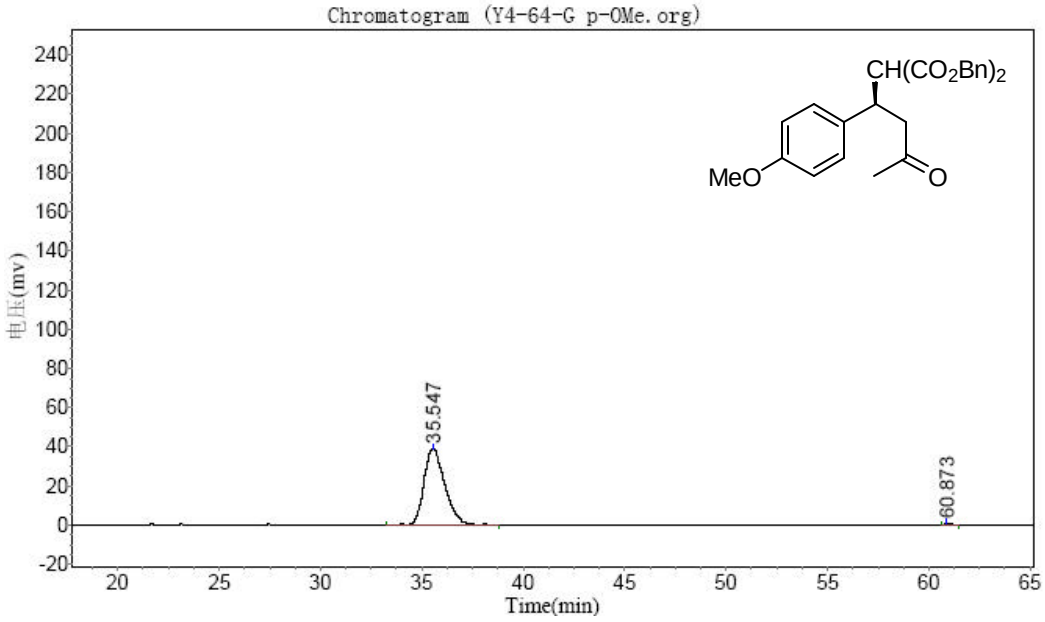
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		23.838	36614.727	2021049.125	99.7360
2		36.475	566.317	5349.400	0.2640
Total			37181.043	2026398.525	100.0000

HPLC spectra for compound **4ei**



Results

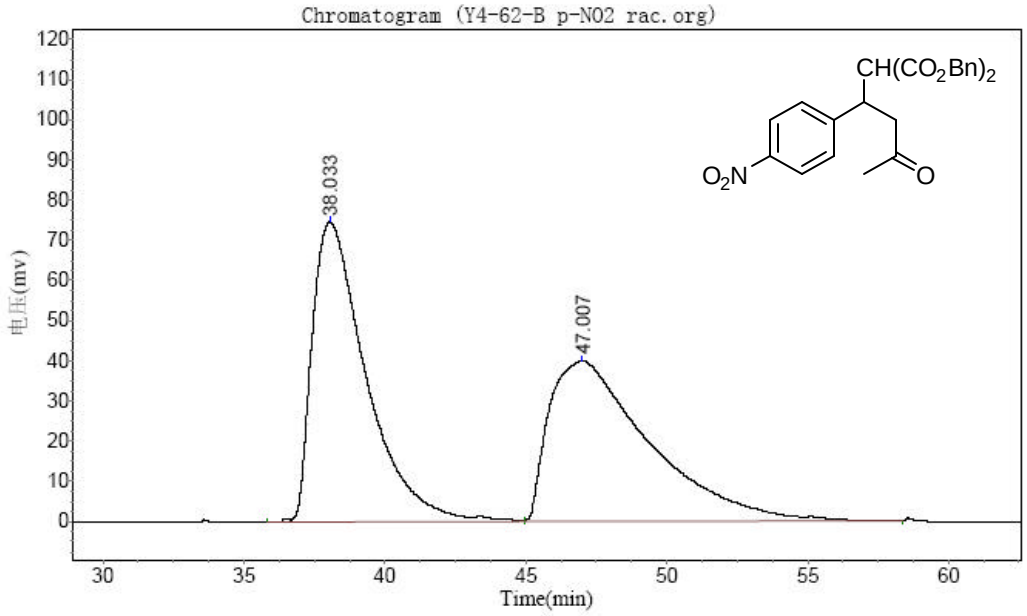
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		34.655	10996.101	755356.375	49.8759
2		58.765	6264.052	759116.500	50.1241
Total			17260.152	1514472.875	100.0000



Results

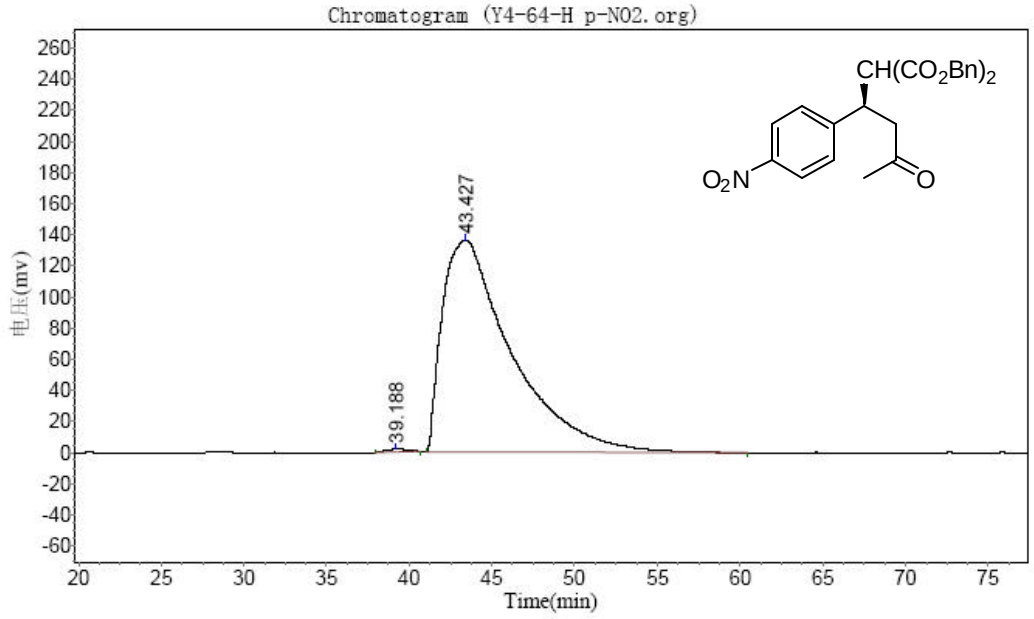
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		35.547	39178.848	2854415.000	99.9165
2		60.873	74.240	2383.950	0.0834
Total			39253.087	2856798.950	100.0000

HPLC spectra for compound **4ej**



Results

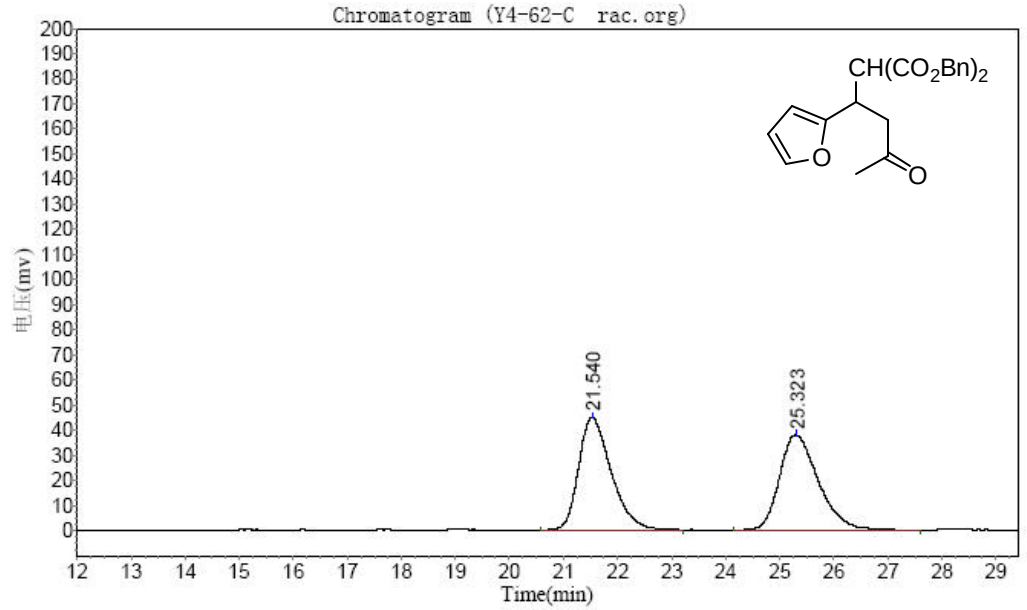
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		38.033	74661.117	9948830.000	50.0652
2		47.007	39918.914	9922903.000	49.9348
Total			114580.031	19871733.000	100.0000



Results

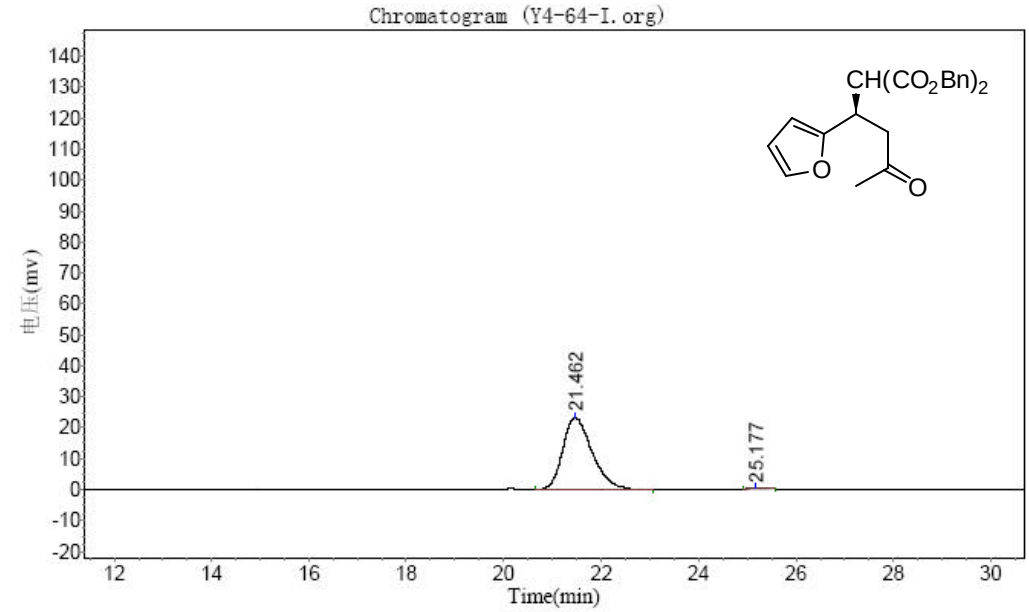
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		39.188	1969.246	177258.844	0.4458
2		43.427	136408.156	39586828.000	99.5542
Total			138377.402	39764086.844	100.0000

HPLC spectra for compound **4ek**



Results

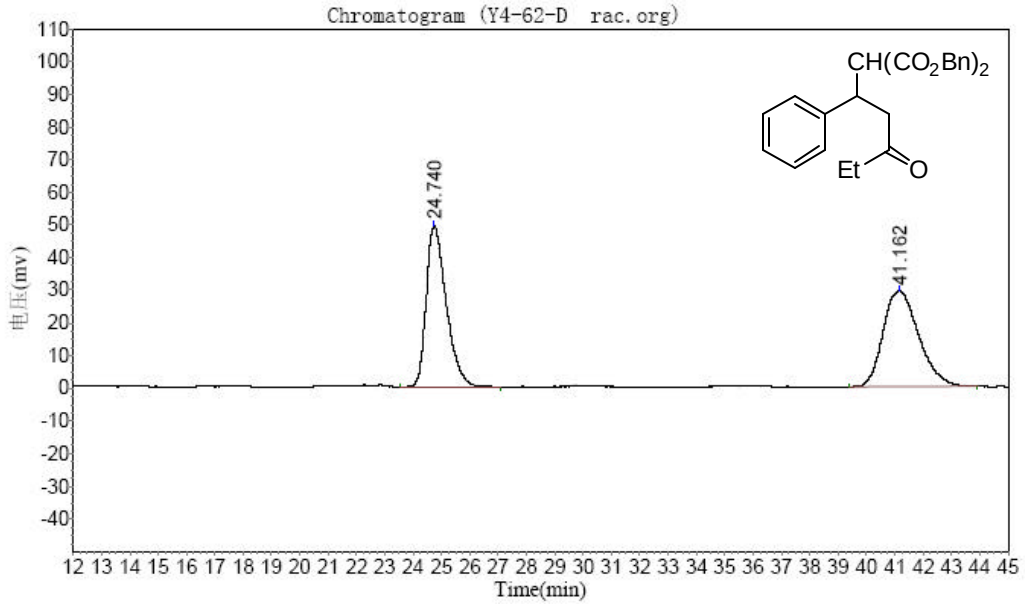
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		21.540	44728.180	1868051.625	49.8852
2		25.323	37891.691	1876650.875	50.1148
Total			82619.871	3744702.500	100.0000



Results

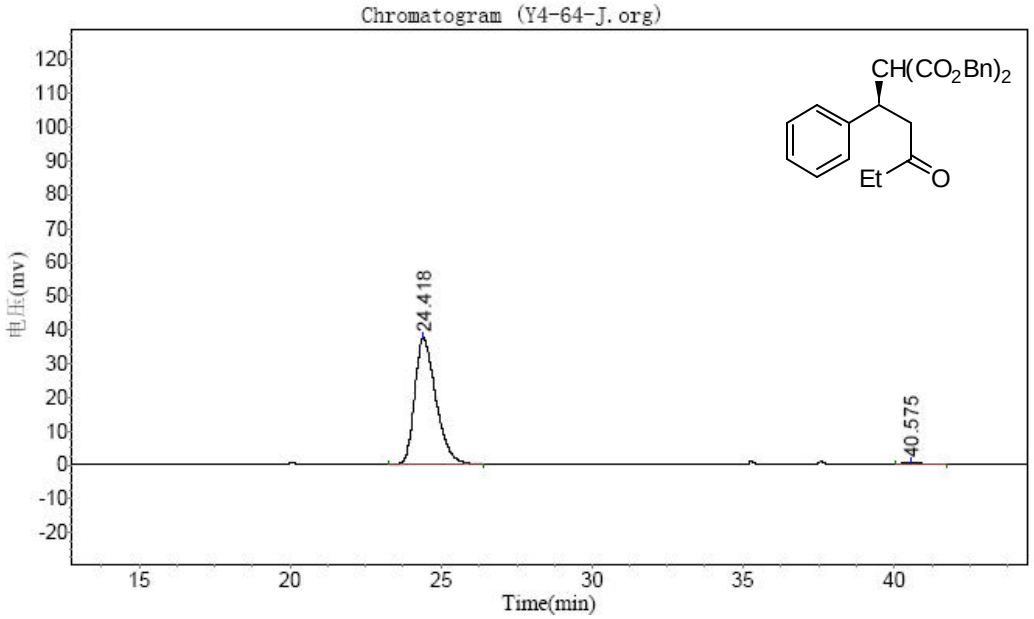
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		21.462	23288.359	970952.438	99.4465
2		25.177	223.382	5404.400	0.5535
Total			23511.742	976356.837	100.0000

HPLC spectra for compound **4el**



Results

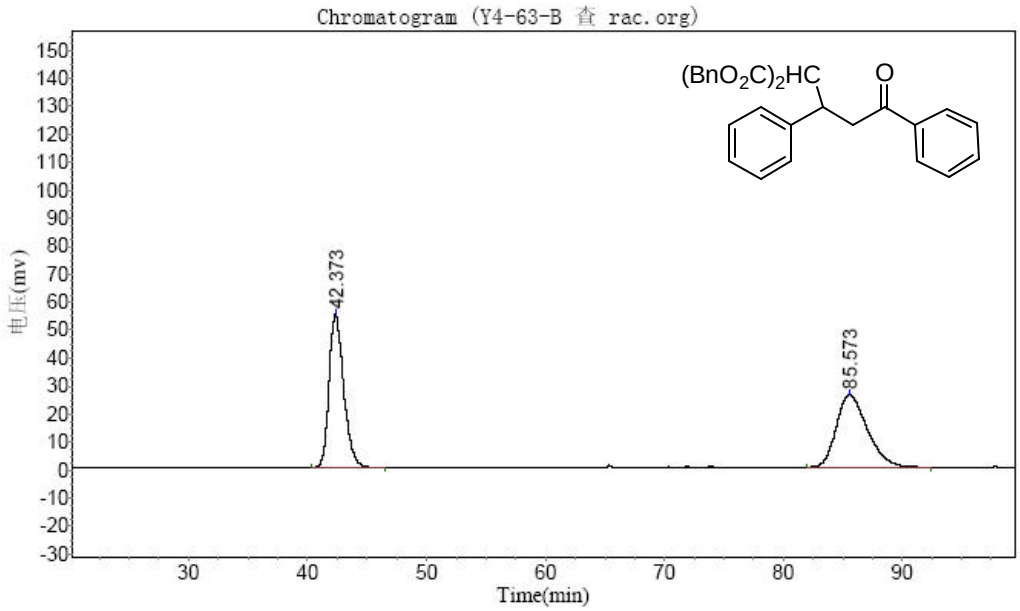
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		24.740	49303.113	2416972.750	48.4954
2		41.162	29237.162	2566946.500	51.5046
Total			78540.275	4983919.250	100.0000



Results

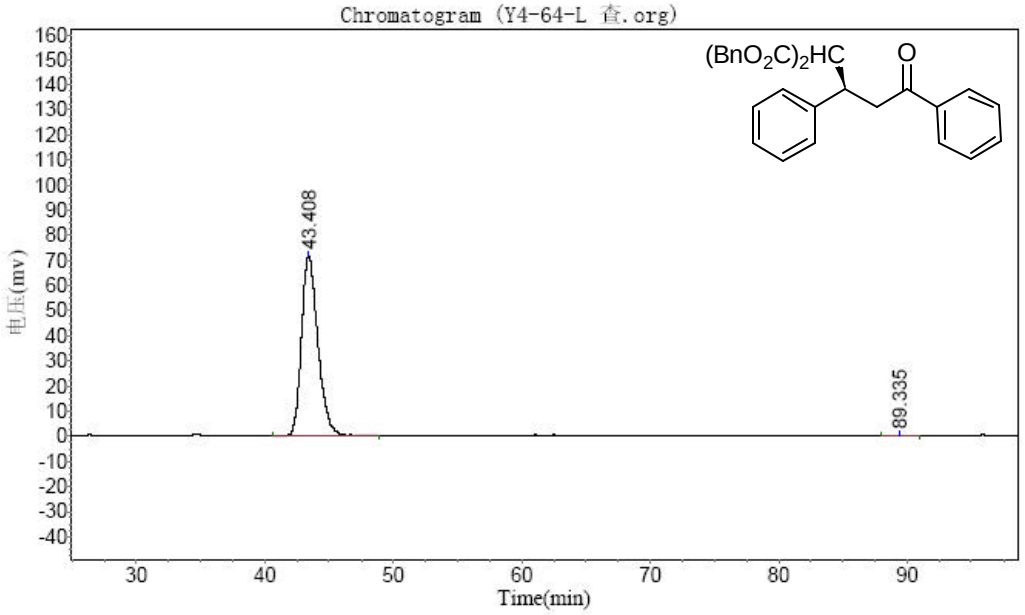
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		24.418	37281.668	1806331.625	99.5054
2		40.575	161.320	8978.604	0.4946
Total			37442.988	1815310.229	100.0000

HPLC spectra for compound **4em**



Results

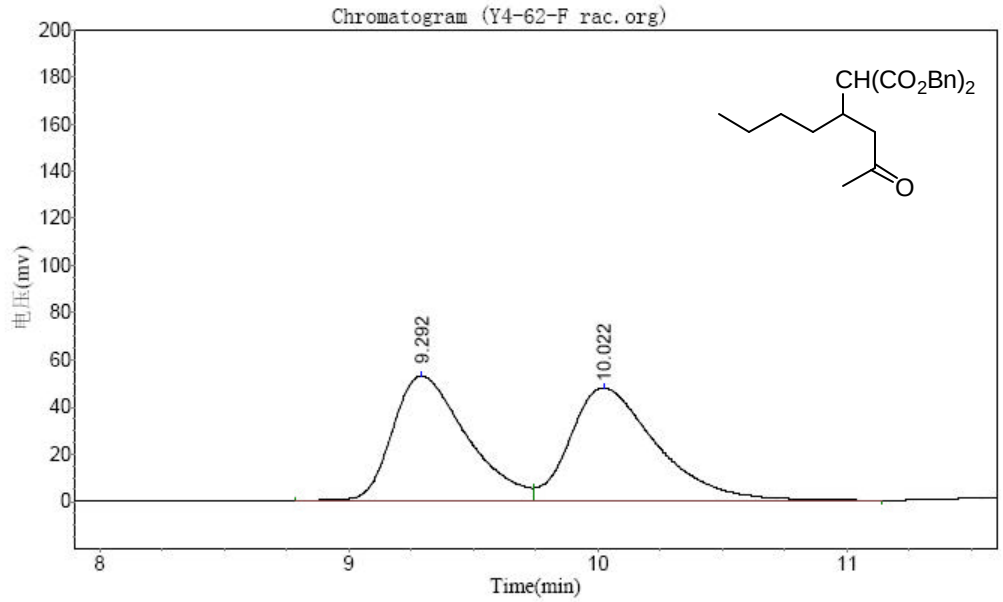
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		42.373	54598.988	4673873.500	49.6945
2		85.573	25924.840	4731344.500	50.3055
Total			80523.828	9405218.000	100.0000



Results

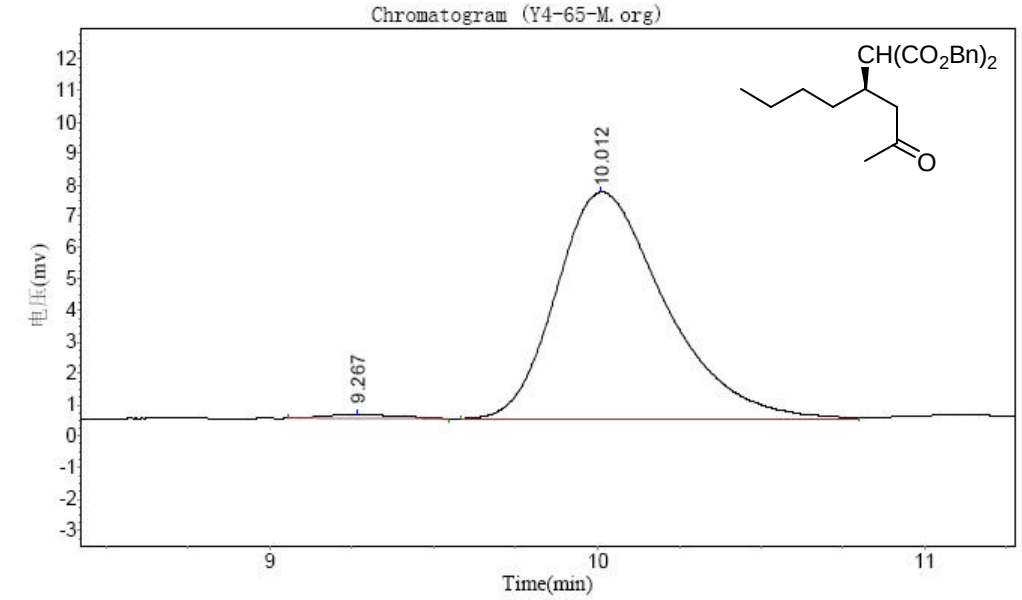
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		43.408	71452.352	6306455.500	99.8190
2		89.335	122.231	11432.351	0.1810
Total			71574.582	6317887.851	100.0000

HPLC spectra for compound **4en**



Results

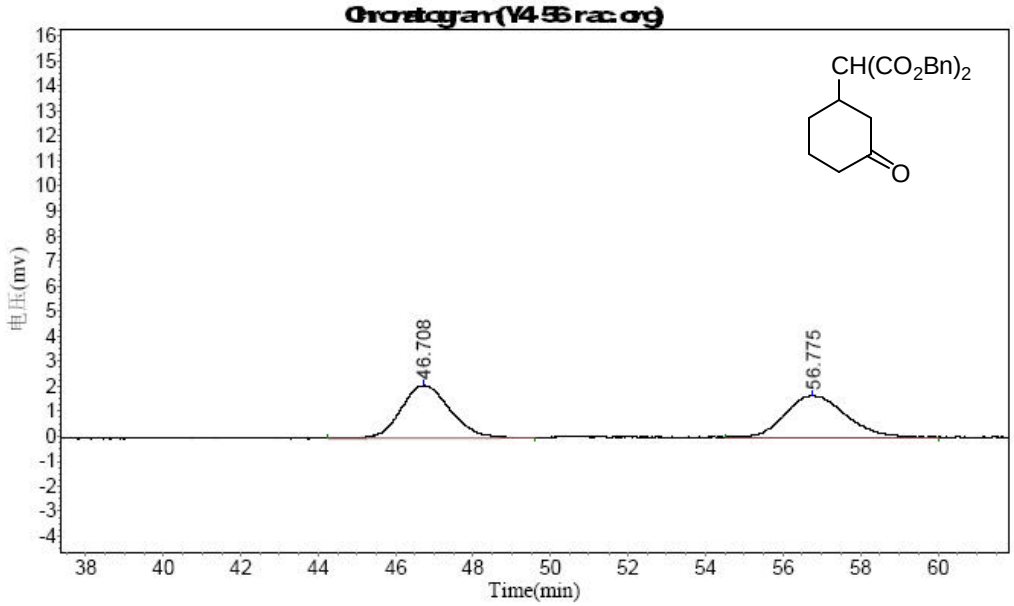
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		9.292	52589.023	1079342.250	48.7096
2		10.022	47638.102	1136528.625	51.2904
Total			100227.125	2215870.875	100.0000



Results

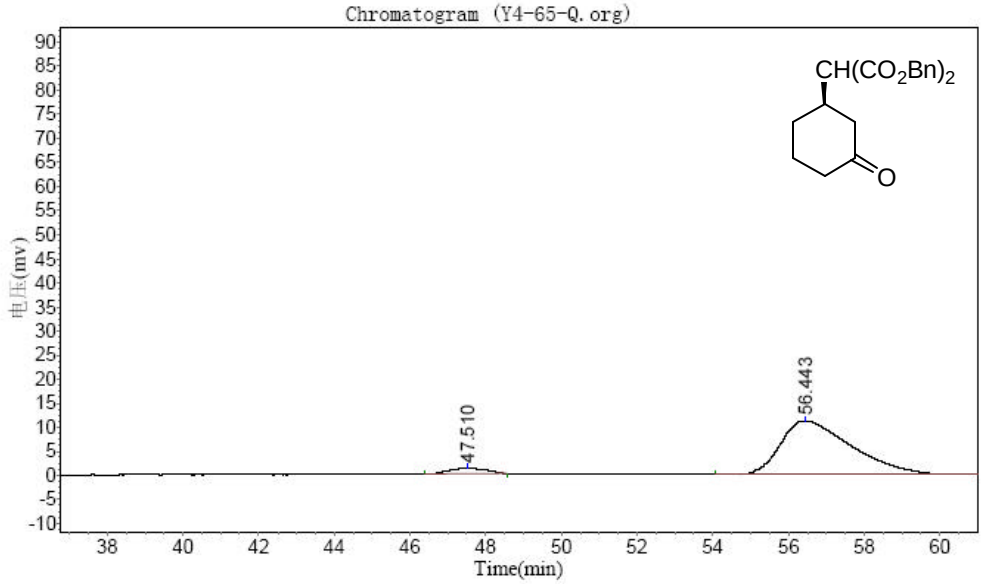
Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		9.267	124.459	2087.701	1.2324
2		10.012	7213.943	167318.844	98.7676
Total			7338.403	169406.544	100.0000

HPLC spectra for compound **4eo**



Results

Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		46.708	2122.032	188054.563	49.8466
2		56.775	1706.475	189211.672	50.1534
Total			3828.507	377266.234	100.0000



Results

Peak No.	Peak ID	Ret Time	Height	Area	Conc.
1		47.510	1112.948	76518.453	4.9893
2		56.443	11140.774	1457132.250	95.0107
Total			12253.722	1533650.703	100.0000