Supplementary Material (ESI) for Chemical Communications

Supporting Information

Asymmetric Multifunctional Organocatalytic Michael Addition of Nitroalkanes to α, β-Unsaturated Ketones

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A: General Information and Starting Materials

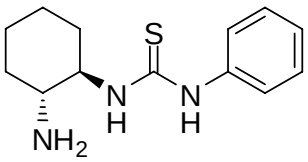
General. The ^{1}H-NMR and ^{13}C-NMR were recorded on a Bruke DRX 400 (400 MHz) instrument. (s = singlet, d = doublet, dd = double doublet, t = triplet, q = quartet, m = multiplet). Chromatography was carried out with silica gel (350-400 mesh) using mixtures of petroleum ether and ethyl acetate as eluent. Enantiomeric excess was determined by chiral HPLC using Agilent 1100 Series or chiral GC using Agilent GC6890. Chiralpak AD-H (0.46cm x 25 cm), Chiralpak OD-H (0.46cm x 25 cm), or Chirasil Dex CB (# CP 7502).

Materials. All solvent and inorganic reagents were of p.a. quality and used without purification. β-alkyl-α, β-unsaturated cyclic ketones was synthesized according to the literature. [1] Both aromatic enones and heteroaromatic enone were prepared following the literature procedures. [2] Unless otherwise noted, materials were obtained from commercial sources and used without purification.

B: General Procedure for the synthesis of multifunctional catalysts

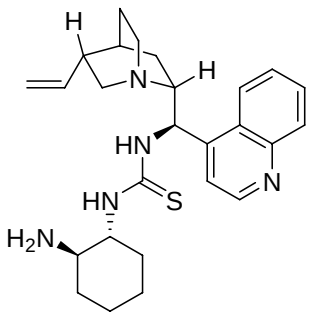
The multifunctional catalysts were prepared following the literature procedures [3].

Catalyst 1



Prepared from aniline and (1R, 2R)-cyclohexane-1, 2-diamine. ^{1}H NMR ($CDCl_3$): δ 7.50 (d, J = 8 Hz, 1H), 7.41-7.24 (m, 5H), 5.30 (s, 1H), 3.79 (s, 1H), 3.29-3.25 (m, 1H), 2.15-2.03 (m, 2H), 1.85-1.82 (m, 2H), 1.67-1.22 (m, 4H). ^{13}C NMR ($CDCl_3$): δ 188.8, 136.4, 130.3, 127.7, 124.7, 65.1, 63.2, 33.2, 30.0, 24.9, 24.1.

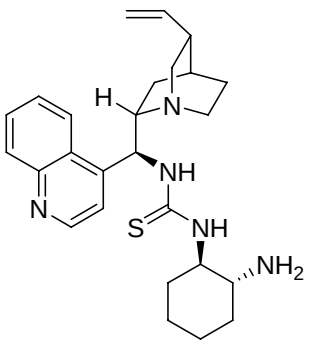
Catalyst 2



Prepared from 9-amino (9-deoxy) epicinchonine and (1R, 2R)-cyclohexane-1, 2-diamine. ^{1}H NMR ($CDCl_3$): δ 8.90 (d, J = 4 Hz, 1H), 8.37 (broad, 1H), 8.16 (d, J = 8 Hz, 1H), 7.76-7.65 (m, 2H), 7.45 (broad, 1H), 5.90-5.81 (m, 1H), 5.20-5.15 (m, 2H), 4.12 (m, 1H), 3.80-3.70 (m, 2H), 3.09-2.95 (m, 5H), 2.32-2.31 (m, 1H), 2.05 (m, 2H), 1.64-1.57 (m, 6H), 1.28-0.89 (m, 5H). ^{13}C NMR ($CDCl_3$): δ 182.8, 150.5, 148.9, 139.7, 130.7, 129.7, 127.3, 127.1, 124.2, 120.3, 115.7, 73.0, 61.3, 60.6, 55.9, 49.1,

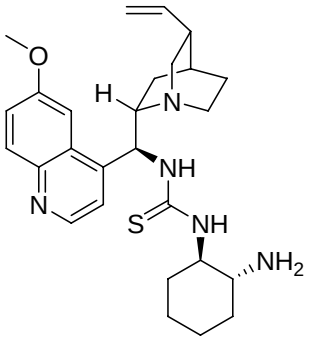
47.6, 39.3, 34.1, 33.1, 32.3, 29.9, 27.7, 25.5, 24.7.

Catalyst 3



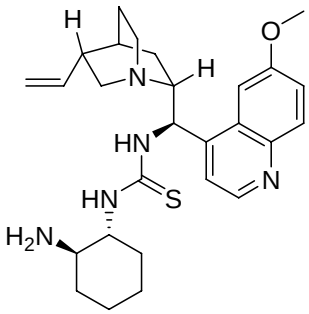
Prepared from 9-amino (9-deoxy) epicinchonidine and (1R, 2R)-cyclohexane-1, 2-diamine. ^{1}H NMR ($CDCl_3$): δ 8.96 (d, J = 4 Hz, 1H), 8.65 (broad, 1H), 8.13 (d, J = 8 Hz, 1H), 7.76-7.64 (m, 3H), 5.85-5.71 (m, 1H), 5.15-5.07 (m, 2H), 4.37-4.33 (m, 1H), 3.79 (m, 2H), 3.34-3.22 (m, 2H), 2.95 (m, 2H), 2.50-2.48 (m, 2H), 2.06-1.69 (m, 6H), 1.35-1.17 (m, 6H), 0.96-0.91 (m, 1H). ^{13}C NMR ($CDCl_3$): δ 182.4, 150.6, 148.9, 139.3, 132.3, 130.6, 129.5, 128.8, 127.3, 124.5, 120.6, 116.4, 73.0, 67.3, 61.3, 57.4, 55.9, 54.9, 53.7, 42.5, 38.5, 34.3, 32.5, 27.2, 25.5, 24.8.

Catalyst 4



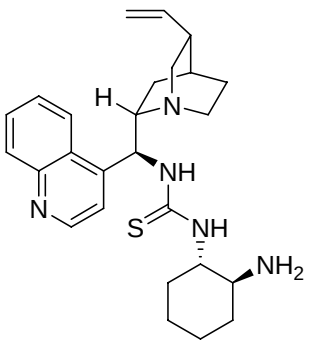
Prepared from (1R, 2R)-cyclohexane-1, 2-diamine and 9-amino (9-deoxy) epiquinine. ^{1}H NMR ($CDCl_3$): δ 8.75 (d, J = 3.2 Hz, 1H), 8.05-7.98 (m, 2H), 7.47-7.38 (m, 2H), 7.36-7.35 (m, 1H), 5.75 (m, 1H), 5.05-4.98 (m, 3H), 4.02 (s, 3H), 3.71 (m, 2H), 3.15 (m, 3H), 2.97-2.65 (m, 3H), 2.49-2.28 (m, 2H), 1.87 (m, 2H), 1.70-1.56 (m, 4H), 1.41-1.19 (m, 4H), 0.96-0.91 (m, 1H). ^{13}C NMR ($CDCl_3$): δ 182.4, 158.4, 147.8, 145.1, 141.5, 141.0, 131.0, 128.7, 122.5, 121.5, 114.6, 102.7, 73.0, 60.7, 56.6, 56.2, 55.8, 55.5, 41.8, 41.2, 40.1, 39.4, 35.0, 32.4, 27.6, 25.8, 25.0.

Catalyst 5



Prepared from (1R, 2R)-cyclohexane-1, 2-diamine and 9-amino (9-deoxy) epiquinidine. ^{1}H NMR ($CDCl_3$): δ 8.74 (d, J = 4.8 Hz, 1H), 8.05-7.97 (m, 2H), 7.67-7.38 (m, 2H), 7.36-7.35 (m, 1H), 5.76 (m, 1H), 5.05-4.99 (m, 3H), 4.03 (s, 3H), 3.89-3.79 (m, 2H), 3.32-3.12 (m, 3H), 2.91-2.50 (m, 3H), 2.33 (m, 2H), 2.01-1.88 (m, 2H), 1.69-1.60 (m, 4H), 1.43-1.21 (m, 4H), 0.96-0.91 (m, 1H). ^{13}C NMR ($CDCl_3$): δ 182.4, 158.4, 148.0, 145.2, 140.9, 132.3, 131.8, 128.8, 122.0, 121.8, 115.2, 102.8, 73.0, 60.7, 56.6, 56.3, 55.8, 55.5, 41.9, 41.2, 40.1, 39.4, 34.2, 32.5, 27.5, 25.9, 25.0.

Catalyst 6



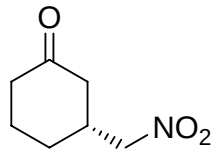
Prepared from 9-amino (9-deoxy) epicinchonidine and (1S, 2S)-cyclohexane-1, 2-diamine. ^{1}H NMR ($CDCl_3$): δ 8.92 (d, J = 4.4 Hz, 1H), 8.52 (broad, 1H), 8.14 (d, J = 8.4 Hz, 1H), 7.77-7.64 (m, 3H), 5.73-5.67 (m, 1H), 5.31 (m, 1H), 5.01-4.94 (m, 2H), 3.79-3.68 (m, 2H), 3.25-3.19 (m, 2H), 2.80-2.75 (m, 2H), 2.30 (m, 2H), 2.94-1.57 (m, 6H), 1.28-1.08 (m, 6H), 0.90-0.87 (m, 1H). ^{13}C NMR ($CDCl_3$): δ 182.3, 150.3, 148.4, 141.8, 141.2, 132.0, 130.3, 129.1, 128.6, 126.7, 124.1, 114.6, 72.8, 68.8, 66.1, 61.7, 56.3, 55.5, 53.5, 41.3, 39.5, 33.9, 31.9, 27.5, 25.8, 24.6.

C: General Procedure for Asymmetric Michael Addition

To a solution of ethyl acetate (0.5 mL) was added α, β-unsaturated cyclic ketone **7** or **10** (1.0 mmol), nitroalkane **8** (3.0 mmol), catalyst (0.05-0.20 mmol). The reaction mixture was stirred at room temperature for the time indicated in Table 2 or Table 3 and then the solvent was removed under vacuum. The residue was added 1 M hydrochloric acid (5.0 mL) and extracted with CH_2Cl_2 three times. The combined organic phases were dried over unhydrous Na_2SO_4, filtered and evaporated under vacuum. The residue was purified by column chromatography on silica gel (350-400 mesh) to yield the desired addition product.

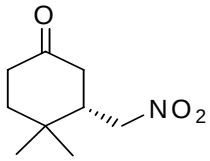
D: Characterization Data of Addition Products [4]

3-(nitromethyl)cyclohexanone



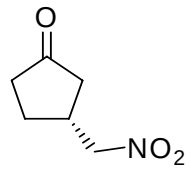
Yellowy oil. ^{1}H-NMR ($CDCl_3$): δ 4.42–4.26 (m, 2H), 2.65–2.64 (m, 1H), 2.52–2.43 (m, 1H), 2.32-2.29 (m, 1H), 2.21–2.11 (m, 2H), 2.06–1.96 (m, 1H), 1.80-1.73 (m, 2H), 1.54–1.50 (m, 1H). ^{13}C-NMR ($CDCl_3$): δ 208.4, 80.3, 44.7, 41.1, 37.4, 28.4, 24.4. The enantiomeric excess was determined by HPLC. [AD-H column, 220 nm, hexane: IPA = 9:1, 0.8 mL/min]: 18.9 min (major), 21.8 min (minor).

4,4-dimethyl-3-(nitromethyl)cyclohexanone



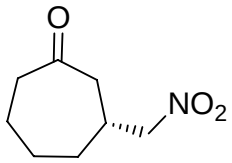
Yellowy oil. ^{1}H-NMR ($CDCl_3$): δ 4.58 (dd, J = 4.0, 12.4 Hz, 1H), 4.16 (dd, J = 10.0, 12.0 Hz, 1H), 2.52–2.25 (m, 5H), 2.18–1.73 (m, 2H), 1.15 (s, 3H), 1.07 (s, 3H). ^{13}C-NMR ($CDCl_3$): δ 208.4, 45.1, 41.3, 39.9, 37.9, 32.5, 28.7, 19.8. The enantiomeric excess was determined by HPLC. [AD-H column, 220 nm, hexane: IPA = 40:1, 0.8 mL/min]: 27.2 min (minor), 29.2 min (major).

3-(nitromethyl)cyclopentanone



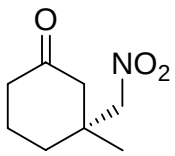
Yellowy oil. ^{1}H-NMR ($CDCl_3$): δ 4.49 (dd, J = 1.0, 7.2 Hz, 2H), 3.02 (m, 1H), 2.57–2.51 (m, 1H), 2.42-2.37 (m, 1H), 2.34-2.27 (m, 2H), 2.06-1.99 (m, 1H), 1.77-1.69 (m, 1H). ^{13}C-NMR ($CDCl_3$): δ 215.6, 79.3, 42.3, 38.0, 35.4, 26.9. The enantiomeric excess was determined by HPLC. [OD-H column, 220 nm, hexane: IPA = 9:1, 0.8 mL/min]: 31.0 min (major), 34.6 min (minor).

3-(nitromethyl)cycloheptanone



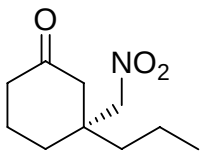
Colorless oil. ^{1}H-NMR ($CDCl_3$): δ 4.31 (dd, J= 7.6, 1.2 Hz, 2H), 2.62-2.57 (m, 1H), 2.55–2.48 (m, 4H), 1.99-1.91 (m, 3H), 1.64-1.62 (m, 1H), 1.53-1.42 (m, 2H). ^{13}C-NMR ($CDCl_3$): δ 211.3, 80.8, 46.6, 44.0, 35.0, 33.8, 28.2, 24.3. The enantiomeric excess was determined by GC. [Chirasil-Dex CB column, 1.0 mL/min, 10°C/min from 70°C to 140°C then hold for 55 min.]: 54.3 min (minor), 55.3 min (major).

3-methyl-3-(nitromethyl)cyclohexanone



Colorless oil. ^{1}H-NMR ($CDCl_3$): δ 4.31 (dd, J = 10.8, 19.2Hz, 2H), 2.26-2.45 (m, 4H), 1.72-2.02 (m, 4H), 1.13 (s, 3H). ^{13}C-NMR ($CDCl_3$): δ 209.10, 85.15, 50.99, 40.73, 40.02, 33.73, 3.38, 21.55. The enantiomeric excess was determined by GC. [Chirasil-Dex CB column, 1.0 mL/min, 10°C/min from 70°C to 180°C then hold for 10 min.]: 16.5 min (major), 16.6 min (minor).

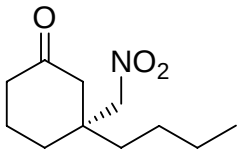
3-(nitromethyl)-3-propylcyclohexanone



Yellowy oil. ^{1}H-NMR ($CDCl_3$): δ 4.34 (s, 2H), 2.43-2.31 (m, 4H), 2.03–1.74 (m, 4H), 1.42-1.25 (m, 4H), 0.93 (t, *J* = 6.8 Hz, 3H). ^{13}C-NMR ($CDCl_3$): δ 209.4, 82.2, 49.7, 42.7, 40.8, 38.0, 31.6, 21.2, 16.3, 14.6. The enantiomeric excess was determined by GC. [Chirasil-Dex CB column, 1.0 mL/min, 10°C/min from 70°C

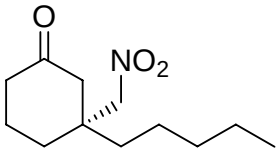
to 200°C then hold for 5 min.]: 17.3 min (minor), 17.4 min (major).

3-butyl-3-(nitromethyl)cyclohexanone



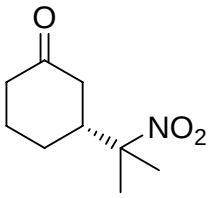
Orange oil. ^{1}H-NMR ($CDCl_3$): δ 4.34 (s, 2H), 2.43-2.28 (m, 4H), 2.03–1.70 (m, 4H), 1.45-1.22 (m, 6H), 0.91 (t, J = 7.0 Hz, 3H). ^{13}C-NMR ($CDCl_3$): δ 209.4, 82.2, 49.8, 42.6, 40.8, 35.4, 31.6, 25.1, 23.2, 21.2, 14.1. The enantiomeric excess was determined by GC. [Chirasil-Dex CB column, 1.0 mL/min, 10°C/min from 70°C to 200°C then hold for 10 min.]: 18.6 min (minor), 18.8 min (major).

3-(nitromethyl)-3-pentylcyclohexanone



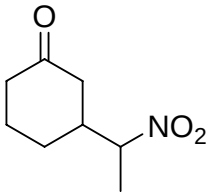
Orange oil. ^{1}H-NMR ($CDCl_3$): δ 4.34 (s, 2H), 2.43-2.28 (m, 4H), 1.99–1.73 (m, 4H), 1.42-1.25 (m, 8H), 0.89 (t, J = 6.8 Hz, 3H). ^{13}C-NMR ($CDCl_3$): δ 209.4, 82.1, 49.7, 42.6, 40.8, 35.6, 32.2, 31.6, 22.6, 22.5, 21.1, 14.2. The enantiomeric excess was determined by GC. [Chirasil-Dex CB column, 1.0 mL/min, 10°C/min from 70°C to 200°C then hold for 10 min.]: 20.6 min (minor), 20.9 min (major).

3-(2-nitropropan-2-yl)cyclohexanone



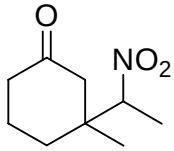
White solid. ^{1}H-NMR ($CDCl_3$): δ 2.45-2.35 (m, 3H), 2.26–2.24 (m, 1H), 2.16–2.12 (m, 2H), 1.83–1.78 (m, 1H), 1.65–1.60 (m, 1H), 1.58 (s, 3H), 1.57 (s, 3H), 1.47–1.37 (m, 1H). ^{13}C-NMR ($CDCl_3$): δ 209.2, 90.9, 46.9, 43.0, 41.1, 26.3, 24.7, 23.9, 22.8. The enantiomeric excess was determined by GC. [Chirasil-Dex CB column, 1.0 mL/min, 10°C/min from 70°C to 140°C then hold for 40 min.]: 41.4 min (minor), 42.1 min (major).

3-(1-nitroethyl)cyclohexanone



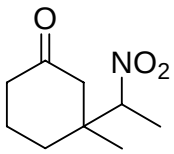
Damask oil. ^{1}H-NMR (an inseparable mixture of diastereomers, $CDCl_3$): δ 4.54–4.46 (m, 1Hmaj and 1Hmin), 2.44–2.12 (m, 6Hmaj and 6Hmin), 1.98–1.84 (m, 1Hmaj and 1Hmin), 1.69–1.66 (m, 1Hmaj and 1Hmin), 1.56 (d, J =6.8Hz, 3Hmaj), 1.54 (d, J =6.8Hz, 3Hmin), 1.49–1.45 (m, 1Hmaj and 1Hmin). The enantiomeric excess was determined by HPLC. [AD-H column, 220 nm, hexane: IPA = 40:1, 0.8 mL/min]: 35.2 min (minor1), 39.8 min (major1), 51.0 (major2), 58.8 min (minor2).

3-methyl-3-(1-nitroethyl)cyclohexanone (Diastereomer major)



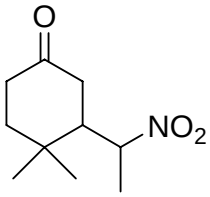
Colorless oil. ^{1}H-NMR ($CDCl_3$): δ 4.53 (dd, J = 6.8, 13.6 Hz, 1H), 2.38–2.35 (m, 1H), 2.31–2.29 (m, 1H), 2.26–2.21 (m, 2H), 2.08-2.05 (m, 1H), 1.80–1.65 (m, 3H), 1.52 (d, J =6.8 Hz, 3H), 1.04 (s, 3H). ^{13}C-NMR ($CDCl_3$): δ209.5, 90.6, 50.2, 42.0, 40.8, 32.8, 21.6, 20.3, 13.9. The enantiomeric excess was determined by GC. [Chirasil-Dex CB column, 1.0 mL/min, 10°C/min from 70°C to 160°C then hold for 20 min.]: 20.8 min (major), 21.3 min (minor).

3-methyl-3-(1-nitroethyl)cyclohexanone (Diastereomer minor)



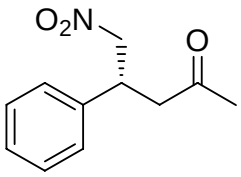
Colorless oil. ^{1}H-NMR ($CDCl_3$): δ 4.51 (dd, J = 6.9, 13.7 Hz, 1H), 2.53 (d, J = 13.7 Hz, 1H), 2.41–2.37 (m, 1H), 2.29–2.26 (m, 1H), 2.17-2.12 (m, 1H), 2.01-1.99 (m, 1H), 1.90–1.80 (m, 1H), 1.71-1.64 (m, 2H), 1.53 (d, J =7.3 Hz, 3H), 1.00 (s, 3H). The enantiomeric excess was determined by GC. [Chirasil-Dex CB column, 1.0 mL/min, 10°C/min from 70°C to 140°C then hold for 20 min.]: 34.0 min (major), 35.3 min (minor).

4,4-dimethyl-3-(1-nitroethyl)cyclohexanone



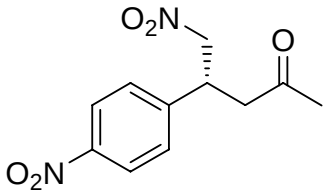
Colorless solid. ^{1}H-NMR (DMSO-D6): δ5.03–4.93 (m, 1Hmaj and 1Hmin), 2.53–1.95 (m, 6Hmaj and 6Hmin), 1.59–1.57 (m, 1Hmaj and 1Hmin), 1.46 (d, J = 6.8 Hz, 3Hmaj), 1.39 (d, J = 6.8 Hz, 3Hmin), 1.11–1.00 (m, 6Hmaj and 6Hmin). ^{13}C-NMR (DMSO-D6): δ 209.4 (maj), 83.5 (min), 8.30 (maj), 49.0 (maj), 48.6 (min), 38.4(min), 38.0 (maj), 37.5, 33.4, 28.4 (maj), 28.3 (min), 19.3 (min), 19.0 (maj), 16.0. The enantiomeric excess was determined by GC. [Chirasil-Dex CB column, 1.0 mL/min, 10°C/min from 70°C to 140°C then hold for 45 min.]: 42.0 min (major1), 43.8min (minor1), 49.0 (major2), 50.0 min (minor2).

5-nitro-4-phenylpentan-2-one



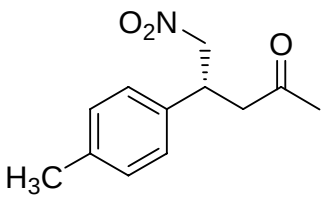
White solid. ^{1}H-NMR ($CDCl_3$): δ 7.33–7.26 (m, 3H), 7.23–7.20 (m, 2H), 4.69 (dd, J = 6.8, 12.4 Hz, 1H), 4.60 (dd, J = 7.6, 12.4 Hz, 1H), 4.00 (apparent qn, J = 7.2 Hz, 1H), 2.91 (d, J = 7.2 Hz, 2H), 2.12 (s, 3H). ^{13}C-NMR ($CDCl_3$): δ 205.6, 139.1, 129.3, 128.2, 127.6, 79.7, 46.4, 39.3, 30.6. The enantiomeric excess was determined by HPLC. [AD-H column, 220 nm, hexane: IPA = 20:1, 0.8 mL/min.]: 20.3 min (minor), 22.2 min (major).

5-nitro-4-(4-nitrophenyl)pentan-2-one



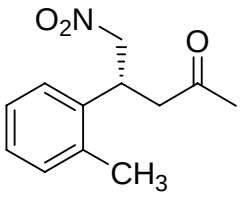
Orange oil. ^{1}H-NMR ($CDCl_3$): δ 8.20 (d, J = 10.0 Hz, 2H), 7.43 (d, J = 10.0 Hz, 2H), 4.76 (dd, J = 6.4, 12.8 Hz, 1H), 4.65 (dd, J = 8.4, 12.8 Hz, 1H), 4.18-4.11 (m, 1H), 2.97 (dd, J = 3.2, 6.8 Hz, 2H), 2.16 (s, 3H). ^{13}C-NMR ($CDCl_3$): δ 204.6, 147.8, 146.6, 128.8, 124.5, 78.8, 45.9, 38.9, 30.5. The enantiomeric excess was determined by HPLC. [AD-H column, 220 nm, hexane: IPA = 9:1, 0.8 mL/min.]: 43.4 min (minor), 60.0 min (major).

5-nitro-4-p-tolylpentan-2-one



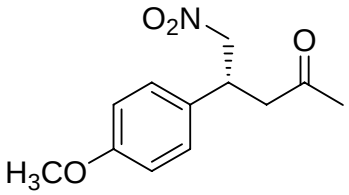
Orange solid. ^{1}H-NMR ($CDCl_3$): δ 7.14-7.08 (m, 4H), 4.66 (dd, J = 7.0, 12.2 Hz, 1H), 4.57 (dd, J = 7.8, 12.2 Hz, 1H), 4.0-3.93 (m, 1H), 2.91 (d, J = 6.8 Hz, 2H), 2.31 (s, 3H), 2.11 (s, 3H). ^{13}C-NMR ($CDCl_3$): δ 205.7, 137.9, 136.0, 130.0, 127.5, 79.9, 46.4, 39.0, 30.7, 21.3. The enantiomeric excess was determined by HPLC. [AD-H column, 220 nm, hexane:IPA =9:1, 0.8mL/min.]: 11.1min (minor), 12.4min (major).

5-nitro-4-o-tolylpentan-2-one



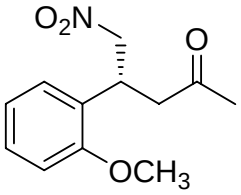
Colorless oil. ^{1}H-NMR ($CDCl_3$): δ 7.19-7.14 (m, 4H), 4.64 (dd, J = 7.4, 12.2 Hz, 1H), 4.56 (dd, J = 7.2, 12.4 Hz, 1H), 4.31 (m, 1H), 2.90 (dd, J = 2.6, 7.0 Hz, 2H), 2.44 (s, 3H), 2.10 (s, 3H). ^{13}C-NMR ($CDCl_3$): δ 205.7, 137.3, 136.6, 131.3, 127.8, 126.8, 125.6, 79.2, 47.0, 34.4, 30.6, 19.8. The enantiomeric excess was determined by HPLC. [AD-H column, 220 nm, hexane: IPA = 20:1, 0.8mL/min.]: 14.5 min (minor), 15.7 min (major).

4-(4-methoxyphenyl)-5-nitropentan-2-one



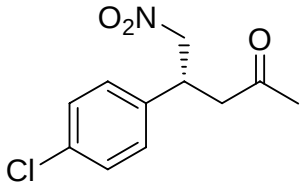
White solid. ^{1}H-NMR ($CDCl_3$): δ 7.13 (d, J = 11.6 Hz, 2H), 6.85 (d, J = 11.6 Hz, 2H), 4.65 (dd, J = 6.8, 12.4 Hz, 1H), 4.55 (dd, J = 7.8, 12.2 Hz, 1H), 3.95 (m, 1H), 3.77 (s, 3H), 2.88 (d, J = 7.2 Hz, 2H), 2.11 (s, 3H). ^{13}C-NMR ($CDCl_3$): δ 205.8, 159.4, 130.9, 128.7, 114.7, 80.0, 55.5, 46.5, 38.7, 30.7. The enantiomeric excess was determined by HPLC. [AD-H column, 220 nm, hexane: IPA = 9:1, 0.8mL/min.]: 17.2 min (minor), 19.2 min (major).

4-(2-methoxyphenyl)-5-nitropentan-2-one



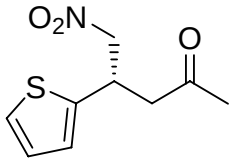
Yellowy solid. ^{1}H-NMR ($CDCl_3$): δ 7.26-7.23 (m, 2H), 7.13 (dd, J = 7.4, 1.4 Hz, 1H), 6.91-6.87 (m, 2H), 4.74 (dd, J = 7.0, 12.2 Hz, 1H), 4.70 (dd, J = 6.6, 12.2 Hz, 1H), 4.25-4.18 (m, 1H), 3.86 (s, 3H), 3.05-2.92 (m, 2H), 2.12 (s, 3H). ^{13}C-NMR ($CDCl_3$): δ 206.4, 157.3, 129.5, 129.2, 126.7, 121.6, 111.2, 78.1, 55.6, 44.7, 35.6, 30.5. The enantiomeric excess was determined by HPLC. [OD-H column, 220 nm, hexane: IPA = 9:1, 0.8mL/min.]: 19.8 min (major), 21.1 min (minor).

4-(4-chlorophenyl)-5-nitropentan-2-one



White solid. ^{1}H-NMR ($CDCl_3$): δ 7.30 (d, J = 6.4 Hz, 2H), 7.16 (d, J = 6.4 Hz, 1H), 4.68 (dd, J = 4.0, 12.0 Hz, 1H), 4.58 (dd, J = 8.0, 12.0 Hz, 1H), 4.03-3.95 (m, 1H), 2.89 (d, J = 8.0 Hz, 2H), 2.12 (s, 3H). ^{13}C-NMR ($CDCl_3$): δ 205.2, 137.6, 134.0, 130.2, 129.1, 79.4, 46.2, 38.6, 30.6. The enantiomeric excess was determined by HPLC. [AD-H column, 220 nm, hexane: IPA = 9:1, 0.8mL/min.]: 15.3 min (minor), 17.6 min (major).

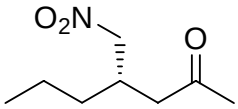
5-nitro-4-(thiophen-2-yl)pentan-2-one



Brown oil. ^{1}H-NMR ($CDCl_3$): δ 7.20 (dd, J = 1.2, 4.8 Hz, 1H), 6.90–6.95 (m, 2H), 4.71 (dd, J = 12.4, 6.4 Hz, 1H), 4.62 (dd, J = 12.4, 7.6 Hz, 1H), 4.32 (m, 1H), 2.97 (d, J = 6.8 Hz, 2H), 2.16 (s, 3H). ^{13}C-NMR ($CDCl_3$): δ 205.2, 141.8, 127.4, 125.8, 125.0, 79.9, 47.1, 34.7, 30.6. The enantiomeric excess was determined by HPLC. [OD-H column, 220 nm, hexane: IPA = 9:1, 0.8mL/min.]: 30.7 min (major), 38.4 min (minor).

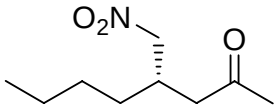
4-(nitromethyl)heptan-2-one

Colorless oil. ^{1}H-NMR ($CDCl_3$): δ 4.45 (d, J = 7.2 Hz, 2H), 2.64-2.53 (m, 3H), 2.17 (s, 3H),



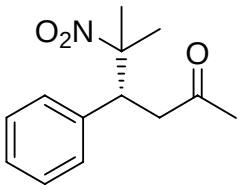
1.39-1.34 (m, 4H), 0.92 (t, J = 7.2 Hz, 3H). ^{13}C-NMR ($CDCl_3$): δ 206.9, 78.6, 44.8, 33.8, 33.0, 30.6, 20.0, 14.1. The enantiomeric excess was determined by GC. [Chirasil-Dex CB column, 1.0 mL/min, 10°C/min from 70°C to 150°C then hold for 10 min.]: 13.9 min (major), 14.1 min (minor).

4-(nitromethyl)octan-2-one



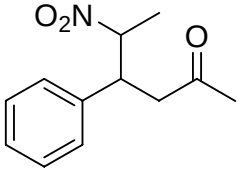
Colorless oil. ^{1}H-NMR ($CDCl_3$): δ 4.45 (d, J = 7.2 Hz, 2H), 2.64-2.53 (m, 3H), 2.17 (s, 3H), 1.41-1.29 (m, 6H), 0.90 (t, J = 6.8 Hz, 3H). ^{13}C-NMR ($CDCl_3$): δ 206.9, 78.6, 44.9, 33.2, 31.4, 30.7, 29.0, 22.7, 14.1. The enantiomeric excess was determined by GC. [Chirasil-Dex CB column, 1.0 mL/min, 10°C/min from 70°C to 150°C then hold for 10 min.]: 16.4 min (major), 16.6 min (minor).

5-methyl-5-nitro-4-phenylhexan-2-one



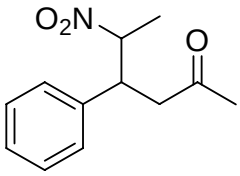
Yellowy oil. ^{1}H-NMR ($CDCl_3$): δ 7.32–7.20 (m, 3H), 7.20–7.18 (m, 2H), 3.93 (dd, J = 3.4, 10.6 Hz, 1H), 3.09 (dd, J = 10.6, 17.0 Hz, 1H), 2.72 (dd, J = 3.6, 17.2 Hz, 1H), 2.02 (s, 3H), 1.55 (s, 3H), 1.48 (s, 3H). ^{13}C-NMR ($CDCl_3$): δ 205.3, 137.9, 129.4, 128.8, 128.1, 91.3, 49.0, 44.3, 30.5, 26.1, 22.7. The enantiomeric excess was determined by GC. [Chirasil-Dex CB column, 1.0 mL/min, 10°C/min from 70°C to 150°C then hold for 35 min.]: 40.8 min (major), 41.5 min (minor).

5-nitro-4-phenylhexan-2-one(Diastereomer major)



Colorless oil. ^{1}H-NMR ($CDCl_3$): δ 7.35–7.18 (m, 5H), 4.76 (qd, J = 6.8, 10.0 Hz, 1H), 3.71 (apparent td, J = 4.4, 9.6 Hz, 1H), 2.97 (dd, J = 9.6, 16.8 Hz, 1H), 2.74 (dd, J = 4.4, 17.2 Hz, 1H), 2.01 (s, 3H), 1.32 (d, J = 6.8 Hz, 3H). ^{13}C-NMR ($CDCl_3$): δ 205.1, 138.5, 129.3, 128.4, 128.1, 87.4, 46.5, 45.6, 30.7, 18.0. The enantiomeric excess was determined by GC. [Chirasil-Dex CB column, 1.0 mL/min, 10°C/min from 70°C to 135°C then hold for 65 min.]: 60.6 min (minor), 61.6 min (major).

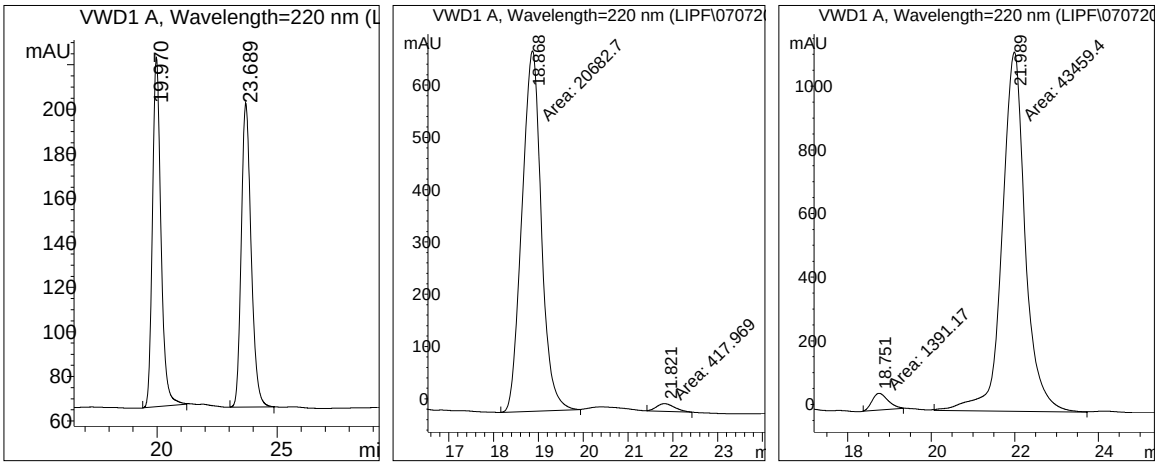
5-nitro-4-phenylhexan-2-one(Diastereomer minor)



Colorless oil. ^{1}H-NMR ($CDCl_3$): δ 7.33–7.26 (m, 3H), 7.15–7.13 (m, 2H), 4.88 (qn, J = 6.8 Hz, 1H), 3.73 (apparent q, J = 6.8 Hz, 1H), 3.05 (dd, J = 6.8, 17.6 Hz, 1H), 2.89 (dd, J = 7.6, 17.6 Hz, 1H), 2.11 (s, 3H), 1.48 (d, J = 8.0 Hz, 3H). ^{13}C-NMR ($CDCl_3$): δ206.0, 138.1, 129.0, 128.4, 128.2, 86.1, 45.0, 44.8, 30.8, 17.0. The enantiomeric excess was determined by GC. [Chirasil-Dex CB column, 1.0 mL/min, 10°C/min from 70°C to 135°C then hold for 65 min.]: 67.3 min (major), 69.3 min (minor).

E: CSP-HPLC or CSP-GC Analysis of Addition Products

3-(nitromethyl)cyclohexanone



Racemic adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	19.97	3864.8	156.9	0.3762	49.778	0.796
2	23.689	3899.2	136.6	0.4378	50.222	0.771

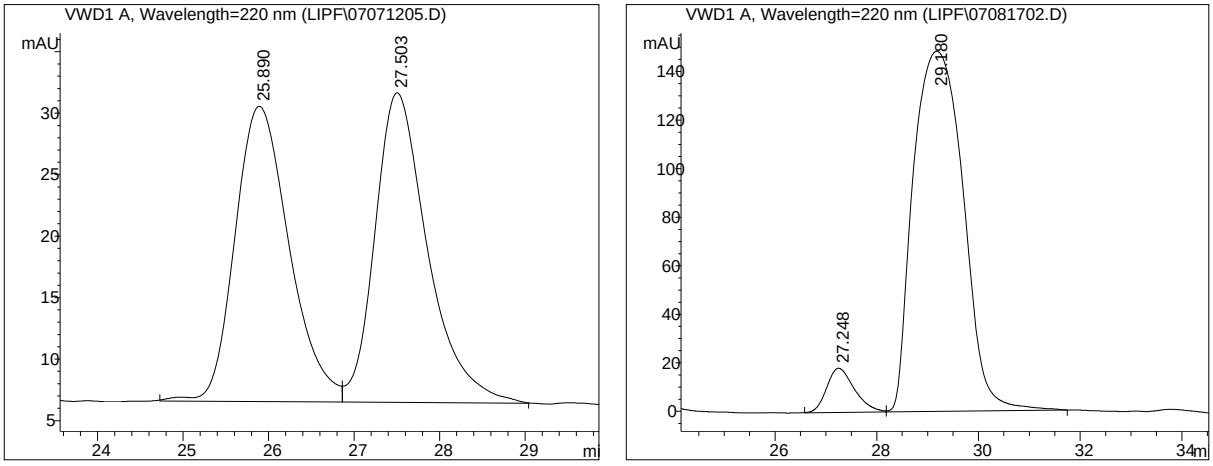
Asymmetric adduct (Catalyzed by **3**)

#	Time	Area	Height	Width	Area%	Symmetry
1	18.868	20682.7	689.5	0.5	98.019	1.127
2	21.821	418	14.9	0.469	1.981	0.729

Asymmetric adduct (Catalyzed by **6**)

#	Time	Area	Height	Width	Area%	Symmetry
1	18.751	1391.2	52.8	0.439	3.102	0.765
2	21.989	43459.4	1128.7	0.6417	96.898	1.08

4,4-dimethyl-3-(nitromethyl)cyclohexanone



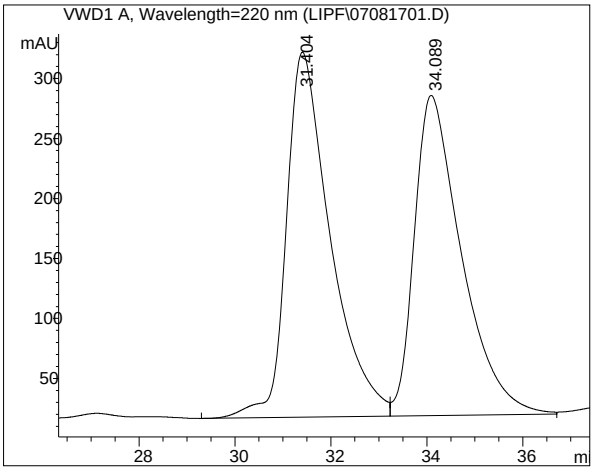
Racemic adduct

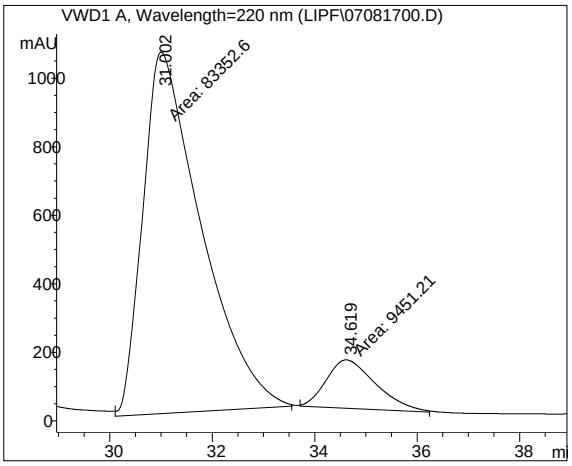
#	Time	Area	Height	Width	Area%	Symmetry
1	25.89	1058.5	24	0.6845	49.555	0.779
2	27.503	1077.5	25.2	0.6461	50.445	0.684

Asymmetric adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	27.248	690.5	18.2	0.5735	6.381	0.713
2	29.18	10130.9	148.4	1.1636	93.619	0.851

3-(nitromethyl)cyclopentanone





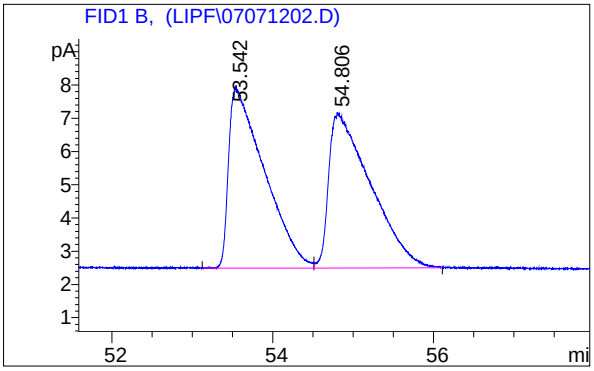
Racemic adduct

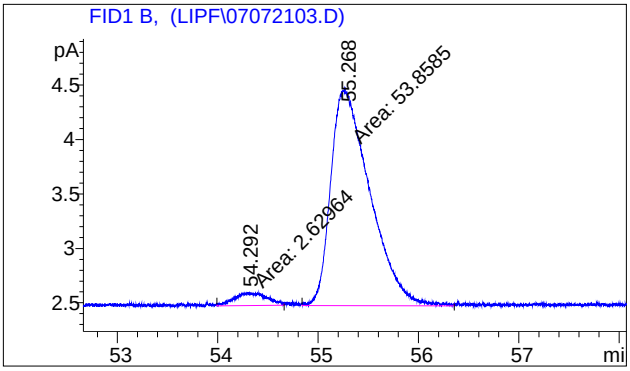
#	Time	Area	Height	Width	Area%	Symmetry
1	31.404	19379.6	304.3	0.9424	51.497	0.561
2	34.089	18252.6	267	1.0218	48.503	0.522

Asymmetric adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	31.002	83352.6	1054.7	1.3172	89. 816	0.452
2	34.619	9451.2	141.1	1.1166	10.184	0.65

3-(nitromethyl)cycloheptanone





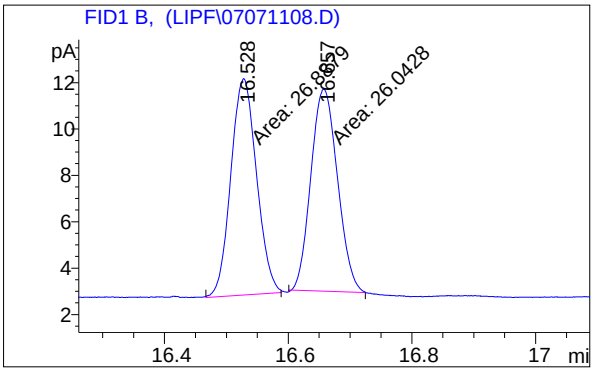
Racemic adduct

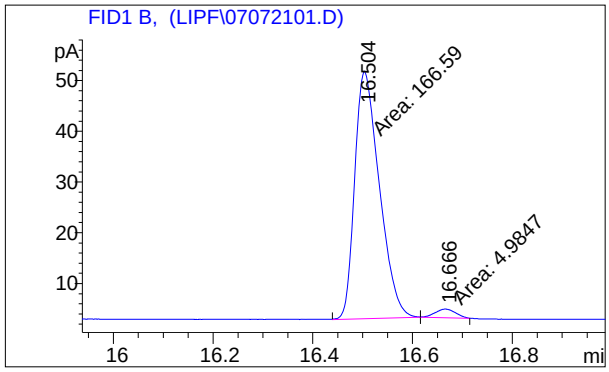
#	Time	Area	Height	Width	Area%	Symmetry
1	53.542	166.6	5.5	0.3621	49.741	0.249
2	54.806	168.3	4.7	0.4263	50.259	0.264

Asymmetric adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	54.292	2.6	1.2E-1	0.3599	4.655	0.667
2	55.268	53.9	2	0.4483	95.345	0.556

3-methyl-3-(nitromethyl)cyclohexanone





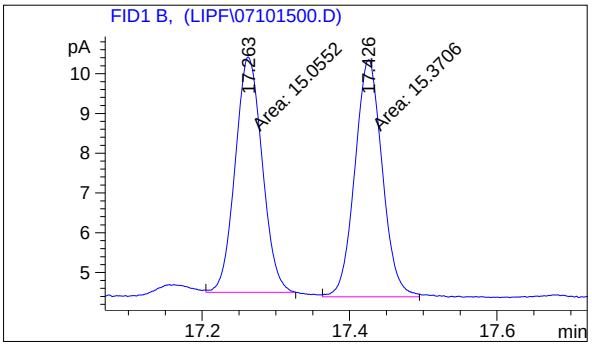
Racemic adduct

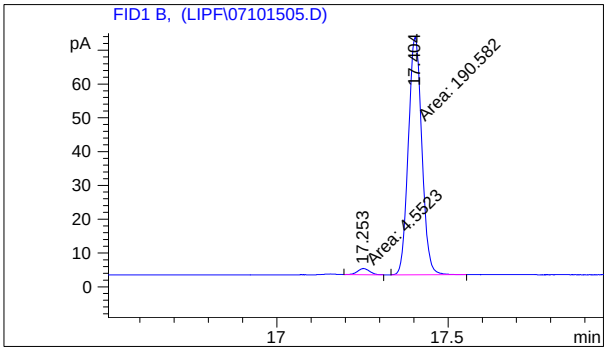
#	Time	Area	Height	Width	Area%	Symmetry
1	16.528	26.9	9.4	0.0479	50.798	0.919
2	16.657	26	8.7	0.0497	49.202	0.752

Asymmetric adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	16.504	166.6	48.7	0.057	97.095	0.751
2	16.666	5	1.7	0.0484	2.905	0.769

3-(nitromethyl)-3-propylcyclohexanone





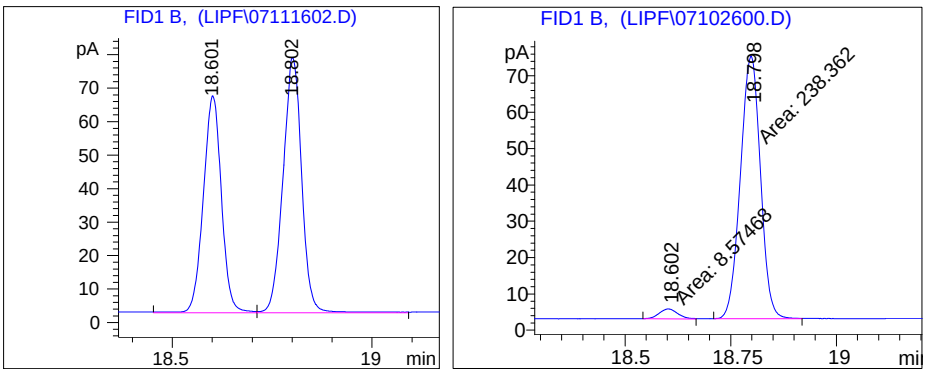
Racemic adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	17.263	15.1	5.9	0.0424	49.482	1.138
2	17.426	15.4	6	0.0427	50.518	0.806

Asymmetric adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	17.253	4.6	1.8	0.0411	2.333	0.705
2	17.404	190.6	70.8	0.0448	97.667	1.194

3-butyl-3-(nitromethyl)cyclohexanone



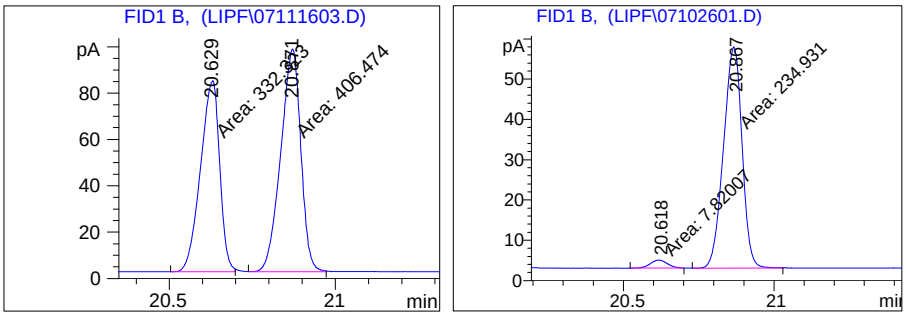
Racemic adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	18.601	204.6	64.4	0.0491	45.194	1.034
2	18.802	248.1	75.5	0.0503	54.806	1.054

Asymmetric adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	18.602	8.6	2.8	0.0516	3.472	0.936
2	18.798	238.4	72.4	0.0548	96.528	0.984

3-(nitromethyl)-3-pentylcyclohexanone



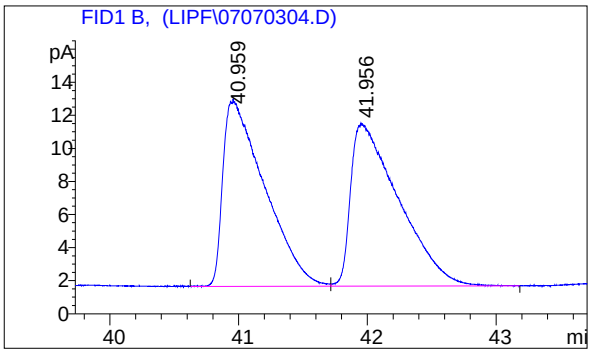
Racemic adduct

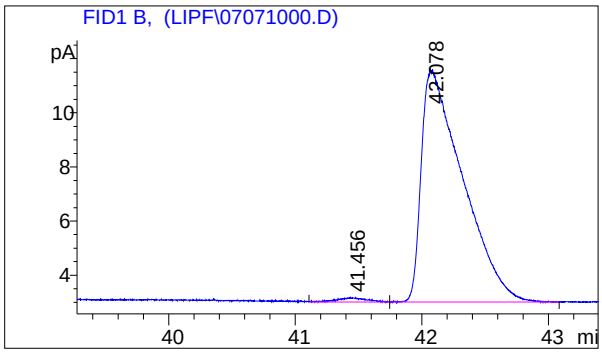
#	Time	Area	Height	Width	Area%	Symmetry
1	20.629	332.3	83	0.0667	44.982	1.662
2	20.871	406.5	96.7	0.0701	55.018	1.4

Asymmetric adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	20.618	7.8	2	0.0651	3.221	0.894
2	20.867	234.9	54.9	0.0714	96.779	1.396

3-(2-nitropropan-2-yl)cyclohexanone





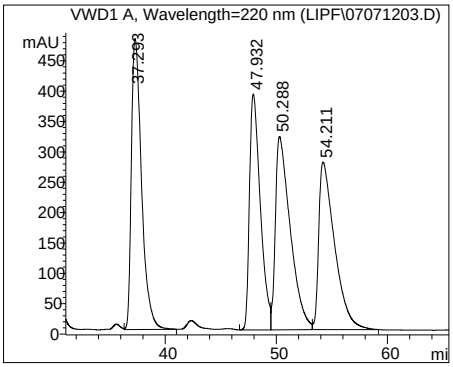
Racemic adduct

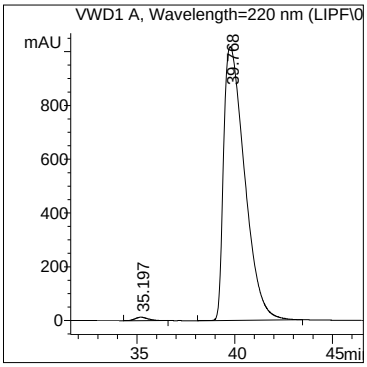
#	Time	Area	Height	Width	Area%	Symmetry
1	40.959	252.8	11.2	0.2924	49.897	0.306
2	41.956	253.8	9.8	0.3149	50.103	0.294

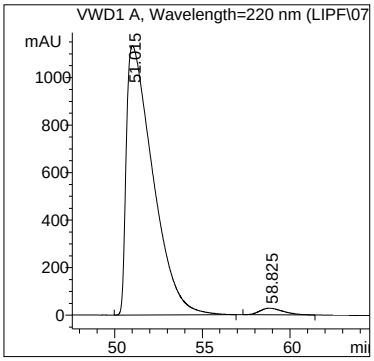
Asymmetric adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	41.456	2.6	1.5E-1	0.2009	1.290	1.174
2	42.078	195.2	8.5	0.3015	98.710	0.313

3-(1-nitroethyl)cyclohexanone







Racemic adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	37.293	30595.1	479.1	1.0021	26.830	0.527
2	47.932	26288.4	388	1.0321	23.054	0.506
3	50.288	29665.9	318.2	1.3847	26.016	0.356
4	54.211	27481.8	275.9	1.4562	24.100	0.347

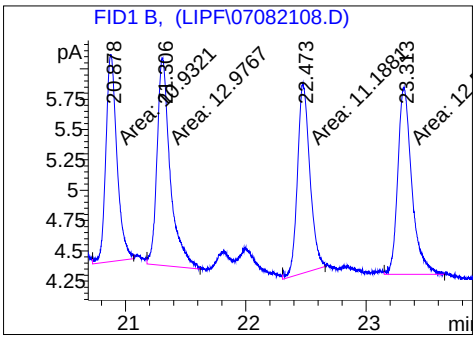
Asymmetric adduct (Minor)

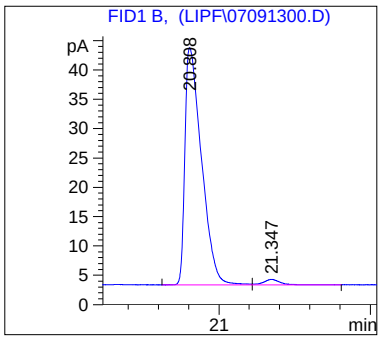
#	Time	Area	Height	Width	Area%	Symmetry
1	35.197	596.9	12.6	0.721	0.782	0.717
2	39.768	75696	1017.5	1.1621	99.218	0.424

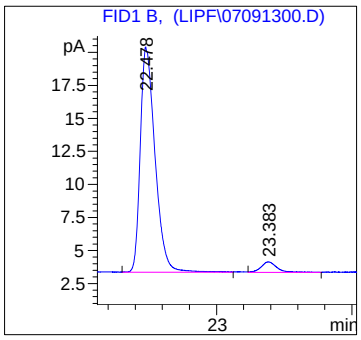
Asymmetric adduct (Major)

#	Time	Area	Height	Width	Area%	Symmetry
3	51.015	118938.5	1132.2	1.5401	97.873	0.278
4	58.825	2584.8	27.9	1.4056	2.127	0.671

3-methyl-3-(1-nitroethyl)cyclohexanone







Racemic adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	20.878	10.9	1.7	0.1068	22.965	0.833
2	21.306	13	1.7	0.1268	27.260	0.649
3	22.473	11.2	1.6	0.1195	23.503	0.722
4	23.313	12.5	1.5	0.136	26.272	0.66

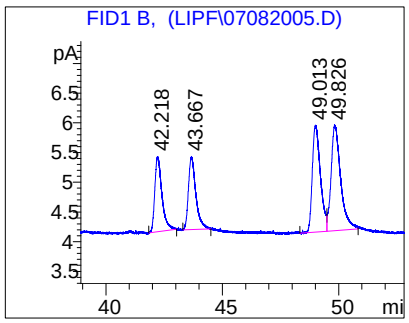
Asymmetric adduct (Major)

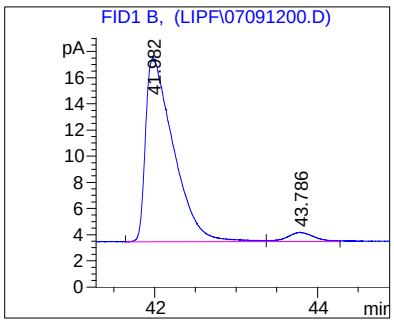
#	Time	Area	Height	Width	Area%	Symmetry
1	20.808	306.4	40.3	0.1126	97.625	0.387
2	21.347	7.5	9.2E-1	0.1225	2.375	0.75

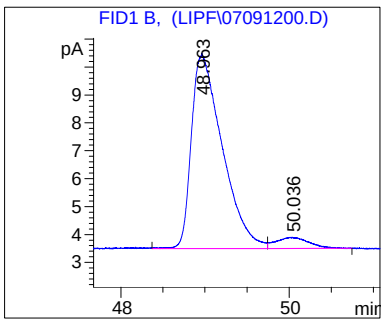
Asymmetric adduct (Minor)

#	Time	Area	Height	Width	Area%	Symmetry
3	22.478	129.2	17	0.1185	95.262	0.582
4	23.383	6.4	7.8E-1	0.1202	4.738	0.785

4,4-dimethyl-3-(1-nitroethyl)cyclohexanone







Racemic adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	42.218	27	1.3	0.2926	18.205	0.624
2	43.667	27.1	1.2	0.2979	18.239	0.624
3	49.013	43.6	1.8	0.3021	29.365	0.708
4	49.826	50.8	1.8	0.3457	34.191	0.602

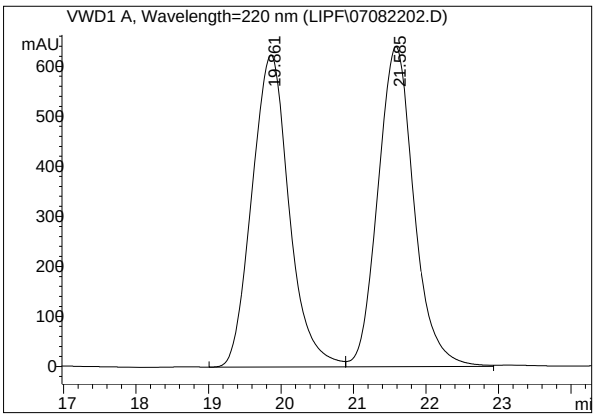
Asymmetric adduct (Major)

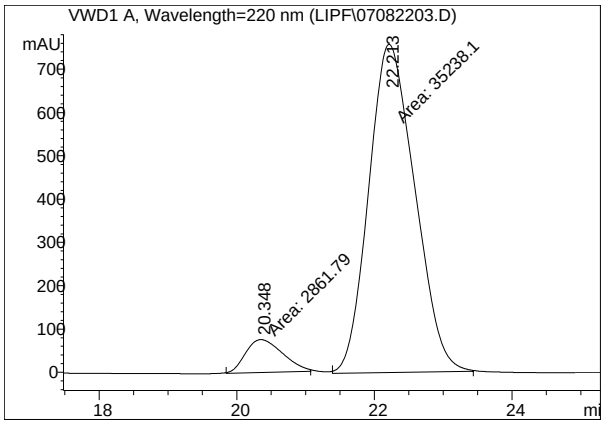
#	Time	Area	Height	Width	Area%	Symmetry
1	41.982	333.6	14.1	0.3078	95.423	0.337
2	43.786	16	7.1E-1	0.2745	4.577	0.866

Asymmetric adduct (Minor)

#	Time	Area	Height	Width	Area%	Symmetry
3	48.963	177.4	7	0.3026	94.231	0.502
4	50.036	10.9	3.9E-1	0.3279	5.769	0.928

5-nitro-4-phenylpentan-2-one





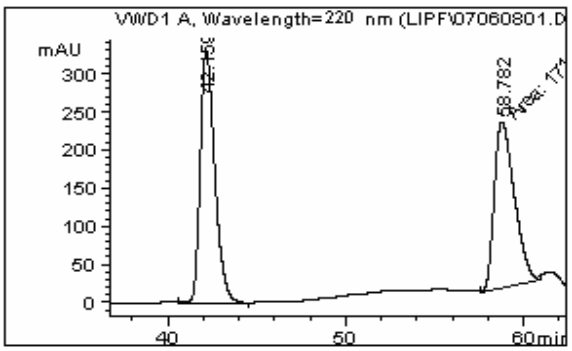
Racemic adduct

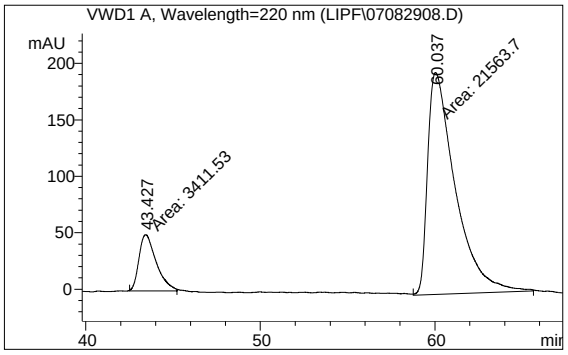
#	Time	Area	Height	Width	Area%	Symmetry
1	19.861	22236.6	623.4	0.553	50.139	0.976
2	21.585	22113.5	639.5	0.5345	49.861	0.939

Asymmetric adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	20.348	2861.8	76.2	0.626	7.511	0.697
2	22.213	35238.1	758.2	0.7746	92.489	0.781

5-nitro-4-(4-nitrophenyl)pentan-2-one





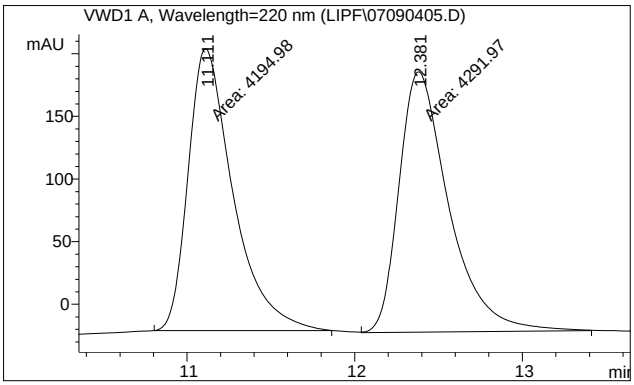
Racemic adduct

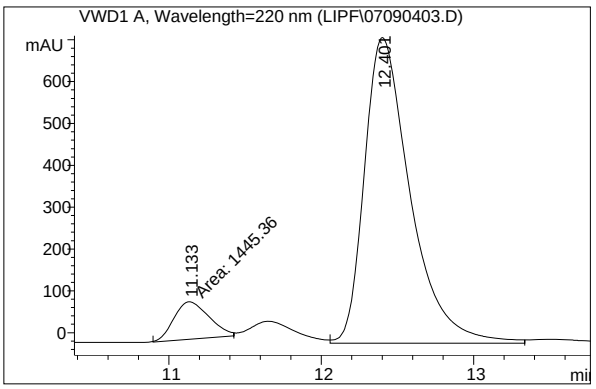
#	Time	Area	Height	Width	Area%	Symmetry
1	42.159	19043.3	332.1	0.8758	52.598	0.669
2	58.782	17162	218	1.3124	47.402	0.604

Asymmetric adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	43.427	3411.5	49.7	1.1434	13.660	0.614
2	60.037	21563.7	196.4	1.8296	86.340	0.39

5-nitro-4-p-tolylpentan-2-one





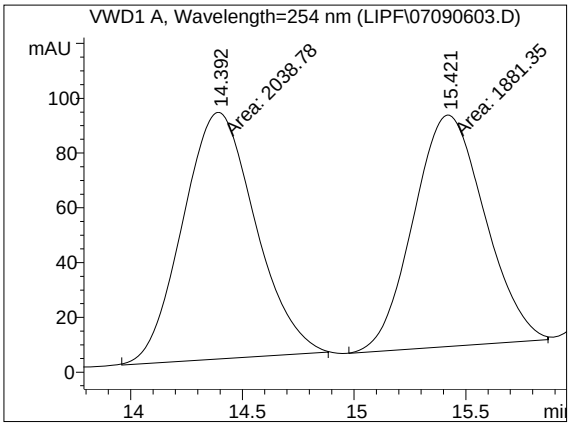
Racemic adduct

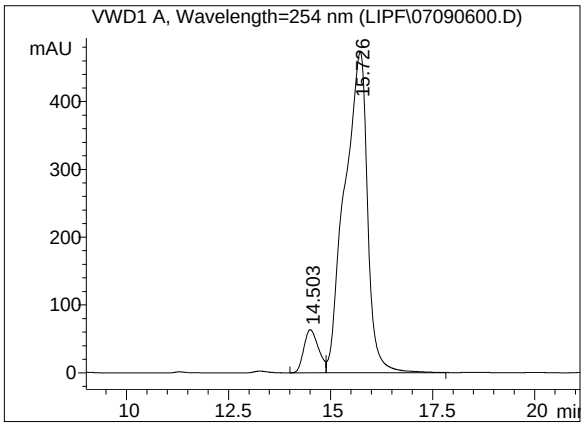
#	Time	Area	Height	Width	Area%	Symmetry
1	11.111	4195	225.2	0.3105	49.429	0.618
2	12.381	4292	207.8	0.3442	50.571	0.616

Asymmetric adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	11.133	1445.4	89.9	0.268	8.629	0.776
2	12.4014	15305.3	730.5	0.3158	91.371	0.597

5-nitro-4-o-tolylpentan-2-one





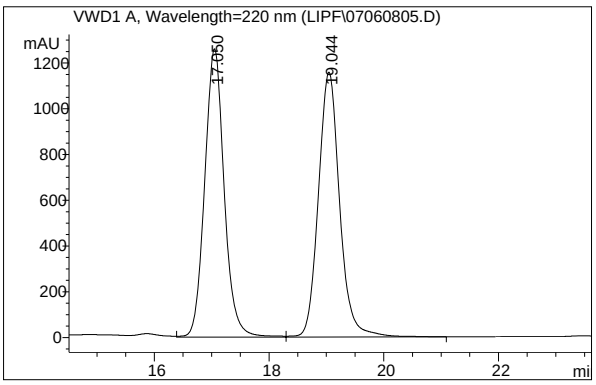
Racemic adduct

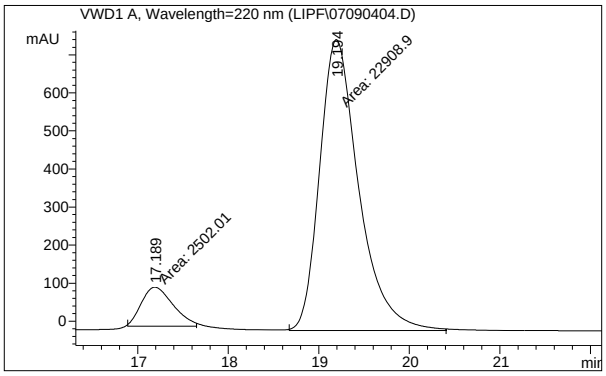
#	Time	Area	Height	Width	Area%	Symmetry
1	14.392	2038.8	90	0.3773	52.008	0.929
2	15.421	1881.4	84.5	0.3711	47.992	0.925

Asymmetric adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	14.503	1595.1	63.6	0.3872	7.999	0.756
2	15.726	18346.7	473.5	0.5438	92.001	1.958

4-(4-methoxyphenyl)-5-nitropentan-2-one





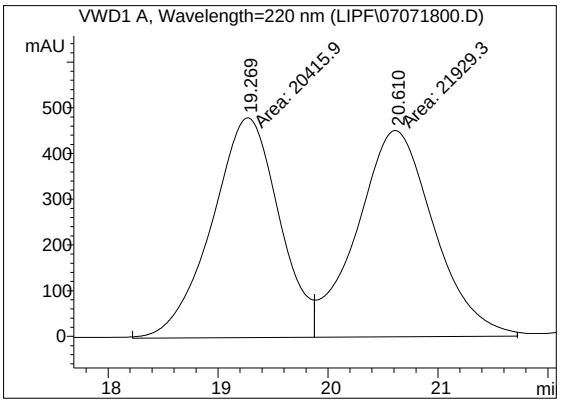
Racemic adduct

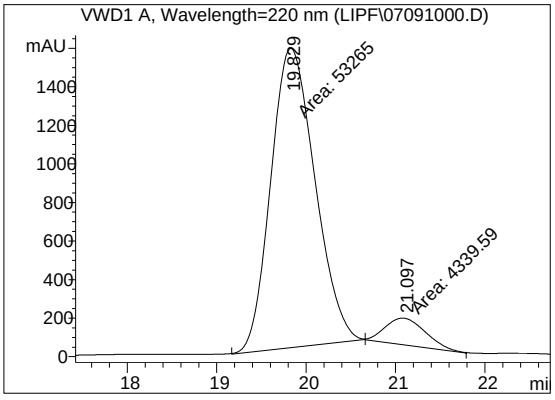
#	Time	Area	Height	Width	Area%	Symmetry
1	17.05	29631.3	1260.3	0.3602	49.957	0.949
2	19.044	29682.2	1157.3	0.3924	50.043	0.908

Asymmetric adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	17.189	2502	102.9	0.4051	9.846	0.718
2	419.194	22908.9	764.4	0.4995	90.154	0.715

4-(2-methoxyphenyl)-5-nitropentan-2-one





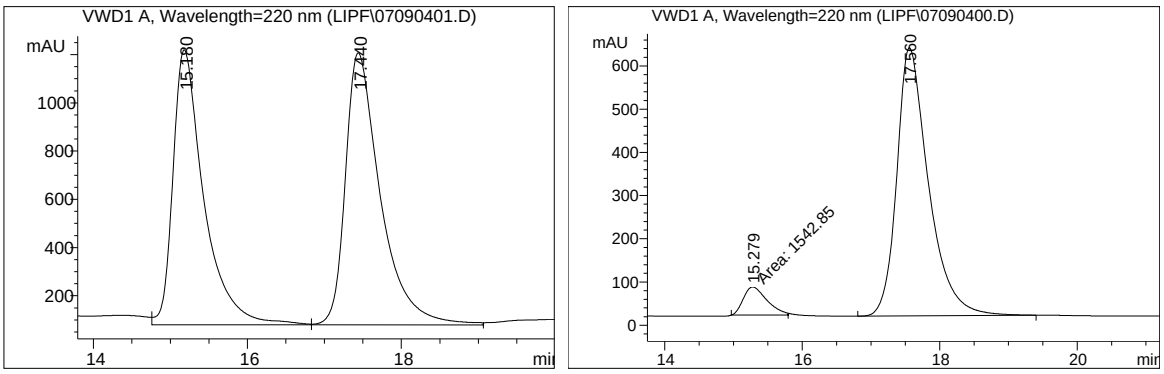
Racemic adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	19.269	20415.9	480.4	0.7083	48.213	1.123
2	20.610	21929.3	450.7	0.8109	51.787	0.95

Asymmetric adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	19.829	53265	1552.6	0.5718	92.467	0.805
2	21.097	4339.6	138.6	0.5219	7.533	0.707

4-(4-chlorophenyl)-5-nitropentan-2-one



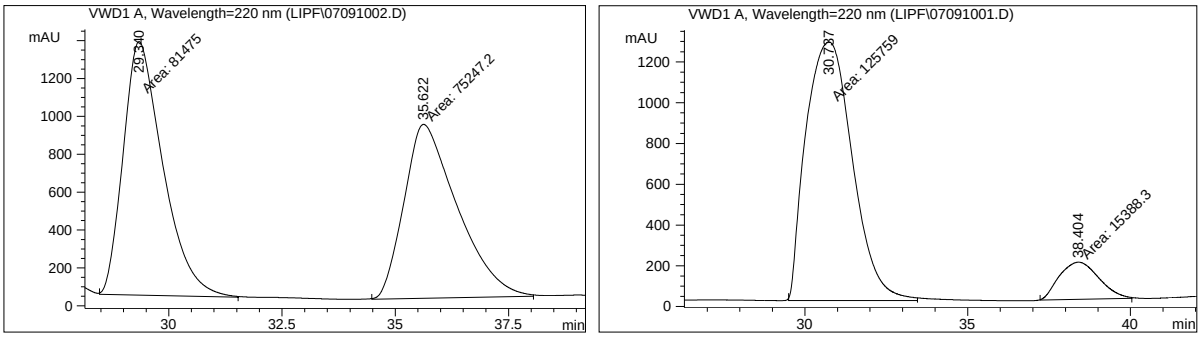
Racemic adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	15.18	31762.1	1140.2	0.408	47.208	0.529
2	17.44	35518.5	1127.8	0.465	52.792	0.538

Asymmetric adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	15.279	1542.8	65	0.3957	7.193	0.631
2	17.56	19907.6	620.6	0.4747	92.807	0.622

5-nitro-4-(thiophen-2-yl)pentan-2-one



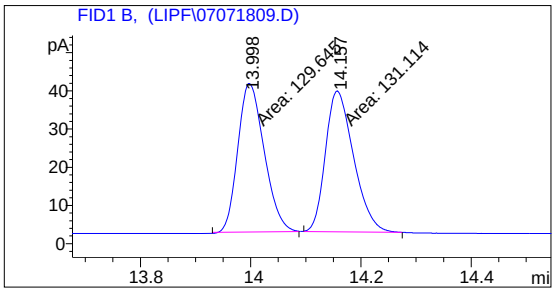
Racemic adduct

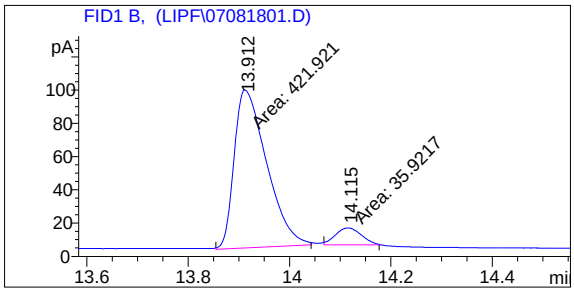
#	Time	Area	Height	Width	Area%	Symmetry
1	29.34	81475	1339.1	1.014	51.987	0.638
2	35.622	75247.2	918.6	1.3652	48.013	0.567

Asymmetric adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	30.737	125759.1	1267.4	1.6537	89.098	0.925
2	38.404	15388.3	182	1.4095	10.902	0.921

4-(nitromethyl)heptan-2-one





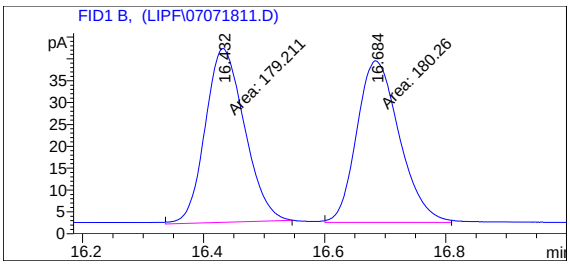
Racemic adduct

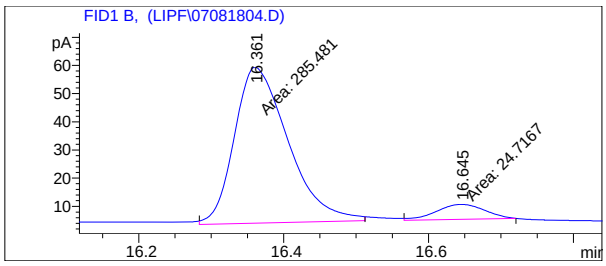
#	Time	Area	Height	Width	Area%	Symmetry
1	13.998	129.6	39.1	0.0552	49.718	0.753
2	14.157	131.1	37	0.059	50.282	0.683

Asymmetric adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	13.912	421.9	95	0.074	92.154	0.571
2	14.115	35.9	10.2	0.0589	7.846	0.889

4-(nitromethyl)octan-2-one





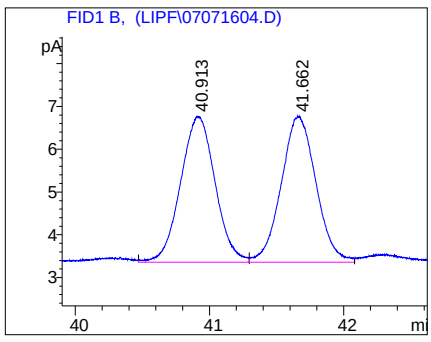
Racemic adduct

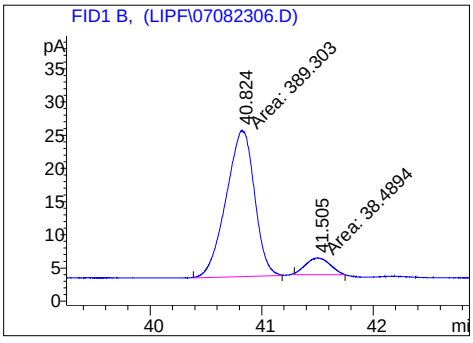
#	Time	Area	Height	Width	Area%	Symmetry
1	16.432	179.2	39.9	0.0748	49.854	0.762
2	16.684	180.3	37	0.0813	50.146	0.883

Asymmetric adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	16.361	285.5	55.5	0.0857	92.032	0.548
2	16.645	24.7	5.3	0.0773	7.968	1.159

5-methyl-5-nitro-4-phenylhexan-2-one





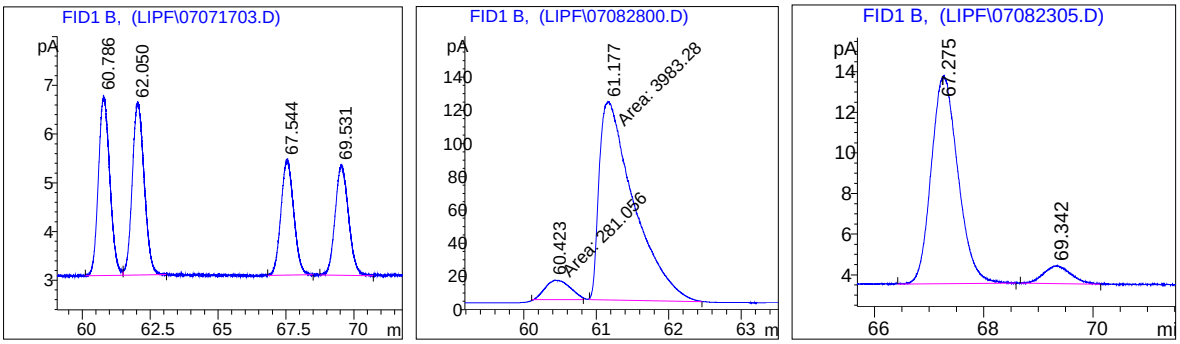
Racemic adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	40.913	60.9	3.4	0.2389	49.860	0.987
2	41.662	61.3	3.4	0.2386	50.140	0.98

Asymmetric adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	40.824	389.3	22	0.295	91.003	1.303
2	41.505	38.5	2.5	0.2548	8.997	1.039

5-nitro-4-phenylhexan-2-one



Racemic adduct

#	Time	Area	Height	Width	Area%	Symmetry
1	60.786	107	3.7	0.3574	28.932	0.781
2	62.050	108	3.5	0.3903	29.221	0.822
3	67.544	77.5	2.4	0.4151	20.949	0.907
4	69.531	77.3	2.3	0.4109	20.898	0.811

Asymmetric adduct (major)

#	Time	Area	Height	Width	Area%	Symmetry
1	60.423	281.1	11.7	0.4004	6.591	0.586
2	61.177	3983.3	119.3	0.5565	93.409	0.388

Asymmetric adduct (minor)

#	Time	Area	Height	Width	Area%	Symmetry
1	67.275	347.5	10.3	0.4013	91.948	0.89
2	69.342	30.4	8.6E-1	0.4215	8.052	0.932

E: References

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