Supporting Information

Asymmetric Synthesis of Functionalized Cyclopentanones via a Multicatalytic Secondary Amine/*N*-Heterocyclic Carbene Cascade Sequence

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Table of Contents:

Materials and Methods

All reactions were carried out under an atmosphere of argon with magnetic stirring. HPLC grade Chloroform preserved with pentane was purchased from Fisher Scientific. Column chromatography was performed on SiliCycle®Silica*Flash*® P60, 40-63μm 60A. Thin layer chromatography was performed on SiliCycle® 250μm 60A plates. Visualization was accomplished with UV light or cerium ammonium molybdenate stain followed by heating.

^{1}H NMR spectra were recorded on Varian 300 or 400 MHz spectrometers at ambient temperature unless otherwise stated. Data is reported as follows: chemical shift in parts per million (δ, ppm) from $CDCl_3$ (7.26 ppm), toluene-d_8 (7.09, 7.0, 6.98, 2.09 ppm) or benzene-d_6 (7.16 ppm) multiplicity (s = singlet, bs = broad singlet, d = doublet, t = triplet, q = quartet, and m = multiplet), coupling constants (Hz). ^{13}C NMR was recorded on Varian 300 or 400 MHz spectrometers (at 75 or 100 MHz) at ambient temperature. Chemical shifts are reported in ppm from $CDCl_3$ (77.2 ppm) or toluene-d_8 (137.86 (1), 129.4 (3), 128.33 (3), 125.49 (3), 20.4 (5) ppm).

α,β-Aldehydes and 1,3 dicarbonyls were either purchased from Aldrich or Acros or prepared via literature procedures (**4d**[1], **4e**[2], **4f**[3], **4g**[4], **4h**[5], **8c**[6]). *β*-ketoester **8g** was purchased form Aldrich as the HCl salt. The free base was generated by stirring in saturated $NaHCO_3$ and extraction with ethyl acetate. 3,5-bistrifluoromethyl diphenyl prolinol TMS **5** ether catalyst was prepared according to literature procedure.[7] Pentafluorophenyl triazolium catalyst **6** was prepared according to literature procedure.[8]

General Procedures

General Procedure for Multicatalytic Cascade Michael/Benzoin Reaction:

A 1 dram vial was equipped with a magnetic stir bar under argon and charged with 8.0 mg (0.022 mmol) of triazolium salt **6**. $CHCl_3$ (1 ml), 1,3 dicarbonyl (0.448 mmol), and enal (0.224 mmol) were added sequentially followed by 26.3 mg (0.044 mmol) of siloxy prolinol **5** and 1.8 mg (0.022 mmol) of sodium acetate in one portion. After stirring at ambient temperature for 12 h the reaction was filtered through a 1in plug of silica, eluted with Et_2O (~10 ml) and concentrated *in vacuo*. The resulting crude product was purified by flash silica gel chromatography.

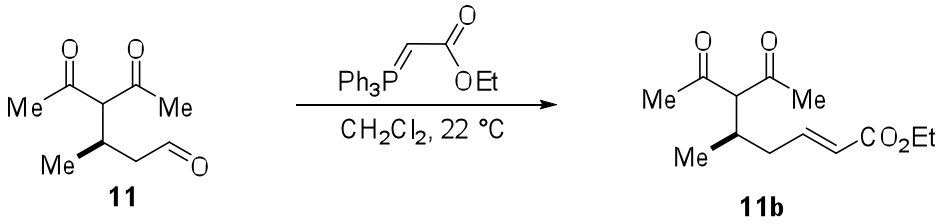
Procedure for preparation of 10a on 2.4 mmol Scale

A 10 ml round bottom flask was equipped with a magnetic stir bar under argon and charged with 44.0 mg (0.12 mmol) of triazolium salt **6**. $CHCl_3$ (5 ml), methyl acetoacetate 520 μl (4.82 mmol), and crotonaldehyde 200 μl (2.41 mmol) were added sequentially followed by 144 mg (0.241 mmol) of siloxy prolinol **5** and 10.0 mg (0.12 mmol) of sodium acetate in one portion. After stirring at ambient temperature for 12 h the reaction was pre-absorbed on silca gel and purified by flash silica gel chromatography (4:1 hexanes/EtOAc, R_f = 0.3 2:1 hexanes/EtOAc). 404 mg of the desired product **10a** was isolated as a separable mixture of diatereomers (90% yield). 64:33:3:<1 dr, 91% ee (major diastereomer).

Procedure for Preparation of Aldehyde 11:

A 1 dram vial was equipped with a magnetic stir bar and placed under an argon atomosphere. $CHCl_3$ (1 ml), acetylacetone 48 µl (0.448 mmol), and crotonaldehdye 19 µl (0.224 mmol) were added sequentially followed by 26.3 mg (0.044 mmol) of siloxy prolinol **5.** After stirring at ambient temperature for 12 h the reaction was filtered through a 1 in plug of silica, eluted with Et_2O (~10 ml) and concentrated *in vacuo*. The resulting crude product was submitted to flash silica gel chromatography (2:1 hexanes/EtOAc, R_f = 0.2, 2:1 hexanes/EtOAc) to afford 27 mg of semi-pure material (~80% pure) in 70% yield. For complete characterization and determination of ee the resultant aldehyde **11** was converted to the α,β-unsaturated ethyl ester via wittig reaction (*vida infra)*.

Procedure for Preparation of α,β-unsaturated Ethyl Ester 11b.



11 **11b**

Aldehyde **11**, 20 mg (0.118 mmol) was dissolved in CH_2Cl_2 (1 ml) and added to a 1 dram vial equipped with magnetic stir bar. (Carbethoxymethylene)-triphenylphosphorane 41 mg (0.118 mmol) was added and the reaction was allowed to stir at ambient temperature. After stirring for 30 minutes the reaction was filtered through a 1 in plug of silica, eluted with Et_2O (~10 ml) and concentrated *in vacuo*. The resulting crude product was purified by flash silica gel chromatography (4:1 hexanes/EtOAc, R_f = 0.4, 2:1 hexanes/EtOAc). 21 mg of desired product **11b** was isolated as a separable mixture of olefin isomers (75% yield) 5:1 *E/Z*, 60% ee (*E*

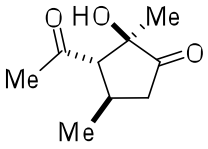
isomer). Chiracel A-DH column 97:3 hexanes/*iso*-propanol, 1.0 ml/min, peaks appear at 11.85 (minor) and 13.00 (major).

Procedure for Preparation of Cyclopentanone 7 from Aldehyde 11

A 1 dram vial was equipped with a magnetic stir bar under argon and charged with 4.3 mg (0.012 mmol) of triazolium salt **6**. $CHCl_3$ (1 ml), aldehyde **11** 20mg (0.118 mmol), were added sequentially followed by sodium acetate 1 mg (0.012 mmol). After stirring at ambient temperature for 12 h the reaction was filtered through a 1in plug of silica, eluted with Et_2O (~10 ml) and concentrated *in vacuo*. The resulting crude product was purified by flash silica gel chromatography (2:1 hexanes/EtOAc, R_f = 0.3 2:1 hexanes/EtOAc). 13 mg of the desired product **7** was isolated as an inseparable mixture of diatereomers (65% yield). 85:15 :<1:<1 dr, 58% ee (major diastereomer). Chiraldex BDM-2 column at 140 °C at 1 mL/min; peaks appear at 8.55 minutes (major) and 8.88 minutes (minor).

Characterization Data for Cyclopentanone Products

Compound 7a: (2*R*,3*S*,4*R*)-3-acetyl-2-hydroxy-2,4-dimethylcyclo-pentanone



Major Diastereomer

Yield: 35mg, 93%, 86% ee (Major) 85:15:<1:<1 dr (Isolated as an inseparable mixture of two diastereomers)

Physical State: white solid, mp = 58-61 °C (from CH_2Cl_2)

R_f: 0.3 (2:1 hex/EtOAc), Purified 2:1 hexanes/EtOAc

$[\alpha]_D^{21}$ = -32.8 (c = 0.010 g/ml, CH_2Cl_2)

GC Analysis: Chiraldex BDM-2 column at 140 °C at 1 mL/min; peaks appear at 8.55 minutes (major) and 8.88 minutes (minor).

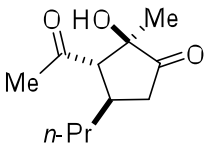
IR: (NaCl, neat) 3447 (br), 2966, 2925, 2873, 1767, 1711, 1362, 1271, 1168, 1132 cm^{-1}

^{1}H NMR: (400 MHz, $CDCl_3$) δ 2.95 (bs, 1H), 2.75 (d, *J* = 11.0 Hz, 1H), 2.66 (dd, *J* = 19.4, 9.2, 1H), 2.55 (m, 1H), 2.26 (s, 1H), 1.90 (dd, *J* = 19.6, 10.0, 1H) 1.03 (d, *J* = 6.2, 3H), 1.01 (s, 3H)

^{13}C NMR: (100 MHz, $CDCl_3$): δ 217.8, 207.4, 80.2, 66.0, 41.3, 32.0, 26.5, 20.3, 19.8

HRMS: (ESI-) calculated for $C_9H_{14}O_3$, 170.0943. Found 170.0941.

Compound 7b: (2*R*,3*S*,4*R*)-3-acetyl-2-hydroxy-2-methyl-4-propylcyclopentanone



Major Diastereomer

Yield: 34.0 mg, 77%, 93% ee (Major) 85:15:<1:<1 dr (Isolated as an inseparable mixture of two diastereomers)

Physical State: colorless oil

R_f: 0.4 (2:1 hex/EtOAc), Purified 3:1 hex/EtOAc

$[\alpha]_D^{21}$ = -42.2 (c = 0.010 g/ml, CH_2Cl_2)

GC Analysis: Chiraldex BDM-2 column at 140 °C at 1 mL/min; peaks appear at 17.07 minutes (major) and 17.96 minutes (minor).

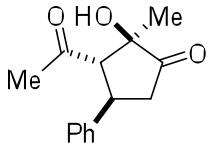
IR: (NaCl, neat) 3457 (br), 2960, 2919, 2863, 1757, 1706, 1373, 1275, 1183, 1137 cm^{-1}

^{1}H NMR: (400 MHz, $CDCl_3$) δ 2.97 (bs, 1H), 2.83 (d, *J* = 11.0 Hz, 1H), 2.69 (dd, *J* = 9.5, 19.4 Hz, 1H), 2.55 (m, 1H), 2.29 (s, 1H), 1.93 (dd, *J* = 9.7, 19.6 Hz, 1H), 1.48 (m, 1H), 1.28 (m, 2H), 1.13 (m, 1H), 1.04 (s, 3H) 0.89 (t, *J* = 7.0 Hz, 3H)

^{13}C NMR: (100 MHz, $CDCl_3$): δ 217.7, 207.5, 80.0, 64.6, 39.4, 37.8, 32.1, 31.4, 21.3, 20.5, 14.3

HRMS: (ESI+) Calculated for $C_{11}H_{18}O_3$, 198.1256. Found 198.1258.

Compound 7c: (2*R*,3*S*,4*R*)-3-acetyl-2-hydroxy-2-methyl-4-phenylcyclopentanone



Major Diastereomer

Yield: 31.0 mg, 60%, 85% ee (Major) 80:20:<1:<1 dr (Isolated as an inseparable mixture of two diastereomers)

Physical State: off white solid, mp = 90-92 °C (from CH_2Cl_2)

R_f: 0.37 (2:1 hex/EtOAc), Purified 3:1 hex/EtOAc

$[\alpha]_D^{21}$ = +4.5 (c = 0.010 g/ml, CH_2Cl_2)

GC Analysis: Chiraldex BDM-1 column at 170 °C at 2 mL/min; peaks appear at 14.47 minutes (major) and 14.95 minutes (minor).

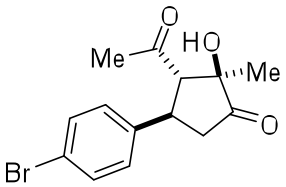
IR: (NaCl, neat) 3226 (br), 3021, 2914, 2848, 1751, 1711, 1367, 1270, 1168 cm^{-1}

^{1}H NMR: (400 MHz, $CDCl_3$) δ 7.28 (m, 5H), 3.75 (ddd, *J* = 20.0, 11.5, 9.3 Hz, 1H), 3.38 (d, *J* = 11.5 Hz, 1H), 2.98 (dd, *J* = 20.1, 9.5 Hz, 1H), 2.48 (dd, *J* = 20.1, 10.6 Hz, 1H), 2.20 (s, 3H), 1.17 (s, 3H)

^{13}C NMR: (100 MHz, $CDCl_3$): δ 216.6, 206.3, 141.6, 129.0, 127.6, 127.3, 80.3, 65.6, 41.6, 37.2, 32.0, 20.5

HRMS: (ESI+) Calculated for $C_{14}H_{16}O_3$, 232.1099. Found 232.11.

Compound 7d: (2*R*,3*S*,4*R*)-3-acetyl-4-(4-bromophenyl)-2-hydroxy-2-methylcyclo-pentanone



Major Diastereomer

Yield: 49.0 mg, 70%, 80% ee (Major) 85:15:<1:<1 (Isolated as an inseparable mixture of two diastereomers)

Physical State: white solid, mp = 128-130 °C (from CH_2Cl_2)

R_f: 0.3 (2:1 hex/EtOAc), Purified 3:1 hex/EtOAc

$[\alpha]_D^{21}$ = -5.9 (c = 0.010 g/ml, CH_2Cl_2)

HPLC Analysis: Chiracel O-DH column 90:10 hexanes/*iso*-propanol, 1.0 mL/min; peaks appear at 10.25 minutes (minor) and 15.98 minutes (major).

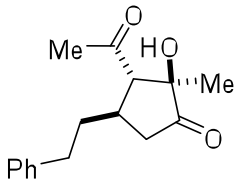
IR: (NaCl, neat) 3442 (br), 2960, 2924, 2863, 1751, 1701, 1491, 1368, 1178, 1137 cm^{-1}

^{1}H NMR: (400 MHz, $CDCl_3$) δ 7.36 (d, *J* = 8.5 Hz, 2H), 7.06 (d, *J* = 8.5 Hz, 2H) 3.64 (ddd, *J* = 10.4, 10.4, 10.4 Hz, 1H), 3.23 (d, *J* = 11.7 Hz, 1H), 2.88 (dd, *J* = 20.0, 9.6 Hz, 1H) 2.35 (dd, *J* = 20.2, 10.6 Hz, 1H) 2.12 (s, 3H), 1.07 (s, 3H)

^{13}C NMR: (100 MHz, $CDCl_3$): δ 216.1, 206.0, 140.7, 132.2, 129.4, 121.2, 80.2, 65.7, 41.4, 36.7, 31.9, 20.5

HRMS: (ESI-) Calculated for $C_{14}H_{15}BrO_3$, 370.0416. Found 370.0423.

Compound 7e: (2*R*,3*S*,4*R*)-3-acetyl-2-hydroxy-2-methyl-4-phenethylcyclopentanone



Major Diastereomer

Yield: 34.0 mg, 59%, 95% ee 80:20:<1:<1 dr (Major) (Isolated as an inseparable mixture of two diastereomers)

Physical State: colorless oil

R_f: 0.3 (2:1 hex/EtOAc), Purified 4:1 hex/EtOAc

$[\alpha]_D^{21}$ = -14.2 (c = 0.010 g/ml, CH_2Cl_2)

GC Analysis: Chiraldex BDM-1 column at 170 °C at 2 mL/min; peaks appear at 34.26 minutes (major) and 36.08 minutes (minor).

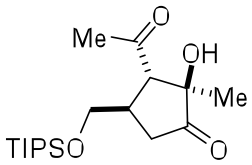
IR: (NaCl, neat) 3431 (br), 3057, 3016, 2929, 2853, 1757, 1706, 1460, 1362 cm^{-1}

^{1}H NMR: (400 MHz, $CDCl_3$) δ 7.20 (m, 5H), 2.84 (d, *J* = 11.0 Hz, 1H), 2.69 (dd, *J* = 19.4, 9.2 Hz, 1H), 2.59 (m, 3H), 2.26 (s, 3H), 1.97 (dd, *J* = 19.6, 9.6 Hz, 1H), 1.88, (1H, m), 1.43 (1H, m)

^{13}C NMR: (100 MHz, $CDCl_3$): δ 217.1, 207.2, 141.5, 128.7, 128.4, 126.3, 79.8, 64.5, 39.3, 37.1, 34.4, 31.9, 31.4, 20.4

HRMS: (ESI-) Calculated for $C_{16}H_{20}O_3$, 260.14124. Found 260.14119.

Compound 7f: (2*R*,3*S*,4*R*)-3-acetyl-2-hydroxy-2-methyl-4-((triisopropylsilyloxy)-methyl)cyclopentanone



Major Diastereomer

Yield: 48.0 mg, 63%, 92% ee 75:25:<1:<1 dr (Major) (Isolated as an inseparable mixture of two diastereomers)

Physical State: colorless oil

R_f: 0.4 (3:1 hex/EtOAc), Purified 6:1 hex/EtOAc

$[\alpha]_D^{21}$ = -8.2 (c = 0.010 g/ml, CH_2Cl_2)

HPLC Analysis: Chiracel O-DH column 98:2 hexanes/*iso*-propanol, 1.0 mL/min; peaks appear at 7.94 minutes (minor) and 9.90 minutes (major).

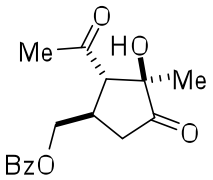
IR: (NaCl, neat) 3421 (br), 2934, 2920, 2863, 1757, 1711, 1450, 1383, 1122, 1096 cm^{-1}

^{1}H NMR: (400 MHz, $CDCl_3$) δ 3.66 (ddd, *J* = 17.0, 10.2, 3.8 Hz, 2H), 3.17 (d, *J* = 10.7 Hz, 1H), 2.7 (m, 1H), 2.52 (dd, *J* = 19.6, 9.2 Hz, 1H), 2.38 (dd, *J* = 19.8, 9.8 Hz, 1H), 2.27 (s, 3H), 1.05 (s, 1H), 1.0 (m, 21H)

^{13}C NMR: (100 MHz, $CDCl_3$): δ 217.2, 207.5, 80.1, 63.1, 59.5, 35.3, 33.9, 31.6, 20.5, 18.1, 12.0

HRMS: (ESI+) Calculated for $C_{18}H_{34}O_4Si$, 342.2229. Found 342.2227.

Compound 7g: ((1*R*,2*S*,3*R*)-2-acetyl-3-hydroxy-3-methyl-4-oxocyclopentyl)methyl benzoate



Major Diastereomer

Yield: 47.0 mg, 72%, 95% ee (Major) 80:20:<1:<1 (Isolated as an inseparable mixture of two diastereomers)

Physical State: off white solid mp = 119-121 °C (from CH_2Cl_2)

R_f: 0.2 (2:1 hex/EtOAc), Purified 2:1 hex/EtOAc

$[\alpha]_D^{21}$ = -9.2 (c = 0.010 g/ml, CH_2Cl_2)

HPLC Analysis: Chiracel O-DH column 90:10 hexanes/*iso*-propanol, 1.0 mL/min; peaks appear at 14.39 minutes (minor) and 15.82 minutes (major).

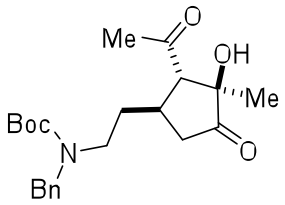
IR: (NaCl, neat) 3457 (br), 3058, 2955, 2924, 2899, 1752, 1701, 1372, 1291, 1127 cm^{-1}

^{1}H NMR: (400 MHz, $CDCl_3$) δ 7.95 (d, *J* = 7.7 Hz, 1H), 7.55 (t, *J* = 7.5 Hz, 1H), 7.42 (t, *J* = 8.1 Hz, 1H), 4.35 (dd, *J* = 11.1, 4.7 Hz, 1H), 4.25 (dd, *J* = 11.1, 4.5 Hz, 1H) 3.06 (m, 1H), 3.05 (d, *J* = 6.6 Hz, 1H), 2.72 (dd, *J* = 19.8, 8.5 Hz, 1H), 2.29 (s, 3H), 2.27 (dd, *J* = 19.8, 8.0 Hz, 1H), 1.08 (s, 3H)

^{13}C NMR: (100 MHz, $CDCl_3$): δ 215.9, 206.5, 166.6, 133.5, 129.8, 128.7, 79.9, 65.6, 60.5, 35.9, 31.1, 20.4

HRMS: (ESI+) Calculated for $C_{16}H_{18}O_5$, 290.1154. Found 290.1157.

Compound 7h: *tert*-butyl 2-((1*R*,2*S*,3*R*)-2-acetyl-3-hydroxy-3-methyl-4-oxocyclopentyl)ethyl(benzyl)carbamate



Major Diastereomer

Yield: 52.0 mg, 60%, 90% ee (Major) 85:15:<1:<1 (Isolated as an inseparable mixture of two diastereomers)

Physical State: yellow oil

R_f: 0.2 (2:1 hex/EtOAc), Purified 2:1 hex/EtOAc

$[\alpha]_D^{21}$ = -26.7 (c = 0.010 g/ml, CH_2Cl_2)

HPLC Analysis: Chiracel OD-H column 95:5 hexanes/*iso*-propanol, 1.0 mL/min; peaks appear at 14.96 minutes (minor) and 19.80 minutes (major).

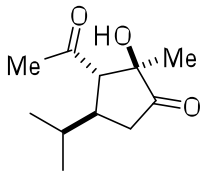
IR: (NaCl, neat) 3441 (br), 2960, 2924, 2863, 1751, 1701, 1491, 1367, 1280, 1178 cm^{-1}

^{1}H NMR: (300 MHz, 95 °C, toluene-d_8) δ 7.10 (m, 5H), 4.30 (q, *J* = 23.8, 15.5 Hz, 2H) 3.03 (m, 2H) 2.43 (d, *J* = 10.6 Hz, 1H) 2.29 (dd, *J* = 18.5, 9.2, 1H) 2.28 (m, 1H) 2.0 (s, 3H) 1.59 (dd, *J* = 19.0, 9.0 Hz, 1H) 1.58 (m, 1H) 1.40 (s, 9H), 1.08 (m, 1H) 0.77 (s, 3H)

^{13}C NMR: (75 MHz, 95 °C, toluene-d_8): δ 214.8 204.8, 155.4, 139.0, 128.3, 128.4, 127.1, 79.2, 79.1, 64.3, 50.6, 45.1, 38.8, 33.5, 30.6, 29.2, 28.2, 22.9

HRMS: (ESI+) Calculated for $C_{22}H_{31}NO_5$, 389.2202. Found 389.2208.

Compound 7i: (2*R*,3*S*,4*S*)-3-acetyl-2-hydroxy-4-isopropyl-2-methylcyclopentanone



Major Diastereomer

Yield: 14.0 mg, 32%, 82% ee (Major) 67:33:<1:<1 dr (Isolated as an inseparable mixture of two diastereomers)

Physical State: colorless oil

R_f: 0.35 (2:1 hex/EtOAc), Purified 3:1 hex/EtOAc.

$[\alpha]_D^{21}$ = -22.8 (c = 0.010 g/ml, CH_2Cl_2)

GC Analysis: Chiraldex BDM-2 column at 140 °C at 1 mL/min; peaks appear at 15.36 minutes (major) and 15.93 minutes (minor).

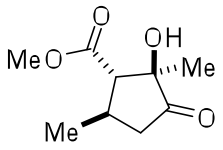
IR: (NaCl, neat) 3442 (br), 2966, 2925, 2873, 1757, 1706, 1372, 1280, 1250, 1193 cm^{-1}

^{1}H NMR: (400 MHz, $CDCl_3$) δ 2.93 (d, *J* = 11.1 Hz, 1H), 2.57 (dd, *J* =19.6, 9.8 Hz, 1H), 2.47 (m, 1H), 2.27 (s, 3H), 2.00 (dd, *J* = 19.6, 9.2 Hz, 1H), 1.55 (m, 1H), 1.01 (s, 3H), 0.82 (d, *J* = 6.8 Hz, 3H), 0.80 (d, *J* = 6.8 Hz, 3H)

^{13}C NMR: (100 MHz, $CDCl_3$): δ 217.5, 207.7, 80.5, 62.0, 38.1, 36.3, 32.0, 23.6, 21.6, 20.8, 19.0

HRMS: (ESI+) Calculated for $C_{11}H_{18}O_3$, 198.1256. Found 198.1259.

Compound 10a: (1*S*,2*R*,5*R*)-methyl 2-hydroxy-2,5-dimethyl-3-oxocyclopentane-carboxylate



Major Diastereomer

Yield: 38.0 mg, 90% yield, 91% ee (Major) 64:33:3:<1 dr (Major diastereomer is separable from other diastereomers).

Physical State: white solid, mp = 79-81 °C (from CH_2Cl_2)

R_f: 0.3 (2:1 hex/EtOAc), Purified 4:1 hex/EtOAc

$[\alpha]_D^{21}$ = -51.1 (c = 0.010 g/ml, CH_2Cl_2)

GC Analysis: Chiraldex BDM-2 column at 140 °C at 2 mL/min; peaks appear at 21.55 minutes (major) and 22.48 minutes (minor).

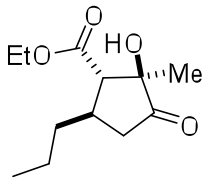
IR: (NaCl, neat) 3431 (br), 2971, 2909, 1746, 1716, 1440, 1363, 1244, 1209, 1163 cm^{-1}

^{1}H NMR: (400 MHz, benzene-d_6) δ 3.21 (s, 3H), 2.59 (bs, 1H), 2.36 (d, *J* = 11.1 Hz, 1H), 2.03 (m, 1H) 1.91 (dd, *J* = 19.8, 8.7 Hz, 1H), 1.25 (dd, *J* = 19.2, 10.4 Hz, 1H), 0.92 (s, 1H) 0.61 (d, *J* = 6.4 Hz, 3H).

^{13}C NMR: (75 MHz, $CDCl_3$): δ 216.8, 172.0, 80.1, 59.4, 52.3, 41.6, 28.4, 20.6, 19.7.

HRMS: (ESI-) Calculated for $C_9H_{14}O_4$, 186.0892. Found 186.0892.

Compound 10b: (1*S*,2*R*,5*R*)-ethyl 2-hydroxy-2-methyl-3-oxo-5-propylcyclopentane-carboxylate



Major Diastereomer

Yield: 41.0 mg, 80%, 93% ee (Major) 60:30:8:2 dr (Major diastereomer is separable from other diastereomers)

Physical State: colorless oil

R_f: 0.3 (2:1 hex/EtOAc) Purified 4:1 hex/EtOAc.

$[\alpha]_D^{21}$ = -55.2 (c = 0.010 g/ml, CH_2Cl_2)

GC Analysis: Chiraldex BDM-2 column at 140 °C at 2 mL/min; peaks appear at 21.55 minutes (major) and 22.48 minutes (minor).

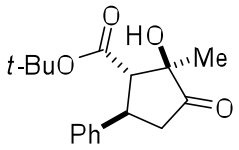
IR: (NaCl, neat) 3421 (br), 2955, 2934, 2873, 1751, 1726, 1654, 1383, 1270, 1188 cm^{-1}

^{1}H NMR: (400 MHz, $CDCl_3$) δ 4.23 (q, *J* = 14.1, 6.4 Hz, 2H) 2.68 (dd, *J* = 19.6, 8.7 Hz, 1H) 2.64 (d, *J* = 11.5 Hz 1H) 2.43 (m, 1H) 1.94 (dd, *J* = 19.6, 10.0 Hz, 1H) 1.58 (m, 1H) 1.4-1.2 (m, 3H) 1.29 (t, *J* = 7.0 Hz, 3H) 1.16 (s, 3H) 0.90 (t, *J* = 7.2 Hz, 3)

^{13}C NMR: (100 MHz, $CDCl_3$): δ 216.7, 171.6, 79.9, 61.2, 58.1, 39.6, 37.6, 33.1, 21.0, 20.7, 14.6, 14.2

HRMS: (ESI+) Calculated for $C_{12}H_{20}O_4$, 228.1362. Found 228.1358.

Compound 10c: (1*S*,2*R*,5*R*)-tert-butyl 2-hydroxy-2-methyl-3-oxo-5-phenylcyclo-pentanecarboxylate



Major Diastereomer

Yield: 56.0 mg, 86%, 97% ee (Major) 60:35:5:<1 dr (Major diastereomer is separable from other diastereomers).

Physical State: white solid, mp = 103-105 °C (from CH_2Cl_2)

R_f: 0.6 (2:1 hex/EtOAc), Purified 5:1 hex/EtOAc

$[\alpha]_D^{21}$ = -112 (c = 0.010 g/ml, CH_2Cl_2)

GC Analysis: Chiraldex BDM-1 column at 170 °C at 3 mL/min; peaks appear at 27.62 minutes (major) and 27.62 minutes (minor).

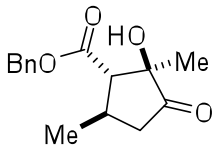
IR: (NaCl, neat) 3439 (br), 3059, 3021, 3005, 2980, 2929, 1751, 1726, 1388, 1210 cm^{-1}

^{1}H NMR: (300 MHz, $CDCl_3$) δ 7.28 (m, 5H), 3.84 (ddd, *J* = 11.5, 11.5, 8.2 Hz, 1H) 3.76 (s, 1H), 3.01 (dd, *J* = 19.2, 8.4 Hz, 1H), 2.81 (d, *J* = 11.5 Hz, 1H), 2.43 (dd, *J* = 19.2, 11.3 Hz, 1H), 1.43 (s, 3H), 1.31 (s, 9H)

^{13}C NMR: (100 MHz, $CDCl_3$): δ 211.8, 171.6, 140.9, 128.9, 127.5, 127.6, 82.6, 59.2, 43.5, 41.7, 28.2, 21.7

HRMS: (ESI+) Calculated for $C_{17}H_{22}O_4$, 290.1518. Found 290.1516.

Compound 10d: (1S,2R,5R)-benzyl 2-hydroxy-2,5-dimethyl-3-oxocyclopentane-carboxylate



Major Diastereomer

Yield: 53.0 mg, 90% yield, 82% ee (Major) 58:39:2:<1 dr (Major diastereomer is separable from other diastereomers).

Physical State: white solid, mp = 49-51 °C (from CH_2Cl_2)

R_f: 0.3 (2:1 hex/EtOAc), Purified 3:1 hex/EtOAc

$[\alpha]_D^{21}$ = -39.5 (c = 0.010 g/ml, CH_2Cl_2)

GC Analysis: Chiraldex BDM-2 column at 180 °C at 3 mL/min; peaks appear at 19.50 minutes (minor) and 20.10 minutes (major).

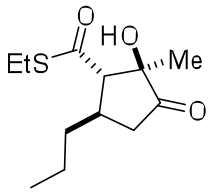
IR: (NaCl, neat) 3459 (br), 2961, 2931, 1752, 1731, 1456, 1383, 1190, 1156, 1084 cm^{-1}

^{1}H NMR: (400 MHz, $CDCl_3$) δ 7.32 (m, 5H), 5.22 (dd, *J* = 15.6, 12.4 Hz, 2H), 2.67 (dd, *J* = 19.6, 8.7 Hz, 1H) 2.66 (d, *J* = 11.3 Hz, 1H), 2.49 (m, 1H), 1.94 (dd, *J* = 19.6, 10.4 Hz, 1H) 1.14 (d, *J* = 6.4 Hz, 3H), 1.10 (s, 1H).

^{13}C NMR: (75 MHz, $CDCl_3$): δ 216.5, 171.3, 135.9, 128.8, 128.5, 128.4, 80.2, 66.9, 59.5, 41.5, 28.4, 20.5, 19.7.

HRMS:

Compound 10e: (1*S*,2*R*,5*R*)-tert-butyl 2-hydroxy-2-methyl-3-oxo-5-phenylcyclopentane-carboxylate



Major Diastereomer

Yield: 31.0 mg, 56%, 81% ee (Major) 69:22:6:3 dr (Major diastereomer is separable from other diastereomers).

Physical State: yellow oil

R_f: 0.5 (2:1 hex/EtOAc), Purified 8:1 hex/EtOAc

$[\alpha]_D^{21}$ = -112 (c = 0.010 g/ml, CH_2Cl_2)

GC Analysis: Chiraldex BDM-2 column at 140 °C at 3 mL/min; peaks appear at 37.19 minutes (major) and 39.13 minutes (minor).

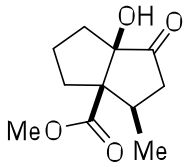
IR: (NaCl, neat) 3462(br), 2955, 2928, 2866, 1752, 1679, 1454, 1365, 1128, 1074 cm^{-1}

^{1}H NMR: (300 MHz, $CDCl_3$) δ 2.93 (q, *J* = 7.7 Hz, 2H) 2.87 (d, *J* = 11.1 Hz, 1H) 2.68 (dd, *J* = 19.6, 9.2 Hz, 1H) 2.57 (m, 1H) 1.94 (dd, *J* = 19.6, 10.0 Hz, 1H) 1.52 (m, 1H) 1.28 (m, 3H) 1.27 (t, *J* = 7.5 Hz, 3H) 1.13 (s, 3H) 0.88 (t, *J* = 7.0 Hz, 3H)

^{13}C NMR: (100 MHz, $CDCl_3$): δ 216.6, 197.9, 80.2, 66.2, 39.7, 37.4, 33.1, 23.9, 21.1, 20.4, 14.8, 14.2

HRMS: (ESI+) Calculated for $C_{12}H_{20}O_3S$, 244.1133. Found 244.1136.

Compound 10f: (3*R*,3a*R*,6a*R*)-methyl 6a-hydroxy-3-methyl-1-oxooctahydropentalene-3a-carboxylate



Major Diastereomer

Yield: 38.0 mg, 79%, 94% ee (Major) 4:1 dr (Major diastereomer is separable from other diastereomers).

Physical State: colorless oil

R_f: 0.2 (2:1 hex/EtOAc), Purified 2:1 hex/EtOAc

$[\alpha]_D^{21}$ = -18.4 (c = 0.010 g/ml, CH_2Cl_2)

GC Analysis: Chiraldex BDM-2 column at 140 °C at 3 mL/min; peaks appear at 12.61 minutes (minor) and 13.11 minutes (major).

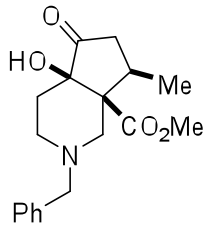
IR: (NaCl, neat) 3468 (br), 2965, 2873, 1739, 1710, 1448, 1258, 1156, 1042 cm^{-1}

^{1}H NMR: (300 MHz, $CDCl_3$) δ 2.64 (s, 3H) 2.63 (dd, *J* = 18.9, 8.7 Hz, 1H) 2.38 (m, 1H) 2.19 (dd, *J* = 19, 10.9 Hz, 1H) 2.11-1.7 (m, 6H) 1.00 (d, *J* = 5.1 Hz, 3H)

^{13}C NMR: (100 MHz, $CDCl_3$): δ 216.0, 173.0, 91.3, 67.9, 51.9, 40.9, 36.2, 34.4, 30.8, 22.6, 15.4

HRMS: (ESI+) Calculated for $C_{11}H_{16}O_4$, 212.1049. Found 212.1048.

Compound 10g: (4a*R*,7*R*,7a*S*)-methyl 2-benzyl-4a-hydroxy-7-methyl-5-oxooctahydro-1H-cyclopenta[c]pyridine-7a-carboxylate



Major Diastereomer

Yield: 54.0 mg, 76%, 90% ee (Major) 5:1 (Major diastereomer is separable from other diastereomers).

Physical State: colorless oil

R_f: 0.3 (2:1 hex/EtOAc), Purified 3:1 hex/EtOAc

$[\alpha]_D^{21}$ = -10.8 (c = 0.010 g/ml, CH_2Cl_2)

HPLC Analysis: Chiracel O-DH column 95:5 hexanes/*iso*-propanol, 1.0 mL/min; peaks appear at 16.66 minutes (major) and 20.35 minutes (major).

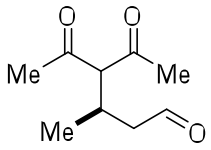
IR: (NaCl, neat) 3252 (br), 3021, 2961, 2815, 2768, 1758, 1736, 1451, 1258, 1229 cm^{-1}

^{1}H NMR: (400 MHz, $CDCl_3$) δ 7.28 (m, 5H), 3.61 (s, 3H) 3.56 (dd, *J* = 18.1, 13.2 Hz, 2H) 3.07 (ddq, *J* = 7.3, 6.2, 7.0, 10.2, 6.8 Hz, 1H) 2.96 (d, *J* = 12.4 Hz, 1H) 2.69 (ddd, *J* = 9.6, 2.6, 2.6 Hz, 1H) 2.65 (dd, *J* = 19.4, 9.8 Hz, 1H) 2.38 (d, *J* = 12.4, 1H) 2.43 (ddd, *J* = 11.9, 11.9, 2.8 Hz, 1H) 2.15 (dd, *J* = 19.4, 9.8 Hz, 1H) 1.84 (ddd, *J* = 12.8, 12.8, 4.9 Hz, 1H) 1.43 (ddd, *J* = 14.1, 14.1, 2.6 Hz, 1H) 0.90 (d, *J* = 7.0 Hz, 3H)

^{13}C NMR: (100 MHz, $CDCl_3$): δ 215.8, 173.1, 138.7, 128.8, 128.5, 127.3, 79.2, 62.7, 57.7, 51.7, 50.7, 48.4, 39.3, 31.9, 29.3, 15.4

HRMS: (ESI+) Calculated for$C_{18}H_{23}NO_4$, 317.1627. Found 317.1625.

Compound 11: (*R*)-4-acetyl-3-methyl-5-oxohexanal



Yield: 27.0 mg, 70%, 60% ee as determined by conversion to **11b** *vida infra*

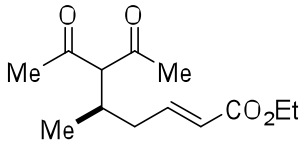
Physical State: colorless oil

R_f: 0.2 (2:1 hex/EtOAc), Purified 2:1 hex/EtOAc

^{1}H NMR: (400 MHz, $CDCl_3$) δ 9.68 (s, 1H), 3.66 (d, *J* = 9.2 Hz, 1H), 2.88 (m, 1H), 2.38 (m, 1H), 2.26 (m, 1H), 2.17 (s, 6H), 0.94 (d, *J* = 5.1 Hz, 3H)

^{13}C NMR: (100 MHz, $CDCl_3$): δ 204.0, 203.7, 201.0, 74.0, 48.2, 30.4, 29.8, 28.3, 18.2.

Compound 11b: (*R*,*E*)-ethyl 6-acetyl-5-methyl-7-oxooct-2-enoate



Yield: 21.0 mg, 75%, 60% ee (Major olefin isomer).

Physical State: colorless oil

R_f: 0.4 (2:1 hex/EtOAc), Purified 4:1 hex/EtOAc

$[\alpha]_D^{21}$ = -41.3 (c = 0.010 g/ml, CH_2Cl_2)

HPLC Analysis: Chiracel A-DH column 97:3 hexanes/*iso*-propanol, 1.0 mL/min; peaks appear at 11.85 minutes (minor) and 13.00 minutes (minor).

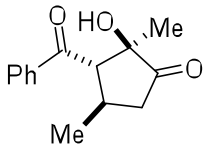
IR: (NaCl, neat) 2977, 2936, 1716, 1698, 1651, 1360, 1268, 1179, 1044 cm^{-1}

^{1}H NMR: (400 MHz, $CDCl_3$) δ 6.81 (ddd, *J* = 15.3, 8.5, 6.6 Hz, 1H), 5.77 (ddd, *J* = 15.6, 1.3, 1.3 Hz, 1H) 4.14 (q, *J* = 14.3, 7.0 Hz, 2H), 3.50, (d, *J* = 10.2 Hz, 1H), 2.53 (m, 1H) 2.16 (m, 1H) 2.13 (s, 3H), 2.12 (s, 1H), 1.97 (m, 1H), 1.24 (t, *J* = 7.0 Hz, 3H), 0.86 (d, *J* = 6.8 Hz).

^{13}C NMR: (100 MHz, $CDCl_3$): δ 204.0, 203.8, 166.3, 145.5, 124.1, 75.3, 60.5, 37.0, 32.0, 30.1, 29.7, 17.3, 14.4

HRMS: (ESI+) Calculated for $C_{13}H_{21}O_4$ 240.1362, Found 240.1363

Compound 13: (2*S*,3*R*,4*S*)-3-benzoyl-2-hydroxy-2,4-dimethylcyclopentanone



Major Diastereomer

Yield: 39.0 mg, 74%, 87% ee (Major) 4:1 Major:Σ Minor (Major diastereomer is separable from other regio- and diastereomers).

Physical State: white solid, mp = 87-90 °C (from CH_2Cl_2)

R_f: 0.5 (2:1 hex/EtOAc), Purified 5:1 hex/EtOAc

$[\alpha]_D^{21}$ = -62.0 (c = 0.010 g/ml, CH_2Cl_2)

GC Analysis: Chiraldex BDM-2 column at 170 °C at 2 mL/min; peaks appear at 19.37 minutes (major) and 20.06 minutes (minor).

IR: (NaCl, neat) 3471 (br), 2961, 2929, 2869, 1751, 1672, 1451, 1368, 1213 cm^{-1}

^{1}H NMR: (400 MHz, $CDCl_3$) δ 8.12 (d, *J* = 7.2 Hz, 2H) 7.57 (t, *J* = 7.6 Hz, 1H) 7.46 (t, *J* = 7.6 Hz, 2H) 3.66 (*d*, J = 10.7 Hz, 1H) 2.84 (m, 1H) 2.76 (dd, *J* = 19.0, 8.7 Hz, 1H) 2.06 (dd, *J* = 19.2, 10.2 Hz, 1H) 1.06 (d, *J* = 6.2 Hz, 3H), 1.05 (s, 3H)

^{13}C NMR: (100 MHz, $CDCl_3$): δ 217.9, 199.2, 138.0 133.7, 129.4, 128.7, 80.8, 61.0, 41.6, 28.2, 20.7, 19.7

HRMS: (ESI+) Calculated for $C_{14}H_{16}O_3$, 232.1099. Found 232.1096.

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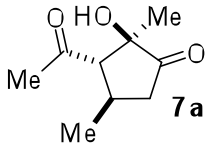
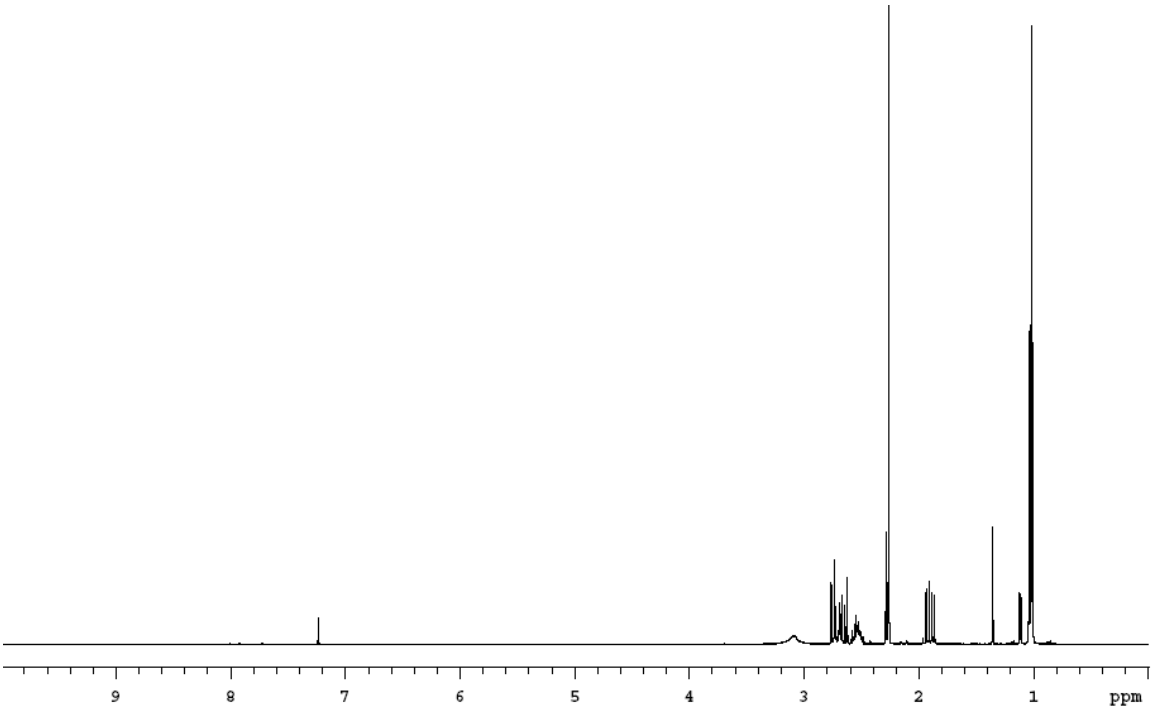
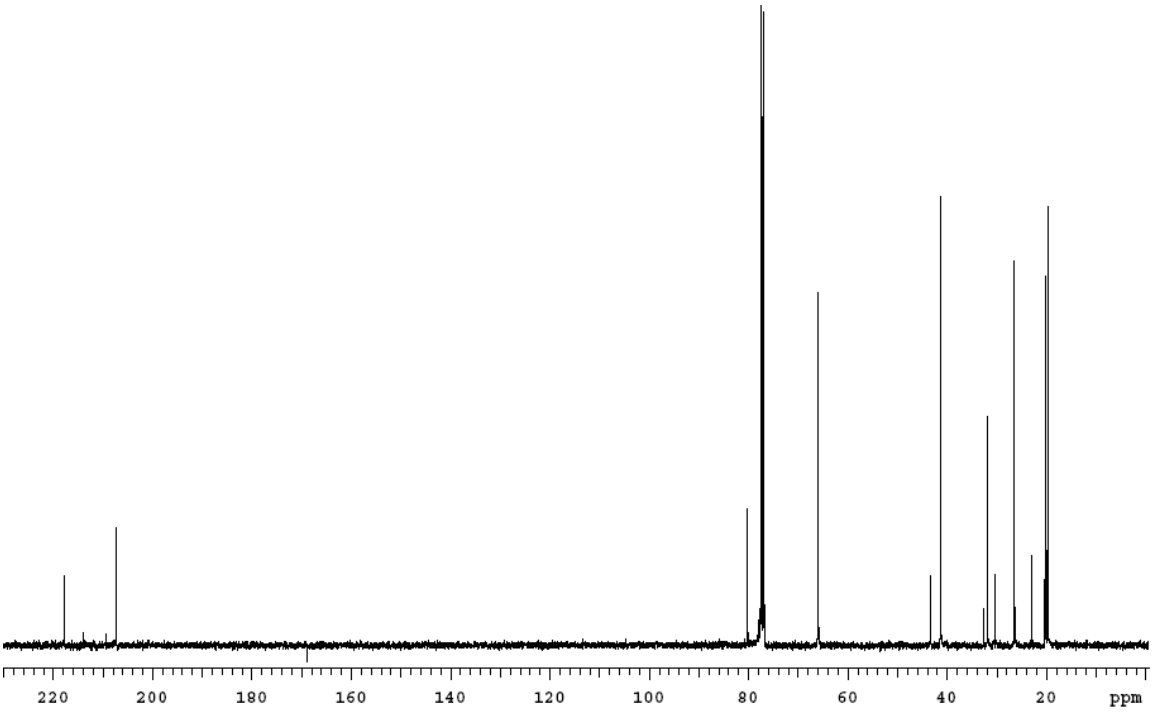
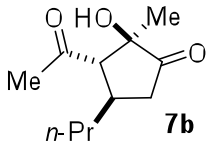


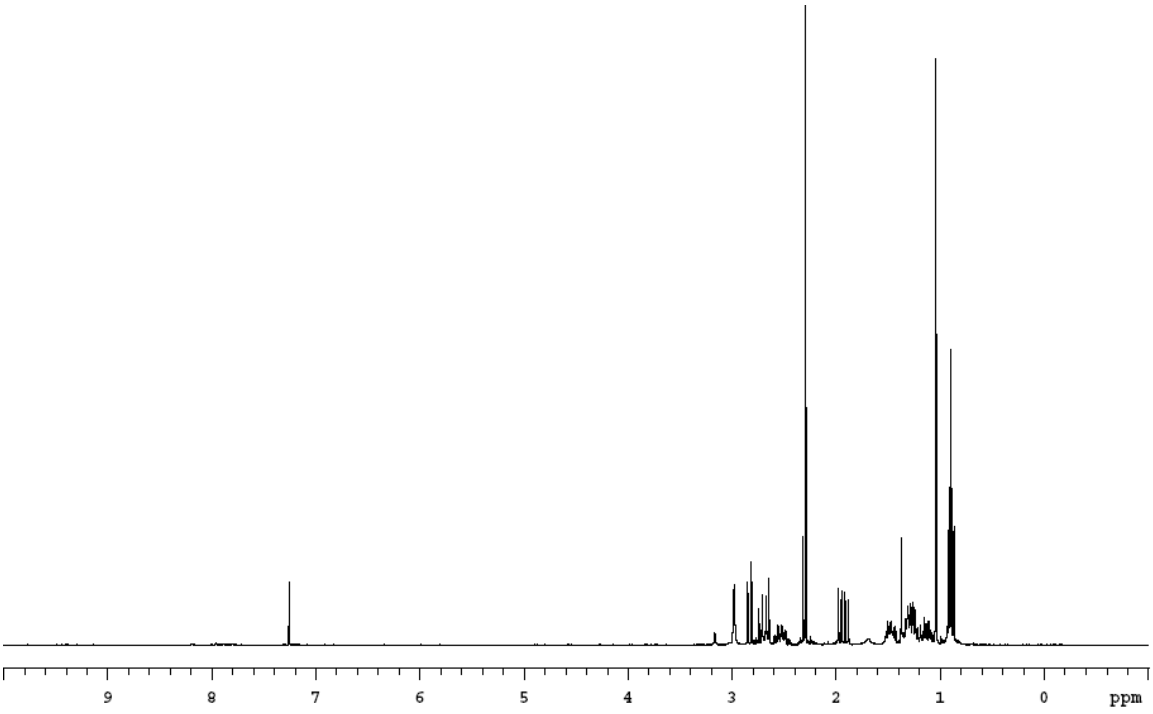
7a mixture of diastereomers

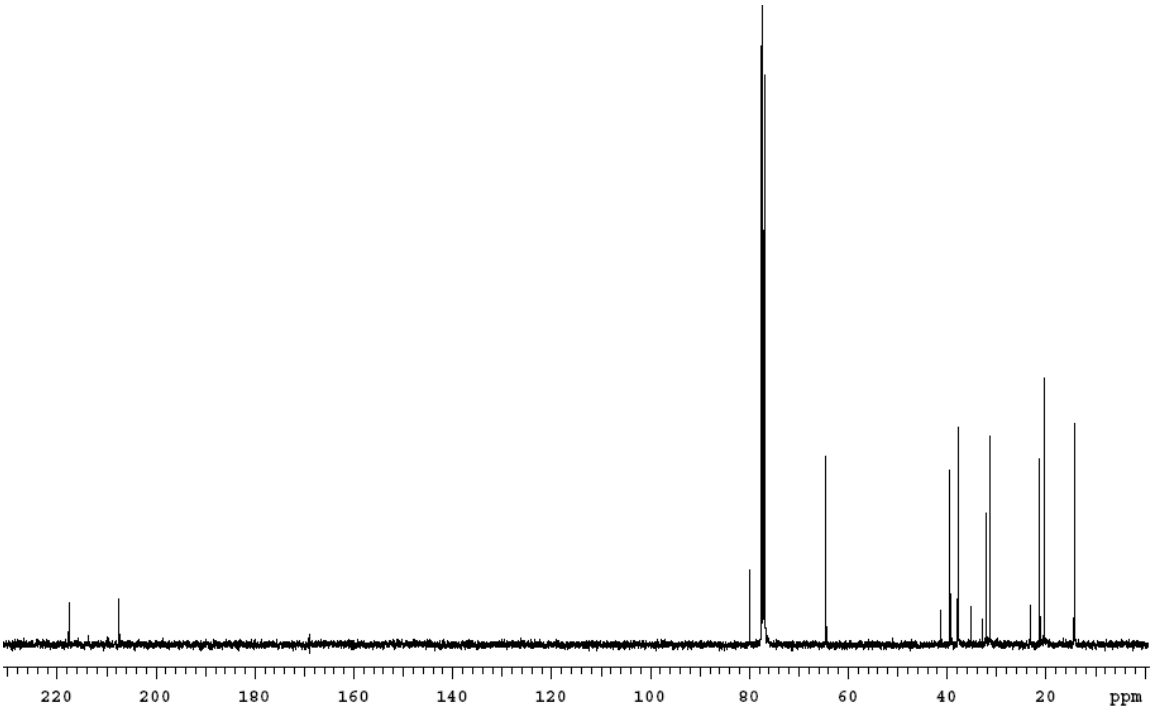


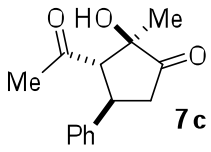




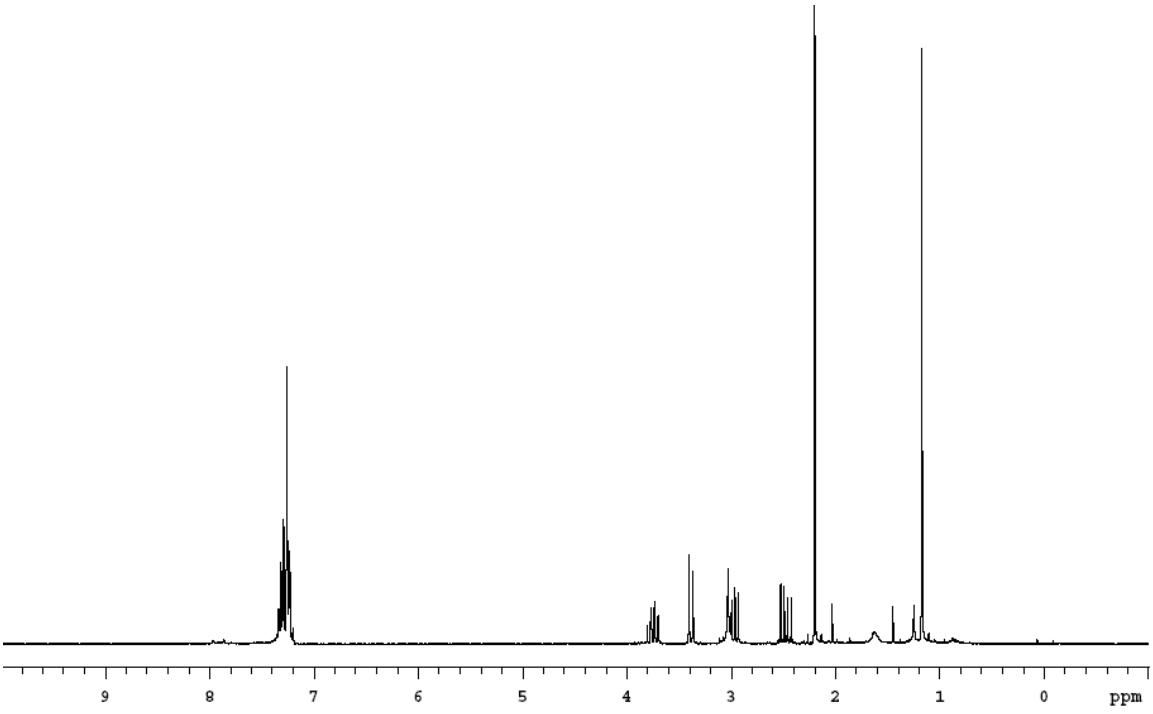
7b mixture of diastereomers

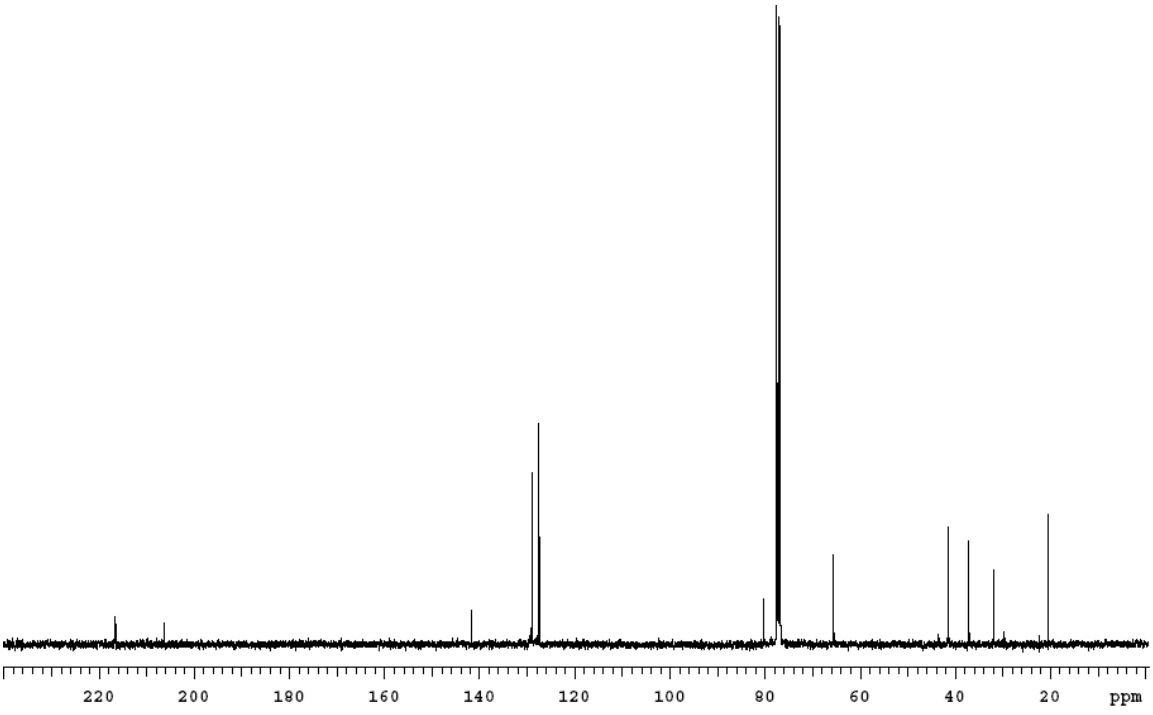


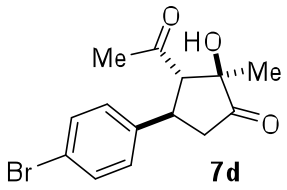




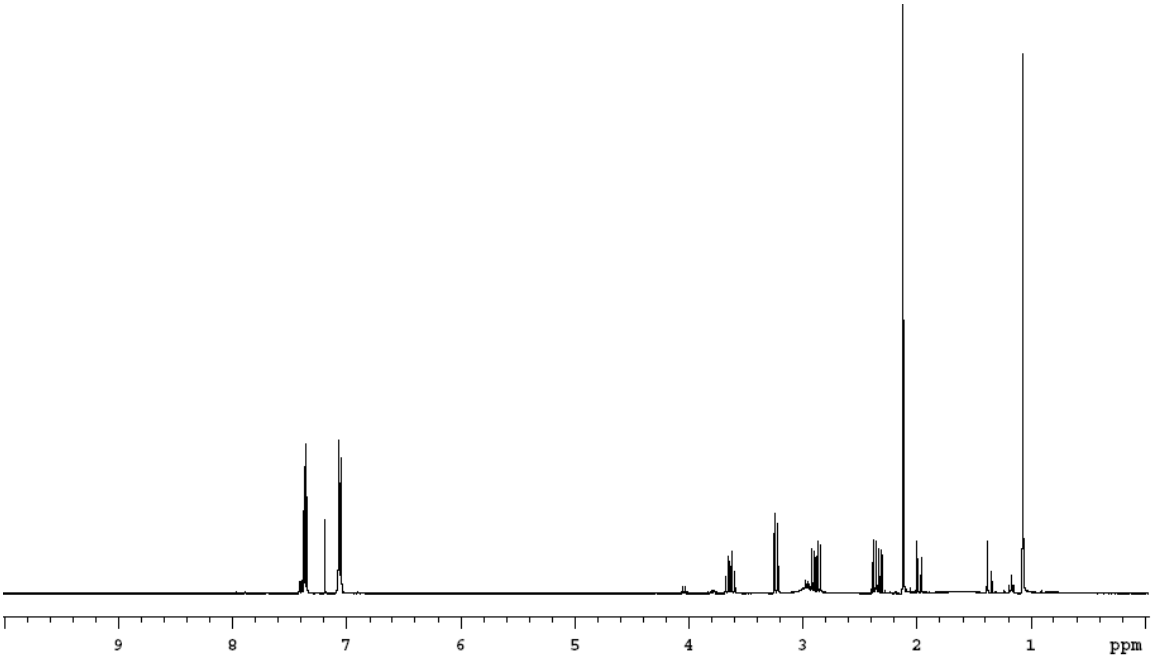
7c mixture of diastereomers

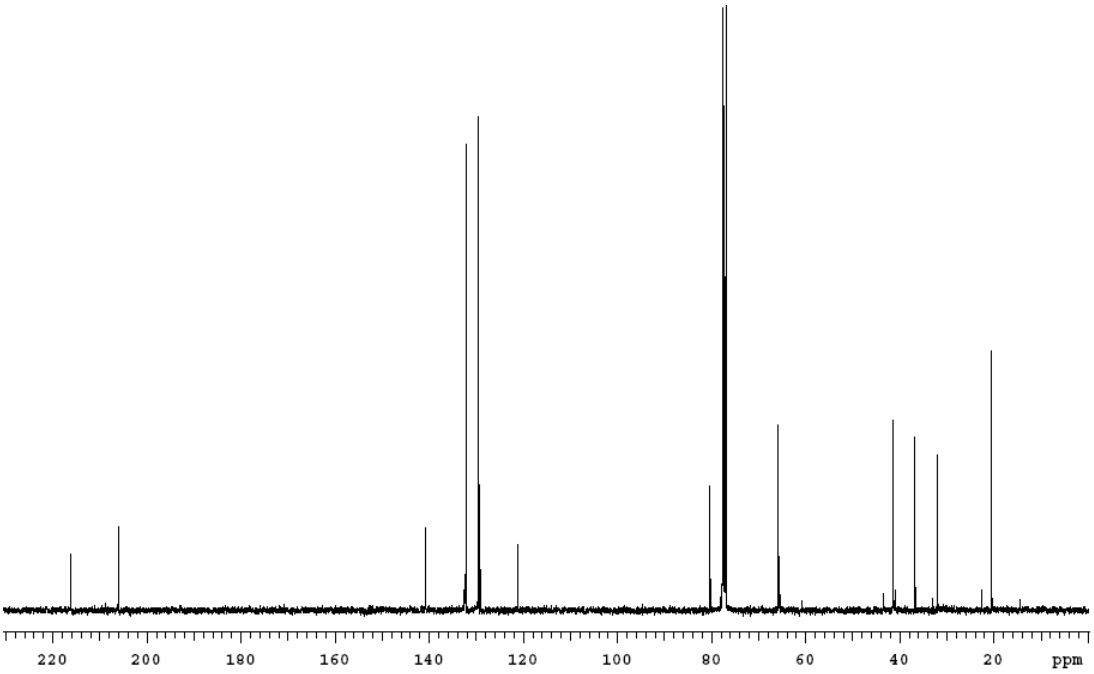


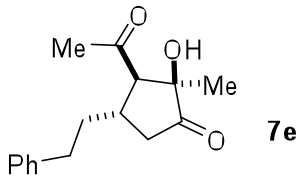




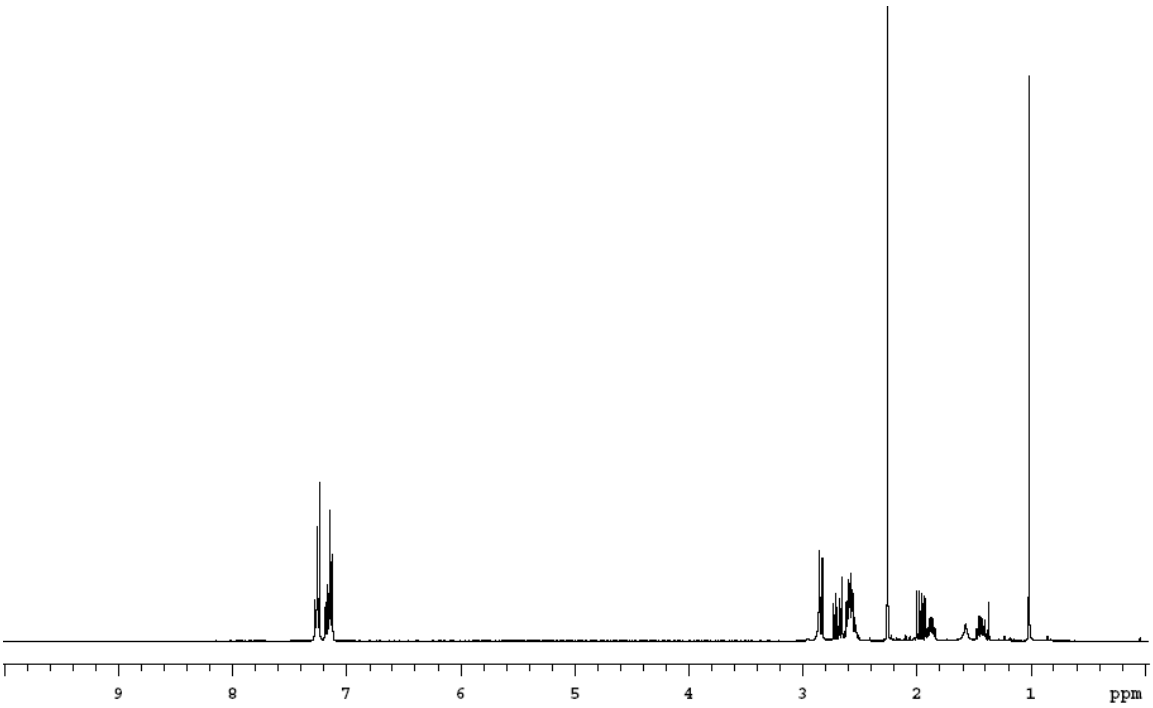
7d mixture of diastereomers






Me
O
OH
Me
O
Ph

7e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7
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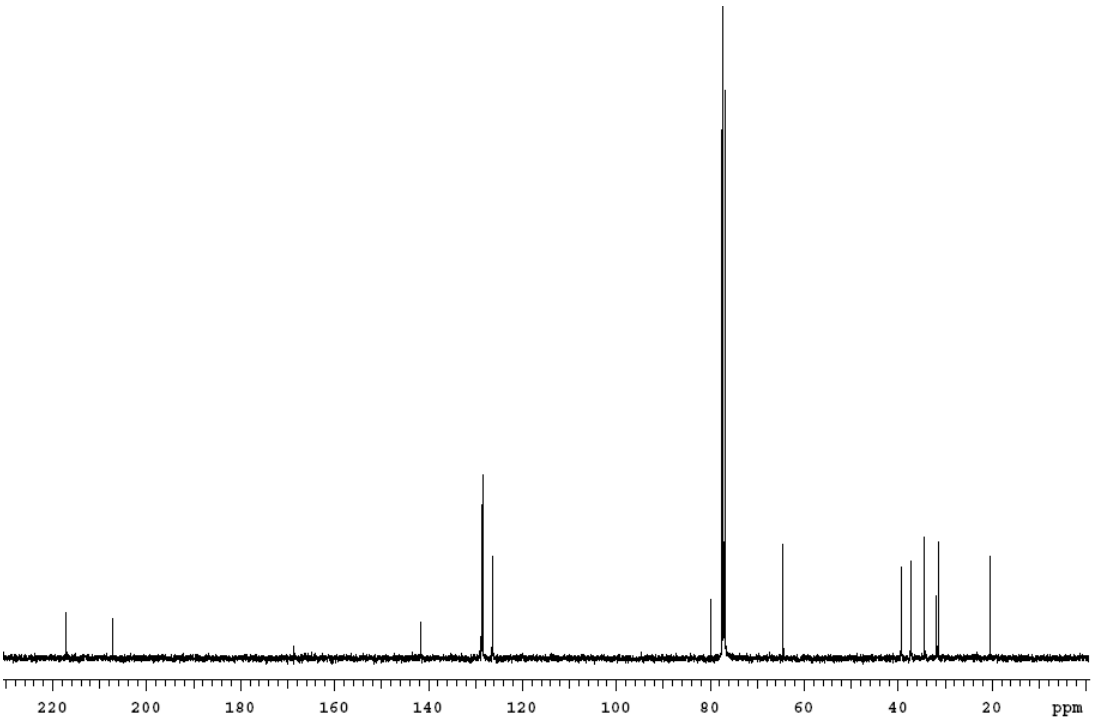
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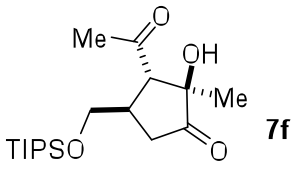
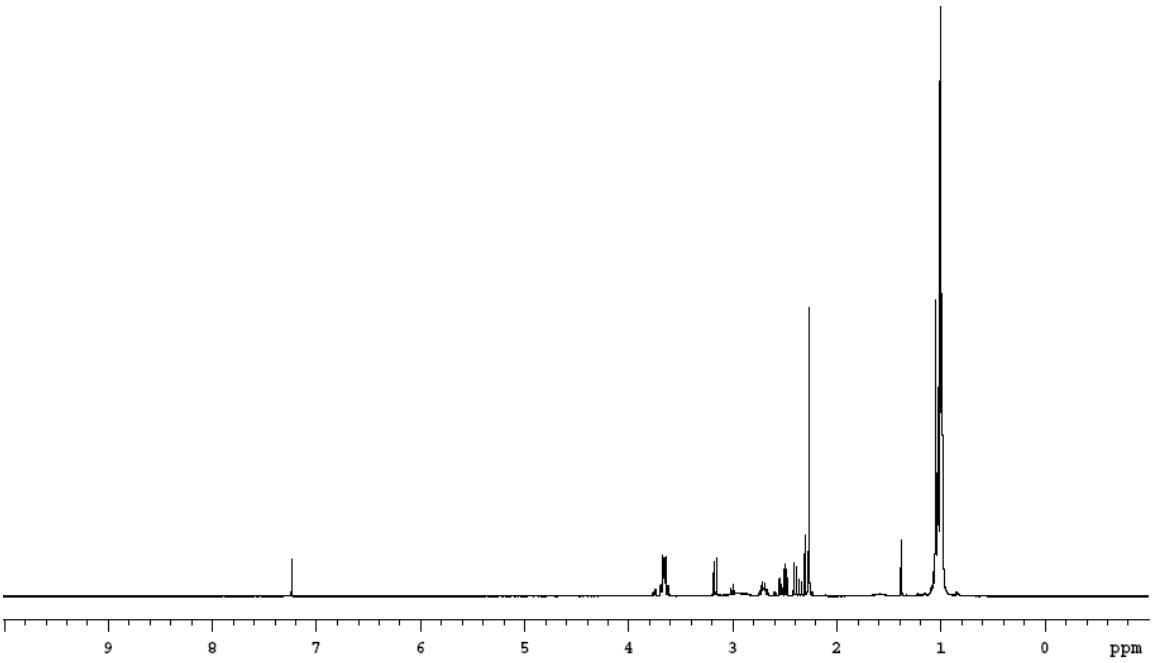
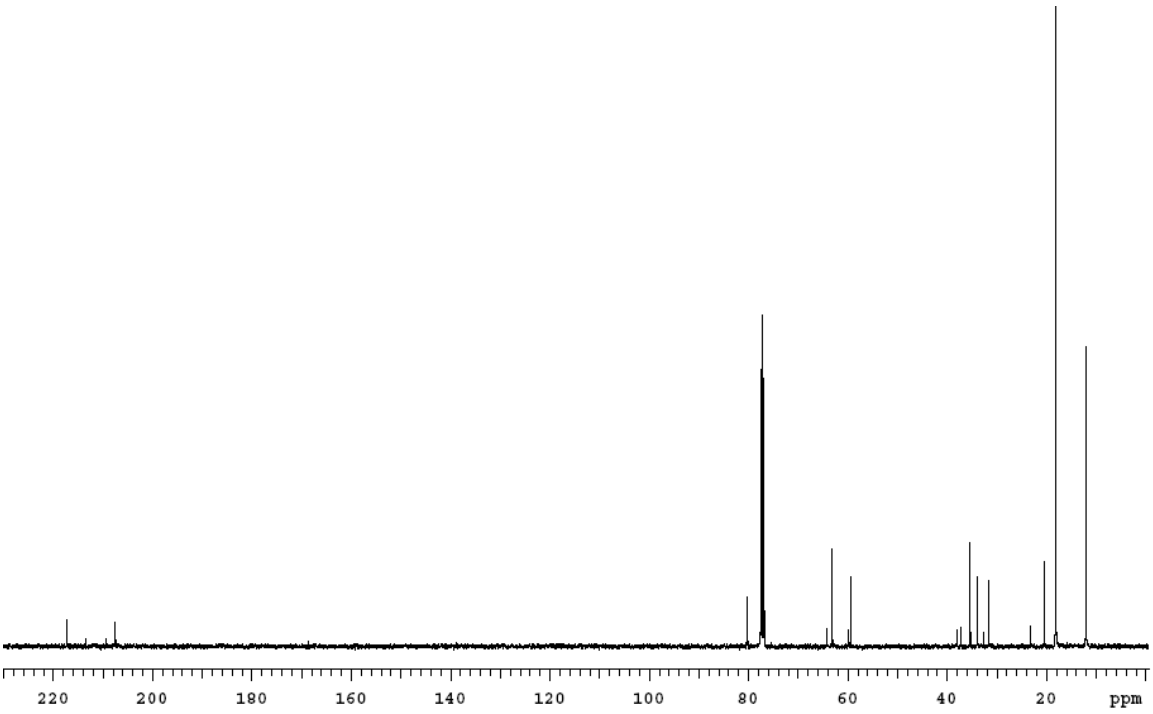
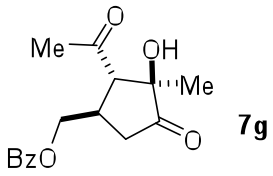


7f mixture of diastereomers

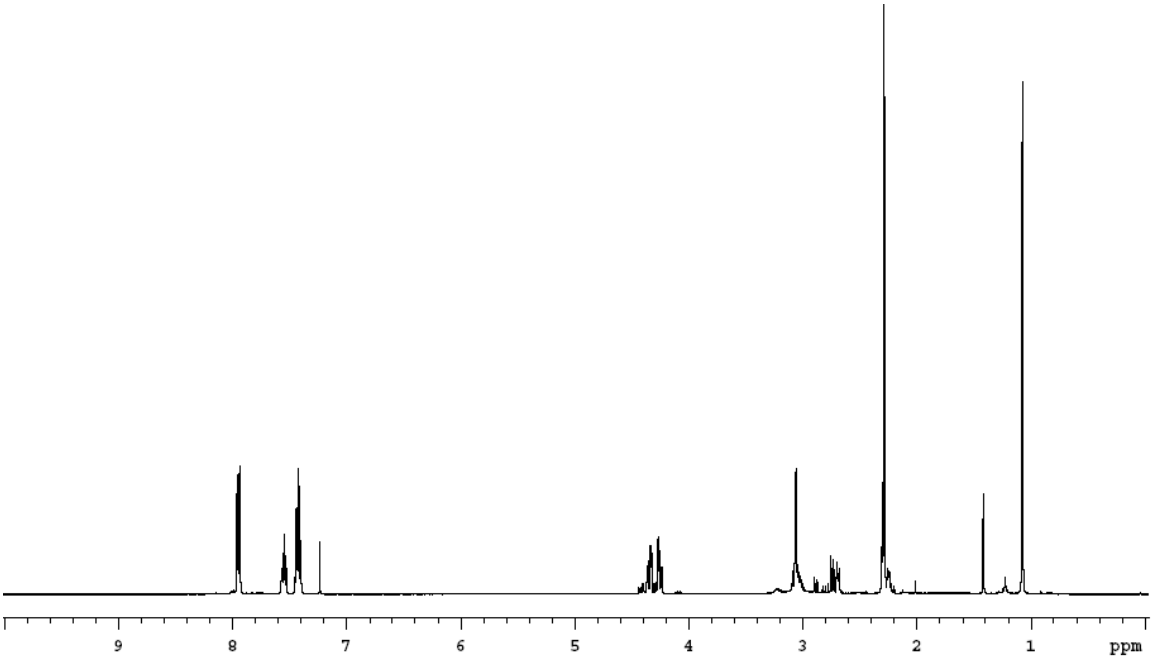


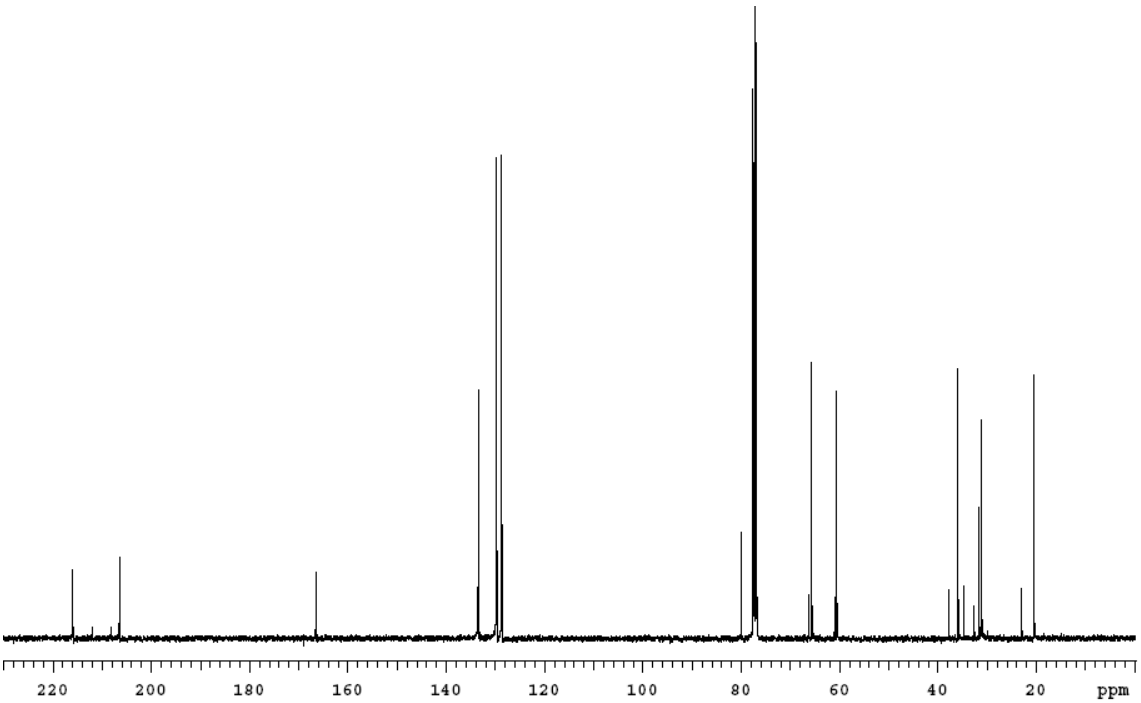


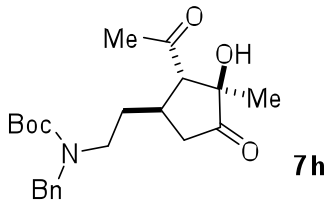


7g

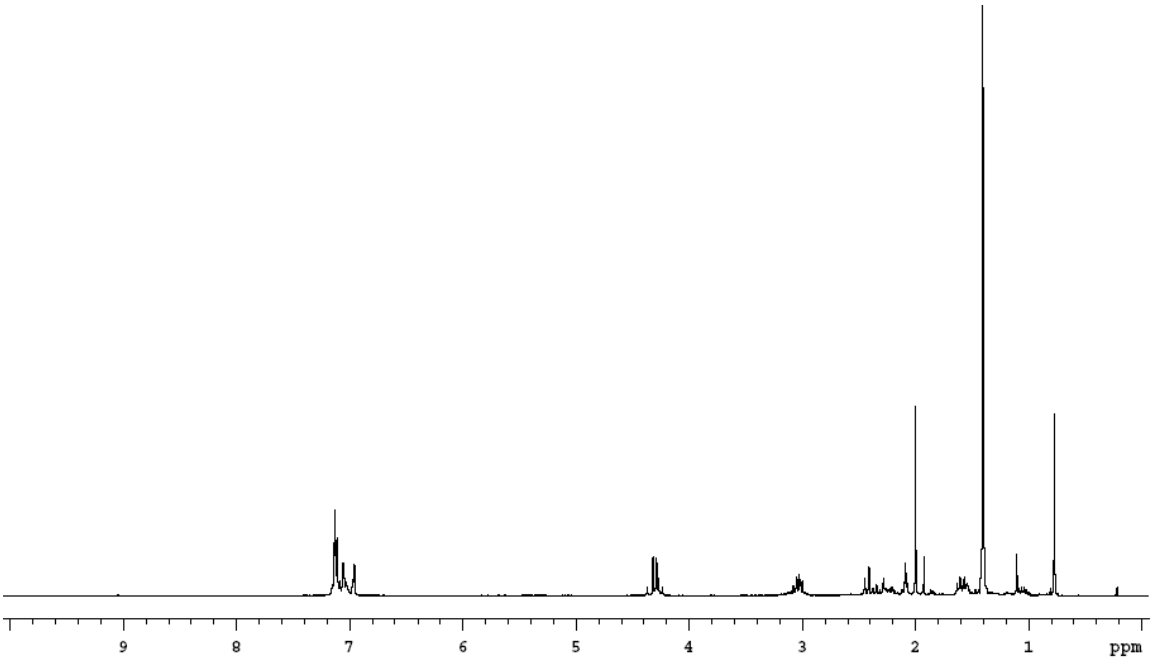
mixture of diastereomers






Me
O
OH
Me
Boc
N
Bn
O

7h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6
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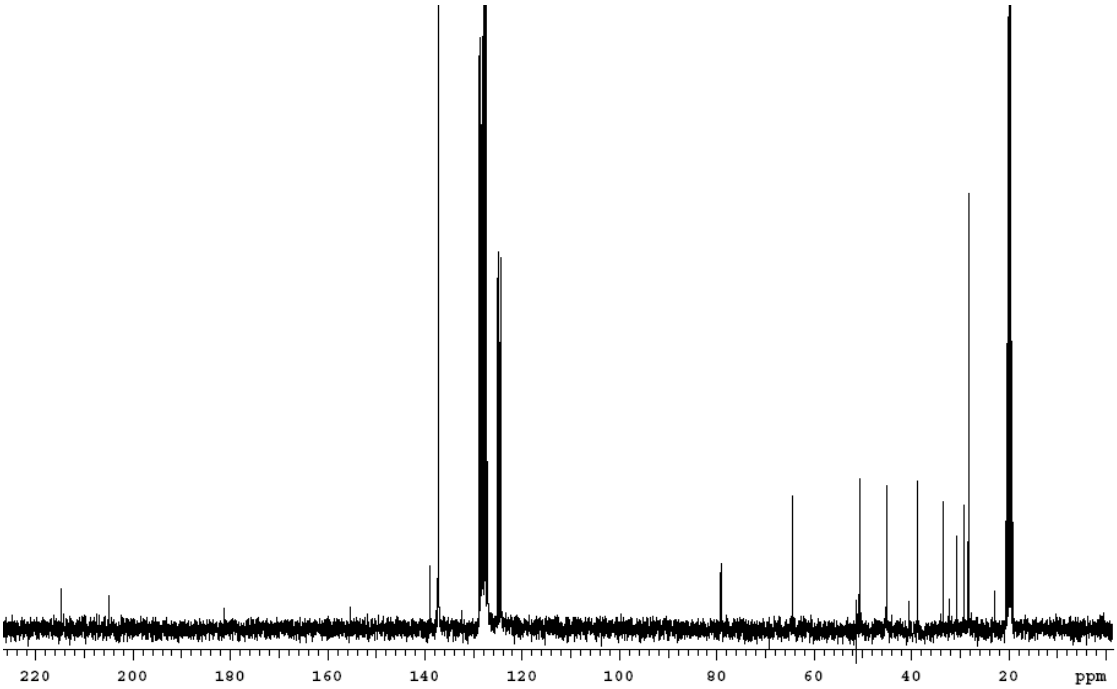
ppm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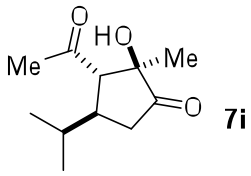
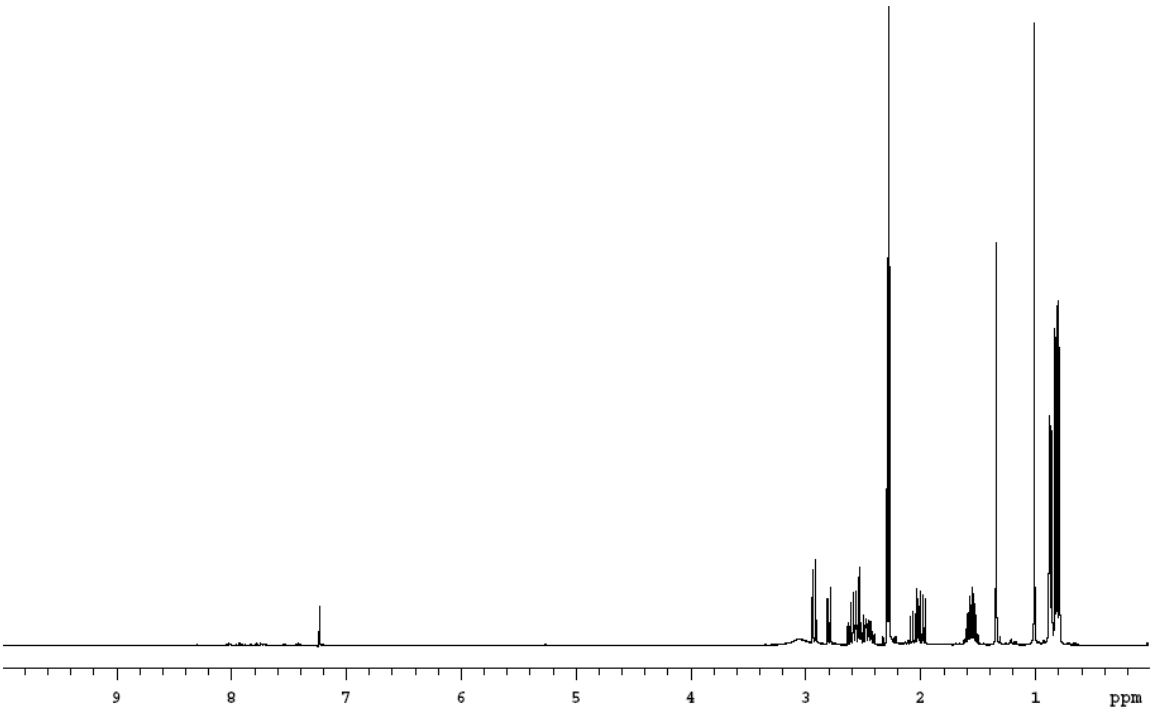
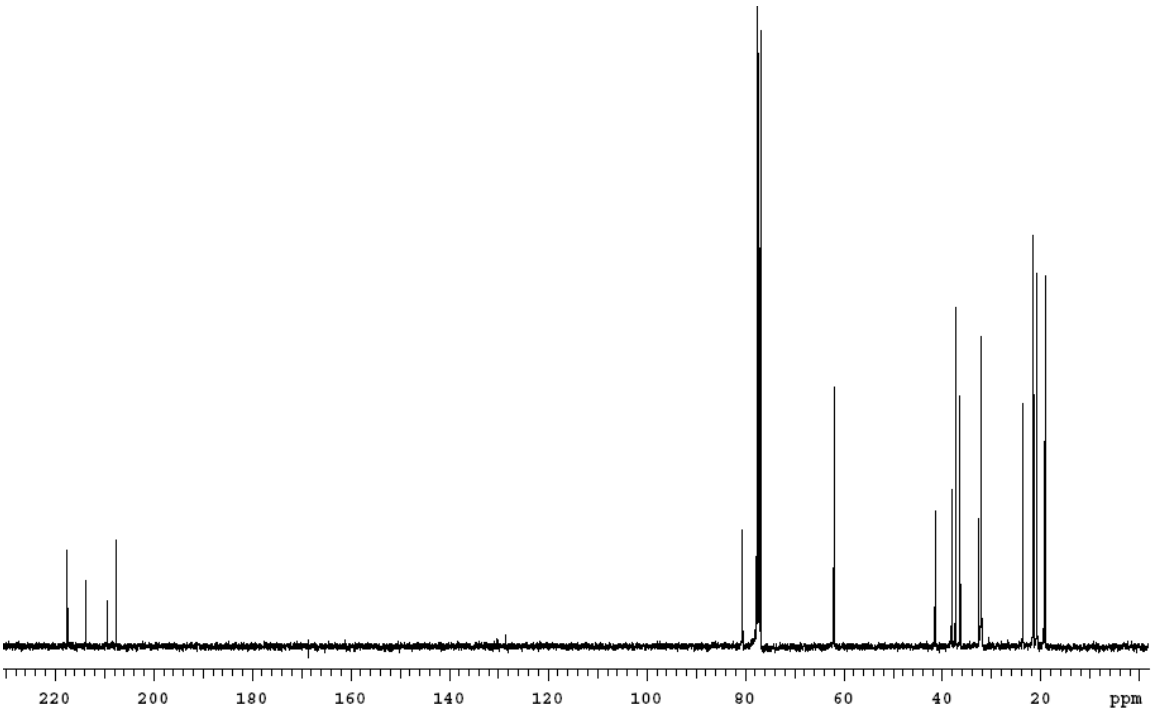
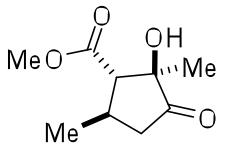


7i

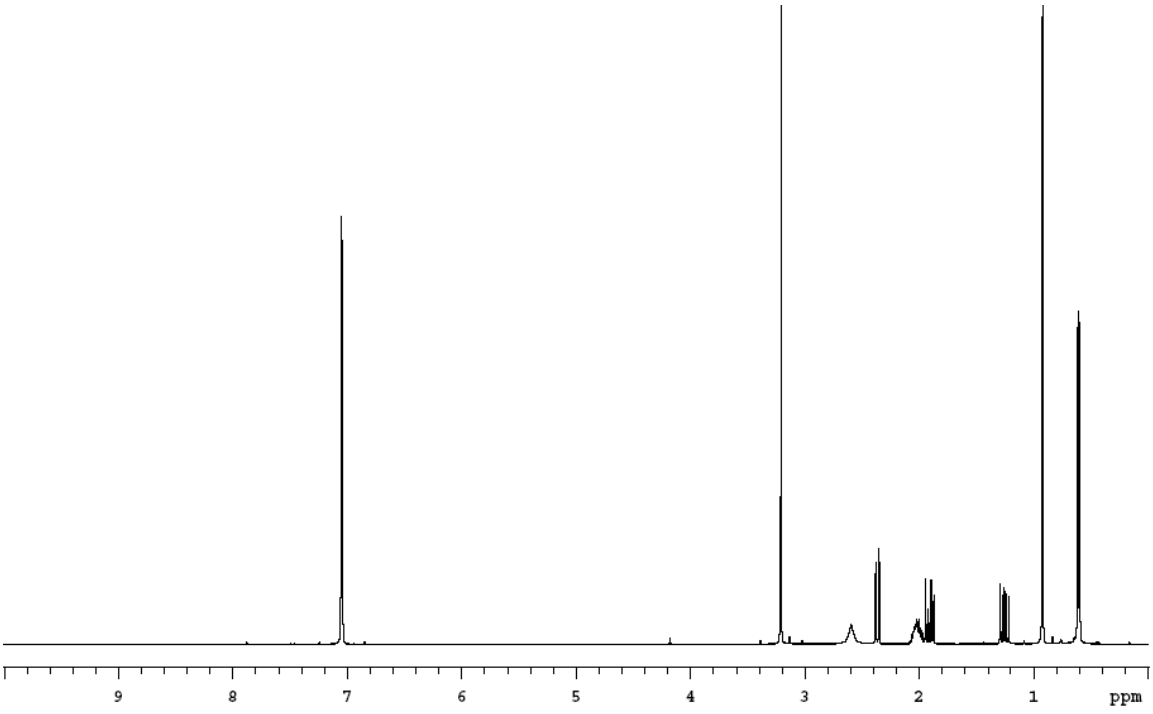
mixture of diastereomers

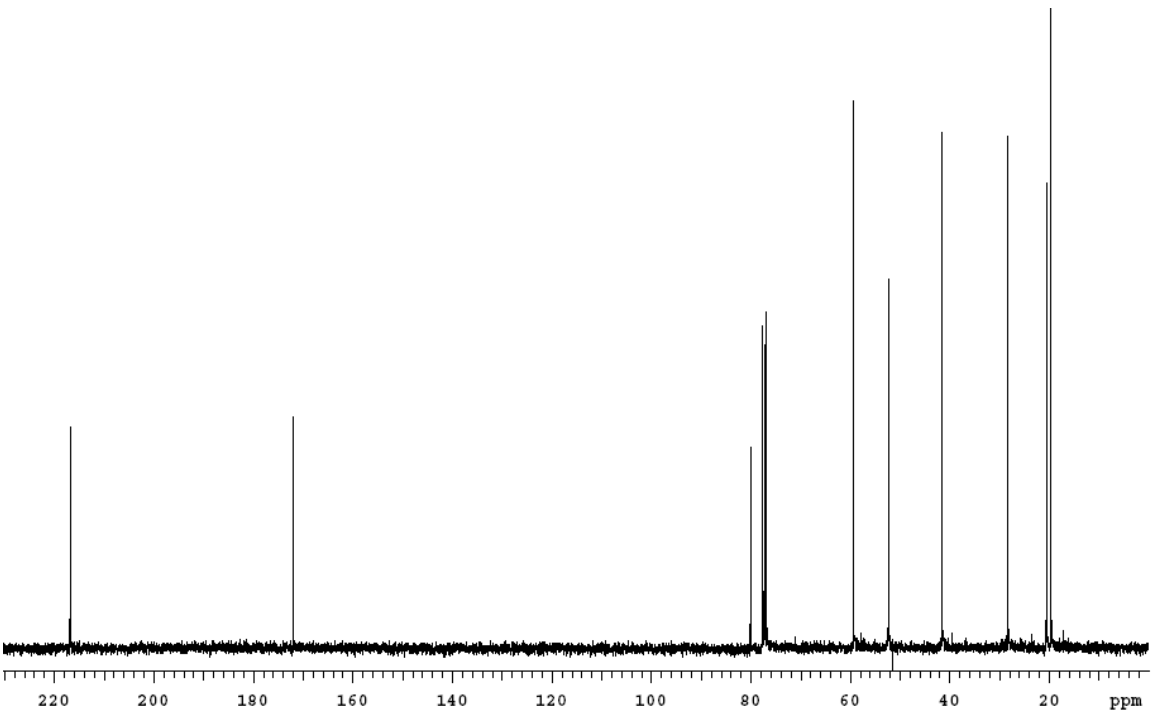


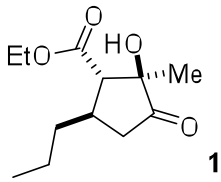




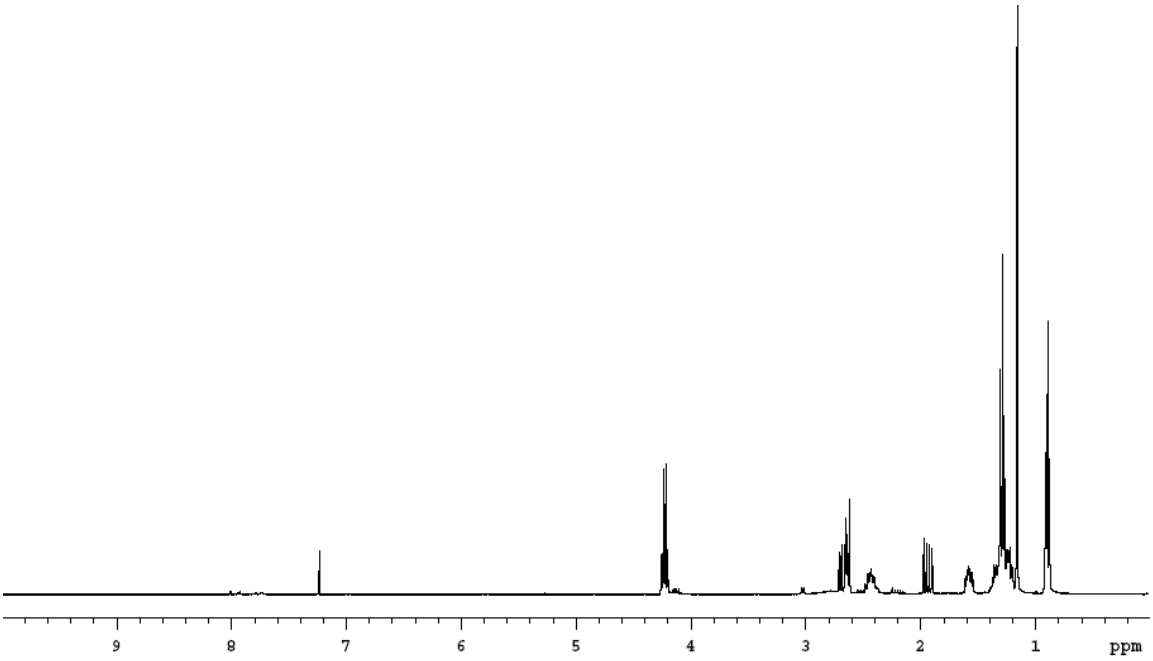
10a major diastereomer

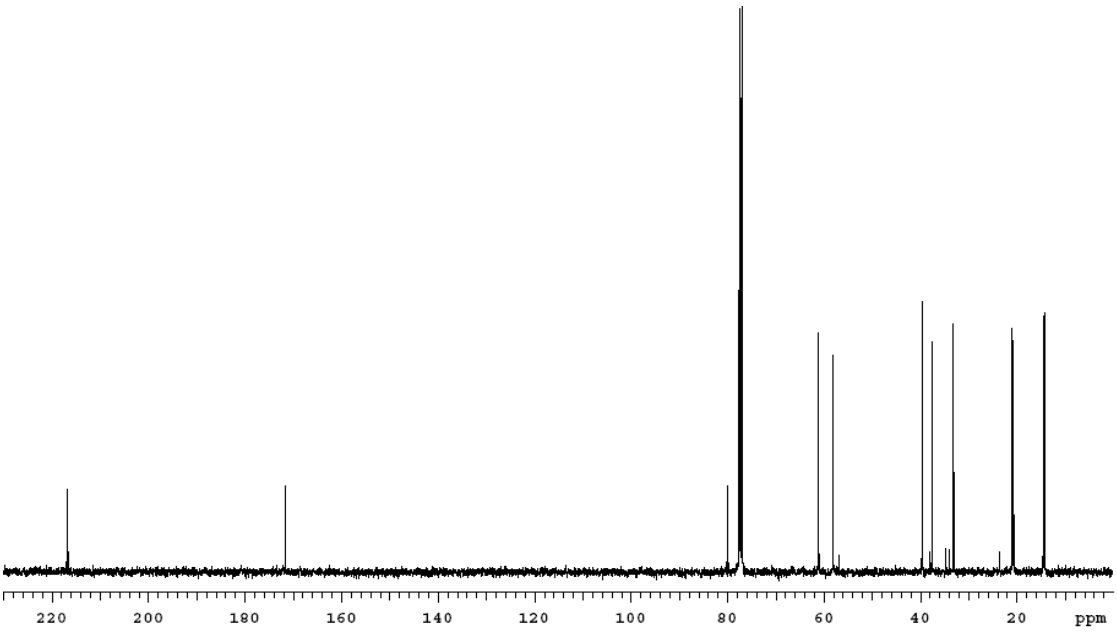


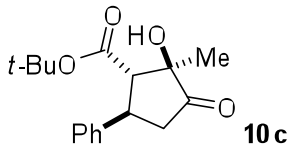




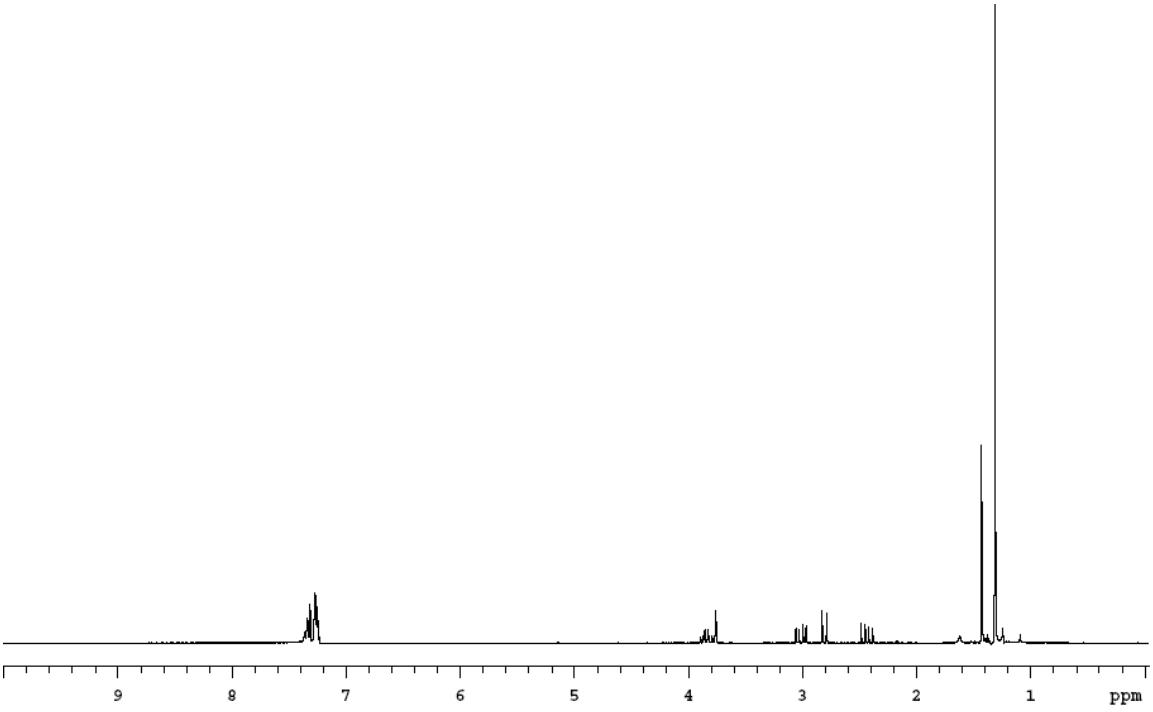
10b major diastereomer






O
HO
t-BuO
Me
O
Ph

10c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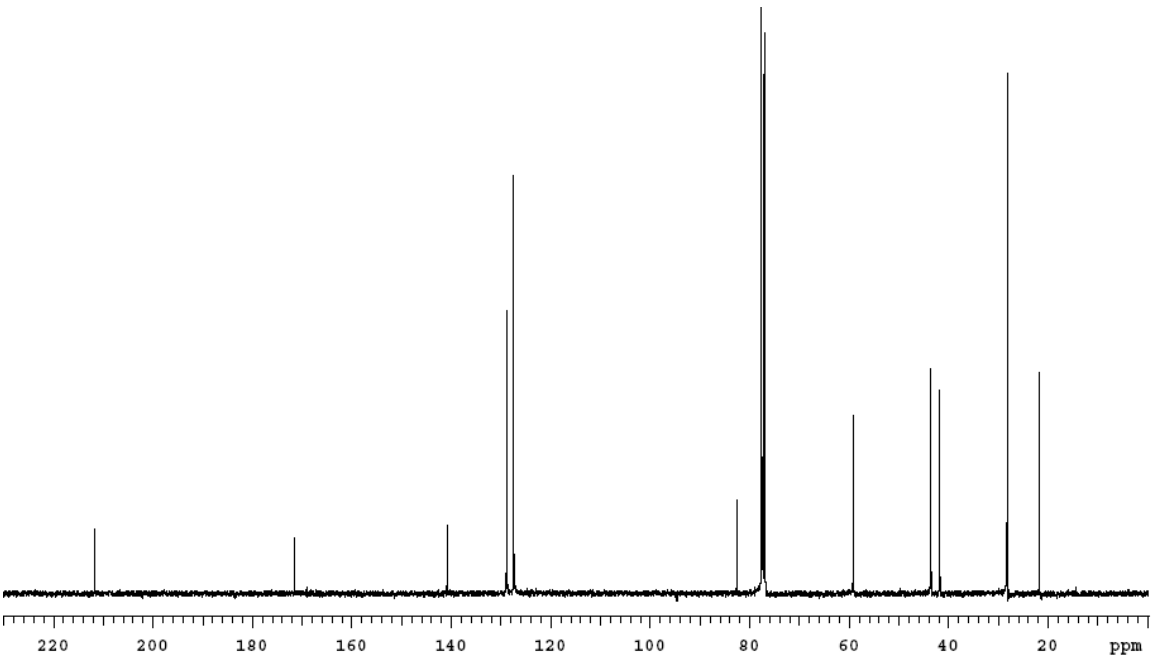
1
ppm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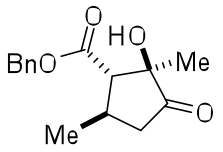
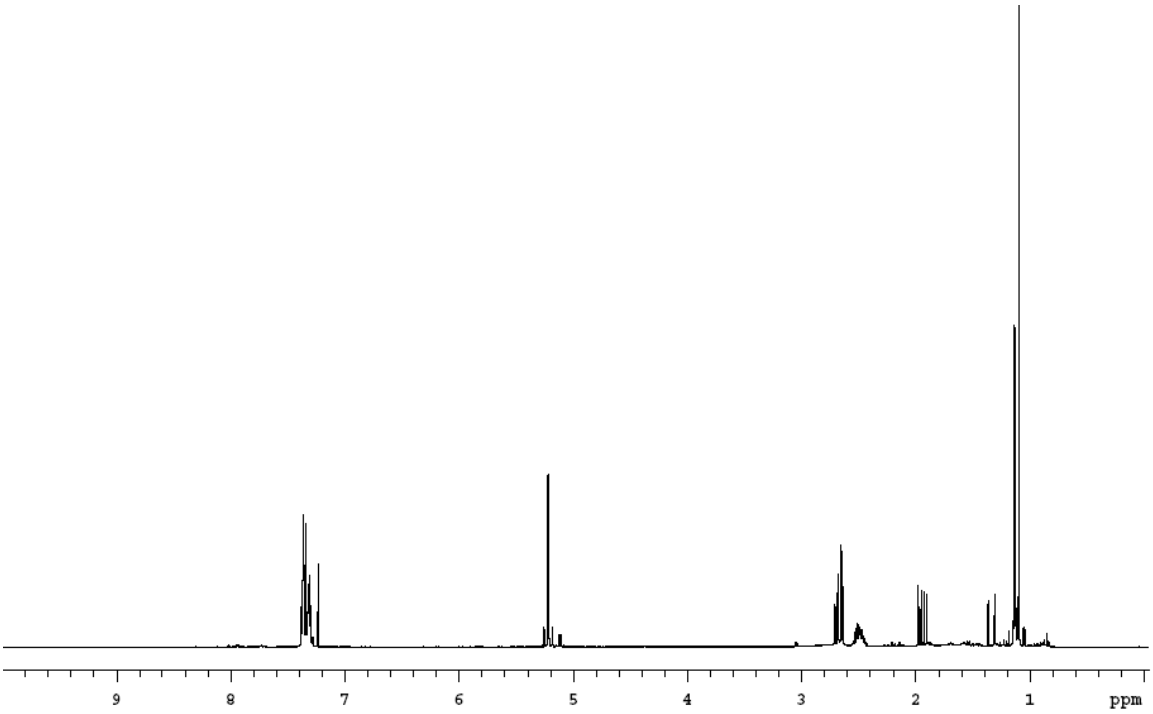
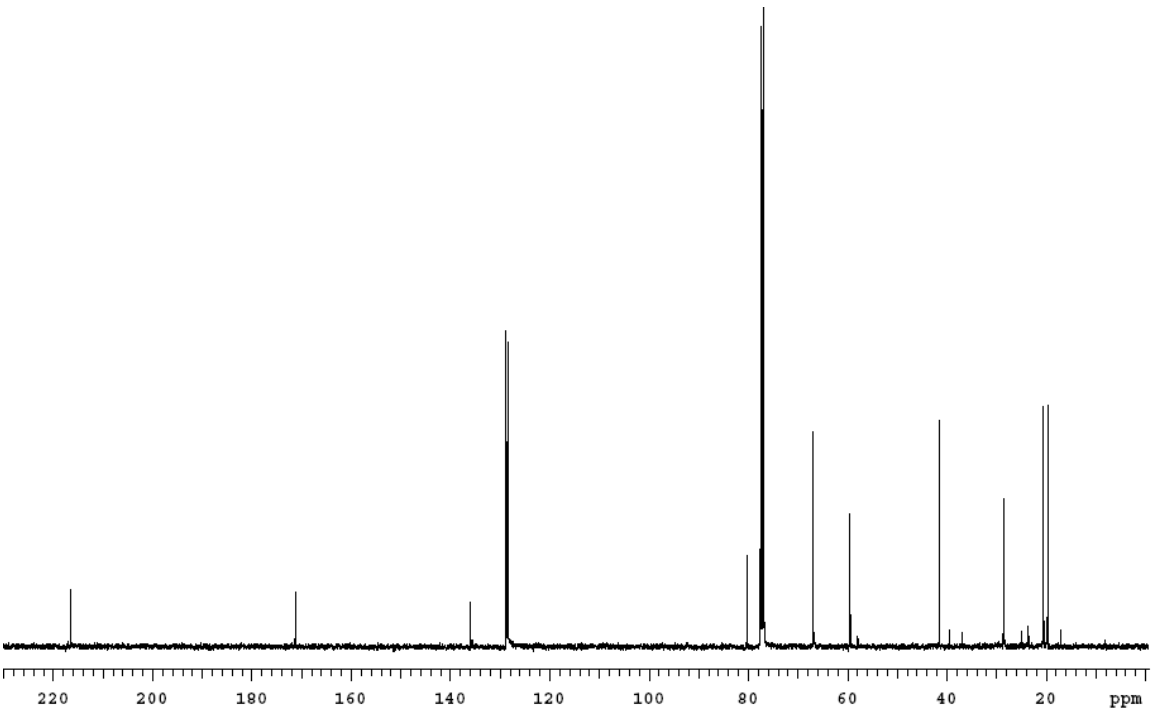
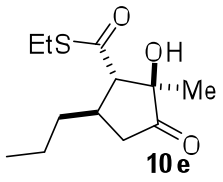


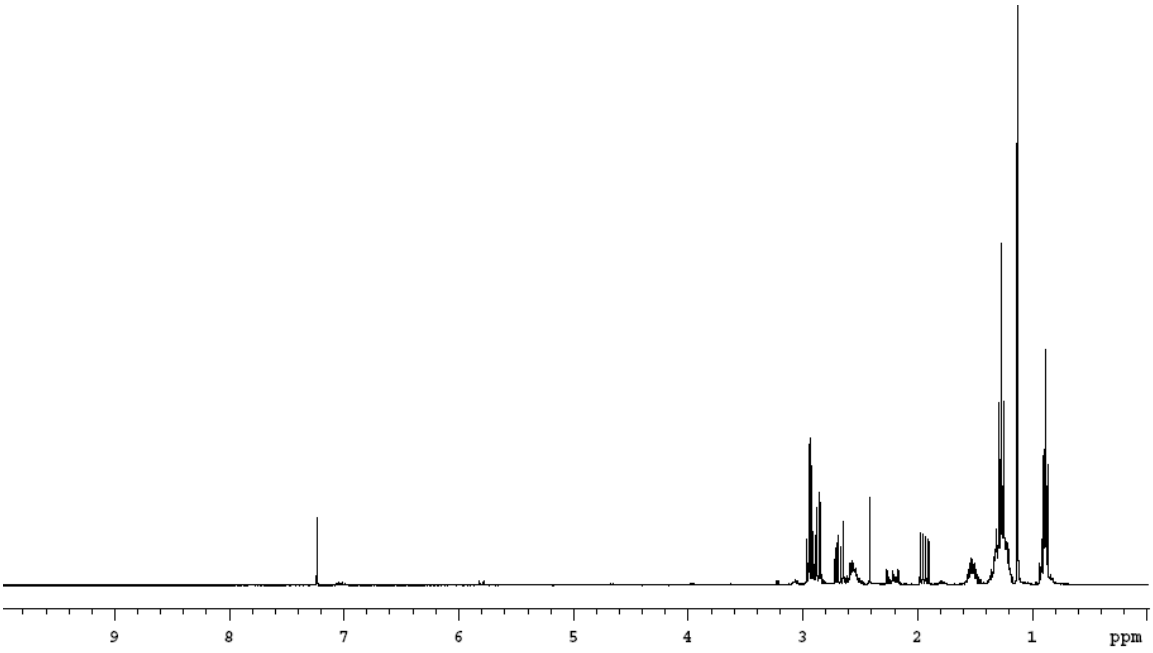
10d Major diastereomer

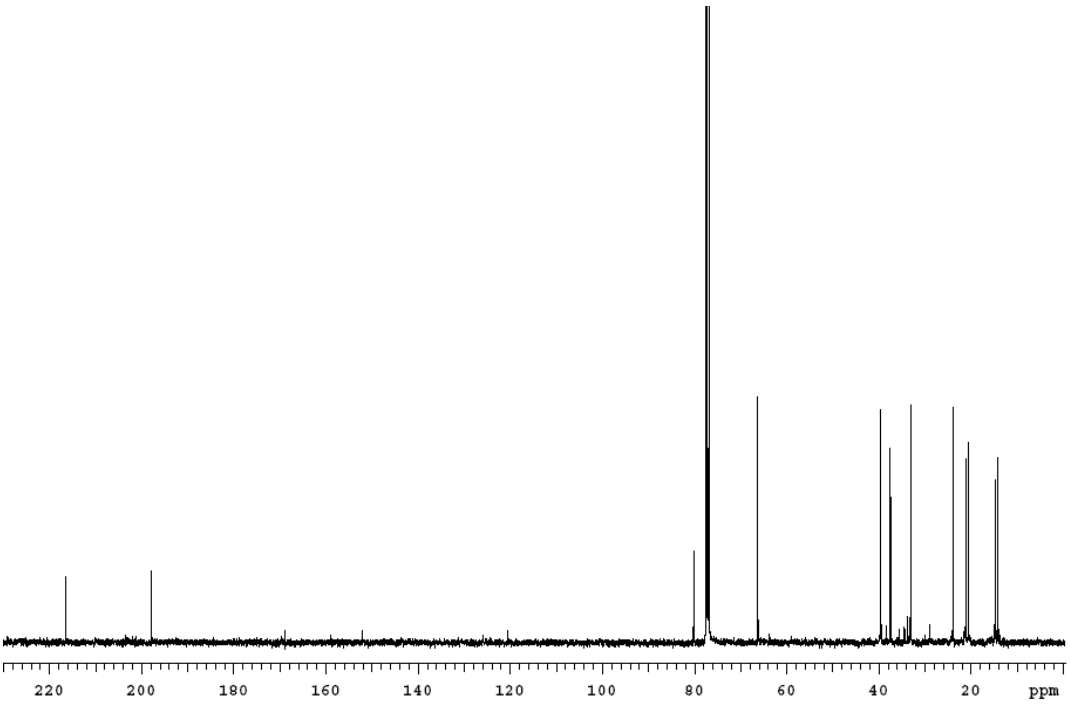


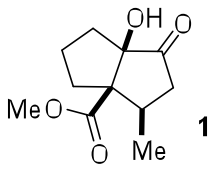




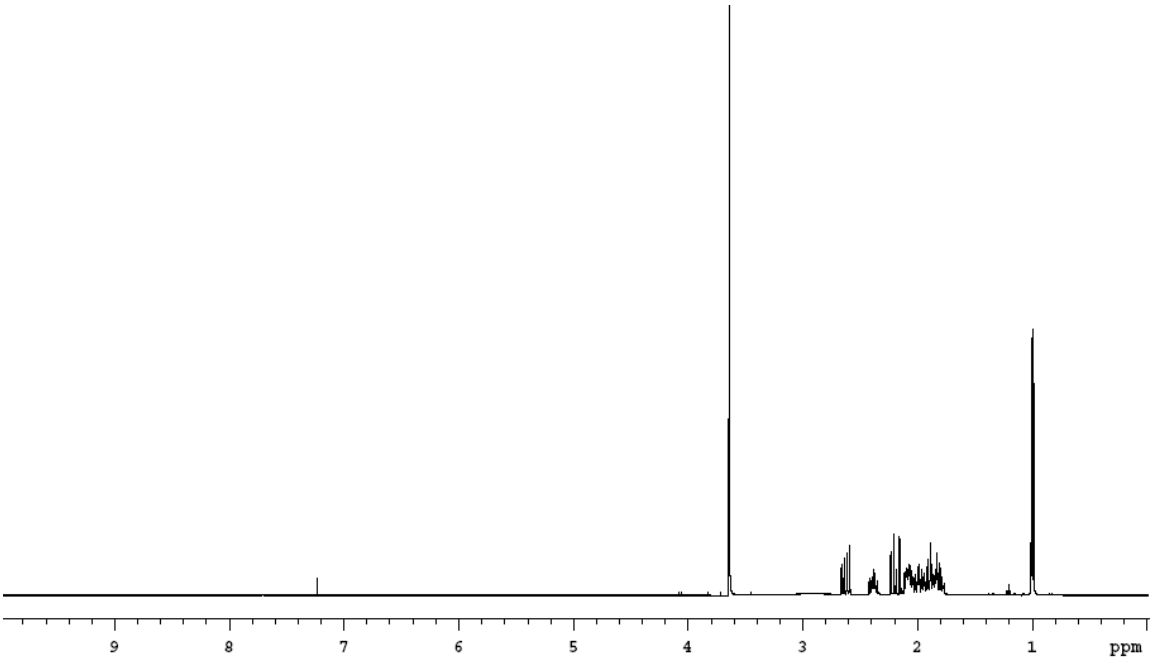
10 e major diastereomer

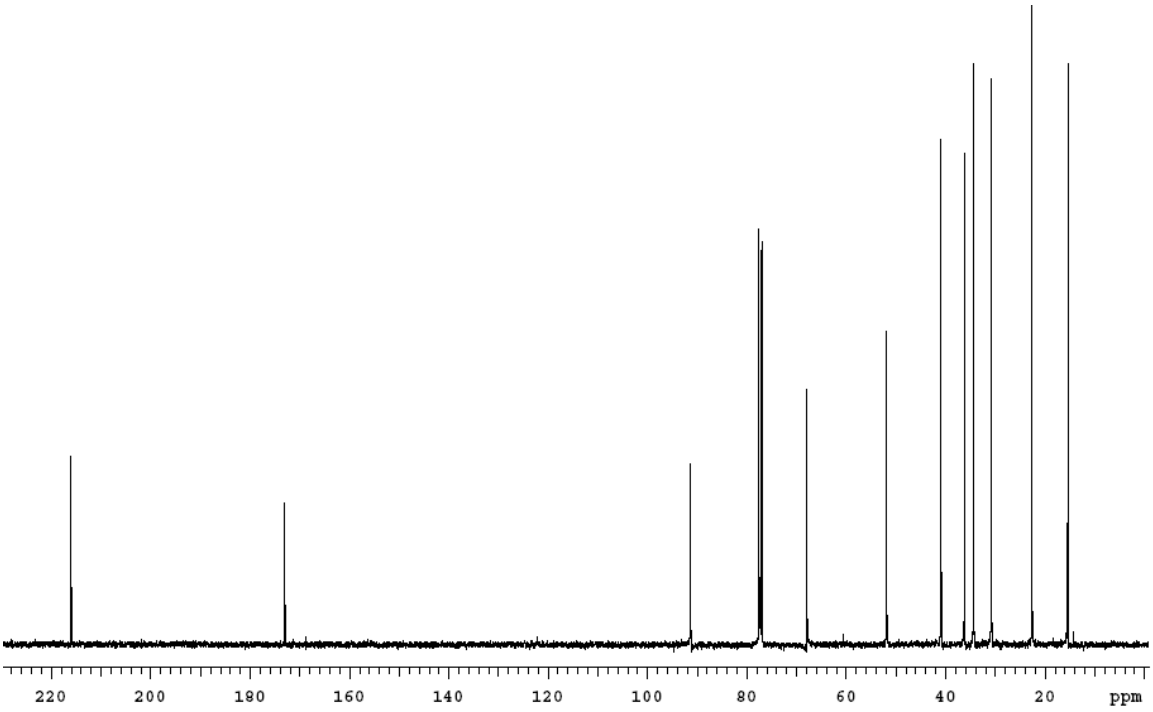


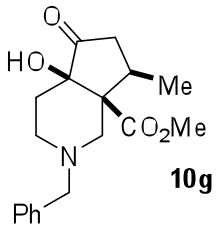




10f major diastereomer

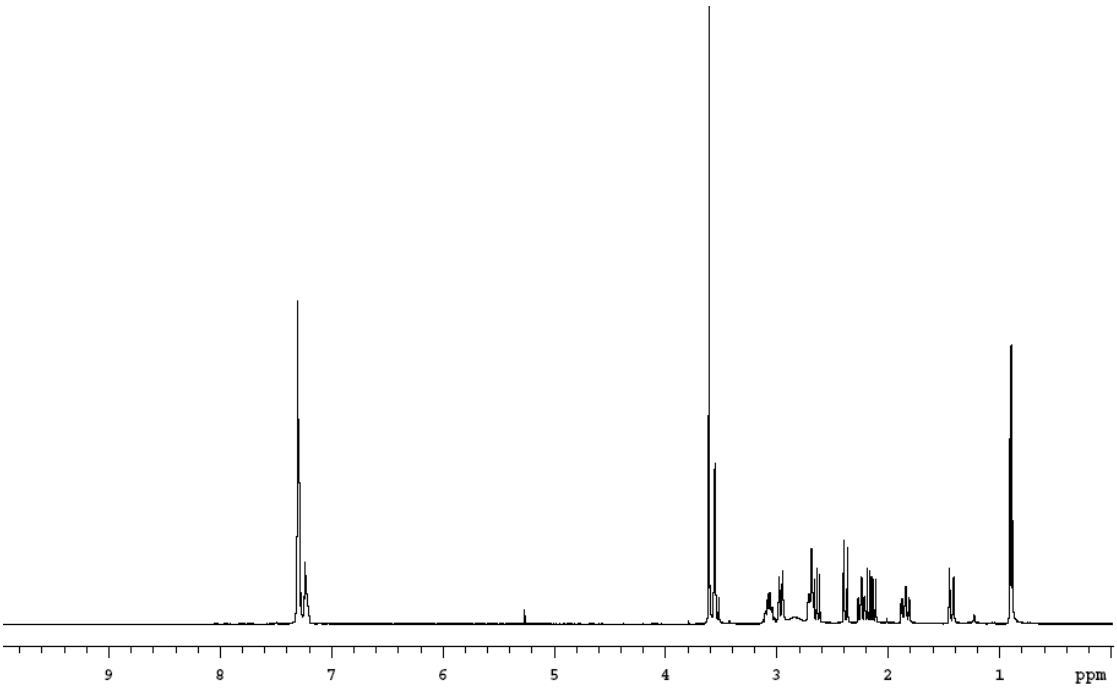


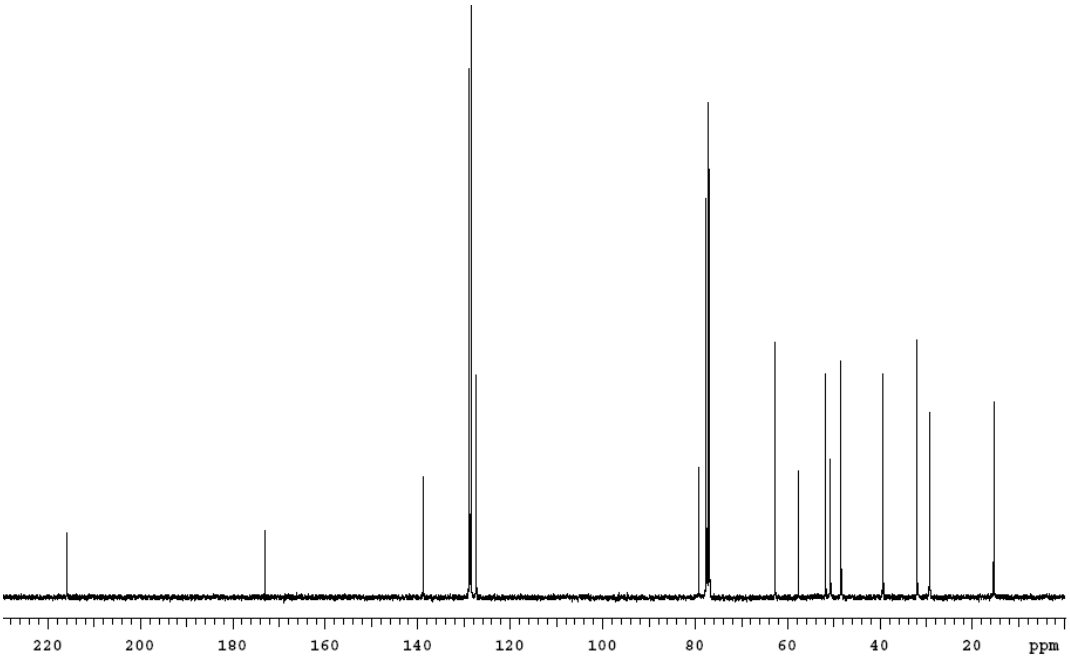


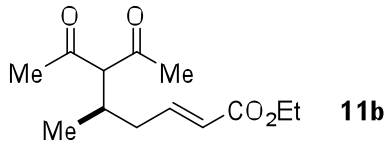


10g

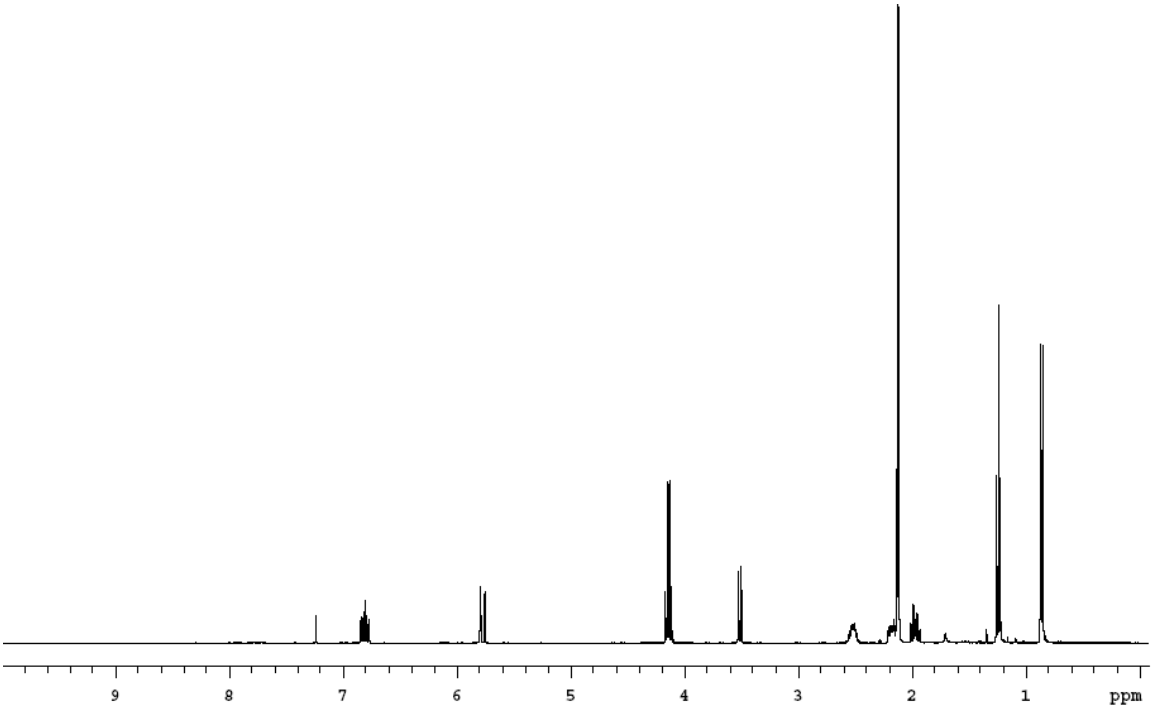
major diastereomer






O
O
Me
Me
Me
CO2Et

11b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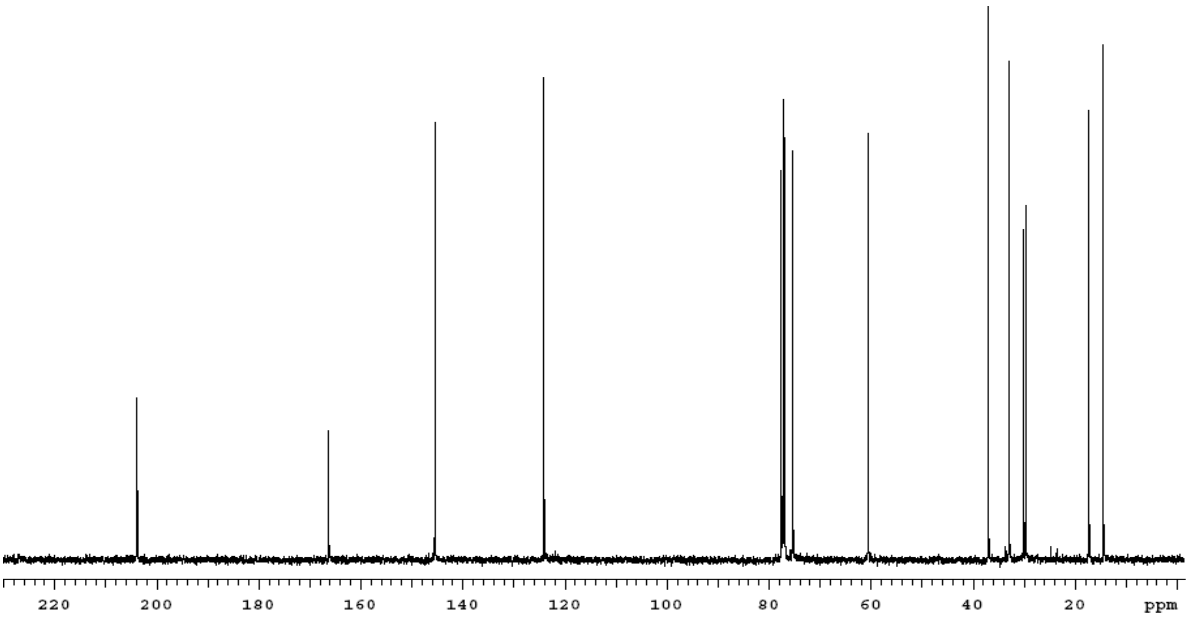
6
5
4
3
2
1
ppm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120
100
80
60
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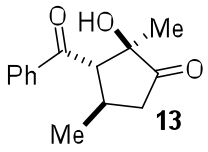
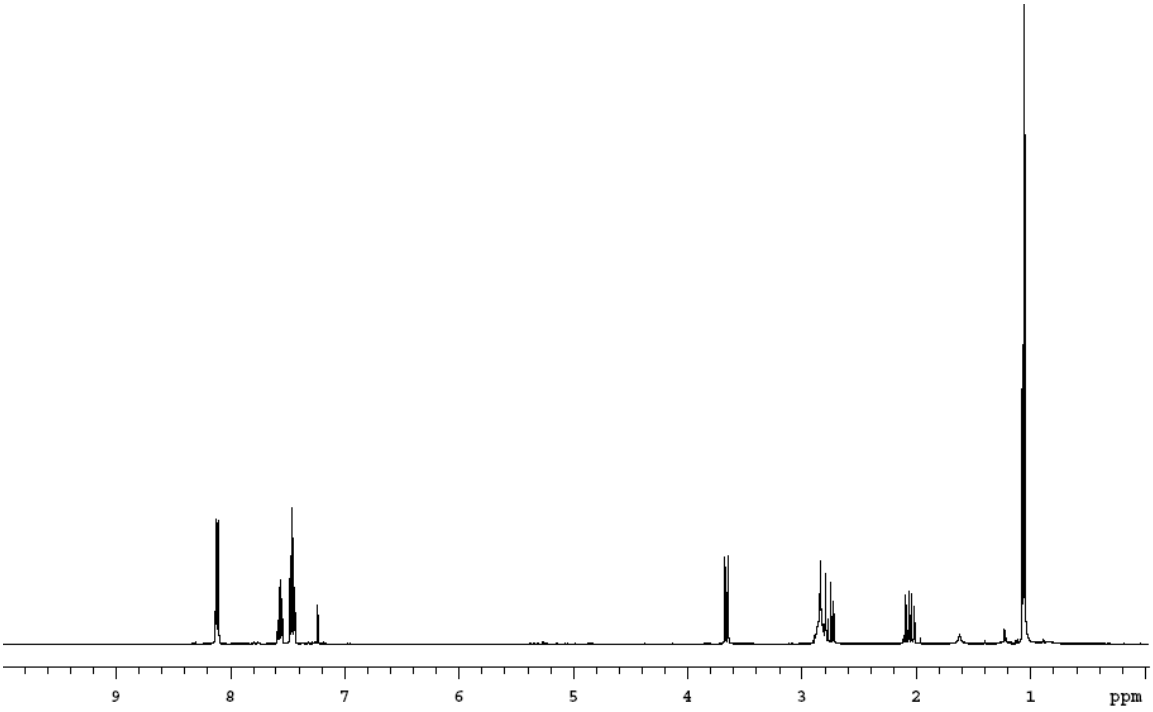
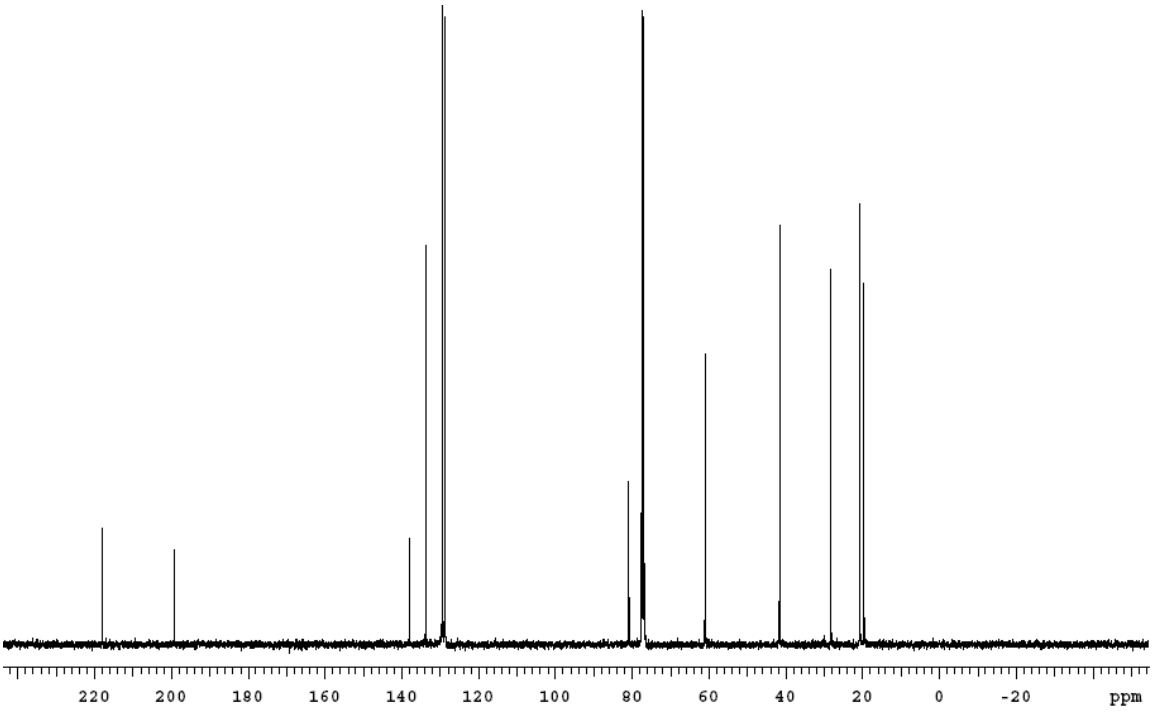
20
ppm

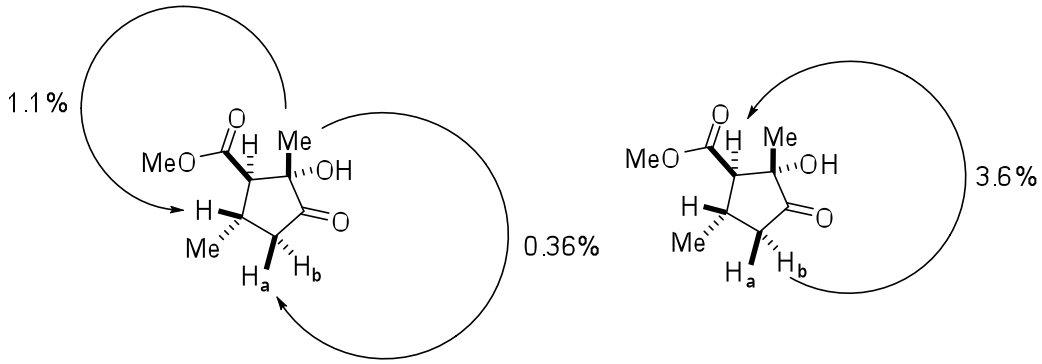


13 major diastereomer and regioisomer

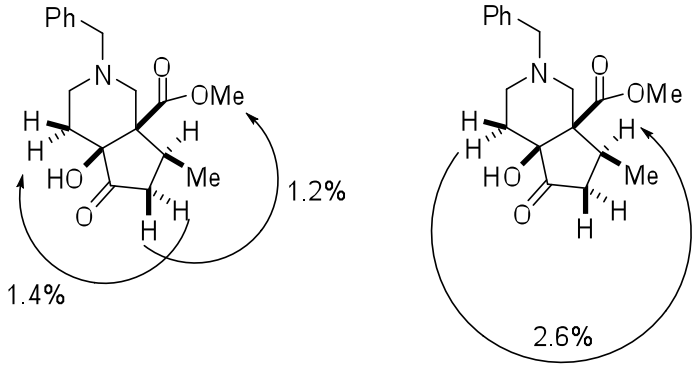




nOe For Compound **10a**, Major Diastereomer



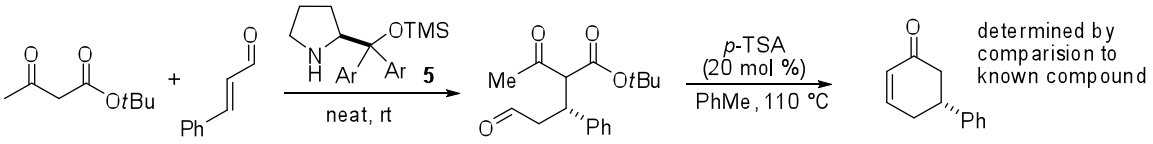
nOe For Compound **10f**, Major Diastereomer



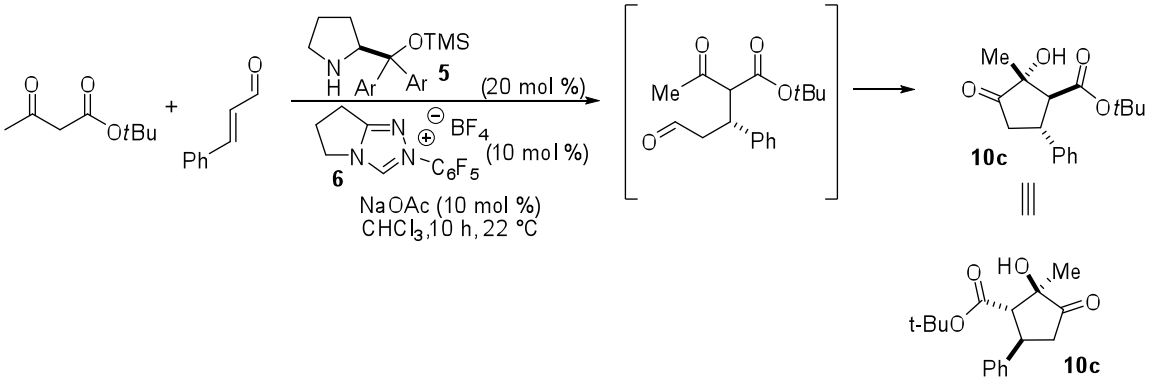
Determination of Absolute Configuration

Absolute configuration was assigned based on analogy to work done by Jørgensen and co-workers (Carlone, A.; Marigo, M.; North, C.; Landa, A.; Jørgensen, K. A. *Chem. Commun.* **2006**, 4928.)

Jørgensen



This Work

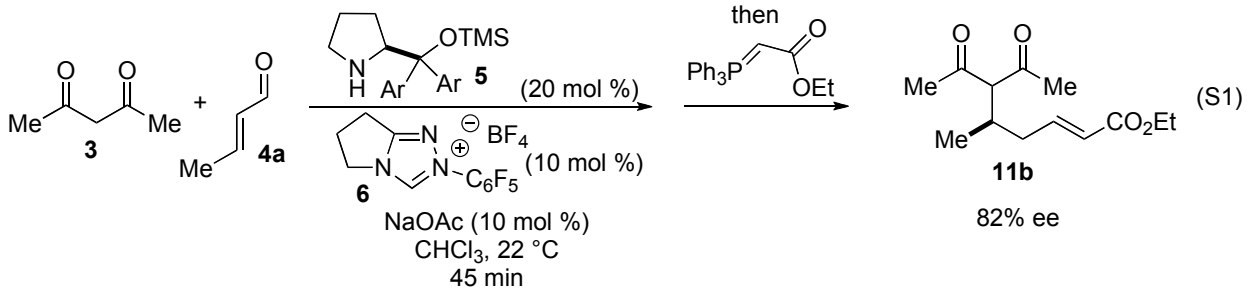


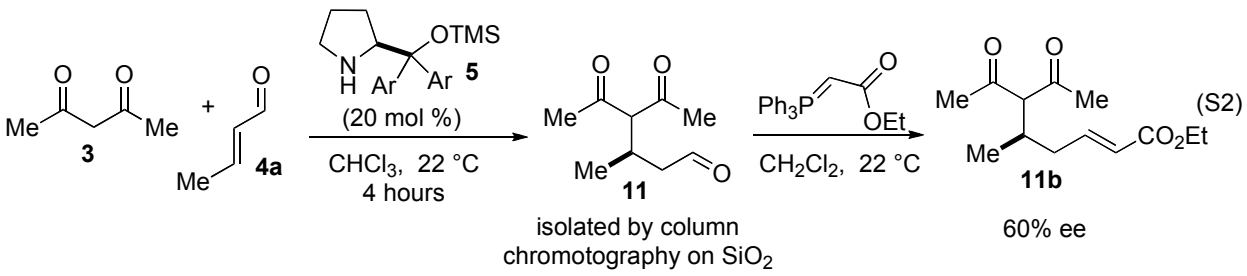
All cyclopentanone products described in this paper are based on this analogy.

Evidence for a retro-Michael in the absence of azolium

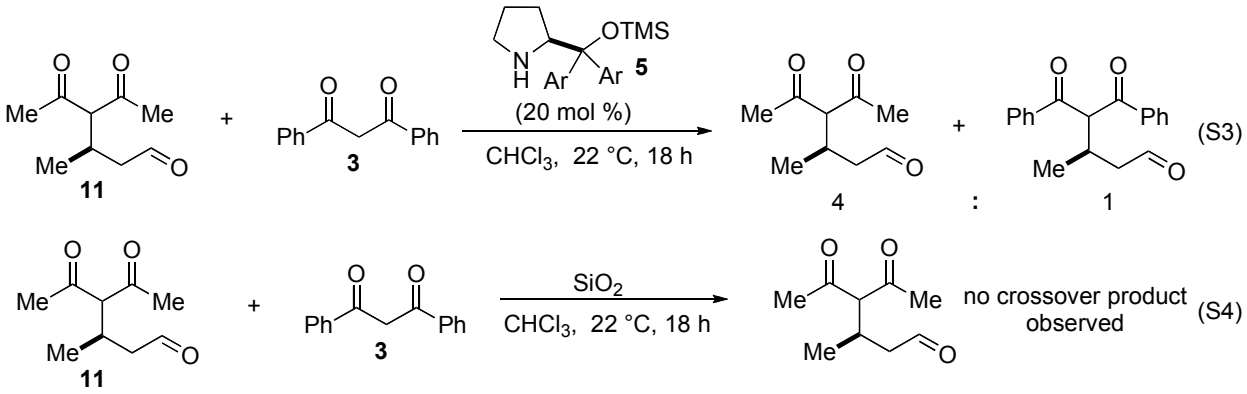
When the one-pot reaction is allowed to stir for 45 min and then the Wittig reagent is added we obtain the enoate **11b** in 82% ee (eq S1) matching closely the ee of **7** (86% ee). However when the intermediate aldehyde is isolated by column chromatography and then subjected to the Wittig

reaction the enoate **11b** is isolated in 60% ee which matches our two step ee of cyclopentanone **7** (eq S2) suggesting that an apparent epimerization reaction occurs upon purification.



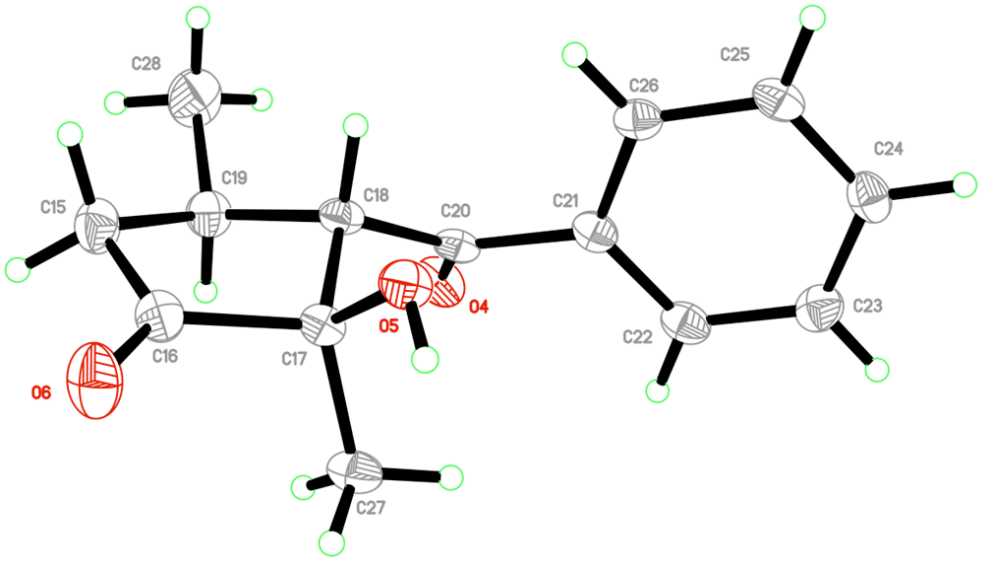


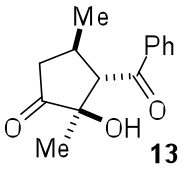
Further support for the epimerization is provided by the following experiments: subjection of aldehyde **11** to prolinol catalyst in the presence of dibenzoylmethane leads to partial generation of the crossover product in a 4:1 ratio (S3). This reaction does not proceed in the absence of prolinol **5** (eq S4) indicating that a retro-Michael is most likely responsible for the degradation of selectivity in the two-step reaction.



Crystal Structure for Compound 13

(Major Diastereomer)





13

Table 1. Crystal data and structure refinement for compound **13** (major diastereomer).

Identification code	**13**
Empirical formula	$C_{14}H_{16}O_3$
Formula weight	232.27
Temperature	120 K
Wavelength	0.71073 Å
Crystal system	Monoclinic
Space group	$P2_1$
Unit cell dimensions	*a* = 5.7342(5) Å a= 90°.
	b = 15.4013(12) Å b= 93.861(3)°.

	c = 13.9378(10) Å g = 90°.
Volume	1228.11(17) Å^3
Z	4
Density (calculated)	1.256 Mg/m^3
Absorption coefficient	0.087 mm^{-1}
F(000)	496
Crystal size	0.35 x 0.13 x 0.09 mm^3
Theta range for data collection	1.97 to 28.29°.
Index ranges	-7<=h<=7, -20<=k<=20, -18<=l<=17
Reflections collected	21792
Independent reflections	5896 [R(int) = 0.0346]
Completeness to theta = 28.29°	99.7 %
Absorption correction	Semi-empirical from equivalents
Max. and min. transmission	0.9924 and 0.9700
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	5896 / 1 / 313
Goodness-of-fit on F^2	1.075
Final R indices [I>2sigma(I)]	R1 = 0.0385, wR2 = 0.0867
R indices (all data)	R1 = 0.0481, wR2 = 0.0911
Absolute structure parameter	0.2(7)
Largest diff. peak and hole	0.203 and -0.219 e.Å^{-3}

Table 2. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3) for **13**. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
C(1)	3951(3)	3915(1)	1346(1)	19(1)
C(2)	4423(3)	2985(1)	1619(1)	22(1)
C(3)	2915(3)	2812(1)	2471(1)	19(1)
C(4)	2779(3)	3710(1)	2962(1)	17(1)
C(5)	2579(3)	4367(1)	2113(1)	19(1)
C(6)	786(3)	3771(1)	3624(1)	22(1)
C(7)	954(3)	4369(1)	4469(1)	21(1)
C(8)	2799(3)	4957(1)	4625(1)	23(1)
C(9)	2880(3)	5505(1)	5419(1)	29(1)
C(10)	1140(3)	5471(1)	6061(1)	31(1)
C(11)	-695(3)	4888(1)	5915(1)	31(1)
C(12)	-792(3)	4344(1)	5120(1)	26(1)
C(13)	3897(3)	2109(1)	3154(1)	26(1)
C(14)	97(3)	4490(1)	1677(1)	28(1)
C(15)	4225(3)	3155(1)	6605(1)	26(1)
C(16)	4523(3)	3672(1)	7519(1)	22(1)
C(17)	3307(3)	3202(1)	8333(1)	17(1)
C(18)	2662(3)	2307(1)	7868(1)	18(1)
C(19)	2304(3)	2487(1)	6779(1)	23(1)
C(20)	629(3)	1884(1)	8308(1)	19(1)
C(21)	922(3)	1565(1)	9324(1)	18(1)
C(22)	-929(3)	1669(1)	9918(1)	22(1)
C(23)	-770(3)	1325(1)	10840(1)	24(1)
C(24)	1193(3)	853(1)	11167(1)	22(1)
C(25)	3026(3)	743(1)	10577(1)	21(1)
C(26)	2917(3)	1110(1)	9662(1)	19(1)
C(27)	1196(3)	3739(1)	8576(1)	24(1)
C(28)	2385(4)	1674(1)	6161(1)	36(1)
O(1)	4510(2)	4285(1)	623(1)	27(1)
O(2)	3674(2)	5167(1)	2388(1)	23(1)
O(3)	-982(2)	3329(1)	3460(1)	36(1)

O(4)	-1284(2)	1813(1)	7861(1)	26(1)
O(5)	4897(2)	3074(1)	9143(1)	22(1)
O(6)	5538(2)	4355(1)	7641(1)	33(1)

Table 3. Bond lengths [Å] and angles [°] for **13**.

C(1)-O(1)	1.2185(18)
C(1)-C(2)	1.502(2)
C(1)-C(5)	1.536(2)
C(2)-C(3)	1.539(2)
C(3)-C(13)	1.524(2)
C(3)-C(4)	1.546(2)
C(4)-C(6)	1.520(2)
C(4)-C(5)	1.555(2)
C(5)-O(2)	1.4238(18)
C(5)-C(14)	1.521(2)
C(6)-O(3)	1.2295(18)
C(6)-C(7)	1.492(2)
C(7)-C(12)	1.397(2)
C(7)-C(8)	1.399(2)
C(8)-C(9)	1.390(2)
C(9)-C(10)	1.386(2)
C(10)-C(11)	1.388(3)
C(11)-C(12)	1.388(3)
C(15)-C(16)	1.503(2)
C(15)-C(19)	1.538(2)
C(16)-O(6)	1.209(2)
C(16)-C(17)	1.551(2)
C(17)-O(5)	1.4164(18)
C(17)-C(27)	1.523(2)
C(17)-C(18)	1.557(2)
C(18)-C(20)	1.502(2)
C(18)-C(19)	1.543(2)
C(19)-C(28)	1.522(3)
C(20)-O(4)	1.2290(18)
C(20)-C(21)	1.498(2)
C(21)-C(26)	1.396(2)
C(21)-C(22)	1.399(2)
C(22)-C(23)	1.387(2)
C(23)-C(24)	1.391(2)

C(24)-C(25)	1.388(2)
C(25)-C(26)	1.392(2)

O(1)-C(1)-C(2)	127.00(14)
O(1)-C(1)-C(5)	122.66(14)
C(2)-C(1)-C(5)	110.34(12)
C(1)-C(2)-C(3)	105.05(13)
C(13)-C(3)-C(2)	113.72(13)
C(13)-C(3)-C(4)	112.72(12)
C(2)-C(3)-C(4)	103.55(12)
C(6)-C(4)-C(3)	112.76(13)
C(6)-C(4)-C(5)	113.69(13)
C(3)-C(4)-C(5)	104.42(12)
O(2)-C(5)-C(14)	112.56(12)
O(2)-C(5)-C(1)	110.03(12)
C(14)-C(5)-C(1)	106.68(12)
O(2)-C(5)-C(4)	110.50(12)
C(14)-C(5)-C(4)	113.82(13)
C(1)-C(5)-C(4)	102.67(12)
O(3)-C(6)-C(7)	119.81(14)
O(3)-C(6)-C(4)	119.76(14)
C(7)-C(6)-C(4)	120.43(13)
C(12)-C(7)-C(8)	119.01(15)
C(12)-C(7)-C(6)	118.98(14)
C(8)-C(7)-C(6)	122.01(14)
C(9)-C(8)-C(7)	120.09(15)
C(10)-C(9)-C(8)	120.30(17)
C(9)-C(10)-C(11)	120.14(16)
C(10)-C(11)-C(12)	119.80(15)
C(11)-C(12)-C(7)	120.67(16)
C(16)-C(15)-C(19)	105.18(13)
O(6)-C(16)-C(15)	127.35(15)
O(6)-C(16)-C(17)	122.67(14)
C(15)-C(16)-C(17)	109.99(13)
O(5)-C(17)-C(27)	112.13(12)
O(5)-C(17)-C(16)	110.55(12)

C(27)-C(17)-C(16)	108.19(12)
O(5)-C(17)-C(18)	109.36(12)
C(27)-C(17)-C(18)	113.78(12)
C(16)-C(17)-C(18)	102.40(12)
C(20)-C(18)-C(19)	115.12(13)
C(20)-C(18)-C(17)	112.50(12)
C(19)-C(18)-C(17)	105.21(12)
C(28)-C(19)-C(15)	114.26(14)
C(28)-C(19)-C(18)	113.66(14)
C(15)-C(19)-C(18)	103.11(12)
O(4)-C(20)-C(21)	119.31(14)
O(4)-C(20)-C(18)	121.48(14)
C(21)-C(20)-C(18)	119.18(13)
C(26)-C(21)-C(22)	119.71(14)
C(26)-C(21)-C(20)	121.41(13)
C(22)-C(21)-C(20)	118.69(13)
C(23)-C(22)-C(21)	119.96(14)
C(22)-C(23)-C(24)	120.27(15)
C(25)-C(24)-C(23)	119.87(14)
C(24)-C(25)-C(26)	120.30(14)
C(25)-C(26)-C(21)	119.84(14)

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters ($Å^2 x\ 10^3$) for **13**. The anisotropic displacement factor exponent takes the form: $-2p^2[\ h^2a^{*2}U^{11} + ... + 2\ h\ k\ a^*\ b^*\ U^{12}\ ]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
C(1)	19(1)	18(1)	18(1)	-2(1)	-4(1)	-3(1)
C(2)	26(1)	18(1)	22(1)	-2(1)	3(1)	1(1)
C(3)	20(1)	16(1)	21(1)	0(1)	-1(1)	-2(1)
C(4)	16(1)	18(1)	17(1)	-1(1)	0(1)	-1(1)
C(5)	20(1)	15(1)	21(1)	1(1)	-1(1)	-1(1)
C(6)	20(1)	23(1)	24(1)	1(1)	2(1)	-3(1)
C(7)	20(1)	23(1)	20(1)	2(1)	1(1)	3(1)
C(8)	23(1)	26(1)	21(1)	0(1)	4(1)	-3(1)
C(9)	31(1)	30(1)	27(1)	-4(1)	3(1)	-5(1)
C(10)	35(1)	35(1)	24(1)	-7(1)	4(1)	2(1)
C(11)	28(1)	41(1)	26(1)	2(1)	10(1)	5(1)
C(12)	19(1)	32(1)	26(1)	2(1)	4(1)	-1(1)
C(13)	29(1)	20(1)	29(1)	5(1)	-3(1)	-4(1)
C(14)	21(1)	23(1)	38(1)	4(1)	-5(1)	1(1)
C(15)	27(1)	30(1)	20(1)	4(1)	1(1)	0(1)
C(16)	16(1)	25(1)	24(1)	3(1)	-1(1)	-1(1)
C(17)	17(1)	16(1)	19(1)	0(1)	-2(1)	0(1)
C(18)	19(1)	17(1)	19(1)	-1(1)	-2(1)	5(1)
C(19)	23(1)	25(1)	19(1)	0(1)	-2(1)	1(1)
C(20)	21(1)	12(1)	23(1)	-3(1)	-1(1)	2(1)
C(21)	18(1)	14(1)	23(1)	-1(1)	-1(1)	-3(1)
C(22)	18(1)	18(1)	30(1)	2(1)	-1(1)	0(1)
C(23)	22(1)	23(1)	28(1)	-1(1)	7(1)	-3(1)
C(24)	26(1)	16(1)	22(1)	2(1)	-2(1)	-6(1)
C(25)	21(1)	15(1)	26(1)	-1(1)	-4(1)	1(1)
C(26)	18(1)	15(1)	24(1)	-3(1)	1(1)	-1(1)
C(27)	20(1)	19(1)	34(1)	-1(1)	1(1)	3(1)
C(28)	50(1)	36(1)	24(1)	-7(1)	1(1)	-2(1)
O(1)	40(1)	21(1)	20(1)	1(1)	4(1)	-6(1)
O(2)	26(1)	13(1)	29(1)	-1(1)	-1(1)	-1(1)
O(3)	26(1)	44(1)	38(1)	-11(1)	9(1)	-18(1)

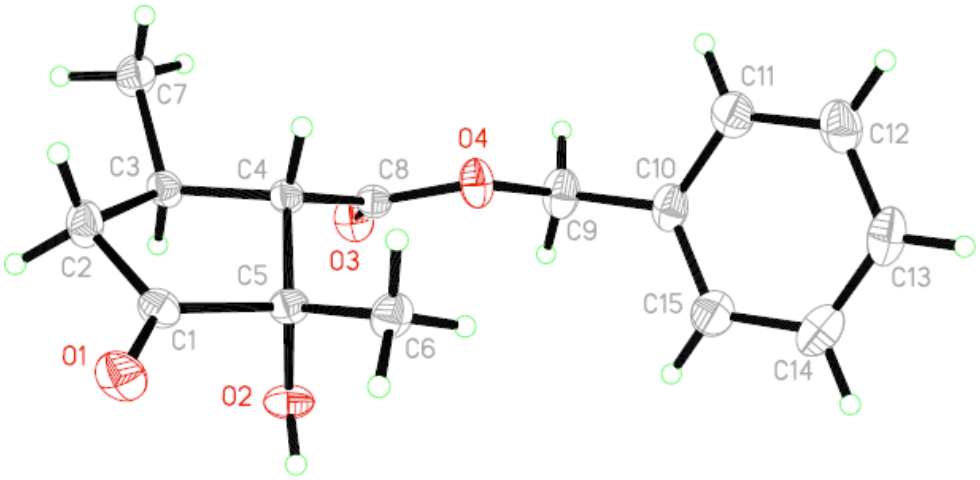
O(4)	21(1)	25(1)	30(1)	3(1)	-8(1)	-3(1)
O(5)	25(1)	22(1)	18(1)	-2(1)	-4(1)	3(1)
O(6)	34(1)	35(1)	31(1)	1(1)	2(1)	-15(1)

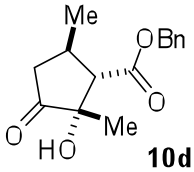
Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters ($Å^2$x 10^3) for **13**.

	x	y	z	U(eq)
H(2A)	6066	2899	1807	26
H(2B)	3981	2601	1086	26
H(3)	1343	2642	2221	23
H(4)	4254	3815	3341	21
H(8)	3973	4982	4197	27
H(9)	4108	5896	5519	35
H(10)	1202	5840	6590	38
H(11)	-1855	4862	6350	38
H(12)	-2033	3958	5020	31
H(13A)	4006	1572	2810	39
H(13B)	2880	2035	3668	39
H(13C)	5422	2278	3415	39
H(14A)	-807	4796	2123	42
H(14B)	-598	3933	1540	42
H(14C)	130	4819	1093	42
H(15A)	5672	2865	6474	31
H(15B)	3755	3528	6065	31
H(18)	4018	1923	7973	22
H(19)	779	2766	6650	27
H(22)	-2266	1968	9695	26
H(23)	-1981	1411	11241	29
H(24)	1278	611	11779	26
H(25)	4332	423	10793	25
H(26)	4171	1052	9277	23
H(27A)	409	3455	9076	36
H(27B)	144	3796	8014	36
H(27C)	1704	4304	8792	36
H(28A)	2182	1832	5495	55
H(28B)	1155	1286	6317	55
H(28C)	3867	1392	6283	55

H(2)	2862	5573	2180	34
H(5)	4834	3490	9508	33

X-Ray Crystal Structure for Compound 10d (Minor Diastereomer)





10d

Table 6. Crystal data and structure refinement for **10d** (minor diastereomer).

Identification code	**10d**	
Empirical formula	$C_{15}H_{18}O_4$	
Formula weight	262.29	
Temperature	120 K	
Wavelength	0.71073 Å	
Crystal system	Monoclinic	
Space group	$P2_1$	
Unit cell dimensions	a = 11.8387(6) Å	α = 90°.
	b = 4.9870(3) Å	β = 107.049(3)°.
	c = 12.2899(6) Å	γ = 90°.
Volume	693.70(6) Å^3	
Z	2	
Density (calculated)	1.256 Mg/m^3	
Absorption coefficient	0.090 mm^{-1}	
F(000)	280	
Crystal size	0.33 x 0.32 x 0.28 mm^3	

Theta range for data collection	1.73 to 32.59°.
Index ranges	-17<=h<=17, -7<=k<=7, -17<=l<=18
Reflections collected	17342
Independent reflections	4947 [R(int) = 0.0342]
Completeness to theta = 32.59°	99.9 %
Absorption correction	Semi-empirical from equivalents
Max. and min. transmission	0.9753 and 0.9710
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	4947 / 1 / 175
Goodness-of-fit on F^2	1.035
Final R indices [I>2sigma(I)]	R1 = 0.0434, wR2 = 0.1091
R indices (all data)	R1 = 0.0526, wR2 = 0.1158
Absolute structure parameter	-0.3(7)
Largest diff. peak and hole	0.363 and -0.281 e.$Å^{-3}$

Table 7. Atomic coordinates (x 10^4) and equivalent isotropic displacement parameters ($Å^2$x 10^3) for **10d**. U(eq) is defined as one third of the trace of the orthogonalized U^{ij} tensor.

	x	y	z	U(eq)
C(1)	6745(1)	9272(2)	239(1)	21(1)
C(2)	7958(1)	9599(3)	99(1)	25(1)
C(3)	8812(1)	8255(2)	1141(1)	20(1)
C(4)	8168(1)	8575(2)	2054(1)	17(1)
C(5)	6853(1)	8108(2)	1427(1)	18(1)
C(6)	5981(1)	9235(3)	1995(1)	24(1)
C(7)	10047(1)	9467(3)	1470(1)	26(1)
C(8)	8618(1)	6737(2)	3067(1)	19(1)
C(9)	8510(1)	5804(3)	4935(1)	29(1)
C(10)	7658(1)	6491(3)	5590(1)	25(1)
C(11)	7885(1)	8629(3)	6352(1)	30(1)
C(12)	7089(1)	9287(3)	6939(1)	32(1)
C(13)	6067(1)	7795(3)	6785(1)	34(1)
C(14)	5832(1)	5674(3)	6027(1)	38(1)
C(15)	6623(1)	5037(3)	5428(1)	32(1)
O(1)	5814(1)	9740(2)	-476(1)	28(1)
O(2)	6701(1)	5267(2)	1229(1)	24(1)
O(3)	9249(1)	4817(2)	3111(1)	27(1)
O(4)	8208(1)	7518(2)	3925(1)	25(1)

Table 8. Bond lengths [Å] and angles [°] for **10d**.

C(1)-O(1)	1.2141(13)	O(2)-C(5)-C(1)	103.77(9)
C(1)-C(2)	1.5051(16)	C(6)-C(5)-C(1)	114.71(9)
C(1)-C(5)	1.5416(16)	C(4)-C(5)-C(1)	102.01(9)
C(2)-C(3)	1.5338(16)	O(3)-C(8)-O(4)	123.86(11)
C(3)-C(7)	1.5228(16)	O(3)-C(8)-C(4)	125.65(11)
C(3)-C(4)	1.5389(15)	O(4)-C(8)-C(4)	110.49(9)
C(4)-C(8)	1.5110(15)	O(4)-C(9)-C(10)	106.64(9)
C(4)-C(5)	1.5390(15)	C(15)-C(10)-C(11)	119.00(12)
C(5)-O(2)	1.4399(14)	C(15)-C(10)-C(9)	120.50(12)
C(5)-C(6)	1.5134(16)	C(11)-C(10)-C(9)	120.49(12)
C(8)-O(3)	1.2057(14)	C(12)-C(11)-C(10)	120.36(13)
C(8)-O(4)	1.3415(14)	C(11)-C(12)-C(13)	120.18(14)
C(9)-O(4)	1.4622(15)	C(14)-C(13)-C(12)	119.86(13)
C(9)-C(10)	1.5025(18)	C(13)-C(14)-C(15)	119.95(14)
C(10)-C(15)	1.3870(18)	C(14)-C(15)-C(10)	120.64(14)
C(10)-C(11)	1.3927(19)	C(8)-O(4)-C(9)	116.31(9)
C(11)-C(12)	1.384(2)		
C(12)-C(13)	1.385(2)		
C(13)-C(14)	1.383(2)		
C(14)-C(15)	1.387(2)		
O(1)-C(1)-C(2)	126.21(11)		
O(1)-C(1)-C(5)	124.33(10)		
C(2)-C(1)-C(5)	109.41(9)		
C(1)-C(2)-C(3)	105.94(9)		
C(7)-C(3)-C(2)	113.23(10)		
C(7)-C(3)-C(4)	114.07(9)		
C(2)-C(3)-C(4)	102.56(9)		
C(8)-C(4)-C(3)	114.03(9)		
C(8)-C(4)-C(5)	112.40(9)		
C(3)-C(4)-C(5)	105.32(9)		
O(2)-C(5)-C(6)	112.05(9)		
O(2)-C(5)-C(4)	106.95(9)		
C(6)-C(5)-C(4)	116.11(9)		

Symmetry transformations used to generate equivalent atoms:

Table 9. Anisotropic displacement parameters ($Å^2 x\ 10^3$) for **10d**. The anisotropic displacement factor exponent takes the form: $-2\pi^2[\ h^2 a^{*2} U^{11} + ... + 2\ h\ k\ a^*\ b^*\ U^{12}\ ]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
C(1)	18(1)	22(1)	19(1)	-1(1)	1(1)	2(1)
C(2)	20(1)	36(1)	19(1)	4(1)	5(1)	2(1)
C(3)	15(1)	26(1)	17(1)	-2(1)	4(1)	1(1)
C(4)	15(1)	21(1)	16(1)	-1(1)	4(1)	-1(1)
C(5)	14(1)	20(1)	19(1)	1(1)	3(1)	1(1)
C(6)	18(1)	28(1)	27(1)	1(1)	9(1)	3(1)
C(7)	16(1)	38(1)	25(1)	1(1)	6(1)	-2(1)
C(8)	14(1)	24(1)	18(1)	-1(1)	2(1)	-2(1)
C(9)	26(1)	38(1)	22(1)	10(1)	7(1)	8(1)
C(10)	22(1)	35(1)	17(1)	8(1)	4(1)	5(1)
C(11)	23(1)	42(1)	21(1)	3(1)	1(1)	-1(1)
C(12)	33(1)	42(1)	20(1)	3(1)	5(1)	4(1)
C(13)	34(1)	45(1)	29(1)	9(1)	17(1)	6(1)
C(14)	31(1)	42(1)	45(1)	5(1)	19(1)	-4(1)
C(15)	31(1)	34(1)	31(1)	1(1)	11(1)	-2(1)
O(1)	19(1)	35(1)	24(1)	2(1)	-2(1)	5(1)
O(2)	16(1)	20(1)	30(1)	-1(1)	0(1)	-1(1)
O(3)	23(1)	32(1)	24(1)	4(1)	5(1)	7(1)
O(4)	28(1)	31(1)	18(1)	5(1)	8(1)	7(1)

Table 10. Hydrogen coordinates (x 10^4) and isotropic displacement parameters ($Å^2$x 10^3) for **10d**.

	x	y	z	U(eq)
H(2A)	8150	11483	69	30
H(2B)	8001	8740	-596	30
H(3)	8868	6342	981	24
H(4)	8265	10432	2327	21
H(6A)	6022	8221	2669	35
H(6B)	5196	9123	1479	35
H(6C)	6171	11076	2195	35
H(7A)	10543	8533	2117	40
H(7B)	10004	11327	1656	40
H(7C)	10372	9306	843	40
H(9A)	9315	6136	5395	34
H(9B)	8436	3929	4716	34
H(11)	8576	9619	6468	35
H(12)	7240	10735	7437	38
H(13)	5540	8218	7191	41
H(14)	5145	4675	5919	45
H(15)	6457	3622	4913	38
H(2)	5997	4932	948	35