

# Room Temperature, Palladium-Mediated *P*-Arylation of Secondary Phosphine Oxides

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## Supporting Information

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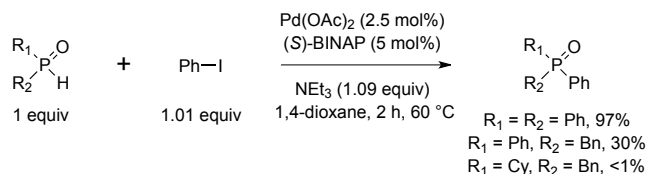
**General Experimental Procedures.** All reactions were performed in single-neck, flame-dried, round-bottomed flasks fitted with rubber septa or in 1-dram vials fitted with a Teflon-lined screw cap (13-mm diameter, 425 GPI thread; supplied by Qorpak, Bridgeville, Pennsylvania) under an atmosphere of nitrogen, unless otherwise noted. Air- and moisture-sensitive reagents were transferred via syringe or stainless steel cannula, or were handled in a nitrogen-filled drybox (working oxygen level <5 ppm). Organic solutions were concentrated by rotary evaporation at 30–33 °C. Flash-column chromatography was performed as described by Still et al.,<sup>1</sup> employing silica gel (60 Å, 40–63 µm particle size) purchased from Silicycle (Quebec, Canada). In some instances (so noted) samples were purified using a Biotage Isolera purification system. Specific elution parameters accompany each experimental. Analytical thin-layered chromatography (TLC) was performed using glass plates pre-coated with silica gel (250 µm, 60 Å pore size) impregnated with a fluorescent indicator (254 nm). TLC plates were visualized by exposure to ultraviolet light (UV) and/or submersion in aqueous potassium permanganate solution (KMnO<sub>4</sub>), followed by brief heating on a hot plate (120 °C, 10–15 s).

**Materials.** Commercial solvents and reagents were used as received with the following exceptions. Toluene was purified according to the method of Pangborn et al.<sup>2</sup> 1,4-Dioxane was deoxygenated by three freeze-pump-thaw cycles, and stored under nitrogen in a drybox. Triethylamine was distilled from calcium hydride immediately before use. Diisopropylamine was distilled from calcium hydride and stored under nitrogen. Dimethylphosphine oxide (**2a**),<sup>3</sup> *t*-butylphenylphosphine oxide,<sup>4</sup> and 2-iodofuran<sup>5</sup> (stabilized with 1% BHT) were prepared according to published procedures. Benzylcyclohexylphosphine oxide (**2b**), benzylphenylphosphine oxide (**2f**), cyclohexyl-(2,4,6-trimethylbenzyl)phosphine oxide (**2h**), methylphenylphosphine oxide (**2e**), neopentylphenylphosphine oxide (**3g**), *tert*-butylmethylphosphine oxide (**2c**),  $\alpha,\alpha'$ -di(phenylhydrophosphoxyl)-*meta*-xylene,  $\alpha,\alpha'$ -di(*tert*-butylhydrophosphoxyl)-*meta*-xylene and 1,3-diformyl-2-iodo-5-methylbenzene were prepared according to the procedure of Bloomfield et al.<sup>6</sup>

**Instrumentation.** Proton nuclear magnetic resonance spectra (<sup>1</sup>H NMR) were recorded at 400 or 500 MHz at 24 °C, unless otherwise noted. Chemical shifts are expressed in parts per million (ppm,  $\delta$  scale) downfield from tetramethylsilane, and are referenced to residual protium in the NMR solvent (CHCl<sub>3</sub>,  $\delta$  7.26). Data are represented as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, quint = quintet, m = multiplet and/or multiple resonances, br = broad, app = apparent), integration, coupling constant in Hertz, and assignment. Inverse-gated, proton-decoupled phosphorus nuclear magnetic resonance spectra (<sup>31</sup>P NMR) were recorded at 162 or 200 MHz at 24 °C, unless

otherwise noted. Chemical shifts are expressed in parts per million (ppm,  $\delta$  scale) and are referenced to phosphoric acid ( $\delta$  0.00). Proton-decoupled carbon nuclear magnetic resonance spectra ( $^{13}\text{C}$  NMR) were recorded at 100 or 125 MHz at 24 °C, unless otherwise noted. Chemical shifts are expressed in parts per million (ppm,  $\delta$  scale) downfield from tetramethylsilane, and are referenced to the carbon resonances of the solvent ( $\text{CDCl}_3$ ,  $\delta$  77.16). Data are represented as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, m = multiplet and/or multiple resonances, app = apparent), coupling constant in Hertz. Attenuated total reflectance Fourier transform infrared (ATR-FTIR) spectra were obtained using a Thermo Electron Corporation Nicolet 6700 FTIR spectrometer referenced to a polystyrene standard. Data are represented as follows: frequency of absorption ( $\text{cm}^{-1}$ ), intensity of absorption (s = strong, m = medium, w = weak, br = broad, assignment). High-resolution mass spectrometry (HRMS) data was obtained on a Waters analytical ultra high-performance liquid chromatography-mass spectrometry (UPLC/HRMS) instrument equipped with an electrospray (ESI) mass spectrometry detector and photodiode array detector. Unless otherwise noted, samples were eluted over a reverse-phase C-18 column (1.7  $\mu\text{m}$  particle size, 2.1  $\times$  50 mm) with a linear gradient of 5% acetonitrile–water to 95% acetonitrile–water containing 0.1% formic acid over 3 min at a flow rate of 0.8 mL/min. Analytical chiral stationary phase HPLC was performed on an Agilent 1100 series chromatograph equipped with a CHIRALPAK® AS-H column and photodiode array detector. Samples were eluted with 50.0% isopropanol–hexanes at a flow rate of 0.8 mL/min. Analytical chiral stationary phase chromatographic data are represented as follows: retention time ( $t_R$ ) in minutes. X-ray crystallography was performed at 93 K, using a Rigaku Saturn 944+ CCD, operating with a rotating anode, emitting 1.54187 nm radiation (Cu K-alpha). Structure refinement was performed with SHELXL-97.

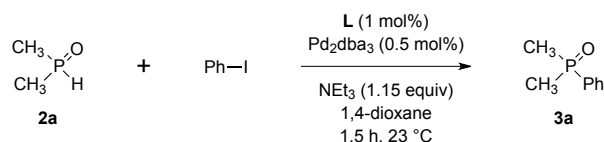
## Synthetic Procedures.



### Evaluation of $\text{Pd(OAc)}_2$ -BINAP:

Palladium acetate (16.8 mg, 74.9  $\mu\text{mol}$ , 2.5 mol%), (S)-BINAP (95.2 mg, 153  $\mu\text{mol}$ , 5.0 mol%), triethylamine (460  $\mu\text{L}$ , 3.30 mmol, 1.09 equiv) and dioxane (3.0 mL) were combined in a 1-dram vial that had been charged with a Teflon-coated magnetic stirbar. The vial was sealed with a Teflon-lined cap and the mixture was stirred for 20 min at 80  $^\circ\text{C}$ . The vial was allowed to cool over 10 min to 24  $^\circ\text{C}$ . The cooled, dark red solution was divided evenly between three separate 1-dram vials (1.0 mL to each vial) that had each been charged with a Teflon-coated magnetic stirbar. A solution of the SPO (1 mmol) and 4-iodotoluene (1 mmol) in dioxane (2.50 mL) was added to each of the three vials. The three vials were sealed with Teflon-lined caps and the reaction mixture was stirred and heated at 60  $^\circ\text{C}$ . After 2 h at 60  $^\circ\text{C}$ , the product mixtures were transferred to an NMR tube and the solutions were analyzed by P-31 NMR spectroscopy.

SPO	Amount of SPO	Amount of Iodotoluene	Yield of TPO
$\text{Ph}_2\text{P(O)H}$	205 mg, 1.01 mmol	223 mg, 1.02 mmol	97%
$\text{BnPhP(O)H}$	220 mg, 1.02 mmol	225 mg, 1.03 mmol	30%
$\text{BnCyP(O)H}$	222 mg, 1.00 mmol	223 mg, 1.02 mmol	<1%



*Coupling of Dimethylphosphine Oxide and Iodobenzene; Evaluation of Ligands:*

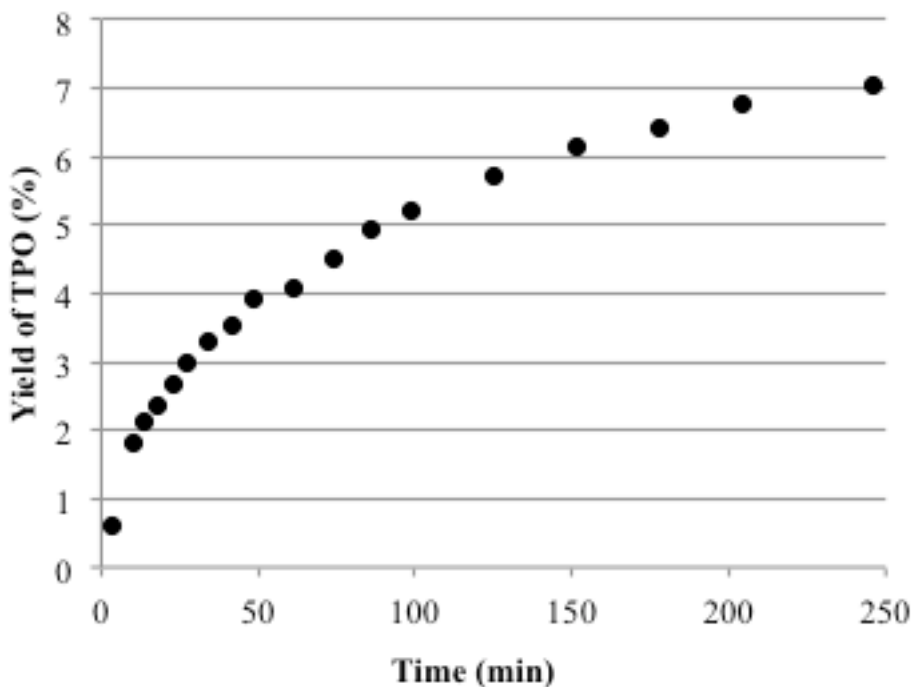
In a nitrogen-filled drybox, a 1-dram vial was charged sequentially with dimethylphosphine oxide (97.2 mg, 1.25 mmol, 1 equiv), iodobenzene (150  $\mu\text{L}$ , 1.35 mmol, 1.08 equiv), triethylamine (200  $\mu\text{L}$ , 1.44 mmol, 1.15 equiv) and dioxane (1.5 mL). In five separate 1-dram vials, catalyst solutions were prepared by combining 4  $\mu\text{mol}$  of  $\text{Pd}_2\text{dba}_3$  (8  $\mu\text{mol}$  Pd) and 8  $\mu\text{mol}$  of a bisphosphine ligand (see table below) in dioxane (250  $\mu\text{L}$ ). A Teflon-coated magnetic stirbar was added to each vial containing the catalyst–ligand solution, and the solutions were stirred for 20 min at 24  $^\circ\text{C}$ . Any remaining solids were allowed to settle. The supernatant catalyst solutions were each transferred to an NMR tube. An aliquot of the SPO–iodobenzene–triethylamine solution prepared above (250  $\mu\text{L}$ ) was added to each NMR tube. The tubes were sealed with a plastic cap and the reaction mixtures were allowed to stand for 1.5 h at 24  $^\circ\text{C}$ . A solution of triphenylphosphine oxide in dioxane (180 mM, 200  $\mu\text{L}$ , 0.144 equiv) was then added to each NMR tube, and the resulting mixtures were analyzed by P-31 NMR spectroscopy.

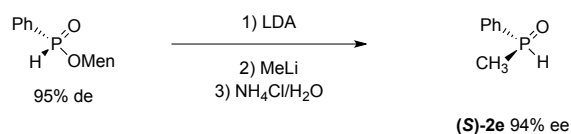
Ligand	Amount of Pd	Amount of Ligand	Catalyst Loading	Yield of TPO
( <i>S</i> )-BINAP	8.3 $\mu\text{mol}$ Pd	8.5 $\mu\text{mol}$	5.0 mol%	1.7%
Josiphos	8.3 $\mu\text{mol}$ Pd	7.9 $\mu\text{mol}$	4.8 mol%	0%
Dppf	8.1 $\mu\text{mol}$ Pd	7.9 $\mu\text{mol}$	4.8 mol%	85%
Xantphos ( <b>1</b> )	8.5 $\mu\text{mol}$ Pd	8.6 $\mu\text{mol}$	5.2 mol%	97%
none	8.5 $\mu\text{mol}$ Pd	none	5.2 mol%	0.5%

*Determination of Initial Turn Over Frequency:*

In a nitrogen filled drybox, benzylcyclohexylphosphine oxide (**2b**, 112 mg, 505  $\mu\text{mol}$ , 1 equiv), 4-iodotoluene (113 mg, 518  $\mu\text{mol}$ , 1.03 equiv), triethylamine (75  $\mu\text{l}$ , 539  $\mu\text{mol}$ , 1.07 equiv) and dioxane (1.00 mL) were combined in a 1-dram vial. The resulting mixture was stirred at 24  $^{\circ}\text{C}$  until homogenous (*ca.* 5 min). The contents of the vial were then transferred to a J. Young NMR tube. In a separate 1-dram vial,  $\text{Pd}_2\text{dba}_3$  (2.3 mg, 5.5  $\mu\text{mol}$ , 10.9  $\mu\text{mol}$  Pd), Xantphos (**1**, 5.9 mg, 10.2  $\mu\text{mol}$ ), triethylamine (250  $\mu\text{L}$ , 1.79 mmol) and dioxane (370  $\mu\text{L}$ ) were combined (catalyst solution). The catalyst solution was stirred at for 10 min at 24  $^{\circ}\text{C}$ . An aliquot of the catalyst solution (50.0  $\mu\text{L}$ , Pd: 0.82  $\mu\text{mol}$ , 0.16 mol%) was added to the J. Young NMR tube. The tube was sealed and the sealed tube was immediately inserted into the probe of an NMR spectrometer. The progress of the reaction was monitored by  $^{31}\text{P}$  spectroscopy.

Arylation of benzylcyclohexylphosphine oxide (**2b**) with 4-iodotoluene (400 mM each) employing 0.16 mol% Xantphos (**1**) and 0.08 mol%  $\text{Pd}_2\text{dba}_3$ :





### Enantioenriched Methylphenylphosphine Oxide (**S**)-**2e**:

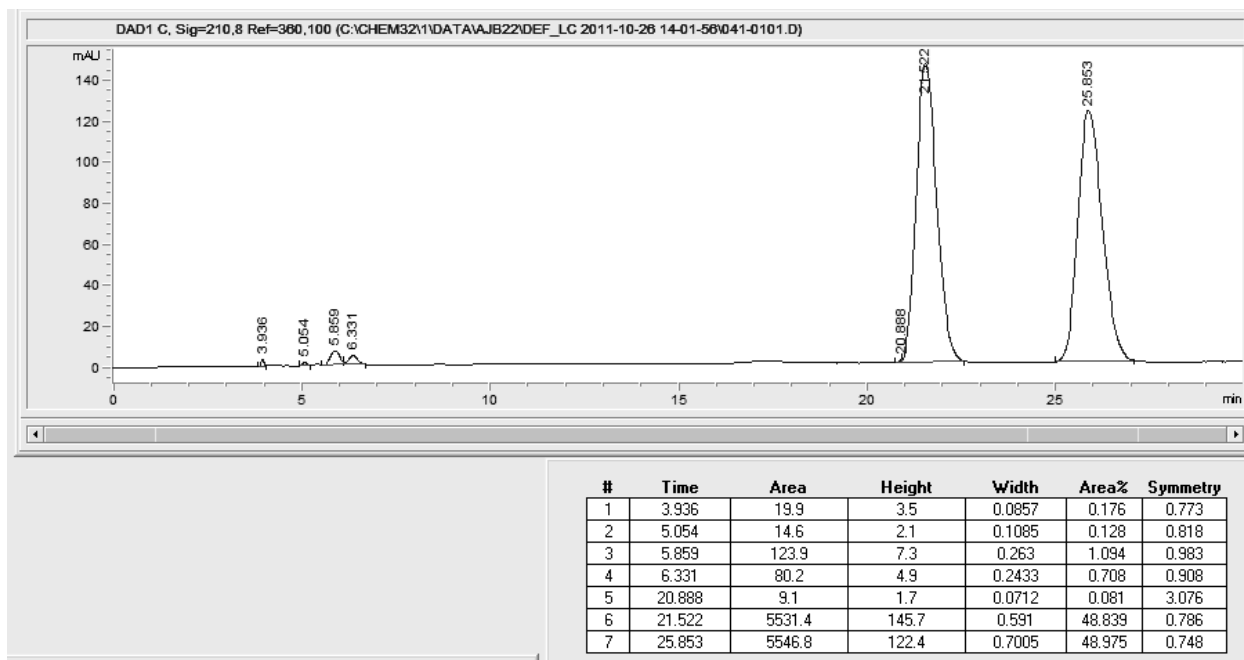
(-)-Menthyl phenylphosphinate was prepared as a mixture of diastereomers, as previously described.<sup>7</sup> (-)-Menthyl (*R<sub>P</sub>*)-phenylphosphinate was isolated in 95% de by fractional crystallization from hexane (*ca.* 15 mL/g) at -78 °C.

A 10-mL pear-shaped flask equipped with a Teflon-coated magnetic stirbar was charged with *iso*-propylamine (282 µL, 2.00 mmol, 2.46 equiv) and tetrahydrofuran (2.0 mL) under an atmosphere of argon. The resulting mixture was cooled to 0 °C. A solution of *n*-butyllithium in hexanes (2.32 M, 520 µL, 1.21 mmol, 1.49 equiv) was added, and the reaction mixture was stirred for 1 h at 0 °C. The resulting solution of lithium diisopropylamide was then cooled to -78 °C. A solution of (-)-menthyl (*R<sub>P</sub>*)-phenylphosphinate (228 mg, 814 µmol, 1 equiv) in tetrahydrofuran (250 µL) was added dropwise over 4 min to the cold solution. The resulting mixture was stirred for 20 min at -78 °C. Separately, a 10-mL round-bottom flask was charged with a Teflon-coated magnetic stirbar and a solution of methyllithium in diethyl ether (1.6 M, 2.00 mL, 3.20 mmol, 3.93 equiv). The methyllithium solution was cooled to -78 °C, with stirring. The solution of the lithiated phosphinate was then transferred via cannula to the cold solution of methyllithium. The reaction mixture was stirred for 5 min at -78 °C, and then was warmed to 0 °C. The warmed mixture was stirred for 1 h at 0 °C. The mixture was then cooled to -78 °C and the cooled solution was diluted slowly with saturated aqueous ammonium chloride solution (1.0 mL). The diluted mixture was warmed over 15 min to 24 °C. The warmed solution was transferred to a separatory funnel and diluted sequentially with hexanes (50 mL) and water (50 mL). The layers that formed were separated, and the organic layer was extracted with water (3 × 50 mL). The aqueous layers were combined and the combined aqueous layers were washed with hexanes (3 × 50 mL). The hexane washes were combined and discarded. The aqueous layer was then extracted with dichloromethane (4 × 50 mL). The dichloromethane layers were combined, and the combined organic layers were dried over sodium sulfate. The dried solution was filtered and the filtrate was concentrated. The residue obtained was purified by flash chromatography (eluting with 3% methanol–dichloromethane) to afford methylphenyl phosphine oxide [(**S**)-**2e**, 45.8 mg, 40%].

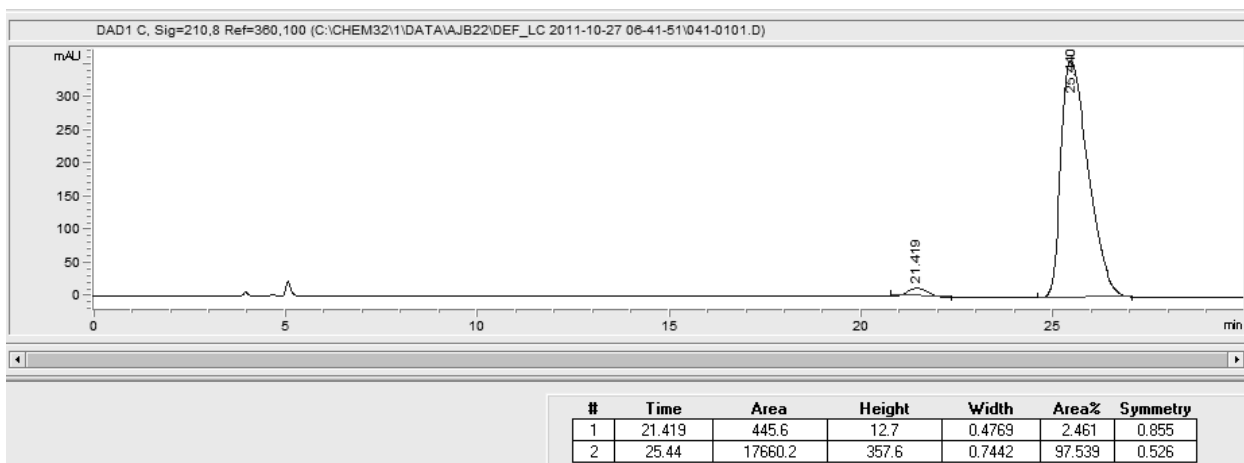
<sup>1</sup>H and <sup>31</sup>P spectra of methylphenyl phosphine oxide (**S**)-**2e** were in agreement with those reported.<sup>7</sup> The enantiomeric excess was determined to be 94.9 ± 0.6 % ee by chiral stationary phase HPLC analysis

( $t_{R(\text{minor})}$  = 21.4 min;  $t_{R(\text{major})}$  = 25.4 min, see accompanying chromatographs).

(±)-**2e**:



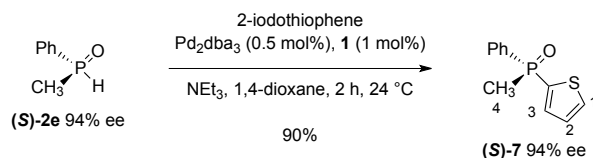
Enantioenriched (**S**)-**2e**:





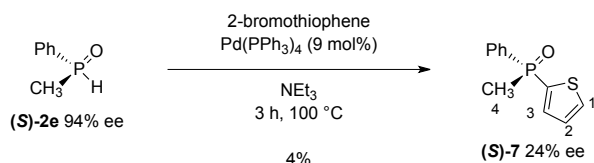
### Enantioenriched Methylphenyl(2-thiophenyl)phosphine oxide (**7**):

#### Method A:



In a nitrogen-filled drybox, a neat mixture of (*S*)-methylphenylphosphine oxide [**(S)-2e**, 42.4 mg, 303  $\mu\text{mol}$ , 1 equiv, 94.9% ee] and 2-iodothiophene (74.4 mg, 354  $\mu\text{mol}$ , 1.17 equiv) was prepared in a 1-dram vial that had been charged with a Teflon-coated magnetic stirbar. Dioxane (500  $\mu\text{L}$ ) was added, and the resulting mixture was stirred at 24 °C until homogenous (ca. 1 min). In a separate 1-dram vial, a dry mixture of tris(dibenzylideneacetone)dipalladium (3.4 mg, 3.7  $\mu\text{mol}$ , 7.4  $\mu\text{mol}$  Pd) and Xantphos (**1**, 4.3 mg, 7.4  $\mu\text{mol}$ ) was dissolved in dioxane (250  $\mu\text{L}$ ). The resulting mixture was stirred at 24 °C until homogenous (5–10 min). During this time, the catalyst solution changed color from dark purple to brown. The catalyst solution was transferred to the vial containing the SPO and iodothiophene reagents. The vial was sealed with a Teflon-lined cap, and the sealed vial was removed from the drybox. The reaction mixture was stirred for 2 h at 24 °C. The vial was periodically shaken to facilitate mixing. The product mixture was transferred to a separatory funnel, and the vial containing the product mixture was rinsed with dichloromethane (5 mL). The rinses were added to the separatory funnel, and the organic layer was washed with saturated aqueous sodium bicarbonate solution (25 mL). The aqueous layer was extracted with dichloromethane (3  $\times$  25 mL). The organic layers were combined, and the combined organic layers were dried over sodium sulfate. The dried solution was filtered and the filtrate was concentrated. The residue obtained was purified by flash-column chromatography using a Biotage Isolera purification system (eluting with 100% ethyl acetate initially, grading to 10% methanol–ethyl acetate) to afford the tertiary phosphine oxide **(S)-7** as a white, crystalline solid (60.4 mg, 90%).

#### Method B:<sup>9</sup>



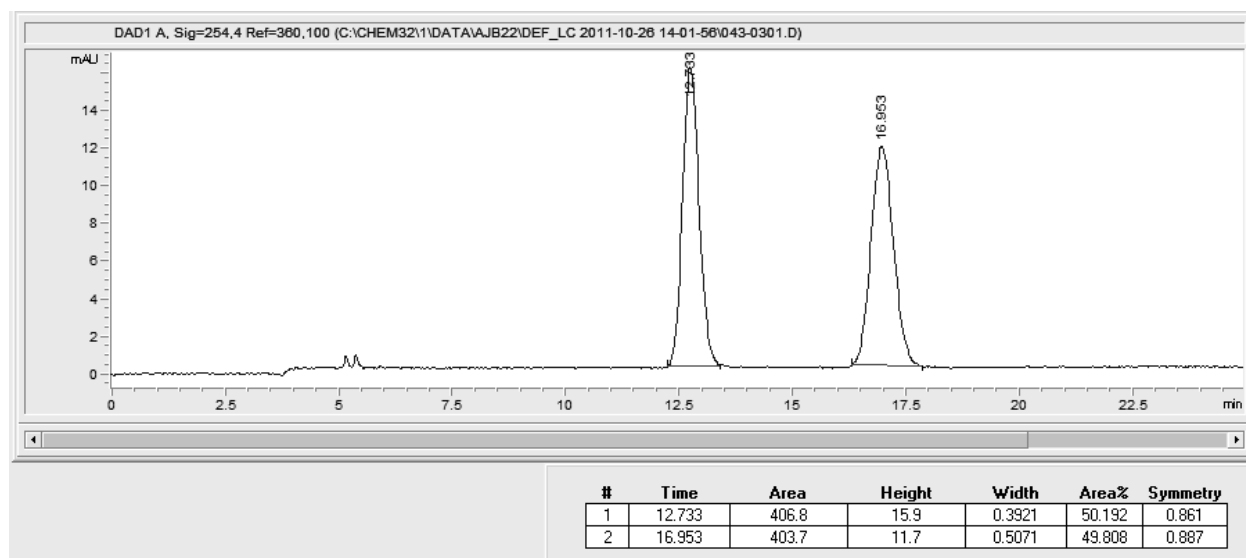
In a nitrogen-filled drybox, a neat mixture of (*S*)-methylphenylphosphine oxide (**(S)-2e**, 53.6 mg, 383  $\mu\text{mol}$ , 1 equiv, 94.9% ee), 2-bromothiophene (69.6 mg, 461  $\mu\text{mol}$ , 1.20 equiv), triethylamine (60  $\mu\text{L}$ , 431  $\mu\text{mol}$ , 1.13 equiv) and tetrakis(triphenylphosphine)palladium (0) (40.1 mg, 34.7  $\mu\text{mol}$ , 9.1 mol%) was prepared in a 1-dram vial that had been charged with a Teflon-coated magnetic stirbar. The vial was

sealed with a Teflon-lined cap, and the sealed vial was removed from the drybox. The reaction mixture was stirred for 3 h at 100 °C. The product mixture was transferred to a separatory funnel, and the vial containing the product mixture was rinsed with dichloromethane (5 mL). The rinses were added to the separatory funnel, and the organic layer was washed with saturated aqueous sodium bicarbonate solution (25 mL). The aqueous layer was extracted with dichloromethane (3 × 25 mL). The organic layers were combined, and the combined organic layers were dried over sodium sulfate. The dried solution was filtered and the filtrate was concentrated. The residue obtained was purified by flash-column chromatography using a Biotage Isolera purification system (eluting with 100% ethyl acetate initially, grading to 10% methanol–ethyl acetate) to afford the tertiary phosphine oxide (**S**)-**7** as a white, crystalline solid (3.9 mg, 4%).

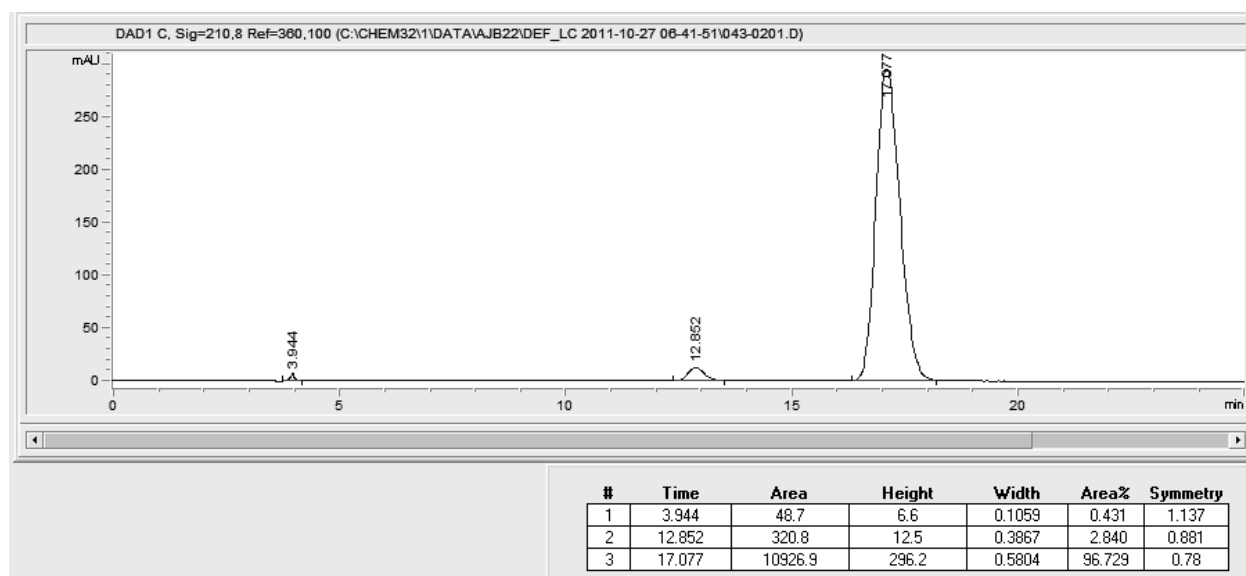
R<sub>f</sub>: 0.31 (3% methanol–ethyl acetate; UV). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.81–7.73 (m, 2H, Ph), 7.70–7.65 (m, 1H, H<sub>1</sub>), 7.55–7.45 (m, 4H, Ph and H<sub>3</sub>), 7.18–7.13 (m, 1H, H<sub>2</sub>), 2.05 (d, *J*<sub>HP</sub> = 13.6 Hz, H<sub>4</sub>). <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>) δ 135.2 (d, *J*<sub>CP</sub> = 108.0 Hz), 135.0 (d, *J*<sub>CP</sub> = 9.6 Hz), 134.0 (d, *J*<sub>CP</sub> = 107.5 Hz), 133.1 (d, *J*<sub>CP</sub> = 4.7 Hz), 132.1 (d, *J*<sub>CP</sub> = 3.0 Hz), 130.4 (d, *J*<sub>CP</sub> = 10.3 Hz), 128.8 (d, *J*<sub>CP</sub> = 12.1 Hz), 128.4 (d, *J*<sub>CP</sub> = 13.5 Hz), 18.7 (d, *J*<sub>CP</sub> = 77.6 Hz). <sup>31</sup>P (162 MHz, CDCl<sub>3</sub>) δ 24.1. IR (thin film), cm<sup>-1</sup>: 30 57.9 (m), 2981.0 (w), 2910.0 (w), 1436.5 (m), 1405.9 (s), 1172.0 (s). LC/HRMS-ESI (*m/z*): [M + H]<sup>+</sup> calcd for C<sub>11</sub>H<sub>12</sub>OPS, 223.0346; found 223.0283.

The enantiomeric excess of the tertiary phosphine oxide (**7**) obtained by method A was determined to be 94.3 ± 0.1 % ee by chiral stationary phase HPLC analysis (*t*<sub>R(minor)</sub> = 12.9 min; *t*<sub>R(major)</sub> = 17.1 min, see accompanying chromatograph). [α]<sub>D</sub><sup>20</sup> = –3.6° (CDCl<sub>3</sub>, 20 °C). The crystal used for X-ray structural determination (absolute configuration) was recovered and shown to contain exclusively the major enantiomer by chiral stationary phase HPLC analysis. The enantiomeric excess of **7** obtained by method B was determined to be 24.2 ± 0.1 % ee.

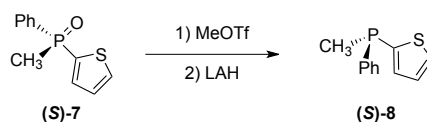
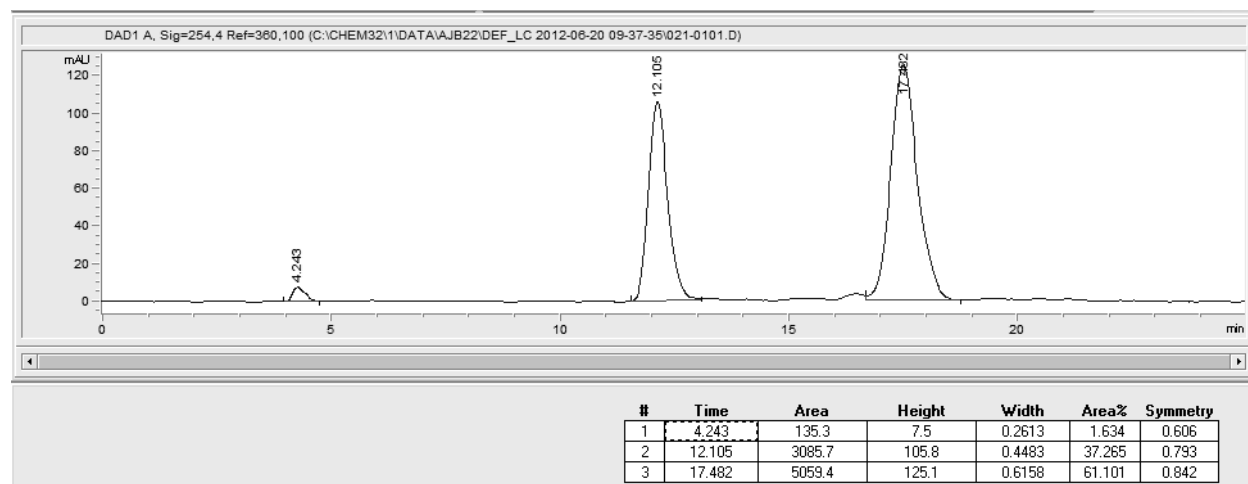
(±)-7:



Enantioenriched 7 from method A:



Enantioenriched **7** from method B:



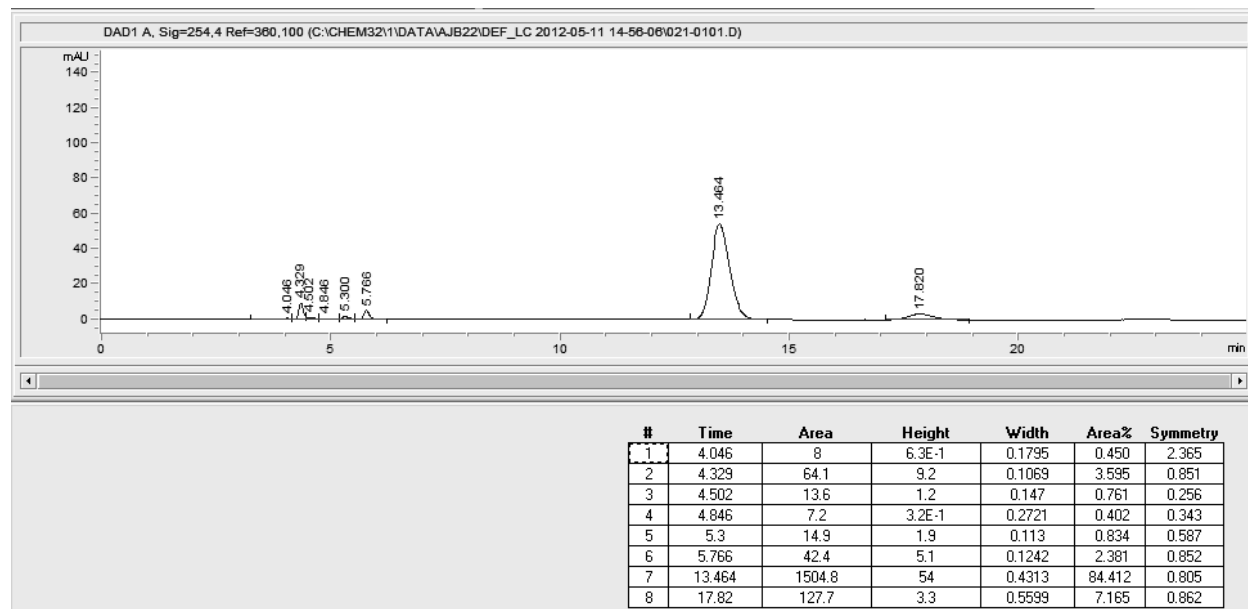
*Enantioenriched Methylphenyl(2-thiophenyl)phosphine (8):*

A 10 mL flask equipped with a small Teflon-coated magnetic stirbar and a Teflon valve was charged with (*S*)-methylphenyl(2-thiophenyl)phosphine oxide [(*S*)-**7**, 32.5 mg, 146  $\mu\text{mol}$ , 1 equiv, 94% ee]. The flask was evacuated and filled with argon three times, then anhydrous and degassed dimethoxyethane (150  $\mu\text{L}$ ) was added. The mixture was stirred at 24  $^{\circ}\text{C}$  for 10 min, producing a homogenous clear solution. The reaction was cooled to 0  $^{\circ}\text{C}$ , and methyl triflate (16.1  $\mu\text{L}$ , 147  $\mu\text{mol}$ , 1.00 equiv) was added via syringe. The flask was sealed and the reaction mixture was stirred for 2 h at 0  $^{\circ}\text{C}$ . The flask was then immersed in a  $-60$   $^{\circ}\text{C}$  bath. A solution of lithium aluminum hydride in tetrahydrofuran (1.0 M, 360  $\mu\text{L}$ , 360 mmol, 2.47 equiv) cooled to  $-60$   $^{\circ}\text{C}$  was transferred to the reaction flask by canula over 10 s. The reaction flask was sealed, and the mixture was stirred for 5 h at  $-60$   $^{\circ}\text{C}$ . The reaction was then allowed to warm to 24  $^{\circ}\text{C}$  over 20 min. The warmed mixture was concentrated to dryness. The residue obtained was extracted with degassed benzene. The extract was passed through a short plug of silica in a nitrogen-filled drybox, and concentrated, yielding the phosphine as an analytically pure clear oil (27.0 mg, 90%).

$^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.58–7.54 (m, 1H), 7.47–7.39 (m, 2H), 7.37–7.27 (m, 4H), 7.11 (t,  $J = 4.0$  Hz, 1H), 1.72 (d,  $J_{\text{HP}} = 2.0$  Hz).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ )  $\delta$  141.0 (d,  $J_{\text{CP}} = 18.7$  Hz), 140.8 (s), 134.9 (d,  $J_{\text{CP}} = 26.4$  Hz), 131.2 (d,  $J_{\text{CP}} = 18.3$  Hz), 131. (s), 128.5 (app t,  $J_{\text{CP}} = 2.9$  Hz), 127.9 (d,  $J_{\text{CP}} = 7.3$  Hz),

14.4 (d,  $J_{\text{CP}} = 10.2$  Hz).  $^{31}\text{P}$  (162 MHz,  $\text{CDCl}_3$ )  $\delta$  -36.7. LC/HRMS-ESI ( $m/z$ ):  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{11}\text{H}_{12}\text{PS}$ , 207.0397; found 207.0400.

The phosphine was oxidized with *t*-butyl hydrogen peroxide, which is known to undergo stereospecific oxidation, and enantiomeric excess of the tertiary phosphine oxide (**7**) was determined to be  $84.7 \pm 0.1$  % ee by chiral stationary phase HPLC analysis ( $t_{\text{R(major)}} = 13.5$  min;  $t_{\text{R(minor)}} = 17.8$  min, see accompanying chromatograph).



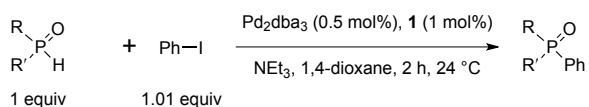
#### Benchmark Coupling Test:

A 50 mL round bottom flask equipped with a rubber septum, a Teflon valve and a Teflon-coated stirbar was charged with benzylcyclohexylphosphine oxide (**2b**, 222 mg, 1.00 mmol, 1 equiv). The flask was then evacuated and refilled with argon three times. Under an atmosphere of argon, iodobenzene (112  $\mu\text{L}$ , 1.01 mmol, 1.01 equiv), triethylamine (163  $\mu\text{L}$ , 1.17 mmol, 1.17 equiv) and dioxane (1.40 mL) were added, and the resulting mixture was stirred for 10 min at  $24^\circ\text{C}$ . A 1-dram vial was charged with tris(dibenzylideneacetone)dipalladium (22.7 mg, 24.8  $\mu\text{mol}$ , 4.9 mol% Pd) and Xantphos (**1**, 28.5 mg, 49.3  $\mu\text{mol}$ , 4.9 mol%). The vial was then sealed with a rubber septum, and evacuated and refilled with argon three times. Under an argon atmosphere, dioxane (1.0 mL) was added. The resulting mixture was stirred at  $24^\circ\text{C}$  until homogenous (5–10 min). During this time, the catalyst solution changed color from dark purple to brown. The catalyst solution was added to the reaction flask in a single portion by syringe. The reaction flask was then sealed, and the reaction stirred for 2 h at  $24^\circ\text{C}$ . The product mixture was

transferred to a separatory funnel, and the vial containing the product mixture was rinsed with dichloromethane (5 mL). The rinses were added to the separatory funnel, and the organic layer was washed with saturated aqueous sodium bicarbonate solution (25 mL). The layers that formed were separated, and the aqueous layer was extracted with dichloromethane (3 × 25 mL). The organic layers were combined, and the combined organic layers were dried over sodium sulfate. The dried solution was filtered and the filtrate was concentrated. Purification by flash-column chromatography (eluting with ethyl acetate) afforded **3b** as a white crystalline solid (222 mg, 75%). See characterization data in General procedure section below.

*Low-Temperature Coupling Test:*

In a nitrogen-filled glovebox, a neat mixture of benzylcyclohexylphosphine oxide (**2b**, 111 mg, 500 μmol, 1 equiv) and 3,5-dimethyliodobenzene (119 mg, 513 μmol, 1.03 equiv) was prepared in a 25 mL round bottom flask, equipt with a rubber septem, a Teflon valve and a Teflon-coated stirbar. THF (700 μL) and triethylamine (82 μL, 589 μmol, 1.18 equiv) were added, and the resulting mixture was stirred for 5 min at 24°C. The reaction mixture was then cooled to 0°C. In a nitrogen-filled glovebox, a mixture of tris(dibenzylideneacetone)dipalladium (12.2 mg, 13.3 μmol, 1.3 mol% Pd), Xantphos (13.4 mg, 23.1 μmol, 2.3 mol%) and THF (1.0 mL) were combined in a 1-dram vial. The resulting mixture was stirred at 24 °C until homogenous (5–10 min). During this time, the catalyst solution changed color from dark purple to brown. The catalyst solution was added to the reaction flask at 0°C, dropwise over 2 min. After the addition, the reaction flask was sealed, and the mixture was stirred for 12 h at 0°C. The product mixture was transferred to a separatory funnel, and the vial containing the product mixture was rinsed with dichloromethane (5 mL). The rinses were added to the separatory funnel, and the organic layer was washed with saturated aqueous sodium bicarbonate solution (25 mL). The layers that formed were separated, and the aqueous layer was extracted with dichloromethane (3 × 25 mL). The organic layers were combined, and the combined organic layers were dried over sodium sulfate. The dried solution was filtered and the filtrate was concentrated. Purification by flash-column chromatography (eluting with ethyl acetate) afforded **4c** as a white crystalline solid (151 mg, 93%). See characterization data in General procedure section below.



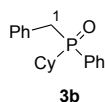
*General Procedure for the P-Arylation of Secondary Phosphine Oxides:*

In a nitrogen-filled drybox, a neat mixture of the secondary phosphine oxide (1.00 mmol, 1 equiv) and the aryl iodide (1.01 mmol, 1.01 equiv) was prepared in a 1-dram vial that had been charged with a Teflon-coated magnetic stirbar. Dioxane (1.4 mL) was added, and the resulting mixture was stirred at 24 °C until homogenous (ca. 10 min). In a separate 1-dram vial, a dry mixture of tris(dibenzylideneacetone)dipalladium (24.0 mg, 26.2 μmol, 52.4 μmol Pd) and Xantphos (**1**, 30.8 mg, 53.2 μmol) was dissolved in dioxane (1.8 mL). Triethylamine (1.17 mL, 8.39 mmol) was added, and the resulting mixture was stirred at 24 °C until homogenous (5–10 min). During this time, the catalyst solution changed color from dark purple to brown. An aliquot of the brown catalyst solution (500 μL, 1 mol% Pd, 1 mol% Xantphos, 1.17 equiv triethylamine based on the starting secondary phosphine oxide) was added to the mixture of the secondary phosphine oxide and aryl iodide. The vial containing the reaction mixture was sealed with a Teflon-lined cap, and the sealed vial was removed from the drybox. The reaction mixture was stirred for 2 h at 24 °C. In some instances, rapid conversion of the starting materials induced formation of a gelatinous mixture. In these cases, the vial was periodically shaken to facilitate mixing. The product mixture was transferred to a separatory funnel, and the vial containing the product mixture was rinsed with dichloromethane (5 mL). The rinses were added to the separatory funnel, and the organic layer was washed with saturated aqueous sodium bicarbonate solution (25 mL). The layers that formed were separated, and the aqueous layer was extracted with dichloromethane (3 × 25 mL). The organic layers were combined, and the combined organic layers were dried over sodium sulfate. The dried solution was filtered and the filtrate was concentrated. The products were further purified as specified below.



*Dimethylphenylphosphine oxide (3a)*: Purification by flash-column chromatography (eluting with acetone) afforded the title compound as a clear oil (132 mg, 86%).

<sup>1</sup>H and <sup>31</sup>P spectra were in agreement with those reported.<sup>8</sup>



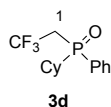
*Benzylcyclohexylphenylphosphine oxide (3b)*: Purification by flash-column chromatography (eluting with ethyl acetate) afforded the title compound as a white crystalline solid (276 mg, 93%).

R<sub>f</sub>: 0.72 (3% methanol–ethyl acetate; UV). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.53–7.46 (m, 2H, **Ph**), 7.44–7.38 (m, 1H, **Ph**), 7.37–7.33 (m, 2H, **Ph**), 7.17–7.00 (m, 5H, **Ph**), 3.40–3.20 (m, 2H, H<sub>1</sub>), 2.10–1.98 (br, 1H, **Cy**), 1.99–1.76 (m, 2H, **Cy**), 1.74–1.54 (br, 3H, **Cy**), 1.48–1.35 (m, 1H, **Cy**), 1.34–1.06 (m, 4H, **Cy**). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 131.8 (d, J<sub>CP</sub> = 7.3 Hz), 131.4 (d, J<sub>CP</sub> = 2.6 Hz), 131.2 (d, J<sub>CP</sub> = 8.0 Hz), 130.5 (d, J<sub>CP</sub> = 90.4 Hz), 129.8 (d, J<sub>CP</sub> = 5.1 Hz), 128.3 (d, J<sub>CP</sub> = 2.5 Hz), 128.1 (d, J<sub>CP</sub> = 11.1 Hz), 126.5 (d, J<sub>CP</sub> = 3.0 Hz), 37.2 (d, J<sub>CP</sub> = 69.5 Hz), 35.1 (d, J<sub>CP</sub> = 60.5 Hz), 26.2 (d, J<sub>CP</sub> = 13.2 Hz), 26.2 (d, J<sub>CP</sub> = 12.8 Hz), 25.7 (d, J<sub>CP</sub> = 1.5 Hz), 25.3 (d, J<sub>CP</sub> = 2.9 Hz), 24.8 (d, J<sub>CP</sub> = 3.3 Hz). <sup>31</sup>P NMR (162 MHz, CDCl<sub>3</sub>) δ 40.5. IR (thin film), cm<sup>-1</sup>: 3062.8 (w), 2934.1 (m), 2853.7 (w), 1602.1 (w), 1166.0 (s). LC/HRMS-ESI (*m/z*): [M + H]<sup>+</sup> calcd for C<sub>19</sub>H<sub>24</sub>OP, 299.1487; found 299.1575.



*tert-Butylmethylphenylphosphine oxide (3c)*: Purification by flash-column chromatography using a Biotage Isolera purification system (eluting with ethyl acetate, grading to 20% methanol–ethyl acetate) afforded the title compound as white crystals (126 mg, 64%).

<sup>1</sup>H and <sup>31</sup>P spectra were in agreement with those reported.<sup>9</sup>



*Cyclohexylphenyl(2,2,2-trifluoroethyl)phosphine oxide (3d)*: Purification by flash-column chromatography using a Biotage Isolera purification system (eluting with ethyl acetate, grading to 10% methanol–ethyl acetate) afforded the title compound as white crystals (208 mg, 72%).

R<sub>f</sub>: (3% methanol–ethyl acetate; KMnO<sub>4</sub>). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.75–7.67 (m, 2H, **Ph**), 7.61–7.55 (m, 1H, **Ph**), 7.55–7.47 (m, 2H, **Ph**), 3.06–2.79 (m, 2H, H<sub>x</sub>), 2.09–1.93 (m, 2H, **Cy**), 1.93–1.85 (m, 1H, **Cy**), 1.83–1.73 (m, 1H, **Cy**), 1.73–1.66 (m, 1H, **Cy**), 1.66–1.58 (m, 1H, **Cy**), 1.53–1.40 (m, 1H, **Cy**), 1.40–1.10 (m, 4H, **Cy**). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 132.4 (d, J<sub>CP</sub> = 3.0 Hz), 131.0 (d, J<sub>CP</sub> = 9.1 Hz),



129.6 (d,  $J_{\text{CP}} = 95.5$  Hz), 128.8 (d,  $J_{\text{CP}} = 11.4$  Hz), 124.4 (qd,  $J_{\text{CF}} = 276.8$  Hz,  $J_{\text{CP}} = 3.8$  Hz), 38.6 (d,  $J_{\text{CP}} = 73.1$  Hz), 34.0 (app sextet,  $J = 28.9$  Hz), 26.2 (d,  $J_{\text{CP}} = 14.2$  Hz), 26.2 (d,  $J_{\text{CP}} = 13.4$  Hz), 25.7 (d,  $J_{\text{CP}} = 1.4$  Hz), 24.9 (d,  $J_{\text{CP}} = 2.6$  Hz), 224.6 (d,  $J_{\text{CP}} = 3.7$  Hz).  $^{31}\text{P}$  NMR (162 MHz,  $\text{CDCl}_3$ )  $\delta$  35.7 (q,  $J_{\text{FP}} = 5.3$  Hz).  $^{19}\text{F}$  NMR (376 MHz,  $\text{CDCl}_3$ )  $\delta$  -55.7 (d,  $J_{\text{FP}} = 5.3$  Hz). IR (thin film),  $\text{cm}^{-1}$ : 2930.8 (m), 2854.9 (w), 1438.9 (w), 1305.9 (s), 1244.7 (s), 1181.2 (s), 1114.5 (s) 1058.3 (s). LC/HRMS-ESI ( $m/z$ ):  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{14}\text{H}_{19}\text{F}_3\text{OP}$ , 291.1126; found 291.1159.



*Methylbis(diphenylphosphine) oxide (3e)*: Purification by flash-column chromatography (eluting with acetone), afforded the title compound as white crystals (177 mg, 82%).

$^1\text{H}$  and  $^{31}\text{P}$  spectra were in agreement with those reported.<sup>8</sup>



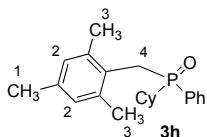
*Benzyldiphenylphosphine oxide (3f)*: Purification by flash-column chromatography using a Biotage Isolera purification system (eluting with 100% ethyl acetate initially, grading to 20% methanol–ethyl acetate), afforded the title compound as a white crystalline solid (258 mg, 89%).

$^1\text{H}$  and  $^{31}\text{P}$  spectra were in agreement with those reported.<sup>10</sup>



*Neopentylbis(diphenylphosphine) oxide (3g)*: Purification by flash-column chromatography (eluting with ethyl acetate) afforded the title compound as white crystals (234 mg, 86%).

$^1\text{H}$  and  $^{31}\text{P}$  spectra were in agreement with those reported.<sup>11</sup>



*Cyclohexylphenyl(2,4,6-trimethylbenzyl)phosphine oxide (3h)*: Purification by flash-column chromatography (eluting with ethyl acetate) afforded the title compound as a white crystalline solid (216 mg, 64%).

R<sub>f</sub>: 0.84 (3% methanol–ethyl acetate; UV). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.58–7.53 (m, 2H, **Ph**), 7.51–7.45 (m, 1H, **Ph**), 7.41–7.36 (m, 2H, **Ph**) 6.75 (s, 2H, **2**), 3.52 (dd, *J*<sub>HP</sub> = 15.2, *J*<sub>HH</sub> = 14.8, 1H, **4**), 3.27 (dd, *J*<sub>HP</sub> = 11.2, *J*<sub>HH</sub> = 14.8, 1H, **4'**), 2.20 (s, 3H, **2**), 2.10–2.15 (br, 1H, **Cy**), 2.08 (s, 6H, **3**), 2.00–1.87 (m, 2H, **Cy**), 1.80–1.52 (m, 3H, **Cy**), 1.55–1.48 (br, 1H, **Cy**), 1.46–1.18 (m, 4H, **Cy**). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 137.0 (d, *J*<sub>CP</sub> = 4.1 Hz), 135.5 (d, *J*<sub>CP</sub> = 3.1 Hz), 132.0 (d, *J*<sub>CP</sub> = 88.9 Hz), 131.1 (d, *J*<sub>CP</sub> = 2.8 Hz), 130.9 (d, *J*<sub>CP</sub> = 8.3 Hz), 128.9 (d, *J*<sub>CP</sub> = 2.8 Hz), 128.0 (d, *J*<sub>CP</sub> = 10.6 Hz), 126.2 (d, *J*<sub>CP</sub> = 8.2 Hz), 38.1 (d, *J*<sub>CP</sub> = 87.6 Hz), 30.0 (d, *J*<sub>CP</sub> = 61.0 Hz), 26.3, 26.2, 25.2 (d, *J*<sub>CP</sub> = 2.6 Hz), 24.6 (d, *J*<sub>CP</sub> = 3.6 Hz), 20.7, 20.6. <sup>31</sup>P NMR (162 MHz, CDCl<sub>3</sub>) δ 39.5. IR (thin film), cm<sup>-1</sup>: 2927.7 (m), 2853.6 (w), 1449.5 (m), 1178.4 (m). LC/HRMS-ESI (*m/z*): [M + H]<sup>+</sup> calcd for C<sub>22</sub>H<sub>30</sub>OP, 341.2029; found 341.2007.



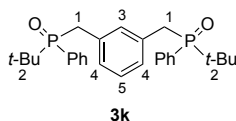
*Triphenylphosphine oxide (3i)*: Purification by flash-column chromatography (eluting with 100% ethyl acetate) afforded the title compound as white crystals (243 mg, 87%).

<sup>1</sup>H and <sup>31</sup>P spectra were in agreement with a commercial sample (Strem Chemicals).



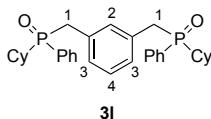
*Diethylphenylphosphonate (3j)*: Purification by flash-column chromatography using a Biotage Isolera purification system (eluting with ethyl acetate initially, grading to 20% methanol–ethyl acetate) afforded the title compound as a white crystalline solid (201 mg, 94%).

$^1\text{H}$  and  $^{31}\text{P}$  spectra were in agreement with those reported.<sup>12</sup>



$\alpha, \alpha'$ -Bis-(tert-butylphenylphosphoryl)-m-xylene (**3k**): Purification by flash-column chromatography using a Biotage Isolera purification system (eluting with 16% acetone–dichloromethane initially, grading to 20% methanol–16% acetone–dichloromethane) afforded the title compound as a clear, colorless oil (79 mg, 34%, 1:1 d.r.).

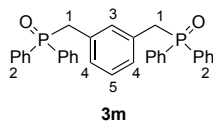
R<sub>f</sub>: 0.49 (3% methanol–ethyl acetate; UV).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.71–7.63 (m, 4H), 7.46–7.35 (m, 7H), 7.08–6.95 (m, 3H), 3.52–3.28 (m, 4H, H<sub>1</sub>), 1.09 (d,  $J_{\text{HP}}$  = 14.8 Hz, 9H, H<sub>2</sub>), 1.06 (d,  $J_{\text{HP}}$  = 14.4 Hz, 9H, H<sub>2</sub>).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ )  $\delta$  132.4 (app t,  $J$  = 5.2 Hz), 132.3–132.0 (m), 131.6–131.4 (m), 130.1 (br), 129.3–129.2 (m), 128.6–128.4 (m), 128.2 (d,  $J_{\text{CP}}$  = 10.9 Hz), 128.2 (d,  $J_{\text{CP}}$  = 11.0 Hz), 33.5 (app dd,  $J_{\text{CP}}$  = 68.1 Hz,  $J$  = 3.3 Hz), 31.3 (d,  $J_{\text{CP}}$  = 58.5 Hz), 24.8 (app d,  $J$  = 4.0 Hz).  $^{31}\text{P}$  (162 MHz,  $\text{CDCl}_3$ )  $\delta$  46.9, 46.8. IR (thin film),  $\text{cm}^{-1}$ : 3056.7 (w), 2960.1 (m), 1604.5 (w), 1169.3 (s). LC/HRMS-ESI ( $m/z$ ):  $[\text{M} + \text{Na}]^+$  calcd for  $\text{C}_{28}\text{H}_{37}\text{O}_2\text{P}_2$ , 489.2088; found 489.2017.



$\alpha, \alpha'$ -Biscyclohexylphenylphosphoryl)-m-xylene (**3l**): Purification by flash-column chromatography using a Biotage Isolera purification system (eluting with dichloromethane initially, grading to 20% methanol–dichloromethane) afforded the title compound as a clear, colorless oil (331 mg, 64%, 1:1 d.r.).

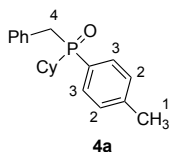
R<sub>f</sub>: (3% methanol–ethyl acetate; UV).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.48–7.26 (m, 10H, **Ph**), 6.98–6.85 (m, 3H), 6.80–6.74 (m, 1H), 3.33–3.08 (m, 4H), 2.13–1.85 (m, 2H, **Cy**), 1.85–1.46 (m, 9H, **Cy**), 1.40–1.03 (m, 11H, **Cy**).  $^{13}\text{C}$  NMR (125 MHz,  $\text{CDCl}_3$ )  $\delta$  132.2–132.0 (m), 131.6–131.3 (m), 131.3 (app d,  $J$  = 8.2 Hz), 130.6 (d,  $J_{\text{CP}}$  = 90.8 Hz, major), 130.5 (d,  $J_{\text{CP}}$  = 90.6 Hz, minor), 128.5 (t,  $J_{\text{CP}}$  = 2.0 Hz, major), 128.4 (t,  $J_{\text{CP}}$  = 2.0 Hz, minor), 128.2 (m), 37.6 (d,  $J_{\text{CP}}$  = 69.6 Hz, major), 37.5 (d,  $J_{\text{CP}}$  = 69.3 Hz, minor),

34.9 (d,  $J_{\text{CP}} = 60.5$  Hz), 26.4–26.2 (m), 25.9–25.8 (m), 25.5–25.4 (m), 25.0–24.8 (m).  $^{31}\text{P}$  (162 MHz,  $\text{CDCl}_3$ )  $\delta$  41.0 (minor), 40.8 (major). IR (thin film),  $\text{cm}^{-1}$ : 2930.0 (m), 2854.3 (w), 1604.1 (w), 1174.1 (s). LC/HRMS-ESI ( $m/z$ ):  $[\text{M} + \text{Na}]^+$  calcd for  $\text{C}_{32}\text{H}_{40}\text{O}_2\text{P}_2\text{Na}$ , 541.2401; found 541.2292.



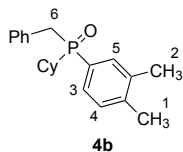
*α,α'*-Bis-(diphenylphosphoryl)-*m*-xylene (**3m**): Purification by trituration with hexanes, afforded the title compound as a light yellow amorphous solid (195 mg, 77%).

$^1\text{H}$  and  $^{31}\text{P}$  spectra were in agreement with those reported.<sup>13</sup>



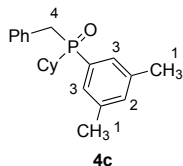
*Preparation of benzylcyclohexyl(4-tolyl)phosphine oxide (4a)*: Purification by flash-column chromatography (eluting with ethyl acetate) afforded the title compound as a white crystalline solid (291 mg, 93%).

$R_f$ : 0.78 (3% methanol–ethyl acetate; UV).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.38–7.32 (m, 2H,  $\text{H}_3$ ), 7.12–7.00 (m, 7H, **Ph** +  $\text{H}_2$ ), 3.34–3.15 (m, 2H,  $\text{H}_4$ ), 2.24 (s, 3H,  $\text{H}_1$ ), 2.03–1.93 (br, 1H, **Cy**), 1.80–1.67 (m, 2H, **Cy**), 1.65–1.48 (br, 3H, **Cy**), 1.40–1.25 (m, 1H, **Cy**), 1.25–1.00 (m, 4H, **Cy**).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ )  $\delta$  141.5 (d,  $J_{\text{CP}} = 2.6$  Hz), 131.8 (d,  $J_{\text{CP}} = 7.6$  Hz), 131.0 (d,  $J_{\text{CP}} = 8.3$  Hz), 129.6 (d,  $J_{\text{CP}} = 4.7$  Hz), 128.7 (d,  $J_{\text{CP}} = 11.4$  Hz), 128.1 (d,  $J_{\text{CP}} = 2.5$  Hz), 126.9 (d,  $J_{\text{CP}} = 92.9$  Hz), 126.3 (d,  $J_{\text{CP}} = 2.9$  Hz), 37.2 (d,  $J_{\text{CP}} = 69.9$  Hz), 34.9 (d,  $J_{\text{CP}} = 60.8$  Hz), 26.0 (d,  $J_{\text{CP}} = 13.5$  Hz), 26.0 (d,  $J_{\text{CP}} = 12.9$  Hz), 25.5 (d,  $J_{\text{CP}} = 1.1$  Hz), 25.2 (d,  $J_{\text{CP}} = 2.9$  Hz), 24.6 (d,  $J_{\text{CP}} = 3.2$  Hz), 21.3 (d,  $J_{\text{CP}} = 1.1$  Hz).  $^{31}\text{P}$  NMR (162 MHz,  $\text{CDCl}_3$ )  $\delta$  40.5. IR (thin film),  $\text{cm}^{-1}$ : 2933.2 (m), 2854.0 (w), 1602.7 (w), 1165.4 (s). LC/HRMS-ESI ( $m/z$ ):  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{20}\text{H}_{26}\text{OP}$ , 313.1716; found 313.1532.



*Benzylcyclohexyl-(3,4-dimethylphenyl)phosphine oxide (4b)*: Purification by flash-column chromatography (eluting with ethyl acetate) afforded the title compound as a white crystalline solid (271 mg, 83%).

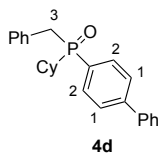
$R_f$ : 0.39 (3% methanol–ethyl acetate; UV).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.46 (d,  $J = 10.4$  Hz, 1H,  $\text{H}_4$ ), 7.42–7.37 (m, 7H, **Ph**  $\text{H}_3$ ,  $\text{H}_5$ ), 3.54–3.38 (m, 2H,  $\text{H}_6$ ), 2.38 (s, 3H,  $\text{H}_2$ ), 2.36 (s, 3H,  $\text{H}_1$ ), 2.24–1.15 (br, 1H, **Cy**), 2.00–1.91 (m, 2H, **Cy**), 1.89–1.73 (br, 3H, **Cy**), 1.63–1.48 (m, 1H, **Cy**), 1.47–1.21 (m, 4H, **Cy**).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ )  $\delta$  140.3 (d,  $J_{\text{CP}} = 2.9$  Hz), 136.5 (d,  $J_{\text{CP}} = 11.0$  Hz), 132.3 (d,  $J_{\text{CP}} = 8.0$  Hz), 132.0 (d,  $J_{\text{CP}} = 7.2$  Hz), 129.8 (d,  $J_{\text{CP}} = 4.7$  Hz), 129.3 (d,  $J_{\text{CP}} = 11.7$  Hz), 128.4 (d,  $J_{\text{CP}} = 8.3$  Hz), 128.2 (d,  $J_{\text{CP}} = 2.6$  Hz), 127.2 (d,  $J_{\text{CP}} = 92.5$ ), 126.3 (d,  $J_{\text{CP}} = 2.9$  Hz), 37.2 (d,  $J_{\text{CP}} = 69.9$  Hz), 35.0 (d,  $J_{\text{CP}} = 60.4$  Hz), 26.1 (d,  $J_{\text{CP}} = 13.6$  Hz), 26.1 (d,  $J_{\text{CP}} = 12.9$  Hz), 25.6 (d,  $J_{\text{CP}} = 0.8$  Hz), 25.3 (d,  $J_{\text{CP}} = 2.6$  Hz), 24.7 (d,  $J_{\text{CP}} = 3.3$  Hz), 19.7 (s), 19.5 (s).  $^{31}\text{P}$  NMR (162 MHz,  $\text{CDCl}_3$ )  $\delta$  42.7. IR (thin film),  $\text{cm}^{-1}$ : 2929.3 (m), 2854.8 (w), 1495.0 (m), 1449.3 (m), 1173.0 (s). LC/HRMS-ESI ( $m/z$ ):  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{21}\text{H}_{28}\text{OP}$ , 327.1878; found 327.1824.



*Benzylcyclohexyl-(3,5-dimethylphenyl)phosphine oxide (4c)*: Purification by flash-column chromatography (eluting with ethyl acetate) afforded the title compound as a white crystalline solid (250 mg, 77%).

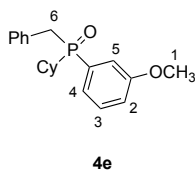
$R_f$ : 0.39 (3% methanol–ethyl acetate; UV).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.42–7.21 (m, 8H, **Ph**  $\text{H}_2$ ,  $\text{H}_3$ ), 3.56–3.41 (m, 2H,  $\text{H}_4$ ), 2.44 (s, 6H,  $\text{H}_1$ ), 2.25–1.17 (br, 1H, **Cy**), 2.03–1.91 (m, 2H, **Cy**), 1.89–1.73 (br, 3H, **Cy**), 1.66–1.52 (m, 1H, **Cy**), 1.51–1.22 (m, 4H, **Cy**).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ )  $\delta$  137.8 (d,  $J_{\text{CP}} = 11.7$  Hz), 133.2 (d,  $J_{\text{CP}} = 2.6$  Hz), 132.2 (d,  $J_{\text{CP}} = 7.3$  Hz), 130.2 (d,  $J_{\text{CP}} = 90.0$  Hz), 129.9 (d,  $J_{\text{CP}} = 4.8$  Hz), 128.9 (d,  $J_{\text{CP}} = 8.3$  Hz), 128.4 (d,  $J_{\text{CP}} = 2.1$  Hz), 126.6 (d,  $J_{\text{CP}} = 2.5$  Hz), 37.2 (d,  $J_{\text{CP}} = 69.1$  Hz), 35.2 (d,  $J_{\text{CP}} = 60.0$  Hz), 26.3 (d,  $J_{\text{CP}} = 13.2$  Hz), 26.3 (d,  $J_{\text{CP}} = 12.8$  Hz), 25.8 (d,  $J_{\text{CP}} = 0.8$  Hz), 25.4 (d,  $J_{\text{CP}} = 2.6$  Hz), 24.9 (d,  $J_{\text{CP}} = 3.2$  Hz), 21.3 (s).  $^{31}\text{P}$  NMR (162 MHz,  $\text{CDCl}_3$ )  $\delta$  42.9. IR (thin film),  $\text{cm}^{-1}$ : 2924.5 (s), 2850.7 (m), 1494.7 (m), 1449.0 (m), 1173.1 (s). LC/HRMS-ESI ( $m/z$ ):  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{21}\text{H}_{28}\text{OP}$ ,

327.1878; found 327.1819.



*Benzyl-(4-biphenyl)-cyclohexylphosphine oxide (4d)*: Purification by flash-column chromatography (eluting with ethyl acetate) afforded the title compound as a white powder (314 mg, 84%).

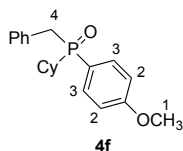
R<sub>f</sub>: 0.82 (3% methanol–ethyl acetate; UV). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.65–7.57 (m, 6H), 7.48–7.42 (m, 2H), 7.40–7.34 (m, 1H), 7.23–7.16 (m, 3H), 7.16–7.12 (m, 2H), 3.48–3.29 (m, 2H), 2.18–2.07 (m, 1H), 1.97–1.81 (m, 2H), 1.80–1.64 (m, 3H), 1.56–1.40 (m, 1H), 1.40–1.13 (4H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 144.2, 140.0, 132.0–131.7 (m), 130.0 (d, J<sub>CP</sub> = 3.7 Hz), 129.0, 128.6, 128.1, 127.3, 127.0–126.7 (m), 37.4 (d, J<sub>CP</sub> = 70.2 Hz), 35.3 (d, J<sub>CP</sub> = 61.6 Hz), 26.4 (d, J<sub>CP</sub> = 13.2 Hz), 26.3 (d, J<sub>CP</sub> = 12.3 Hz), 25.9–25.8 (m), 25.6–25.5 (m), 25.0–24.9 (m). <sup>31</sup>P (162 MHz, CDCl<sub>3</sub>) δ 40.9. IR (thin film), cm<sup>-1</sup>: 3028.5 (w), 2929.0 (m), 2852.9 (w), 1598.9 (w), 1175.0 (m). LC/HRMS-ESI (*m/z*): [M + H]<sup>+</sup> calcd for C<sub>25</sub>H<sub>28</sub>OP = 375.1872; found 375.1840.



*Benzylcyclohexyl(3-methoxyphenyl)phosphine oxide (4e)*: Purification by flash-column chromatography using a Biotage Isolera purification system (eluting with ethyl acetate initially, grading to 20% methanol–ethyl acetate) afforded the title compound as a white crystalline solid (276 mg, 84%).

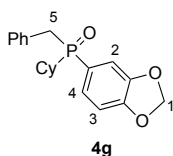
R<sub>f</sub>: 0.77 (3% methanol–ethyl acetate; UV). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.35–7.29 (m, 1H), 7.23–7.16 (m, 3H), 7.14–6.98 (m, 5H), 3.78 (s, 3H, H<sub>1</sub>), 3.45–3.26 (m, 2H, H<sub>6</sub>), 2.13–2.05 (br, 1H, Cy), 1.93–1.80 (m, 2H, Cy), 1.77–1.60 (m, 3H, Cy), 1.56–1.41 (m, 1H, Cy), 1.39–1.13 (m, 5H, Cy). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 159.1 (d, J<sub>CP</sub> = 13.2 Hz), 131.7 (d, J<sub>CP</sub> = 89.2 Hz), 131.6 (d, J<sub>CP</sub> = 7.2 Hz), 129.6 (d, J<sub>CP</sub> = 5.1 Hz), 129.1 (d, J<sub>CP</sub> = 3.2 Hz), 128.1 (d, J<sub>CP</sub> = 2.2 Hz), 126.3 (d, J<sub>CP</sub> = 2.6 Hz), 122.6 (d, J<sub>CP</sub> = 8.6 Hz), 117.3 (d, J<sub>CP</sub> = 2.2 Hz), 116.0 (d, J<sub>CP</sub> = 8.3 Hz), 55.0, 37.0 (d, J<sub>CP</sub> = 69.6 Hz), 34.8 (d, J<sub>CP</sub> = 60.4 Hz), 25.9 (d, J<sub>CP</sub> = 13.6 Hz), 25.9 (d, J<sub>CP</sub> = 12.8 Hz), 25.4 (d, J<sub>CP</sub> = 0.8 Hz), 25.0 (d, J<sub>CP</sub> = 2.5 Hz), 24.5 (d, J<sub>CP</sub> = 3.3

Hz).  $^{31}\text{P}$  NMR (162 MHz,  $\text{CDCl}_3$ )  $\delta$  41.1. IR (thin film),  $\text{cm}^{-1}$ : 3062.7 (w), 3029.9 (w), 2929.5 (m), 2853.7 (w), 1590.1 (w), 1235.8 (s), 1174.0 (s). LC/HRMS-ESI ( $m/z$ ):  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{20}\text{H}_{26}\text{O}_2\text{P}$ , 329.1665; found 329.1602.



*Benzylcyclohexyl(4-methoxyphenyl)phosphine oxide (4f)*: Purification by flash-column chromatography using a Biotage Isolera purification system (eluting with ethyl acetate initially, grading to 20% methanol–ethyl acetate) afforded the title compound as a white crystalline solid (318 mg, 97%).

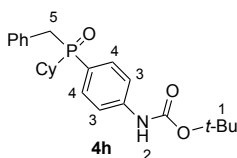
$R_f$ : 0.66 (3% methanol–ethyl acetate; UV).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.48–7.41 (m, 2H,  $\text{H}_3$ ), 7.16–7.04 (m, 5H, **Ph**), 6.87–6.82 (m, 2H,  $\text{H}_2$ ), 3.72 (s, 3H,  $\text{H}_1$ ), 3.39–3.20 (m, 2H,  $\text{H}_4$ ), 2.08–2.00 (br, 1H, **Cy**), 1.86–1.73 (m, 2H, **Cy**), 1.71–1.53 (m, 3H, **Cy**), 1.46–1.33 (m, 1H, **Cy**), 1.33–1.03 (m, 4H, **Cy**).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ )  $\delta$  161.9 (d,  $J_{\text{CP}} = 2.9$  Hz), 132.9 (d,  $J_{\text{CP}} = 9.6$  Hz), 132.0 (d,  $J_{\text{CP}} = 7.3$  Hz), 129.8 (d,  $J_{\text{CP}} = 5.1$  Hz), 128.3 (d,  $J_{\text{CP}} = 2.2$  Hz), 126.4 (d,  $J_{\text{CP}} = 2.9$  Hz), 121.2 (d,  $J_{\text{CP}} = 96.3$  Hz), 113.7 (d,  $J_{\text{CP}} = 11.7$  Hz), 55.1, 37.2 (d,  $J_{\text{CP}} = 69.9$  Hz), 35.1 (d,  $J_{\text{CP}} = 60.8$  Hz), 26.1 (d,  $J_{\text{CP}} = 13.6$  Hz), 26.1 (d,  $J_{\text{CP}} = 12.5$  Hz), 25.7 (d,  $J_{\text{CP}} = 0.8$  Hz), 25.3 (d,  $J_{\text{CP}} = 2.5$  Hz), 24.7 (d,  $J_{\text{CP}} = 3.3$  Hz).  $^{31}\text{P}$  NMR (162 MHz,  $\text{CDCl}_3$ )  $\delta$  40.3. IR (thin film),  $\text{cm}^{-1}$ : 2930.9 (m), 2854.7 (w), 1596.6 (w), 1075.2 (s). LC/HRMS-ESI ( $m/z$ ):  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{20}\text{H}_{26}\text{O}_2\text{P}$ , 329.1665; found 329.1595.



*Benzylcyclohexyl(3,4-methylenedioxyphenyl)phosphine oxide (4g)*: Purification by flash-column chromatography using a Biotage Isolera purification system (eluting with ethyl acetate initially, grading to 20% methanol–ethyl acetate), afforded the title compound as a white crystalline solid (192 mg, 56%).

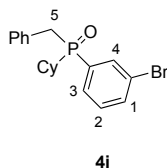
$R_f$ : 0.71 (3% methanol–ethyl acetate; UV).  $^1\text{H}$  NMR (500 MHz,  $\text{CDCl}_3$ )  $\delta$  7.15–7.03 (m, 5H, **Ph**), 7.02–6.98 (m, 1H,  $\text{H}_4$ ), 6.90 (dd,  $J = 1.0$  Hz,  $J = 9.5$  Hz, 1H,  $\text{H}_2$ ), 6.75 (dd,  $J = 2.5$  Hz,  $J = 8.0$  Hz, 1H,  $\text{H}_3$ ), 5.90–5.88 (m, 2H,  $\text{H}_1$ ), 3.33–3.26 (m, 1H,  $\text{H}_5$ ), 3.22–3.15 (m, 1H,  $\text{H}_5'$ ), 2.03–1.95 (br, 1H, **Cy**), 1.80–1.70

(m, 2H, **Cy**), 1.70–1.63 (br, 1H, **Cy**), 1.63–1.53 (br, 2H, **Cy**), 1.44–1.33 (m, 1H, **Cy**), 1.28–1.06 (m, 4H, **Cy**).  $^{13}\text{C}$  NMR (125 MHz,  $\text{CDCl}_3$ )  $\delta$  150.3 (d,  $J_{\text{CP}} = 2.8$  Hz), 147.7 (d,  $J_{\text{CP}} = 16.5$  Hz), 131.8 (d,  $J_{\text{CP}} = 7.3$  Hz), 129.8 (d,  $J_{\text{CP}} = 5.0$  Hz), 128.3 (d,  $J_{\text{CP}} = 2.3$  Hz), 126.5 (d,  $J_{\text{CP}} = 2.8$  Hz), 126.2 (d,  $J_{\text{CP}} = 9.2$  Hz), 123.3 (d,  $J_{\text{CP}} = 93.9$  Hz), 110.5 (d,  $J_{\text{CP}} = 10.9$  Hz), 108.3 (d,  $J_{\text{CP}} = 13.7$  Hz), 101.4, 37.5 (d,  $J_{\text{CP}} = 70.1$  Hz), 35.1 (d,  $J_{\text{CP}} = 61.0$  Hz), 26.2 (d,  $J_{\text{CP}} = 13.3$  Hz), 26.1 (d,  $J_{\text{CP}} = 12.8$  Hz), 25.6 (d,  $J_{\text{CP}} = 0.8$  Hz), 25.3 (d,  $J_{\text{CP}} = 2.8$  Hz), 24.7 (d,  $J_{\text{CP}} = 3.1$  Hz).  $^{31}\text{P}$  NMR (200 MHz,  $\text{CDCl}_3$ )  $\delta$  40.7. IR (thin film),  $\text{cm}^{-1}$ : 2929.6 (m), 2854.4 (w), 1601.0 (w), 1479.7 (s), 1239.1 (s). LC/HRMS-ESI ( $m/z$ ):  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{20}\text{H}_{24}\text{O}_3\text{P}$ , 343.1458; found 343.1455.



*N*-Boc-4-(benzylcyclohexylphosphoryl)aniline (**4h**): Purification by flash-column chromatography using a Biotage Isolera purification system (eluting with ethyl acetate initially, grading to 10% methanol–ethyl acetate) afforded the title compound as a white crystalline solid (364 mg, 88%).

$R_f$ : (3% methanol–ethyl acetate; UV).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.49–7.37 (m, 4H,  $\text{H}_1$ ,  $\text{H}_2$ ), 7.17–7.12 (m, 3H, **Ph**), 7.10–6.05 (m, 2H, **Ph**), 3.42–3.23 (m, 2H,  $\text{H}_3$ ), 2.10–2.02 (br, 1H, **Cy**), 1.87–1.75 (m, 2H, **Cy**), 1.75–1.57 (m, 3H, **Cy**), 1.49 (s, 9H, H), 1.50–1.35 (m, 1H, **Cy**), 1.32–1.05 (m, 4H, **Cy**).  $^{13}\text{C}$  NMR (100 MHz)  $\delta$  152.7 (s), 142.0 (d,  $J_{\text{CP}} = 2.9$  Hz), 132.3 (d,  $J_{\text{CP}} = 8.9$  Hz), 132.0 (d,  $J_{\text{CP}} = 7.6$  Hz), 130.0 (d,  $J_{\text{CP}} = 5.1$  Hz), 128.5 (d,  $J_{\text{CP}} = 2.2$  Hz), 126.7 (d,  $J_{\text{CP}} = 2.8$  Hz), 123.4 (d,  $J_{\text{CP}} = 95.4$  Hz), 117.8 (d,  $J_{\text{CP}} = 11.4$  Hz), 80.9 (s), 37.5 (d,  $J_{\text{CP}} = 69.9$  Hz), 35.2 (d,  $J_{\text{CP}} = 60.8$  Hz), 28.4 (s), 26.4 (d,  $J_{\text{CP}} = 13.6$  Hz), 26.3 (d,  $J_{\text{CP}} = 12.8$  Hz), 25.9 (d,  $J_{\text{CP}} = 1.1$  Hz), 25.5 (d,  $J_{\text{CP}} = 2.7$  Hz), 24.9 (d,  $J_{\text{CP}} = 3.2$  Hz).  $^{31}\text{P}$  (162 MHz,  $\text{CDCl}_3$ )  $\delta$  43.2. IR (thin film),  $\text{cm}^{-1}$ : 2930.7 (m), 2854.2 (w), 1721.1 (m), 1593.5 (m), 1526.4 (m), 1157.4 (s). LC/HRMS-ESI ( $m/z$ ):  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{24}\text{H}_{33}\text{NO}_3\text{P}$ , 414.2198; found 414.2211.

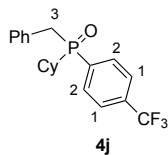


*Benzylcyclohexyl(3-bromophenyl)phosphine oxide* (**4i**): Purification by flash-column chromatography using a Biotage Isolera purification system (eluting with ethyl acetate initially, grading to 20% methanol–



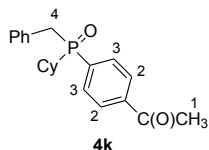
ethyl acetate) afforded the title compound as a white crystalline solid (294 mg, 78%).

*R*<sub>f</sub>: 0.76 (3% methanol–ethyl acetate; UV). <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>) δ 7.67 (dt, *J* = 11.5 Hz, *J* = 1.5 Hz, 1H, H<sub>1</sub>), 7.61 (dm, *J* = 8.0 Hz, 1H, H<sub>4</sub>), 7.84–7.44 (m, 1H, H<sub>2</sub>), 7.31–7.26 (m, 1H, H<sub>3</sub>), 7.25–7.17 (m, 3H, **Ph**), 7.12–7.08 (m, 2H, **Ph**), 3.45–3.29 (m, 2H, H<sub>5</sub>), 2.14–2.05 (br, 1H, **Cy**), 1.93–1.84 (m, 2H, **Cy**), 1.80–1.74 (br, 1H, **Cy**), 1.74–1.67 (br, 1H, **Cy**), 1.65–1.57 (m, 1H, **Cy**), 1.54–1.44 (m, 1H, **Cy**), 1.38–1.23 (m, 2H, **Cy**) 1.22–1.15 (m, 2H, **Cy**). <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>) δ 134.6 (d, *J*<sub>CP</sub> = 2.8 Hz), 134.1 (d, *J*<sub>CP</sub> = 8.7 Hz), 133.4 (d, *J*<sub>CP</sub> = 86.1 Hz), 131.5 (d, *J*<sub>CP</sub> = 7.8 Hz), 129.9 (d, *J*<sub>CP</sub> = 5.2 Hz), 129.9 (d, *J*<sub>CP</sub> = 10.2 Hz), 129.8 (d, *J*<sub>CP</sub> = 7.8 Hz), 128.6 (d, *J*<sub>CP</sub> = 2.3 Hz), 126.9 (d, *J*<sub>CP</sub> = 2.8 Hz), 123.0 (d, *J*<sub>CP</sub> = 13.7 Hz), 37.3 (d, *J*<sub>CP</sub> = 69.6 Hz), 35.2 (d, *J*<sub>CP</sub> = 60.8 Hz), 26.3 (d, *J*<sub>CP</sub> = 13.3 Hz), 26.3 (d, *J*<sub>CP</sub> = 12.8 Hz), 25.7 (d, *J*<sub>CP</sub> = 1.4 Hz), 25.4 (d, *J*<sub>CP</sub> = 3.1 Hz), 24.8 (d, *J*<sub>CP</sub> = 3.6 Hz). <sup>31</sup>P NMR (200 MHz, CDCl<sub>3</sub>) δ 40.0. IR (thin film), cm<sup>-1</sup>: 3032.1 (m), 2924.0 (m), 2845.8 (w), 1173.4 (s), 1116.2 (s). LC/HRMS-ESI (*m/z*): [M + H]<sup>+</sup> calcd for C<sub>19</sub>H<sub>23</sub><sup>79</sup>BrOP, 377.0670; found 377.0659; for C<sub>19</sub>H<sub>23</sub><sup>81</sup>BrOP 379.0649; found 379.0663.



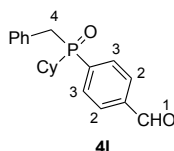
*Benzylcyclohexyl(4-trifluoromethylphenyl)phosphine oxide* (**4j**): Purification by flash-column chromatography (eluting with ethyl acetate) afforded the title compound as a white crystalline solid (339 mg, 93%).

*R*<sub>f</sub>: 0.79 (3% methanol–ethyl acetate; UV). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.67–7.56 (m, 4H, H<sub>1</sub> + H<sub>2</sub>), 7.17–7.08 (m, 3H, **Ph**), 7.06–7.02 (m, 2H, **Ph**), 3.42–3.21 (m, 2H, H<sub>3</sub>), 2.10–2.00 (br, 1H, **Cy**), 1.94–1.79 (m, 2H, **Cy**), 1.73–1.59 (br, 2H, **Cy**), 1.58–1.50 (br, 1H, **Cy**), 1.50–1.38 (m, 1H, **Cy**), 1.35–1.05 (m, 4H, **Cy**). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 135.2 (d, *J*<sub>CP</sub> = 86.4 Hz), 133.2 (dq, *J*<sub>CF</sub> = 32.6 Hz, *J*<sub>CP</sub> = 2.6 Hz), 131.7 (d, *J*<sub>CP</sub> = 8.0 Hz), 131.3 (d, *J*<sub>CP</sub> = 7.2 Hz), 129.8 (d, *J*<sub>CP</sub> = 5.1 Hz), 128.5 (d, *J*<sub>CP</sub> = 2.6 Hz), 126.8 (d, *J*<sub>CP</sub> = 2.9 Hz), 124.7–125.1 (m), 123.6 (q, *J*<sub>CF</sub> = 272.7 Hz), 37.2 (d, *J*<sub>CP</sub> = 69.5 Hz), 35.0 (d, *J*<sub>CP</sub> = 61.1 Hz), 26.1 (d, *J*<sub>CP</sub> = 13.6 Hz), 26.1 (d, *J*<sub>CP</sub> = 12.9 Hz), 25.6 (d, *J*<sub>CP</sub> = 1.2 Hz), 25.3 (d, *J*<sub>CP</sub> = 3.2 Hz), 24.7 (d, *J*<sub>CP</sub> = 3.3 Hz). <sup>31</sup>P NMR (162 MHz, CDCl<sub>3</sub>) δ 40.0. <sup>19</sup>F NMR (376 MHz, CDCl<sub>3</sub>) δ -63.1. IR (thin film), cm<sup>-1</sup>: 2940.1 (m), 2856.0 (w), 1601.0 (w), 1163.7 (s), 1121.6 (s), 1062.4 (s). LC/HRMS-ESI (*m/z*): [M + H]<sup>+</sup> calcd for C<sub>20</sub>H<sub>23</sub>OPF<sub>3</sub>, 367.1433; found 367.1393.



*4-(Benzylcyclohexylphosphoryl)acetophenone (4k)*: Purification by flash-column chromatography using a Biotage Isolera purification system (eluting with ethyl acetate initially, grading to 10% methanol–ethyl acetate) afforded the title compound as a white crystalline solid (270 mg, 80%).

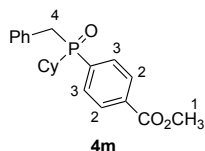
R<sub>f</sub>: (3% methanol–ethyl acetate; UV). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.95 (dd, *J*<sub>HH</sub> = 8.0 Hz, *J*<sub>HP</sub> = 0.8 Hz, 2H, H<sub>2</sub>), 7.64 (dd, *J*<sub>HP</sub> = 9.4 Hz, *J*<sub>HH</sub> = 8.0 Hz, 2H, H<sub>3</sub>), 7.21–7.13 (m, 3H, **Ph**), 7.10–7.06 (m, 2H, **Ph**), 3.48–3.28 (m, 2H, H<sub>4</sub>), 2.61 (s, 3H, H<sub>1</sub>), 2.14–2.06 (br, 1H, **Cy**), 1.97–1.83 (m, 2H, **Cy**), 1.77–1.65 (m, 2H, **Cy**), 1.62–1.53 (m, 1H, **Cy**), 1.53–1.42 (m, 1H, **Cy**), 1.38–1.12 (m, 4H, **Cy**). <sup>13</sup>C NMR (100 MHz) δ 197.8 (s), 139.3 (d, *J*<sub>CP</sub> = 2.6 Hz), 136.1 (d, *J*<sub>CP</sub> = 86.4 Hz), 131.8 (d, *J*<sub>CP</sub> = 8.0 Hz), 131.5 (d, *J*<sub>CP</sub> = 7.5 Hz), 129.9 (d, *J*<sub>CP</sub> = 4.8 Hz), 128.7 (d, *J*<sub>CP</sub> = 2.6 Hz), 127.9 (d, *J*<sub>CP</sub> = 10.6 Hz), 126.9 (d, *J*<sub>CP</sub> = 2.7 Hz), 37.5 (d, *J*<sub>CP</sub> = 69.4 Hz), 35.2 (d, *J*<sub>CP</sub> = 60.7 Hz), 26.9 (s), 26.3 (d, *J*<sub>CP</sub> = 13.6 Hz), 26.3 (d, *J*<sub>CP</sub> = 12.8 Hz), 25.8 (d, *J*<sub>CP</sub> = 0.8 Hz), 25.5 (d, *J*<sub>CP</sub> = 2.8 Hz), 24.9 (d, *J*<sub>CP</sub> = 3.1 Hz). <sup>31</sup>P (162 MHz, CDCl<sub>3</sub>) δ 42.6. IR (thin film), cm<sup>-1</sup>: 2929.5 (s), 2853.7 (m), 1685.1 (vs), 1263.1 (s), 1176.2 (s). LC/HRMS-ESI (*m/z*): [M + H]<sup>+</sup> calcd for C<sub>21</sub>H<sub>26</sub>O<sub>2</sub>P, 341.1670; found 341.1592.



*4-(benzylcyclohexylphosphoryl)benzaldehyde (4l)*: Purification by flash-column chromatography using a Biotage Isolera purification system (eluting with ethyl acetate initially, grading to 20% methanol–ethyl acetate) afforded the title compound as a white crystalline solid (228 mg, 70%).

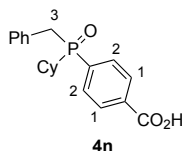
R<sub>f</sub>: 0.75 (3% methanol–ethyl acetate; UV). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 10.03 (s, 1H, H<sub>1</sub>), 7.92–7.86 (m, 2H, H<sub>2</sub>), 7.73–7.66 (m, 2H, H<sub>3</sub>), 7.19–7.14 (m, 3H, **Ph**), 7.07–7.03 (m, 2H, **Ph**), 3.49–3.27 (m, 2H, H<sub>4</sub>), 2.12–2.05 (br, 1H, **Cy**), 1.97–1.83 (m, 2H, **Cy**), 1.77–1.64 (m, 2H, **Cy**), 1.59–1.42 (m, 2H, **Cy**), 1.38–1.11 (m, 4H, **Cy**). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 191.9 (s), 138.2 (d, *J*<sub>CP</sub> = 2.5 Hz), 137.6 (d, *J*<sub>CP</sub> = 85.2 Hz), 132.1 (d, *J*<sub>CP</sub> = 8.0 Hz), 131.3 (d, *J*<sub>CP</sub> = 7.3 Hz), 129.9 (d, *J*<sub>CP</sub> = 5.1 Hz), 129.1 (d, *J*<sub>CP</sub> = 11.0 Hz), 128.7 (d, *J*<sub>CP</sub> = 2.5 Hz), 127.0 (d, *J*<sub>CP</sub> = 2.9 Hz), 37.4 (d, *J*<sub>CP</sub> = 69.1 Hz), 35.2 (d, *J*<sub>CP</sub> = 60.8 Hz), 26.2 (app d, *J*<sub>CP</sub> = 13.6 Hz), 25.7 (d, *J*<sub>CP</sub> = 1.2 Hz), 25.4 (d, *J*<sub>CP</sub> = 2.9 Hz), 24.9 (d, *J*<sub>CP</sub> = 3.3 Hz). <sup>31</sup>P (162 MHz, CDCl<sub>3</sub>) δ 42.8. IR (thin film), cm<sup>-1</sup>: 2931.0 (m), 2854.9 (w), 1702.5 (s), 1173.2 (s). LC/HRMS-ESI (*m/z*):

$[M + H]^+$  calcd for  $C_{20}H_{24}O_2P$ , 327.1514; found 327.1535.



*Methyl 4-(benzylcyclohexylphosphoryl)benzoate (4m)*: Purification by flash-column chromatography using a Biotage Isolera purification system (eluting with ethyl acetate initially, grading to 20% methanol–ethyl acetate) afforded the title compound as a white crystalline solid (270 mg, 76%).

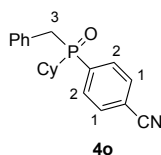
R<sub>f</sub>: 0.75 (3% methanol–ethyl acetate; UV). <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>) δ 7.95 (app d, *J* = 8.0 Hz, 2H, H<sub>2</sub>), 7.55 (app t, *J* = 9.0 Hz, 2H, H<sub>3</sub>), 7.09–7.01 (m, 3H, **Ph**), 7.00–6.97 (m, 2H, **Ph**), 3.80 (s, 3H, H<sub>1</sub>), 3.38–3.32 (m, 1H, H<sub>4</sub>), 3.27–3.19 (m, 1H, H<sub>4</sub>'), 2.04–1.96 (br, 1H, **Cy**), 1.88–1.73 (m, 2H, **Cy**), 1.66–1.53 (br, 2H, **Cy**), 1.53–1.45 (br, 1H, **Cy**), 1.45–1.34 (m, 1H, **Cy**), 1.29–1.04 (m, 4H, **Cy**). <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>) δ 166.1, 135.7 (d, *J*<sub>CP</sub> = 86.6 Hz), 132.6 (d, *J*<sub>CP</sub> = 2.8 Hz), 131.3 (d, *J*<sub>CP</sub> = 6.9 Hz), 131.2 (d, *J*<sub>CP</sub> = 8.2 Hz), 129.7 (d, *J*<sub>CP</sub> = 5.0 Hz), 128.9 (d, *J*<sub>CP</sub> = 10.6 Hz), 128.3 (d, *J*<sub>CP</sub> = 1.9 Hz), 126.6 (d, *J*<sub>CP</sub> = 2.8 Hz), 52.2, 37.2 (d, *J*<sub>CP</sub> = 69.3 Hz), 34.9 (d, *J*<sub>CP</sub> = 60.5 Hz), 26.0 (d, *J*<sub>CP</sub> = 13.7 Hz), 26.0 (d, *J*<sub>CP</sub> = 12.4 Hz), 25.5 (d, *J*<sub>CP</sub> = 0.8 Hz), 25.2 (d, *J*<sub>CP</sub> = 3.1 Hz), 24.6 (d, *J*<sub>CP</sub> = 3.3 Hz). <sup>31</sup>P (200 MHz, CDCl<sub>3</sub>) δ 40.4. IR (thin film), cm<sup>-1</sup>: 2932.6 (m), 2854.0 (w), 1722.4 (s), 1602.8 (w), 1270.1 (s). LC/HRMS-ESI (*m/z*):  $[M + H]^+$  calcd for  $C_{21}H_{26}O_3P$ , 357.1614; found 357.1584.



*4-(Benzylcyclohexylphosphoryl)benzoic acid (4n)*: The unpurified reaction mixture was dissolved in 3 M aqueous sodium hydroxide solution (1.0 mL). This solution was washed with dichloromethane (1 × 5 mL). The washed aqueous solution was transferred to a 1-dram vial. A 5-dram vial was charged with hydrochloric acid (11.7 M, 3.0 mL), the 1-dram vial containing the basic solution of **28** was placed in the larger vial, which was sealed with a Teflon-lined cap. Slow vapor diffusion of HCl neutralized the inner solution, causing the neutral carboxylic acid product to crystallize. The crystalline precipitate was isolated by filtration, and washed with cold water (2.0 mL) and dried in vacuo to afford the title compound as

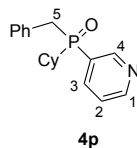
white crystals (215mg, 63%).

R<sub>f</sub>: 0.42 (3% methanol–ethyl acetate; UV). <sup>1</sup>H NMR (400 MHz, CD<sub>3</sub>OD, K salt) δ 8.02 (dd, *J*<sub>HP</sub> = 2.4 Hz, *J*<sub>HH</sub> = 8.4 Hz, 2H, H<sub>1</sub>), 7.66 (dd, *J*<sub>HP</sub> = 10.4 Hz, *J*<sub>HH</sub> = 8.4 Hz, 2H, H<sub>2</sub>), 7.18–7.11 (m, 3H, **Ph**), 7.10–7.07 (m, 2H, **Ph**), 3.64–3.54 (m, 1H, H<sub>3</sub>), 3.50–3.42 (m, 1H, H<sub>3</sub>'), 2.16–2.04 (m, 2H, **Cy**), 1.91–1.83 (m, 1H, **Cy**), 1.78–1.66 (m, 2H, **Cy**), 1.64–1.51 (br, 1H, **Cy**), 1.50–1.13 (m, 5H, **Cy**). <sup>13</sup>C NMR (100 MHz, CD<sub>3</sub>OD, K salt) δ 173.0 (s), 141.3 (d, *J*<sub>CP</sub> = 2.6 Hz), 132.9 (d, *J*<sub>CP</sub> = 91.5 Hz), 132.7 (d, *J*<sub>CP</sub> = 8.4 Hz), 132.1 (d, *J*<sub>CP</sub> = 9.2 Hz), 131.1 (d, *J*<sub>CP</sub> = 5.1 Hz), 130.1 (d, *J*<sub>CP</sub> = 11.3 Hz), 129.3 (d, *J*<sub>CP</sub> = 2.5 Hz), 127.7 (d, *J*<sub>CP</sub> = 2.9 Hz), 38.6 (d, *J*<sub>CP</sub> = 69.1 Hz), 35.2 (d, *J*<sub>CP</sub> = 61.6 Hz), 27.2 (d, *J*<sub>CP</sub> = 12.9 Hz), 27.2 (d, *J*<sub>CP</sub> = 13.5 Hz), 26.9 (d, *J*<sub>CP</sub> = 0.9 Hz), 26.3 (d, *J*<sub>CP</sub> = 2.9 Hz), 25.8 (d, *J*<sub>CP</sub> = 3.6 Hz). <sup>31</sup>P NMR (162 MHz, CD<sub>3</sub>OD, K salt) δ 46.0. IR (thin film), cm<sup>-1</sup>: 3358.1 (s, br), 2930.9 (w), 2852.3 (w), 1691.1 (m). LC/HRMS-ESI (*m/z*): [M + H]<sup>+</sup> calcd for C<sub>20</sub>H<sub>24</sub>O<sub>3</sub>P, 343.1458; found 343.1376.



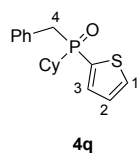
*4*-(Benzylcyclohexylphosphoryl)benzonitrile (**4o**): Purification by flash-column chromatography using a Biotage Isolera purification system (eluting with ethyl acetate initially, grading to 10% methanol–ethyl acetate) afforded the title compound as a white crystalline solid (304 mg, 94%).

R<sub>f</sub>: (3% methanol–ethyl acetate; UV). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.65–7.57 (m, 4H, H<sub>1</sub>, H<sub>2</sub>), 7.18–7.12 (m, 3H, **Ph**), 7.03–6.98 (m, 2H, **Ph**), 3.46–3.24 (m, 2H, H<sub>3</sub>), 2.11–2.06 (br, 1H, **Cy**), 1.92–1.82 (m, 2H, **Cy**), 1.75–1.62 (br, 2H, **Cy**), 1.54–1.40 (m, 2H, **Cy**), 1.35–1.08 (m, 4H, **Cy**). <sup>13</sup>C NMR (100 MHz) δ 136.5 (d, *J*<sub>CP</sub> = 84.9 Hz), 131.9 (d, *J*<sub>CP</sub> = 8.0 Hz), 131.6 (d, *J*<sub>CP</sub> = 11.0 Hz), 131.0 (d, *J*<sub>CP</sub> = 7.7 Hz), 129.8 (d, *J*<sub>CP</sub> = 5.1 Hz), 128.6 (d, *J*<sub>CP</sub> = 2.5 Hz), 127.0 (d, *J*<sub>CP</sub> = 2.9 Hz), 118.0 (d, *J*<sub>CP</sub> = 1.5 Hz), 115.2 (d, *J*<sub>CP</sub> = 2.9 Hz), 37.2 (d, *J*<sub>CP</sub> = 69.2 Hz), 35.0 (d, *J*<sub>CP</sub> = 61.1 Hz), 26.1 (d, *J*<sub>CP</sub> = 13.2 Hz), 26.1 (d, *J*<sub>CP</sub> = 12.8 Hz), 25.6 (d, *J*<sub>CP</sub> = 1.1 Hz), 25.3 (d, *J*<sub>CP</sub> = 2.9 Hz), 24.7 (d, *J*<sub>CP</sub> = 3.3 Hz). <sup>31</sup>P (162 MHz, CDCl<sub>3</sub>) δ 42.5. IR (thin film), cm<sup>-1</sup>: 2930.7 (m), 2855.5 (w), 2231.1 (w), 1495.1 (m), 1450.1 (m), 1391.1 (m), 1172.7 (s). LC/HRMS-ESI (*m/z*): [M + H]<sup>+</sup> calcd for C<sub>20</sub>H<sub>23</sub>NOP, 324.1517; found 324.1476.



*Benzylcyclohexyl(3-pyridyl)phosphine oxide (4p)*: Reaction conducted with 2.5 mol% Pd<sub>2</sub>dba<sub>3</sub> and 5 mol% Xantphos (**1**). Purification by flash-column chromatography using a Biotage Isolera and increasing with a linear gradient to 20% methanol–ethyl acetate) afforded the title compound as a white crystalline solid (266 mg, 89%).

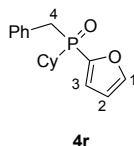
R<sub>f</sub>: 0.56 (3% methanol–ethyl acetate; UV). <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>) δ 8.50–8.47 (m, 1H, H<sub>1</sub>), 8.43–8.40 (m, 1H, H<sub>2</sub>), 7.68–7.63 (m, 1H, H<sub>4</sub>), 7.08–7.04 (m, 1H, H<sub>3</sub>), 6.95–6.85 (m, 5H, **Ph**), 3.27–3.19 (m, 1H, H<sub>5</sub>), 3.15–3.08 (m, 1H, H<sub>5</sub>'), 1.91–1.83 (br, 1H, **Cy**), 1.74–1.65 (m, 1H, **Cy**), 1.65–1.63 (m, 1H, **Cy**), 1.53–1.46 (br, 1H, **Ph**), 1.46–1.36 (m, 2H, **Ph**), 1.30–1.20 (m, 1H, **Ph**), 1.15–0.89 (m, 4H, **Ph**). <sup>13</sup>C NMR (125 MHz) δ 151.7 (d, J<sub>CP</sub> = 1.4 Hz), 150.9 (d, J<sub>CP</sub> = 6.7 Hz), 139.0 (d, J<sub>CP</sub> = 5.9 Hz), 130.7 (d, J<sub>CP</sub> = 7.8 Hz), 129.3 (d, J<sub>CP</sub> = 5.0 Hz), 126.3 (d, J<sub>CP</sub> = 2.6 Hz), 126.3 (d, J<sub>CP</sub> = 86.6 Hz), 122.8 (d, J<sub>CP</sub> = 8.2 Hz), 37.0 (d, J<sub>CP</sub> = 69.6 Hz), 34.7 (d, J<sub>CP</sub> = 60.9 Hz), 25.6 (d, J<sub>CP</sub> = 12.8 Hz), 25.6 (d, J<sub>CP</sub> = 12.9 Hz), 25.2, 24.8 (d, J<sub>CP</sub> = 2.8 Hz), 24.2 (d, J<sub>CP</sub> = 3.3 Hz). <sup>31</sup>P (162 MHz) δ 38.9. IR (thin film), cm<sup>-1</sup>: 3036.8 (w), 2923.0 (m), 2851.3 (w), 1603.3 (w), 1170.0 (s). LC/HRMS-ESI (*m/z*): [M + H]<sup>+</sup> calcd for C<sub>18</sub>H<sub>23</sub>NOP, 300.1517; found 300.1498.



*Benzylcyclohexyl(2-thiophenyl)phosphine oxide (4q)*: Reaction conducted with 2.5 mol% Pd<sub>2</sub>dba<sub>3</sub> and 5 mol% Xantphos (**1**). Purification by flash-column chromatography using a Biotage Isolera purification system (eluting with ethyl acetate initially, grading to 20% methanol–ethyl acetate), afforded the title compound as a white crystalline solid (283 mg, 93%).

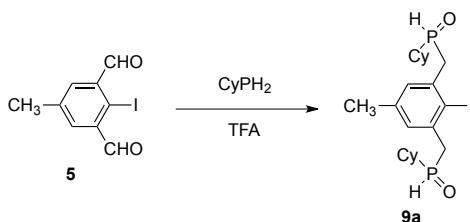
R<sub>f</sub>: 0.75 (3% methanol–ethyl acetate; UV). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.61–7.56 (m, 1H, H<sub>1</sub>), 7.33–7.28 (m, 1H, H<sub>3</sub>), 7.19–7.08 (m, 5H, **Ph**), 7.08–7.03 (m, 1H, H<sub>2</sub>), 3.40–3.20 (m, 2H, H<sub>4</sub>), 2.10–2.00 (br, 1H, **Cy**), 1.85–1.66 (m, 4H, **Cy**), 1.66–1.55 (br, 1H, **Cy**), 1.40–1.02 (m, 5H, **Cy**). <sup>13</sup>C NMR (100 MHz,

CDCl<sub>3</sub>)  $\delta$  135.4 (d,  $J_{CP}$  = 7.6 Hz), 132.6 (d,  $J_{CP}$  = 3.6 Hz), 131.4 (d,  $J_{CP}$  = 6.2 Hz), 130.9 (d,  $J_{CP}$  = 92.9 Hz), 129.7 (d,  $J_{CP}$  = 5.5 Hz), 128.3 (d,  $J_{CP}$  = 2.2 Hz), 128.0 (d,  $J_{CP}$  = 12.5 Hz), 126.6 (d,  $J_{CP}$  = 2.9 Hz), 38.6 (d,  $J_{CP}$  = 73.1 Hz), 36.6 (d,  $J_{CP}$  = 64.0 Hz), 26.1 (d,  $J_{CP}$  = 14.0 Hz), 26.0 (d,  $J_{CP}$  = 13.2 Hz), 25.6 (d,  $J_{CP}$  = 1.2 Hz), 25.4 (d,  $J_{CP}$  = 2.6 Hz), 24.7 (d,  $J_{CP}$  = 3.3 Hz). <sup>31</sup>P NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  38.1. IR (diamond, thin film), cm<sup>-1</sup>: 2925.0 (m), 2853.6 (w), 1602.6 (w), 1166.7 (s). LC/HRMS-ESI ( $m/z$ ): [M + H]<sup>+</sup> calcd for C<sub>17</sub>H<sub>22</sub>OPS, 305.1123; found 305.1089.



*Benzylcyclohexyl(2-thiophenyl)phosphine oxide (4r)*: Reaction conducted with 2.5 mol% Pd<sub>2</sub>dba<sub>3</sub> and 5 mol% Xantphos (**1**). Purification by flash-column chromatography using a Biotage Isolera purification system (eluting with ethyl acetate initially, grading 20% methanol–ethyl acetate) afforded the title compound as a white crystalline solid (254 mg, 88%).

R<sub>f</sub>: 0.75 (3% methanol–ethyl acetate; UV). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  7.64–7.57 (m, 1H, H<sub>1</sub>), 7.20–7.12 (m, 3H, **Ph**), 7.12–7.05 (m, 2H, **Ph**), 6.99–6.95 (m, 1H, H<sub>3</sub>), 6.42–6.36 (m, 1H, H<sub>2</sub>), 3.41–3.23 (m, 2H, H<sub>4</sub>), 2.05–1.95 (br, 1H, **Cy**), 1.92–1.57 (m, 5H, **Cy**), 1.41–1.05 (m, 5H, **Cy**). <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>)  $\delta$  147.2 (d,  $J_{CP}$  = 6.5 Hz), 146.8 (d,  $J_{CP}$  = 119.7 Hz), 131.3 (d,  $J_{CP}$  = 8.4 Hz), 129.6 (d,  $J_{CP}$  = 5.0 Hz), 128.5 (d,  $J_{CP}$  = 2.6 Hz), 126.7 (d,  $J_{CP}$  = 3.0 Hz), 122.8 (d,  $J_{CP}$  = 15.0 Hz), 37.8 (d,  $J_{CP}$  = 73.5 Hz), 34.8 (d,  $J_{CP}$  = 64.1 Hz), 26.1 (d,  $J_{CP}$  = 14.0 Hz), 26.1 (d,  $J_{CP}$  = 13.9 Hz), 25.7 (d,  $J_{CP}$  = 1.5 Hz), 25.3 (d,  $J_{CP}$  = 2.9 Hz), 24.6 (d,  $J_{CP}$  = 2.9 Hz). <sup>31</sup>P NMR (200 MHz, CDCl<sub>3</sub>)  $\delta$  34.9. IR (thin film), cm<sup>-1</sup>: 2926.8 (m), 2852.2 (w), 1450.3 (m), 1162.5 (m). LC/HRMS-ESI ( $m/z$ ): [M + H]<sup>+</sup> calcd for C<sub>17</sub>H<sub>22</sub>O<sub>2</sub>P, 289.1352; found 289.1313.

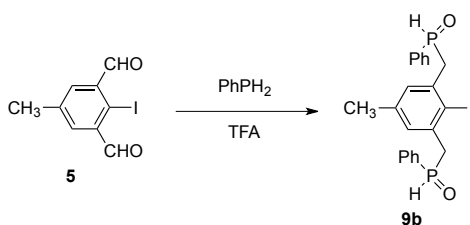


*$\alpha,\alpha'$ -Di(cyclohexylhydrophosphoxyl)-2-iodo-mesitylene (9a)*:

1,3-Diformyl-2-iodo-5-methylbenzene (**5**, 162 mg, 591  $\mu$ mol, 1 equiv) was dissolved in trifluoroacetic acid (1.80 mL) in a 1-dram vial under argon. The solution was cooled to 0 °C in an ice

bath. Cyclohexylphosphine (160  $\mu$ L, 1.21 mmol, 2.04 equiv) was added to the cold solution. The vial was sealed with a Teflon-lined cap. The reaction mixture was stirred and heated for 8 h at 80  $^{\circ}$ C. The product solution was cooled over 10 min to 24  $^{\circ}$ C. The cooled solution was slowly poured into a separatory funnel that had been charged with saturated sodium bicarbonate solution (50 mL). The aqueous layer was extracted with dichloromethane (4  $\times$  10 mL). The organic layers were combined, and the combined organic layers were dried over sodium sulfate. The dried solution was filtered, and the filtrate was concentrated. The residue obtained was purified by flash-column chromatography using a Biotage Isolera purification system (eluting with 50% tetrahydrofuran–dichloromethane initially, grading to 10% methanol–50% tetrahydrofuran–dichloromethane) to afford the title compound as a clear, colorless oil (204 mg, 68%, 1:1 d.r.).

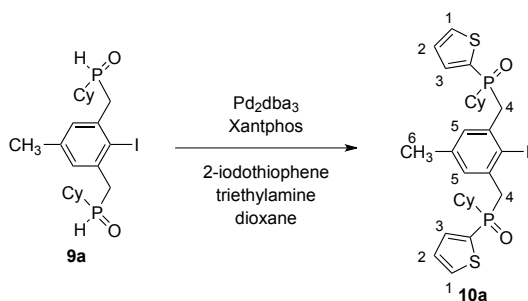
$^1\text{H}$  and  $^{31}\text{P}$  spectra were in agreement with those reported.<sup>6</sup>



$\alpha,\alpha'$ -Di(phenylhydrophosphoxyl)-2-iodo-mesitylene (**9b**):

1,3-Diformyl-2-iodo-5-methylbenzene (**5**, 160 mg, 584  $\mu$ mol, 1 equiv) was dissolved in trifluoroacetic acid (1.80 mL) in a 1-dram vial under argon. The solution was cooled to 0  $^{\circ}$ C in an ice bath. Phenylphosphine (131  $\mu$ L, 1.19 mmol, 2.04 equiv) was added to the cold solution. The vial was then sealed with a Teflon-lined cap. The reaction mixture was stirred and heated for 8 h at 80  $^{\circ}$ C. The product solution was cooled over 10 min to 24  $^{\circ}$ C. The cooled solution was slowly poured into a separatory funnel that had been charged with saturated sodium bicarbonate solution (50 mL). The aqueous layer was extracted with dichloromethane (4  $\times$  10 mL). The organic layers were combined, and the combined organic layers were dried over sodium sulfate. The dried solution was filtered, and the filtrate was concentrated. The residue obtained was purified by flash-column chromatography using a Biotage Isolera purification system (eluting with 50% tetrahydrofuran–dichloromethane initially, grading to 10% methanol–50% tetrahydrofuran–dichloromethane), afforded the title compound as a clear, colorless oil (178 mg, 61%, 1:1 d.r.).

$^1\text{H}$  and  $^{31}\text{P}$  spectra were in agreement with those reported.<sup>6</sup>

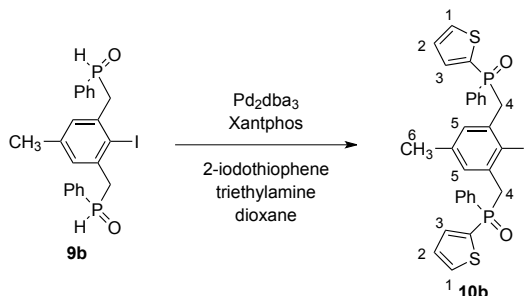


*α,α′-Bis-(cyclohexyl-[2-thiophenyl]-phosphoryl)-2-iodo-mesitylene (10a):* *α,α′*-Di(cyclohexylhydrophosphoxyl)-2-iodo-mesitylene (**9a**, 279 mg, 551 μmol, 1 equiv), 2-iodothiophene (239 mg, 1.14 mmol, 1.03 equiv per SPO), and dioxane (1.25 mL) were combined in a 1-dram vial that had been charged with a Teflon-coated magnetic stirbar. The mixture was heated and stirred at 80 °C until homogenous (*ca.* 5 min). The homogeneous mixture was cooled to *ca.* 50 °C (**9a** precipitates out of solution if it cools too much before catalyst addition), and then a solution of Pd<sub>2</sub>dba<sub>3</sub> (4.2 mg, 4.6 μmol, 0.008 equiv Pd per SPO), Xantphos (**1**, 5.8 mg, 10.0 μmol, 0.009 equiv per SPO), and triethylamine (150 μL, 1.07 mmol, 12.08 equiv) in dioxane (200 μL) was added. The resulting mixture was stirred for 2 h at 24 °C. After this time, additional Pd<sub>2</sub>dba<sub>3</sub> (4.3 mg, 4.7 μmol, 0.008 equiv per SPO), Xantphos (**1**, 5.6 mg, 9.7 μmol, 0.009 equiv per SPO) and triethylamine (75 μL, 539 μmol, 0.49 equiv per SPO) in dioxane (200 μL) was added. The reaction mixture was stirred for an additional 10 h at 24 °C. The product mixture was transferred to a separatory funnel, and the vial containing the product mixture was rinsed with dichloromethane (5 mL). The rinses were added to the separatory funnel, and the organic layer was washed with saturated aqueous sodium bicarbonate solution (25 mL). The layers that formed were separated, and the aqueous layer was extracted with dichloromethane (3 × 25 mL). The organic layers were combined, and the combined organic layers were dried over sodium sulfate. The dried solution was filtered and the filtrate was concentrated. The residue obtained was purified by flash-column chromatography (eluting with 2% methanol–dichloromethane initially, grading to 8% methanol–dichloromethane) to afford the title compound as a clear, pale yellow oil (309 mg, 84%, 1:1 d.r.).

R<sub>f</sub>: 0.43 (3% methanol–ethyl acetate; UV). <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 7.68–7.63 (m, 2H, H<sub>1</sub>), 7.41–7.33 (m, 2H, H<sub>3</sub>), 7.16–7.12 (m, 2H, H<sub>2</sub>), 7.07–7.04 (br, 2H, H<sub>5</sub>), 3.85–3.70 (m, 2H, H<sub>4</sub>), 3.63–3.51 (m, 2H, H<sub>4′</sub>), 2.12 (s, 3H, H<sub>6</sub>), 2.10–2.02 (br, 2H, Cy), 1.98–1.75 (m, 8H, Cy), 1.75–1.66 (br, 2H, Cy), 1.52–1.16 (m, 10H, Cy). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>) δ 137.9–137.8 (m), 136.6–136.4 (m), 135.8–135.5 (m), 133.3–132.9 (m), 132.0–131.8 (m), 131.1–130.9 (m), 130.5–130.3 (m), 128.4–128.1 (m), 106.7–106.4 (m), 43.2–43.0 (m), 42.6–42.3 (m), 40.3–40.1 (m), 39.6–39.4 (m), 26.6–26.1 (m), 26.0–25.6 (m), 25.2–



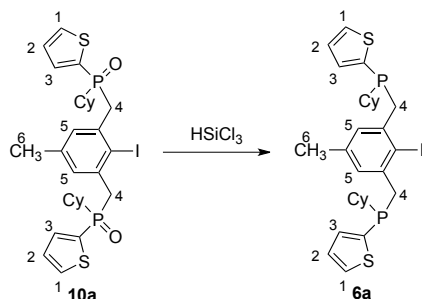
25.0 (m).  $^{31}\text{P}$  (162 MHz,  $\text{CDCl}_3$ )  $\delta$  38.5, 38.4. IR (thin film),  $\text{cm}^{-1}$ : 2928.8 (m), 2852.9 (w), 1406.5 (w), 1174.6 (m). LC/HRMS-ESI ( $m/z$ ):  $[\text{M} + \text{Na}]^+$  calcd for  $\text{C}_{29}\text{H}_{37}\text{IO}_2\text{P}_2\text{S}_2\text{Na}$ , 693.0653; found 693.0724.



*$\alpha,\alpha'$ -Bis-(phenyl-[2-thiophenyl]-phosphoryl)-2-iodo-mesitylene* (**10b**):  $\alpha,\alpha'$ -Di(phenylhydrophosphoxyl)-2-iodo-mesitylene (**9b**, 43.7 mg, 88.5  $\mu\text{mol}$ , 1 equiv), 2-iodothiophene (52.2 mg, 249  $\mu\text{mol}$ , 1.41 equiv per SPO), and dioxane (200  $\mu\text{L}$ ) were combined in a 1-dram vial that had been charged with a Teflon-coated magnetic stirbar. The mixture was stirred until homogenous at 24  $^{\circ}\text{C}$ . A solution of  $\text{Pd}_2\text{dba}_3$  (4.2 mg, 4.6  $\mu\text{mol}$ , 0.052 equiv Pd per SPO), Xantphos (5.8 mg, 10.0  $\mu\text{mol}$ , 0.057 equiv per SPO) and triethylamine (30  $\mu\text{L}$ , 215  $\mu\text{mol}$ , 1.22 equiv per SPO) in dioxane (250  $\mu\text{L}$ ) was added. The reaction was stirred for 2 h at 24  $^{\circ}\text{C}$ . The product mixture was transferred to a separatory funnel, and the vial containing the product mixture was rinsed with dichloromethane (5 mL). The rinses were added to the separatory funnel, and the organic layer was washed with saturated aqueous sodium bicarbonate solution (25 mL). The layers that formed were separated, and the aqueous layer was extracted with dichloromethane ( $3 \times 25$  mL). The organic layers were combined, and the combined organic layers were dried over sodium sulfate. The dried solution was filtered and the filtrate was concentrated. Purification by flash-column chromatography (Isolera), eluted with 100% ethyl acetate, and increasing with a linear gradient to 15% methanol–ethyl acetate, afforded the title compound as a clear, pale yellow oil (37.8 mg, 61%, 1:1 d.r.).

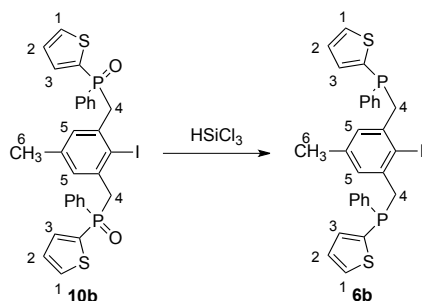
$R_f$ : 0.58 (3% methanol–ethyl acetate; UV).  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.79–7.70 (m, 4H,  $\text{H}_x$ ), 7.70–7.64 (m, 2H,  $\text{H}_x$ ), 7.57–7.51 (m, 2H,  $\text{H}_x$ ), 7.47–7.35 (m, 6H,  $\text{H}_x$ ), 7.16–7.10 (m, 4H,  $\text{H}_x$ ), 4.05–3.79 (m, 4H,  $\text{H}_4$ ), 2.14 (s, 3H,  $\text{H}_6$ ).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ )  $\delta$  137.9–137.8 (m), 136.0 (app d,  $J = 9.2$  Hz), 135.8 (app d,  $J = 7.9$  Hz), 133.5 (app d,  $J = 3.8$  Hz), 133.2 (app dd,  $J = 90.3$  Hz,  $J = 2.0$  Hz), 132.6–132.5 (m), 132.4–132.2 (m), 131.8–131.7 (m), 131.3 (app d,  $J = 9.6$  Hz), 130.8–130.7 (m), 128.6 (app dd,  $J = 12.3$  Hz,  $J = 2.0$  Hz), 128.4 (app dd,  $J = 13.8$  Hz,  $J = 4.4$  Hz), 107.5–107.3 (m), 45.9 (app d,  $J = 70.2$  Hz),

20.8 (app s).  $^{31}\text{P}$  (162 MHz,  $\text{CDCl}_3$ )  $\delta$  24.0, 23.9. IR (thin film),  $\text{cm}^{-1}$ : 3058.8 (w), 1436.4 (m), 1405.6 (m), 1195.8 (s). LC/HRMS-ESI ( $m/z$ ):  $[\text{M} + \text{Na}]^+$  calcd for  $\text{C}_{29}\text{H}_{25}\text{IO}_2\text{P}_2\text{S}_2\text{Na}$ , 680.9714; found 680.9738.



$\alpha, \alpha'$ -Bis-(cyclohexyl-[2-thiophenyl]-phosphino)-2-iodo-mesitylene (**6a**):  $\alpha, \alpha'$ -Bis-(cyclohexyl-[2-thiophenyl]-phosphoryl)-2-iodo-mesitylene (**10a**, 309 mg, 461  $\mu\text{mol}$ , 1 equiv) was dissolved in toluene (52 mL) in a flame-dried 100 mL round-bottomed flask that had been fused to a Teflon-coated valve, and equipped with a Teflon-coated magnetic stirbar. Trichlorosilane (1.63 mL, 16.1 mmol, 35 equiv.) was added dropwise via syringe. The vessel was sealed and the reaction mixture was stirred and heated for 3 h at 115  $^{\circ}\text{C}$ . With rigorous exclusion of air, the product mixture was concentrated in vacuo. The vessel was sealed and the sealed vessel was transferred to a nitrogen-filled drybox. The residue was dissolved in  $\text{C}_6\text{D}_6$  and found to be pure by NMR spectroscopy. (240 mg, 82%) (For mass determination, samples were protected as bisphosphine-borane adducts to prevent oxidation during analysis.)

$^1\text{H}$  NMR (400 MHz,  $\text{C}_6\text{D}_6$ )  $\delta$  7.16–7.08 (m, 4H), 6.73–6.68 (m, 2H), 6.60 (s, 1H), 6.53 (s, 1H), 3.65–3.57 (m, 2H), 3.31–3.21 (m, 2H), 2.05–1.85 (m, 5H), 1.80 (app. d,  $J = 10.0$  Hz, 3H), 1.75–1.66 (m, H), 1.65–1.47 (m, H), 1.45–1.30 (m, H), 1.24–1.05 (m, H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ )  $\delta$  142.2 (app. t,  $J = 5.8$  Hz), 139.2–139.0 (m), 138.7–138.6 (m), 137.5 (d,  $J_{\text{CP}} = 29.0$  Hz), 137.3 (d,  $J_{\text{CP}} = 28.5$  Hz), 136.9–136.8 (m), 131.0 (d,  $J_{\text{CP}} = 4.7$  Hz), 129.0 (app dd,  $J = 7.6$  Hz,  $J = 2.9$  Hz), 105.6 (t,  $J_{\text{CP}} = 4.7$  Hz), 105.4 (t,  $J_{\text{CP}} = 4.7$  Hz), 42.7 (d,  $J_{\text{CP}} = 16.0$  Hz), 42.5 (d,  $J_{\text{CP}} = 15.8$  Hz), 39.5 (d,  $J_{\text{CP}} = 10.4$  Hz), 39.4 (d,  $J_{\text{CP}} = 10.6$  Hz), 30.4 (d,  $J_{\text{CP}} = 17.0$  Hz), 30.3 (d,  $J_{\text{CP}} = 17.0$ ), 29.9 (d,  $J_{\text{CP}} = 11.3$  Hz), 29.8 (d,  $J_{\text{CP}} = 11.2$  Hz), 27.2–26.9 (m), 20.5 (d,  $J_{\text{CP}} = 1.3$  Hz).  $^{31}\text{P}$  (162 MHz,  $\text{CDCl}_3$ )  $\delta$  -5.8, -6.1. LC/HRMS-ESI ( $m/z$ ):  $[\text{M} + \text{Na}]^+$  calcd for  $\text{C}_{29}\text{H}_{43}\text{B}_2\text{IP}_2\text{S}_2\text{Na}$ , 661.0754; found 661.0770.

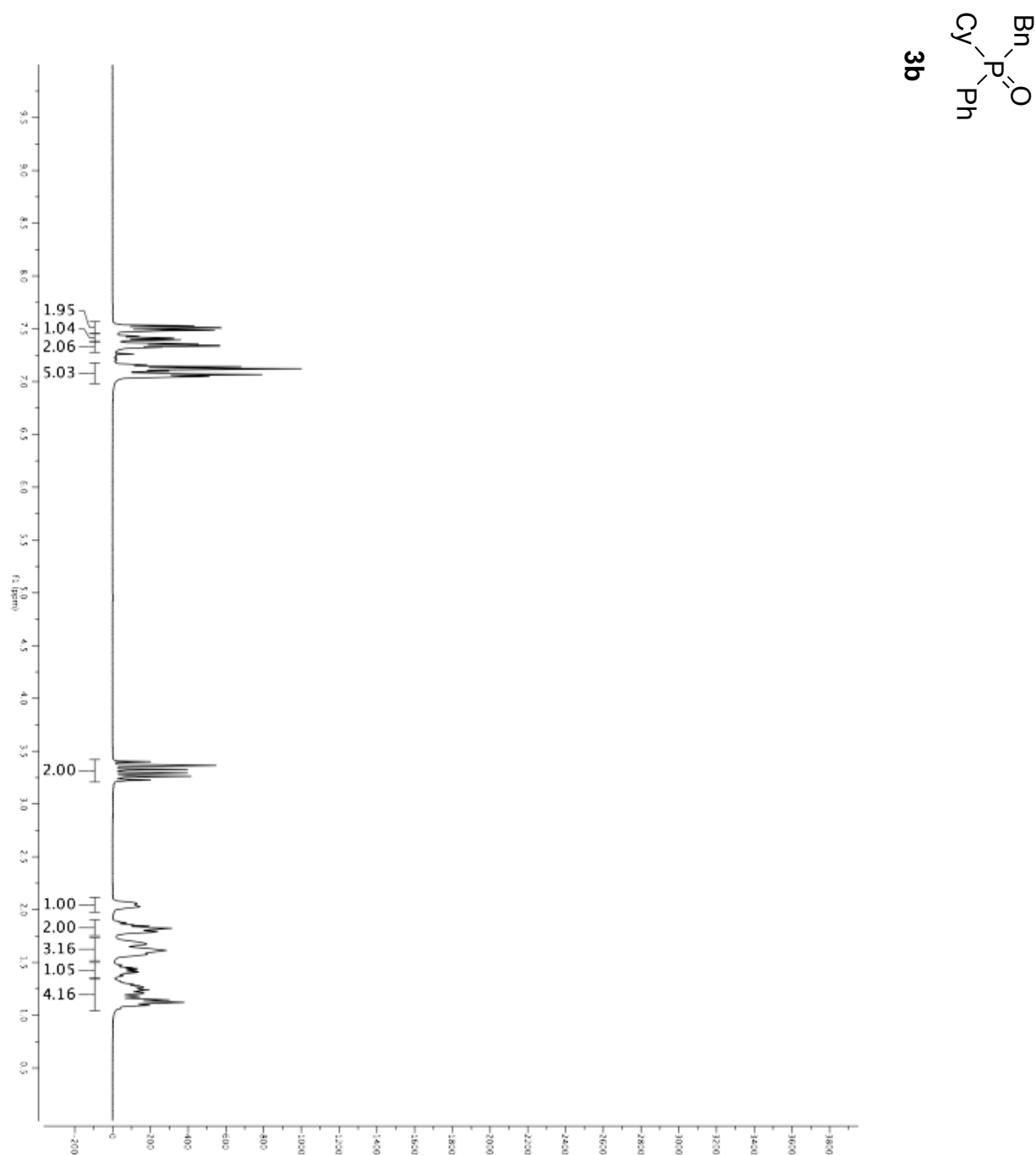


$\alpha,\alpha'$ -Bis-(phenyl-[2-thiophenyl]-phosphino)-2-iodo-mesitylene **7**) (**6b**): Bis-TPO **10b** (52.0 mg, 79.0  $\mu\text{mol}$  1 equiv.) was dissolved in toluene (8.8 mL) in a flame-dried 25 mL round-bottomed flask that had been fused to a Teflon-coated valve, and equipped with a Teflon-coated magnetic stirbar. Under an argon atmosphere,  $\text{HSiCl}_3$  (280  $\mu\text{L}$ , 2.77 mmol, 35 equiv.) was added dropwise. The reaction flask was then sealed under argon and stirred for 3 h at 115  $^\circ\text{C}$ . With rigorous exclusion of air, the product mixture was concentrated in vacuo. The vessel was sealed and the sealed vessel was transferred to a nitrogen-filled drybox. The residue was dissolved in  $\text{C}_6\text{D}_6$  and found to be pure by NMR spectroscopy. (44.2 mg, 89%) (For molecular mass determination, samples were protected as bisphosphine-borane adducts to prevent oxidation during analysis.)

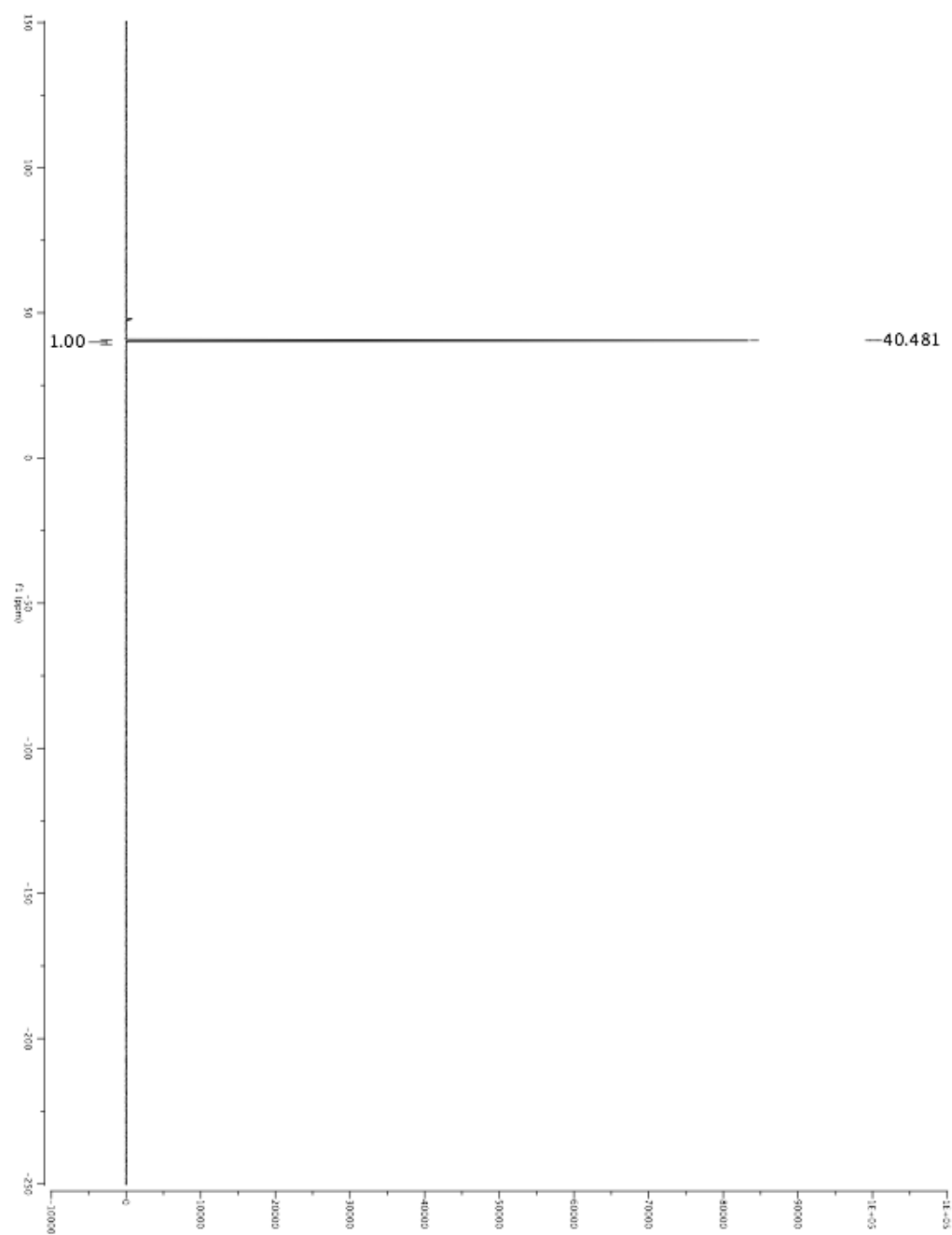
$^1\text{H}$  NMR (400 MHz,  $\text{C}_6\text{D}_6$ )  $\delta$  7.66–7.58 (m, 4H), 7.28–7.23 (m, 4H), 7.22–7.13 (m, 6H), 6.84–6.80 (m, 2H), 6.52 (s, 2H), 3.88–3.80 (m, 4H), 1.82 (s, 3H).  $^{13}\text{C}$  NMR (100 MHz,  $\text{C}_6\text{D}_6$ )  $\delta$  141.3 (app dd,  $J = 7.2$  Hz,  $J = 1.7$  Hz), 139.3 (app dd,  $J = 16.1$  Hz,  $J = 3.3$  Hz), 138.9 (app dd,  $J = 35.4$  Hz,  $J = 1.1$  Hz), 136.9 (br), 136.4 (app dd,  $J = 27.0$  Hz,  $J = 13.0$  Hz), 132.8 (app dd,  $J = 19.2$  Hz,  $J = 6.7$  Hz), 131.5 (app d,  $J = 5.1$  Hz), 129.5 (app dd,  $J = 7.7$  Hz,  $J = 2.8$  Hz), 128.7–128.6 (m), 106.0–105.9 (m), 45.1 (app d,  $J = 15.0$  Hz), 20.4 (s).  $^{31}\text{P}$  (162 MHz,  $\text{C}_6\text{D}_6$ )  $\delta$  -13.1, -13.2. LC/HRMS-ESI ( $m/z$ ):  $[\text{M} + \text{Na}]^+$  calcd for  $\text{C}_{29}\text{H}_{31}\text{B}_2\text{IP}_2\text{S}_2\text{Na}$ , 648.9815; found 648.9833.

# Catalog of Nuclear Magnetic Resonance and Infrared Spectra.

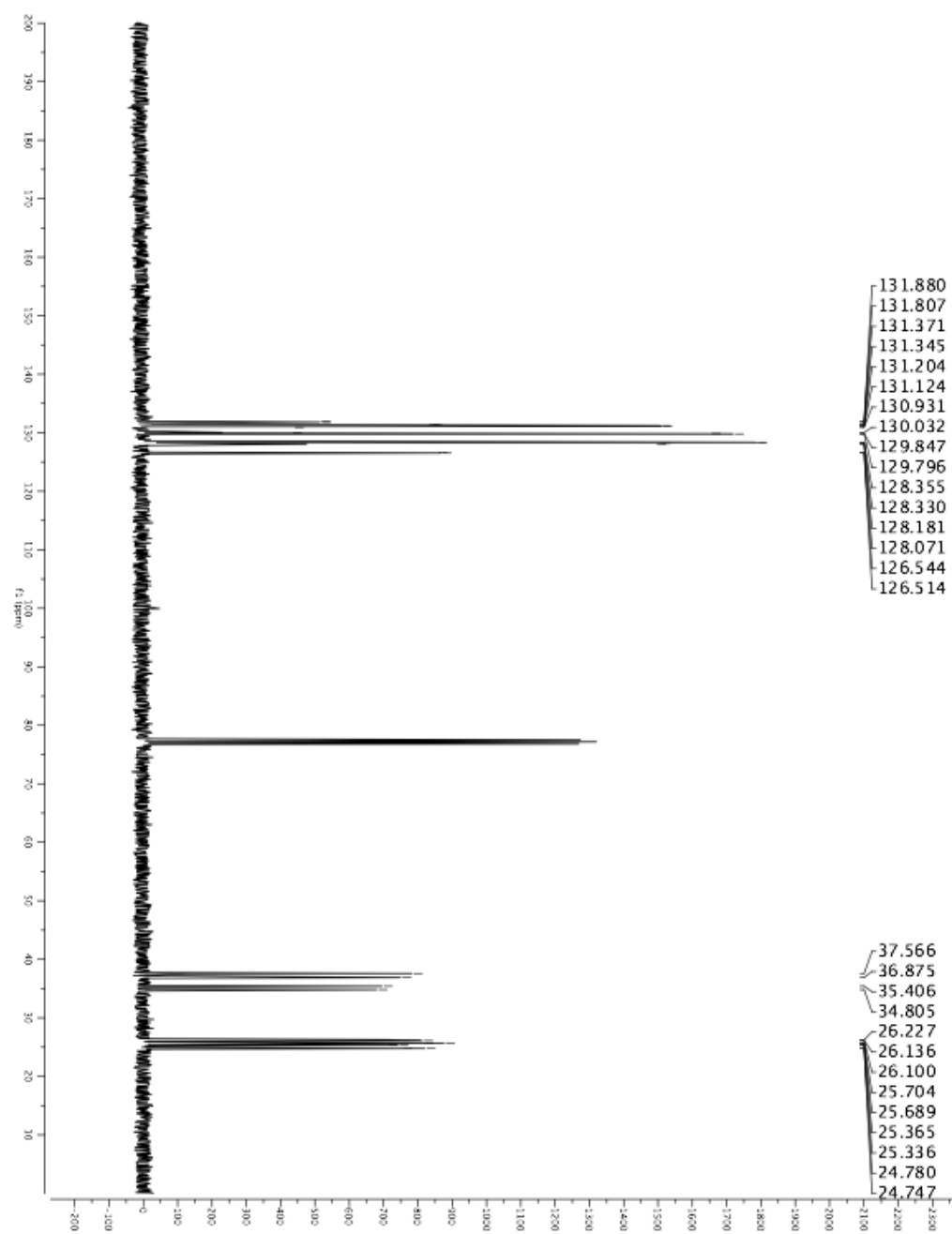
$^1\text{H}$  NMR



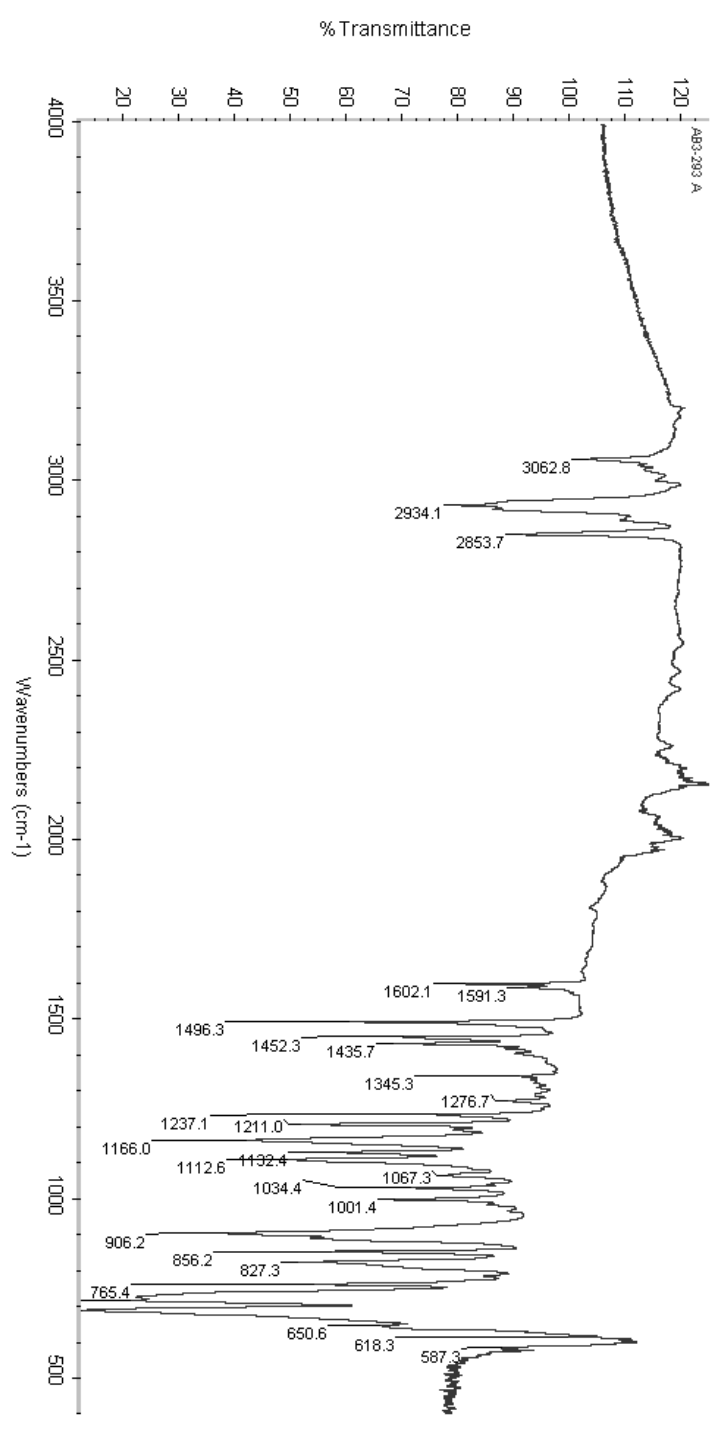
$^{31}\text{P}$  NMR



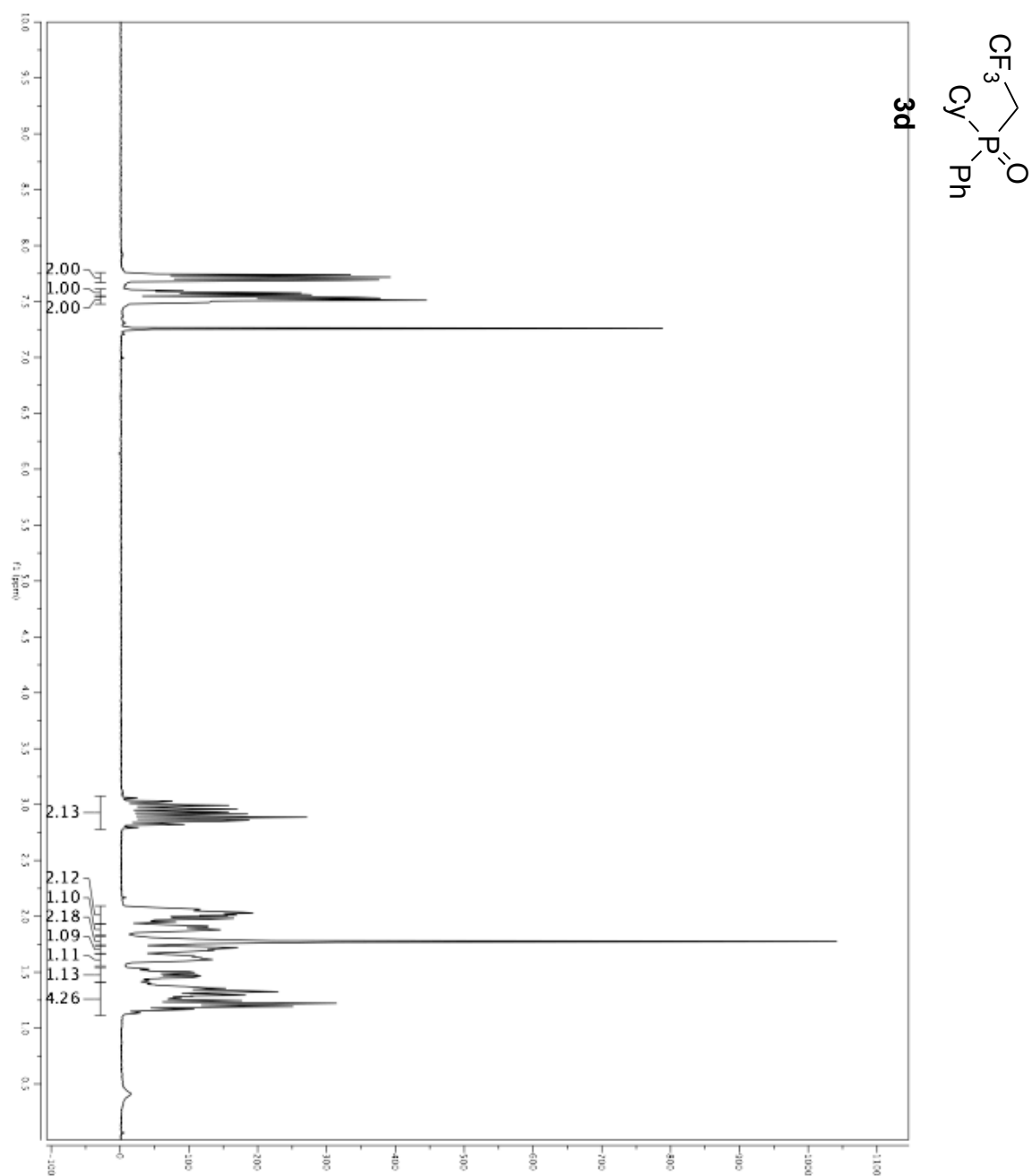
$^{13}\text{C}$  NMR



IR

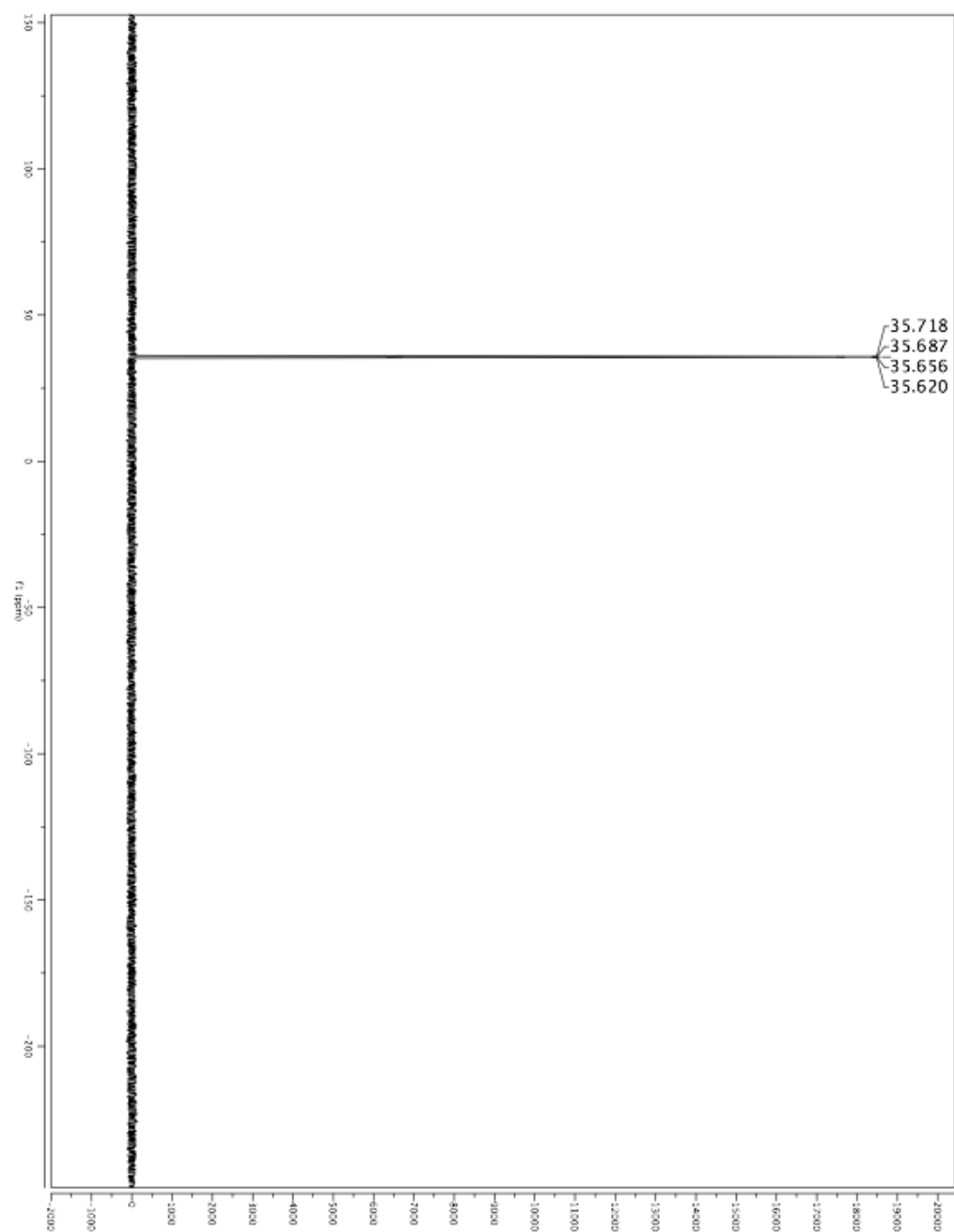


<sup>1</sup>H NMR

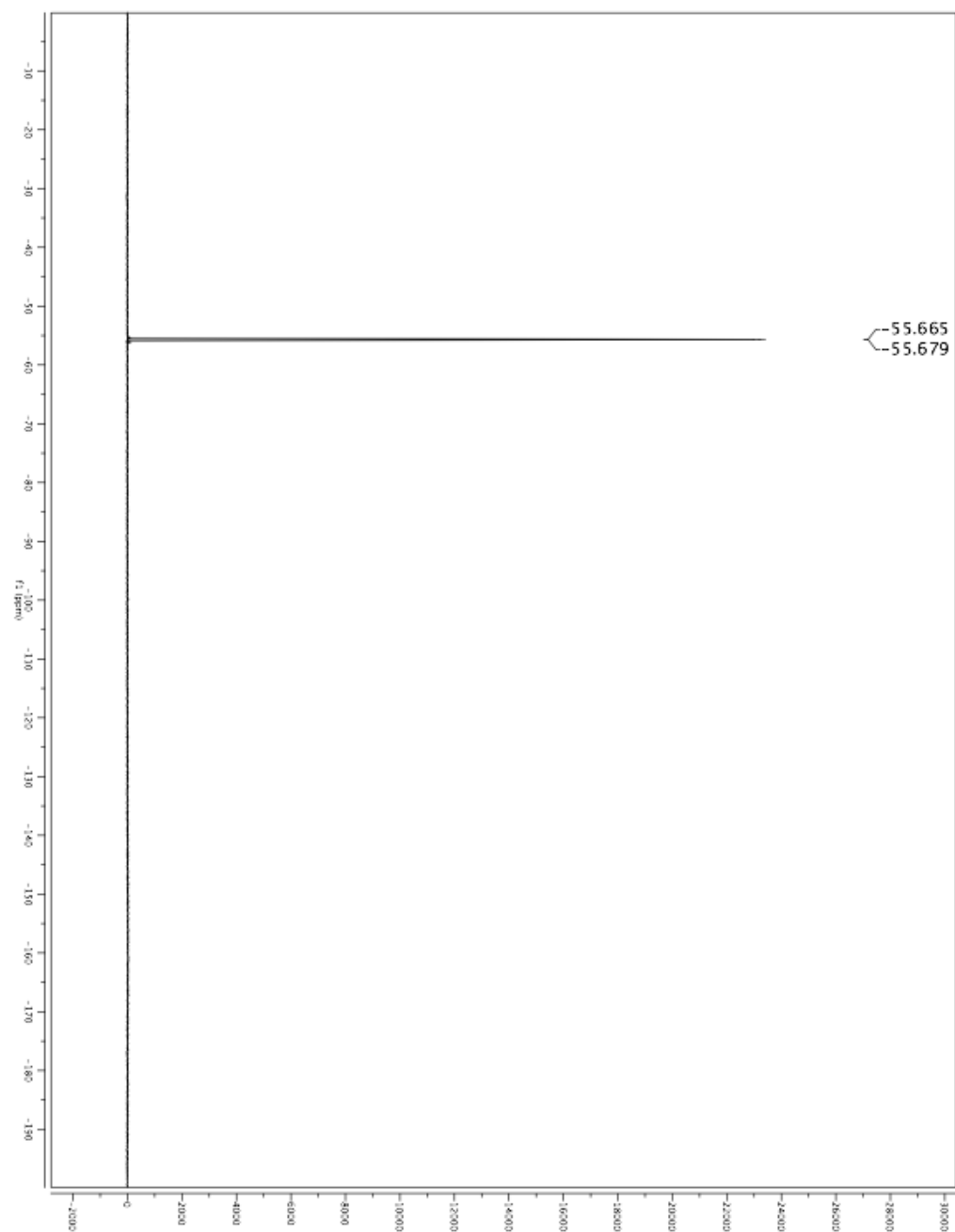




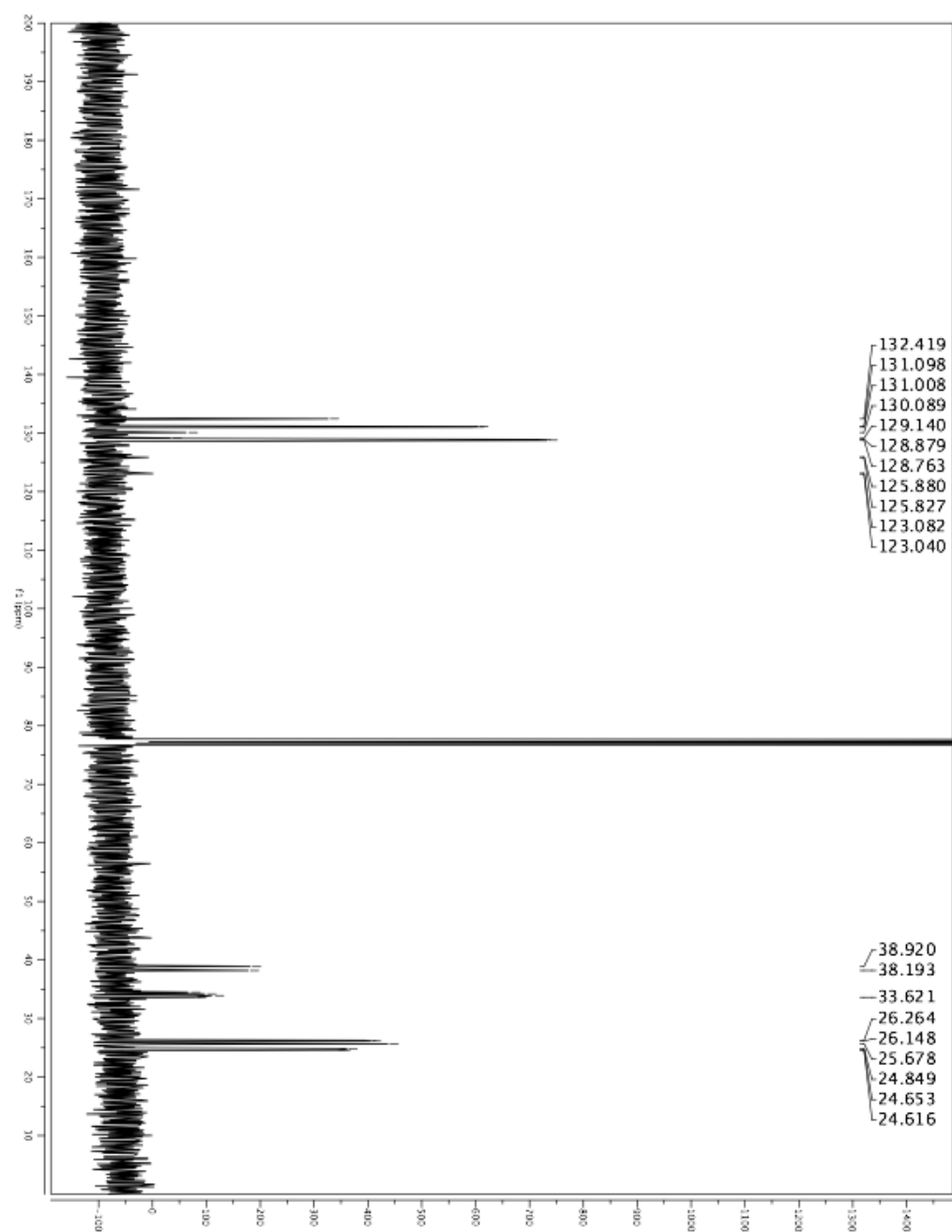
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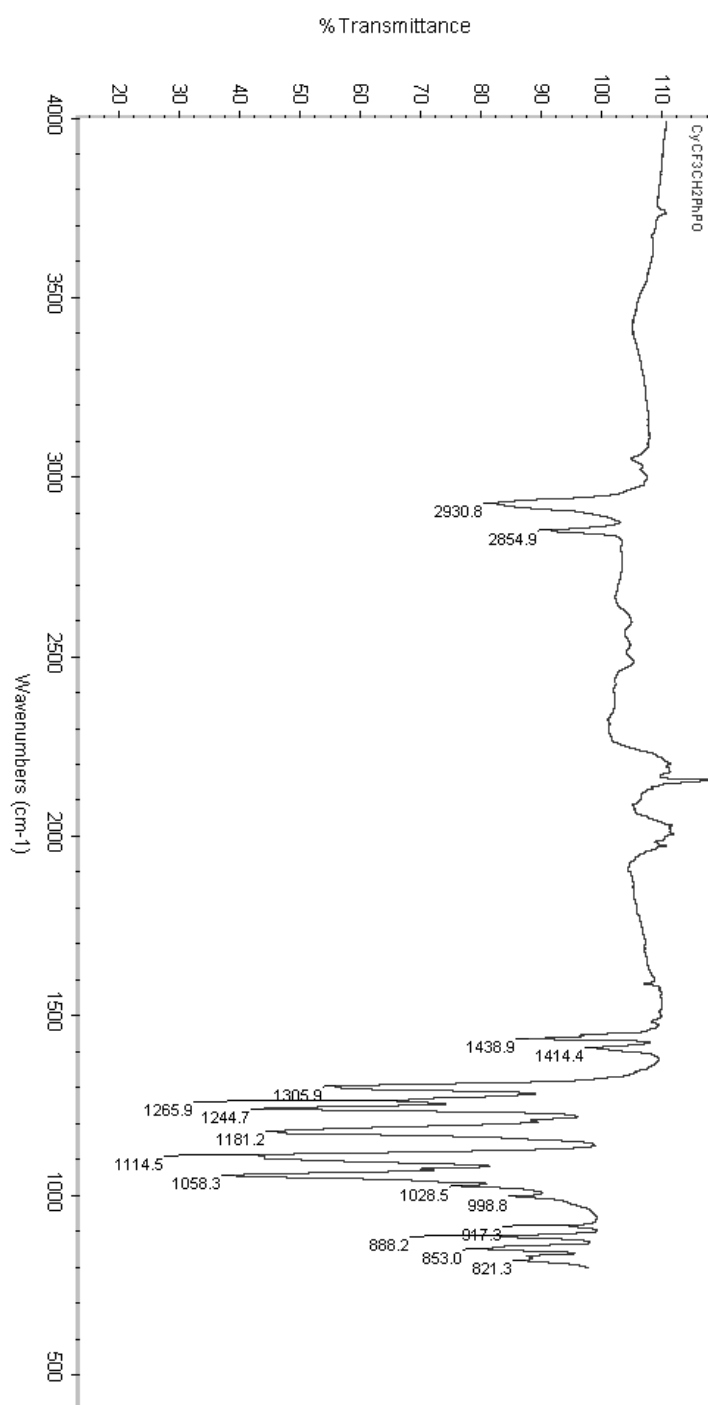
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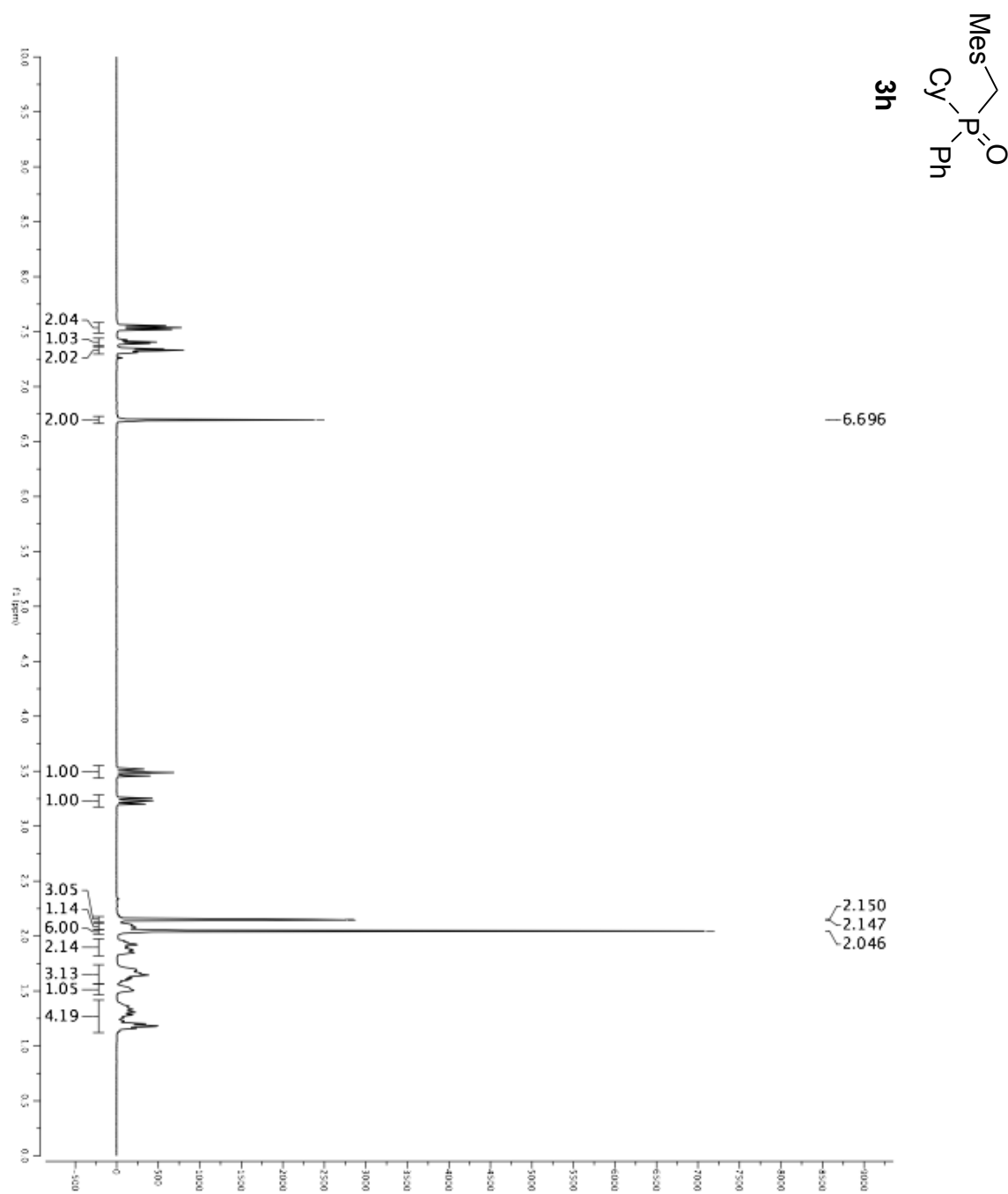
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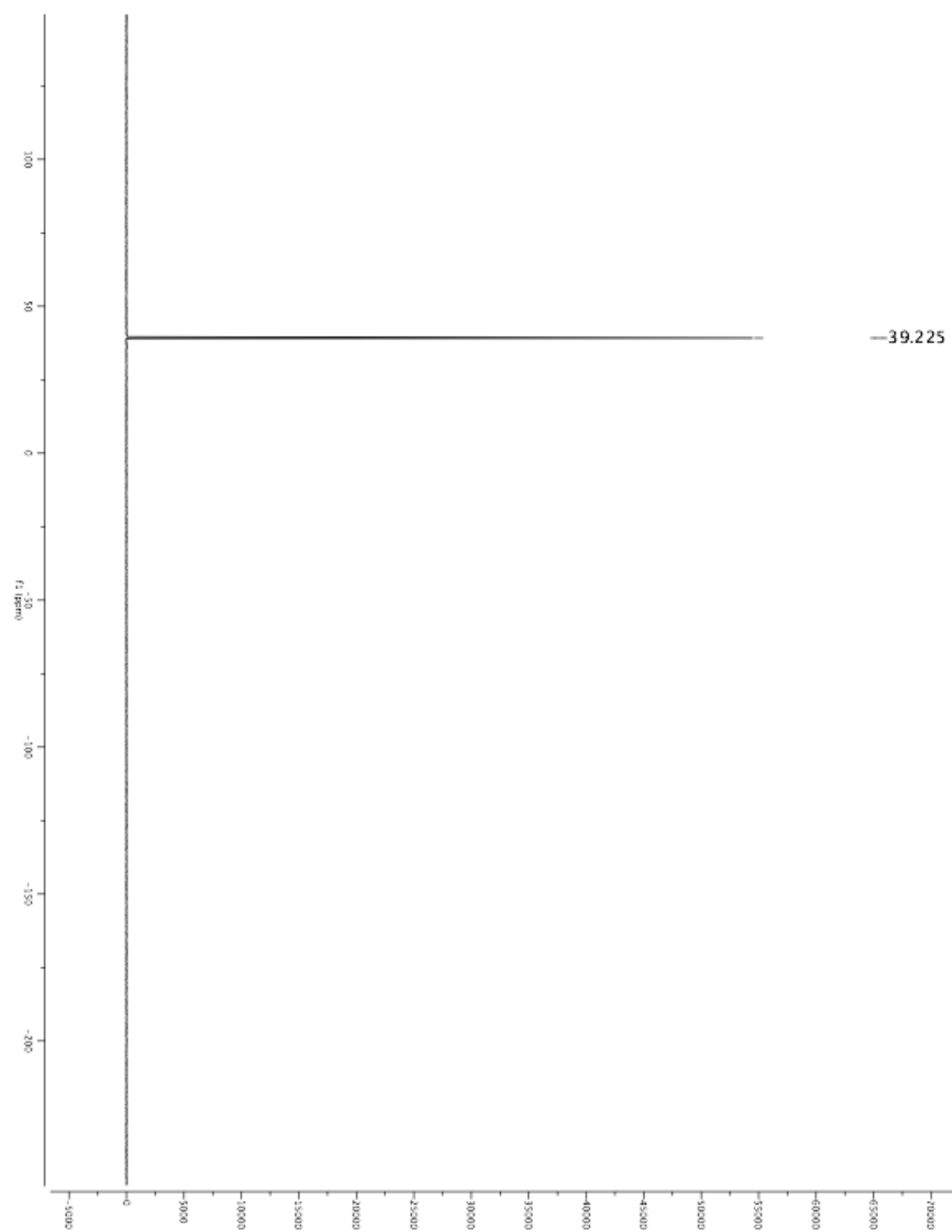
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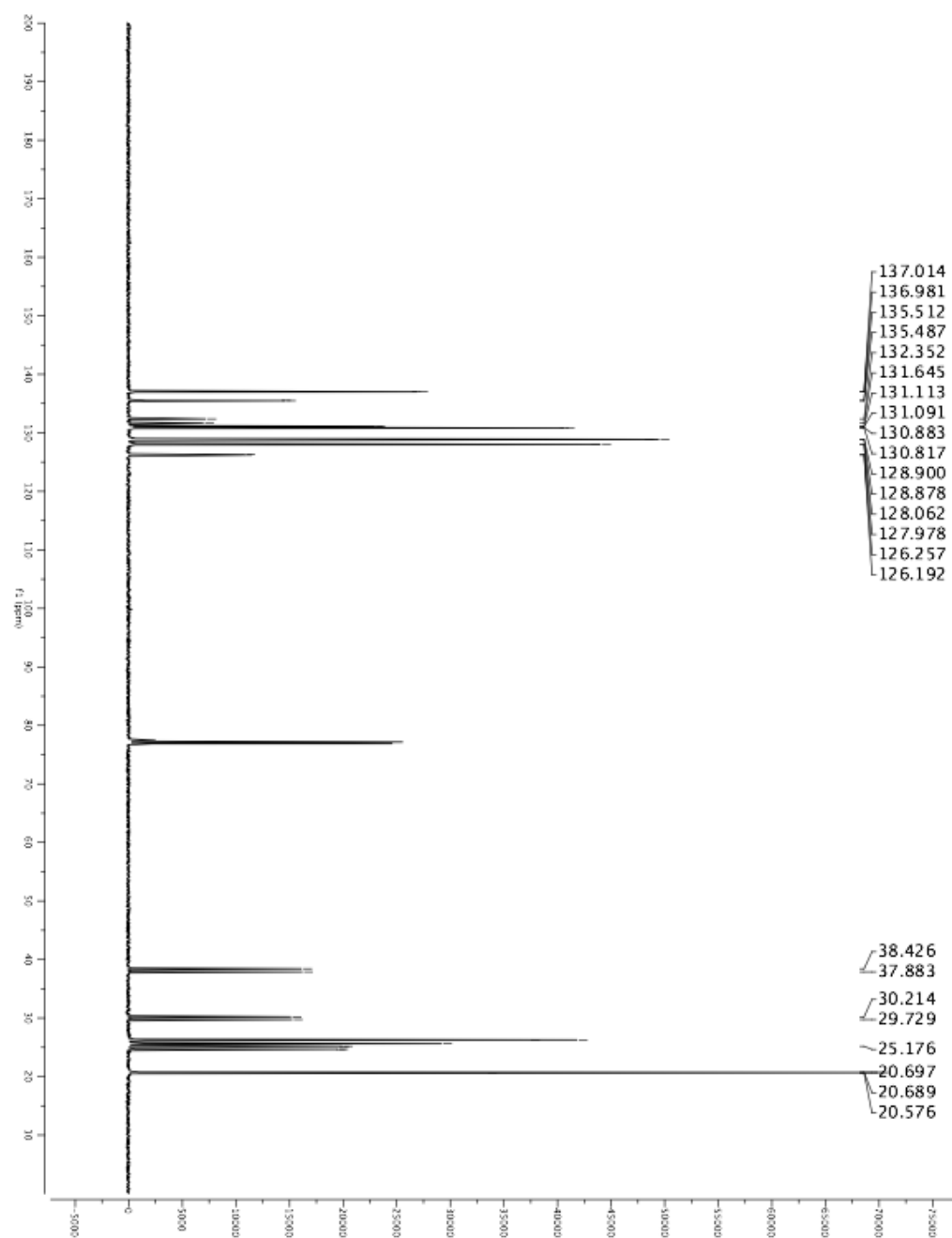
<sup>1</sup>H NMR



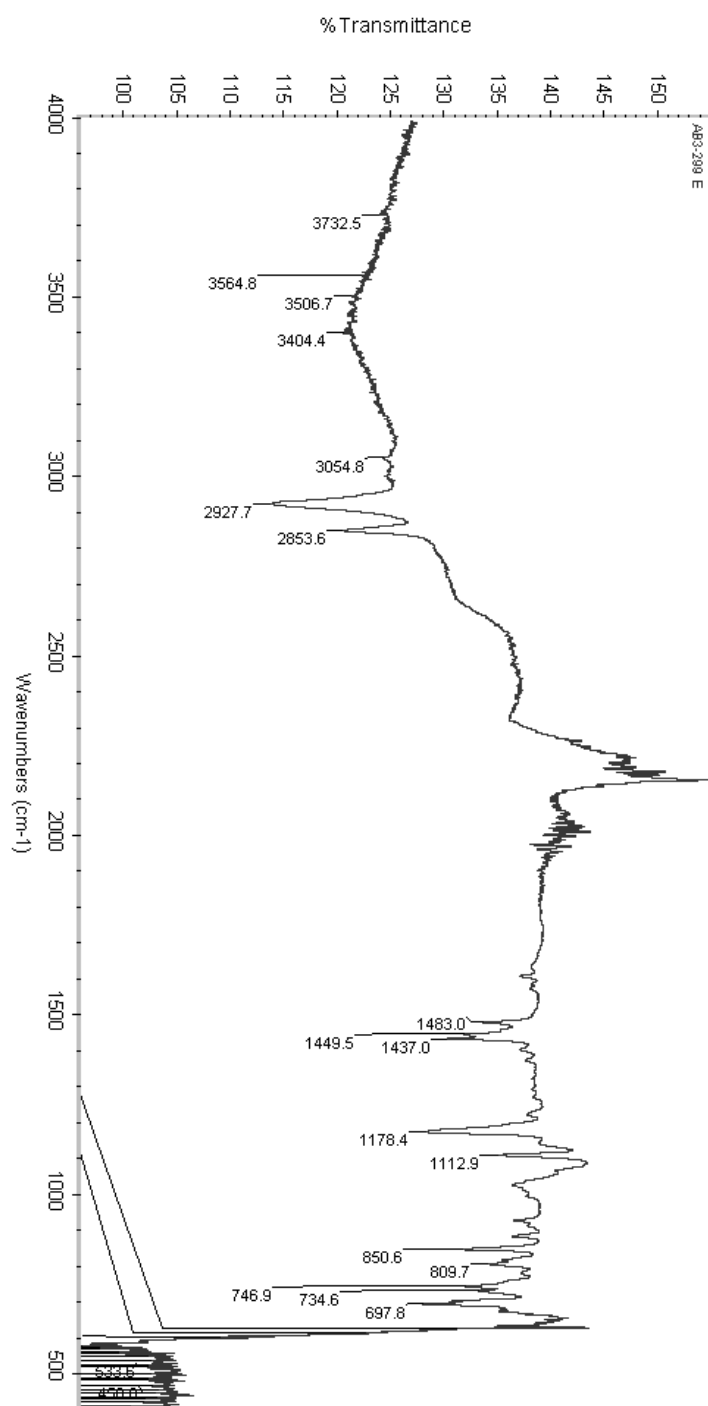
$^{31}\text{P}$  NMR



$^{13}\text{C}$  NMR

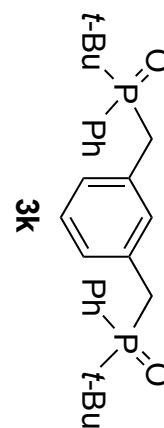
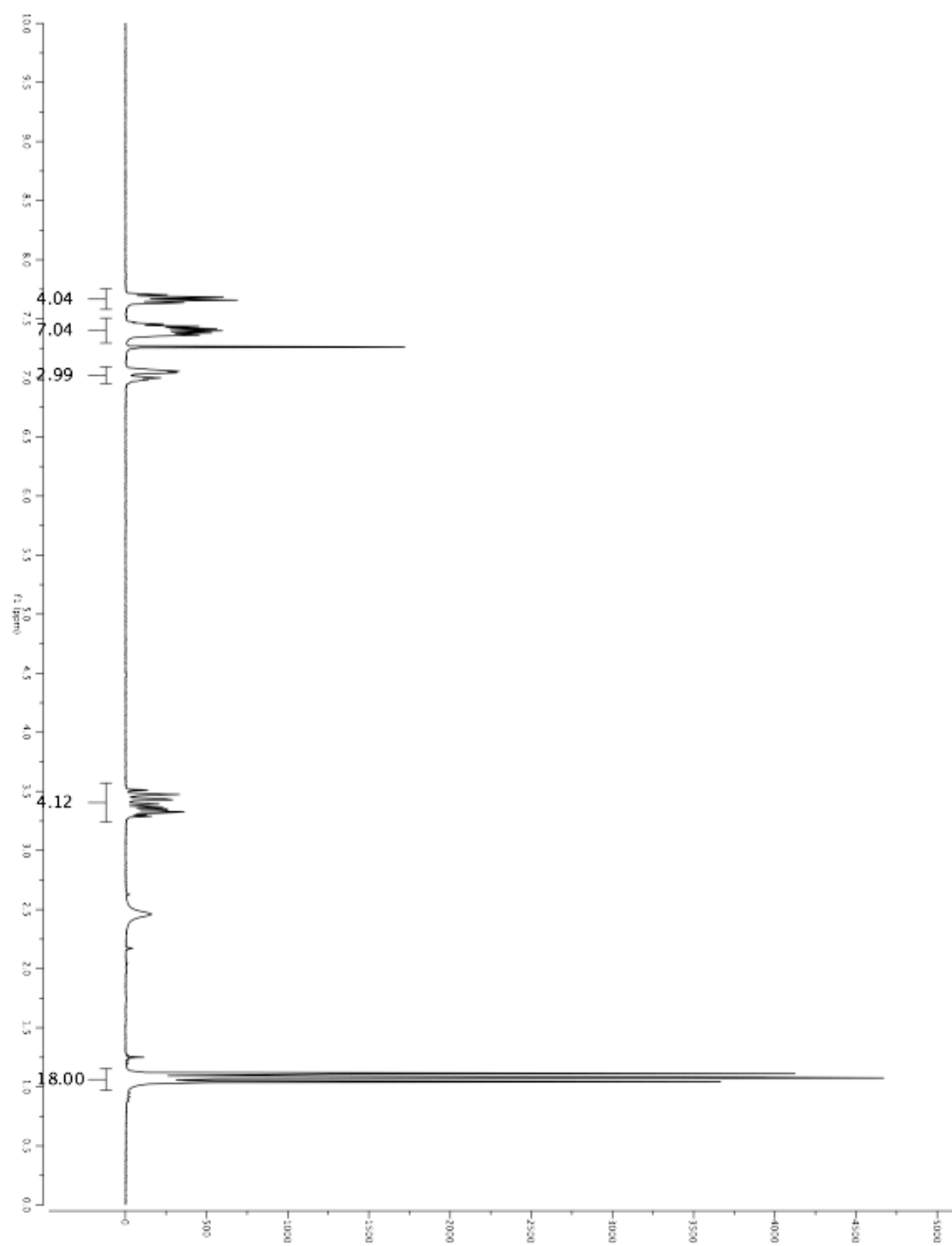


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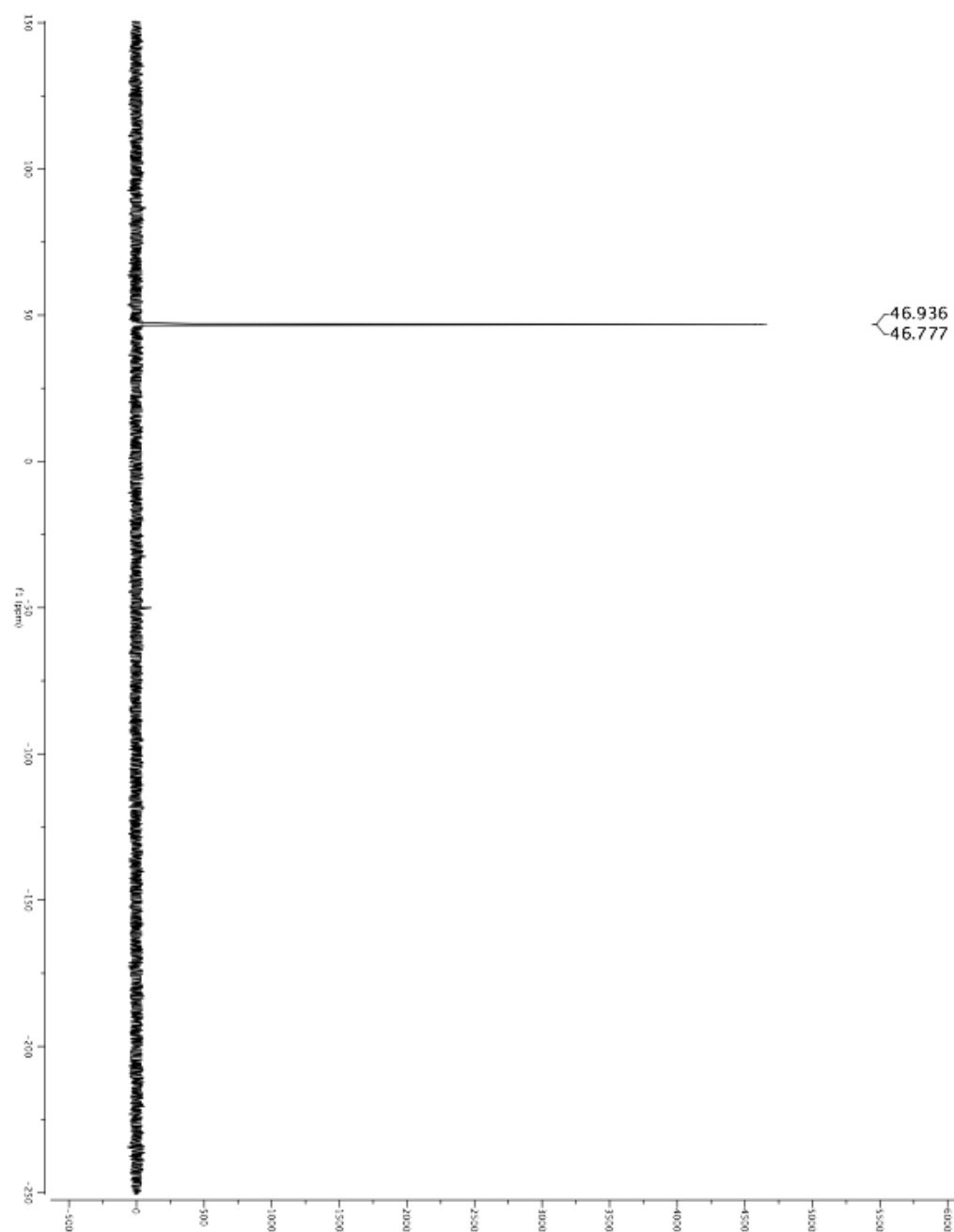




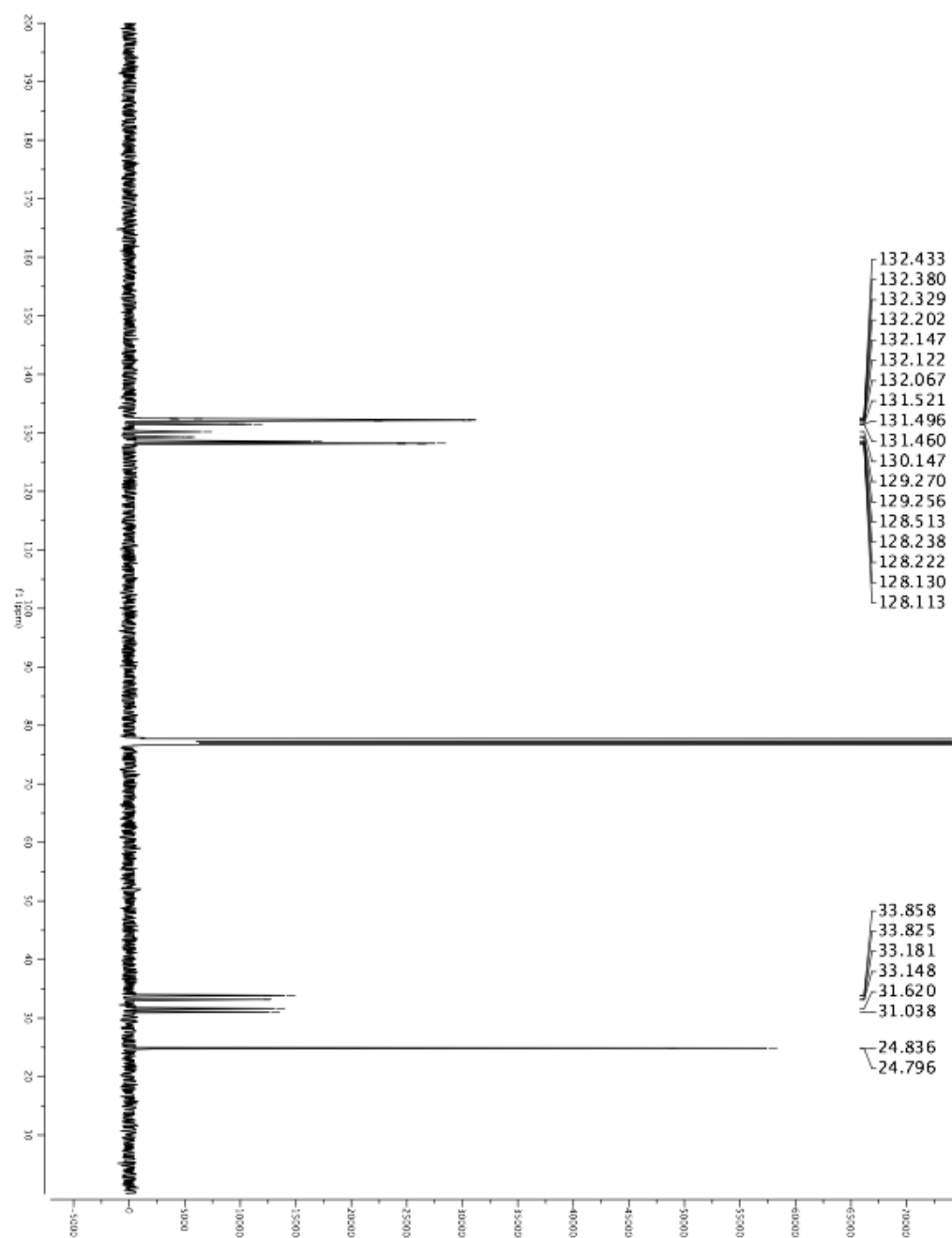
$^1\text{H}$  NMR



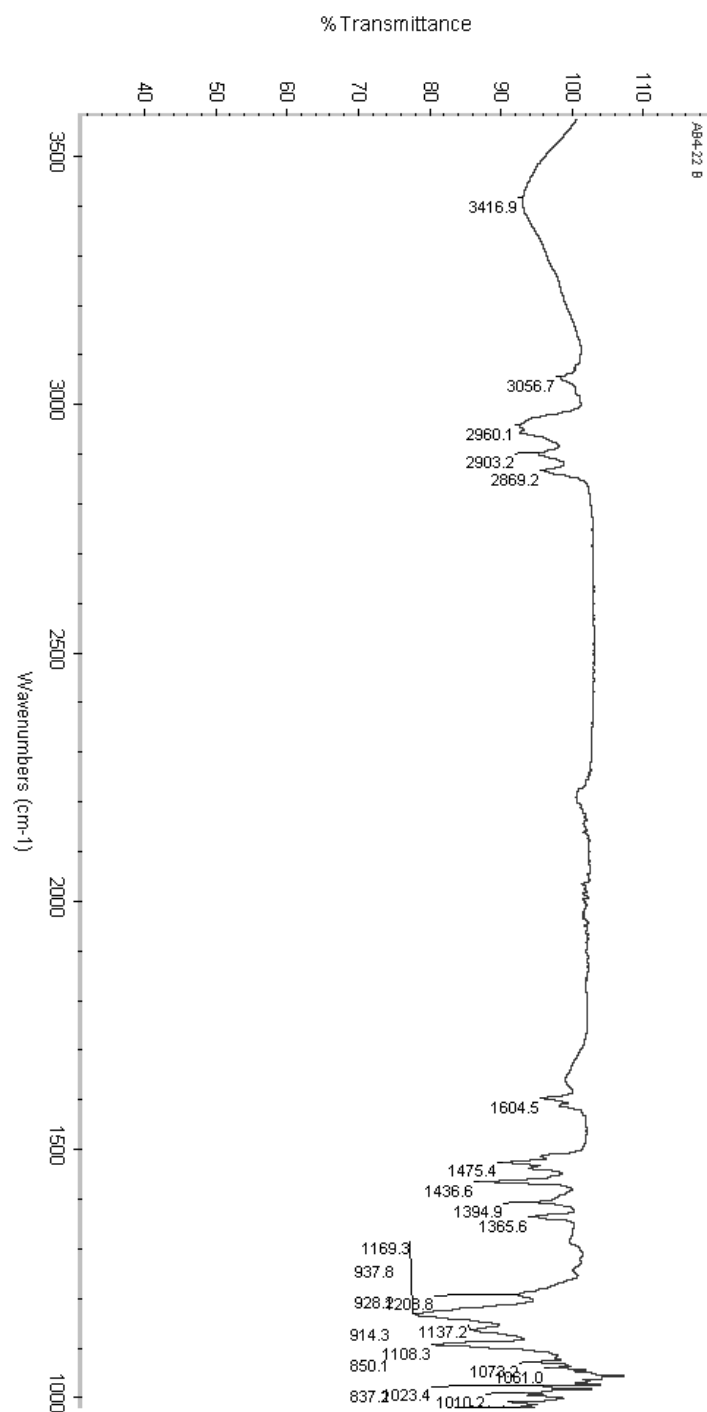
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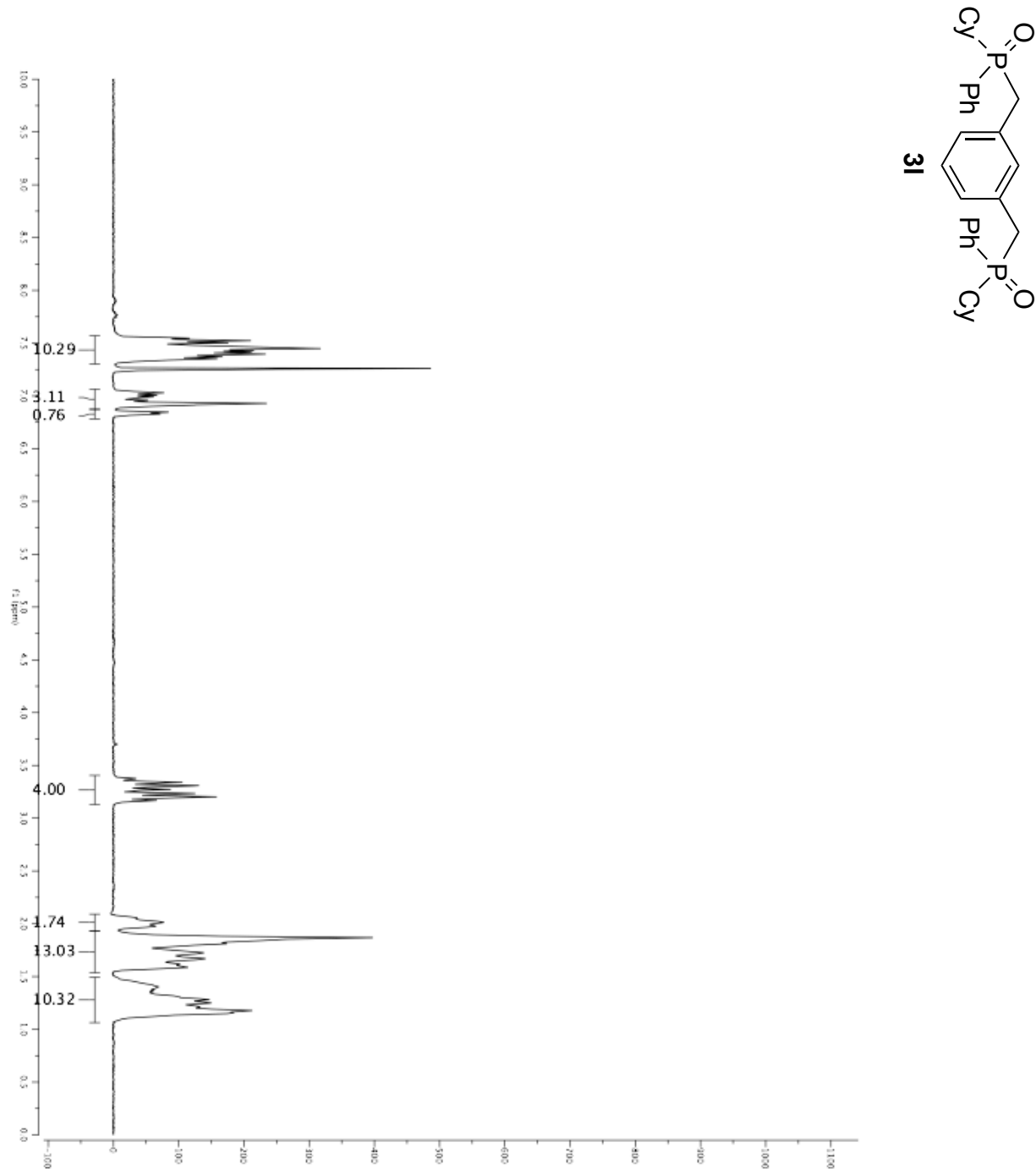
<sup>13</sup>C NMR



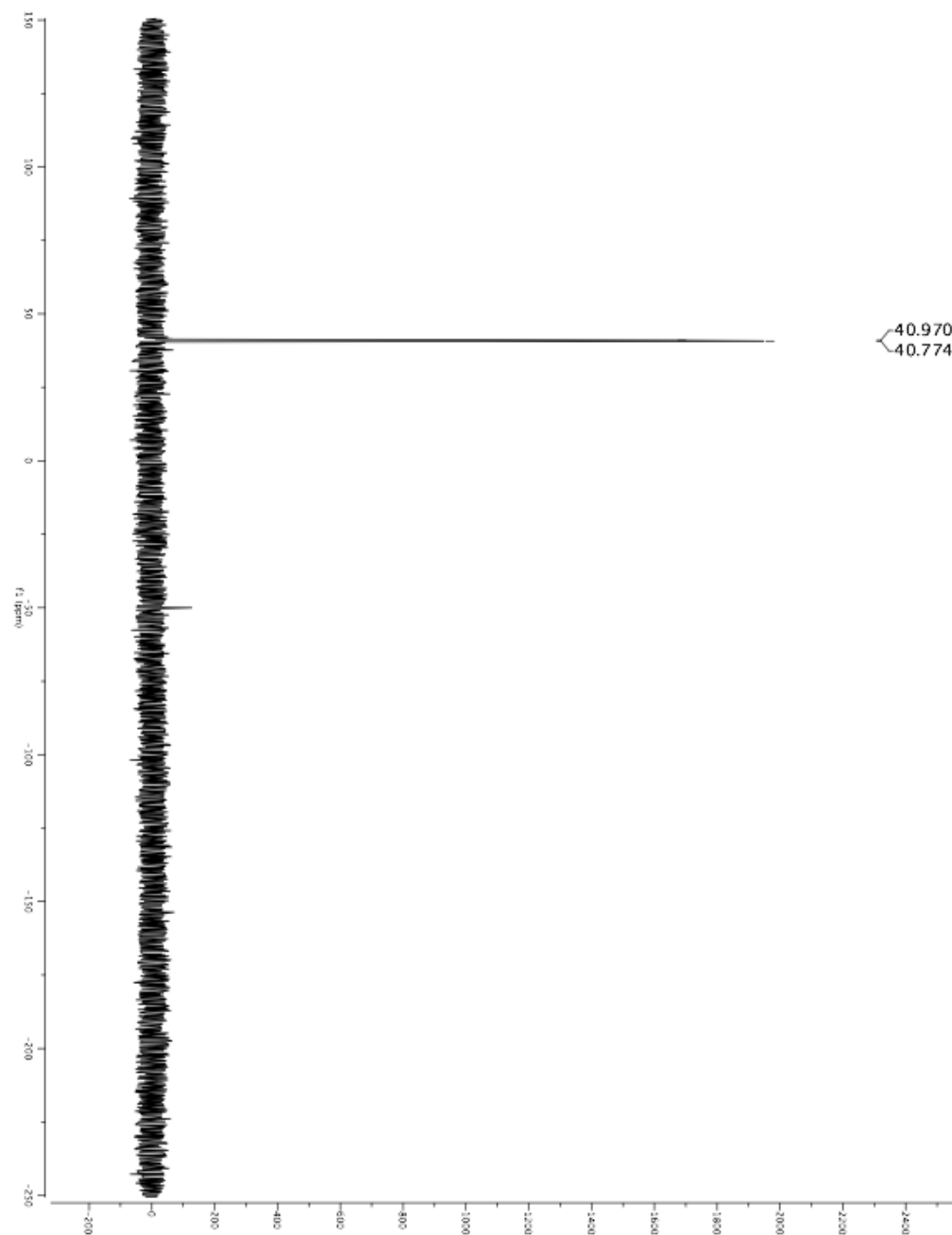
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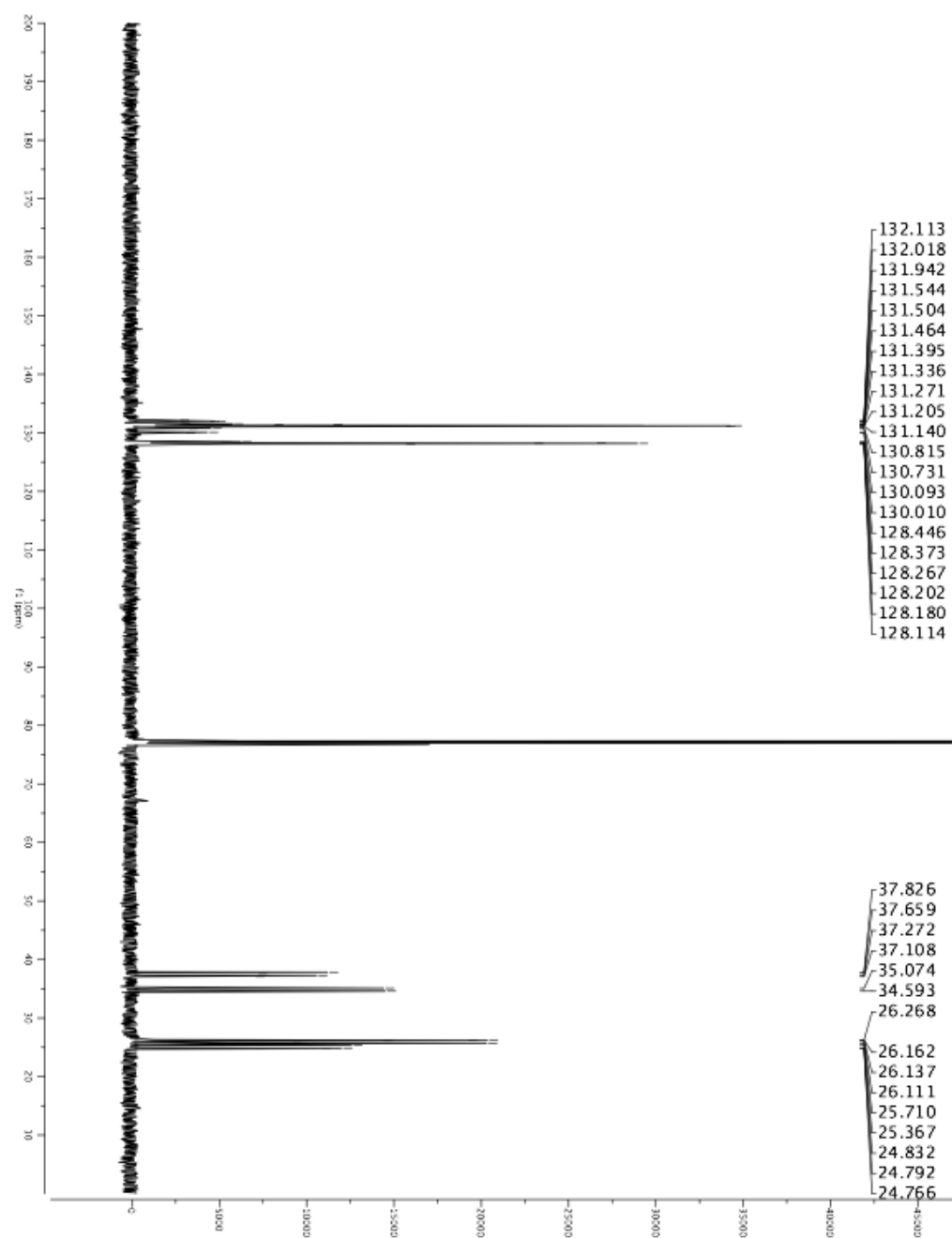
$^1\text{H}$  NMR



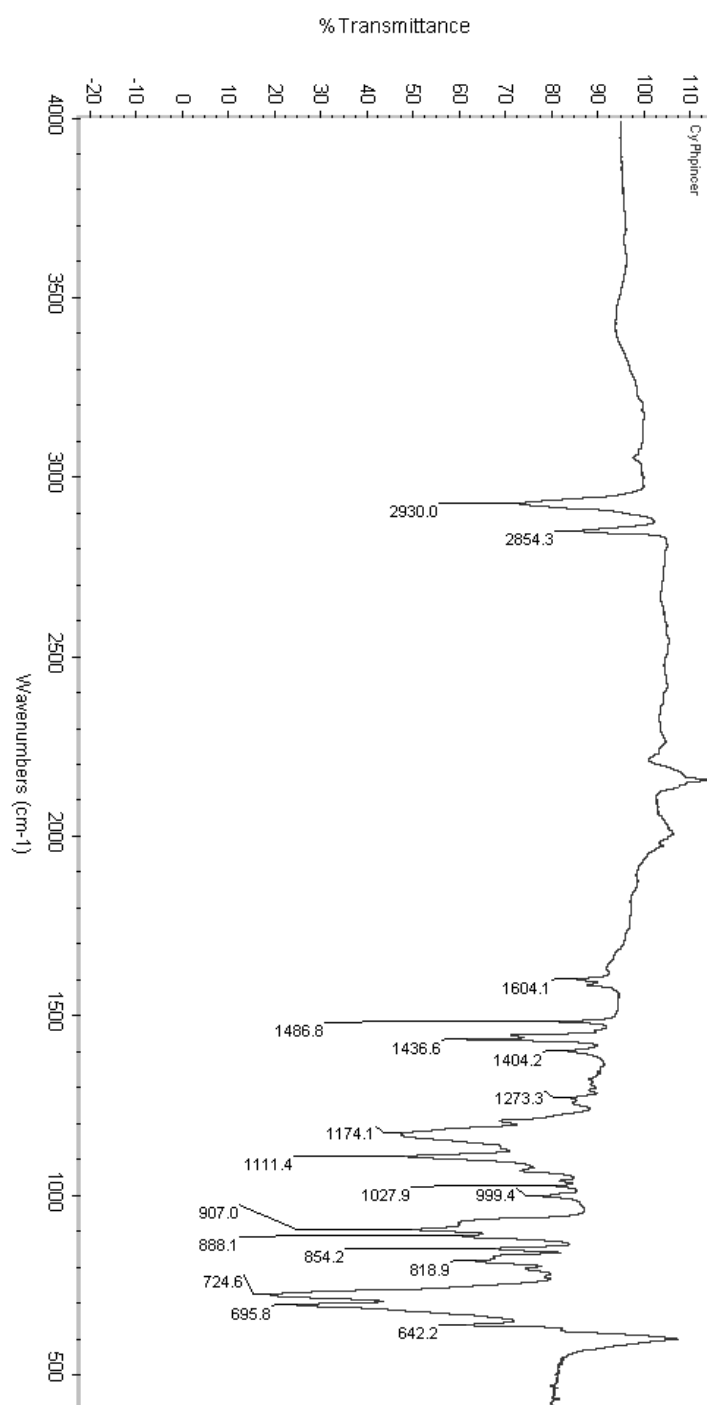
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$^{13}\text{C}$  NMR

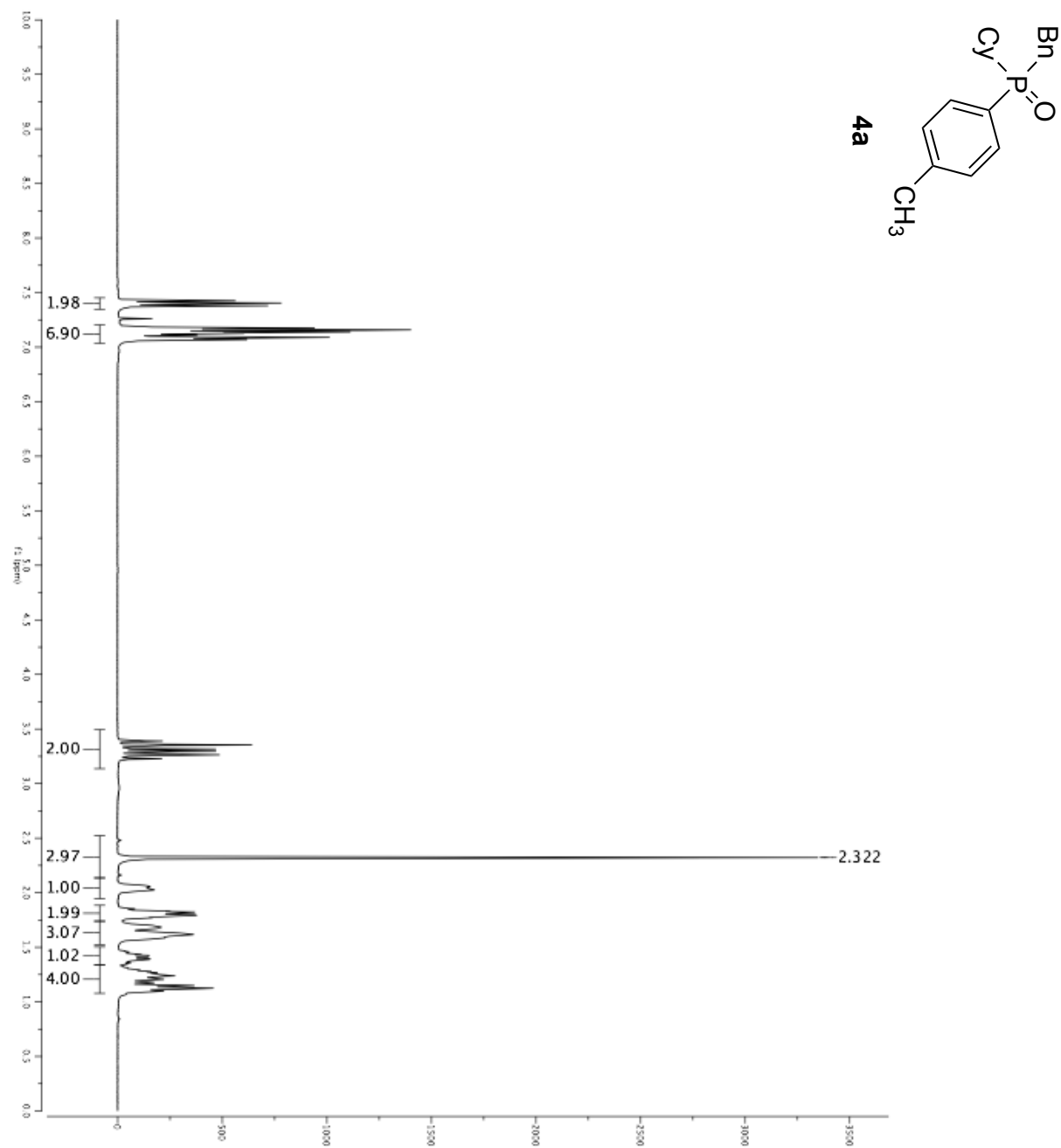


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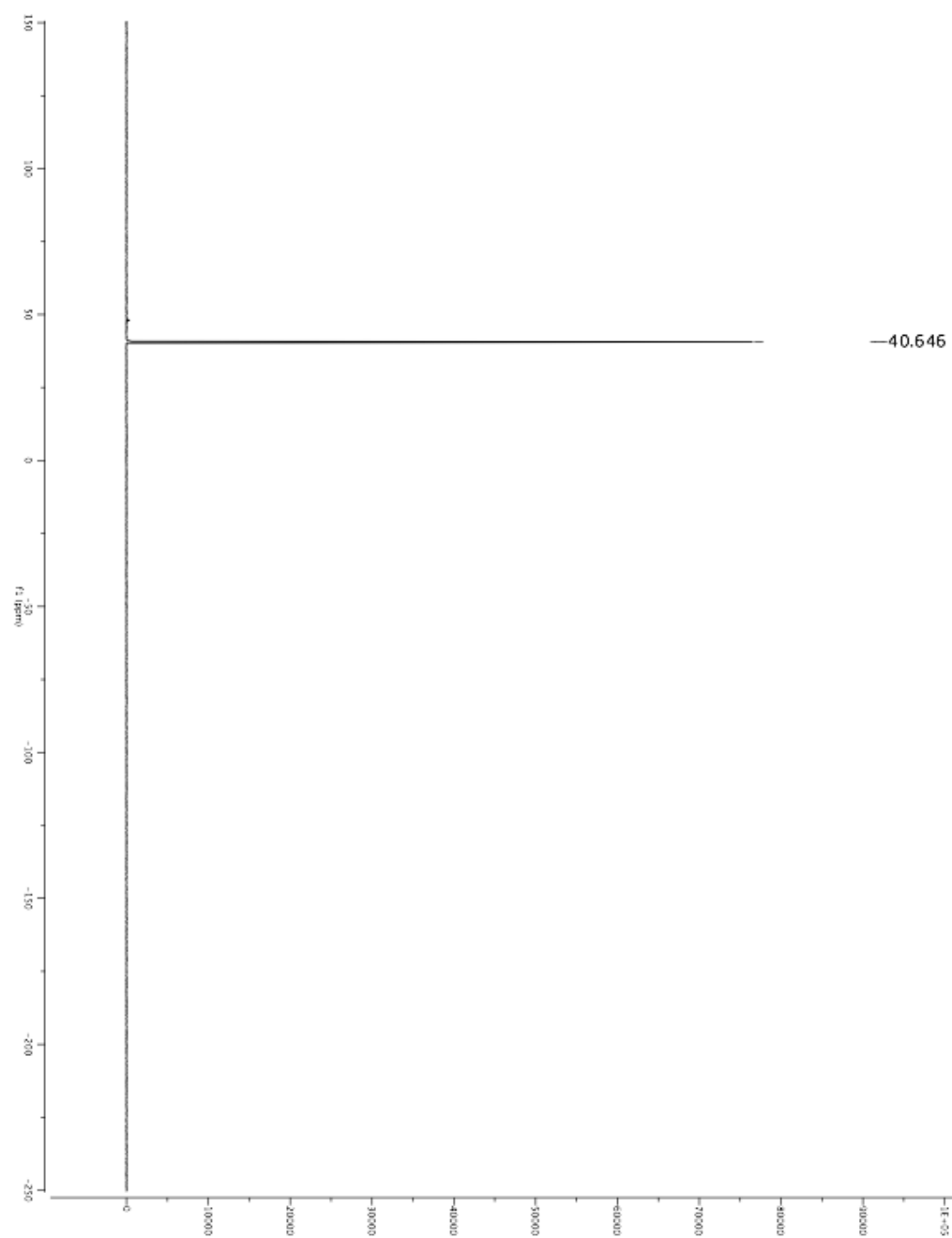




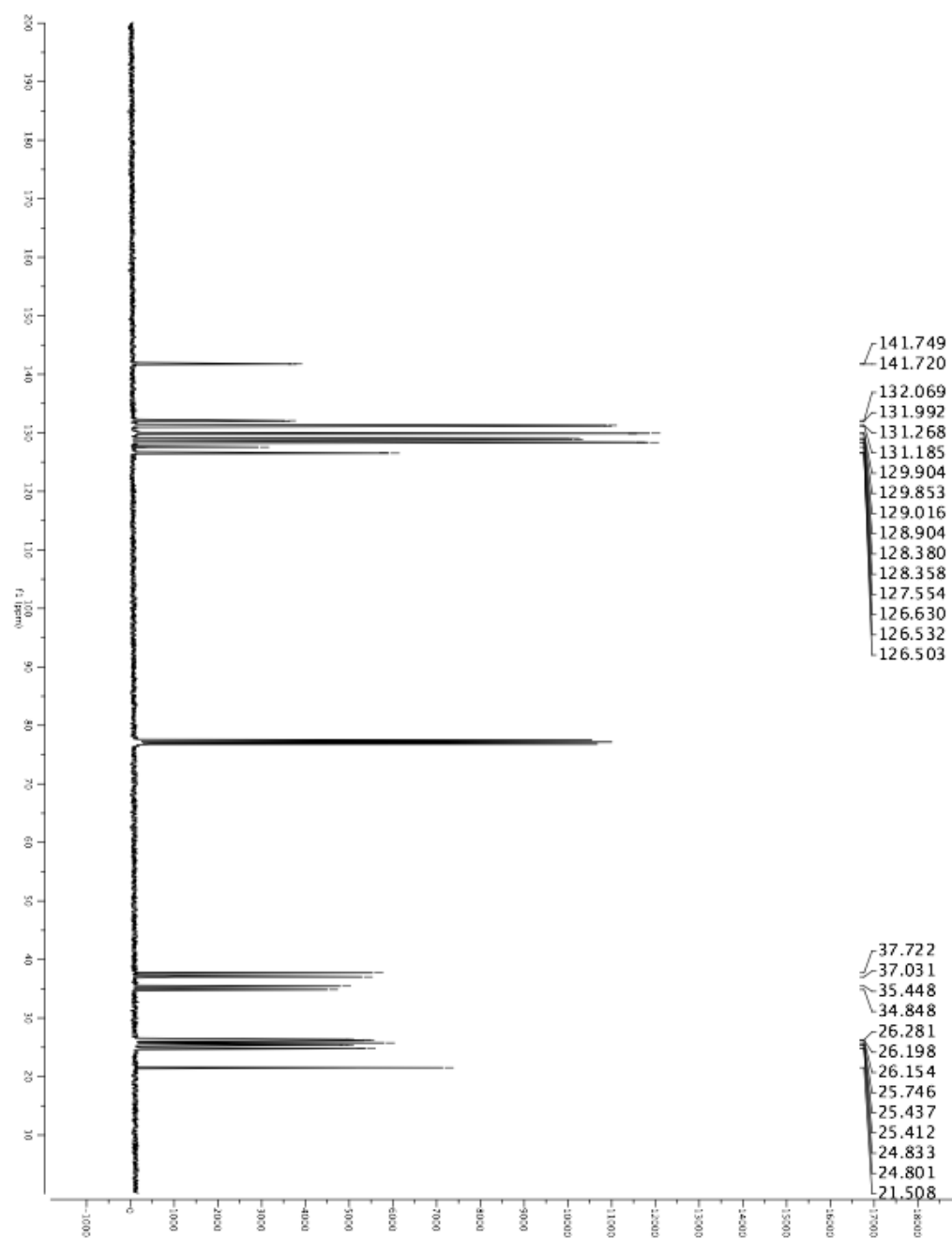
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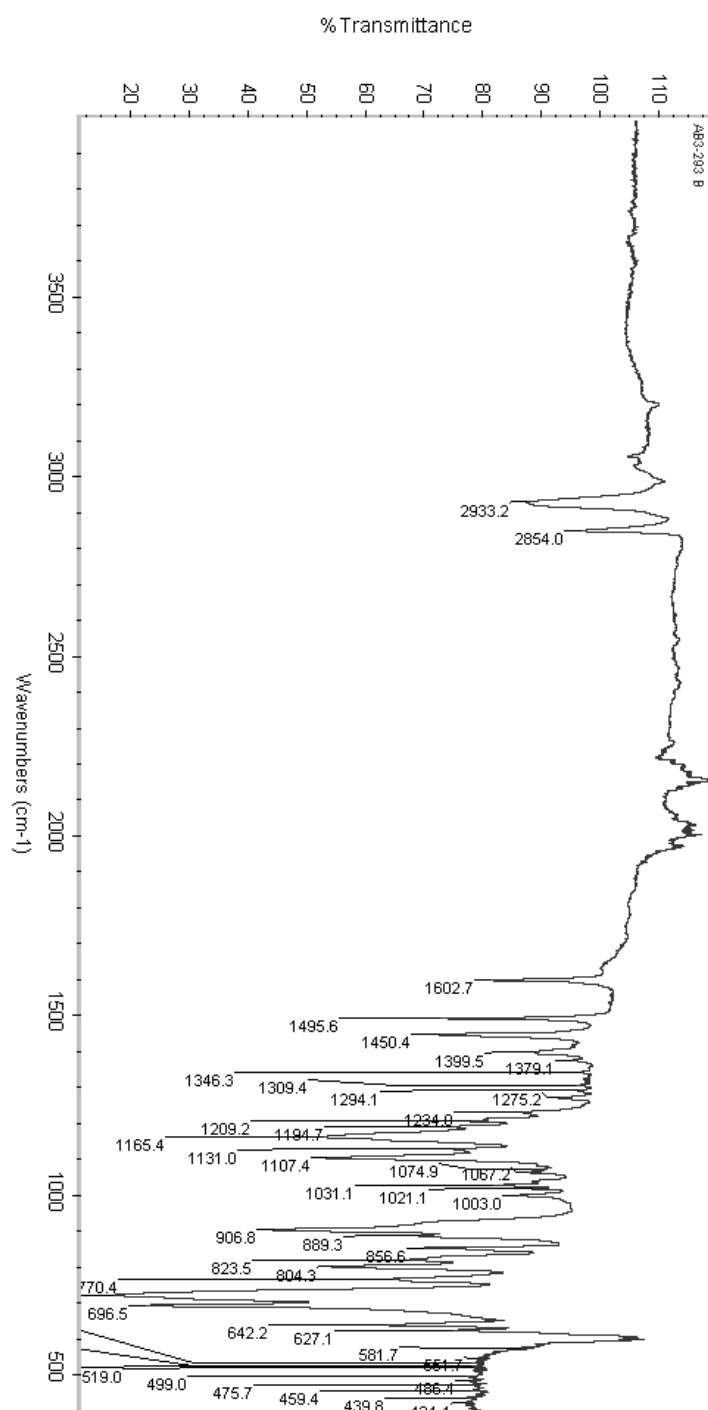
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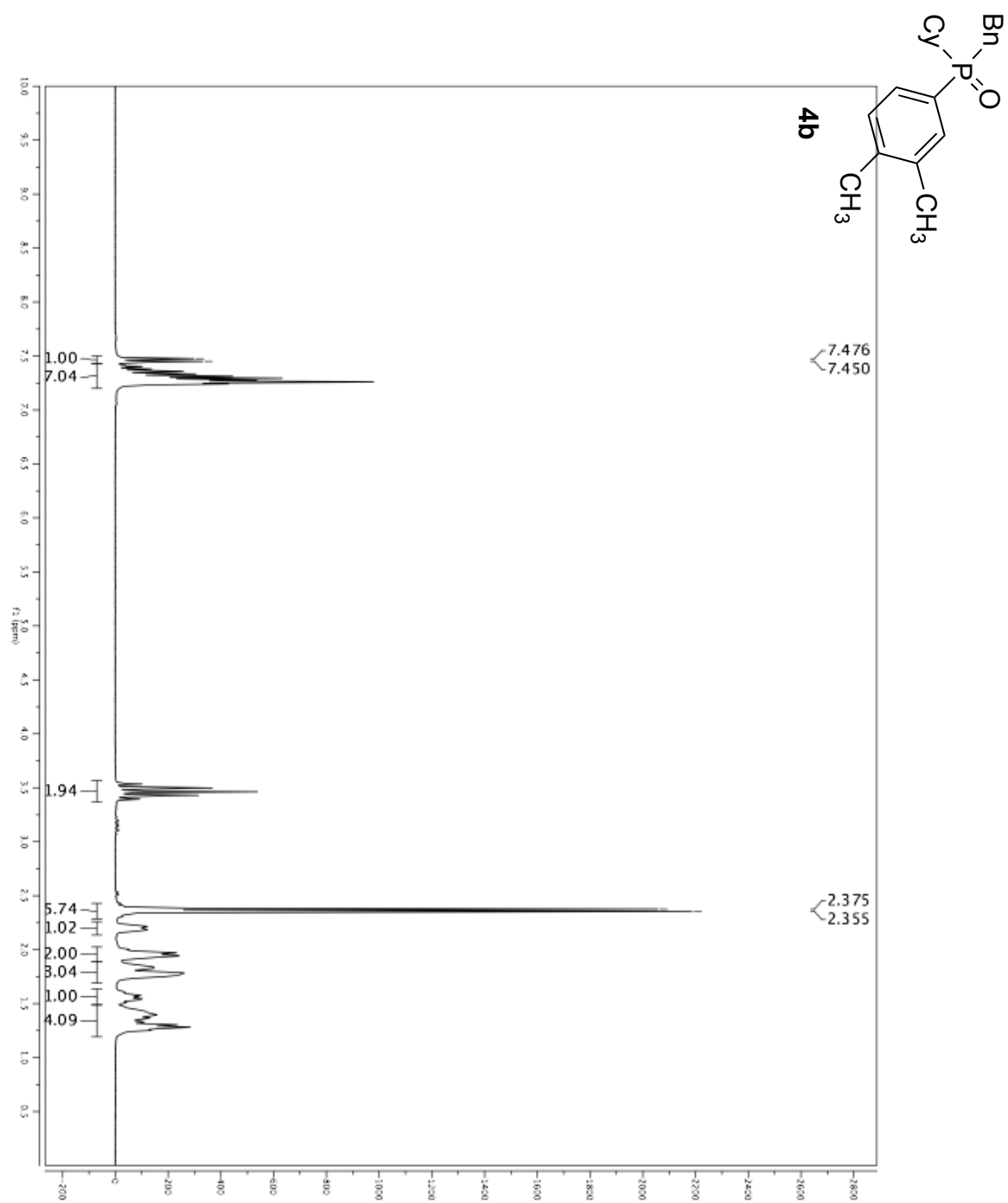
<sup>13</sup>C NMR



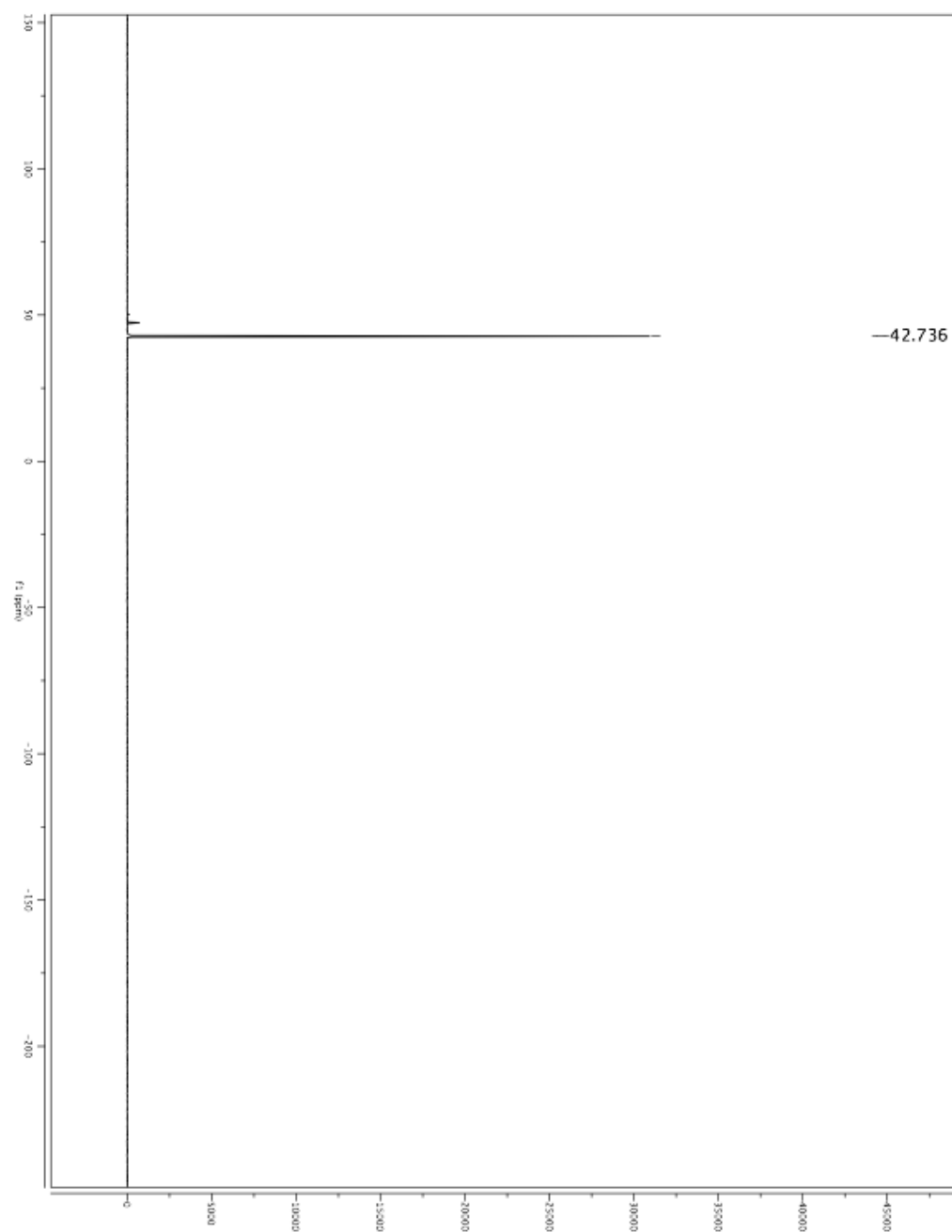
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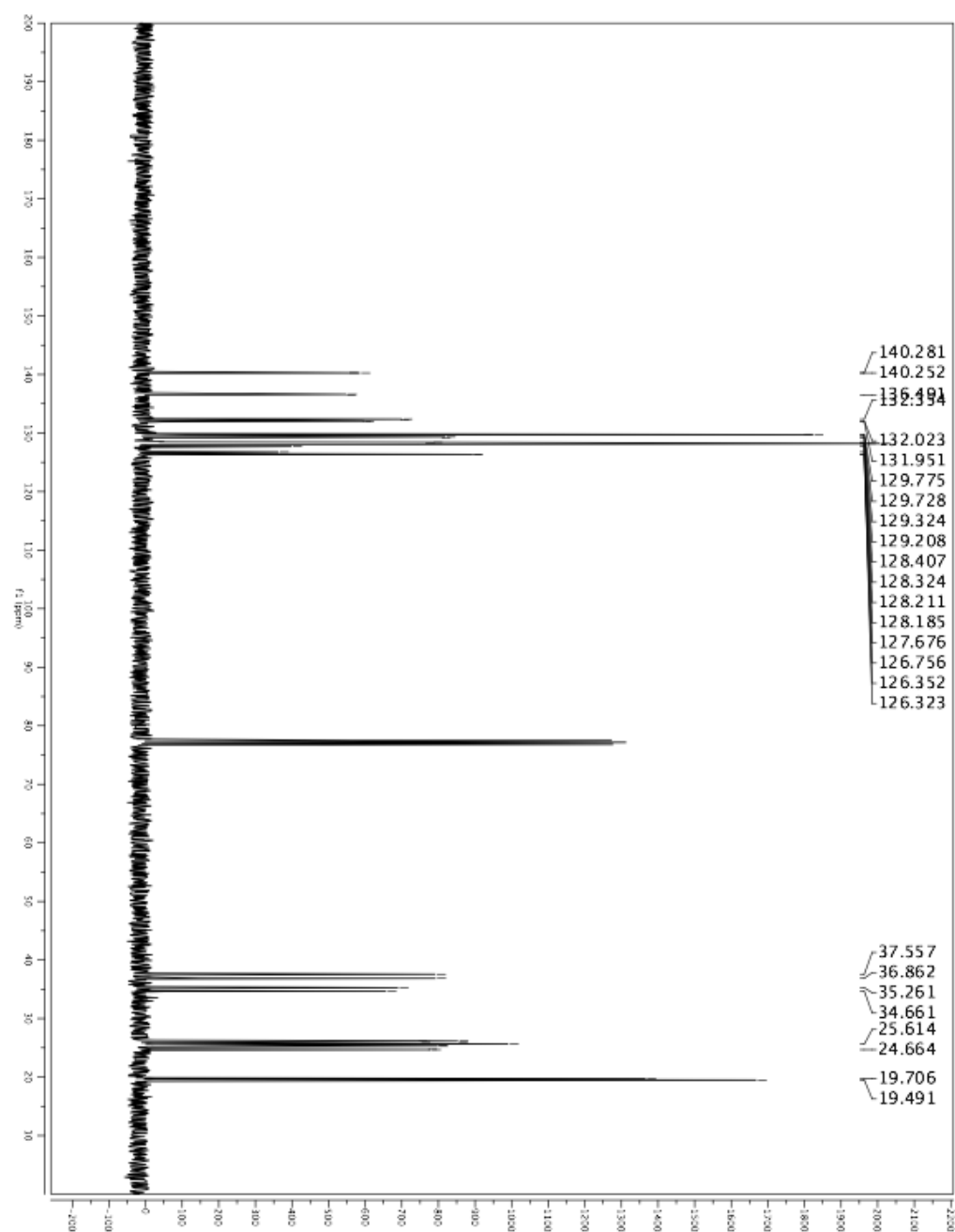
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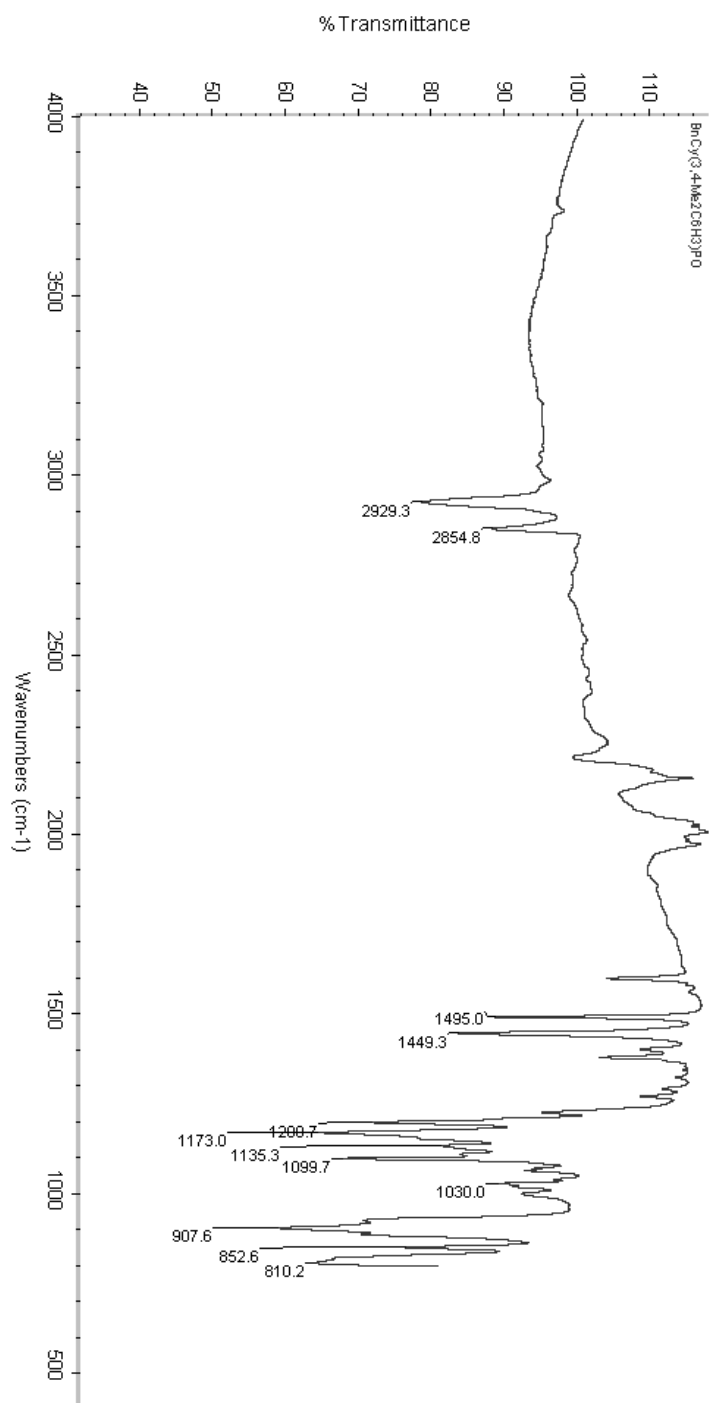
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<sup>13</sup>C NMR

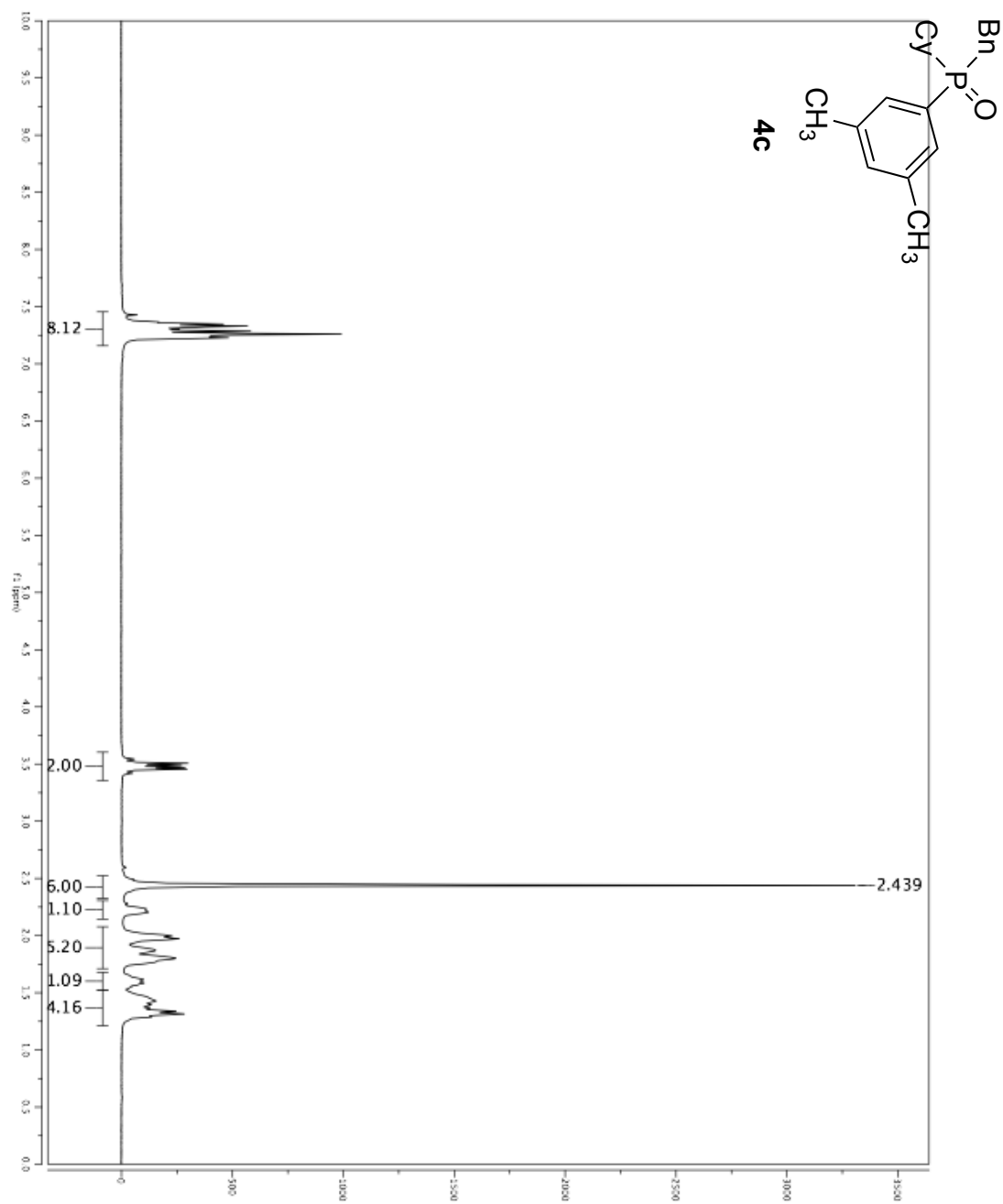


IR

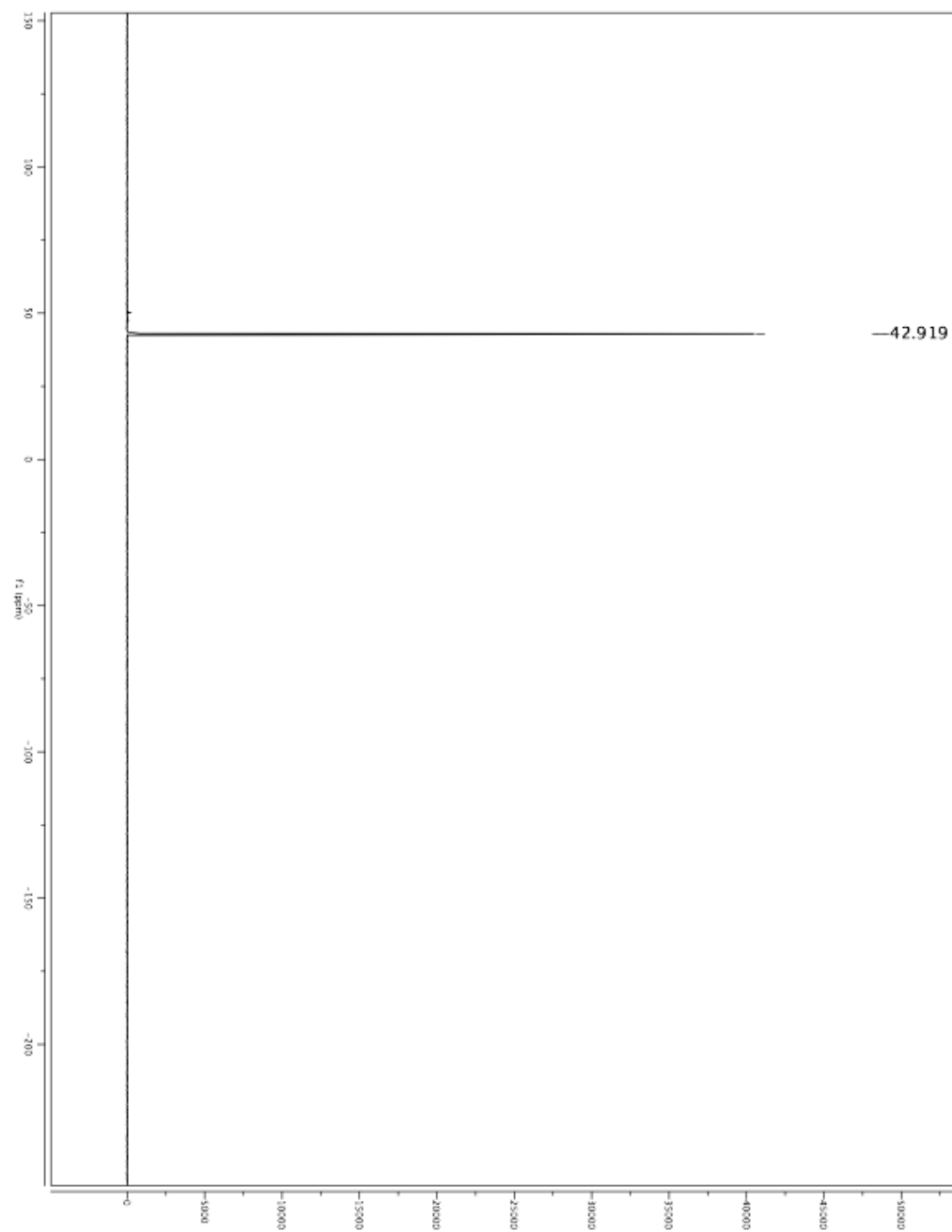




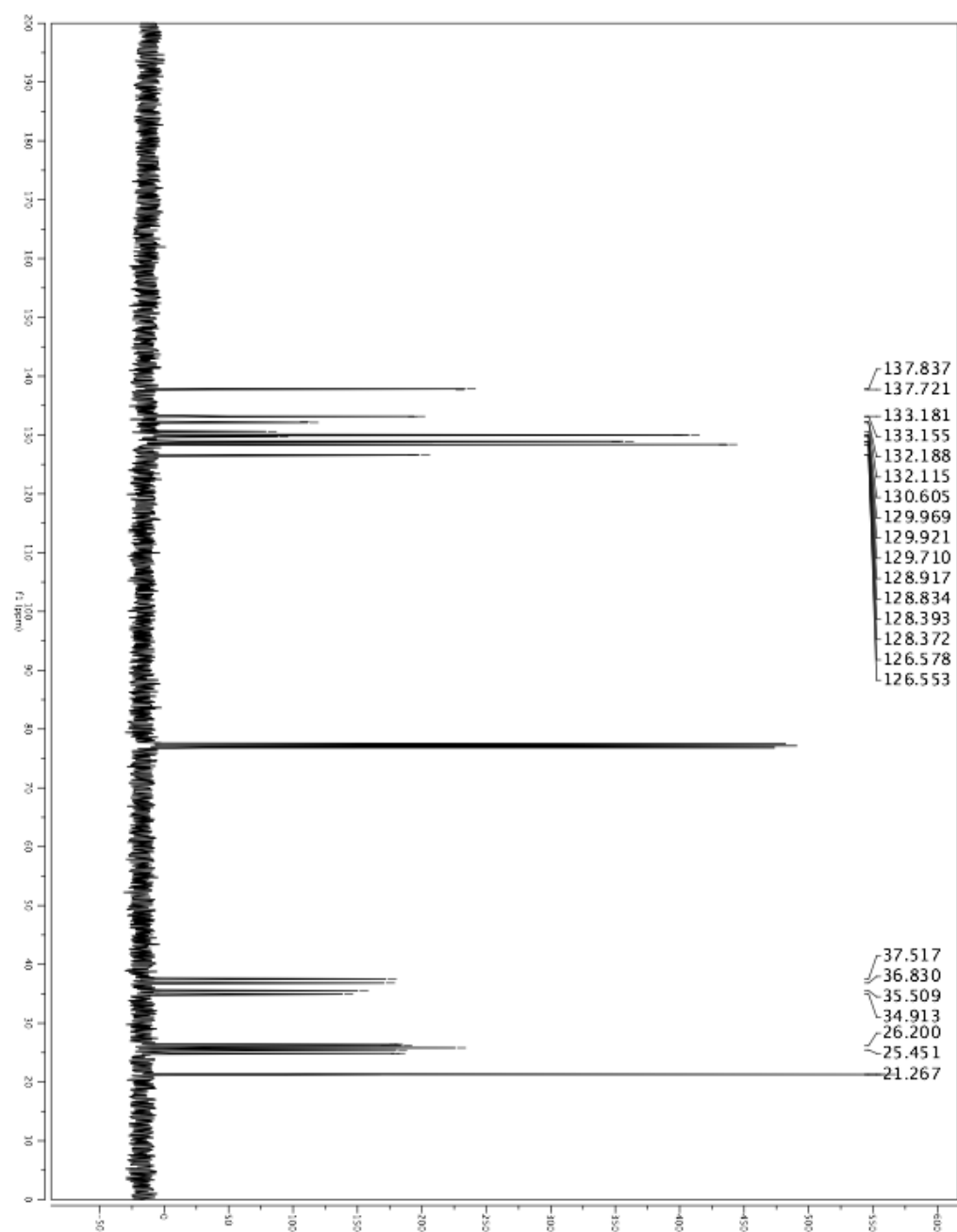
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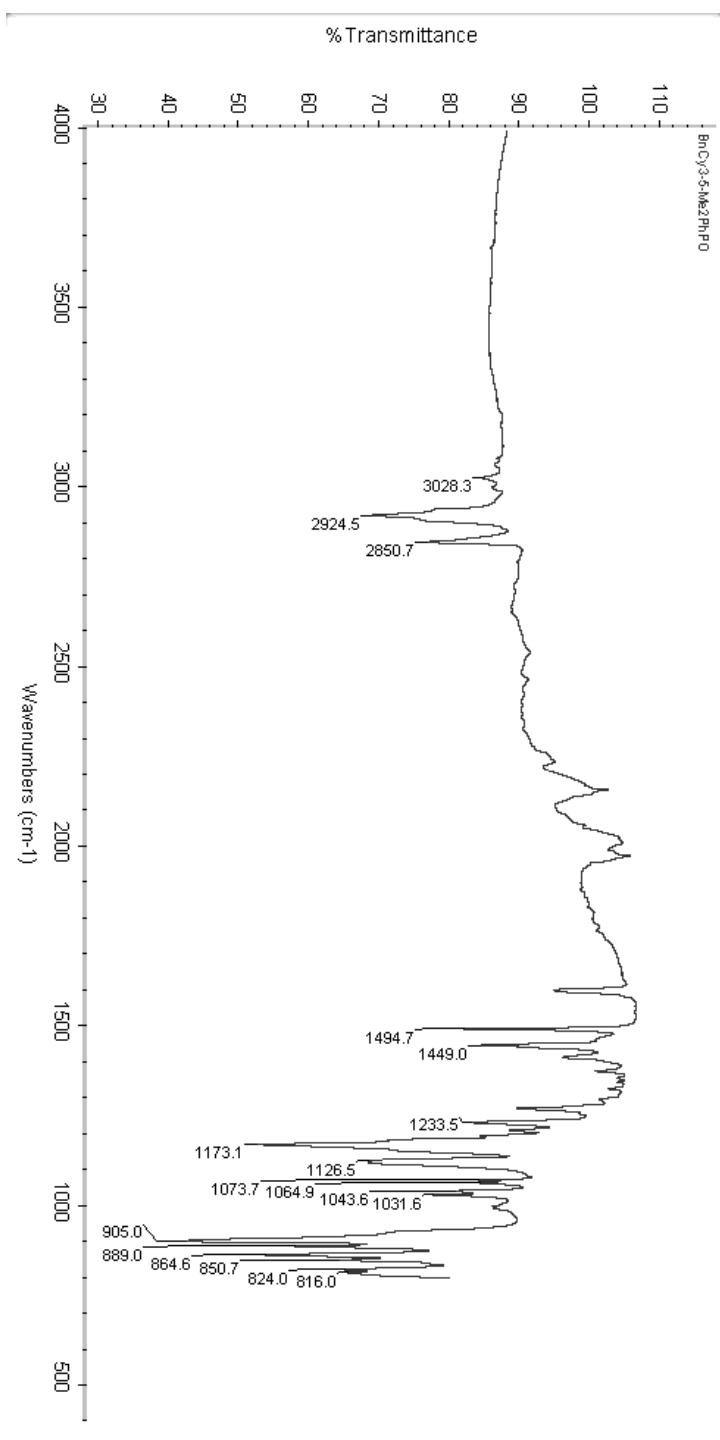
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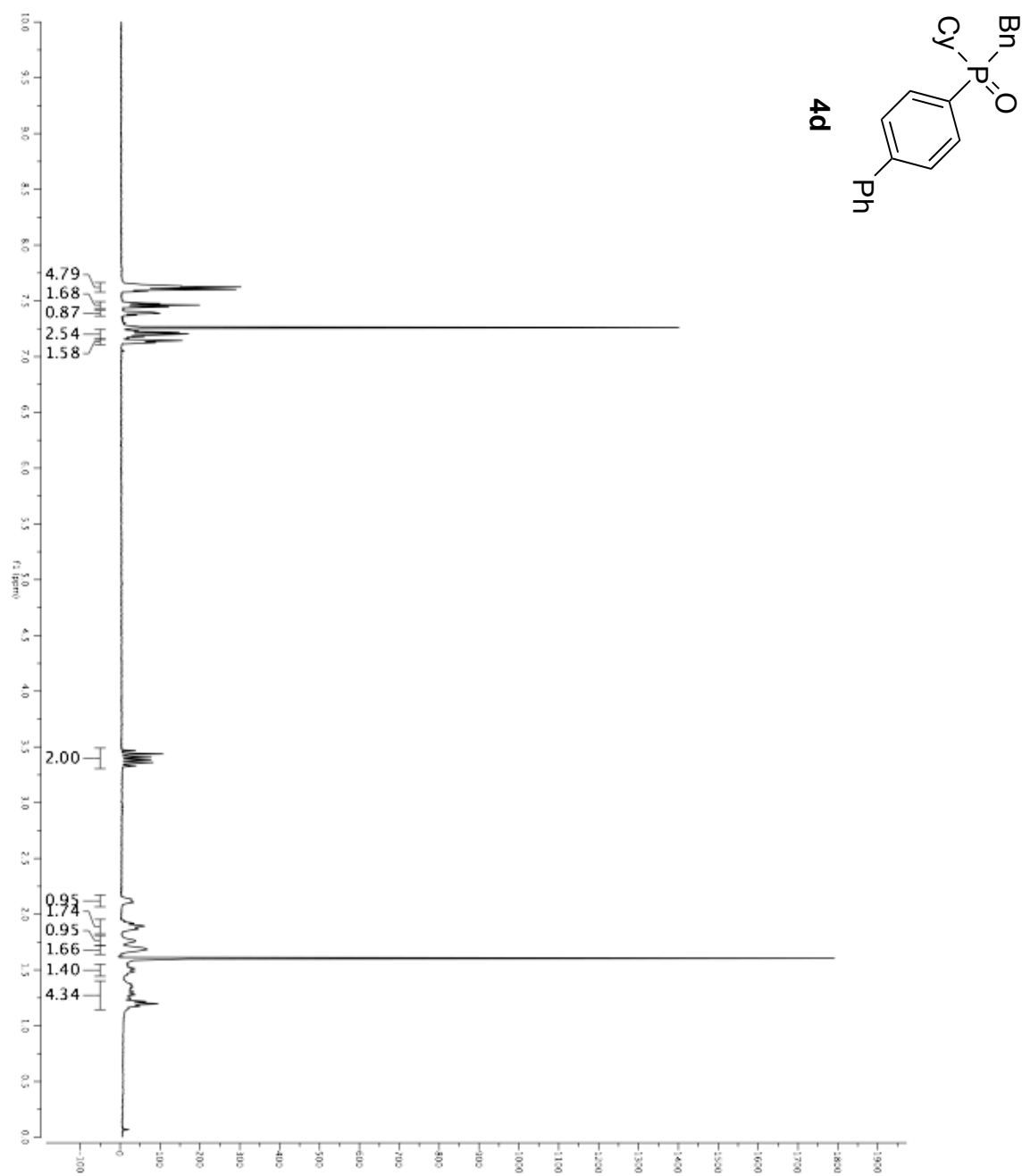
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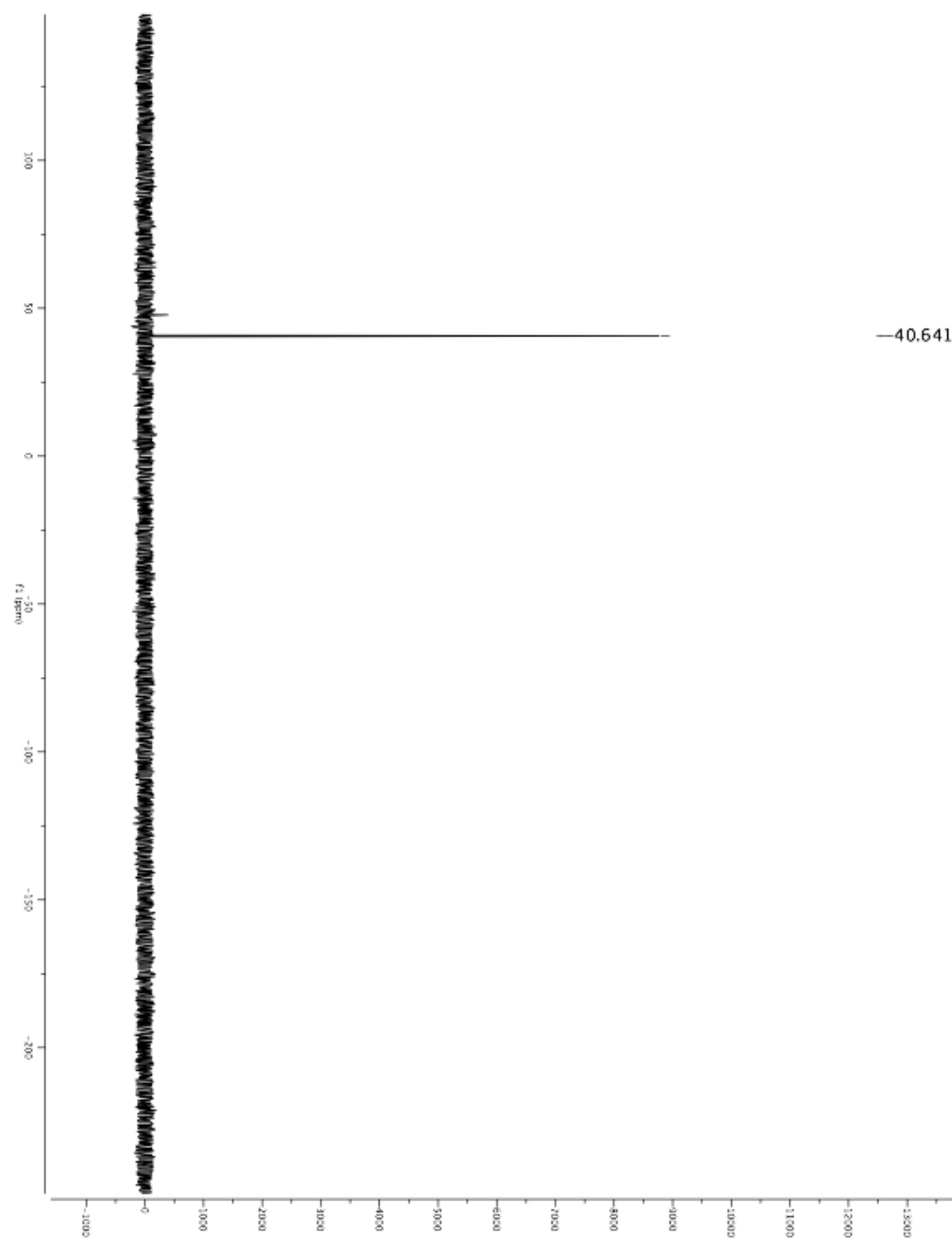
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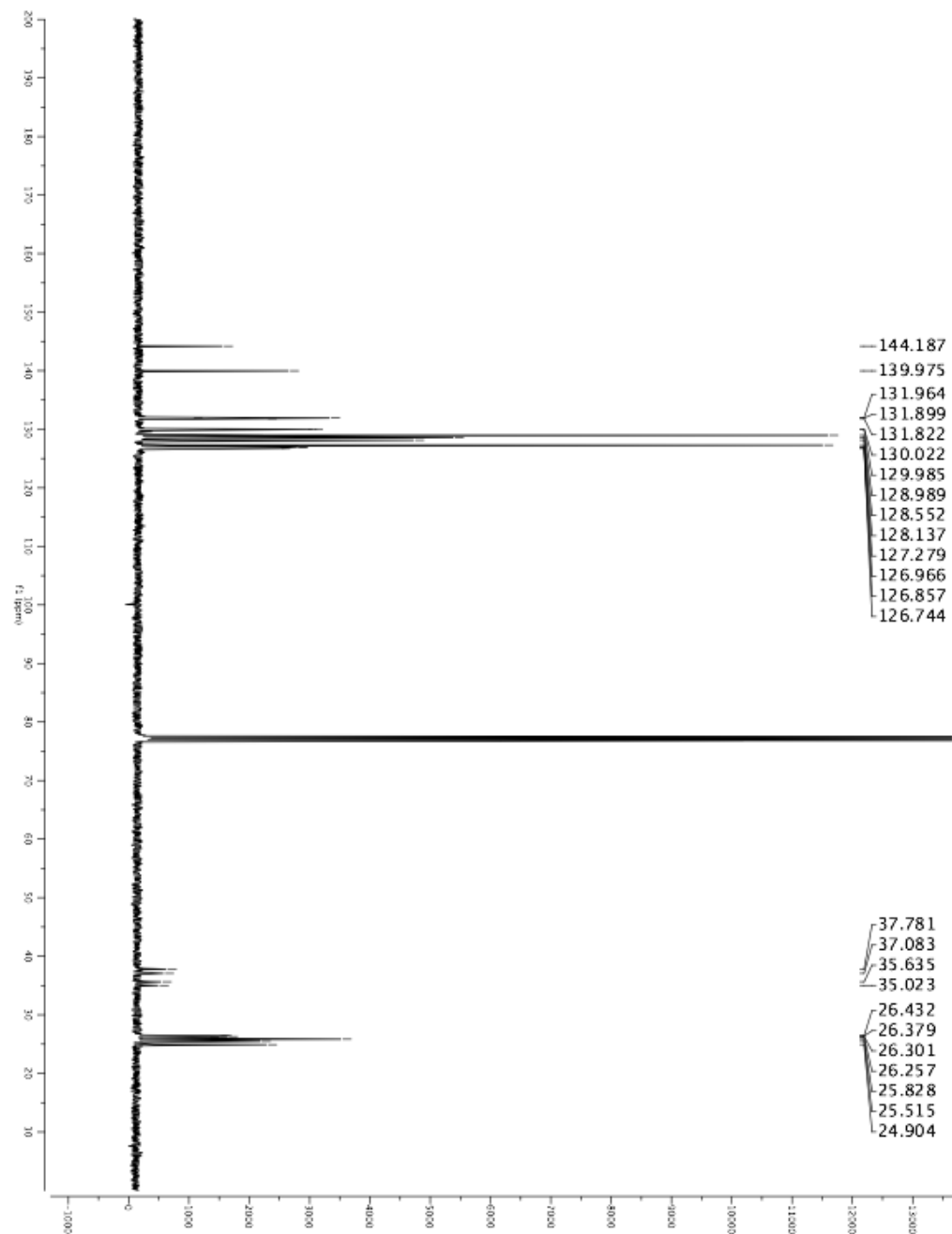
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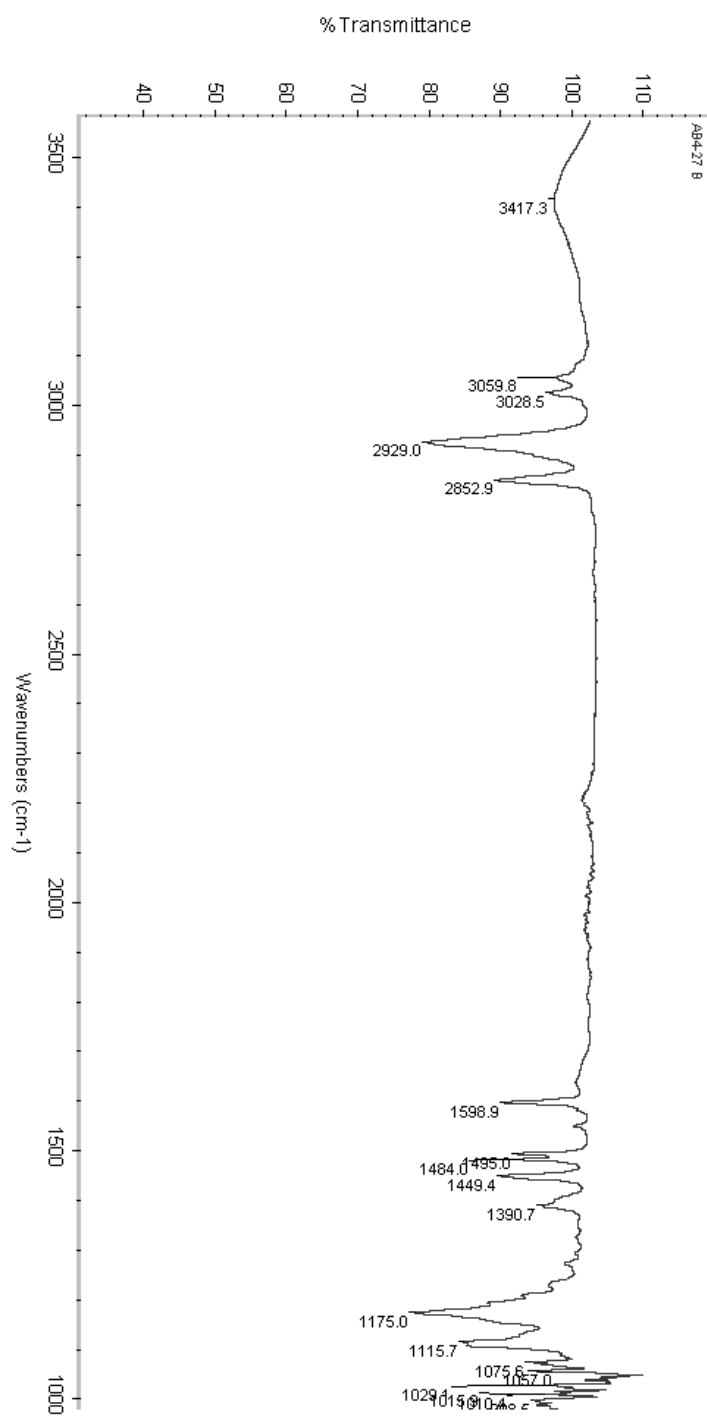
$^{31}\text{P}$  NMR



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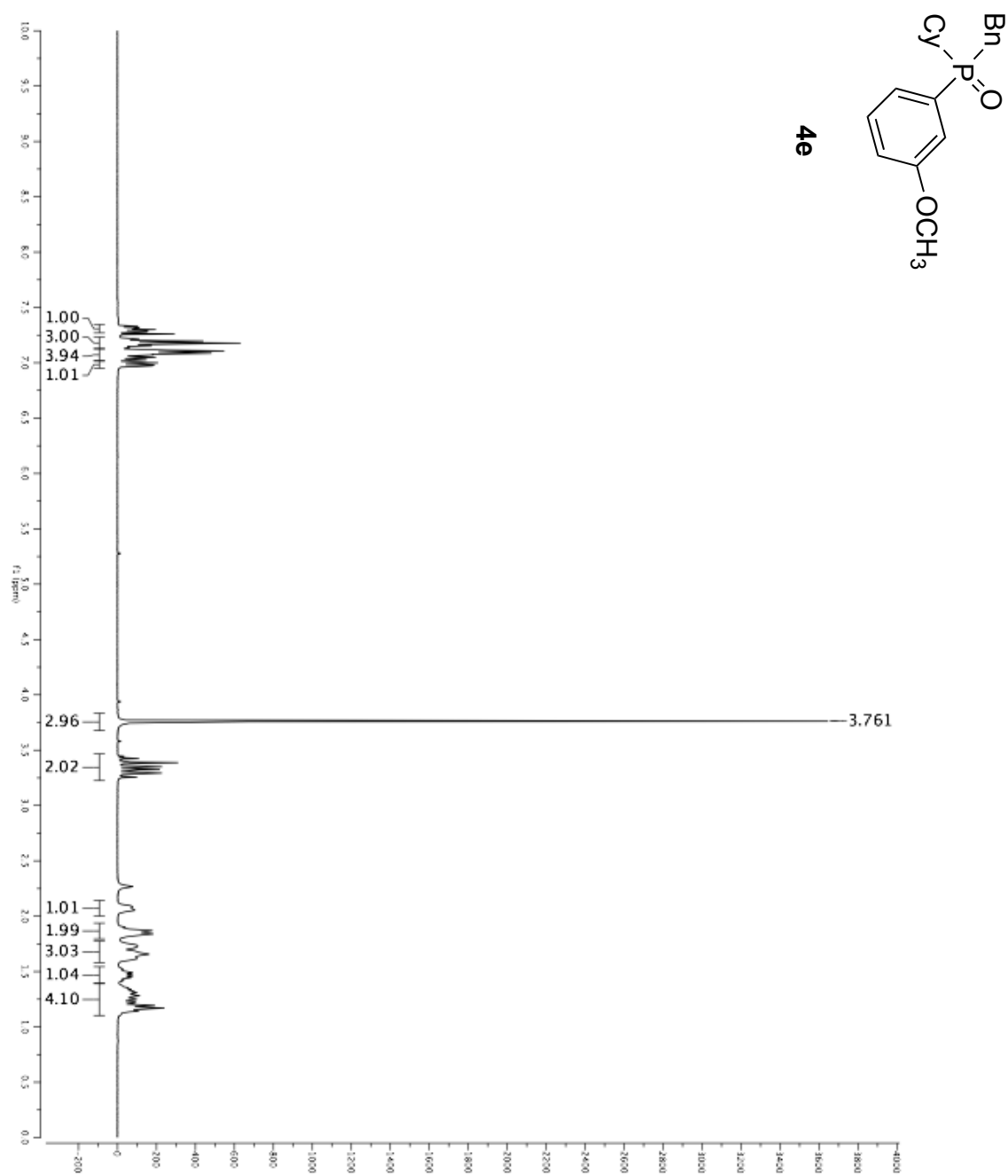


IR

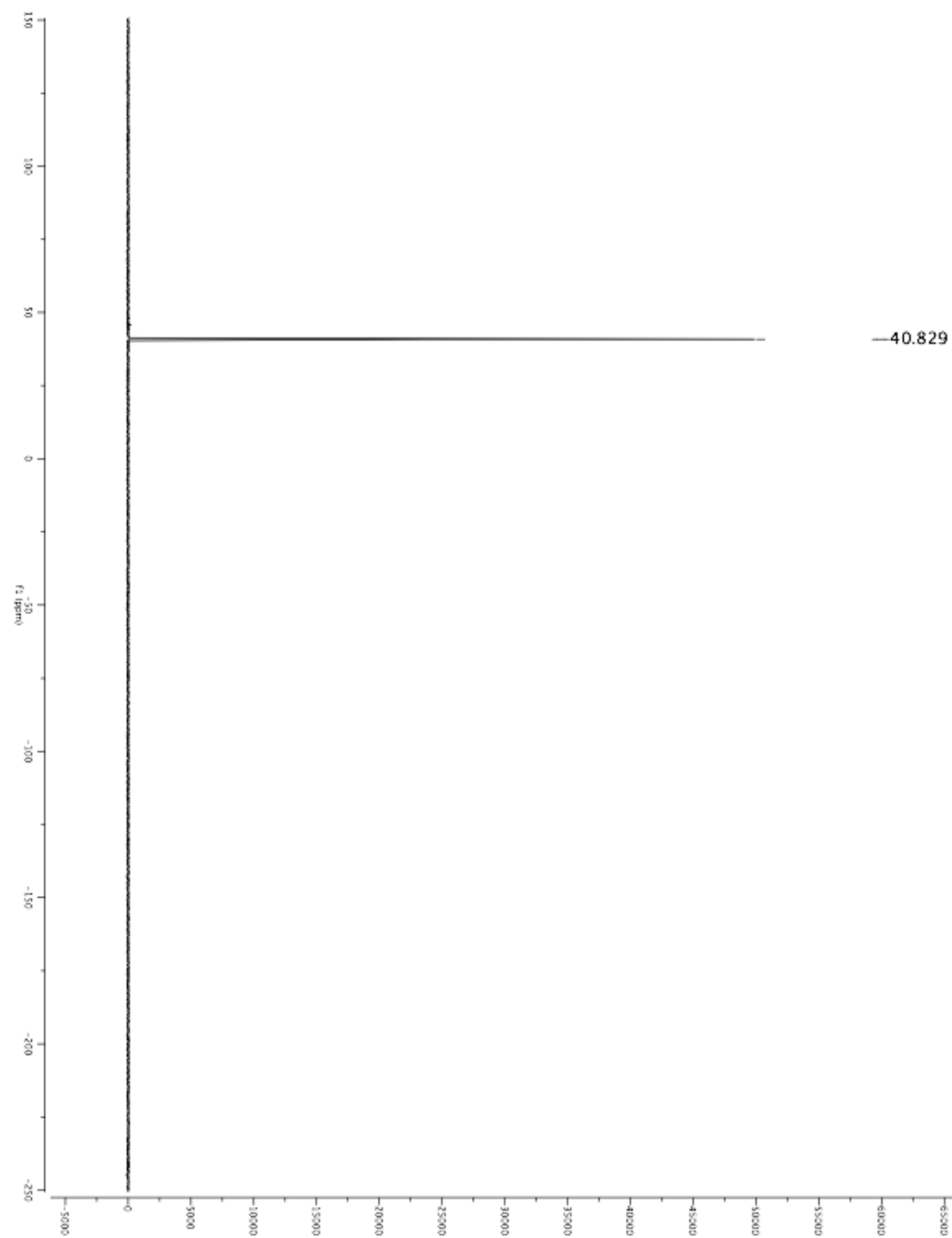




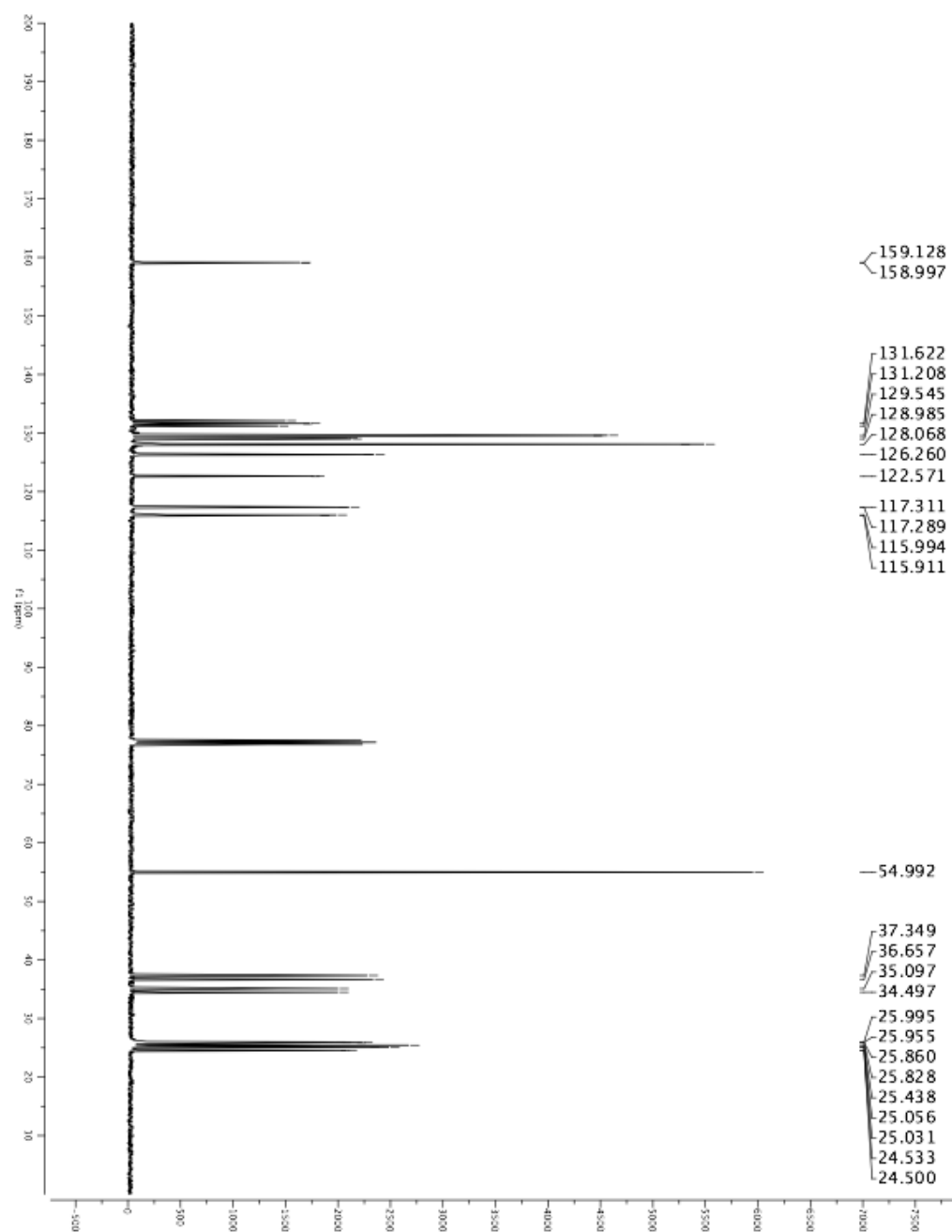
<sup>1</sup>H NMR



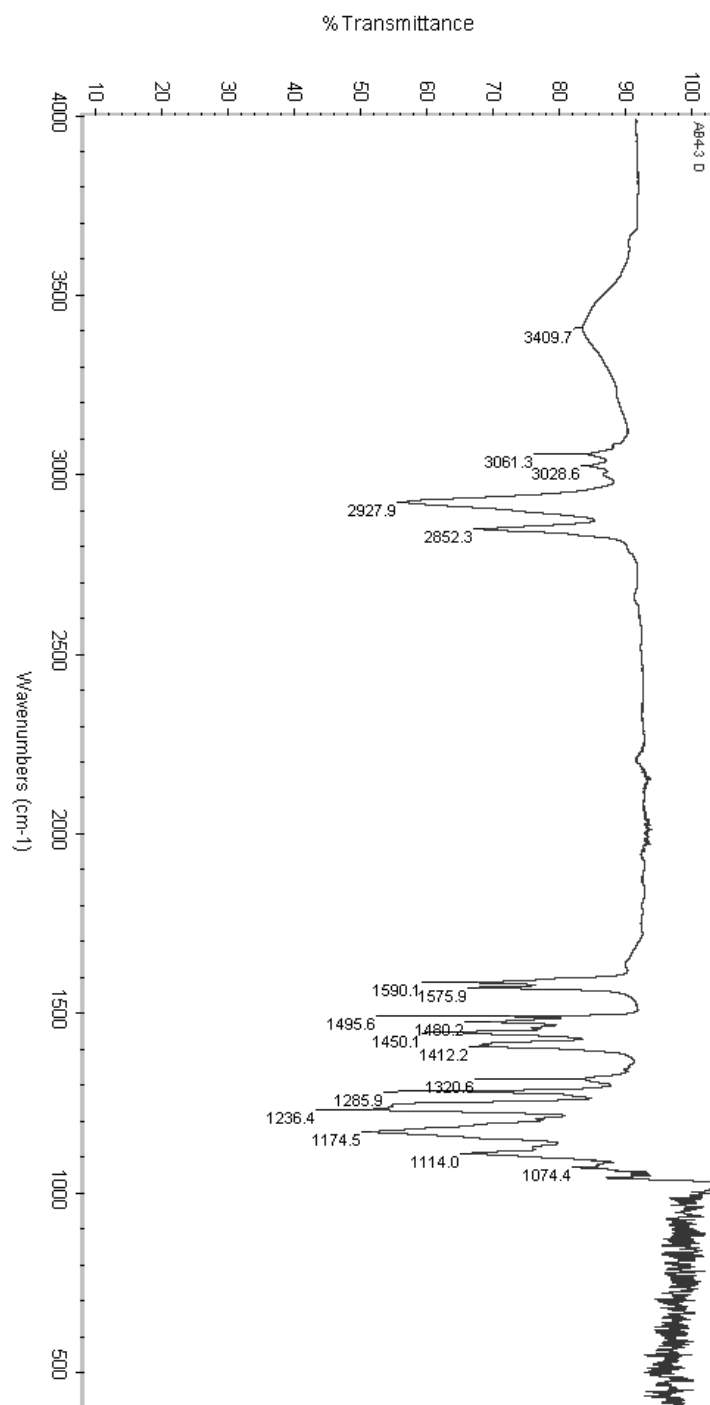
$^{31}\text{P}$  NMR



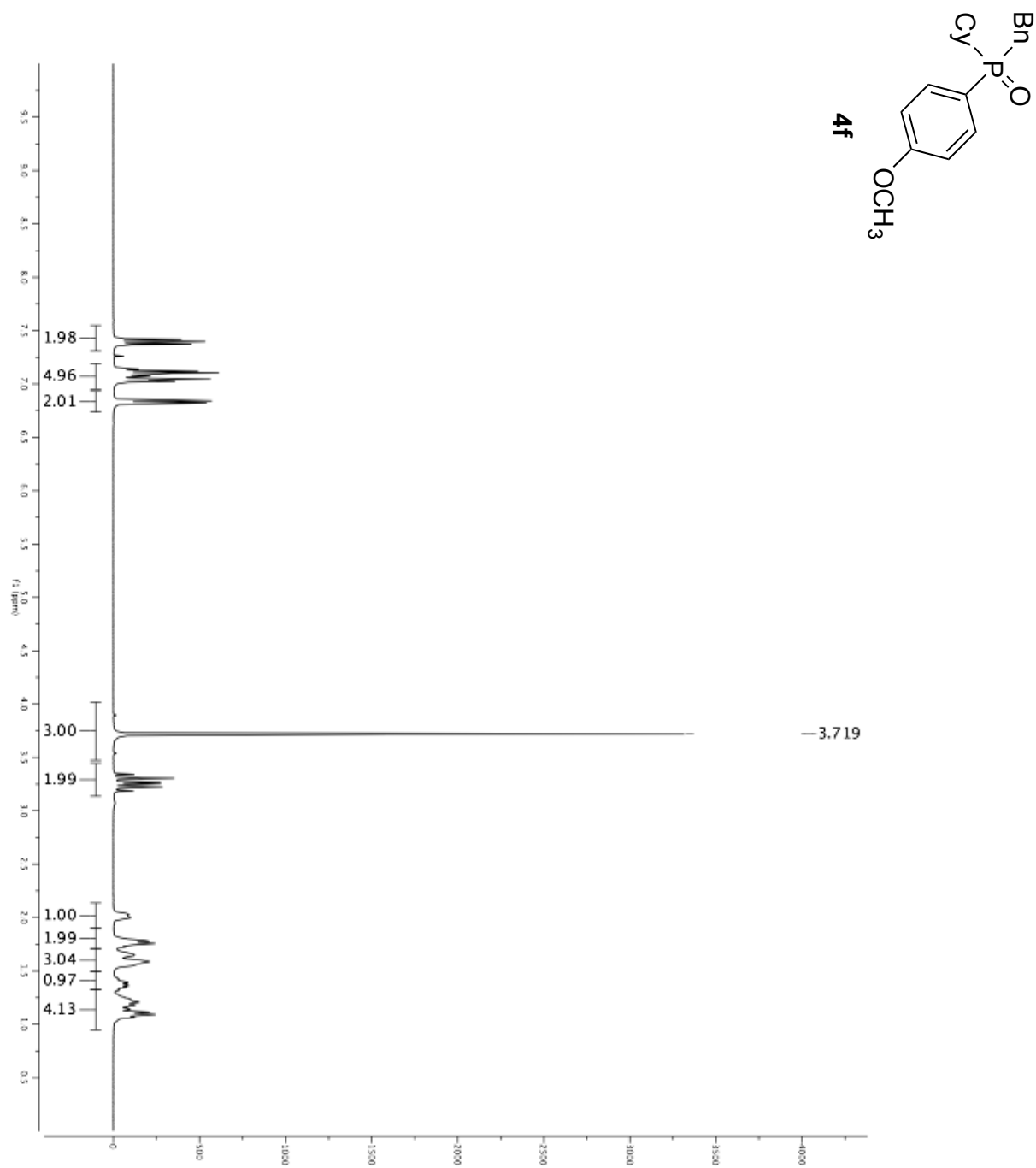
<sup>13</sup>C NMR



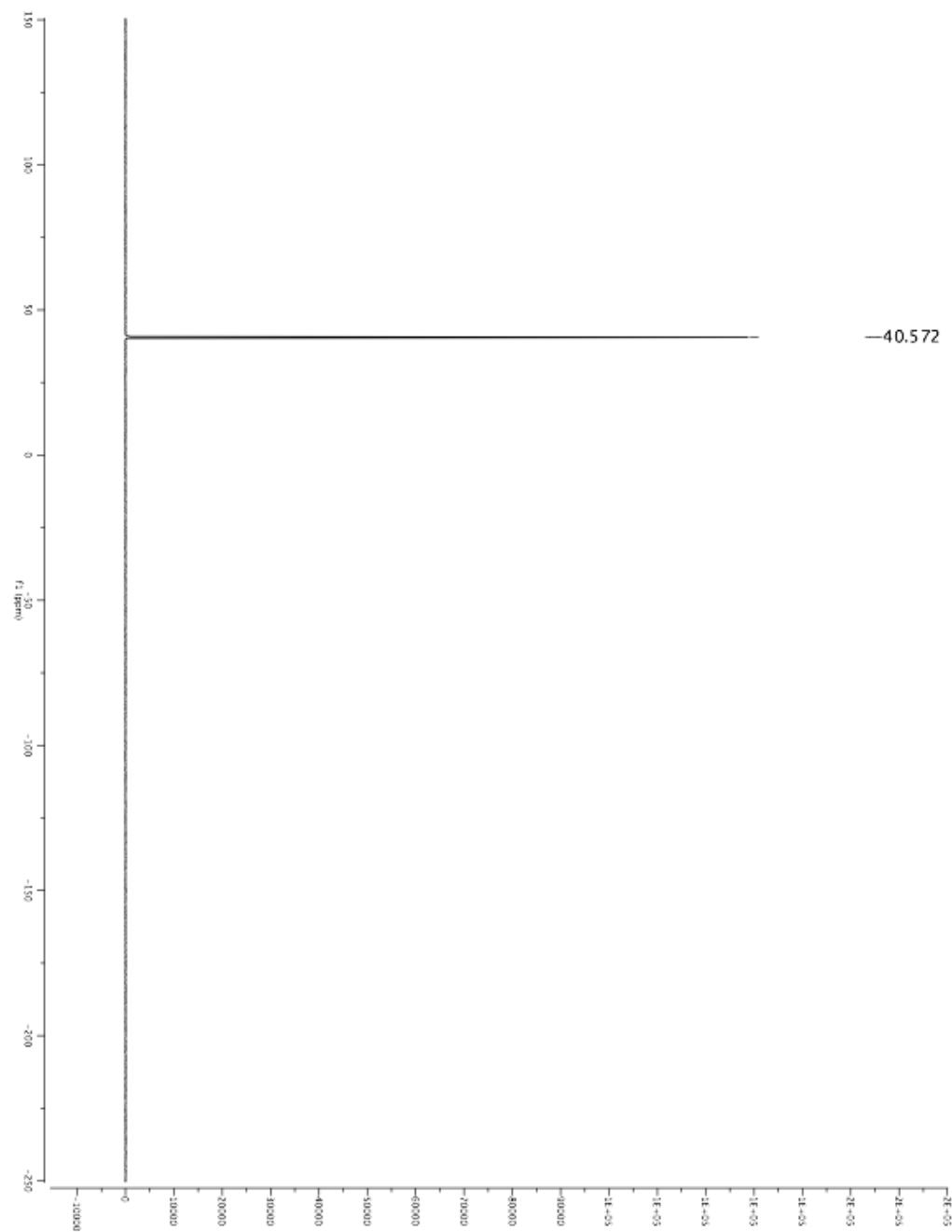
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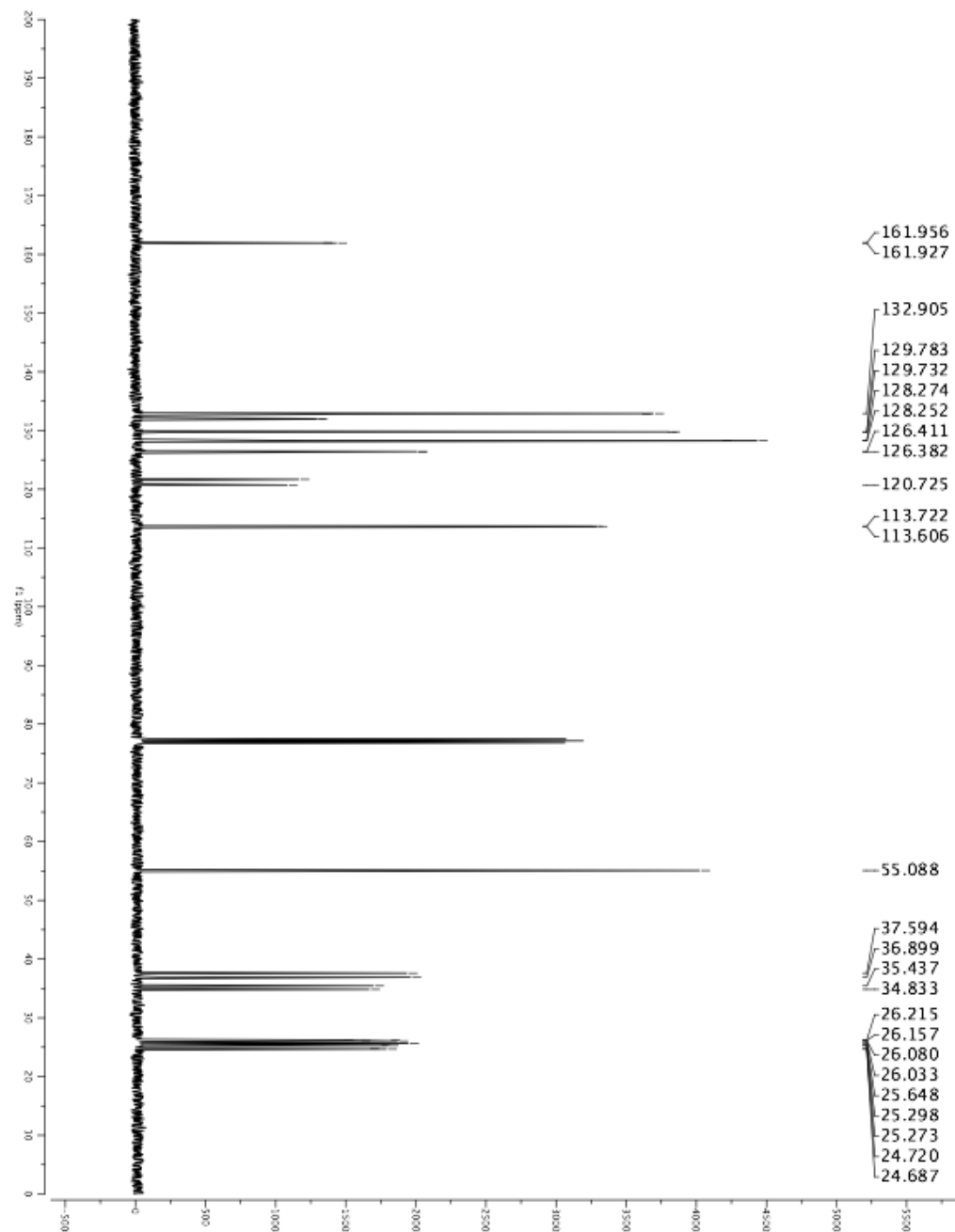
<sup>1</sup>H NMR



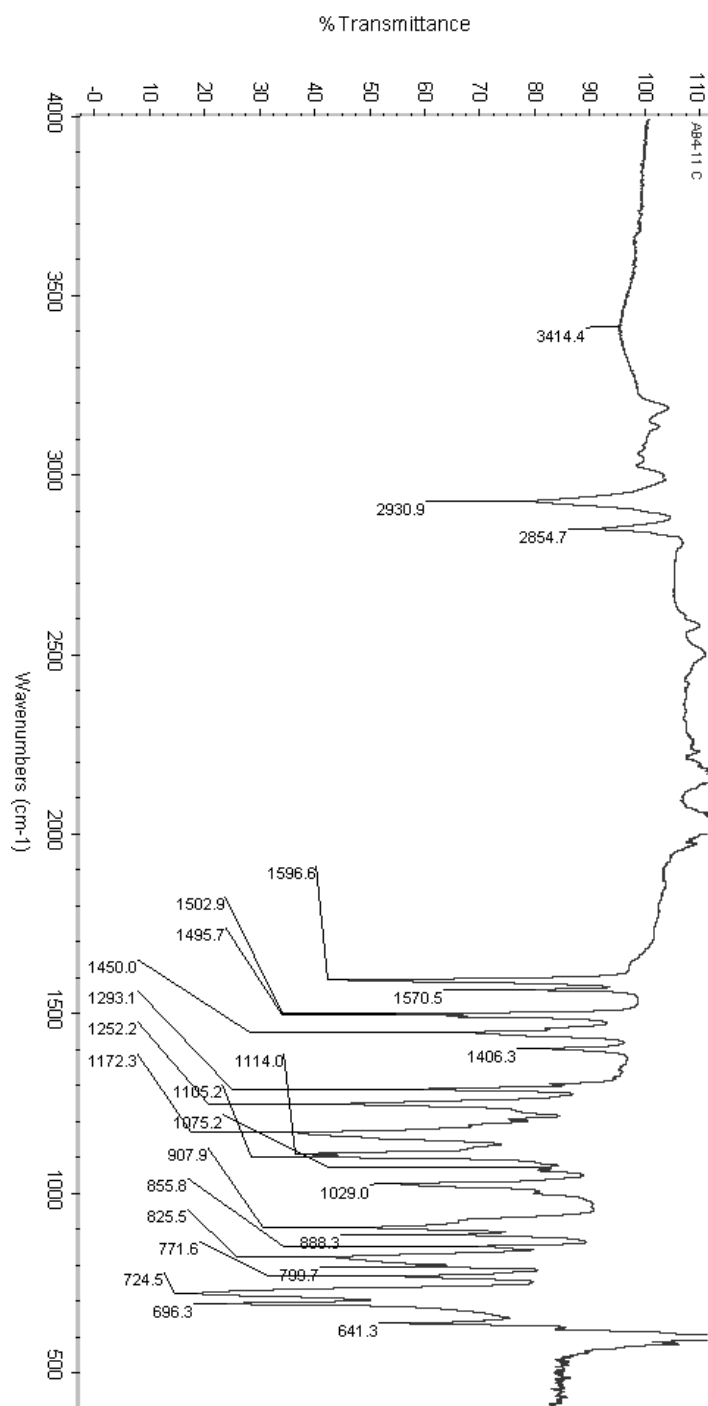
$^{31}\text{P}$  NMR



$^{13}\text{C}$  NMR

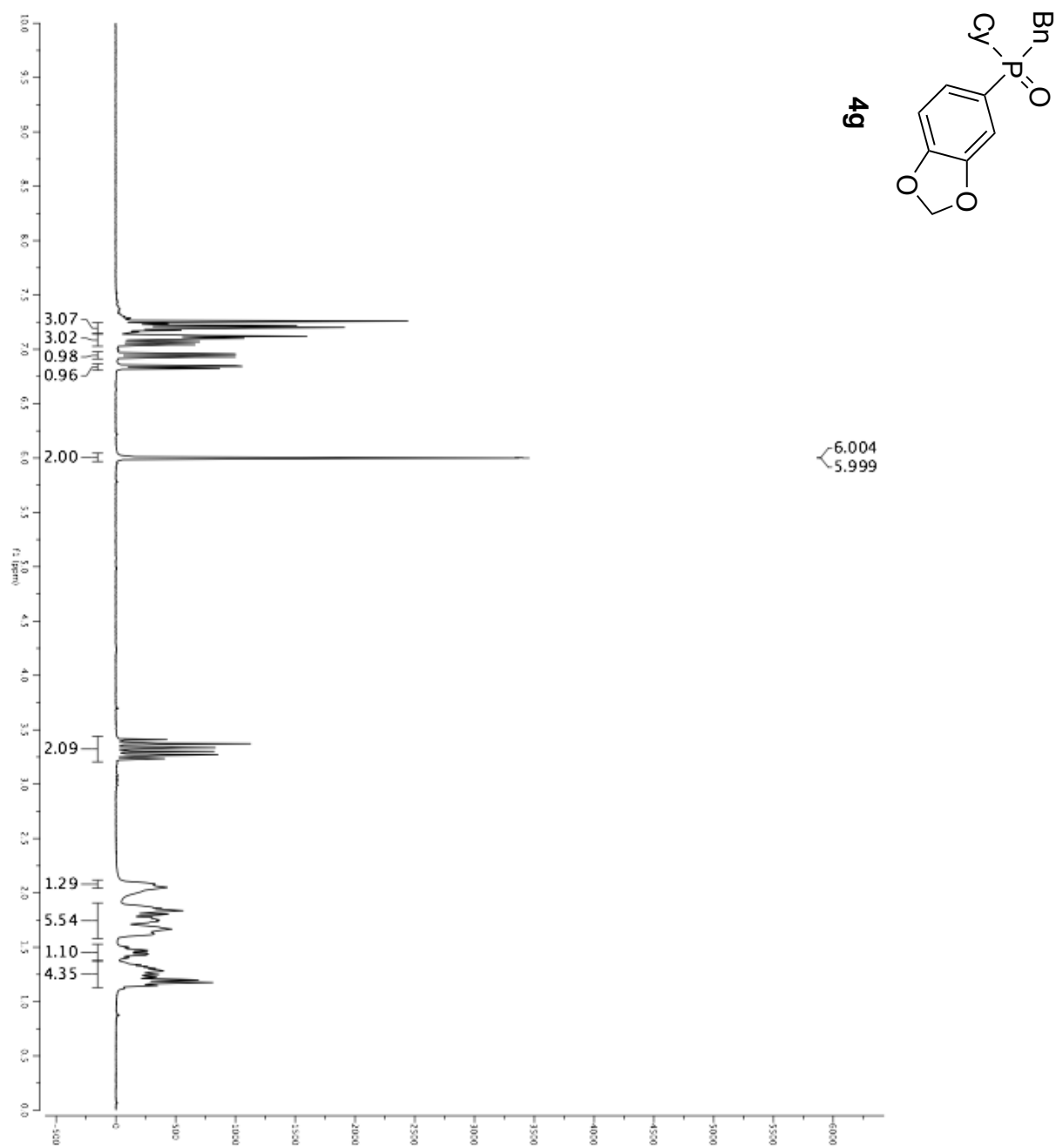


IR

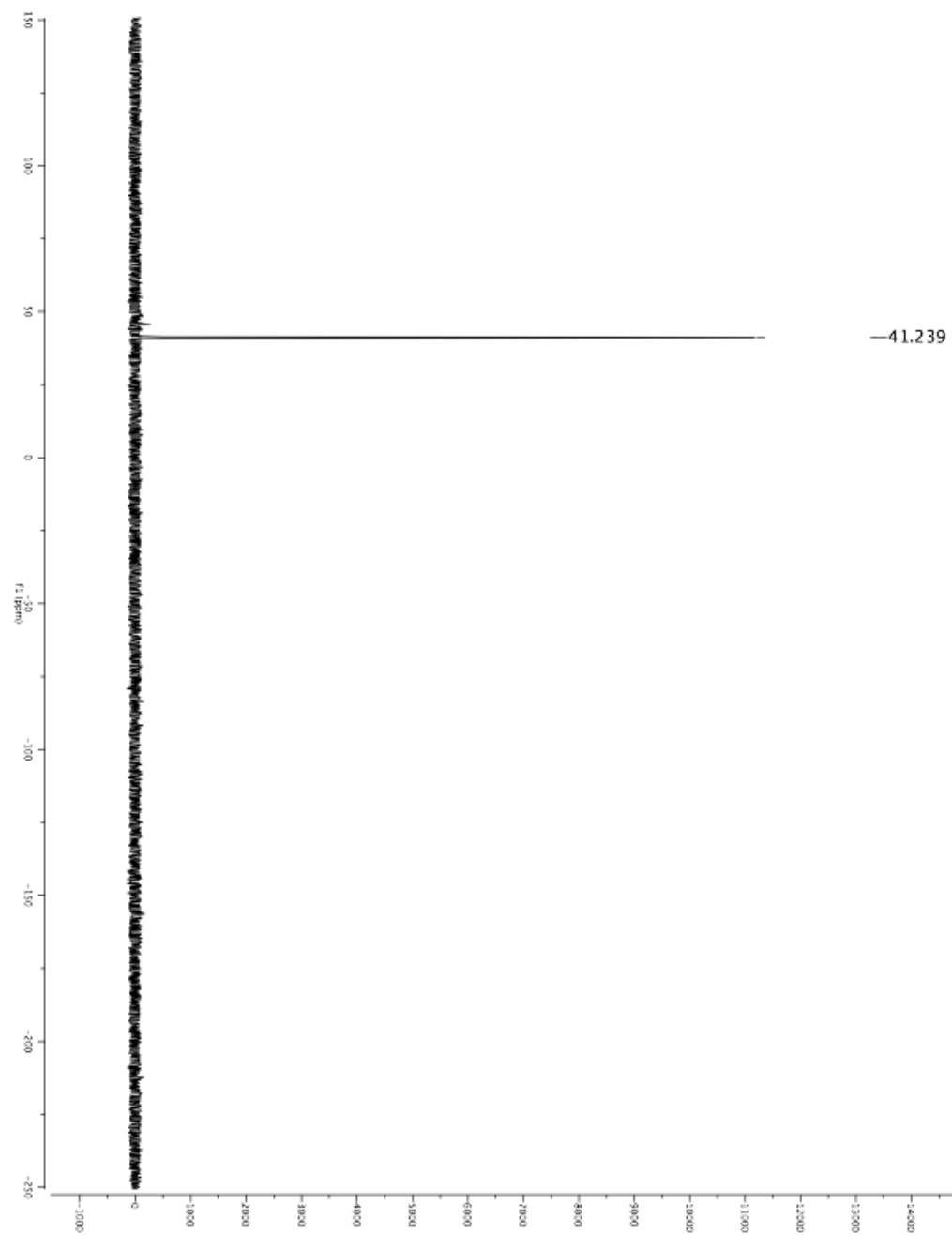




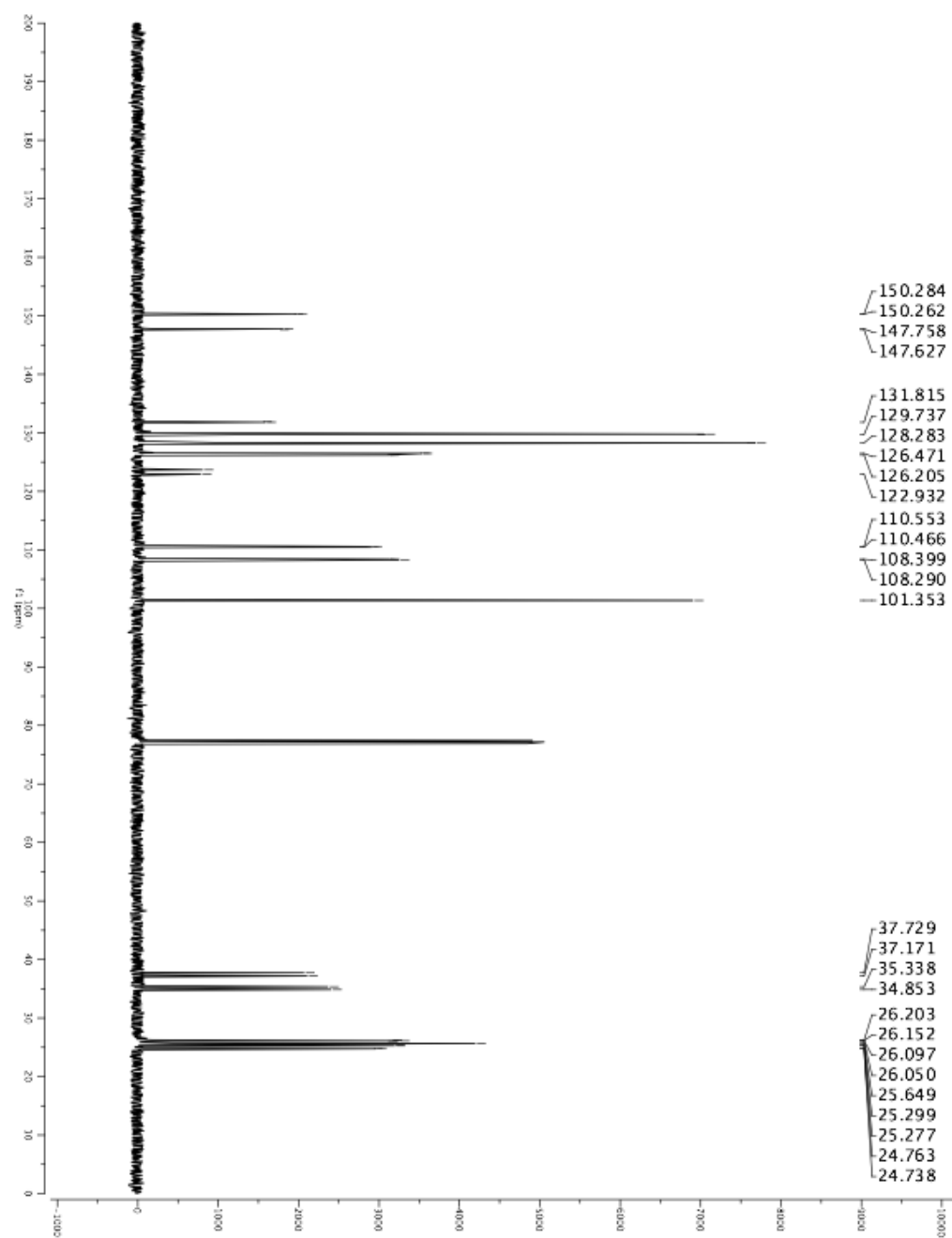
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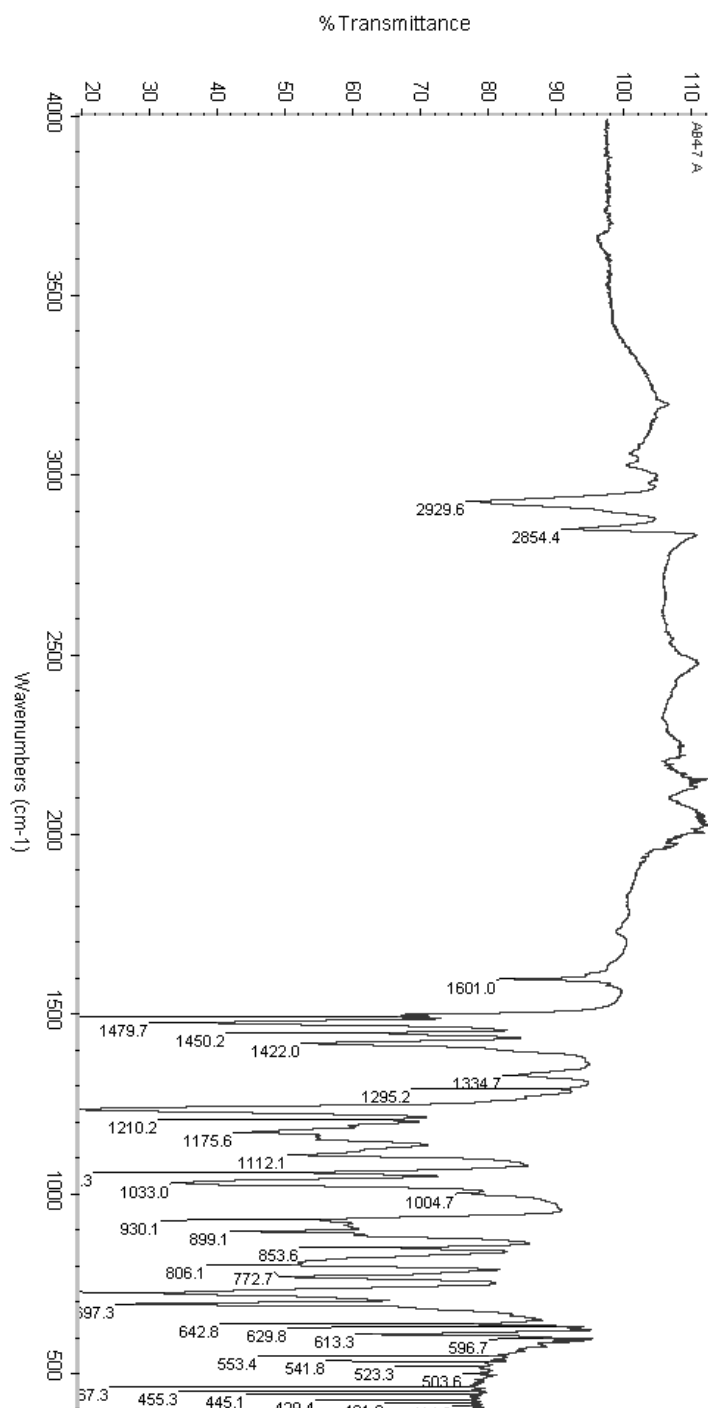
$^{31}\text{P}$  NMR



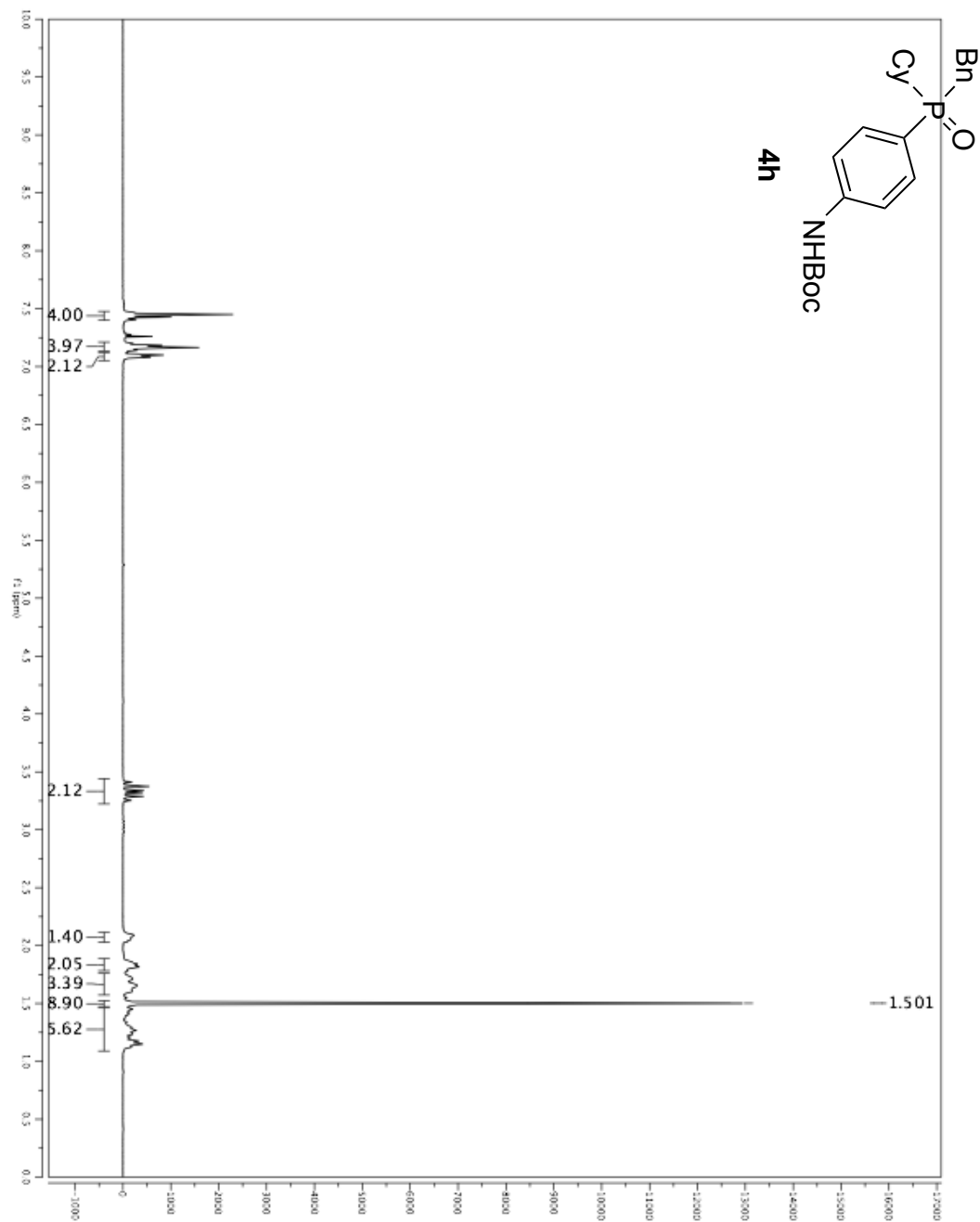
<sup>13</sup>C NMR



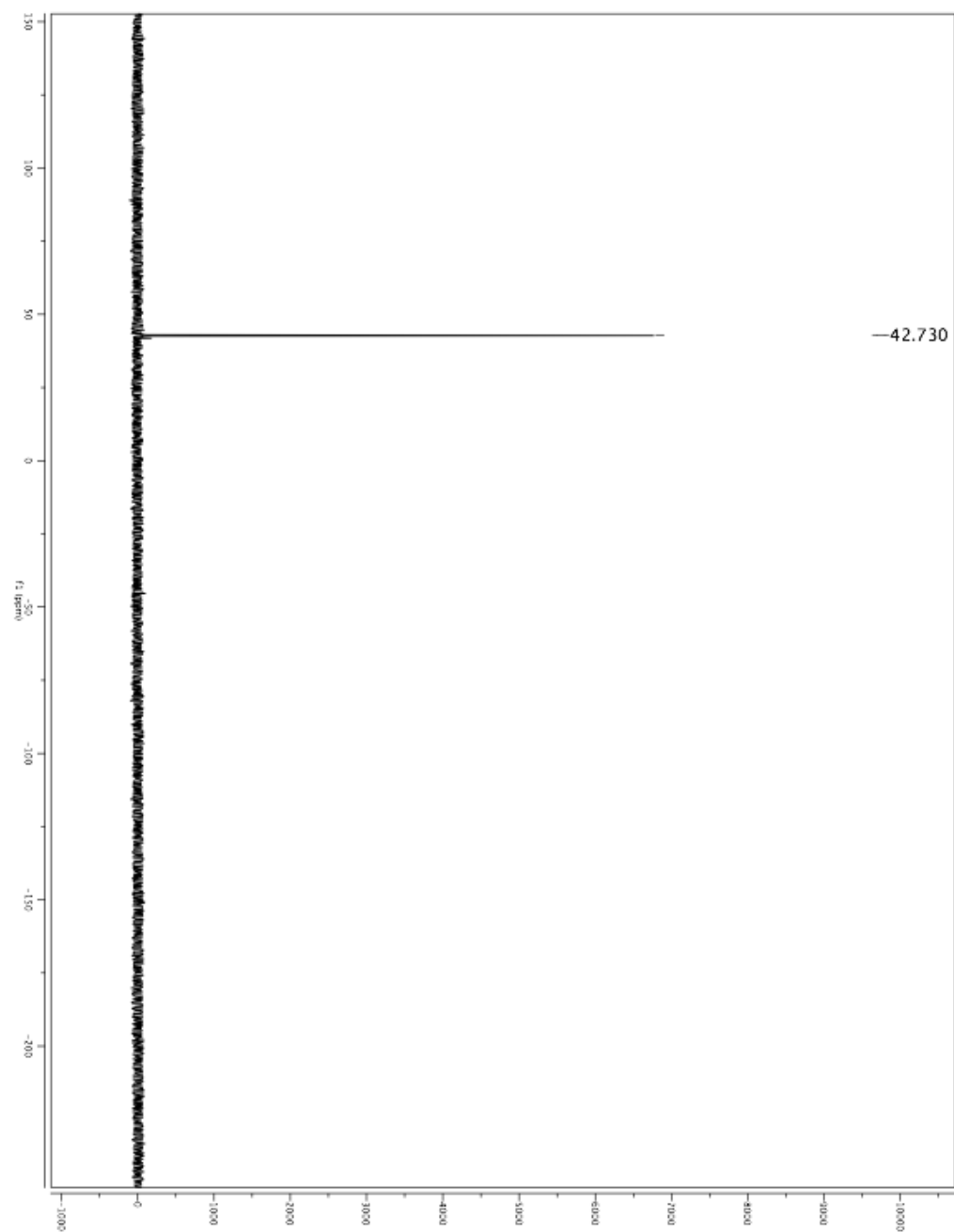
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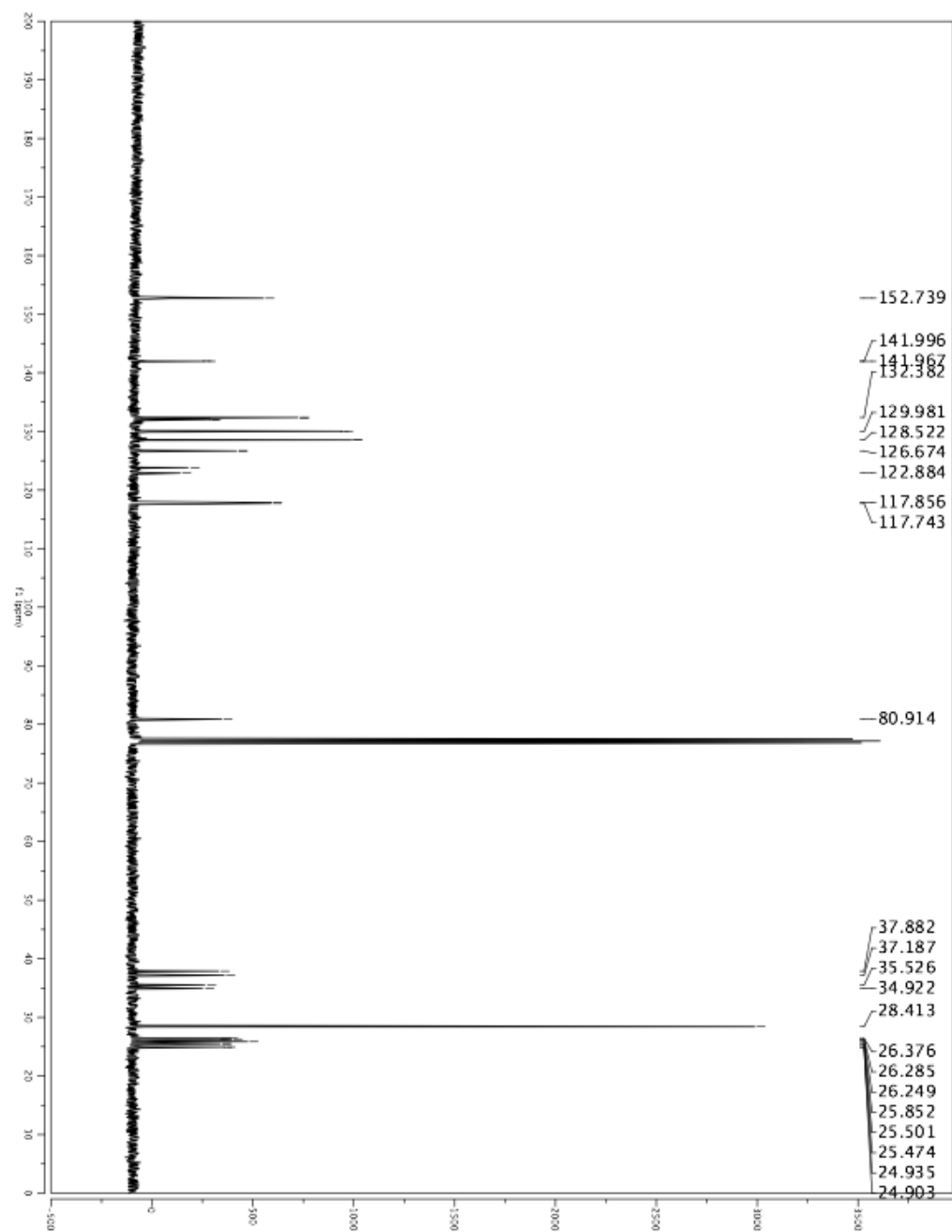
$^1\text{H}$  NMR



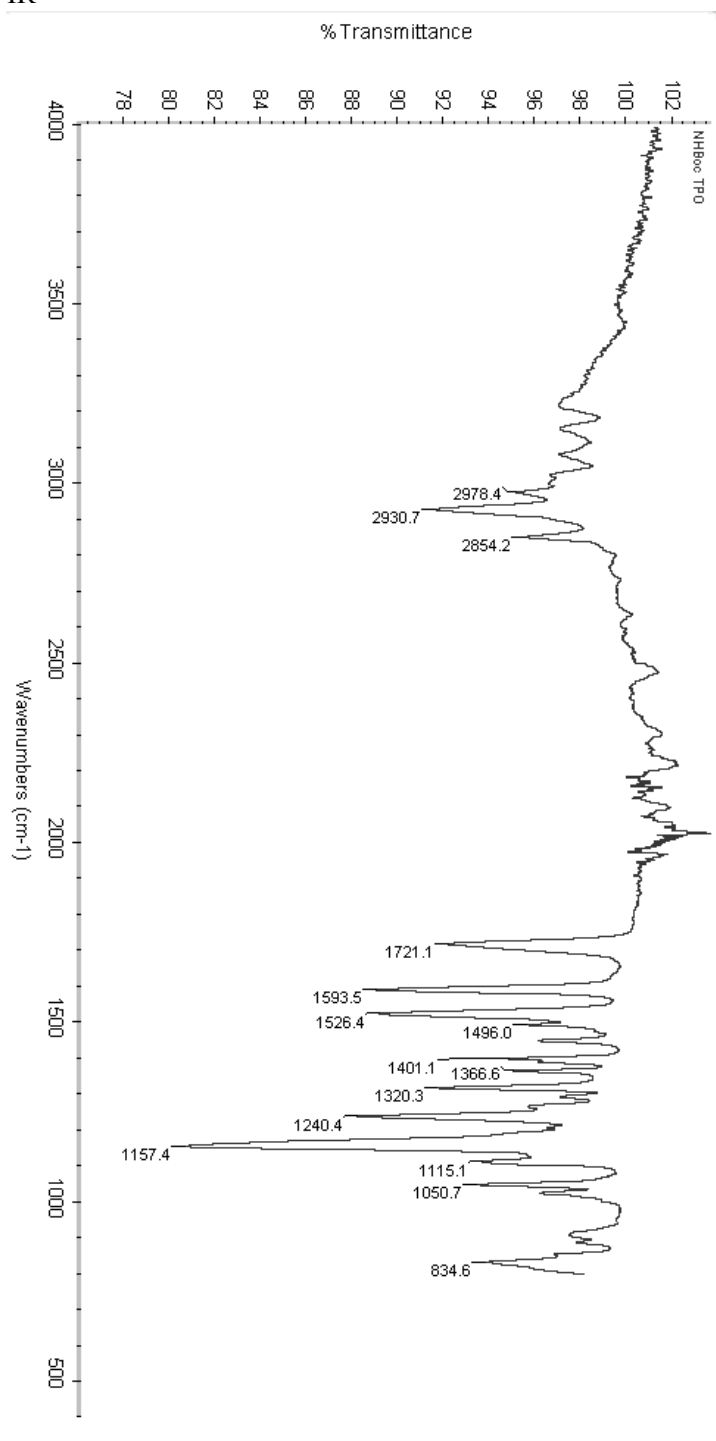
$^{31}\text{P}$  NMR



$^{13}\text{C}$  NMR

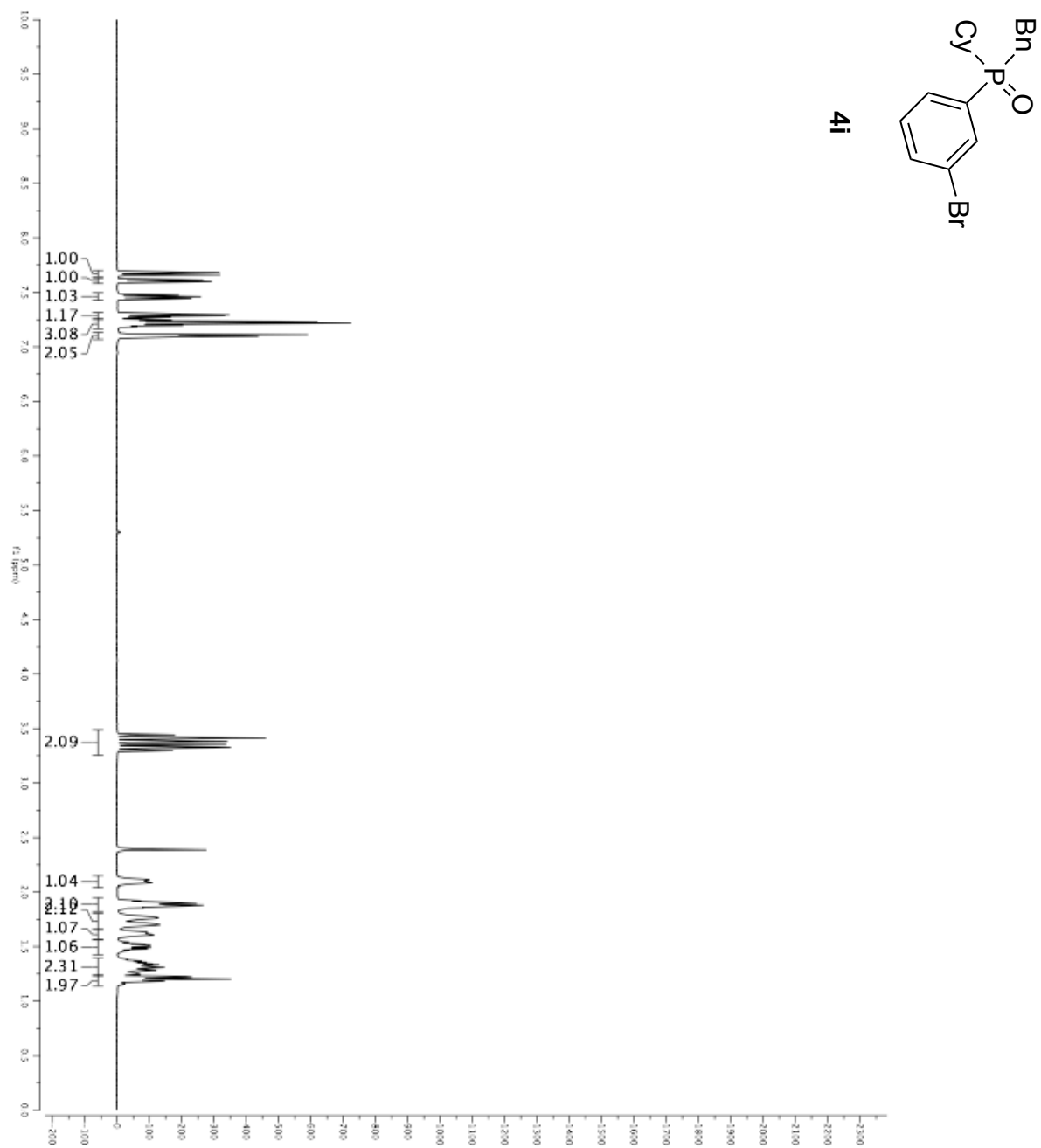


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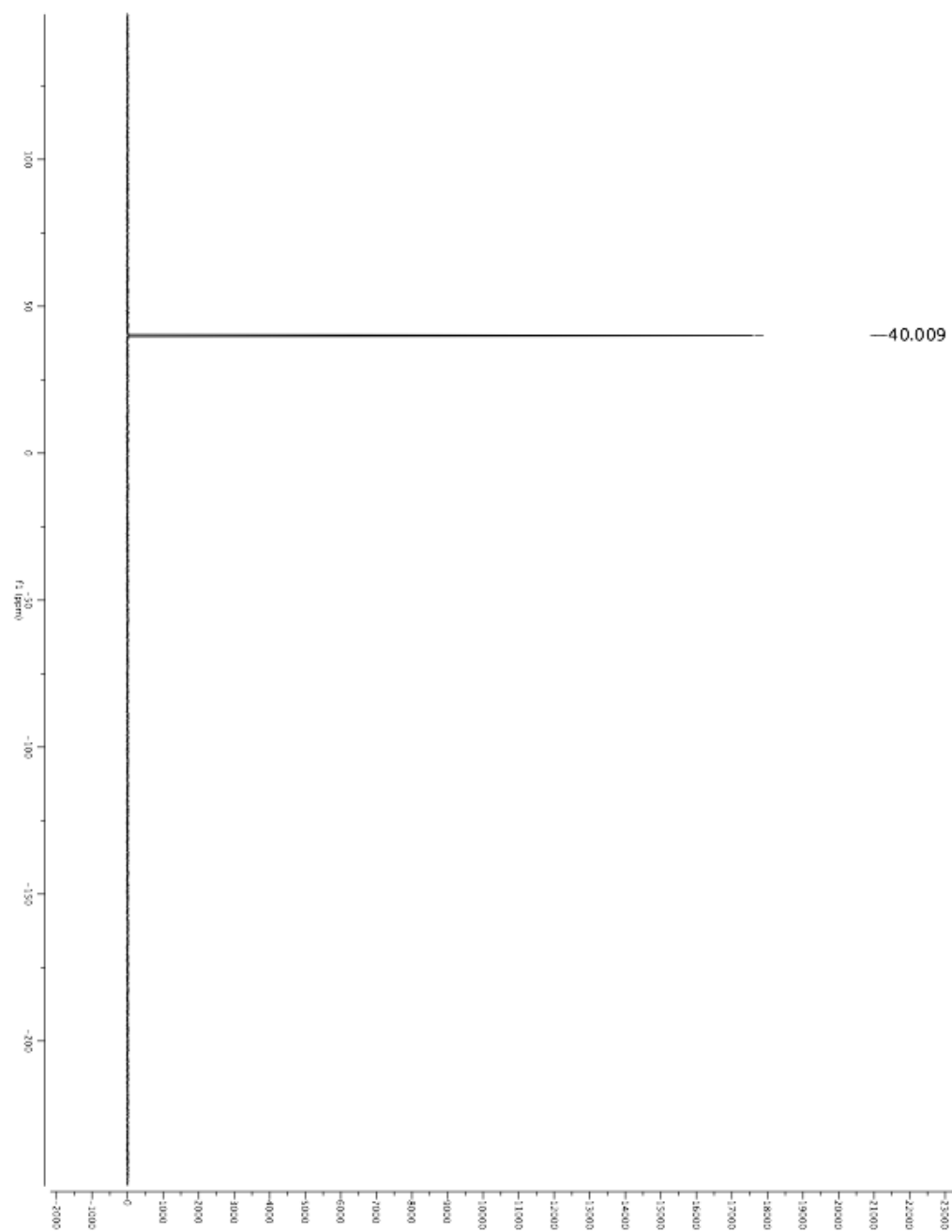




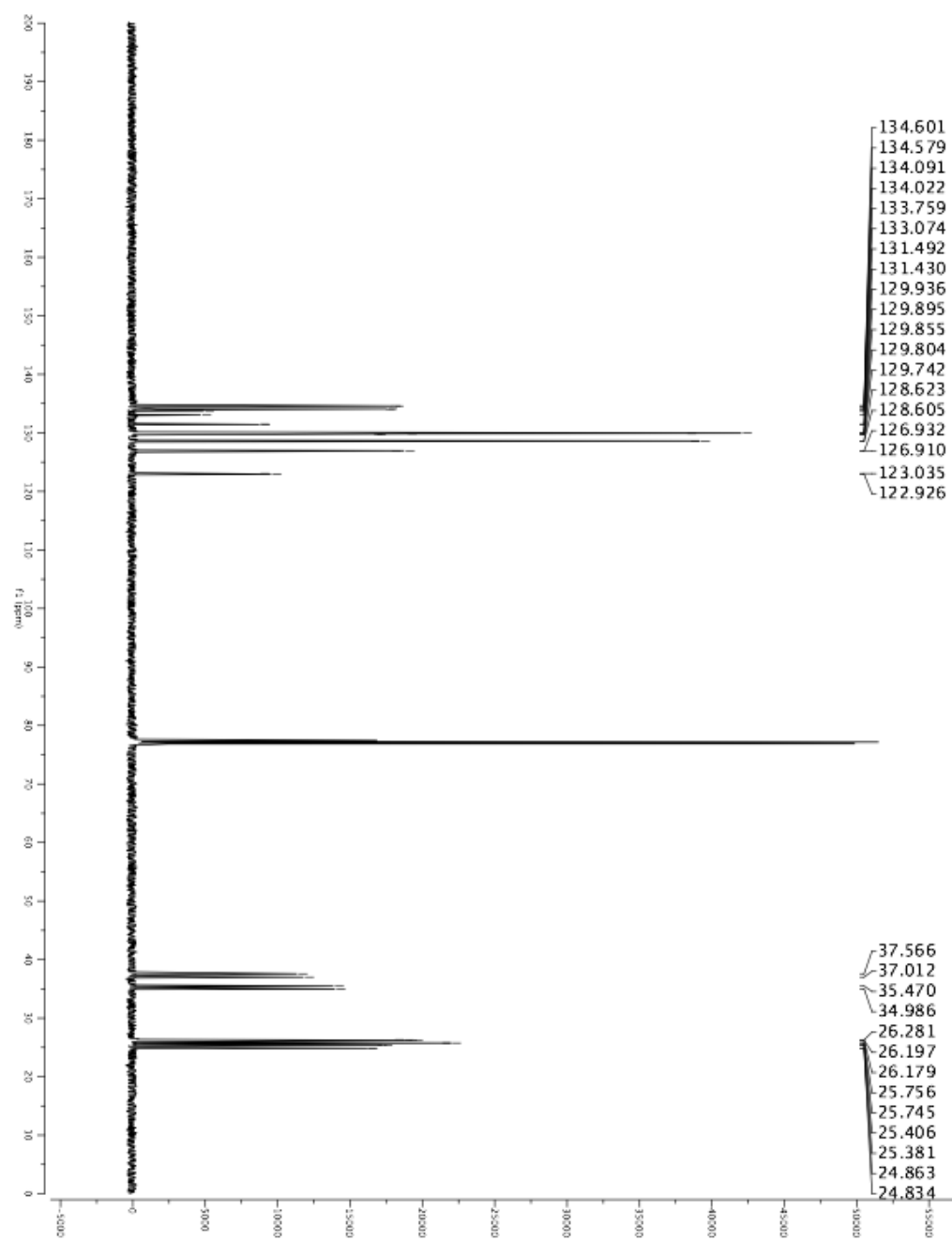
<sup>1</sup>H NMR



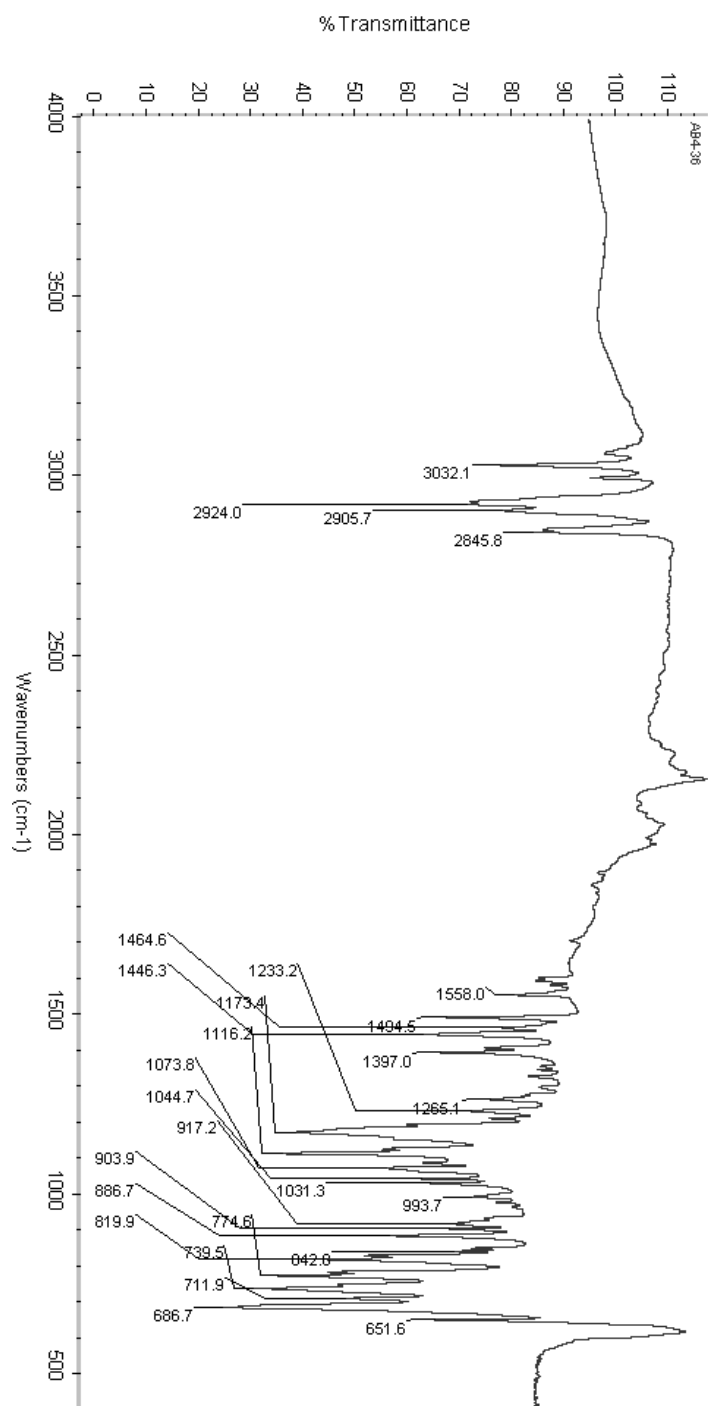
$^{31}\text{P}$  NMR



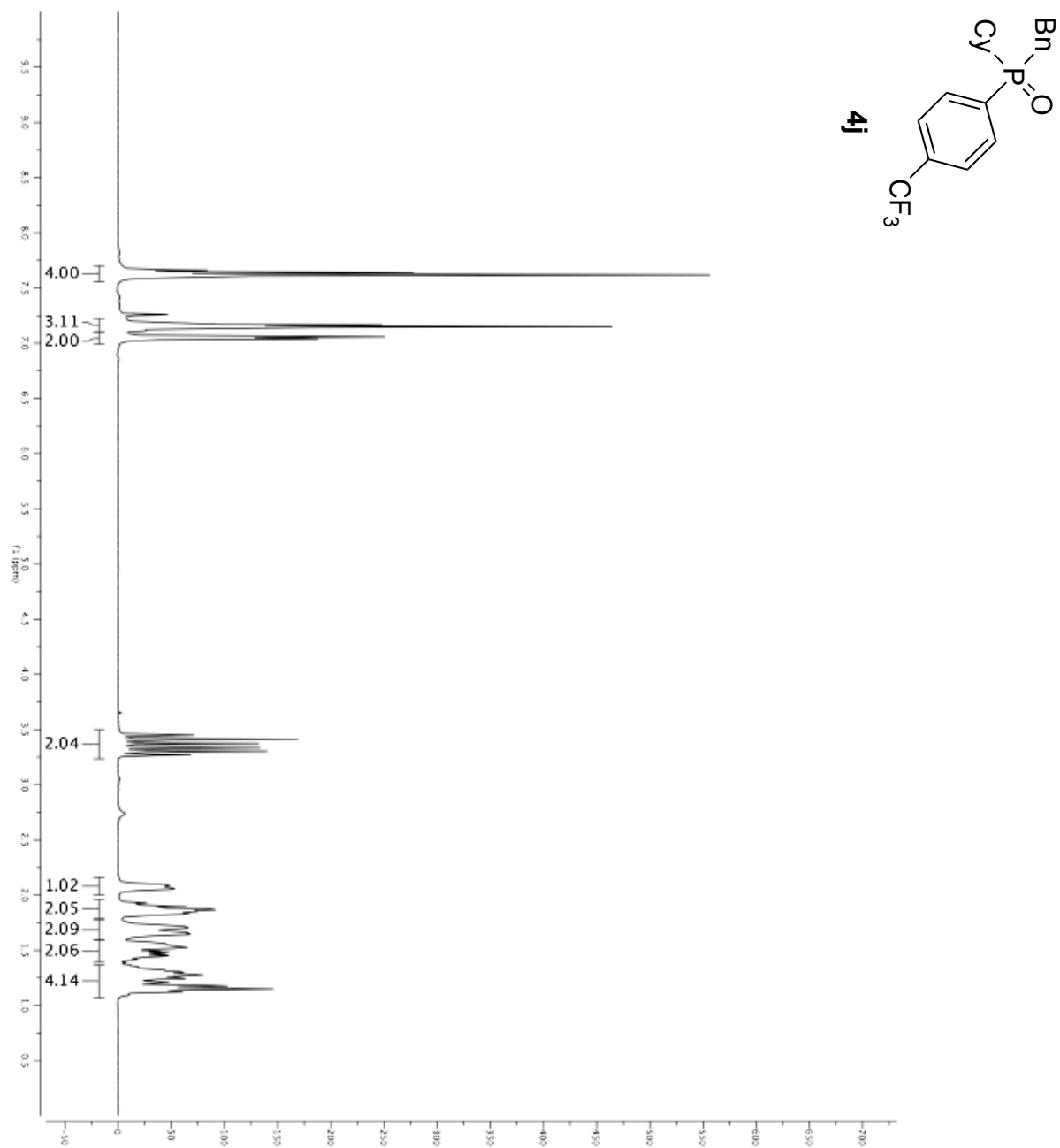
$^{13}\text{C}$  NMR



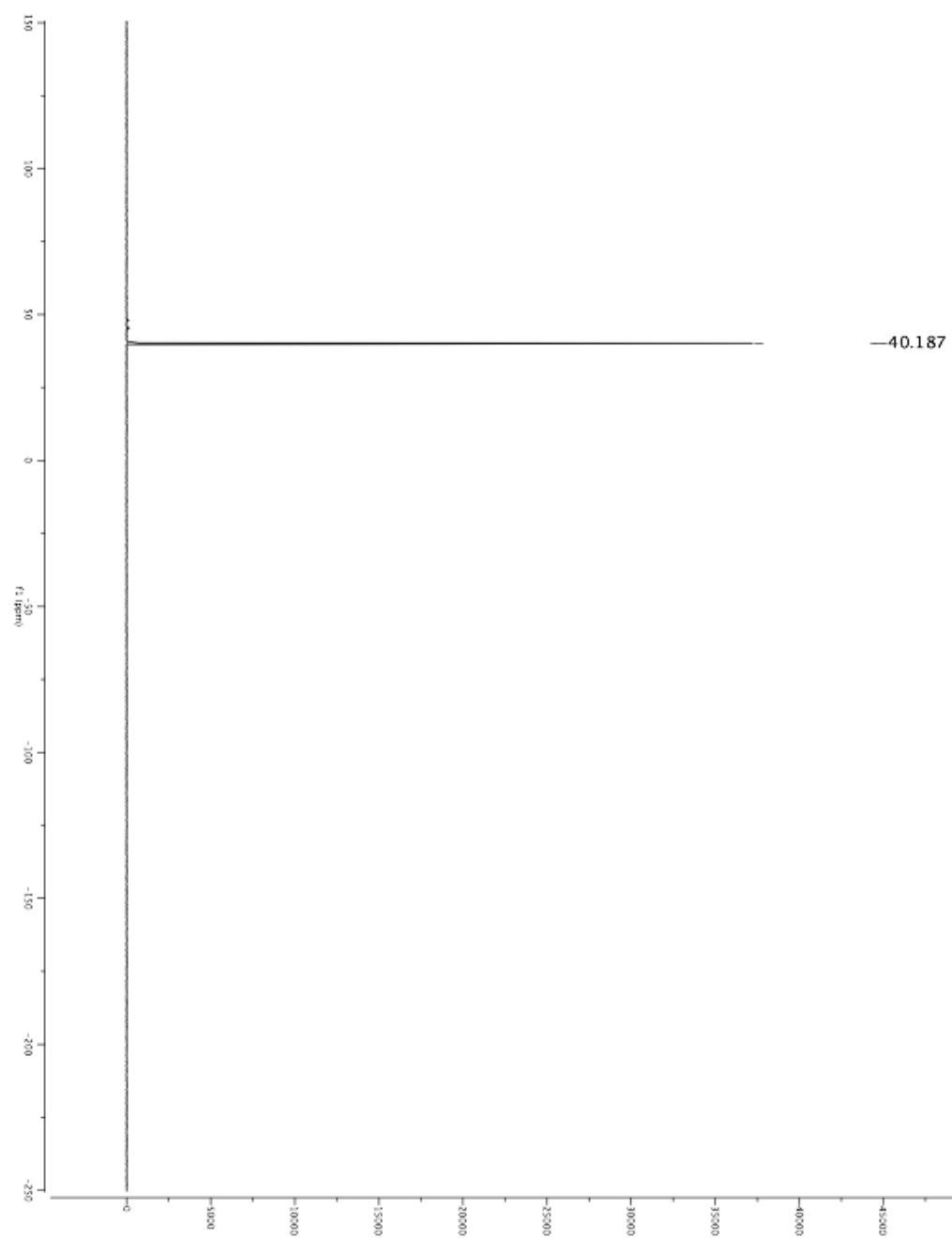
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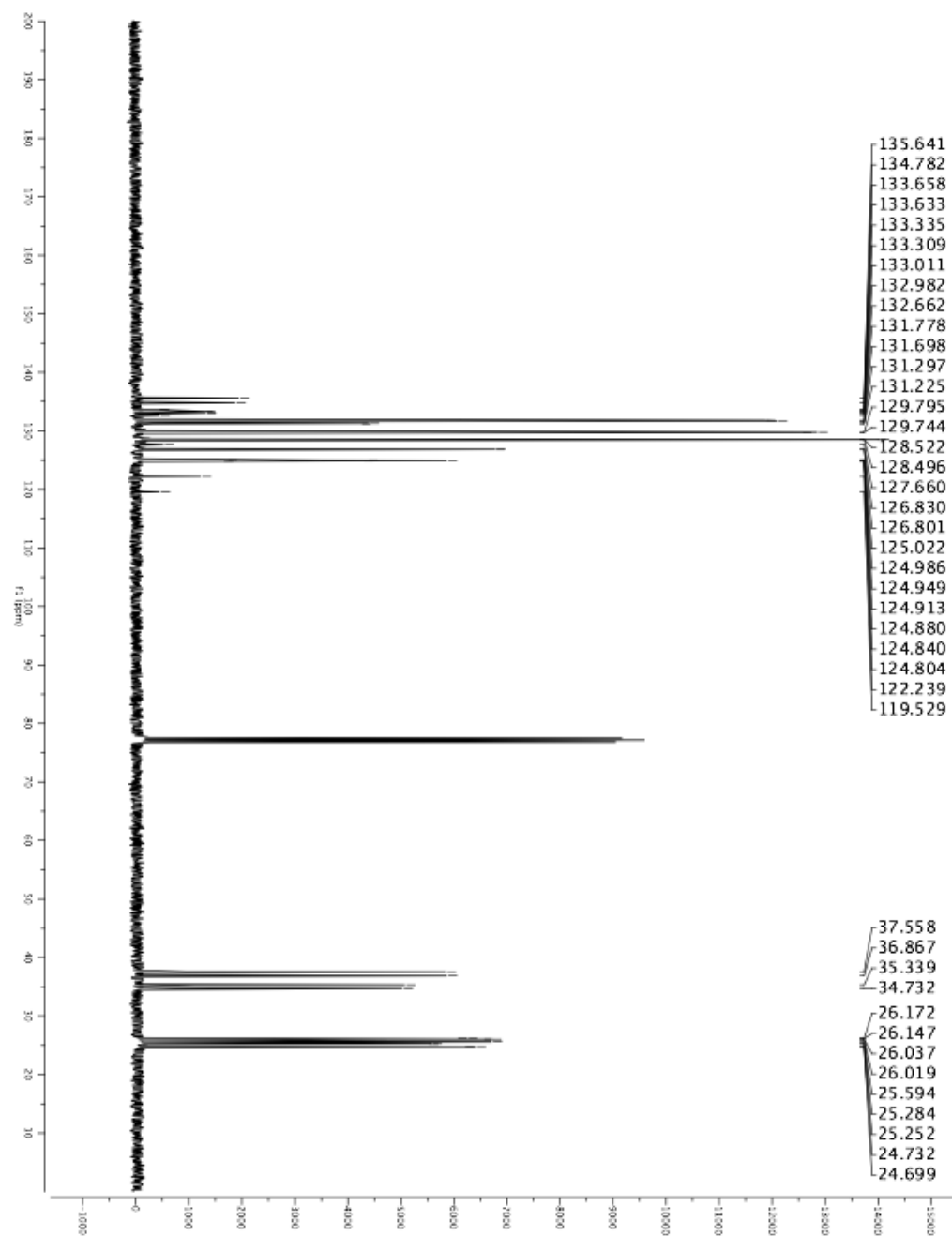
<sup>1</sup>H NMR



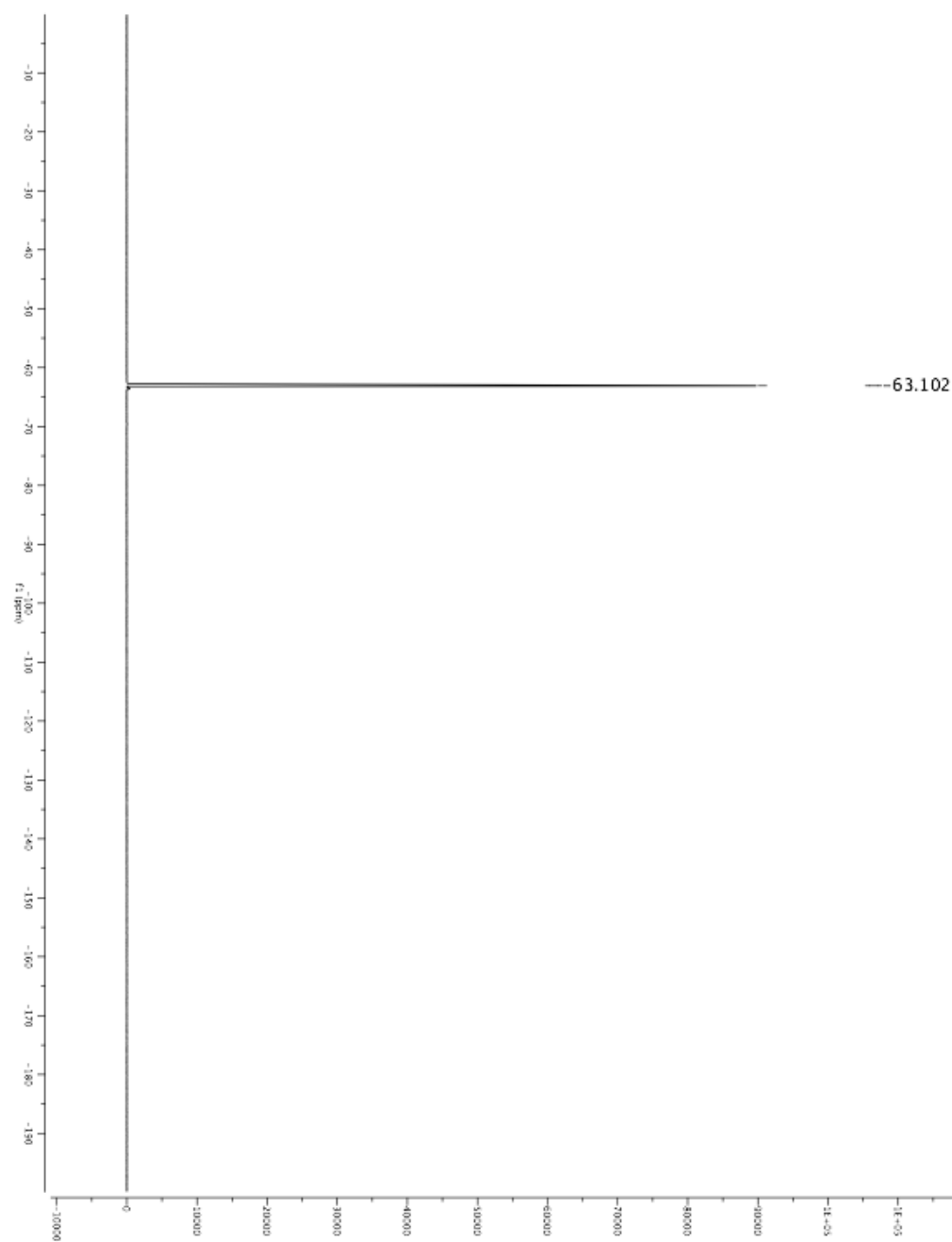
$^{31}\text{P}$  NMR



<sup>13</sup>C NMR

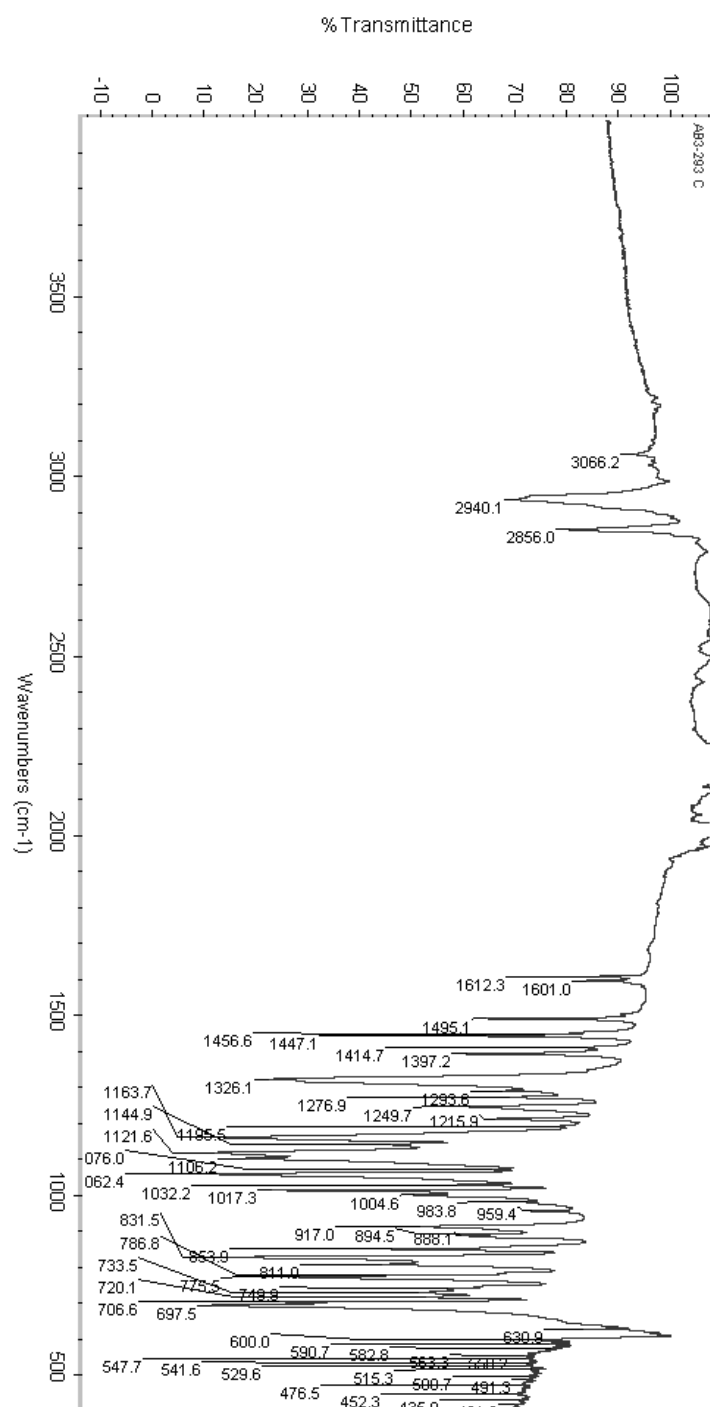


$^{19}\text{F}$  NMR

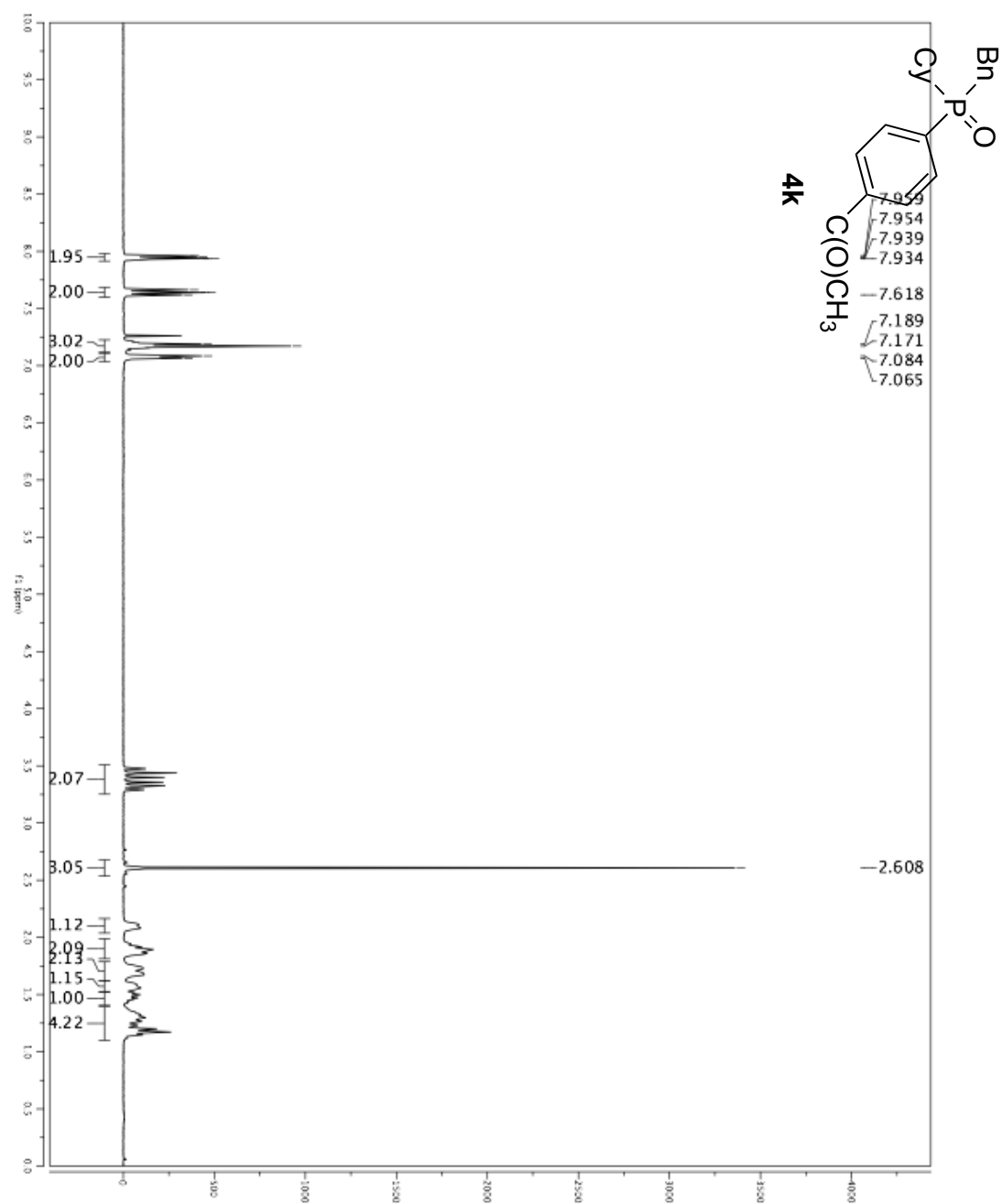




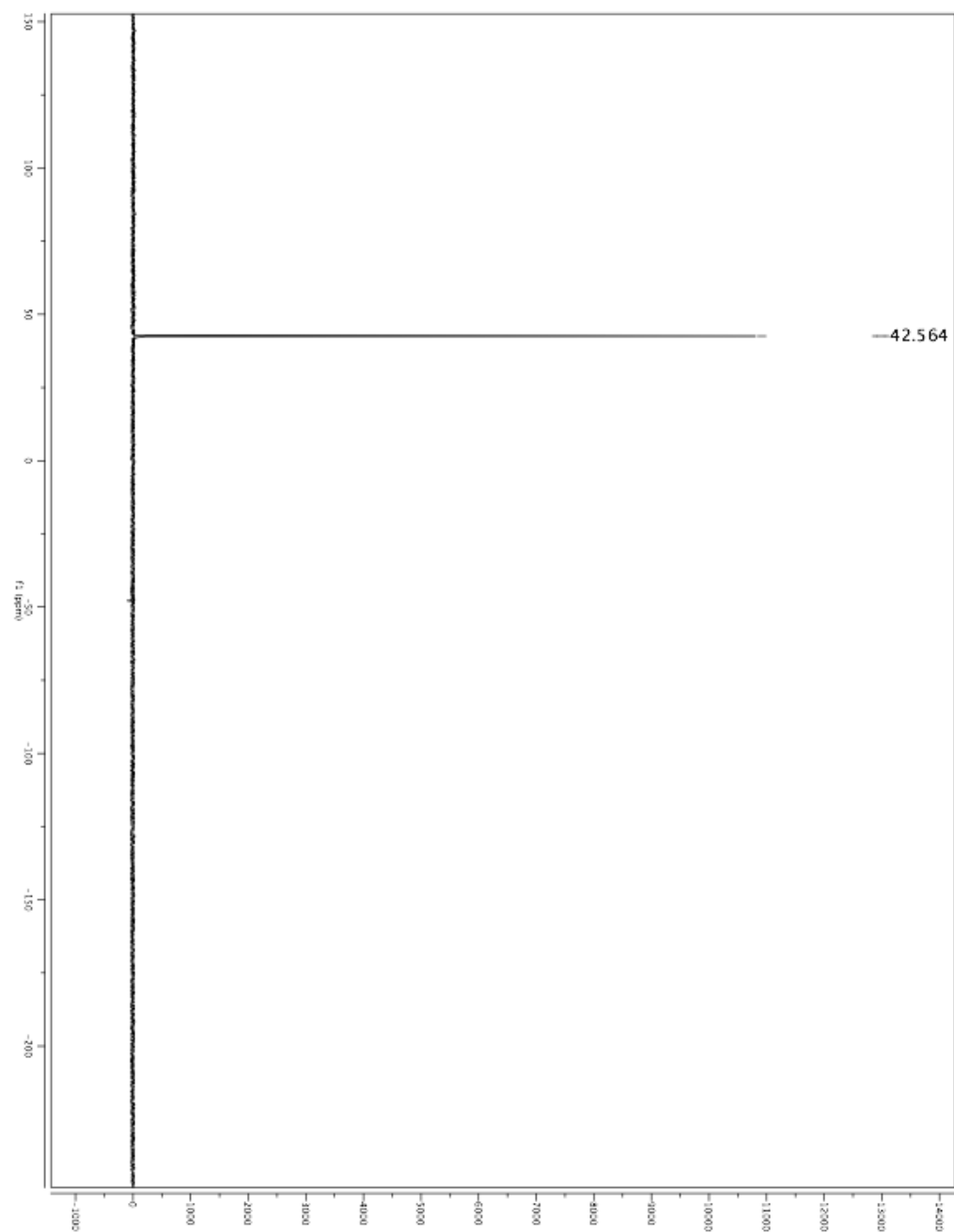
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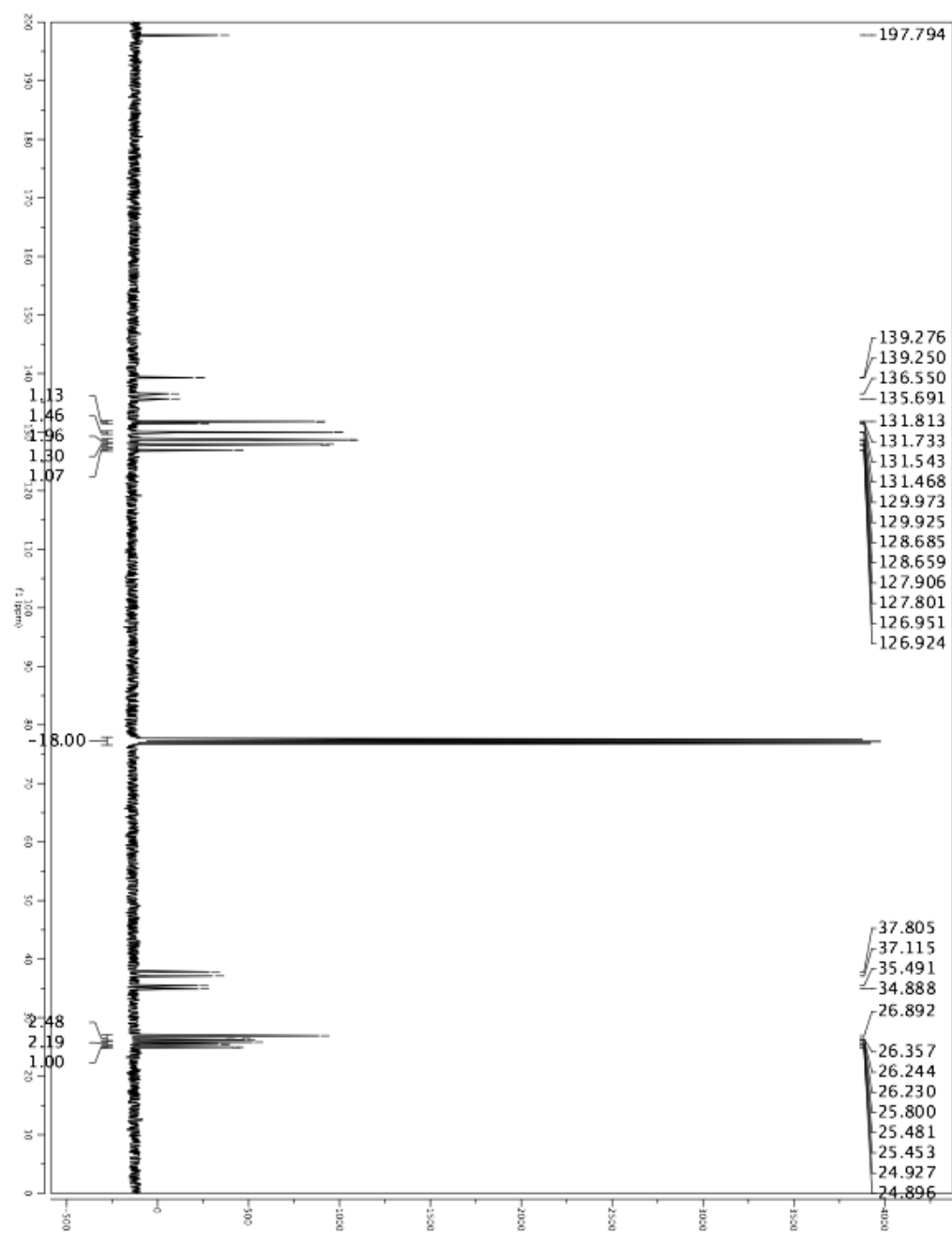
<sup>1</sup>H NMR



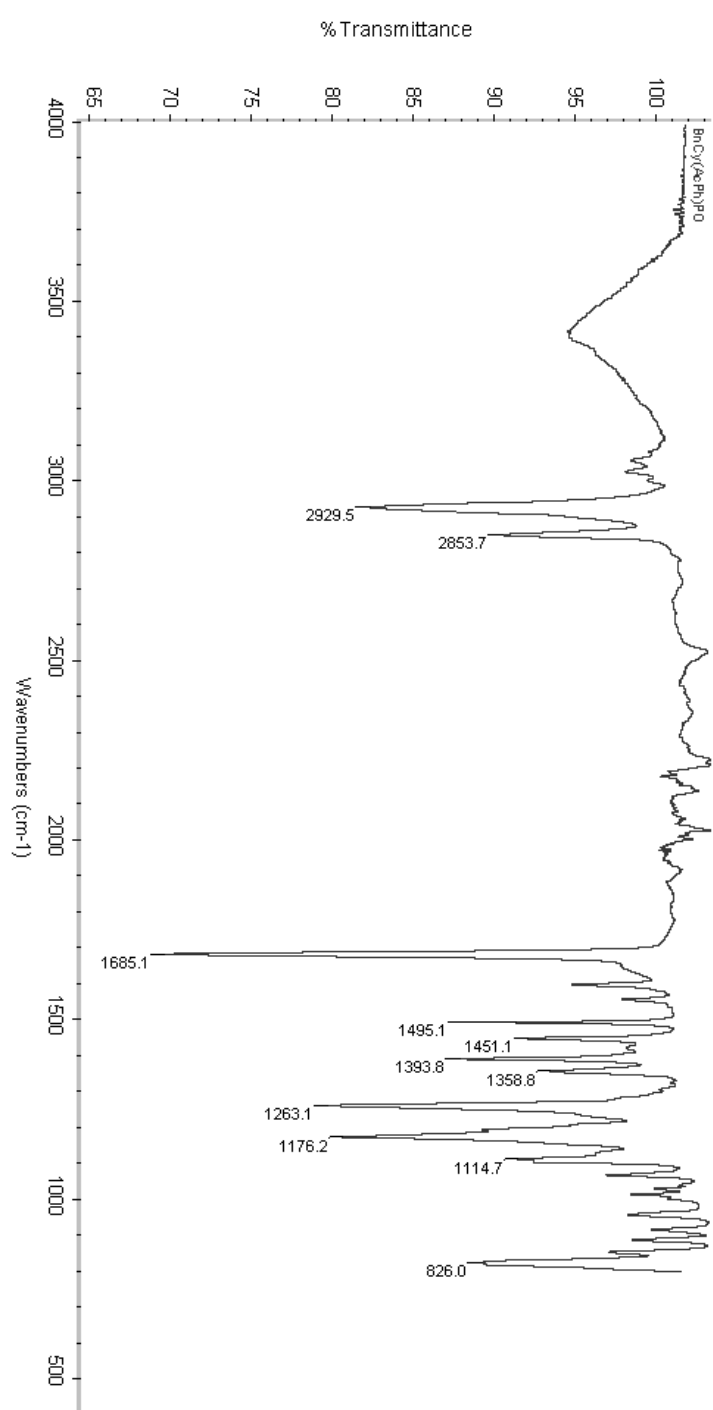
$^{31}\text{P}$  NMR



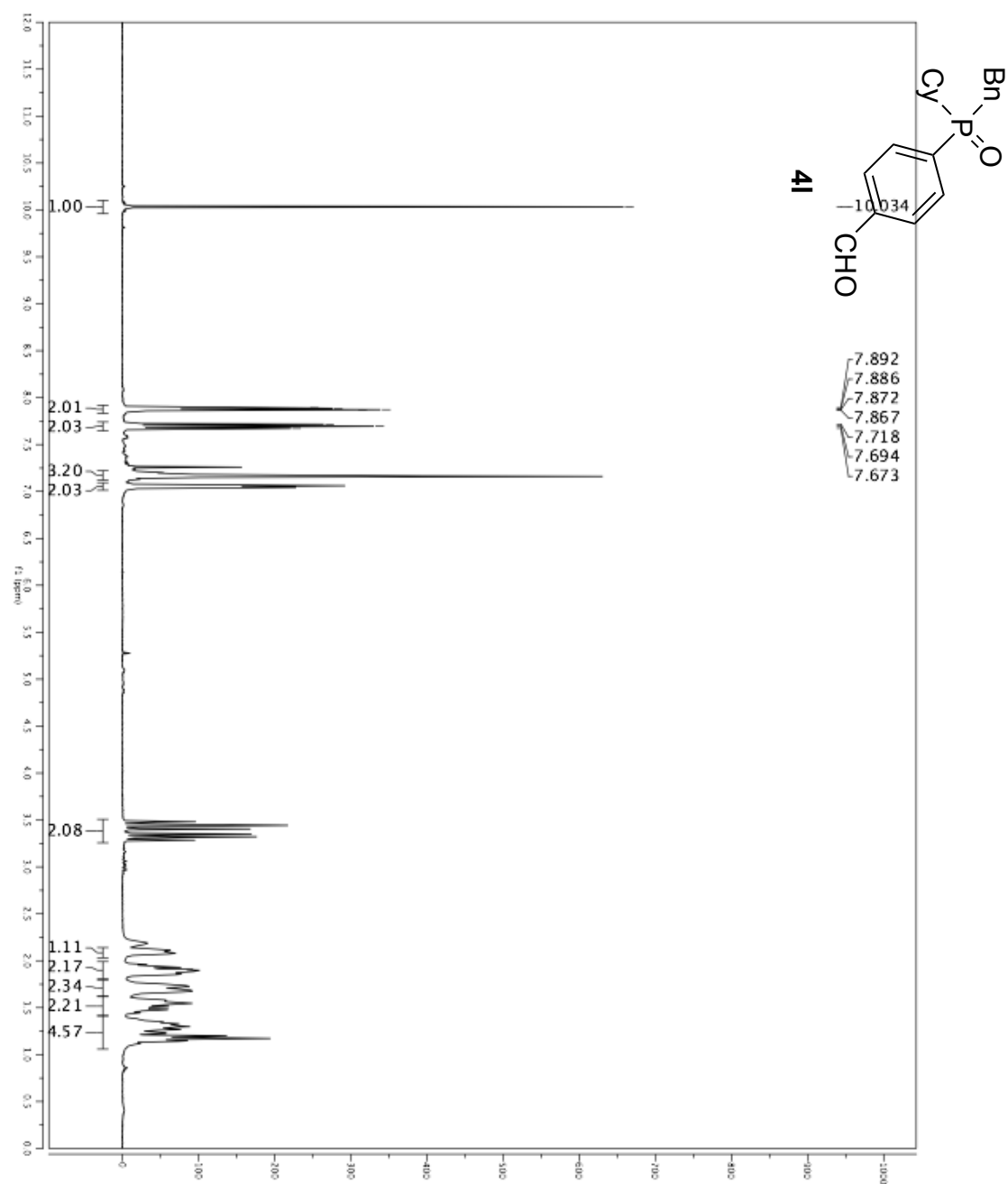
$^{13}\text{C}$  NMR



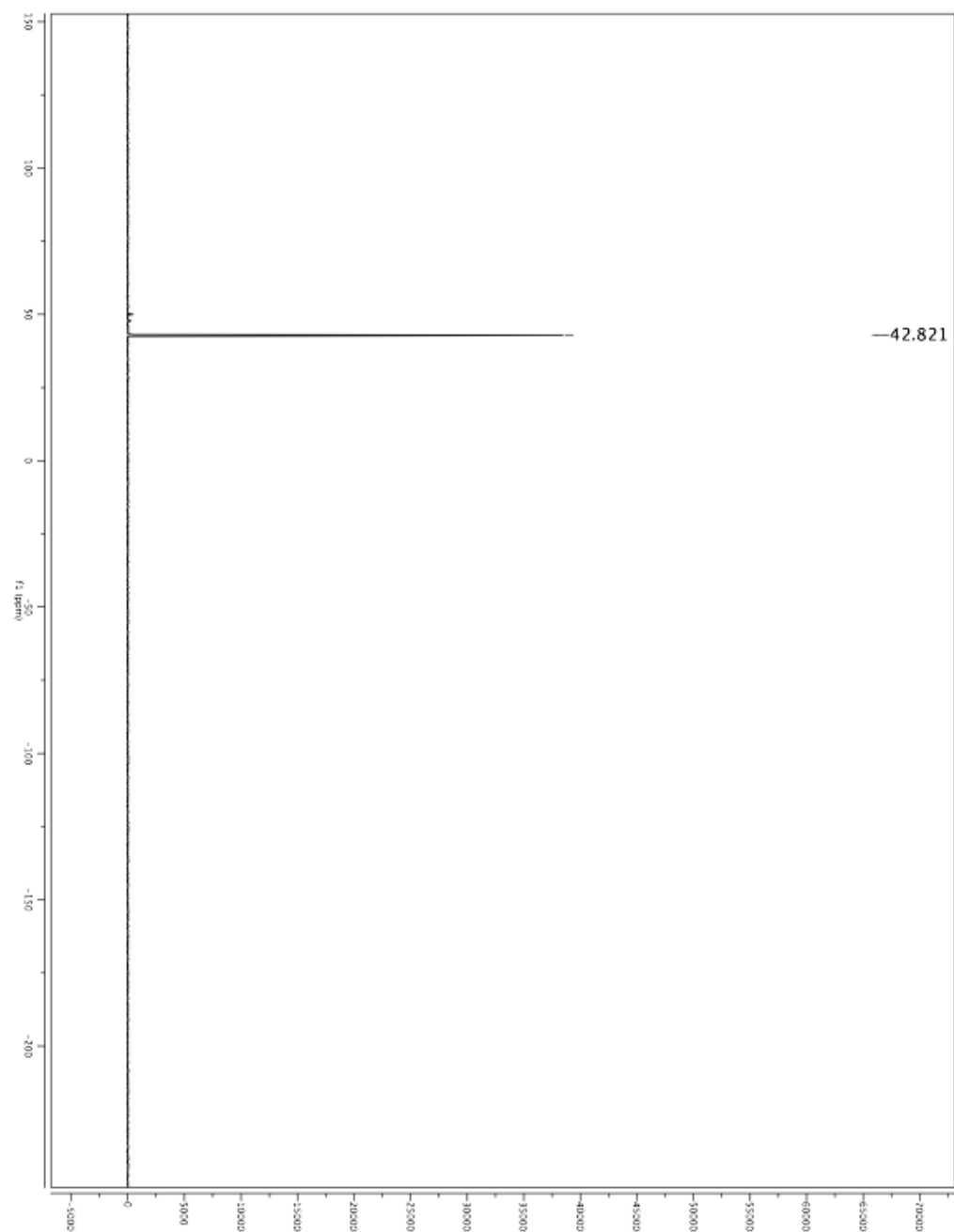
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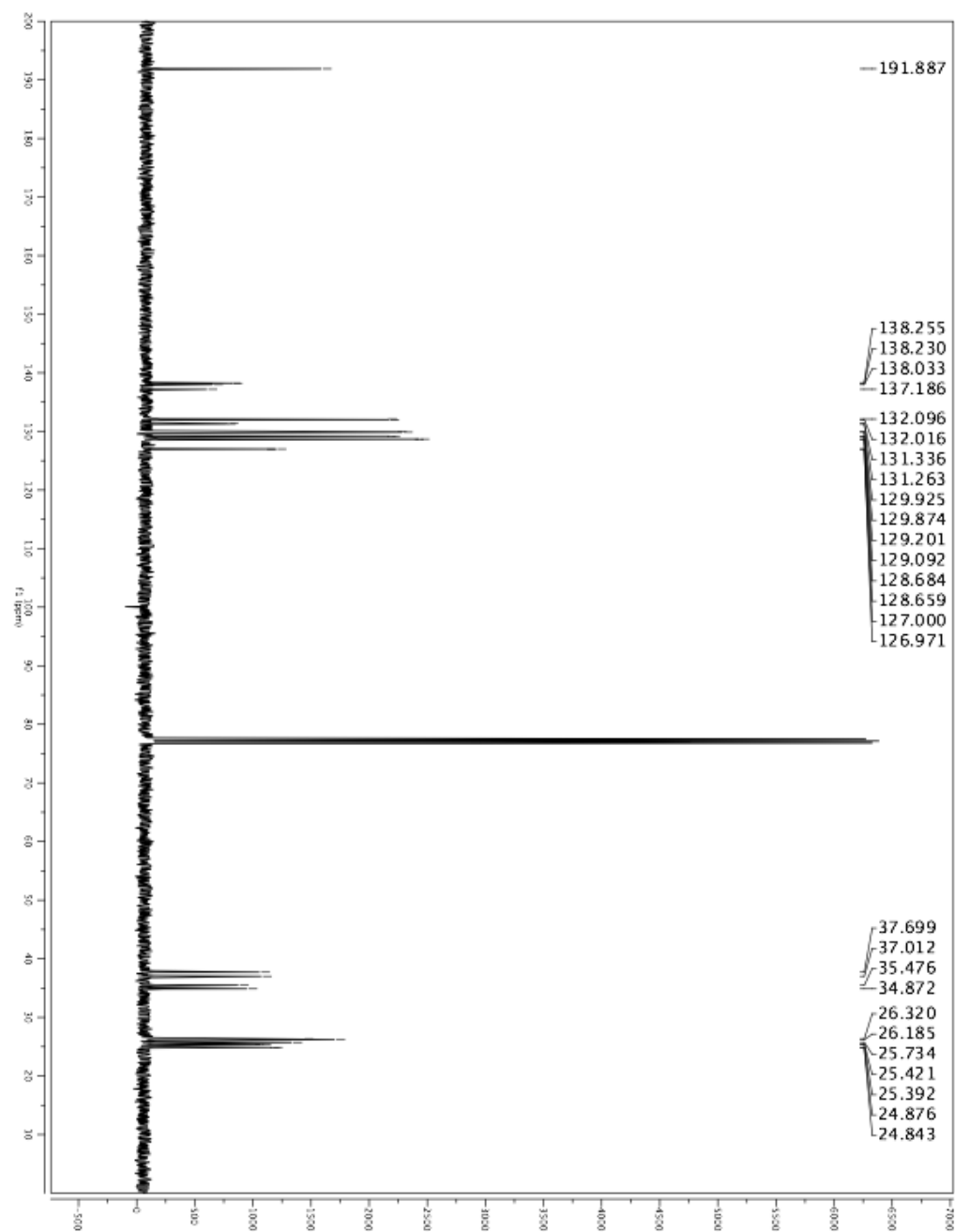
<sup>1</sup>H NMR



$^{31}\text{P}$  NMR

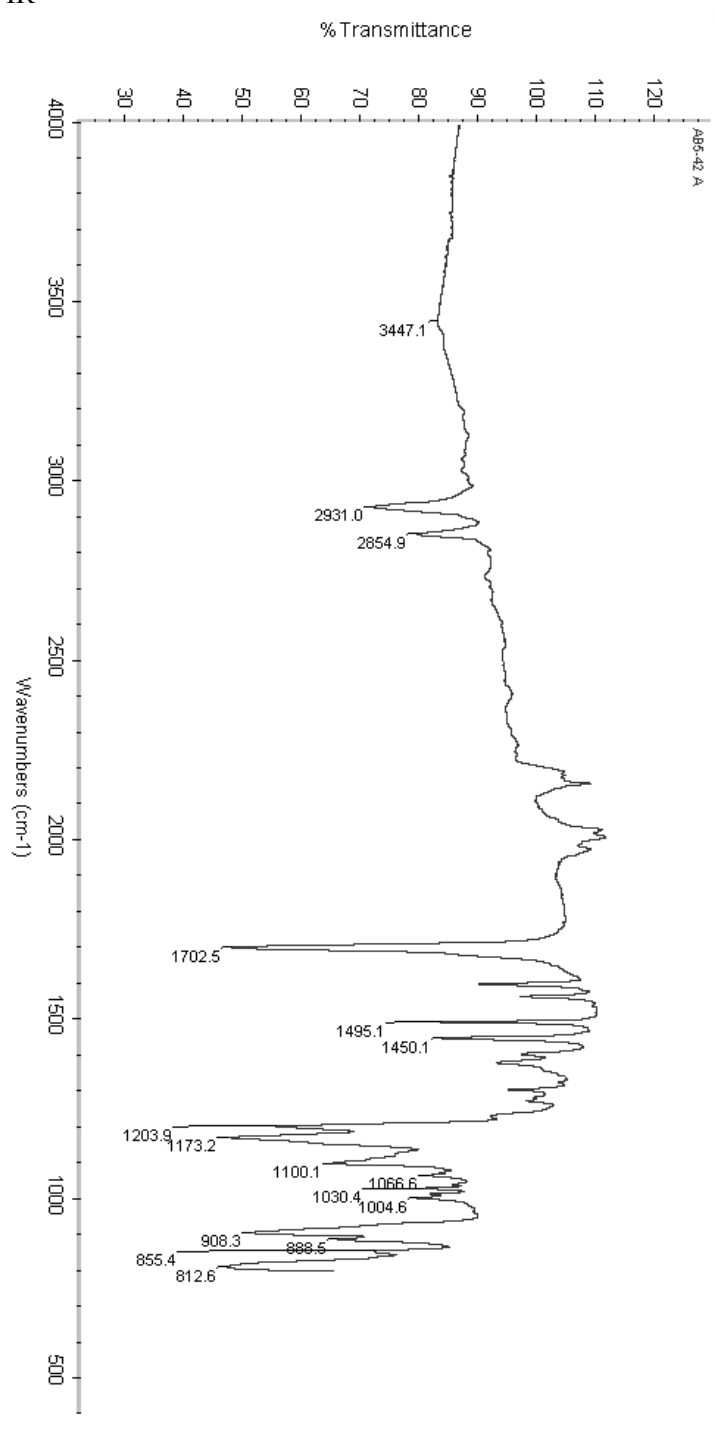


<sup>13</sup>C NMR

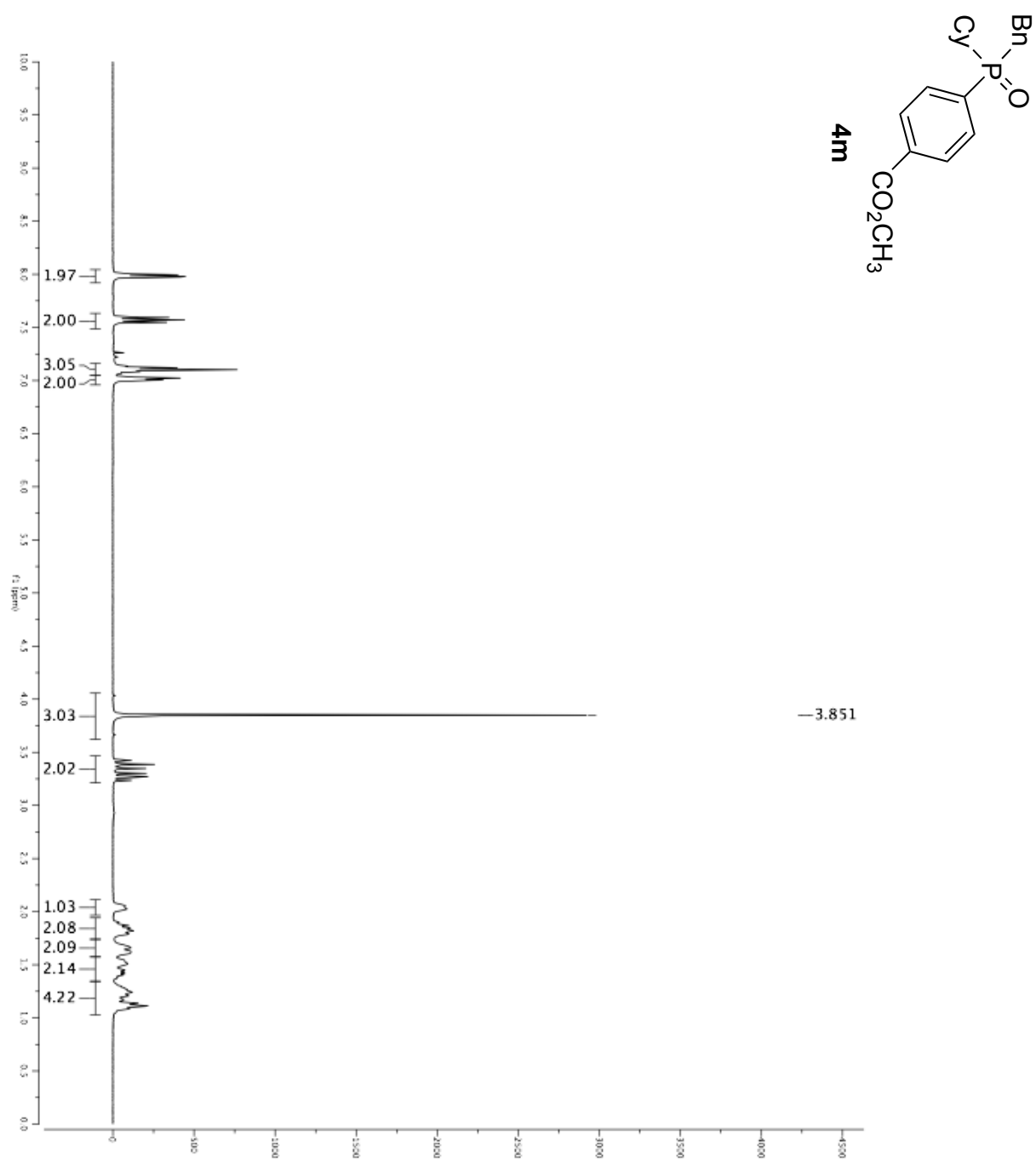




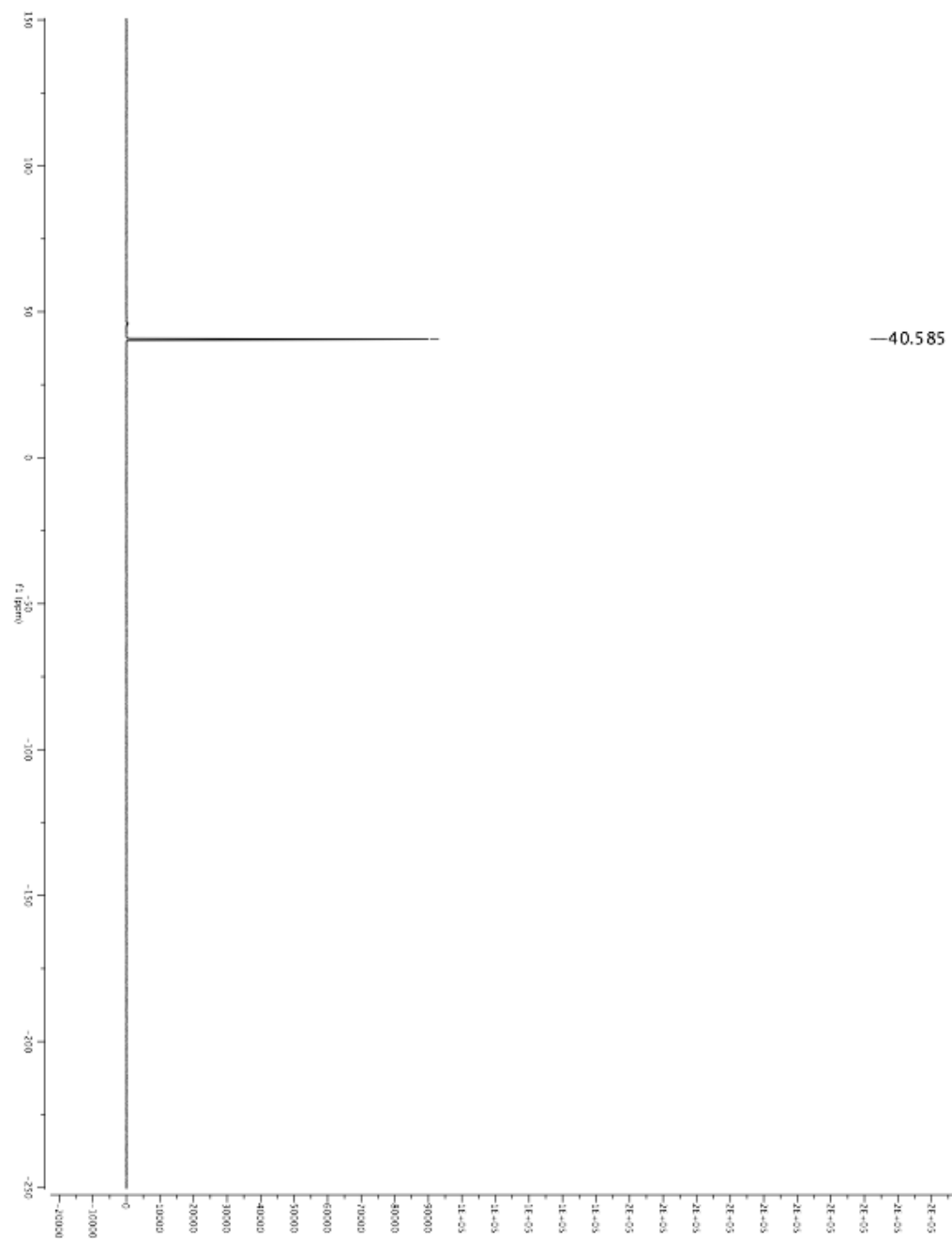
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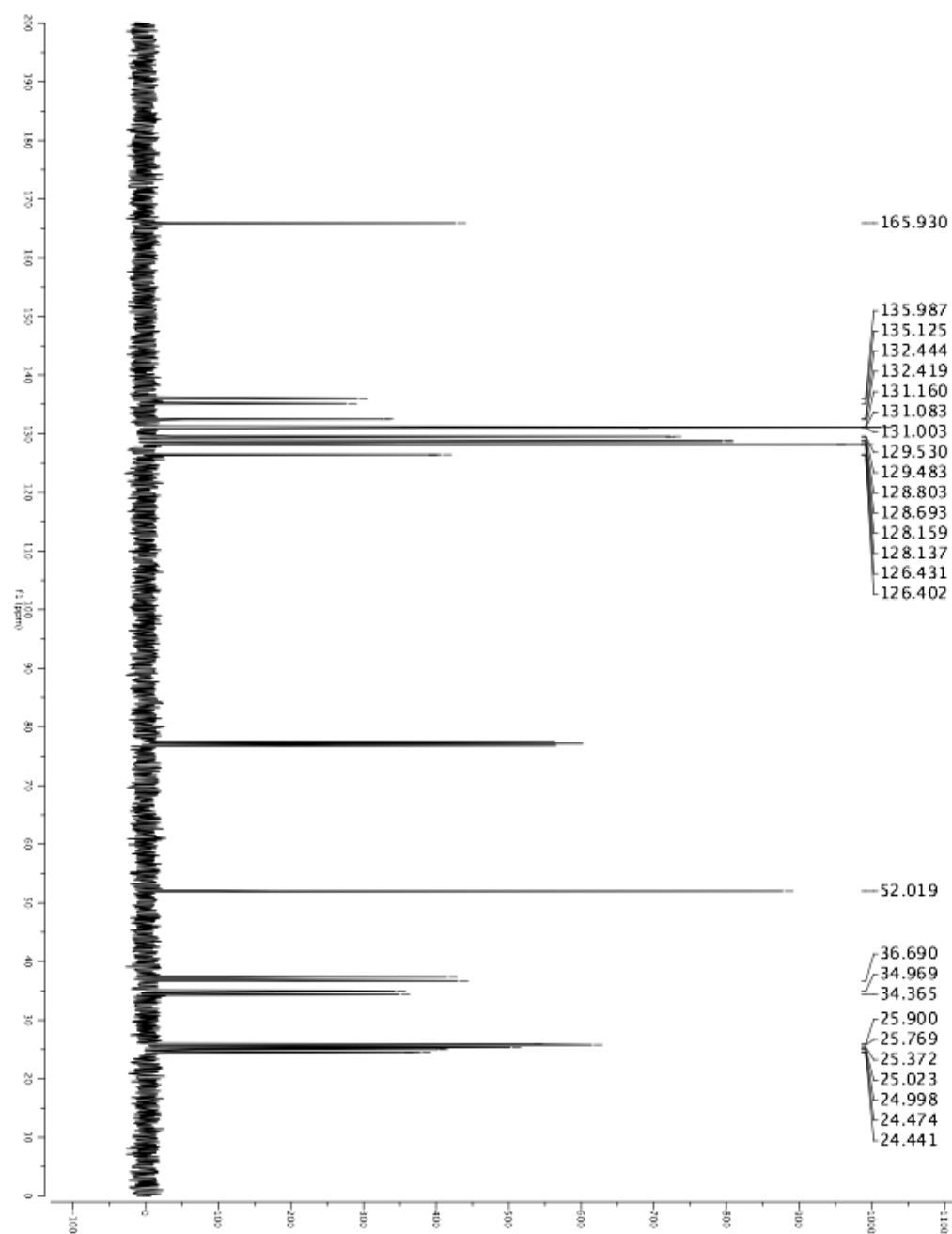
$^1\text{H}$  NMR



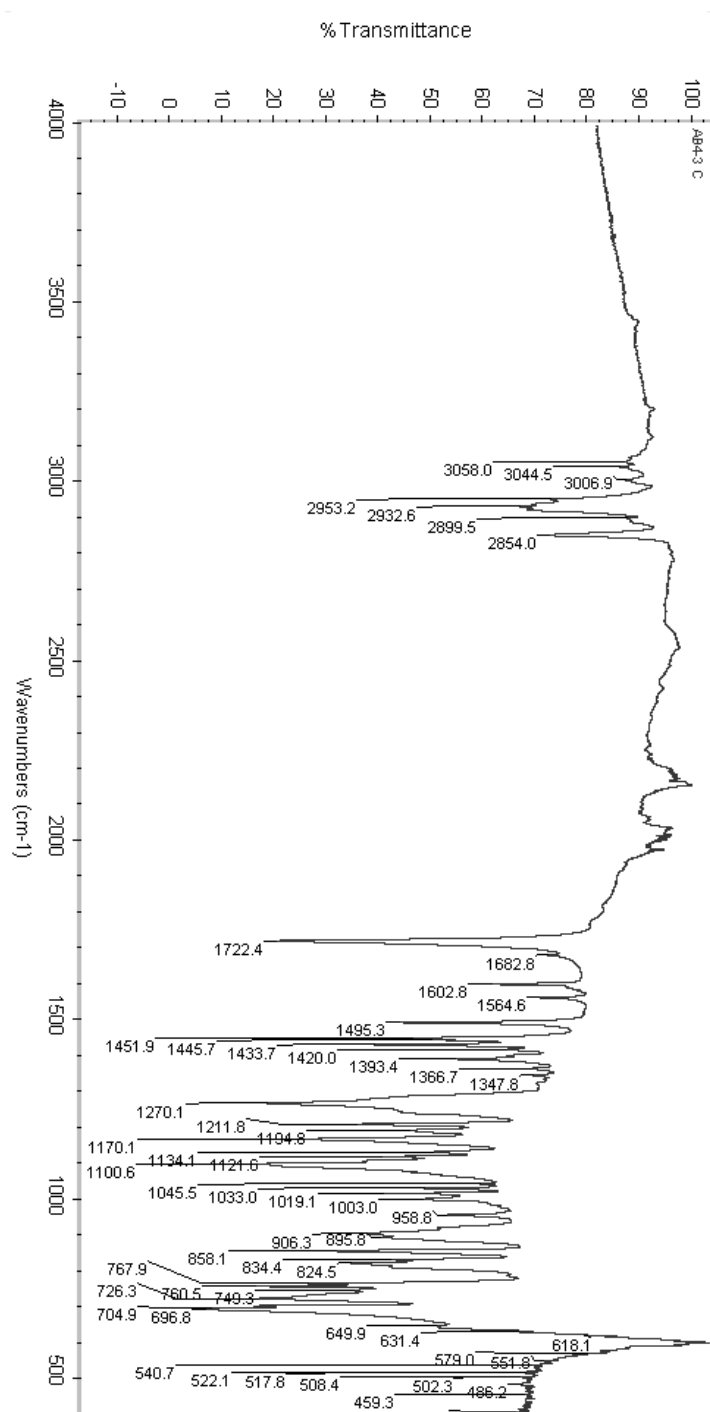
$^{31}\text{P}$  NMR



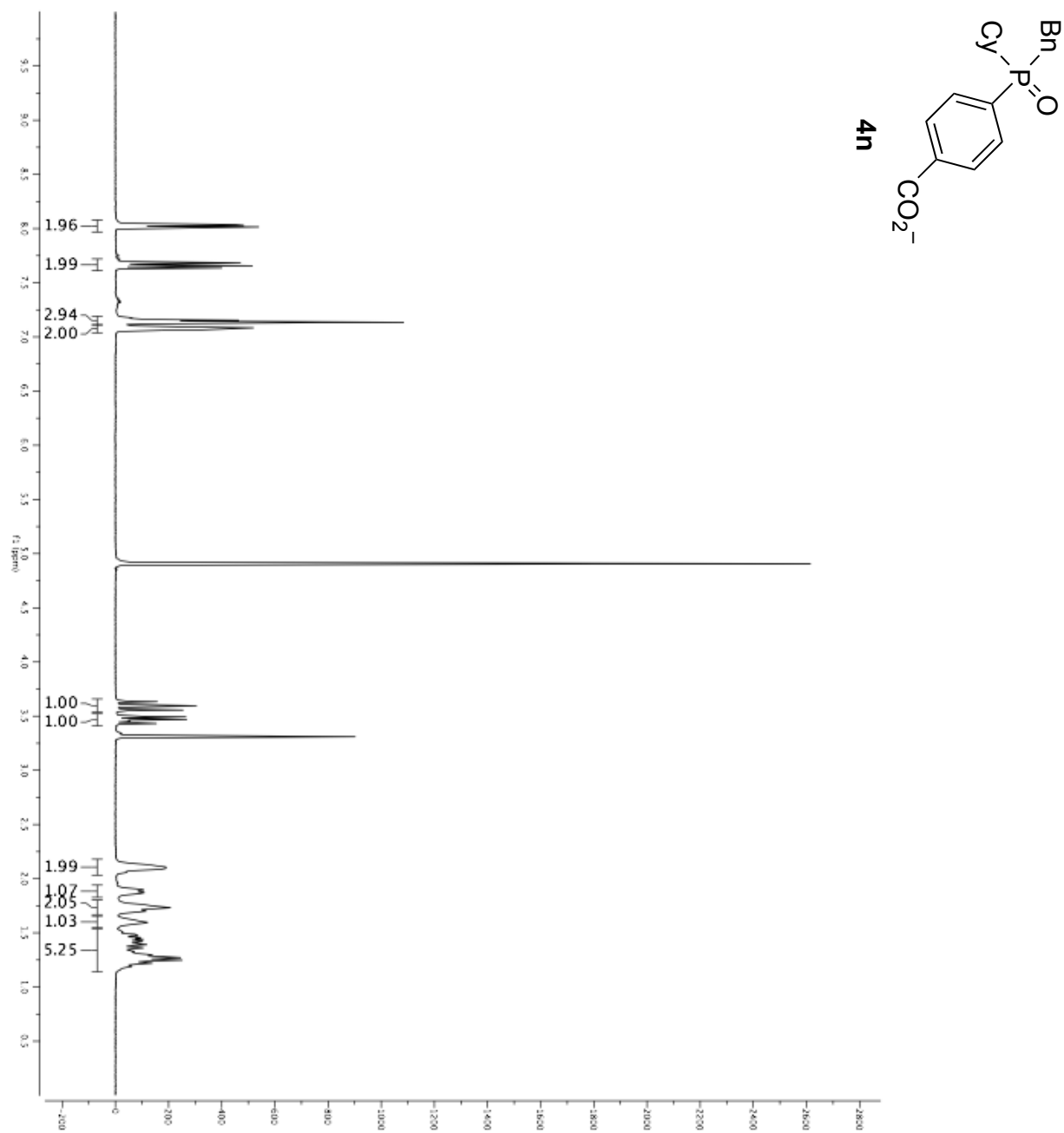
<sup>13</sup>C NMR



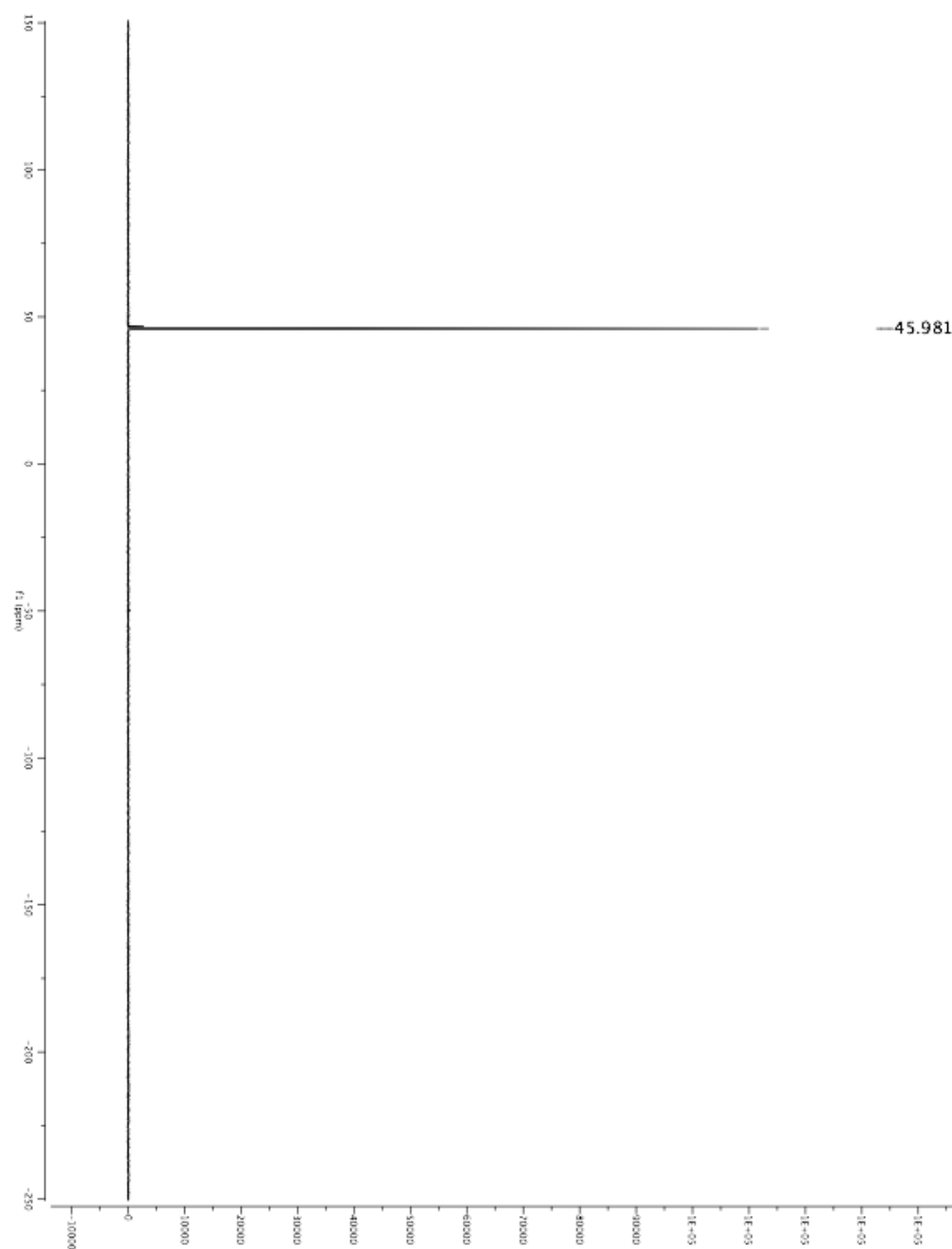
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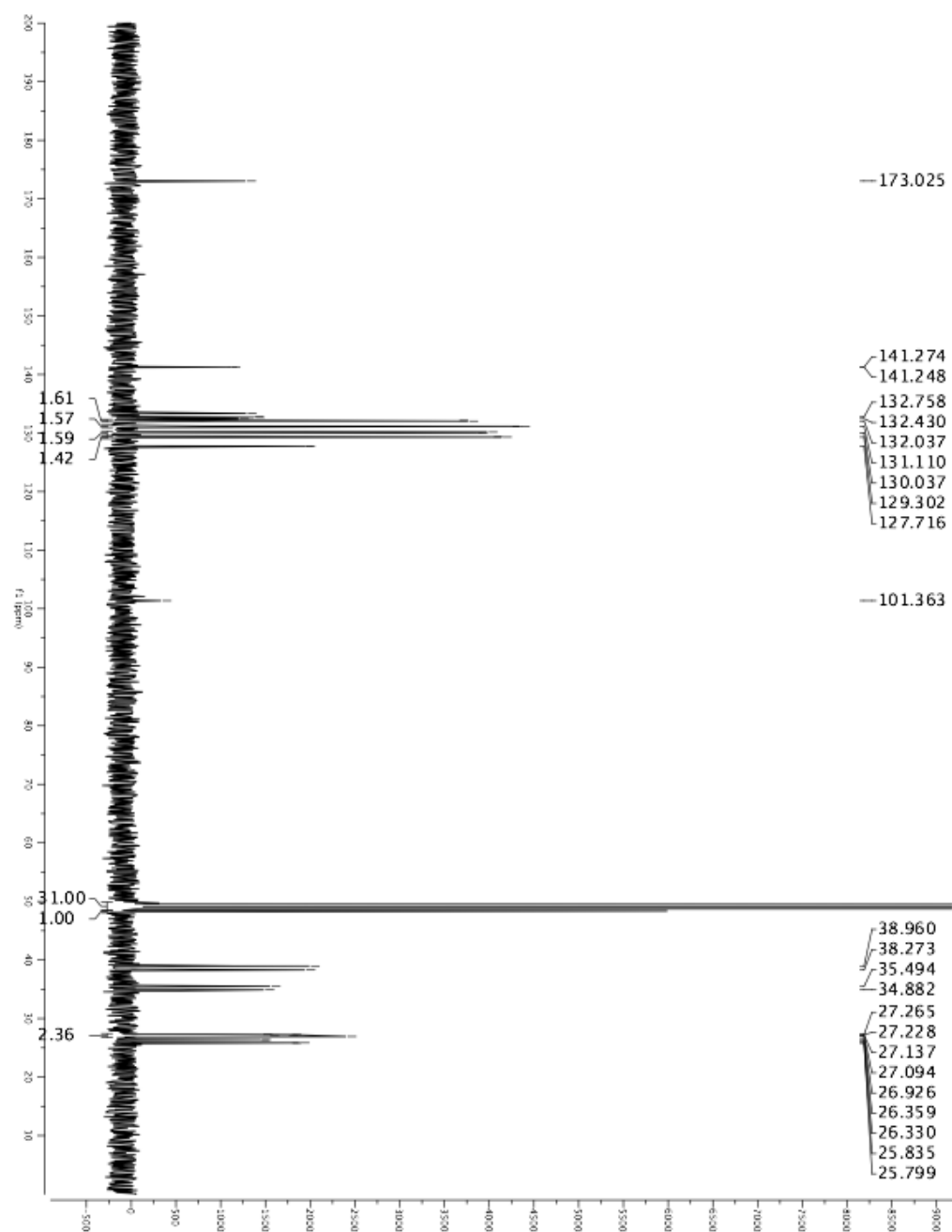
<sup>1</sup>H NMR



$^{31}\text{P}$  NMR

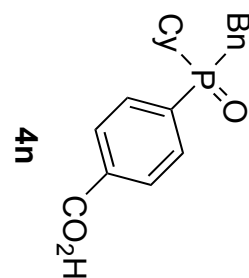
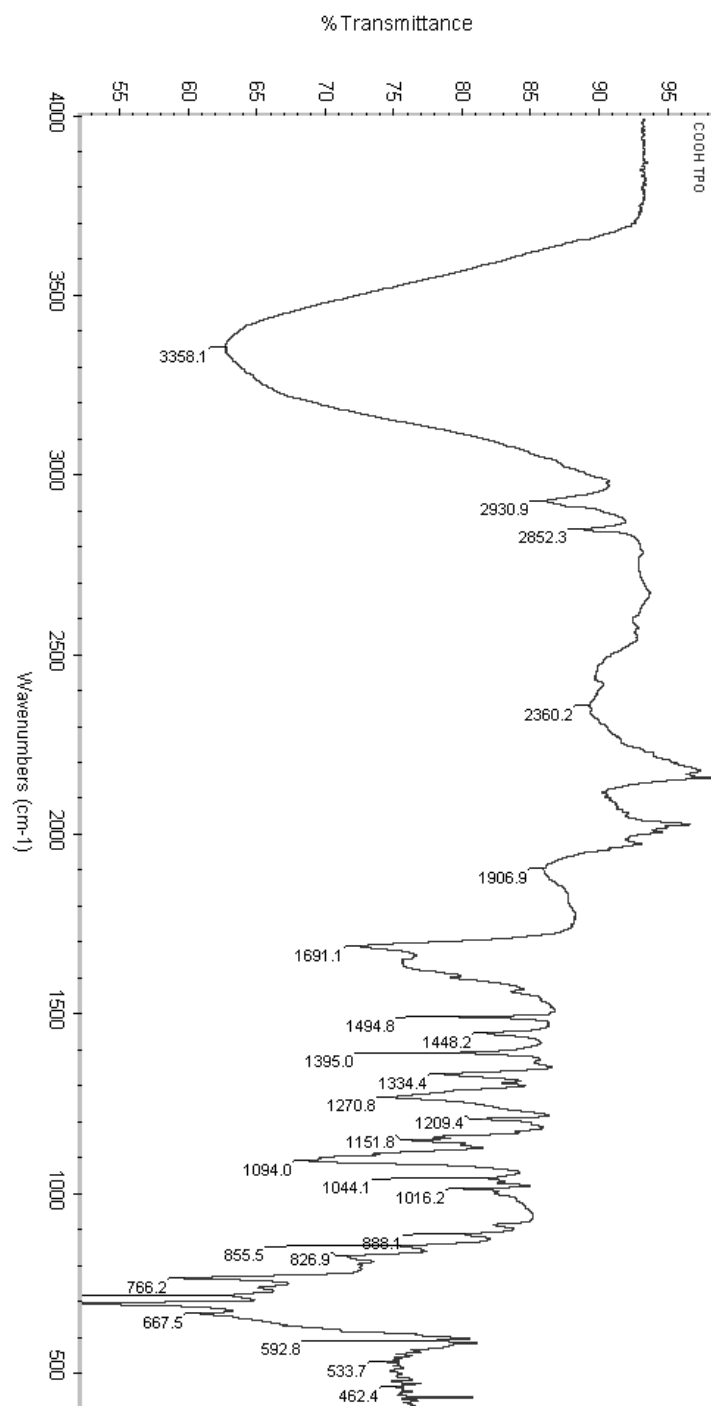


$^{13}\text{C}$  NMR

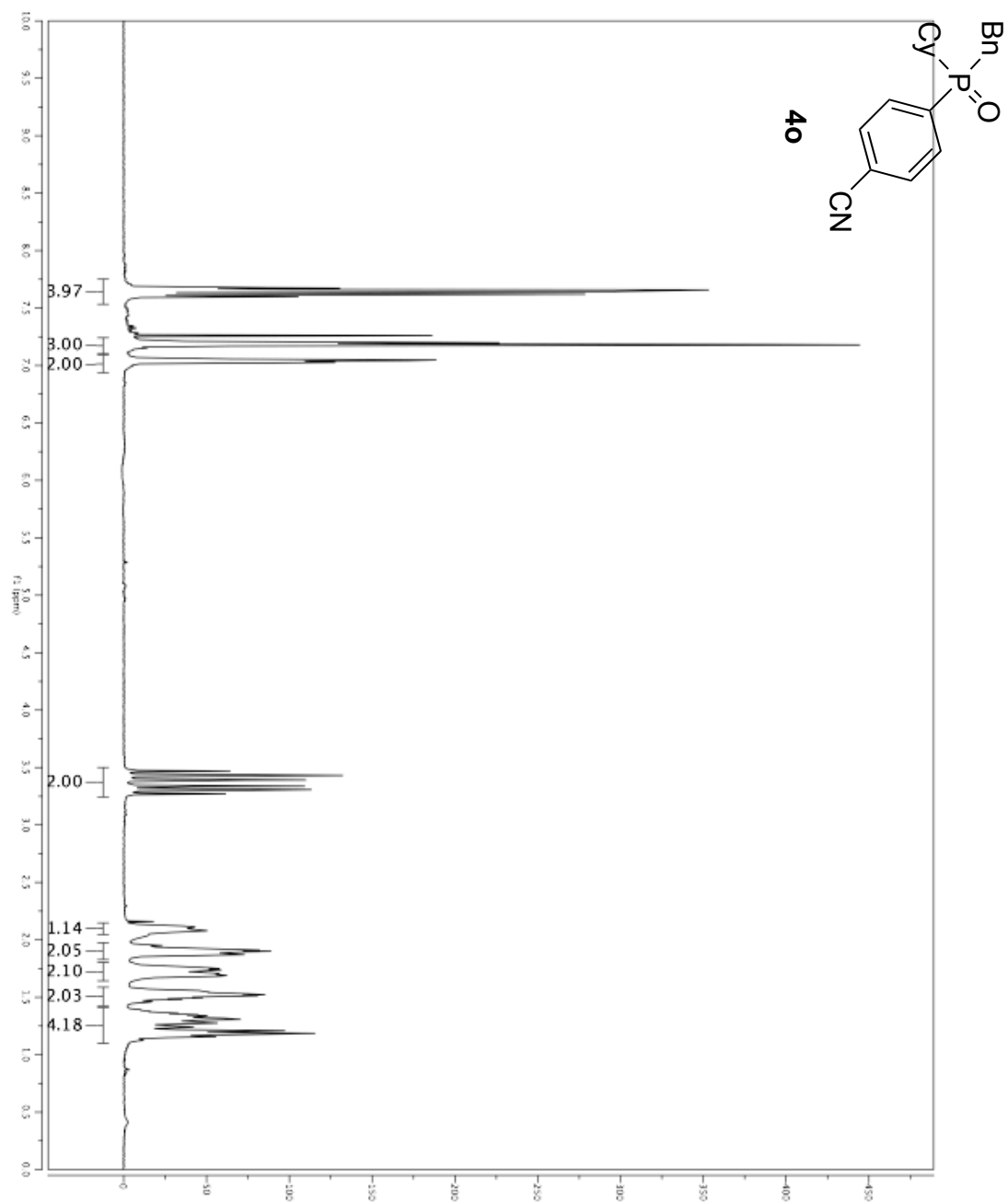




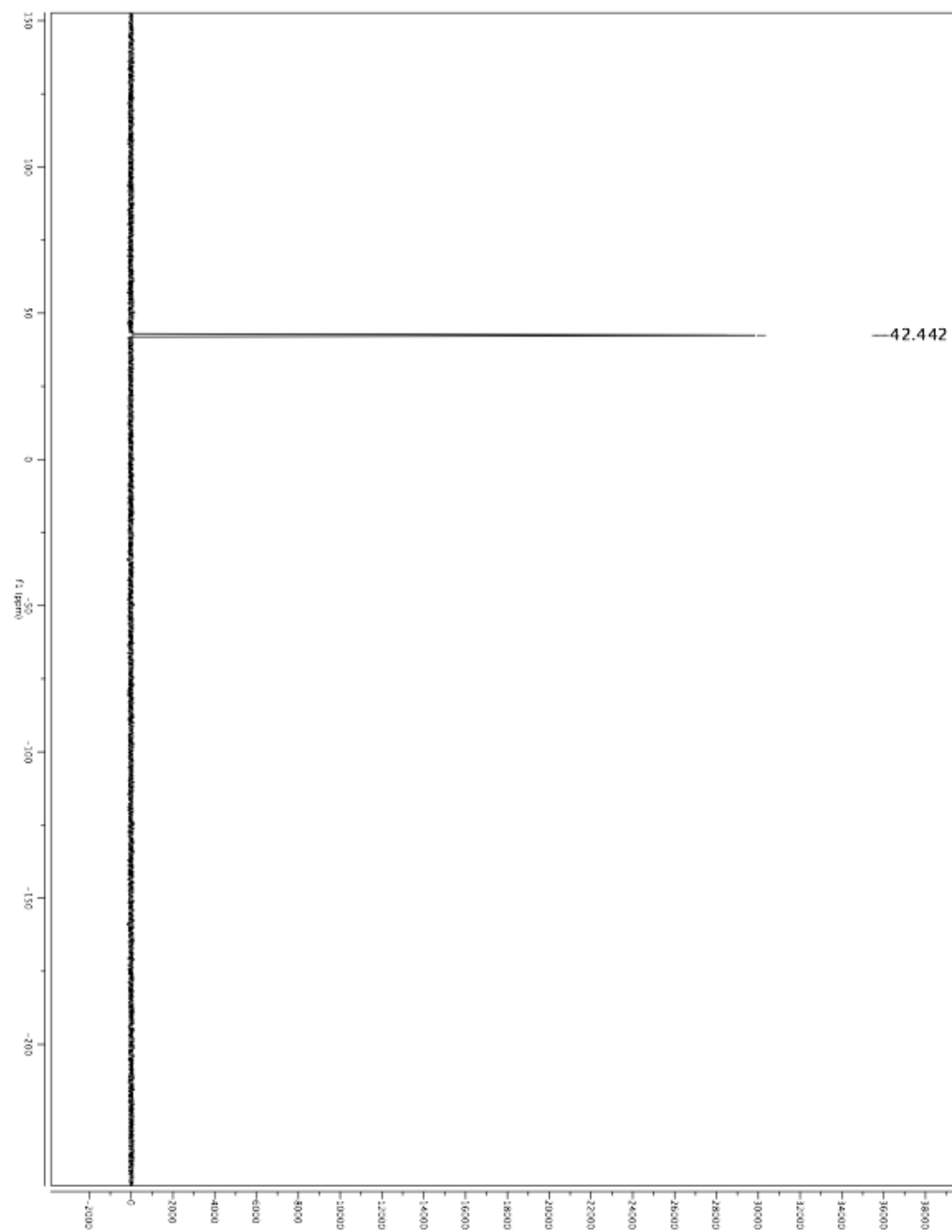
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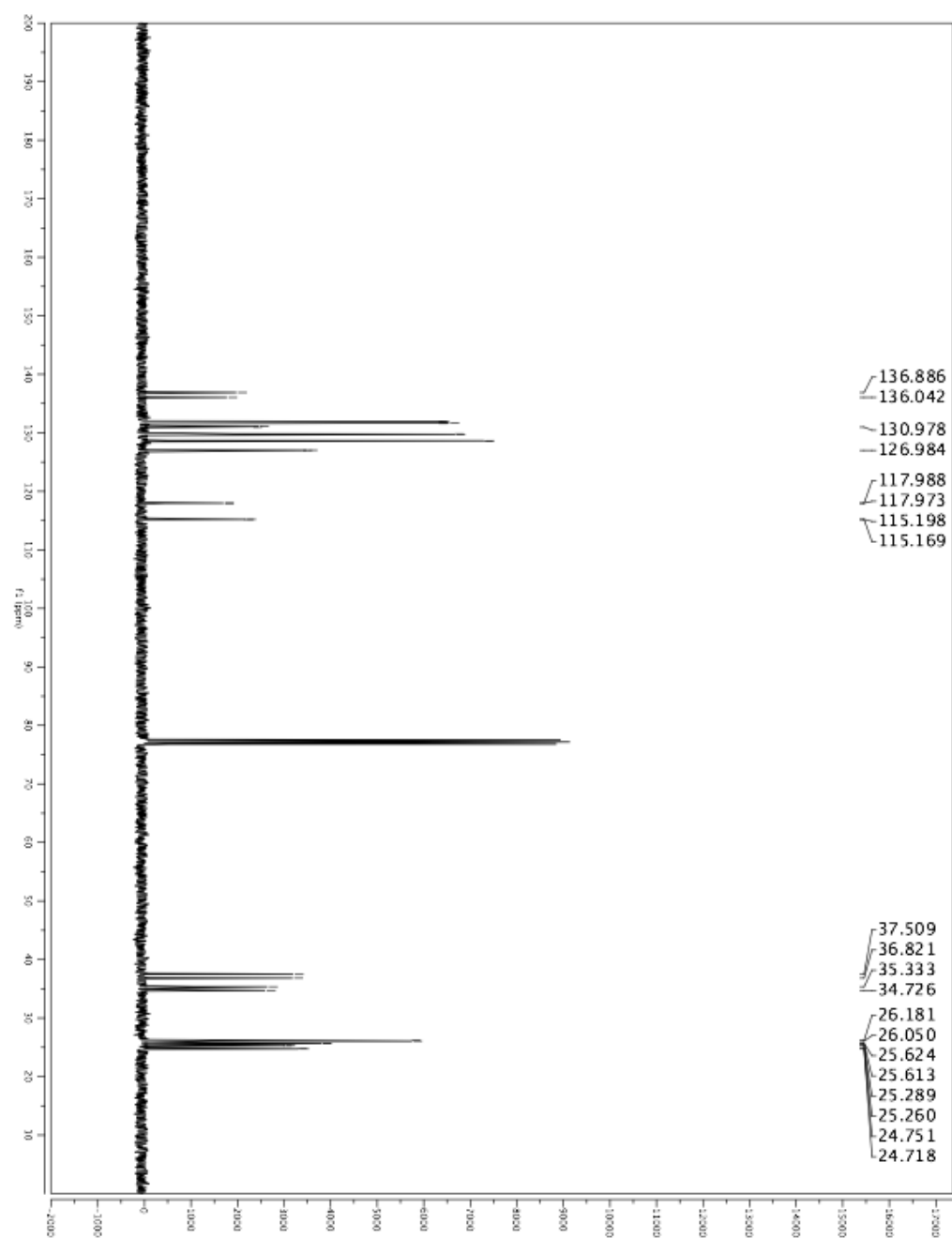
<sup>1</sup>H NMR



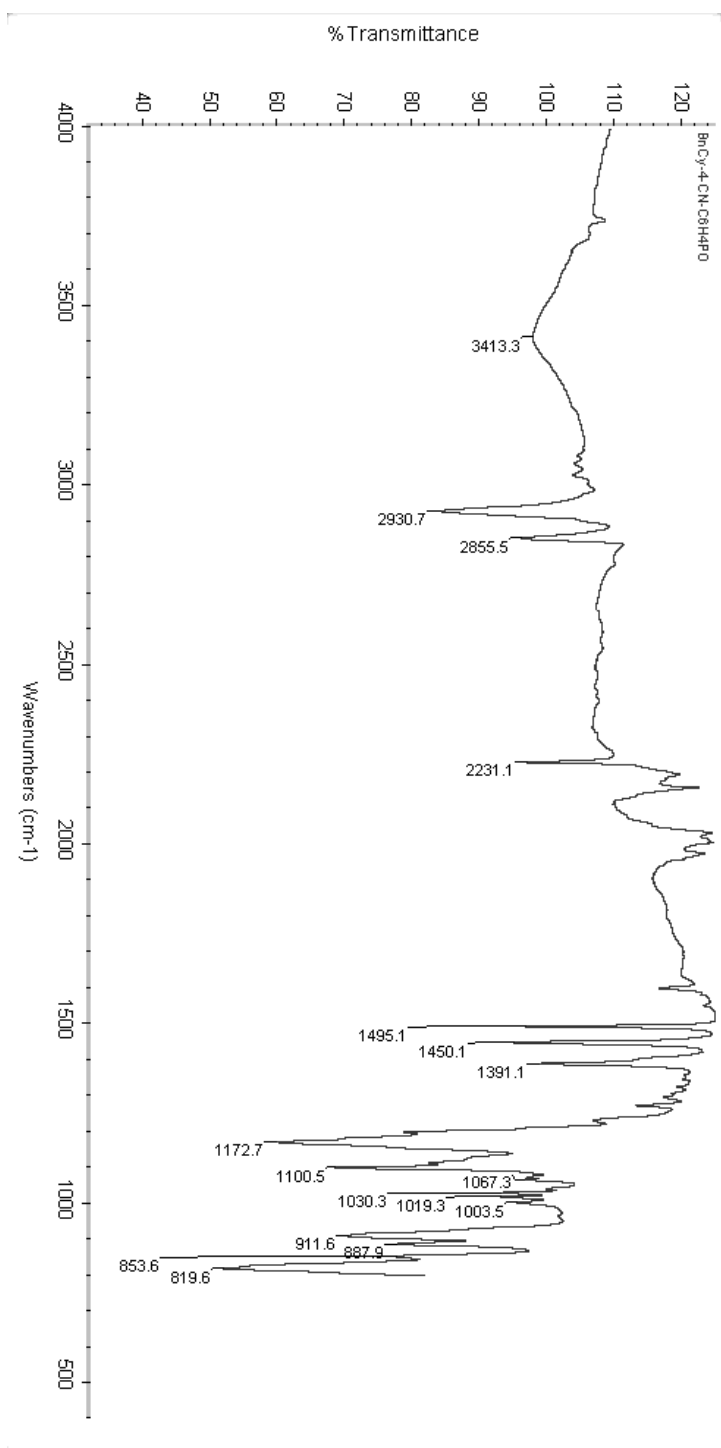
$^{31}\text{P}$  NMR



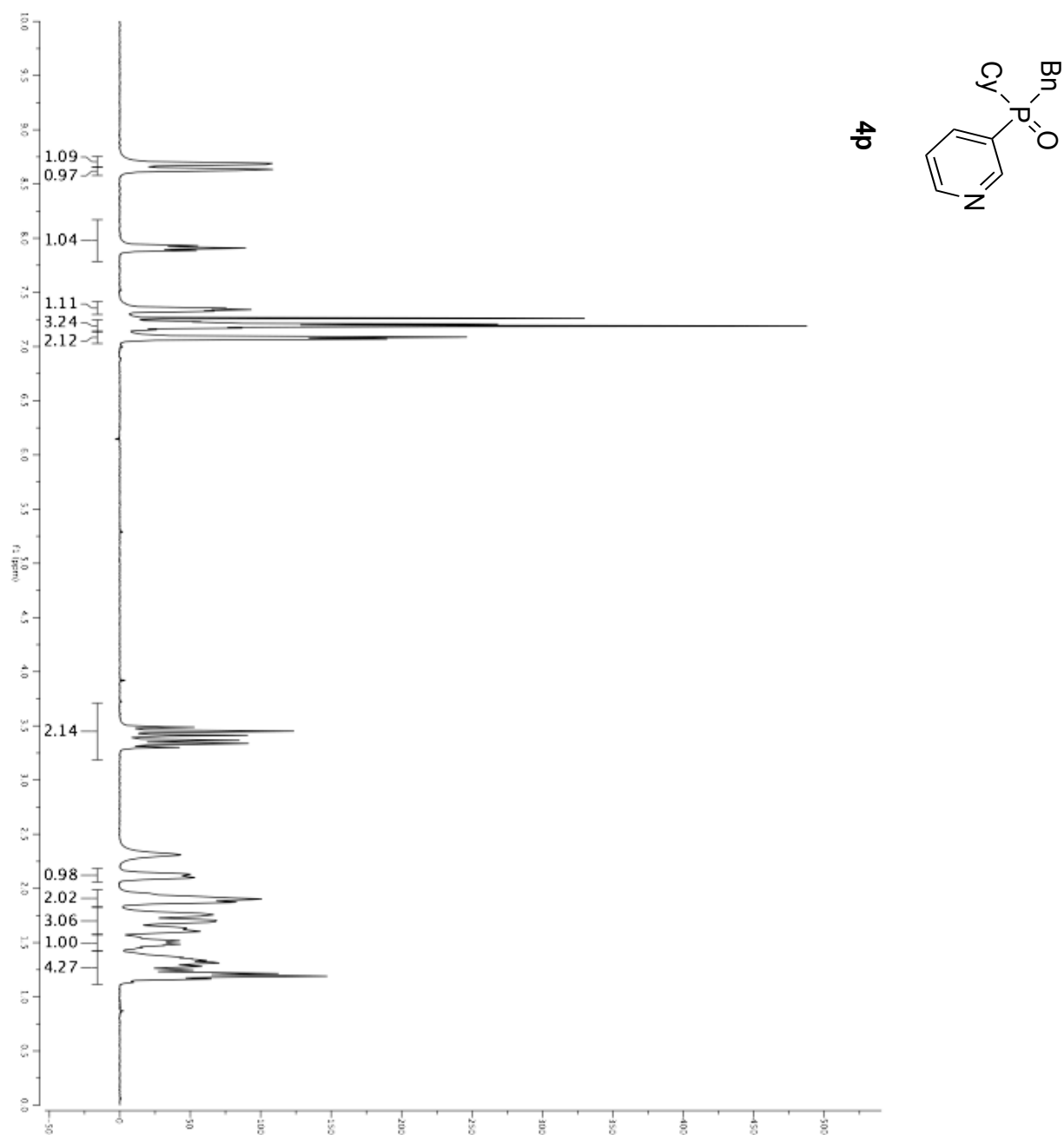
$^{13}\text{C}$  NMR



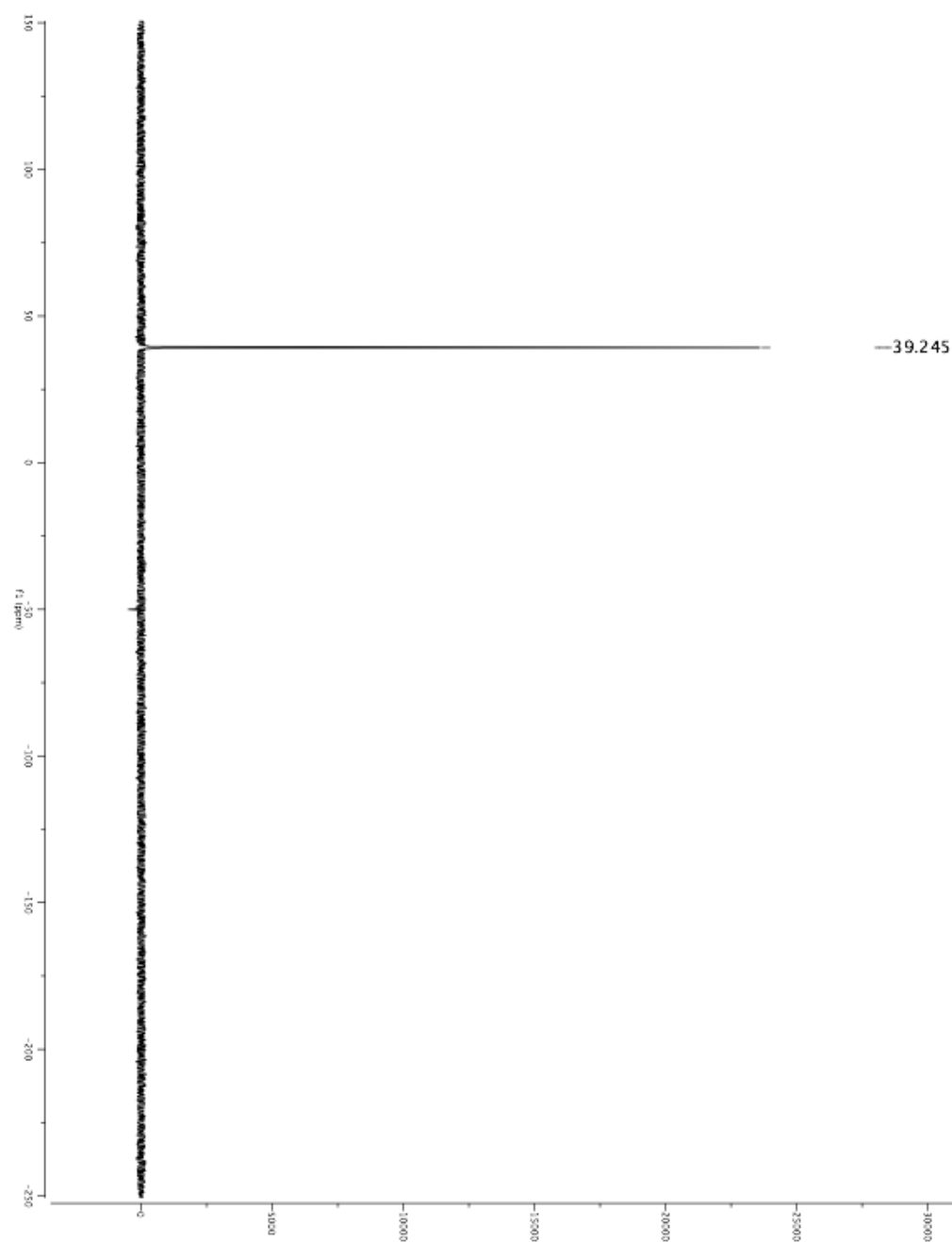
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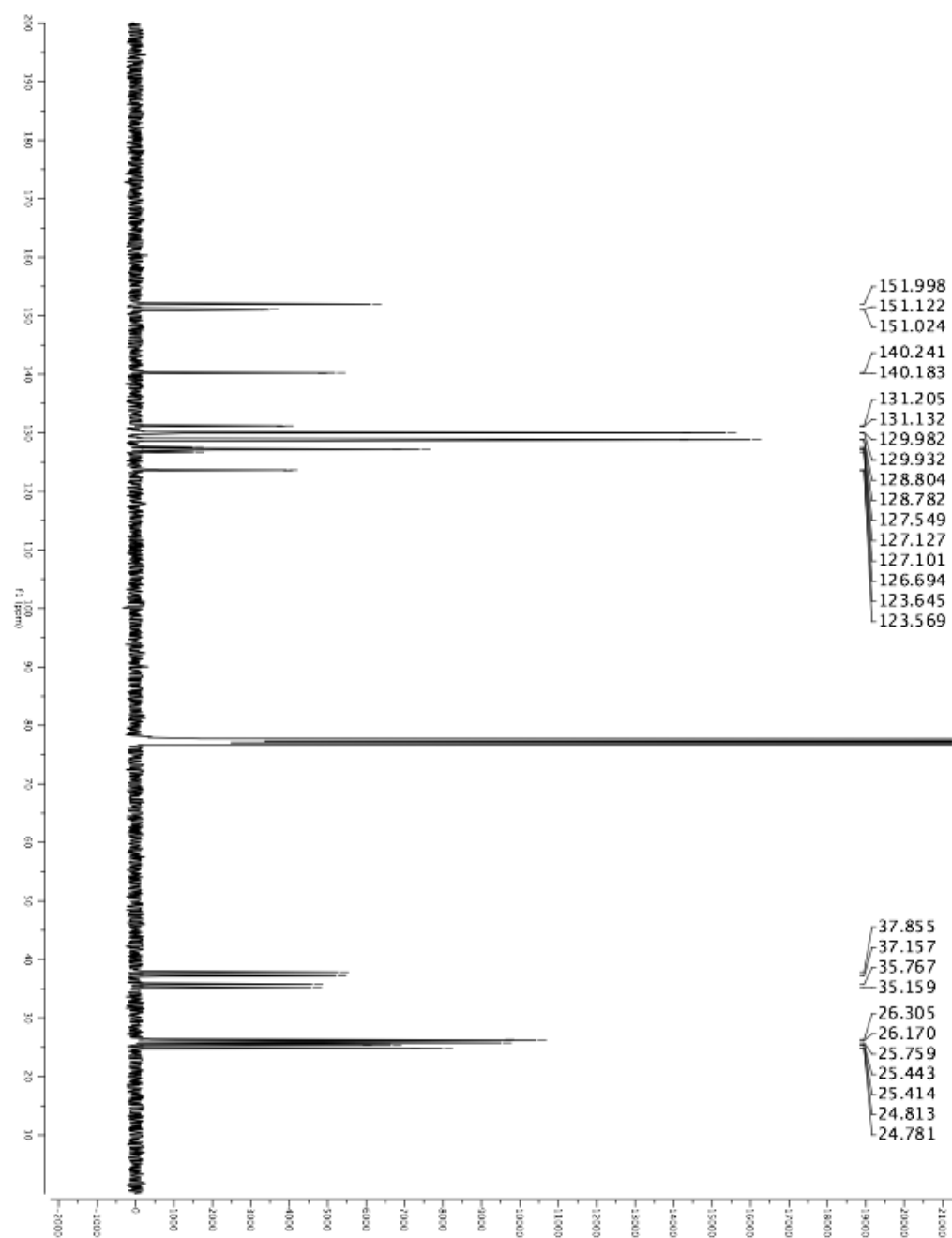
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$^{31}\text{P}$  NMR

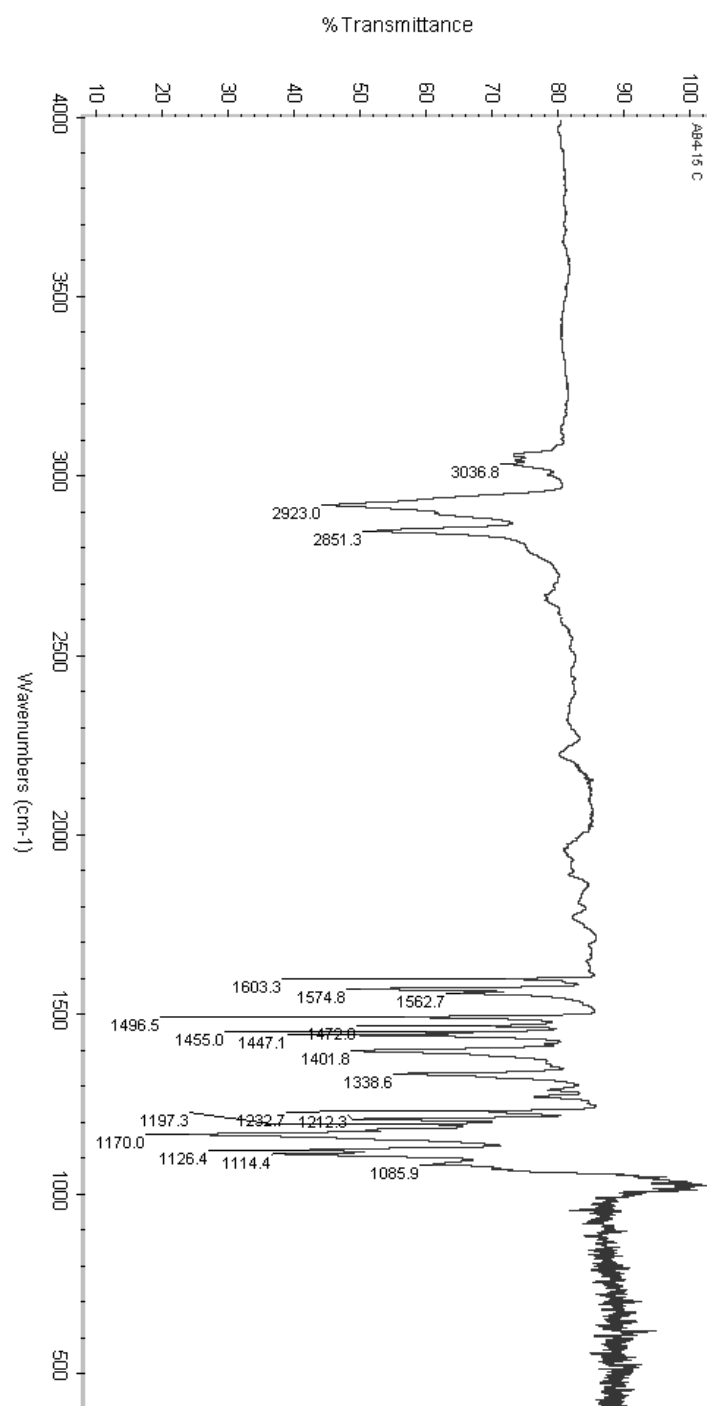


<sup>13</sup>C NMR

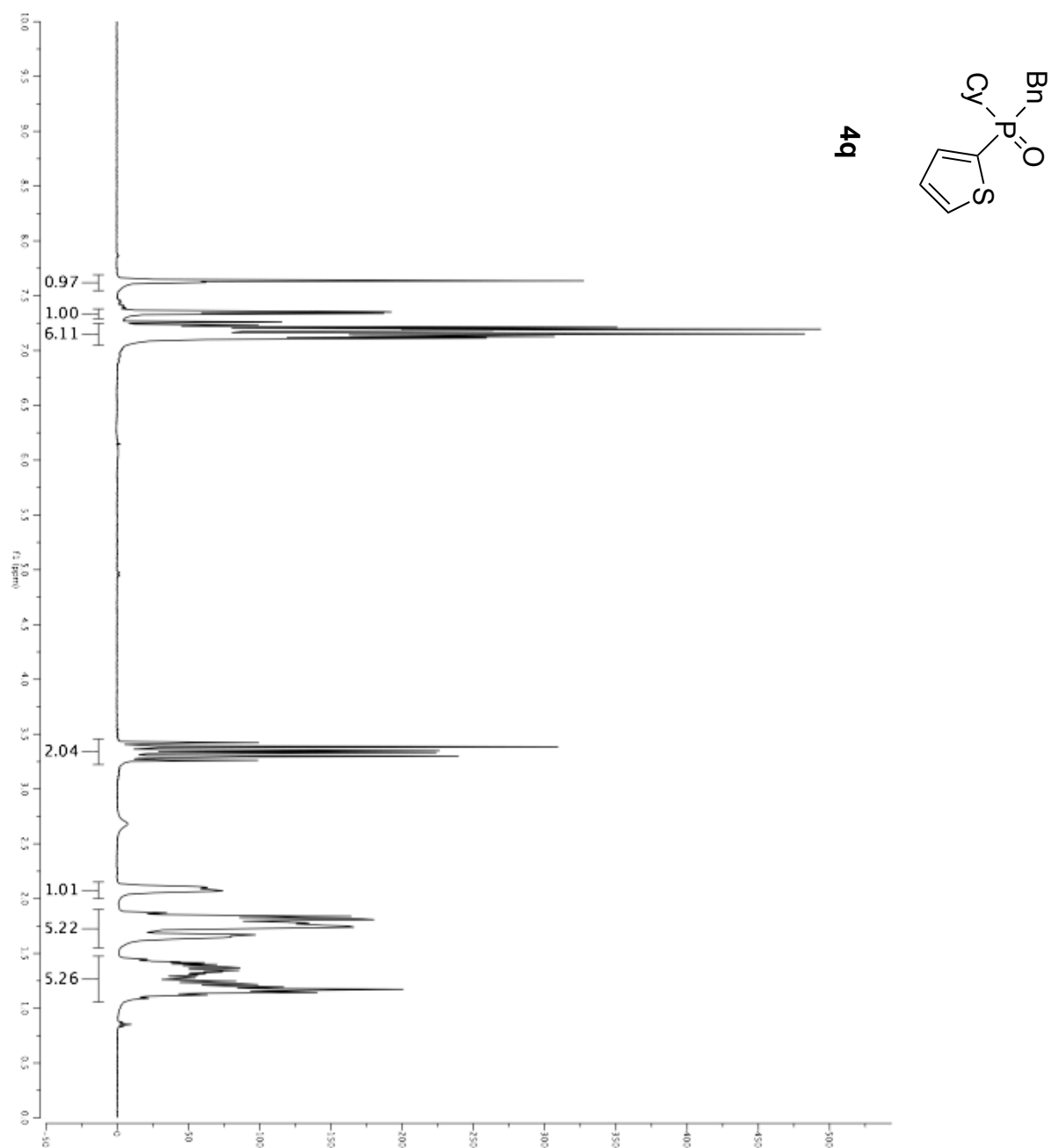




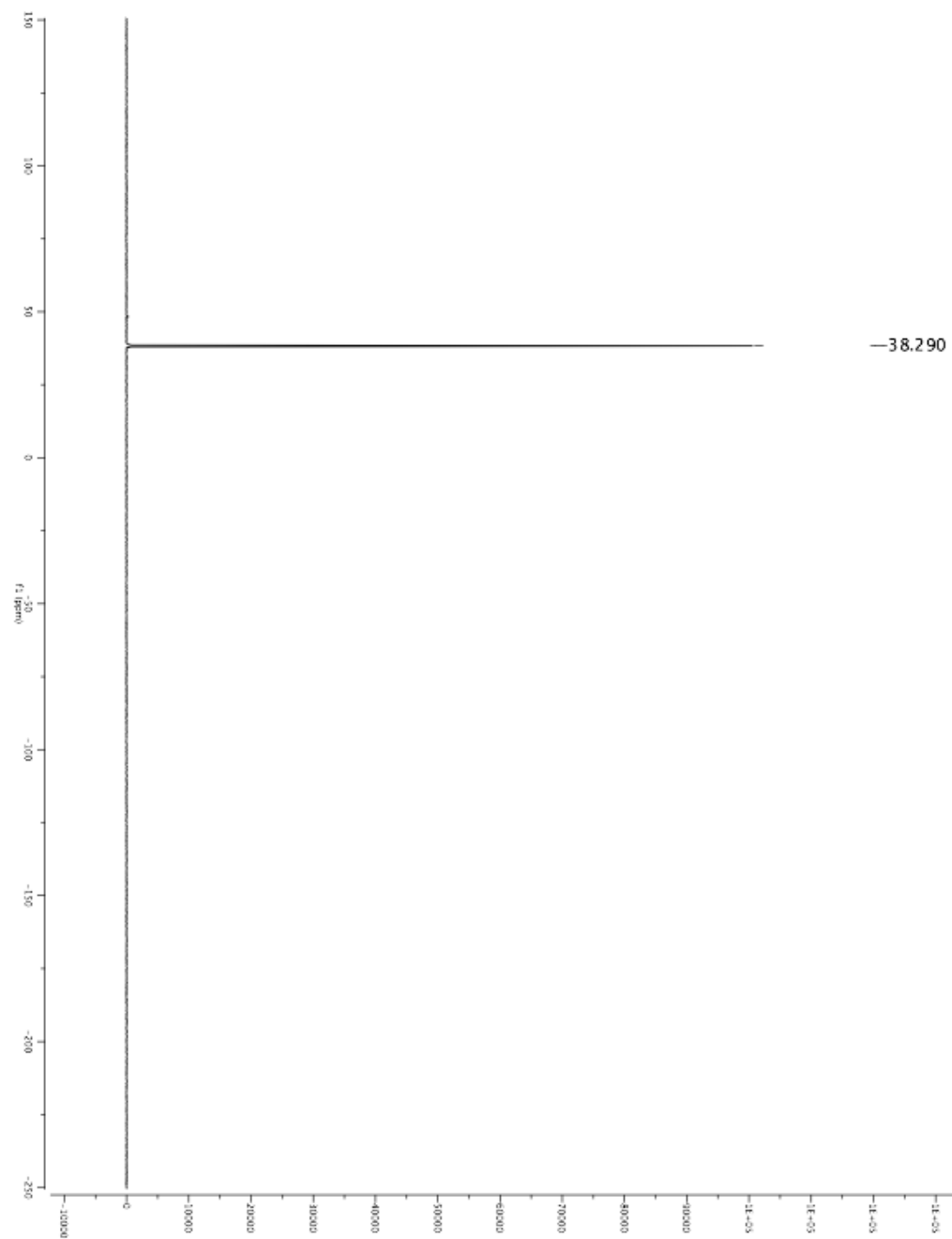
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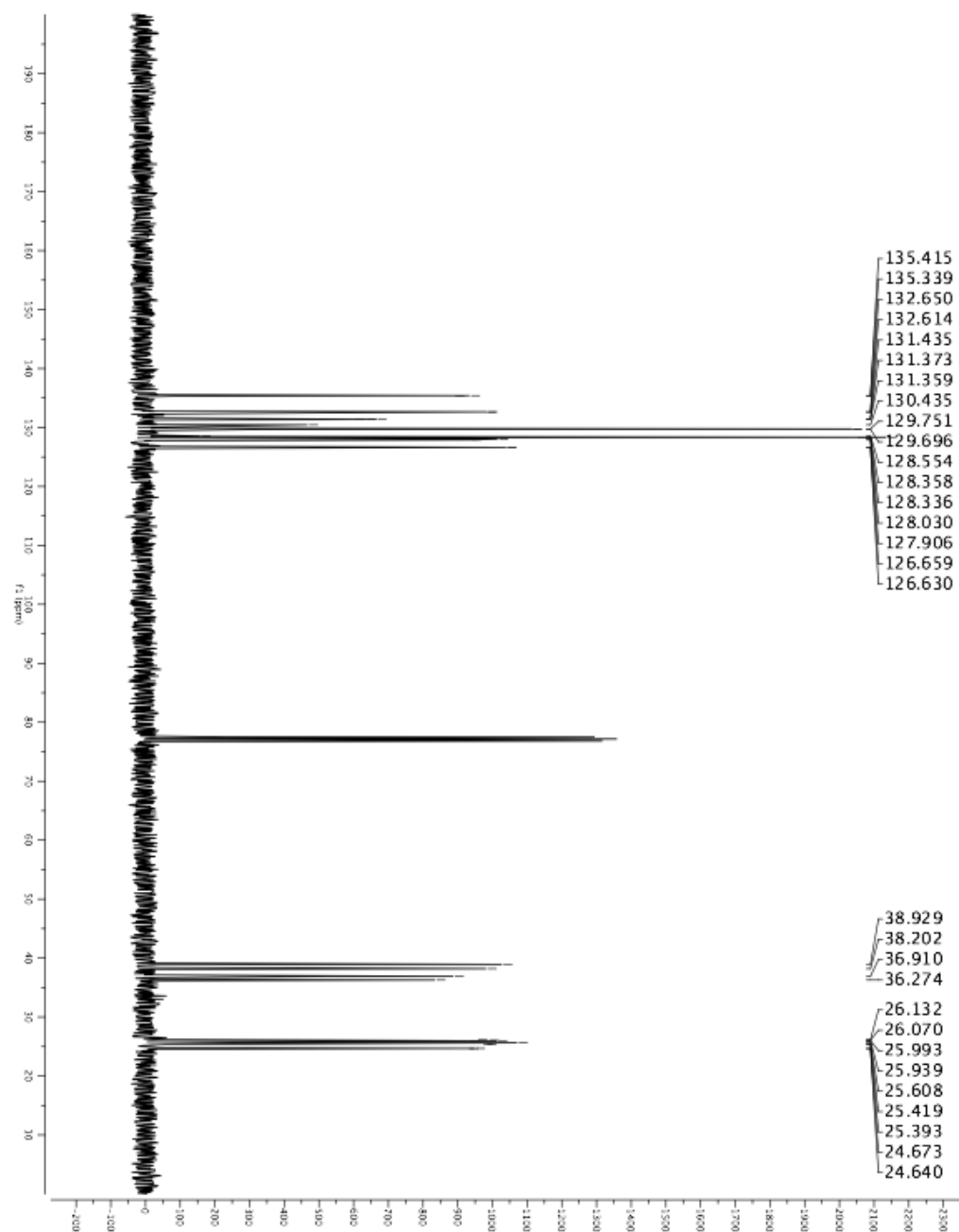
<sup>1</sup>H NMR



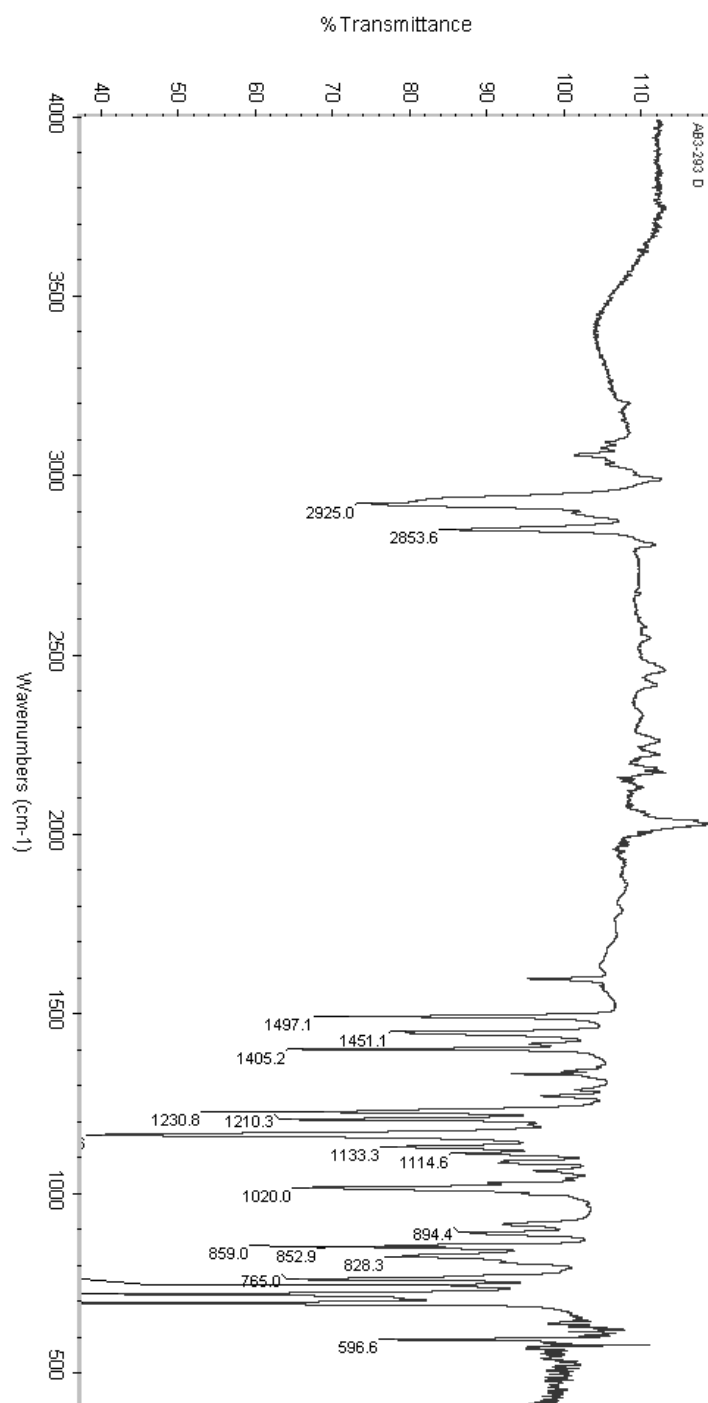
$^{31}\text{P}$  NMR



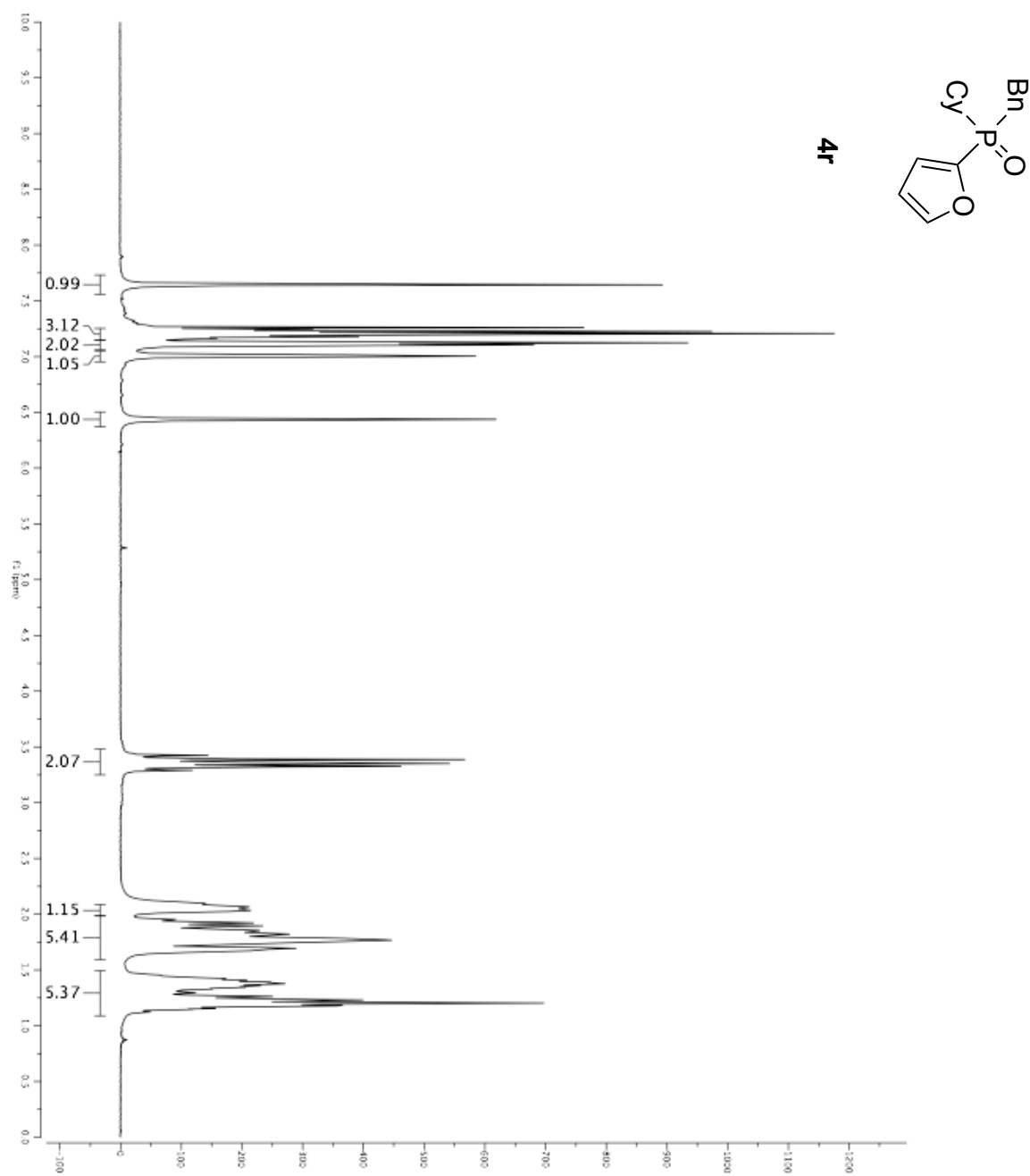
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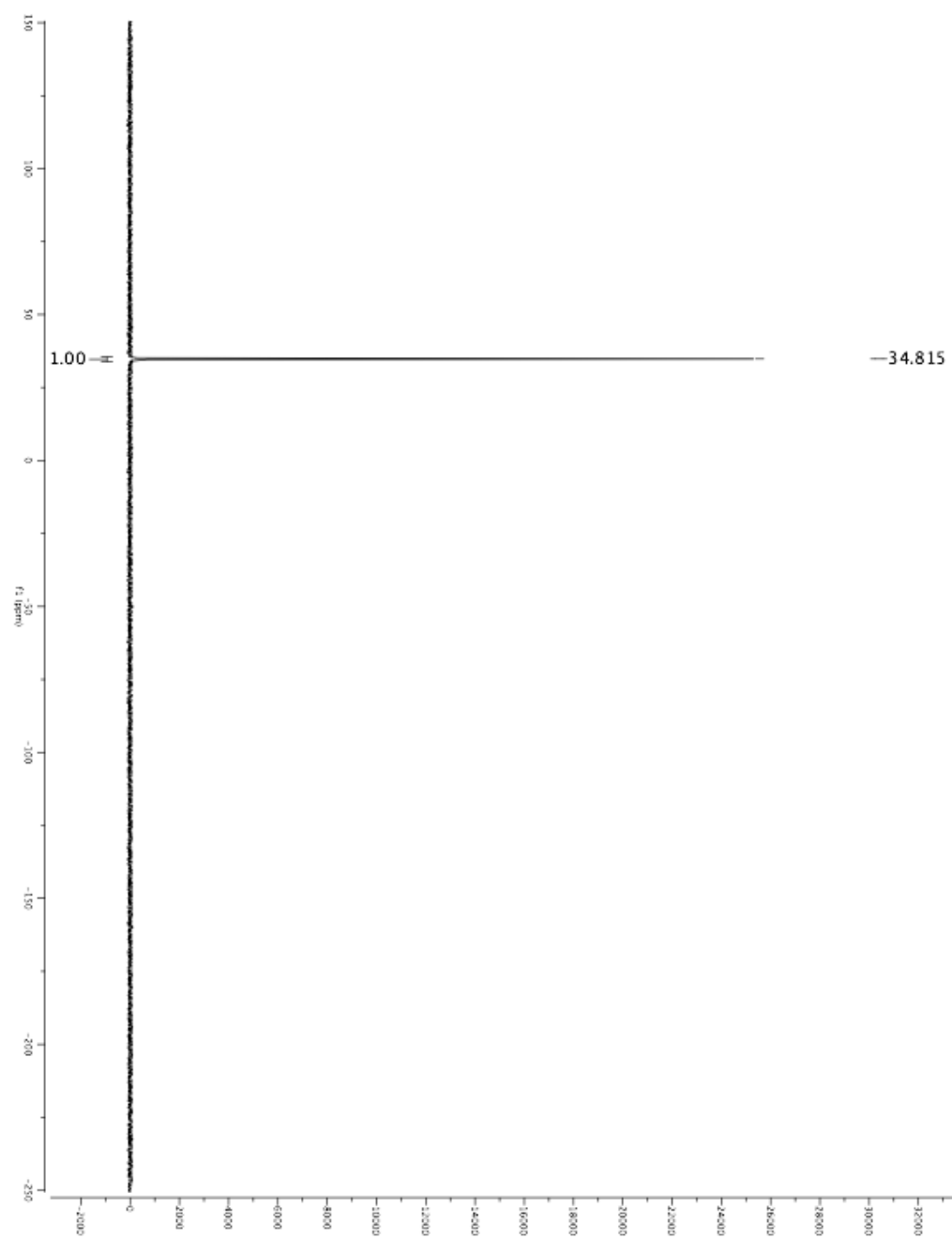
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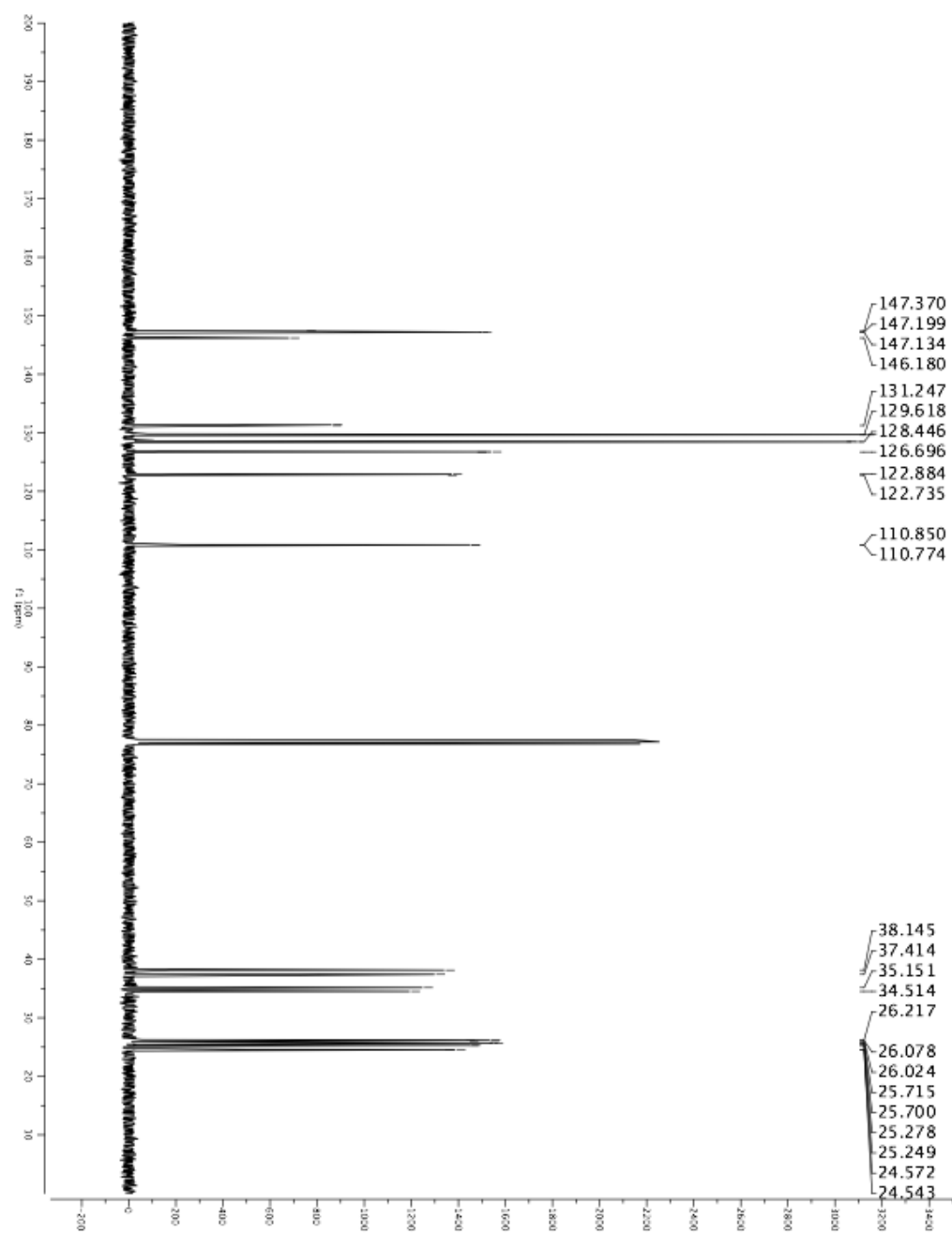
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$^{31}\text{P}$  NMR

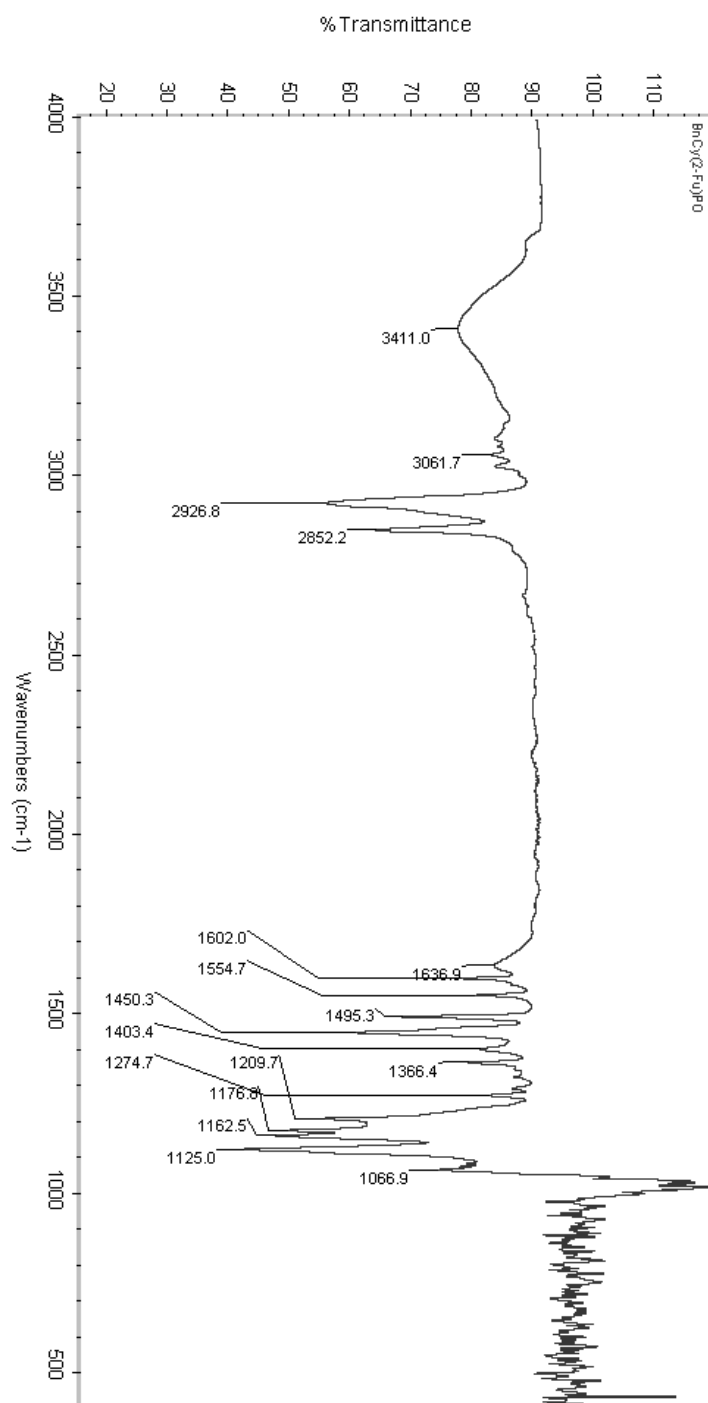


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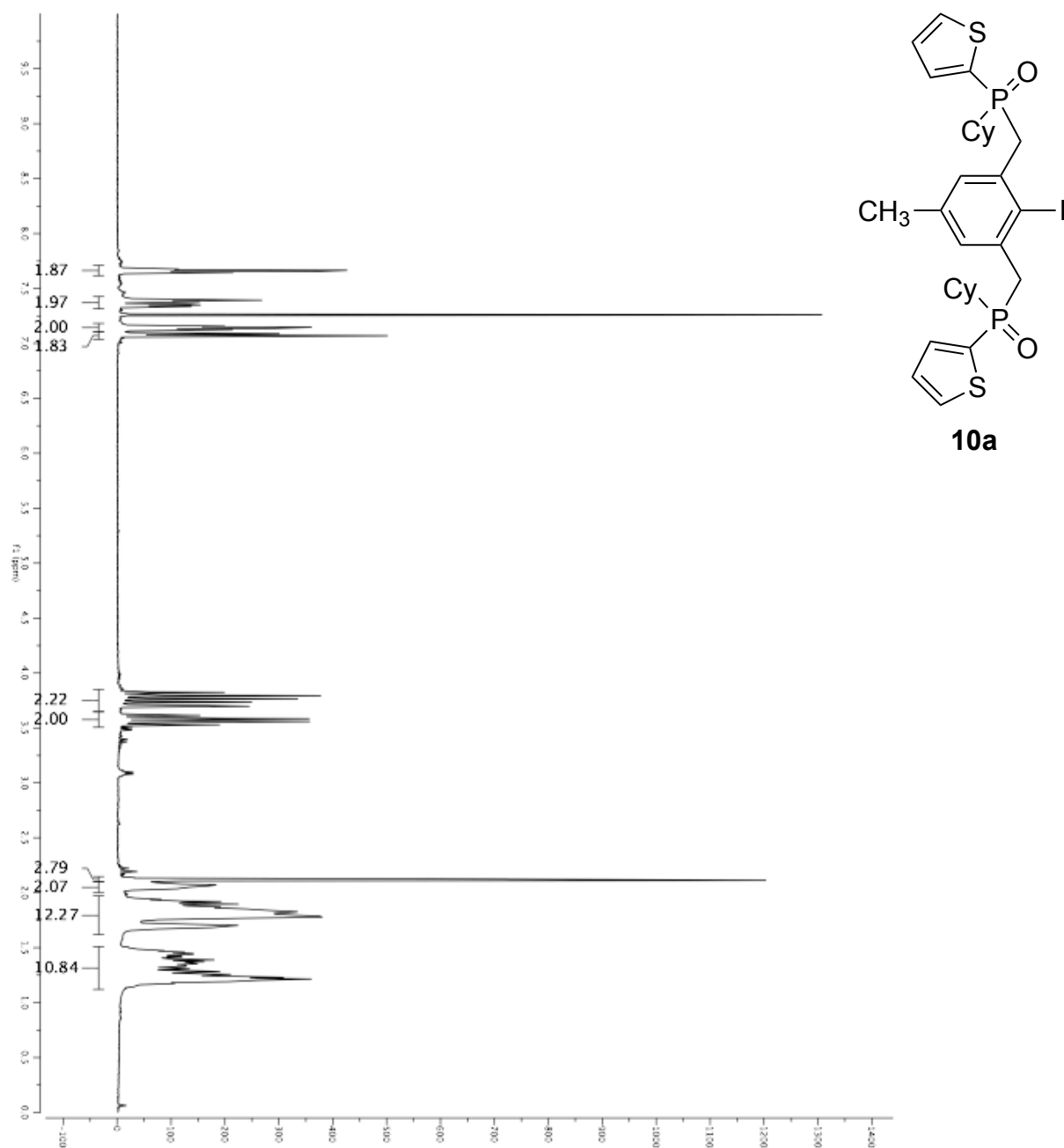




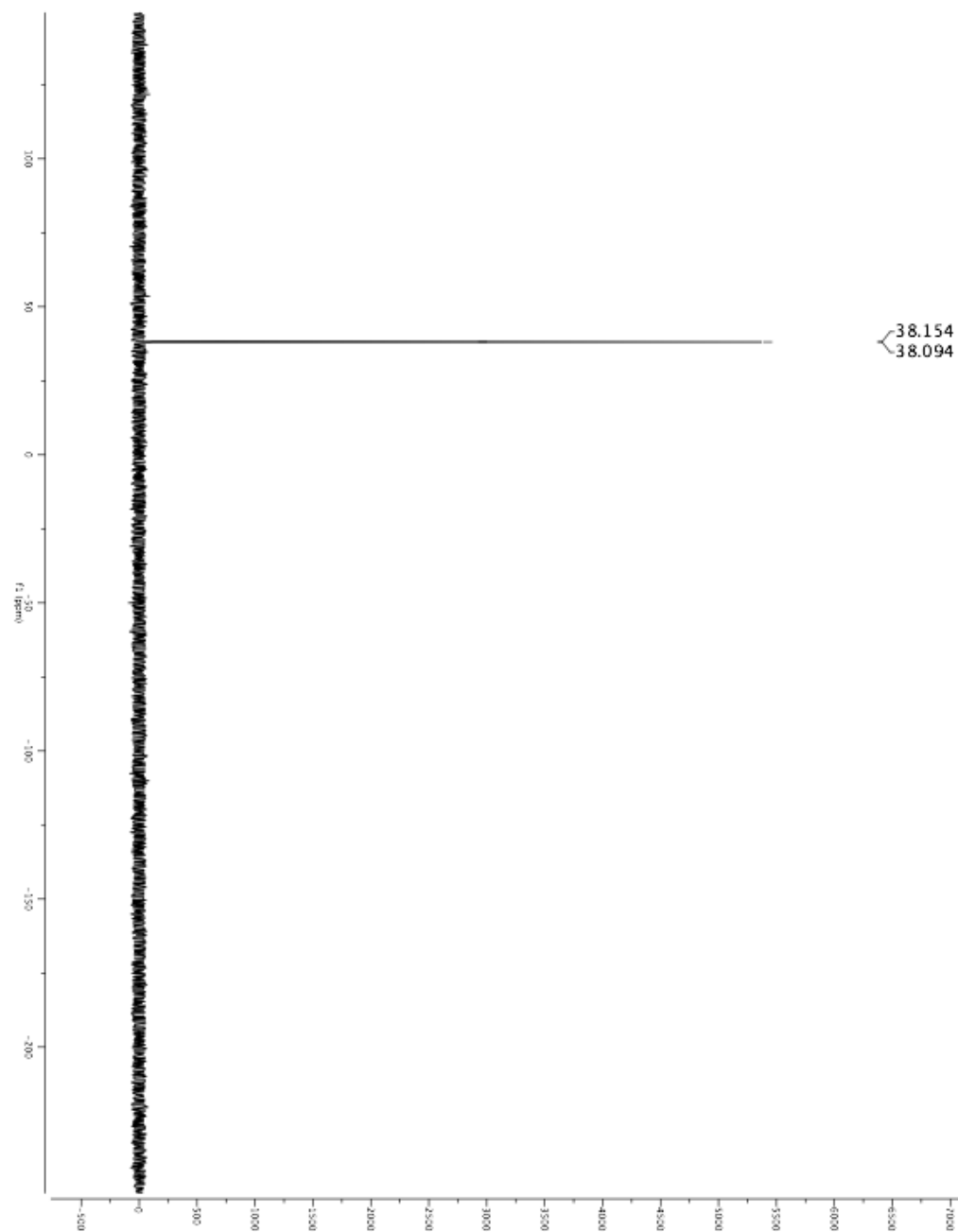
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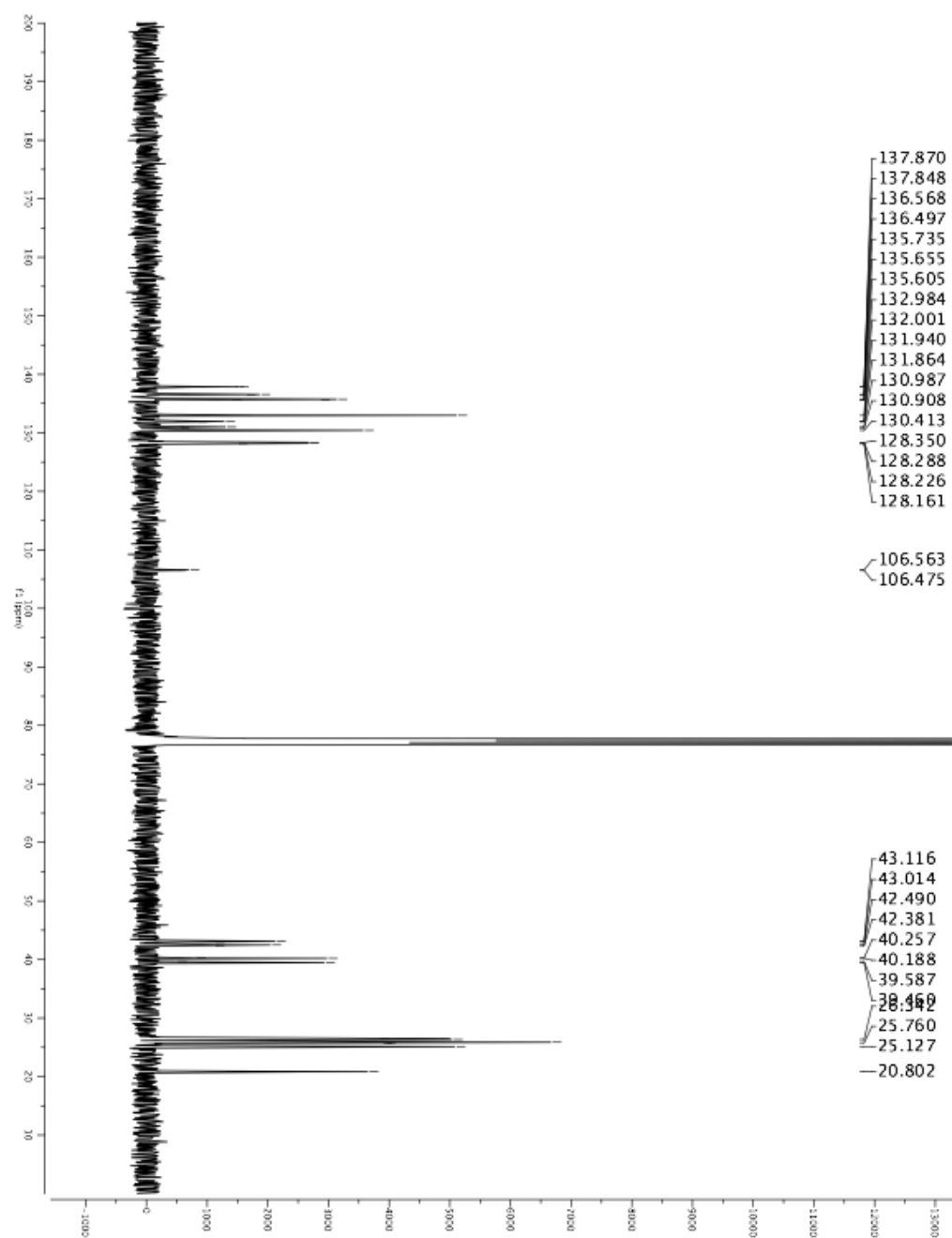
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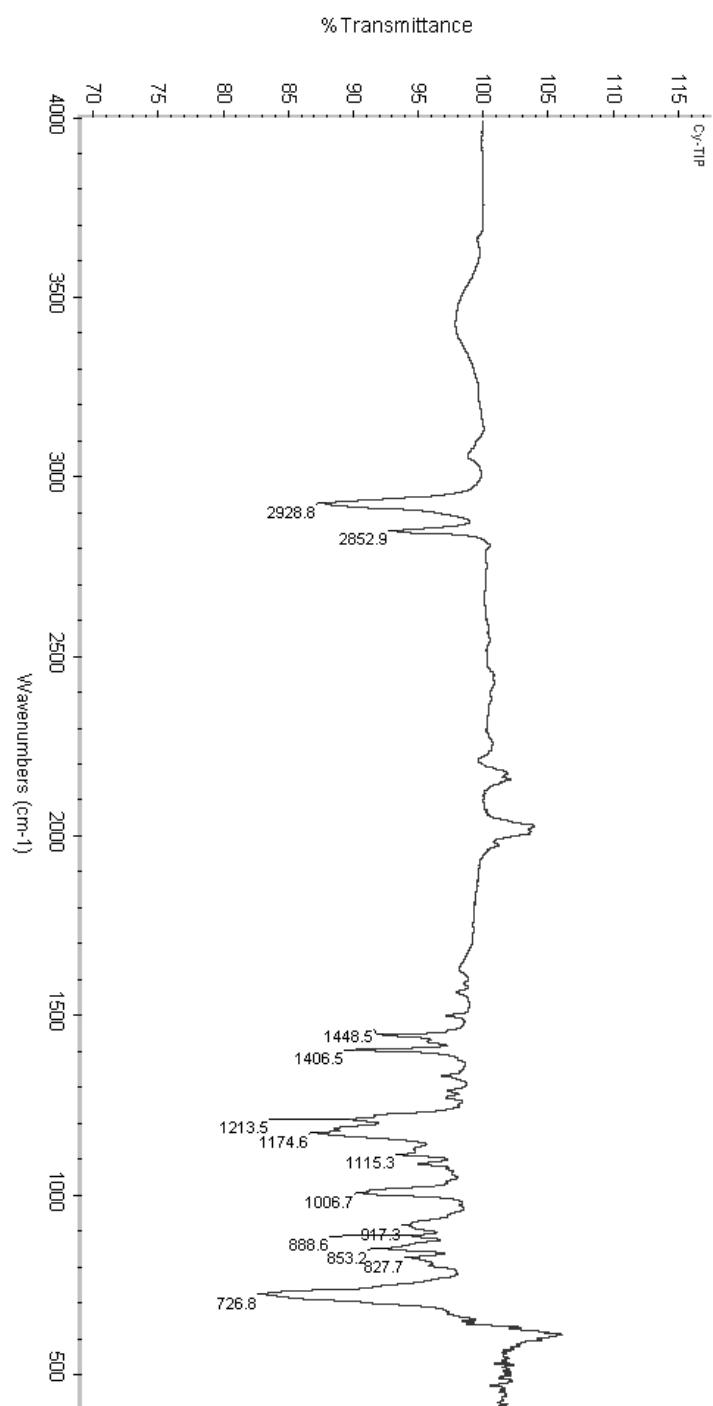
$^{31}\text{P}$  NMR



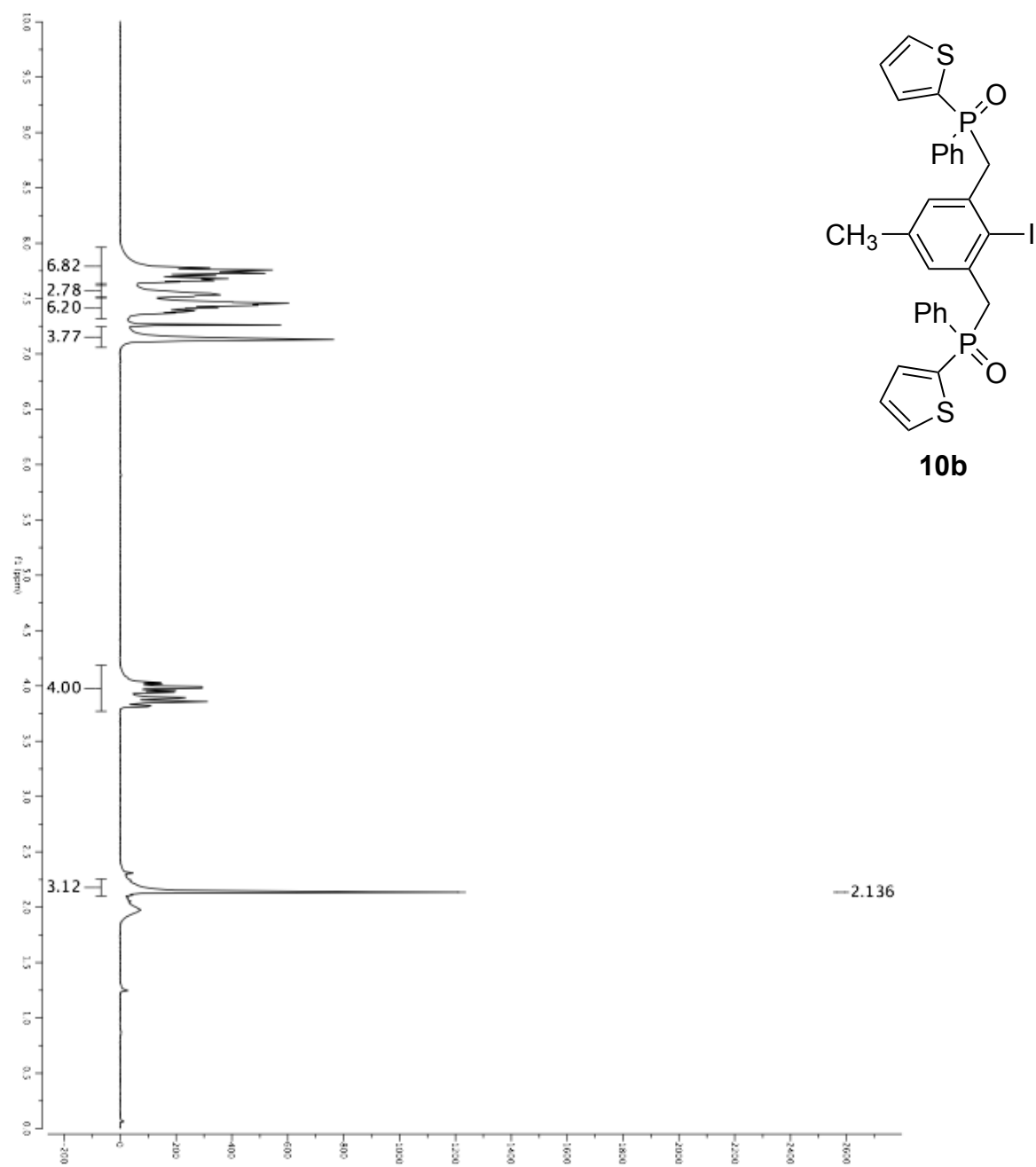
$^{13}\text{C}$  NMR



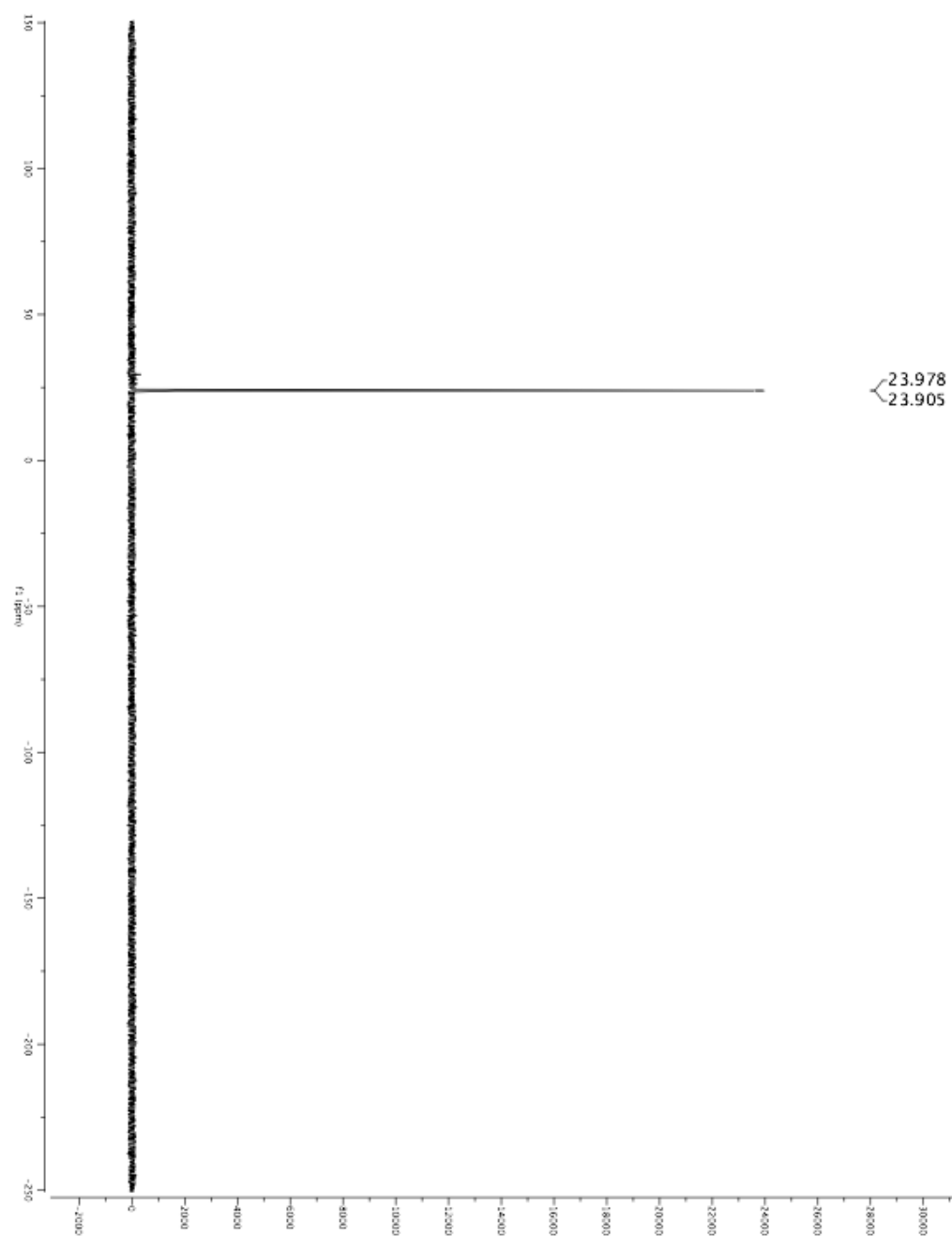
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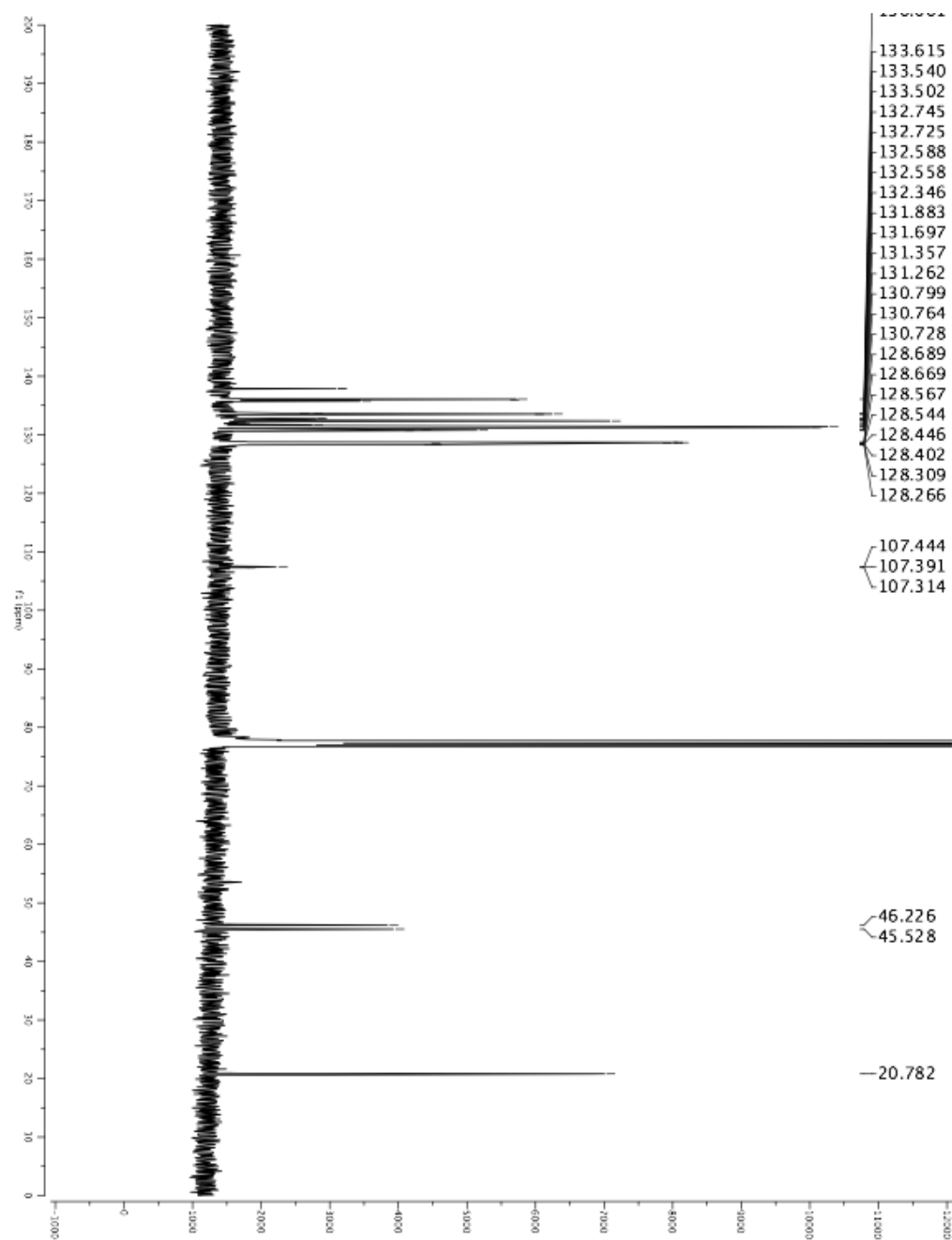
<sup>1</sup>H NMR



$^{31}\text{P}$  NMR

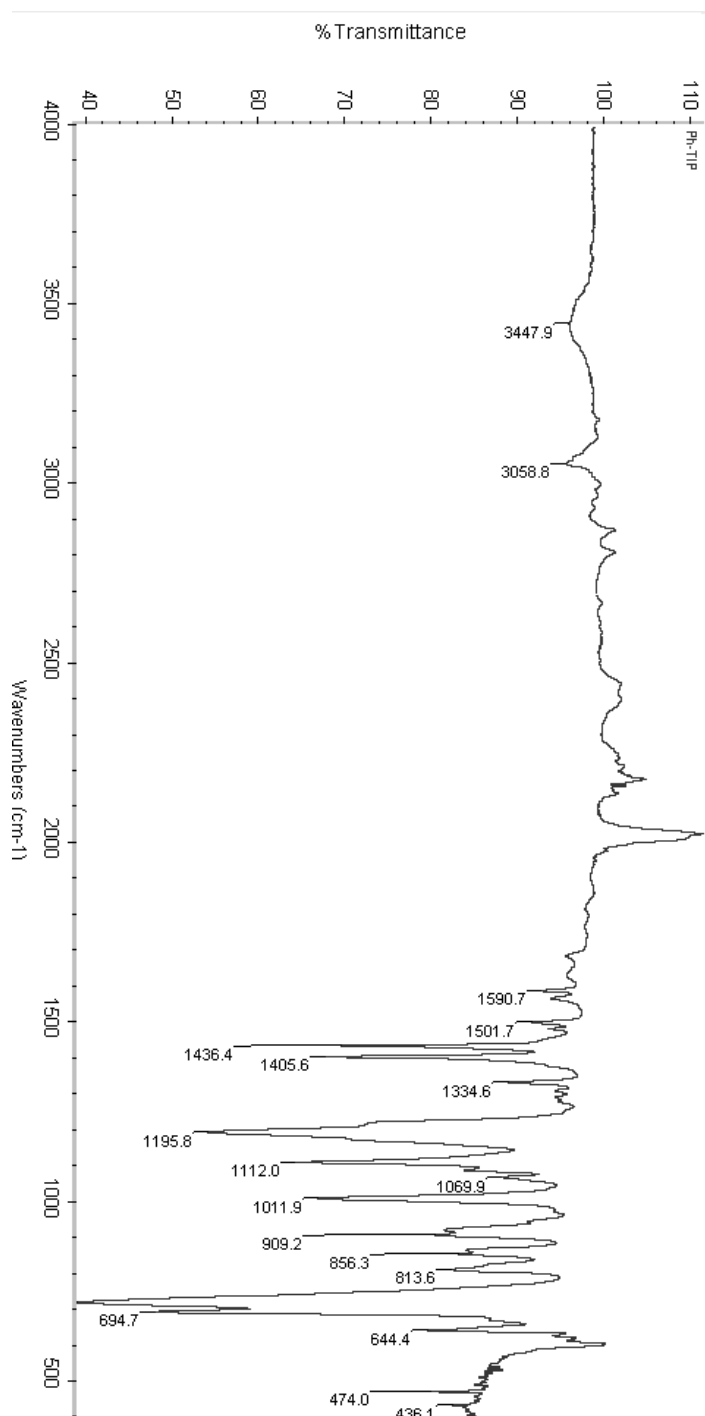


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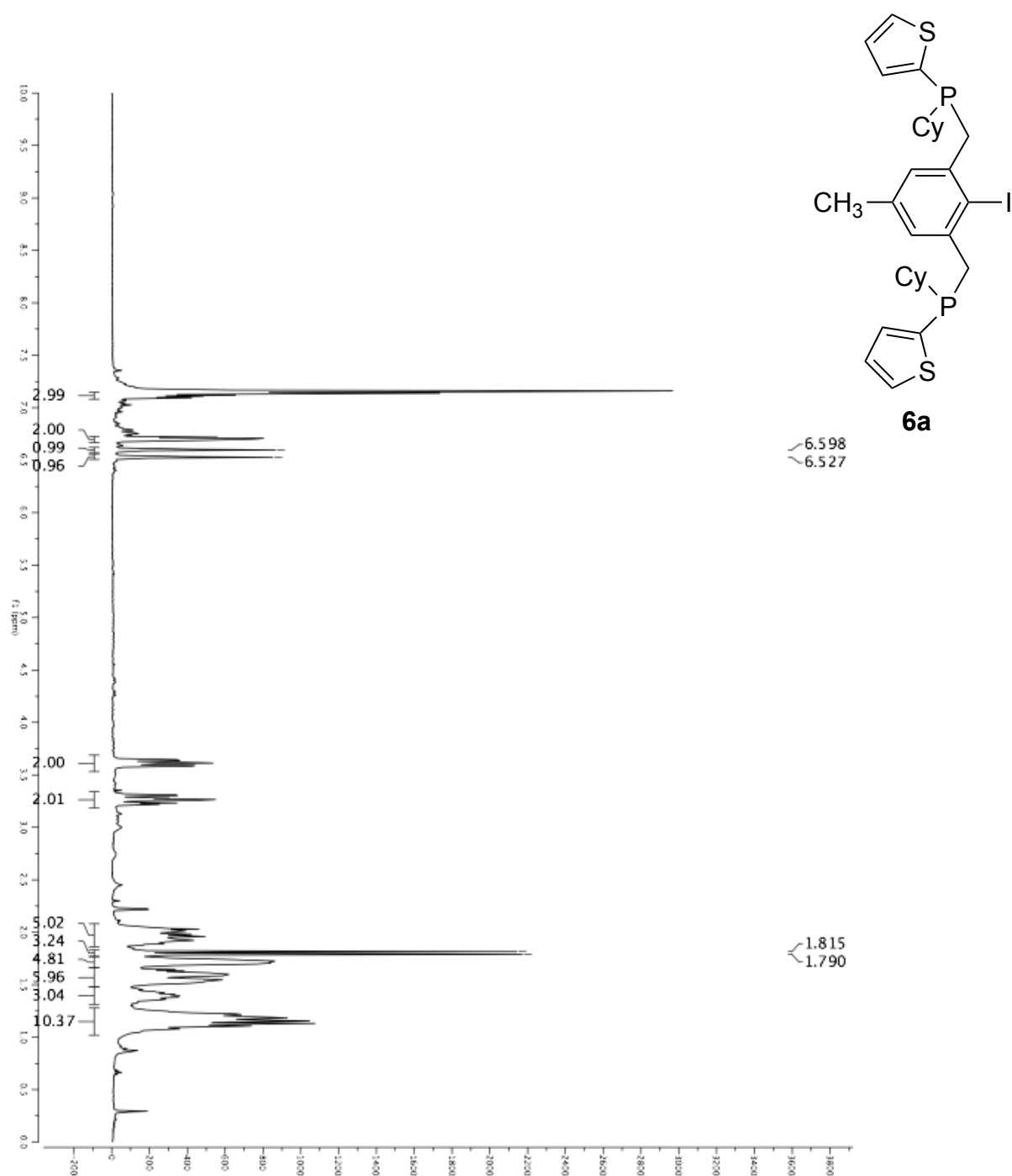




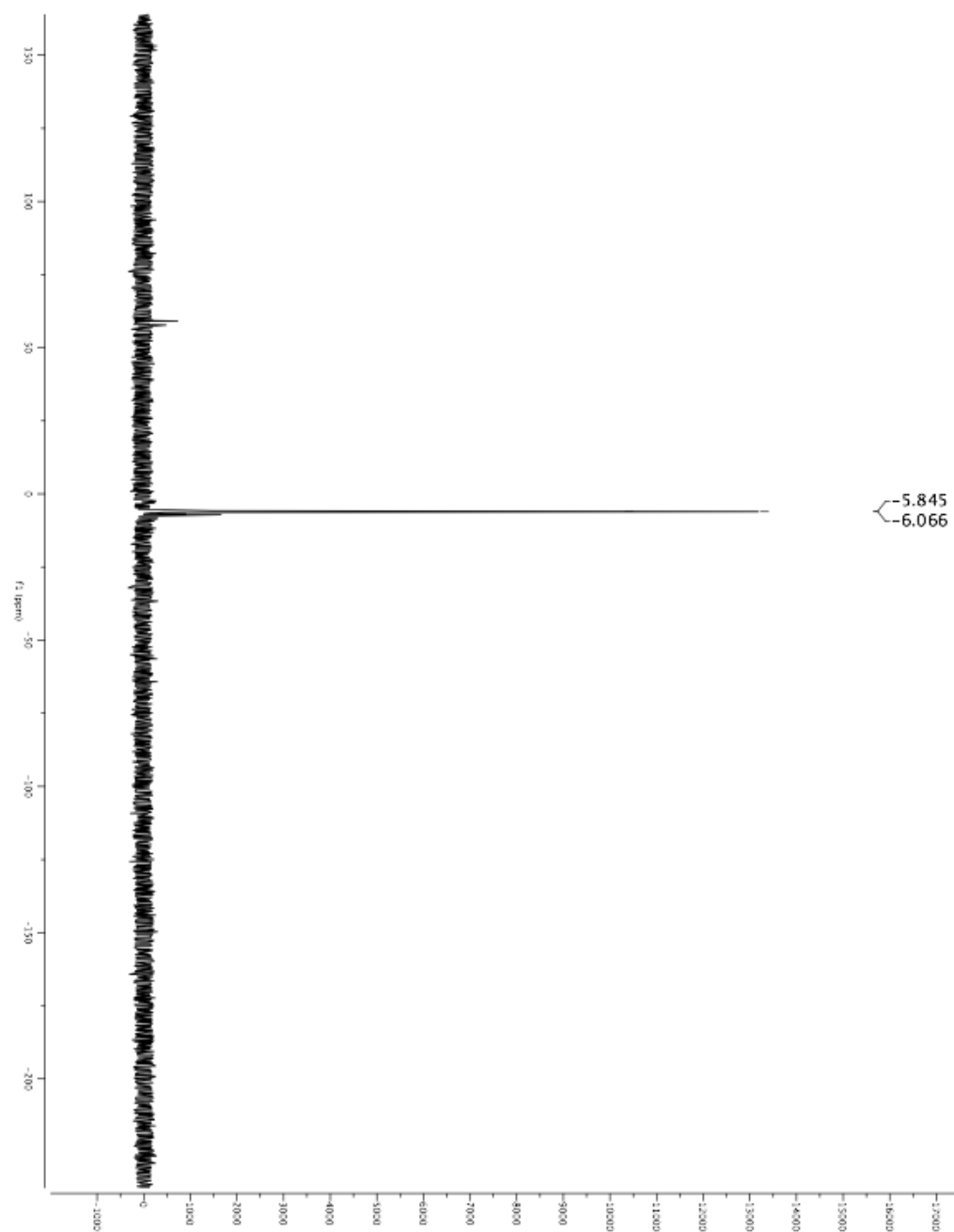
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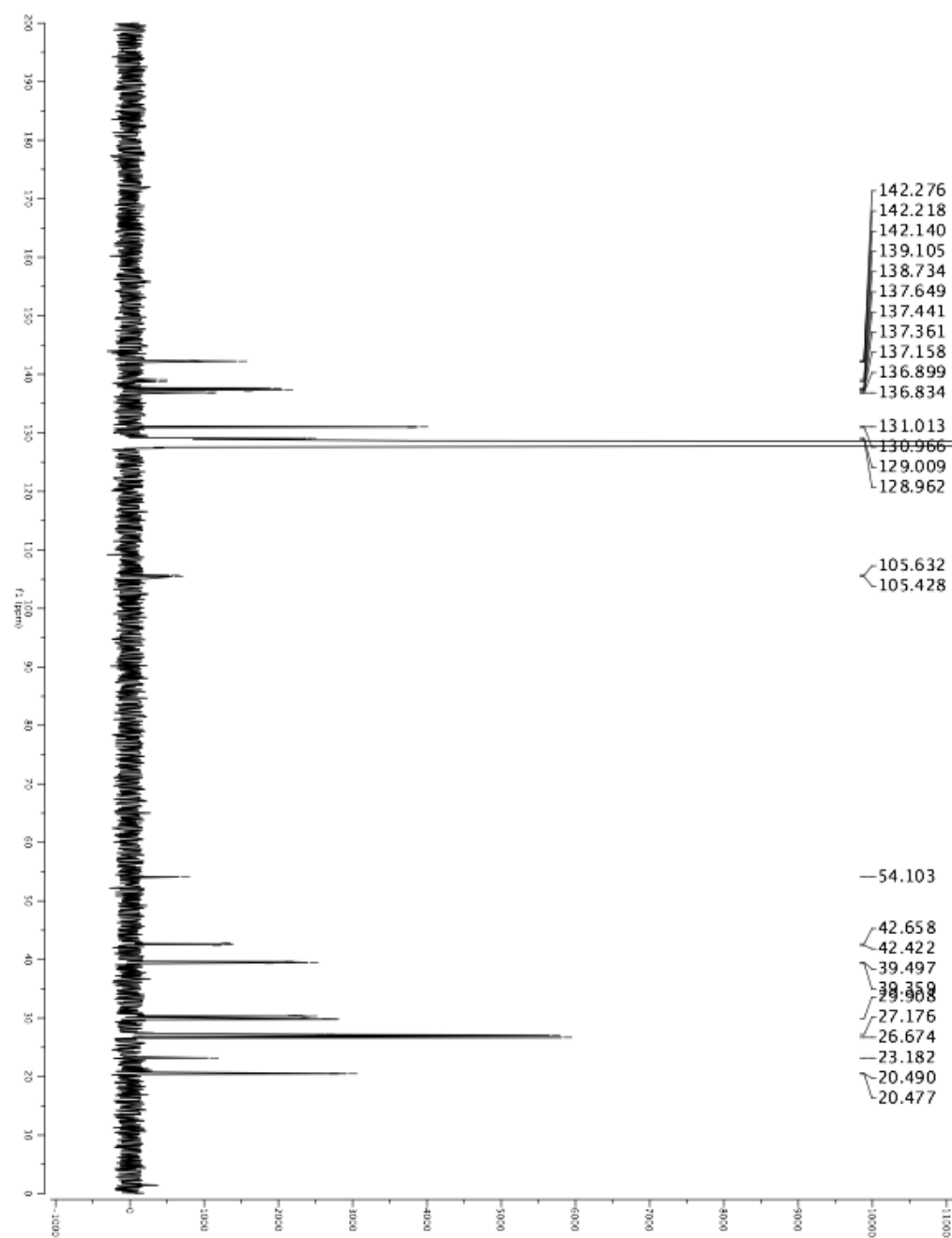
$^1\text{H}$  NMR



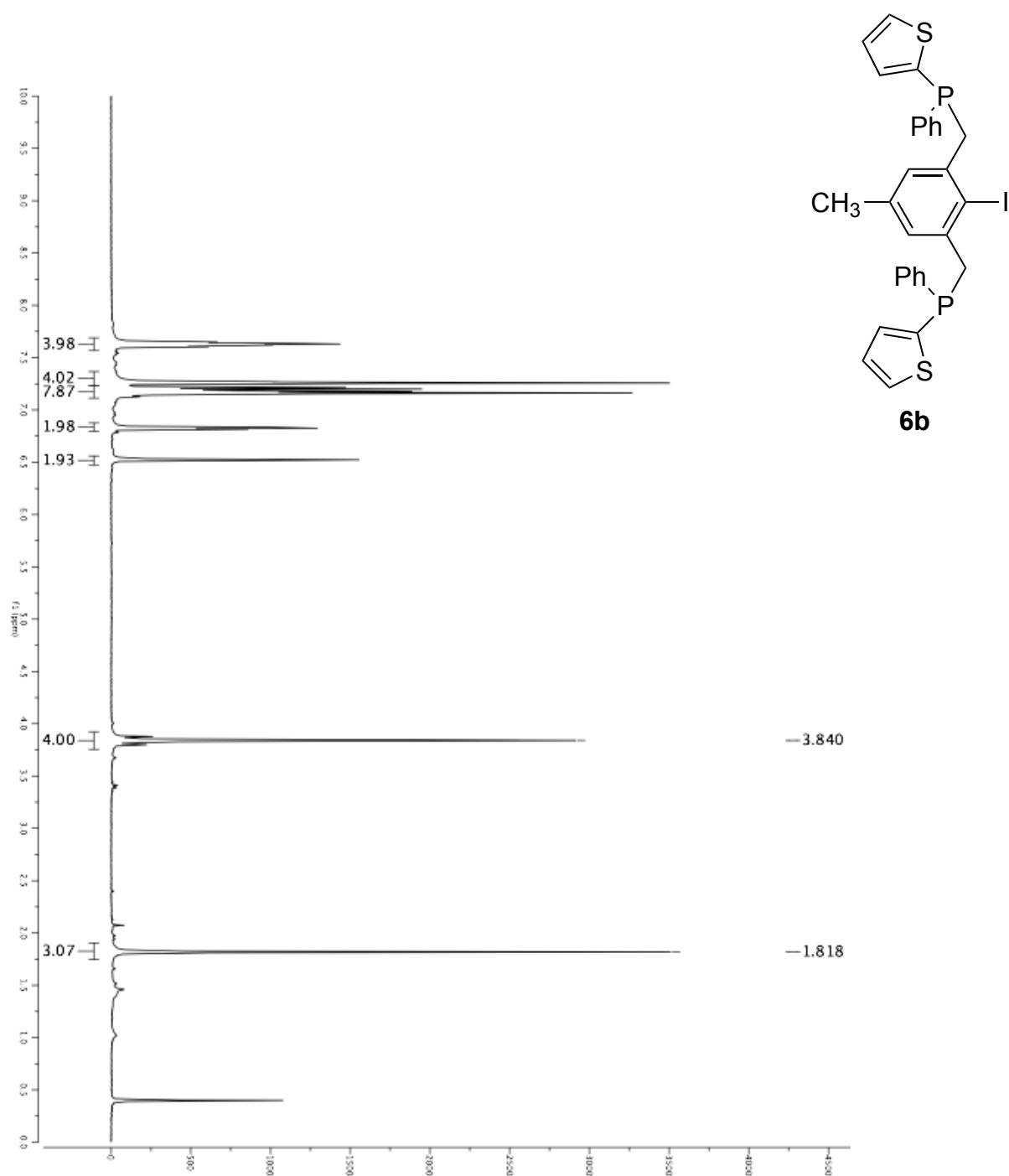
$^{31}\text{P}$  NMR



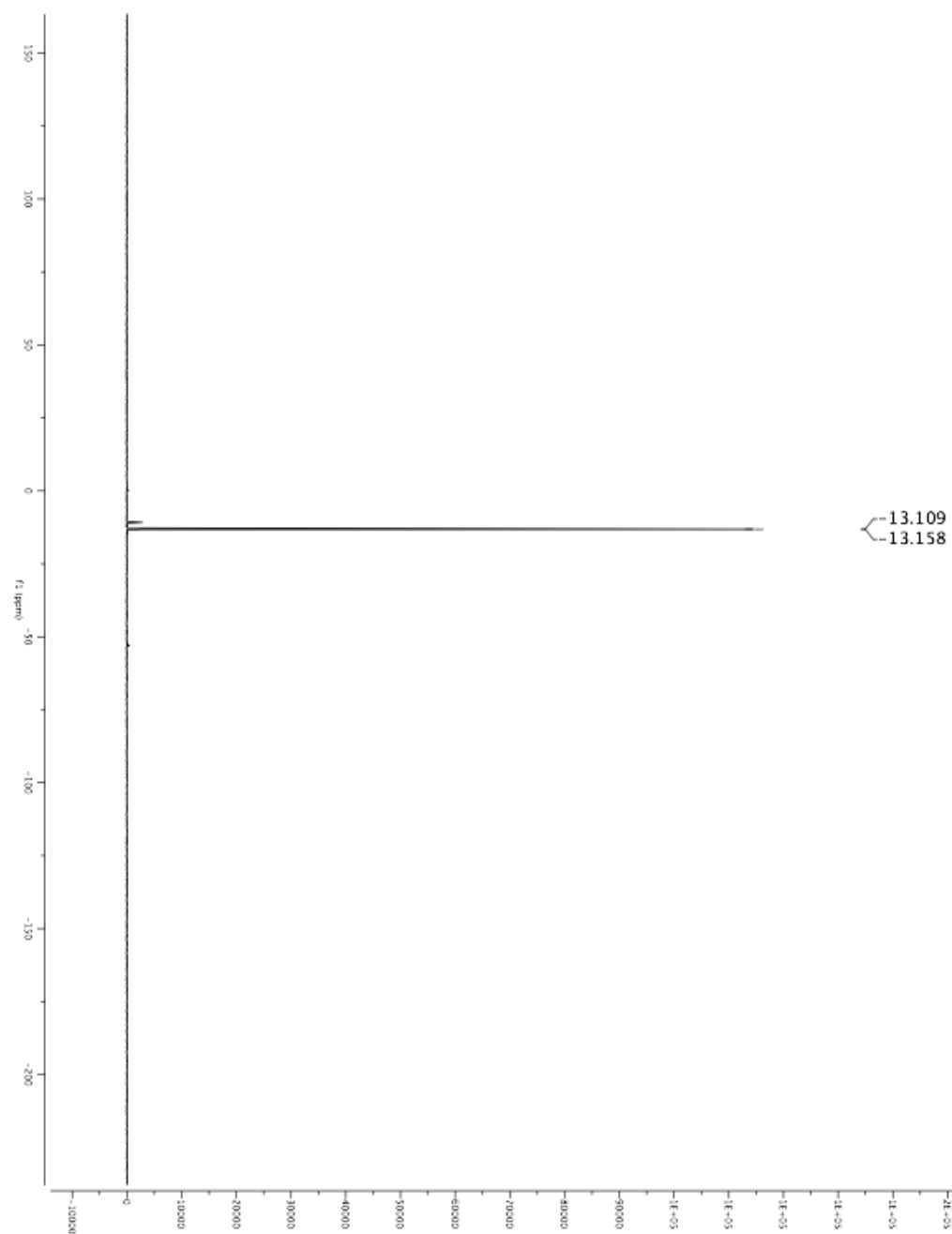
$^{13}\text{C}$  NMR



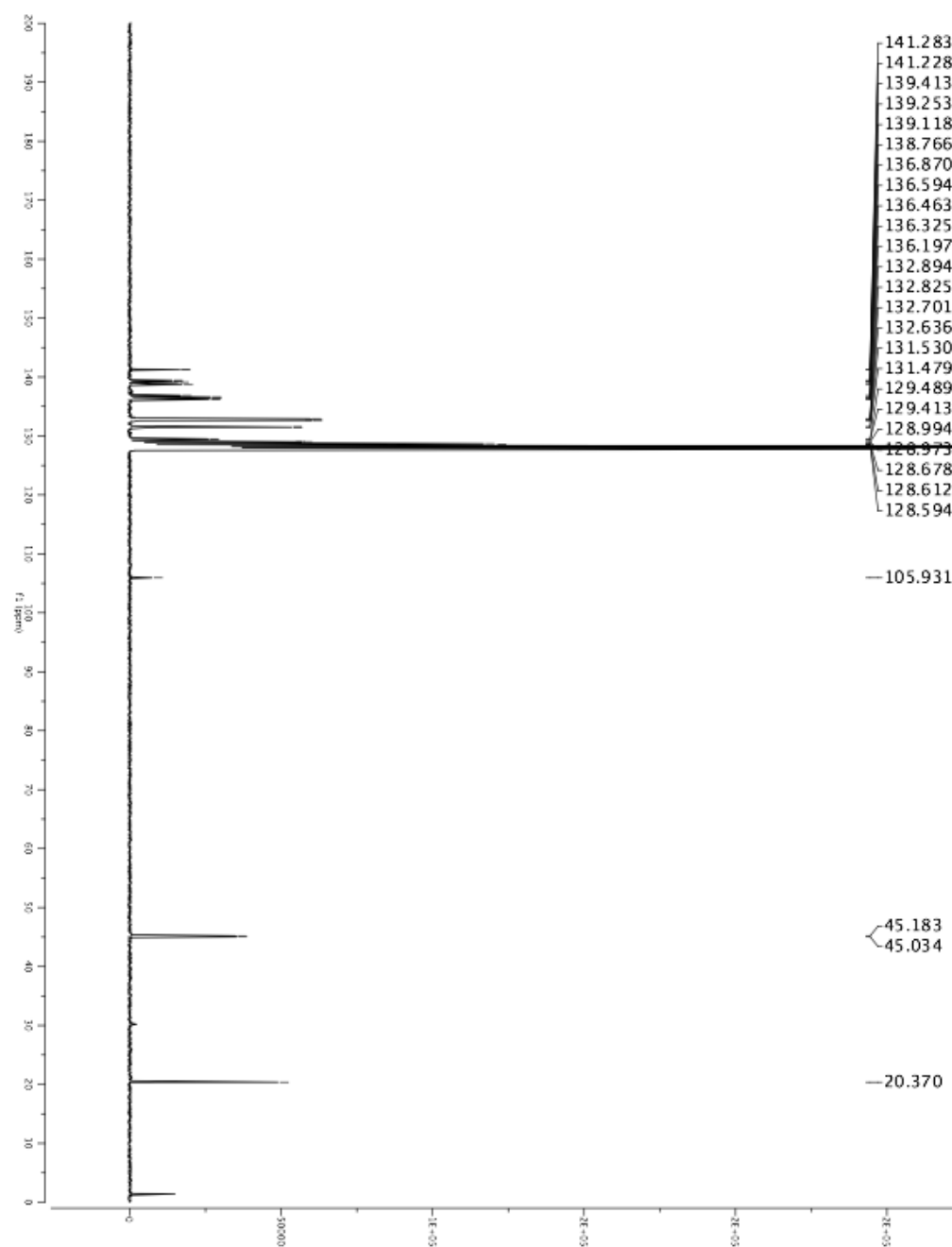
$^1\text{H}$  NMR



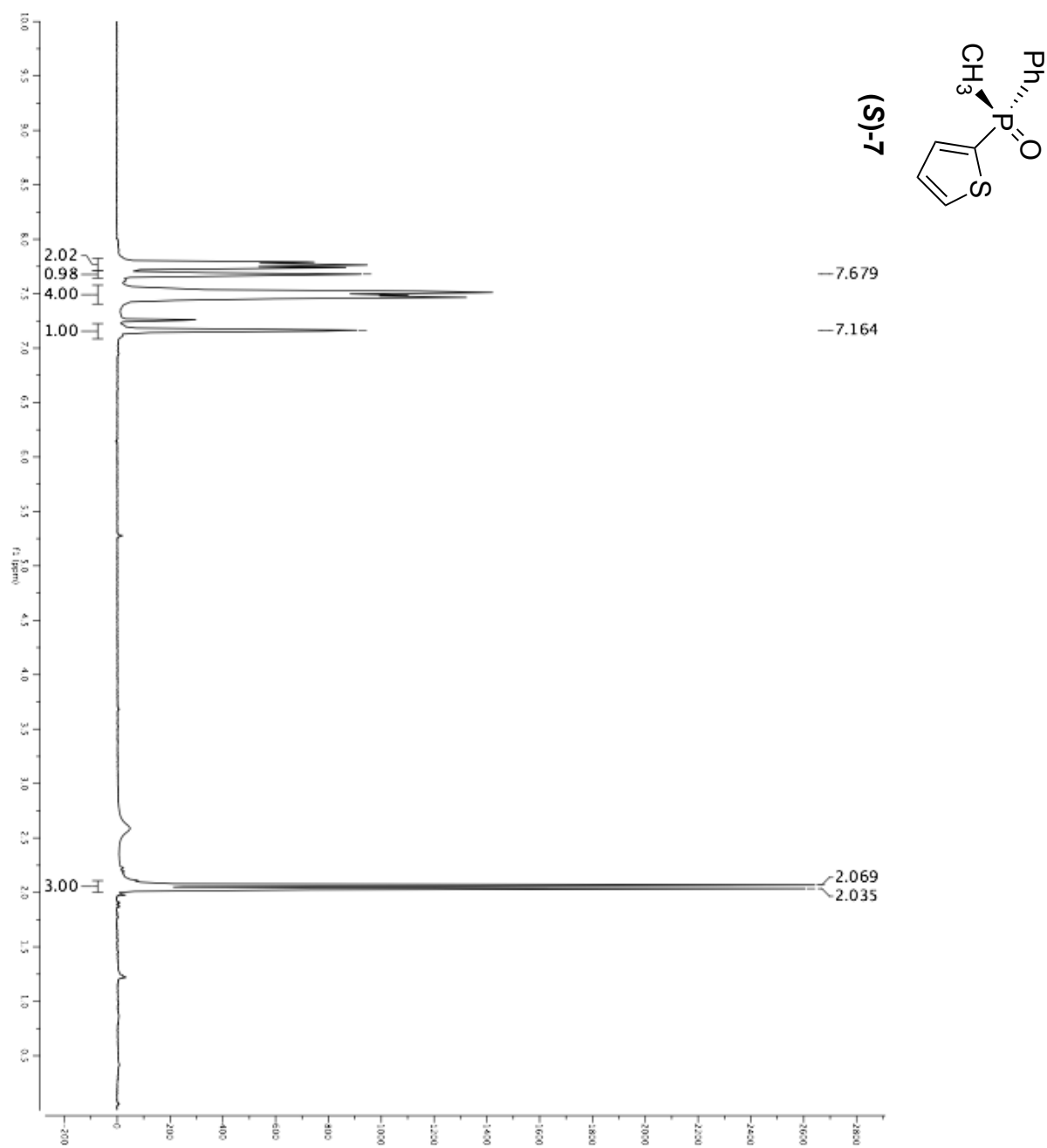
$^{31}\text{P}$  NMR



$^{13}\text{C}$  NMR

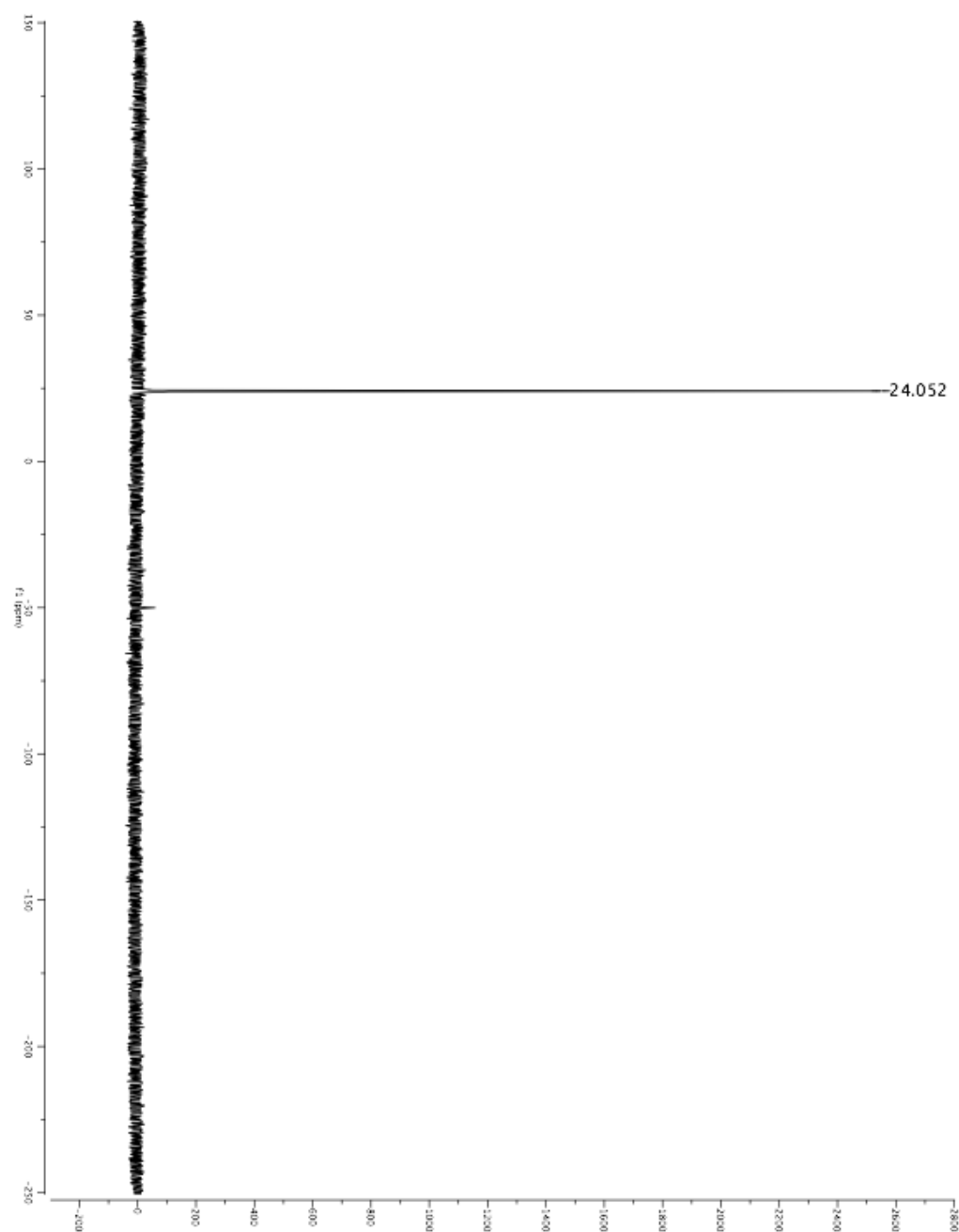


<sup>1</sup>H NMR

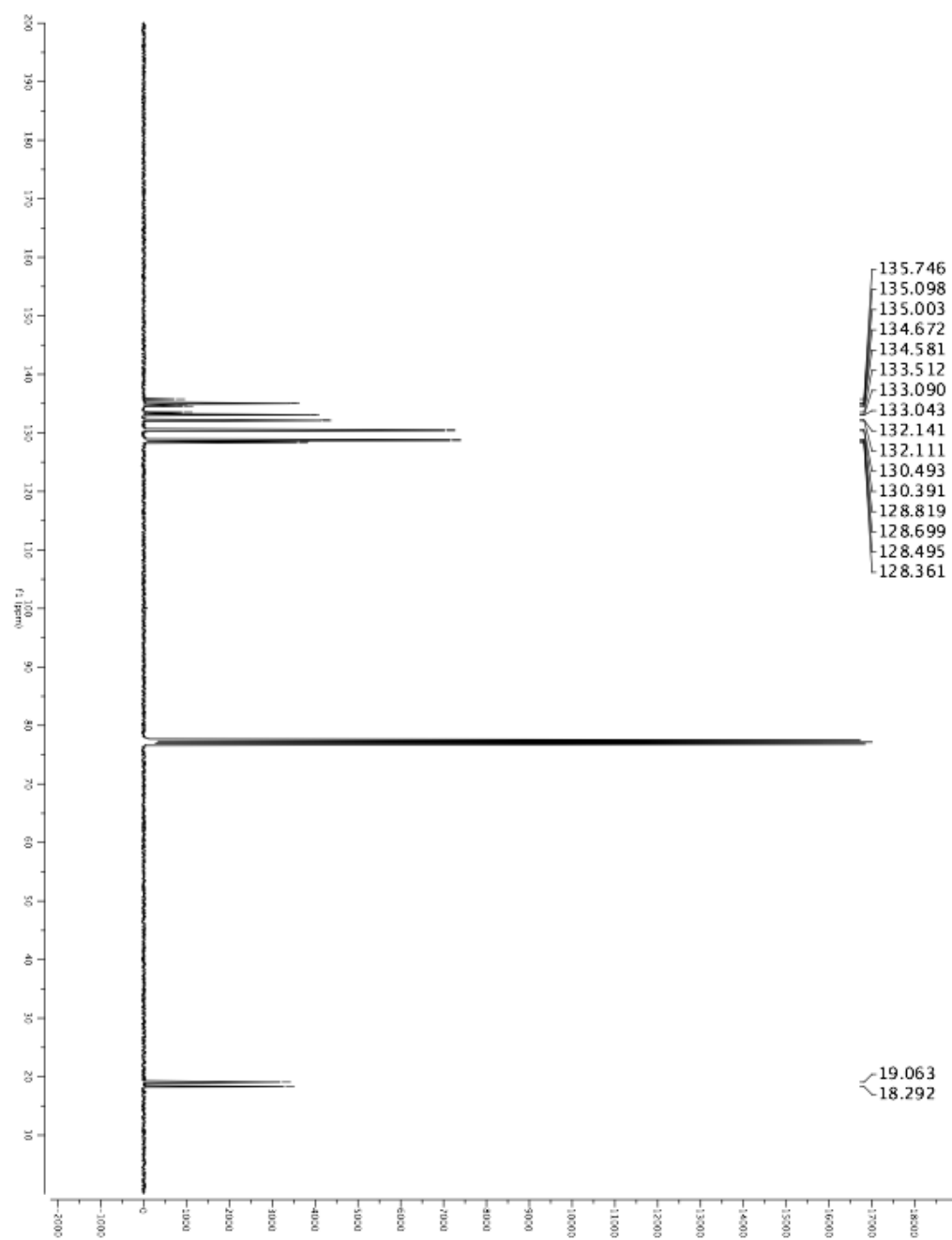




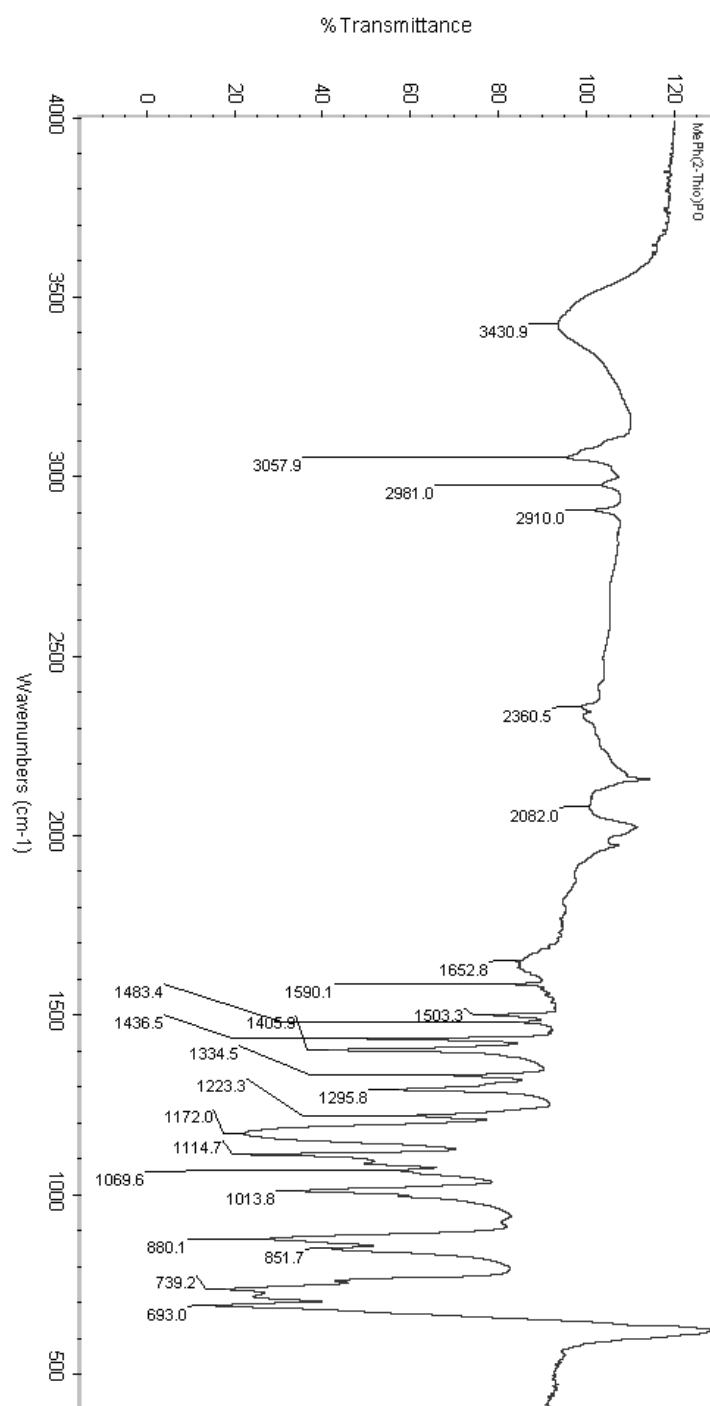
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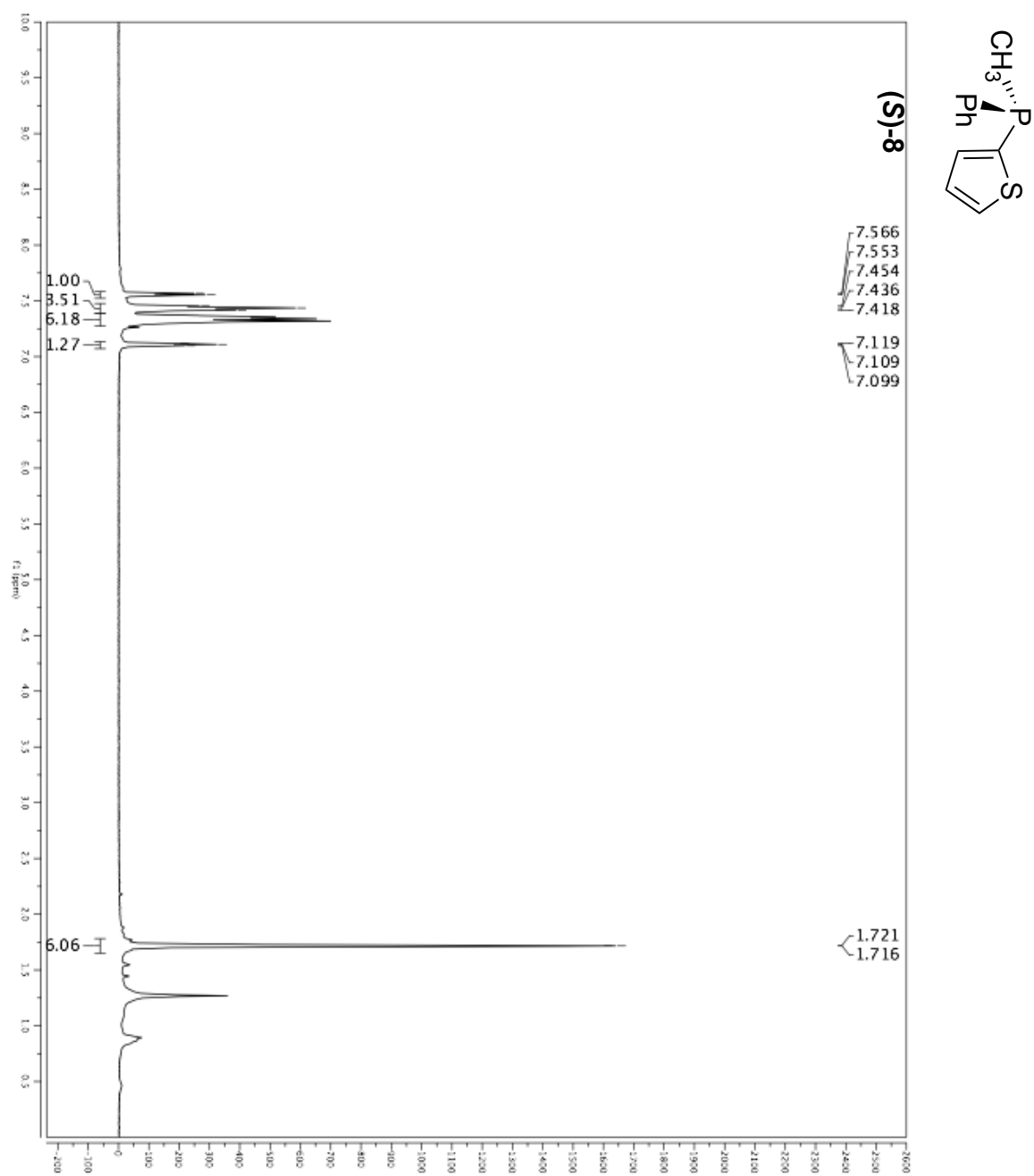
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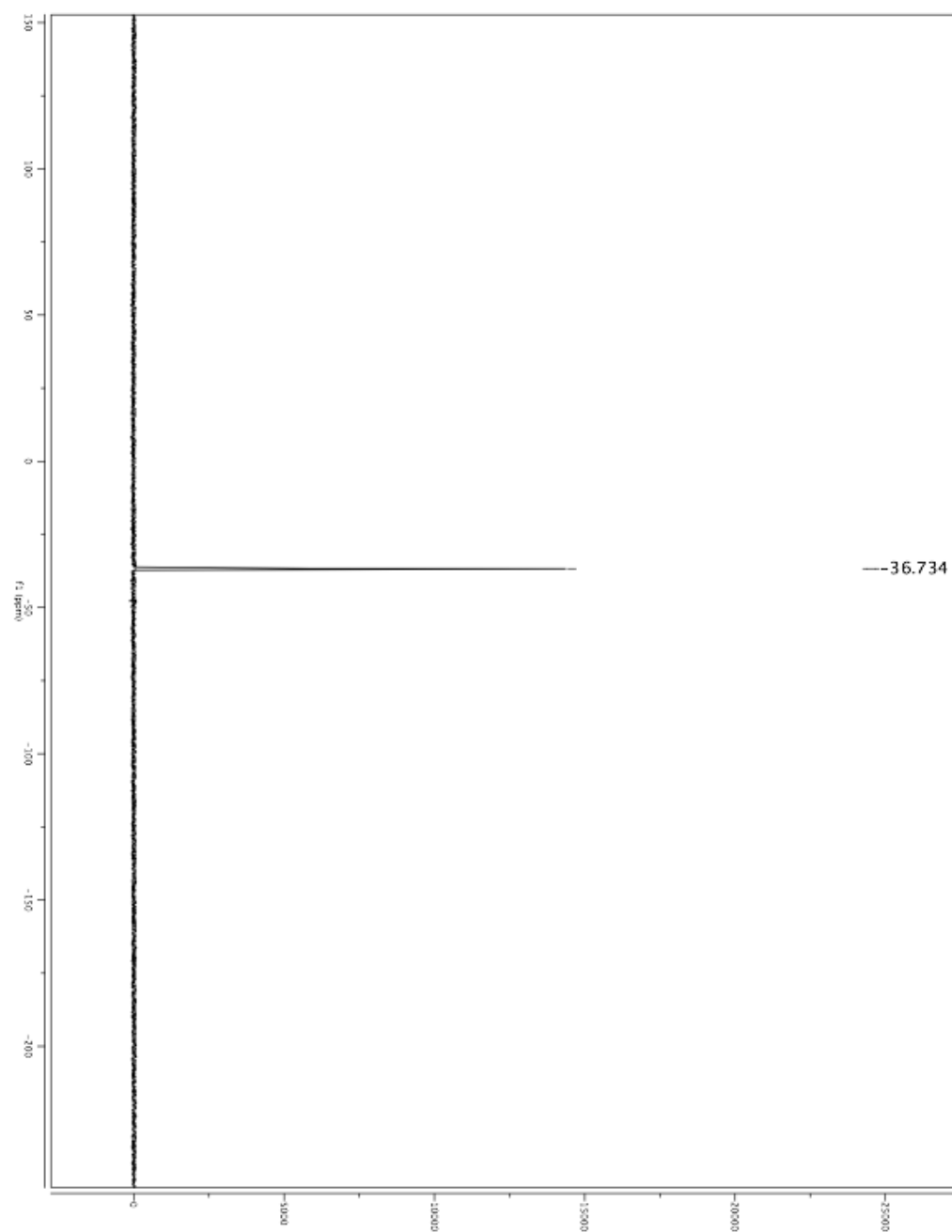
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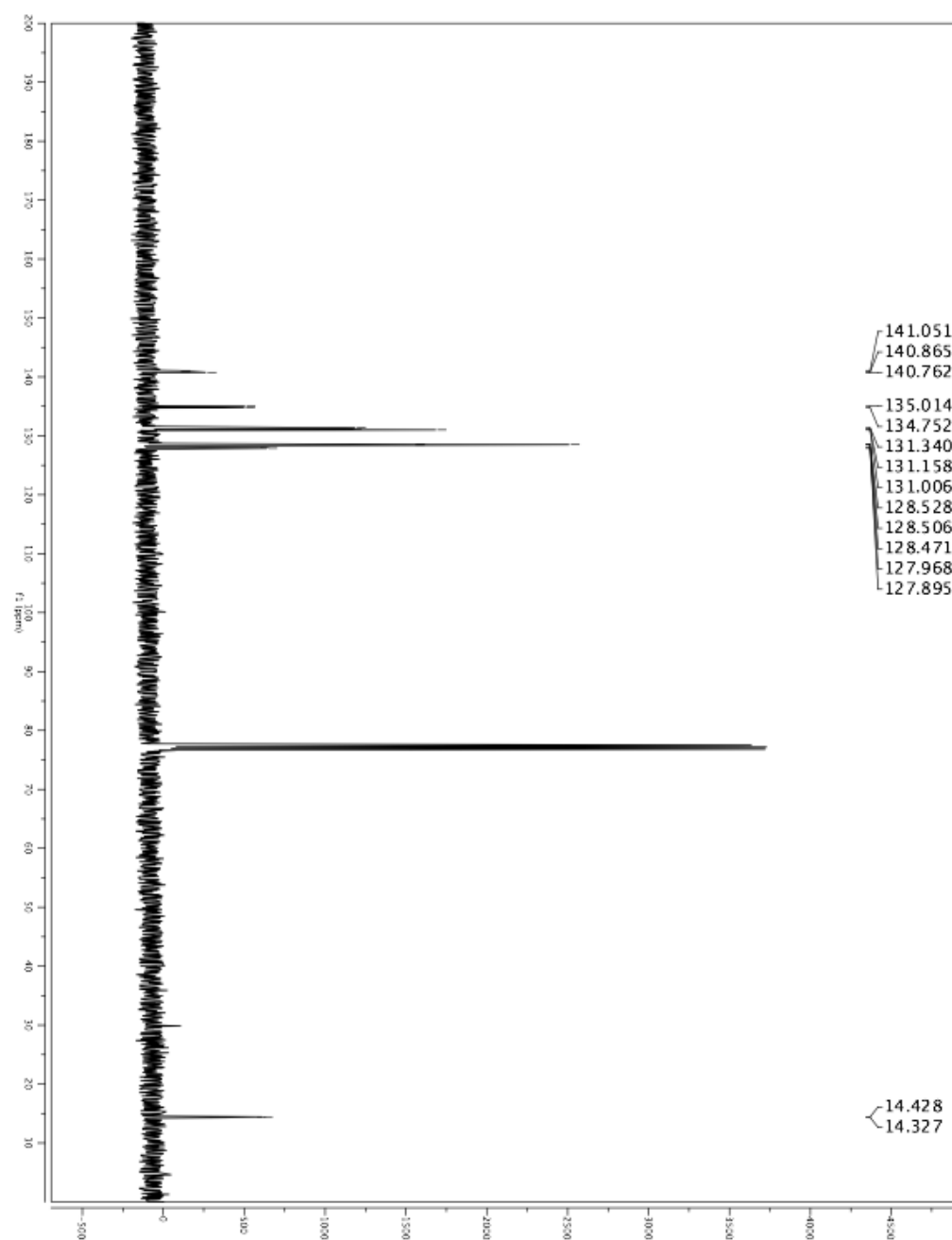
$^1\text{H}$  NMR



$^{31}\text{P}$  NMR



$^{13}\text{C}$  NMR



## Bibliography.

1. Still, W. C.; Kahn, M.; Mitra, A. *J. Org. Chem.* **1978**, *43*, 2923.
2. Pangborn, A. B.; Giardello, M. A.; Grubbs, R. H.; Rosen, R. K.; Timmers, F. J. *Organometallics* **1996**, *15*, 1518.
3. Neumaier, H. Preparation of Secondary Phosphine Oxides via Grignard Reaction of Phosphinic Acid Esters. D.E. Patent 88-3824776, 1990.
4. Holt, J.; Maj, A. M.; Schudde, E. P.; Pietrusiewicz, K. M. Ç.; Siero, L. Ç.; Wieczorek, W.; Jerphagnon, T.; Arends, I. W. C. E.; Hanefeld, U.; Minnaard, A. J. *Synthesis* **2009**, 2061.
5. Fuji, K.; Morimoto, T.; Tsutsumi, K.; Kakiuchi, K. *Chem. Commun.* **2005**, 3295.
6. Bloomfield, A. J.; Qian, J. M.; Herzon, S. B. *Organometallics* **29**, 4193.
7. Xu, Q.; Zhao, C.-Q.; Han, L.-B. *J. Am. Chem. Soc.* **2008**, *130*, 12648.
8. Renard, P.-Y.; Vayron, P.; Leclerc, E.; Valleix, A.; Mioskowski, C. *Angew. Chem., Int. Ed. Engl.* **2003**, *42*, 2389.
9. Lebel, H. I. n.; Morin, S. b.; Paquet, V. r. *Org. Lett.* **2003**, *5*, 2347.
10. Dabkowski, W.; Ozarek, A.; Olejniczak, S.; Cypriak, M.; Chojnowski, J.; Michalski, J. *Chem. – Eur. J.* **2009**, *15*, 1747.
11. Singh, G.; Reddy, G. S. *J. Org. Chem.* **1979**, *44*, 1057.
12. Berrino, R.; Cacchi, S.; Fabrizi, G.; Goggiamani, A.; Stabile, P. *Org. Biomol. Chem.* **2010** *8*, 4518.
13. Ronde, N. J.; Totev, D.; Müller, C.; Lutz, M.; Spek, A. L.; Vogt, D. *ChemSusChem* **2009**, *2*, 558.