Electronic Supplementary Material (ESI) for Organic & Biomolecular Chemistry.

High Pressure-Assisted Low-Loading Asymmetric Organocatalytic Conjugate Addition of Nitroalkanes to Chalcones

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Supporting Information

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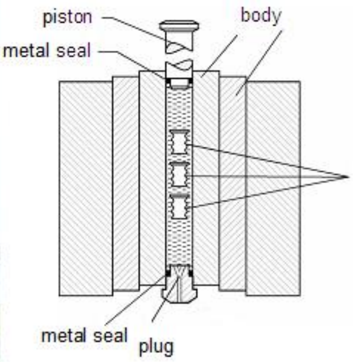
General Information:

All solvents were used as received, unless otherwise noted. Purification of products was performed using forced-flow chromatography on silica gel (Merck Kieselgel 60, 230-400 mesh) with mixtures of hexane/ethyl acetate, or hexane/dichloromethane as eluents. Thin-layer chromatography (TLC) was performed on silica gel plates (Merck Kieselgel 60 F_{254}). Visualization of the developed chromatogram was accomplished using UV light or *p*-anisaldehyde and cerium molybdate stains.

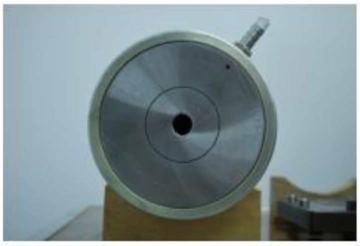
All reported NMR spectra were recorded in $CDCl_3$ using Agilent 400-MR (400 MHz) spectrometer. Chemical shifts of ^{1}H NMR and ^{13}C NMR are reported as δ values relative to TMS (δ=0.00) and $CDCl_3$ (δ=77.0), respectively. The following abbreviations are used to indicate the multiplicity: s - singlet; d - doublet; t - triplet; q - quartet; m – multiplet; dm **-** doublet of multiplets**.**

Optical rotation was recorded on a Perkin Elmer 241 polarimeter. Enantiomeric ratios of the products were determined using high performance liquid chromatography (HPLC) techniques. HPLC analyses were performed on a Merck chromatograph equipped with the diode-array detector (DAD) and Chiralpak® IA (25 cm x 0.46 cm, 5 μm), Chiralpak® IB (25 cm x 0.46 cm, 5 μm), Chiralpak® IC (25 cm x 0.46 cm, 5 μm) or Chiralpak® ID (25 cm x 0.46 cm, 5 μm) columns eluted with *iso*-propanol in hexane. GC analyses to determine yields of model reaction were performed on a Agilent 7890A gas chromatograph equipped with a split-mode capillary injection system and flame ionization detector using capillary column: HP-5 (30 m × 0.32 mm, Hewlett-Packard). Chromatography conditions: carrier gas – nitrogen, injector temperature 280 °C; detector temperature 280 °C.

High pressure experiments were performed at room temperature using laboratory high pressure set-up U101 from Unipress (Warsaw, Poland) equipped with a direct, single-stage piston-cylinder apparatus with a hydraulic press and a liquid piston vessel (LV/30/16) with working volume up to 50 mL. Experiments were conducted in 1.0, 2.0, 3.0, 5.0 and 10 mL Teflon ampoules inserted into the high-pressure vessel filled with hexane as a transmission medium.



Teflon® ampoules
for reaction mixture



High-pressure vessel

Starting materials

All commercially available chemicals were used as received, unless otherwise noted.

Catalysts: Cinchona alkaloid derived thioureas **1a-c** [1, 2] and squaramides **1d**, **1e** [3] and cupreidine 9-*O*-benzyl ether (**1g**) [4] were prepared according to the literature methods.[1-4] Quinidine (**1f**) and (1*R*,2*R*)-Takemoto catalyst (**1h**) were purchased from commercial suppliers and used as received.

Enones were prepared according to the literature procedures, typically through aldol condensation of acetophenone or 4-acetylpyridine with corresponding aromatic aldehyde in ethanol/water in the presence of sodium hydroxide. Selected chalcones: ((*E*)-3-(2-chlorophenyl)-1-phenylprop-2-en-1-one, (*E*)-1-phenyl-3-(2-(trifluoromethyl)phenyl)prop-2-en-1-one, (*E*)-1-phenyl-3-o-tolylprop-2-en-1-one, (*E*)-1-phenyl-3-(pyridin-2-yl)prop-2-en-1-one; (*E*)-1-phenyl-3-(thiophen-2-yl)prop-2-en-1-one; (*E*)-1-(furan-2-yl)-3-phenylprop-2-en-1-one) were obtained in the Wittig reaction of ylide (α-(triphenylphosphoranylidene)acetophenone or α-(triphenylphosphoranylidene)acetylfuran) with corresponding aromatic aldehyde.

Commercially available nitromethane and 2-nitropropane were used as received.

General synthetic procedures:

The model reaction study of chalcone with nitromethane

a) Catalyst Screening:

- Stock solution of reagents **I** was used: 2.090 g of chalcone **2a** (10.0 mmol, c = 1.0 mol/L), 1.63 mL of nitromethane (1.84 g, 30 mmol, 3.0 equiv), 340 mg of biphenyl (GC internal standard) and toluene in 10.0 mL volumetric flask.

A 4 mL vial was charged with catalyst **1** (0.01 mmol, 0.5 mol%), followed by 2.0 mL of stock solution of reagents **I** (2.0 mmol of chalcone **2a**, 6.0 mmol of nitromethane and 68 mg of biphenyl in toluene). Part of the reaction mixture was transferred to 1.0 mL Teflon ampoule and compressed in high-pressure apparatus up to 9 kbar at 20-25 °C and decompressed after 2h. The yield and conversion of the reactions carried out under high pressure and atmospheric pressure (remaining ~1 mL) were analyzed by GC on HP-5 capillary column. The GC yield and conversion was determined using biphenyl as an internal standard and calculated with a GC response factor. The enantiomeric excess was determined by HPLC analysis on Chiralpak ® IC chiral column after filtration through a short pad of silica gel with DCM and concentration.

b) Model reaction optimization studies with catalyst 1a (Figure 2 and Table 2)

- Solution of catalyst **1a** (c = 0.010 mol/L) in toluene was used: 12.0 mg (0.02 mmol) of **1a** in 2.0 mL volumetric flask.
- Stock solution of reagents **II** was used: 2.086 g of chalcone **2a** (10.0 mmol, **c = 2.0 mol/L**), 1.64 mL of nitromethane (1.85 g, 30 mmol, 3.0 equiv), 340 mg of biphenyl (GC internal standard) and toluene in 5.0 mL volumetric flask.

A 4 mL vial was charged with 1.0 mL of stock solution of reagents **II** (2.0 mmol of chalcone **2a**, 6.0 mmol of nitromethane and 68 mg of biphenyl in toluene), 400 μL (0.2 mol%) of catalyst **1a** solution (c = 0.010 mol/L) and diluted with 600 μL of toluene. Part of the reaction mixture was transferred to 1.0 mL Teflon ampoule and compressed in high-pressure apparatus up to 9 kbar at 20-25 °C for 5h. The yield, conversion and enantiomeric excess were determined by GC and HPLC (for details see Catalyst Screening).

c) Optimization studies with catalyst 1d and 1e (see Table 2)**:**

Squaramide catalysts **1d** and **1e** were used directly because of relatively low solubility in toluene. A 4 mL vial was charged with catalyst **1d** or **1e** (3.8 mg, 0.006 mmol, 0.2 mol%), followed by 3.0 mL of stock solution of reagents **I** (3.0 mmol of chalcone **2a**, 9.0 mmol of nitromethane and 102 mg of biphenyl in toluene). After dissolution of the catalyst, part of the reaction mixture was transferred to 2.0 mL Teflon ampoule and compressed in high-pressure apparatus up to 9 kbar at 20-25 °C for 5h. The reaction mixture was analyzed as previously reported.

General procedure for asymmetric high-pressure mediated addition of nitromethane to chalcones: A 3 mL Teflon ampoule was charged with 9.0 mg (0.015 mmol, 0.5 mol%) of catalyst **1a** (or 9.5 mg of **1d**), 3.0 mmol of chalcone,[a)] ~1 mL of toluene and 485-495 μL of nitromethane (9 mmol, 3.0 equiv).[b)] The Teflon ampoule was filled up with toluene and after complete dissolution of all reactants was closed. Then the Teflon ampoule with homogenous reaction mixture was placed in a high-pressure chamber filled with the inert liquid (hexane or petroleum ether) and the pressure was slowly increased to 9 kbar at ambient temperature (20–25 °C) by hexane compressing. After the pressure was stabilized, the reaction mixture was kept under these conditions typically for 2 h. After decompression, the reaction mixture was concentrated to remove excess of nitromethane, dissolved in toluene and directly chromatographed on a silica gel using hexane/AcOEt as an eluent to afford γ-*nitroketones* **3**. The enantioselectivity was determined by HPLC analysis.

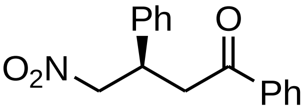
[a)] Reactions were carried out also on 5 mmol or 2 mmol scale in 5 mL or 2 mL Teflon ampoule respectively. [b)] The reaction mixture can be also prepared in separate vial and then transferred into Teflon ampoule and filled up with toluene.

General procedure for asymmetric high-pressure mediated addition of 2-nitropropane to chalcones: A 2 mL Teflon ampoule was charged with 12.0 mg (0.02 mmol, 1 mol%) of catalyst **1a**, 2.0 mmol of chalcone and 545-550 μL of 2-nitropropane (6 mmol, 3.0 equiv). The Teflon ampoule was filled up with toluene and after complete dissolution of all reactants was closed. Then the Teflon ampoule with homogenous reaction mixture was placed in a high-pressure chamber filled with the inert liquid (hexane or petroleum ether) and the pressure was slowly increased to 9 kbar at ambient temperature (20–25 °C) by hexane compressing. After the pressure was stabilized, the reaction mixture was kept under these conditions typically for 5 h. After decompression, the reaction mixture was concentrated to remove excess of 2-nitropropane, dissolved in toluene and directly chromatographed on a silica gel using hexane/AcOEt as an eluent to afford γ-nitroketones **4**.

The **absolute configuration** of products **3a**, **4a**, (3*S*,4*R*)-**5** and (3*R*,4*R*)-**6** was determined by comparison of the optical rotations with the literature values (for details, see in *Analytical data of products*).

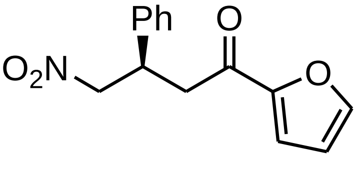
Analytical data of products 3a-p, 4a-i, 5 and 6

(*R*)-4-Nitro-1,3-diphenylbutan-1-one (3a): [1, 3-9]



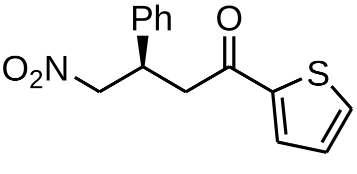
white solid, 88-94% yield, 1.265g of **3a** after reaction in 5 mL Teflon ampoule with 5 mmol of chalcone, 0.5 mol% of **1a** at 9 kbar for 2h (see Table 1 and 2, Figure 2); $[\alpha]_D^{25}$ = +21.7 (c 1.05, $CHCl_3$, 95.5% ee with cat. **1a**), [lit. (ref. 1): (*R*)-**3a** $[\alpha]_D^{25}$ = +26.7 (c 1.00, $CHCl_3$, 96% ee); (ref. 6): (*R*)-**3a** $[\alpha]_D^{20}$ = +21.1 (c 0.36, $CHCl_3$, 93% ee)], [(*S*)-**3a**: 90-93% yield, 98% ee with 0.2 or 0.5 mol% of **1d** at 9 kbar for 5h and 2h respectively]; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.94–7.88 (m, 2H, COPh), 7.60–7.53 (m, 1H, COPh), 7.48–7.41 (m, 2H, COPh), 7.36–7.23 (m, 5H, Ph), 4.83 (dd, *J* = 12.5, 6.6 Hz, 1H, CH_2NO_2), 4.68 (dd, *J* = 12.5, 8.0 Hz, 1H, CH_2NO_2), 4.26–4.18 (m, 1H, $C\underline{H}Ph$), 3.48 (dd, *J* = 17.7, 6.4 Hz, 1H, CH_2CO), 3.42 (dd, *J* = 17.7, 7.5 Hz, 1H, CH_2CO); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.8 (CO), 139.1 (C), 136.3 (C), 133.5 (CH), 129.0 (2xCH), 128.7 (2xCH), 128.0 (2xCH), 127.8 (CH), 127.4 (2xCH), 79.5 (CH_2), 41.5 (CH_2), 39.2 (CH); enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 75/25, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(*S*) t_r = 11.4 min and *ent*-(*R*) t_r = 12.7 min.

(*R*)-1-(Furan-2-yl)-4-nitro-3-phenylbutan-1-one (3b): [5-7]



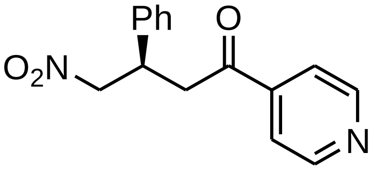
white solid; 95% yield, 737 mg, 96% ee (reaction in 3 mL Teflon ampoule with 3 mmol of enone, 0.5 mol% of **1a** at 9 kbar for 2h); [(*S*)-**3b**: 93% yield, 97% ee with 0.5 mol% of **1d** at 9 kbar for 2h]; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.56 (dd, *J* = 1.7, 0.7 Hz, 1H, furyl), 7.35–7.23 (m, 5H, Ph), 7.18 (dd, *J* = 3.6, 0.7 Hz, 1H, furyl), 6.52 (dd, *J* = 3.6, 1.7 Hz, 1H, furyl), 4.80 (dd, *J* = 12.5, 6.6 Hz, 1H, CH_2NO_2), 4.68 (dd, *J* = 12.5, 8.1 Hz, 1H, CH_2NO_2), 4.23–4.13 (m, 1H, $C\underline{H}Ph$), 3.35 (dd, *J* = 17.1, 6.7 Hz, 1H, CH_2CO), 3.26 (dd, *J* = 17.1, 7.6 Hz, 1H, CH_2CO); ^{13}C NMR (100 MHz, $CDCl_3$) δ 185.9 (CO), 152.3 (C), 146.6 (CH), 138.7 (C), 129.0 (2xCH), 127.9 (CH), 127.4 (2xCH), 117.5 (CH), 112.5 (CH), 79.4 (CH_2), 41.2 (CH_2), 39.1 (CH); enantiomeric excess was determined by HPLC analysis using a Chiralpak® IA column (Hexane/*i*-PrOH: 80/20, flow rate 1.0 mL/min, λ = 256 nm): *ent*-(*S*) t_r = 10.7 min and *ent*-(*R*) t_r = 12.4 min.

(*R*)-4-Nitro-3-phenyl-1-(thiophen-2-yl)butan-1-one (3c): [5, 8]



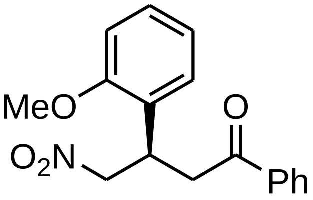
white solid; 96% yield, 790 mg, 95% ee (reaction in 3 mL Teflon ampoule with 3 mmol of enone, 0.5 mol% of **1a** at 9 kbar for 2h), [(*S*)-**3c**: 95% yield, 97.5% ee with 0.5 mol% of **1d** at 9 kbar for 2h]; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.69 (dd, *J* = 3.8, 1.1 Hz, 1H, thienyl), 7.64 (dd, *J* = 5.0, 1.1 Hz, 1H, thienyl), 7.35–7.23 (m, 5H, Ph), 7.11 (dd, *J* = 5.0, 3.8 Hz, 1H, thienyl), 4.83 (dd, *J* = 12.6, 6.6 Hz, 1H, CH_2NO_2), 4.69 (dd, *J* = 12.6, 8.1 Hz, 1H, CH_2NO_2), 4.24–4.15 (m, 1H, $C\underline{H}Ph$), 3.40 (dd, *J* = 16.9, 6.5 Hz, 2H, CH_2CO), 3.34 (dd, *J* = 16.9, 7.3 Hz, 2H, CH_2CO); ^{13}C NMR (100 MHz, $CDCl_3$) δ 189.7 (CO), 143.5 (C), 138.8 (C), 134.3 (CH), 132.2 (CH), 129.0 (2xCH), 128.2 (CH), 127.9 (CH), 127.4 (2xCH), 79.3 (CH_2), 42.1 (CH_2), 39.4 (CH); enantiomeric excess was determined by HPLC analysis using a Chiralpak® IB column (Hexane/*i*-PrOH: 75/25, flow rate 1.0 mL/min, λ = 256 nm): *ent*-(*R*) t_r = 16.2 min and *ent*-(*S*) t_r = 18.1 min.

(*R*)-4-Nitro-3-phenyl-1-(pyridin-4-yl)butan-1-one (3d):



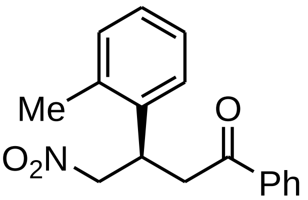
white solid; 92% yield, 496 mg, 91.5% ee (reaction in 2 mL Teflon ampoule with 2 mmol of enone, 0.5 mol% of **1a** at 9 kbar for 2h), [(*S*)-**3d**: 94% yield, 95% ee with 0.5 mol% of **1d** at 9 kbar for 2h]; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.79 (dm, *J* = 6.1 Hz, 2H, pyridyl), 7.66 (dm, *J* = 6.1 Hz, 2H, pyridyl), 7.36–7.31 (m, 2H, Ph), 7.30–7.24 (m, 3H, Ph), 4.80 (dd, *J* = 12.5, 7.1 Hz, 1H, CH_2NO_2), 4.69 (dd, *J* = 12.5, 7.4 Hz, 1H, CH_2NO_2), 4.21 (ps quint, *J* = 7.1 Hz, 1H, $\mathrm{C\underline{H}Ph}$), 3.48 (dd, *J* = 18.0, 6.8 Hz, 1H, CH_2CO), 3.44 (dd, *J* = 18.0, 7.0 Hz, 1H, CH_2CO); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.4 (CO), 150.9 (2 x CH), 142.0 (C), 138.5 (C), 129.1 (2 x CH), 128.0 (CH), 127.3 (2 x CH), 120.7 (2 x CH), 79.2 (CH_2), 41.7 (CH), 38.9 (CH_2); LR-MS (ESI): mass calculated for $[M+H]^+$ ($C_{15}H_{15}N_2O_3^+$) *m/z* 271.11, found *m/z* 271.1; enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 60/40, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(*R*) t_r = 26.4 min and *ent*-(*S*) t_r = 36.1 min.

(*R*)-3-(2-Methoxyphenyl)-4-nitro-1-phenylbutan-1-one (3e): [5,8]



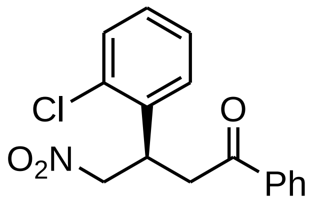
white solid; 97% yield, 869 mg, 94.5% ee ee (reaction in 3 mL Teflon ampoule with 3 mmol of enone, 0.5 mol% of **1a** at 9 kbar for 2h), [(*S*)-**3d**: 95% yield, 97.5% ee with 0.5 mol% of **1d** at 9 kbar for 2h]; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.96–7.90 (m, 2H, COPh), 7.59–7.53 (m, 1H, COPh), 7.48–7.41 (m, 2H, COPh), 7.28–7.18 (m, 2H, Ar), 6.93–6.85 (m, 2H, Ar), 4.85 (d, *J* = 6.9 Hz, 2H, CH_2NO_2), 4.42 (quint, *J* = 6.9 Hz, 1H, $\mathrm{C\underline{H}Ar}$), 3.86 (s, 3H, OCH_3), 3.53 (d, *J* = 6.9 Hz, 2H, CH_2CO); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.6 (CO), 157.1 (C), 136.6 (C), 133.3 (CH), 129.5 (CH), 128.9 (CH), 128.6 (2xCH), 128.0 (2xCH), 126.6 (C), 120.9 (CH), 111.0 (CH), 77.9 (CH_2), 55.3(CH_3), 39.8 (CH_2), 35.9 (CH); enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 75/25, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(*R*) t_r = 13.3 min and *ent*-(*S*) t_r = 14.4 min.

(*R*)-4-Nitro-1-phenyl-3-(*o*-tolyl)butan-1-one (3f): [1, 10]



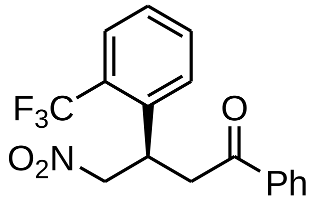
colorless viscous oil; 95% yield, 537 mg, 93.5% ee (reaction in 2 mL Teflon ampoule with 2 mmol of enone, 0.5 mol% of **1a** at 9 kbar for 2h), [(*S*)-**3e**: 91% yield, 96.5% ee with 0.5 mol% of **1d** at 9 kbar for 2h]; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.93–7.88 (m, 2H, COPh), 7.59–7.53 (m, 1H, COPh), 7.47–7.41 (m, 2H, COPh), 7.21–7.11 (m, 4H, Ar), 4.78 (dd, *J* = 12.4, 7.1 Hz, 1H, CH_2NO_2), 4.65 (dd, *J* = 12.4, 7.6 Hz, 1H, CH_2NO_2), 4.58–4.48 (m, 1H, $\mathrm{C\underline{H}Ar}$), 3.46 (dd, *J* = 17.8, 6.5 Hz, 1H, CH_2CO), 3.38 (dd, *J* = 17.8, 7.3 Hz, 1H, CH_2CO), 2.46 (s, 3H, CH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.9 (CO), 137.3 (C), 136.5 (C), 136.3 (C), 133.5 (CH), 131.2 (CH), 128.7 (2xCH), 128.0 (2xCH), 127.5 (CH), 126.6 (CH), 125.4 (CH), 79.0 (CH_2), 41.6 (CH_2), 34.4 (CH), 19.6 (CH_3); enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 75/25, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(*S*) t_r = 9.3 min and *ent*-(*R*) t_r = 10.4 min.

(*R*)-3-(2-Chlorophenyl)-4-nitro-1-phenylbutan-1-one (3g): [5, 6, 8]



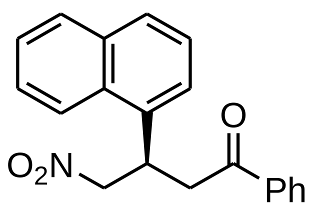
colorless viscous oil; 96% yield, 580 mg, 94.5% ee (reaction in 2 mL Teflon ampoule with 2 mmol of enone, 0.5 mol% of **1a** at 9 kbar for 2h), [(*S*)-**3f**: 93% yield, 97.5% ee with 0.5 mol% of **1d** at 9 kbar for 2h]; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.01–7.89 (m, 2H, COPh), 7.62–7.55 (m, 1H, COPh), 7.51–7.44 (m, 2H, COPh), 7.43–7.38 (m, 1H, Ar), 7.32–7.19 (m, 3H, Ar), 4.89 (dd, *J* = 12.8, 6.9 Hz, 1H, CH_2NO_2), 4.86 (dd, *J* = 12.8, 6.7 Hz, 1H, CH_2NO_2), 4.69 (ps quint, *J* = ~6.7 Hz, 1H, C$\underline{\text{H}}$Ar), 3.58 (dd, *J* = 17.9, 7.4 Hz, 1H, CH_2CO), 3.53 (dd, *J* = 17.9, 6.3 Hz, 1H, CH_2CO); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.7 (CO), 136.2 (C), 136.2 (C), 133.8 (C), 133.6 (CH), 130.4 (CH), 129.0 (CH), 128.7 (2xCH), 128.4 (CH), 128.0 (2xCH), 127.4 (CH), 77.5 (CH_2), 39.9 (CH_2), 36.1 (CH); enantiomeric excess was determined by HPLC analysis using a Chiralpak® IB column (Hexane/*i*-PrOH: 80/20, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(*S*) t_r = 12.2 min and *ent*-(*R*) t_r = 13.6 min.

(*R*)-4-Nitro-1-phenyl-3-(2-(trifluoromethyl)phenyl)butan-1-one (3h): [11]



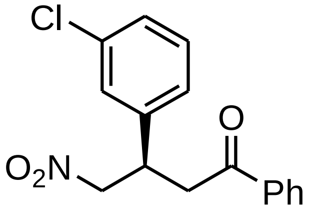
colorless viscous oil; 95% yield, 639 mg, 95.5% ee (reaction in 2 mL Teflon ampoule with 2 mmol of enone, 0.5 mol% of **1a** at 9 kbar for 2h), [(*S*)-**3h**: 96% yield, 96% ee with 0.5 mol% of **1d** at 9 kbar for 2h]; this enone is very active at atmospheric pressure: 29% yield after 20h. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.95–7.89 (m, 2H, COPh), 7.71 (d, *J* = 7.9 Hz, 1H, Ar), 7.61–7.55 (m, 1H, COPh), 7.54 (d, *J* = 7.4 Hz, 1H, Ar), 7.49–7.43 (m, 3H, COPh and Ar), 7.42–7.37 (m, 1H, Ar), 4.88 (dd, *J* = 12.7, 6.5 Hz, 1H, CH_2NO_2), 4.81 (dd, *J* = 12.7, 7.1 Hz, 1H, CH_2NO_2), 4.69–4.60 (m, 1H, C$\underline{\text{H}}$Ar), 3.54 (dd, *J* = 17.8, 8.3 Hz, 1H, CH_2CO), 3.46 (dd, *J* = 17.8, 5.3 Hz, 1H, CH_2CO); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.3 (CO), 137.9 (q, *J* = 1.5 Hz, C), 136.0 (C), 133.6 (CH), 132.4 (q, *J* = 1.0 Hz, CH), 128.7 (2 x CH), 128.6 (q, *J* = 29.8 Hz, **C**-CF_3), 128.0 (2 x CH), 127.8 (CH), 127.5 (CH), 126.8 (q, *J* = 5.9 Hz, CH), 124.1 (q, *J* = 274.0 Hz, CF_3), 78.3 (CH_2), 41.5 (CH_2), 34.6 (q, *J* = 2.0 Hz, CH); ^{19}F NMR (376 MHz, $CDCl_3$) δ -58.9 (s, 3F); enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 90/10, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(*R*) t_r = 12.7 min and *ent*-(*S*) t_r = 15.1 min.

(*R*)-3-(Naphthalen-1-yl)-4-nitro-1-phenylbutan-1-one (3i): [6, 9]



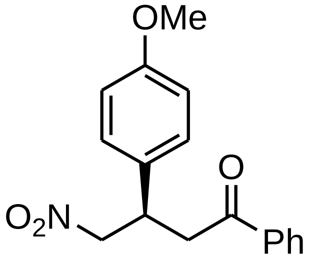
colorless viscous oil; 92% yield, 585 mg, 96% ee (reaction in 2 mL Teflon ampoule with 2 mmol of enone, 0.5 mol% of **1a** at 9 kbar for 2h), [(*S*)-**3g**: 84% yield, 98% ee with 0.5 mol% of **1d** at 9 kbar for 2h]; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.22 (d, *J* = 8.5 Hz, 1H, Nf), 7.94–7.89 (m, 2H, COPh), 7.87 (dm, *J* = 8.1 Hz, 1H, Nf), 7.78 (dd, *J* = 7.1, 2.2 Hz, 1H, Nf), 7.62–7.49 (m, 3H, 1H – COPh, 2H – Nf), 7.46–7.35 (m, 4H, 2H – COPh, 2H – Nf), 5.17 (ps quint, *J* = ~6.9 Hz, 1H, C$\underline{\text{H}}$Ar), 4.92 (dd, *J* = 12.5, 6.7 Hz, 1H, CH_2NO_2), 4.87 (dd, *J* = 12.5, 7.0 Hz, 1H, CH_2NO_2), 3.63 (dd, *J* = 18.1, 6.3 Hz, 1H, CH_2CO), 3.59 (dd, *J* = 18.1, 7.2 Hz, 1H, CH_2CO); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.9 (CO), 136.3 (C), 135.1 (C), 134.2 (C), 133.6 (CH), 130.9 (C), 129.2 (CH), 128.7 (2xCH), 128.4 (CH), 128.0 (2xCH), 126.9 (CH), 126.0 (CH), 125.2 (CH), 123.4 (CH, broad), 122.4 (CH), 78.8 (CH_2), 41.4 (CH_2), 33.5 (CH, broad); enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 80/20, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(*S*) t_r = 13.2 min and *ent*-(*R*) t_r = 14.7 min.

(***R***)-3-(3-Chlorophenyl)-4-nitro-1-phenylbutan-1-one (3j): [5, 8]



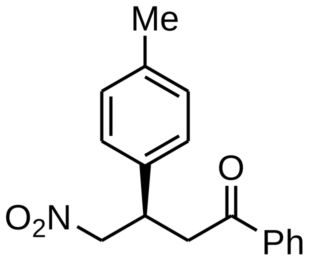
colorless viscous oil (solidified upon standing); 94% yield, 570 mg, 95% ee (reaction in 2 mL Teflon ampoule with 2 mmol of enone, 0.5 mol% of **1a** at 9 kbar for 2h), [(*S*)-**3h**: 95% yield, 97.5% ee with 0.5 mol% of **1d** at 9 kbar for 2h]; ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.94–7.89 (m, 2H, COPh), 7.61–7.55 (m, 1H, COPh), 7.50–7.43 (m, 2H, COPh), 7.31–7.22 (m, 3H, Ar), 7.19 (ddd, *J* = 4.5, 3.2, 1.9 Hz, 1H, Ar), 4.82 (dd, *J* = 12.7, 6.4 Hz, 1H, CH$_2$NO$_2$), 4.67 (dd, *J* = 12.7, 8.2 Hz, 1H, CH$_2$NO$_2$), 4.26–4.17 (m, 1H, C$\underline{\text{H}}$Ar), 3.46 (dd, *J* = 17.8, 6.5 Hz, 1H, CH$_2$CO), 3.41 (dd, *J* = 17.8, 7.3 Hz, 1H, CH$_2$CO); ^{13}C NMR (100 MHz, CDCl$_3$) δ 196.4 (CO), 141.2 (C), 136.2 (C), 134.8 (C), 133.7 (CH), 130.3 (CH), 128.8 (2xCH), 128.1 (CH), 128.0 (2xCH), 127.7 (CH), 125.8 (CH), 79.2 (CH$_2$), 41.3 (CH$_2$), 38.9 (CH); enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 75/25, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(*S*) t$_r$ = 9.8 min and *ent*-(*R*) t$_r$ = 10.8 min.

(***R***)-3-(4-Methoxyphenyl)-4-nitro-1-phenylbutan-1-one (3k): [3, 5-9, 11]



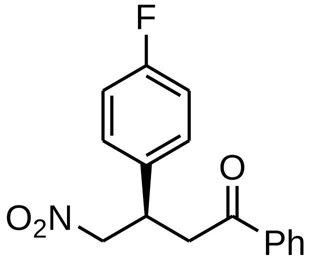
white solid; 93% yield, 554 mg, 94.5% ee (reaction in 2 mL Teflon ampoule with 2 mmol of enone, 1 mol% of **1a** at 9 kbar for 2h), [(*S*)-**3i**: 85% yield, 98% ee with 0.5 mol% of **1d** at 9 kbar for 2h]; ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.94–7.89 (m, 2H, COPh), 7.60–7.54 (m, 1H, COPh), 7.49–7.42 (m, 2H, COPh), 7.20 (dm, *J* = 8.7 Hz, 2H, Ar), 6.85 (dm, *J* = ~8.5 Hz, 2H, Ar), 4.80 (ddd, *J* = 12.3, 6.6, 0.8 Hz, 1H, CH$_2$NO$_2$), 4.64 (ddd, *J* = 12.3, 8.0, 1.2 Hz, 1H, CH$_2$NO$_2$), 4.22–4.13 (m, 1H, C$\underline{\text{H}}$Ar), 3.77 (d, *J* = 2.2 Hz, 3H, OCH$_3$), 3.39 (ddd, *J* = 17.6, 7.4, 1.2 Hz, 1H, CH$_2$CO), 3.45 (dd, *J* = 17.6, 6.6 Hz, 1H, CH$_2$CO); ^{13}C NMR (100 MHz, CDCl$_3$) δ 196.9 (CO), 159.0 (C), 136.4 (C), 133.5 (CH), 131.0 (C), 128.7 (2xCH), 128.5 (2xCH), 128.0 (2xCH), 114.4 (2xCH), 79.8 (CH$_2$), 55.2 (CH$_3$), 41.6 (CH$_2$), 38.6 (CH); enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 75/25, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(*S*) t$_r$ = 16.6 min and *ent*-(*R*) t$_r$ = 18.1 min.

(***R***)-4-nitro-1-phenyl-3-***p***-tolylbutan-1-one (3l): [3, 5, 6, 8, 11]



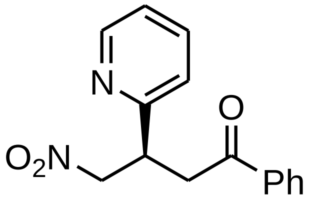
white solid; 81% yield, 457 mg, 97% ee (reaction in 2 mL Teflon ampoule with 2 mmol of enone, 1 mol% of **1e** at 9 kbar for 5h), [(*S*)-**3j**: 79% yield, 98% ee with 1 mol% of **1d** at 9 kbar for 5h]; ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.93–7.88 (m, 2H, COPh), 7.59–7.53 (m, 1H, COPh), 7.48–7.41 (m, 2H, COPh), 7.19-7.10 (m, 4H, Ar), 4.80 (dd, *J* = 12.4, 6.6 Hz, 1H, CH$_2$NO$_2$), 4.65 (dd, *J* = 12.4, 8.0 Hz, 1H, CH$_2$NO$_2$), 4.23–4.14 (m, 1H, C$\underline{\text{H}}$Ar), 3.45 (dd, *J* = 17.5, 6.5 Hz, 1H, CH$_2$CO), 3.40 (dd, *J* = 17.5, 7.4 Hz, 1H, CH$_2$CO), 2.30 (s, 3H, CH$_3$); ^{13}C NMR (100 MHz, CDCl$_3$) δ 196.9 (CO), 137.5 (C), 136.3 (C), 136.0 (C), 133.5 (CH), 129.7 (2xCH), 128.7 (2xCH), 128.0 (2xCH), 127.2 (2xCH), 79.7 (CH$_2$), 41.5 (CH$_2$), 38.9 (CH), 21.0 (CH$_3$); enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 85/15, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(*S*) t$_r$ = 17.4 min and *ent*-(*R*) t$_r$ = 18.7 min [or Chiralpak® IB column (Hexane/*i*-PrOH: 85/15, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(*S*) t$_r$ = 13.4 min and *ent*-(*R*) t$_r$ = 15.3 min].

(*R*)-3-(4-Fluorophenyl)-4-nitro-1-phenylbutan-1-one (3m): [1,7,10]



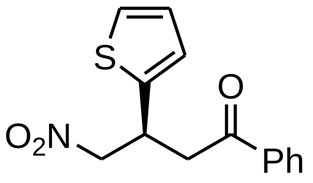
white solid; 95% yield, 544 mg, 95% ee (reaction in 2 mL Teflon ampoule with 2 mmol of enone, 0.5 mol% of **1a** at 9 kbar for 2h), [(*S*)-**3m**: 94% yield, 96% ee with 0.5 mol% of **1d** at 9 kbar for 2h]; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.93–7.88 (m, 2H, COPh), 7.61–7.55 (m, 1H, COPh), 7.49–7.42 (m, 2H, COPh), 7.29–7.23 (m, 2H, Ar), 7.05–6.95 (m, 2H, Ar), 4.81 (dd, *J* = 12.5, 6.5 Hz, 1H, CH_2NO_2), 4.65 (dd, *J* = 12.5, 8.2 Hz, 1H, CH_2NO_2), 4.27–4.18 (m, 1H, $C\underline{H}Ar$), 3.45 (dd, *J* = 17.7, 6.7 Hz, 1H, CH_2CO), 3.41 (dd, *J* = 17.7, 7.3 Hz, 1H, CH_2CO); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.6 (CO), 162.1 (d, *J* = 246.7 Hz, CF), 136.2 (C), 134.8 (d, *J* = 3.2 Hz, C), 133.6 (CH), 129.1 (d, *J* = 8.2 Hz, 2 x CH), 128.7 (2 x CH), 127.9 (2 x CH), 115.9 (d, *J* = 21.6 Hz, 2 x CH), 79.5 (CH_2), 41.5 (CH_2), 38.5 (CH_3); ^{19}F NMR (376 MHz, $CDCl_3$) δ –114.2 (m, F); enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 90/10, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(*S*) t$_r$ = 20.1 min and *ent*-(*R*) t$_r$ = 23.7.

(*S*)-4-Nitro-1-phenyl-3-(pyridin-2-yl)butan-1-one (3n): [12]



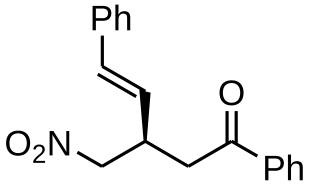
white solid; 88% yield, 475 mg, 90.5% ee (reaction in 2 mL Teflon ampoule with 2 mmol of enone, 0.5 mol% of **1a** at 9 kbar for 2h), [(*R*)-**3k**: 83% yield, 97.5% ee with 0.5 mol% of **1d** at 9 kbar for 2h]; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.51 (dm, *J* = 4.9 Hz, 1H, pyridyl); 7.96–7.88 (m, 2H, COPh), 7.63 (td, *J* = 7.7, 1.8 Hz, 1H, pyridyl), 7.59–7.53 (m, 1H, COPh), 7.48–7.41 (m, 2H, COPh), 7.36 (dm, *J* = 7.7 Hz, 1H, pyridyl), 7.16 (ddd, *J* = 7.5, 4.9, 1.1 Hz, 1H, pyridyl), 4.95 (dd, *J* = 13.0, 8.5 Hz, 1H, CH_2NO_2), 4.82 (dd, *J* = 13.0, 6.0 Hz, 1H, CH_2NO_2), 4.41–4.32 (m, 1H, $C\underline{H}$pyridyl), 3.69 (dd, *J* = 17.9, 7.3 Hz, 1H, CH_2CO), 3.37 (dd, *J* = 17.9, 6.3 Hz, 1H, CH_2CO); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.9 (CO), 158.7 (C), 149.5 (CH), 136.9 (CH), 136.3 (C), 133.5 (CH), 128.7 (2xCH), 128.0 (2xCH), 124.1 (CH), 122.5 (CH), 78.2 (CH_2), 40.8 (CH_2), 40.4 (CH); enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 75/25, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(*R*) t$_r$ = 11.7 min and *ent*-(*S*) t$_r$ = 13.6 min.

(*S*)-4-Nitro-1-phenyl-3-(thiophen-2-yl)butan-1-one (3o): [8, 13]



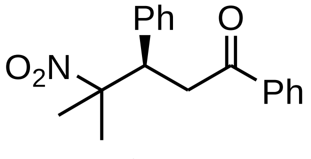
white solid; 89% yield, 488 mg, 88% ee (reaction in 2 mL Teflon ampoule with 2 mmol of enone, 1 mol% of **1a** at 9 kbar for 2h), [(*R*)-**3l**: 87% yield, 97.5% ee with 1 mol% of **1d** at 9 kbar for 2h]; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.96–7.91 (m, 2H, COPh), 7.61–7.56 (m, 1H, COPh), 7.50–7.44 (m, 2H, COPh), 7.20 (dd, *J* = 5.0, 1.3 Hz, 1H, thienyl), 6.96 (ddd, *J* = 3.5, 1.3, 0.6 Hz, 1H, thienyl), 6.93 (dd, *J* = 5.0, 3.5 Hz, 1H, thienyl), 4.84 (dd, *J* = 12.6, 6.3 Hz, 1H, CH_2NO_2), 4.70 (dd, *J* = 12.6, 7.6 Hz, 1H, CH_2NO_2), 4.59–4.51 (m, 1H, $C\underline{H}$thienyl), 3.54 (dd, *J* = 17.8, 6.3 Hz, 1H, CH_2CO), 3.48 (dd, *J* = 17.8, 7.3 Hz, 1H, CH_2CO); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.4 (CO), 141.8 (C), 136.2 (C), 133.7 (CH), 128.7 (2xCH), 128.0 (2xCH), 127.1 (CH), 125.5 (CH), 124.7 (CH), 79.8 (CH_2), 42.3 (CH_2), 34.7 (CH); enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 75/25, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(*R*) t$_r$ = 11.8 min and *ent*-(*S*) t$_r$ = 13.7 min.

(*R*,*E*)-3-(Nitromethyl)-1,5-diphenylpent-4-en-1-one (3p): [3, 8, 14-16]



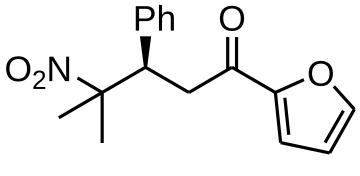
white solid; 82% yield, 483 mg, 96% ee (reaction in 2 mL Teflon ampoule with 2 mmol of enone, 2 mol% of **1a** at 9 kbar for 5h), [(*S*)-**3m**: 77% yield, 97.5% ee with 1 mol% of **1d** at 9 kbar for 5h]; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.97–7.93 (m, 2H, COPh), 7.62–7.56 (m, 1H, COPh), 7.51–7.45 (m, 2H, COPh), 7.35–7.20 (m, 5H, Ph), 6.57 (d, *J* = 15.9 Hz, 1H, -$\underline{H}$C=CH-), 6.16 (dd, *J* = 15.9, 8.6 Hz, 1H, -HC=C$\underline{H}$-), 4.71 (dd, *J* = 12.1, 5.9 Hz, 1H, CH_2NO_2), 4.61 (dd, *J* = 12.1, 7.4 Hz, 1H, CH_2NO_2), 3.80–3.70 (m, 1H, C$\underline{H}$vinyl), 3.29 (d, *J* = 6.6 Hz, 2H, CH_2CO); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.0 (CO), 136.4 (C), 136.2 (C), 133.6 (CH), 133.4 (CH), 128.7 (2xCH), 128.5 (2xCH), 128.0 (2xCH), 127.9 (CH), 126.5 (CH), 126.4 (2xCH), 78.8 (CH_2), 40.3 (CH_2), 37.3 (CH); enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 85/15, flow rate 1.0 mL/min, λ = 256 nm): *ent*-(*S*) t_r = 15.1 min and *ent*-(*R*) t_r = 16.2 min.

(*R*)-4-Methyl-4-nitro-1,3-diphenylpentan-1-one (4a): [10,17-19]



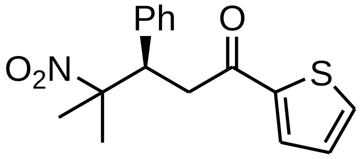
white solid; 92% yield, 818 mg, 91% ee (reaction in 3 mL Teflon ampoule with 3 mmol of chalcone, 1 mol% of **1a** at 9 kbar for 5h); $[\alpha]_D^{25}$ = +73.9 (c 1.00, $CHCl_3$, 91% ee), [lit. (ref. 10): $[\alpha]_D^{25}$ = +67 (c 1.00, $CHCl_3$, 92% ee); (ref. 19): (*S*)-**4a** $[\alpha]_D^{24}$ = -77.5 (c 1.0, $CHCl_3$, 92% ee); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.90–7.81 (m, 2H, COPh), 7.56–7.51 (m, 1H, COPh), 7.46–7.38 (m, 2H, COPh), 7.32–7.19 (m, 5H, Ph), 4.15 (dd, *J* = 10.4, 3.4 Hz, 1H, C$\underline{H}$Ph), 3.68 (dd, *J* = 17.2, 10.4 Hz, 1H, CH_2CO), 3.27 (dd, *J* = 17.2, 3.4 Hz, 1H, CH_2CO), 1.63 (s, 3H, CH_3), 1.54 (s, 3H, CH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.7 (CO), 137.8 (C), 136.6 (C), 133.2 (CH), 129.2 (2xCH), 128.6 (2xCH), 128.4 (2xCH), 127.9 (2xCH), 127.7 (CH), 91.2 (C), 48.9 (CH), 39.1 (CH_2), 26.1 (CH_3), 22.6 (CH_3); enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 80/20, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(*R*) t_r = 7.5 min and *ent*-(*S*) t_r = 10.1 min.

(*R*)-1-(Furan-2-yl)-4-methyl-4-nitro-3-phenylpentan-1-one (4b): [17, 18]



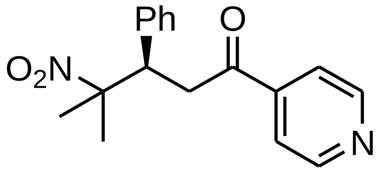
white solid; 84% yield, 485 mg, 89% ee (reaction in 2 mL Teflon ampoule with 2 mmol of enone, 1 mol% of **1a** at 9 kbar for 5h); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.54 (dd, *J* = 1.7, 0.7 Hz, 1H, furyl), 7.30–7.19 (m, 5H, Ph), 7.12 (dd, *J* = 3.6, 0.7 Hz, 1H, furyl), 6.49 (dd, *J* = 3.6, 1.7 Hz, 1H, furyl), 4.12 (dd, *J* = 10.7, 3.6 Hz, 1H, C$\underline{H}$Ph), 3.58 (dd, *J* = 16.8, 10.7 Hz, 1H, CH_2CO), 3.09 (dd, *J* = 16.8, 3.6 Hz, 1H, CH_2CO), 1.62 (s, 3H, CH_3), 1.54 (s, 3H, CH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ 185.9 (CO), 152.4 (C), 146.3 (CH), 137.5 (C), 129.2 (2xCH), 128.4 (2xCH), 127.8 (CH), 117.1 (CH), 112.3 (CH), 91.2 (C), 48.7 (CH), 38.8 (CH_2), 25.8 (CH_3), 22.7 (CH_3); LR-MS (ESI): mass calculated for $[M+H]^+$ ($C_{16}H_{18}NO_4^+$) *m/z* 288.12, found *m/z* 288.18; enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 80/20, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(*R*) t_r = 16.5 min and *ent*-(*S*) t_r = 18.2 min.

(*R*)-4-Methyl-4-nitro-3-phenyl-1-(thiophen-2-yl)pentan-1-one (4c): [17, 18]



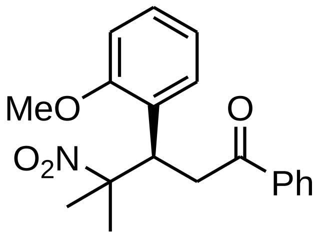
white solid; 94% yield, 567 mg, 87% ee (reaction in 2 mL Teflon ampoule with 2 mmol of enone, 1 mol% of **1a** at 9 kbar for 5h); ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.71 (dd, *J* = 3.8, 1.1 Hz, 1H, thienyl), 7.59 (dd, *J* = 5.0, 1.1 Hz, 1H, thienyl), 7.31–7.20 (m, 5H, Ph), 7.10 (dd, *J* = 5.0, 3.8 Hz, 1H, thienyl), 4.12 (dd, *J* = 10.5, 3.5 Hz, 1H, C<u>H</u>Ph), 3.59 (dd, *J* = 16.6, 10.5 Hz, 1H, CH$_2$CO), 3.21 (dd, *J* = 16.6, 3.5 Hz, 1H, CH$_2$CO), 1.62 (s, 3H, CH$_3$), 1.54 (s, 3H, CH$_3$); ^{13}C NMR (100 MHz, CDCl$_3$) δ 189.5 (CO), 143.7 (C), 137.5 (C), 133.9 (CH), 131.9 (CH), 129.2 (2xCH), 128.4 (2xCH), 128.1 (CH), 127.8 (CH), 91.1 (C), 49.1 (CH), 39.8 (CH$_2$), 26.1 (CH$_3$), 22.6 (CH$_3$); LR-MS (ESI): mass calculated for [M+H]$^+$ ($C_{16}H_{18}NO_3S^+$) *m/z* 304.10, found *m/z* 304.15; enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 80/20, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(*R*) t$_r$ = 11.3 min and *ent*-(*S*) t$_r$ = 15.7 min.

(*R*)-4-Methyl-4-nitro-3-phenyl-1-(pyridin-4-yl)pentan-1-one (4d): [20]



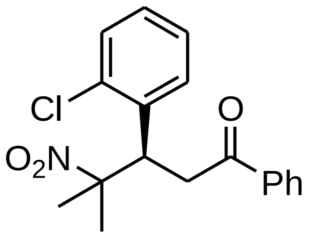
white solid; 88% yield, 524 mg, 92% ee (reaction in 2 mL Teflon ampoule with 2 mmol of enone, 1 mol% of **1a** at 9 kbar for 5h); ^{1}H NMR (400 MHz, CDCl$_3$) δ 8.77 (dm, *J* = 6.1 Hz, 2H, pyridyl), 7.61 (dm, *J* = 6.1 Hz, 2H, pyridyl), 7.33–7.18 (m, 5H, Ph), 4.11 (dd, *J* = 10.5, 3.4 Hz, 1H, C<u>H</u>Ph), 3.66 (dd, *J* = 17.4, 10.5 Hz, 1H, CH$_2$CO), 3.27 (dd, *J* = 17.4, 3.4 Hz, 1H, CH$_2$CO), 1.63 (s, 3H, CH$_3$), 1.54 (s, 3H, CH$_3$); ^{13}C NMR (100 MHz, CDCl$_3$) δ 196.4 (CO), 150.9 (2 x CH), 142.2 (C), 137.2 (C), 129.1 (2 x CH), 128.5 (2 x CH), 128.0 (CH), 120.8 (2 x CH), 91.0 (C), 48.7 (CH), 39.5 (CH$_2$), 26.3 (CH$_3$), 22.2 (CH$_3$); LR-MS (ESI): mass calculated for [M+H]$^+$ ($C_{17}H_{19}N_2O_3^+$) *m/z* 299.14, found *m/z* 299.16; enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 60/40, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(*R*) t$_r$ = 18.7 min and *ent*-(*S*) t$_r$ = 30.7 min.

(*R*)-3-(2-Methoxyphenyl)-4-methyl-4-nitro-1-phenylpentan-1-one (4e):



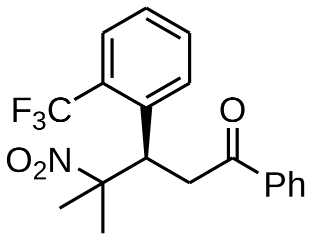
white solid; 91% yield, 596 mg, 87% ee (reaction in 2 mL Teflon ampoule with 2 mmol of enone, 1 mol% of **1a** at 9 kbar for 5h); ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.88–7.83 (m, 2H, COPh), 7.55–7.49 (m, 1H, COPh), 7.45–7.38 (m, 2H, COPh), 7.23–7.17 (m, 1H, Ar), 7.09 (dd, *J* = 8.0, 1.6 Hz, 1H, Ar), 6.89–6.83 (m, 2H, Ar), 4.73 (bd, *J* = ~8 Hz, 1H, C<u>H</u>Ar), 3.82 (s, 3H, OCH$_3$), 3.67 (bdd, *J* = 17.2, 10.5 Hz, 1H, CH$_2$CO), 3.33 (dd, *J* = 17.2, 3.8 Hz, 1H, CH$_2$CO), 1.59 (s, 3H, CH$_3$), 1.56 (s, 3H, CH$_3$); ^{13}C NMR (100 MHz, CDCl$_3$) δ 197.3 (CO), 157.9 (C), 136.7 (C), 133.0 (CH), 128.6 (CH), 128.5 (2xCH), 127.9 (2xCH), 126.7 (C), 120.5 (CH), 111.2 (CH), 91.6 (C), 55.6 (CH), 39.0 (CH$_2$), 26.3 (CH$_3$), 22.3 (b, CH$_3$); HRMS (ESI) exact mass calculated for [M+H]$^+$ ($C_{19}H_{22}NO_4$) requires *m/z* 328.1543, found *m/z* 328.1541; enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 80/20, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(*R*) t$_r$ = 7.6 min and *ent*-(*S*) t$_r$ = 11.3 min.

(*R*)-3-(2-chlorophenyl)-4-methyl-4-nitro-1-phenylpentan-1-one (4f): [21]



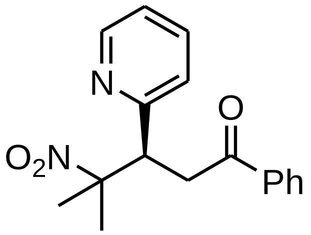
colorless viscous oil; 92% yield, 609 mg, 90.5% ee (reaction in 2 mL Teflon ampoule with 2 mmol of enone, 1 mol% of **1a** at 9 kbar for 5h); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.89–7.84 (m, 2H, COPh), 7.56–7.51 (m, 1H, COPh), 7.46–7.37 (m, 3H, 2H – COPh, 1H – Ar), 7.21–7.11 (m, 3H, Ar), 4.84 (dd, *J* = 10.5, 3.5 Hz, 1H, $C\underline{H}Ar$), 3.63 (dd, *J* = 17.5, 10.5 Hz, 1H, CH_2CO), 3.44 (dd, *J* = 17.5, 3.5 Hz, 1H, CH_2CO), 1.65 (s, 3H, CH_3), 1.62 (s, 3H, CH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.5 (CO), 136.3 (C), 136.2 (C), 133.3 (CH), 130.1 (CH), 128.7 (CH), 128.6 (2xCH), 128.0 (2xCH + CH), 126.9 (CH), 91.4 (C), 43.3 (CH), 39.8 (CH_2), 26.3 (CH_3), 22.4 (CH_3); LR-MS (ESI): mass calculated for $[M+H]^+$ ($C_{18}H_{19}ClNO_3^+$) *m/z* 332.11, found *m/z* 332.16; enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 80/20, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(*R*) t_r = 6.5 min and *ent*-(*S*) t_r = 7.8 min.

(*R*)-4-Methyl-4-nitro-1-phenyl-3-(2-(trifluoromethyl)phenyl)pentan-1-one (4g):



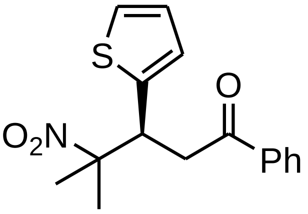
colorless viscous oil; 84% yield, 615 mg, 94% ee (reaction in 2 mL Teflon ampoule with 2 mmol of enone, 1 mol% of **1a** at 9 kbar for 5h); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.90–7.85 (m, 2H, COPh), 7.67 (dm, *J* = 8.0 Hz, 1H, Ar), 7.57–7.48 (m, 2H, COPh and Ar), 7.46–7.33 (m, 4H, COPh and Ar), 4.58 (dd, *J* = 7.9, 5.0 Hz, 1H, $C\underline{H}Ph$), 3.86 (dd, *J* = 16.8, 5.0 Hz, 1H, CH_2CO), 3.32 (dd, *J* = 16.8, 7.9 Hz, 1H, CH_2CO), 1.60 (s, 3H, CH_3), 1.57 (s, 3H, CH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.4 (CO), 137.7 (q, *J* = 1.3 Hz, C), 136.3 (C), 133.3 (CH), 132.0 (q, *J* = 1.0 Hz, CH), 129.8 (q, *J* = 29.2 Hz, **C**-CF_3), 128.6 (2 x CH), 128.5 (CH), 128.1 (2 x CH), 127.8 (CH), 126.8 (q, *J* = 5.9 Hz, CH), 124.1 (q, *J* = 274.5 Hz, CF_3), 91.2 (C), 43.0 (q, *J* = 2.2 Hz, CH), 40.7 (CH_2), 27.0 (q, *J* = 0.7 Hz, CH_3), 23.7 (q, *J* = 1.4 Hz, CH_3); ^{19}F NMR (376 MHz, $CDCl_3$) δ -56.3 (s, 3F); LR-MS (ESI): mass calculated for $[M+H]^+$ ($C_{19}H_{19}F_3NO_3^+$) *m/z* 366.13, found *m/z* 366.17; enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 95/5, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(*R*) t_r = 8.5 min and *ent*-(*S*) t_r = 9.8 min.

(*S*)-4-Methyl-4-nitro-1-phenyl-3-(pyridin-2-yl)pentan-1-one (4h): [22]



white solid; 88% yield, 527 mg, 85% ee (reaction in 2 mL Teflon ampoule with 2 mmol of enone, 1 mol% of **1a** at 9 kbar for 5h); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.46 (ddd, *J* = 4.8, 1.8, 0.8 Hz, 1H, pyridyl), 7.93–7.87 (m, 2H, COPh), 7.61 (ddd, *J* = 7.7, 1.9, 1.8 Hz, 1H, pyridyl), 7.55–7.49 (m, 1H, COPh), 7.45–7.38 (m, 2H, COPh), 7.35 (dm, *J* = 7.8 Hz, 1H, pyridyl), 7.13 (ddd, *J* = 7.5, 4.8, 1.1 Hz, 1H, pyridyl), 4.32 (dd, *J* = 10.7, 2.1 Hz, 1H, $C\underline{H}$pyridyl), 4.22 (dd, *J* = 17.2, 10.7 Hz, 1H, CH_2CO), 3.08 (dd, *J* = 17.2, 2.1 Hz, 1H, CH_2CO), 1.74 (s, 3H, CH_3), 1.52 (s, 3H, CH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.3 (CO), 157.7 (C), 148.9 (CH), 136.6 (C), 136.3 (CH), 133.1 (CH), 128.5 (2xCH), 128.0 (2xCH), 126.3 (CH), 122.4 (CH), 91.3 (C), 49.6 (CH), 38.5 (CH_2), 25.5 (CH_3), 22.7 (CH_3); LR-MS (ESI): mass calculated for $[M+H]^+$ ($C_{17}H_{19}N_2O_3^+$) *m/z* 299.14, found *m/z* 299.18; enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 80/20, flow rate 1.0 mL/min, λ = 256 nm): *ent*-(*S*) t_r = 8.5 min and *ent*-(*R*) t_r = 9.9 min.

(*S*)-4-Methyl-4-nitro-1-phenyl-3-(thiophen-2-yl)pentan-1-one (4i): [22]



white solid; 86% yield, 520 mg, 89% ee (reaction in 2 mL Teflon ampoule with 2 mmol of enone, 2 mol% of **1a** at 9 kbar for 20h); ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.90–7.84 (m, 2H, COPh), 7.58–7.52 (m, 1H, COPh), 7.47–7.40 (m, 2H, COPh), 7.16 (dd, *J* = 5.1, 1.1 Hz, 1H, thienyl), 6.94 (dd, *J* = 3.6, 1.1 Hz, 1H, thienyl), 6.91 (dd, *J* = 5.1, 3.6 Hz, 1H, thienyl), 4.54 (dd, *J* = 10.6, 2.9 Hz, 1H, CHthienyl), 3.64 (dd, *J* = 17.1, 10.6 Hz, 1H, CH$_2$CO), 3.17 (dd, *J* = 17.1, 2.9 Hz, 1H, CH$_2$CO), 1.71 (s, 3H, CH$_3$), 1.60 (s, 3H, CH$_3$); ^{13}C NMR (100 MHz, CDCl$_3$) δ 196.1 (CO), 140.5 (C), 136.5 (C), 133.3 (CH), 128.6 (2xCH), 128.0 (2xCH), 127.5 (CH), 126.8 (CH), 124.8 (CH), 91.1 (C), 44.4 (CH), 40.8 (CH$_2$), 26.0 (CH$_3$), 22.6 (CH$_3$); LR-MS (ESI): mass calculated for [M+H]$^+$ (C$_{16}$H$_{18}$NO$_3$S$^+$) *m/z* 304.10, found *m/z* 304.15; enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 80/20, flow rate 1.0 mL/min, λ = 256 nm): *ent*-(*S*) t$_r$ = 8.3 min and *ent*-(*R*) t$_r$ = 12.1 min.

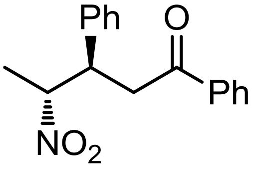
4-Nitro-1,3-diphenylpentan-1-one (5): [9,10,3]

Reaction carried out in 3 mL Teflon ampoule with 3 mmol of chalcone, 3 equiv of nitroethane and 0.5 mol% of **1a** or **1d** in toluene at 9 kbar for 2h.

With catalyst **1a**: 94% yield, 800 mg, (quantitative conversion)**,** *anti*-**5**/*syn*-**5** ratio 2:1 (by NMR and GC), (3*R*,4*R*)-**5**: 95% ee and (3*R*,4*S*)-**5**: 94% ee.

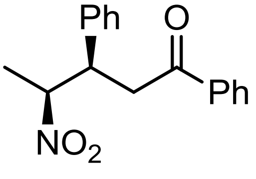
With catalyst **1d**: 93% yield, 790 mg, (quantitative conversion)**,** *anti*-**5**/*syn*-**5** ratio 1:1.2 (by NMR and GC), (3*S*,4*S*)-**5**: 97% ee and (3*S*,4*R*)-**5**: 98% ee.

anti-**5: (3*R*,4*R*)-4-Nitro-1,3-diphenylpentan-1-one** (95% ee) obtained with **1a** or **(3*S*,4*S*)-4-nitro-1,3-diphenylpentan-1-one** (97% ee) obtained with **1d:** [9]



white solid; less polar (in hexane/AcOEt 95:5 → 9:1); ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.86–7.81 (m, 2H, COPh), 7.56–7.50 (m, 1H, COPh), 7.44–7.38 (m, 2H, COPh), 7.33–7.28 (m, 2H, Ph), 7.26–7.21 (m, 3H, Ph), 4.89 (dq, *J* = 9.8, 6.6 Hz, 1H, CHNO$_2$), 3.95 (ps td, *J* = ~9.7, 4.1 Hz, 1H, CHPh), 3.55 (dd, *J* = 17.1, 9.5 Hz, 1H, CH$_2$CO), 3.26 (dd, *J* = 17.1, 4.1 Hz, 1H, CH$_2$CO), 1.37 (d, *J* = 6.7 Hz, 3H, CH$_3$); ^{13}C NMR (100 MHz, CDCl$_3$) δ 196.5 (CO), 138.3 (C), 136.5 (C), 133.3 (CH), 128.9 (2 x CH), 128.6 (2 x CH), 128.3 (2 x CH), 127.9 (2 x CH), 127.7 (CH), 87.2 (CH), 45.5 (CH), 41.4 (CH$_2$), 17.9 (CH$_3$); enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 92/8, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(3*R*,4*R*) t$_r$ = 16.2 min and *ent*-(3*S*,4*S*) t$_r$ = 18.2 min.

(*syn*-5): (3*R*,4*S*)-4-Nitro-1,3-diphenylpentan-1-one (94% ee) obtained with **1a** or **(3*S*,4*R*)-4-nitro-1,3-diphenylpentan-1-one** (98% ee) obtained with **1d:** [9]



white solid; more polar (in hexane/AcOEt 95:5 → 9:1); ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.94–7.88 (m, 2H, COPh), 7.58–7.52 (m, 1H, COPh), 7.47–7.40 (m, 1H, COPh), 7.31–7.17 (m, 5H, Ph), 4.99 (ps quint, *J* = 6.7 Hz, 1H, CHNO$_2$), 3.97 (dd, *J* = 13.5, 6.5 Hz, 1H, CHPh), 3.60 (dd, *J* = 17.7, 6.4 Hz, 1H, CH$_2$CO), 3.46 (dd, *J* = 17.7, 7.3 Hz, 1H, CH$_2$CO), 1.54 (d, *J* = 6.7 Hz, 3H, CH$_3$); ^{13}C NMR (100 MHz, CDCl$_3$) δ 197.1 (CO), 138.1 (C), 136.5 (C), 133.4 (CH), 1286 (2 x CH), 128.6 (2 x CH), 128.1 (2 x CH), 127.9 (2 x CH), 127.8 (CH), 86.1 (CH), 44.6 (CH), 39.9 (CH$_2$), 16.82 (CH$_3$); enantiomeric excess was determined by HPLC analysis using a Chiralpak® IC column (Hexane/*i*-PrOH: 92/8, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(3*R*,4*S*) t$_r$ = 13.9 min and *ent*-(3*S*,4*R*) t$_r$ = 17.2 min.

(3*S*,4*R*)-**5** (obtained with **1d**): $[\alpha]_D^{23}$ = –39.9 (c 1.2, CHCl$_3$, 98% ee), [lit. (ref. 9): for (3*R*,4*S*)-**5** $[\alpha]_D^{25}$ = +33.2 (c 1.2, CHCl$_3$, 84% ee).

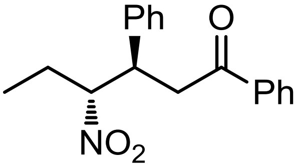
4-Nitro-1,3-diphenylhexan-1-one (6): [9]

Reaction carried out in 2 mL Teflon ampoule with 2 mmol of chalcone, 3 equiv of 1-nitropropane and 0.5 mol% of **1a** or **1d** in toluene at 9 kbar for 2h.

With catalyst **1a**: 96% yield, 569 mg, (quantitative conversion), *anti*-**6**/*syn*-**6** ratio 1.7:1 (by NMR and GC), (3*R*,4*R*)-**6**: 93.5% ee and (3*R*,4*S*)-**6**: 87.7% ee.

With catalyst **1d**: 95% yield, 566 mg, (quantitative conversion), *anti*-**6**/*syn*-**6** ratio 1:1.4 (by NMR and GC), (3*S*,4*S*)-**6**: 97% ee and (3*S*,4*R*)-**6**: 98% ee.

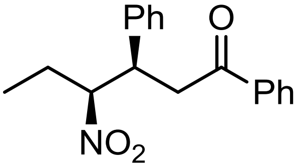
(3*R*,4*R*)-4-Nitro-1,3-diphenylhexan-1-one (93.5% ee) obtained with **1a** or **(3*S*,4*S*)-4-nitro-1,3-diphenylhexan-1-one** (97% ee) obtained with **1d:** [9]



white solid; less polar (in hexane/AcOEt 95:5 → 9:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.84–7.80 (m, 2H, COPh), 7.54–7.49 (m, 1H, COPh), 7.43–7.37 (m, 2H, COPh), 7.32–7.19 (m, 5H, Ph), 4.71 (td, J = 10.6, 3.2 Hz, 1H, $CHNO_2$), 3.93 (td, J = 10.1, 3.5 Hz, 1H, $C\underline{H}Ph$), 3.56 (dd, J = 17.0, 10.1 Hz, 1H, CH_2CO), 3.20 (dd, J = 17.0, 3.5 Hz, 1H, CH_2CO), 1.93–1.80 (m, 1H, $C\underline{H_2}CH_3$), 1.58–1.46 (m, 1H, $C\underline{H_2}CH_3$), 0.86 (t, J = 7.4 Hz, 3H, CH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.4 (CO), 138.6 (C), 136.4 (C), 133.2 (CH), 128.9 (2 x CH), 128.5 (2 x CH), 128.1 (2 x CH), 127.9 (2 x CH), 127.6 (CH), 94.4 (CH), 44.7 (CH), 41.4 (CH_2), 25.6 (CH_2), 10.3 (CH_3); enantiomeric excess was determined by HPLC analysis using a Chiralpak® ID column (Hexane/*i*-PrOH: 95/5, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(3*R*,4*R*) t_r = 17.8 min and *ent*-(3*S*,4*S*) t_r = 25.1 min.

(3*R*,4*R*)-**6** (obtained with **1a**): $[\alpha]_D^{26}$ = +14.2 (c 1.2, $CHCl_3$, 94% ee), [lit. (ref. 9): for (3*R*,4*R*)-**5** $[\alpha]_D^{25}$ = +12.3 (c 1.5, $CHCl_3$, 81% ee).

(3*R*,4*S*)-4-Nitro-1,3-diphenylhexan-1-one (87.5% ee) obtained with **1a** or **(3*S*,4*R*)-4-nitro-1,3-diphenylhexan-1-one** (98% ee) obtained with **1d**: [9]



white solid; more polar (in hexane/AcOEt 95:5 → 9:1); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.94–7.88 (m, 2H, COPh), 7.59–7.53 (m, 1H, COPh), 7.48–7.41 (m, 2H, COPh), 7.32–7.17 (m, 5H, Ph), 4.82 (ddd, J = 10.5, 6.8, 3.8 Hz, 1H, $CHNO_2$), 3.98 (ps q, J = 6.8 Hz, 1H, $C\underline{H}Ph$), 3.59 (dd, J = 17.7, 6.5 Hz, 1H, CH_2CO), 3.42 (dd, J = 17.7, 7.0 Hz, 1H, CH_2CO), 2.06–1.93 (m, 1H, $C\underline{H_2}CH_3$), 1.91–1.80 (m, 1H, $C\underline{H_2}CH_3$), 0.98 (t, J = 7.3 Hz, 3H, CH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.1 (CO), 138.4 (C), 136.6 (C), 133.4 (CH), 128.7 (2 x CH), 128.6 (2 x CH), 128.2 (2 x CH), 128.0 (2 x CH), 127.8 (CH), 93.3 (CH), 43.7 (CH), 40.5 (CH_2), 24.6 (CH_2), 10.5 (CH_3); enantiomeric excess was determined by HPLC analysis using a Chiralpak® ID column (Hexane/*i*-PrOH: 95/5, flow rate 1.0 mL/min, λ = 225 nm): *ent*-(3*R*,4*S*) t_r = 20.5 min and *ent*-(3*S*,4*R*) t_r = 22.2 min.

References:

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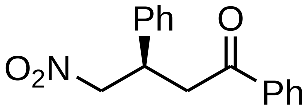
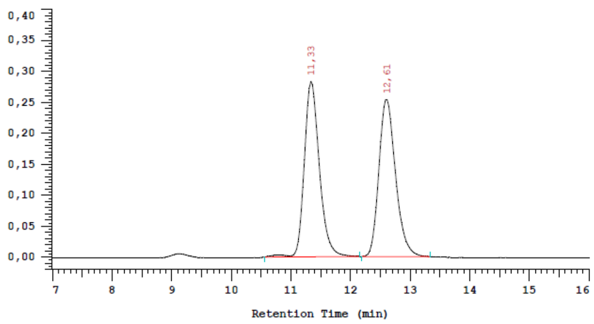
HPLC chromatograms:

3a



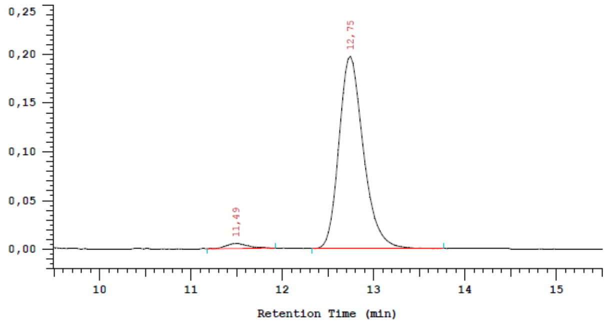
CHIRALPAK® IC
Hexane/*i*-PrOH: 75/25; flow rate 1.0 mL/min
225 nm

RACEMATE



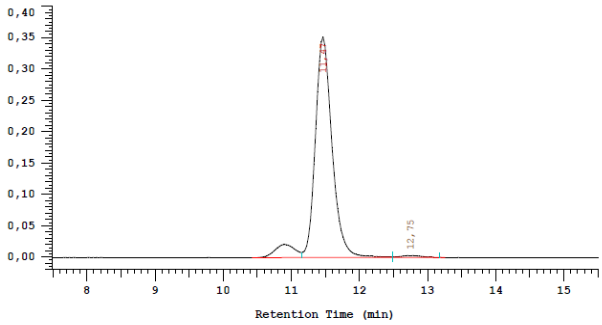
RT	Area	Conc 1
11,33 12,61	2485159 2465974	50,194 49,806
	4951133	100,000

(*R*)-**3a**: 95.6% ee with **1a**



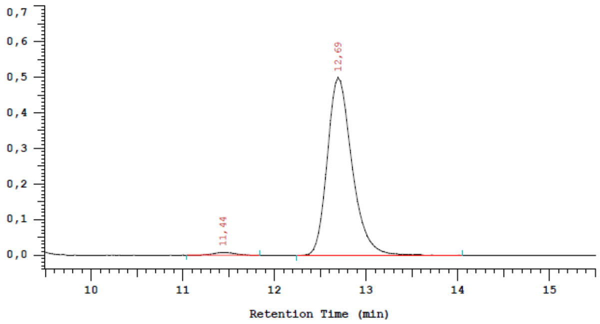
RT	Area	Conc 1
11,49 12,75	41061 1829042	2,196 97,804
	1870103	100,000

(*S*)-**3a**: 98% ee with **1d**



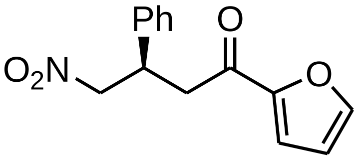
RT	Area	Conc 1
11,47 12,75	3010687 21981	99,275 0,725
	3032668	100,000

(*R*)-**3a**: 97.4% ee with **1e**



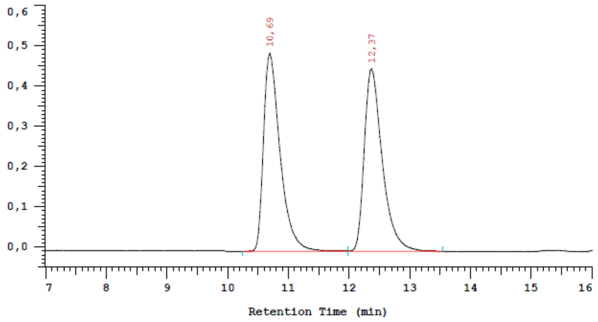
RT	Area	Conc 1
11,44 12,69	60964 4683074	1,285 98,715
	4744038	100,000

3b



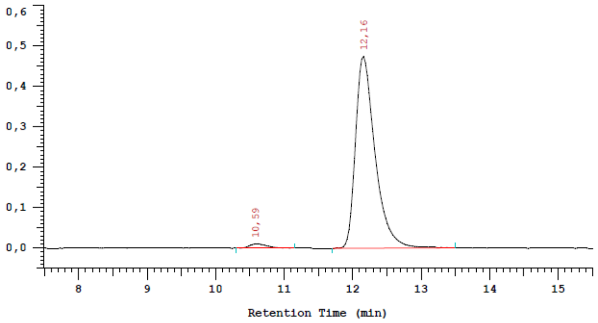
CHIRALPAK® IA
Hexane/*i*-PrOH: 80/20; flow rate 1.0 mL/min
256 nm

RACEMATE



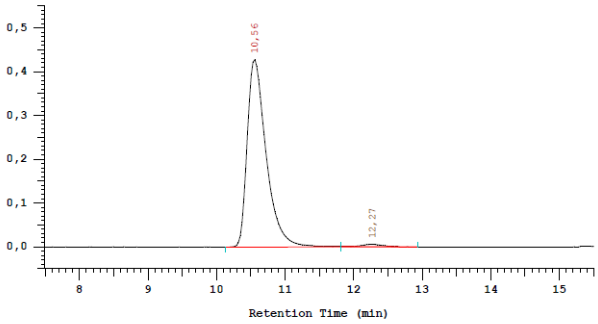
RT	Area	Conc 1
10,69	4673817	49,918
12,37	4689155	50,082
	9362972	100,000

96.0% ee with **1a**



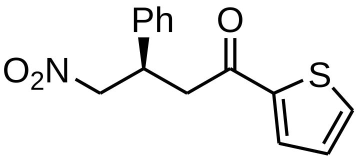
RT	Area	Conc 1
10,59	96299	2,003
12,16	4711033	97,997
	4807332	100,000

97.2% ee with **1d**



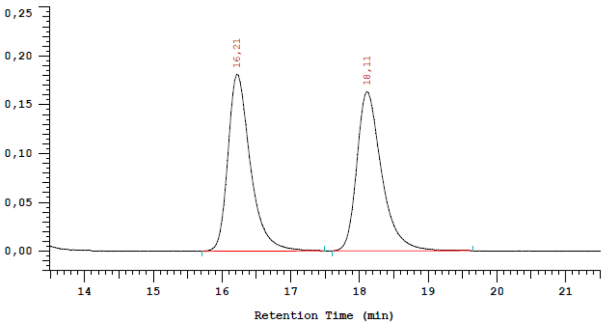
RT	Area	Conc 1
10,56	4140956	98,585
12,27	59450	1,415
	4200406	100,000

3c



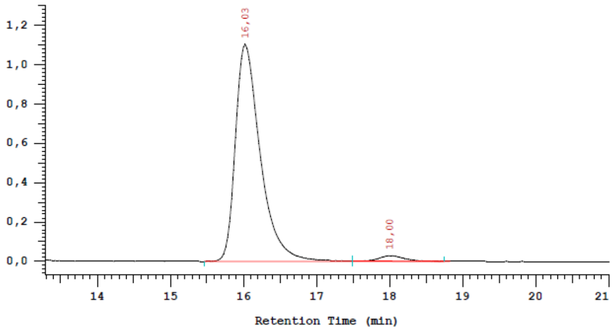
CHIRALPAK®IB
Hexane/*i*-PrOH: 75/25; flow rate 1.0 mL/min
256 nm

RACEMATE



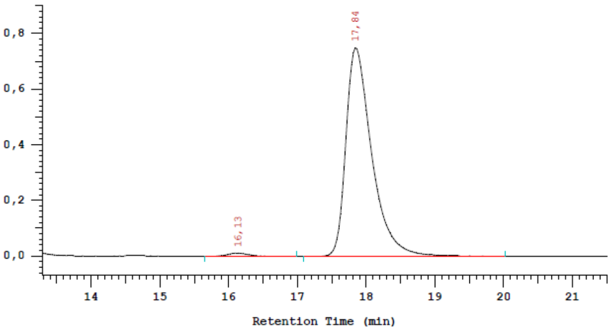
RT	Area	Conc 1
16,21	2053977	50,158
18,11	2041007	49,842
	4094984	100,000

95.2% ee with **1a**



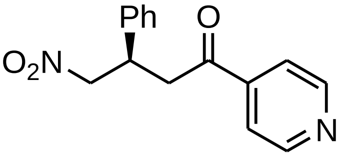
RT	Area	Conc 1
16,03	13141817	97,623
18,00	320022	2,377
	13461839	100,000

97.3% ee with **1d**



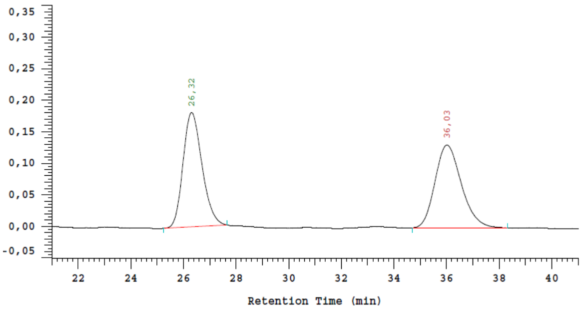
RT	Area	Conc 1
16,13	135682	1,362
17,84	9826892	98,638
	9962574	100,000

3d



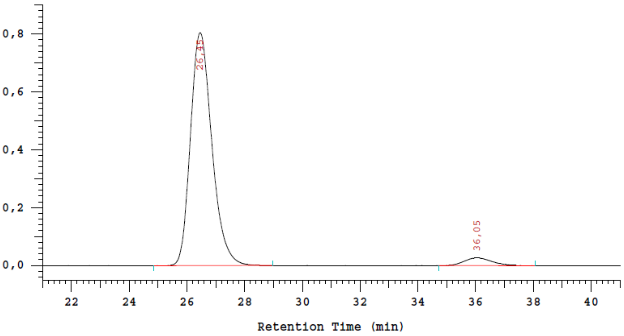
CHIRALPAK ®IC
Hexane/*i*-PrOH: 60/40; flow rate 1.0 mL/min
225 nm

RACEMATE



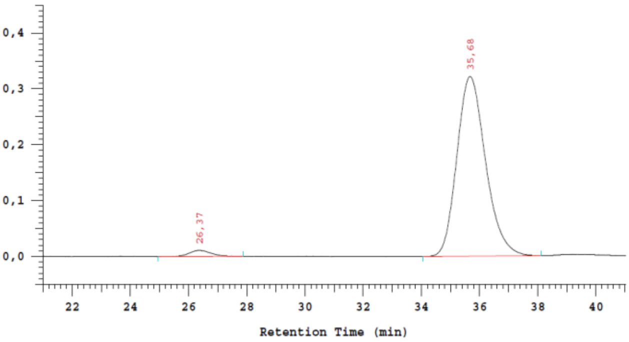
RT	Area	Conc 1
26,32	4536586	49,823
36,03	4568904	50,177
	9105490	100,000

91.6% ee with **1a**



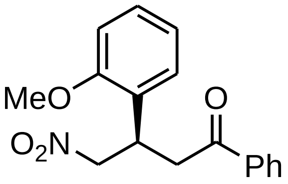
RT	Area	Conc 1
26,45	20711934	95,782
36,05	912104	4,218
	21624038	100,000

95.0% ee with **1d**



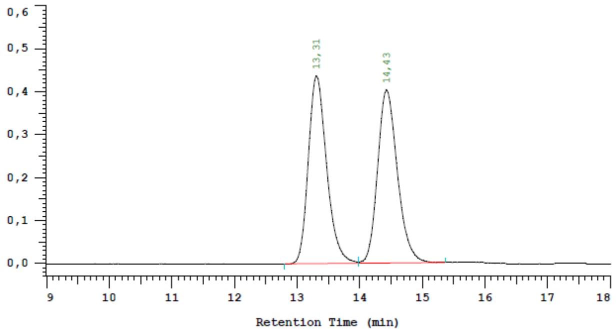
RT	Area	Conc 1
26,37	284916	2,520
35,68	11020518	97,480
	11305434	100,000

3e



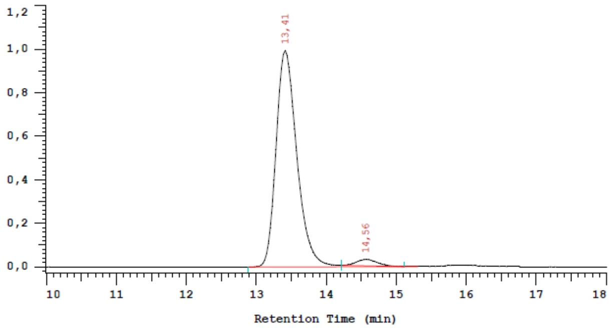
CHIRALPAK ® IC
Hexane/*i*-PrOH: 75/25; flow rate 1.0 mL/min
225 nm

RACEMATE



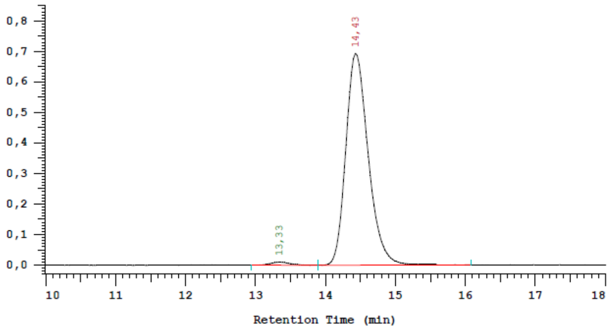
RT	Area	Conc 1
13,31	4446907	50,038
14,43	4440184	49,962
	8887091	100,000

94.3% ee with **1a**



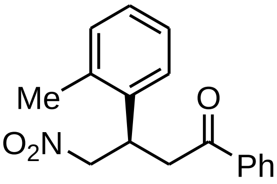
RT	Area	Conc 1
13,41	10358047	97,161
14,56	302638	2,839
	10660685	100,000

97.5% ee with **1d**



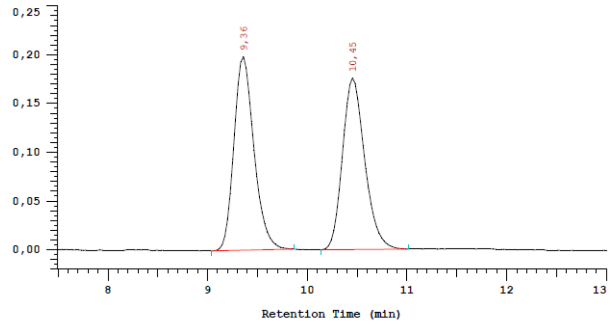
RT	Area	Conc 1
13,33	97461	1,246
14,43	7725065	98,754
	7822526	100,000

3f



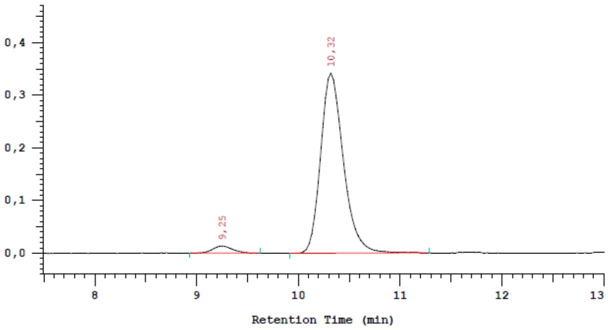
CHIRALPAK® IC
Hexane/*i*-PrOH: 75/25; flow rate 1.0 mL/min
225 nm

RACEMATE



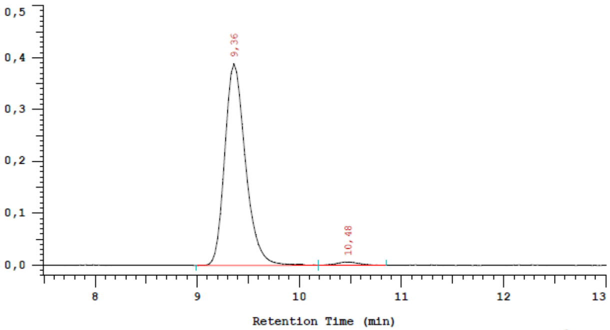
RT	Area	Conc 1
9,36	1385455	50,421
10,45	1362302	49,579
	2747757	100,000

93.4% ee with **1a**



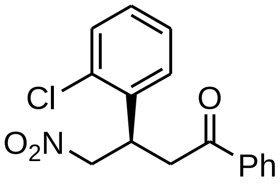
RT	Area	Conc 1
9,25	90829	3,312
10,32	2651215	96,688
	2742044	100,000

96.4% ee with **1d**



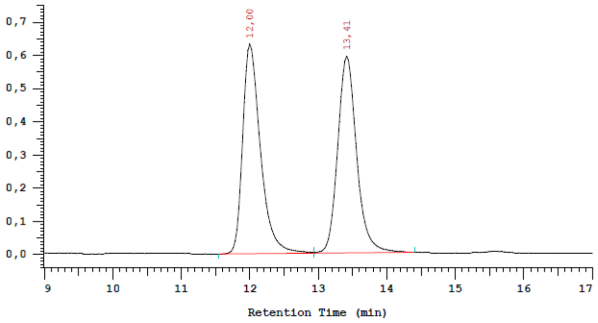
RT	Area	Conc 1
9,36	2745298	98,198
10,48	50390	1,802
	2795688	100,000

3g



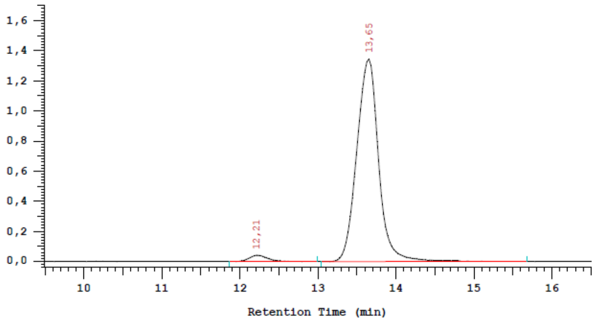
CHIRALPAK® IB
Hexane/*i*-PrOH: 80/20; flow rate 1.0 mL/min
225nm

RACEMATE



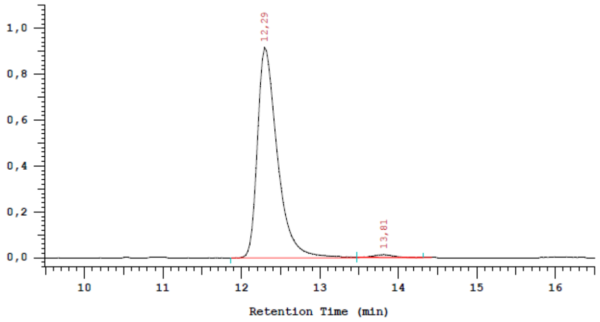
RT	Area	Conc 1
12,00	5678448	50,021
13,41	5673592	49,979
	11352040	100,000

94.5% ee with **1a**



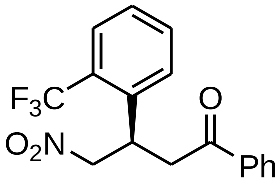
RT	Area	Conc 1
12,21	367206	2,728
13,65	13094744	97,272
	13461950	100,000

97.6% ee with **1d**



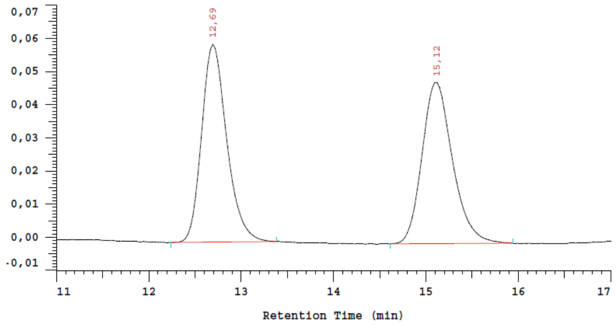
RT	Area	Conc 1
12,29	8152962	98,818
13,81	97524	1,182
	8250486	100,000

3h



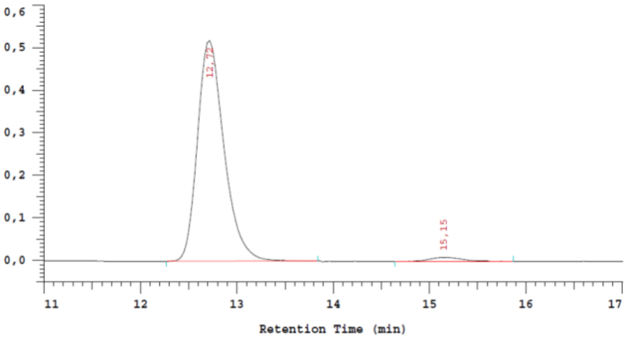
CHIRALPAK® IC
Hexane/*i*-PrOH: 90/10; flow rate 1.0 mL/min
225 nm

RACEMATE



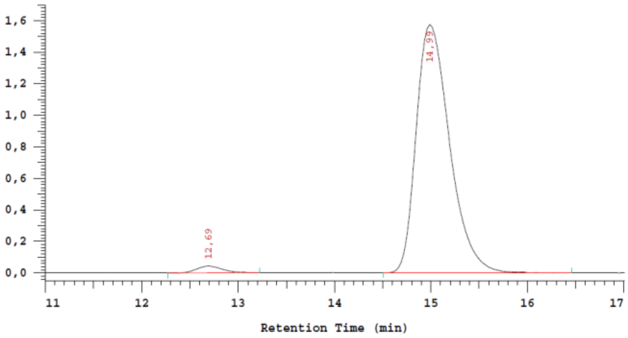
RT	Area	Conc 1
12,69	562268	50,144
15,12	559030	49,856
	1121298	100,000

95.6% ee with **1a**



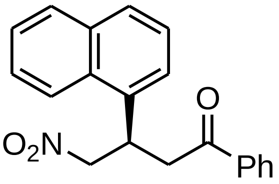
RT	Area	Conc 1
12,72	4951715	97,791
15,15	111872	2,209
	5063587	100,000

95.8% ee with **1d**



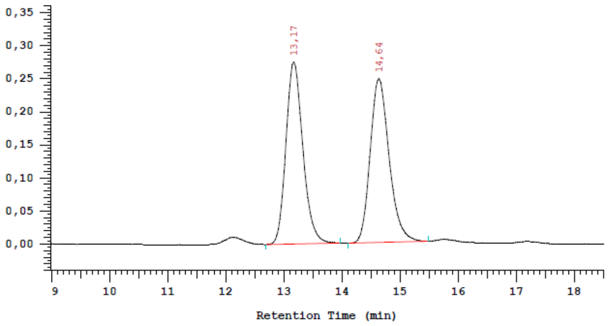
RT	Area	Conc 1
12,69	408987	2,110
14,99	18974227	97,890
	19383214	100,000

3i



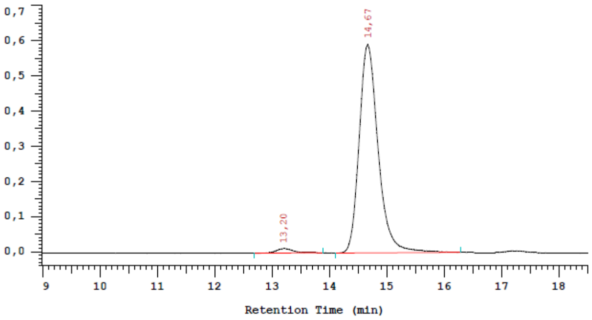
CHIRALPAK® IC
Hexane/*i*-PrOH: 80/20; flow rate 1.0 mL/min
225 nm

RACEMATE



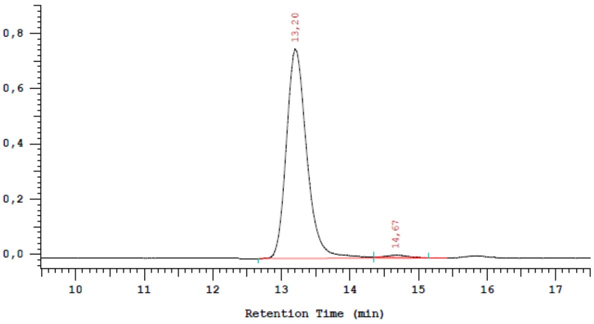
RT	Area	Conc 1
13,17	2788984	49,900
14,64	2800142	50,100
	5589126	100,000

96.2% ee with **1a**



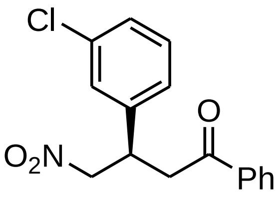
RT	Area	Conc 1
13,20	130432	1,880
14,67	6807728	98,120
	6938160	100,000

98.0% ee with **1d**



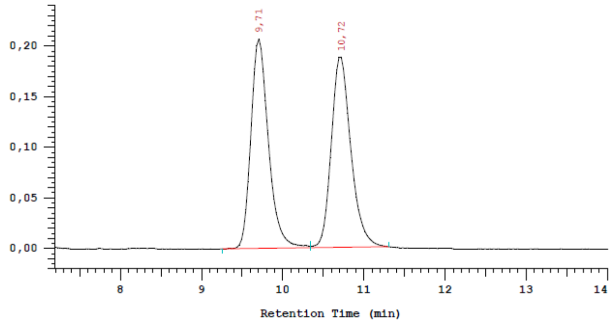
RT	Area	Conc 1
13,20	7874051	98,984
14,67	80815	1,016
	7954866	100,000

3j



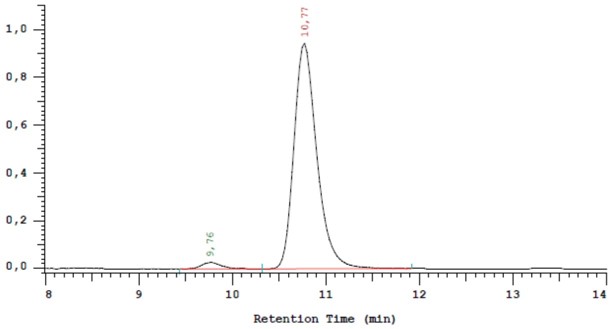
CHIRALPAK® IC
Hexane/*i*-PrOH: 75/25; flow rate 1.0 mL/min
225 nm

RACEMATE



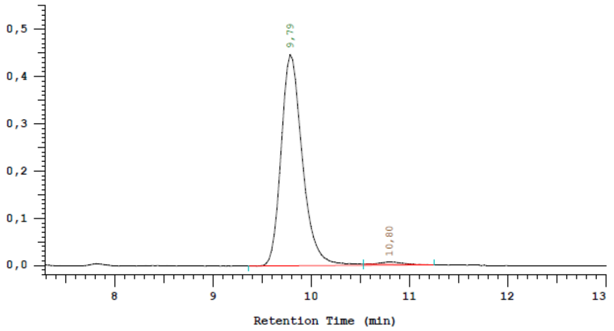
RT	Area	Conc 1
9,71	1557360	49,685
10,72	1577137	50,315
	3134497	100,000

95.2% ee with **1a**



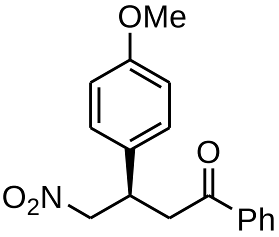
RT	Area	Conc 1
9,76	195980	2,383
10,77	8029068	97,617
	8225048	100,000

97.6% ee with **1d**



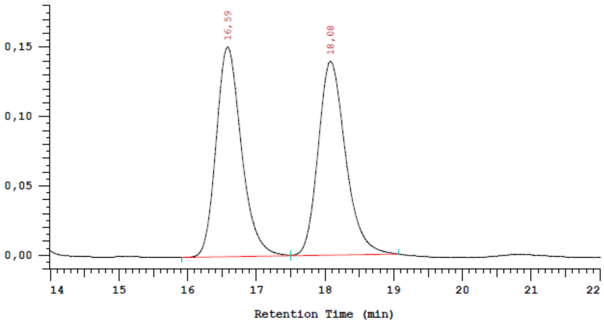
RT	Area	Conc 1
9,79	3384448	98,822
10,80	40342	1,178
	3424790	100,000

3k



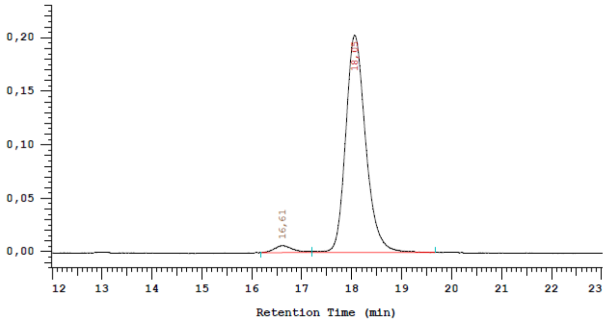
CHIRALPAK® IC
Hexane/*i*-PrOH: 75/25; flow rate 1.0 mL/min
225 nm

RACEMATE



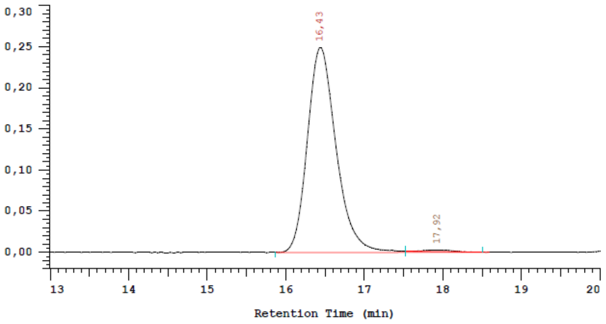
RT	Area	Conc 1
16,59	1932674	49,930
18,08	1938078	50,070
	3870752	100,000

94.3% ee with **1a**



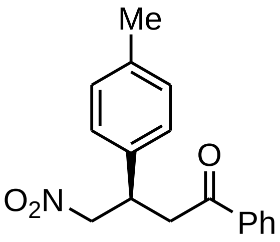
RT	Area	Conc 1
16,61	82762	2,845
18,05	2826697	97,155
	2909459	100,000

98% ee with **1d**



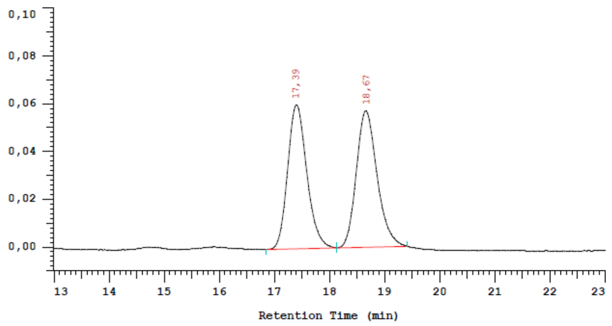
RT	Area	Conc 1
16,43	3195389	99,234
17,92	24652	0,766
	3220041	100,000

3l



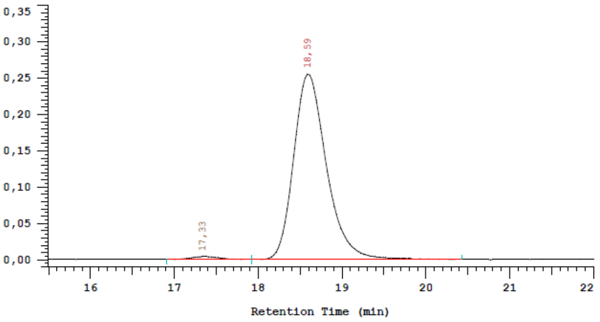
CHIRALPAK ® IC
Hexane/*i*-PrOH: 85/15; flow rate 1.0 mL/min
225 nm

RACEMATE



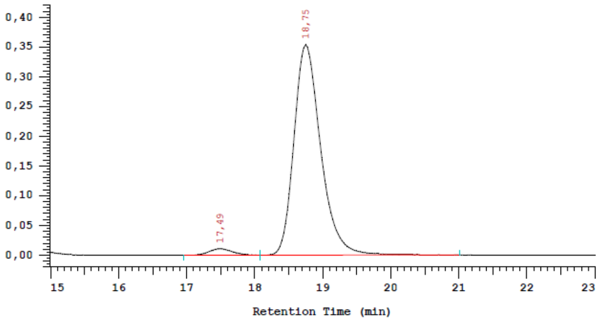
RT	Area	Conc 1
17,39	729680	49,266
18,67	751423	50,734
	1481103	100,000

97.3% ee with **1e**



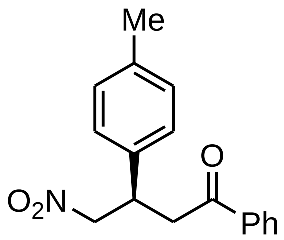
RT	Area	Conc 1
17,33	47889	1,363
18,59	3466854	98,637
	3514743	100,000

94.6% ee with **1a**



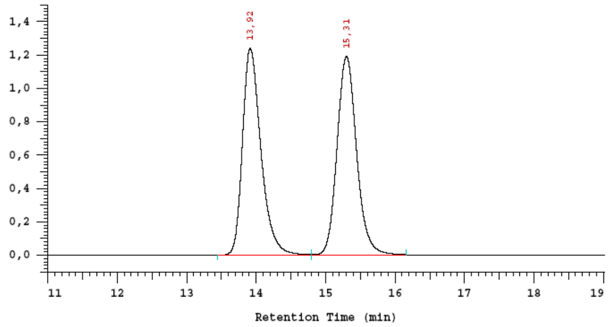
RT	Area	Conc 1
17,49	134138	2,695
18,75	4843536	97,305
	4977674	100,000

3l



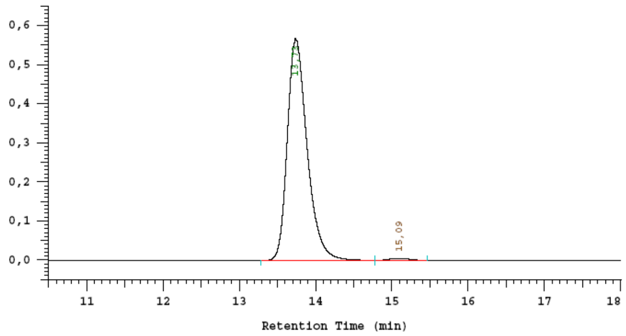
CHIRALPAK® IB
Hexane/*i*-PrOH: 85/15; flow rate 1.0 mL/min
225 nm

RACEMATE



RT	Area	Conc 1
13,92	11504372	49,854
15,31	11571960	50,146
	23076332	100,000

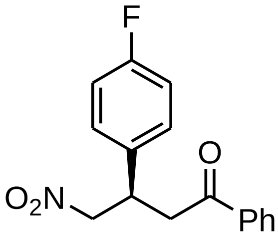
97.9% ee with **1d**



RT	Area	Conc 1
13,73	5118031	98,970
15,09	53278	1,030
	5171309	100,000

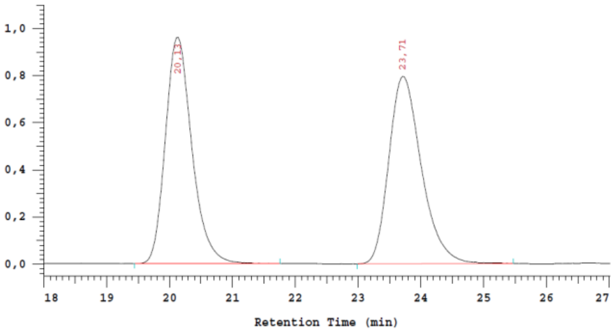
For the reaction with catalyst **1d** enantiomeric excess was determined using a Chiralpak® IB column. For Chiralpak® IC column in this case we observed small amount of impurity overlapping with minor enantiomer.

3m



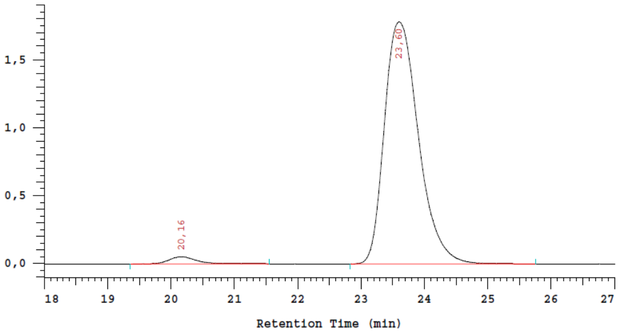
CHIRALPAK® IC
Hexane/*i*-PrOH: 90/10; flow rate 1.0 mL/min
225 nm

RACEMATE



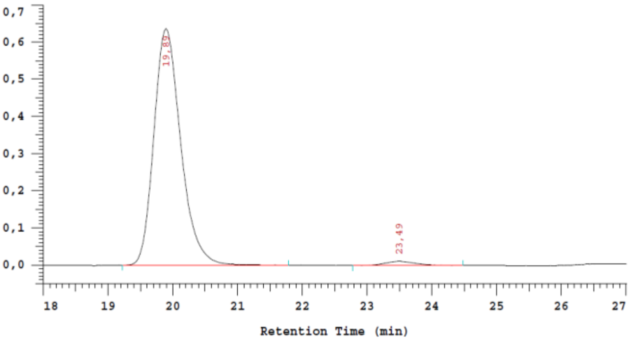
RT	Area	Conc 1
20,13	14128680	49,727
23,71	14284054	50,273
	28412734	100,000

95.2% ee with **1a**



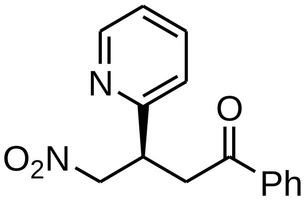
RT	Area	Conc 1
20,16	821255	2,414
23,60	33192665	97,586
	34013920	100,000

96.1% ee with **1d**



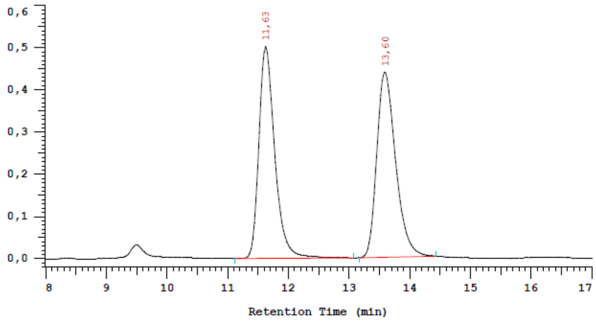
RT	Area	Conc 1
19,89	9152591	98,029
23,49	184041	1,971
	9336632	100,000

3n



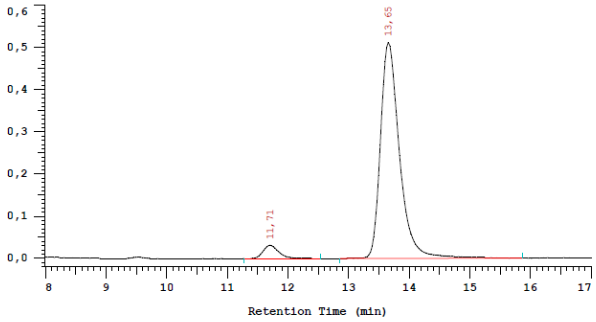
CHIRALPAK® IC
Hexane/*i*-PrOH: 75/25; flow rate 1.0 mL/min
225 nm

RACEMATE



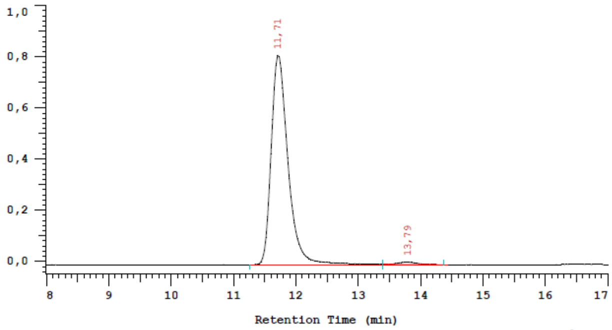
RT	Area	Conc 1
11,63	4568105	49,120
13,60	4731823	50,880
	9299928	100,000

90.3% ee with **1a**



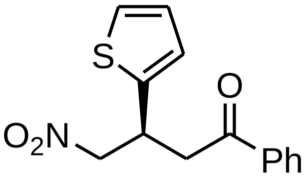
RT	Area	Conc 1
11,71	283643	4,832
13,65	5586374	95,168
	5870017	100,000

97.5% ee with **1d**



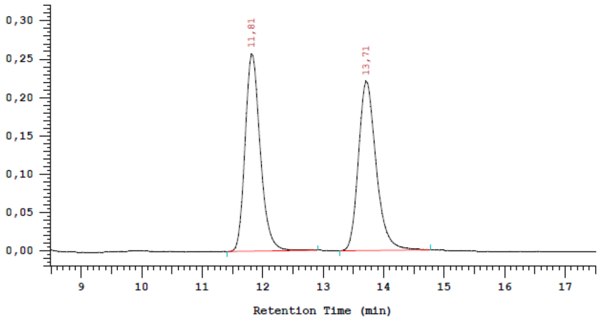
RT	Area	Conc 1
11,71	7690432	98,773
13,79	95521	1,227
	7785953	100,000

3o



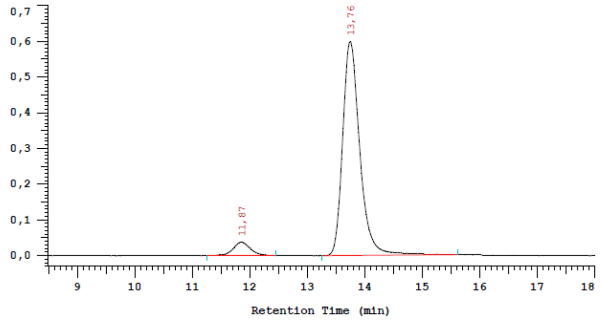
CHIRALPAK® IC
Hexane/*i*-PrOH: 75/25; flow rate 1.0 mL/min
225 nm

RACEMATE



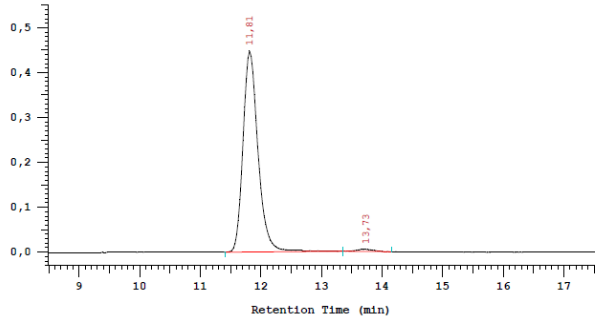
RT	Area	Conc 1
11,81	2235752	49,935
13,71	2241567	50,065
	4477319	100,000

87.9% ee with **1a**



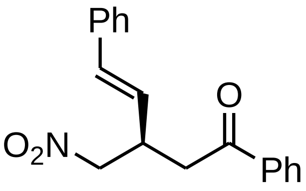
RT	Area	Conc 1
11,87	396968	6,031
13,76	6185144	93,969
	6582112	100,000

97.7% ee with **1d**



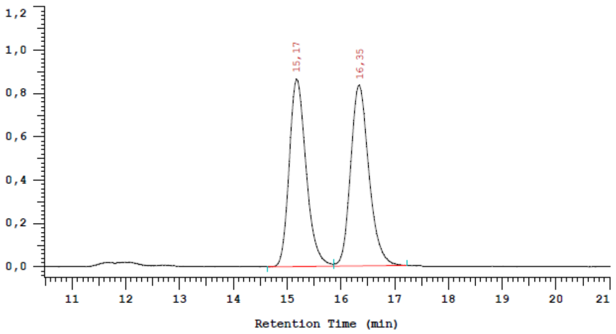
RT	Area	Conc 1
11,81	3846206	98,853
13,73	44613	1,147
	3890819	100,000

3p



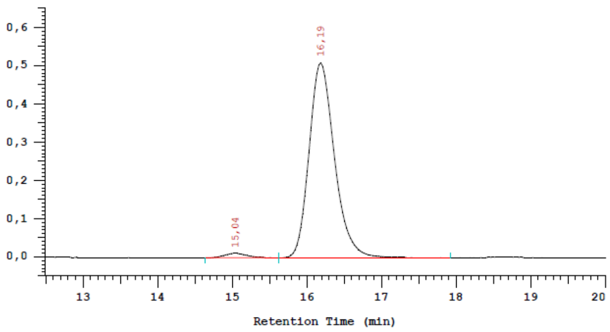
CHIRALPAK® IC
Hexane/*i*-PrOH: 85/15; flow rate 1.0 mL/min
256 nm

RACEMATE



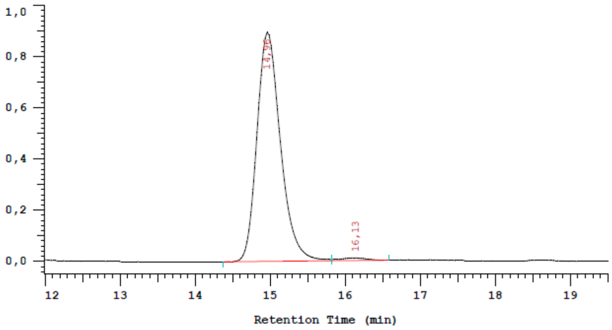
RT	Area	Conc 1
15,17	9439298	48,872
16,35	9875133	51,128
	19314431	100,000

95.9% ee with **1a**



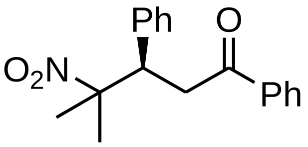
RT	Area	Conc 1
15,04	124864	2,027
16,19	6034560	97,973
	6159424	100,000

97.5% ee with **1d**



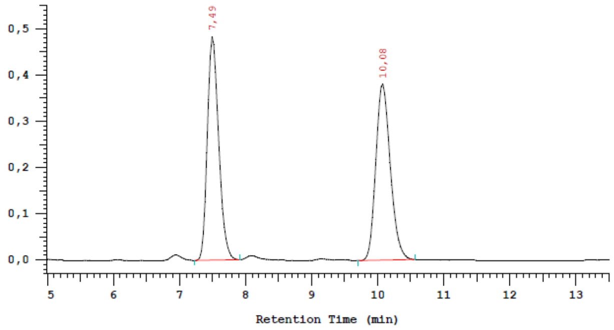
RT	Area	Conc 1
14,96	9712423	98,748
16,13	123137	1,252
	9835560	100,000

4a



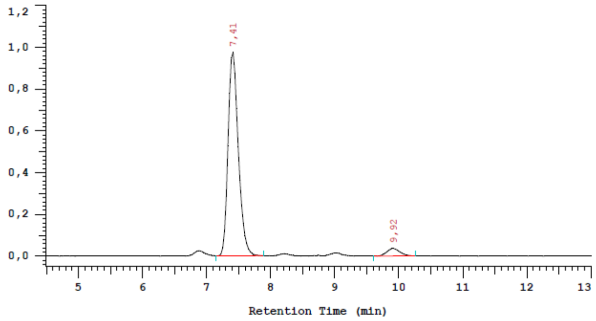
CHIRALPAK® IC
Hexane/*i*-PrOH: 80/20; flow rate 1.0 mL/min
225 nm

RACEMATE



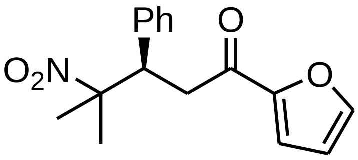
RT	Area	Conc 1
7,49	2879780	49,813
10,08	2901434	50,187
	5781214	100,000

(*R*)-**4a**: 91.1% ee with **1a**



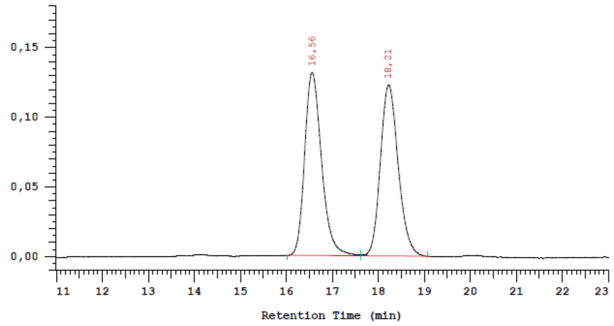
RT	Area	Conc 1
7,41	5410514	95,553
9,92	251777	4,447
	5662291	100,000

4b



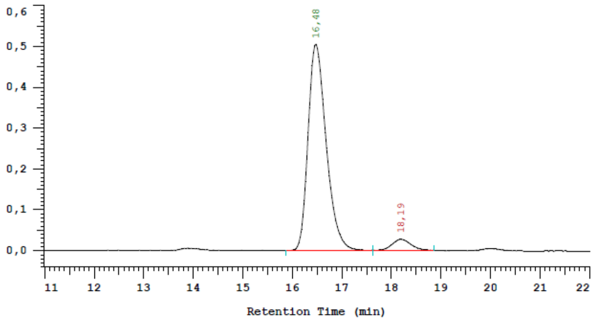
CHIRALPAK® IC
Hexane/*i*-PrOH: 80/20; flow rate 1.0 mL/min
225nm

RACEMATE



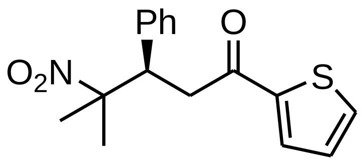
RT	Area	Conc 1
16,56	1681618	50,414
18,21	1654022	49,586
	3335640	100,000

89.3% ee with **1a**



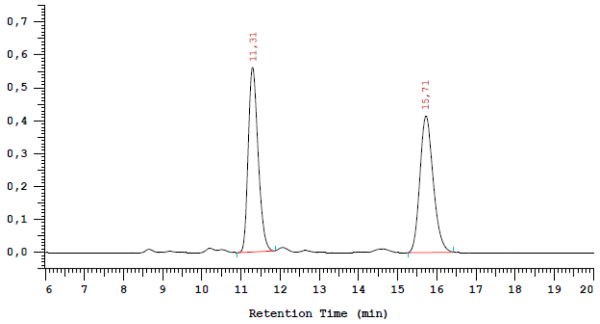
RT	Area	Conc 1
16,48	6415989	94,627
18,19	364298	5,373
	6780287	100,000

4c



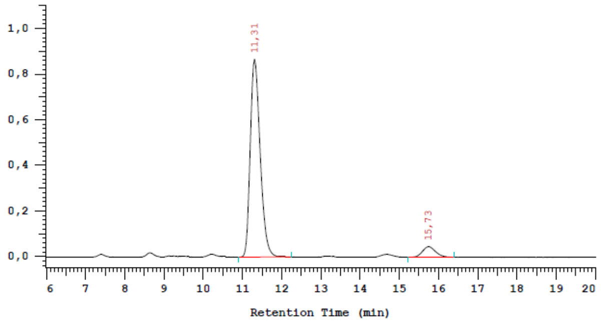
CHIRALPAK® IC
Hexane/*i*-PrOH: 80/20; flow rate 1.0 mL/min
225nm

RACEMATE



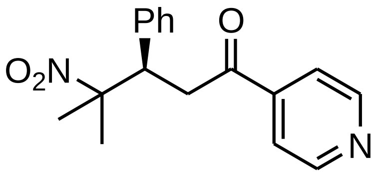
RT	Area	Conc 1
11,31	4886806	49,912
15,71	4904071	50,088
	9790877	100,000

86.9 %ee with **1a**



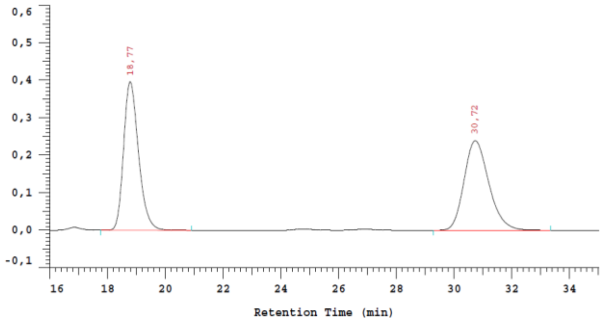
RT	Area	Conc 1
11,31	7570363	93,427
15,73	532576	6,573
	8102939	100,000

4d



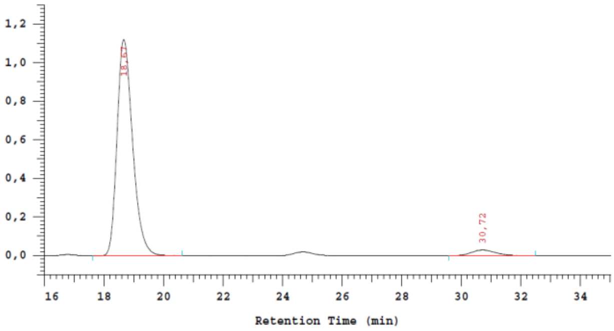
CHIRALPAK® IC
Hexane/*i*-PrOH: 60/40; flow rate 1.0 mL/min
225nm

RACEMATE



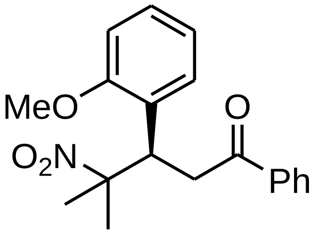
RT	Area	Conc 1
18,77	7125096	50,001
30,72	7124909	49,999
	14250005	100,000

91.8 %ee with **1a**



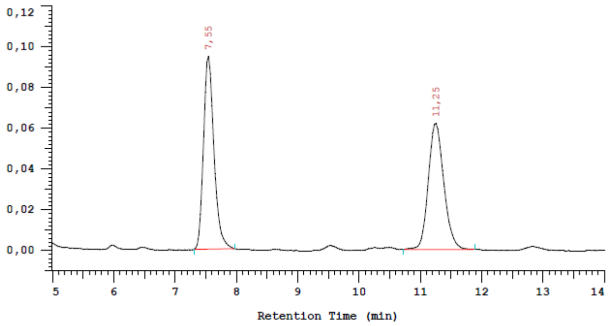
RT	Area	Conc 1
18,67	20434788	95,898
30,72	874056	4,102
	21308844	100,000

4e



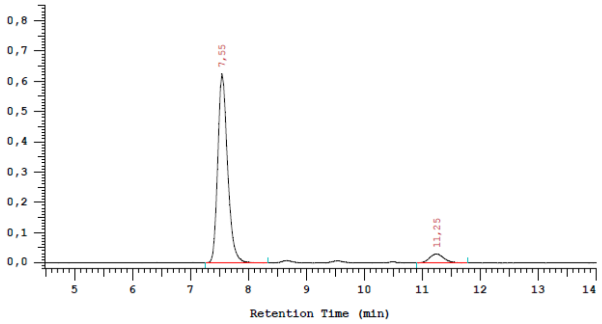
CHIRALPAK® IC
Hexane/*i*-PrOH: 80/20; flow rate 1.0 mL/min
225 nm

RACEMATE



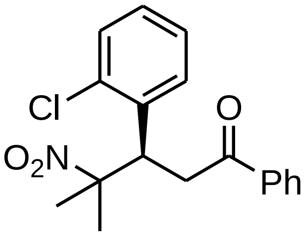
RT	Area	Conc 1
7,55	560949	50,763
11,25	544084	49,237
	1105033	100,000

86.9% ee with **1a**



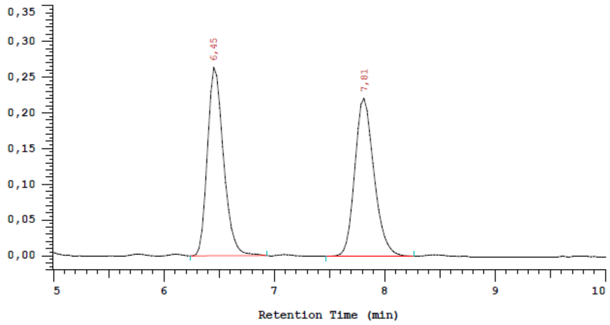
RT	Area	Conc 1
7,55	3668061	93,429
11,25	257966	6,571
	3926027	100,000

4f



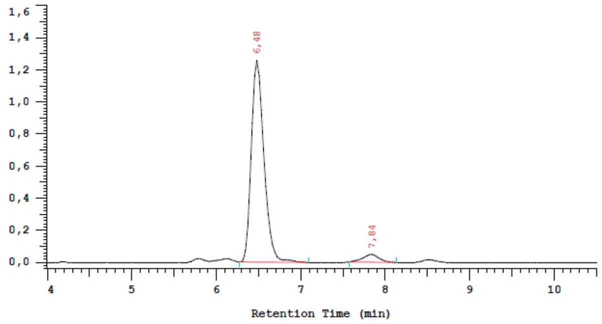
CHIRALPAK® IC
Hexane/*i*-PrOH: 80/20; flow rate 1.0 mL/min
225 nm

RACEMATE



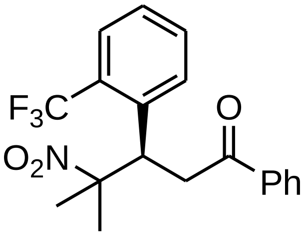
RT	Area	Conc 1
6,45	1332843	49,968
7,81	1334537	50,032
	2667380	100,000

90.6%ee with **1a**



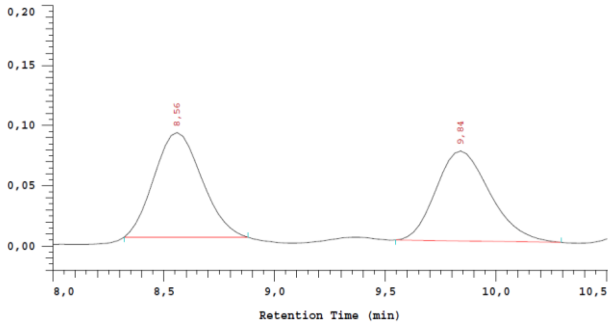
RT	Area	Conc 1
6,48	6529791	95,305
7,84	321711	4,695
	6851502	100,000

4g



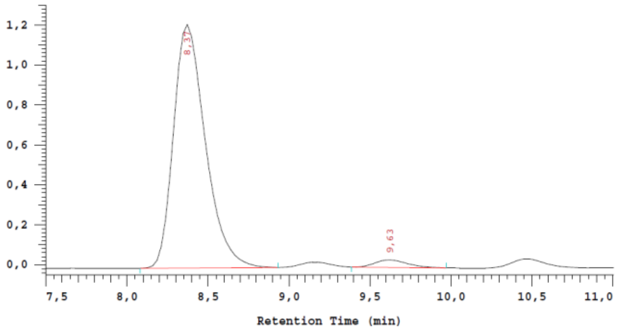
CHIRALPAK® IC
Hexane/*i*-PrOH: 95/5; flow rate 1.0 mL/min
225 nm

RACEMATE



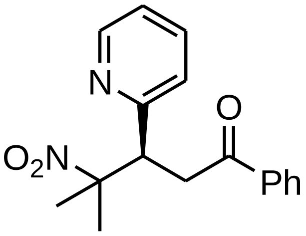
RT	Area	Conc 1
8,56	652815	50,690
9,84	635039	49,310
	1287854	100,000

93.9%ee with **1a**



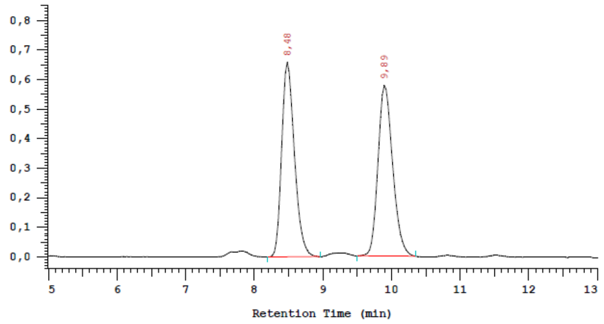
RT	Area	Conc 1
8,37	8333301	96,969
9,63	260452	3,031
	8593753	100,000

4h



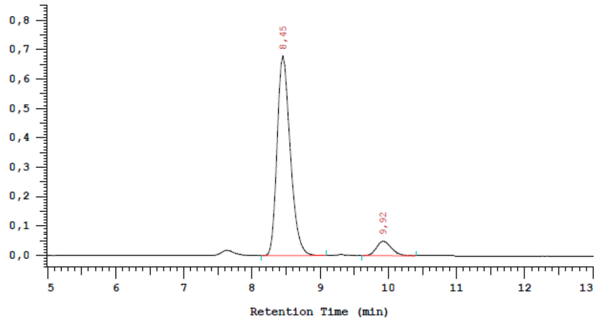
CHIRALPAK® IC
Hexane/*i*-PrOH: 80:20; flow rate 1.0 mL/min
256 nm

RACEMATE



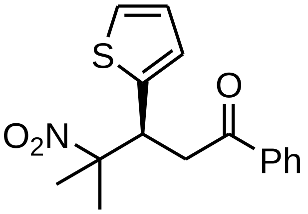
RT	Area	Conc 1
8,48	4241294	49,747
9,89	4284446	50,253
	8525740	100,000

84.6%ee with **1a**



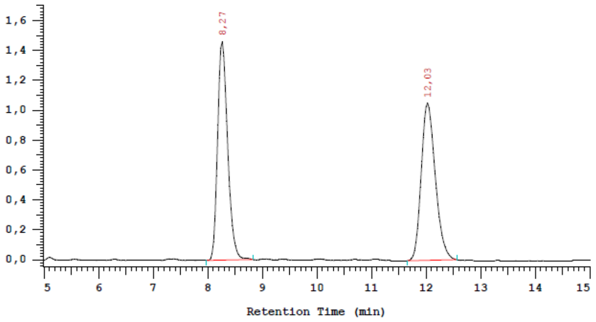
RT	Area	Conc 1
8,45	4548998	92,304
9,92	379275	7,696
	4928273	100,000

4i



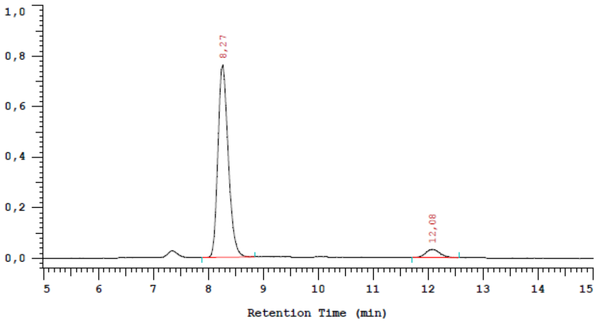
CHIRALPAK® IC
Hexane/*i*-PrOH: 80/20; flow rate 1.0 mL/min
256 nm

RACEMATE



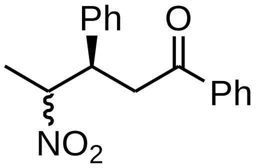
RT	Area	Conc 1
8,27	9343152	49,739
12,03	9441296	50,261
	18784448	100,000

89.0% ee with **1a**



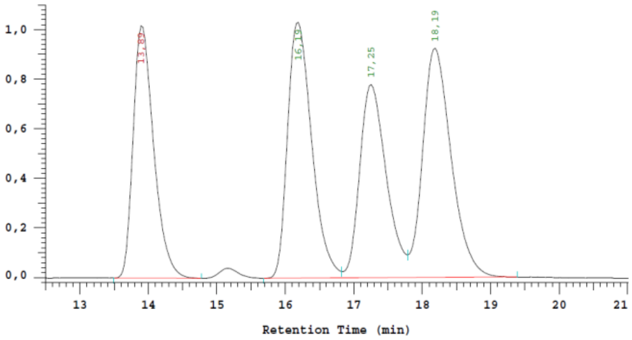
RT	Area	Conc 1
8,27	4938812	94,495
12,08	287710	5,505
	5226522	100,000

5



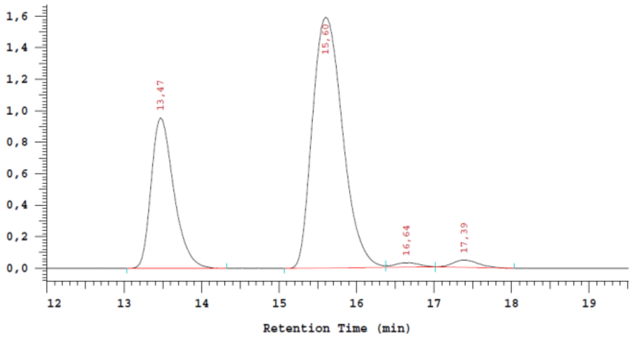
CHIRALPAK® IC
Hexane/*i*-PrOH: 92/8; flow rate 1.0 mL/min
225 nm

RACEMATE



RT	Area	Conc 1
13,89	10612631	22,496
16,19	12634403	26,782
17,25	10489170	22,234
18,19	13439198	28,488
	47175402	100,000

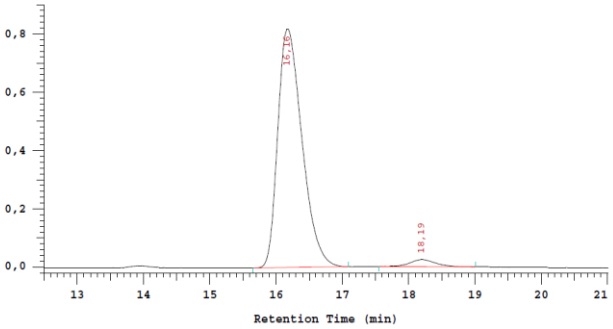
93.8% and 95.2% ee with **1a**
(3*R*,4*S*)-**5** (3*R*,4*R*)-**5**



RT	Area	Conc 1
13,47	9684388	30,103
15,60	21655163	67,312
16,64	307408	0,956
17,39	524394	1,630
	32171353	100,000

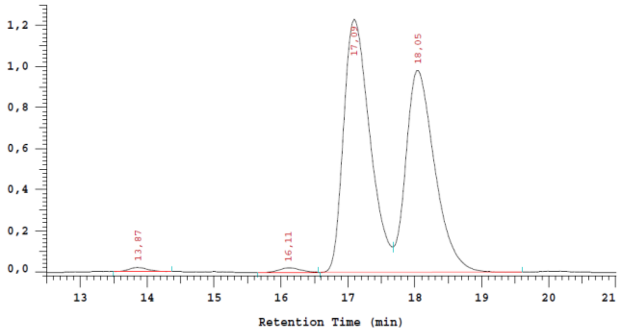
Major diastereoisomer with **1a**: 93.9% ee

(3*R*,4*R*)-**5**



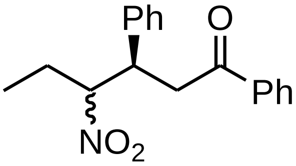
RT	Area	Conc 1
16,16	10368747	96,928
18,19	328572	3,072
	10697319	100,000

with **1d** 97.8% and 96.9% ee
(3*S*,4*R*)-**5** (3*S*,4*S*)-**5**



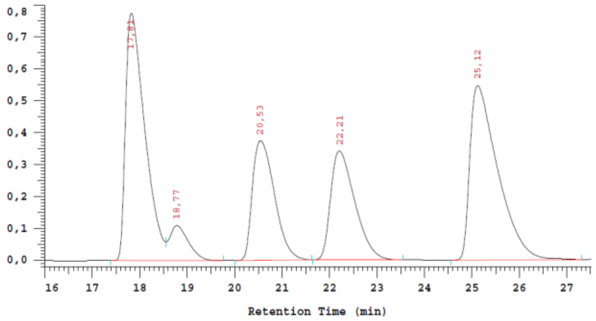
RT	Area	Conc 1
13,87	190176	0,593
16,11	233250	0,727
17,09	16841054	52,513
18,05	14805964	46,167
	32070444	100,000

6



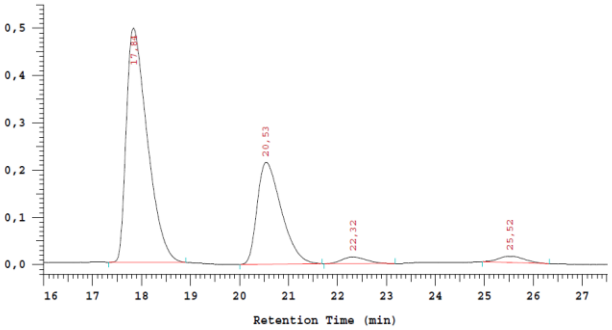
CHIRALPAK® ID
Hexane/*i*-PrOH: 95/5; flow rate 1.0 mL/min
225 nm

RACEMATE



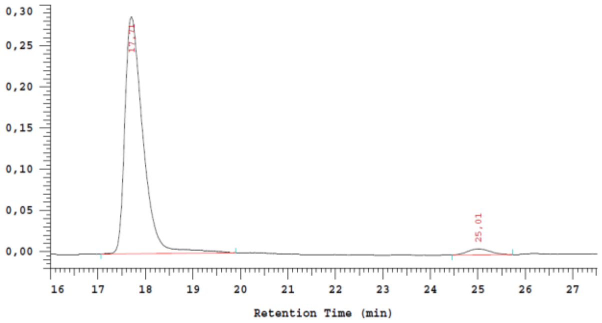
RT	Area	Conc 1
17,81	10882517	30,453
18,77	1542164	4,315
20,53	6053340	16,939
22,21	6046080	16,919
25,12	11211676	31,374
	35735777	100,000

93.5% and 87.6% ee with **1a**
(3*R*,4*R*)-**6** (3*R*,4*S*)-**6**



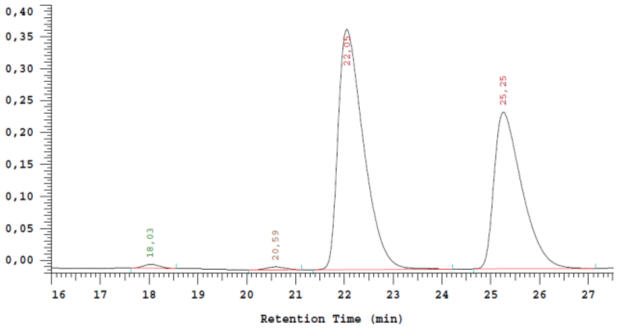
RT	Area	Conc 1
17,84	7374154	63,904
20,53	3674658	31,844
22,32	242463	2,101
25,52	248220	2,151
	11539495	100,000

Major diastereoisomer with **1a**: 94.0% ee
(3*R*,4*R*)-**6**



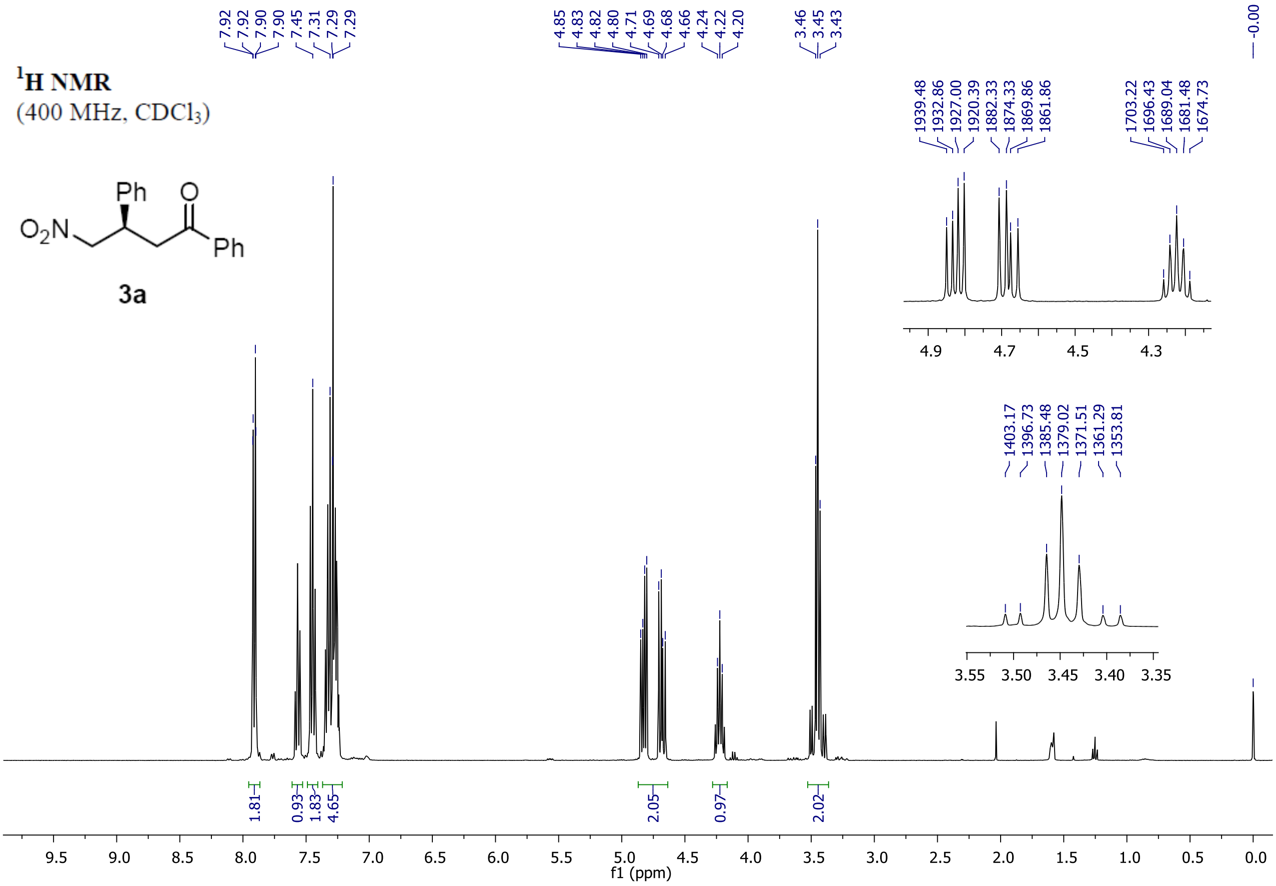
RT	Area	Conc 1
17,71	3823096	97,012
25,01	117754	2,988
	3940850	100,000

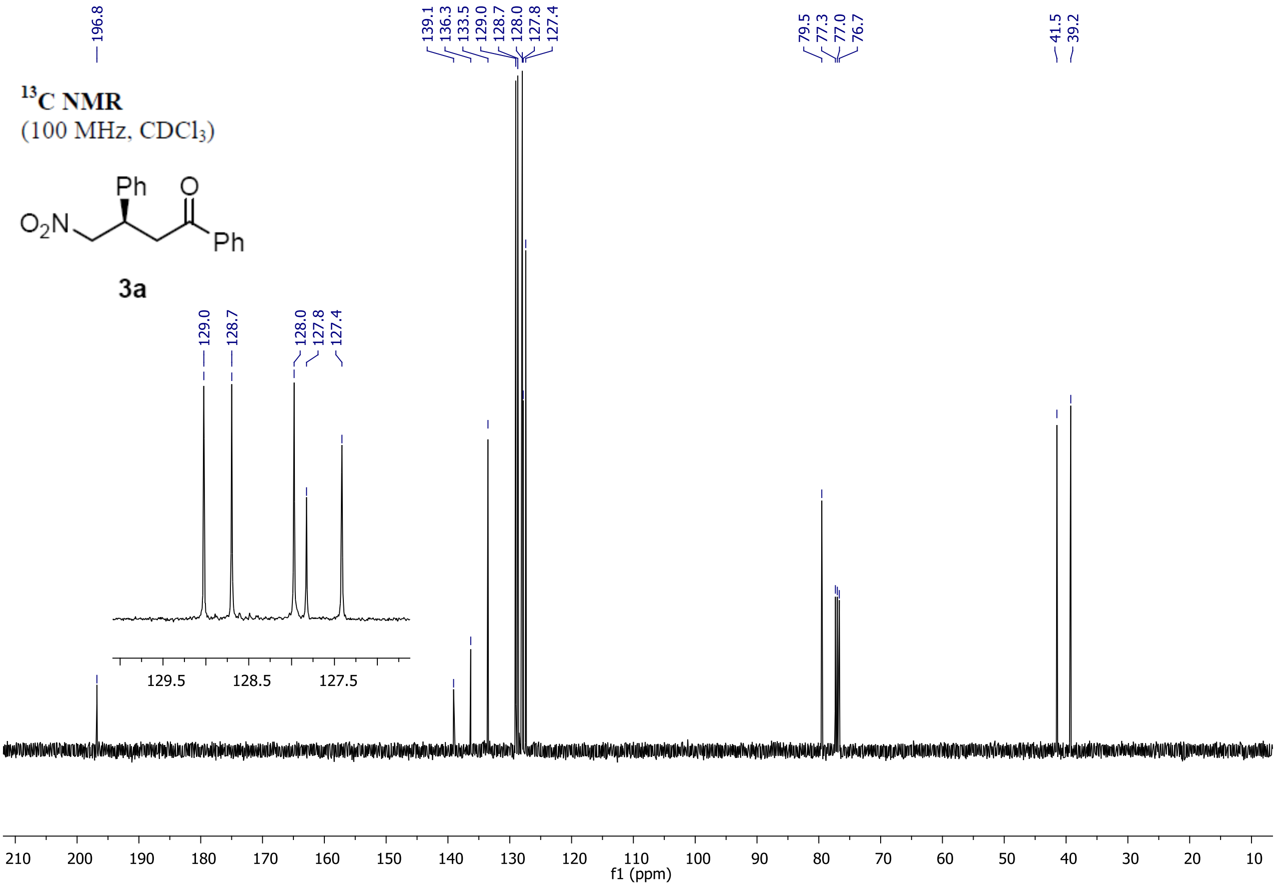
with **1d** 98.2% and 97.1%
(3*S*,4*R*)-**6** (3*S*,4*S*)-**6**

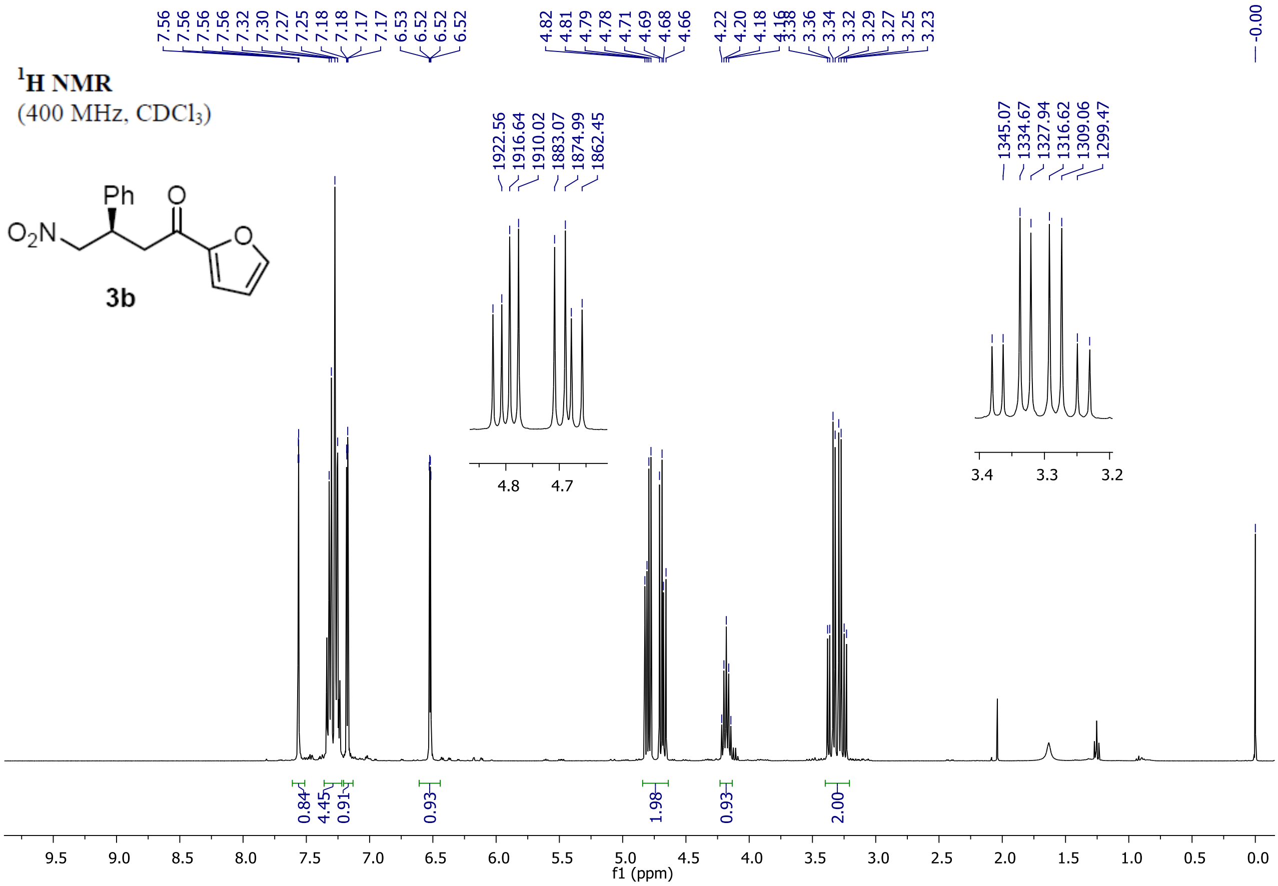


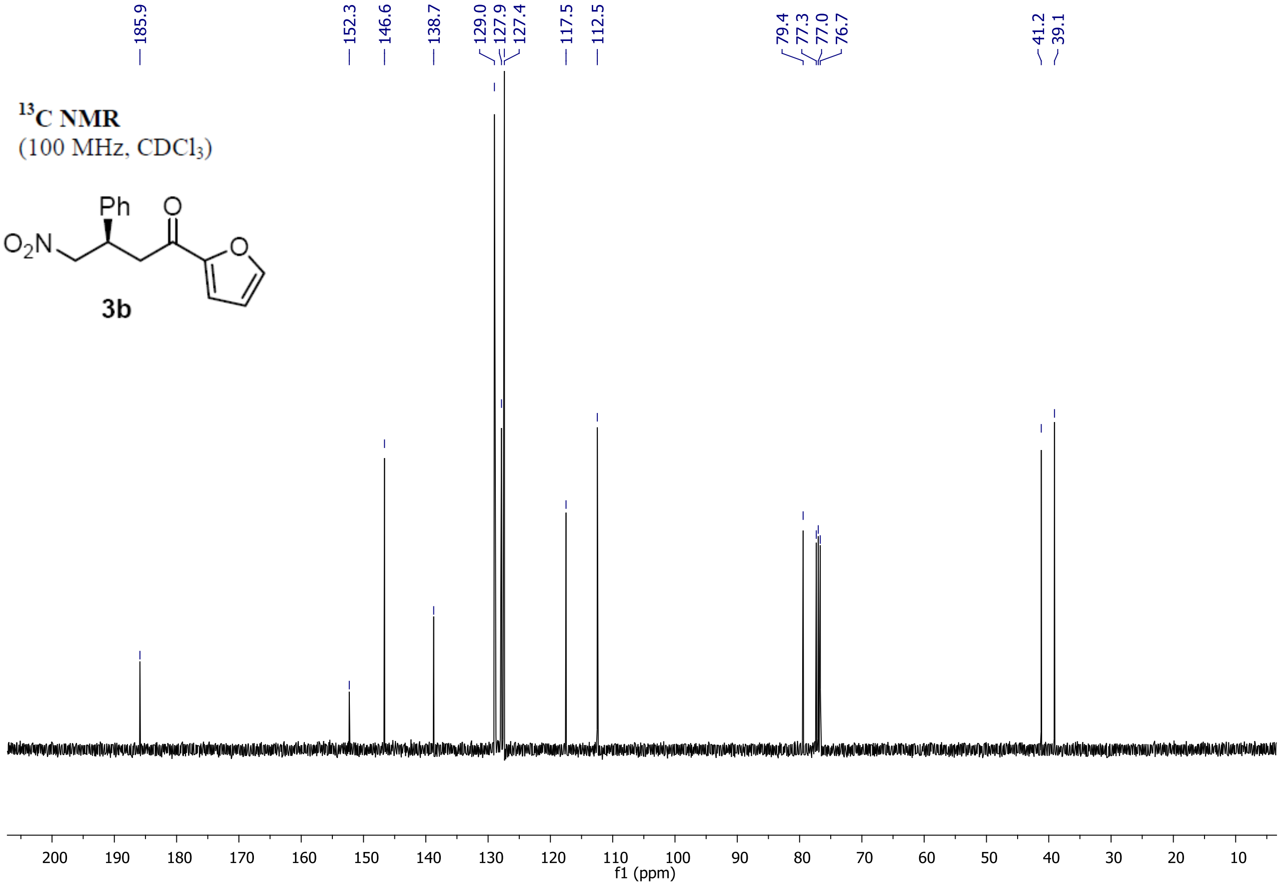
RT	Area	Conc 1
18,03	70710	0,599
20,59	60536	0,513
22,05	6797862	57,554
25,25	4882155	41,335
	11811263	100,000

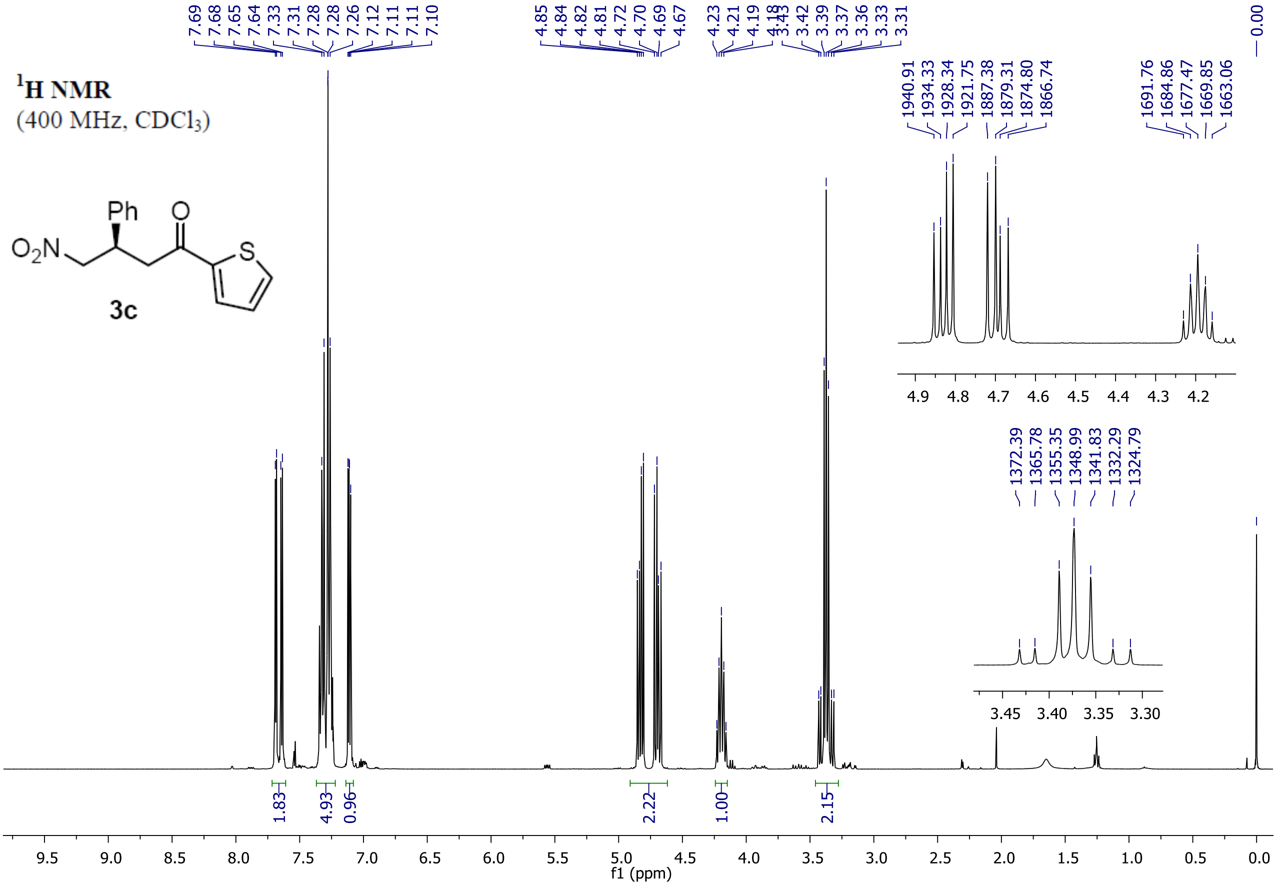
Copies of NMR spectra





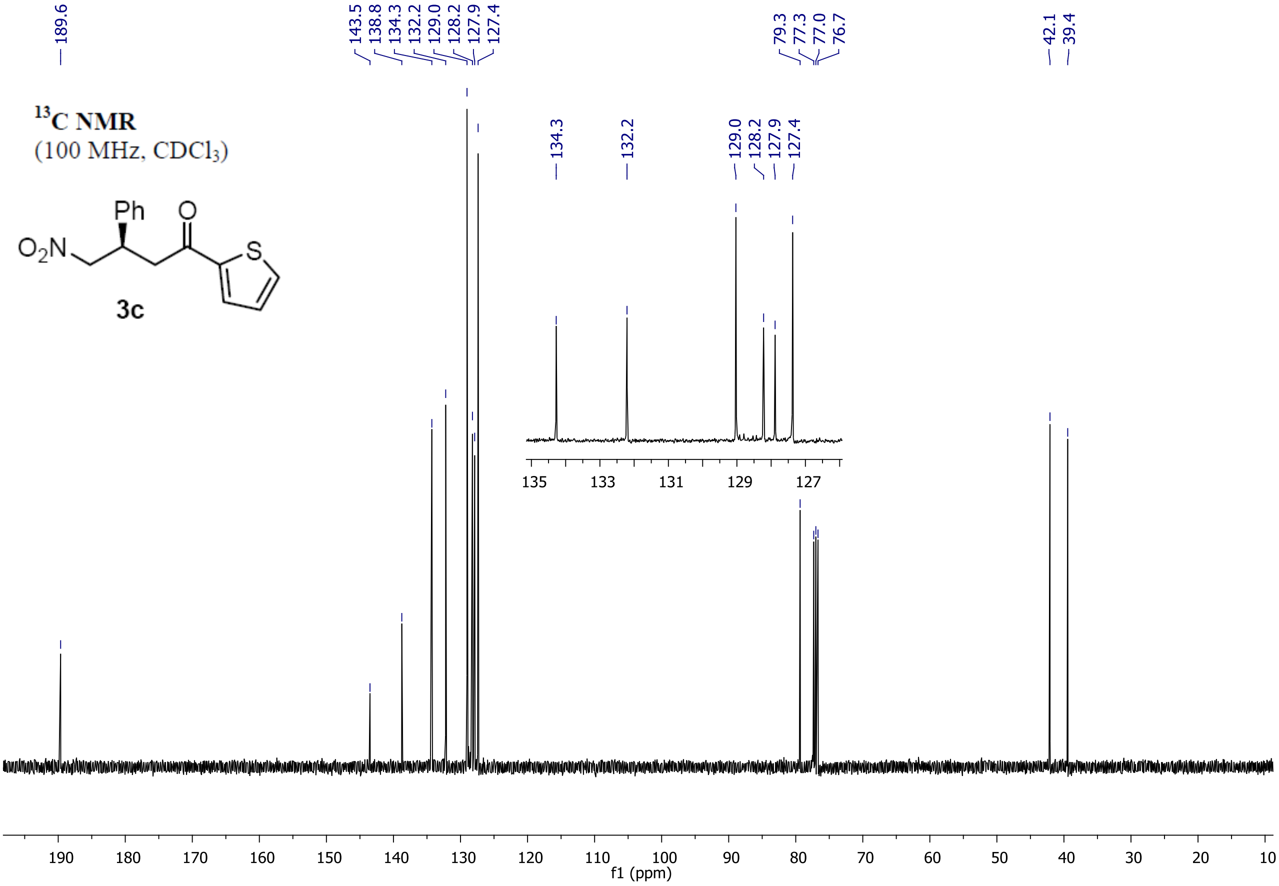

^{1}H NMR
(400 MHz, CDCl$_3$)
Ph
O
O_2N
O
3b
7.56
7.56
7.56
7.56
7.32
7.30
7.27
7.25
7.18
7.18
7.17
7.17
6.53
6.52
6.52
6.52
4.82
4.81
4.79
4.78
4.71
4.69
4.68
4.66
4.22
4.20
4.18
4.16
3.38
3.36
3.34
3.32
3.29
3.27
3.25
3.23
-0.00
1922.56
1916.64
1910.02
1883.07
1874.99
1862.45
4.8
4.7
1345.07
1334.67
1327.94
1316.62
1309.06
1299.47
3.4
3.3
3.2
0.84
4.45
0.91
0.93
1.98
0.93
2.00
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)


^{13}C NMR
(100 MHz, CDCl$_3$)
Ph
O
O_2N
O
3b
185.9
152.3
146.6
138.7
129.0
127.9
127.4
117.5
112.5
79.4
77.3
77.0
76.7
41.2
39.1
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)



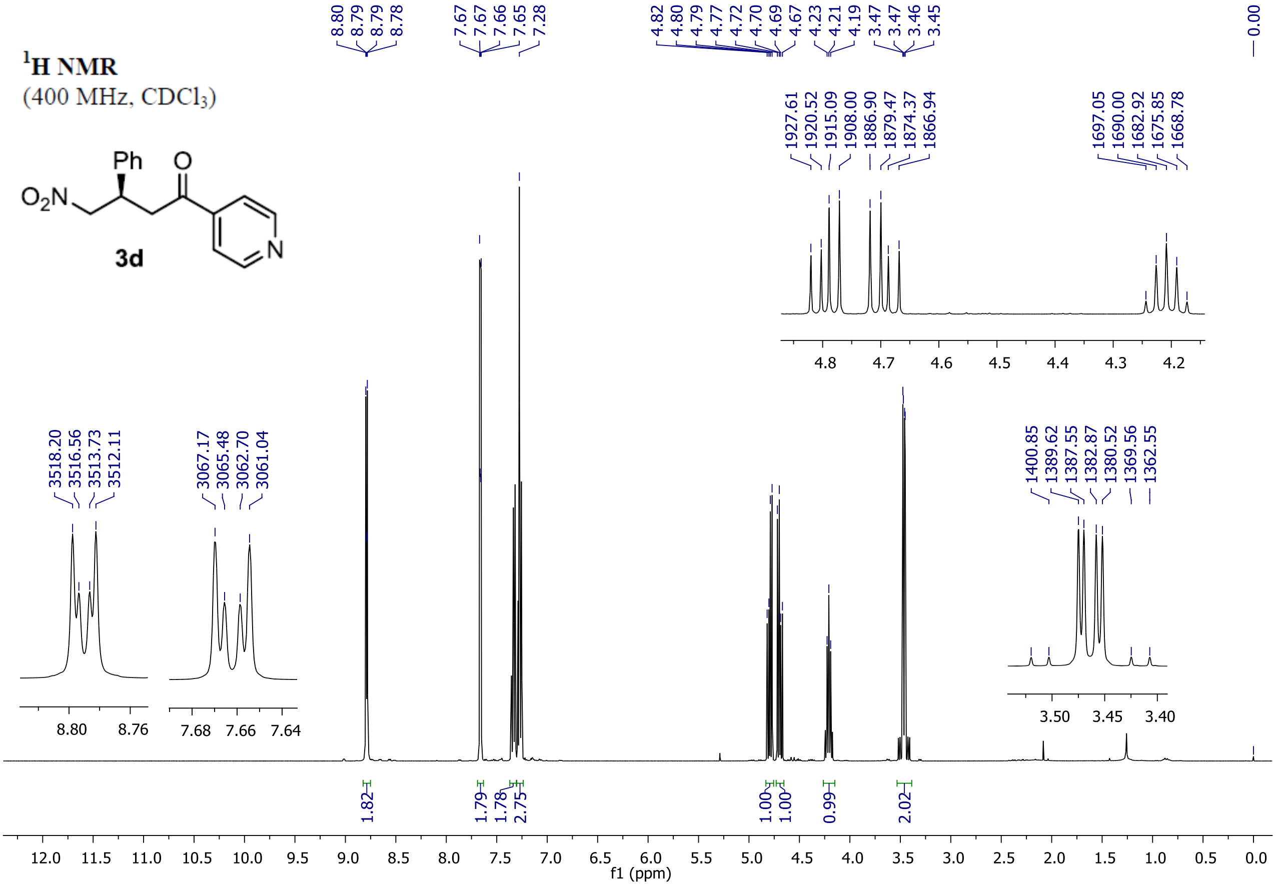
^{1}H NMR
(400 MHz, $CDCl_3$)

3c



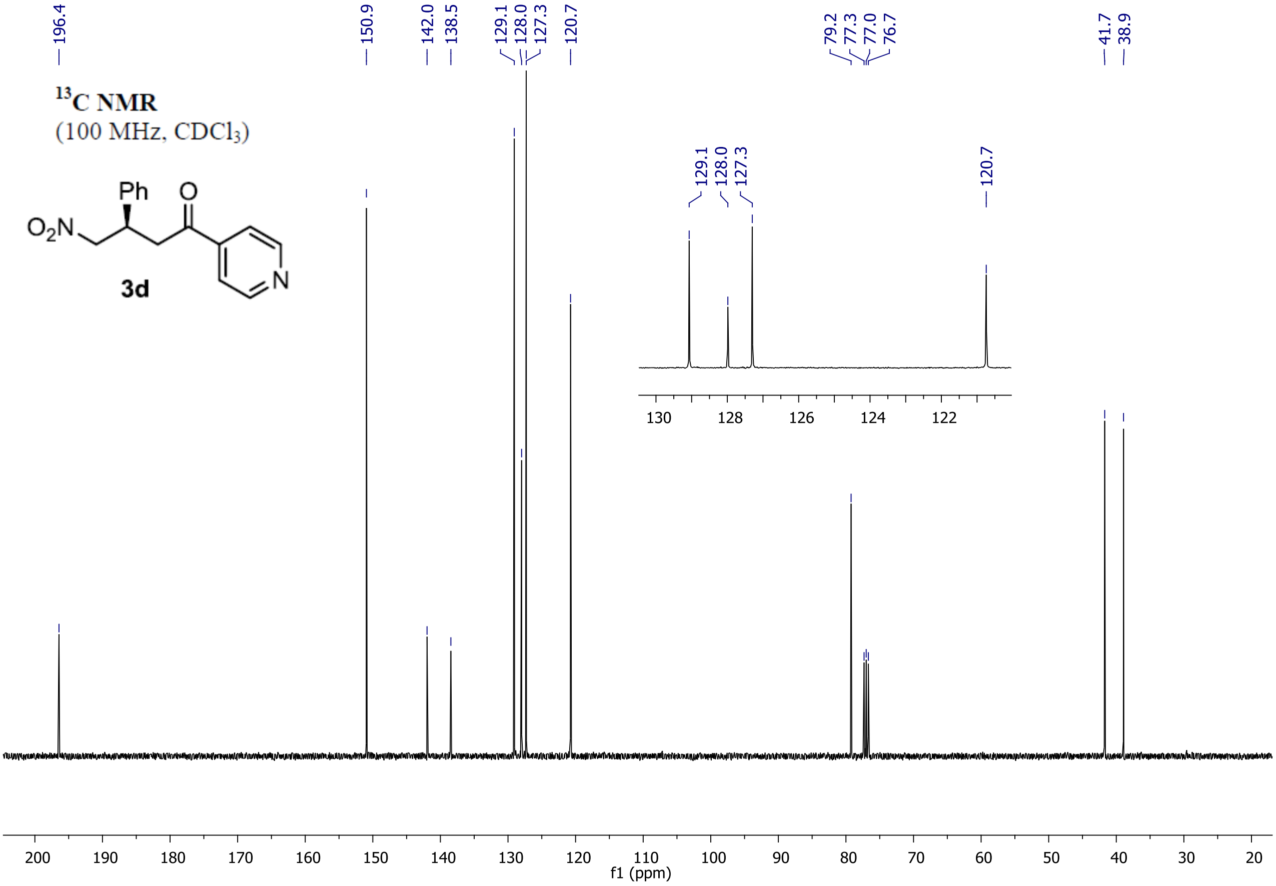
^{13}C NMR
(100 MHz, $CDCl_3$)

3c



^{1}H NMR
(400 MHz, CDCl$_3$)

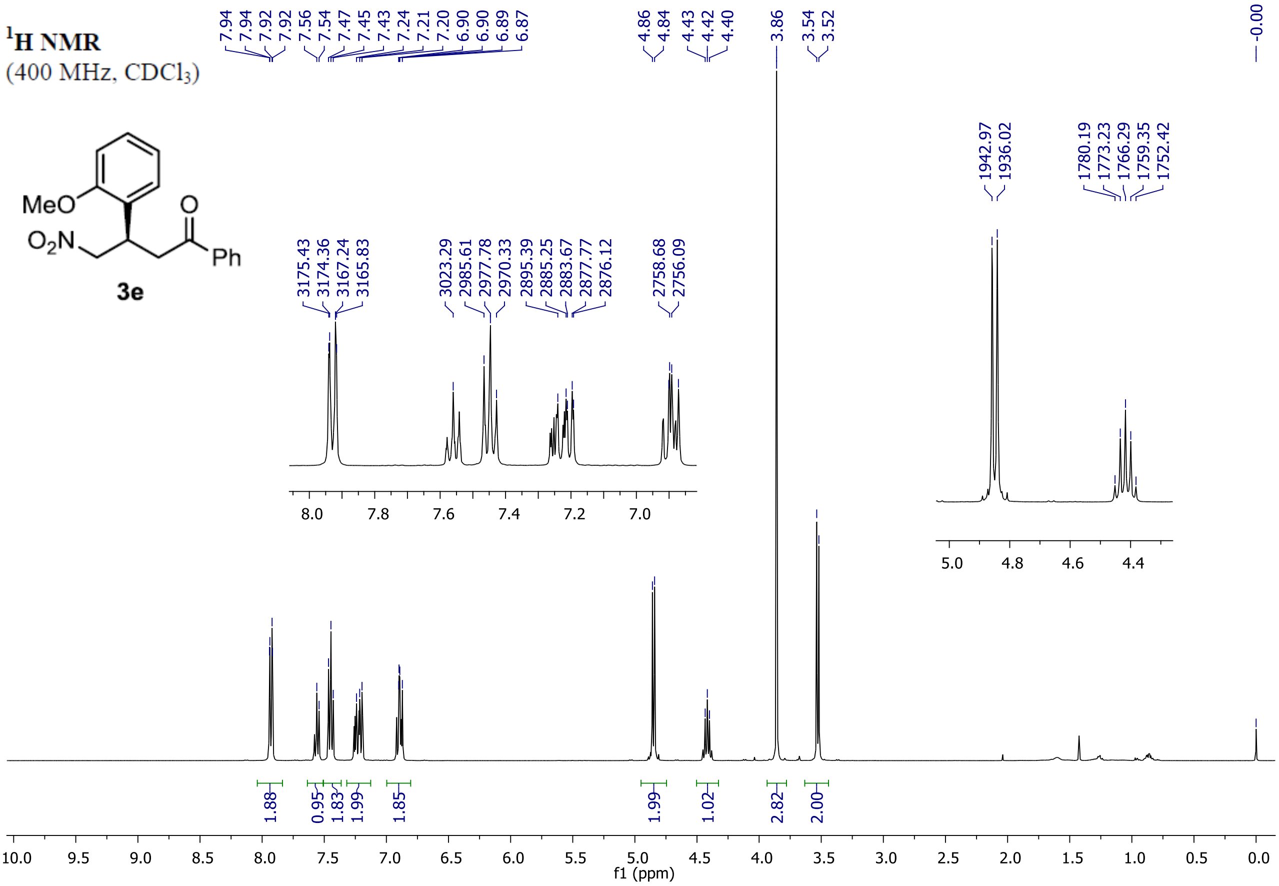
3d



^{13}C NMR
(100 MHz, CDCl$_3$)

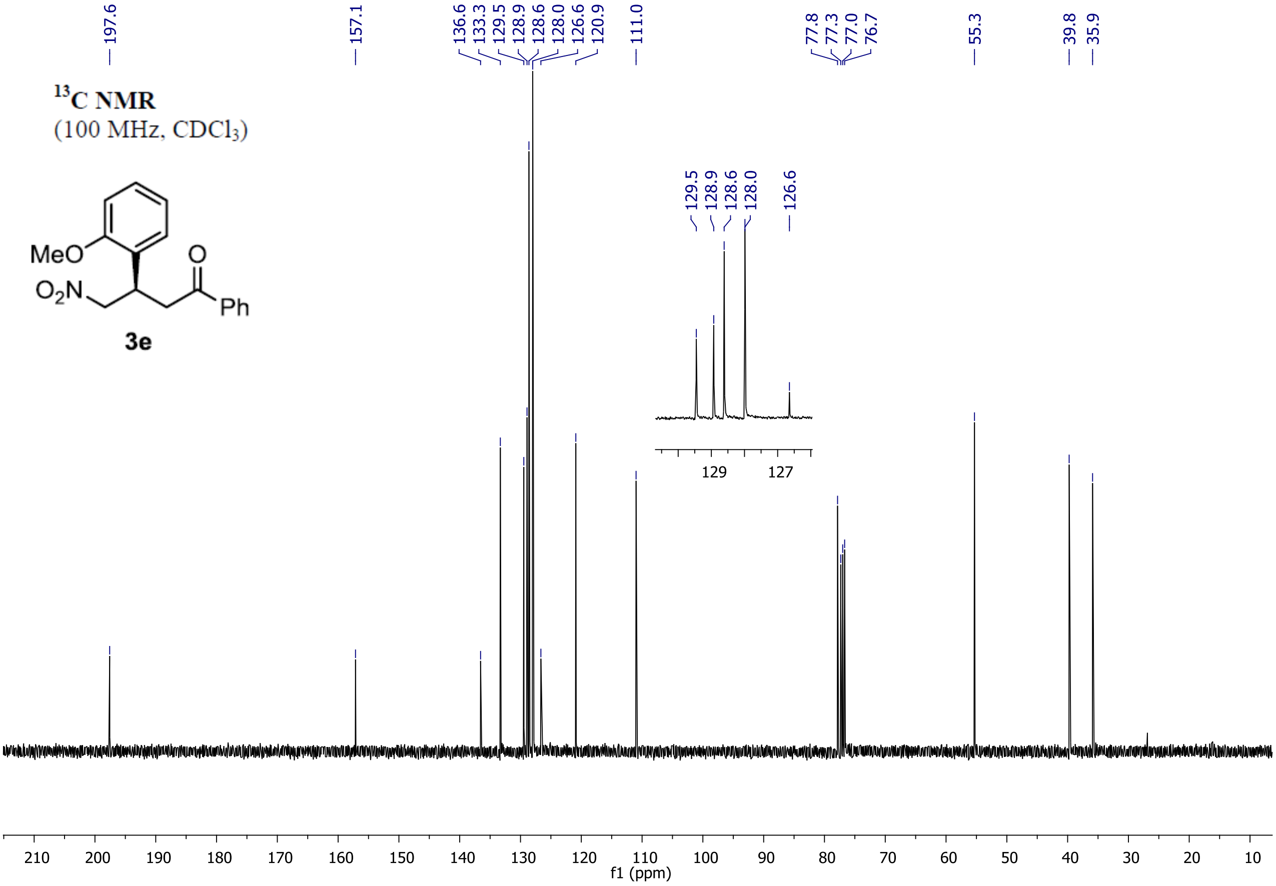
3d

^{1}H NMR
(400 MHz, $CDCl_3$)

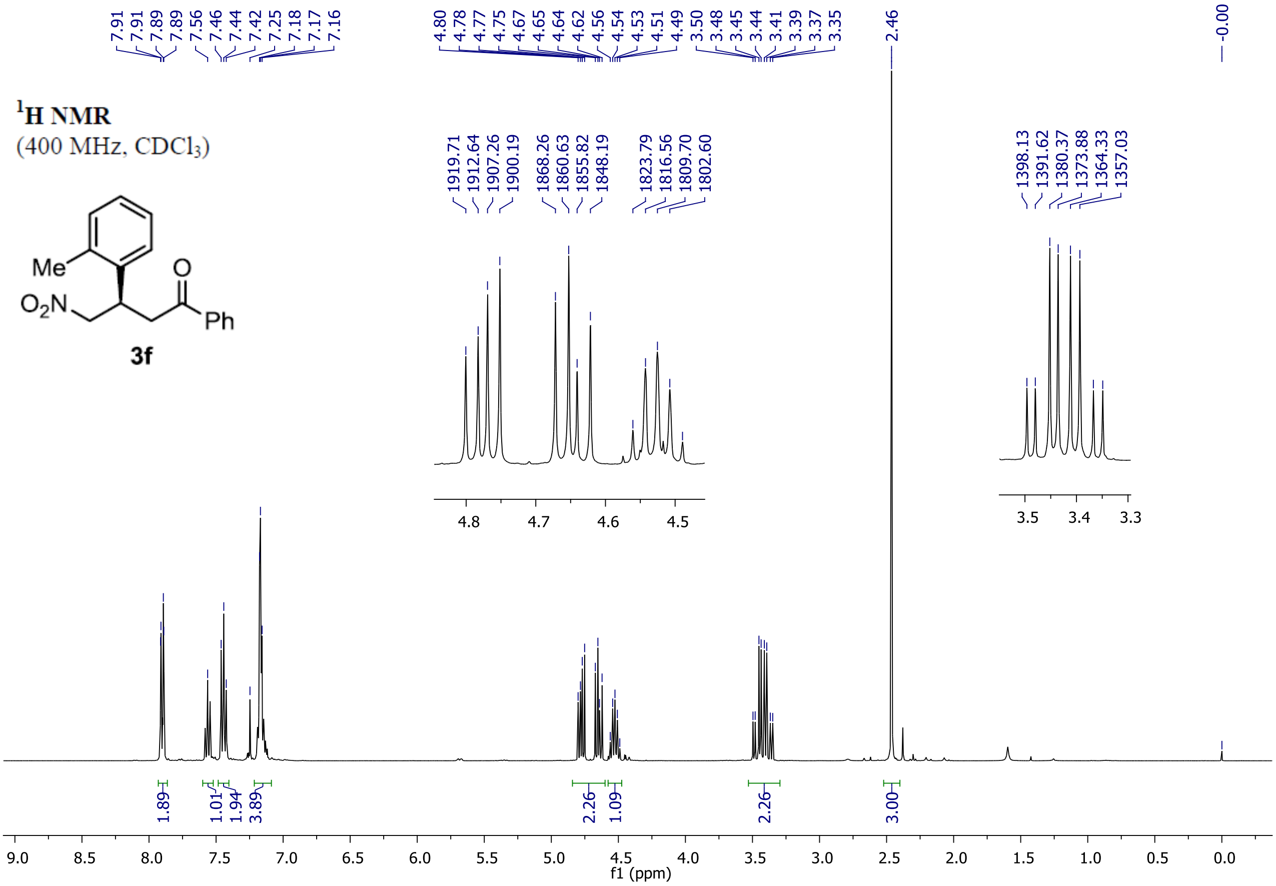


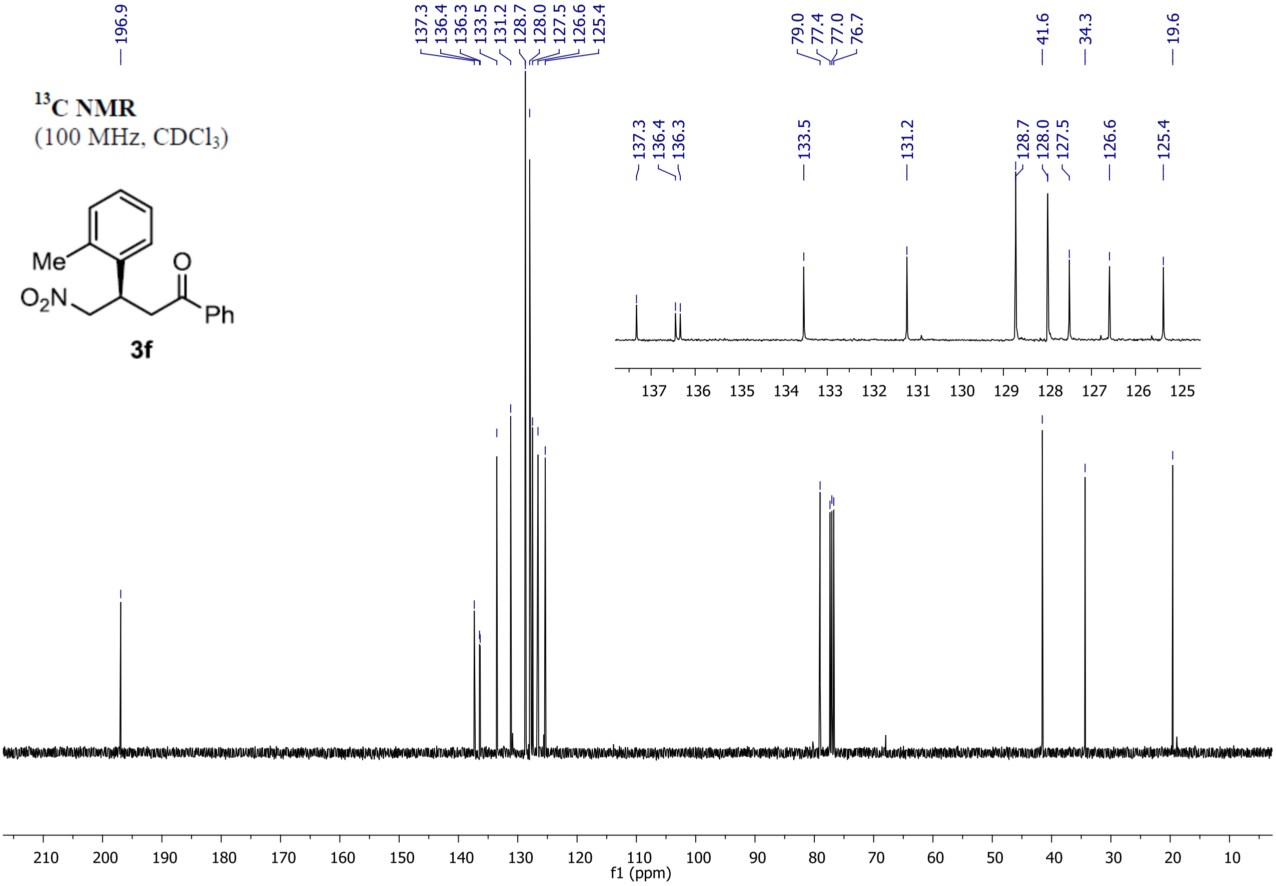
3e

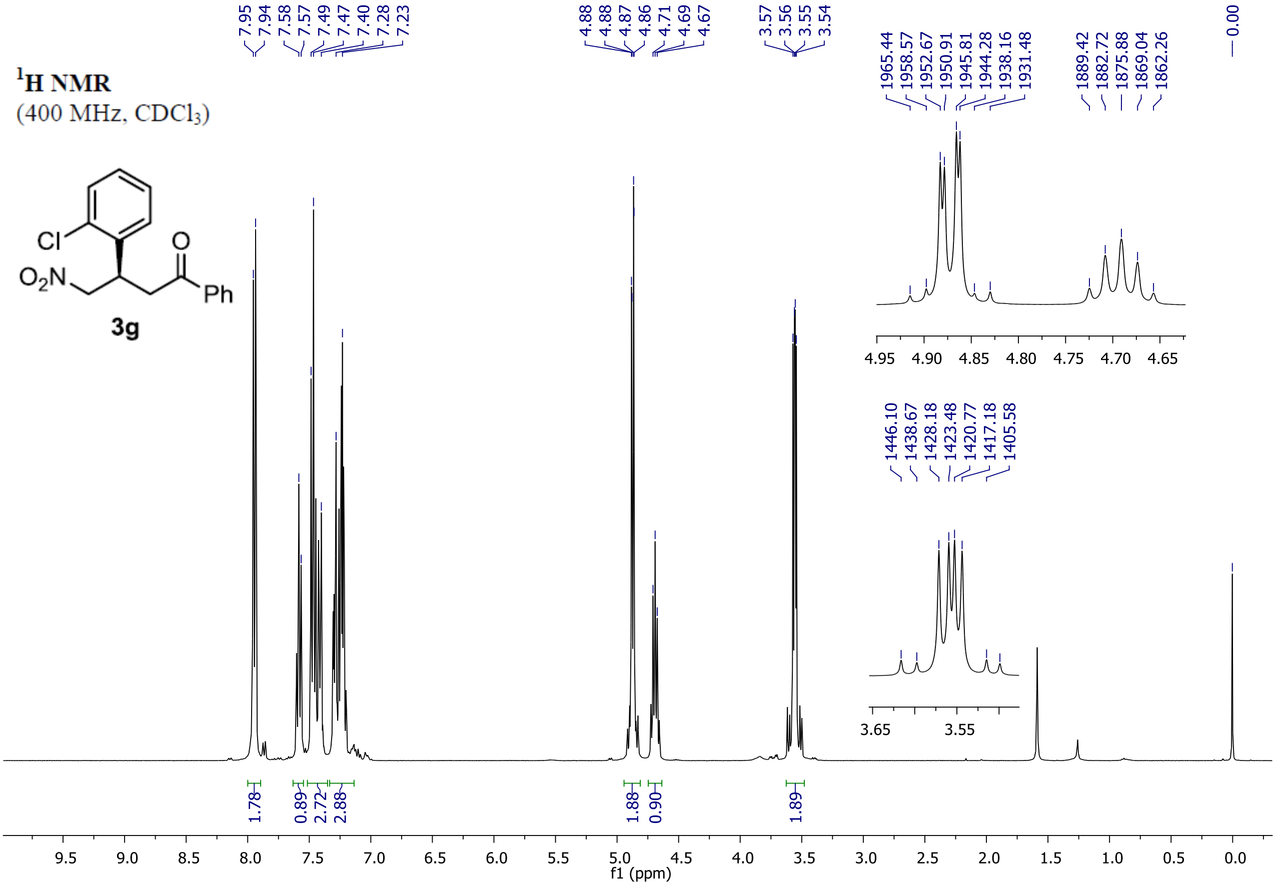
^{13}C NMR
(100 MHz, $CDCl_3$)



3e

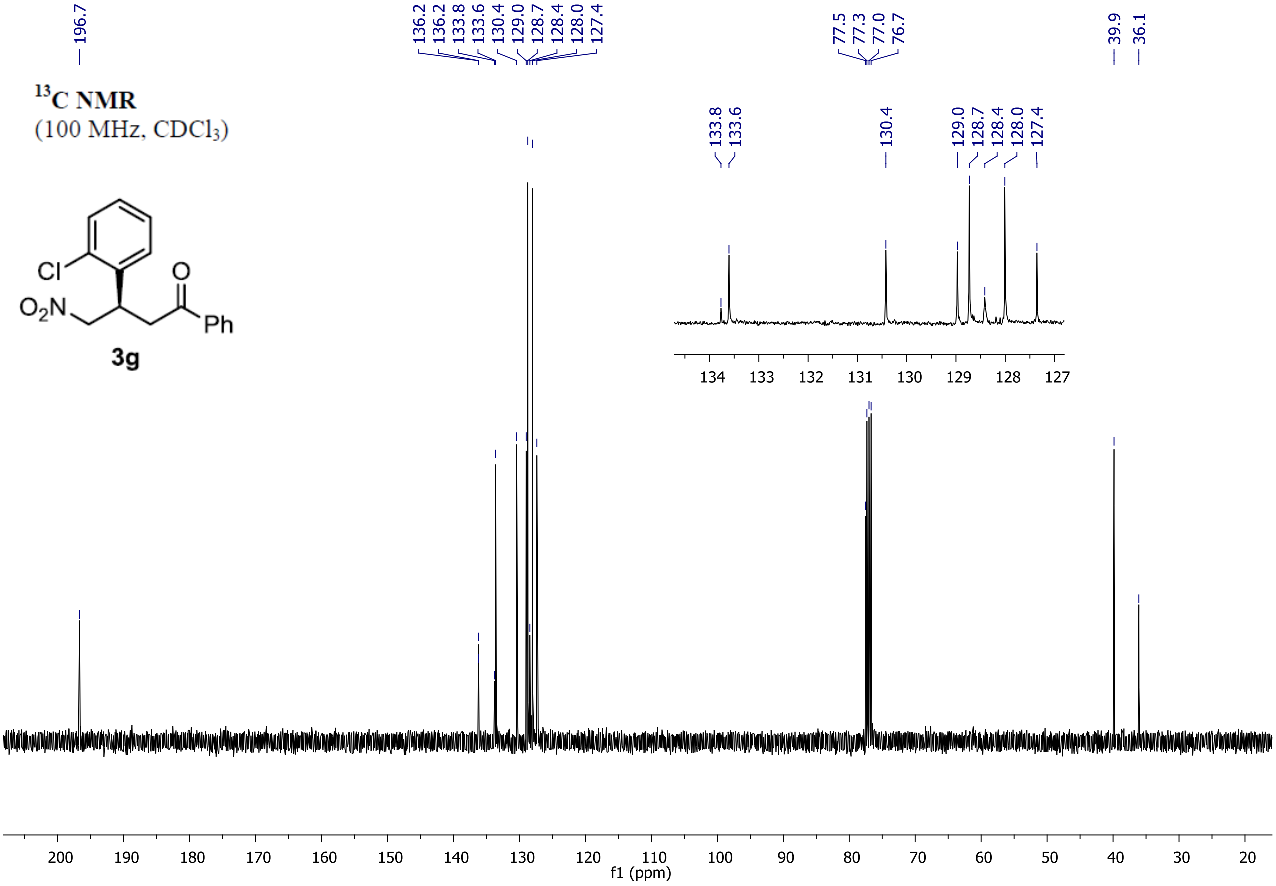

7.91
7.91
7.89
7.89
7.56
7.46
7.44
7.42
7.25
7.18
7.17
7.16
4.80
4.78
4.77
4.75
4.67
4.65
4.64
4.62
4.56
4.54
4.53
4.51
4.49
3.50
3.48
3.45
3.44
3.41
3.39
3.37
3.35
2.46
-0.00
^{1}H NMR
(400 MHz, $CDCl_3$)
Me
O_2N
O
Ph
3f
1919.71
1912.64
1907.26
1900.19
1868.26
1860.63
1855.82
1848.19
1823.79
1816.56
1809.70
1802.60
4.8
4.7
4.6
4.5
1398.13
1391.62
1380.37
1373.88
1364.33
1357.03
3.5
3.4
3.3
1.89
1.01
1.94
3.89
2.26
1.09
2.26
3.00
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)


196.9
137.3
136.4
136.3
133.5
131.2
128.7
128.0
127.5
126.6
125.4
79.0
77.4
77.0
76.7
41.6
34.3
19.6
^{13}C NMR
(100 MHz, $CDCl_3$)
Me
O_2N
O
Ph
3f
137.3
136.4
136.3
133.5
131.2
128.7
128.0
127.5
126.6
125.4
137
136
135
134
133
132
131
130
129
128
127
126
125
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)



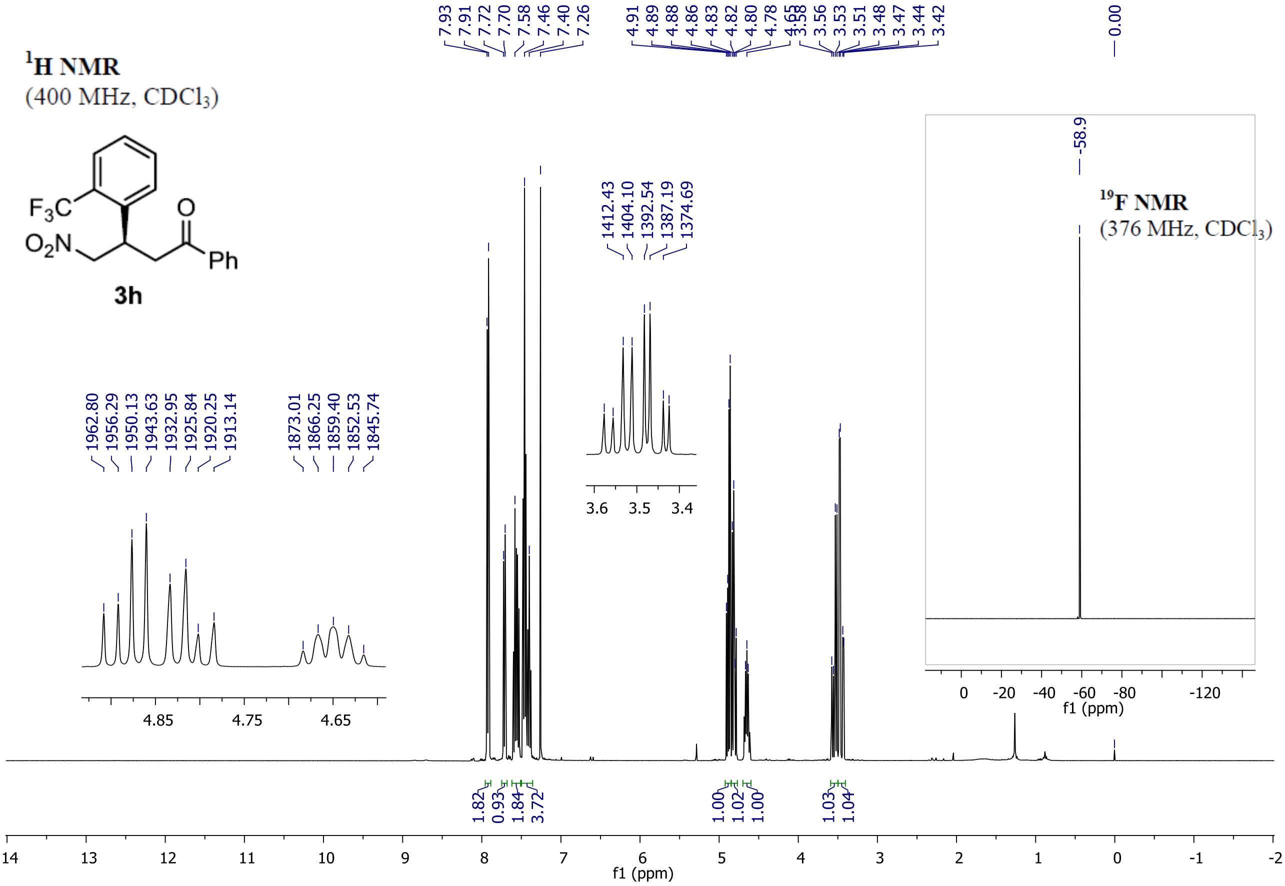
^{1}H NMR
(400 MHz, $CDCl_3$)

3g

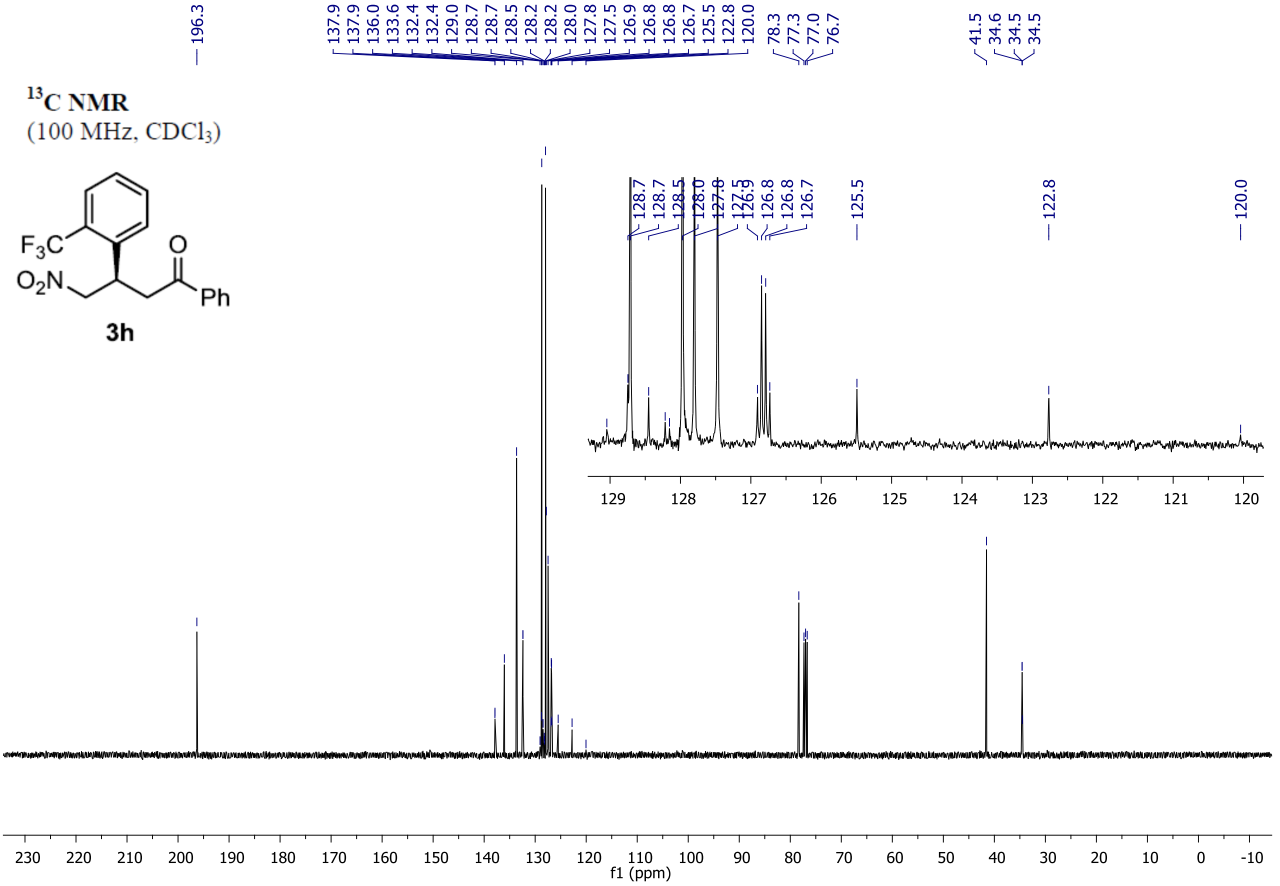


^{13}C NMR
(100 MHz, $CDCl_3$)

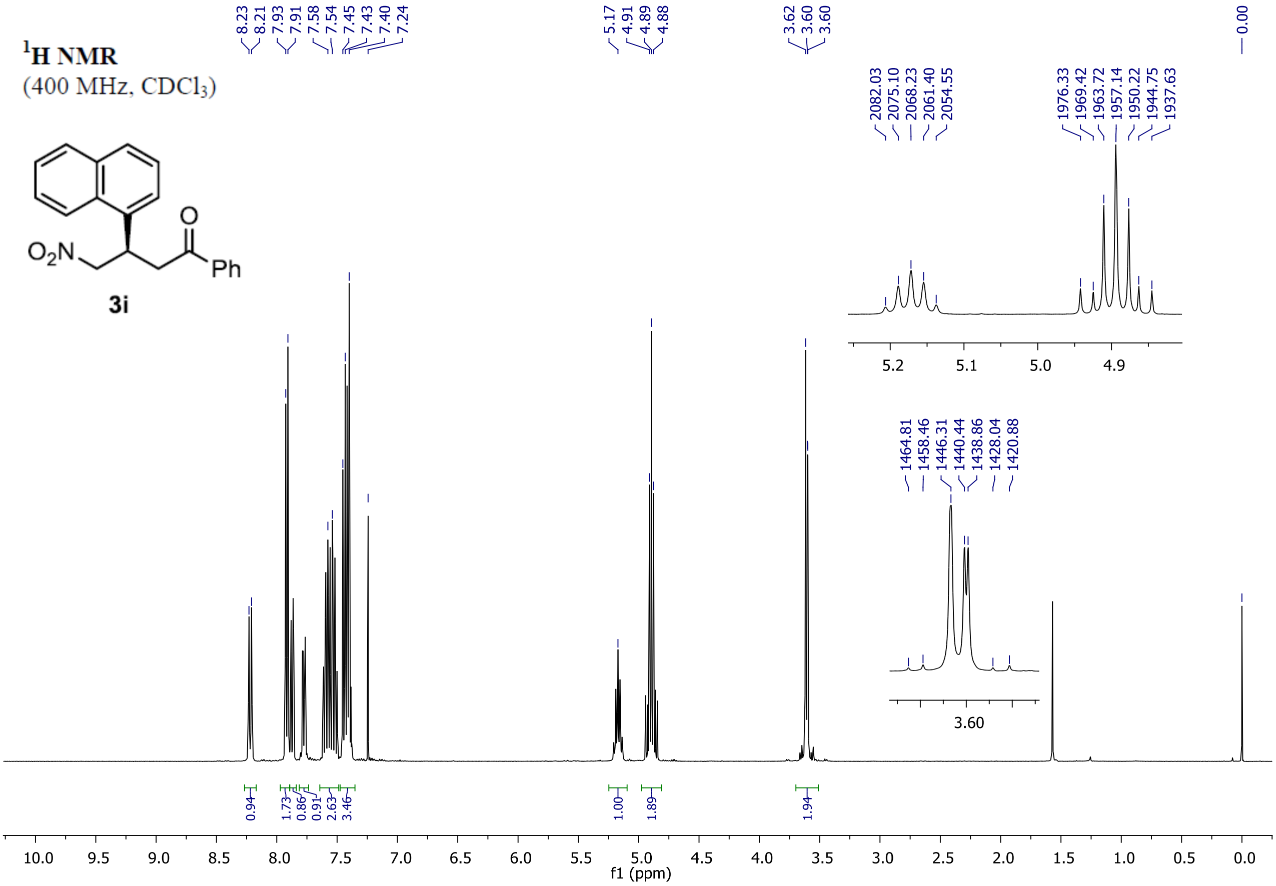
3g



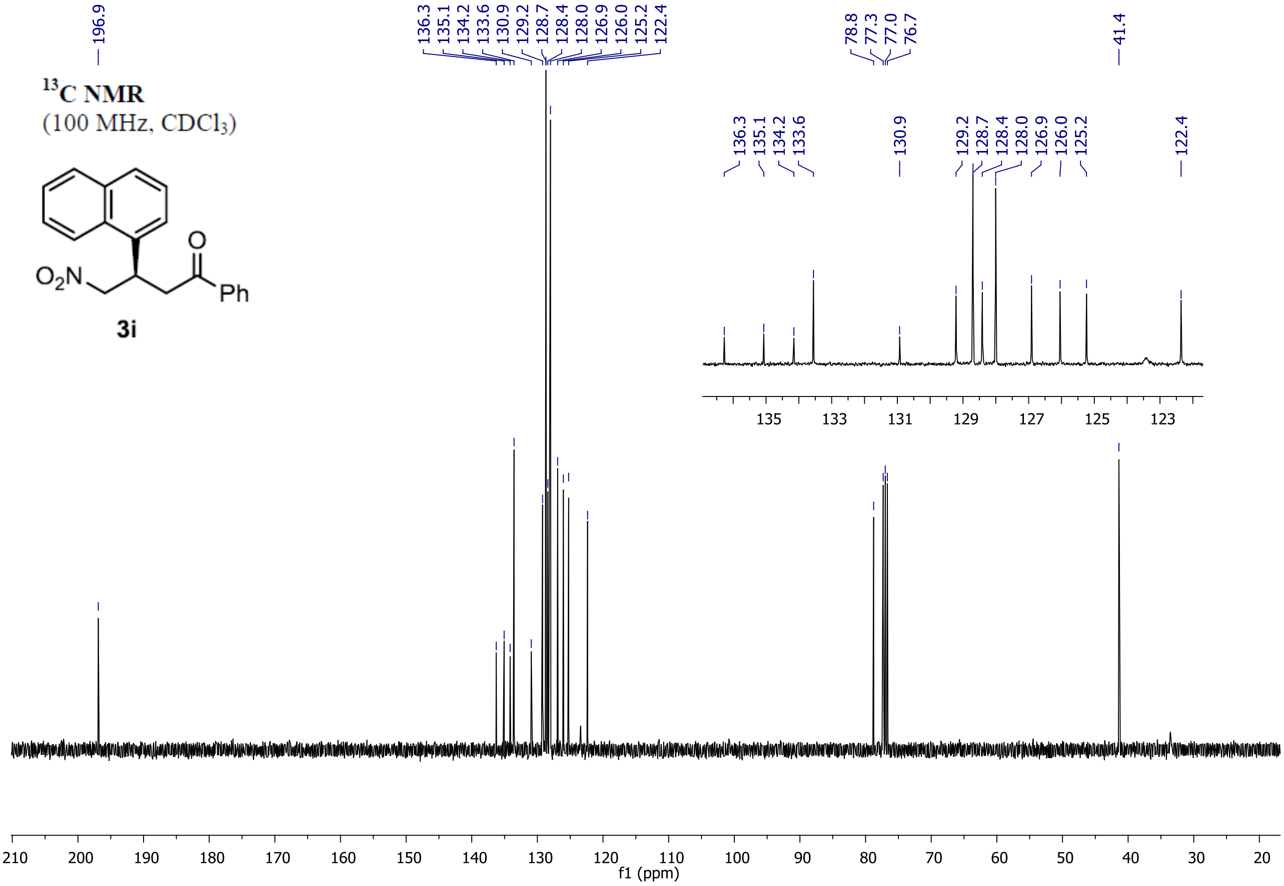
^{1}H NMR
(400 MHz, CDCl$_3$)
F$_3$C
O$_2$N
O
Ph
3h
7.93 7.91 7.72 7.70 7.58 7.46 7.40 7.26
4.91 4.89 4.88 4.86 4.83 4.82 4.80 4.78 4.65 3.58 3.56 3.53 3.51 3.48 3.47 3.44 3.42
0.00
1962.80 1956.29 1950.13 1943.63 1932.95 1925.84 1920.25 1913.14
1873.01 1866.25 1859.40 1852.53 1845.74
4.85 4.75 4.65
1412.43 1404.10 1392.54 1387.19 1374.69
3.6 3.5 3.4
-58.9
^{19}F NMR
(376 MHz, CDCl$_3$)
0 -20 -40 -60 -80 -120
f1 (ppm)
1.82 0.93 1.84 3.72
1.00 1.02 1.00
1.03 1.04
14 13 12 11 10 9 8 7 6 5 4 3 2 1 0 -1 -2
f1 (ppm)



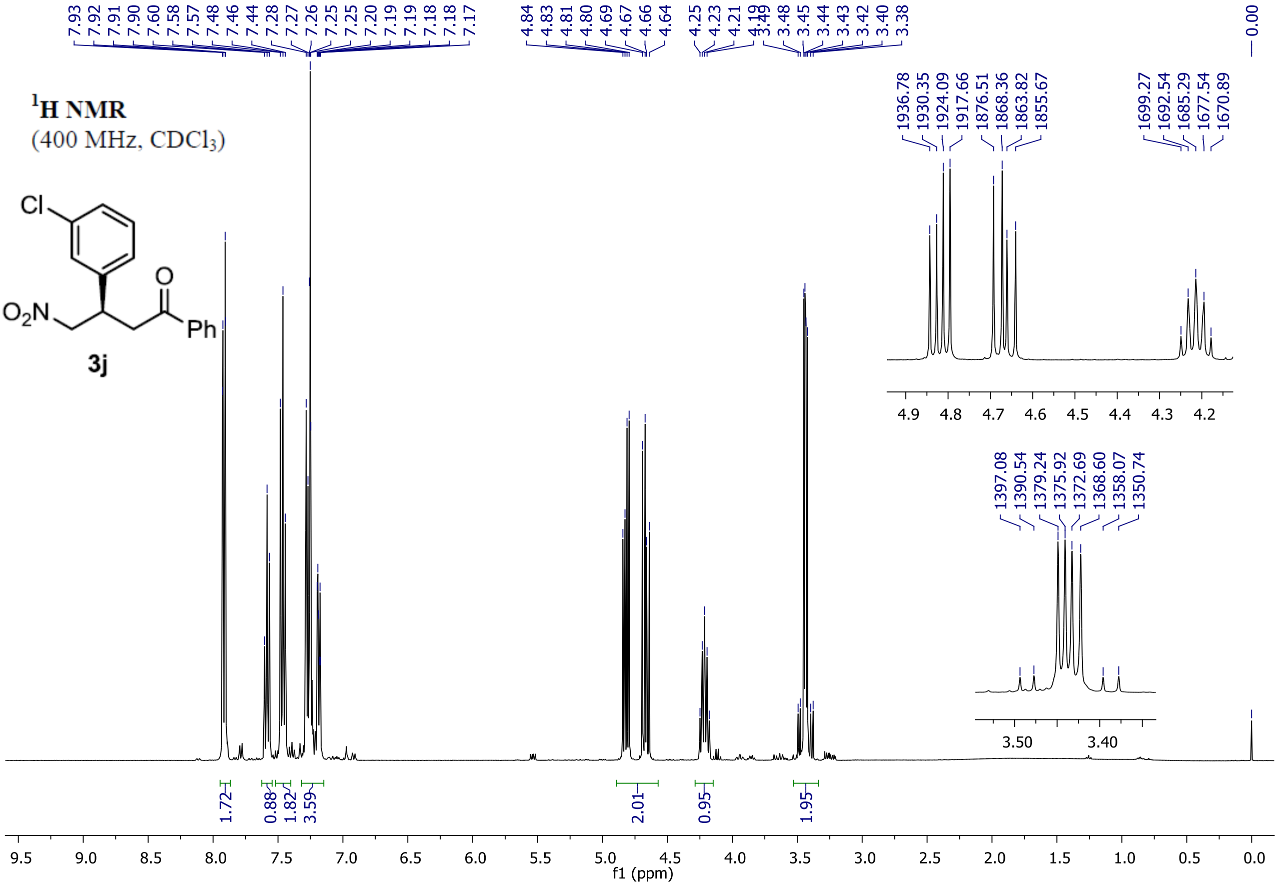
^{13}C NMR
(100 MHz, CDCl$_3$)
F$_3$C
O$_2$N
O
Ph
3h
196.3
137.9 137.9 136.0 133.6 132.4 132.4 129.0 128.7 128.7 128.5 128.2 128.2 128.0 127.8 127.5 126.9 126.8 126.8 126.7 125.5 122.8 120.0
78.3 77.3 77.0 76.7
41.5 34.6 34.5 34.5
128.7 128.7 128.5 128.0 127.8 127.5 126.9 126.8 126.8 126.7 125.5 122.8 120.0
129 128 127 126 125 124 123 122 121 120
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

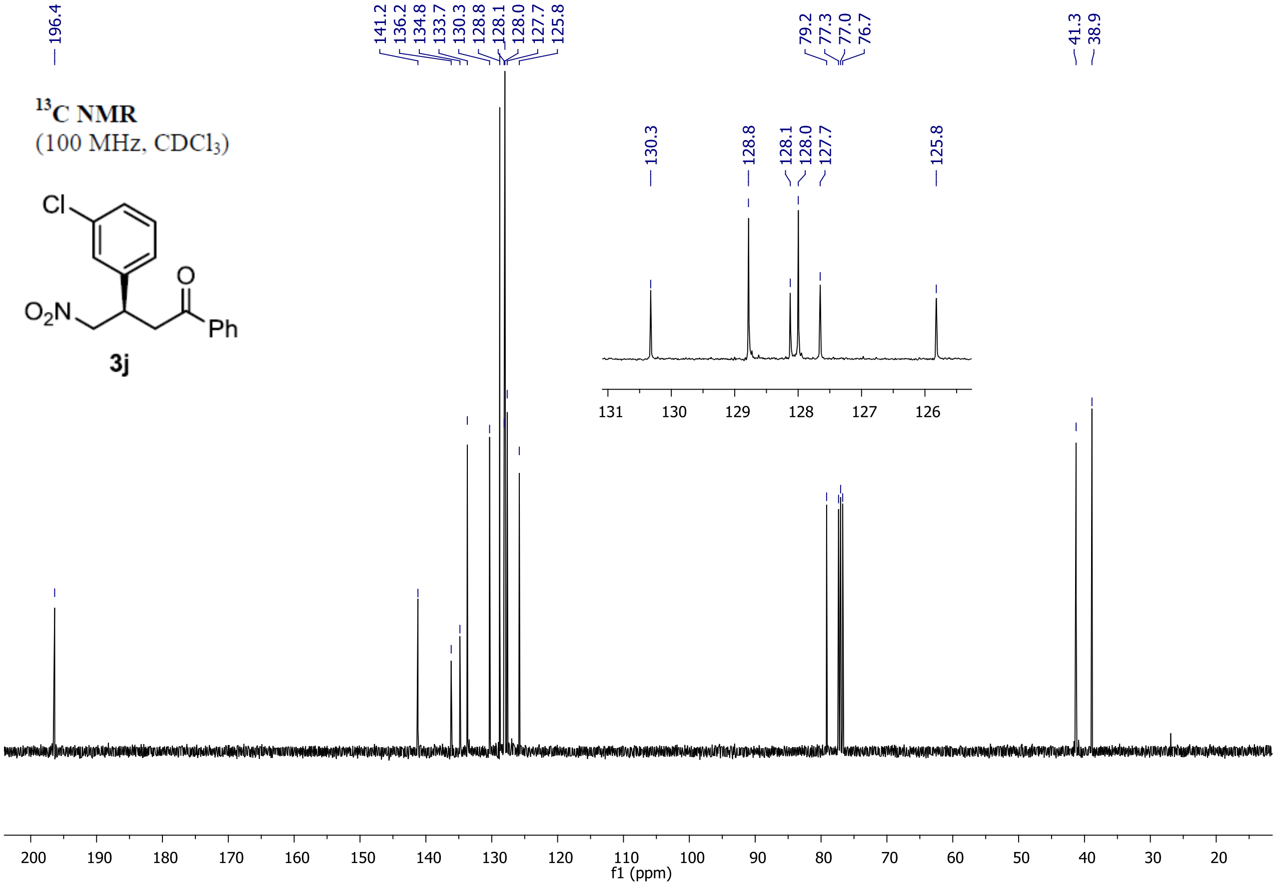


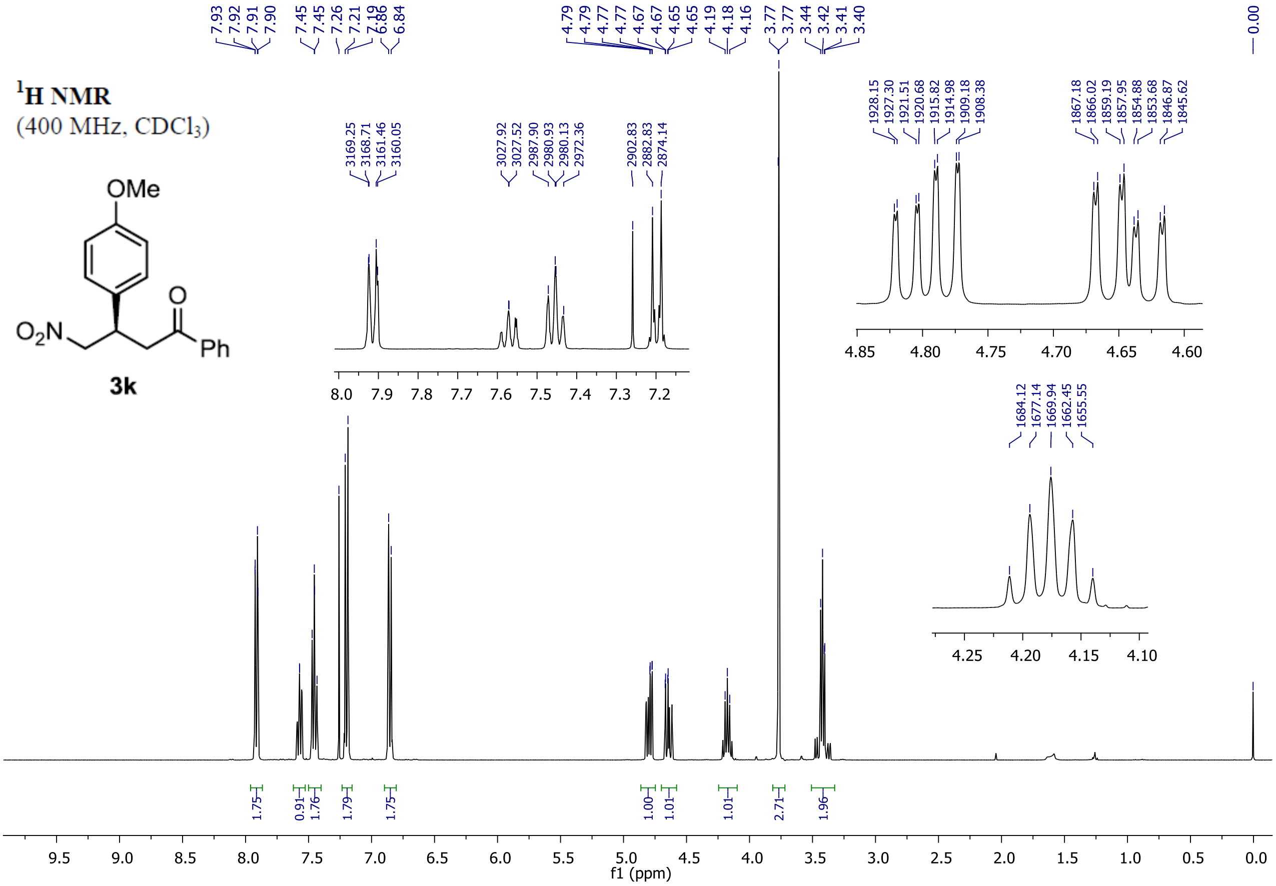
^{1}H NMR
(400 MHz, CDCl$_3$)
O$_2$N
O
Ph
3i
8.23
8.21
7.93
7.91
7.58
7.54
7.45
7.43
7.40
7.24
5.17
4.91
4.89
4.88
3.62
3.60
3.60
0.00
2082.03
2075.10
2068.23
2061.40
2054.55
1976.33
1969.42
1963.72
1957.14
1950.22
1944.75
1937.63
5.2
5.1
5.0
4.9
1464.81
1458.46
1446.31
1440.44
1438.86
1428.04
1420.88
3.60
0.94
1.73
0.86
0.91
2.63
3.46
1.00
1.89
1.94
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)



^{13}C NMR
(100 MHz, CDCl$_3$)
O$_2$N
O
Ph
3i
196.9
136.3
135.1
134.2
133.6
130.9
129.2
128.7
128.4
128.0
126.9
126.0
125.2
122.4
78.8
77.3
77.0
76.7
41.4
135
133
131
129
127
125
123
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
f1 (ppm)


^{1}H NMR
(400 MHz, CDCl$_3$)
Cl
O
O_2N
Ph
3j
7.93 7.92 7.91 7.90 7.60 7.58 7.57 7.48 7.46 7.44 7.28 7.27 7.26 7.25 7.25 7.20 7.19 7.19 7.18 7.18 7.17
4.84 4.83 4.81 4.80 4.69 4.67 4.66 4.64
4.25 4.23 4.21 4.19 3.49 3.48 3.45 3.44 3.43 3.42 3.40 3.38
0.00
1936.78 1930.35 1924.09 1917.66 1876.51 1868.36 1863.82 1855.67
1699.27 1692.54 1685.29 1677.54 1670.89
4.9 4.8 4.7 4.6 4.5 4.4 4.3 4.2
1397.08 1390.54 1379.24 1375.92 1372.69 1368.60 1358.07 1350.74
3.50 3.40
1.72 0.88 1.82 3.59 2.01 0.95 1.95
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

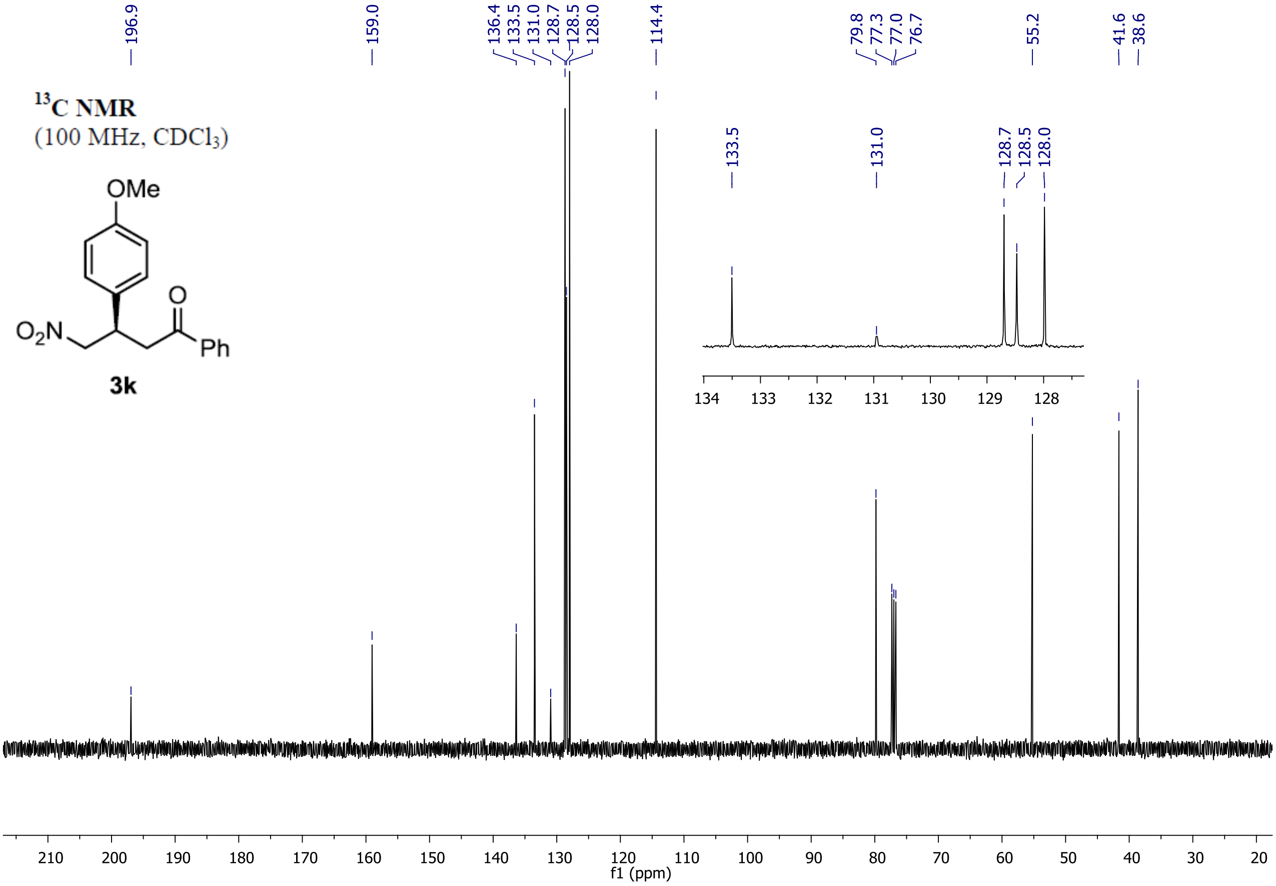

196.4
141.2 136.2 134.8 133.7 130.3 128.8 128.1 128.0 127.7 125.8
79.2 77.3 77.0 76.7
41.3 38.9
^{13}C NMR
(100 MHz, CDCl$_3$)
Cl
O
O_2N
Ph
3j
130.3 128.8 128.1 128.0 127.7 125.8
131 130 129 128 127 126
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20
f1 (ppm)



^{1}H NMR

(400 MHz, $CDCl_3$)

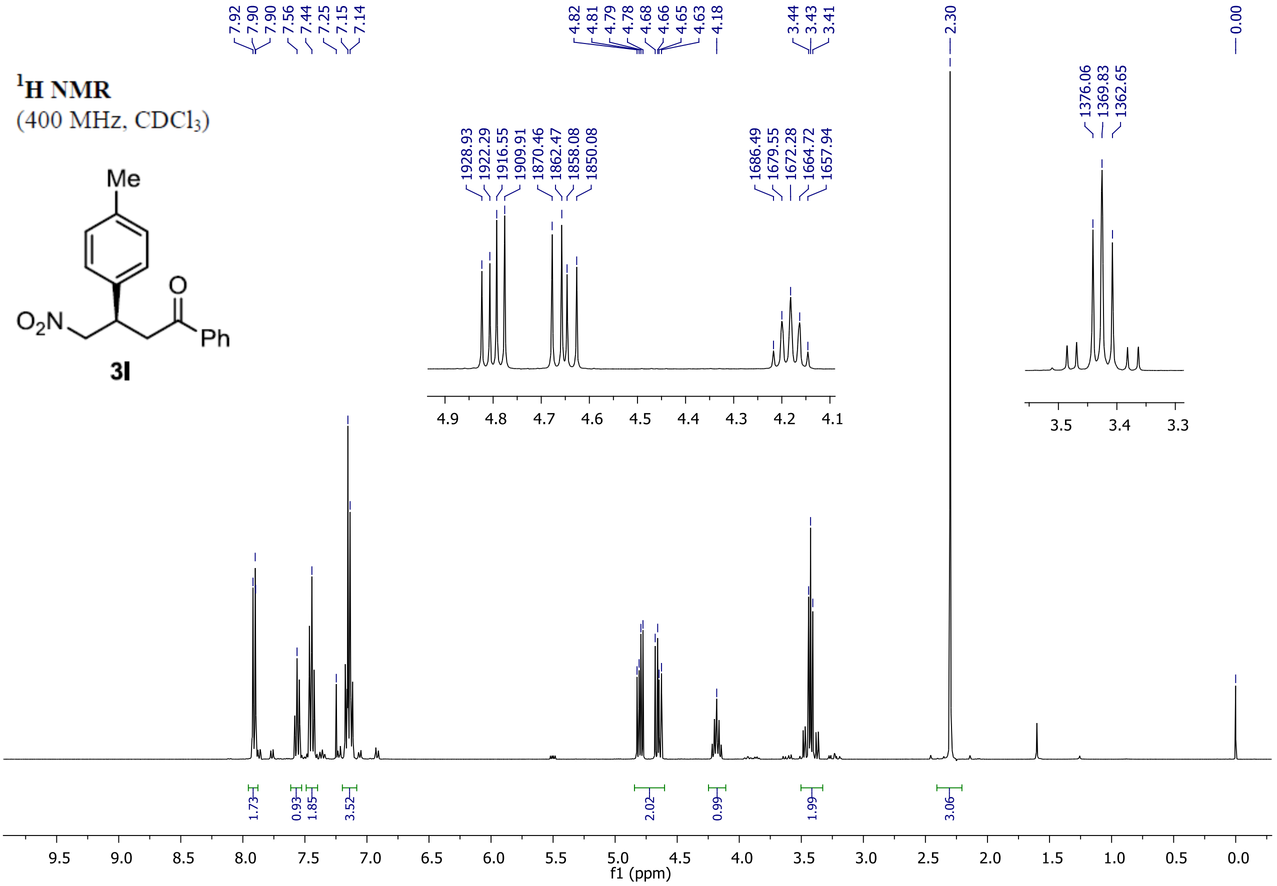
3k



^{13}C NMR

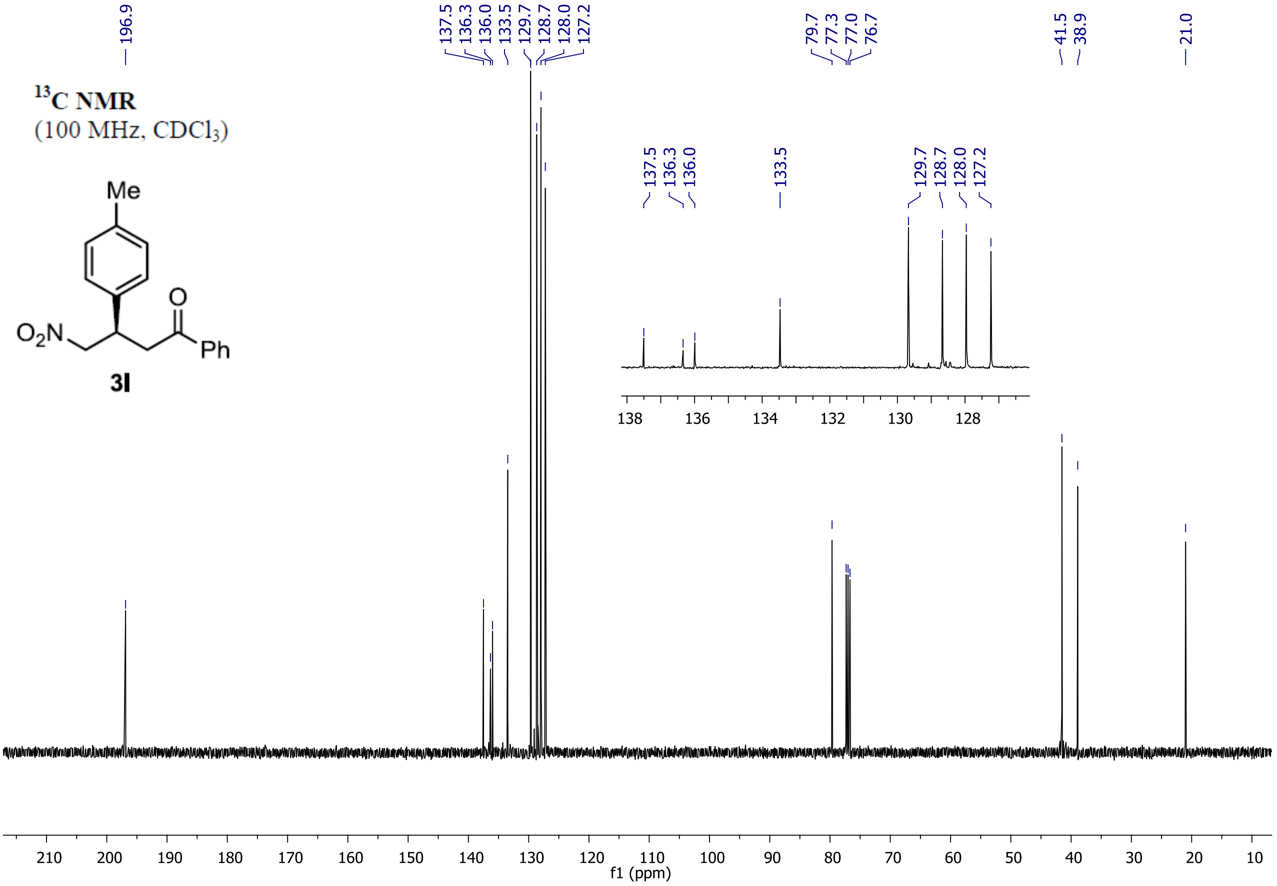
(100 MHz, $CDCl_3$)

3k



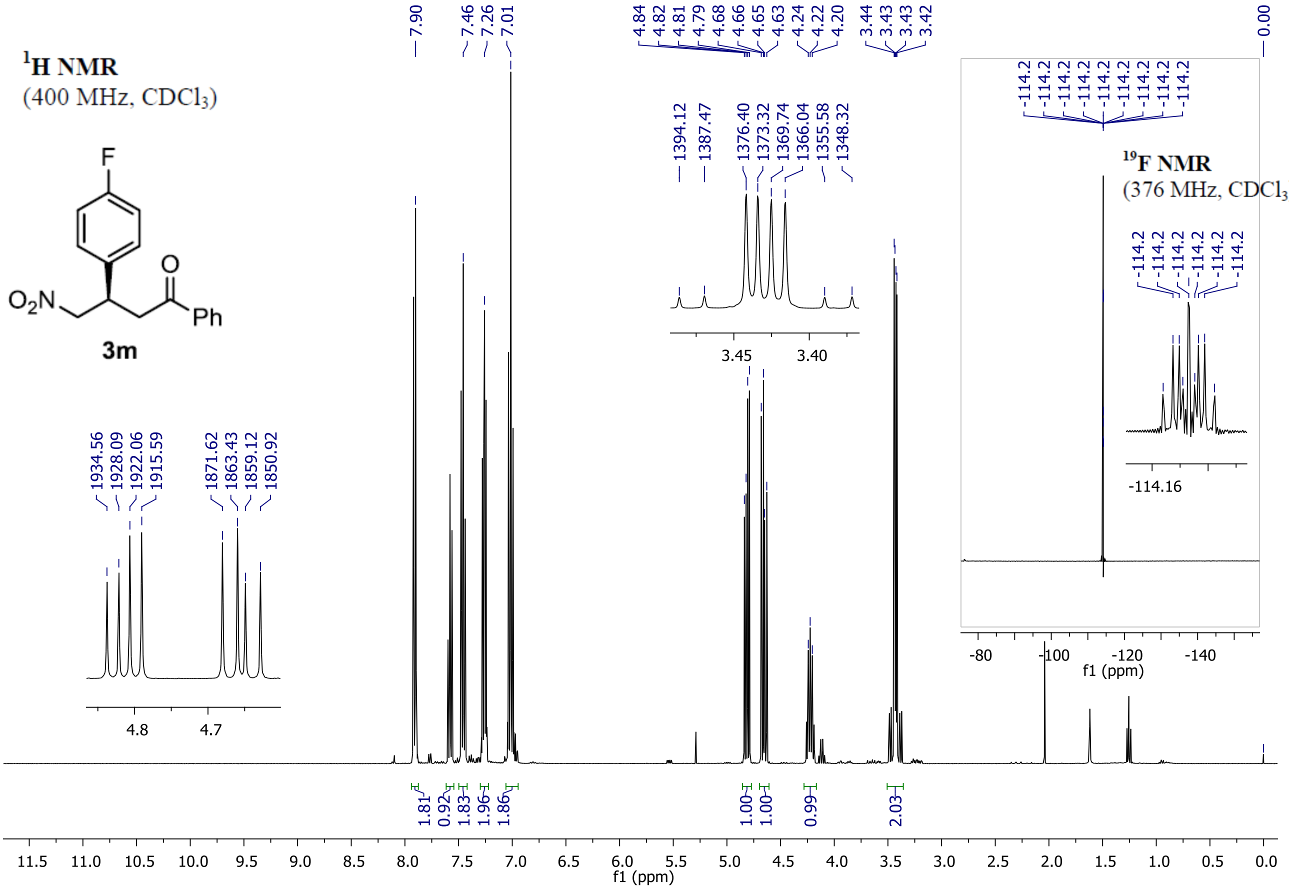
^{1}H NMR
(400 MHz, $CDCl_3$)

3l

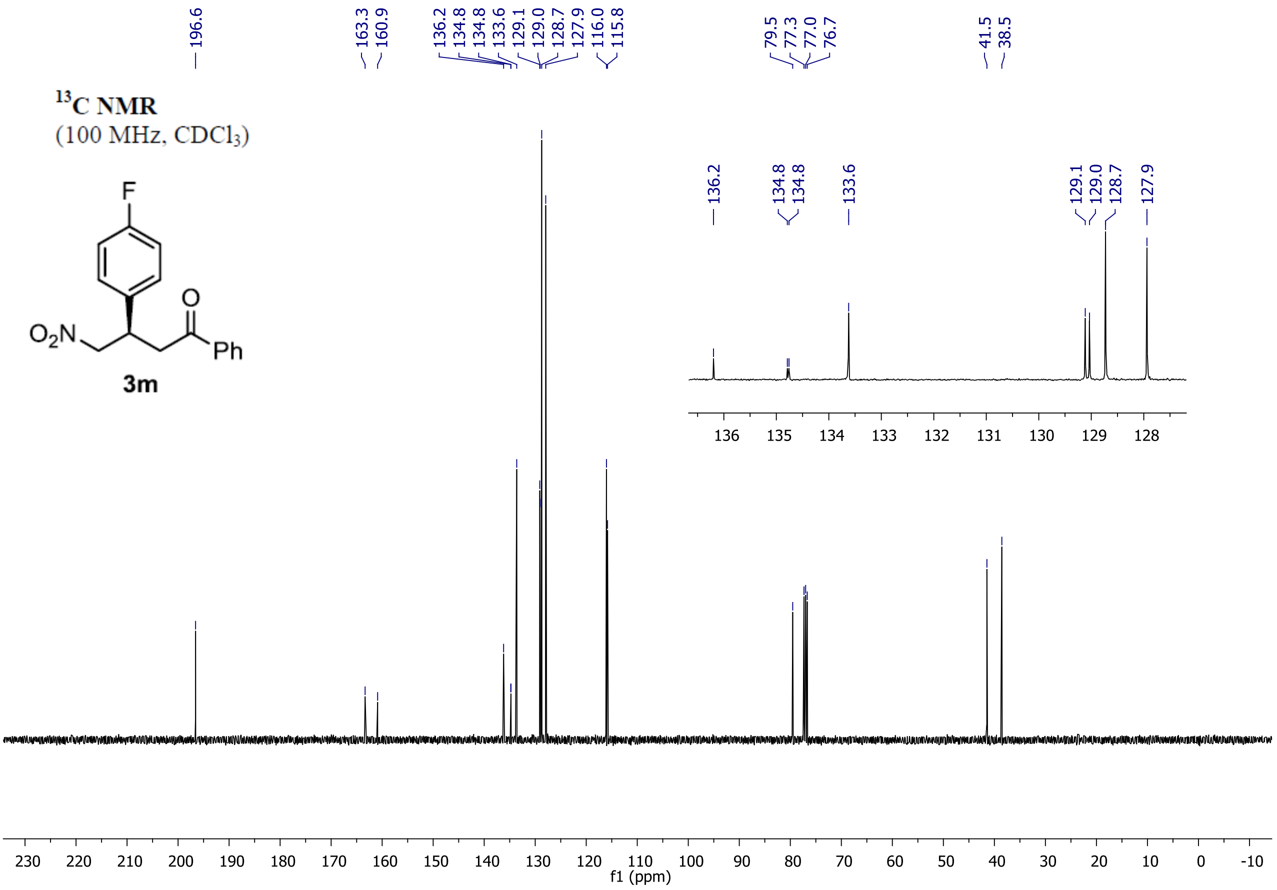


^{13}C NMR
(100 MHz, $CDCl_3$)

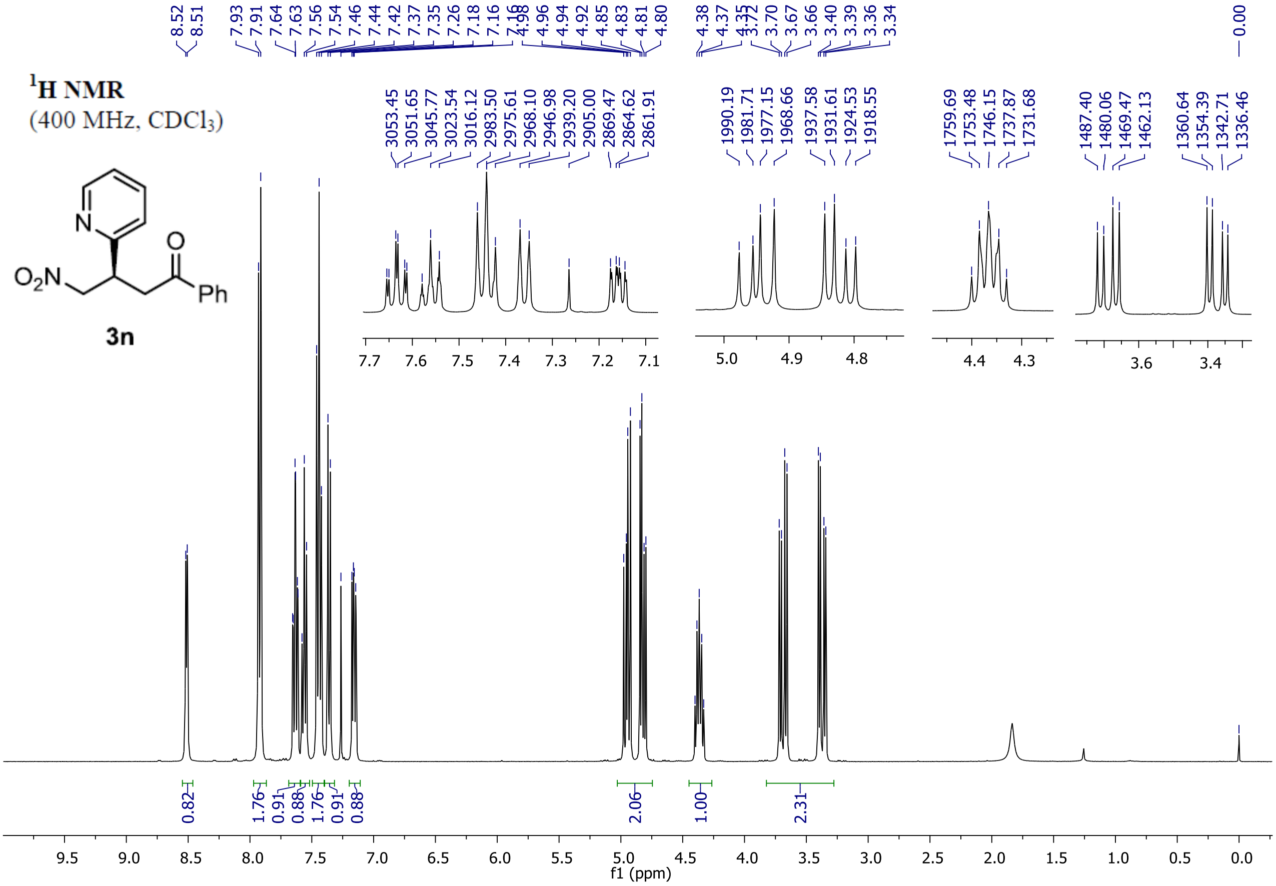
3l



1H NMR
(400 MHz, CDCl3)
F
O
O2N
Ph
3m
7.90
7.46
7.26
7.01
4.84
4.82
4.81
4.79
4.68
4.66
4.65
4.63
4.24
4.22
4.20
3.44
3.43
3.43
3.42
0.00
1934.56
1928.09
1922.06
1915.59
1871.62
1863.43
1859.12
1850.92
4.8
4.7
1394.12
1387.47
1376.40
1373.32
1369.74
1366.04
1355.58
1348.32
3.45
3.40
19F NMR
(376 MHz, CDCl3)
-114.2
-114.16
-80
-100
-120
-140
f1 (ppm)
1.81
0.92
1.83
1.96
1.86
1.00
1.00
0.99
2.03
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

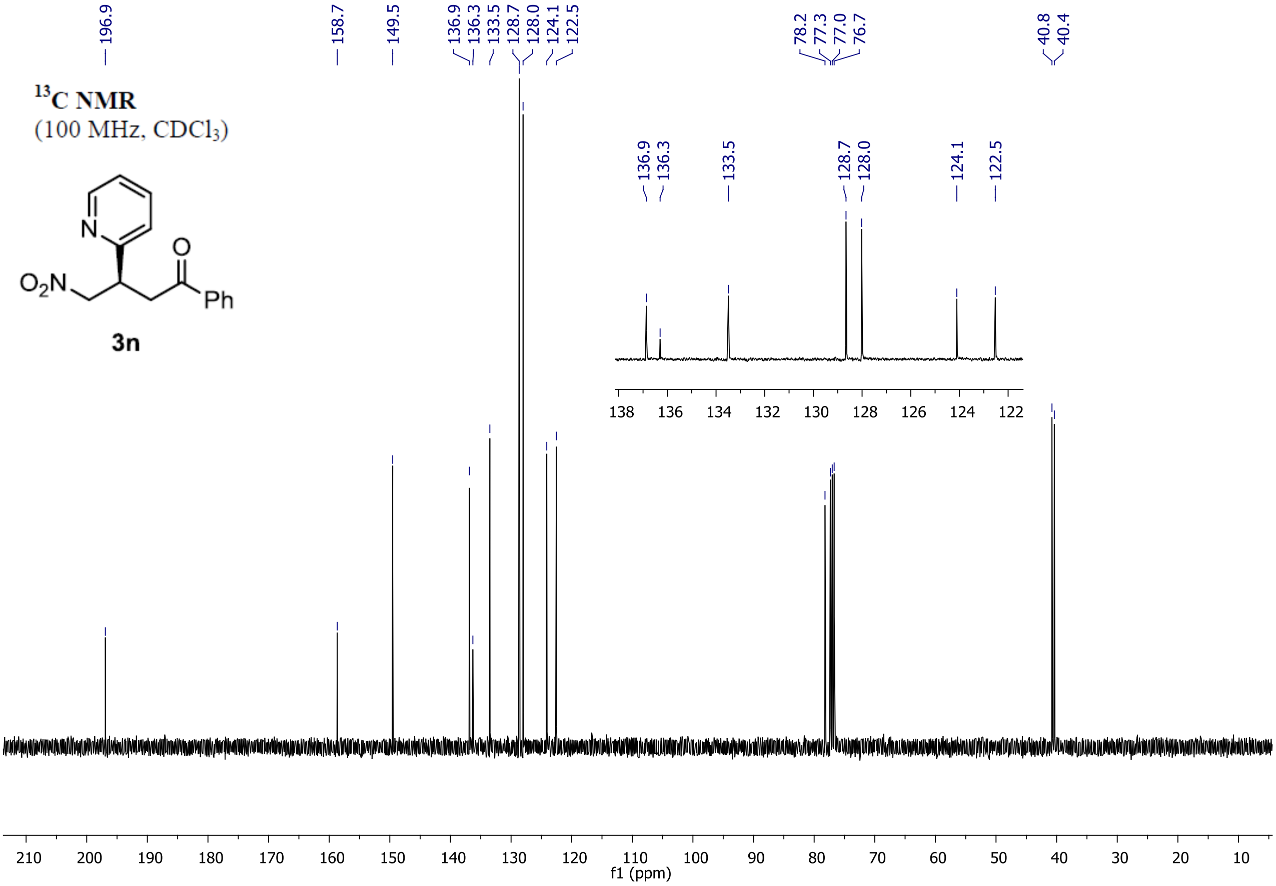


13C NMR
(100 MHz, CDCl3)
F
O
O2N
Ph
3m
196.6
163.3
160.9
136.2
134.8
134.8
133.6
129.1
129.0
128.7
127.9
116.0
115.8
79.5
77.3
77.0
76.7
41.5
38.5
136
135
134
133
132
131
130
129
128
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)



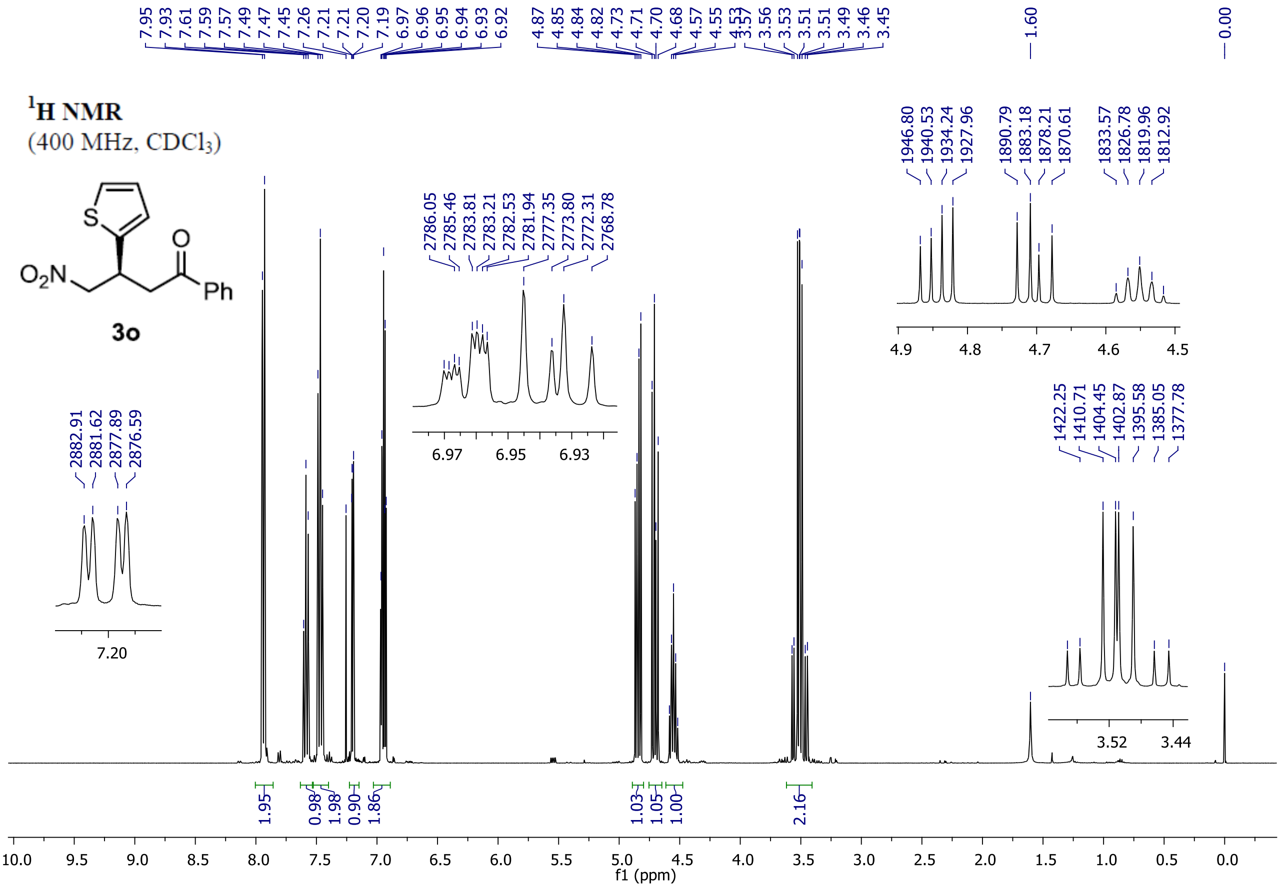
^{1}H NMR
(400 MHz, $CDCl_3$)

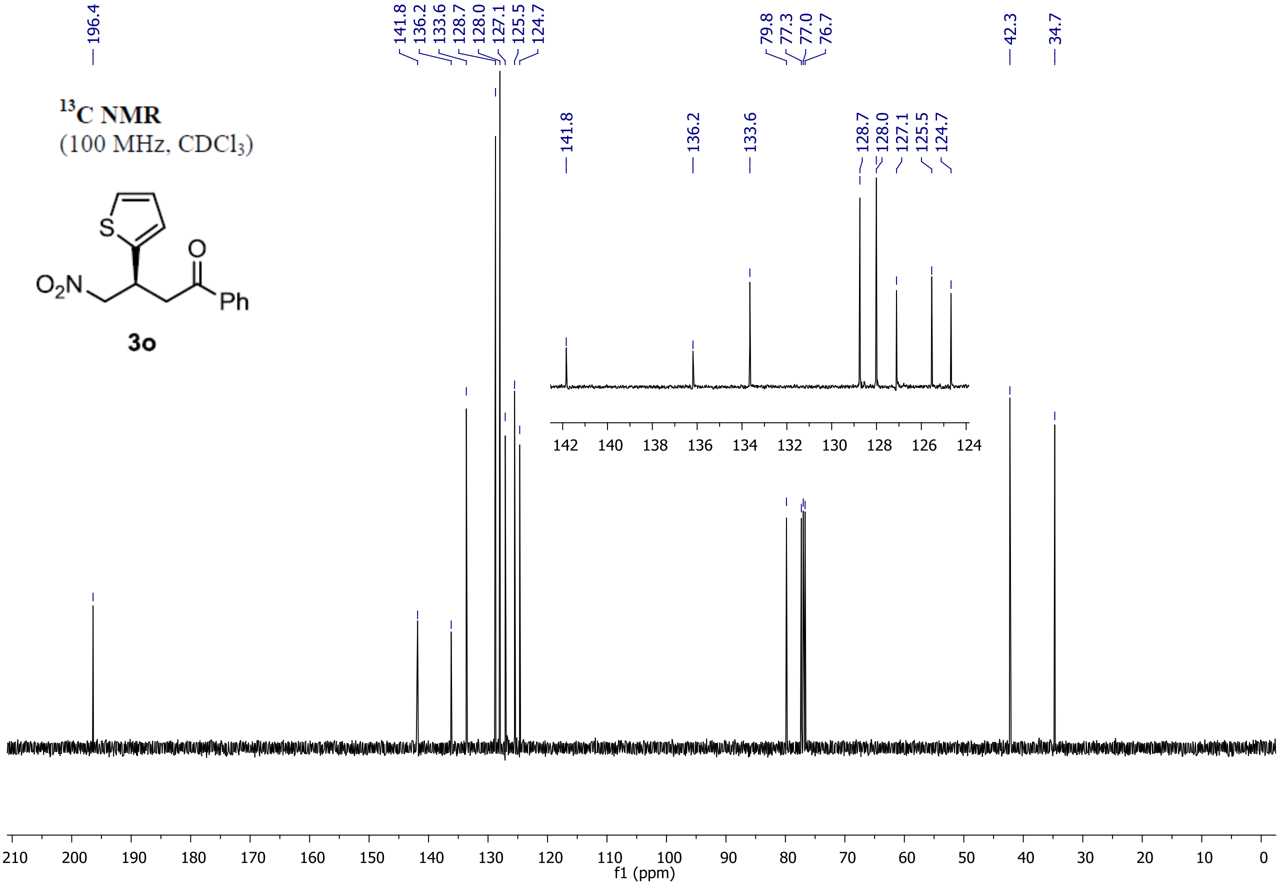
3n

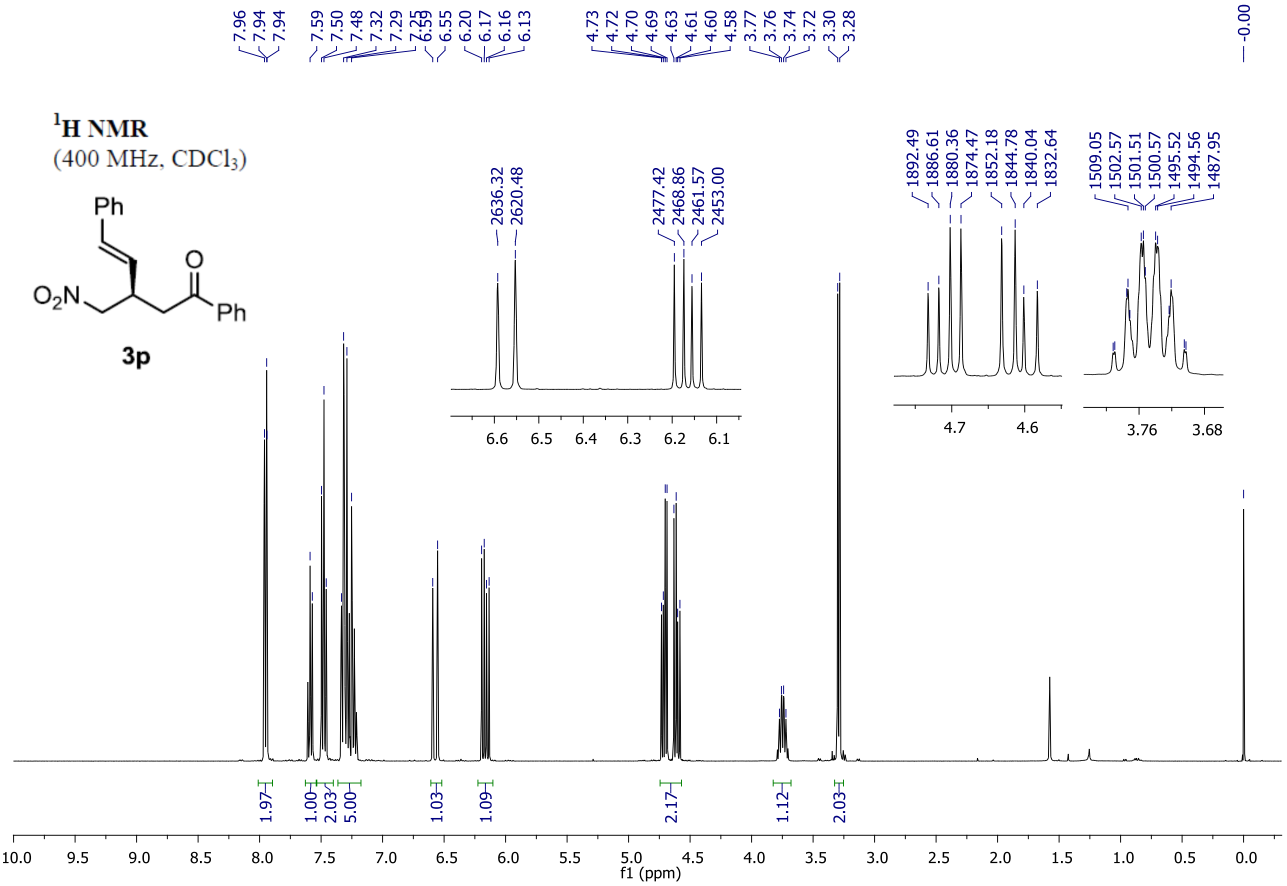


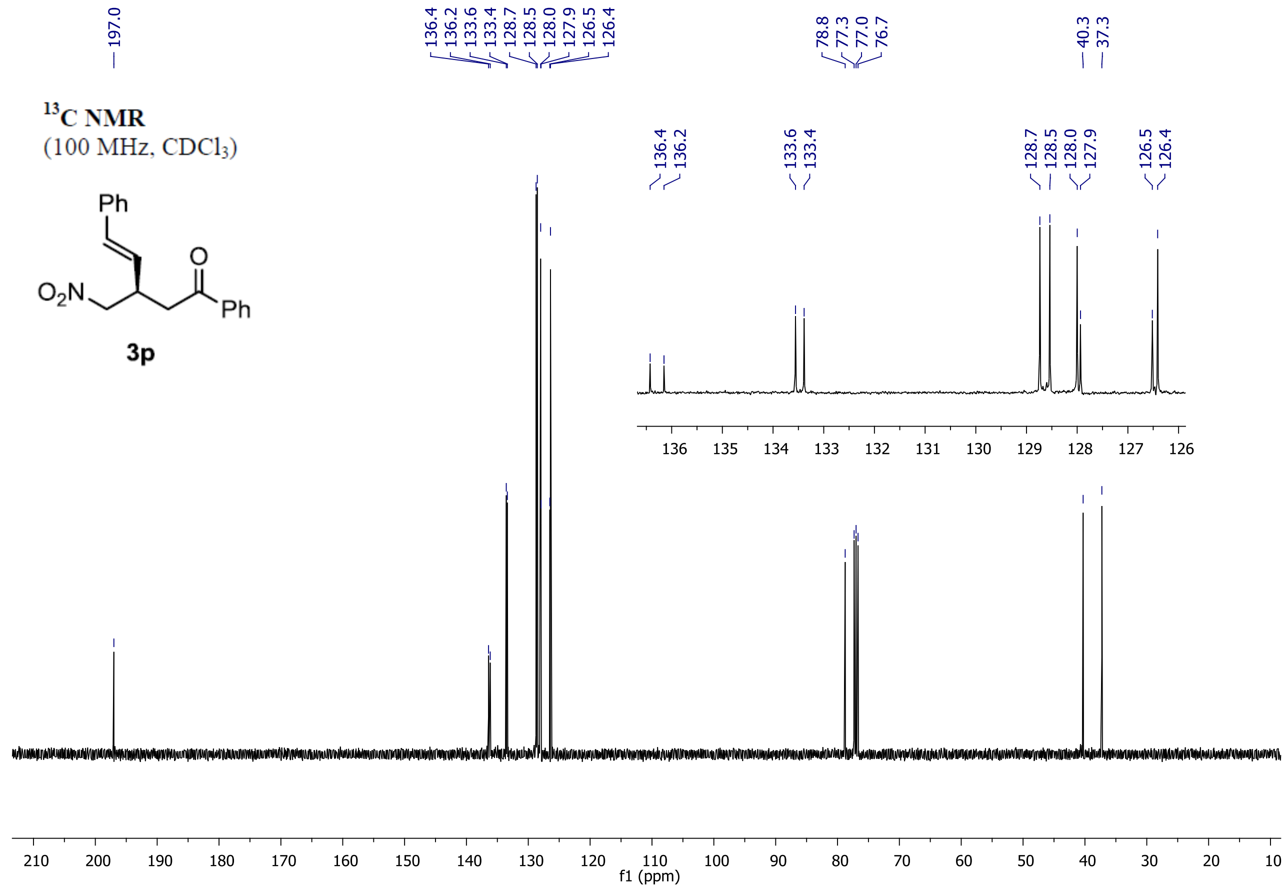
^{13}C NMR
(100 MHz, $CDCl_3$)

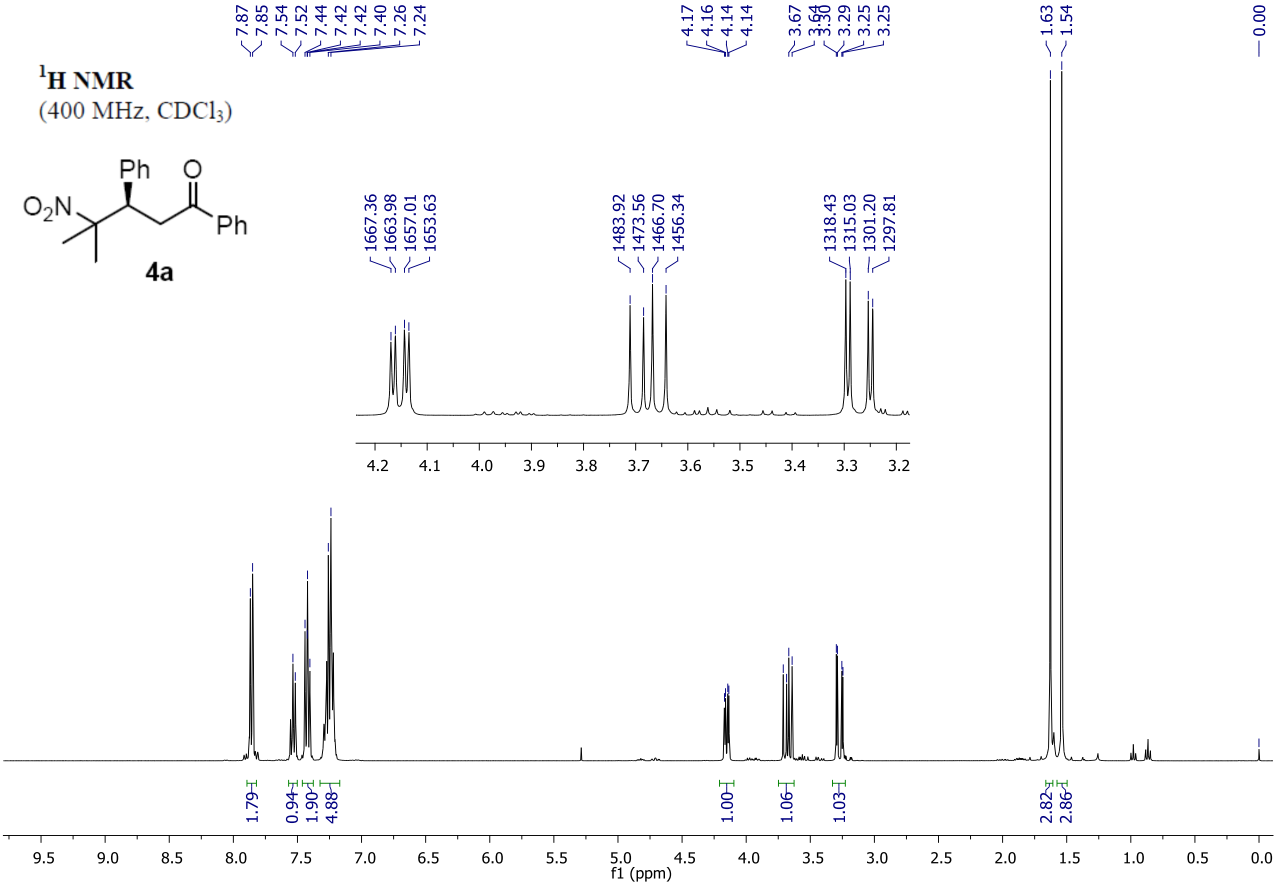
3n


^{1}H NMR
(400 MHz, CDCl$_3$)
3o
O_2N
S
O
Ph
7.95 7.93 7.61 7.59 7.57 7.49 7.47 7.45 7.26 7.21 7.21 7.20 7.19 6.97 6.96 6.95 6.94 6.93 6.92
4.87 4.85 4.84 4.82 4.73 4.71 4.70 4.68 4.57 4.55 4.53 3.57 3.56 3.53 3.51 3.51 3.49 3.46 3.45
1.60
0.00
2882.91 2881.62 2877.89 2876.59
2786.05 2785.46 2783.81 2783.21 2782.53 2781.94 2777.35 2773.80 2772.31 2768.78
1946.80 1940.53 1934.24 1927.96 1890.79 1883.18 1878.21 1870.61 1833.57 1826.78 1819.96 1812.92
1422.25 1410.71 1404.45 1402.87 1395.58 1385.05 1377.78
1.95 0.98 1.98 0.90 1.86 1.03 1.05 1.00 2.16
f1 (ppm)

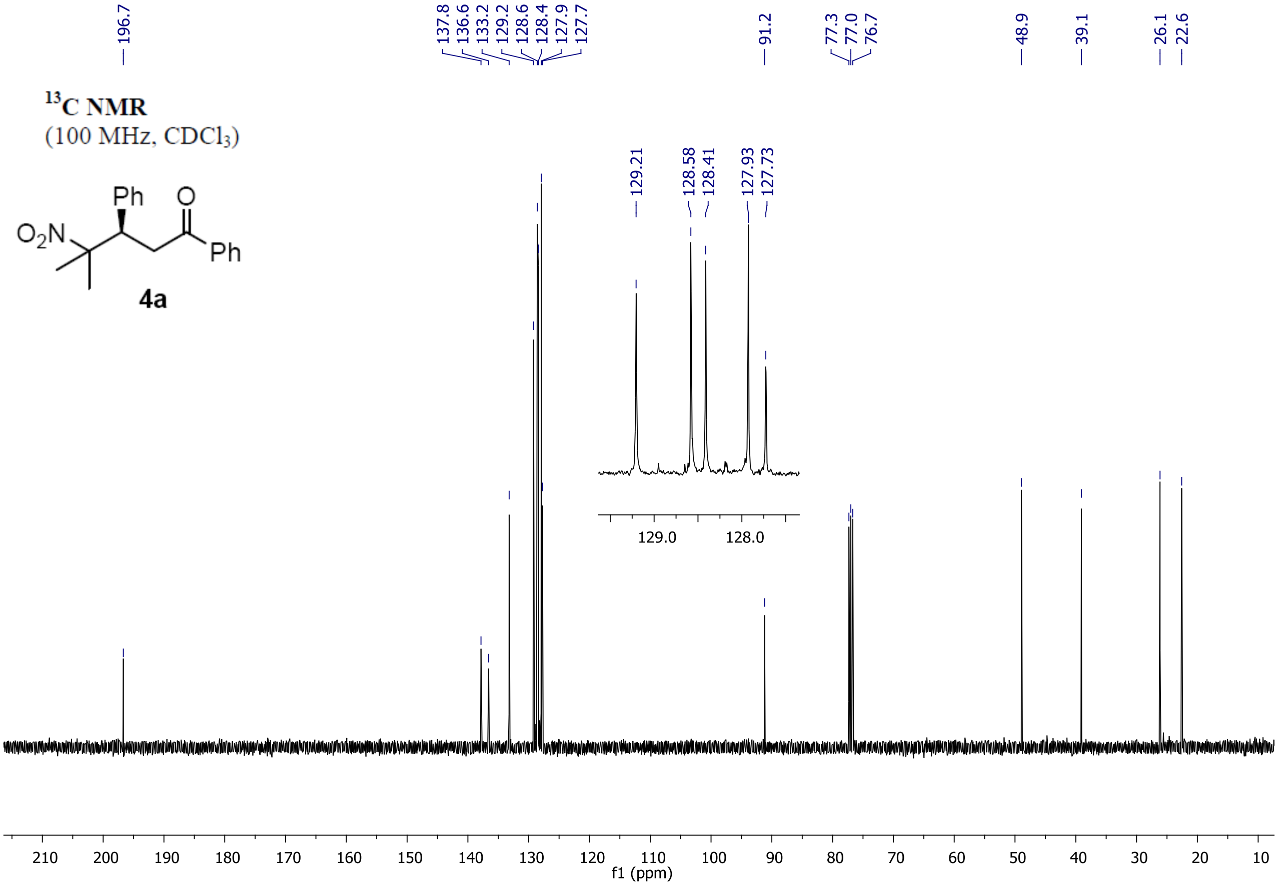

^{13}C NMR
(100 MHz, CDCl$_3$)
3o
O_2N
S
O
Ph
196.4
141.8 136.2 133.6 128.7 128.0 127.1 125.5 124.7
79.8 77.3 77.0 76.7
42.3
34.7
f1 (ppm)


1H NMR
(400 MHz, CDCl3)
Ph
O
O2N
Ph
3p
7.96
7.94
7.94
7.59
7.50
7.48
7.32
7.29
7.25
6.59
6.55
6.20
6.17
6.16
6.13
4.73
4.72
4.70
4.69
4.63
4.61
4.60
4.58
3.77
3.76
3.74
3.72
3.30
3.28
-0.00
2636.32
2620.48
2477.42
2468.86
2461.57
2453.00
1892.49
1886.61
1880.36
1874.47
1852.18
1844.78
1840.04
1832.64
1509.05
1502.57
1501.51
1500.57
1495.52
1494.56
1487.95
6.6
6.5
6.4
6.3
6.2
6.1
4.7
4.6
3.76
3.68
1.97
1.00
2.03
5.00
1.03
1.09
2.17
1.12
2.03
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)

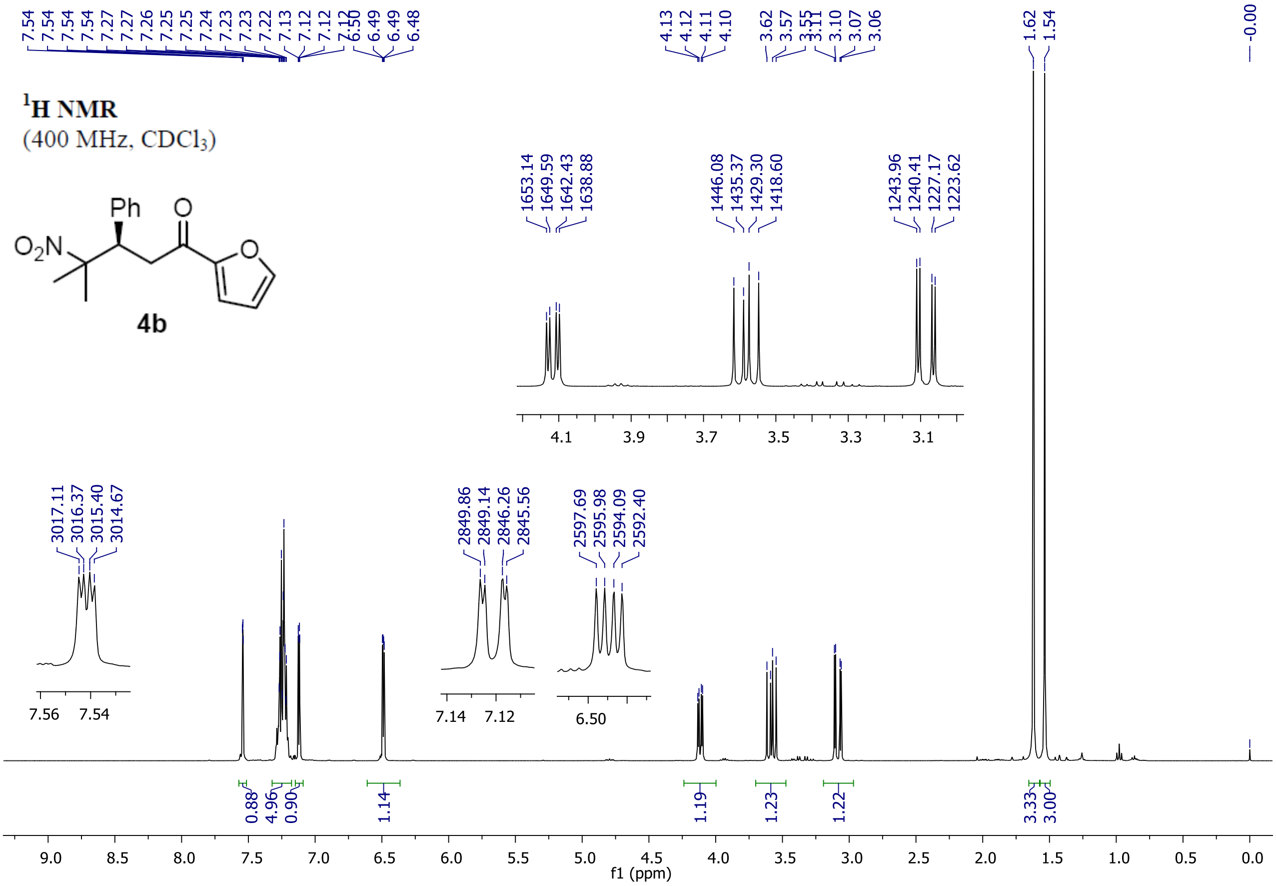

13C NMR
(100 MHz, CDCl3)
Ph
O
O2N
Ph
3p
197.0
136.4
136.2
133.6
133.4
128.7
128.5
128.0
127.9
126.5
126.4
78.8
77.3
77.0
76.7
40.3
37.3
136
135
134
133
132
131
130
129
128
127
126
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)



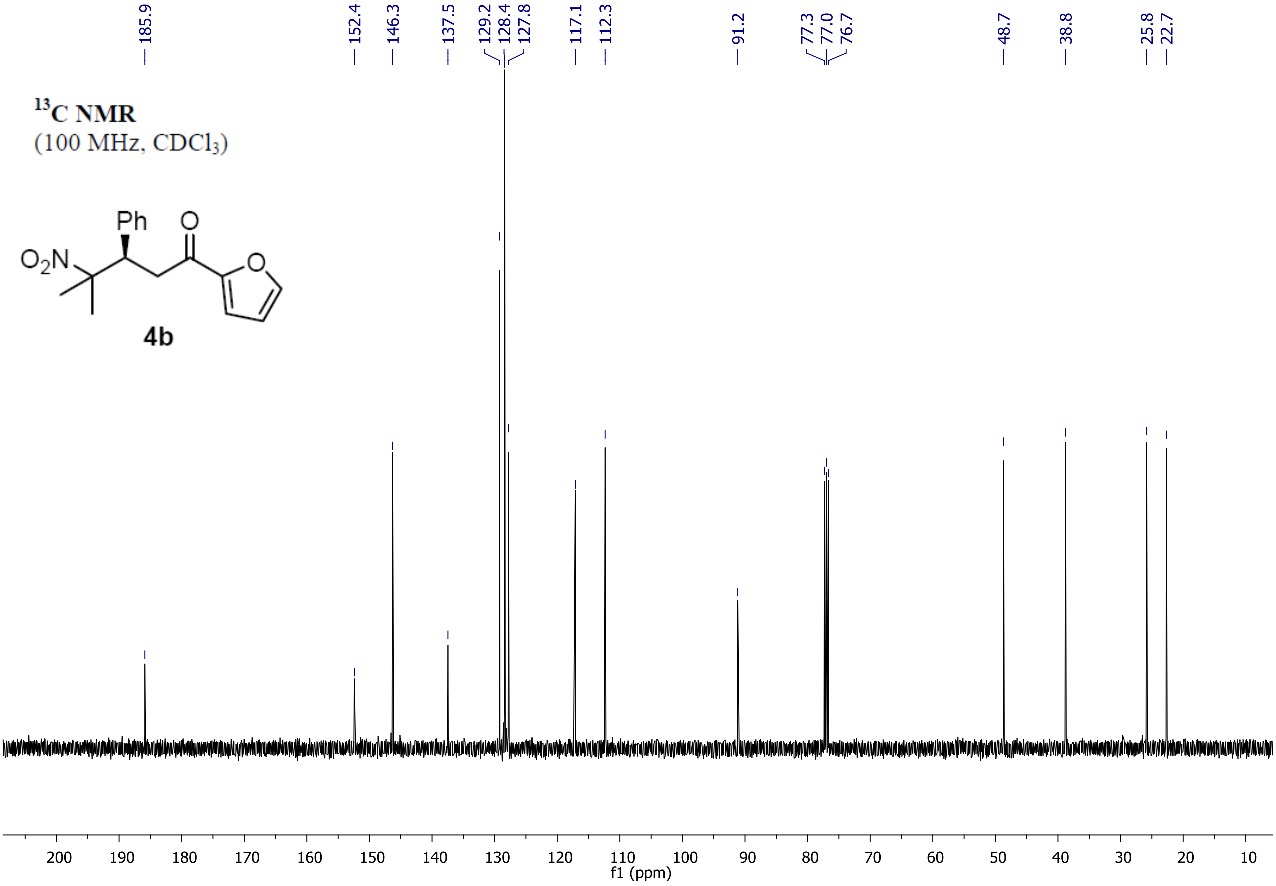
7.87
7.85
7.54
7.52
7.44
7.42
7.42
7.40
7.26
7.24
4.17
4.16
4.14
4.14
3.67
3.64
3.30
3.29
3.25
3.25
1.63
1.54
0.00
^{1}H NMR
(400 MHz, CDCl$_3$)
Ph
O
O$_2$N
Ph
4a
1667.36
1663.98
1657.01
1653.63
1483.92
1473.56
1466.70
1456.34
1318.43
1315.03
1301.20
1297.81
4.2
4.1
4.0
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
1.79
0.94
1.90
4.88
1.00
1.06
1.03
2.82
2.86
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)



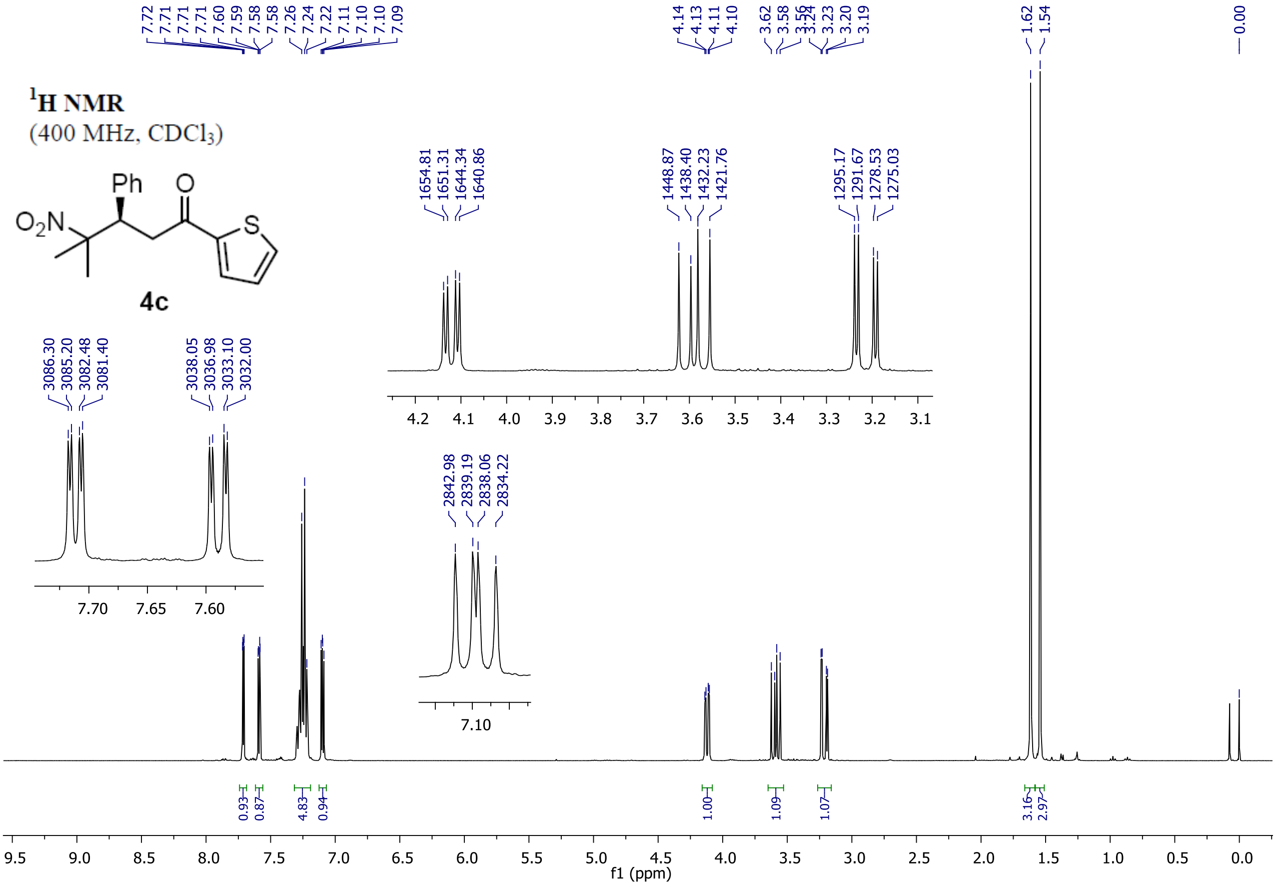
196.7
137.8
136.6
133.2
129.2
128.6
128.4
127.9
127.7
91.2
77.3
77.0
76.7
48.9
39.1
26.1
22.6
^{13}C NMR
(100 MHz, CDCl$_3$)
Ph
O
O$_2$N
Ph
4a
129.21
128.58
128.41
127.93
127.73
129.0
128.0
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

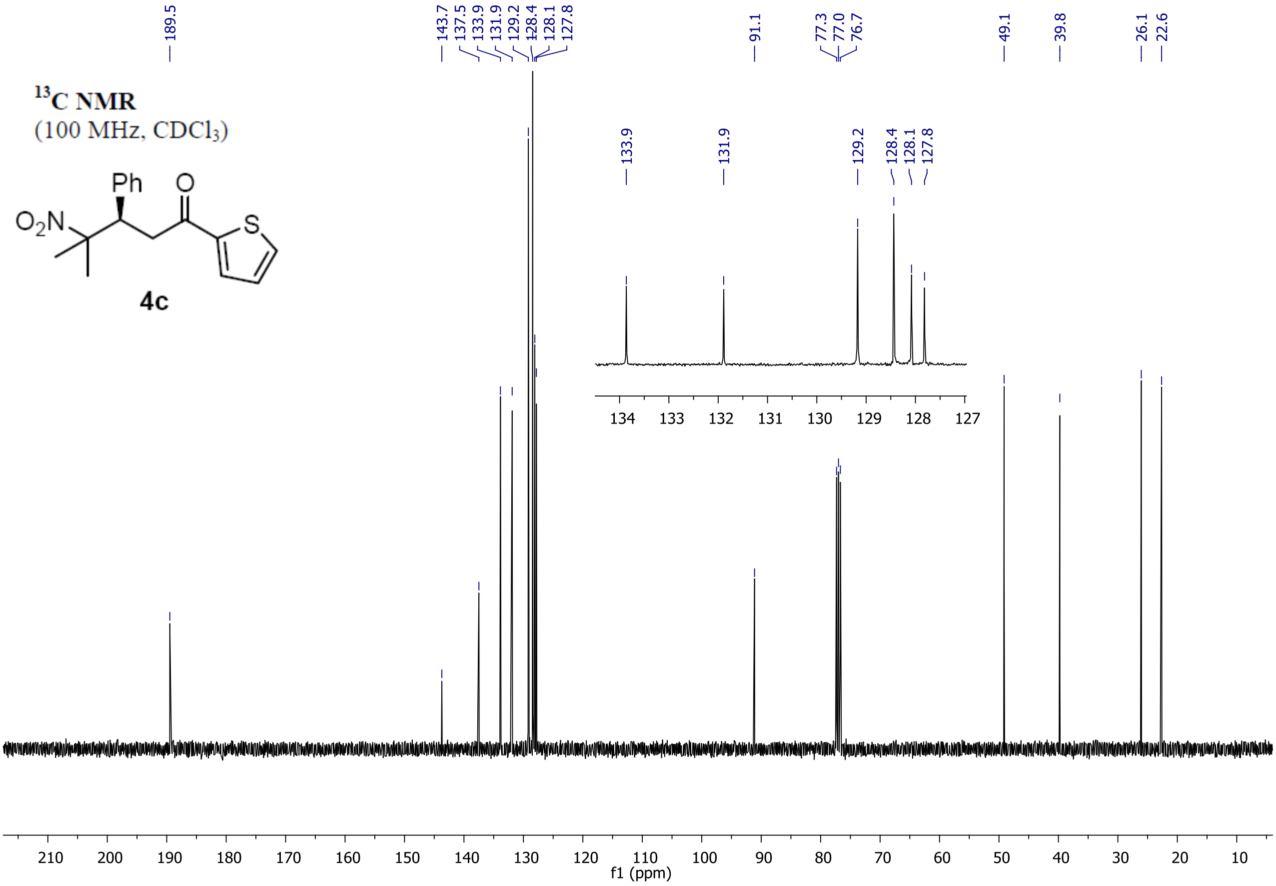


1H NMR
(400 MHz, CDCl3)
Ph
O
O2N
O
4b
7.54
7.54
7.54
7.54
7.27
7.27
7.26
7.25
7.25
7.24
7.23
7.23
7.22
7.13
7.12
7.12
7.12
6.50
6.49
6.49
6.48
4.13
4.12
4.11
4.10
3.62
3.57
3.55
3.11
3.10
3.07
3.06
1.62
1.54
-0.00
1653.14
1649.59
1642.43
1638.88
1446.08
1435.37
1429.30
1418.60
1243.96
1240.41
1227.17
1223.62
4.1
3.9
3.7
3.5
3.3
3.1
3017.11
3016.37
3015.40
3014.67
7.56
7.54
2849.86
2849.14
2846.26
2845.56
7.14
7.12
2597.69
2595.98
2594.09
2592.40
6.50
0.88
4.96
0.90
1.14
1.19
1.23
1.22
3.33
3.00
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)



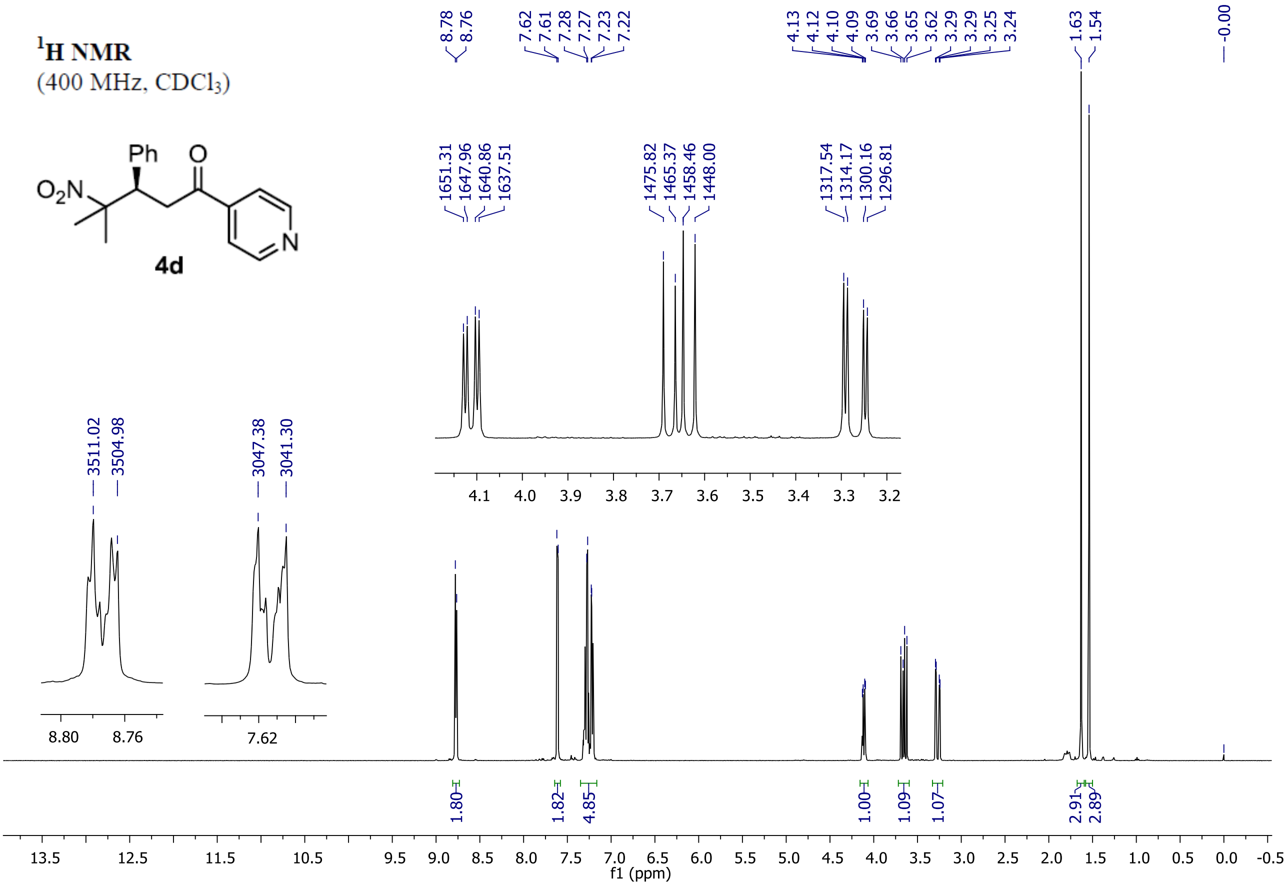
13C NMR
(100 MHz, CDCl3)
Ph
O
O2N
O
4b
185.9
152.4
146.3
137.5
129.2
128.4
127.8
117.1
112.3
91.2
77.3
77.0
76.7
48.7
38.8
25.8
22.7
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)


¹H NMR
(400 MHz, CDCl₃)
Ph
O
O₂N
S
4c
7.72 7.71 7.71 7.71 7.60 7.59 7.58 7.58 7.26 7.24 7.22 7.11 7.10 7.10 7.09
4.14 4.13 4.11 4.10 3.62 3.58 3.56 3.24 3.23 3.20 3.19
1.62 1.54
0.00
3086.30 3085.20 3082.48 3081.40
3038.05 3036.98 3033.10 3032.00
7.70 7.65 7.60
1654.81 1651.31 1644.34 1640.86
1448.87 1438.40 1432.23 1421.76
1295.17 1291.67 1278.53 1275.03
4.2 4.1 4.0 3.9 3.8 3.7 3.6 3.5 3.4 3.3 3.2 3.1
2842.98 2839.19 2838.06 2834.22
7.10
0.93 0.87 4.83 0.94 1.00 1.09 1.07 3.16 2.97
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


¹³C NMR
(100 MHz, CDCl₃)
Ph
O
O₂N
S
4c
189.5
143.7 137.5 133.9 131.9 129.2 128.4 128.1 127.8
91.1
77.3 77.0 76.7
49.1
39.8
26.1 22.6
133.9 131.9 129.2 128.4 128.1 127.8
134 133 132 131 130 129 128 127
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)

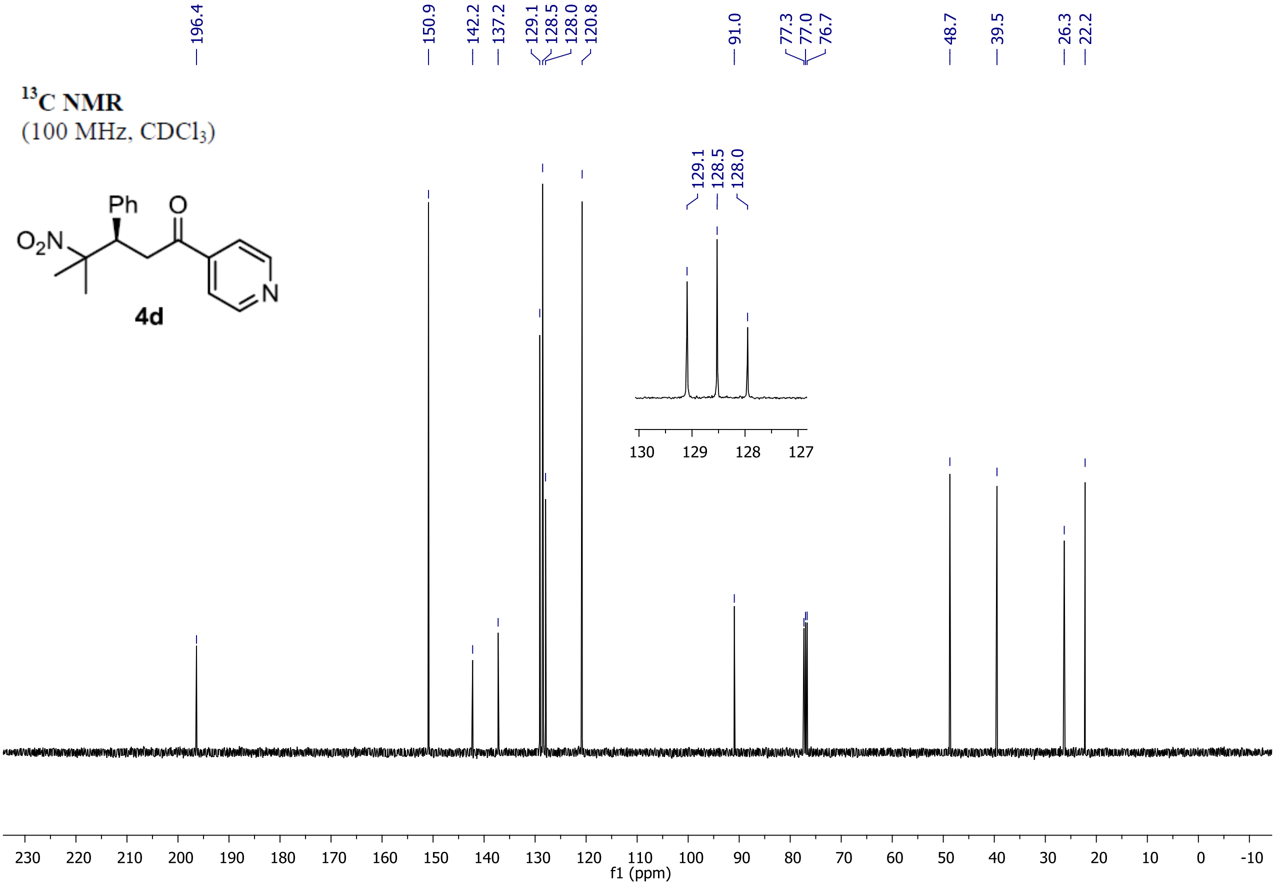
^{1}H NMR
(400 MHz, $CDCl_3$)

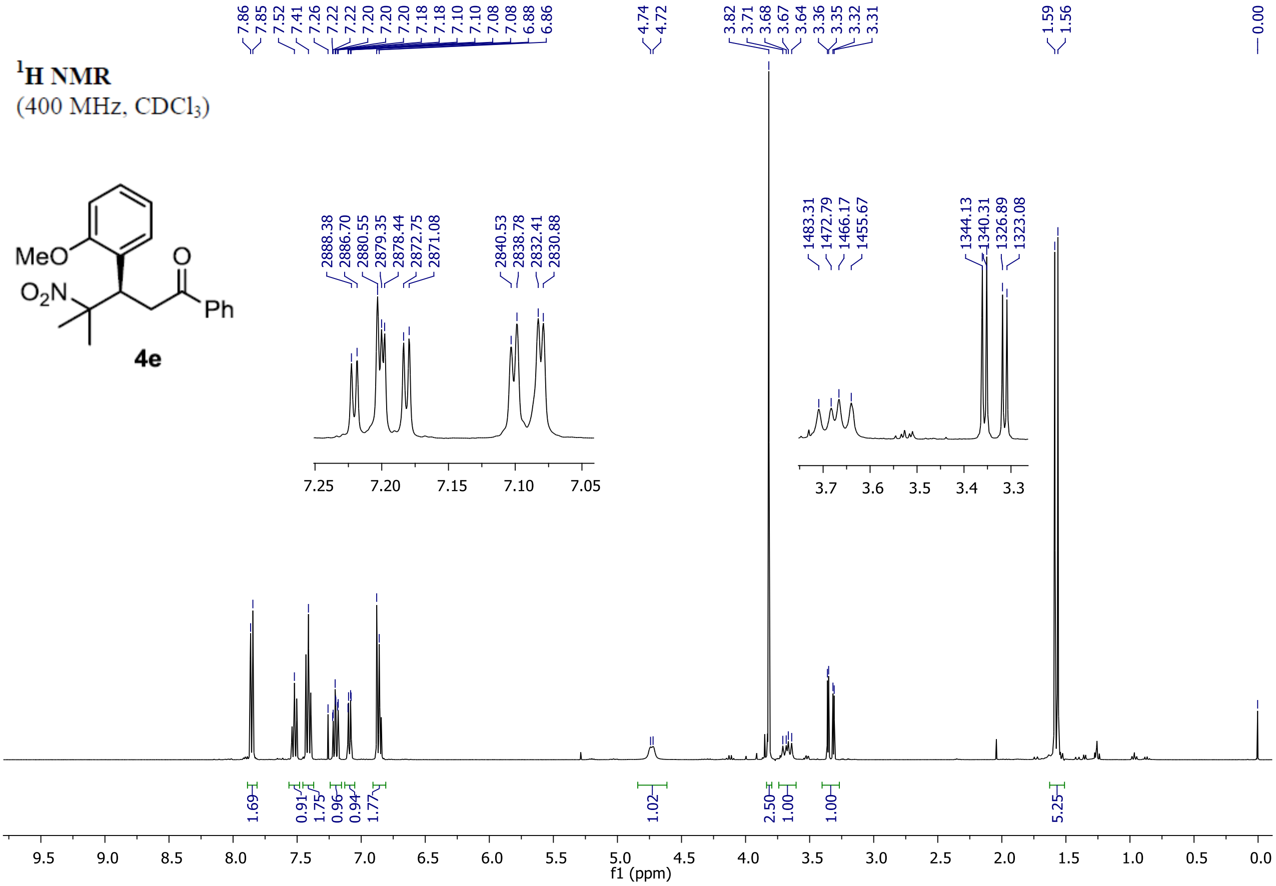
4d

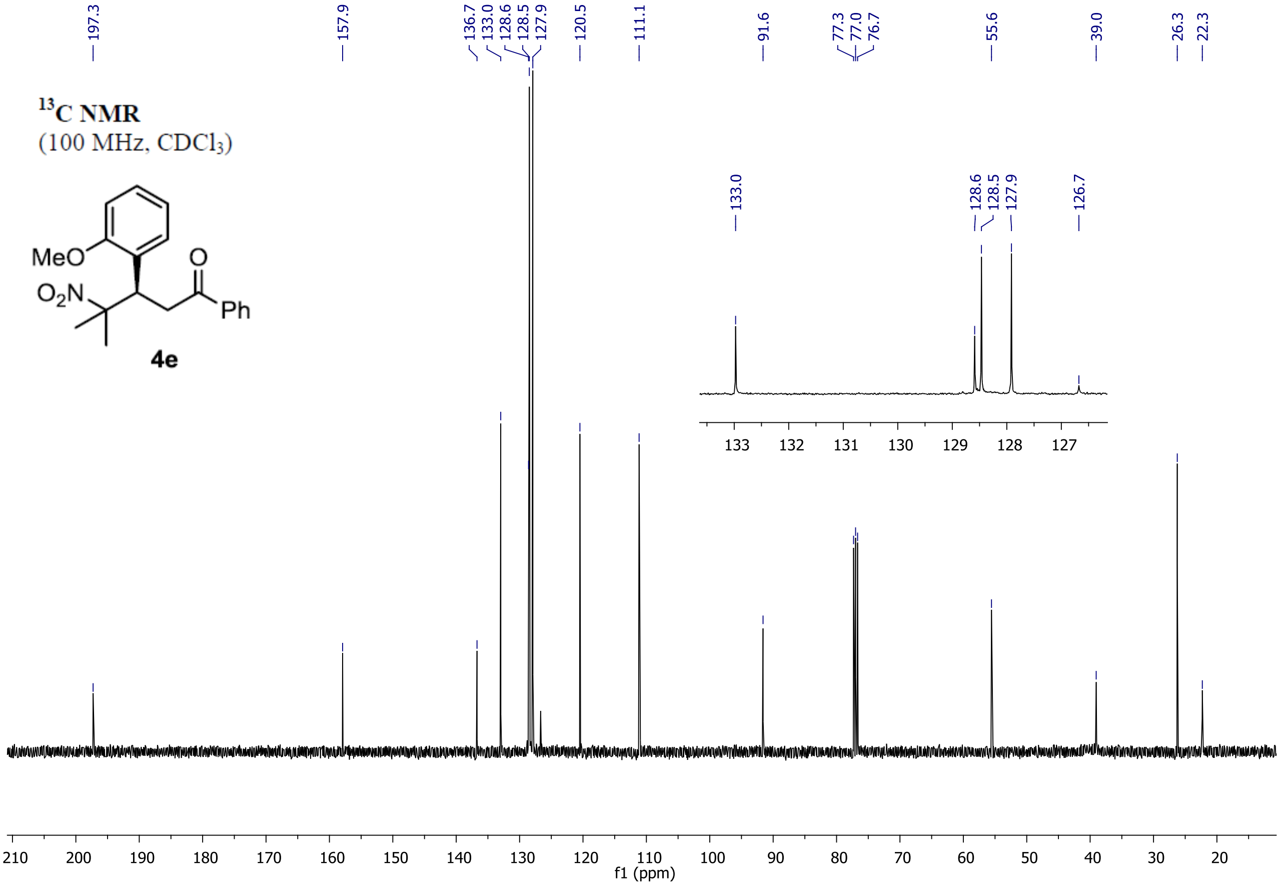


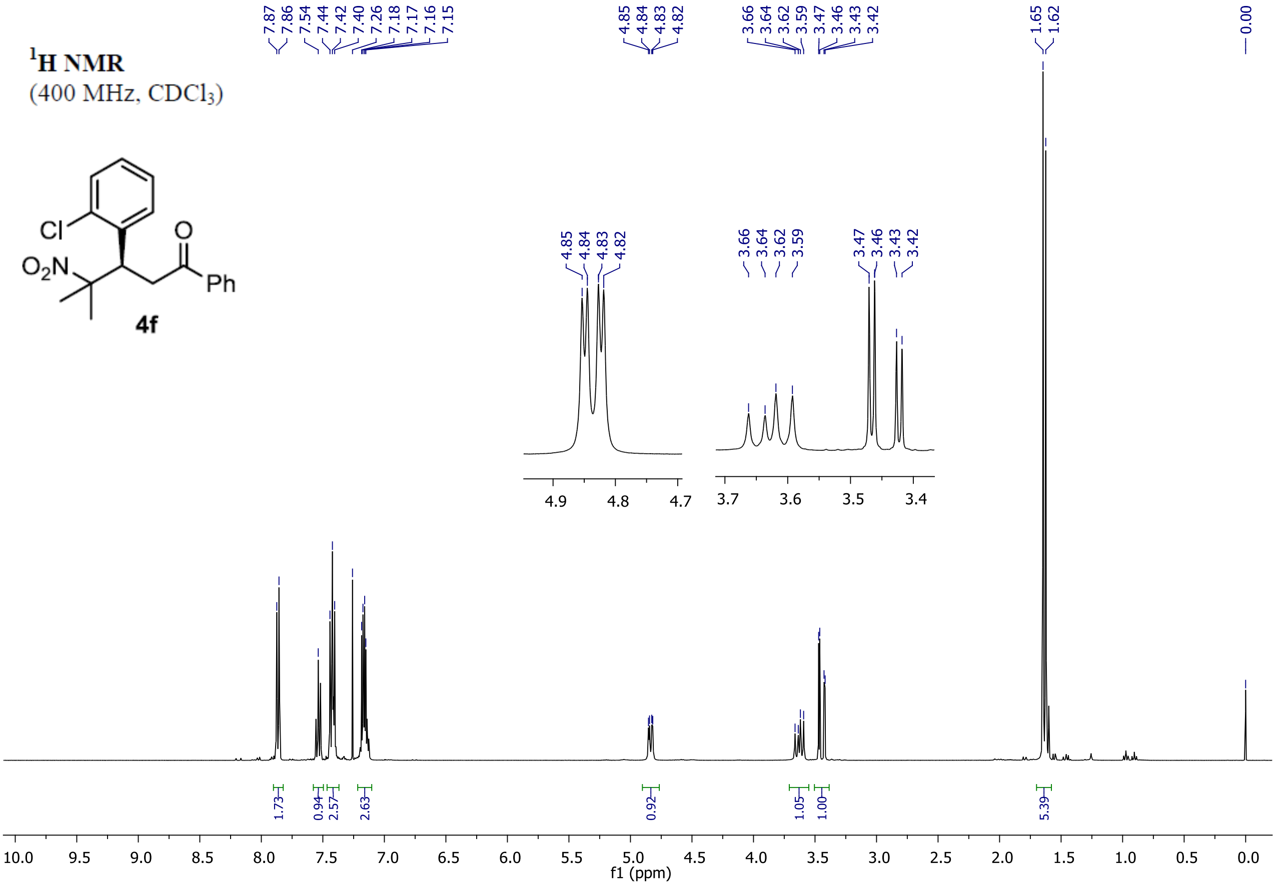
^{13}C NMR
(100 MHz, $CDCl_3$)

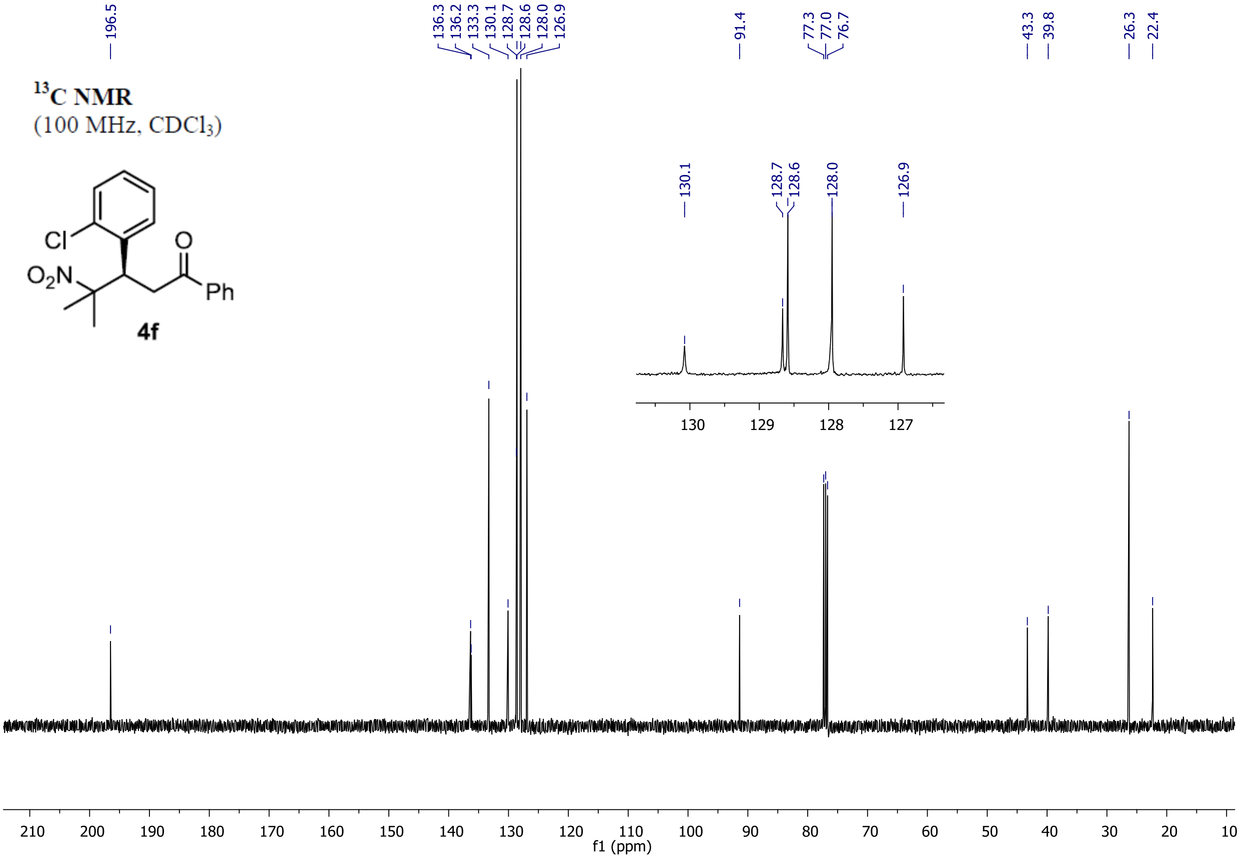
4d

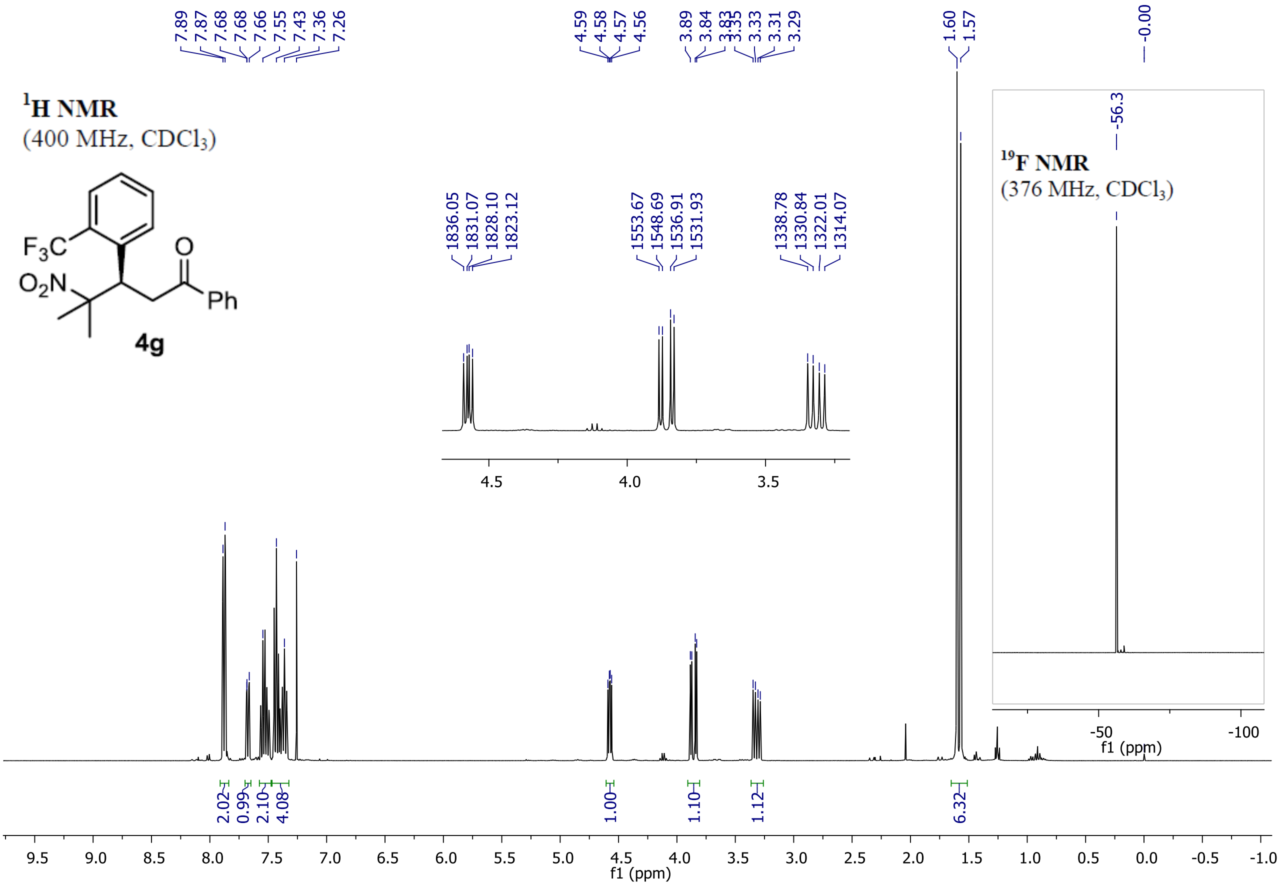


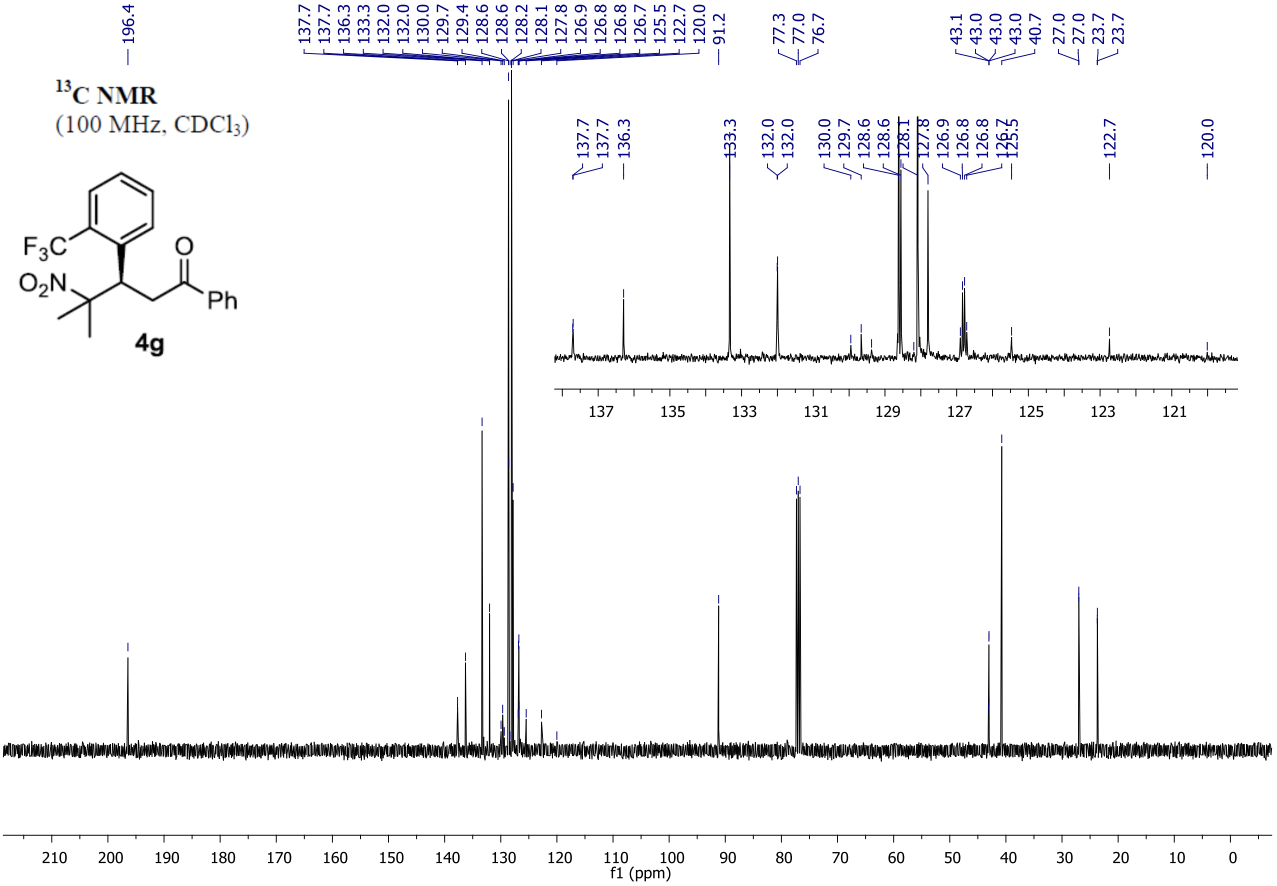

^{1}H NMR
(400 MHz, CDCl$_3$)
MeO
O
O_2N
Ph
4e
7.86 7.85 7.52 7.41 7.26 7.22 7.22 7.20 7.20 7.20 7.18 7.18 7.10 7.10 7.08 7.08 6.88 6.86
4.74 4.72
3.82 3.71 3.68 3.67 3.64 3.36 3.35 3.32 3.31
1.59 1.56
0.00
2888.38 2886.70 2880.55 2879.35 2878.44 2872.75 2871.08
2840.53 2838.78 2832.41 2830.88
7.25 7.20 7.15 7.10 7.05
1483.31 1472.79 1466.17 1455.67
1344.13 1340.31 1326.89 1323.08
3.7 3.6 3.5 3.4 3.3
1.69 0.91 1.75 0.96 0.94 1.77 1.02 2.50 1.00 1.00 5.25
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


^{13}C NMR
(100 MHz, CDCl$_3$)
MeO
O
O_2N
Ph
4e
197.3
157.9
136.7 133.0 128.6 128.5 127.9
120.5
111.1
91.6
77.3 77.0 76.7
55.6
39.0
26.3 22.3
133.0
128.6 128.5 127.9
126.7
133 132 131 130 129 128 127
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20
f1 (ppm)

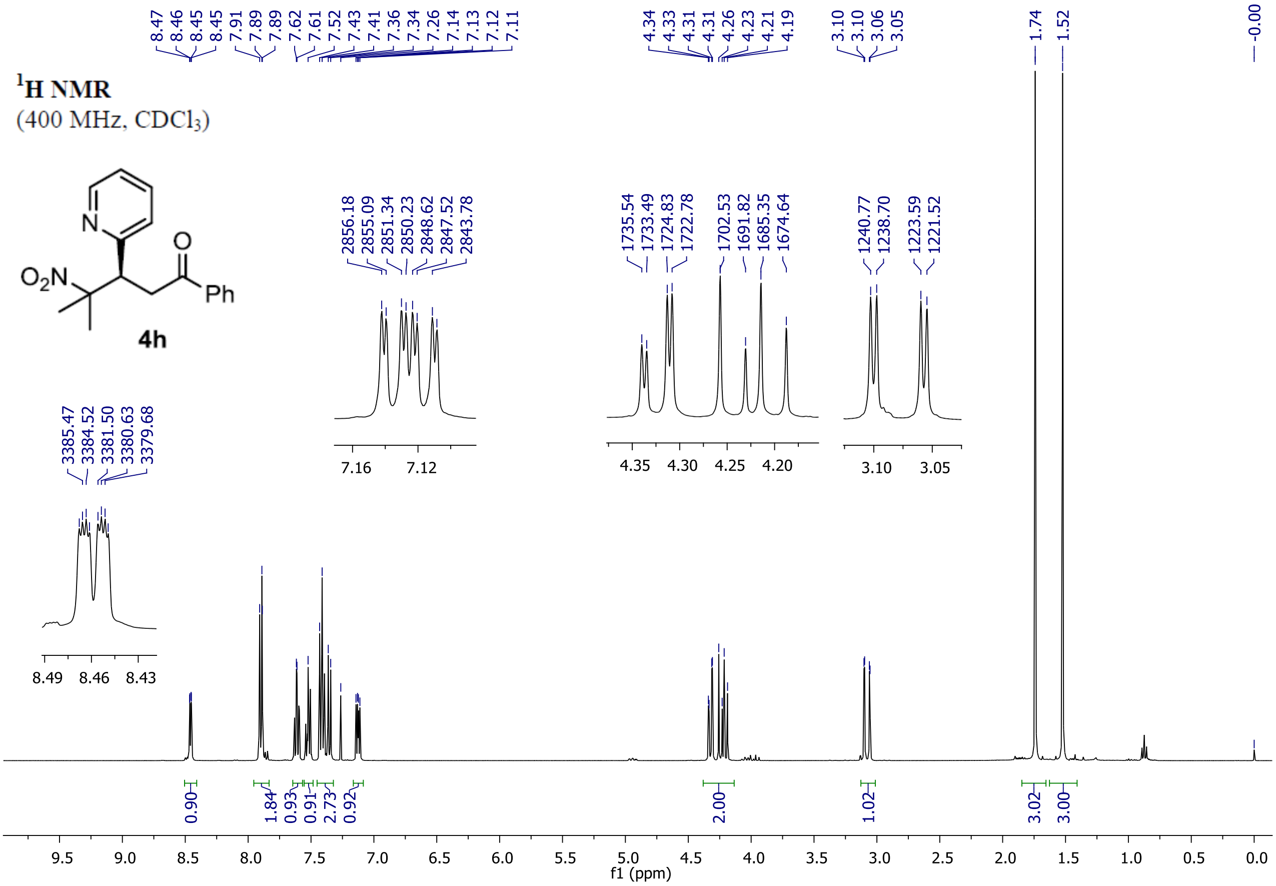

^{1}H NMR
(400 MHz, CDCl$_3$)
Cl
O
O_2N
Ph
4f
7.87 7.86 7.54 7.44 7.42 7.40 7.26 7.18 7.17 7.16 7.15
4.85 4.84 4.83 4.82
3.66 3.64 3.62 3.59 3.47 3.46 3.43 3.42
1.65 1.62
0.00
4.9 4.8 4.7
3.7 3.6 3.5 3.4
1.73 0.94 2.57 2.63 0.92 1.05 1.00 5.39
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


^{13}C NMR
(100 MHz, CDCl$_3$)
Cl
O
O_2N
Ph
4f
196.5
136.3 136.2 133.3 130.1 128.7 128.6 128.0 126.9
91.4
77.3 77.0 76.7
43.3 39.8
26.3 22.4
130.1 128.7 128.6 128.0 126.9
130 129 128 127
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)

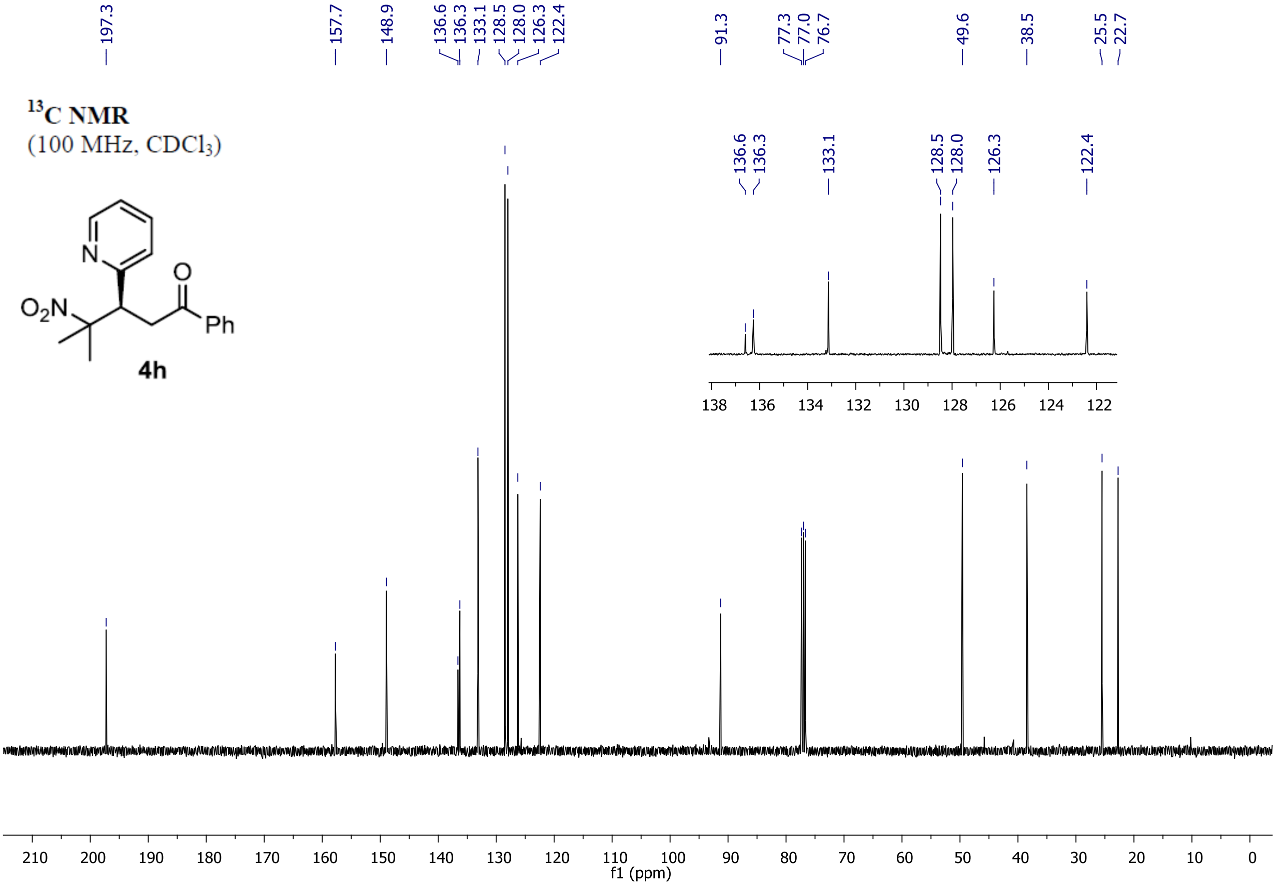

1H NMR
(400 MHz, CDCl3)
F3C
O2N
O
Ph
4g
7.89
7.87
7.68
7.68
7.66
7.55
7.43
7.36
7.26
4.59
4.58
4.57
4.56
3.89
3.84
3.83
3.35
3.33
3.31
3.29
1.60
1.57
-0.00
1836.05
1831.07
1828.10
1823.12
1553.67
1548.69
1536.91
1531.93
1338.78
1330.84
1322.01
1314.07
4.5
4.0
3.5
19F NMR
(376 MHz, CDCl3)
-56.3
-50
-100
f1 (ppm)
2.02
0.99
2.10
4.08
1.00
1.10
1.12
6.32
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
f1 (ppm)

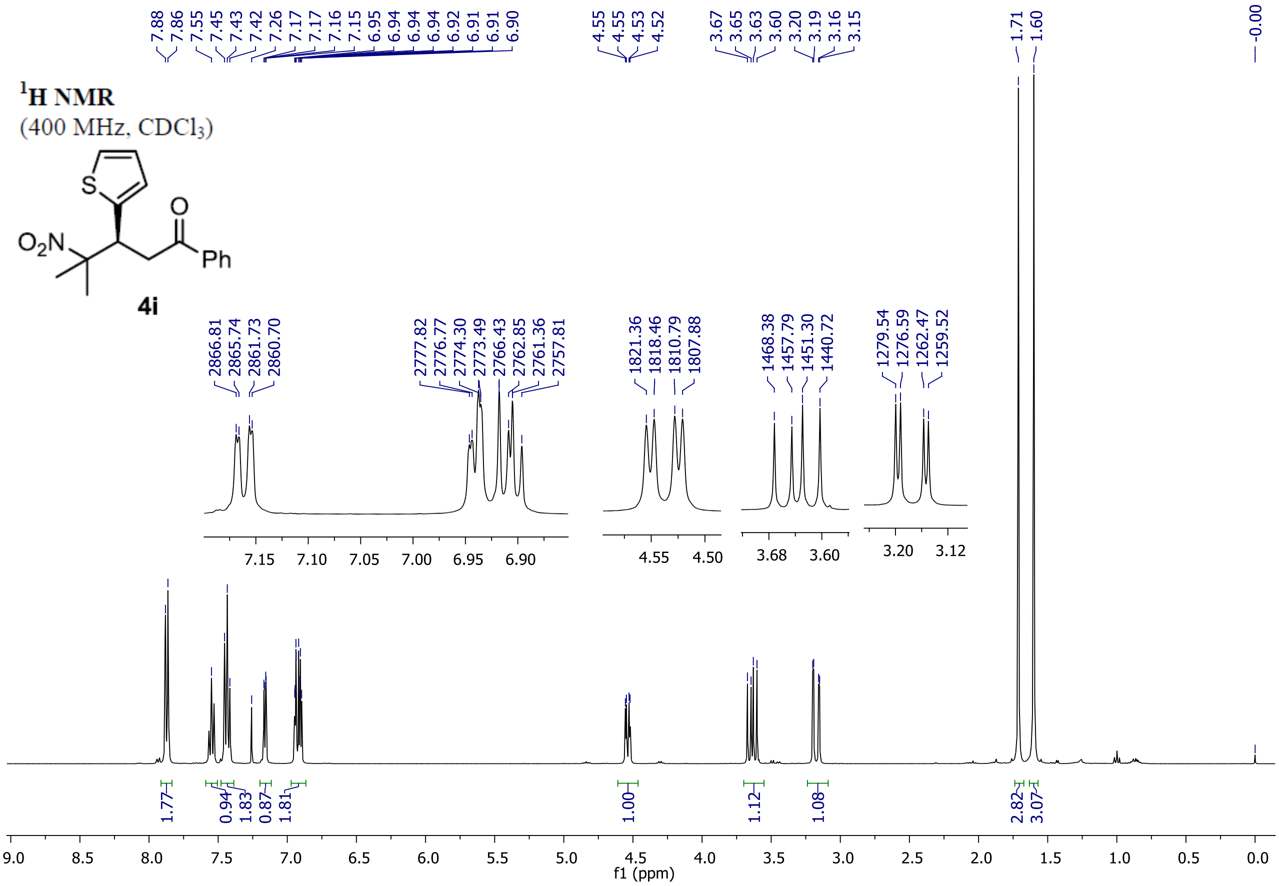

13C NMR
(100 MHz, CDCl3)
F3C
O2N
O
Ph
4g
196.4
137.7
137.7
136.3
133.3
132.0
132.0
130.0
129.7
129.4
128.6
128.6
128.2
128.1
127.8
126.9
126.8
126.8
126.7
125.5
122.7
120.0
91.2
77.3
77.0
76.7
43.1
43.0
43.0
43.0
40.7
27.0
27.0
23.7
23.7
137.7
137.7
136.3
133.3
132.0
132.0
130.0
129.7
128.6
128.6
128.1
127.8
126.9
126.8
126.8
126.7
125.5
122.7
120.0
137
135
133
131
129
127
125
123
121
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

^{1}H NMR
(400 MHz, CDCl$_3$)

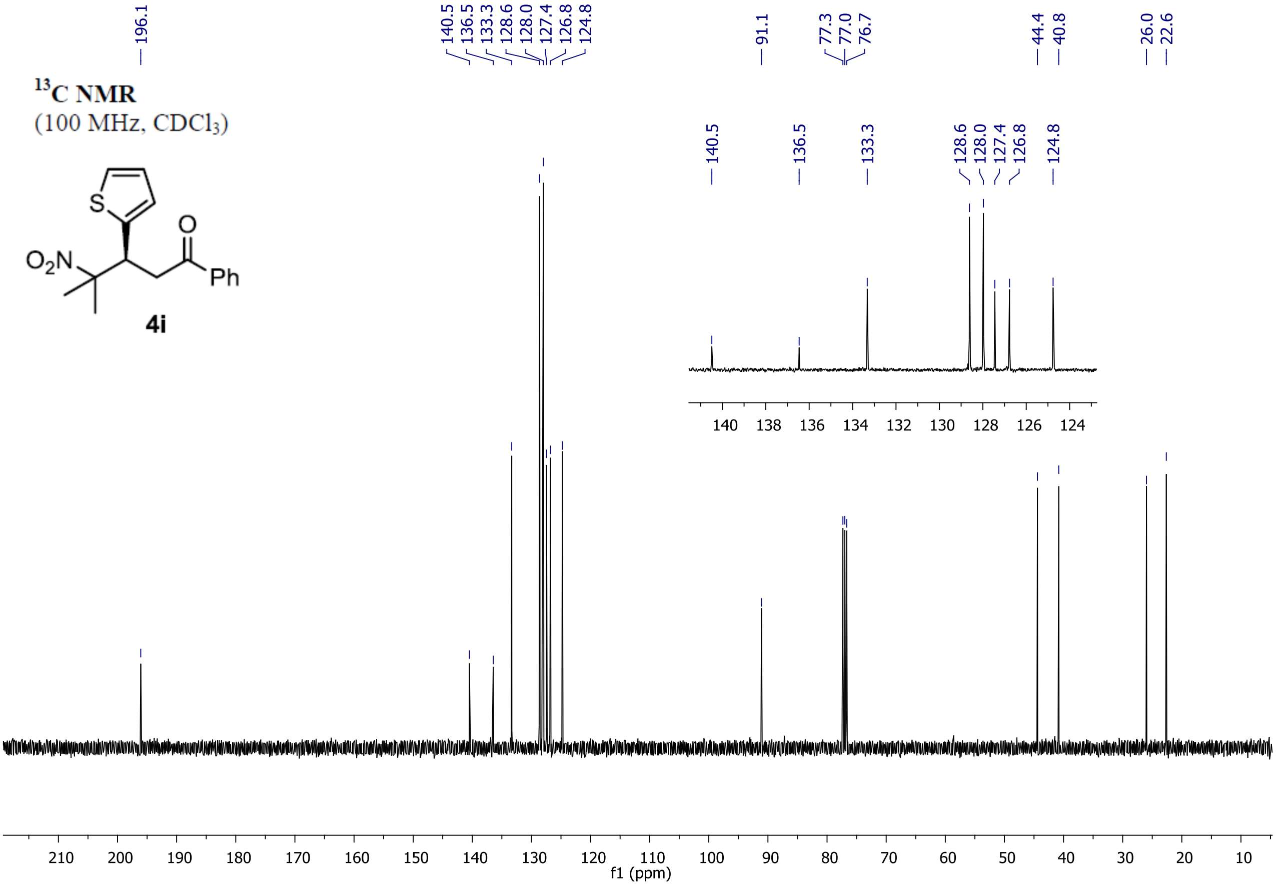


^{13}C NMR
(100 MHz, CDCl$_3$)

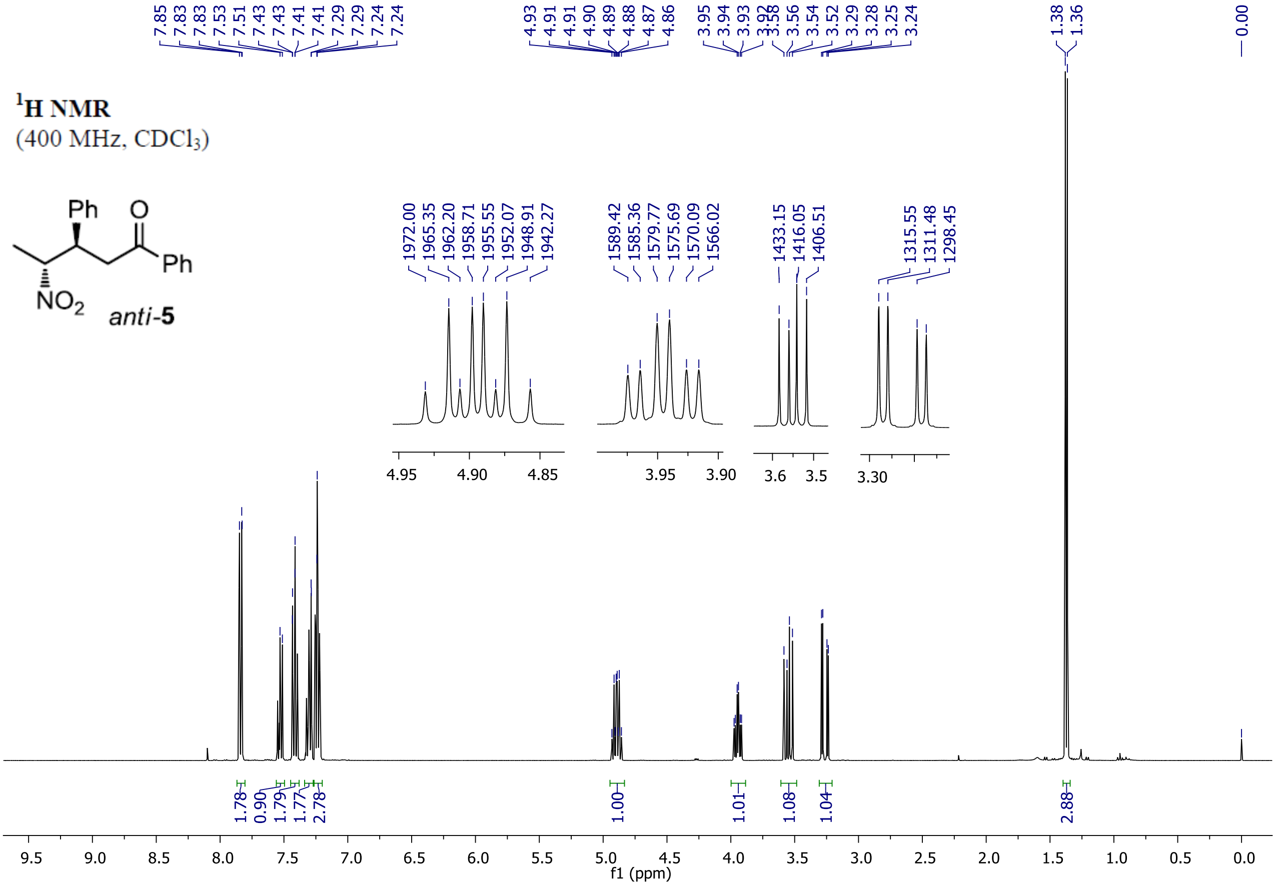




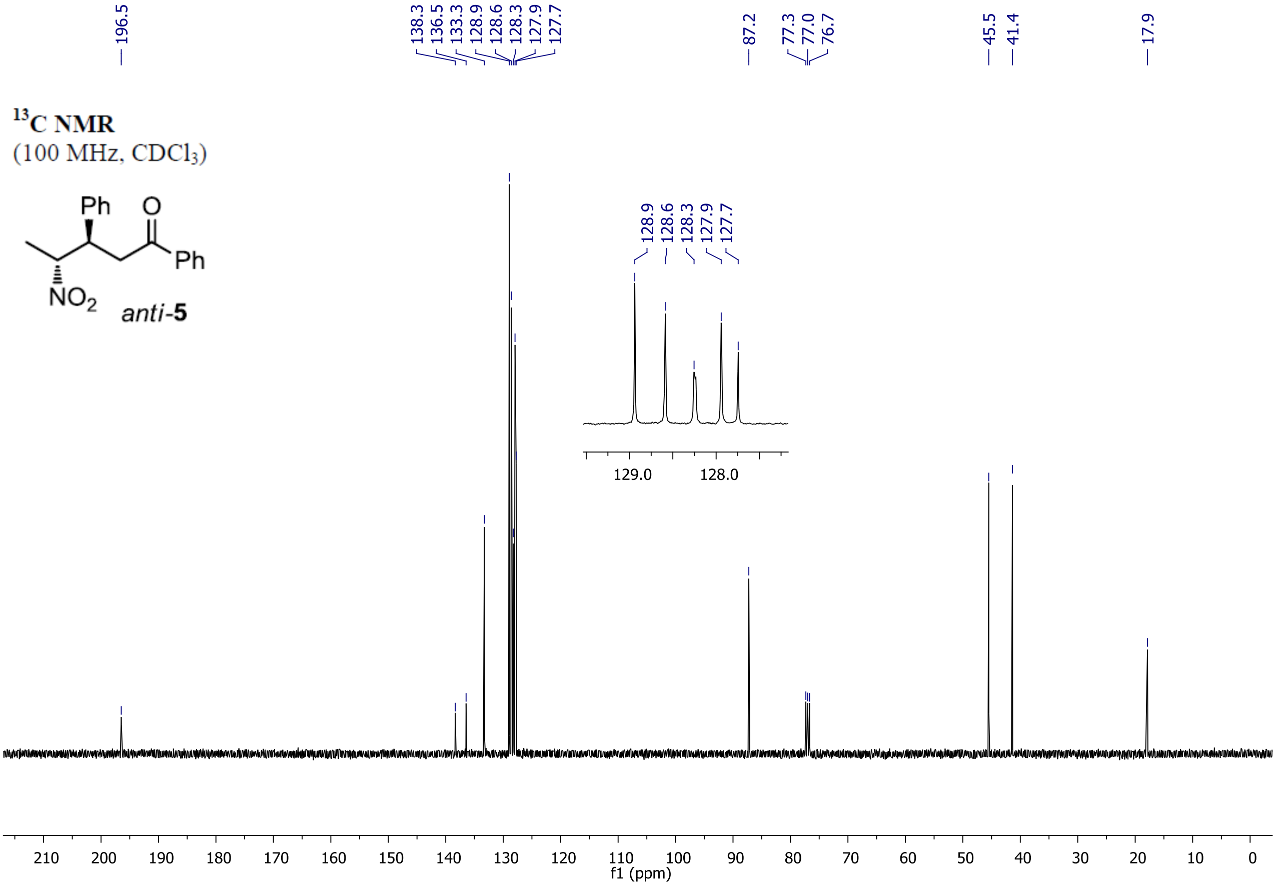
7.88
7.86
7.55
7.45
7.43
7.42
7.26
7.17
7.17
7.16
7.15
6.95
6.94
6.94
6.94
6.92
6.91
6.91
6.90
4.55
4.55
4.53
4.52
3.67
3.65
3.63
3.60
3.20
3.19
3.16
3.15
1.71
1.60
-0.00
1H NMR
(400 MHz, CDCl3)
S
O
O2N
Ph
4i
2866.81
2865.74
2861.73
2860.70
2777.82
2776.77
2774.30
2773.49
2766.43
2762.85
2761.36
2757.81
1821.36
1818.46
1810.79
1807.88
1468.38
1457.79
1451.30
1440.72
1279.54
1276.59
1262.47
1259.52
7.15
7.10
7.05
7.00
6.95
6.90
4.55
4.50
3.68
3.60
3.20
3.12
1.77
0.94
1.83
0.87
1.81
1.00
1.12
1.08
2.82
3.07
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)



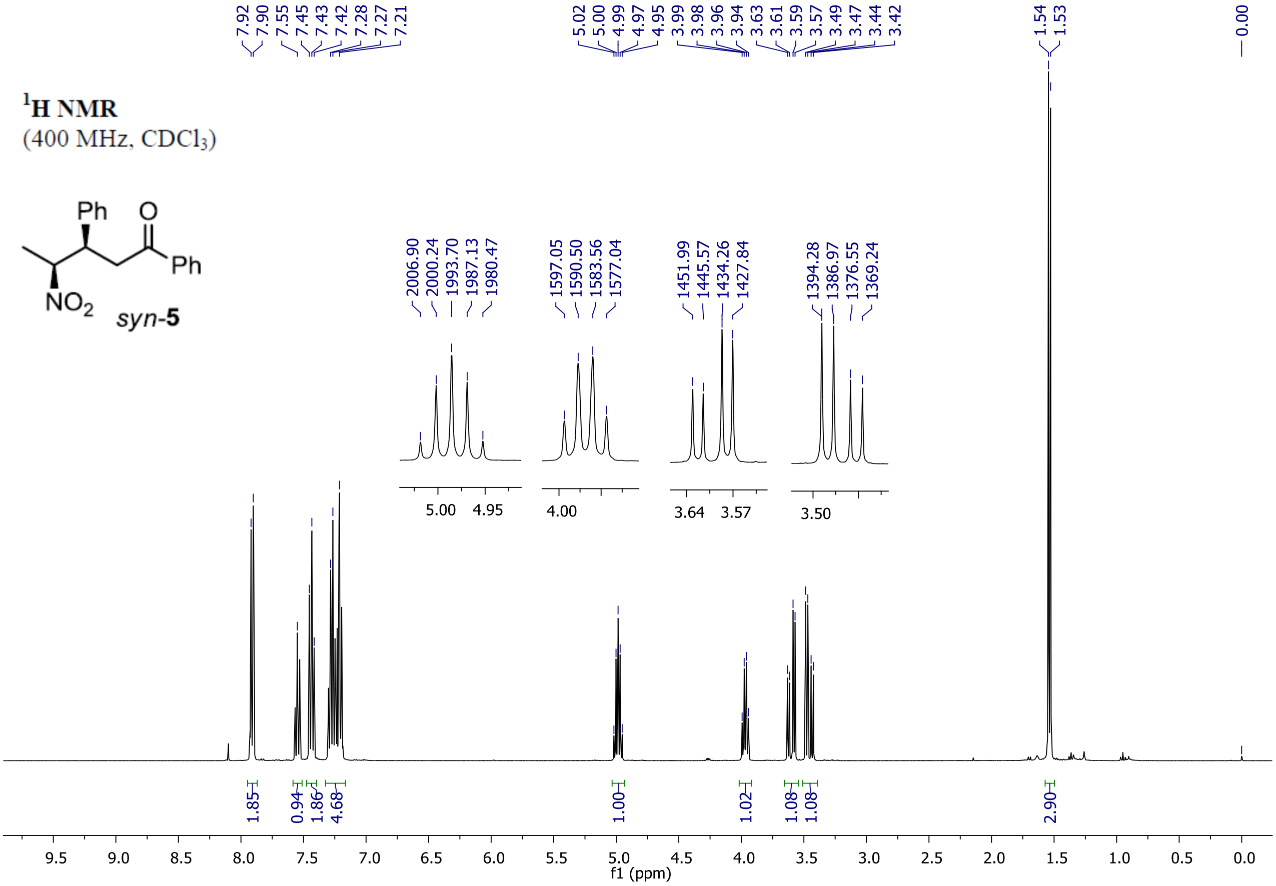
196.1
140.5
136.5
133.3
128.6
128.0
127.4
126.8
124.8
91.1
77.3
77.0
76.7
44.4
40.8
26.0
22.6
13C NMR
(100 MHz, CDCl3)
S
O
O2N
Ph
4i
140.5
136.5
133.3
128.6
128.0
127.4
126.8
124.8
140
138
136
134
132
130
128
126
124
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)



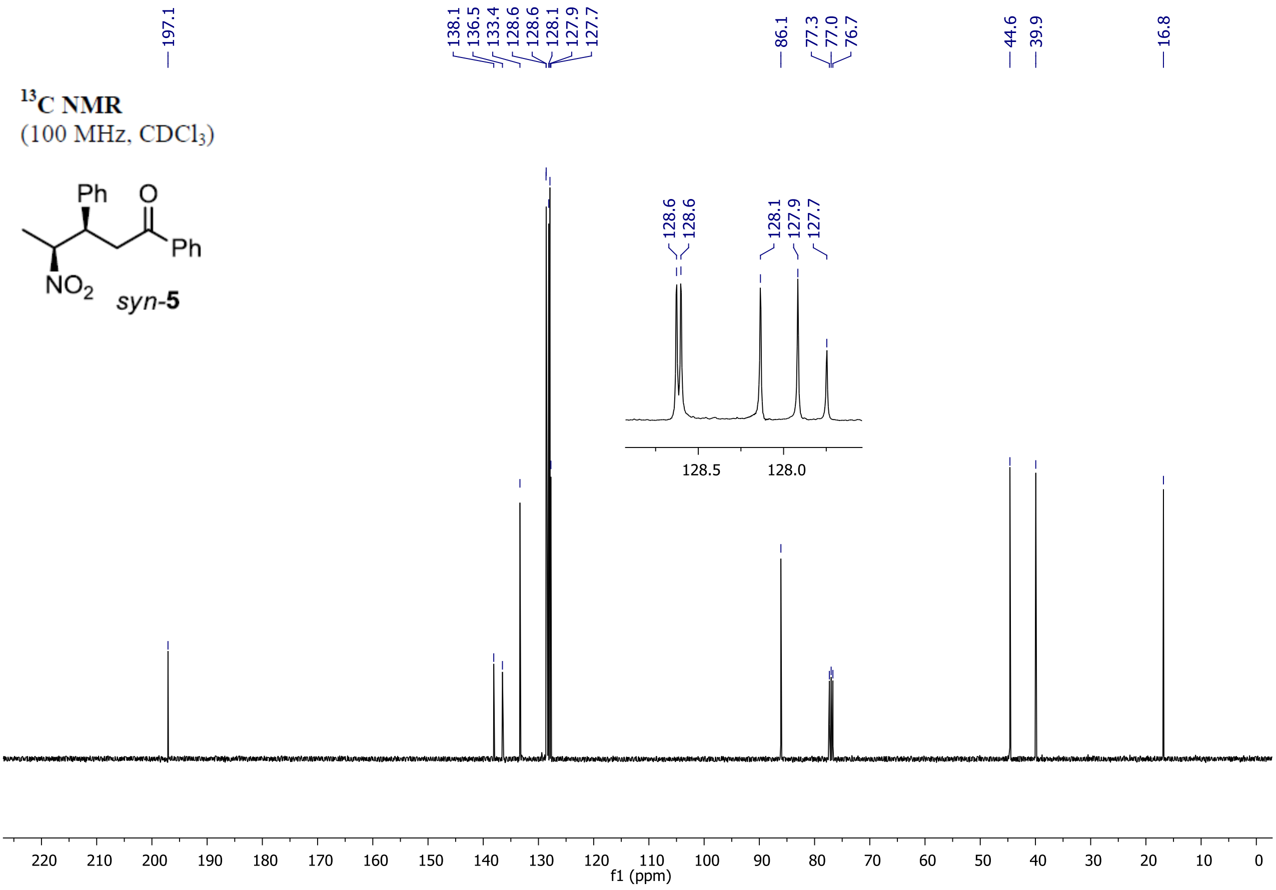
7.85
7.83
7.83
7.53
7.51
7.43
7.43
7.41
7.41
7.29
7.29
7.24
7.24
4.93
4.91
4.91
4.90
4.89
4.88
4.87
4.86
3.95
3.94
3.93
3.92
3.58
3.56
3.54
3.52
3.29
3.28
3.25
3.24
1.38
1.36
0.00
^{1}H NMR
(400 MHz, CDCl$_3$)
Ph
O
Ph
NO$_2$
anti-5
1972.00
1965.35
1962.20
1958.71
1955.55
1952.07
1948.91
1942.27
1589.42
1585.36
1579.77
1575.69
1570.09
1566.02
1433.15
1416.05
1406.51
1315.55
1311.48
1298.45
4.95
4.90
4.85
3.95
3.90
3.6
3.5
3.30
1.78
0.90
1.79
1.77
2.78
1.00
1.01
1.08
1.04
2.88
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)



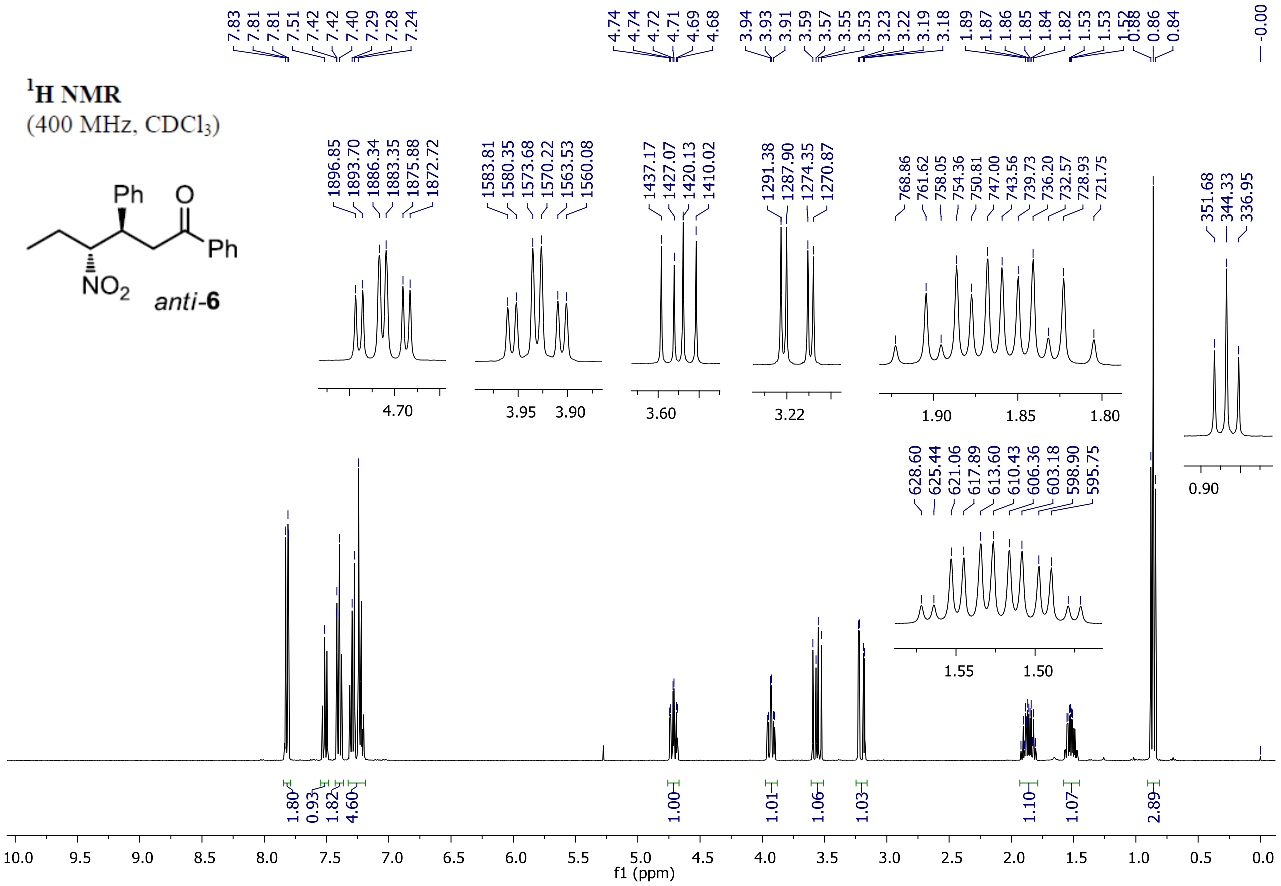
196.5
138.3
136.5
133.3
128.9
128.6
128.3
127.9
127.7
87.2
77.3
77.0
76.7
45.5
41.4
17.9
^{13}C NMR
(100 MHz, CDCl$_3$)
Ph
O
Ph
NO$_2$
anti-5
128.9
128.6
128.3
127.9
127.7
129.0
128.0
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

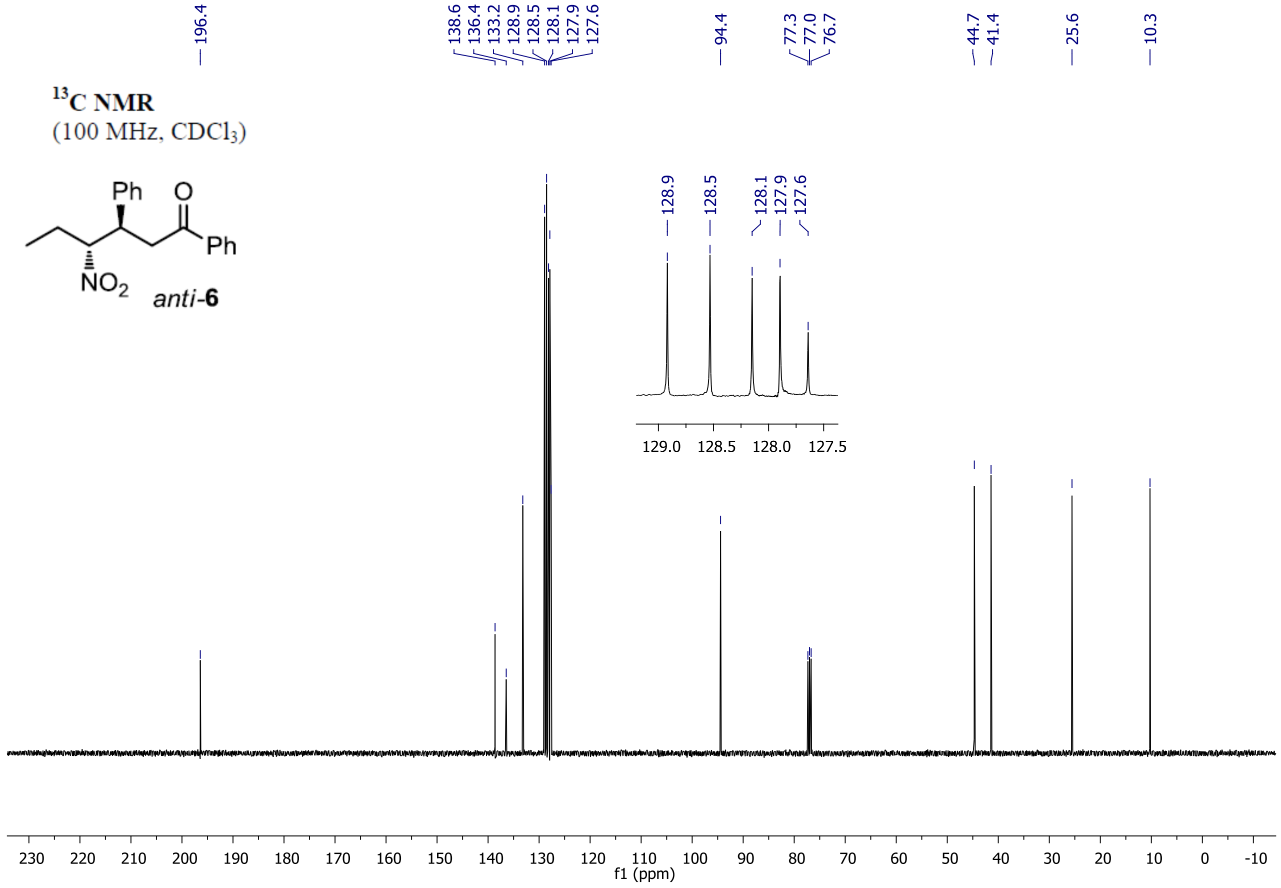

^{1}H NMR
(400 MHz, $CDCl_3$)

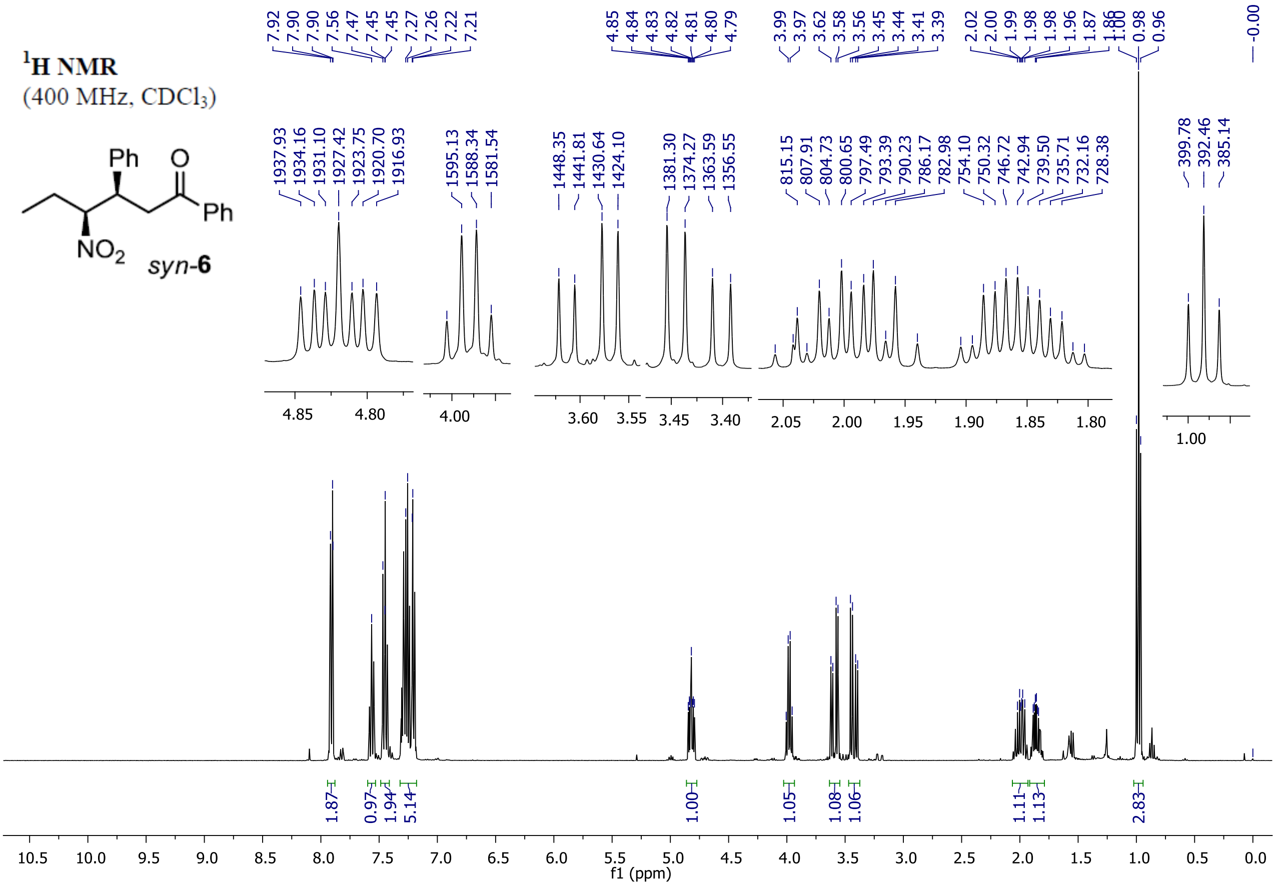
syn-**5**


^{13}C NMR
(100 MHz, $CDCl_3$)

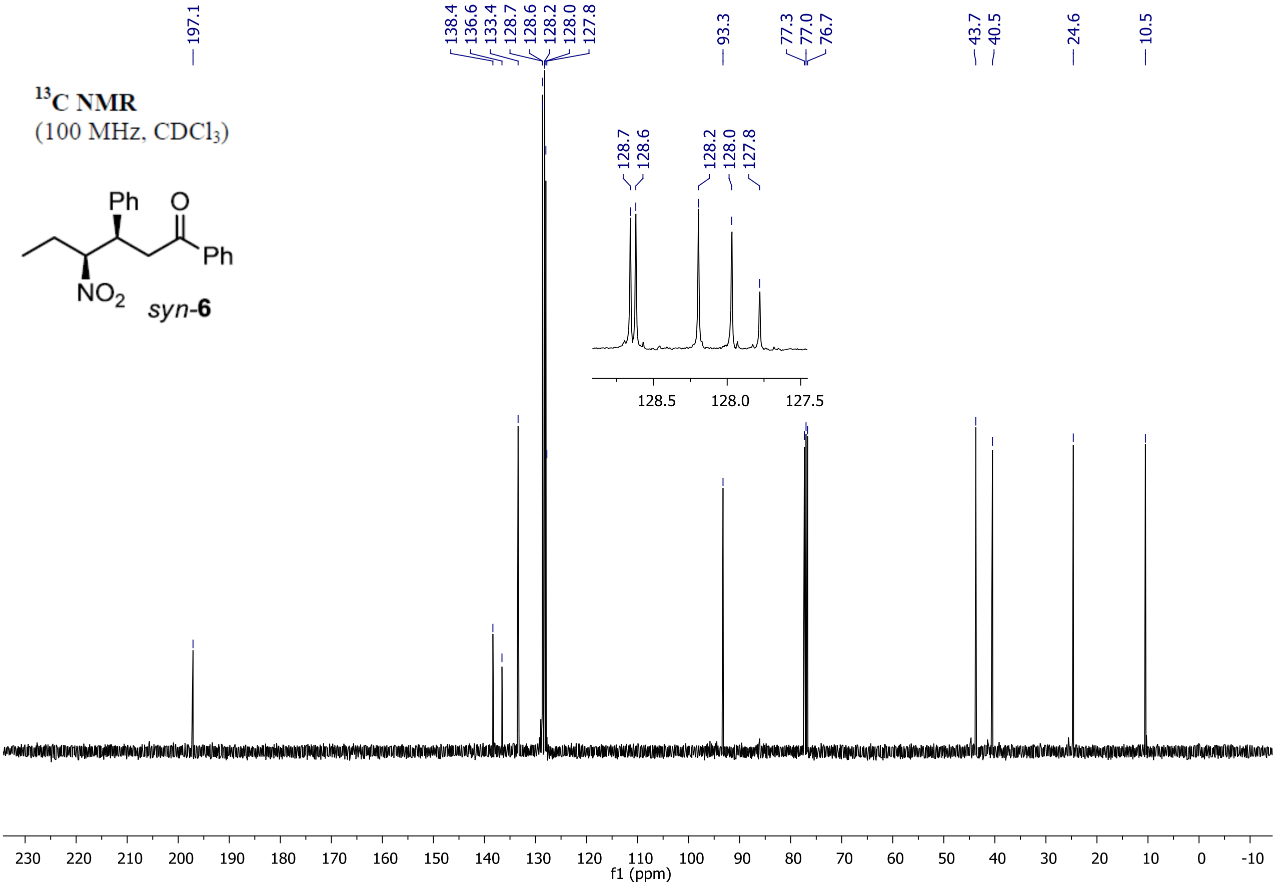
syn-**5**


1H NMR
(400 MHz, CDCl3)
Ph
O
Ph
NO2
anti-6
7.83 7.81 7.81 7.51 7.42 7.42 7.40 7.29 7.28 7.24
4.74 4.74 4.72 4.71 4.69 4.68
3.94 3.93 3.91
3.59 3.57 3.55 3.53
3.23 3.22 3.19 3.18
1.89 1.87 1.86 1.85 1.84 1.82
1.53 1.53 1.52
0.88 0.86 0.84
-0.00
1896.85 1893.70 1886.34 1883.35 1875.88 1872.72
1583.81 1580.35 1573.68 1570.22 1563.53 1560.08
1437.17 1427.07 1420.13 1410.02
1291.38 1287.90 1274.35 1270.87
768.86 761.62 758.05 754.36 750.81 747.00 743.56 739.73 736.20 732.57 728.93 721.75
351.68 344.33 336.95
628.60 625.44 621.06 617.89 613.60 610.43 606.36 603.18 598.90 595.75
4.70
3.95 3.90
3.60
3.22
1.90 1.85 1.80
0.90
1.55 1.50
1.80 0.93 1.82 4.60 1.00 1.01 1.06 1.03 1.10 1.07 2.89
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


13C NMR
(100 MHz, CDCl3)
Ph
O
Ph
NO2
anti-6
196.4
138.6 136.4 133.2 128.9 128.5 128.1 127.9 127.6
94.4
77.3 77.0 76.7
44.7 41.4
25.6
10.3
128.9 128.5 128.1 127.9 127.6
129.0 128.5 128.0 127.5
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



^{1}H NMR
(400 MHz, CDCl$_3$)
Ph
O
Ph
NO$_2$
syn-6
7.92 7.90 7.90 7.56 7.47 7.45 7.45 7.27 7.26 7.22 7.21
4.85 4.84 4.83 4.82 4.81 4.80 4.79
3.99 3.97 3.62 3.58 3.56 3.45 3.44 3.41 3.39
2.02 2.00 1.99 1.98 1.98 1.96 1.87 1.86 1.00 0.98 0.96
-0.00
1937.93 1934.16 1931.10 1927.42 1923.75 1920.70 1916.93
1595.13 1588.34 1581.54
1448.35 1441.81 1430.64 1424.10
1381.30 1374.27 1363.59 1356.55
815.15 807.91 804.73 800.65 797.49 793.39 790.23 786.17 782.98 754.10 750.32 746.72 742.94 739.50 735.71 732.16 728.38
399.78 392.46 385.14
4.85 4.80
4.00
3.60 3.55 3.45 3.40
2.05 2.00 1.95 1.90 1.85 1.80
1.00
1.87 0.97 1.94 5.14 1.00 1.05 1.08 1.06 1.11 1.13 2.83
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)



^{13}C NMR
(100 MHz, CDCl$_3$)
Ph
O
Ph
NO$_2$
syn-6
197.1
138.4 136.6 133.4 128.7 128.6 128.2 128.0 127.8
93.3
77.3 77.0 76.7
43.7 40.5
24.6
10.5
128.7 128.6 128.2 128.0 127.8
128.5 128.0 127.5
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)