Highly enantioselective benzoin condensation reactions involving a bifunctional protic pentafluorophenyl substituted triazolium precatalyst

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1.0 General

Proton Nuclear Magnetic Resonance spectra were recorded on 400 MHz and 600 MHz spectrometers in $CDCl_3$ referenced relative to residual $CHCl_3$ (δ = 7.26 ppm), DMSO-d_6 referenced relative to residual DMSO (H) (δ = 2.51 ppm) and CD_3CN referenced relative to residual CH_3CN (δ = 1.96 ppm). Chemical shifts are reported in ppm and coupling constants in Hertz. Fluorine 19 spectra were referenced externally (0.05% trifluorotoluene: -62.7 ppm). Carbon NMR spectra were recorded on the same instruments (100 MHz and 150 MHz) with total proton decoupling. All melting points are uncorrected. Infrared spectra were obtained using neat samples on a FT-IR spectrometer equipped with a universal ATR sampling accessory. Flash chromatography was carried out using silica gel, particle size 0.04-0.063 mm. TLC analysis was performed on precoated $60F_{254}$ slides, and visualised by either UV irradiation or $KMnO_4$ staining. Optical rotation measurements are quoted in units of 10^{-1} deg cm^2 g^{-1}. Toluene, ether and THF were distilled from sodium. Methylene chloride and triethylamine were distilled from calcium hydride. Analytical CSP-HPLC was performed using Daicel CHIRALCEL AD (4.6 mm x 25 cm) and CHIRALCEL OD-H (4.6 mm x 25 cm) and CHIRALCEL OJ-H (4.6 mm x 25 cm) columns. Unless otherwise stated, all chemicals were obtained from commercial sources and used as received. All reactions were carried out in oven-dried glassware with magnetic stirrers under an atmosphere of argon, unless specified.

2.0 Reaction conditions

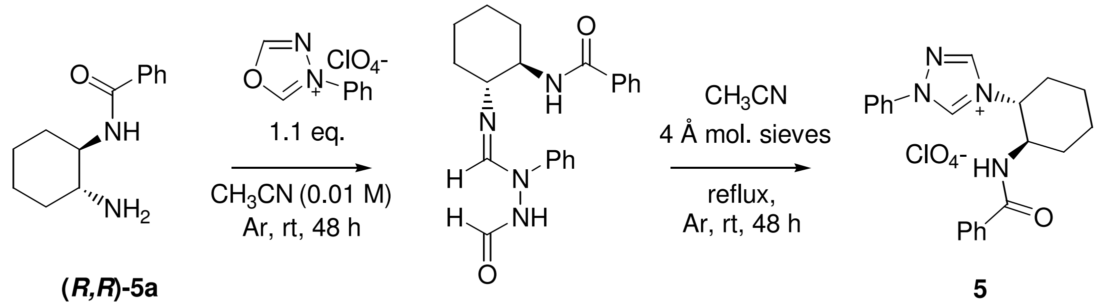
Optimised conditions – Rb_2CO_3 as base

To a 5 mL round bottom flask, equipped with a magnetic stirring bar, Rb_2CO_3 (99.995%, anhydrous, 0.044 mmol, 10.16 mg) that had been finely ground using a mortar and pestle, was added. The reaction vessel was put under vacuum and heated with a heat gun for 1 minute over two-minute intervals for a total of 4 minutes. Upon cooling, the appropriate catalyst (0.044 mmol) and (*E*)-stilbene (0.138 mmol, 24.78 mg) were added and the flask was fitted with a septum seal. The reaction was evacuated for 4 min and put under an atmosphere of Ar. The required aldehyde was distilled under vacuum and used directly. THF (1.1 M) was charged to the reaction, followed by the aldehyde (1.100 mmol). The reaction was stirred at room temperature for 20 h after which CH_2Cl_2 (3.0 mL) and deionised H_2O (3.0 mL) were added. The lower organic layer was removed and the aqueous layer was washed with CH_2Cl_2 (4 x 3.0 mL). The organic layers were combined, dried ($MgSO_4$), filtered and the solvent removed under reduced pressure. The product was purified using column chromatography.

3.0 Characterization data

Synthesis of catalysts

4-(2-Benzoylamino-cyclohexyl)-1-phenyl-1*H*-[1,2,4]triazol-4-ium perchlorate (5)

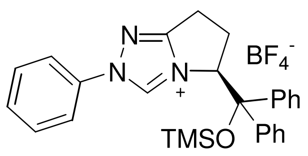


A 10 mL round bottom flask, containing a stirring bar, was charged with oxadiazolium perchlorate (2.07 mmol, 0.501 g). The flask was fitted with a septum and placed under an Ar atmosphere (balloon). 5a (1.880 mmol, 0.398 g) dissolved in CH_3CN (20.0 mL) was added dropwise, *via* syringe, to the flask and the reaction was stirred at room temperature for 45 min. The crude reaction mixture was concentrated *in vacuo* and recrystallisation from hot CH_3CN gave the acylic intermediate (0.420 mmol, 0.153 g) as a white solid. A 10 mL round bottom flask containing a stirring bar was charged with the resulting crystalline solid (0.420 mmol, 0.153 g) and 4 Å molecular sieves (0.100 g). The flask was fitted with a reflux condenser and septum and placed under an Ar atmosphere (balloon). CH_3CN

(2.0 mL) was added *via* syringe and the resulting solution heated, under reflux, at 90 °C for 48 h. The reaction mixture was filtered to remove the molecular sieves and washed with CH_3CN (3 x 5 mL). The resulting solution was concentrated *in vacuo* resulting in a pale yellow solid. Recrystallization from hot acetonitrile gave **5** (0.054 g, 6 %) as a white crystalline solid, mp 218-219 °C, $[\alpha]_D^{20}$ = -94.2 (c 0.60 in CH_3OH).

^{1}H NMR (600 MHz, DMSO-d_6) δ 1.40 – 1.52 (m, 2H), 1.67 – 1.78 (m, 1H), 1.86 – 2.01 (m, 3H), 2.11 – 2.26 (m, 1H), 2.30 – 2.39 (m, 1H) 4.22 – 4.47 (m, 2H), 7.42 (app. t, 2H), 7.45 -7.55 (m, 1H), 7.56-7.75 (m, 5H), 7.85 (d, J = 12.0 Hz, 2H), 8.60 (d, J = 11.3 Hz, 1H), 9.43 (s, 1H), 11.18 (s, 1H). ^{13}C NMR (150 MHz, DMSO-d_6) δ 24.6, 24.7, 32.1, 32.4, 51.7, 61.4, 120.2, 127.8, 128.5, 128.6, 130.3, 131.7, 135.0 (q), 140.6 (q), 154.7, 160.1, 167.1 (C=O). λ_{max} (neat)/cm^{-1} 721, 972, 1044, 1318, 1519, 1572, 1651, 3391. HRMS (ES) Found: 347.1862 (M^+ -ClO_4^-) $C_{21}H_{23}N_4O$ requires 347.1872.

(*S*)-5-(Diphenyl-trimethylsilanyloxy-methyl)-2-phenyl-6,7-dihydro-5*H*-pyrrolo[2,1-c][1,2,4] triazol-2-ium tetrafluoroborate (2a)

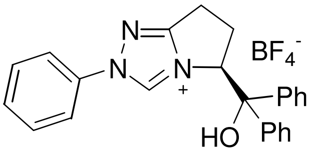


2a

This compound was synthesised according to the literature. Recrystallisation from hot MeOH gave **2a** (1.578 g, 58 %) as pale yellow crystals, mp 199-200 °C, lit.[1] 196-198 °C. $[\alpha]_D^{20}$ = -122.6 (c 0.50 in CH_3CN), lit.[1] $[\alpha]_D^{20}$ = -113.8 (c 0.50 in CH_3CN).

^{1}H NMR (400 MHz, $CDCl_3$) δ 0.07 (s, 9H), 2.06 – 2.10 (m, 1H), 2.76 – 2.82 (m, 1H), 2.89 – 2.94 (m, 1H), 3.30 – 3.36 (m, 1H), 6.14 (d, J = 9.01 Hz, 1H), 7.30 – 7.36 (m, 2H), 7.38 – 7.43 (m, 5H), 7.48 – 7.52 (m, 3H), 7.58 – 7.61 (m, 3H), 7.71 – 7.73 (m, 2H), 8.90 (s, 1H).

(*S*)-5-[Hydroxy(diphenyl)methyl]-2-phenyl-6,7-dihydro-5*H*-pyrrolo[2,1-c][1,2,4]triazol-2-ium tetrafluoroborate (2b)



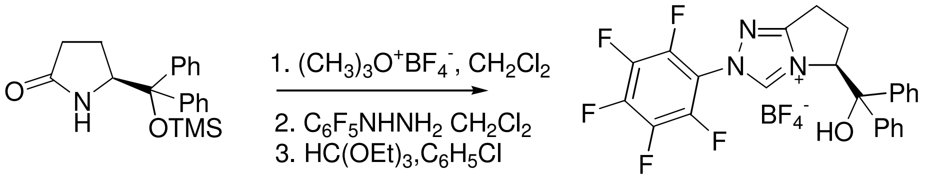
2b

A 100 mL round bottom flask was charged with **2a** (1.352 mmol, 0.713 g). The flask was fitted with a rubber septum and placed under an atmosphere of Ar (balloon). MeOH (67.5 mL) was added *via* syringe. To this reaction mixture TMSBr (10 % solution in MeOH) (3.4 mL) was added *via* syringe. The reaction mixture was stirred at room temperature for 2 h and then concentrated *in vacuo* to give **2b**

(0.615 g, 99 %) as an off-white crystalline solid, mp 197-180 °C. $[\alpha]_D^{20}$ = -55.4 (c 0.5, CH_3OH), lit.[2] $[\alpha]_D^{20}$ = -58.6 (c 0.5, CH_3CN).

^{1}H NMR (600 MHz, DMSO-*d*$_6$) δ 2.50 - 2.59 (m, 1H), 2.93 – 2.95 (m, 2H), 3.13 – 3.16 (m, 1H), 6.13 (d, J = 9.8 Hz, 1H), 6.58 (s, 1H), 7.30 (t, J = 7.2 Hz, 1H), 7.37 – 7.39 (m, 3H), 7.45 (app. t, 2H), 7.52 (d, J = 7.8 Hz, 2H), 7.58 (d, J = 7.8 Hz, 2H), 7.63-7.68 (m, 3H), 7.78 (d, J = 7.8 Hz, 2H), 9.60 (s, 1H). HRMS (ES) Found: 368.1754 (M^+ -BF_4^-) $C_{24}H_{22}N_3O$ requires 368.1763.

5-(Hydroxy-diphenyl-methyl)-2-pentafluorophenyl-6,7-dihydro-5*H*-pyrrolo[2,1-c][1,2,4] triazol-2-ium tetrafluoroborate (8)



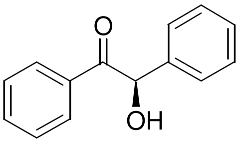
8

A 100 mL round bottom flask was charged with (*S*)-5-(diphenyl-trimethylsilanyloxy-methyl)-pyrrolidin-2-one (5.89 mmol, 2.00 g). CH_2Cl_2 (28 mL) was added *via* syringe followed by trimethyloxonium tetrafluoroborate (5.891 mmol, 0.871 g). The flask was fitted with a rubber septum and placed under an atmosphere of Ar (balloon) and the resulting solution stirred at room temperature for 15 h. Pentafluorophenylhydrazine (5.891 mmol, 1.167 g) was added to the reaction, which was then allowed stir at room temperature for 2 h. The crude reaction mixture was concentrated *in vacuo* resulting in a pale yellow residue. Chlorobenzene (54 mL) was added, followed by triethylorthoformate (2.5 mL) and the mixture was heated under reflux at 120 °C for 12 h. Additional triethylorthoformate (2.5 mL) was added and reflux was continued for a further 12 h. Upon cooling, the reaction mixture was concentrated *in vacuo* resulting in a pale brown residue. A 100 mL round bottom flask was charged with the crude reaction material (6.787 mmol, 4.190 g). The flask was fitted with a rubber septum and placed under an atmosphere of Ar (balloon). MeOH (200 mL) was added *via* syringe. To this reaction mixture TMSBr (10 % solution in MeOH) (1.69 mL) was added *via* syringe. The reaction mixture was stirred at room temperature for 24 h and then concentrated *in vacuo*. Recrystallisation from EtOAc gave **8** (1.141 g, 31 %) as a pale yellow crystalline solid mp 225-226 °C, $[\alpha]_D^{20}$ = -205.5 (c 1.0, CH_3Cl).

^{1}H NMR (600 MHz, DMSO-*d*$_6$) δ 2.70 (app. t., 1H), 2.89 – 2.93 (m, 1H), 3.01 - 3.05 (m, 1H), 3.19 – 3.21 (m, 1H), 6.16 (d, J = 6.6 Hz, 1H), 6.80 (s, 1H), 7.32 (app. t., 1H), 7.36 – 7.40 (m, 3H), 7.43 – 7.47 (m, 4H), 7.55 (d, J = 7.4 Hz, 2H), 9.61 (s, 1H). ^{13}C NMR (600 MHz, DMSO-*d*$_6$) δ 21.4, 29.7, 68.1, 78.8 (q), 111.2 (q), 126.1, 127.7, 128.1, 128.5, 128.9, 136.6 (m), 138.2 (m), 141.7 (m), 142.2 (m), 142.8 (q), 143.2 (q), 143.5, 164.7 (q). ^{19}F NMR (376 MHz, DMSO-*d*$_6$) δ -145.5 (d, J = 5.6 Hz, 1F), -147.7 (t, J = 6.2 Hz, 1F), -160.1 (dd, J = 5.6, 2.7 Hz, 1F). λ_{max} (neat)/cm^{-1} 694, 872, 1002, 1071, 1523, 3185. HRMS (ES) Found: 458.1294 (M^+-BF_4^-) $C_{24}H_{17}N_3OF_5$ requires 458.1292.

Synthesis of benzoins

(*R*)-2-Hydroxy-1,2-diphenyl-ethanone (6)



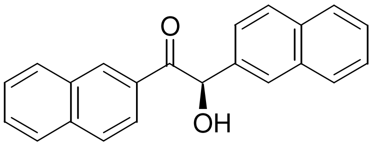
(*R*)-6

Prepared according to the optimised reaction conditions (above) using catalyst **8**. Purification by column chromatography (6:4 CH_2Cl_2:hexane, R_f 0.2) gave **(*R*)-6** (105 mg, 90%) as a white solid, mp 131-132 °C, lit.[4] 132-133 °C, 99.8 % ee. $[\alpha]_D^{20}$ = -35.1 (c 1.0 in CH_3OH), lit.[5] $[\alpha]_D^{20}$ = -113.8 (c 1.5 in CH_3COCH_3), for *R* enantiomer with 99 % ee.

Chiralpak AD (4.6 mm x 25 cm), hexane/IPA: 9/1, 1.0 mL min^{-1}, RT, UV detection at 220 nm, retention times: 20.4 min (major enantiomer) and 26.9 (minor enantiomer).

^{1}H NMR (400 MHz, $CDCl_3$) δ 4.58 (bs, 1H), 5.98 (s, 1H), 7.29-7.40 (m, 5H (overlapping with $CHCl_3$ resonance)), 7.43 (app. t, 2H), 7.55 (t, J = 8.0 Hz, 1H), 7.95 (d, J = 8.0 Hz, 2H).

(*R*)-2-Hydroxy-1,2-di-naphthalen-2-yl-ethanone (18)



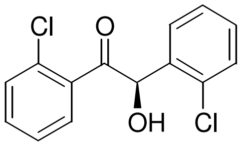
(*R*)-18

Prepared according to the optimised reaction conditions (above) using catalyst **8**. Purification by column chromatography (6:4 CH_2Cl_2:hexane, R_f 0.1) gave **(*R*)-18** (147.9 mg, 86%) as a white solid, mp 124-125 °C, lit.[6] 125-126 °C, 94 % ee. $[\alpha]_D^{20}$ = +105.5 (c 0.5 in CH_3OH), lit.[7] $[\alpha]_D^{20}$ = -48.3 (c 0.5 in CH_3OH) for *S* enantiomer with 92 % ee.

Chiralpak AD (4.6 mm x 25 cm), hexane/IPA: 8/2, 1.0 mL min^{-1}, RT, UV detection at 254 nm, retention times: 26.4 min (major enantiomer) and 44.8 (minor enantiomer).

^{1}H NMR (400 MHz, $CDCl_3$) δ 4.78 (bs, 1H), 6.31 (s, 1H), 7.48-7.66 (m, 5H), 7.78-7.85 (m, 5H), 7.90 (d, J = 8.0 Hz, 1H), 7.95 (s, 1H), 8.00 (d, J = 8.0 Hz, 1H), 8.54 (s, 1H).

(*R*)-1,2-Bis-(2-chloro-phenyl)-2-hydroxy-ethanone (19)



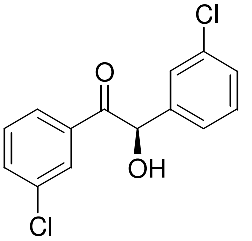
(*R*)-19

Prepared according to the optimised reaction conditions (above) using catalyst **8**. Purification by column chromatography (6:4 CH_2Cl_2:hexane, R_f 0.2) gave **(*R*)-19** (26.6 mg, 17%) as a pale yellow solid, mp 65-66 °C, lit.[8] 64 °C, 43 % ee. $[\alpha]_D^{20}$ = -25.1 (c 1.0 in $CHCl_3$), lit.[5] $[\alpha]_D^{20}$ = -46.0 (c 1.0 in $CHCl_3$) for *R* enantiomer with 97 % ee.

Chiralpak AD (4.6 mm x 25 cm), hexane/IPA: 9/1, 0.8 mL min^{-1}, RT, UV detection at 254 nm, retention times: 22.2 min (minor enantiomer) and 24.9 (major enantiomer).

^1H NMR (400 MHz, $CDCl_3$) δ 4.46 (bs, 1H), 6.38 (s, 1H), 7.23-7.26 (m, 5H (overlapping with $CHCl_3$ resonance)), 7.31 - 7.40 (m, 3H).

(*R*)-1,2-Bis-(3-chloro-phenyl)-2-hydroxy-ethanone (20)



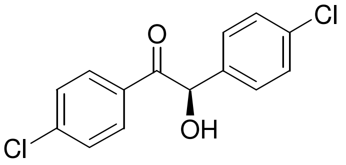
(*R*)-20

Prepared according to the optimised reaction conditions (above) using catalyst **8**. Purification by column chromatography (6:4 CH_2Cl_2:hexane, R_f 0.3) gave **(*R*)-20** (134.2 mg, 87%) as a white solid, mp 77-78 °C, lit.[8] 76-77 °C, 83 % ee. $[\alpha]_D^{20}$ = -100.5 (c 1.1 in $CHCl_3$), lit.[5] $[\alpha]_D^{20}$ = -31.0 (c 1.2 in $CHCl_3$) for *R* enantiomer with 99 % ee.

Chiralpak AD (4.6 mm x 25 cm), hexane/IPA: 9/1, 0.8 mL min^{-1}, RT, UV detection at 254 nm, retention times: 19.5 min (major enantiomer) and 26.6 (minor enantiomer).

^1H NMR (400 MHz, $CDCl_3$) δ 4.58 (bs, 1H), 5.91 (s, 1H), 7.23-7.29 (m, 3H (overlapping with $CHCl_3$ resonance)), 7.35 – 7.38 (m, 2H) 7.51 (d, J = 7.0 Hz, 1H), 7.75 (d, J = 8.0 Hz, 1H), 7.92 (s, 1H).

(***R***)-1,2-Bis-(4-chloro-phenyl)-2-hydroxy-ethanone (21)



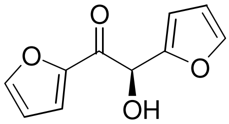
(*R*)-21

Prepared according to the optimised reaction conditions using catalyst **8**. Purification by column chromatography (6:4 CH_2Cl_2:hexane, R_f 0.3) gave **(*R*)-21** (139.7 mg, 91%) as a white solid, mp 87-88 °C, lit.[8] 87-88 °C, 92 % ee. $[\alpha]_D^{20}$ = -31.1 (c 1.0 in CH_3OH), lit.[9] $[\alpha]_D^{20}$ = -12.3 (c 1.0 in CH_3OH), for *R* enantiomer with 29% ee.

Chiralpak OJ-H (4.6 mm x 25 cm), hexane/IPA: 95/5, 0.6 mL min^{-1}, RT, UV detection at 220 nm, retention times: 34.1 min (minor enantiomer) and 36.2 (major enantiomer).

^1H NMR (400 MHz, $CDCl_3$) δ 4.49 (bs, 1H), 5.90 (s, 1H), 7.26-7.27 (d, 2H (overlapping with $CHCl_3$ resonance)), 7.32 (d, J = 8.0 Hz, 2H), 7.40 (d, J = 7.8 Hz, 2H), 7.84 (d, J = 7.8 Hz, 2H).

(***R***)-1,2-Di-furan-2-yl-2-hydroxy-ethanone (22)



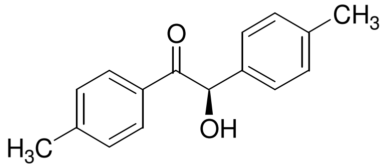
(*R*)-22

Prepared according to the optimised reaction conditions using catalyst **8**. Purification by column chromatography (CH_2Cl_2, R_f 0.2) gave **(*R*)-22** (97.5 mg, 92%) as a white solid, mp 137-138 °C, lit.[10] 135-136 °C, 90 % ee. $[\alpha]_D^{20}$ = -40.9 (c 1.0 in CH_3OH), lit.[5] $[\alpha]_D^{20}$ = -21.6 (c 1.0 in CH_3OH) for *R* enantiomer with 92 % ee.

Chiralpak AD (4.6 mm x 25 cm), hexane/IPA: 9/1, 0.8 mL min^{-1}, RT, UV detection at 254 nm, retention times: 26.5 min (minor enantiomer) and 32.1 (major enantiomer).

^1H NMR (400 MHz, $CDCl_3$) δ 4.22 (bs, 1H), 5.82 (bs, 1H), 6.37 (dd, J = 3.0, 1.5 Hz, 1H), 6.42 (d, J = 3.5Hz, 1H), 6.56 (dd, J = 4.0, 2.2 Hz, 1H), 7.27 (m, 1H (overlapping with $CHCl_3$ resonance)), 7.39 (d, J = 1.5 Hz, 1H), 7.63 (app. s, 1H).

(*R*)-1,2-Bis-(4-chloro-phenyl)-2-hydroxy-ethanone (24)



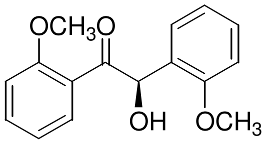
(*R*)-24

Prepared according to the optimised reaction conditions using catalyst **8**. Purification by column chromatography (6:4 CH_2Cl_2:hexane, R_f 0.1) gave **(*R*)-24** (116.1 mg, 87%) as a white solid, mp 89-90 °C, lit.[8] 89-90 °C, 95 % ee. $[\alpha]_D^{20}$ = -90.8 (c 1.0 in CH_3OH), lit.[11] $[\alpha]_D^{20}$ = -130.8 (c 1.0 in CH_3OH) for *R* enantiomer with 92 % ee.

Chiralpak AD (4.6 mm x 25 cm), hexane/IPA: 9/1, 0.8 mL min^{-1}, RT, UV detection at 254 nm, retention times: 28.8 min (major enantiomer) and 33.1 (minor enantiomer).

^{1}H NMR (400 MHz, $CDCl_3$) δ 2.31 (s, 3H), 2.38 (s, 3H), 4.57 (bs, 1H), 5.92 (bs, 1H), 7.14-7.15 (d, J = 7.5 Hz, 2H), 7.20-7.27 (m, 4H), 7.84 (d, J = 8.5 Hz, 2H).

(*R*)-2-Hydroxy-1,2-bis-(2-methoxy-phenyl)ethanone (25)



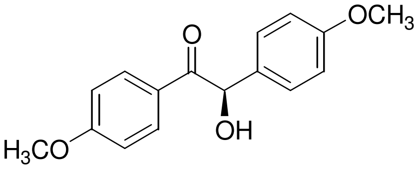
(R)-25

Prepared according to the optimised reaction conditions using catalyst **8**. Purification by column chromatography (CH_2Cl_2, R_f 0.2) gave **(*R*)-25** (30.8 mg, 21%) as an off white solid, mp 99-100 °C, lit.[12] mp 98-99 °C, 82 % ee. $[\alpha]_D^{20}$ = -43.1 (c 0.3 in $CHCl_3$), lit.[5] $[\alpha]_D^{20}$ = -125.0 (c 0.9 in $CHCl_3$) for *R* enantiomer with 99 % ee.

Chiralpak OD-H (4.6 mm x 25 cm), hexane/IPA: 85/15, 0.5 mL min^{-1}, RT, UV detection at 254 nm, retention times: 30.8 min (major enantiomer) and 43.7 (minor enantiomer).

^{1}H NMR (400 MHz, $CDCl_3$) δ 3.73 (s, 3H), 3.74 (s, 3H), 4.50 (d, J = 5.5 Hz, 1H), 6.13 (d, J = 5.5 Hz, 1H), 6.78 (app. t, 2H), 6.85 (app. t, 1H), 6.94 (app. t, 1H), 7.16 – 7.21 (m, 2H), 7.36 – 7.41 (m, 1H), 7.70 (dd, J = 5.9, 1.8 Hz, 1H).

(*R*)-2-Hydroxy-1,2-bis-(4-methoxy-phenyl)-ethanone (26)



(R)-26

Prepared according to the optimised reaction conditions using catalyst **8**. Purification by column chromatography (CH_2Cl_2, R_f 0.2) gave **(*R*)-26** (38.3 mg, 21%) as a white solid, mp 111-112 °C, lit.[10] mp 109-110°C, 97 % ee. $[\alpha]_D^{20}$ = -13.1 (c 1.1 in CH_3OH), lit.[5] $[\alpha]_D^{20}$ = -90.4 (c 1.0 in CH_3OH) for *R* enantiomer with 99 % ee.

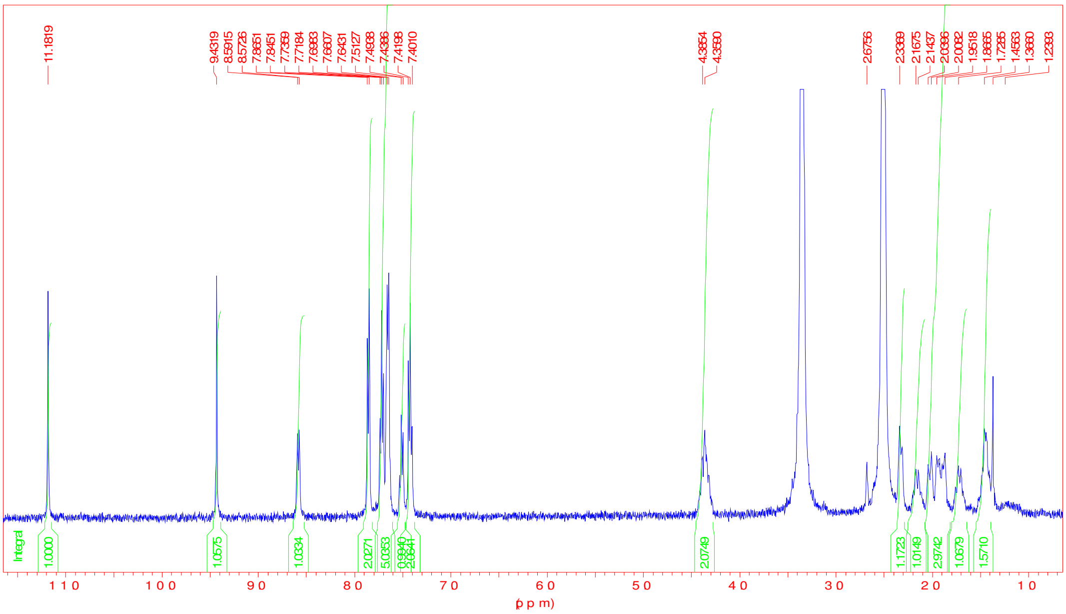
Chiralpak AD (4.6 mm x 25 cm), hexane/IPA: 75/25, 0.95 mL min^{-1}, RT, UV detection at 254 nm, retention times: 27.2 min (major enantiomer) and 32.0 (minor enantiomer).

^{1}H NMR (400 MHz, $CDCl_3$) δ 3.77 (s, 3H), 3.84 (s, 3H), 4.61 (bs, 1H), 5.87 (s, 1H), 6.84 – 6.90 (m, 4H), 7.25 – 7.29 (d, 2H (overlapping with $CHCl_3$ resonance)), 7.92 (d, J = 8.9 Hz, 2H).

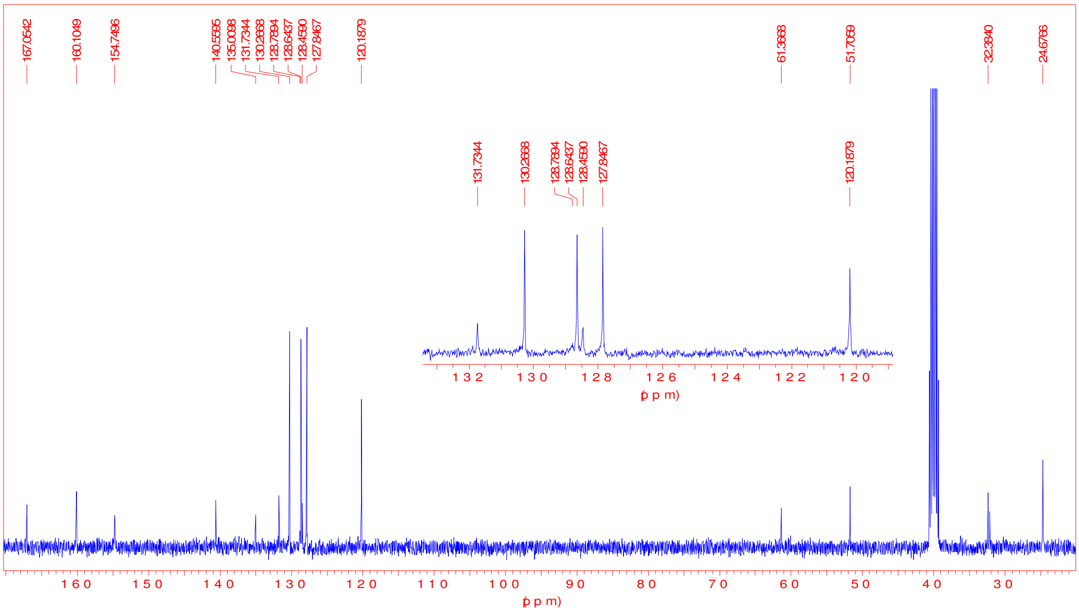
4.0 NMR Spectra

Catalyst NMR Spectra

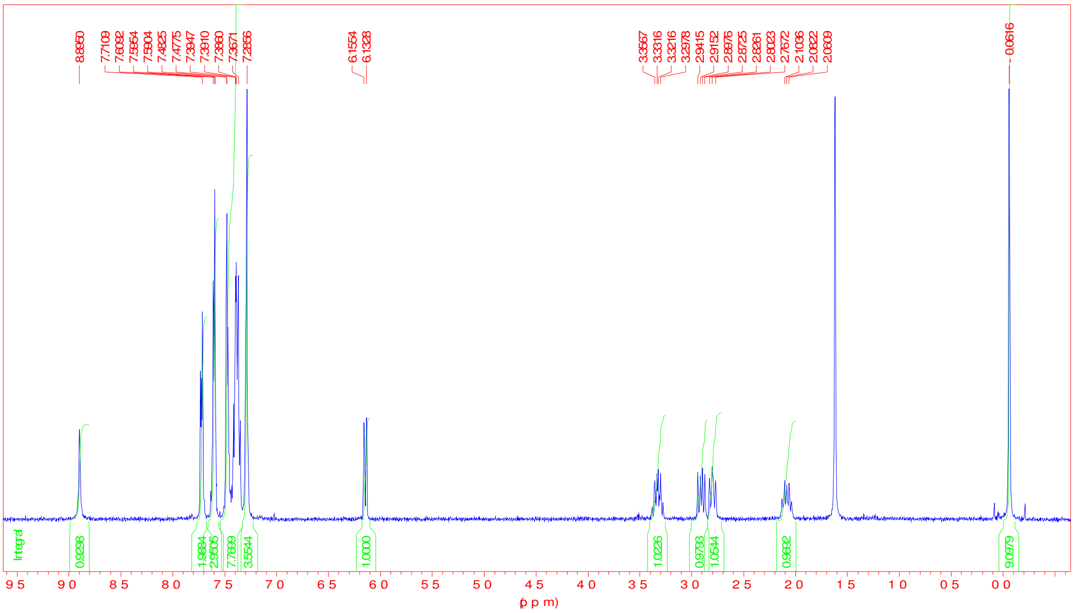
^{1}H NMR (600 MHz, DMSO-d_6) spectrum of catalyst 5



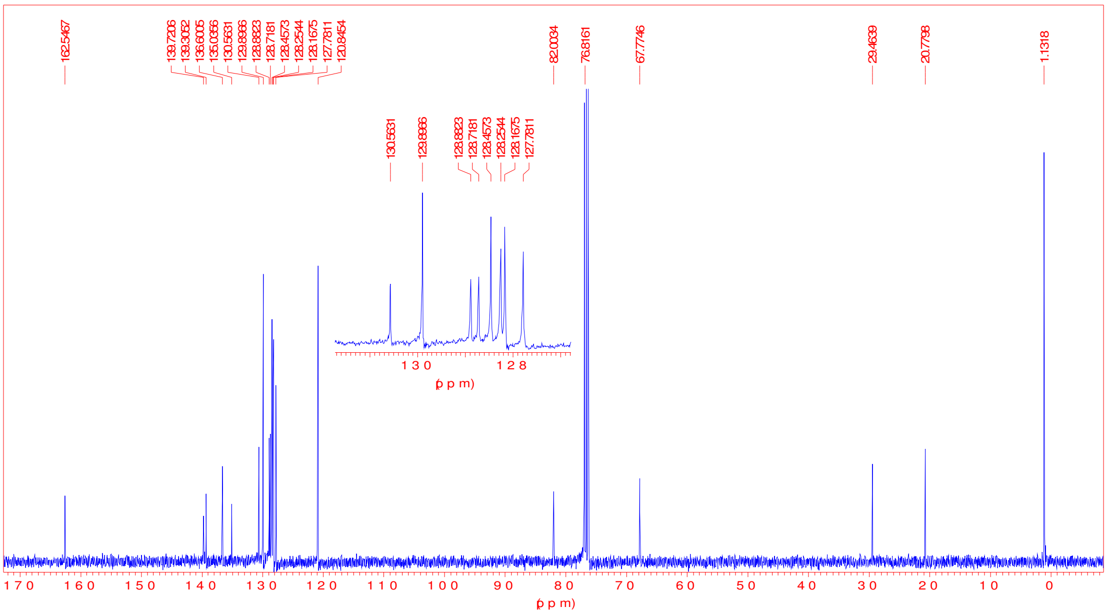
^{13}C NMR (150 MHz, DMSO-d_6) spectrum of catalyst 5



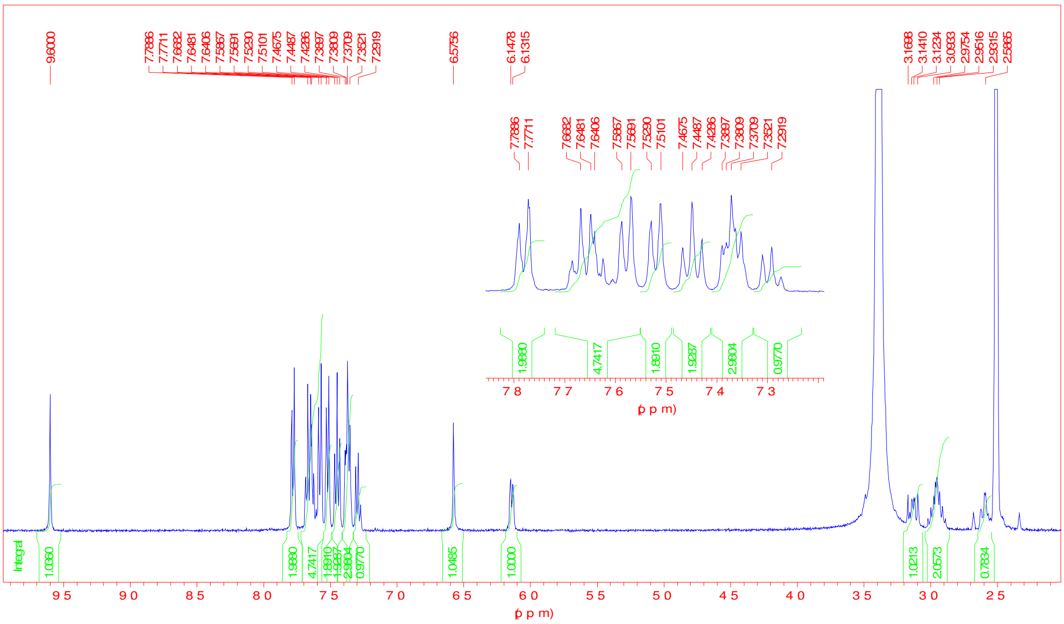
^{1}H NMR spectrum (400 MHz, CDCl$_3$) of catalyst 2a



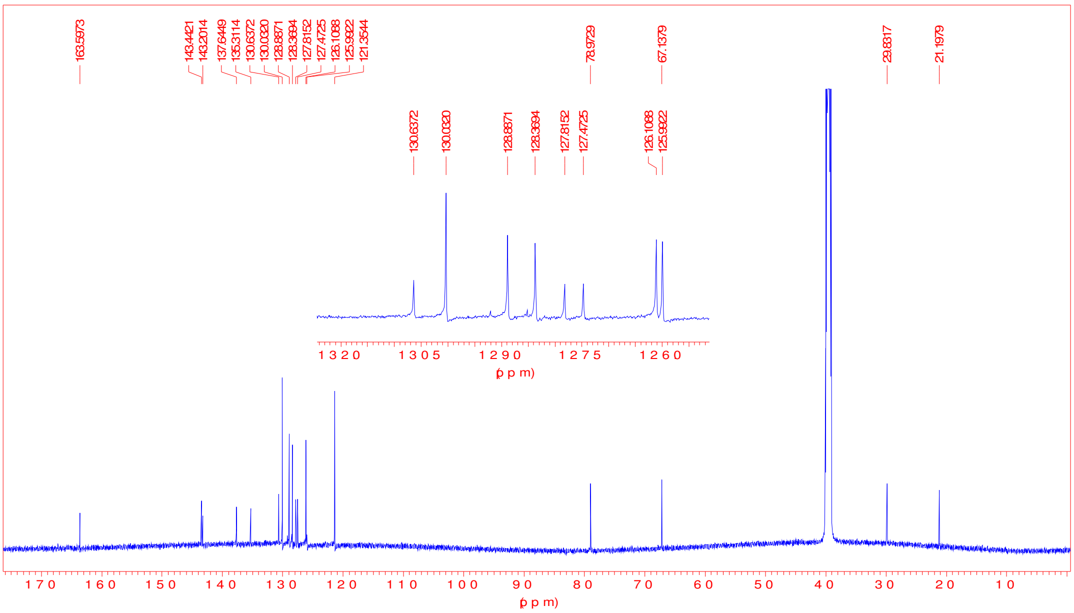
^{13}C NMR spectrum (100 MHz, CDCl$_3$) of catalyst 2a



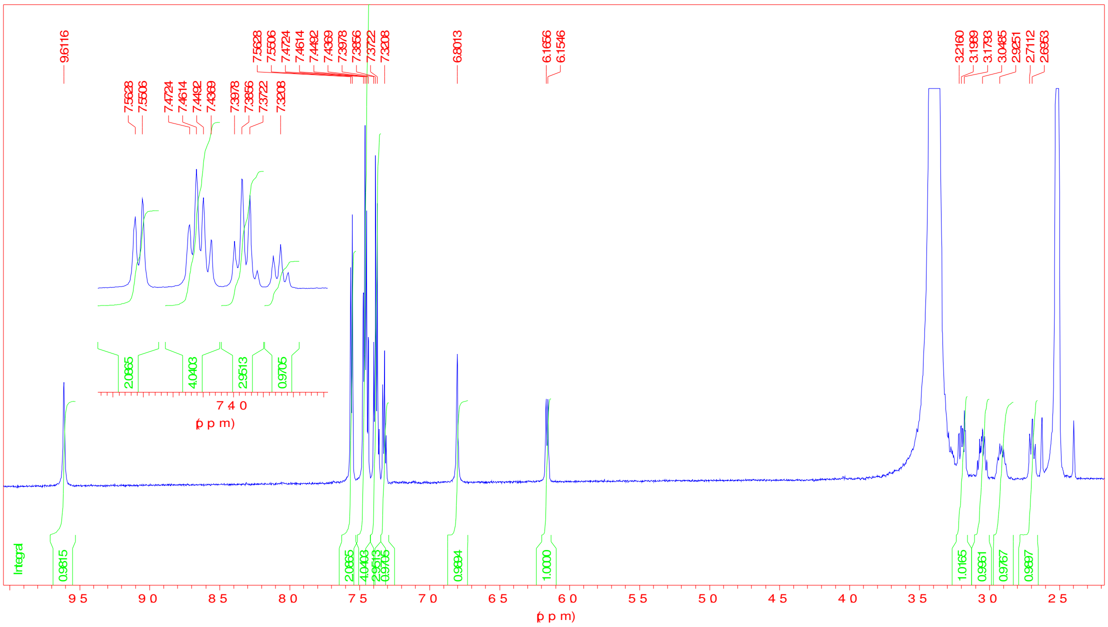
^{1}H NMR spectrum (600 MHz, DMSO-d_6) of catalyst 2b



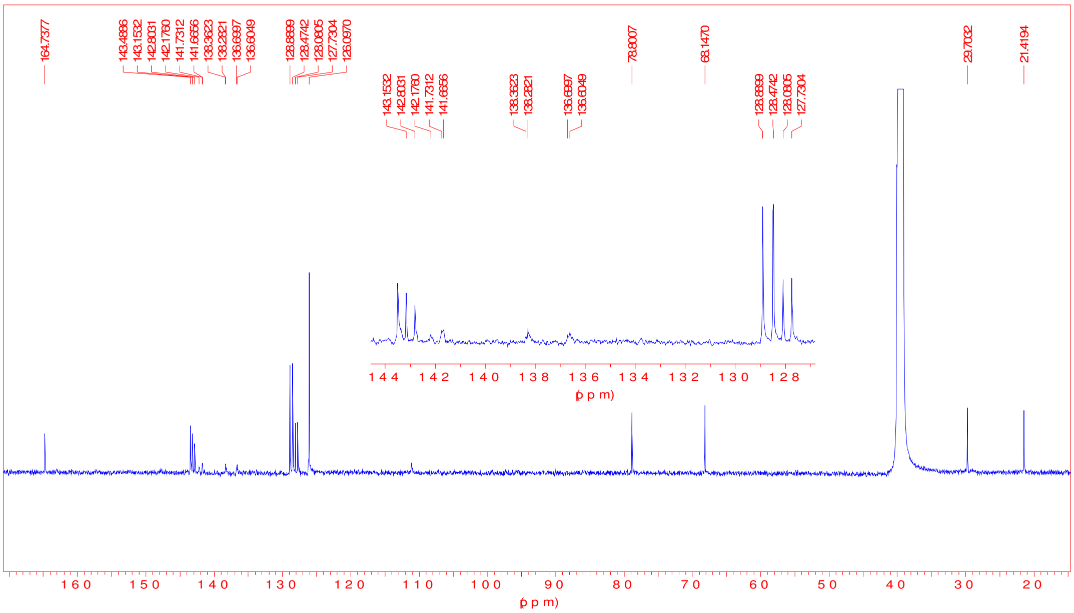
^{13}C NMR spectrum (150 MHz, DMSO-d_6) of catalyst 2b



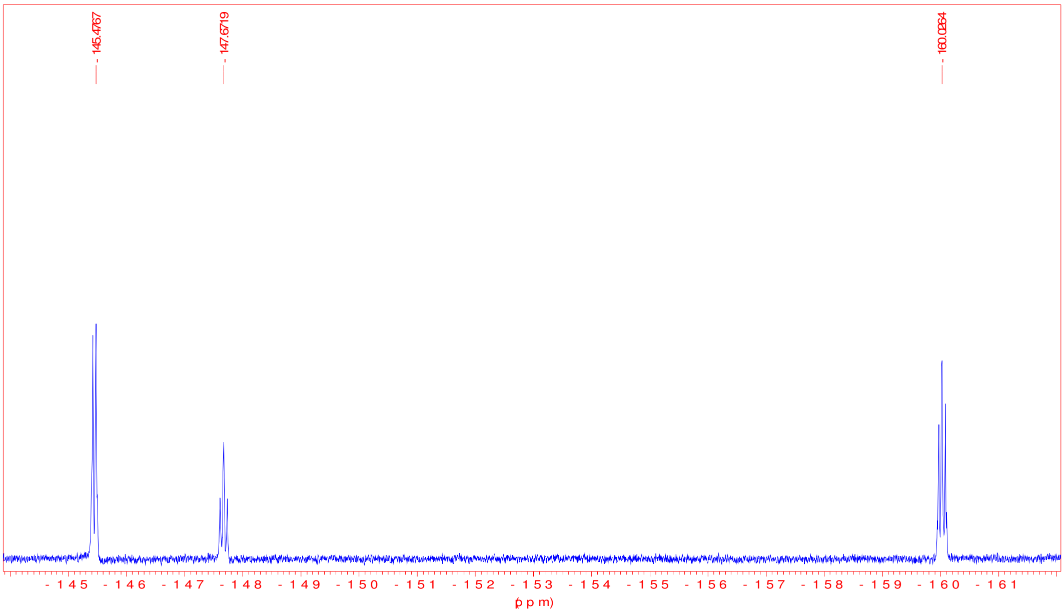
^{1}H NMR spectrum (600 MHz, DMSO-d_6) of catalyst 8



^{13}C NMR spectrum (150 MHz, DMSO-d_6) of catalyst 8

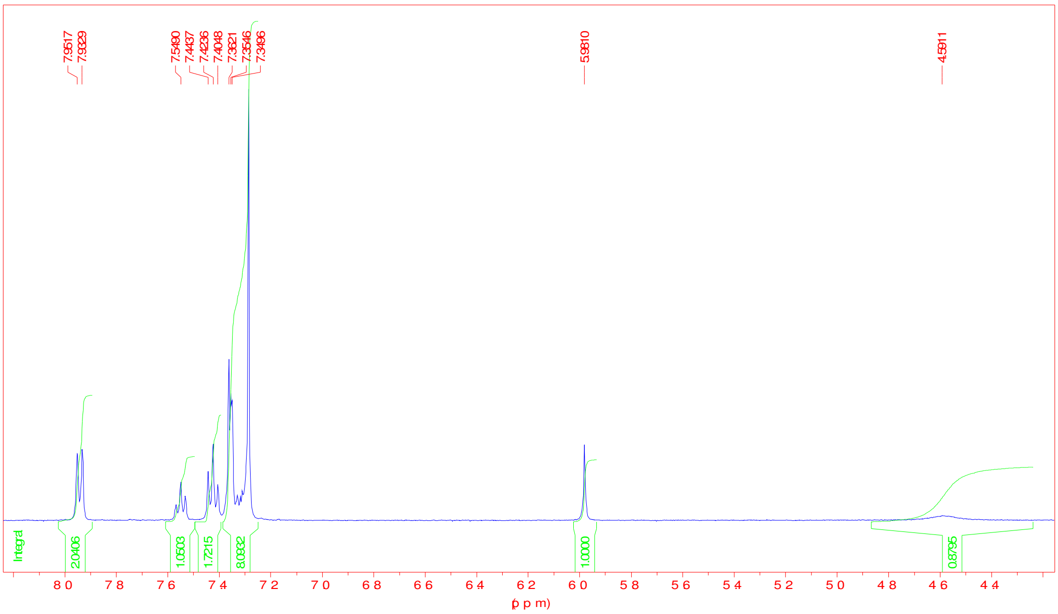


^{19}F NMR spectrum (400 MHz, DMSO-d_6) of catalyst 8

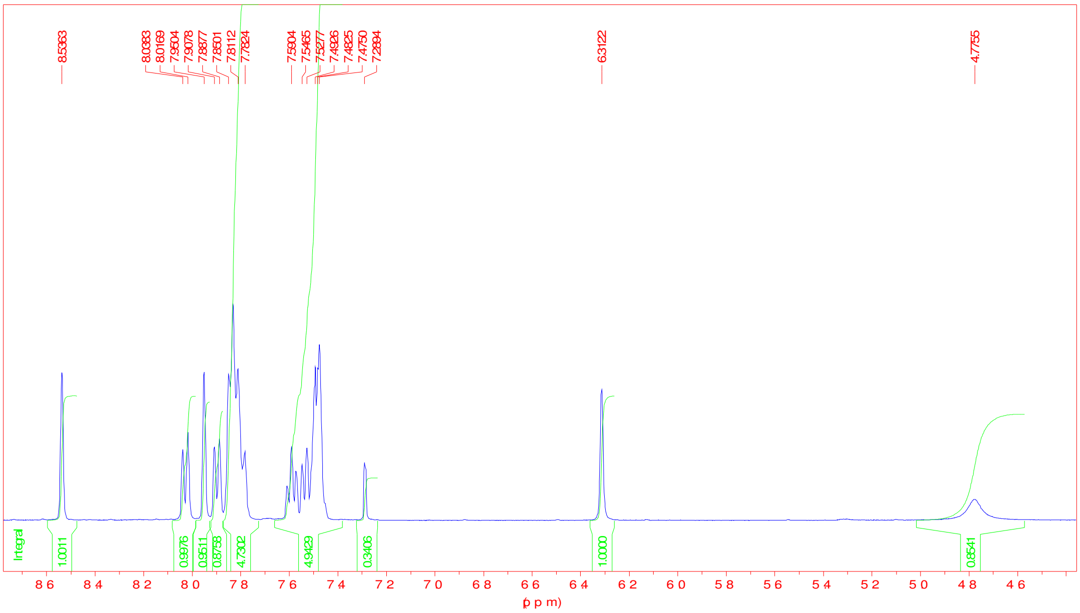


NMR Spectra of Acyloins 6-26

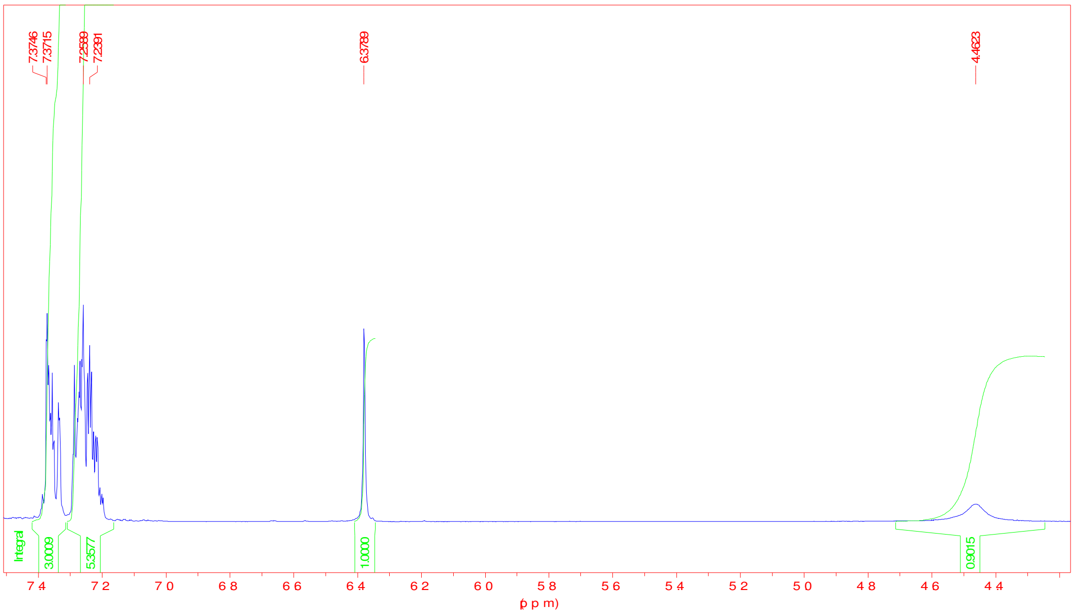
^{1}H NMR spectrum (400 MHz, CDCl$_3$) of (*R*)-6



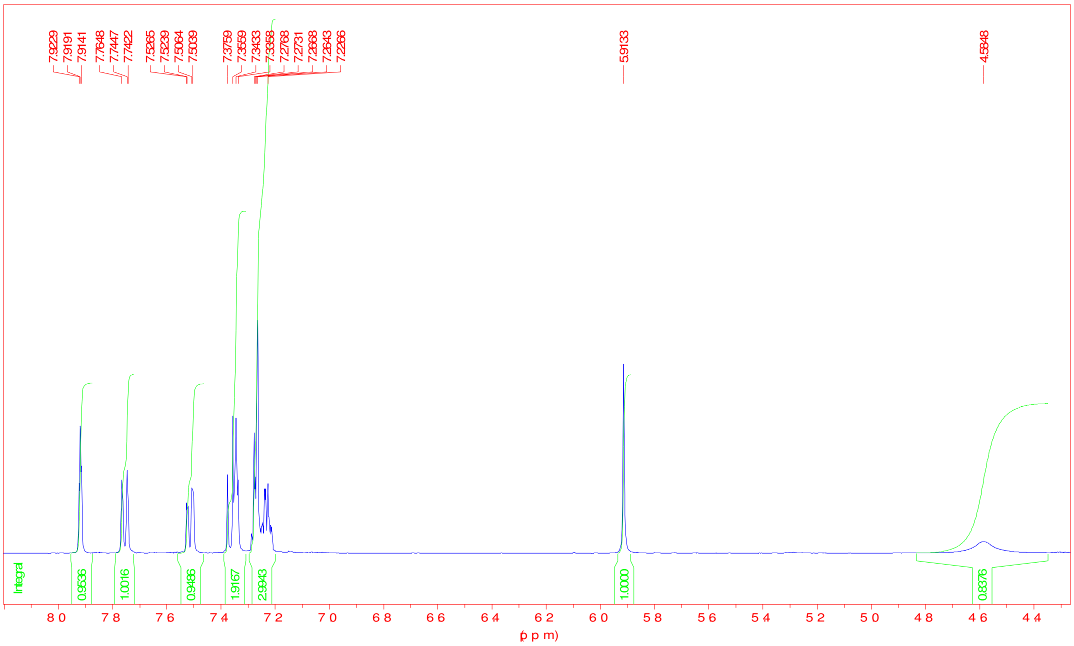
^{1}H NMR spectrum (400 MHz, $CDCl_3$) of (*R*)-18



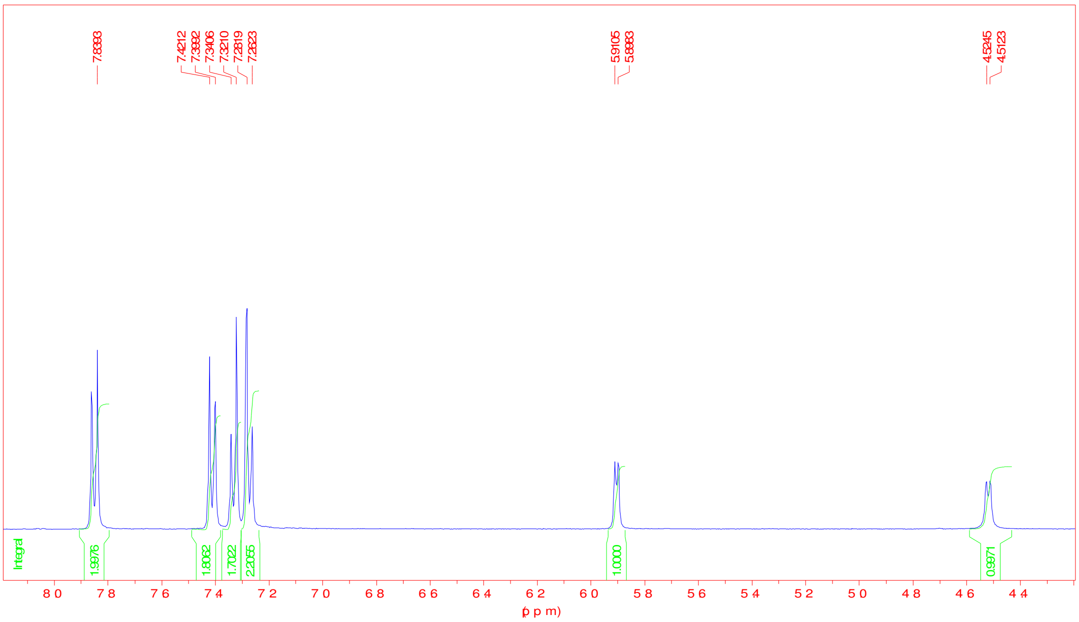
^{1}H NMR spectrum (400 MHz, $CDCl_3$) of (*R*)-19



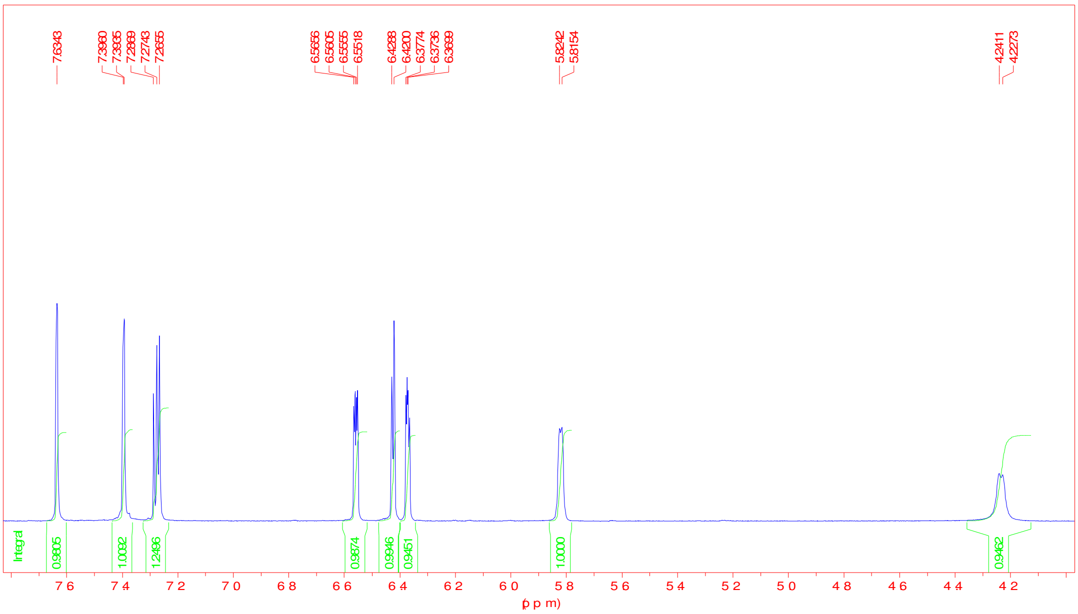
^{1}H NMR spectrum (400 MHz, $CDCl_3$) of (*R*)-20



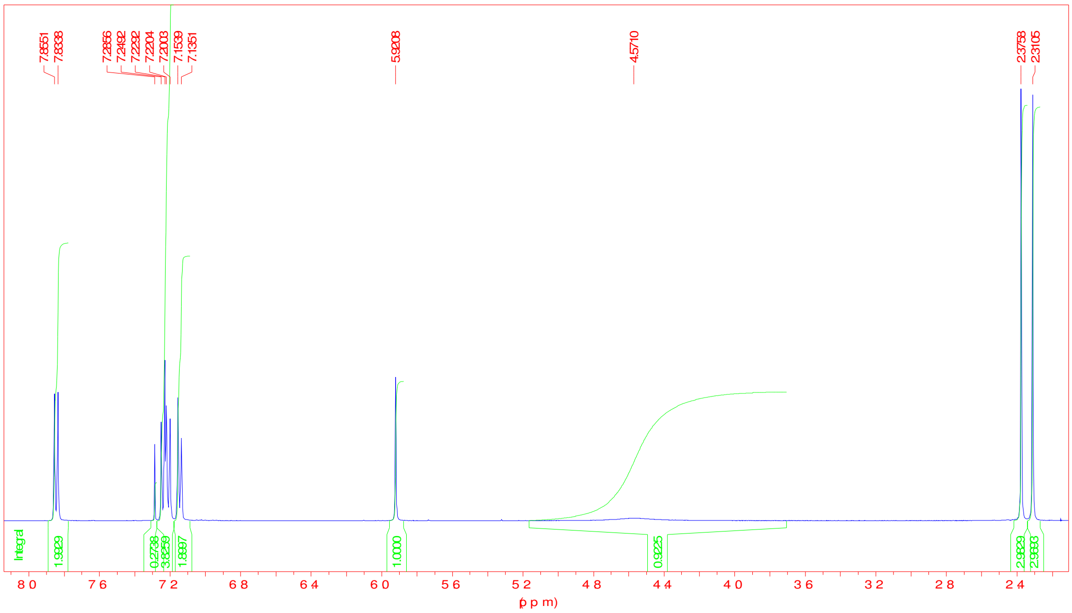
^{1}H NMR spectrum (400 MHz, $CDCl_3$) of (*R*)-21



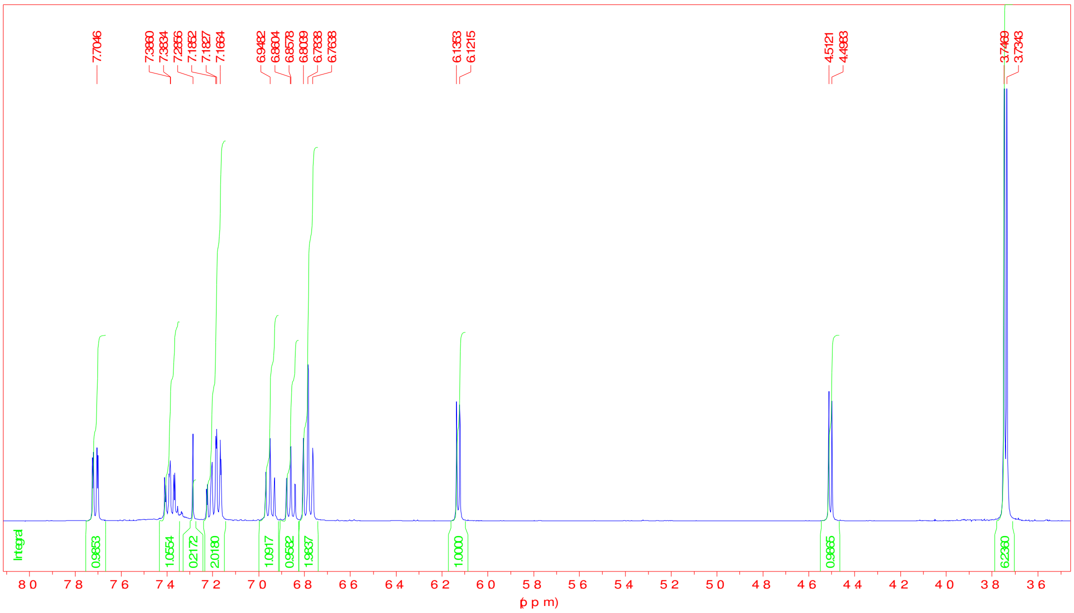
^{1}H NMR spectrum (400 MHz, CDCl$_3$) of (*R*)-22



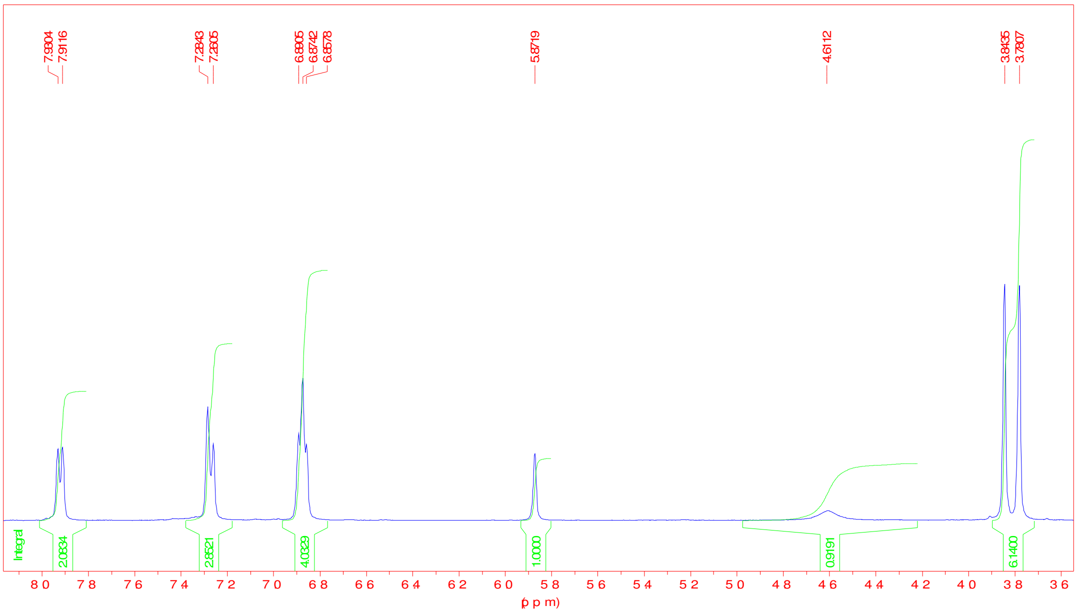
^{1}H NMR spectrum (400 MHz, CDCl$_3$) of (*R*)-24



^{1}H NMR spectrum (400 MHz, $CDCl_3$) of (*R*)-25



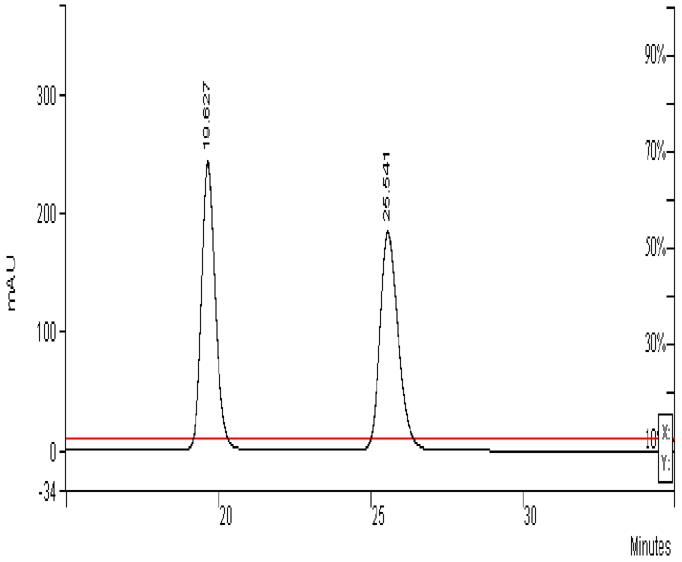
^{1}H NMR spectrum (400 MHz, $CDCl_3$) of (*R*)-26



5.0 HPLC Chromatograms

HPLC Chromatograms of Acyloins

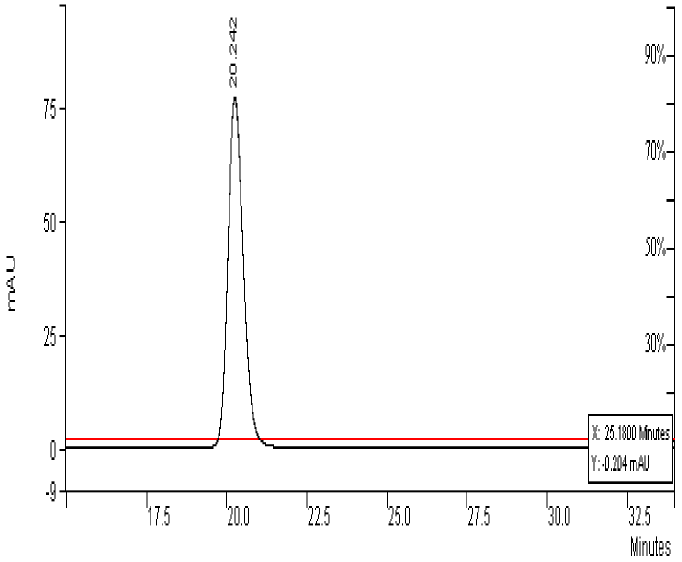
HPLC Chromatograms of benzoin 6



Enantiomeric excess was determined by HPLC with chiralpak AD-H (4.6 mm x 25 cm), Hexane:IPA 90:10, 1.0 mL min^{-1}, 220nm

Peak	Result	Ret. Time (min)	Area (counts)
1	28.455	19.627	77271216
2	28.373	25.541	77047920

Resolved HPLC chromatogram for benzoin 6 – racemate

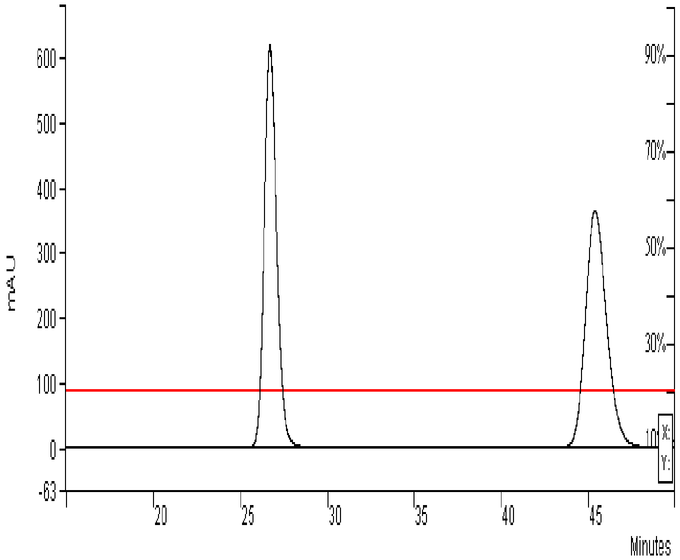


Peak	Result	Ret. Time (min)	Area (counts)
1	14.830	20.424	26048570
2	0.0130	26.904	00000304

Resolved HPLC chromatogram for enantioenriched benzoin (*R*)-6

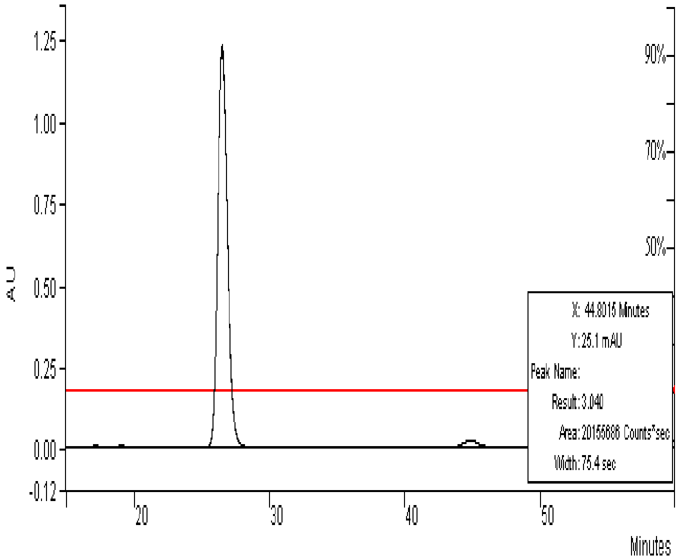
HPLC Chromatograms of benzoin 18

Enantiomeric excess was determined by HPLC with chiralpak AD-H (4.6 mm x 25 cm), Hexane:IPA 80:20, 1.0 mL min^{-1}, 254nm.



Resolved HPLC chromatogram for acyloin 18 – racemate

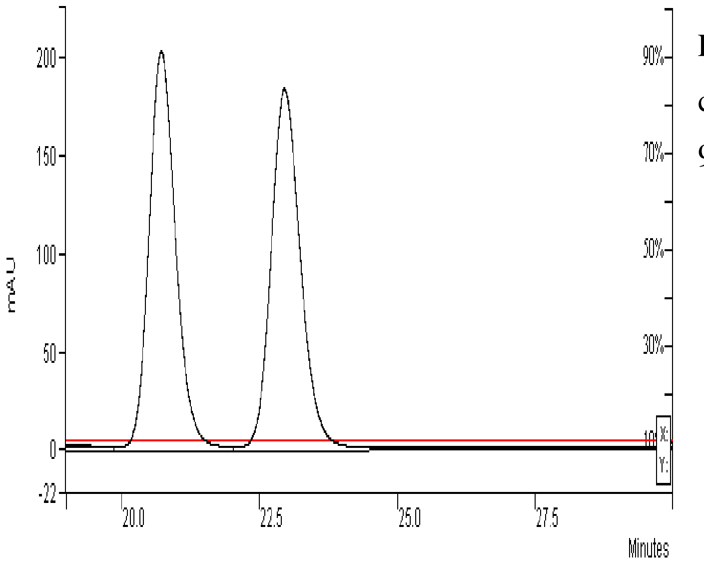
Peak	Result	Ret. Time (min)	Area (counts)
1	47.564	26.668	31328844
2	46.915	45.350	30901443



Resolved HPLC chromatogram for enantioenriched acyloin (*R*)-18

Peak	Result	Ret. Time (min)	Area (counts)
1	93.040	26.475	61691692
2	3.0398	44.801	20155686

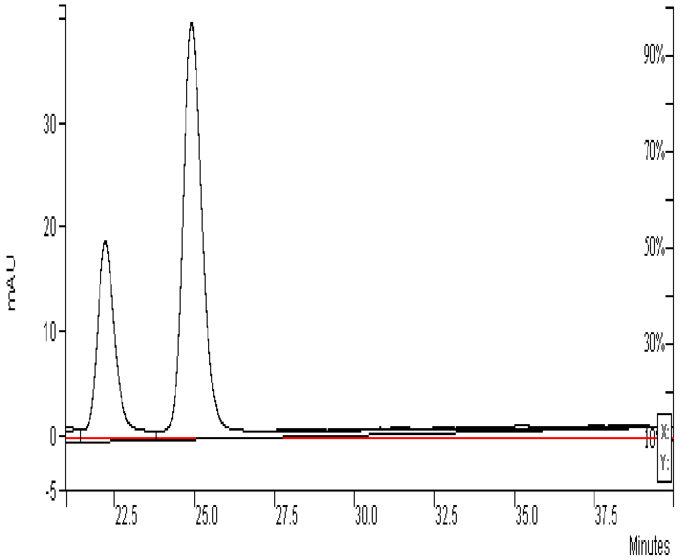
HPLC Chromatograms of benzoin 19



Enantiomeric excess was determined by HPLC with chiralpak AD-H (4.6 mm x 25 cm), Hexane:IPA 90:10, 0.8 mL min^{-1}, 254nm.

Peak	Result	Ret. Time (min)	Area (counts)
1	24.706	20.715	69356096
2	26.709	22.948	74977248

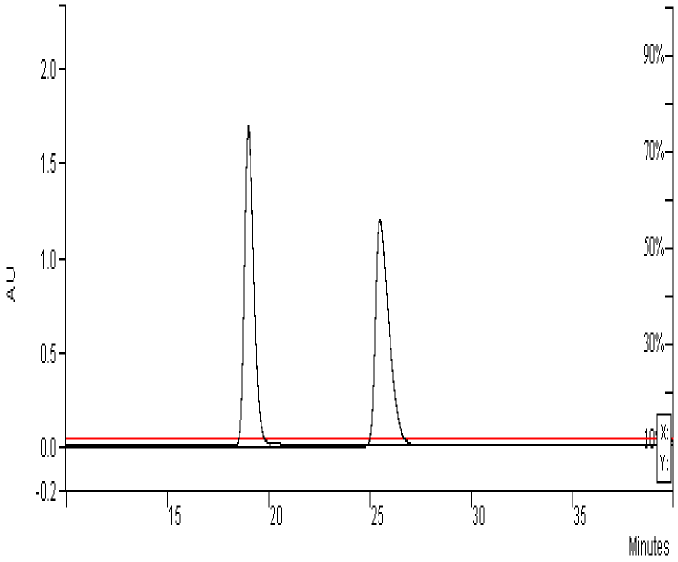
Resolved HPLC chromatogram for acyloin 19 – racemate



Peak	Result	Ret. Time (min)	Area (counts)
1	13.368	22.203	7947933
2	33.461	24.902	19894148

Resolved HPLC chromatogram for enantioenriched acyloin (*R*)-19

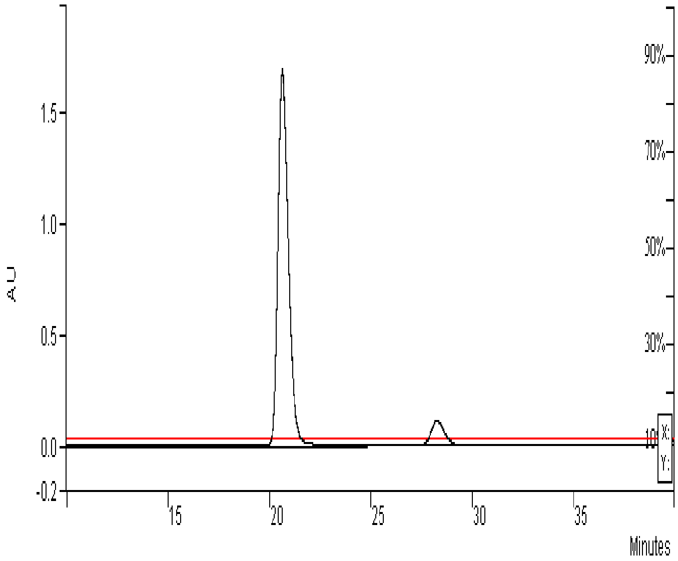
HPLC Chromatograms of benzoin 20



Enantiomeric excess was determined by HPLC with chiralpak AD-H (4.6 mm x 25 cm), Hexane:IPA 90:10, 0.8 mL min^{-1}, 254nm.

Peak	Result	Ret. Time (min)	Area (counts)
1	46.303	18.972	55033817
2	47.700	25.469	56694713

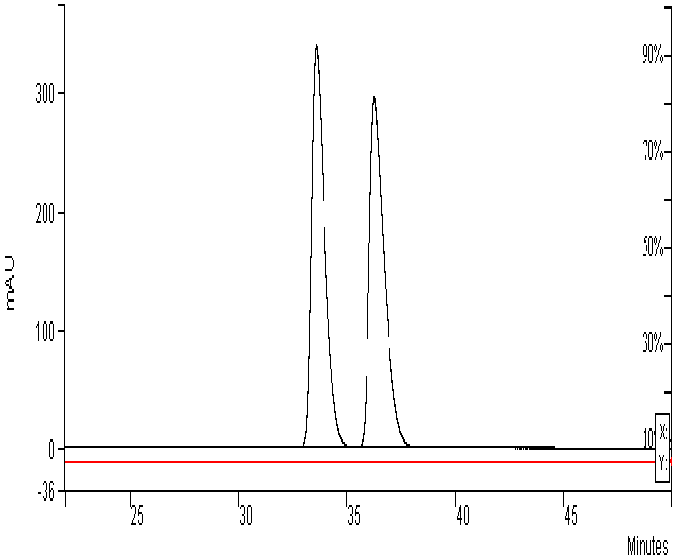
Resolved HPLC chromatogram for acyloin 20 – racemate



Peak	Result	Ret. Time (min)	Area (counts)
1	85.981	20.611	61274854
2	8.132	28.232	57953436

Resolved HPLC chromatogram for enantioenriched acyloin (*R*)-20

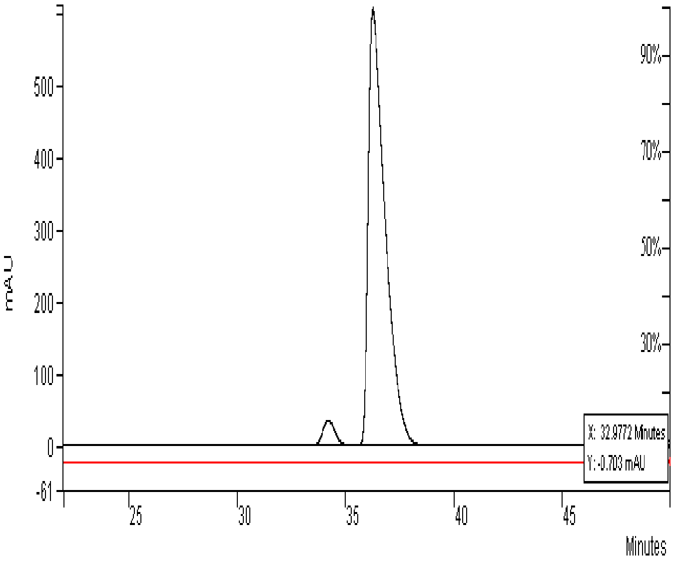
HPLC Chromatograms of benzoin 21



Enantiomeric excess was determined by HPLC with chiralpak OJ-H (4.6 mm x 25 cm), Hexane:IPA 95:5, 0.6 mL min^{-1}, 220nm.

Peak	Result	Ret. Time (min)	Area (counts)
1	48.138	33.564	14373272
2	48.124	36.230	14369081

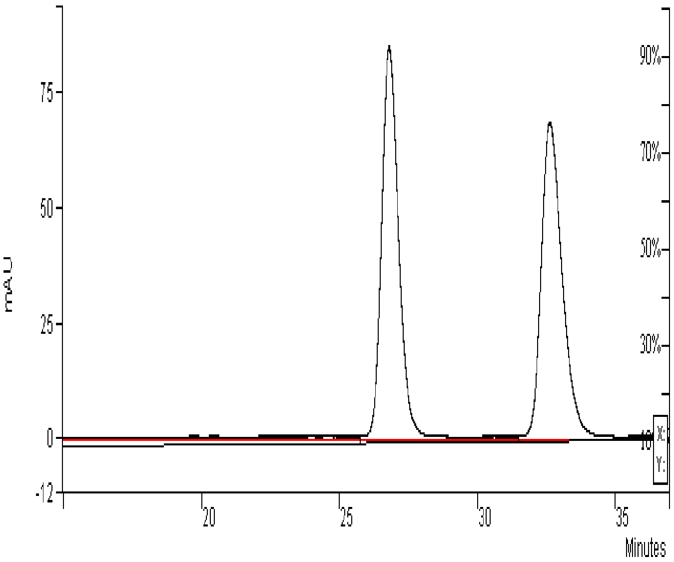
Resolved HPLC chromatogram for acyloin 21 – racemate



Peak	Result	Ret. Time (min)	Area (counts)
1	4.028	34.173	14307333
2	92.578	36.235	32878755

Resolved HPLC chromatogram for enantioenriched acyloin (*R*)-21

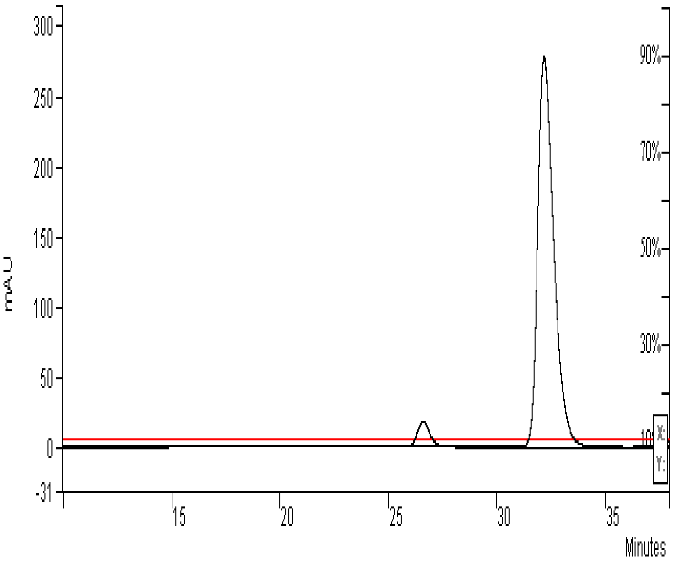
HPLC Chromatograms of benzoin 22



Resolved HPLC chromatogram for acyloin 22 – racemate

Enantiomeric excess was determined by HPLC with chiralpak AD-H (4.6 mm x 25 cm), Hexane:IPA 90:10, 0.8 mL min^{-1}, 254nm.

Peak	Result	Ret. Time (min)	Area (counts)
1	34.968	26.794	40173352
2	36.262	32.616	41659188

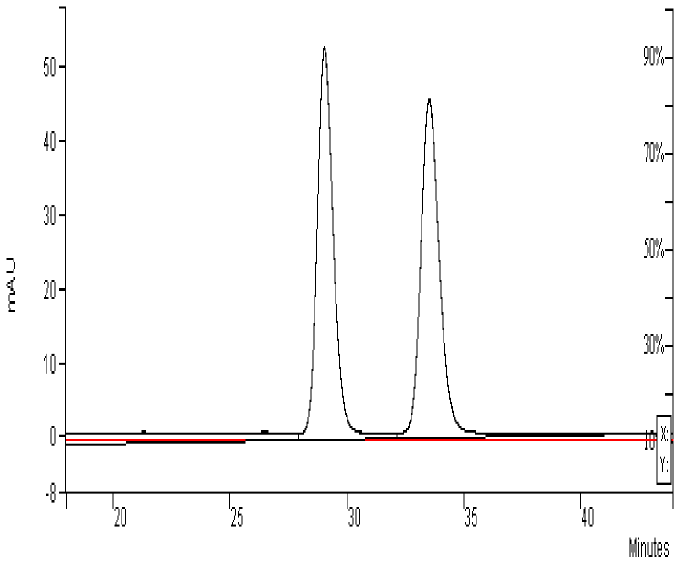


Peak	Result	Ret. Time (min)	Area (counts)
1	4.7132	26.563	7694518
2	87.804	32.156	14334528

Resolved HPLC chromatogram for enantioenriched acyloin (*R*)-22

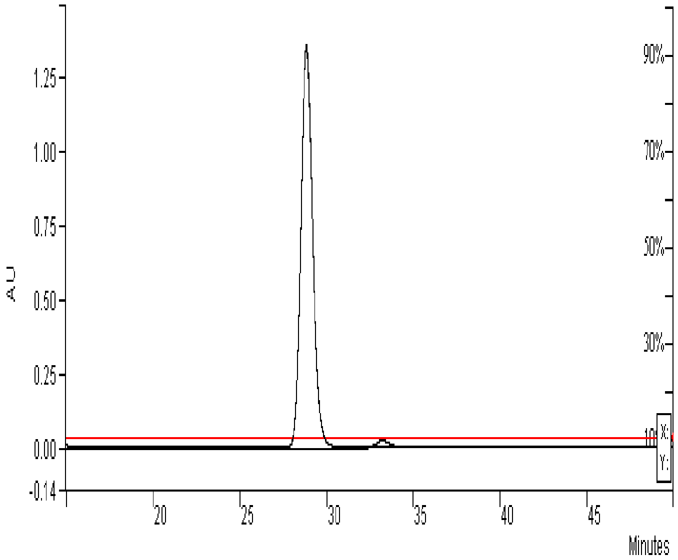
HPLC Chromatograms of benzoin 24

Enantiomeric excess was determined by HPLC with chiralpak AD-H (4.6 mm x 25 cm), Hexane:IPA 90:10, 0.8 mL min^{-1}, 254nm.



Peak	Result	Ret. Time (min)	Area (counts)
1	29.339	29.028	26523302
2	29.613	33.507	26771498

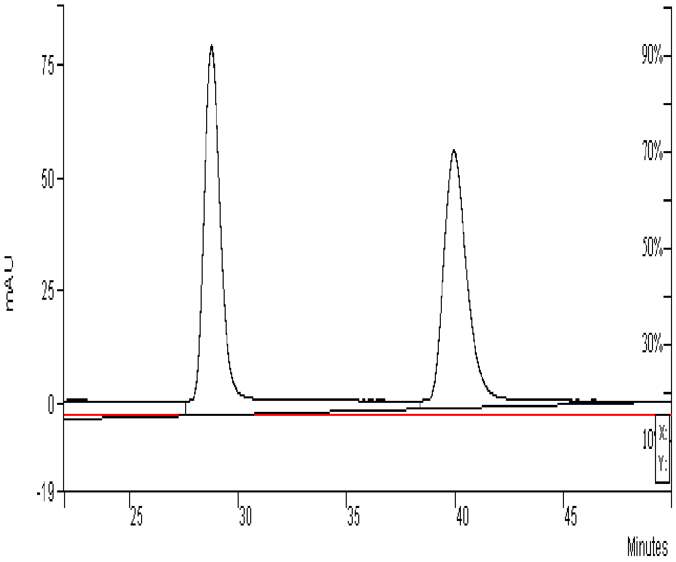
Resolved HPLC chromatogram for acyloin 24 – racemate



Peak	Result	Ret. Time (min)	Area (counts)
1	92.643	28.806	64194944
2	2.4052	33.179	16666401

Resolved HPLC chromatogram for enantioenriched acyloin (*R*)-24

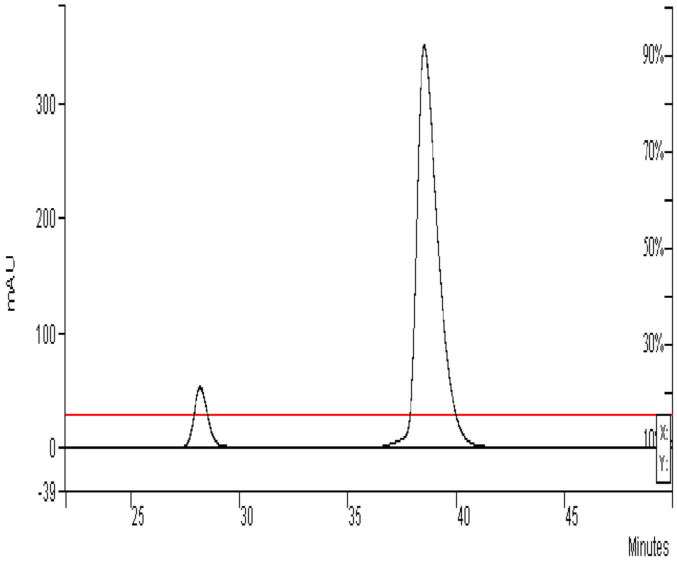
HPLC Chromatograms of benzoin 25



Enantiomeric excess was determined by HPLC with chiralpak OD-H (4.6 mm x 25 cm), Hexane:IPA 85:15, 0.5 mL min^{-1}, 254nm.

Peak	Result	Ret. Time (min)	Area (counts)
1	31.642	28.758	57558092
2	25.267	39.918	46698948

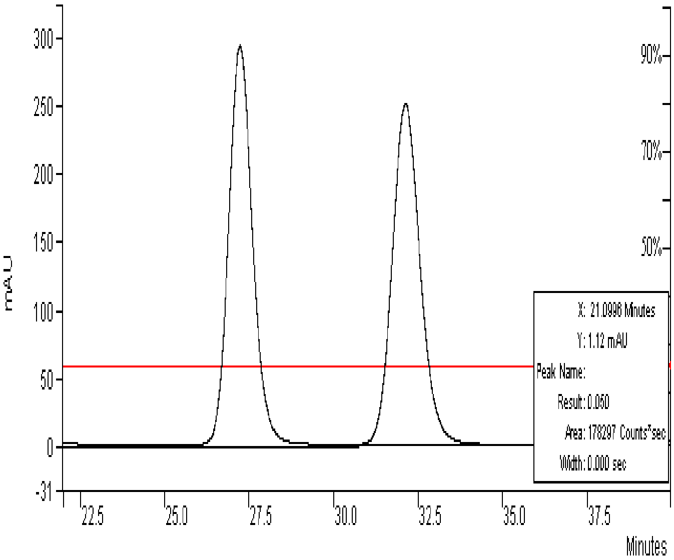
Resolved HPLC chromatogram for acyloin 25 – racemate



Peak	Result	Ret. Time (min)	Area (counts)
1	8.4909	28.169	23629110
2	86.600	38.505	24099636

Resolved HPLC chromatogram for enantioenriched acyloin (*R*)-25

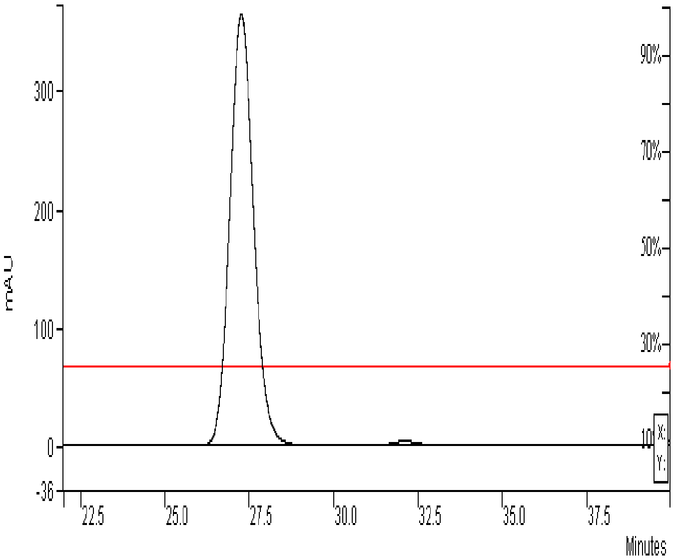
HPLC Chromatograms of benzoin 26



Enantiomeric excess was determined by HPLC with chiralpak AD-H (4.6 mm x 25 cm), Hexane:IPA 75:25, 0.95 mL min^{-1}, 254nm.

Peak	Result	Ret. Time (min)	Area (counts)
1	40.887	27.217	14604347
2	40.892	32.114	14606011

Resolved HPLC chromatogram for acyloin 26 – racemate



Peak	Result	Ret. Time (min)	Area (counts)
1	89.508	27.253	17904705
2	1.1691	32.091	2338560

Resolved HPLC chromatogram for enantioenriched acyloin (*R*)-26

6.0 References

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