

Nickel-Catalyzed Negishi Cross-Coupling Reactions of Secondary Alkylzinc Halides and Aryl Iodides

*Amruta Joshi-Pangu, Madhu Ganesh, and Mark R. Biscoe**

Department of Chemistry, The City College of New York, 160 Convent Avenue, New York, NY 10031

Supporting Information

General: Reagent Information. BDH brand toluene was purchased from VWR. EMD brand Omnisolv THF (unstabilized) was also purchased from VWR. These solvents were transferred to separate 20L solvent-delivery kegs and vigorously purged with argon for 2 h. The solvents were further purified by passing them under argon pressure through two packed columns of neutral alumina (for THF) or through neutral alumina and copper (II) oxide (for toluene). All reagents and solvents were used as received unless otherwise noted. Anhydrous NiCl₂ was purchased from Strem, terpyridine was purchased from Sigma-Aldrich. Flash chromatography was performed using Silicycle silica gel (ultra pure grade).

General Analytical Information. All compounds were characterized by ¹H NMR and ¹³C NMR spectroscopy. Copies of the ¹H and ¹³C spectra can be found at the end of the Supporting Information. All previously unreported compounds were additionally characterized by IR spectroscopy and elemental analysis. Nuclear Magnetic Resonance spectra were recorded on a Varian 300 or 500 MHz instrument. All ¹H NMR experiments are reported in δ units, parts per million (ppm), and were measured relative to the signals for residual chloroform (7.26 ppm). All ¹³C NMR spectra are reported in ppm relative to deuteriochloroform (77.16 ppm), and were obtained with ¹H decoupling. All GC analyses were performed on a Shimadzu GC-2010 gas chromatograph with an FID detector using a 25 m x 0.20 mm capillary column with cross-linked methyl siloxane as the stationary phase. IR spectra were obtained on a Perkin-Elmer Model 2000 FT-IR using NaCl plates (thin film).

General Procedural Information.

General procedure for the preparation of isopropyl and sec-butylzinc iodide¹

Zinc granules (3 g, 45 mmol) were added to a flame dried 100 mL Schlenk flask with a stir bar and heated at 80 °C under vacuum for 1 h while stirring. After the flask was cooled to room temperature under argon, iodine crystals (3.8 g, 15 mmol) were added, and the flask was evacuated and backfilled with argon 3 times. The flask was cooled using an ice bath and dry THF (24 mL) was then added via syringe. The reaction mixture was stirred until the red color of the solution faded to colorless-yellow. The

secondary alkyl iodide (30 mmol) was then added via syringe. The reaction mixture was stirred at room temperature until complete consumption of the alkyl halide (1-2 days) as judged by GC. The solution was transferred into a flame dried pear shaped flask via cannula and stored under argon on the bench-top. The molarity of the resulting solution was determined using iodine titration.² The molarities were typically between 0.8 M and 1.0 M.

General procedure for the preparation of alkylzinc iodides from Table 3:

Zinc granules (1.96 g, 30 mmol) were added to a flame dried 50 mL 2-neck round bottom flask equipped with a condenser and a stir bar. Under vacuum, the flask was heated to 80 °C for 1 h while stirring. The flask was backfilled with argon and the temperature was lowered to 60 °C. A solution of iodine (3 g, 12 mmol) in THF (6 mL) was added via syringe. The reddish color of the solution faded to colorless within a few minutes. The secondary alkyl iodide (6 mmol) in THF (2 mL) was then added via syringe and the reaction mixture was refluxed at 60 °C for 20 h. The solution was transferred while hot* into a flame dried round bottom flask via syringe/needle and stored under argon. Molarity of the resulting solution was determined by iodine titration.² The molarities of these alkyl zinc iodides typically ranged from 0.4 M to 0.7 M.

*Note: If the solution is cooled, a solid precipitate may form, which will clog the syringe. Hence, it is necessary to transfer the organozinc solution while it is hot. If solid precipitate forms in the round bottom receiving flask, extra THF can be added.

General procedure for the cross-coupling of aryl iodides and secondary alkylzinc iodides:

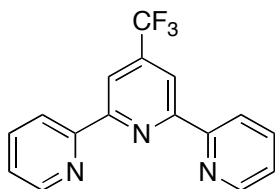
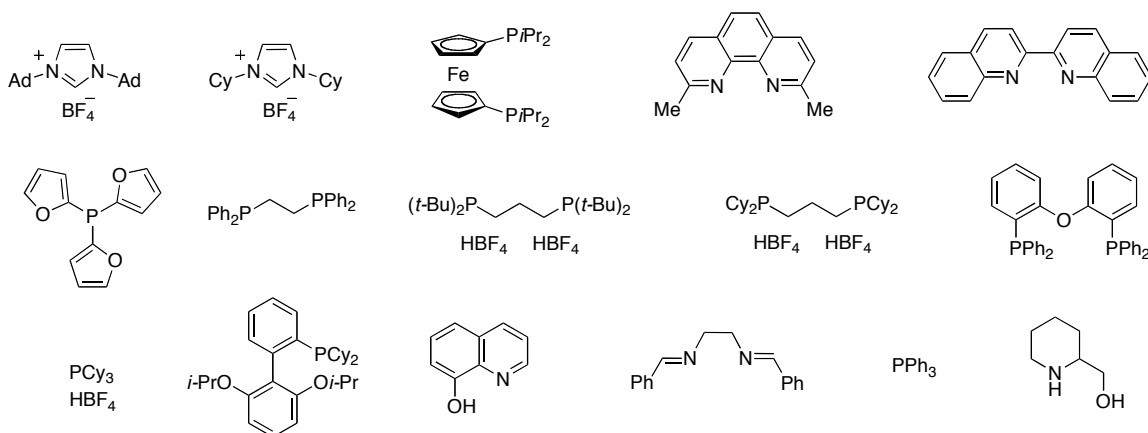
Anhydrous NiCl₂ (2.6 mg, 0.02 mmol) and terpyridine (4.6 mg, 0.02 mmol) were weighed out on the benchtop in a flame-dried 1 dram vial with stir bar. The aryl iodide (1 mmol) was then added to the vial. The vial was sealed using a screw cap lined with a teflon septum. The vial was evacuated and backfilled with argon using a needle attached to a vacuum manifold. If the aryl iodide was a liquid, it was added via microsyringe after having backfilled the vial with argon. The secondary alkylzinc iodide (1.5 mmol) was then added via syringe under a positive pressure of argon. The vial was sealed with electrical tape and the reaction mixture was stirred for 17 h on the benchtop at 40 °C with no additional argon pressure. Progress of the reaction was monitored by GC. The reaction mixture was poured into a separatory funnel containing saturated aqueous NH₄Cl (ca. 10 mL) and extracted with EtOAc (3 x 20 mL). The combined organic layers were washed with brine and dried over Na₂SO₄. The crude product was purified by column chromatography.

General procedure for experiments of Table 4:

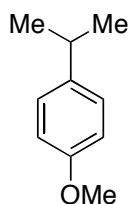
Anhydrous NiCl₂ (1.6 mg, 0.0125 mmol), terpyridine (2.9 mg, 0.00125 mmol), and methyl 4-iodobenzoate (65.5 mg, 0.25 mmol) were weighed out on the benchtop into an oven-dried 1 dram vial with stir bar. The reaction vial was transferred to a nitrogen-filled

glovebox. The salt (0.25mmol) was added to the vial. The vial was capped with a screw cap lined with a teflon septum. This screw cap was additionally sealed with electrical tape and was removed from the glovebox. *i*PrZnI in THF (1.0 M, 400 μ l, 0.400 mmol) was added via syringe to the reaction vial. The vial was heated to 40 $^{\circ}$ C for 20 h in a reactor block. The reaction mixture was poured into a 2 dram vial containing saturated aqueous NH_4Cl (ca. 1 mL) and extracted with EtOAc (ca. 1 mL). The EtOAc layer was analyzed by GC.

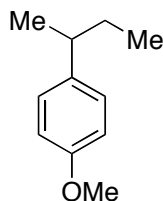
Additional ligands tested in initial screen (all produced <10% desired product):



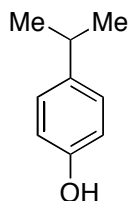
4'-(Trifluoromethyl)-2,2':6',2''-terpyridine.³ To a flame dried 50 mL 2-neck round bottom flask equipped with a stir bar and a condenser, 2,6-dichloro-4-trifluoromethylpyridine (120 mg, 0.56 mmol), 2-pyridyl-tributyl stannane (511 mg, 1.39 mmol) and toluene (10 mL) was added. The flask was evacuated/backfilled with argon thrice. Palladium tetrakis(triphenylphosphine) was then added in one portion under argon pressure and the reaction mixture was heated to reflux for 20 h. The reaction was monitored by proton NMR. When no more starting material was left, the reaction was quenched by adding saturated aqueous NH_4Cl (ca. 5 mL). The mixture was then poured into a separatory funnel and extracted three times with EtOAc. The combined organic layers were washed with brine and dried over Na_2SO_4 . After column chromatography (20:1 CH_2Cl_2 : MeOH), the desired product was obtained as a solid (90 mg, 30%). The product was then digested in hexane (ca. 1-2 mL) to provide off-white solid. ^1H NMR (500 MHz, CDCl_3) δ : 8.74 (m, 2H), 8.72 (s, 2H), 8.64 (d, J = 8.3 Hz, 2H), 7.90 (td, J = 7.8, 1.5 Hz, 2H), 7.40 (m, 2H) ppm. Anal. Calcd. for $\text{C}_{16}\text{H}_{10}\text{N}_3\text{F}_3$: C, 63.79; H, 3.35. Found: C, 63.24; H, 3.49.



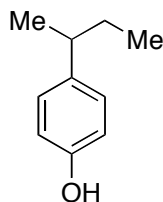
1-(*iso*-Propyl)-4-methoxybenzene (Table 2, Row 1, Column 1, Entry 1). The general procedure was employed with the following modification: ether used for extractions during work-up. A colorless liquid (138 mg, 92%) was isolated by column chromatography (95:5 Hex:Ether). ^1H NMR (500 MHz, CDCl_3) δ : 7.17 (d, $J = 8.3$ Hz, 2H), 6.86 (d, $J = 8.8$ Hz, 2H), 3.81 (s, 3H), 2.88 (septet, $J = 6.8$ Hz, 1H), 1.25 (d, $J = 6.8$ Hz, 6H) ppm. ^{13}C NMR (125 MHz, CDCl_3) δ : 157.8, 141.2, 127.4, 113.8, 55.4, 33.4, 24.2 ppm.



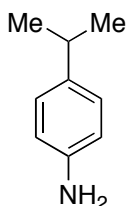
1-(*sec*-Butyl)-4-methoxybenzene (Table 2, Row 1, Column 1, Entry 2). The general procedure was employed with the following modification: ether used for extractions during work-up. A colorless liquid (149 mg, 91%) was isolated by column chromatography (95:5 Hex:Ether). ^1H NMR (500 MHz, CDCl_3) δ : 7.11 (d, $J = 8.7$ Hz, 2H), 6.85 (d, $J = 8.7$ Hz, 2H), 3.80 (s, 3H), 0.9 Hz, 1H), 3.81 (s, 3H), 2.56 (app. sextet, $J = 7.1$ Hz, 1H), 1.57 (app. pentet, $J = 7.4$ Hz, 2H), 1.22 (d, $J = 6.9$ Hz, 3H), 0.83 (t, $J = 7.4$ Hz, 3H) ppm. ^{13}C NMR (75 MHz, CDCl_3) δ : 157.8, 139.9, 128.0, 113.8, 55.4, 41.0, 31.5, 22.2, 12.4 ppm.



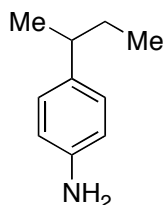
4-(*iso*-Propyl)phenol (Table 2, Row 1, Column 2, Entry 1). The general procedure was employed with the following modifications: 2.5 equiv. alkylzinc reagent employed, 5 mol% NiCl_2 and terpyridine employed, 22 h reaction time. A white solid (115 mg, 85%) was isolated by column chromatography (gradient from 70:30 to 65:35 Hex:EtOAc). Mp: 62-64 °C. ^1H NMR (500 MHz, CDCl_3) δ : 7.10 (d, $J = 8.3$ Hz, 2H), 6.76 (d, $J = 8.8$ Hz, 2H), 4.54 (s, 1H), 2.85 (septet, $J = 7.3$ Hz, 1H), 1.22 (d, $J = 7.3$ Hz, 6H) ppm. ^{13}C NMR (75 MHz, CDCl_3) δ : 153.6, 141.4, 127.6, 115.2, 33.4, 24.4 ppm.



4-(*sec*-Butyl)phenol (Table 2, Row 1, Column 2, Entry 2). The general procedure was employed with the following modifications: 2.5 equiv. alkylzinc reagent employed, 5 mol% NiCl₂ and terpyridine employed, 40 h reaction time. A white solid (123 mg, 87%) was isolated by column chromatography (gradient from 70:30 to 65:35 Hex:EtOAc). Mp: 58-60 °C. ¹H NMR (500 MHz, CDCl₃) δ: 7.05 (d, *J* = 8.5 Hz, 2H), 6.76 (d, *J* = 8.5 Hz, 2H), 4.53 (bs, 1H), 2.53 (m, 1H), 1.54 (m, 2H), 1.20 (d, *J* = 6.8 Hz, 3H), 0.81 (t, *J* = 7.3 Hz, 3H) ppm. ¹³C NMR (125 MHz, CDCl₃) δ: 153.5, 140.1, 128.2, 115.1, 41.0, 31.5, 22.2, 12.4 ppm.

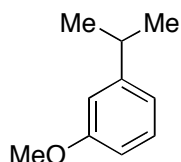


4-(*iso*-Propyl)aniline (Table 2, Row 1, Column 3, Entry 1). The general procedure was employed with the following modifications: 2.5 equiv. alkylzinc reagent employed, 5 mol% NiCl₂ and terpyridine employed, reaction conducted at 80 °C, 14 h reaction time, reaction quenched with saturated aqueous NaHCO₃. A yellow-orange liquid (91 mg, 67%) was isolated by column chromatography (gradient from 75:25 to 70:30 Hex:EtOAc). ¹H NMR (500 MHz, CDCl₃) δ: 7.03 (d, *J* = 8.3 Hz, 2H), 6.65 (d, *J* = 8.7 Hz, 2H), 3.57 (bs, 2H), 2.82 (septet, *J* = 6.8 Hz, 1H), 1.21 (d, *J* = 6.8 Hz, 6H) ppm. ¹³C NMR (125 MHz, CDCl₃) δ: 144.3, 139.3, 127.3, 115.3, 33.4, 24.4 ppm.

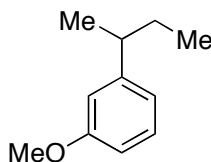


4-(*sec*-Butyl)aniline (Table 2, Row 1, Column 3, Entry 2). The general procedure was employed with the following modifications: 2.5 equiv. alkylzinc reagent employed, 5 mol% NiCl₂ and terpyridine employed, reaction conducted at 80 °C, 15 h reaction time, reaction quenched with saturated aqueous NaHCO₃. A yellow-orange liquid (93 mg, 62%) was isolated by column chromatography (gradient from 70:30 to 65:35 Hex:EtOAc). ¹H NMR (500 MHz, CDCl₃) δ: 6.99 (d, *J* = 8.4 Hz, 2H), 6.65 (d, *J* = 8.5 Hz, 2H), 3.57 (bs, 2H), 2.50 (app. sextet, *J* = 7.1 Hz, 1H), 1.55 (m, 2H), 1.20 (d, *J* = 7.0

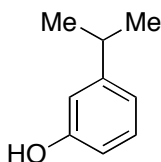
Hz, 3H), 0.82 (t, $J = 7.4$ Hz, 3H) ppm. ^{13}C NMR (75 MHz, CDCl_3) δ : 144.3, 138.1, 127.9, 115.3, 40.9, 31.5, 22.1, 12.4 ppm.



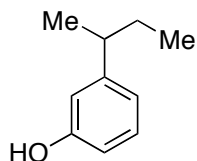
1-(*iso*-Propyl)-3-methoxybenzene (Table 2, Row 2, Column 1, Entry 1). The general procedure was employed with the following modifications: LiBF_4 (93.7 mg, 1mmol) was weighed out and added to the reaction vial in a nitrogen-filled glove box, 30 h reaction time, ether used for extractions during work-up. A pale yellow liquid (136 mg, 91%) was isolated by column chromatography (95:5 Hex:Ether). ^1H NMR (500 MHz, CDCl_3) δ : 7.23 (t, $J = 7.8$ Hz, 1H), 6.84 (d, $J = 7.5$ Hz, 1H), 6.79 (m, 1H), 6.73 (d, $J = 7.8$ Hz, 1H), 3.82 (s, 3H), 2.89 (septet, $J = 6.8$ Hz, 1H), 1.26 (d, $J = 6.8$ Hz, 6H) ppm. ^{13}C NMR (75 MHz, CDCl_3) δ : 159.8, 150.8, 129.4, 119.0, 112.6, 110.9, 55.3, 34.3, 24.1 ppm.



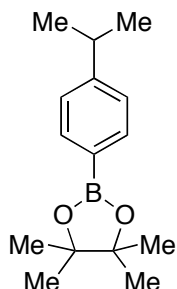
1-(*sec*-Butyl)-3-methoxybenzene (Table 2, Row 2, Column 1, Entry 2). The general procedure was employed with the following modifications: 18 h reaction time, ether used for extractions during work-up. A colorless liquid (141 mg, 86%) was isolated by column chromatography (95:5 Hex:Ether). ^1H NMR (500 MHz, CDCl_3) δ : 7.22 (td, $J = 7.6$ Hz, 0.9 Hz, 1H), 6.79 (d, $J = 7.6$ Hz, 1H), 6.75 (d, $J = 0.9$ Hz, 1H), 6.73 (dd, $J = 2.6$ Hz, 0.9 Hz, 1H), 3.81 (s, 3H), 2.58 (app. sextet, $J = 7.1$ Hz, 1H), 1.60 (m, 2H), 1.24 (d, $J = 7.0$ Hz, 3H), 0.84 (t, $J = 7.4$ Hz, 3H) ppm. ^{13}C NMR (125 MHz, CDCl_3) δ : 159.7, 149.6, 129.3, 119.7, 113.2, 110.8, 55.2, 41.9, 31.2, 22.0, 12.4 ppm.



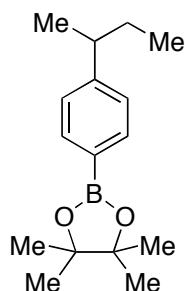
3-(*iso*-Propyl)phenol (Table 2, Row 2, Column 2, Entry 1). The general procedure was employed with the following modifications: 2.5 equiv. alkylzinc reagent employed, 5 mol% NiCl_2 and terpyridine employed, reaction conducted at 80 $^\circ\text{C}$, 17 h reaction time. A colorless liquid (110 mg, 81%) was isolated by column chromatography (gradient from 70:30 to 65:35 Hex:EtOAc). ^1H NMR (500 MHz, CDCl_3) δ : 7.16 (t, $J = 7.8$ Hz, 1H), 6.81 (d, $J = 7.8$ Hz, 1H), 6.71 (m, 1H), 6.67 (m, 1H), 4.70 (bs, 1H), 2.86 (septet, $J = 6.8$ Hz, 1H), 1.24 (d, 6.8 Hz, 6H) ppm. ^{13}C NMR (125 MHz, CDCl_3) δ : 155.6, 151.1, 129.6, 119.2, 113.5, 112.7, 34.1, 24.0 ppm.



3-(*sec*-Butyl)phenol (Table 2, Row 2, Column 2, Entry 2). The general procedure was employed with the following modifications: 2.5 equiv. alkylzinc reagent employed, 5 mol% NiCl₂ and terpyridine employed, reaction conducted at 80 °C, 14 h reaction time. A colorless liquid (120 mg, 80%) was isolated by column chromatography (gradient from 70:30 to 65:35 Hex:EtOAc). ¹H NMR (500 MHz, CDCl₃) δ: 7.16 (t, *J* = 7.8 Hz, 1H), 6.77 (d, *J* = 7.3 Hz, 1H), 6.66 (m, 2H), 4.86 (s, 1H), 2.55 (app. sextet, *J* = 7.3 Hz, 1H), 1.58 (m, 2H), 1.22 (d, *J* = 6.8 Hz, 3H), 0.83 (t, *J* = 7.6 Hz, 3H) ppm. ¹³C NMR (75 MHz, CDCl₃) δ: 155.5, 150.0, 129.5, 119.9, 114.1, 112.8, 41.7, 31.2, 21.9, 12.4 ppm.

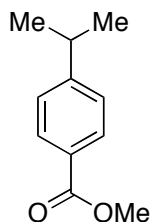


2-(4-(*iso*-Propyl)phenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (Table 2, Row 2, Column 3, Entry 1). The general procedure was employed with the following modification: 30 h reaction time. A white solid (211 mg, 86%) was isolated by column chromatography (gradient from 93:7 to 90:10 Hex:EtOAc). Mp: 78-80 °C. ¹H NMR (500 MHz, CDCl₃) δ: 7.76 (d, *J* = 7.8 Hz, 2H), 7.25 (d, *J* = 7.8 Hz, 2H), 2.95 (septet, *J* = 6.8 Hz, 1H), 1.34 (s, 12H), 1.26 (d, *J* = 6.8 Hz, 6H) ppm. ¹³C NMR (125 MHz, CDCl₃) δ: 152.5, 135.1, 126.1, 83.7, 34.5, 25.0, 24.0 ppm. ¹¹B NMR (160 MHz, CDCl₃) δ: 30.9 ppm.

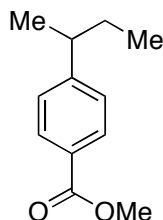


2-(4-(*sec*-Butyl)phenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (Table 2, Row 2, Column 3, Entry 2). The general procedure was employed with the following modification: 30 h reaction time. A white solid (238 mg, 92%) was isolated by column chromatography (gradient from 93:7 to 90:10 Hex:EtOAc). Mp: 88-91 °C. ¹H NMR (500 MHz, CDCl₃) δ: 7.74 (d, *J* = 8.5 Hz, 2H), 7.20 (d, *J* = 8.0 Hz, 2H), 2.60 (m, 1H), 1.60 (m, 2H), 1.34 (s, 12H), 1.23 (d, *J* = 7.3 Hz, 3H), 0.81 (t, *J* = 7.3 Hz, 3H) ppm. ¹³C

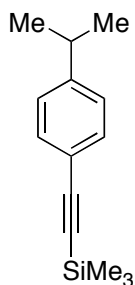
NMR (75 MHz, CDCl₃) δ : 151.3, 135.0, 126.7, 83.7, 42.1, 31.1, 25.0, 21.9, 12.4 ppm. ¹¹B NMR (160 MHz, CDCl₃) δ : 31.0 ppm. IR (neat, cm⁻¹): 3047, 2961, 2930, 2866, 1611, 1460, 1398, 1360, 1323, 1271, 1143, 1107, 1090, 859, 740, 662. Anal. Calcd. for C₁₆H₂₅BO₂: C, 73.86; H, 9.69. Found: C, 74.14; H, 9.64.



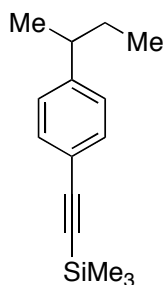
Methyl 4-(*iso*-propyl)benzoate (Table 2, Row 3, Column 1, Entry 1). The general procedure was employed with the following modifications: LiBF₄ (93.7 mg, 1mmol) was weighed out and added to the reaction vial in a nitrogen-filled glove box, 5 mol% NiCl₂ and terpyridine employed, 40 h reaction time. A colorless liquid (163 mg, 91%) was isolated by column chromatography (85:15 Hex:EtOAc). ¹H NMR (500 MHz, CDCl₃) δ : 7.97 (d, *J* = 8.7 Hz, 2H), 7.29 (d, *J* = 8.4 Hz, 2H), 3.90 (s, 3H), 2.96 (septet, *J* = 6.8 Hz, 1H), 1.27 (d, *J* = 6.8 Hz, 6H) ppm. ¹³C NMR (125 MHz, CDCl₃) δ : 167.3, 154.4, 129.9, 127.9, 126.6, 52.1, 34.4, 23.8 ppm.



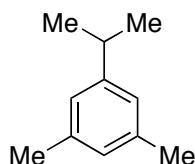
Methyl 4-(*sec*-butyl)benzoate (Table 2, Row 3, Column 1, Entry 2). The general procedure was employed with the following modifications: 5 mol% NiCl₂ and terpyridine employed, 30 h reaction time. A yellow-orange liquid (180 mg, 86%) was isolated by column chromatography (85:15 Hex:EtOAc). ¹H NMR (500 MHz, CDCl₃) δ : 7.96 (d, *J* = 8.3 Hz, 2H), 7.25 (d, *J* = 8.3, 2H), 3.90 (s, 3H), 2.65 (m, 1H), 1.61 (m, 2H), 1.25 (d, *J* = 7.3 Hz, 3H), 0.81 (t, *J* = 7.5 Hz, 3H) ppm. ¹³C NMR (125 MHz, CDCl₃) δ : 167.4, 153.5, 129.8, 127.9, 127.2, 52.1, 41.9, 31.1, 21.7, 12.3 ppm.



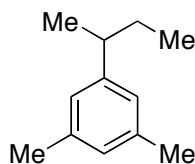
((4-*iso*-Propylphenyl)ethynyl)trimethylsilane (Table 2, Row 3, Column 2, Entry 1). The general procedure was employed with the following modification: 42 h reaction time. A yellow liquid (197 mg, 91%) was isolated by column chromatography (95:5 Hex:Ether). ^1H NMR (500 MHz, CDCl_3) δ : 7.39 (d, $J = 7.8$ Hz, 2H), 7.15 (d, $J = 7.8$ Hz, 2H), 2.89 (septet, $J = 6.9$ Hz, 1H), 1.23 (d, $J = 6.9$ Hz, 6H), 0.24 (s, 9H) ppm. ^{13}C NMR (75 MHz, CDCl_3) δ : 149.7, 132.1, 126.5, 120.6, 105.5, 93.3, 34.2, 23.9, 0.2 ppm.



((4-*sec*-Butylphenyl)ethynyl)trimethylsilane (Table 2, Row 3, Column 2, Entry 2). The general procedure was employed with the following modification: 36 h reaction time. A yellow liquid (215 mg, 93%) was isolated by column chromatography (95:5 Hex:Ether). ^1H NMR (500 MHz, CDCl_3) δ : 7.39 (d, $J = 8.3$ Hz, 2H), 7.10 (d, $J = 8.3$ Hz, 2H), 2.59 (m, 1H), 1.56 (m, 2H), 1.21 (d, $J = 6.8$ Hz, 3H), 0.79 (t, $J = 7.3$ Hz, 3H), 0.24 (s, 9H) ppm. ^{13}C NMR (125 MHz, CDCl_3) δ : 148.5, 132.0, 127.1, 120.5, 105.5, 93.3, 41.8, 31.1, 21.8, 12.3, 0.2 ppm. IR (neat, cm^{-1}): 3081, 3028, 2961, 2929, 2875, 2158, 1501, 1460, 1250, 842, 900, 760. Anal. Calcd. for $\text{C}_{15}\text{H}_{22}\text{Si}$: C, 78.19; H, 9.62. Found: C, 77.55; H, 9.45.

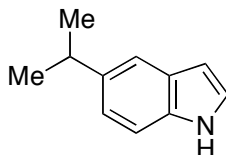


1-(*iso*-Propyl)-3,5-dimethylbenzene (Table 2, Row 3, Column 3, Entry 1). The general procedure was employed with the following modification: ether used for extractions during work-up. A colorless liquid (133 mg, 90%) was isolated by column chromatography (97:3 Hex:Ether). ^1H NMR (500 MHz, CDCl_3) δ : 6.87 (m, 3H), 2.87 (septet, $J = 6.8$ Hz), 2.33 (s, 6H), 1.27 (d, $J = 6.8$ Hz, 6H) ppm. ^{13}C NMR (125 MHz, CDCl_3) δ : 150.0, 137.9, 127.6, 124.4, 34.1, 24.2, 21.5 ppm.

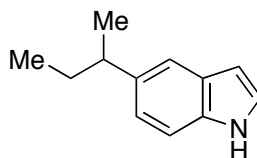


1-(*sec*-butyl)-3,5-dimethylbenzene (Table 2, Row 3, Column 3, Entry 2). The general procedure was employed with the following modification: ether used for extractions during work-up. A colorless liquid (149 mg, 92%) was isolated by column chromatography (97:3 Hex:Ether). ^1H NMR (500 MHz, CDCl_3) δ : 6.86 (s, 1H), 6.83 (s,

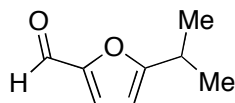
2H), 2.54 (app. sextet, $J = 7.3$ Hz, 1H), 2.33 (s, 6H), 1.61 (m, 2H), 1.24 (d, $J = 6.8$ Hz, 3H), 0.86 (t, $J = 7.3$ Hz, 3H) ppm. ^{13}C NMR (125 MHz, CDCl_3) δ : 147.9, 137.7, 127.6, 125.0, 41.7, 31.3, 22.0, 21.5, 12.5 ppm.



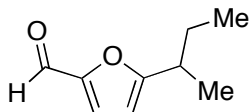
5-(*iso*-Propyl)-1H-indole (Table 2, Row 4, Column 1, Entry 1). The general procedure was employed with the following modifications: 2.5 equiv. alkylzinc reagent employed, 5 mol% NiCl_2 and terpyridine employed, 48 h reaction time. A yellow-brown liquid (120 mg, 75%) was isolated by column chromatography (gradient from 75:25 to 70:30 Hex:EtOAc). ^1H NMR (500 MHz, CDCl_3) δ : 8.04 (bs, 1H), 7.51 (s, 1H), 7.33 (d, $J = 8.4$ Hz, 1H), 7.18 (t, $J = 2.8$ Hz, 1H), 7.12 (dd, $J = 8.4$ Hz, 1.6 Hz, 1H), 6.52 (m, 1H), 3.03 (septet, $J = 6.9$ Hz, 1H), 1.33 (d, $J = 6.9$ Hz, 6H) ppm. ^{13}C NMR (125 MHz, CDCl_3) δ : 140.6, 134.5, 128.1, 124.4, 121.4, 117.7, 110.9, 102.5, 34.3, 24.8 ppm.



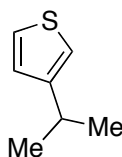
5-(*sec*-Butyl)-1H-indole (Table 2, Row 4, Column 1, Entry 2). The general procedure was employed with the following modifications: 2.5 equiv. alkylzinc reagent employed, 5 mol% NiCl_2 and terpyridine employed, 48 h reaction time. A yellow liquid (130mg, 75 %) was isolated by column chromatography (gradient from 75:25 to 70:30 Hex:EtOAc). ^1H NMR (500 MHz, CDCl_3) δ : 8.04 (bs, 1H), 7.47 (s, 1H), 7.33 (d, $J = 8.3$ Hz, 1H), 7.18 (m, 1H), 7.08 (dd, $J = 8.8$ Hz, 1.5 Hz, 1H), 6.52 (m, 1H), 2.71 (m, 1H), 1.67 (m, 2H), 1.32 (d, $J = 6.8$ Hz, 3H), 0.87 (t, $J = 7.3$ Hz, 3H) ppm. ^{13}C NMR (125 MHz, CDCl_3) δ : 139.3, 134.5, 128.0, 124.3, 121.8, 118.6, 110.8, 102.4, 41.9, 31.8, 22.7, 12.6 ppm. IR (neat, cm^{-1}): 3415, 2960, 2927, 2872, 1475, 1455, 1414, 1354, 1092, 894, 805, 726. Anal. Calcd. for $\text{C}_{12}\text{H}_{15}\text{N}$: C, 83.19; H, 8.73. Found: C, 82.76; H, 8.87.



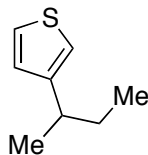
5-(*iso*-Propyl)furan-2-carbaldehyde (Table 2, Row 4, Column 2, Entry 1). The general procedure was employed with the following modification: 12 h reaction time. A brown oil (111 mg, 73%) was isolated by column chromatography (gradient from 75:25 to 70:30 Hex:EtOAc). ^1H NMR (300 MHz, CDCl_3) δ : 9.52 (s, 1H), 7.17 (d, $J = 3.3$ Hz, 1H), 6.22 (d, $J = 3.3$ Hz, 1H), 3.04 (septet, $J = 6.9$ Hz, 1H), 1.31 (d, $J = 6.9$ Hz, 6H) ppm. ^{13}C NMR (125 MHz, CDCl_3) δ : 177.2, 169.1, 151.8, 123.6, 106.8, ppm.



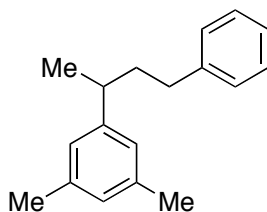
5-(*sec*-Butyl)furan-2-carbaldehyde (Table 2, Row 4, Column 2, Entry 2). The general procedure was employed with the following modifications: 5 mol% NiCl₂ and terpyridine employed, 22 h reaction time. A brown oil (118 mg, 71%) was isolated by column chromatography (gradient from 75:25 to 70:30 Hex:EtOAc). ¹H NMR (300 MHz, CDCl₃) δ: 9.50 (s, 1H), 7.15 (d, *J* = 3.5 Hz, 1H), 6.20 (d, *J* = 3.5 Hz, 1H), 2.81 (app. sextet, *J* = 6.9 Hz, 1H), 1.66 (m, 2H), 1.26 (d, *J* = 7.1 Hz, 2H), 0.87 (t, *J* = 7.4 Hz, 3H) ppm. ¹³C NMR (75 MHz, CDCl₃) δ: 177.1, 168.2, 151.8, 123.5, 107.6, 35.3, 28.4, 18.3, 11.5 ppm.



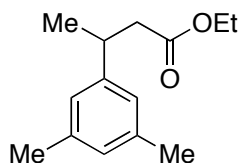
3-(*iso*-Propyl)thiophene (Table 2, Row 4, Column 3, Entry 1). The general procedure was employed with the following modifications: LiBF₄ (93.7 mg, 1mmol) was weighed out and added to the reaction vial in a nitrogen-filled glove box, 5 mol% NiCl₂ and terpyridine employed, 19 h reaction time, ether used for extractions during work-up. A pale yellow liquid (77 mg, 61%) was isolated by column chromatography (95:5 Hex:Ether). ¹H NMR (500 MHz, CDCl₃) δ: 7.25 (dd, *J* = 5.0, 2.9 Hz, 1H), 7.01 (dd, *J* = 5.0, 1.3 Hz, 1H), 6.95 (m, 1H), 2.99 (septet, *J* = 6.9 Hz, 1H), 1.27 (d, *J* = 6.9 Hz, 6H) ppm. ¹³C NMR (125 MHz, CDCl₃) δ: 150.0, 127.1, 125.3, 118.3, 29.8, 23.8 ppm



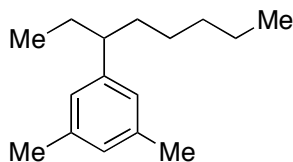
3-(*sec*-Butyl)thiophene (Table 2, Row 4, Column 3, Entry 2). The general procedure was employed with the following modifications: 5 mol% NiCl₂ and terpyridine employed, 26 h reaction time, ether used for extractions during work-up. A pale yellow liquid (77 mg, 61%) was isolated by column chromatography (95:5 Hex:Ether). ¹H NMR (500 MHz, CDCl₃) δ: 7.26 (m, 1H), 6.99 (dd, *J* = 5.0, 1.3 Hz, 1H), 6.95 (m, 1H), 2.78 (app. sextet, *J* = 7.0 Hz, 2H), 1.62 (m, 2H), 1.27 (d, *J* = 7.0 Hz, 3H), 0.88 (t, *J* = 7.4 Hz, 3H) ppm. ¹³C NMR (125 MHz, CDCl₃) δ: 148.7, 127.0, 125.1, 119.0, 37.0, 31.1, 21.4, 12.1 ppm.



1,3-Dimethyl-5-(4-phenylbutan-2-yl)benzene (Table 3, Row 1, Column 1). The general procedure was employed with the following modifications: 1.3 equiv of alkylzinc reagent employed, reaction conducted at 80 °C, 15 h reaction time, ether used for extractions during work-up. A colorless liquid (215 mg, 90 %) was isolated by column chromatography (95:5 Hex:Ether). ¹H NMR (500 MHz, CDCl₃) δ: 7.29 (m, 2H), 7.18 (m, 3H), 6.86 (m, 3H), 2.69 (m, 1H), 2.58 (m, 2H), 2.35 (s, 3H), 1.88–2.01 (m, 2H), 1.30 (d, *J* = 6.8 Hz) ppm. ¹³C NMR (125 MHz, CDCl₃) δ: 147.5, 142.8, 137.9, 128.5, 128.4, 127.8, 125.7, 125.0, 40.1, 39.6, 34.2, 22.6, 21.5 ppm. IR (neat, cm⁻¹): 3085, 3062, 3026, 2960, 2917, 1605.3, 1496, 1454, 847, 746, 699. Anal. Calcd. for C₁₈H₂₂: C, 90.70; H, 9.30. Found: C, 90.86; H, 9.28.



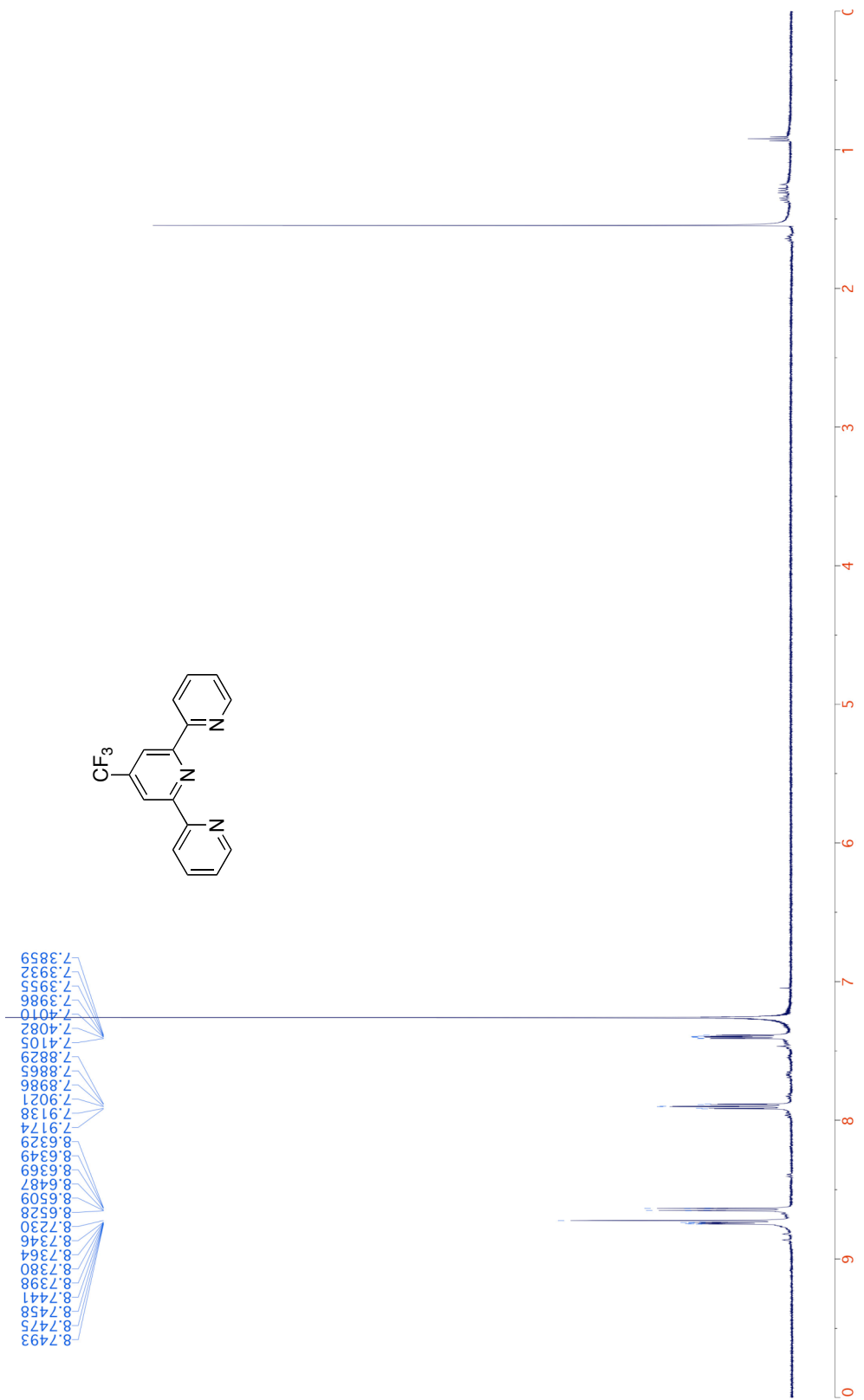
Ethyl 3-(3,5-dimethylphenyl)butanoate (Table 3, Row 1, Column 2). The general procedure was employed with the following modifications: 5 mol% NiCl₂ and terpyridine employed, 15 h reaction time, reaction conducted at 80 °C. ¹H NMR (500 MHz, CDCl₃) δ: 6.84 (app. s, 3H), 4.10 (q, *J* = 7.3 Hz, 2H), 3.21 (m, 1H), 2.50–2.60 (m, 2H), 2.30 (s, 6H), 1.28 (d, *J* = 6.8 Hz, 3H), 1.21 (t, *J* = 7.3 Hz, 3H) ppm. ¹³C NMR (125 MHz, CDCl₃) δ: 172.6, 145.9, 138.0, 128.1, 124.7, 60.3, 43.2, 36.5, 21.9, 21.5, 14.3 ppm. IR (neat, cm⁻¹): 2967, 2920, 2872, 1736, 1606, 1462, 1286, 1176, 1159, 1030, 847, 704. Anal. Calcd. for C₁₄H₂₀O₂: C, 76.33; H, 9.15. Found: C, 76.53; H, 9.26.

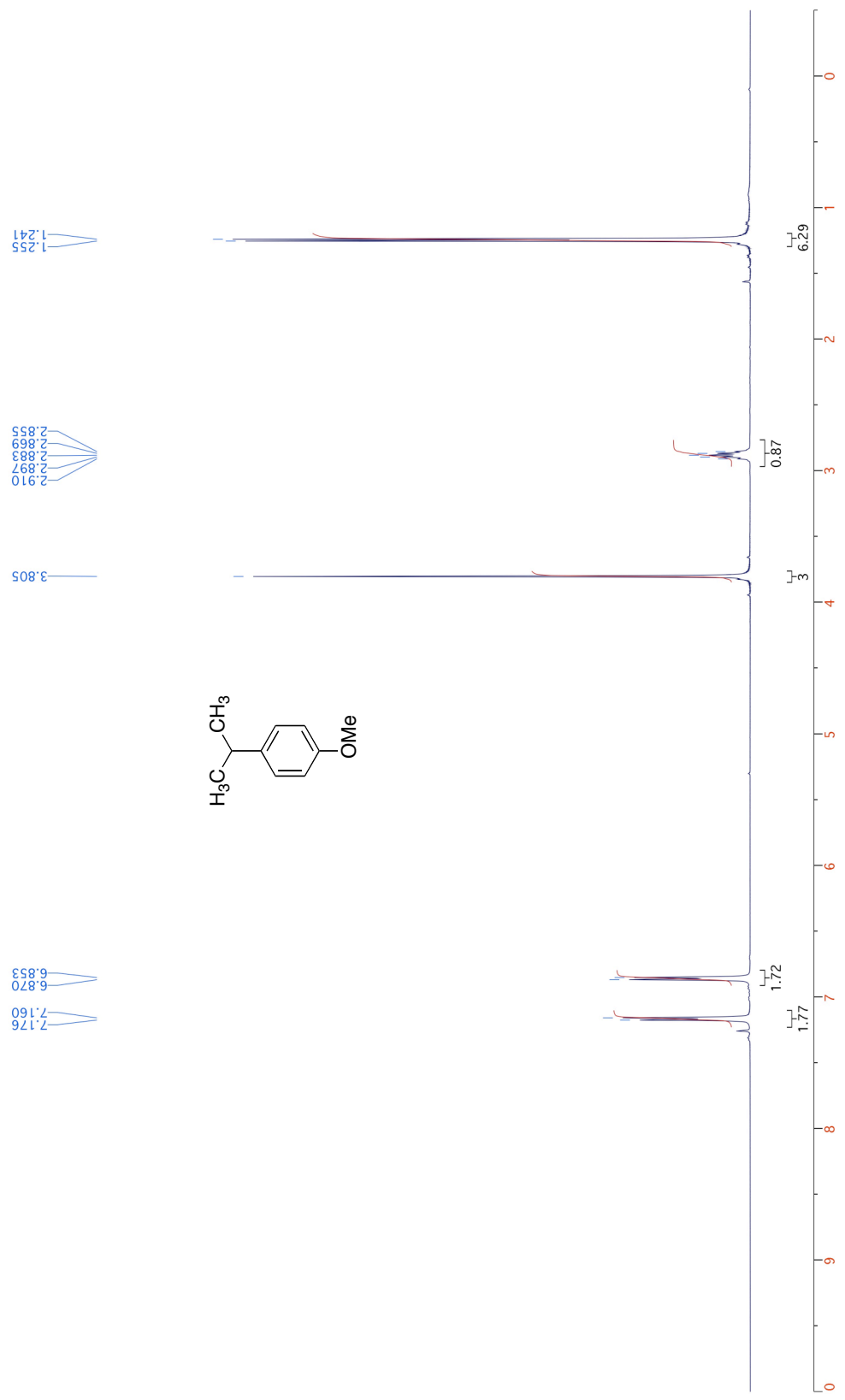


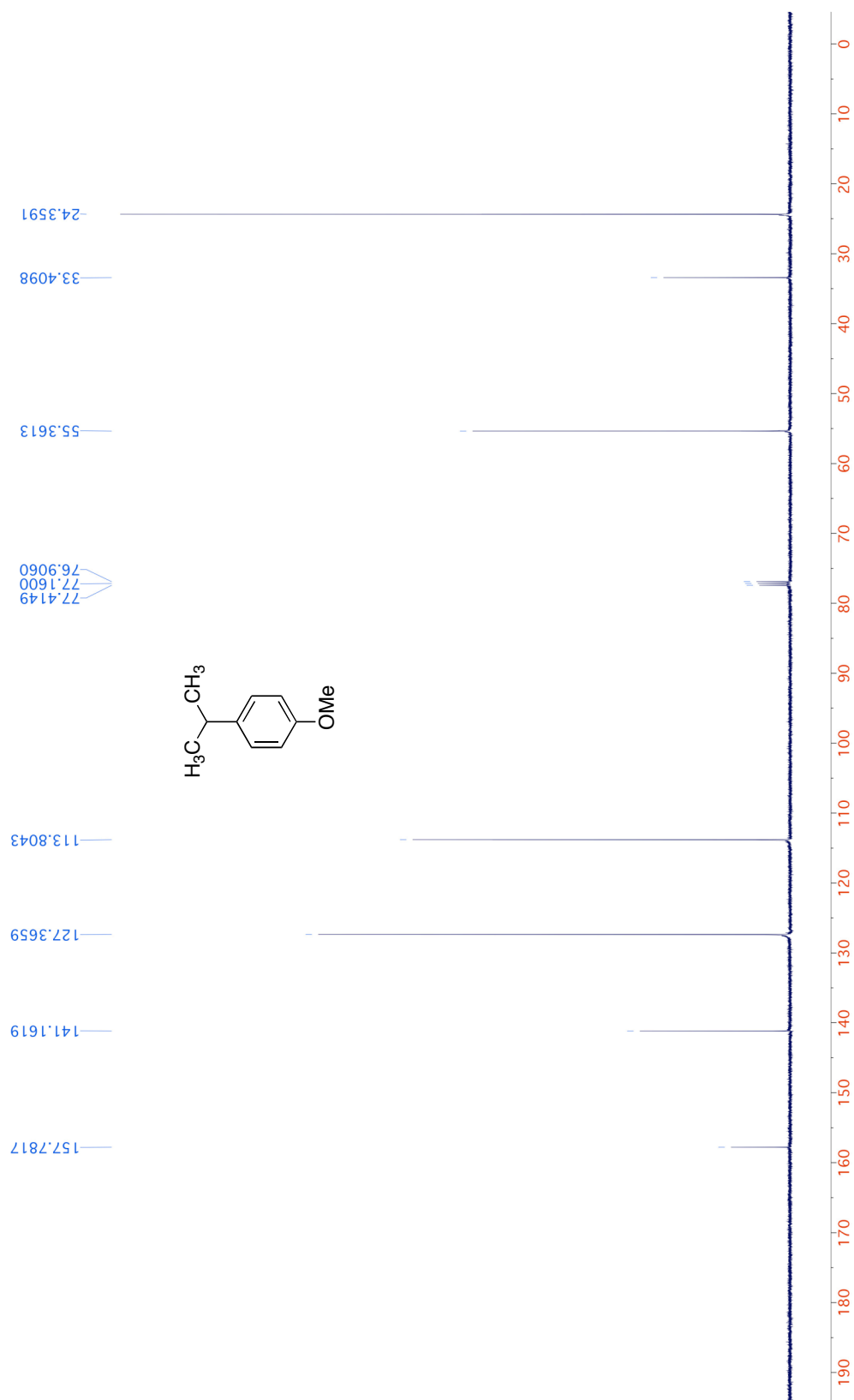
1,3-Dimethyl-5-(octan-3-yl)benzene (Table 3, Row 1, Column 3). The general procedure was employed with the following modifications: 5 mol% NiCl₂ and terpyridine employed, 15 h reaction time, reaction conducted at 80 °C, ether used for extractions during work-up. A pale yellow liquid (199 mg, 91 %) was isolated by column chromatography (95:5 Hex:Ether). ¹H NMR (500 MHz, CDCl₃) δ: 6.84 (s, 1H), 6.76 (s, 2H), 2.34 (m, 1H), 2.32 (s, 6H), 1.60–1.68 (m, 2H), 1.52–1.58 (m, 2H), 1.18–1.28 (m, 6H), 0.87 (t, *J* = 6.8 Hz, 3H), 0.79 (t, *J* = 7.3 Hz, 3H) ppm. ¹³C NMR (125 MHz, CDCl₃) δ: 146.3, 137.5, 127.5, 125.7, 47.9, 36.6, 32.2, 29.8, 27.5, 22.7, 21.5, 14.3, 12.4 ppm.

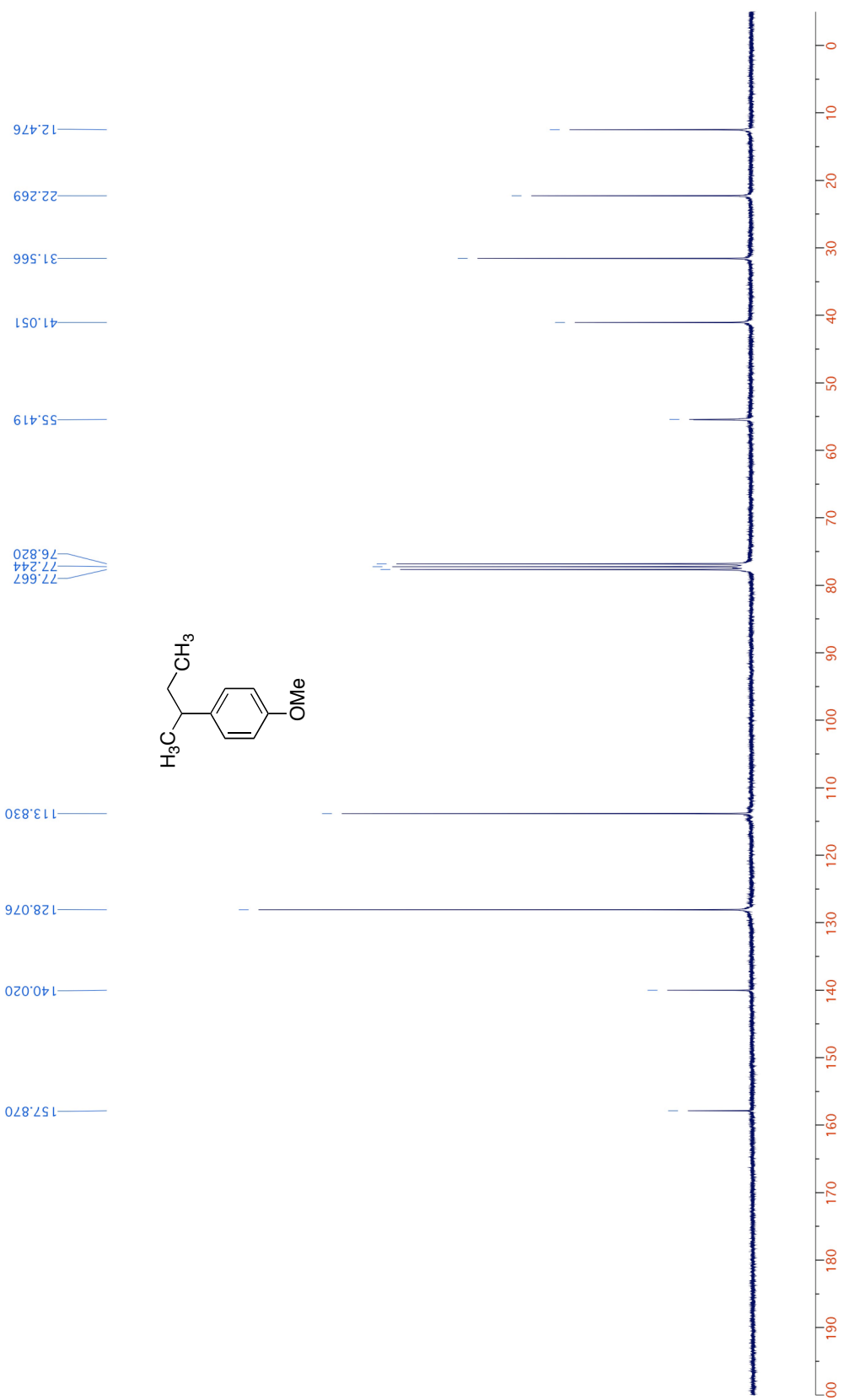
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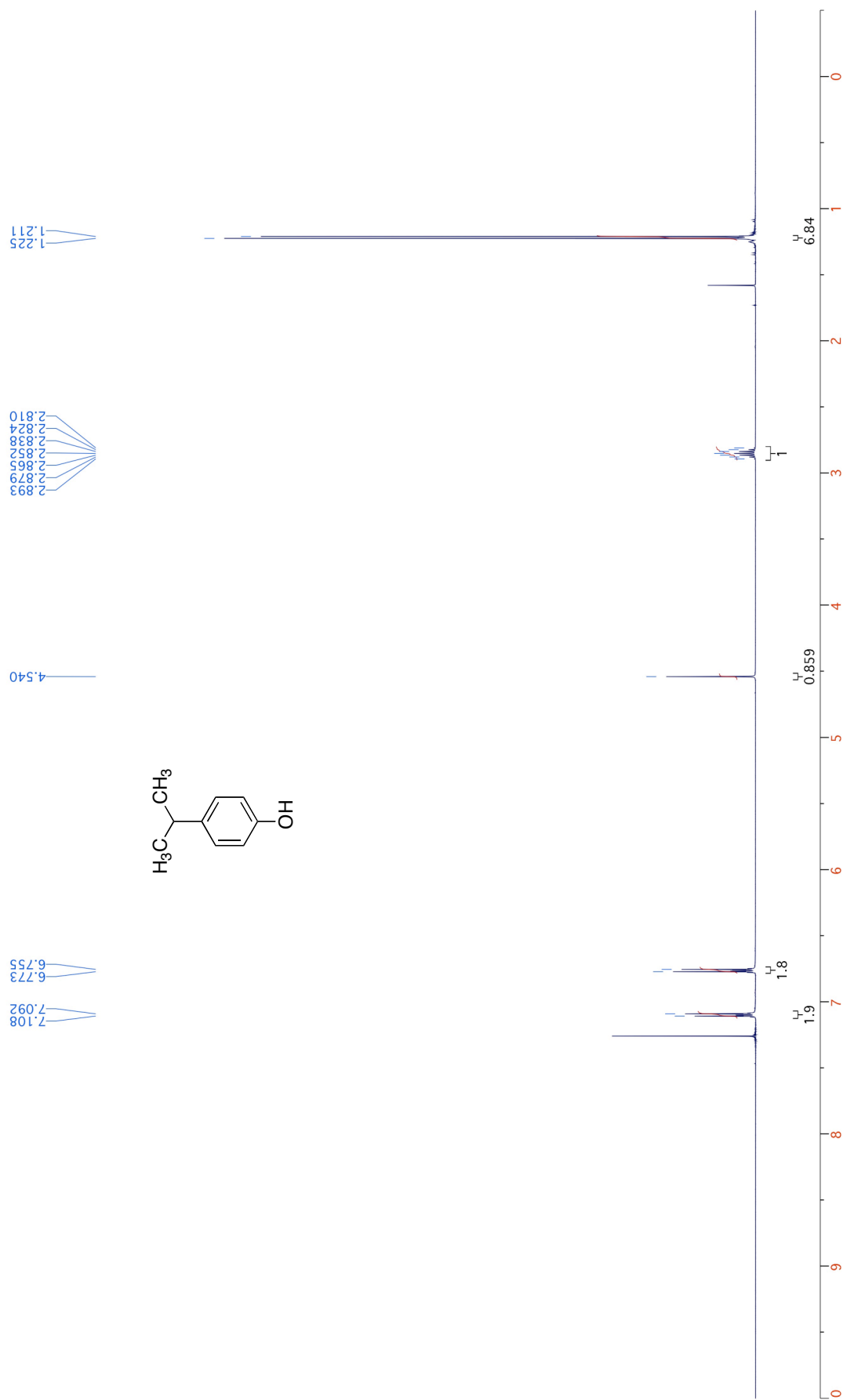
- 1) Smith, S. W.; Fu, G. C. *Angew. Chem. Int. Ed.* **2008**, 47, 9334-9336.
- 2) Krasovskiy, A.; Knochel, P. *Synthesis* **2006**, 5, 890-891.
- 3) Fallahpour, R.; Neuburger, M.; Zehnder, M. *New J. Chem.* **1999**, 23, 53-61.

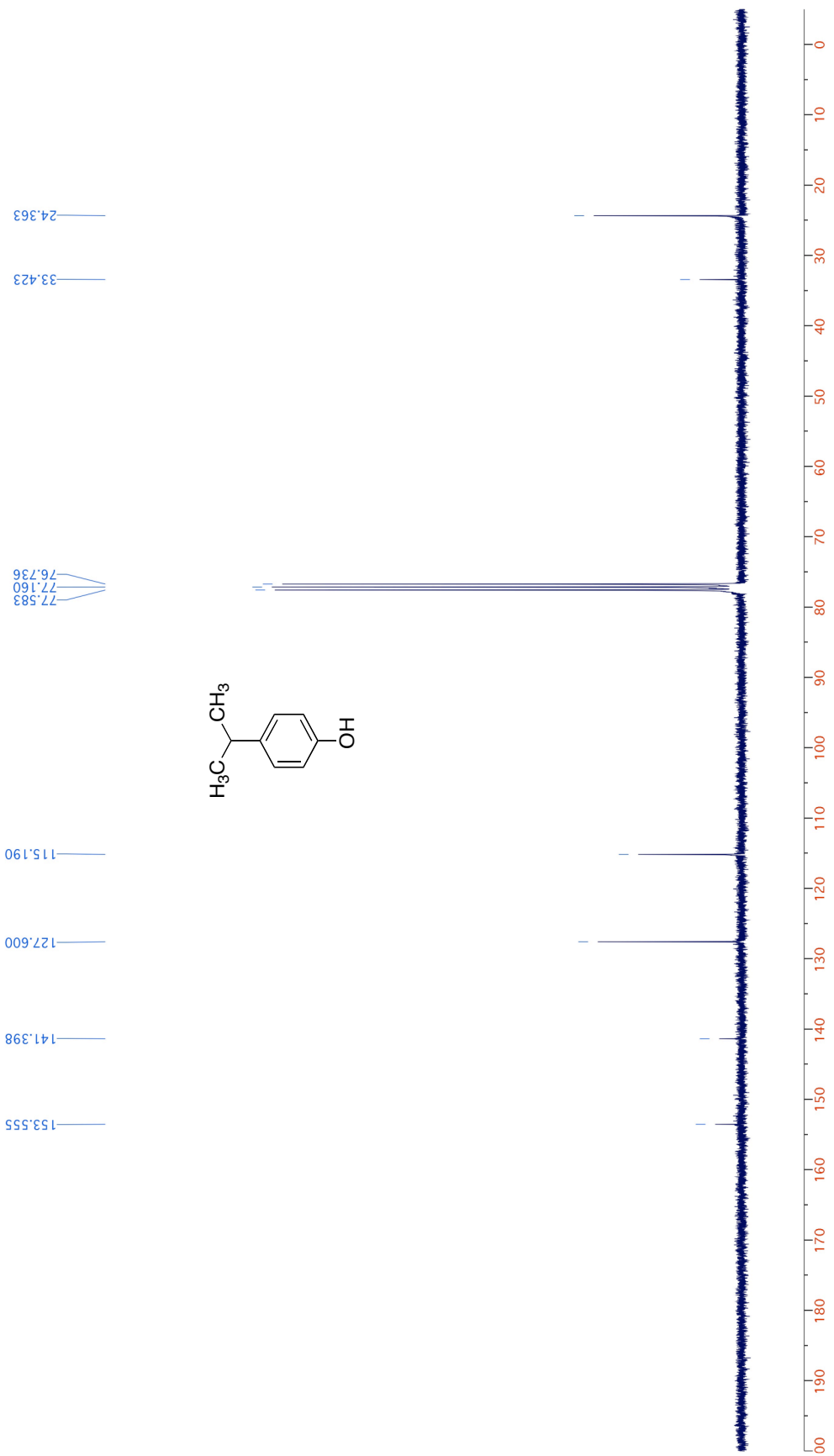


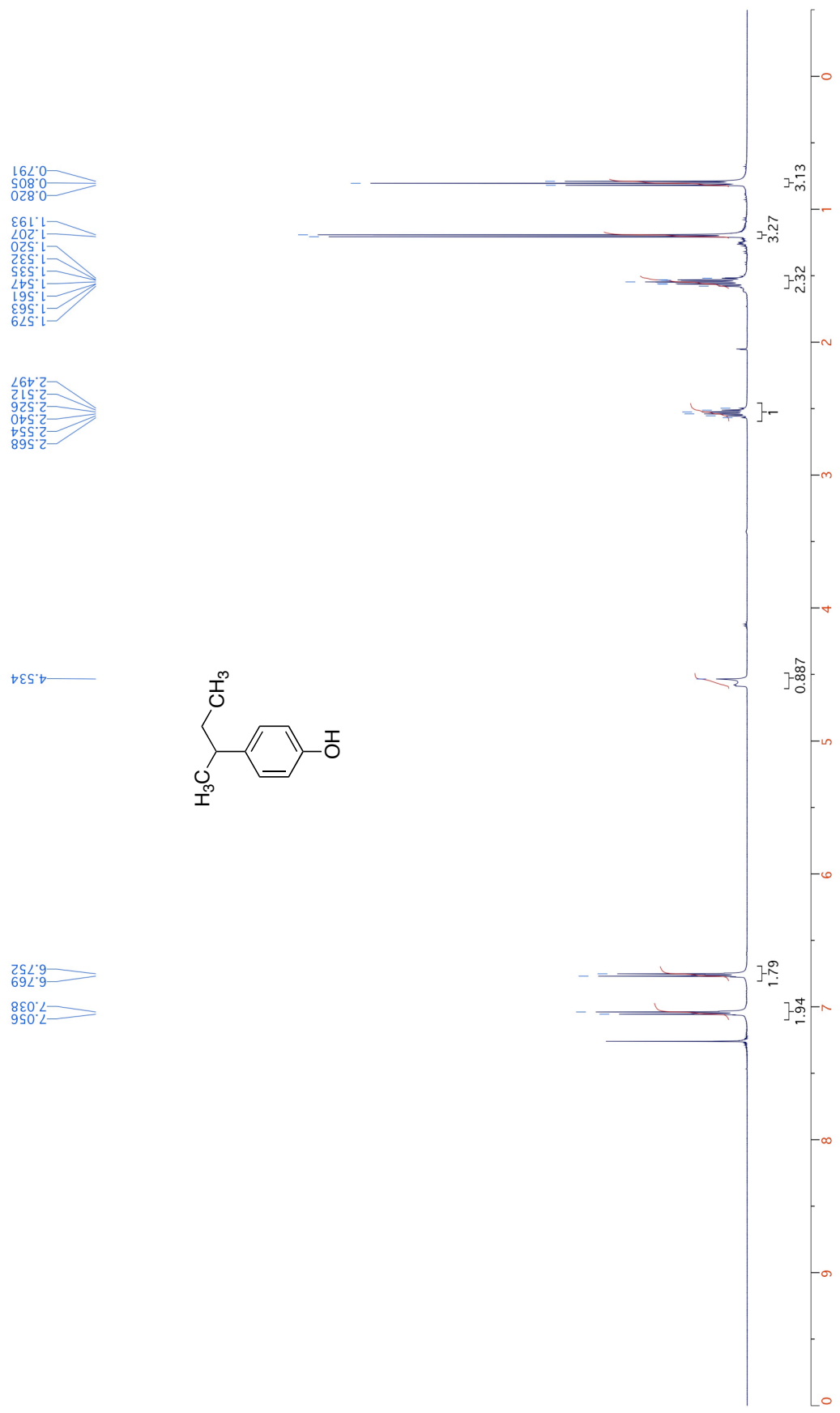




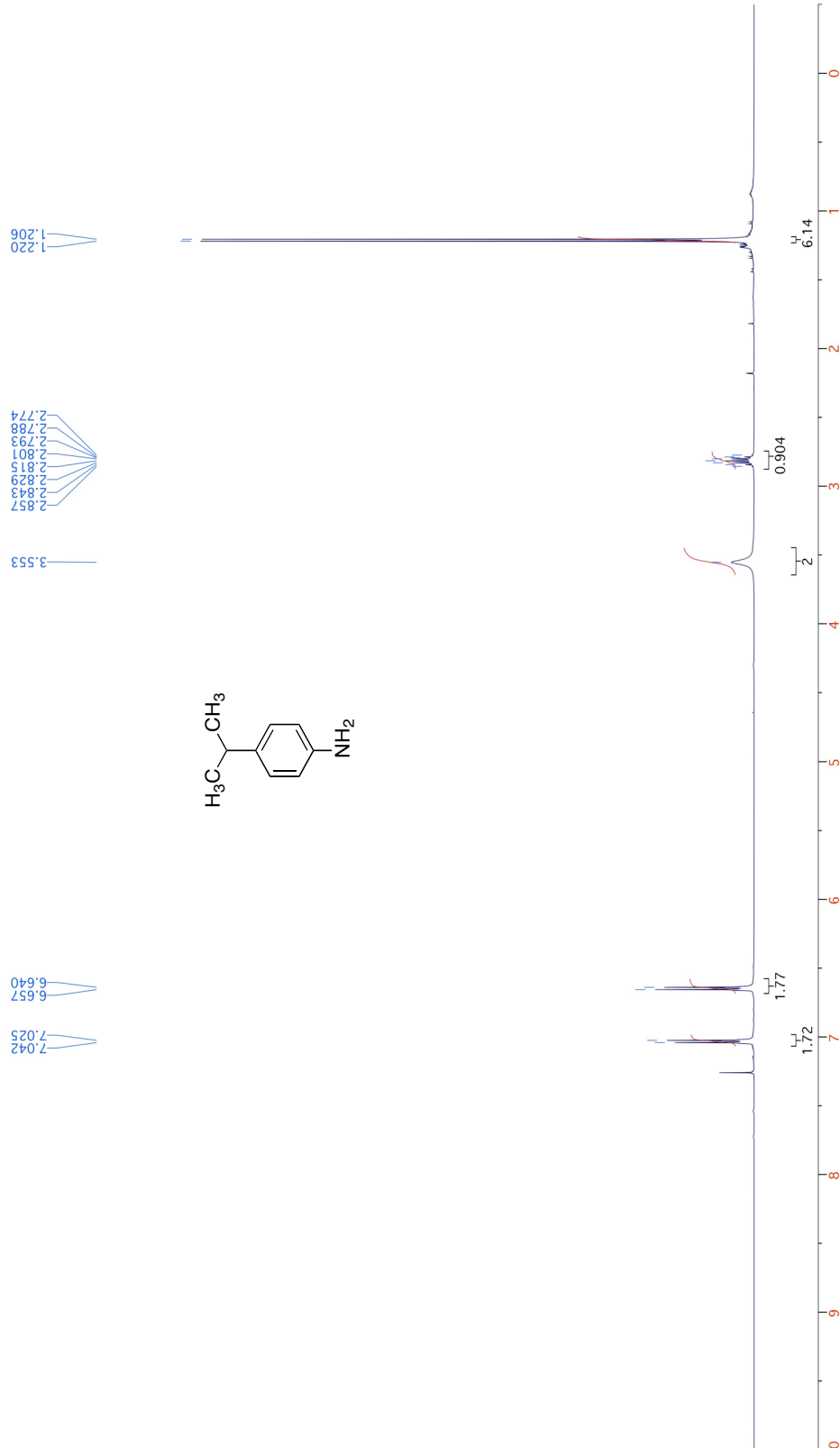


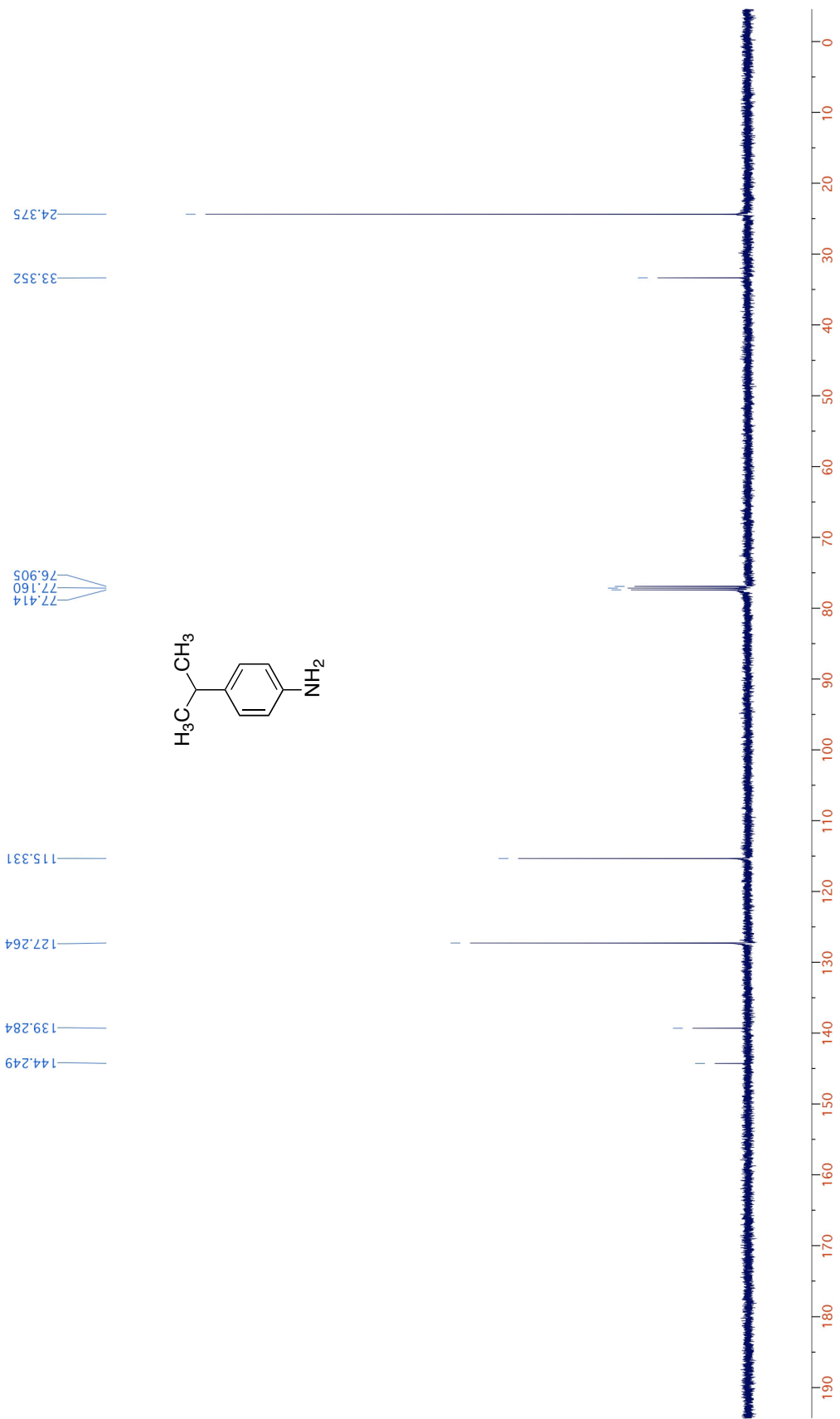


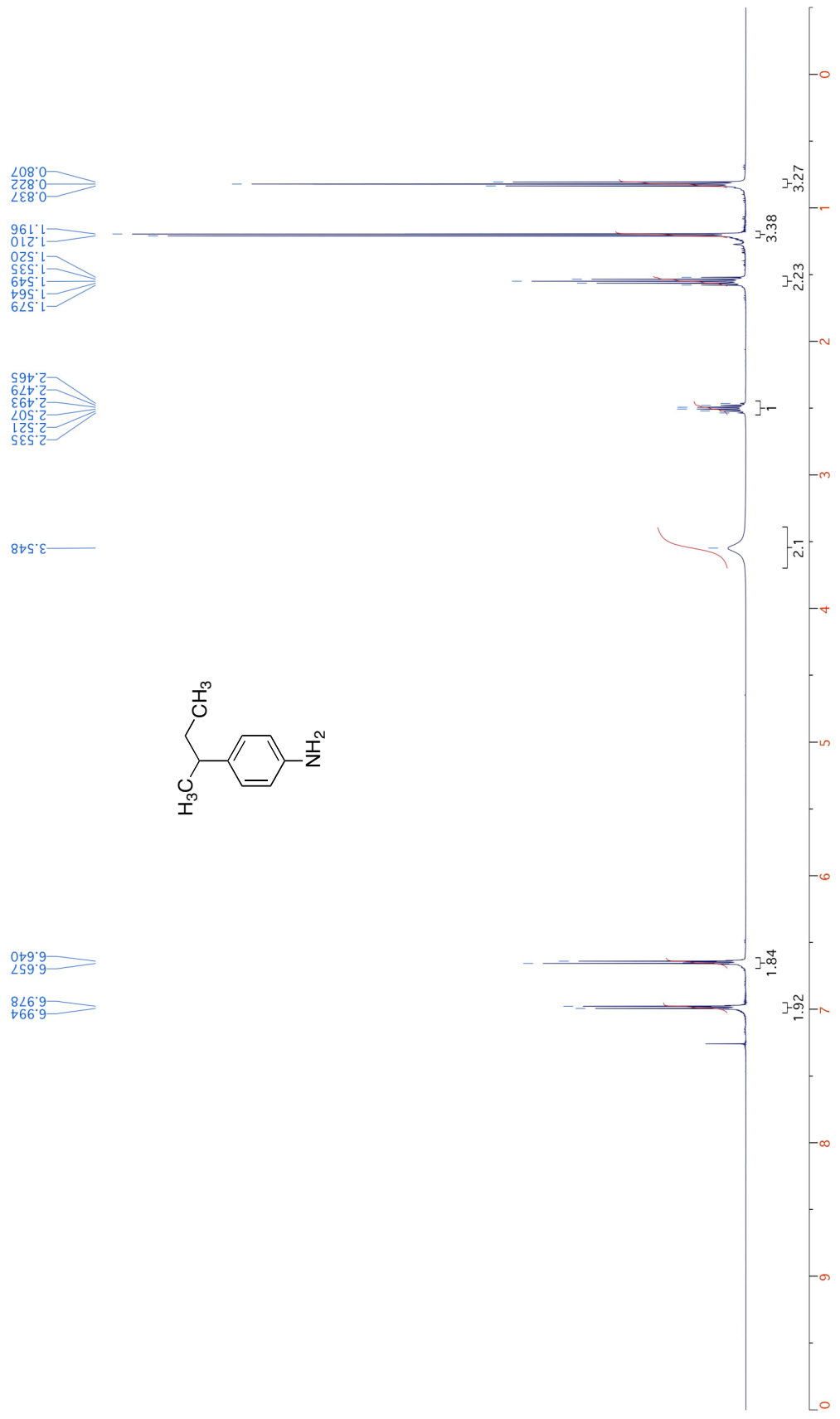


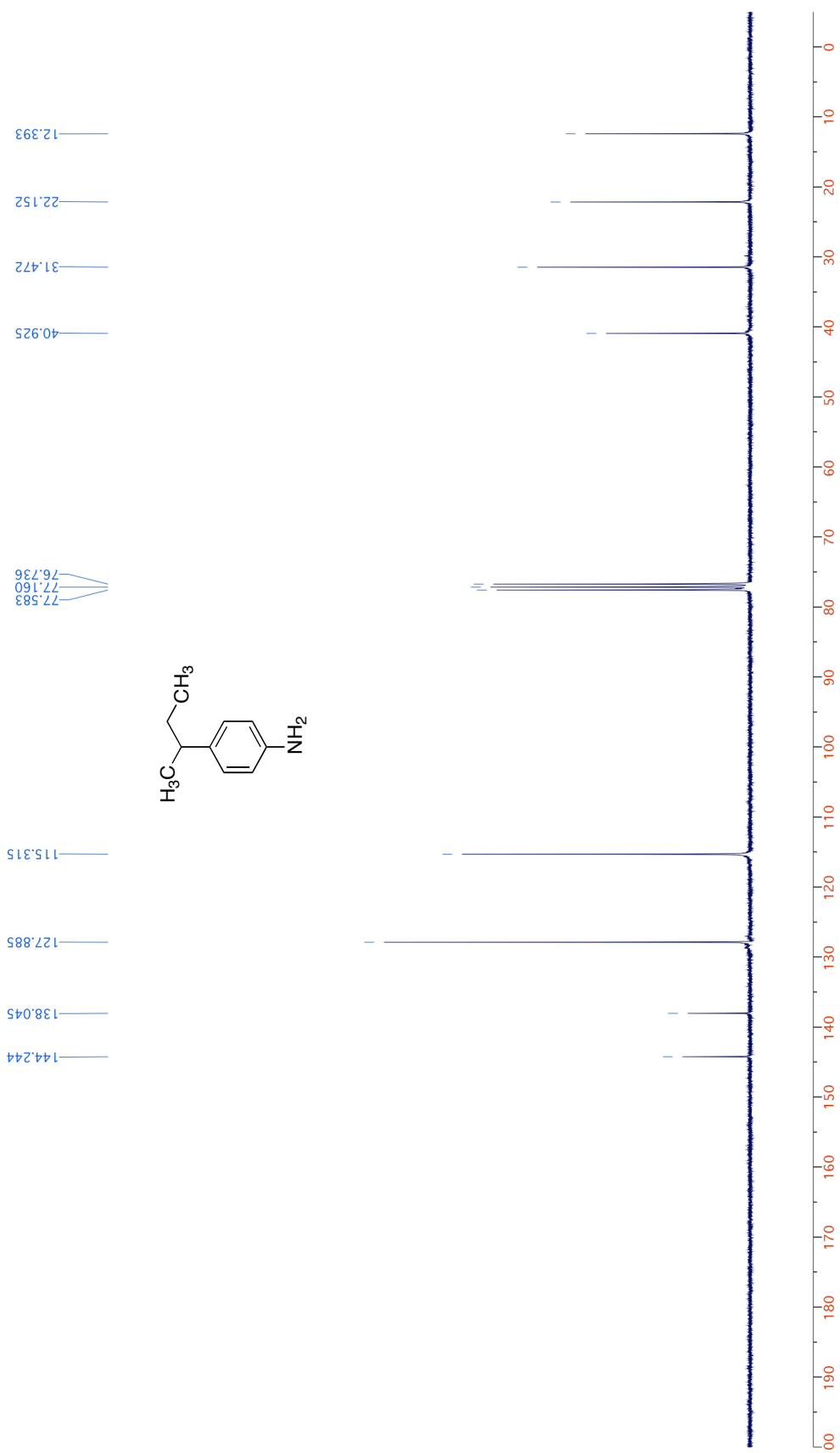


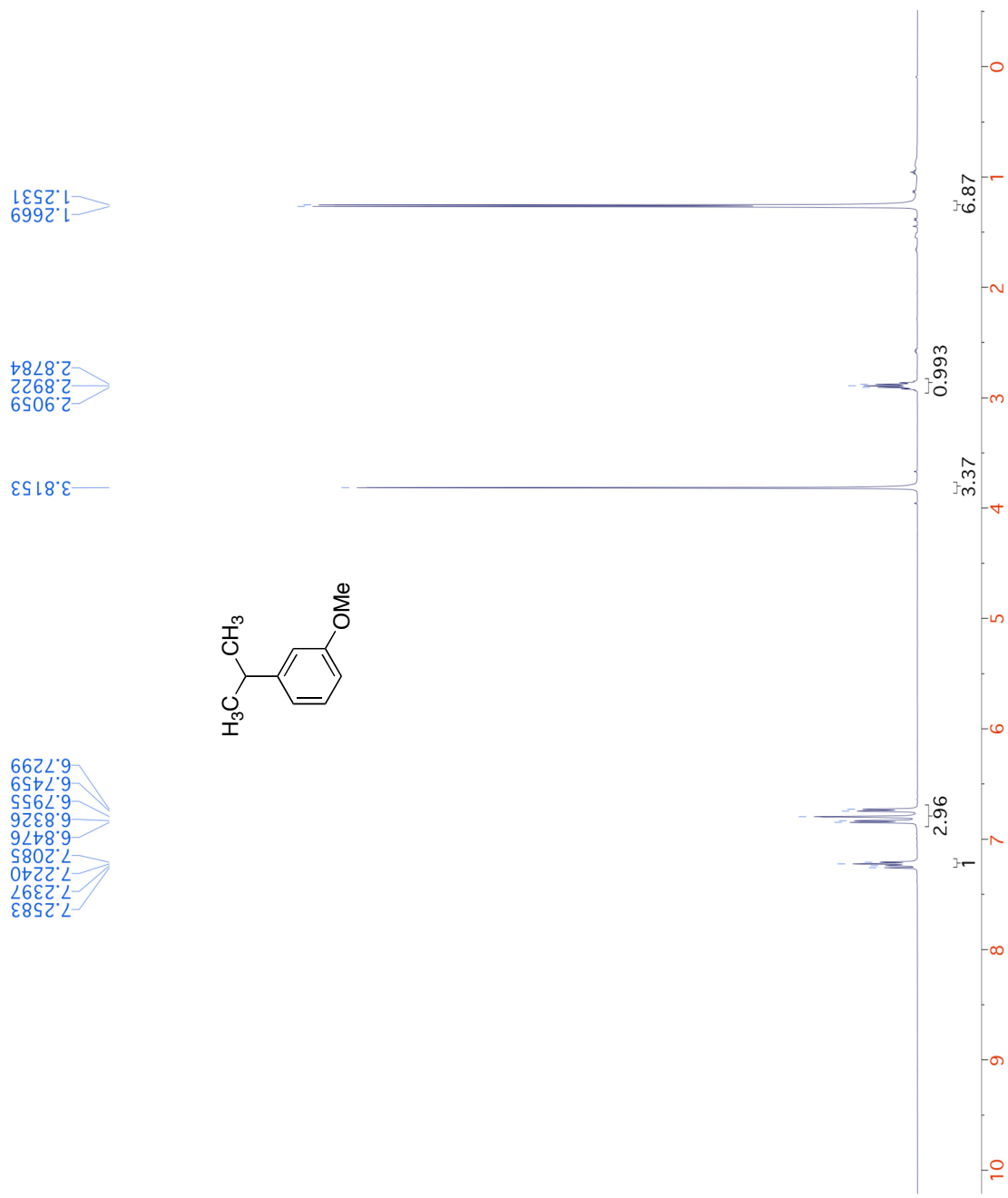


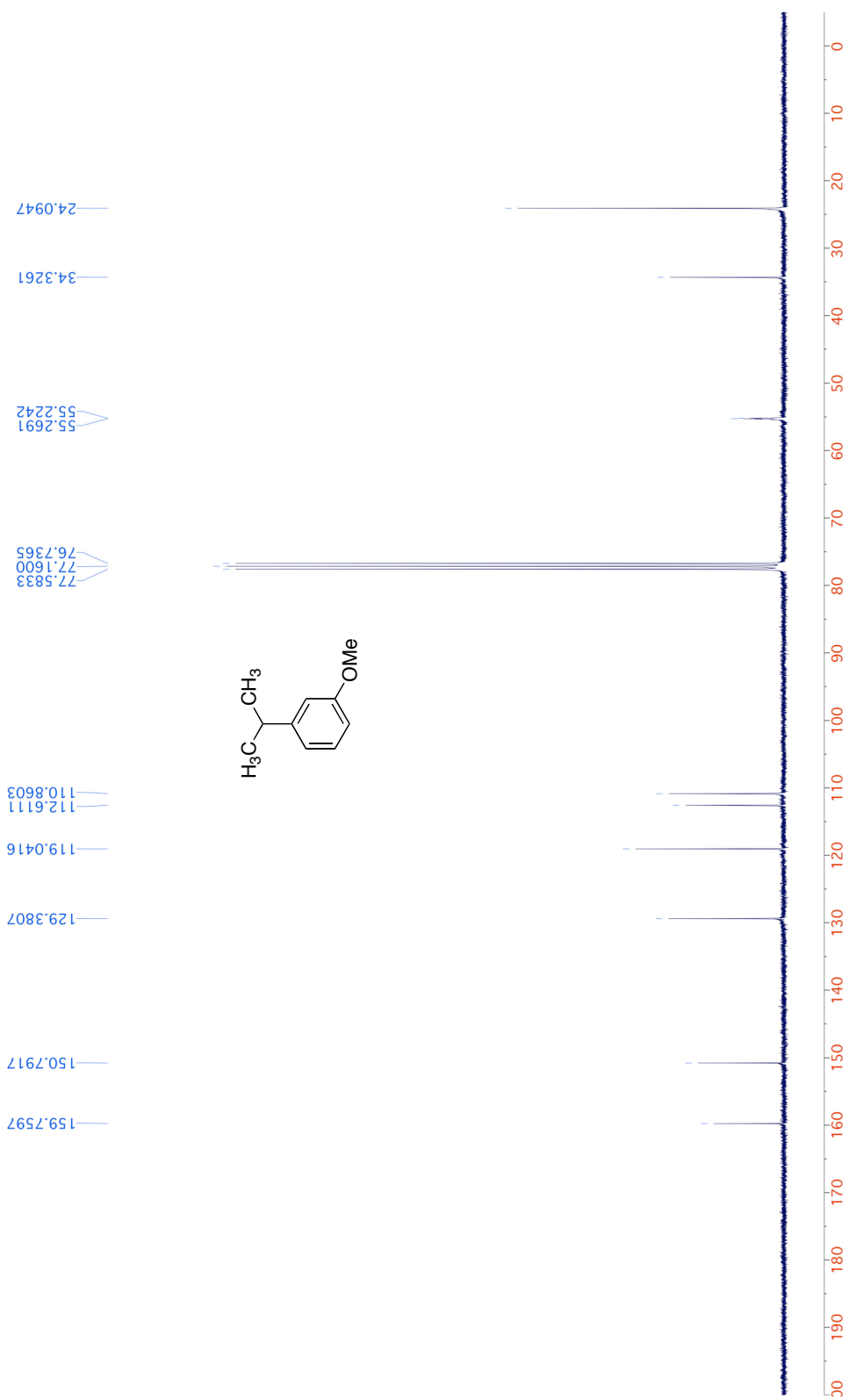


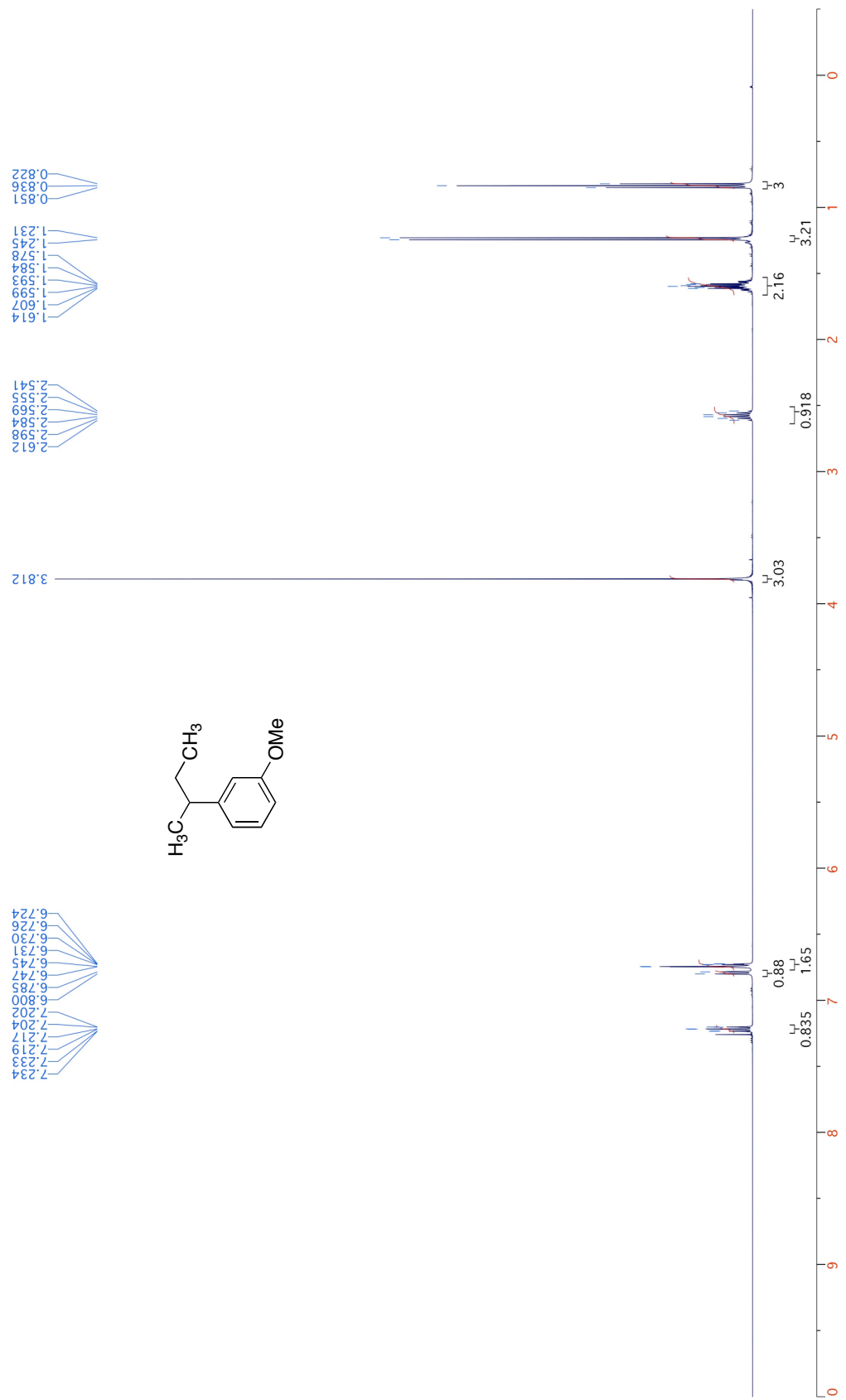


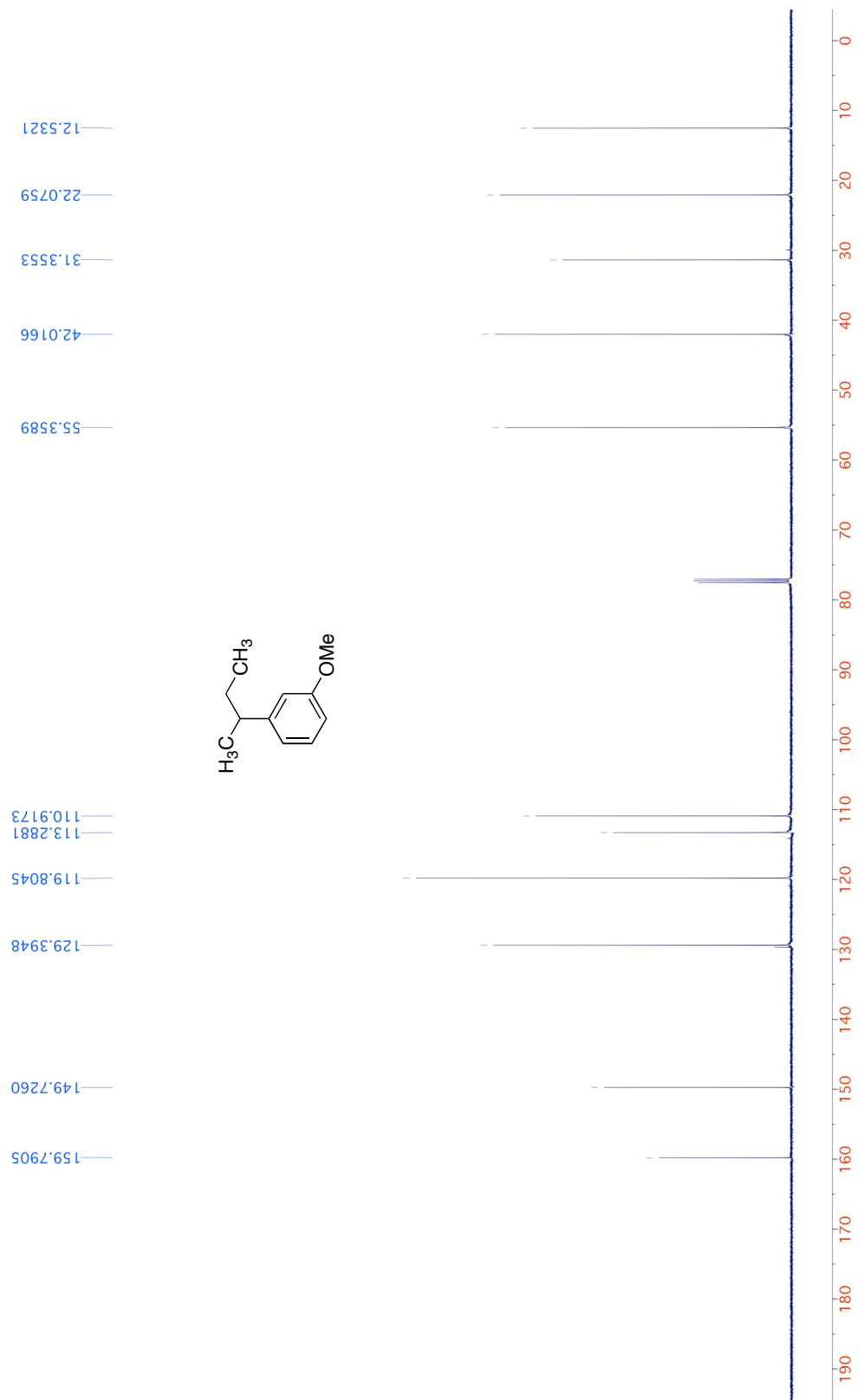


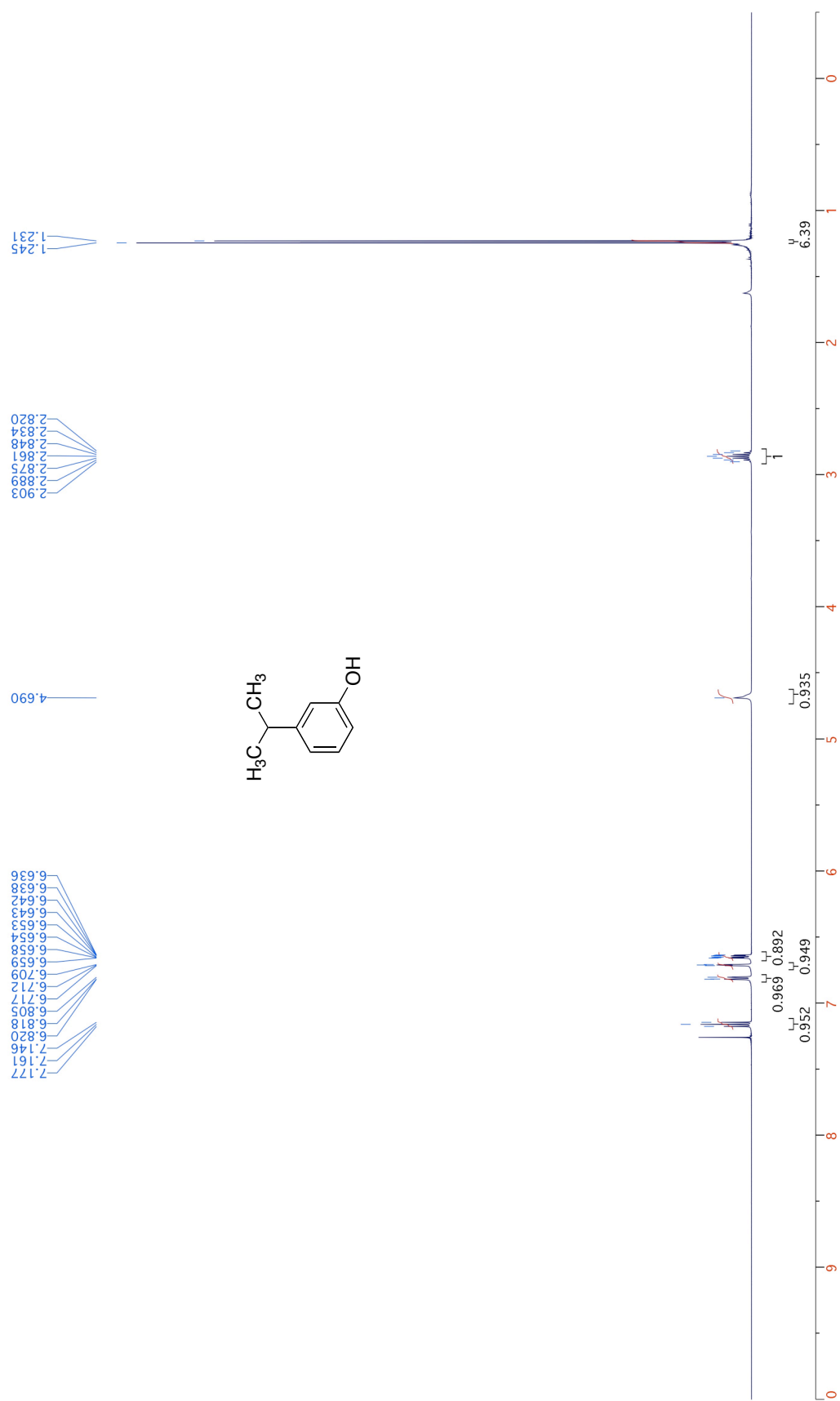


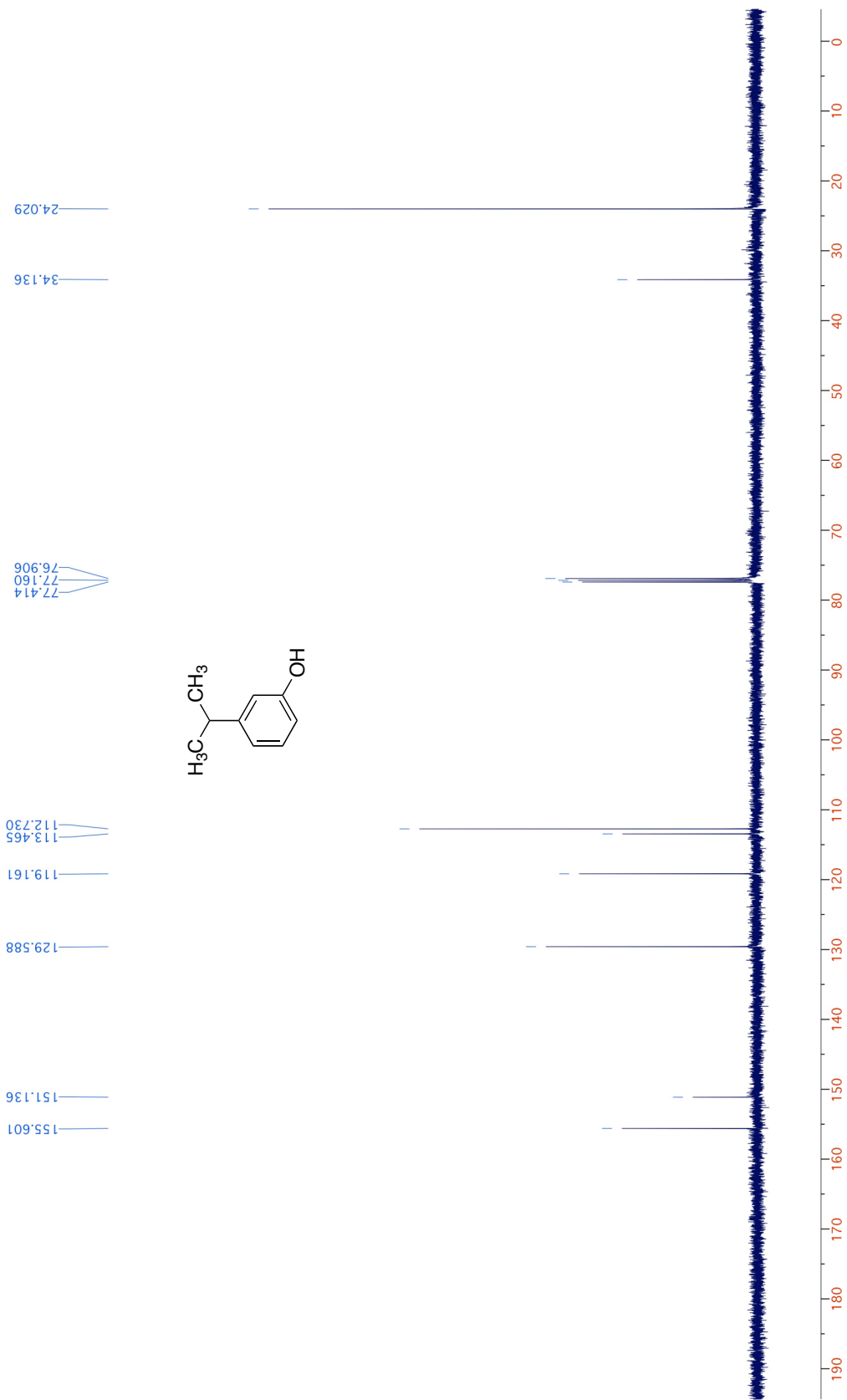


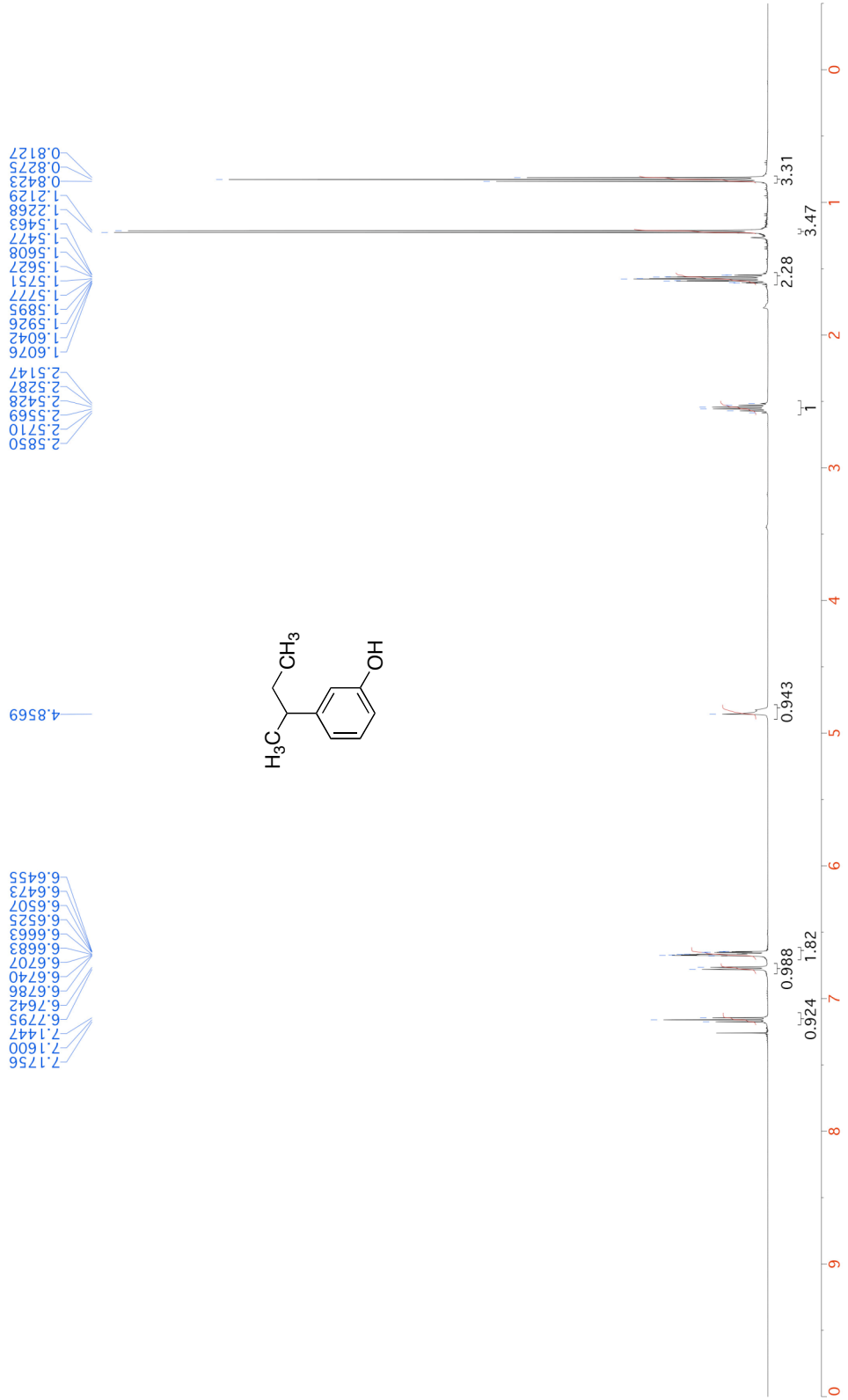


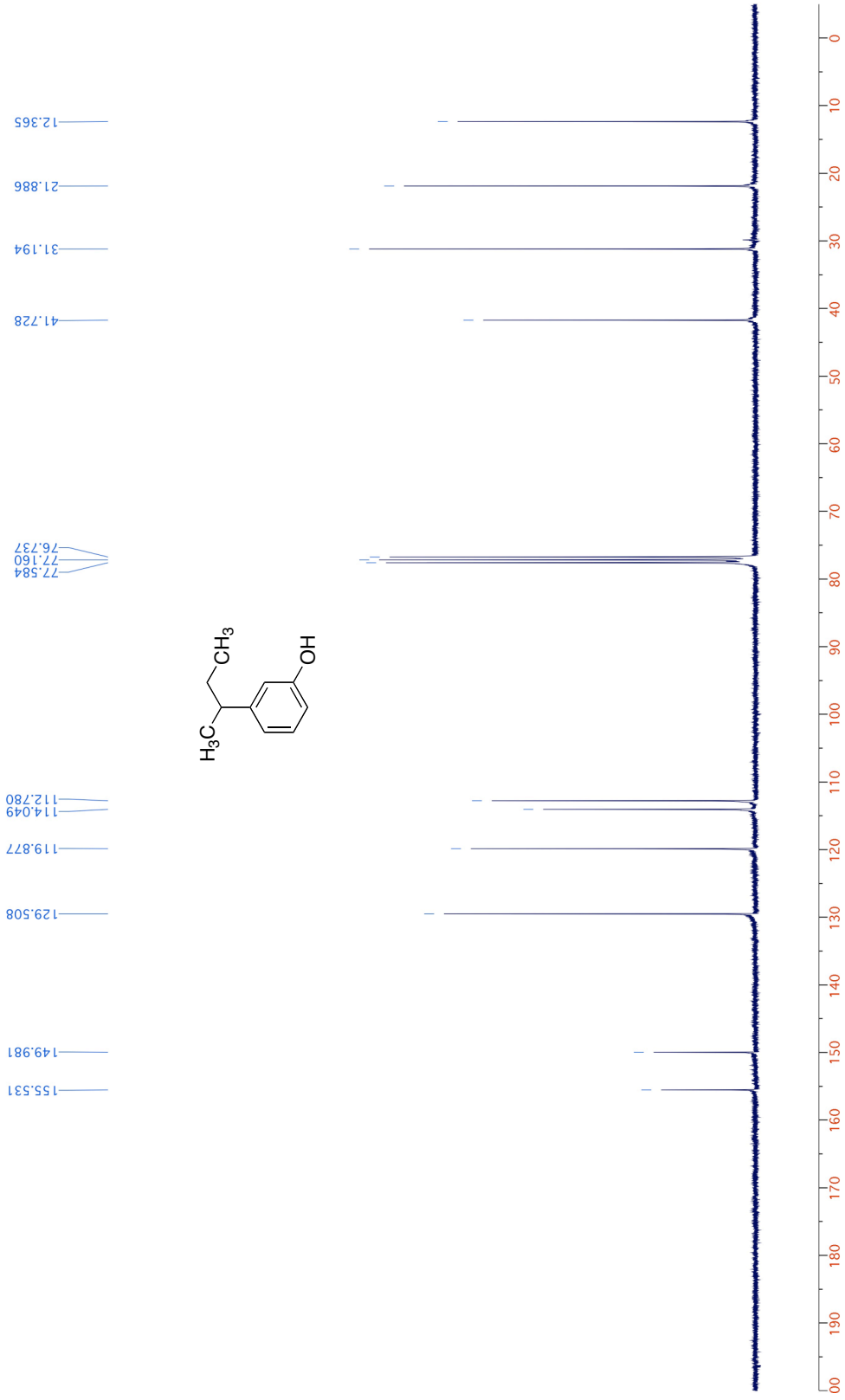


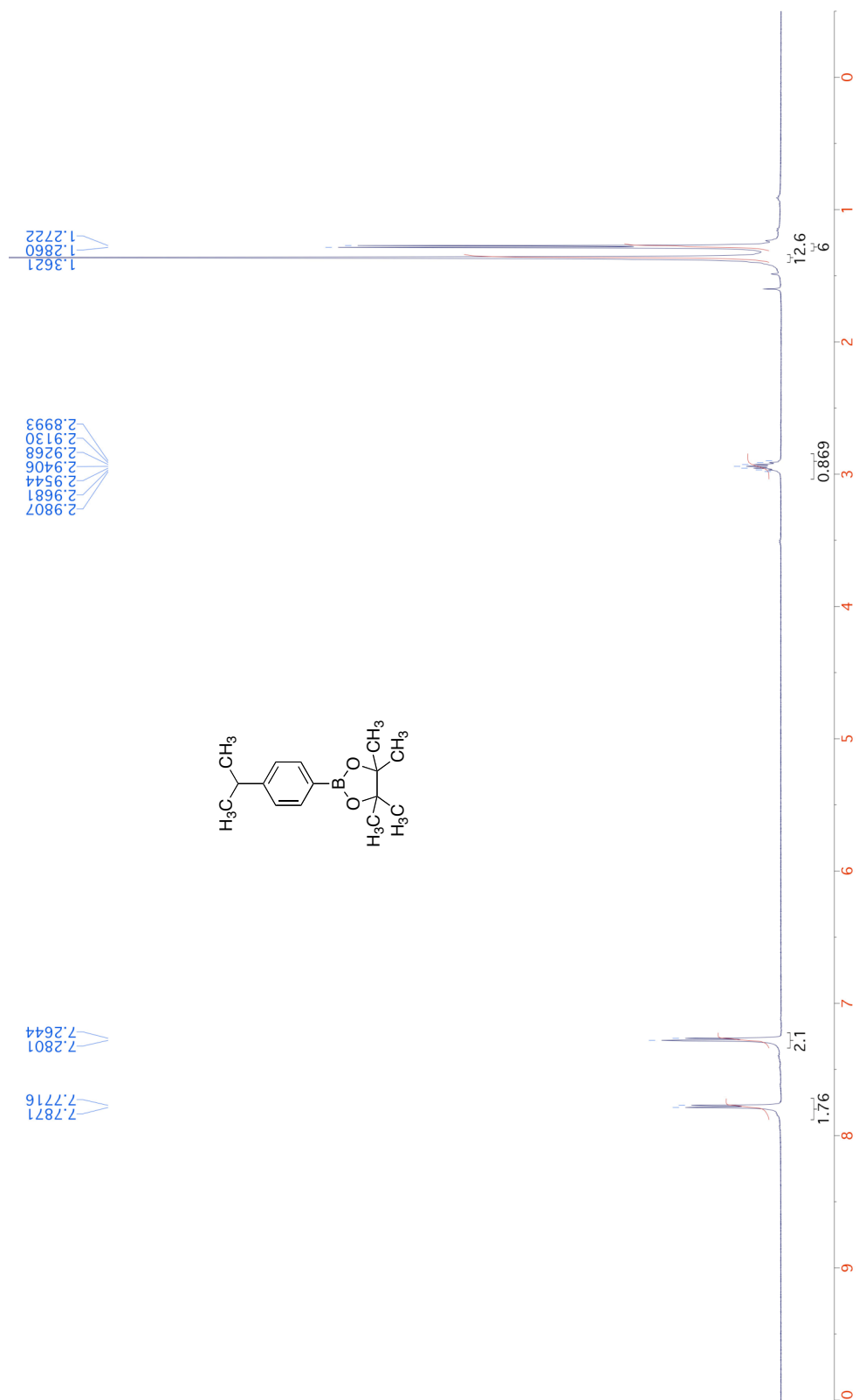


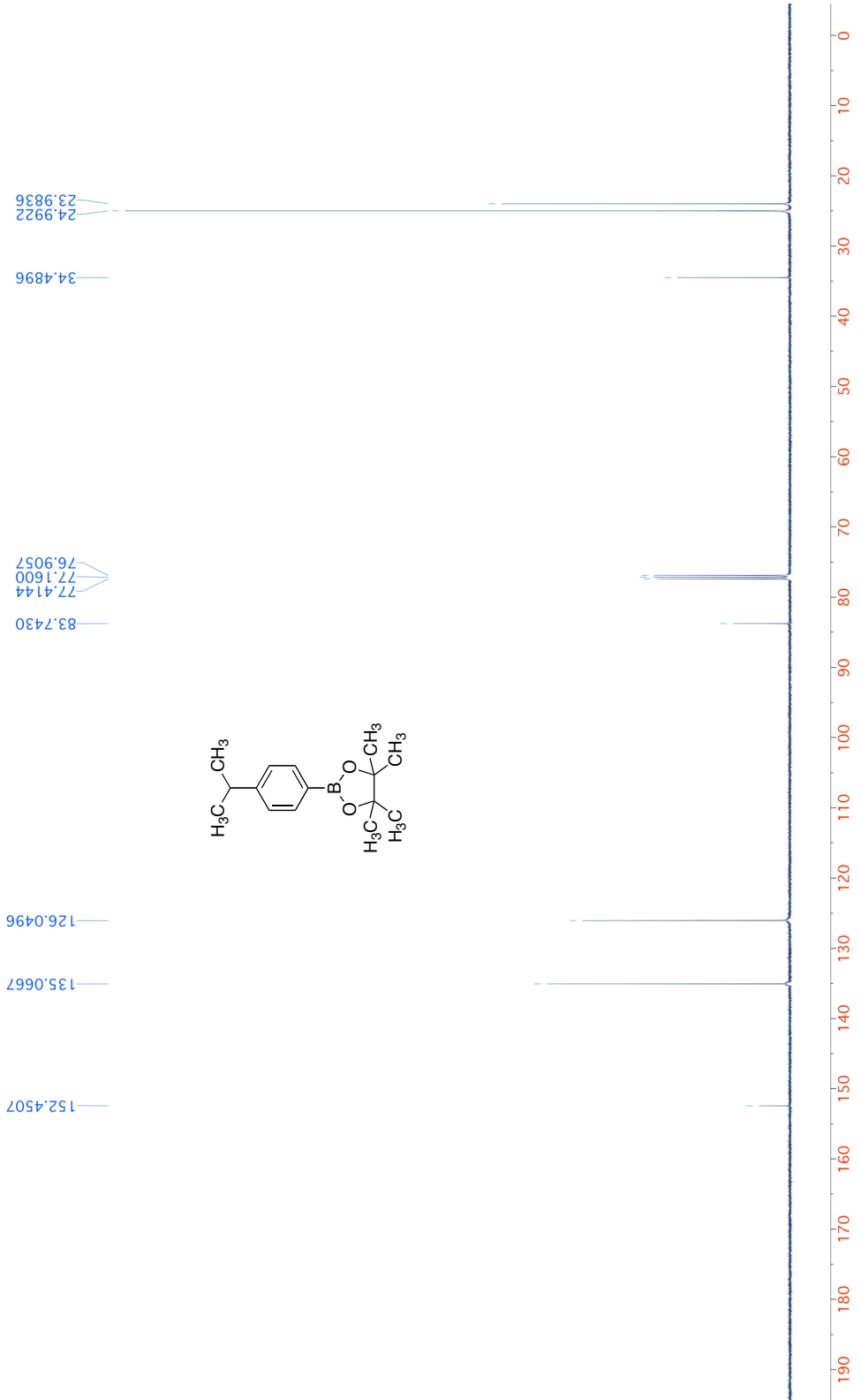


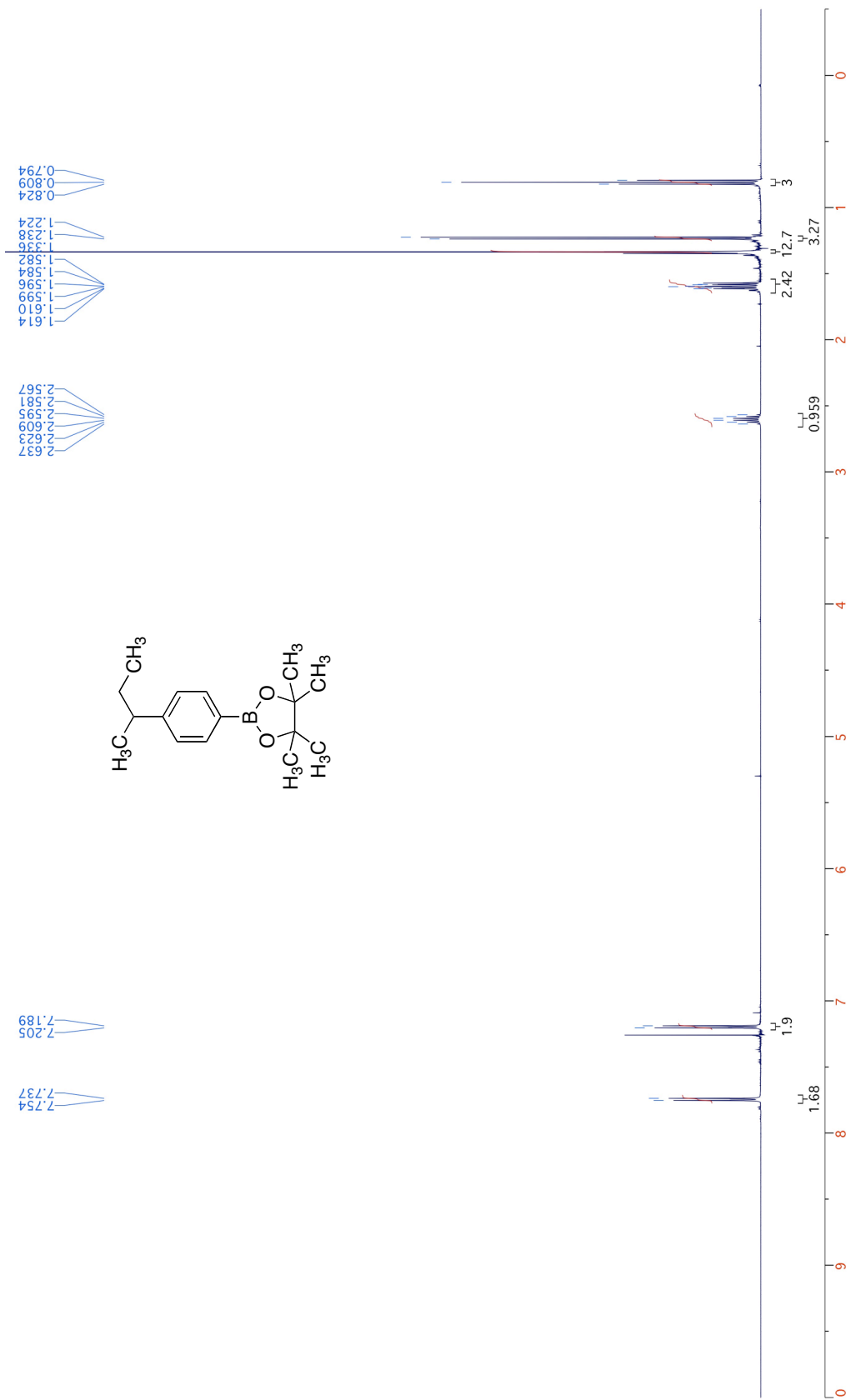


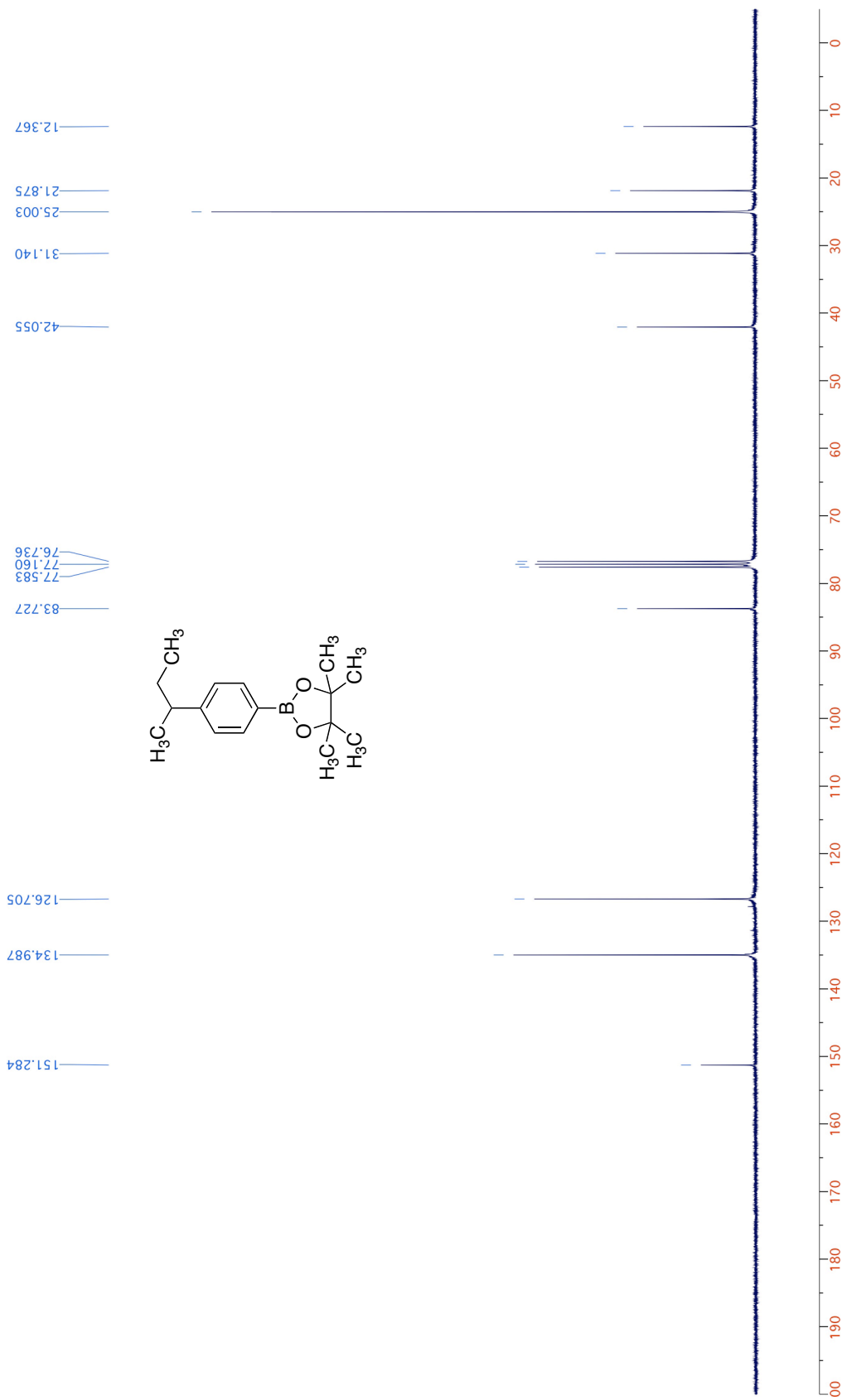


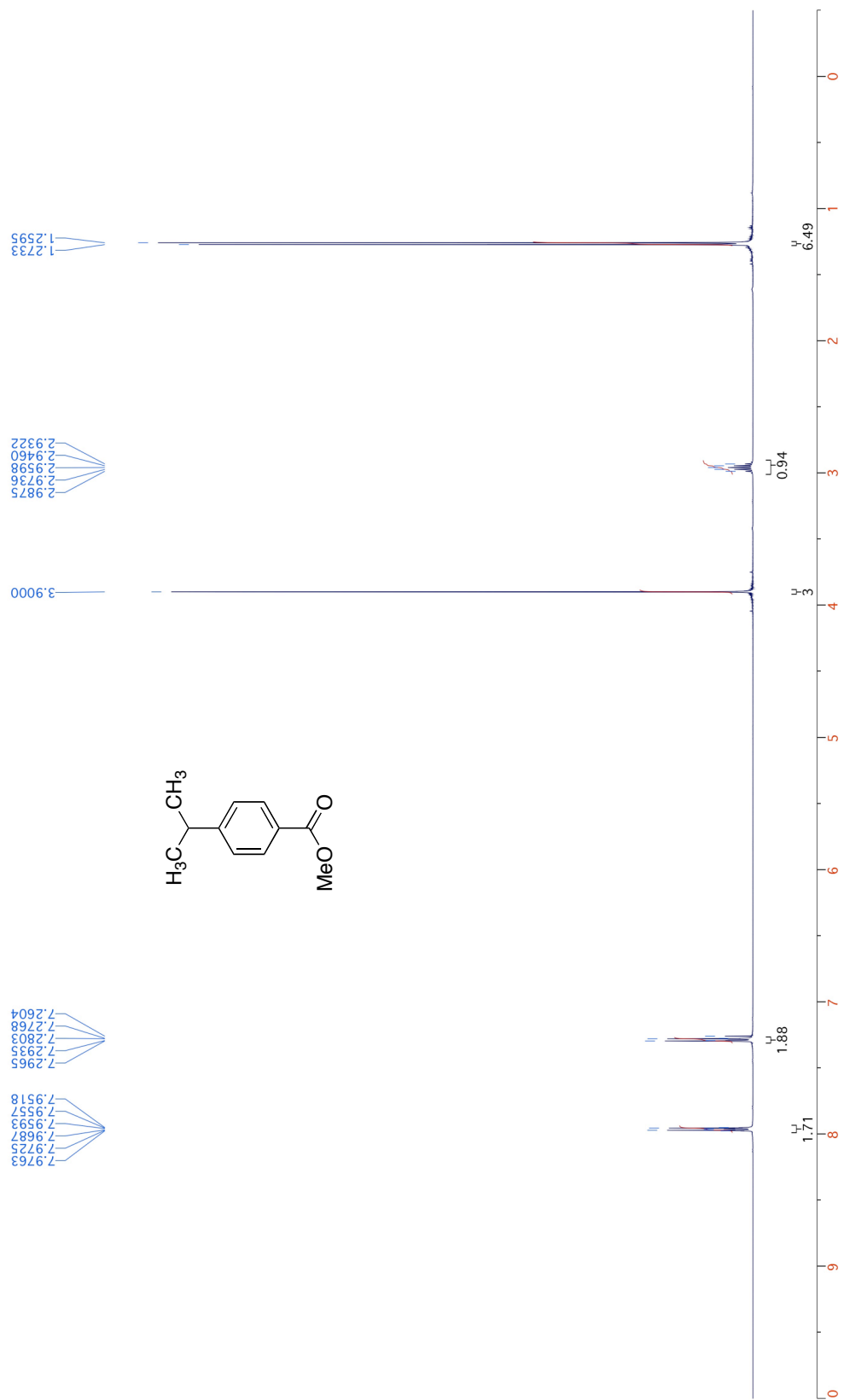


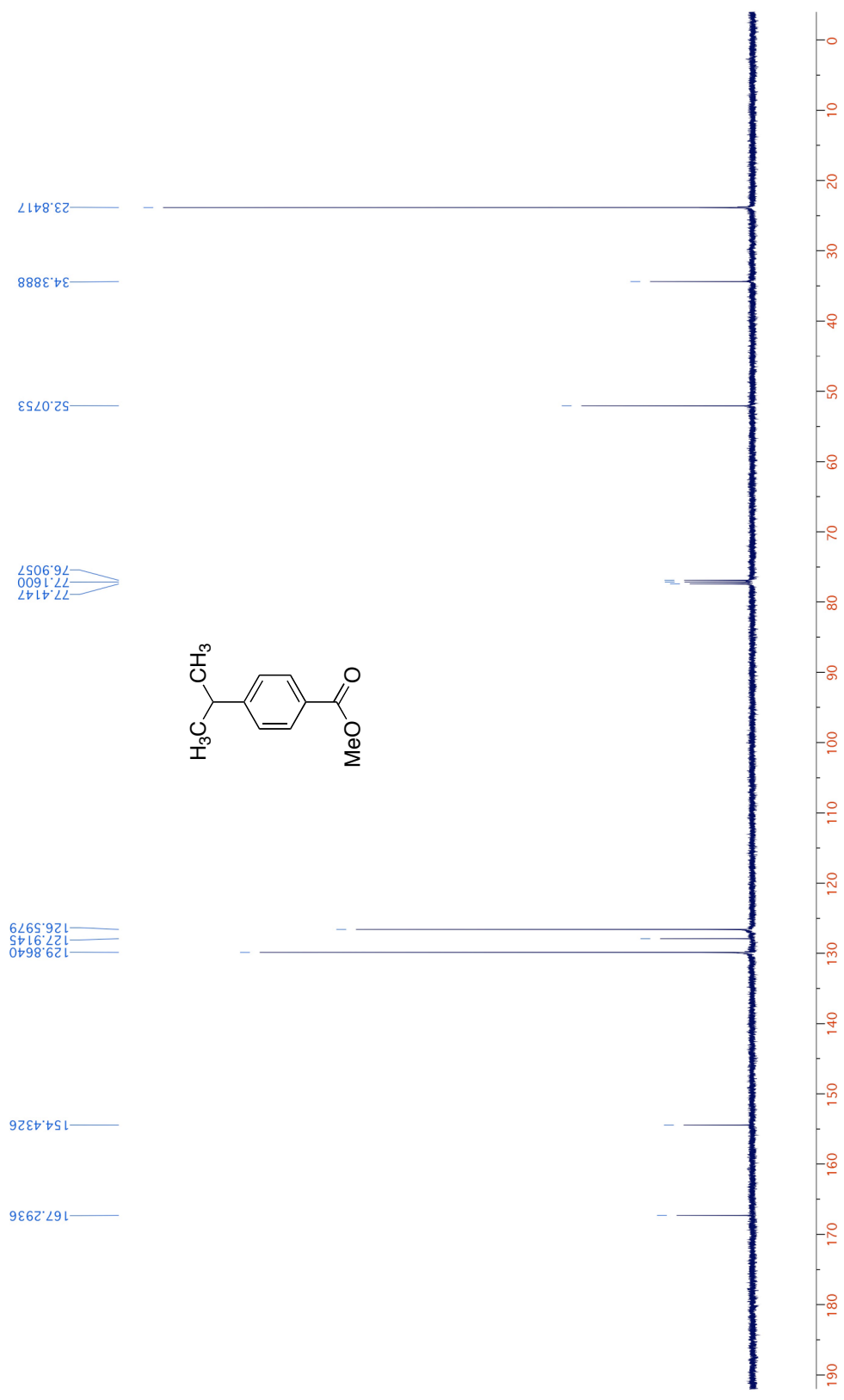


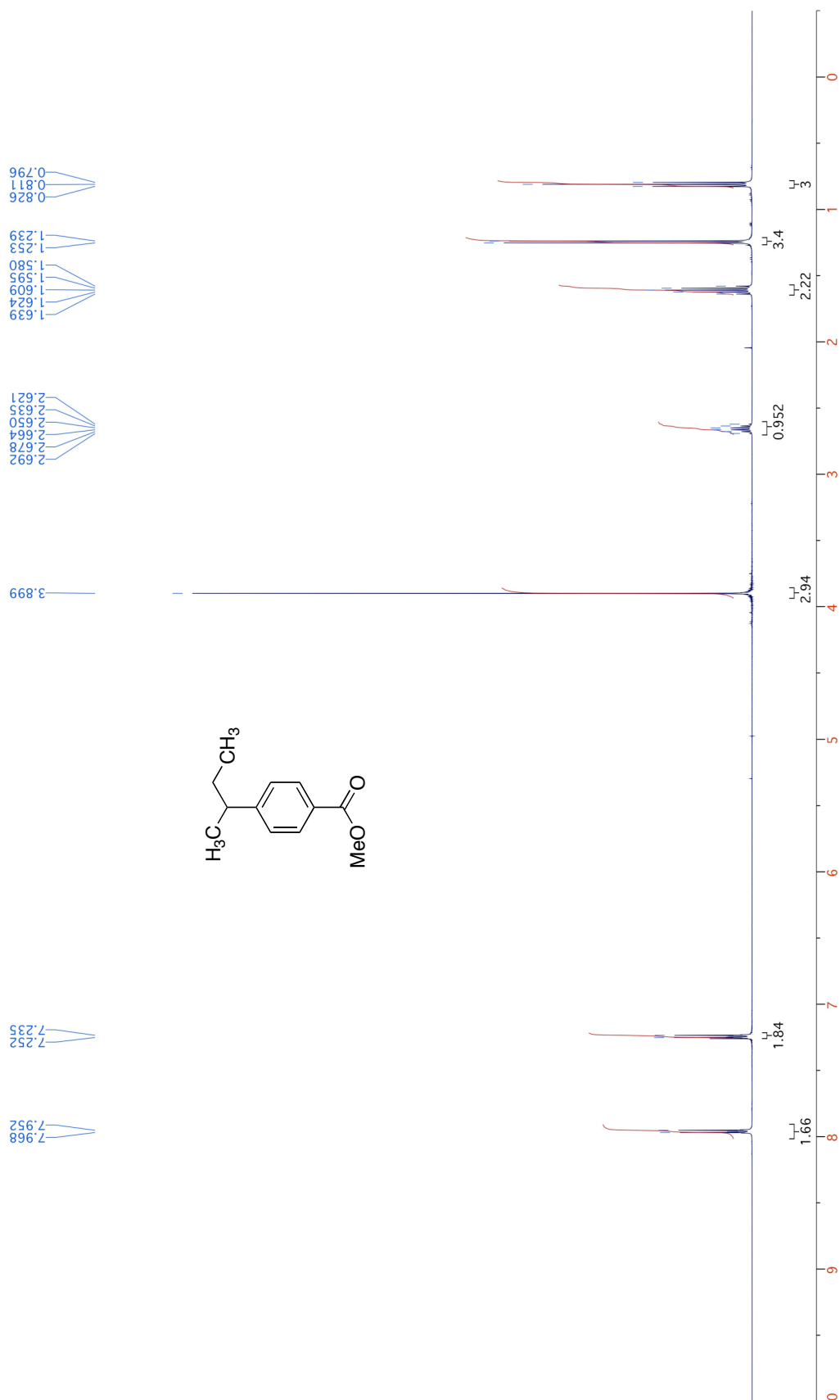


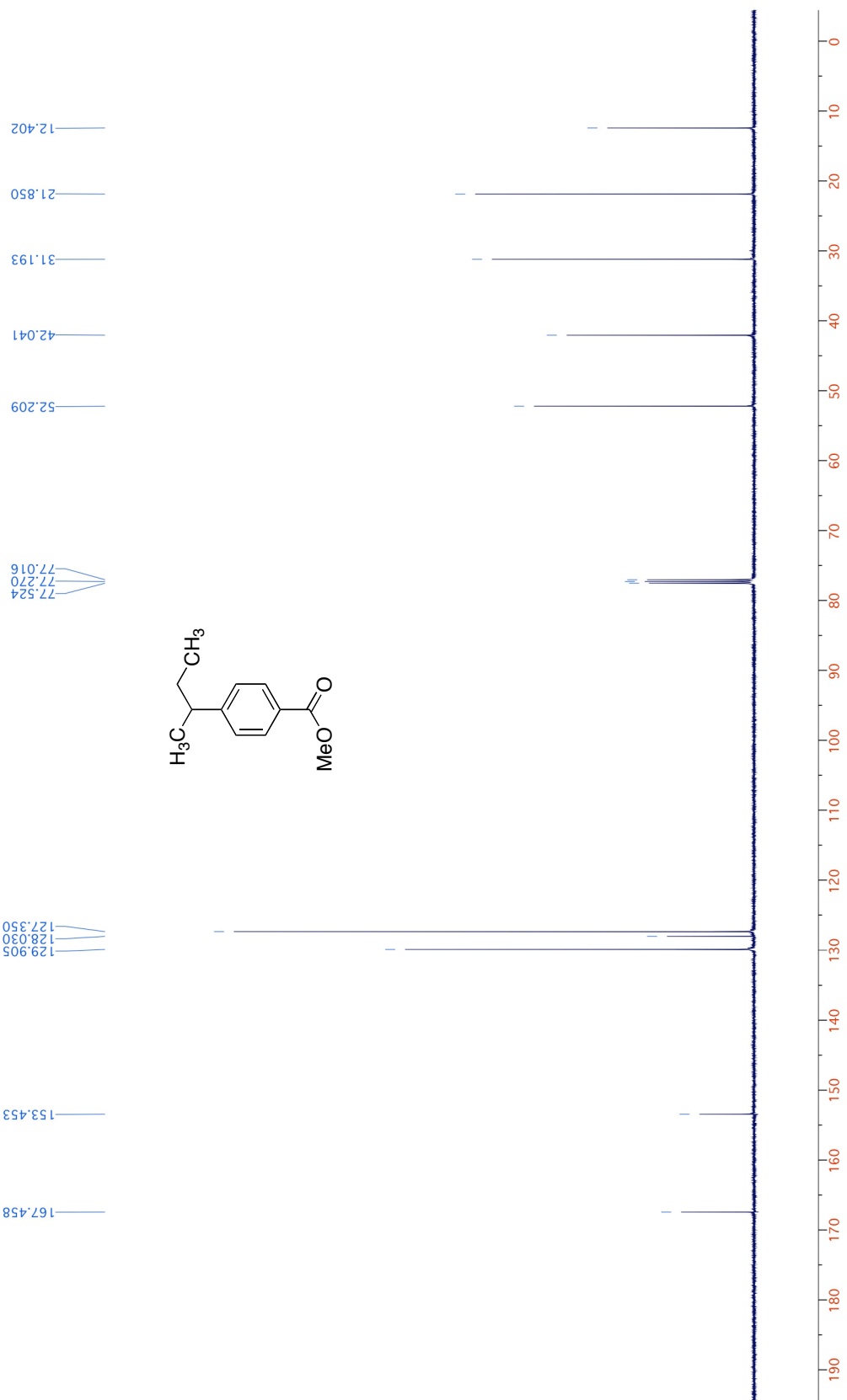


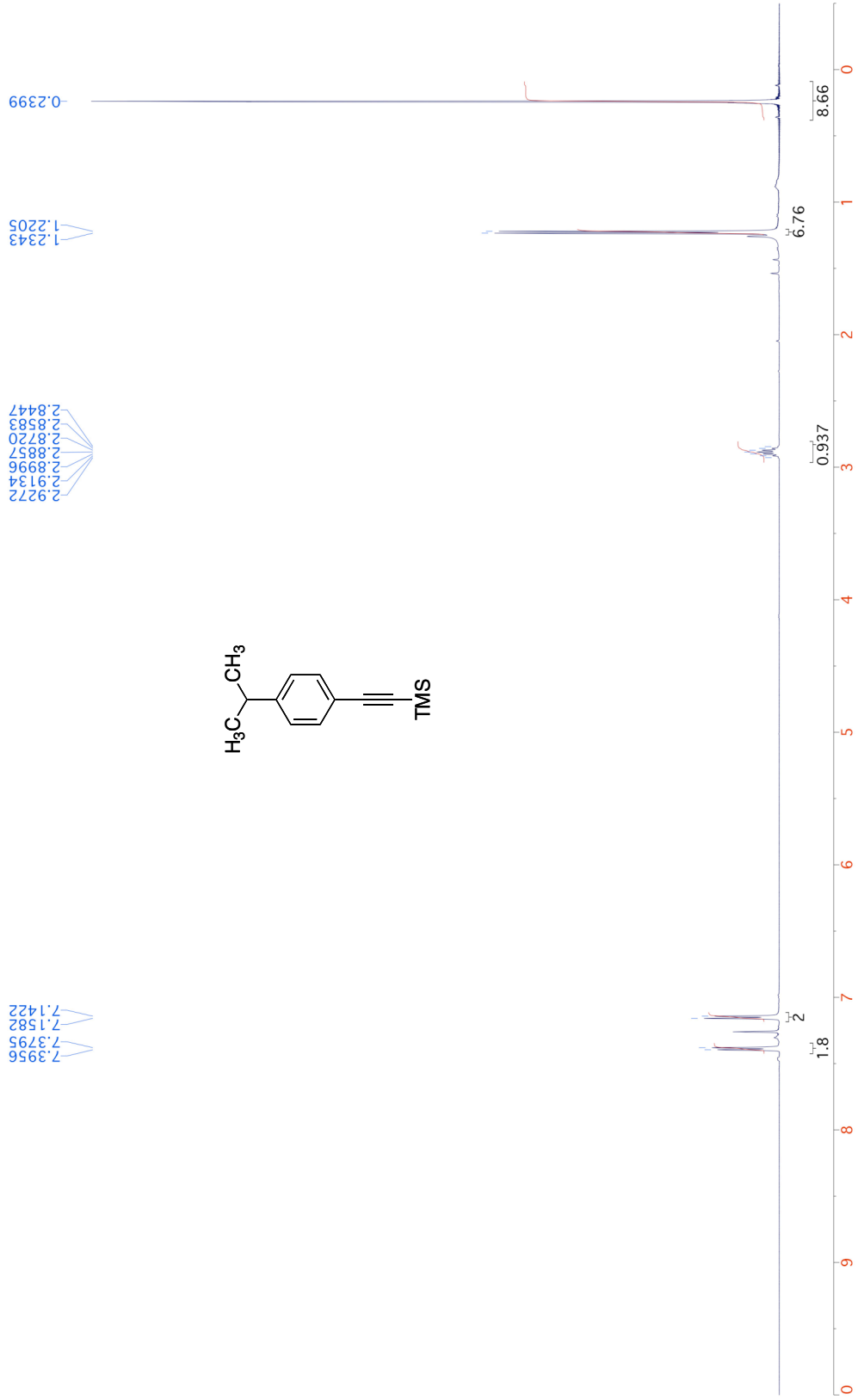


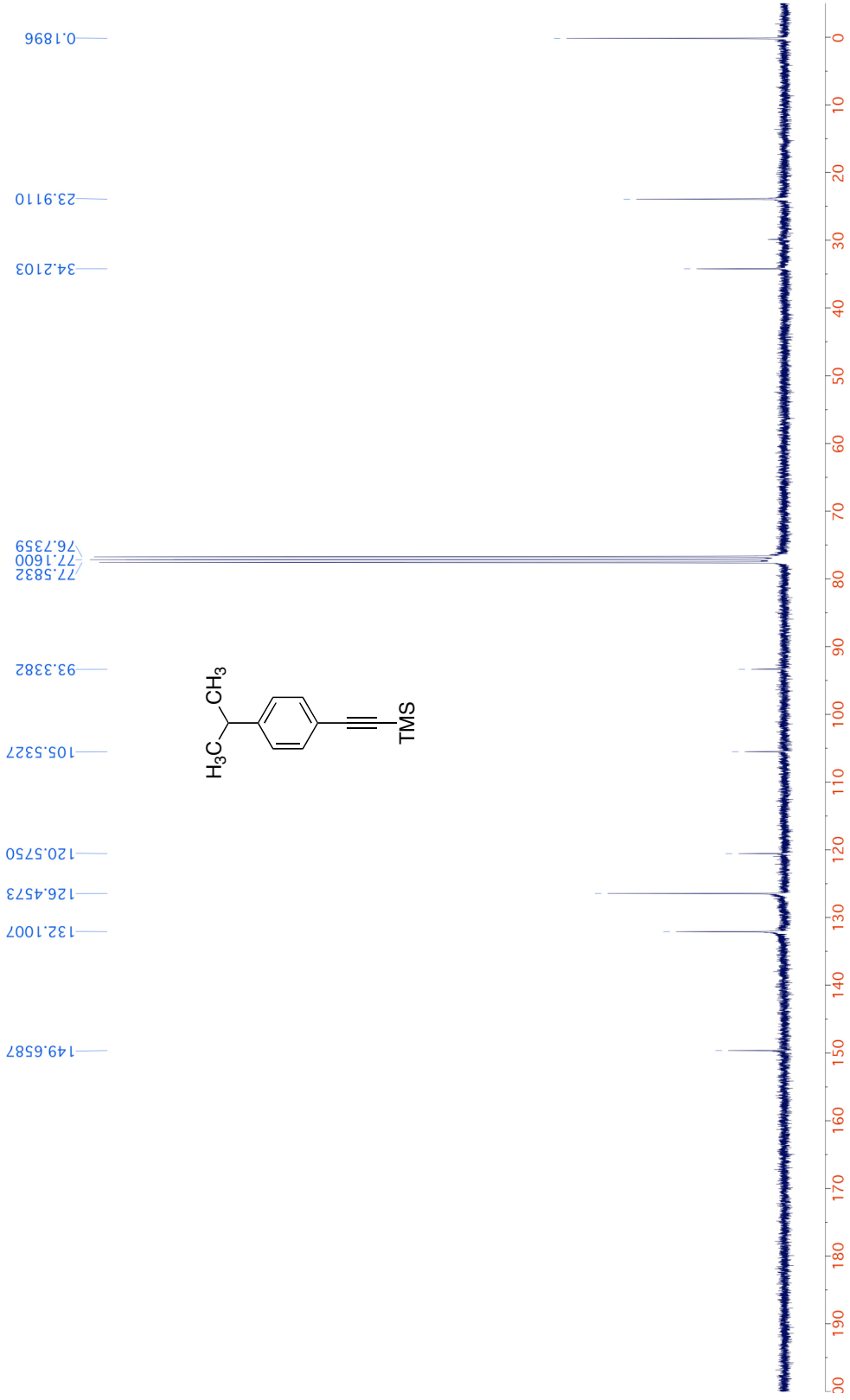


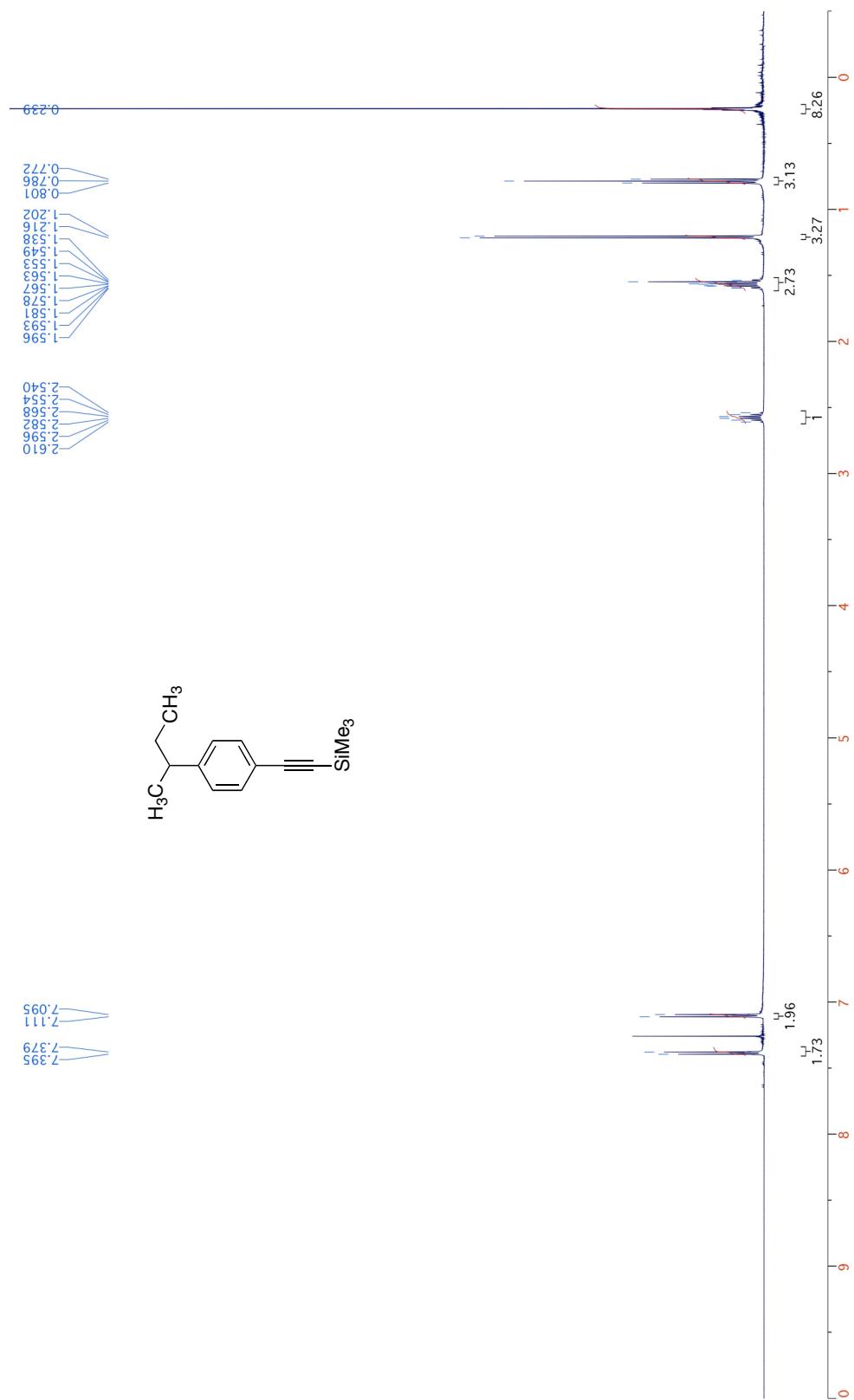


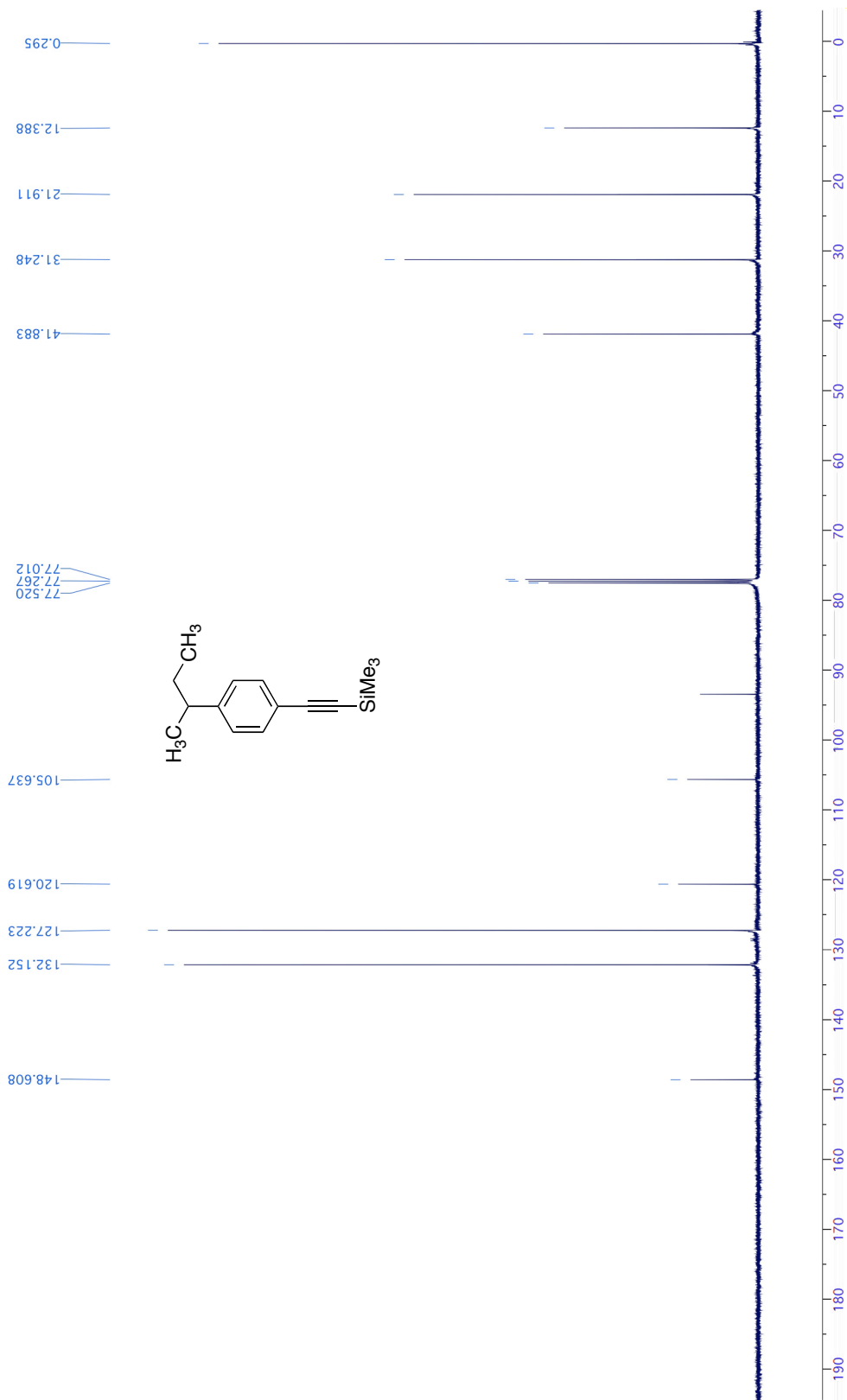


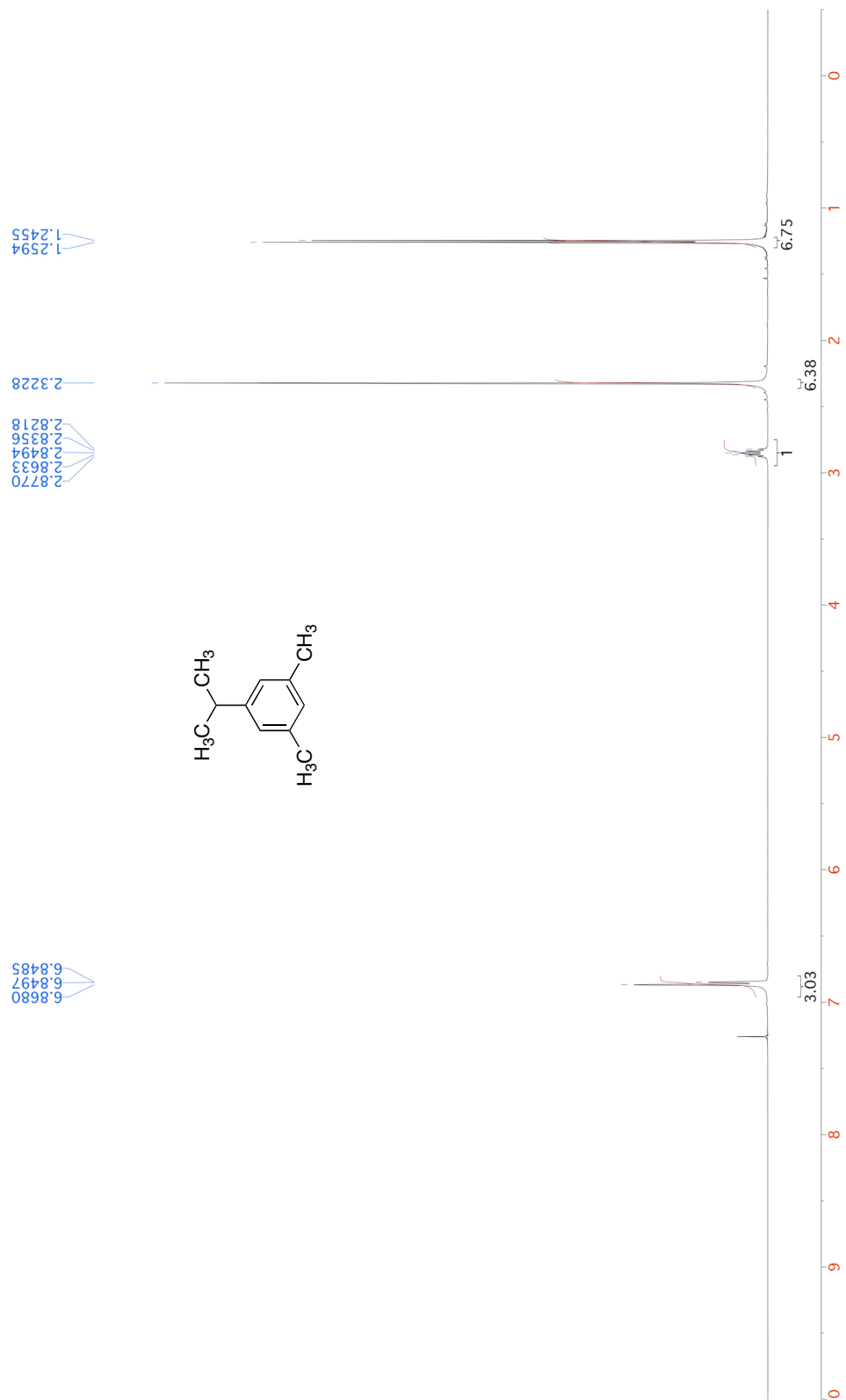


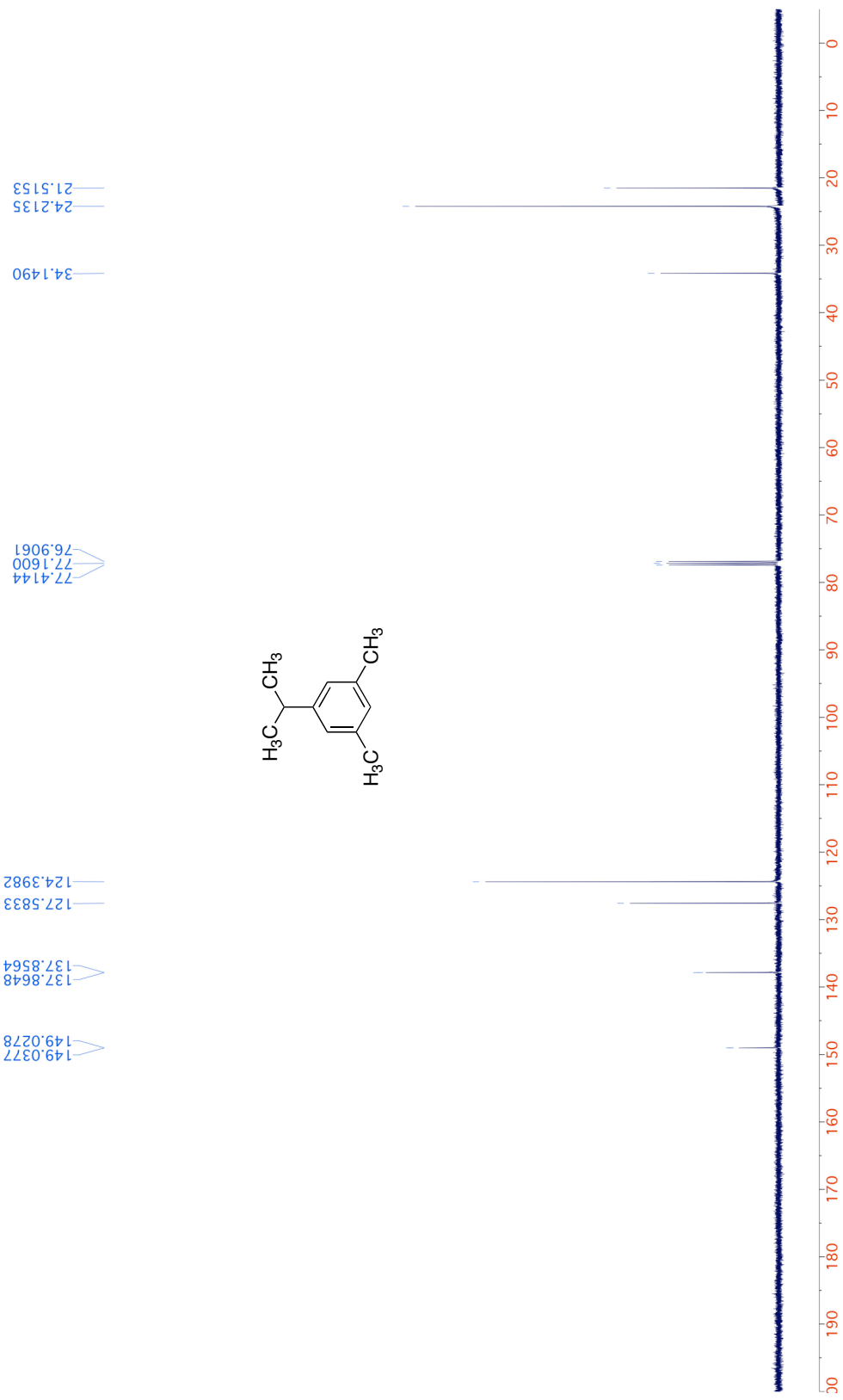




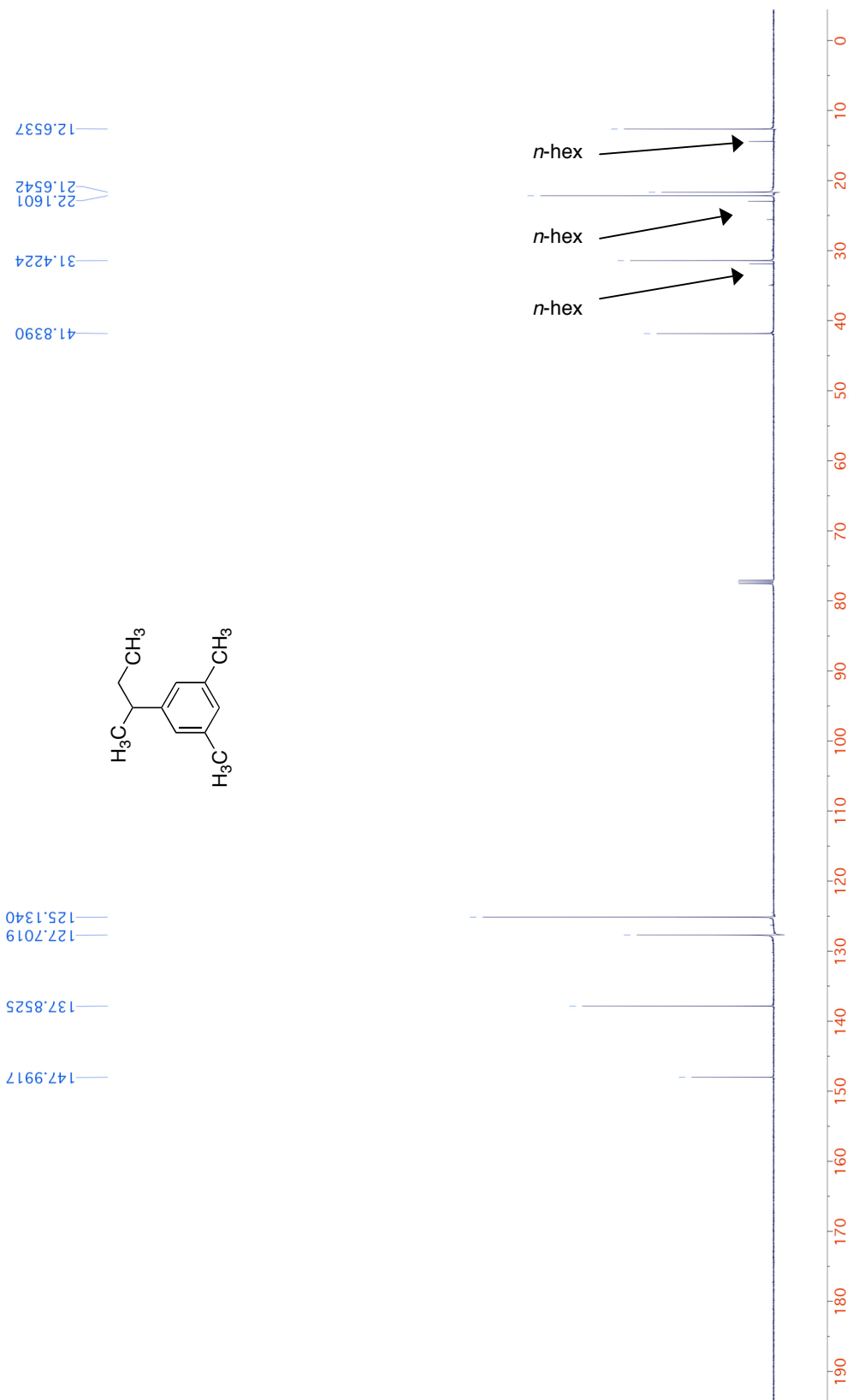


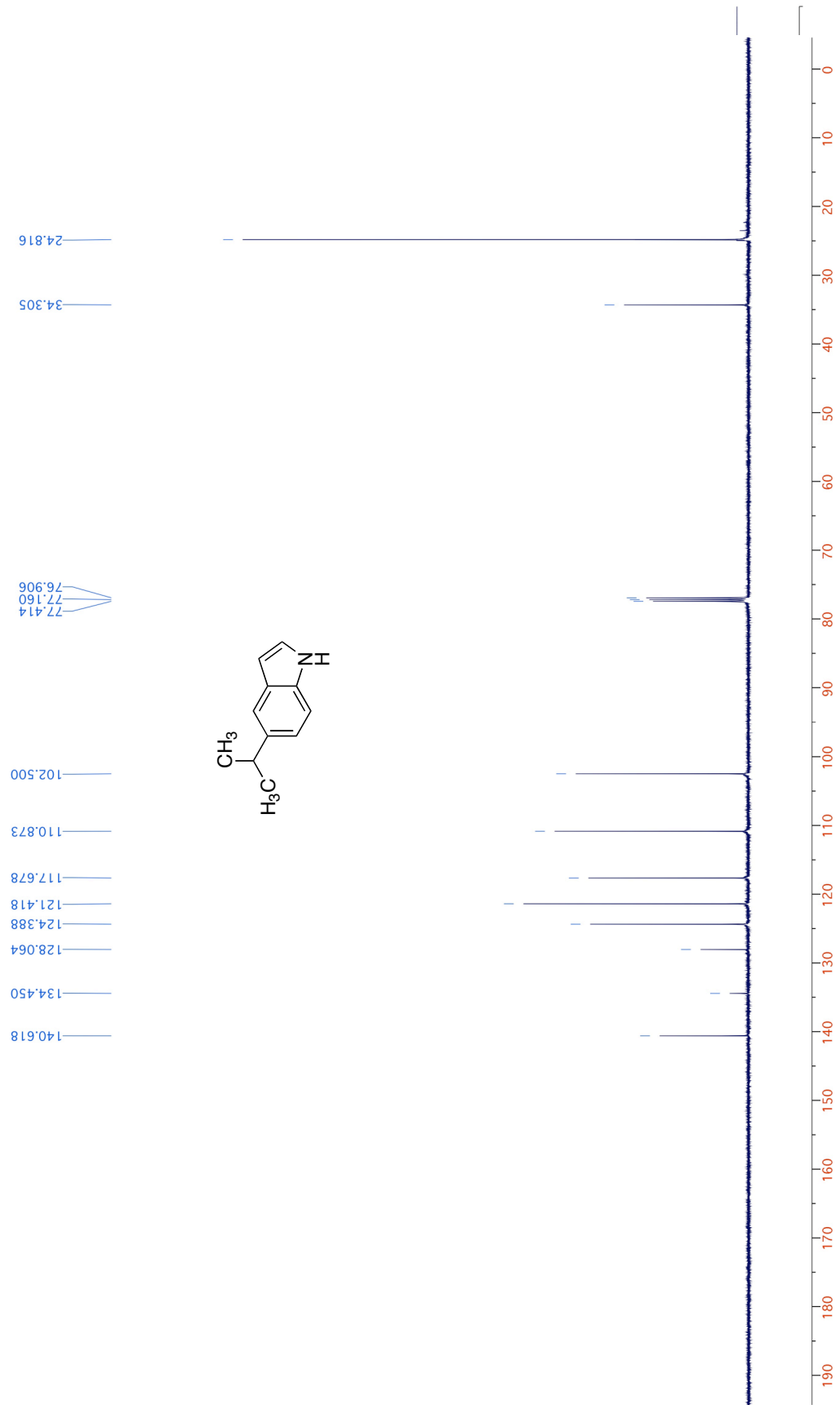


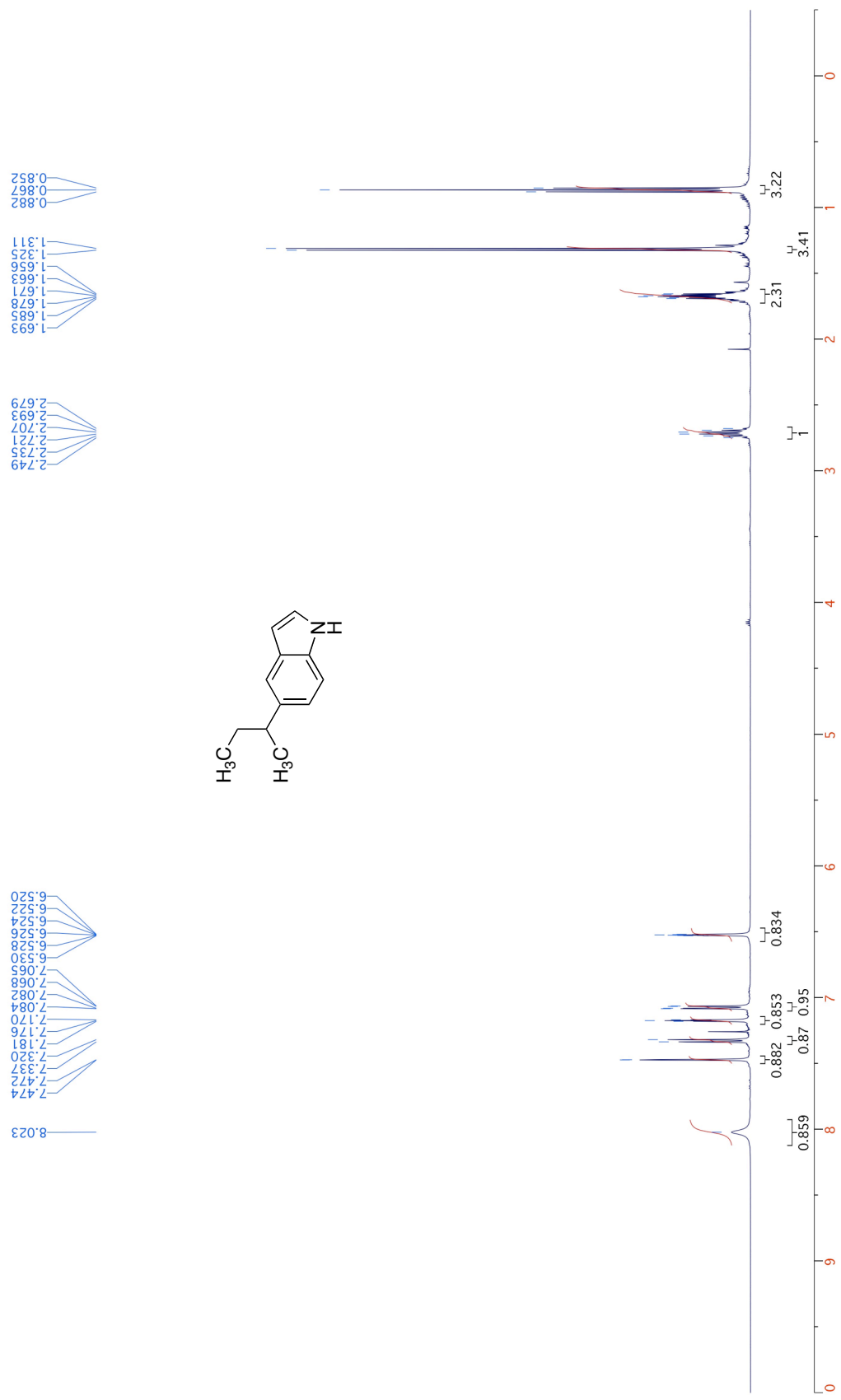


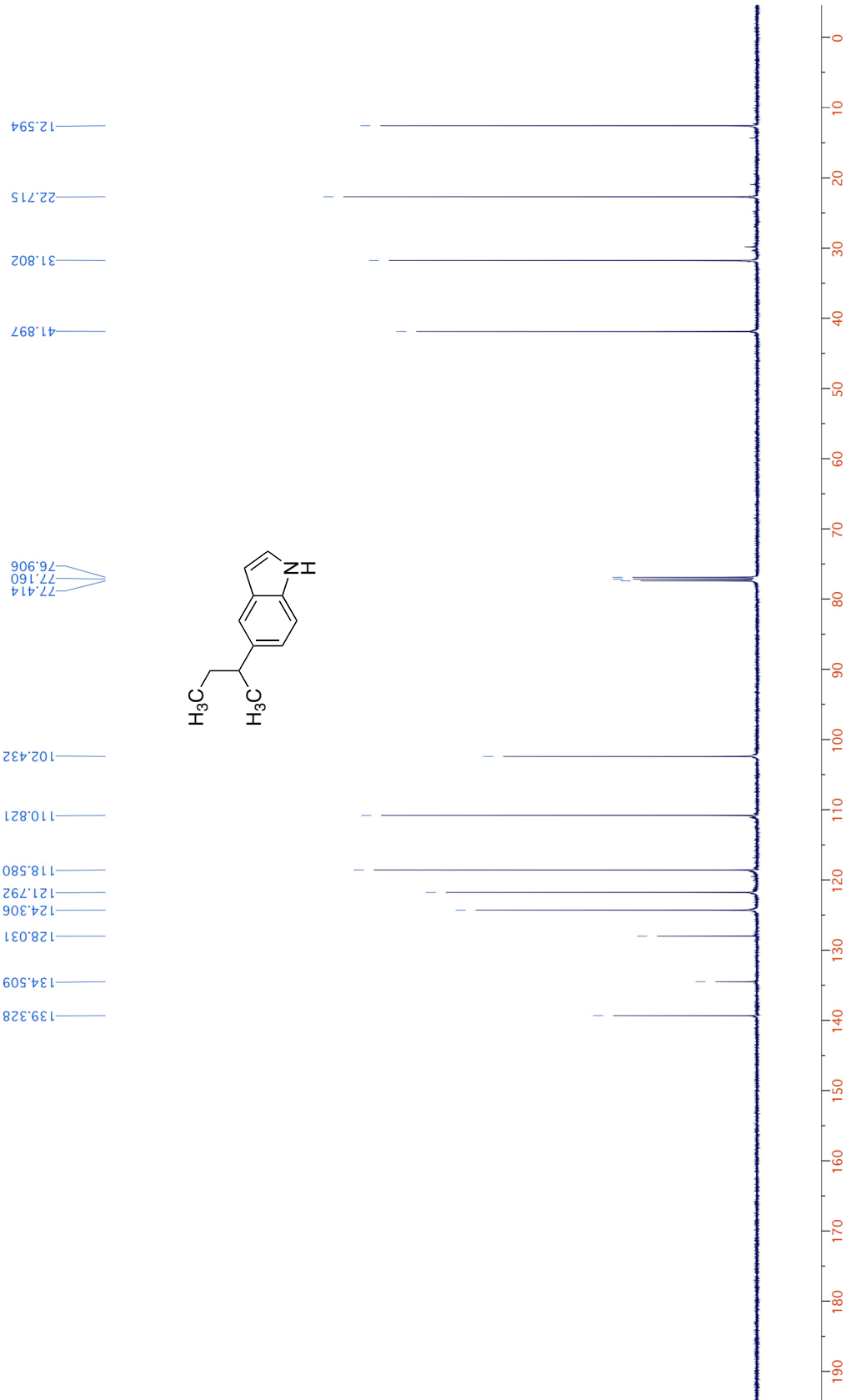


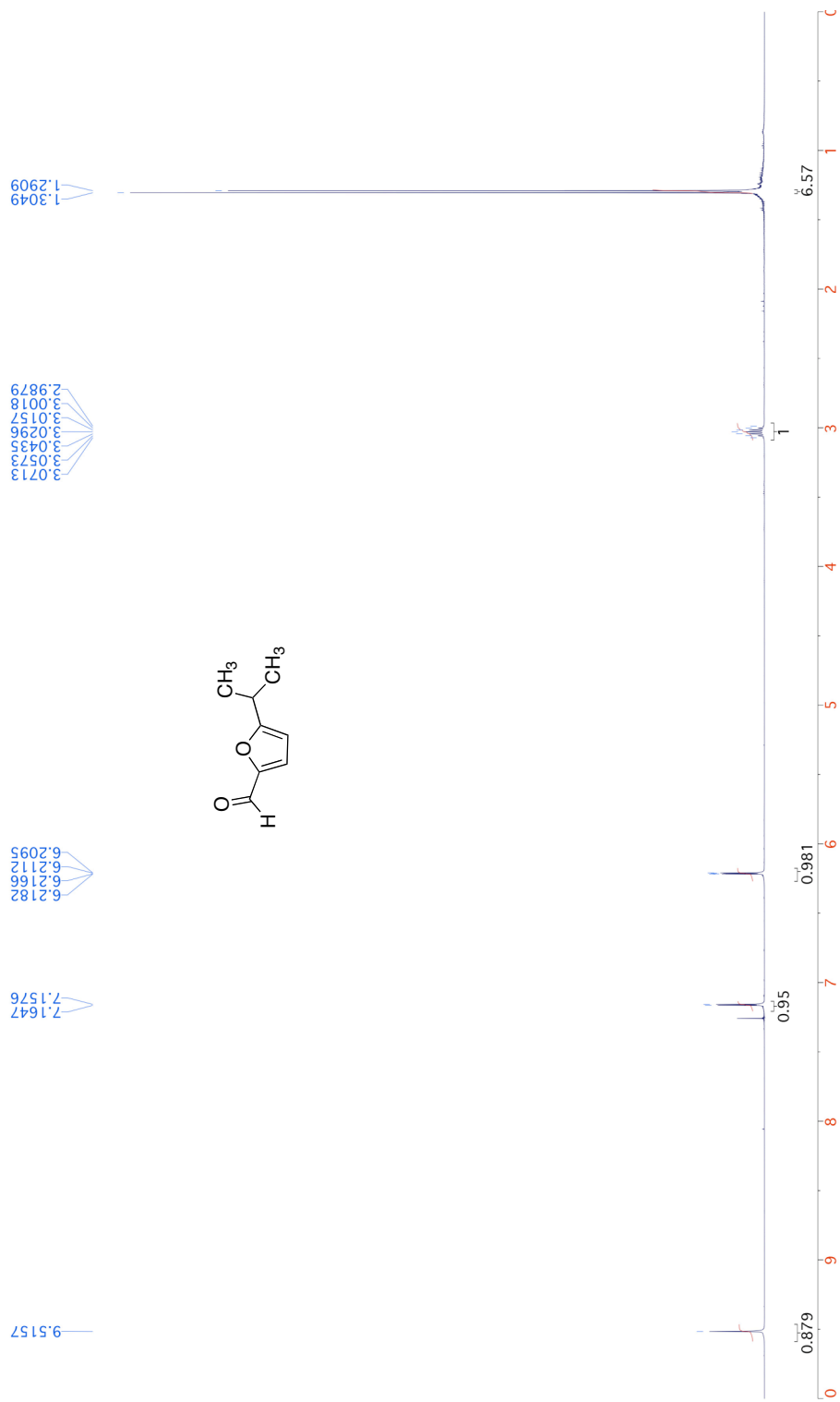


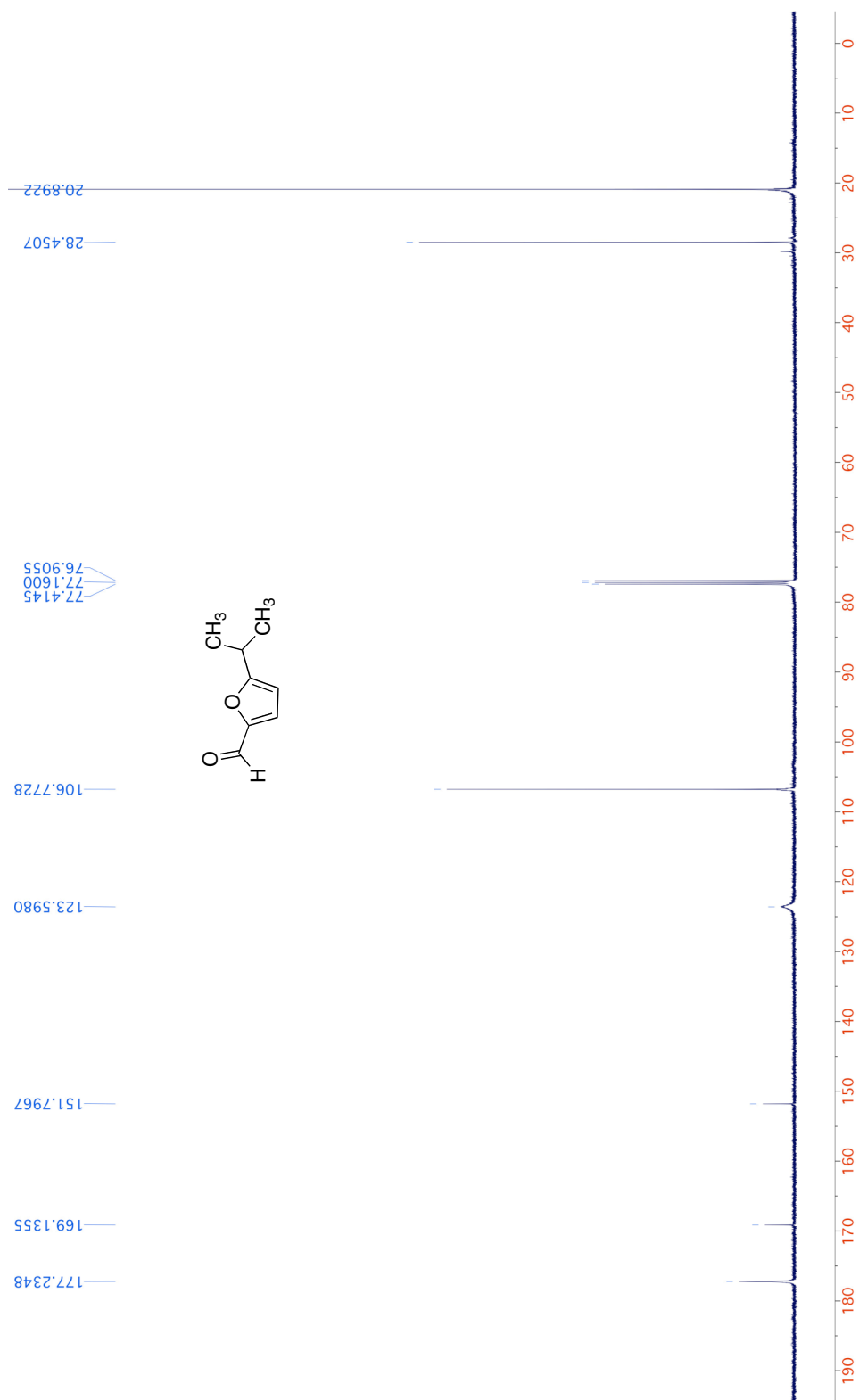


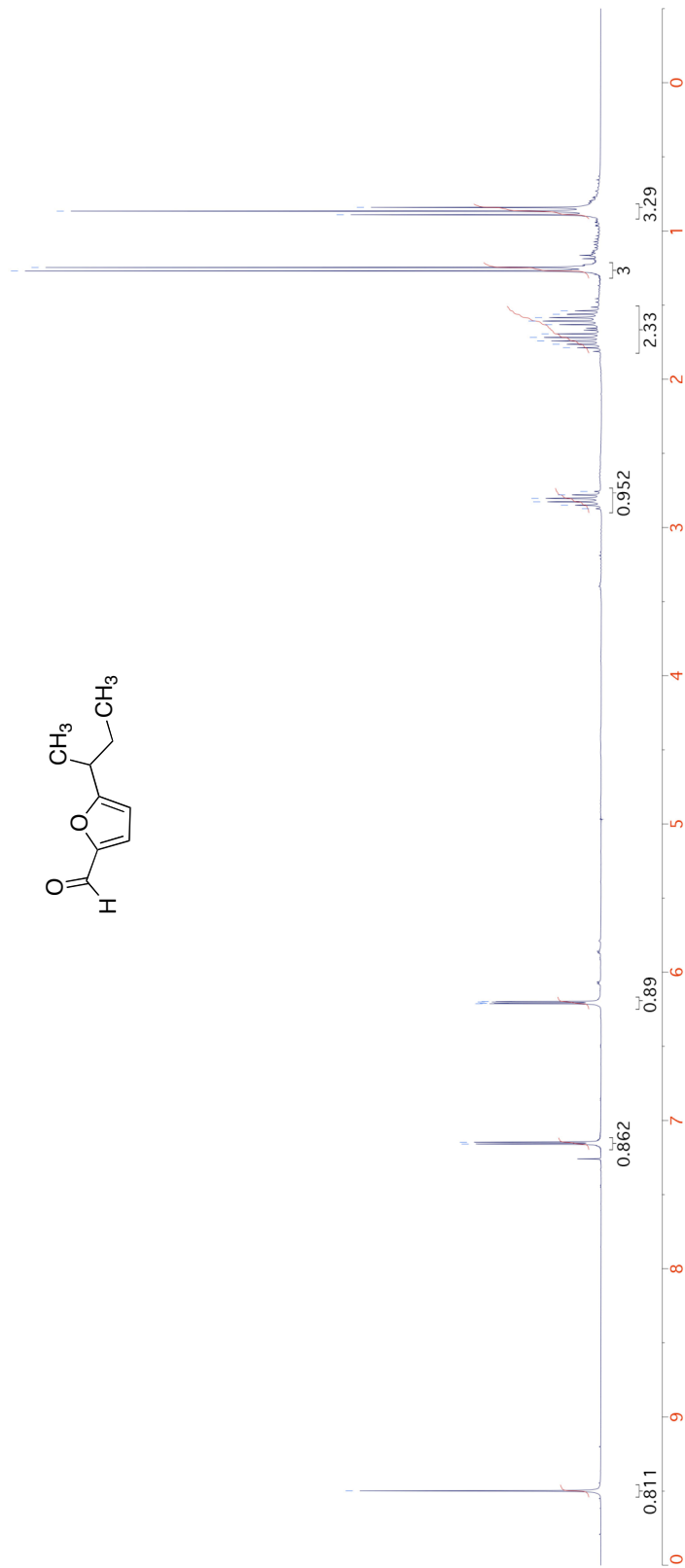












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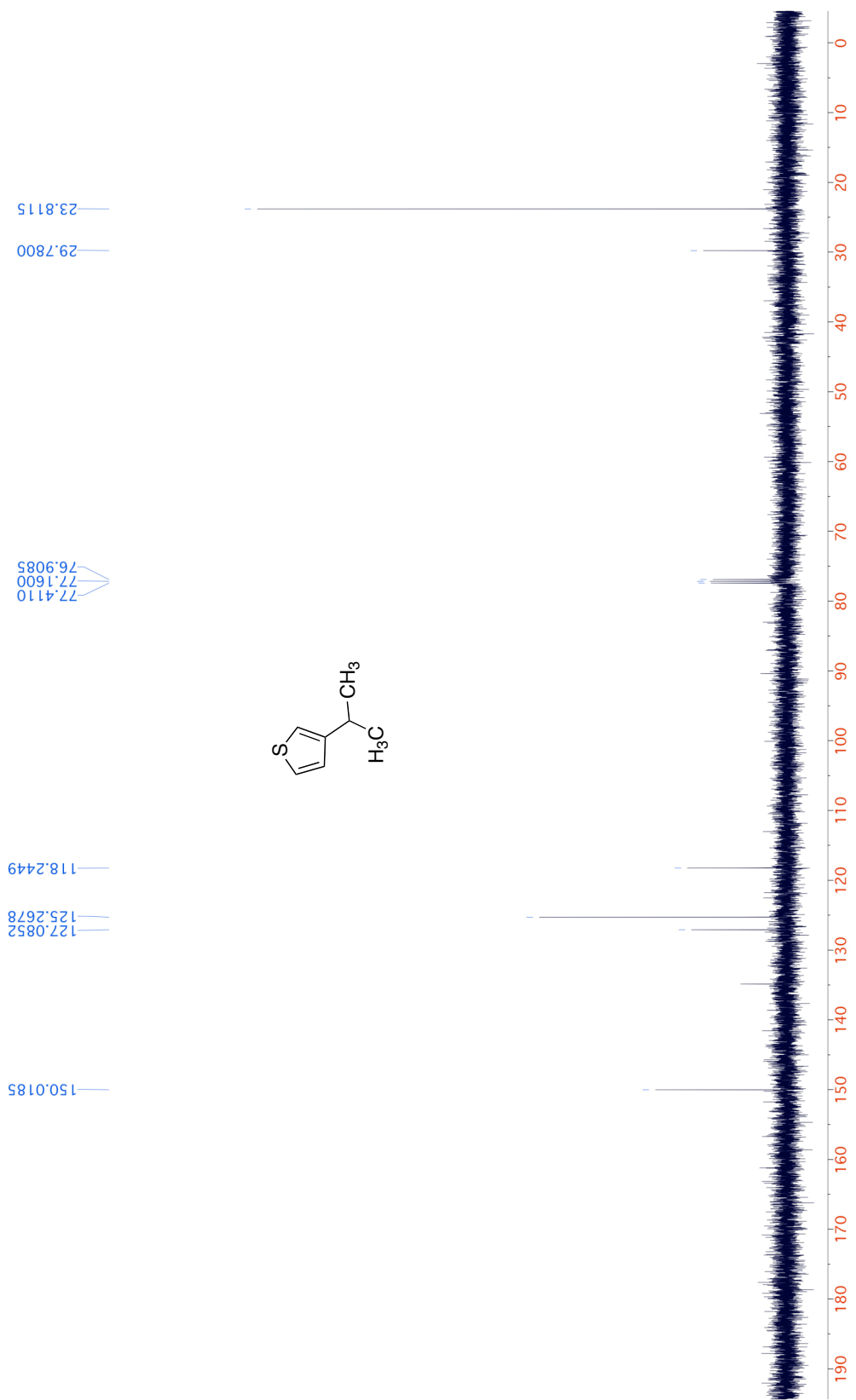
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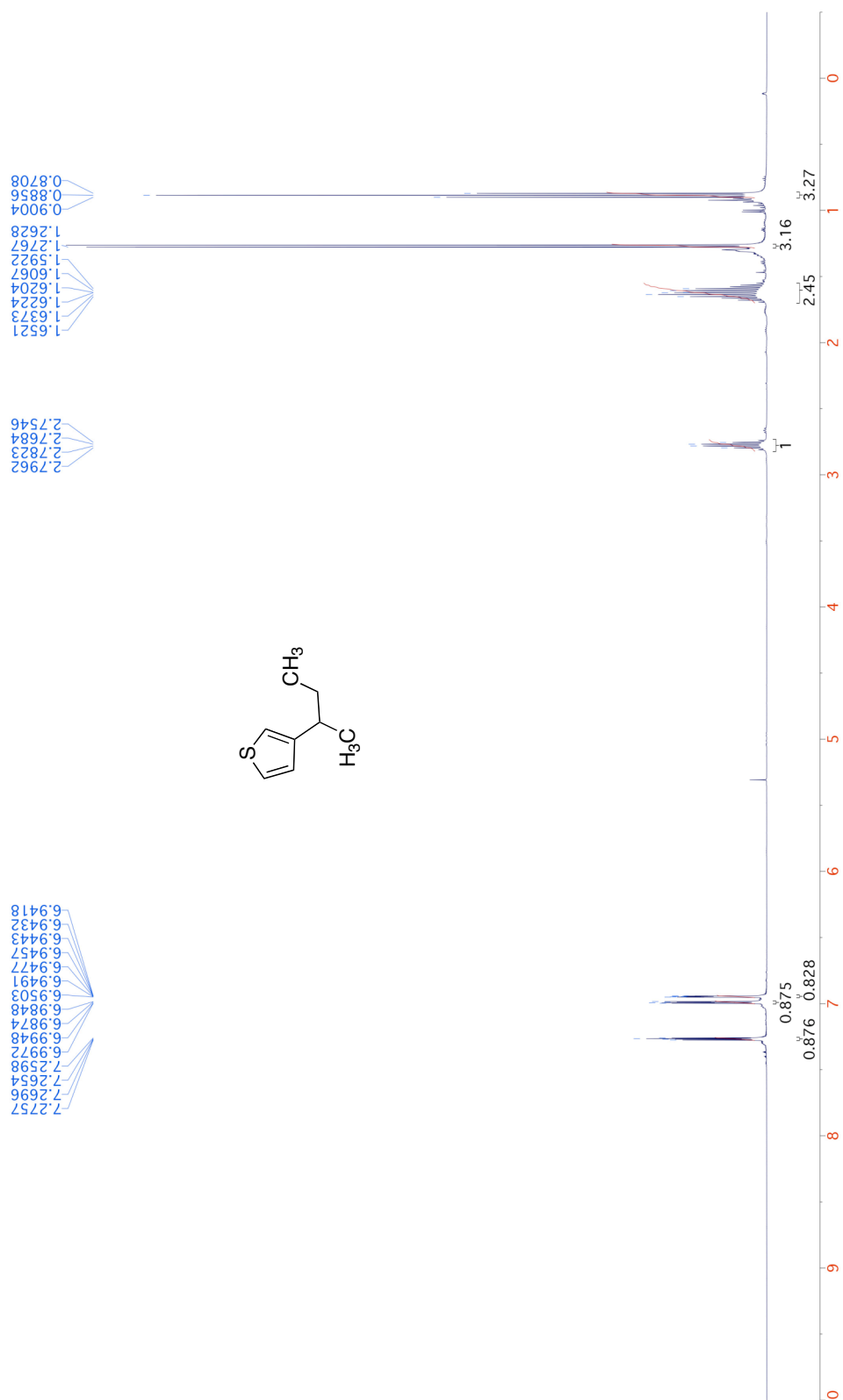
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 6.2102
 6.2001
 6.1984

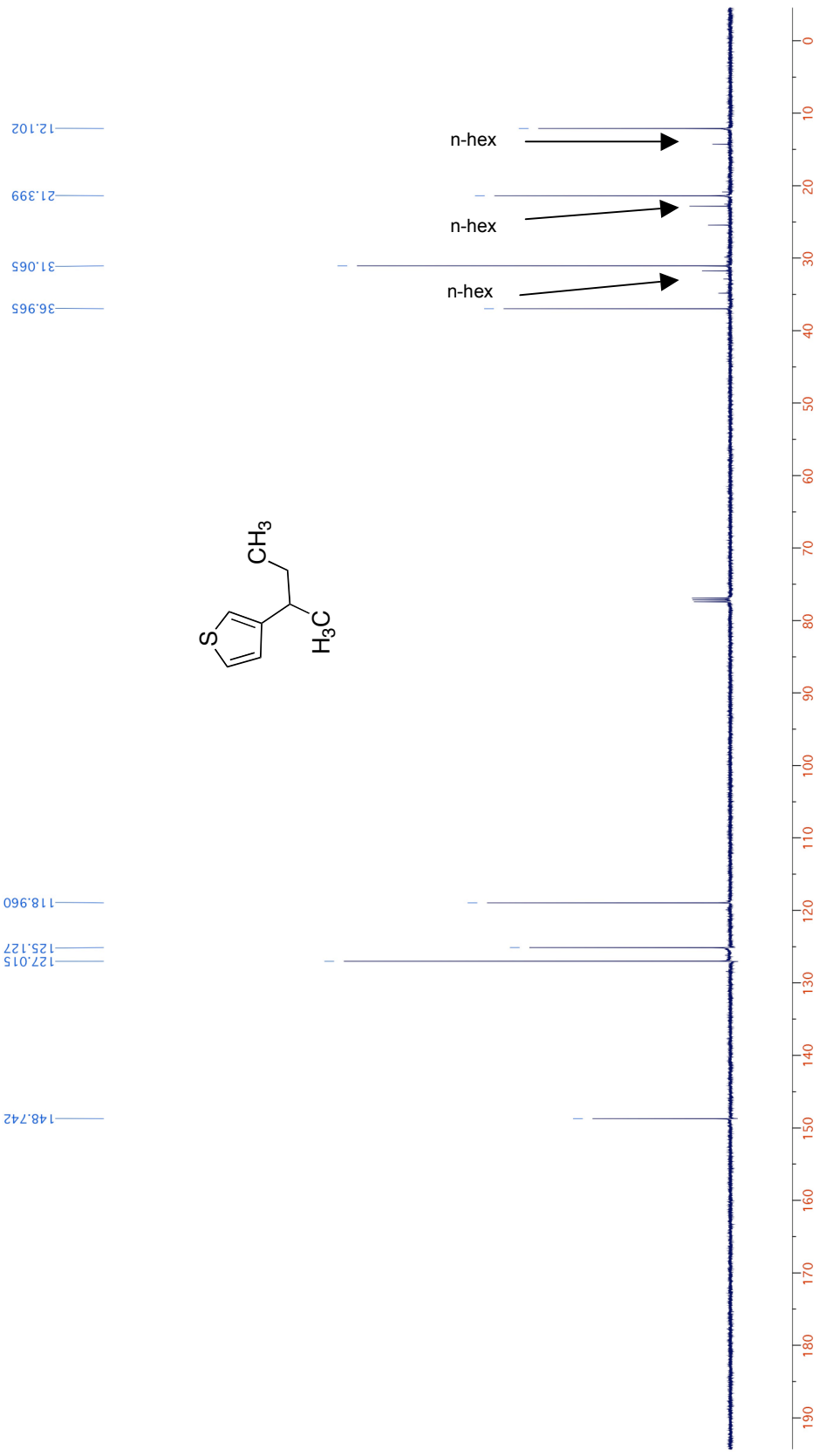
7.1466
 7.1584

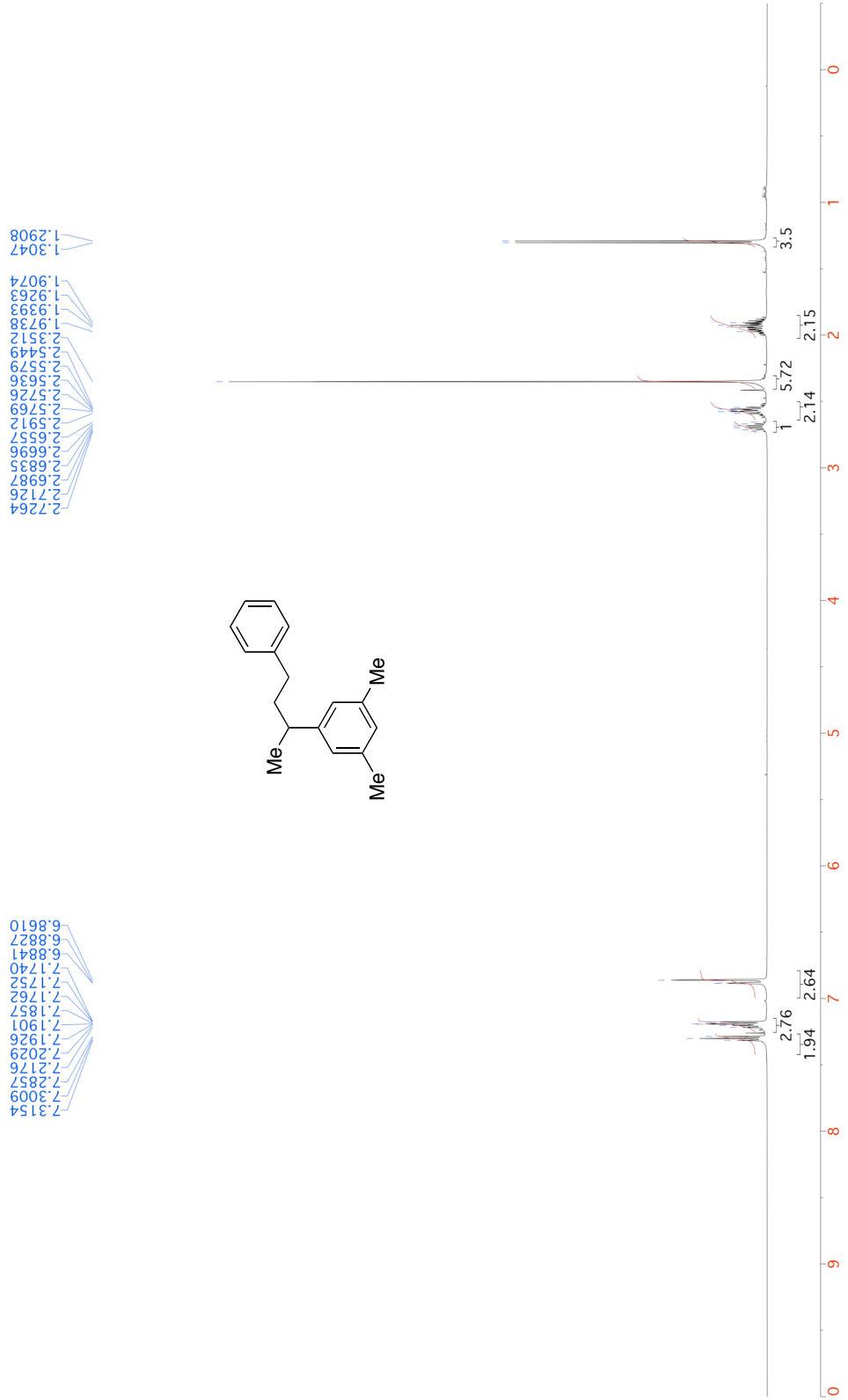
9.4983



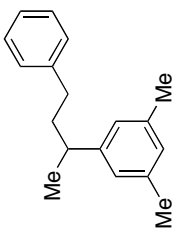








21.5289
22.6352
34.1691
39.5486
40.0645



125.0013
125.7204
127.7410
128.3615
128.4998
137.8729
142.8133
147.4651

