A Dual Photoredox-Nickel Strategy for Remote Functionalization via Iminyl Radicals: Radical Ring-Opening–Arylation, –Vinylation and –Alkylation Cascades

Elizabeth M. Dauncey,[a]† Shashikant U. Dighe,[a]† James J. Douglas[b] and Daniele Leonori[a]*

[a] *School of Chemistry, University of Manchester, Oxford Road, Manchester M13 9PL, UK.*
[b] *Early Chemical Development, Pharmaceutical Sciences, R&D, AstraZeneca, Macclesfield SK10 2NA, UK.*
† These authors have contributed equally to this work.

daniele.leonori@manchester.ac.uk

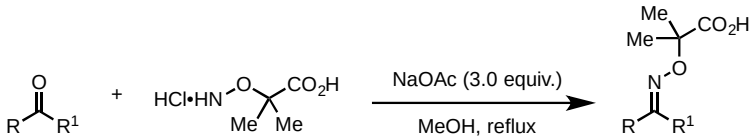
1 Table of Contents

2 General Experimental Details

All required fine chemicals were used directly without purification unless stated otherwise. All air and moisture sensitive reactions were carried out under nitrogen atmosphere using standard Schlenk manifold technique. THF was distilled from sodium/benzophenone, CH_2Cl_2 and was distilled from CaH_2, CH_3CN was distilled from activated 4Å molecular sieves, EtN(*i*-Pr)$_2$ was distilled over KOH. ^1H and ^{13}C Nuclear Magnetic Resonance (NMR) spectra were acquired at various field strengths as indicated and were referenced to $CHCl_3$ (7.26 and 77.0 ppm for ^1H and ^{13}C respectively). ^1H NMR coupling constants are reported in Hertz and refer to apparent multiplicities and not true coupling constants. Data are reported as follows: chemical shift, integration, multiplicity (s = singlet, br s = broad singlet, d = doublet, t = triplet, q = quartet, qi = quintet, sx = sextet, sp = septet, m = multiplet, dd = doublet of doublets, etc.), proton assignment (determined by 2D NMR experiments: COSY, HSQC and HMBC) where possible. High-resolution mass spectra were obtained using a JEOL JMS-700 spectrometer or a Fissions VG Trio 2000 quadrupole mass spectrometer. Spectra were obtained using electron impact ionization (EI) and chemical ionization (CI) techniques, or positive electrospray (ES). Infra-red spectra were recorded using a JASCO FT/IR 410 spectrometer or using an ATI Mattson Genesis Seris FTIR spectrometer as evaporated films or liquid films. Analytical TLC: aluminum backed plates pre-coated (0.25 mm) with Merck Silica Gel 60 F254. Compounds were visualized by exposure to UV-light or by dipping the plates in permanganate ($KMnO_4$) stain followed by heating. Flash column chromatography was performed using Merck Silica Gel 60 (40–63 μm). All mixed solvent eluents are reported as v/v solutions. UV/Vis spectra were obtained using an Agilent 6453 spectrometer and 1 mm High Precision Cell made of quartz from Hellma Analytics. The LEDs used are Kessil H150-blue. All the reactions were conducted in CEM 10 mL glass microwave tubes.

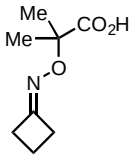
3 Starting Material Preparation

General Procedure for Oxime Preparation – GP1



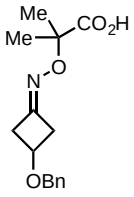
A solution of the ketone (1.0 equiv.) in MeOH (0.2 M) was treated with 1-carboxy-1-methylethoxyammonium chloride (1.5 equiv.), anhydrous NaOAc (3.0 equiv.) and heated under reflux until the reaction was judged complete by TLC analysis (1 to 6 h). The mixture was cooled to room temperature and diluted with K_2CO_3(aq) and Et_2O. The layers were separated and the organic layer washed with K_2CO_3(aq) (x 2). The combined aqueous extractions were then acidified with HCl (30% in H_2O) and extracted with CH_2Cl_2 (x 3). The combined organic layers were dried ($MgSO_4$), filtered and evaporated.

2-((Cyclobutylideneamino)oxy)-2-methylpropanoic Acid (1)



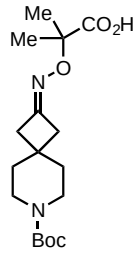
Following **GP1**, cyclobutanone (1.0 g, 14.3 mmol) gave **1** (1.757 g, 72%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.95 (4H, dd, *J* = 12.5, 7.8 Hz), 2.03 (2H, p, *J* = 8.1 Hz), 1.50 (6H, s); ^{13}C NMR (101 MHz, $CDCl_3$) δ 178.2, 162.2, 81.2, 32.2, 31.7, 24.6, 14.9. Data in accordance with the literature.[1]

2-(((3-(Benzyloxy)cyclobutylidene)amino)oxy)-2-methylpropanoic Acid (S1)



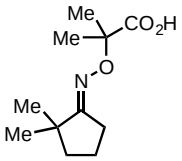
Following **GP1**, 3-(benzyloxy)cyclobutan-1-one (200 mg, 1.14 mmol) gave **S1** (252 mg, 80%) as an oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.39–7.28 (5H, m), 4.48 (2H, s), 4.26–4.20 (1H, m), 3.29–3.21 (1H, m), 3.20–3.13 (1H, m), 3.01–2.85 (2H, m), 1.50 (3H, s), 1.49 (3H, s); ^{13}C NMR (126 MHz, $CDCl_3$) δ 178.7, 149.8, 130.2, 128.7, 127.8, 127.3, 81.7, 73.8, 73.2, 71.2, 37.7, 35.0, 24.1; HRMS (ASAP) Found MH^+ 278.1385, $C_{15}H_{20}NO_4$ requires 278.1387.

2-(((7-(*tert*-Butoxycarbonyl)-7-azaspiro[3.5]nonan-2-ylidene)amino)oxy)-2-methylpropanoic acid (S2)



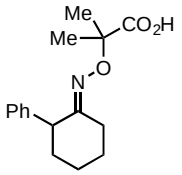
Following **GP1**, *tert*-Butyl 2-oxo-7-azaspiro[3.5]nonane-7-carboxylate (0.5 g, 2.1 mmol) gave **S2** (654 mg, 92%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 3015, 1682, 1435, 1355, 1215, 1173; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.97 (1H, br s), 3.41–3.27 (4H, m), 2.67 (2H, s), 2.63 (2H, s), 1.58 (4H, t, *J* = 5.6 Hz), 1.48 (6H, s), 1.43 (9H, s); ^{13}C NMR (101 MHz, $CDCl_3$) δ 179.1, 156.4, 155.0, 80.8, 79.8, 41.9, 41.2, 36.5, 33.4, 28.5, 24.2; HRMS (ESI) Found MH^- 339.1925, $C_{17}H_{28}N_2O_5$ requires 339.1920.

2-(((2,2-Dimethylcyclopentylidene)amino)oxy)-2-methylpropanoic Acid (S3)



Following **GP1**, 2,2-dimethylcyclopentanone (0.22 mL, 1.79 mmol) gave **S3** (381 mg, quant.) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.54 (2H, t, *J* = 7.5 Hz), 1.82–1.74 (2H, m), 1.64 (2H, t, *J* = 6.9 Hz), 1.49 (6H, s), 1.16 (6H, s); ^{13}C NMR (101 MHz, $CDCl_3$) δ 176.6, 175.1, 81.1, 42.8, 40.7, 27.7, 26.4, 24.3, 20.8. Data in accordance with the literature.[1]

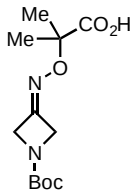
2-((Cyclohexylideneamino)oxy)-2-methylpropanoic Acid (S4)



Following **GP1**, 2-phenylcyclohexan-1-one (500 mg, 2.87 mmol) gave **S4** (552 mg, 70%) as an oil. ^{1}H NMR (500 MHz, $CDCl_3$, *E/Z* isomers) δ 7.34–7.14 (5H, m), 4.74 (0.4H, br s), 3.56 (0.6H, dd, *J* = 8.4, 6.7 Hz), 2.82–2.71 (0.6H, m), 2.39–2.22 (1.4H, m), 2.16–1.88 (2H, m), 1.84–1.66 (2H, m), 1.61–1.41 (2H, m), 1.32 (1.2H, s), 1.3 (1.8H, s); ^{13}C NMR (101 MHz, $CDCl_3$) δ 180.7, 180.6, 162.6, 162.3, 141.3, 140.1, 128.6, 128.5, 128.3, 127.4, 126.5, 126.1,

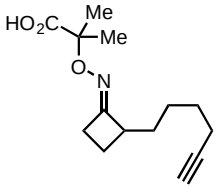
82.3, 82.3, 47.2, 37.7, 33.5, 26.7, 25.9, 25.5, 25.4, 25.1, 24.9, 24.5, 23.8. Data in accordance with the literature.[1]

2-(((1-(*tert*-Butoxycarbonyl)azetidin-3-ylidene)amino)oxy)-2-methylpropanoic acid (S5)

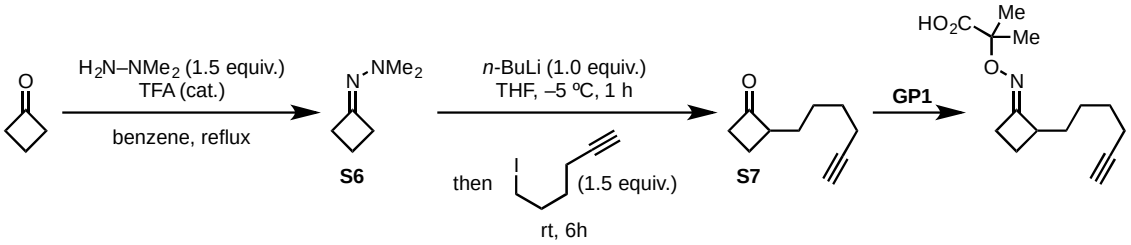


Following **GP1**, *tert*-butyl 3-oxoazetidine-1-carboxylate (0.5 g, 2.3 mmol) gave **S5** (450 mg, 86%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 2995, 1690, 1532,1171, 974, 755; ^{1}H NMR (400 MHz, $CDCl_3$) δ 11.20 (1H, br s), 4.63 (4H, dd, *J* = 8.2, 2.9 Hz), 1.51 (6H, s), 1.45 (9H, s); ^{13}C NMR (101 MHz, $CDCl_3$) δ 179.0, 156.4, 149.0, 81.6, 80.9, 58.38, 28.4, 24.0; HRMS (ESI) Found MH^- 271.1298, $C_{12}H_{20}N_2O_5$ requires 271.1294.

(*E*)-2-(((2-(Hex-5-yn-1-yl)cyclobutylidene)amino)oxy)-2-methylpropanoic Acid (44)



This compound was prepared using the following procedure:



2-Cyclobutylidene-1,1-dimethylhydrazine (S6)

A solution of cyclobutanone (3.2 mL, 42 mmol, 1.0 equiv.) in benzene (75 mL) was treated with *N*,*N*-dimethylhydrazine (2.7 mL, 64 mmol, 1.5 equiv.) and TFA (5 drops). The mixture was heated under reflux in a Dean-Stark apparatus for 16 h. The mixture was cooled to r.t. and diluted with Et_2O (50 mL) and H_2O (30 mL). The aqueous layer was extracted with Et_2O (2 × 30 mL). The combined organic phases were washed NaCl(aq) (20 mL), dried ($MgSO_4$), filtered and evaporated. Distillation under reduced pressure (76 °C, 10 mbar) gave **S6** (3.8 g, 84%) as a liquid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.95 (2H, t, *J* = 8.0Hz), 2.89 (2H, t, *J* = 8.0 Hz), 2.55 (6H, s), 1.94 (2H, qt, *J* = 8.0 Hz, 4.0

Hz); ^{13}C NMR (101 MHz, $CDCl_3$) δ 160.4, 46.8, 35.7, 35.2, 14.4. Data in accordance with the literature.[2]

2-(Hex-5-yn-1-yl)cyclobutan-1-one (S7)

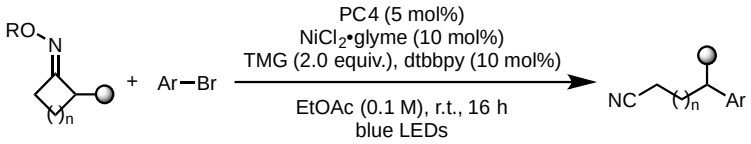
S6 (1.5 g, 13.3 mmol, 1 equiv.) was dissolved in dry THF (30 mL), cooled to –5 °C and treated, dropwise, with *n*-BuLi (8.0 mL, 1.5 equiv., 2.5M in hexane). The mixture was stirred for 1 h at –5 °C and 6-iodo-1-hexyne (2.6 mL, 20.0 mmol, 1.5 equiv.) was added. After 1 h, the mixture was warmed to r.t. and stirred for 6 h. The mixture was diluted with HCl(aq) (15 mL, 10%) and stirred overnight. The aqueous layer was extracted with EtOAc (5 × 30 mL). The combined organic layers were washed with $NaHCO_3$(aq) (30 mL), $Na_2S_2O_3$(aq) (30 mL) and NaCl(aq) (30 mL). The combined organic layers were dried ($MgSO_4$), filtered, and evaporated. The crude product was used in the next step without further purification.

(*E*)-2-(((2-(Hex-5-yn-1-yl)cyclobutylidene)amino)oxy)-2-methylpropanoic Acid (44)

Following **GP1**, **S7** (0.4 g, 2.6 mmol) gave **44** (448 mg, 67%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 3095, 2241, 1710, 1131, 836, 744; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.47 (1H, br s), 2.65–2.38 (7H, m), 2.01 (1H, t, *J* = 2.6 Hz), 1.92–1.82 (2H, m), 1.66–1.42 (8H, m), 1.20–1.10 (2H, m); ^{13}C NMR (101 MHz, $CDCl_3$) δ 177.9, 172.0, 82.3, 80.9, 69.3, 38.6, 34.1, 33.3, 28.1, 24.5, 24.3, 22.6, 17.1, 14.2; HRMS (ESI) Found MNa^+ 274.1418, $C_{14}H_{21}O_3NNa$ requires 274.1419.

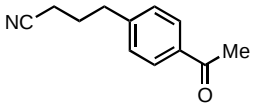
4 Ring-Opening–Arylation Cascades

General Procedure for Ring-Opening–Arylation Cascades – GP2



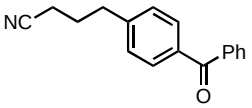
To an oven dried microwave vial, was added the oxime (1.5 equiv.), $[Ir(dtbbpy)(ppy)_2](PF_6)$ (5 mol%), and, if solid, the aryl bromide (1.0 equiv.). The microwave vial was sealed and evacuated and back-filled with nitrogen (3 cycles). A separate microwave vial was charged with $NiCl_2$•glyme (10 mol%) and ligand (10 mol%). This vial was evacuated and back-filled with nitrogen (3 cycles) then the solvent (0.1M) was added and the mixture stirred for 10-15 mins. The Ni mixture was then added to the other microwave vial along with TMG (2 eq.), and this resulting solution was degassed with nitrogen. If liquid, the aryl bromide (1.0 equiv) was added, the lid sealed with parafilm and the vial irradiated with a blue lamp and cooled with a fan for 16h. The reaction was diluted with brine (5 mL), and extracted with EtOAc (3 x 15 mL). The layers were separated and the combined organic layers were dried ($MgSO_4$), filtered and evaporated. The residue was purified by column chromatography on silica gel.

4-(4-Acetylphenyl)butanenitrile (3)



Following **GP2** running the reaction in EtOAc, 1-(4-bromophenyl)ethan-1-one (20 mg, 0.1 mmol) gave **3** (11 mg, 59%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.92 (2H, d, *J* = 8.3 Hz), 7.30 (2H, d, *J* = 8.2 Hz), 2.85 (2H, t, *J* = 7.5 Hz), 2.59 (3H, s), 2.36 (2H, t, *J* = 7.0 Hz), 2.06–1.98 (2H, m); ^{13}C NMR (101 MHz, $CDCl_3$) δ 197.6, 145.3, 135.5, 128.7, 128.6, 119.1, 34.2, 26.5, 26.4, 16.3. Data in accordance with the literature.[3]

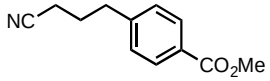
4-(4-Benzoylphenyl)butanenitrile (4)



Following **GP2** running the reaction in EtOAc, (4-bromophenyl)(phenyl)methanone (26 mg, 0.1 mmol) gave **4** (18 mg, 73%) as a solid. FT-IR ν_{max} (film)/cm^{-1} 2921, 2851, 1655, 1606, 1279; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.82–7.75 (4H, m), 7.60 (1H, t, *J* = 7.4 Hz), 7.49 (2H, t, *J* = 7.5 Hz), 7.31 (2H, d, *J* = 7.9 Hz), 2.88 (2H, t, *J* = 7.5 Hz), 2.37 (2H, t, *J* = 7.0 Hz), 2.09–

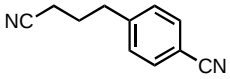
1.99 (2H, m); ^{13}C NMR (126 MHz, $CDCl_3$) δ 196.3, 144.7, 137.6, 136.0, 132.4, 130.6, 130.0, 128.4, 128.3, 119.2, 34.4, 26.6, 16.5; HRMS (ESI) Found MNa^+ 272.1042, $C_{17}H_{15}ONNa$ requires 272.1046.

Methyl 4-(3-cyanopropyl)benzoate (5)



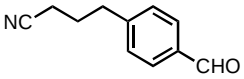
Following **GP2** running the reaction in DME, methyl 4-bromobenzoate (21 mg, 0.1 mmol) gave **5** (12 mg, 58%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.01–7.97 (2H, m), 7.28–7.24 (2H, m), 3.91 (3H, s), 2.84 (2H, t, *J* = 7.2 Hz), 2.06–1.96 (2H, m); ^{13}C NMR (101 MHz, $CDCl_3$) 166.8, 145.0, 129.9, 128.4, 119.2, 52.0, 34.3, 26.5, 26.5. Data in accordance with the literature.[4]

4-(3-Cyanopropyl)benzonitrile (6)



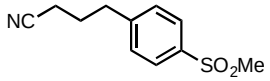
Following **GP2** running the reaction in DME, 4-bromobenzonitrile (18 mg, 0.1 mmol) gave **6** (13 mg, 76%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.61 (2H, d, *J* = 8.1 Hz), 7.31 (2H, d, *J* = 7.9 Hz), 2.85 (2H, d, *J* = 7.7 Hz), 2.36 (2H, t, *J* = 7.0 Hz), 2.06–1.93 (2H, m); ^{13}C NMR (101 MHz, $CDCl_3$) δ 145.3, 132.5, 129.2, 118.9, 118.7, 110.5, 34.4, 26.3, 16.5. Data in accordance with the literature.[4]

4-(4-Formylphenyl)butanenitrile (7)



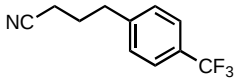
Following **GP2** running the reaction in DME, 4-bromobenzaldehyde (19 mg, 0.1 mmol) gave **7** (12 mg, 67%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.96 (1H, s), 7.84 (2H, dd, *J* = 8.2, 2.4 Hz), 7.37 (2H, d, *J* = 7.9 Hz), 2.88 (2H, t, *J* = 7.5 Hz), 2.36 (2H, t, *J* = 7.0 Hz), 2.07–1.98 (2H, m); ^{13}C NMR (101 MHz, $CDCl_3$) δ 191.8, 147.0, 134.9, 130.1, 129.1, 119.1, 34.4, 26.4, 16.4. Data in accordance with the literature.[5]

4-(4-(Methylsulfonyl)phenyl)butanenitrile (8)



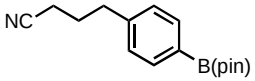
Following **GP2** running the reaction in EtOAc, 1-bromo-4-(methylsulfonyl)benzene (23 mg, 0.1 mmol) gave **2** (13 mg, 57%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 2957, 2924, 2849, 1305, 1148; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.90 (2H, d, *J* = 8.4 Hz), 7.41 (2H, d, *J* = 8.3 Hz), 3.05 (3H, s), 2.90 (2H, t, *J* = 7.5 Hz), 2.37 (2H, t, *J* = 7.0 Hz), 2.08–1.97 (2H, m); ^{13}C NMR (101 MHz, $CDCl_3$) δ 146.3, 139.0, 129.4, 127.9, 118.9, 44.6, 34.3, 26.5, 16.6; HRMS (ESI) Found MNa^+ 246.0557, $C_{11}H_{13}O_2NSNa$ requires 246.0559.

4-(4-(Trifluoromethyl)phenyl)butanenitrile (9)



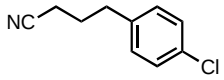
Following **GP2** running the reaction in DME, 1-bromo-4-chlorobenzene (22 mg, 0.1 mmol) gave **9** (13 mg, 59%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.56 (2H, d, *J* = 8.0 Hz), 7.30 (2H, d, *J* = 8.0 Hz), 2.85 (2H, t, *J* = 7.6 Hz), 2.35 (2H, t, *J* = 7.2 Hz), 2.04–1.96 (2H, m); ^{13}C NMR (126 MHz, $CDCl_3$) δ 143.8, 129.5, 128.8, 125.7 (q, *J* = 3.7 Hz), 124.1 (q, *J* = 271.0 Hz), 119.1, 34.2, 26.6, 16.5; ^{19}F NMR (376 MHz, $CDCl_3$) δ –62.4. Data in accordance with the literature.[4]

4-(4-(4,4,5,5-Tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl)butanenitrile (10)



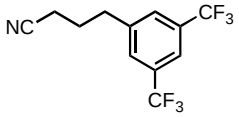
Following **GP2** running the reaction in EtOAc, 2-(4-bromophenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (56 mg, 0.2 mmol) gave **10** (11 mg, 38%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.76 (2H, d, *J* = 8.0 Hz), 7.20 (2H, d, *J* = 8.0 Hz), 2.79 (2H, t, *J* = 7.4 Hz), 2.31 (2H, t, *J* = 7.1 Hz), 2.07–1.92 (2H, m), 1.34 (12H, s); ^{13}C NMR (126 MHz, $CDCl_3$) δ 143.0, 135.2, 132.5, 127.9, 119.4, 83.8, 34.6, 26.8, 24.9, 16.4; HRMS (APCI) Found MH^+ 272.1809, $C_{16}H_{23}O_2NB$ requires 272.1816.

4-(4-Chlorophenyl)butanenitrile (11)



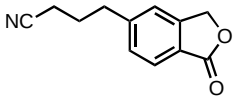
Following **GP2** running the reaction in DME, 1-bromo-4-(trifluoromethyl)benzene (19 mg, 0.1 mmol) gave **11** (5 mg, 25%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.30–7.25 (2H, m), 7.15–7.10 (2H, m), 2.76 (2H, t, *J* = 7.2 Hz), 2.32 (2H, t, *J* = 7.2 Hz), 2.20–1.90 (2H, m); ^{13}C NMR (126 MHz, $CDCl_3$) δ 138.0, 132.3, 129.7, 128.7, 119.3, 33.6, 26.7, 16.3. Data in accordance with the literature.[4]

4-(3,5-Bis(trifluoromethyl)phenyl)butanenitrile (13)



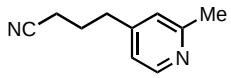
Following **GP2** running the reaction in EtOAc, 1-bromo-3,5-bis(trifluoromethyl)benzene (29 mg, 0.1 mmol) gave **13** (17 mg, 62%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 2928, 1381, 1278, 1173, 1131; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.77 (1H, s), 7.66 (2H, s), 3.00–2.90 (2H, m), 2.41 (2H, t, *J* = 6.9 Hz), 2.10–2.00 (2H, m); ^{13}C NMR (126 MHz, $CDCl_3$) δ 142.2, 132.0 (q, *J* = 33.2 Hz), 128.5, 123.2 (q, *J* = 272.6 Hz), 120.8 (p, *J* = 3.9 Hz), 118.7, 34.2, 26.6, 16.7; ^{19}F NMR (471 MHz, $CDCl_3$) δ –62.9; HRMS (ESI) Found M^- 280.0567, $C_{12}H_8NF_6$ requires 280.0566.

4-(1-Oxo-1,3-dihydroisobenzofuran-5-yl)butanenitrile (14)



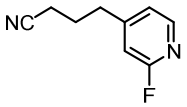
Following **GP2** running the reaction in EtOAc, 5-bromoisobenzofuran-1(3*H*)-one (21 mg, 0.1 mmol) gave **14** (11 mg, 56%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 2916, 2851, 1759, 1044; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.88 (1H, d, *J* = 7.8 Hz), 7.37 (1H, d, *J* = 7.9 Hz), 7.33 (1H, s), 5.31 (2H, s), 2.94 (2H, t, *J* = 7.4 Hz), 2.38 (2H, t, *J* = 6.9 Hz), 2.09–2.00 (2H, m); ^{13}C NMR (126 MHz, $CDCl_3$) δ 170.7, 147.4, 146.9, 129.6, 126.1, 124.4, 122.0, 118.9, 69.4, 34.7, 26.7, 16.6; HRMS (ESI) Found MNa^+ 224.0681, $C_{12}H_{11}O_2NNa$ requires 224.0682.

4-(2-Methylpyridin-4-yl)butanenitrile (16)



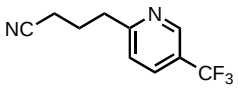
In this case, the reaction was run using **GP2** but using ($Ir[dF(CF_3)ppy]_2(dtbpy))(PF_6$) as the photocatalyst, $NiCl_2$•glyme as the nickel catalyst, 4,4'-dimethyl-2,2'-dipyridyl as the ligand in DMF, 4-bromo-2-methylpyridine (17 mg, 0.1 mmol) gave **16** (8 mg, 47%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 2925, 2852, 1606, 1214; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.42 (1H, d, *J* = 5.2 Hz), 7.00 (1H, s), 6.93 (1H, d, *J* = 5.4 Hz), 2.75 (2H, t, *J* = 7.6 Hz), 2.54 (3H, s), 2.35 (2H, t, *J* = 7.0 Hz), 2.04–1.96 (2H, m); ^{13}C NMR (126 MHz, $CDCl_3$) δ 158.8, 149.4, 148.8, 123.3, 120.8, 119.0, 33.6, 25.9, 24.4, 16.5; HRMS (ESI) Found MNa^+ 183.0892, $C_{10}H_{12}N_2Na$ requires 183.0893.

4-(2-Fluoropyridin-4-yl)butanenitrile (17)



In this case, the reaction was run using **GP2** but using ($Ir[dF(CF_3)ppy]_2(dtbpy))(PF_6$) as the photocatalyst, $NiCl_2$•glyme as the nickel catalyst, 4,4'-dimethyl-2,2'-dipyridyl as the ligand in DMF, 4-bromo-2-fluoropyridine (18 mg, 0.1 mmol) gave **17** (11 mg, 62%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 2921, 2851, 1613, 1413; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.16 (1H, d, *J* = 5.1 Hz), 7.08–6.98 (1H, m), 6.86–6.71 (1H, m), 2.90–2.78 (2H, m), 2.39 (2H, t, *J* = 7.0 Hz), 2.07–1.97 (2H, m); ^{13}C NMR (126 MHz, $CDCl_3$) δ 164.2 (d, *J* = 239.0 Hz), 154.6 (d, *J* = 7.5 Hz), 147.9 (d, *J* = 15.3 Hz), 121.5 (d, *J* = 4.0 Hz), 118.7, 109.2 (d, *J* = 36.8 Hz), 33.5 (d, *J* = 3.1 Hz), 25.7, 16.6; ^{19}F NMR (471 MHz, $CDCl_3$) δ –68.0; HRMS (ESI) Found MH^+ 165.0820, $C_9H_{10}N_2F$ requires 165.0823.

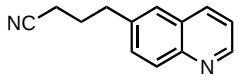
4-(5-(Trifluoromethyl)pyridin-2-yl)butanenitrile (18)



In this case, the reaction was run using **GP2** but using ($Ir[dF(CF_3)ppy]_2(dtbpy))(PF_6$) as the photocatalyst, $NiCl_2$•glyme as the nickel catalyst, 4,4'-dimethyl-2,2'-dipyridyl as the ligand in DMF, 2-Bromo-5-(trifluoromethyl)pyridine (22 mg, 0.1 mmol) gave **18** (12 mg, 56%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.80–8.65 (1H, m), 7.80 (1H, dd, *J* = 8.1 Hz), 7.30 (1H, d, *J* = 8.1 Hz), 3.04 (2H, t, *J* = 7.4 Hz), 2.44 (2H, t, *J* = 7.0 Hz), 2.24–2.09 (2H, m); ^{13}C NMR

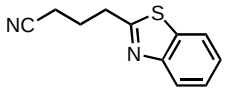
(101 MHz, $CDCl_3$) δ 161.2 (q, *J* = 1.4 Hz), 147.3 (q, *J* = 4.0 Hz), 133.7 (q, *J* = 3.5 Hz), 124.5 (q, *J* = 33.1 Hz), 123.6 (q, *J* = 272.3 Hz), 122.9, 119.2, 36.2, 24.4, 16.6. Data in accordance with the literature.[6]

4-(Quinolin-6-yl)butanenitrile (19)



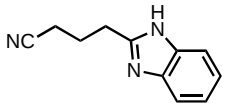
Following **GP2** running the reaction in EtOAc but using K_2CO_3 as the base, 6-bromoquinoline (21 mg, 0.1 mmol) gave **19** (10 mg, 51%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 2931, 2855, 1610, 1217; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.89 (1H, dd, *J* = 4.3, 1.7 Hz), 8.12 (1H, dt, *J* = 8.4, 1.2 Hz), 8.07 (1H, d, *J* = 8.7 Hz), 7.63 (1H, s), 7.56 (1H, dd, *J* = 8.6, 2.0 Hz), 7.41 (1H, dd, *J* = 8.3, 4.2 Hz), 2.99 (2H, t, *J* = 7.4 Hz), 2.37 (2H, t, *J* = 7.0 Hz), 2.15–2.05 (2H, m); ^{13}C NMR (126 MHz, $CDCl_3$) δ 150.2, 147.3, 138.0, 135.6, 130.4, 129.9, 128.3, 126.7, 121.4, 119.3, 34.3, 26.7, 16.5; HRMS (ESI) Found MNa^+ 219.0890, $C_{13}H_{12}N_2Na$ requires 219.0893.

4-(Benzo[*d*]thiazol-2-yl)butanenitrile (20)



Following **GP2** running the reaction in EtOAc, 2-bromobenzo[*d*]thiazole (21 mg, 0.1 mmol) gave **20** (15 mg, 75%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) 7.96 (1H d, *J* = 8.1 Hz), 7.81 (1H, t, *J* = 8.2 Hz), 7.50–7.44 (1H, m), 7.40–7.35 (1H, m), 3.27 (2H, t, *J* = 7.2 Hz), 2.55 (2H, t, *J* = 7.1 Hz), 2.33–2.24 (2H, m); ^{13}C NMR (101 MHz, $CDCl_3$) δ 168.5, 152.9, 134.7, 125.9, 124.8, 122.4, 121.3, 118.8, 32.1, 24.4, 16.2. Data in accordance with the literature.[7]

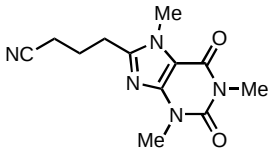
4-(1*H*-Benzo[*d*]imidazol-2-yl)butanenitrile (21)



In this case, the reaction was run using **GP2** but using ($Ir[dF(CF_3)ppy]_2(dtbpy))(PF_6$) as the photocatalyst, $NiCl_2$•glyme as the nickel catalyst, 4,4'-dimethyl-2,2'-dipyridyl as the ligand in DMF, 2-bromo-1*H*-benzo[*d*]imidazole (20gm, 0.1 mmol) gave **21** (10 mg, 55%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 2923, 2854, 1456, 1214; ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.03 (1H, br s), 7.71 (1H, br s), 7.42 (1H, br. s), 3.09 (2H, t, *J* = 7.1 Hz), 2.56 (2H, t, *J* = 6.9 Hz), 2.34–

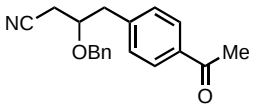
2.25 (2H, m); ^{13}C NMR (126 MHz, $CDCl_3$) δ 151.8, 119.2, 118.7, 27.5, 23.3, 16.6; HRMS (ESI) Found MNa^+ 208.0845, $C_{11}H_{11}N_3Na$ required 208.0845.

4-(1,3,7-Trimethyl-2,6-dioxo-2,3,6,7-tetrahydro-1*H*-purin-8-yl)butanenitrile (22)



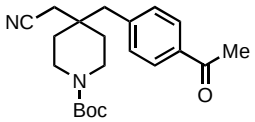
Following modified **GP2** running the reaction in DME but using $NiCl_2$•dtbbpy **S7**, 8-bromo-1,3,7-trimethyl-3,7-dihydro-1*H*-purine-2,6-dione (27 mg, 0.1 mmol) gave **22** (12 mg, 46%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.94 (3H, s), 3.55 (3H, s), 3.40 (3H, s), 2.89 (2H, t, *J* = 7.1 Hz), 2.59 (2H, t, *J* = 6.9 Hz), 2.22 (2H, p, *J* = 7.0 Hz); ^{13}C NMR (126 MHz, $CDCl_3$) δ 155.3, 151.6, 151.5, 147.7, 118.9, 107.5, 31.6, 29.7, 27.9, 24.8, 22.5, 16.8; HRMS (ESI) Found MNa^+ 284.1113, $C_{12}H_{15}O_2N_5Na$ requires 284.1118. Data in accordance with literature.[7]

4-(4-Acetylphenyl)-3-(benzyloxy)butanenitrile (23)



Following **GP2** running the reaction in EtOAc, **S1** (56 mg, 0.2 mmol) gave **23** (12 mg, 20%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.91 (2H, d, *J* = 8.2 Hz), 7.36–7.29 (5H, m), 7.26–7.22 (2H, m), 4.59 (1H, d, *J* = 11.7 Hz), 4.51 (1H, d, *J* = 11.7 Hz), 3.91 (1H, p, *J* = 5.9 Hz), 3.08 (1H, dd, *J* = 13.9, 6.8 Hz), 2.98 (1H, dd, *J* = 13.8, 5.9 Hz), 2.61 (3H, s), 2.53 (1H, dd, *J* = 16.8, 5.4 Hz), 2.47 (1H, dd, *J* = 16.8, 5.5 Hz); ^{13}C NMR (126 MHz, $CDCl_3$) δ 197.7, 142.2, 137.0, 136.0, 129.8, 128.7, 128.6, 128.1, 127.8, 117.2, 75.0, 72.2, 40.3, 26.6, 22.7; HRMS (ESI) Found MNa^+ 316.1304, $C_{19}H_{19}O_2NNa$ requires 316.1308.

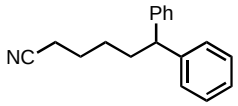
***tert*-Butyl 4-(4-acetylbenzyl)-4-(cyanomethyl)piperidine-1-carboxylate (24)**



Following **GP2** running the reaction in EtOAc, 4′-bromoacetophenone (20 mg, 0.1 mmol) gave **24** (22 mg, 62%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 2941, 2836, 2232, 1780, 1730, 1621, 1587, 1325, 974; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.91 (2H, d, *J* = 7.8 Hz,), 7.29 (2H, d, *J* = 7.9

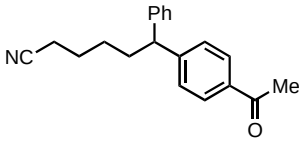
Hz), 3.64 (2H, dt, *J* = 12.1, 5.0 Hz), 3.29 (2H, ddd, *J* = 13.6, 8.6, 3.9 Hz), 2.87 (2H, s), 2.59 (3H, s), 2.23 (2H, s), 1.61 (2H, td, *J* = 8.5, 2.9 Hz), 1.52 (2H, ddd, *J* = 13.8, 6.4, 4.0 Hz), 1.45 (9H, s); ^{13}C NMR (101 MHz, $CDCl_3$) δ 197.7, 154.8, 141.6, 136.1, 130.7, 128.6, 117.7, 80.1, 43.3, 39.5, 35.8, 34.2, 28.5, 26.7, 25.0.; HRMS (ESI) Found MH^+ 357.2183, $C_{21}H_{29}N_2O_3$ requires 357.2178.

6,6-Diphenylhexanenitrile (26)



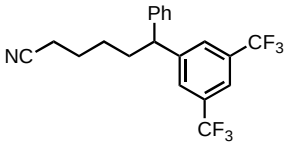
Following **GP2** running the reaction in EtOAc, bromobenzene (16 mg, 0.1 mmol) gave **26** (11 mg, 41%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.32–7.18 (8H, m), 7.12–7.09 (2H, m), 3.88 (1H, t, *J* = 7.8 Hz), 2.26–2.09 (2H, m), 2.03–1.95 (2H, m), 1.82–1.76 (2H, m), 1.39–1.34 (2H, m); ^{13}C NMR (101 MHz, $CDCl_3$) δ 143.6, 128.5, 128.4, 126.9, 126.2, 119.2, 51.1, 35.1, 27.8, 25.3, 16.6. Data in accordance with the literature.[8]

6-(4-Acetylphenyl)-6-phenylhexanenitrile (27)



Following **GP2** running the reaction in EtOAc, 4′-bromoacetophenone (20 mg, 0.1 mmol) gave **27** (17 mg, 56%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 2928, 2232, 1740, 1131,836; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85 (2H, d, *J* = 8.6 Hz), 7.38-7.28 (4H, m), 7.18-7.15 (3H, m), 3.93 (1H, t, *J* = 7.8 Hz), 2.61 (3H, s), 2.42–2.28 (2H, m), 2.09–2.01 (2H, m), 1.89–1.82 (2H, m), 1.51–1.38 (2H, m); ^{13}C NMR (101 MHz, $CDCl_3$) δ 197.2, 149.0, 143.1, 132.0, 129.9, 128.6, 128.5, 127.0, 119.2, 51.1, 35.2, 27.9, 26.7, 25.5, 17.2; HRMS (ESI) Found MNa^+ 314.1517, $C_{20}H_{21}NONa$ requires 314.1521.

6-(3,5-Bis(trifluoromethyl)phenyl)-6-phenylhexanenitrile (28)

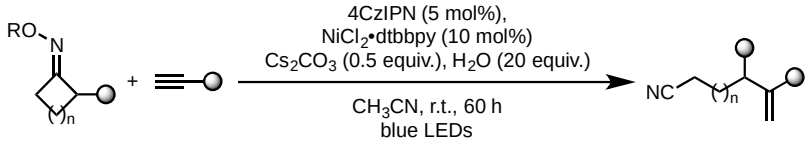


Following **GP2** running the reaction in EtOAc, 1-Bromo-3,5-bis(trifluoromethyl)benzene (30 mg, 0.1 mmol) gave **28** (24 mg, 58%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.87 (2H, s),

7.85 (1H, s), 7.31–7.27 (2H, m), 7.22–7.17 (3H, m), 4.00 (1H, t, J = 7.8 Hz), 2.40 (2H, t, J = 6.7 Hz), 2.42–1.39 (2H, m), 1.75–1.61 (2H, m); ^{13}C NMR (101 MHz, $CDCl_3$) δ 146.7, 140.3, 132.3 (q, J = 33.5 Hz), 129.3, 129.2, 128.3, 125.4, 122.4 (t, J = 16 Hz), 121.7, 119.6, 51.2, 33.0, 31.9, 27.4, 24.8, 21.6, 17.2; ^{19}F NMR (471 MHz, $CDCl_3$) δ –62.9. Data in accordance with the literature.[8]

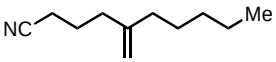
5 Ring-Opening–Vinylation Cascades

General Procedure for Ring-Opening–Vinylation Cascades – GP3



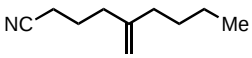
To an oven dried microwave vial, was added the oxime (1.0 equiv.), 4CzIPN (5 mol%), $NiCl_2$•dtbbpy (10 mol%), Cs_2CO_3 (0.5 equiv.) and, if solid, alkyne (1.3 equiv.). The microwave vial was sealed and evacuated and back-filled with nitrogen (3 cycles). Acetonitrile (0.1M) and water (20 equiv.) were added and the mixture degassed for 10 mins. Next, if liquid, the alkyne (1.3 equiv.) was added, the lid sealed with parafilm and the vial irradiated and cooled with a fan for 60 h. The reaction was diluted with brine (5 mL), and extracted with EtOAc (3 x 15 mL). The layers were separated and the combined organic layers were dried ($MgSO_4$), filtered and evaporated. The residue was purified *via* silica gel chromatography.

5-Methylenedecanenitrile (30)



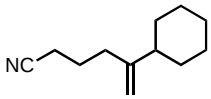
Following **GP3**, hept-1-yne (12 mg, 0.13 mmol) gave **30** (12 mg, 73%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 2930, 2851; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.80 (1H, s), 4.75 (1H, s), 2.34 (2H, t, *J* = 7.2 Hz), 2.16 (2H, t, *J* = 7.4 Hz), 2.03–1.95 (2H, m), 1.80 (2H, p, *J* = 7.2 Hz), 1.48–1.20 (10H, m); ^{13}C NMR (126 MHz, $CDCl_3$) δ 147.5, 119.8, 110.6, 35.9, 34.8, 31.9, 27.8, 23.5, 22.8, 16.7, 14.3; HRMS (ASAP) Found MH^+ 165.1512, $C_{11}H_{20}N$ requires 165.1517.

5-Methylenenonanenitrile (31)



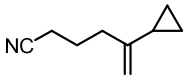
Following **GP3**, hex-1-yne (11 mg, 0.13 mmol) gave **31** (10 mg, 64%) as an oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ 4.80 (1H, s), 4.75 (1H, s), 2.34 (2H, t, *J* = 7.2 Hz), 2.17 (2H, t, *J* = 7.5 Hz), 2.00 (2H, t, *J* = 7.6 Hz), 1.80 (2H, p, *J* = 7.3 Hz), 1.37–1.28 (4H, m), 0.91 (3H, t, *J* = 7.2 Hz); ^{13}C NMR (126 MHz, $CDCl_3$) δ 147.2, 119.4, 110.3, 35.4, 34.6, 29.9, 23.4, 22.3, 16.4, 13.8. Data in accordance with literature.[9]

5-Cyclohexylhex-5-enenitrile (32)



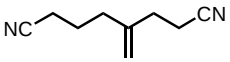
Following **GP3**, ethynylcyclohexane (14 mg, 0.13 mmol) gave **32** (9 mg, 49%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 2925, 2853; ^{1}H NMR (500 MHz, $CDCl_3$) δ 4.81 (1H, s), 4.71 (1H, s), 2.34 (2H, t, *J* = 7.0 Hz), 2.18 (2H, t, *J* = 7.6 Hz), 1.84–1.72 (10H, m), 1.31–1.23 (4H, m); ^{13}C NMR (126 MHz, $CDCl_3$) δ 152.7, 119.7, 108.4, 44.0, 33.6, 32.4, 26.7, 26.3, 23.8, 16.6; HRMS (ASAP) Found MH^+ 178.1588, $C_{12}H_{20}N$ requires 178.1596.

5-cyclopropylhex-5-enenitrile (33)



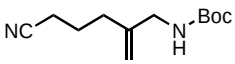
Following **GP3**, ethynylcyclopropane (12μL, 0.13 mmol) gave **33** (33%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.68 (s, 1H), 4.67 (s, 1H), 2.36 (2H, t, *J* = 7.2 Hz), 2.22 (2H, t, *J* = 7.4 Hz), 1.92–1.83 (2H, m), 1.40–1.32 (1H, m), 0.68–0.64 (2H, m), 0.46–0.41 (2H, m).

4-Methyleneoctanedinitrile (34)



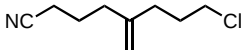
Following **GP3**, pent-4-ynenitrile (10 mg, 0.13 mmol) gave **34** (5 mg, 35%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 2928, 2859; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.98 (1H, s), 4.95 (1H, s), 2.54–2.49 (2H, m), 2.42–2.36 (4H, m), 2.22 (2H, t, *J* = 7.6 Hz), 1.89–1.79 (2H, m); HRMS (ASAP) Found MH^+ 149.1072, $C_9H_{13}N_2$ requires 149.1073.

***tert*-Butyl (5-cyano-2-methylenepentyl)carbamate (35)**



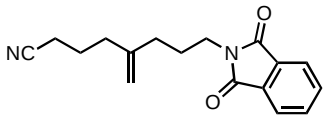
Following **GP3**, *tert*-butyl prop-2-yn-1-ylcarbamate (20 mg, 0.13 mmol) gave **35** (10.5 mg, 45%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 3347, 2927, 1702, 1509, 1367, 1214, 1167; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.99 (1H, s), 4.89 (1H, s), 4.64 (1H, br s, NH), 3.73–3.61 (2H, m), 2.36 (2H, t, *J* = 7.1 Hz), 2.20 (2H, t, *J* = 7.6 Hz), 1.84 (2H, p, *J* = 7.2 Hz), 1.45 (9H, s); ^{13}C NMR (126 MHz, $CDCl_3$) δ 155.9, 144.3, 119.4, 111.6, 79.6, 44.8, 32.4, 28.4, 23.2, 16.6; HRMS (ESI) Found MNa^+ 247.1412, $C_{12}H_{20}O_2N_2Na$ requires 247.1417.

8-Chloro-5-methyleneoctanenitrile (36)



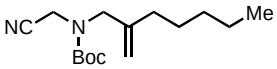
Following **GP3**, 5-chloropent-1-yne (13 mg, 0.13 mmol) gave **36** (6 mg, 35%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 2923, 2852, 1456, 1215, 756; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.86 (1H, s), 4.84 (1H, s), 3.55 (2H, t, *J* = 6.5 Hz), 2.35 (2H, t, *J* = 7.1 Hz), 2.18 (4H, m), 1.96–1.87 (2H, m), 1.82 (2H, p, *J* = 7.2 Hz); ^{13}C NMR (126 MHz, $CDCl_3$) δ 145.5, 111.6, 44.4, 34.6, 32.6, 31.0, 23.3, 16.6; HRMS (ASAP) Found MH$^+$ 172.0883, $C_9H_{15}NCl$ requires 172.0888.

8-(1,3-Dioxoisoindolin-2-yl)-5-methyleneoctanenitrile (37)



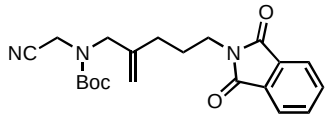
Following **GP3**, 2-(pent-4-yn-1-yl)isoindoline-1,3-dione (28 mg, 0.13 mmol) gave **37** (16 mg, 57%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 2921, 2851, 1710, 1467, 1396, 1215; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85 (2H, dd, *J* = 5.4, 3.1 Hz), 7.72 (2H, dd, *J* = 5.5, 3.0 Hz), 4.86 (1H, s), 4.81 (1H, s), 3.69 (2H, t, *J* = 7.3 Hz), 2.34 (2H, t, *J* = 7.2 Hz), 2.18 (2H, t, *J* = 7.5 Hz), 2.11–2.05 (2H, m), 1.89–1.73 (4H, m); ^{13}C NMR (126 MHz, $CDCl_3$) δ 168.4, 145.6, 134.0, 132.1, 123.2, 119.6, 111.2, 37.6, 34.6, 32.9, 26.4, 23.3, 16.5; HRMS (ASAP) Found MH$^+$ 283.1432, $C_{17}H_{19}N_2O_2$ requires 283.1441.

***tert*-Butyl (cyanomethyl)(2-methyleneheptyl)carbamate (38)**



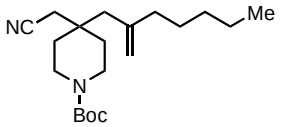
Following **GP3**, 1-heptyne (13 mg, 0.13 mmol) gave **38** (12.0 mg, 41%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 2855, 2347, 2198, 1624, 1587, 1345, 954, 648; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.96 (1H, s), 4.88 (1H, s), 4.13 (1H, br s), 4.00 (1H, br s), 3.99 (2H, s), 1.95 (2H, t, *J* = 7.6 Hz), 1.53–1.43 (11H, m) 1.33–1.25 (4H, m), 0.89 (3H, td, *J* = 7.0, 2.2 Hz).; ^{13}C NMR (126 MHz, $CDCl_3$) δ 154.8, 143.9, 119.7, 116.0, 113.2, 81.8, 51.8, 33.3, 31.6, 28.3, 28.3, 27.4, 22.6, 14.2; HRMS (ESI) Found MNa$^+$ 289.1887, $C_{15}H_{26}O_2N_2Na$ requires 289.1892.

***tert*-Butyl (cyanomethyl)(5-(1,3-dioxoisoindolin-2-yl)-2-methylenepentyl)carbamate (39)**



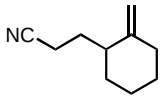
Following **GP3**, *N*-(4-Pentynyl)phthalimide (28 mg, 0.13 mmol) gave **39** (24.0 mg, 48%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 3085, 2997, 2245, 2202, 1786, 1760, 1630, 1335, 1145; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.84 (2H, dd, *J* = 5.5, 3.0 Hz), 7.71 (2H, dd, *J* = 5.4, 3.0 Hz), 5.03 (1H, s), 4.95 (1H, s), 4.14–4.02 (2H, m), 3.92 (2H, s), 3.69 (2H, t, *J* = 7.1 Hz), 2.05–2.02 (2H, m) 1.88–1.84 (2H, m), 1.55–1.44 (9H, m); ^{13}C NMR (126 MHz, $CDCl_3$) δ 168.5, 156.3, 149.8, 134.1, 132.2, 123.4, 115.9, 113.7, 82.1, 51.8, 37.6, 30.4, 28.3, 26.3, 24.1; HRMS (ESI) Found MNa^+ 406.1740, $C_{21}H_{25}O_4N_3Na$ requires 406.1743.

***tert*-Butyl 4-(cyanomethyl)-4-(2-methyleneheptyl)piperidine-1-carboxylate (40)**



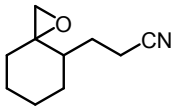
Following **GPX**, 1-heptyne (13 mg, 0.13 mmol) gave **40** (26 mg, 58%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 2963, 2845, 2213, 2178, 1780, 1582, 1344, 1165, 974; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.02 (1H, s), 4.87 (1H, s), 3.56–3.30 (4H, m), 2.42 (2H, s), 2.24 (2H, s), 2.07–2.01 (2H, m) 1.54–1.53 (4H, m), 1.48 (9H, s), 1.36–1.27 (6H, m), 0.91 (3H, t, *J* = 6.8 HZ); ^{13}C NMR (126 MHz, $CDCl_3$) δ 154.9, 145.0, 118.0, 115.6, 80.0, 42.8, 41.0, 38.4, 35.4, 31.6, 28.5, 25.7, 24.0, 22.7, 17.4, 14.2; HRMS (ESI) Found MNa^+ 357.2511, $C_{20}H_{34}O_2N_2Na$ requires 357.2518.

3-(2-Methylenecyclohexyl)propanenitrile (45)



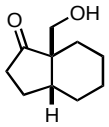
Following **GP3**, **44** (200 mg, 0.8 mmol) gave **27** (55 mg, 46%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 3009, 2198, 1750, 1620, 1235, 985, 755; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.75 (1H, s), 4.61 (1H, s), 2.41–2.29 (2H, m), 2.27–2.15 (2H, m), 2.10–1.94 (2H, m), 1.81–1.70 (1H, m), 1.69–1.48 (5H, m), 1.40–1.32 (1H, m); ^{13}C NMR (101 MHz, $CDCl_3$) δ 150.2, 120.0, 107.3, 42.0, 33.9, 33.3, 28.4, 27.6, 23.5, 15.2; HRMS (ESI) Found MH^+ 150.1277, $C_{10}H_{16}N$ requires 150.1283.

3-(1-Oxaspiro[2.5]octan-4-yl)propanenitrile (S8)



A solution of **45** (50 mg, 0.33 mmol, 1.0 equiv.) in CH_2Cl_2 (2 mL) at room temperature was treated with *m*-CPBA (70 mg, 0.4 mmol) and $NaHCO_3$ (34 mg, 0.4 mmol). The mixture was stirred for 2 h, and then Na_2SO_3 (5%) aqueous solution was added. The organic layer was dried ($MgSO_4$), filtered and evaporated. The crude was purified by column chromatography on silica gel, eluting with hexane–EtOAc (90:10), to give **S8** (46 mg, 92%) as an oil as a mixture of diastereomers. FT-IR ν_{max} (film)/cm^{-1} 2978, 2745, 2260, 1680, 1356, 1245, 1132, 835; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.67–2.64 (1H, m), 2.50 (1H, dd, *J* = 6.1, 4.5 Hz), 2.42–2.28 (2H, m), 1.93–1.87 (1H, m), 1.86–1.21 (10H, m); ^{13}C NMR (101 MHz, $CDCl_3$) δ 119.9^M, 119.7^m, 61.0^M, 60.7^m, 53.2^M, 50.8^m, 40.2^M, 39.4^m, 33.4^M, 31.4^m, 30.4^M, 29.4^m, 25.6^M, 25.1^m, 25.1^M, 25.0^m, 23.6^M, 21.9^m, 15.6^M, 15.3^m; HRMS (ESI) Found MNa^+ 188.1046, $C_{10}H_{15}ONNa$ requires 188.1051.

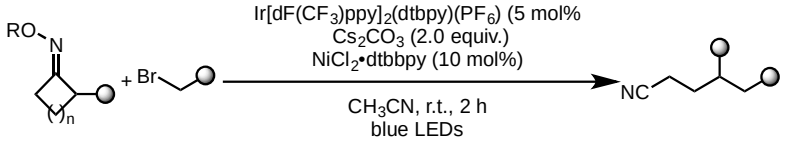
7a-(Hydroxymethyl)octahydro-1*H*-inden-1-one (46)



A mixture of Cp_2TiCl_2 (150 mg, 2.50 mmol) and Zn (110 mg, 1.6 mmol) in deoxygenated THF (4 mL) was stirred at r.t. until the solution turned green. In a separate flask, **S8** (40 mg, 0.24 mmol) was dissolved in deoxygenated THF (5 mL). The green Ti(III) solution was slowly added via syringe to **S8**. After 30 min, an excess of NaH_2PO_3(aq) was added, and the mixture was stirred for 20 min. The aqueous layer was extracted with Et_2O (x 3). The combined organic layers were washed with $NaHCO_3$(aq) and NaCl(aq), dried ($MgSO_4$), filtered and evaporated. Purification by column chromatography on silica gel, eluting with hexane–EtOAc (90:10), gave **46** (35 mg, 88%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 2978, 2745, 2260, 1680, 1356, 1245, 1132, 835; ^{1}H NMR (400 MHz, $CDCl_3$) 3.66 (1H, d, *J* = 11.2 Hz), 3.56 (1H, d, *J* = 11.2 Hz), 2.63 (1H, br s), 2.41–2.33 (1H, m), 2.20–1.87 (2H, m), 1.88–1.78 (2H, m), 1.60–1.27 (8H, m); ^{13}C NMR (101 MHz, $CDCl_3$) δ 224.0, 63.6, 52.6, 36.6, 36.5, 25.2, 24.1, 22.8, 21.5, 21.1; HRMS (ESI) Found MNa^+ 191.1043, $C_{10}H_{16}O_2Na$ requires 191.1048.

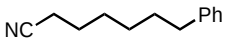
6 Ring-Opening–Alkylation Cascades

General Procedure for Ring-Opening–Alkylation Cascades – GP4



To an oven dried microwave vial, was added the oxime (1.5 equiv.), $Ir[dF(CF_3)ppy]_2(dtbpy)(PF_6)$ (5 mol%), $NiCl_2$•dtbbpy complex (10 mol%) and Cs_2CO_3 (2 equiv.). The microwave vial was sealed and evacuated and back-filled with nitrogen (3 cycles). The solvent (0.1M) was added and the mixture degassed for 10 mins. The alkyl bromide (1.0 equiv.) was added, the lid sealed with parafilm and the vial irradiated and cooled with a fan for 2h. The reaction was diluted with brine (5 mL), and extracted with EtOAc (3 x 15 mL). The layers were separated and the combined organic layers were dried ($MgSO_4$), filtered and evaporated. The residue was purified *via* silica gel chromatography.

7-Phenylheptanenitrile (48)

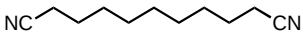


Following **GP4**, (3-bromopropyl)benzene (20 mg, 0.1 mmol) gave **48** (12 mg, 66%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.32–7.26 (2H, m), 7.22–7.14 (3H, m), 2.62 (2H, t, *J* = 7.5 Hz), 2.32 (2H, t, *J* = 7.0 Hz), 1.72–1.58 (4H, m), 1.52–1.33 (4H, m); ^{13}C NMR (126 MHz, $CDCl_3$) δ 142.5, 128.5, 128.3, 125.6, 119.9, 35.7, 31.0, 28.4, 28.2, 25.2, 17.0; HRMS (ESI) Found MNa^+ 210.1247, $C_{13}H_{17}NNa$ requires 210.1253. Data in accordance with the literature.[10]

Ethyl 7-cyanoheptanoate (49)

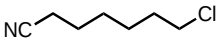
Following **GP4**, ethyl 4-bromobutanoate (20 mg, 0.1 mmol) gave **49** (10 mg, 55%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) 4.12 (2H, q, *J* = 7.1 Hz), 2.35–2.28 (4H, m), 1.70–1.60 (4H, m), 1.51–1.44 (2H, m), 1.42–1.32 (2H, m), 1.26 (3H, t, *J* = 7.1 Hz); ^{13}C NMR (126 MHz, $CDCl_3$) 173.5, 119.7, 60.3, 34.1, 28.3, 28.2, 25.2, 24.6, 17.1, 14.2; HRMS (ESI) Found MNa^+ 206.1146, $C_{10}H_{17}NO_2Na$ requires 206.1152. Data in accordance with the literature.[11]

Decanedinitrile (50)



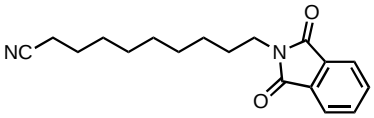
Following **GP4**, 6-bromohexanenitrile (18 mg, 0.1 mmol) gave **50** (11.0 mg, 64%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.55 (4H, td, *J* = 6.9, 1.2 Hz), 2.40 (4H, t, *J* = 6.9 Hz), 1.88–1.43 (8H, m); ^{13}C NMR (101 MHz, $CDCl_3$) δ 119.4, 42.9, 27.0, 24.9, 21.1, 17.2. Data in accordance with the literature.[12]

6-Chlorohexanenitrile (51)



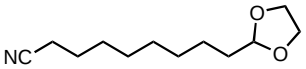
Following **GP4**, 1-bromo-2-chloroethane (28 mg, 0.2 mmol) gave **51** (16.0 mg, 60%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.56 (2H, t, *J* = 6.5 Hz), 2.38 (2H, t, *J* = 6.9 Hz), 1.88-1.77 (2H, m), 1.75–1.67 (2H, m), 1.66-1.59 (2H, m); ^{13}C NMR (101 MHz, $CDCl_3$) δ 119.4, 43.4, 31.6, 26.0, 24.7, 17.1. Data in accordance with the literature.[13]

9-(1,3-Dioxoisoindolin-2-yl)nonanenitrile (52)



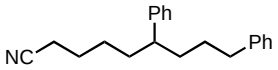
Following **GP4**, 2-(5-bromopentyl)isoindoline-1,3-dione (30 mg, 0.1 mmol) gave **52** (15.0 mg, 52%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 3019, 2253, 1690, 1650, 1375, 1038, 917, 735; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.77 (2H, dd, *J* = 5.4, 3.1 Hz), 7.65 (2H, dd, *J* = 5.5, 3.1 Hz), 3.63 (2H, t, *J* = 7.1 Hz), 2.28 (2H, t, *J* = 7.1 Hz), 1.69–1.62 (2H, m), 1.47–1.34 (10H, m); ^{13}C NMR (101 MHz, $CDCl_3$) δ 168.4, 134.1, 132.1, 123.3, 119.6, 41.0, 37.4, 27.8, 27.0, 25.9, 25.0, 17.1; HRMS (ESI) Found MNa^+ 307.1419, $C_{17}H_{20}O_2N_2Na$ requires 307.1422.

8-(1,3-Dioxolan-2-yl)octanenitrile (53)



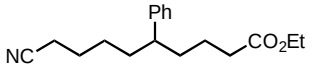
Following **GP4**, 2-(4-Bromobutyl)-1,3-dioxolane (21 mg, 0.1 mmol) gave **53** (10.0 mg, 46%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 2975, 2836, 1611, 1583, 1552, 1099, 921, 884, 763, 614; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.73 (1H, t, *J* = 4.5 Hz), 3.85–3.82 (2H, m), 3.74–3.70 (2H, m), 2.40 (2H, t, *J* = 7.0 Hz), 2.28–2.21 (4H, m), 1.68–1.53 (6H, m), 1.49–1.43 (2H, m); ^{13}C NMR (101 MHz, $CDCl_3$) δ 119.6, 103.9, 64.9, 42.8, 32.8, 25.3, 24.8, 23.0, 21.0, 17.1; HRMS (ESI) Found MNa^+ 220.1315, $C_{11}H_{19}O_2NNa$ requires 220.1313.

6,9-Diphenylnonanenitrile (56)



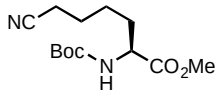
Following **GP4**, (3-bromopropyl)benzene (20 mg, 0.1 mmol) gave **56** (19.0 mg, 65%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 2997, 2226, 1698, 1337, 1284, 774; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.36–7.31 (4H, m), 7.26–7.20 (6H, m), 2.73–2.67 (5H, m), 2.43–2.35 (4H, m), 2.05–1.97 (2H, m), 1.86–1.68 (4H, m); ^{13}C NMR (101 MHz, $CDCl_3$) δ 141.4, 141.3, 128.6, 128.6, 128.5, 128.4, 126.2, 126.1, 119.7, 40.3, 35.1, 35.0, 33.4, 30.3, 26.3, 24.9, 17.1; HRMS (ESI) Found MH^+ 292.2069, $C_{21}H_{26}N$ requires 292.2065.

Ethyl 9-cyano-5-phenylnonanoate (57)



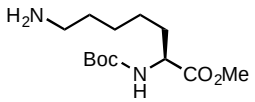
Following **GP4**, ethyl 4-bromobutanoate (20 mg, 0.1 mmol) gave **57** (19.0 mg, 68%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 3251, 2854, 2264, 1766, 1622, 1389, 1145, 965, 741; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.38–7.26 (3H, m), 7.18–7.15 (2H, m), 4.17 (2H, q, *J* = 7.1 Hz), 2.58–2.44 (5H, m), 2.32–2.16 (4H, m), 2.08–1.82 (6H, m), 1.29 (3H, t, *J* = 7.1 Hz); ^{13}C NMR (101 MHz, $CDCl_3$) δ 171.1, 141.2, 128.5, 128.4, 126.3, 126.1, 119.7, 60.4, 41.0, 35.0, 30.3, 25.0, 24.9, 21.1, 17.1, 14.2; HRMS (ESI) Found MNa^+ 310.1778, $C_{18}H_{25}O_2NNa$ requires 310.1783.

Methyl (*S*)-2-((*tert*-Butoxycarbonyl)amino)-6-cyanohexanoate (59)



Following **GP4**, L-Br-serine **58** (28 mg, 0.1 mmol) gave **59** (10.0 mg, 36%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 3257, 2998, 2278, 2146, 1785, 1702, 1521, 1470, 1323, 1149, 941, 825; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.04 (1H, d, *J* = 8.5 Hz), 4.31–4.26 (1H, m), 3.73 (3H, s), 2.67 (2H, t, *J* = 6.8 Hz), 1.83–1.77 (2H, m), 1.67–1.59 (2H, m), 1.43 (9H, s), 1.44–1.42 (2H, m); ^{13}C NMR (101 MHz, $CDCl_3$) δ 173.5, 155.5, 79.8, 53.6, 51.2, 32.6, 31.0, 30.5, 28.4, 23.5, 18.5; HRMS (ESI) Found MH^+ 271.1658, $C_{13}H_{23}N_2O_4$ requires 271.1652.

Methyl (*S*)-7-Amino-2-((*tert*-butoxycarbonyl)amino)heptanoate (60)



A solution of $CoCl_2$•$6H_2O$ (5 mg, 0.02 mmol) and **59** (27 mg, 0.1 mmol) in THF (6 mL) and H_2O (3 mL) was stirred vigorously and cooled intermittently with an ice-water bath while $NaBH_4$ (53 mg, 1.4 mmol) was added in portions over 8 min. The reaction was exothermic, producing black precipitate and ample quantities of hydrogen. After a total time of 2h, aqueous NH_4OH solution (2 ml) was added and the mixture was then filtered through Celite and washed with methanol. The combined supernatants were concentrated at reduced pressure, then the aqueous residue was extracted with (4 x 10 ml) of DCM. The combined DCM layers were dried ($MgSO_4$) and concentrated to afford **60** (16.5 mg, 59%) as an oil. FT-IR ν_{max} (film)/cm^{-1} 3526, 3214, 2989, 2265, 1764, 1780, 1724, 1556, 865, 705; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.10 (1H, d, *J* = 8.5 Hz), 4.28–4.22 (1H, m), 3.69 (3H, s), 3.14 (2H, t, *J* = 7.1 Hz), 1.96 (2H, t, *J* = 1.4 Hz),1.80–1.75 (2H, m), 1.64–1.56 (2H, m), 1.40 (9H, s), 1.42–1.34 (4H, m); ^{13}C NMR (101 MHz, $CDCl_3$) δ 173.5, 155.5, 80.0, 53.5, 52.4, 42.0, 33.3, 32.7, 31.1, 28.4, 22.7; HRMS (ESI) Found MNa^+ 297.1793, $C_{13}H_{26}O_4N_2Na$ requires 297.1790.

7 Flow Procedures

Flow equipment set up

The flow process was performed using a standard setup on the commercially available VapourTech E series 3-pump EasyMedchem fitted with a photochemical 450 nm LED reactor [Part number 50-1319, 10 mL internal volume] and a heating mode at 40°C. A single pump fitted with a blue pump tube [Part number 50-1301] was used to transfer the homogeneous batch solution through the photochemical reactor. The output of the flow reactor was a homogenous solution of a darker yellow/orange compared to the input solution which was yellow.

General Flow Procedure – GP5

To a 1 neck 100 ml flask open to the air, was added **1** (1.5 equiv), $[Ir(dtbbpy)(ppy)_2](PF_6)$ (5.0 mol%) and the bromoarene (1.0 equiv.). The flask was sealed with a septum and evacuated and backfilled with N_2 (x 3). A separate flask was charged with $NiCl_2 \cdot 6H_2O$ (10 mol%) and dtbbpy (10 mol%) and a magnetic stirrer bar. The flask was sealed with a septum and evacuated and backfilled with N_2 (x 3). Anhydrous DME and DMF (5:2, 0.05M) were added and the solvent stirred and degassed by bubbling with N_2 for 10 min. The green solution was then added to the first flask, followed by TMG (1.7 equiv.) and the septum sealed with parafilm. Prior to the pumping of the reagent the reactor was fully liquid filled with DME:DMF (5:2) from the solvent reservoir. The reaction solution was pumped at 0.35 mL/min (input flowrate on control interface) resulting in a theoretical residence time of 28.5 min within the photochemical reactor. Once the entire contents of the flask had been pumped from the flask DME:DMF mixture (5:2) was pumped from the solvent reservoir until it was deemed all the reaction solution had been collected. The resulting solution was diluted with water (20 mL) then extracted with ethyl acetate (3 x 100 mL). The combined organic layers were dried ($MgSO_4$), filtered and evaporated. The residue was purified by FCC with 5%→20% EtOAc:hexane to give desired product.

4-(4-Acetylphenyl)butanenitrile (3)

Following **GP5**, 4'bromoacetophenone (796 mg, 4 mmol, 1 equiv) gave **3** (417 mg, 2.24 mmol, 56%) at a flow rate of 0.35mL/min and reactor temperature of 40 °C.

4-(3-Cyanopropyl)benzonitrile (6)

Following **GP5**, 4-bromobenzonitrile (364 mg, 2 mmol, 1 equiv) gave **6** (195 mg, 1.14 mmol, 57%) at a flow rate of 0.35mL/min and reactor temperature of 40°C.

The temperature was monitored during the flow run as well as NMR samples of aliquots of the reaction solution. The temperature within the photochemical reactor was set at 40 °C with minimal deviation from this observed during the course of the run.

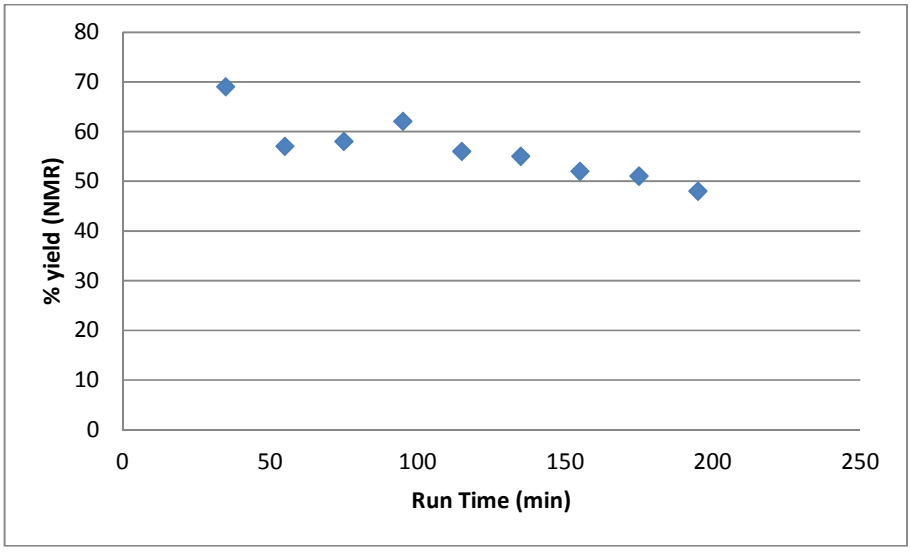


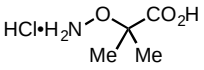
Figure S1. Graph showing % product (NMR) during the run.

To aliquots of the reaction solution was added TNCB as a standard in EtOAc. The resulting solution was diluted with water and EtOAc. The aqueous layer was washed with EtOAc (3x5 mL) and the combined organics were dried over $MgSO_4$, filtered and the solvent removed in vacuo. The ^1H NMR data shows a gradual decrease in yield as the reaction progresses.

A reaction was ran after the pre-mixed reaction solution had been stored overnight and there was no significant drop in yield, suggesting the mixture does not decompose over time.

8 Safety Tests

(Aminooxy)-2-methylpropanoic Acid Hydrochloride



This chemical was purchased from Fluorochem (Cat.No.447946, Lot:FCBO16818).

The heat of decomposition for this sample (Figure S2) is above the 800 J/g threshold value which would indicate potential explosive properties.[14] Thus, indicating that the material may have explosive properties. Subsequent high-rate Carius tube test results indicated that the material does not have explosive properties. Although not explosive this energetic material could be hazardous depending on usage.

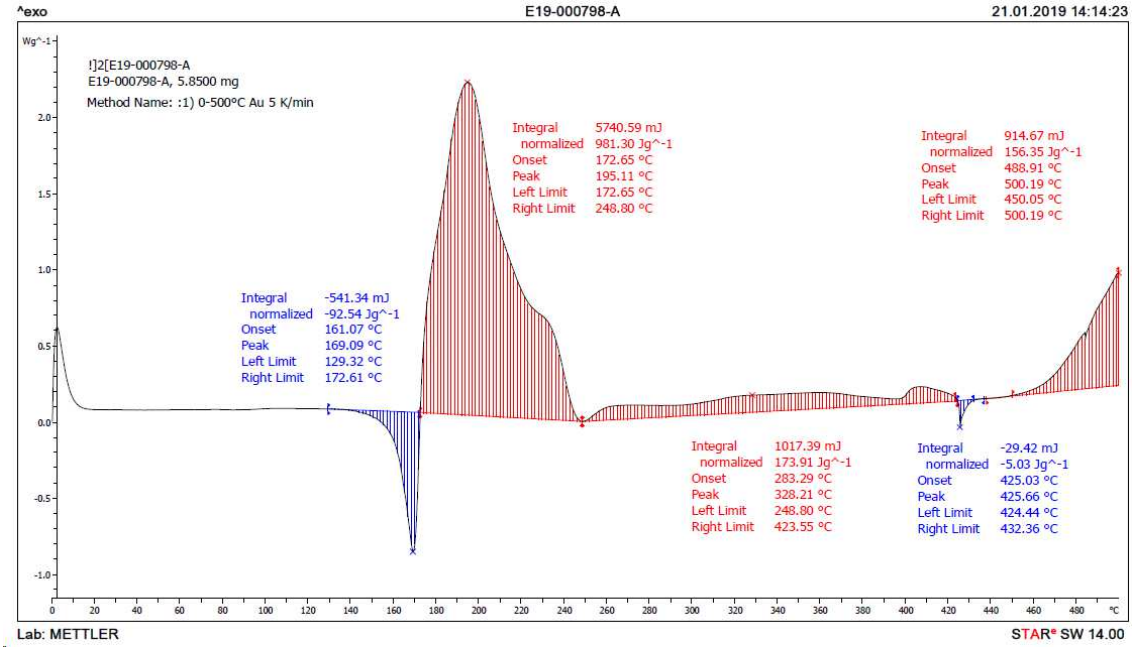
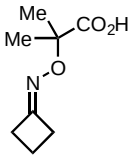


Figure S2. DSC result for (Aminooxy)-2-methylpropanoic acid hydrochloride

2-[(Cyclobutylideneamino)oxy]-2-methylpropanoic acid (1)



The heat of decomposition for this sample (Figure S3) is above the 800 J/g threshold value which would indicate potential explosive properties.[14] Thus, indicating that the material may have explosive properties. Subsequent high-rate Carius tube test results indicated that the

material does not have explosive properties. Although not explosive this energetic material could be hazardous depending on usage.

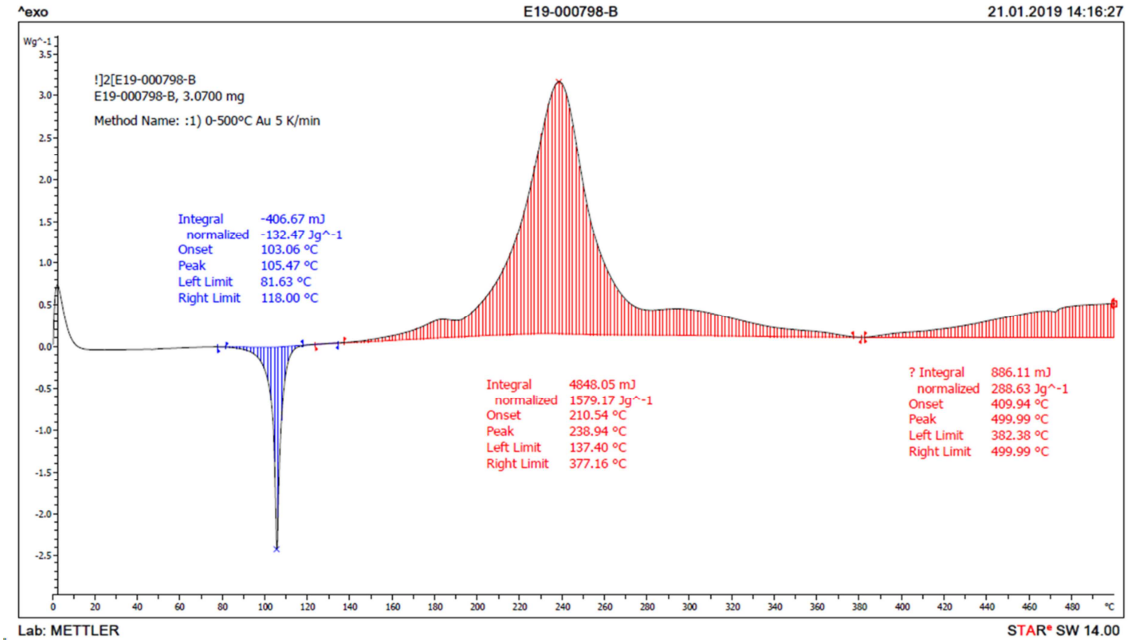
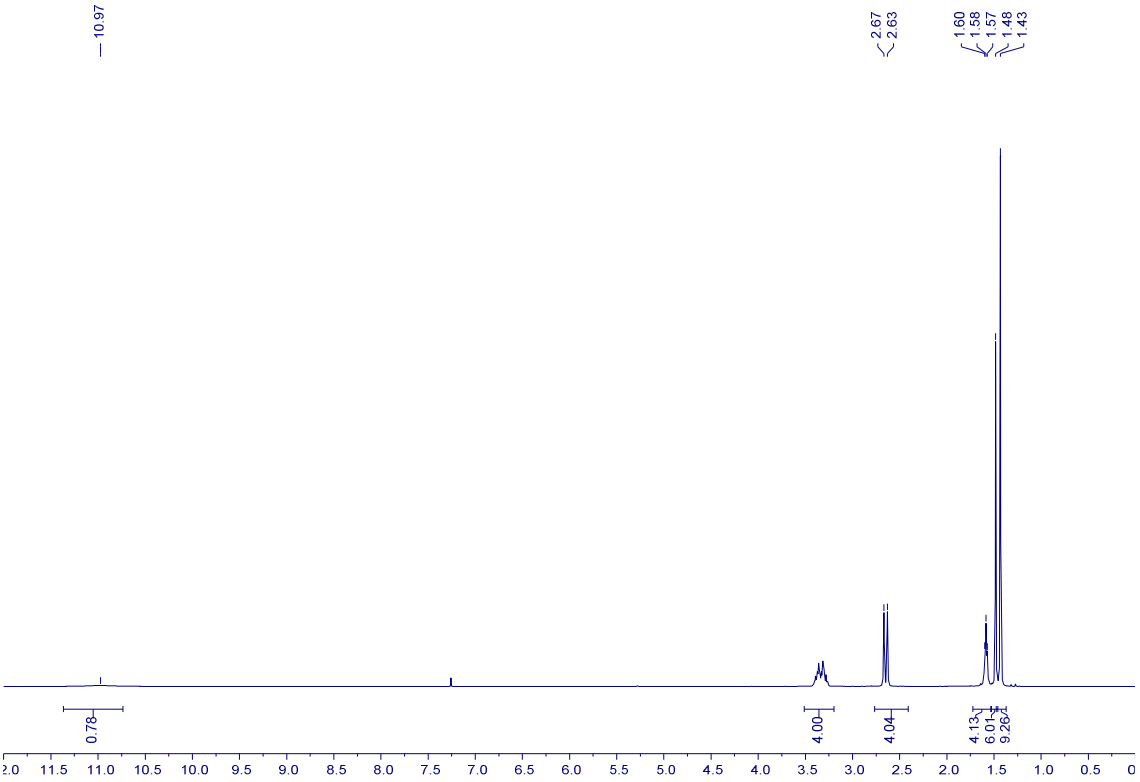


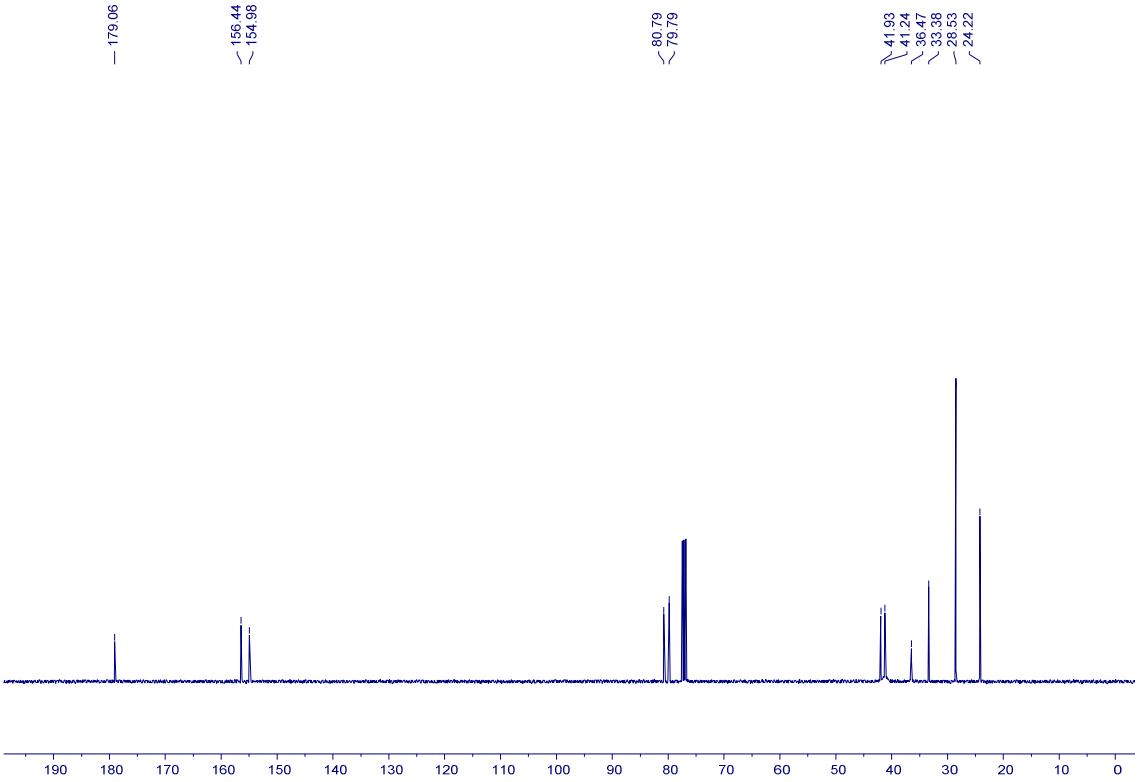
Figure S3. DSC result for 2-[(cyclobutylideneamino)oxy]-2-methylpropanoic acid 1.

9 NMR Spectra

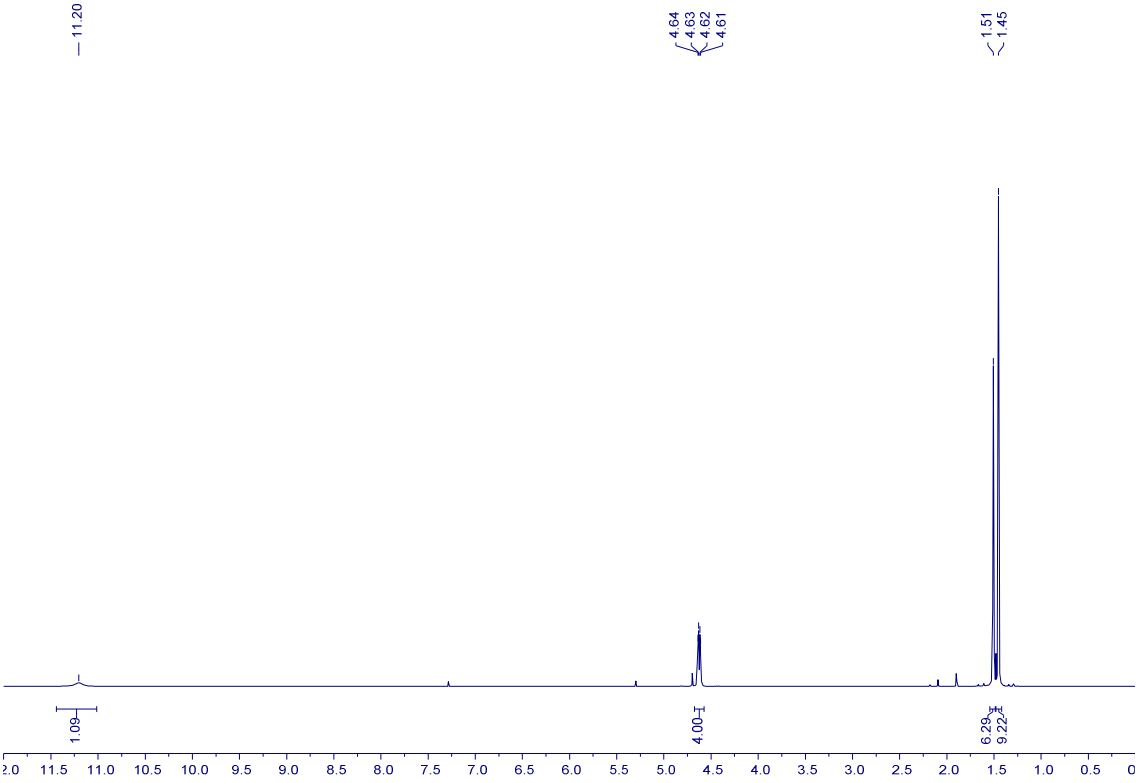
S2 ^{1}H NMR (400 MHz, $CDCl_3$)



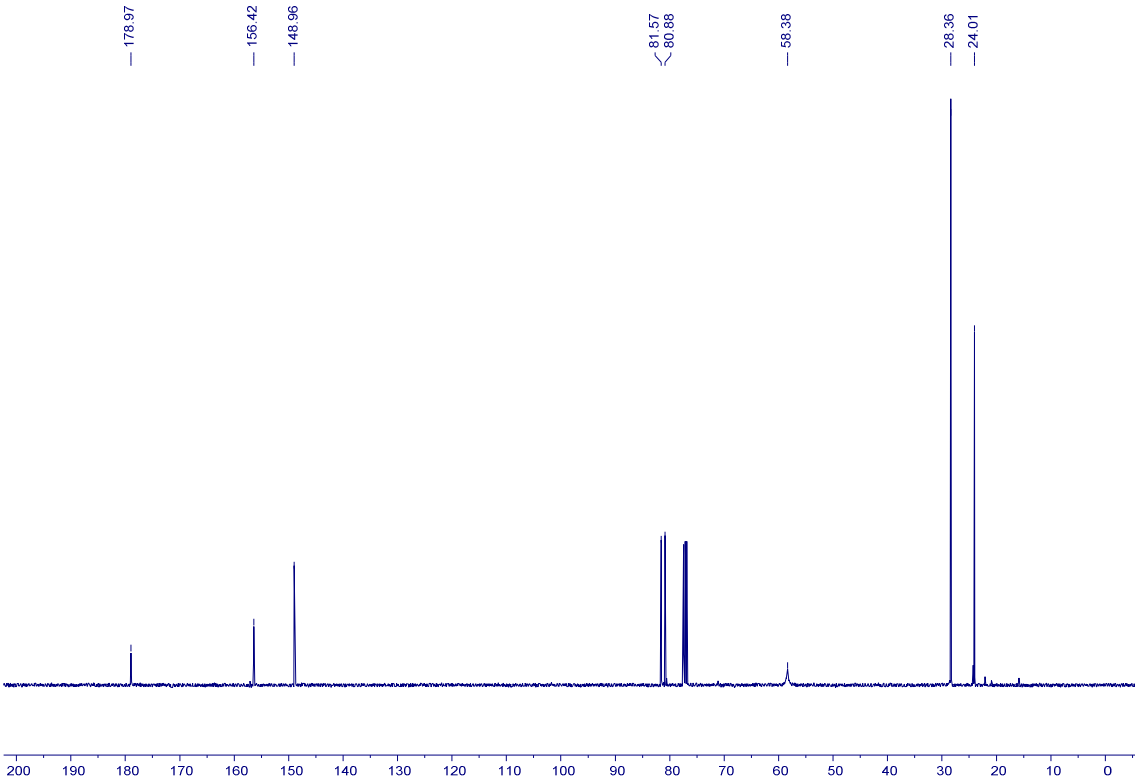
S2 ^{13}C NMR (101 MHz, $CDCl_3$)



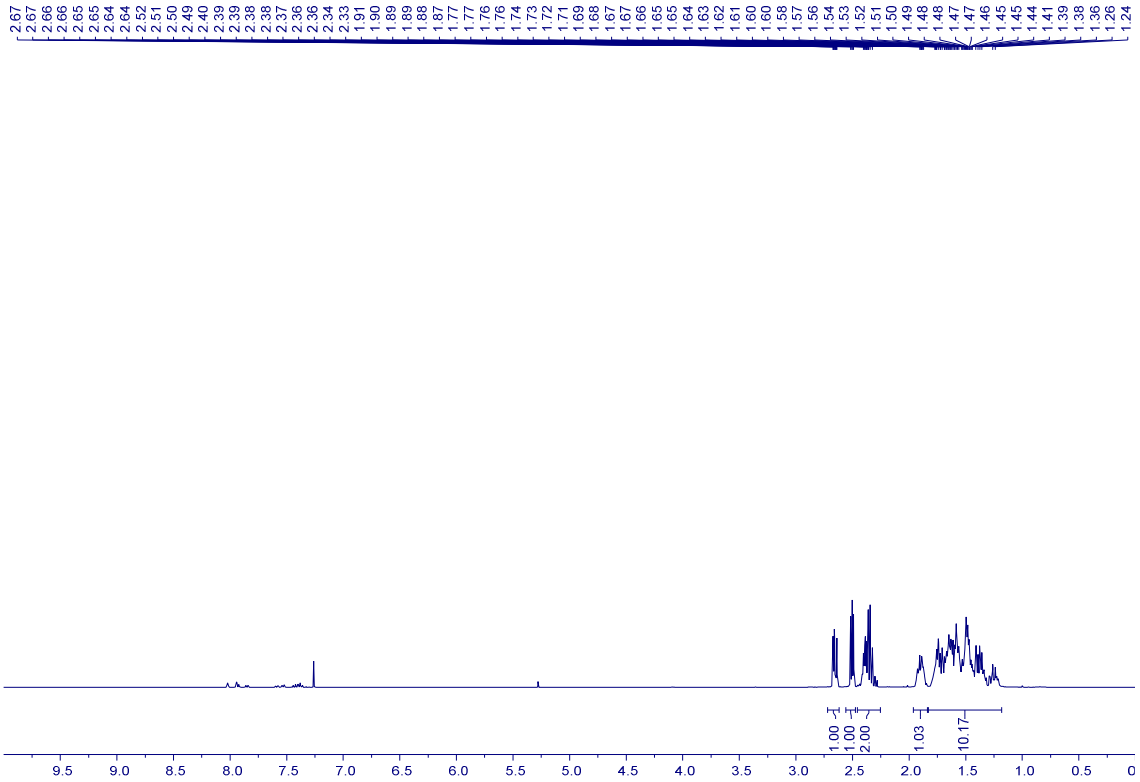
S5 ^{1}H NMR (400 MHz, $CDCl_3$)



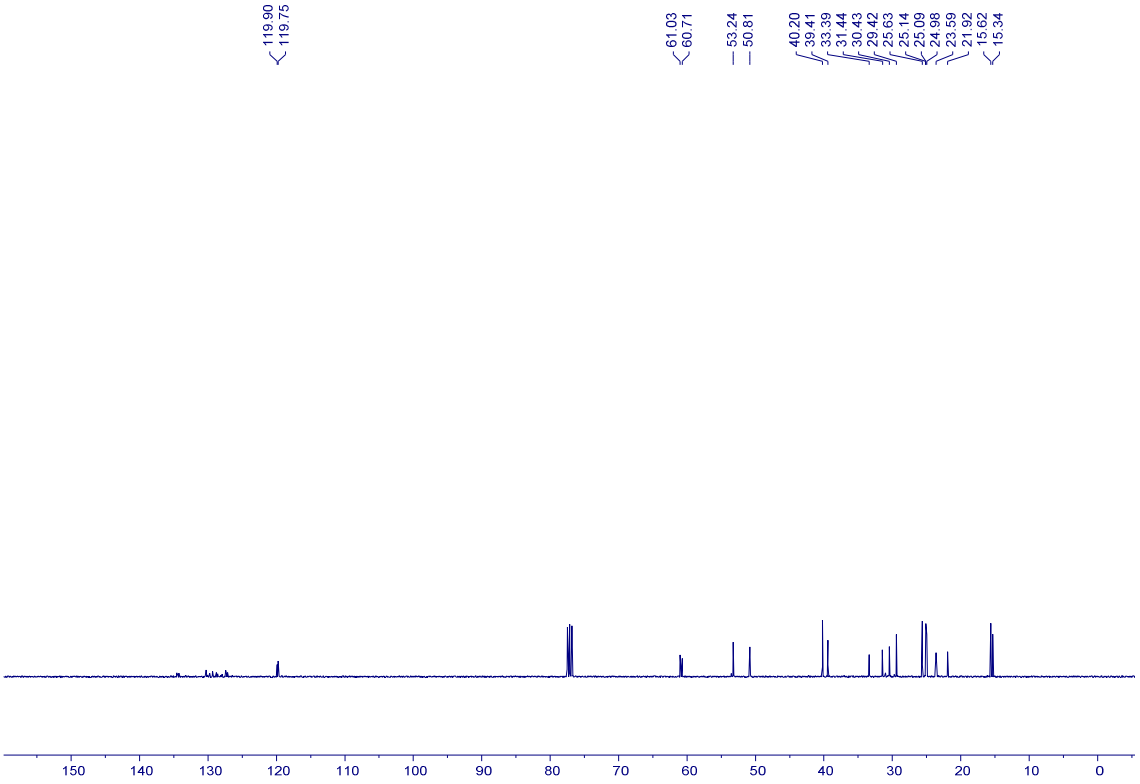
S5 ^{13}C NMR (101 MHz, $CDCl_3$)



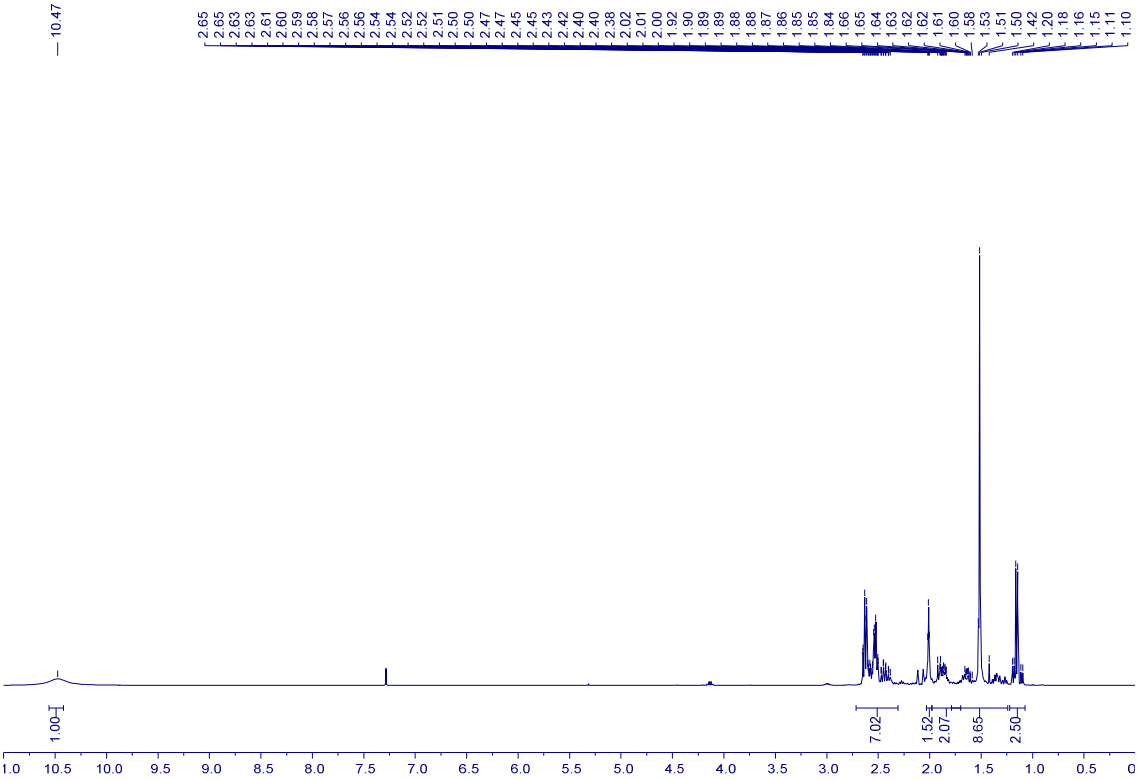
S8 ^{1}H NMR (400 MHz, $CDCl_3$)



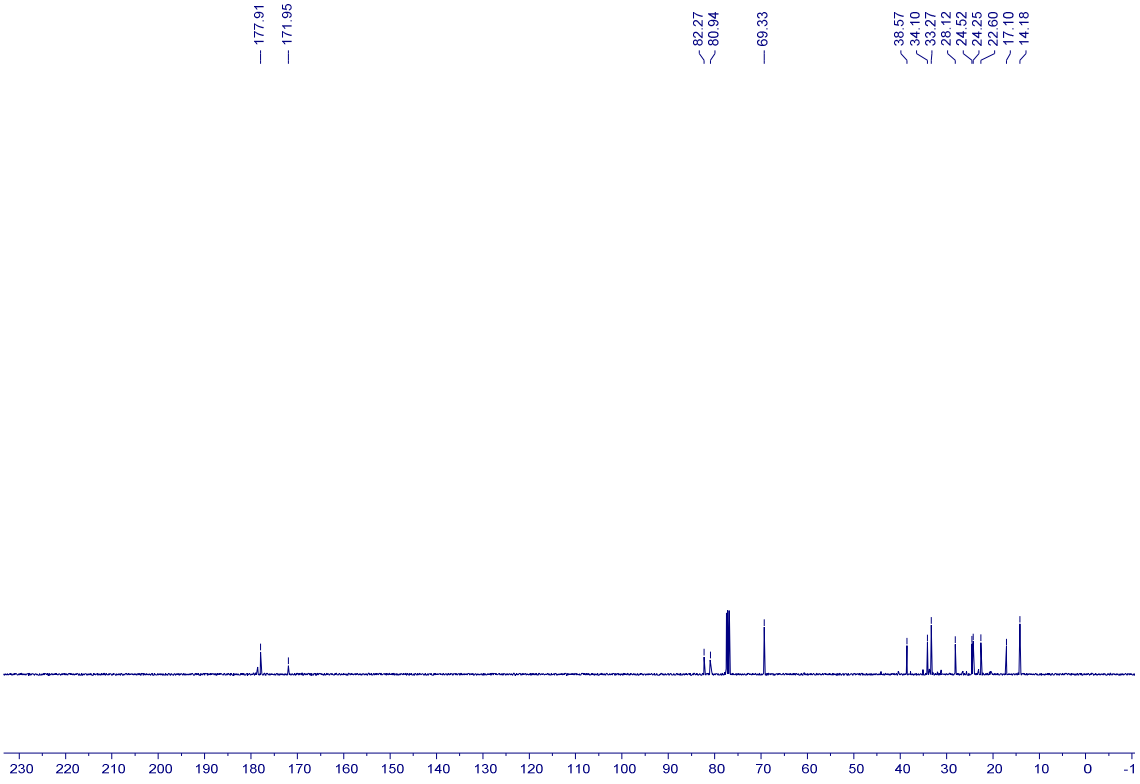
S8 ^{13}C NMR (101 MHz, $CDCl_3$)



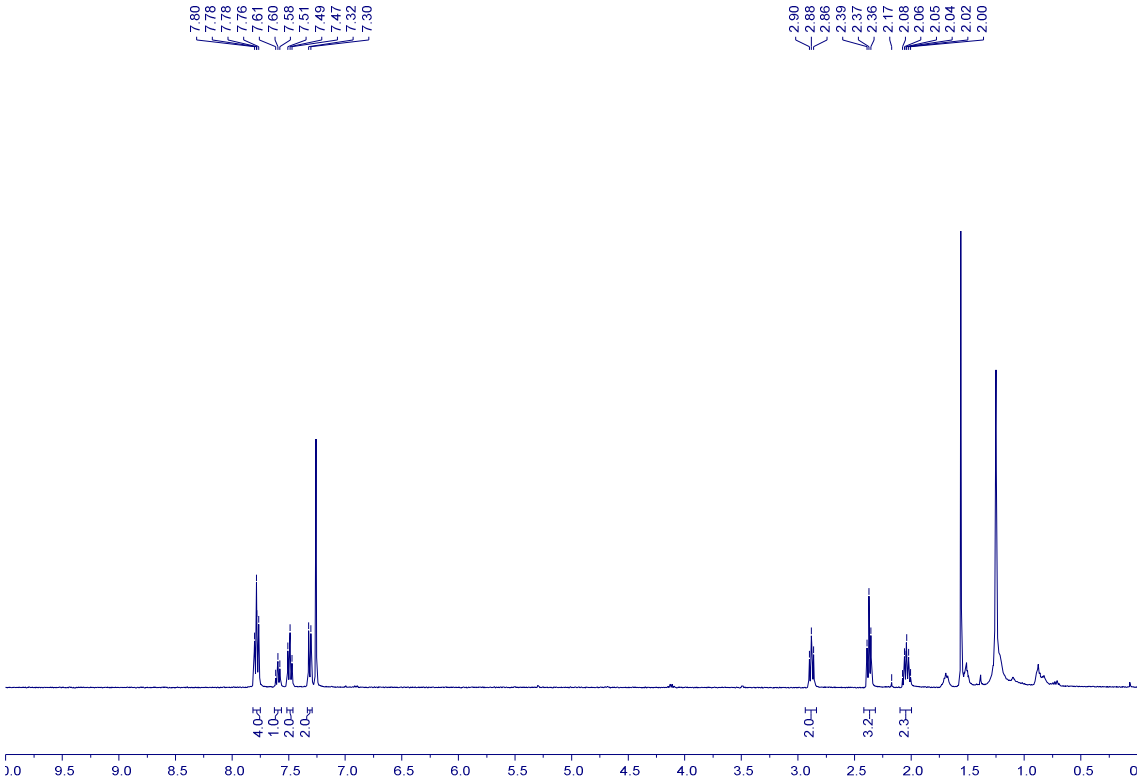
44 ^{1}H NMR (400 MHz, $CDCl_3$)



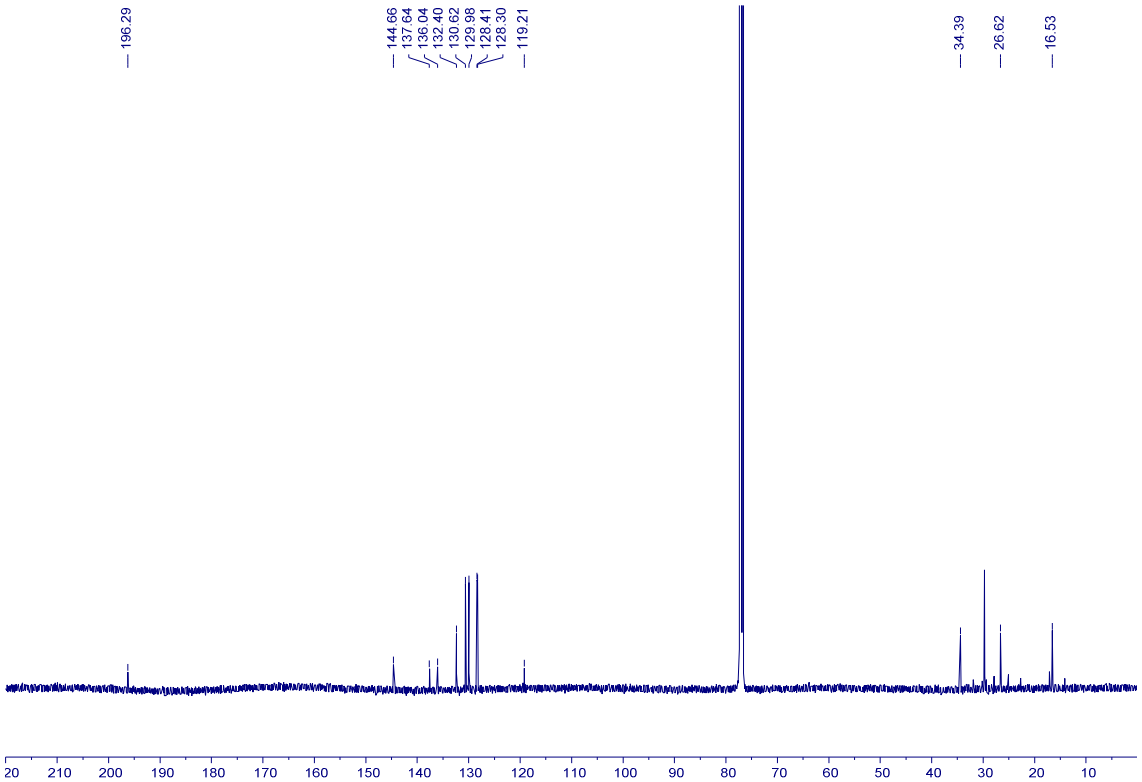
44 ^{13}C NMR (101 MHz, $CDCl_3$)



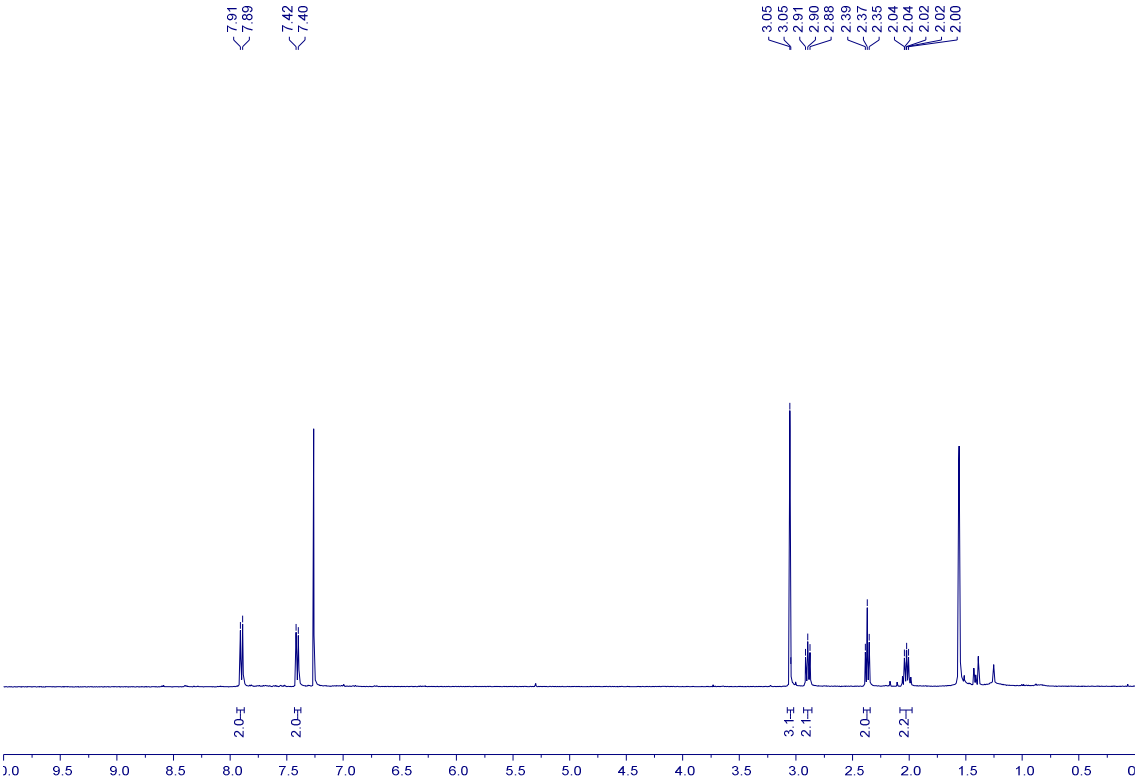
4 ^{1}H NMR (400 MHz, $CDCl_3$)



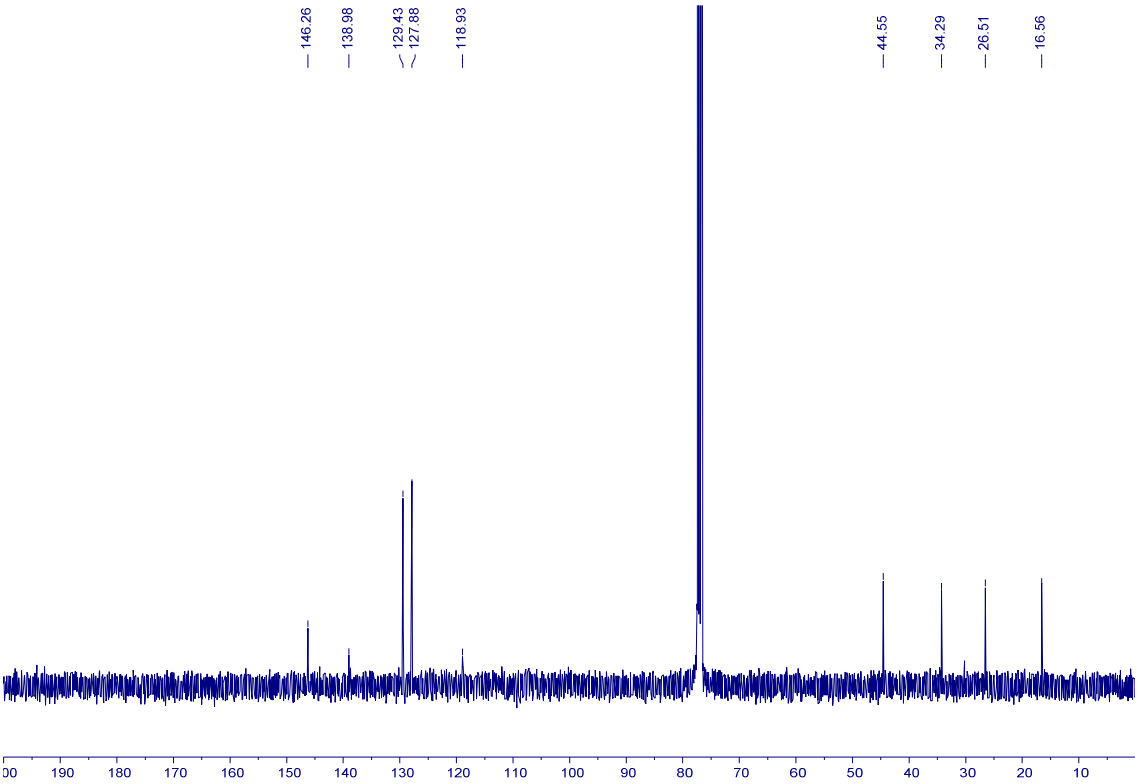
4 ^{13}C NMR (126 MHz, $CDCl_3$)



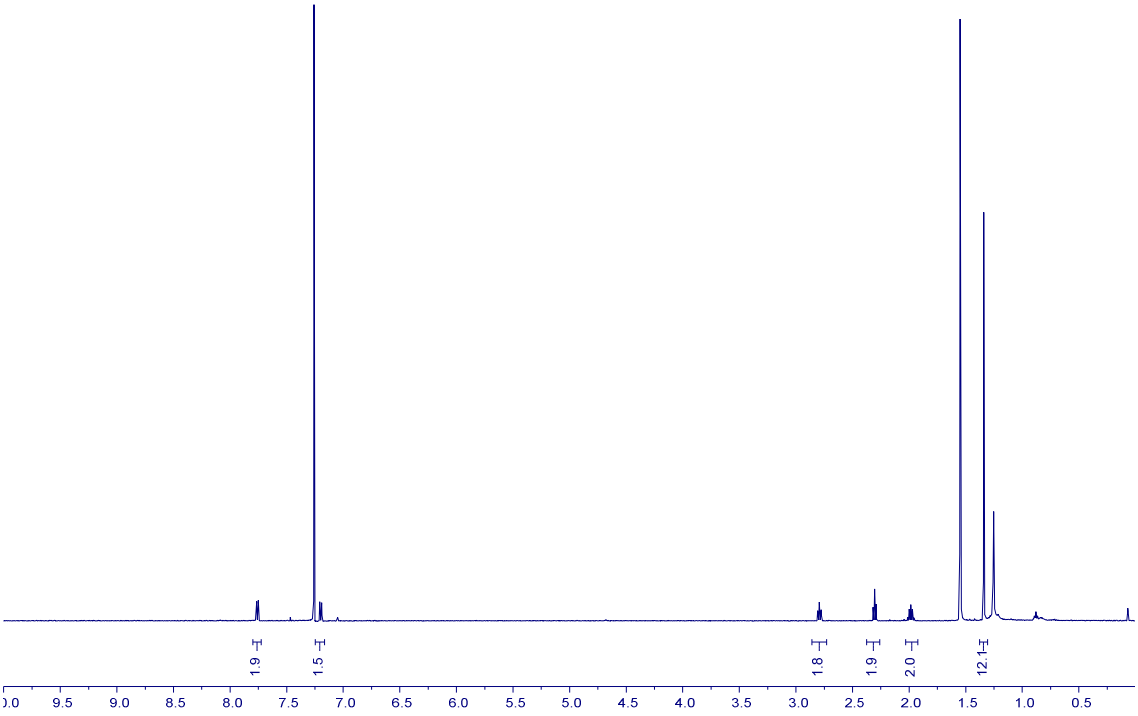
8 ^{1}H NMR (400 MHz, $CDCl_3$)



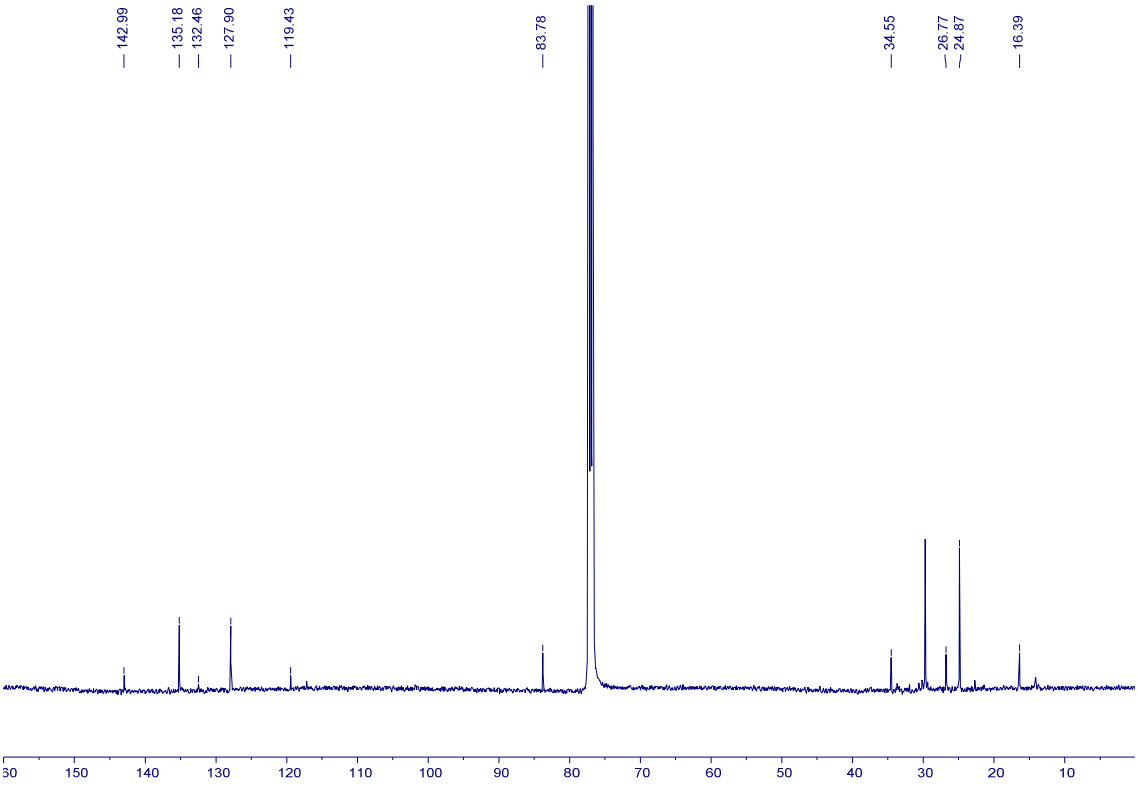
8 ^{1}H NMR (101MHz, $CDCl_3$)



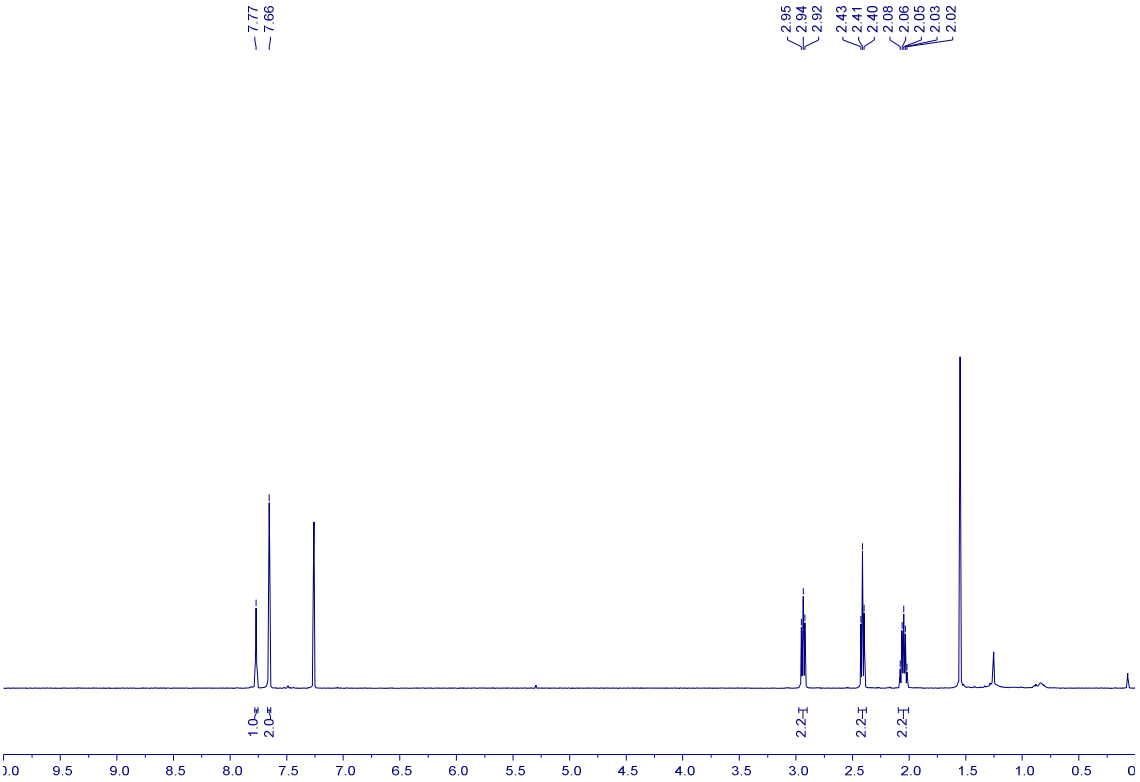
10 ^{1}H NMR (400 MHz, $CDCl_3$)



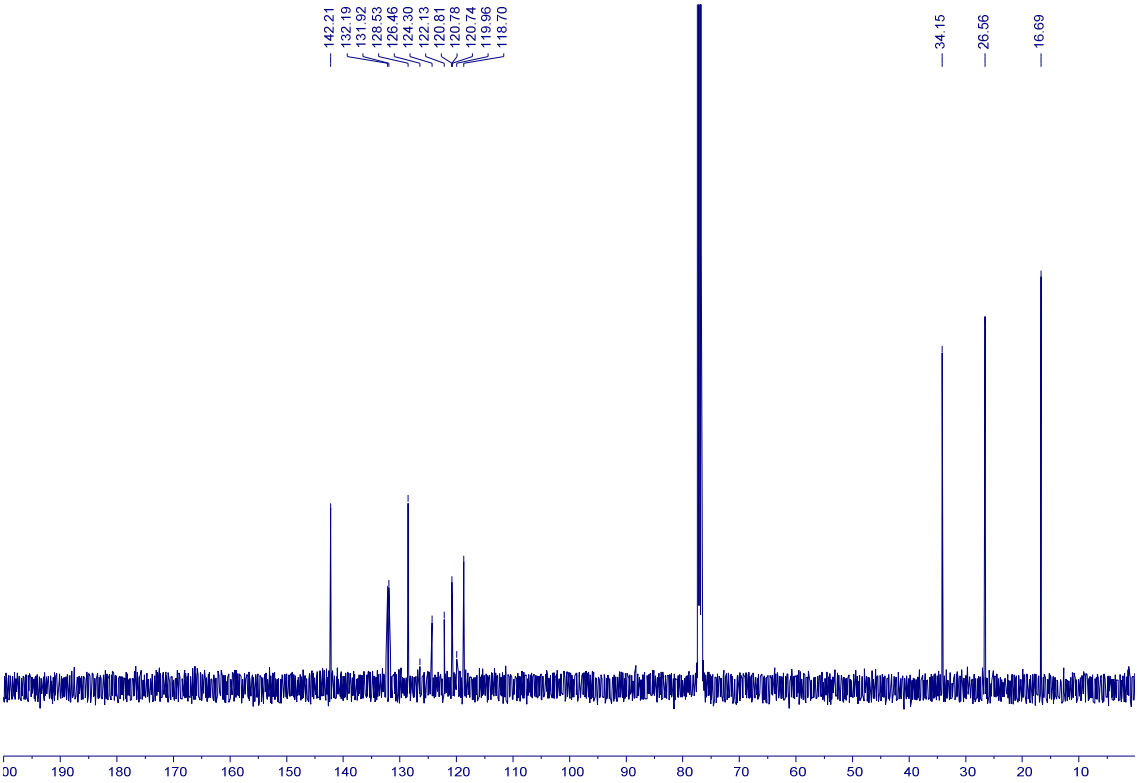
10 ^{13}C NMR (126MHz, $CDCl_3$)



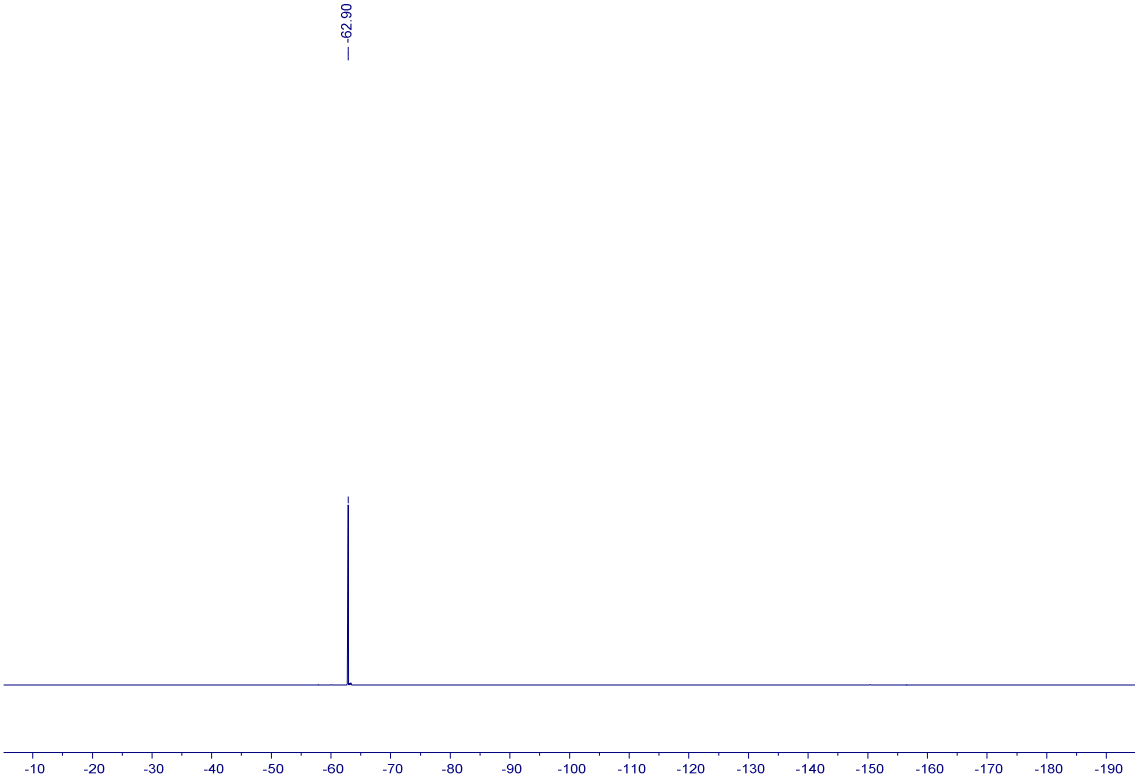
13 ^{1}H NMR (400 MHz, $CDCl_3$)



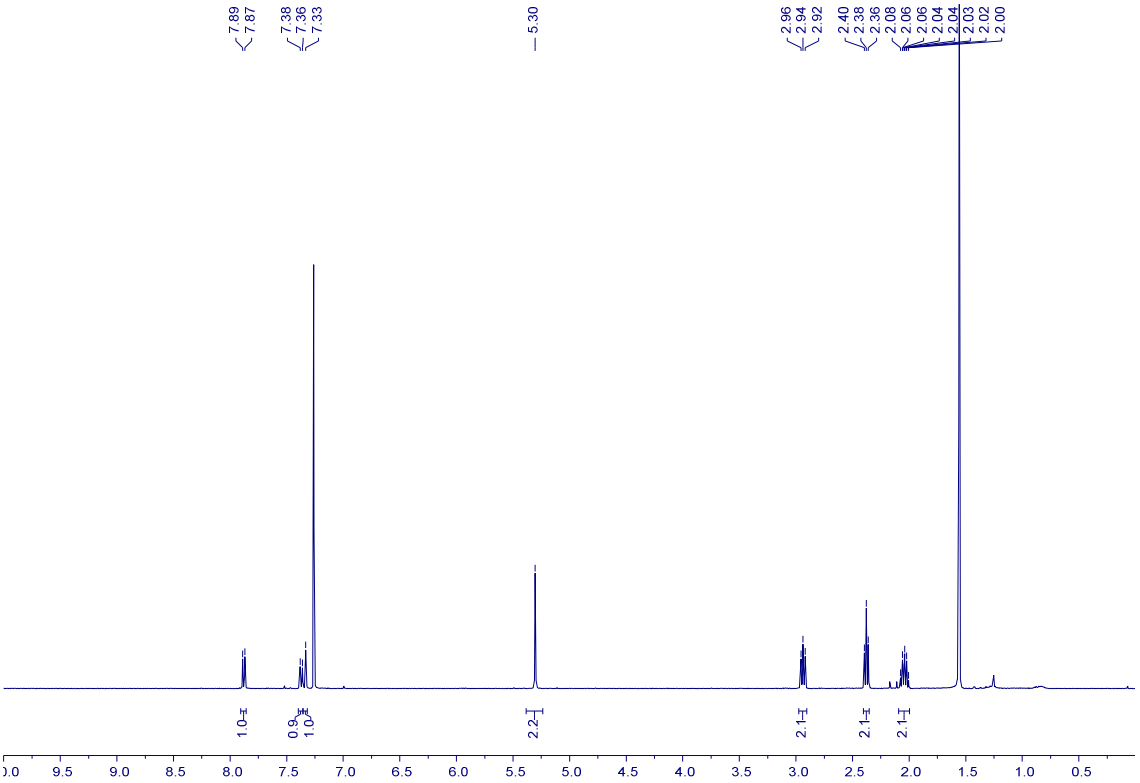
13 ^{13}C NMR (126 MHz, $CDCl_3$)



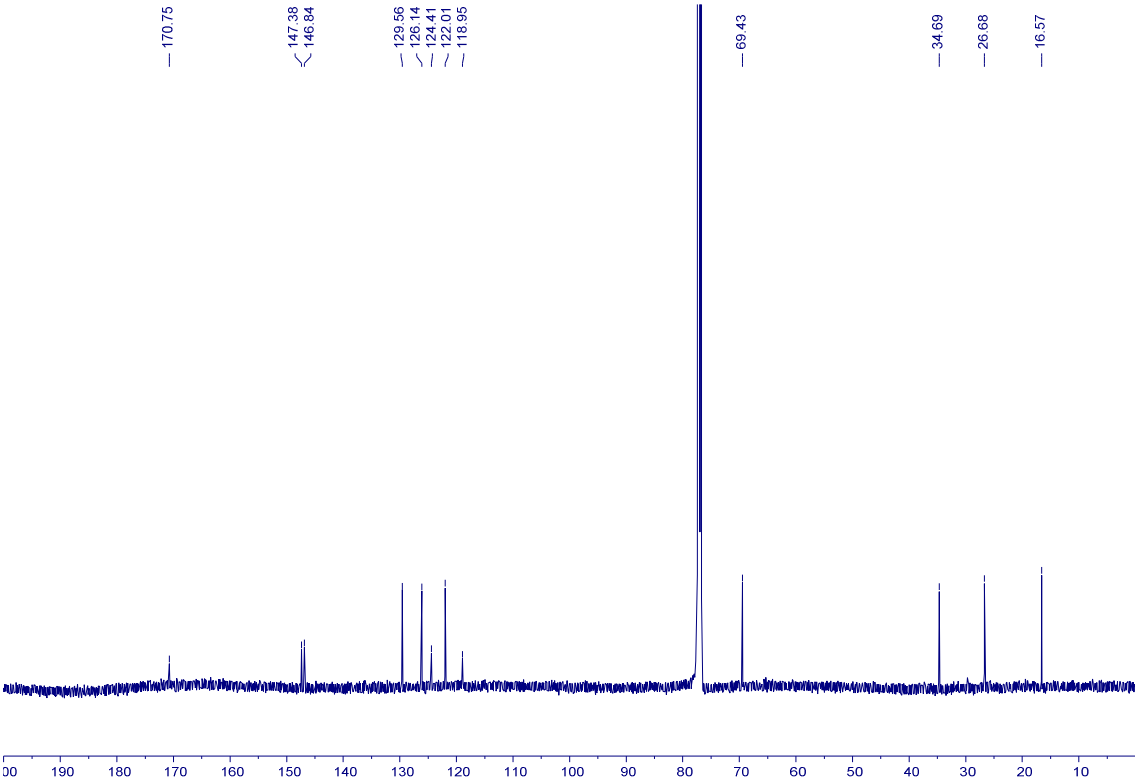
13 ^{19}F NMR (471 MHz, $CDCl_3$)



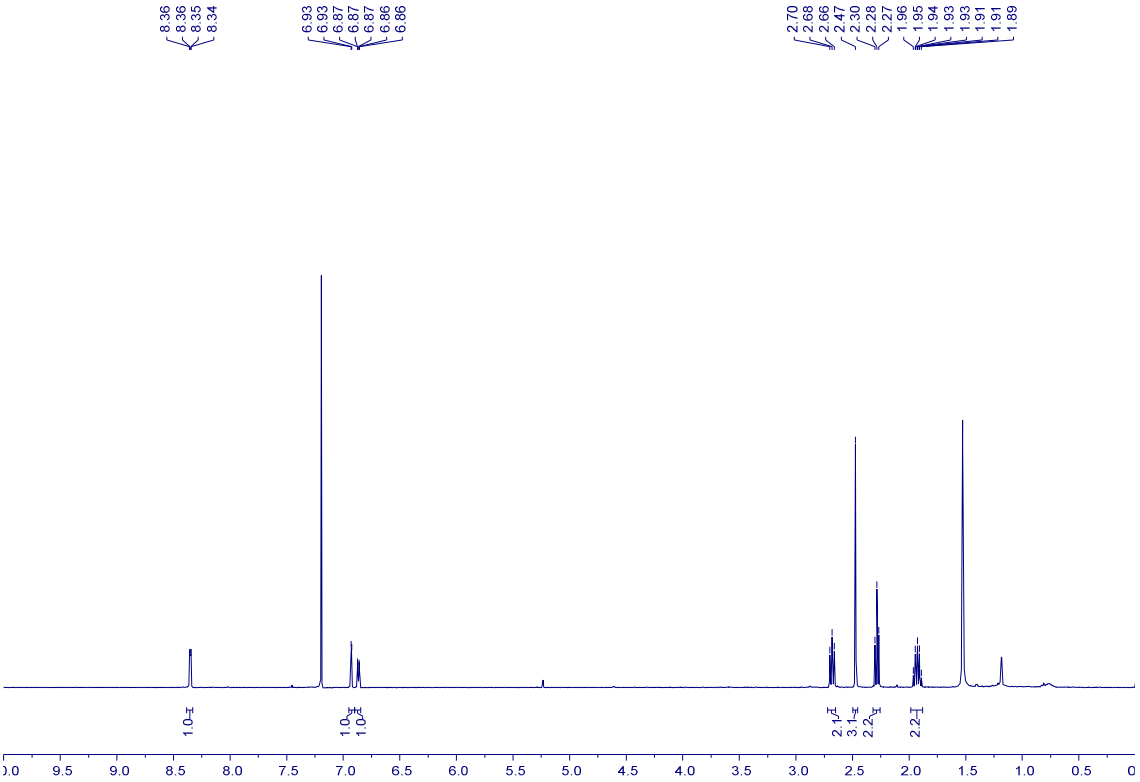
14 ^{1}H NMR (400 MHz, $CDCl_3$)



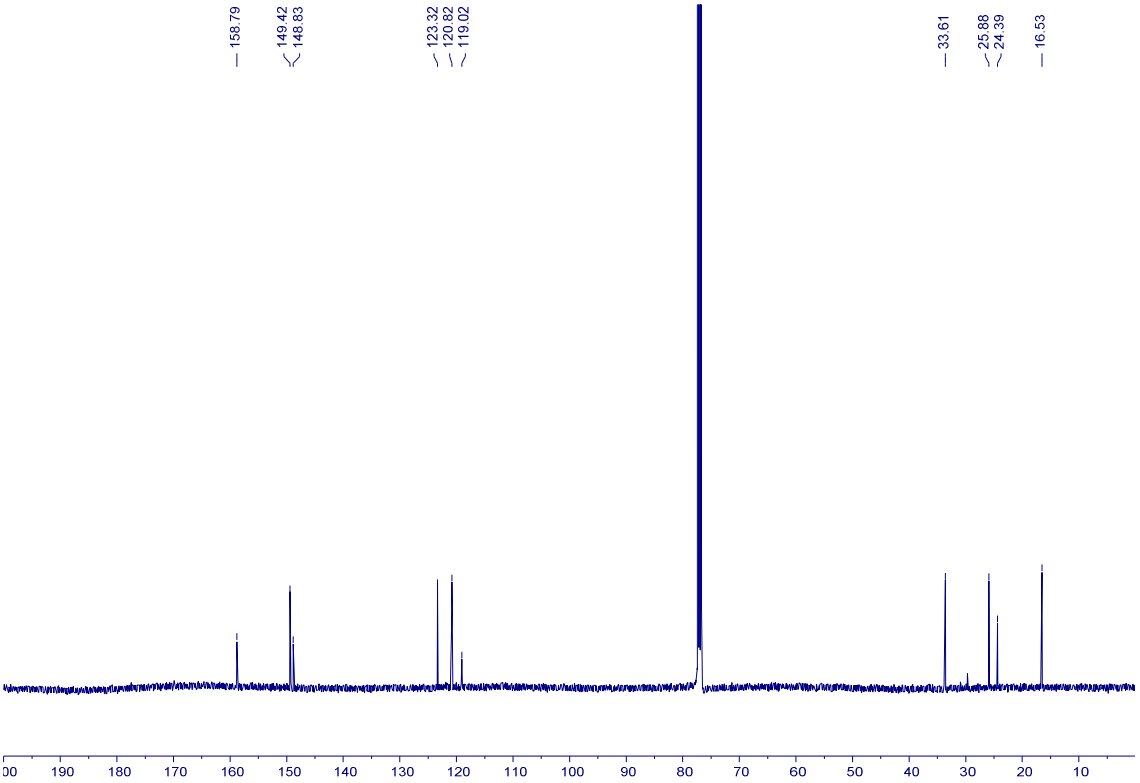
14 ^{13}C NMR (126 MHz, $CDCl_3$)



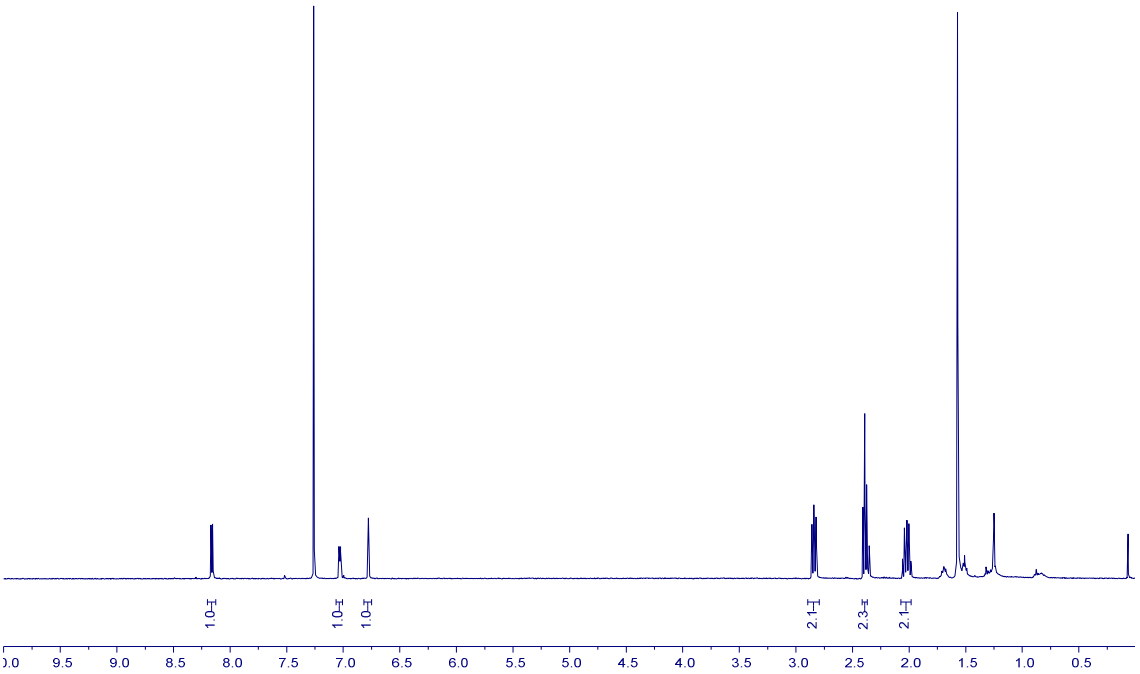
16 ^{1}H NMR (400 MHz, $CDCl_3$)



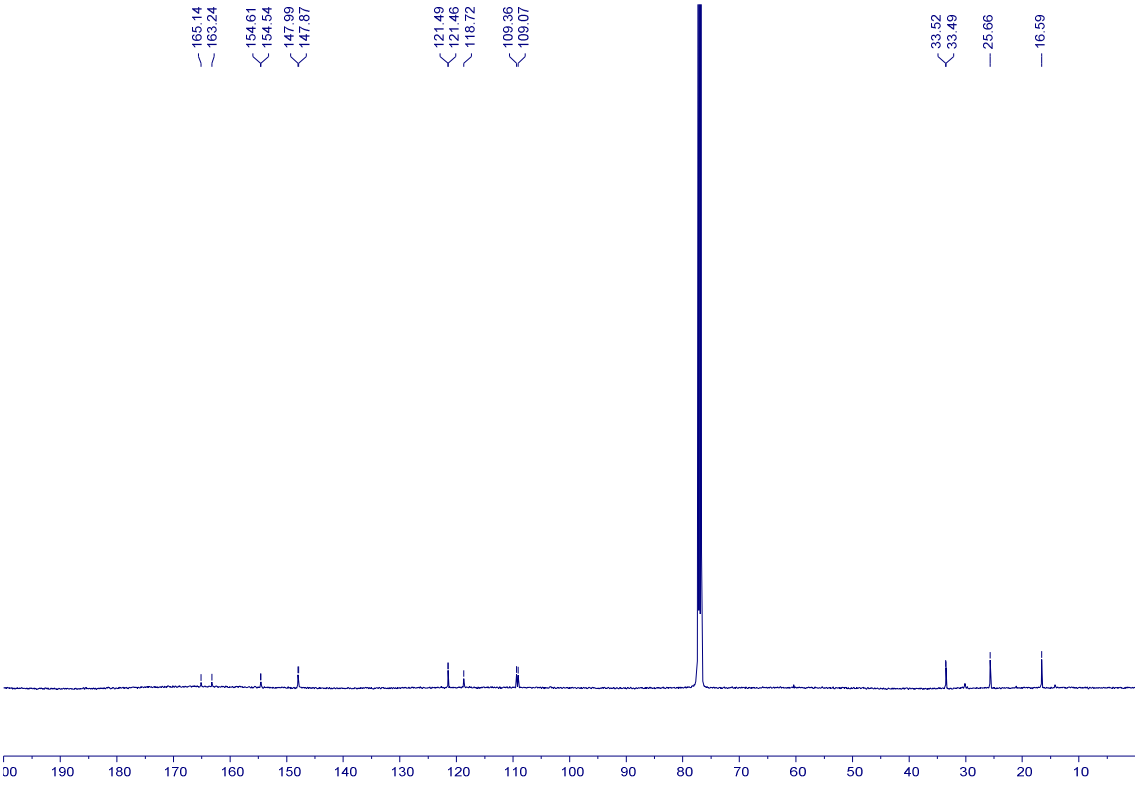
16 ^{13}C NMR (126 MHz, $CDCl_3$)



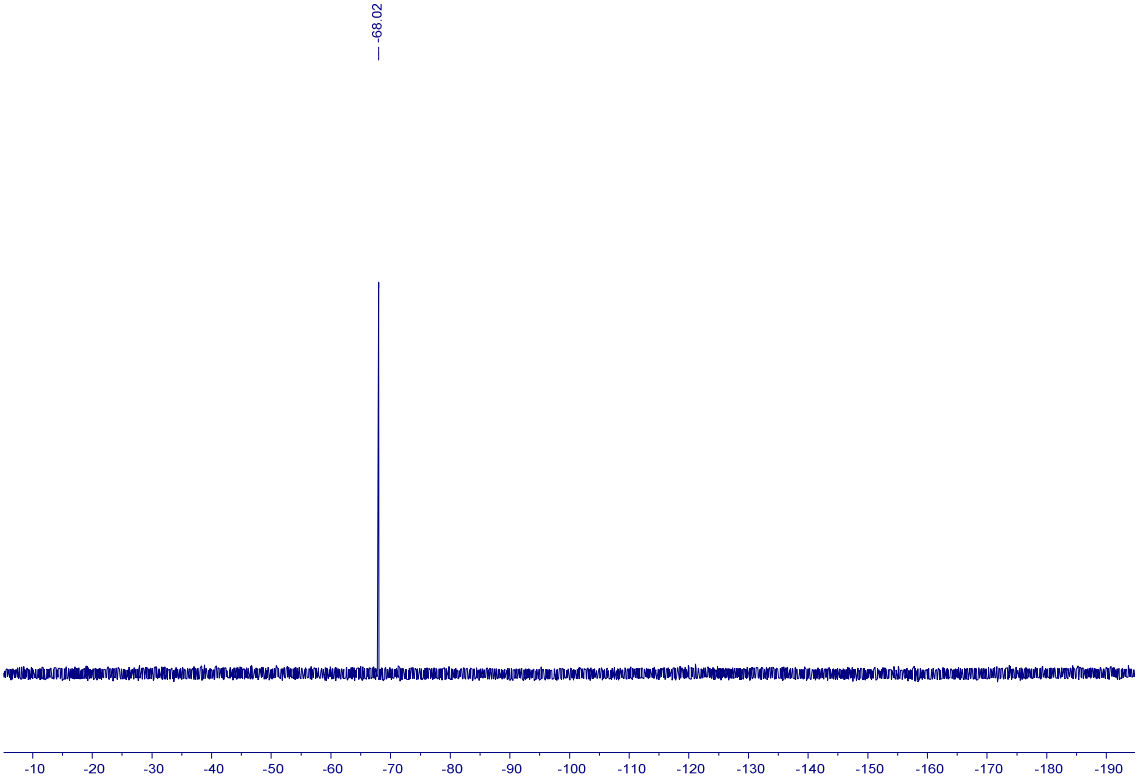
17 ^{1}H NMR (400 MHz, $CDCl_3$)



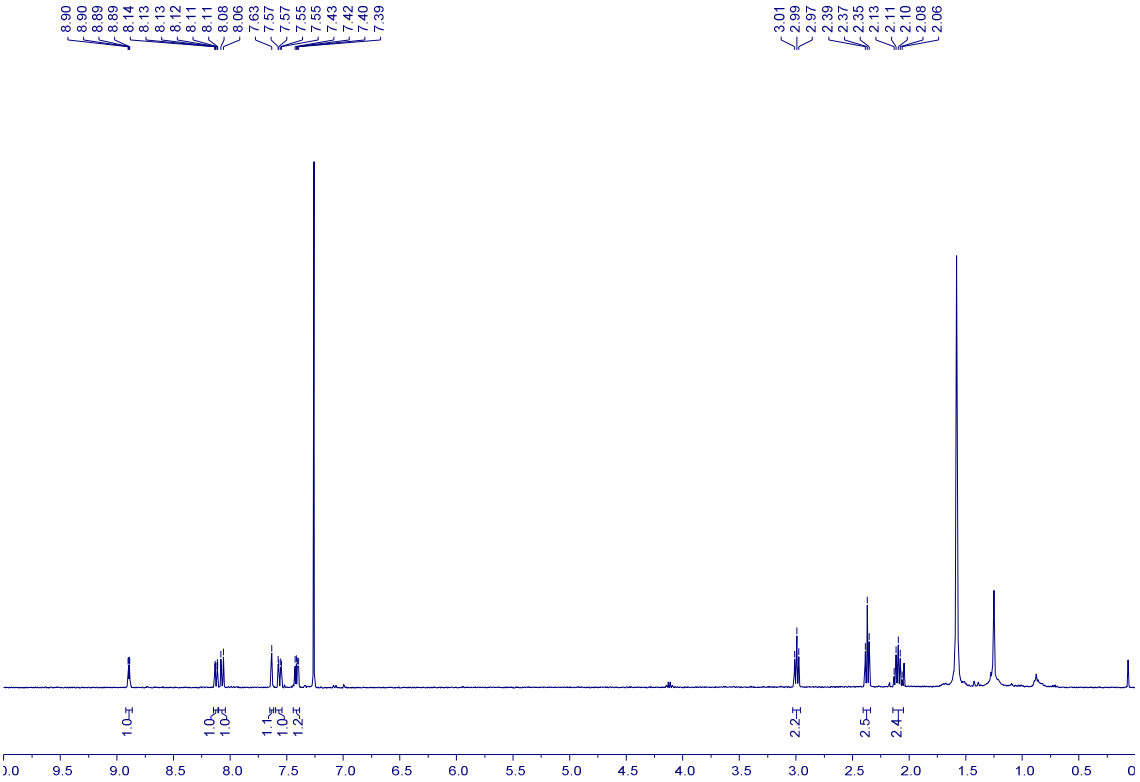
17 ^{13}C NMR (126 MHz, $CDCl_3$)



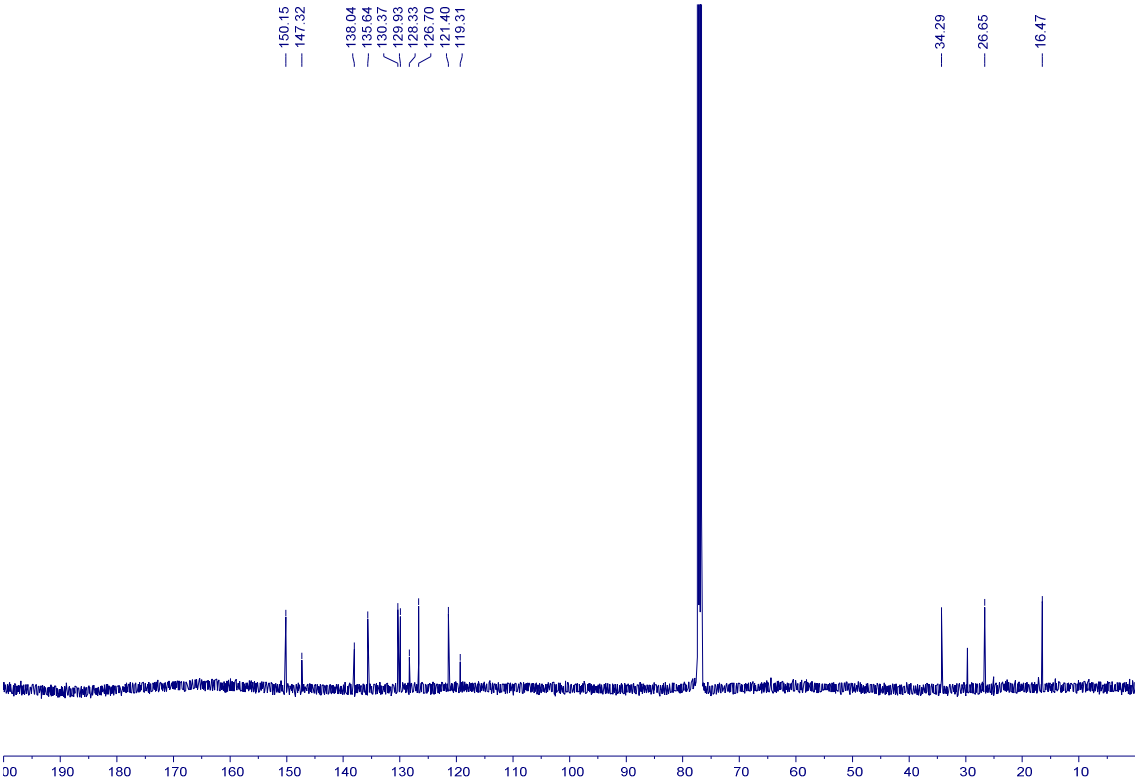
17 ^{19}F NMR (471 MHz, $CDCl_3$)



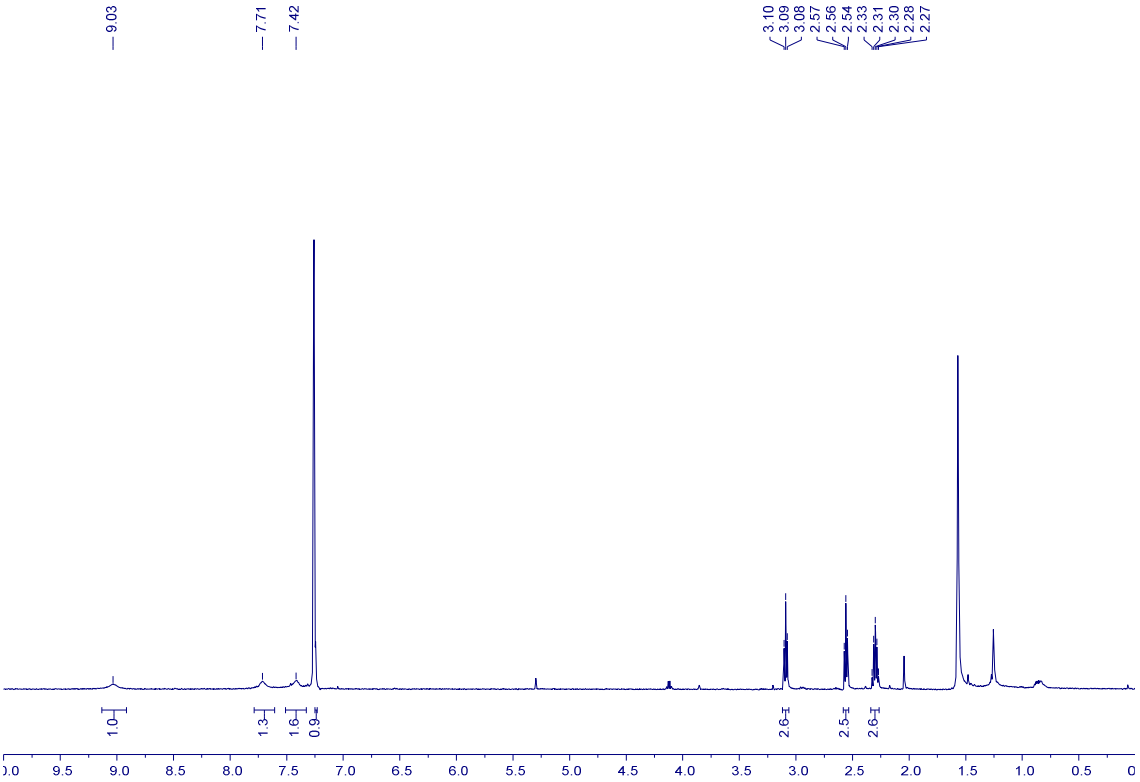
19 ^{1}H NMR (400 MHz, $CDCl_3$)



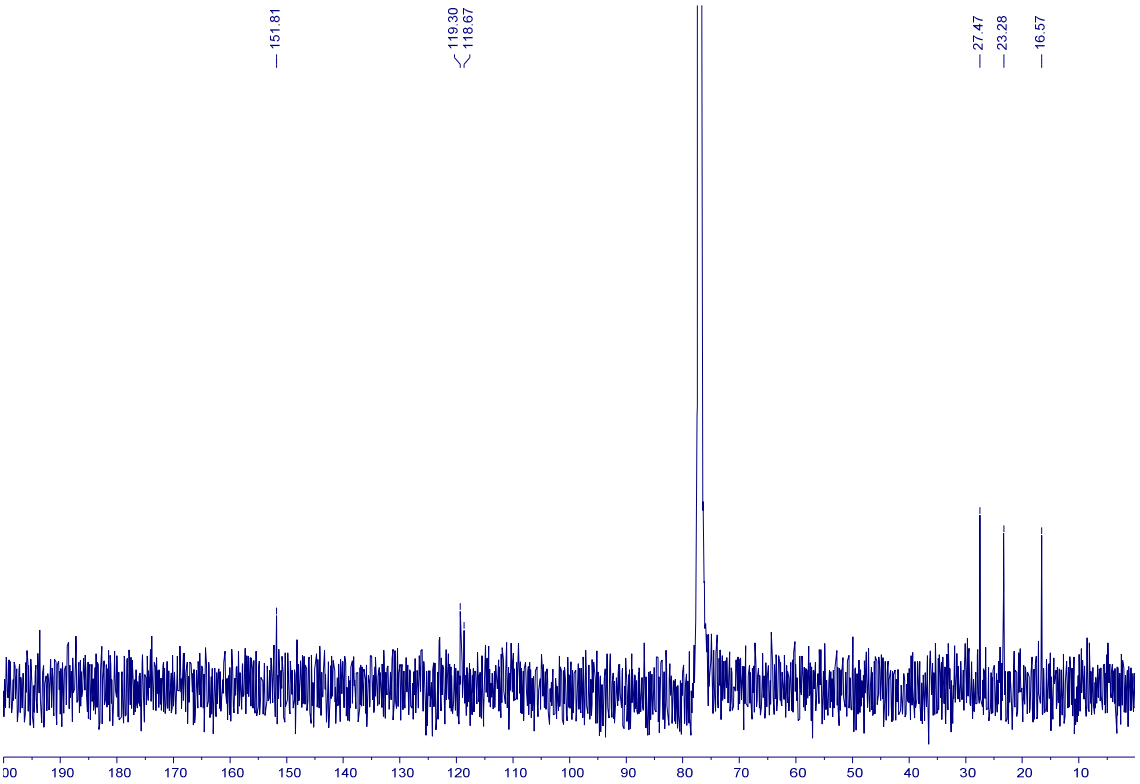
19 ^{13}C NMR (126 MHz, $CDCl_3$)



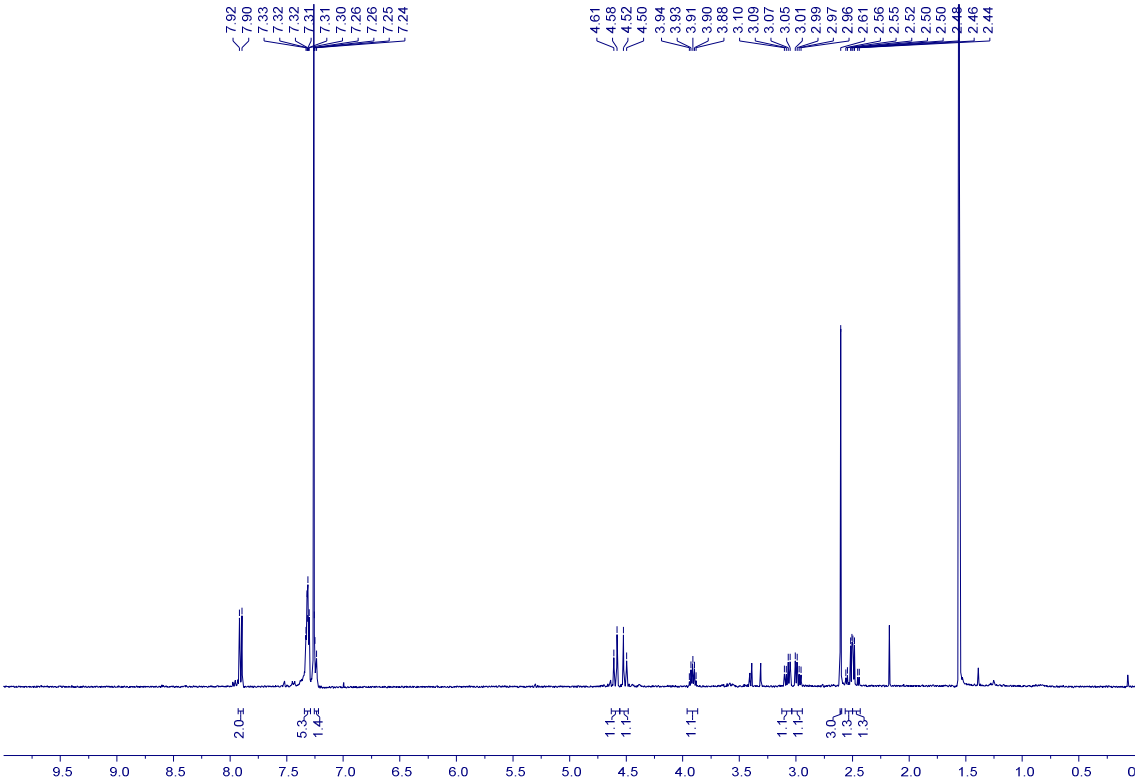
21 ^{1}H NMR (500 MHz, $CDCl_3$)



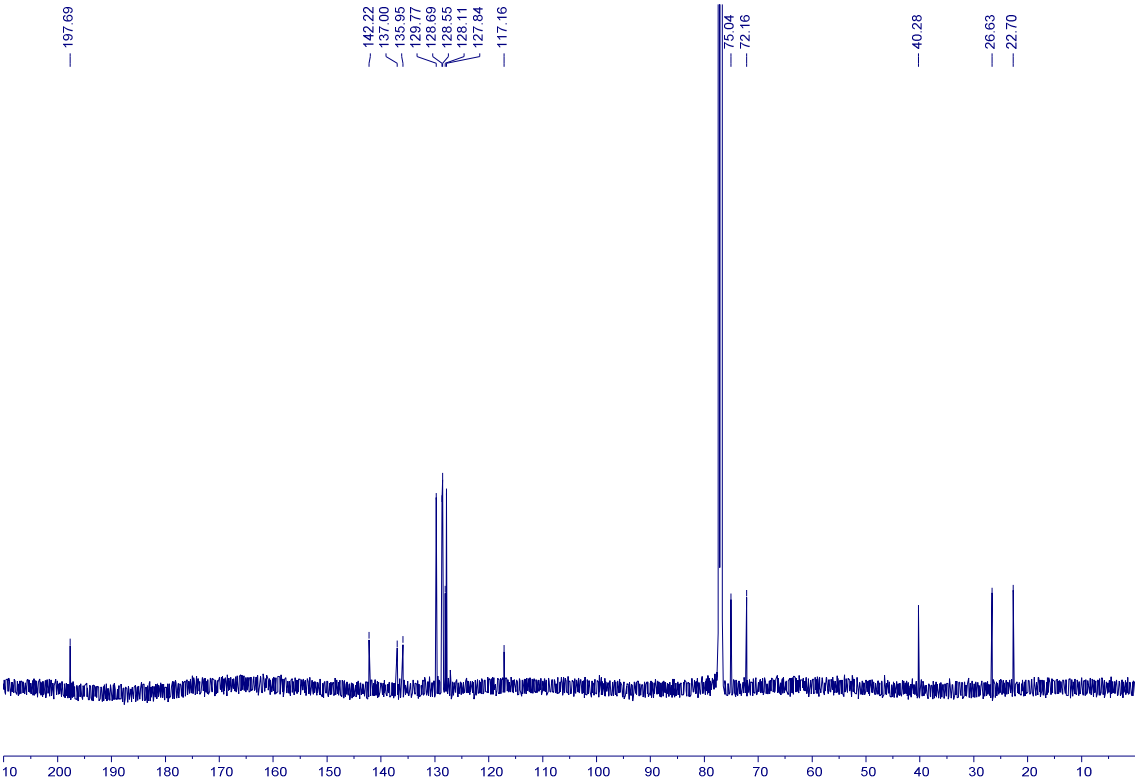
21 ^{13}C NMR (126 MHz, $CDCl_3$)



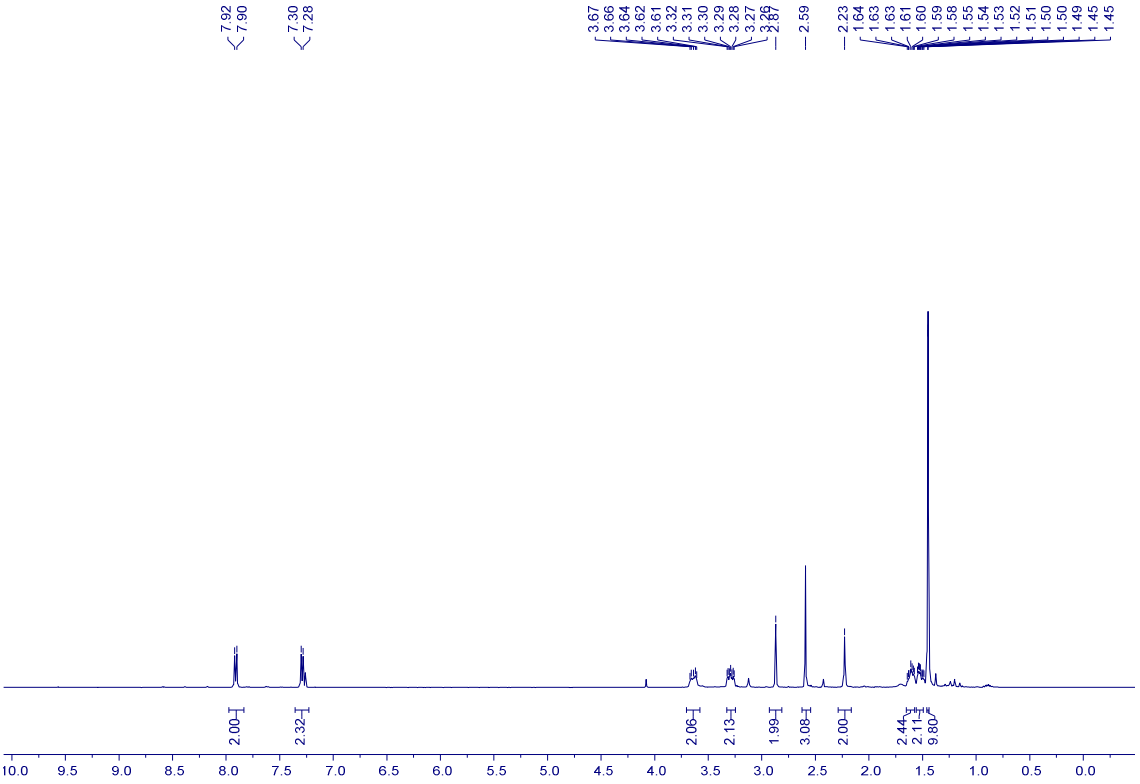
23 ^{1}H NMR (400 MHz, $CDCl_3$)



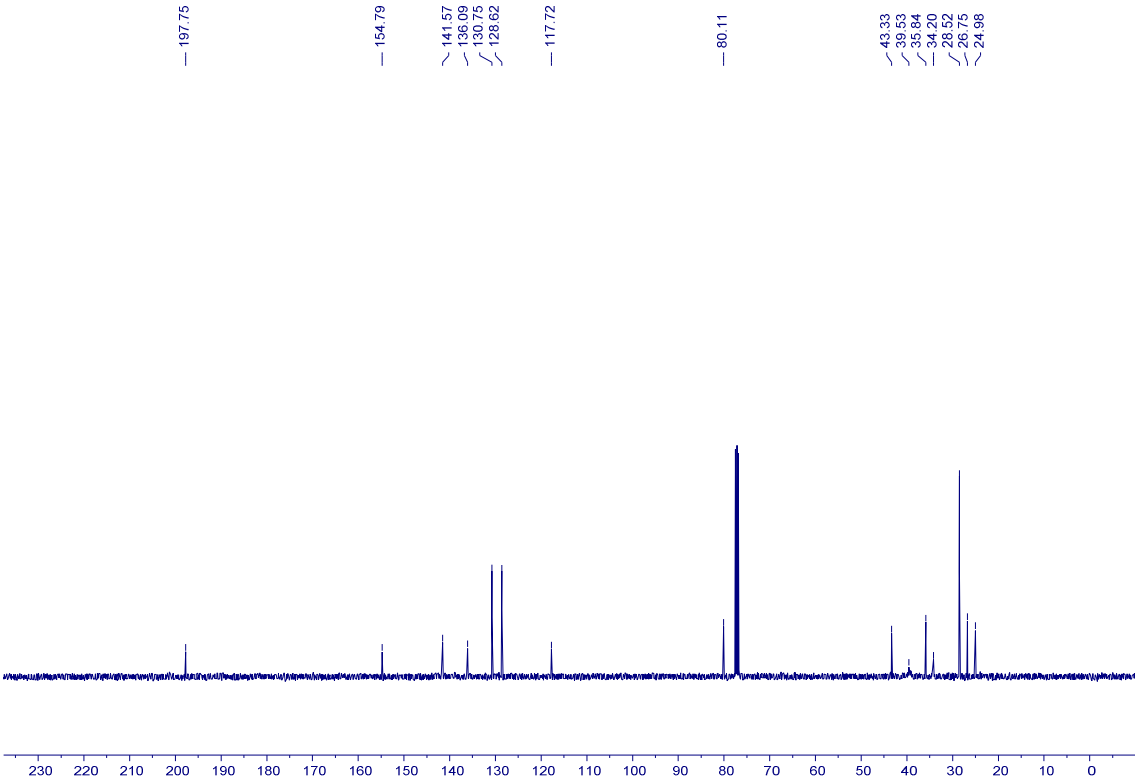
23 ^{13}C NMR (126 MHz, $CDCl_3$)



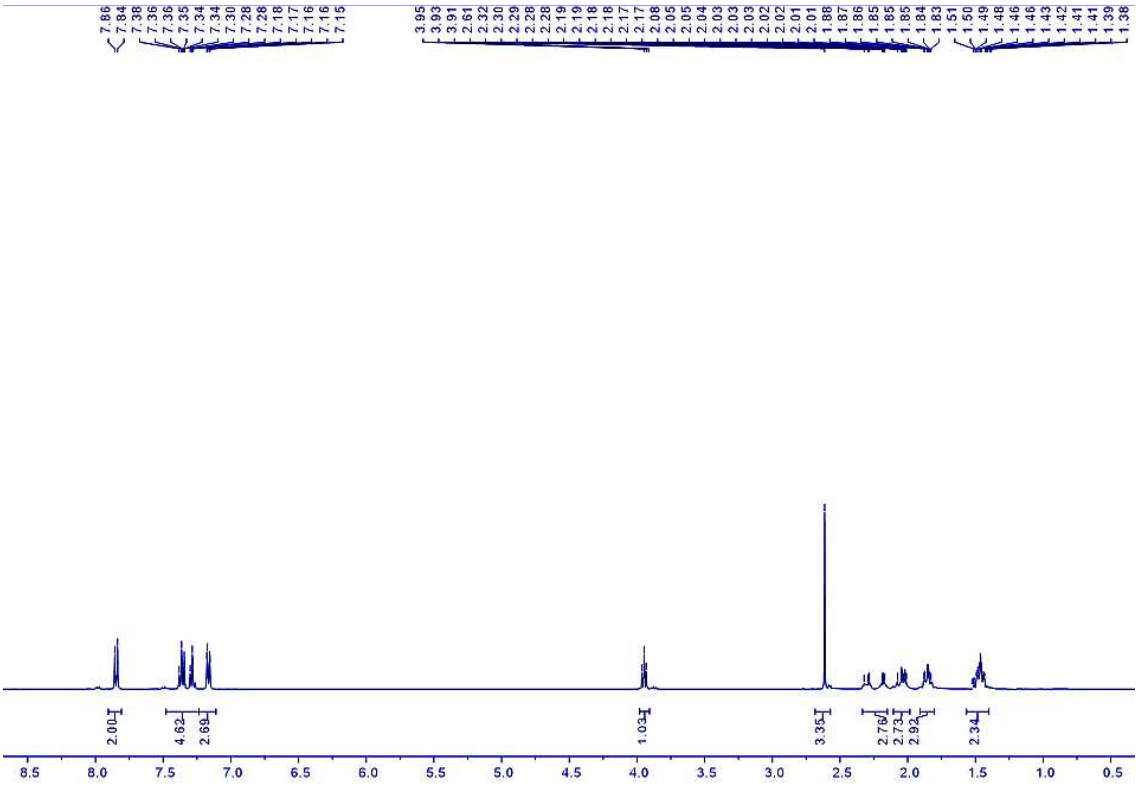
24 ^{1}H NMR (400 MHz, $CDCl_3$)



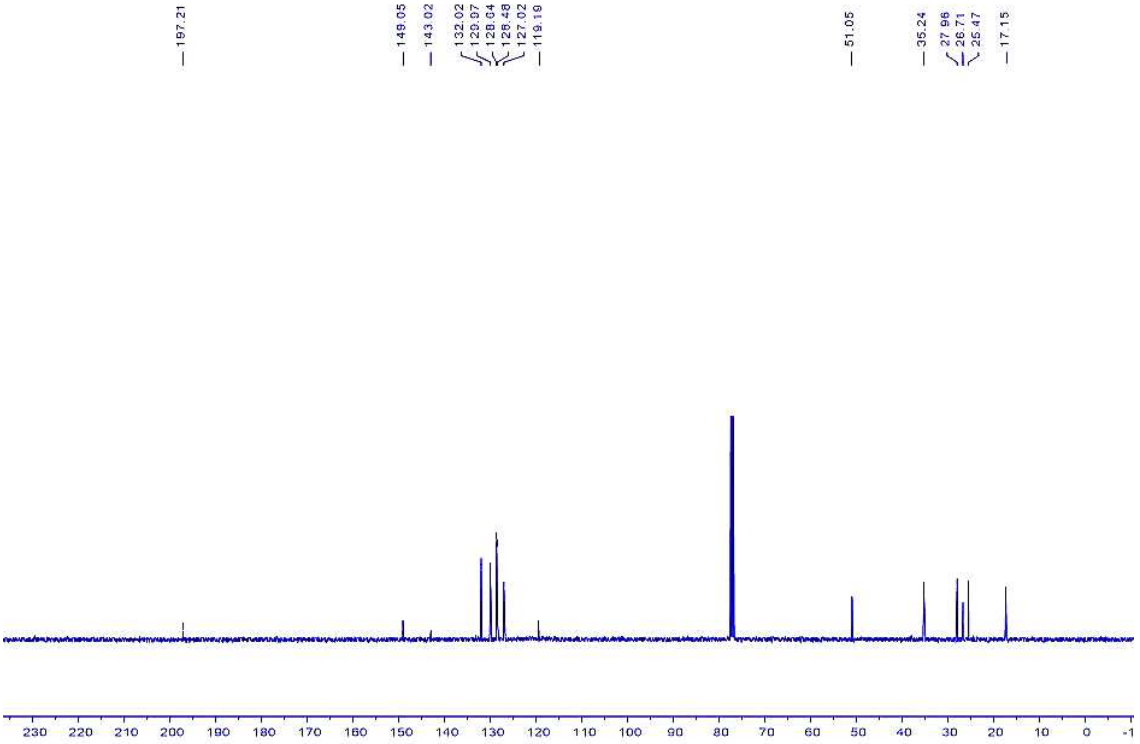
24 ^{13}C NMR (101 MHz, $CDCl_3$)



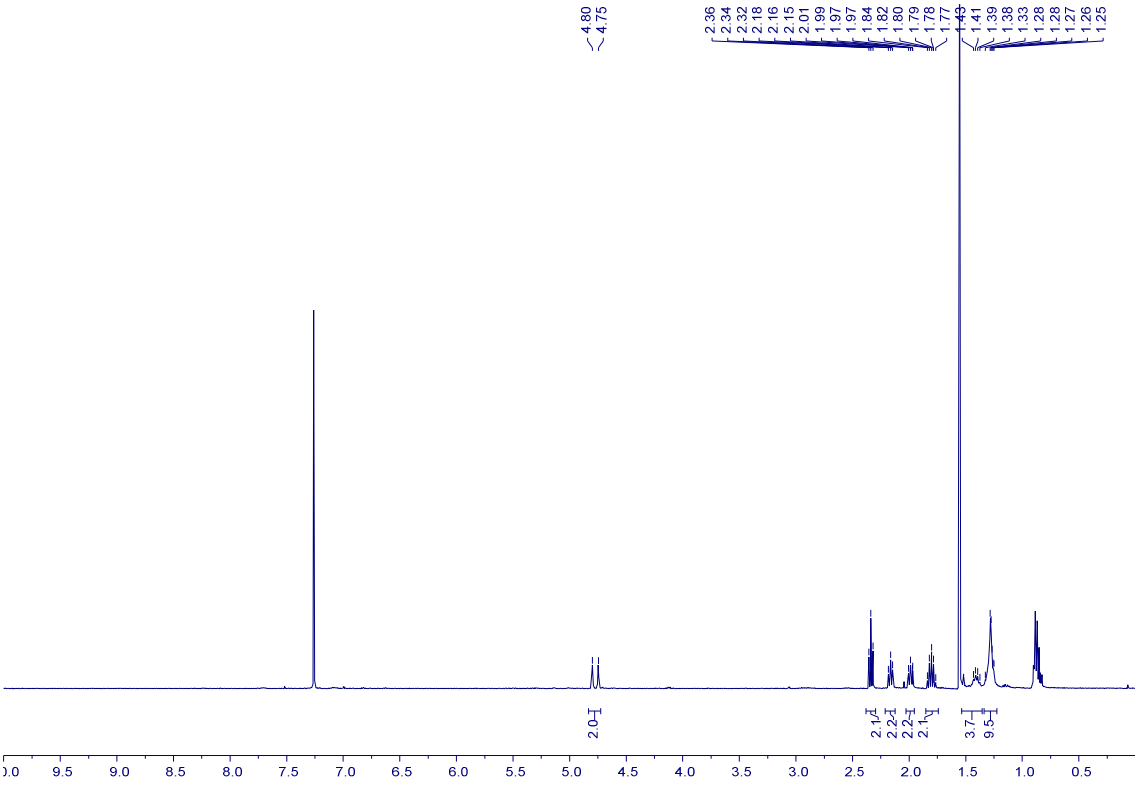
27 ^{1}H NMR (400MHz, $CDCl_3$)



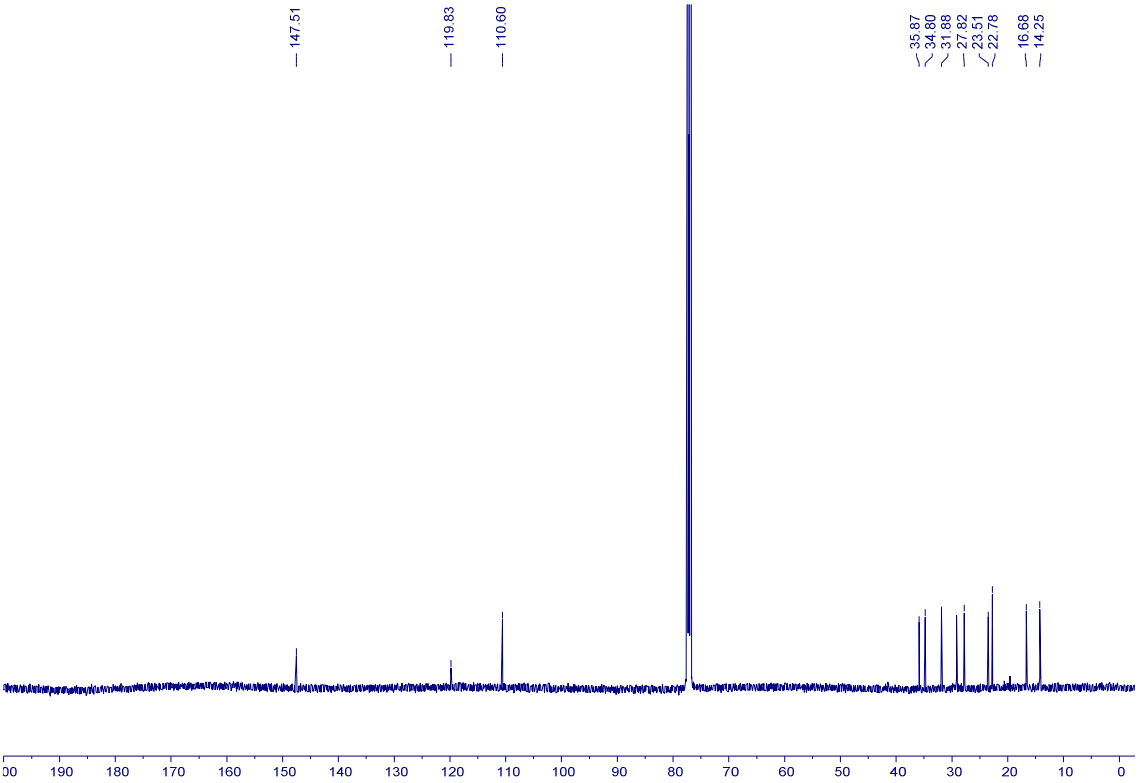
27 ^{13}C NMR (101 MHz, $CDCl_3$)



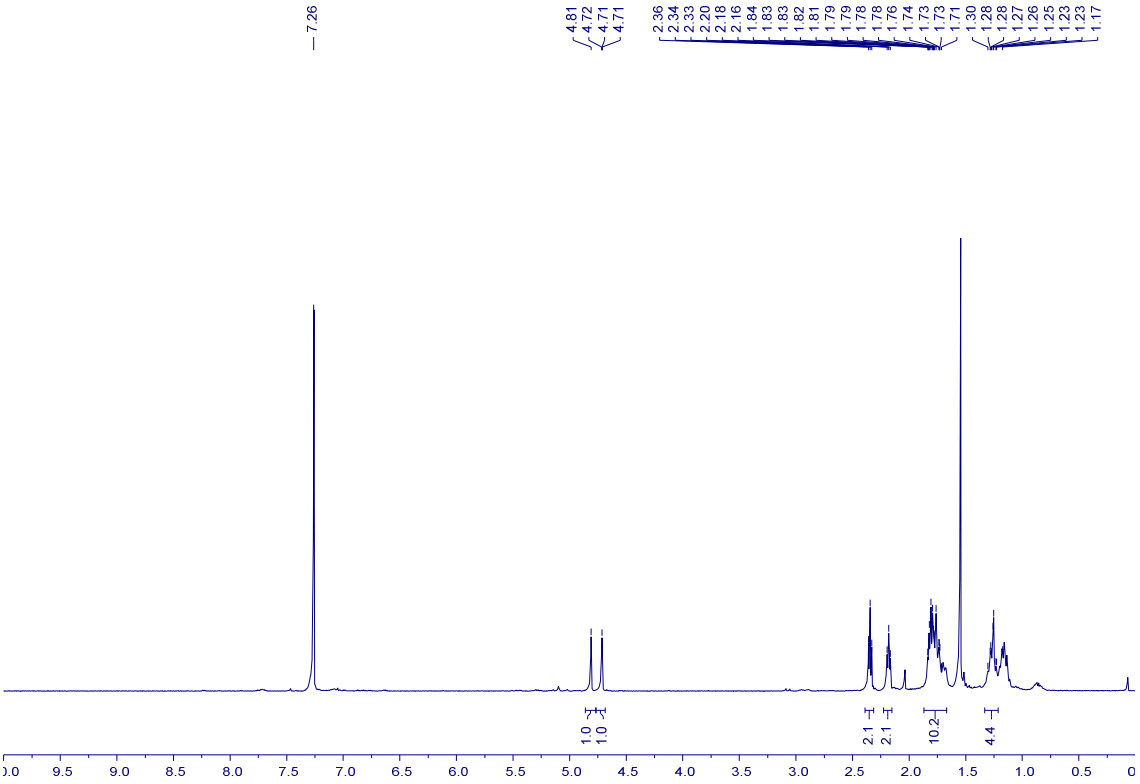
30 ^{1}H NMR (400 MHz, $CDCl_3$)



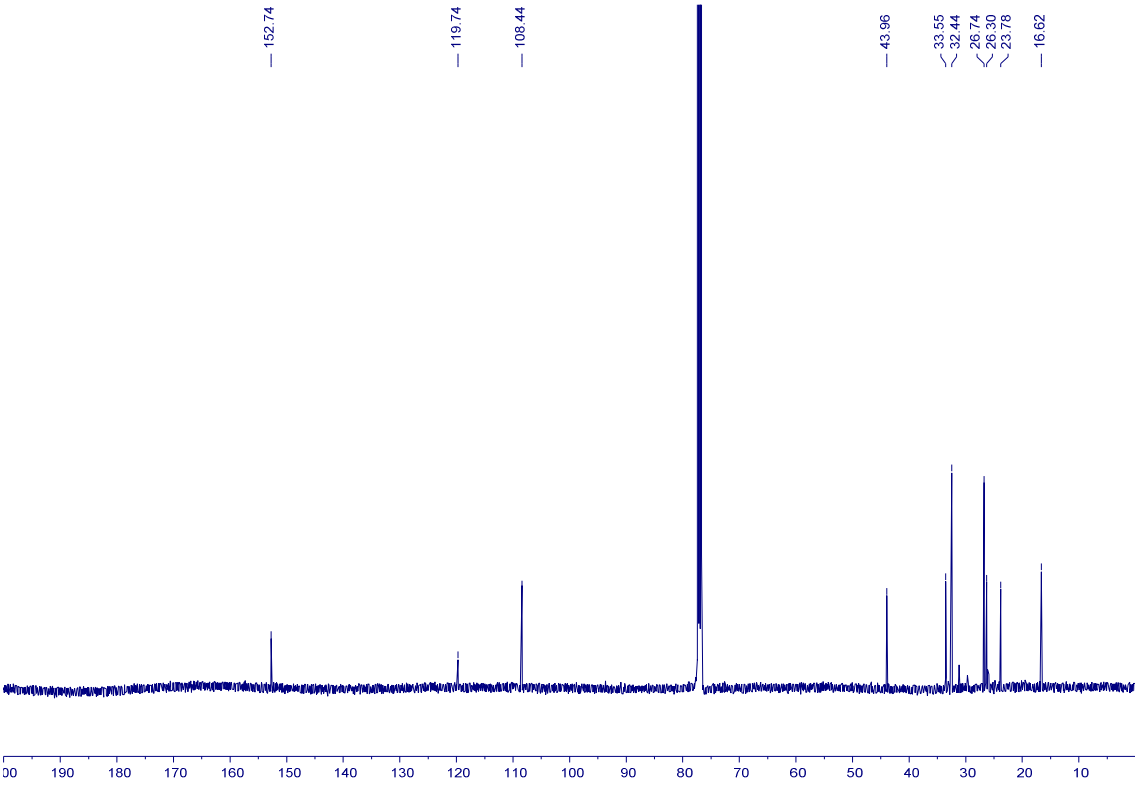
30 ^{13}C NMR (126 MHz, $CDCl_3$)



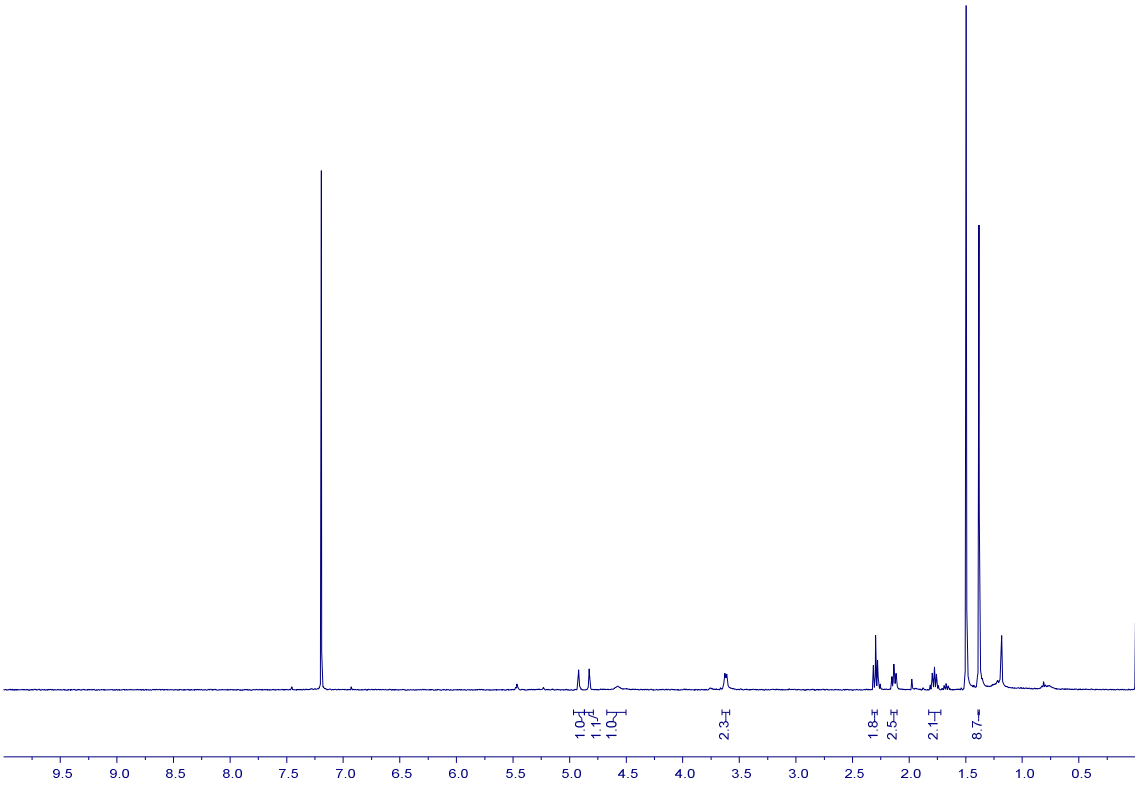
32 ^{1}H NMR (500 MHz, $CDCl_3$)



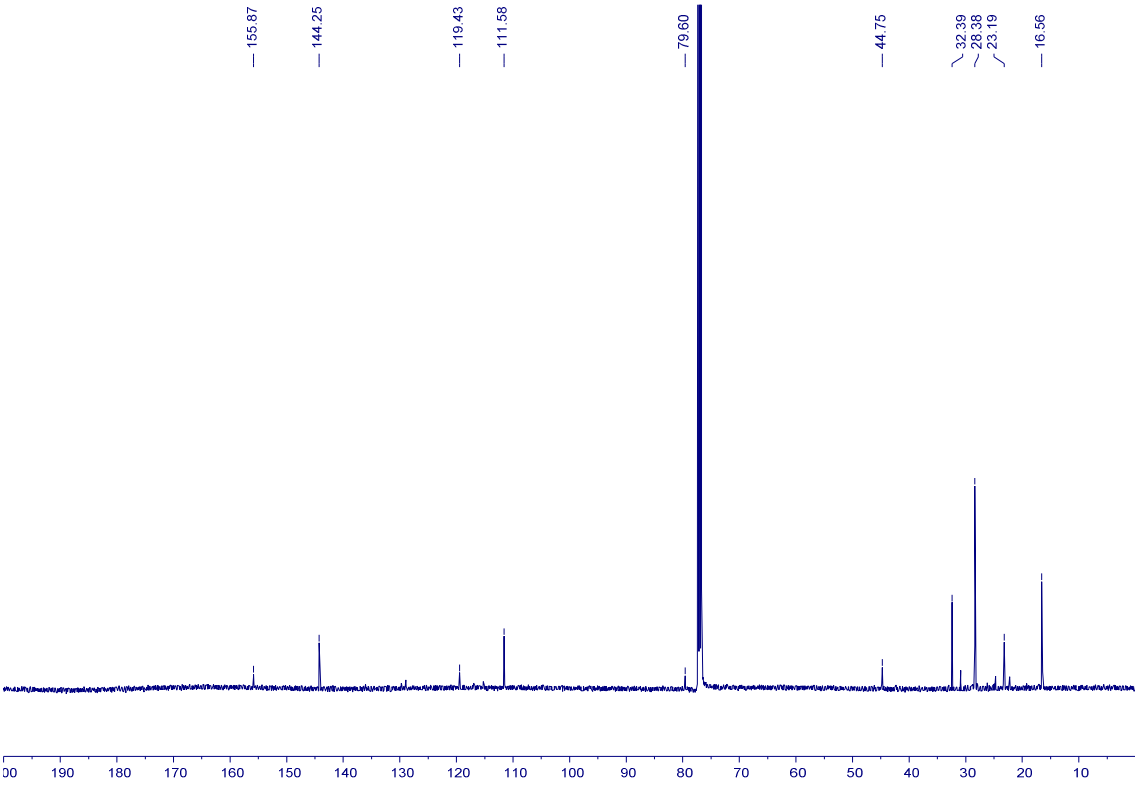
32 ^{13}C NMR (126 MHz, $CDCl_3$)



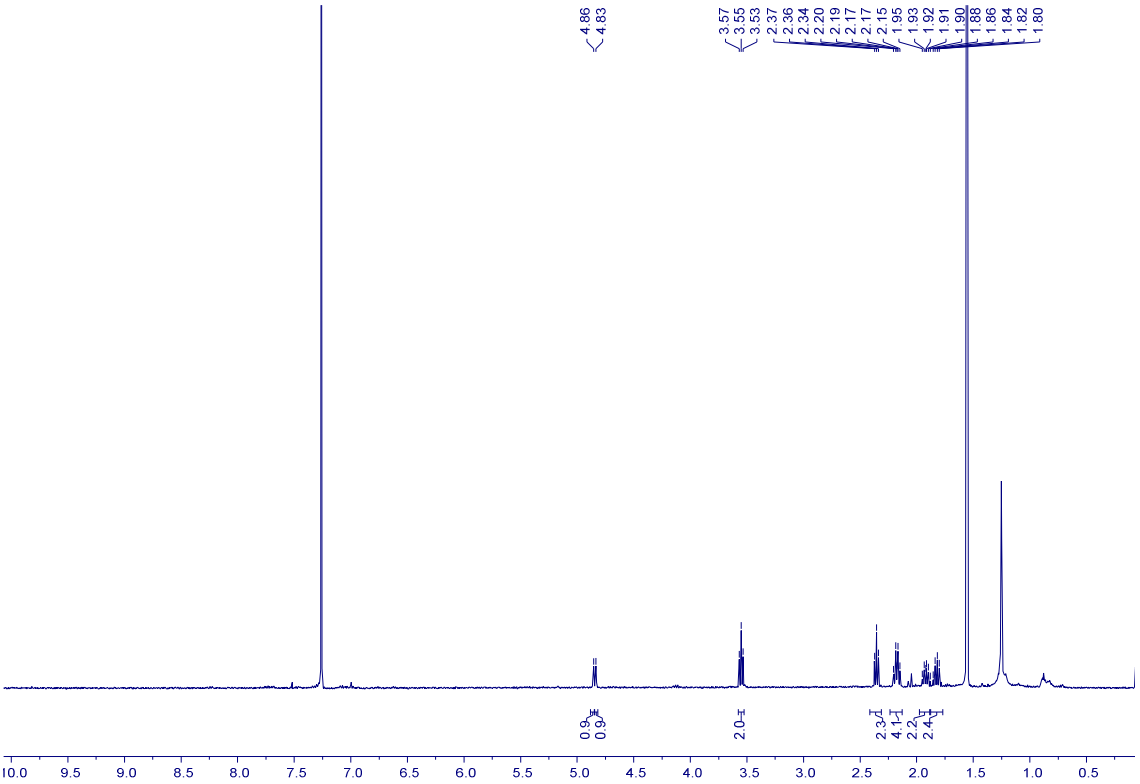
35 ^{1}H NMR (400 MHz, $CDCl_3$)



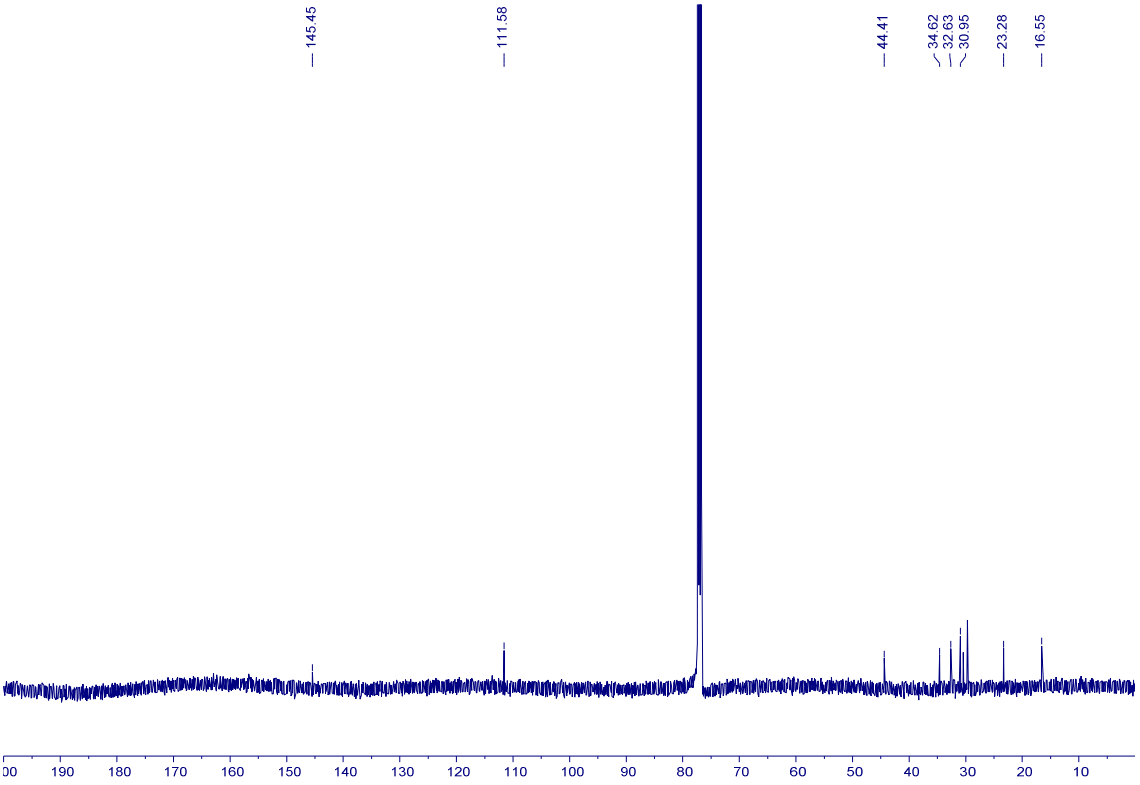
35 ^{13}C NMR (126 MHz, $CDCl_3$)



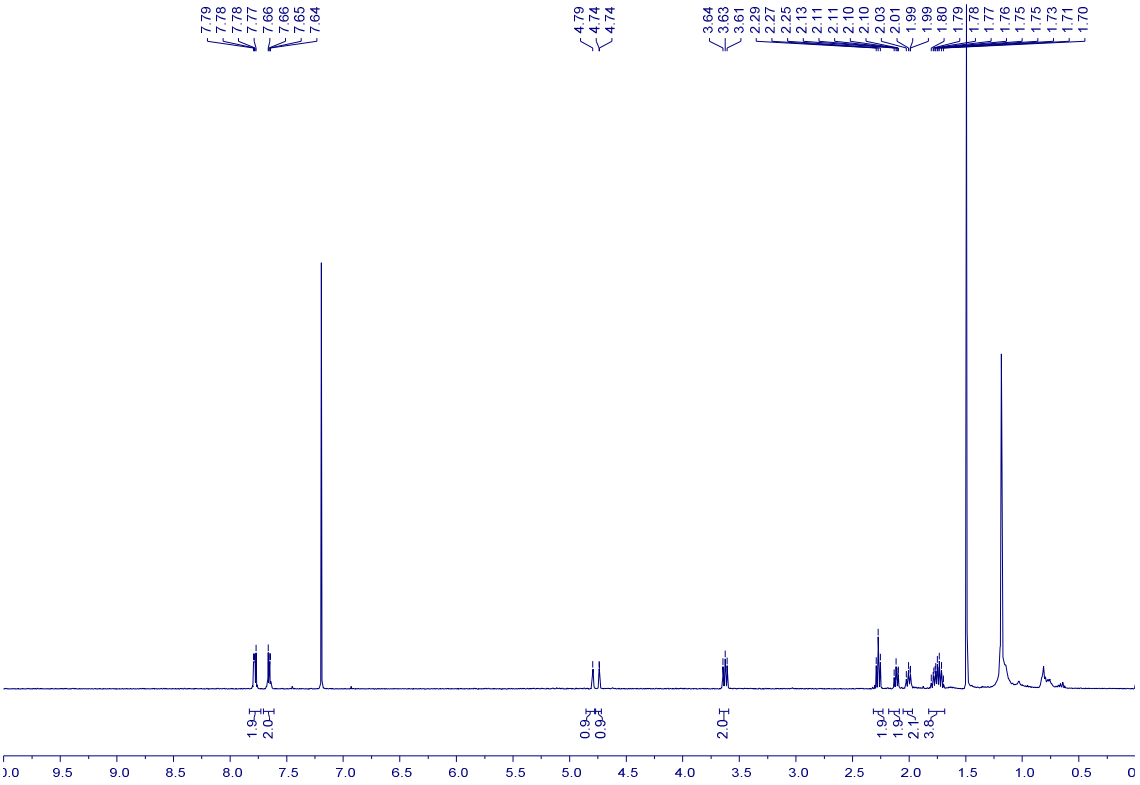
36 ^{1}H NMR (400 MHz, $CDCl_3$)



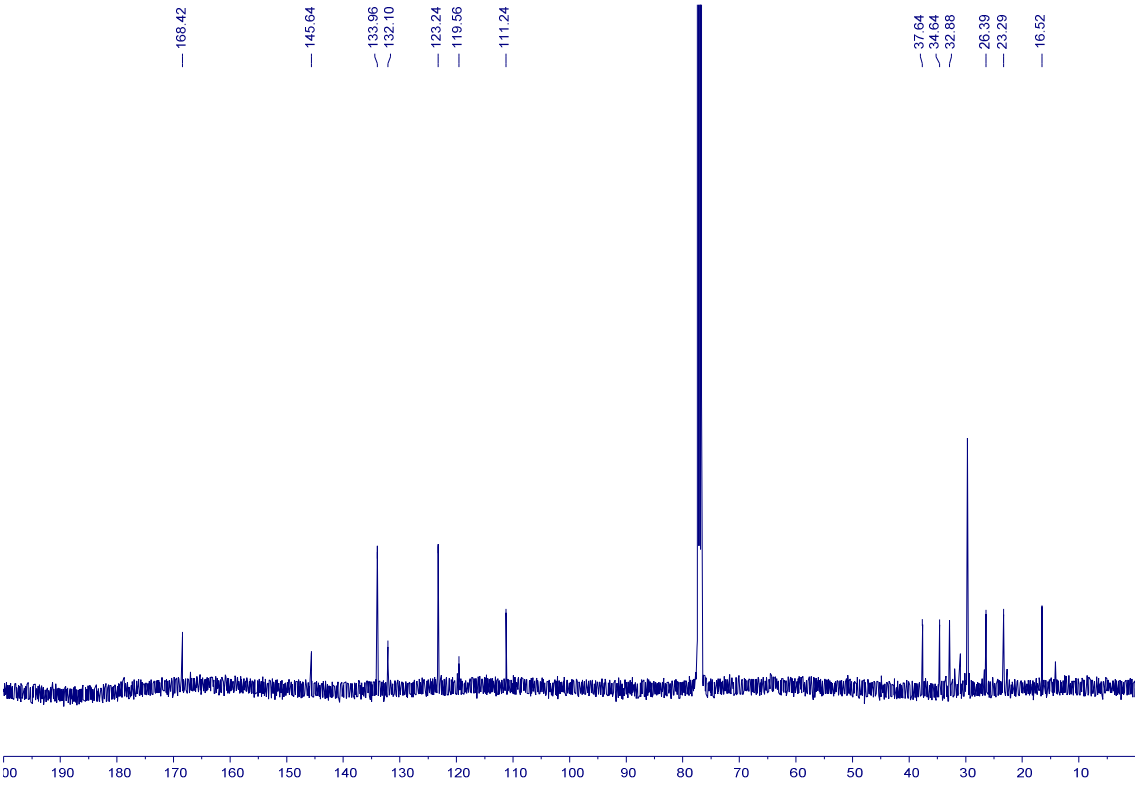
36 ^{13}C NMR (126 MHz, $CDCl_3$)



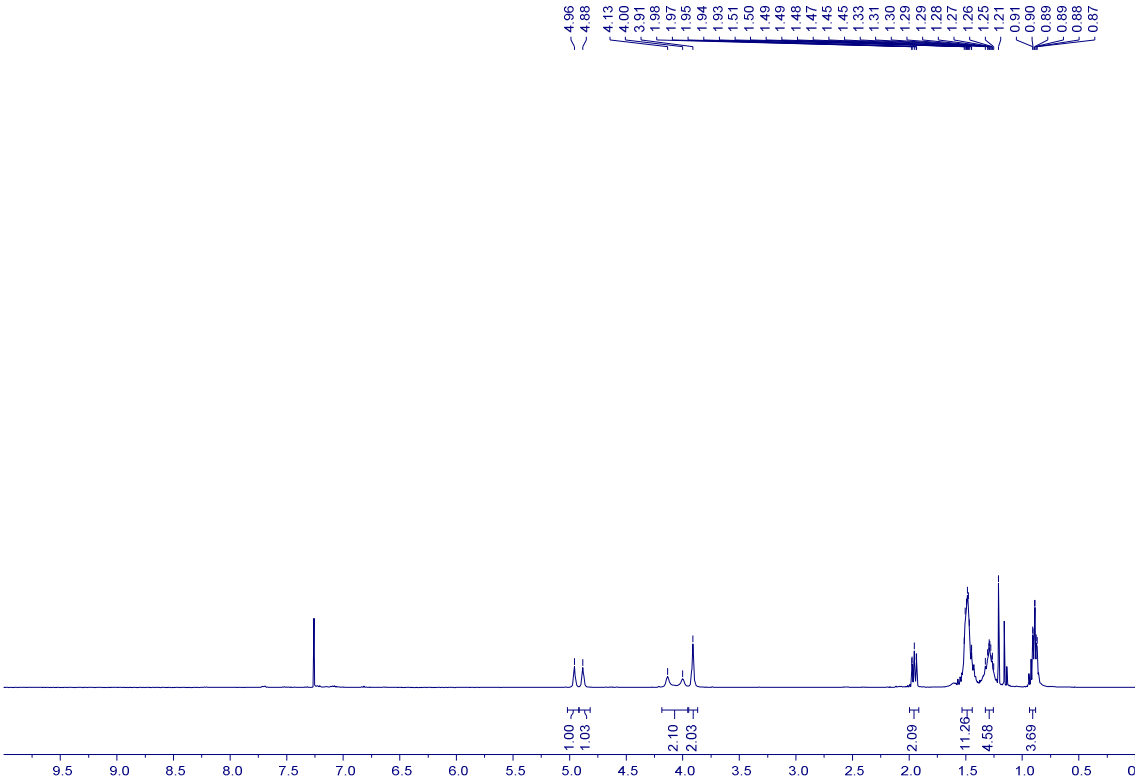
37 ^{1}H NMR (400 MHz, $CDCl_3$)



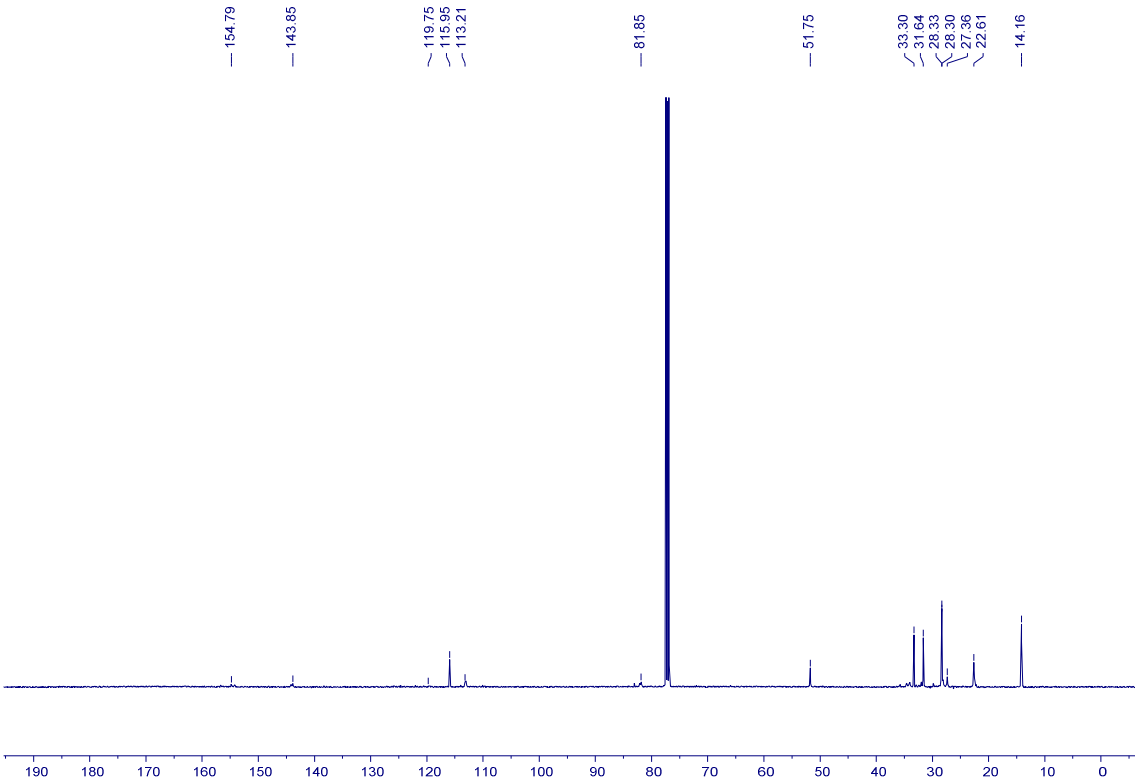
37 ^{13}C NMR (126 MHz, $CDCl_3$)



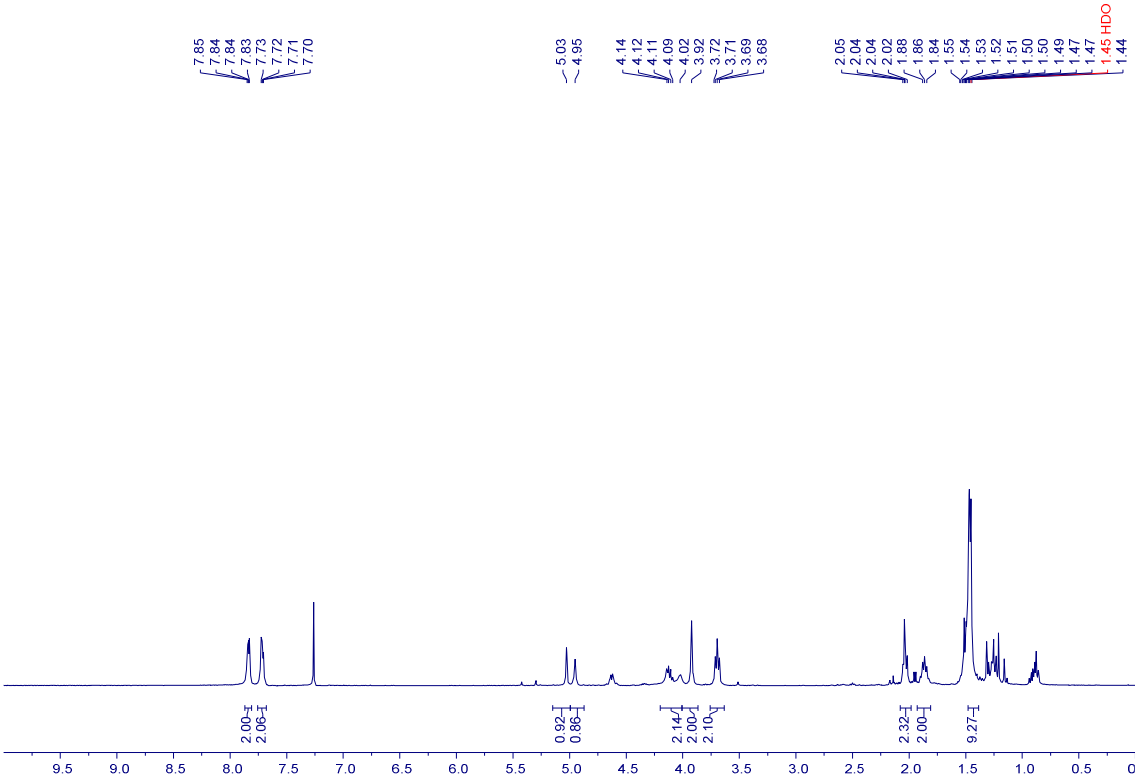
38 ^{1}H NMR (400 MHz, $CDCl_3$)



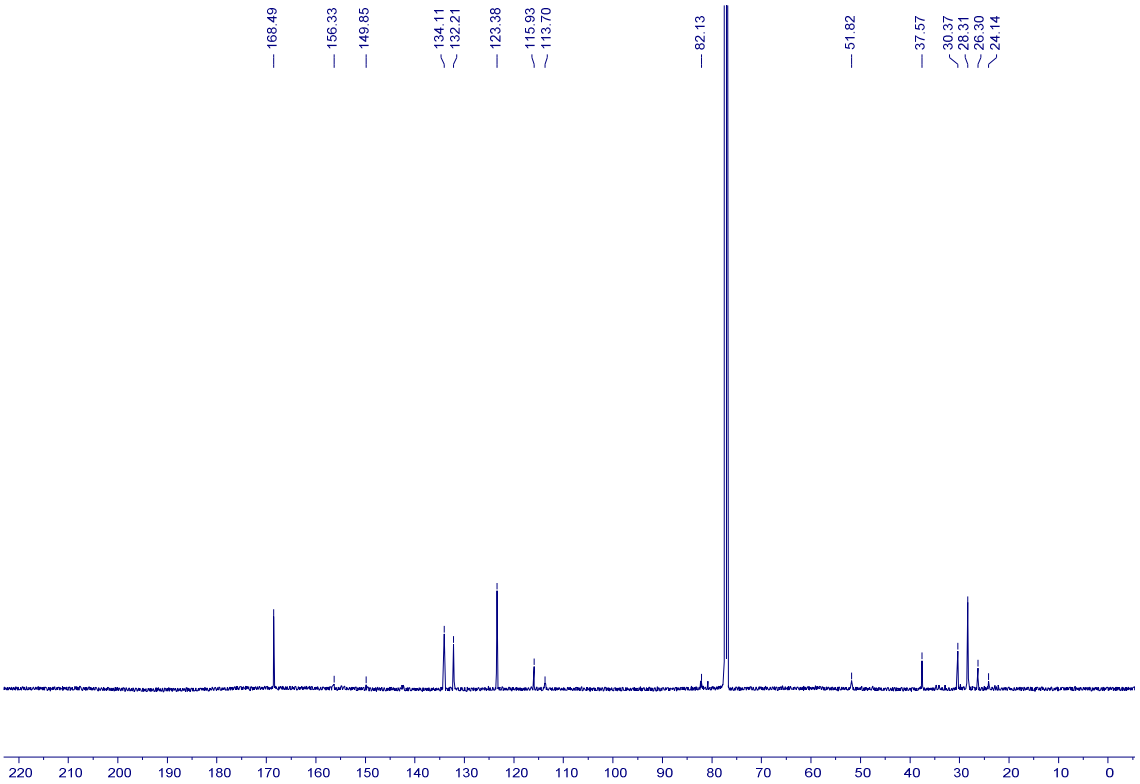
38 ^{13}C NMR (126 MHz, $CDCl_3$)



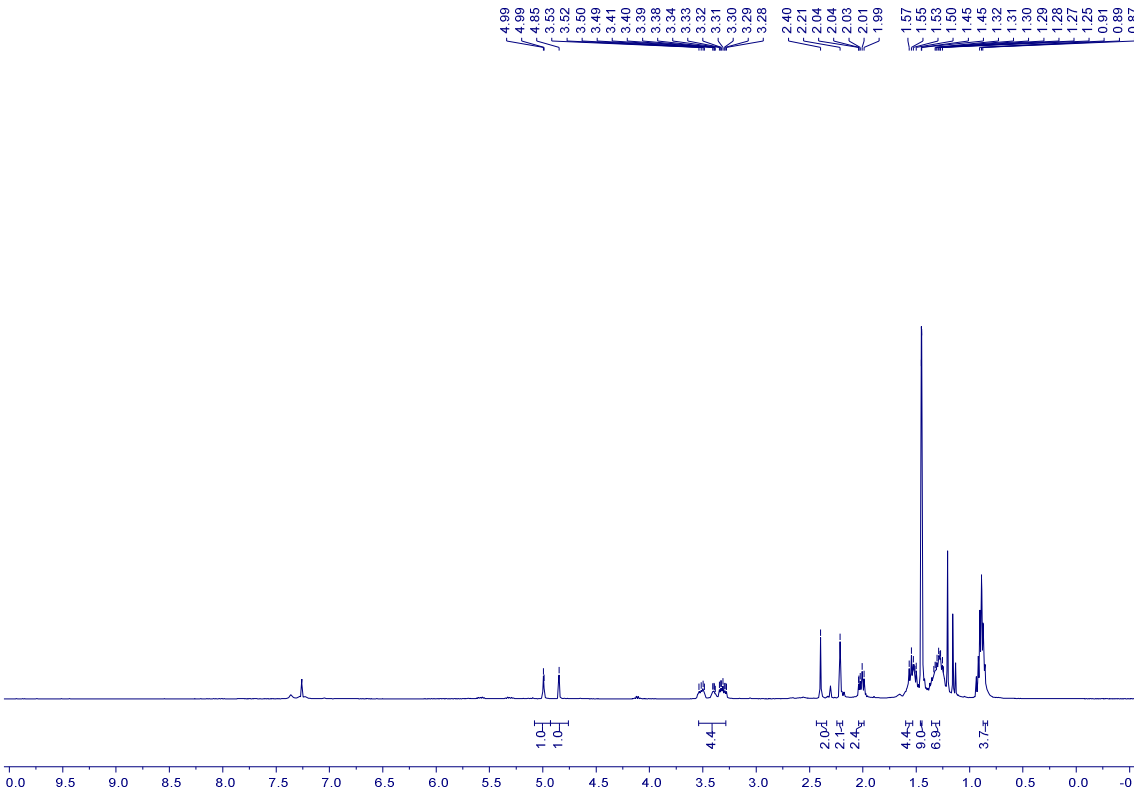
39 ^{1}H NMR (400 MHz, $CDCl_3$)



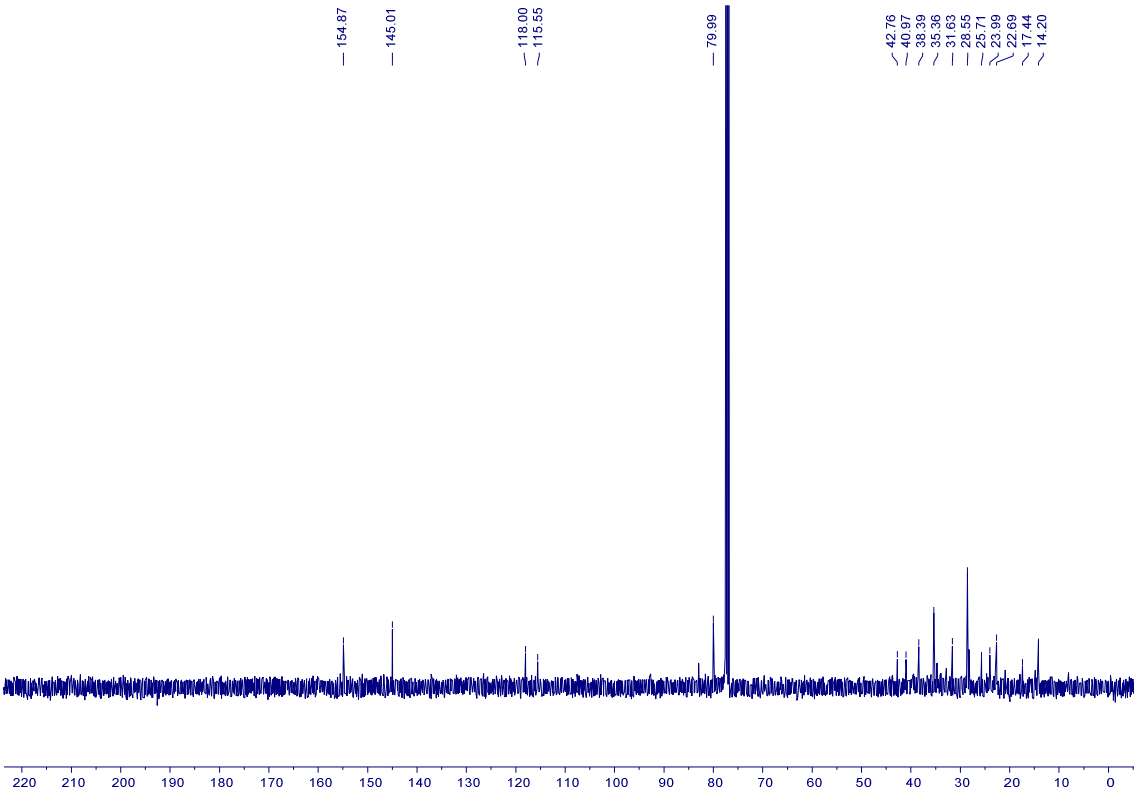
39 ^{13}C NMR (126 MHz, $CDCl_3$)



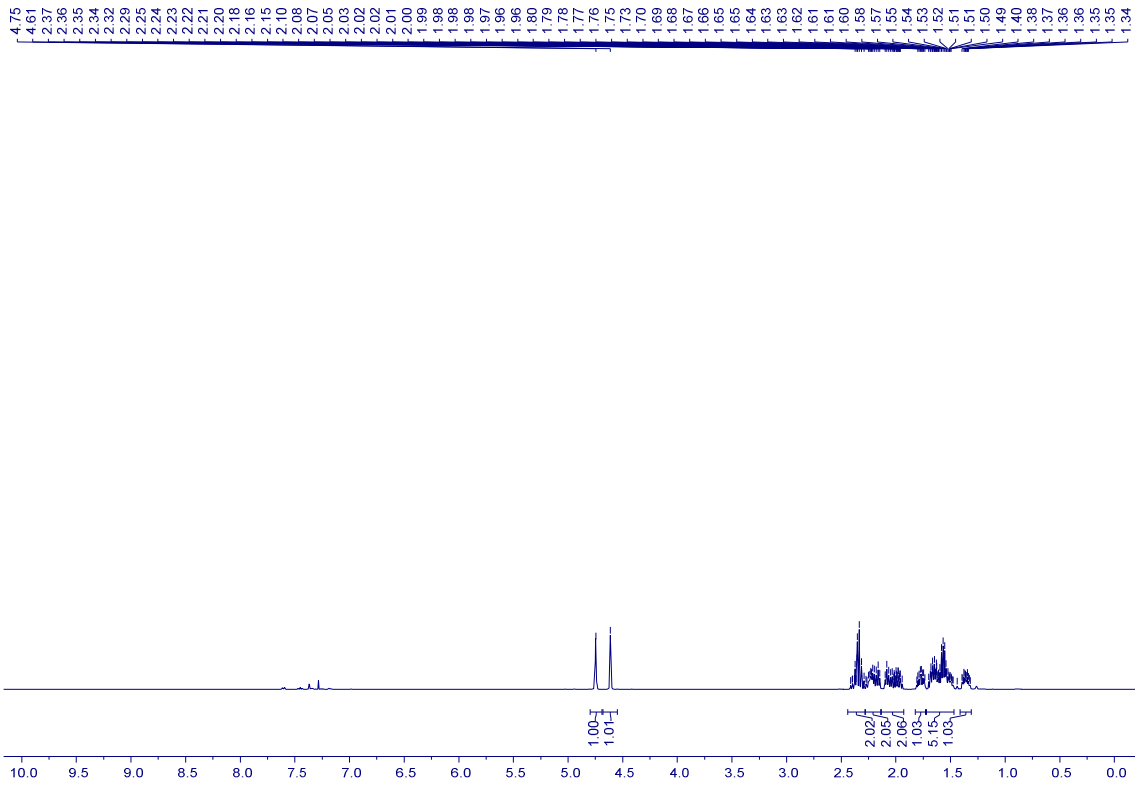
40 ^{1}H NMR (400 MHz, $CDCl_3$)



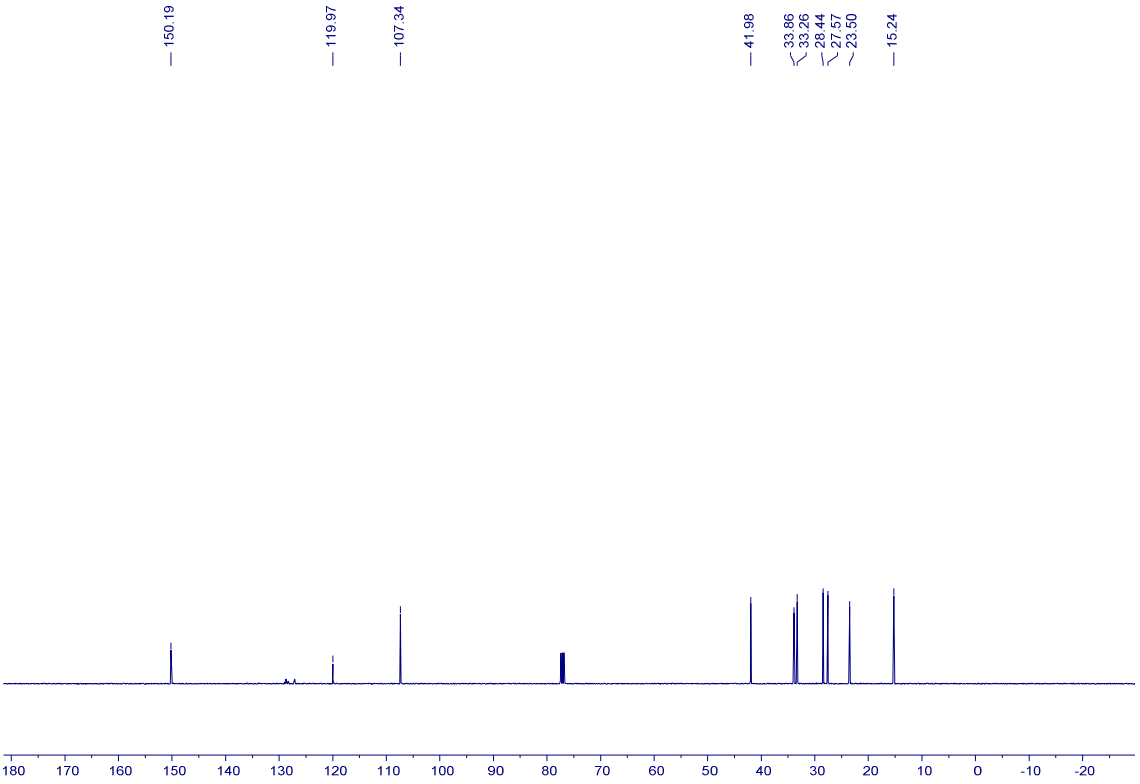
40 ^{13}C NMR (101 MHz, $CDCl_3$)



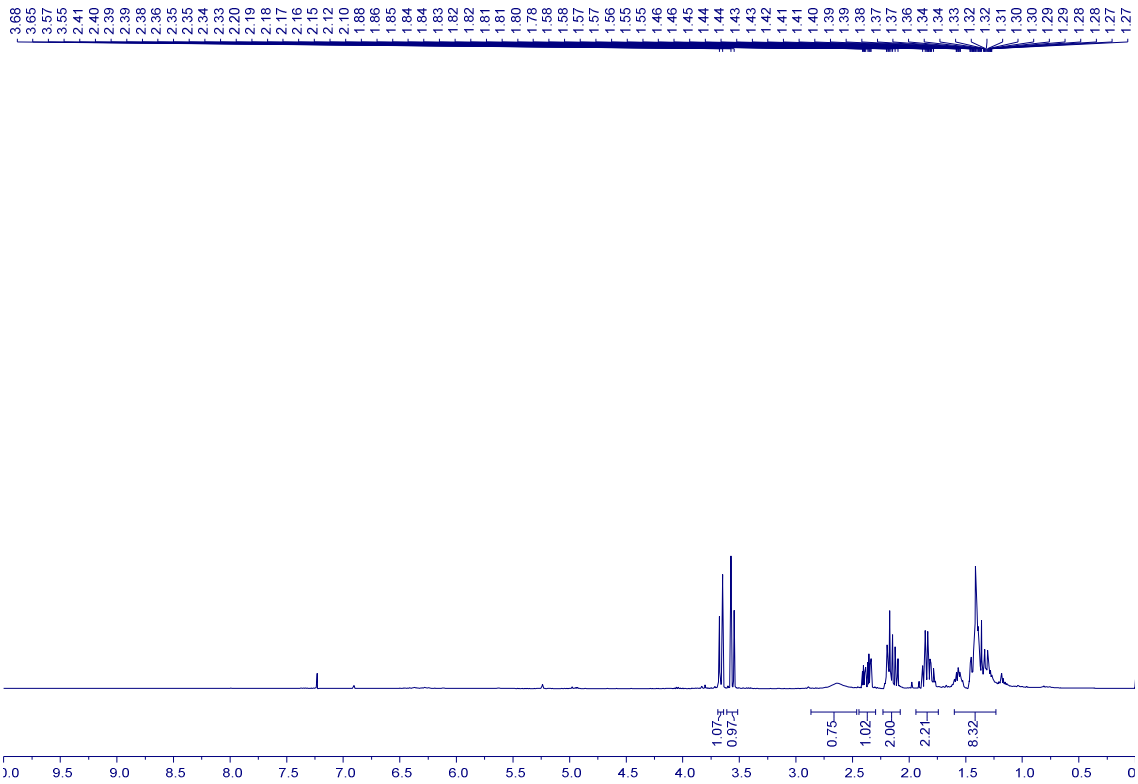
45 ^{1}H NMR (400 MHz, $CDCl_3$)



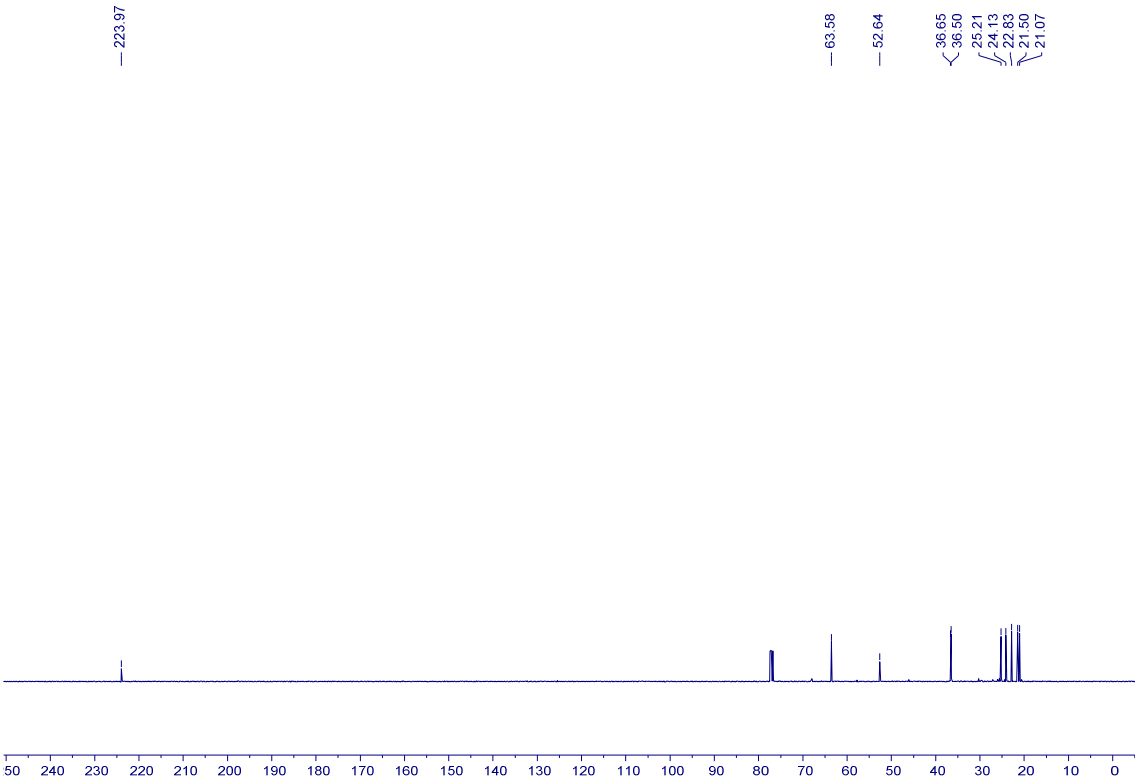
45 ^{13}C NMR (101 MHz, $CDCl_3$)



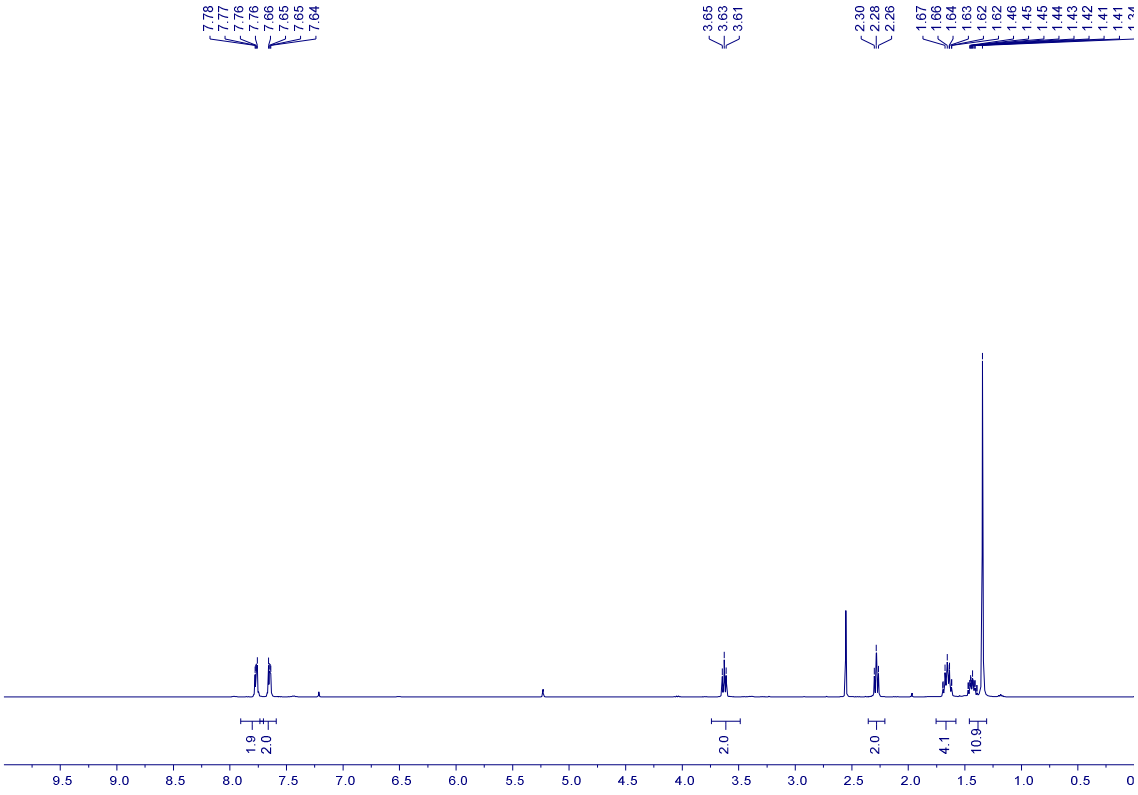
46 ^{1}H NMR (400 MHz, $CDCl_3$)



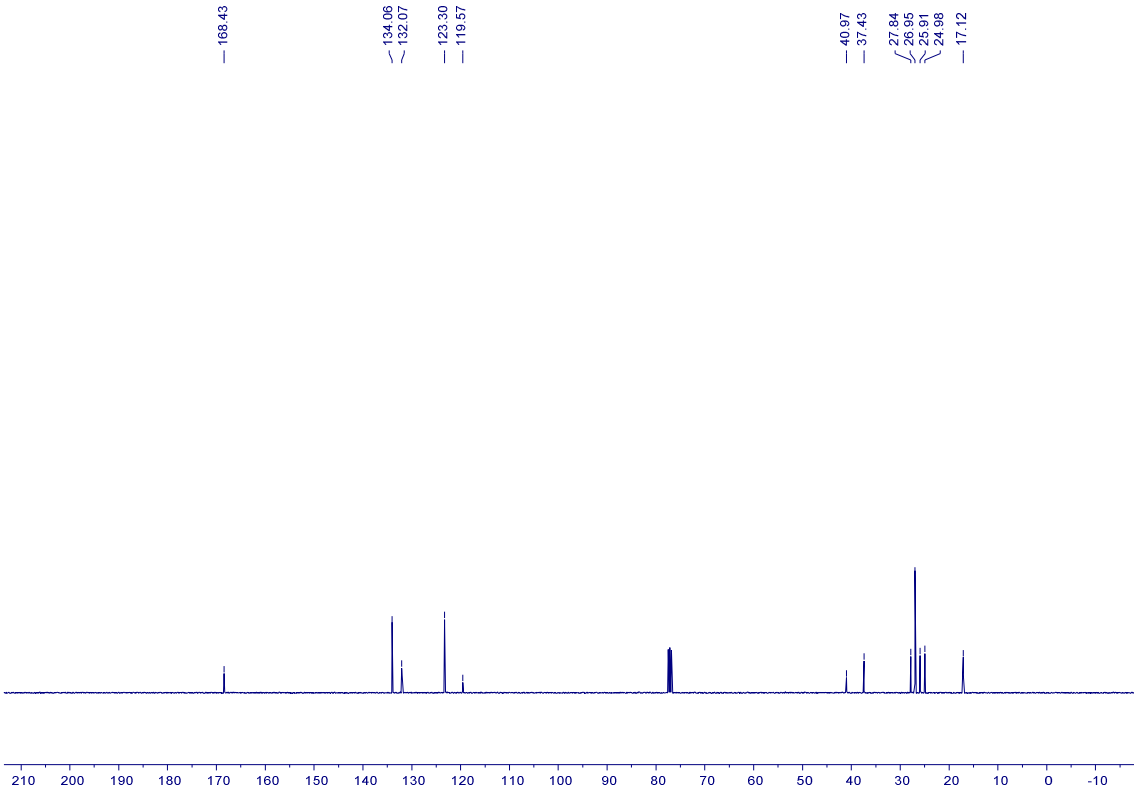
46 ^{13}C NMR (101 MHz, $CDCl_3$)



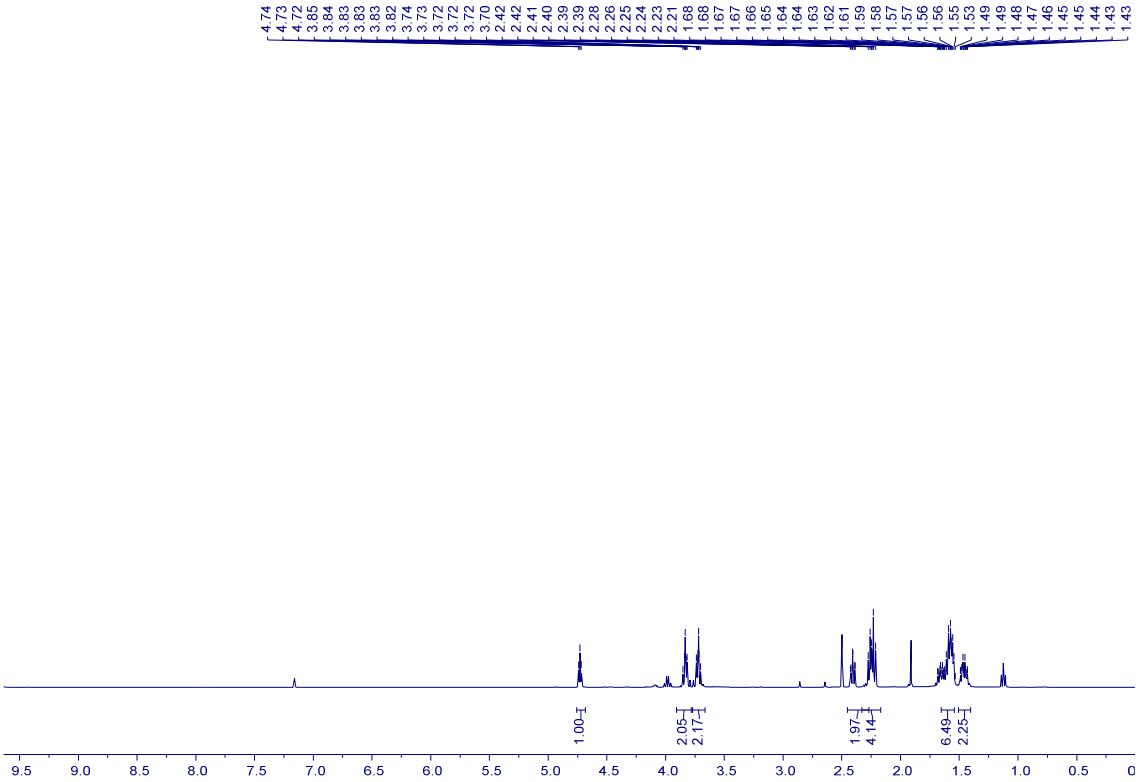
52 ^{1}H NMR (400 MHz, $CDCl_3$)



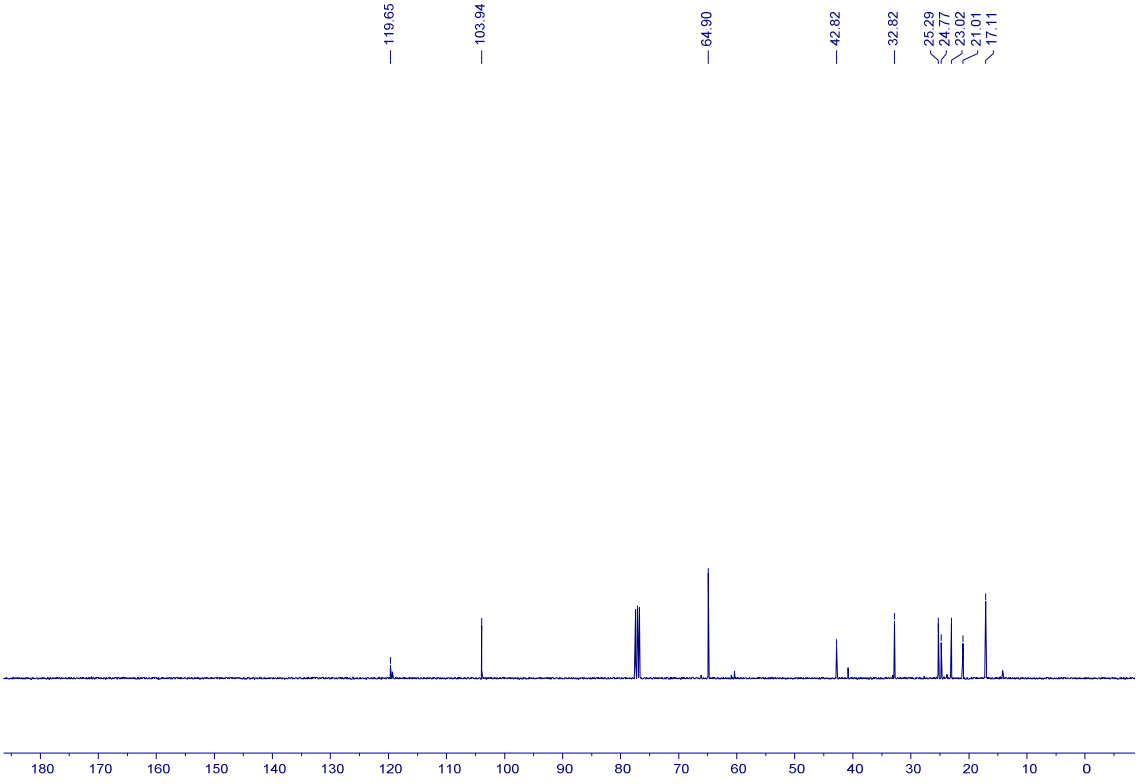
52 ^{13}C NMR (101 MHz, $CDCl_3$)



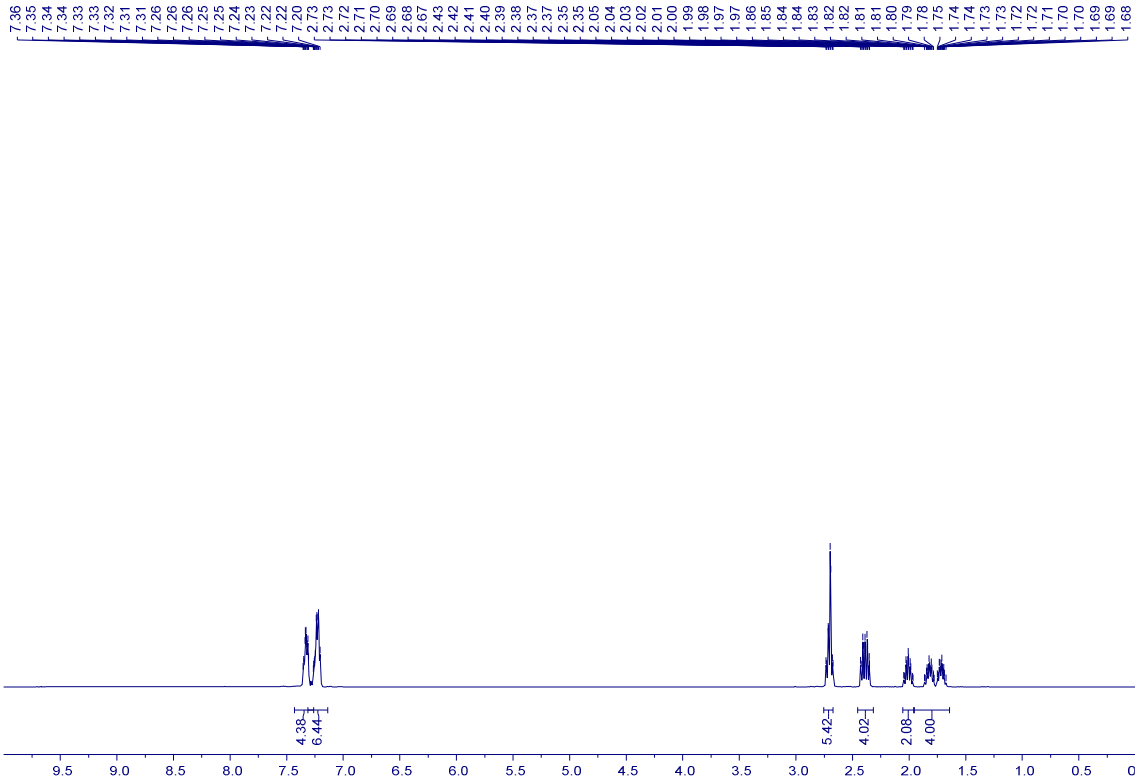
53 ^{1}H NMR (400 MHz, $CDCl_3$)



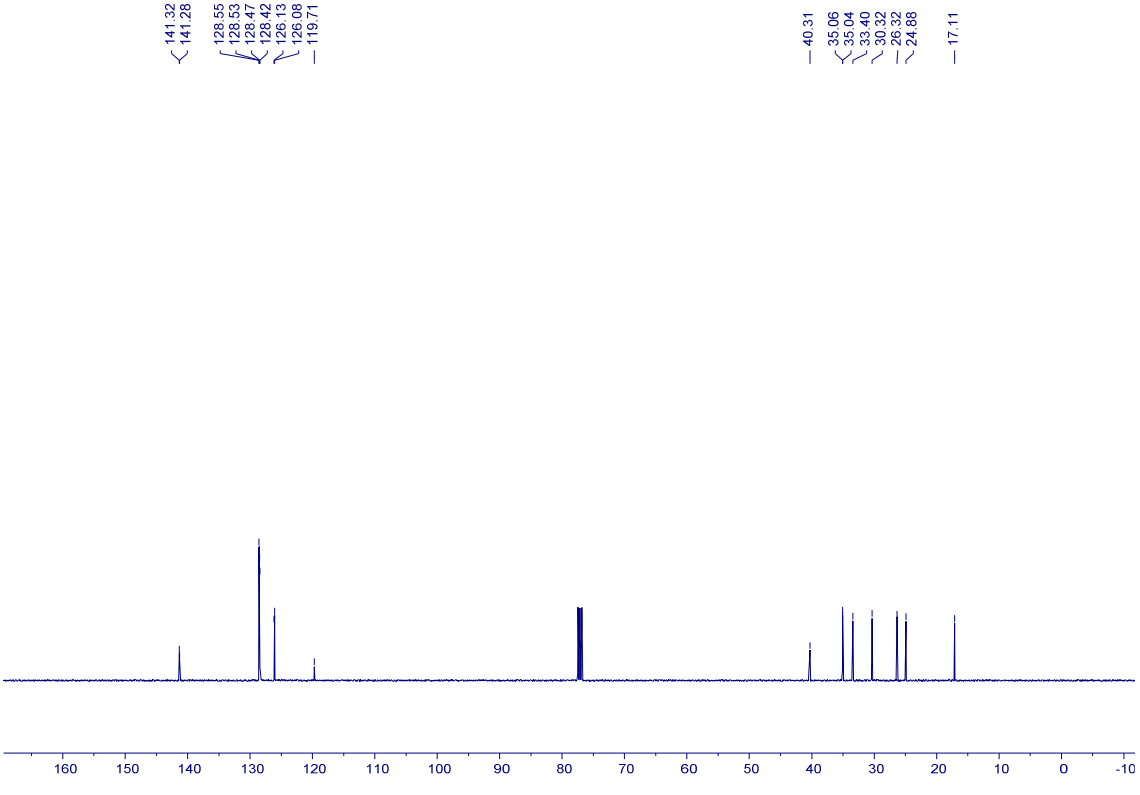
53 ^{13}C NMR (101 MHz, $CDCl_3$)



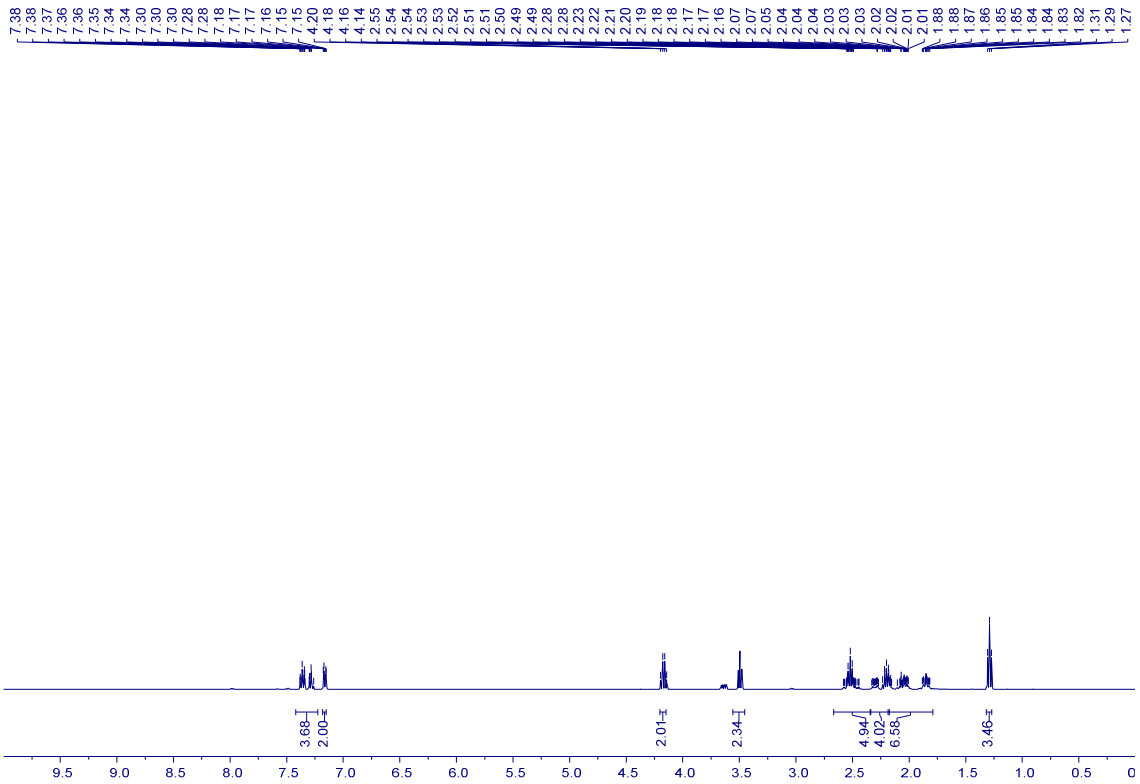
56 ^{1}H NMR (400 MHz, $CDCl_3$)



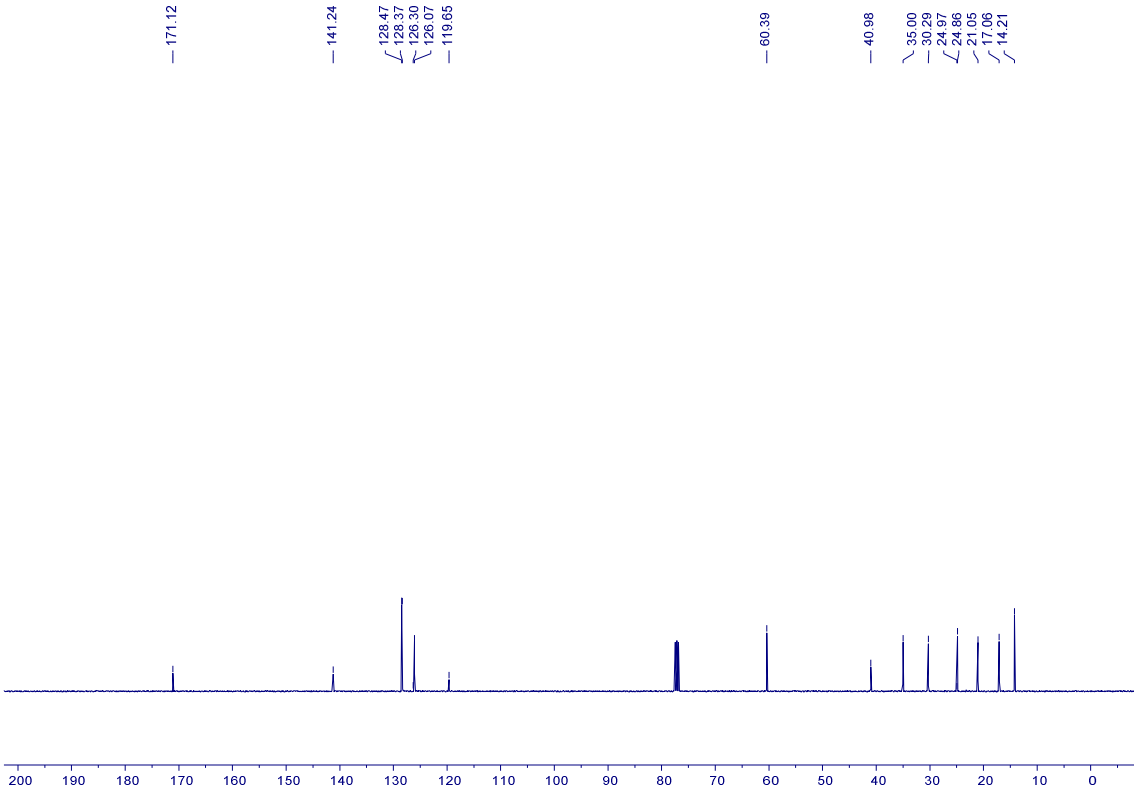
56 ^{13}C NMR (101 MHz, $CDCl_3$)



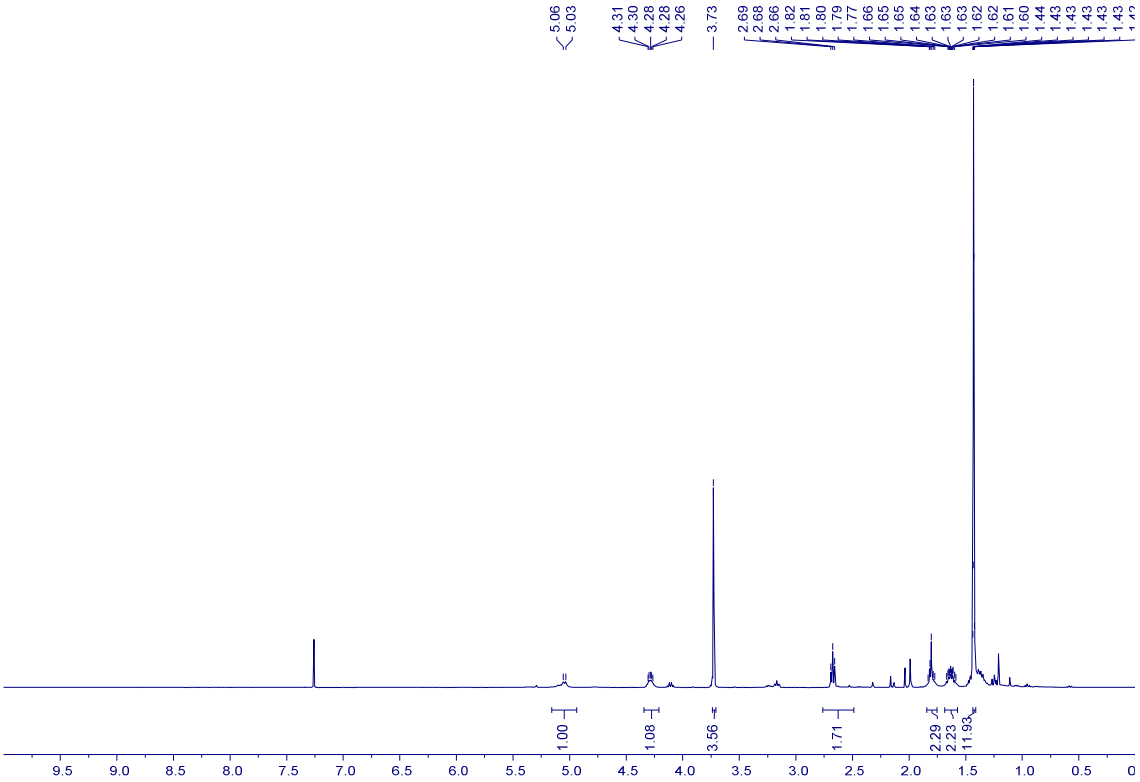
57 ^{1}H NMR (400 MHz, $CDCl_3$)



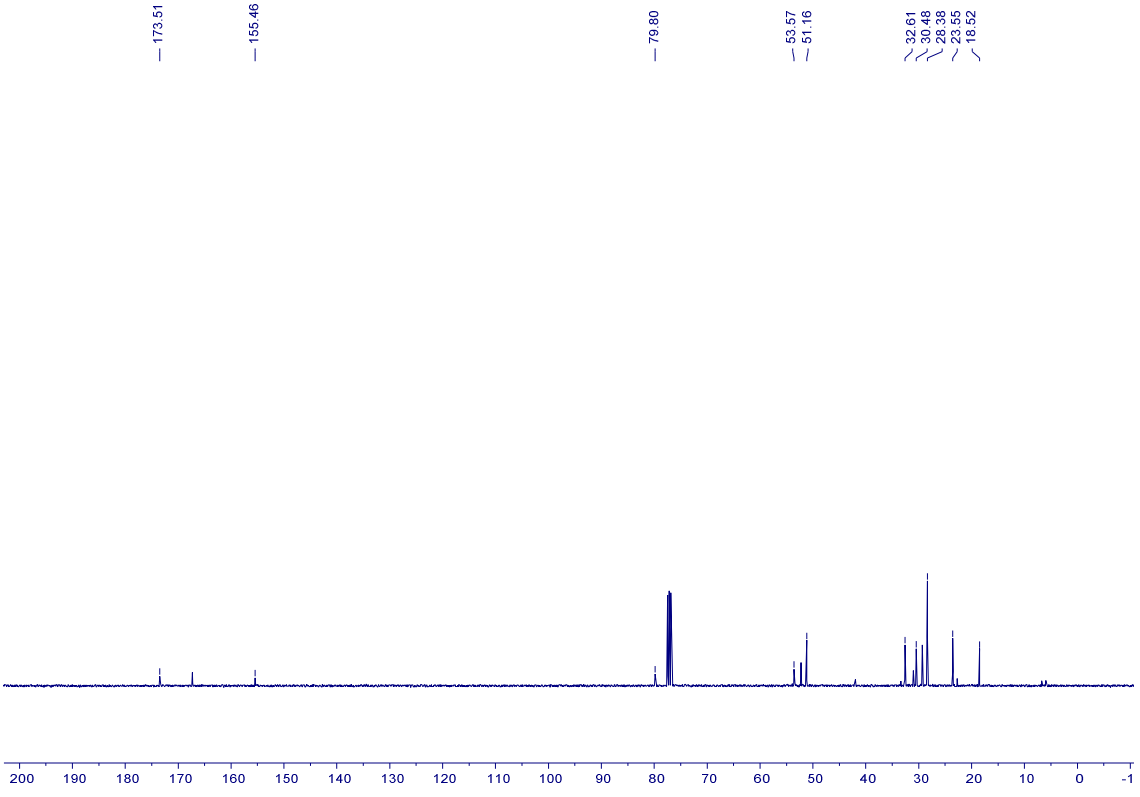
57 ^{13}C NMR (101 MHz, $CDCl_3$)



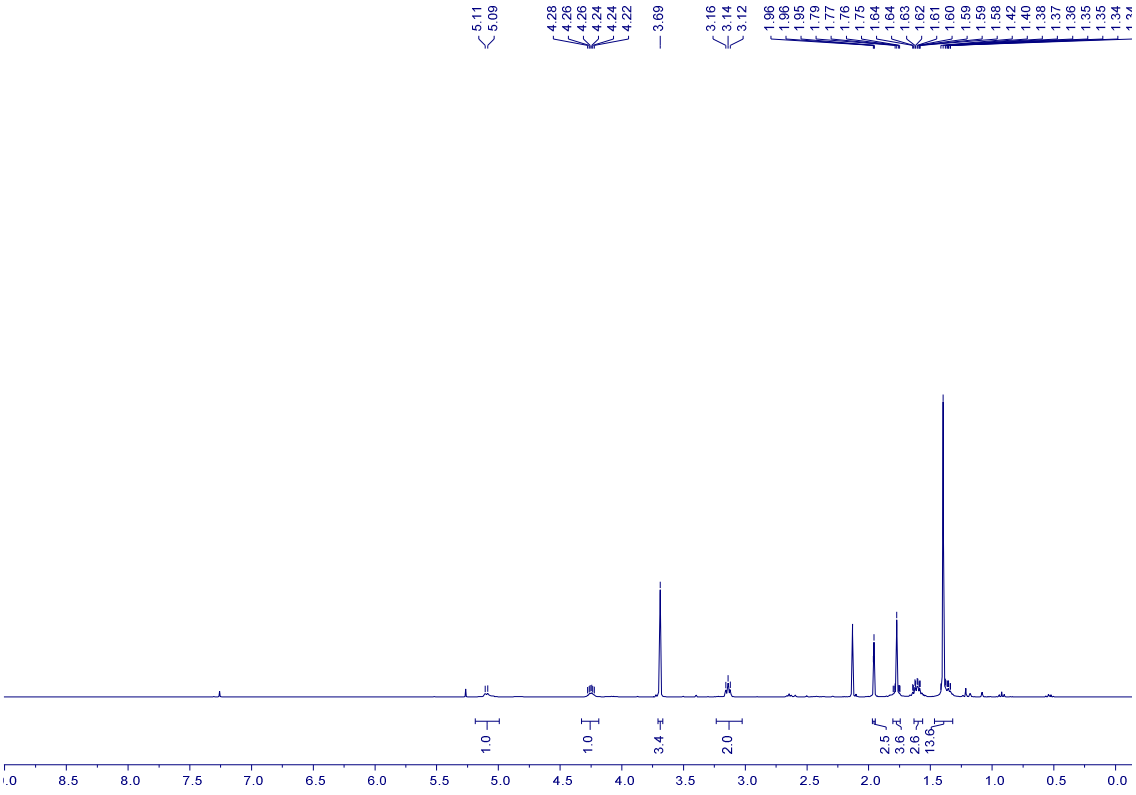
59 ^{1}H NMR (400 MHz, $CDCl_3$)



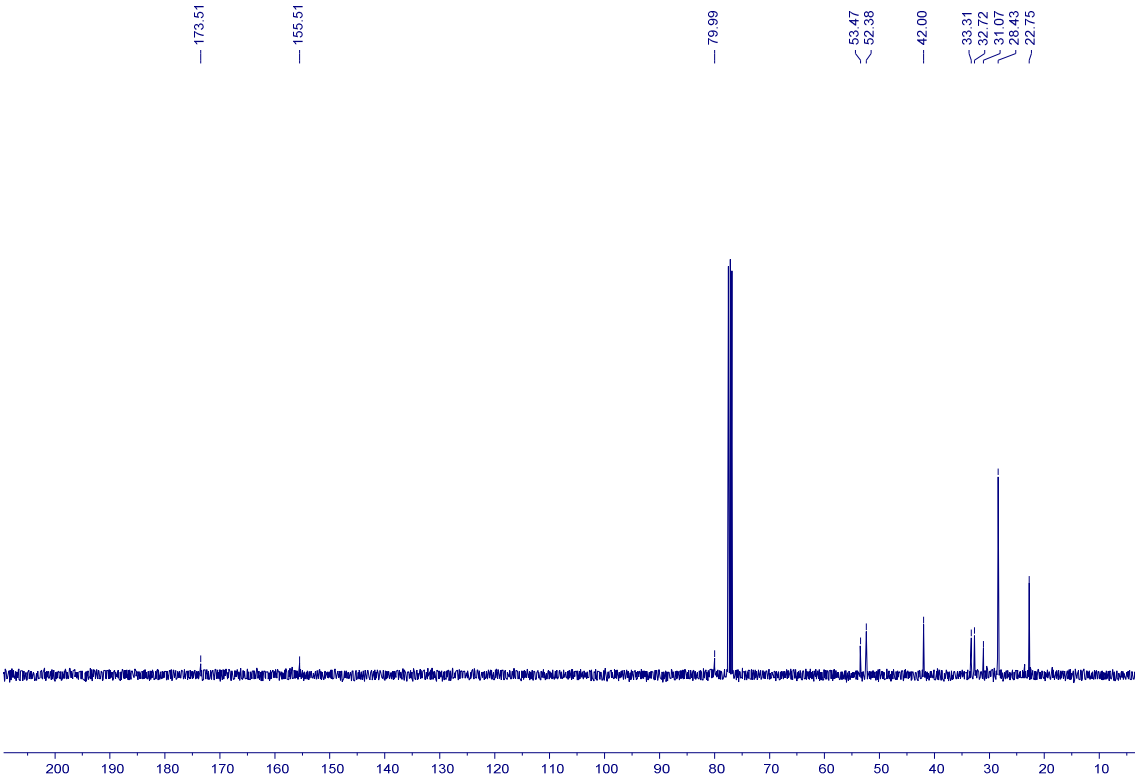
59 ^{13}C NMR (101 MHz, $CDCl_3$)



60 ^{1}H NMR (400MHz, $CDCl_3$)



60 ^{13}C NMR (101 MHz, $CDCl_3$)



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