

Supporting Information

for

Asymmetric Synthesis of α,β -Unsaturated δ -Lactones through Copper(I)-Catalyzed Direct Vinylogous Aldol Reaction

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1. General information

All reagents were obtained commercially unless otherwise noted. Nuclear Magnetic Resonance (NMR) spectra were acquired on an Agilent 400 or Bruker 400 spectrometer. For ^1H NMR, chemical shifts were reported in δ ppm referenced to an internal SiMe_4 standard. For ^{19}F NMR, CFCl_3 was used as the reference with chemical shift at 0 ppm. For ^{13}C NMR, chemical shifts were reported in the scale relative to NMR solvent (CDCl_3 ; δ 77.0 ppm) as an internal reference. Multiplicities are reported using the following abbreviations: br = broad, s = singlet, d = doublet, t = triplet, q = quartet, p = pentet, m = multiplet. Mass spectra (EI) were measured on Agilent Technologies 5973N GC-MS. High-resolution mass spectra (EI) were measured on Waters Micromass GCT Premier spectrometer. Mass spectra (ESI) were measured on Agilent Technologies 1100 Series LC-MS. High-resolution mass spectra (ESI) were measured on Thermo Scientific LTQ FT Ultra FT-MS. Mass spectra (DART) and high-resolution mass spectra (DART) were measured on Thermo Fisher Scientific LTQ FTICR-MS. Infrared (IR) spectra were recorded on Thermo Scientific Nicolet iS5 FT-IR. Optical rotation was measured using a 1 mL cell with 1.0 dm path length on a JASCO P-1030 polarimeter. HPLC analysis was conducted on a Shimadzu HPLC system equipped with Daicel chiral-stationary-phase columns (ϕ 4.6 mm $\times$ 250 mm).

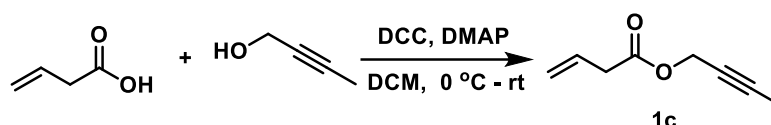
2. Preparation of β,γ -unsaturated esters

2.1. Preparation of **1a** and **1b**

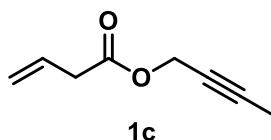
1a was prepared according to a known method.¹

1b was prepared according to a known method.²

2.2. Preparation of **1c**



To a stirred solution of but-3-enoic acid (4.30 g, 50.0 mmol, 1.0 equiv) and 2-butyn-1-ol (3.68 g, 52.5 mmol, 1.05 equiv) in DCM (50 mL, 1.0 M) were added DCC (10.83 g, 52.5 mmol, 1.05 equiv) and DMAP (61.1 mg, 0.5 mmol, 0.01 equiv) at 0 °C. The reaction mixture was allowed to warm up to room temperature and stirred for additional 2 hours. The precipitate was filtered off and washed with CH₂Cl₂. After removal of solvent under reduced pressure, the crude was purified by silica gel column chromatography (petroleum ether/ethyl acetate = 50/1) to afford **1c** (5.07 g, 36.7 mmol, 73% yield) as a colorless oil.



¹H NMR (400 MHz, CDCl₃) δ 5.98-5.88 (m, 1H), 5.21-5.20 (m, 1H), 5.17-5.16 (m, 1H), 4.67 (q, J = 2.2 Hz, 2H), 3.14 (d, J = 6.9 Hz, 2H), 1.86 (t, J = 2.4 Hz, 3H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 170.62, 129.72, 118.56, 83.05, 72.87, 52.80, 38.63, 3.40 ppm.

MS (EI) m/z [M]⁺: 138.

HRMS (EI) m/z [M]⁺: calcd. 138.0681, found 138.0684.

IR (film): 2923, 2118, 1743, 1325, 1247, 1161, 985, 923 cm⁻¹.

3. Preparation of aldehydes

Most of aldehydes were commercially available and purified using standard methods.

5j was prepared according to a known method.³

5k & **5l** were prepared according to known methods.^{4,5,6}

5n was prepared according to a known method.⁷

5p was prepared according to a known method.⁸

5q was prepared according to a known method.⁹

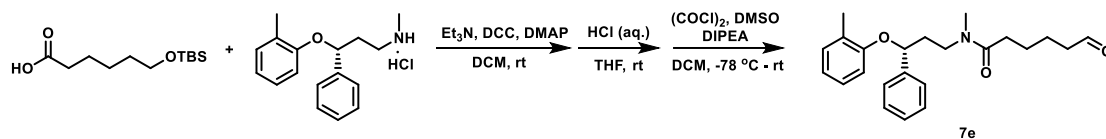
5r was prepared according to a known method.¹⁰

5s was prepared according to a known method.¹¹

7f was prepared according to a known method.¹²

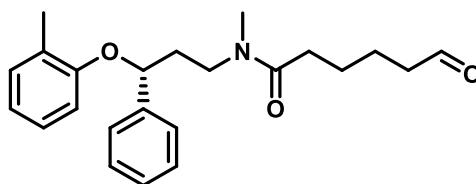
7g was prepared according to a known method.¹³

7e was prepared according to the following method.



To a stirred solution of 6-(*tert*-butyldimethylsilyloxy)hexanoic acid^{14,15} (2.0 g, 8.2 mmol, 1.2 equiv) and Atomoxetine hydrochloride (2.0 g, 6.8 mmol, 1.0 equiv) in DCM (20 mL, 0.34 M) were added triethylamine (0.94 mL, 6.8 mmol, 1.0 equiv), DCC (2.1 g, 10.2 mmol, 1.5 equiv) and DMAP (8.5 mg, 0.07 mmol, 0.01 equiv) at room temperature. The reaction mixture was stirred overnight. The precipitate was filtered off and washed with CH₂Cl₂. After removal of solvent under reduced pressure, the crude was dissolved in THF (20 mL) and 2 M aqueous HCl (19 mL, 68 mmol, 10.0 equiv) was added dropwise. The reaction mixture was stirred for 5 minutes, after which the resulting solution was poured into brine (20 mL) and extracted with EA (3 × 40 mL). The combined organic layers were dried over anhydrous Na₂SO₄, and concentrated under reduced pressure to give the crude product which was used in next step without further purification.

To a solution of (COCl)₂ (1.2 mL, 13.6 mmol, 2.0 equiv) in dry DCM (20 mL) was added dropwise DMSO (1.6 mL, 25 mmol, 3.8 equiv) at -78 °C under N₂ atmosphere. After the mixture was stirred for 10 min, a solution of the above crude (6.8 mmol, 1.0 equiv) in dry DCM (10 mL) was added dropwise to the reaction mixture. The mixture was stirred for additional 1 hour, then DIPEA (10 mL, 57.5 mmol, 8.5 equiv) was added to the reaction mixture at -78 °C. After the mixture was stirred for 1 hour at -78 °C, the reaction mixture was allowed to warm up to room temperature and stirred overnight. Saturated aqueous NH₄Cl (20 mL) was added to the reaction mixture. The organic phase was separated and the aqueous phase was extracted with DCM (20 mL × 3). The organic extracts were dried over anhydrous Na₂SO₄ and the solvent was removed under reduced pressure. The residue was purified by silica gel column chromatography (petroleum ether/ethyl acetate = 2/1 to 1/1) to afford aldehyde **7e** (1.17 g, 3.2 mmol, 47% yield for three steps) as a yellow oil. (Rotamers were observed in a ratio of 1.1/1 in CDCl₃ at room temperature).



7e

¹H NMR (400 MHz, CDCl₃) δ 9.75/9.69 (s, 1H), 7.36-7.20 (m, 5H), 7.12 (t, *J* = 7.3 Hz, 1H), 6.94 (t, *J* = 7.7 Hz, 1H), 6.77 (q, *J* = 7.4 Hz, 1H), 6.56 (dd, *J* = 13.5, 8.2 Hz, 1H), 5.19-5.13 (m, 1H), 3.68-3.40 (m, 2H), 2.94 (d, *J* = 7.2 Hz, 3H), 2.45 (s, 1H), 2.35-2.10 (m, 8H), 1.66-1.42 (m, 4H) ppm.
¹³C NMR (100 MHz, CDCl₃) δ 202.37, 202.33, 172.38, 172.21, 155.69, 155.26, 141.58, 140.92, 130.74, 130.56, 128.79, 128.55, 127.79, 127.49, 126.83, 126.71, 126.54, 126.52, 125.62, 125.43, 120.56, 120.23, 112.60, 112.37, 77.52, 76.04, 46.16, 45.36, 43.70, 43.57, 37.47, 36.47, 36.42, 35.74, 33.19, 33.13, 32.26, 24.62, 24.37, 21.74, 21.61, 16.50 ppm.

MS (ESI) *m/z* [M+H]⁺: 368.15.

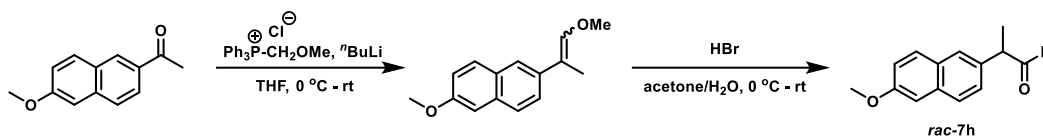
HRMS (ESI) *m/z* [M+H]⁺: calcd. 368.2220, found 368.2215.

IR (film): 2931, 1722, 1643, 1492, 1452, 1238, 1119, 753 cm⁻¹.

Optical rotation: [α]_D²⁶ = -16.35 (*c* = 1.040, CHCl₃).

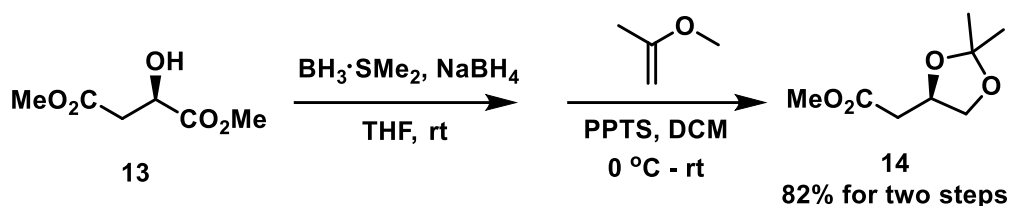
Chiral **7h** was prepared according to a known method.¹⁶

Racemic **rac-7h** was prepared according to the following method.

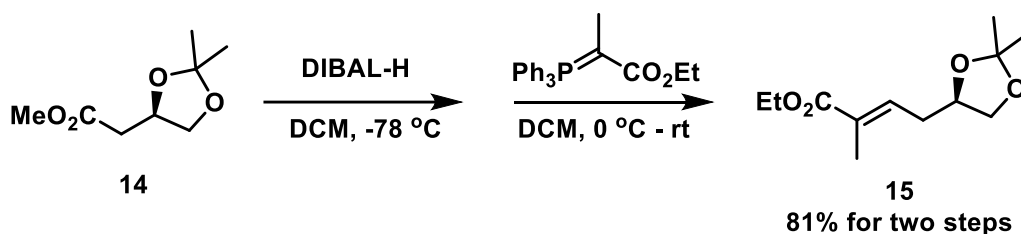


(Methoxymethyl)triphenylphosphonium chloride (2.74 g, 8.0 mmol, 1.6 equiv) was suspended in 20 mL of anhydrous THF in a 100 mL round bottom flask. The resulting mixture was cooled to 0 °C and *n*-BuLi (3.2 mL (2.5 M in hexane), 8.0 mmol, 1.6 equiv) was added to the suspension slowly under N₂ atmosphere to give a dark red solution. The reaction mixture was then warmed up to room temperature and stirred for 30 minutes. A solution of 6-methoxy-2-acetylnaphthalene (1.0 g, 5 mmol, 1.0 equiv) in 10 mL of anhydrous THF was added slowly over 10 minutes. The reaction mixture was stirred at room temperature overnight. When the reaction was complete as monitored by TLC, 50 mL of H₂O was added to quench the reaction. The resulting mixture was extracted with ethyl acetate (40 mL × 3). The combined organic phase was dried over anhydrous Na₂SO₄. All solvents were removed under reduced pressure and the residue was purified by silica gel column chromatography (petroleum ether/ethyl acetate) to give the enol ether intermediate. The enol ether intermediate was dissolved in 10 mL acetone and 2.5 mL water. The solution was stirred and cooled to 0 °C. 1.0 mL of HBr (48%) was added and the reaction was left to stir at 0 °C for another 30 minutes before it was allowed to warm up to ambient temperature. After the completion of the reaction as monitored by TLC, the mixture was quenched carefully with saturated aqueous solution of NaHCO₃. After removal of acetone under reduced pressure, the aqueous phase was extracted with CH₂Cl₂ (20 mL × 3). The combined organic phase was washed with brine and dried over anhydrous Na₂SO₄. All solvents were removed under reduced pressure and the residue was purified by silica gel column chromatography (petroleum ether/ethyl acetate = 20/1) to afford racemic aldehyde **rac-7h** (0.41 g, 1.9 mmol, 38% yield for two steps) as a white powder.

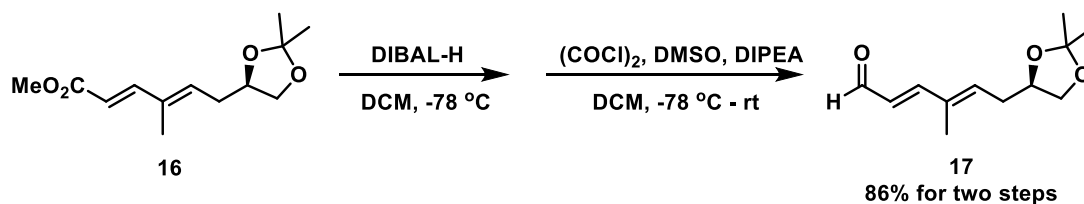
17 was prepared according to the following method.



(*R*)-Dimethyl-malate **13** (14.76 g, 91.0 mmol, 1.0 equiv) was dissolved in dry THF (150 ml) at room temperature. Borane-methyl sulfide complex (46.4 mL (2 M in THF), 92.8 mmol, 1.02 equiv) was added dropwise and the reaction was stirred for 0.5 h. The solution was cooled to 0 °C and sodium borohydride (172 mg, 4.55 mmol, 0.05 equiv) was added in one portion. The solution was stirred for 0.5 h. Then further sodium borohydride (30 mg, 0.8 mmol, 0.09 equiv) was added and stirring was continued for 1 h. The reaction was quenched by dry methanol (60 mL) and then stirred overnight. The solvent was removed under reduced pressure and the residue was dissolved in dry methanol (60 mL) again. After removal of the solvent under reduced pressure, the residue was dissolved in dry DCM (60 mL) and the resulting solution was cooled to 0 °C. Pyridinium *p*-toluenesulfonate (2.284 g, 9.1 mmol, 0.1 equiv) and 2-methoxypropene (17.4 mL, 182.0 mmol, 2.0 equiv) were added and the reaction was stirred for 1 h at 0 °C and overnight at ambient temperature. Brine (50 mL) was added to the reaction mixture. The organic phase was separated and the aqueous phase was extracted with DCM (50 mL $\times$ 3). The organic extracts were dried over anhydrous Na_2SO_4 and the solvent was removed under reduced pressure. Reduced pressure distillation (14 mbar, 80-84 °C) yielded ester **14** (13.017 g, 74.7 mmol, 82% yield for two steps) as a colorless oil.¹⁷

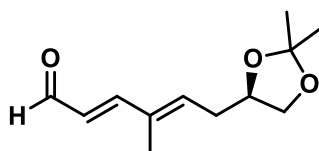


Ester **14** (7.766 g, 44.6 mmol, 1.0 equiv) was dissolved in dry DCM (45 mL) and the resulting solution was cooled to -78 °C. DIBAL-H (31.2 mL (1.5 M in toluene), 46.8 mmol, 1.05 equiv) was added dropwise (0.5 mL/min). The resulting solution was stirred for 0.5 h and then quenched at -78 °C by the very cautious addition of saturated aqueous NH_4Cl (12 mL) and 1 M HCl (22 mL). The resulting mixture was dried over anhydrous MgSO_4 , filtered through Celite and washed with DCM. The solvent was removed under reduced pressure and the residue was dissolved in dry DCM (45 mL). The solution was cooled to 0 °C and $\text{Ph}_3\text{P}=\text{C}(\text{Me})\text{CO}_2\text{Et}$ ¹⁸ (19.4 g, 53.5 mmol, 1.2 equiv) was added in one portion. The reaction mixture was allowed to warm up to room temperature and stirred for additional 1 hour. Then, the solvent was removed under reduced pressure and a hexane/ Et_2O mixture (1/1) was added to the residue. The precipitated solid was removed by Celite filtration and washed for several times with a cold hexane/ Et_2O mixture (1/1). The solvent was removed under reduced pressure and the residue was purified by silica gel column chromatography (petroleum ether/ethyl acetate = 9/1) to afford ester **15** (8.24 g, 36.1 mmol, 81% yield for two steps) as a colorless oil.¹⁹



Ester **16** (2.4 g, 10 mmol, 1.0 equiv) was dissolved in dry DCM (10mL) and the solution was cooled to $-78\text{ }^\circ\text{C}$. DIBAL-H (20 mL (1.5 M in toluene), 30 mmol, 3.0 equiv) was added dropwise (2.0 mL/min). The resulting solution was stirred for 0.5 h and then quenched at $-78\text{ }^\circ\text{C}$ by the very cautious addition of saturated aqueous NH_4Cl (8 mL) and 1 M HCl (15 mL). The resulting mixture was dried over anhydrous MgSO_4 , filtered through Celite and washed with DCM. The solvent was removed under reduced pressure to give the crude product which was used in next step without further purification.

To a solution of $(\text{COCl})_2$ (1.36 mL, 15.6 mmol, 1.56 equiv) in dry DCM (10 mL) was added dropwise DMSO (1.76 mL, 27.3 mmol, 2.73 equiv) at $-78\text{ }^\circ\text{C}$ under N_2 atmosphere. After the mixture was stirred for 10 min, a solution of the above crude (10 mmol, 1.0 equiv) in dry DCM (5 mL) was added dropwise to the reaction mixture. The mixture was stirred for additional 1 hour, then DIPEA (11.3 mL, 65 mmol, 6.5 equiv) was added to the reaction mixture at $-78\text{ }^\circ\text{C}$. After the mixture was stirred for 1 hour at $-78\text{ }^\circ\text{C}$, the reaction mixture was allowed to warm up to room temperature and stirred overnight. Saturated aqueous NH_4Cl (20 mL) was added to the reaction mixture. The organic phase was separated and the aqueous phase was extracted with DCM (20 mL $\times$ 3). The organic extracts were dried over anhydrous Na_2SO_4 and the solvent was removed under reduced pressure. The residue was purified by silica gel column chromatography (petroleum ether/ethyl acetate = 10/1) to afford aldehyde **17** (1.8 g, 8.6 mmol, 86% yield for two steps) as a yellow oil.



17

^1H NMR (400 MHz, CDCl_3) δ 9.57 (d, J = 7.8 Hz, 1H), 7.14 (d, J = 15.6 Hz, 1H), 6.13 (dd, J = 15.6, 7.8 Hz, 1H), 6.06 (t, J = 7.3 Hz, 1H), 4.27-4.19 (m, 1H), 4.10-4.06 (m, 1H), 3.60 (t, J = 7.3 Hz, 1H), 2.61-2.48 (m, 2H), 1.85 (s, 3H), 1.44 (s, 3H), 1.36 (s, 3H) ppm.

^{13}C NMR (100 MHz, CDCl_3) δ 194.05, 157.02, 138.16, 135.41, 127.32, 109.21, 74.74, 68.80, 33.24, 26.79, 25.42, 12.53 ppm.

MS (EI) m/z $[\text{M}-\text{CH}_3]^+$: 195.

HRMS (EI) m/z $[\text{M}-\text{CH}_3]^+$: calcd. 195.1021, found 195.1024.

IR (film): 2985, 2935, 2876, 1678, 1627, 1604, 1370, 1216, 1134, 1061, 971, 842 cm^{-1} .

Optical rotation: $[\alpha]_{\text{D}}^{30} = +5.80$ (c = 1.165, CHCl_3).

4. Catalytic asymmetric DVAR of aldehydes

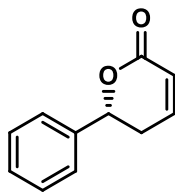
4.1. General procedure for catalytic asymmetric DVAR of aromatic and heteroaromatic aldehydes

Procedure A:

A dried 25 mL Schlenk tube equipped with a magnetic stirring bar was charged with $[\text{Cu}(\text{CH}_3\text{CN})_4]\text{PF}_6$ (7.5 mg, 0.02 mmol, 0.05 equiv) and (*R*)-DTBM-SEGPHOS (23.6 mg, 0.02 mmol, 0.05 equiv) in a glove box under Ar atmosphere. Anhydrous THF (2.0 mL, 0.2 M) was added via syringe. The mixture was stirred for 15 minutes to give a colorless catalyst solution. Then **1b** (97.3 mg, 0.6 mmol, 1.5 equiv) and aromatic aldehyde **2** (0.4 mmol, 1.0 equiv) were added sequentially. After cooling to -20 °C, Barton's Base (4 μL , 0.02 mmol, 0.05 equiv) was added. The resulting reaction mixture was stirred at -20 °C for 48 hours. Then, the reaction mixture was quenched by acetic acid (100 μL (0.4 M in THF), 0.04 mmol, 0.1 equiv). The mixture was stirred for additional 20 minutes at -20 °C, and then the solvent was removed under reduced pressure. The residue was dissolved in toluene (1 mL) and Ph_2PMe (7.5 μL , 0.04 mmol, 0.1 equiv) was added. The resulting solution was stirred at 100 °C for 8 hours. The solvent was removed under reduced pressure, and then the residue was purified by silica gel column chromatography (petroleum ether/ethyl acetate) to give the product.

Procedure B:

A dried 25 mL Schlenk tube equipped with a magnetic stirring bar was charged with $[\text{Cu}(\text{CH}_3\text{CN})_4]\text{PF}_6$ (7.5 mg, 0.02 mmol, 0.05 equiv) and (*R*)-DTBM-SEGPHOS (23.6 mg, 0.02 mmol, 0.05 equiv) in a glove box under Ar atmosphere. Anhydrous THF (2.0 mL, 0.2 M) was added via syringe. The mixture was stirred for 15 minutes to give a colorless catalyst solution. Then **1b** (97.3 mg, 0.6 mmol, 1.5 equiv) and aromatic aldehyde **2** (0.4 mmol, 1.0 equiv) were added sequentially. After cooling to 0 °C, Barton's Base (4 μL , 0.02 mmol, 0.05 equiv) was added. The resulting reaction mixture was stirred at 0 °C for 48 hours. Then, the reaction mixture was quenched by acetic acid (100 μL (0.4 M in THF), 0.04 mmol, 0.1 equiv). The mixture was stirred for additional 20 minutes at 0 °C, and then the solvent was removed under reduced pressure. The residue was dissolved in toluene (1 mL) and Ph_2PMe (7.5 μL , 0.04 mmol, 0.1 equiv) was added. The resulting solution was stirred at 100 °C for 8 hours. The solvent was removed under reduced pressure, and then the residue was purified by silica gel column chromatography (petroleum ether/ethyl acetate) to give the product.



4a

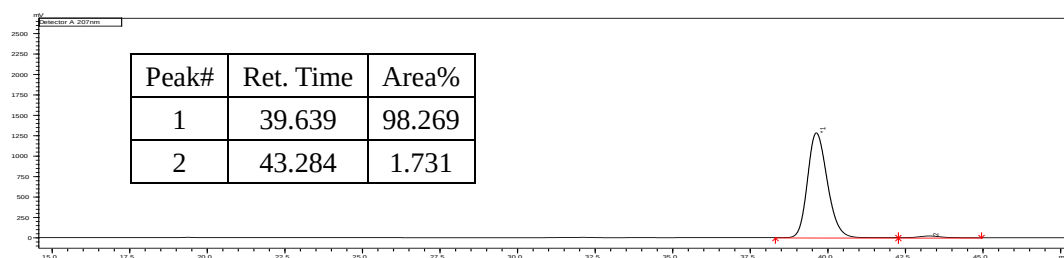
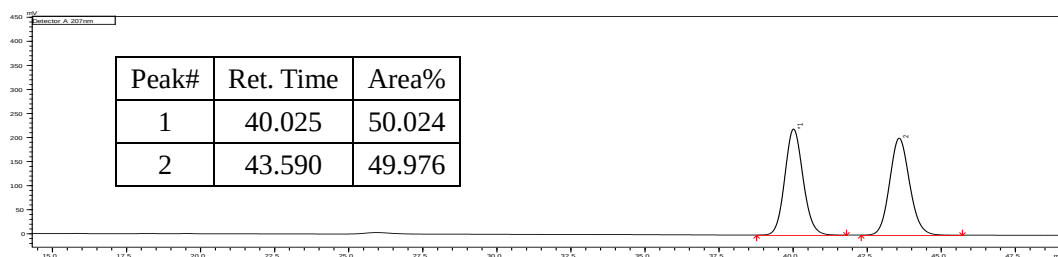
4a: Procedure A, 59.9 mg, white powder, 86% yield.²¹

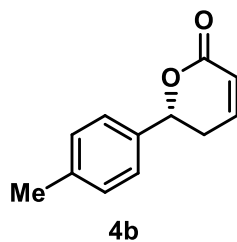
¹H NMR (400 MHz, CDCl₃) δ 7.40-7.32 (m, 5H), 6.96 (ddd, J = 9.6, 5.5, 3.0 Hz, 1H), 6.14-6.11 (m, 1H), 5.44 (dd, J = 10.7, 5.3 Hz, 1H), 2.66-2.61 (m, 2H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 164.03, 144.92, 138.36, 128.57, 128.52, 125.96, 121.54, 79.16, 31.56 ppm.

Optical rotation: $[\alpha]_D^{27} = +214.79$ (c = 1.025, CHCl₃, 97% ee).

HPLC: DAICEL CHIRALPAK IC, hexane/*i*-PrOH = 3/1, flow rate: 0.5 mL/min, λ = 207 nm, t_R (major) = 39.6 min, t_R (minor) = 43.3 min, ee = 97%.





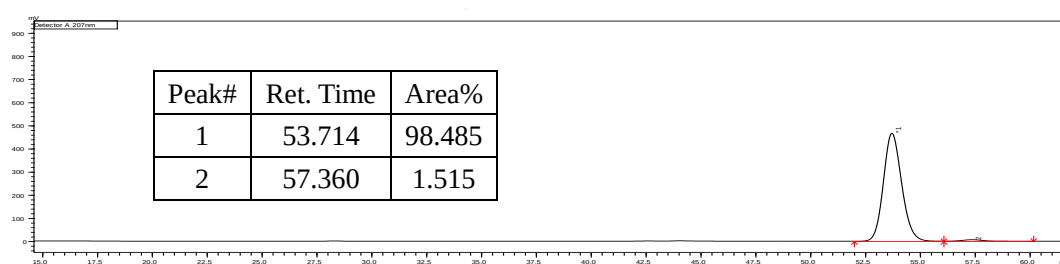
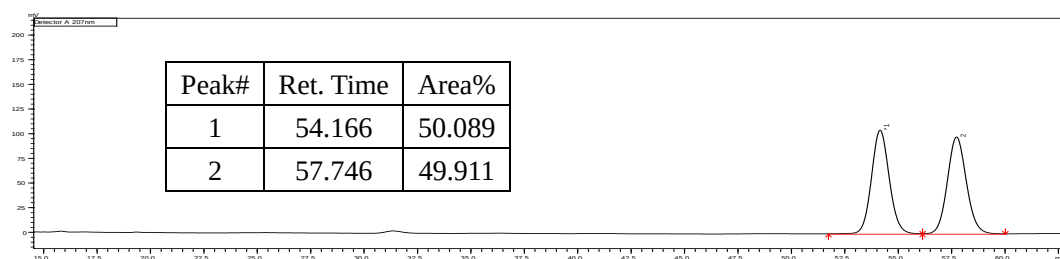
4b: Procedure A, 68.6 mg, white powder, 91% yield.²²

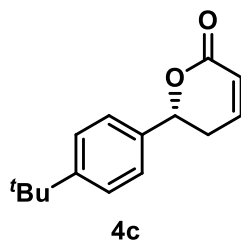
¹H NMR (400 MHz, CDCl₃) δ 7.30 (d, J = 8.1 Hz, 2H), 7.20 (d, J = 8.0 Hz, 2H), 6.96 (ddd, J = 9.6, 5.8, 2.6 Hz, 1H), 6.15-6.12 (m, 1H), 5.43 (dd, J = 11.4, 4.5 Hz, 1H), 2.71-2.55 (m, 2H), 2.37 (s, 3H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 164.18, 144.95, 138.39, 135.42, 129.22, 125.97, 121.56, 79.16, 31.55, 21.10 ppm.

Optical rotation: $[\alpha]_D^{26} = +191.29$ (c = 1.035, CHCl₃, 97% ee).

HPLC: DAICEL CHIRALPAK IC, hexane/*i*-PrOH = 4/1, flow rate: 0.5 mL/min, λ = 207 nm, t_R (major) = 53.7 min, t_R (minor) = 57.4 min, ee = 97%.





4c: Procedure A, 83.0 mg, white powder, 90% yield.

¹H NMR (400 MHz, CDCl₃) δ 7.41 (d, *J* = 8.4 Hz, 2H), 7.34 (d, *J* = 8.4 Hz, 2H), 6.98-6.94 (m, 1H), 6.12 (dd, *J* = 9.7, 1.2 Hz, 1H), 5.42 (dd, *J* = 11.4, 4.5 Hz, 1H), 2.71-2.55 (m, 2H), 1.32 (s, 9H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 164.14, 151.62, 144.96, 135.32, 125.80, 125.48, 121.56, 79.09, 34.54, 31.36, 31.21 ppm.

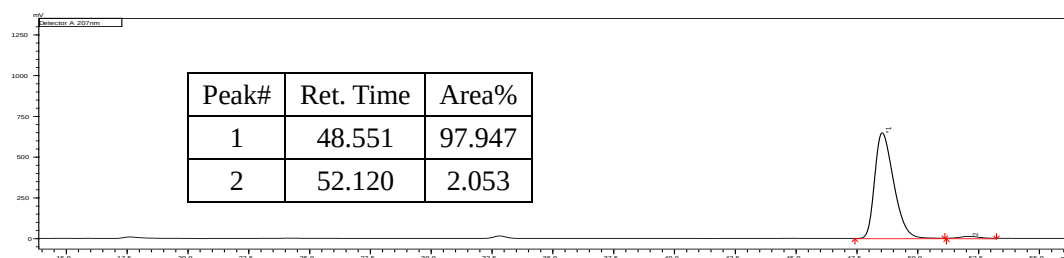
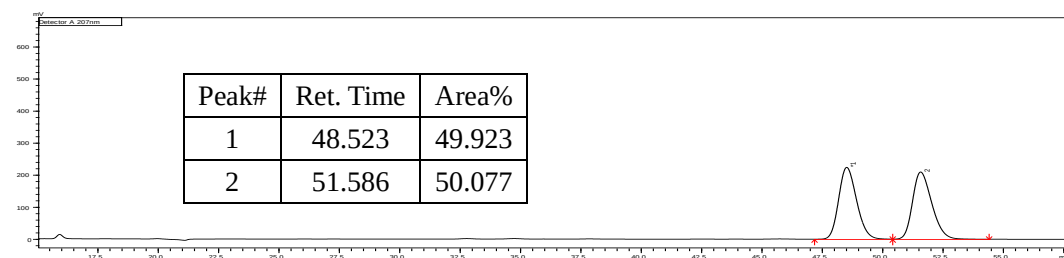
MS (ESI) *m/z* [M+ Na]⁺: 253.2.

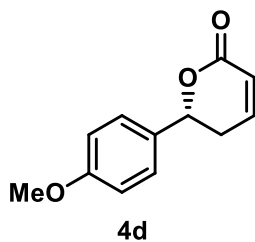
HRMS (ESI) *m/z* [M+Na]⁺: calcd. 253.1199, found 253.1201.

IR (film): 2960, 1713, 1381, 1244, 1061, 815 cm⁻¹.

Optical rotation: [α]_D²⁶ = +158.91 (*c* = 1.125, CHCl₃, 96% ee).

HPLC: DAICEL CHIRALPAK ID, hexane/*i*-PrOH = 47/3, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 48.6 min, *t*_R(minor) = 52.1 min, ee = 96%.





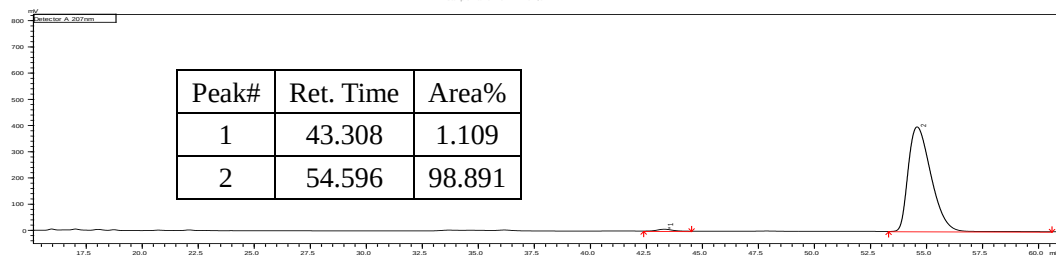
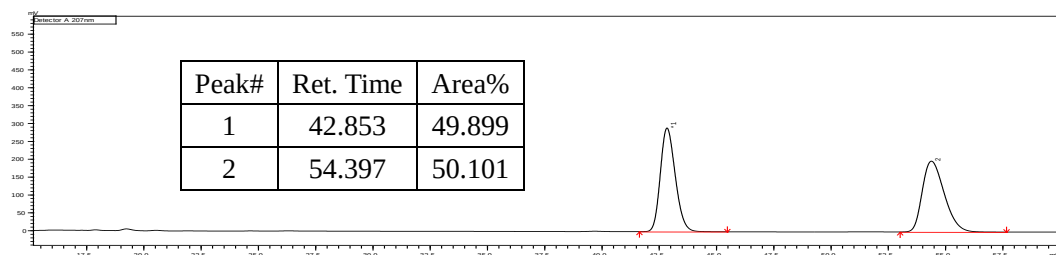
4d: Procedure A, 71.2 mg, pale yellow powder, 87% yield.²³

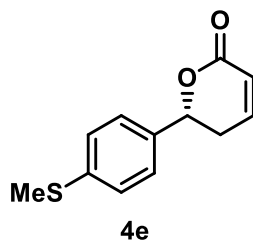
¹H NMR (400 MHz, CDCl₃) δ 7.33 (d, J = 8.6 Hz, 2H), 6.96 (ddd, J = 9.5, 5.9, 2.4 Hz, 1H), 6.91 (d, J = 8.7 Hz, 2H), 6.11 (dd, J = 9.8, 2.1 Hz, 1H), 5.39 (dd, J = 11.8, 4.1 Hz, 1H), 3.81 (s, 3H), 2.70-2.52 (m, 2H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 164.24, 159.67, 145.06, 130.39, 127.51, 121.44, 113.86, 79.04, 55.21, 31.40 ppm.

Optical rotation: $[\alpha]_D^{26} = +175.38$ (c = 1.080, CHCl₃, 98% ee).

HPLC: DAICEL CHIRALPAK ID, hexane/*i*-PrOH = 4/1, flow rate: 0.5 mL/min, λ = 207 nm, t_R (major) = 54.6 min, t_R (minor) = 43.3 min, ee = 98%.





4e: Procedure A, 75.6 mg, white powder, 86% yield.

¹H NMR (400 MHz, CDCl₃) δ 7.32 (d, *J* = 7.5 Hz, 2H), 7.26 (d, *J* = 7.5 Hz, 2H), 6.96 (dd, *J* = 7.4, 4.5 Hz, 1H), 6.12 (d, *J* = 9.4 Hz, 1H), 5.42-5.39 (m, 1H), 2.67-2.60 (m, 2H), 2.48 (s, 3H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 163.99, 144.89, 139.15, 134.99, 126.50, 126.31, 121.50, 78.81, 31.43, 15.51 ppm.

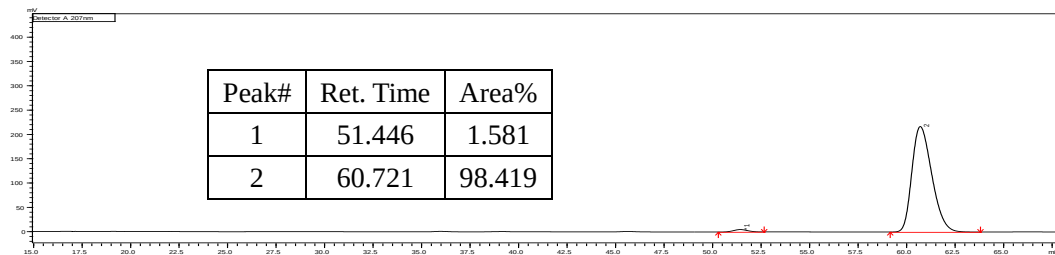
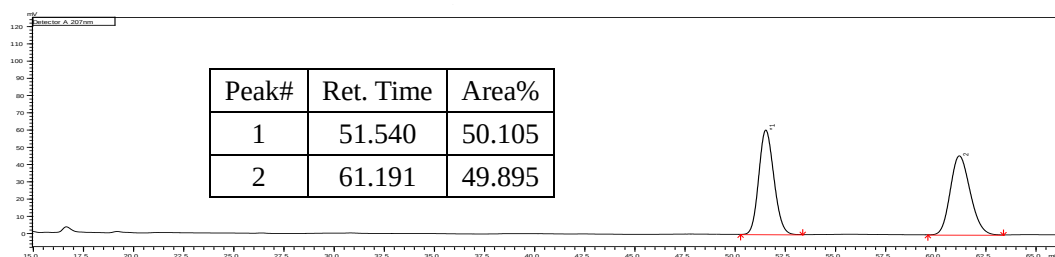
MS (ESI) *m/z* [M+Na]⁺: 243.0.

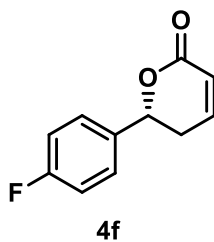
HRMS (ESI) *m/z* [M+Na]⁺: calcd. 243.0450, found 243.0452.

IR (film): 1716, 1382, 1255, 1055, 1025, 972, 811 cm⁻¹.

Optical rotation: [α]_D²⁶ = +181.61 (*c* = 1.010, CHCl₃, 97% ee).

HPLC: DAICEL CHIRALPAK ID, hexane/*i*-PrOH = 4/1, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 60.7 min, *t*_R(minor) = 51.4 min, ee = 97%.





4f: Procedure A, 71.8 mg, white powder, 93% yield.²⁴

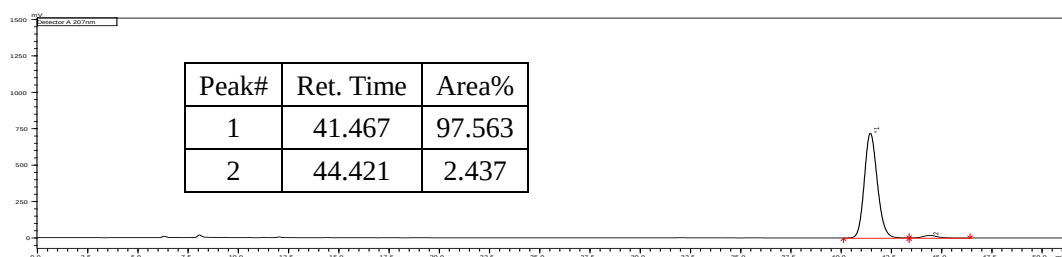
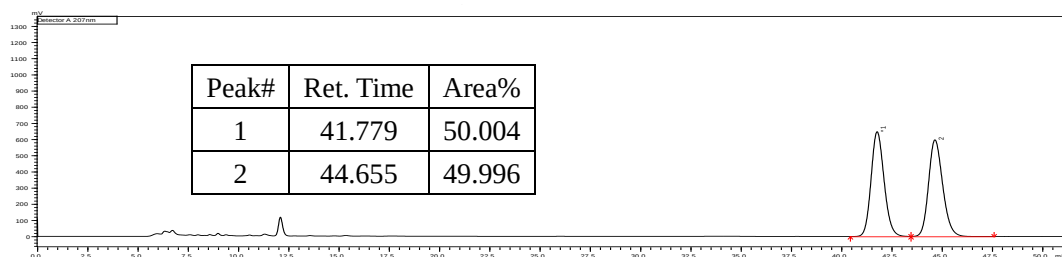
¹H NMR (400 MHz, CDCl₃) δ 7.39 (dd, J = 8.5, 5.3 Hz, 2H), 7.07 (t, J = 8.6 Hz, 2H), 6.97 (ddd, J = 9.5, 5.2, 3.1 Hz, 1H), 6.14-6.11 (m, 1H), 5.43 (dd, J = 10.5, 5.5 Hz, 1H), 2.64-2.60 (m, 2H) ppm.

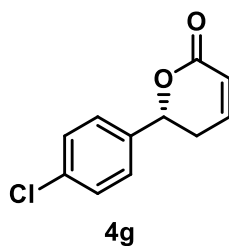
¹³C NMR (100 MHz, CDCl₃) δ 163.83, 162.51 (d, J = 247.2 Hz), 144.94 (d, J = 1.6 Hz), 134.18 (d, J = 3.2 Hz), 127.84 (d, J = 8.3 Hz), 121.33, 115.41 (d, J = 21.7 Hz), 78.48, 31.44 ppm.

¹⁹F NMR (376 MHz, CDCl₃) δ -113.12 ~ -113.19 (m) ppm.

Optical rotation: $[\alpha]_D^{26}$ = +185.17 (c = 1.025, CHCl₃, 95% ee).

HPLC: DAICEL CHIRALPAK IC, hexane/*i*-PrOH = 4/1, flow rate: 0.5 mL/min, λ = 207 nm, t_R (major) = 41.5 min, t_R (minor) = 44.4 min, ee = 95%.





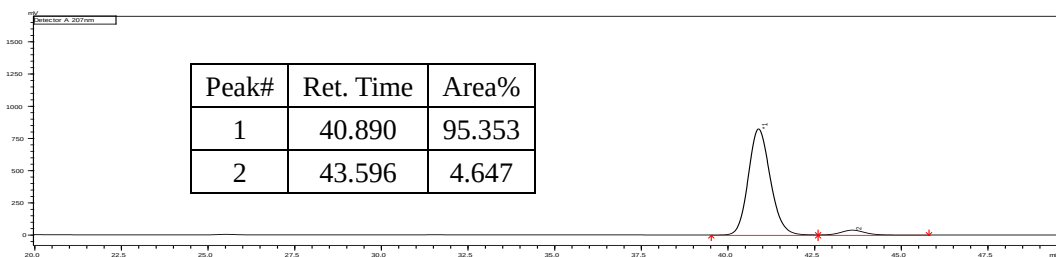
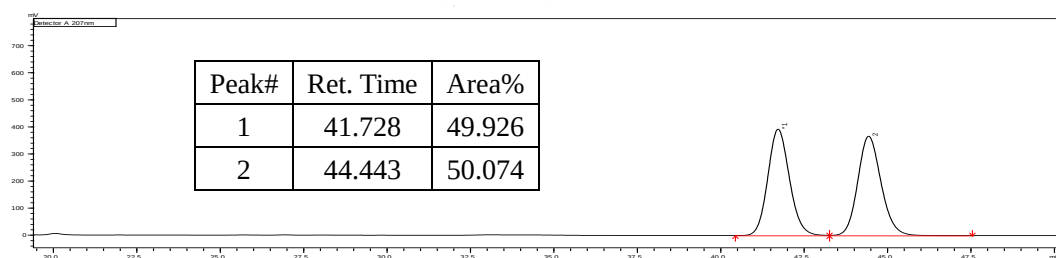
4g: Procedure A, 60.0 mg, white powder, 72% yield.²²

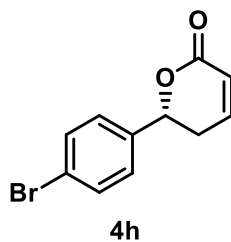
¹H NMR (400 MHz, CDCl₃) δ 7.38-7.33 (m, 4H), 6.99-6.94 (m, 1H), 6.13 (d, *J* = 9.8 Hz, 1H), 5.42 (t, *J* = 8.0 Hz, 1H), 2.62-2.59 (m, 2H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 163.71, 144.77, 136.88, 134.30, 128.75, 127.33, 121.49, 78.37, 31.47 ppm.

Optical rotation: [α]_D²⁷ = +185.71 (*c* = 1.010, CHCl₃, 91% ee).

HPLC: DAICEL CHIRALPAK IC, hexane/*i*-PrOH = 4/1, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 40.9 min, *t*_R(minor) = 43.6 min, ee = 91%.





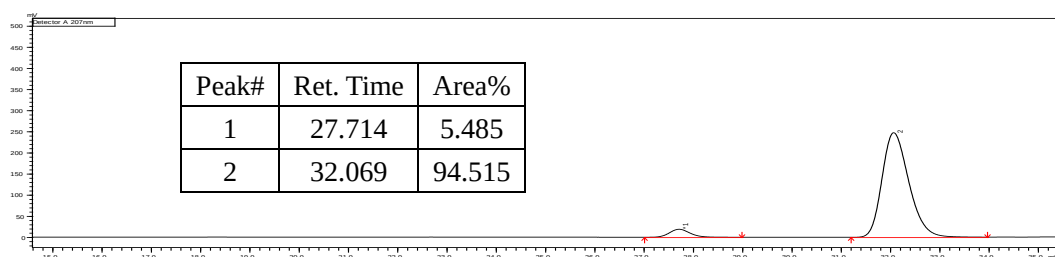
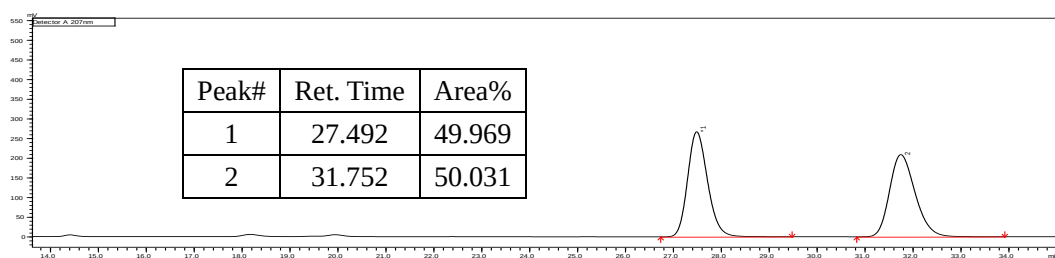
4h: Procedure A, 68.0 mg, pale green powder, 67% yield.²⁵

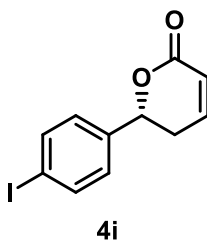
¹H NMR (400 MHz, CDCl₃) δ 7.52 (d, *J* = 8.4 Hz, 2H), 7.29 (d, *J* = 8.4 Hz, 2H), 6.97 (dt, *J* = 9.5, 4.3 Hz, 1H), 6.13 (d, *J* = 9.8 Hz, 1H), 5.41 (t, *J* = 8.0 Hz, 1H), 2.62-2.59 (m, 2H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 163.69, 144.77, 137.39, 131.70, 127.61, 122.44, 121.48, 78.38, 31.43 ppm.

Optical rotation: [α]_D²⁷ = +152.72 (*c* = 1.080, CHCl₃, 89% ee).

HPLC: DAICEL CHIRALPAK ID, hexane/*i*-PrOH = 4/1, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 32.1 min, *t*_R(minor) = 27.7 min, ee = 89%.





4i: Procedure A, 90.3 mg, white powder, 75% yield.

¹H NMR (400 MHz, CDCl₃) δ 7.72 (d, *J* = 8.3 Hz, 2H), 7.16 (d, *J* = 8.3 Hz, 2H), 6.98-6.94 (m, 1H), 6.12 (d, *J* = 9.8 Hz, 1H), 5.39 (t, *J* = 8.0 Hz, 1H), 2.61-2.58 (m, 2H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 163.64, 144.73, 138.05, 137.64, 127.75, 121.49, 94.15, 78.42, 31.41 ppm.

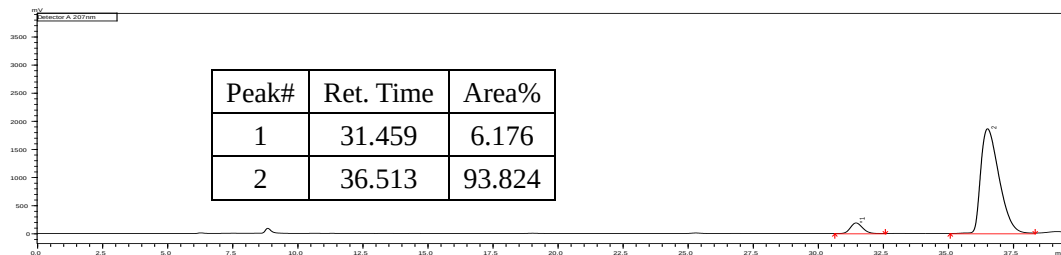
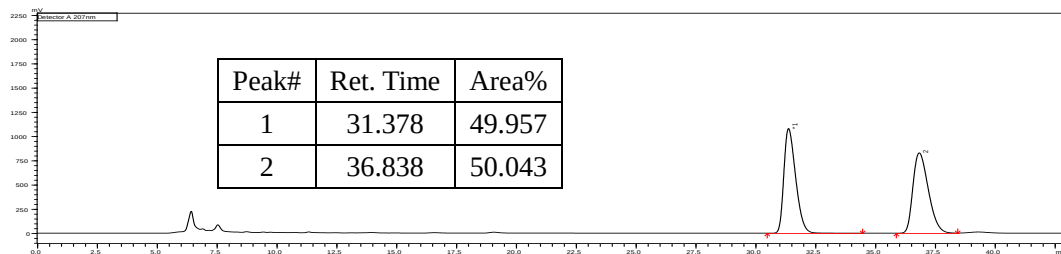
MS (ESI) *m/z* [M+Na]⁺: 323.0.

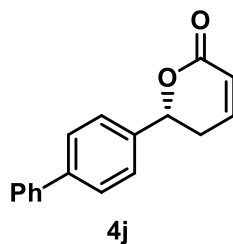
HRMS (ESI) *m/z* [M+Na]⁺: calcd. 322.9539, found 322.9536.

IR (film): 1699, 1252, 1005, 813 cm⁻¹.

Optical rotation: [α]_D²⁷ = +124.52 (*c* = 1.115, CHCl₃, 88% ee).

HPLC: DAICEL CHIRALPAK ID, hexane/*i*-PrOH = 4/1, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 36.5 min, *t*_R(minor) = 31.5 min, ee = 88%.





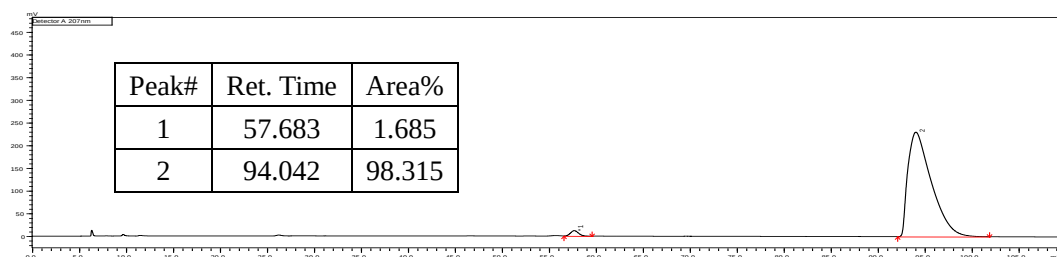
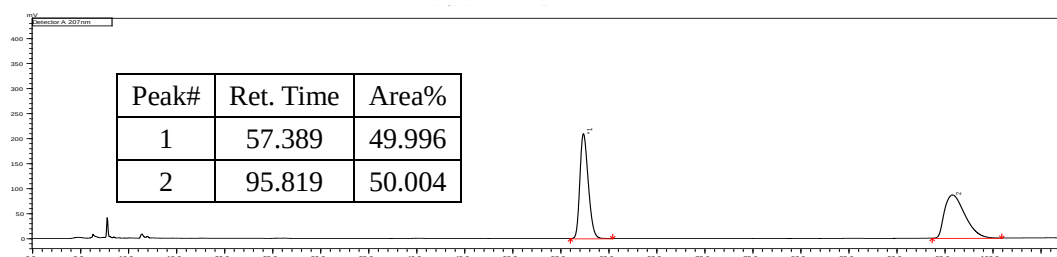
4j: Procedure A, 88.0 mg, white powder, 88% yield.²⁶

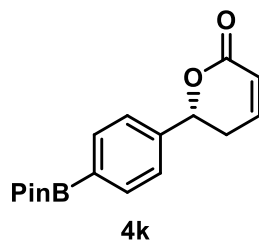
¹H NMR (400 MHz, CDCl₃) δ 7.61-7.57 (m, 4H), 7.47-7.41 (m, 4H), 7.35 (t, *J* = 7.3 Hz, 1H), 6.96 (ddd, *J* = 8.1, 5.2, 2.6 Hz, 1H), 6.13 (d, *J* = 9.8 Hz, 1H), 5.48 (dd, *J* = 10.8, 5.0 Hz, 1H), 2.72-2.59 (m, 2H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 164.02, 144.91, 141.43, 140.30, 137.31, 128.76, 127.48, 127.27, 127.01, 126.44, 121.57, 78.94, 31.50 ppm.

Optical rotation: [α]_D²⁶ = +162.14 (*c* = 1.075, CHCl₃, 97% ee).

HPLC: DAICEL CHIRALPAK ID, hexane/*i*-PrOH = 43/7, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 94.0 min, *t*_R(minor) = 57.7 min, ee = 97%.





4k: Procedure A, 89.0 mg, white powder, 74% yield.

¹H NMR (400 MHz, CDCl₃) δ 7.84 (d, *J* = 7.9 Hz, 2H), 7.41 (d, *J* = 7.9 Hz, 2H), 7.98-6.93 (m, 1H), 6.13 (d, *J* = 9.8 Hz, 1H), 5.47 (t, *J* = 8.0 Hz, 1H), 2.63-2.60 (m, 2H), 1.35 (s, 12H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 163.96, 144.83, 141.32, 135.02, 125.07, 121.57, 83.86, 79.00, 31.62, 24.80, 24.78 ppm.

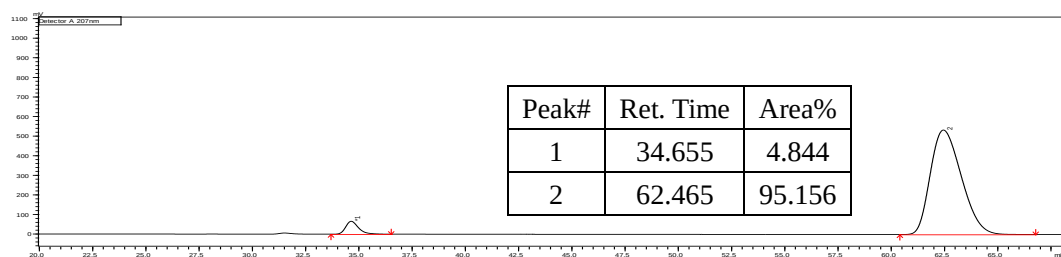
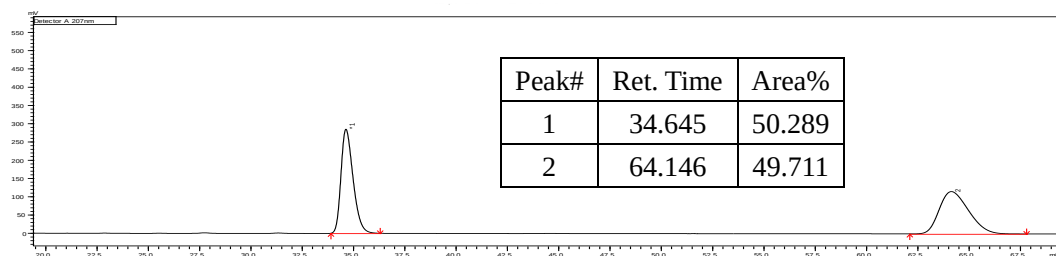
MS (ESI) *m/z* [M+Na]⁺: 322.2 (C₁₇H₂₁O₄¹⁰BNa).

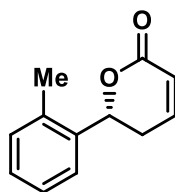
HRMS (ESI) *m/z* [M+Na]⁺: calcd. 322.1461 for (C₁₇H₂₁O₄¹⁰BNa), found 322.1466.

IR (film): 2980, 2929, 1722, 1614, 1364, 1290, 1268, 1145 cm⁻¹.

Optical rotation: [α]_D²⁷ = +134.77 (*c* = 1.035, CHCl₃, 90% ee).

HPLC: DAICEL CHIRALPAK ID, hexane/*i*-PrOH = 4/1, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 62.5 min, *t*_R(minor) = 34.7 min, ee = 90%.





4l

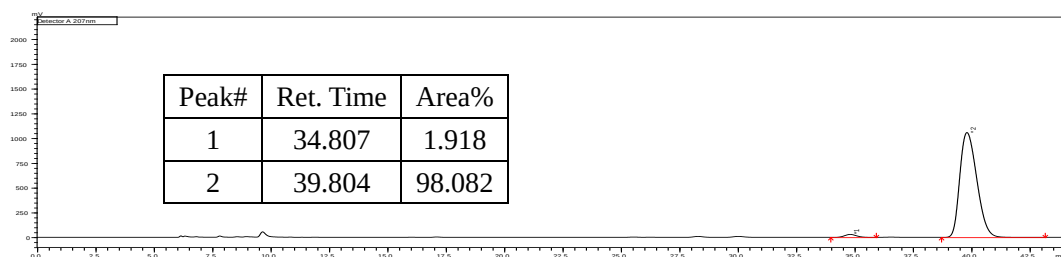
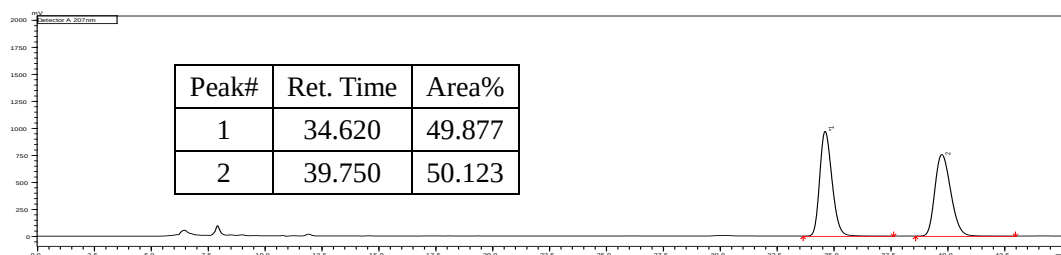
4l: Procedure A, 68.7 mg, brown oil, 91% yield.²⁵

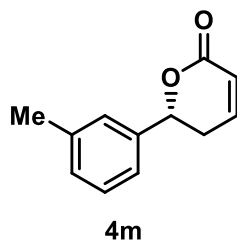
¹H NMR (400 MHz, CDCl₃) δ 7.51-7.48 (m, 1H), 7.26-7.24 (m, 2H), 7.19-7.17 (m, 1H), 6.99 (ddd, J = 9.5, 6.0, 2.3 Hz, 1H), 6.14 (dd, J = 9.7, 2.2 Hz, 1H), 5.65 (dd, J = 12.0, 4.1 Hz, 1H), 2.64-2.55 (m, 2H), 2.36 (s, 3H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 164.36, 145.11, 136.30, 134.70, 130.61, 128.42, 126.39, 126.12, 121.50, 76.61, 30.38, 19.01 ppm.

Optical rotation: $[\alpha]_D^{27}$ = +180.75 (c = 0.990, CHCl₃, 96% ee).

HPLC: DAICEL CHIRALPAK ID, hexane/*i*-PrOH = 43/7, flow rate: 0.5 mL/min, λ = 207 nm, t_R (major) = 39.8 min, t_R (minor) = 34.8 min, ee = 96%.





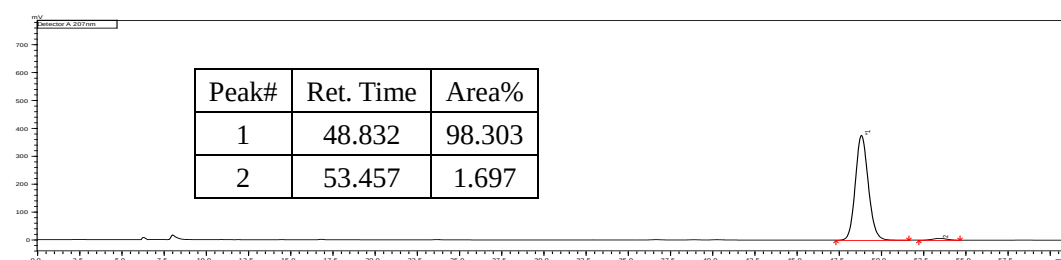
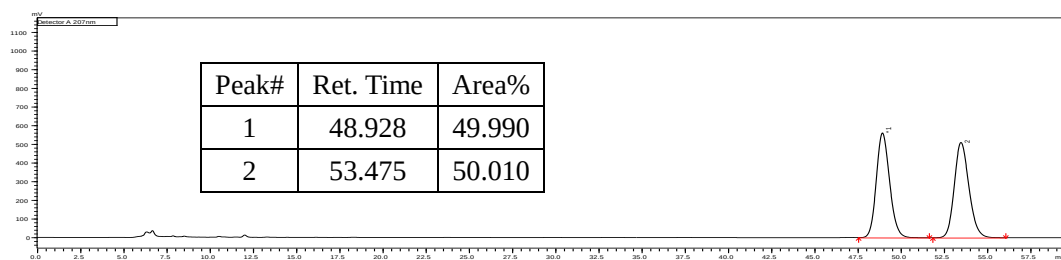
4m: Procedure A, 68.4 mg, brown oil, 91% yield.²³

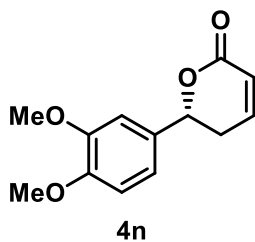
¹H NMR (400 MHz, CDCl₃) δ 7.29-7.24 (m, 2H), 7.17 (t, *J* = 8.3 Hz, 2H), 6.96 (ddd, *J* = 9.6, 5.5, 2.9 Hz, 1H), 6.12 (dd, *J* = 9.7, 1.2 Hz, 1H), 5.40 (dd, *J* = 10.9, 5.1 Hz, 1H), 2.64-2.59 (m, 2H), 2.36 (s, 3H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 164.10, 144.99, 138.31, 138.28, 129.21, 128.42, 126.61, 122.96, 121.46, 79.19, 31.55, 21.32 ppm.

Optical rotation: [α]_D²⁷ = +191.80 (*c* = 1.009, CHCl₃, 97% ee).

HPLC: DAICEL CHIRALPAK IC, hexane/*i*-PrOH = 4/1, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 48.8 min, *t*_R(minor) = 53.5 min, ee = 97%.





4n: Procedure B, 72.1 mg, brown powder, 77% yield.

¹H NMR (400 MHz, CDCl₃) δ 6.99-6.91 (m, 3H), 6.86 (d, *J* = 8.2 Hz, 1H), 6.12 (dd, *J* = 9.8, 1.9 Hz, 1H), 5.39 (dd, *J* = 11.8, 4.2 Hz, 1H), 3.90 (s, 3H), 3.88 (s, 3H), 2.72-2.55 (m, 2H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 164.14, 149.06, 148.92, 145.03, 130.80, 121.37, 118.46, 110.73, 109.15, 79.13, 55.80, 55.78, 31.50 ppm.

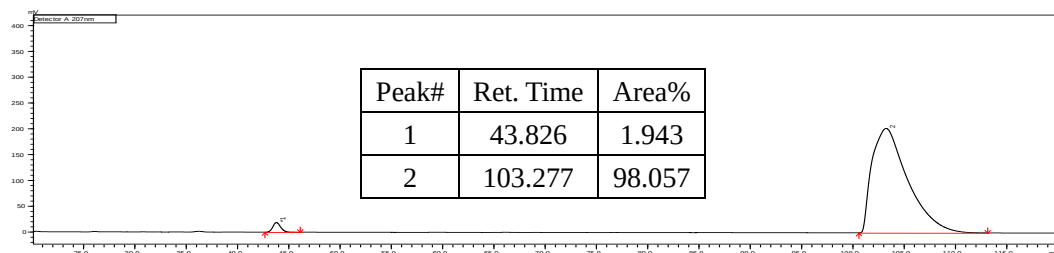
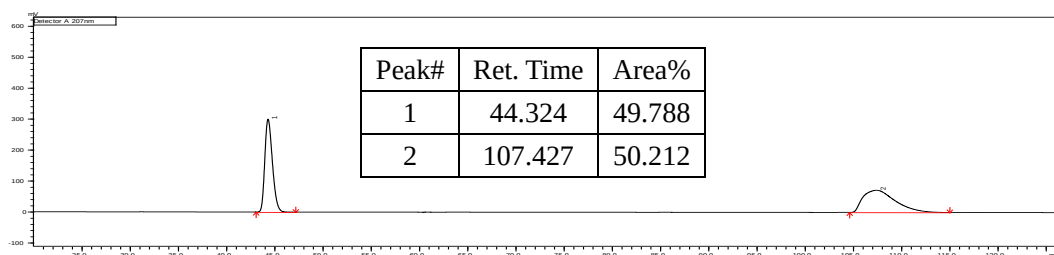
MS (ESI) m/z [M+Na]⁺: 257.1.

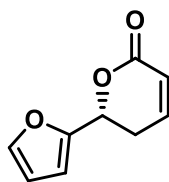
HRMS (ESI) m/z [M+Na]⁺: calcd. 257.0784, found 257.0786.

IR (film): 2990, 2965, 1729, 1519, 1422, 1380, 1254 cm⁻¹.

Optical rotation: [α]_D²⁶ = +170.82 (*c* = 1.020, CHCl₃, 96% ee).

HPLC: DAICEL CHIRALPAK ID, hexane/*i*-PrOH = 3/2, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 103.3 min, *t*_R(minor) = 43.8 min, ee = 96%.





4o

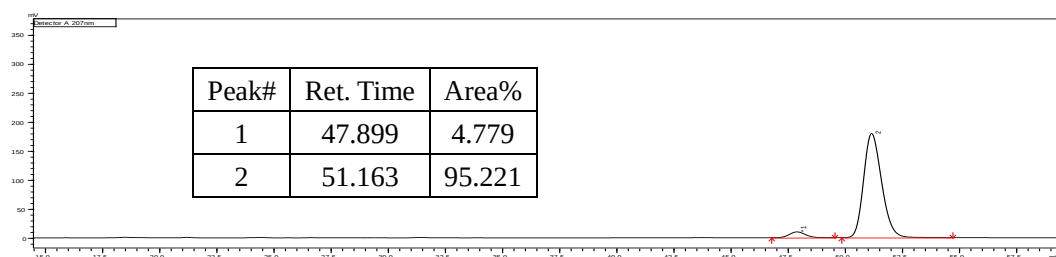
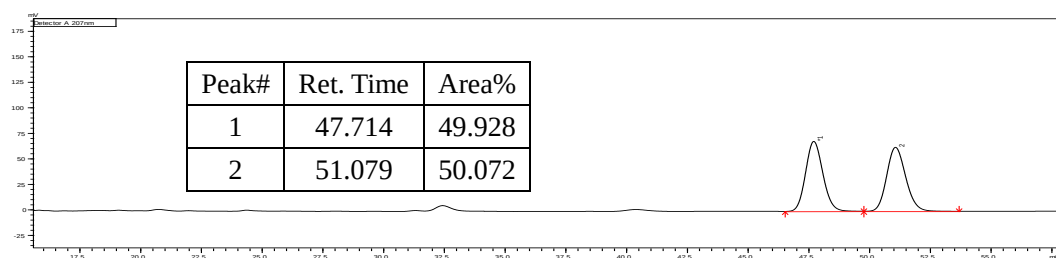
4o: Procedure A, 36.7 mg, brown oil, 56% yield.^{23,27}

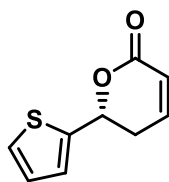
¹H NMR (400 MHz, CDCl₃) δ 7.44-7.43 (m, 1H), 6.96 (ddd, *J* = 9.8, 5.7, 2.8 Hz, 1H), 6.43 (d, *J* = 3.3 Hz, 1H), 6.38 (dd, *J* = 3.3, 1.8 Hz, 1H), 6.10 (ddd, *J* = 9.8, 2.5, 1.1 Hz, 1H), 5.50 (dd, *J* = 11.1, 4.3 Hz, 1H), 2.94 (ddt, *J* = 18.5, 11.1, 2.7 Hz, 1H), 2.68-2.60 (m, 1H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 163.33, 150.40, 144.57, 143.06, 121.42, 110.45, 109.01, 72.30, 27.59 ppm.

Optical rotation: [α]_D²⁵ = +57.03 (*c* = 0.225, CHCl₃, 90% ee).

HPLC: DAICEL CHIRALPAK ID, hexane/*i*-PrOH = 22/3, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 51.2 min, *t*_R(minor) = 47.9 min, ee = 90%.





4p

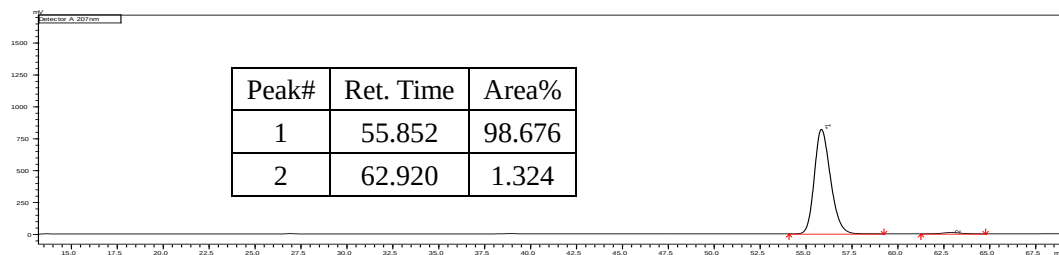
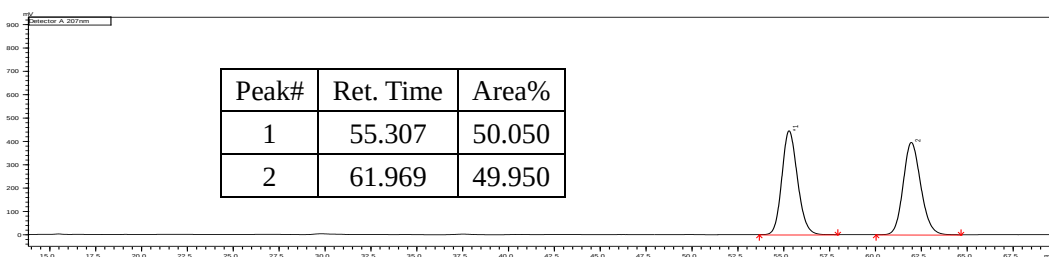
4p: Procedure A, 57.5 mg, brown oil, 80% yield.^{23,27}

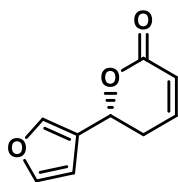
¹H NMR (400 MHz, CDCl₃) δ 7.33 (dd, J = 5.0, 0.9 Hz, 1H), 7.10 (d, J = 3.5 Hz, 1H), 7.00 (dd, J = 5.0, 3.7 Hz, 1H), 6.98-6.94 (m, 1H), 6.11 (dd, J = 9.8, 1.1 Hz, 1H), 5.69 (dd, J = 10.5, 4.8 Hz, 1H), 2.85-2.71 (m, 2H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 163.37, 144.60, 140.90, 126.69, 125.99, 125.83, 121.51, 74.87, 31.25 ppm.

Optical rotation: $[\alpha]_D^{26}$ = +82.07 (c = 0.920, CHCl₃, 97% ee).

HPLC: DAICEL CHIRALPAK IC, hexane/*i*-PrOH = 4/1, flow rate: 0.5 mL/min, λ = 207 nm, t_R (major) = 55.9 min, t_R (minor) = 62.9 min, ee = 97%.





4q

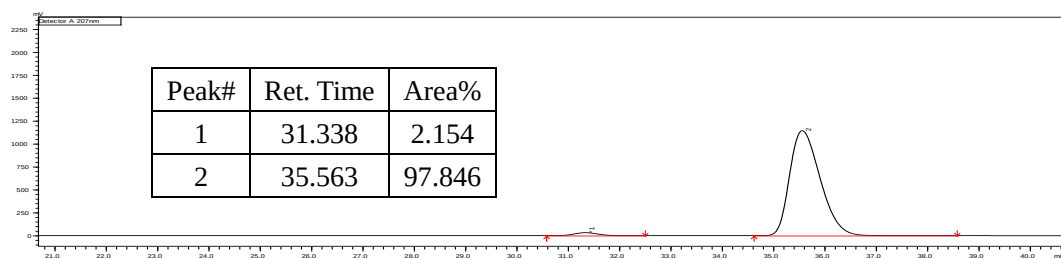
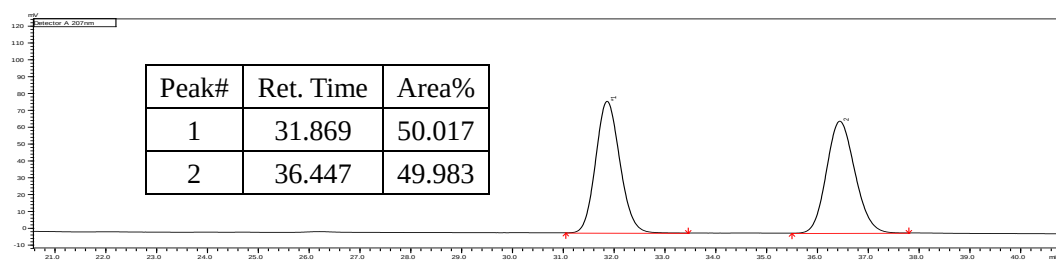
4q: Procedure A, 32.8 mg, brown oil, 50% yield.^{23,28}

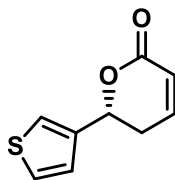
¹H NMR (400 MHz, CDCl₃) 7.50 (s, 1H), 7.43 (s, 1H), 6.96 (ddd, *J* = 9.5, 5.3, 3.1 Hz, 1H), 6.47 (s, 1H), 6.11 (dd, *J* = 9.8, 0.8 Hz, 1H), 5.46 (dd, *J* = 10.3, 5.1 Hz, 1H), 2.68-2.63 (m, 2H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 163.81, 144.73, 143.63, 139.90, 123.76, 121.57, 108.51, 72.39, 30.08 ppm.

Optical rotation: [α]_D²⁶ = +92.75 (*c* = 0.965, CHCl₃, 96% ee).

HPLC: DAICEL CHIRALPAK ID, hexane/*i*-PrOH = 4/1, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 35.6 min, *t*_R(minor) = 31.3 min, ee = 96%.





4r

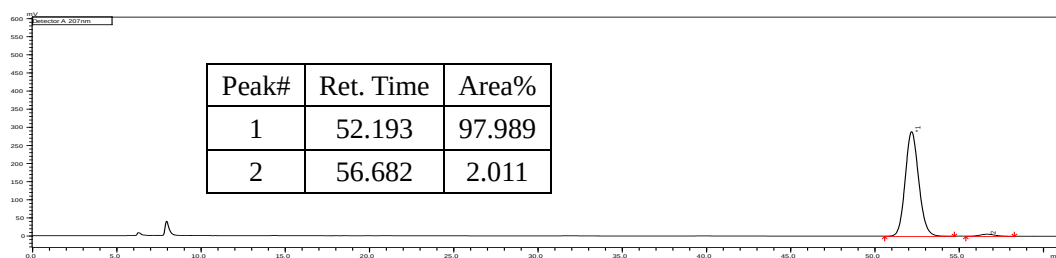
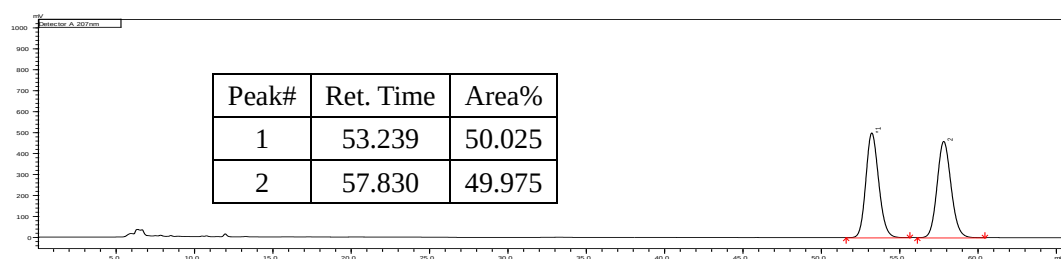
4r: Procedure A, 55.8 mg, brown oil, 78% yield.²³

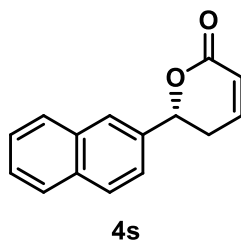
¹H NMR (400 MHz, CDCl₃) δ 7.36-7.34 (m, 2H), 7.13 (dd, J = 4.8, 1.4 Hz, 1H), 6.96 (ddd, J = 9.6, 5.0, 3.4 Hz, 1H), 6.13-6.10 (m, 1H), 5.55 (dd, J = 9.7, 5.8 Hz, 1H), 2.72-2.68 (m, 2H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 163.87, 144.72, 139.52, 126.62, 125.48, 122.48, 121.66, 75.45, 30.71 ppm.

Optical rotation: $[\alpha]_D^{26} = +150.03$ (c = 0.953, CHCl₃, 96% ee).

HPLC: DAICEL CHIRALPAK IC, hexane/*i*-PrOH = 4/1, flow rate: 0.5 mL/min, λ = 207 nm, t_R (major) = 52.2 min, t_R (minor) = 56.7 min, ee = 96%.





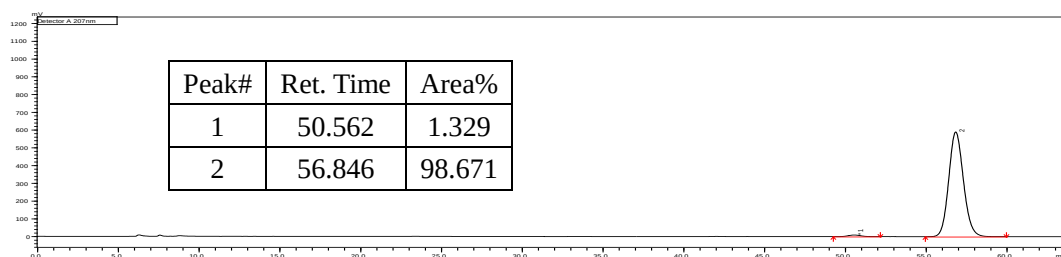
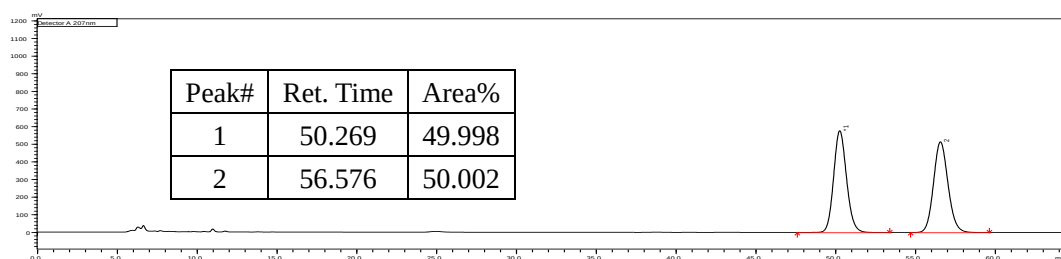
4s: Procedure A, 76.0 mg, white powder, 85% yield.²⁹

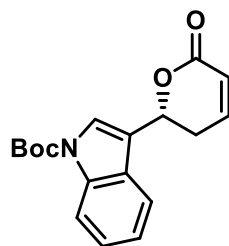
¹H NMR (400 MHz, CDCl₃) δ 7.83-7.80 (m, 4H), 7.49-7.44 (m, 3H), 6.94-6.90 (m, 1H), 6.12 (d, *J* = 9.7 Hz, 1H), 5.54 (dd, *J* = 10.8, 5.1 Hz, 1H), 2.65-2.60 (m, 2H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 163.99, 144.95, 135.65, 133.05, 132.88, 128.41, 127.96, 127.57, 126.36, 126.33, 125.02, 123.41, 121.38, 79.13, 31.45 ppm.

Optical rotation: [α]_D²⁷ = +195.51 (*c* = 1.070, CHCl₃, 97% ee).

HPLC: DAICEL CHIRALPAK IC, hexane/*i*-PrOH = 3/1, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 56.8 min, *t*_R(minor) = 50.6 min, ee = 97%.





4t

4t: Procedure B, 88.1 mg, brown oil, 70% yield.

^1H NMR (400 MHz, CDCl_3) δ 8.16 (d, J = 8.1 Hz, 1H), 7.64-7.61 (m, 2H), 7.34 (t, J = 7.6 Hz, 1H), 7.24 (t, J = 7.6 Hz, 1H), 7.01-6.97 (m, 1H), 6.13 (dd, J = 9.8, 1.6 Hz, 1H), 5.71 (dd, J = 11.5, 4.0 Hz, 1H), 2.89-2.68 (m, 2H), 1.66 (s, 9H) ppm.

^{13}C NMR (100 MHz, CDCl_3) δ 163.97, 149.30, 145.08, 135.49, 127.76, 124.74, 123.37, 122.73, 121.36, 119.44, 118.12, 115.29, 84.05, 73.27, 29.67, 28.00 ppm.

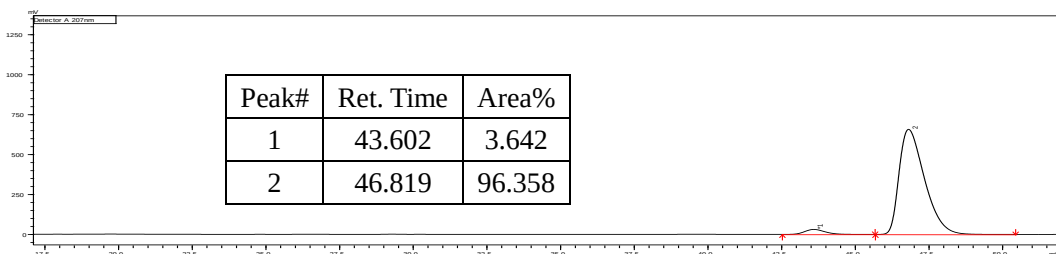
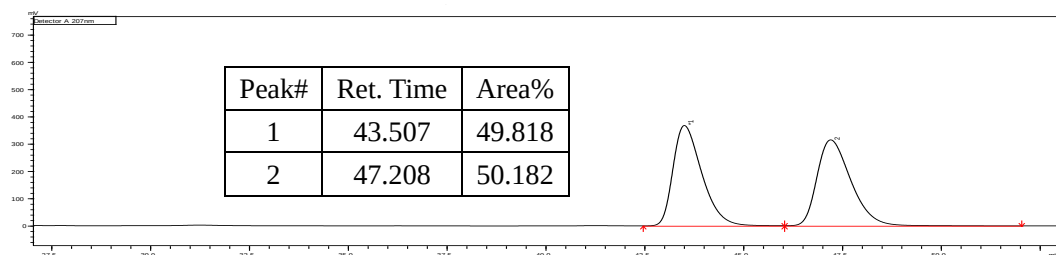
MS (ESI) m/z $[\text{M}+\text{Na}]^+$: 336.1.

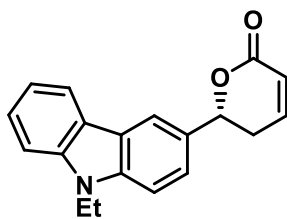
HRMS (ESI) m/z $[\text{M}+\text{Na}]^+$: calcd. 336.1206, found 336.1209.

IR (film): 2979, 2933, 1731, 1453, 1732, 1252, 1153, 1094, 1059, 816, 747 cm^{-1} .

Optical rotation: $[\alpha]_{\text{D}}^{27}$ = +84.09 (c = 1.045, CHCl_3 , 93% ee).

HPLC: DAICEL CHIRALPAK ID, hexane/*i*-PrOH = 43/7, flow rate: 0.5 mL/min, λ = 207 nm, $t_{\text{R}}(\text{major})$ = 46.8 min, $t_{\text{R}}(\text{minor})$ = 43.6 min, ee = 93%.





4u

4u: Procedure B, 101.3 mg, yellow foam, 87% yield.

¹H NMR (400 MHz, CDCl₃) δ 8.12 (s, 1H), 8.07 (d, *J* = 7.8 Hz, 1H), 7.48-7.43 (m, 2H), 7.39-7.34 (m, 2H), 7.23 (t, *J* = 7.3 Hz, 1H), 6.97-6.92 (m, 1H), 6.14 (dd, *J* = 9.7, 1.8 Hz, 1H), 5.57 (dd, *J* = 12.1, 3.8 Hz, 1H), 4.31 (q, *J* = 7.2 Hz, 2H), 2.80-2.57 (m, 2H), 1.38 (t, *J* = 7.2 Hz, 3H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 164.51, 145.21, 140.21, 139.81, 128.72, 125.88, 123.85, 122.72, 122.56, 121.47, 120.37, 118.97, 118.37, 108.55, 108.42, 80.10, 37.50, 32.04, 13.69 ppm.

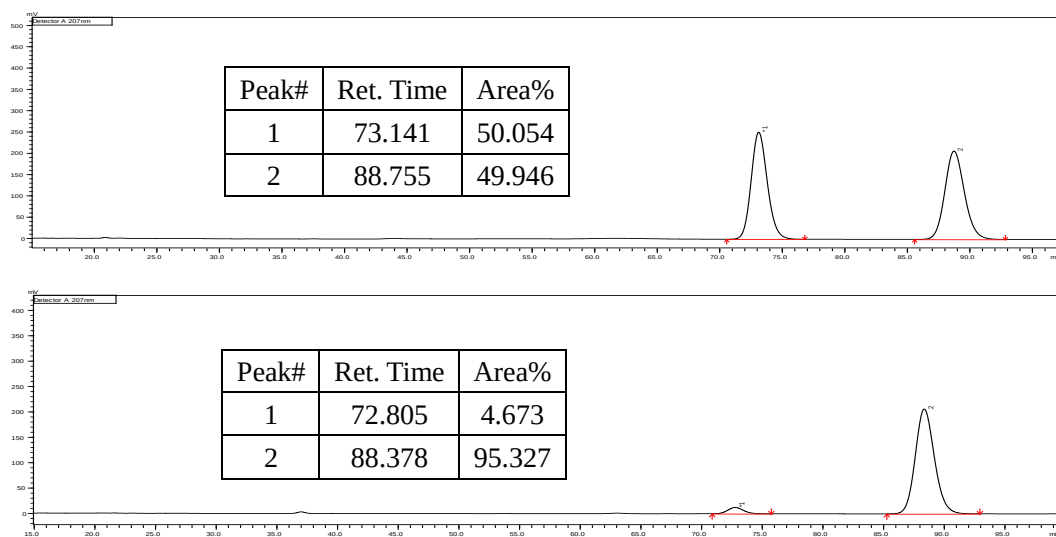
MS (ESI) *m/z* [M+Na]⁺: 314.1.

HRMS (ESI) *m/z* [M+Na]⁺: calcd. 314.1152, found 314.1153.

IR (film): 2975, 1712, 1492, 1471, 1380, 1244, 1017, 815 cm⁻¹.

Optical rotation: [α]_D²⁷ = +132.20 (*c* = 1.015, CHCl₃, 91% ee).

HPLC: DAICEL CHIRALPAK IC, hexane/*i*-PrOH = 7/3, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 88.4 min, *t*_R(minor) = 72.8 min, ee = 91%.



4.2. General procedure for catalytic asymmetric DVAR of aliphatic aldehydes

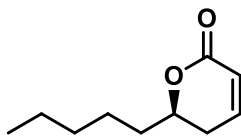
In most cases, it is very difficult to separate the CP from the mixture of CP, LP and 2-butyne-1-ol by silica gel column chromatography. Therefore, after the completion of the reaction, acetic anhydride and DMAP were added to the reaction mixture to transform alcohols to esters so that CP could be purified by silica gel column chromatography conveniently.

Procedure C:

A dried 10 mL Schlenk tube equipped with a magnetic stirring bar was charged with mesitylcopper (3.6 mg, 0.02 mmol, 0.05 equiv) and (*R,R*)-Ph-BPE (10.1 mg, 0.02 mmol, 0.05 equiv) in a glove box under Ar atmosphere. Anhydrous THF (2.0 mL, 0.2 M) was added via syringe. The mixture was stirred for 15 minutes to give a brown catalyst solution. Then **1c** (82.9 mg, 0.6 mmol, 1.5 equiv) and aliphatic aldehyde **5** or **7** (0.4 mmol, 1.0 equiv) were added sequentially at room temperature. The resulting reaction mixture was stirred at room temperature for 12 hours. Then, to the reaction mixture were added acetic anhydride (41 μ L, 0.44 mmol, 1.1 equiv) and DMAP (4.9 mg, 0.04 mmol, 0.1 equiv). The mixture was stirred for additional 2 hours at room temperature, and then the solvent was removed under reduced pressure. The residue was purified by silica gel column chromatography (petroleum ether/ethyl acetate) to give the product.

Procedure D:

A dried 10 mL Schlenk tube equipped with a magnetic stirring bar was charged with mesitylcopper (3.6 mg, 0.02 mmol, 0.05 equiv) and (*S,S*)-Ph-BPE (10.1 mg, 0.02 mmol, 0.05 equiv) in a glove box under Ar atmosphere. Anhydrous THF (2.0 mL, 0.2 M) was added via syringe. The mixture was stirred for 15 minutes to give a brown catalyst solution. Then **1c** (82.9 mg, 0.6 mmol, 1.5 equiv) and aliphatic aldehyde **7** (0.4 mmol, 1.0 equiv) were added sequentially at room temperature. The resulting reaction mixture was stirred at room temperature for 12 hours. Then, to the reaction mixture were added acetic anhydride (41 μ L, 0.44 mmol, 1.1 equiv) and DMAP (4.9 mg, 0.04 mmol, 0.1 equiv). The mixture was stirred for additional 2 hours at room temperature, and then the solvent was removed under reduced pressure. The residue was purified by silica gel column chromatography (petroleum ether/ethyl acetate) to give the product.



6a

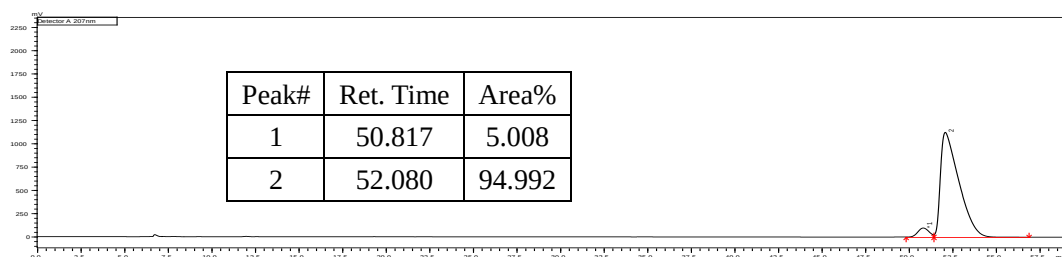
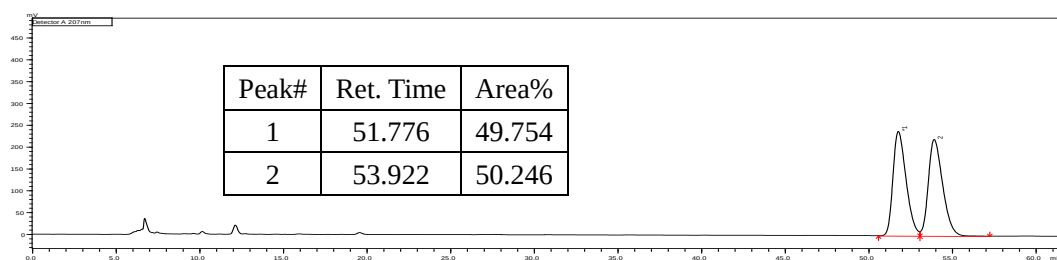
6a: Procedure C, 45.8 mg, colorless oil, 68% yield.³⁰

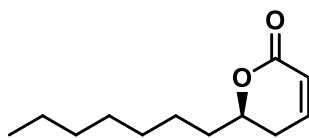
¹H NMR (400 MHz, CDCl₃) δ 6.92-6.87 (m, 1H), 6.03-6.00 (m, 1H), 4.46-4.39 (m, 1H), 2.36-2.31 (m, 2H), 1.80-1.32 (m, 8H), 0.90 (t, *J* = 6.6 Hz, 3H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 164.53, 145.07, 121.25, 77.94, 34.72, 31.42, 29.28, 24.38, 22.40, 13.88 ppm.

Optical rotation: [α]_D²⁷ = -76.94 (*c* = 1.035, CHCl₃, 90% ee).

HPLC: DAICEL CHIRALPAK IE, hexane/*i*-PrOH = 47/3, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 52.1 min, *t*_R(minor) = 50.8 min, ee = 90%.





6b

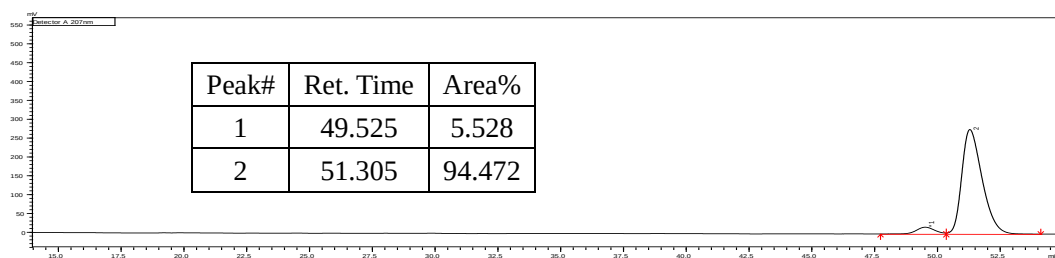
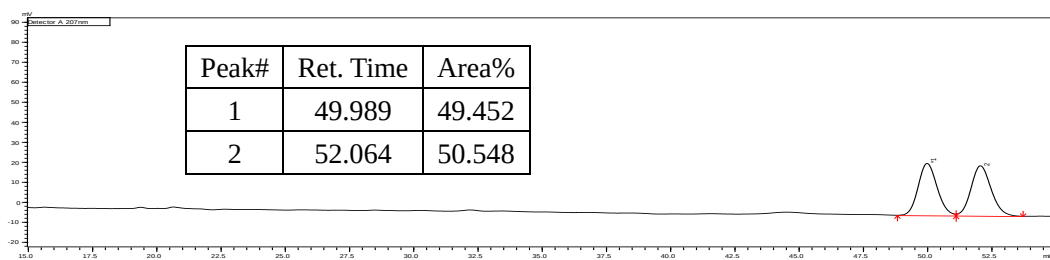
6b: Procedure C, 52.6 mg, colorless oil, 67% yield.³¹

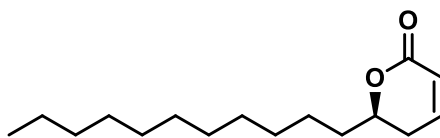
¹H NMR (400 MHz, CDCl₃) δ 6.89 (ddd, *J* = 9.6, 5.4, 3.0 Hz, 1H), 6.01 (ddd, *J* = 9.7, 2.2, 1.3 Hz, 1H), 4.46-4.39 (m, 1H), 2.36-2.31 (m, 2H), 1.86-1.28 (m, 12H), 0.88 (t, *J* = 6.8 Hz, 3H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 164.54, 145.09, 121.20, 77.92, 34.73, 31.61, 29.26, 29.19, 29.00, 24.68, 22.49, 13.96 ppm.

Optical rotation: [α]_D²⁹ = -66.19 (*c* = 0.965, CHCl₃, 89% ee).

HPLC: DAICEL CHIRALPAK IE, hexane/*i*-PrOH = 47/3, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 51.3 min, *t*_R(minor) = 49.5 min, ee = 89%.





6c

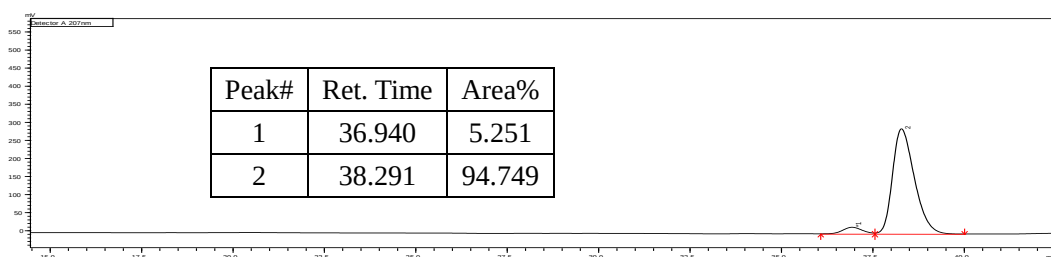
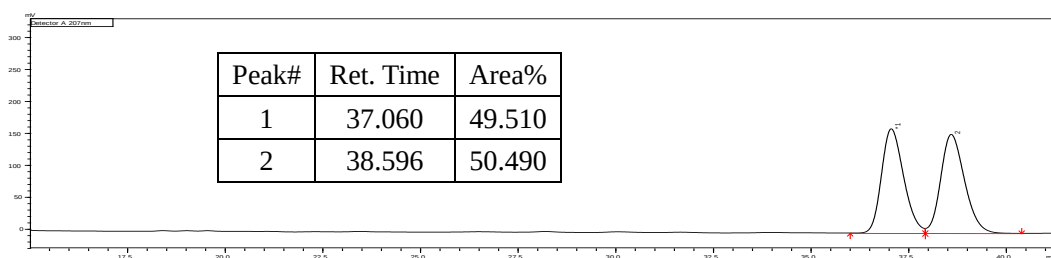
6c: Procedure C, 68.5 mg, colorless powder, 68% yield.³²

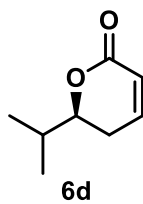
¹H NMR (400 MHz, CDCl₃) δ 6.91-6.86 (m, 1H), 6.02 (d, *J* = 10.0 Hz, 1H), 4.45-4.38 (m, 1H), 2.35-2.31 (m, 2H), 1.81-1.26 (m, 20H), 0.88 (t, *J* = 6.8 Hz, 3H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 164.56, 145.05, 121.28, 77.95, 34.78, 31.82, 29.54, 29.52, 29.45, 29.38, 29.30, 29.28, 29.25, 24.72, 22.60, 14.04 ppm.

Optical rotation: [α]_D²⁹ = -55.25 (*c* = 1.005, CHCl₃, 90% ee).

HPLC: DAICEL CHIRALPAK IE, hexane/*i*-PrOH = 47/3, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 38.3 min, *t*_R(minor) = 36.9 min, ee = 90%.





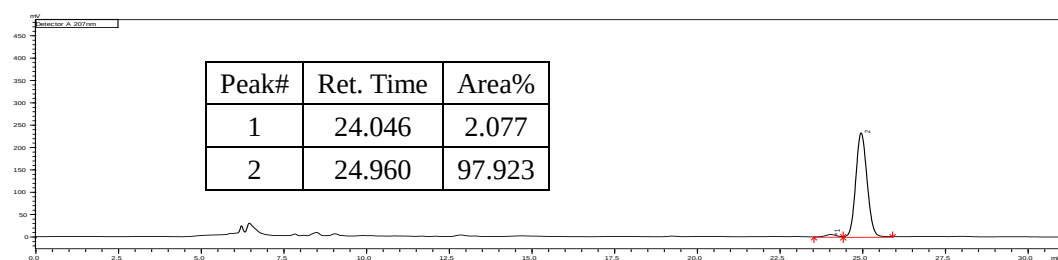
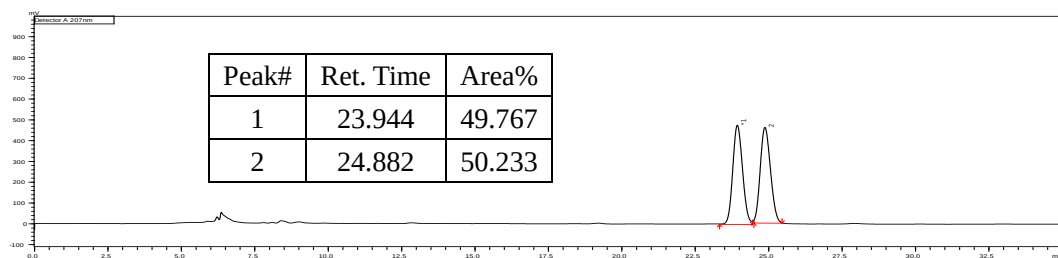
6d: Procedure C, 40.4 mg, colorless oil, 72% yield.³³

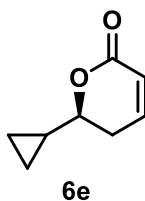
¹H NMR (400 MHz, CDCl₃) δ 6.95-6.90 (m, 1H), 6.03-6.00 (m, 1H), 4.22-4.16 (m, 1H), 2.36-2.32 (m, 2H), 2.01-1.93 (m, 1H), 1.04 (d, *J* = 6.8 Hz, 3H), 1.01 (d, *J* = 6.9 Hz, 3H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 164.72, 145.37, 121.07, 82.50, 31.86, 26.27, 17.75, 17.68 ppm.

Optical rotation: [α]_D²⁹ = -117.54 (*c* = 0.950, CHCl₃, 96% ee).

HPLC: DAICEL CHIRALPAK IBN-3, hexane/*i*-PrOH = 24/1, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 25.0 min, *t*_R(minor) = 24.0 min, ee = 96%.





6e: Procedure C, 43.3 mg, colorless oil, 78% yield.

¹H NMR (400 MHz, CDCl₃) δ 6.94-6.89 (m, 1H), 6.02 (d, *J* = 9.7 Hz, 1H), 3.74 (dd, *J* = 15.8, 8.0 Hz, 1H), 2.52-2.49 (m, 2H), 1.21-1.13 (m, 1H), 0.70-0.58 (m, 2H), 0.54-0.48 (m, 1H), 0.35-0.28 (m, 1H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 164.39, 145.11, 121.14, 82.36, 29.30, 14.65, 3.23, 1.97 ppm.

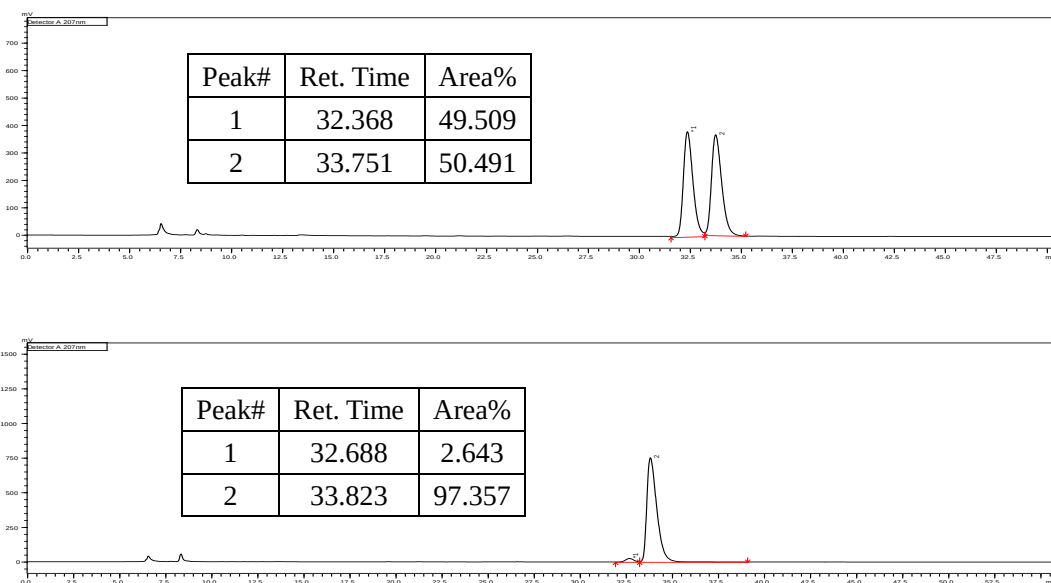
MS (ESI) *m/z* [M+H]⁺: 139.20.

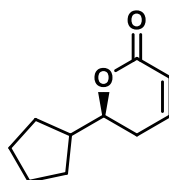
HRMS (DART) *m/z* [M+H]⁺: calcd. 139.0754, found 139.0753.

IR (film): 1717, 1195, 1033, 817 cm⁻¹.

Optical rotation: [α]_D²⁸ = -74.80 (*c* = 1.030, CHCl₃, 95% ee).

HPLC: DAICEL CHIRALPAK IBN-3, hexane/*i*-PrOH = 47/3, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 33.8 min, *t*_R(minor) = 32.7 min, ee = 95%.





6f

6f: Procedure C, 49.3 mg, colorless oil, 74% yield.

^1H NMR (400 MHz, CDCl_3) δ 6.93-6.88 (m, 1H), 6.02-6.00 (m, 1H), 4.26-4.20 (m, 1H), 2.39-2.33 (m, 2H), 2.20-2.10 (m, 1H), 1.97-1.23 (m, 8H) ppm.

^{13}C NMR (100 MHz, CDCl_3) δ 164.61, 145.23, 121.06, 81.60, 43.88, 28.50, 28.41, 28.24, 25.25, 25.11 ppm.

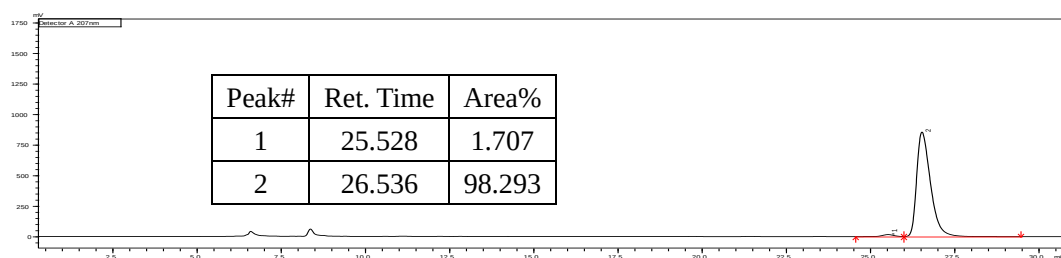
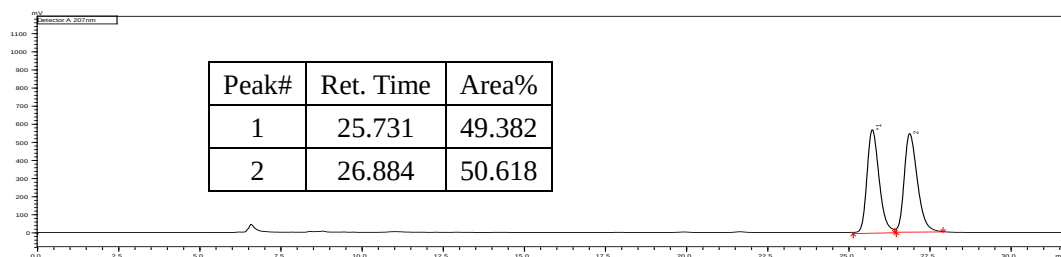
MS (ESI) m/z $[\text{M}+\text{H}]^+$: 167.15.

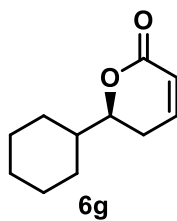
HRMS (DART) m/z $[\text{M}+\text{H}]^+$: calcd. 167.1067, found 167.1067.

IR (film): 2954, 2869, 1718, 1249, 1055, 1030, 816 cm^{-1} .

Optical rotation: $[\alpha]_{\text{D}}^{28} = -78.10$ ($c = 1.000$, CHCl_3 , 97% ee).

HPLC: DAICEL CHIRALPAK IBN-3, hexane/*i*-PrOH = 47/3, flow rate: 0.5 mL/min, $\lambda = 207$ nm, $t_{\text{R}}(\text{major}) = 26.5$ min, $t_{\text{R}}(\text{minor}) = 25.5$ min, ee = 97%.





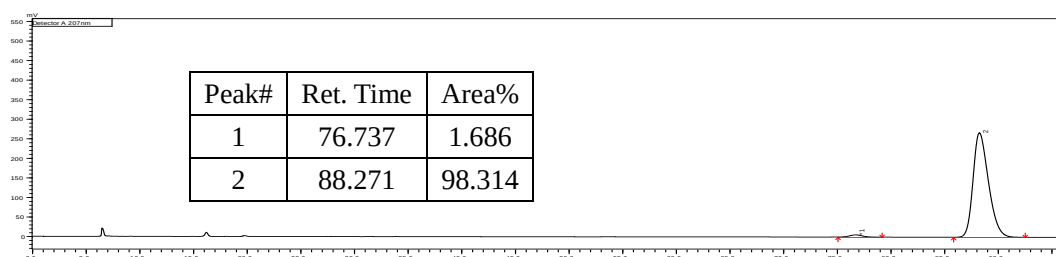
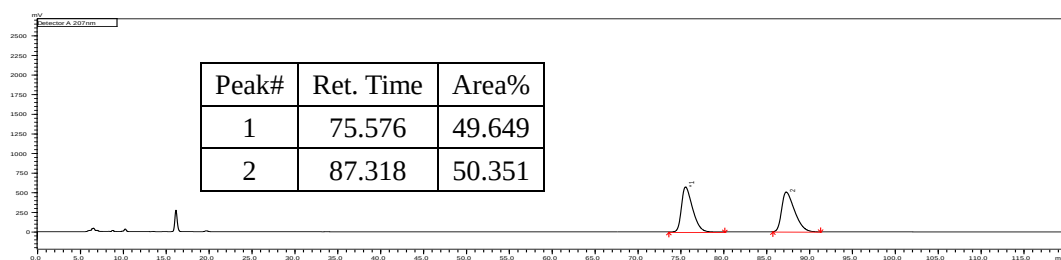
6g: Procedure C, 52.0 mg, colorless powder, 72% yield.³⁰

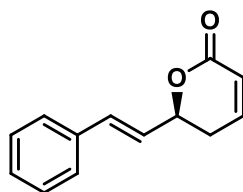
¹H NMR (400 MHz, CDCl₃) δ 6.94-6.85 (m, 1H), 6.01 (dd, *J* = 9.7, 1.3 Hz, 1H), 4.22-4.17 (m, 1H), 2.37-2.32 (m, 2H), 1.96 (d, *J* = 12.7 Hz, 1H), 1.80-1.06 (m, 10H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 164.62, 145.37, 121.08, 81.87, 41.49, 28.03, 26.40, 26.08, 25.73, 25.61 ppm.

Optical rotation: [α]_D²⁹ = -86.96 (*c* = 0.940, CHCl₃, 97% ee).

HPLC: DAICEL CHIRALPAK IC, hexane/*i*-PrOH = 9/1, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 88.3 min, *t*_R(minor) = 76.7 min, ee = 97%.





6h

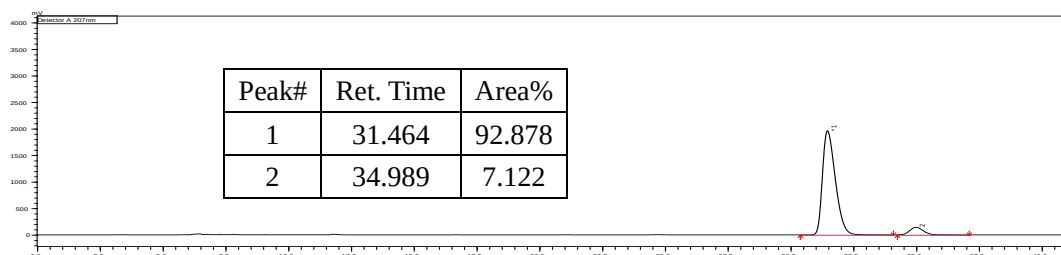
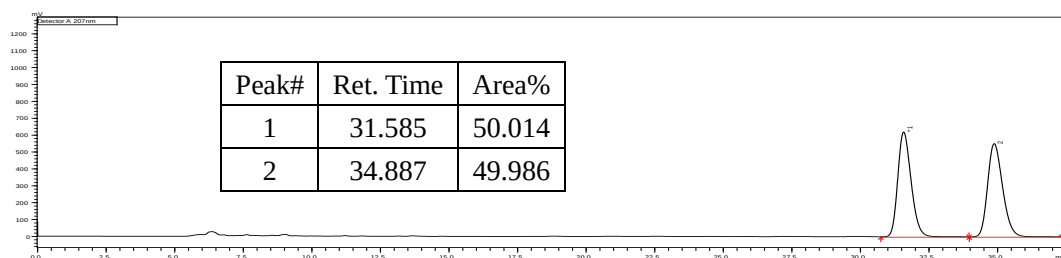
6h: Procedure C, 56.0 mg, white powder, 70% yield.³⁴

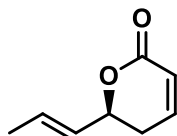
¹H NMR (400 MHz, CDCl₃) δ 7.40-7.26 (m, 5H), 6.94-6.89 (m, 1H), 6.72 (d, J = 16.0 Hz, 1H), 6.27 (dd, J = 16.0, 6.3 Hz, 1H), 6.08 (d, J = 9.9 Hz, 1H), 5.09 (dd, J = 14.3, 6.4 Hz, 1H), 2.55-2.51 (m, 2H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 163.84, 144.66, 135.65, 133.00, 128.60, 128.27, 126.61, 125.55, 121.51, 77.87, 29.78 ppm.

Optical rotation: $[\alpha]_D^{29} = -120.96$ (c = 1.130, CHCl₃, 86% ee).

HPLC: DAICEL CHIRALPAK ID, hexane/*i*-PrOH = 4/1, flow rate: 0.5 mL/min, λ = 207 nm, t_R (major) = 31.5 min, t_R (minor) = 35.0 min, ee = 86%.





6i

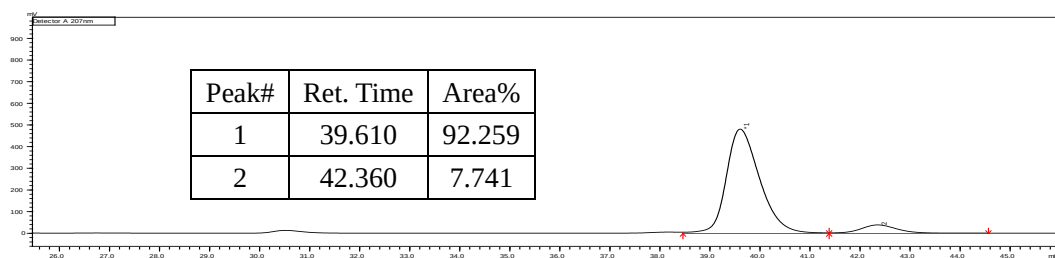
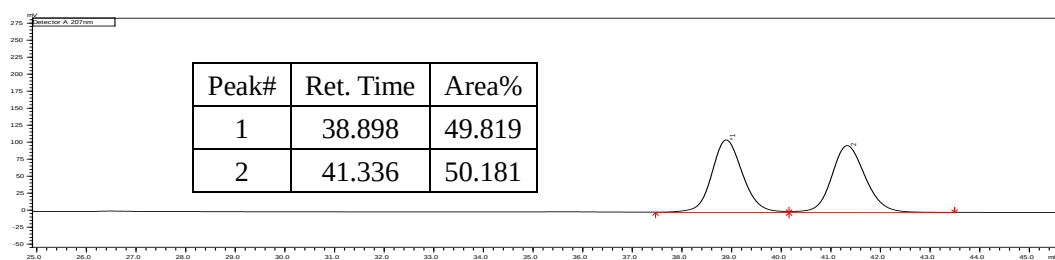
6i: Procedure C, 37.0 mg, colorless oil, 67% yield.³⁵

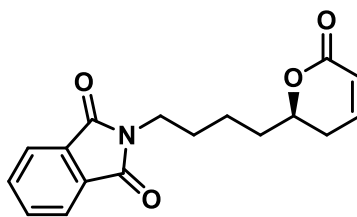
¹H NMR (400 MHz, CDCl₃) δ 6.92-6.87 (m, 1H), 6.03 (d, *J* = 9.6 Hz, 1H), 5.85 (td, *J* = 13.1, 6.4 Hz, 1H), 5.61 (dd, *J* = 15.2, 6.6 Hz, 1H), 4.87 (dd, *J* = 14.5, 7.1 Hz, 1H), 2.45-2.42 (m, 2H), 1.75 (d, *J* = 6.4 Hz, 3H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 164.08, 144.80, 130.46, 127.92, 121.31, 78.17, 29.61, 17.58 ppm.

Optical rotation: [α]_D²⁹ = -91.01 (*c* = 1.115, CHCl₃, 85% ee).

HPLC: DAICEL CHIRALPAK ID, hexane/*i*-PrOH = 9/1, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 39.6 min, *t*_R(minor) = 42.4 min, ee = 85%.





6j

6j: Procedure C, 75.1 mg, white powder, 63% yield.

^1H NMR (400 MHz, CDCl_3) δ 7.84 (dd, J = 5.4, 3.1 Hz, 2H), 7.73 (dd, J = 5.5, 3.0 Hz, 2H), 6.89 (ddd, J = 9.5, 4.9, 3.4 Hz, 1H), 6.01 (dd, J = 9.8, 1.4 Hz, 1H), 4.46-4.39 (m, 1H), 3.71 (t, J = 7.1 Hz, 2H), 2.37-2.33 (m, 2H), 1.86-1.45 (m, 6H) ppm.

^{13}C NMR (100 MHz, CDCl_3) δ 168.25, 164.27, 144.97, 133.82, 131.88, 123.06, 121.18, 77.53, 37.42, 34.15, 29.17, 28.15, 21.96 ppm.

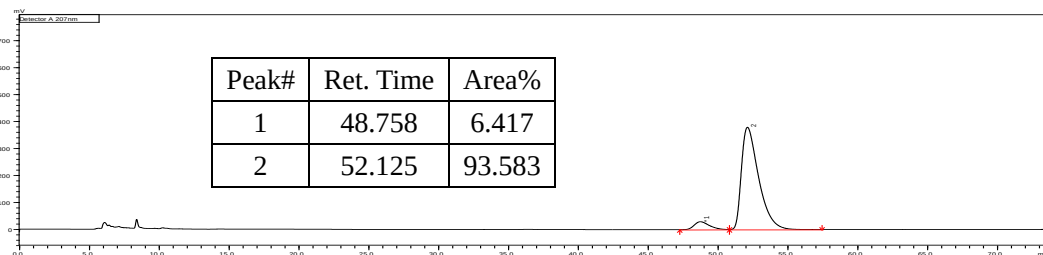
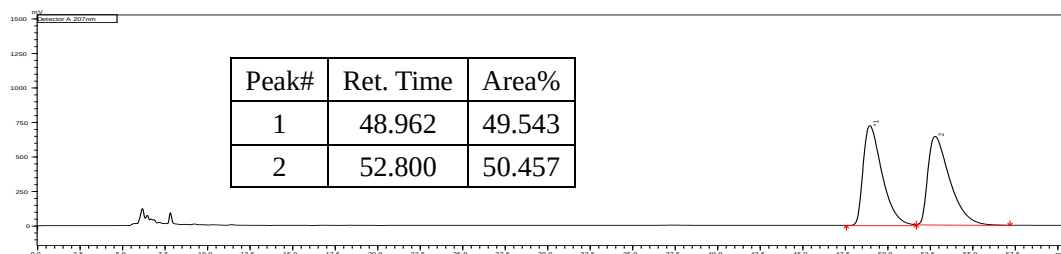
MS (ESI) m/z $[\text{M}+\text{Na}]^+$: 322.10.

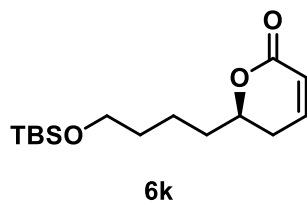
HRMS (DART) m/z $[\text{M}+\text{H}]^+$: calcd. 300.1230, found 300.1230.

IR (film): 2942, 1771, 1708, 1397 cm^{-1} .

Optical rotation: $[\alpha]_{\text{D}}^{28}$ = -50.76 (c = 1.040, CHCl_3 , 87% ee).

HPLC: DAICEL CHIRALPAK ODH, hexane/*i*-PrOH = 4/1, flow rate: 0.5 mL/min, λ = 207 nm, $t_{\text{R}}(\text{major})$ = 52.1 min, $t_{\text{R}}(\text{minor})$ = 48.8 min, ee = 87%.





6k: Procedure C, 74.2 mg, colorless oil, 65% yield.

¹H NMR (400 MHz, CDCl₃) δ 6.85 (ddd, *J* = 9.5, 5.5, 3.0 Hz, 1H), 6.08-5.85 (m, 1H), 4.42-4.35 (m, 1H), 3.58 (t, *J* = 6.0 Hz, 2H), 2.32-2.27 (m, 2H), 1.81-1.41 (m, 6H), 0.84 (s, 9H), 0.00 (s, 6H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 164.43, 145.02, 121.21, 77.81, 62.67, 34.47, 32.30, 29.18, 25.83, 21.07, 18.20, -5.42 ppm.

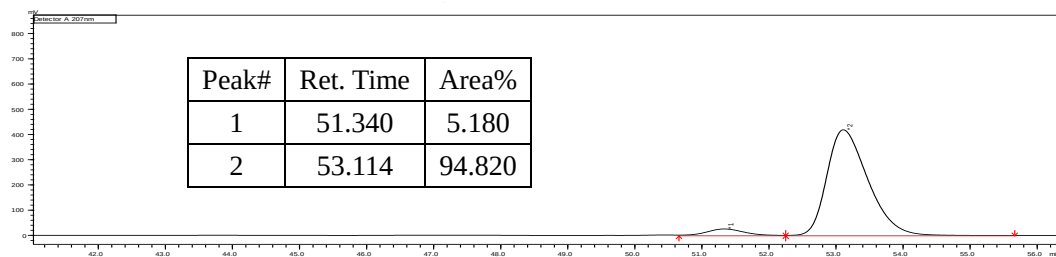
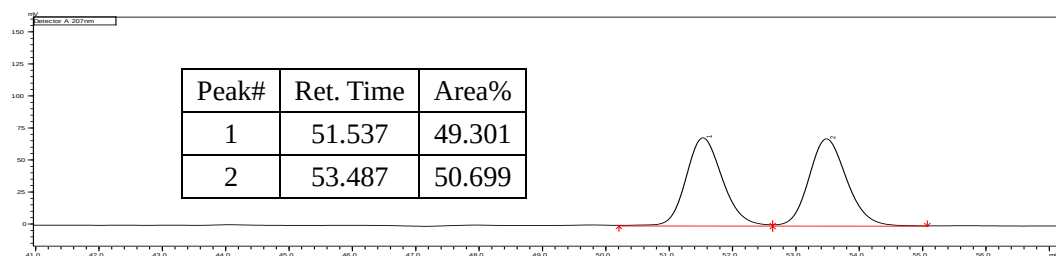
MS (ESI) *m/z* [M+Na]⁺: 307.15.

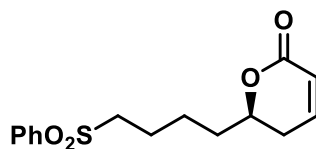
HRMS (DART) *m/z* [M+H]⁺: calcd. 285.1880, found 285.1880.

IR (film): 2930, 2857, 1728, 1251, 1099, 836 cm⁻¹.

Optical rotation: [α]_D²⁸ = -46.68 (*c* = 1.000, CHCl₃, 90% ee).

HPLC: DAICEL CHIRALPAK IE connected with DAICEL CHIRALPAK IG-3 in series, hexane/*i*-PrOH = 47/3, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 53.1 min, *t*_R(minor) = 51.3 min, ee = 90%.





6l

6l: Procedure C, 68.3 mg, white powder, 58% yield.

^1H NMR (400 MHz, CDCl_3) δ 7.92-7.90 (m, 2H), 7.68 (t, $J = 7.4$ Hz, 1H), 7.59 (t, $J = 7.6$ Hz, 2H), 6.90-6.85 (m, 1H), 6.01-5.99 (m, 1H), 4.42-4.35 (m, 1H), 3.11 (t, $J = 7.9$ Hz, 2H), 2.33-2.29 (m, 2H), 1.80-1.52 (m, 6H) ppm.

^{13}C NMR (100 MHz, CDCl_3) δ 164.14, 144.95, 138.88, 133.70, 129.26, 127.88, 121.20, 77.14, 55.85, 34.14, 29.21, 23.49, 22.31 ppm.

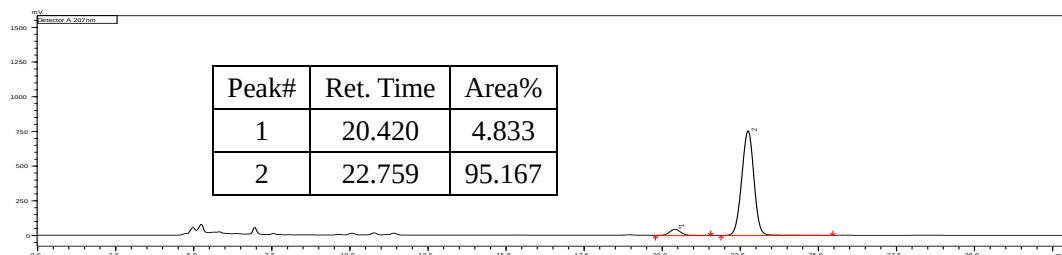
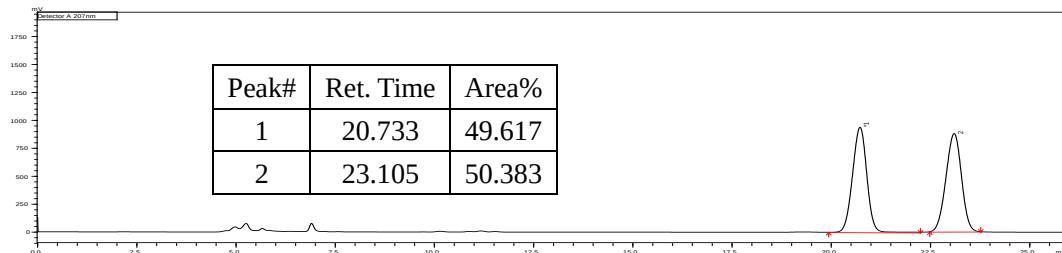
MS (ESI) m/z $[\text{M}+\text{Na}]^+$: 317.05.

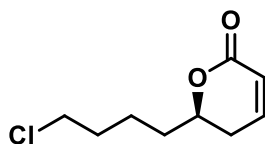
HRMS (DART) m/z $[\text{M}+\text{H}]^+$: calcd. 295.0999, found 295.0999.

IR (film): 2944, 1718, 1389, 1303, 1249, 1147 cm^{-1} .

Optical rotation: $[\alpha]_{\text{D}}^{28} = -49.93$ ($c = 0.995$, CHCl_3 , 90% ee).

HPLC: DAICEL CHIRALPAK ADH, hexane/*i*-PrOH = 2/1, flow rate: 0.6 mL/min, $\lambda = 207$ nm, $t_{\text{R}}(\text{major}) = 22.8$ min, $t_{\text{R}}(\text{minor}) = 20.4$ min, ee = 90%.





6m

6m: Procedure C, 45.5 mg, colorless oil, 60% yield.

^1H NMR (400 MHz, CDCl_3) δ 6.93-6.88 (m, 1H), 6.02 (d, J = 9.7 Hz, 1H), 4.45-4.44 (m, 1H), 3.56 (t, J = 6.5 Hz, 2H), 2.38-2.35 (m, 2H), 1.85-1.69 (m, 6H) ppm.

^{13}C NMR (100 MHz, CDCl_3) δ 164.31, 145.03, 121.19, 77.55, 44.59, 33.92, 32.06, 29.20, 22.14 ppm.

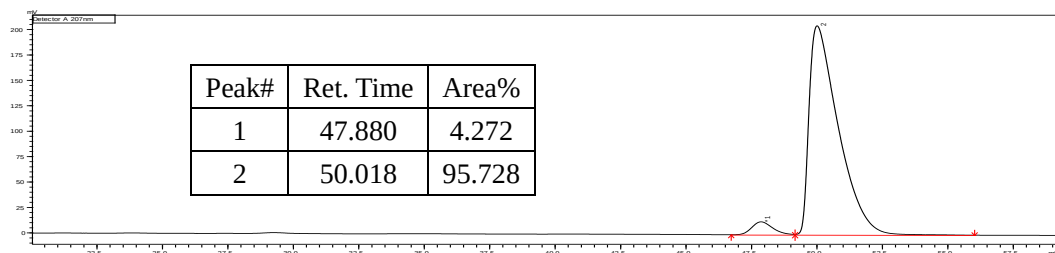
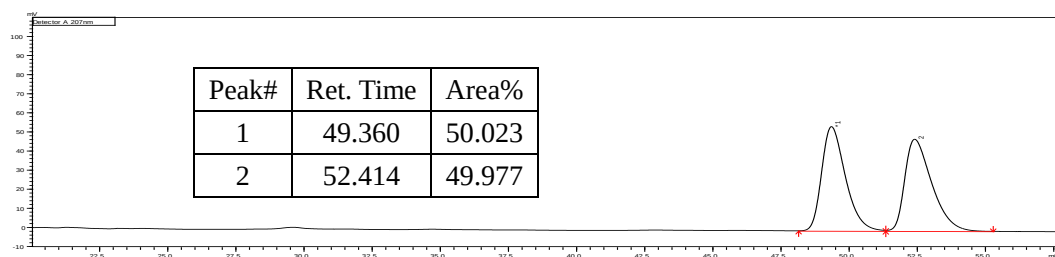
MS (ESI) m/z $[\text{M}+\text{Na}]^+$: 211.15.

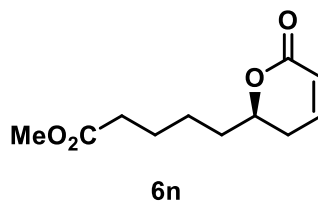
HRMS (DART) m/z $[\text{M}+\text{H}]^+$: calcd. 189.0677, found 189.0676.

IR (film): 2945, 1720, 1389, 1248, 817 cm^{-1} .

Optical rotation: $[\alpha]_{\text{D}}^{28}$ = -58.19 (c = 1.390, CHCl_3 , 91% ee).

HPLC: DAICEL CHIRALPAK ODH, hexane/*i*-PrOH = 47/3, flow rate: 0.5 mL/min, λ = 207 nm, $t_{\text{R}}(\text{major})$ = 50.0 min, $t_{\text{R}}(\text{minor})$ = 47.9 min, ee = 91%.





6n: Procedure C, 52.6 mg, colorless oil, 62% yield.

^1H NMR (400 MHz, CDCl_3) δ 6.90 (ddd, $J = 9.4, 5.2, 3.2$ Hz, 1H), 6.03-6.00 (m, 1H), 4.47-4.40 (m, 1H), 3.67 (s, 3H), 2.36-2.32 (m, 4H), 1.83-1.45 (m, 6H) ppm.

^{13}C NMR (100 MHz, CDCl_3) δ 173.75, 164.35, 145.01, 121.19, 77.54, 51.42, 34.35, 33.66, 29.22, 24.44, 24.23 ppm.

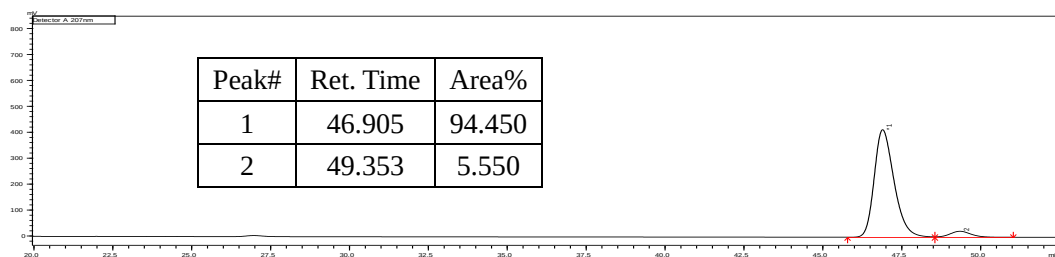
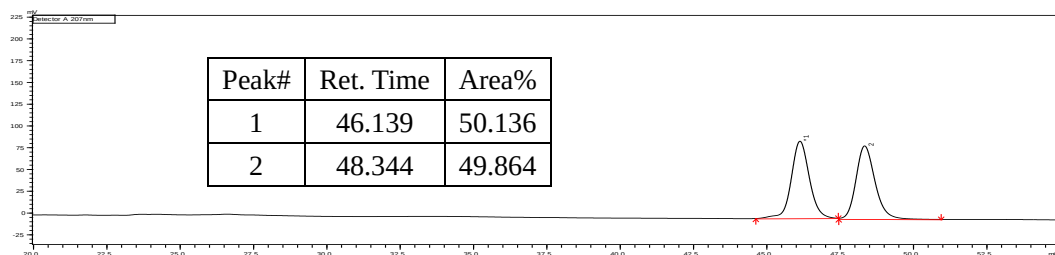
MS (ESI) m/z $[\text{M}+\text{Na}]^+$: 235.10.

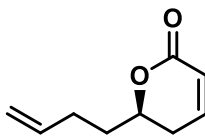
HRMS (DART) m/z $[\text{M}+\text{H}]^+$: calcd. 213.1121, found 213.1122.

IR (film): 2949, 1735, 1436, 1388, 1250, 1036, 818 cm^{-1} .

Optical rotation: $[\alpha]_{\text{D}}^{28} = -71.77$ ($c = 1.030$, CHCl_3 , 89% ee).

HPLC: DAICEL CHIRALPAK IG-3, hexane/*i*-PrOH = 4/1, flow rate: 0.5 mL/min, $\lambda = 207$ nm, $t_{\text{R}}(\text{major}) = 46.9$ min, $t_{\text{R}}(\text{minor}) = 49.4$ min, ee = 89%.





6o

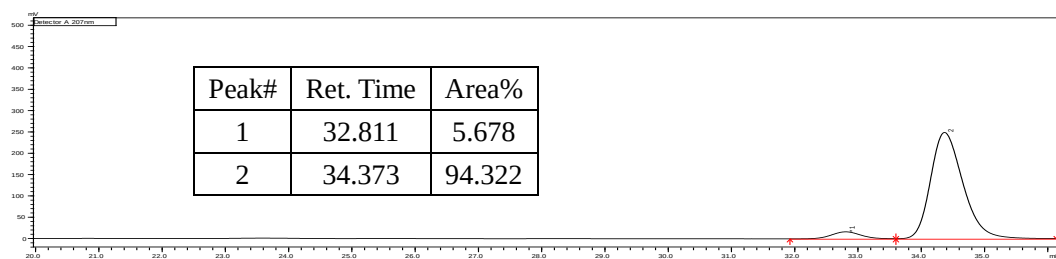
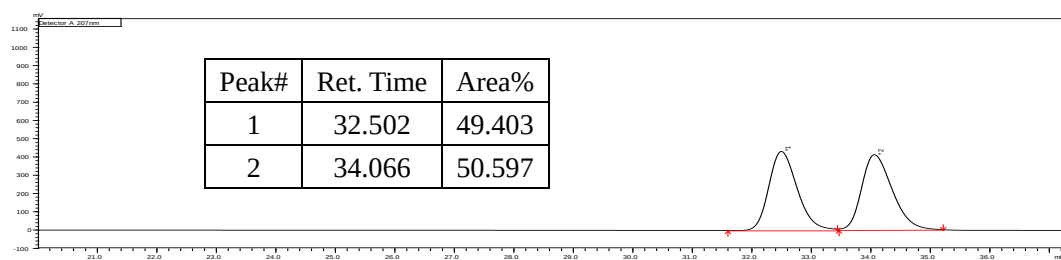
6o: Procedure C, 32.8 mg, pale yellow oil, 54% yield.³⁶

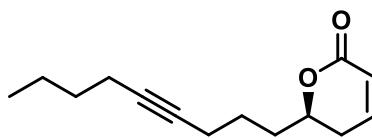
¹H NMR (400 MHz, CDCl₃) δ 6.91-6.87 (m, 1H), 6.03 (d, J = 9.8 Hz, 1H), 5.86-5.76 (m, 1H), 5.10-5.00 (m, 2H), 4.48-4.41 (m, 1H), 2.37-2.21 (m, 4H), 1.95-1.71 (m, 2H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 164.41, 144.95, 137.08, 121.36, 115.58, 77.11, 33.87, 29.29, 28.84 ppm.

Optical rotation: $[\alpha]_D^{29} = -82.63$ ($c = 0.995$, CHCl₃, 89% ee).

HPLC: DAICEL CHIRALPAK IBN-3, hexane/*i*-PrOH = 24/1, flow rate: 0.5 mL/min, $\lambda = 207$ nm, $t_R(\text{major}) = 34.4$ min, $t_R(\text{minor}) = 32.8$ min, ee = 89%.





6p

6p: Procedure C, 52.1 mg, colorless oil, 59% yield.

^1H NMR (400 MHz, CDCl_3) δ 6.90 (ddd, $J = 9.5, 5.2, 3.2$ Hz, 1H), 6.04-6.01 (m, 1H), 4.50-4.43 (m, 1H), 2.38-2.34 (m, 2H), 2.22-2.20 (m, 2H), 2.14-2.12 (m, 2H), 1.88-1.36 (m, 8H), 0.91 (t, $J = 7.1$ Hz, 3H) ppm.

^{13}C NMR (100 MHz, CDCl_3) δ 164.39, 145.02, 121.22, 80.92, 78.94, 77.46, 33.74, 31.03, 29.29, 24.13, 21.80, 18.32, 18.25, 13.50 ppm.

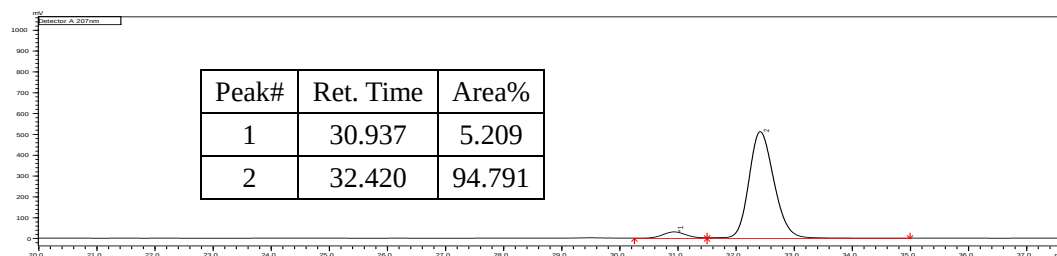
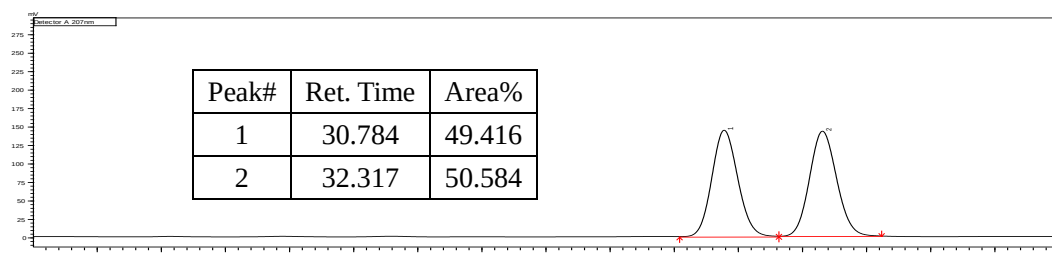
MS (ESI) m/z $[\text{M}+\text{Na}]^+$: 243.15.

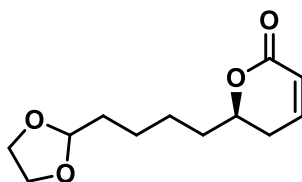
HRMS (DART) m/z $[\text{M}+\text{H}]^+$: calcd. 221.1536, found 221.1536.

IR (film): 2932, 1719, 1250, 817 cm^{-1} .

Optical rotation: $[\alpha]_{\text{D}}^{28} = -59.29$ ($c = 1.060$, CHCl_3 , 90% ee).

HPLC: DAICEL CHIRALPAK IG-3, hexane/*i*-PrOH = 47/3, flow rate: 0.5 mL/min, $\lambda = 207$ nm, $t_{\text{R}}(\text{major}) = 32.4$ min, $t_{\text{R}}(\text{minor}) = 30.9$ min, ee = 90%.





6q

6q: Procedure C, 56.4 mg, colorless oil, 62% yield.

^1H NMR (400 MHz, CDCl_3) δ 6.89 (ddd, $J = 9.5, 5.1, 3.3$ Hz, 1H), 6.03-6.00 (m, 1H), 4.85 (t, $J = 4.7$ Hz, 1H), 4.47-4.40 (m, 1H), 3.98-3.83 (m, 4H), 2.35-2.31 (m, 2H), 1.86-1.45 (m, 8H) ppm.

^{13}C NMR (100 MHz, CDCl_3) δ 164.44, 145.00, 121.26, 104.22, 77.70, 64.74, 34.66, 33.52, 29.27, 24.61, 23.63 ppm.

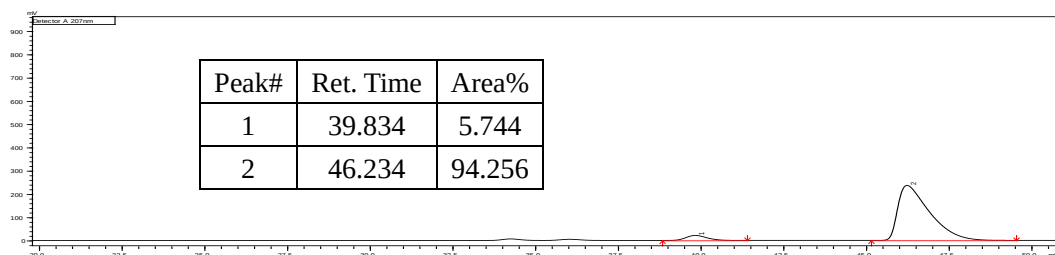
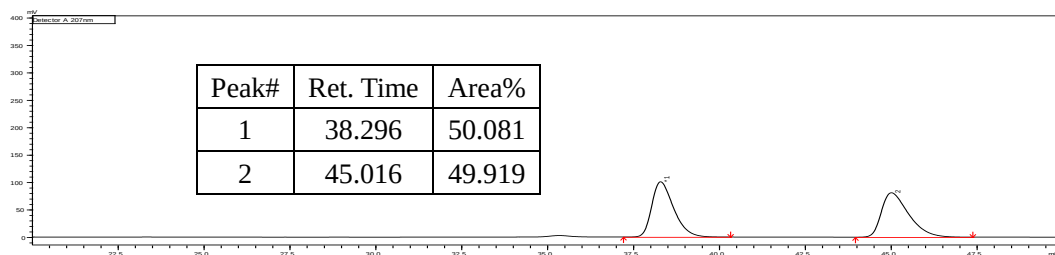
MS (ESI) m/z $[\text{M}+\text{Na}]^+$: 249.10.

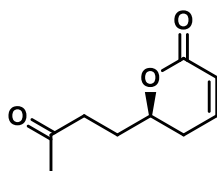
HRMS (DART) m/z $[\text{M}+\text{H}]^+$: calcd. 227.1278, found 227.1277.

IR (film): 2945, 1720, 1389, 1251, 1140, 1035, 817 cm^{-1} .

Optical rotation: $[\alpha]_{\text{D}}^{28} = -64.96$ ($c = 0.900$, CHCl_3 , 89% ee).

HPLC: DAICEL CHIRALPAK IE, hexane/*i*-PrOH = 2/1, flow rate: 0.6 mL/min, $\lambda = 207$ nm, $t_{\text{R}}(\text{major}) = 46.2$ min, $t_{\text{R}}(\text{minor}) = 39.8$ min, ee = 89%.





6r

6r: Procedure C, 44.0 mg, colorless oil, 65% yield.

^1H NMR (400 MHz, CDCl_3) δ 6.90 (ddd, J = 9.6, 5.7, 2.7 Hz, 1H), 6.01 (ddd, J = 9.8, 2.5, 1.0 Hz, 1H), 4.49-4.42 (m, 1H), 2.75-2.71 (m, 2H), 2.42-2.31 (m, 2H), 2.18 (s, 3H), 2.07-1.88 (m, 2H) ppm.

^{13}C NMR (100 MHz, CDCl_3) δ 207.64, 164.14, 145.09, 121.11, 76.76, 38.27, 29.96, 29.48, 28.29 ppm.

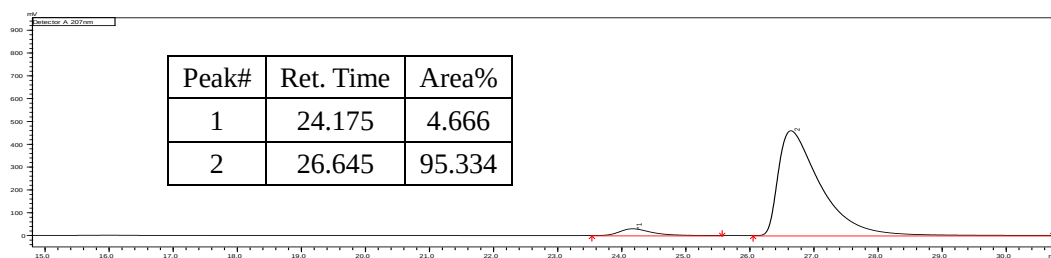
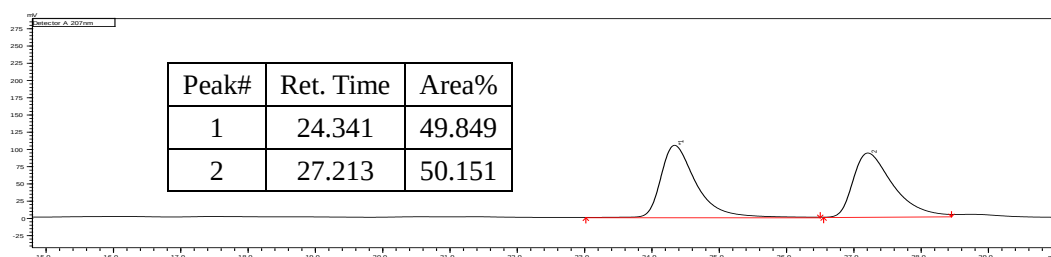
MS (ESI) m/z $[\text{M}+\text{Na}]^+$: 191.10.

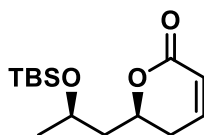
HRMS (DART) m/z $[\text{M}+\text{H}]^+$: calcd. 169.0859, found 169.0859.

IR (film): 2929, 1711, 1259, 815 cm^{-1} .

Optical rotation: $[\alpha]_{\text{D}}^{28}$ = -57.95 (c = 1.035, CHCl_3 , 91% ee).

HPLC: DAICEL CHIRALPAK ODH, hexane/*i*-PrOH = 4/1, flow rate: 0.5 mL/min, λ = 207 nm, t_{R} (major) = 26.6 min, t_{R} (minor) = 24.2 min, ee = 91%.





6s

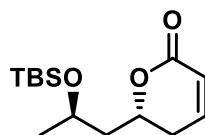
6s: Procedure C, 62.1 mg, colorless oil, 57% yield, dr = >20/1 (Diastereoselectivity was determined by ^1H NMR analysis of reaction crude mixture).³⁷

^1H NMR (400 MHz, CDCl_3) δ 6.86 (ddd, J = 9.6, 5.6, 2.8 Hz, 1H), 5.99 (ddd, J = 9.8, 2.3, 1.0 Hz, 1H), 4.58-4.50 (m, 1H), 4.05 (dd, J = 12.2, 6.1 Hz, 1H), 2.38-2.32 (m, 2H), 2.05-1.98 (m, 1H), 1.69 (dt, J = 13.9, 6.1 Hz, 1H), 1.17 (d, J = 6.1 Hz, 3H), 0.84 (s, 9H), 0.03 (s, 3H), 0.01 (s, 3H) ppm.

^{13}C NMR (100 MHz, CDCl_3) δ 164.42, 145.02, 121.34, 75.40, 64.76, 44.10, 29.55, 25.72, 23.31, 17.91, -4.37, -4.93 ppm.

Optical rotation: $[\alpha]_{\text{D}}^{29} = -77.05$ (c = 1.020, CHCl_3 , dr = >20/1).

Preparation of the diastereoisomer **6s'** of the product **6s**



6s'

6s': Procedure D, 47.2 mg, colorless oil, 44% yield, dr = >20/1 (Diastereoselectivity was determined by ¹H NMR analysis of reaction crude mixture).

¹H NMR (400 MHz, CDCl₃) δ 6.84 (dt, *J* = 9.6, 4.3 Hz, 1H), 5.97 (dt, *J* = 9.7, 1.7 Hz, 1H), 4.58-4.51 (m, 1H), 4.17-4.09 (m, 1H), 2.29-2.26 (m, 2H), 1.83-1.75 (m, 1H), 1.57 (ddd, *J* = 14.2, 10.1, 2.5 Hz, 1H), 1.11 (d, *J* = 6.1 Hz, 3H), 0.82 (s, 9H), 0.03 (s, 3H), 0.01 (s, 3H) ppm.

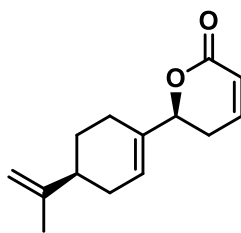
¹³C NMR (100 MHz, CDCl₃) δ 164.26, 145.30, 121.32, 74.67, 63.84, 44.84, 29.90, 25.78, 24.35, 17.91, -4.42, -4.89 ppm.

MS (ESI) m/z [M+Na]⁺: 293.15.

HRMS (DART) m/z [M+H]⁺: calcd. 271.1724, found 271.1724.

IR (film): 2929, 2856, 1735, 1251 cm⁻¹.

Optical rotation: [α]_D²⁸ = -8.03 (*c* = 1.415, CHCl₃, dr = >20/1).



8a

8a: Procedure C, 63.1 mg, colorless oil, 72% yield, dr = 13/1 (Diastereoselectivity was determined by ^1H NMR analysis of reaction crude mixture).

^1H NMR (400 MHz, CDCl_3) δ 6.93 (ddd, J = 9.5, 6.0, 2.4 Hz, 1H), 6.03 (dd, J = 9.8, 2.1 Hz, 1H), 5.85 (s, 1H), 4.79 (dd, J = 12.0, 3.6 Hz, 1H), 4.72 (d, J = 12.7 Hz, 2H), 2.59-2.50 (m, 1H), 2.39-2.32 (m, 1H), 2.24-2.14 (m, 4H), 2.02-1.95 (m, 1H), 1.91-1.85 (m, 1H), 1.74 (s, 3H), 1.55-1.45 (m, 1H) ppm.

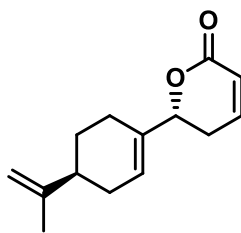
^{13}C NMR (100 MHz, CDCl_3) δ 164.32, 149.04, 145.22, 134.01, 125.15, 121.14, 108.73, 80.94, 40.44, 30.10, 28.03, 26.95, 24.34, 20.66 ppm.

MS (ESI) m/z $[\text{M}+\text{H}]^+$: 219.15.

HRMS (DART) m/z $[\text{M}+\text{H}]^+$: calcd. 219.1380, found 219.1379.

IR (film): 3077, 2918, 1716, 1643, 1379, 1244, 1019, 814 cm^{-1} .

Optical rotation: $[\alpha]_{\text{D}}^{29}$ = -132.35 (c = 1.167, CHCl_3 , dr = 13/1).



9a

9a: Procedure D, 64.0 mg, colorless oil, 73% yield, dr = 11/1 (Diastereoselectivity was determined by ^1H NMR analysis of reaction crude mixture).

^1H NMR (400 MHz, CDCl_3) δ 6.94 (ddd, J = 9.4, 6.2, 2.2 Hz, 1H), 6.03 (dd, J = 9.7, 2.5 Hz, 1H), 5.85 (s, 1H), 4.79 (dd, J = 12.3, 3.6 Hz, 1H), 4.73 (d, J = 7.1 Hz, 2H), 2.62-2.53 (m, 1H), 2.36-1.97 (m, 6H), 1.91-1.85 (m, 1H), 1.74 (s, 3H), 1.55-1.45 (m, 1H) ppm.

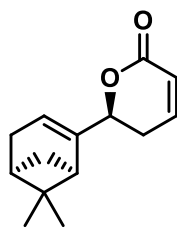
^{13}C NMR (100 MHz, CDCl_3) δ 164.47, 149.13, 145.32, 134.17, 126.39, 121.10, 108.79, 81.57, 40.75, 30.31, 27.95, 27.07, 24.28, 20.56 ppm.

MS (ESI) m/z $[\text{M}+\text{H}]^+$: 219.15.

HRMS (DART) m/z $[\text{M}+\text{H}]^+$: calcd. 219.1380, found 219.1380.

IR (film): 3078, 2919, 1719, 1643, 1379, 1245, 1019, 815 cm^{-1} .

Optical rotation: $[\alpha]_{\text{D}}^{29}$ = +15.84 (c = 1.013, CHCl_3 , dr = 11/1).



8b

8b: Procedure C, 50.6 mg, colorless oil, 58% yield, dr = 16/1 (Diastereoselectivity was determined by ^1H NMR analysis of reaction crude mixture).

^1H NMR (400 MHz, CDCl_3) δ 6.89 (ddd, J = 9.4, 5.7, 2.8 Hz, 1H), 6.01 (d, J = 9.8 Hz, 1H), 5.64-5.61 (m, 1H), 4.80 (dd, J = 10.9, 3.7 Hz, 1H), 2.51-2.26 (m, 6H), 2.14-2.08 (m, 1H), 1.31 (s, 3H), 1.17 (d, J = 8.7 Hz, 1H), 0.86 (s, 3H) ppm.

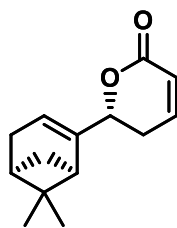
^{13}C NMR (100 MHz, CDCl_3) δ 164.40, 144.91, 144.40, 121.15, 120.61, 79.29, 42.12, 40.56, 37.89, 31.45, 31.00, 27.60, 25.92, 21.07 ppm.

MS (ESI) m/z $[\text{M}+\text{H}]^+$: 219.15.

HRMS (DART) m/z $[\text{M}+\text{H}]^+$: calcd. 219.1380, found 219.1379.

IR (film): 2919, 1731, 1382, 1247, 814 cm^{-1} .

Optical rotation: $[\alpha]_{\text{D}}^{28}$ = -117.85 (c = 0.887, CHCl_3 , dr = 16/1).



9b

9b: Procedure D, 56.4 mg, colorless oil, 65% yield, dr = 11/1 (Diastereoselectivity was determined by ^1H NMR analysis of reaction crude mixture).

^1H NMR (400 MHz, CDCl_3) δ 6.90 (ddd, J = 9.5, 6.0, 2.5 Hz, 1H), 6.02-5.99 (m, 1H), 5.64-5.61 (m, 1H), 4.84 (dd, J = 11.7, 3.9 Hz, 1H), 2.48-2.22 (m, 6H), 2.14-2.08 (m, 1H), 1.31 (s, 3H), 1.24 (d, J = 8.8 Hz, 1H), 0.82 (s, 3H) ppm.

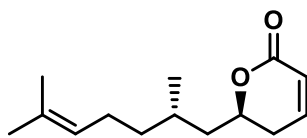
^{13}C NMR (100 MHz, CDCl_3) δ 164.43, 145.05, 144.52, 121.59, 121.15, 79.97, 41.82, 40.47, 37.64, 31.43, 31.01, 27.64, 25.89, 21.16 ppm.

MS (ESI) m/z $[\text{M}+\text{H}]^+$: 219.15.

HRMS (DART) m/z $[\text{M}+\text{H}]^+$: calcd. 219.1380, found 219.1379.

IR (film): 2916, 1727, 1382, 1248, 814 cm^{-1} .

Optical rotation: $[\alpha]_{\text{D}}^{28}$ = +38.07 (c = 1.065, CHCl_3 , dr = 11/1).



8c

8c: Procedure C, 62.5 mg, colorless oil, 70% yield, dr = >20/1 (Diastereoselectivity was determined by chiral-stationary-phase HPLC analysis).

¹H NMR (400 MHz, CDCl₃) δ 6.89 (ddd, *J* = 9.5, 5.0, 3.4 Hz, 1H), 6.01 (d, *J* = 9.4 Hz, 1H), 5.09 (t, *J* = 7.1 Hz, 1H), 4.56–4.49 (m, 1H), 2.38–2.26 (m, 2H), 2.07–1.77 (m, 4H), 1.68 (s, 3H), 1.60 (s, 3H), 1.37–1.16 (m, 3H), 0.93 (d, *J* = 6.6 Hz, 3H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 164.46, 145.07, 131.22, 124.30, 121.22, 75.79, 42.20, 37.33, 29.99, 27.95, 25.57, 25.19, 18.87, 17.51 ppm.

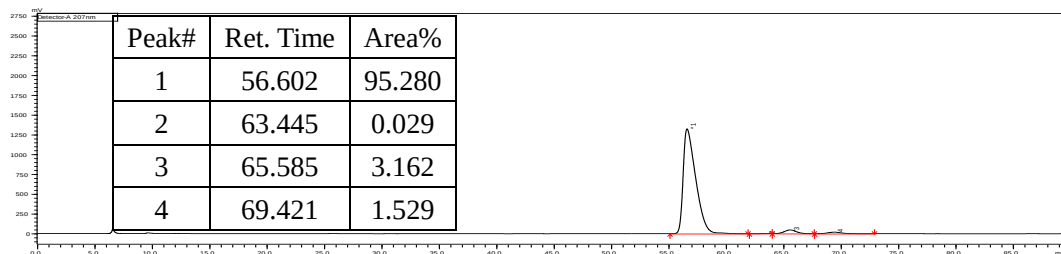
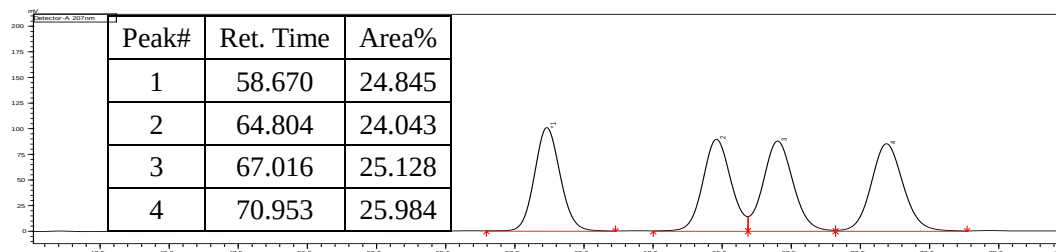
MS (EI) *m/z* [M]⁺: 222.

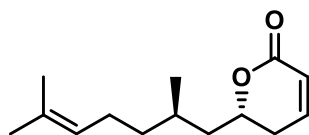
HRMS (EI) *m/z* [M]⁺: calcd. 222.1620, found 222.1623.

IR (film): 2962, 2924, 1720, 1382, 1248, 822 cm⁻¹.

Optical rotation: [α]_D²⁹ = -74.28 (*c* = 1.070, CHCl₃, dr = >20/1, ee = >99%).

HPLC: DAICEL CHIRALPAK IC, hexane/*i*-PrOH = 47/3, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 56.6 min, *t*_R(minor) = 63.4 min, ee = >99%.





ent-8c

ent-8c: Procedure D, 58.2 mg, colorless oil, 65% yield, dr = 7/1 (Diastereoselectivity was determined by chiral-stationary-phase HPLC analysis).

¹H NMR (400 MHz, CDCl₃) δ 6.90 (ddd, *J* = 9.5, 5.0, 3.3 Hz, 1H), 6.01 (d, *J* = 10.0 Hz, 1H), 5.09 (t, *J* = 7.1 Hz, 1H), 4.56-4.49 (m, 1H), 2.41-2.23 (m, 2H), 2.07-1.79 (m, 4H), 1.68 (s, 3H), 1.60 (s, 3H), 1.37-1.16 (m, 3H), 0.94 (d, *J* = 6.6 Hz, 3H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 164.45, 145.08, 131.21, 124.28, 121.20, 75.78, 42.19, 37.32, 29.98, 27.94, 25.57, 25.18, 18.86, 17.51 ppm.

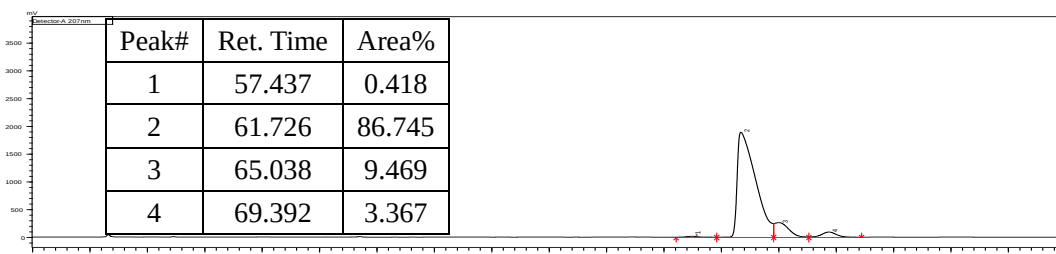
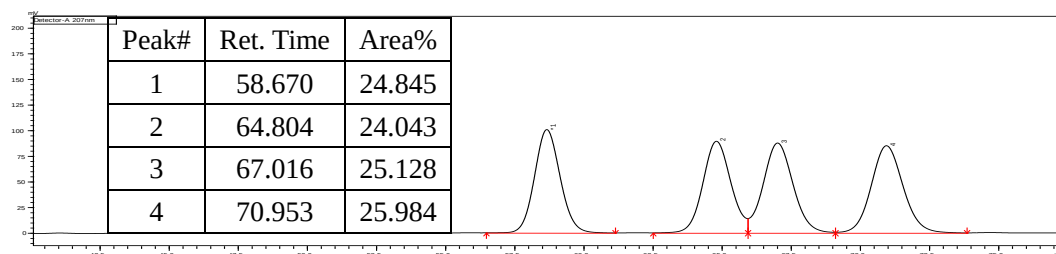
MS (EI) *m/z* [M]⁺: 222.

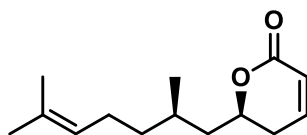
HRMS (EI) *m/z* [M]⁺: calcd. 222.1620, found 222.1615.

IR (film): 2962, 2925, 1723, 1382, 1248, 821 cm⁻¹.

Optical rotation: [α]_D²⁹ = +72.74 (*c* = 0.955, CHCl₃, dr = 7/1, ee = >99%).

HPLC: DAICEL CHIRALPAK IC, hexane/*i*-PrOH = 47/3, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 61.7 min, *t*_R(minor) = 57.4 min, ee = >99%.





8d

8d: Procedure C, 55.0 mg, colorless oil, 62% yield, dr = 7/1 (Diastereoselectivity was determined by chiral-stationary-phase HPLC analysis).

^1H NMR (400 MHz, CDCl_3) δ 6.88 (ddd, J = 9.4, 5.9, 2.5 Hz, 1H), 6.02 (dd, J = 9.7, 1.7 Hz, 1H), 5.08 (t, J = 7.0 Hz, 1H), 4.55-4.48 (m, 1H), 2.40-2.22 (m, 2H), 2.07-1.85 (m, 2H), 1.74-1.67 (m, 5H), 1.6-1.56 (m, 4H), 1.47-1.12 (m, 2H), 0.94 (d, J = 6.3 Hz, 3H) ppm.

^{13}C NMR (100 MHz, CDCl_3) δ 164.48, 144.93, 131.34, 124.29, 121.33, 76.39, 42.14, 36.61, 29.60, 28.54, 25.62, 25.16, 19.69, 17.59 ppm.

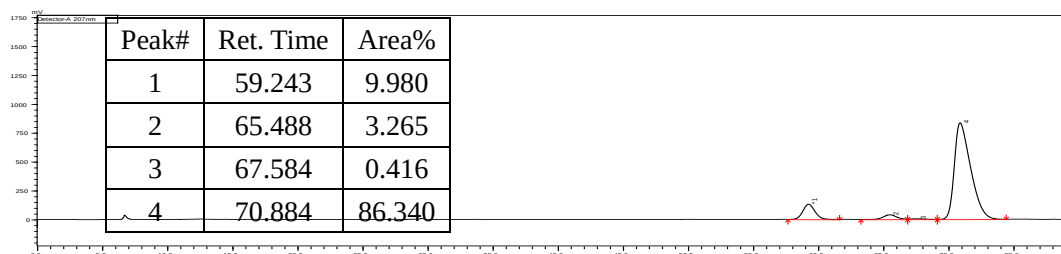
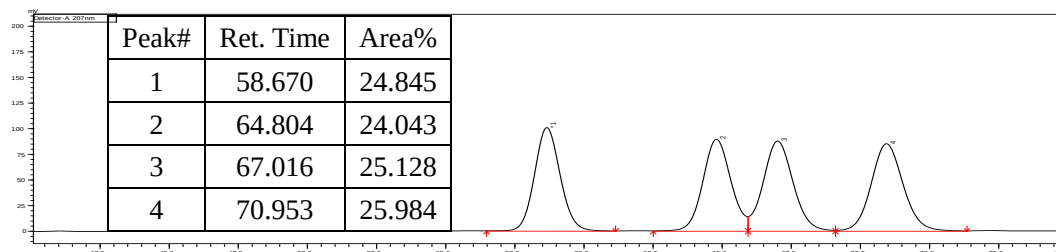
MS (EI) m/z $[\text{M}]^+$: 222.

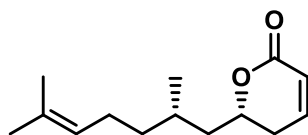
HRMS (EI) m/z $[\text{M}]^+$: calcd. 222.1620, found 222.1626.

IR (film): 2925, 1723, 1382, 1248, 1037, 815 cm^{-1} .

Optical rotation: $[\alpha]_{\text{D}}^{29}$ = -57.84 (c = 1.107, CHCl_3 , dr = 7/1, ee = >99%).

HPLC: DAICEL CHIRALPAK IC, hexane/*i*-PrOH = 47/3, flow rate: 0.5 mL/min, λ = 207 nm, t_{R} (major) = 70.9 min, t_{R} (minor) = 67.6 min, ee = >99%.





ent-8d

ent-8d: Procedure D, 61.7 mg, colorless oil, 69% yield, dr = >20/1 (Diastereoselectivity was determined by chiral-stationary-phase HPLC analysis).

¹H NMR (400 MHz, CDCl₃) δ 6.89 (ddd, *J* = 9.5, 5.9, 2.5 Hz, 1H), 6.01 (dd, *J* = 9.7, 1.6 Hz, 1H), 5.08 (t, *J* = 7.1 Hz, 1H), 4.55-4.48 (m, 1H), 2.41-2.22 (m, 2H), 2.08-1.85 (m, 2H), 1.75-1.66 (m, 5H), 1.61-1.55 (m, 4H), 1.46-1.37 (m, 1H), 1.22-1.13 (m, 1H), 0.94 (d, *J* = 6.3 Hz, 3H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 164.44, 144.95, 131.27, 124.26, 121.25, 76.36, 42.10, 36.57, 29.56, 28.50, 25.57, 25.13, 19.66, 17.55 ppm.

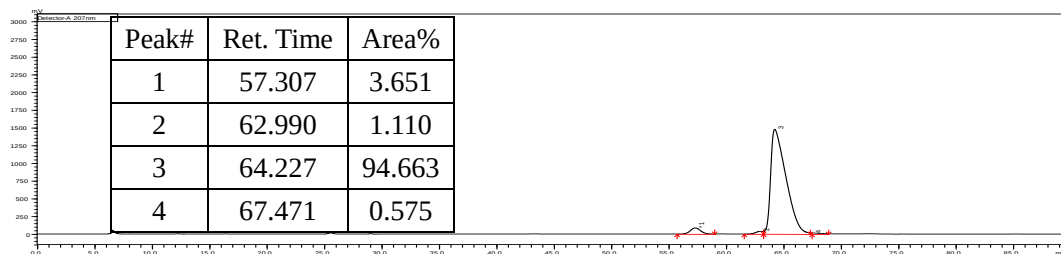
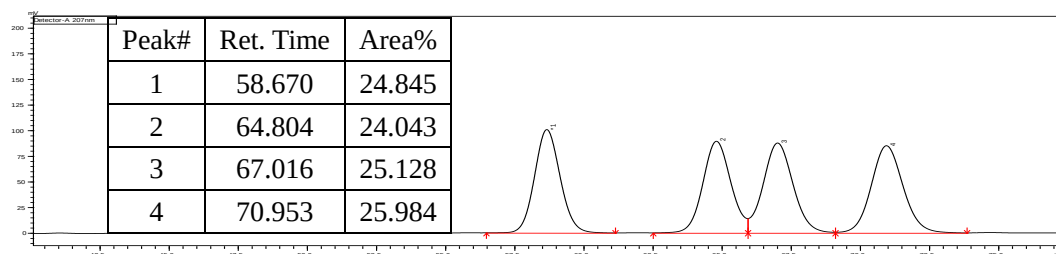
MS (EI) *m/z* [M]⁺: 222.

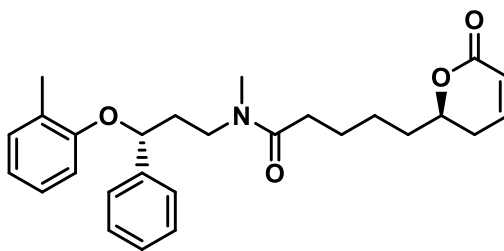
HRMS (EI) *m/z* [M]⁺: calcd. 222.1620, found 222.1626.

IR (film): 2924, 1721, 1382, 1248, 1037, 815 cm⁻¹.

Optical rotation: [α]_D²⁹ = +54.74 (*c* = 0.947, CHCl₃, dr = >20/1, ee = >99%).

HPLC: DAICEL CHIRALPAK IC, hexane/*i*-PrOH = 47/3, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 64.2 min, *t*_R(minor) = 67.5 min, ee = >99%.





8e

8e: Procedure C, 108.0 mg, colorless oil, 62% yield, dr = 13/1 (Diastereoselectivity was determined by chiral-stationary-phase HPLC analysis. Rotamers were observed in a ratio of ~ 1/1 in CDCl₃ at room temperature).

¹H NMR (400 MHz, CDCl₃) δ 7.34-7.20 (m, 5H), 7.12 (t, *J* = 7.6 Hz, 1H), 6.94 (t, *J* = 7.7 Hz, 1H), 6.88-6.83 (m, 1H), 6.77 (q, *J* = 7.2 Hz, 1H), 6.56 (dd, *J* = 12.6, 8.2 Hz, 1H), 6.01 (d, *J* = 9.5 Hz, 1H), 5.19-5.14 (m, 1H), 4.45-4.33 (m, 1H), 3.67-3.41 (m, 2H), 2.94 (d, *J* = 8.5 Hz, 3H), 2.35-2.10 (m, 9H), 1.85-1.25 (m, 6H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 172.62, 172.47, 164.49, 164.48, 155.69, 155.26, 145.08, 145.02, 141.57, 140.91, 130.72, 130.55, 128.78, 128.54, 127.78, 127.48, 126.83, 126.66, 126.54, 126.52, 125.61, 125.43, 121.30, 121.27, 120.51, 120.21, 112.58, 112.38, 77.67, 77.62, 77.52, 76.09, 46.21, 45.33, 37.48, 36.41, 35.75, 34.60, 34.48, 33.21, 32.36, 29.30, 29.23, 24.77, 24.54, 24.52, 24.37, 16.52, 16.50 ppm.

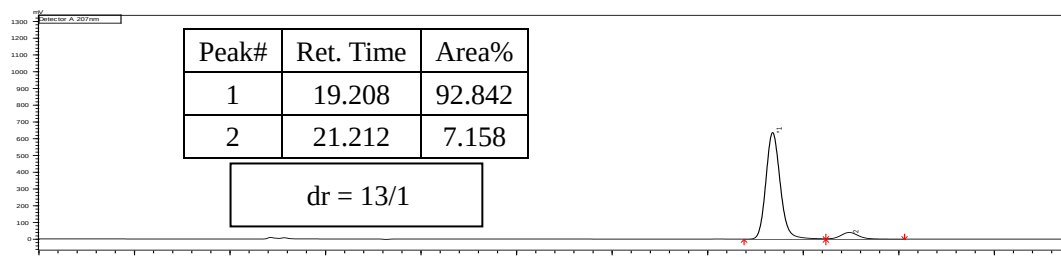
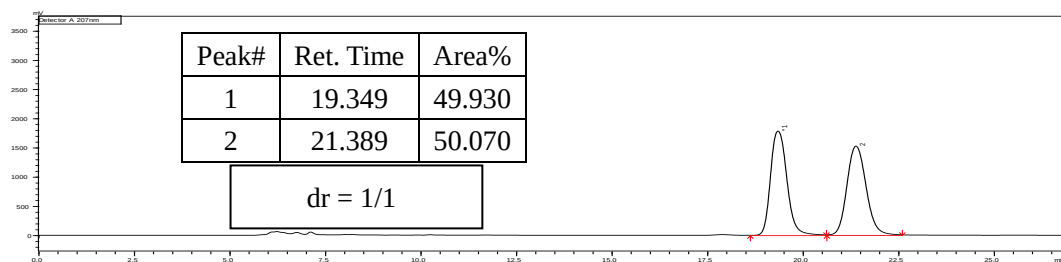
MS (ESI) *m/z* [M+Na]⁺: 458.15.

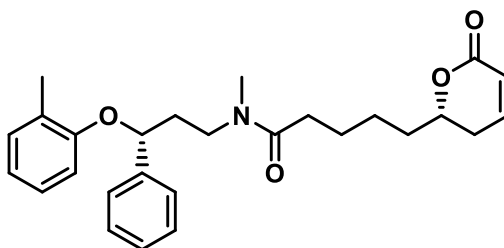
HRMS (ESI) *m/z* [M+H]⁺: calcd. 436.2482, found 436.2494.

IR (film): 2941, 1720, 1642, 1492, 1238, 753 cm⁻¹.

Optical rotation: [α]_D²⁶ = -46.29 (*c* = 1.068, CHCl₃, dr = 13/1).

HPLC: DAICEL CHIRALPAK ADH, hexane/*i*-PrOH = 4/1, flow rate: 0.5 mL/min, λ = 207 nm.





9e

9e: Procedure D, 107.4 mg, colorless oil, 62% yield, dr = 11/1 (Diastereoselectivity was determined by chiral-stationary-phase HPLC analysis. Rotamers were observed in a ratio of ~ 1/1 in CDCl₃ at room temperature).

¹H NMR (400 MHz, CDCl₃) δ 7.35-7.20 (m, 5H), 7.11 (t, *J* = 8.2 Hz, 1H), 6.94 (t, *J* = 7.8 Hz, 1H), 6.87-6.83 (m, 1H), 6.76 (q, *J* = 7.1 Hz, 1H), 6.56 (dd, *J* = 12.9, 8.2 Hz, 1H), 5.99 (d, *J* = 9.7 Hz, 1H), 5.19-5.14 (m, 1H), 4.44-4.31 (m, 1H), 3.67-3.41 (m, 2H), 2.93 (d, *J* = 7.2 Hz, 3H), 2.35-2.10 (m, 9H), 1.85-1.22 (m, 6H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 172.55, 172.41, 164.44, 164.42, 155.61, 155.20, 145.08, 145.02, 141.51, 140.85, 130.65, 130.49, 128.71, 128.47, 127.71, 127.41, 126.75, 126.60, 126.47, 126.45, 125.55, 125.36, 121.19, 121.16, 120.43, 120.15, 112.51, 112.31, 77.65, 77.61, 77.45, 76.02, 46.16, 45.27, 37.42, 36.35, 35.70, 34.53, 34.48, 33.16, 32.30, 29.22, 29.18, 24.78, 24.47, 24.45, 24.39, 16.46, 16.44 ppm.

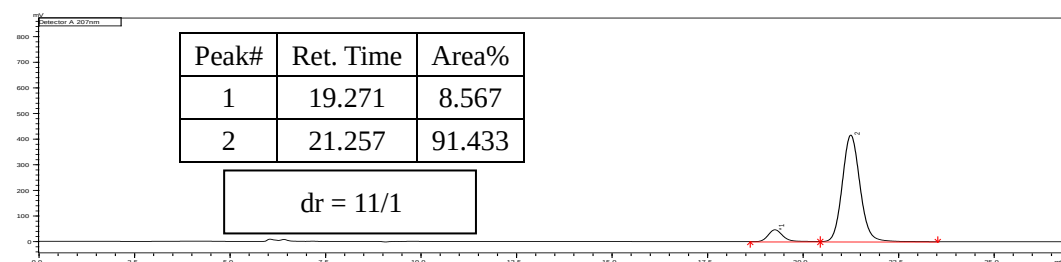
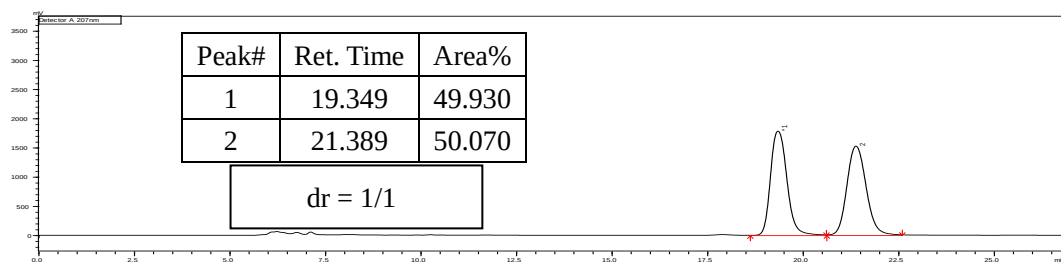
MS (ESI) m/z [M+Na]⁺: 458.15.

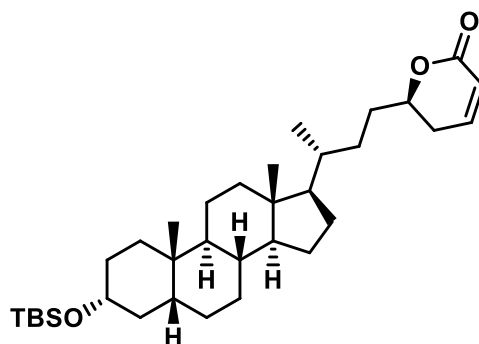
HRMS (ESI) m/z [M+H]⁺: calcd. 436.2482, found 436.2486.

IR (film): 2933, 1717, 1644, 1491, 1238, 753 cm⁻¹.

Optical rotation: [α]_D²⁶ = +17.20 (*c* = 1.205, CHCl₃, dr = 11/1).

HPLC: DAICEL CHIRALPAK ADH, hexane/*i*-PrOH = 4/1, flow rate: 0.5 mL/min, λ = 207 nm.





8f

8f: Procedure C, 132.2 mg, white powder, 61% yield, dr = >20/1 (Diastereoselectivity was determined by ^1H NMR analysis of reaction crude mixture).

^1H NMR (400 MHz, CDCl_3) δ 6.90-6.85 (m, 1H), 6.01 (d, J = 9.8 Hz, 1H), 4.42-4.35 (m, 1H), 3.61-3.54 (m, 1H), 2.35-2.32 (m, 2H), 1.95-1.04 (m, 28H), 0.93-0.89 (m, 15H), 0.64 (s, 3H), 0.06 (s, 6H) ppm.

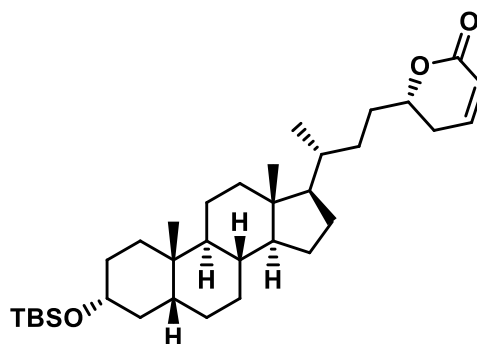
^{13}C NMR (100 MHz, CDCl_3) δ 164.56, 145.00, 121.37, 78.40, 72.74, 56.32, 55.89, 42.63, 42.21, 40.13, 40.08, 36.85, 35.79, 35.51, 35.41, 34.51, 31.35, 30.96, 30.75, 29.42, 28.24, 27.23, 26.34, 25.92, 24.14, 23.34, 20.74, 18.50, 18.27, 11.97, -4.65 ppm.

MS (ESI) m/z $[\text{M}+\text{Na}]^+$: 565.40.

HRMS (ESI) m/z $[\text{M}+\text{Na}]^+$: calcd. 565.4047, found 565.4054.

IR (film): 2928, 2861, 1716, 1251, 1096, 1081, 835 cm^{-1} .

Optical rotation: $[\alpha]_{\text{D}}^{28}$ = -2.18 (c = 1.050, CHCl_3 , dr = >20/1).



9f

9f: Procedure D, 136.9 mg, white powder, 63% yield, dr = >20/1 (Diastereoselectivity was determined by ^1H NMR analysis of reaction crude mixture).

^1H NMR (400 MHz, CDCl_3) δ 6.91-6.86 (m, 1H), 6.02 (d, J = 9.6 Hz, 1H), 4.40-4.33 (m, 1H), 3.62-3.54 (m, 1H), 2.41-2.26 (m, 2H), 1.96-1.04 (m, 28H), 0.94-0.89 (m, 15H), 0.64 (s, 3H), 0.06 (s, 6H) ppm.

^{13}C NMR (100 MHz, CDCl_3) δ 164.51, 144.95, 121.35, 78.57, 72.72, 56.32, 55.86, 42.60, 42.17, 40.11, 40.06, 36.82, 35.75, 35.48, 35.42, 34.48, 31.32, 30.93, 30.81, 29.27, 28.23, 27.20, 26.32, 25.90, 24.11, 23.31, 20.72, 18.46, 18.25, 11.95, -4.67 ppm.

MS (ESI) m/z $[\text{M}+\text{Na}]^+$: 565.45.

HRMS (ESI) m/z $[\text{M}+\text{Na}]^+$: calcd. 565.4047, found 565.4059.

IR (film): 2928, 2861, 1716, 1251, 1096, 1081, 835 cm^{-1} .

Optical rotation: $[\alpha]_{\text{D}}^{28} = +50.65$ (c = 1.110, CHCl_3 , dr = >20/1).

CCDC number **1863075** contains the supplementary crystallographic data for this report. These data can be obtained free of charge from The Cambridge Crystallographic Data Center via www.ccdc.cam.ac.uk/data_request/cif.

Figure SI-1. The Full Numbering Scheme of CCDC: 1863075

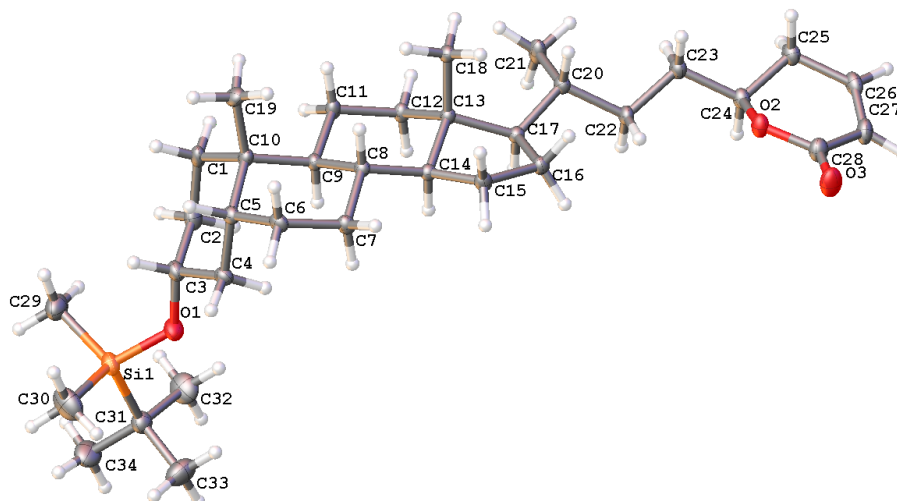
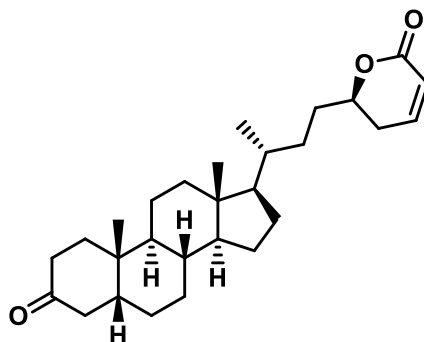


Table SI-1. Crystal Data and Structure Refinement for 1863075

Identification code	1863075	
Empirical formula	C ₃₄ H ₅₈ O ₃ Si	
Formula weight	542.89	
Temperature	170.01 K	
Wavelength	1.34139 Å	
Crystal system	Monoclinic	
Space group	P 1 21 1	
Unit cell dimensions	a = 7.18340(10) Å	α = 90°.
	b = 11.0051(2) Å	β = 97.1420(10)°.
	c = 21.1383(3) Å	γ = 90°.
Volume	1658.10(4) Å ³	
Z	2	
Density (calculated)	1.087 Mg/m ³	
Absorption coefficient	0.544 mm ⁻¹	
F(000)	600	
Crystal size	0.15 x 0.12 x 0.1 mm ³	
Theta range for data collection	3.667 to 54.970°.	
Index ranges	-8 ≤ h ≤ 8, -13 ≤ k ≤ 13, -25 ≤ l ≤ 25	
Reflections collected	18921	
Independent reflections	6220 [R(int) = 0.0440]	
Completeness to theta = 53.594°	99.7 %	
Absorption correction	Semi-empirical from equivalents	
Max. and min. transmission	0.7508 and 0.6216	
Refinement method	Full-matrix least-squares on F ²	
Data / restraints / parameters	6220 / 1 / 351	
Goodness-of-fit on F ²	1.087	
Final R indices [I > 2σ(I)]	R1 = 0.0426, wR2 = 0.0894	
R indices (all data)	R1 = 0.0527, wR2 = 0.0956	
Absolute structure parameter	0.030(17)	
Extinction coefficient	n/a	
Largest diff. peak and hole	0.181 and -0.218 e.Å ⁻³	



8g

8g: Procedure C, 104.4 mg, white powder, 61% yield, dr = >20/1 (Diastereoselectivity was determined by ^1H NMR analysis of reaction crude mixture).

^1H NMR (400 MHz, CDCl_3) δ 6.92-6.87 (m, 1H), 6.01 (d, J = 9.7 Hz, 1H), 4.42-4.35 (m, 1H), 2.70 (t, J = 14.2 Hz, 1H), 2.39-2.30 (m, 3H), 2.15 (d, J = 14.4 Hz, 1H), 2.07-2.00 (m, 3H), 1.91-1.79 (m, 4H), 1.62-1.05 (m, 18H), 1.02 (s, 3H), 0.94 (d, J = 6.4 Hz, 3H), 0.69 (s, 3H) ppm.

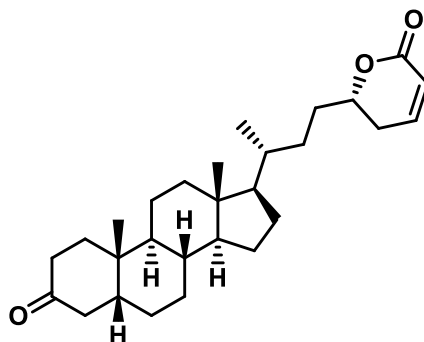
^{13}C NMR (100 MHz, CDCl_3) δ 213.21, 164.46, 145.04, 121.19, 78.27, 56.22, 55.79, 44.17, 42.56, 42.19, 40.51, 39.87, 37.05, 36.85, 35.34, 35.29, 34.71, 31.27, 30.66, 29.34, 28.09, 26.45, 25.59, 23.98, 22.49, 21.02, 18.40, 11.92 ppm.

MS (ESI) m/z $[\text{M}+\text{Na}]^+$: 449.25.

HRMS (ESI) m/z $[\text{M}+\text{Na}]^+$: calcd. 449.3026, found 449.3034.

IR (film): 2931, 2684, 1716, 1249 cm^{-1} .

Optical rotation: $[\alpha]_{\text{D}}^{28}$ = +49.46 (c = 1.060, CHCl_3 , dr = >20/1).



9g

9g: Procedure D, 109.0 mg, white powder, 64% yield, dr = >20/1 (Diastereoselectivity was determined by ^1H NMR analysis of reaction crude mixture).

^1H NMR (400 MHz, CDCl_3) δ 6.91-6.87 (m, 1H), 6.02 (d, J = 9.8 Hz, 1H), 4.31-4.35 (m, 1H), 2.70 (t, J = 14.2 Hz, 1H), 2.41-2.26 (m, 3H), 2.16 (d, J = 14.7 Hz, 1H), 2.04-2.01 (m, 3H), 1.92-1.09 (m, 22H), 1.02 (s, 3H), 0.94 (d, J = 6.5 Hz, 3H), 0.69 (s, 3H) ppm.

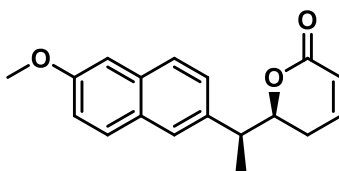
^{13}C NMR (100 MHz, CDCl_3) δ 213.27, 164.48, 144.97, 121.26, 78.49, 56.28, 55.81, 44.18, 42.61, 42.22, 40.56, 39.91, 37.08, 36.87, 35.37, 35.36, 34.74, 31.28, 30.73, 29.21, 28.13, 26.48, 25.63, 24.00, 22.53, 21.05, 18.44, 11.95 ppm.

MS (ESI) m/z $[\text{M}+\text{Na}]^+$: 449.30.

HRMS (ESI) m/z $[\text{M}+\text{Na}]^+$: calcd. 449.3026, found 449.3030.

IR (film): 2937, 2684, 1715, 1249 cm^{-1} .

Optical rotation: $[\alpha]_{\text{D}}^{28}$ = -7.06 (c = 1.085, CHCl_3 , dr = >20/1).



8h

8h: Procedure C with chiral aldehyde **7h** (88% ^1H NMR yield, 11/1 dr, 97% ee; 82.6 mg, white powder, 73% isolated yield, >20/1 dr, 97% ee. Diastereoselectivity was determined by ^1H NMR and HPLC analysis and the diastereoisomer can be separated by silica gel column chromatography (petroleum ether/ethyl acetate = 9/1)).

^1H NMR (400 MHz, CDCl_3) δ 7.70 (dd, J = 8.3, 6.9 Hz, 2H), 7.57 (s, 1H), 7.29 (dd, J = 8.5, 1.5 Hz, 1H), 7.15 (dd, J = 8.9, 2.5 Hz, 1H), 7.12 (d, J = 2.2 Hz, 1H), 6.75-6.71 (m, 1H), 5.99 (dd, J = 9.7, 2.0 Hz, 1H), 4.54-4.48 (m, 1H), 3.91 (s, 3H), 3.18-3.11 (m, 1H), 2.24-2.15 (m, 1H), 2.06-1.99 (m, 1H), 1.53 (d, J = 6.9 Hz, 3H) ppm.

^{13}C NMR (100 MHz, CDCl_3) δ 164.40, 157.54, 145.24, 137.10, 133.61, 129.03, 128.87, 127.26, 126.21, 126.16, 121.07, 119.05, 105.49, 82.01, 55.24, 44.48, 27.88, 17.80 ppm.

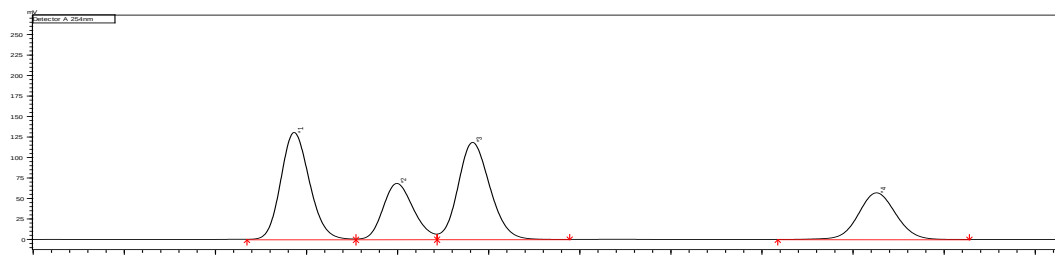
MS (ESI) m/z $[\text{M}+\text{H}]^+$: 283.05.

HRMS (ESI) m/z $[\text{M}+\text{H}]^+$: calcd. 283.1329, found 283.1331.

IR (film): 2958, 2925, 1721, 1606, 1248, 1032, 815 cm^{-1} .

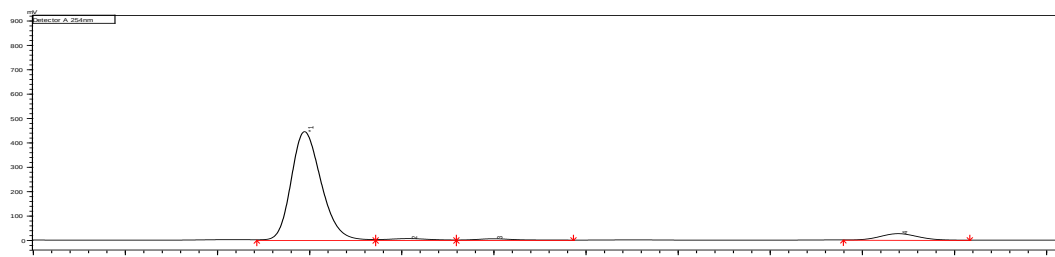
Optical rotation: $[\alpha]_{\text{D}}^{27}$ = -37.97 (c = 1.093, CHCl_3 , dr = >20/1, 97% ee).

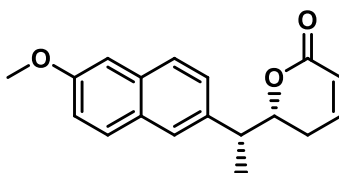
HPLC: DAICEL CHIRALPAK ADH, hexane/*i*-PrOH = 47/3, flow rate: 0.5 mL/min, λ = 254 nm, t_{R} (major) = 52.4 min, t_{R} (minor) = 57.5 min, ee = 97%.



Peak#	Ret. Time	Area%
1	52.170	31.947
2	54.989	17.715
3	57.068	32.129
4	68.153	18.208

Peak#	Ret. Time	Area%
1	52.370	90.625
2	55.180	1.585
3	57.501	1.246
4	68.481	6.544

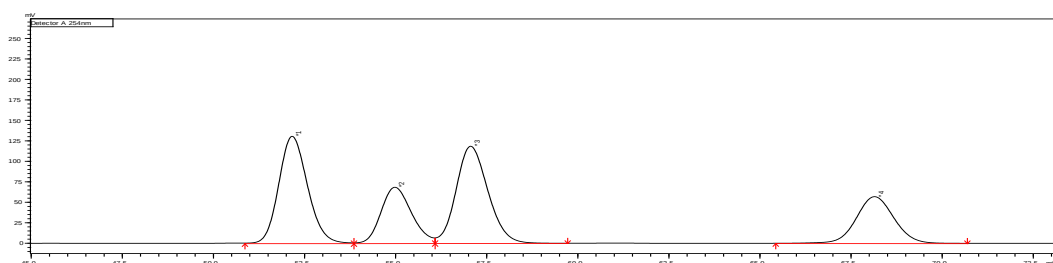




ent-8h

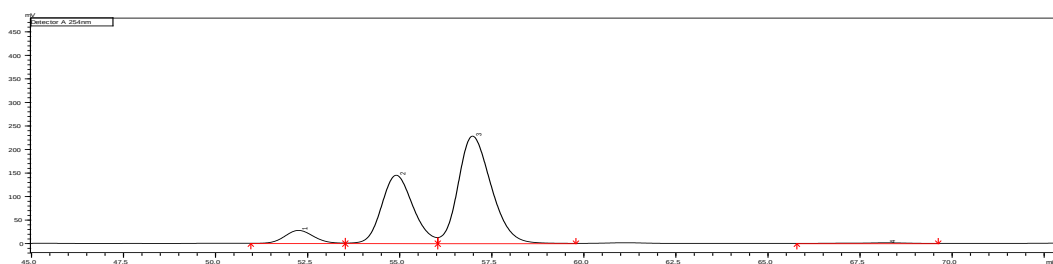
ent-8h: Procedure D with chiral aldehyde **7h** (73% ^1H NMR yield, 1.8/1 dr, 81% ee. Diastereoselectivity was determined by ^1H NMR and HPLC analysis).

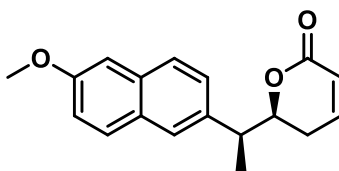
HPLC: DAICEL CHIRALPAK ADH, hexane/*i*-PrOH = 47/3, flow rate: 0.5 mL/min, λ = 254 nm, $t_{\text{R}}(\text{major})$ = 57.0 min, $t_{\text{R}}(\text{minor})$ = 52.3 min, ee = 81%.



Peak#	Ret. Time	Area%
1	52.170	31.947
2	54.989	17.715
3	57.068	32.129
4	68.153	18.208

Peak#	Ret. Time	Area%
1	52.263	6.071
2	54.915	35.165
3	56.987	58.303
4	68.217	0.461

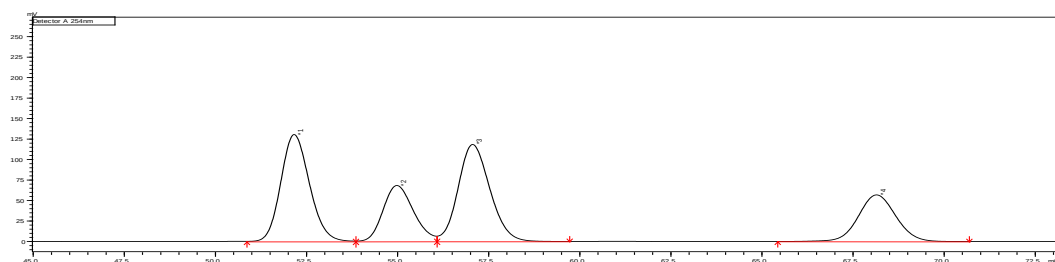




8h

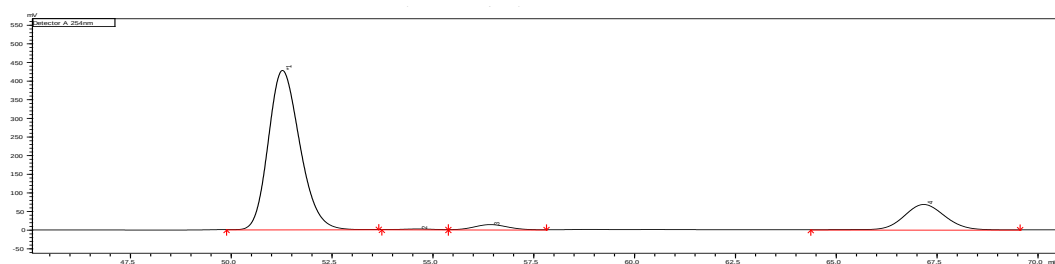
8h: Procedure C with racemic aldehyde *rac*-**7h** (87% ¹H NMR yield, 5/1 dr, 94% ee; 74.0 mg, white powder, 66% isolated yield, >20/1 dr, 94% ee. Diastereoselectivity was determined by ¹H NMR and HPLC analysis and the diastereoisomer can be separated by silica gel column chromatography (petroleum ether/ethyl acetate = 9/1)).

HPLC: DAICEL CHIRALPAK ADH, hexane/*i*-PrOH = 47/3, flow rate: 0.5 mL/min, λ = 254 nm, t_R (major) = 51.3 min, t_R (minor) = 56.4 min, ee = 94%.



Peak#	Ret. Time	Area%
1	52.170	31.947
2	54.989	17.715
3	57.068	32.129
4	68.153	18.208

Peak#	Ret. Time	Area%
1	51.278	80.599
2	54.638	0.253
3	56.431	2.648
4	67.176	16.501



5. Insights to the reaction mechanism

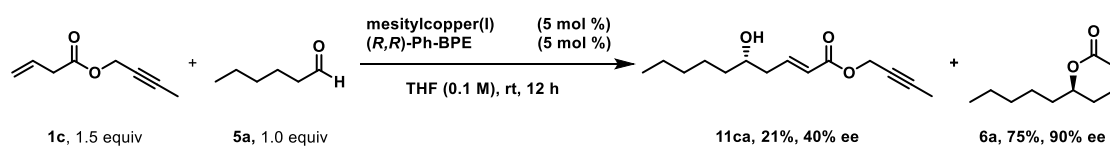
5.1. Preparation of *rac*-3aa, *rac*-3ba, *rac*-3ca, *rac*-4a, *rac*-6a, *rac*-11ca, and *rac*-12ca

A dried 10 mL Schlenk tube equipped with a magnetic stirring bar was charged with mesitylcopper (7.2 mg, 0.04 mmol, 0.05 equiv) and *rac*-BINAP (24.8 mg, 0.04 mmol, 0.05 equiv) in a glove box under Ar atmosphere. Anhydrous THF (4.0 mL, 0.2 M) was added via syringe. The mixture was stirred for 15 minutes to give a brown catalyst solution. Then **1a** or **1b** or **1c** (1.2 mmol, 1.5 equiv) and corresponding aldehyde **2a** or **5a** (0.8 mmol, 1.0 equiv) were added sequentially at room temperature. The resulting reaction mixture was stirred at room temperature for 12 hours. Then, the solvent was removed under reduced pressure. The residue was purified by silica gel column chromatography (petroleum ether/ethyl acetate) to give the corresponding product.

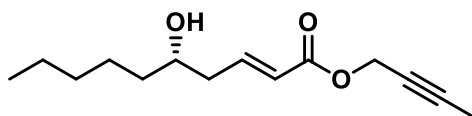
5.2. Preparation of *rac*-10aa

rac-10aa was prepared according to a reported procedure with modification.³⁸ A dried 25 mL Schlenk tube equipped with a magnetic stirring bar was charged with LDA (1.0 mL (2 M solution in hexane/THF), 2 mmol, 1.0 equiv) under N₂ atmosphere. Anhydrous THF (2 mL) was added via syringe. The mixture was cooled to -78 °C and HMPA (358.4 mg, 2 mmol, 1.0 equiv) was added. The resulting mixture was stirred for 30 minutes and then **1a** (422.7 mg, 2.4 mmol, 1.2 equiv) was added. After 30 minutes, benzaldehyde **2a** (318.4 mg, 3 mmol, 1.5 equiv) was added and stirred for 20 minutes. The resulting reaction mixture was quenched by saturated aqueous NH₄Cl (5 mL) at -78 °C. The aqueous phase was extracted with EA (10 mL × 3). The organic extracts were dried over anhydrous Na₂SO₄ and the solvents were removed under reduced pressure. The residue was purified by silica gel column chromatography (petroleum ether/ethyl acetate = 9/1) to give *rac*-10aa (201.9 mg, 36% yield, dr = 1.6/1) as a pale yellow powder.

5.3. Catalytic asymmetric DVAR of **1c** with **5a**



(**11ca** showed significantly lower ee than **6a** and they owned opposite absolute configuration).

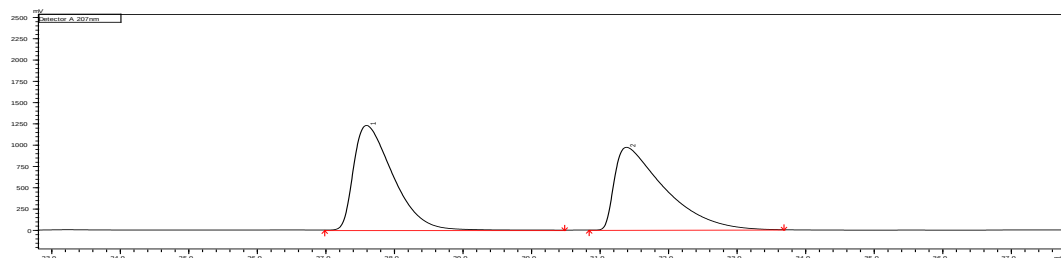


11ca

¹H NMR (400 MHz, CDCl₃) δ 7.08-7.00 (m, 1H), 5.93 (d, *J* = 15.7 Hz, 1H), 4.71 (q, *J* = 2.3 Hz, 2H), 3.79-3.74 (m, 1H), 2.45-2.30 (m, 2H), 1.86 (t, *J* = 2.3 Hz, 3H), 1.70-1.22 (m, 9H), 0.89 (t, *J* = 6.7 Hz, 3H) ppm.

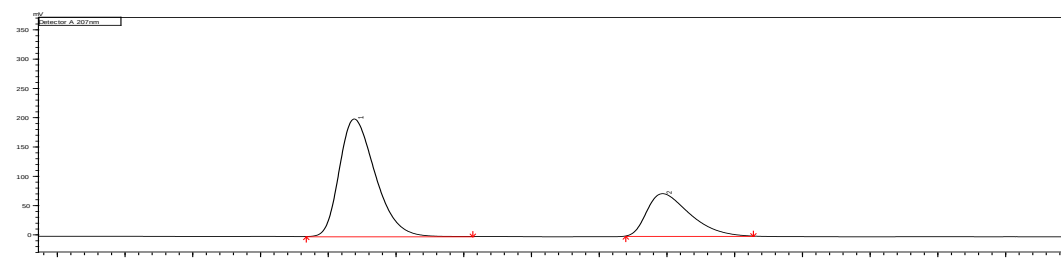
¹³C NMR (100 MHz, CDCl₃) δ 165.58, 146.47, 123.00, 83.14, 73.17, 70.51, 52.68, 40.22, 37.10, 31.70, 25.23, 22.57, 13.98, 3.64 ppm.

HPLC: DAICEL CHIRALPAK IE, hexane/*i*-PrOH = 47/3, flow rate: 0.5 mL/min, λ = 207 nm, *t*_R(major) = 29.4 min, *t*_R(minor) = 33.9 min, ee = 40%.



Peak#	Ret. Time	Area%
1	27.597	49.960
2	31.391	50.040

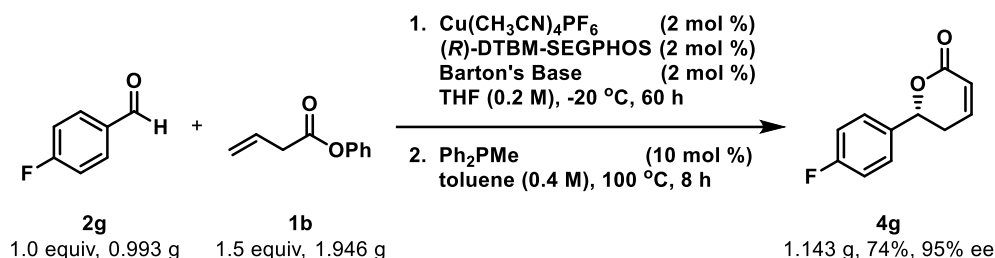
Peak#	Ret. Time	Area%
1	29.388	70.038
2	33.941	29.962



6. Gram-scale reaction and application of present catalytic asymmetric DVAR

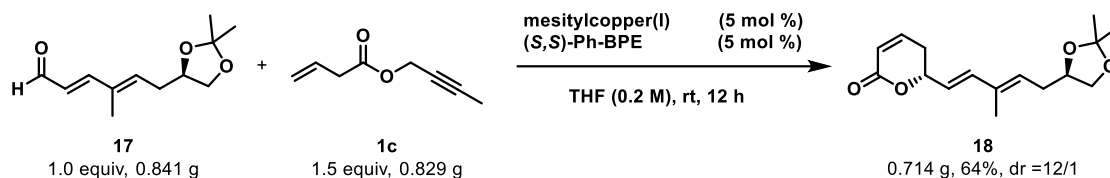
DVAR

6.1. Gram-scale reaction and application of present catalytic asymmetric DVAR in the formal synthesis of ezetimibe



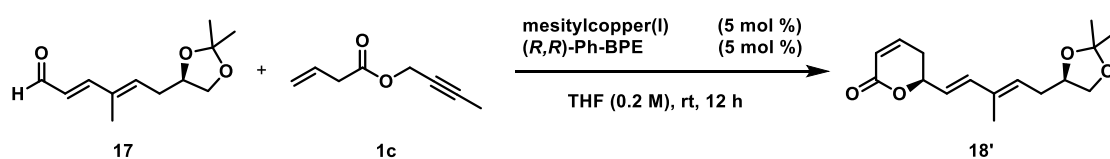
A dried 100 mL round bottom flask equipped with a magnetic stirring bar was charged with $[\text{Cu}(\text{CH}_3\text{CN})_4]\text{PF}_6$ (59.6 mg, 0.16 mmol, 0.02 equiv) and $(R)\text{-DTBM-SEGPBOS}$ (188.7 mg, 0.16 mmol, 0.02 equiv) in a glove box under Ar atmosphere. Anhydrous THF (40 mL, 0.2 M) was added via syringe. The mixture was stirred for 15 minutes to give a colorless catalyst solution. Then **1b** (1.946 g, 12 mmol, 1.5 equiv) and 4-fluorobenzaldehyde **2g** (0.993 g, 8 mmol, 1.0 equiv) were added sequentially. After cooling to $-20\text{ }^\circ\text{C}$, Barton's Base (27.4 mg, 0.16 mmol, 0.02 equiv) was added. The resulting reaction mixture was stirred at $-20\text{ }^\circ\text{C}$ for 60 hours. Then, the reaction mixture was quenched by acetic acid (0.8 mL (0.4 M in THF), 0.32 mmol, 0.04 equiv). The mixture was stirred for additional 20 minutes at $-20\text{ }^\circ\text{C}$, and then the solvent was removed under reduced pressure. The residue was dissolved in toluene (20 mL) and Ph_2PMe (160.2 mg, 0.8 mmol, 0.1 equiv) was added. The resulting solution was stirred at $100\text{ }^\circ\text{C}$ for 8 hours. The solvent was removed under reduced pressure, and then the residue was purified by silica gel column chromatography (petroleum ether/ethyl acetate = 5/1) to give the product **4g** (1.143g, 74% yield, 95% ee) as a pale yellow powder.

6.2. Application of present catalytic asymmetric DVAR in the formal synthesis of fostriecin



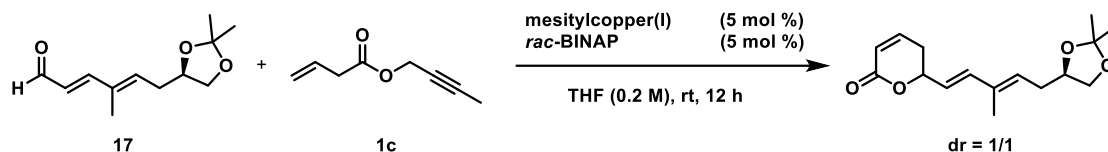
A dried 50 mL round bottom flask equipped with a magnetic stirring bar was charged with mesitylcopper (36.5 mg, 0.2 mmol, 0.05 equiv) and (S,S)-Ph-BPE (101.3 mg, 0.2 mmol, 0.05 equiv) in a glove box under Ar atmosphere. Anhydrous THF (20 mL, 0.2 M) was added via syringe. The mixture was stirred for 15 minutes to give a brown catalyst solution. Then **1c** (829 mg, 6 mmol, 1.5 equiv) and aldehyde **17** (841 mg, 4 mmol, 1.0 equiv) were added sequentially at room temperature. The resulting reaction mixture was stirred at room temperature for 12 hours. Then, to the reaction mixture were added acetic anhydride (410 μ L, 4.4 mmol, 1.1 equiv) and DMAP (49 mg, 0.4 mmol, 0.1 equiv). The mixture was stirred for additional 2 hours at room temperature, and then the solvent was removed under reduced pressure. The residue was purified by silica gel column chromatography (petroleum ether/ethyl acetate = 4/1) to give the product **18** (714.1 mg, 64% yield, 12/1 dr) as a pale yellow oil. (It is very difficult to separate the CP from the mixture of CP and LP by silica gel column chromatography. Therefore, after the completion of the reaction, acetic anhydride and DMAP were added to the reaction mixture to transform alcohol to ester so that CP could be purified by silica gel column chromatography conveniently).

Preparation of the diastereoisomer **18'** of the product **18**



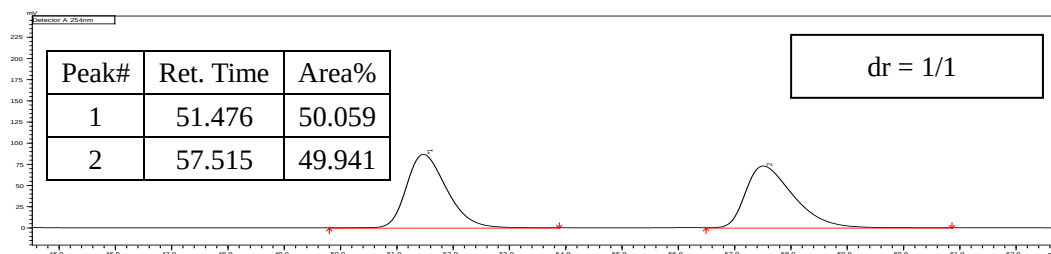
A dried 10 mL Schlenk tube equipped with a magnetic stirring bar was charged with mesitylcopper (3.6 mg, 0.02 mmol, 0.05 equiv) and (R,R)-Ph-BPE (10.1 mg, 0.02 mmol, 0.05 equiv) in a glove box under Ar atmosphere. Anhydrous THF (2.0 mL, 0.2 M) was added via syringe. The mixture was stirred for 15 minutes to give a brown catalyst solution. Then **1c** (82.9 mg, 0.6 mmol, 1.5 equiv) and aldehyde **17** (0.4 mmol, 1.0 equiv) were added sequentially at room temperature. The resulting reaction mixture was stirred at room temperature for 12 hours. Then, to the reaction mixture were added acetic anhydride (41 μ L, 0.44 mmol, 1.1 equiv) and DMAP (4.9 mg, 0.04 mmol, 0.1 equiv). The mixture was stirred for additional 2 hours at room temperature, and then the solvent was removed under reduced pressure. The residue was purified by silica gel column chromatography (petroleum ether/ethyl acetate = 4/1) to give the product **18'** (70.0 mg, 63% yield, 12/1 dr) as a pale yellow oil.

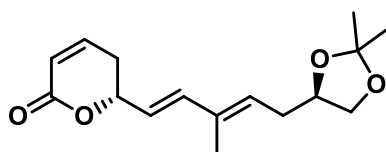
Preparation of the diastereoisomer **18** and **18'** with *rac*-BINAP



A dried 10 mL Schlenk tube equipped with a magnetic stirring bar was charged with mesitylcopper (3.6 mg, 0.02 mmol, 0.05 equiv) and *rac*-BINAP (12.4 mg, 0.02 mmol, 0.05 equiv) in a glove box under Ar atmosphere. Anhydrous THF (2.0 mL, 0.2 M) was added via syringe. The mixture was stirred for 15 minutes to give a brown catalyst solution. Then **1c** (82.9 mg, 0.6 mmol, 1.5 equiv) and aldehyde **17** (0.4 mmol, 1.0 equiv) were added sequentially at room temperature. The resulting reaction mixture was stirred at room temperature for 12 hours. Then, to the reaction mixture were added acetic anhydride (41 μ L, 0.44 mmol, 1.1 equiv) and DMAP (4.9 mg, 0.04 mmol, 0.1 equiv). The mixture was stirred for additional 2 hours at room temperature, and then the solvent was removed under reduced pressure. The residue was purified by silica gel column chromatography (petroleum ether/ethyl acetate = 4/1) to give the product **18** and **18'** in a ratio of 1/1 (Diastereoselectivity was determined by chiral-stationary-phase HPLC analysis).

HPLC: DAICEL CHIRALPAK IBN-3, hexane/*i*-PrOH = 47/3, flow rate: 0.5 mL/min, λ = 254 nm.





18

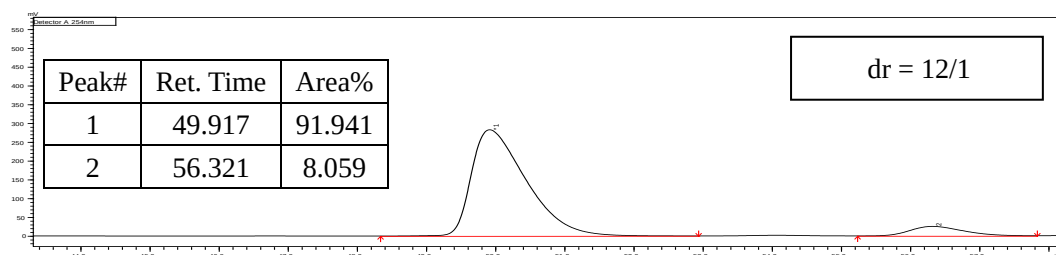
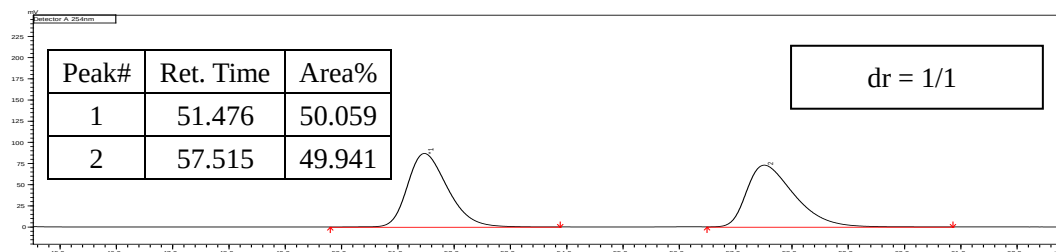
18: 714.1 mg, pale yellow oil, 64% yield, dr = 12/1 (Diastereoselectivity was determined by chiral-stationary-phase HPLC analysis).³⁹

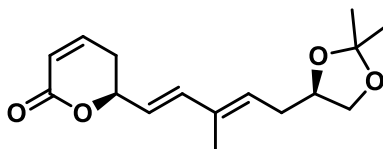
¹H NMR (400 MHz, CDCl₃) δ 6.93-6.89 (m, 1H), 6.37 (d, *J* = 15.7 Hz, 1H), 6.05 (d, *J* = 9.8 Hz, 1H), 5.68 (dd, *J* = 15.7, 6.6 Hz, 1H), 5.56 (t, *J* = 7.4 Hz, 1H), 4.98 (dd, *J* = 14.6, 7.1 Hz, 1H), 4.16 (p, *J* = 6.3 Hz, 1H), 4.03 (dd, *J* = 7.9, 6.1 Hz, 1H), 3.58-3.54 (m, 1H), 2.54-2.37 (m, 4H), 1.77 (s, 3H), 1.42 (s, 3H), 1.35 (s, 3H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 163.89, 144.68, 137.67, 134.68, 128.99, 123.35, 121.39, 108.86, 78.17, 75.18, 68.80, 32.47, 29.79, 26.75, 25.46, 12.44 ppm.

Optical rotation: [α]_D²⁸ = +32.65 (*c* = 1.205, CHCl₃, dr = 12/1).

HPLC: DAICEL CHIRALPAK IBN-3, hexane/*i*-PrOH = 47/3, flow rate: 0.5 mL/min, λ = 254 nm.





18'

18': 70.0 mg, pale yellow oil, 63% yield, dr = 12/1 (Diastereoselectivity was determined by chiral-stationary-phase HPLC analysis).

¹H NMR (400 MHz, CDCl₃) δ 6.94-6.89 (m, 1H), 6.36 (d, *J* = 15.7 Hz, 1H), 6.05 (d, *J* = 9.8 Hz, 1H), 5.68 (dd, *J* = 15.7, 6.7 Hz, 1H), 5.56 (t, *J* = 7.3 Hz, 1H), 4.98 (dd, *J* = 14.6, 7.2 Hz, 1H), 4.16 (p, *J* = 6.3 Hz, 1H), 4.04 (dd, *J* = 7.8, 6.2 Hz, 1H), 3.56 (t, *J* = 7.4 Hz, 1H), 2.54-2.36 (m, 4H), 1.77 (s, 3H), 1.42 (s, 3H), 1.35 (s, 3H) ppm.

¹³C NMR (100 MHz, CDCl₃) δ 163.87, 144.70, 137.76, 134.66, 129.07, 123.34, 121.36, 108.85, 78.24, 75.18, 68.79, 32.51, 29.79, 26.74, 25.44, 12.42 ppm.

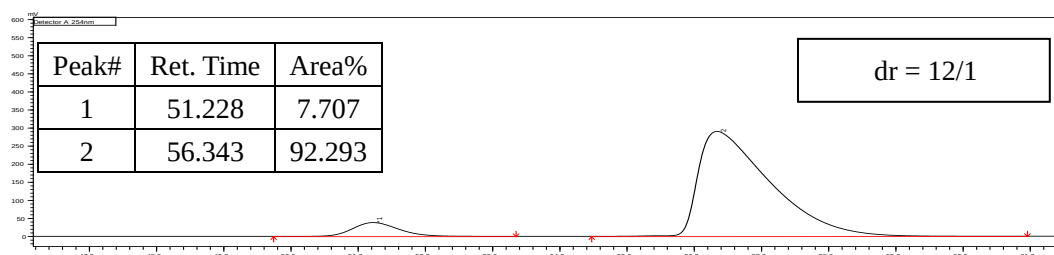
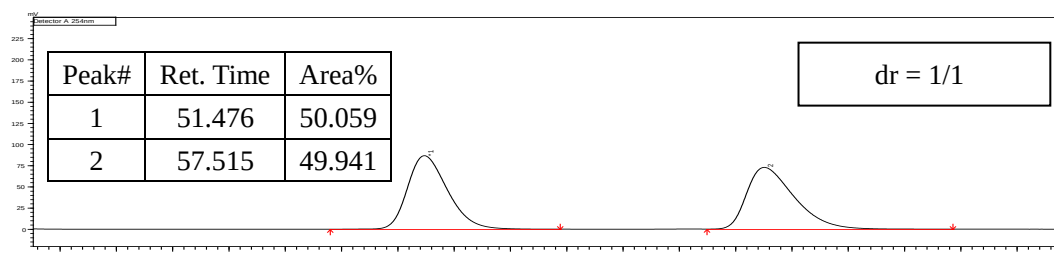
MS (EI) *m/z* [M-CH₃]⁺: 263.

HRMS (EI) *m/z* [M-CH₃]⁺: calcd. 263.1283, found 263.1279.

IR (film): 2985, 2933, 1724, 1381, 1246, 1155, 1061, 970, 817 cm⁻¹.

Optical rotation: [α]_D²⁸ = -41.43 (*c* = 1.072, CHCl₃, dr = 12/1).

HPLC: DAICEL CHIRALPAK IBN-3, hexane/*i*-PrOH = 47/3, flow rate: 0.5 mL/min, λ = 254 nm.



7. References

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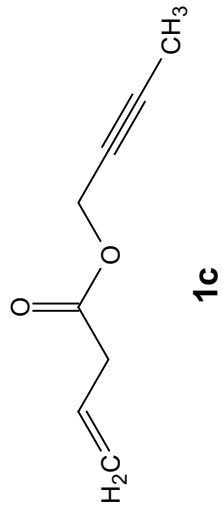
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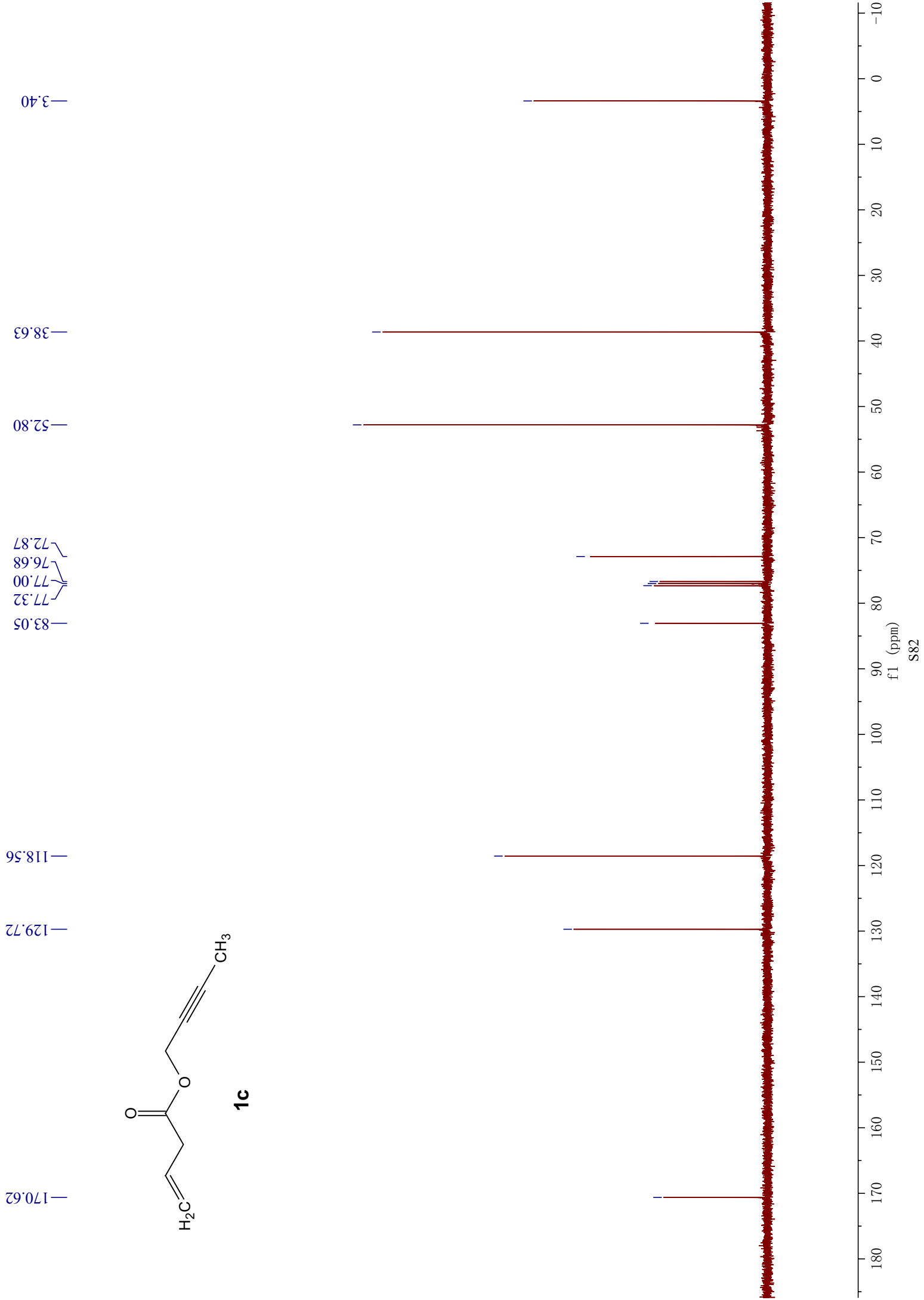
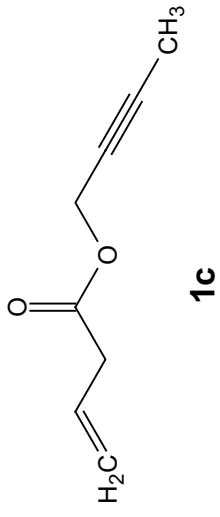
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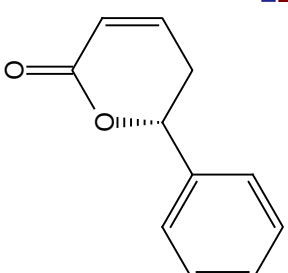
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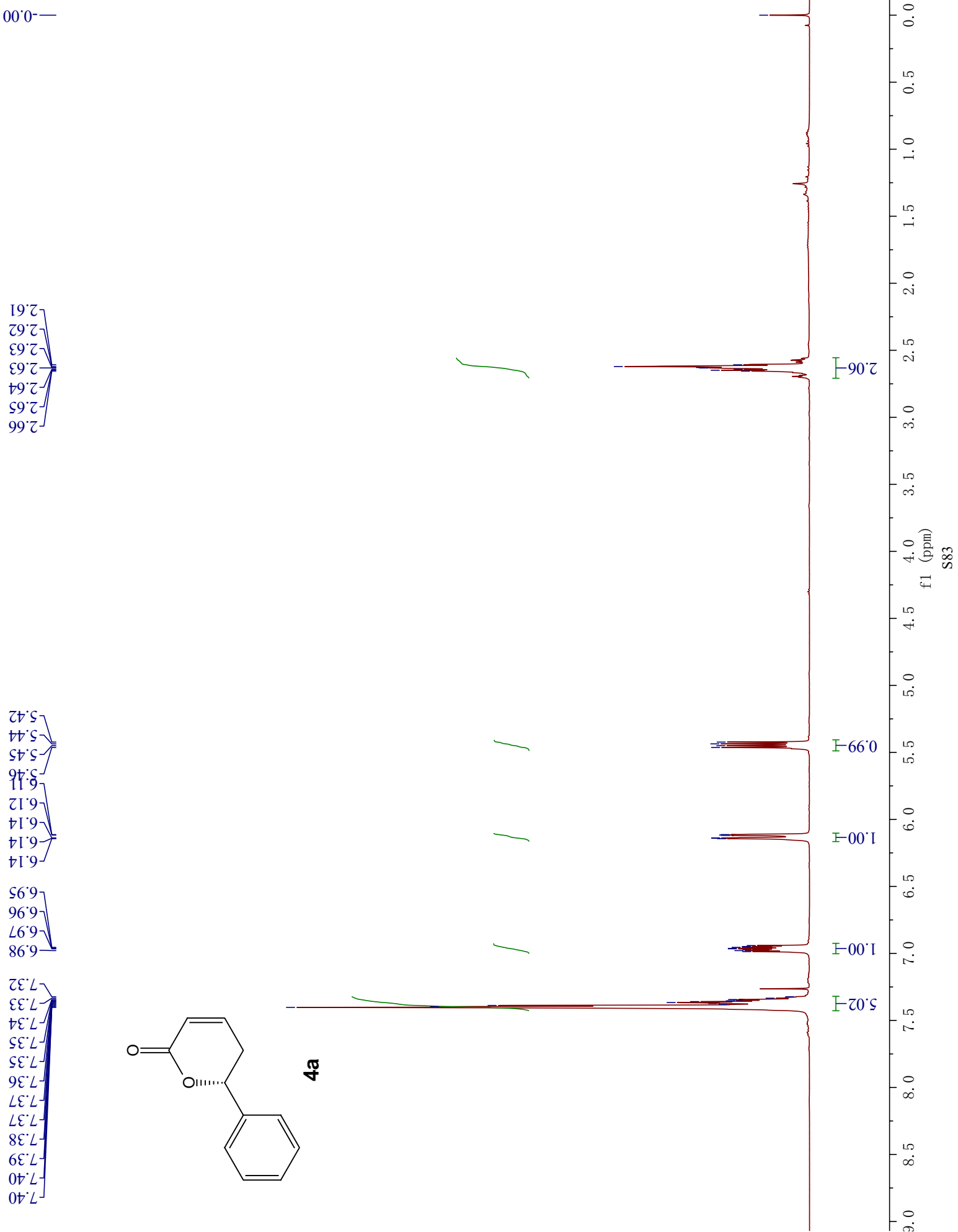
8. ^1H , ^{13}C and ^{19}F NMR spectra of compounds

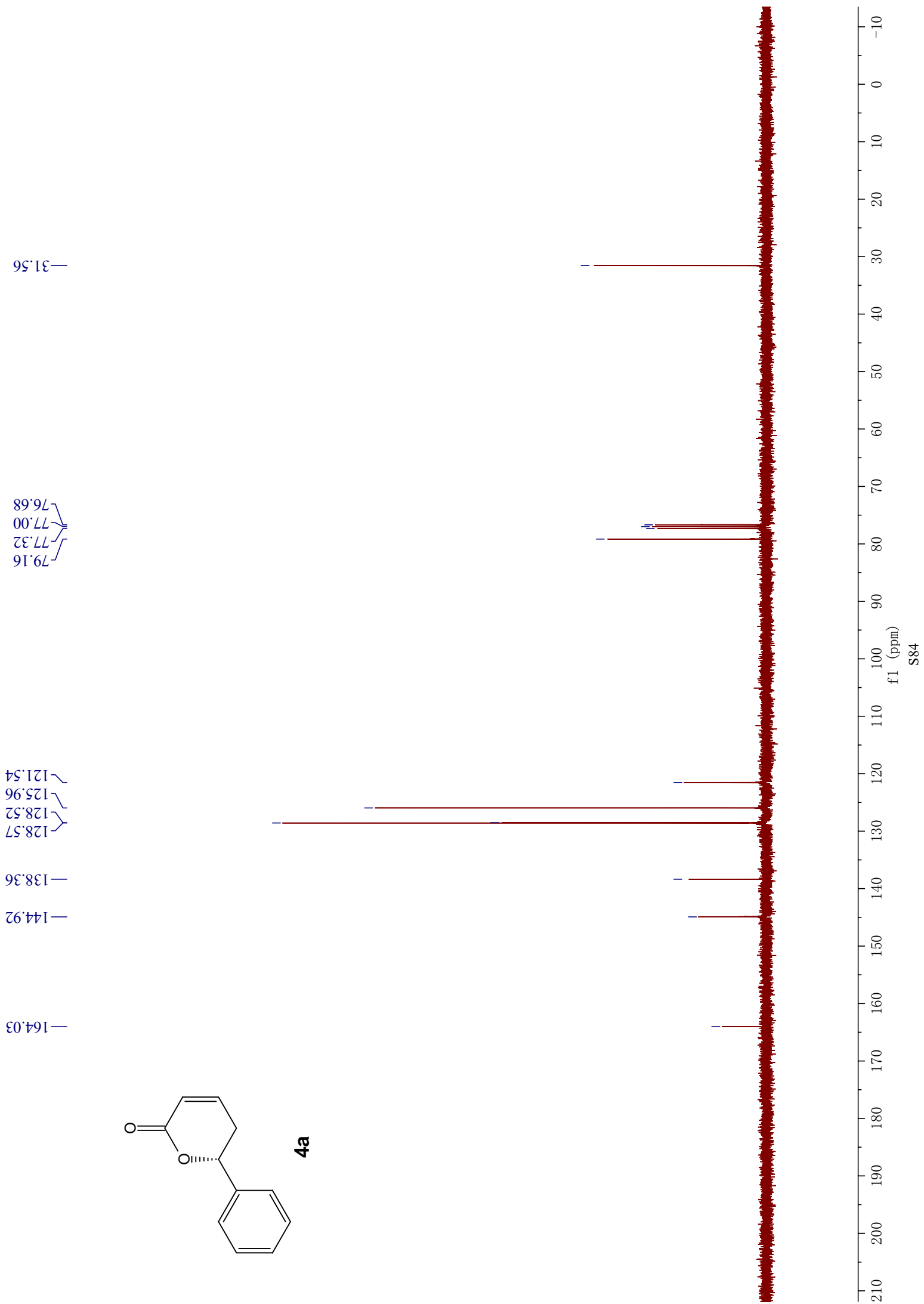
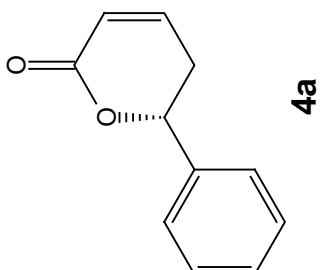


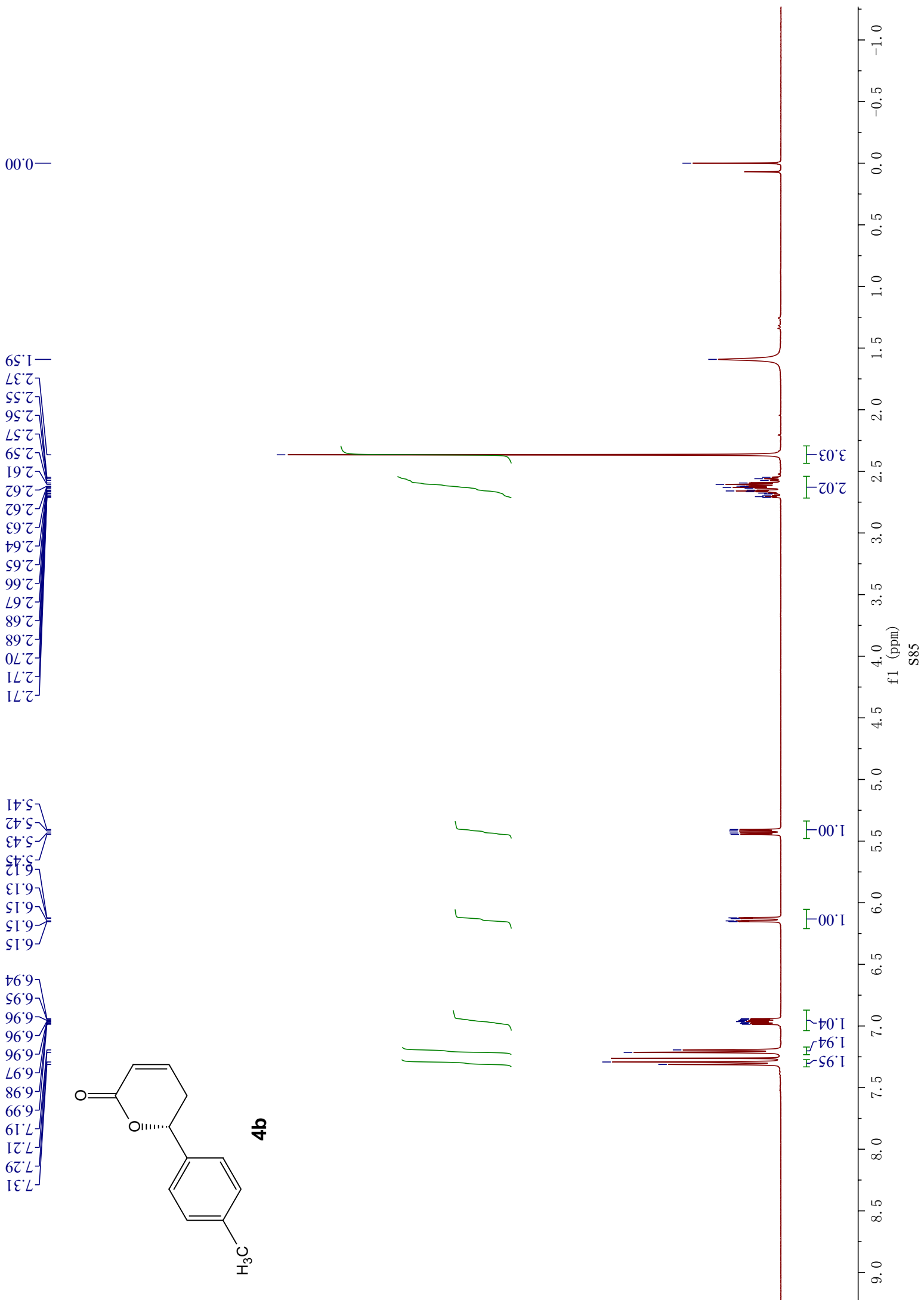


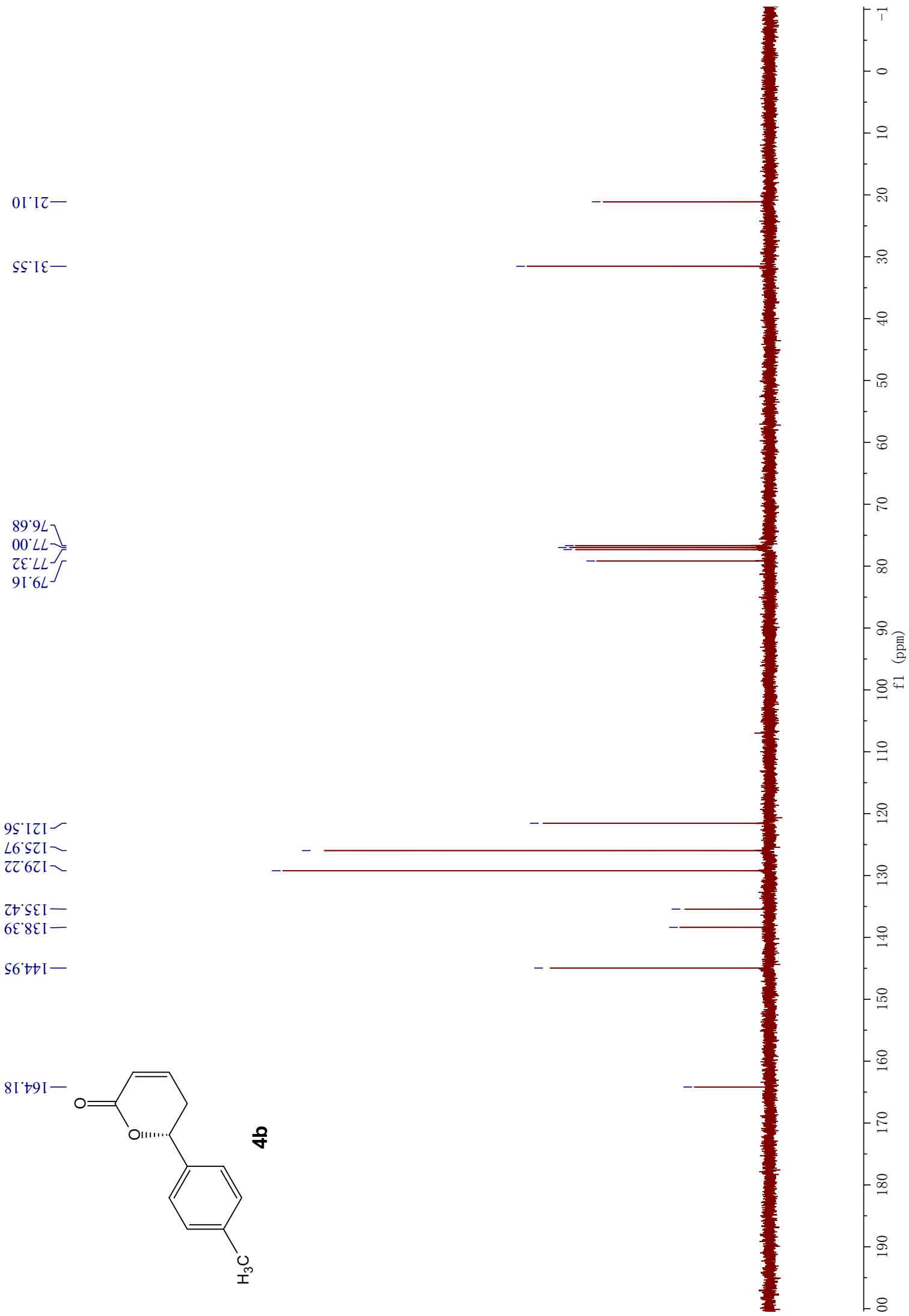


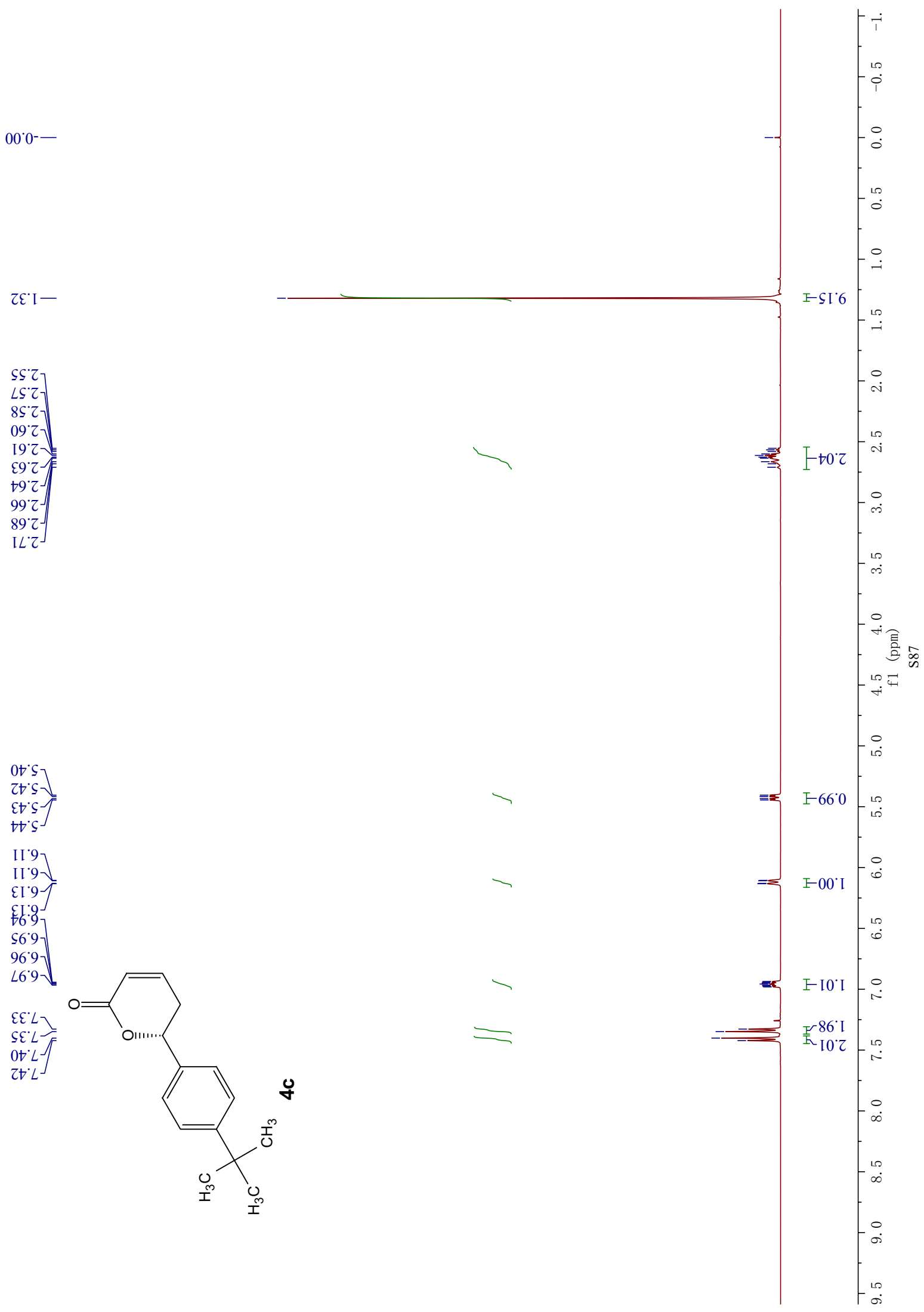
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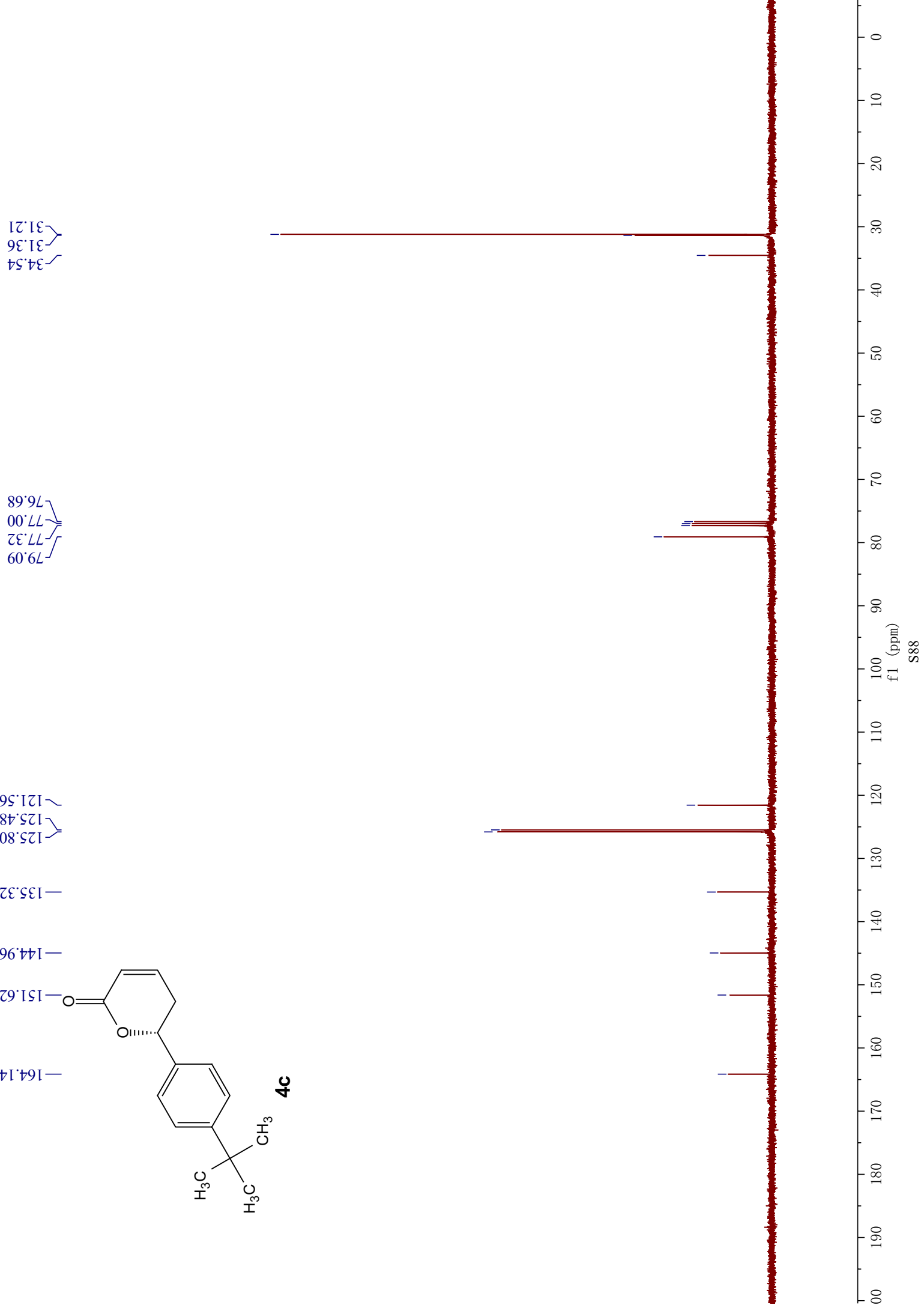


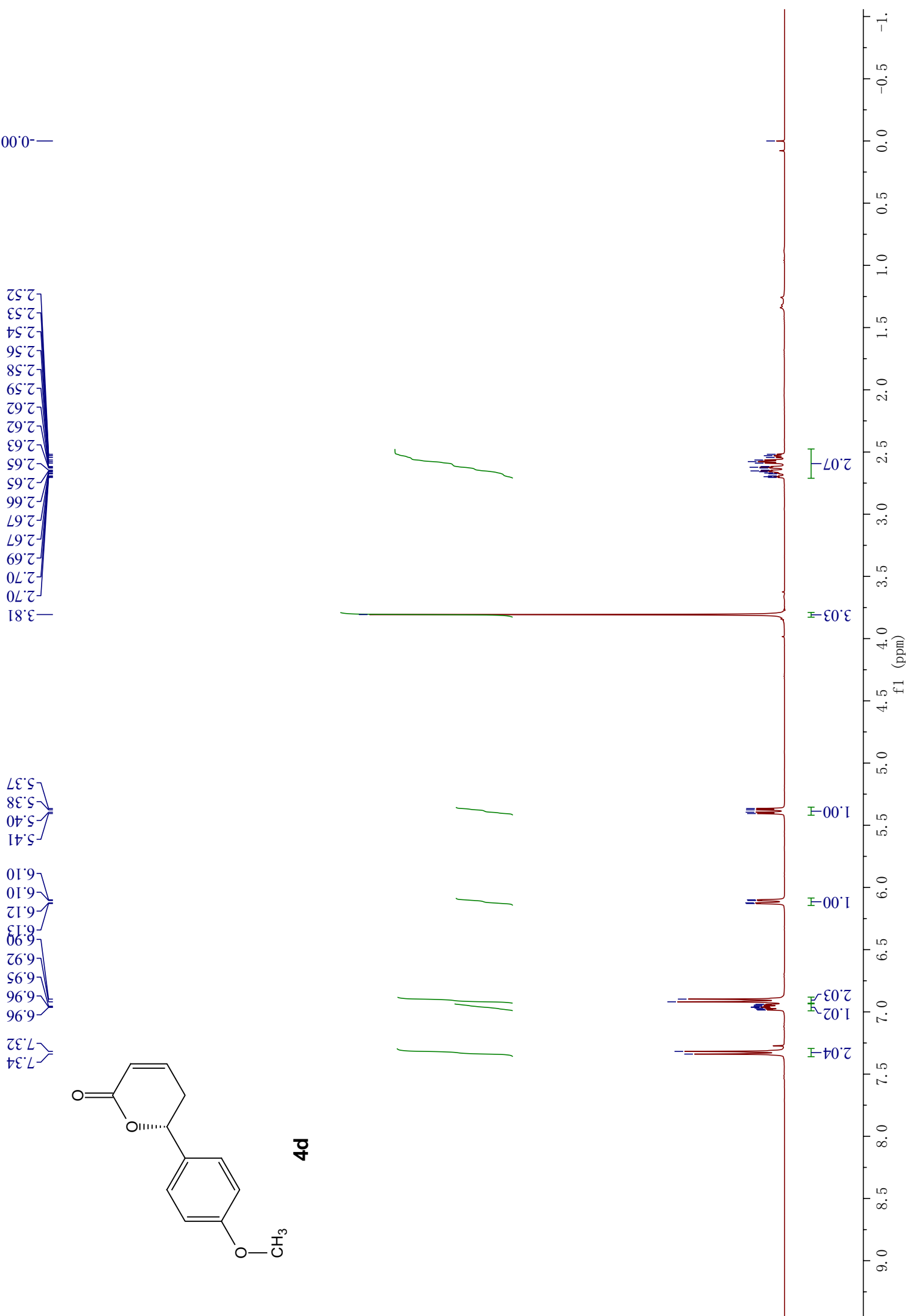
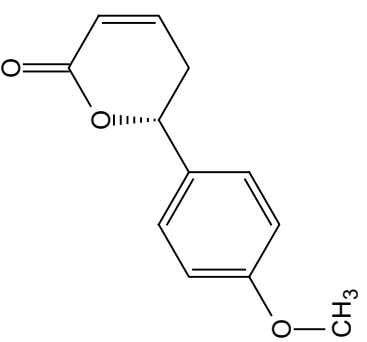


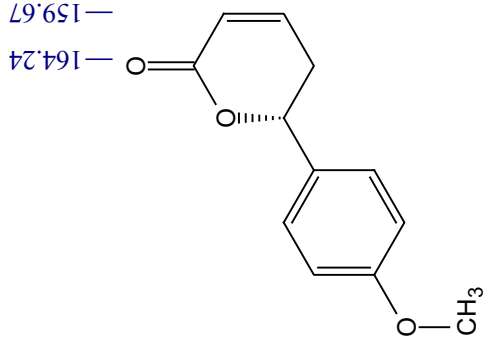




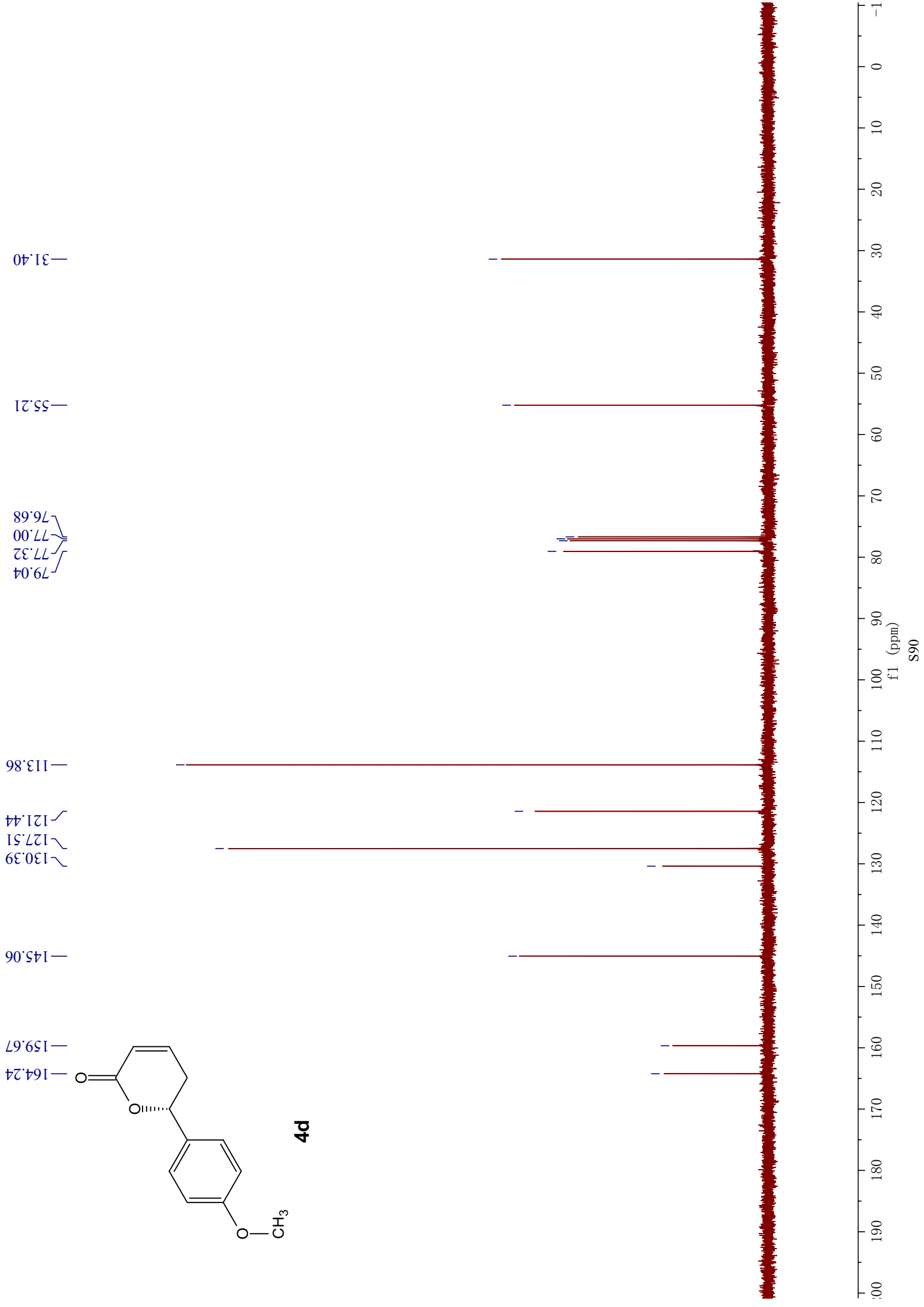




4d



4d



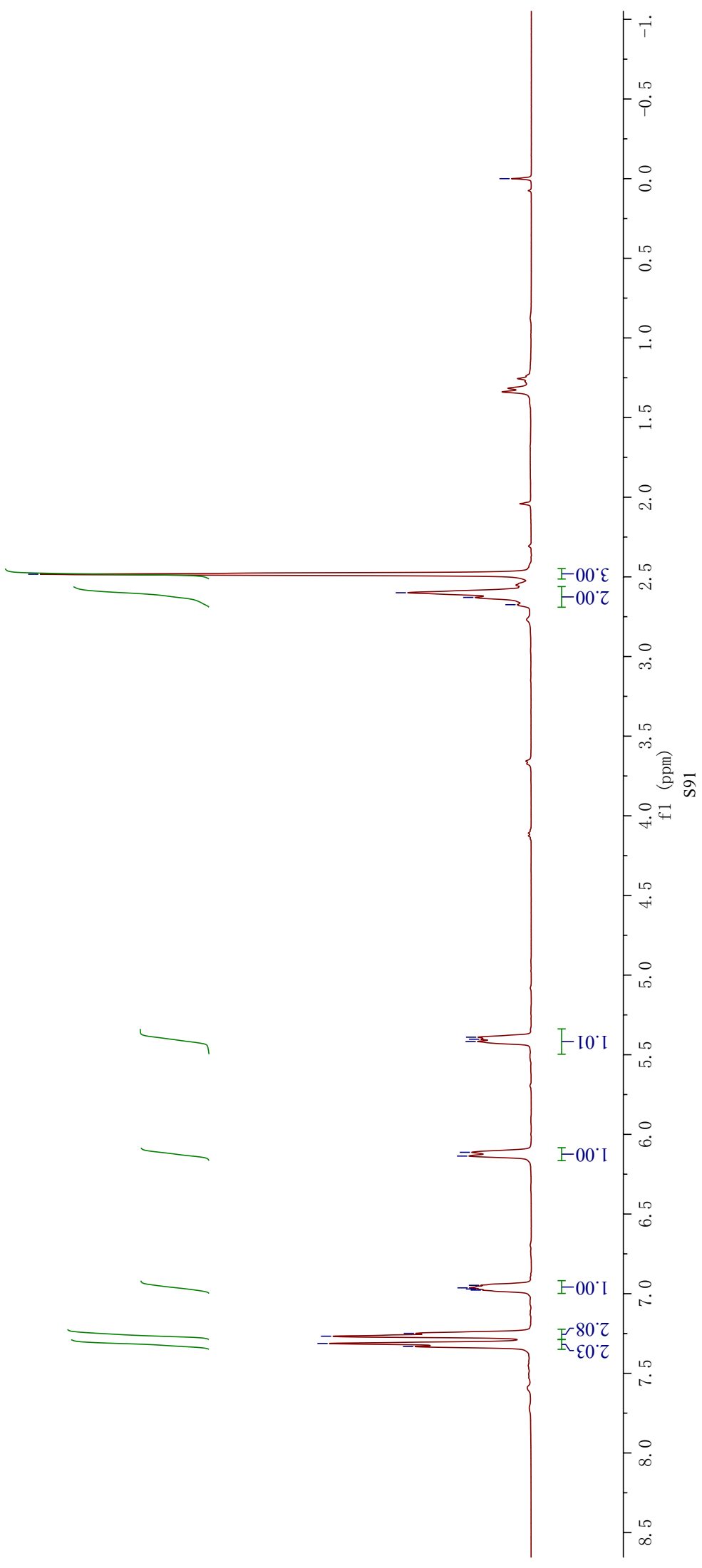
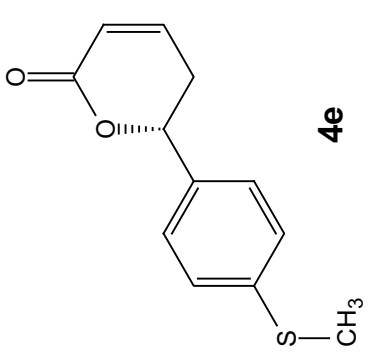
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2.60
2.48

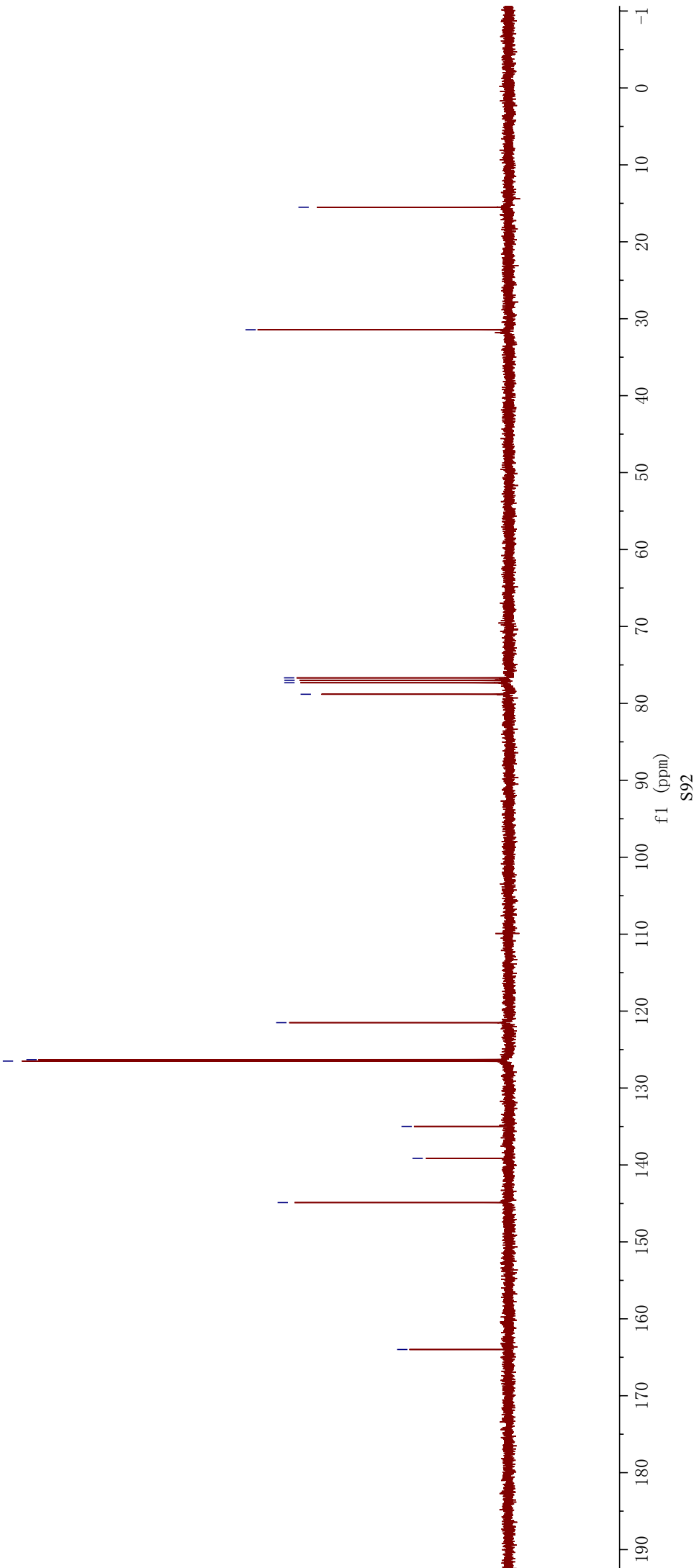
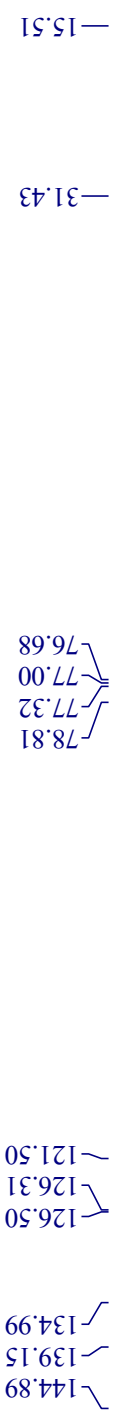
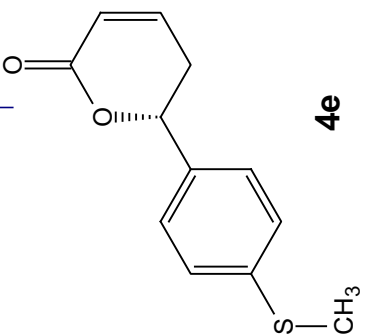
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5.42

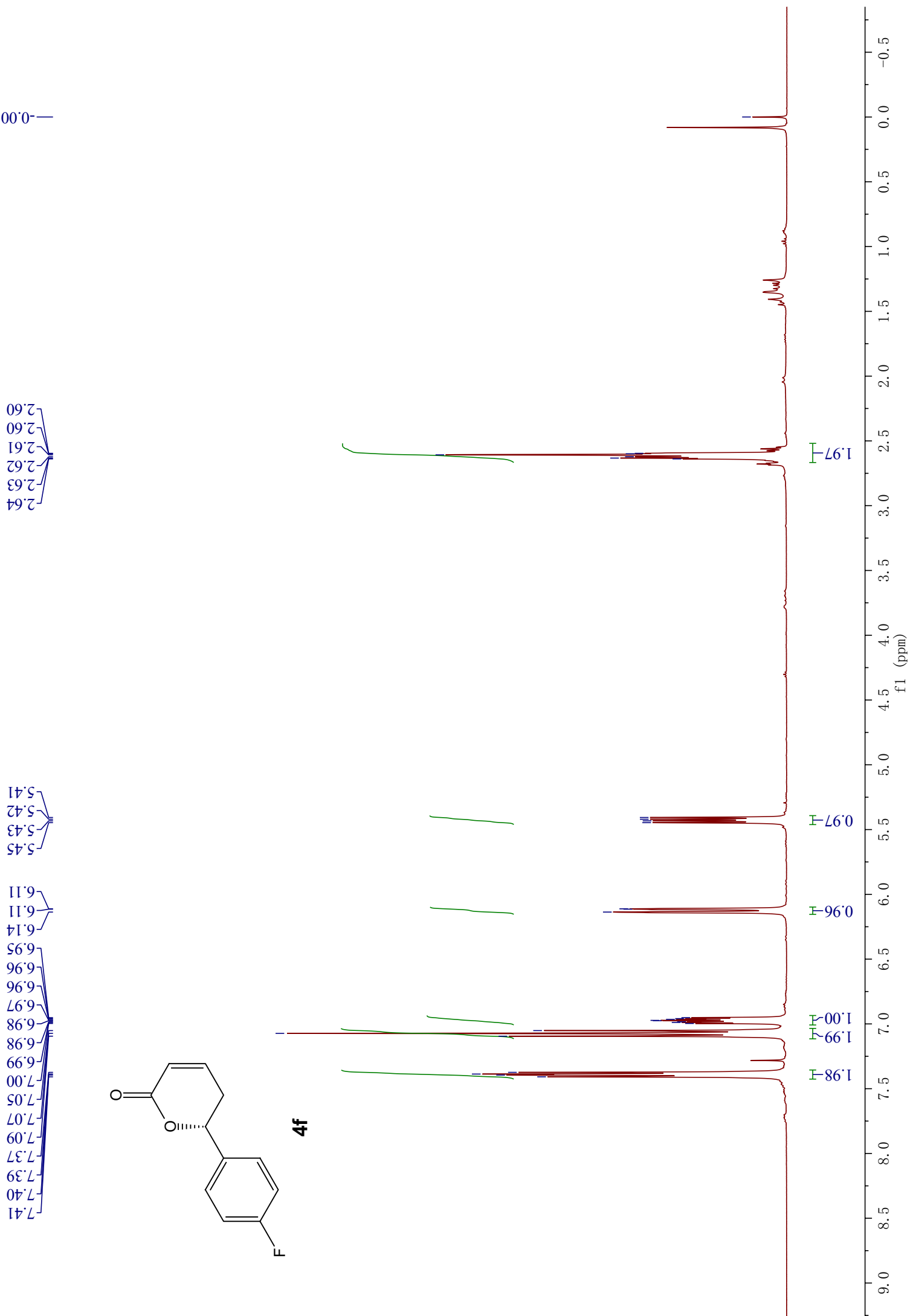
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6.14

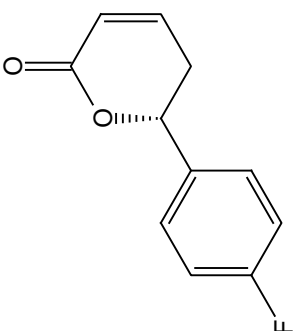
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7.31
7.27
7.25
6.98
6.97
6.96
6.95



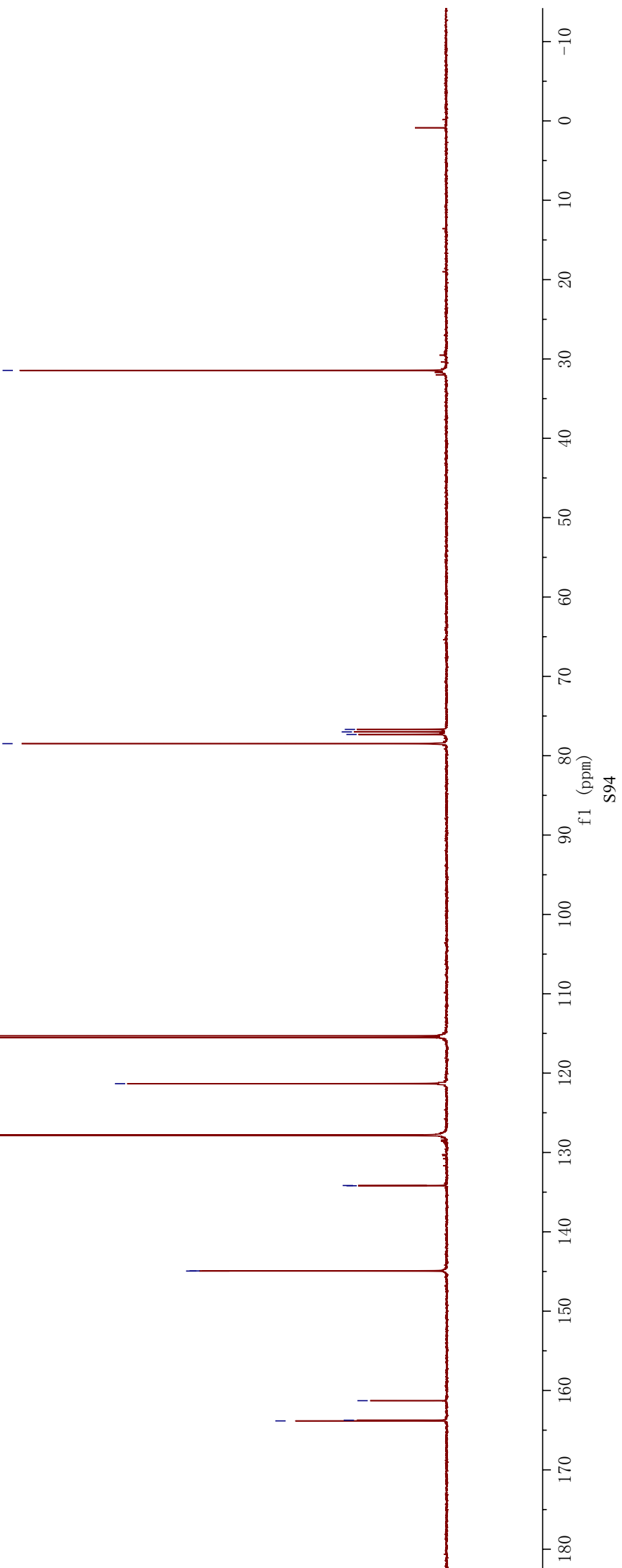
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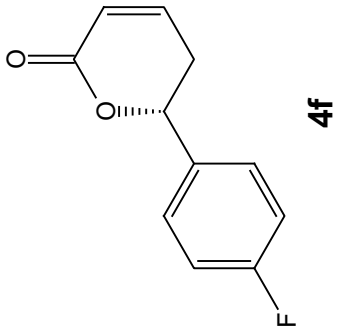






163.83
163.74
161.28
144.94
144.93
134.20
134.16
127.88
127.80
121.33
115.52
115.31
78.48
77.32
77.00
76.68
31.44

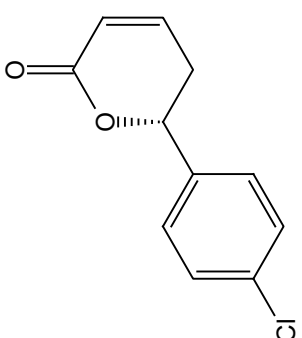




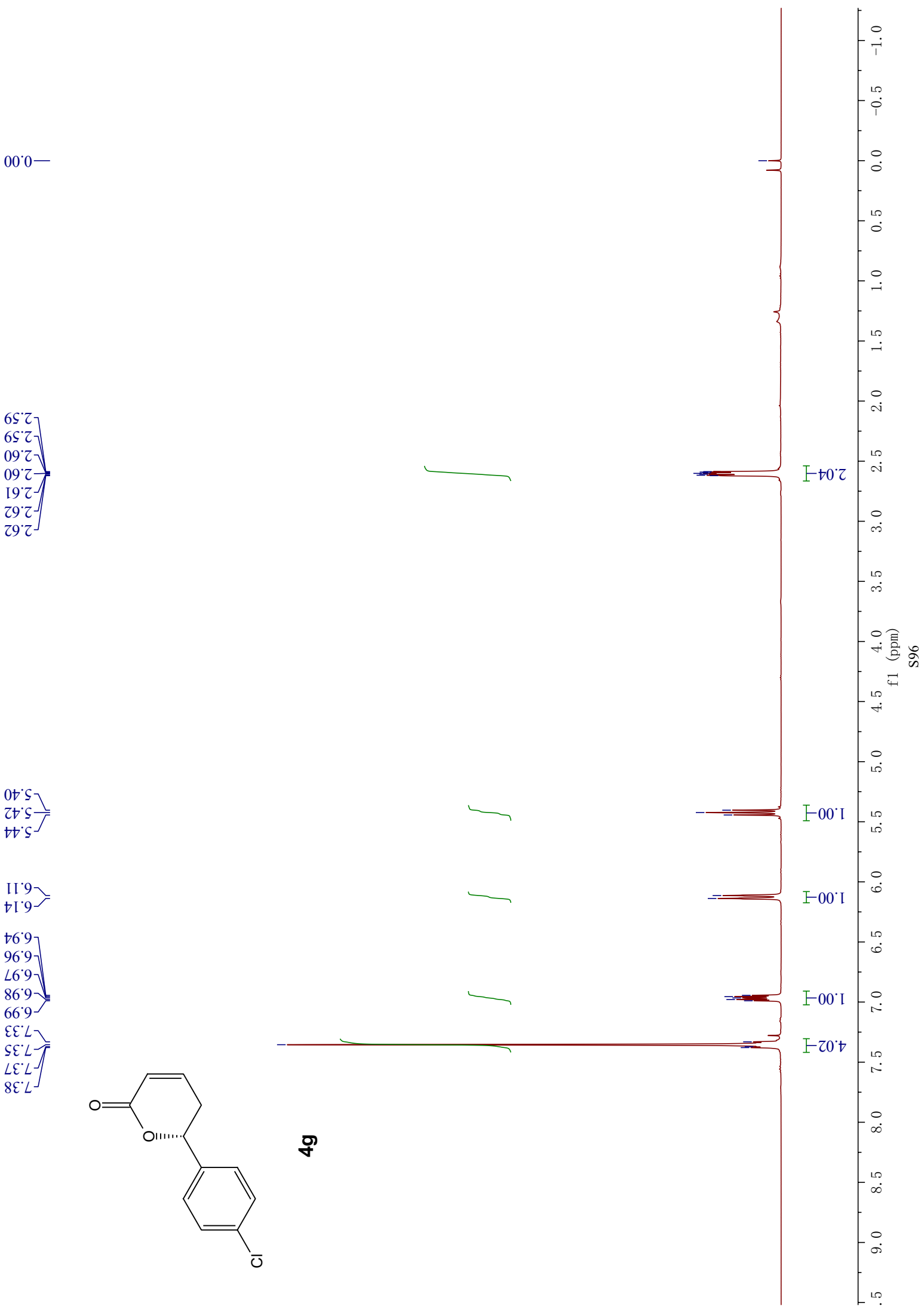
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-113.13
-113.14
-113.15
-113.16
-113.17
-113.17
-113.18
-113.19

f1 (ppm)

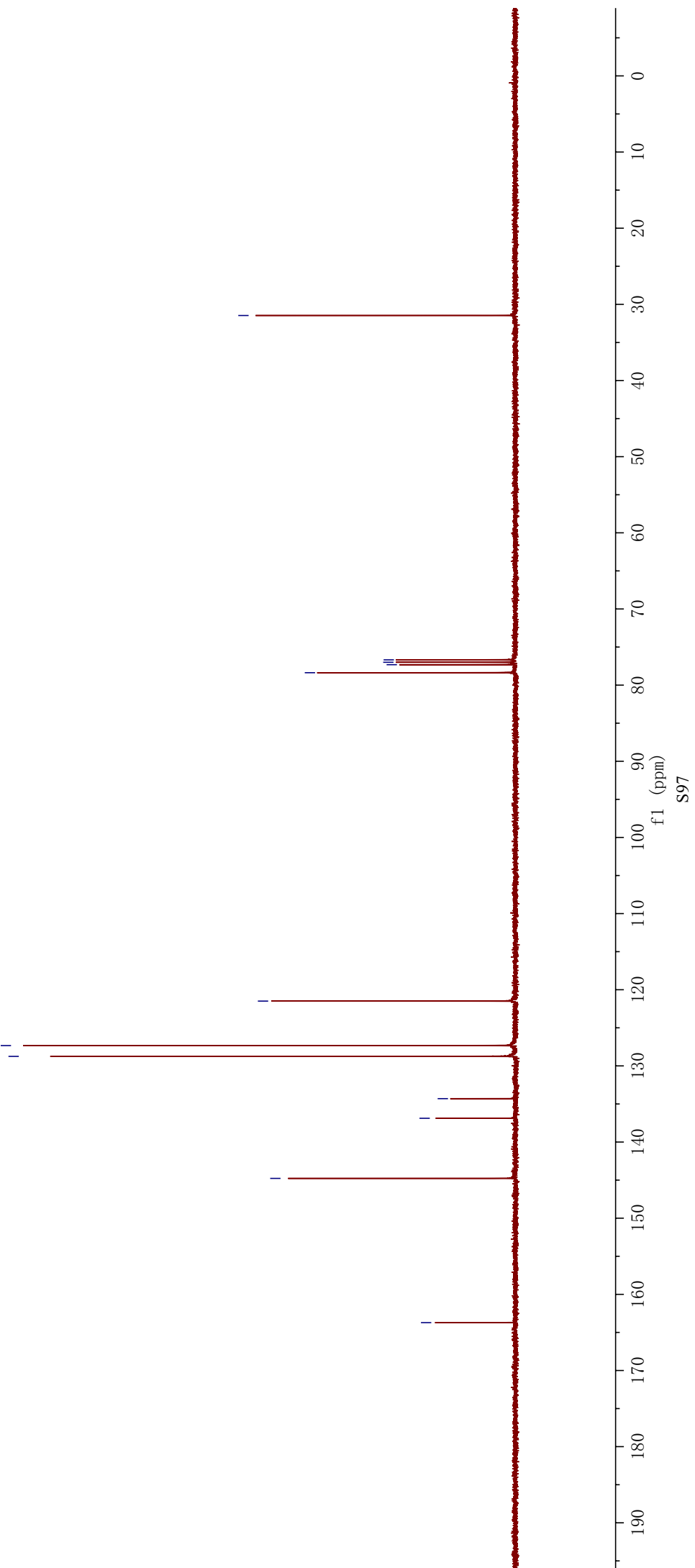
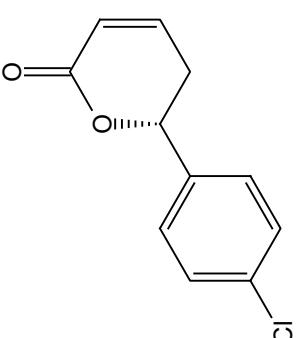
S95

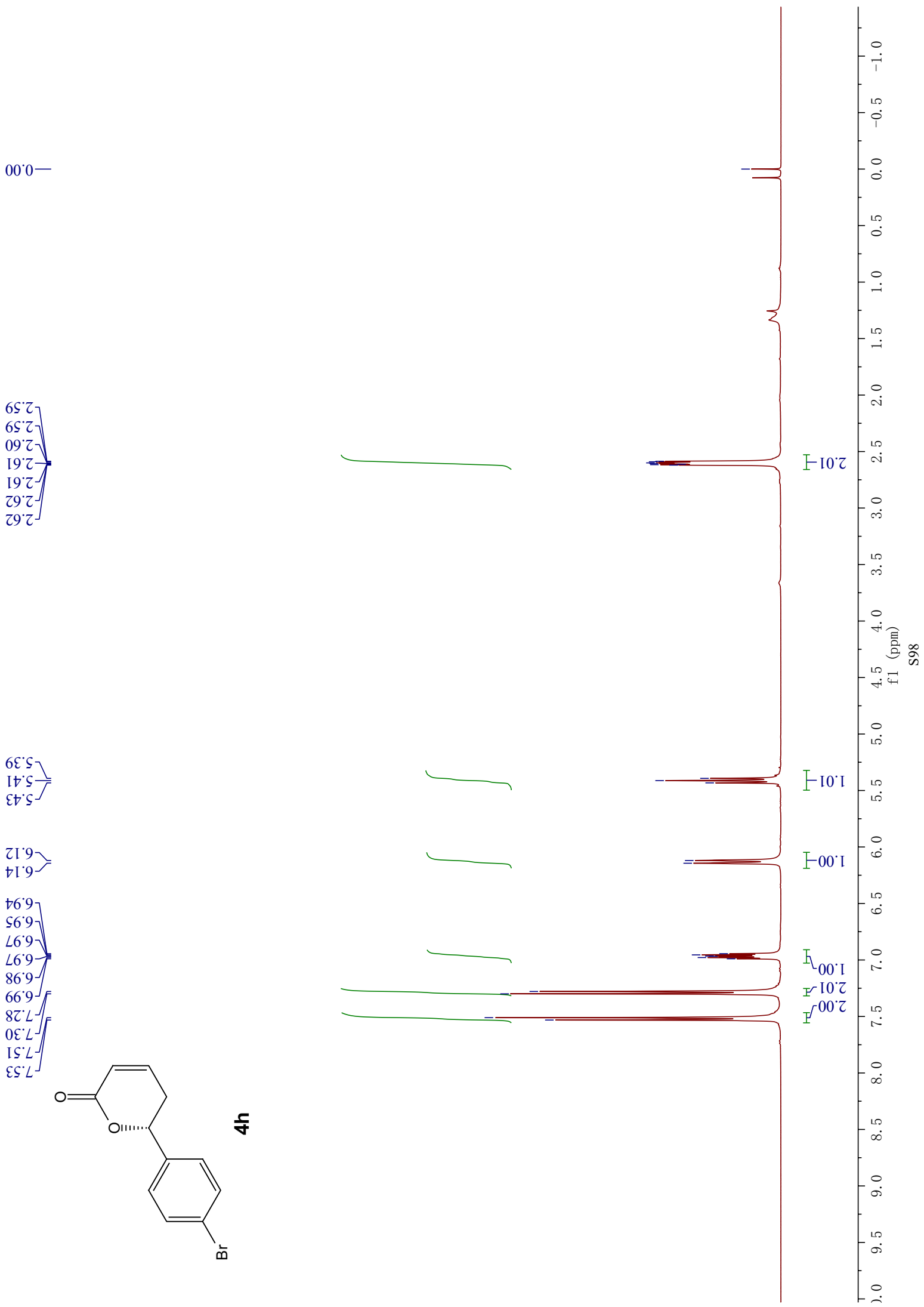


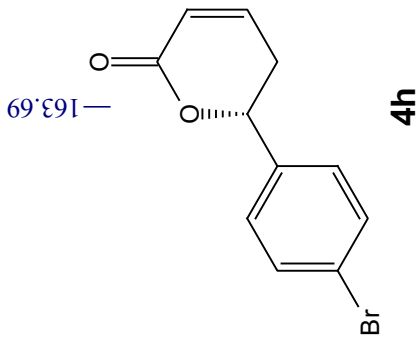
4g



4g







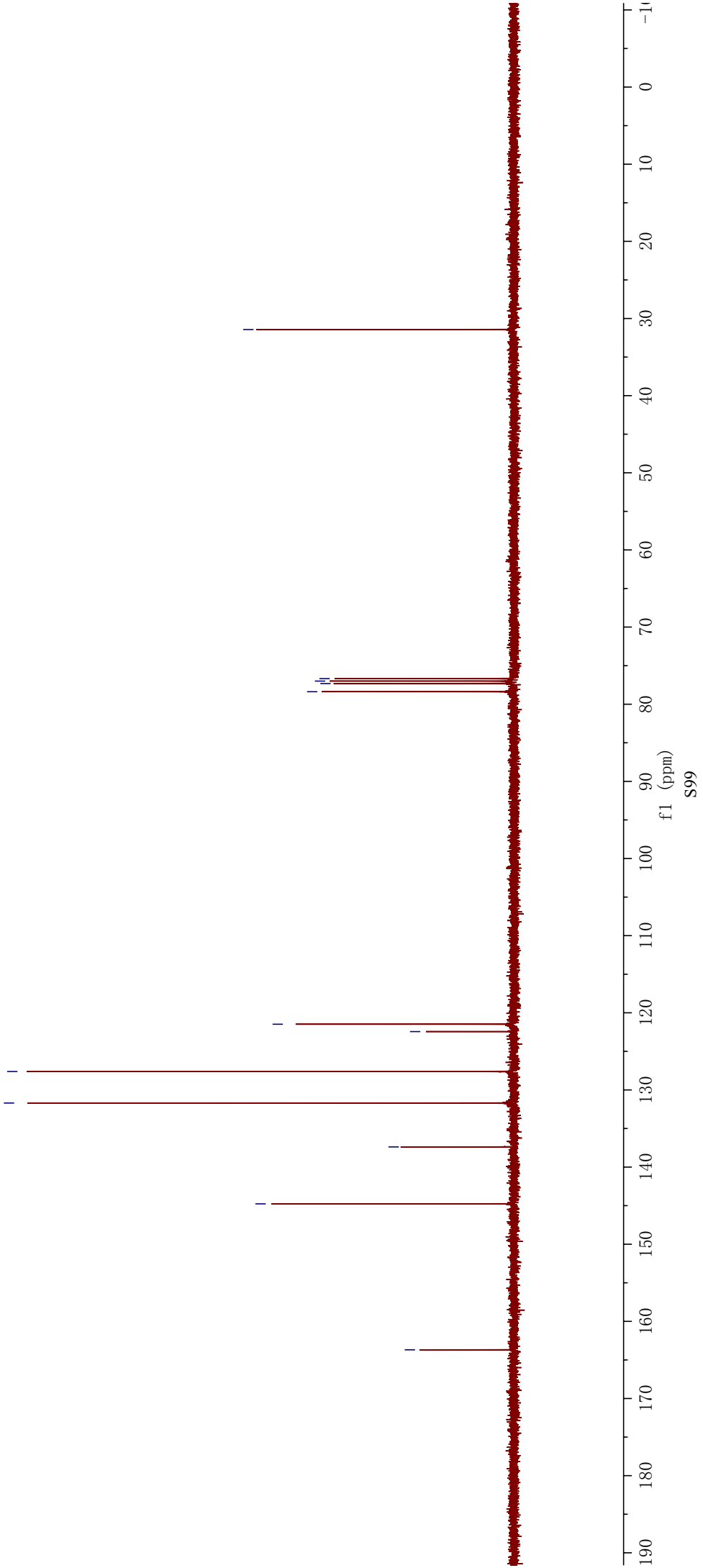
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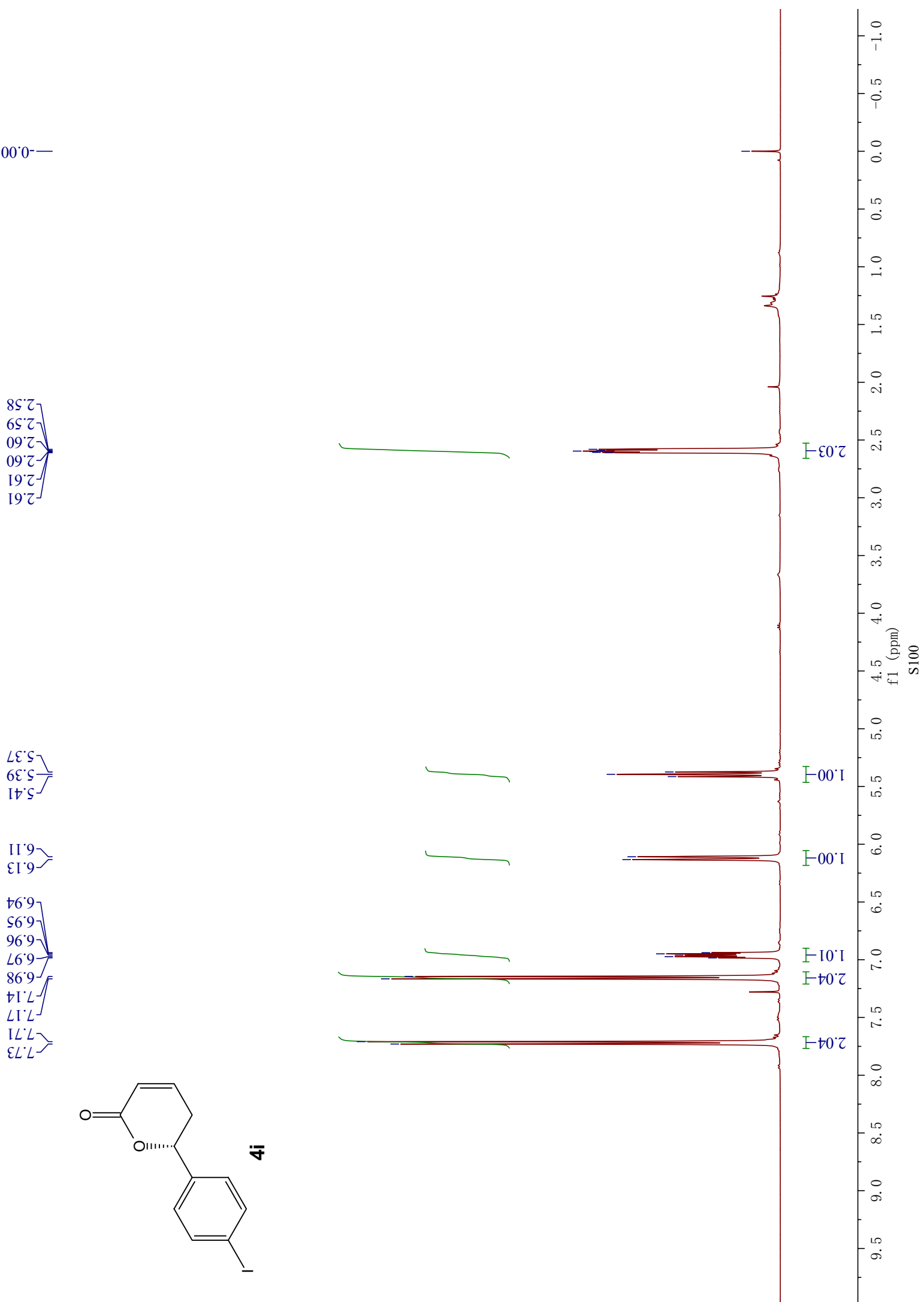
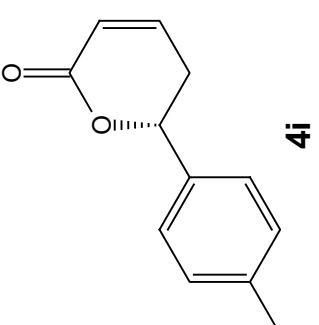
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77.00
77.32
78.38

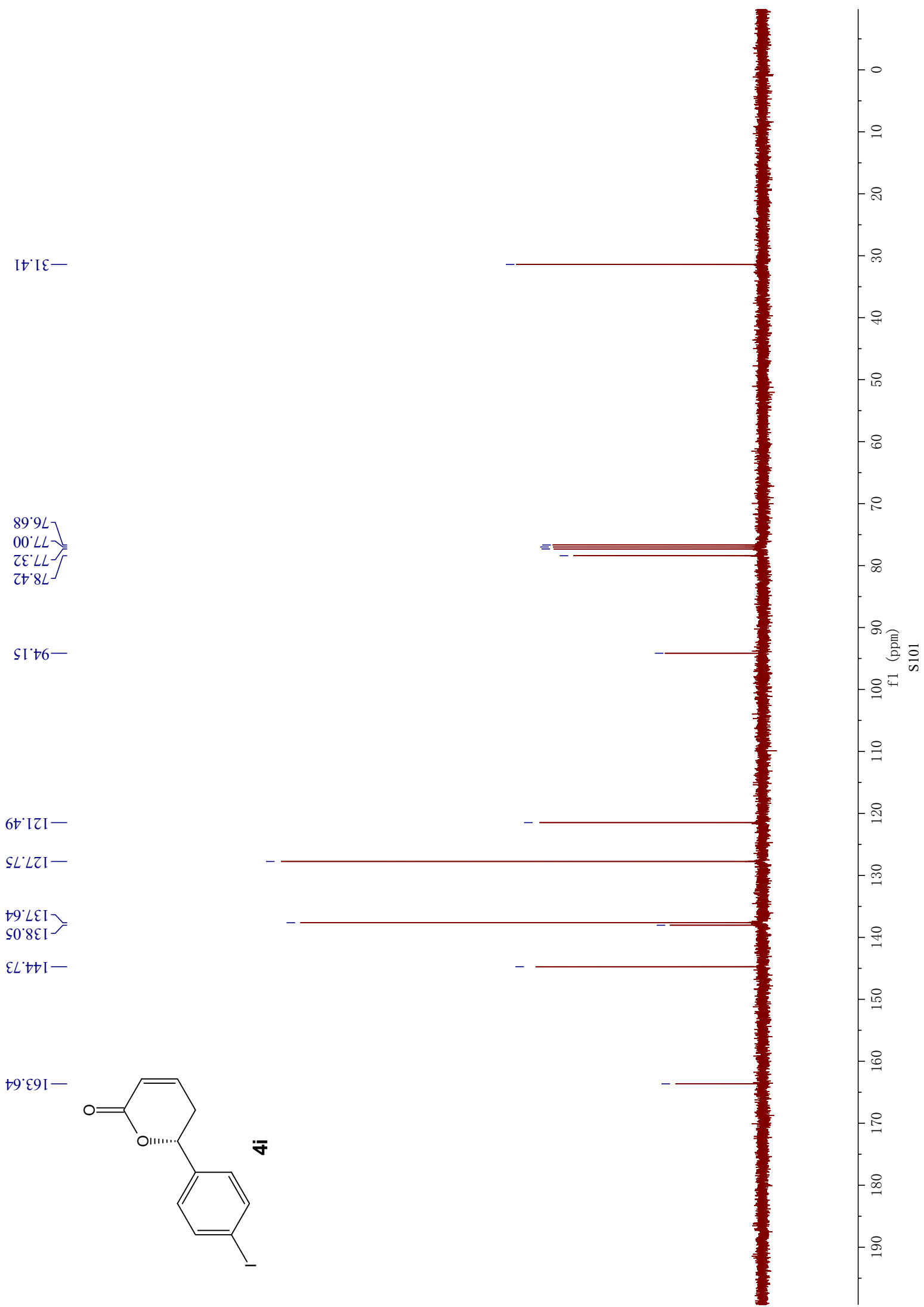
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127.61
131.70
137.39

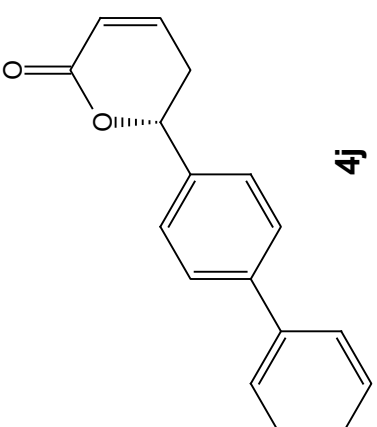
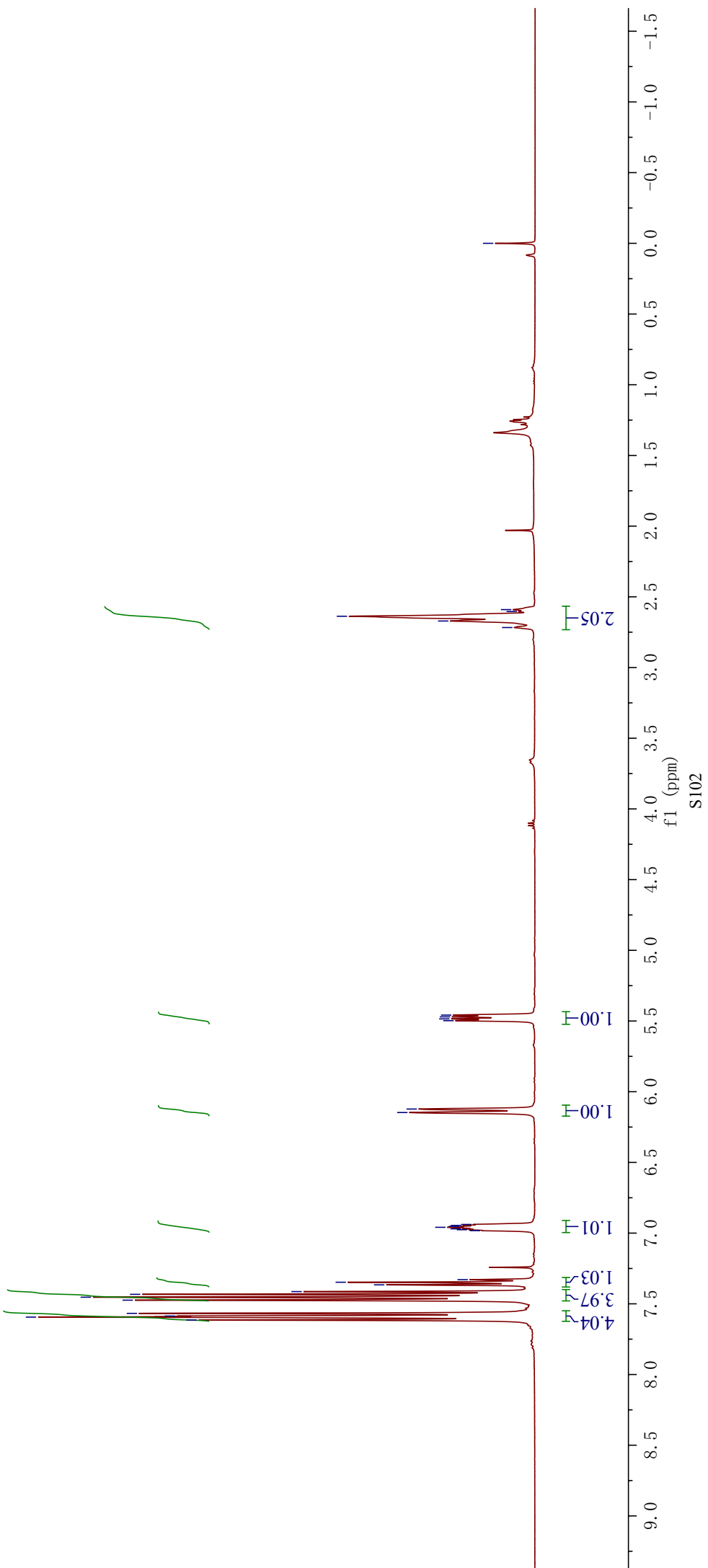
— 144.77

— 163.69







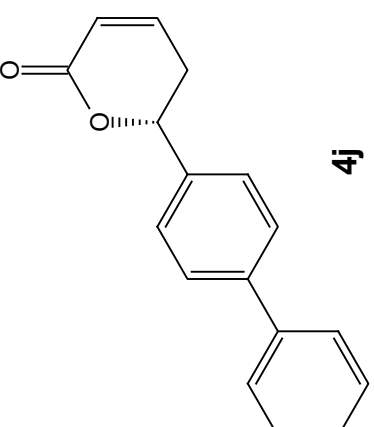


2.72
2.67
2.64
2.60
2.59

5.50
5.49
5.47
5.46

7.61
7.59
7.59
7.57
7.47
7.45
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6.13
6.12

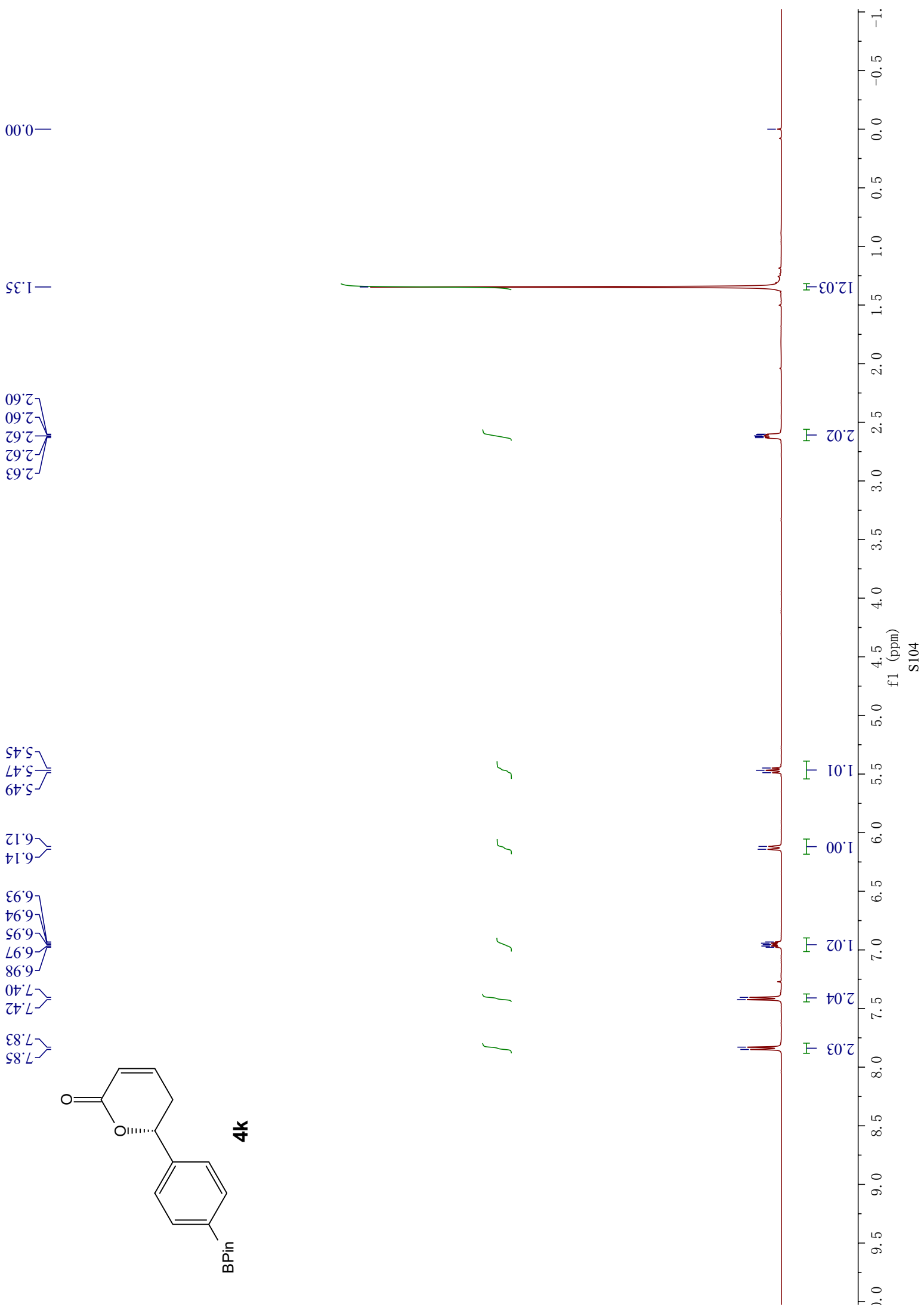
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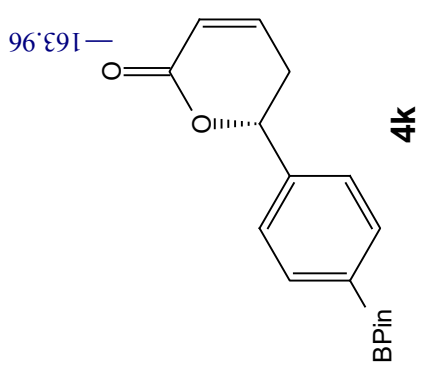


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144.91
141.43
140.30
137.31
128.76
127.48
127.27
127.01
126.44
121.57
78.94
77.94
77.32
77.00
76.68
31.50

S103

f1 (ppm)



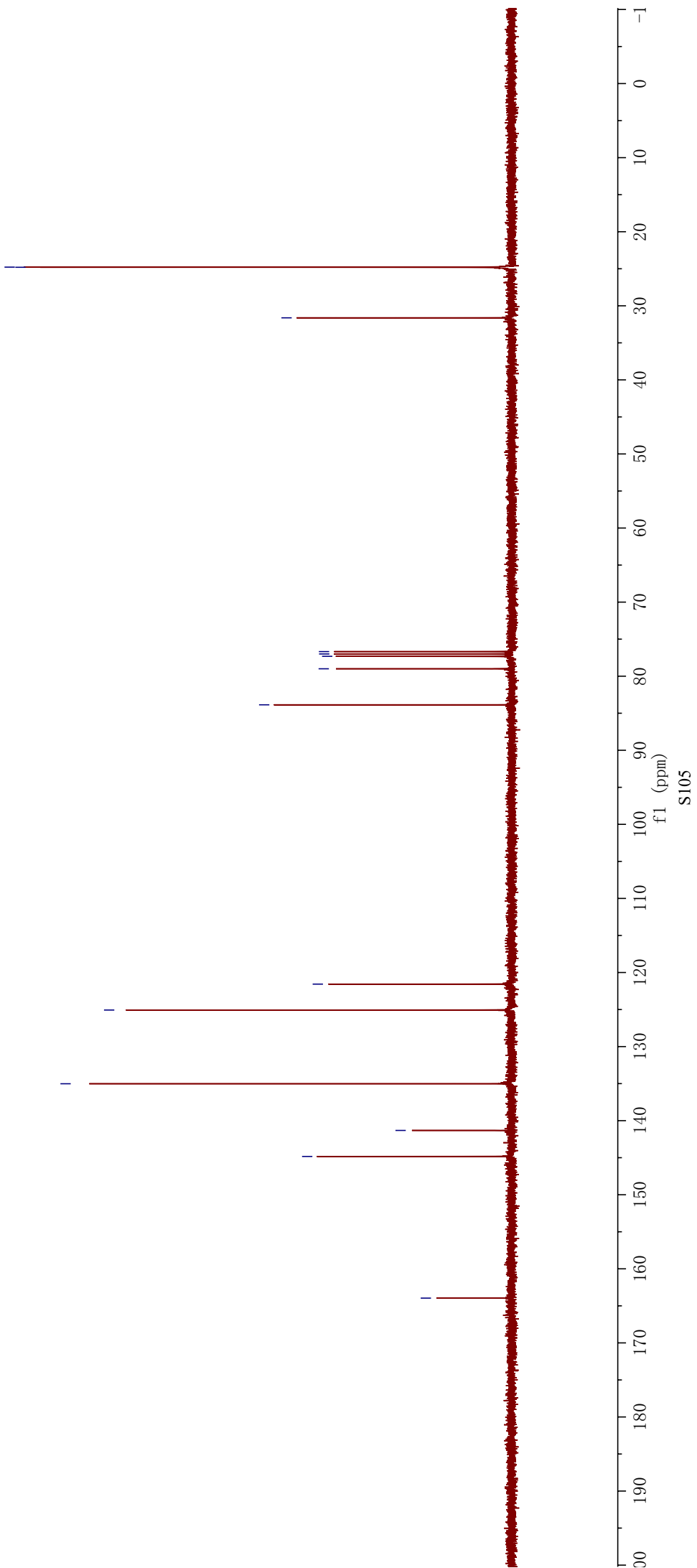


— 31.62
— 24.80
— 24.78

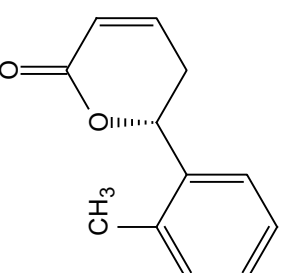
— 83.86
— 79.00
— 77.32
— 77.00
— 76.68

— 144.83
— 141.32
— 135.02
— 125.07
— 121.57

— 163.96



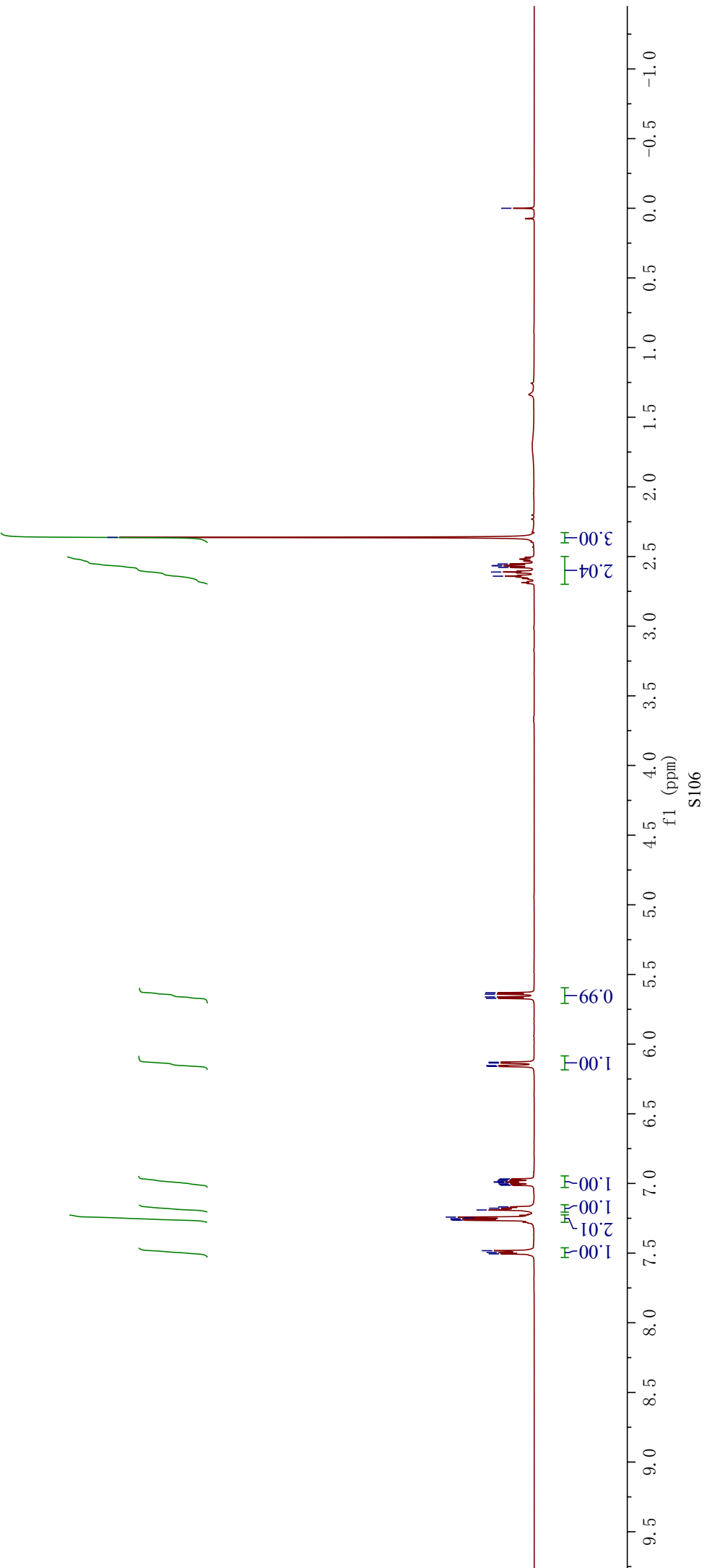
4l



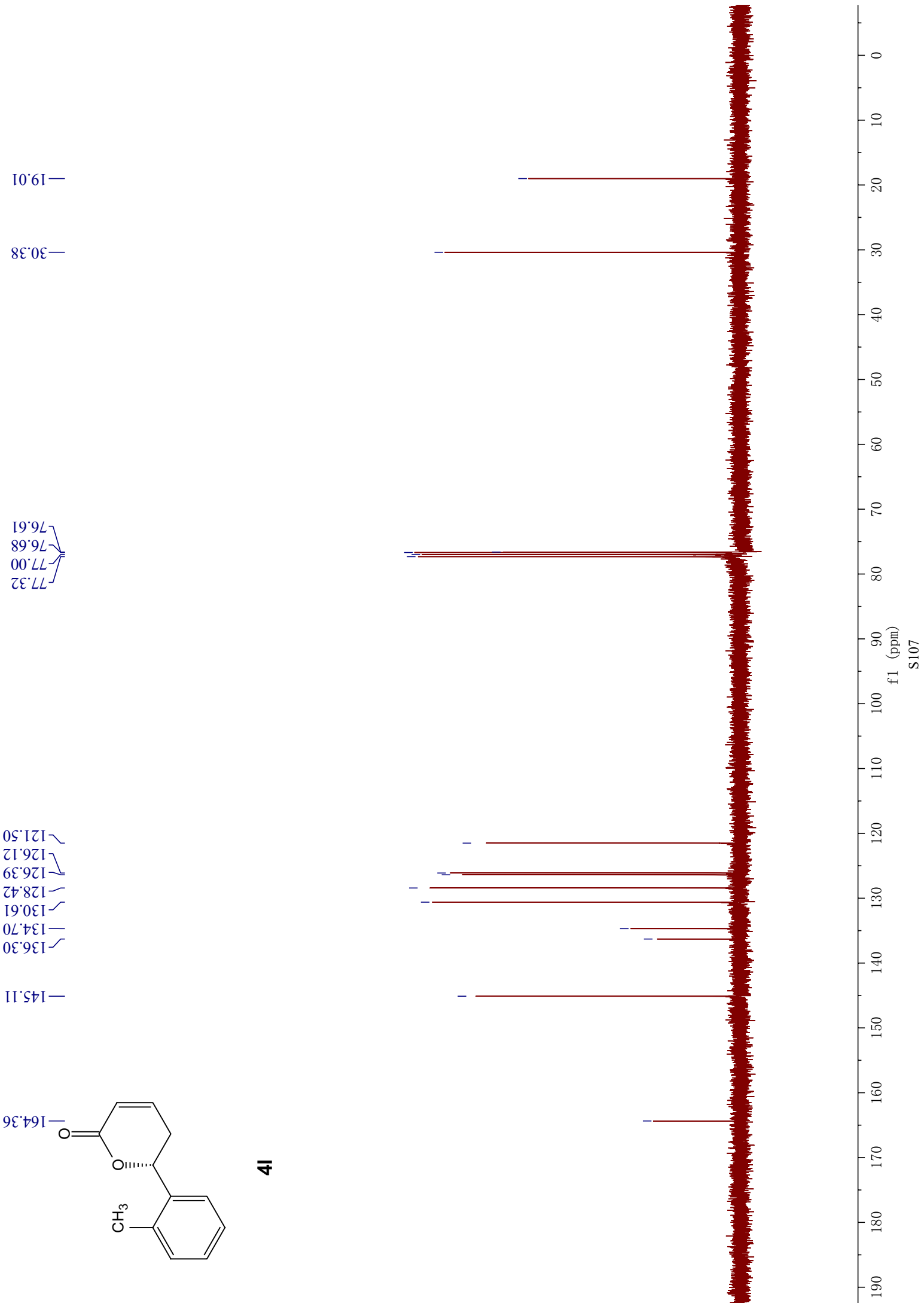
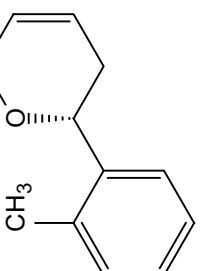
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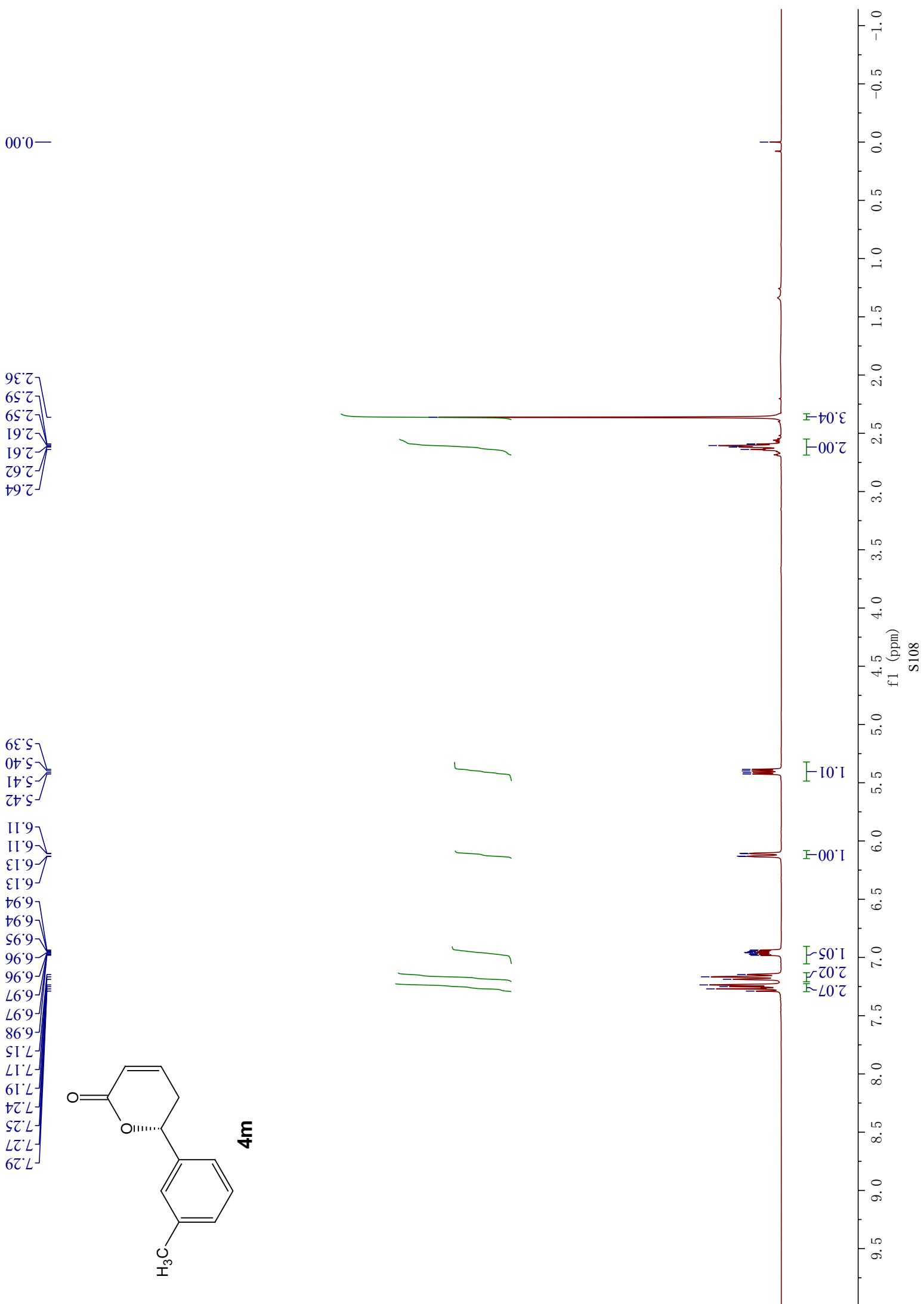
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2.36

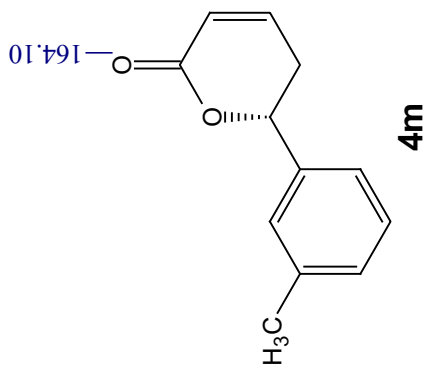
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7.25
7.24
7.19
7.18
7.17
7.01
7.01
7.00
6.99
6.99
6.98
6.97
6.16
6.15
6.14
6.13
5.67
5.66
5.64
5.63



4l





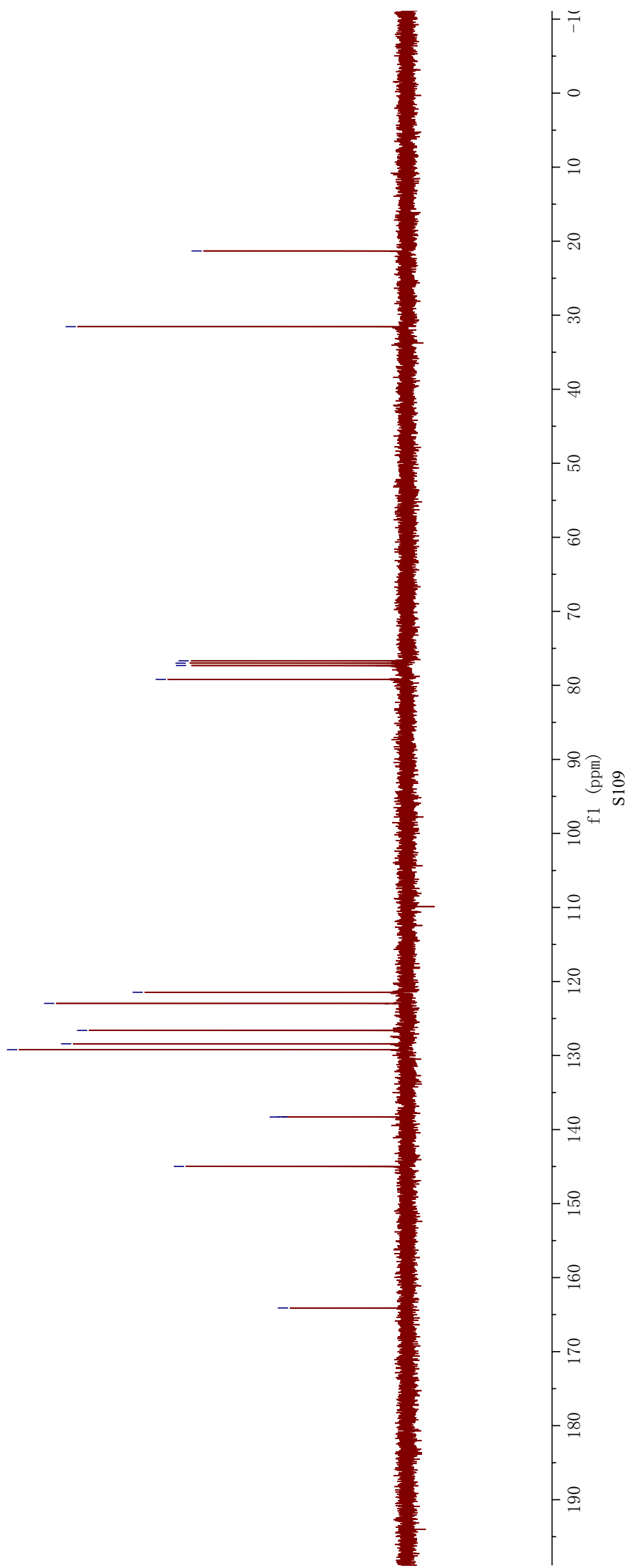


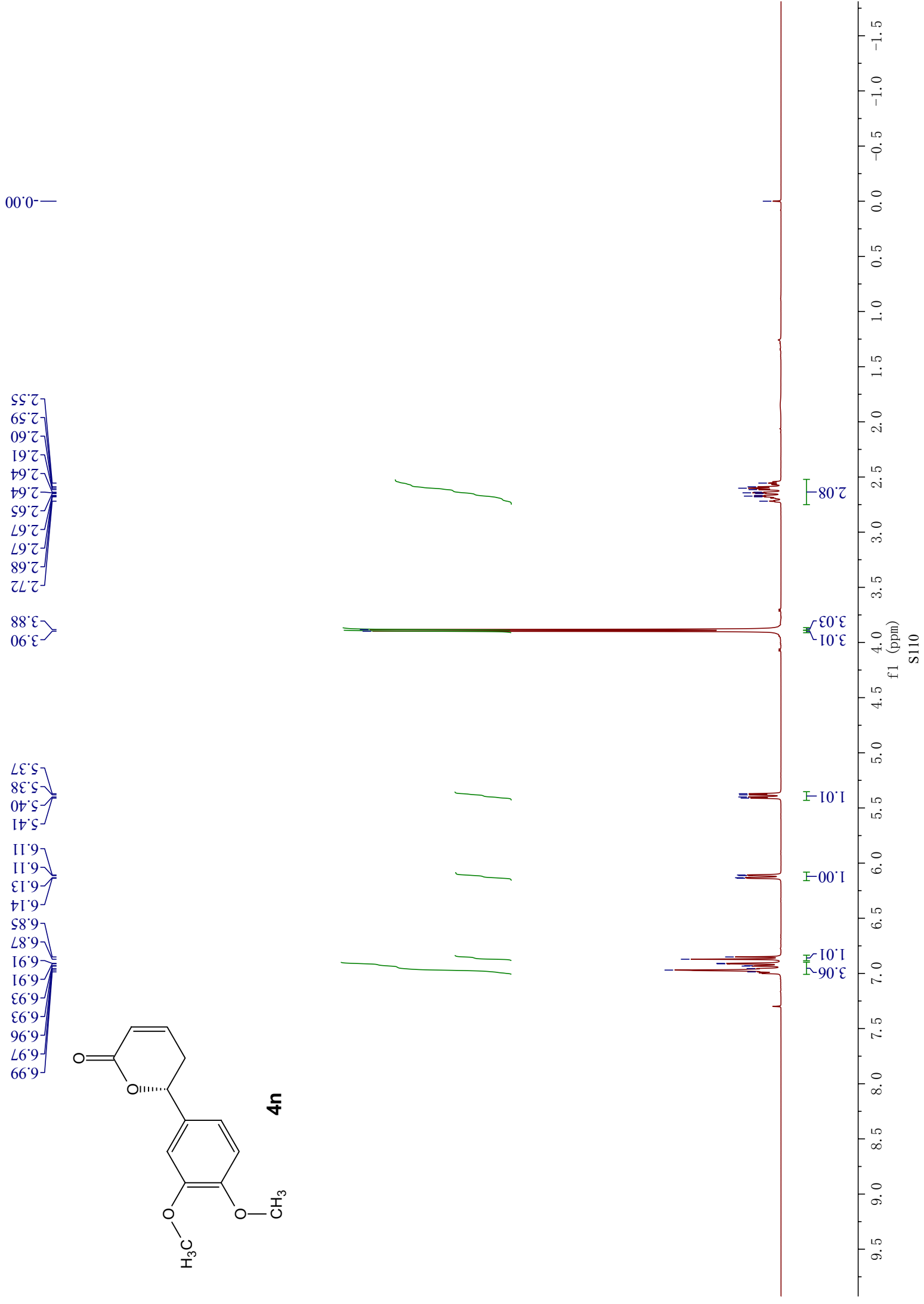
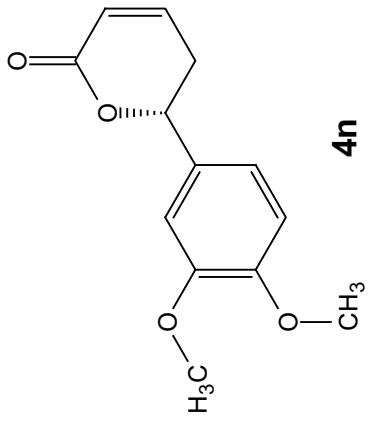
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122.96
121.46

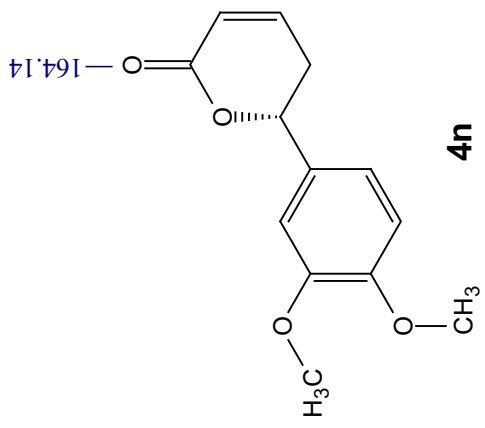
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31.55

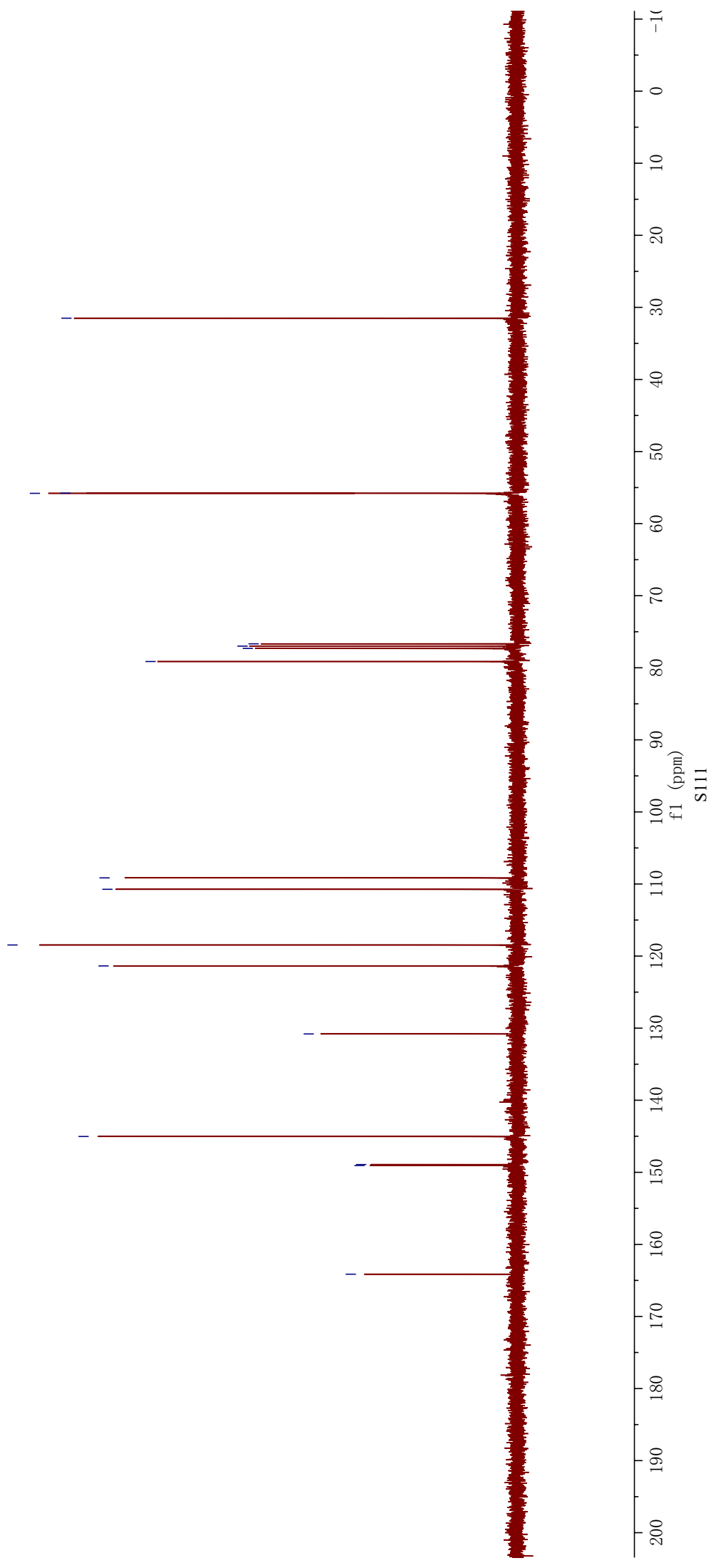
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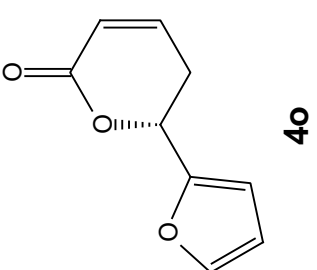
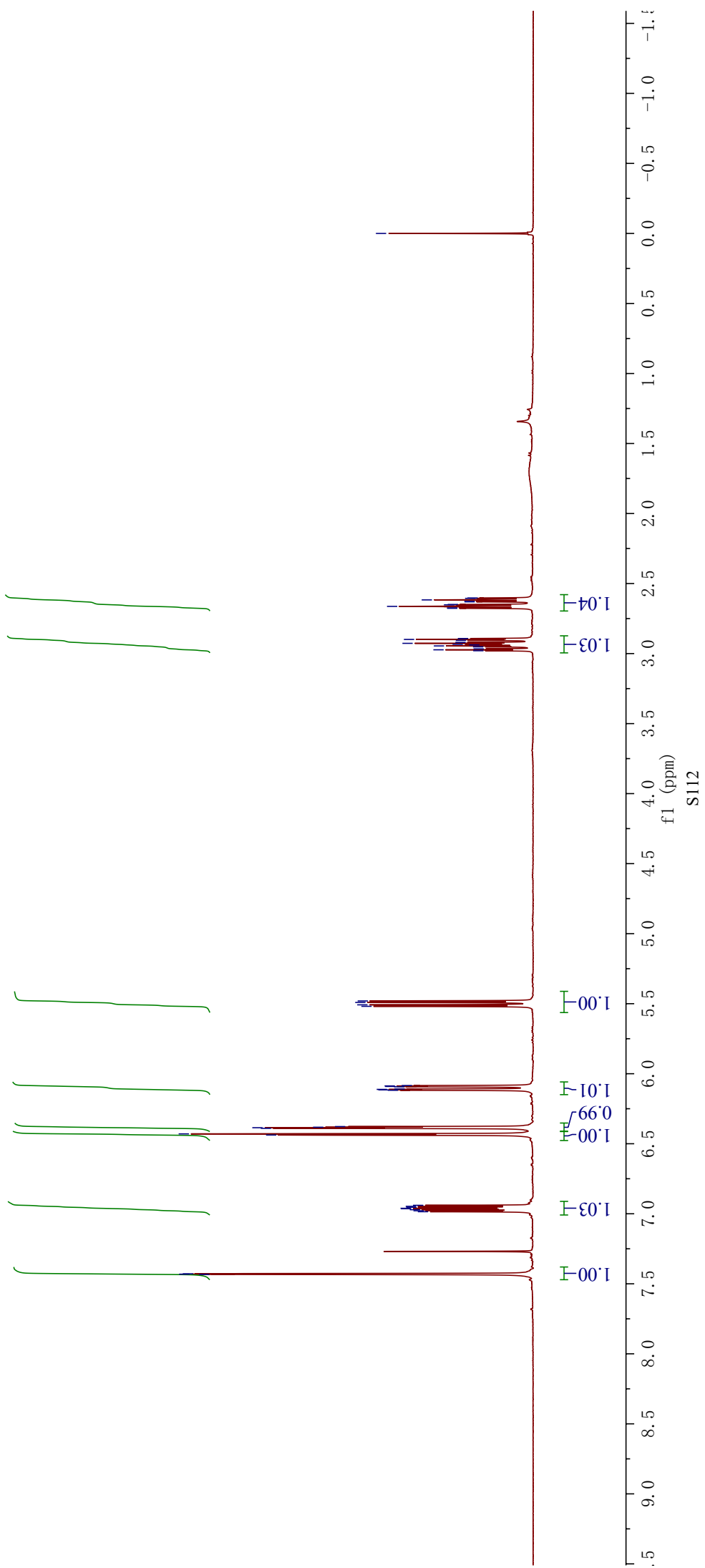






149.06
 148.92
 145.03
 130.80
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 118.46
 110.73
 109.15
 79.13
 77.32
 77.00
 76.68
 55.80
 55.78
 31.50

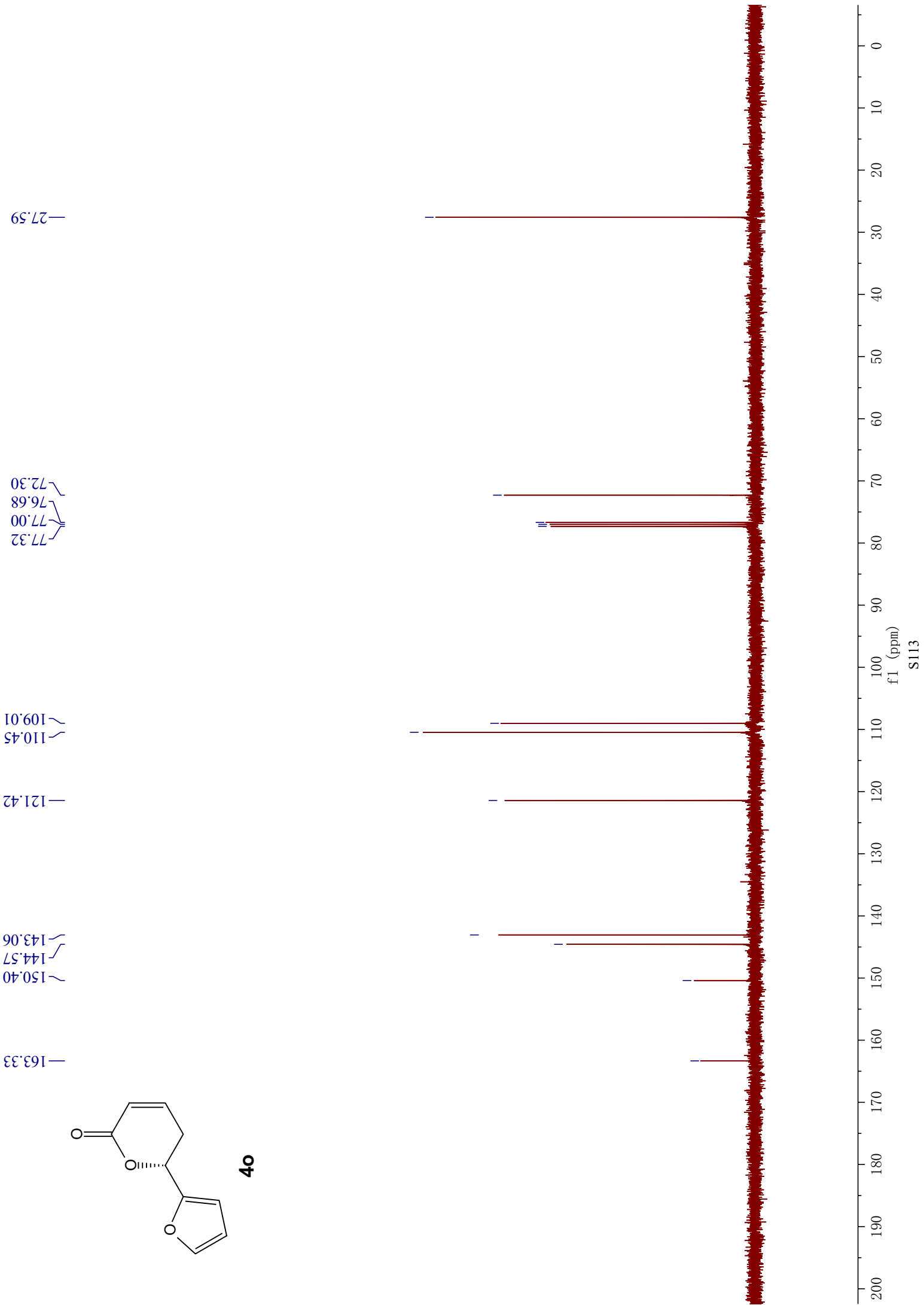


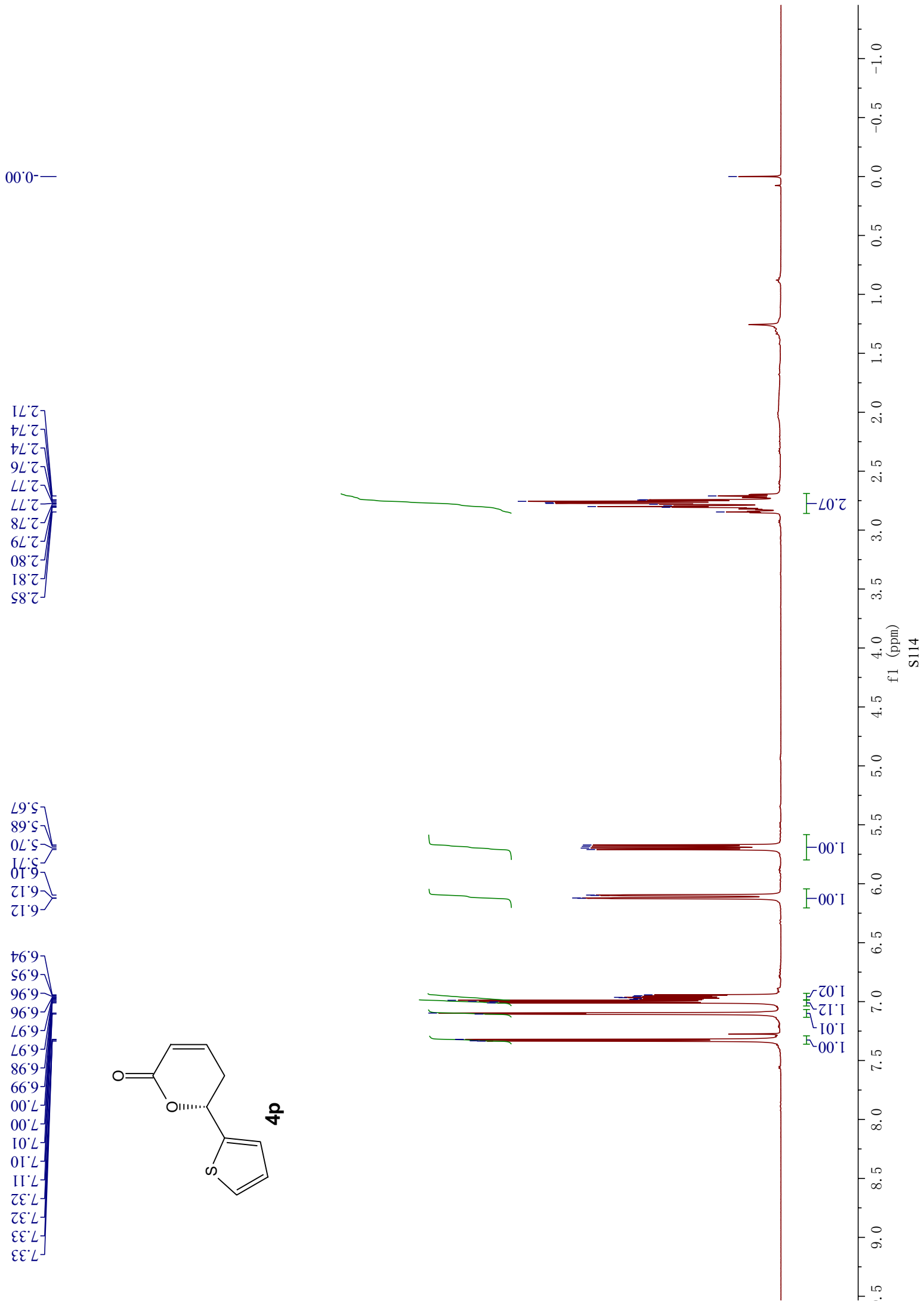


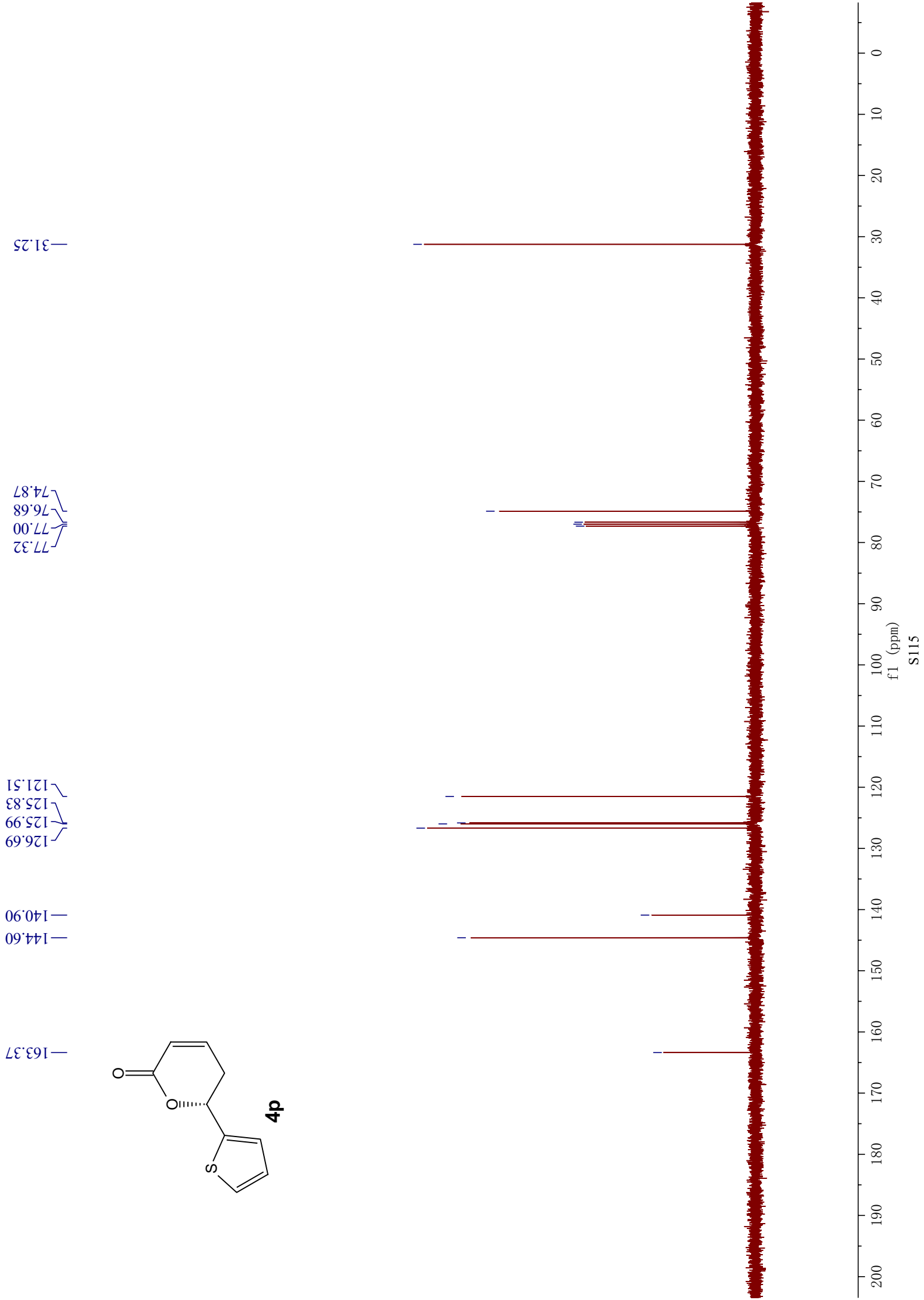
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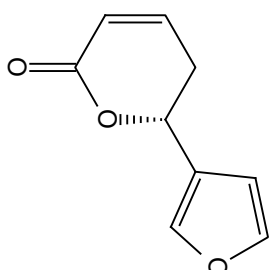
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2.91
2.92
2.93
2.93
2.94
2.95
2.95
2.97
2.97
2.98

5.48
5.49
5.51
5.52
6.38
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6.39
6.43
6.44
6.95
6.96
6.96
7.43
7.43
7.43









4q

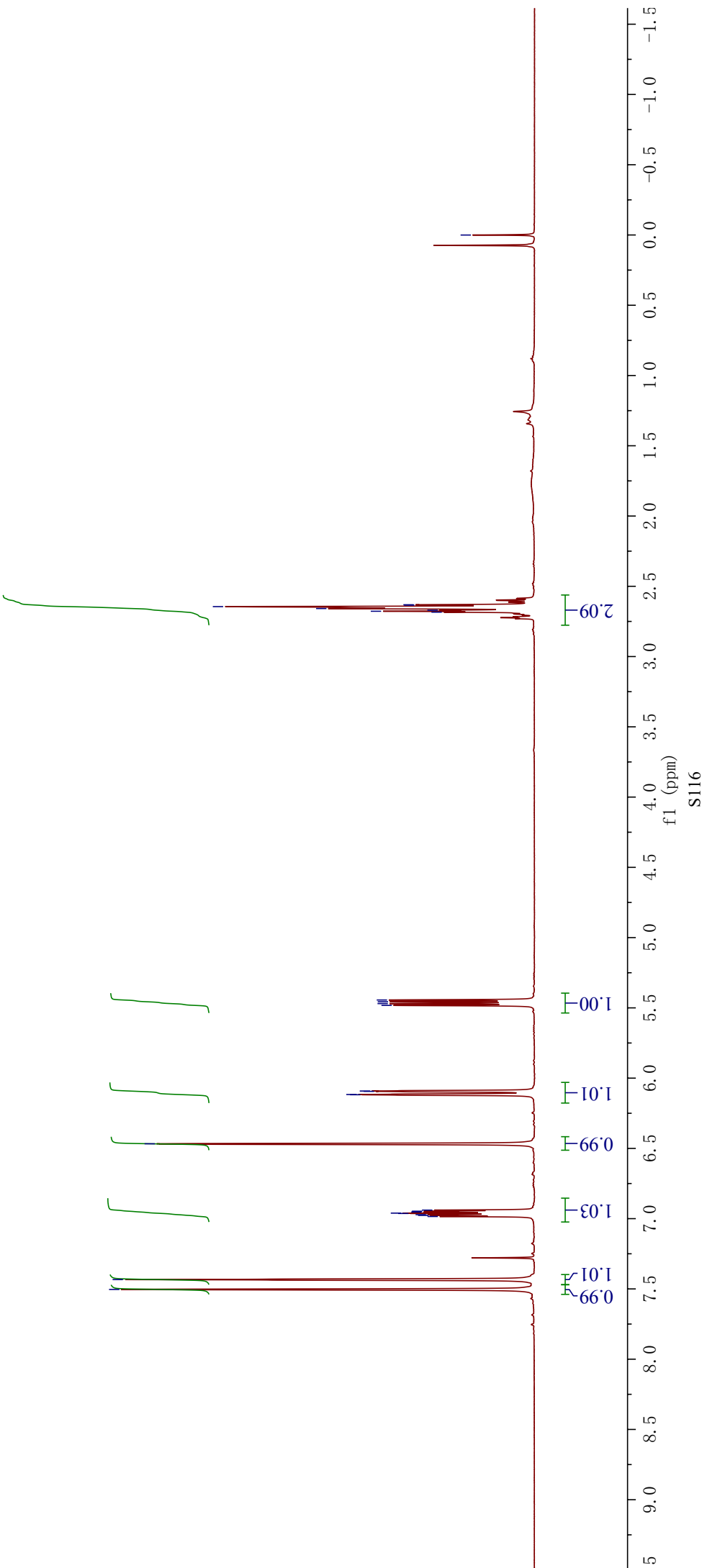
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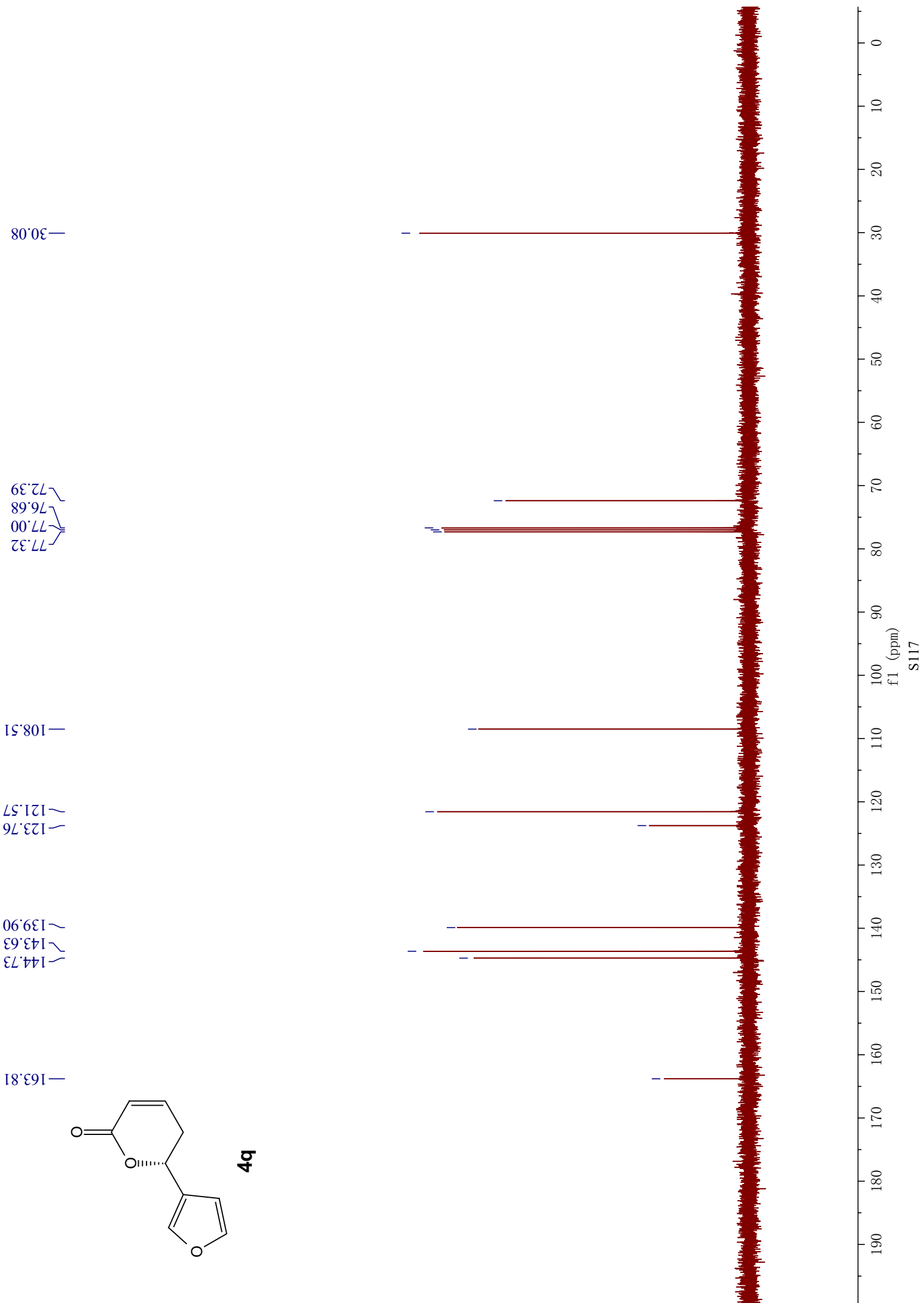
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2.68

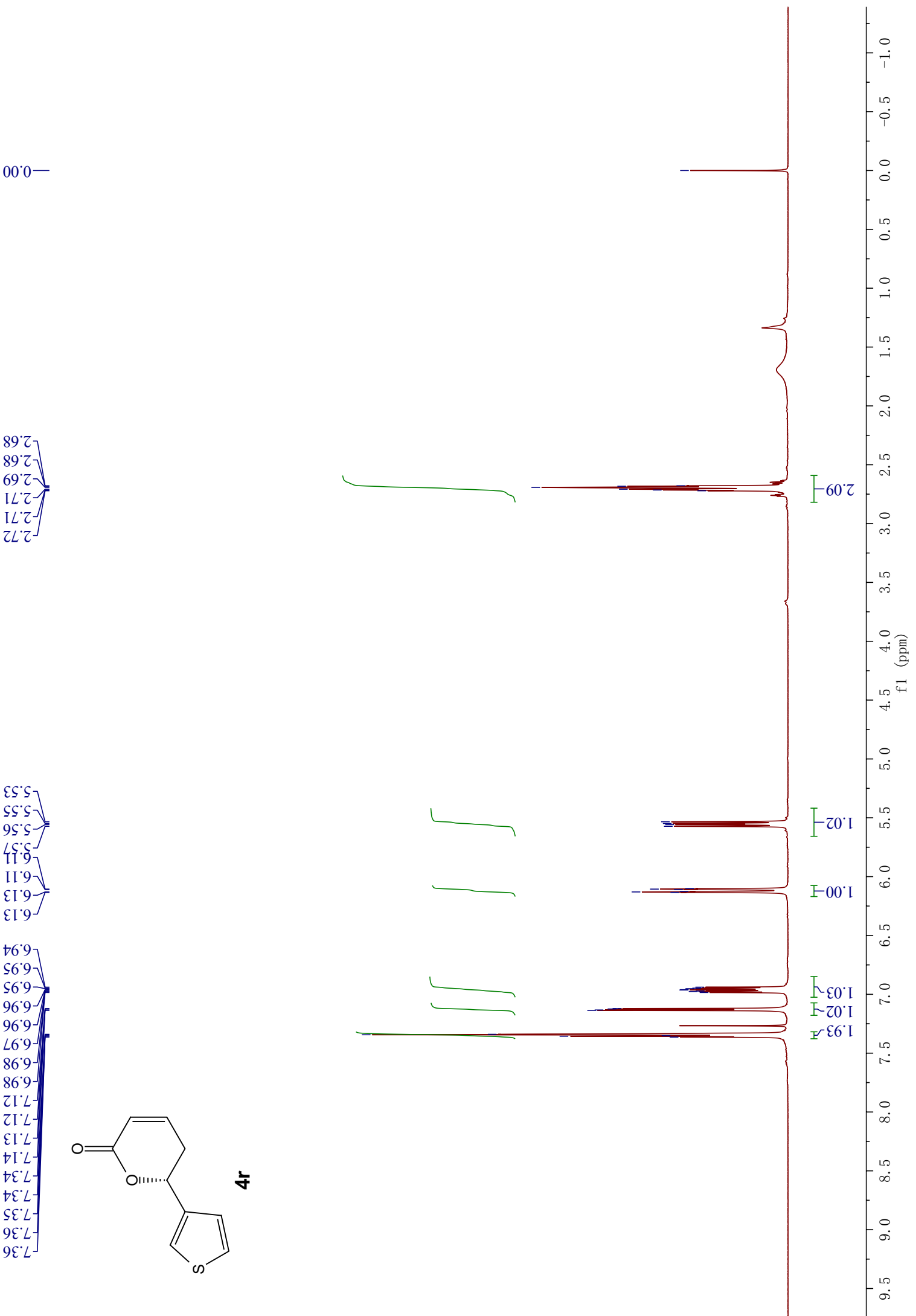
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6.12

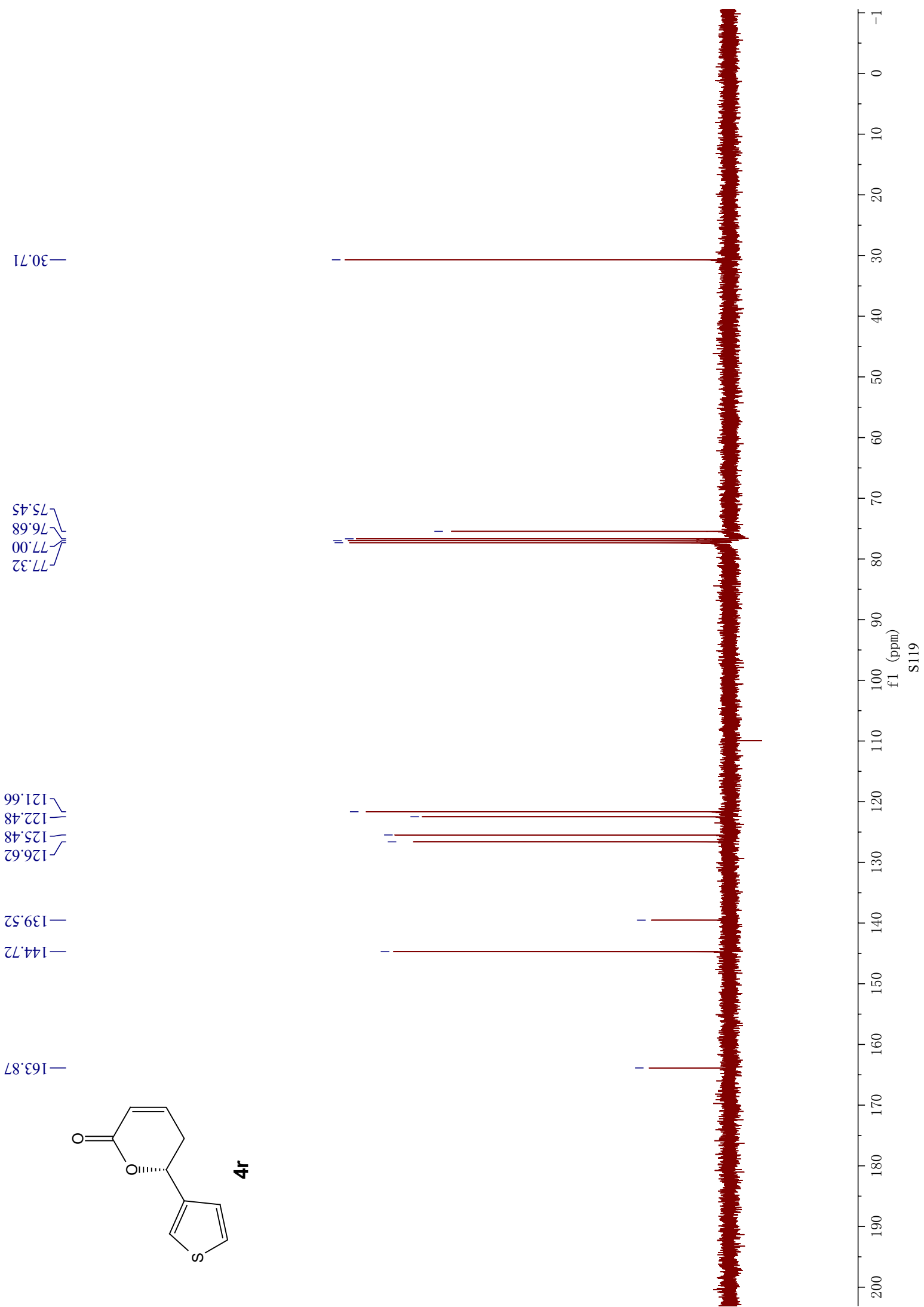
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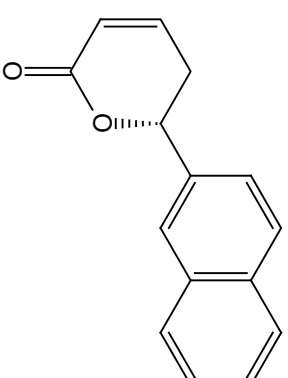
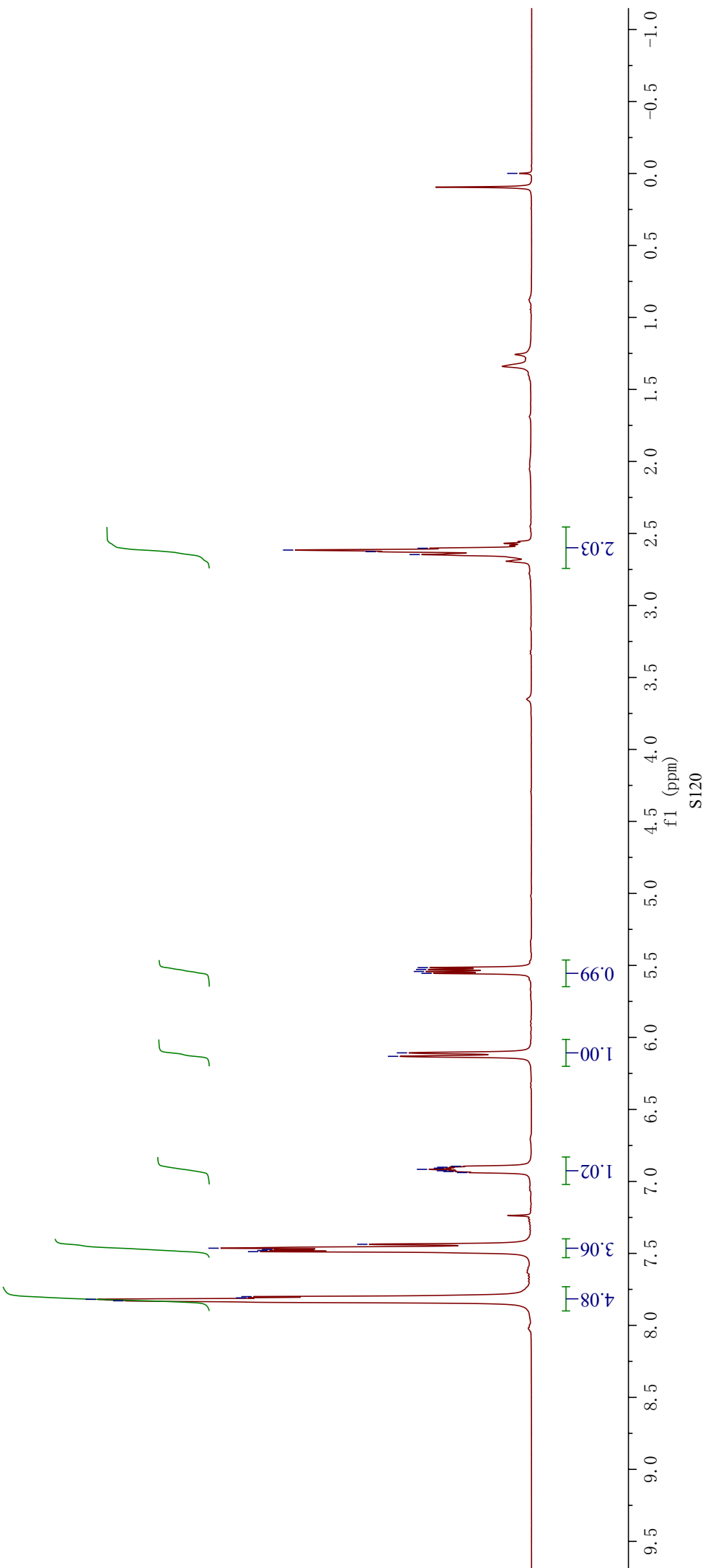
7.43
7.50





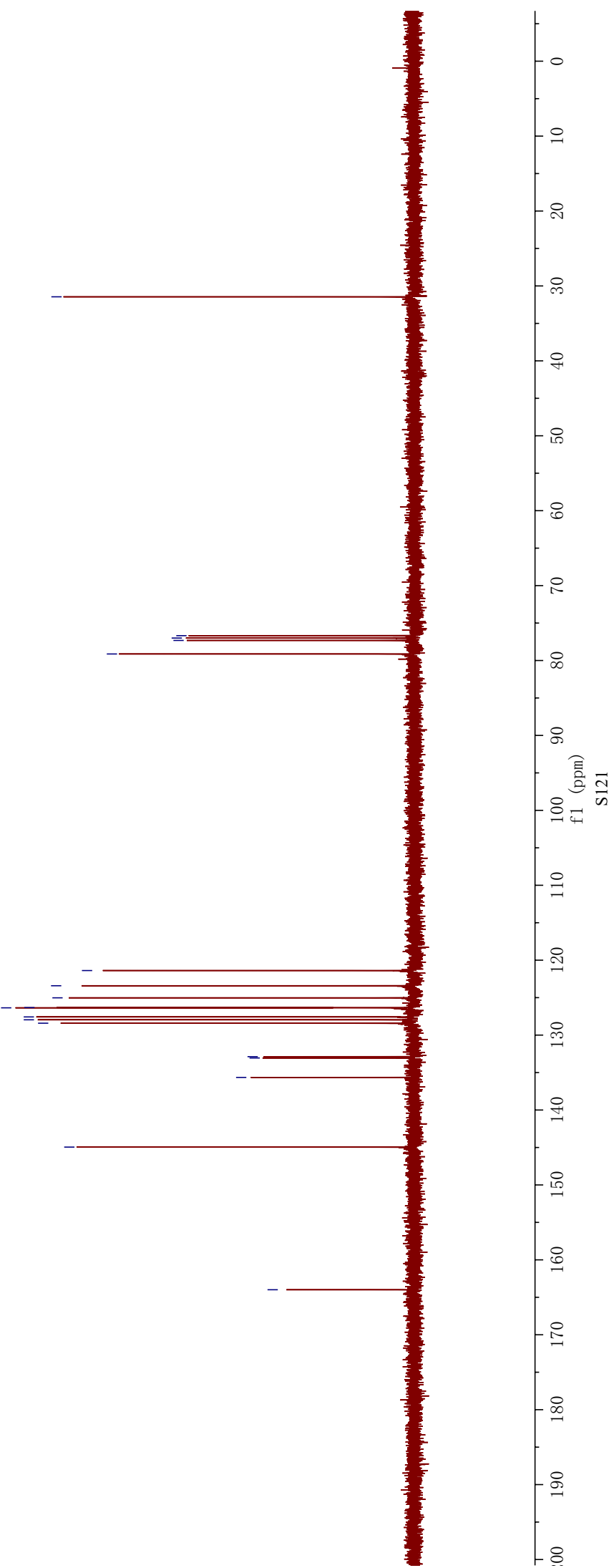
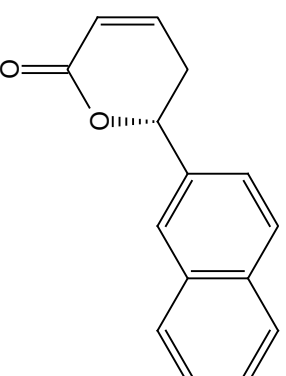


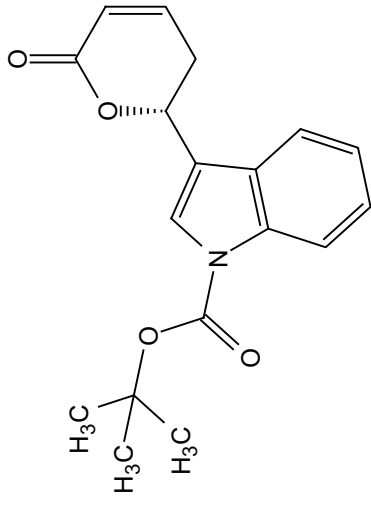




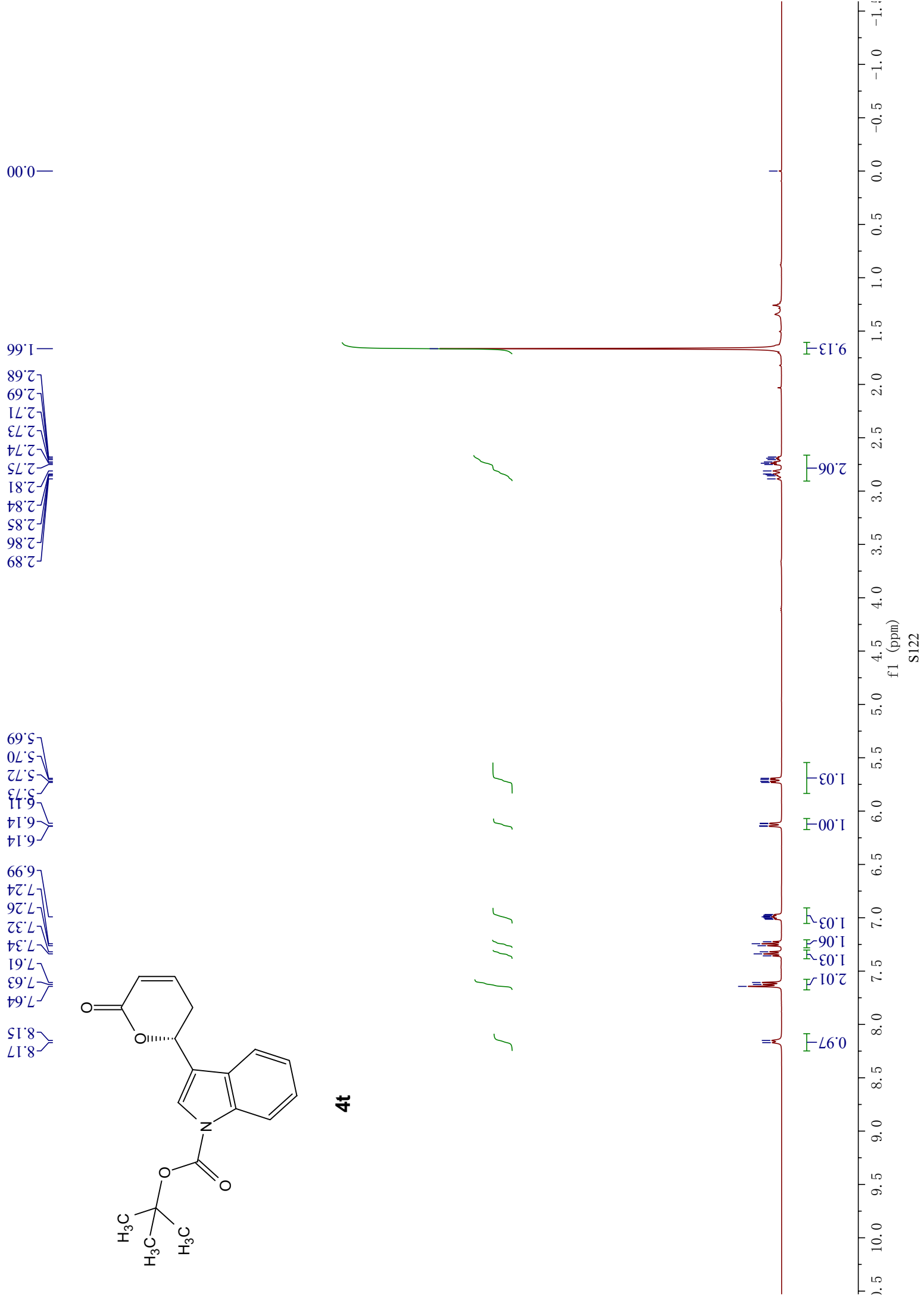
4s

4s

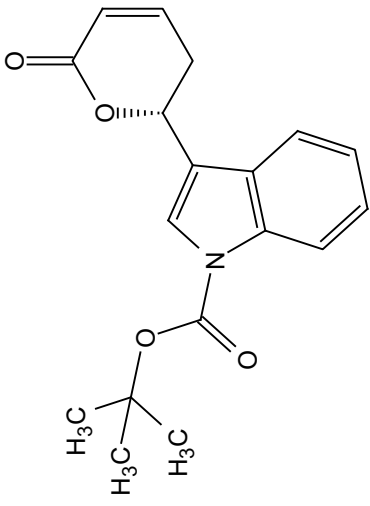




4t



4t



~29.67
~28.00

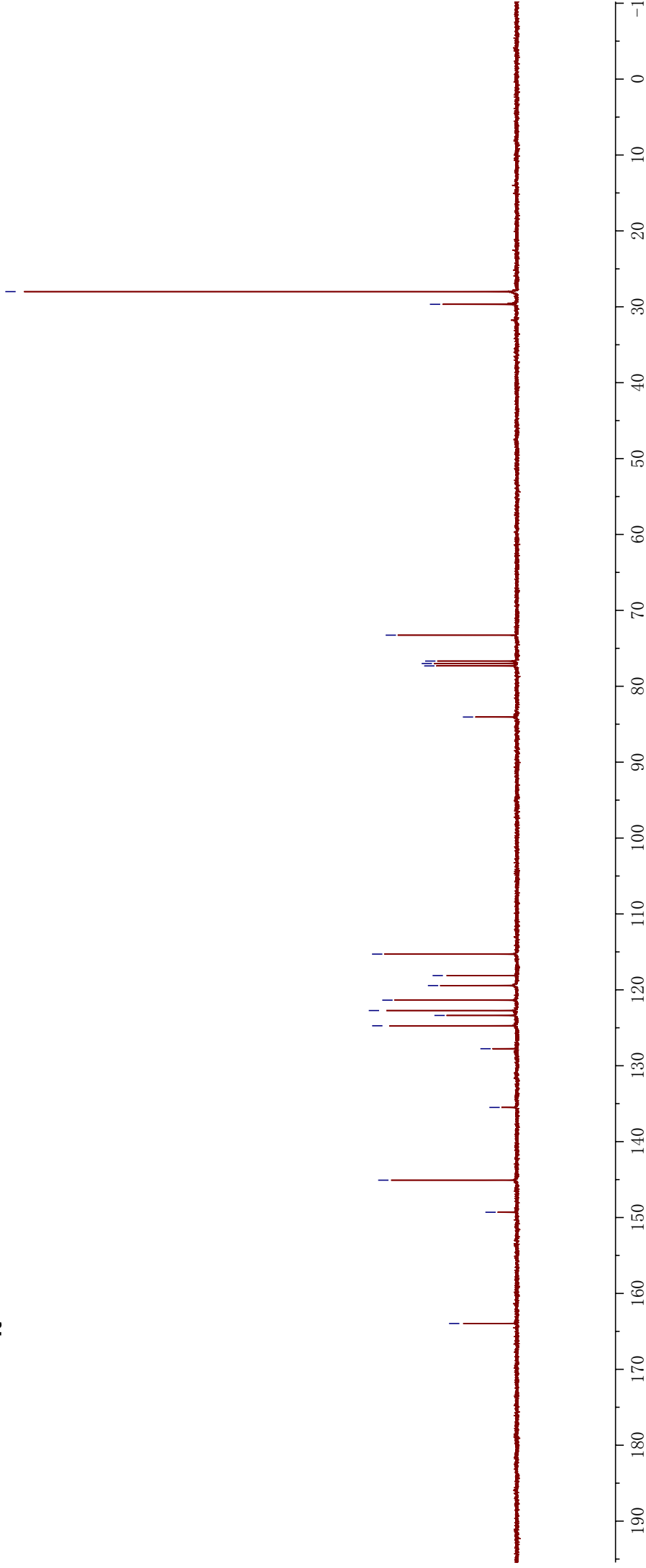
84.05
77.32
77.00
76.68
73.27

135.49
127.76
124.74
123.37
122.73
121.36
119.44
118.12
115.29

163.97
149.30
145.08

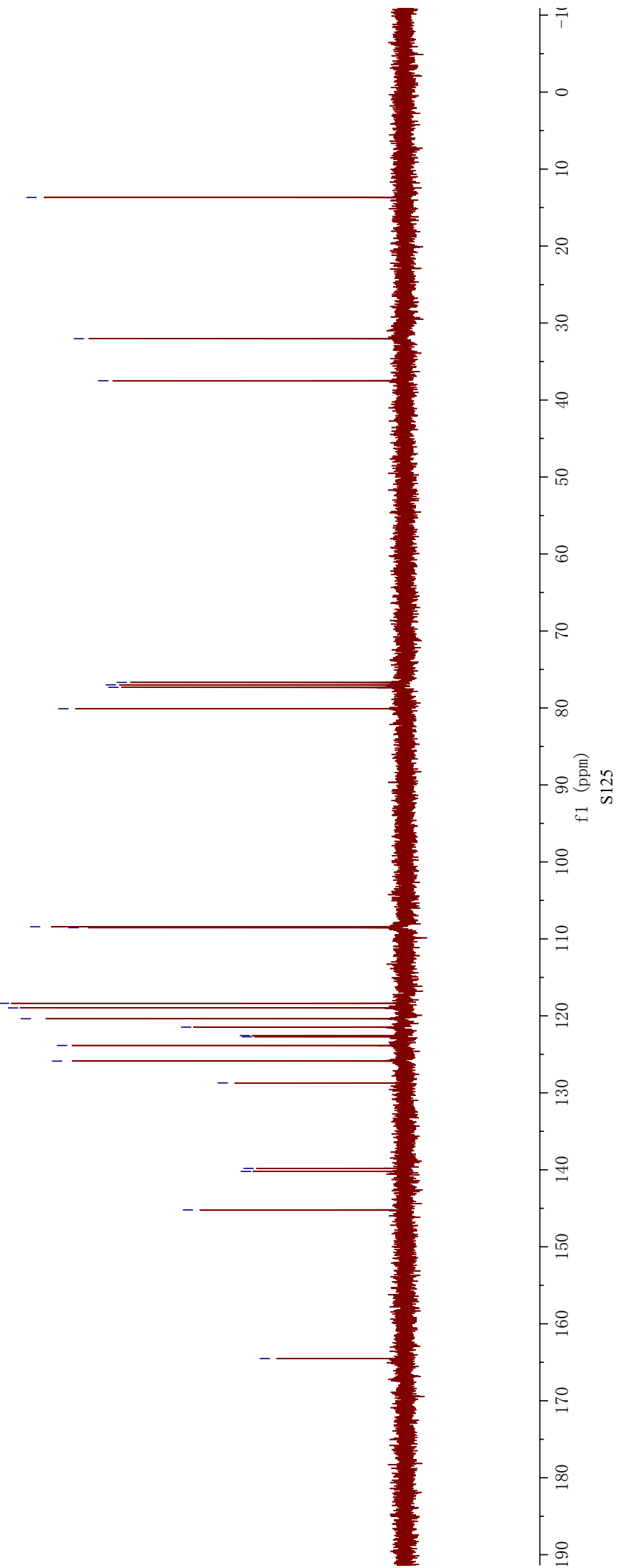
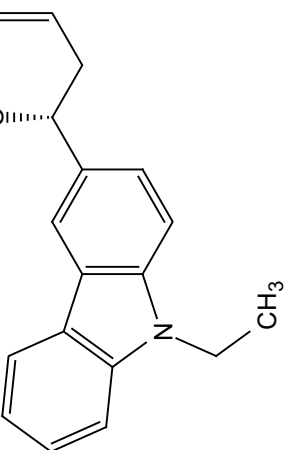
S123

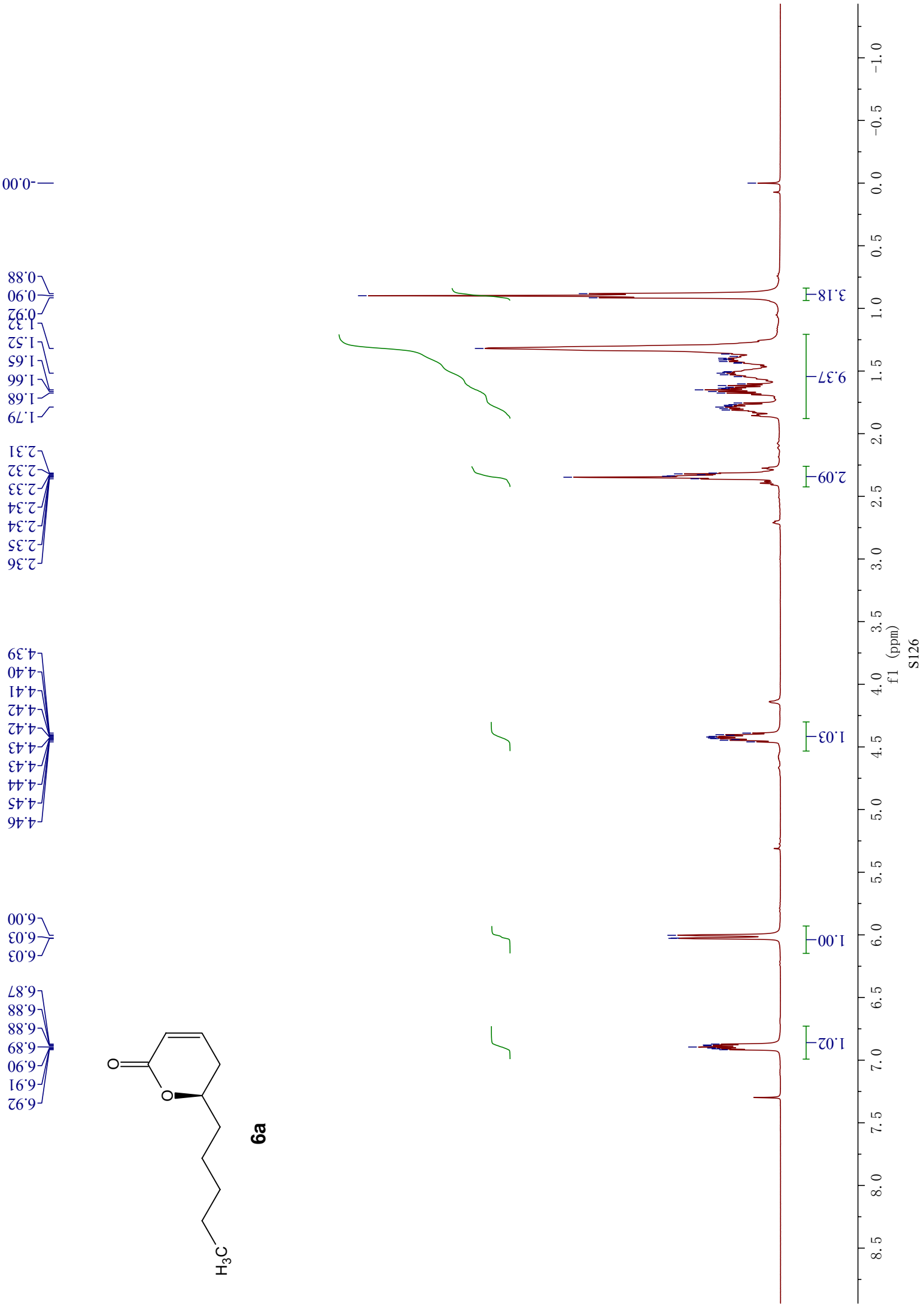
f1 (ppm)



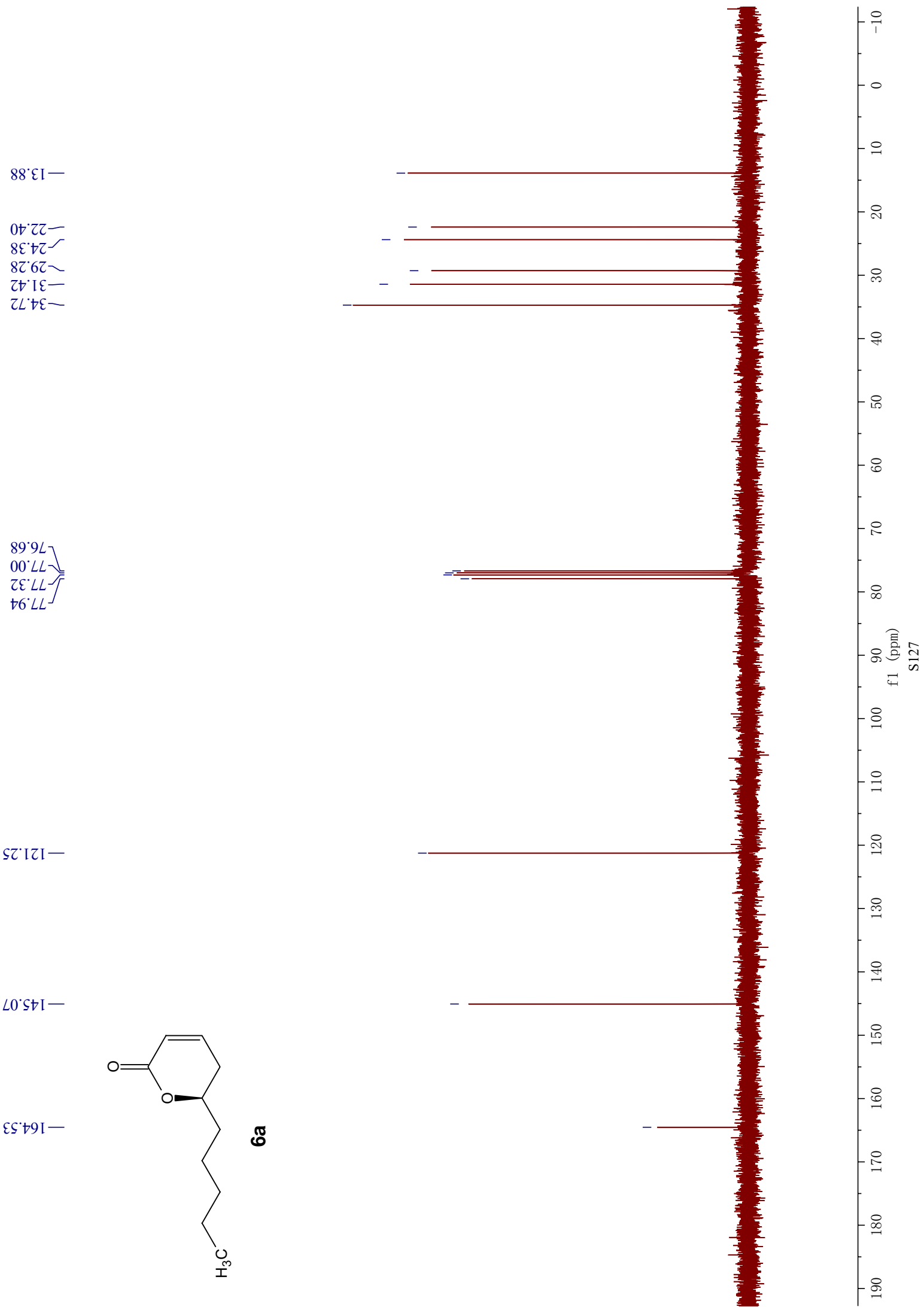
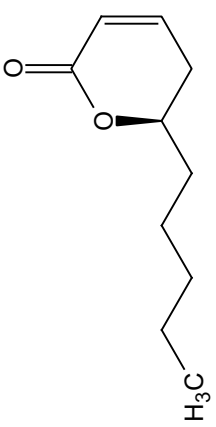


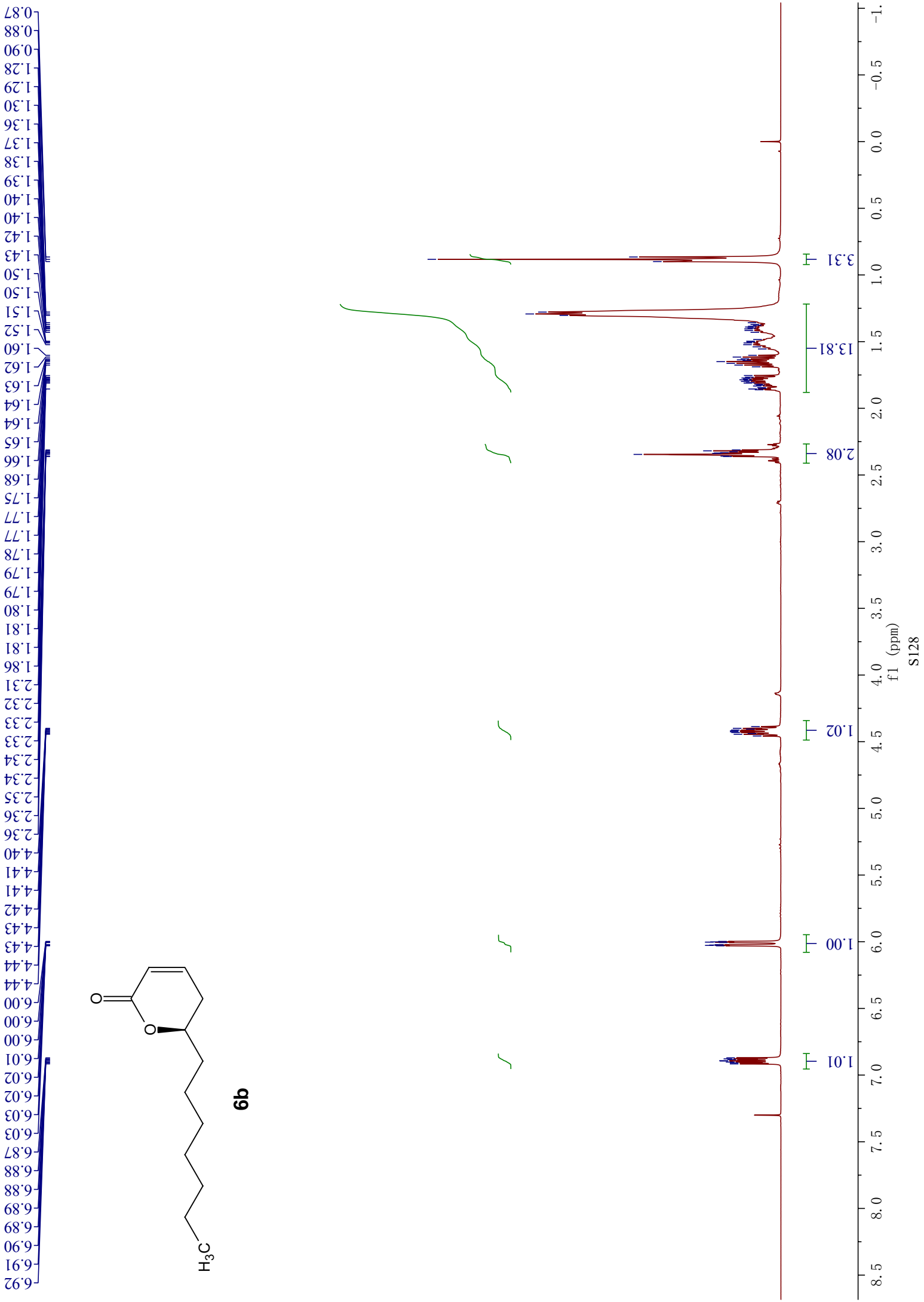
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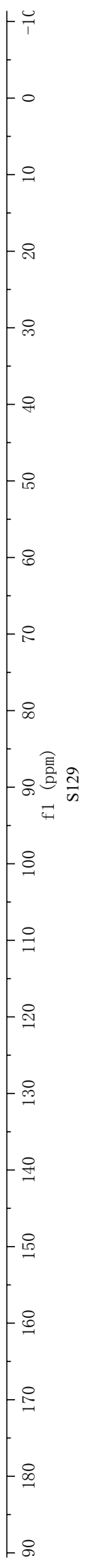




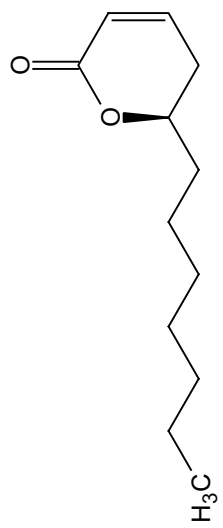
6a

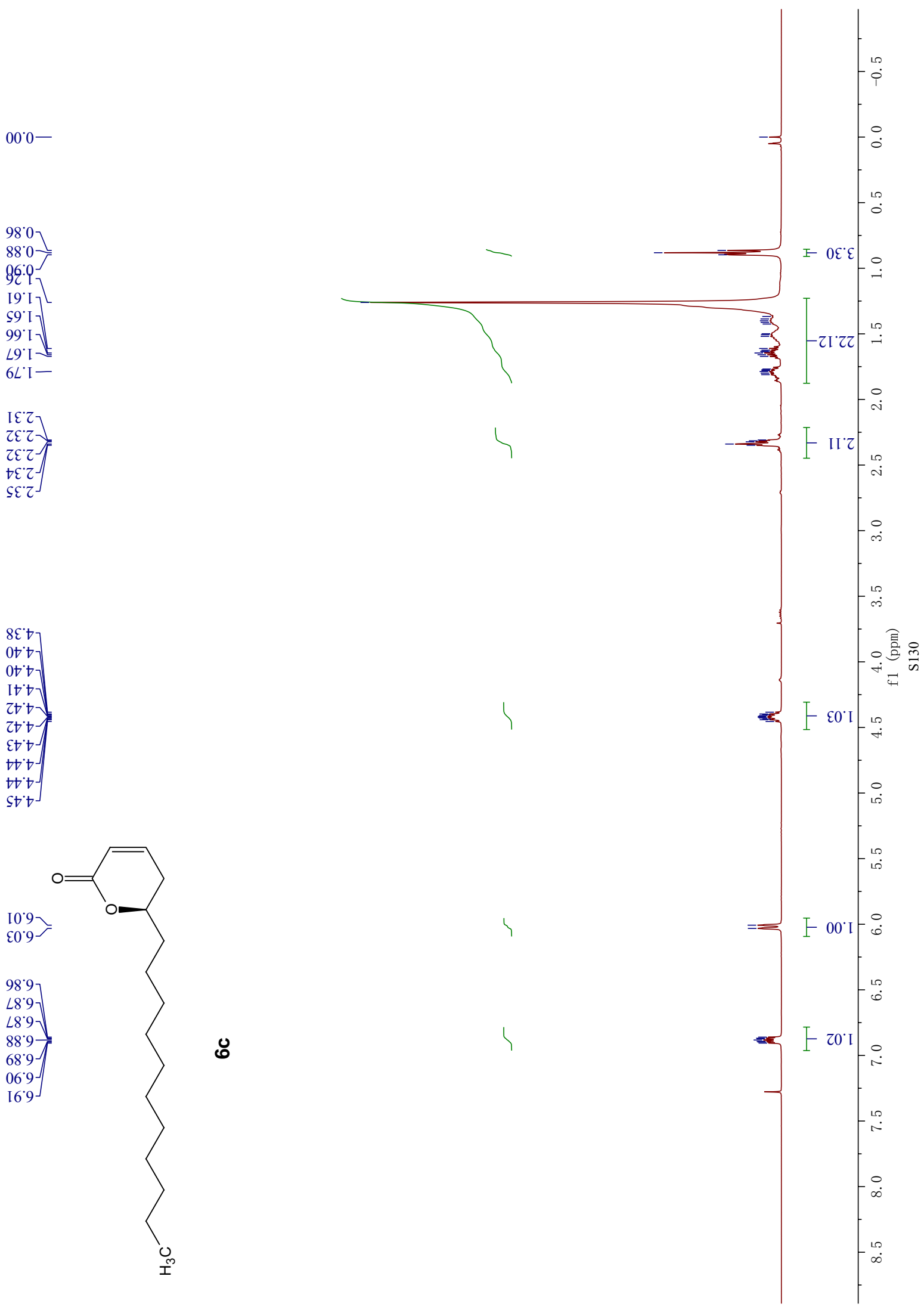






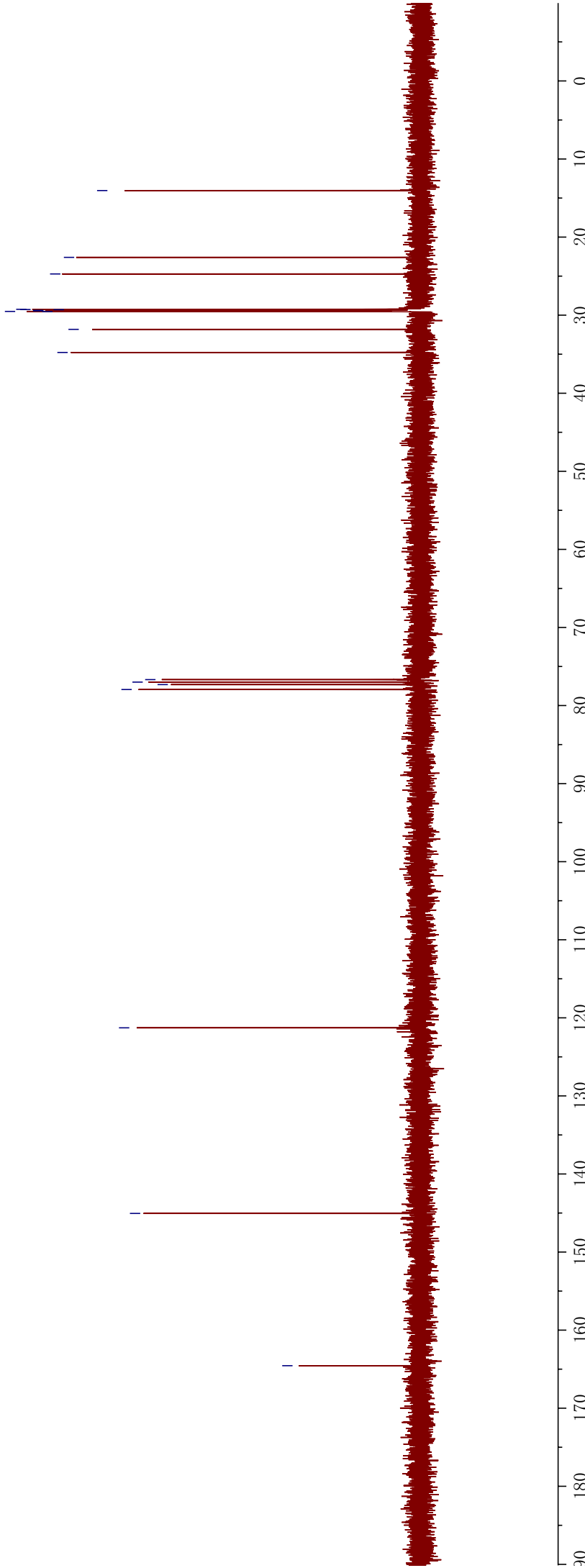
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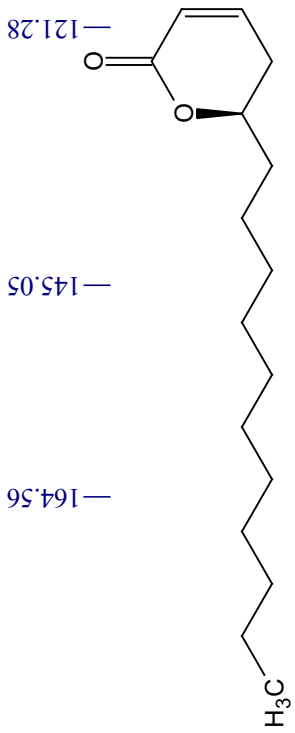


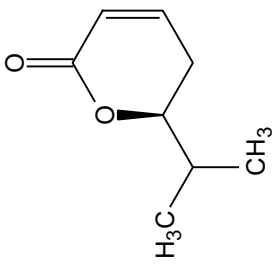
S131

f1 (ppm)

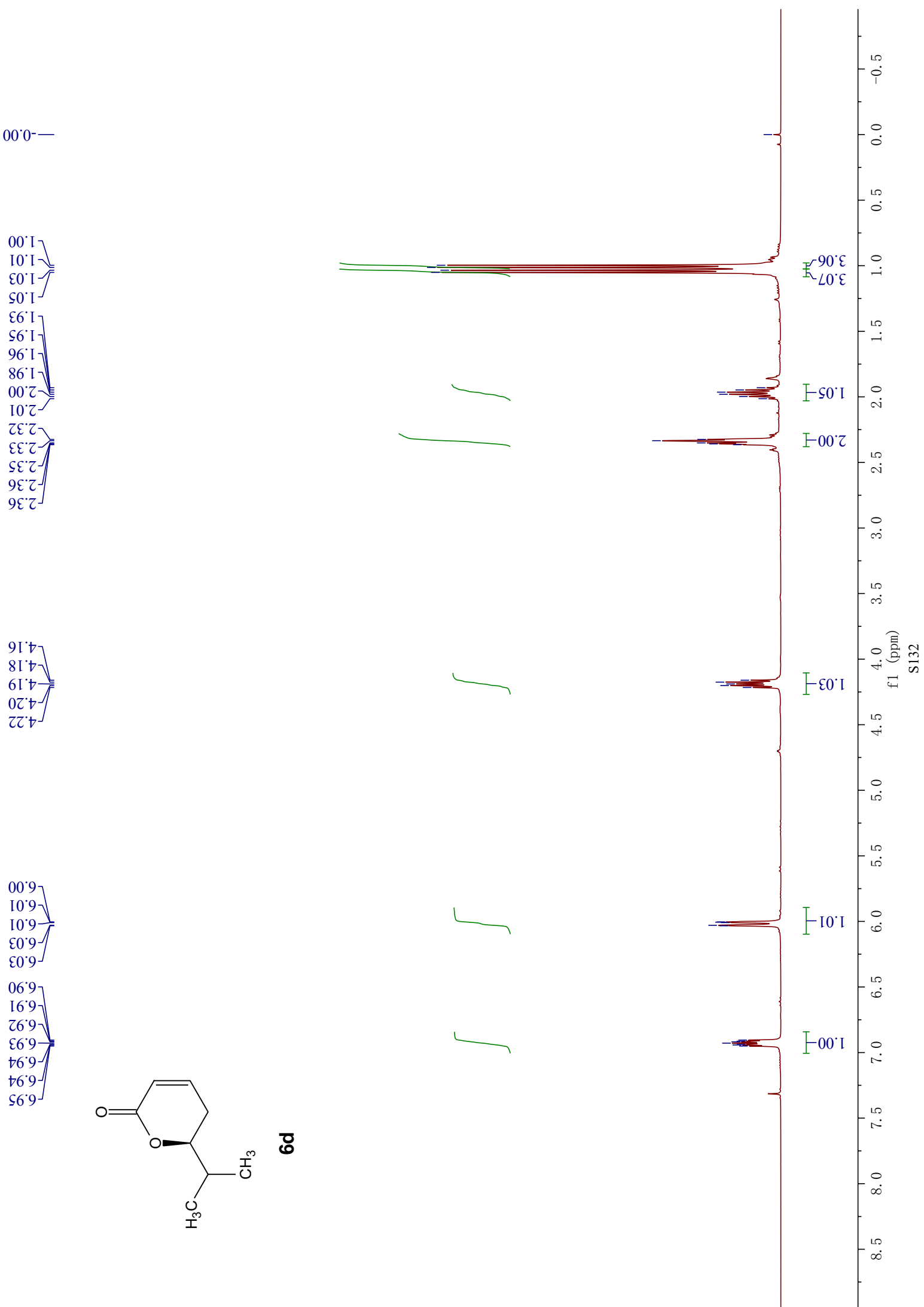


6c

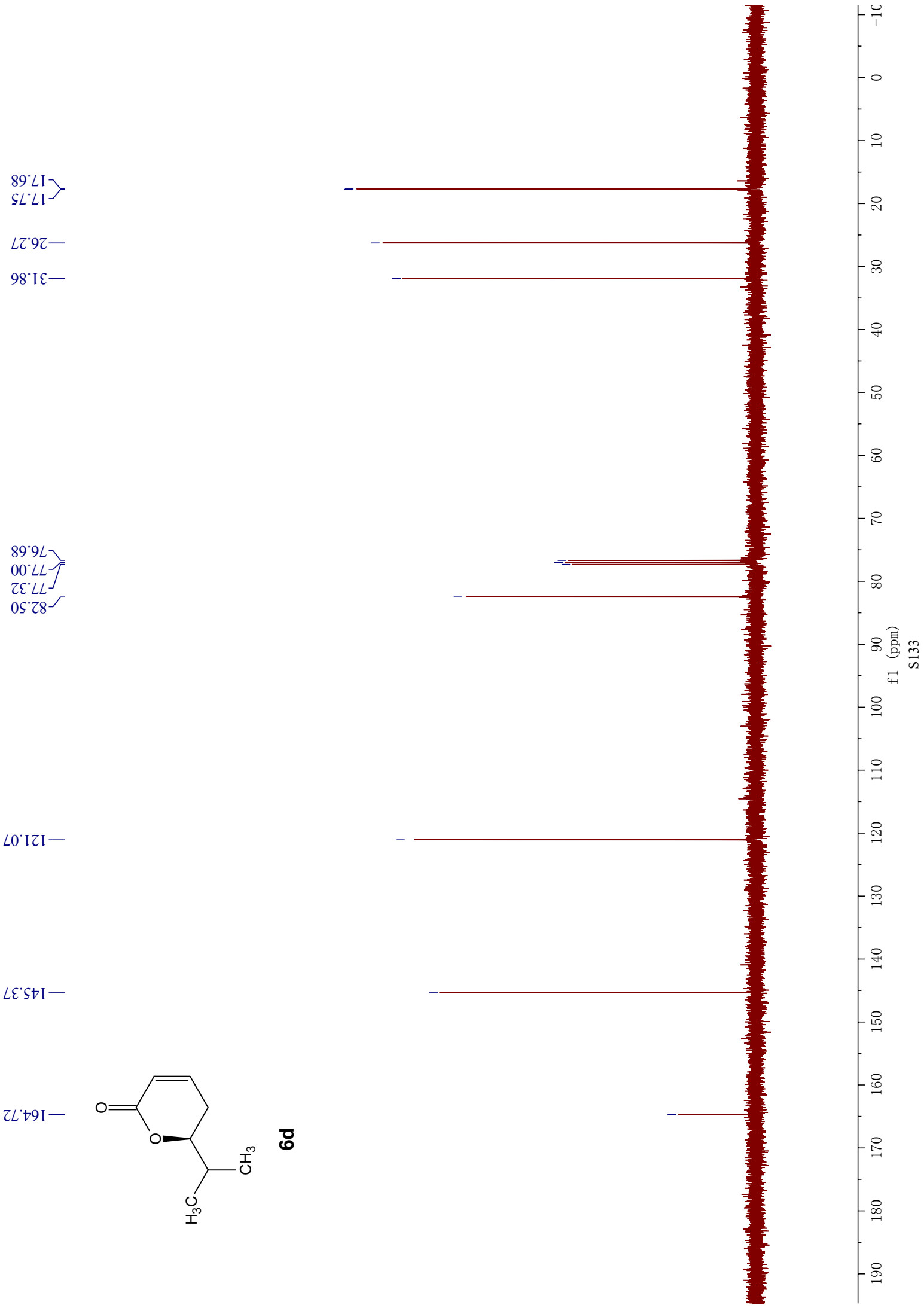
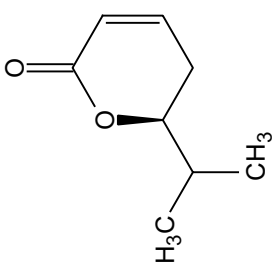


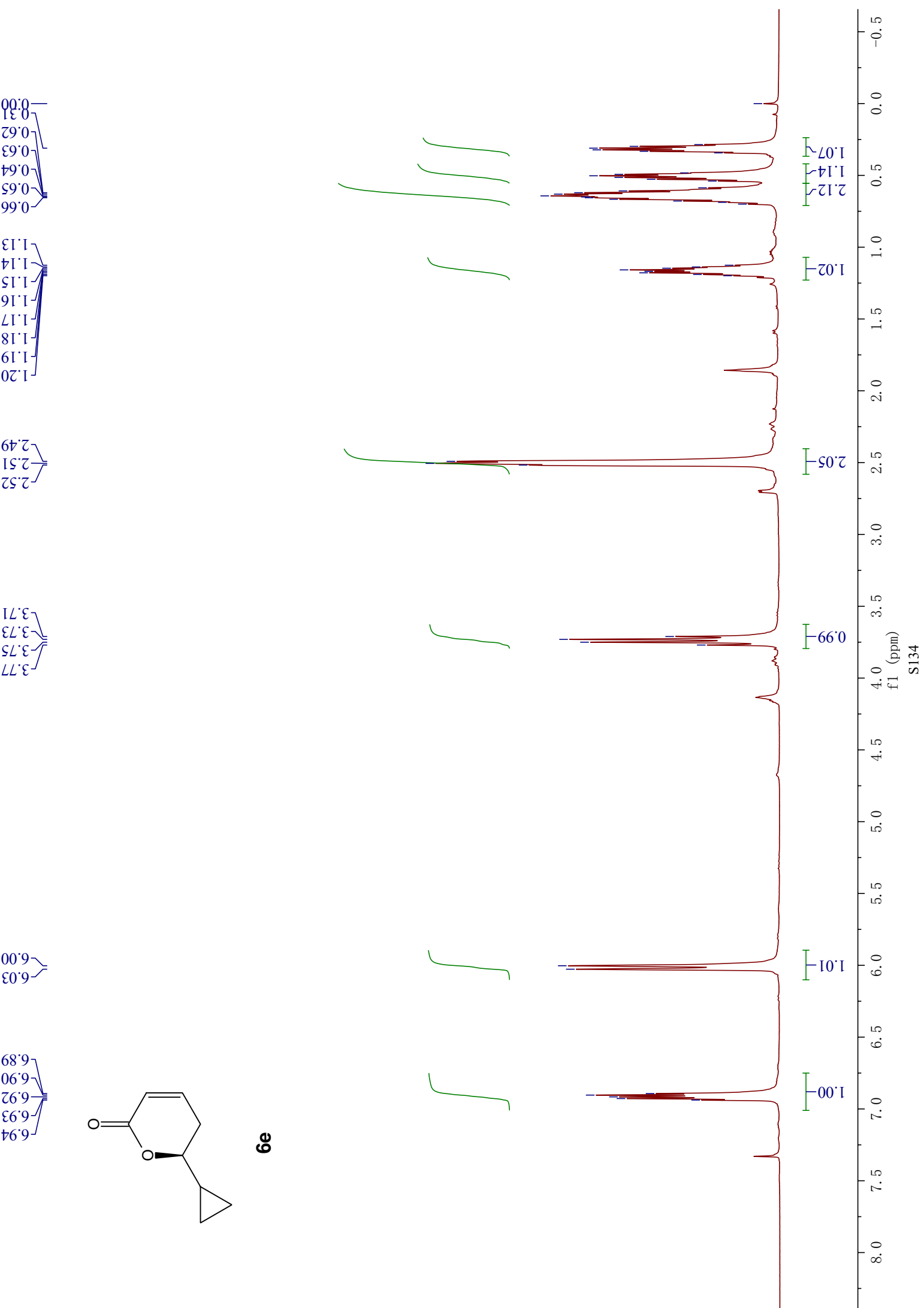


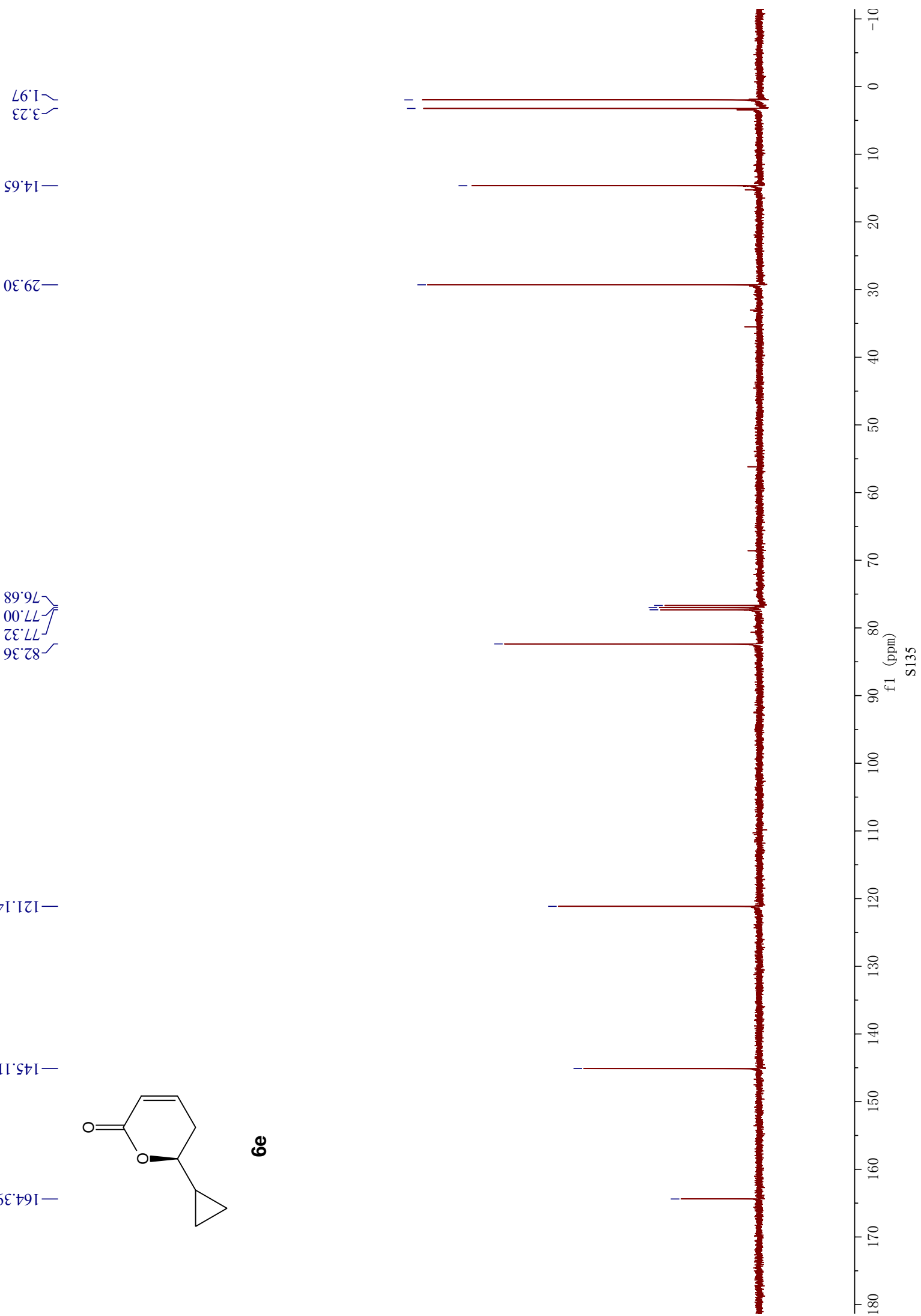
6d

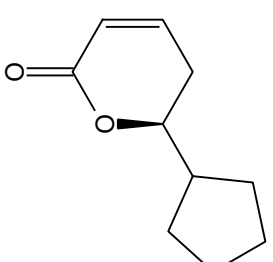


6d

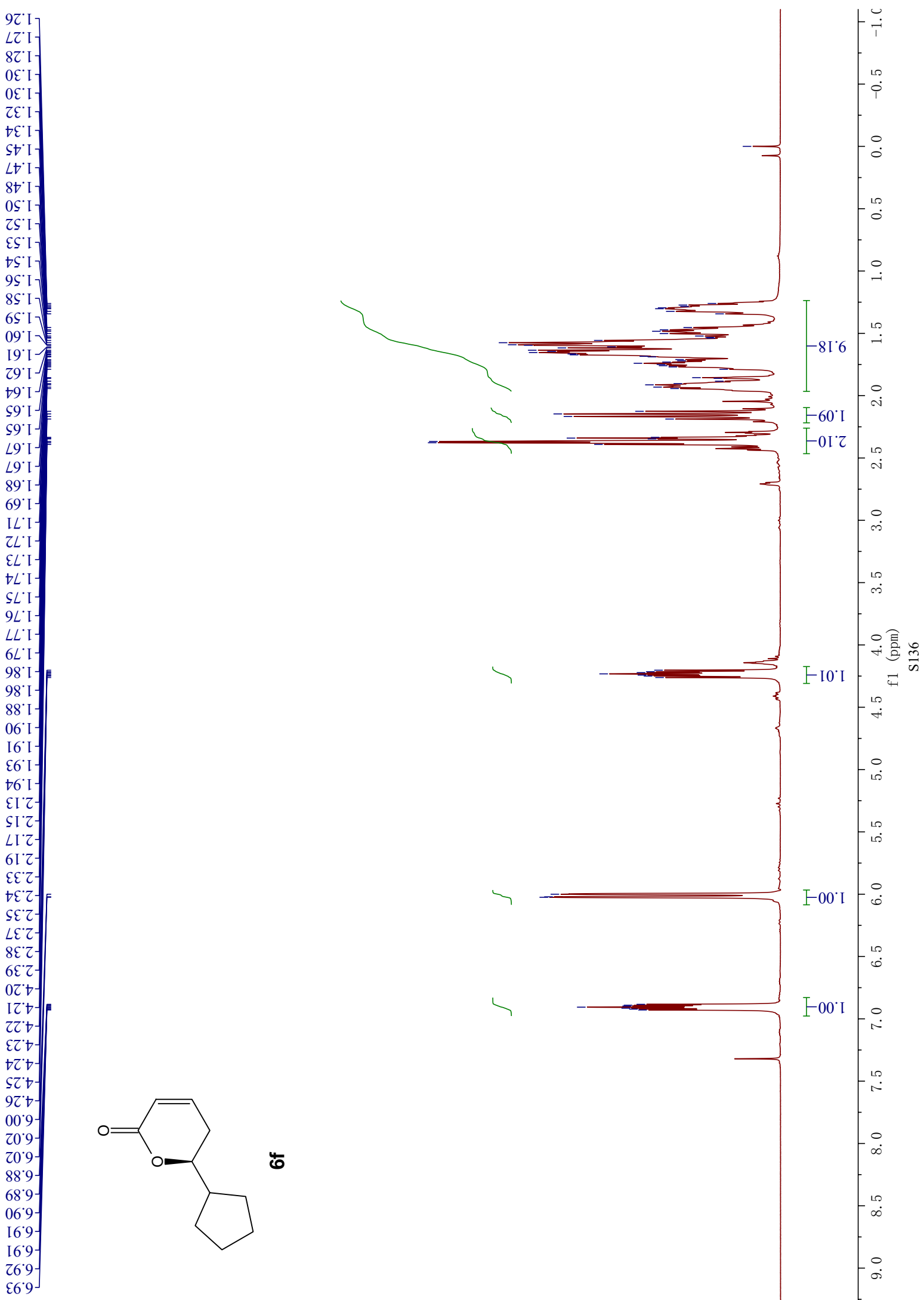




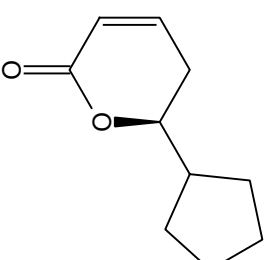




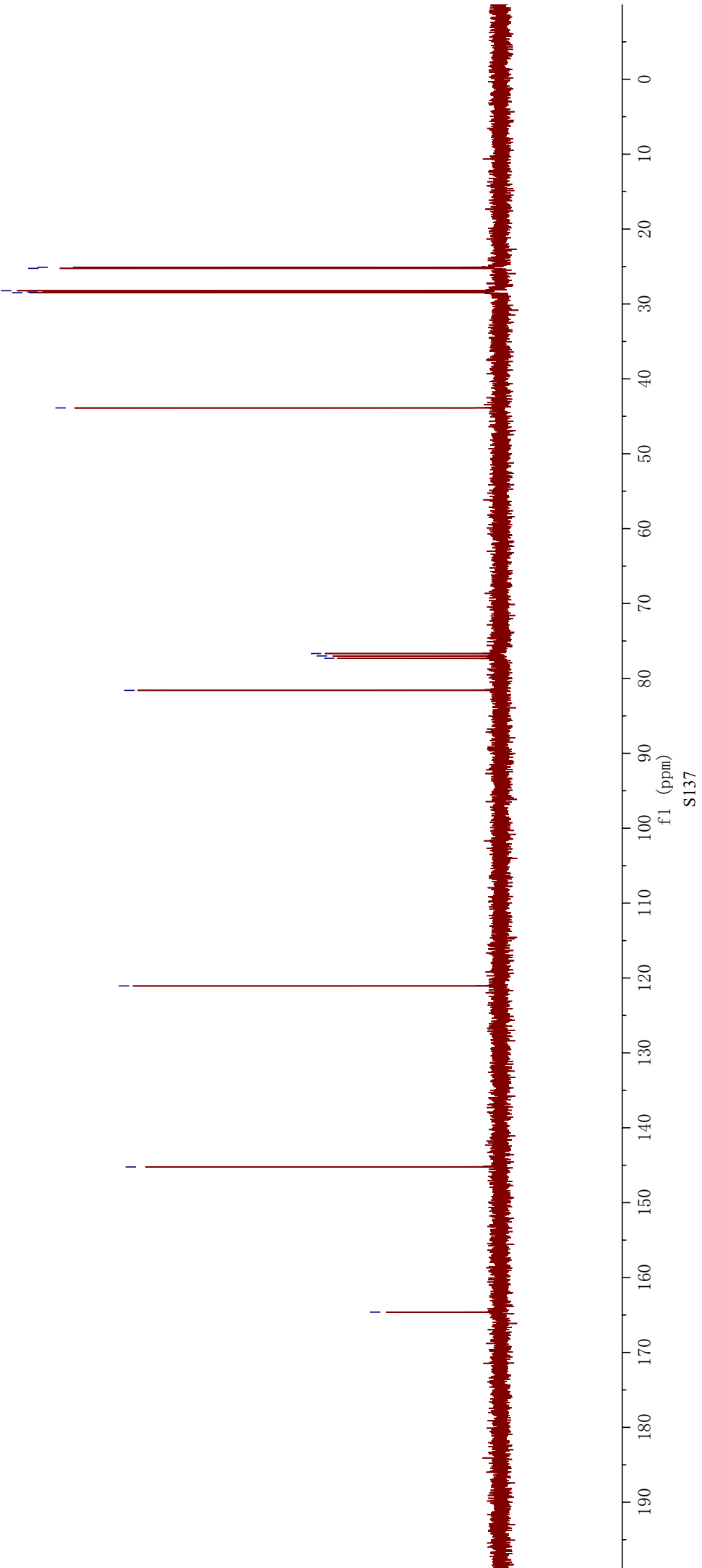
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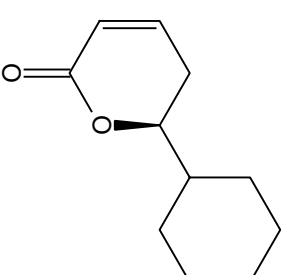


6f

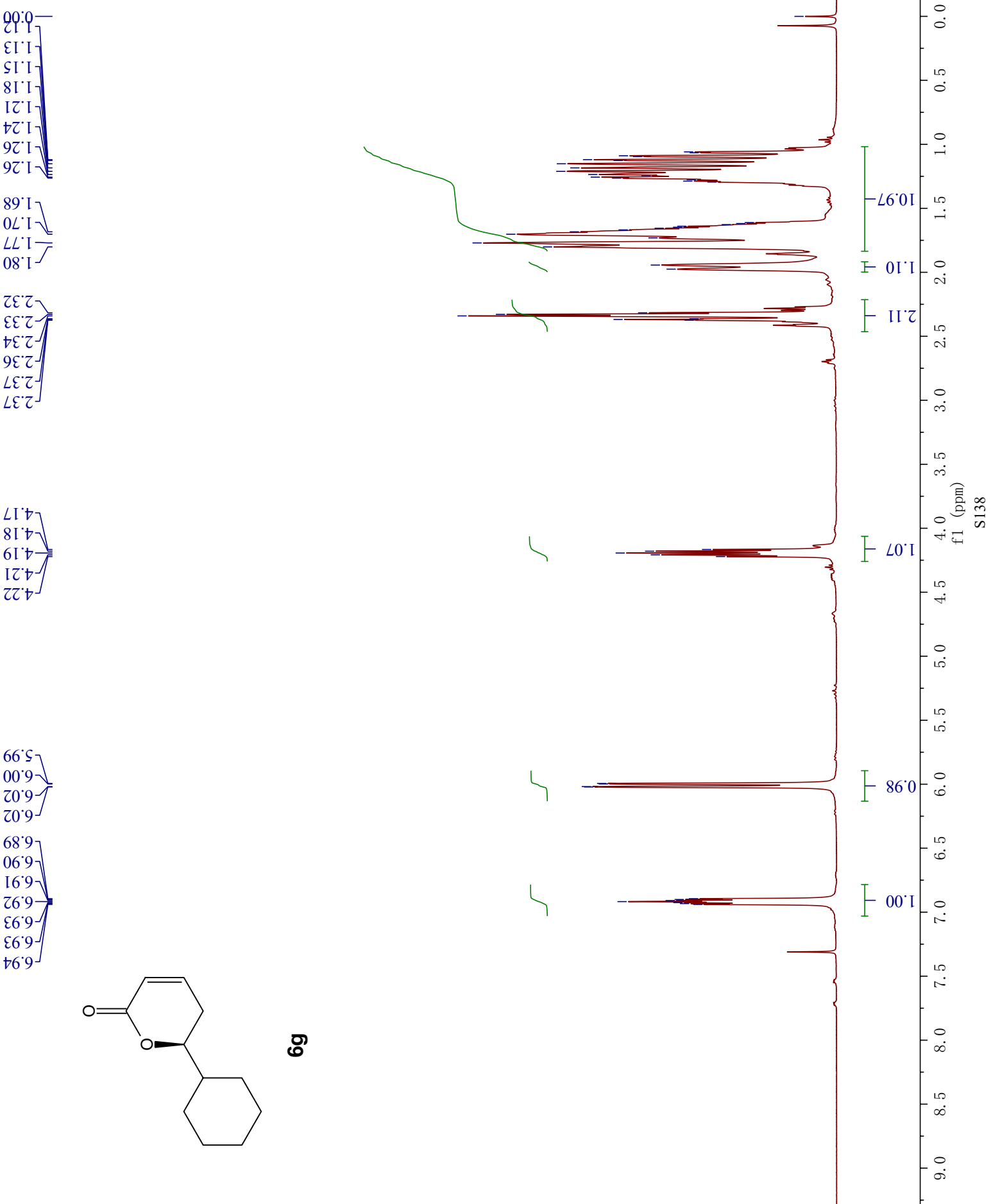


164.61
145.23
121.06
81.60
77.32
77.00
76.68
43.88
28.50
28.41
28.24
25.25
25.11

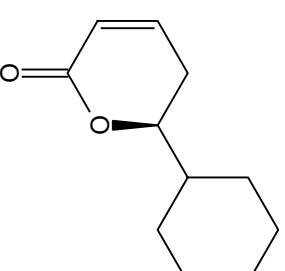




6g



6g



25.61
25.73
26.08
26.40
28.03

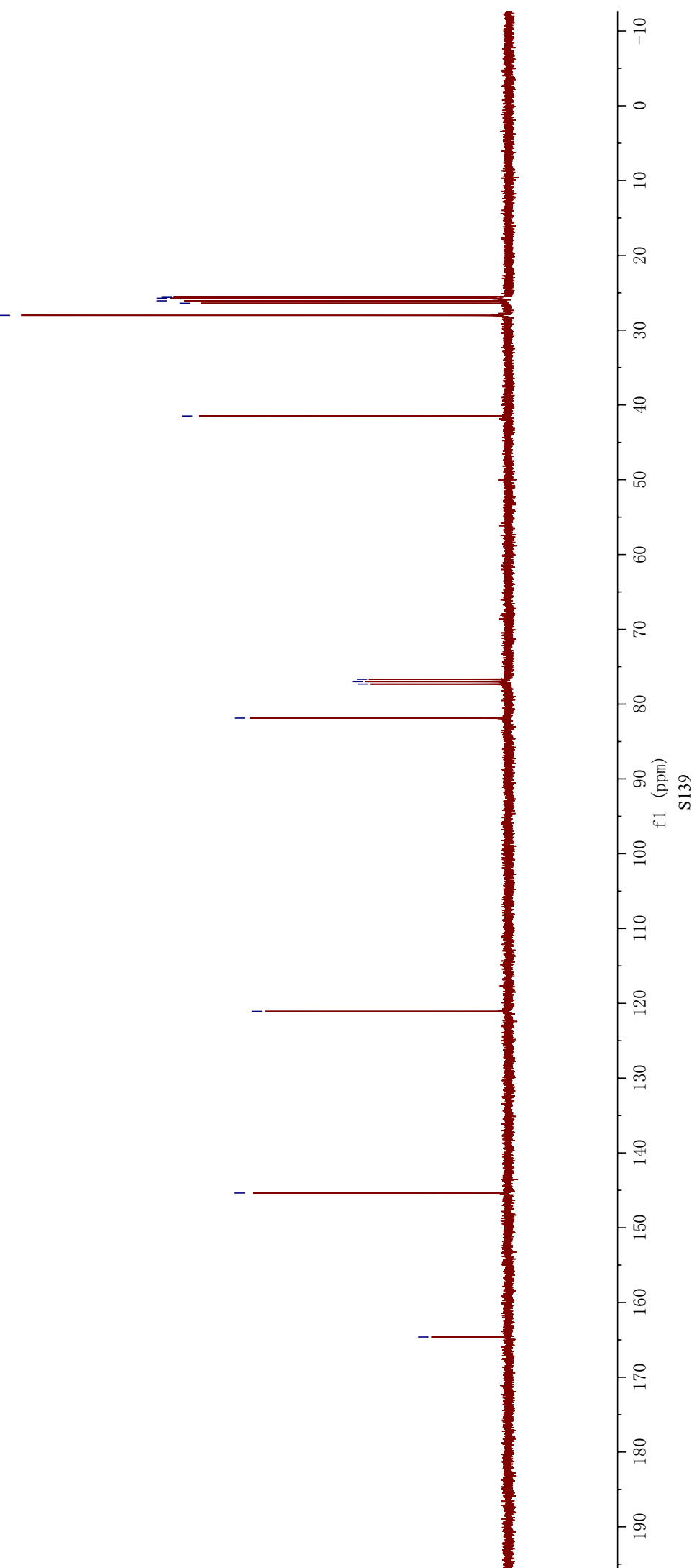
41.49

76.68
77.00
77.32
81.87

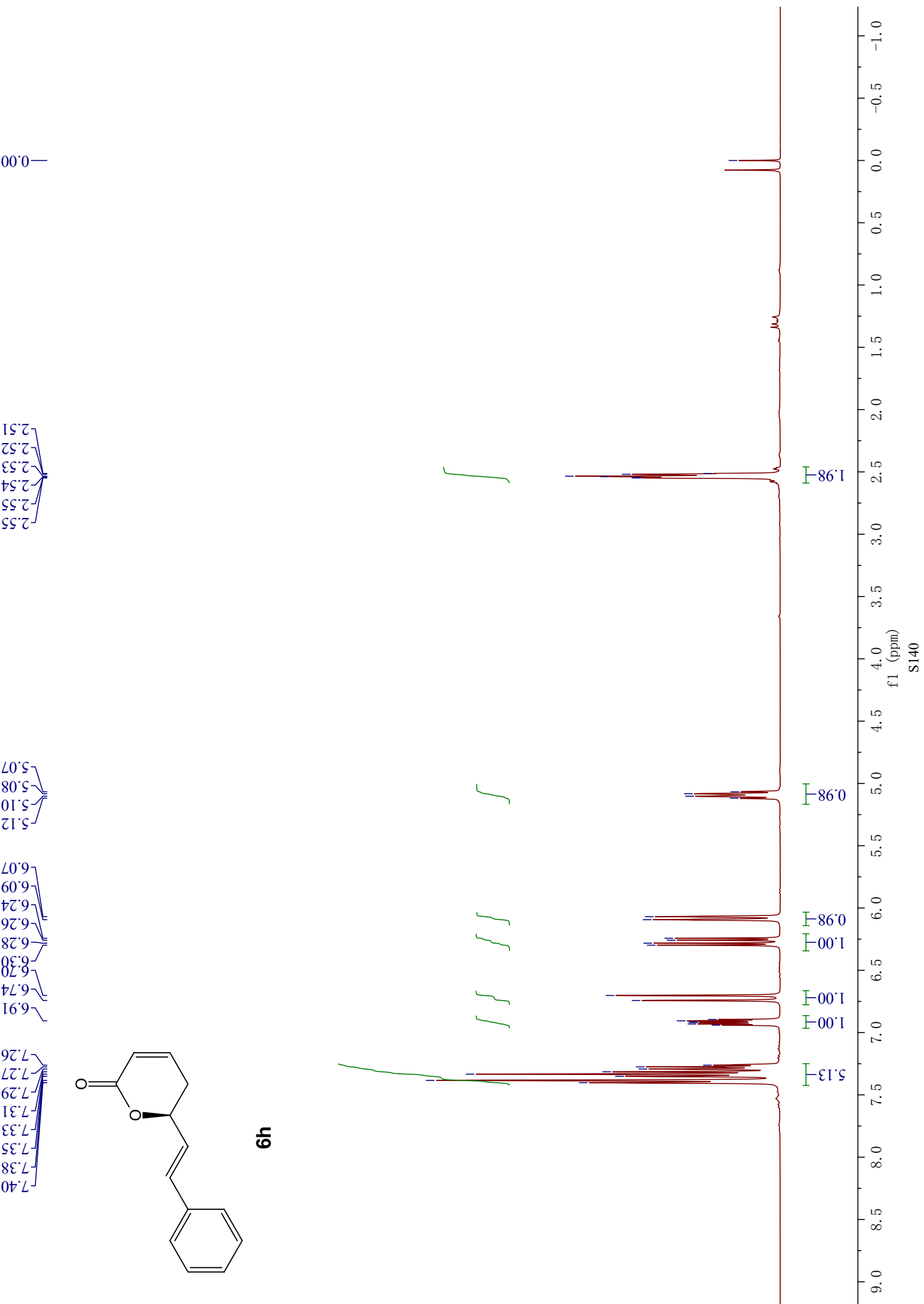
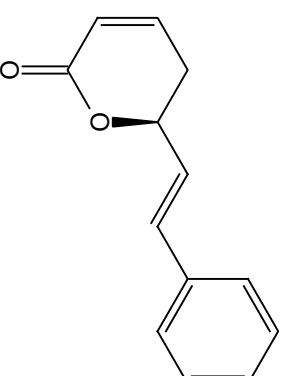
121.08

145.37

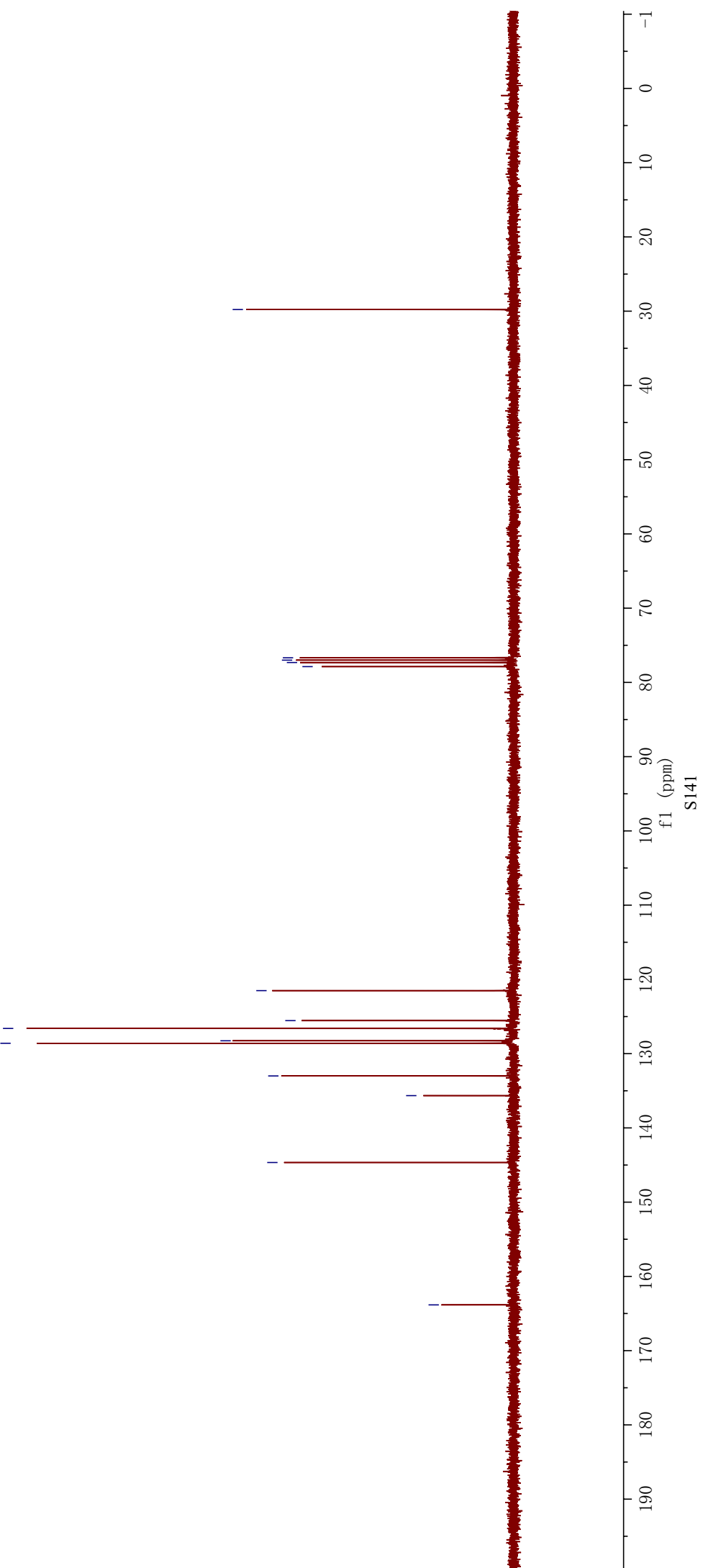
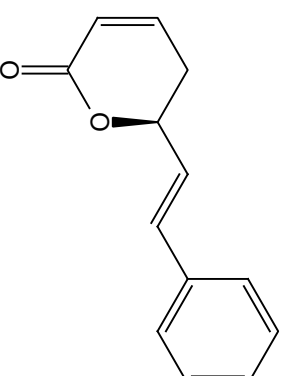
164.62

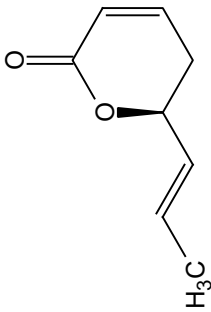


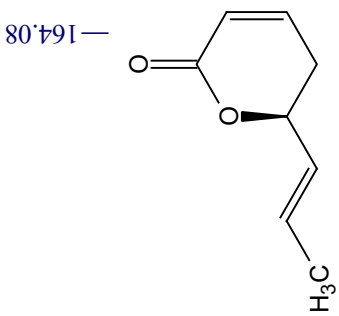
6h



6h







164.08

144.80

130.46

127.92

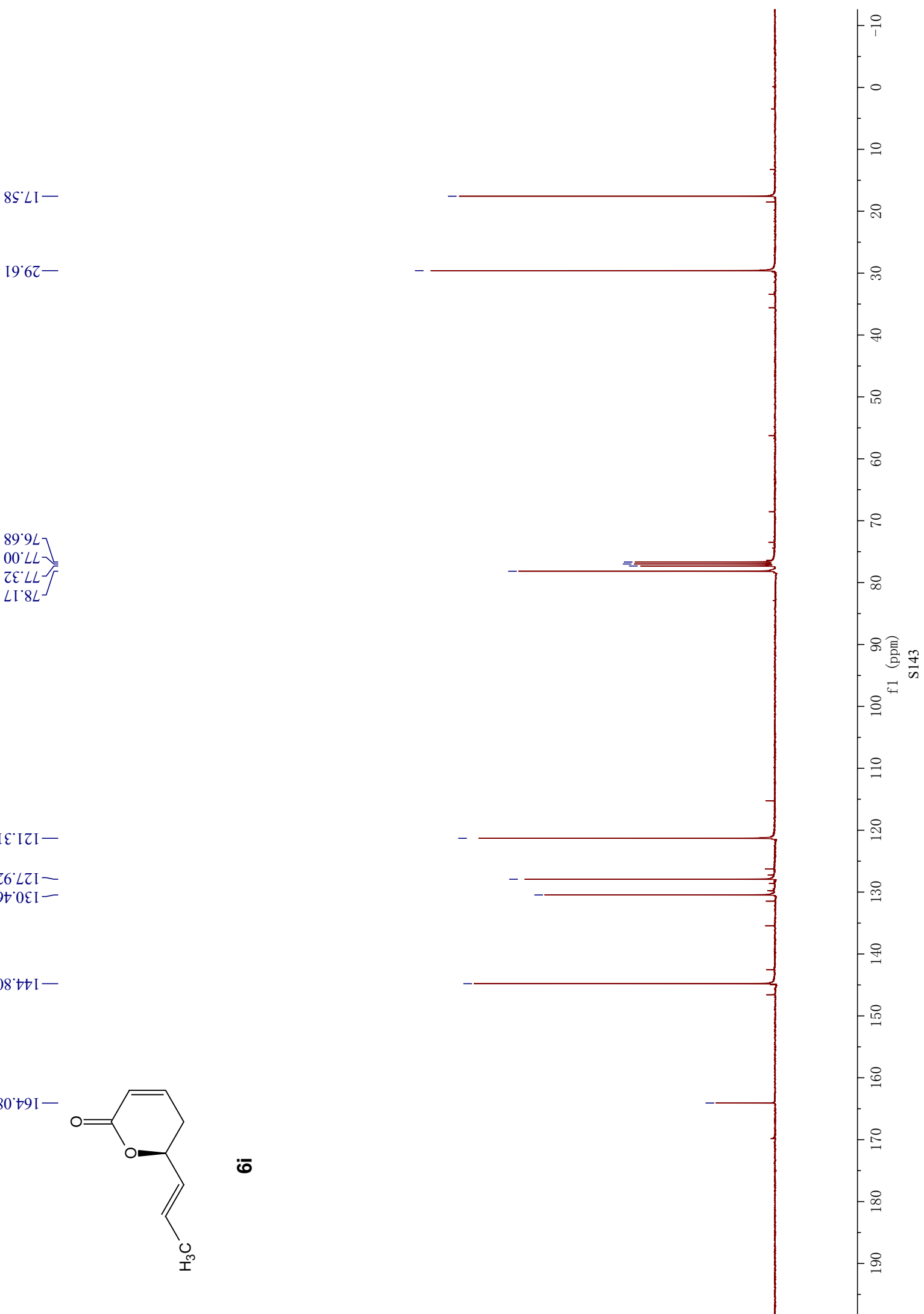
121.31

78.17
77.32
77.00
76.68

29.61

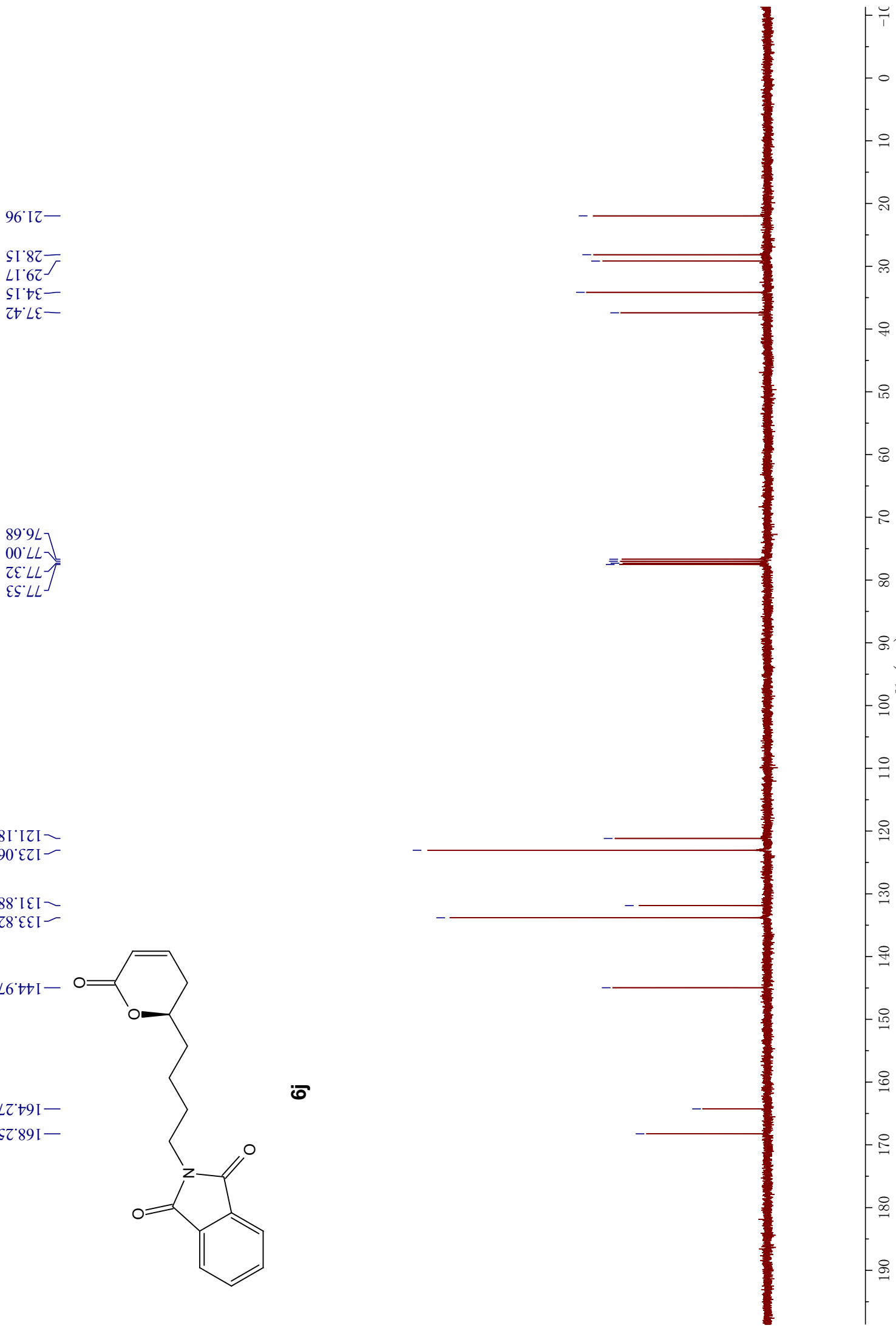
17.58

6i

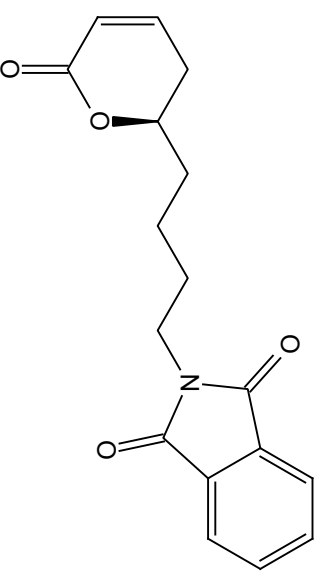


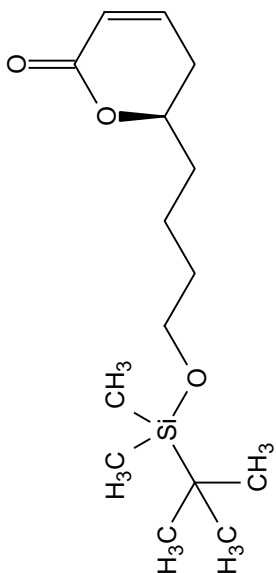
S145

f1 (ppm)

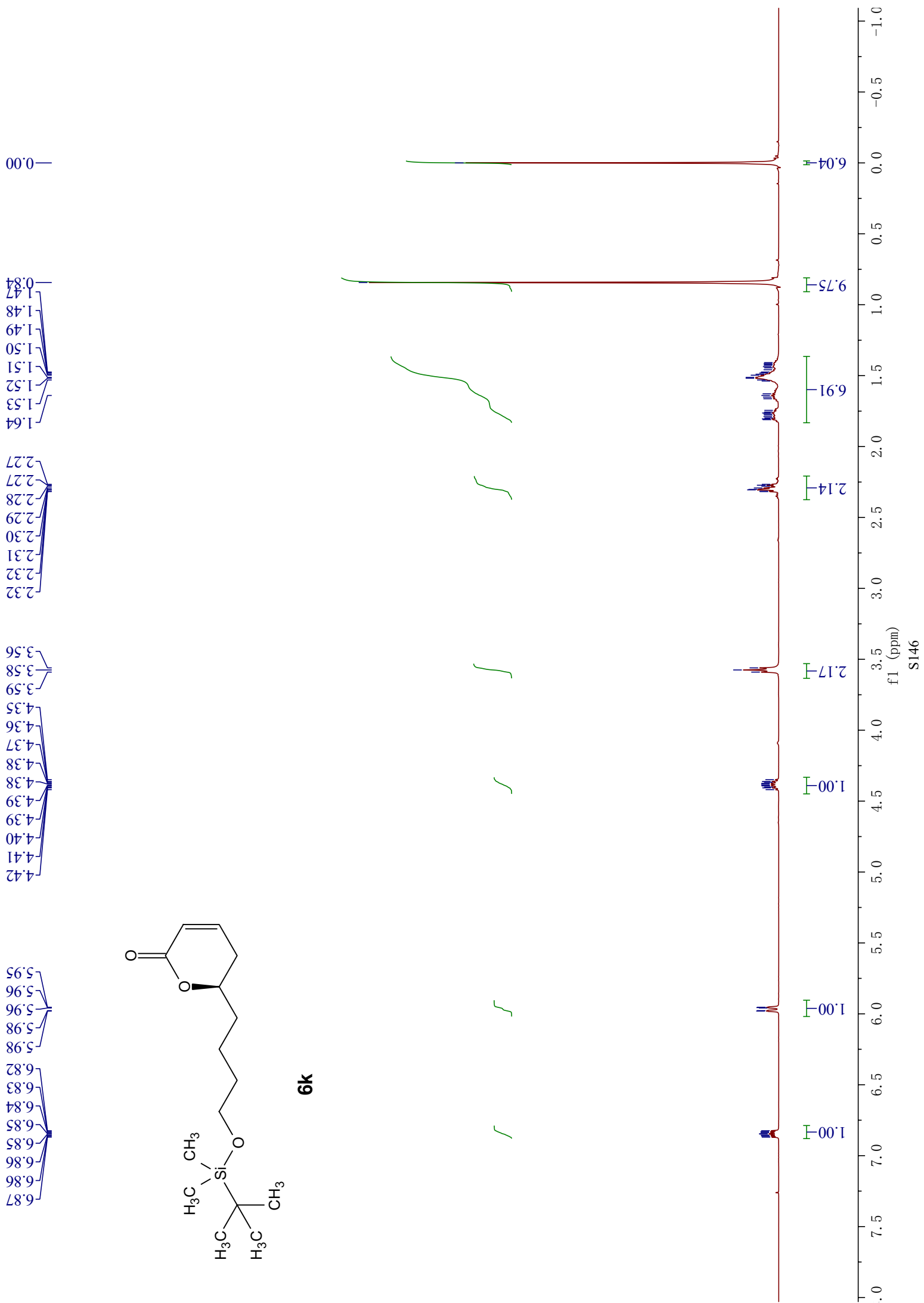


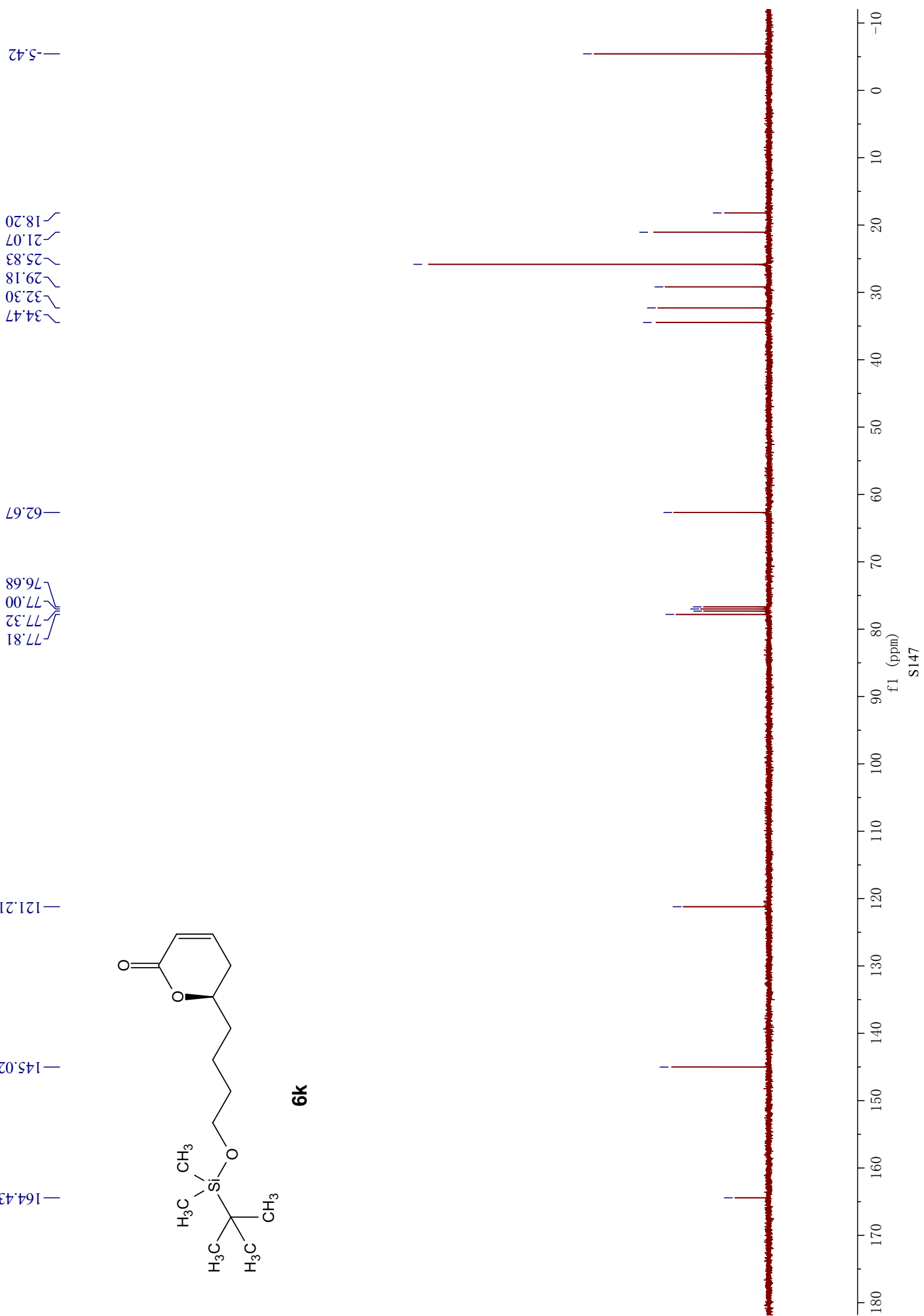
6j

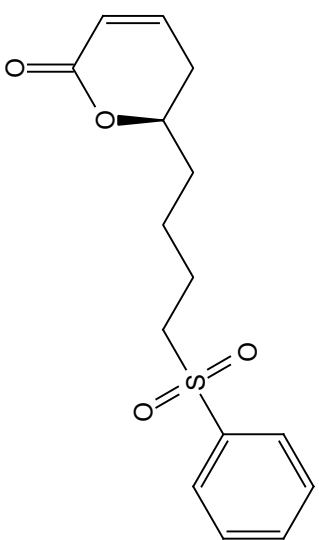
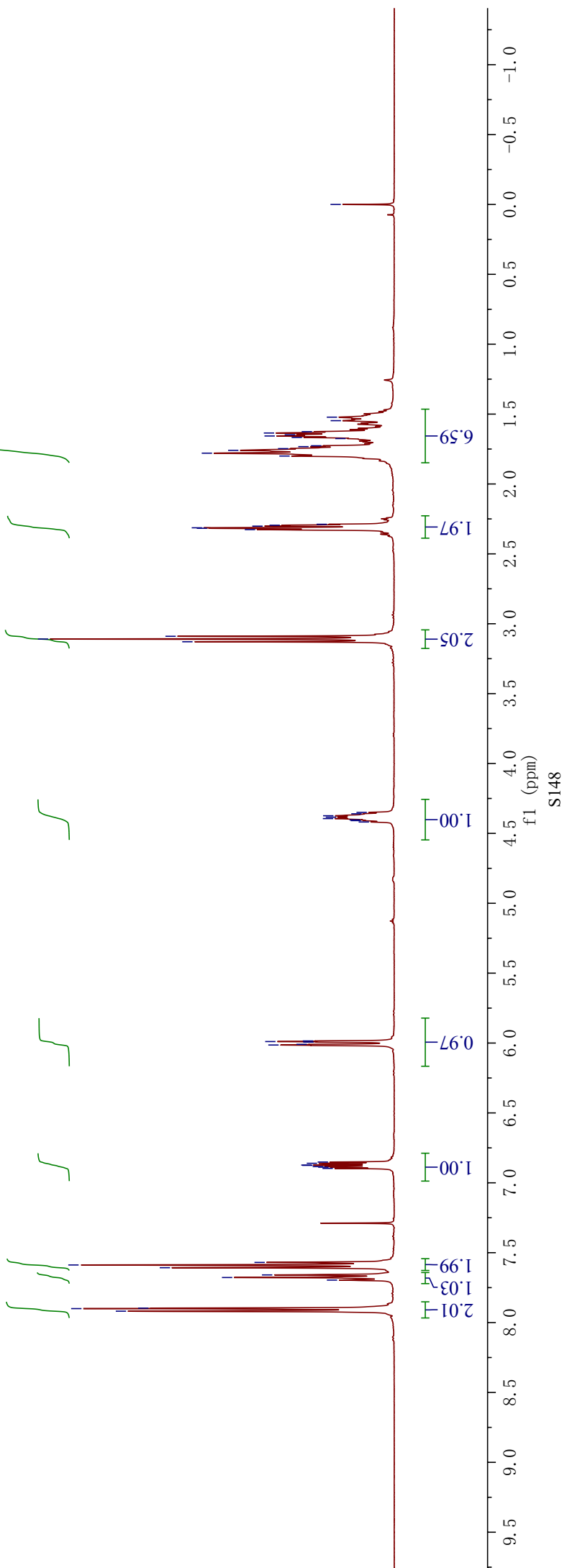




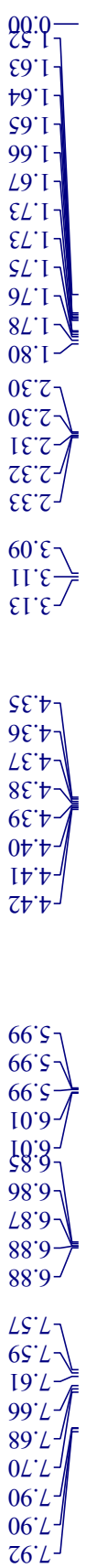
6k



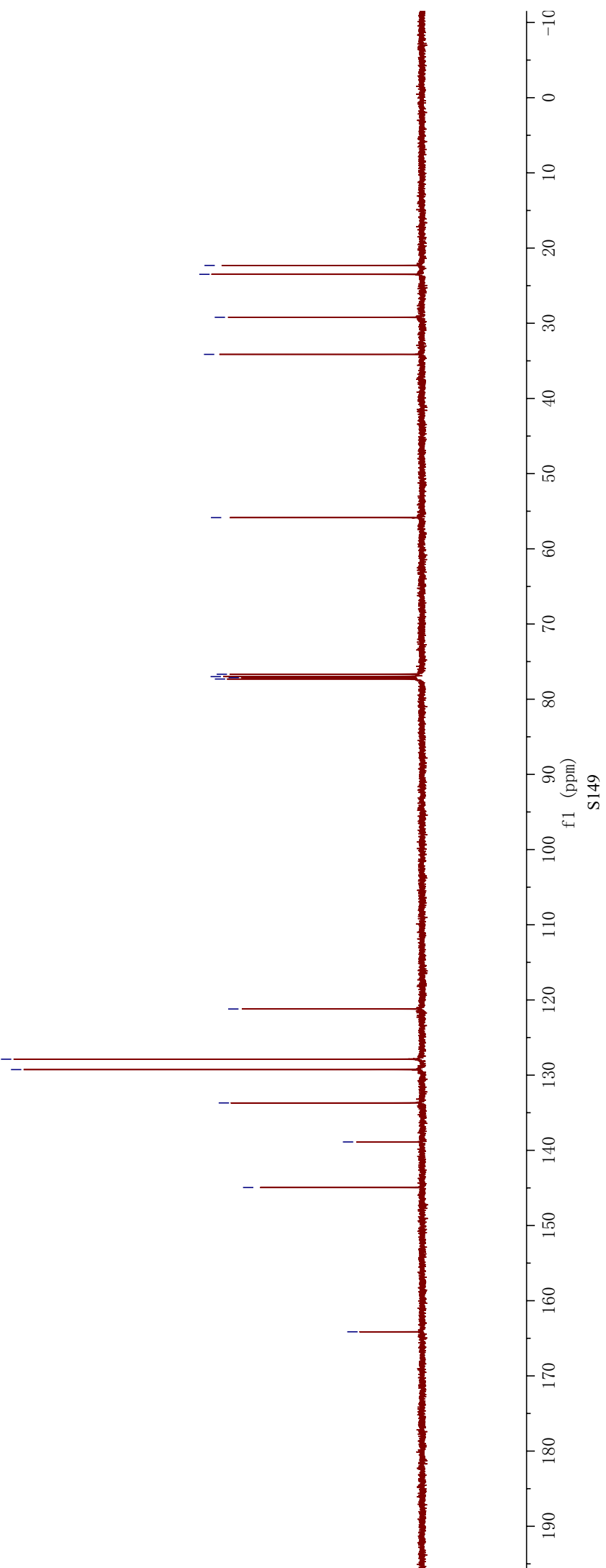
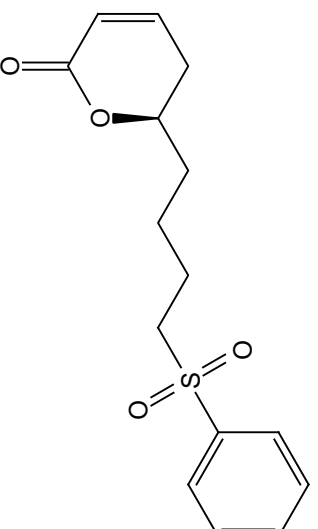




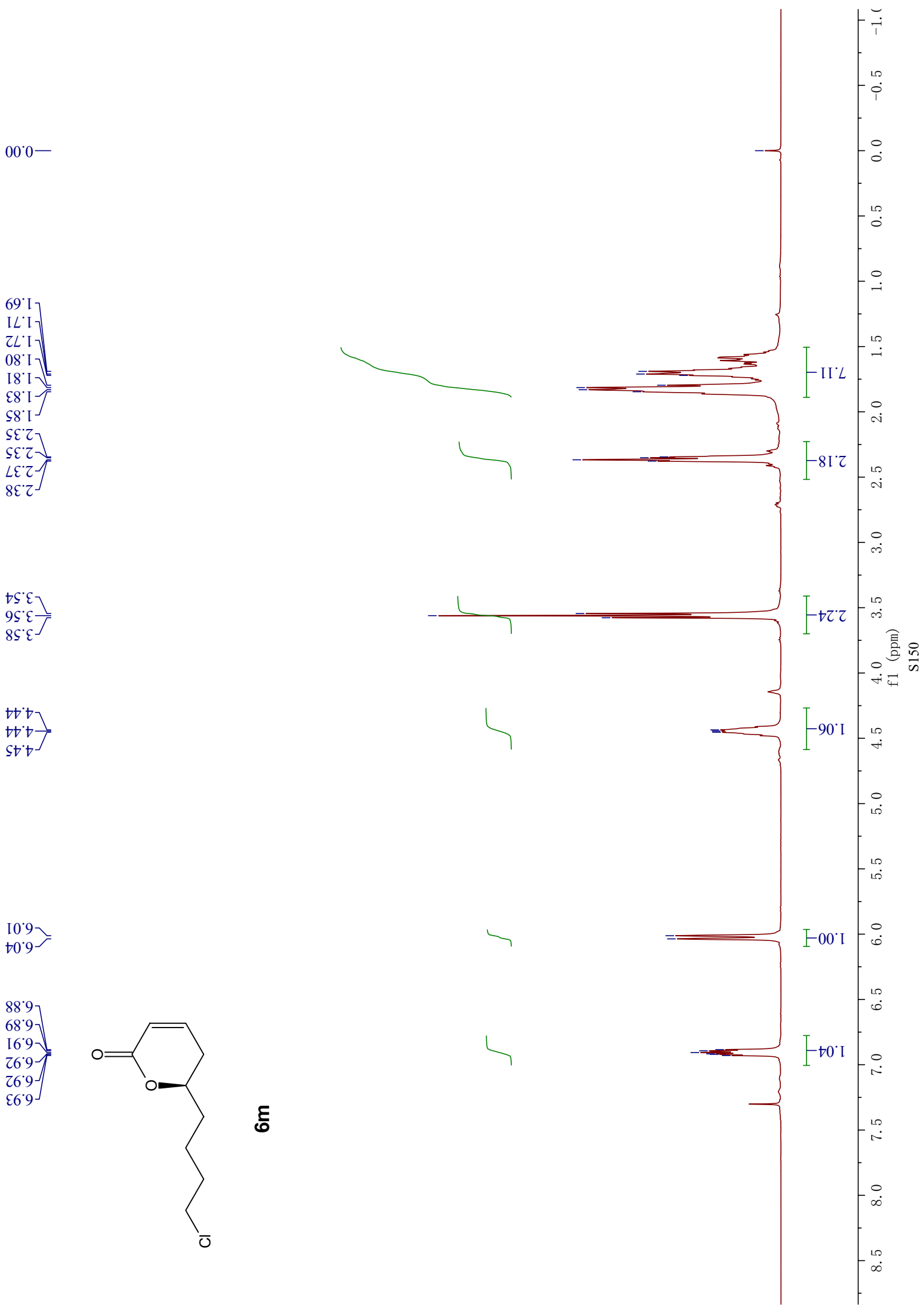
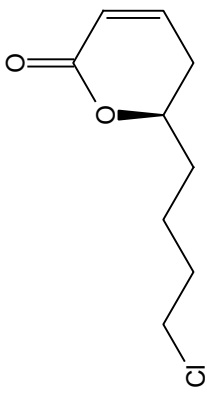
19



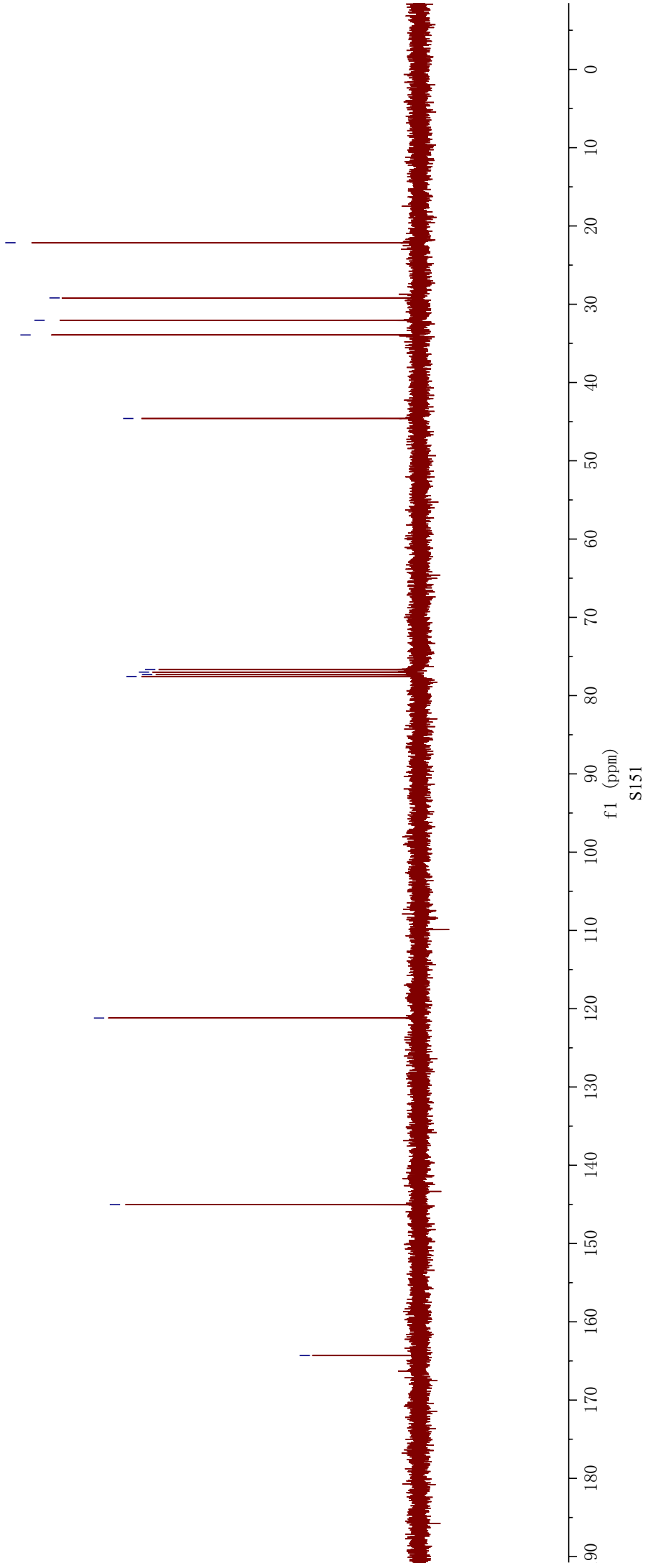
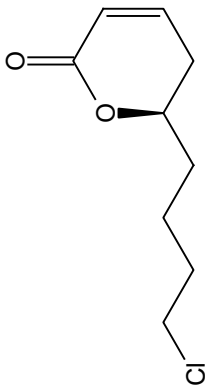
19

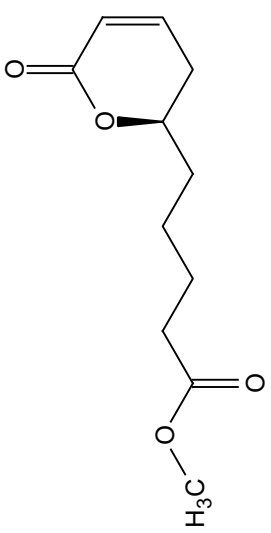


6m

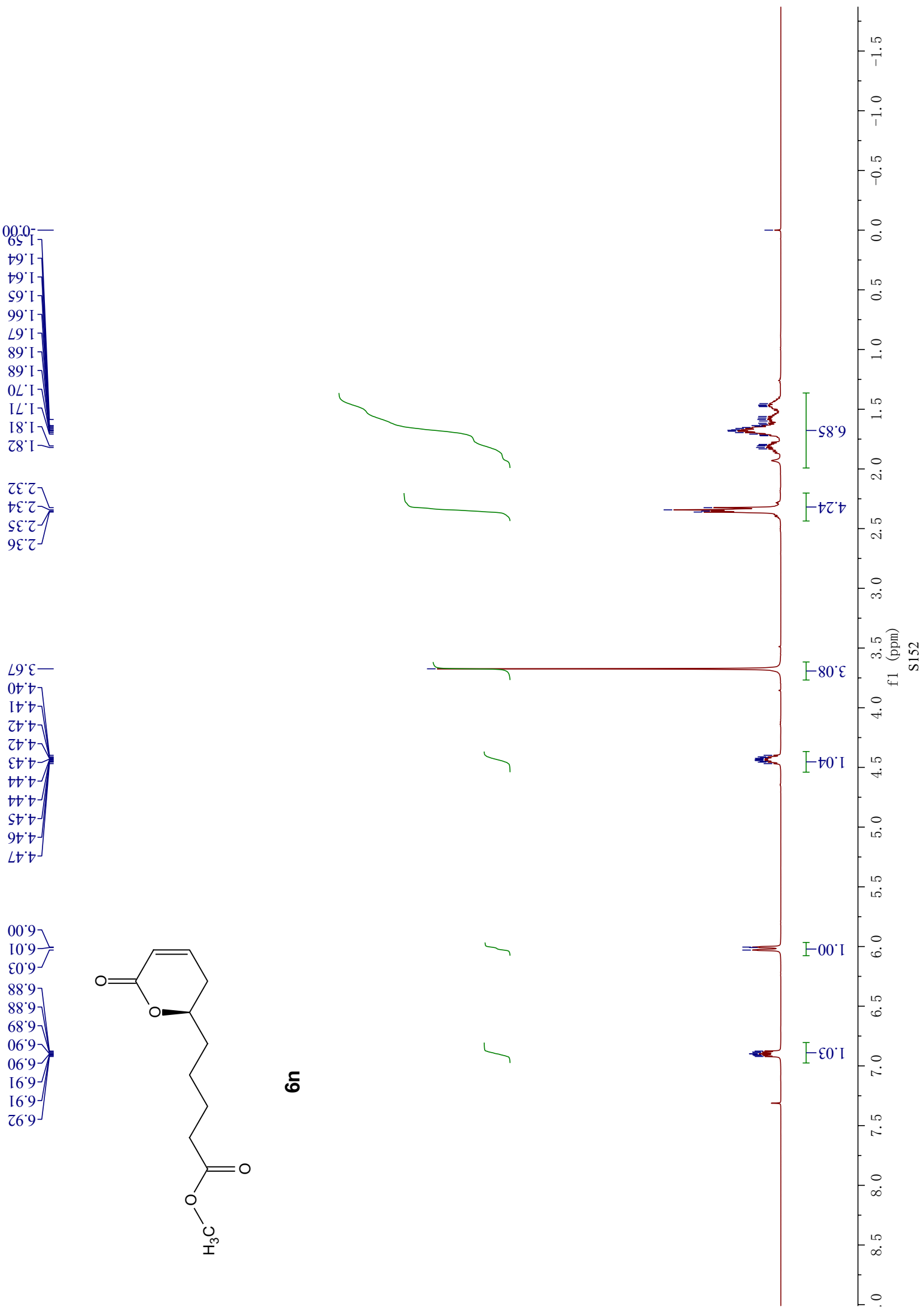


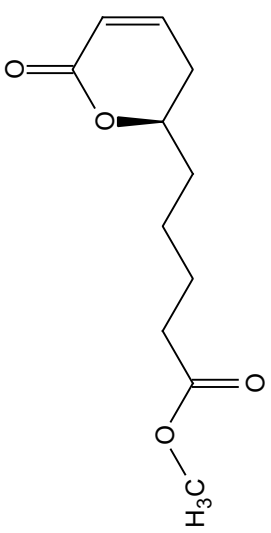
6m



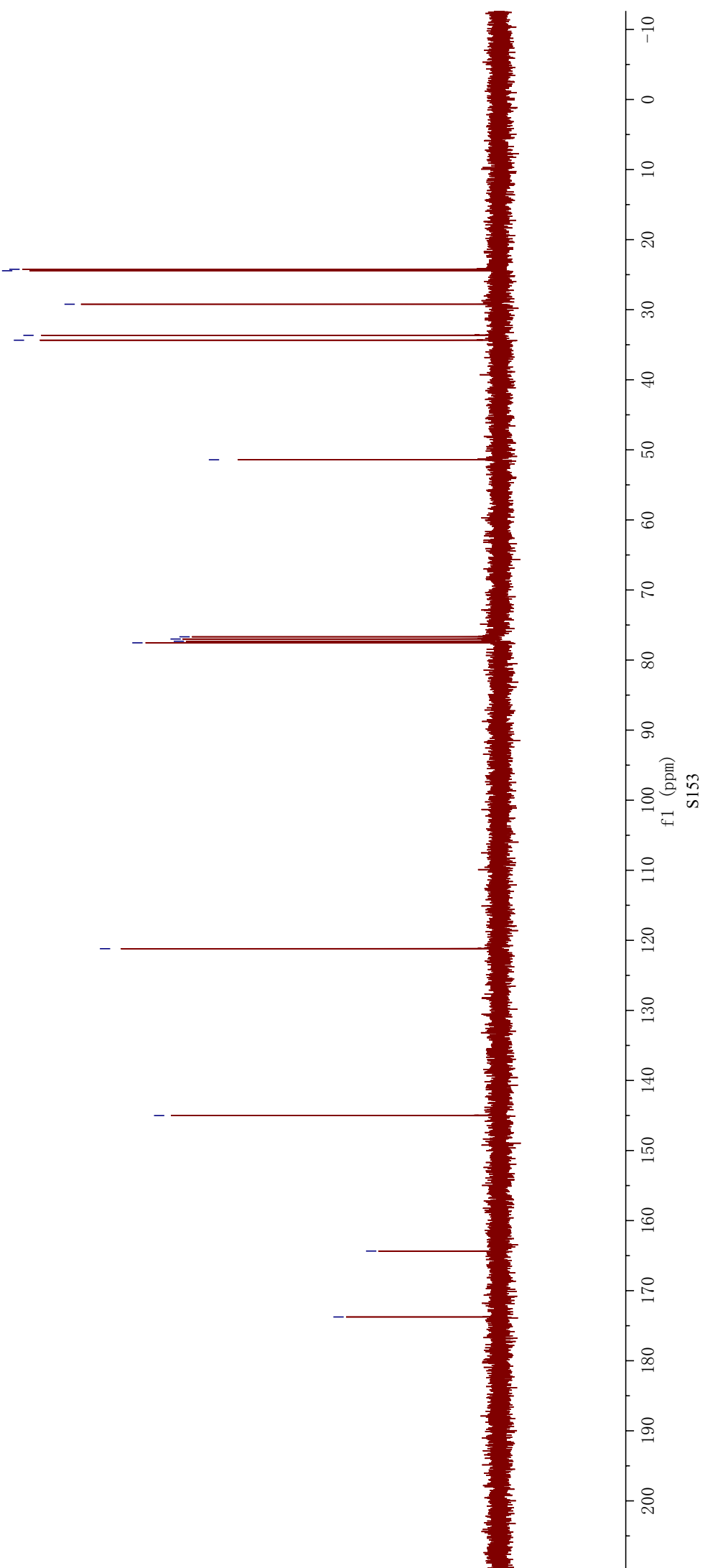


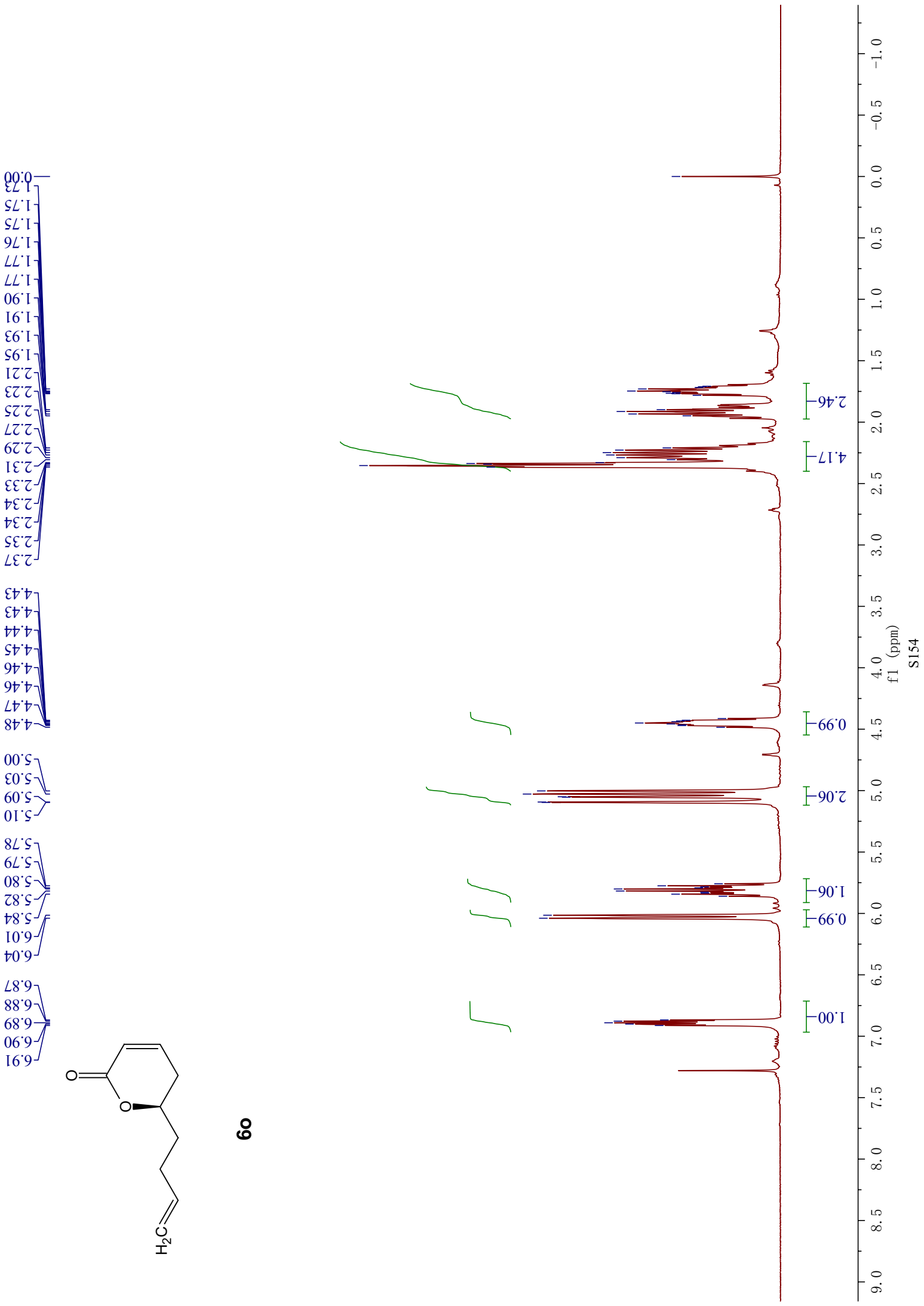
6n





6n





33.87
29.29
28.84

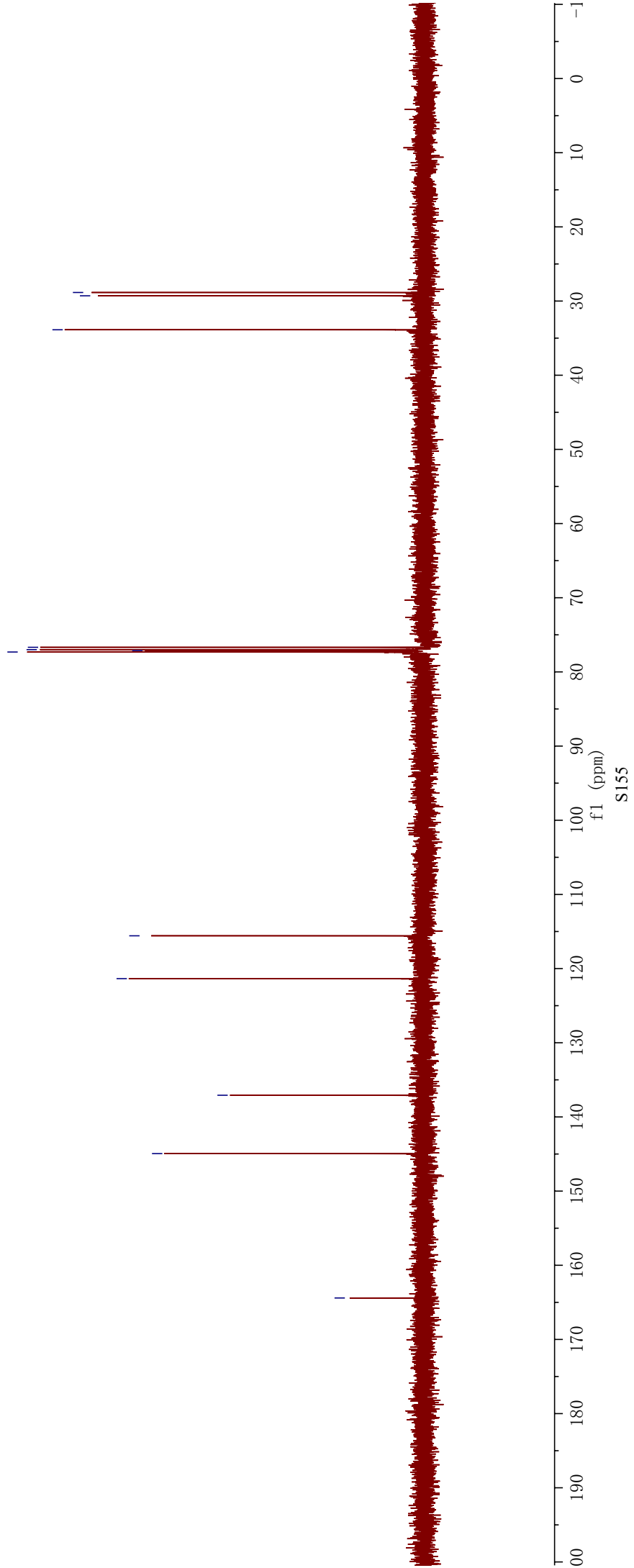
77.32
77.11
77.00
76.68

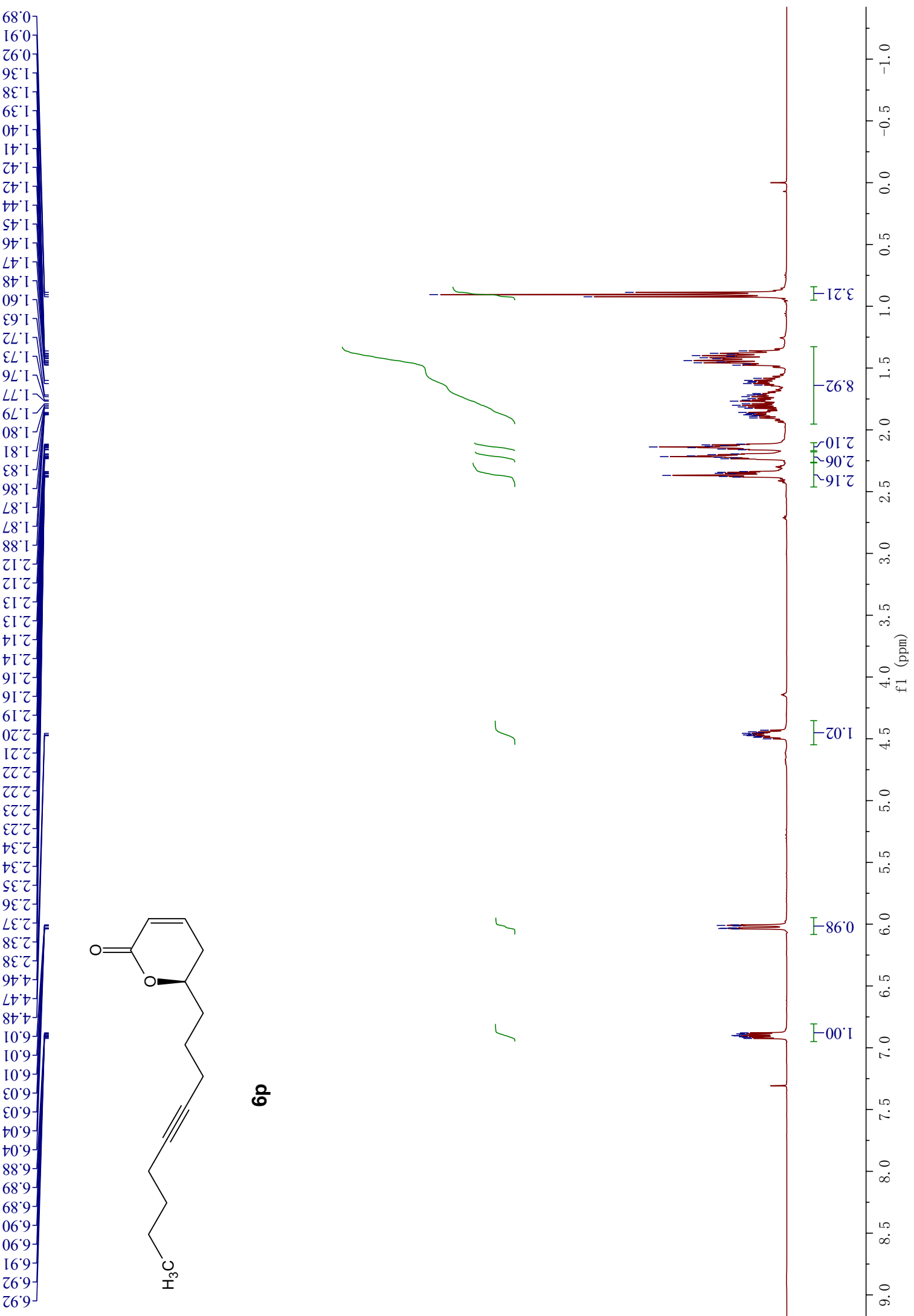
115.58
121.36

137.08
144.95

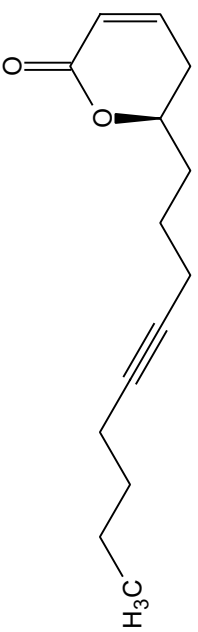
164.41

69





6d



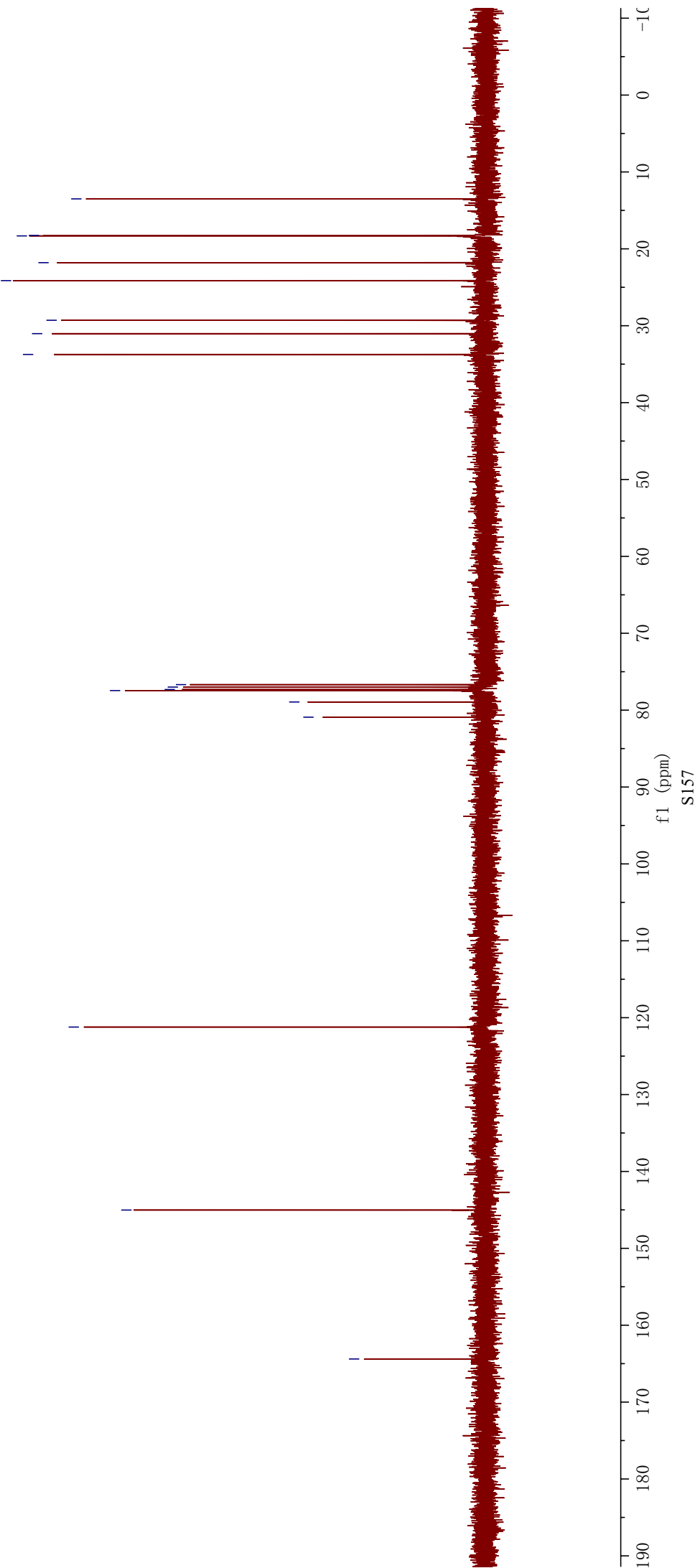
— 13.50
— 18.25
— 18.32
— 21.80
— 24.13
— 29.29
— 31.03
— 33.74

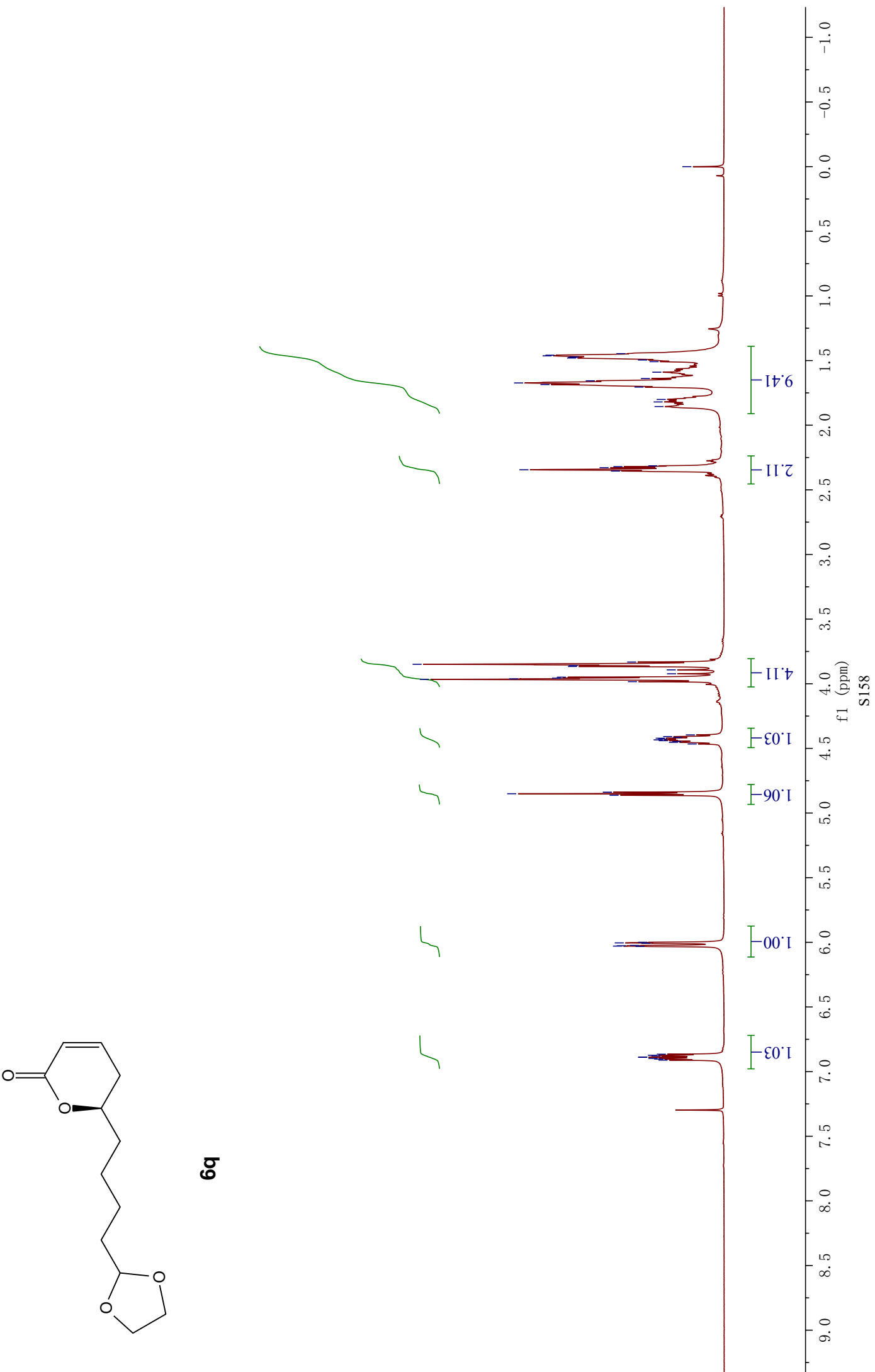
— 76.68
— 77.00
— 77.32
— 77.46
— 78.94
— 80.92

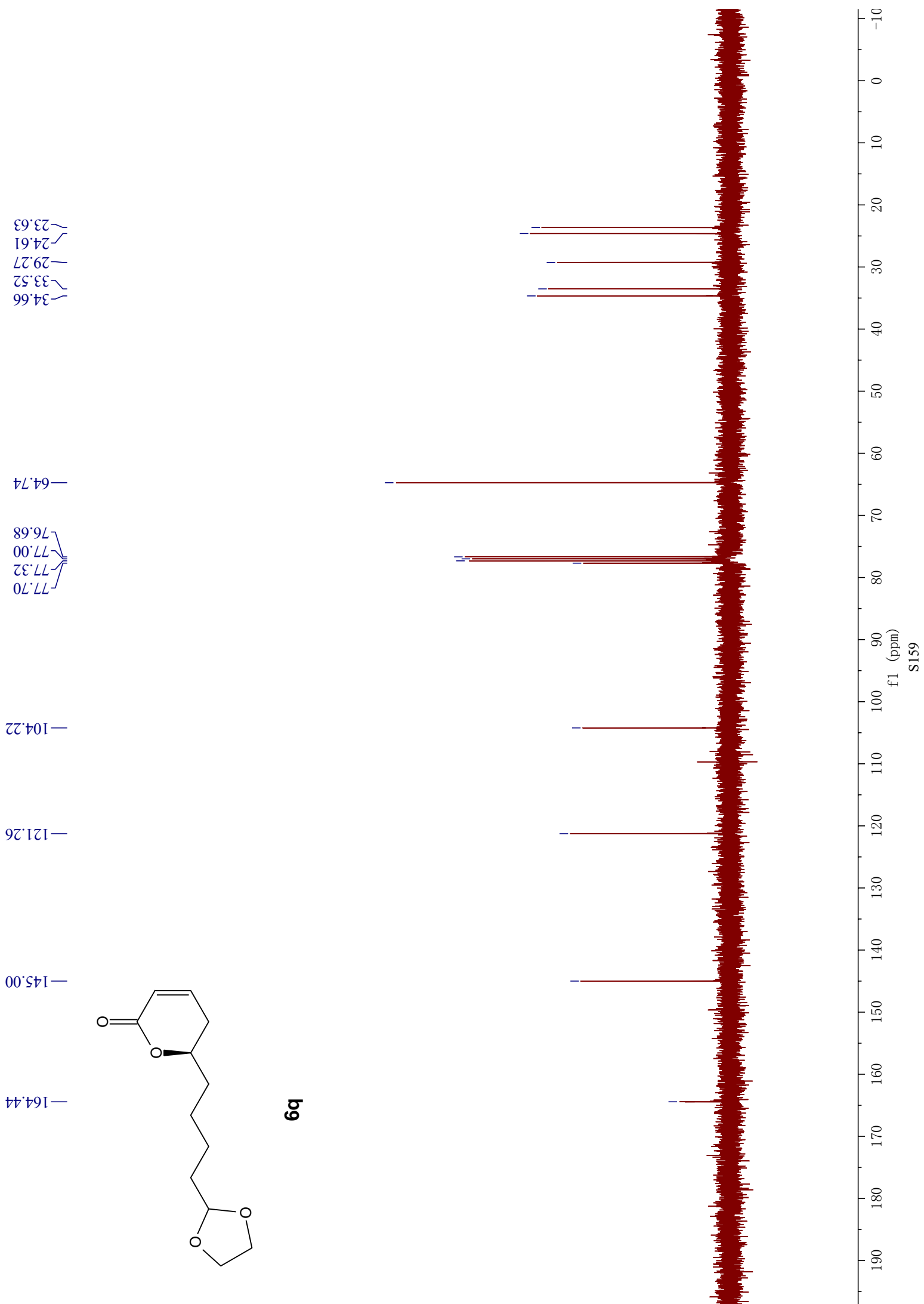
— 121.22

— 145.02

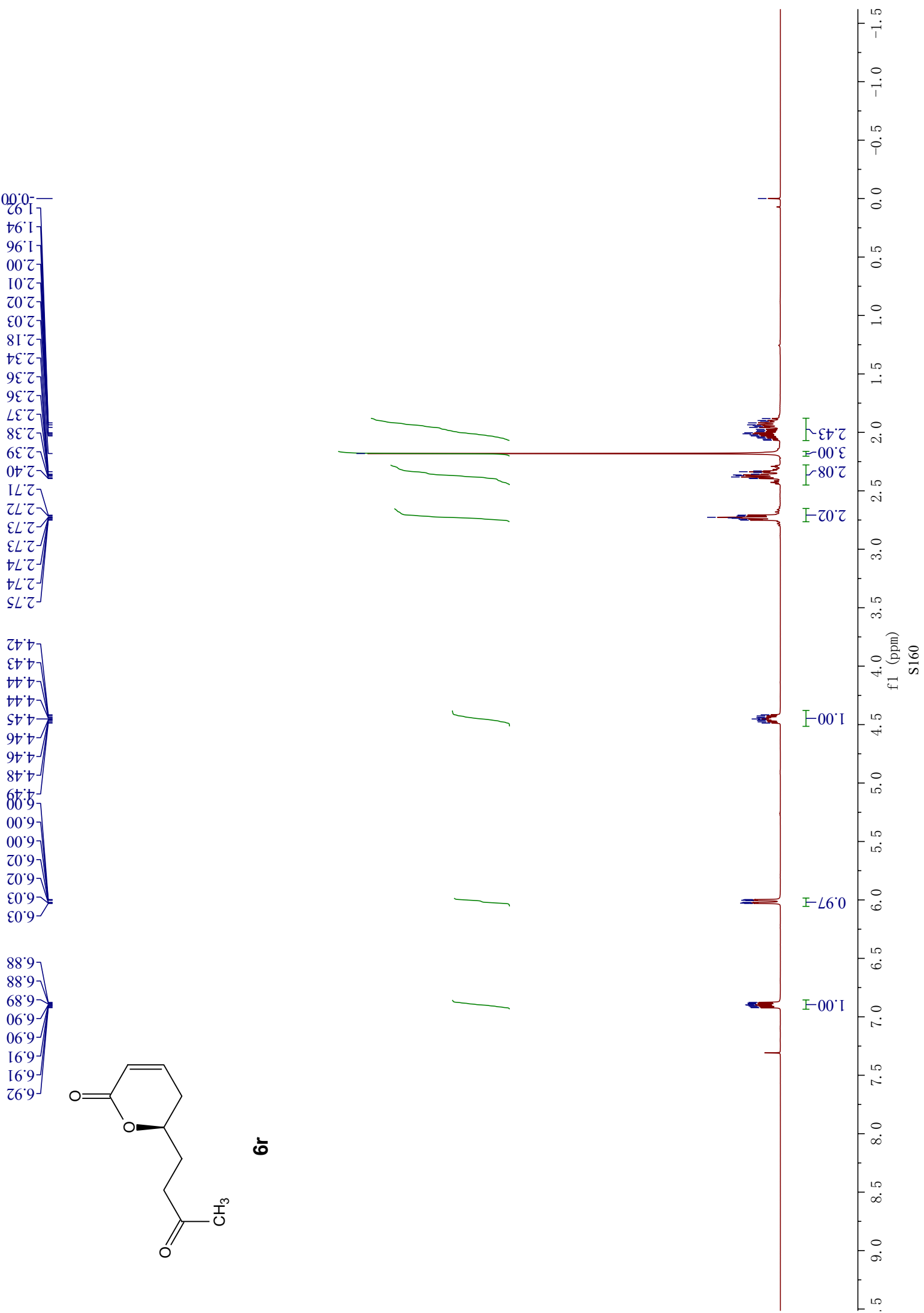
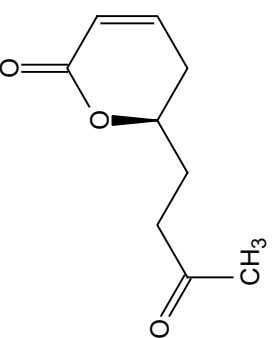
— 164.39



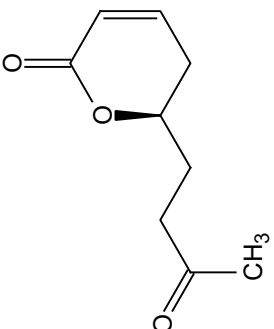




6r



6r



28.29
29.48
29.96
38.27

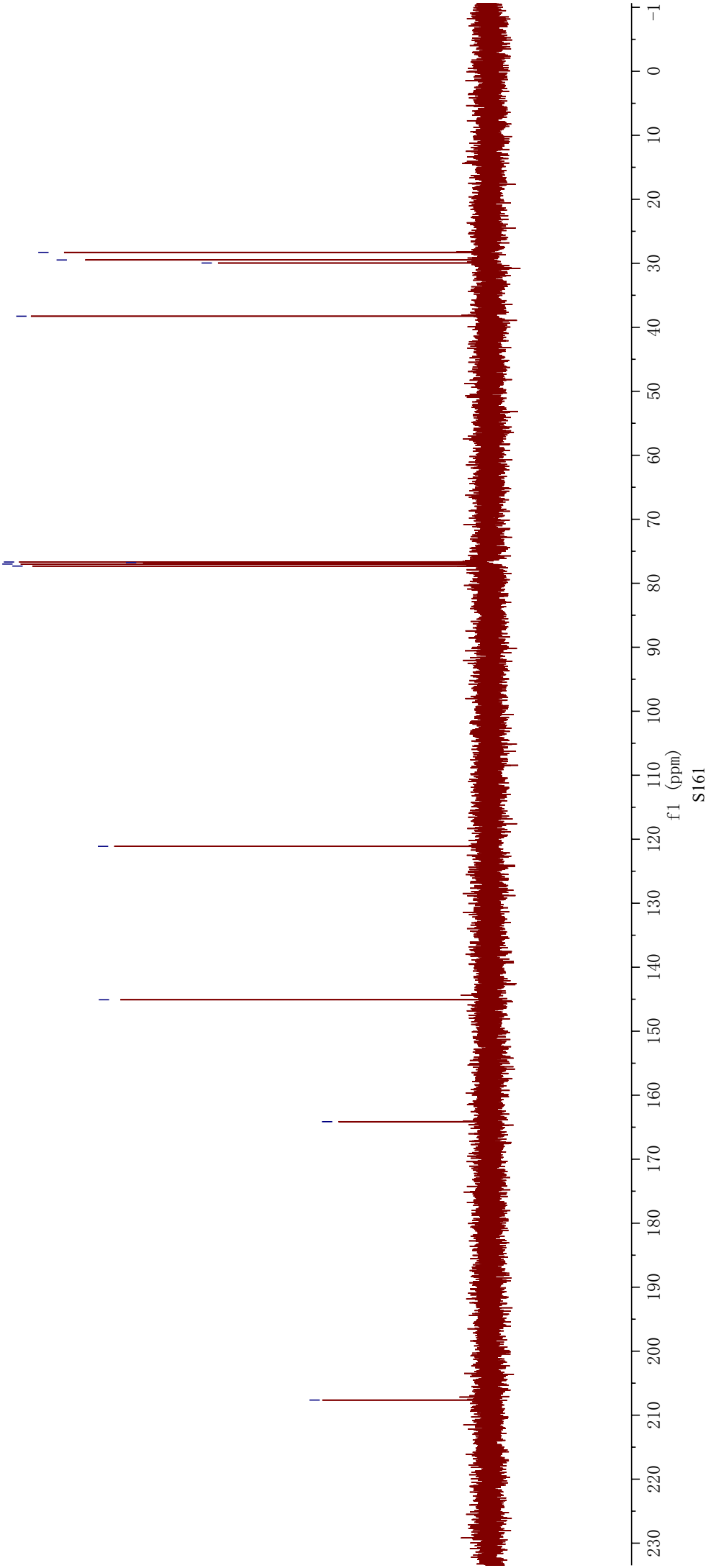
76.68
76.76
77.00
77.32

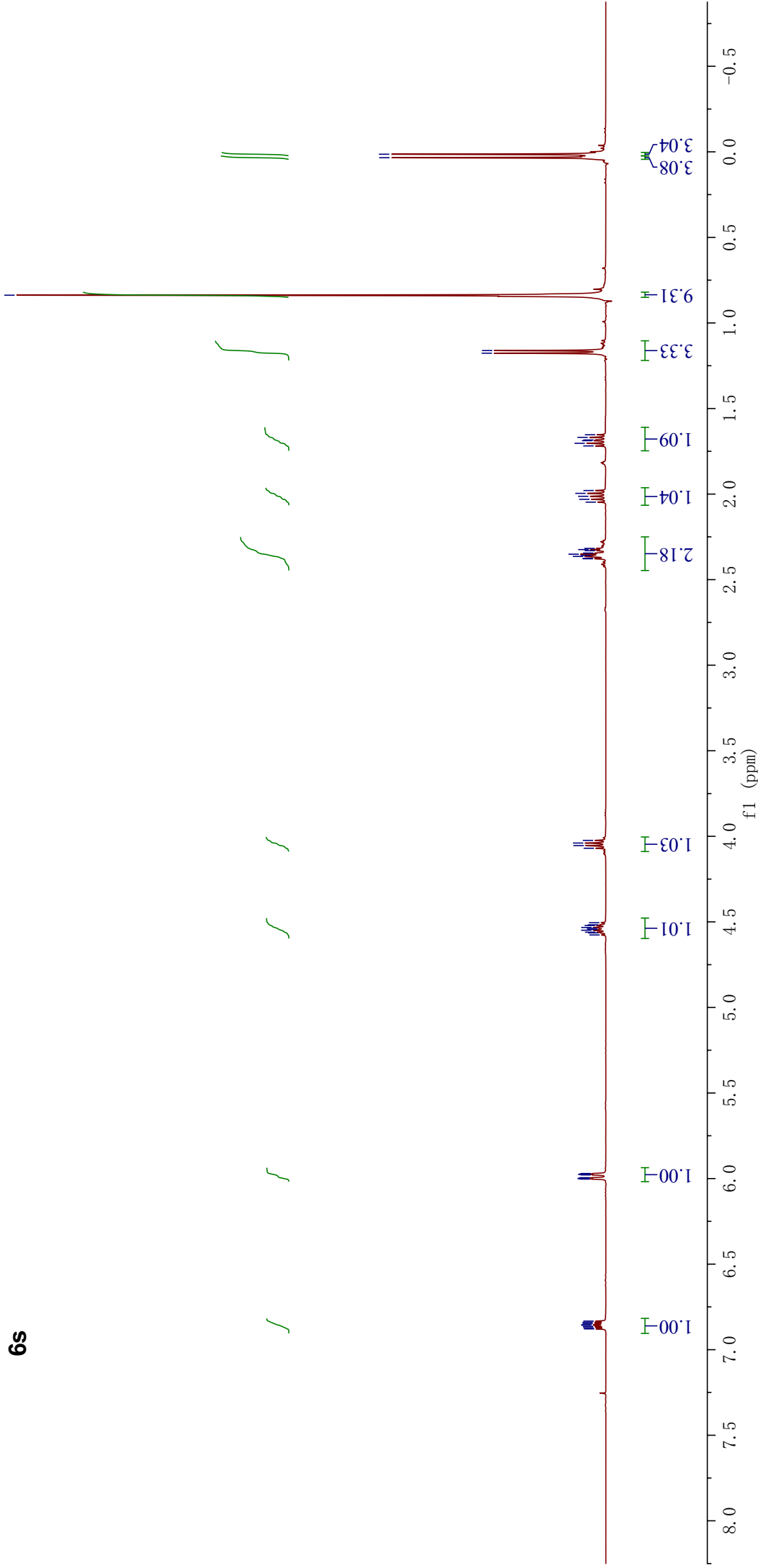
121.11

145.09

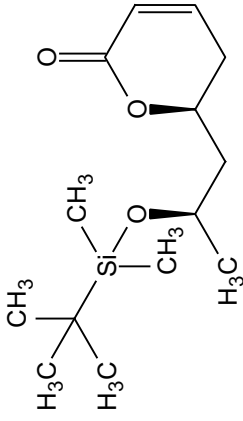
164.14

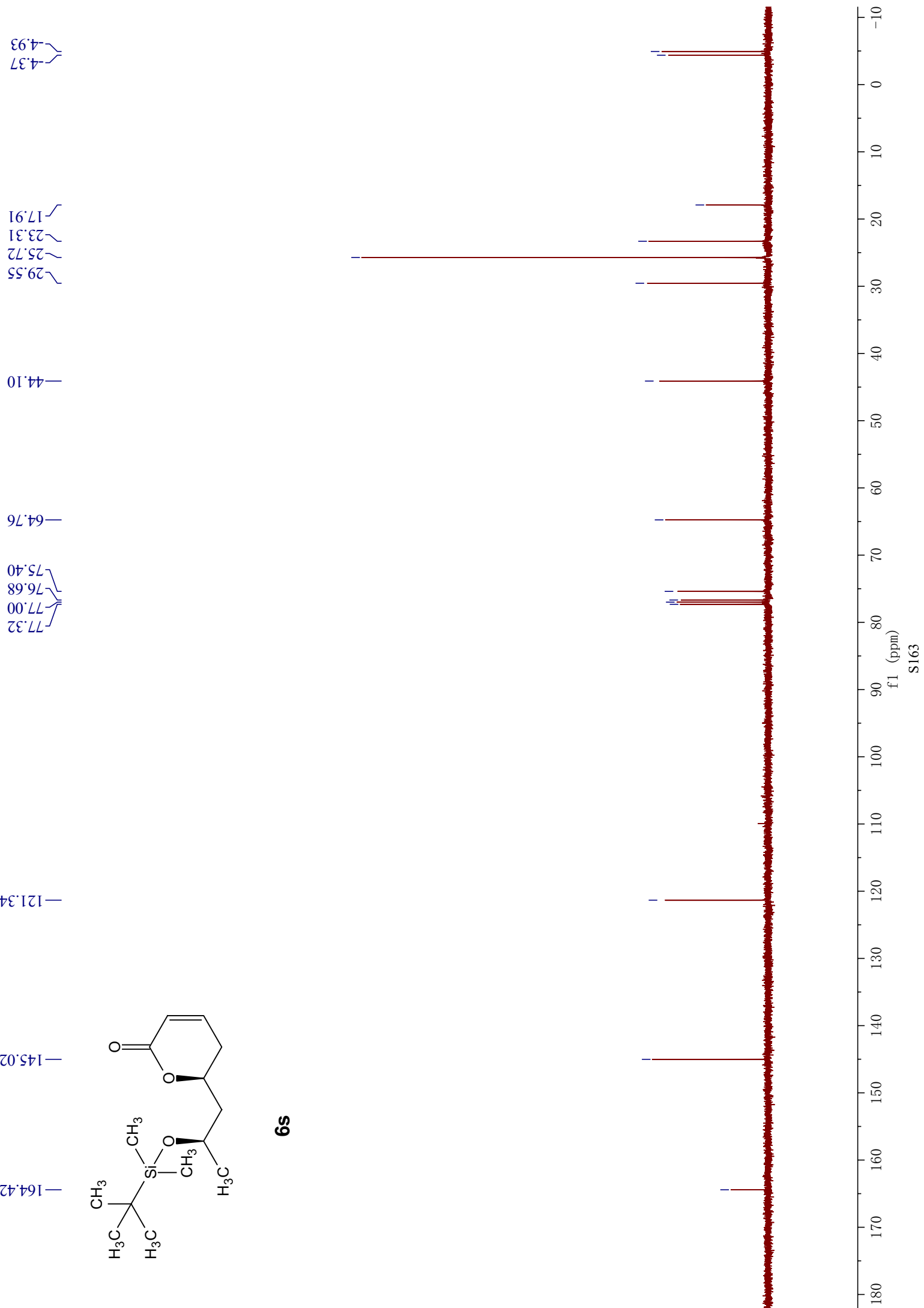
207.64

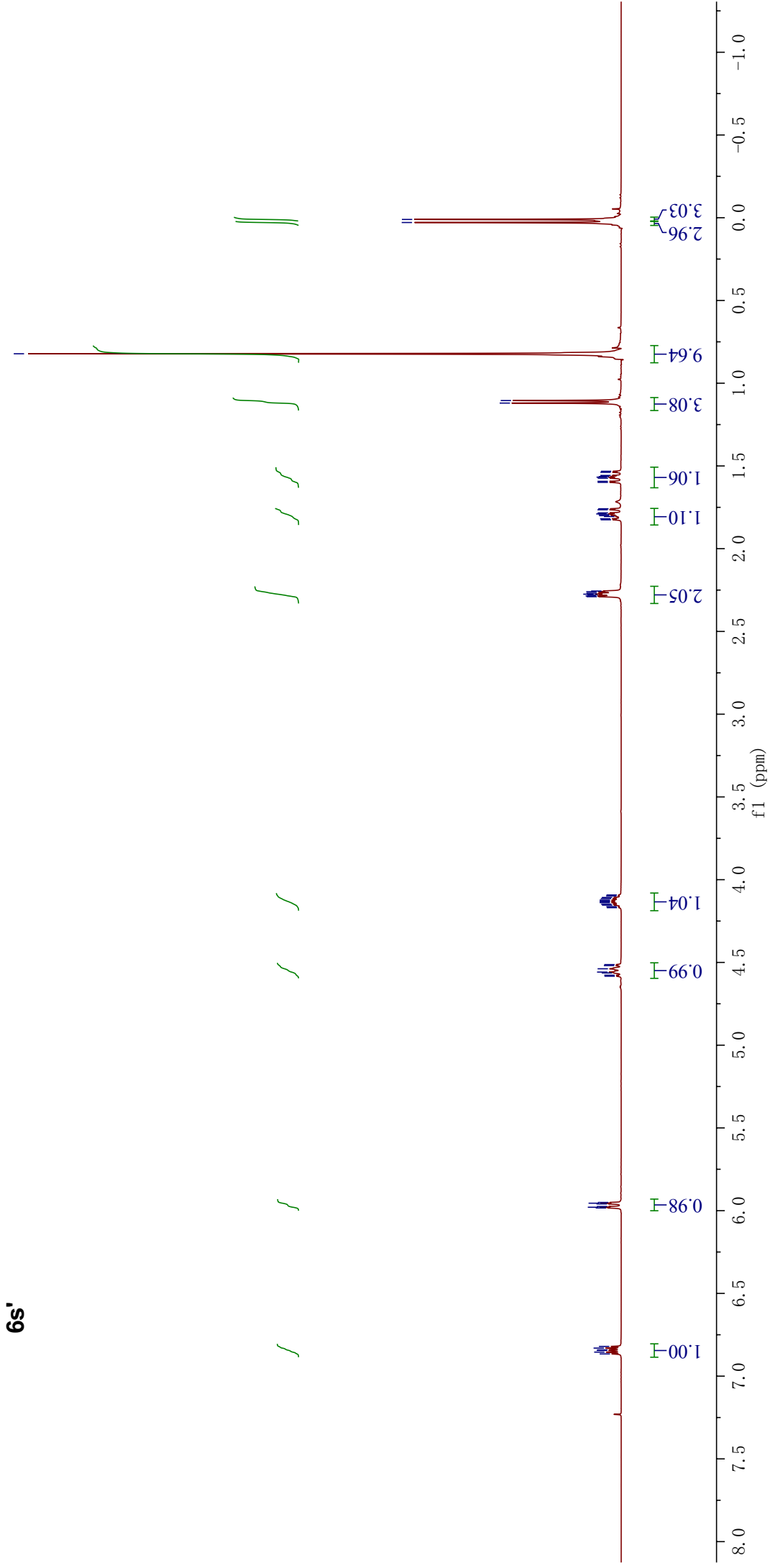




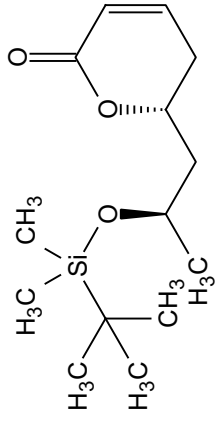
6s







6s'

0.03
0.01

-0.82

1.10

1.12

1.59

1.60

1.76

1.79

2.26

2.26

2.27

2.27

2.28

2.29

2.29

4.10

4.11

4.11

4.12

4.13

4.13

4.14

4.15

4.15

4.51

4.52

4.54

4.56

4.56

4.58

4.58

5.95

5.95

5.96

5.97

5.98

6.82

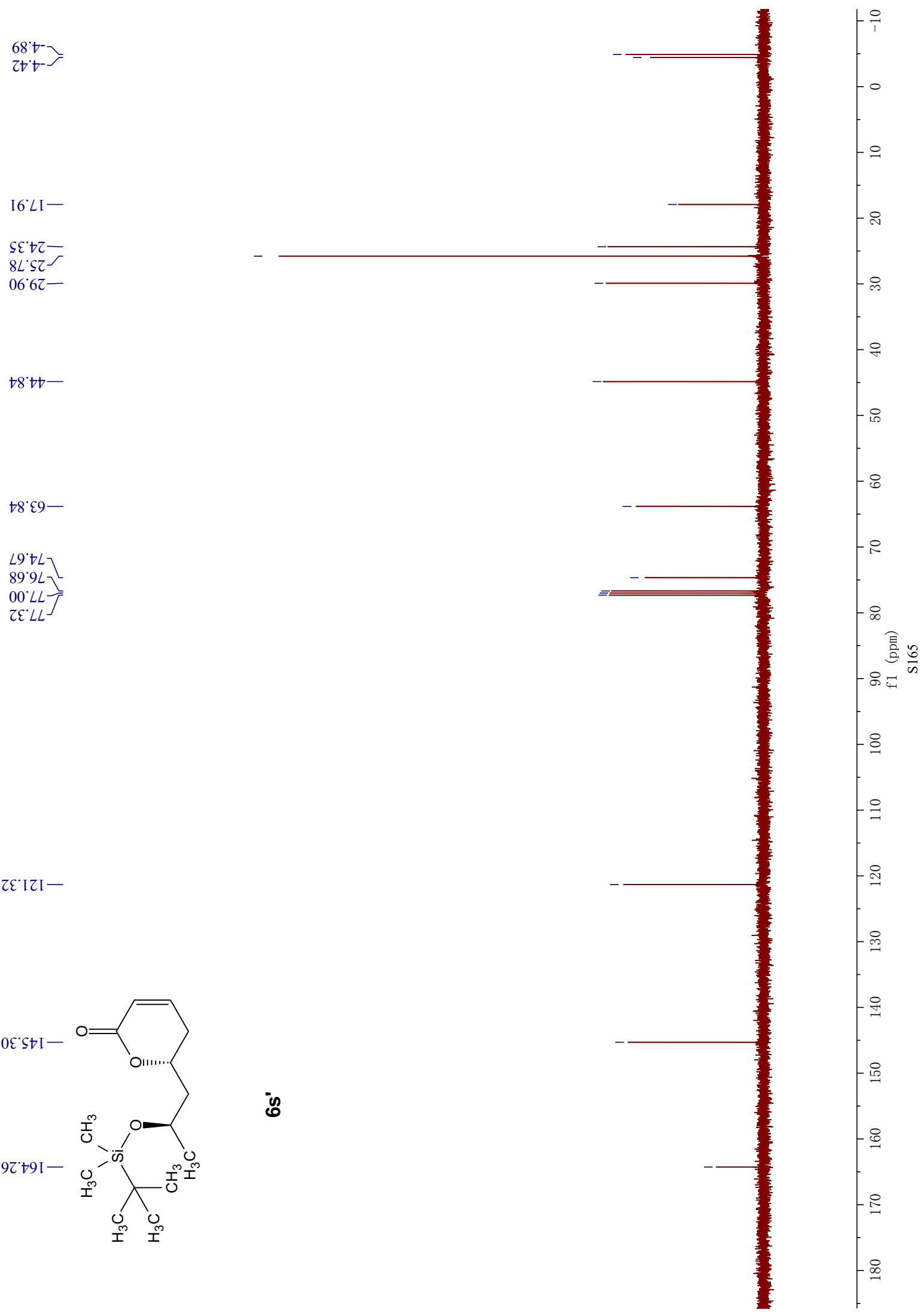
6.83

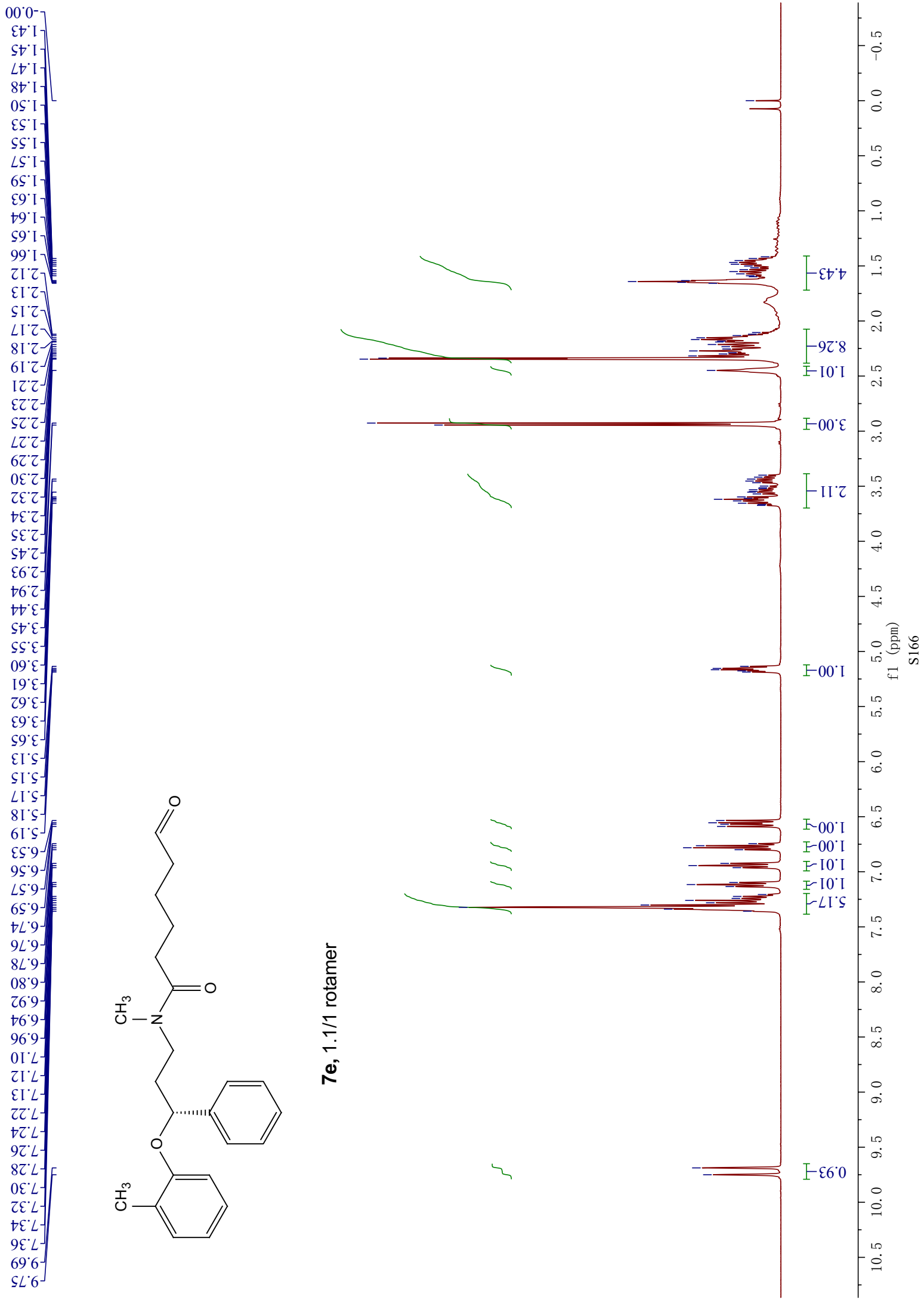
6.84

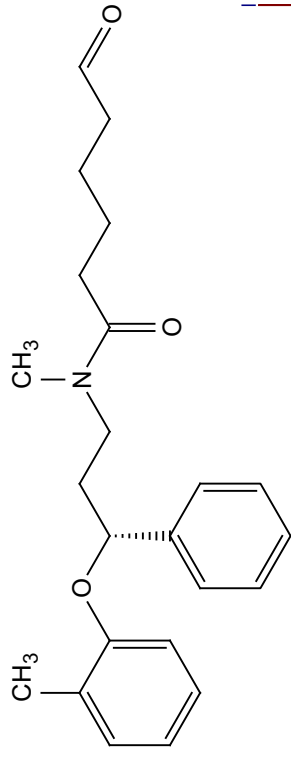
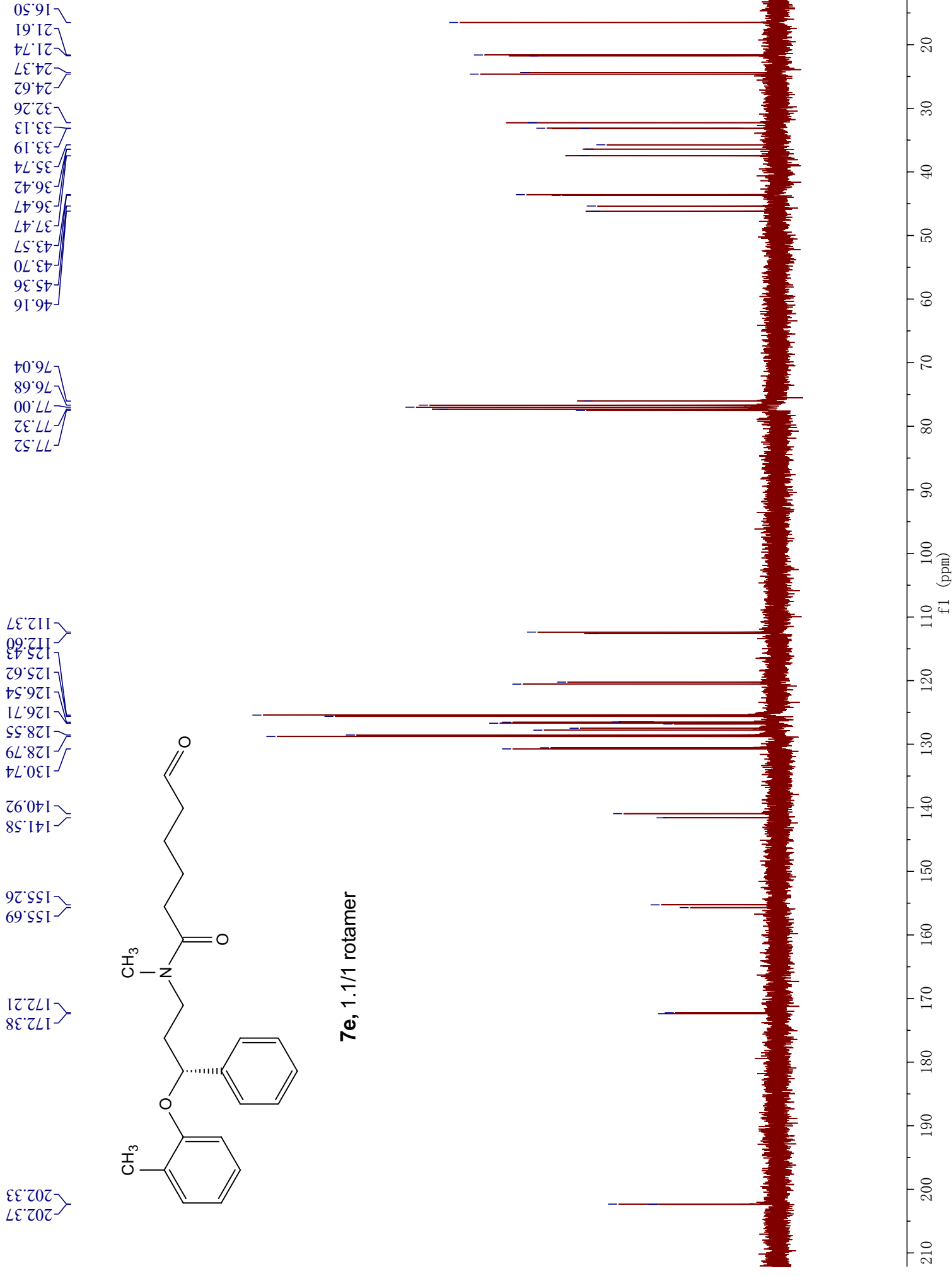
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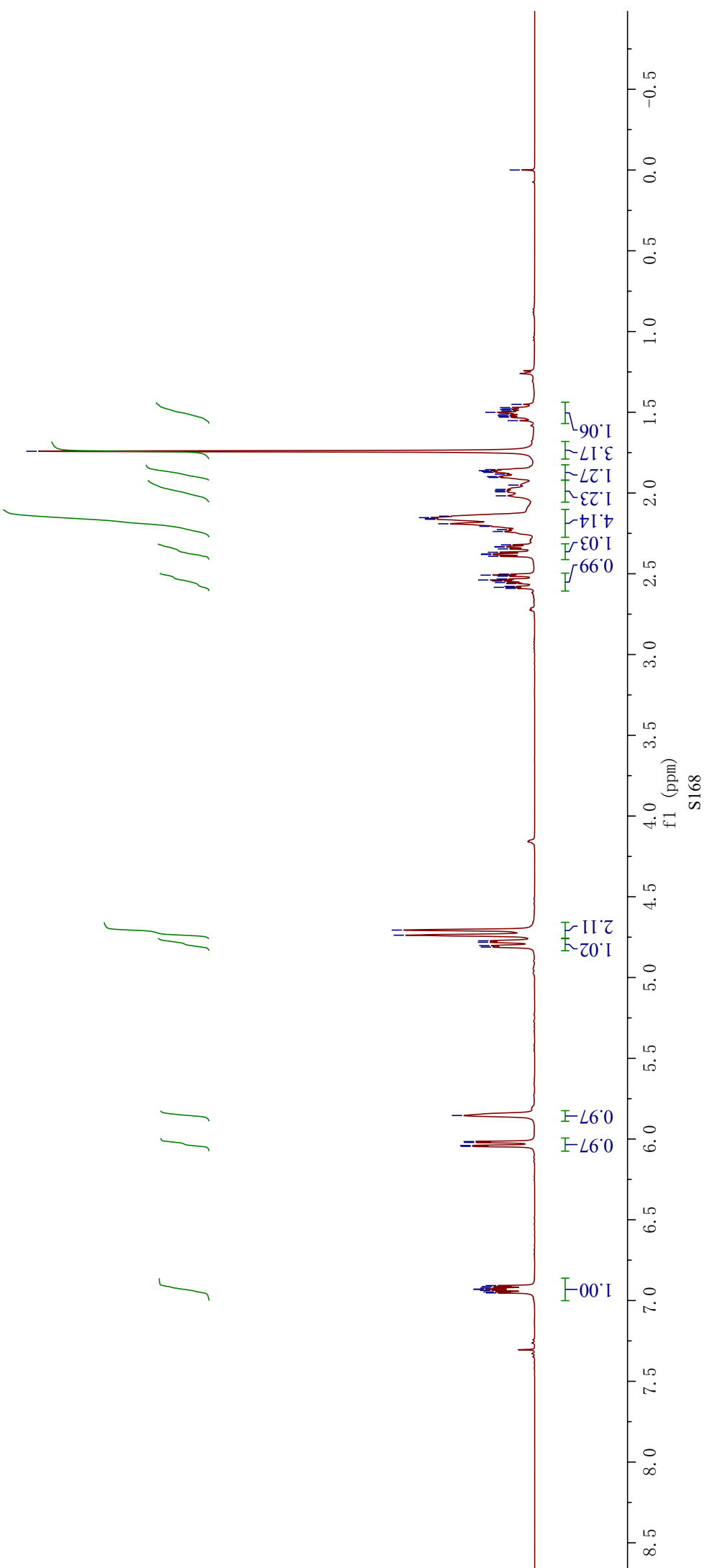
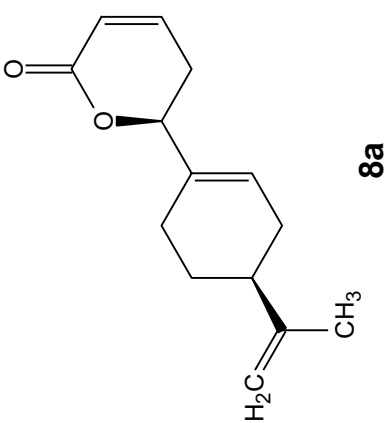
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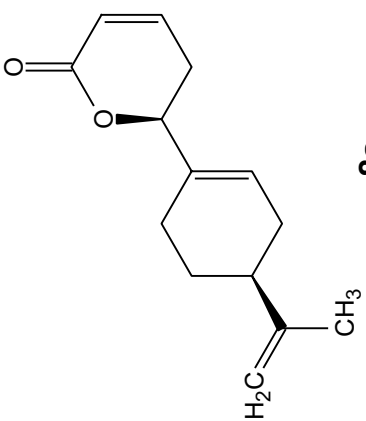
6.87





**7e**, 1.1/1 rotamer





20.66
24.34
26.95
28.03
30.10

40.44

76.68
77.00
77.32
80.94

108.73

121.14

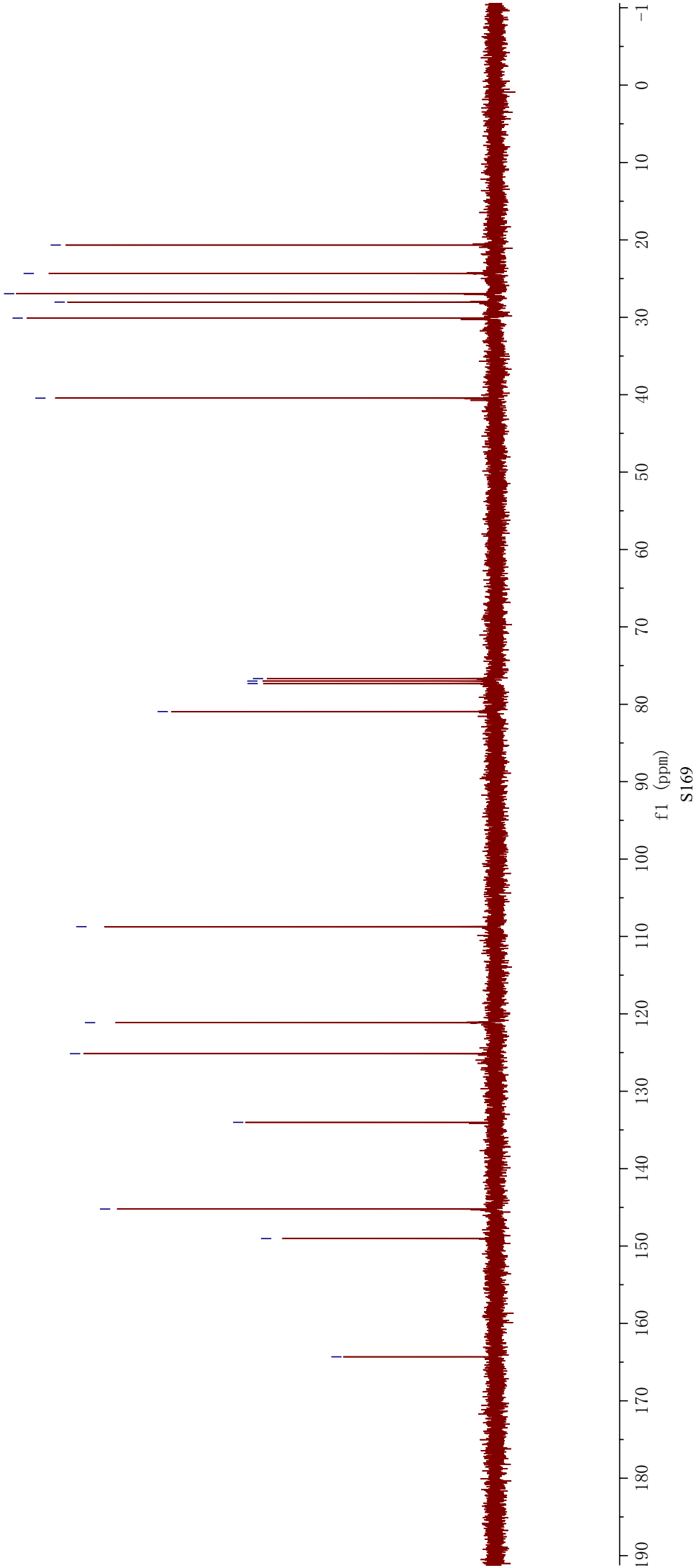
125.15

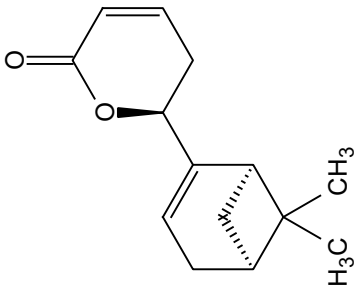
134.01

145.22

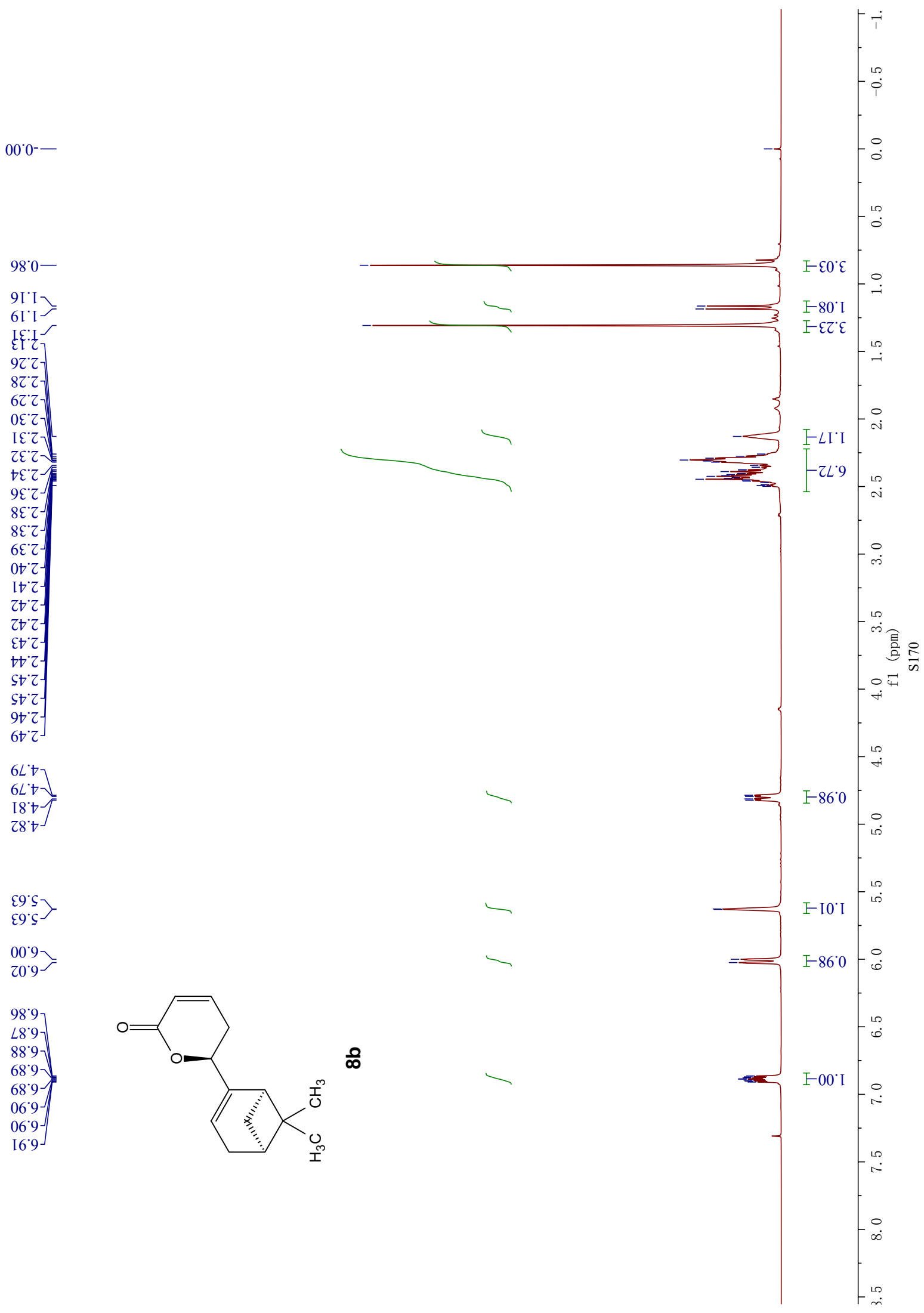
149.04

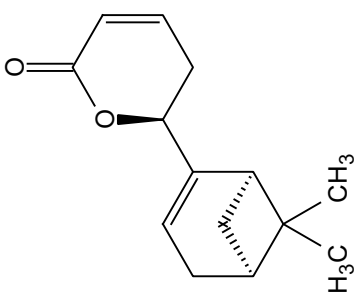
164.32





8b





8b

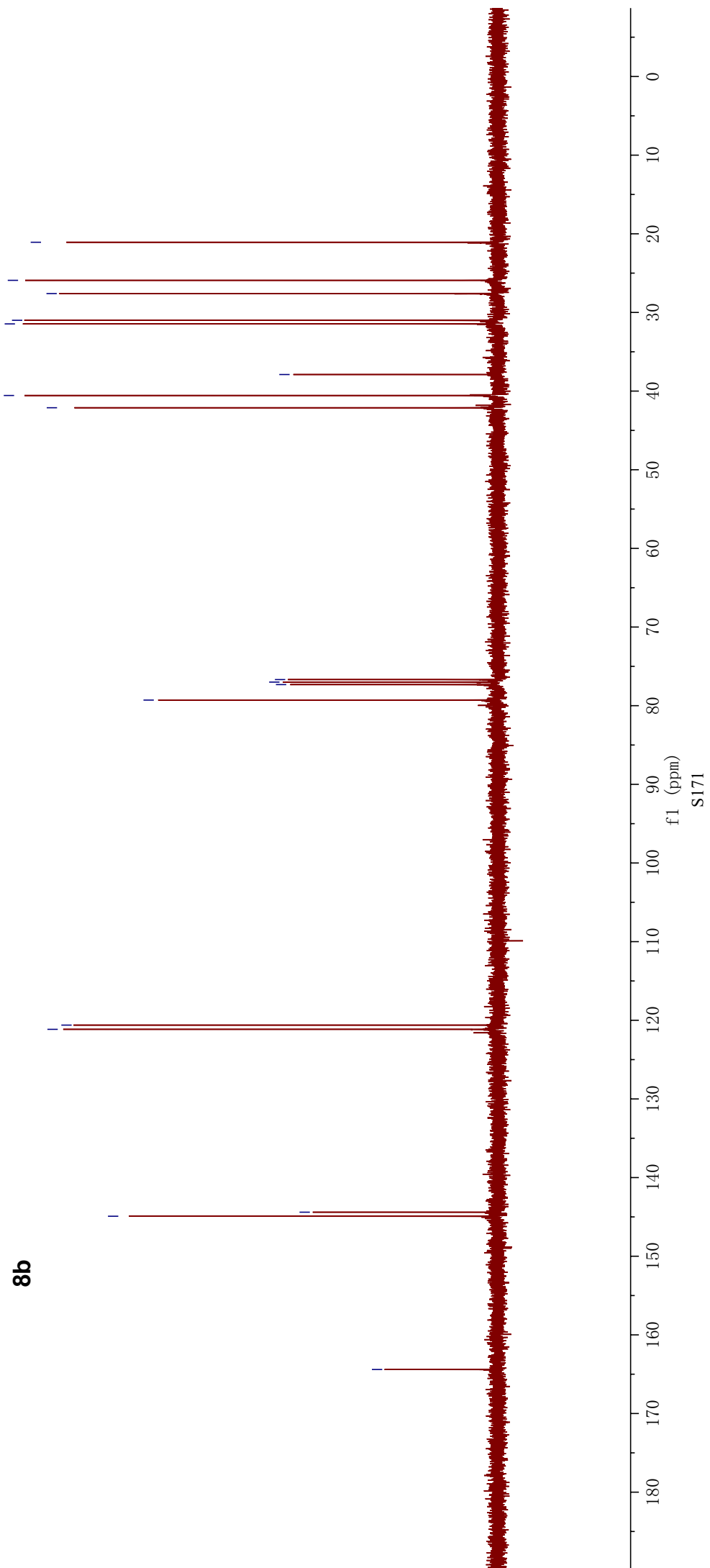
~21.07
~25.92
~27.60
~31.00
~31.45
~37.89
~40.56
~42.12

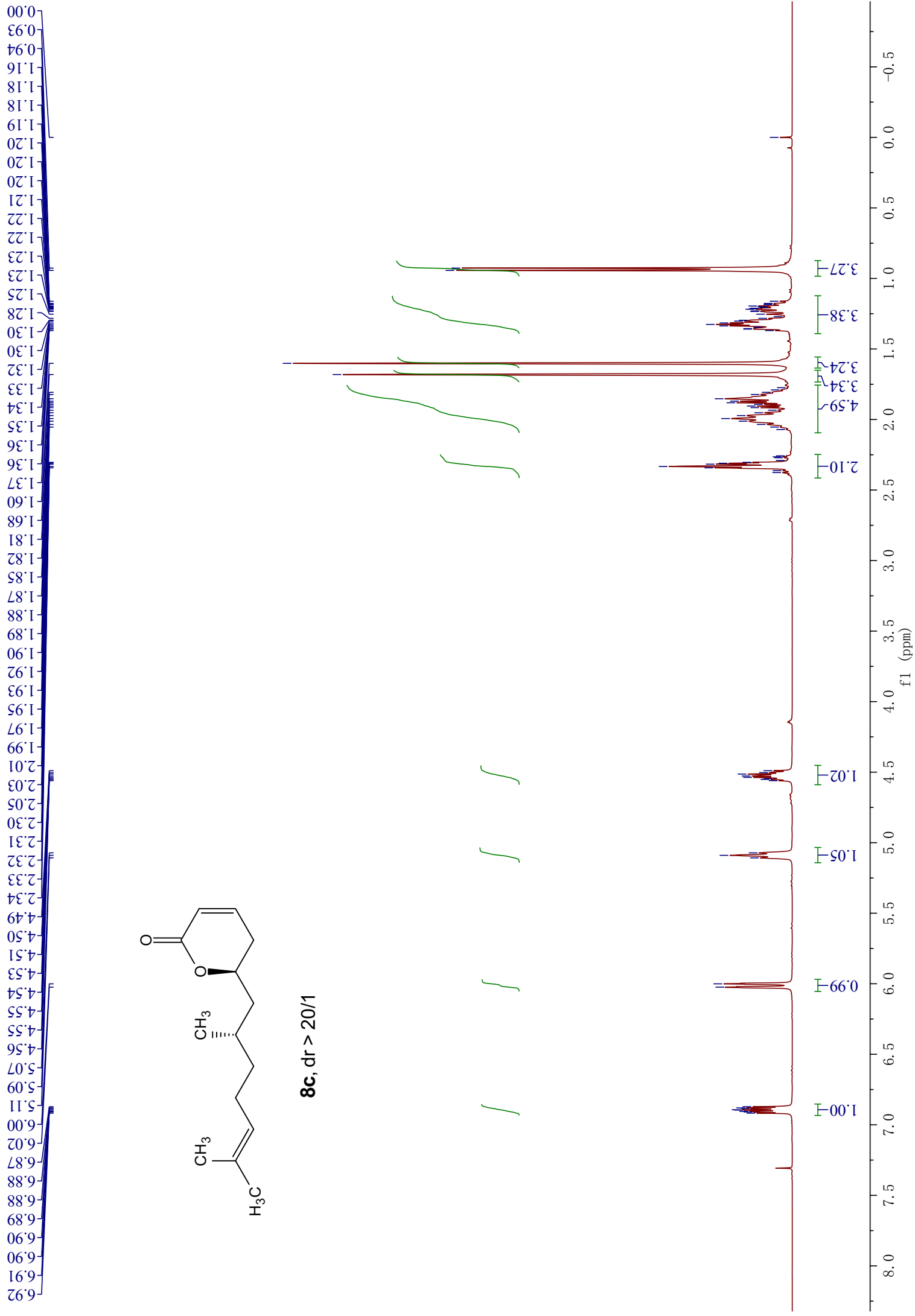
~76.68
~77.00
~77.32
~79.29

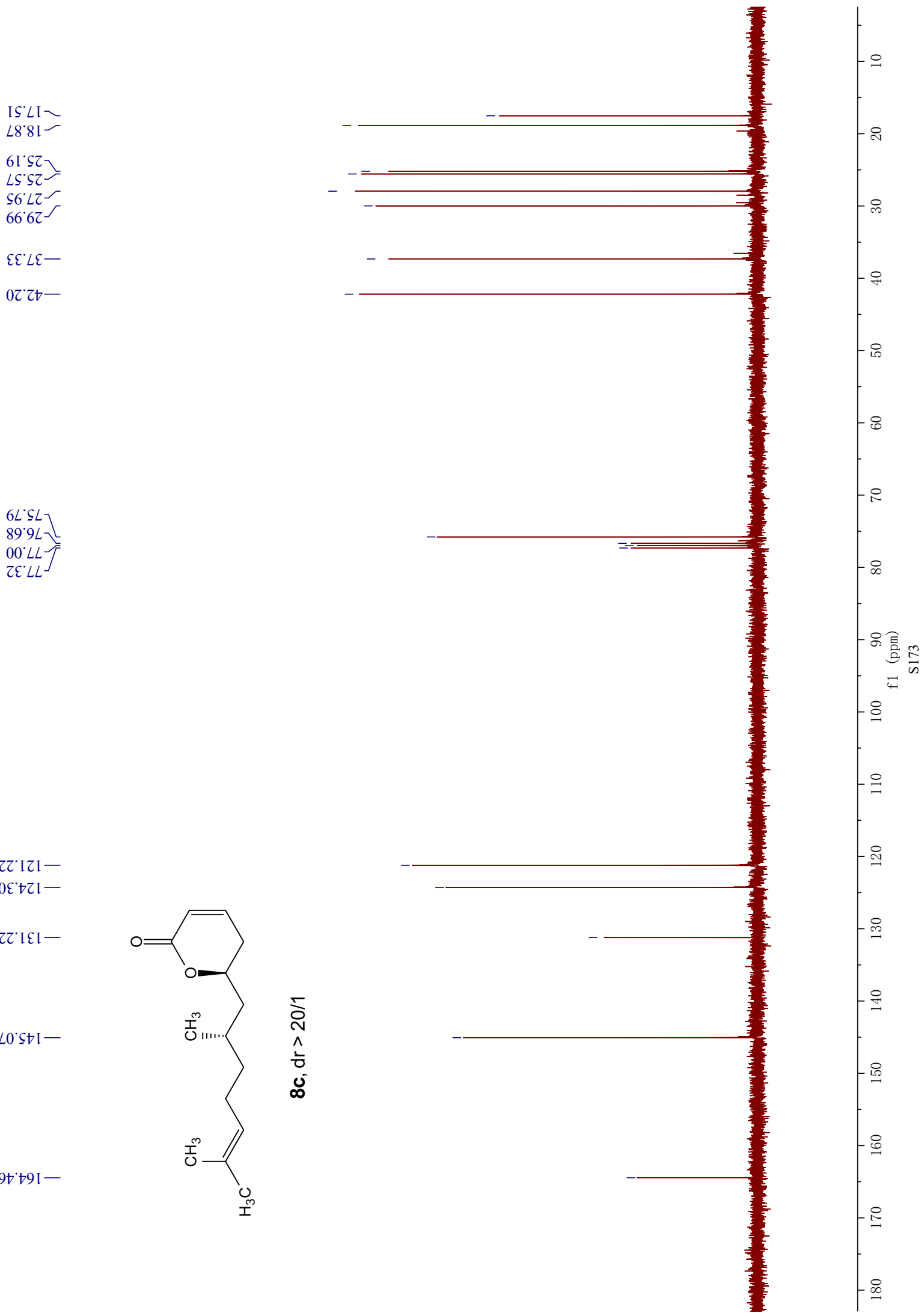
~120.61
~121.15

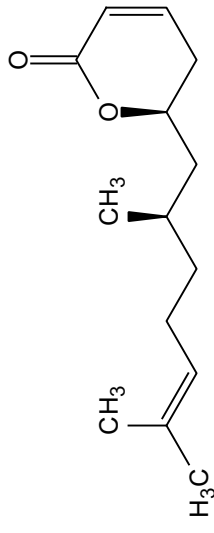
~144.40
~144.91

~164.40

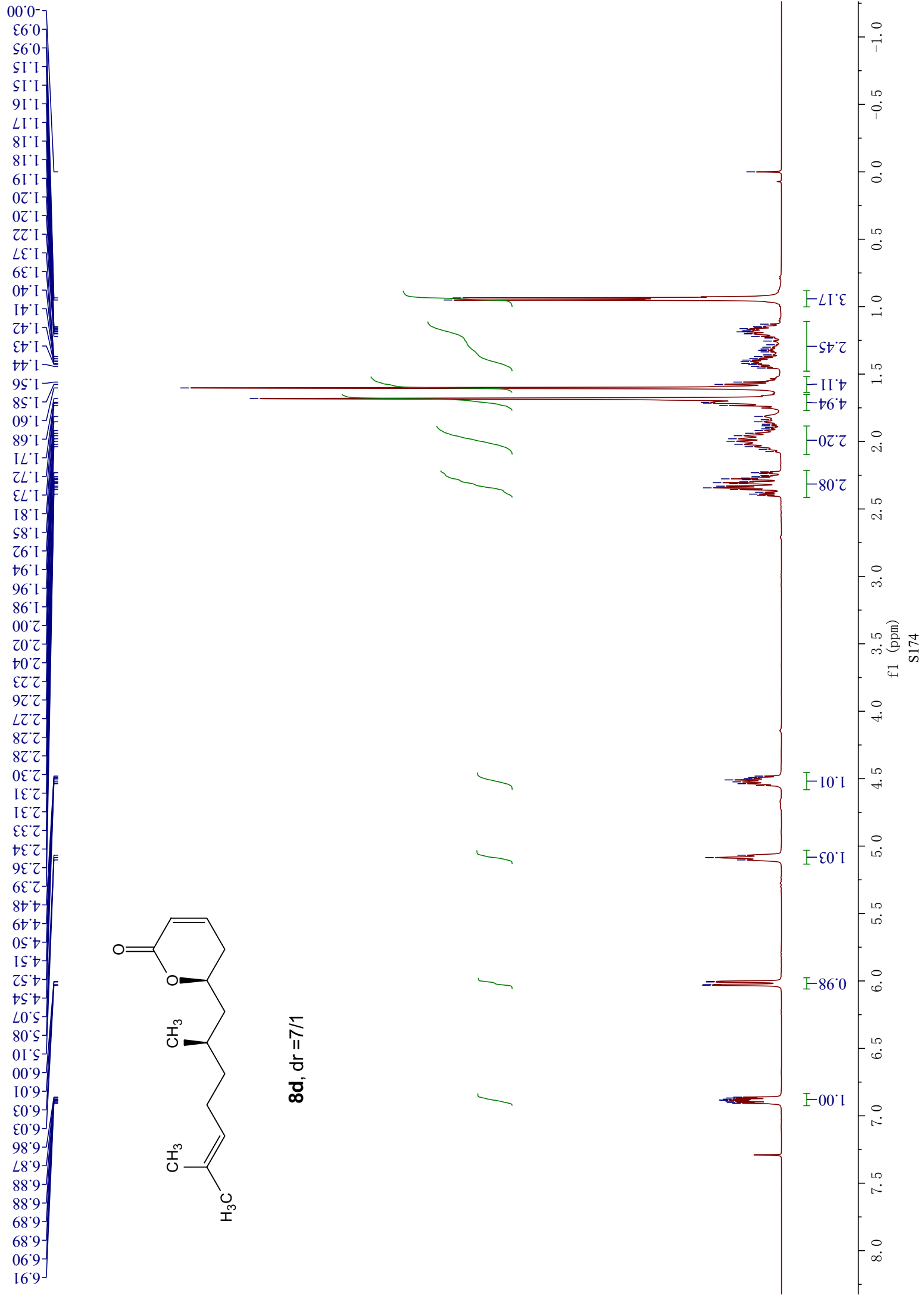




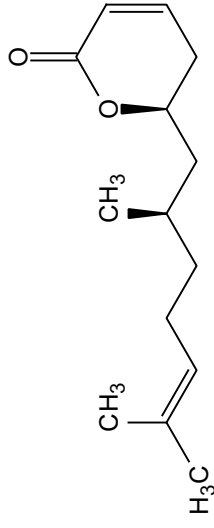




8d, dr = 7/1



8d, dr = 7/1

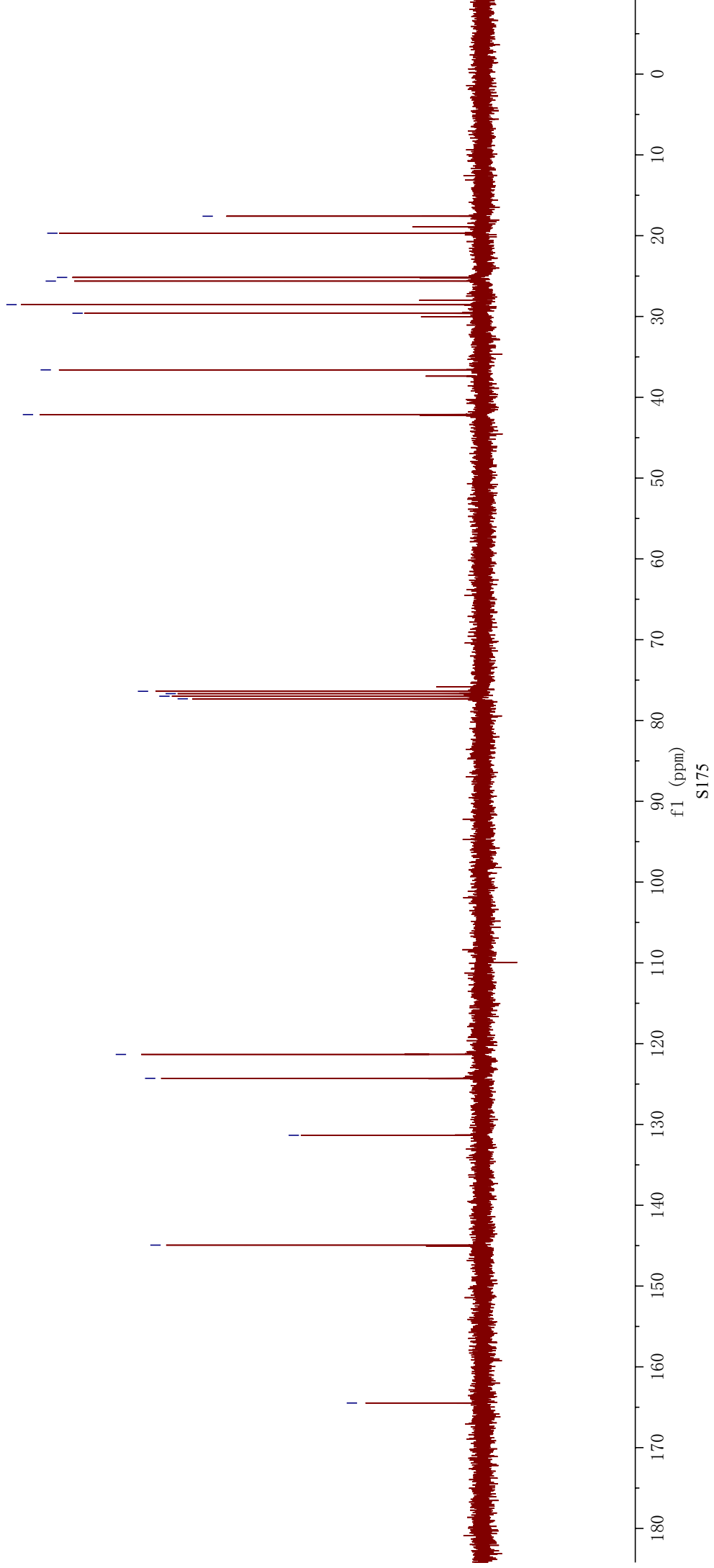


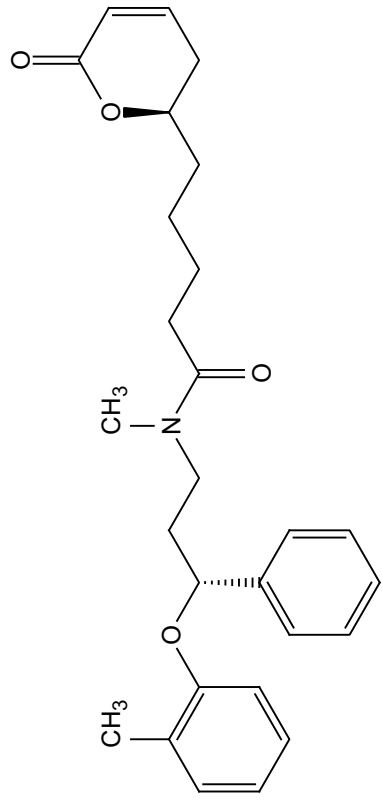
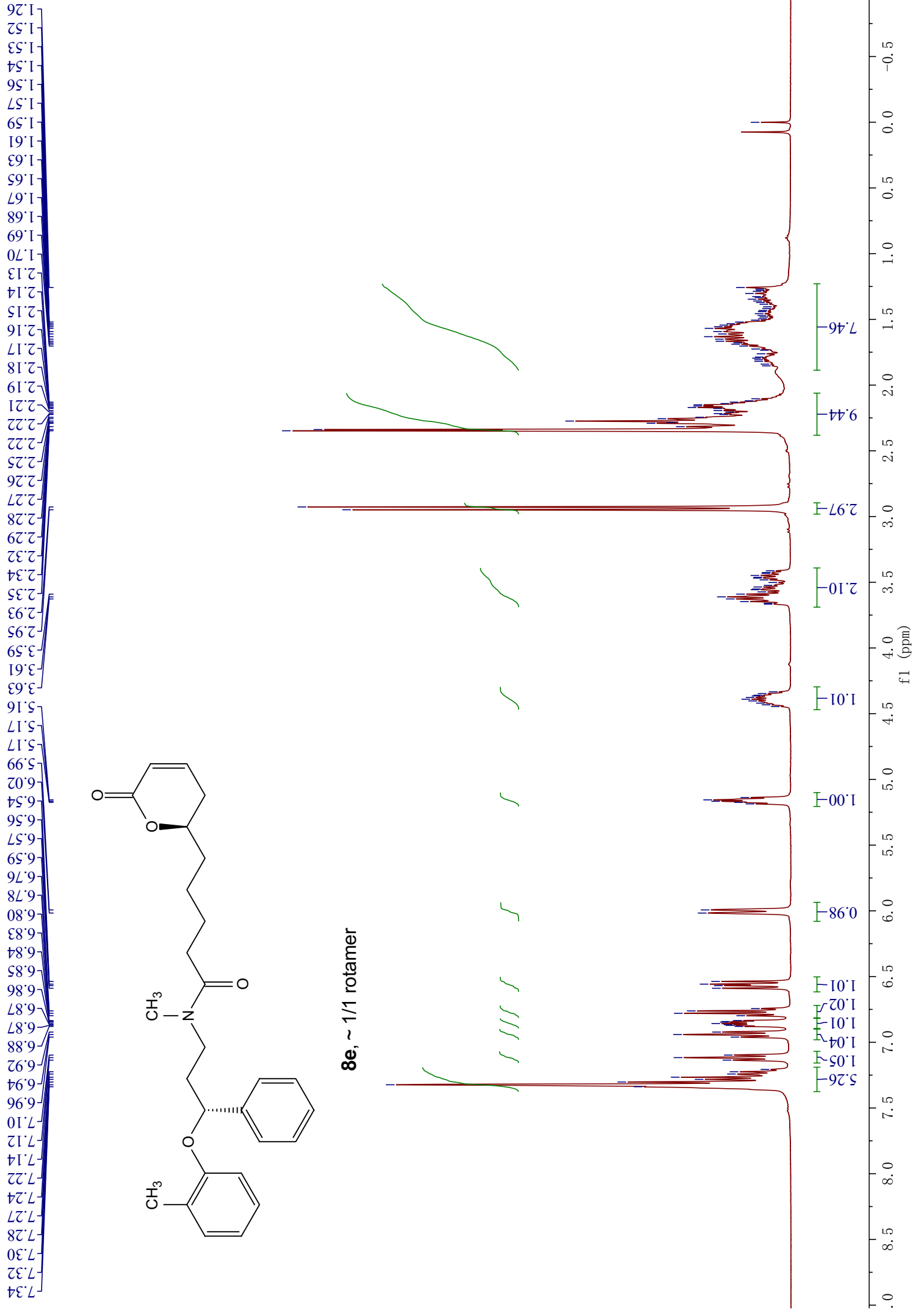
— 164.48
— 144.93
— 131.34
— 124.29
— 121.33

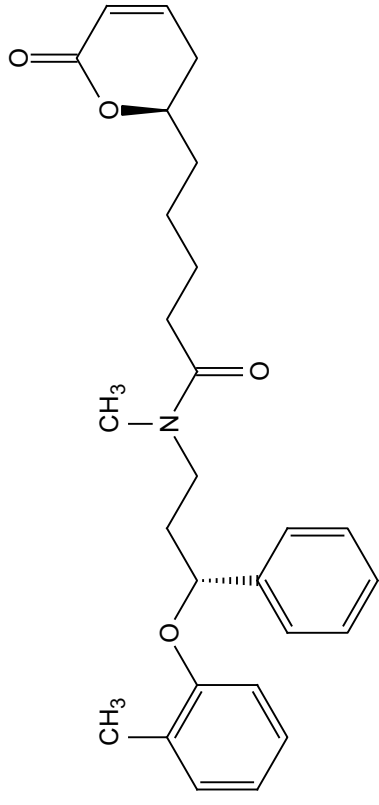
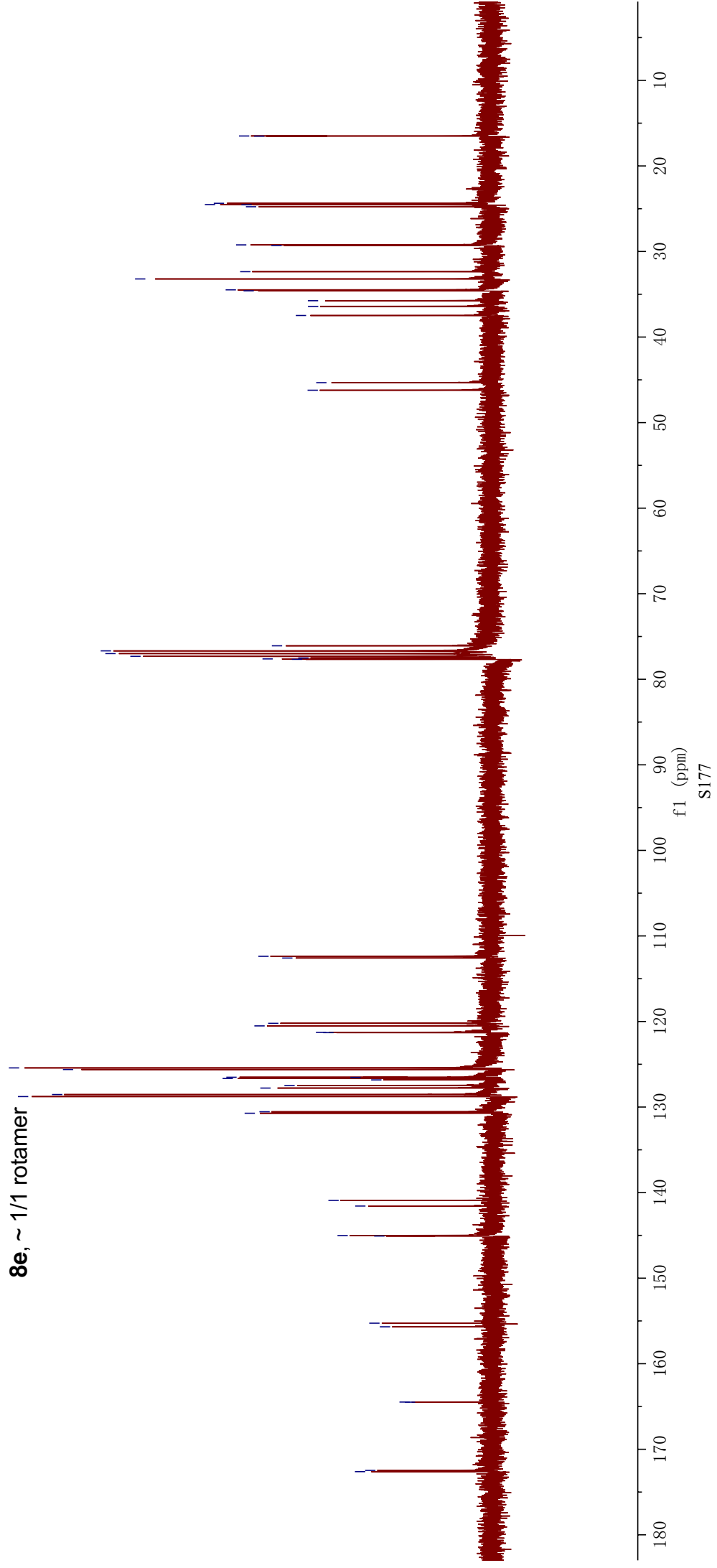
— 77.32
— 77.00
— 76.68
— 76.39

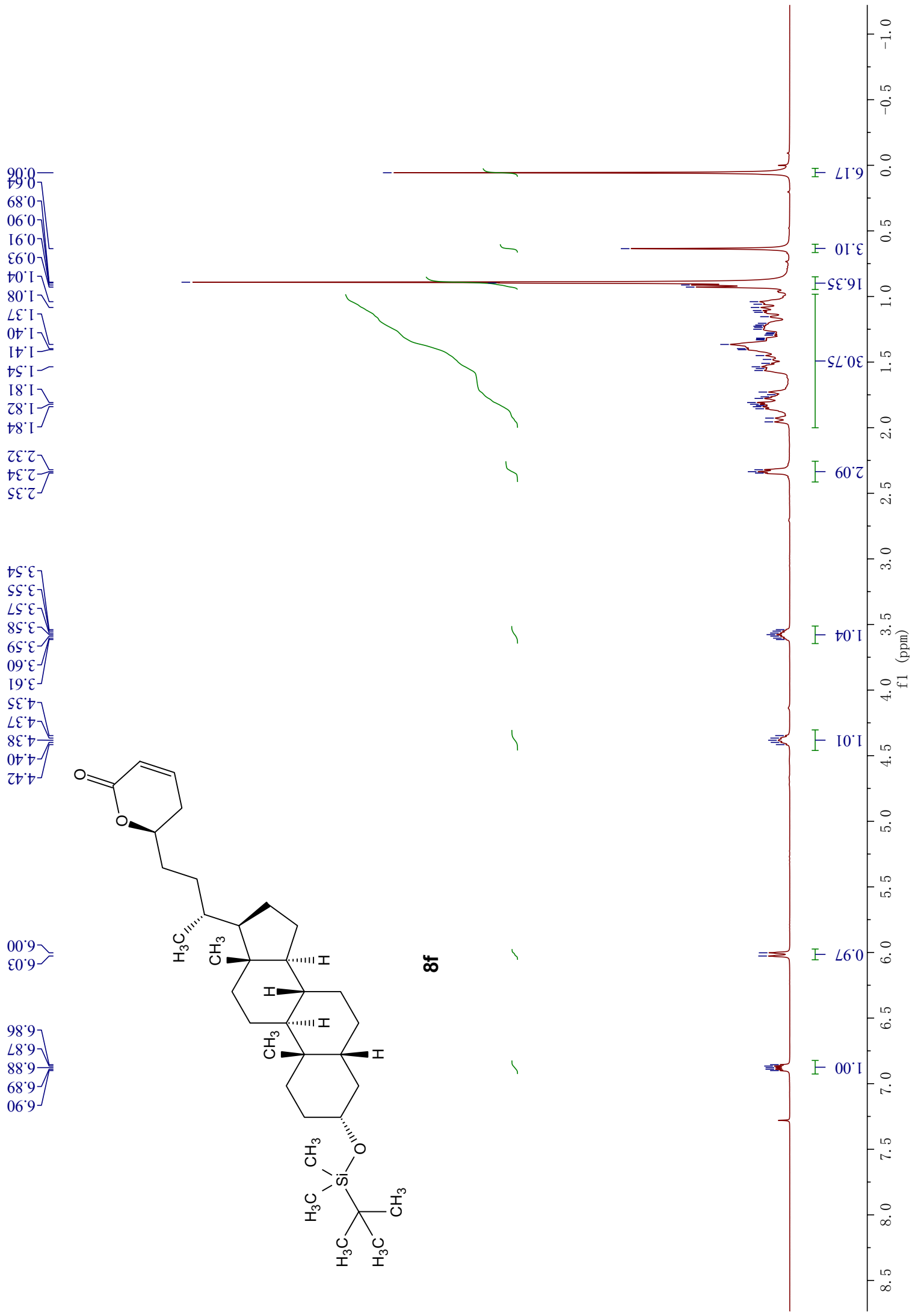
— 42.14
— 36.61

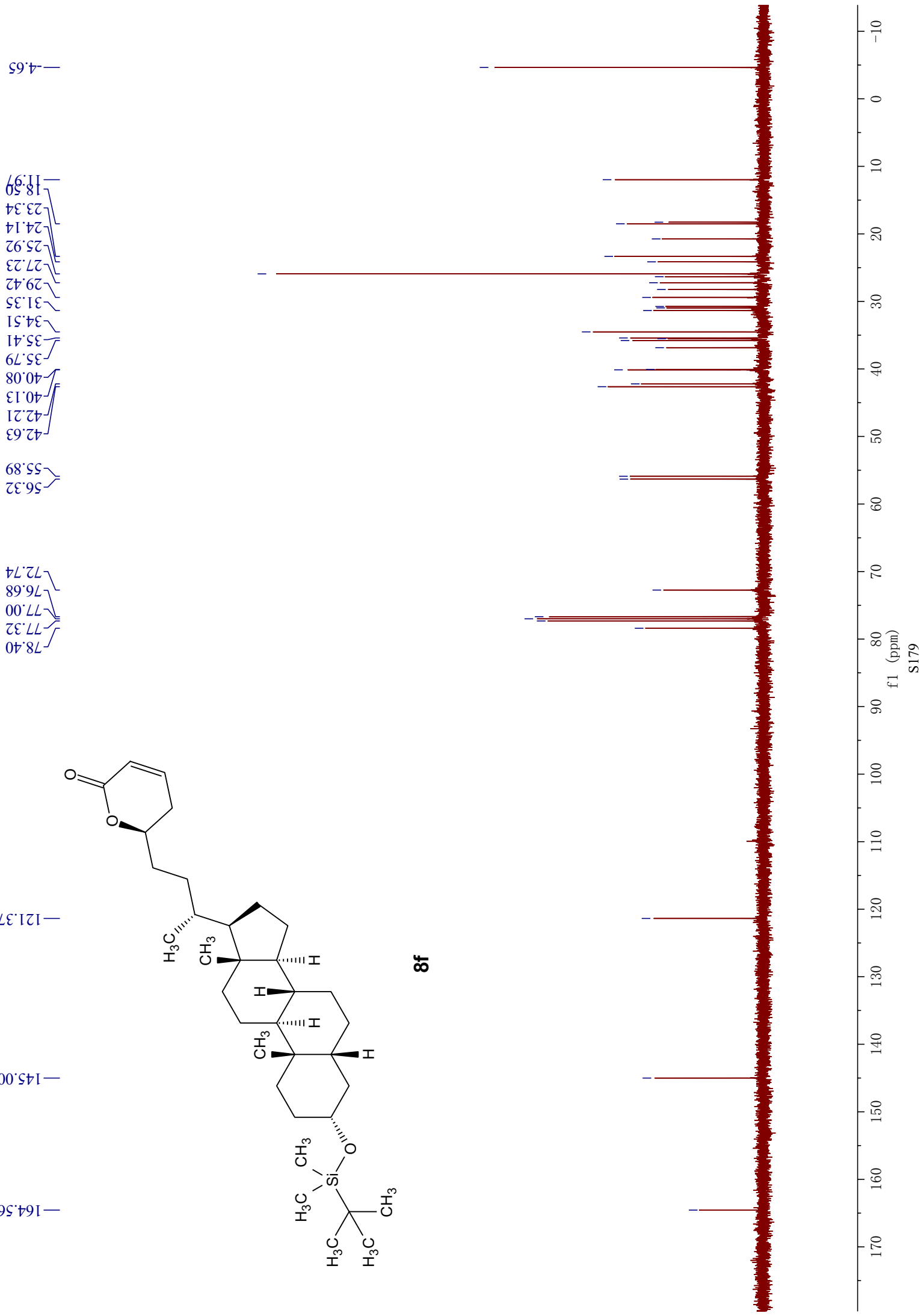
— 29.60
— 28.54
— 25.62
— 25.16
— 19.69
— 17.59

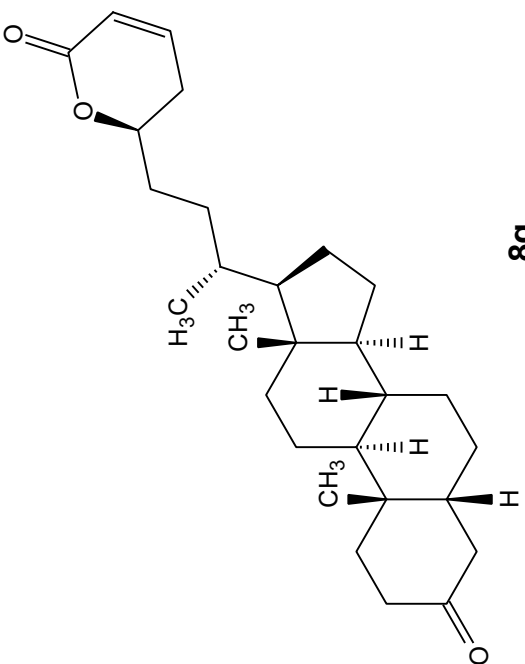


**8e, ~ 1/1 rotamer**

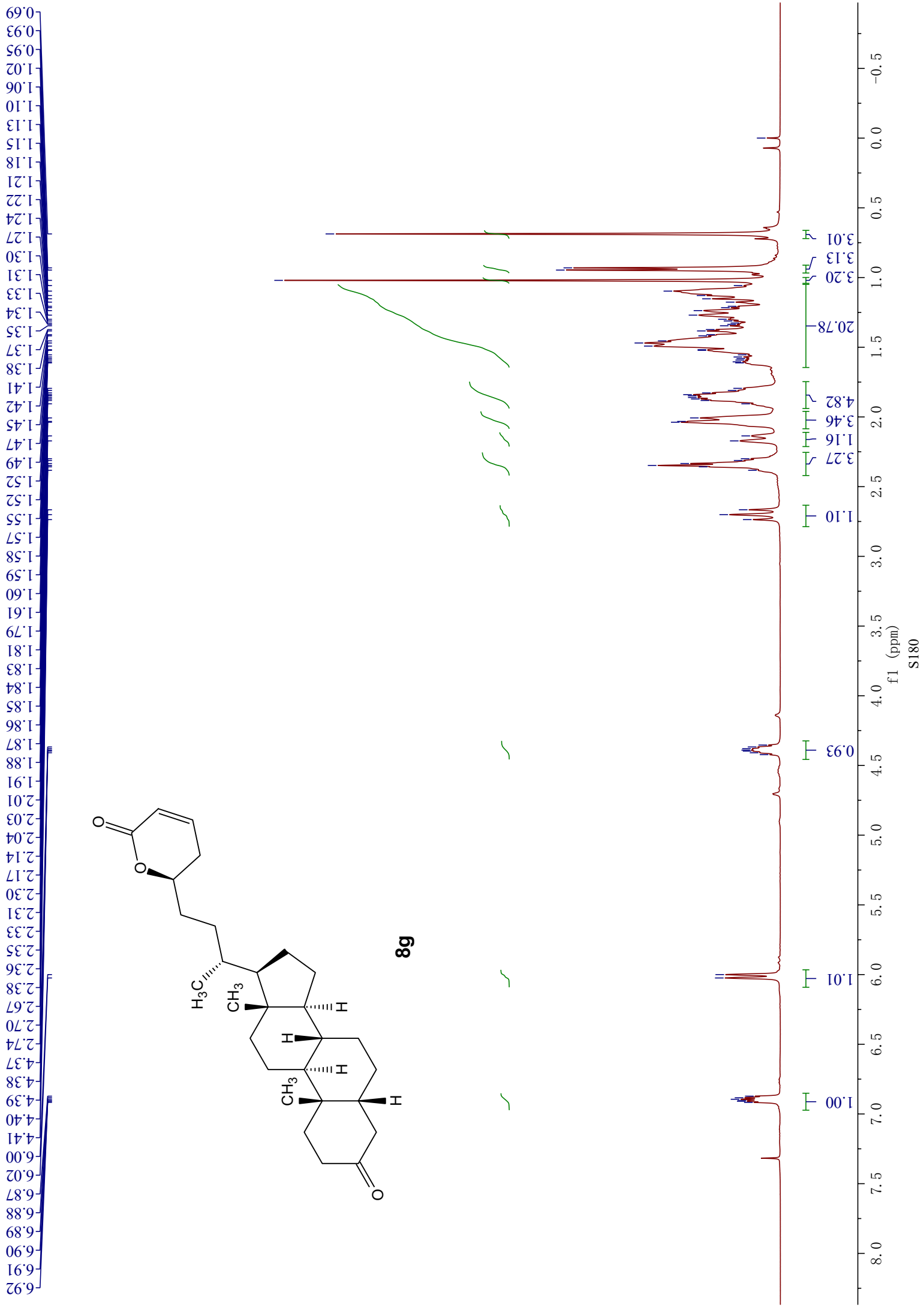




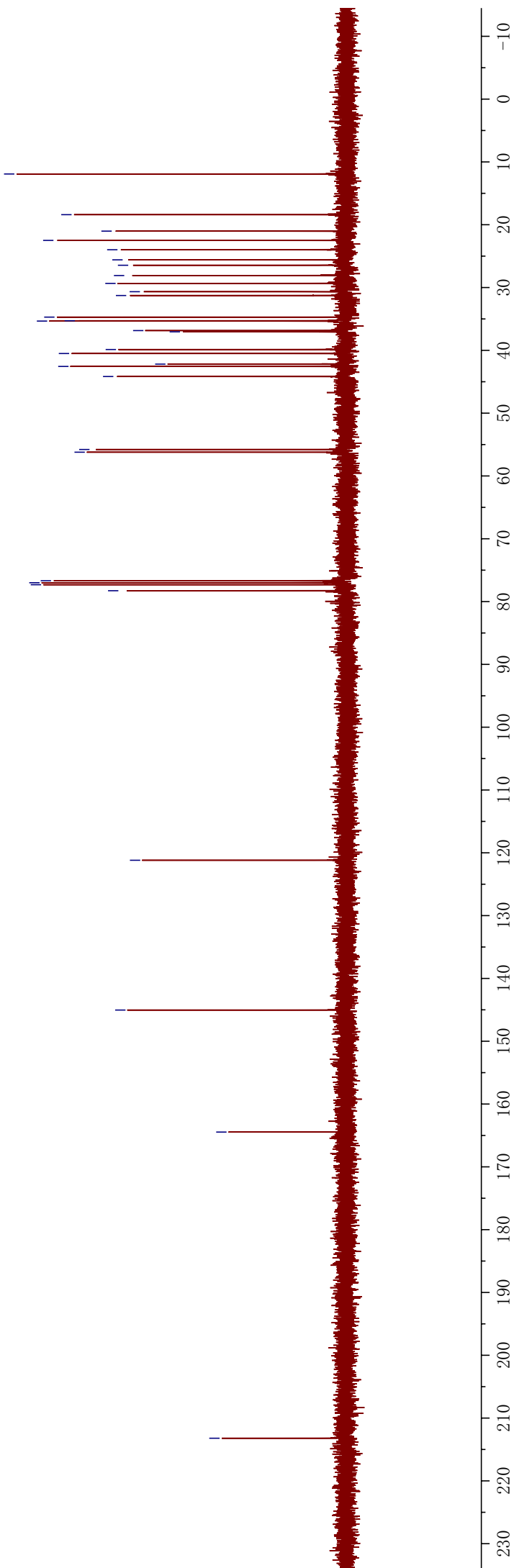




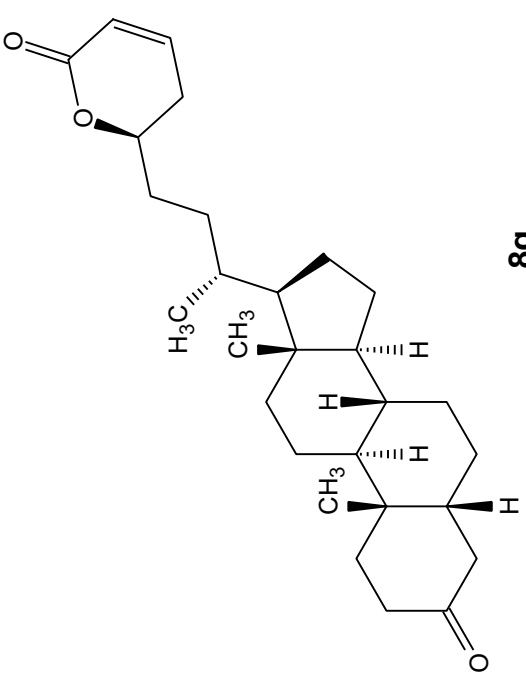
8g



f1 (ppm)



8g

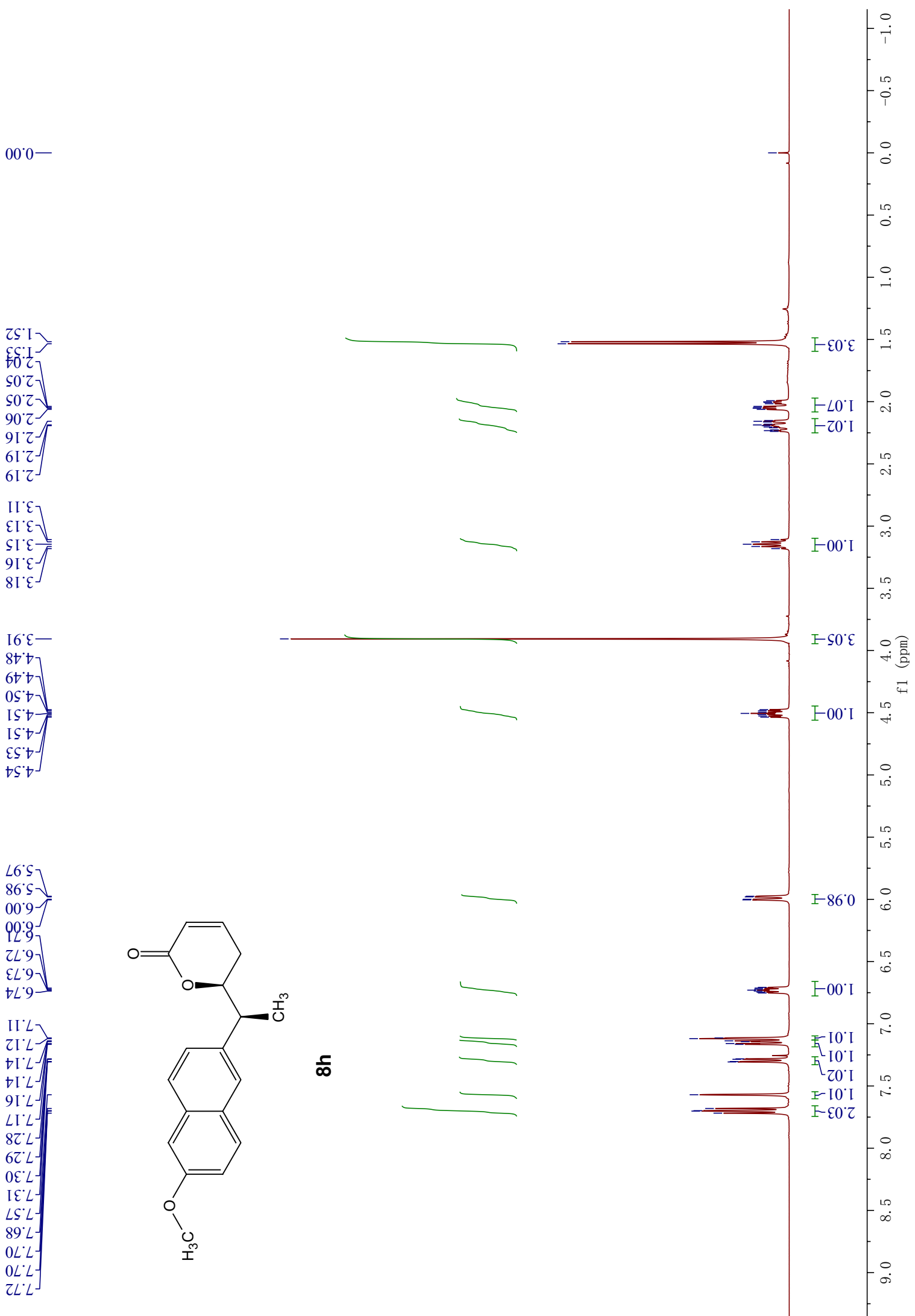


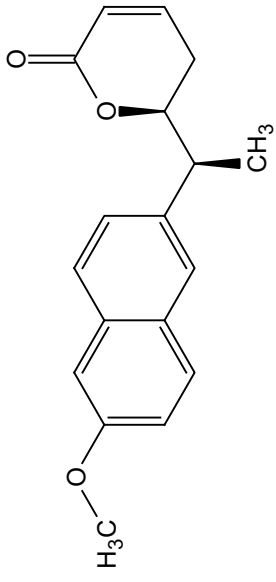
—121.19

—145.04

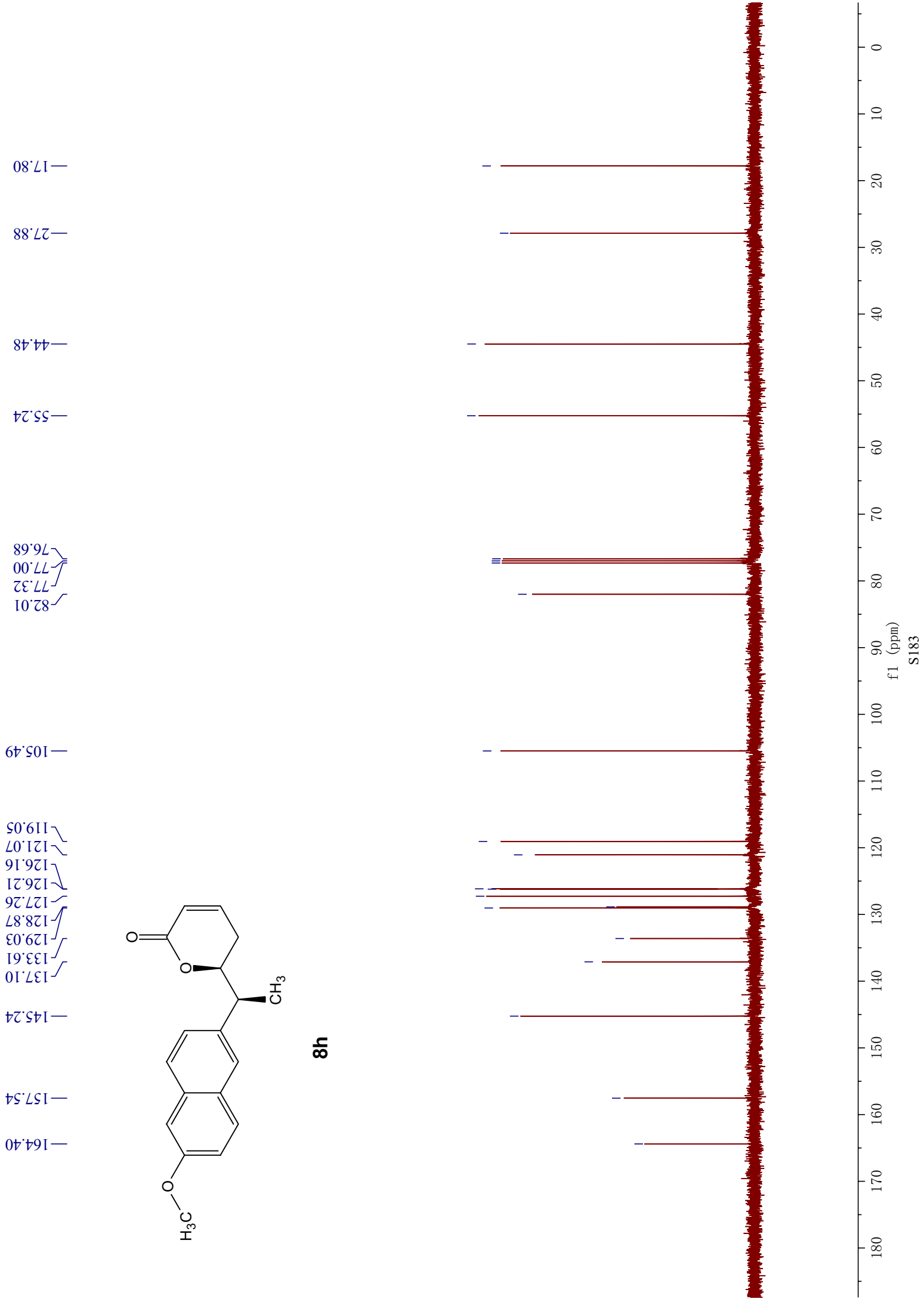
—164.46

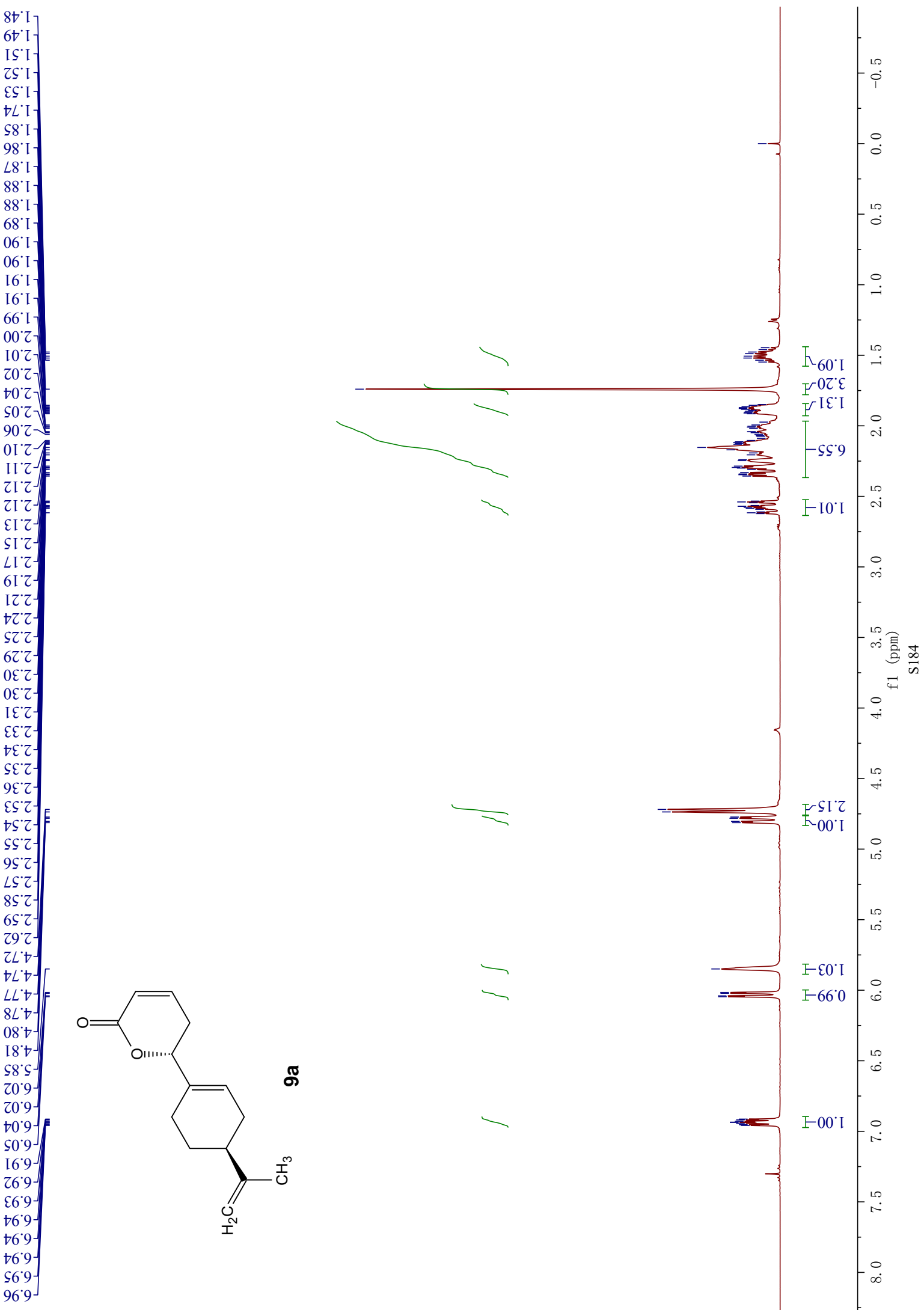
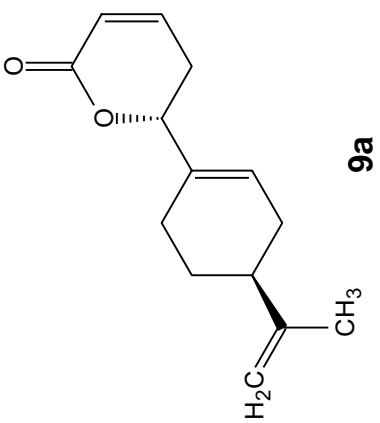
—213.21

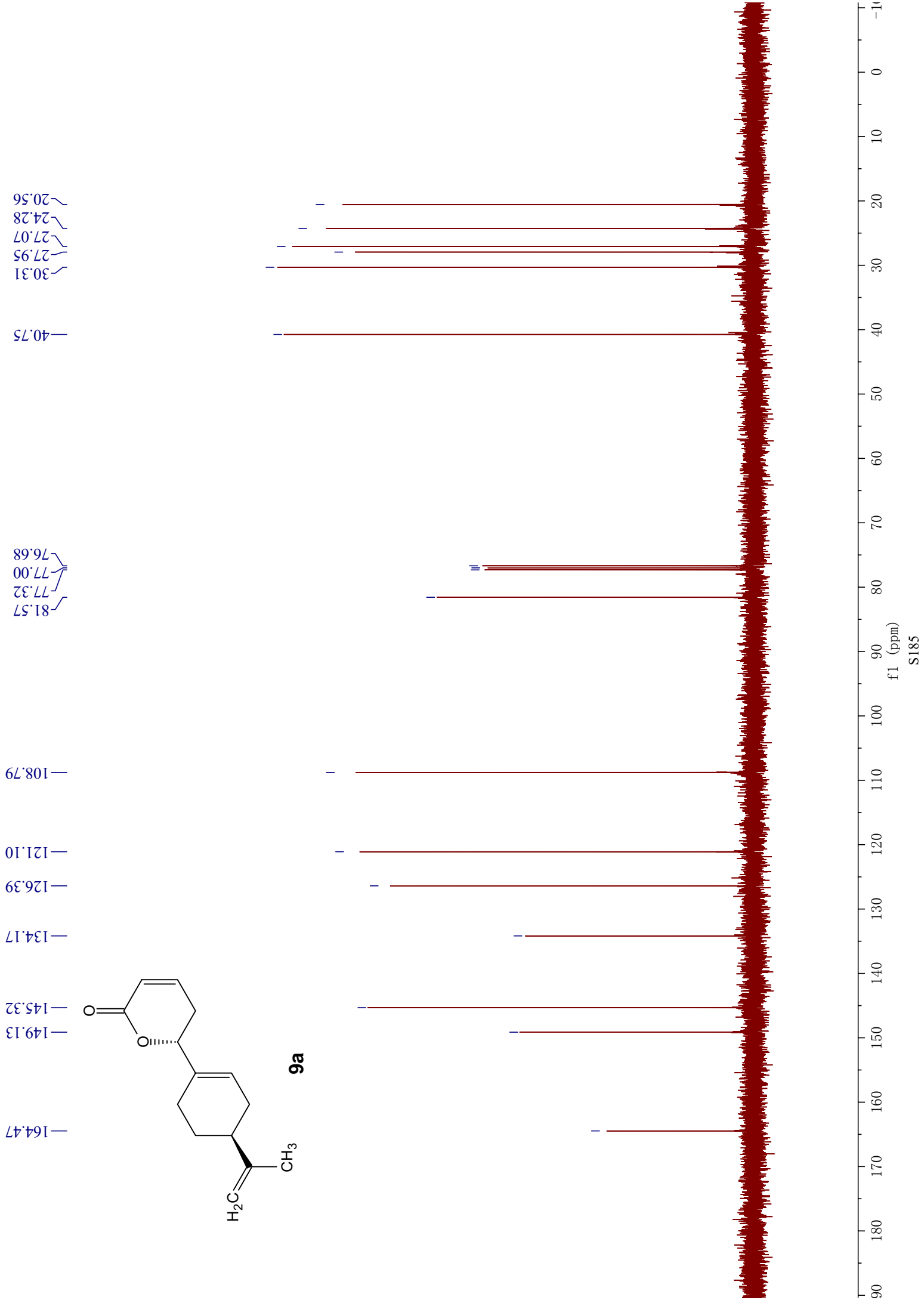


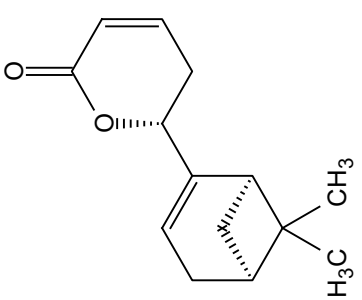


8h

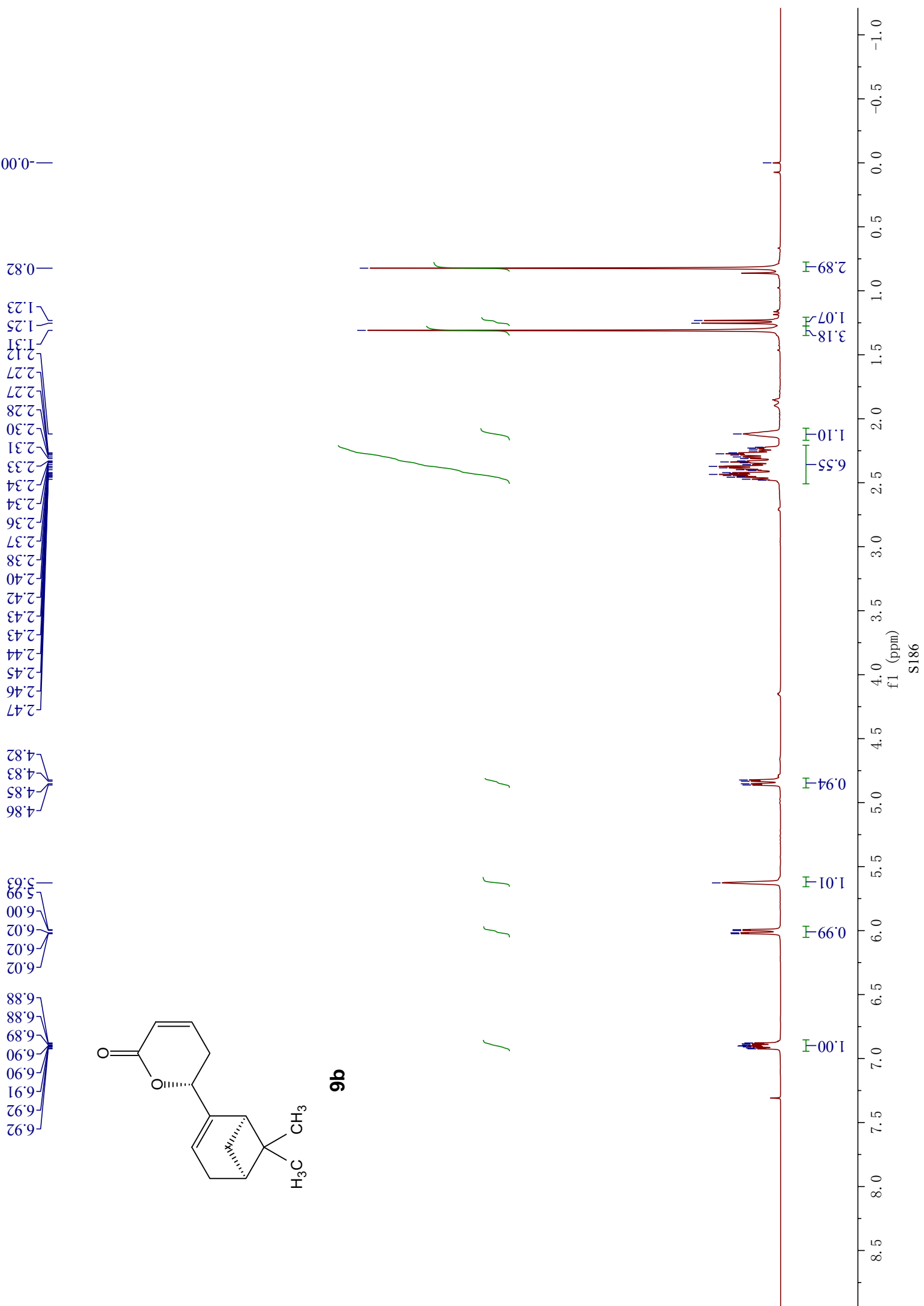


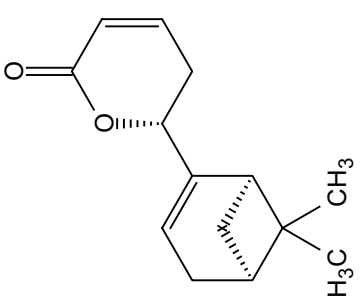






9b





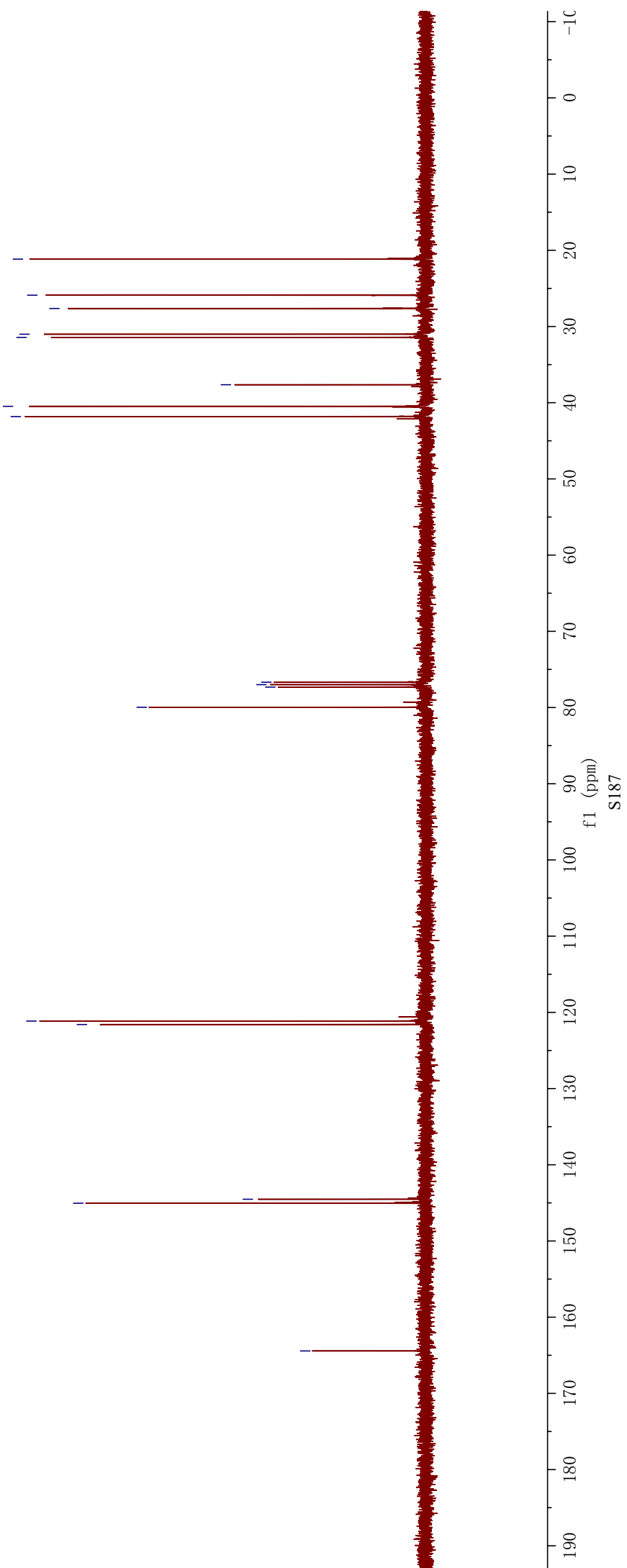
~21.16
 ~25.89
 ~27.64
 ~31.01
 ~31.43
 ~37.64
 ~40.47
 ~41.82

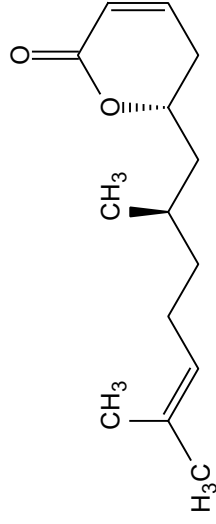
~76.68
 ~77.00
 ~77.32
 ~79.97

~121.15
 ~121.59

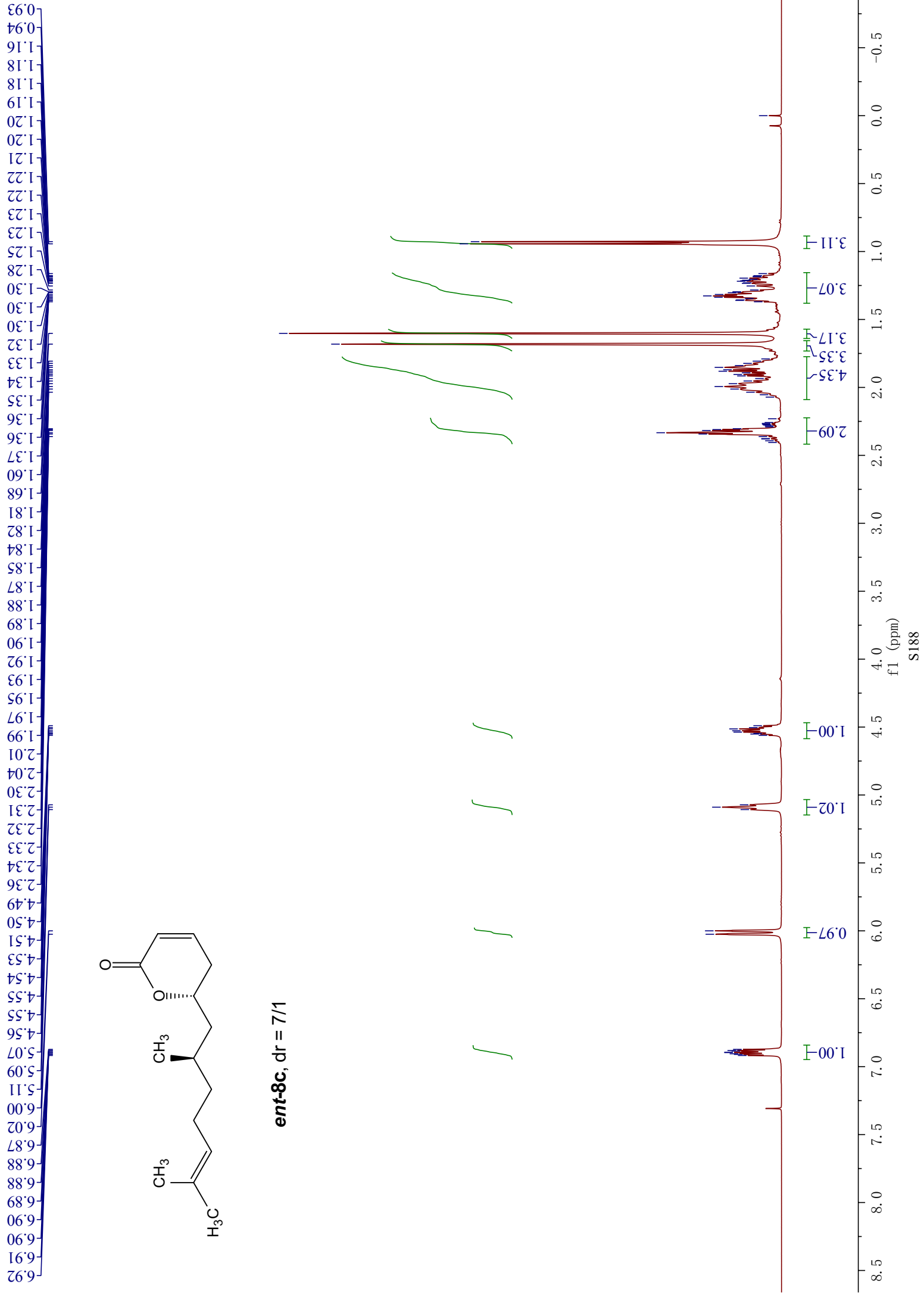
~144.52
 ~145.05

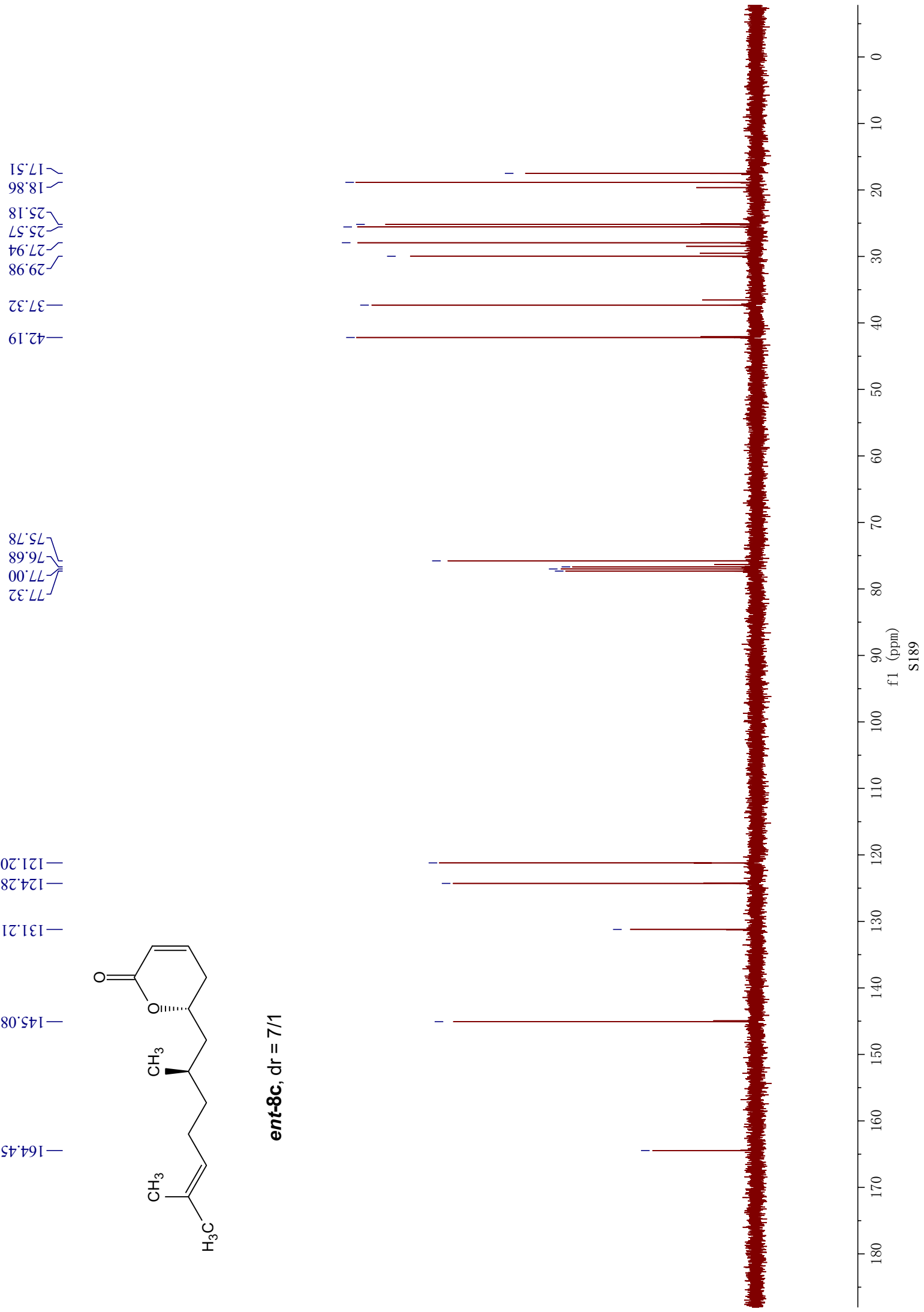
—164.43

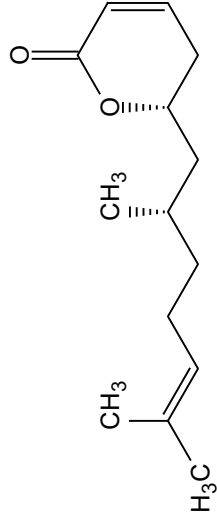




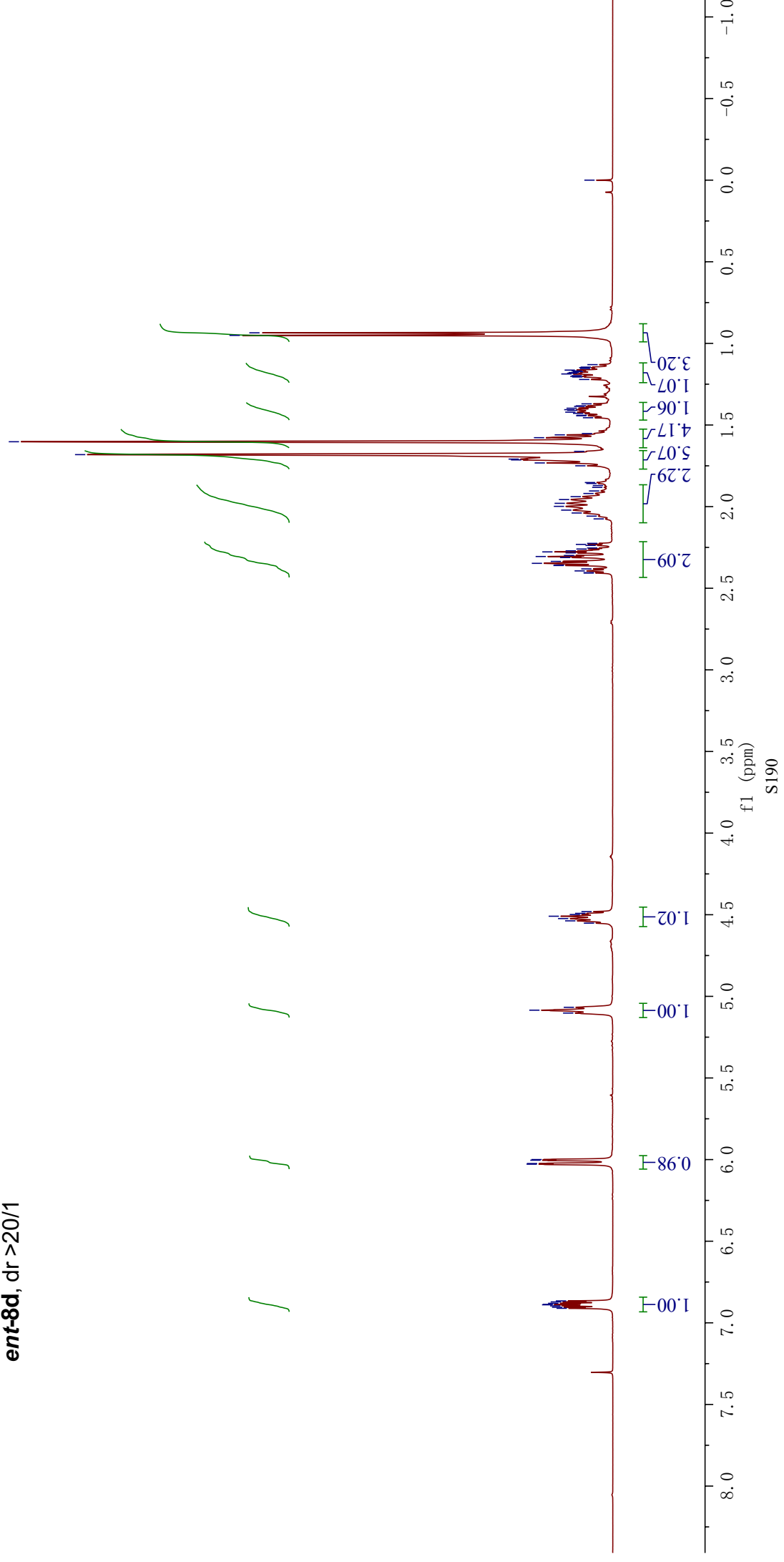
***ent*-8c**, dr = 7/1

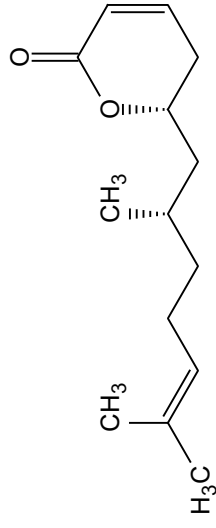




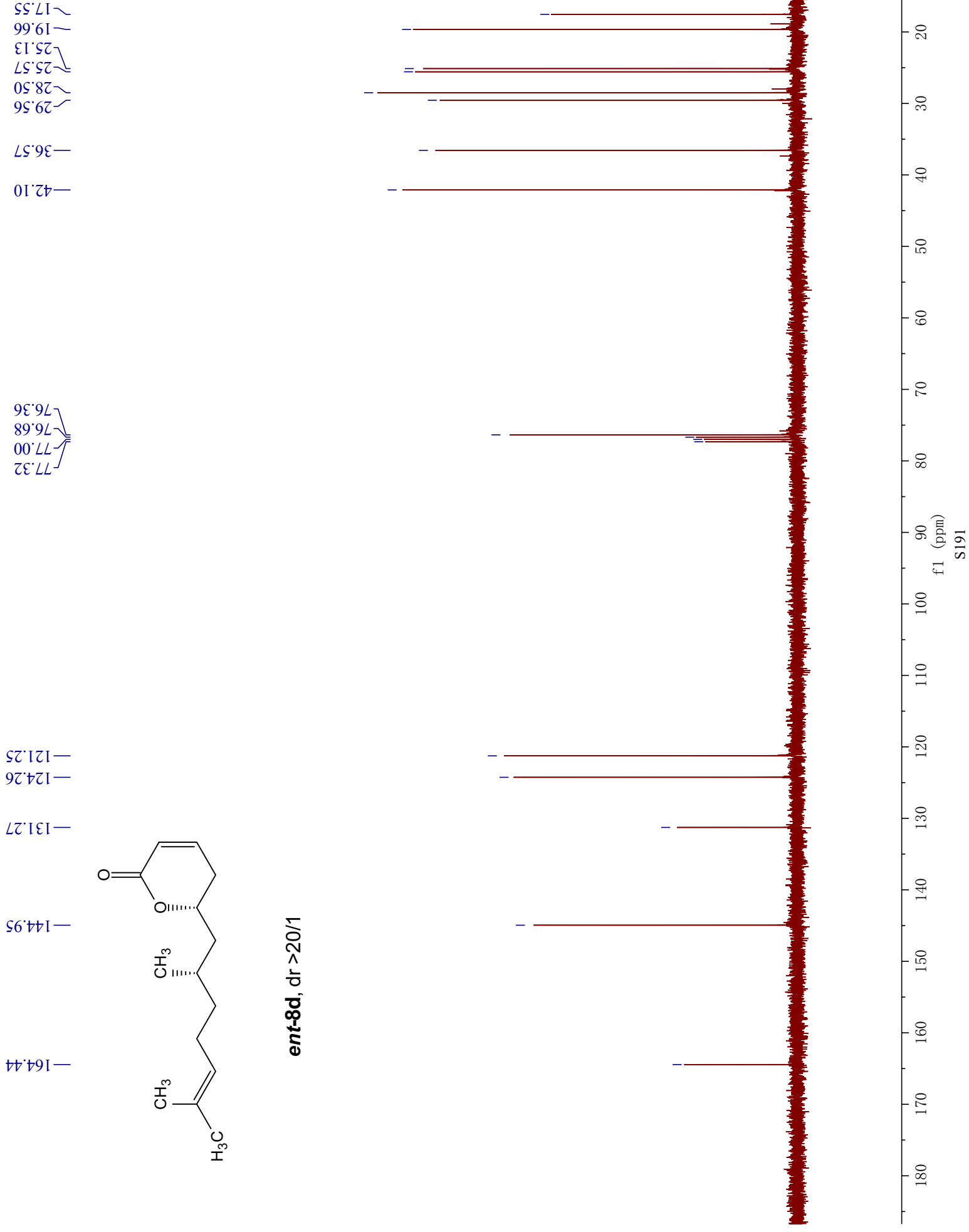


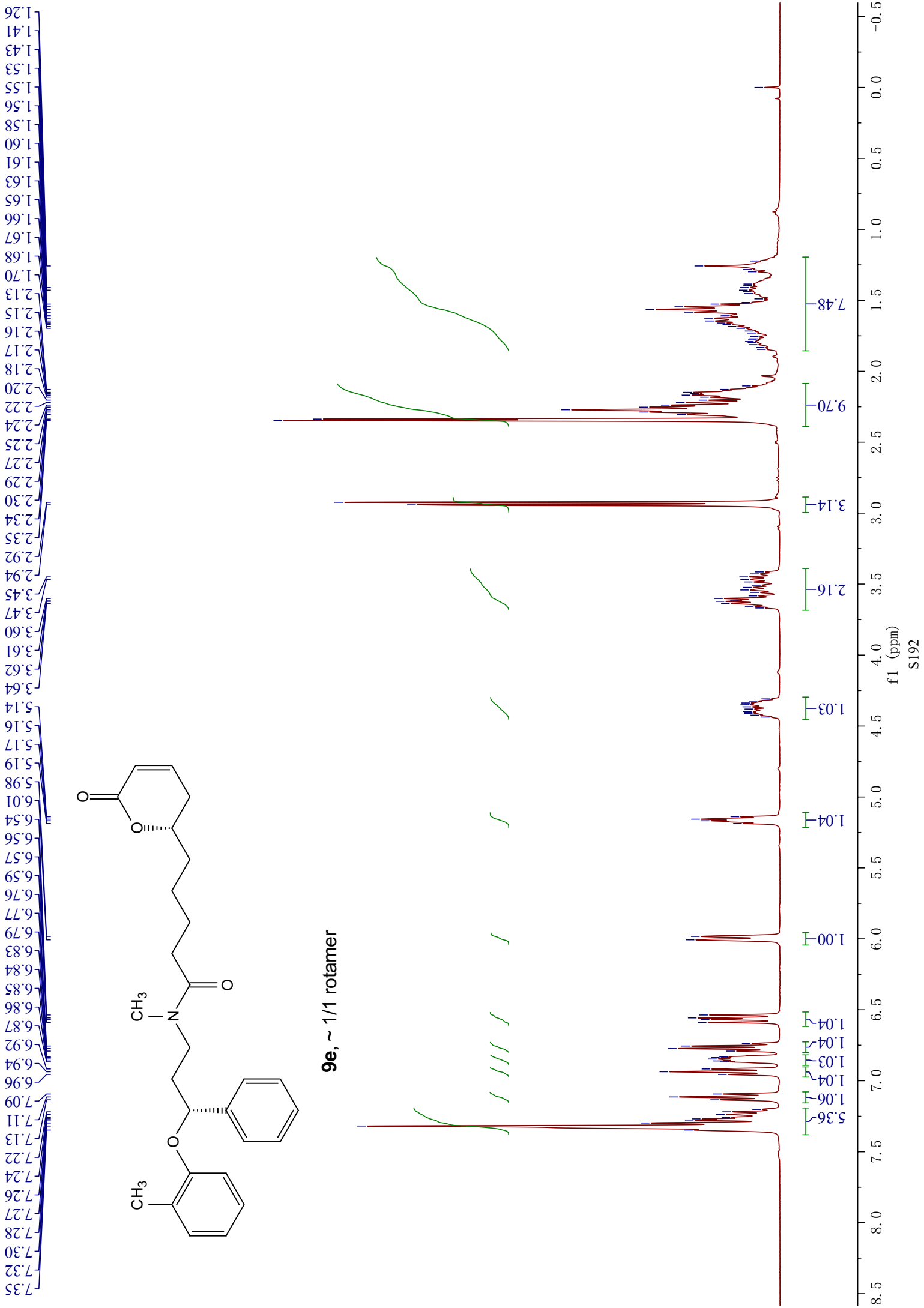
***ent*-8d**, dr >20/1





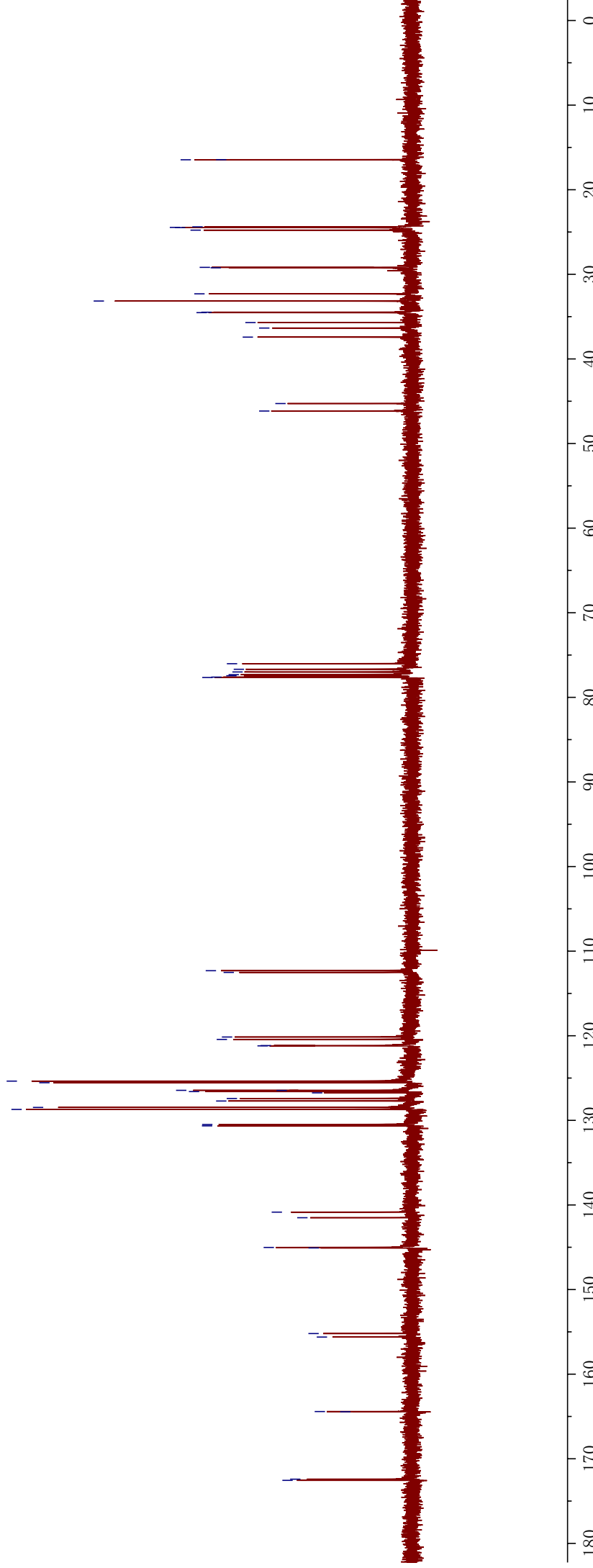
***ent*-8d**, dr >20/1



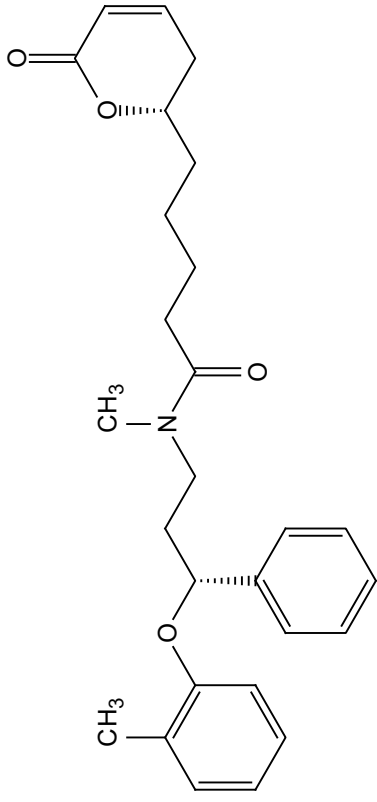


S193

f1 (ppm)



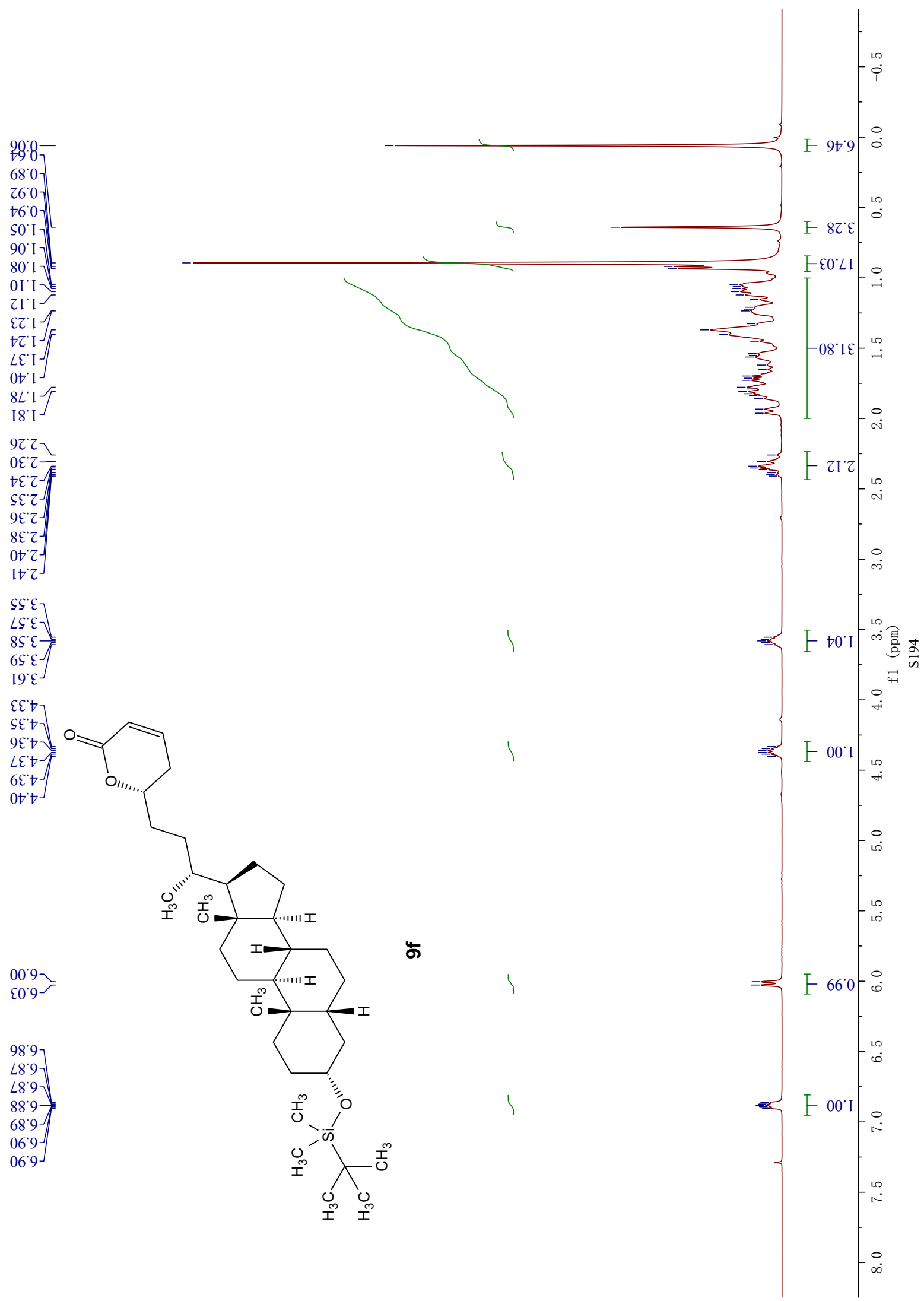
9e, ~ 1/1 rotamer

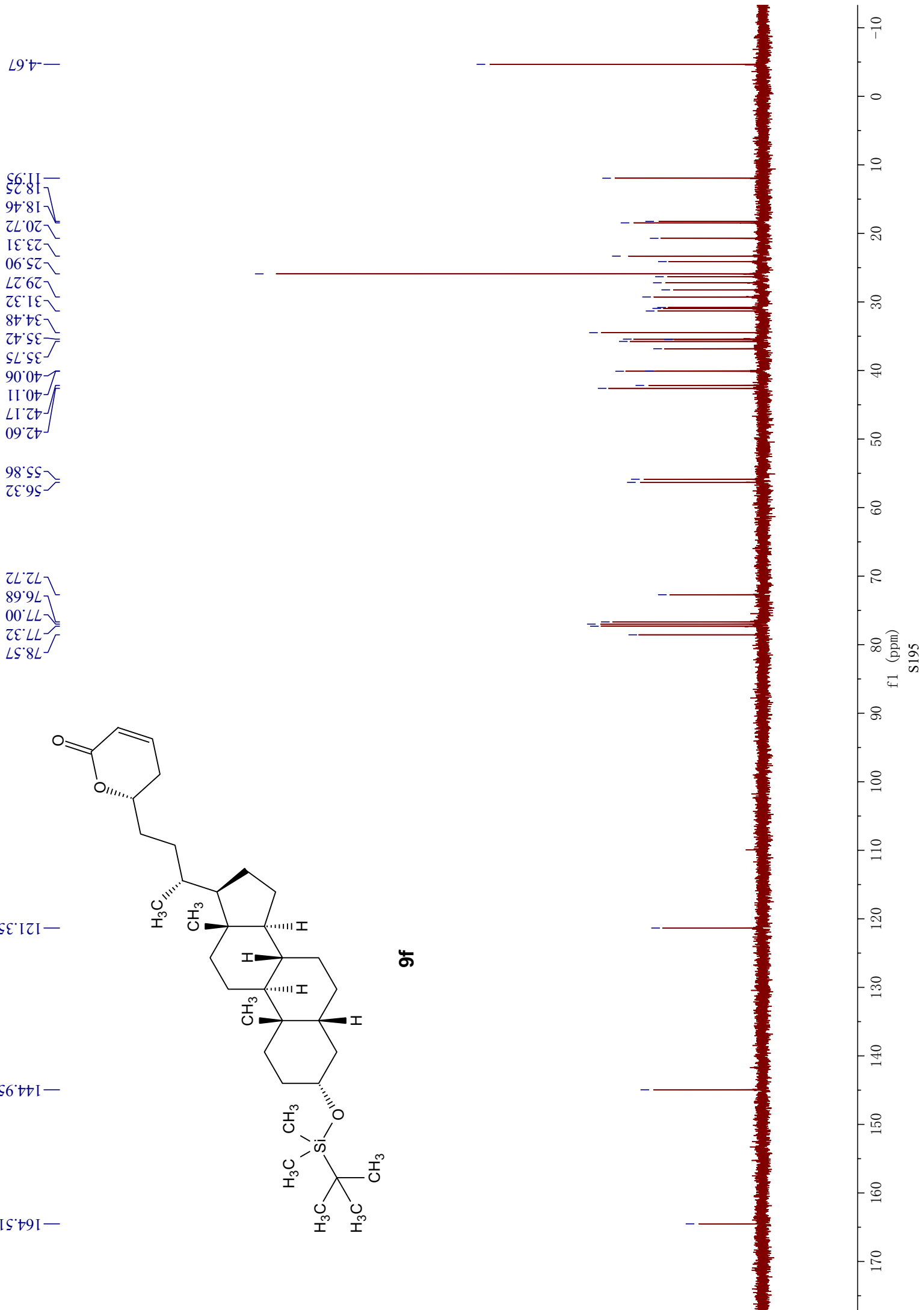


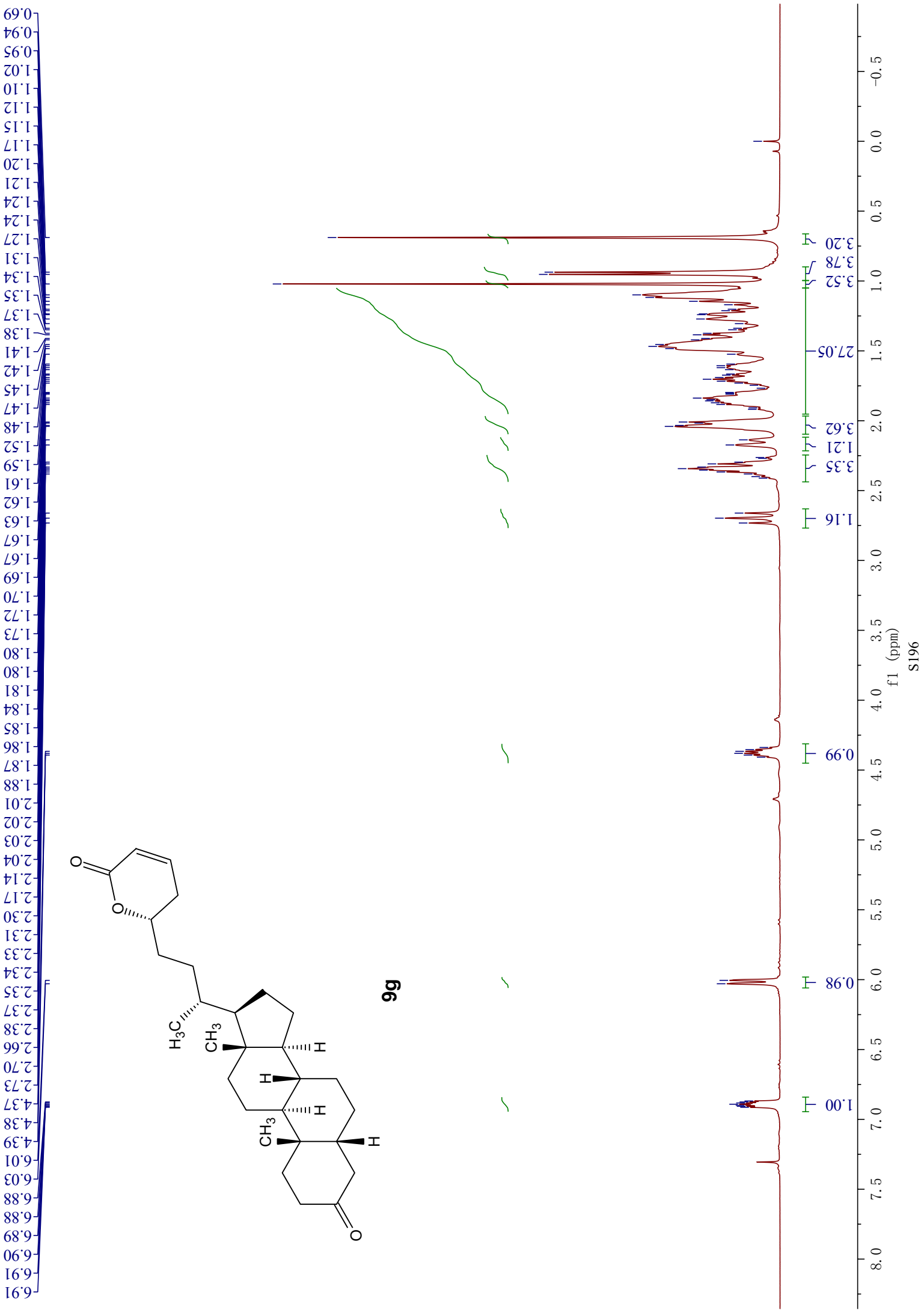
16.44
16.46
24.39
24.45
24.47
24.78
29.18
32.30
33.16
34.53

46.16
45.27
76.02
76.68
77.00
77.32
77.45
77.61
77.65

112.31
125.36
125.55
126.45
126.60
128.47
128.71
130.49
130.65
140.85
141.51
145.02
145.08
155.20
155.61
164.42
164.44
172.41
172.55

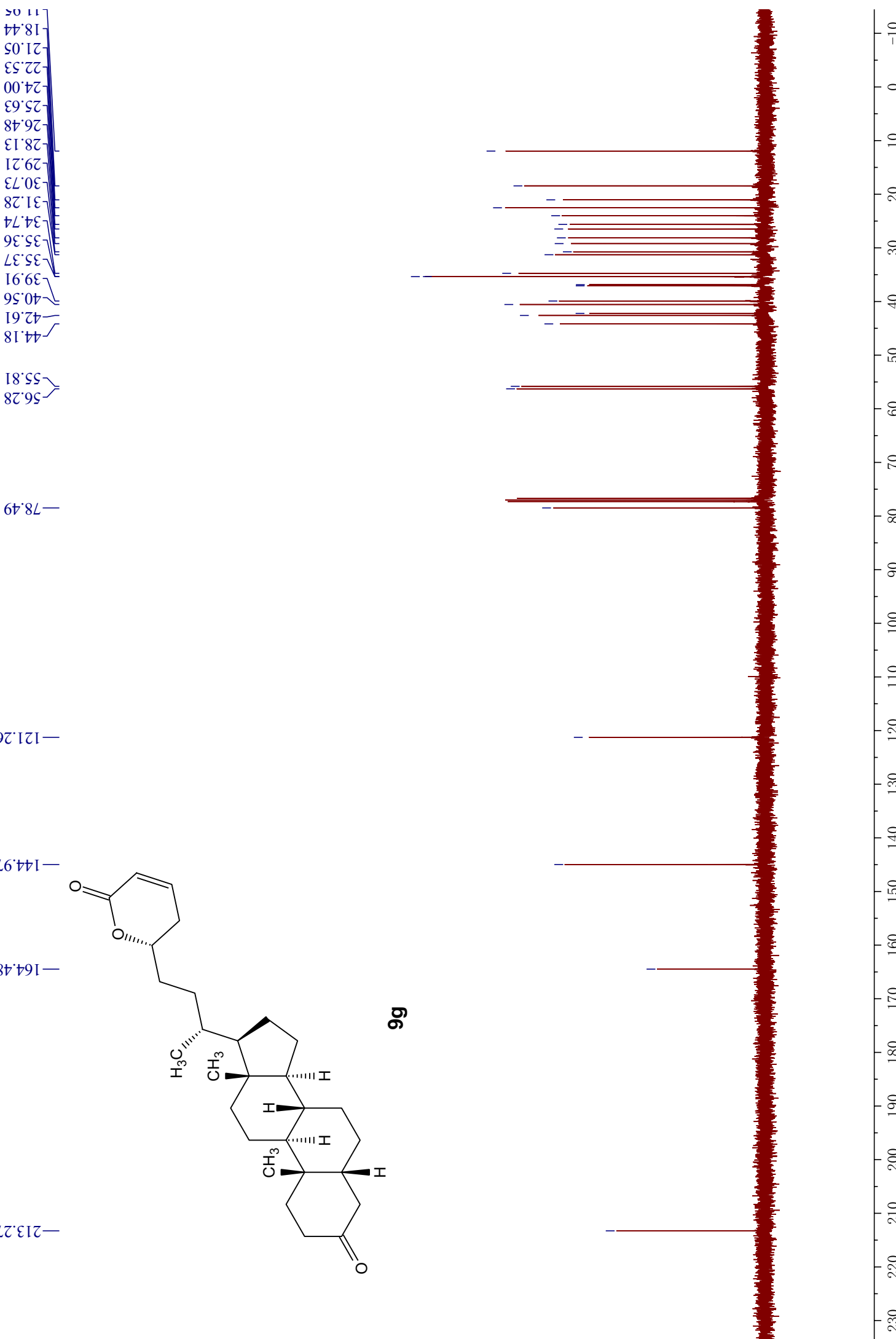




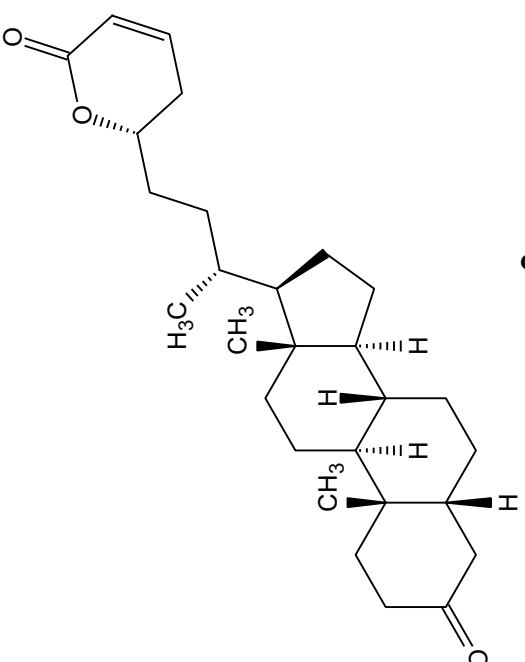


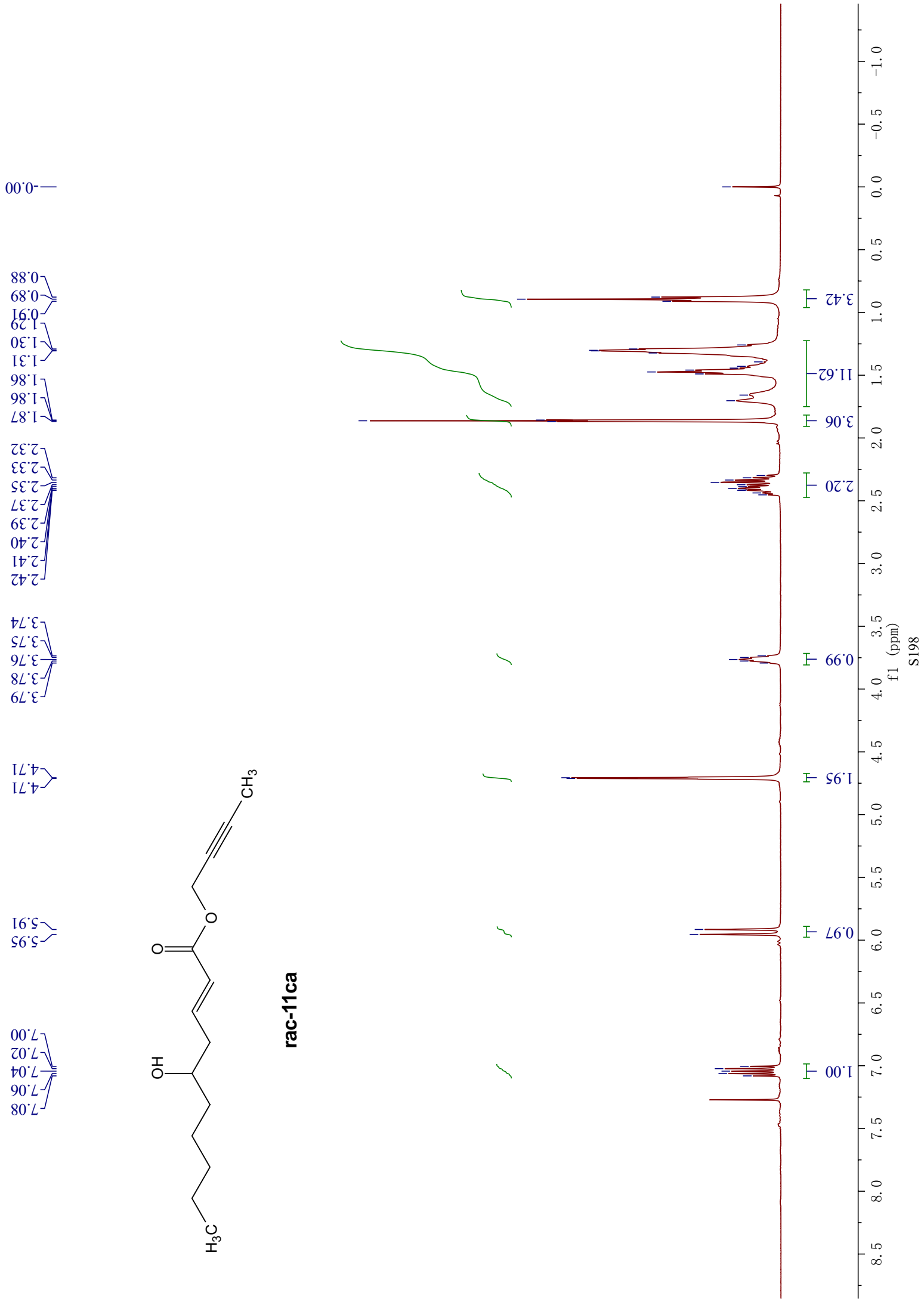
S197

f1 (ppm)

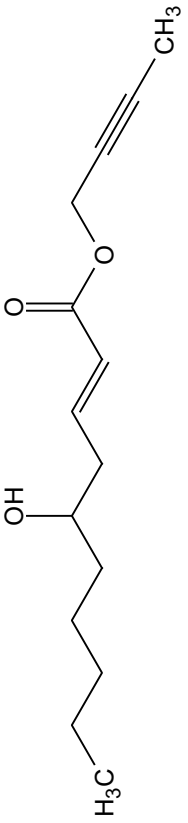


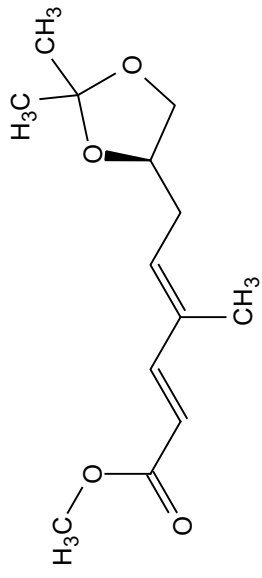
9g



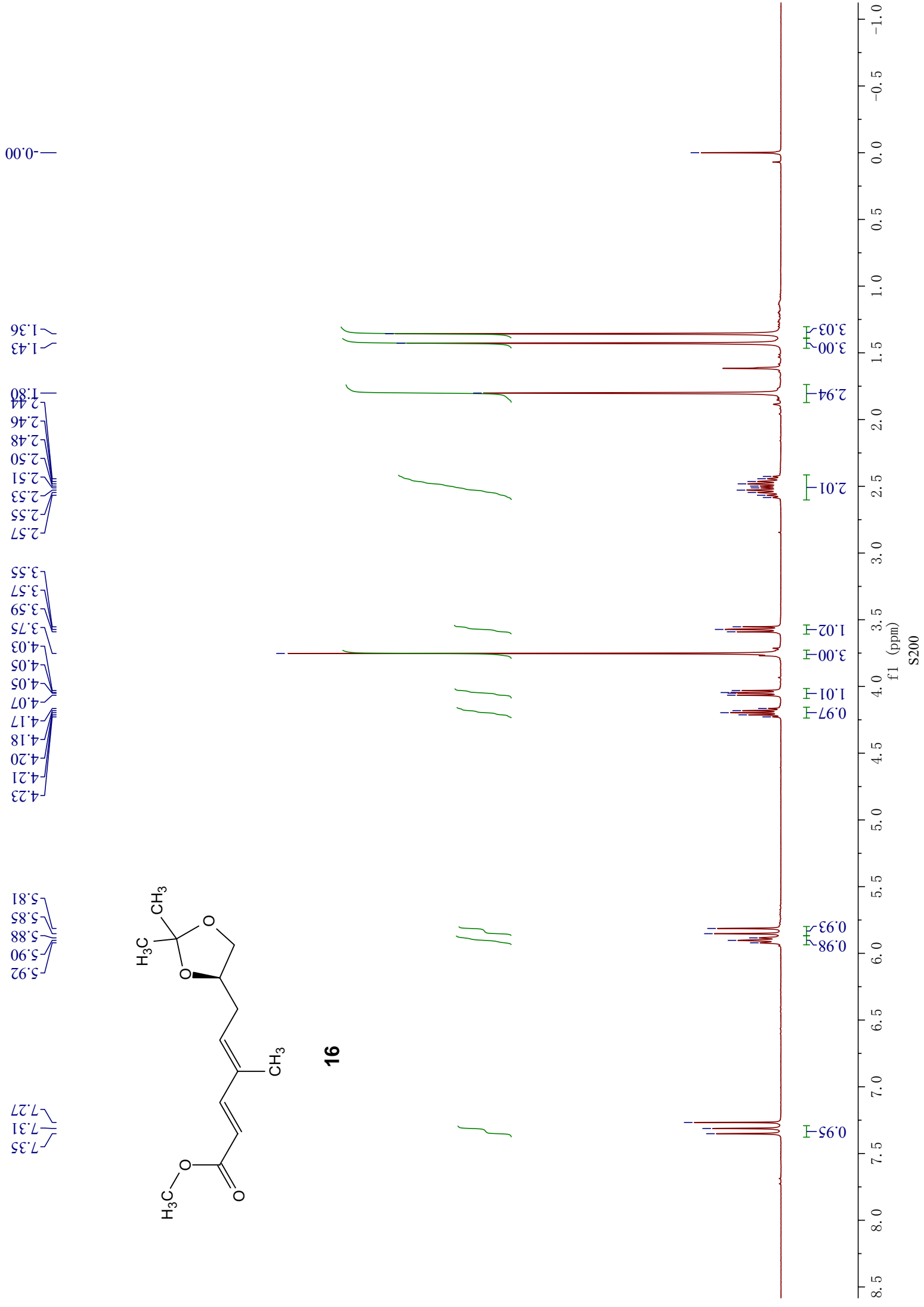


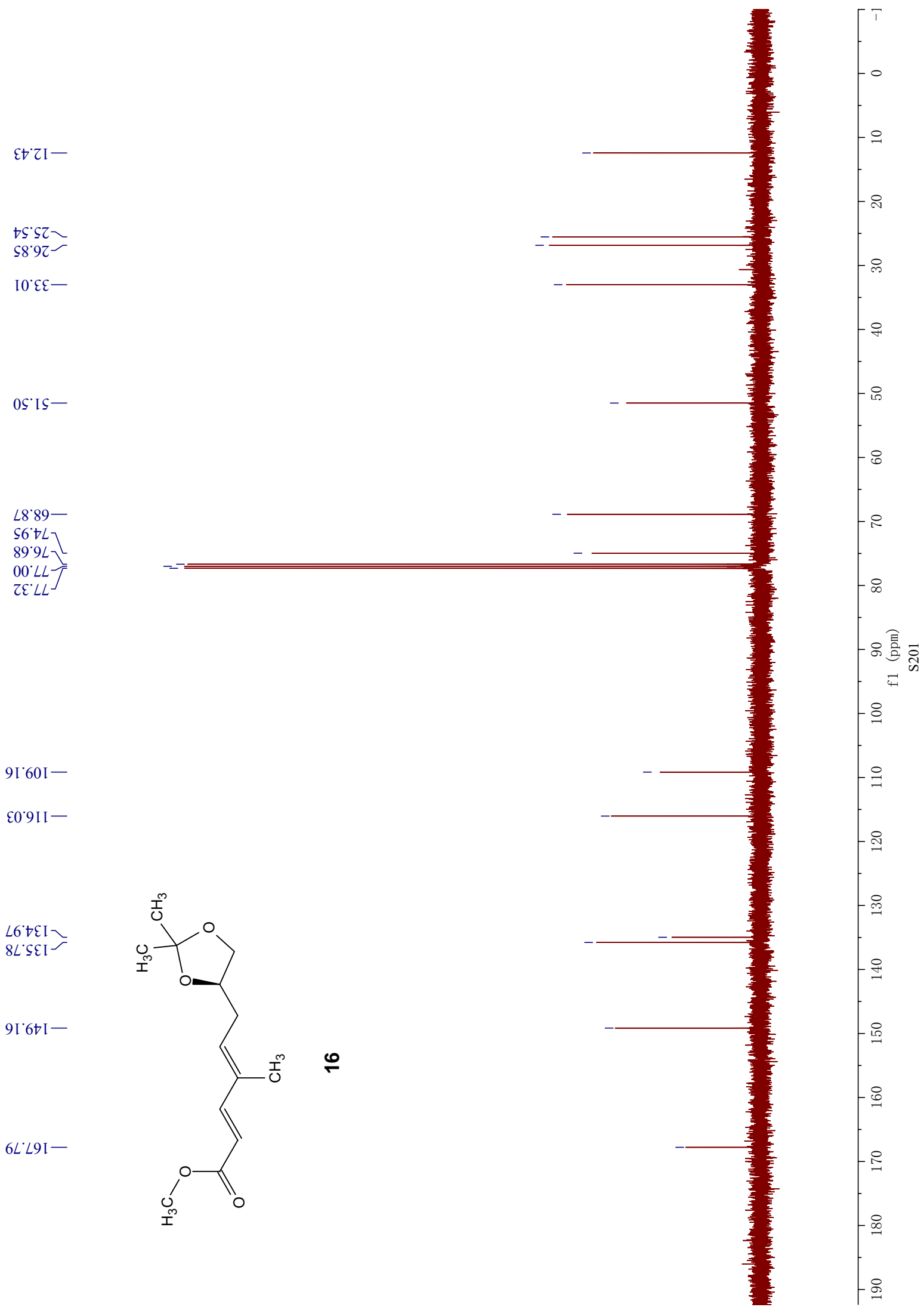
rac-11ca

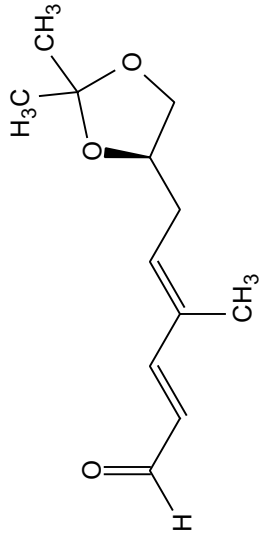




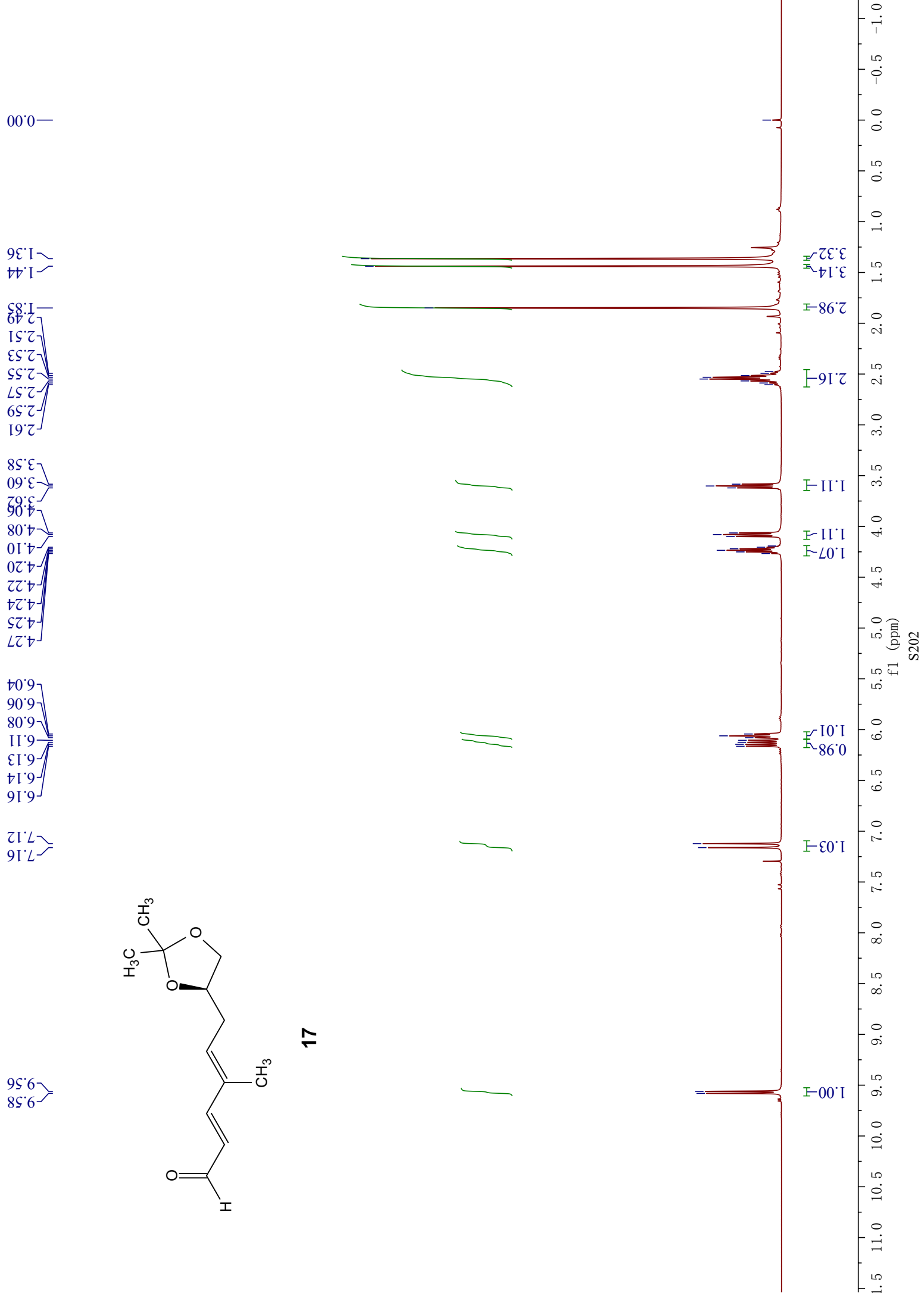
16

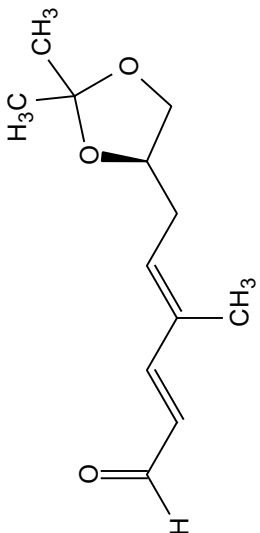




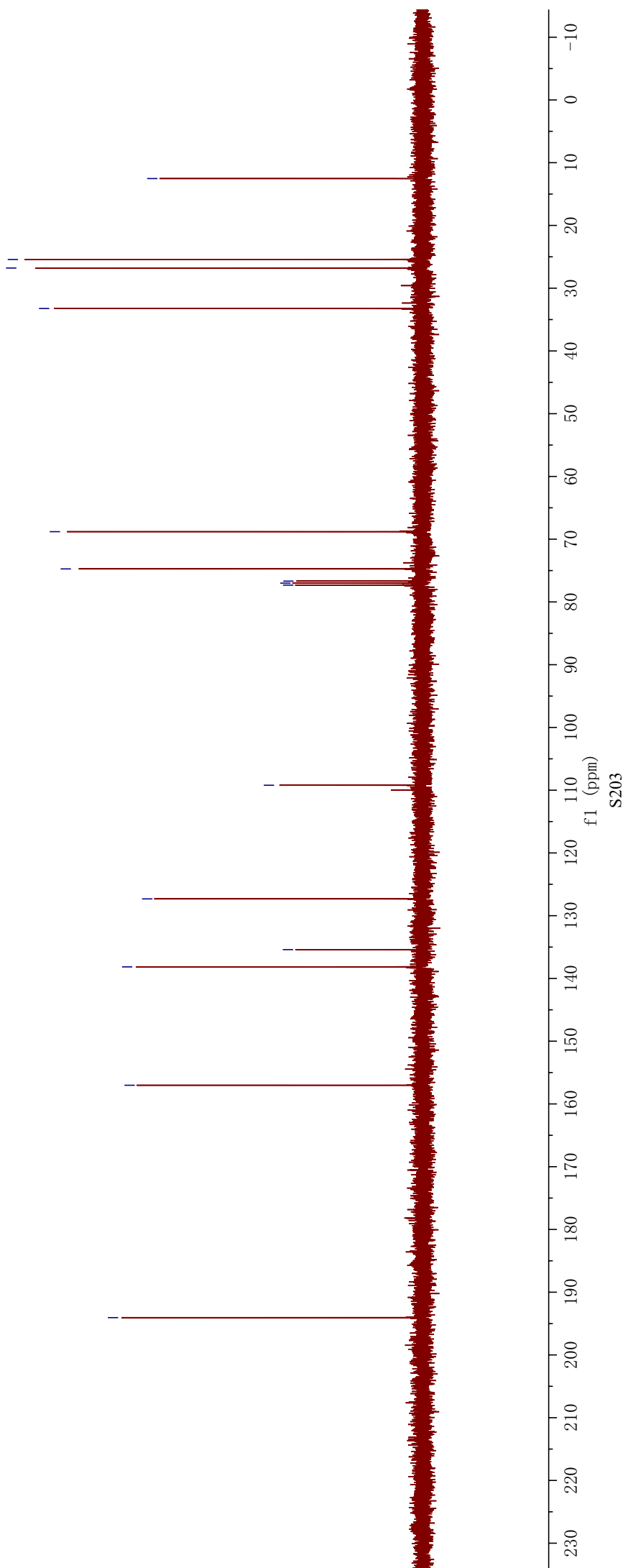
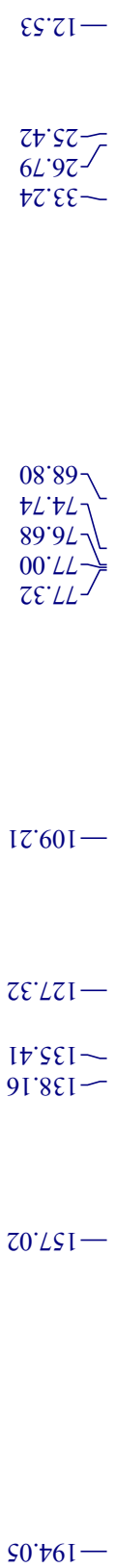


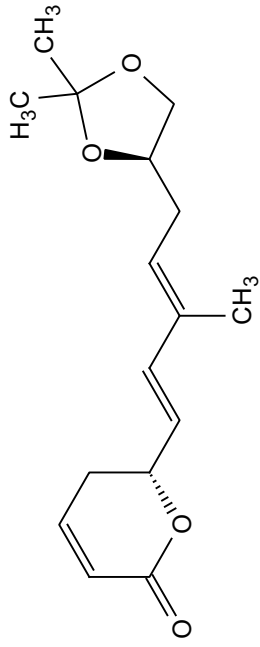
17



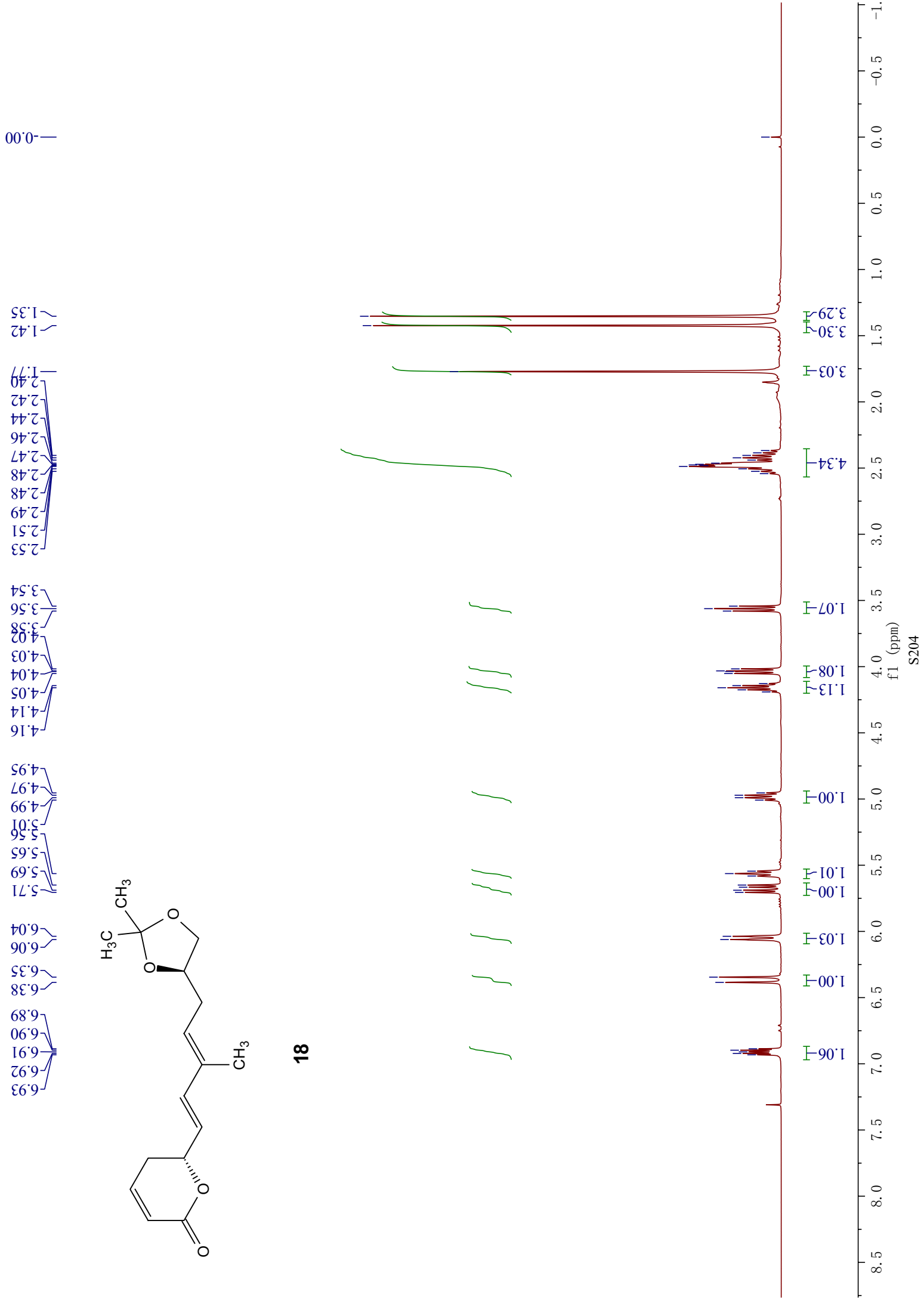


17





18



18

