

# Transition Metal-Free Hydrogenation of Aryl Halides: From Alcohol to Aldehyde

Hong-Xing Zheng,<sup>†</sup> Xiang-Huan Shan,<sup>†</sup> Jian-Ping Qu,<sup>\*‡</sup> and Yan-Biao Kang<sup>\*†</sup>

<sup>†</sup>Department of Chemistry, University of Science and Technology of China, Hefei, Anhui 230026, China

<sup>‡</sup>Institute of Advanced Synthesis, School of Chemistry and Molecular Engineering, Jiangsu National Synergetic Innovation Center for Advanced Materials, Nanjing Tech University, Nanjing 211816, China

E-mail: ybkang@ustc.edu.cn, ias\_jpqu@njtech.edu.cn

## Contents

1. General information	S1
2. General procedures	S1–S15
3. Kinetic studies and isotopic labelling experiment	S15-16
4. References	S17
5. NMR spectra	S18–S75

## 1. General information

Solvents were pre-dried over activated 4 Å molecular sieves and heated to reflux over sodium (toluene and octane) or calcium hydride (DMF, DMA, DMSO and 1,4-dioxane) under argon atmosphere and collected by distillation. <sup>1</sup>H, <sup>13</sup>C NMR spectra were recorded on a Bruker 400 spectrometer; Chemical shifts are reported in δ units relative to CDCl<sub>3</sub> [<sup>1</sup>H δ = 7.26, <sup>13</sup>C δ = 77.36]. Aryl halides **1d**, **1f–1h**, **1n**, **1o**, **1r–1w** were purchased from commercial sources.

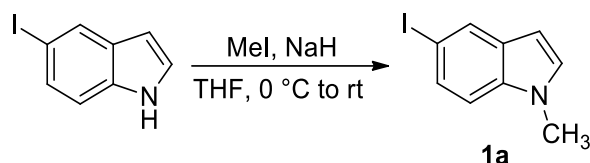
## 2. General procedures

### 2.1. Dehalogenation of Aryl Halides

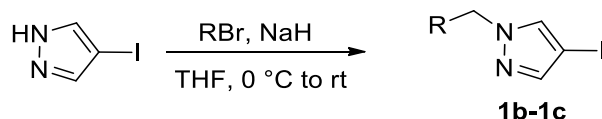
#### 2.1.1. Screening reaction conditions (Table 1)

The <sup>t</sup>BuOK (1.0 mmol, 112mg) was weighed directly into a Schlenk tube and dried under high vacuum for 15 min. Solvent (1 mL), **1a** (129 mg), and PhCHO or BnOH were added and stirred at 90 °C, monitored by TLC. The reaction mixture was directly examined by <sup>1</sup>H NMR spectrometer to determine the conversion and selectivity by using dibenzyl ether (24 μL) as an internal standard.

### 2.2 Preparation of starting materials



5-Iodoindole was weighed directly into a Schlenk tube and dried under vacuum for 15 min. Then THF was added and stirred. NaH (1.5 equiv) was slowly added at 0 °C. After stirring for 30 min, methyl iodide (1.5 equiv) was added. The mixture was then warmed up to r.t. and the resulting reaction mixture was monitored by TLC. The reaction was quenched by H<sub>2</sub>O and extracted with Et<sub>2</sub>O. The combined organic extracts were washed with brine, dried over anhydrous MgSO<sub>4</sub>, filtered, concentrated and purified on silica gel chromatography (EtOAc/petroleum ether as eluent) to give **1a** as a yellow solid, 1.3 g, 85%. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.94 (s, 1H), 7.44 (d, *J* = 8.4 Hz, 1H), 7.07 (d, *J* = 8.4 Hz, 1H), 6.99 (d, *J* = 2.4 Hz, 1H), 6.39 (d, *J* = 2.4 Hz, 1H), 3.74 (s, 3H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 135.8, 131.0, 129.8, 129.7, 129.6, 111.3, 100.3, 83.0, 33.0.<sup>1</sup>



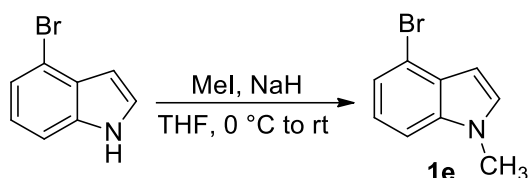
General procedure: 4-Iodopyrazole (5 mmol) was weighed directly into a Schlenk tube and dried under high vacuum for 15 min. Then THF and NaH (1.5 equiv) were added at 0 °C. After stirring for 30 min at 0 °C, RBr (1.1 equiv) was added. The mixture was warmed up to r.t. and the resulting reaction was monitored by TLC. Then the reaction was quenched by H<sub>2</sub>O and extracted with Et<sub>2</sub>O. The combined organic extracts were washed with brine, dried over anhydrous MgSO<sub>4</sub>, filtered, concentrated and purified on silica gel chromatography (EtOAc/petroleum ether as eluent) to give the product.<sup>1</sup>



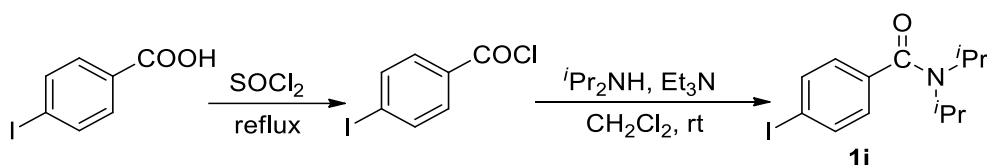
Prepared according to the general procedure, yellow oil, 1.48 g, quant. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.49 (s, 1H), 7.41 (s, 1H), 4.10 (t, *J* = 7.2 Hz, 2H), 1.87–1.79 (m, 2H), 1.29–1.25 (m, 8H), 0.87 (t, *J* = 6.8 Hz, 3H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 144.1, 133.3, 55.5, 52.7, 31.6, 30.3, 28.7, 26.5, 22.5, 14.0. HRMS (ESI) calcd for C<sub>10</sub>H<sub>18</sub>IN<sub>2</sub><sup>+</sup> [M+H]<sup>+</sup> 293.0509, found 293.0522.



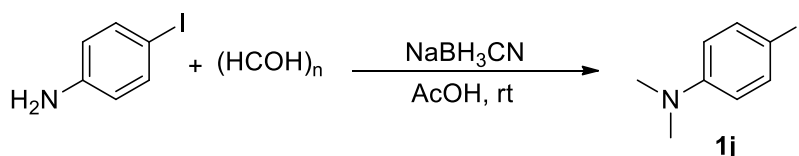
Prepared according to the general procedure, yellow oil, 1.48 g, quant. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.53 (s, 1H), 7.38 (s, 1H), 7.37–7.29 (m, 3H), 7.22–7.20 (m, 2H), 5.28 (s, 2H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 144.6, 135.8, 133.7, 129.0, 128.4, 127.9, 56.6, 56.5.<sup>2</sup>



4-Bromoindole was weighed directly into a Schlenk tube and dried under vacuum for 15 min. Then THF and NaH (1.5 equiv) were added at 0 °C. After stirring for 30 min at 0 °C, methyl iodide (1.5 equiv) was added. The mixture was then warmed up to r.t. and the resulting reaction mixture was monitored by TLC. Then the reaction was quenched by H<sub>2</sub>O and extracted with Et<sub>2</sub>O. The combined organic extracts were washed with brine, dried over anhydrous MgSO<sub>4</sub>, filtered, concentrated and purified on silica gel chromatography (EtOAc/petroleum ether as eluent) to give the product **1e** as a yellow oil, 1.1 g, quant. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.25 (dd, *J* = 8.0, 0.8 Hz, 1H), 7.20 (dt, *J* = 8.0, 0.8 Hz, 1H), 7.05–7.01 (m, 2H), 6.50 (dd, *J* = 7.2, 0.8 Hz, 1H), 3.70 (s, 3H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 137.1, 129.5, 129.2, 122.4, 122.3, 114.9, 108.6, 101.3, 33.2.<sup>3</sup>

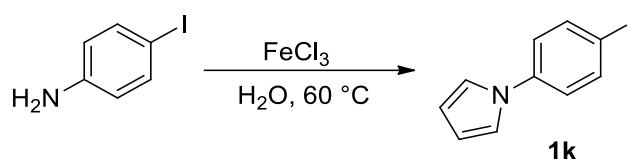


The solution of 4-iodobenzoic acid (6 mmol) was refluxed in 10 mL SOCl<sub>2</sub> for 2 h. The mixture was cooled to r.t. and the excess SOCl<sub>2</sub> was removed under vacuum to give 4-iodobenzoyl chloride. The acyl chloride was dissolved in 10 mL dry CH<sub>2</sub>Cl<sub>2</sub> and added dropwise to a 20 mL solution of *i*Pr<sub>2</sub>NH (6 mmol) and Et<sub>3</sub>N (12 mmol) in dry CH<sub>2</sub>Cl<sub>2</sub> at 0 °C. After stirring for 6 h at r.t., the resulting mixture was washed with brine, and extracted with CH<sub>2</sub>Cl<sub>2</sub>, dried over anhydrous MgSO<sub>4</sub>, filtered, concentrated and purified on silica gel chromatography (EtOAc/petroleum ether as eluent) to give the product **1i** as a yellow solid, 2.0g, quant.<sup>4</sup> <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.72 (dt, *J* = 8.4, 2.0 Hz, 2H), 7.06 (dt, *J* = 8.4, 2.0 Hz, 2H), 3.76 (brs, 1H), 3.56 (brs, 1H), 1.47 (brs, 6H), 1.17 (brs, 6H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 170.0, 138.3, 137.6, 127.4, 94.4, 50.5, 45.9, 20.7.<sup>5</sup>

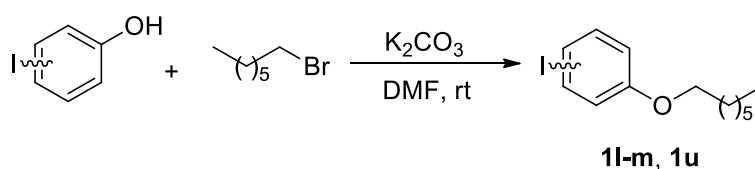


4-Iodoaniline (10 mmol) was dissolved in acetic acid (50 mL). Paraformaldehyde (100 mmol) was added and slowly added sodium cyanoborohydride (50 mmol). The reaction mixture was stirred at room temperature for 12 h. Then the solution of NaOH (1 M) was slowly added until it turned strongly basic. The mixture was extracted with ethyl acetate and the combined organic extracts were washed with brine, dried over anhydrous MgSO<sub>4</sub>, filtered, concentrated and purified on silica gel chromatography (EtOAc/petroleum ether as eluent) to give the **1j** as a green solid, 704 mg, 29%. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.46 (dt, *J* = 9.6, 2.6 Hz, 2H), 6.48 (dt, *J* = 9.6, 2.6 Hz, 2H), 2.91 (s, 6H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 150.0, 137.6,

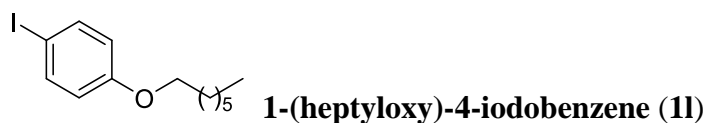
114.7, 77.5, 40.4.<sup>6</sup>



4-Iodoaniline (5 mmol) and 2,5-dimethoxytetrahydrofuran (6 mmol) were dissolved in water (4 mL) at 60 °C, then FeCl<sub>3</sub> (2 mol%) was added. The mixture was stirred for 4 h and extracted with Et<sub>2</sub>O. The combined organic extracts were washed with brine, dried over anhydrous MgSO<sub>4</sub>, filtered, concentrated and purified on silica gel chromatography (EtOAc/petroleum ether as eluent) to give the **1k** as a yellow solid, 880 mg, 66%. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.71 (dt, *J* = 9.6, 2.4 Hz, 2H), 7.13 (dt, *J* = 9.6, 2.4 Hz, 2H), 7.04 (t, *J* = 2.2 Hz, 2H), 6.35 (t, *J* = 2.2 Hz, 2H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 140.4, 138.6, 122.2, 119.1, 111.0, 89.4.<sup>7</sup>



General procedure: To a solution of 2-iodophenol (5.0 mmol) in DMF (10 mL) potassium carbonate (15 mmol) was added under stirring. After 10 min 1-bromoheptane (6.0 mmol) was added to the reaction mixture. The reaction was stirred at r.t. overnight. The reaction was quenched by H<sub>2</sub>O and extracted with ethyl acetate. The combined organic extracts were washed with brine, dried over anhydrous MgSO<sub>4</sub>, filtered, concentrated and purified on silica gel chromatography (EtOAc/petroleum ether as eluent) to give the product.<sup>8</sup>

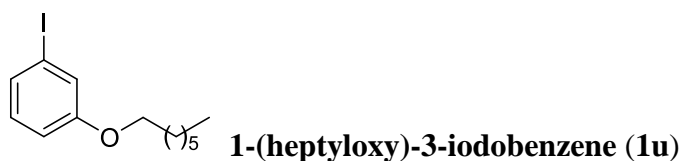


Prepared according to the general procedure, colorless oil, 1.58 g, 99%. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.53 (dt, *J* = 9.6, 2.8 Hz, 2H), 6.60 (dt, *J* = 9.6, 2.8 Hz, 2H), 3.90 (t, *J* = 6.6 Hz, 2H), 1.79–1.72 (m, 2H), 1.46–1.39 (m, 2H), 1.37–1.26 (m, 6H), 0.89 (t, *J* = 7.0 Hz, 3H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 159.0, 138.2, 116.9, 82.4, 68.1, 31.8, 29.2, 29.1, 26.0, 22.6, 14.1.<sup>9</sup>

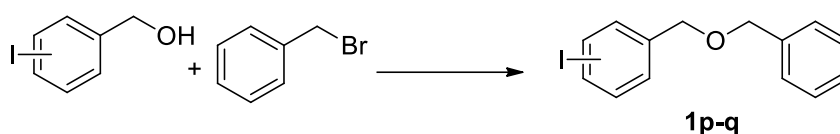


Prepared according to the general procedure, colorless oil, 1.6 g, quant. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.76 (dd, *J* = 7.6, 1.6 Hz, 1H), 7.29–7.25 (m, 1H), 6.79 (dd, *J* = 8.4, 1.2 Hz, 1H), 6.68 (dt, *J* = 7.6, 1.2 Hz,

1H), 4.00 (t,  $J = 6.4$  Hz, 2H), 1.86–1.79 (m, 2H), 1.53–1.48 (m, 2H), 1.40–1.29 (m, 6H), 0.90 (t,  $J = 6.8$  Hz, 3H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ )  $\delta$  157.6, 139.4, 129.4, 122.3, 112.1, 86.7, 69.2, 31.8, 29.1, 29.0, 26.1, 22.6, 14.1. HRMS (ESI) calcd for  $\text{C}_{13}\text{H}_{20}\text{IO}^+$   $[\text{M}+\text{H}]^+$  319.0553, found 319.0550.



Prepared according to the general procedure, colorless oil, 1.58 g, 99%.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.25 (d,  $J = 8.0$  Hz, 2H), 6.97 (t,  $J = 8.0$  Hz, 1H), 6.85 (d,  $J = 8.8$  Hz, 1H), 3.91 (t,  $J = 6.4$  Hz, 2H), 1.79–1.72 (m, 2H), 1.46–1.41 (m, 2H), 1.40–1.30 (m, 6H), 0.89 (t,  $J = 6.4$  Hz, 3H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ )  $\delta$  159.8, 130.7, 129.6, 123.6, 114.2, 94.4, 68.2, 31.8, 29.2, 29.1, 26.0, 22.6, 14.1. HRMS (ESI) calcd for  $\text{C}_{13}\text{H}_{20}\text{IO}^+$   $[\text{M}+\text{H}]^+$  319.0553, found 319.0576.



(4-iodophenyl)methanol was weighed directly into a Schlenk tube and dried under vacuum for 15 min. Then THF was added and stirred. NaH (1.5 equiv) was slowly added at 0 °C. After stirring for 30 min, benzyl bromide (1.1 equiv) was added. The mixture was then warmed up to r.t. and the resulting reaction mixture was monitored by TLC. The reaction was quenched by  $\text{H}_2\text{O}$  and extracted with  $\text{Et}_2\text{O}$ . The combined organic extracts were washed with brine, dried over anhydrous  $\text{MgSO}_4$ , filtered, concentrated and purified on silica gel chromatography ( $\text{EtOAc}$ /petroleum ether as eluent) to give the product.



Prepared according to the general procedure, colorless oil, 1.2 g, 46%.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.72 (s, 1H), 7.61 (d,  $J = 8.0$  Hz, 1H), 7.36–7.23 (m, 6H), 7.07 (t,  $J = 8.0$  Hz, 1H), 4.55 (s, 2H), 4.48 (s, 2H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ )  $\delta$  140.8, 137.9, 136.7, 136.6, 130.2, 128.5, 127.9, 127.8, 126.9, 94.5, 72.4, 71.2.<sup>10</sup>



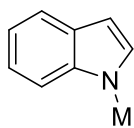
Prepared according to the general procedure, colorless oil, 1.1 g, 73%.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.66 (d,  $J = 8.4$  Hz, 2H), 7.35–7.27 (m, 5H), 7.10 (d,  $J = 8.0$  Hz, 2H), 4.53 (s, 2H), 4.47 (s, 2H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ )  $\delta$  138.1, 137.6, 129.7, 128.5, 127.9, 127.8, 93.1, 72.3, 71.4.<sup>11</sup>

### 2.3. General procedure of dehalogenation of aryl halides

**General procedure A (PhCHO):**  $t\text{BuOK}$  (1.0 mmol, 112mg) was weighed directly into a Schlenk tube and dried under high vacuum for 15 min. Then DMF (1 mL), **1**, and PhCHO (52  $\mu\text{L}$ ) were added under

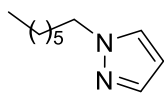
argon and stirred at 90 °C and the reaction was monitored by TLC. Upon completion, the reaction mixture was directly purified by silica gel column to give the target product.

**General procedure B (PhCH<sub>2</sub>OH):** <sup>t</sup>BuOK (1.0 mol, 112mg) was weighed directly into a Schlenk tube and dried under high vacuum for 15 min. Then DMF (1 mL), **1**, and BnOH (52 μL) were added and stirred at 90 °C under argon and the reaction was monitored by TLC. Upon completion, the reaction mixture was directly purified by silica gel column to give the target product.



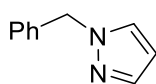
Me **1-methyl-1H-indole (2a or 2e)**

Prepared according to the general procedure A, colorless oil. From **1a**, 56.6 mg, 86%; from **1e**, 57 mg, 87%; general procedure B, from **1a**, 60.5 mg, 86%; from **1e**, 57 mg, 87%. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.62 (dt, *J* = 8.0, 1.0 Hz, 1H), 7.30 (dd, *J* = 8.0, 0.8 Hz, 1H), 7.12–7.08 (m, 1H), 7.01 (d, *J* = 3.2 Hz, 1H), 6.47 (dd, *J* = 3.2, 0.8 Hz, 1H), 3.74 (s, 3H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 136.8, 128.9, 128.5, 121.5, 120.9, 119.3, 109.3, 101.1, 32.7.<sup>12</sup>



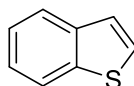
**1-heptyl-1H-pyrazole (2b)**

Prepared according to the general procedure A, yellow oil, 76.5 mg, 92%; procedure B, 76.5 mg, 92%. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.50 (d, *J* = 2.0 Hz, 1H), 7.37 (d, *J* = 2.0 Hz, 1H), 6.23 (t, *J* = 2.0 Hz, 1H), 4.12 (t, *J* = 7.2 Hz, 2H), 1.89–1.82 (m, 2H), 1.30–1.25 (m, 8H), 0.87 (t, *J* = 6.8 Hz, 3H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 139.0, 128.8, 105.1, 52.2, 31.7, 30.5, 28.8, 26.6, 22.5, 14.0. HRMS (ESI) calcd for C<sub>10</sub>H<sub>19</sub>N<sub>2</sub><sup>+</sup> [M+H]<sup>+</sup> 167.1543, found 167.1554.



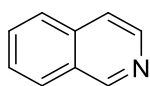
Ph **1-benzyl-1H-pyrazole (2c)**

Prepared according to the general procedure A, white solid, 73.3 mg, 93%; procedure B, 73.3 mg, 93%. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.54 (d, *J* = 1.6 Hz, 1H), 7.36 (d, *J* = 2.0 Hz, 1H), 7.35–7.26 (m, 3H), 7.20–7.18 (m, 2H), 6.27 (t, *J* = 6.0 Hz, 1H), 5.31 (s, 2H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 139.6, 136.7, 129.3, 128.8, 128.0, 127.7, 106.0, 55.9.<sup>13</sup>



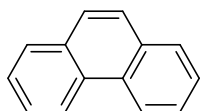
**Thianaphthene (2d)**

Prepared according to the general procedure A, yellow solid, 47 mg, 70%; procedure B, 51.7 mg, 77%. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.94–7.85 (m, 2H), 7.47 (dd, *J* = 5.4, 1.0 Hz, 1H), 7.43–7.36 (m, 3H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 139.8, 139.6, 126.4, 124.3, 124.2, 123.9, 123.7, 122.6.<sup>14</sup>



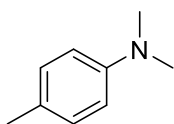
**Isoquinoline (2f)**

Prepared according to the general procedure A, colorless oil, 54 mg, 84%; procedure B, 54 mg, 84%.  $^1\text{H NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  9.25 (s, 1H), 8.52 (d,  $J = 5.2$  Hz, 1H), 7.94 (d,  $J = 8.0$  Hz, 1H), 7.79 (d,  $J = 8.0$  Hz, 1H), 7.681–7.56 (m, 3H).  $^{13}\text{C NMR}$  (100 MHz,  $\text{CDCl}_3$ )  $\delta$  152.5, 142.9, 135.8, 130.4, 128.7, 127.7, 127.3, 126.5, 120.5.<sup>15</sup>



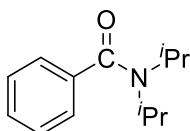
**Phenanthrene (2g)**

Prepared according to the general procedure A, white solid, 71 mg, 80%; procedure B, 72.9 mg, 82%.  $^1\text{H NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  8.68 (d,  $J = 8.0$  Hz, 2H), 7.80 (d,  $J = 8.0$  Hz, 2H), 7.73 (s, 2H), 7.64 (t,  $J = 7.6$  Hz, 2H), 7.58 (t,  $J = 7.6$  Hz, 2H).  $^{13}\text{C NMR}$  (100 MHz,  $\text{CDCl}_3$ )  $\delta$  132.1, 130.3, 128.6, 126.9, 126.6, 122.7.<sup>16</sup>



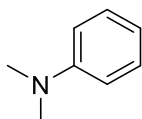
***N,N*,4-trimethylaniline (2h)**

Prepared according to the general procedure B, colorless oil, 50.6 mg, 75%.  $^1\text{H NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.04 (d,  $J = 8.4$  Hz, 2H), 6.67 (d,  $J = 8.4$  Hz, 2H), 2.83 (s, 6H), 2.25 (s, 3H).  $^{13}\text{C NMR}$  (100 MHz,  $\text{CDCl}_3$ )  $\delta$  148.9, 129.6, 126.1, 113.3, 41.10, 20.3.<sup>17</sup>



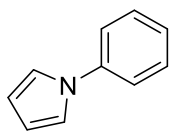
***N,N*-diisopropylbenzamide (2i)**

Prepared according to the general procedure A, white solid, 99.8 mg, 98%; procedure B, 102 mg, 99%.  $^1\text{H NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.39–7.28 (m, 5H), 3.84 (brs, 1H), 3.53 (brs, 1H), 1.52 (brs, 6H), 1.15 (brs, 6H).  $^{13}\text{C NMR}$  (100 MHz,  $\text{CDCl}_3$ )  $\delta$  171.1, 138.9, 128.6, 128.5, 125.6, 50.8, 45.7, 20.7.<sup>18</sup>



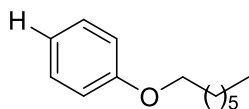
***N,N*-dimethylaniline (2j)**

Prepared according to the general procedure A, yellow oil, 55 mg, 91%; procedure B, 45.2 mg, 75%.  $^1\text{H NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.26–7.22 (m, 2H), 6.76–6.70 (m, 3H), 2.93 (s, 6H).  $^{13}\text{C NMR}$  (100 MHz,  $\text{CDCl}_3$ )  $\delta$  150.7, 129.1, 116.7, 112.7, 40.7.<sup>19</sup>



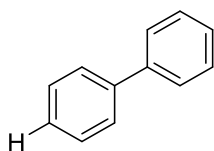
**1-Phenyl-1H-pyrrole (2k)**

Prepared according to the general procedure A, white solid, 52.6 mg, 74%; procedure B, 52.6 mg, 74%.  $^1\text{H NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.43–7.37 (m, 2H), 7.25–7.21 (m, 1H), 7.09 (t,  $J = 2.2$  Hz, 2H), 6.35 (t,  $J = 2.2$  Hz, 2H).  $^{13}\text{C NMR}$  (100 MHz,  $\text{CDCl}_3$ )  $\delta$  140.8, 129.6, 125.6, 120.6, 119.3, 110.4.<sup>20</sup>



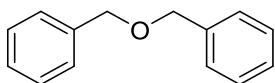
**(Heptyloxy)benzene (2l, 2m or 2u)**

Prepared according to the general procedure A, colorless oil, from **1l**, 89.4 mg, 93%; from **1m**, 92mg, 96%; from **1u**, 76.1 mg, 79%; procedure B, from **1l**, 87.1 mg, 91%; from **1m**, 85.8 mg, 89%.  $^1\text{H NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.29–7.24 (m, 2H), 6.94–6.87 (m, 3H), 3.94 (t,  $J = 6.6$  Hz, 2H), 1.81–1.74 (m, 2H), 1.48–1.37 (m, 2H), 1.31–1.26 (m, 6H), 0.89 (t,  $J = 7.0$  Hz, 3H).  $^{13}\text{C NMR}$  (100 MHz,  $\text{CDCl}_3$ )  $\delta$  159.2, 129.4, 120.5, 114.5, 67.9, 31.8, 29.3, 29.1, 26.1, 22.7, 14.1.<sup>21</sup>



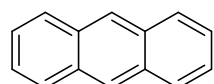
**1,1'-Biphenyl (2n or 2o)**

Prepared according to the general procedure A, white solid, from **1n**, 74.3, 96%; from **1o** 75.1 mg, 97%; procedure B, from **1n**, 76 mg, 98%; from **1o** 74.3 mg, 96%.  $^1\text{H NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.59–7.57 (m, 4H), 7.44–7.40 (m, 4H), 7.32 (tt,  $J = 7.4, 1.4$  Hz, 2H).  $^{13}\text{C NMR}$  (100 MHz,  $\text{CDCl}_3$ )  $\delta$  141.3, 128.8, 127.3 (two peaks).<sup>22</sup>



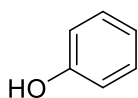
**Benzyl ether (2p or 2q)**

Prepared according to the general procedure B, colorless oil, from **1p**, 77 mg, 78%; from **1q**, 81 mg, 97%.  $^1\text{H NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.35–7.27 (m, 10H), 4.54 (s, 4H).  $^{13}\text{C NMR}$  (100 MHz,  $\text{CDCl}_3$ )  $\delta$  138.4, 128.5, 127.9, 127.7, 72.2.<sup>10</sup>



**Anthracene (2r)**

Prepared according to the general procedure, white solid, 67.8 mg, 76%.  $^1\text{H NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  8.42 (s, 2H), 8.01–7.98 (m, 4H), 7.48–7.44 (m, 4H).  $^{13}\text{C NMR}$  (100 MHz,  $\text{CDCl}_3$ )  $\delta$  131.7, 128.2, 126.3, 125.4.<sup>27</sup>



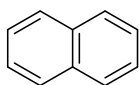
**Phenol (2s)**

Prepared according to the general procedure A. 80% of yields were determined by GC using mesitylene (69  $\mu$ L) as internal standard. The structure was confirmed by standard phenol sample by GC.



**Benzene (2v)**

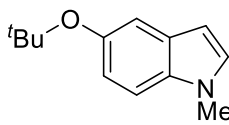
Prepared according to the general procedure A. 99% of yields were determined by GC using mesitylene (69  $\mu$ L) as internal standard. The structure was confirmed by standard benzene sample by GC.



**Naphthalene (2w)**

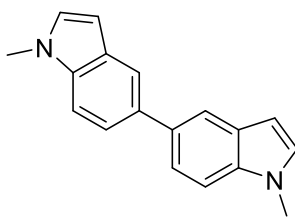
Prepared according to the general procedure A. 94% of yields were determined by GC using mesitylene (69  $\mu$ L) as internal standard. The structure was confirmed by standard naphthalene sample by GC.

### 2.3. Dimers and Ethers.



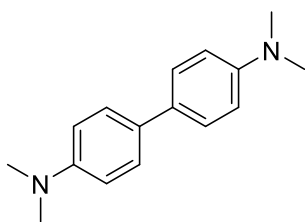
**5-(*tert*-butoxy)-1-methyl-indole (7)**

**$^1\text{H NMR}$**  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.49 (s, 1H), 7.18 (d,  $J = 8.8$  Hz, 1H), 7.02 (d,  $J = 2.8$ , 1H), 6.91 (d,  $J = 8.8$  Hz, 1H) 6.41(d,  $J = 2.8$ , 1H), 3.77 (s, 3H), 1.34 (s, 9H).  **$^{13}\text{C NMR}$**  (100 MHz,  $\text{CDCl}_3$ )  $\delta$  148.2, 133.8, 129.3, 128.5, 119.8, 115.7, 108.8, 100.6, 77.9, 33.0, 28.9. **HRMS (ESI)** calcd for  $\text{C}_{13}\text{H}_{18}\text{NO}^+$   $[\text{M}+\text{H}]^+$  204.1383, found 204.1387.



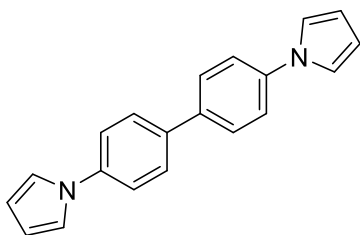
**1,1'-dimethyl-5,5'-biindole (1a-dimer)**

**$^1\text{H NMR}$**  (400 MHz,  $\text{CDCl}_3$ )  $\delta$ . 7.87 (s, 2H), 7.54 (dd,  $J = 7.6$  1.2 Hz, 2H), 7.36 (d,  $J = 6.4$  Hz, 2H), 7.04(d,  $J = 2.8$  Hz, 2H), 6.52 (d,  $J = 2.8$  Hz, 2H), 3.78 (s, 6H).  **$^{13}\text{C NMR}$**  (100 MHz,  $\text{CDCl}_3$ )  $\delta$  135.9, 134.3, 129.3, 129.0, 109.3, 101.2, 33.0. **HRMS (ESI)** calc. for  $\text{C}_{18}\text{H}_{17}\text{N}_2^+$   $[\text{M}+\text{H}]^+$  261.1386, found 261.1394.



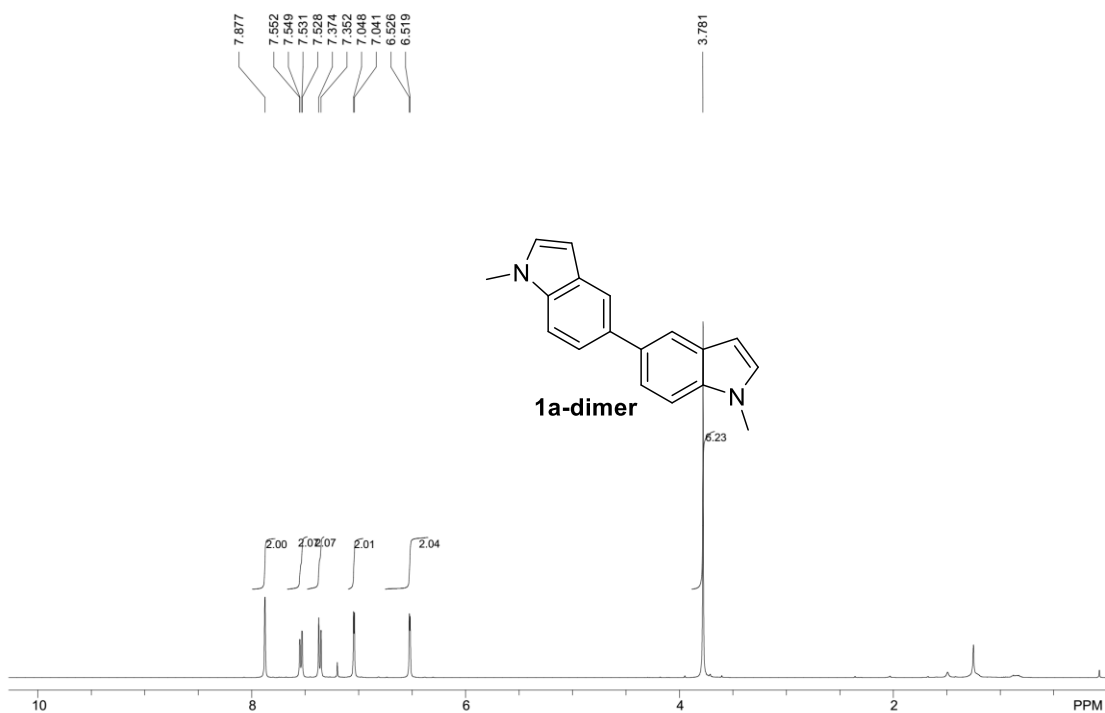
***N,N',N'',N'''*-tetramethyl-[1,1'-biphenyl]-4,4'-diamine (1j-dimer)**

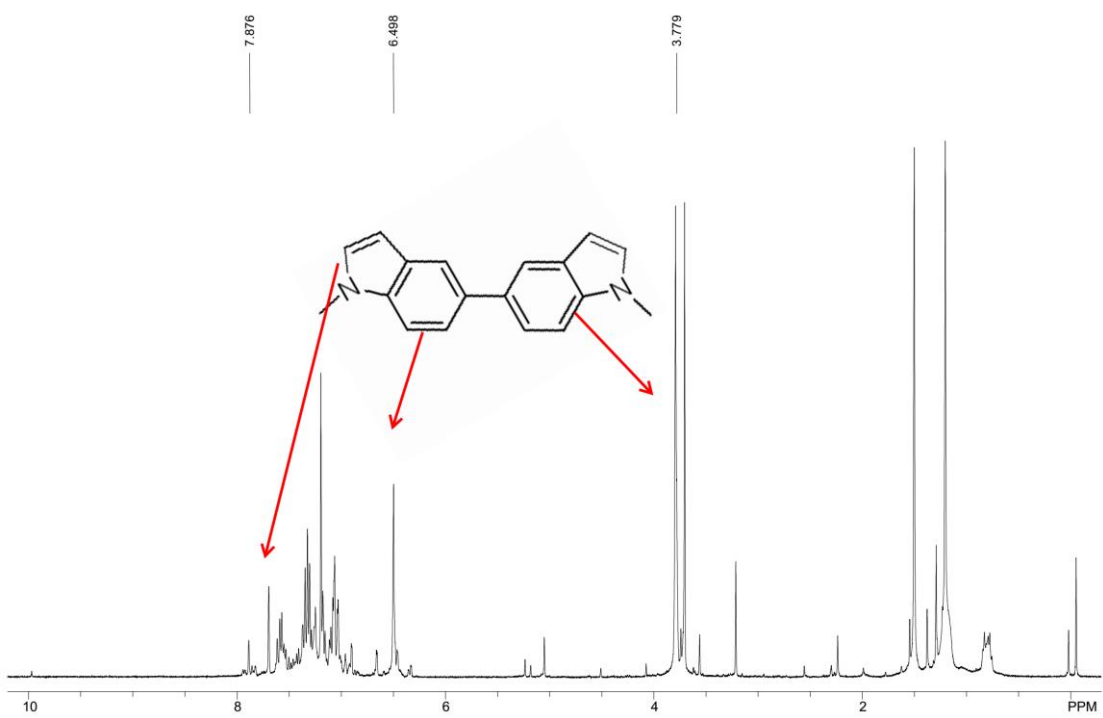
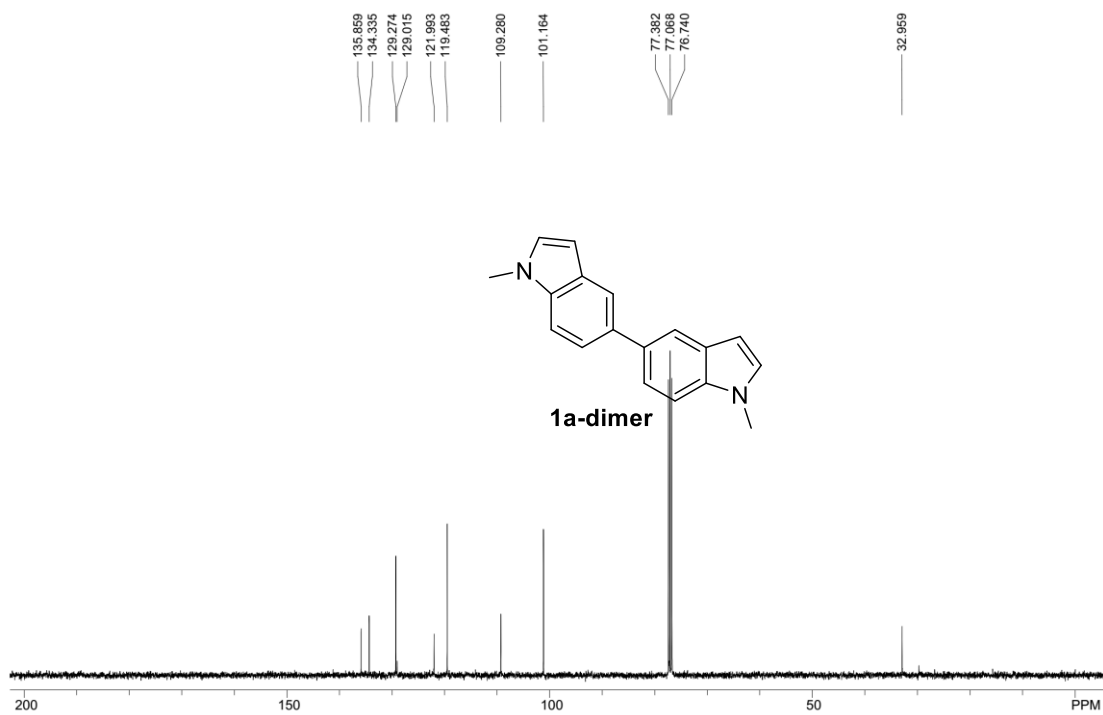
**<sup>1</sup>H NMR** (400 MHz, CDCl<sub>3</sub>) δ. 7.45 (dd, *J* = 9.0, 2.4 Hz, 4H), 6.79 (dd, *J* = 9.0, 2.4 Hz, 4H), 2.96 (s, 12H). **<sup>13</sup>C NMR** (100 MHz, CDCl<sub>3</sub>) δ 149.3, 129.9, 127.0, 113.1, 40.8.<sup>28</sup>

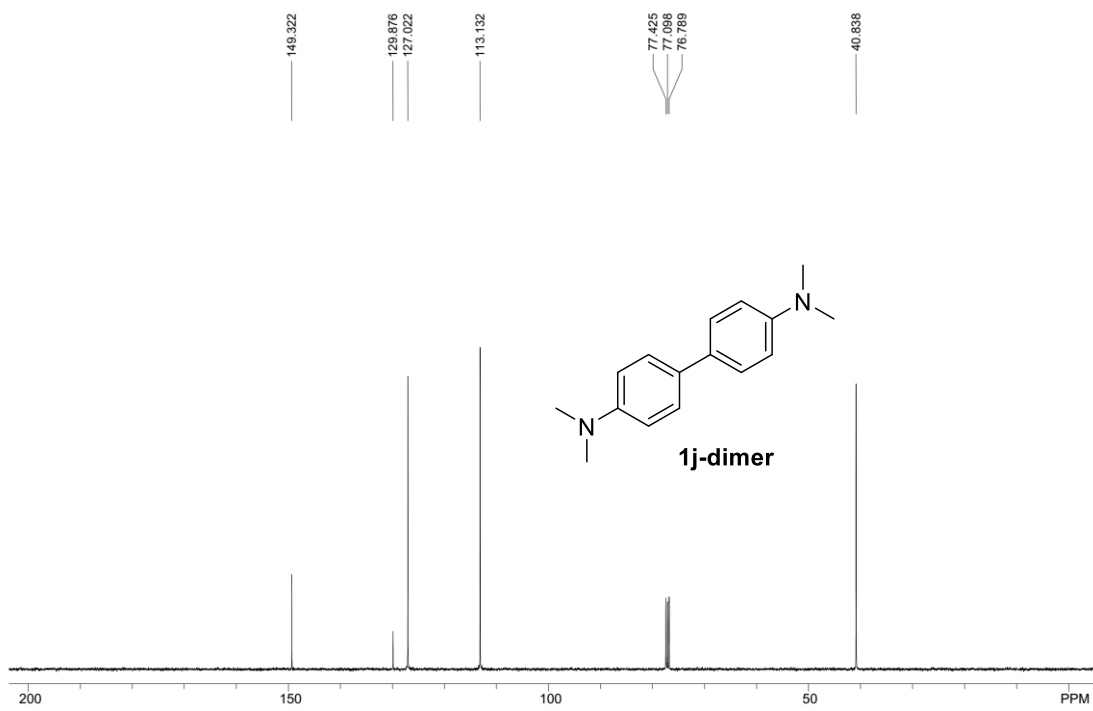
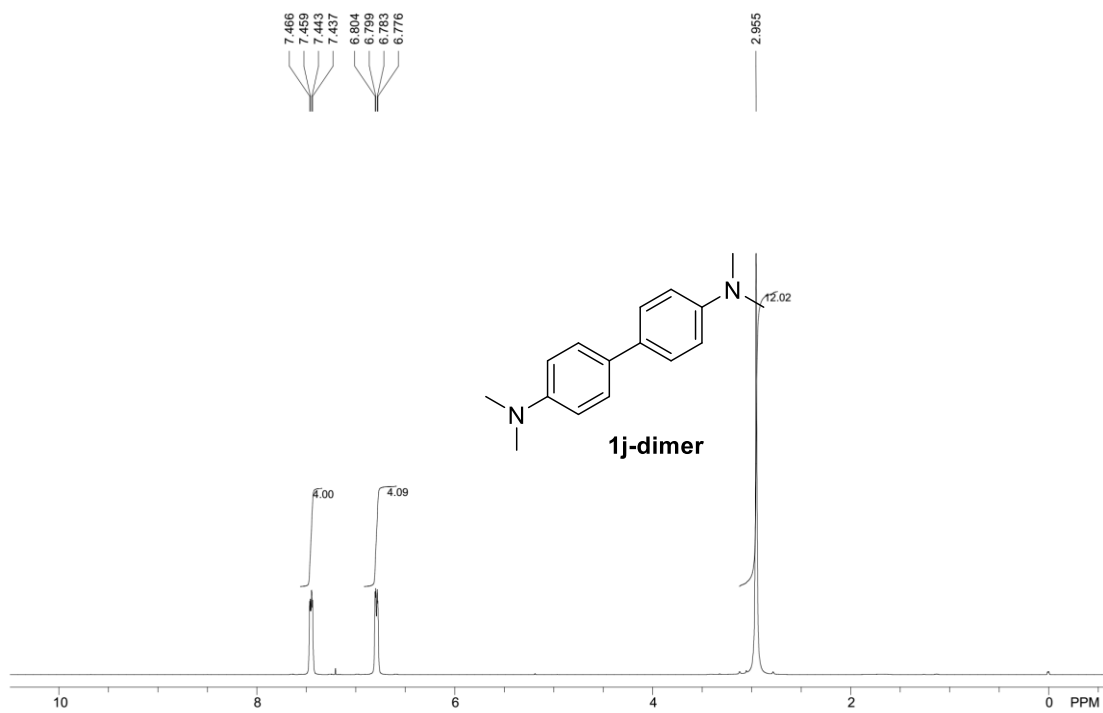


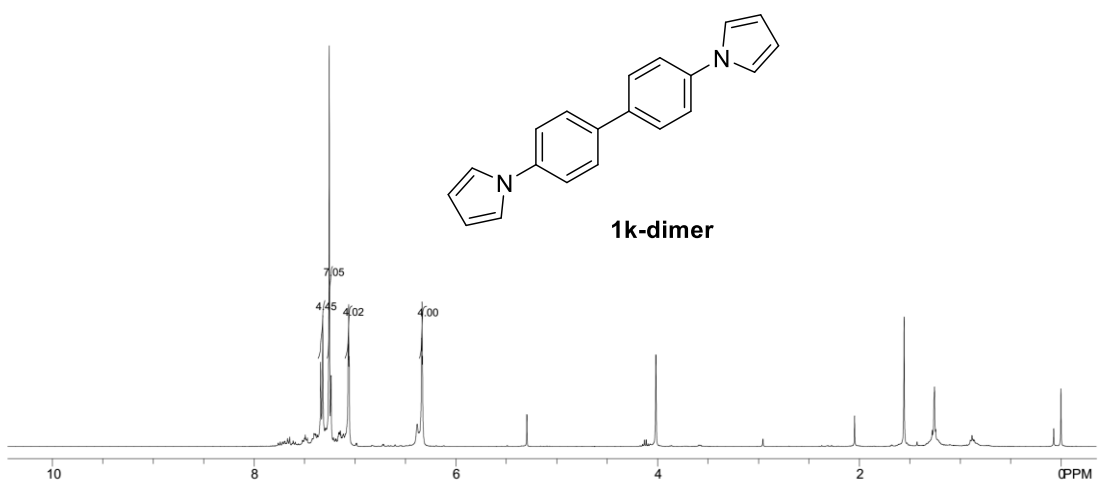
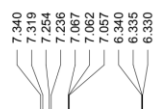
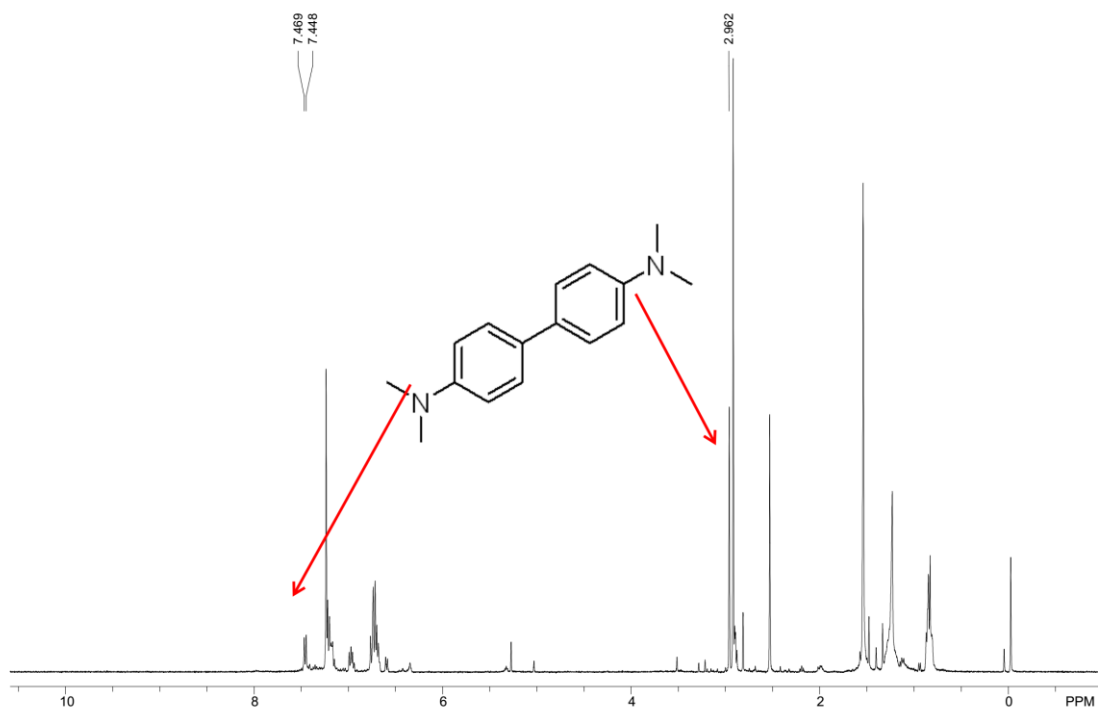
**4,4'-di(pyrrol-1-yl)-1,1'-biphenyl (1k-dimer)**

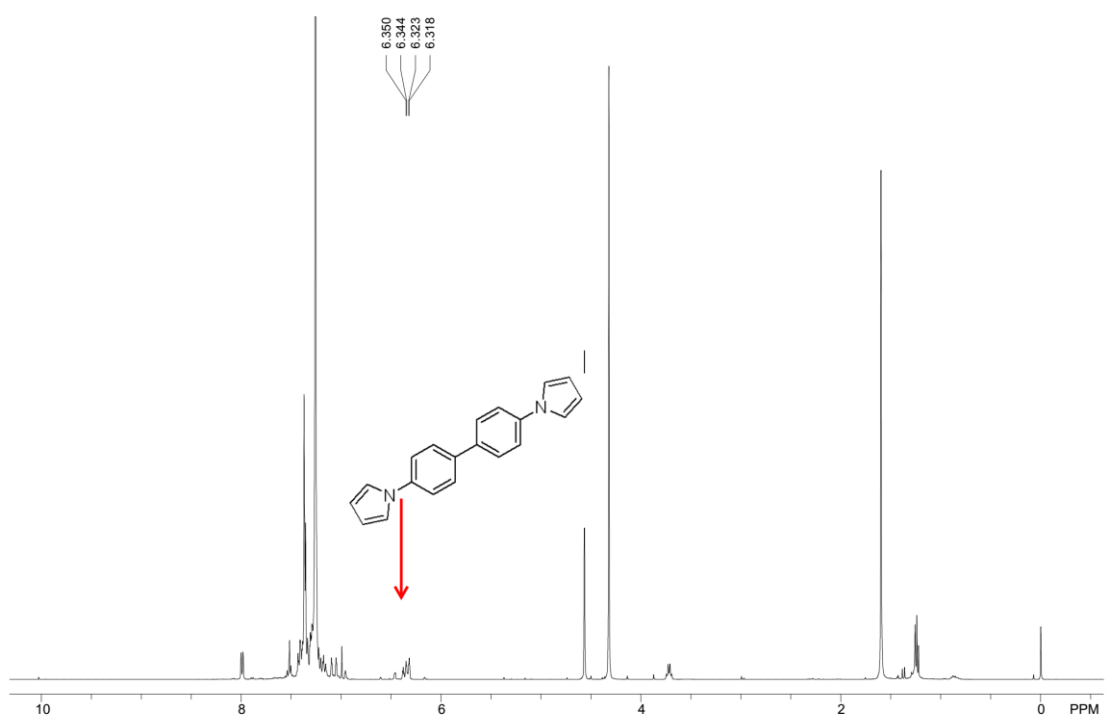
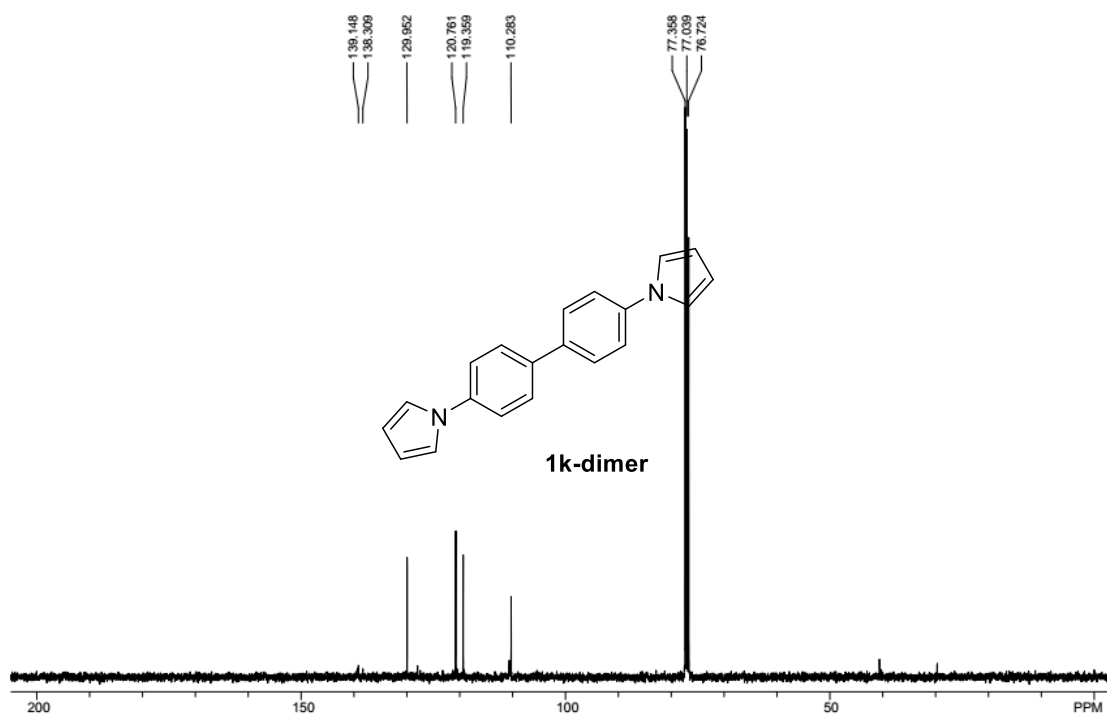
**<sup>1</sup>H NMR** (400 MHz, CDCl<sub>3</sub>) δ. 7.33 (d, *J* = 8.4 Hz, 4H). 7.24 (d, *J* = 8.4 Hz, 4H), 7.06 (t, *J* = 2.0 Hz, 4H), 6.34 (t, *J* = 2.0 Hz, 4H). **<sup>13</sup>C NMR** (100 MHz, CDCl<sub>3</sub>) δ 110.3, 119.4, 120.8, 130.0, 138.3, 139.1. **HRMS (ESI)** calc. for C<sub>20</sub>H<sub>17</sub>N<sub>2</sub><sup>+</sup> [M+H]<sup>+</sup> 285.1386, found 285.1379.



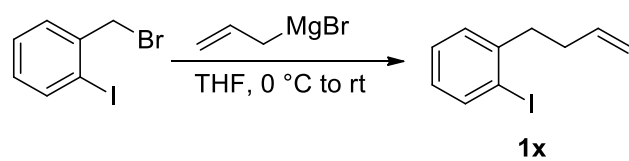








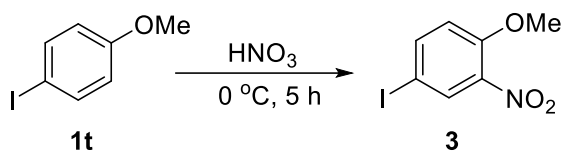
#### 2.4. Preparation of 1x



Vinyl magnesium bromide (2.0 equiv, 1.0 M in THF) was added slowly to a stirred solution of freshly distilled 1-(bromomethyl)-2-iodobenzene (1.0 equiv) in THF (0.5 M) below 5 °C. After 15 min, the reaction

was allowed to warm to r.t. and stirred for additional 3 h. The reaction was quenched with sat.  $\text{NH}_4\text{Cl}$  aq. and extracted with  $\text{Et}_2\text{O}$ . The combined organic extracts were washed with brine, dried over  $\text{MgSO}_4$ , filtered, concentrated and purified on silica gel chromatography ( $\text{EtOAc}$ /petroleum ether as eluent) to give the **1x** as a colorless oil, 630 mg, 76%.<sup>23</sup>  $^1\text{H NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.80 (dd,  $J = 8.0, 1.2$  Hz, 1H), 7.28–7.18 (m, 2H), 6.87 (td,  $J = 8.0, 2.0$  Hz, 1H), 5.94–5.84 (m, 1H), 5.07 (dq,  $J = 17.2, 1.6$  Hz, 1H), 5.02–4.99 (m, 1H), 2.82–2.78 (m, 2H), 2.38–2.31 (m, 2H).  $^{13}\text{C NMR}$  (100 MHz,  $\text{CDCl}_3$ )  $\delta$  144.3, 139.5, 137.6, 129.5, 128.3, 127.8, 115.3, 100.6, 40.3, 34.2.<sup>24</sup>

## 2.5. Preparation of 3



1-Iodo-4-methoxybenzene (5.0 mmol) was dissolved in conc.  $\text{HNO}_3$  (10 mL) at 0 °C, and the mixture stirred for 5 h at 0 °C.<sup>25</sup> Then the reaction was quenched by adding  $\text{H}_2\text{O}$  and extracted with  $\text{Et}_2\text{O}$ . The combined organic extracts were washed with brine, dried over anhydrous  $\text{MgSO}_4$ , filtered, concentrated under vacuum and purified by silica gel chromatography to give the product as a yellow solid, 1.38 g, 82%.  $^1\text{H NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  8.11 (s, 1H), 7.81 (d,  $J = 8.8$  Hz, 1H), 6.87 (d,  $J = 8.8$  Hz, 1H), 3.95 (s, 3H).  $^{13}\text{C NMR}$  (100 MHz,  $\text{CDCl}_3$ )  $\delta$  152.8, 142.7, 140.4, 133.9, 115.6, 80.6, 56.7.<sup>26</sup>

## 3. Kinetic studies and isotopic labelling experiment

### 3.1. Deuterium labeling experiments

**1n** (0.25 mmol) and  $t\text{BuOK}$  (56 mg) was weighed directly into a Schlenk tube and dried under high vacuum for 15 min. Then the dioxane (0.5ml) and  $\text{PhCHO}/\text{DMF-}d_7$  or  $\text{PhCDO}/\text{DMF}$  (1.0 equiv) was added and stirred at 90 °C, the reaction mixture was monitored by TLC. The mixture was subjected to run a silica gel column to give the target products.

### 3.2. Kinetic Study

**1n** (0.5 mmol) was weighed directly into a Schlenk tube and dried under vacuum for 15 min. Then solvent (DMF, 1 mL) and  $\text{PhCHO}$  or  $\text{PhCH}_2\text{OH}$  (1.0 equiv) were added and stirred respectively.  $t\text{BuOK}$  (2.0 equiv) was added. Mesitylene (69  $\mu\text{L}$ ) was added as internal standard, and the mixture was stirred at 35 °C. Timing starts from adding  $t\text{BuOK}$ . T at regular intervals 10  $\mu\text{L}$  mixture solution was sampled from the Schlenk tube. The sample mixture was used to collect GC data. The conversion of **2n** was determined by mesitylene from the GC spectra.

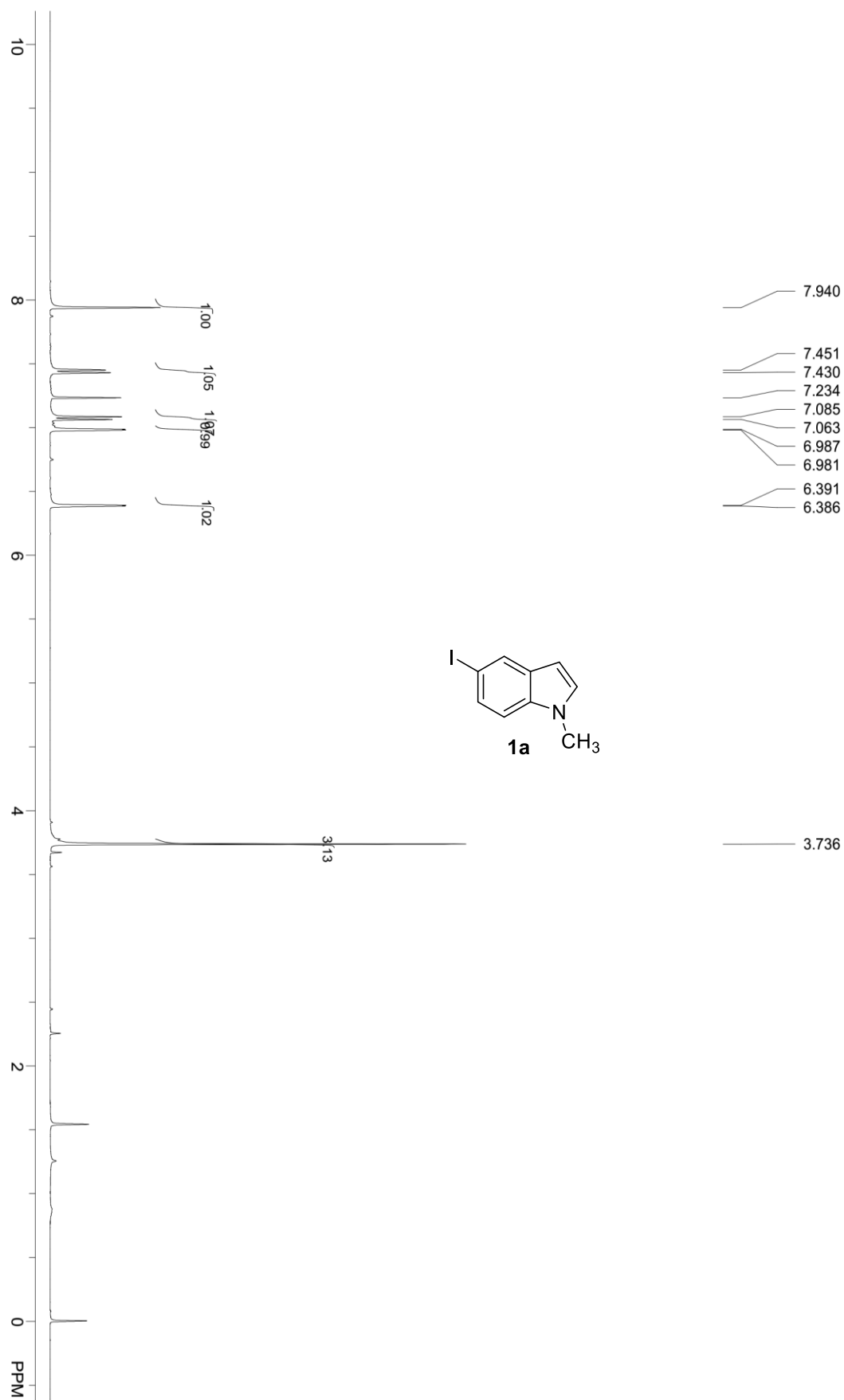
### 3.3. Kinetic Isotopic Effect

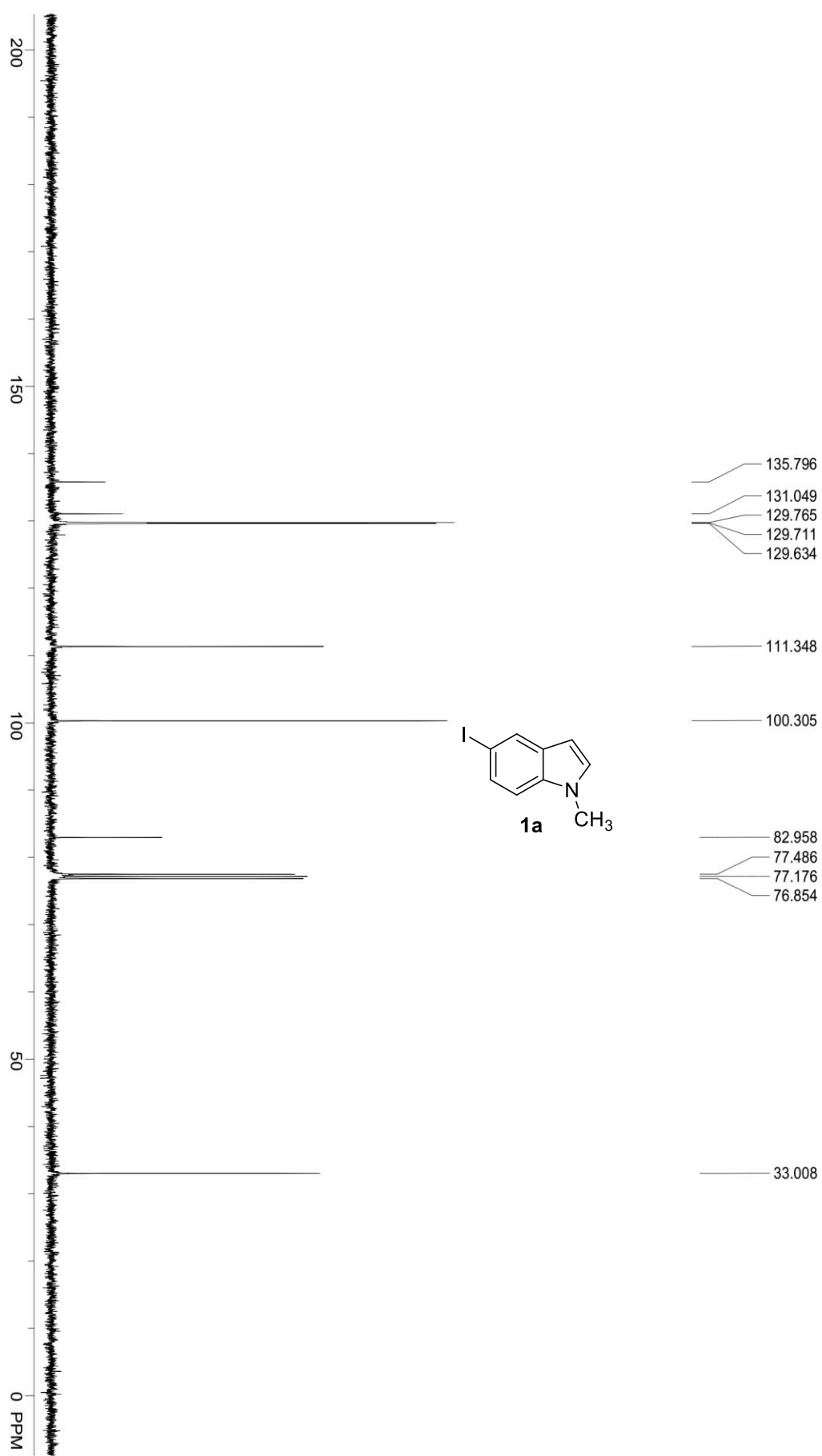
Two parallel reactions with **1n** were ran at same time. **1n** (0.25 mmol) was weighed directly into a Schlenk tube and dried under vacuum for 15 min. Then solvent (DMF, 1 mL) and PhCHO/PhCDO or PhCH<sub>2</sub>OH/PhCD<sub>2</sub>OH(1.0 equiv) were added and stirred respectively. <sup>t</sup>BuOK (2.0 equiv) was added. Mesitylene (69 μL) was added as internal standard, and the mixture was stirred at 50°C for 5 mintues. Timing starts from adding <sup>t</sup>BuOK. The sample mixture was used to collect GC data. The conversion of **2n** was determined by mesitylene from the GC spectra.

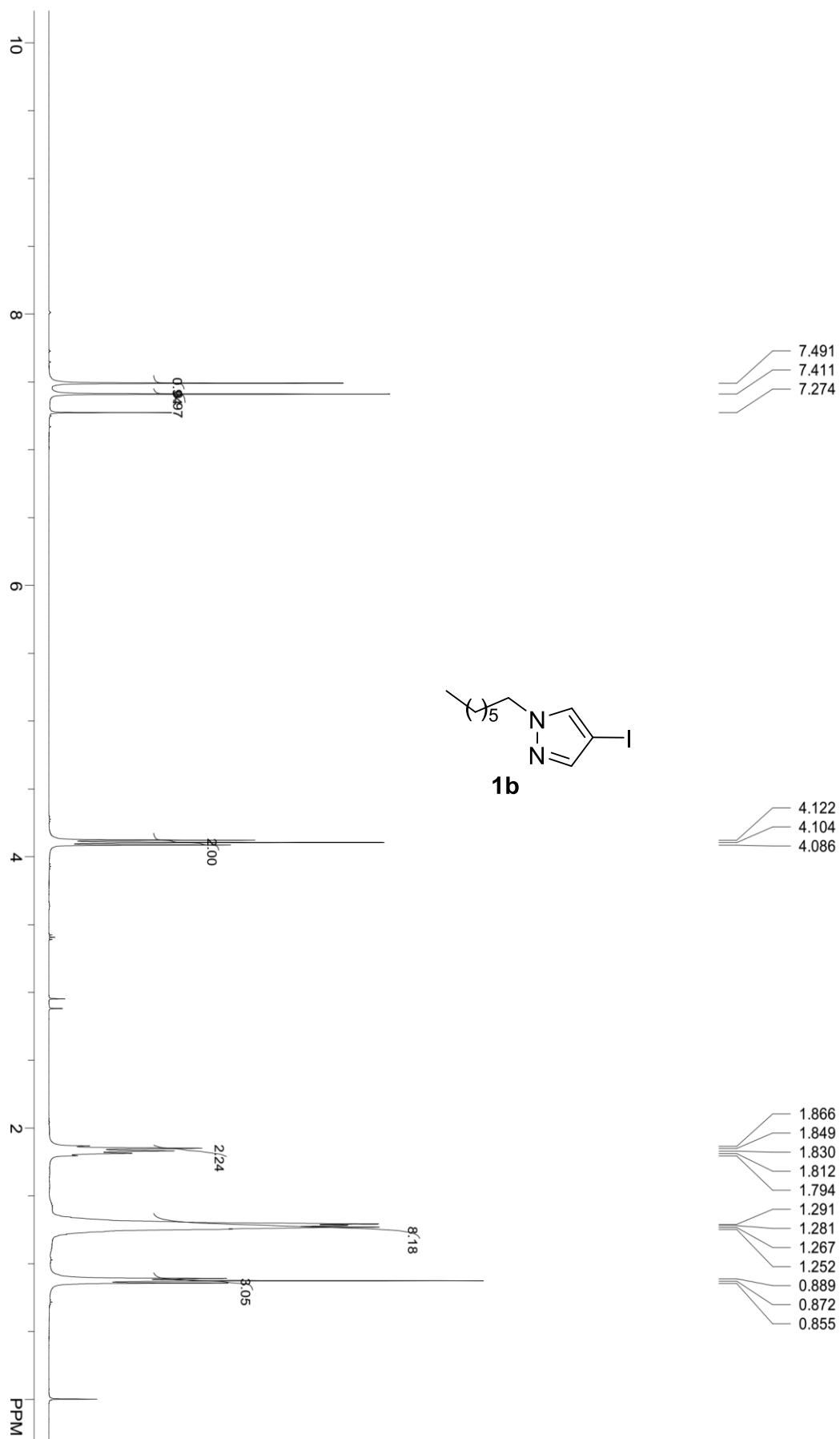
#### 4. References

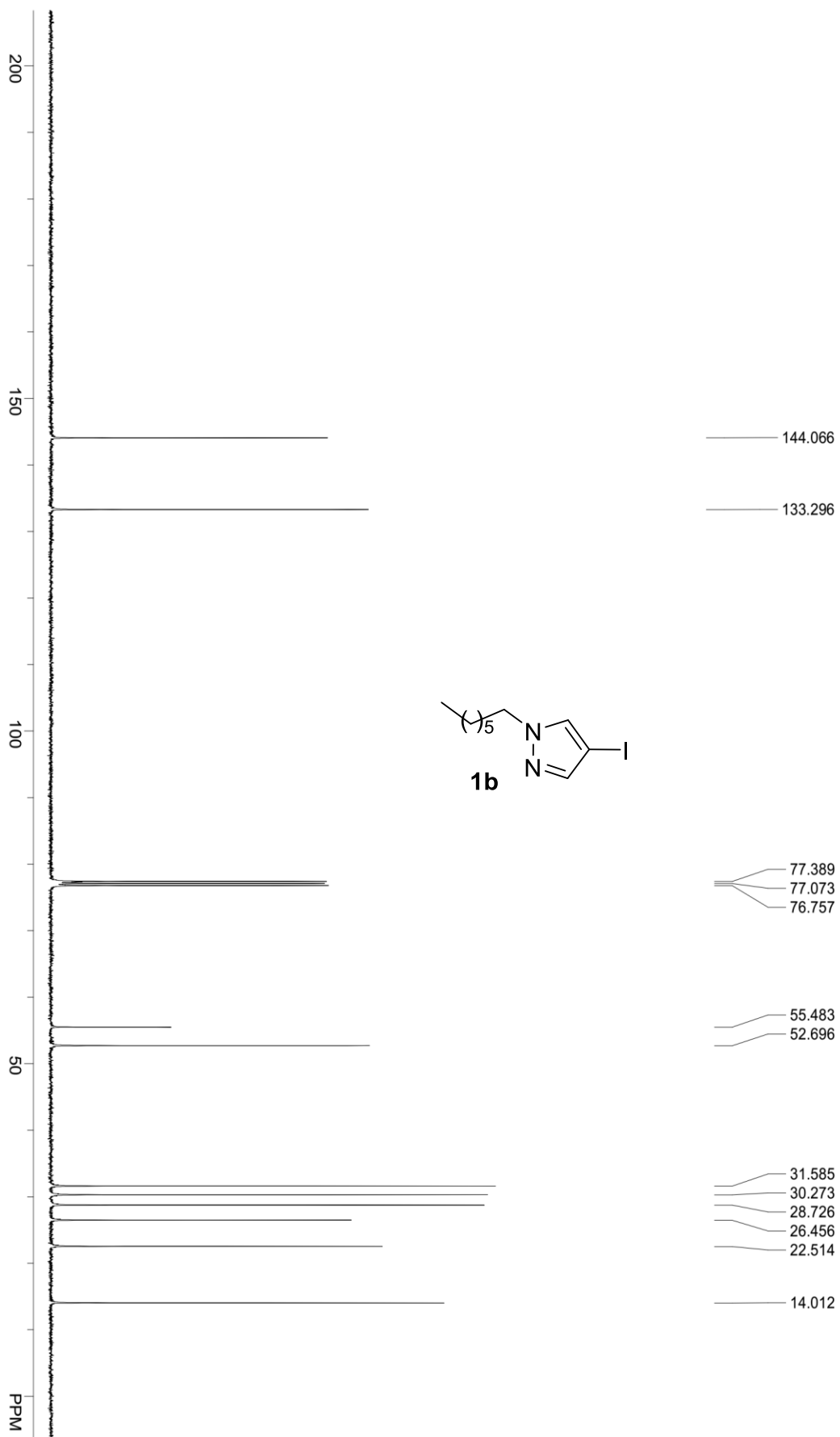
1. Tolnai, G.; Ganes, S.; Brand, J. P.; Waser, J. *Org. Lett.* **2013**, *15*, 112.
2. Rodríguez-Franco, M. I.; Dorronsoro, I.; Hernández-Higueras, A. I.; Antequera, G. *Tetrahedron Lett.* **2001**, *42*, 863.
3. Tolnai, G. L.; Székely, A.; Makò, Z.; Gáti, T.; Daru, J.; Bihari, T.; Stirling, A.; Novák, Z. *Chem. Commun.* **2015**, *51*, 4488.
4. Zhan, B.-B.; Liu, Y.-H.; Hu, F.; Shi, B.-F. *Chem. Commun.* **2016**, *52*, 4934.
5. Schröder, N.; Wencel-Delord, J.; Glorius, F. *J. Am. Chem. Soc.* **2012**, *134*, 8298.
6. Nauth, A. M.; Otto, N.; Opatz, T. *Adv. Synth. Catal.* **2015**, *357*, 3424.
7. Azizi, N.; Khajeh-Amiri, A.; Ghafuri, H.; Bolourtchian, M.; Saidi, M. R. *Synlett* **2009**, *14*, 2245.
8. Zhu, C.; Yoshimura, A.; Ji, L.; Wei, Y.; Nemykin, V. N.; Zhdankin, V. V. *Org. Lett.* **2012**, *14*, 3170.
9. Arakawa, Y.; Nakajima, S.; Ishige, R.; Uchimura, M.; Kang, S.; Konishi, G.; Watanabe, J. *J. Mater. Chem.* **2012**, *22*, 8394.
10. Dewanji, A.; Mück-Lichtenfeld, C.; Studer, A. *Angew. Chem., Int. Ed.* **2016**, *55*, 58.
11. Leung, C. S.; Zeevaart, J. G.; Domoal, R. A.; Bollini, M.; Thakur, V. V.; Spasov, K. A.; Anderson, K. S.; Jorgensen, W. L. *Bioorg. Med. Chem. Lett.* **2010**, *20*, 2485.
12. Glasnov, T. N.; Holbrey, J. D.; Kappe, C. O.; Seddon, K. R.; Yan, T. *Green Chem.* **2012**, *14*, 3071.
13. Damkaci, F.; Alawaed, A.; Vik, E. *Tetrahedron Lett.* **2016**, *57*, 2197.
14. Czaplik, W. M.; Grupe, S.; Mayer, M.; Wangelin, *Chem. Commun.* **2010**, *46*, 6350.
15. Kokatla, H. P.; Thomson, P. F.; Bae, S.; Doddi, V. R.; Lakshman, M. K. *J. Org. Chem.* **2011**, *76*, 7842.
16. Barbero, N.; Martin, R. *Org. Lett.* **2012**, *14*, 796.
17. Jiang, X.; Wang, C.; Wei, Y.; Xue, D.; Liu, Z.; Xiao, J. *Chem. E. J.* **2014**, *20*, 58.
18. Nguyen, T. V.; Lyons, D. J. M. *Chem. Commun.* **2015**, *51*, 3131.
19. Wang, D.; Kuang, D.; Zhang, F.; Yang, C.; Zhu, X. *Adv. Synth. Catal.* **2015**, *357*, 714.
20. Patra, Y.; Aakanksha, S. A.; Maiti, D. *Chem. Commun.* **2013**, *49*, 69.
21. Cano, R.; Ramón, D. J.; Yus, M. *J. Org. Chem.* **2011**, *76*, 654.
22. Cheng, Y.; Gu, X.; Li, P. *Org. Lett.* **2013**, *15*, 2664.
23. Watson, D. G.; Ritter, S.; Toste, F. D. *J. Am. Chem. Soc.* **2009**, *131*, 2056.
24. Bailey, W. F.; Carson, M. W. *J. Org. Chem.* **1998**, *63*, 9960.
25. Bhattacharjya, A.; Klumphu, P.; Lipshutz, B. H. *Org. Lett.* **2015**, *17*, 1122.
26. Leboeuf, D.; Ciesielski, J.; Frontier, A. J. *Synlett* **2014**, *25*, 399.
27. Wheeler, S. E.; McNeil, A. J.; Müller, P.; Swager, T. M.; Houk, K.N. *J. Am. Chem. Soc.* **2010**, *132*, 3304.
28. oncomble, A.; Floch, P. L.; Gosmini, C. *Chem. Eur. J.* **2009**, *15*, 4770.

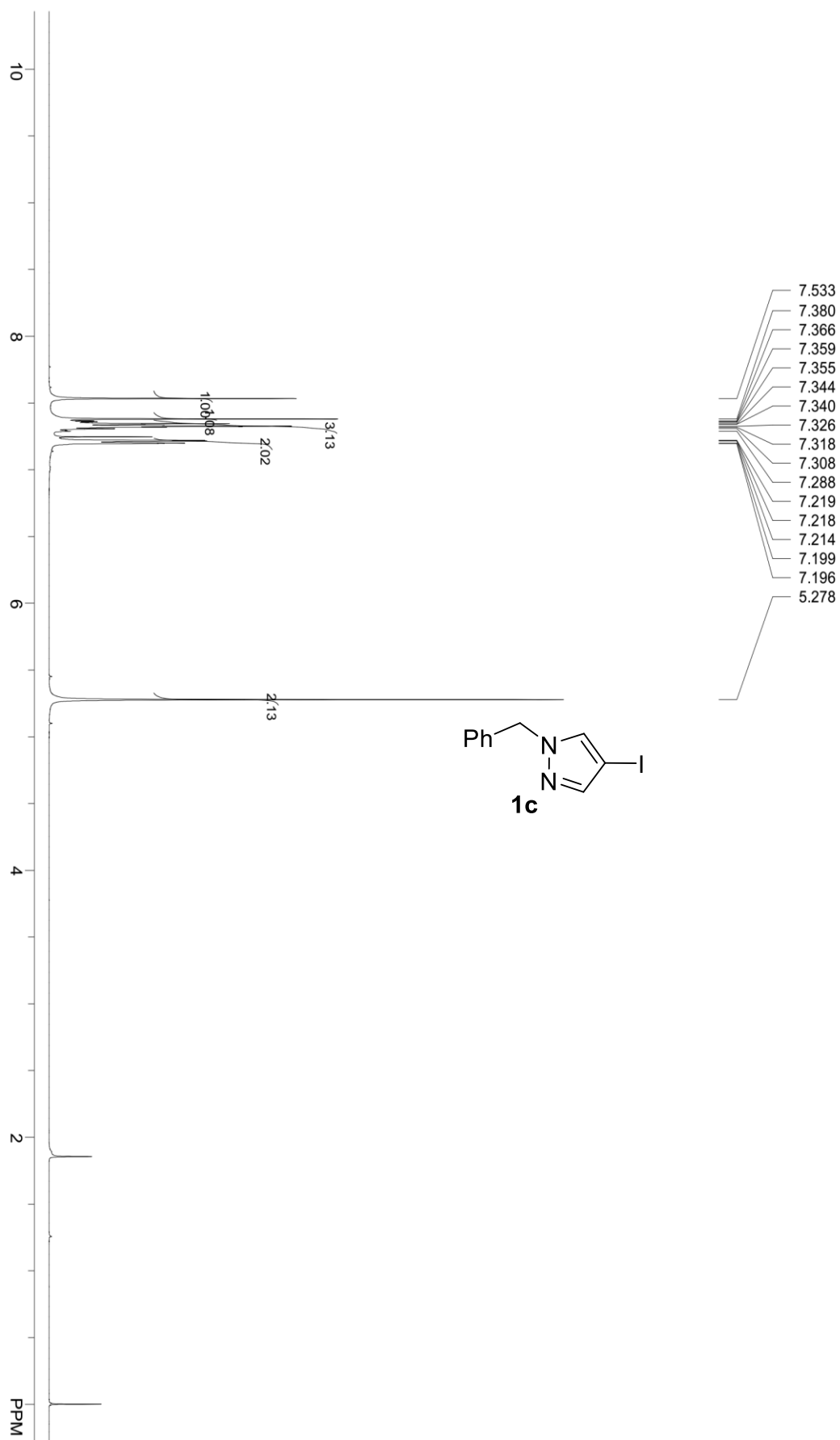
## 5. NMR spectra

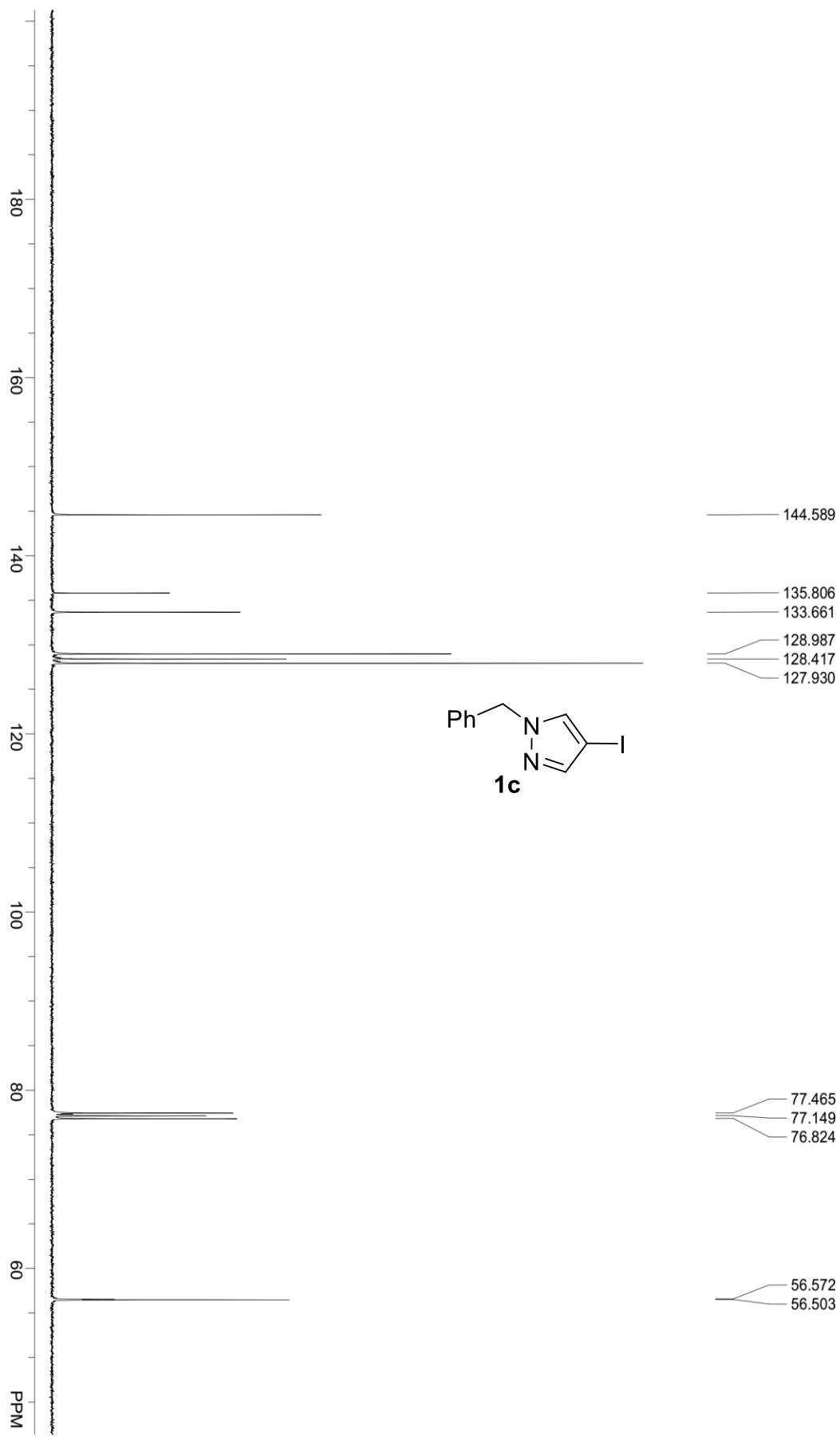


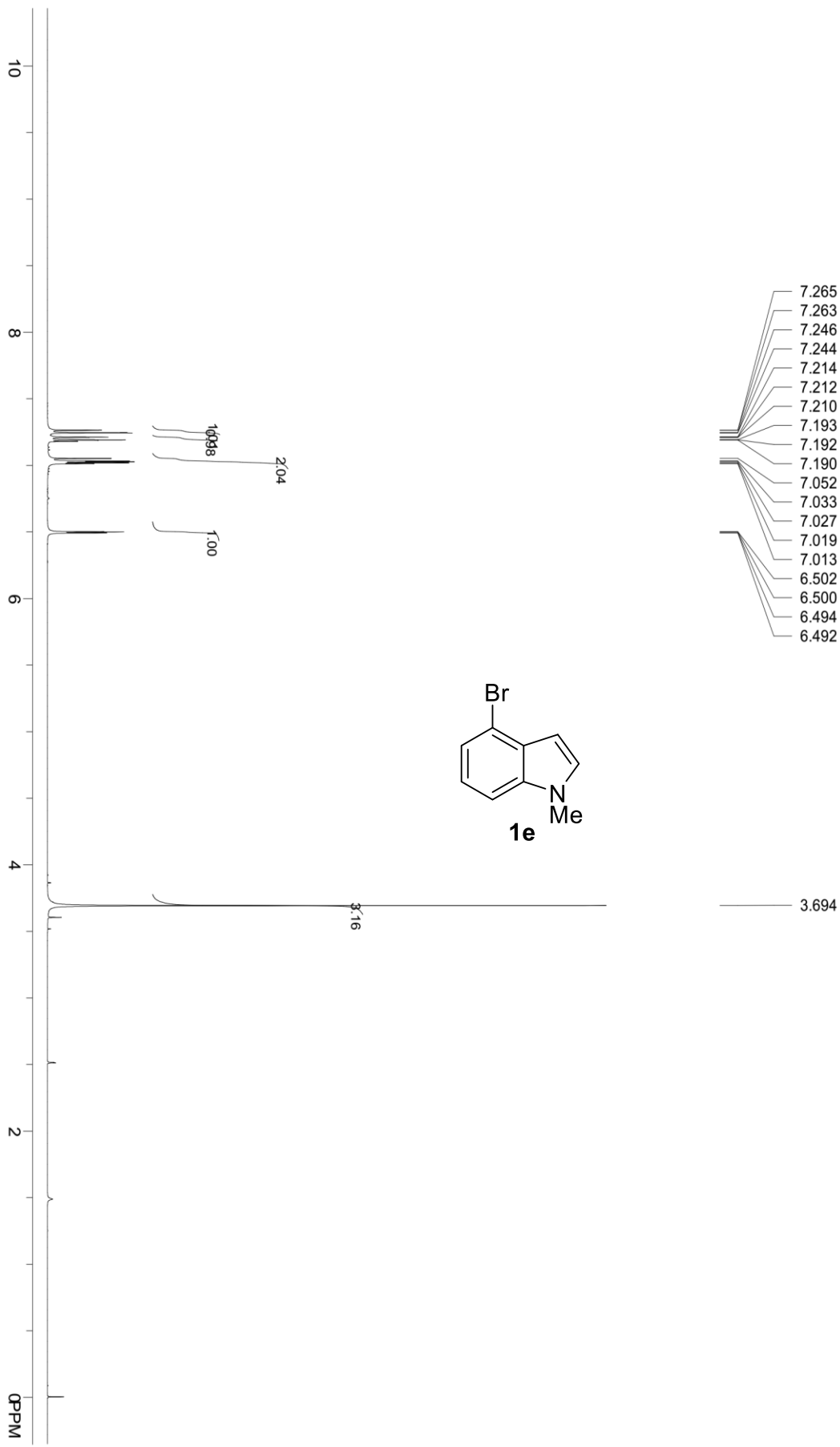


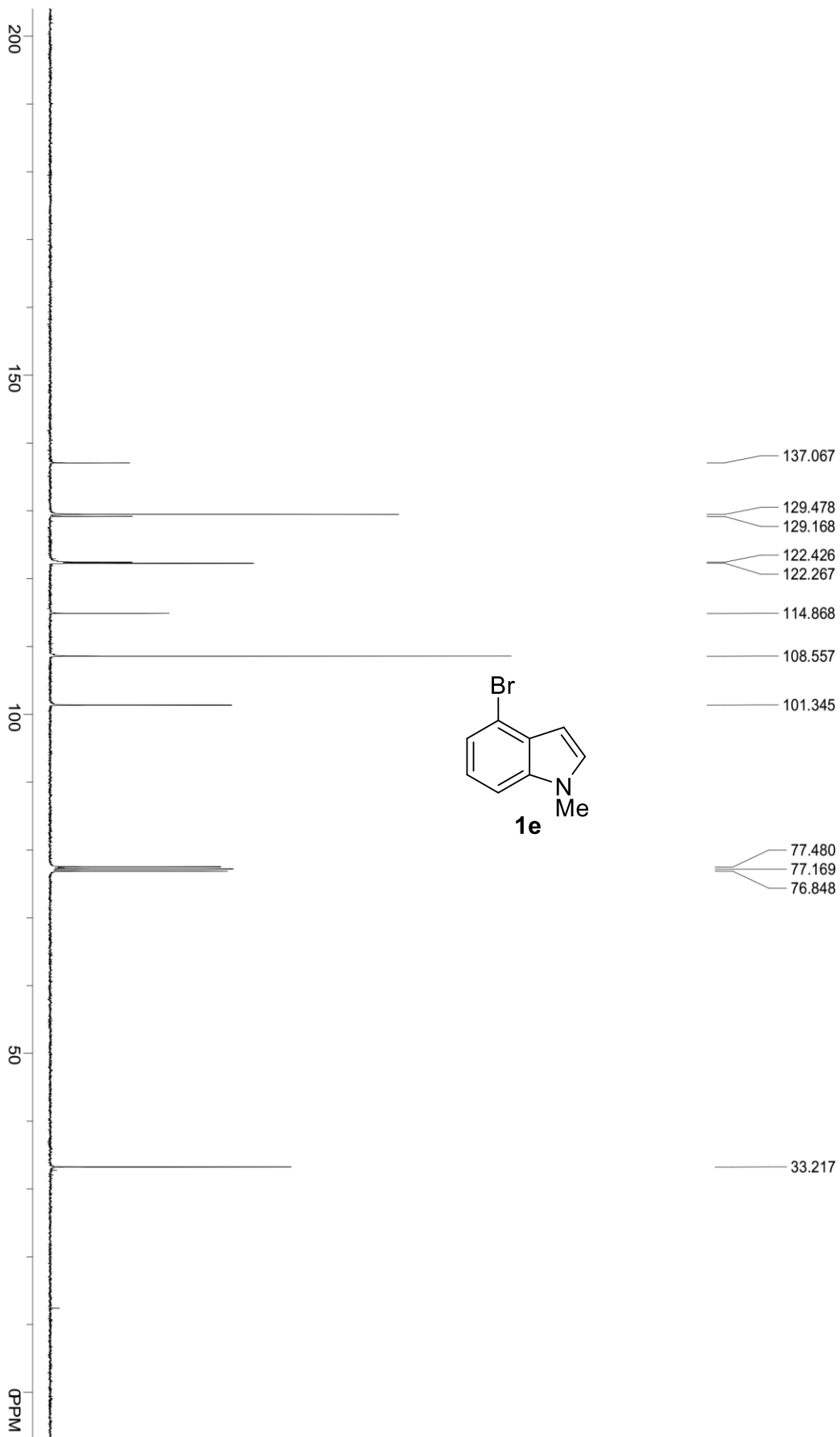


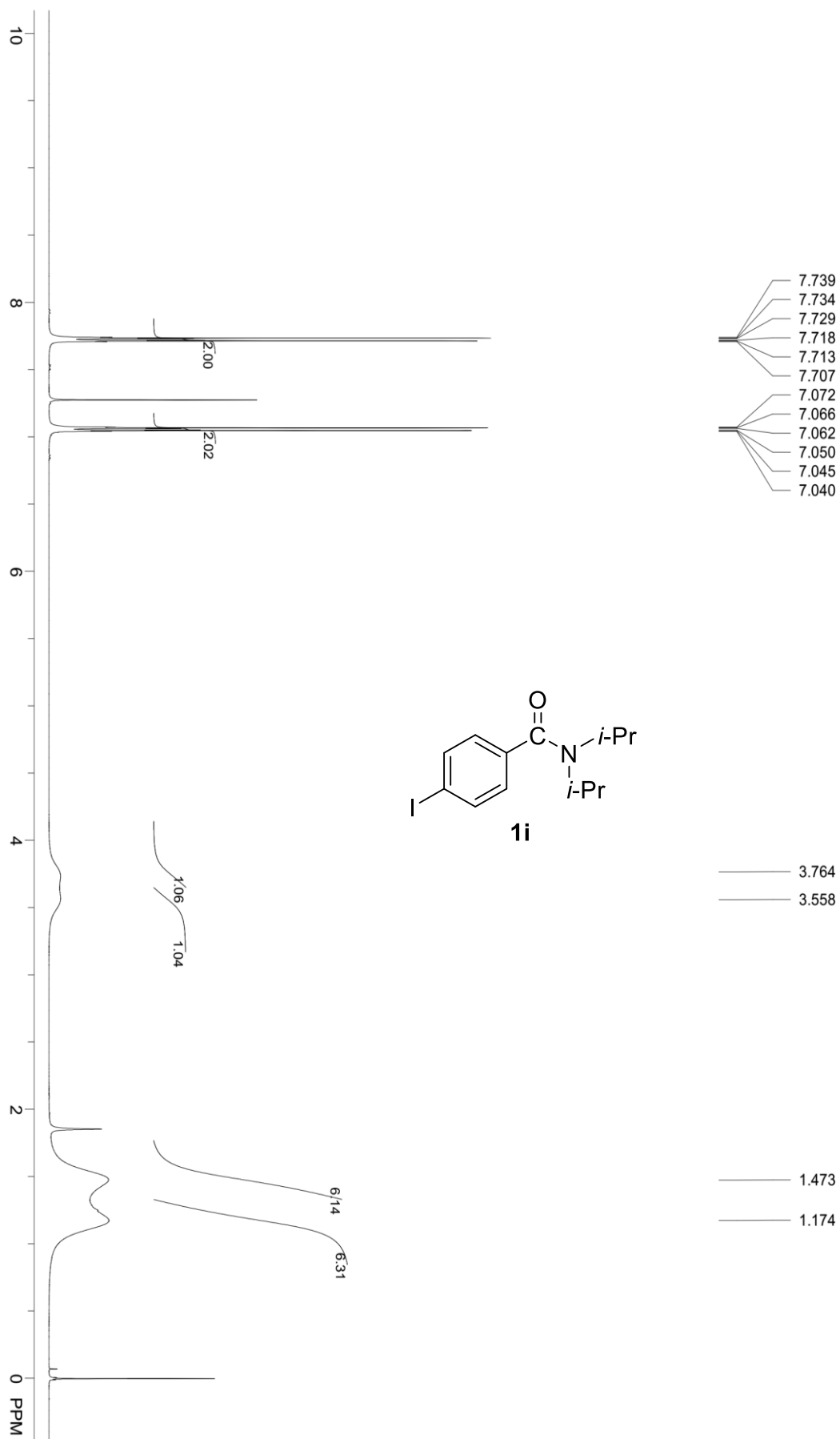


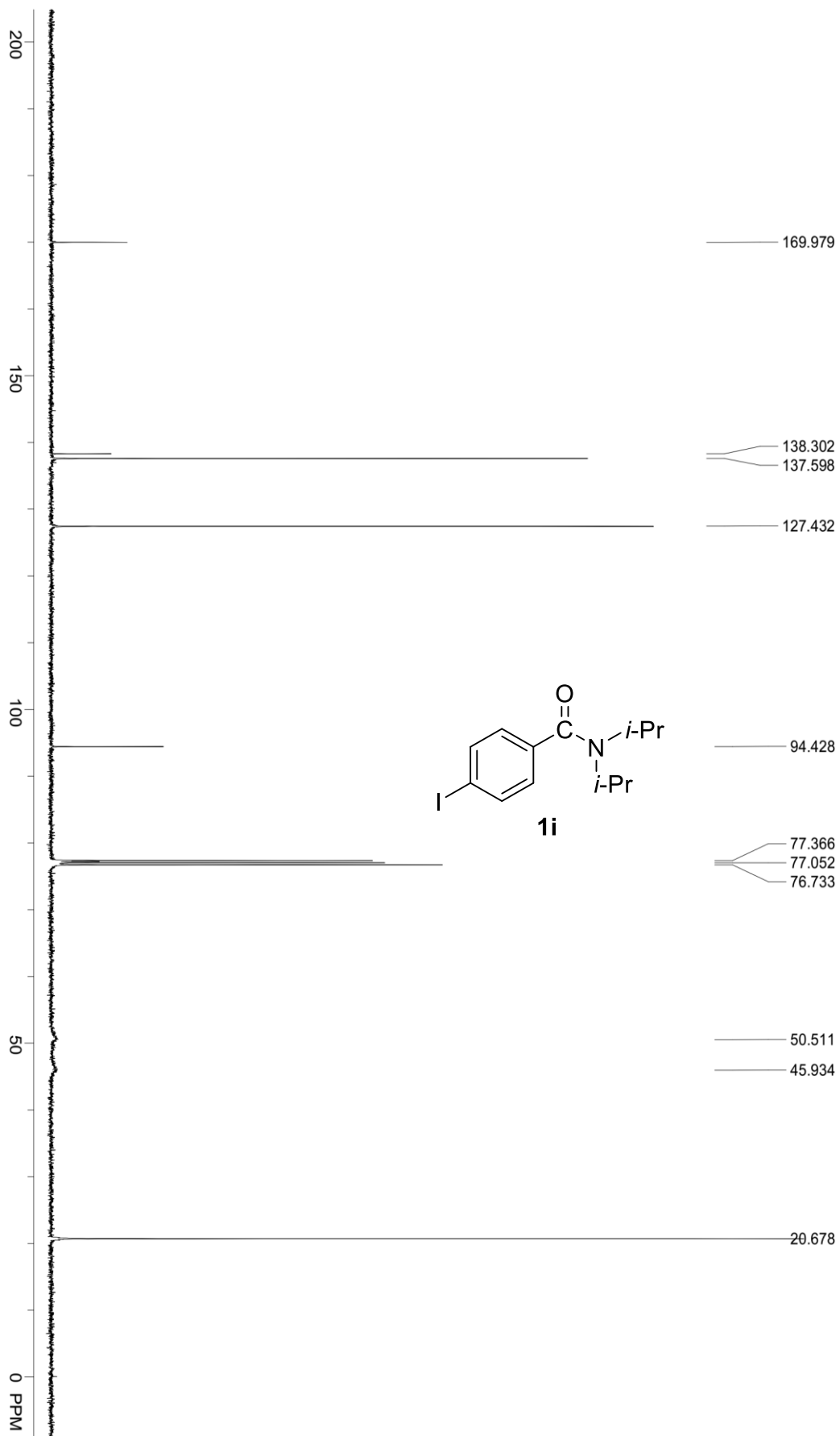


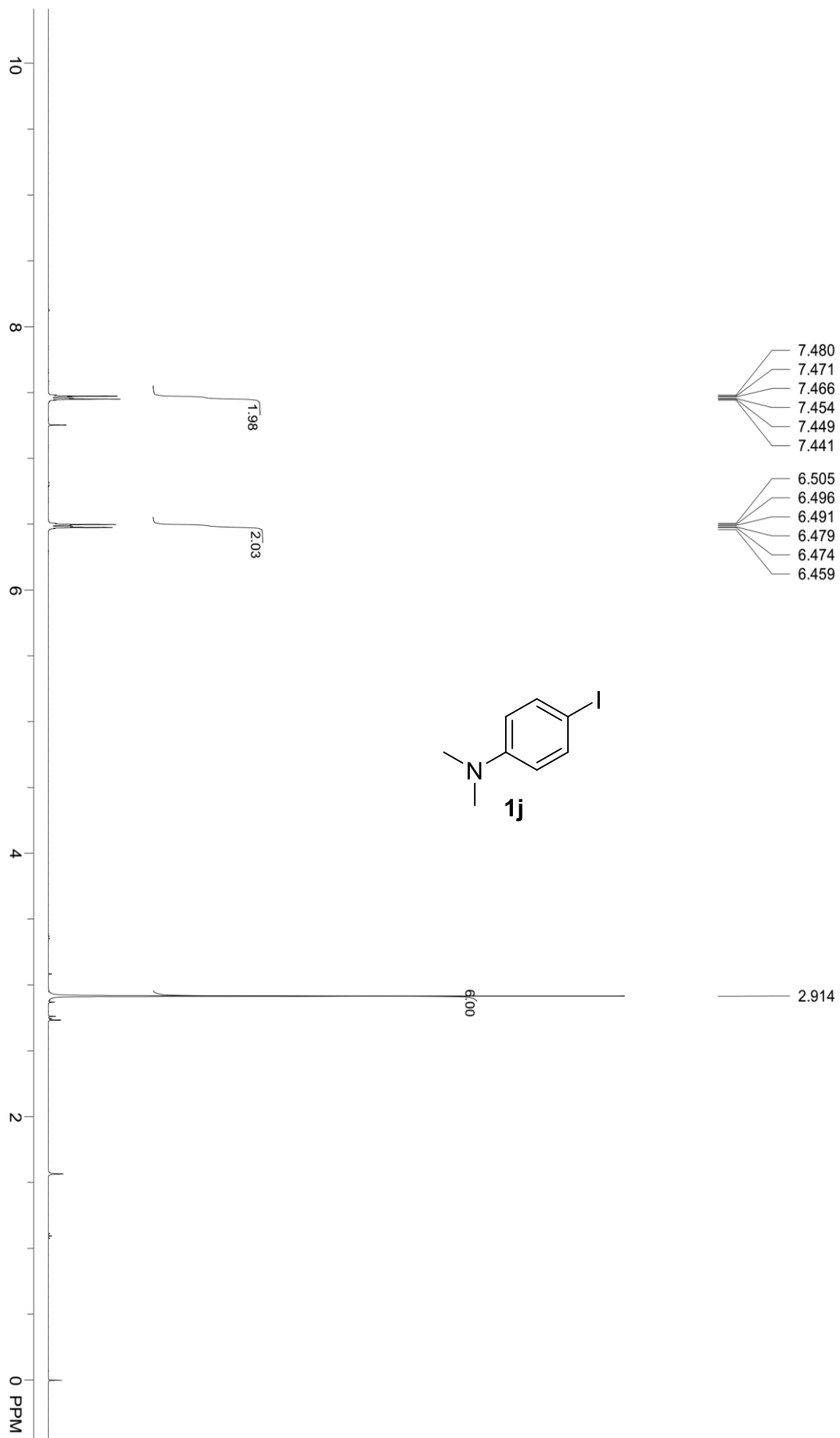


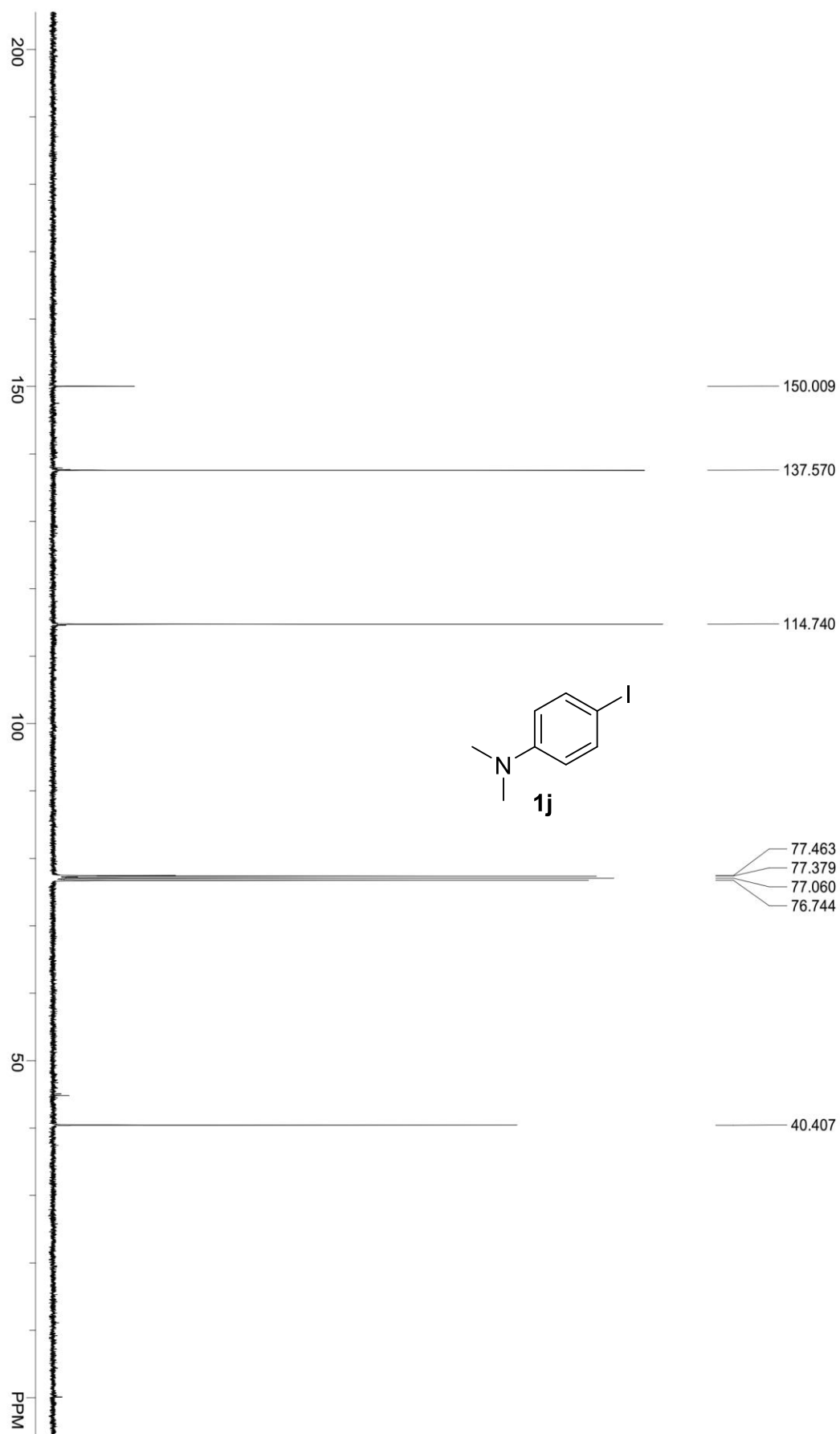


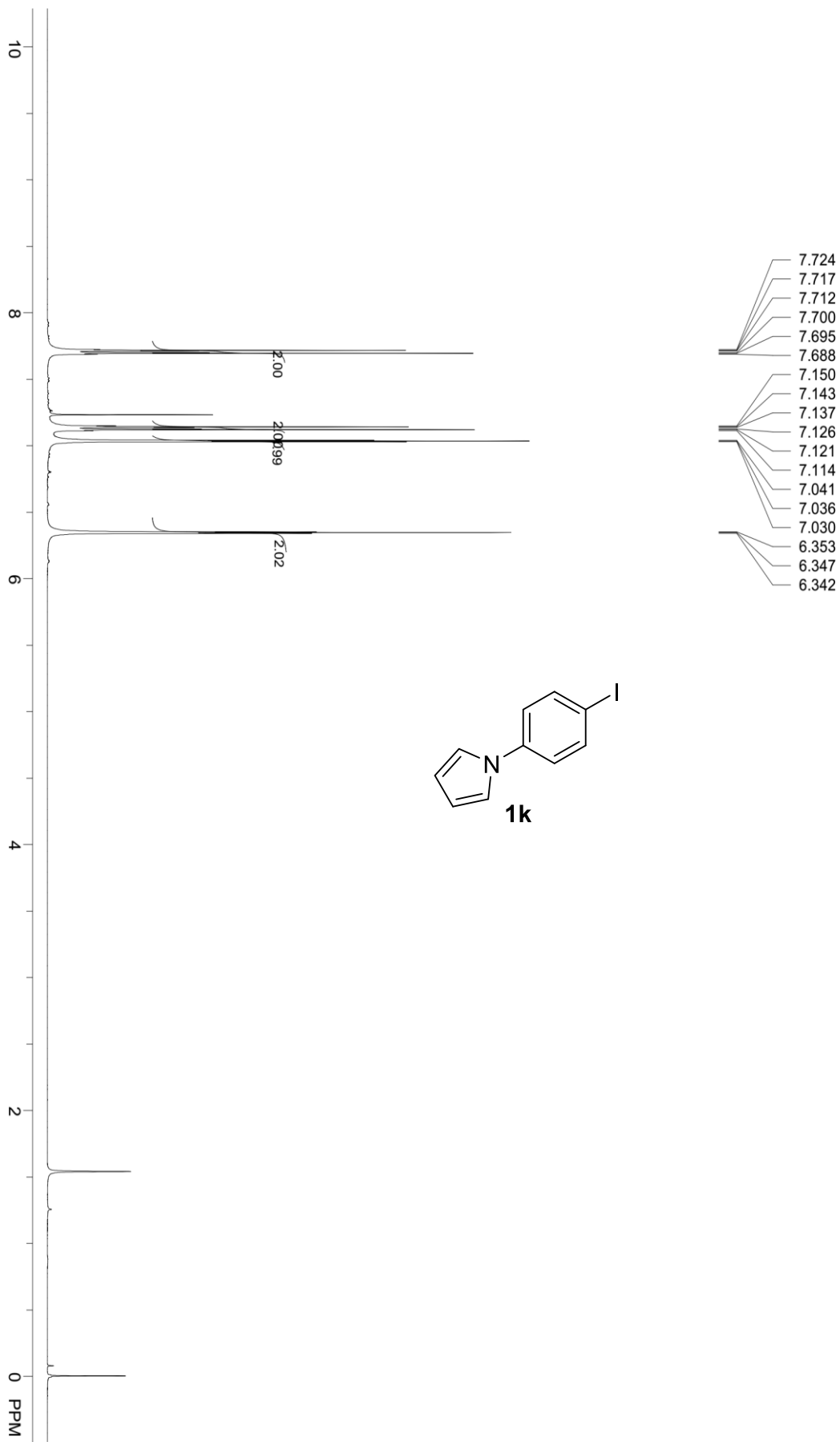


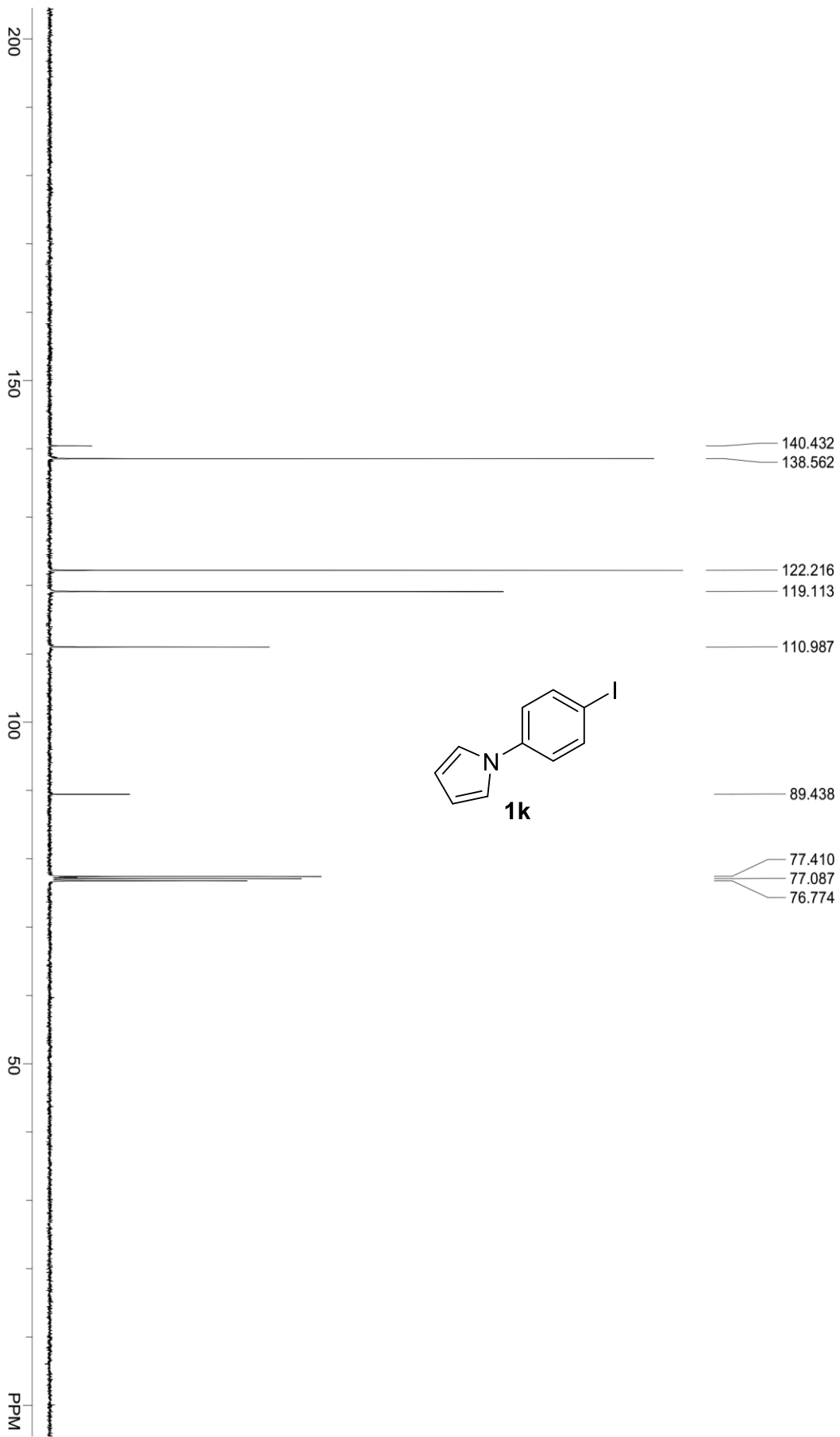


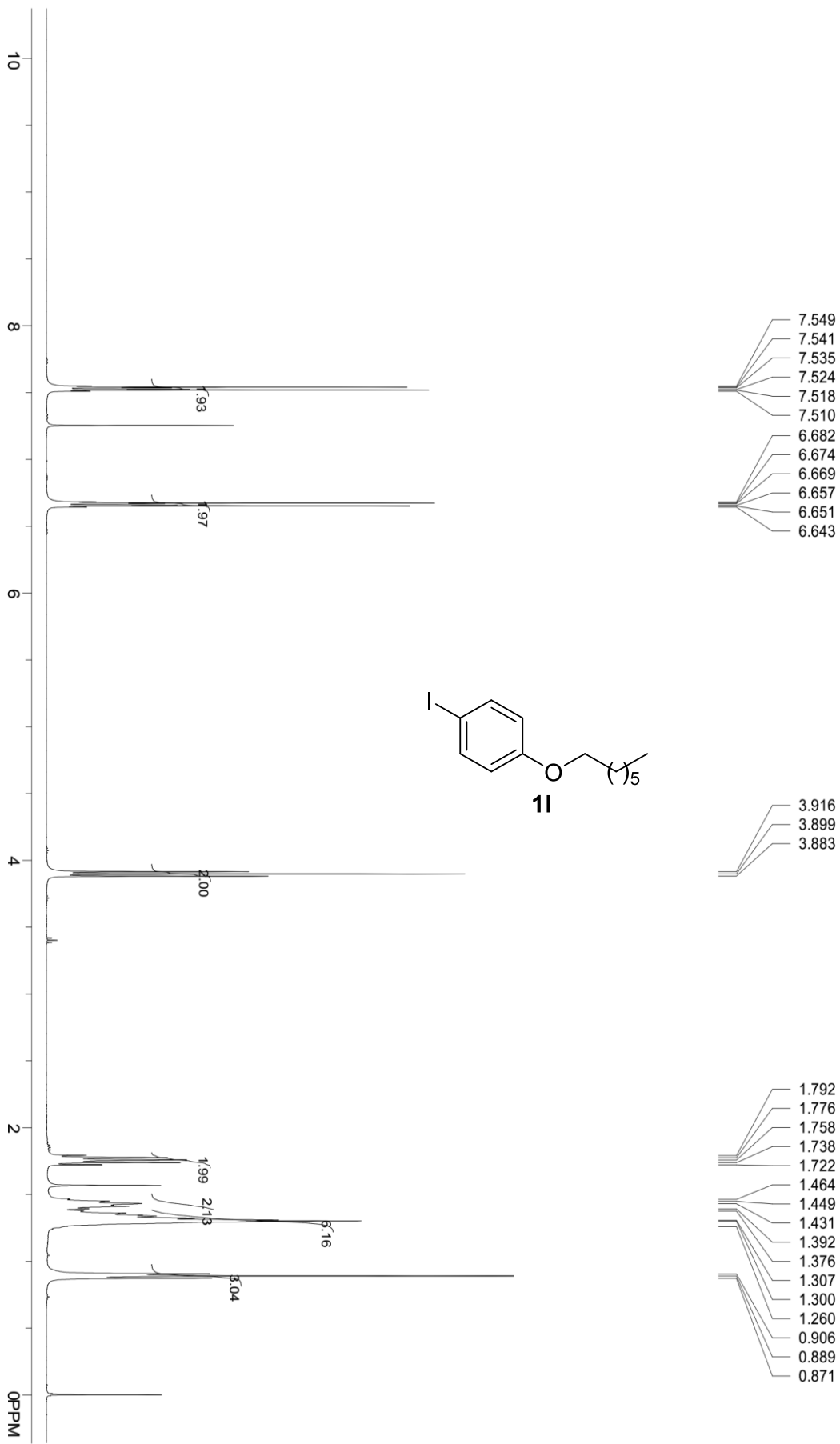


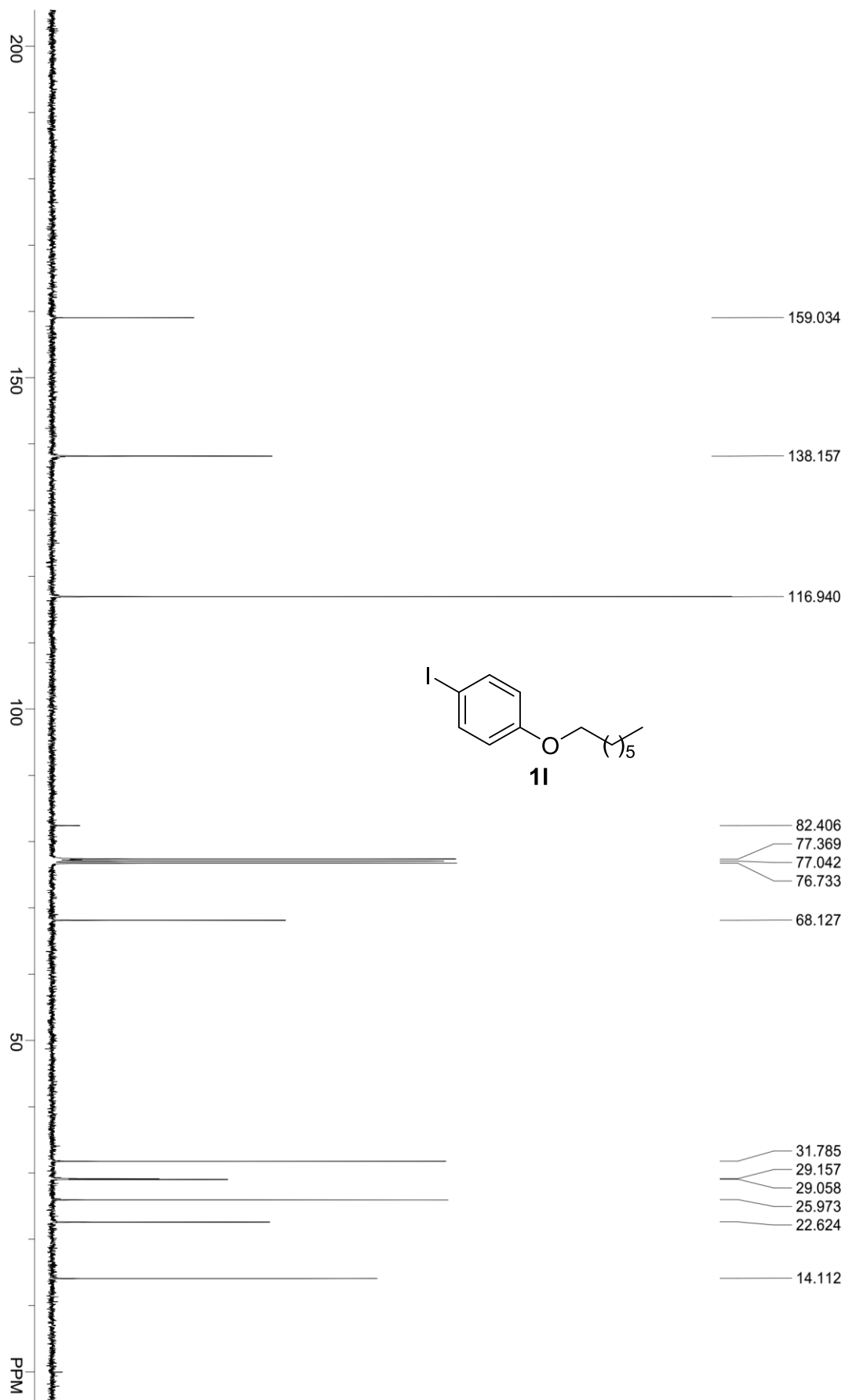


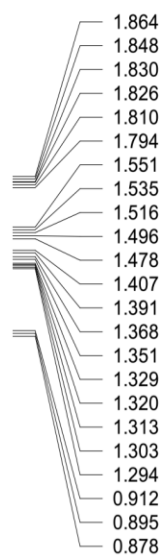
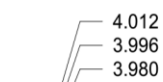
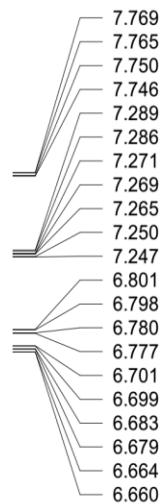
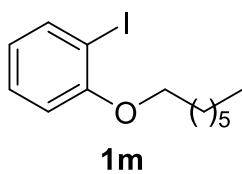
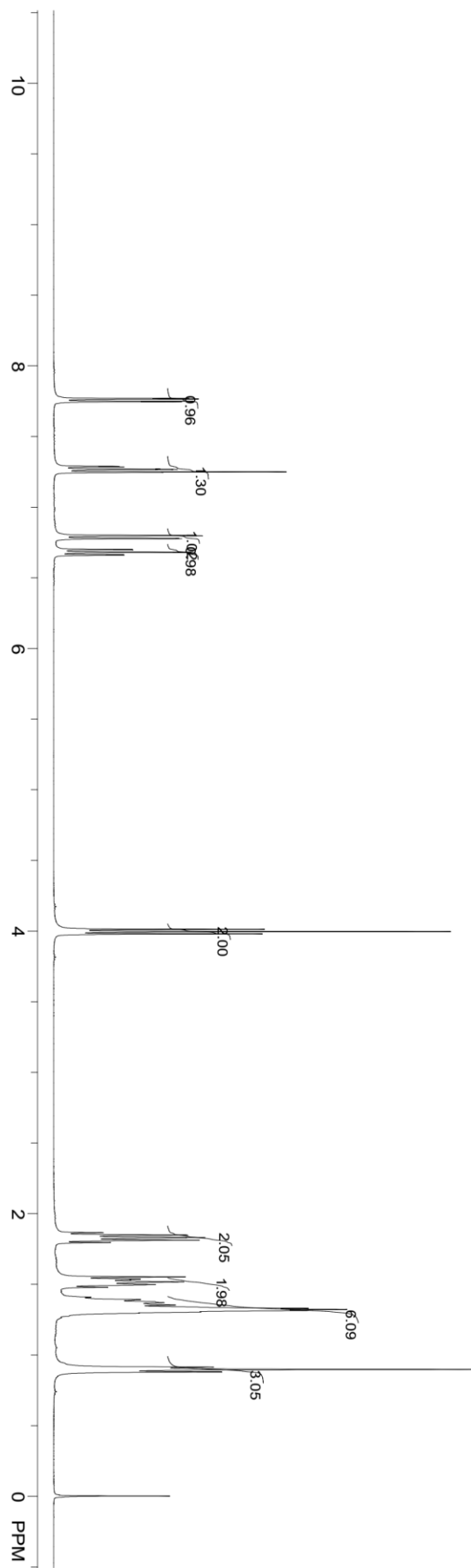


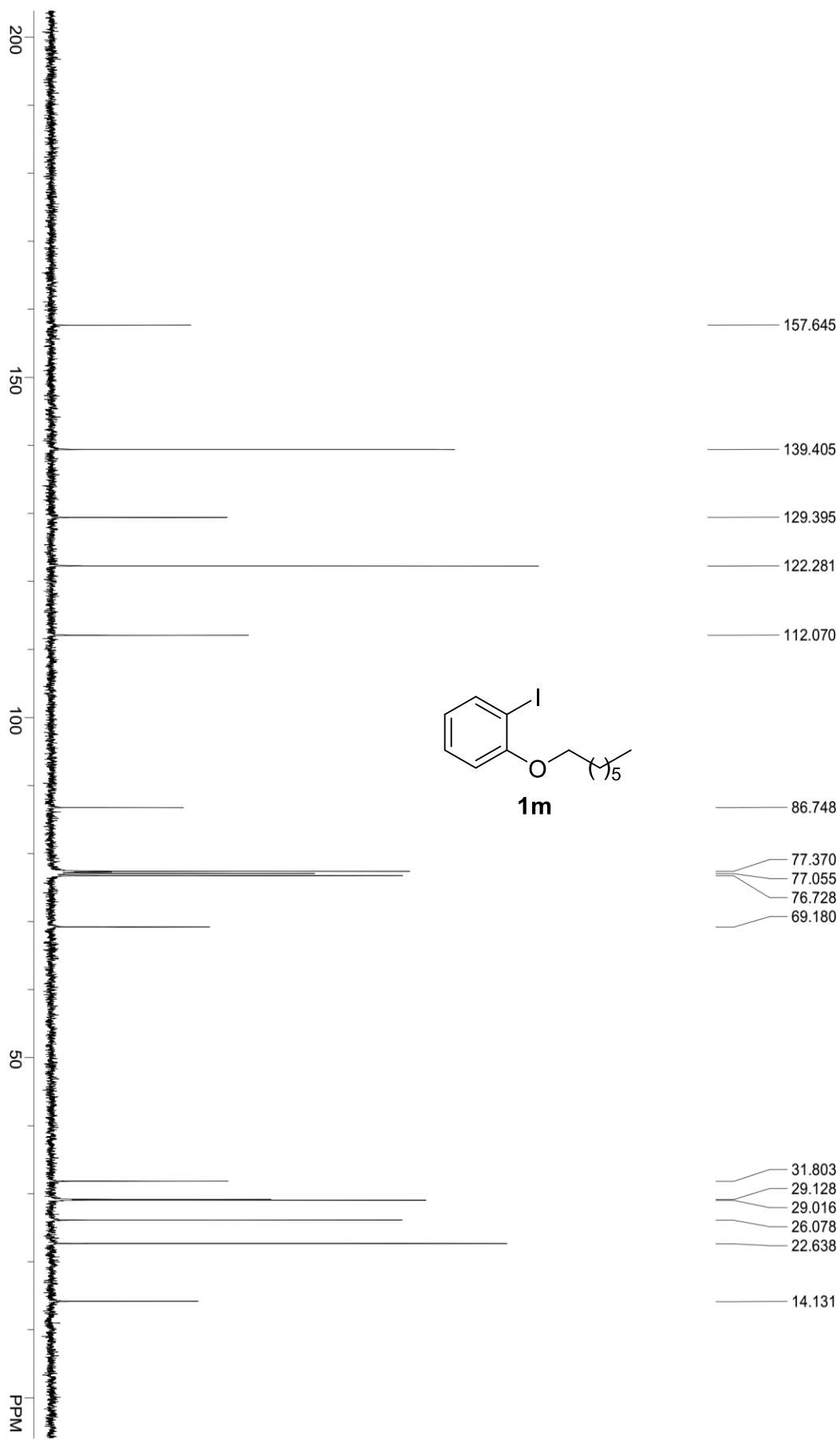


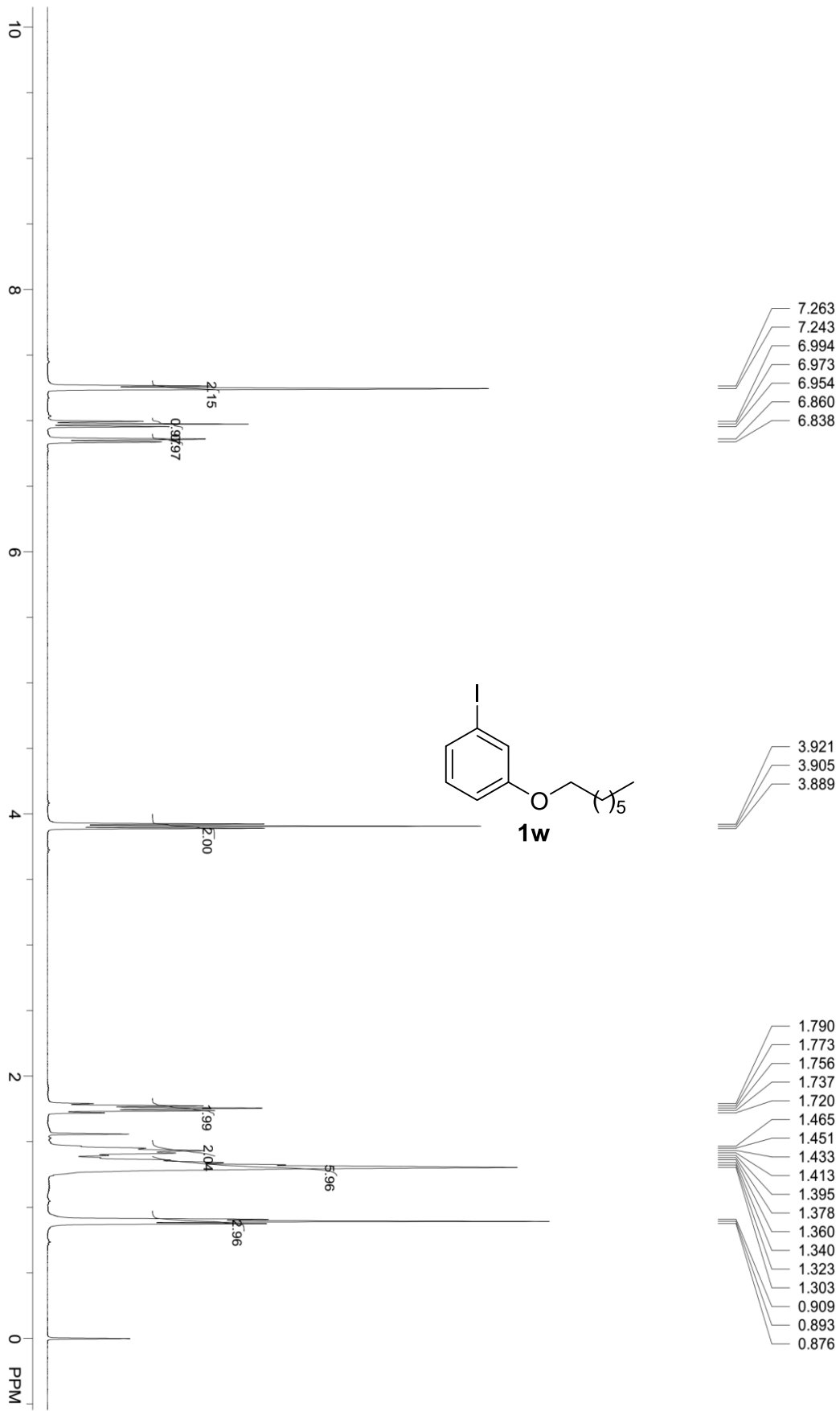


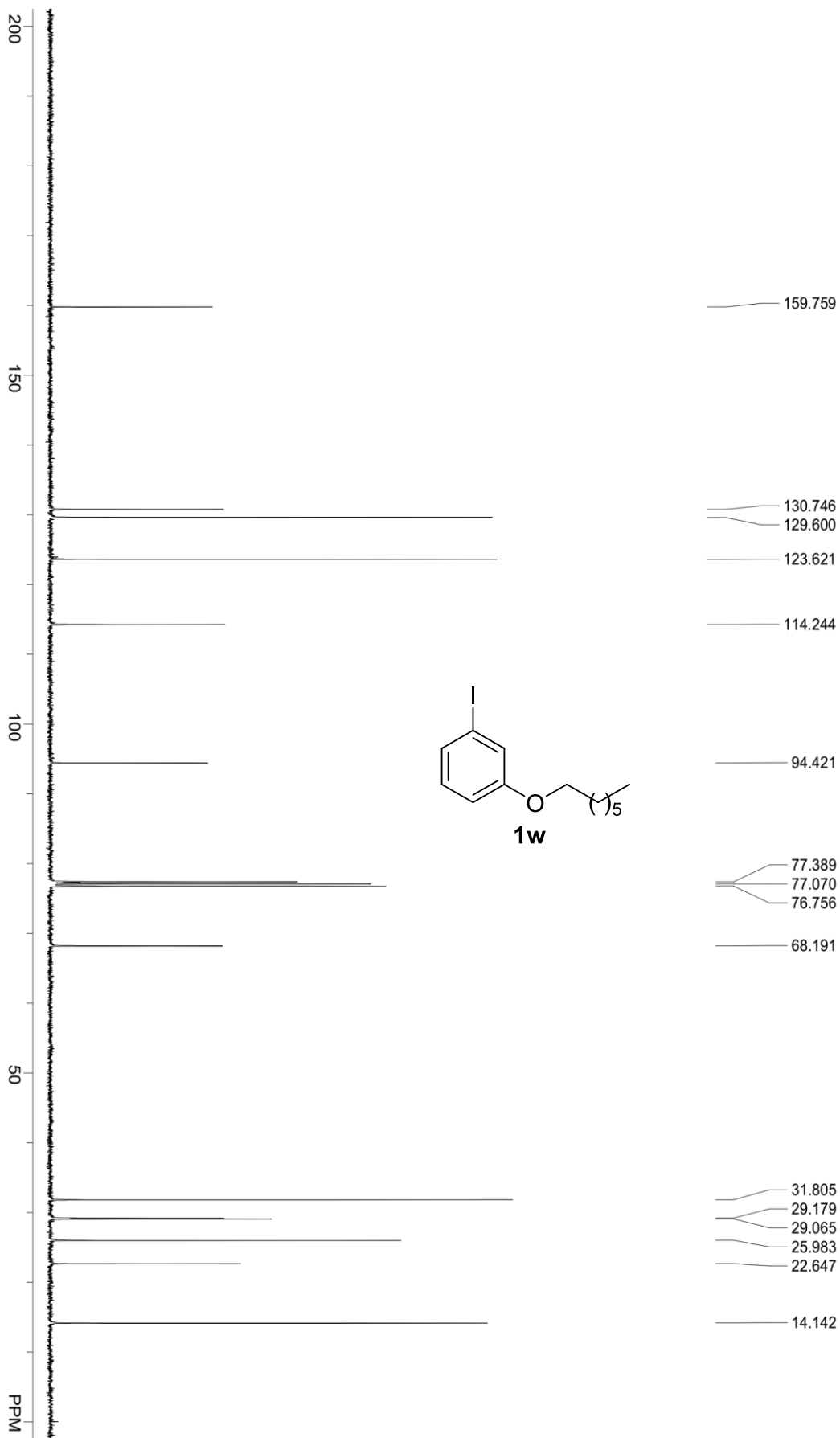




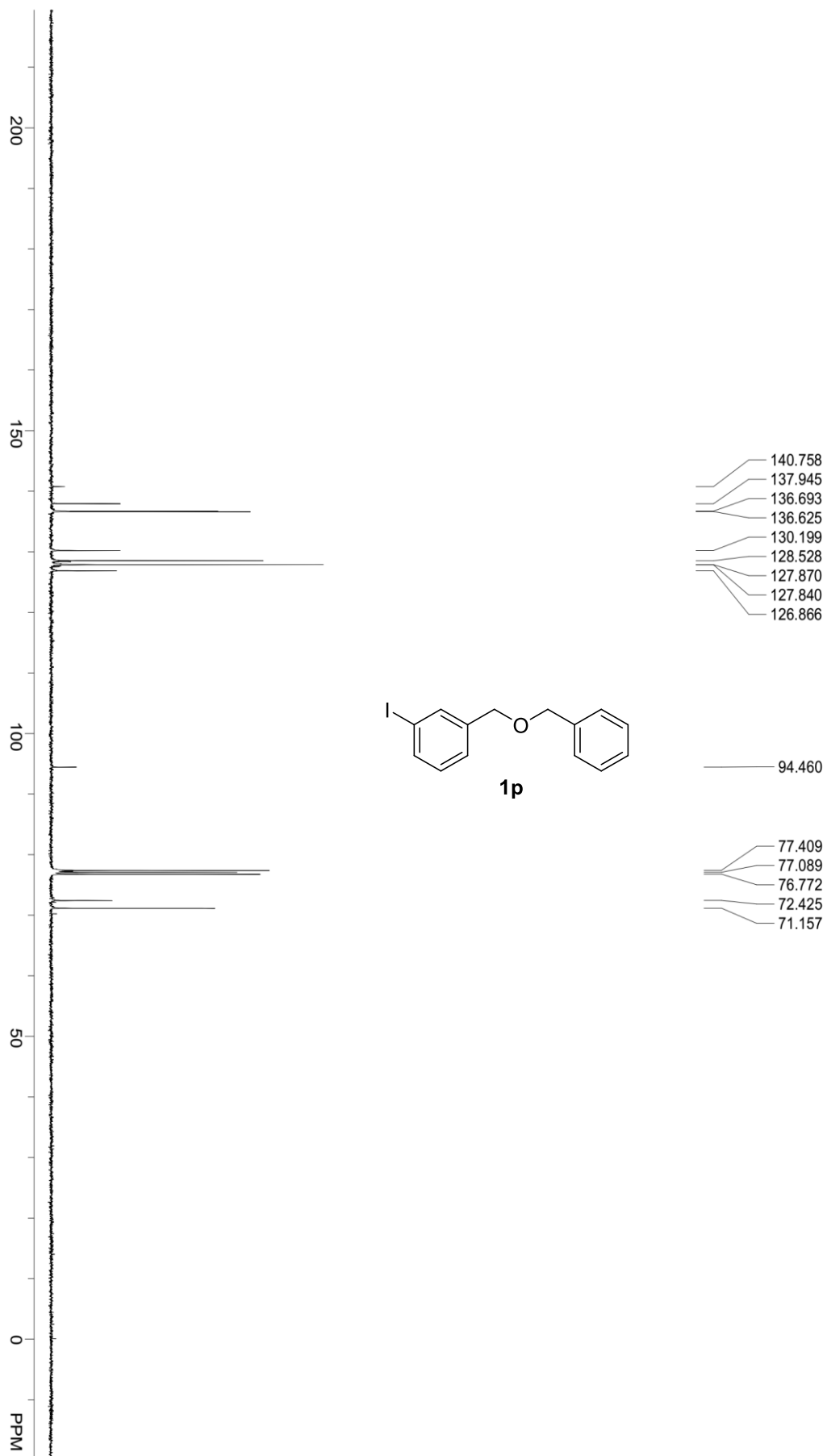


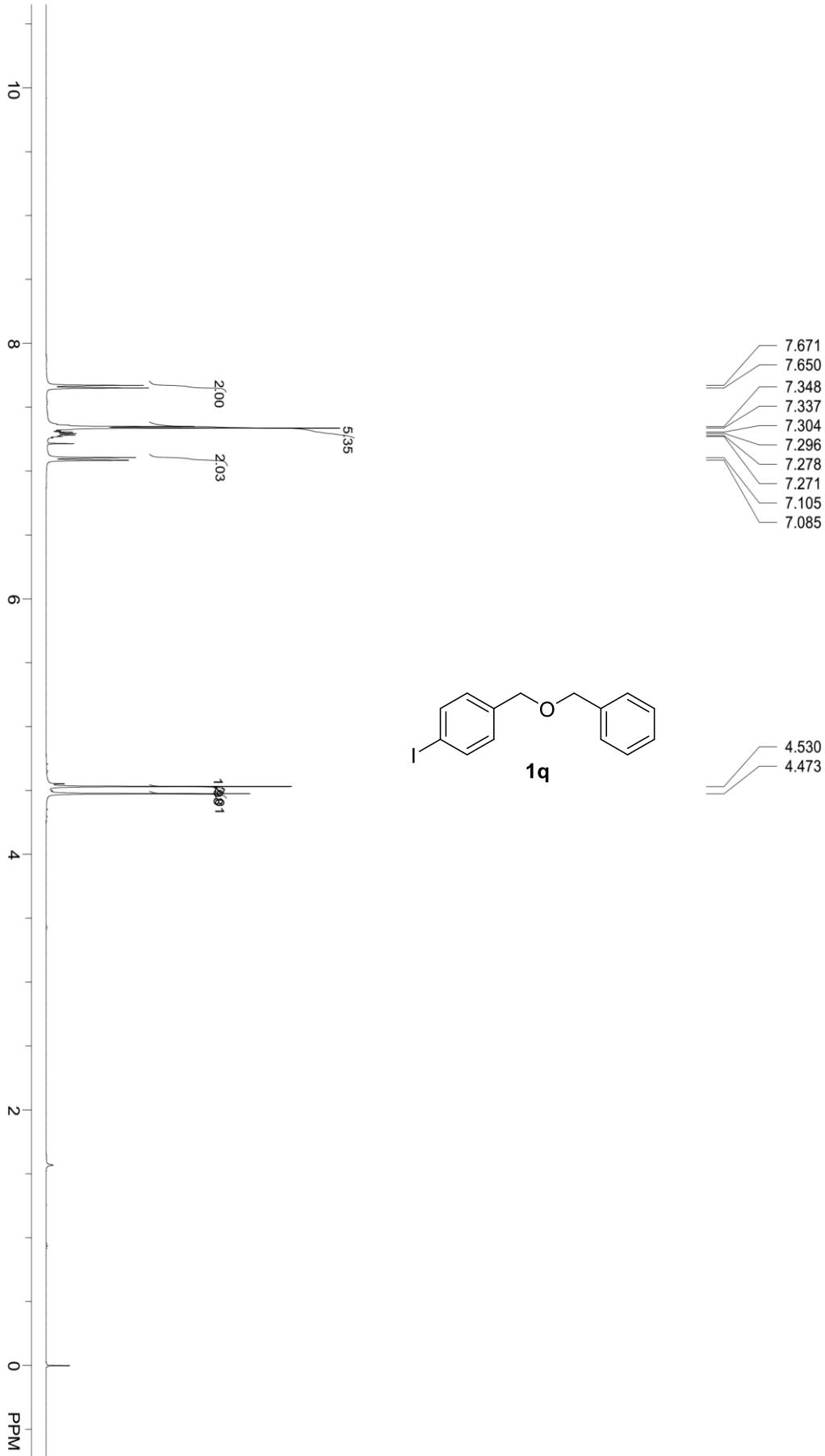


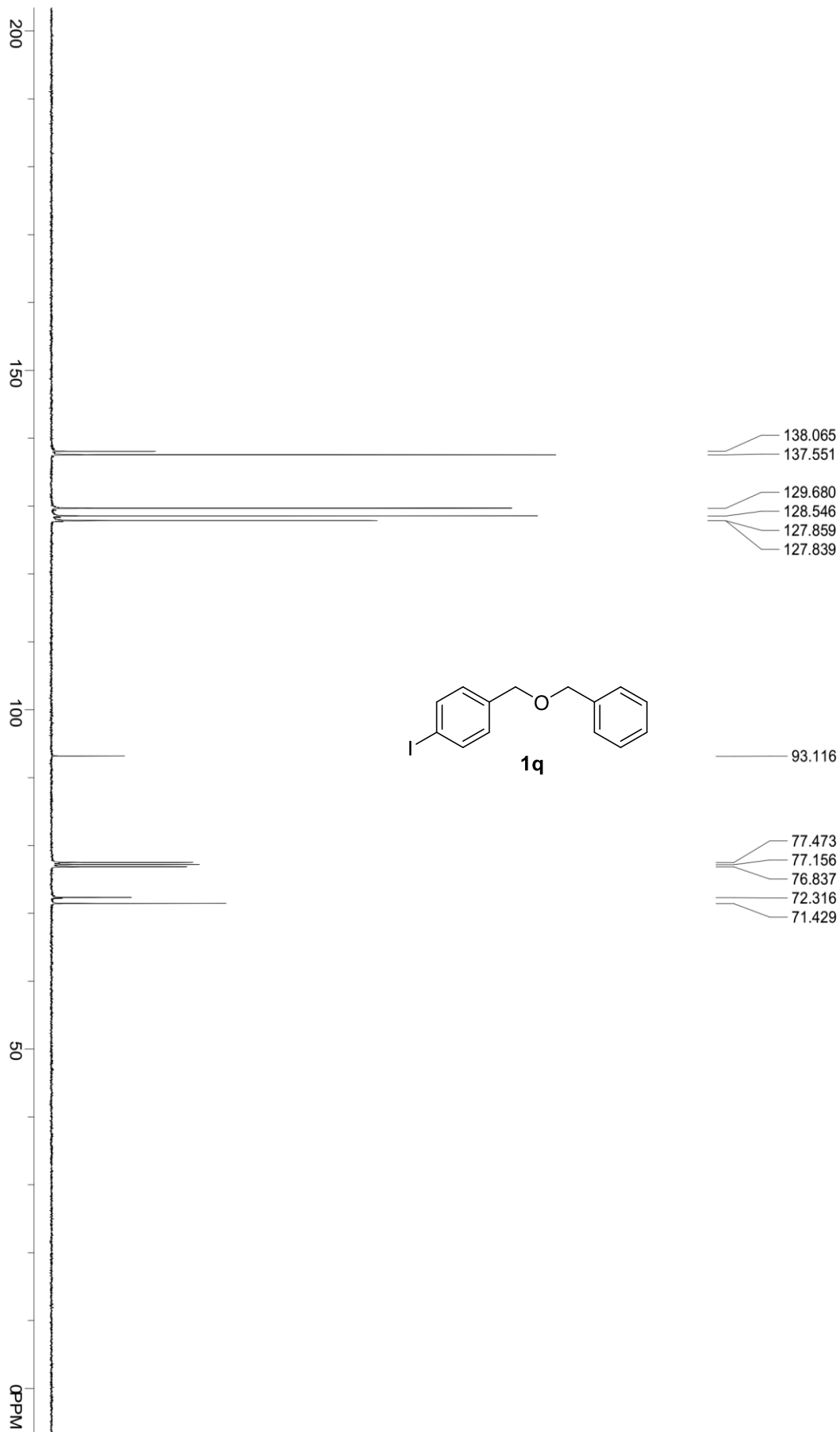


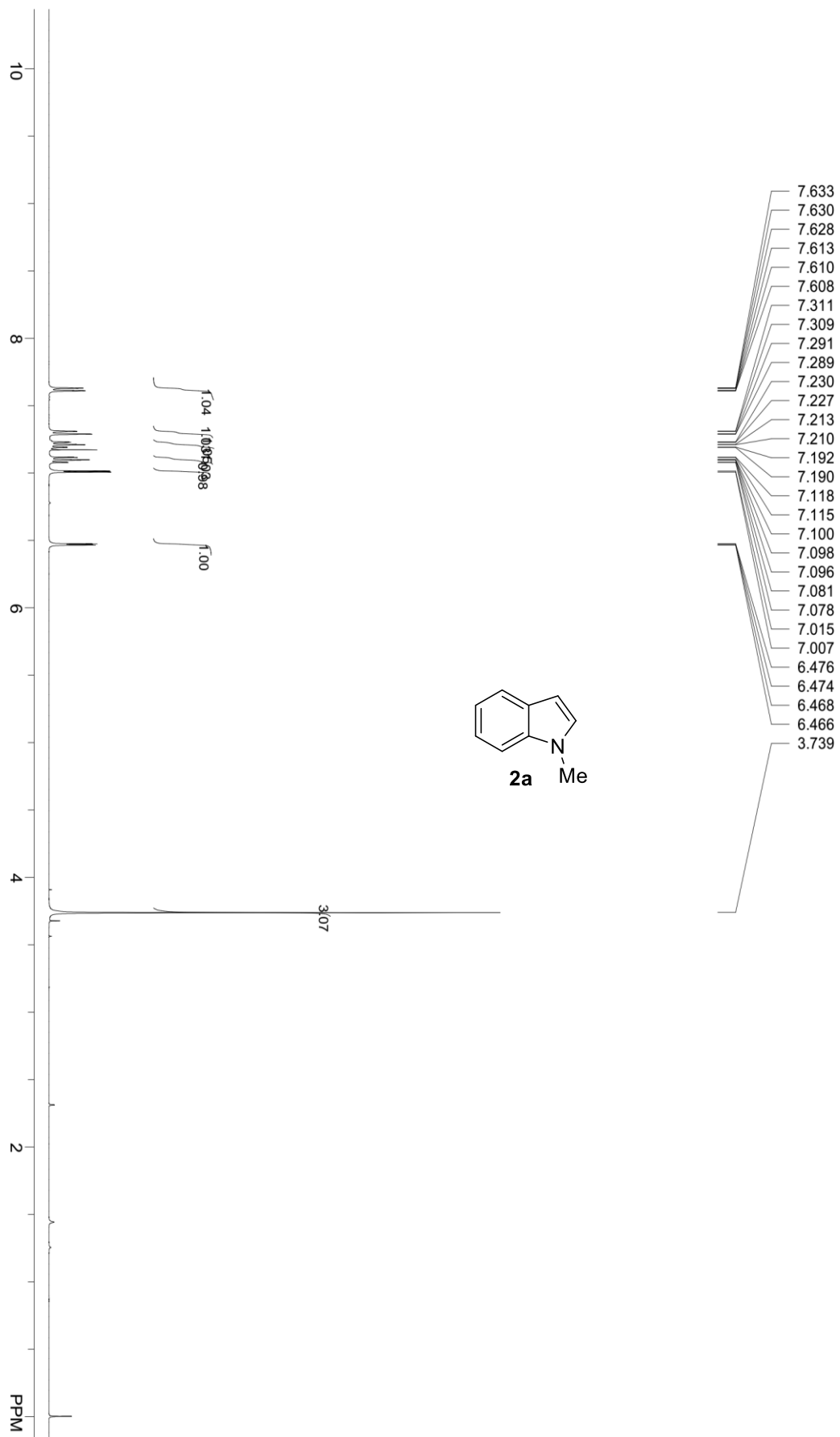


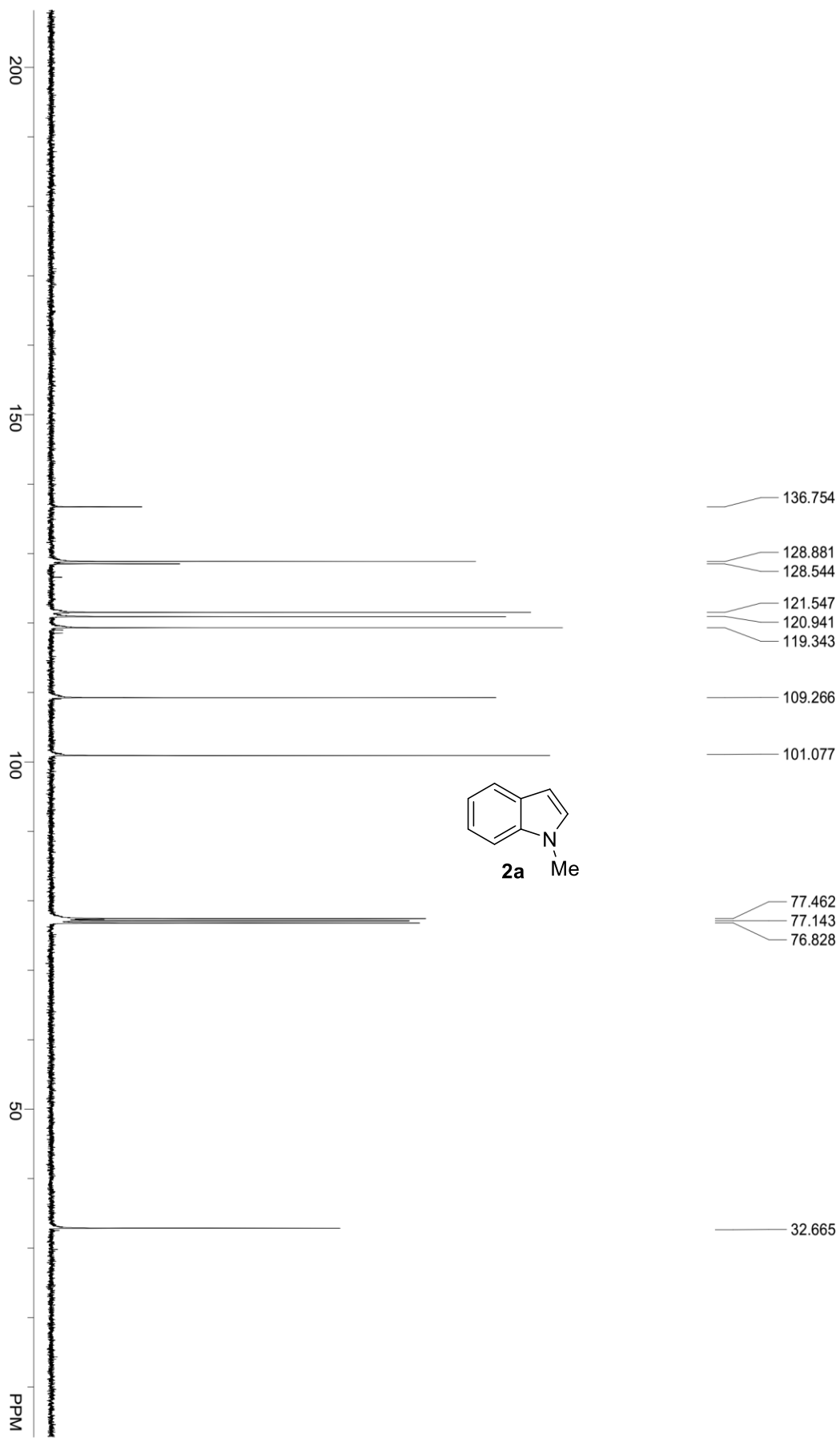


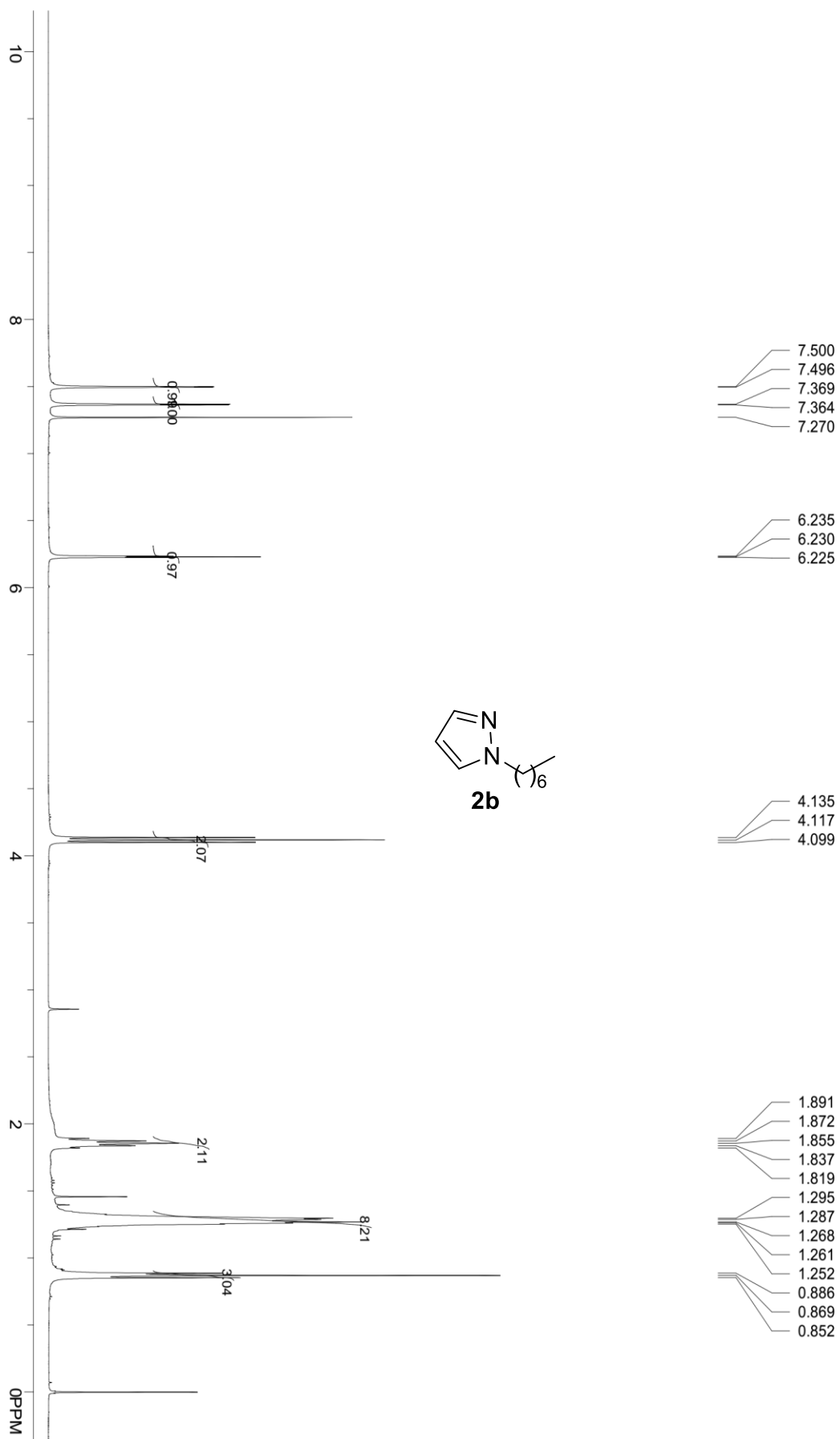


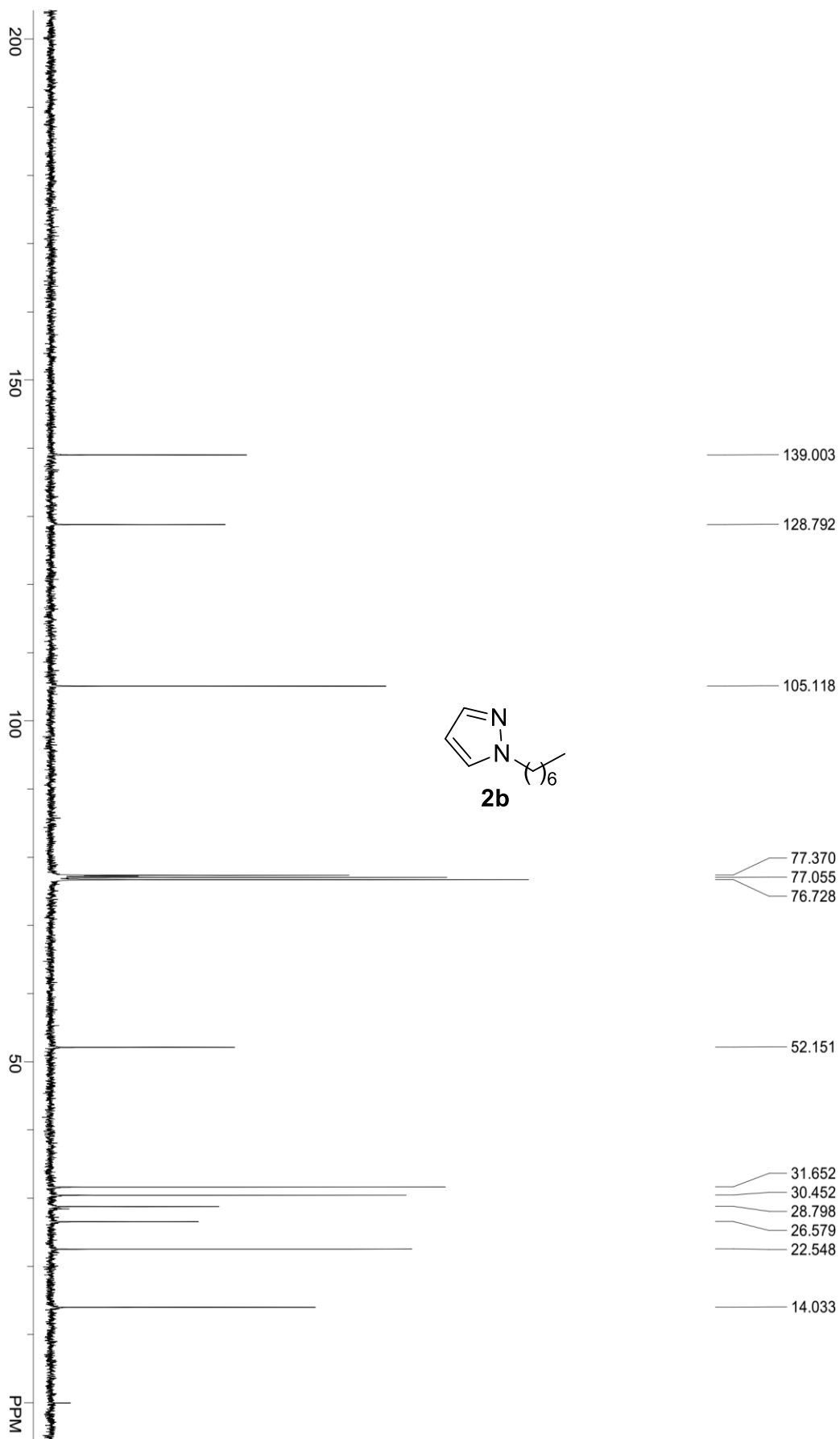


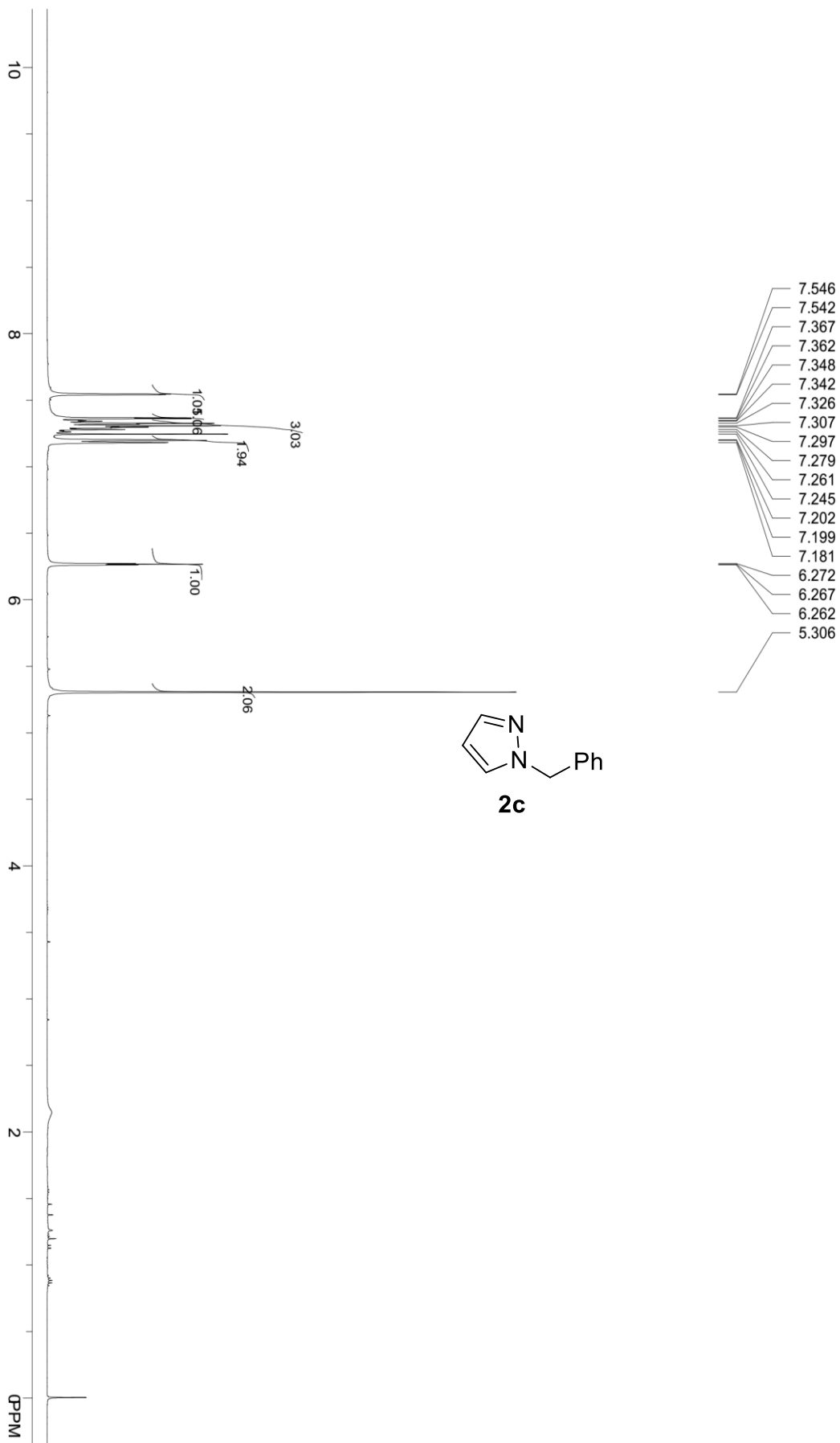


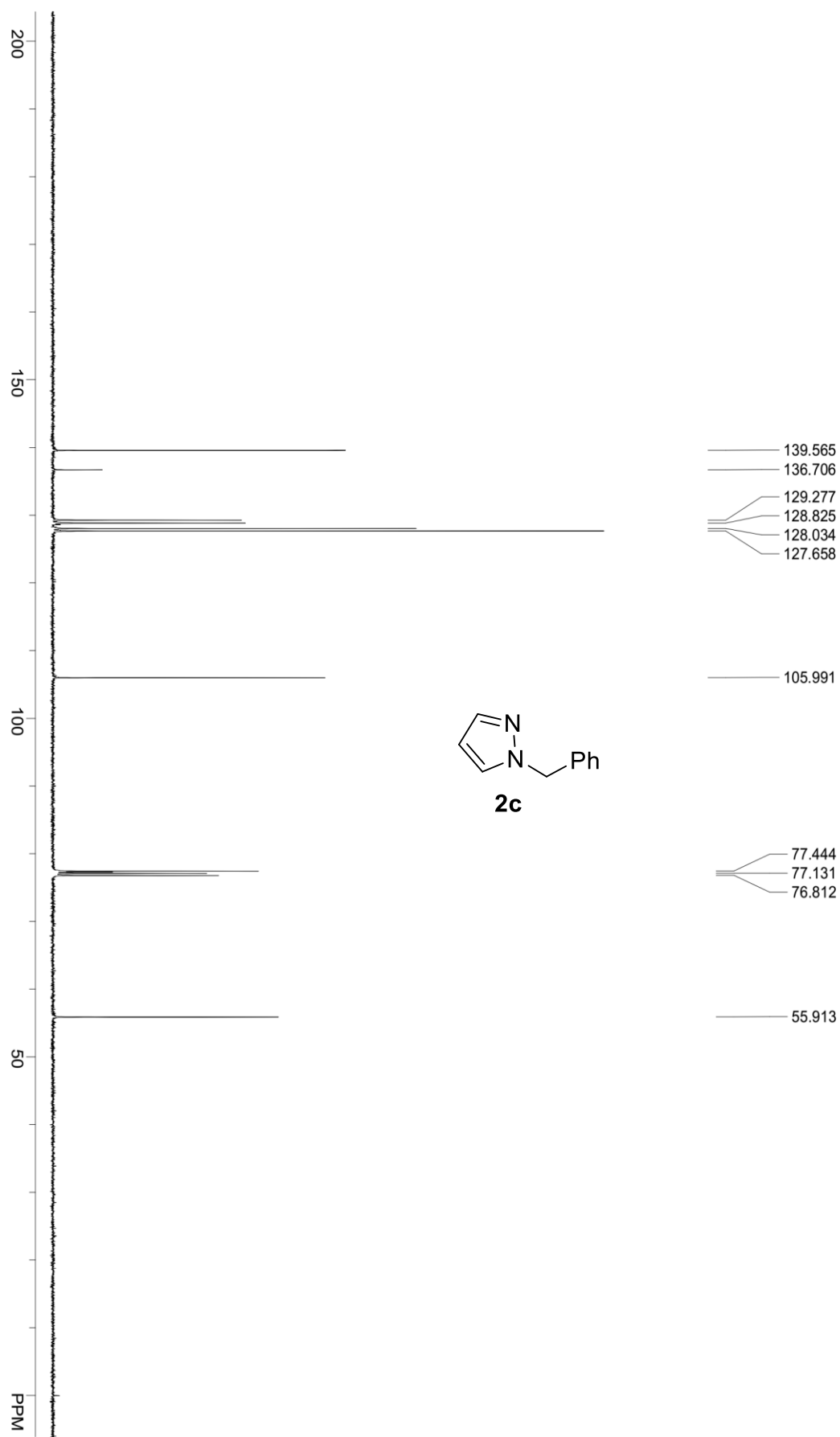


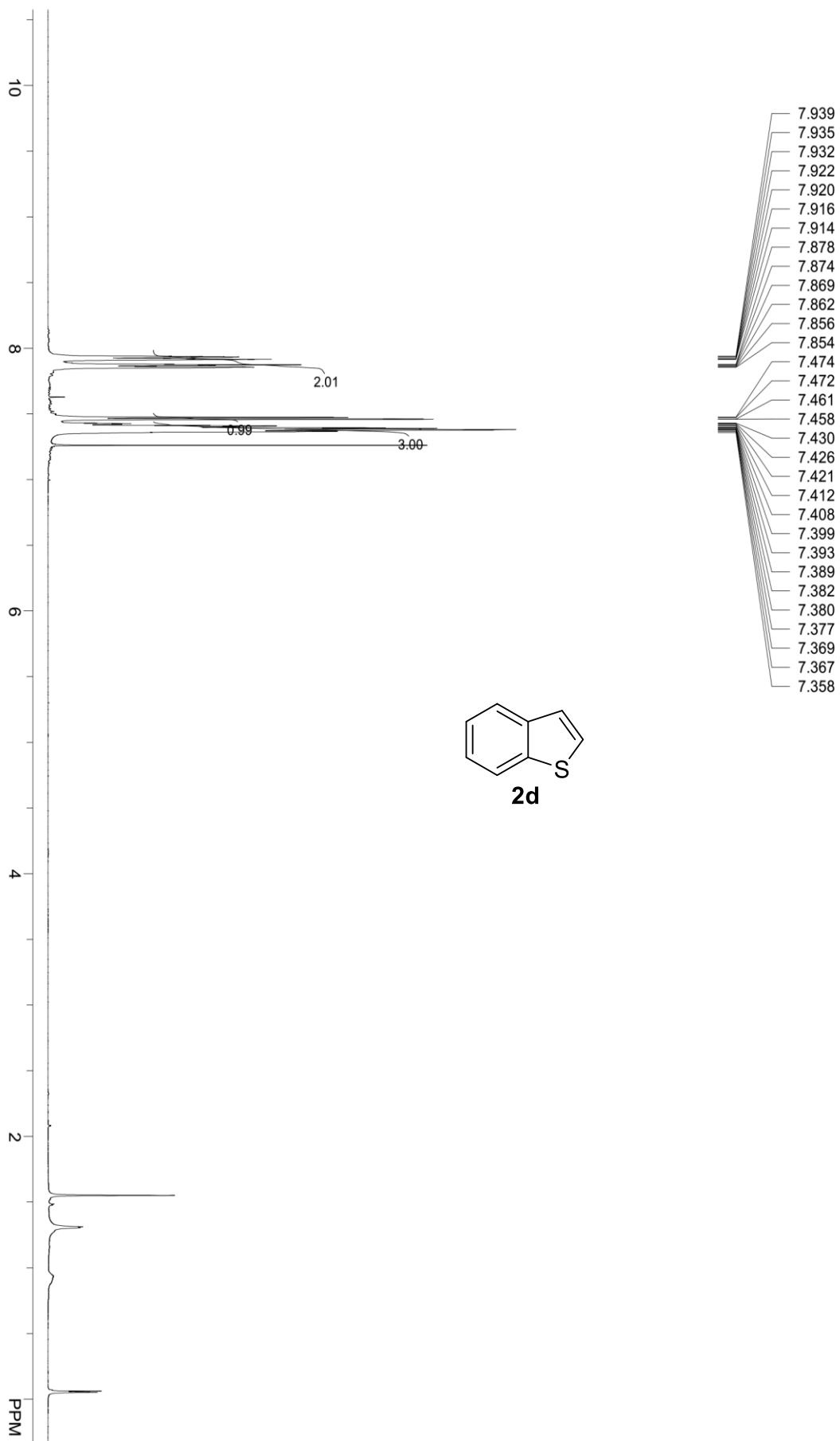


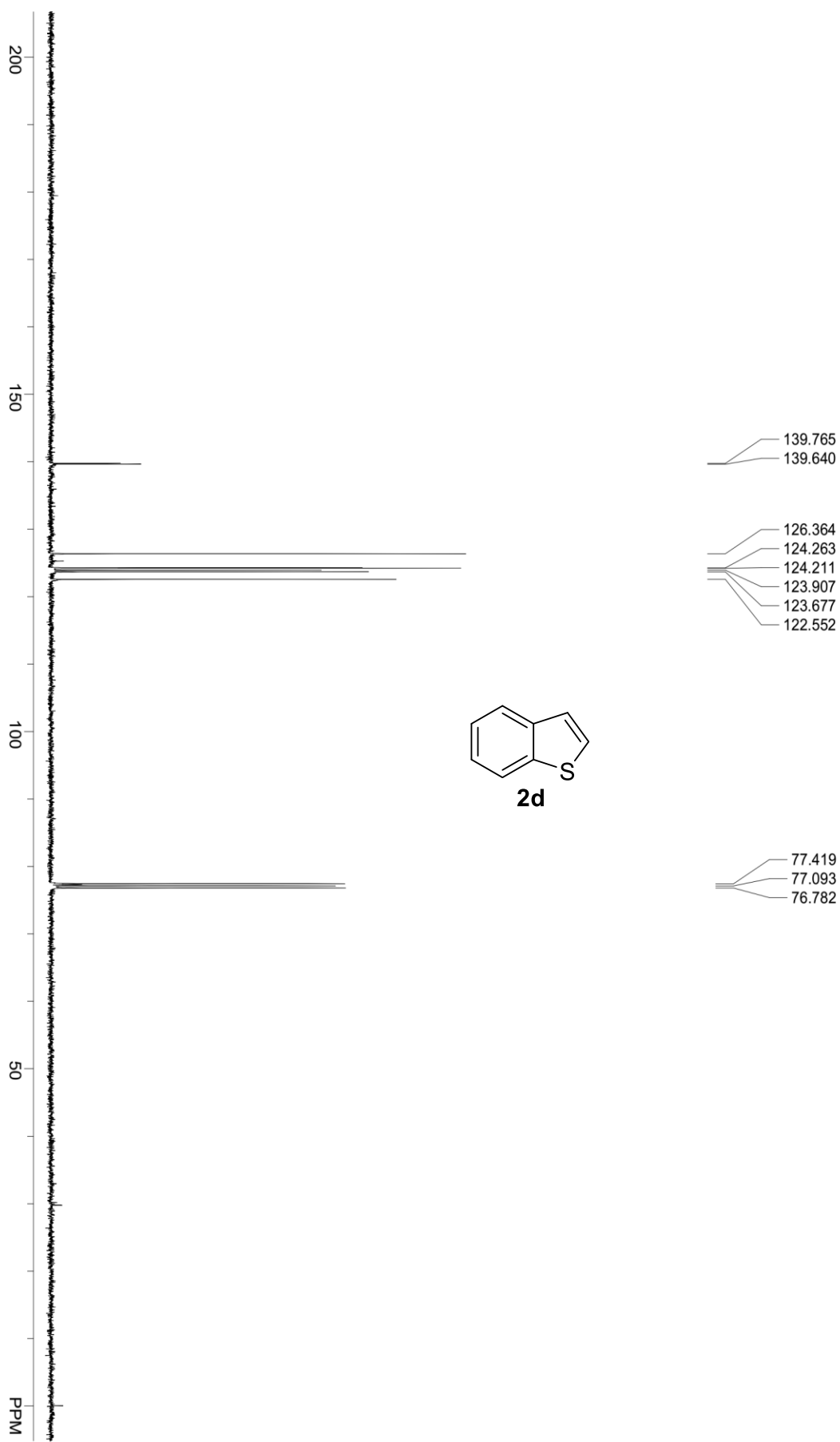


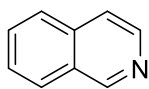
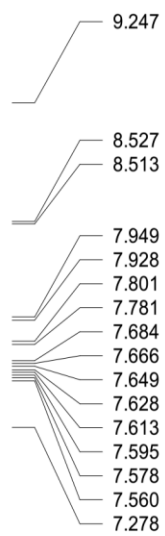
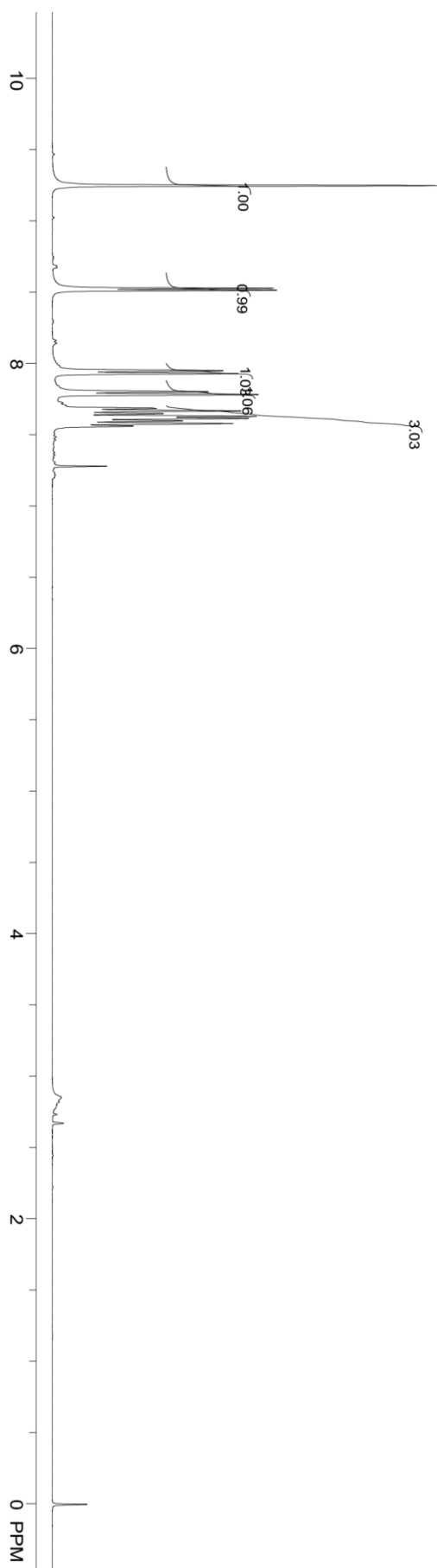












**2f**

