Chemoselective Decarboxylative Protonation Enabled by Cooperative Earth-Abundant Element Catalysis

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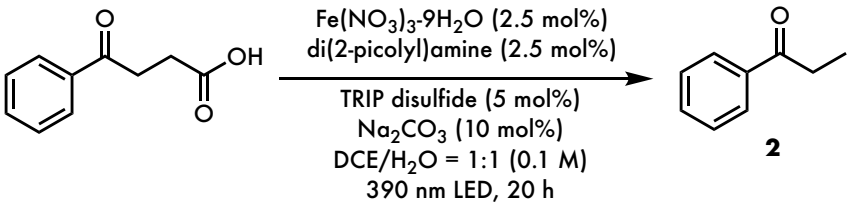
General Information

All reagents were purchased from the commercially available sources and used without further purification. All reactions were carried out in a vial with magnetic stirring. All reactions were monitored by either ^{1}H NMR or thin layer chromatography (TLC) carried out on 0.25 mm pre-coated silia plates (F-254) purchased from Silicycle, Quebec, Canada, using shortwave UV light as visualizing agent and $KMnO_4$ or phosphomolybdic acid (PMA) as developing agents. Flash column chromatography was performed using SiliaFlash-P60 silica gel (40 – 63 μm) purchased from Silicycle, Quebec, Canada. ^{1}H and ^{13}C spectra were recorded on a Bruker DRX-600 spectrometers operating at 600 MHz for proton nuclei and 151 MHz for carbon nuclei. Peaks were calibrated using residual undeuterated solvent as an internal reference ($CDCl_3$: 7.26 ppm ^{1}H NMR and 77.20 ppm ^{13}C NMR). For reporting NMR peak multiplicities, the following abbreviations were used: s = singlet, d = doublet, t = triplet, q = quartet, quin = quintet, hept = heptet, m = multiplet. High-resolution mass spectra (HRMS) were recorded on an Agilent UHPLC TOF mass spectrometer using electrospray ionization time-of-flight (ESI-TOF) or chemical ionization time-of-flight (CI-TOF) reflectron experiments. Kessil lamp (390 nm and 427 nm) used in this work was purchased from the following website: https://kessil.com/science/PR160L.php

Experimental Section

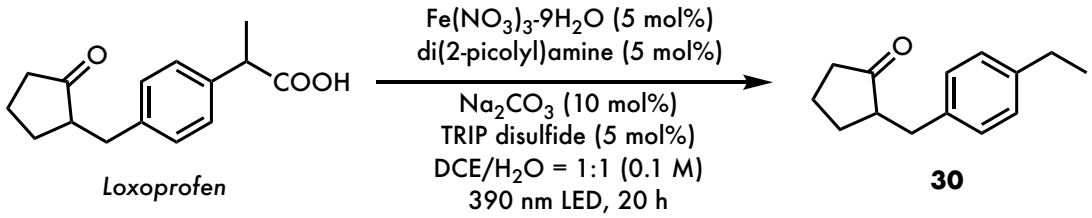
General procedure for the iron-catalyzed decarboxylative protonation



4-Oxo-4-phenylbutanoic acid **1** (71.3 mg, 0.4 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (4.04 mg, 0.01 mmol, 2.5 mol%), di(2-picolyl)amine (1.99 mg, 0.01 mmol, 2.5 mol%), Na_2CO_3 (4.24 mg, 0.04 mmol, 10 mol%) and TRIP disulfide (9.41 mg, 0.02 mmol, 5 mol%) were loaded to a vial; then evacuated and charged with N_2 twice. DCE (2 mL) and H_2O (2 mL) were subsequently added to the mixture, sparged with nitrogen balloon for 5 min and sealed the vial with parafilm. The reaction was stirred vigorously under the irradiation of 390 nm LED light (5 to 10 cm to the reaction vial) for 20 h. Upon completion, the reaction was extracted with CH_2Cl_2, dried over Na_2SO_4, filtered and concentrated in vacuo for column purification to afford decarboxylation product **2** (46.7 g, 0.348 mmol, 87%).

* For volatile compounds **5**, **6**, **14**, **21**, **22** and readily decomposed compound **17**, product formations were characterized directly by crude NMR spectra without further purification (These compounds were reported previously).

Procedure for the iron-catalyzed decarboxylative protonation on gram scale



Loxoprofen **30**

Loxoprofen (1.5 g, 6.09 mmol, 1.0 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (122.8 mg, 0.304 mmol, 5 mol%), di(2-picolyl)amine (60.57 mg, 0.304 mmol, 5 mol%), Na_2CO_3 (64.4 mg, 0.608 mmol, 10 mol%) and TRIP disulfide (143.1 mg, 0.304 mmol, 5 mol%) were loaded to a 200 mL round bottle flask; then evacuated and charged with N_2 twice. DCE (30 mL) and H_2O (30 mL) were subsequently added to the mixture and sparged with nitrogen balloon for 20 min. The reaction was stirred vigorously under the irradiation of 390 nm LED light (5 cm to the reaction vial) for 20 h. Upon completion, the reaction was extracted with CH_2Cl_2, dried over Na_2SO_4, filtered and concentrated in vacuo for column purification to afford decarboxylation product **30** (1.01 g, 4.99 mmol, 82%).

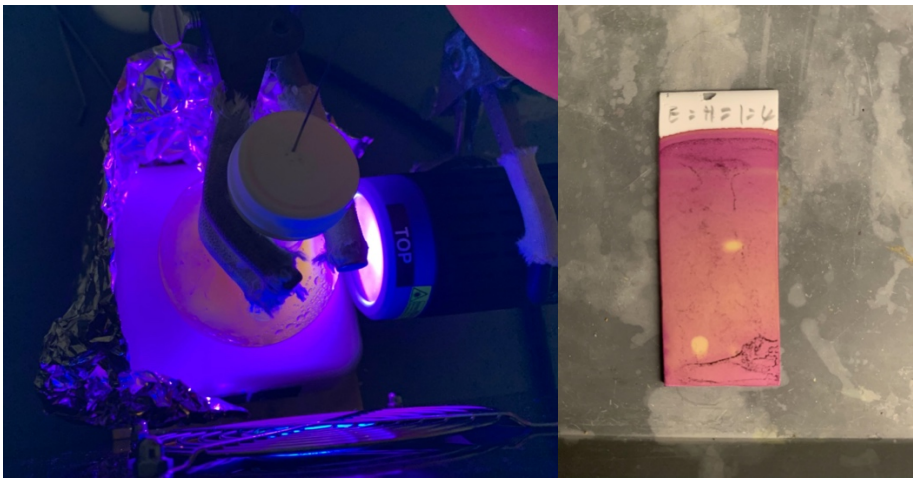
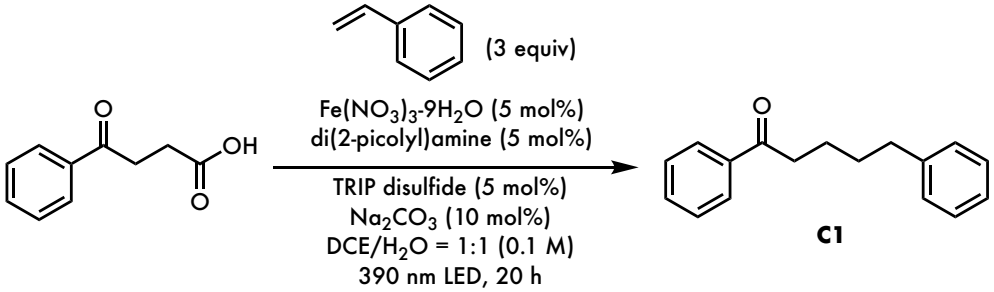


Figure S1: Gram-scale reaction setup

General procedure for the iron-catalyzed decarboxylative coupling with styrene

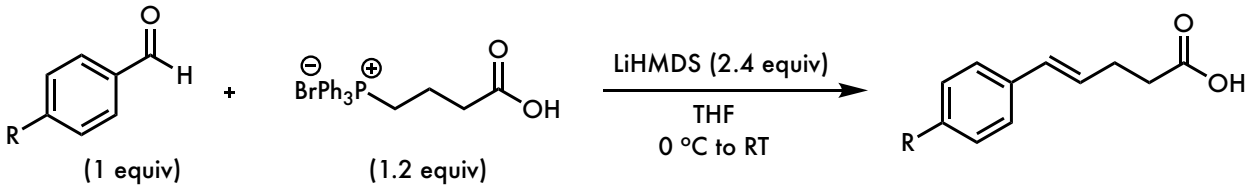


4-Oxo-4-phenylbutanoic acid **1** (71.3 mg, 0.4 mmol, 1.0 equiv), styrene (124.98 mg, 1.2 mmol, 3.0 equiv), $Fe(NO_3)_3{\cdot}9H_2O$ (8.08 mg, 0.02 mmol, 5 mol%), di(2-picolyl)amine (3.98 mg, 0.02 mmol, 5 mol%), Na_2CO_3 (4.24 mg, 0.04 mmol, 10 mol%) and TRIP disulfide (9.41 mg, 0.02 mmol, 5 mol%) were loaded to a vial; then evacuated and charged with N_2 twice. DCE (2 mL) and H_2O (2 mL) were subsequently added to the mixture, sparged with nitrogen balloon for 5 min and sealed the vial with parafilm. The reaction was stirred vigorously under the irradiation of 390 nm LED light (5 to 10 cm to the reaction vial) for 20 h. Upon completion, the reaction was extracted with CH_2Cl_2, dried over Na_2SO_4, filtered and concentrated in vacuo for preparative TLC purification to afford decarboxylation coupling product **C1**. The reaction yield (27%) was determined by ^1H NMR spectroscopy using trimethoxybenzene as an internal standard.

*__C1__ and decarboxylative protonation product of **1** possess similar polarity on TLC.

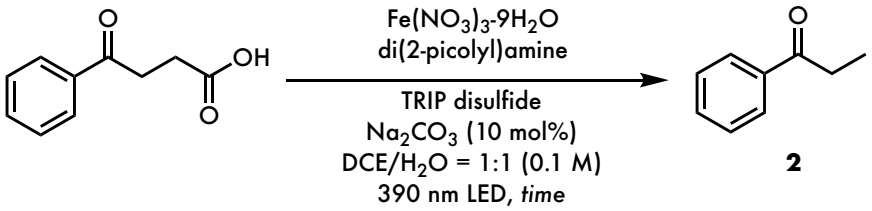
*No product was observed in the absence of TRIP disulfide.

Synthesis of (*E*)-5-phenylpent-4-enoic acid substrates[S1]



To a solution of (3-carboxypropyl)triphenylphosphonium bromide (8.81 mmol, 1.2 equiv) in THF (10 mL) was added LiHMDS (17.6 mmol, 2.4 equiv, 1M in THF) at 0 °C and stirred for 30 min while keeping the solution at 0 °C. Anisaldehyde solution (7.34 mmol, 1.0 equiv) in THF (3 mL) was then slowly added and allowed to react at RT for overnight. Until completion, the reaction mixture was quenched by NaOH solution then extracted with ethyl acetate. The separated aqueous layer was collected, acidified by HCl until the indication of acidic solution (or the appearance of precipitate) and extracted with ethyl acetate. The resulting organic solution was dried over Na_2SO_4, filtered and concentrated in vacuo for column purification to afford the product.

Kinetic studies to determine the reaction rate law



4-Oxo-4-phenylbutanoic acid **1**, $Fe(NO_3)_3 \cdot 9H_2O$, di(2-picolyl)amine, Na_2CO_3 and TRIP disulfide were loaded to a 20 mL vial according to Table S1; then evacuated and charged with N_2 twice. DCE (5 mL) and H_2O (5 mL) were subsequently added to the mixture, sparged with nitrogen balloon for 5 min and sealed the vial with parafilm. The reaction was stirred vigorously for extra 5 min before shining the light to make sure all solid has dissolved. The sample was then irradiated with a 390 nm LED Kessil lamp (5 to 10 cm to the reaction vial). 0.05 mL aliquots (DCE phase) were transferred from the solution via syringe at specific time points directly to NMR tubes.

Figure S2: Reaction setup for kinetic studies (one lamp)

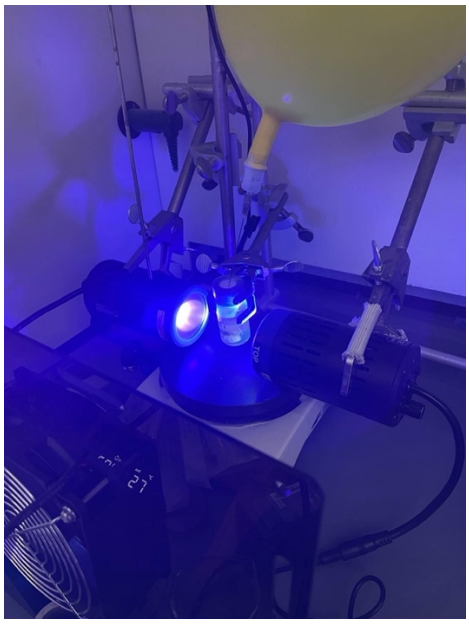
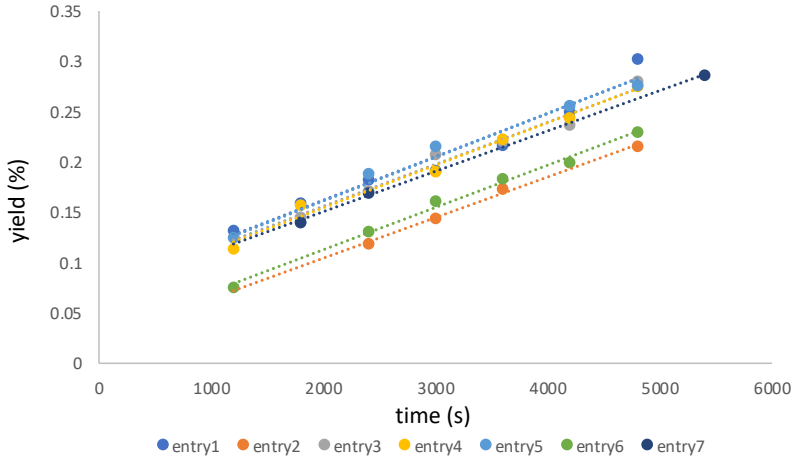


Figure S3: Reaction setup for kinetic studies (two lamps)

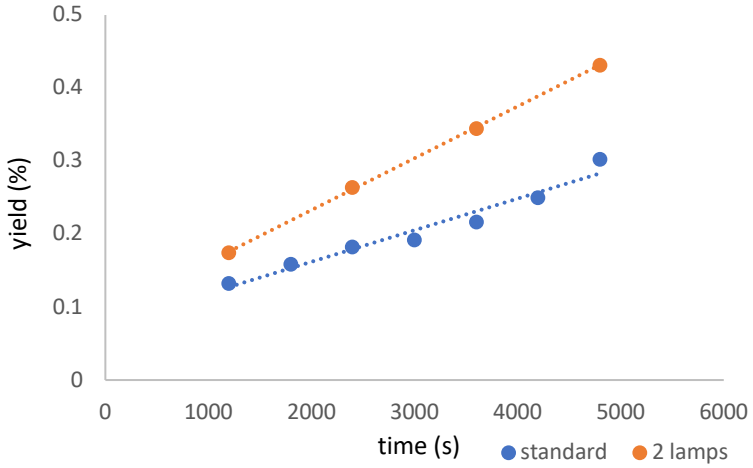
Table S1: Initial rate data with different initial concentrations of acid and catalysts

Entry	mmol acid	mmol iron/ligand	mmol disulfide	Initial rate (M/s)
1	1	0.025	0.05	4.33×10^{-6}
2	1	0.0125	0.05	4.05×10^{-6}
3	1	0.0375	0.05	4.19×10^{-6}
4	1	0.025	0.025	4.22×10^{-6}
5	1	0.025	0.075	4.33×10^{-6}
6	0.5	0.025	0.05	4.20×10^{-6}
7	1.5	0.025	0.05	4.34×10^{-6}
8 (2 lamps)	1	0.025	0.05	7.1×10^{-6}

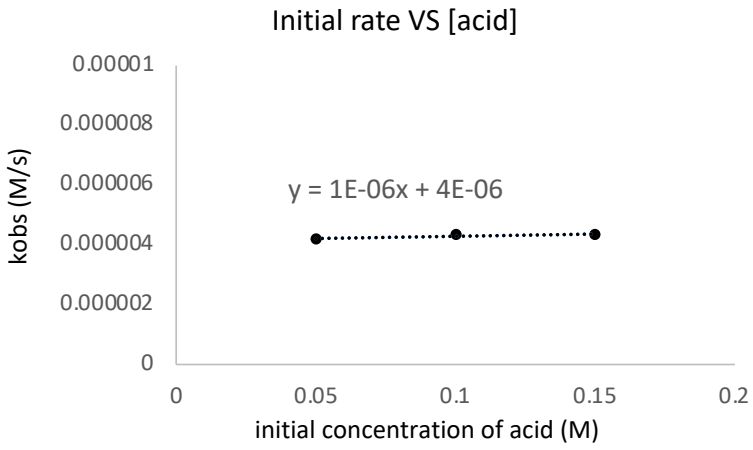
(a)


0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
yield (%)
0
1000
2000
3000
4000
5000
6000
time (s)
entry1
entry2
entry3
entry4
entry5
entry6
entry7

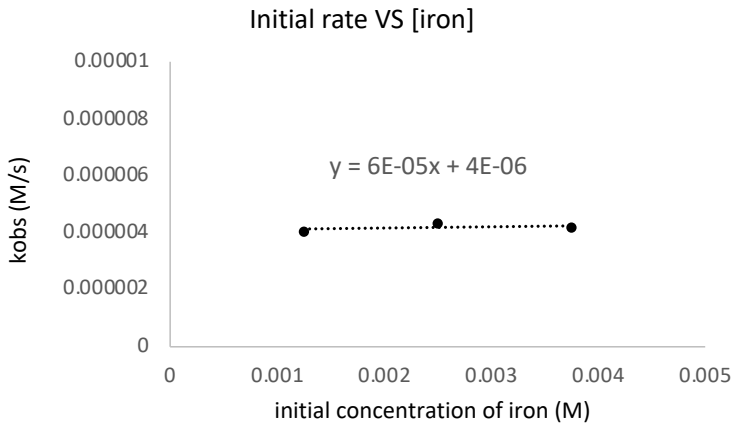
(b)


0.5
0.4
0.3
0.2
0.1
0
yield (%)
0
1000
2000
3000
4000
5000
6000
time (s)
standard
2 lamps

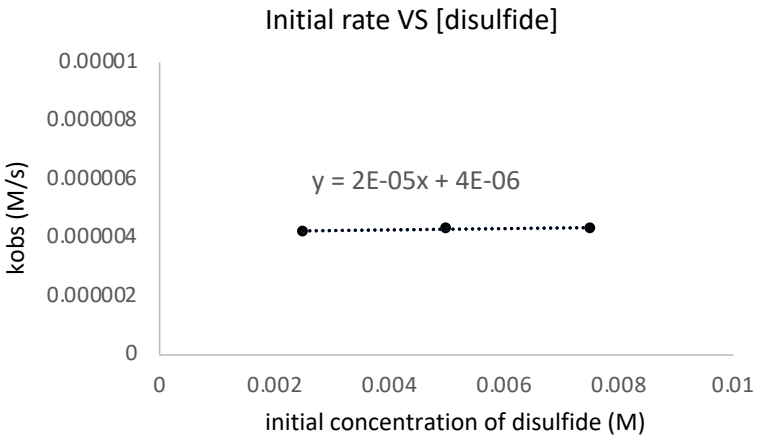
(c)


Initial rate VS [acid]
0.00001
0.000008
0.000006
0.000004
0.000002
0
kobs (M/s)
y = 1E-06x + 4E-06
0
0.05
0.1
0.15
0.2
initial concentration of acid (M)

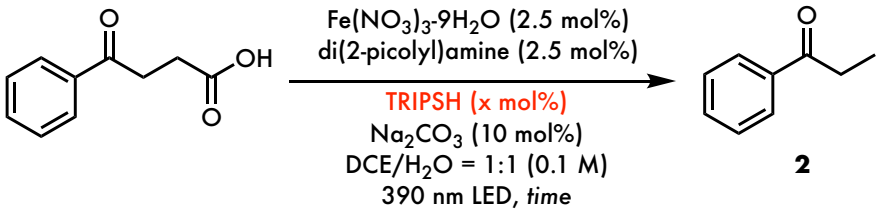
(d)


Initial rate VS [iron]
0.00001
0.000008
0.000006
0.000004
0.000002
0
kobs (M/s)
y = 6E-05x + 4E-06
0
0.001
0.002
0.003
0.004
0.005
initial concentration of iron (M)

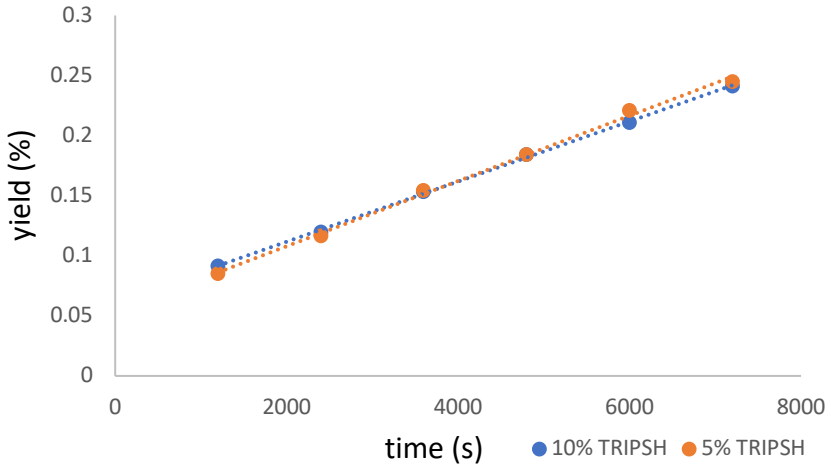
(e)


Initial rate VS [disulfide]
0.00001
0.000008
0.000006
0.000004
0.000002
0
kobs (M/s)
y = 2E-05x + 4E-06
0
0.002
0.004
0.006
0.008
0.01
initial concentration of disulfide (M)

Kinetic studies to determine the rate law of TRIPSH

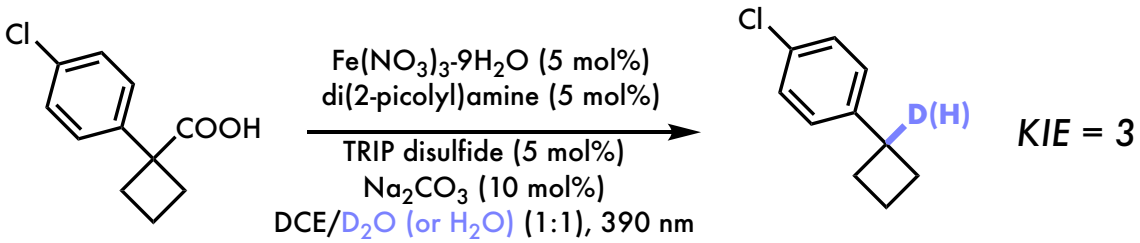


*The experimental protocol was identical to the kinetic studies using TRIP disulfide.



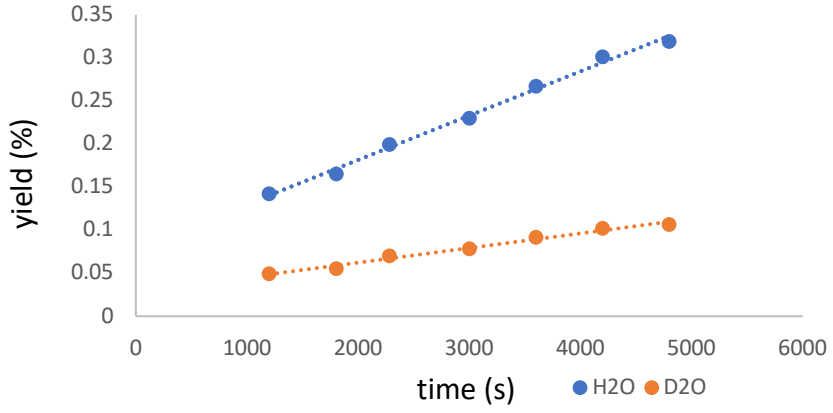
	5 mol% TRIPSH	10 mol% TRIPSH
initial rate(M/s)	2.5×10^{-6}	2.71×10^{-6}

KIE studies

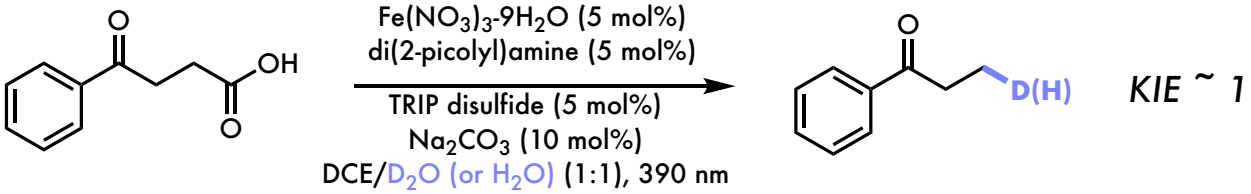


1-(4-chlorophenyl)cyclobutane-1-carboxylic acid (210.66 mg, 1.0 mmol, 1 equiv), $Fe(NO_3)_3 \cdot 9H_2O$ (20.2 mg, 0.05 mmol, 5 mol%), di(2-picolyl)amine (9.96 mg, 0.05 mmol, 5 mol%), TRIP disulfide (23.54 mg, 0.05 mmol, 5 mol%) and Na_2CO_3 (10.59 mg, 0.1, 10 mol%) were loaded to a 20 mL vial; then evacuated and charged with N_2 twice. DCE (5 mL) and D_2O (or H_2O) (5 mL) were subsequently added to the mixture, sparged with nitrogen balloon for 5 min and sealed the vial with parafilm. The reaction was stirred vigorously for extra 5 min before shining the light to make sure all solid has dissolved. The sample was then irradiated with a 390 nm LED Kessil lamp (5 to 10 cm to the reaction vial). 0.05 mL aliquots (DCE phase) were transferred from the solution via syringe at specific time points directly to NMR tubes.

*Note: Pure product was isolated using preparative TLC due to its similar polarity with TRIP disulfide/thiol.



	reaction in H_2O	reaction in D_2O	KIE
initial rate(M/s)	5.14×10^{-6}	1.70×10^{-6}	3.030250077



KIE ~ 1

	reaction in H_2O	reaction in D_2O	KIE
initial rate(M/s)	4.33×10^{-6}	4.52×10^{-6}	0.9579646

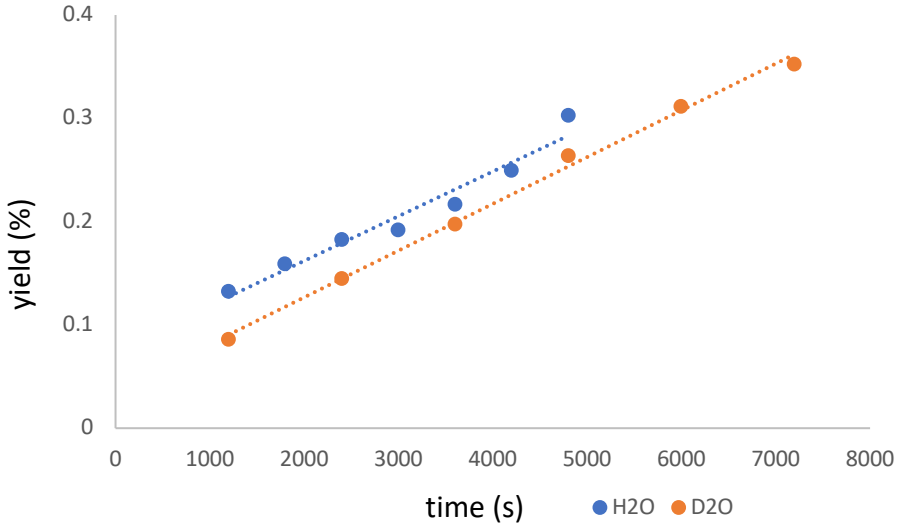
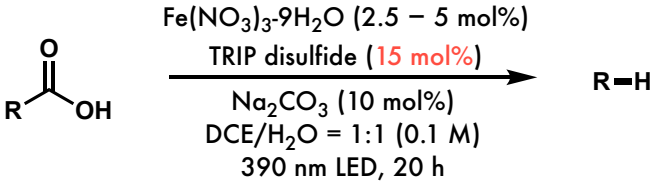
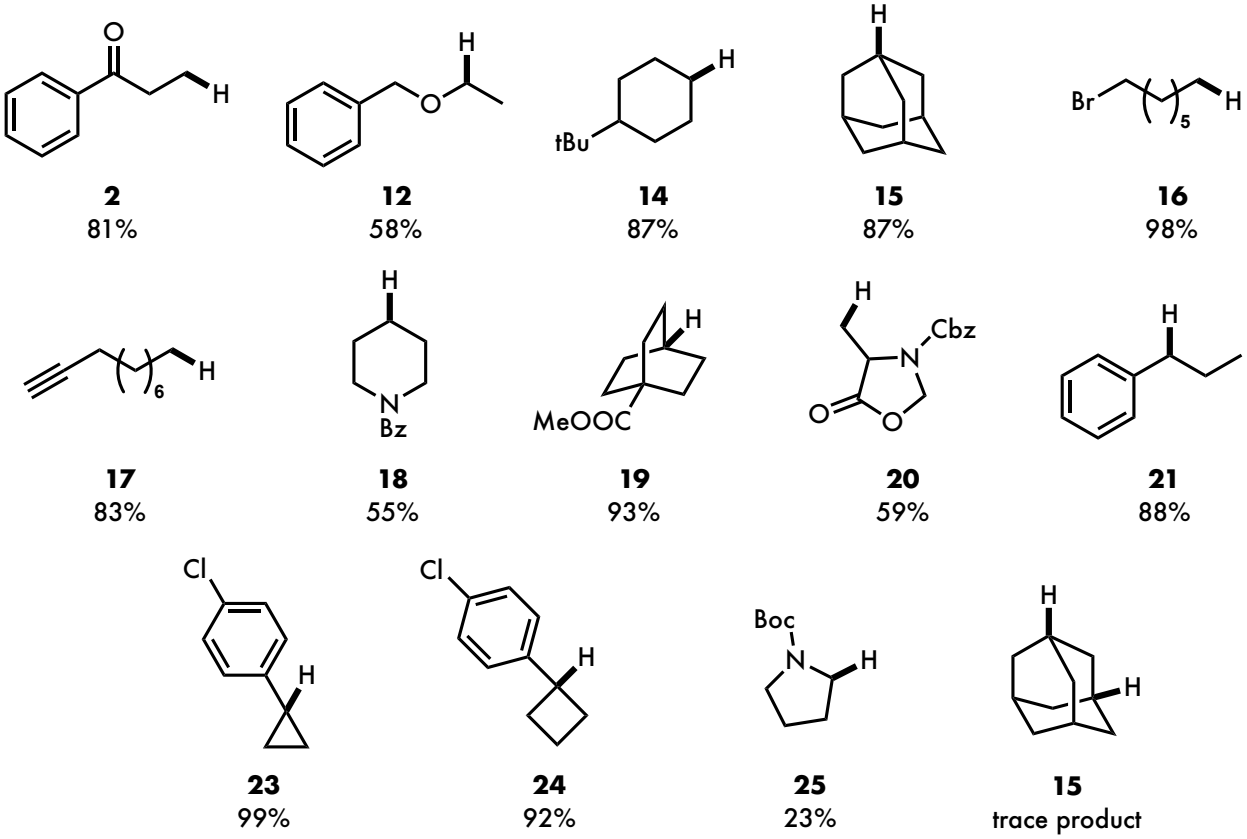


Table S2: Scope exploration of ligand-free conditions

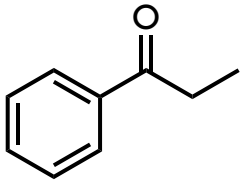




* Same $Fe(NO_3)_3 \cdot 9H_2O$ loadings were subjected in accordance with the general conditions shown in manuscript, Table 2.

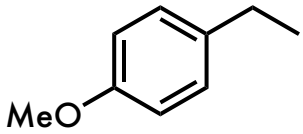
Characterization of decarboxylative protonation compounds

propiophenone (2)[S2]



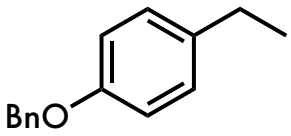
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.96 – 7.91 (m, 2H), 7.55 – 7.49 (m, 1H), 7.45 – 7.39 (m, 2H), 2.97 (q, *J* = 7.26 Hz, 2H), 1.20 (t, *J* = 7.2 Hz, 3H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 200.9, 137.0, 133.0, 128.6, 128.1, 31.9, 8.3. **HRMS (APCI):** calc'd for $C_9H_{11}O$ $[M+H]^+$ 135.0804; Found 135.0806.

1-ethyl-4-methoxybenzene (3)[S3]



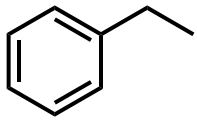
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.15 (d, *J* = 8.5 Hz, 2H), 6.86 (d, *J* = 8.6 Hz, 2H), 3.81 (s, 3H), 2.62 (q, *J* = 7.6 Hz, 2H), 1.24 (t, *J* = 7.6 Hz, 3H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 157.8, 136.5, 128.8, 113.9, 55.4, 28.1, 16.0. **HRMS (APCI):** calc'd for $C_9H_{13}O$ $[M+H]^+$ 137.0961; Found 137.0956.

1-(benzyloxy)-4-ethylbenzene (4)[S4]



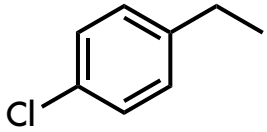
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.53 (d, *J* = 8.7 Hz, 2H), 7.47 (t, *J* = 7.7 Hz, 2H), 7.41 (t, *J* = 7.4 Hz, 1H), 7.21 (d, *J* = 8.3 Hz, 2H), 7.01 (dt, *J* = 8.5, 3.1 Hz, 2H), 5.12 (s, 2H), 2.69 (q, *J* = 7.6 Hz, 2H), 1.31 (t, *J* = 7.6 Hz, 3H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 157.0, 137.4, 136.8, 128.9, 128.7, 128.0, 127.6, 114.8, 70.1, 28.1, 16.0. **HRMS (APCI):** calc'd for $C_{15}H_{15}O$ $[M-H]^+$ 211.1117; Found 211.1114.

ethylbenzene (5)[S3]



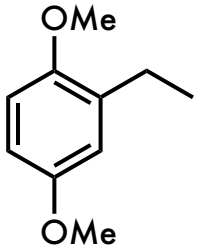
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.27 (d, *J* = 15.6 Hz, 2H), 7.21 – 7.12 (m, 3H), 2.63 (q, *J* = 7.6 Hz, 2H), 1.22 (t, *J* = 7.6 Hz, 3H).

1-chloro-4-ethylbenzene (6)[S5]



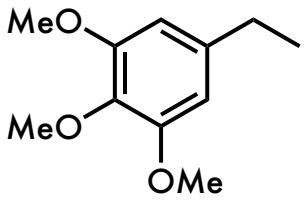
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.22 (d, *J* = 6.8 Hz, 2H), 7.11 (d, *J* = 7.9 Hz, 2H), 2.60 (q, *J* = 7.3 Hz, 2H), 1.22 – 1.17 (m, 3H).

2-ethyl-1,4-dimethoxybenzene (7)[S6]



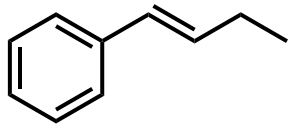
^{1}H NMR (600 MHz, $CDCl_3$): δ 6.81 – 6.77 (m, 2H), 6.74 – 6.69 (m, 1H), 3.81 (s, 3H), 3.80 (s, 3H), 2.66 (q, *J* = 7.5 Hz, 2H), 1.26 – 1.19 (m, 3H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 153.6, 151.7, 134.0, 115.6, 111.1, 110.5, 56.0, 55.7, 23.5, 14.3. **HRMS (APCI):** calc'd for $C_{10}H_{15}O_2$ $[M+H]^+$ 167.1067; Found 167.1062.

5-ethyl-1,2,3-trimethoxybenzene (8)[S7]



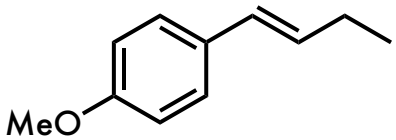
^{1}H NMR (600 MHz, $CDCl_3$): δ 6.40 (s, 2H), 3.84 (s, 6H), 3.81 (s, 3H), 2.58 (q, *J* = 7.6 Hz, 2H), 1.22 (t, *J* = 7.6 Hz, 3H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 153.1, 140.1, 136.0, 104.7, 60.9, 56.0, 29.3, 15.7. **HRMS (APCI):** calc'd for $C_{11}H_{17}O_3$ $[M+H]^+$ 197.1172; Found 197.1167.

(E)-but-1-en-1-ylbenzene (9a)[S8]



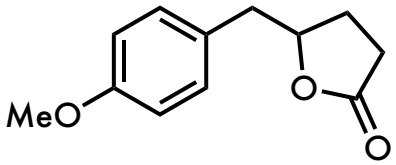
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.36 (d, *J* = 7.4 Hz, 2H), 7.31 (t, *J* = 7.5 Hz, 2H), 7.21 (t, *J* = 7.3 Hz, 1H), 6.39 (d, *J* = 15.8 Hz, 1H), 6.33 – 6.26 (m, 1H), 2.25 (quint, *J* = 7.2 Hz, 2H), 1.11 (t, *J* = 7.5 Hz, 3H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 138.1, 132.8, 128.9, 128.6, 126.9, 126.0, 26.2, 13.8. **HRMS (APCI):** calc'd for $C_{10}H_{13}$ $[M+H]^+$ 133.1012; Found 133.1009.

(E)-1-(but-1-en-1-yl)-4-methoxybenzene (10a)[S8]



^{1}H NMR (600 MHz, $CDCl_3$): δ 7.30 (d, *J* = 8.3 Hz, 2H), 6.86 (d, *J* = 8.6 Hz, 2H), 6.35 (d, *J* = 15.2 Hz, 1H), 6.19 – 6.12 (m, 1H), 3.81 (s, 3H), 2.23 (quint, *J* = 7.2 Hz, 2H), 1.11 (t, *J* = 7.8 Hz, 3H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 158.7, 130.9, 130.7, 128.3, 127.1, 114.1, 55.4, 26.2, 14.0. **HRMS (APCI):** calc'd for $C_{11}H_{15}O$ $[M+H]^+$ 163.1117; Found 163.1114.

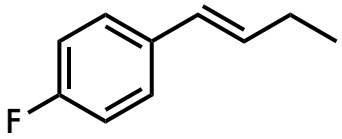
5-(4-methoxybenzyl)dihydrofuran-2(3H)-one (10b)[S9]



^{1}H NMR (600 MHz, $CDCl_3$): δ 7.14 (d, *J* = 8.5 Hz, 2H), 6.85 (d, *J* = 8.6 Hz, 2H), 4.69 (quint, *J* = 6.8 Hz, 1H), 3.79 (s, 3H), 3.00 (dd, *J* = 5.9, 14.1 Hz, 1H), 2.88 (dd, *J* = 6.2, 14.1 Hz, 1H), 2.50 – 2.40 (m, 1H), 2.39 –2.30 (m, 1H), 2.28 – 2.19 (m, 1H), 1.99 – 1.89 (m, 1H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ

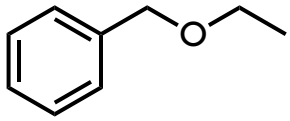
177.3, 158.8, 130.7, 128.0, 114.2, 81.1, 55.4, 40.6, 28.8, 27.1. **HRMS (APCI):** calc'd for $C_{12}H_{15}O_3$ $[M+H]^+$ 207.1016; Found 207.1010.

(E)-1-(but-1-en-1-yl)-4-fluorobenzene (11a)[S10]



^{1}H NMR (600 MHz, $CDCl_3$): δ 7.35 – 7.28 (m, 2H), 7.02 – 6.97 (m, 2H), 6.36 (d, *J* = 15.8 Hz, 1H), 6.23 – 6.16 (m, 1H), 2.24 (quint, *J* = 10.8 Hz, 2H), 1.11 (t, *J* = 7.5 Hz, 3H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 162.1 (d, $J_{C\text{-}F}$ = 243.9 Hz), 134.2 (d, $J_{C\text{-}F}$ = 3.2 Hz), 132.5 (d, $J_{C\text{-}F}$ = 2.0 Hz), 127.8, 127.4 (d, $J_{C\text{-}F}$ = 7.7 Hz), 115.4 (d, $J_{C\text{-}F}$ = 20.9 Hz), 26.2, 13.8. **^{19}F NMR (565 Hz, CDCl3):** δ -115.87 – -116.04 (m, 1F). **HRMS (APCI):** calc'd for $C_{10}H_{12}F$ $[M+H]^+$ 151.0918; Found 151.0914.

(ethoxymethyl)benzene (12)[S11]

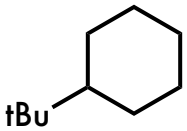


^{1}H NMR (600 MHz, $CDCl_3$): δ 7.38 – 7.24 (m, 5H), 4.50 (s, 2H), 3.54 (q, *J* = 7.0 Hz, 2H), 1.25 (t, *J* = 7.0 Hz, 3H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 138.7, 128.5, 127.8, 127.6, 72.9, 65.9. 15.4. **HRMS (APCI):** calc'd for $C_9H_{11}O$ $[M-H]^+$ 135.0804; Found 135.0805.

dodecane (13)[S12]

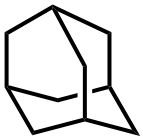
^{1}H NMR (600 MHz, $CDCl_3$): δ 1.34 – 1.22 (m, 20H), 0.89 (t, *J* = 6.9 Hz, 6H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 32.2, 30.0, 29.9, 29.6, 22.9, 14.3.

tert-butylcyclohexane (14)[S13]



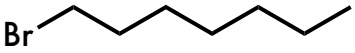
^{1}H NMR (Crude spectrum, 600 MHz, $CDCl_3$): δ 1.79 – 1.71 (m, 4H), 1.66 – 1.61 (m, 1H), 1.23 – 1.04 (m, 3H), 1.00 – 0.87 (m, 3H), 0.83 (s, 9H).

adamantane (15)[S14]



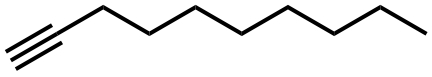
^{1}H NMR (600 MHz, $CDCl_3$): δ 1.87 (s, 4H), 1.77 – 1.72 (m, 12H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 37.9, 28.5. **HRMS (APCI):** calc'd for $C_{10}H_7$ $[M+H]^+$ 137.1325; Found 137.1327.

1-bromoheptane (16)[S15]



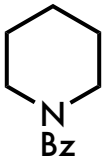
^{1}H NMR (600 MHz, $CDCl_3$): δ 3.40 (t, *J* = 6.9 Hz, 2H), 1.85 (quint, *J* = 6.9 Hz, 2H), 1.45 – 1.37 (m, 2H), 1.34 – 1.23 (m, 6H), 0.87 (t, *J* = 7.0 Hz, 3H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 34.2, 33.0, 31.8, 28.6, 28.3, 22.7, 14.2. **HRMS (APCI):** calc'd for $C_7H_{16}Br$ $[M+H]^+$ 179.0430; Found 179.0283.

dec-1-yne (17)[S16]



^{1}H NMR (Crude spectrum, 600 MHz, $CDCl_3$): δ 2.18 (td, *J* = 2.6, 7.1 Hz, 2H), 1.94 (t, *J* = 2.64 Hz, 1H), 1.54 – 1.49 (m, 2H), 1.43 – 1.35 (m, 2H), 1.33 – 1.25 (m, 8H), 0.88 (t, *J* = 7.0 Hz, 3H).

phenyl(piperidin-1-yl)methanone (18)[S17]

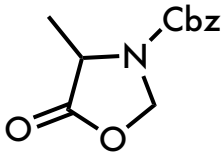


^{1}H NMR (600 MHz, $CDCl_3$): δ 7.38 (s, 5H), 3.71 (br, 2H), 3.33 (br, 2H), 1.67 (br, 4H), 1.50 (br, 2H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 170.3, 136.5, 129.3, 128.4, 126.8, 48.7, 43.1, 26.5, 25.6, 24.6. **HRMS (APCI):** calc'd for $C_{12}H_{16}NO$ $[M+H]^+$ 190.1226; Found 190.1220.

methyl bicyclo[2.2.2]octane-1-carboxylate (19)[S18]

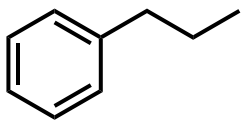
^{1}H NMR (600 MHz, $CDCl_3$): δ 3.60 (s, 3H), 1.73 – 1.66 (m, 6H), 1.61 – 1.51 (m, 7H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 179.0, 51.6, 38.3, 28.1, 25.4, 23.8. **HRMS (APCI):** calc'd for $C_{10}H_{17}O_2$ $[M+H]^+$ 169.1223; Found 169.1223.

benzyl 4-methyl-5-oxooxazolidine-3-carboxylate (20)[S19]



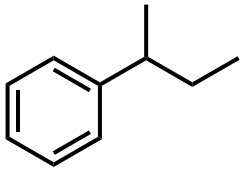
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.39 – 7.32 (m, 5H), 5.40 (br, 1H), 5.32 – 5.12 (m, 3H), 4.28 (br, 1H), 1.54 (br, 3H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 172.9, 152.8, 135.5, 128.8, 128.6, 128.3, 77.4, 67.8, 50.7, 16.7. **HRMS (APCI):** calc'd for $C_{12}H_{14}NO_4$ $[M+H]^+$ 236.0917; Found 236.0914.

propylbenzene (21)[S20]



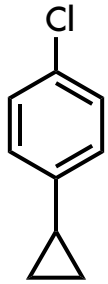
^{1}H NMR (Crude spectrum, 600 MHz, $CDCl_3$): δ 7.30 – 7.24 (m, 2H), 7.19 – 7.15 (m, 3H), 2.59 (t, *J* = 7.6 Hz, 2H), 1.64 (sext, *J* = 7.4 Hz, 2H), 0.94 (t, *J* = 7.4 Hz, 3H).

sec-butylbenzene (22)[S21]



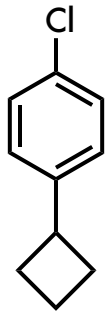
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.29 (t, *J* = 5.8 Hz, 2H), 7.18 (d, *J* = 6.9 Hz, 3H), 2.63 – 2.54 (m, 1H), 1.63 – 1.54 (m, 2H), 1.29 – 1.21 (m, 3H), 0.82 (t, *J* = 7.8 Hz, 3H).

1-chloro-4-cyclopropylbenzene (23)[S22]



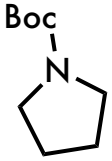
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.25 – 7.19 (m, 2H), 7.03 – 6.97 (m, 2H), 1.90 – 1.84 (m, 1H), 1.00 – 0.94 (m, 2H), 0.70 – 0.63 (m, 2H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 142.6, 131.0, 128.4, 127.1, 15.0, 9.4. **HRMS (APCI):** calc'd for $C_9H_{10}Cl$ $[M+H]^+$ 153.0466; Found 153.0461.

1-chloro-4-cyclobutylbenzene (24)[S23]



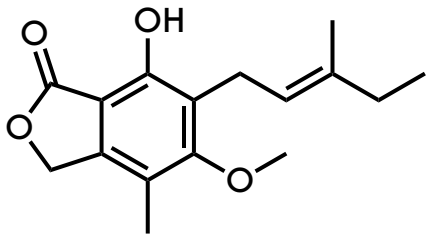
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.25 (d, *J* = 8.5 Hz, 2H), 7.14 (d, *J* = 8.3 Hz, 2H), 3.51 (quint, *J* = 8.5 Hz, 1H), 2.40 – 2.29 (m, 2H), 2.17 – 2.06 (m, 2H), 2.06 – 1.96 (m, 1H), 1.90 – 1.80 (m, 1H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 144.8, 131.4, 128.4, 127.8, 39.9, 29.9, 18.3. **HRMS (APCI):** calc'd for $C_{10}H_{12}Cl$ $[M+H]^+$ 167.0622; Found 167.0619.

tert-butyl pyrrolidine-1-carboxylate (25)[S24]



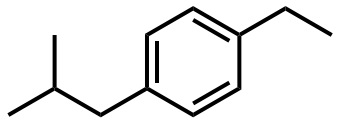
^{1}H NMR (600 MHz, $CDCl_3$): δ 3.28 (s, 2H), 3.22 (s, 2H), 1.78 (s, 4H), 1.41 (s, 9H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 154.8, 78.9, 46.0, 45.7, 28.6, 25.8, 25.1. **HRMS (APCI):** calc'd for $C_9H_{18}NO_2$ $[M+H]^+$ 172.1332; Found 172.1332.

(*E*)-7-hydroxy-5-methoxy-4-methyl-6-(3-methylpent-2-en-1-yl)isobenzofuran-1(3*H*)-one (26)



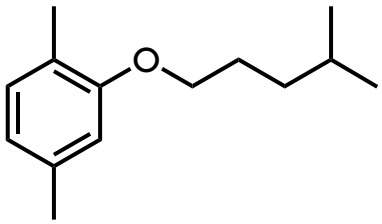
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.61 (br, 1H), 5.15 (s, 3H), 3.74 (s, 3H), 3.35 (d, *J* = 6.8 Hz, 2H), 2.12 (s, 3H), 1.95 (q, *J* = 7.3 Hz, 2H), 1.75 (s, 3H), 0.93 (t, *J* = 7.4 Hz, 3H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 173.0, 163.8, 153.7, 144.0, 137.8, 122.7, 120.6, 116.8, 106.4, 70.1, 61.1, 32.4, 22.7, 16.2, 12.7, 11.6. **HRMS (APCI):** calc'd for $C_{16}H_{21}O_4$ $[M+H]^+$ 277.1434; Found 277.1433.

1-ethyl-4-isobutylbenzene (27)[S25]



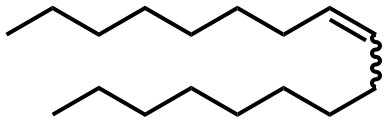
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.13 (d, *J* = 7.6 Hz, 2H), 7.09 (d, *J* = 7.4 Hz, 2H), 2.65 (q, *J* = 7.6 Hz, 2H), 2.46 (d, *J* = 7.1 Hz, 2H), 1.87 (sept, *J* = 6.7 Hz, 1H), 1.25 (t, *J* = 7.6 Hz, 3H), 0.92 (d, *J* = 6.5 Hz, 6H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 141.6, 139.0, 129.2, 127.7, 45.2, 30.4, 28.6, 22.6, 15.8. **HRMS (APCI):** calc'd for $C_{12}H_{19}$ $[M+H]^+$ 163.1481; Found 163.1482.

1,4-dimethyl-2-((4-methylpentyl)oxy)benzene (28)[S26]



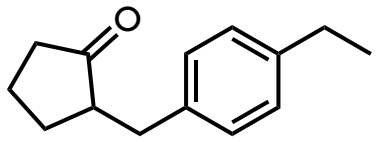
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.07 (d, *J* = 7.5, 1H), 6.72 (d, *J* = 7.5, 1H), 6.70 (s, 1H), 3.99 (t, *J* = 6.5 Hz, 2H), 2.38 (s, 3H), 2.26 (s, 3H), 1.90 – 1.83 (m, 2H), 1.70 (hept, *J* = 6.7 Hz, 1H), 1.47 – 1.40 (m, 2H), 1.01 (s, 3H), 1.00 (s, 3H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 157.3, 136.6, 130.4, 123.8, 120.7, 112.1, 68.3, 35.5, 28.0, 27.5, 22.8, 21.6, 16.0. **HRMS (APCI):** calc'd for $C_{14}H_{23}O$ $[M+H]^+$ 207.1743; Found 207.1743.

heptadec-8-ene (29)[S27]



^{1}H NMR (major isomer, 600 MHz, $CDCl_3$): δ 5.37 – 5.32 (m, 2H), 2.07 – 1.98 (m, 4H), 1.38 – 1.21 (m, 22H), 0.88 (t, *J* = 6.8 Hz, 6H). **^{13}C NMR (major isomer, 150 MHz, $CDCl_3$):** δ 130.1, 32.1, 32.1, 30.0, 29.9, 29.8, 29.6, 29.5, 29.46, 29.44, 27.4, 22.9, 14.3. **HRMS (APCI):** calc'd for $C_{17}H_{35}$ $[M+H]^+$ 239.2733; Found 239.2734.

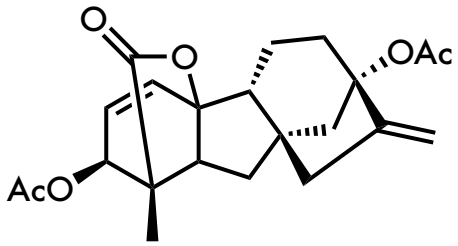
2-(4-ethylbenzyl)cyclopentan-1-one (30)



^{1}H NMR (600 MHz, $CDCl_3$): δ 7.12 (d, *J* = 8.0 Hz, 2H), 7.09 (d, *J* = 8.1 Hz, 2H), 3.12 (dd, *J* = 4.1, 13.9 Hz, 1H), 2.62 (q, *J* = 7.6 Hz, 2H), 2.52 (dd, *J* = 9.5, 13.9 Hz, 1H), 2.38 – 2.29 (m, 2H), 2.15 – 2.05 (m, 2H), 2.00 – 1.91 (m, 1H), 1.78 – 1.68 (m, 1H), 1.61 – 1.52 (m, 1H), 1.24 (t, *J* = 7.6 Hz, 3H). **^{13}C NMR**

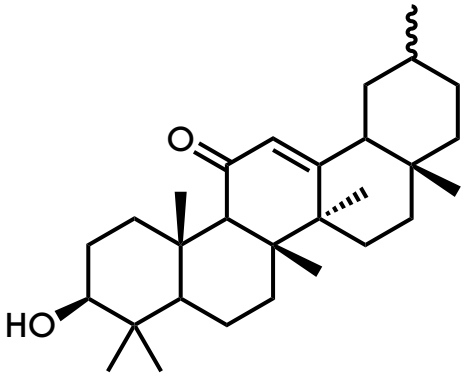
(150 MHz, $CDCl_3$): δ 142.0, 137.2, 128.9, 127.9, 51.1, 38.3, 35.2, 29.2, 28.5, 20.6, 15.6. **HRMS (APCI):** calc'd for $C_{14}H_{19}O$ $[M+H]^+$ 203.1430; Found 203.1430.

(1*R*,2*S*,4b*R*,7*S*,9a*R*)-1-methyl-8-methylene-13-oxo-1,2,5,6,8,9,10,10a-octahydro-4a,1-(epoxymethano)-7,9a-methanobenzo[*a*]azulene-2,7(4b*H*)-diyl diacetate (31)



^{1}H NMR (600 MHz, $CDCl_3$): δ 6.34 (d, *J* = 9.4 Hz, 1H), 5.78 (dd, *J* = 3.8, 9.3 Hz, 1H), 5.27 (d, *J* = 3.8 Hz, 1H), 5.07 (s, 1H), 4.90 (s, 1H), 2.79 (dd, *J* = 8.0, 11.2 Hz, 1H), 2.50 – 2.44 (m, 1H), 2.32 (dd, *J* = 8.7, 12.6 Hz, 1H), 2.25 (d, *J* = 15.5 Hz, 1H), 2.09 – 2.02 (m, 4H), 1.97 (s, 3H), 1.94 – 1.87 (m, 2H), 1.79 – 1.70 (m, 2H), 1.67 – 1.59 (m, 2H), 1.15 (s, 3H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 177.6, 169.93, 169.9, 154.9, 134.8, 128.9, 107.0, 91.7, 84.9, 70.4, 52.3, 51.1, 50.4, 48.2, 46.7, 39.9, 36.7, 35.0, 22.2, 20.9, 16.6, 14.6. **HRMS (APCI):** calc'd for $C_{22}H_{27}O_6$ $[M+H]^+$ 387.1802; Found 387.1802.

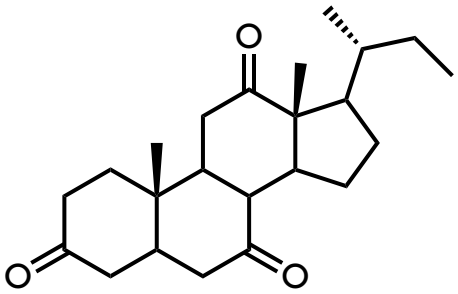
(4a*R*,6a*S*,6b*R*,10*S*,12a*S*)-10-hydroxy-2,4a,6a,6b,9,9,12a-heptamethyl-1,3,4,4a,5,6,6a,6b,7,8,8a,9,10,11,12,12a,12b,14b-octadecahydropicen-13(2*H*)-one (32)



^{1}H NMR (major isomer (1.8:1 dr), 600 MHz, $CDCl_3$): δ 5.54 (s, 1H), 4.05 (q, *J* = 7.1 Hz, 1H), 3.18 – 3.12 (m, 1H), 2.76 – 2.68 (m, 1H), 2.28 (s, 1H), 2.13 – 0.98 (m, 27H), 0.98 – 0.71 (m, 13H), 0.64 (d,

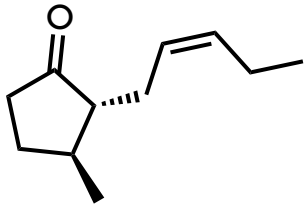
J = 11.7 Hz, 1H). **^{13}C NMR (isomeric mixture (1.8:1 dr)150 MHz, $CDCl_3$):** δ 200.4, 200.3, 171.1, 170.9, 170.4, 127.95, 127.93, 78.6, 61.8, 60.4, 54.9, 51.7, 45.4, 45.39, 45.36, 43.4, 43.3, 41.4, 40.8, 39.16, 39.1, 37.7, 37.1, 34.3, 33.3, 32.79, 32.77, 32.38, 30.6, 28.9, 28.7, 28.1, 27.6, 27.3, 26.8, 26.63, 26.6, 26.5, 26.4, 23.34, 23.3, 22.4, 21.0, 18.7, 18.67, 17.5, 16.9, 16.3, 15.6, 14.2. **HRMS (APCI):** calc'd for $C_{29}H_{47}O_2$ $[M+H]^+$ 427.3571; Found 427.3570.

(10*S*,13*R*)-17-((*R*)-*sec*-butyl)-10,13-dimethyldodecahydro-3*H*-cyclopenta[*a*]phenanthrene-3,7,12(2*H*,4*H*)-trione (33)[S18]



^{1}H NMR (600 MHz, $CDCl_3$): δ 2.93 – 2.79 (m, 3H), 2.37 – 2.15 (m, 6H), 2.14 – 1.90 (m, 6H), 1.86 – 1.78 (m, 1H), 1.59 (td, *J* = 4.4, 14.5 Hz, 1H), 1.51 – 1.42 (m, 1H), 1.38 (s, 3H), 1.32 – 1.06 (m, 5H), 1.05 (s, 3H), 0.85 (t, *J* = 7.4 Hz, 3H), 0.81 (d, *J* = 6.5 Hz, 2H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 212.2, 209.2, 208.9, 57.0, 51.9, 49.1, 46.9, 45.6, 45.5, 45.1, 42.9, 38.7, 37.5, 36.6, 36.1, 35.3, 27.9, 27.8, 25.3, 22.0, 18.5, 11.9, 10.9. **HRMS (APCI):** calc'd for $C_{23}H_{35}O_3$ $[M+H]^+$ 359.2581; Found 359.2578.

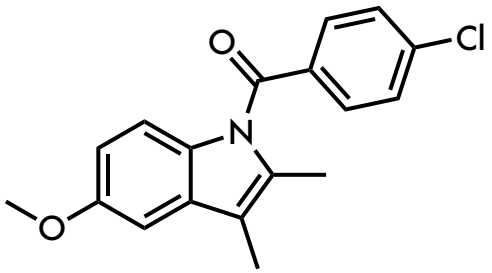
(2R,3S)-3-methyl-2-((Z)-pent-2-en-1-yl)cyclopentan-1-one (34)



^{1}H NMR (major isomer (10:1), 600 MHz, $CDCl_3$): δ 5.44 – 5.37 (m, 1H), 5.28 – 5.22 (m, 1H), 2.39 – 2.24 (m, 3H), 2.11 – 2.00 (m, 4H), 1.93 – 1.85 (m, 1H), 1.72 – 1.65 (m, 1H), 1.41 – 1.31 (m, 1H), 1.13 (d, *J* = 6.4 Hz, 3H), 0.94 (t, *J* = 7.5 Hz, 3H). **^{13}C NMR (major isomer(10:1), 150 MHz, $CDCl_3$):** δ

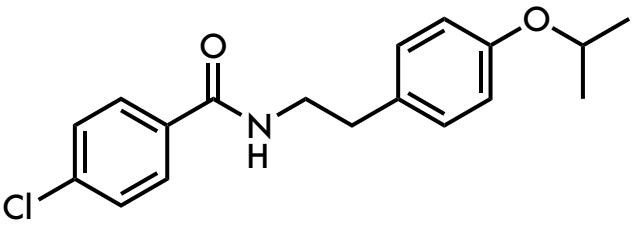
220.9, 133.6, 125.7, 56.7, 38.4, 36.5, 29.7, 25.2, 20.7, 19.8, 14.3. **HRMS (APCI):** calc'd for $C_{11}H_{19}O$ $[M+H]^+$ 167.1430; Found 167.1429.

(4-chlorophenyl)(5-methoxy-2,3-dimethyl-1*H*-indol-1-yl)methanone (35)[S18]



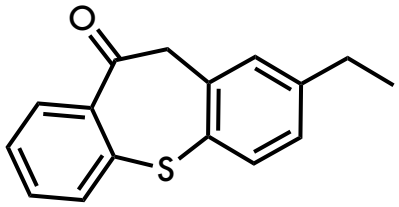
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.67 – 7.61 (m, 2H), 7.48 – 7.42 (m, 2H), 6.92 (d, *J* = 8.9 Hz, 1H), 6.90 (d, *J* = 2.5 Hz, 1H), 6.67 (dd, *J* = 2.6, 8.9 Hz, 1H), 3.85 (s, 3H), 2.31 (s, 3H), 2.19 (s, 3H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 168.3, 156.0, 138.9, 134.5, 133.8, 132.0, 131.1, 130.9, 129.1, 115.5, 115.0, 111.2, 101.3, 55.8, 13.4, 8.86. **HRMS (APCI):** calc'd for $C_{18}H_{17}ClNO_2$ $[M+H]^+$ 314.0942; Found 314.0942.

4-chloro-*N*-(4-isopropoxyphenethyl)benzamide (36)[S28]



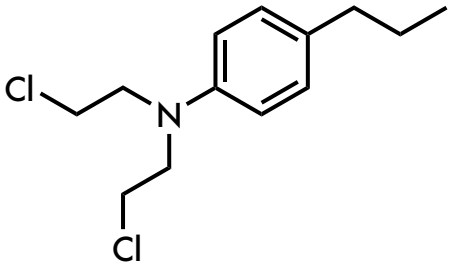
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.62 (d, *J* = 8.5 Hz, 2H), 7.35 (d, *J* = 6.7 Hz, 2H), 7.11 (d, *J* = 7.4, 2H), 6.84 (d, *J* = 8.2 Hz, 2H), 6.23 (br, 1H), 4.52 (hept, *J* = 6.1 Hz, 1H), 3.66 (d, *J* = 5.8 Hz, 2H), 2.85 (t, *J* = 6.8 Hz, 2H), 1.32 (d, *J* = 6.1 Hz, 6H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 166.6, 166.5, 156.8, 137.7, 133.2, 130.7, 129.9, 128.9, 128.4, 116.3, 70.1, 41.5, 34.8, 22.2. **HRMS (APCI):** calc'd for $C_{18}H_{21}ClNO_2$ $[M+H]^+$ 318.1255; Found 318.1255.

2-ethyldibenzo[b,f]thiepin-10(11H)-one (37)



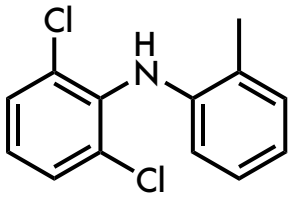
^{1}H NMR (600 MHz, $CDCl_3$): δ 8.19 (d, *J* = 6.7 Hz, 1H), 7.58 (d, *J* = 7.9 Hz, 1H), 7.53 (d, *J* = 7.9 Hz), 7.43 – 7.36 (m, 1H), 7.32 – 7.26 (m, 2H), 7.01 (d, *J* = 7.9 Hz, 1H), 4.33 (s, 2H), 2.63 (q, *J* = 7.6 Hz, 2H), 1.24 – 1.18 (m, 3H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 191.8, 146.8, 140.8, 137.7, 136.3, 132.5, 131.6, 131.5, 131.3, 130.9, 129.1, 126.9, 126.8, 51.2, 28.7, 15.5. **HRMS (APCI):** calc'd for $C_{16}H_{15}OS$ $[M+H]^+$ 255.0838; Found 255.0829.

N,N-bis(2-chloroethyl)-4-propylaniline (38)[S26]



^{1}H NMR (600 MHz, $CDCl_3$): δ 7.11 (d, *J* = 8.6 Hz, 2H), 6.66 (d, *J* = 8.7 Hz, 2H), 3.72 (t, *J* = 7.3 Hz, 4H), 3.65 (t, *J* = 7.3 Hz, 4H), 2.53 (t, *J* = 7.5 Hz, 2H), 1.63 (sex, *J* = 7.4 Hz, 2H), 0.97 (t, *J* = 7.3 Hz, 3H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 144.2, 132.1, 129.7, 112.2, 53.8, 40.7, 37.0, 24.9, 14.0. **HRMS (APCI):** calc'd for $C_{13}H_{20}Cl_2N$ $[M+H]^+$ 260.0960; Found 260.0967.

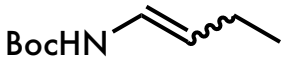
2,6-dichloro-N-(o-tolyl)aniline (39)



^{1}H NMR (600 MHz, $CDCl_3$): δ 7.38 (d, *J* = 8.1 Hz, 2H), 7.20 (d, *J* = 7.4 Hz, 1H), 7.10 – 7.01 (m, 2H), 6.90 (t, *J* = 7.3 Hz, 1H), 6.45 (d, *J* = 8.0 Hz, 1H), 5.54 (br, 1H), 3.12 (s, 3H). **^{13}C NMR (150 MHz,**

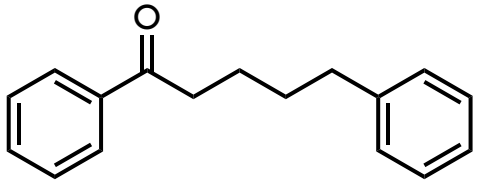
$CDCl_3$): δ 141.7, 137.5, 130.7, 130.6, 129.0, 126.5, 126.1, 124.9, 121.3, 115.6, 18.0. **HRMS (APCI):** calc'd for $C_{13}H_{12}Cl_2N$ $[M+H]^+$ 252.0341; Found 252.0334.

tert-butyl but-1-en-1-ylcarbamate (40)[S29]



***E* isomer: ^{1}H NMR (600 MHz, $CDCl_3$):** δ 6.40 (t, *J* = 12.2 Hz, 1H), 6.18 (br, 1H), 5.01 – 4.92 (m, 1H), 2.01 – 1.91 (m, 2H), 1.43 (s, 9H), 0.95 (t, *J* = 7.4 Hz, 3H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 153.1, 123.0, 111.7, 80.2, 28.4, 23.0, 14.5. **HRMS (APCI):** calc'd for $C_9H_{18}NO_2$ $[M+H]^+$ 172.1332; Found 172.1332.
***Z* isomer: ^{1}H NMR (600 MHz, $CDCl_3$):** δ 6.35 (t, *J* = 9.6 Hz, 1H), 6.21 (br, 1H), 4.54 (q, *J* = 7.6 Hz, 1H), 2.01 – 1.91 (m, 2H), 1.45 (s, 9H), 0.98 (t, *J* = 7.5 Hz, 3H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 153.0, 121.6, 110.1, 80.4, 28.4, 18.9, 14.2.

1,5-diphenylpentan-1-one (C1)



^{1}H NMR (600 MHz, $CDCl_3$): δ 7.97 – 7.92 (m, 2H), 7.55 (t, *J* = 7.4 Hz, 1H), 7.45 (t, *J* = 7.9 Hz, 2H), 7.30 – 7.25 (m, 2H), 7.21 – 7.15 (m, 3H), 2.99 (t, *J* = 7.1 Hz, 2H), 2.67 (t, *J* = 7.7 Hz, 2H), 1.83 – 1.68 (m, 4H). **^{13}C NMR (150 MHz, $CDCl_3$):** δ 200.4, 142.4, 137.2, 133.1, 128.7, 128.5, 128.4, 128.2, 125.9, 38.5, 35.9, 31.2, 24.1. **HRMS (APCI):** calc'd for $C_{17}H_{19}O$ $[M+H]^+$ 239.1436; Found 239.1437.

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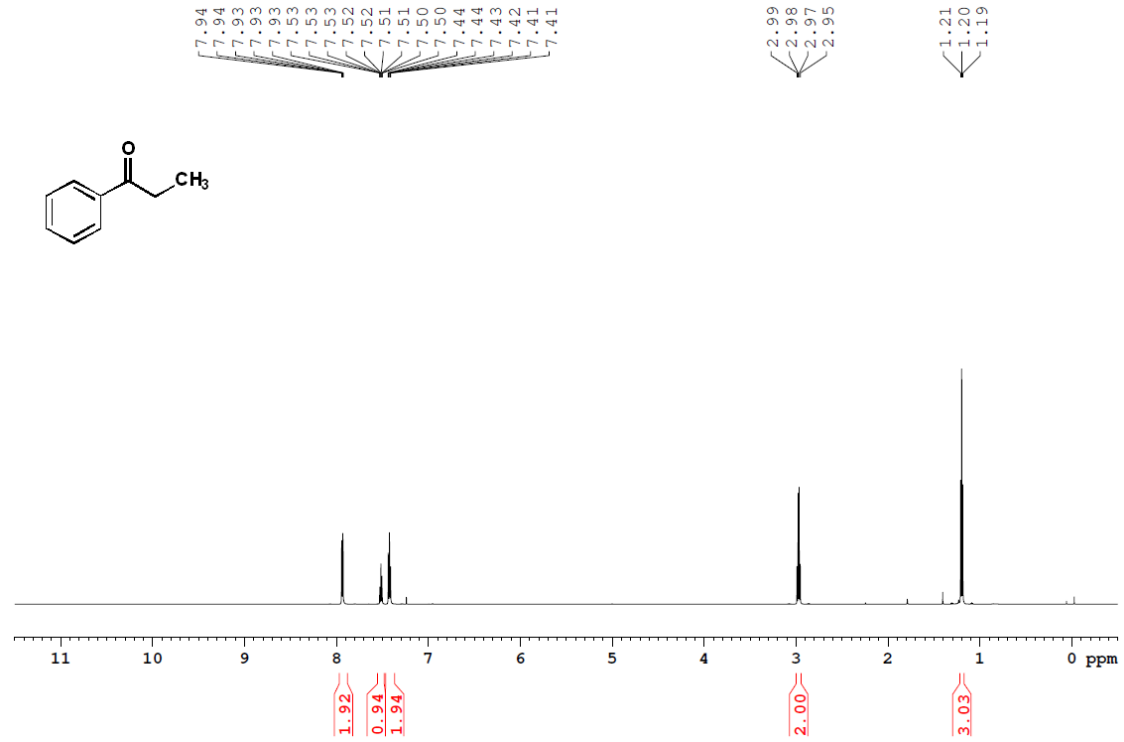
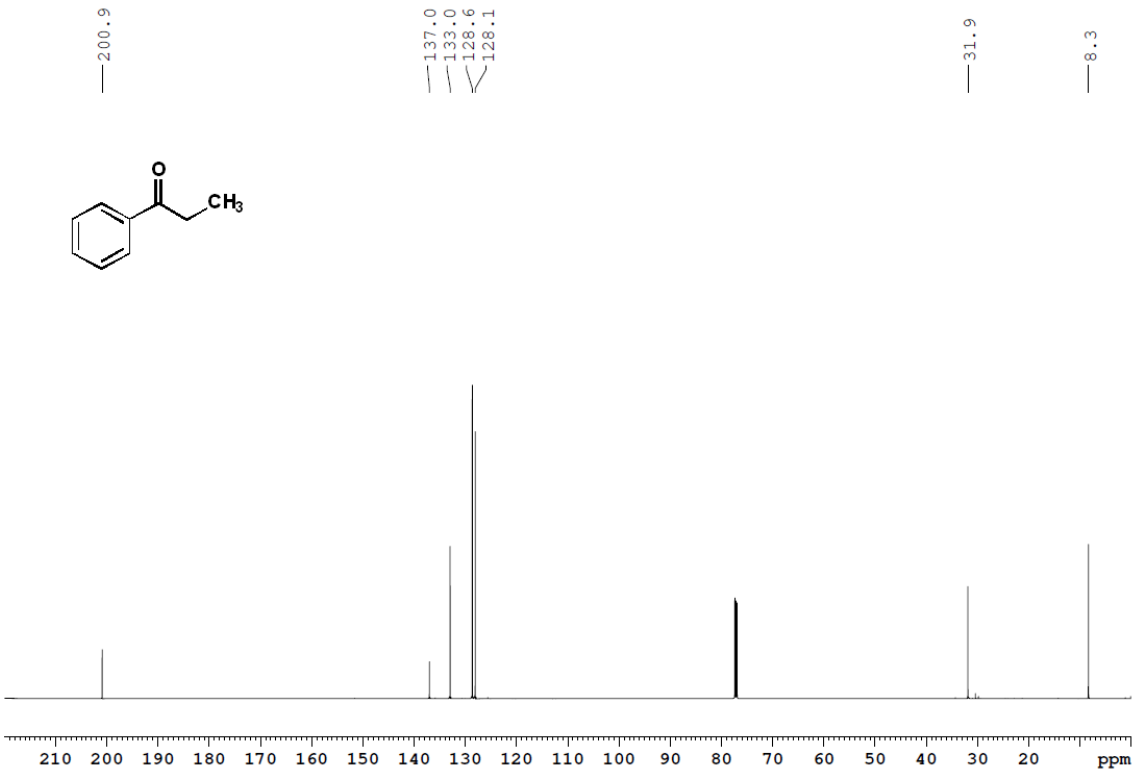
NMR spectra of decarboxylation compounds

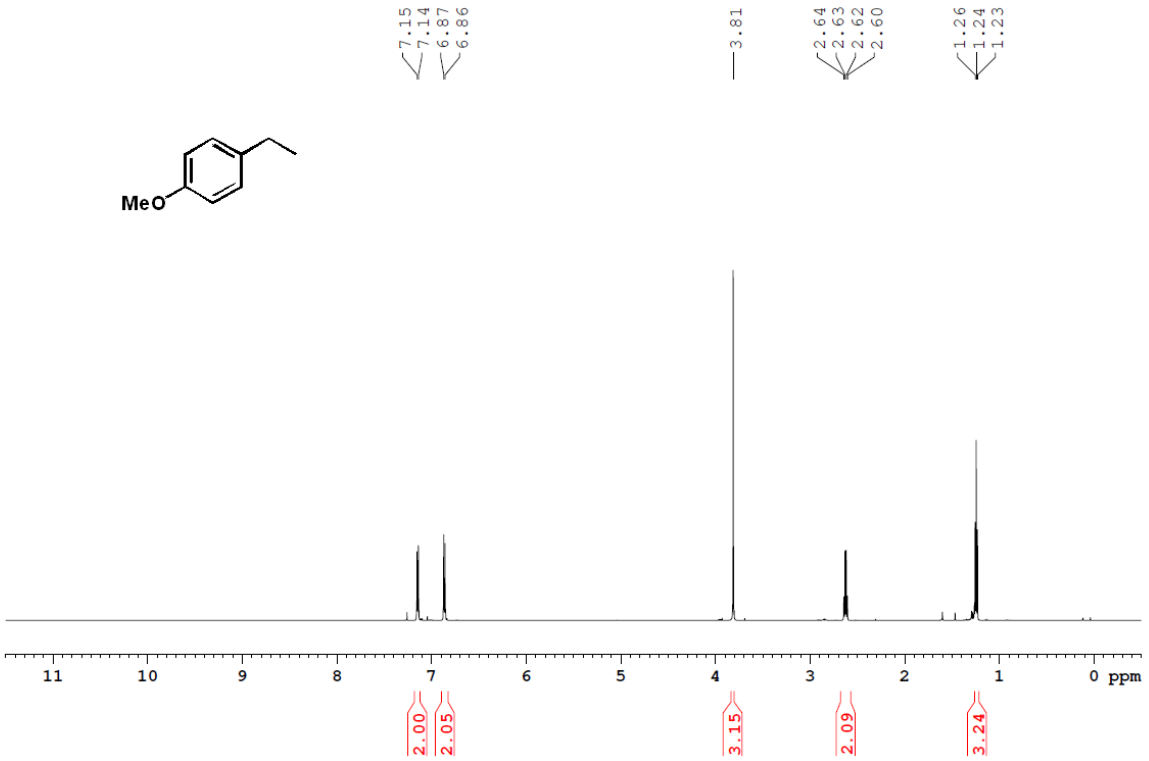
^{1}H NMR spectrum of **2** (600 MHz, $CDCl_3$)



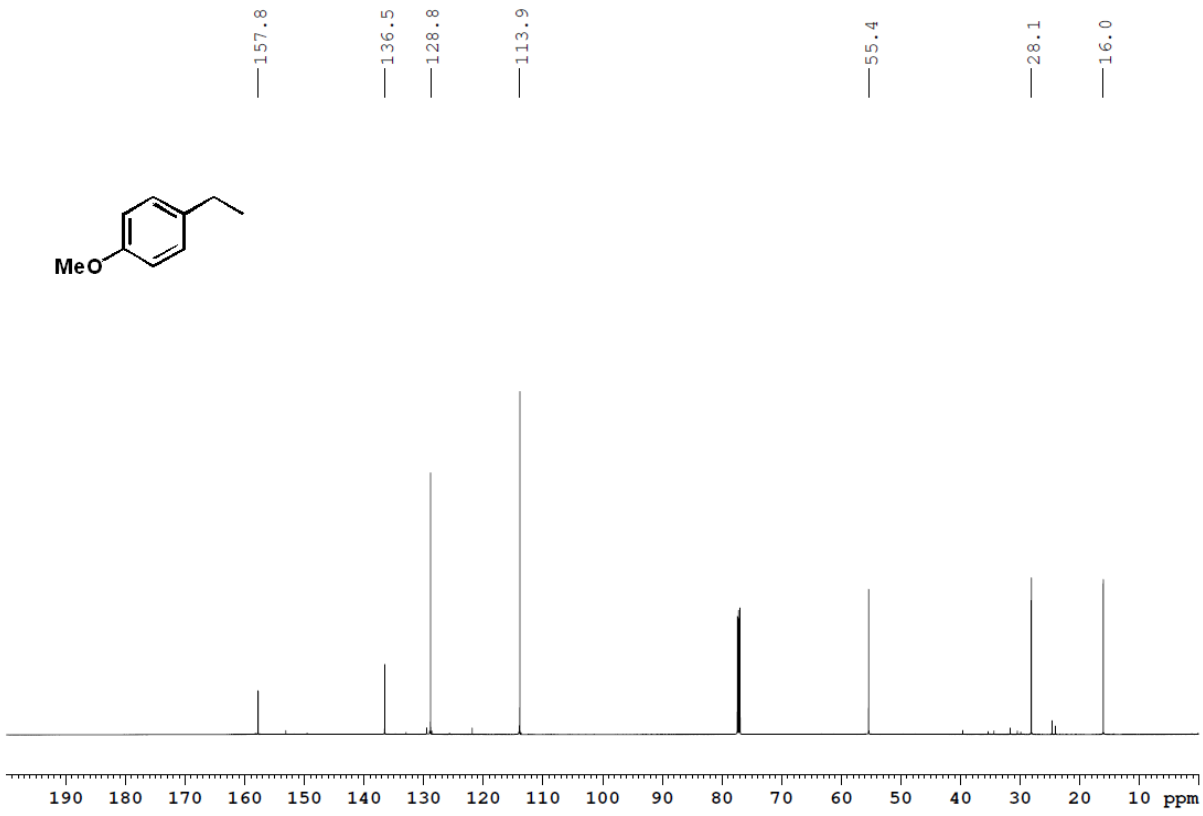
^{13}C NMR spectrum of **2** (150 MHz, $CDCl_3$)



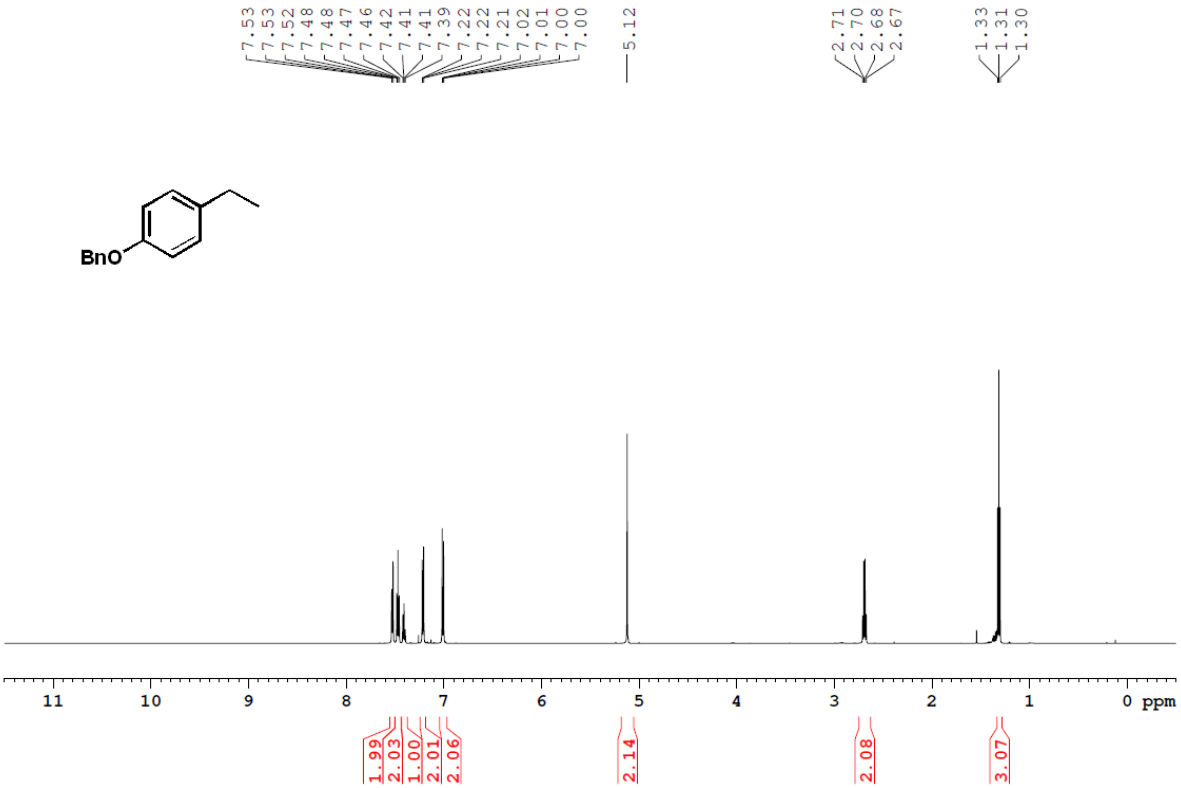
^{1}H NMR spectrum of **3** (600 MHz, $CDCl_3$)



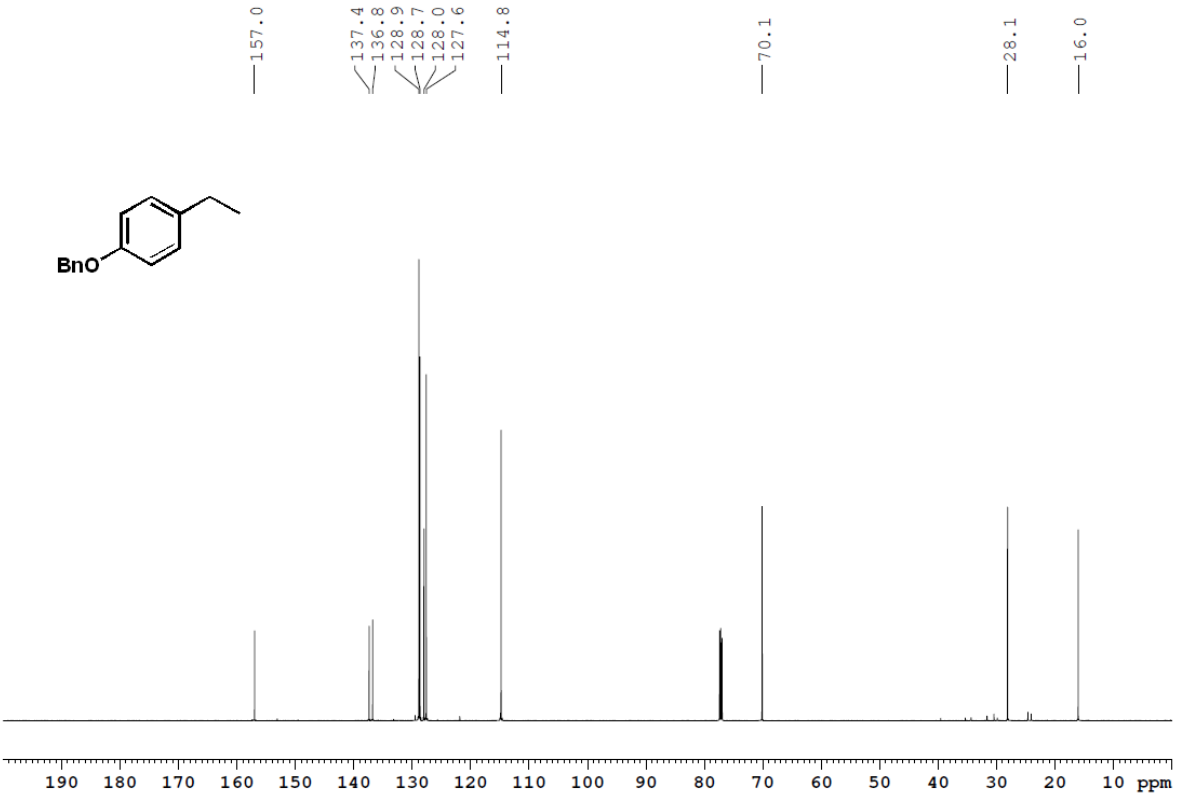
^{13}C NMR spectrum of **3** (150 MHz, $CDCl_3$)



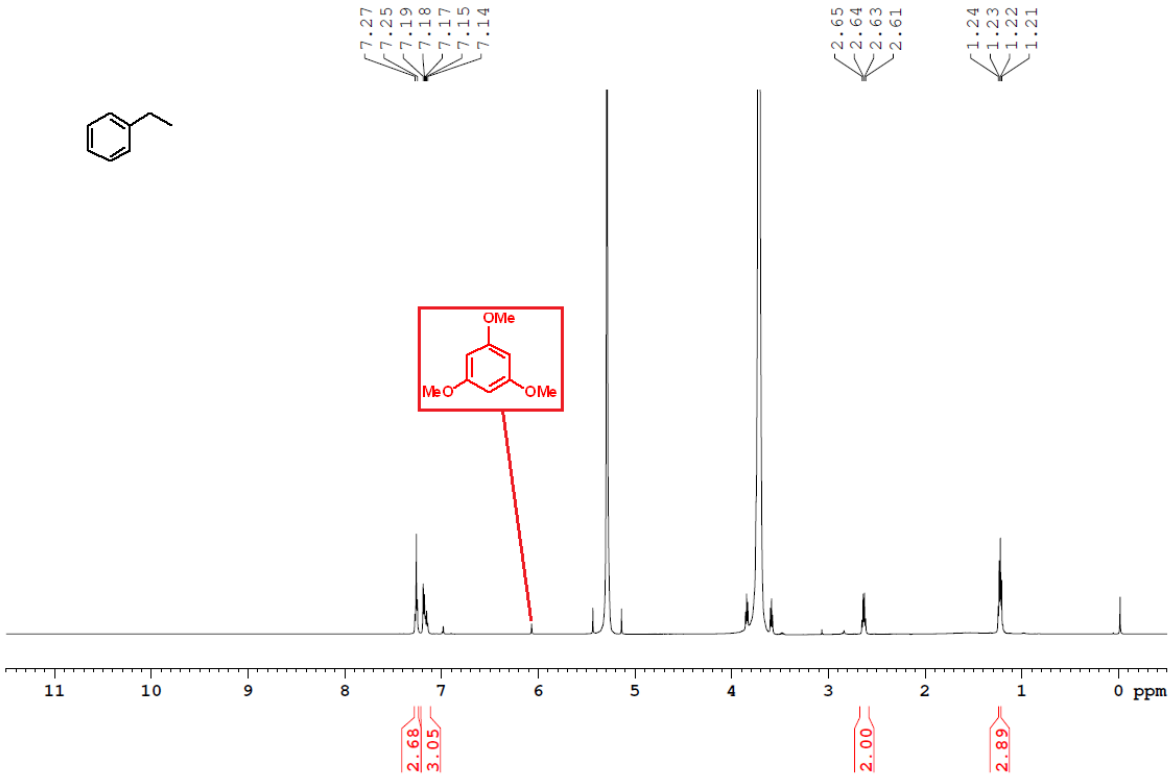
^{1}H NMR spectrum of **4** (600 MHz, $CDCl_3$)



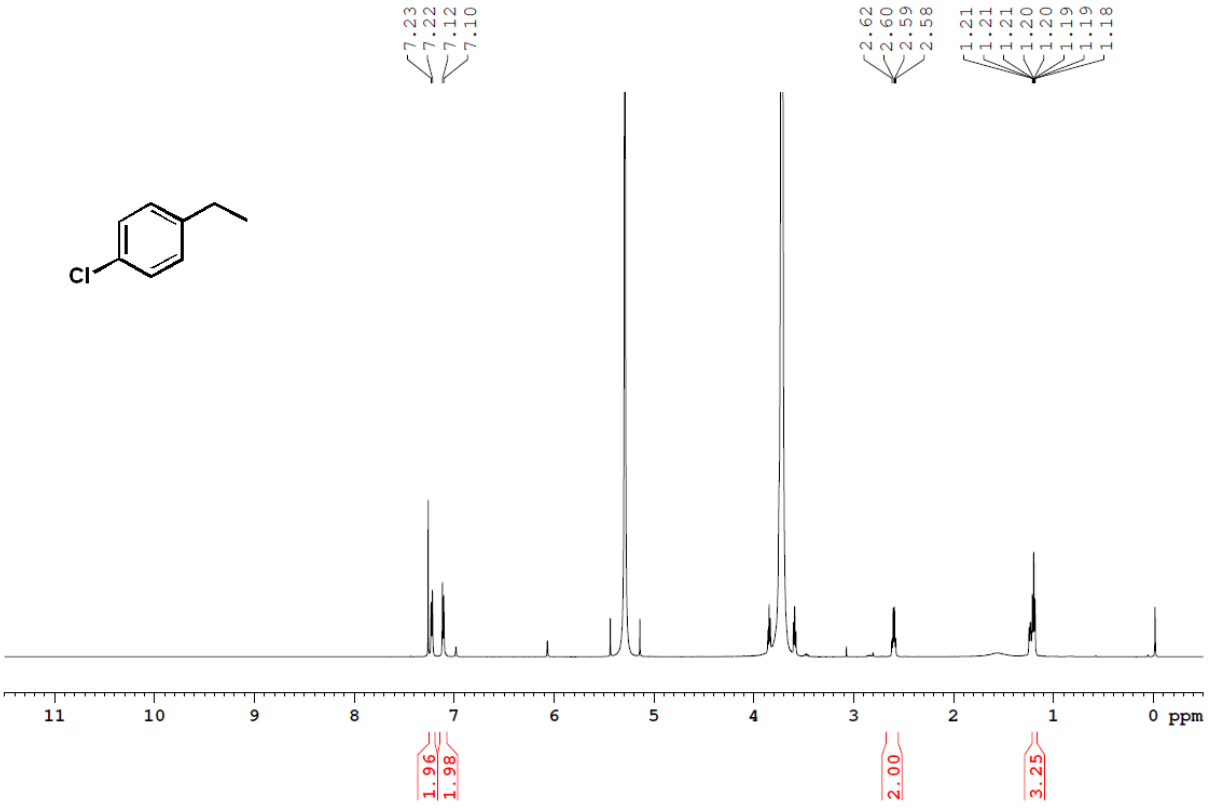
^{13}C NMR spectrum of **4** (150 MHz, $CDCl_3$)



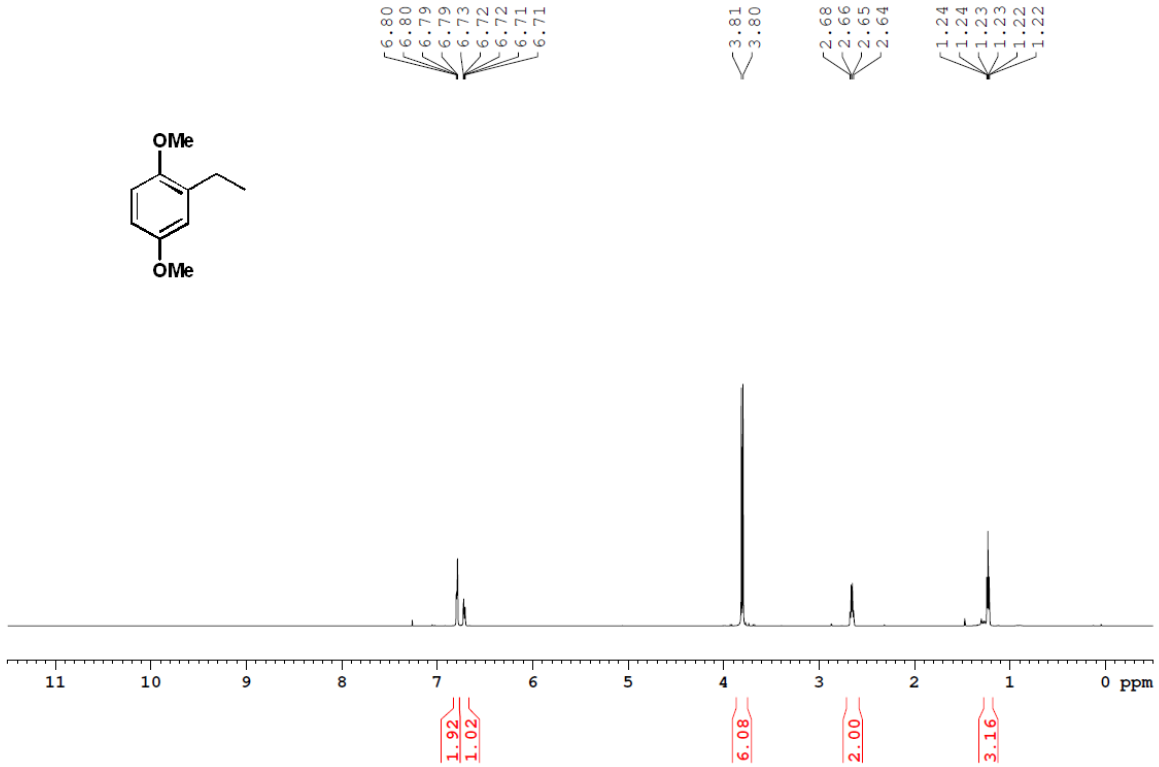
Crude ^{1}H NMR spectrum of **5** (600 MHz, $CDCl_3$)



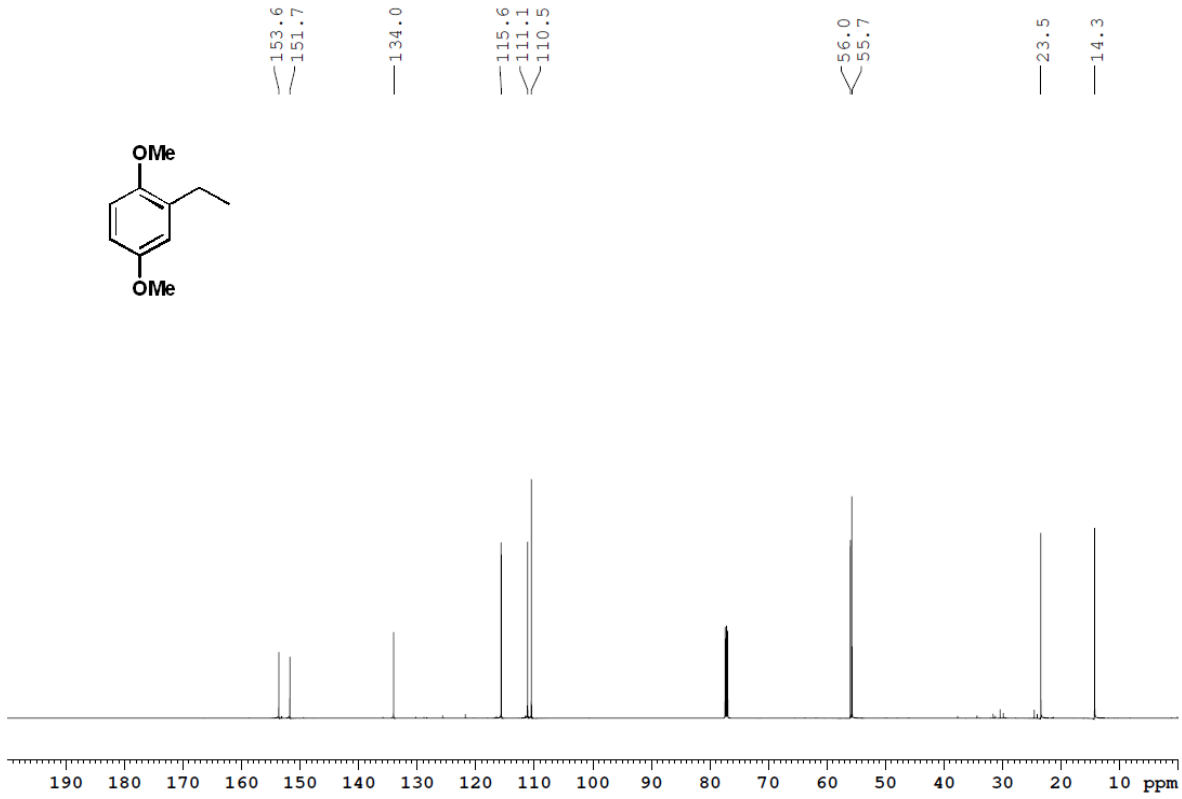
Crude ^{1}H NMR spectrum of **6** (600 MHz, $CDCl_3$)



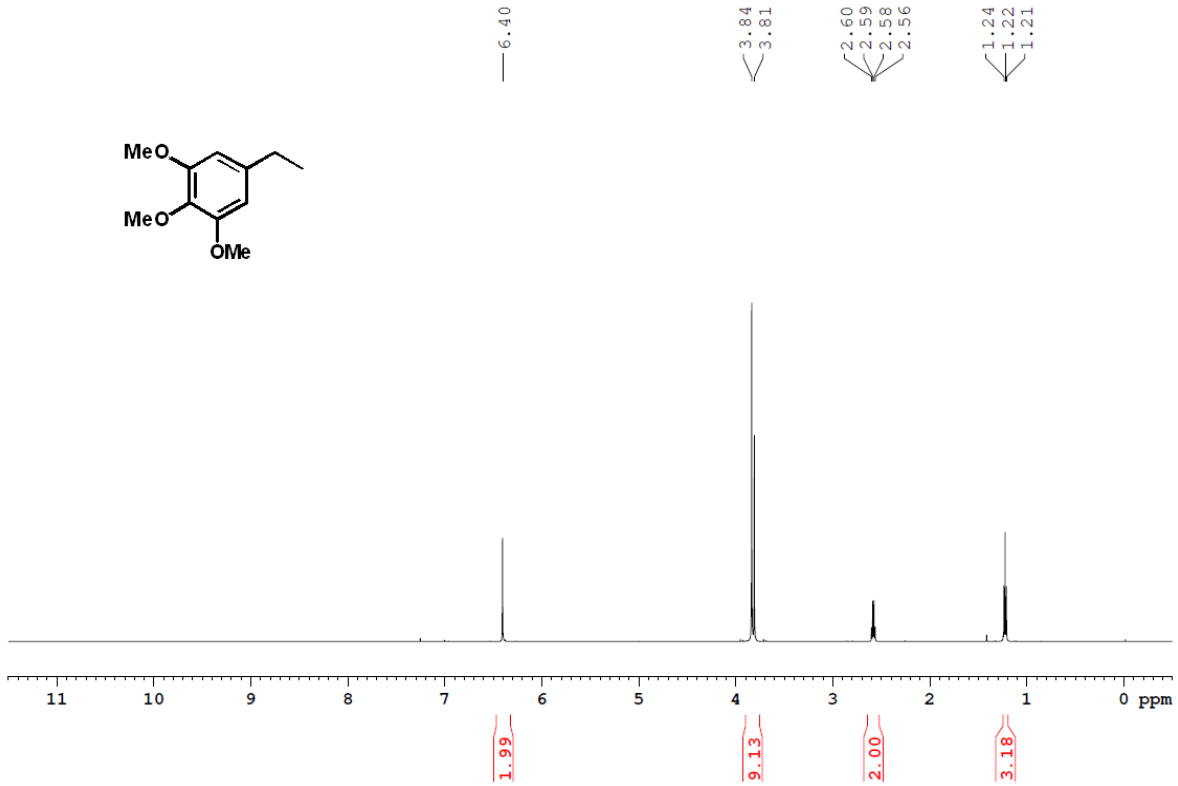
^{1}H NMR spectrum of **7** (600 MHz, $CDCl_3$)



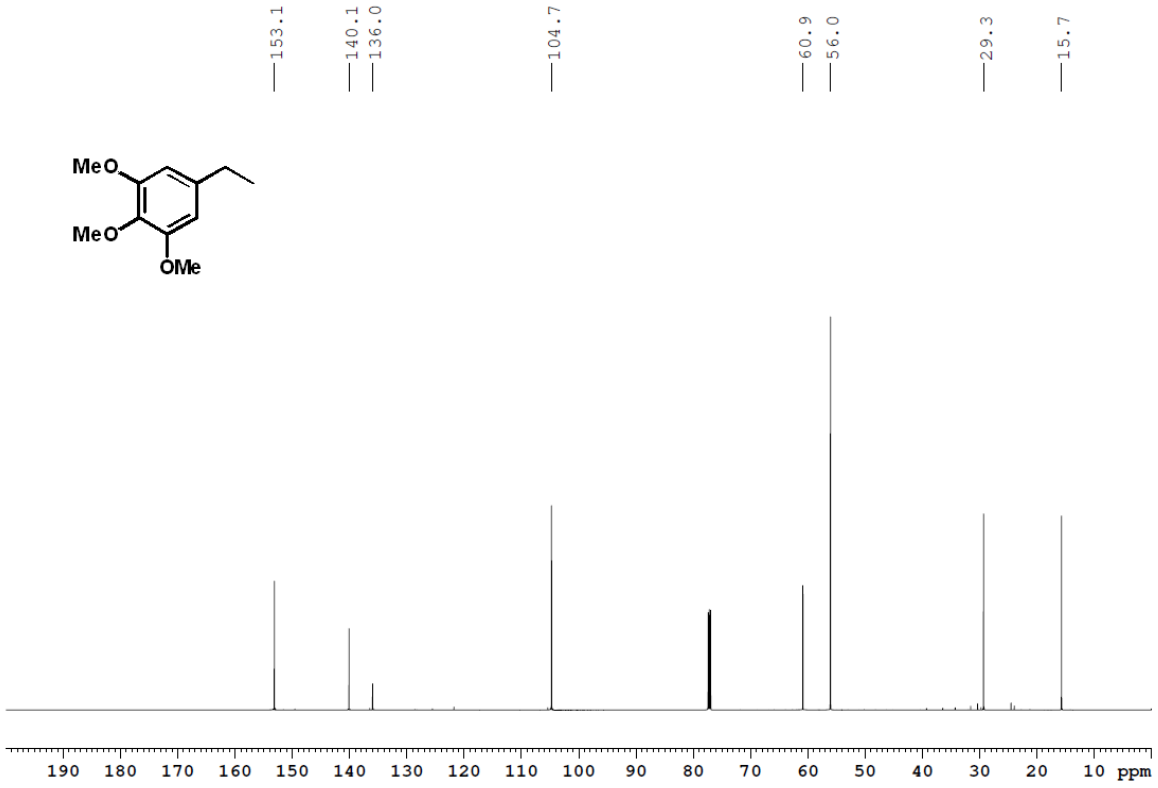
^{13}C NMR spectrum of **7** (150 MHz, $CDCl_3$)



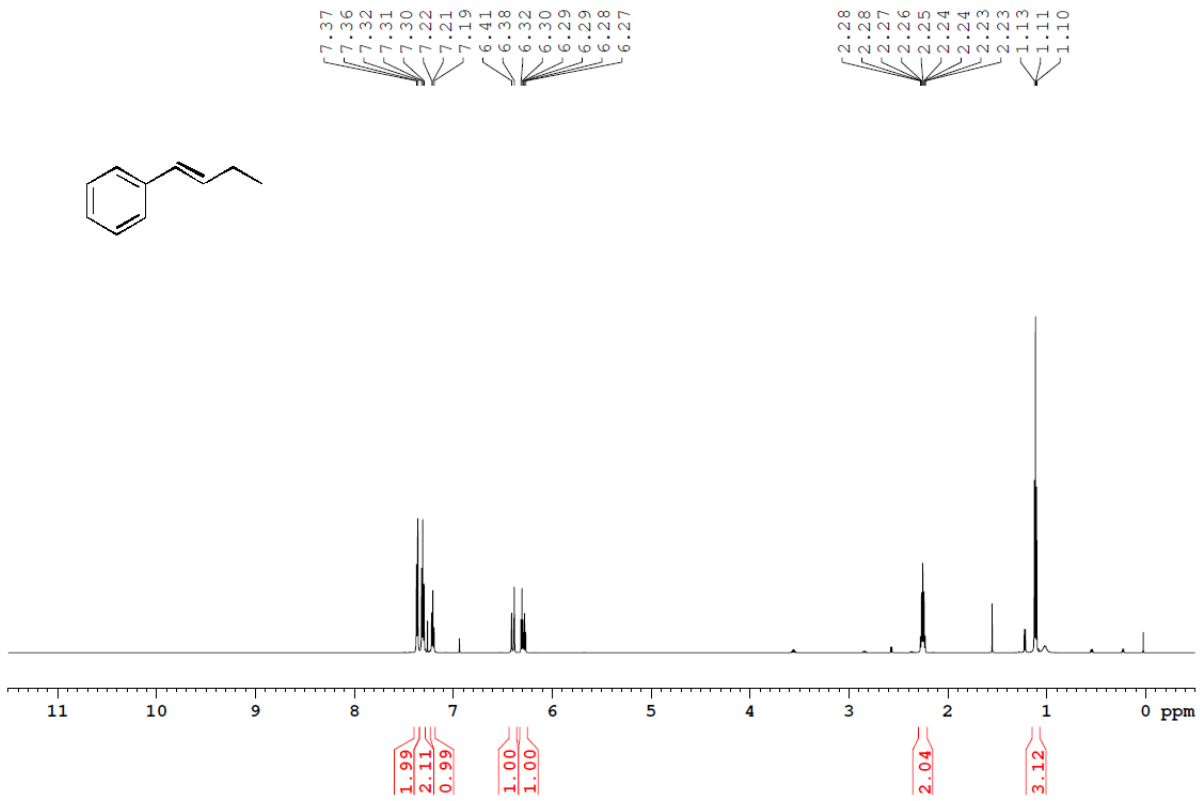
^{1}H NMR spectrum of **8** (600 MHz, $CDCl_3$)



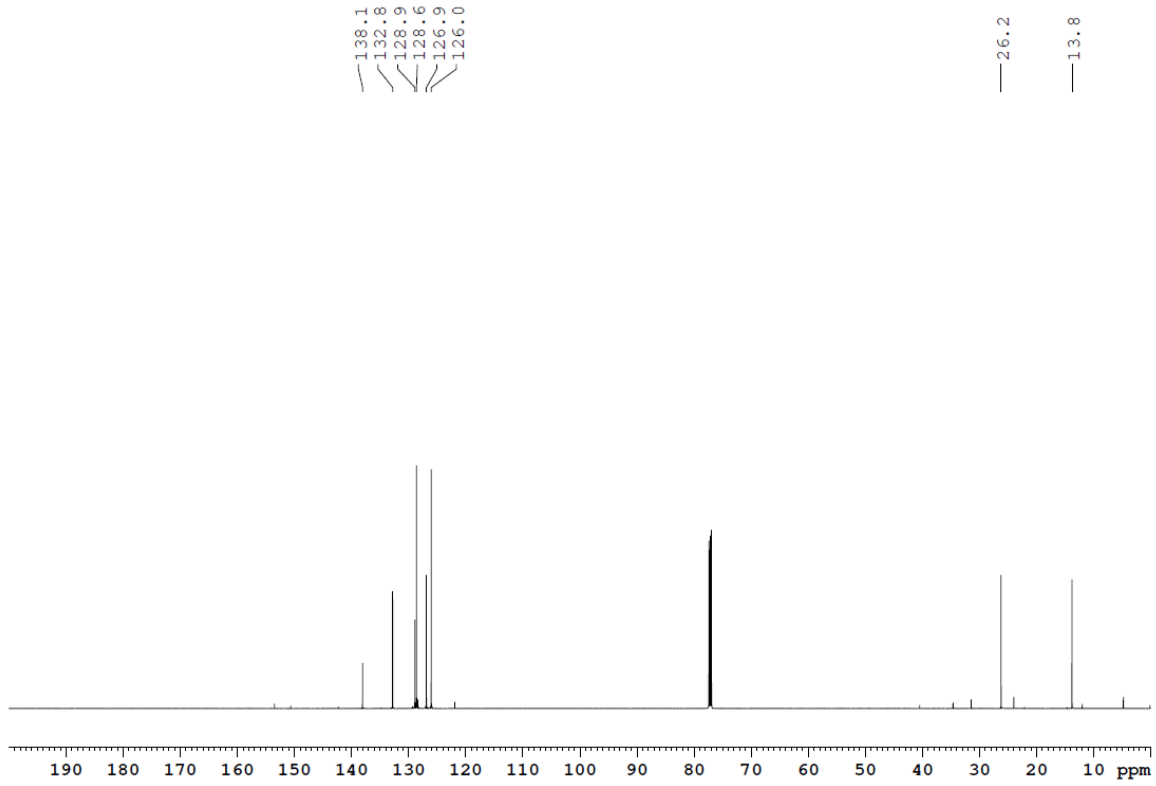
^{13}C NMR spectrum of **8** (150 MHz, $CDCl_3$)



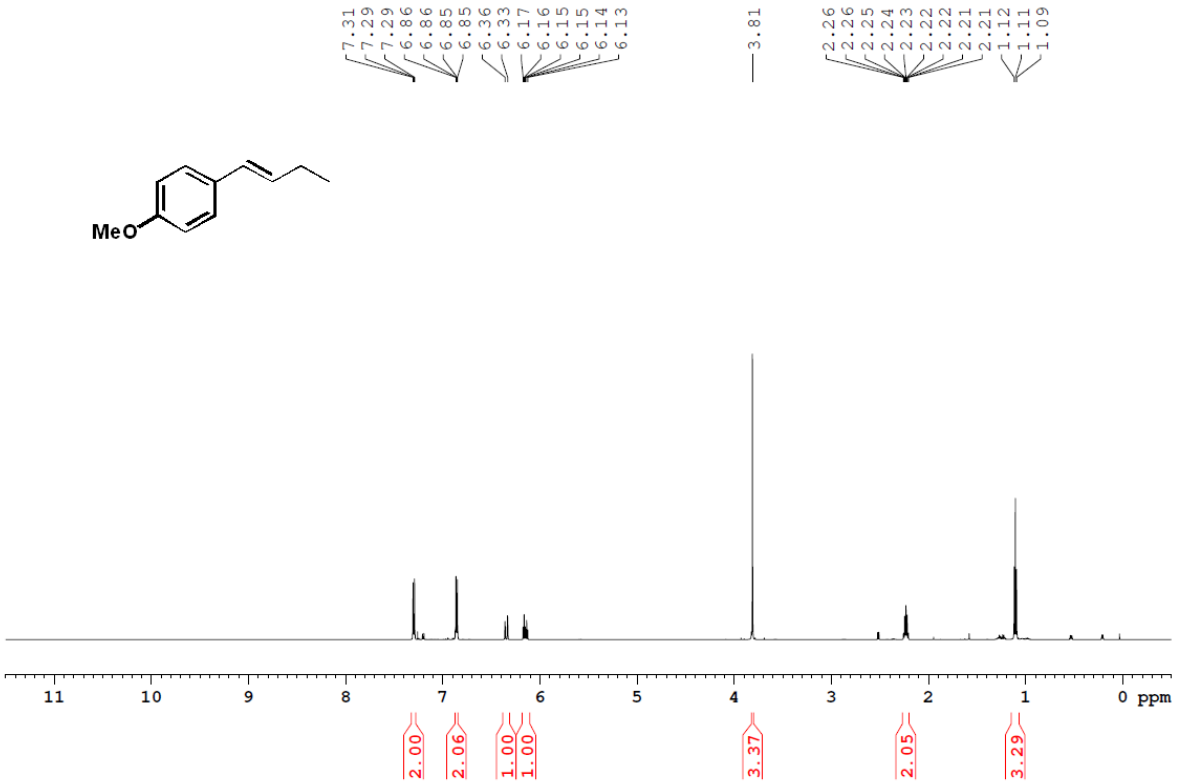
^{1}H NMR spectrum of **9a** (600 MHz, $CDCl_3$)



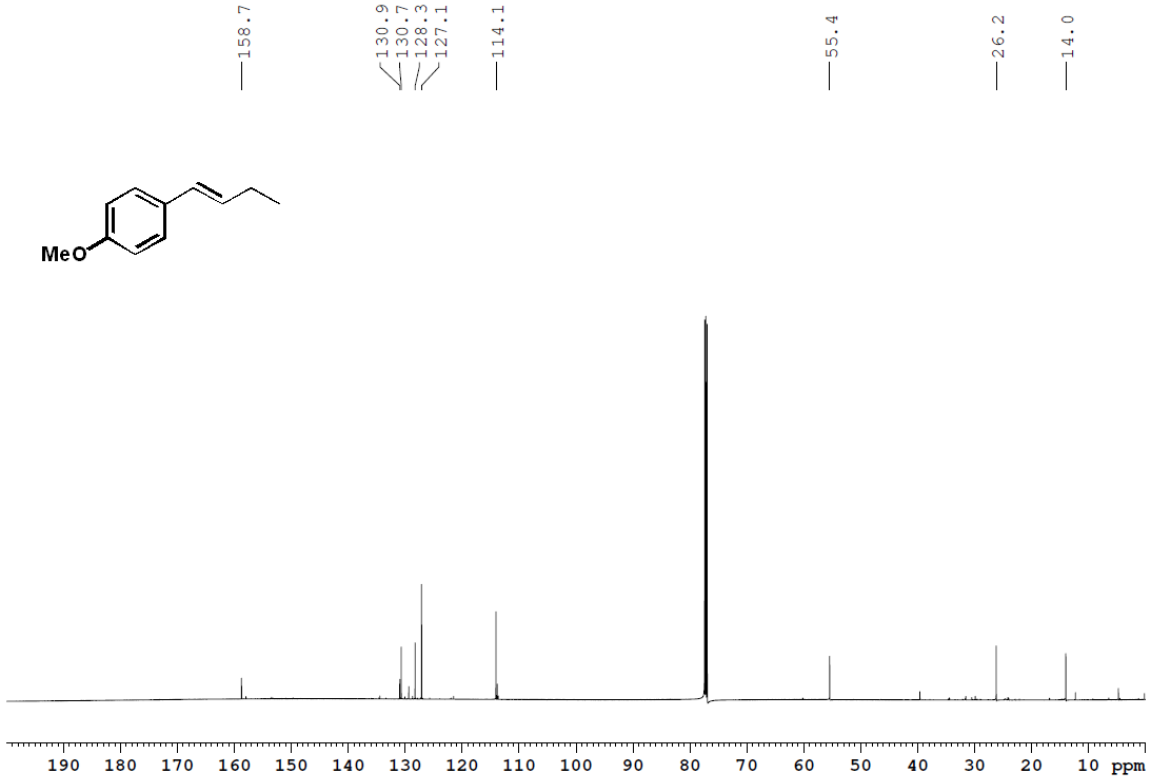
^{13}C NMR spectrum of **9a** (150 MHz, $CDCl_3$)



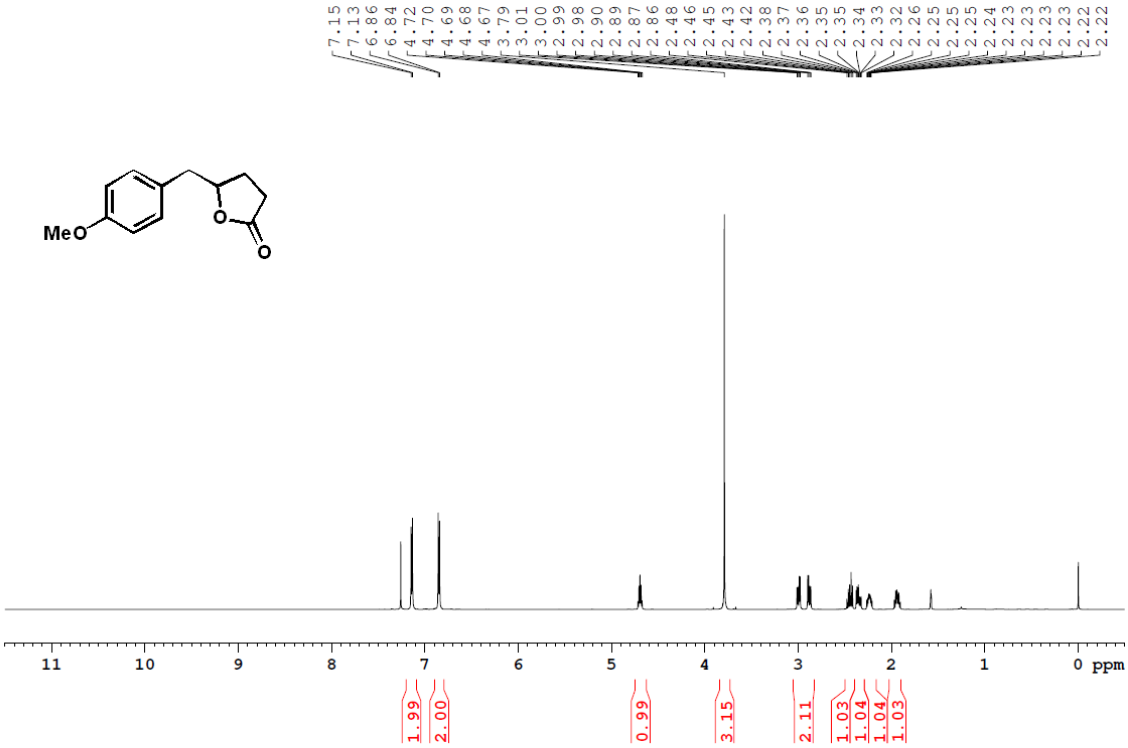
^{1}H NMR spectrum of **10a** (600 MHz, $CDCl_3$)



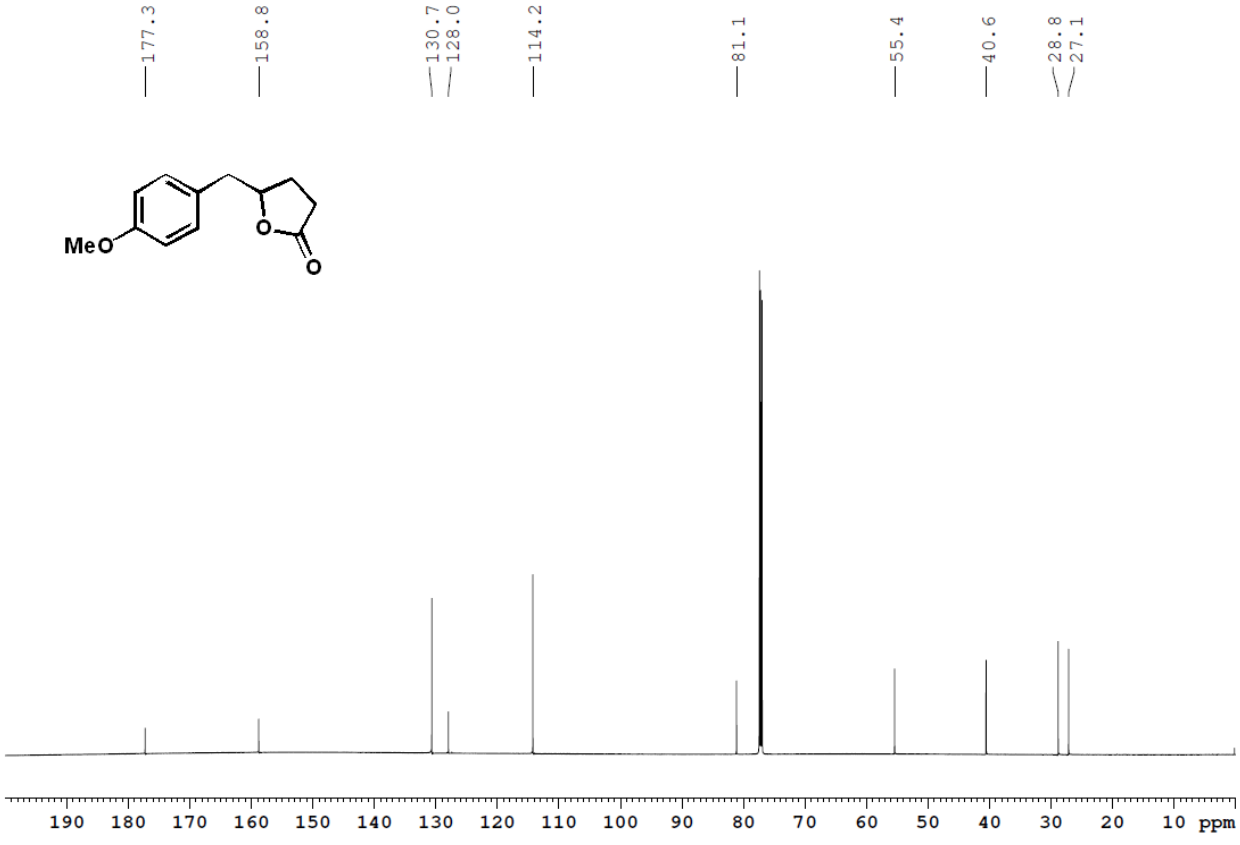
^{13}C NMR spectrum of **10a** (150 MHz, $CDCl_3$)



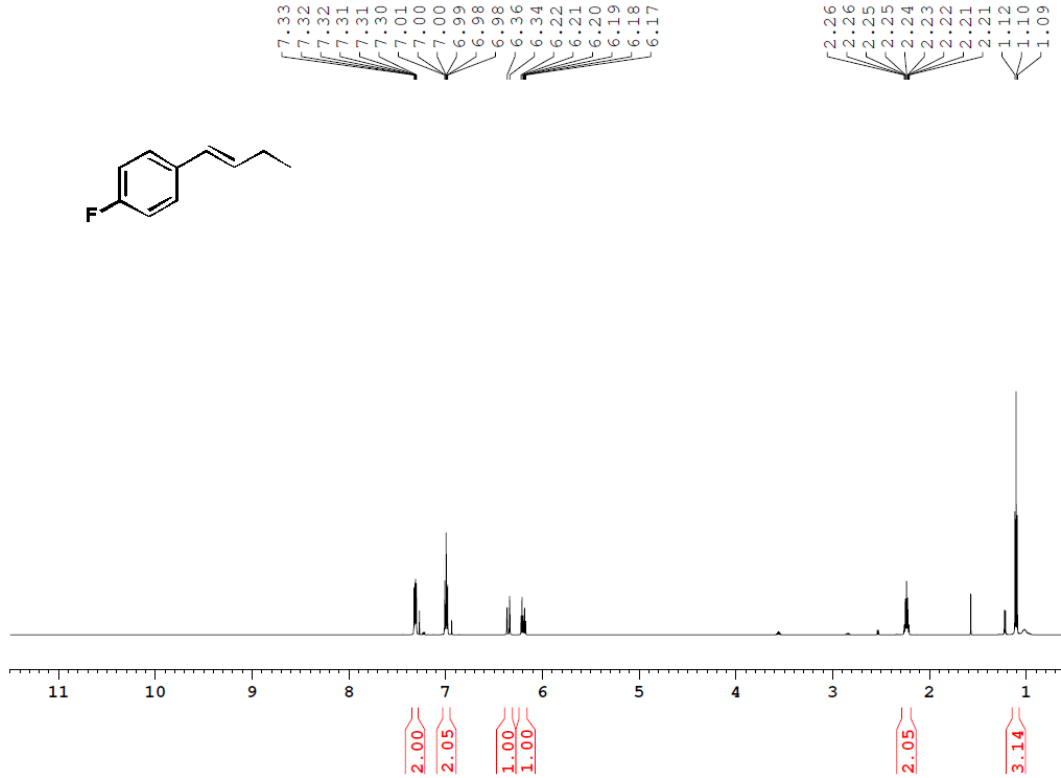
^{1}H NMR spectrum of **10b** (600 MHz, $CDCl_3$)



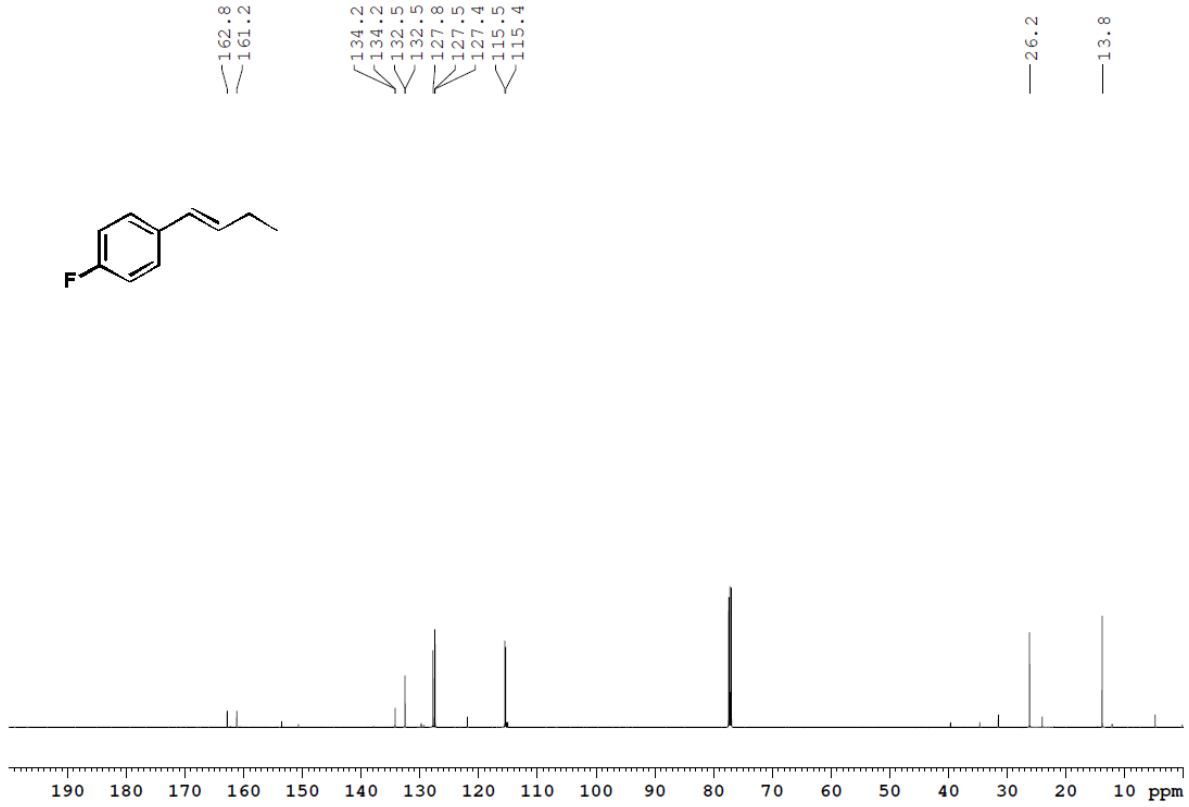
^{13}C NMR spectrum of **10b** (150 MHz, $CDCl_3$)



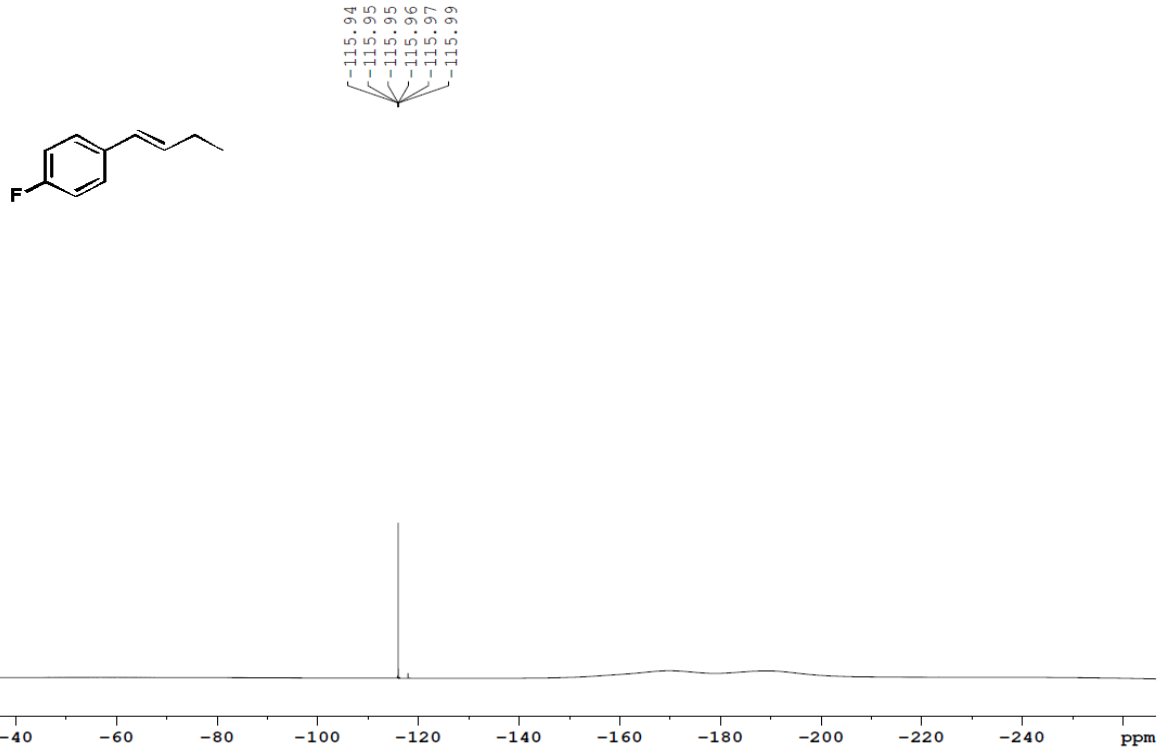
^{1}H NMR spectrum of **11a** (600 MHz, $CDCl_3$)



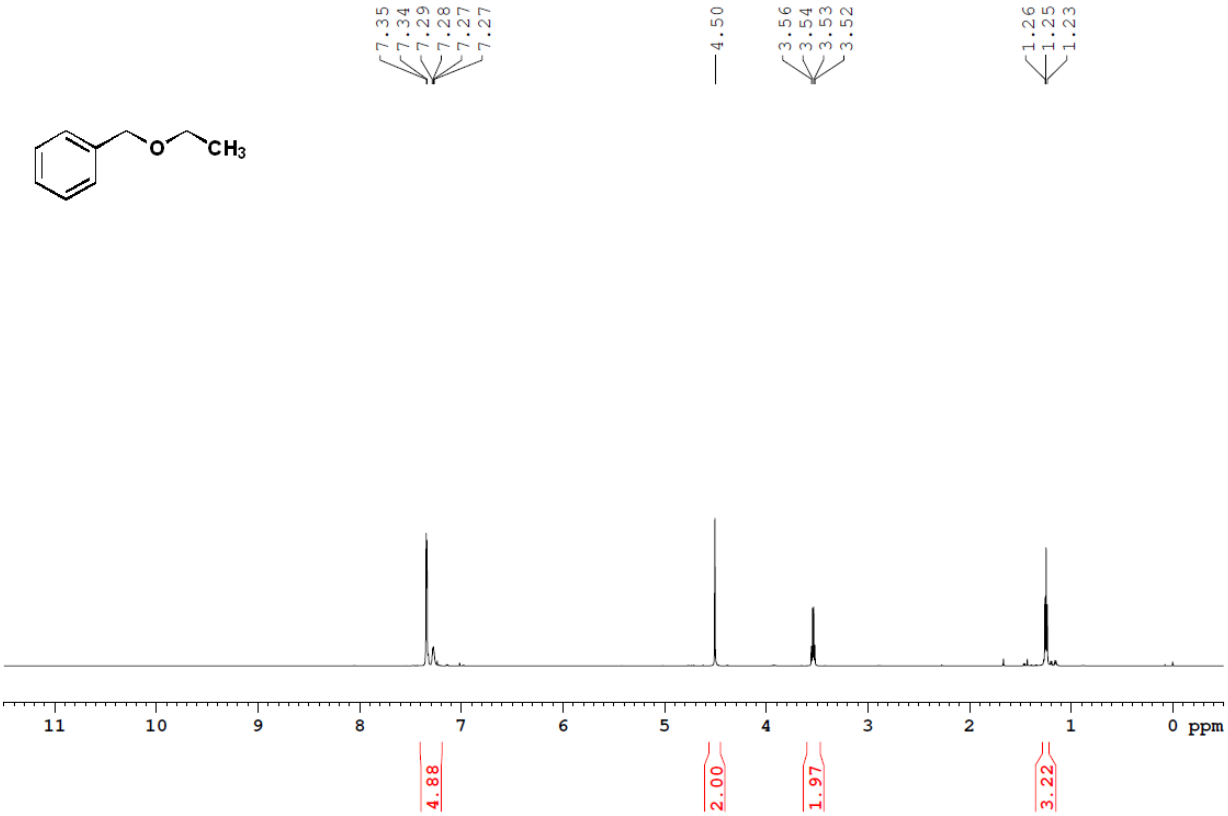
^{13}C NMR spectrum of **11a** (150 MHz, $CDCl_3$)



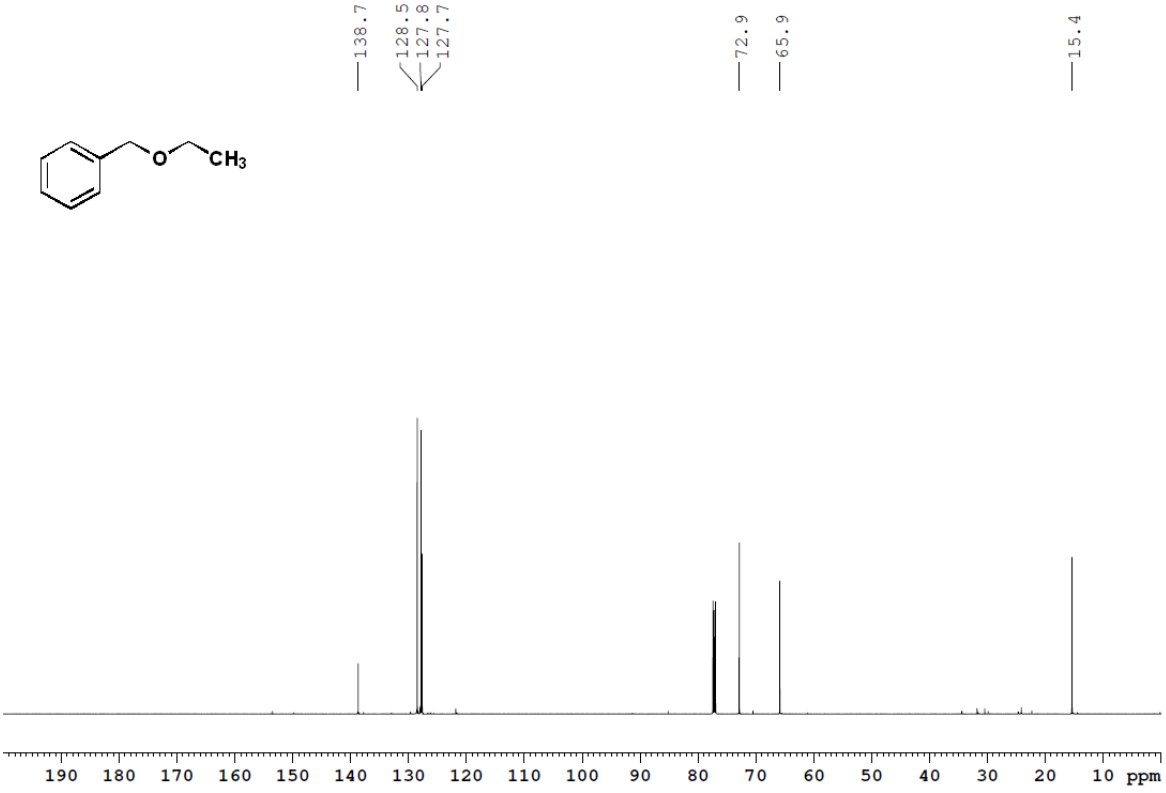
^{19}F NMR spectrum of **11a** (565 MHz, $CDCl_3$)



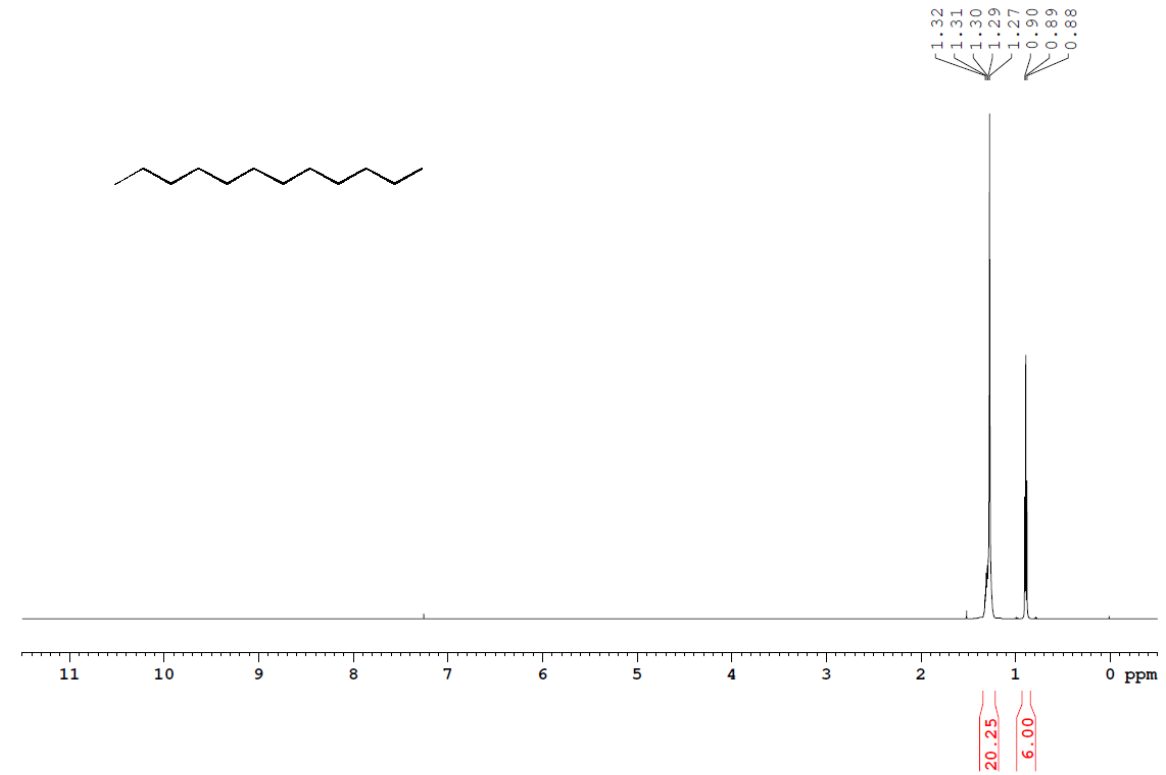
^{1}H NMR spectrum of **12** (600 MHz, $CDCl_3$)



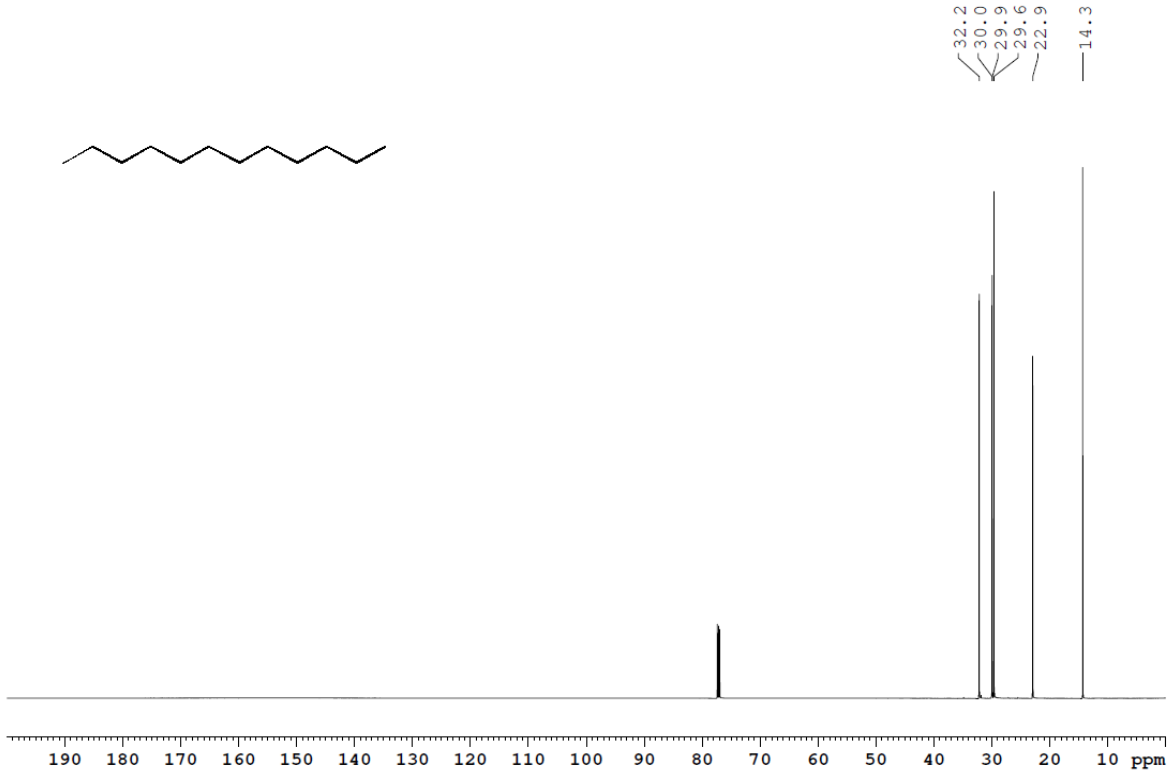
^{13}C NMR spectrum of **12** (150 MHz, $CDCl_3$)



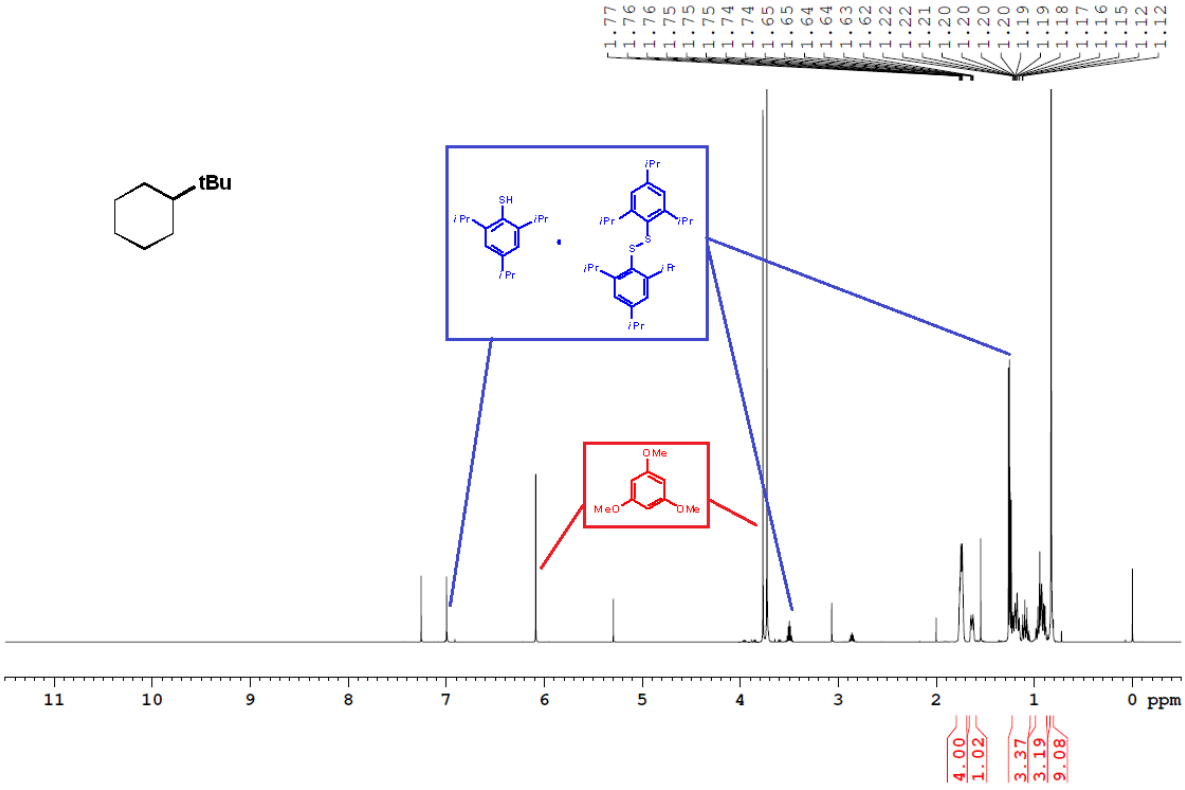
^{1}H NMR spectrum of **13** (600 MHz, $CDCl_3$)



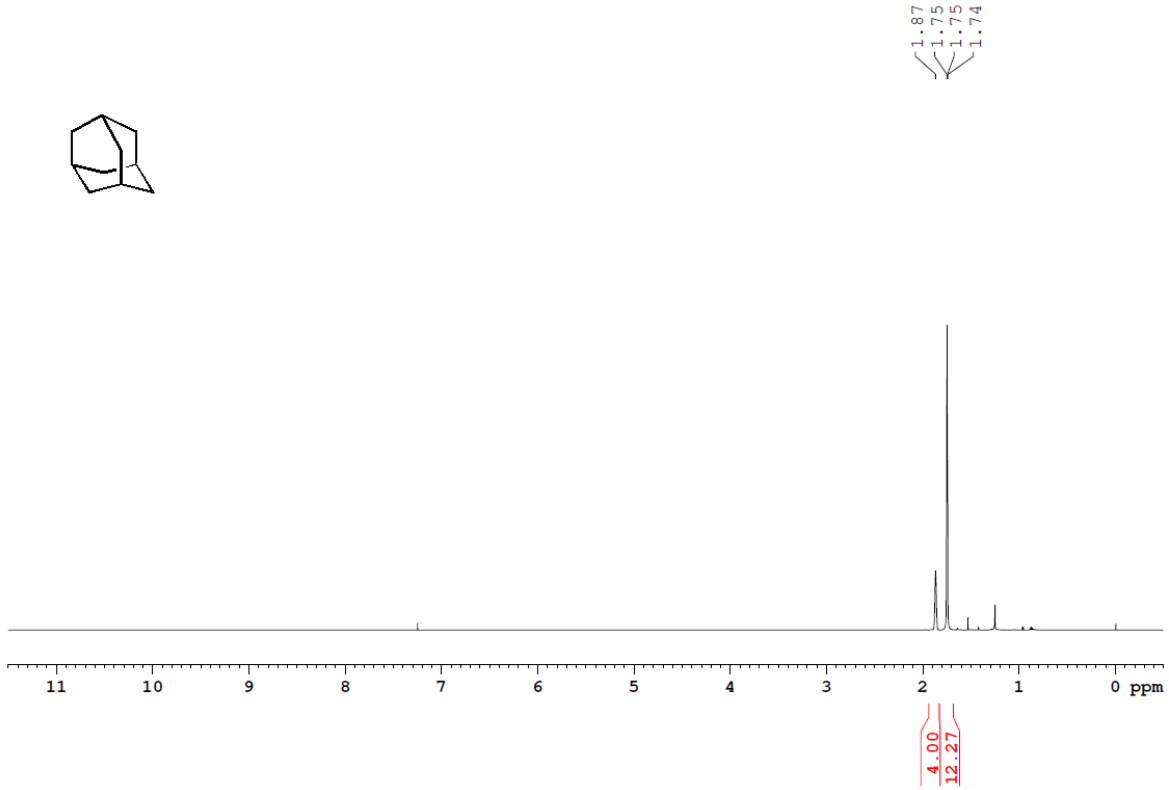
^{13}C NMR spectrum of **13** (150 MHz, $CDCl_3$)



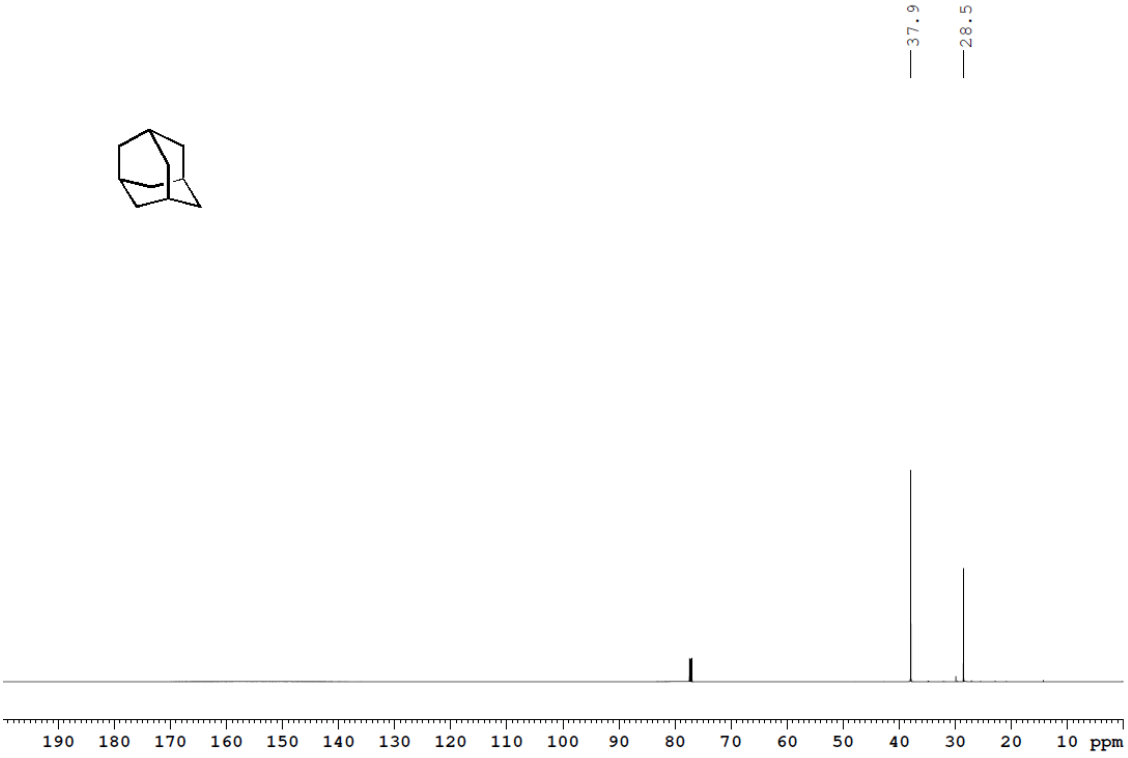
Crude ^{1}H NMR spectrum of **14** (600 MHz, $CDCl_3$)



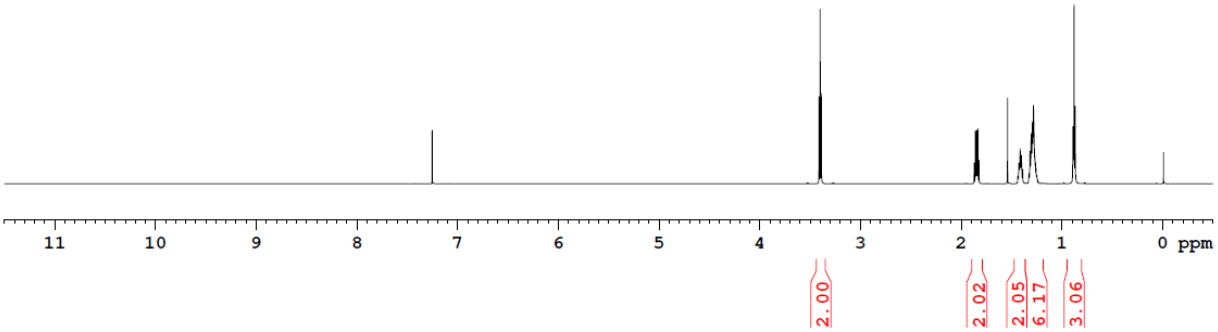
^{1}H NMR spectrum of **15** (600 MHz, $CDCl_3$)



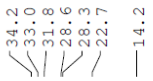
^{13}C NMR spectrum of **15** (150 MHz, $CDCl_3$)

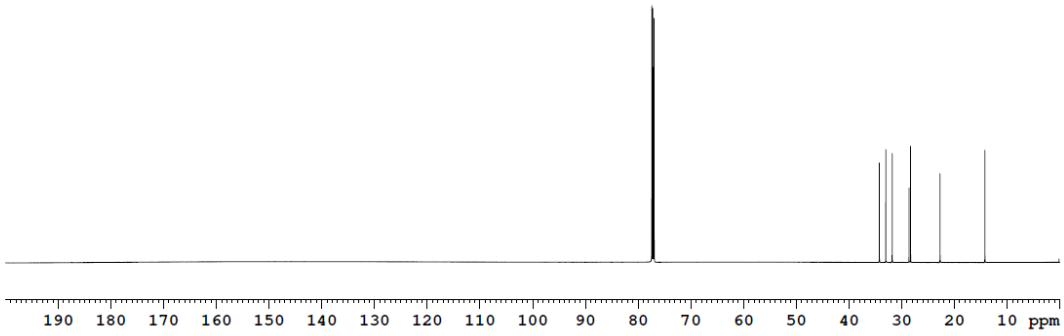


^{1}H NMR spectrum of **16** (600 MHz, $CDCl_3$)

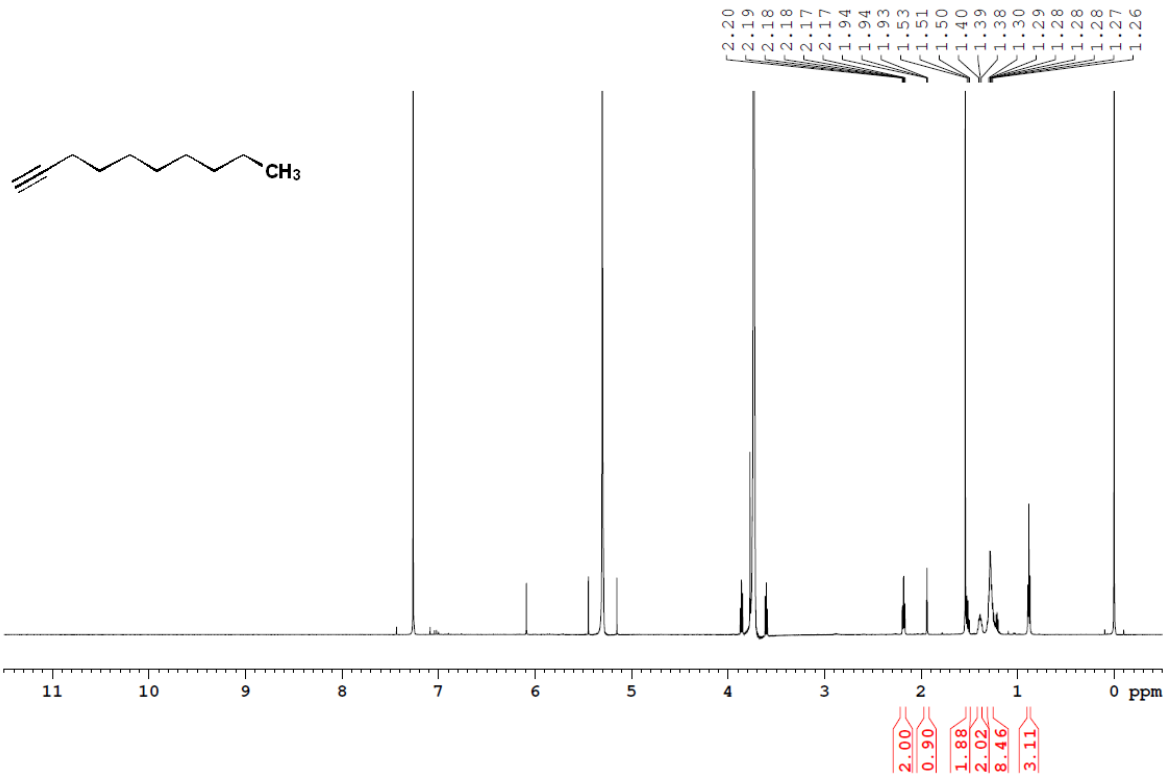


^{13}C NMR spectrum of **16** (150 MHz, $CDCl_3$)

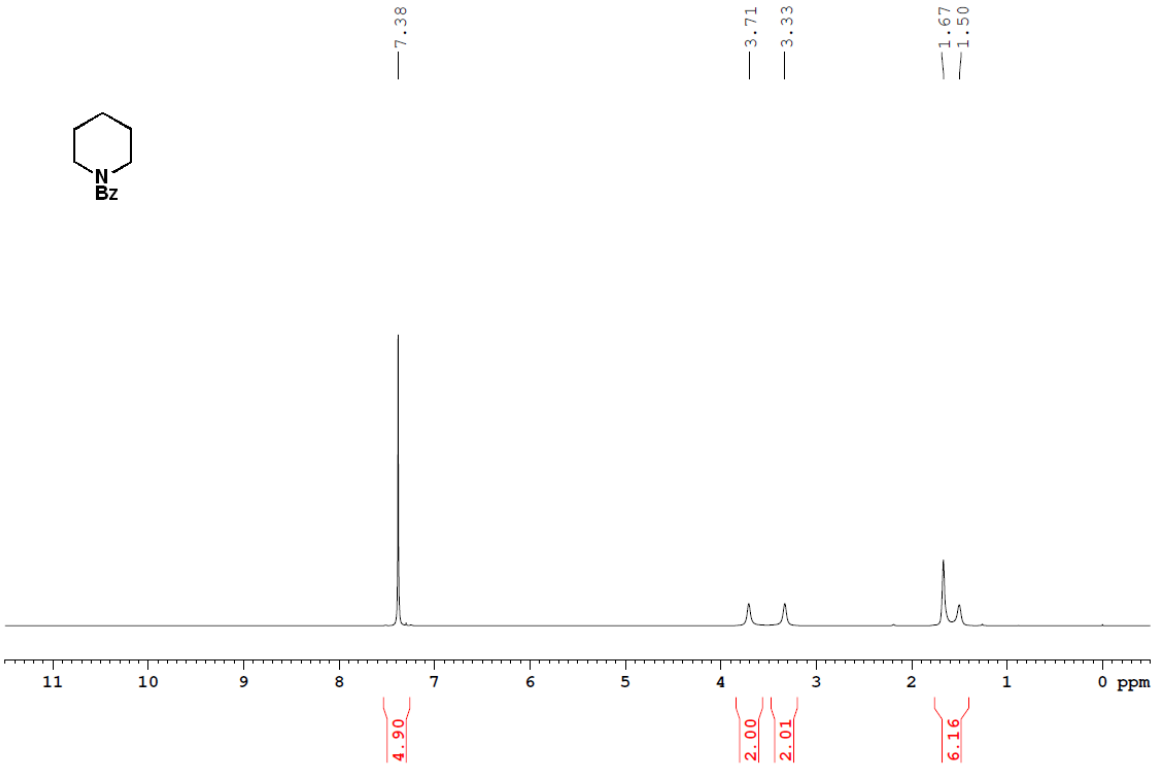




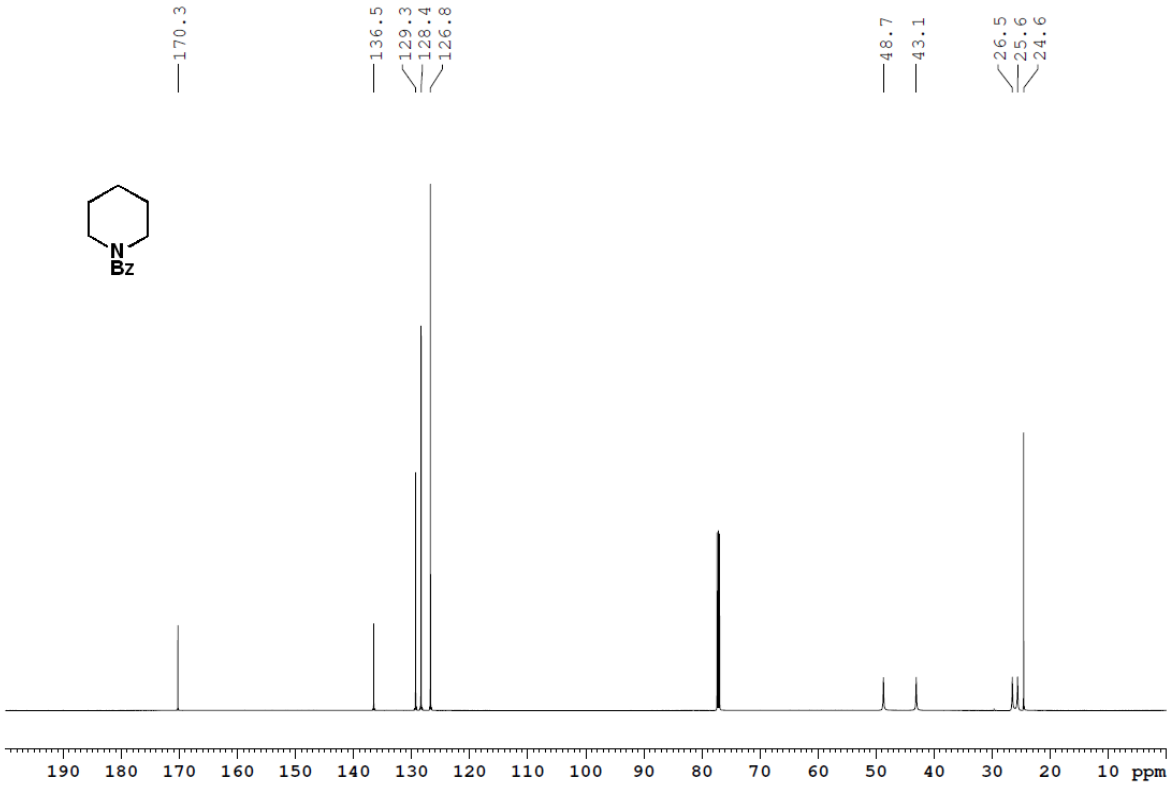
Crude ^{1}H NMR spectrum of **17** (600 MHz, $CDCl_3$)



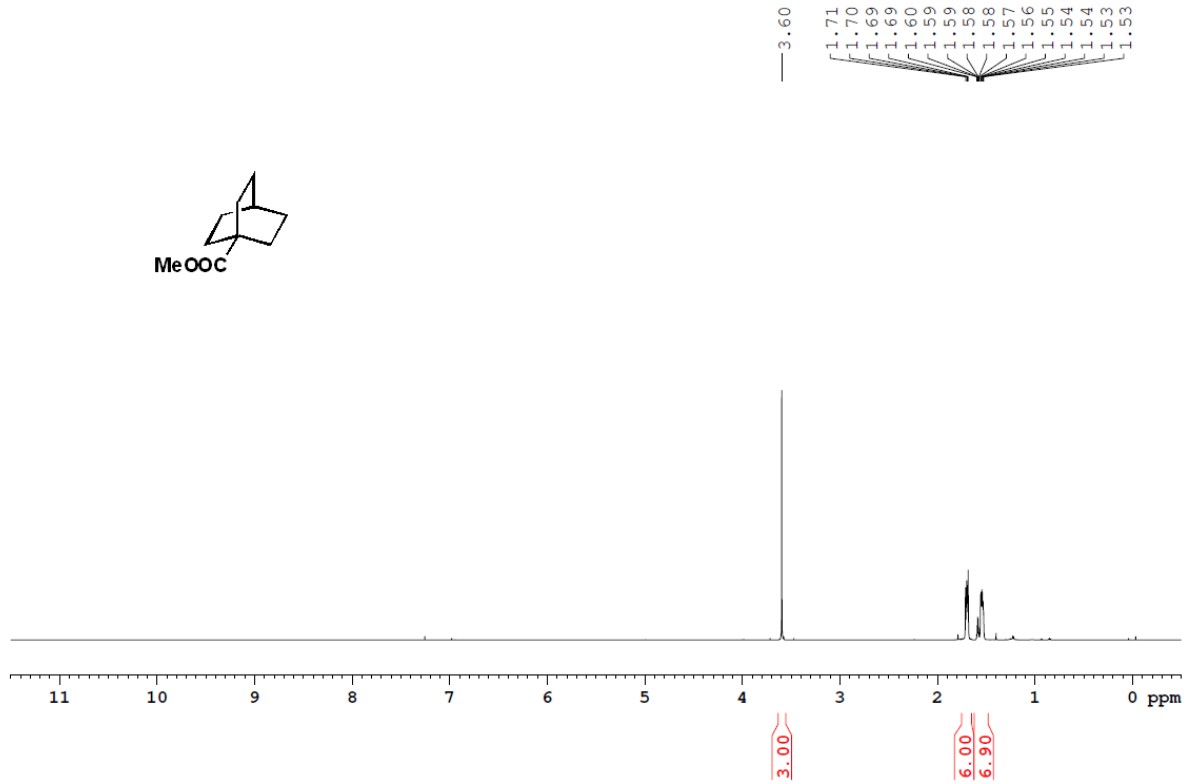
^{1}H NMR spectrum of **18** (600 MHz, $CDCl_3$)



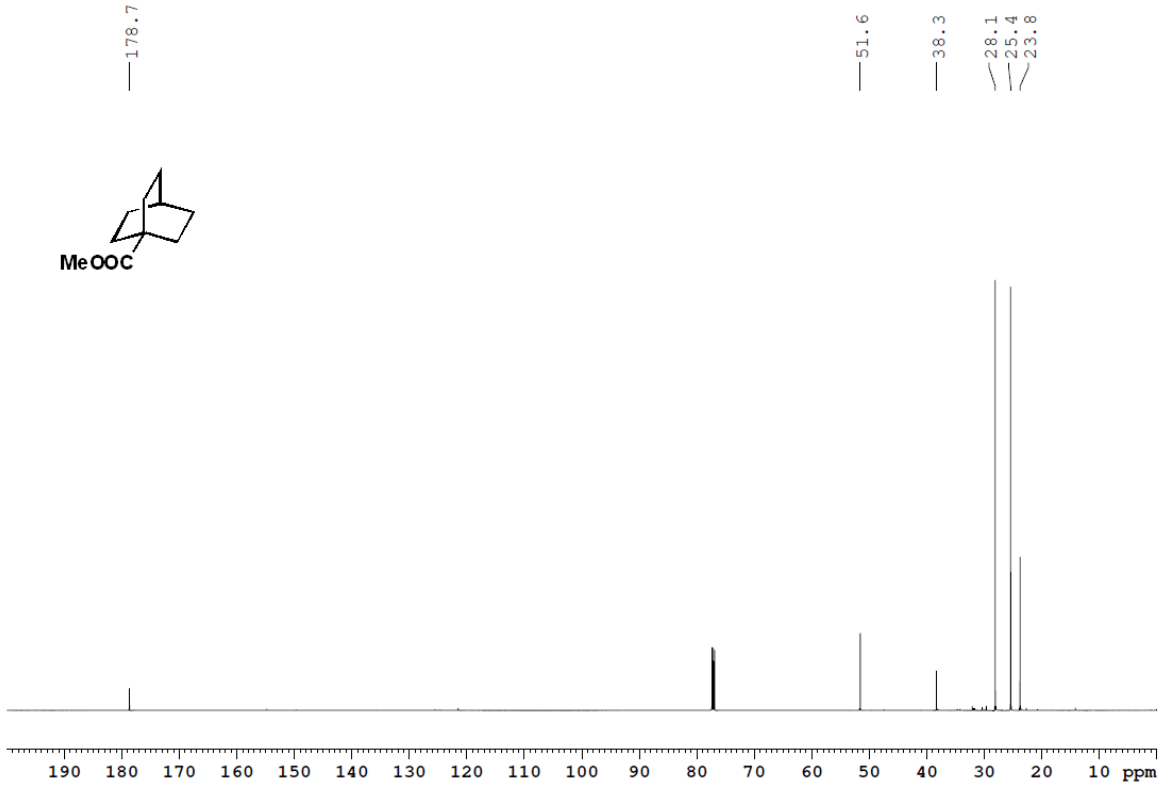
^{13}C NMR spectrum of **18** (150 MHz, $CDCl_3$)



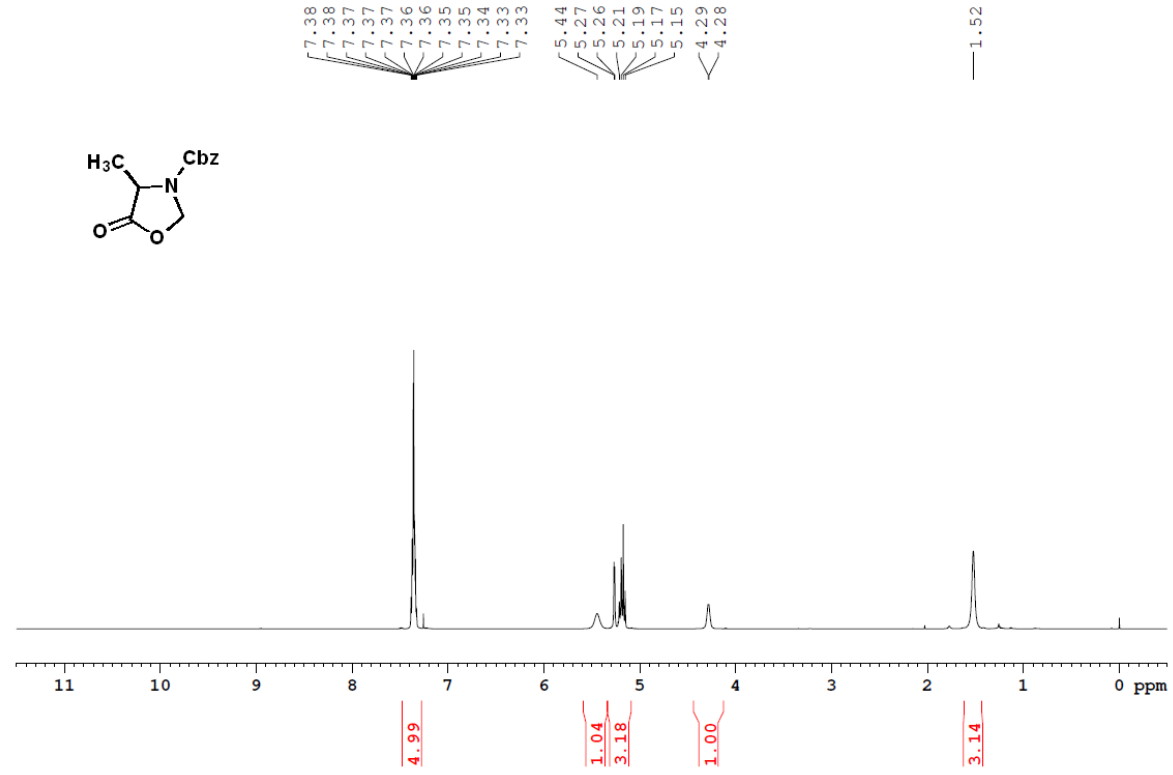
^{1}H NMR spectrum of **19** (600 MHz, $CDCl_3$)



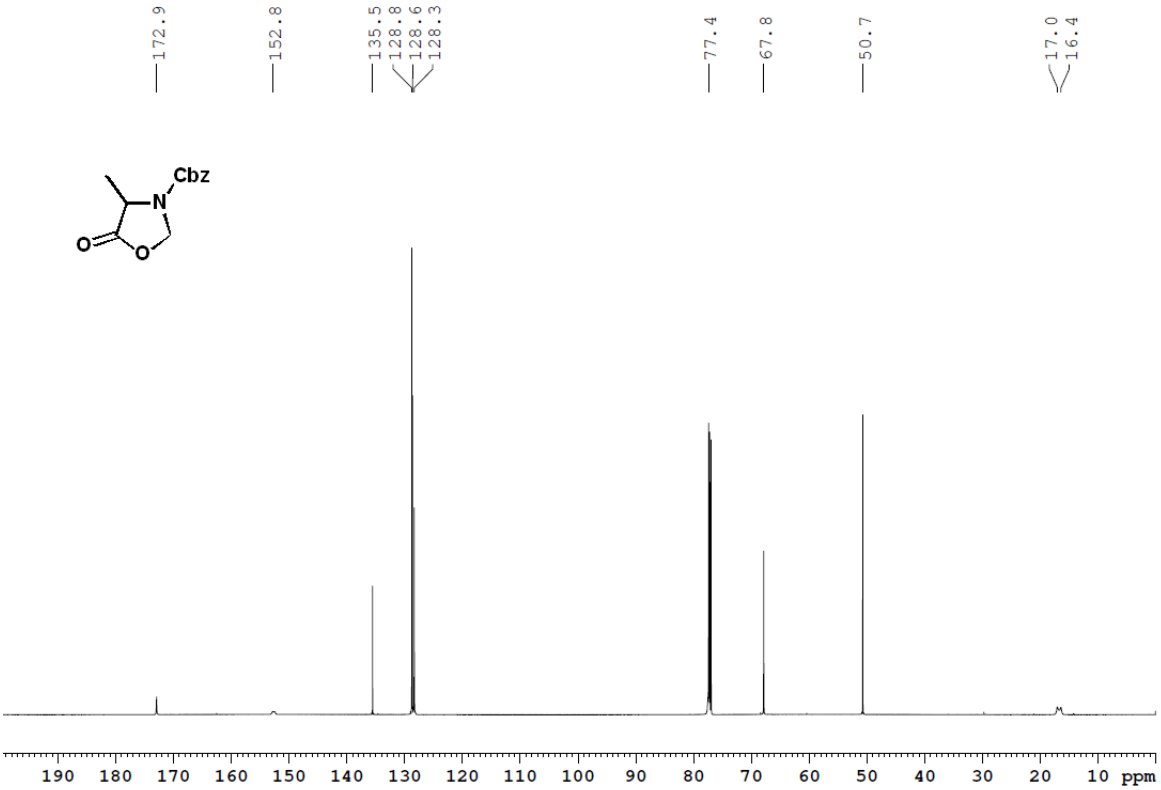
^{13}C NMR spectrum of **19** (150 MHz, $CDCl_3$)



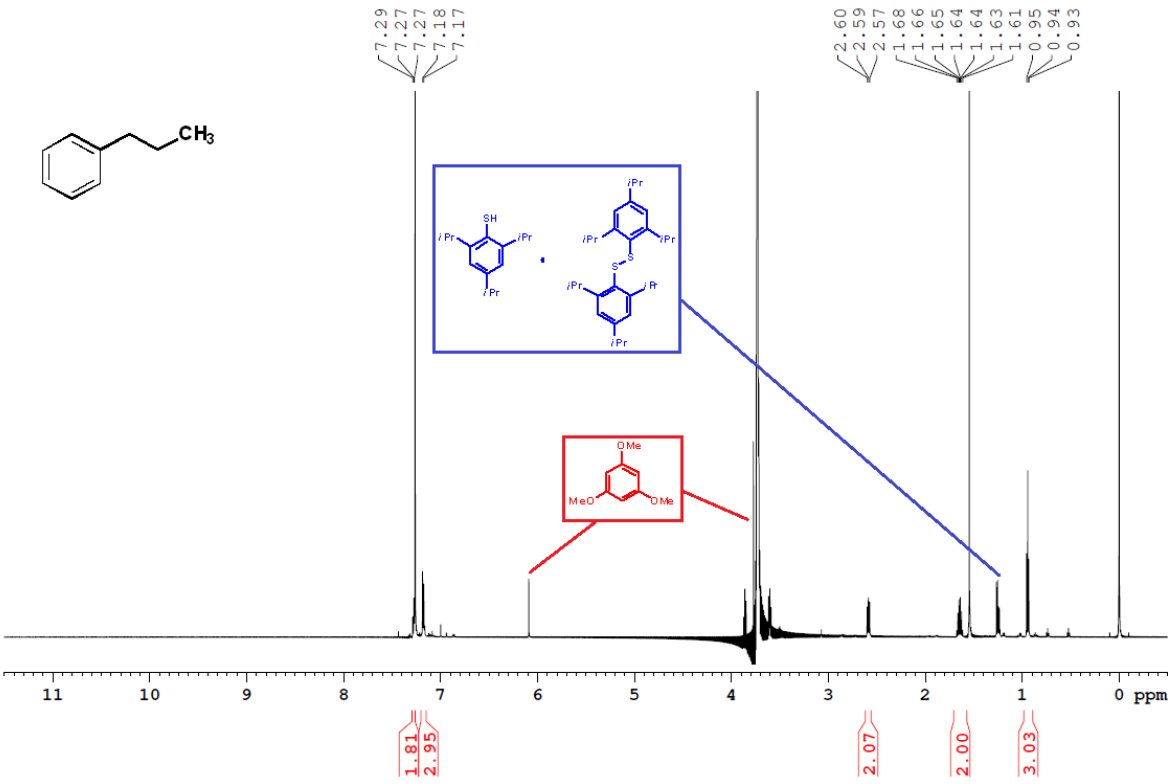
^{1}H NMR spectrum of **20** (600 MHz, $CDCl_3$)



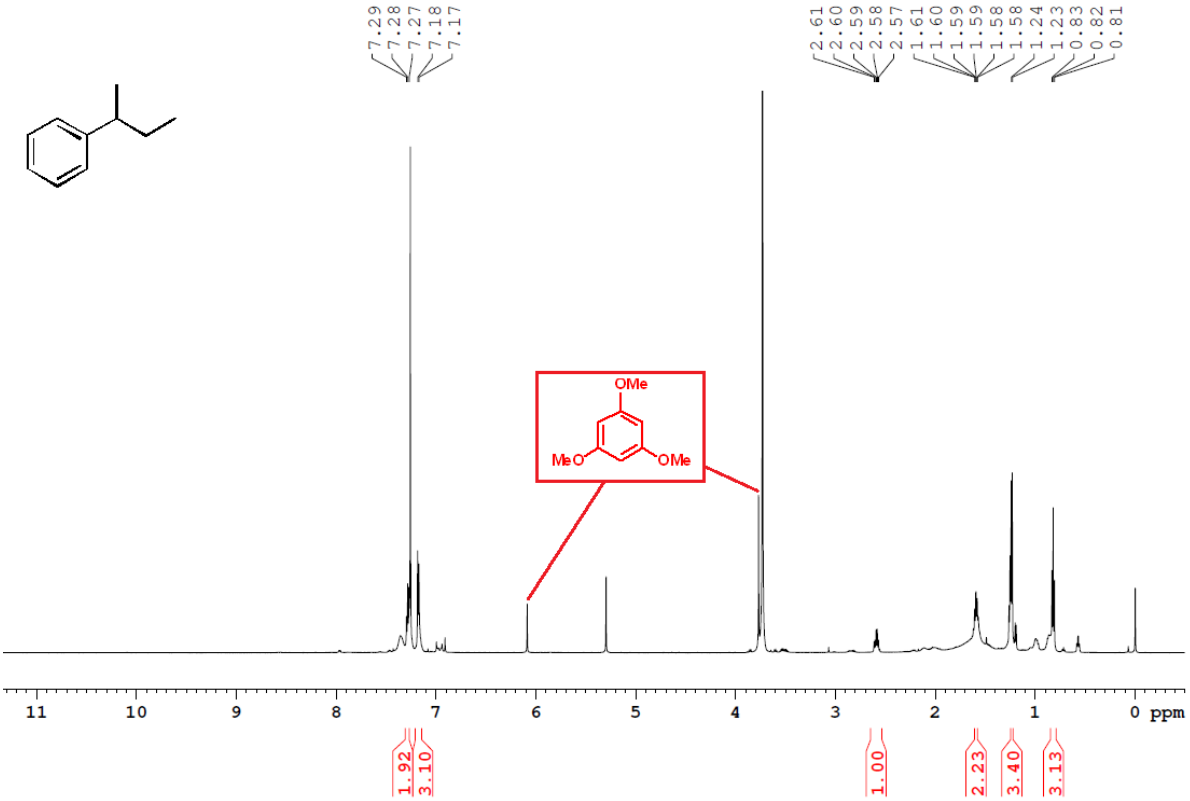
^{13}C NMR spectrum of **20** (150 MHz, $CDCl_3$)



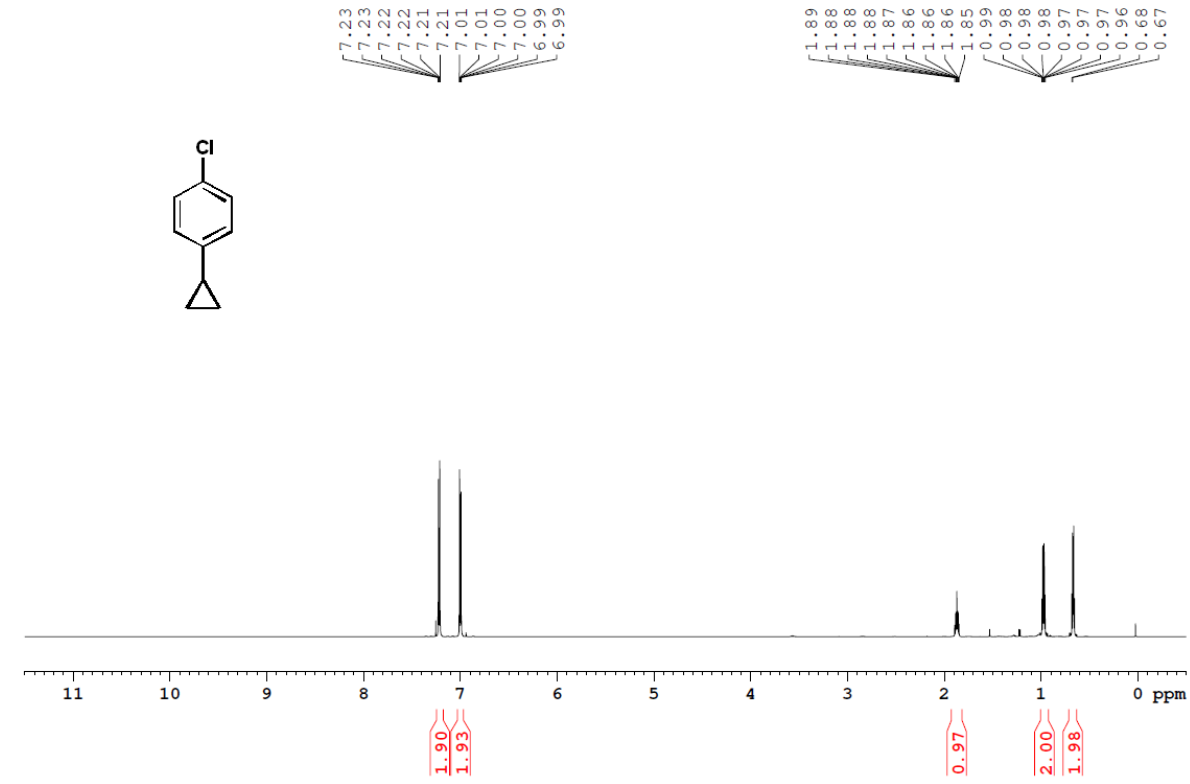
Crude ^{1}H NMR spectrum of **21** (600 MHz, $CDCl_3$)



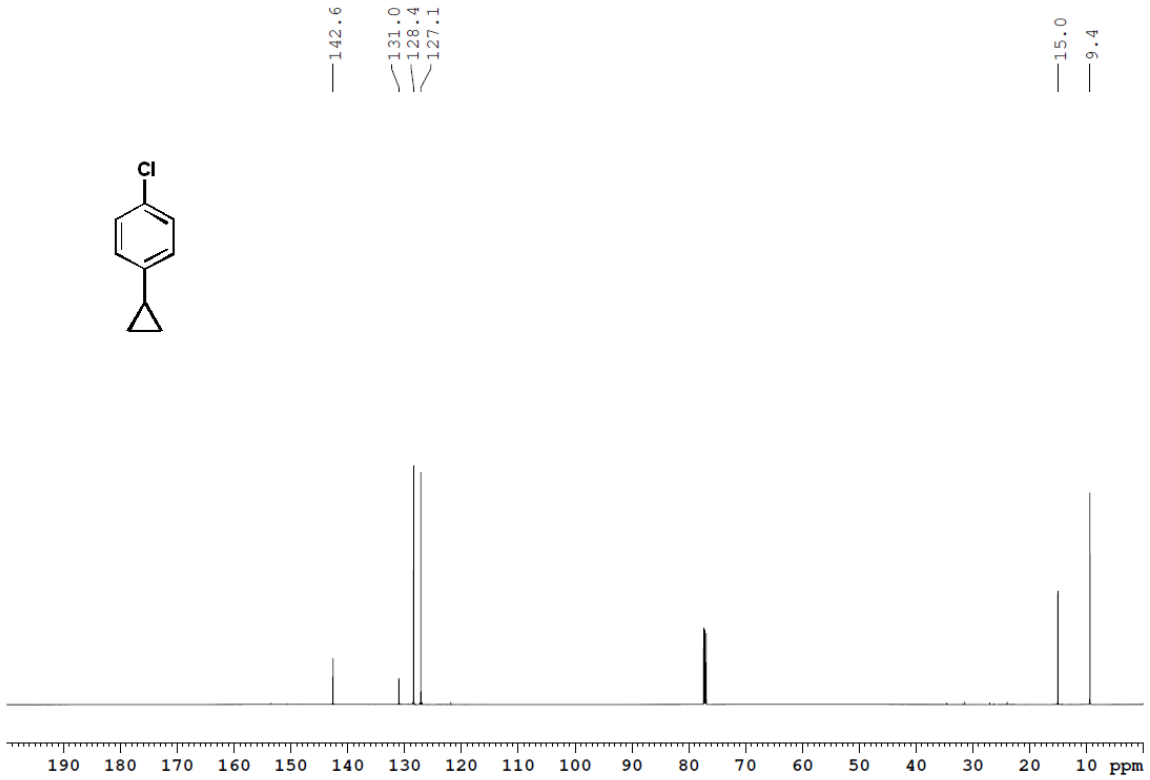
Crude ^{1}H NMR spectrum of **22** (600 MHz, $CDCl_3$)



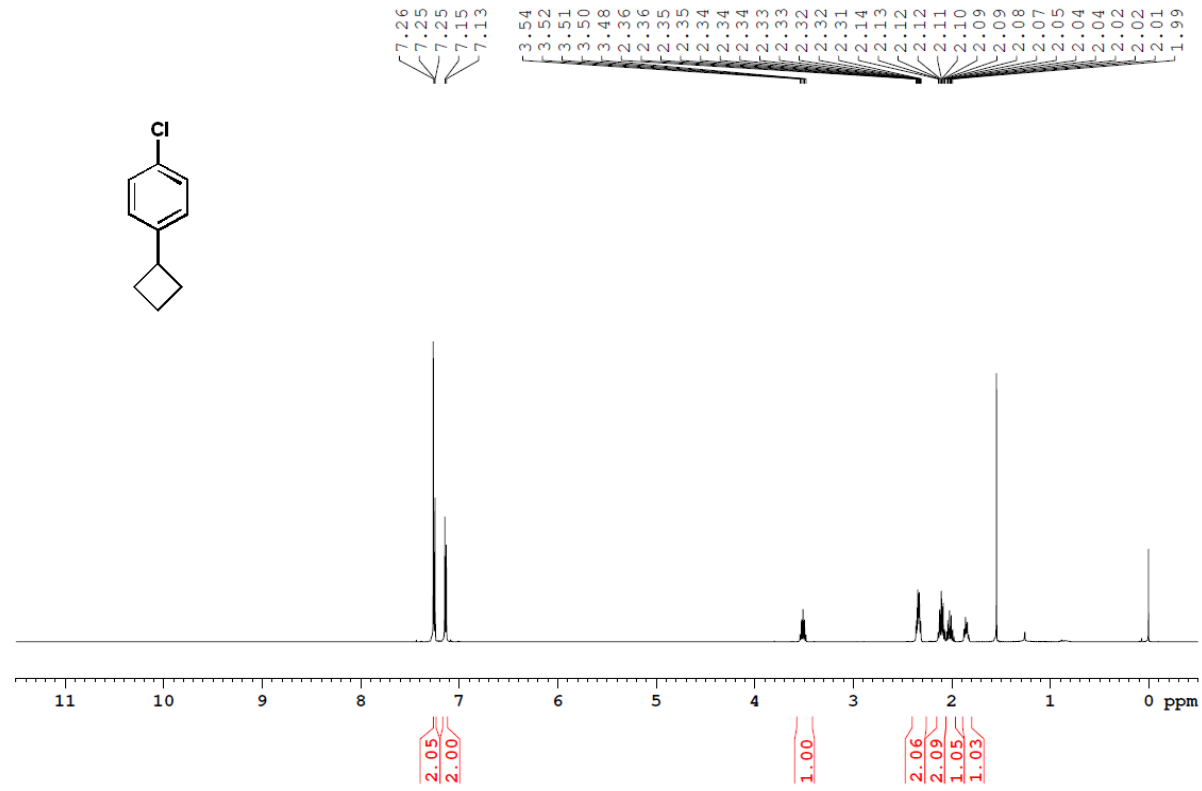
^{1}H NMR spectrum of **23** (600 MHz, $CDCl_3$)



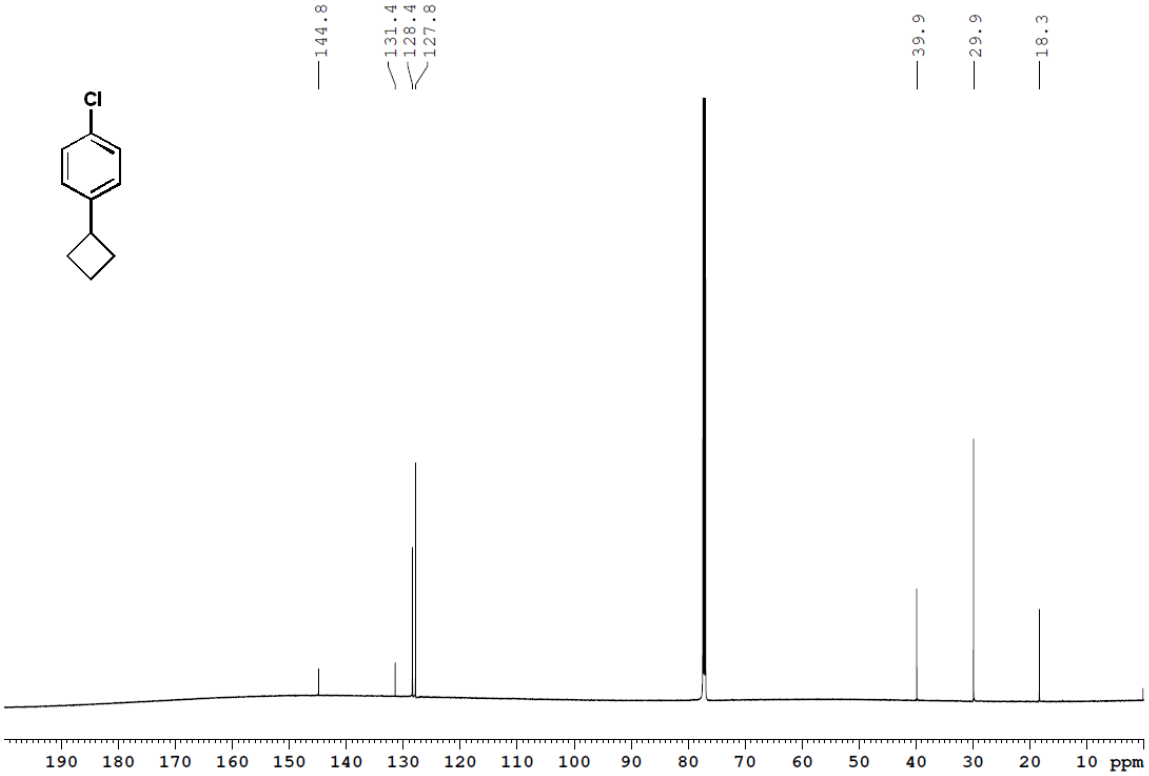
^{13}C NMR spectrum of **23** (150 MHz, $CDCl_3$)



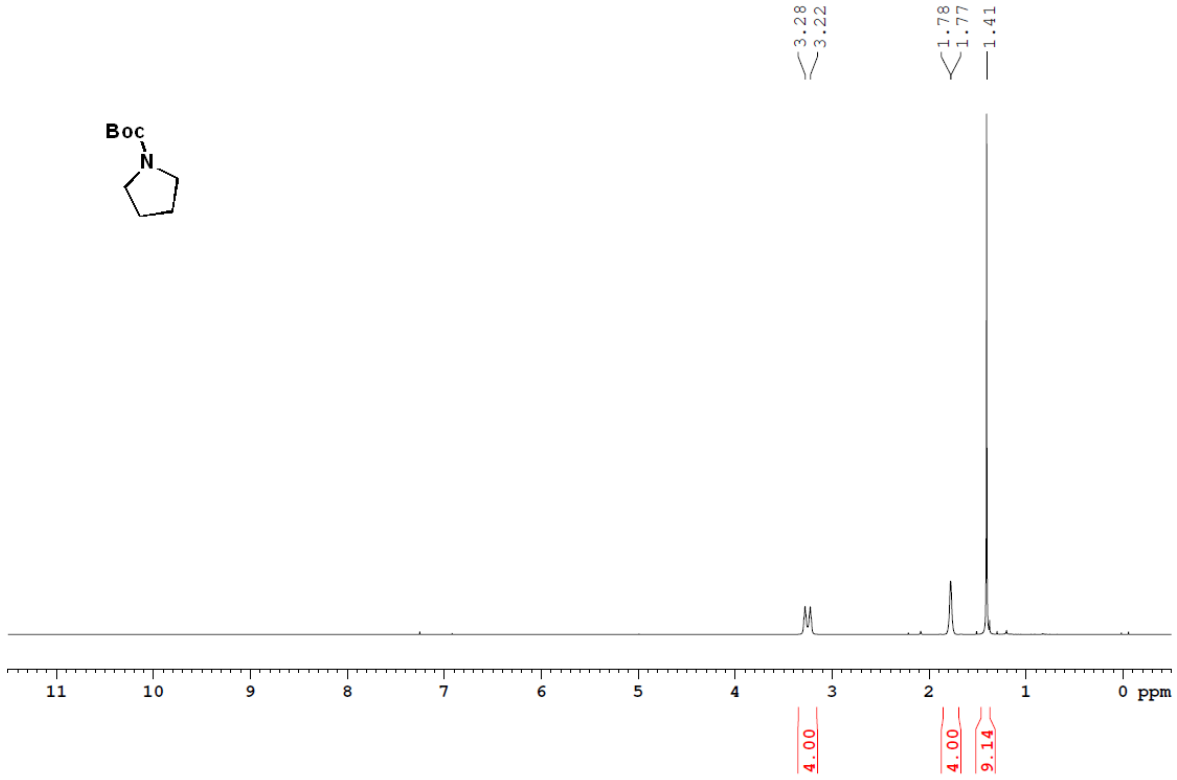
^{1}H NMR spectrum of **24** (600 MHz, $CDCl_3$)



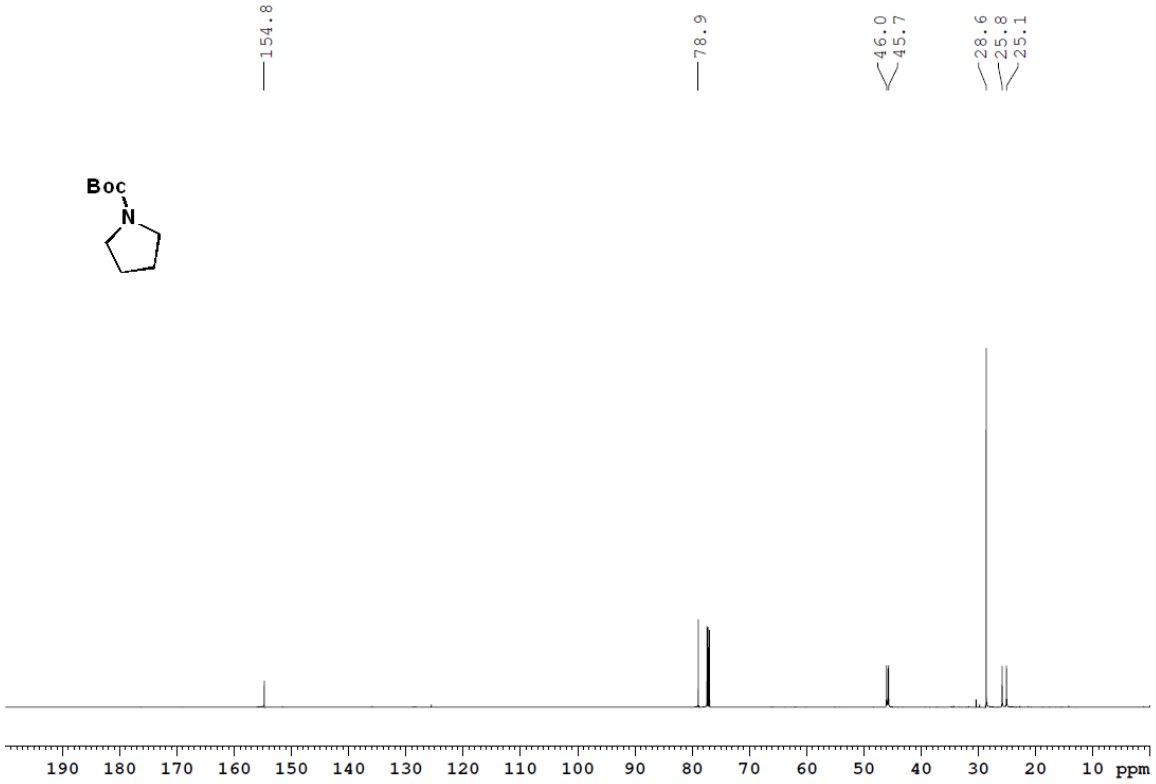
^{13}C NMR spectrum of **24** (150 MHz, $CDCl_3$)



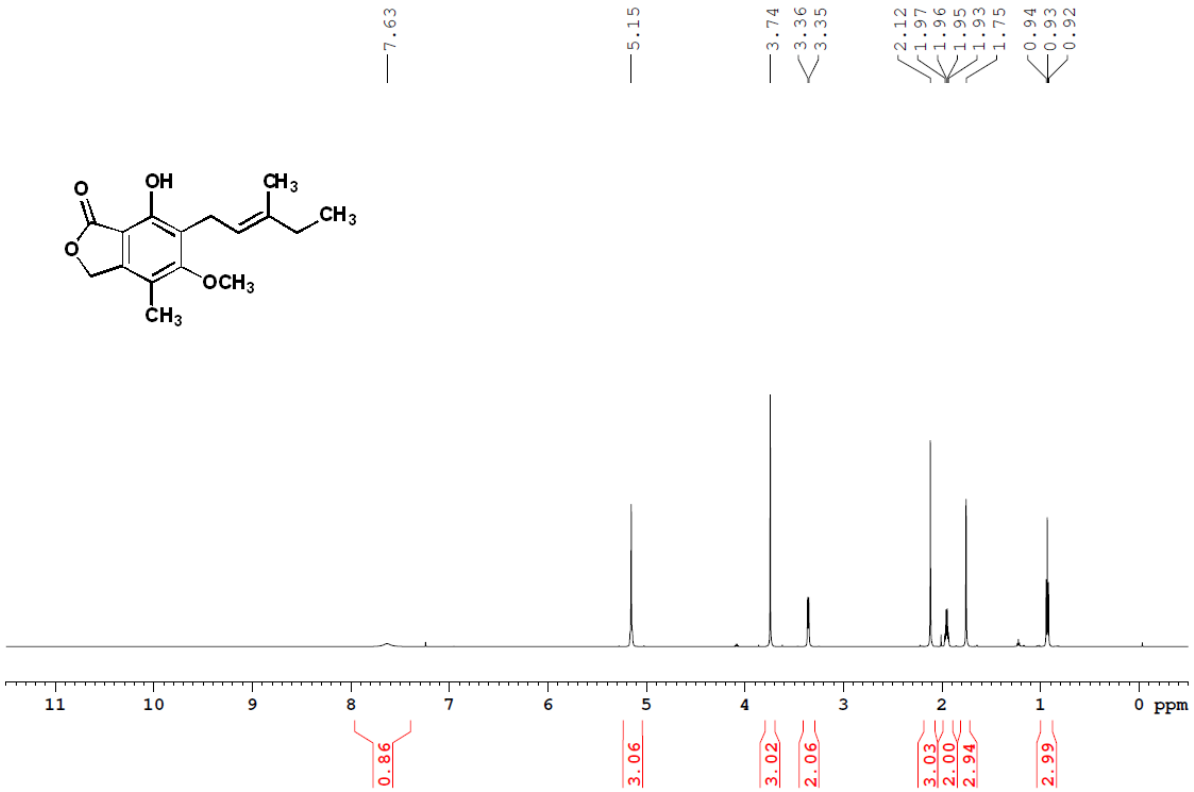
^{1}H NMR spectrum of **25** (600 MHz, $CDCl_3$)



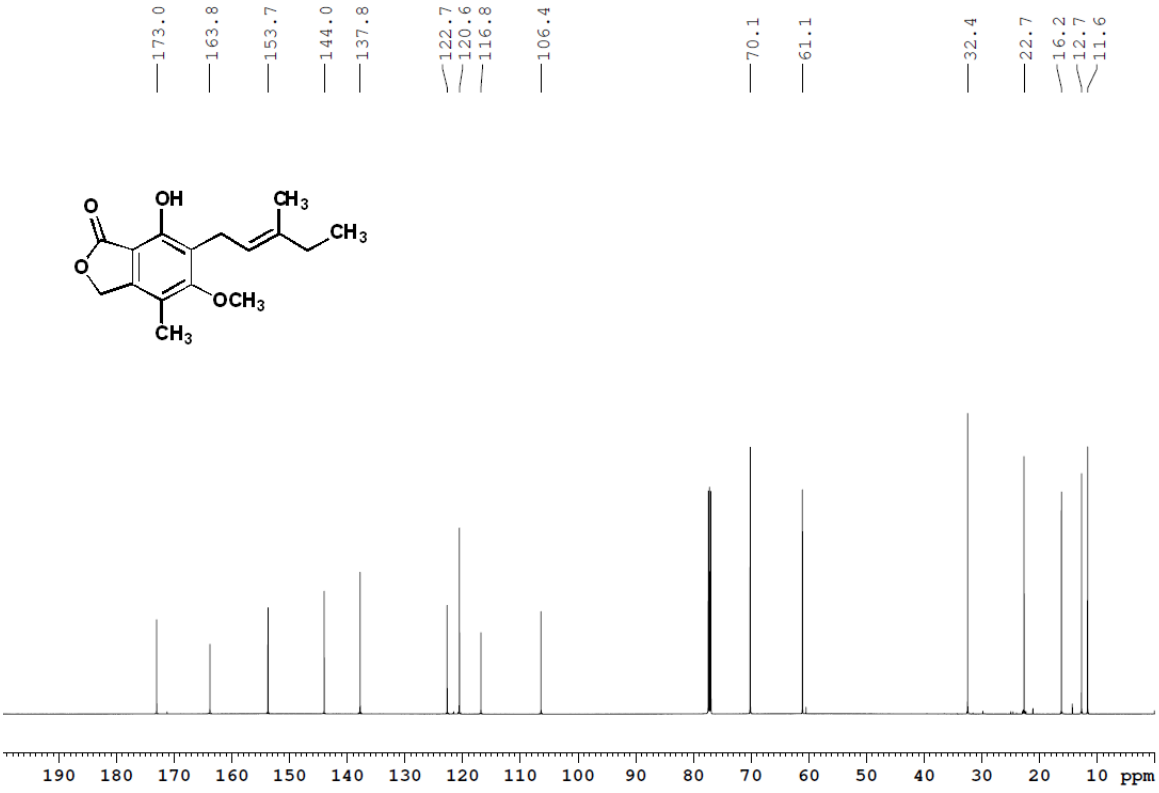
^{13}C NMR spectrum of **25** (150 MHz, $CDCl_3$)



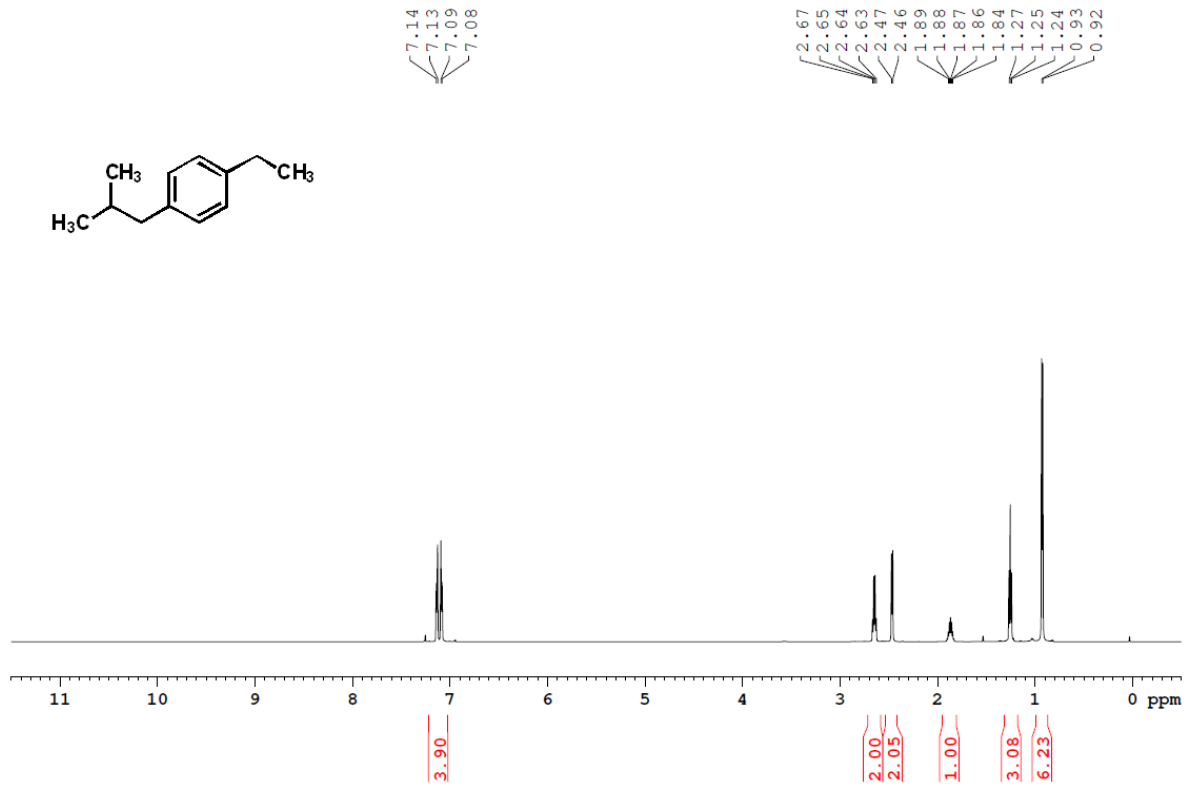
^{1}H NMR spectrum of **26** (600 MHz, $CDCl_3$)



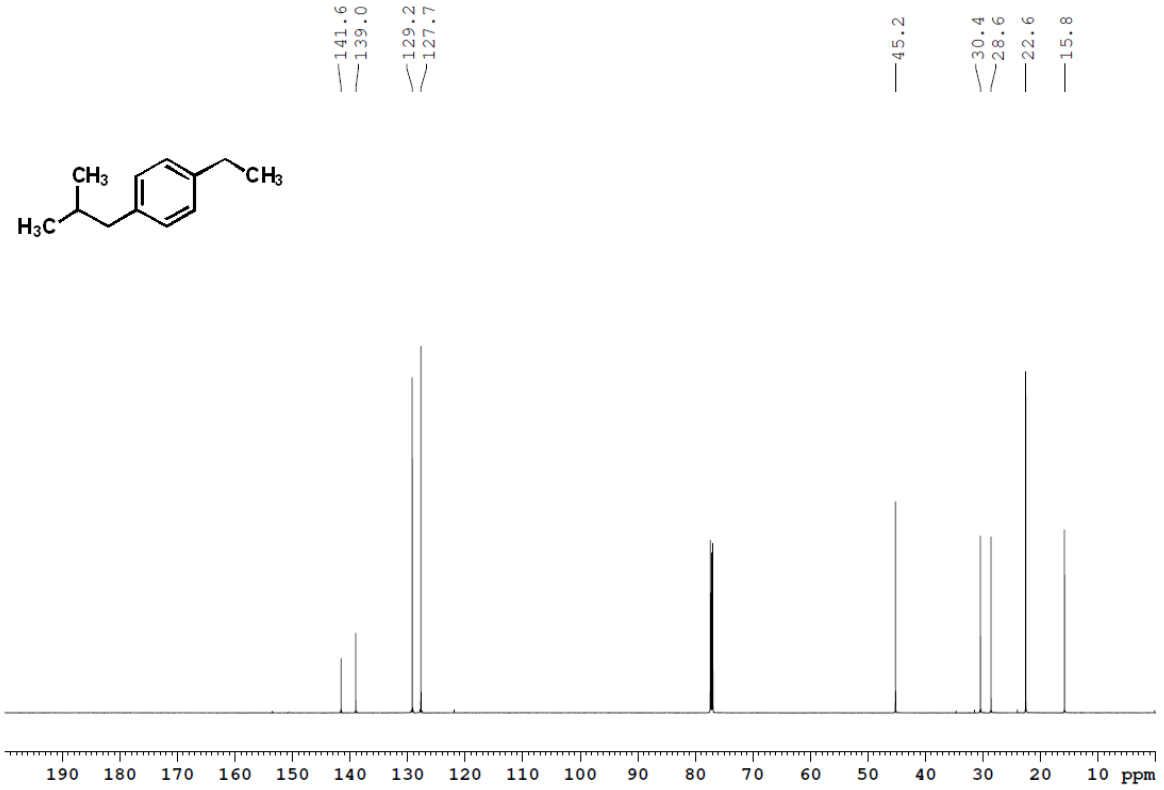
^{13}C NMR spectrum of **26** (150 MHz, $CDCl_3$)



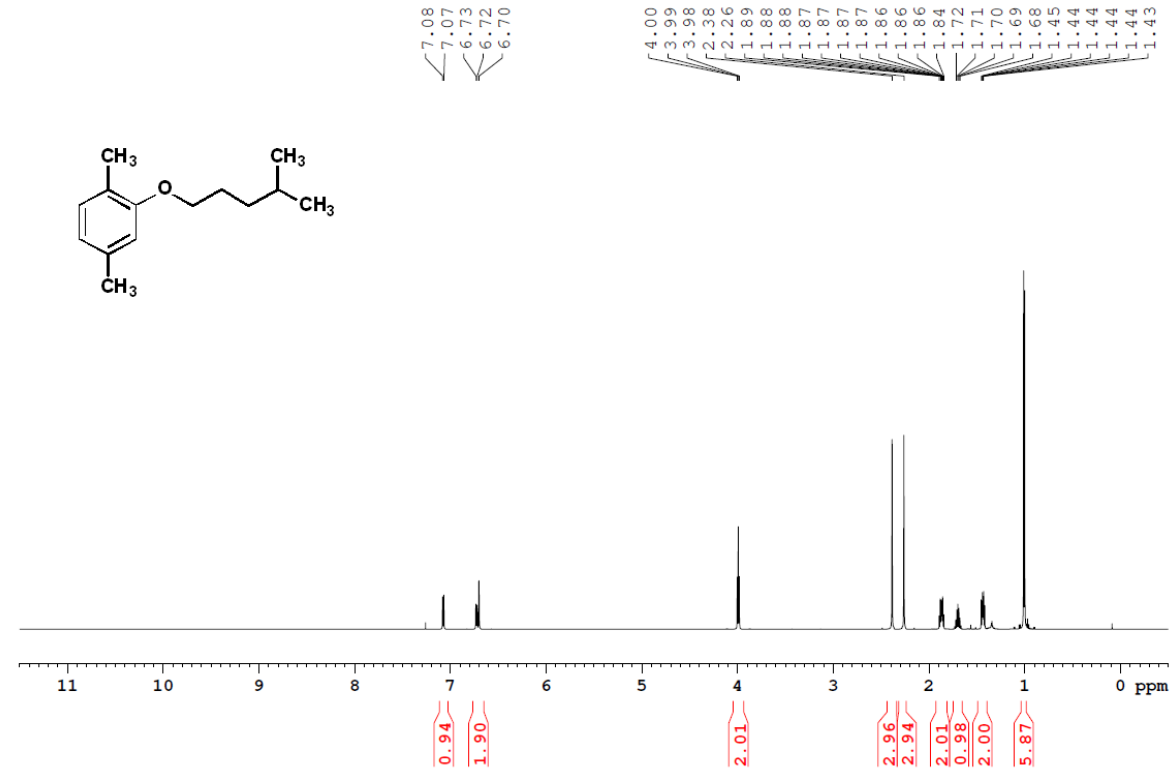
^{1}H NMR spectrum of **27** (600 MHz, $CDCl_3$)



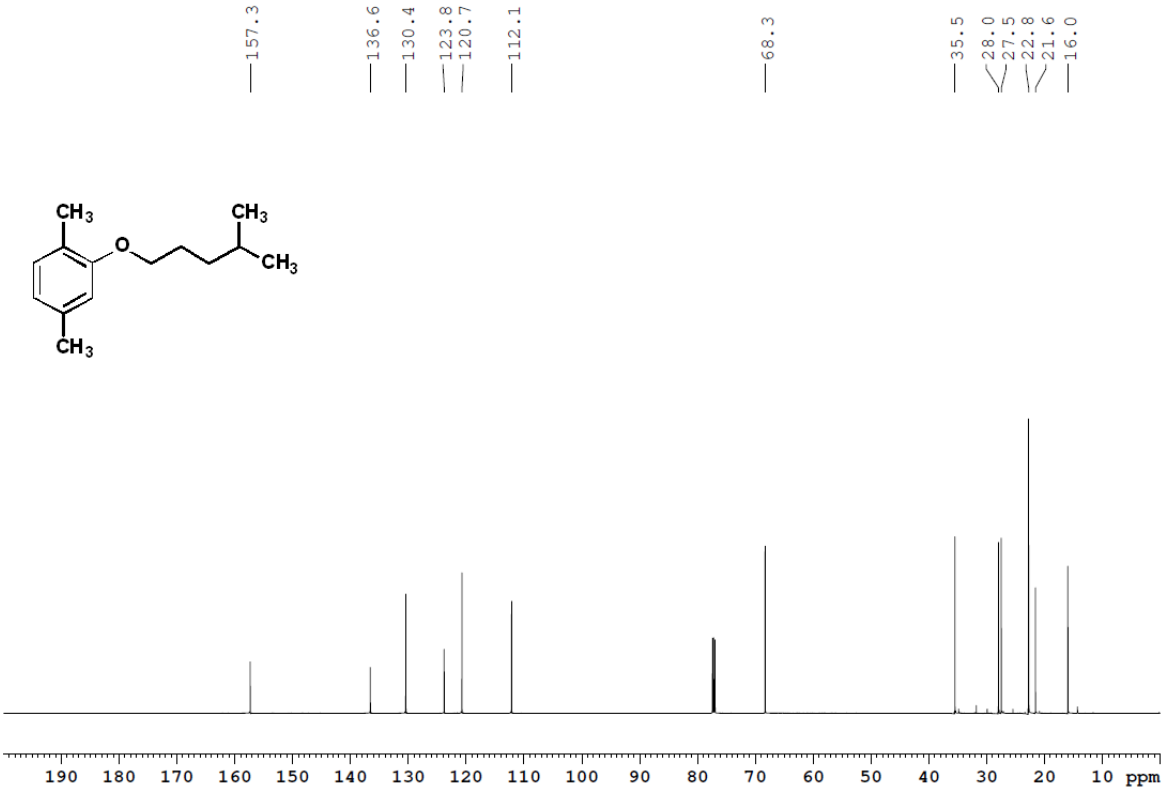
^{13}C NMR spectrum of **27** (150 MHz, $CDCl_3$)



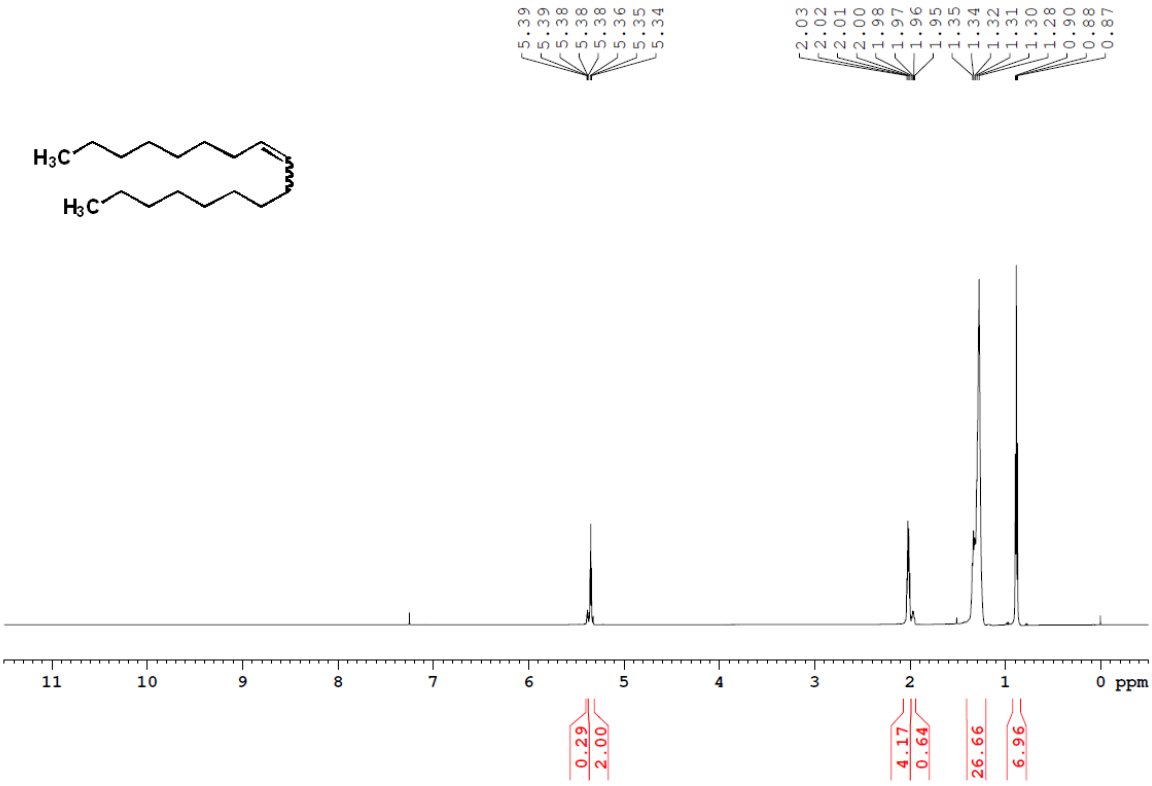
^{1}H NMR spectrum of **28** (600 MHz, $CDCl_3$)



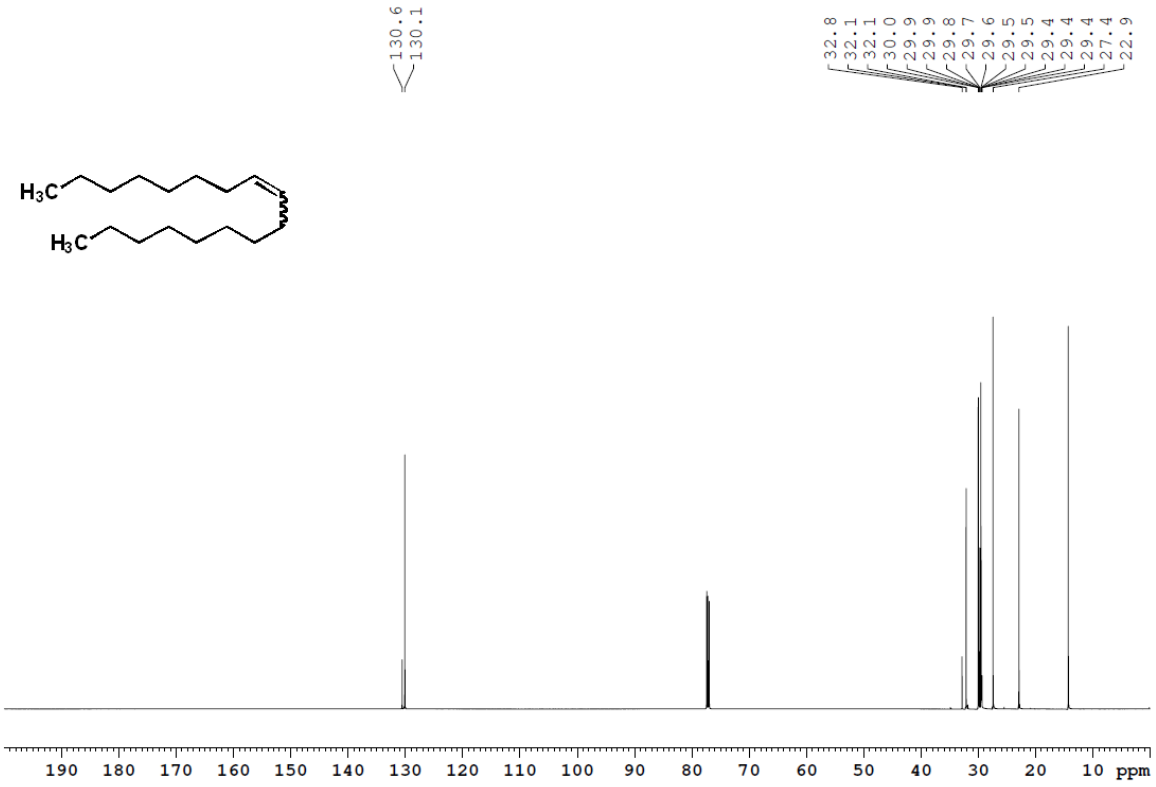
^{13}C NMR spectrum of **28** (150 MHz, $CDCl_3$)



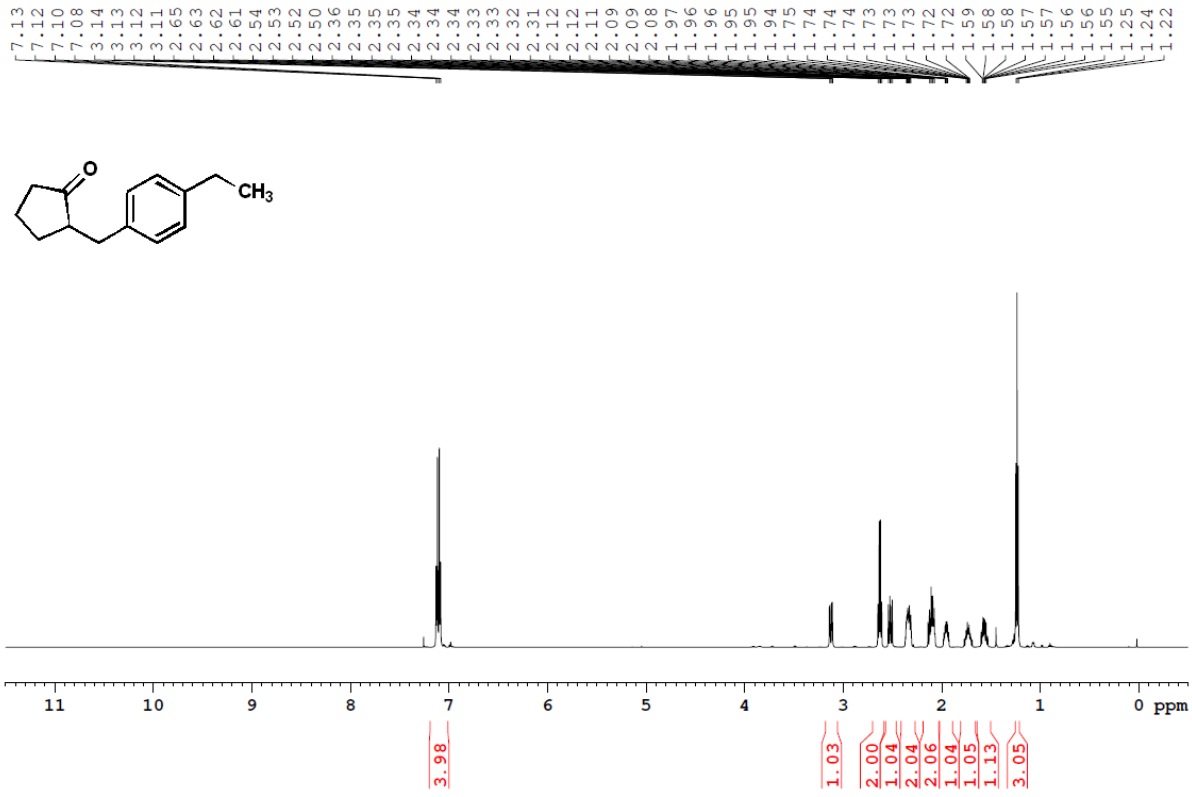
^{1}H NMR spectrum of **29** (600 MHz, $CDCl_3$)



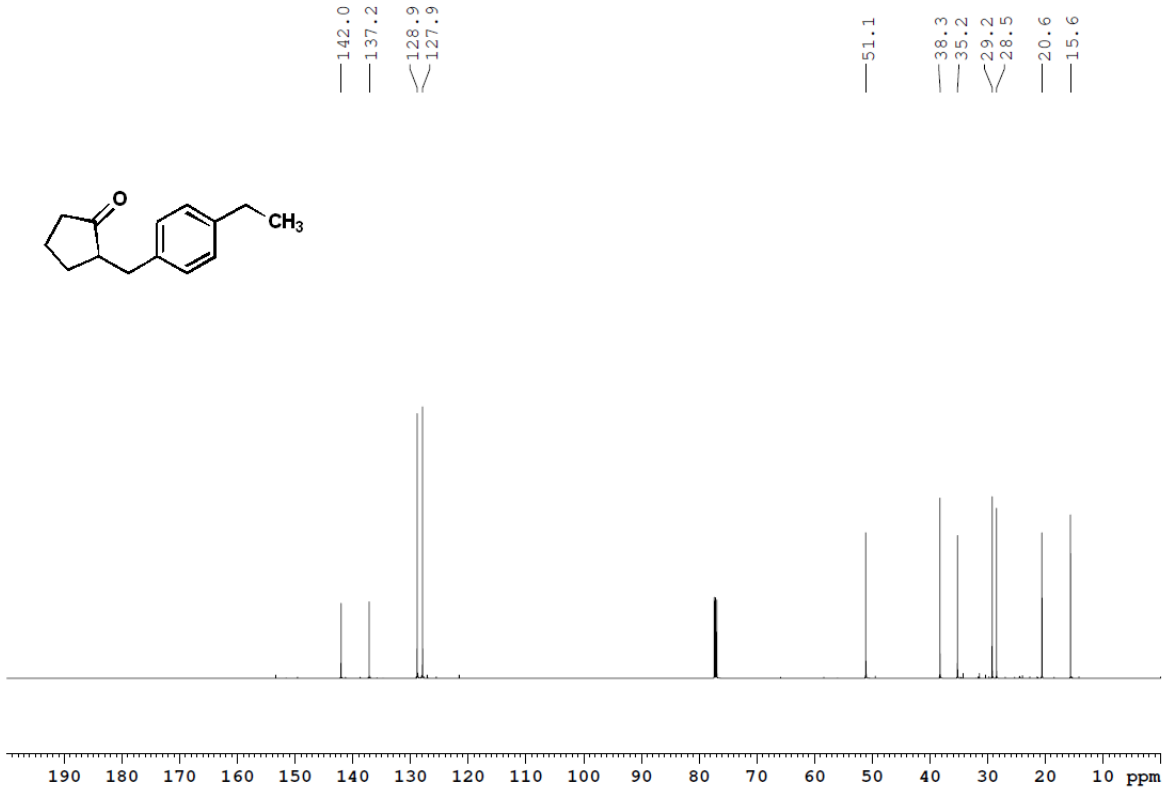
^{13}C NMR spectrum of **29** (150 MHz, $CDCl_3$)



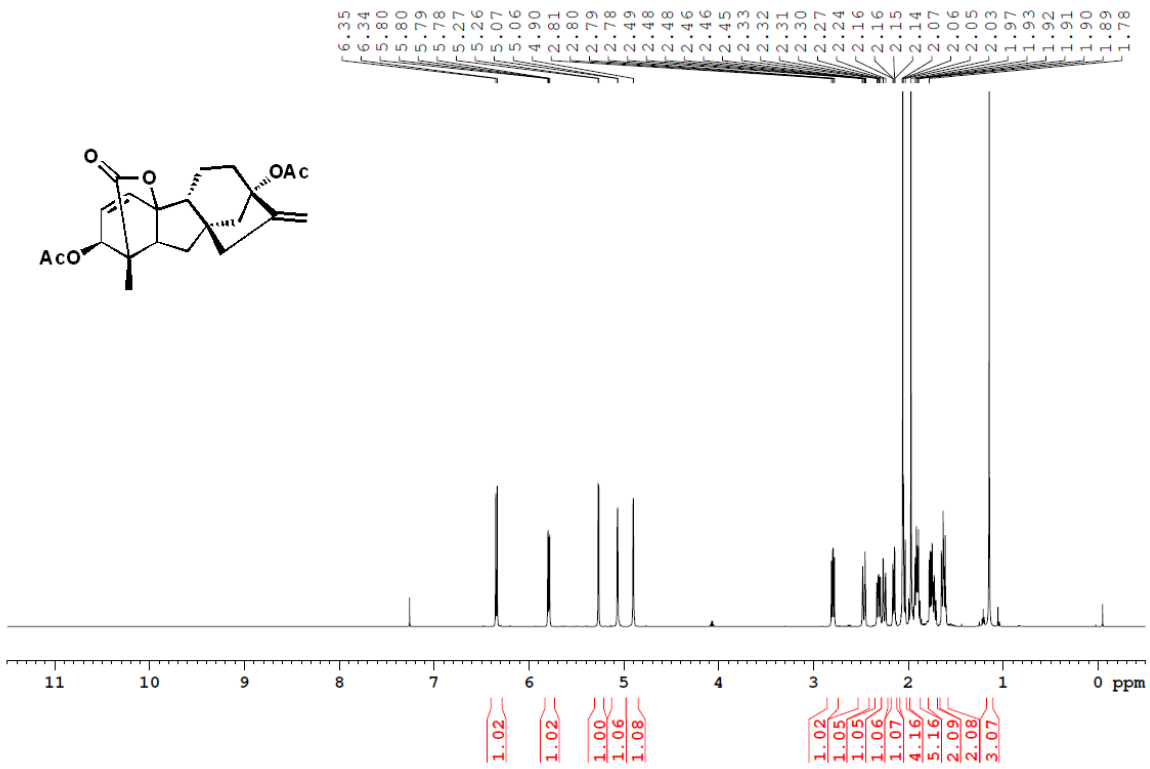
^{1}H NMR spectrum of **30** (600 MHz, $CDCl_3$)



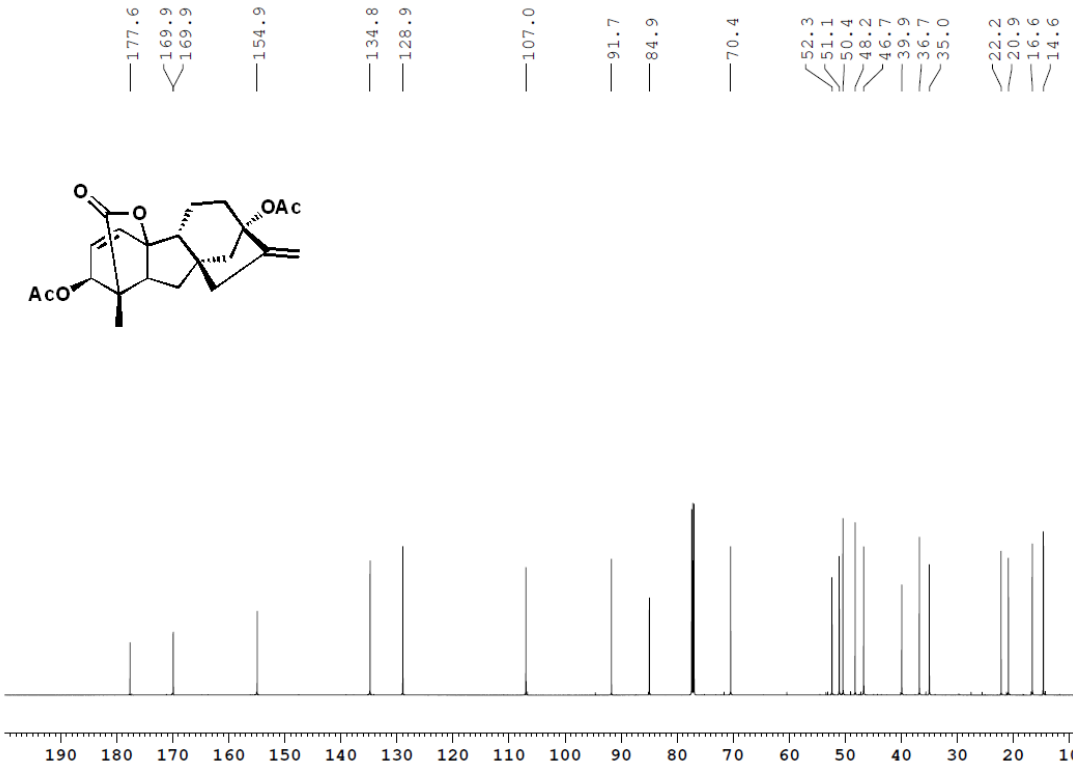
^{13}C NMR spectrum of **30** (150 MHz, $CDCl_3$)



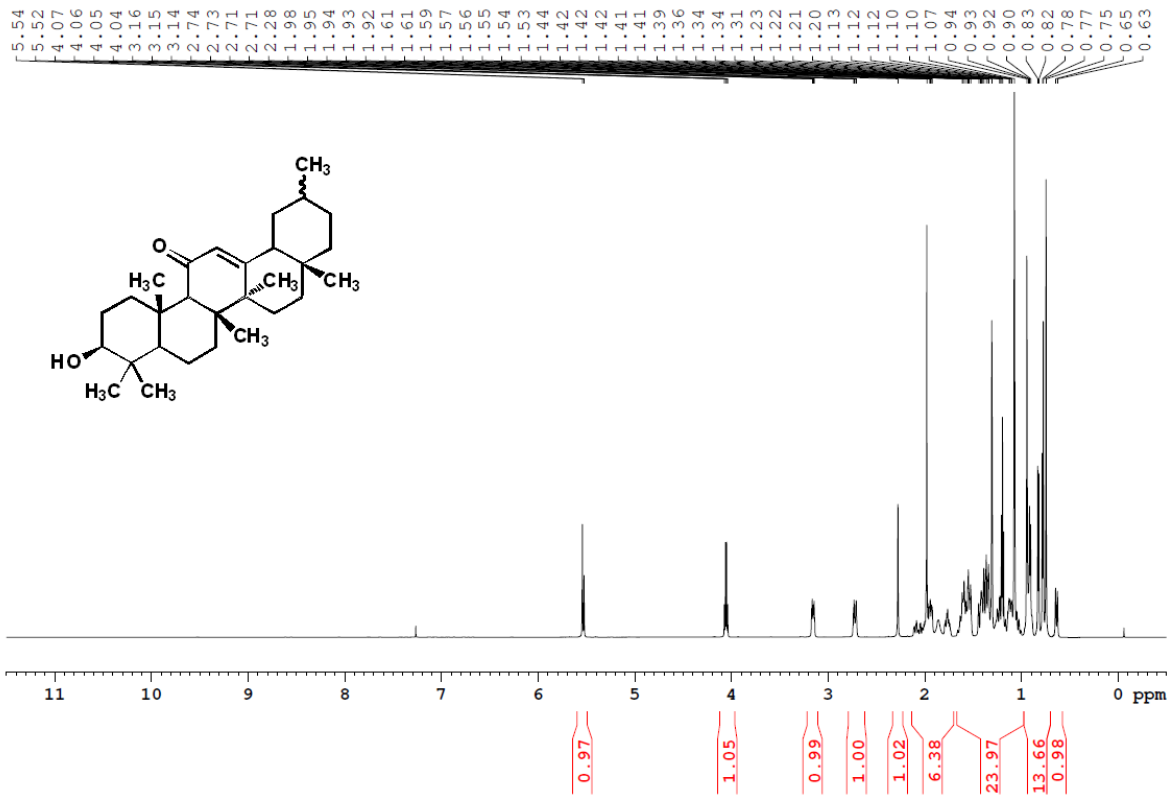
^{1}H NMR spectrum of **31** (600 MHz, $CDCl_3$)



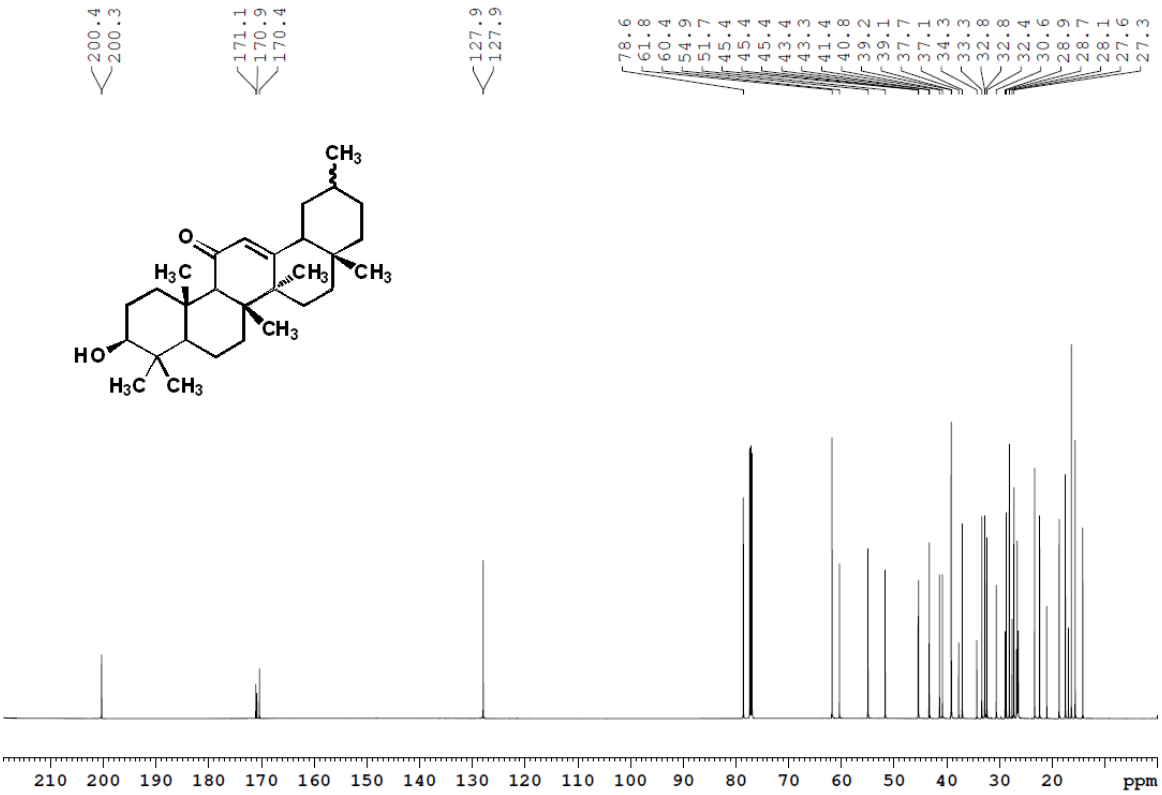
^{13}C NMR spectrum of **31** (150 MHz, $CDCl_3$)



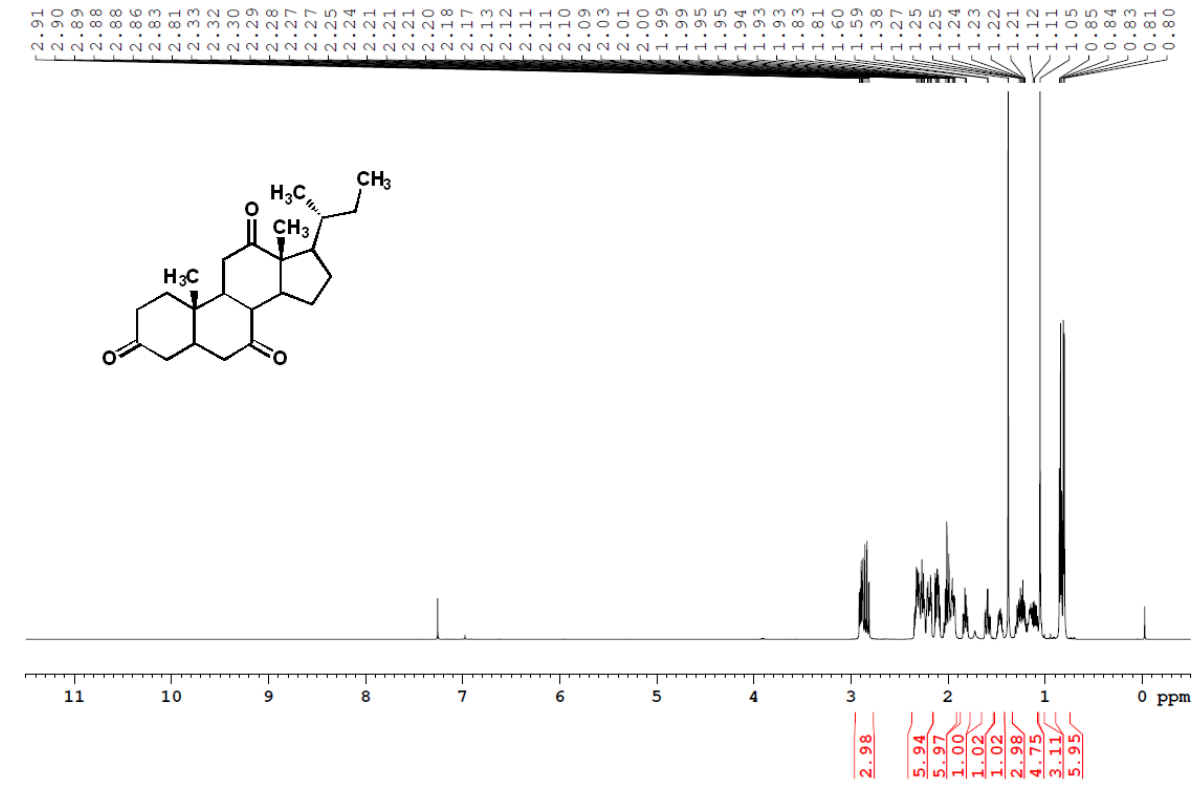
^{1}H NMR spectrum of **32** (600 MHz, $CDCl_3$)



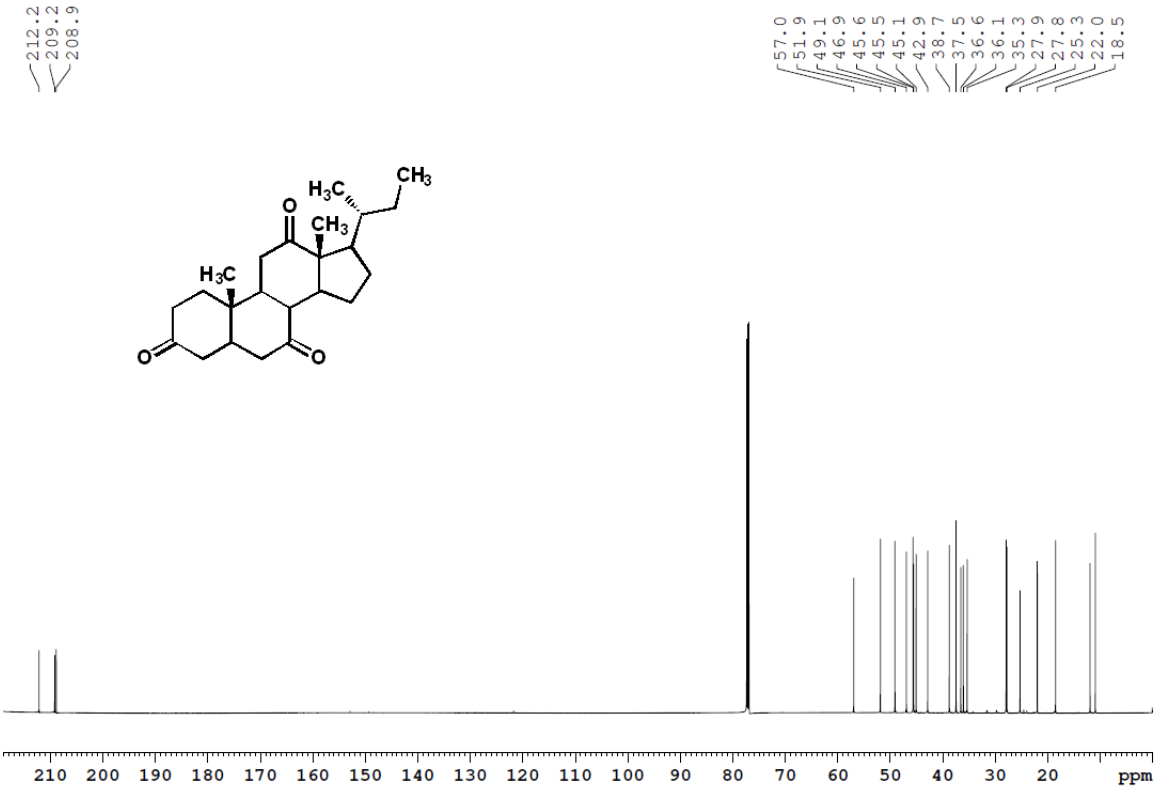
^{13}C NMR spectrum of **32** (150 MHz, $CDCl_3$)



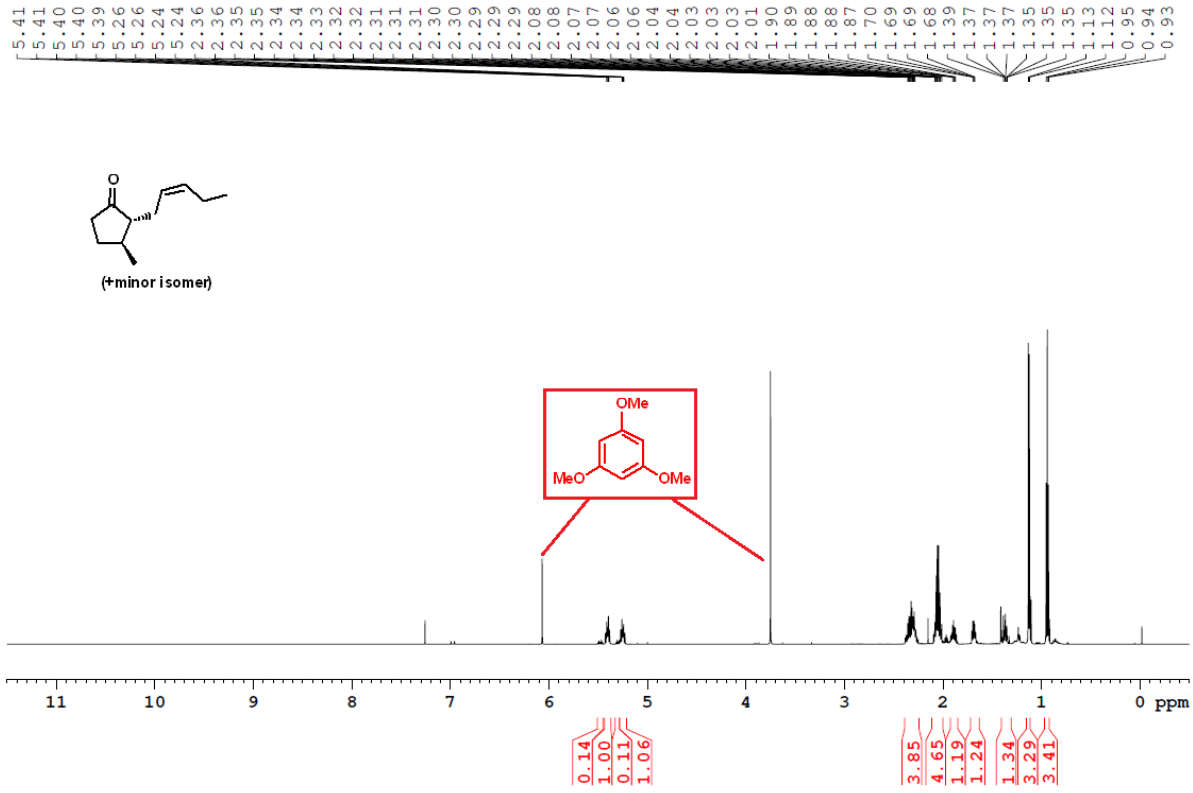
^{1}H NMR spectrum of **33** (600 MHz, $CDCl_3$)



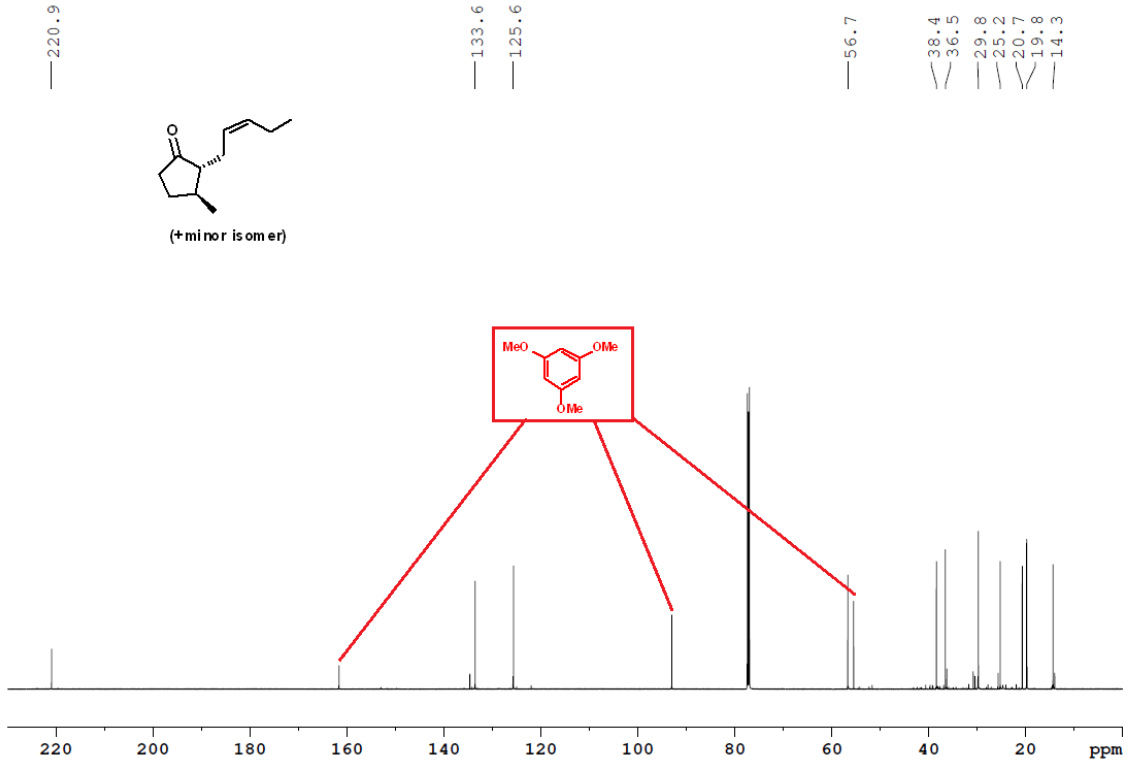
^{13}C NMR spectrum of **33** (150 MHz, $CDCl_3$)



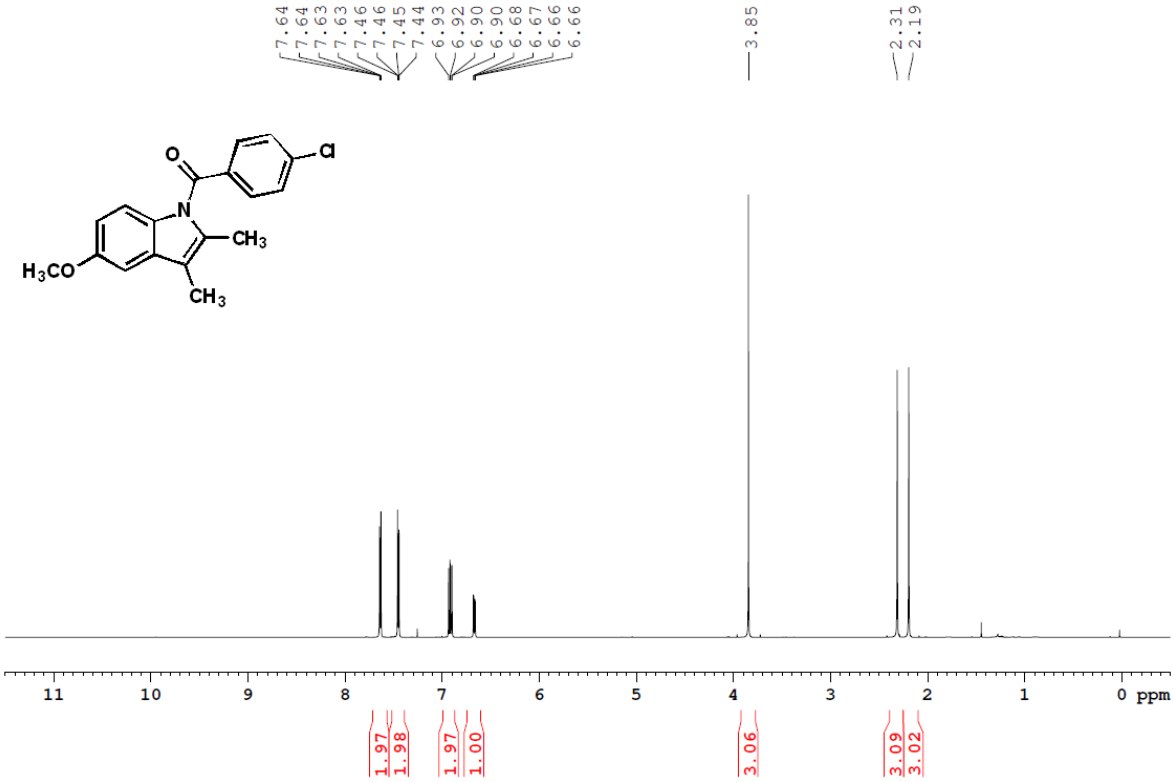
^{1}H NMR spectrum of **34** (600 MHz, $CDCl_3$) *trimethoxybenzene inseparable



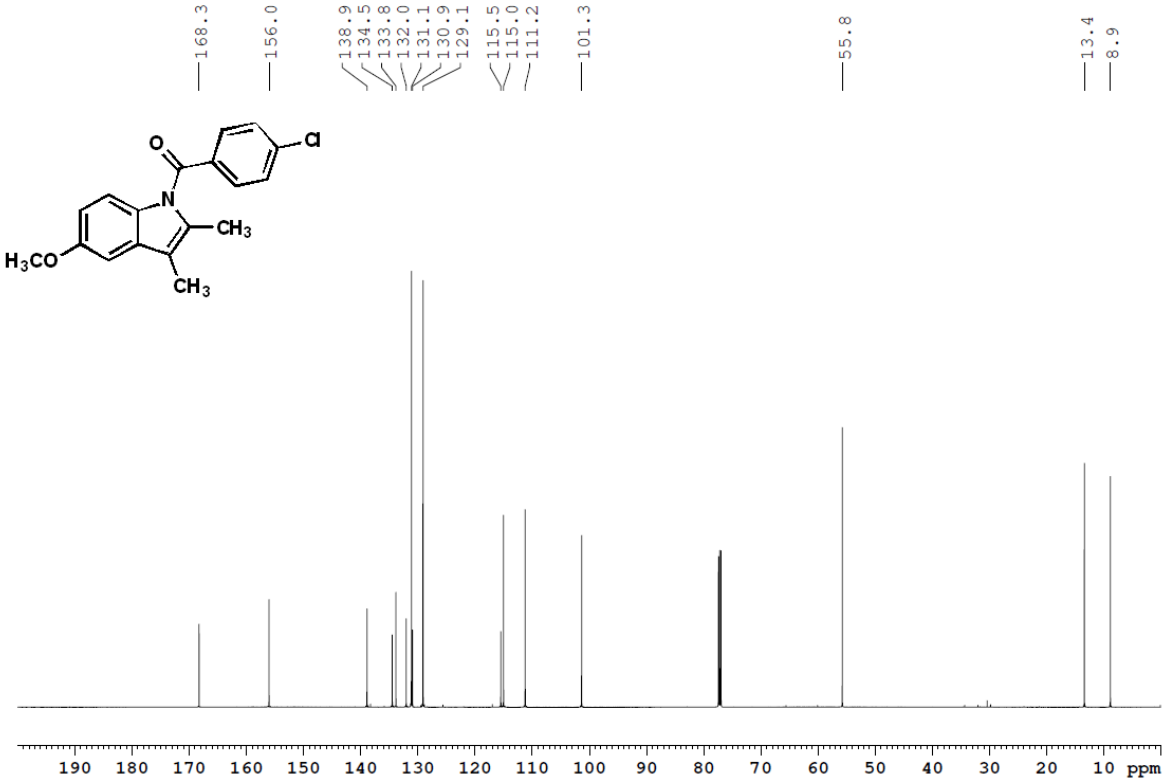
^{13}C NMR spectrum of **34** (150 MHz, $CDCl_3$)



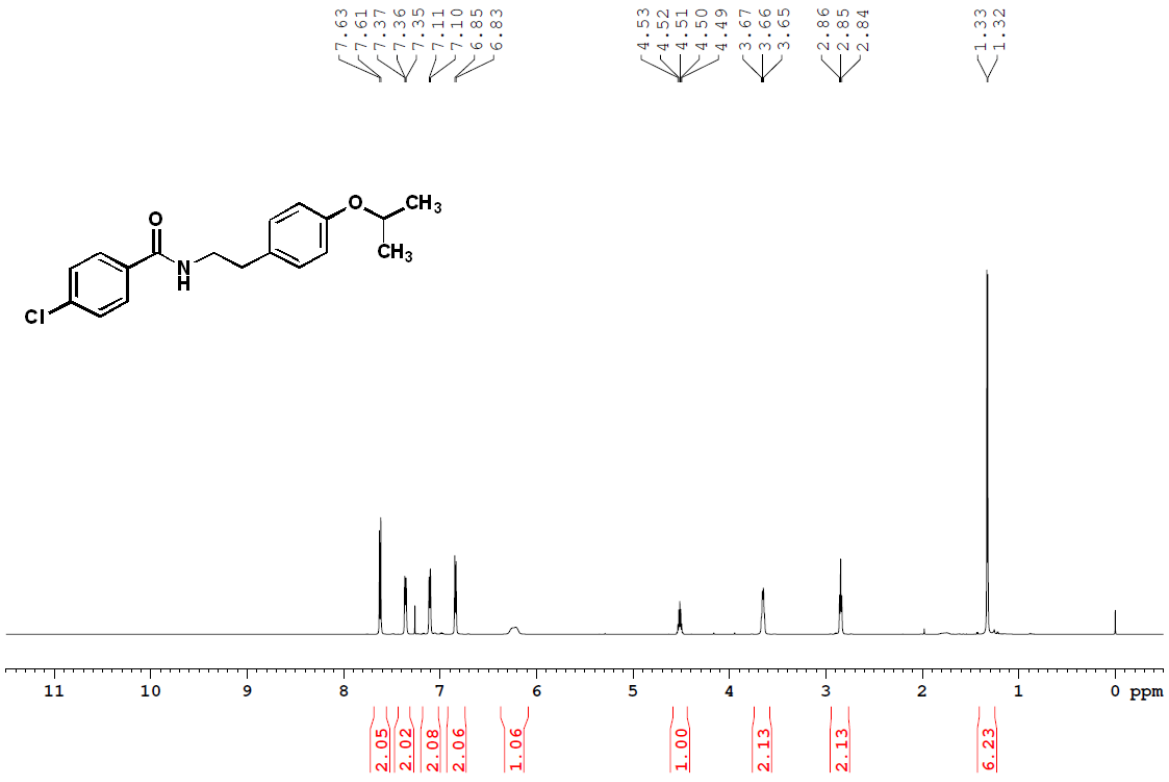
^{1}H NMR spectrum of **35** (600 MHz, $CDCl_3$)



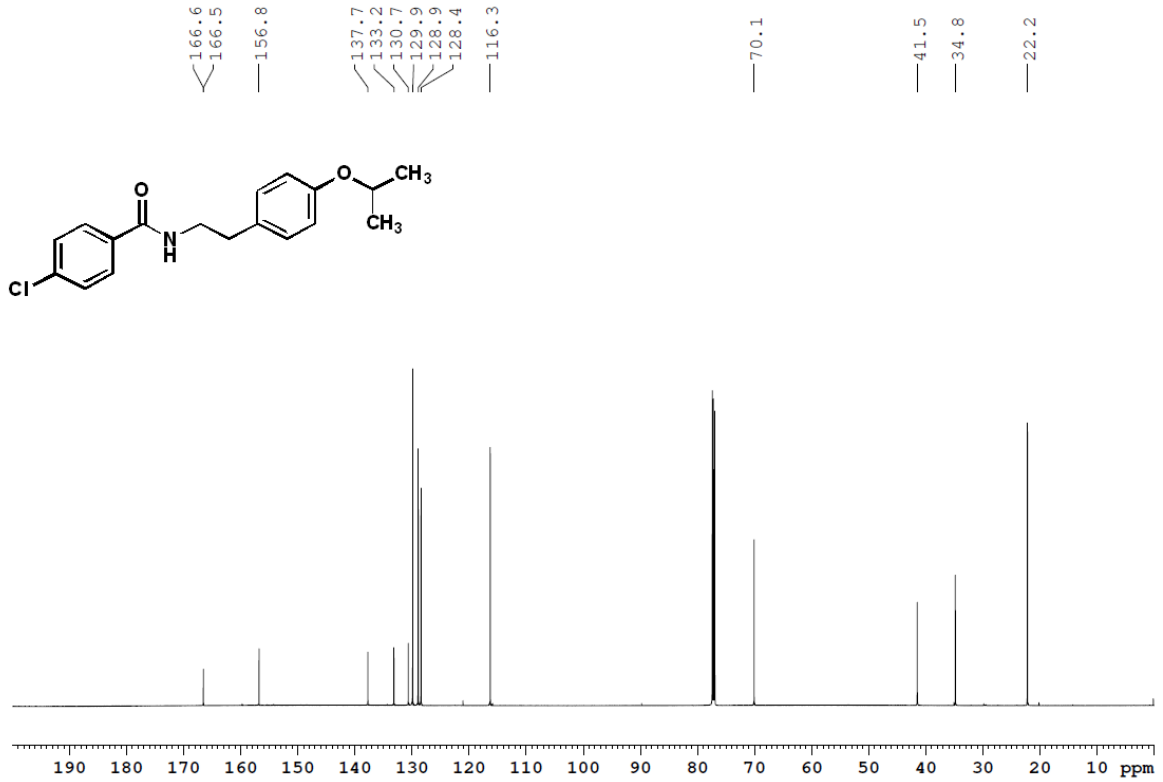
^{13}C NMR spectrum of **35** (150 MHz, $CDCl_3$)



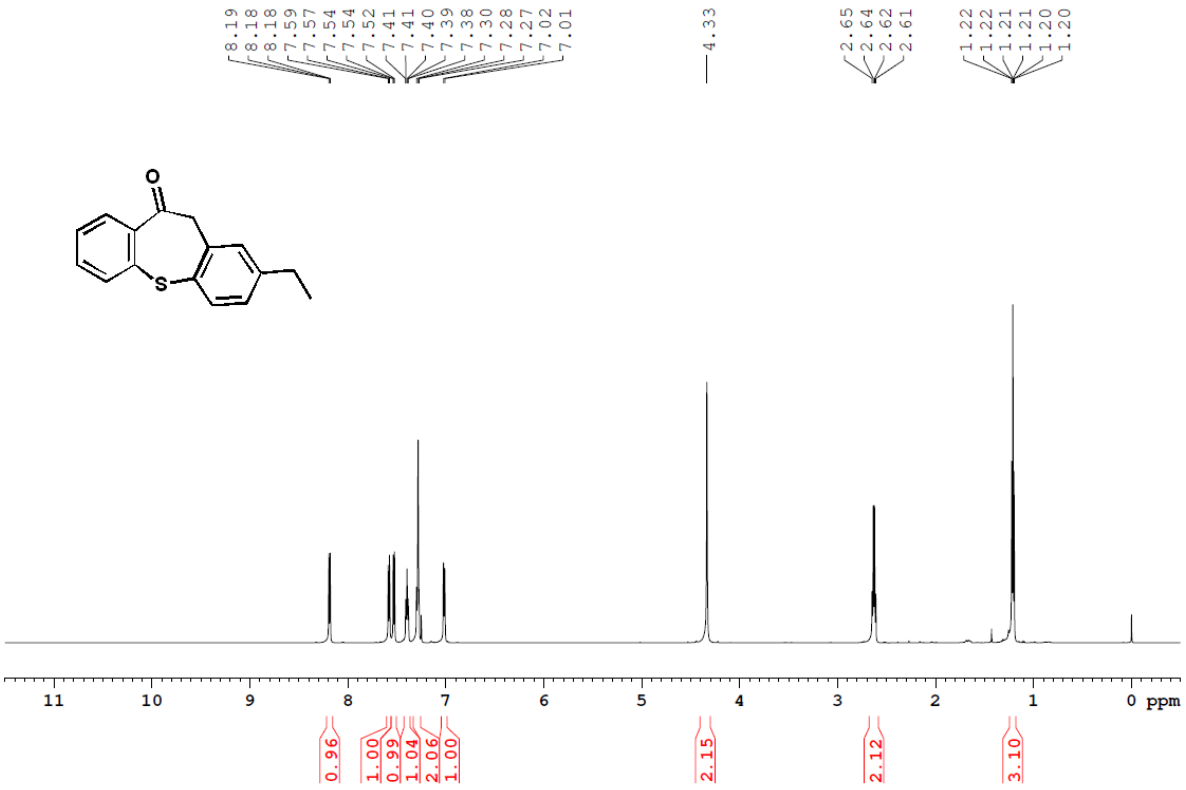
^{1}H NMR spectrum of **36** (600 MHz, $CDCl_3$)



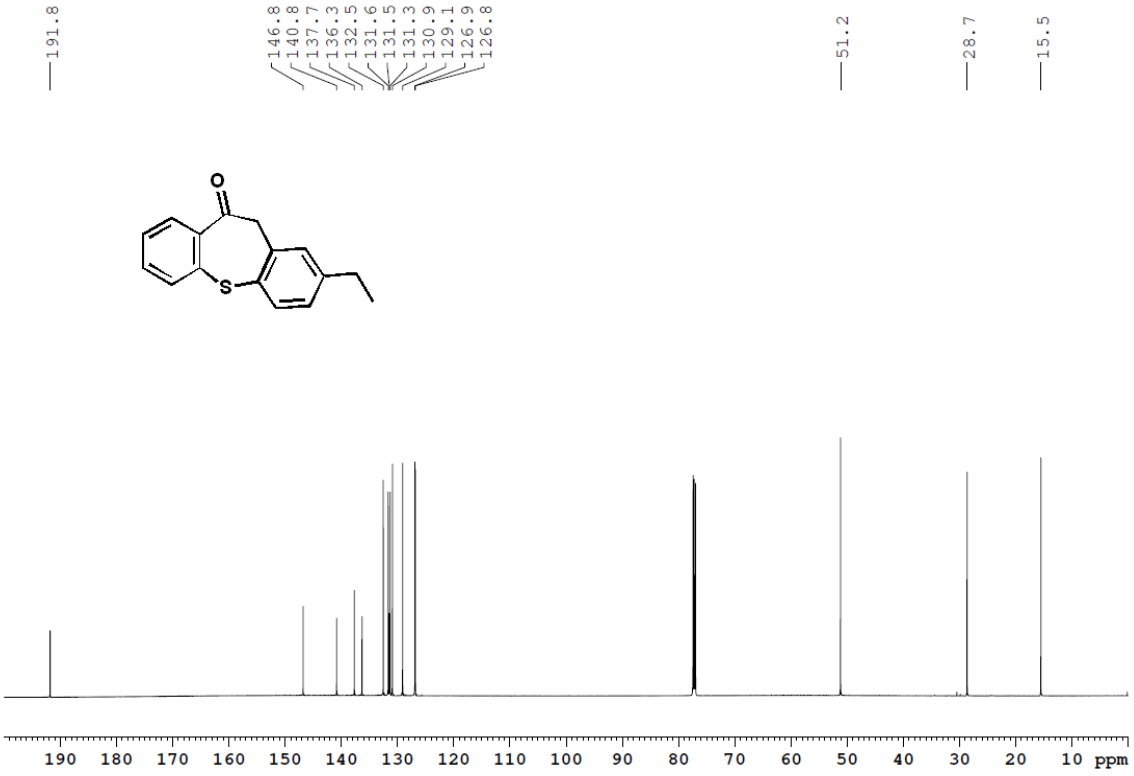
^{13}C NMR spectrum of **36** (150 MHz, $CDCl_3$)



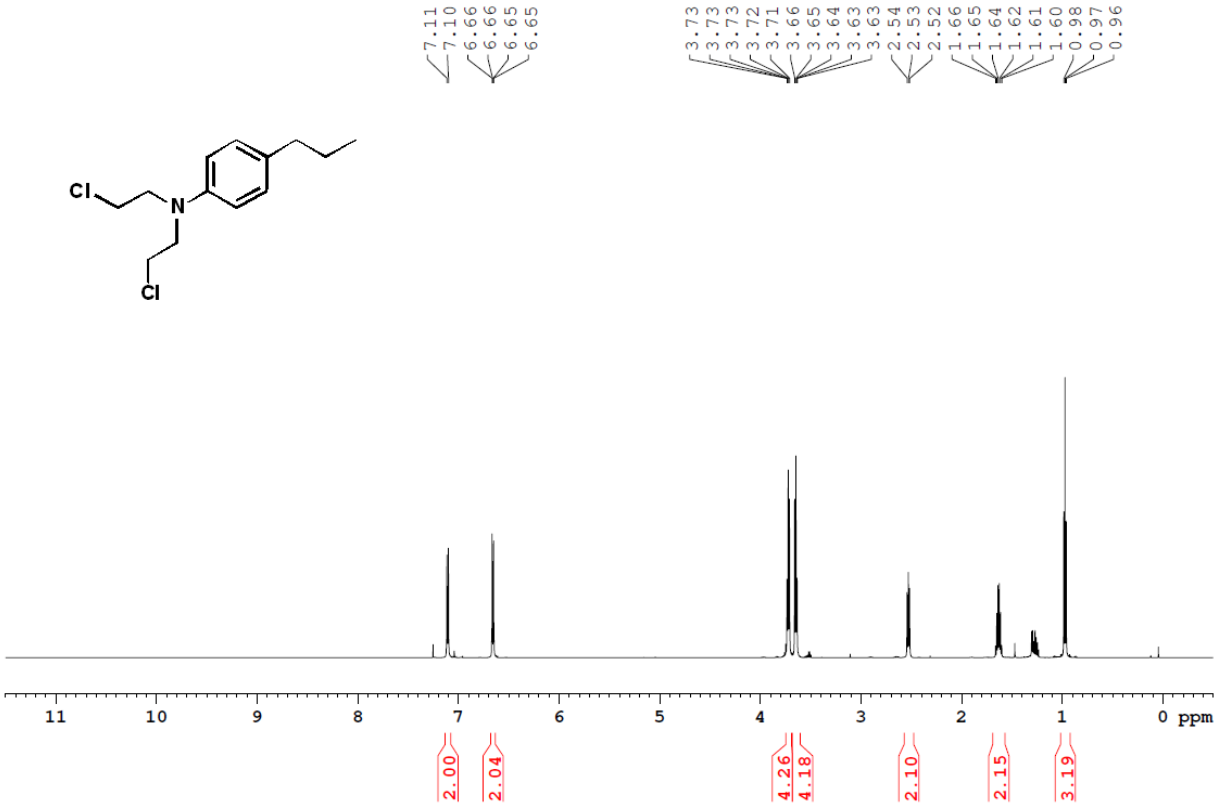
^{1}H NMR spectrum of **37** (600 MHz, $CDCl_3$)



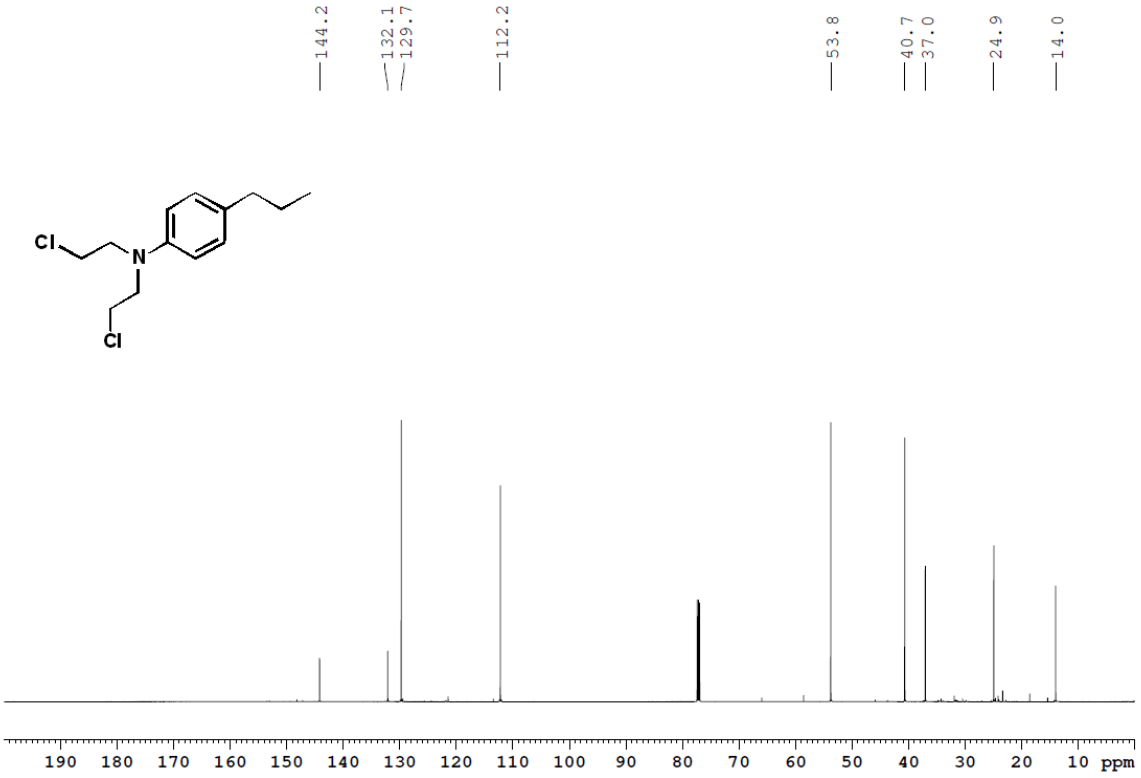
^{13}C NMR spectrum of **37** (150 MHz, $CDCl_3$)



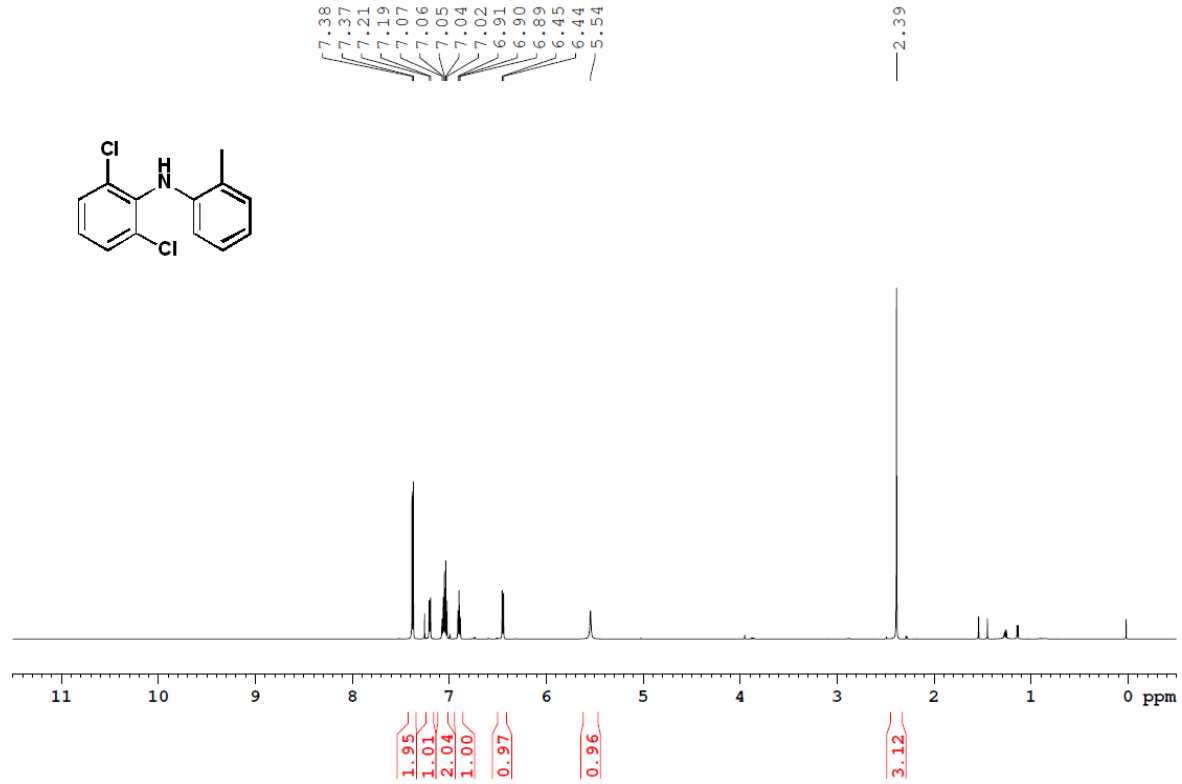
^{1}H NMR spectrum of **38** (600 MHz, $CDCl_3$)



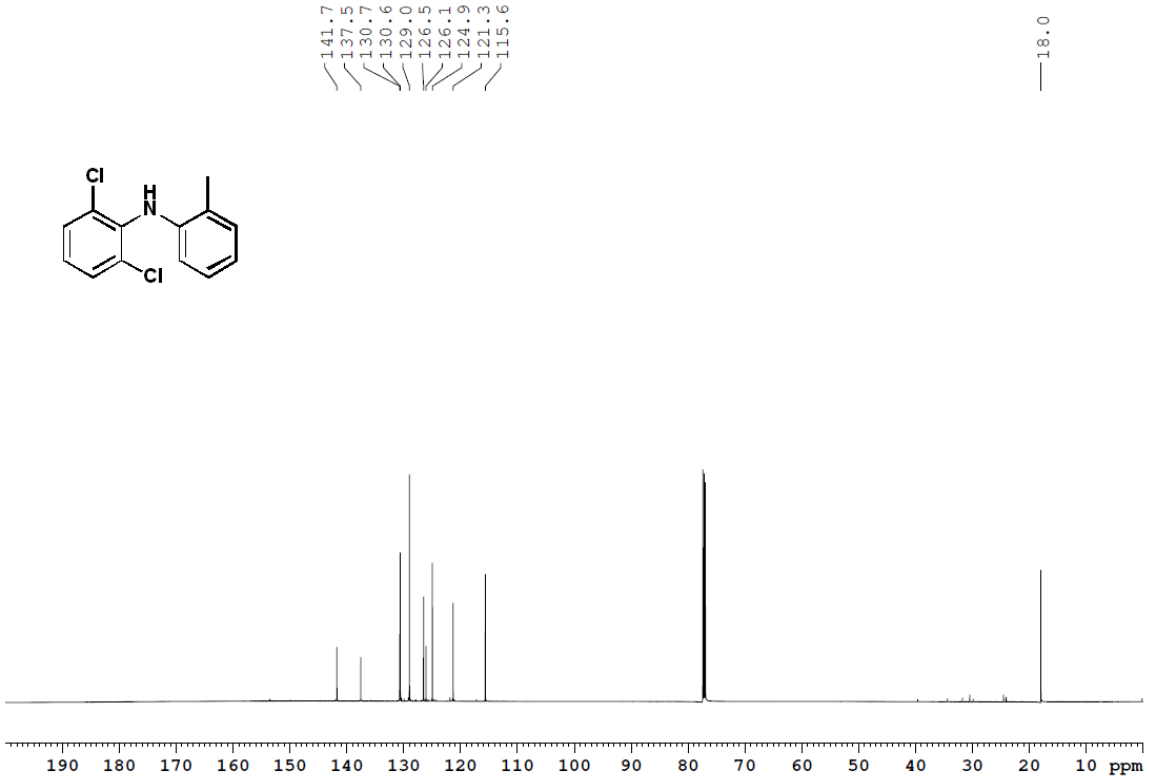
^{13}C NMR spectrum of **38** (150 MHz, $CDCl_3$)



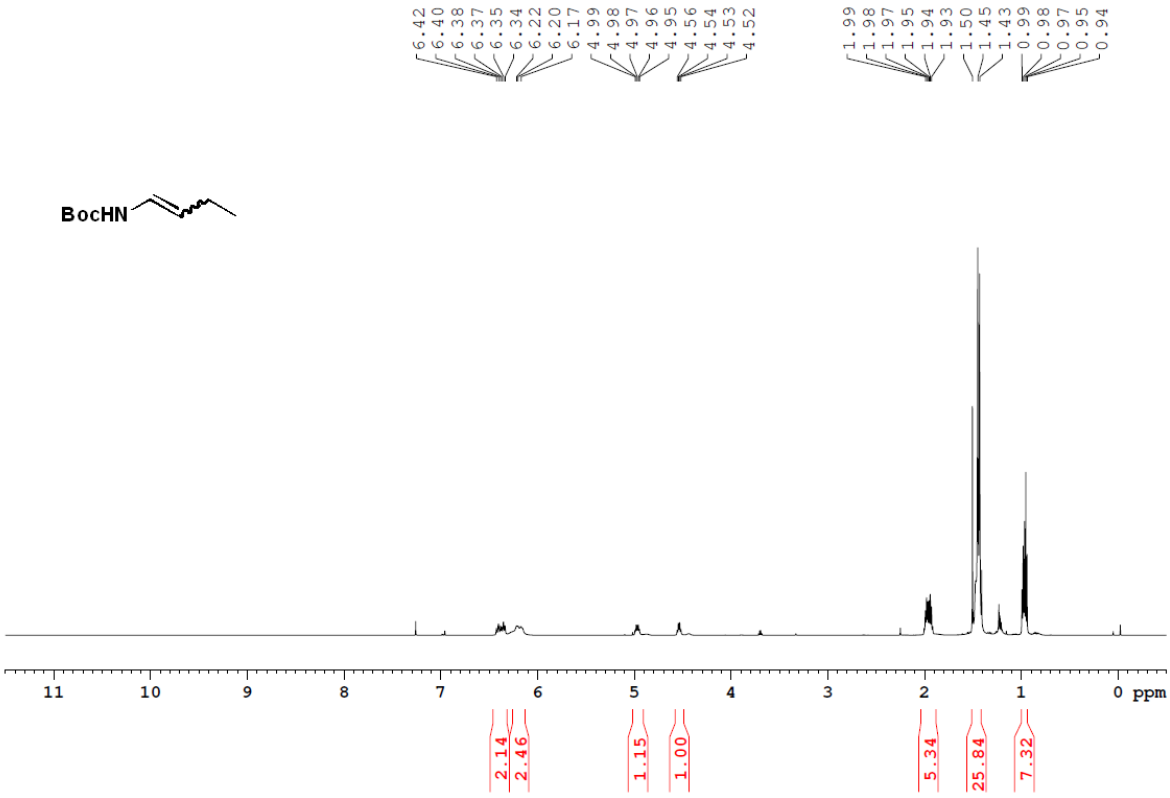
^{1}H NMR spectrum of **39** (600 MHz, $CDCl_3$)



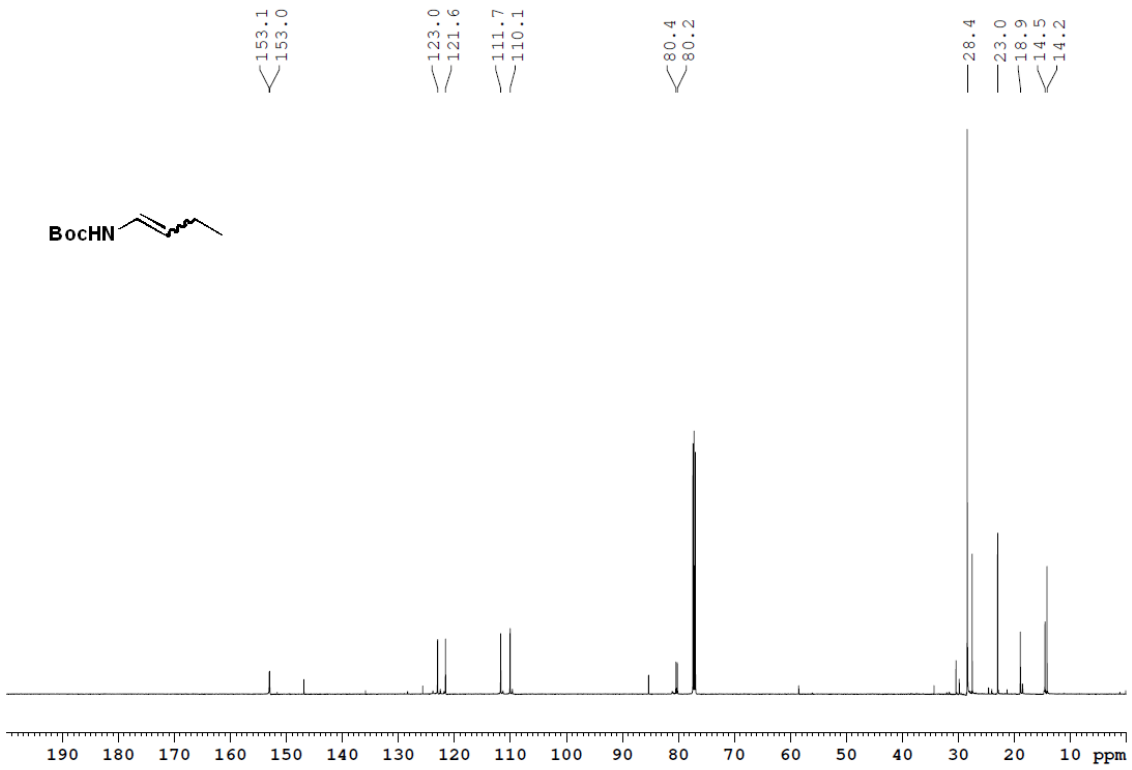
^{13}C NMR spectrum of **39** (150 MHz, $CDCl_3$)



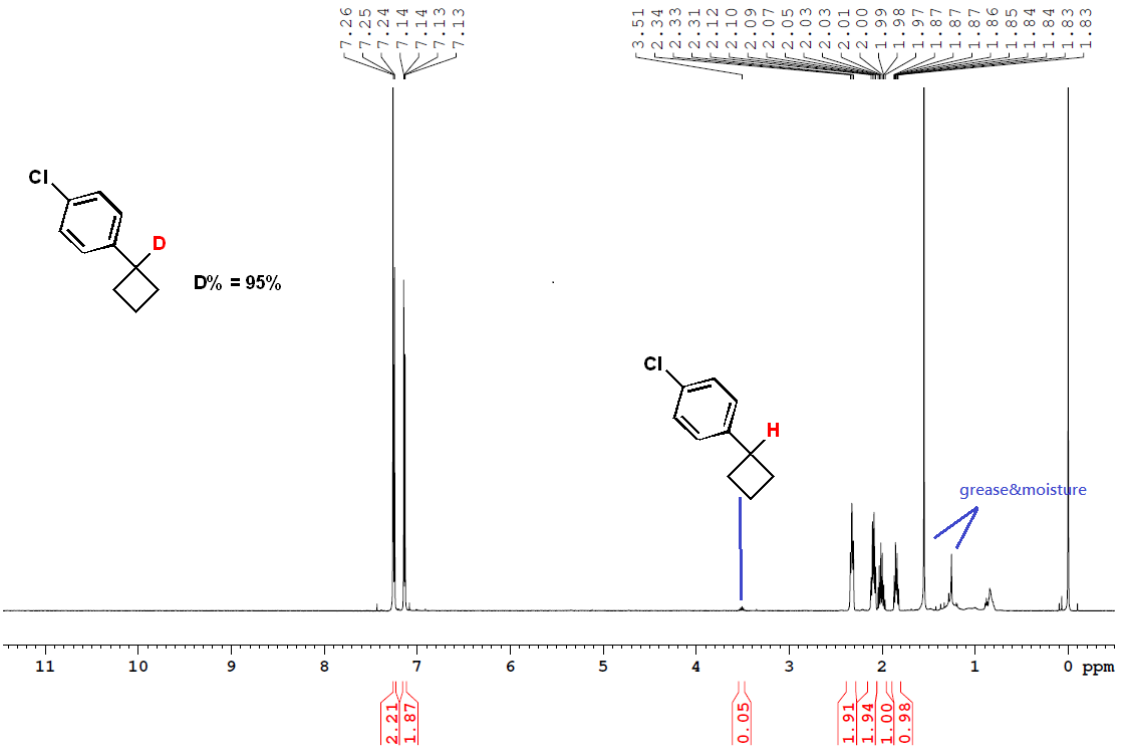
^{1}H NMR spectrum of **40** (600 MHz, $CDCl_3$)



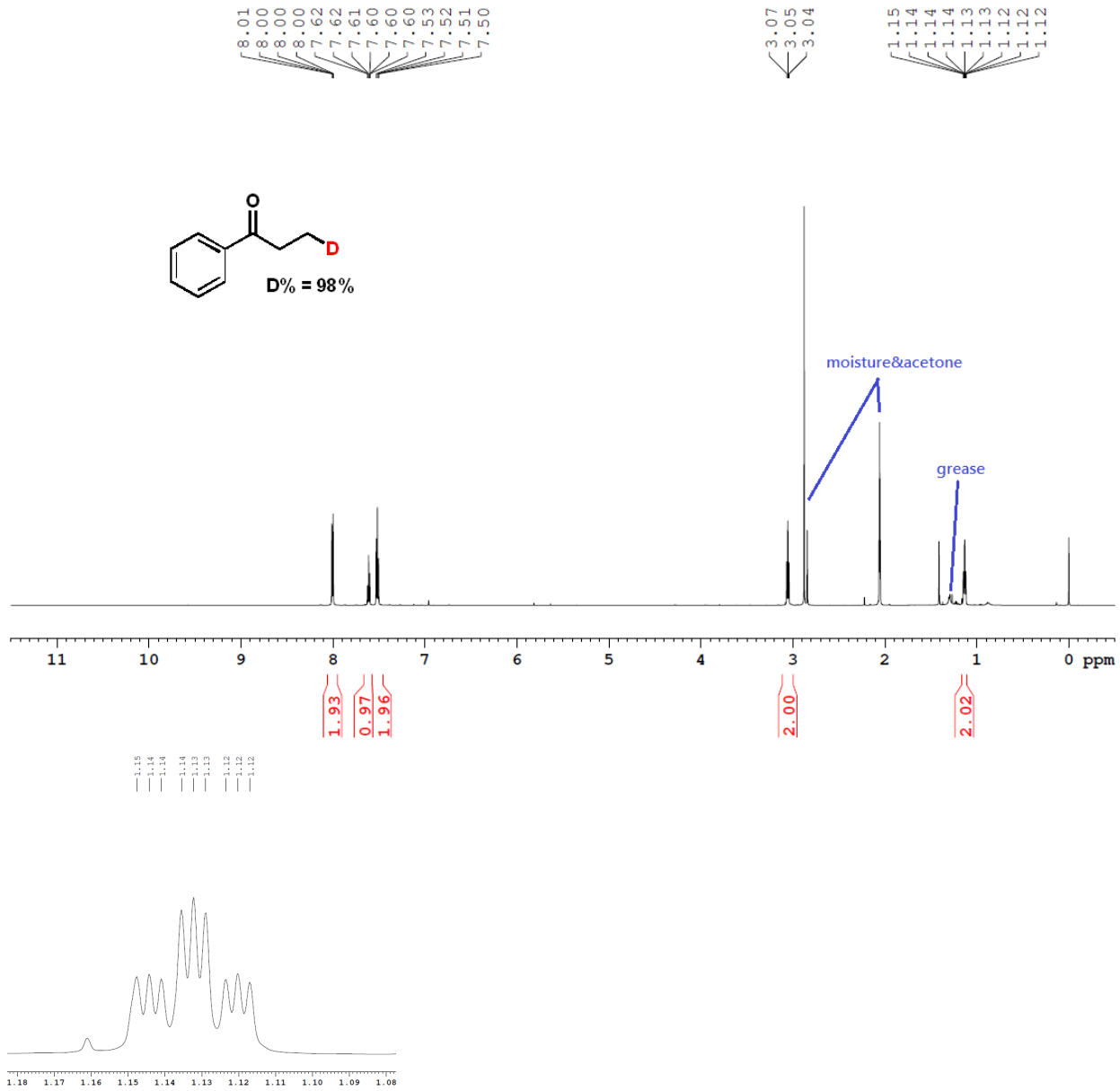
^{13}C NMR spectrum of **40** (150 MHz, $CDCl_3$)



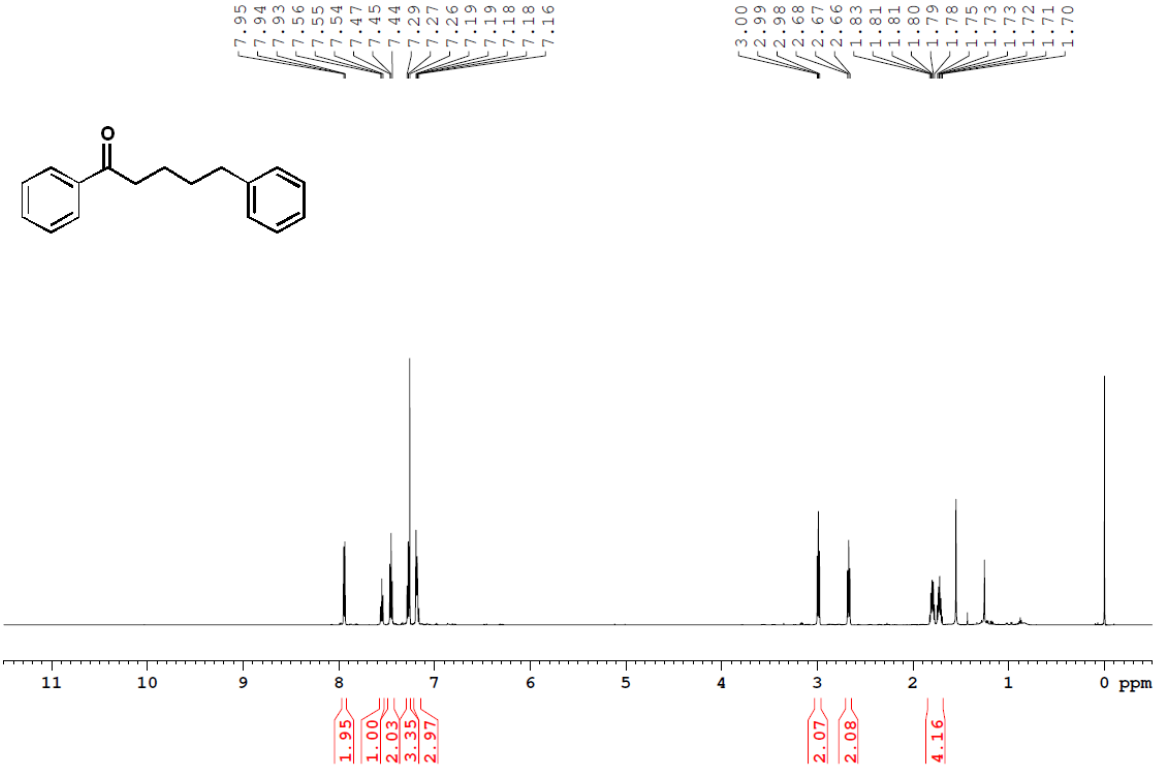
^{1}H NMR spectrum of deuterated **24´** (600 MHz, $CDCl_3$)



^{1}H NMR spectrum of deuterated **2´** (600 MHz, Acetone-d6)



^{1}H NMR spectrum of **C1** (600 MHz, $CDCl_3$)



^{13}C NMR spectrum of **C1** (150 MHz, $CDCl_3$)