Supporting Information

Ni-Catalyzed Reductive Coupling of Electron-Rich Aryl Iodides with Tertiary Alkyl Halides

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I. Experimental Section

Part 1. General Information

1. Chemicals and Reagents

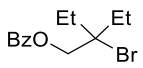
All manipulations were carried out under an atmosphere of nitrogen using standard Schlenk or glove box techniques. DMA (*N*,*N*-dimethylacetamide, 99.5%, extra dry, Acros) was purchased and used directly. Deuterated solvents were used as received ($CDCl_3$ from Maclin Co., China). $NiCl_2$ (Alfa Aesar), $NiBr_2$ (Alfa Aesar), NiI_2 (Alfa Aesar), $Ni(COD)_2$ (Strem), $Ni(ClO_4)_2$ (Alfa Aesar), $Ni(acac)_2$ (Maclin Co., China) were used as received. Zinc powder (Aladdin) was activated with hydrochloric acid before use. Anhydrous $MgCl_2$ (Alfa Aesar) was purchased, and used directly. 2-Bromo-2-methylpropane was purchased from TCI (98%). 4-Iodoanisole was purchased from Adamas. Unless otherwise noted, all other reagents and starting materials were purchased from commercial sources and used without further purification.

2. Physical Method

Column chromatography was performed using silica gel 200-300 mesh (purchased from Qingdao-Haiyang Co., China) as the solid support. All NMR spectra were recorded on Bruker Avance 500 MHz or 600 MHz spectrometer at STP and JEOL 400 MHz. ^{1}H NMR and ^{13}C NMR chemical shifts are reported in δ units, parts per million (ppm) relative to the chemical shift of residual solvent. Reference peaks for chloroform in ^{1}H NMR and ^{13}C NMR spectra were set at 7.26 ppm and 77 ppm, respectively. High-resolution mass spectra (HRMS) were obtained using Bruker APEXIII 7.0 and IonSpec 4.7 TESLA FTMS. Melting point was recorded on a micro melting point apparatus (X-4, YUHUA Co., Ltd, Gongyi, China).

Part 2. Preparation of *Tertiary* Alkyl Halides.

2-Bromo-2-ethylbutyl benzoate



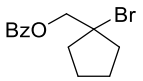
To a solution of 2-bromo-2-ethylbutan-1-ol (1.0 g, 5.5 mmol, 1.1 equiv) in DCM (10 mL) was added Et_3N (1.5 equiv), DMAP (10%) in an ice bath, followed by addition of a solution of benzoyl chloride (0.7 g, 5.0 mmol, 1 equiv) in DCM (5 mL) dropwise. The alcohol was prepared from reduction of its aldehyde precursors by $NaBH_4$.[1,2] The reaction mixture was allowed to stir for 1 h. After the reaction was completed, the reaction mixture was partitioned with water. The organic phase was collected and washed with an aqueous HCl solution (1 M) and a saturated $NaHCO_3$ solution. The organic layer was collected and dried over $MgSO_4$, and concentrated under reduced pressure. The residue was purified by flash chromatography (SiO_2: 1% ethyl acetate in petroleum ether) to afford the title compound in 80% yield as a colorless liquid.

^{1}H NMR (600 MHz, $CDCl_3$): δ 8.06 (dd, J = 8.0 Hz, 1.2 Hz, 2 H), 7.58 (tt, J = 7.8 Hz, 1.2 Hz, 1 H), 7.46 (t, J = 7.8 Hz, 2H), 4.53 (s, 2H), 2.00 (m, 4 H), 1.08 (t, J = 7.4 Hz, 6H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 165.8, 133.3, 129.8, 129.7, 128.5, 73.2, 68.7, 32.7, 9.7.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{13}H_{17}BrNaO_2$: 307.0304. Found 307.0308.

(1-Bromocyclopentyl)methyl benzoate



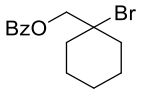
This compound was prepared following the procedure used for the preparation of 2-bromo-2-ethylbutyl benzoate. Et_3N (1.5 equiv) and DMAP (10%) were added to a solution of (1-bromocyclopentyl)methanol (1.0 g, 5.6 mmol, 1.1 equiv) in DCM (10 mL) in an ice bath followed by addition of a solution of benzoyl chloride (0.7 g, 5.0 mmol, 1 equiv) in DCM (5 mL) dropwise. The alcohol was prepared from reduction of its aldehyde precursors by $NaBH_4$.[1,2] After work-up with aqueous HCl and $NaHCO_3$, flash chromatography (SiO_2: 1% ethyl acetate in petroleum ether) afforded the title compound in 82% yield as a colorless liquid.

^{1}H NMR (600 MHz, $CDCl_3$): δ 8.09 (dd, J = 8.0 Hz, 1.2 Hz, 2 H), 7.58 (tt, J = 7.8 Hz, 1.2 Hz, 1H), 7.46 (t, J = 7.8 Hz, 2 H), 4.61 (s, 2 H), 2.31 (m, 2 H), 2.03 (m, 4H), 1.81 (m, 2H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 166.0, 133.2, 129.8, 129.7, 128.4, 72.8, 71.2, 40.7, 23.4.

HRMS (ESI) m/z ([M+Na]$^+$) calcd for $C_{13}H_{15}BrNaO_2$: 305.0148. Found 305.0135.

(1-Bromocyclohexyl)methyl benzoate



Following the procedure used for the preparation of 2-bromo-2-ethylbutyl benzoate, to a solution of 2-bromo-2-ethylbutan-1-ol (1.0 g, 5.5 mmol, 1.1 equiv) in DCM (10 mL) was added Et_3N (1.5 equiv), DMAP (10%) in an ice bath, followed by addition of a solution of benzoyl chloride (0.7 g, 5.0 mmol, 1 equiv) in DCM (5 mL) dropwise. The alcohol was prepared from reduction of its aldehyde precursors by $NaBH_4$.[1,2] The reaction mixture was stirring for 1h. After work-up with aqueous HCl and $NaHCO_3$, flash chromatography (SiO_2: 1% ethyl acetate in petroleum ether) afforded the title compound in 82% yield as a colorless liquid.

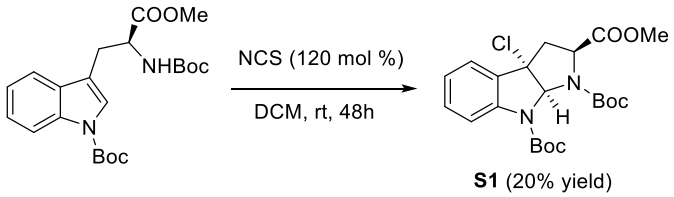
^{1}H NMR (600 MHz, $CDCl_3$): δ 8.03 (d, J = 7.3 Hz, 2H), 7.58 (t, J = 7.3 Hz, 1H), 7.46 (t, J = 7.6 Hz, 2H), 4.55 (s, 2H), 2.13 (m, 2H), 1.83 (m, 2H), 1.69 (m, 6H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 166.0, 133.2, 129.8, 129.7, 128.4, 73.0, 70.3, 37.4, 25.2, 22.4.

HRMS (ESI) m/z ([M+Na]$^+$) calcd for $C_{14}H_{17}BrNaO_2$: 319.0304. Found 319.0299.

1,8-Di-tert-butyl 2-methyl

(2S,3aS,8aS)-3a-chloro-2,3,3a,8a-tetrahydropyrrolo[2,3-b]indole-1,2,8-tricarboxylate (S1)



S1 (20% yield)

To an oven-dried round bottom flask was added the Boc-protected tryptophan ester (10.0 g, 24.0 mmol, 1 equiv) and NCS (1.2 equiv) in DCM (200 mL).[3] The reaction mixture was allowed to stir for 48h. It was then washed with H_2O and extract with DCM for 3 times. The organic layer was concentrated under reduced pressure. Flash column chromatography (SiO2: 5% ethyl acetate in petroleum) provided **S1** in 20% yield as a yellow solid.

^{1}H NMR (600 MHz, $CDCl_3$): δ 7.56 (br, 1H), 7.28 (t, J = 7.8 Hz, 1H), 7.25 (m, 1H), 7.03 (t, J = 7.5 Hz, 1H), 6.34 (s, 1H), 4.59 (br, 1H), 3.13 (m, 1H), 3.12 (s, 3H), 2.94 (dd, J = 12.5, 9.8 Hz, 1H), 1.57 (s, 9H), 1.45 (s,

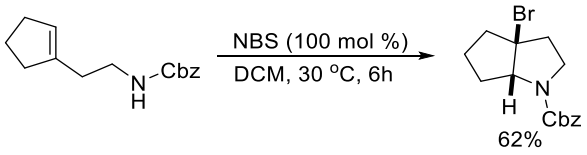
9H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 170.6, 152.8, 152.0, 142.7, 131.1, 130.7, 123.7, 123.6, 117.9, 83.4, 81.9, 81.3, 71.0, 59.4, 51.9, 42.2, 28.2, 28.1.

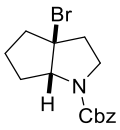
HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{22}H_{29}ClN_2NaO_6$: 475.1606. Found 475.1598.

M.P. 54-56 °C

$[\alpha]_D^{22}$ = 43.0 (c = 0.67, $CHCl_3$)



Benzyl (3a, 6a)-3a-bromohexahydrocyclopenta[b]pyrrole-1(2H)-carboxylate



To a solution of benzyl (2-(cyclopent-1-en-1-yl)ethyl)carbamate (1.0 g, 4.0 mmol, 1.0 equiv) in DCM (10 mL) was added a solution of NBS (1.0 equiv) in DCM (5 mL) under N_2 atmosphere at 0 °C. Upon completion of the addition of NBS, the reaction mixture was transferred to an oil bath at 30 °C and was continued to stir for 6 h. After work-up with aqueous HCl and $NaHCO_3$, flash chromatography (SiO_2: 5% ethyl acetate in petroleum ether) afforded the title compound in 62% yield as a colorless oil.

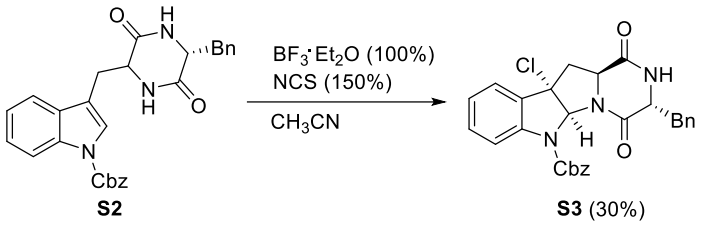
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.34 (m, 5H), 5.06 (s, 2H), 4.25 (m, 1H), 3.44 (m, 2H), 2.58 (m, 1H), 2.14 (m, 2H), 2.01 (m, 2H), 1.93 (m, 3H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 151.6, 136.1, 128.4, 128.1, 128.0, 90.8, 68.9, 57.0, 40.6, 34.7, 34.2, 28.2, 20.6.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{15}H_{18}BrNNaO_2$: 346.0413. Found 346.0419.

Benzyl

(3R,5aS,10bS)-3-benzyl-10b-chloro-1,4-dioxo-1,2,3,4,5a,10b,11,11a-octahydro-6H-pyrazino[1',2':1,5]pyrrolo[2,3-b]indole-6-carboxylate (S3)



S2 **S3** (30%)

According to a literature procedure for the bromo-analog of **S3**,[4] to an oven-dried round bottom flask was added **S2**[4] (2.0 g, 4.3 mmol, 1 equiv) and CH_3CN (20.0 mL) under N_2 atmosphere. Upon addition of $BF_3{\cdot}Et_2O$, the reaction mixture was allowed to stir to result in a homogenous solution, at which point a solution of NCS (1.5 equiv) in CH_3CN was added dropwise. After the reaction was stirred overnight at 40 °C, it was concentrated under reduced pressure and the residue was directly loaded onto a silica column. Flash column chromatography (SiO_2: 10% to 40% ethyl acetate in petroleum) provided **S3** in 30% yield as a white solid.

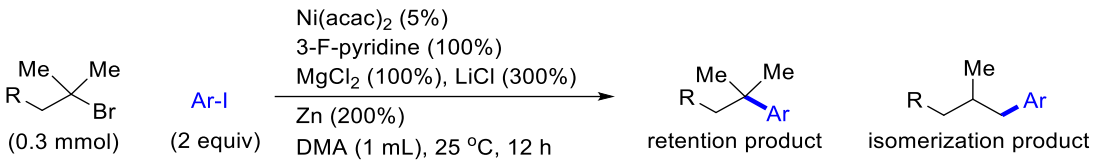
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.74 (d, J = 8.0 Hz, 1H), 7.53 (d, J = 7.3 Hz, 2H), 7.42 (t, J = 7.3 Hz, 2H), 7.36 (t, J = 7.3 Hz, 1H), 7.29 (m, 3H), 7.23 (t, J = 7.3 Hz, 2H), 7.08 (m, 4H), 5.84 (s, 1H), 5.39 (m, 2H), 4.08 (m, 1H), 3.21 (dd, J = 13.5 Hz, 4.8 Hz, 1H), 2.91 (m, 2H), 2.86 (t, J = 8.1 Hz, 1H), 2.75 (dd, J = 13.5, 8.5 Hz, 1H),

^{13}C NMR (150 MHz, $CDCl_3$): δ 167.8, 165.2, 152.8, 139.9, 135.5, 134.8, 132.6, 130.7, 129.9, 128.8, 128.7, 128.6, 128.5, 127.7, 124.6, 124.1, 116.4, 84.1, 69.5, 68.5, 58.6, 54.5, 40.7, 40.2.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{28}H_{24}ClN_3NaO_4$: 524.1348. Found 524.1346.

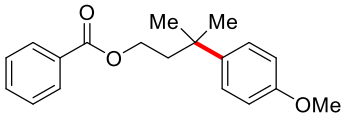
M.P. 123–125 °C

Part 3. Reductive Coupling of Tertiary Alkyl Halides with Aryl Iodides and Vinyl Bromides



General procedure: To an oven-dried Schlenk tube was charged with tertiary alkyl halides (0.3 mmol, 1 equiv, if the alkyl halide is a solid), aryl iodide (2 equiv, if the aryl iodide is a solid), Zn (2 equiv), $Ni(acac)_2$ (5 mol %), $MgCl_2$ (1 equiv) and LiCl (3 equiv). The tube was capped with a rubber septum, evacuated and back-filled with nitrogen three times, at which point DMA (1 mL) was added via a syringe prior to the addition of tertiary alkyl halides (if the alkyl halide is a liquid) and/or aryl iodide (if the aryl iodide is a liquid), followed by addition of 3-fluoropyridine via a syringe. The reaction mixture was allowed to stir at 25 °C for 12 h, at which point it was directly loaded onto a silica column without work-up. The residue in the tube was rinsed with a small amount of DCM or eluent. Flash column chromatography provided a mixture of the quaternary product and its isomerization product; the ratio of retention to isomerization products (R:I) was determined by ^1H NMR analysis.

3-(4-Methoxyphenyl)-3-methylbutyl (2a)



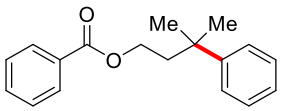
This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mg, 1 equiv) and 4-iodoanisole (0.6 mmol, 140.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 1% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 71% yield (64.0 mg, 0.215 mmol, R:I = 10:1) as a colorless oil.

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.91 (d, J = 7.9 Hz, 2H), 7.53 (t, J = 7.4 Hz, 1H), 7.40 (t, J = 7.9 Hz, 2H), 7.30 (d, J = 8.8 Hz, 2H), 6.85 (d, J = 8.8 Hz, 2H), 4.18 (t, J = 7.2 Hz, 2H), 3.78 (s, 3H), 2.12 (t, J = 7.3 Hz, 2 H), 1.40 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 166.6, 157.5, 140.4, 132.7, 130.3, 129.5, 128.2, 126.6, 113.6, 62.6, 55.2, 42.5, 36.1, 29.4.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{19}H_{22}NaO_3$:321.1461. Found 321.1449.

3-Methyl-3-phenylbutyl benzoate (2b)



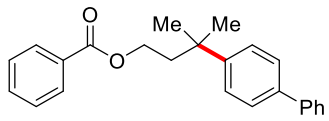
This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mg, 1 equiv) and iodobenzene (0.6 mml, 122.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 1% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 68% yield (55.0 mg, 0.205 mmol, R:I = 12:1) as a colorless oil.

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.90 (dd, J = 8.0 Hz, 1.2 Hz, 2H), 7.53 (tt, J = 7.5 Hz, 1.2 Hz, 1H), 7.40 (m, 4H), 7.32 (t, J = 7.5 Hz, 2H), 7.19 (tt, J = 7.5 Hz, 1.2 Hz, 1H), 4.18 (t, J = 7.3 Hz, 2H), 2.16 (t, J = 7.3 Hz, 2H), 1.42 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 166.6, 148.3, 132.7, 130.3, 129.5, 128.3, 128.2, 125.8, 125.6, 62.6, 42.4, 36.7, 29.2.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{18}H_{20}NaO_2$: 291.1356. Found 291.1349.

3-([1,1'-Biphenyl]-4-yl)-3-methylbutyl benzoate (2c)

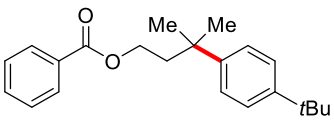


This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mg, 1 equiv) and 4-iodo-1,1'-biphenyl (0.6 mmol, 168 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 2% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 51% yield (53.0 mg, 0.154 mmol, R:I = 15:1) as a colorless oil.

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.89 (dd, J = 8.0 Hz, 1.3 Hz, 2H), 7.56 (m, 4H), 7.50 (tt, J = 7.5 Hz, 1.3 Hz, 1H), 7.45 (m. 4H), 7.35 (m. 3H), 4.24 (t, J = 7.2 Hz, 2H), 2.20 (J = 7.2 Hz, 2H), 1.46 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 166.6, 147.5, 140.8, 138.6, 132.7, 130.3, 129.5, 128.7, 128.2, 127.1, 127.0, 127.0, 126.1, 62.5, 42.4, 36.6, 29.3.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{24}H_{24}NaO_2$:367.1669. Found 367.1660.



3-(4-(*tert*-Butyl)phenyl)-3-methylbutyl benzoate (2d)

This compound was prepared according to the general procedure, using

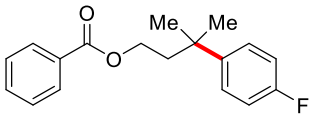
3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mg, 1 equiv) and 1-(tert-butyl)-4-iodobenzene (0.6 mmol, 156.0 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 1% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 60% yield (58.0 mg, 0.179 mmol, R:I = 10:1) as a colorless oil.

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.95 (dd, J = 8.0 Hz, 1.3 Hz, 2H), 7.53 (tt, J = 7.5 Hz, 1.3 Hz, 1H), 7.40 (t, J = 8.0 Hz, 2H), 7.32 (m, 4H), 4.19 (t, J = 7.3 Hz, 2H), 2.14 (t, J = 7.3 Hz, 2H), 1.41 (s, 6H), 1.30 (s, 9H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 166.6, 148.4, 145.1, 132.7, 130.4, 129.5, 128.2, 125.3, 125.1, 62.7, 42.4, 36.3, 34.2, 31.3, 29.3.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{22}H_{28}NaO_2$: 347.1982. Found 347.1982.

3-(4-Fluorophenyl)-3-methylbutyl benzoate (2e)



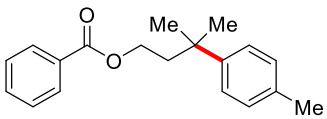
This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mg, 1 equiv) and 1-fluoro-4-iodobenzene (0.6 mmol, 133.2 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 1% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 66% yield (57 mg, 0.199 mmol, R:I = 12:1) as a colorless oil.

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.89 (dd, J = 8.0 Hz, 1.3 Hz, 2H), 7.53 (tt, J = 7.5 Hz, 1.3 Hz, 1H), 7.40 (t, J = 8.0 Hz, 2H), 7.33 (m. 2H), 6.99 (m. 2H), 4.17 (t, J = 7.3 Hz, 2H), 2.13 (t, J = 7.3 Hz, 2H), 1.40 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 166.5, 162.0, 160.1, 144.0, 144.0, 132.8, 130.2, 129.4, 128.2, 127.2, 127.1, 115.0, 114.8, 62.4, 42.5, 36.4, 29.4.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{18}H_{19}FNaO_2$: 309.1261. Found 309.1269.

3-Methyl-3-(p-tolyl)butyl benzoate (2f)



This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mg, 1 equiv) and 1-iodo-4-methylbenzene (0.6 mmol, 130.8 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 1% ethyl acetate in petroleum ether), the title compound along with its

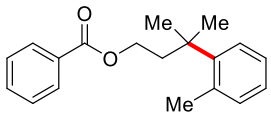
isomers was isolated in 67% yield (56.0 mg, 0.198 mmol, R:I = 10:1) as a colorless oil.

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.90 (dd, J = 8.0 Hz, 1.2 Hz, 2H), 7.53 (tt, J = 7.5 Hz, 1.2 Hz, 1H), 7.40 (t, J = 8.0 Hz, 2H), 7.28 (d, J = 8.2 Hz, 2H), 7.13 (d, J = 8.2 Hz, 2H), 4.18 (t, J = 7.2 Hz, 2H), 2.31 (s, 3H), 2.13 (t, J = 7.2 Hz, 2H), 1.41 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 166.5, 145.3, 135.2, 132.7, 130.3, 129.5, 129.0, 128.2, 125.5, 62.6, 42.4, 36.3, 29.3, 20.8.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{19}H_{22}NaO_2$: 305.1512. Found 305.1517.

3-Methyl-3-(o-tolyl)butyl benzoate (2g)



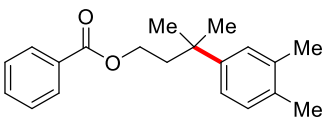
This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mg, 1 equiv) and 1-iodo-2-methylbenzene (0.6 mmol, 130.8 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 1% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 50% yield (42.0 mg, 0.149 mmol, R:I = 15:1) as a colorless oil.

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.91 (dd, J = 8.0 Hz, 1.2 Hz, 2H), 7.53 (tt, J = 7.5 Hz, 1.2 Hz, 1H), 7.40 (t, J = 7.9 Hz, 2H), 7.34 (d, J = 7.5 Hz, 1H), 7.12 (m, 3H), 4.16 (t, J = 7.2 Hz, 2H), 2.57 (s, 3H), 2.31 (t, J = 7.2 Hz, 2H), 1.51 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 166.5, 145.0, 136.1, 133.0, 132.7, 130.3, 129.5, 128.2, 126.9, 126.2, 126.0, 62.8, 39.8, 38.0, 29.8, 23.3.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{19}H_{22}NaO_2$: 305.1512. Found 305.1518.

3-(3,4-Dimethylphenyl)-3-methylbutyl benzoate (2h)



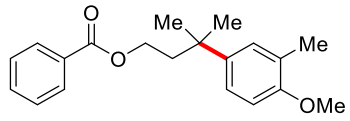
This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mmol, 1 equiv) and 4-iodo-1,2-dimethylbenzene (0.6 mmol, 139.2 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 1% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 60% yield (54.0 mg, 0.182 mmol, R:I = 8:1) as a colorless oil.

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.90 (dd, J = 8.0 Hz, 1.3 Hz, 2H), 7.53 (tt, J = 7.5 Hz, 1.3 Hz, 1H), 7.39 (t, J = 8.0 Hz, 2H), 7.11 (m, 3H), 4.19 (t, J = 7.3 Hz, 2H), 2.24 (s, 3H), 2.21 (s, 3H), 2.13 (t, J = 7.2 Hz, 2H), 1.40 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 166.5, 145.8, 136.2, 133.8, 132.7, 130.4, 129.5, 129.4, 128.2, 127.0, 123.0, 62.7, 42.4, 36.2, 29.3, 20.0, 19.2.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{20}H_{24}NaO_2$: 319.1669. Found 319.1665.

3-(4-Methoxy-3-methylphenyl)-3-methylbutyl benzoate (2i)



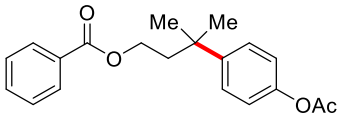
This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mg, 1 equiv) and 4-iodo-1-methoxy-2-methylbenzene (0.6 mmol, 148.8 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 1% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 65% yield (61.0 mg, 0.195 mmol, R:I = 9:1) as a colorless oil.

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.90 (dd, J = 8.0 Hz, 1.3 Hz, 2H), 7.53 (tt, J = 7.5 Hz, 1.3 Hz, 1H), 7.40 (t, J = 8.0 Hz, 2H), 7.15 (m, 2 H), 6.75 (d, J = 8.2 Hz, 1H), 4.19 (t, J = 7.2 Hz, 2H), 3.80 (s, 3H), 2.21 (s, 3H), 2.11 (t, J = 7.2 Hz, 2H), 1.39 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 166.6, 155.7, 140.0, 132.7, 130.4, 129.5, 128.2, 128.1, 126.1, 123.7, 109.5, 62.7, 55.2, 42.5, 36.0, 29.4, 16.5.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{20}H_{24}NaO_3$: 335.1618. Found 335.1617.

3-(4-Acetoxyphenyl)-3-methylbutyl benzoate (2j)



This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mg, 1 equiv) and 4-iodophenyl acetate (0.6 mmol, 157.2 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 2% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 66% yield (65.0 mg, 0.199 mmol, R:I = 10:1) as a colorless oil.

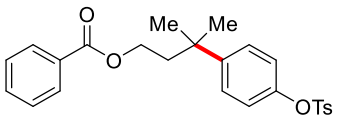
^{1}H NMR (500 MHz, $CDCl_3$): δ 7.92 (dd, J = 8.0 Hz, 1.3 Hz, 2H), 7.53 (tt, J = 7.4 Hz, 1.3 Hz, 1H), 7.40 (t, J =

7.9 Hz, 2H), 7.39 (d, J = 8.7 Hz, 2H), 7.04 (d, J = 8.7 Hz, 2H), 4.19 (t, J = 7.3 Hz, 2H), 2.29 (s, 3H), 2.14 (t, J = 7.3 Hz, 2H), 1.41 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 169.5, 166.5, 148.6, 145.9, 132.8, 130.3, 129.4, 128.2, 126.7, 121.1, 62.4, 42.4, 36.5, 29.2, 21.1.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{20}H_{22}NaO_4$: 349.1410. Found 349.1409.

3-Methyl-3-(4-(tosyloxy)phenyl)butyl benzoate (2k)



This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mg, 1 equiv) and 4-iodophenyl 4-methylbenzenesulfonate (0.6 mmol, 224.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 5% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 57% yield (75 mg, 0.171 mmol, R:I = 11:1) as a white solid.

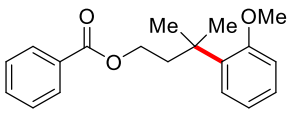
^{1}H NMR (500 MHz, $CDCl_3$): δ 7.91 (dd, J = 8.0 Hz, 1.3 Hz, 2H), 7.69 (d, J = 8.3 Hz, 2H), 7.54 (tt, J = 7.5 Hz, 1.3 Hz, 1H), 7.41 (t, J = 7.9 Hz, 2H), 7.30 (m, 4H), 6.92 (d, J = 8.5 Hz, 2H), 4.11 (t, J =7.3 Hz, 2H), 2.43 (s, 3H), 2.10 (t, J = 7.3 Hz, 2H), 1.37 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 166.5, 147.6, 147.4, 145.2, 132.9, 132.5, 130.1, 130.0, 129.4, 128.5, 128.3, 126.9, 122.0, 62.3, 42.3, 36.6, 29.2, 21.7.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{25}H_{26}NaO_5S$: 461.1393. Found 461.1396.

M.p. 75-77 ºC

3-(2-Methoxyphenyl)-3-methylbutyl benzoate (2l)



This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mg, 1 equiv) and 2-iodoanisole (0.6 mmol, 140.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 1% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 43% yield (38.0 mg, 0.127 mmol, R:I = 10:1) as a colorless oil.

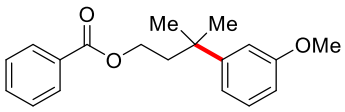
^{1}H NMR (500 MHz, $CDCl_3$): δ 7.88 (dd, J = 8.0 Hz, 1.2 Hz, 2H), 7.52 (tt, J = 7.5 Hz, 1.2 Hz, 1H), 7.39 (t, J =

8.0 Hz, 2H), 7.26 (dd, 7.7 Hz, 1.6 Hz, 1H), 7.19 (td, 8.0 Hz, 1.6Hz, 1H), 6.90 (td, J = 7.6Hz, 1.2 Hz, 1H), 6.85 (d, J = 8.0 Hz, 1H), 4.13 (t, J = 7.1 Hz, 2H), 3.82 (s, 3H), 2.37 (t, J = 7.1 Hz, 2H), 1.46 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 166.6, 158.3, 135.3, 132.6, 130.5, 129.5, 128.1, 127.4, 127.4, 120.5, 111.4, 63.3, 54.9, 38.9, 37.0, 28.7.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{19}H_{22}NaO_3$: 321.1461. Found 321.1456.

3-(3-Methoxyphenyl)-3-methylbutyl benzoate (2m)



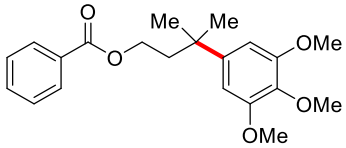
This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mg, 1 equiv) and 3-iodoanisole (0.6 mmol, 140.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 1% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 66% yield (59.0 mg, 0.198 mmol, R:I = 10:1) as a colorless oil.

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.91 (dd, J = 8.0 Hz, 1.3 Hz, 2H), 7.53 (tt, J = 7.5 Hz, 1.3 Hz, 1H), 7.40 (t, 8.0 Hz, 2H), 7.24 (t, J = 8.0 Hz, 1H), 6.98 (m, 1H), 6.94 (t, J = 2.3 Hz, 1H), 6.72 (ddd, J = 8.0 Hz, 2.5 Hz, 0.66 Hz, 1H), 4.18 (t, J = 7.2 Hz, 2H), 3.80 (s, 3H), 2.14 (t, J = 7.2 Hz, 2H), 1.41 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 166.5, 159.5, 150.1, 132.7, 130.3, 129.5, 129.2, 128.2, 118.2, 112.5, 110.2, 62.5, 55.1, 42.4, 36.8, 29.2.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{19}H_{22}NaO_3$: 321.1461. Found 321.1457.

3-Methyl-3-(3,4,5-trimethoxyphenyl)butyl benzoate (2n)



This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mg, 1 equiv) and 5-iodo-1,2,3-trimethoxybenzene (0.6 mmol, 176.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 3% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 63% yield (68 mg, 0.190 mmol, R:I = 10:1) as a white solid.

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.92 (dd, J = 8.0 Hz, 1.3 Hz, 2H), 7.52 (tt, J = 7.5 Hz, 1.3 Hz, 1H), 7.40 (t, J = 8.0 Hz, 2H), 6.58 (s, 2H), 4.20 (t, J = 7.2 Hz, 2H), 3.86 (s, 6H), 3.80 (s, 3H), 2.12 (t, J = 7.2 Hz, 2H), 1.40 (s,

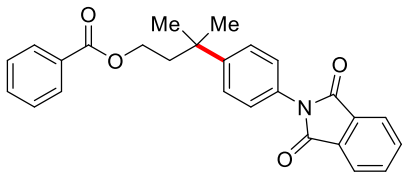
6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 166.5, 152.8, 144.1, 136.1, 132.8, 130.2, 129.4, 128.2, 103.2, 62.5, 60.7, 56.1, 42.4, 36.9, 29.4.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{21}H_{26}NaO_5$: 381.1672. Found 381.1674.

M.p. 70-72 °C.

3-(4-(1,3-Dioxoisoindolin-2-yl)phenyl)-3-methylbutyl benzoate (2o)



This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mg, 1 equiv) and 2-(4-iodophenyl) isoindoline-1,3-dione (0.6 mmol, 209.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 5% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 60% yield (74.0 mg, 0.179 mmol, R:I > 20:1) as a white solid.

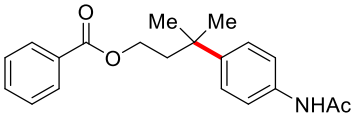
^{1}H NMR (500 MHz, $CDCl_3$): δ 7.95 (m, 4H), 7.79 (m, 2H), 7.53 (m, 3H), 7.41 (m, 4H), 4.24 (t, J = 7.3 Hz, 2H), 2.19 (t, J = 7.3 Hz, 2H), 1.45 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 167.3, 166.5, 148.4, 134.3, 132.8, 131.8, 130.3, 129.5, 129.4, 128.3, 126.4, 126.1, 123.7, 62.4, 42.3, 36.8, 29.2.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{26}H_{23}NNaO_4$: 436.1519. Found 436.1513.

M.p. 185-187 °C

3-(4-Acetamidophenyl)-3-methylbutyl benzoate (2p)



This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mg, 1 equiv) and N-(4-iodophenyl)acetamide (2 equiv). After purification by flash column chromatography (SiO_2: 10% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 60% yield (58.0 mg, R:I = 10:1) as a white solid.

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.91 (dd, J = 8.0, 1.3 Hz, 2H), 7.52 (tt, J = 7.5 Hz, 1.2 Hz, 1H), 7.43 (d, J = 8.6

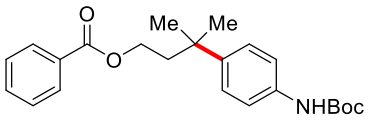
Hz, 2H), 7.39 (m, 3H), 7.32 (d, J = 8.6 Hz, 2H), 4.16 (t, J = 7.3 Hz, 2H), 2.16 (s, 3H), 2.12 (t, J = 7.3 Hz, 2H), 1.38 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 168.3, 166.6, 144.3, 135.6, 132.7, 130.2, 129.4, 128.2, 126.2, 119.8, 62.5, 42.3, 36.4, 29.2, 24.5.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{20}H_{23}NNaO_3$: 348.1570. Found 348.1566..

M.P. 72-74 °C.

3-(4-((*tert*-Butoxycarbonyl)amino)phenyl)-3-methylbutyl benzoate (2q)



This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mg, 1 equiv) and *tert*-butyl (4-iodophenyl)carbamate (0.6 mmol, 191.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 2% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 75% yield (86.0 mg, 0.224 mmol, R:I = 8:1) as a white solid.

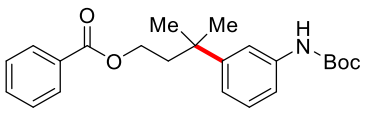
^{1}H NMR (500 MHz, $CDCl_3$): δ 7.91 (dd, J = 8.0 Hz, 1.3 Hz, 2H), 7.52 (tt, J = 7.5 Hz, 1.3 Hz, 1H), 7.40 (t, J = 7.9 Hz, 2H), 7.29 (br, 4H), 6.44 (br, 1H), 4.17 (t, J = 7.2 Hz, 2H), 2.11 (t, J = 7.2 Hz, 2H), 1.52 (s, 9H), 1.38 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 166.5, 152.8, 143.0, 136.1, 132.7, 130.3, 129.5, 128.2, 126.2, 118.5, 80.4, 62.5, 42.4, 36.3, 29.3, 28.3.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{23}H_{29}NNaO_4$: 406.1989. Found 406.1984.

M.P. 76-78 °C.

3-(3-((*tert*-Butoxycarbonyl)amino)phenyl)-3-methylbutyl benzoate (2r)



This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mg, 1 equiv) and *tert*-butyl (3-iodophenyl)carbamate (0.6 mmol, 191.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 2% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 56% yield (64.0 mg, 0.167 mmol, R:I = 11:1) as a white solid.

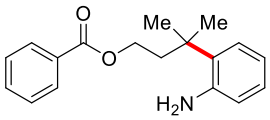
^{1}H NMR (500 MHz, $CDCl_3$): δ 7.91 (d, J = 7.5 Hz, 2H), 7.52 (t, J = 7.5 Hz, 1H), 7.39 (t, J = 7.7 Hz, 2H), 7.34 (s, 1H), 7.23 (m, 2H), 7.05 (m, 1H), 6.54 (br, 1H), 4.18 (t, J = 7.2 Hz, 2H), 2.13 (t, J = 7.2 Hz, 2H), 1.52 (s, 9H), 1.40 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 166.5, 152.7, 149.3, 138.3, 132.7, 130.3, 129.5, 128.8, 128.2, 123.9, 120.4, 116.0, 80.3, 62.5, 42.3, 36.7, 29.2, 28.3.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{23}H_{29}NNaO_4$: 406.1989. Found 406.1986.

M.P. 55-57°C.

3-(2-Aminophenyl)-3-methylbutyl benzoate (2s)



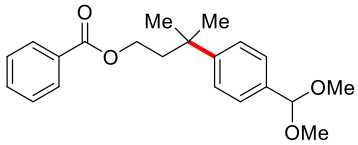
This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mg, 1 equiv) and 2-iodoaniline (0.6 mmol, 131.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 1% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 38% yield (32.0 mg, 0.113 mmol, R:I > 20:1) as a colorless oil

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.92 (dd, J = 8.0 Hz, 1.3 Hz, 2H), 7.53 (tt, J = 7.5 Hz, 1.3 Hz, 1H), 7.40 (t, J = 8.0 Hz, 2H), 7.22 (dd, J = 7.9 Hz, 1.4 Hz, 1H), 7.04 (td, J = 7.5 Hz, 1.3 Hz, 1H), 6.76 (td, J = 7.6 Hz, 1.3 Hz, 1H), 6.65 (dd, J = 7.7 Hz, 1.3 Hz, 1H), 4.19 (t, J = 7.2 Hz, 2H), 3.82 (br, 2H), 2.31 (t, J = 7.2 Hz, 2H), 1.51 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 166.6, 144.4, 132.7, 131.4, 130.3, 129.5, 128.2, 127.4, 127.3, 119.2, 118.3, 62.8, 38.5, 36.6, 28.8.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{18}H_{21}NNaO_2$: 306.1465. Found 306.1484.

3-(4-(Dimethoxymethyl)phenyl)-3-methylbutyl benzoate (2t)



This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mg, 1 equiv) and 1-(dimethoxymethyl)-4-iodobenzene (0.6 mmol, 166.8 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 1% ethyl

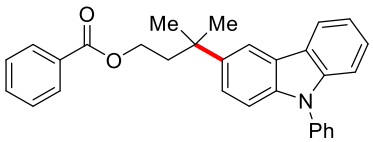
acetate in petroleum ether), the title compound along with its isomers was isolated in 50% yield (51.0 mg, 0.149 mmol, R:I = 20:1) as a colorless oil.

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.92 (d, J = 7.3 Hz, 2H), 7.53 (t, J = 7.3 Hz, 1H), 7.39 (m, 6H), 5.35 (s, 1H), 4.16 (t, J = 6.8 Hz, 2H), 3.32 (s, 6H), 2.15 (t, J = 6.8 Hz, 2H), 1.41 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 166.5, 148.6, 135.5, 132.7, 130.3, 129.5, 128.2, 126.6, 125.5, 103.2, 62.5, 52.8, 42.4, 36.6, 29.2.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{21}H_{26}O_4$: 365.1723. Found 365.1727.

3-Methyl-3-(9-phenyl-9H-carbazol-3-yl)butyl benzoate (2u)



This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mg, 1 equiv) and 3-iodo-9-phenyl-9H-carbazole (0.6 mmol, 221.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 3% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 78% yield (101.0 mg, 0.233 mmol, R:I = 10:1) as a white solid.

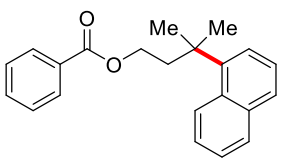
^{1}H NMR (500 MHz, $CDCl_3$): δ 8.16 (m, 2H), 7.86 (dd, J = 8.0 Hz, 1.4 Hz, 2H), 7.56 (m, 4H), 7.46 (m, 3H), 7.40 (m, 2H), 7.35 (d, J = 8.6 Hz, 1H), 7.28 (m, 3H), 4.25 (t, J = 7.2 Hz, 2H), 2.27 (t, J = 7.2 Hz, 2H), 1.57 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 166.5, 141.1, 140.1, 139.1, 137.8, 132.6, 130.3, 129.8, 129.4, 128.1, 127.2, 126.9, 125.8, 124.0, 123.5, 123.2, 120.2, 119.7, 117.0, 109.7, 109.5, 62.7, 43.0, 36.8, 29.9.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{30}H_{27}NNaO_2$: 456.1934. Found 456.1926.

M.P. 58-60 °C.

3-Methyl-3-(naphthalen-1-yl)butyl benzoate (2v)



This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mg, 1 equiv) and 1-iodonaphthalene (0.6 mmol, 152.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 2% ethyl acetate in petroleum ether), the title compound along with its isomers

was isolated in 52% yield (50.0 mg, 0.157 mmol, R:I = 20:1) as a colorless oil.

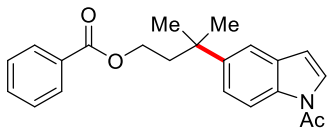
^{1}H NMR (500 MHz, $CDCl_3$): δ 8.48 (d, J = 8.8 Hz, 1H), 7.86 (dd, J = 8.0 Hz, 1.3 Hz, 1H), 7.70 (dd, J = 8.0 Hz, 1.3 Hz, 3H), 7.48 (m, 4H), 7.38 (t, J = 7.9 Hz, 1H), 7.33 (t, J = 8.0 Hz, 2H), 4.15 (t, J = 7.0 Hz, 2H), 2.64 (t, J = 7.0 Hz, 2H), 1.72 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 166.4, 143.1, 135.1, 132.6, 131.6, 130.1, 130.0, 129.3, 128.1, 127.9, 126.2, 125.2, 124.9, 124.7, 124.6, 62.7, 40.5, 38.4, 30.7.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{22}H_{22}NaO_2$: 341.1512. Found 341.1504.

M.P. 75-77 ºC.

3-(1-Acetyl-1H-indol-5-yl)-3-methylbutyl benzoate (2w)



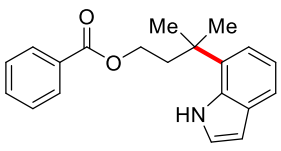
This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mg, 1 equiv) and 1-(5-iodo-1H-indol-1-yl)ethan-1-one (0.6 mmol, 171.0 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 5% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 71% yield (74.0 mg, 0.212 mmol, R:I = 10:1) as a white solid.

^{1}H NMR (500 MHz, $CDCl_3$): δ 8.32 (br, 1H), 7.86 (dd, J = 8.2 Hz, 1.4 Hz, 2H), 7.55 (d, J = 1.8 Hz, 1H), 7.49 (tt, J = 7.5 Hz, 1.3 Hz, 1H), 7.40 (m, 2H), 7.34 (t, J = 7.9 Hz, 2H), 6.6 (d, J = 3.6 Hz, 1H), 4.18 (t, J = 7.2 Hz, 2H), 2.62 (s, 3H), 2.20 (t, J = 7.2 Hz, 2H), 1.48 (s, 6 H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 168.4, 166.5, 143.8, 133.7, 132.6, 130.5, 130.2, 129.4, 128.1, 125.3, 123.2, 117.7, 116.2, 109.3, 62.5, 42.7, 36.7, 29.6, 23.8.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{22}H_{23}NNaO_3$: 372.1570. Found 372.1570.

3-(1H-indol-7-yl)-3-methylbutyl benzoate (2x)



This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl benzoate (0.3 mmol, 81.3 mmol, 1 equiv) and 7-iodo-1H-indole (0.6 mmol, 145.8 mg, 2 equiv). 7-Iodo-1H-indole was prepared from a Cu-catalyzed conversion of the bromo-precursor.[5] After purification by flash column chromatography

(SiO_2: 2% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 63% yield (58.0 mg, 0.189 mmol, R:I = 20:1) as a white solid.

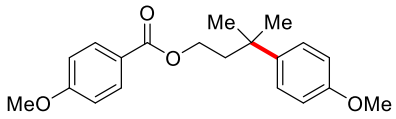
^{1}H NMR (600 MHz, $CDCl_3$): δ 8.46 (s, 1H), 7.82 (d, J = 7.8 Hz, 2H), 7.54 (m, 2H), 7.39 (t, J = 7.8 Hz, 2H), 7.22 (br, 1H), 7.15 (d, J = 7.6 Hz, 1H), 7.09 (t, J = 7.6 Hz, 1H), 6.58 (br, 1H), 4.21 (t, J = 7.2 Hz, 2H), 2.38 (t, J = 7.2 Hz, 2H), 1.62 (s, 6H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 166.6, 133.3, 132.8, 130.6, 130.1, 129.4, 129.1, 128.2, 123.6, 119.9, 119.6, 119.4, 102.7, 62.5, 40.5, 36.8, 28.9.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{20}H_{21}NNaO_2$: 330.1465. Found 330.1470.

M.P. 105-107 °C.

3-(4-Methoxyphenyl)-3-methylbutyl 4-methoxybenzoate (3)



This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl 4-methoxybenzoate (0.3 mmol, 90.3 mmol, 1 equiv) and 4-iodoanisole (0.6 mmol, 140.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 3% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 70% yield (69.0 mg, 0.210 mmol, R:I = 10:1) as a white solid.

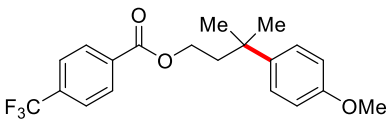
^{1}H NMR (500 MHz, $CDCl_3$): δ 7.86 (d, J = 8.9 Hz, 2H), 7.29 (d, J = 8.9 Hz, 2H), 6.87 (d, J = 8.9 Hz, 2H), 6.84 (d, J = 8.9 Hz, 2H), 4.14 (t, J = 7.3 Hz, 2H), 3.85 (s, 3H), 3.78 (s, 3H), 2.10 (t, J = 7.3 Hz, 2H), 1.39 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 166.3, 163.2, 157.5, 140.5, 131.5, 126.6, 122.8, 113.5, 113.4, 62.3, 55.4, 55.2, 42.6, 36.1, 29.4.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{20}H_{24}NaO_4$: 351.1567. Found 351.1568.

M.P. 48-50 °C.

3-(4-Methoxyphenyl)-3-methylbutyl 4-(trifluoromethyl)benzoate (4)



This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl 4-(trifluoromethyl)benzoate (0.3 mmol, 101.7 mg,

1 equiv) and 4-iodoanisole (0.6 mmol, 140.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 2% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 60% yield (66.0 mg, 0.180 mmol, R:I = 10:1) as a white solid.

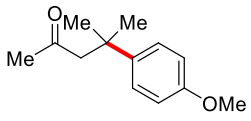
^{1}H NMR (500 MHz, $CDCl_3$): δ 7.97 (d, J = 8.0 Hz, 2H), 7.65 (d, J = 8.0 Hz, 2H), 7.29 (d, J = 8.8 Hz, 2H), 6.83 (d, J = 8.8 Hz, 2H), 4.22 (t, J = 7.1 Hz, 2H), 3.75 (s, 3H), 2.13 (t, J = 7.1 Hz, 2H), 1.40 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 165.3, 157.5, 140.3, 134.6, 134.3, 134.1, 133.8, 133.5, 129.9, 126.9, 126.6, 125.2, 125.2, 125.2, 125.1, 124.7, 122.5, 120.4, 113.6, 63.1, 55.1, 42.5, 36.1, 29.4.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{20}H_{21}F_3NaO_3$: 389.1335. Found 389.1343.

M.P. 56-58 °C.

4-(4-Methoxyphenyl)-4-methylpentan-2-one (5)



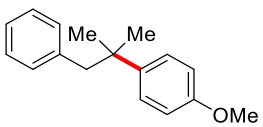
This compound was prepared according to the general procedure, using 4-bromo-4-methylpentan-2-one (0.3 mmol, 53.7 mg, 1 equiv) and 4-iodoanisole (0.6 mmol, 140.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 2% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 50% yield (31.0 mg, 0.15 mmol) as a colorless oil.

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.28 (d, J = 8.8 Hz, 2H), 6.86 (d, J = 8.8 Hz, 2H), 3.79 (s, 3H), 2.70 (s, 2H), 1.79 (s, 3H), 1.40 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 208.4, 157.6, 140.2, 126.5, 113.5, 57.1, 55.2, 36.7, 31.9, 29.1.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{13}H_{18}NaO_2$: 229.1199. Found 229.1203.

1-Methoxy-4-(2-methyl-1-phenylpropan-2-yl)benzene (6)



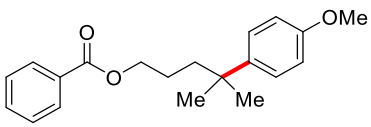
This compound was prepared according to the general procedure, using (2-bromo-2-methylpropyl) benzene (0.3 mmol, 63.9 mg, 1 equiv) and 4-iodoanisole (0.6 mmol, 140.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 1% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 65% yield (47.0 mg, 0.195 mmol, R:I = 6:1) as a colorless oil.

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.21 (d, J = 8.8, 2H), 7.15 (m, 3H), 6.84 (d, J = 8.8 Hz, 2H), 6.8 (m, 2H), 3.82 (s, 3H), 2.85 (s, 2H), 1.31 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 157.4, 141.1, 139.0, 130.4, 127.4, 127.2, 125.8, 113.2, 55.2, 51.2, 38.2, 28.4.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for C17H20NaO: 263.1406. Found 263.1401.

4-(4-Methoxyphenyl)-4-methylpentyl benzoate (7)



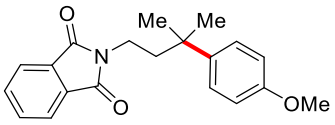
This compound was prepared according to the general procedure, using 4-bromo-4-methylpentyl benzoate (0.3 mmol, 85.5 mg, 1 equiv) and 4-iodoanisole (0.6 mmol, 140.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 1% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 56% yield (52 mg, 0.167 mmol, R:I = 5:1) as a colorless oil

^{1}H NMR (500 MHz, $CDCl_3$): δ 8.02 (dd, J = 8.0 Hz, 1.2 Hz, 2H), 7.55 (tt, J = 7.5 Hz, 1.3 Hz, 1H), 7.44 (t, J = 7.8 Hz, 2H), 7.27 (d, J = 8.9 Hz, 2H), 6.85 (d, J = 8.9 Hz, 2H), 4.22 (t, J = 6.6 Hz, 2H), 3.80 (s, 3H), 1.73 (m, 2H), 1.54 (m, 2H), 1.32 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 166.6, 157.4, 140.9, 132.8, 130.4, 129.5, 128.3, 126.7, 113.4, 65.5, 55.2, 40.6, 36.8, 29.1, 24.3.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{20}H_{24}NaO_3$: 335.1618. Found 335.1623.

2-(3-(4-Methoxyphenyl)-3-methylbutyl)isoindoline-1,3-dione (8)



This compound was prepared according to the general procedure, using 2-(3-bromo-3-methylbutyl) isoindoline-1,3-dione (0.3 mmol, 88.8 mg, 1 equiv) and 4-iodoanisole (0.6 mmol, 140.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 4% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 57% yield (55.0 mg, 0.170 mmol, R:I > 20:1) as a white solid.

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.72 (dd, J = 5.4, 3.0, 2H), 7.64 (dd, J = 5.4, 3.0, 2H), 7.25 (d, J = 8.8 Hz, 2H), 6.73 (d, J = 8.8 Hz, 2H), 3.66 (s, 3H), 3.55 (t, J = 7.7 Hz, 2H), 2.04 (t, J = 7.7 Hz, 2H), 1.37 (s, 6H).

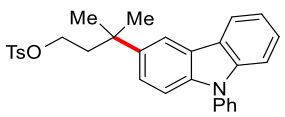
^{13}C NMR (125 MHz, $CDCl_3$): δ 168.2, 157.3, 139.8, 133.5, 132.1, 126.6, 122.8, 113.4, 55.0, 41.4, 36.1, 34.8,

29.3.

HRMS (ESI) m/z ([M+Na]$^+$) calcd for $C_{20}H_{21}NNaO_3$: 346.1414. Found 346.1415.

M.P. 83-85 °C.

3-Methyl-3-(9-phenyl-9H-carbazol-3-yl)butyl 4-methylbenzenesulfonate (9)



This compound was prepared according to the general procedure, using 3-bromo-3-methylbutyl 4-methylbenzenesulfonate (0.3 mmol, 96.3 mg, 1 equiv) and 3-iodo-9-phenyl-9H-carbazole (0.6 mmol, 221.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 10% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 62% yield (90.0 mg, 0.186 mmol, R:I > 20:1) as a white solid.

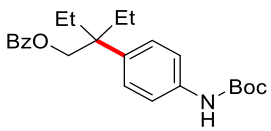
^{1}H NMR (600 MHz, $CDCl_3$): δ 8.12 (d, J = 7.7 Hz, 1H), 7.98 (s, 1H), 7.63 (m, 4H), 7.56 (d, J = 7.6 Hz, 2H), 7.48 (t, J = 7.3 Hz, 1H), 7.43 (m, 2H), 7.30 (m, 3H), 7.16 (d, J = 8.0 Hz, 2H), 3.90 (t, J = 7.4 Hz, 2H), 2.29 (s, 3H), 2.16 (t, J = 7.4 Hz, 2H), 1.44 (s, 6H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 144.4, 141.1, 139.1, 139.0, 137.7, 132.9, 129.8, 129.6, 127.7, 127.3, 126.8, 125.9, 123.7, 123.3, 123.1, 120.1, 119.9, 116.8, 109.8, 109.6, 68.4, 42.9, 36.6, 29.8, 21.4.

HRMS (ESI) m/z ([M+Na]$^+$) calcd for $C_{30}H_{29}NNaO_3S$: 506.1760. Found 506.1748.

M.P. 40-42 °C.

2-(4-((*tert*-Butoxycarbonyl)amino)phenyl)-2-ethylbutyl benzoate (10)



This compound was prepared according to the general procedure, using 2-bromo-2-ethylbutyl benzoate (0.3 mmol, 85.5 mg, 1 equiv) and *tert*-butyl (4-iodophenyl)carbamate (0.6 mmol, 191.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 2% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 42% yield (50 mg, 0.126 mmol, R:I > 20:1) as a white solid.

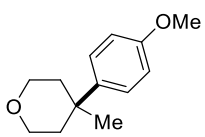
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.97 (d, J = 7.6 Hz, 2H), 7.54 (t, J = 7.6 Hz, 1H), 7.42 (t, J = 7.6 Hz, 2H), 7.34 (d, J = 7.5 Hz, 2H), 7.25 (d, J = 7.5 Hz, 2H), 6.50 (br, 1H), 4.52 (s, 2H), 1.83 (q, J = 7.5 Hz, 4H), 1.51 (s, 9H), 0.74 (t, J = 7.5 Hz, 6H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 166.5, 152.8, 138.4, 136.2, 132.9, 130.3, 129.5, 128.3, 127.1, 118.3, 80.4, 67.5, 44.1, 28.6, 28.3, 8.1.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{24}H_{31}NaO_4$: 420.2145. Found 420.2135.

M.P. 105-107 °C.

4-(4-methoxyphenyl)-4-methyltetrahydro-2H-pyran (11)



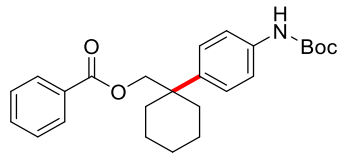
This compound was prepared according to the general progress. Using 4-bromo-4-methyltetrahydro-2H-pyran (0.3 mmol, 53.7 mg, 1 equiv), 4-iodoanisole (0.6 mmol, 140.4 mg, 2 equiv). After purification by column chromatograph (SiO_2: 5% to 10% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 68% yield (42.0 mg, 0.204 mmol, R:I = 3:1) as a colorless oil.

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.24 (d, J = 8.9 Hz, 2H), 6.88 (d, J = 8.9 Hz, 2H), 3.81 (s, 3H), 3.75 (m, 2H), 3.67 (m, 2H), 2.08 (m, 2H), 1.73 (m, 2H), 1.27 (s, 3H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 157.5, 140.9, 126.6, 113.7, 64.4, 55.2, 37.8, 37.3, 35.0.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{13}H_{18}NaO_2$: 229.1199. Found 229.1203.

(1-(4-((*tert*-Butoxycarbonyl)amino)phenyl)cyclohexyl)methyl benzoate (12)



This compound was prepared according to the general procedure, using (1-bromocyclohexyl) methyl benzoate (0.3 mmol, 89.1 mg, 1 equiv) and *tert*-butyl (4-iodophenyl) carbamate (0.6 mmol, 191.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 2% ethyl acetate in petroleum ether), the title compound was isolated in 50% yield (62 mg, 0.151 mmol, R:I > 50:1) as a white solid.

^{1}H NMR (600 MHz, $CDCl_3$): δ 7.94 (d J = 7.8 Hz, 2H), 7.53 (t, J = 7.2 Hz, 1H), 7.40 (t, J = 7.8 Hz, 2H), 7.37 (m, 4H), 6.52 (br, 1H), 4.21 (s, 2H), 2.22 (d, J = 11.2 Hz, 2H), 1.73 (t, J = 11.2 Hz, 2H), 1.58-1.38 (m, 6H), 1.51 (s, 9H).

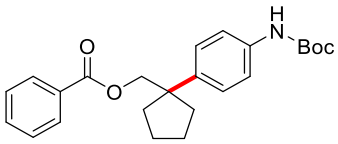
^{13}C NMR (150 MHz, $CDCl_3$): δ 166.4, 152.8, 138.0, 136.3, 132.8, 130.3, 129.5, 128.3, 127.8, 118.4, 80.4,

73.6, 41.6, 32.7, 28.3, 26.3, 21.8.

HRMS (ESI) m/z ([M+Na]$^+$) calcd for $C_{25}H_{31}NNaO_4$: 432.2145. Found 432.2139.

M.P. 122-124 ^oC.

(1-(4-((*tert*-Butoxycarbonyl)amino)phenyl)cyclopentyl)methyl benzoate (13)



This compound was prepared according to the general procedure, using (1-bromocyclopentyl) methyl benzoate (0.3 mmol, 84.9 mg, 1 equiv) and tert-butyl (4-iodophenyl) carbamate (0.6 mmol, 191.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 2% ethyl acetate in petroleum ether), the title compound was isolated in 42% yield (50 mg, 0.126 mmol, R:I > 50:1) as a white solid.

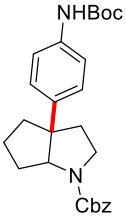
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.93 (d, J = 7.6 Hz, 2H), 7.53 (t, J = 7.4 Hz, 1H), 7.40 (t, J = 7.6 Hz, 2H), 7.32 (br-s, 4H), 6.50 (s, 1H), 4.29 (s, 2H), 2.08 (m ,2H), 1.98 (m, 2H), 1.78 (m, 4H), 1.50 (s, 9H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 166.6, 152.8, 141.3, 136.3, 132.8, 130.2, 129.5, 128.3, 127.6, 118.2, 80.4, 71.2, 50.5, 35.2, 28.3, 23.7.

HRMS (ESI) m/z ([M+Na]$^+$) calcd for $C_{24}H_{29}NNaO_4$: 418.1989. Found 418.1990.

M.P. 113-115 ^oC.

***cis*-Benzyl 3a-(4-((tert-butoxycarbonyl)amino)phenyl) hexahydrocyclopenta[b]pyrrole -1(2H)-carboxylate (14)**



This compound was prepared according to the general procedure, using tert-butyl 3a-bromohexahydrocyclopenta[b]pyrrole-1(2H)-carboxylate (0.3 mmol, 97.2 mg, 1 equiv) and tert-butyl (4-iodophenyl) carbamate (0.6 mmol, 191.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 10% ethyl acetate in petroleum ether), the title compound was isolated in 15% yield (20 mg, 0.045 mmol, R:I > 50:1) as a white solid.

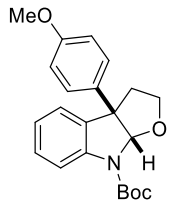
^{1}H NMR (600 MHz, $CDCl_3$): δ: 7.31 (d, J = 7.8 Hz, 2H), 7.01 (d, J = 7.8 Hz, 2H), 6.49 (br, 1H), 6.11 (d, J = 9.7 Hz, 2H), 5.73 (d, J = 9.7 Hz, 2H), 5.38 (br, 1H), 4.13 (m. 2H), 3.96 (m, 1H), 3.20 (m, 2H), 2.30 (m, 6H), 1.84 (m, 2H), 1.51 (s, 9H).

^{13}C NMR (100 MHz) δ 157.53, 152.80, 141.33, 137.47, 135.57, 134.21, 128.37, 125.85, 125.16, 119.15, 80.78, 73.76, 58.62, 41.54, 39.95, 35.24, 32.65, 31.02, 28.41, 23.34.

HRMS (ESI) m/z ([M+Na]$^+$) calcd for $C_{26}H_{32}N_2NaO_4$: 459.2254. Found 459.2242.

M.P. 75-77 ^{o}C.

***cis-tert*-Butyl 3a-(4-methoxyphenyl)-2,3,3a,8a-tetrahydro-8H-furo[2,3-b]indole-8-carboxylate (15)**



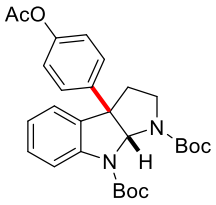
This compound was prepared according to the general procedure, using cis-di-*tert*-butyl-3-chloro-2,3-tetrahydropyrrolo[2,3-b]indole-1,8-dicarboxylate[6] (0.3 mmol, 88.8 mg, 1 equiv) and 4-iodoanisole (0.6 mmol, 140.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 5% ethyl acetate in petroleum ether), the title compound in 73% yield (80.0 mg, 0.218 mmol, single isomer) as a white solid. Note: ^{1}H NMR spectra indicates that there are two broad singlets at 5.9 and 6.1 ppm in $CDCl_3$ at room temperature. However ^{1}H NMR spectra in DMSO (*d*-6) at 18 ^{o}C and 60 ^{o}C only shows a singlet at 5.82 or 5.84 ppm, respectively. This observation may suggest a conformation change in different solvent, possibly due to aggregation in less-polar solvent such as $CDCl_3$.

^{1}H NMR (600 MHz, $CDCl_3$): δ 7.92 (br, 1H), 7.25 (m, 1H), 7.17 (d, J = 8.4 Hz, 2H), 7.10 (m, 1H), 7.02 (t, J = 7.3 Hz, 1H), 6.85 (d, J = 8.4 Hz, 2H), 5.94 (br, 1H), 4.17 (t, J = 7.9 Hz, 1H), 3.78 (s, 3H), 3.59 (m, 1H), 2.76 (m, 1H), 2.48 (m, 1H), 1.58 (s, 9H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 158.4, 152.2, 142.7, 135.2, 134.2, 128.4, 127.3, 124.5, 123.1, 114.6, 113.9, 100.2, 81.3, 68.1, 59.6, 55.2, 40.6, 28.3.

HRMS (ESI) m/z ([M+Na]$^+$) calcd for $C_{22}H_{25}NNaO_4$: 390.1676. Found 390.1669.

***cis*-Di-*tert*-butyl-3a-(4-acetoxyphenyl)-2,3,3a,8a-tetrahydropyrrolo[2,3-b]indole-1,8- dicarboxylate (16a)**



This compound was prepared according to the general procedure, using *cis*-di-*tert*-butyl-3-chloro-2-tetrahydropyrrolo[2,3-b]indole- 1,8-dicarboxylate **S4**[6] (0.3 mmol, 118.5 mg, 1 equiv) and 4-iodophenyl acetate (0.6 mmol, 157.2 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 8% ethyl acetate in petroleum ether),

the title compound was isolated in 70% yield (103 mg, 0.210 mmol, single isomer) as a white solid.

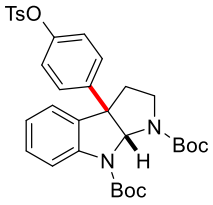
^{1}H NMR (500 MHz, $CDCl_3$): δ 7.62 (br, 1H), 7.23 (m, 3H), 7.10 (d, J = 7.3 Hz, 1H), 7.01 (m, 3H), 6.38 (s, 1H), 3.91 (m, 1H), 2.93 (m, 1H), 2.48 (m, 2H), 2.25 (s, 3H), 1.55 (s, 9H), 1.49 (s, 9H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 169.6, 153.9, 152.4, 149.6, 142.5, 140.7, 135.2, 128.6, 127.1, 124.0, 123.7, 121.9, 117.2, 82.4, 81.8, 80.4, 59.9, 46.2, 37.3, 28.5, 28.4, 21.2.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{28}H_{34}N_2NaO_6$: 517.2309. Found 517.2291.

M.P. 140-142 ºC.

Di-*tert*-butyl-3a-(4-(tosyloxy)phenyl)-2,3,3a,8a-tetrahydropyrrolo[2,3-b]indole-1,8-dicarboxylate (16b)



This compound was prepared according to the general procedure, using *cis*-di-*tert*-butyl-3a-chloro-tetrahydropyrrolo[2,3-b]indole- 1,8-dicarboxylate **S4** (0.3 mmol, 118.5 mg, 1 equiv) and 4-iodophenyl 4-methylbenzenesulfonate (0.6 mmol, 224.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 10% ethyl acetate in petroleum ether), the title compound was isolated in 55% yield (100.0 mg, 0.165 mmol, single isomer) as a white solid.

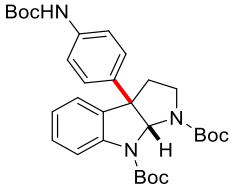
^{1}H NMR (500 MHz, $CDCl_3$): δ 7.68 (d, J = 8.3 Hz, 2H), 7.61 (br, 1H), 7.29 (d, J = 8.2 Hz, 2H), 7.22 (t, J = 8.0 Hz, 1H), 7.14 (d, J = 8.7 Hz, 2H), 7.03 (m, 2H), 6.89 (d, J = 8.7 Hz, 2H), 6.32 (s, 1H), 3.89 (m, 1H), 2.90 (m, 1H), 2.43 (s, 3H), 2.43 (m, 2H), 1.54 (s, 9H), 1.48 (s, 9H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 153.7, 152.2, 148.3, 145.3, 142.2, 142.0, 134.7, 132.3, 129.7, 128.5, 128.3, 127.1, 123.7, 123.6, 122.4, 116.9, 82.1, 81.6, 80.3, 59.6, 46.0, 37.2, 28.3, 28.2, 21.6.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{33}H_{38}N_2NaO_7S$: 629.2292. Found 629.2286.

M.P. 113-115 ºC.

***cis*-Di-*tert*-butyl-3a-(4-((tert-butoxycarbonyl)amino)phenyl)-2,3,3a,8a-tetrahydropyrrolo[2,3-b]indole-1, 8-dicarboxylate (16c)**



This compound was prepared according to the general procedure, using *cis*-di-*tert*-butyl-3a-chloro-tetrahydropyrrolo[2,3-b]indole- 1,8-dicarboxylate **S4** (0.3

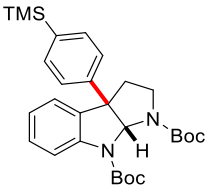
mmol, 118.5 mg, 1 equiv) and tert-butyl (4-iodophenyl) carbamate (0.6 mmol, 191.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 3% ethyl acetate in petroleum ether), the title compound was isolated in 75% yield (124 mg, 0.225 mmol, single isomer) as a white solid.

^{1}H NMR (600 MHz, $CDCl_3$): δ 7.60 (br, 1H), 7.27 (br, 2H), 7.21 (t, J = 7.5 Hz, 1H), 7.13 (m, 2H), 7.07 (d, J = 7.3 Hz, 1H), 7.00 (t, J = 7.3 Hz, 1H), 6.53 (s, 1H), 6.34 (s, 1H), 3.88 (m, 1H), 2.93 (m, 1H), 2.47 (m, 2H), 1.55 (s, 9H), 1.49 (s, 9H), 1.48 (s, 9H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 154.0, 152.7, 152.4, 142.3, 137.7, 137.2, 135.4, 128.3, 127.2, 126.4, 123.8, 123.6, 118.8, 82.3, 81.6, 80.6, 80.3, 59.7, 46.1, 35.9 (br), 28.5, 28.4, 28.3.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{31}H_{41}N_3NaO_6$: 574.2888. Found 574.2887.

cis-Di-tert-butyl-3a-(4-(trimethylsilyl)phenyl)-2,3,3a,8a-tetrahydropyrrolo[2,3-b]indole-1,8-dicarboxylate (16d)

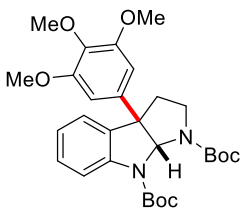


This compound was prepared according to the general procedure, using *cis*-di-*tert*-butyl-3a-chloro-tetrahydropyrrolo[2,3-b]indole- 1,8-dicarboxylate **S4** (0.3 mmol, 118.4 mg, 1 equiv) and 4-iodophenyl 4-methylbenzenesulfonate (0.6 mmol, 165.6 mg, 2 equiv), DMF as the solvent. After purification by flash column chromatography (SiO_2: 3% ethyl acetate in petroleum ether), the title compound was isolated in 70% yield (107.0 mg, 0.21 mmol, single isomer) as a white solid.

^{1}H NMR (600 MHz, $CDCl_3$): δ 7.57 (br, 1H), 7.45 (d, J = 8.0 Hz, 2H), 7.23 (m, 3H), 7.12 (d, J = 7.4 Hz, 1H), 7.02 (t, J = 7.4 Hz, 1H), 6.42 (s, 1H), 3.93 (m, 1H), 2.95 (m, 1H), 2.51 (m, 1H), 1.57 (s, 9H), 1.50 (s, 9H), 0.23 (s, 9H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 153.9, 152.3, 143.7, 142.4, 139.0, 135.3, 133.8, 128.3, 125.1, 123.8, 123.4, 117.1, 82.2, 81.5, 80.2, 60.1, 46.0, 35.9, 28.4, 28.3, -1.22.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{29}H_{40}N_2NaO_4Si$: 531.2650. Found 531.2640.



cis-Di-_tert_-butyl-3a-(3,4,5-trimethoxyphenyl)-2,3,3a,8a-tetrahydropyrrolo[2,3-b]indole-1,8-dicarboxylate (16e)

This compound was prepared according to the general procedure, using *cis*-di-*tert* -butyl-3a-chloro-tetrahydropyrrolo[2,3-b]indole- 1,8-dicarboxylate **S4** (0.3 mmol, 118.4 mg, 1 equiv) and 5-iodo-1,2,3-trimethoxybenzene (0.6 mmol, 176.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 5% ethyl acetate in petroleum ether), the title compound was isolated in 70% yield (110.0 mg, 0.210 mmol, single isomer) as a white solid.

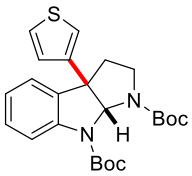
^{1}H NMR (500 MHz, $CDCl_3$): δ 7.58 (br, 1H), 7.23 (m, 1H), 7.14 (d, J = 7.1 Hz, 1H), 7.03 (t, J = 7.2 Hz, 1H), 6.46 (s, 2H), 6.41 (s, 1H), 3.88 (m, 1H), 3.79 (s, 6H), 3.78 (s, 3H), 2.94 (m, 1H), 2.50 (m, 2H), 1.56 (s, 9H), 1.49 (s, 9H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 153.8, 153.2, 152.3, 142.2, 139.0, 137.0, 135.4, 128.4, 123.6, 123.5, 117.4, 103.0, 82.0, 81.5, 80.3, 60.7, 60.1, 56.1, 46.0, 36.8, 28.4, 28.3.

HRMS (ESI) m/z ($[2M+Na]^+$) calcd for $C_{58}H_{76}N_4NaO_{14}$: 1075.5250. Found 1075.5243.

M.P. 98-100 ºC.

***cis*-Di-*tert*-butyl-3a-(thiophen-3-yl)-2,3,3a,8a-tetrahydropyrrolo[2,3-b]indole-1,8-dicarboxylate (16f)**



This compound was prepared according to the general procedure, using *cis*-di-*tert* -butyl-3a-chloro-tetrahydropyrrolo[2,3-b]indole- 1,8-dicarboxylate **S4** (0.3 mmol, 118.4 mg, 1 equiv) and 3-iodofuran (0.6 mmol, 126 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 5% ethyl acetate in petroleum ether), the title compound was isolated in 75% yield (99 mg, 0.224 mmol, single isomer) as a white solid.

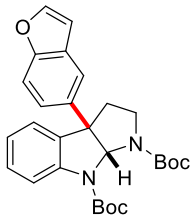
^{1}H NMR (500 MHz, $CDCl_3$): δ 7.62 (br, 1H), 7.25 (m, 2H), 7.16 (d, J = 7.5 Hz, 1H), 7.04 (t, J = 7.5 Hz, 1H), 6.93 (m, 2H), 6.29 (s, 1H), 3.89 (m, 1H), 2.94 (m, 1H), 2.47 (m, 2H), 1.55 (s, 9H), 1.49 (s, 9H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 153.9, 152.5, 144.0, 142.4, 135.0, 128.4, 126.7, 125.9, 123.6, 123.5, 120.4, 117.3, 82.1, 81.5, 80.2, 57.5, 46.0, 37.3, 28.4, 28.3.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{24}H_{30}N_2NaO_4S$: 465.1818. Found 465.1819.

M.P. 112-114 ºC.

***cis*-Di-*tert*-butyl 3a-(benzofuran-5-yl)-2,3,3a,8a-tetrahydropyrrolo[2,3-b]indole-1,8- dicarboxylate (16g)**



This compound was prepared according to the general procedure, using *cis*-di-*tert*-butyl-3a-chloro-tetrahydropyrrolo[2,3-b]indole-1,8-dicarboxylate **S4** (0.3 mmol, 118.4 mg, 1 equiv) and 5-iodobenzofuran (0.6 mmol, 146.4 mg, 2 equiv), DMF as the solvent. After purification by flash column chromatography (SiO_2: 5% ethyl acetate in petroleum ether), the title compound was isolated in 80% yield (114 mg, 0.240 mmol, single isomer) as a white solid.

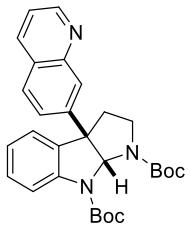
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.72 (br, 1H), 7.61 (s, 1H), 7.47 (s, 1H), 7.44 (d, J = 8.4 Hz, 1H), 7.27 (m, 1H), 7.21 (d, J = 8.0 Hz, 1H), 7.16 (d, J = 6.8 Hz, 1H), 7.06 (d, J = 6.8 Hz, 1H), 6.71(s, 1H), 6.46 (s, 1H), 3.96 (m, 1H), 3.00 (m, 1H), 2.61 (m, 2H), 1.59 (s, 9H), 1.53 (s, 9H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 153.9, 153.8, 152.4, 145.5, 142.3, 137.8, 135.8, 128.3, 127.5, 123.8, 123.5, 122.3, 118.3, 117.3, 111.5, 106.6, 82.6, 81.5, 80.2, 60.1, 46.1, 39.0, 28.4, 28.3.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{28}H_{32}N_2NaO_5$: 499.2203. Found 499.2193.

M.P. 144-146 ºC

***cis*-Di-*tert*-butyl-3a-(quinolin-7-yl)-2,3,3a,8a-tetrahydropyrrolo[2,3-b]indole-1,8-dicarboxylate (16h)**



This compound was prepared according to the general procedure, using *cis*-di-*tert*-butyl-3a-chloro-tetrahydropyrrolo[2,3-b]indole- 1,8-dicarboxylate **S4** (0.3 mmol, 118.4 mg, 1 equiv) and 7-iodoquinoline (0.6 mmol, 153.0 mg, 2 equiv), DMF as the solvent. After purification by flash column chromatography (SiO_2: 5% ethyl acetate in petroleum ether), the title compound was isolated in 41% yield (60 mg, 0.123 mmol, single isomer) as a white solid.

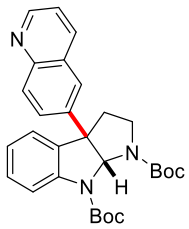
^{1}H NMR (600 MHz, $CDCl_3$): δ 8.88 (br, 1H), 8.10 (d, J = 8.1 Hz, 1H), 8.03 (s, 1H), 7.73 (d, 8.5 Hz, 1H), 7.56 (br, 1H), 7.36 (d, J = 8.3 Hz, 2H), 7.24 (t, J = 7.8 Hz, 1H), 7.13 (m, 1H), 7.01 (m, 1H), 6.50 (s, 1H), 3.99 (m, 1H), 3.00 (m, 1H), 2.69 (m, 1H), 2.57 (m, 1H), 1.57 (s, 9H), 1.49 (s, 9H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 153.8, 152.3, 150.5, 147.7, 144.8, 142.5, 135.9, 134.6, 128.6, 128.5, 127.0, 125.5, 125.3, 124.1, 123.6, 121.1, 116.8, 82.2, 81.6, 80.3, 60.3, 46.1, 38.3, 28.3, 28.2.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{29}H_{33}N_3NaO_4$: 510.2363. Found 510.2365.

M.P. 44-46 °C.

***cis*-Di-*tert*-butyl-3a-(quinolin-6-yl)-2,3,3a,8a-tetrahydropyrrolo[2,3-b]indole-1,8-dicarboxylate (16i)**



This compound was prepared according to the general procedure, using *cis*-di-*tert*-butyl-3a-chloro-tetrahydropyrrolo[2,3-b]indole-1,8-dicarboxylate **S4** (0.3 mmol, 118.4 mg, 1 equiv) and 6-iodoquinoline (0.6 mmol, 153.0 mg, 2 equiv), DMF as the solvent. After purification by flash column chromatography (SiO_2: 5% ethyl acetate in petroleum ether), the title compound was isolated in 55% yield (80.0 mg, 0.164 mmol, single isomer) as a colorless oil.

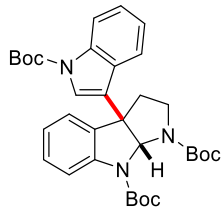
^{1}H NMR (600 MHz, $CDCl_3$): δ 8.85 (br, 1H), 8.05 (m, 2H), 7.70 (br, 1H), 7.62 (m, 2H), 7.35 (m, 1H), 7.25 (m, 1H), 7.16 (d, J = 7.4 Hz, 1H), 7.03 (d, J = 7.4 Hz, 1H), 6.50 (s, 1H), 3.96 (m, 1H), 3.00 (m, 1H), 2.60 (m, 2H), 1.56 (s, 9H), 1.49 (s, 9H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 153.7, 152.2, 150.2, 146.9, 142.4, 141.1, 136.2, 134.6, 129.9, 128.6, 127.9, 127.8, 124.1, 123.8, 123.6, 121.4, 117.1, 82.1, 81.6, 80.3, 60.1, 46.0, 37.4, 28.3, 28.2.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{29}H_{33}N_3NaO_4$: 510.2363. Found 510.2356.

M.P. 200-202 °C.

***cis*-Di-*tert*-butyl-3a-(1-(tert-butoxycarbonyl)-1H-indol-3-yl)-2,3,3a,8a-tetrahydropyrrolo[2,3-b]indole-1,8-dicarboxylate (16j)**



This compound was prepared according to the general procedure, using *cis*-di-*tert*-butyl-3a-chloro-tetrahydropyrrolo[2,3-b]indole- 1,8-dicarboxylate **S4** (0.3 mmol, 118.4 mg, 1 equiv) and tert-butyl 3-iodo-1H-indole-1-carboxylate (0.6 mmol, 205.8 mg, 2 equiv), DMF as the solvent. After purification by flash column chromatography (SiO_2: 5% ethyl acetate in petroleum ether), the title compound was isolated in 52% yield (90.0 mg, 0.156 mmol, single isomer) as a white solid.

^{1}H NMR (600 MHz, $CDCl_3$): δ 8.08 (br, 1H), 7.72 (br, 1H), 7.35 (s, 1H), 7.22 (m, 4H), 7.11 (t, J = 7.3 Hz, 1H), 6.99 (t, J = 7.3 Hz, 1H), 6.50 (s, 1H), 3.99 (m, 1H), 2.96 (m, 1H), 2.67 (m, 1H), 2.34 (m, 1H), 1.62 (s, 9H),

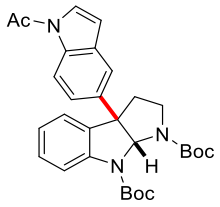
1.52 (s, 9H), 1.48 (s, 9H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 153.8, 152.4, 149.6, 142.6, 136.2, 133.7, 128.7, 128.4, 124.4, 124.0, 123.3, 123.0, 122.7, 119.9, 116.2, 115.5, 83.8, 81.6, 81.0, 80.2, 55.2, 45.6, 37.4, 28.4, 28.3, 28.1.(a carbon not detected).

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{33}H_{41}N_3NaO_6$:598.2888. Found 598.2874.

M.P. 186-188 ºC.

***cis*-Di-*tert*-butyl-3a-(1-acetyl-1H-indol-5-yl)-2,3,3a,8a-tetrahydropyrrolo[2,3-b]indole-1,8-dicarboxylate (16k)**



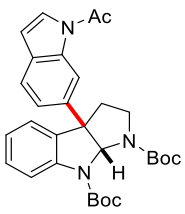
This compound was prepared according to the general procedure, using *cis*-di-*tert*-butyl-3a-chloro-tetrahydropyrrolo[2,3-b]indole-1,8-dicarboxylate **S4** (0.3 mmol, 118.4 mg, 1 equiv) and 1-(5-iodo-1H-indol-1-yl)ethan-1-one (0.6 mmol, 171.0 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 5% ethyl acetate in petroleum ether), the title compound was isolated in 65% yield (101.0 mg, 0.195 mmol, single isomer) as a white solid.

^{1}H NMR (600 MHz, $CDCl_3$): δ 8.34 (d, J = 8.3 Hz, 1H), 7.64 (br, 1H), 7.39 (m, 2H), 7.24 (m, 2H), 7.14 (d, J = 7.3 Hz, 1H), 7.02 (t, J = 7.5 Hz, 1H), 6.54 (d, J = 3.7 Hz, 1H), 6.44 (s, 1H), 3.93 (dd, J = 11.0 Hz, 7.2 Hz, 1H), 2.97 (td, J = 11.0 Hz, 5.5 Hz, 1H), 2.60 (m, 5H), 1.56 (s, 9H), 1.50 (s, 9H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 168.4, 153.9, 152.4, 142.4, 138.7, 135.8, 134.4, 130.6, 128.3, 125.7, 123.8, 123.5, 123.0, 118.0, 117.0, 116.7, 109.1, 82.6, 81.5, 80.1, 60.1, 46.1, 37.2, 28.4, 28.3, 23.8.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{30}H_{35}N_3NaO_5$: 540.2469. Found 540.2461.

M.P. 150-152 ºC.



***cis*-Di-*tert*-butyl 3a-(1-acetyl-1H-indol-6-yl)-2,3,3a,8a-tetrahydropyrrolo[2,3-b] indole-1,8-dicarboxylate (16l)**

This compound was prepared according to the general procedure, using *cis*-di-*tert*-butyl-3a-chloro-tetrahydropyrrolo[2,3-b]indole-1,8-dicarboxylate **S4** (0.3 mmol,

118.4 mg, 1 equiv) and 1-(6-iodo-1H-indol-1-yl)ethan-1-one (0.6 mmol, 171.0 mg, 2 equiv)., DMF as the solvent. After purification by flash column chromatography (SiO_2: 5% ethyl acetate in petroleum ether), the title compound was isolated in 82% yield (127.0 mg, 0.246 mmol, single isomer) as a white solid.

^{1}H NMR (600 MHz, $CDCl_3$): δ 8.49 (s, 1H), 7.63 (br, 1H), 7.43 (d, J = 8.3 Hz, 1H), 7.37 (br, 1H), 7.22 (t, J = 8.0 Hz, 1H), 7.14 (d, J = 6.8 Hz, 1H), 7.06 (d, J = 8.0 Hz, 1H), 7.01 (t, J = 7.2 Hz, 1H), 6.55 (m, 1H), 6.47 (br, 1H), 3.94 (m, 1H), 2.98 (m, 1H), 2.64 (m, 2H), 2.59 (s, 3H), 1.58 (s, 9H), 1.49 (s, 9H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 168.6, 153.8, 152.4, 142.3, 140.5, 136.0, 135.7, 129.2, 128.3, 125.6, 123.8, 123.5, 122.0, 121.0, 117.5, 113.5, 108.7, 82.5, 81.5, 80.1, 60.4, 46.1, 38.9, 28.4, 28.3, 23.9.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{30}H_{35}N_3NaO_5$: 540.2469. 540.2454.

M.P. 150-152 ºC.

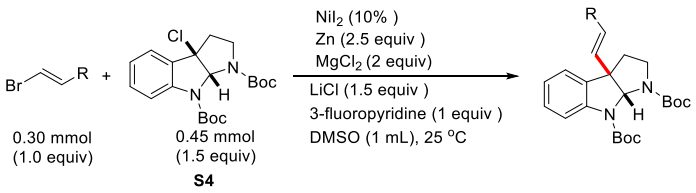
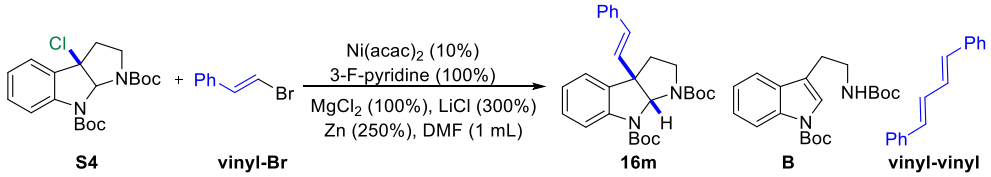


Table S1. Representative conditions for vinylation of the chlorocyclotrypatamine.[a,b]



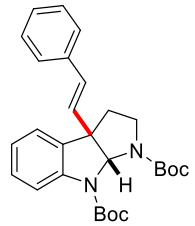
entry	x/y	Ni	$MgCl_2$	LiCl	solvent	yield for **16m**[c]	conversion% from the substrate	
							B[d]	**vinyl-vinyl**[e]
1	1:2	$Ni(acac)_2$	100%	300%	DMA	31%	40%	51%
2	1:2	$Ni(acac)_2$	100%	300%	DMF	42%	17%	41%
3	1.5:1	$Ni(acac)_2$	100%	300%	DMF	67%	40%	9%
4	1.5:1	$Ni(acac)_2$	100%	300%	DMSO	74%	33%	4%
5	1.5:1	$Ni(acac)_2$	200%	150%	DMSO	87%	21%	1%
6	1.5:1	NiI_2	200%	150%	DMSO	93% (76%)[b]	12%	trace

[a] Yield determined by ^{1}H NMR spectroscopy using 2,5-dimethylfuran as an internal standard. [b] Isolated yield. [c] The conversion% is based on the initial amount of limiting reagent used. [d] The conversion% is determined with respect to the initial amount of **S4** used. [e] The conversion% is based on the initial amount of **B** used.

General Procedure for the Coupling of Cyclotryptamine Chloride with Vinyl bromide (GP2). To an oven-dried Schlenk tube was charged with vinyl bromides (0.3 mmol, 1.0 equiv, if solid), **S4** (1.5 equiv), Zn (2.5 equiv),

$Ni(acac)_2$ (10 mol %), $MgCl_2$ (2.0 equiv) and LiCl (1.5 equiv). The tube was capped with a rubber septum, evacuated and back-filled with nitrogen three times, at which point DMSO (1 mL) was added via a syringe prior to the addition of vinyl bromides (if liquid) followed by addition of 3-fluoropyridine via a syringe. The reaction mixture was allowed to stir at 25 °C for 12 h, at which point it was directly loaded onto a silica column without work-up. The residue in the tube was rinsed with a small amount of DCM or eluent. Flash column chromatography provided the target compound.

***cis*-Di-*tert*-butyl 3a-((*E*)-styryl)-2,3,3a,8a-tetrahydropyrrolo[2,3-b]indole-1,8-dicarboxylate (16m)**



This compound was prepared according to the *GP2*, using (E)-(2-bromovinyl) benzene (0.3 mmol, 54.9 mg, 1 equiv) and **S4** (0.45 mmol, 177.7 mg, 1.5 equiv). After purification by flash column chromatography (SiO_2: 3% ethyl acetate in petroleum ether), the title compound was isolated in 76% yield (105 mg, 0.227 mmol, single isomer) as a white solid.

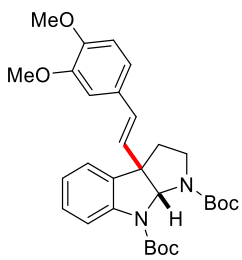
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.63 (br, 1H), 7.27 (m, 5H), 7.19 (t, J = 7.0 Hz, 1H), 7.15 (d, J = 7.3 Hz, 1H), 7.06 (t, J = 7.3 Hz, 1H), 6.39 (d, J = 16.0 Hz, 1H), 6.22 (d, J = 16.0 Hz, 1H), 6.18 (s, 1H), 3.84 (m, 1H), 2.89 (m, 1H), 2.24 (m, 2H), 1.55 (s, 9H), 1.49 (s, 9H).

^{13}C NMR (150 MHz, $CDCl_3$): δ: 153.9, 152.5, 142.9, 136.4, 133.4, 131.4, 130.0, 128.5, 127.6, 126.3, 124.0, 123.3, 116.7, 81.5, 80.9, 80.1, 58.6, 46.1, 37.4, 28.4, 28.3.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for C28H34N2NaO4: 485.2411. Found 485.2406.

M.P. 83-85 °C.

***cis*-Di-*tert*-butyl (3a,8a)-3a-((*E*)-3,4-dimethoxystyryl)- 2,3,3a,8a-tetrahydropyrrolo[2,3-b]indole-1,8-dicarboxylate (16n)**



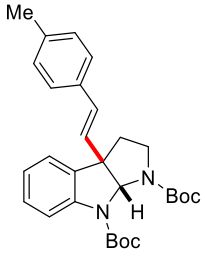
This compound was prepared according to the **GP2**, using E)-4-(2-bromovinyl)-1,2-dimethoxybenzene (0.3 mmol, 73.0 mg, 1 equiv) and **S16** (0.45 mmol, 177.7 mg, 1.5 equiv). After purification by flash column chromatography (SiO_2: 7% ethyl acetate in petroleum ether), the title compound was isolated in 80%

yield. (125.0 mg, 0.240 mmol, single isomer).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.64 (br, 1H), 7.26 (t, J = 7.2 Hz, 1H), 7.18 (m, 1H), 7.07 (t, J = 7.1 Hz, 1H), 6.81 (m, 3H), 6.27 (d, J = 16.0 Hz, 1H), 6.18 (s, 1H), 6.16 (d, J = 16.0 Hz, 1H), 3.87 (s, 3H), 3.85 (s, 3H), 3.84 (m, 1H), 2.89 (m, 1H), 2.24 (m, 2H), 1.55 (s, 9H), 1.44 (s, 9H).

^{13}C NMR (100 MHz,): δ 153.8, 152.5, 148.8, 148.7, 142.9, 133.5, 129.7, 129.4, 128.4, 124.1, 123.3, 119.6, 116.8, 110.8, 108.5, 81.5, 80.9, 80.1, 58.5, 55.8, 55.7, 46.1, 36.9, 28.4, 28.3.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for C30H38N2NaO6: 545.2622. Found 545.2717.



***cis*-Di-*tert*-butyl-3a-((*E*)-4-methylstyryl)-2,3,3a,8a-tetrahydropyrrolo[2,3-b]indole-1,8-dicarboxylate (16o)**

This compound was prepared according to the *GP2*, using ((*E*)-1-(2-bromovinyl)-4-methyl benzene (0.3 mmol, 59.1 mg, 1 equiv) and **S4** (0.45 mmol, 177.7 mg, 1.5 equiv). After purification by flash column chromatography (SiO_2: 3% ethyl acetate in petroleum ether), the title compound was isolated in 79% yield (113 mg, 0.236 mmol, single isomer) as a white solid

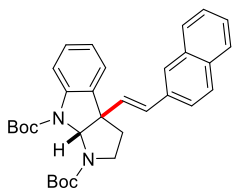
^{1}H NMR (500 MHz, $CDCl_3$): δ 7.66 (br, 1H), 7.26 (t, J = 7.2 Hz, 1H), 7.20 (d, J = 7.8 Hz, 2H), 7.17 (d, J = 7.2 Hz, 1H), 7.09 (m, 3H), 6.36 (d, J = 16.0 Hz, 1H), 6.21 (d, J = 16.0 Hz, 1H), 6.20 (s, 1H), 3.86 (m, 1H), 2.91 (m, 1H), 2.31 (s, 3H), 2.25 (m, 2H), 1.57 (s, 9HJ), 1.51 (s, 9H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 153.9, 152.4, 142.8, 137.3, 133.6, 133.4, 130.3, 129.8, 129.1, 128.4, 126.2, 124.0, 123.3, 116.8, 81.4, 80.9, 80.0, 58.5, 46.0, 37.3, 28.4, 28.2, 21.1.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{29}H_{36}N_2NaO_4$: 499.2567. Found 499.2760.

M.P. 36-38 °C

***cis*-Di-*tert*-butyl-3a-((*E*)-2-(naphthalen-2-yl)vinyl)-2,3,3a,8a-tetrahydropyrrolo[2,3-b]indole-1,8-dicarboxylate (16p)**



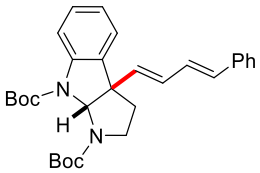
This compound was prepared according to the *GP2*, using (*E*)-2-(2-bromovinyl) naphthalene (0.3 mmol, 69.9 mg, 1 equiv) and **S4** (0.45 mmol, 177.7 mg, 1.5 equiv). After purification by flash column chromatography (SiO_2: 5% ethyl acetate in

petroleum ether), the title compound was isolated in 51% yield (78.0 mg, 0.153 mmol, single isomer) as a white solid

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.77 (m, 3H), 7.71 (br, 1H), 7.65 (s, 1H), 7.55 (m, 1H), 7.44 (m, 2H), 7.30 (t, J = 7.8 Hz, 1H), 7.22 (d, J = 7.3 Hz, 1H), 7.12 (t, J = 7.3 Hz, 1H), 6.55 (d, J = 16.0 Hz, 1H), 6.42 (d, J = 16.0 Hz, 1H), 6.27 (s, 1H), 3.90 (m, 1H), 2.95 (m, 1H), 2.30 (m, 2H), 1.59 (s, 9H), 1.53 (s, 9H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 153.9, 152.5, 142.9, 133.9, 133.4, 133.2, 132.9, 131.7, 130.2, 128.5, 128.1, 127.9, 127.6, 126.4, 126.2, 125.8, 124.1, 123.4, 123.3, 116.8, 81.5, 81.0, 80.2, 58.7, 46.1, 37.0, 28.4, 28.3.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{32}H_{36}N_2NaO_4$: 535.2567. Found 535.2559.



***cis*-Di-*tert*-butyl-3a-((*1E,3E*)-4-phenylbuta-1,3-dien-1-yl)-2,3,3a,8a-tetrahydropyrrolo[2,3-b] indole-1,8-dicarboxylate (16q)**

This compound was prepared according to the *GP2*, using ((1*E*,3*E*)-4-bromobuta-1,3-dien-1-yl)benzene (0.3 mmol, 62.7 mg, 1 equiv) and **S4** (0.45 mmol, 177.7 mg, 1.5 equiv) and DMAP (1 equiv) instead of 3-fluoropyridine. After purification by flash column chromatography (SiO_2: 3% ethyl acetate in petroleum ether), the title compound was isolated in 61% yield (89.0 mg, 0.183 mmol, single isomer) as a white solid

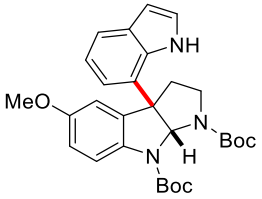
^{1}H NMR (500 MHz, $CDCl_3$): δ 7.64 (br, 1H), 7.34 (d, J = 7.5 Hz, 2H), 7.29 (t, J = 7.8 Hz, 2H), 7.26 (t, J = 7.8 Hz, 1H), 7.21 (t, J = 7.3 Hz, 1H), 7.14 (d, J = 7.3 Hz, 1H), 7.08 (t, J = 7.3 Hz, 1H), 6.73 (m, 1H), 6.44 (d, J = 15.6 Hz, 1H), 6.13 (s, 1H), 6.05 (m, 1H), 6.00 (d, J = 15.6 Hz, 1H), 3.83 (m, 1H), 2.89 (m, 1H), 2.20 (m, 2H), 1.56 (s, 9H), 1.49 (s, 9H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 153.9, 152.5, 142.8, 137.1, 135.5, 133.6, 132.6, 130.5, 128.6, 128.4, 128.1, 127.5, 126.3, 124.0, 123.4, 116.9, 81.5, 81.0, 80.2, 58.6, 46.1, 35.9, 28.4, 28.3.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{30}H_{36}N_2O_4$: 511.2567. Found 511.2566.

M.P. 37-39 ºC.

***cis*-Di-tert-butyl-3a-(1H-indol-7-yl)-5-methoxy-2,3,3a,8a-tetrahydropyrrolo[2,3-b] indole-1,8-dicarboxylate (17a)**



This compound was prepared according to the general procedure, using cis-di-*tert*-butyl-3a-chloro-5-methoxy-2,3,3a,8a-tetrahydropyrrolo [2,3-b]indole-1,8-dicarboxylate[6] (0.3 mmol, 127.5 mg, 1 equiv) and 7-iodo-1H-indole (0.6 mmol, 145.8 mg, 2 equiv). After purification by preparation TLC (SiO2: 20% ethyl acetate in petroleum ether), the title compound was isolated in 60% yield (91.0 mg, 0.180 mmol, single isomer) as a white solid.

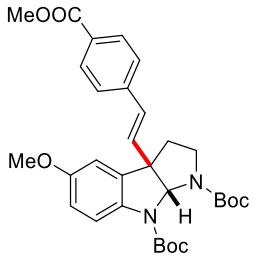
^{1}H NMR (500 MHz, $CDCl_3$): δ 8.37 (br, 1H), 7.66 (br, 1H), 7.57 (d, J = 7.7 Hz, 1H), 7.22 (d, J = 7.5 Hz, 1H), 7.09 (m, 2H), 6.81 (dd, J = 8.9 Hz, 2.1 Hz, 1H), 6.73 (d, J = 2.1 Hz, 1H), 6.68 (br, 1 H), 6.52 (br, 1H), 4.02 (m, 1H), 3.73 (s, 3H), 2.98 (m, 1H), 2.75 (m, 1H), 2.42 (m, 1H), 1.55 (s, 9 H), 1.50 (s, 9H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 156.3, 154.2, 152.7, 135.7, 135.1, 133.2, 129.4, 125.5, 124.6, 120.4, 119.6, 119.5, 116.6, 113.7, 110.7, 102.8, 81.9, 80.7, 80.6, 59.1, 55.6, 45.9, 38.6, 28.3 28.3.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{29}H_{35}N_3NaO_5$: 528.2469. Found 528.2465.

M.P. 228-230 ºC.

***cis*-Di-*tert*-butyl -3a-((*1E,3E*)-4-phenylbuta-1,3-dien-1-yl)-2,3,3a,8a-tetrahydropyrrolo[2,3-b] indole-1,8-dicarboxylate (17b)**



This compound was prepared according to the *GP2*, using methyl (E)-4-(2-bromovinyl) benzoate (0.3 mmol, 72.3 mg, 1 equiv) and *cis*-di-*tert*-butyl cis-(8aR)-3a-chloro-5-methoxy-2,3,3a,8a-tetrahydropyrrolo[2,3-b]indole-1,8-dicarboxylate (0.45 mmol, 191.2 mg, 1.5 equiv), DMAP (0.3 mmol, 36.6 mg, 1 equiv) instead of 3-fluoropyridine, DMSO as the solvent. After purification by flash column chromatography (SiO_2: 8% ethyl acetate in petroleum ether), the title compound was isolated in 57% yield (94.0 mg, 0.170 mmol, single isomer) as a white solid.

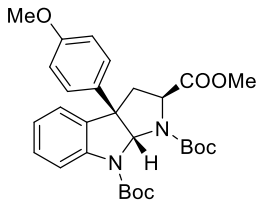
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.94 (d, J = 8.3 Hz, 2H), 7.47 (br, 1H), 7.35 (d, J = 8.3 Hz, 2H), 6.80 (dd, J = 8.8, 2.7 Hz, 1H), 6.70 (d, J = 2.7 Hz, 1H), 6.50 (d, J = 16.0 Hz, 1H), 6.28 (d, J = 16.0 Hz, 1H), 6.17 (s, 1H), 3.88 (s, 3H), 3.84 (m, 1H), 3.79 (s, 3H), 2.93 (m, 1H), 2.23 (m, 2H), 1.53 (s, 9 H), 1.48 (s, 9H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 166.7, 156.2, 153.8, 152.5, 140.9, 136.5, 134.6, 133.7, 129.8, 129.3, 129.0, 126.3, 118.2, 113.2, 110.0, 81.3, 81.0, 80.2, 58.8, 55.6, 52.0, 45.9, 37.3, 28.4, 28.3.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{31}H_{38}N_2NaO_7$: 573.2571. Found 573.2549.

M.P. 135-138 ºC.

1,8-Di-*tert*-butyl 2-methyl (*2S,3aR,8aR*)-3a-(4-methoxyphenyl)-2,3,3a,8a-tetrahydropyrrolo [2,3-b]indole-1,2,8-tricarboxylate (18)



This compound was prepared according to the general procedure, using 1,8-di-tert-butyl 2-methyl (*2S,3aR,8aR*)-3a-chloro-2,3,3a,8a-tetrahydropyrrolo[2,3-b]indole-1,2,8-tricarboxylate **S5** (0.3 mmol, 1 equiv) and 1-iodo-4-methoxybenzene (2 equiv), $Ni(acac)_2$ (5 mol %), dttbpy (6 mol %), pyridine (1 equiv) and $MgCl_2$ (1 equiv), H_2O (5 μL, **important**) and DMA as the solvent. **Note: without H_2O, only trace amount of product was obtained**. After purification by flash column chromatography (SiO_2: 2% ethyl acetate in petroleum ether), the title compound in 75% yield (118.0 mg, single isomer) as a white solid.

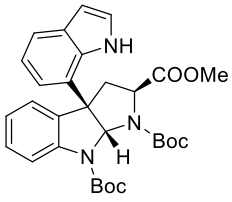
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.48 (br, 1H), 7.25 (m, 1H), 7.18 (d, J = 7.7 Hz, 1H), 7.08 (m, 3H), 6.79 (d, J = 7.8 Hz, 2H), 6.35 (br, 1H), 3.99 (m, 1H), 3.74 (s, 6H), 2.91 (m, 1H), 2.61 (m, 1H), 1.53 (s, 9H), 1.43 (s, 9H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 172.9, 158.7, 153.9, 152.4, 141.7, 135.9, 128.6, 126.8, 124.0, 123.4, 123.3, 118.9, 114.1, 82.5, 81.6, 81.1, 59.7, 58.9, 55.2, 52.2, 38.8, 28.3, 28.2.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for C29H36N2NaO7: 547.2415. Found 547.2422.

M.P. 44-46 ºC.

1,8-Di-*tert*-butyl 2-methyl (*2S,3aR,8aR*)-3a-(1H-indol-7-yl)-2,3,3a,8a-tetrahydropyrrolo [2,3-b]indole-1,2,8-tricarboxylate (19)



This compound was prepared according to the general procedure, using 1,8-di-tert-butyl 2-methyl (*2S,3aR,8aR*)-3a-chloro-2,3,3a,8a-tetrahydropyrrolo[2,3-b]indole-1,2,8-tricarboxylate **S5** (0.3 mmol, 136.0 mg, 1 equiv) and 7-iodo-1H-indole (0.6 mmol, 146.0 mg, 2 equiv), $Ni(acac)_2$ (20%), 3-Fluoropyridine

(1 equiv) and $MgCl_2$ (1 equiv) and LiCl (3 equiv), DMF as the solvent. After purification by flash column chromatographyy (SiO_2: 5% ethyl acetate in petroleum ether), the title compound was isolated in 40% yield (64.0 mg, 0.120 mmol, single isomer) as a white solid.

^{1}H NMR (600 MHz, $CDCl_3$): δ 9.25 (br, 1H), 7.63 (br, 1H), 7.55 (d, J = 7.7 Hz, 1H), 7.37 (m, 2H), 7.30 (br, 1H), 7.21 (t, 7.4 Hz, 1H), 6.94 (t, J = 7.7 Hz, 1H), 6.69 (m, 2H), 6.58 (s, 1H), 4.27 (t, J = 8.3 Hz, 1H), 3.82 (s, 3H), 2.96 (d, J = 8.3 Hz, 2H), 1.46 (s, 9H), 1.41 (s, 9H).

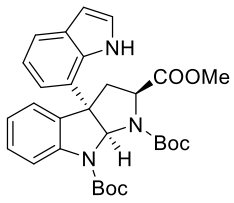
^{13}C NMR (150 MHz, $CDCl_3$): δ 175.5, 153.6, 152.5, 141.8, 134.5, 132.4, 129.4, 128.9, 125.3, 124.9, 123.9, 123.7, 121.0, 120.7, 119.3, 118.5, 102.8, 81.9, 81.4, 81.2, 59.8, 58.3, 52.6, 39.3, 28.2, 28.1.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{30}H_{35}N_3NaO_6$: 556.2418. Found 556.2402.

M.p. 70-72 ºC

$[\alpha]_D^{22}$ = 82.6 (c = 1.10, $CHCl_3$).

1,8-Di-*tert*-butyl 2-methyl (*2S,3aS,8aS*)-3a-(1H-indol-7-yl)-2,3,3a,8a-tetrahydropyrrolo [2,3-b]indole-1,2,8-tricarboxylate (20)



This compound was prepared according to the general procedure, using 1,8-di-tert-butyl 2-methyl (*2S,3aS,8aS*)-3a-chloro-2,3,3a,8a-tetrahydropyrrolo[2,3-b]indole-1,2,8-tricarboxylate **S1** (0.3 mmol, 136.0 mg 1 equiv) and 7-iodo-1H-indole ((0.6 mmol, 146.0 mg, 2 equiv), $Ni(acac)_2$ (20%), 3-Fluoropyridine (1 equiv) and $MgCl_2$ (1 equiv) and LiCl (3 equiv), DMF as the solvent. After purification by flash column chromatographyy (SiO_2: 5% ethyl acetate in petroleum ether), the title compound was isolated in 60% yield (96.0 mg, 0.180 mmol, single isomer) as a white solid.

^{1}H NMR (600 MHz, $CDCl_3$): δ 8.48 (br, 1H), 7.69 (br, 1H), 7.57 (d, J = 7.7 Hz, 1H), 7.24 (t, J = 7.8 Hz, 1H), 7.17 (t, J = 7.8 Hz, 2H), 7.10 (m, 2H), 6.98 (t, J = 7.0 Hz, 1H), 6.76 (s, 1H), 6.52 (s, 1H), 4.83 (m, 1H), 3.26 (s, 3H), 3.17 (m, 1H), 3.11 (m, 1H), 1.59 (s, 9H), 1.47 (s, 9H).

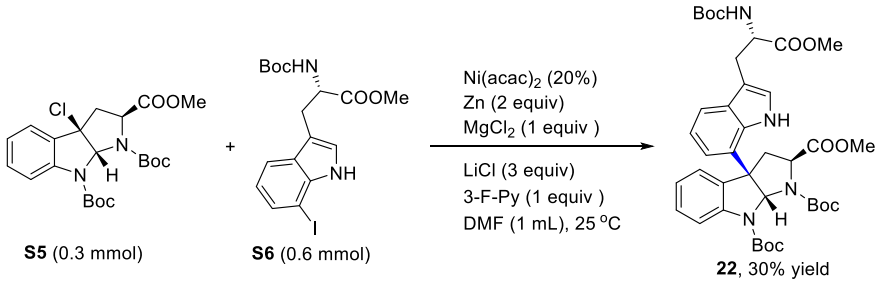
^{13}C NMR (150 MHz, $CDCl_3$): δ 171.5, 153.4, 152.9, 142.1, 133.6, 132.6, 129.5, 129.1, 124.8, 12.7, 124.6, 123.5, 120.5, 119.8, 119.6, 116.7, 102.7, 82.3, 81.2, 81.1, 59.8, 58.2, 52.1, 40.9, 28.3, 28.2.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{30}H_{35}N_3NaO_6$: 556.2418. Found 556.2402.

M.p. 158-160 °C.

$[\alpha]_D^{22}$ = 78.0 (c = 0.87, $CHCl_3$).

1,8-Di-*tert*-butyl 2-methyl (2S,3aS,8aS)-3a-(3-((*R*)-2-((tert-butoxycarbonyl)amino)-3-methoxy-3-oxopropyl)-1H-indol-7-yl)-2,3,3a,8a-tetrahydropyrrolo[2,3-b]indole-1,2,8-tricarboxylate (21)



S5 (0.3 mmol) **S6** (0.6 mmol) **22**, 30% yield

This compound was prepared according to the general procedure, using **S5**[7] (0.3 mmol, 136.0 mg, 1 equiv) and **S6**[8] (0.6 mmol, 266.0 mg, 2 equiv), $Ni(acac)_2$ (20 mol %), 3-fluoropyridine (1 equiv), $MgCl_2$ (1 equiv), LiCl (3 equiv), and DMF (1 mL) as the solvent. Column chromatography (SiO_2: 10% to 30% ethyl acetate in petroleum ether) provided the title compound in 30% yield (66.0 mg, 0.090 mmol, single isomer) as a white solid.

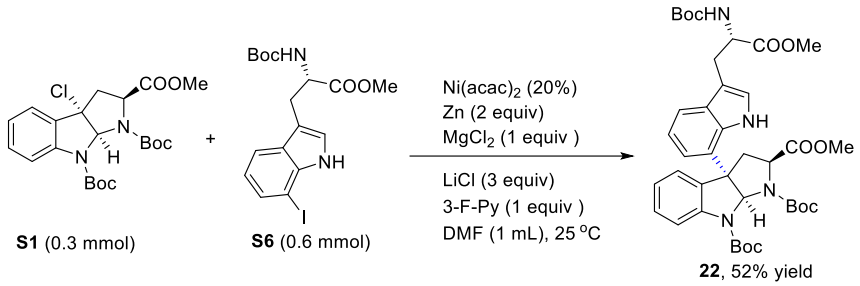
^{1}H NMR (600 MHz, $CDCl_3$): δ 9.16 (s, 1H), 7.59 (br, 1H), 7.45 (d, J = 7.6 Hz, 1H), 7.36 (m, 2H), 7.20 (t, J = 6.85 Hz, 1H), 7.07 (s, 1H), 6.93 (t, J = 7.6 Hz, 1H), 6.67 (m, 1H), 6.64 (s, 1H), 5.07 (m, 1H), 4.64 (m, 1H), 4.24 (m, 1H), 3.82 (s, 3H), 3.68 (s, 3H), 3.28 (m, 2H), 2.94 (m, 2H), 1.43 (m, 27H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 175.6, 175.5, 172.7, 155.2, 152.5, 141.8, 134.4, 132.7, 129.9, 129.8, 129.2, 129.0, 125.3, 123.8, 123.5, 121.3, 119.2, 118.8, 110.3, 81.9, 81.4, 81.2, 79.8, 59.8, 58.3, 55.2, 54.0, 52.7, 52.2, 39.1, 28.3, 28.2, 28.1.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{39}H_{50}N_4NaO_{10}$: 757.3419. Found 757.3411.

$[\alpha]_D^{22}$ = 57.5 (c = 0.80, $CHCl_3$).

1,8-Di-*tert*-butyl 2-methyl (2S,3aS,8aS)-3a-(3-((*R*)-2-((tert-butoxycarbonyl)amino)-3-methoxy-3-oxopropyl)-1H-indol-7-yl)-2,3,3a,8a-tetrahydropyrrolo[2,3-b]indole-1,2,8-tricarboxylate (22)



This compound was prepared according to the general procedure, using **S1** (0.3 mmol, 136.0 mg, 1 equiv) and **S6**[8] (0.6 mmol, 266.0 mg, 2 equiv), $Ni(acac)_2$ (20 mol %), 3-fluoropyridine (1 equiv) and $MgCl_2$ (1 equiv) and LiCl (3 equiv), and DMF (1 mL) as the solvent. Column chromatography (SiO_2: 10% to 30% ethyl acetate in petroleum ether) provided the title compound in 52% yield (115.0 mg, 0.156 mmol, single isomer) as a white solid.

^{1}H NMR (600 MHz, $CDCl_3$): δ 8.41 (br, 1H), 7.67 (s, 1H), 7.46 (d, J = 7.6 Hz, 1H), 7.23 (t, J = 7.6 Hz, 1H), 7.17 (m, 2H), 7.09 (t, J = 7.6 Hz, 1H), 6.98 (t, J = 7.0 Hz, 1H), 6.88 (s, 1H), 6.74 (s, 1H), 5.02 (m, 1H), 4.81 (m, 1H), 4.60 (m, 1H), 3.65 (s, 3H), 3.24 (s, 3H), 3.23 (m, 2H), 3.12 (m, 2H), 1.59 (s, 9H), 1.46 (s, 9H), 1.41 (s, 9H).

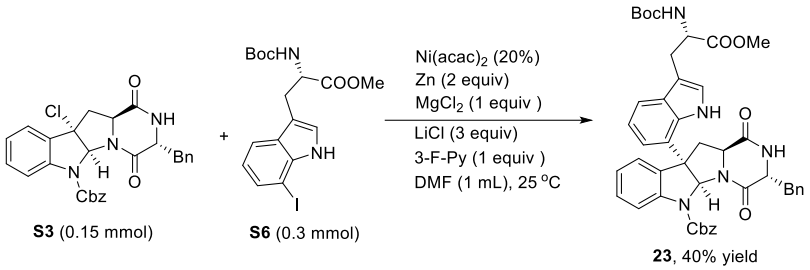
^{13}C NMR (150 MHz, $CDCl_3$): δ 172.6, 171.5, 155.2, 153.4, 153.0, 142.0, 132.9, 129.8, 129.3, 129.1, 124.9, 124.7, 123.5, 123.3, 119.8, 119.6, 118.5, 116.7, 110.2, 82.4, 81.3, 80.9, 79.8, 59.8, 58.1, 54.9, 53.9, 52.2, 52.1, 41.0, 28.3, 28.3, 28.3.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{39}H_{50}N_4NaO_{10}$: 757.3419. Found 757.3399.

M.P. 48-50 ºC.

$[\alpha]_D^{22}$ = 44.5 (c = 1.30, $CHCl_3$).

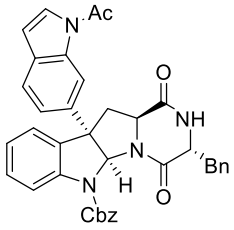
Benzyl (*3R,5aS,10bS,11aS*)-3-benzyl-10b-(3-((*S*)-2-((tert-butoxycarbonyl)amino)-3-methoxy-3-oxopropyl)-1H-indol-7-yl)-1,4-dioxo-1,2,3,4,5a,10b,11,11a-octahydro-6H-pyrazino[1',2':1,5]pyrrolo[2,3-b]indole-6-carboxylate (23)[4]



This compound was prepared according to the general procedure, using **S3** (0.15 mmol, 75.3 mg, 1 equiv) and **S6** (0.3 mmol, 266 mg, 2 equiv), $Ni(acac)_2$ (20 mol %), 3-fluoropyridine (1 equiv), $MgCl_2$ (1 equiv), LiCl (3 equiv), and DMF (1 mL) as the solvent. Flash chromatograph followed by preparation TLC provided the title compound in ~13% yield as white solid which contaminated with ~20% inseparable **S2**. Further purification was carried out using preparation HPLC following a method described in the literature.[4]

^{1}H NMR (400 MHz, Acetone-d6): δ 10.04 (s, 1H), 7.78 (d, *J* = 8.0 Hz, 1H), 7.58 (d, *J* = 7.4 Hz, 1H), 7.51 (m, 3H), 7.36 (m, 3H), 7.24 (m, 7H), 7.20 (m, 1H), 7.05 (t, *J* = 7.5 Hz, 1H), 6.90 (t, *J* = 7.7 Hz, 1H), 6.68 (d, *J* = 7.4 Hz, 1H), 6.60 (s, 1H), 6.11 (d, *J* = 8.1 Hz, 1H), 5.31 (s, 2H), 4.47 (dd, *J* = 13.4, 8.0 Hz, 1H), 4.15 (m, 1H), 4.00 (m, 1H), 3.63 (s, 3H), 3.44 (dd, *J* = 13.7, 5.4 Hz, 1H), 3.26 (dd, *J* = 14.7, 5.2 Hz, 1H), 3.11 (m, 4H), 1.34 (s, 9H).

^{13}C NMR (101 MHz, Acetone-d6) δ : 173.60, 168.89, 167.58, 156.30, 153.50, 140.91, 137.72, 137.61, 136.92, 133.59, 130.72, 130.45, 129.70, 129.48, 129.42, 129.20, 128.99, 127.90, 126.17, 125.79, 124.99, 124.56, 120.42, 120.07, 119.45, 117.12, 112.02, 82.81, 79.42, 68.33, 60.34, 57.62, 56.76, 55.45, 52.33, 39.65, 34.83, 28.61, 28.26.



Benzyl (*3R,5aS,10bS*)-10b-(1-acetyl-1H-indol-6-yl)-3-benzyl-1,4-dioxo-1,2,3,4,5a,10b,11,11a-octahydro-6H-pyrazino[1',2':1,5]pyrrolo[2,3-b]indole-6-carboxylate (24)

This compound was prepared according to the general procedure, using **S3** (0.15 mmol, 75.3 mg, 1 equiv) and 1-(6-iodo-1H-indol-1-yl)ethan-1-one (0.30 mmol, 85.5 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 10% to 30% ethyl acetate in petroleum ether), the isolated mixture was further purified by preparation TLC to provide the title compound in 40% yield (38.0 mg, 0.060 mmol, single isomer) as a white solid.

^{1}H NMR (500 MHz, $CDCl_3$): δ 8.27 (br, 1H), 7.75 (m, 1H), 7.47 (d, J = 6.8 Hz, 2H), 7.41 (m, 2H), 7.35 (m, 4H), 7.28 (m, 2H), 7.25 (m, 2H), 7.17 (d, J = 6.8 Hz, 2H), 7.08 (t, J = 7.3 Hz, 1H), 6.85 (m, 1H), 6.57 (m, 1H),

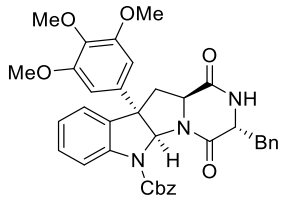
6.21 (s, 1H), 6.09 (s, 1H), 5.37 (m, 2H), 4.11 (br, 1H), 3.21 (m, 2H), 3.05 (m, 2H), 2.87 (m, 1H), 2.59 (s, 3H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 168.5, 165.7, 153.0, 139.9, 139.4, 136.2, 136.0, 135.8, 135.3, 129.9, 129.8, 129.5, 128.9, 128.8, 128.5, 128.4, 128.1, 127.8, 126.0, 125.0, 124.3, 121.6, 121.1, 116.6, 114.2, 108.6, 84.1, 68.1, 59.3, 57.4, 55.5, 40.1, 39.0, 23.9.

HRMS (ESI) m/z ($[M+Na]^+$) calcd for $C_{38}H_{32}N_4NaO_5$: 647.2265. Found 647.2254.

M.P. 66-68 °C.

Benzyl (*3R,5aS,10bS,11aS*)-3-benzyl-1,4-dioxo-10b-(3,4,5-trimethoxyphenyl)-1,2,3,4,5a,10b,11,11a-octahydro-6H-pyrazino[1',2':1,5]pyrrolo[2,3-b]indole-6-carboxylate (25)

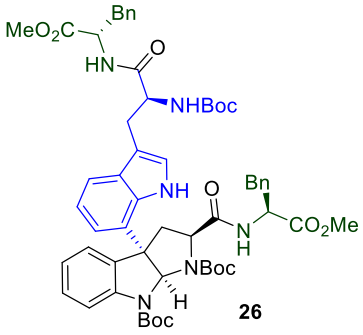


This compound was prepared according to the general procedure, using **S3** (0.15 mmol, 75.3 mg, 1 equiv) and 5-iodo-1,2,3-trimethoxybenzene (0.30 mmol, 88.2 mg, 2 equiv). Flash column chromatography (SiO_2: 10% to 30% ethyl acetate in petroleum ether), the isolated mixture was further purified by preparation TLC to provide the title compound in 40% yield (38.0 mg, 0.060 mmol, single isomer) as a white solid.

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.68 (br, 1H), 7.39 (m, 2H), 7.31 (m, 3H), 7.14 (m, 7H), 6.99 (m, 1H), 6.26 (s, 1H), 6.10 (s, 2H), 5.94 (s, 1H), 5.32 (m, 2H), 4.06 (s, 1H), 3.71 (s, 3H), 3.59 (s, 6H), 3.15 (m, 1H), 2.93 (m, 3H), 2.67 (br, 1H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 168.5, 165.7, 153.3, 152.9, 139.7, 138.0, 137.1, 136.1, 135.9, 135.3, 130.0, 128.9, 128.8, 128.5, 128.4, 127.5, 124.6, 124.3, 116.6, 106.0, 102.8, 83.4, 68.2, 60.8, 59.1, 56.9, 55.9, 55.3, 40.1, 38.3.

HRMS (ESI) m/z ($[M+Na]^+$) calcd $C_{37}H_{35}N_3NaO_7$: 656.2367. Found 656.2354.



26

Di-tert-butyl (*2S,3aS,8aS*)-3a-(3-((*S*)-2-((tert-butoxycarbonyl)amino)-3-(((*S*)-1-methoxy-1-oxo-3-phenylpropan-2-yl)amino)-3-oxopropyl)-1H-indol-7-yl)-2-(((S)-1-methoxy-1-oxo-3-phenylpropan-2-yl)carbamoyl)-2,3,3a,8a-tetrahydropyrrolo[2,3-b]

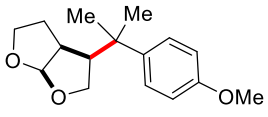
indole-1,8-dicarboxylate (26)[9]

A solution of **22** (120mg, 0.16mmol) was heated under reflux in THF (5 ml), methanol (5 mL), NaOH (1N, 2.5 mL) and water (2 mL) for 5 h, at which point the reaction mixture was allowed to cool to room temperature. The solution was carefully acidified to pH 4~5 with 1N HCl solution. The solution was extracted with ethyl acetate (6*30ml), and the combined organic layers were washed with brine, dried ($MgSO_4$), filtered, and concentrated to give the corresponding crude diacid product, which was used without purification; HATU (380mg, 1mmol) was added to a solution of the crude diacid product, (D)-PheOMe HCl salt (150mg, 0.7 mmol), Et_3N (0.42ml, 3 mmol) and CH_2Cl_2 at RT. After stirring for 6h, the mixture was poured into a solution of saturated aqueous $NaHCO_3$ (120 mL) and NaOH (1N, 4 mL) and extracted with ethyl acetate (4*50ml). The combined organic extracts were washed with a solution of saturated aqueous NH_4Cl (100ml) and 1N HCl (5ml). The acidic aqueous layer was extracted with ethyl acetate (2*50ml), the combined organic layers were dried ($MgSO_4$), filtered, and concentrated. The crude residue was purified by preparative TLC (EA/PE=5:3) to give 142 mg (85% yield) of dipeptide **26** as a yellow solid.

^{1}H NMR (600 MHz, $CDCl_3$): δ 8.16 (br, 1H), 7.55 (d, J = 7.6 Hz, 1H), 7.46 (d, J = 8.0 Hz, 1H), 7.24-7.03 (m, 12H), 6.94-6.79 (m, 5H), 6.74 (s, 1H), 6.24 (d, J = 7.8 Hz, 1H), 5.04 (br, 1H), 4.79 (m, 1H), 4.74 (br, 1H), 4.39 (br, 1H), 4.12 (m, 1H), 3.67 (s, 3H), 3.59 (s, 3H), 3.21-3.10 (m, 3H), 3.05-2.99 (m, 2H), 2.93-2.89 (m, 2H), 2.71 (br, 1H), 1.52 (s, 9H), 1.44 (s, 9H), 1.39 (s, 9H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 171.3, 171.2, 170.6, 170.0, 154.7, 152.4, 141.0, 135.9, 135.4, 133.02, 133.0, 129.3, 129.0, 128.8, 128.5, 128.3, 127.0, 126.8, 125.4, 124.8, 123.7, 123.5, 120.1, 119.8, 118.7, 116.1, 111.0, 82.5, 82.4, 82.1, 80.1, 62.7, 58.1, 54.9, 53.5, 52.9, 52.14, 52.12, 40.6, 38.1, 37.6, 29.7, 28.1.

3-(2-(4-Methoxyphenyl)propan-2-yl) hexahydrofuro[2,3-b]furan (28-H)



This compound was prepared according to the general procedure, using *trans*-3-Bromo-2-((3-methylbut-2-en-1-yl)oxy)tetrahydrofuran **27-H**[7] (0.30 mmol, 70.5 mg, 1 equiv) and 4-iodoanisole (0.60 mmol, 140.4 mg, 2 equiv). After purification by flash column chromatography (SiO_2: 5% to 10% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 40% yield (32.0 mg, 0.121 mmol, R:I = 10:1) as a colorless

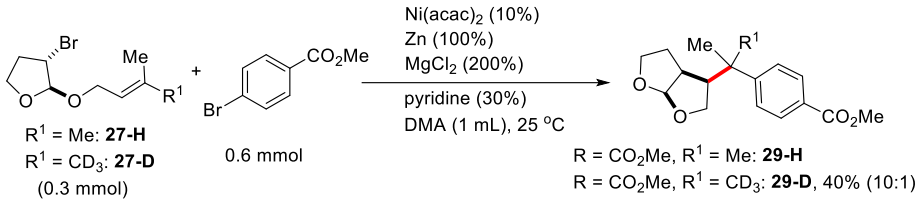
liquid.

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.25 (d. J = 8.8 Hz, 2H), 6.85 (d, J = 8.8 Hz, 2H), 5.56 (m, 1H), 3.94 (m, 1H), 3.82 (m, 2H), 3.80 (s, 3H), 3.65 (m, 1H), 2.53 (m, 2H), 1.70 (m, 1H), 1.59 (m, 1H), 1.41 (s, 6H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 157.7, 140.1, 127.0, 113.4, 109.5, 69.8, 67.4, 55.2, 53.7, 45.5, 37.1, 29.2, 27.6, 25.1.

HRMS (ESI) m/z ($[M+Na]^+$) calcd $C_{16}H_{22}NaO_3$: 285.1461. Found 285.1466.

3-(2-(4-Methoxyphenyl)propan-2-yl) hexahydrofuro[2,3-b]furan (29-D)



R^1 = Me: **27-H**
R^1 = CD_3: **27-D**
(0.3 mmol)

0.6 mmol

R = CO_2Me, R^1 = Me: **29-H**
R = CO_2Me, R^1 = CD_3: **29-D**, 40% (10:1)

Following a previously reported procedure for the preparation of **29-H** (with characteristic germinal methyl peaks at 1.446 and 1.452 ppm as two singlets),[7] this compound was prepared using **27**-D[10] (0.30 mmol, 71.4 mg, 1 equiv) and methyl 4-bromobenzate (0.60 mmol, 129.0 mg, 2 equiv), $Ni(acac)_2$ (0.03 mmol, 7.8 mg, 10 mol %), pyridine (0.09 mmol, 7.1 mg, 30 mol %), MgCl2 (0.3 mmol, 28.6 mg, 1 equiv), Zn (0.6 mmol, 39.2 mg, 2 equiv), DMA (1 mL). After purification by flash column chromatography (SiO_2: 5% to 10% ethyl acetate in petroleum ether), the title compound along with its isomers was isolated in 50% yield (44 mg, 0.150 mmol, R:I = 10:1) as a colorless liquid.

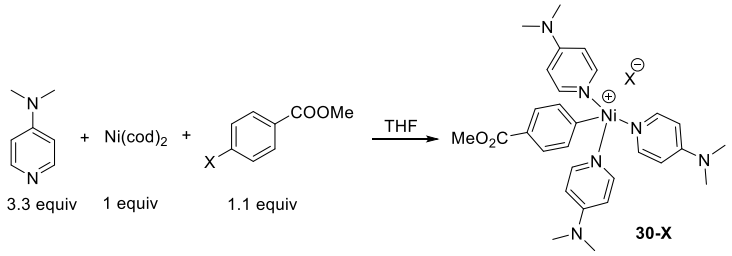
^{1}H NMR (600 MHz, $CDCl_3$): δ 7.99 (d, J = 7.8 Hz, 2H), 7.42 (d, J = 7.8 Hz, 2H), 5.56 (m, 1H), 3.94 (m, 1H), 3.91 (s, 3H), 3.83 (m, 2H), 3.65 (m, 1H), 2.52 (m, 2H), 1.69 (m, 1H), 1.57 (m, 1H), 1.46 (s, 1.5 H), 1.45 (s, 1.5H).

^{13}C NMR (150 MHz, $CDCl_3$): δ 166.9, 153.4, 129.5, 128.0, 126.0, 109.4, 69.7, 67.2, 53.2, 52.1, 45.4, 37.9, 29.1, 26.9, 25.2.

HRMS (ESI) m/z ($[M+Na]^+$) calcd $C_{17}H_{19}D_3NaO_4$: 316.1599. Found 316.1591.

Part 4. Mechanistic Investigation

(1) Preparation of complexes **30-X** (X = I, Br, Cl)



Preparation of complex **30-I**: In a glove box, a suspension of $Ni(cod)_2$ (330.4 mg, 1.20 mmol, 100 mol %) in 8 mL of dry THF was stirred for 1 minute in a 50 mL of flame-dried Schlenk tube, at which point a solution of DMAP (483.1 mg, 1.20 mmol, 330 mol %) in 8 mL of dry THF was added dropwise. The resulting mixture was allowed to stir for 2 hours at ambient temperature. A solution of methyl 4-iodobenzoate (314.4 mg, 1.20 mmol, 100 mol %) in 4 mL of dry THF was added via syringe. The resultant mixture was allowed to stir for 2 hours. Excess pentane was added, and the residue was filtered with a fritted funnel, After filtration, and dried in vacuum, the title compound was obtained in 85% yield (736.4 mg, 1.02 mmol), which was stored in the glove box at -30 °C.

^{1}H NMR (600 MHz, DMSO) δ = 8.38 (d, *J* = 6.2 Hz, 4H), 8.32 – 8.07 (s, br, 2H), 7.77 (d, *J* = 7.7 Hz, 2H), 7.25 (d, *J* = 7.9 Hz, 2H),6.64 – 6.38 (s, br, 2H), 6.47 (d, *J* = 6.6 Hz, 4H), 3.67 (s, 3H), 2.84 (br, 18H).

^{13}C NMR (151 MHz, DMSO) δ 170.2, 168.1, 154.8 (br), 154.5, 150.0, 148.8 (br), 135.9, 125.5, 124.5, 108.4, 108.2 (br), 52.3, 39.5.

Elementary Analysis: calculated for $C_{29}H_{37}IN_6NiO_2$: 50.68% C, 5.43% H; 12.23% N. Found: 50.29% C; 5.52% H; 12.27% N.

Preparation of **30-Br**: In a glove box, a suspension of $Ni(cod)_2$ (137.5 mg, 0.5 mmol, 1 equiv) in 5 mL of dry THF was added a solution of DMAP (201.0 mg, 1.65 mmol, 3.3 equiv) in 5 mL of THF. The mixture was stirred at room temperature, at which point, the color of the solution changed from yellow to brown. Upon the completion of the addition of DMAP, the mixture was stirred for 1h before the addition of a solution of methyl 4-bormobenzoate (118.0 mg, 0.55 mmol, 1.1 equiv) in 3 mL of THF. *Note: the addition of methyl 4-bromobenzoate solution should be dropwise.* The reaction mixture was stirred overnight before addition of

50 mL of dry *n*-pentane. The mixture was then filtered with a fritted funnel, and washed with *n*-pentane, dried in vacuum to provide **30-Br** in 78% yield (250.0 mg, 0.390 mmol) as a green solid, which was stored in glove box at -30 °C.

^{1}H NMR (500 MHz, DMSO-d6): δ 8.36 (d, J = 6.2 Hz, 4H), 8.12 (br, 2H), 7.71 (d, J = 7.5 Hz, 2H), 7.26 (d, J = 7.5 Hz, 2H), 6.56 (br, 2H), 6.51 (d, J = 6.2 Hz, 4H), 3.70 (s, 3H), 2.91 (s, 6H), 2.89 (s, 12H).

^{13}C NMR (125 MHz, DMSO-d6): δ 167.7, 154.1, 149.6, 135.5, 125.1, 124.1, 108.0, 51.9, 39.1. (Note: the three peaks of trans-pyridine with respect to the Ar group which correspond to the broad peaks in **30-I** cannot be found due to a low concentration of the sample was used. At higher concentration, dimerization of the aryl groups and decomposition of **30-Br** proceeds more rapidly in DMSO-d6).

HRMS (ESI) m/z ([M-Br]$^+$) calcd $C_{29}H_{37}N_6NiO_2$: 559.2326. Found 559.2329 ([M-Br]$^+$).

Element Analysis: Cald for $C_{29}H_{37}BrN_6NiO_2$: 54.40% C, 5.83% H, 13.13% N. Found: 52.38% C, 5.82% H, 12.56% N. (*Note: The large numbers of* errors for N and C were attributed to the instability of **30-Br**)

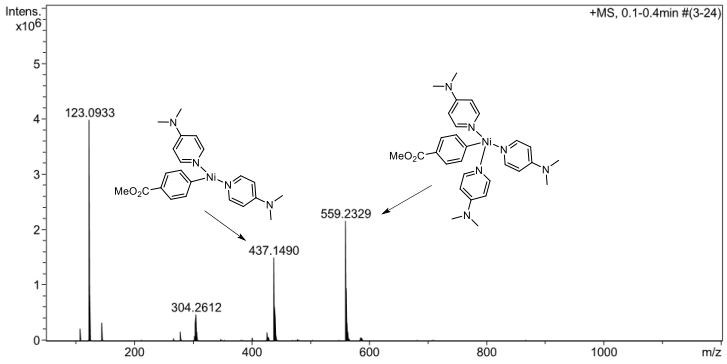


Figure S1. HRMS data obtained from a solution of 30-Br in CH_3CN (set dry heater temperature 180 °C, and set capillary 4500 V).

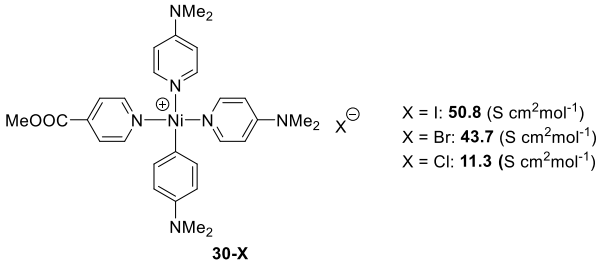
Preparation of complex 30-Cl: The synthesis of complex of **30-Cl** was performed similar to that of **30-Br** or **30-I**, which contains substantial amount of dimerization of aryl groups. This suggests that **30-Cl** may not stable in polar solvents (see Figure S2 on page S48 for the ^{1}H NMR spectra using DMSO-d_6 as the solvent).

(2) Conductivities of complexes **30-X**.

Conductivity measurements were made under an atmosphere of nitrogen using a Lei-Ci DDS-11A

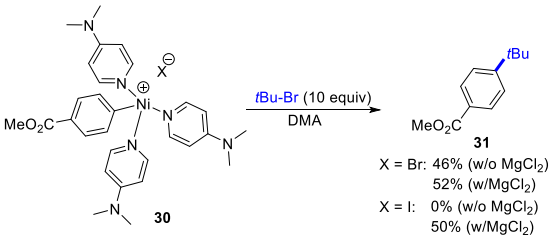
Conductivity meter (Shanghai Electronics Science Instrument) at 25 °C using a Lei-Ci conductivity cell (cell constant K=0.971cm^{-1}). Reference value under the same conditions for *n*-Bu$_4$NBr (1×10^{-3} mol/L) was measured to be 18.9 S cm^{2}mol^{-1} (literature data: 19.0 S cm^{2}mol^{-1} at 25 °C).[11]

The conductivities of **30-X** were determined as follows (using 6 mg of samples in 10 mL of DMA).



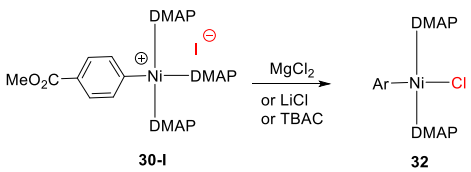
(3) Reactions of (DMAP)$_3$Ni^{III}Ar(X) (**30-X**) with *t*BuBr

To simplify the effect of salts, we focused our studies on the electron-deficient aryl halides, which required $MgCl_2$ as the only additive, and DMAP as the ligand. Stoichiometric reactions of excess *t*Bu–Br with complexes (DMAP)$_3$-Ni^{II}-(Ar)Br (**30-Br**) were carried out. Moderate coupling yields of **31** were observed with or without $MgCl_2$. No reaction occurred for the iodide complex **30-I**. However, addition of $MgCl_2$ and TBAC resulted in **31** in 50% and 40% yields, respectively.



(4) Formation of Ar–Ni^{II}(DMAP)$_2$–Cl (**32**) from the reaction of **30** with $MgCl_2$, LiCl or TBAC

Treatment of complexes **30-X** (X = Cl, Br I) (0.015 mmol) with 10 equiv of $MgCl_2$ or LiCl, or TBAC in DMSO (0.5 mL) revealed complete conversion of **30** into (DMAP)$_2$-Ni^{II}-ArCl (**32**) within 10 min as confirmed by ^{1}H NMR. Note: filtration of the mixtures with micron filter (size: 0.22 μm, Nylon-6) was performed prior to ^{1}H NMR studies.



^{1}H NMR of **30-I** (1 equiv) in the presence of 10 equiv of $MgCl_2$: (500 MHz, DMSO-d_6) δ 8.40 (s, 4H), 7.72 (s, 2H), 7.19 (d, J = 6.5 Hz, 2H), 6.44 (s, 4H), 3.65 (s, 3H), 2.83 (s, 12H).

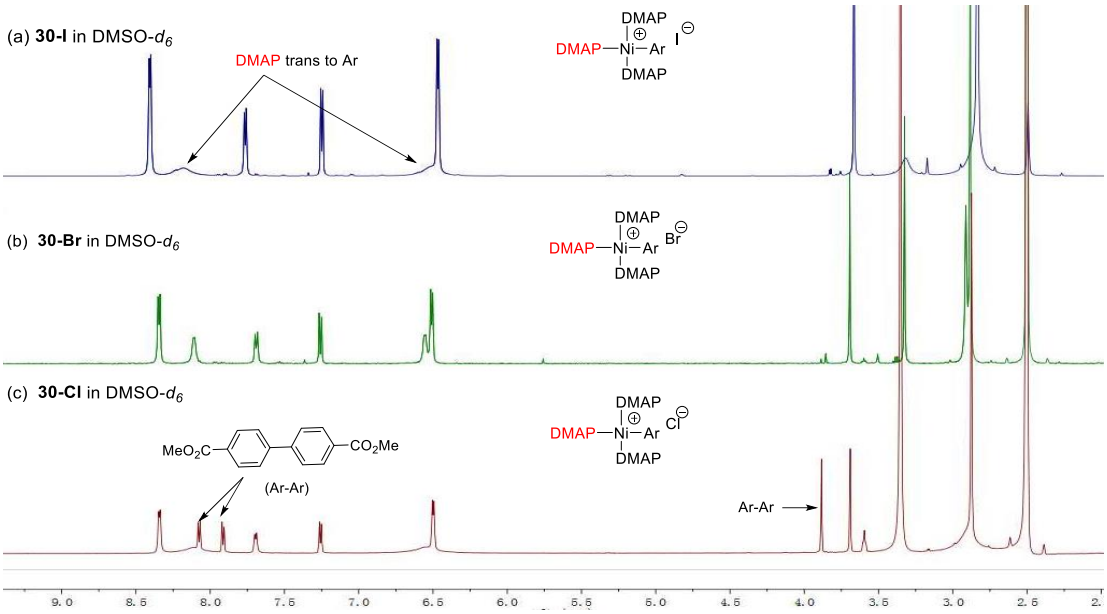


Figure S2. The ^{1}H NMR spectra of complexes **30-X** (X = I, Br, Cl) in DMSO-*d6*.

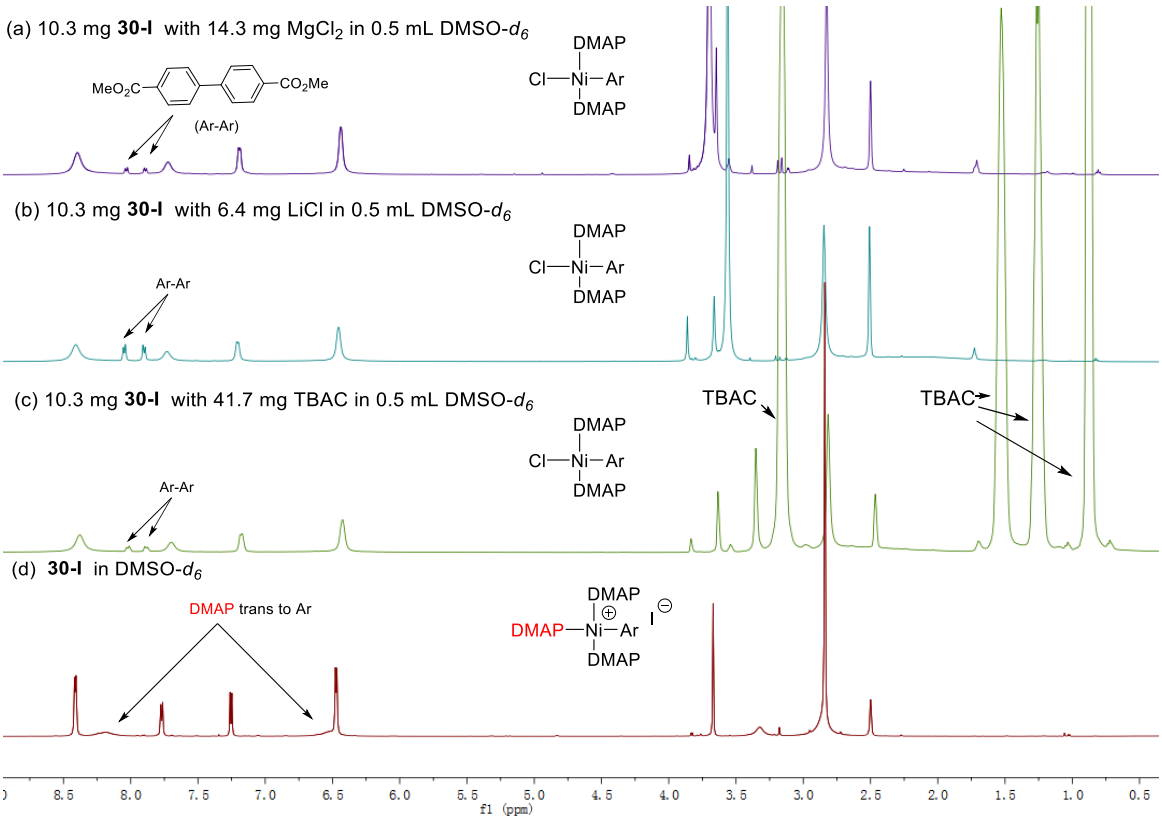


Figure S3. The ^{1}H NMR spectra of complexes **30-I** with different salts.

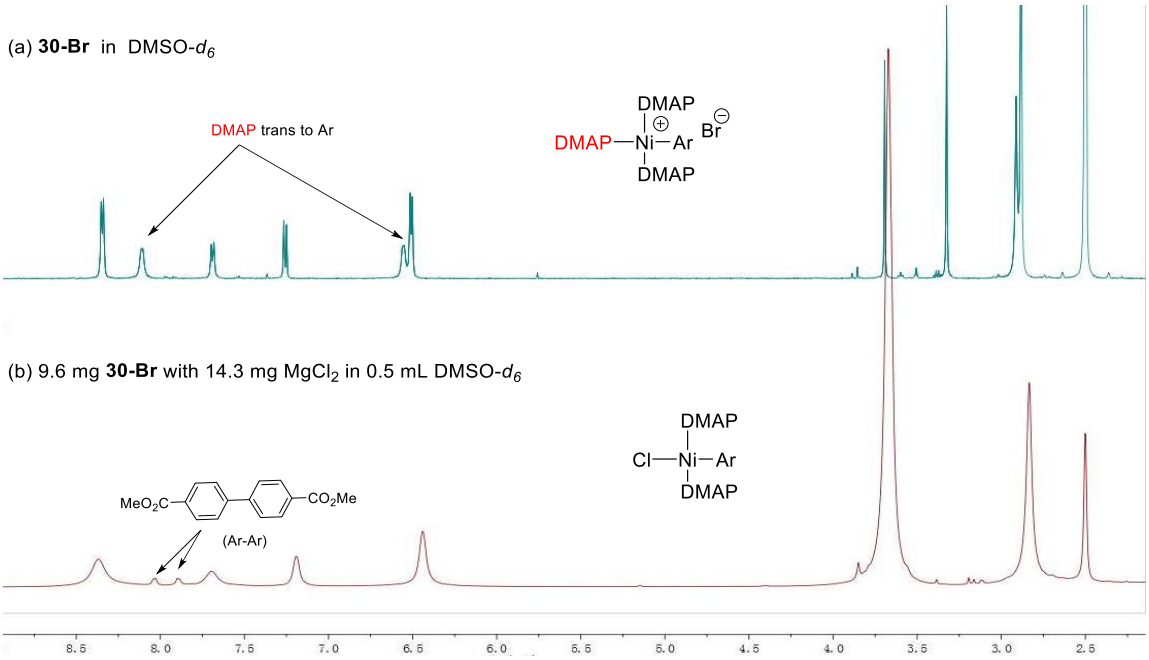


Figure S4. The ^{1}H NMR spectra of complexes **30-Br** with $MgCl_2$.

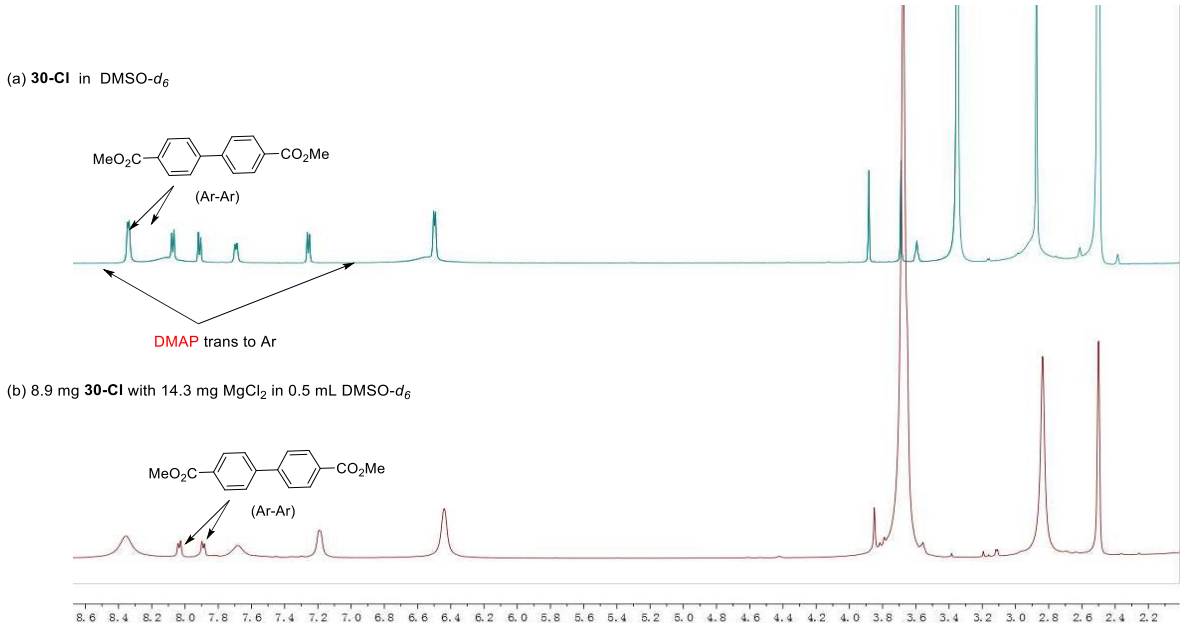


Figure S5. The ^{1}H NMR spectra of complexes **30-Cl** with $MgCl_2$.

HRMS analysis: The ^{1}H NMR spectra for a mixture of **30-I** and TBAC in CD_3CN showed the formation of a possible Ar–$Ni^{II}(DMAP)_2$–Cl complex (see below). HRMS (ESI) analysis of a mixture of **30-X** (X = I, Br, Cl) and TBAC using CH_3CN as the solvent indicated a peak at 519.5391, which corresponds to $(DMAP)_2Ni^{+}Ar(CH_3CN)_2$ (Expected Mass: 519.2013).

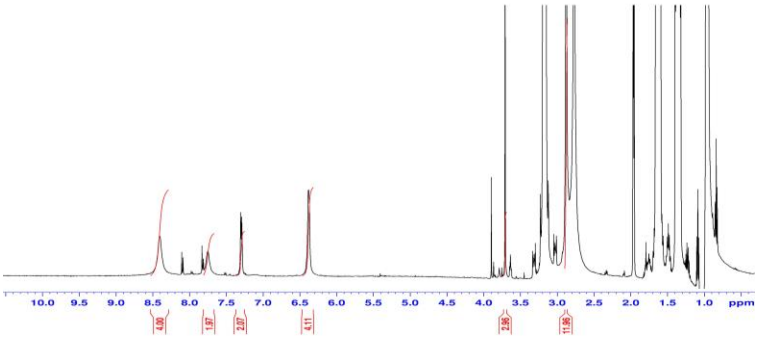


Figure S6. ^{1}H NMR spectra for a mixture of **30-I** and TBAC in CD_3CN.

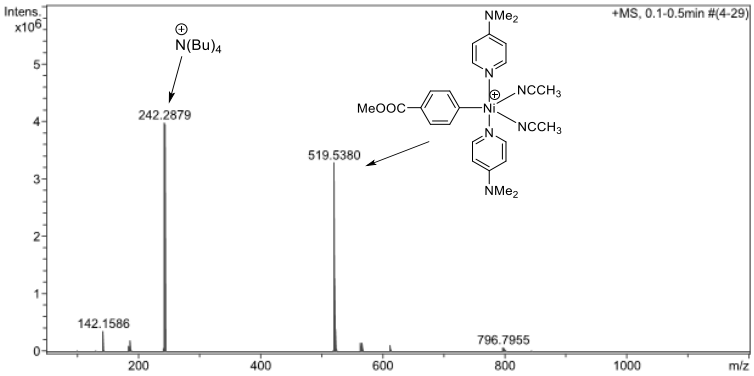


Figure S7. HRMS data obtained from a solution of **30-I** and TABC in CH_3CN (set dry heater temperature 180 °C, and set capillary 4500 V).

(5) Tracking the reaction progress for **30-Br** with *t*BuBr in the absence and presence of $MgCl_2$ or $(n\text{Bu})_4\text{NCl}$ (TBAC) (Note: $MgCl_2$ slowly dissolves into DMA).

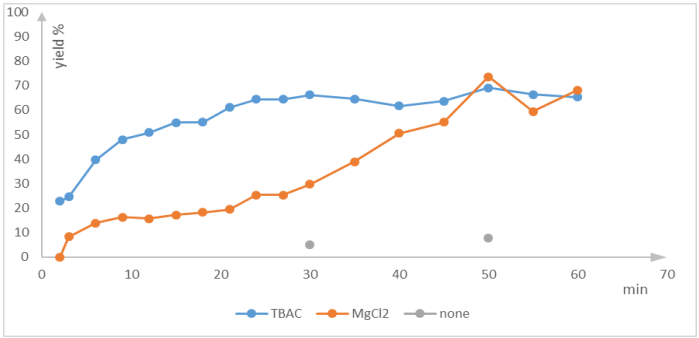


Figure S8. Tracking the reaction progress for **30-Br** with *t*BuBr in the absence and presence of $MgCl_2$ or $(n\text{Bu})_4\text{NCl}$ (TBAC)

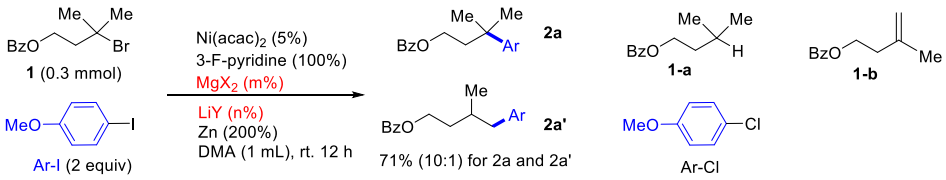
(6) Roles of $MgCl_2$ and LiCl

(a) **Cooperative roles of Mg^{2+}/Cl^- or Li^+/Cl^- ion pair**: For electron-deficient aryl bromides, only $MgCl_2$

was used. However, for electron-rich aryl iodides, both $MgCl_2$ and LiCl are crucial. No reactions took place in the absence of both $MgCl_2$ and LiCl (Table S2, entry 2). Without LiCl, the yield **2a** was obtained in 30% yield (R:I = 12:1, Table S2, entry 3), whereas the absence of $MgCl_2$ gave **2a** in 18% yield (R:I = 50:1, Table S2 entry 4). Increase of the amount of $MgCl_2$ from 1 equiv to 3 equiv in the absence of LiCl led to **2a** in 50% with an R:I of 6:1 (entry 5). The use of 5 equiv of LiCl instead of 3 equiv in the absence of $MgCl_2$ gave **2a** in 26% (R:I = 30:1, entry 6). By comparison, variation of the standard conditions by use of 1 equiv of $Mg(OTf)_2$ and 3 equiv of LiOTf did not yield detectable **2a** (entry 7), so does that of *t*Bu_4NCl or NaCl (both 5 equiv, entries 8-9). A combination of $Mg(OTf)_2$, LiOTf and *t*Bu_4NCl resulted in **2a** in 13% yield (entry 10). In addition, use of $MgBr_2$ and LiBr was much inferior to their chloride salts (entry 11 vs entry 1), whereas use of MgI_2 and LiI did not result in appreciable coupling product (entry 12). These results are consistent with the stoichiometric reaction of **30-Br** or **30-I** with *t*BuBr, where **30-I** did not give the product without $MgCl_2$ (eq 2). The major mass balance for tertiary alkyl bromide **1** include product **2a** and hydrodehalogenation and alkene products **1-a** and **1-b**, whereas that for 4-iodoanisole was determined to be product **2a**, recovered Ar-I and ArCl (Table S1).

Therefore, it is reasonable to conclude that Mg^{2+}/Cl^- or Li^+/Cl^- ion pairs cooperatively determine the transformation efficiency, possibly due to the formation of tightly-bonded ion pairs or complexes of $Mg(DMF)_4Cl_2$ or $Mg(DMF)_{4-x}(3\text{-F-Py})_xCl_2$ (see: Sayyed, F. B.; Sakaki, S. *Chem. Commun*., **2014**, *50*, 13026–13029).

Table S2. Comparison of different salts.



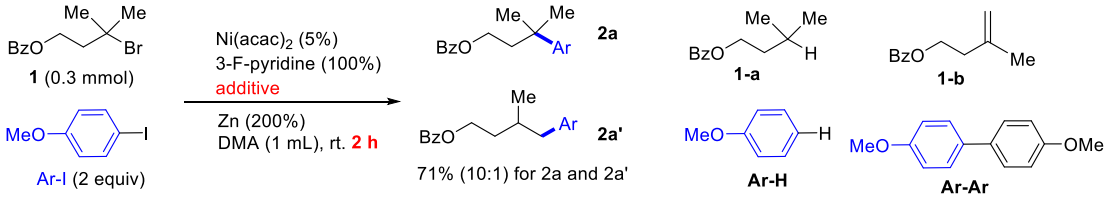
entry	MgX_2	LiY	other additives	yield[b]	Ratio of R:I	recovered **1** (percentage based on **1**)	recovered Ar-I (percentage based on **1**)
1	$MgCl_2$ (100%)	LiCl (300%)	none	71%	10:1	trace	Ar-I (trace), Ar-Cl (80%)
2	$MgCl_2$ (0%)	LiCl (0%)	none	trace	NA[a]	100%	200%
3	$MgCl_2$ (100%)	LiCl (0%)	none	30%	12:1	42	90%
4	0%	LiCl (300%)	none	18%	50:1	10%	115%
5	$MgCl_2$ (300%)	LiCl (0%)	none	50%	6:1	3%	30%
6	0%	LiCl (500%)	none	26%	30:1	7%	83%
7	$Mg(OTf)_2$	LiOTf	none	ND	NA	100%	200%

	(100%)	(300%)					
8	0%	0%	nBu$_4$NCl (500%)	ND[b]	NA[a]	19%[d]	180%
9	0%	0%	NaCl (500%)	ND[b]	NA[a]	100%	200%
10	$Mg(OTf)_2$ (100%)	LiOTf (300%)	nBu$_4$NCl (150%)	13%	NA[a]	61%	100%
11	$MgBr_2$ (100%)	LiBr (300%)	none	28%	12:1	0	8%
12	MgI_2 (100%)	LiI (300%)	none	trace	NA	68%	190%

[a] NA: not applicable. [b] ND: not detected. [c] Substantial amount of hydrolysis byproduct arising from **1** was formed.

(b) Activation of Zn: examination of the effect of $MgCl_2$ was carried out by alternation of the standard reaction conditions (Table S3). Without $MgCl_2$, we only observed recovered starting materials, regardless of presence or absence of $Ni(acac)_2$ (Table S3, entries 1-2). In the absence of $Ni(acac)_2$, Zn can be partially activated by $MgCl_2$ and LiCl as evident by formation of dehydrohalgenation and alkene products **1-a** and **1-b** (Table S3, entries 3-4). This is likely due to the observation by Blum that LiCl salts can remove the organometallic intermediates and inorganic aggregates on its surface.[12]

Table S3. The effect of $MgCl_2$ on the coupling of **1** with 4-iodoanisole.



entry[a]	Ni	salt	yield for **2a**[b]	ratio of R:I[c]	**1**	**1-a**	**1-b**	Ar-I	Ar-Cl	Ar-H	Ar-Ar
1	none	none	ND	0	~100%	0	0	~200%	NA	ND	ND
2	$Ni(acac)_2$ (5%)	none	trace	NA	~100%	NA	NA	~200%	NA	ND	ND
3	none	$MgCl_2$ (100%)	ND	NA	71%	2%	20%	180%	NA	ND	ND
4	none	LiCl (300%)	ND	NA	33%	2%	26%	126%	NA	ND	ND
5	$Ni(acac)_2$ (5%)	$MgCl_2$ (100%)	30%	11:1	42%	3%	7%	90%	~50%	trace	Trace

(c) Converting $Ni(acac)_2$/ligand into more soluble Ni complexes in DMSO:

$Ni(acac)_2$ has very poor solubility in DMA and DMSO. To identify the effect of salts on the solubility of Ni^{II} complexes, we compared the ^1H NMR spectra of $Ni(acac)_2$, $Ni(acac)_2$ (10 mol% or 50 mol%)/DMAP in the presence of TBAC or $MgCl_2$ (Table S4) in DMSO-d6. The mixture was stirred for 30 min before filtration with a micron filter (0.22 μm, Nylon-6), which was immediately used for ^1H NMR studies. It was revealed that the spectra using 50 mol% of $Ni(acac)_2$ with 1 equiv of DMAP in the presence of $MgCl_2$ showed a paramagnetic peak at 35 ppm (Table S4, entry 2, Figure S9). Such a peak was found weak for the case of 10 mol % of $Ni(acac)_2$ (entry 4), likely due to a low concentration of Ni. The 2 equiv of DMAP peaks were not found in the case of 50 mol % of $Ni(acac)_2$ (Table S4, entry 2 and Figure S10). This was attributed to the formation of $(DMAP)_2Ni(X)_2$ (X = Cl or acac or both) complex when $MgCl_2$ was present (see the discussion of the solubility of $(DMAP)_2Ni(acac)_2$ in the following pages. By contrast, the use of $(n\text{Bu})_4NCl$ (TBAC) did not show any of the peak at 35 ppm and acac peak regardless of the amounts of $Ni(acac)_2$ were used (Figures S9-S10). These results clearly suggest that $MgCl_2$ can promote the formation of a more soluble $(DMAP)_2NiX_2$ complex, whereas TBAC cannot.

Table S4. ^1H NMR studies of a mixture of salts and $Ni(acac)_2$ in the presence of DMAP in DMSO-d6 (0.5 mL).

entry	$Ni(acac)_2$	salt	DMAP	time
1	50 mol % (0.15 mmol)	TBAC (100 mol %)	100 mol % (0.3 mmol)	30 min
2	50 mol % (0.15 mmol)	$MgCl_2$ (100 mol %)	100 mol % (0.3 mmol)	30 min
3	10 mol % (0.03 mmol)	TBAC (100 mol %)	100 mol % (0.3 mmol)	30 min
4	10 mol % (0.03 mmol)	$MgCl_2$ (100 mol %)	100 mol % (0.3 mmol)	30 min

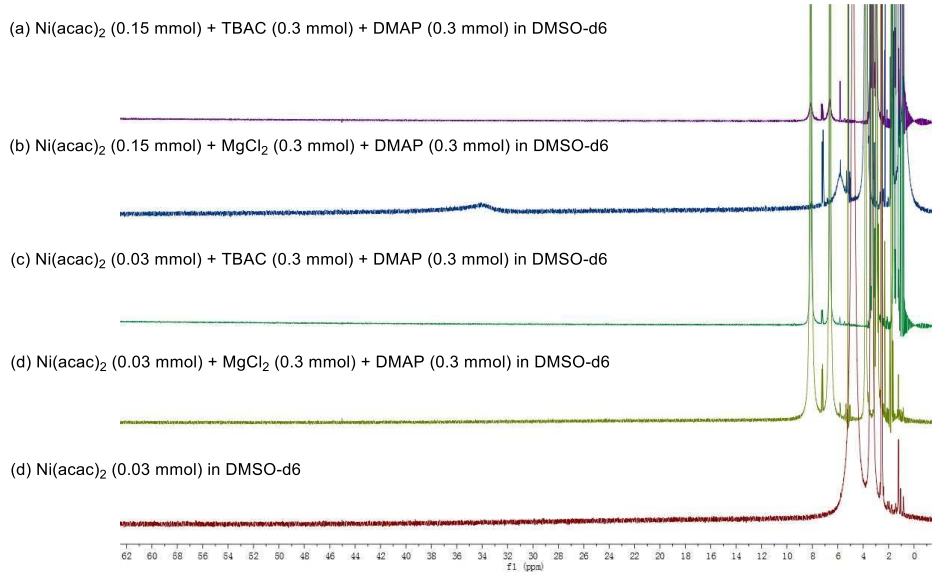


Figure S9. The full regions of ^1H NMR spectra of $Ni(acac)_2$/DMAP with TBAC and $MgCl_2$.

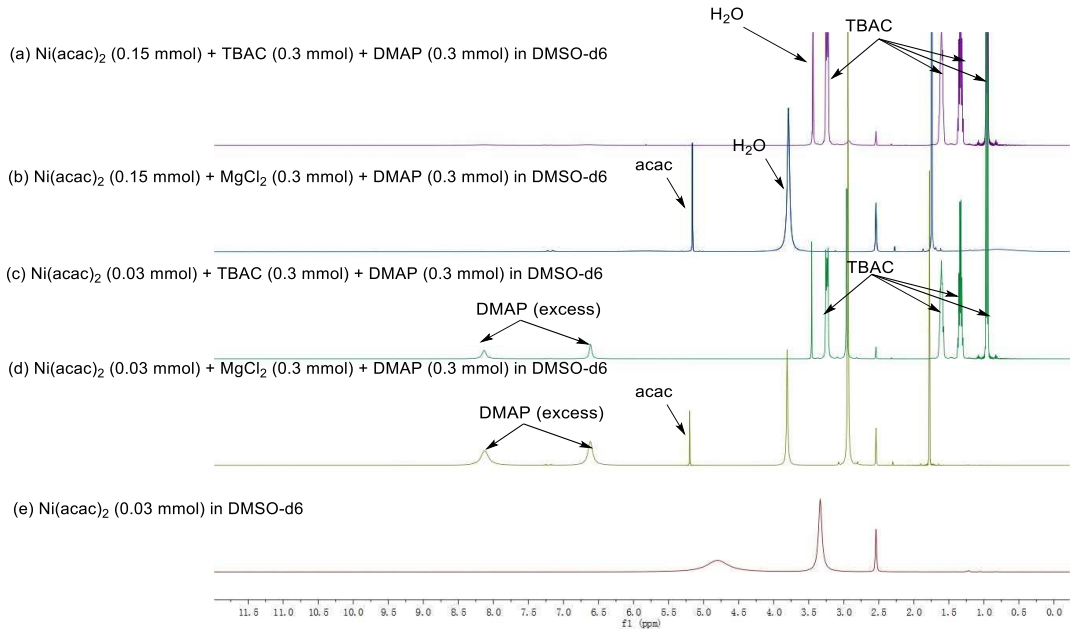


Figure S10. Expansion of upper field regions for the ^{1}H NMR spectra in Figure S9.

To further understand the details for the interactions of salts with Ni(acac)$_2$/DMAP, we prepared a Ni(acac)$_2$(DMAP)$_2$ complex according to literature reports.[13] A solution of Ni(acac)$_2$ (50 mg, 0.195 mmol, 1 equiv) in MeOH (10 mL) was added to a solution of DMAP (190.0 mg, 1.56 mmol, 8.0 equiv) in MeOH (10 mL) at room. Within 5 minutes, a blue precipitate was observed, which was collected and dried after filtration and washing with MeOH and then *n*-pentane. The solid is insoluble in DMSO-d$_6$.

Treatment of the Ni(acac)$_2$(DMAP)$_2$ solid (10 mol %) with LiCl (300 mol %), MgCl$_2$ (100 mol %) or TBAC (100 mol %) in DMSO-d$_6$ for 30 min followed by filtration with a micron filter (size: 0.22 μm, Nylon-6), provided a solution for ^{1}H NMR study (Table S5). The solution arising from TBAC only contains the characteristic peaks for TBAC, whereas the solution arising from LiCl showed trace amount of characteristic peaks for acac (Table S5, entries 1-2, and Figures S11-S12). However, the solution with MgCl$_2$ showed characteristic peaks for acac, along with a paramagnetic peak at 35 ppm (Table S5, entry 2). These results are consistent with the studies in Table S4. A more soluble Ni species is generated, likely due to removal of acac from Ni(acac)$_2$ to form Mg(acac)X (X = Cl or acac) (see Figure S15 for a ^{1}H NMR spectra of Mg(acac)$_2$(H$_2$O)$_2$). Interestingly, use of LiCl did not show apparent effect as MgCl$_2$.

Table S5. ^{1}H NMR studies of $Ni(acac)_2(DMAP)_2$ in DMSO-d6 (0.5 mL) in the presence of different salts, and/or Zn.

entry	$Ni(acac)_2(DMAP)_2$	salt	Zn	time	**^{1}H NMR signals**
1	10 mol % (0.03 mmol)	LiCl (3 equiv)	0 equiv	30 min	acac (trace)
2	10 mol % (0.03 mmol)	TBAC (1 equiv)	0 equiv	30 min	TBAC
3	10 mol % (0.03 mmol)	$MgCl_2$ (1 equiv)	0 equiv	30 min	acac, paramagnetic peak at 35 ppm
4	10 mol % (0.03 mmol)	$MgCl_2$ (1 equiv)	1 equiv	30 min	acac/DMAP = 1:1
5	10 mol % (0.03 mmol)	TBAC (1 equiv)	1 equiv	30 min	TBAC

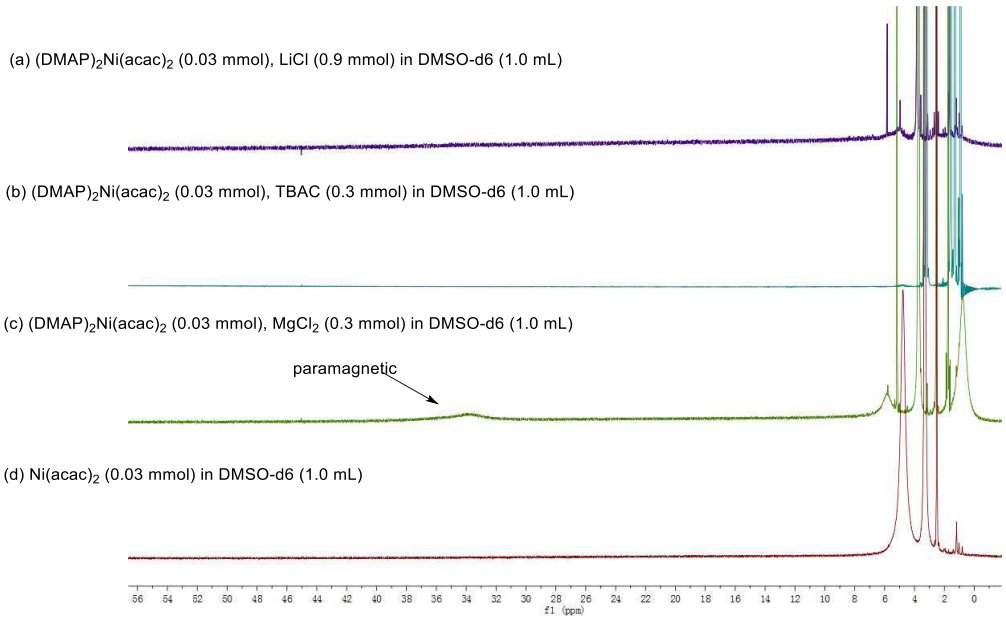


Figure S11. The full regions of ^{1}H NMR spectra of $(DMAP)_2Ni(acac)_2$ with TBAC and $MgCl_2$.

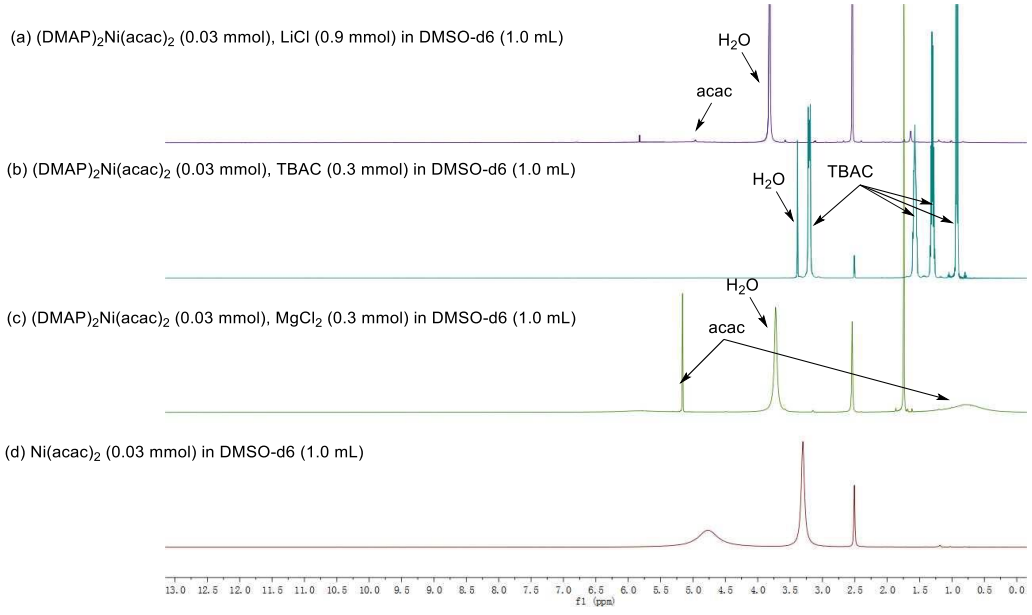


Figure S12. Expansion of upper field regions for the ^{1}H NMR spectra in Figure S11.

Finally, reduction of $(DMAP)_2Ni(acac)_2$ (a suspension in 0.5 mL of DMSO-d6) by Zn in the presence of $MgCl_2$ or TBAC for 30 min was also performed (Table S4, entries 4-5). After filtration with micron filter (size: 0.22 μm, Nylon-6), ^1H NMR spectra of the solution arising from $MgCl_2$ showed a 1:1 ratio of acac and DMAP, whereas the solution arising from TBAC only contains characteristic peaks for TBAC. No paramagnetic peaks were observed for both cases. Therefore, it is reasonable to conclude that $MgCl_2$ assist the solubility of Ni salt, and promotes its reduction to Ni(0).

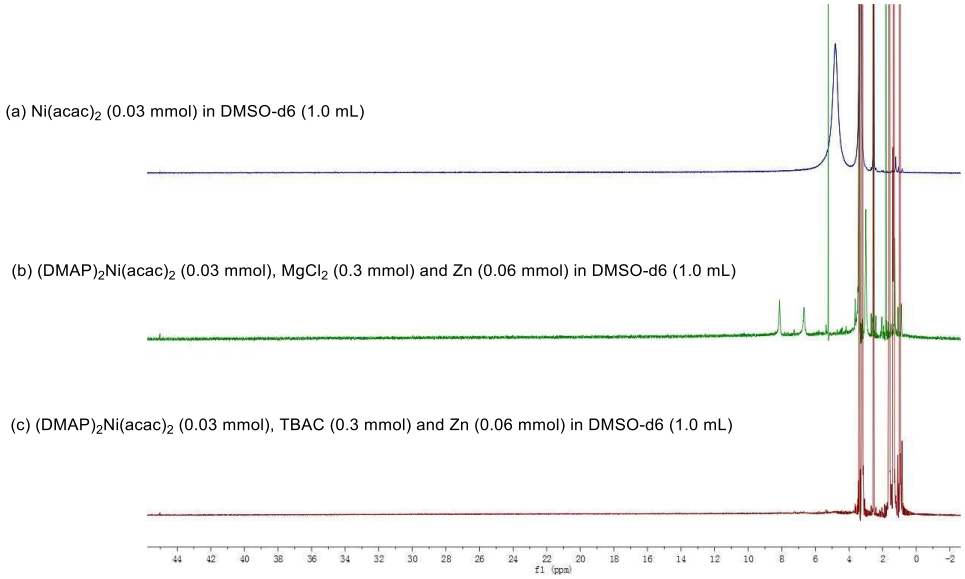


Figure S13. The full regions of ^1H NMR spectra of $(DMAP)_2Ni(acac)_2$ with TBAC and $MgCl_2$ in the presence of Zn.

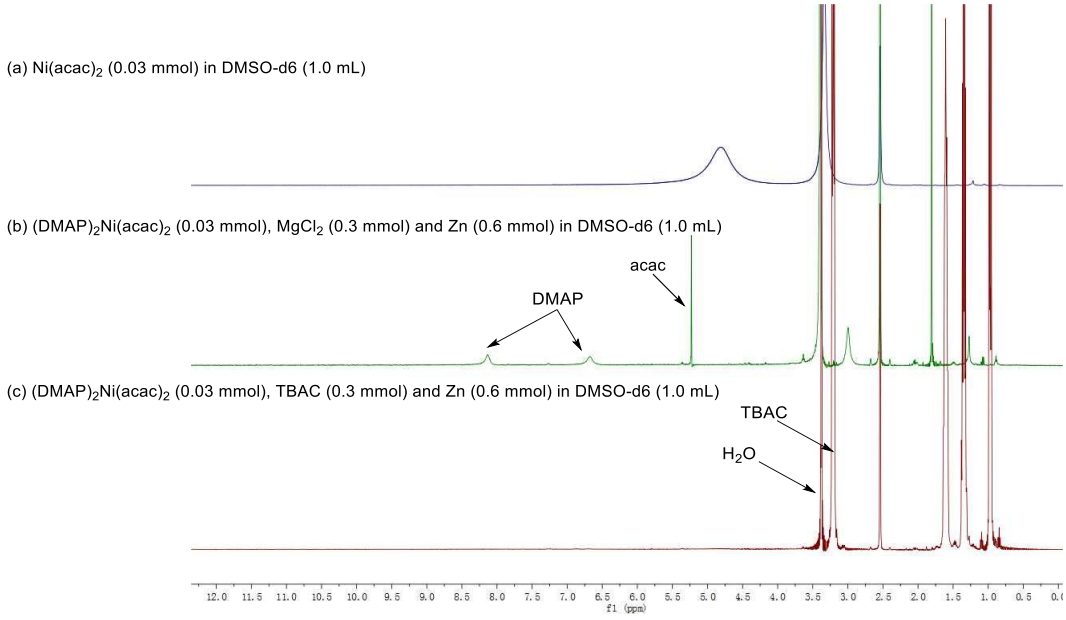


Figure S14. Expansion of upper field regions for the ^1H NMR spectra in Figure S13.

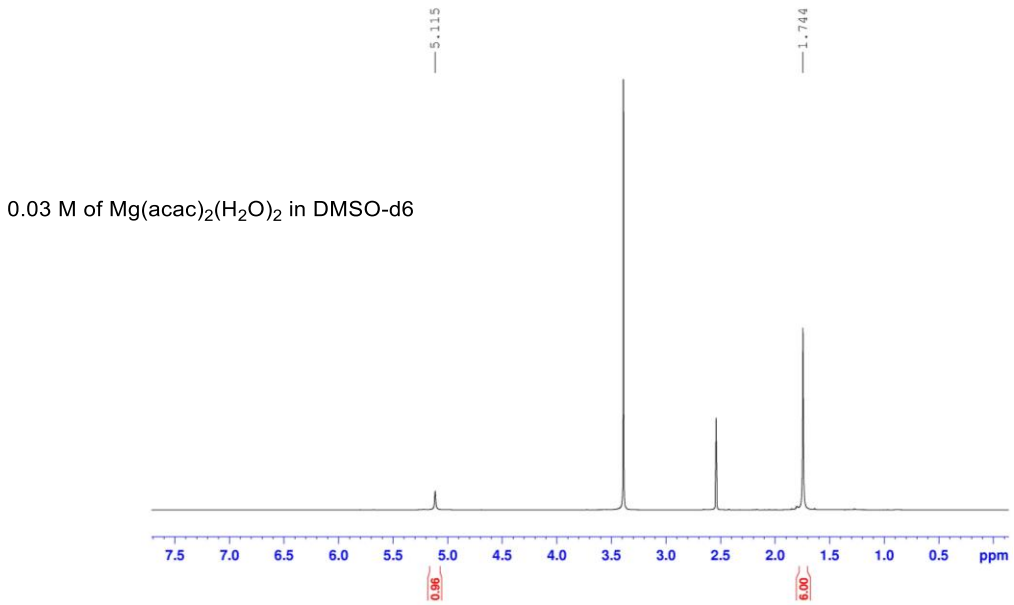


Figure S15. ^{1}H NMR spectra of $Mg(acac)_2(H_2O)_2$ in DMSO-d6.

(7) Tracking the reaction progress

By tracking the reaction progress for the coupling of **1** with 4-iodoanisole, it was found that the reaction went completion within 1 hours. Data was obtained by running parallel reactions, and quenching the reaction at specific point. After a flash column, a mixture containing the coupling product and the starting materials were subjected for ^{1}H NMR analysis.

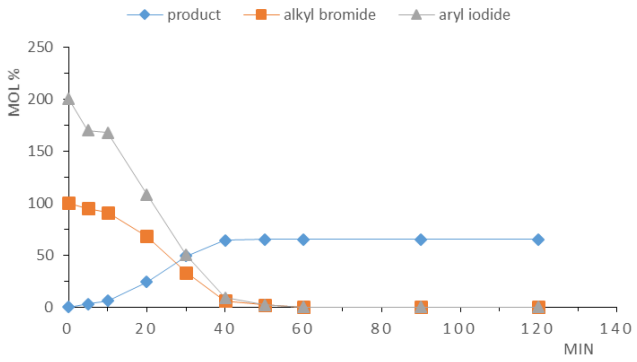


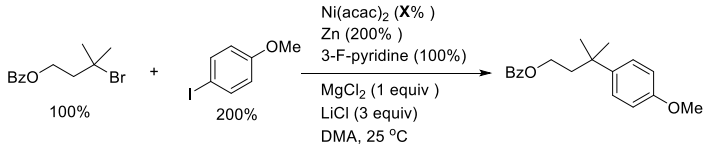
Figure S16. The reaction profile for the coupling of **1** with 4-iodoanisole.

(8) Variation of the concentrations of catalysts, 4-iodoanisole and tertiary alkyl bromide **1**

For the reaction of **1** with 4-iodoanisole, the reaction proceeded rapidly after a 5-minute induction period, and went completion within 1 hour (Figure S17). Although the data were not suited for quantifying the rate

orders, we observed dependence of the reaction rate on the concentrations of $Ni(acac)_2$ precatalyst (Figures S17). Moreover, the concentrations of methyl 4-bromobenzaote and **1** were found irrelevant to the reaction rate (Figures S18). Note that reduction of the concentration of **1** to half led to slower rate. The specific reason for this is not clear in this time (Figure S19). It should be noted that the present process is heterogeneous in nature, and relies on generation of a presumed soluble catalyst in situ and creation of activated surface area of Zn. In addition, $MgCl_2$ and LiCl salts slowly dissolve in DMA. These factors necessarily complicate the reaction kinetics and lead to the observation of an induction period. Based on the mechanistic proposal and our DFT studies, we reason that the heterogeneous behaviors of the reaction should not make difference on the mechanistic process in solution. Given the overall reaction rate can be controlled by the heterogeneous factors, we confined the reductive elimination as the rate-determining step only for the part of the reaction that takes place in solution.

a. Variation of the concentration of catalyst



To an oven-dried round bottom flask (10 mL) was added aryl iodide (560.0 mg, 2.4 mmol, 200 mol %), Zn (160.0 mg, 2.4 mmol, 200 mol %), $MgCl_2$ (114.2 mg, 1.2 mmol, 100 mol %), LiCl (156.0 mg, 3.6 mmol, 300%) and $Ni(acac)_2$. After the flask was evacuated and refilled with N_2 for 3 times, alkyl bromide (325.0 mg, 1.2 mmol, 100%), DMA (4 mL), *n*-dodecane (27 µL, 0.12 mmol, 10 mol %) and 3-fluoropyridine (104 µL, 1.2 mmol, 100 mol %) were sequentially added to the reaction mixture via syringes. An aliquot (50 µL) was collected from the reaction mixture every 1 min via a syringe and was immediately injected into a vial containing aqueous $NaHSO_4$ (1 M). The mixture in the GC vial was partitioned with ethyl acetate (1.5 mL), and was filtered through a short silica pad. The filtrate was analyzed by GC-MS.

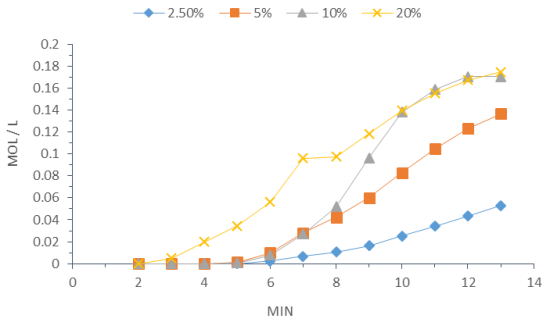
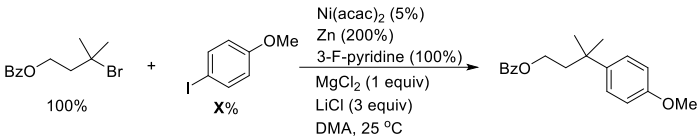


Figure S17. The reaction profiles by variation of the catalyst loading.

b. Variation of the concentration of 4-iodoanisole



To an oven-dried round bottom flask (10 mL) was added aryl iodide, Zn (160.0 mg, 2.4 mmol, 200 mol %), $MgCl_2$ (114.2 mg, 1.2 mmol, 100 mol %), LiCl (156.0 mg, 3.6 mmol, 300 mol %) and $Ni(acac)_2$ (15.6 mg, 0.06 mmol, 5 mol %). After the flask was evacuated and refilled with N_2 for 3 times, alkyl bromide (325.0 mg, 1.2 mmol, 100 mol %), DMA (4 mL), *n*-dodecane (27 µL, 0.12 mmol, 10 mol %) and 3-fluoropyridine (104 µL, 1.2 mmol, 100 mol %) were sequence added to the reaction mixture. An aliquot (50 µL) was collected from the reaction mixture every 1 min via a syringe and was immediately injected into a vial containing aqueous $NaHSO_4$ (1 M). The mixture in the GC vial was partitioned with ethyl acetate (1.5 mL), and was filtered through a short silica pad. The filtrate was analyzed by GC-MS.

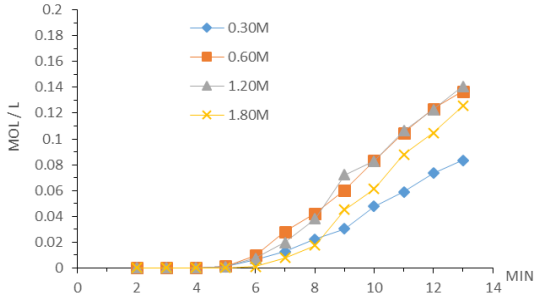
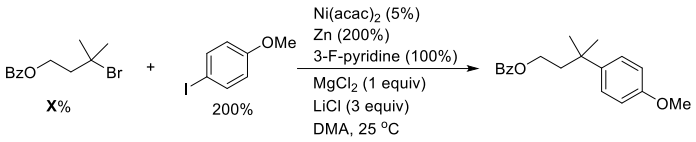


Figure S18. The reaction profiles by variation of the loading of 4-iodoanisole.

c. Variation of the concentration of tertiary alkyl bromide



To an oven-dried round bottom flask (10 mL) was added aryl iodide (560.0 mg, 2.4 mmol, 200 mol %), Zn (160.0 mg, 2.4 mmol, 200 mol %), $MgCl_2$ (114.2 mg, 1.2 mmol, 100 mol %), LiCl (156.0 mg, 3.6 mmol, 300 mol %), and $Ni(acac)_2$ (15.6 mg, 0.06 mmol, 5 mol %). After the flask was evacuated and refilled with N_2 for 3 times, alkyl bromide, *n*-dodecane (27 µl, 0.12 mmol, 10 mol %) and 3-fluoropyridine (104 µL, 1.2 mmol, 100 mol %) were sequence added to the reaction mixture. An aliquot (50 µL) was collected from the reaction mixture every 1 min via a syringe and was immediately injected into a vial containing aqueous $NaHSO_4$ (1 M). The mixture in the GC vial was partitioned with ethyl acetate (1.5 mL), and was filtered through a short silica pad. The filtrate was analyzed by GC-MS.

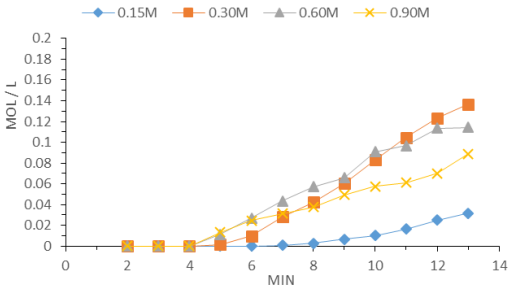


Figure S19. The reaction profiles by variation of the loading of **1**.

Part 5. DFT Studies

Computational Methods: The UltraFine integration grid was used to enhance calculation accuracy, along with the keyword acc2e=11. Geometries were optimized and characterized by frequency calculations to be energy minima (zero imaginary frequencies) or transition states (only one imaginary frequency) at the M06-L[14]/BS1 level in n,n-dimethylacetamide (DMA) solution with solvation effect simulated by the SMD[15] solvent model, BS1 designating a mixed basis set of SDD[16] for nickel and iodine and 6-31G(d,p) for other atoms. The energies were then refined by M06-L/BS2//M06-L/BS1 single-point energy calculations in DMA solution using the SMD solvent model, BS2 denoting a mixed basis set of SDD for nickel and iodine and 6-311++G(d,p) for other atoms. The refined energies were converted to zero-point energy-corrected free energies at 298.15 K and 1 atm, using the M06-L/BS1 harmonic frequencies. Selected key points (i.e., all those shown in Figure 5) were re-computed with the B3LYP-D3 method[17,18] for benchmarking (see Figure S22). The free energies (kcal/mol) were used in the discussions. All calculations were performed with Gaussian 09.[19]

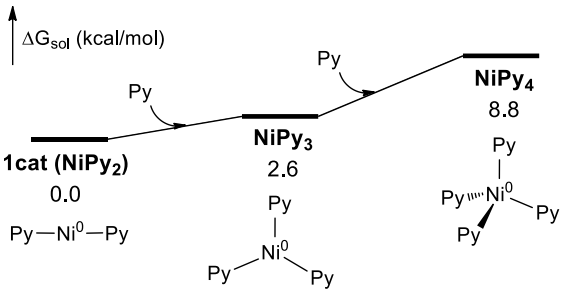


Figure S20. Relative free energies of the three Ni–Py complexes. The formation of **1cat** (**NiPy$_2$**) is more favorable than that of **NiPy$_3$** or **NiPy$_4$**.

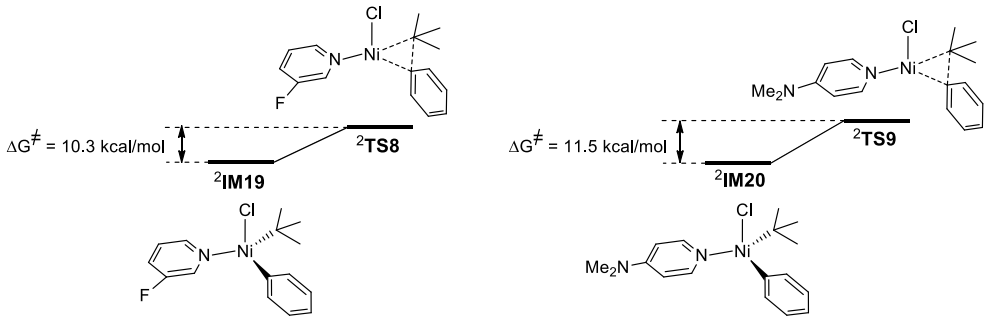


Figure S21. Profile for the rate-determining free energies of activation for ligands 3-fluoropyridine (left) and DMAP (right). Whereas 3-fluoropyridine results in a lower activation energy than does pyridine, DMAP requires 0.8 kcal/mol more energy than pyridine. These computational results agree with the experimental data showing that 3-fluoropyridine is the optimal ligand under the present reaction protocol, but they do not exactly explain the difference in yields of reactions run with different ligands, which can be attributed to limitations of the computational method, variations in experimental conditions, and possible side reactions (e.g., isomerization and hydrodehalogenation).

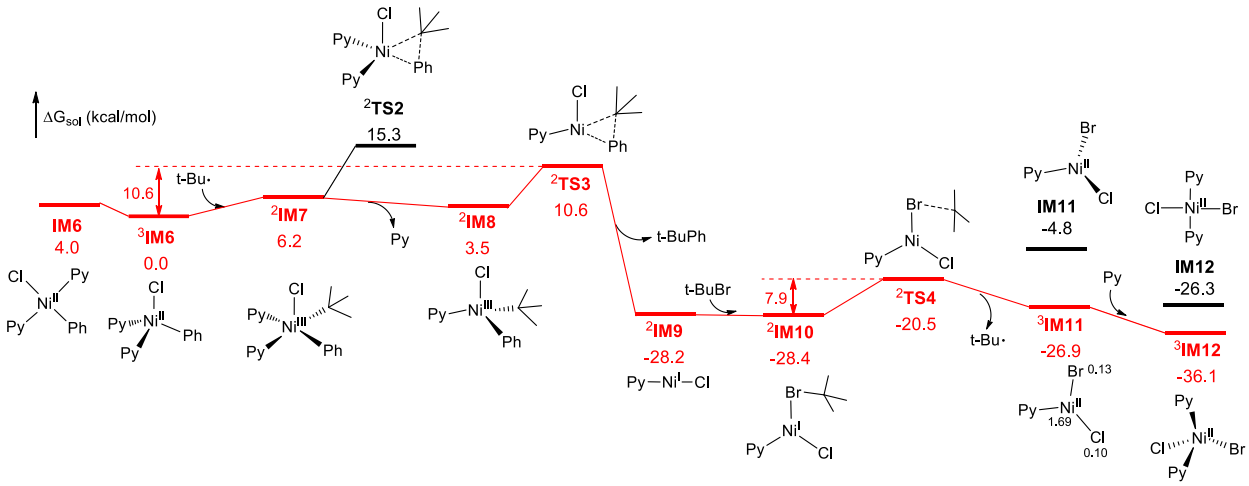


Figure S22. B3LYP-D3/6-311++G(d,p)-SDD-SMD//B3LYP-D3/6-31G(d,p)-SDD-SMD results to benchmark with those of M06L shown in Figure 5. ^{2}**TS3** is 10.6 kcal/mol with respect to ^{3}**IM6**, whereas ^{2}**TS4** is 7.9 kcal/mol with respect to ^{2}**IM10**, indicating that ^{2}**TS3** is the rate-determining barrier. The B3LYP-D3 outcomes are consistent with the M06L outcomes although the pre-transition state lowest points vary.

Cartesian Coordinates, SCF Energies, and Free Energies of DFT-Computed Structures

PhI

E_{sol} optimization: -243.029036887 a.u.

E_{sol} single-point: -243.078657667 a.u.

G_{sol} thermo-corrected: -243.020339667 a.u.

C	0.585247	0.000002	0.000013
C	1.264214	-1.215038	0.000045
C	2.658695	-1.205339	0.000114
C	3.356943	-0.000001	0.000147
C	1.264216	1.215040	0.000044
C	2.658697	1.205337	0.000112
H	0.721296	-2.154431	0.000019
H	4.443068	-0.000003	0.000203
H	0.721302	2.154434	0.000019
H	3.195370	2.150142	0.000140
I	-1.566122	0.000000	-0.000064
H	3.195368	-2.150143	0.000142

t-BuPh

E_{sol} optimization: -389.470843710 a.u.

E_{sol} single-point: -389.552686010 a.u.

G_{sol} thermo-corrected: -389.374182010 a.u.

C	-0.813547	1.218904	-0.000171
C	-0.784005	-1.177353	0.000145
C	-2.208901	1.200354	-0.000141
H	-0.304089	2.178196	-0.000306
C	-2.174724	-1.201549	0.000178
H	-0.239381	-2.119857	0.000279
C	-2.897119	-0.008591	0.000028
H	-2.696918	-2.155149	0.000320
H	-3.983748	-0.023857	0.000050
C	-0.072315	0.032314	-0.000042
H	-2.756734	2.139498	-0.000252
C	1.455841	0.009467	-0.000018
C	2.054819	1.413852	-0.000206
H	3.148029	1.350209	-0.000291
H	1.759210	1.986607	-0.885942
H	1.759373	1.986781	0.885471
C	1.952755	-0.729941	-1.248461

H	3.048311	-0.756454	-1.265357
H	1.596898	-1.764962	-1.277767
H	1.615667	-0.234072	-2.165394
C	1.952671	-0.729587	1.248667
H	1.596734	-1.764575	1.278266
H	3.048224	-0.756165	1.265614
H	1.615576	-0.233422	2.165438

Py

E_{sol} optimization: -248.263340230 a.u.

E_{sol} single-point: -248.318331060 a.u.

G_{sol} thermo-corrected: -248.256923060 a.u.

C	-1.141516	0.719561	0.000093
C	1.141518	0.719559	-0.000171
C	-1.196151	-0.671497	0.000176
H	-2.062145	1.302345	0.000167
C	1.196150	-0.671499	-0.000103
H	2.062147	1.302342	-0.000308
C	-0.000001	-1.382364	0.000075
H	2.154467	-1.181668	-0.000187
H	-0.000001	-2.468938	0.000133
N	0.000001	1.420717	-0.000077
H	-2.154470	-1.181664	0.000316

t-Bu

E_{sol} optimization: -157.780996190 a.u.

E_{sol} single-point: -157.815975569 a.u.

G_{sol} thermo-corrected: -157.728655569 a.u.

C	-0.402369	1.420656	0.020348
C	-0.000294	-0.000199	-0.157597
H	0.321091	2.111684	-0.428582
H	-1.387139	1.627416	-0.414930
H	-0.472961	1.704615	1.085783
C	-1.030127	-1.060156	0.010975
C	1.431907	-0.361270	0.017924
H	-0.717979	-2.011469	-0.435984
H	-1.238254	-1.276764	1.074276
H	-1.990959	-0.773736	-0.432809
H	1.721300	-0.418672	1.082666
H	1.664958	-1.341708	-0.413729
H	2.100871	0.379220	-0.436758

t-BuBr

E_{sol} optimization: -2729.08042506 a.u.

E_{sol} single-point: -2731.89896458 a.u.

G_{sol} thermo-corrected: -2731.80801658 a.u.

C	-0.856327	-0.000277	0.000267
Br	1.175989	0.000236	-0.000136
C	-1.291879	0.393152	-1.394568
H	-2.388147	0.403955	-1.430758
H	-0.937175	1.391004	-1.665077
H	-0.938060	-0.316601	-2.146744
C	-1.290138	-1.405481	0.356995
H	-0.935717	-1.701408	1.347724
H	-2.386339	-1.444000	0.365752
H	-0.934237	-2.137985	-0.372047
C	-1.291354	1.011509	1.038061
H	-2.387625	1.036927	1.066459
H	-0.935620	0.748753	2.037567
H	-0.938514	2.017673	0.797360

1cat

E_{sol} optimization: -667.537595034 a.u.

E_{sol} single-point: -667.643414166 a.u.

G_{sol} thermo-corrected: -667.503285166 a.u.

Ni	0.000000	0.000011	-0.000003
C	2.553085	0.820585	-0.820178
C	2.553067	-0.820580	0.820179
C	3.937014	0.844845	-0.844436
H	1.965485	1.465984	-1.465261
C	3.936996	-0.844864	0.844443
H	1.965453	-1.465970	1.465258
C	4.655505	-0.000016	0.000005
H	4.440954	-1.524664	1.523908
H	5.740946	-0.000026	0.000007
N	1.840211	0.000010	0.000000
C	-2.553085	0.820182	0.820581
C	-2.553068	-0.820178	-0.820580

C	-3.936996	-0.844452	-0.844854
C	-4.655505	-0.000015	-0.000002
C	-3.937014	0.844433	0.844851
H	-1.965484	1.465269	1.465976
H	-1.965454	-1.465254	-1.465974
H	-4.440955	-1.523921	-1.524648
H	-5.740946	-0.000024	-0.000004
N	-1.840211	0.000008	0.000002
H	4.440987	1.524635	-1.523899
H	-4.440986	1.523894	1.524643
H	-5.806049	0.467053	-0.118020
H	-2.188241	-0.234273	2.090437
H	-4.635829	0.039382	2.035675
Ni	-0.030710	-0.059641	0.003383
I	-0.157355	-2.659997	0.032285
H	-4.484935	0.631142	-2.219232
H	-0.722601	4.551728	1.837317
H	4.490484	0.913466	2.048710
H	4.632356	-1.016459	-1.803967
H	1.183071	4.319749	-2.023485

IM2

E_{sol} optimization: -910.658692557 a.u.

E_{sol} single-point: -910.812477730 a.u.

G_{sol} thermo-corrected: -910.594037730 a.u.

C	0.605999	2.485810	-1.084542
C	-0.434317	2.611234	0.983271
C	0.722659	3.865974	-1.152735
H	0.971656	1.842077	-1.879515
C	-0.337479	3.994899	0.990084
H	-0.899305	2.066058	1.799380
C	0.247345	4.637231	-0.096556
H	0.329833	5.719378	-0.120937
C	2.629613	0.438939	1.097313
C	2.705646	-0.608762	-0.960103
C	4.014516	0.476043	1.177805
H	2.004419	0.848029	1.887225
C	4.093058	-0.597471	-0.961317
H	2.139188	-1.037156	-1.782783
C	4.762374	-0.049539	0.128889
H	5.847595	-0.032092	0.159945
N	0.036176	1.865363	-0.033626
N	1.978945	-0.098536	0.050312
C	-1.917249	0.049074	-0.037683
C	-2.593528	0.297598	-1.240635
C	-3.982737	0.442416	-1.272164
C	-4.725344	0.351860	-0.095526
C	-2.678923	-0.038124	1.136694
C	-4.067376	0.113009	1.110406
H	-2.033299	0.382770	-2.172579

^{3}IM2

E_{sol} optimization: -910.663469857 a.u.

E_{sol} single-point: -910.816847497 a.u.

G_{sol} thermo-corrected: -910.602656497 a.u.

Ni	-0.055884	0.200759	0.346408
I	2.229126	0.991421	1.601635
C	-2.897498	-0.612285	0.872002
C	-2.509190	1.745813	0.787880
C	-4.245018	-0.385737	1.163247
H	-2.552792	-1.645578	0.799439
C	-3.853799	1.987672	1.077520
H	-1.848553	2.603683	0.642825
C	-4.728021	0.917822	1.266125
H	-4.219753	3.009796	1.156318
H	-5.776389	1.098942	1.490670
C	-0.681425	1.501950	-2.279521
C	1.345490	0.389269	-2.247849
C	-0.495505	1.887224	-3.599978
H	-1.575475	1.774381	-1.724250
C	1.602260	0.729500	-3.567646
H	2.045910	-0.204878	-1.664862
C	0.665591	1.494072	-4.257234
H	-1.253755	2.481889	-4.097650
H	0.838186	1.777644	-5.291028
C	0.774200	-2.630176	0.788716
C	-0.557218	-2.343446	-1.080140
C	0.831331	-4.002505	0.588616
H	1.283049	-2.152651	1.622699
C	-0.545696	-3.703953	-1.349635

H	-1.101288	-1.642726	-1.709044
C	0.161599	-4.550324	-0.500571
H	-1.084579	-4.086651	-2.209530
H	0.188472	-5.619965	-0.685032
N	0.222384	0.766811	-1.611021
C	-1.988768	0.441871	0.676266
H	-4.919552	-1.227474	1.310022
N	0.093747	-1.811012	-0.030633
H	2.520978	0.398886	-4.039621
H	1.393719	-4.623036	1.277721

IM3

E_{sol} optimization: -1158.95787950 a.u.

E_{sol} single-point: -1159.162592460 a.u.

G_{sol} thermo-corrected: -1158.860814460 a.u.

C	0.499881	-2.671770	0.012325
C	-0.586711	-2.385885	-2.015846
C	0.369103	-4.049824	-0.070352
H	0.992390	-2.191025	0.852093
C	-0.735466	-3.755254	-2.173754
H	-0.957802	-1.683913	-2.756680
C	-0.255376	-4.605243	-1.182264
H	-0.364351	-5.681313	-1.275941
C	1.125598	2.656561	-1.544676
C	-0.400564	2.655177	0.200330
C	1.211306	4.040167	-1.518030
H	1.701986	2.062746	-2.246673
C	-0.349666	4.037578	0.296451
H	-1.028917	2.059001	0.856754
C	0.466471	4.746549	-0.579000
H	0.521470	5.829683	-0.530220
N	0.020941	-1.847340	-0.939908
N	0.327734	1.969413	-0.703217
C	2.056685	-0.103977	-0.622125
C	2.809626	-0.856106	-1.537102
C	4.198019	-0.957731	-1.422510
C	4.863257	-0.328025	-0.372116
C	2.746116	0.534585	0.420617
C	4.130888	0.414345	0.553142
H	2.311829	-1.376886	-2.355088
H	5.942587	-0.414400	-0.275563
H	2.198418	1.138801	1.143854
H	4.638753	0.911207	1.377383
Ni	0.170326	0.059226	-0.797288
I	-0.486750	-0.243121	3.089392
H	4.758494	-1.539005	-2.152113
H	-1.225545	-4.139425	-3.061540
H	1.860846	4.546723	-2.223372
H	-0.947810	4.540704	1.048122
H	0.760782	-4.669927	0.728423
C	-2.354251	1.119349	-1.891172
C	-2.675075	-0.539930	-0.315380
C	-3.720911	1.262181	-2.080793
H	-1.642081	1.726347	-2.444065
C	-4.053843	-0.446980	-0.438075
H	-2.214140	-1.246677	0.370058
C	-4.589546	0.468763	-1.337906
H	-4.089933	1.986832	-2.798400
H	-4.689251	-1.086949	0.164375
H	-5.664489	0.561627	-1.459268
N	-1.829800	0.233034	-1.023506

IM4

E_{sol} optimization: -1147.35697893 a.u.

E_{sol} single-point: -1147.56125252 a.u.

G_{sol} thermo-corrected: -1147.25582952 a.u.

C	0.625704	2.621466	0.992865
C	-0.569399	2.580300	-0.993696
C	0.598964	4.007447	1.023118
H	1.120000	2.042153	1.766197
C	-0.618952	3.965182	-1.037694
H	-1.027208	1.969150	-1.765882
C	-0.029185	4.694897	-0.010375
H	-0.057197	5.780094	-0.016138
C	0.625493	-2.621260	-0.993419
C	-0.568670	-2.580346	0.993713
C	0.599068	-4.007247	-1.023642
H	1.119267	-2.041833	-1.766998
C	-0.617880	-3.965242	1.037750
H	-1.026253	-1.969296	1.766114

C	-0.028422	-4.694831	0.010165
H	-0.056171	-5.780035	0.015960
N	0.044387	1.914609	0.004248
N	0.044482	-1.914533	-0.004526
C	1.940726	0.000058	-0.000031
C	2.665059	0.696472	-0.979016
C	4.061631	0.687415	-0.987686
C	4.764990	0.000242	0.000287
C	2.664929	-0.696266	0.979112
C	4.061501	-0.687024	0.988099
H	2.138433	1.260004	-1.749283
H	5.852026	0.000312	0.000405
H	2.138212	-1.259858	1.749274
H	4.599806	-1.226899	1.764592
Ni	0.041359	0.000031	-0.000112
H	4.600043	1.227362	-1.764054
H	-1.118172	4.454529	-1.866604
H	1.072835	-4.530870	-1.846546
H	-1.116601	-4.454693	1.866898
H	1.072995	4.531172	1.845807
C	-2.666263	-0.736346	-0.890695
C	-2.666180	0.736040	0.890860
C	-4.052839	-0.758128	-0.926646
H	-2.073362	-1.319730	-1.590405
C	-4.052750	0.757471	0.927232
H	-2.073220	1.319573	1.590396
C	-4.761592	-0.000419	0.000400
H	-4.560547	-1.362664	-1.670259
H	-4.560387	1.361875	1.671000
H	-5.847324	-0.000555	0.000563
N	-1.976127	-0.000066	-0.000024

IM5

E_{sol} optimization: -1607.70990423 a.u.

E_{sol} single-point: -1607.94944684 a.u.

G_{sol} thermo-corrected: -1607.64529684 a.u.

C	0.287611	2.681527	0.836029
C	-0.623683	2.476168	-1.286741
C	0.168815	4.063285	0.790174
H	0.674883	2.152219	1.702995
C	-0.765897	3.850822	-1.403743
H	-0.926205	1.802167	-2.083441
C	-0.362840	4.662070	-0.347356
H	-0.462046	5.741463	-0.410205
C	0.901807	-2.555969	-1.170367
C	-0.366543	-2.665485	0.768613
C	0.944010	-3.938811	-1.267631
H	1.395486	-1.917601	-1.896722
C	-0.353220	-4.052479	0.740914
H	-0.849892	-2.094762	1.559566
C	0.307250	-4.704280	-0.295659
H	0.328434	-5.788803	-0.343819
N	-0.104996	1.898195	-0.186385
N	0.250565	-1.925061	-0.173854
C	1.968700	0.172736	-0.181580
C	2.597076	0.929278	-1.183288
C	3.988995	1.026693	-1.257182
C	4.788127	0.382233	-0.314616
C	2.792355	-0.474926	0.753037
C	4.182970	-0.365434	0.695200
H	1.996268	1.458416	-1.923947
H	5.871187	0.462483	-0.365025
H	2.338530	-1.071236	1.544290
H	4.796004	-0.871698	1.438760
Ni	0.075700	-0.012824	-0.112762
H	4.448357	1.614029	-2.050186
H	-1.187403	4.269150	-2.311229
H	1.474268	-4.399644	-2.093883
H	-0.857631	-4.605444	1.526076
H	0.493441	4.654074	1.640013
C	-2.499929	-0.943205	-1.197317
C	-2.743227	0.500505	0.590703
C	-3.873587	-1.024688	-1.376030
H	-1.814577	-1.489486	-1.841135
C	-4.126328	0.467708	0.478765
H	-2.236751	1.069686	1.366411
C	-4.704913	-0.306027	-0.522442
H	-4.276261	-1.641927	-2.171910
H	-4.733827	1.041601	1.170546
H	-5.784051	-0.348838	-0.635631
N	-1.935910	-0.193261	-0.232968

Cl	-0.301783	0.025673	2.974600

IM6_cis

E_{sol} optimization: -1359.42719958 a.u.

E_{sol} single-point: -1359.61184514 a.u.

G_{sol} thermo-corrected: -1359.39014514 a.u.

C	-0.551293	1.913375	1.042247
C	0.639861	2.004310	-0.944057
C	-0.604677	3.296892	1.118444
H	-1.007016	1.282742	1.799995
C	0.610046	3.390627	-0.941847
H	1.135321	1.444198	-1.731353
C	-0.019088	4.052781	0.107664
H	-0.050717	5.137476	0.138343
C	-2.635812	0.206447	-0.935835
C	-2.713649	-1.349119	0.767132
C	-4.020281	0.283562	-0.988305
H	-2.013751	0.803220	-1.598325
C	-4.100791	-1.315735	0.790075
H	-2.148235	-1.995960	1.431374
C	-4.769891	-0.488077	-0.105970
H	-5.854857	-0.445238	-0.116881
N	0.061241	1.271784	0.027560
N	-1.983232	-0.598569	-0.077331
C	1.930723	-0.622767	0.031813
C	2.603801	-0.281511	1.213233
C	3.999210	-0.226397	1.260935
C	4.751501	-0.496670	0.118854
C	2.702306	-0.895006	-1.106598
C	4.096916	-0.827329	-1.067155
H	2.036532	-0.047402	2.114910
H	5.837110	-0.448999	0.152050
H	2.214429	-1.168622	-2.042114
H	4.673393	-1.040300	-1.965640
Ni	0.040826	-0.643385	-0.029104
H	4.498373	0.035733	2.192058
H	1.081165	3.934390	-1.753331
H	-4.494341	0.941575	-1.708638
H	-4.640332	-1.934162	1.499416
H	-1.103498	3.765306	1.959774
Cl	0.037291	-2.872587	-0.080712

IM6

E_{sol} optimization: -1359.43107766 a.u.

E_{sol} single-point: -1359.61557064 a.u.

G_{sol} thermo-corrected: -1359.39326164 a.u.

C	2.583539	0.013932	-1.074845
C	2.613734	-1.172315	0.914594
C	3.969104	0.017379	-1.138589
H	1.976709	0.494925	-1.835344
C	4.000269	-1.187548	0.928888
H	2.028070	-1.644699	1.696377
C	4.694205	-0.587368	-0.117149
H	5.779770	-0.589600	-0.134719
C	-2.583632	0.013282	1.075313
C	-2.613700	-1.172006	-0.914697
C	-3.969210	0.016967	1.138808
H	-1.976855	0.493752	1.836183
C	-4.000234	-1.186986	-0.929237
H	-2.027970	-1.644104	-1.696605
C	-4.694244	-0.587145	0.116944
H	-5.779813	-0.589163	0.134297
N	1.911760	-0.577377	-0.068974
N	-1.911789	-0.577654	0.069267
C	-0.000117	1.315842	0.000295
C	0.813084	2.044555	0.883294
C	0.804417	3.440879	0.894025
C	0.000134	4.145444	-0.000239
C	-0.813205	2.044367	-0.882973
C	-0.804277	3.440686	-0.894238
H	1.470390	1.520705	1.577178
H	0.000238	5.232531	-0.000452
H	-1.470628	1.520382	-1.576645
H	-1.436175	3.978176	-1.598708
Ni	-0.000018	-0.586538	0.000140
H	1.436405	3.978517	1.598301
H	4.519080	-1.670002	1.750002
H	-4.462757	0.497094	1.976612
H	-4.518997	-1.668990	-1.750646
H	4.462589	0.497801	-1.976261

Cl	0.000084	-2.911696	-0.000394

^{3}IM6

E_{sol} optimization: -1359.42995212 a.u.

E_{sol} single-point: -1359.61391463 a.u.

G_{sol} thermo-corrected: -1359.39598563 a.u.

C	-0.609270	-1.504063	-1.518027
C	-1.401158	-2.571670	0.373476
C	-1.127952	-2.489784	-2.344495
H	-0.064395	-0.652105	-1.918309
C	-1.942263	-3.601244	-0.384480
H	-1.489841	-2.546063	1.456697
C	-1.805997	-3.560173	-1.768046
H	-2.220938	-4.349239	-2.387932
C	-0.285398	2.707990	-0.114995
C	-2.162333	1.387990	-0.385373
C	-0.927552	3.808513	-0.665314
H	0.744630	2.761553	0.228692
C	-2.872160	2.438308	-0.949491
H	-2.614156	0.408757	-0.246239
C	-2.244064	3.671766	-1.093602
H	-2.772798	4.513171	-1.531130
N	-0.744034	-1.538917	-0.180891
N	-0.887556	1.514530	0.021310
C	1.917849	0.074831	0.216095
C	2.991847	-0.509444	0.915799
C	4.298240	-0.504719	0.419871
C	4.574554	0.089770	-0.810170
C	2.236592	0.663970	-1.021324
C	3.535913	0.676366	-1.532418
H	2.811145	-0.986873	1.881211
H	5.588806	0.095780	-1.202257
H	1.447409	1.134155	-1.612596
H	3.739649	1.143375	-2.494577
Ni	0.090308	-0.036713	0.967855
H	5.100721	-0.966265	0.992780
H	-2.462575	-4.415172	0.108700
H	-0.398221	4.750912	-0.754586
H	-3.898711	2.285853	-1.264640
H	-0.997039	-2.415670	-3.418610

Cl	-1.098957	-0.249055	2.950288

^{2}IM7

E_{sol} optimization: -1517.24539485 a.u.

E_{sol} single-point: -1517.46273060 a.u.

G_{sol} thermo-corrected: -1517.12696360 a.u.

Ni	-0.184825	-0.443534	0.118287
C	-2.937691	0.186337	0.935303
C	-2.486264	0.331265	-1.416944
C	-4.237320	0.645295	0.713207
H	-2.617279	-0.056978	1.947095
C	-3.786377	0.791718	-1.645487
H	-1.816214	0.217769	-2.270993
C	-4.668733	0.946679	-0.578815
H	-4.106234	1.026374	-2.658904
H	-5.682371	1.299645	-0.751660
C	2.783567	-0.969358	0.663868
C	2.246454	-0.361434	-1.497598
C	4.138925	-0.990612	0.362403
H	2.404659	-1.198330	1.657637
C	3.579865	-0.366704	-1.881984
H	1.455181	-0.104609	-2.200943
C	4.546049	-0.687977	-0.933083
H	4.857342	-1.242156	1.135335
H	5.598837	-0.699266	-1.198953
C	-0.003382	2.481585	-0.803404
C	1.160397	2.105205	1.148782
C	0.453395	3.791318	-0.877473
H	-0.672024	2.076458	-1.559272
C	1.655236	3.402433	1.154331
H	1.409479	1.390808	1.929986
C	1.297343	4.263726	0.121902
H	2.311475	3.723880	1.956356
H	1.669865	5.283480	0.096225
N	1.849204	-0.664229	-0.249982
C	-2.039811	0.017706	-0.125385
H	-4.917664	0.765688	1.554405
N	0.338489	1.646862	0.190056
C	-0.657215	-2.397927	-0.294708
C	-1.942167	-2.861085	0.361793

H	-2.034495	-3.954783	0.260772
H	-1.952747	-2.631432	1.433329
H	-2.832346	-2.414814	-0.089139
C	0.503183	-3.229943	0.228853
H	0.227443	-4.295717	0.179735
H	1.413215	-3.110103	-0.364604
H	0.739231	-3.004562	1.274004
C	-0.734957	-2.490497	-1.804803
H	0.154159	-2.078107	-2.298874
H	-0.797026	-3.547660	-2.111747
H	-1.617895	-1.988452	-2.210757
H	3.848321	-0.120176	-2.903521
H	0.147298	4.422053	-1.705391
Cl	-0.032468	-0.697933	2.530751

^{2}IM8

E_{sol} optimization: -1268.95966970 a.u.

E_{sol} single-point: -1269.12416953 a.u.

G_{sol} thermo-corrected: -1268.87254753 a.u.

Ni	-0.099476	-0.793552	0.462105
C	-2.636264	0.503685	0.697415
C	-1.175897	1.566136	-0.891425
C	-3.598057	1.491703	0.476874
H	-2.852093	-0.295763	1.405975
C	-2.135132	2.557544	-1.111717
H	-0.238348	1.604674	-1.445602
C	-3.349290	2.522577	-0.428319
H	-1.932912	3.354896	-1.823890
H	-4.097926	3.291196	-0.602089
C	1.785525	1.434566	0.565064
C	2.700001	-0.238332	-0.732356
C	2.914870	2.226342	0.418343
H	0.932623	1.766090	1.152024
C	3.865965	0.490412	-0.926445
H	2.580731	-1.224850	-1.171415
C	3.976716	1.747565	-0.343044
H	4.666837	0.070794	-1.525468
H	4.874774	2.342869	-0.477434
C	-1.408494	0.532726	0.022643
H	-4.543211	1.453952	1.014507
N	1.669671	0.220313	-0.003347
C	-0.571517	-1.833950	-1.132867
C	-1.991175	-2.329314	-1.006669
H	-2.132350	-3.219147	-1.638524
H	-2.234737	-2.626815	0.020498
H	-2.715897	-1.575143	-1.325089
C	0.455832	-2.803860	-0.583060
H	0.015714	-3.775464	-0.339143
H	1.309798	-2.940104	-1.251438
H	0.913156	-2.483977	0.390035
C	-0.253465	-1.233708	-2.471797
H	0.744772	-0.785996	-2.508025
H	-0.284056	-2.012416	-3.248591
H	-0.984097	-0.468848	-2.750269
H	2.954128	3.198987	0.896580
Cl	0.155471	-0.870719	2.764472

^{2}IM9

E_{sol} optimization: -879.513630289 a.u.

E_{sol} single-point: -879.595778827 a.u.

G_{sol} thermo-corrected: -879.539715827 a.u.

Ni	-1.173229	-0.000025	-0.000054
C	1.417381	1.159549	0.000053
C	1.417411	-1.159554	0.000070
C	2.801718	1.196526	0.000113
H	0.825749	2.069715	0.000020
C	2.801750	-1.196495	0.000131
H	0.825803	-2.069736	0.000051
C	3.513445	0.000025	0.000153
H	3.308380	-2.155451	0.000160
H	4.598927	0.000040	0.000199
N	0.719534	-0.000012	0.000032
H	3.308323	2.155496	0.000127
Cl	-3.339043	0.000025	-0.000140

^{2}IM10

E_{sol} optimization: -3608.61092538 a.u.

E_{sol} single-point: -3611.50855204 a.u.

G_{sol} thermo-corrected: -3611.34362304 a.u.

Ni	0.299870	1.135836	-0.356356
C	1.963802	-1.295572	-0.248120
C	2.993442	0.703554	0.290430
C	3.131130	-2.003461	-0.010067
H	1.054838	-1.796997	-0.566910
C	4.194941	0.064344	0.546034
H	2.893204	1.780634	0.397642
C	4.272235	-1.317956	0.395835
H	5.053635	0.649055	0.858025
H	5.199850	-1.847548	0.589388
N	1.876826	0.044989	-0.102703
Br	-1.392986	-0.622973	-1.158411
C	-2.319104	-1.024615	0.661182
C	-3.094514	-2.299539	0.442027
H	-3.611698	-2.547752	1.376574
H	-3.852571	-2.192088	-0.337879
H	-2.442124	-3.139022	0.189078
C	-1.197947	-1.175230	1.660412
H	-0.537717	-2.012252	1.417129
H	-0.597108	-0.260488	1.733667
H	-1.639687	-1.370597	2.644961
C	-3.195733	0.171139	0.935856
H	-3.683081	0.023698	1.907164
H	-2.612415	1.096131	0.980376
H	-3.978265	0.285939	0.181577
Cl	-0.821169	3.041609	-0.284240
H	3.136553	-3.079901	-0.144468

IM11

E_{sol} optimization: -3450.77204282 a.u.

E_{sol} single-point: -3453.63779841 a.u.

G_{sol} thermo-corrected: -3453.58477241 a.u.

Ni	0.687940	-0.664926	0.096835
C	-1.780837	0.298370	1.064695
C	-1.872432	-0.829866	-0.971829
C	-3.158682	0.439431	1.086741
H	-1.148178	0.688323	1.854835
C	-3.253141	-0.716571	-1.013041
H	-1.309080	-1.318293	-1.761075
C	-3.908138	-0.072386	0.031741
H	-3.795345	-1.126024	-1.857737
H	-4.988172	0.035061	0.021330
N	-1.154952	-0.335837	0.054975
Br	1.216171	1.529215	-0.245126
Cl	2.644951	-1.558592	0.242088
H	-3.627641	0.949392	1.920530

^{3}IM11

E_{sol} optimization: -3450.80582335 a.u.

E_{sol} single-point: -3453.67020963 a.u.

G_{sol} thermo-corrected: -3453.61759763 a.u.

Ni	-0.659466	0.581367	0.399267
C	1.504497	-1.359873	0.201339
C	2.209121	0.844610	0.002357
C	2.804482	-1.825606	0.085980
H	0.662004	-2.034559	0.324262
C	3.531555	0.449823	-0.122804
H	1.915874	1.889901	-0.027010
C	3.836286	-0.906886	-0.079409
H	4.303238	1.200273	-0.252135
H	4.863915	-1.243816	-0.174051
N	1.212168	-0.046121	0.162088
Br	-2.146743	-1.071171	-0.266072
Cl	-0.776528	2.648822	-0.382401
H	2.996028	-2.891991	0.124353

IM12

E_{sol} optimization: -3699.09440516 a.u.

E_{sol} single-point: -3702.01267698 a.u.

G_{sol} thermo-corrected: -3701.87516698 a.u.

Ni	-0.000002	-0.257406	-0.000009
C	2.601026	0.237481	-1.043210
C	2.581323	-0.778203	1.042145
C	3.987237	0.226346	-1.077106
H	2.011322	0.656256	-1.851645
C	3.967161	-0.803755	1.084661
H	1.975676	-1.177347	1.849111
C	4.685210	-0.297866	0.005983
H	4.465463	-1.221474	1.952401

H	5.770776	-0.311469	0.009554
N	1.911148	-0.262225	-0.003019
Br	0.000010	2.093552	-0.000015
C	-2.581333	-0.778257	-1.042107
C	-2.601028	0.237547	1.043190
C	-3.987239	0.226416	1.077090
C	-4.685217	-0.297857	-0.005966
C	-3.967172	-0.803810	-1.084617
H	-1.975689	-1.177452	-1.849050
H	-2.011322	0.656371	1.851597
H	-4.501595	0.631572	1.941441
H	-5.770782	-0.311459	-0.009533
N	-1.911152	-0.262220	0.003025
H	4.501597	0.631453	-1.941478
H	-4.465476	-1.221579	-1.952331
Cl	-0.000003	-2.503469	0.000016

^{3}IM12

E_{sol} optimization: -3699.10596718 a.u.

E_{sol} single-point: -3702.02394498 a.u.

G_{sol} thermo-corrected: -3701.88934998 a.u.

Ni	-0.000001	-0.124859	0.178261
C	-2.685674	0.539265	-0.940248
C	-2.541787	-1.593324	-0.051875
C	-3.989253	0.319518	-1.359741
H	-2.181846	1.488877	-1.099546
C	-3.840221	-1.887407	-0.439911
H	-1.926591	-2.312950	0.481261
C	-4.578923	-0.914693	-1.106226
H	-4.258692	-2.862956	-0.217959
H	-5.598846	-1.114930	-1.420366
N	-1.969585	-0.399660	-0.295557
Br	0.000007	2.282363	0.481390
C	2.541819	-1.593297	-0.051801
C	2.685641	0.539240	-0.940311
C	3.989217	0.319497	-1.359816
C	4.578920	-0.914685	-1.106234
C	3.840253	-1.887373	-0.439843
H	1.926650	-2.312901	0.481395
H	2.181789	1.488832	-1.099657
H	4.527017	1.108487	-1.874011
H	5.598840	-1.114919	-1.420382
N	1.969586	-0.399662	-0.295548
H	4.258752	-2.862899	-0.217837
H	-4.527081	1.108529	-1.873876
Cl	-0.000009	-1.233238	2.196163

^{2}IM13

E_{sol} optimization: -899.172353994 a.u.

E_{sol} single-point: -899.32722665 a.u.

G_{sol} thermo-corrected: -899.10848865 a.u.

Ni	0.094383	-0.519978	-0.003246
C	0.463014	2.293881	0.866685
C	-0.959407	2.088069	-0.937831
C	0.342947	3.676620	0.858274
H	1.090759	1.783104	1.593468
C	-1.126377	3.463097	-1.019737
H	-1.465568	1.414619	-1.626528
C	-0.464605	4.276645	-0.103892
H	0.877896	4.267484	1.594484
H	-0.576518	5.356106	-0.138981
C	-2.804771	-0.260964	0.560611
C	-2.156871	-2.234628	-0.449667
C	-4.121969	-0.687375	0.638288
H	-2.506516	0.713570	0.937284
C	-3.450362	-2.730114	-0.410192
H	-1.340814	-2.817791	-0.870073
C	-4.458331	-1.944459	0.143630
H	-3.658074	-3.717369	-0.809082
H	-5.481539	-2.304282	0.189616
N	-0.175543	1.499219	-0.013496
N	-1.819166	-1.013447	0.024487
H	-4.868806	-0.037404	1.082212
H	-1.768536	3.882887	-1.787018
C	2.006541	-0.816864	-0.003072
C	2.547015	-2.112019	0.196487
C	2.972696	0.191947	-0.227172
C	3.917074	-2.379710	0.180216
H	1.870107	-2.951157	0.374636
C	4.346274	-0.054777	-0.248334

H	2.639830	1.219569	-0.393714
C	4.828554	-1.347561	-0.042833
H	4.276751	-3.395128	0.341682
H	5.045158	0.761730	-0.426066
H	5.897576	-1.547688	-0.056738

^{2}IM14

E_{sol} optimization: -650.880913051 a.u.

E_{sol} single-point: -650.983034925 a.u.

G_{sol} thermo-corrected: -650.844983925 a.u.

Ni	-0.006177	0.000010	-0.000063
C	2.627955	-1.157336	0.000018
C	2.628065	1.157401	-0.000023
C	4.012805	-1.196705	0.000063
H	2.036048	-2.068106	0.000014
C	4.012919	1.196628	0.000018
H	2.036245	2.068227	-0.000056
C	4.724469	-0.000073	0.000063
H	4.520038	2.155453	0.000015
H	5.810066	-0.000123	0.000097
N	1.929138	0.000067	-0.000023
H	4.519827	-2.155581	0.000097
C	-1.909108	-0.000103	-0.000050
C	-2.669933	-1.193323	-0.000039
C	-2.669783	1.193220	0.000004
C	-4.065290	-1.201987	0.000033
H	-2.155075	-2.155518	-0.000088
C	-4.065139	1.202067	0.000077
H	-2.154798	2.155350	-0.000008
C	-4.772605	0.000084	0.000093
H	-4.604785	-2.147895	0.000041
H	-4.604515	2.148043	0.000119
H	-5.860194	0.000152	0.000150

^{2}IM15

E_{sol} optimization: -3379.97333483 a.u.

E_{sol} single-point: -3382.89073927 a.u.

G_{sol} thermo-corrected: -3382.64323627 a.u.

Ni	-0.246887	-0.176420	-0.412639
C	-0.001399	2.541653	0.725304
C	-1.805689	2.281484	-0.690489
C	-0.338715	3.861814	0.983628
H	0.871417	2.081492	1.183900
C	-2.204710	3.595408	-0.491810
H	-2.363245	1.609288	-1.338471
C	-1.460729	4.404061	0.362580
H	-3.087602	3.970823	-0.998425
H	-1.749901	5.435078	0.542313
N	-0.717507	1.750760	-0.097605
Br	2.163854	0.129007	-0.864177
C	2.949731	-1.098740	0.642089
C	4.444447	-1.040303	0.458109
H	4.907334	-1.667108	1.229449
H	4.755537	-1.428294	-0.515098
H	4.834448	-0.026259	0.576379
C	2.476008	-0.485219	1.935577
H	2.867063	0.525186	2.080651
H	1.381008	-0.457163	1.987496
H	2.836733	-1.107295	2.763637
C	2.362076	-2.463376	0.388344
H	2.727874	-3.145750	1.164864
H	1.267493	-2.446248	0.446035
H	2.659657	-2.866977	-0.582603
H	0.273383	4.450716	1.658608
C	-1.816211	-1.252865	-0.115228
C	-1.883117	-2.622464	-0.469055
C	-2.976537	-0.743215	0.511411
C	-3.005454	-3.415410	-0.222429
H	-1.026861	-3.092402	-0.958013
C	-4.106952	-1.521002	0.765851
H	-3.000181	0.306040	0.815256
C	-4.127278	-2.866740	0.398672
H	-3.006532	-4.464404	-0.515266
H	-4.975222	-1.079250	1.252961
H	-5.004738	-3.478800	0.594307

IM16

E_{sol} optimization: -3222.17788140 a.u.

E_{sol} single-point: -3225.06257420 a.u.

G_{sol} thermo-corrected: -3224.92571520 a.u.

Ni	-0.190258	-0.803878	-0.024873
C	2.486852	-1.336843	0.396523
C	2.212532	0.746520	-0.586119
C	3.865800	-1.211196	0.376090
H	2.003760	-2.224013	0.798832
C	3.584099	0.937406	-0.639715
H	1.518465	1.494893	-0.954001
C	4.429864	-0.052416	-0.149402
H	3.975498	1.855504	-1.063980
H	5.507314	0.076163	-0.176020
N	1.661759	-0.374709	-0.074999
Br	-2.191329	-1.862743	0.001077
H	4.479241	-2.012698	0.772382
C	-0.756766	0.950257	0.068641
C	-1.439098	1.538030	-0.999870
C	-0.442902	1.708844	1.199890
C	-1.789777	2.889000	-0.937944
H	-1.700105	0.954279	-1.879260
C	-0.811832	3.055048	1.258224
H	0.098786	1.262822	2.031596
C	-1.480669	3.648678	0.189270
H	-2.314992	3.343184	-1.775384
H	-0.564751	3.639654	2.141723
H	-1.760409	4.697785	0.234351

^{3}IM16

E_{sol} optimization: -3222.18163321 a.u.

E_{sol} single-point: -3225.06619913 a.u.

G_{sol} thermo-corrected: -3224.93171813 a.u.

Ni	-0.048477	-0.612393	-0.543123
C	2.495431	0.515770	0.500664
C	1.260975	1.983240	-0.799606
C	3.479168	1.469925	0.712873
H	2.560006	-0.483902	0.921836
C	2.205042	2.985764	-0.638557
H	0.356486	2.138559	-1.382220
C	3.333478	2.726492	0.133545
H	2.050320	3.950242	-1.109464
H	4.088146	3.492945	0.281304
N	1.402014	0.767015	-0.240877
Br	0.754318	-2.671407	0.249787
H	4.342535	1.224364	1.321394
C	-1.742234	0.249210	-0.094844
C	-2.957900	-0.291949	-0.550564
C	-1.813375	1.426827	0.668025
C	-4.182716	0.318432	-0.272381
H	-2.958033	-1.211422	-1.137491
C	-3.032869	2.041801	0.956547
H	-0.898199	1.881704	1.049536
C	-4.222209	1.488805	0.483543
H	-5.106343	-0.121355	-0.643471
H	-3.055748	2.954066	1.549451
H	-5.173786	1.966047	0.704692

^{2}IM17

E_{sol} optimization: -3380.00883195 a.u.

E_{sol} single-point: -3382.92522490 a.u.

G_{sol} thermo-corrected: -3382.67521790 a.u.

Ni	0.066404	-0.607185	0.109781
C	-2.601373	0.613947	-0.504068
C	-1.093426	2.155001	0.325280
C	-3.610371	1.565527	-0.554459
H	-2.762680	-0.413900	-0.821523
C	-2.046282	3.163672	0.303975
H	-0.075907	2.340987	0.660081
C	-3.330093	2.864053	-0.141194
H	-1.779737	4.162452	0.632339
H	-4.098876	3.630652	-0.166834
N	-1.361875	0.898224	-0.067958
Br	-0.693423	-2.285789	-1.442143
H	-4.595177	1.286053	-0.913115
C	1.690245	0.389319	-0.156569
C	2.938882	0.312412	0.466918
C	1.578824	1.193159	-1.303746
C	4.042650	1.004470	-0.038813
H	3.079607	-0.292665	1.360111
C	2.678049	1.888793	-1.810427
H	0.622908	1.279558	-1.821033
C	3.915973	1.796551	-1.177174

H	5.003782	0.920829	0.463911
H	2.561748	2.503001	-2.700764
H	4.773563	2.338450	-1.567227
C	0.182372	-0.756255	2.089730
C	-1.295879	-1.050128	2.246094
H	-1.696373	-1.674760	1.433652
H	-1.450732	-1.632448	3.166823
H	-1.898690	-0.141272	2.313374
C	1.023129	-2.001883	2.245420
H	0.970102	-2.348192	3.289226
H	0.660556	-2.827089	1.621498
H	2.080685	-1.838143	2.022120
C	0.641850	0.410363	2.915393
H	0.056054	1.312331	2.712999
H	0.505385	0.175876	3.982502
H	1.700101	0.640516	2.770550

^{2}IM18

E_{sol} optimization: -2990.56545170 a.u.

E_{sol} single-point: -2993.40162684 a.u.

G_{sol} thermo-corrected: -2993.34580984 a.u.

Ni	0.504067	0.024155	0.000048
C	-2.105670	-1.084305	0.000023
C	-2.080549	1.234231	-0.000006
C	-3.490160	-1.107463	0.000001
H	-1.523438	-2.000826	0.000043
C	-3.464671	1.285531	-0.000029
H	-1.479437	2.138191	-0.000008
C	-4.188971	0.096630	-0.000025
H	-4.006628	-2.061162	0.000005
H	-5.274403	0.108049	-0.000043
N	-1.395416	0.067751	0.000019
H	-3.961533	2.249583	-0.000049
Br	2.772210	0.022050	0.000067

$NiPy_3$

E_{sol} optimization: -915.811256354 a.u.

E_{sol} single-point: -915.972348218 a.u.

G_{sol} thermo-corrected: -915.756105218 a.u.

Ni	0.037177	-0.047847	-0.002286
C	2.410318	-1.136520	1.175625
C	2.443571	-1.153024	-1.138449
C	3.670008	-1.704483	1.234334
H	1.862178	-0.889390	2.081857
C	3.704714	-1.721634	-1.152118
H	1.922485	-0.919264	-2.063581
C	4.347847	-2.011282	0.052562
H	4.176905	-1.934622	-2.106742
H	5.336846	-2.457529	0.070177
N	1.767106	-0.847990	0.006802
C	-2.110426	-1.583118	1.151971
C	-2.249331	-1.360230	-1.146816
C	-3.425934	-2.087051	-1.183236
C	-3.970063	-2.582951	0.002924
C	-3.283961	-2.315070	1.188734
H	-1.555777	-1.364904	2.061524
H	-1.807657	-0.959747	-2.056377
H	-3.911088	-2.258962	-2.139545
H	-4.892185	-3.155161	0.003034
N	-1.566886	-1.090050	0.002595
H	4.114009	-1.903663	2.205291
H	-3.652919	-2.673159	2.145300
C	-0.111451	2.602369	1.127068
C	-0.316073	2.552518	-1.176744
C	-0.248751	3.979126	1.146588
H	0.031951	2.038803	2.046017
C	-0.458128	3.927797	-1.230910
H	-0.339621	1.949197	-2.081427
C	-0.426140	4.673326	-0.051188
H	-0.214020	4.500115	2.098812
H	-0.593762	4.407502	-2.195748
H	-0.535307	5.752969	-0.064908
N	-0.140420	1.860039	-0.015774

$NiPy_4$

E_{sol} optimization: -1164.08754794 a.u.

E_{sol} single-point: -1164.30169311 a.u.

G_{sol} thermo-corrected: -1164.00305411 a.u.

Ni	0.272409	0.441428	0.322710

C	-2.076380	-0.239622	2.082180
C	-1.944109	-1.548956	0.196653
C	-2.619029	-1.280703	2.825270
H	-1.912982	0.739613	2.532112
C	-2.470441	-2.646887	0.865132
H	-1.674508	-1.614644	-0.857247
C	-2.814389	-2.518921	2.211031
H	-2.620404	-3.581703	0.332719
H	-3.230355	-3.356417	2.763079
N	-1.713655	-0.351784	0.783360
C	2.584031	-1.220085	0.419310
C	0.952362	-1.955769	1.878163
C	1.703183	-3.067829	2.214904
C	2.954325	-3.265718	1.626853
C	3.388508	-2.307683	0.708766
H	2.903510	-0.461629	-0.291930
H	-0.016117	-1.780154	2.340040
H	1.306124	-3.770080	2.942421
H	3.566543	-4.125947	1.877603
N	1.354460	-1.011290	0.979497
H	-2.885602	-1.119512	3.865622
H	4.352218	-2.395893	0.215613
C	0.698211	-0.970971	-2.274304
C	0.225762	1.263772	-2.560840
C	0.736779	-1.183650	-3.644374
H	0.875145	-1.788588	-1.577277
C	0.248859	1.136473	-3.940846
H	0.026153	2.227457	-2.094150
C	0.507299	-0.112353	-4.505112
H	0.941854	-2.179461	-4.025352
H	0.063449	2.007966	-4.561241
H	0.528473	-0.245922	-5.582262
C	0.878486	3.227822	0.332511
C	-1.390378	2.817645	0.487319
C	0.657928	4.574765	0.098893
H	1.887920	2.826446	0.377800
C	-1.683480	4.153197	0.278366
H	-2.179283	2.081645	0.620153
C	-0.647038	5.067874	0.071310
H	1.510929	5.230771	-0.048870
H	-2.722431	4.470198	0.271318
H	-0.849315	6.120052	-0.101059
N	-0.123032	2.315503	0.515321
N	0.444347	0.233880	-1.711259

^{2}IM19

E_{sol} optimization: -1368.17937059 a.u.

E_{sol} single-point: -1368.37652381 a.u.

G_{sol} thermo-corrected: -1368.13421381 a.u.

Ni	-0.473777	-0.819911	0.530165
C	-2.519421	1.180640	0.692132
C	-0.920904	1.585921	-1.059179
C	-3.165262	2.379337	0.381335
H	-2.910665	0.563047	1.500314
C	-1.563256	2.786572	-1.369830
H	-0.051772	1.285370	-1.643938
C	-2.687964	3.186322	-0.650474
H	-1.185052	3.406450	-2.180084
H	-3.191454	4.118407	-0.893737
C	1.942956	0.786665	0.357785
C	2.277433	-1.135234	-0.878593
C	3.229481	1.209684	0.067893
H	1.280170	1.383474	0.977733
C	3.576286	-0.758910	-1.198746
H	1.863176	-2.071162	-1.239279
C	4.075329	0.445515	-0.719458
H	5.081517	0.785415	-0.940051
C	-1.383288	0.772643	-0.018677
H	-4.043339	2.680923	0.948579
N	1.472556	-0.376796	-0.117784
C	-1.331589	-1.844810	-0.904209
C	-2.812982	-1.921057	-0.626869
H	-3.245134	-2.791091	-1.143694
H	-3.027490	-2.047982	0.441313
H	-3.338866	-1.029324	-0.978407
C	-0.545809	-2.996612	-0.309867
H	-1.198282	-3.803907	0.037076
H	0.205881	-3.395940	-0.995491
H	0.028866	-2.728177	0.615735
C	-0.994392	-1.486841	-2.322477
H	0.076337	-1.312453	-2.470570

H	-1.281278	-2.307994	-2.996211
H	-1.535432	-0.594321	-2.649493
H	4.187917	-1.405999	-1.817502
F	3.648684	2.381473	0.566355
Cl	-0.038535	-0.688936	2.803870

^{2}IM20

E_{sol} optimization: -1402.92826413 a.u.

E_{sol} single-point: -1403.12279249 a.u.

G_{sol} thermo-corrected: -1402.80438249 a.u.

Ni	-1.191504	-0.785981	0.484454
C	-3.173625	1.274247	0.527119
C	-1.365620	1.730085	-0.991685
C	-3.741436	2.514169	0.227161
H	-3.675576	0.620990	1.240594
C	-1.930099	2.972276	-1.292147
H	-0.439347	1.435585	-1.484549
C	-3.119899	3.367781	-0.683429
H	-1.438915	3.629342	-2.007021
H	-3.561152	4.332965	-0.918464
C	1.322888	0.686888	0.657794
C	1.703363	-1.240025	-0.522889
C	2.648951	1.051510	0.598160
H	0.603295	1.320681	1.171485
C	3.049718	-0.968654	-0.637437
H	1.300459	-2.150579	-0.958723
C	3.577856	0.215537	-0.069003
C	-1.973350	0.868678	-0.071681
H	-4.670867	2.812527	0.707877
N	0.821443	-0.441194	0.109934
C	-1.900172	-1.702319	-1.095994
C	-3.408469	-1.698127	-1.047472
H	-3.805798	-2.521827	-1.659788
H	-3.788931	-1.846508	-0.029477
H	-3.825654	-0.764144	-1.433849
C	-1.280472	-2.924269	-0.446916
H	-2.027288	-3.688437	-0.210577
H	-0.478469	-3.362888	-1.046289
H	-0.804616	-2.720521	0.548386
C	-1.333491	-1.312950	-2.430892
H	-0.242644	-1.223572	-2.414943
H	-1.583827	-2.074884	-3.184439
H	-1.750244	-0.363631	-2.780283
H	2.960473	1.975100	1.071256
H	3.682804	-1.673844	-1.162625
N	4.892579	0.529508	-0.154561
C	5.817888	-0.387050	-0.792149
H	5.553118	-0.559456	-1.841676
H	6.819812	0.038359	-0.760286
H	5.841335	-1.358250	-0.282805
C	5.394220	1.733636	0.479050
H	5.257841	1.708625	1.567393
H	6.458517	1.829028	0.269447
H	4.890072	2.627152	0.094259
Cl	-1.155291	-0.807120	2.812191

TS1

E_{sol} optimization: -910.572329118 a.u.

E_{sol} single-point: -910.727816771 a.u.

G_{sol} thermo-corrected: -910.511242771 a.u.

Imaginary frequency: -147.6490 cm^{-1}

C	2.533496	-0.125872	-1.650797
C	2.449072	-2.029227	-0.330315
C	3.911793	-0.218552	-1.754496
H	1.975384	0.671251	-2.134527
C	3.819542	-2.182220	-0.391817
H	1.827311	-2.731057	0.219343
C	4.580246	-1.257051	-1.111712
H	5.659812	-1.350834	-1.182328
C	-2.587803	-2.006909	-0.239571
C	-2.712501	-0.043969	-1.457998
C	-3.970335	-2.120930	-0.220609
H	-1.953708	-2.743259	0.245484
C	-4.099704	-0.097695	-1.481127
H	-2.180093	0.778649	-1.935426
C	-4.756041	-1.158238	-0.849485
H	-5.842014	-1.225498	-0.853596
N	1.771444	-1.010305	-0.932653
N	-1.945004	-0.965435	-0.840037
C	0.126408	0.660424	1.319069

C	1.378273	0.311837	1.857027
C	1.433739	-0.642139	2.882042
C	0.245818	-1.193633	3.400225
C	-1.071439	0.163814	1.879508
C	-0.993646	-0.770346	2.899013
H	2.300332	0.711650	1.444485
H	0.291858	-1.925109	4.198251
H	-2.033291	0.497858	1.494481
H	-1.926285	-1.184305	3.310651
Ni	-0.071173	-0.786588	-0.665020
I	0.024797	2.383874	-0.030401
H	2.397863	-0.950486	3.266584
H	4.282248	-3.019506	0.121650
H	-4.426209	-2.970831	0.280119
H	-4.650777	0.691490	-1.990827
H	4.449539	0.523547	-2.337480

^{2}TS2

E_{sol} optimization: -1517.22539120 a.u.

E_{sol} single-point: -1517.44238935 a.u.

G_{sol} thermo-corrected: -1517.10554235 a.u.

Imaginary frequency: -249.7020 cm^{-1}

Ni	0.274256	-0.363108	-0.659866
C	2.333121	1.520371	-0.330059
C	1.663178	0.486916	1.742444
C	2.896288	2.579380	0.381338
H	2.380056	1.529510	-1.418628
C	2.222024	1.546447	2.448992
H	1.215772	-0.342084	2.288913
C	2.845035	2.600754	1.774848
H	2.180252	1.546790	3.536418
H	3.291840	3.421004	2.329900
C	-1.602326	-2.365261	0.620082
C	-1.468533	-0.387945	1.793835
C	-2.609196	-2.839619	1.450512
H	-1.241533	-2.948478	-0.222625
C	-2.470572	-0.784933	2.668197
H	-0.992893	0.585921	1.888174
C	-3.053054	-2.036889	2.496071
H	-3.035771	-3.820718	1.270534
H	-3.840609	-2.377992	3.161452
C	-0.833517	2.531799	-0.527353
C	-2.417714	0.960359	-1.092787
C	-1.782758	3.546318	-0.503406
H	0.211721	2.733871	-0.301229
C	-3.428848	1.911269	-1.085172
H	-2.615151	-0.083144	-1.326742
C	-3.107354	3.231962	-0.786272
H	-4.448138	1.615580	-1.310999
H	-3.875037	4.000267	-0.772688
N	-1.028531	-1.160759	0.785021
C	1.682123	0.458548	0.332911
H	3.376769	3.392481	-0.159043
N	-1.134424	1.257227	-0.819619
C	2.311712	-1.382056	-0.454237
C	2.746840	-1.229398	-1.899510
H	3.457939	-2.032911	-2.145910
H	1.915364	-1.295426	-2.607141
H	3.275565	-0.285297	-2.065716
C	1.595230	-2.699010	-0.192701
H	2.323677	-3.522018	-0.281385
H	1.187492	-2.749828	0.822757
H	0.791442	-2.895502	-0.907573
C	3.548489	-1.349490	0.434590
H	3.308948	-1.481546	1.493666
H	4.199272	-2.186424	0.139848
H	4.126279	-0.426138	0.328346
H	-2.784991	-0.118543	3.464375
H	-1.481123	4.560248	-0.262106
Cl	-0.699215	-1.477942	-2.579889

^{2}TS3

E_{sol} optimization: -1268.94449960 a.u.

E_{sol} single-point: -1269.10819970 a.u.

G_{sol} thermo-corrected: -1268.85544370 a.u.

Imaginary frequency: -219.6446 cm^{-1}

Ni	0.019030	-0.816445	-0.386244
C	2.373361	0.535615	-1.010234
C	1.055270	1.671480	0.666441
C	3.031237	1.731739	-1.297959

H	2.645559	-0.367683	-1.554360
C	1.720864	2.859103	0.382650
H	0.292131	1.652380	1.443080
C	2.711817	2.895993	-0.601434
H	1.468083	3.761891	0.934178
H	3.235129	3.823657	-0.816211
C	-1.913770	1.399839	-0.460398
C	-2.700957	-0.364658	0.799073
C	-3.114597	2.083682	-0.333200
H	-1.082206	1.817418	-1.022746
C	-3.928875	0.256490	0.979980
H	-2.500955	-1.345094	1.223291
C	-4.142202	1.505300	0.405097
H	-4.699992	-0.238265	1.560674
H	-5.092401	2.016359	0.527238
C	1.353582	0.495195	-0.043931
H	3.800124	1.749119	-2.067002
N	-1.698796	0.195424	0.099013
C	1.425546	-1.200145	1.172230
C	2.064328	-2.361035	0.428293
H	2.454463	-3.082895	1.159867
H	1.363055	-2.906636	-0.214812
H	2.910621	-2.036359	-0.184722
C	0.238148	-1.637194	2.021045
H	0.607969	-2.257368	2.852302
H	-0.285926	-0.783799	2.463704
H	-0.487105	-2.254497	1.476062
C	2.453695	-0.541958	2.077056
H	2.034642	0.291839	2.646140
H	2.797710	-1.296073	2.799409
H	3.329191	-0.179776	1.530616
H	-3.233747	3.052013	-0.807317
Cl	-0.821312	-2.111789	-2.055052

^{2r}TS4

E_{sol} optimization: -3608.60352516 a.u.

E_{sol} single-point: -3611.50212359 a.u.

G_{sol} thermo-corrected: -3611.34108059 a.u.

Imaginary frequency: -68.1343 cm^{-1}

Ni	0.003659	0.873579	-0.602590
C	1.949005	-1.333490	-0.495274
C	2.691933	0.598499	0.537059
C	3.118775	-2.004679	-0.172446
H	1.142315	-1.816652	-1.040892
C	3.887520	-0.005185	0.897822
H	2.469933	1.631160	0.793392
C	4.107760	-1.330743	0.537533
H	4.628425	0.561300	1.451409
H	5.033772	-1.830504	0.805318
N	1.732310	-0.050114	-0.149239
Br	-1.480811	-0.696579	-1.437477
C	-2.206521	-0.633317	1.574509
C	-3.040789	-1.847415	1.459941
H	-3.499375	-2.059772	2.440128
H	-3.862217	-1.722315	0.750187
H	-2.454990	-2.730484	1.190981
C	-0.844279	-0.774241	2.133301
H	-0.258207	-1.523529	1.588314
H	-0.292642	0.170423	2.150585
H	-0.911158	-1.150293	3.168001
C	-2.861303	0.689037	1.527764
H	-3.350261	0.882958	2.497922
H	-2.150867	1.505126	1.361315
H	-3.651177	0.729785	0.772648
H	3.244561	-3.038838	-0.474180
Cl	0.158767	2.971275	0.163087

^{2}TS5

E_{sol} optimization: -3628.22880078 a.u.

E_{sol} single-point: -3631.21139838 a.u.

G_{sol} thermo-corrected: -3630.88843038 a.u.

Imaginary frequency: -229.0327 cm^{-1}

Ni	-0.942094	0.130576	0.414653
C	-3.705390	-0.859058	-0.148783
C	-2.726400	0.127655	-1.992614
C	-4.876438	-1.108506	-0.850502
H	-3.595423	-1.153449	0.892204
C	-3.858614	-0.091034	-2.765065
H	-1.845415	0.614604	-2.404024
C	-4.956048	-0.718464	-2.183941

H	-5.705836	-1.602121	-0.355556
H	-5.857593	-0.901986	-2.760590
C	-0.543688	-2.785402	-0.084621
C	-0.508119	-2.180643	2.146770
C	-0.282105	-4.111325	0.227809
H	-0.673130	-2.458705	-1.113810
C	-0.253448	-3.485732	2.541340
H	-0.598955	-1.375156	2.872236
C	-0.131923	-4.469188	1.564378
H	-0.149859	-3.719409	3.595280
H	0.073722	-5.498999	1.840151
N	-2.644772	-0.247667	-0.703988
N	-0.646569	-1.827947	0.854850
H	-0.200394	-4.845501	-0.566314
H	-3.872151	0.227226	-3.801895
C	-0.930467	2.068321	0.661884
C	-0.643335	2.602474	1.935962
C	-1.133446	3.012273	-0.363326
C	-0.550163	3.975940	2.171836
H	-0.466794	1.925292	2.775581
C	-1.041898	4.388775	-0.146447
H	-1.360486	2.667297	-1.374705
C	-0.746412	4.877015	1.126137
H	-0.319382	4.344011	3.170219
H	-1.199043	5.083253	-0.970159
H	-0.672025	5.947724	1.301221
C	2.000375	0.401782	0.128558
C	2.383205	1.822686	0.293218
H	2.327734	2.149380	1.337467
H	3.432561	1.910117	-0.028863
H	1.782611	2.496216	-0.325978
C	1.351172	-0.038543	-1.103515
H	1.653168	0.563217	-1.965775
H	1.497169	-1.100136	-1.312264
H	0.225155	0.119397	-1.082810
C	2.335401	-0.539504	1.222541
H	3.399416	-0.439741	1.470197
H	1.773537	-0.301844	2.139932
H	2.143359	-1.581833	0.955747
Br	4.872358	-0.272366	-1.235529

^{2}TS6

E_{sol} optimization: -3379.96780330 a.u.

E_{sol} single-point: -3382.88526909 a.u.

G_{sol} thermo-corrected: -3382.64146109 a.u.

Imaginary frequency: -173.0912 cm^{-1}

Ni	-0.198776	-0.103220	-0.663386
C	0.020541	2.612548	0.531177
C	-2.013038	2.203153	-0.481632
C	-0.371077	3.891814	0.897752
H	1.010637	2.229394	0.768530
C	-2.476122	3.472030	-0.163259
H	-2.632514	1.488969	-1.019163
C	-1.642931	4.333623	0.543720
H	-3.475193	3.770574	-0.462666
H	-1.977757	5.330606	0.813894
N	-0.782830	1.770705	-0.145524
Br	2.134344	0.162723	-1.058191
C	2.868091	-1.105749	1.045065
C	4.334161	-0.909792	0.953940
H	4.803032	-1.411812	1.814699
H	4.759576	-1.359829	0.053623
H	4.617199	0.144200	1.006425
C	2.112684	-0.312494	2.043462
H	2.506032	0.700216	2.161764
H	1.043620	-0.267977	1.792264
H	2.187800	-0.815824	3.019152
C	2.317863	-2.439921	0.704630
H	2.474399	-3.109157	1.564251
H	1.236136	-2.397831	0.527431
H	2.813562	-2.891535	-0.157672
H	0.315093	4.527744	1.447113
C	-1.674464	-1.280025	-0.205658
C	-1.741477	-2.602659	-0.705011
C	-2.721730	-0.919376	0.671267
C	-2.767741	-3.488229	-0.370613
H	-0.962850	-2.958757	-1.383611
C	-3.753187	-1.792129	1.020963
H	-2.735305	0.084814	1.101346
C	-3.781905	-3.084913	0.497577
H	-2.776749	-4.495350	-0.784615

H	-4.537390	-1.466308	1.702819
H	-4.583804	-3.769510	0.764324

^{2}TS7

E_{sol} optimization: -3379.99605718 a.u.

E_{sol} single-point: -3382.91291753 a.u.

G_{sol} thermo-corrected: -3382.66126353 a.u.

Imaginary frequency: -221.3248 cm^{-1}

Ni	-0.008155	-0.609187	0.033214
C	2.473777	0.060559	-1.043910
C	1.454300	1.884360	0.168695
C	3.276544	0.971314	-1.730972
H	2.570483	-1.002177	-1.260080
C	2.262028	2.787585	-0.513866
H	0.752486	2.247874	0.917581
C	3.178269	2.336311	-1.466829
H	2.179703	3.850684	-0.298988
H	3.813608	3.043329	-1.993134
C	-2.538023	0.603637	1.101424
C	-1.624022	1.737881	-0.685688
C	-3.656160	1.425819	1.106689
H	-2.439555	-0.210280	1.814594
C	-2.711581	2.596948	-0.753183
H	-0.790913	1.826010	-1.378737
C	-3.747235	2.443751	0.163034
H	-4.438901	1.261864	1.839513
H	-4.610033	3.102574	0.139466
N	-1.526204	0.755849	0.228823
C	1.529221	0.506476	-0.103073
H	3.983792	0.608354	-2.473189
C	1.443157	-0.684438	1.604546
C	1.949805	-2.075555	1.263940
H	2.246509	-2.582325	2.193231
H	1.195459	-2.707410	0.779773
H	2.833746	-2.042276	0.620498
C	0.244030	-0.729585	2.547125
H	0.578926	-1.122384	3.519853
H	-0.175881	0.265001	2.728038
H	-0.558034	-1.398257	2.207987
C	2.547036	0.120038	2.269501
H	2.221481	1.126629	2.544926
H	2.832439	-0.399235	3.195710
H	3.441287	0.207167	1.645627
H	-2.737731	3.370477	-1.513358
Br	-1.099256	-2.331141	-1.180733

^{2}TS8

E_{sol} optimization: -1368.16448876 a.u.

E_{sol} single-point: -1368.36074568 a.u.

G_{sol} thermo-corrected: -1368.11787868 a.u.

Imaginary frequency: -218.8999 cm^{-1}

Ni	-0.380022	-0.866836	0.417781
C	-2.358650	0.998708	0.990912
C	-0.876247	1.721788	-0.775636
C	-2.728274	2.324427	1.218183
H	-2.802665	0.209022	1.594819
C	-1.254474	3.041135	-0.550106
H	-0.163018	1.492137	-1.565637
C	-2.182221	3.349519	0.447522
H	-0.825676	3.834218	-1.158434
H	-2.480896	4.380331	0.616881
C	2.014474	0.835137	0.244033
C	2.329506	-1.188085	-0.825703
C	3.343387	1.165433	0.031200
H	1.344293	1.515161	0.762164
C	3.666368	-0.903291	-1.070790
H	1.888654	-2.128217	-1.142840
C	4.199035	0.304376	-0.635147
H	5.236795	0.573942	-0.798769
C	-1.403792	0.681719	0.009430
H	-3.449593	2.553371	1.999210
N	1.512639	-0.332336	-0.186621
C	-1.881825	-1.026661	-1.088622
C	-2.776979	-1.928451	-0.256222
H	-3.309057	-2.617220	-0.927443
H	-2.225968	-2.549071	0.461539
H	-3.535057	-1.360859	0.291158
C	-0.854948	-1.819708	-1.890231
H	-1.384228	-2.391970	-2.667881
H	-0.138353	-1.168575	-2.401087

H	-0.303139	-2.555516	-1.291349
C	-2.723365	-0.211329	-2.055440
H	-2.115233	0.438520	-2.690149
H	-3.253074	-0.914108	-2.714389
H	-3.473190	0.404021	-1.550348
H	4.283577	-1.623778	-1.596108
F	3.793197	2.345187	0.483715
Cl	0.208660	-2.156980	2.192553

^{2}TS9

E_{sol} optimization: -1402.91266410 a.u.

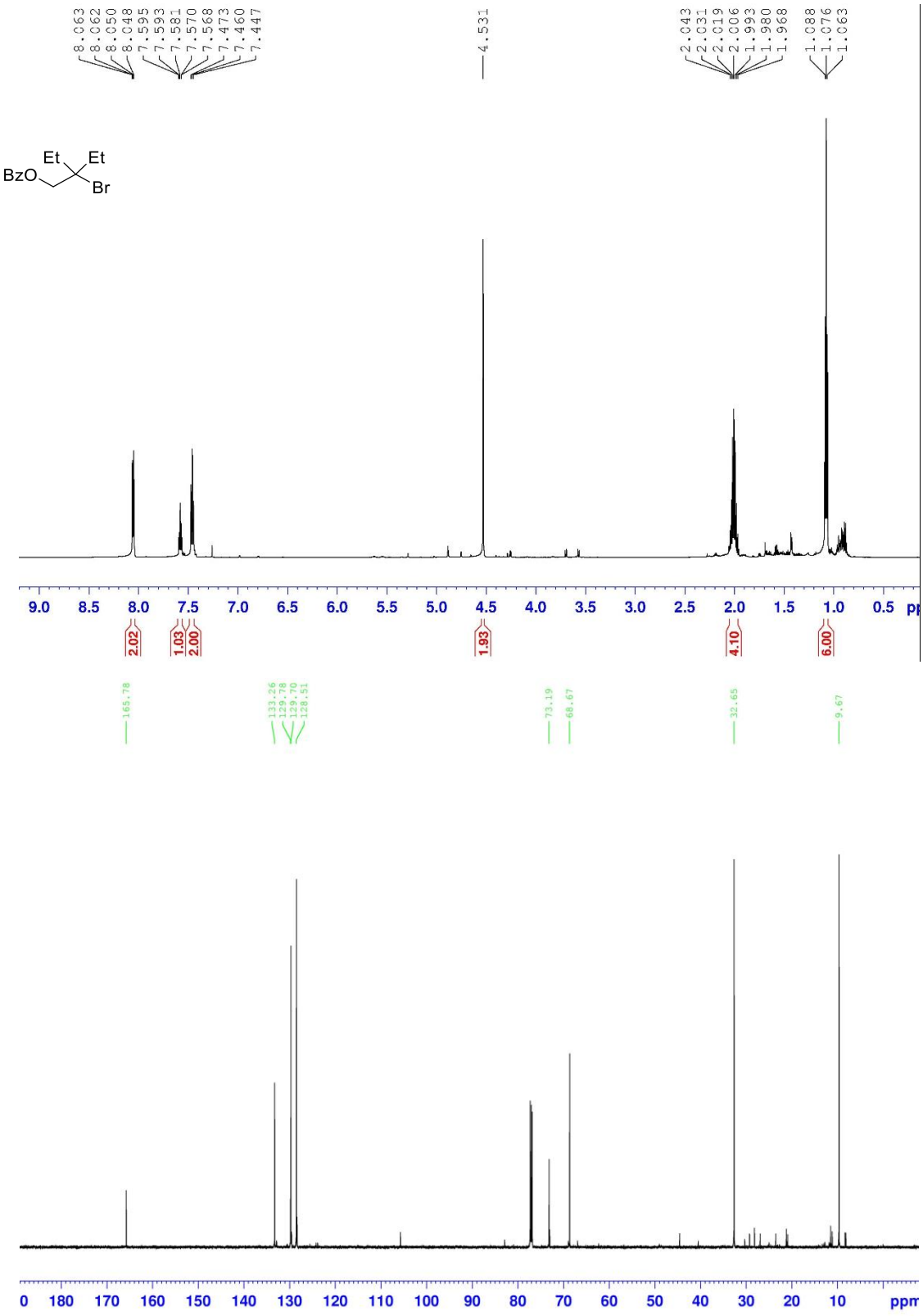
E_{sol} single-point: -1403.10626129 a.u.

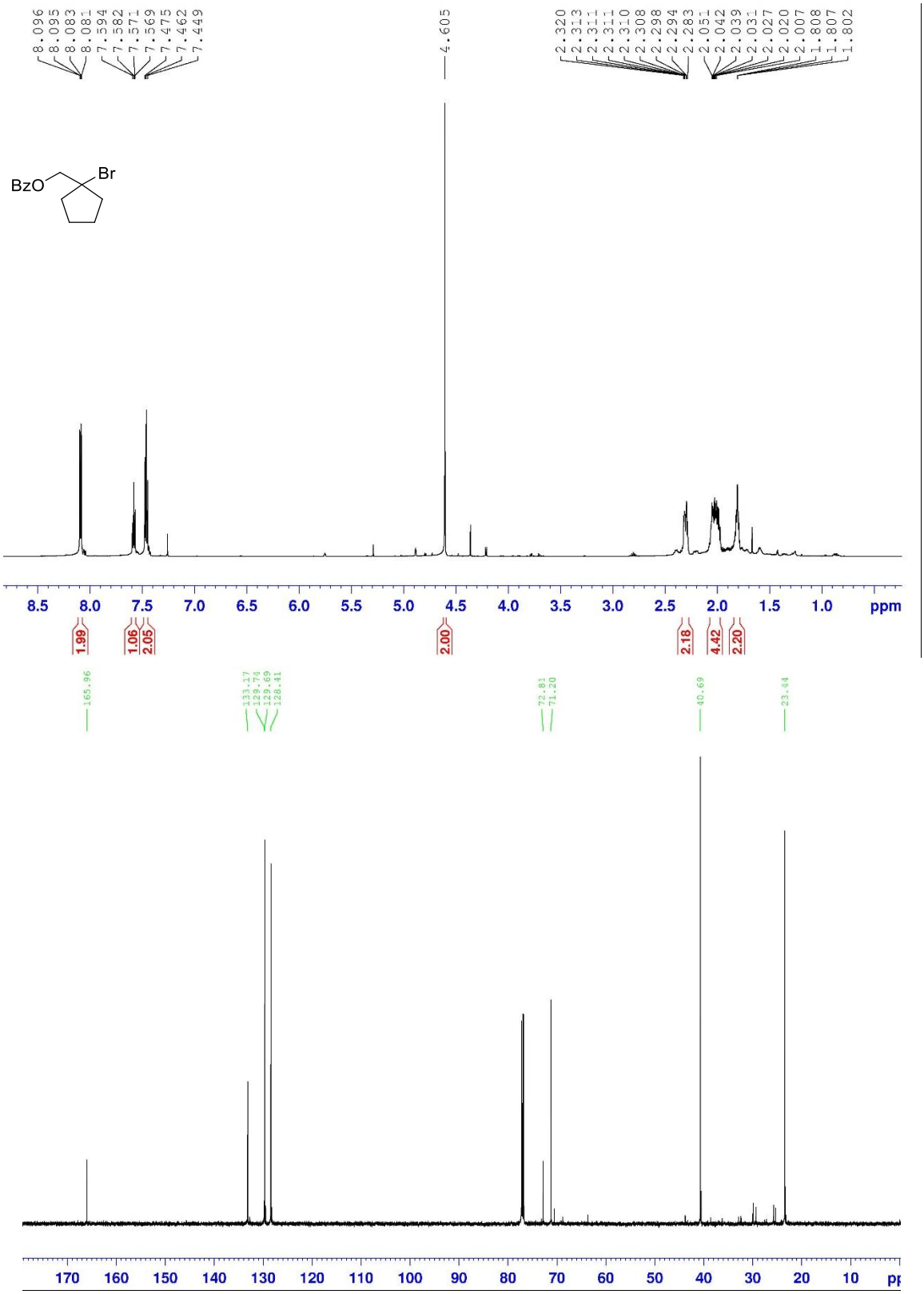
G_{sol} thermo-corrected: -1402.78605529 a.u.

Imaginary frequency: -222.2111 cm^{-1}

Ni	1.089530	-0.842509	-0.413337
C	3.071699	1.054698	-0.845956
C	1.353551	1.833406	0.663560
C	3.432437	2.375619	-1.111833
H	3.612642	0.245574	-1.334528
C	1.722896	3.148491	0.401961
H	0.547801	1.627683	1.366426
C	2.763834	3.427221	-0.487175
H	1.197672	3.962628	0.896428
H	3.053924	4.455402	-0.685266
C	-1.398336	0.776141	-0.570233
C	-1.740656	-1.236563	0.469562
C	-2.738614	1.091914	-0.521239
H	-0.691454	1.468076	-1.022334
C	-3.096214	-1.014504	0.574779
H	-1.314409	-2.164747	0.843076
C	-3.650879	0.190169	0.078103
H	-3.717261	-1.773183	1.036154
C	2.004834	0.764107	0.023033
H	4.243124	2.580413	-1.807386
N	-0.869198	-0.363554	-0.078118
C	2.386856	-0.844621	1.289550
C	3.384595	-1.798499	0.653685
H	3.872114	-2.384895	1.445611
H	2.923044	-2.514463	-0.036750
H	4.175397	-1.265100	0.117461
C	1.276100	-1.582301	2.027986
H	1.709683	-2.080303	2.909449
H	0.499531	-0.900754	2.390005
H	0.801449	-2.370882	1.430883
C	3.104094	0.062194	2.276418
H	2.423271	0.757642	2.774157
H	3.554036	-0.572989	3.053022
H	3.907176	0.641704	1.811937
H	-3.071208	2.032169	-0.944638
N	-4.975138	0.462528	0.169507
C	-5.875551	-0.501932	0.770402
H	-5.591977	-0.724582	1.805599
H	-6.884921	-0.093090	0.776075
H	-5.891398	-1.445918	0.211958
C	-5.501719	1.696400	-0.380271
H	-5.334915	1.762696	-1.462338
H	-6.574290	1.738581	-0.197348
H	-5.040941	2.573243	0.089451
Cl	0.882461	-2.312300	-2.141610

II. NMR Data for New Compounds

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2.313
2.311
2.310
2.308
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2.283
2.042
2.039
2.027
2.020
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1.807
1.802
BzO
Br
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7.5
7.0
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6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
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129.69
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71.20
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20
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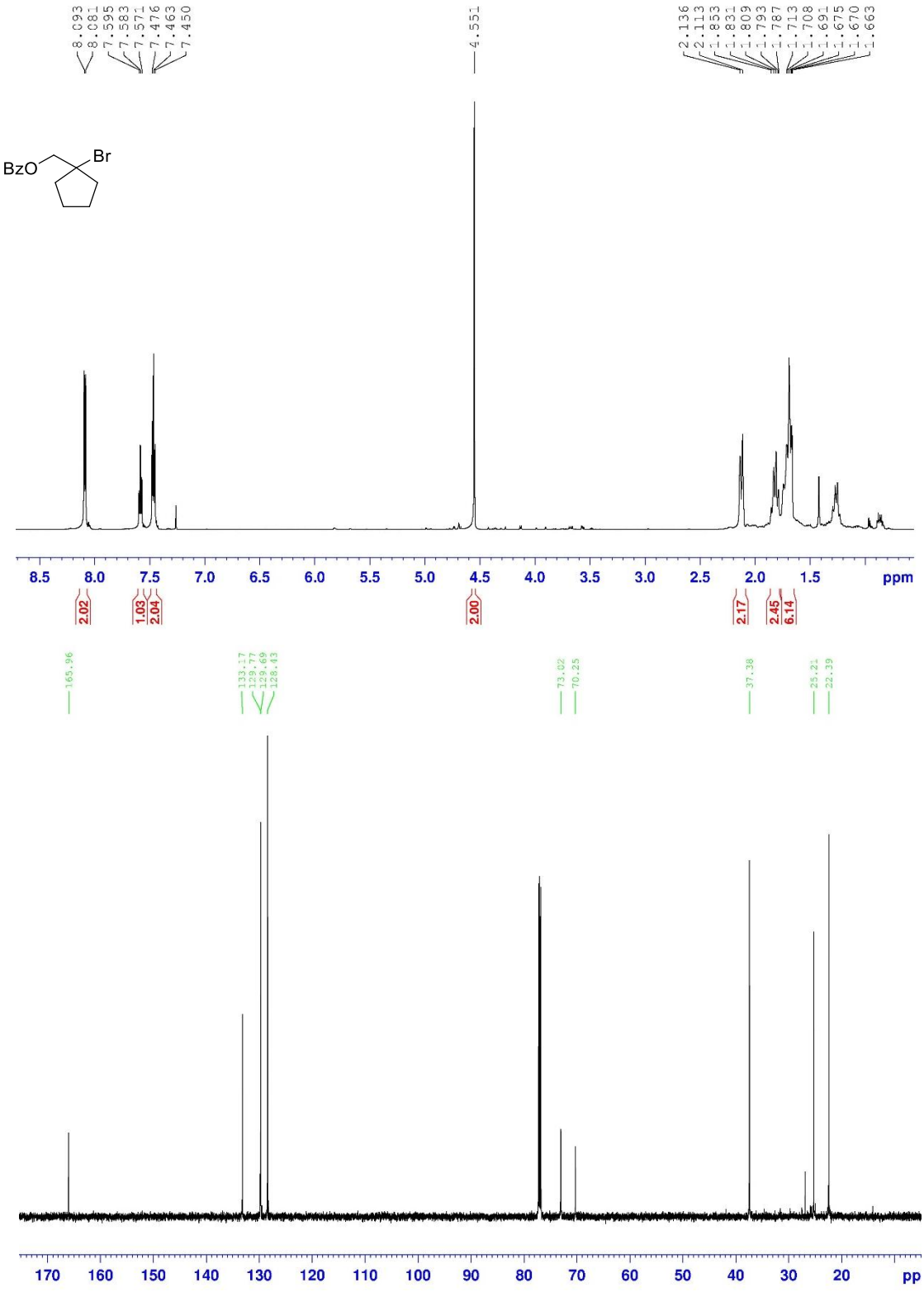
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1.831
1.809
1.793
1.787
1.713
1.708
1.691
1.675
1.670
1.663
BzO
Br
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8.0
7.5
7.0
6.5
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5.5
5.0
4.5
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3.0
2.5
2.0
1.5
ppm
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2.04
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2.45
6.14
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133.17
129.77
129.69
128.43
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37.38
25.21
22.39
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20
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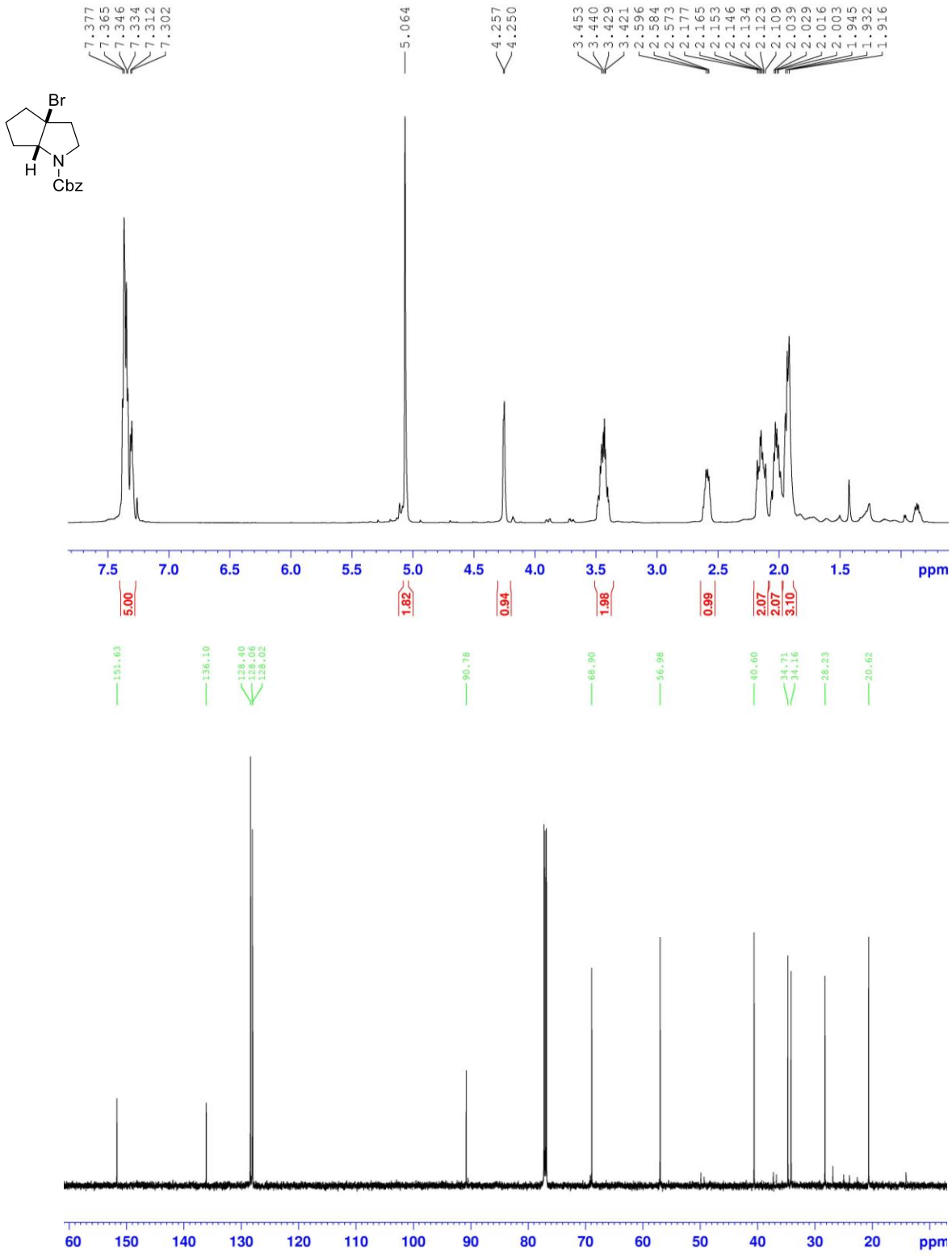
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2.573
2.177
2.165
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2.134
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2.109
2.039
2.029
2.016
2.003
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1.932
1.916
Br
H
N
Cbz
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4.0
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151.63
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128.06
128.02
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56.98
40.60
34.71
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120
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50
40
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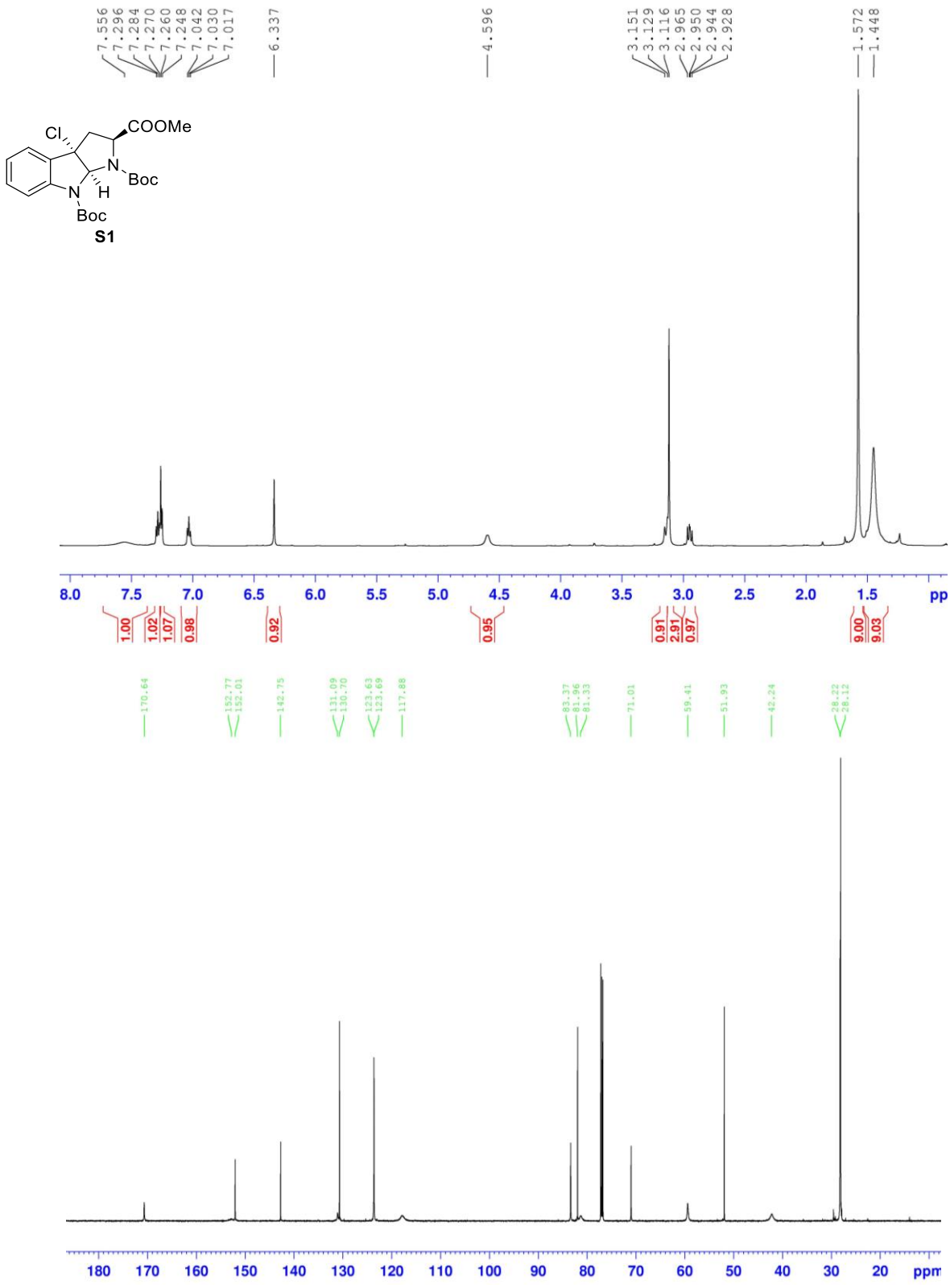
20
ppm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3.116
2.965
2.950
2.944
2.928
1.572
1.448
Cl
COOMe
N
Boc
N
H
Boc
S1
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7.5
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6.0
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4.5
4.0
3.5
3.0
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pp
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0.95
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2.91
0.97
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9.03
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123.69
117.88
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81.96
81.33
71.01
59.41
51.93
42.24
28.22
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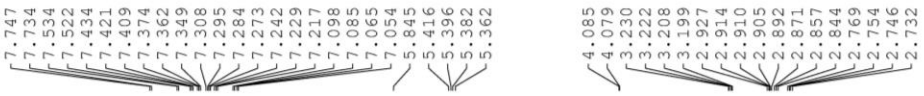
40
30
20
ppm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7.229
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7.098
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7.054
5.845
5.416
5.396
5.382
5.362
4.085
4.079
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3.222
3.208
3.199
2.927
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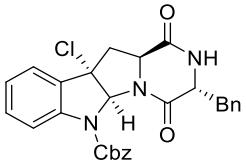
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Cl
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Bn
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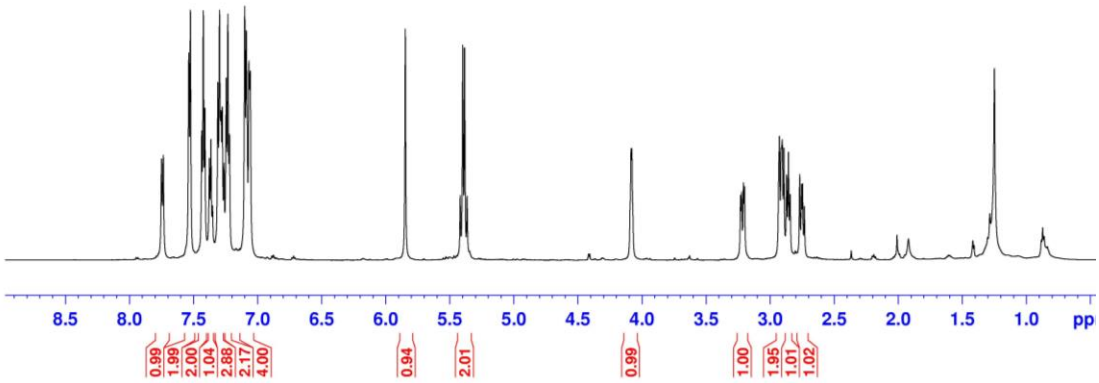
Cbz

S3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0.99
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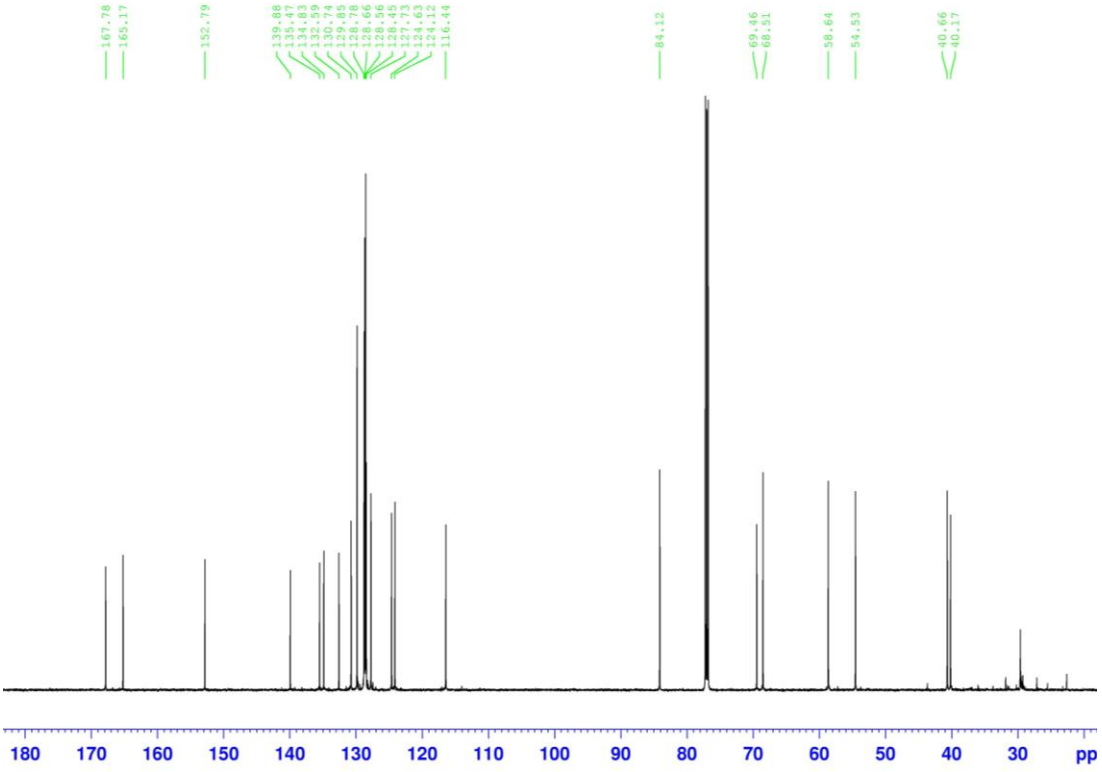
1.95
1.01
1.02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58.64
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50
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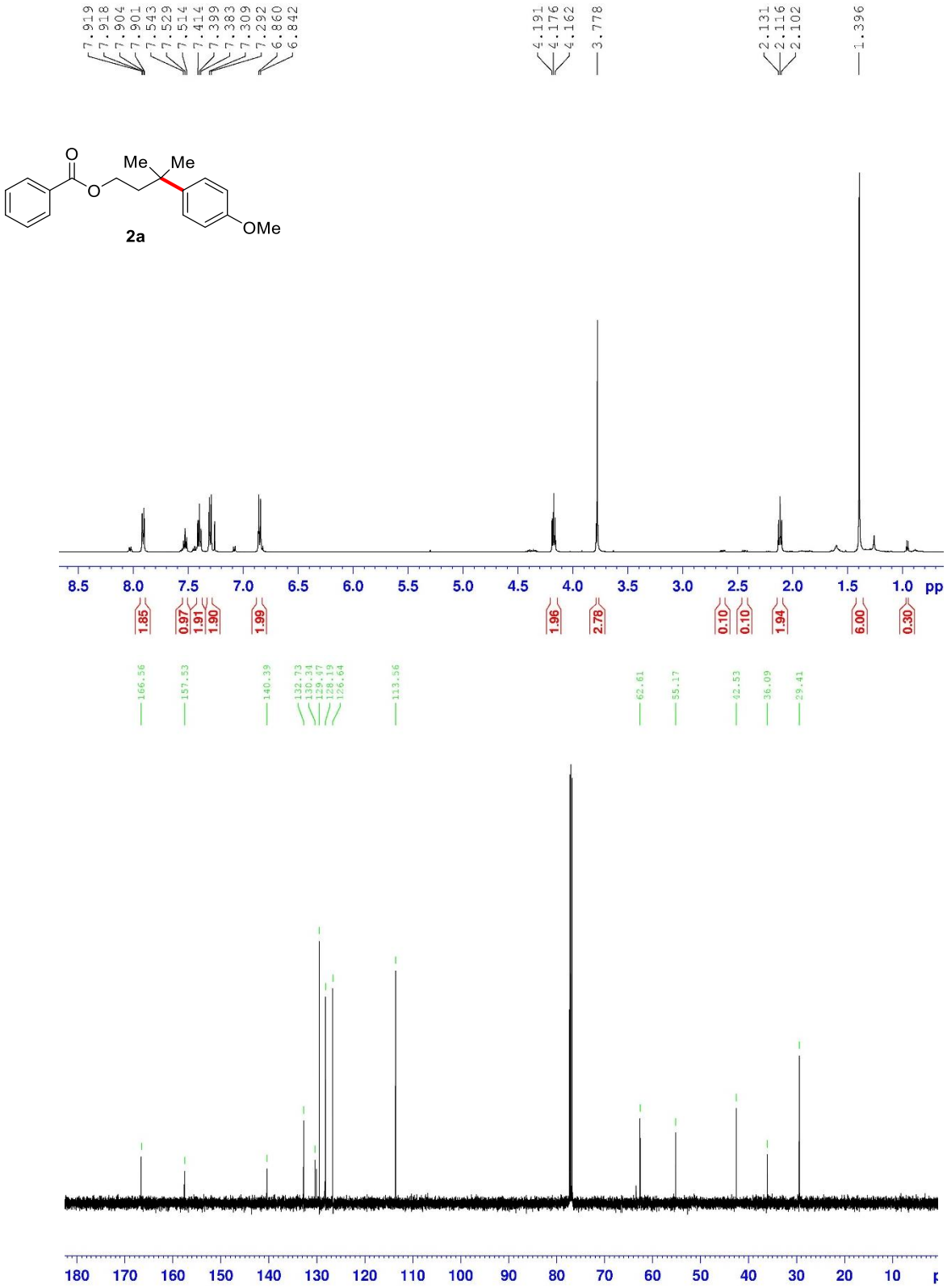
ppm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6.842
4.191
4.176
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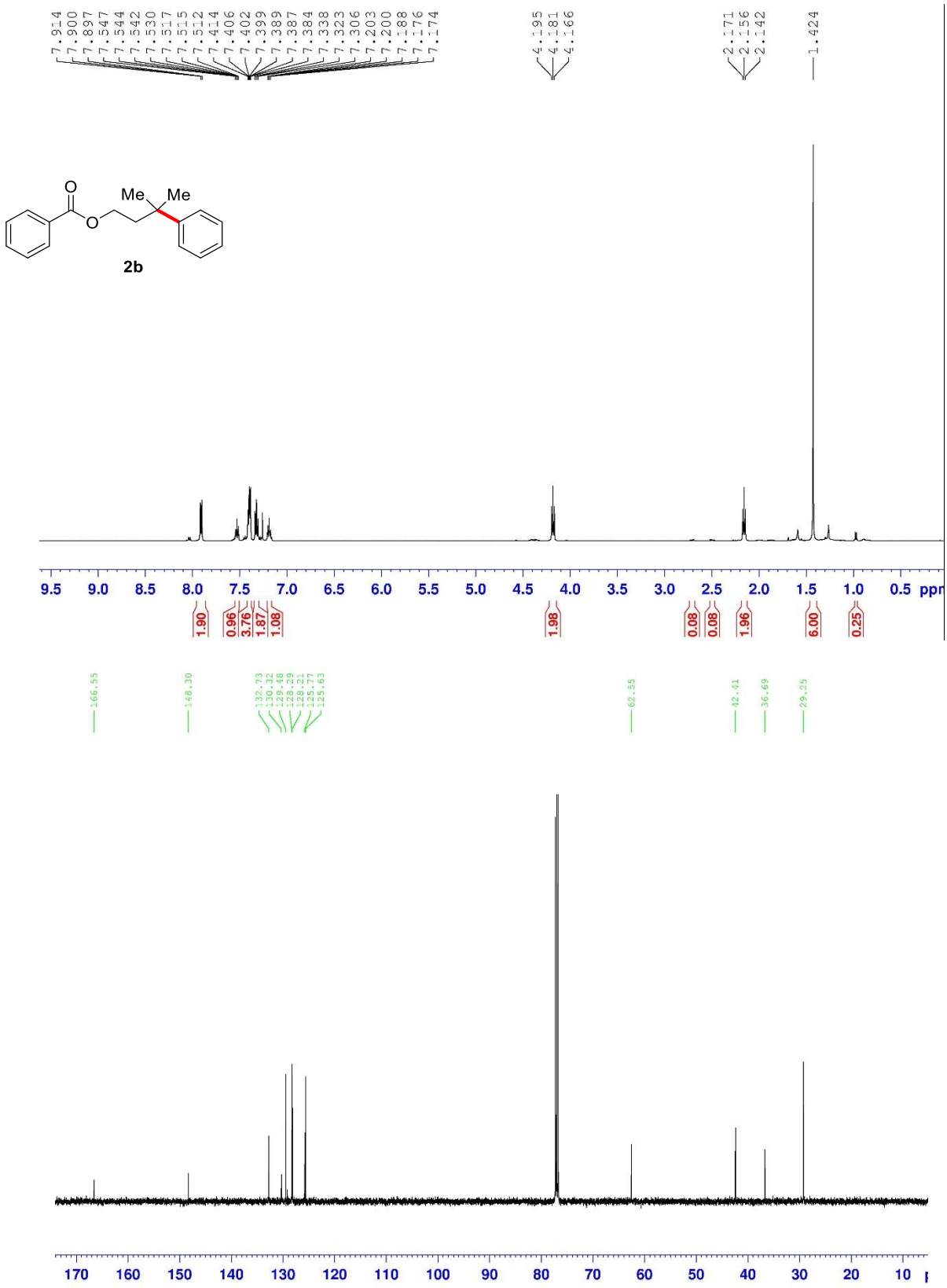
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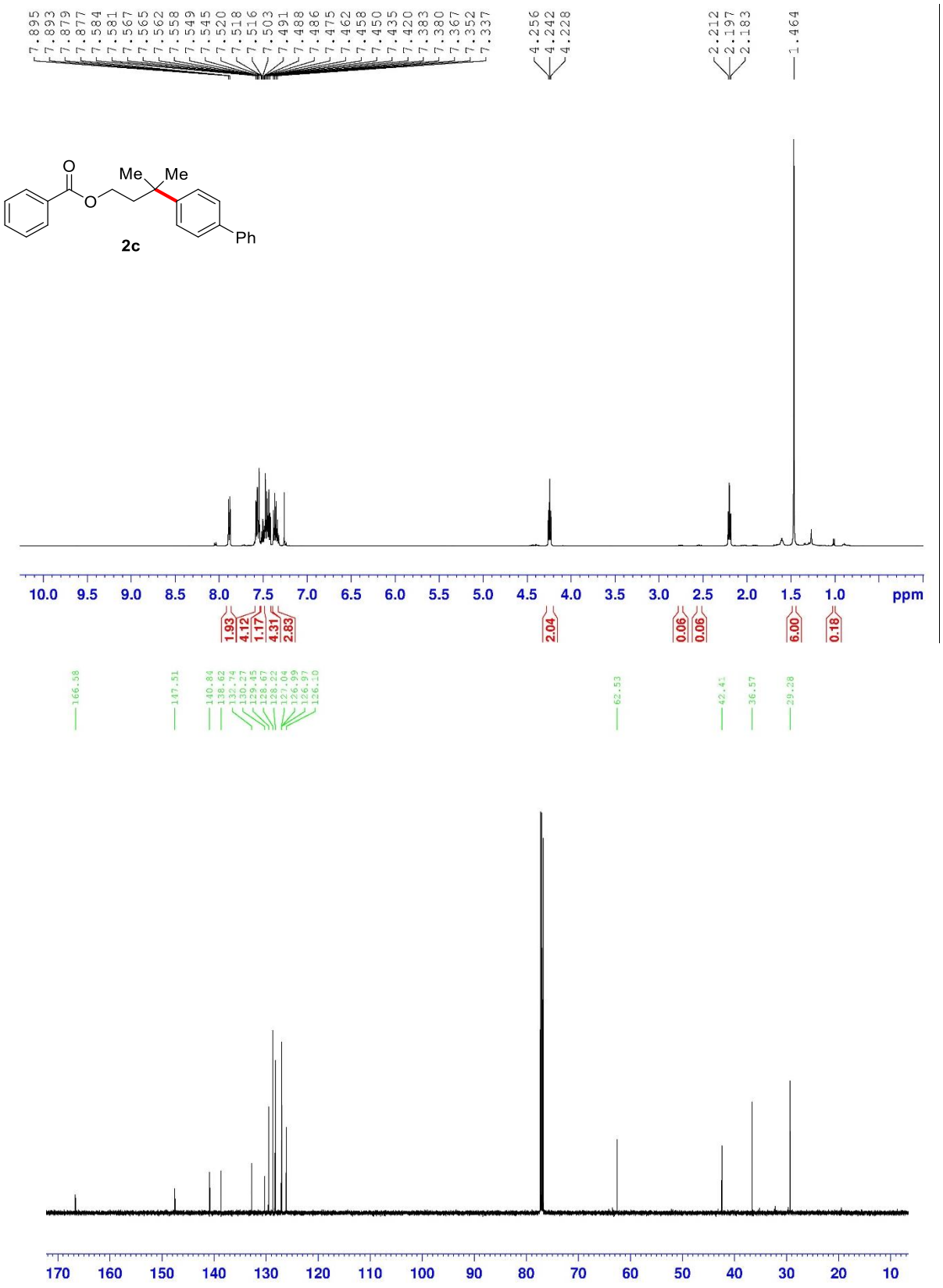
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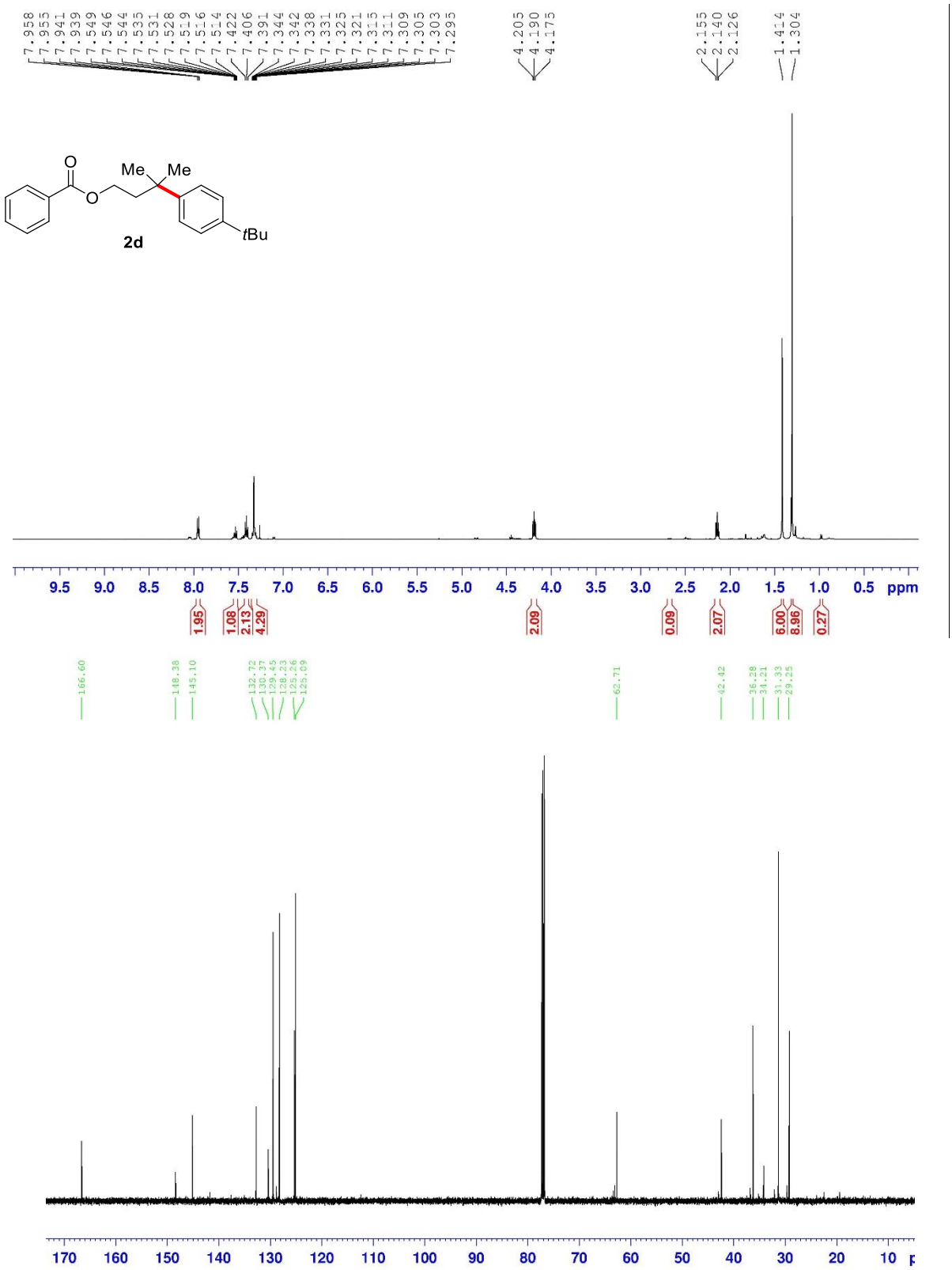
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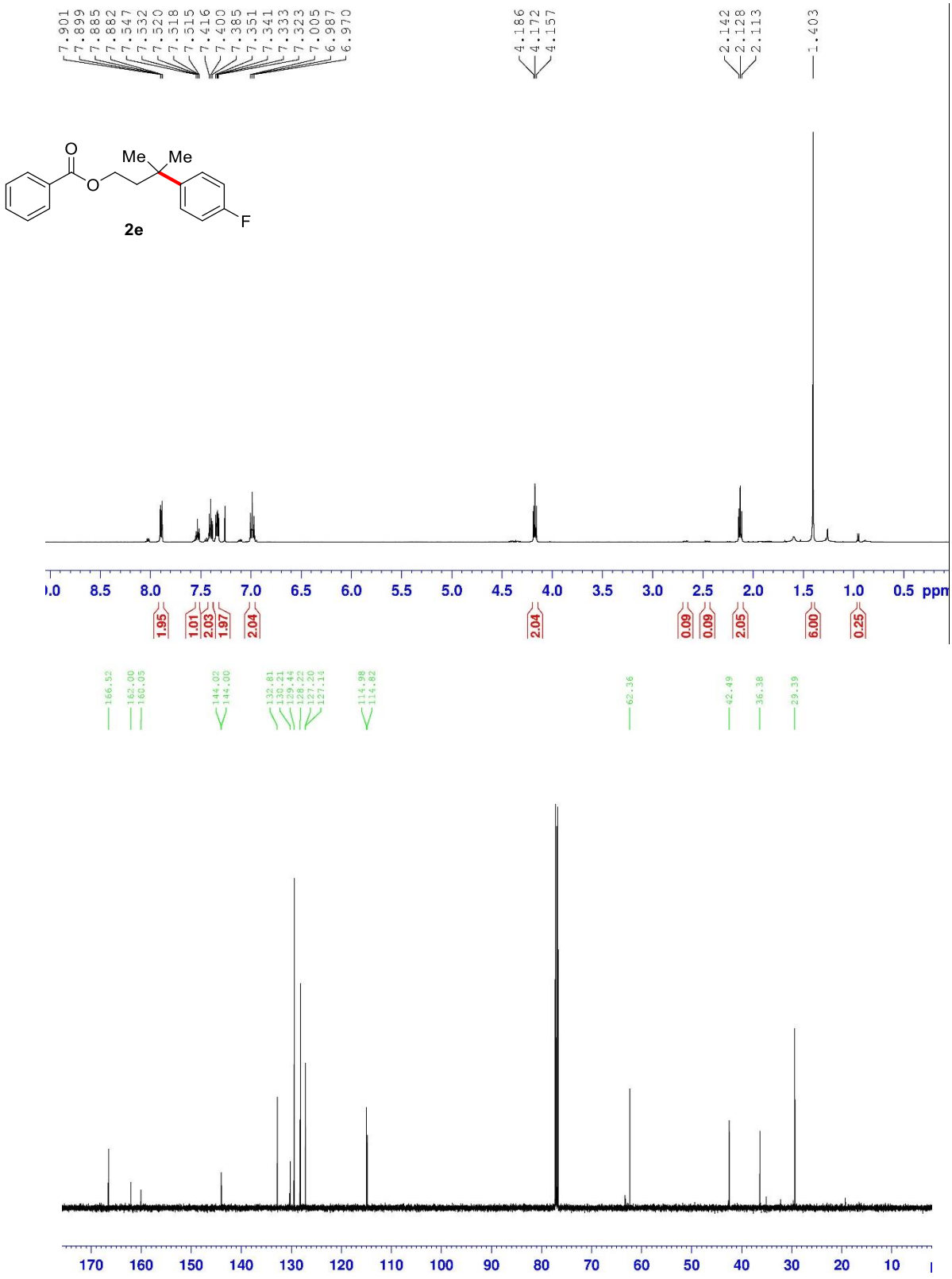
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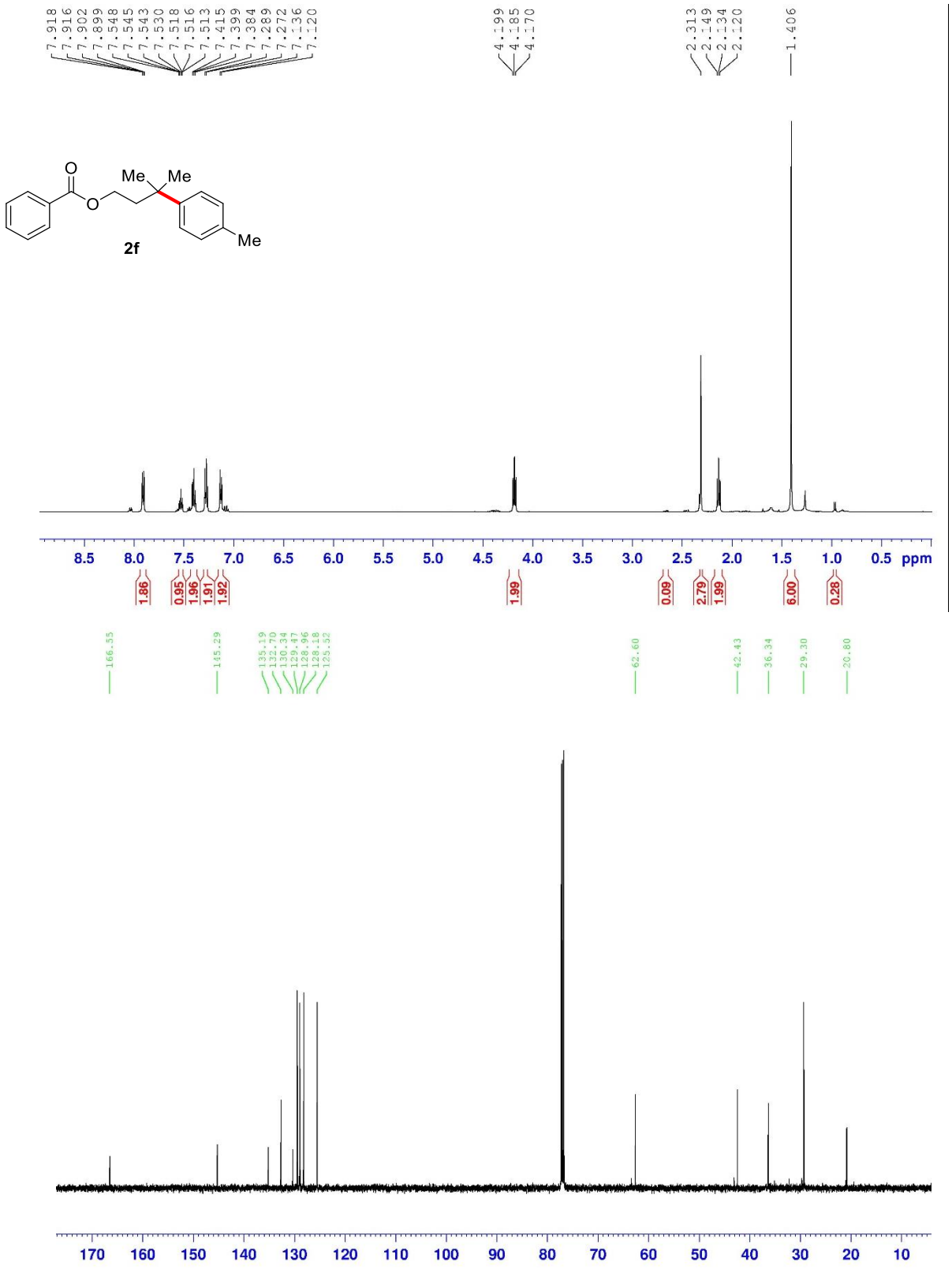
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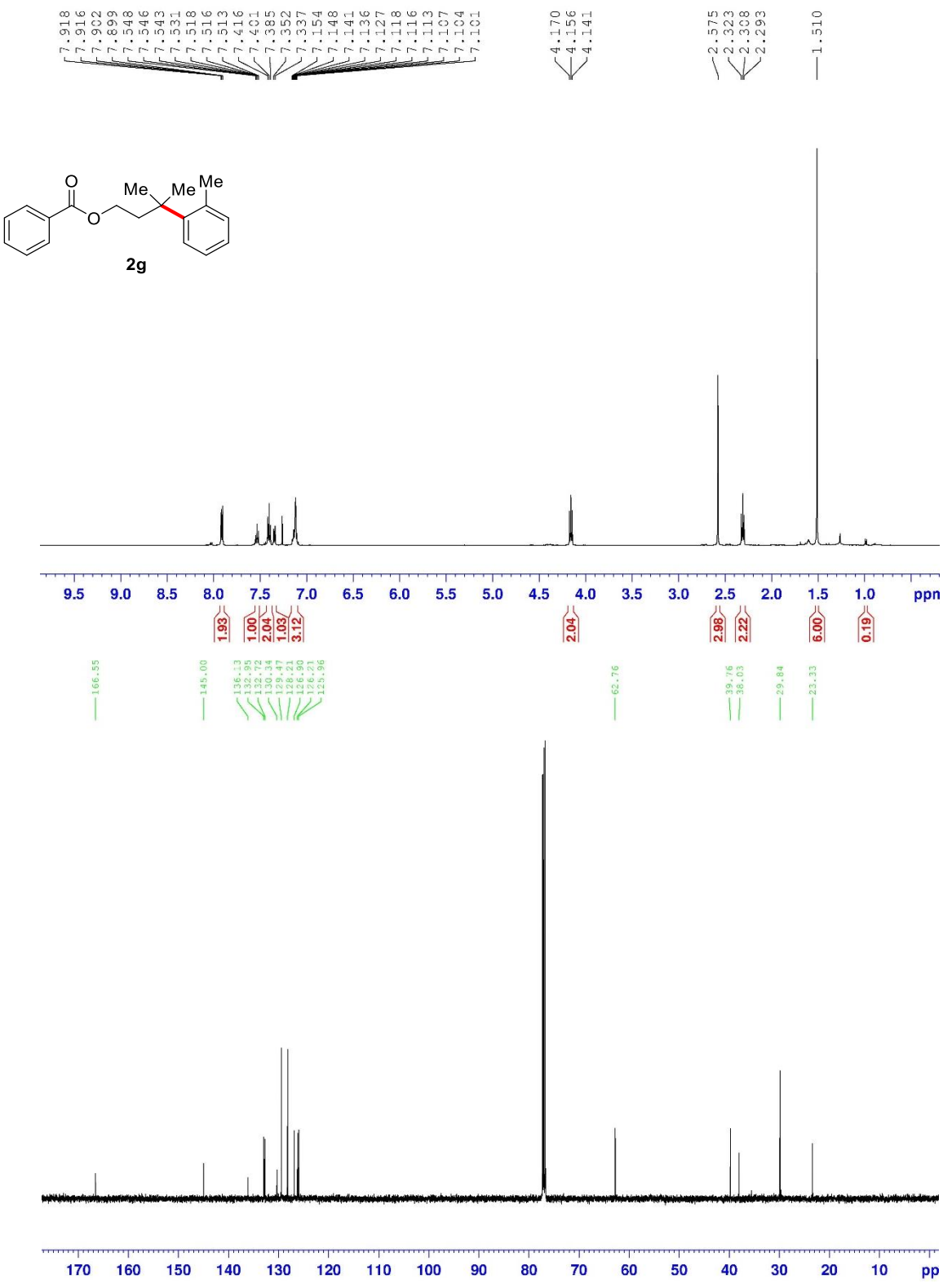
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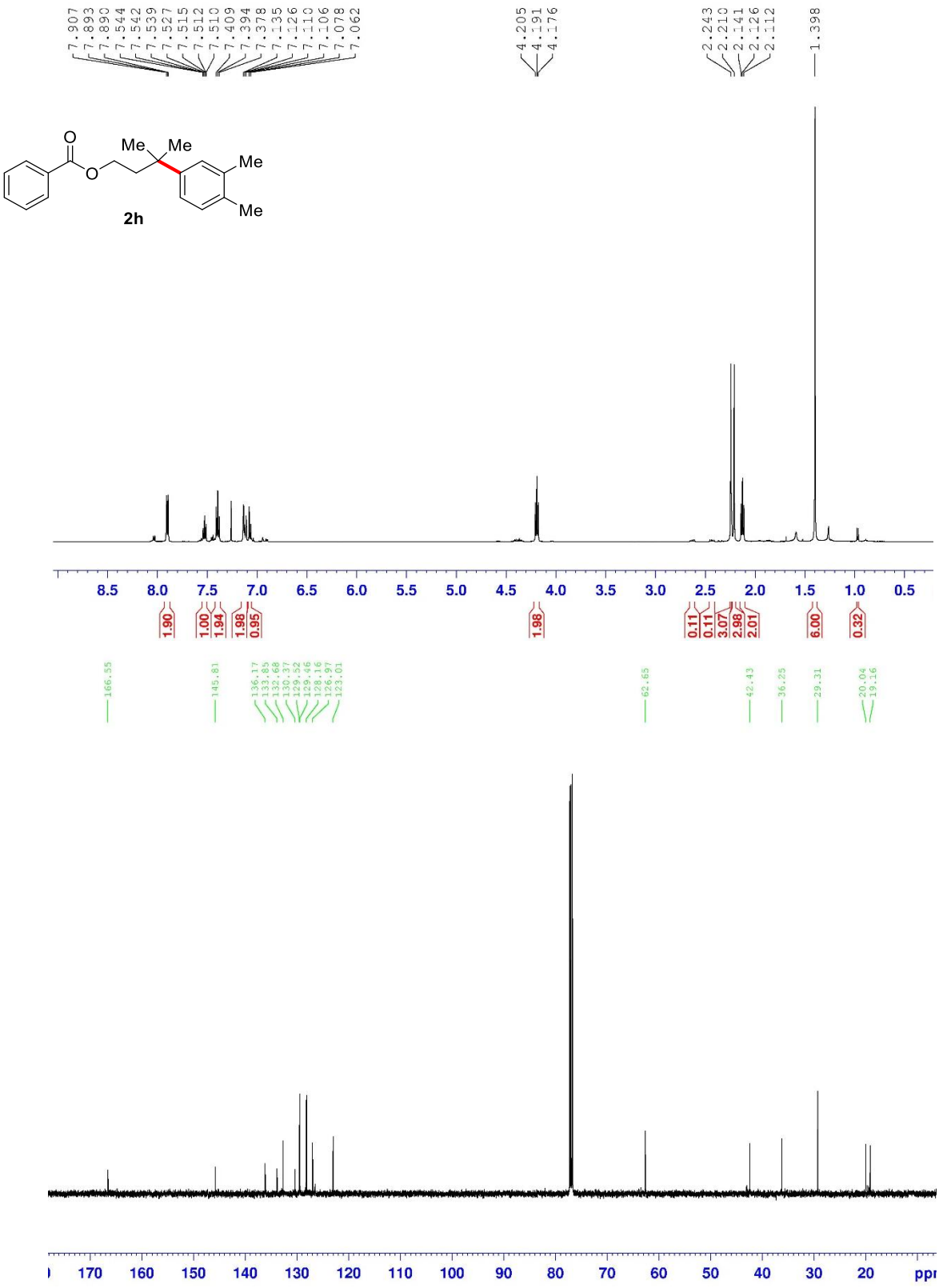
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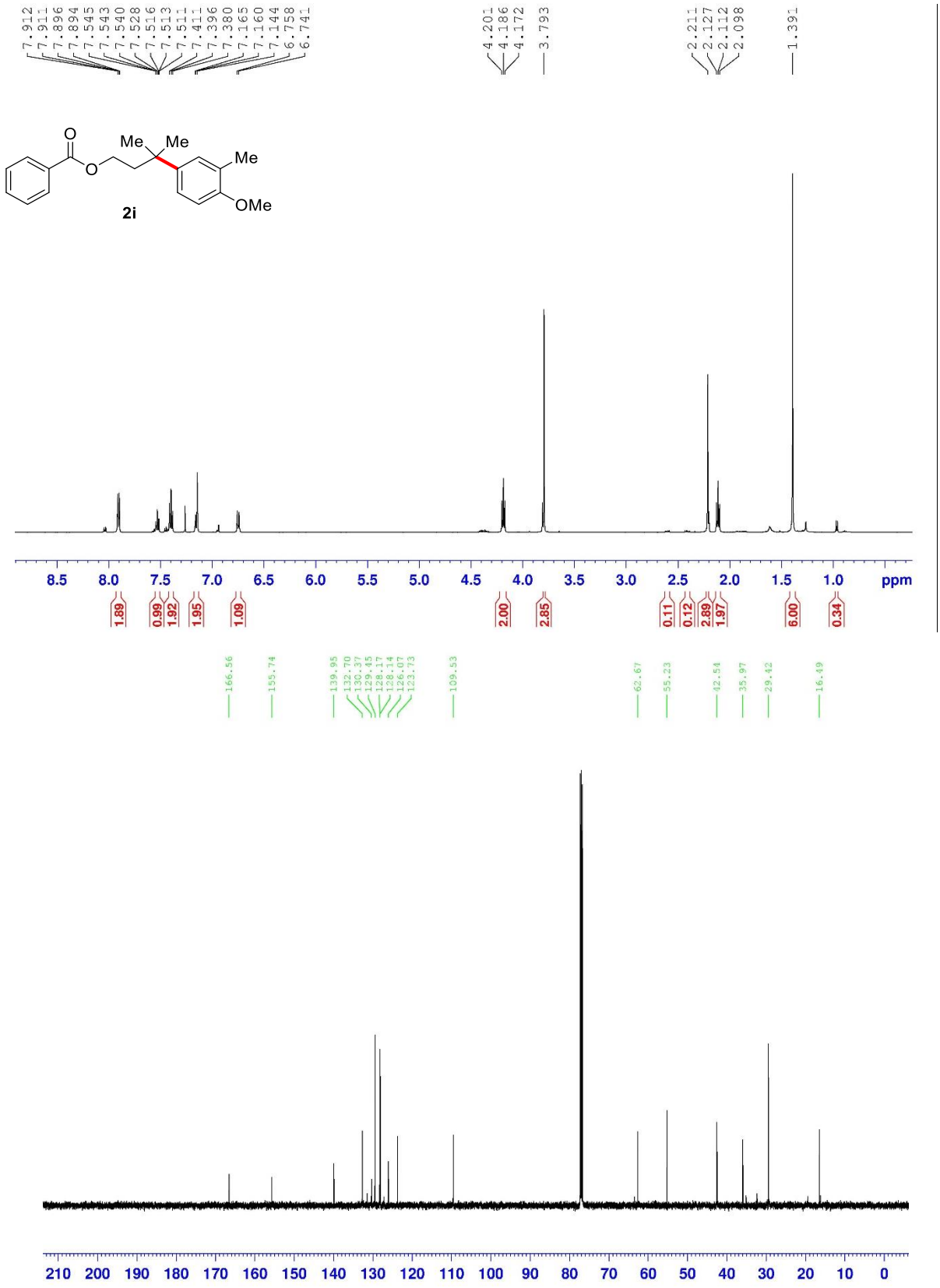
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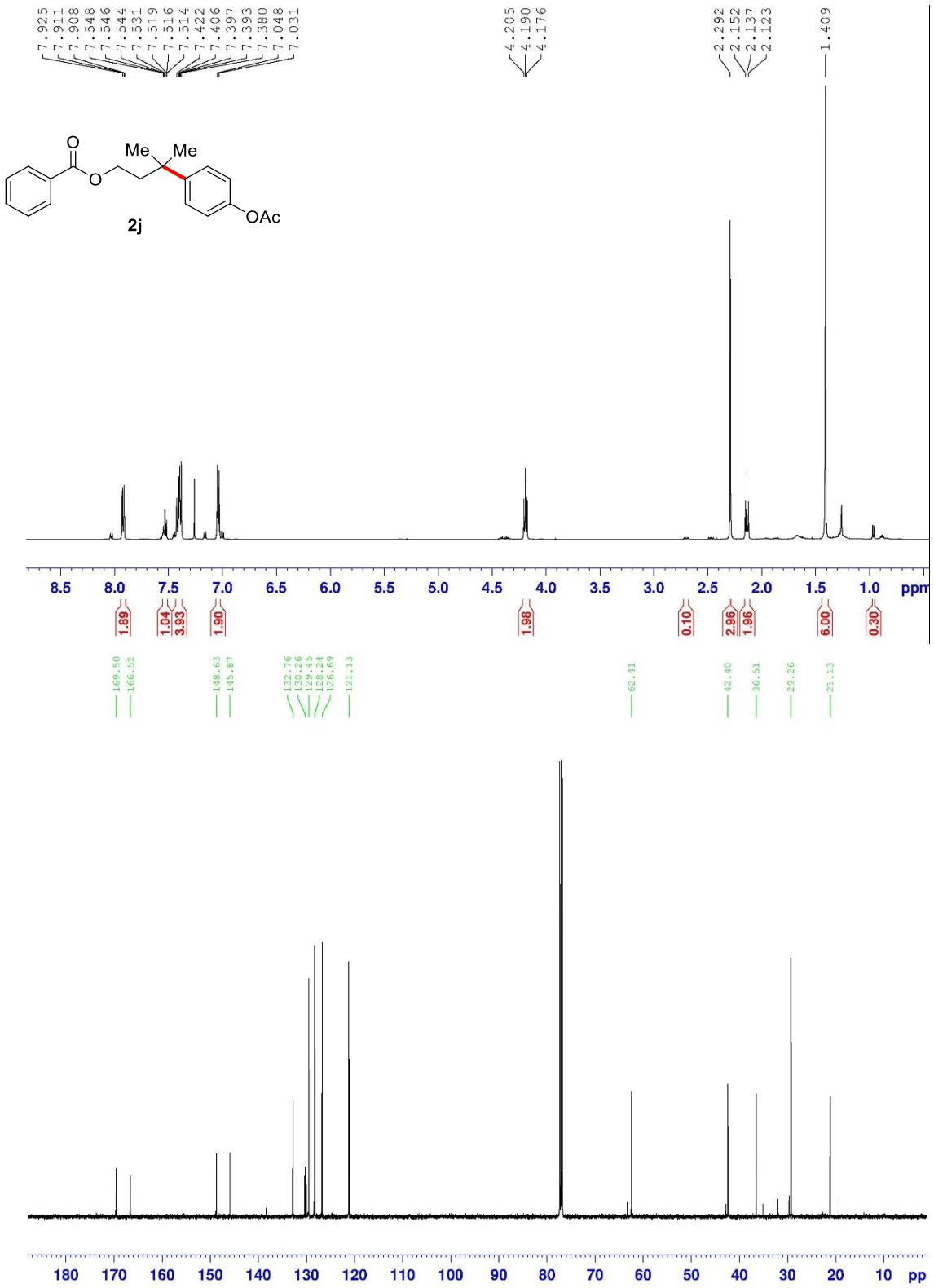
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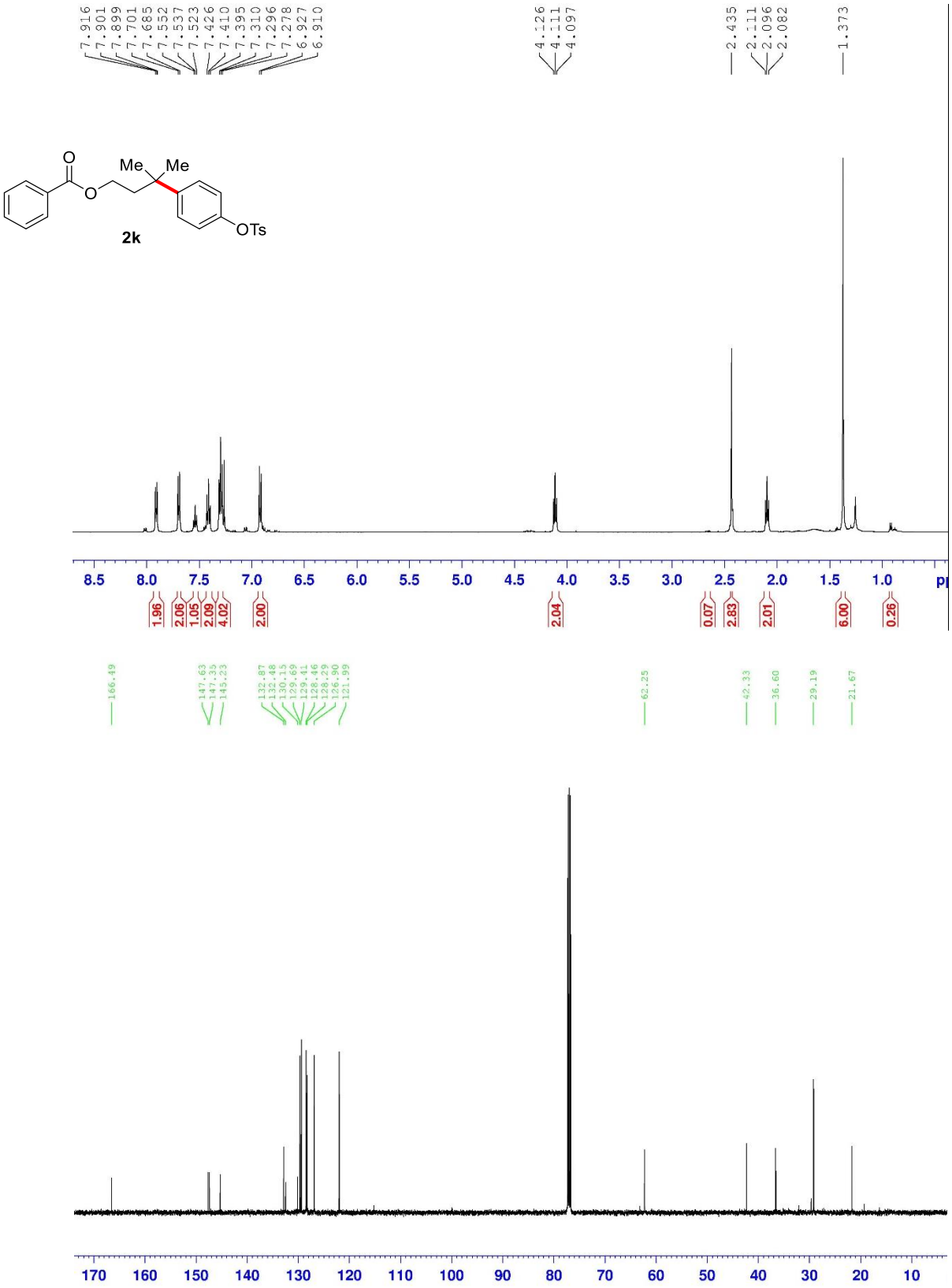
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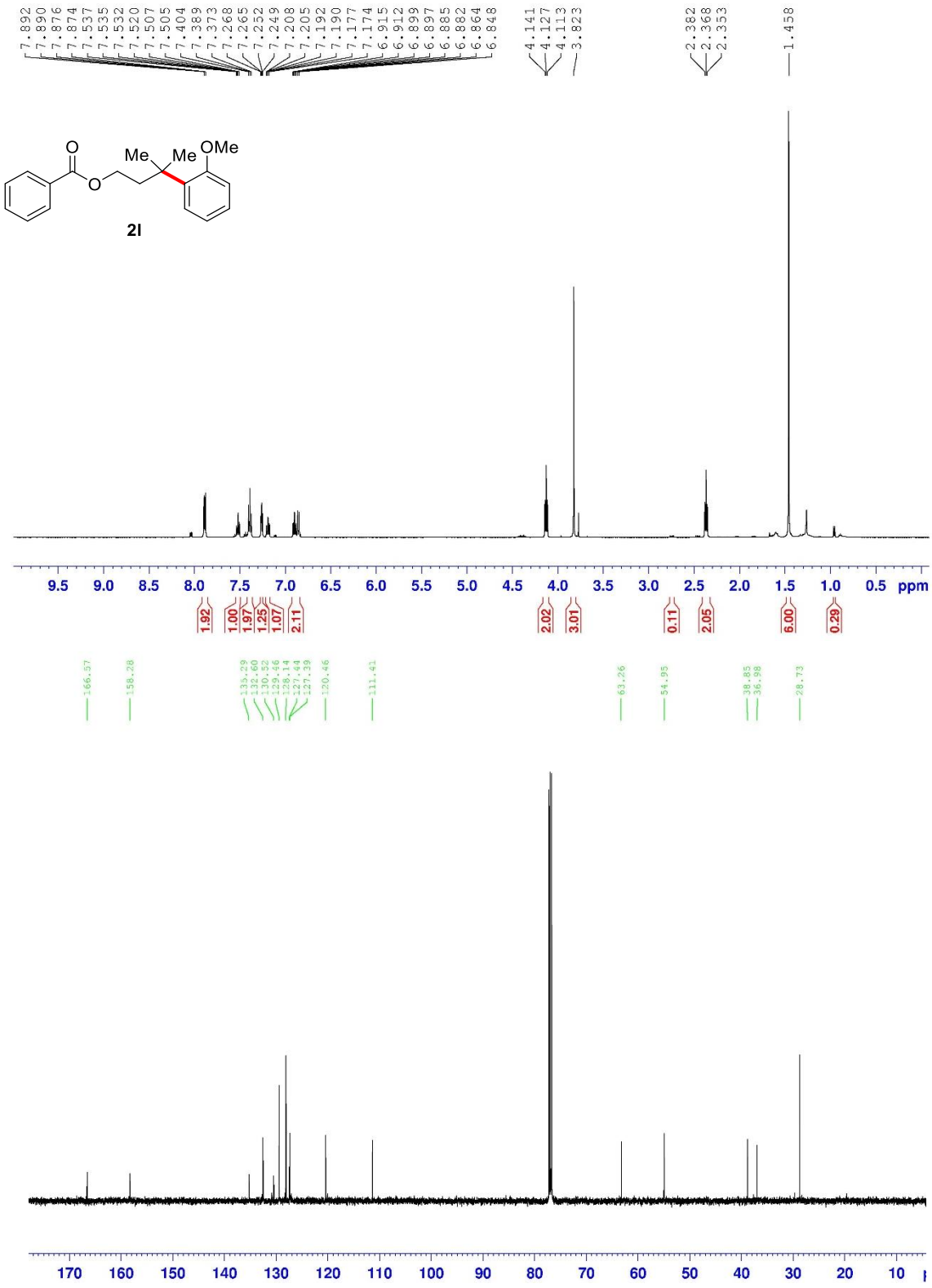
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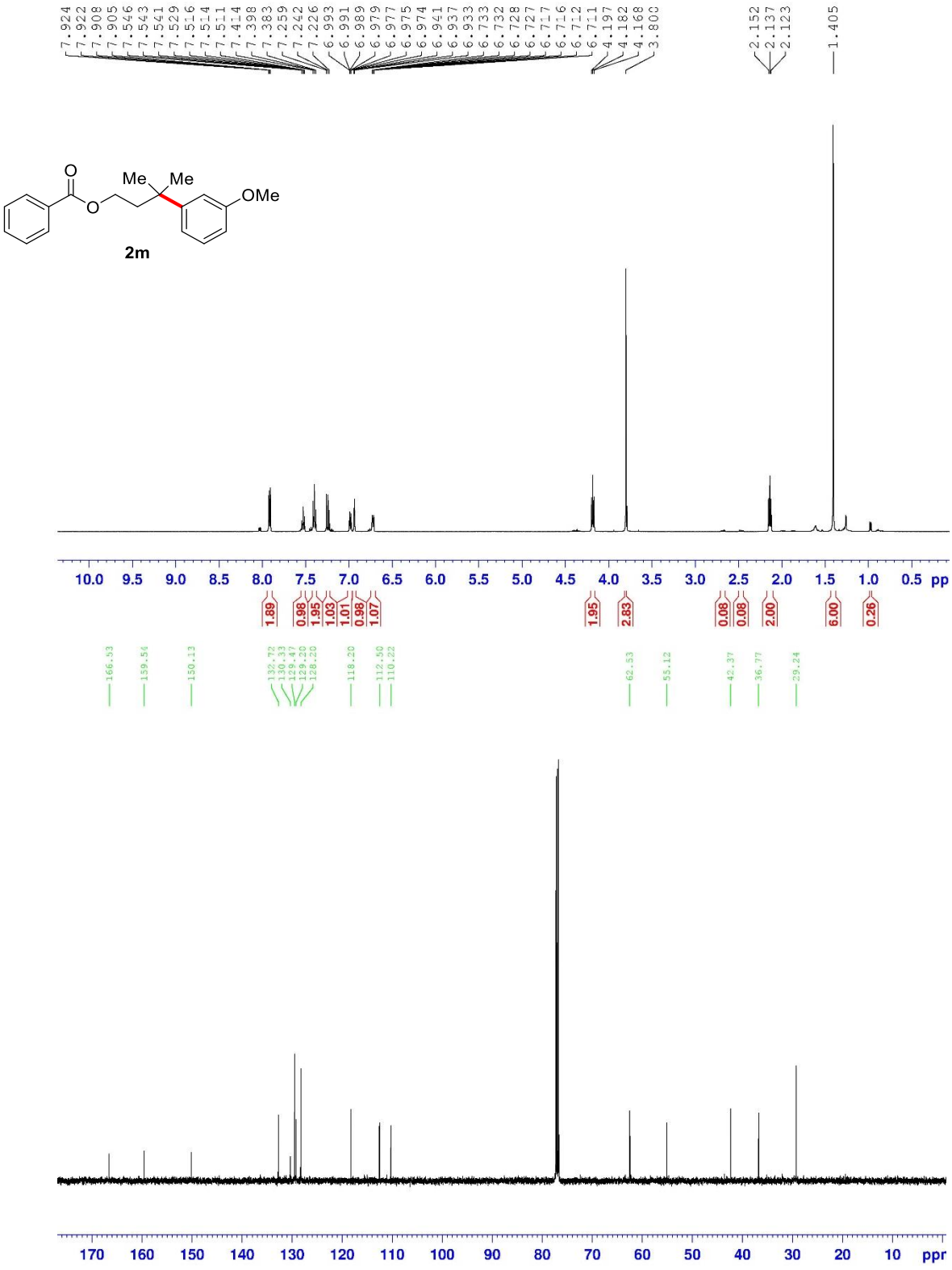
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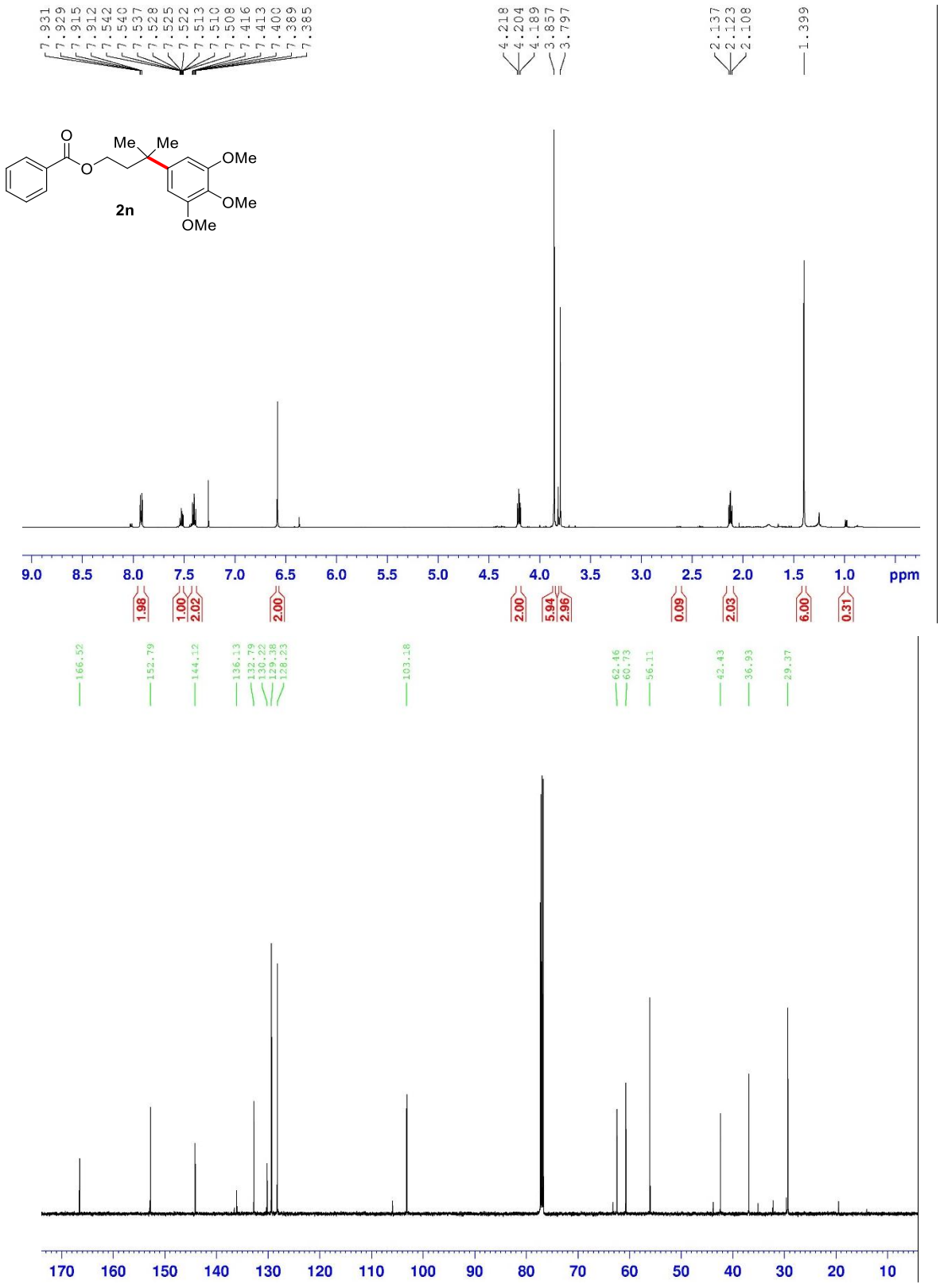
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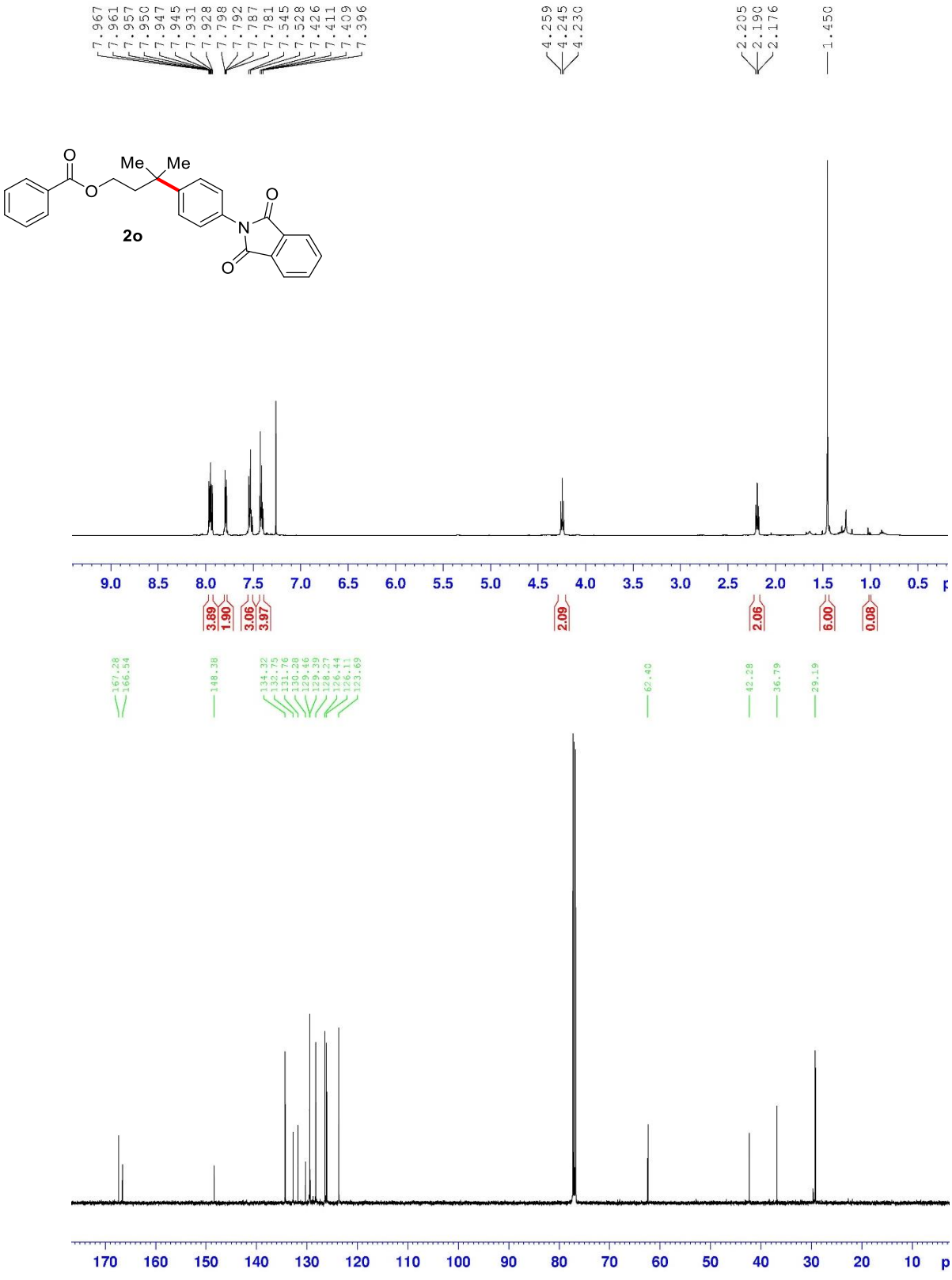
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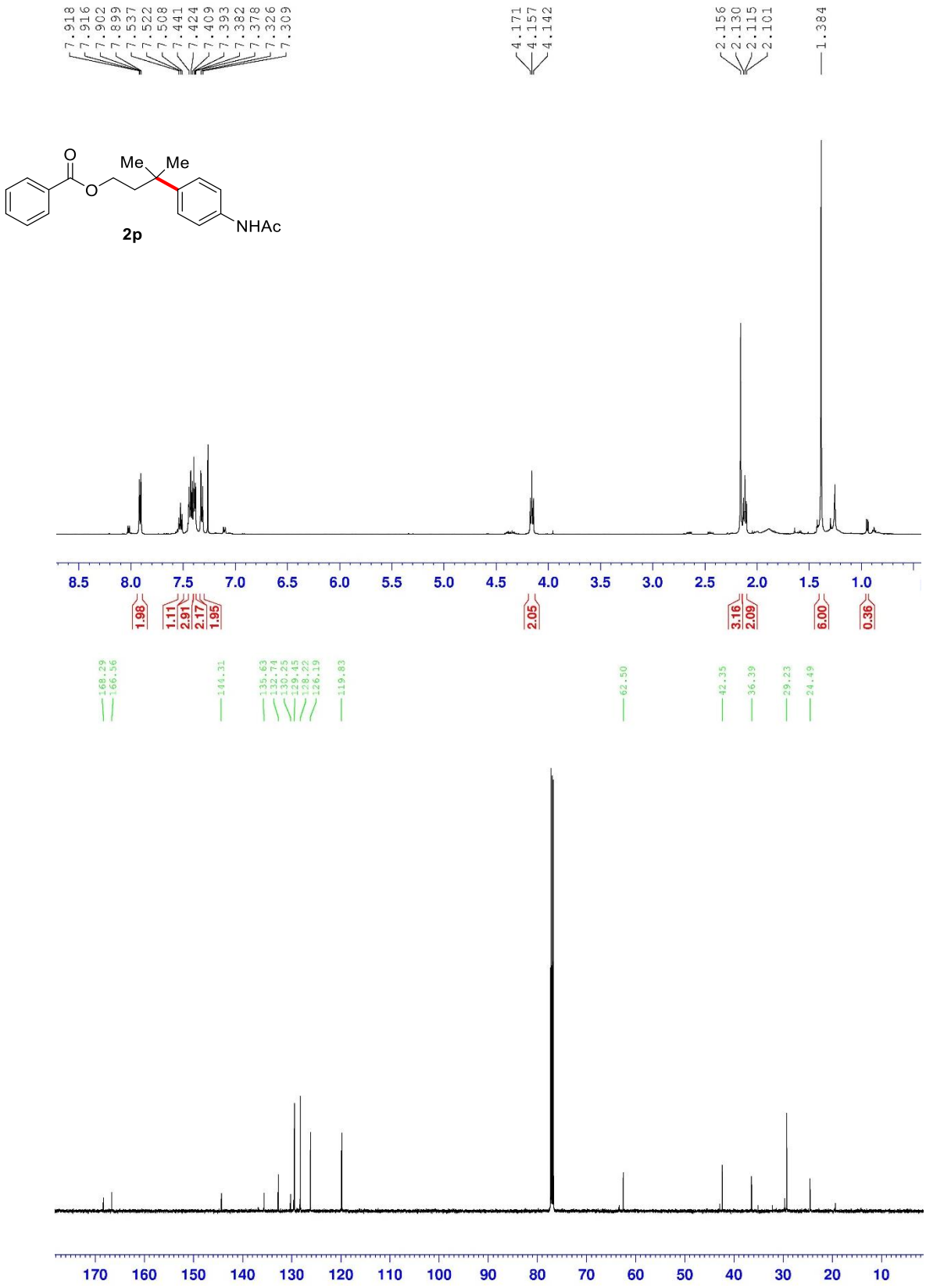
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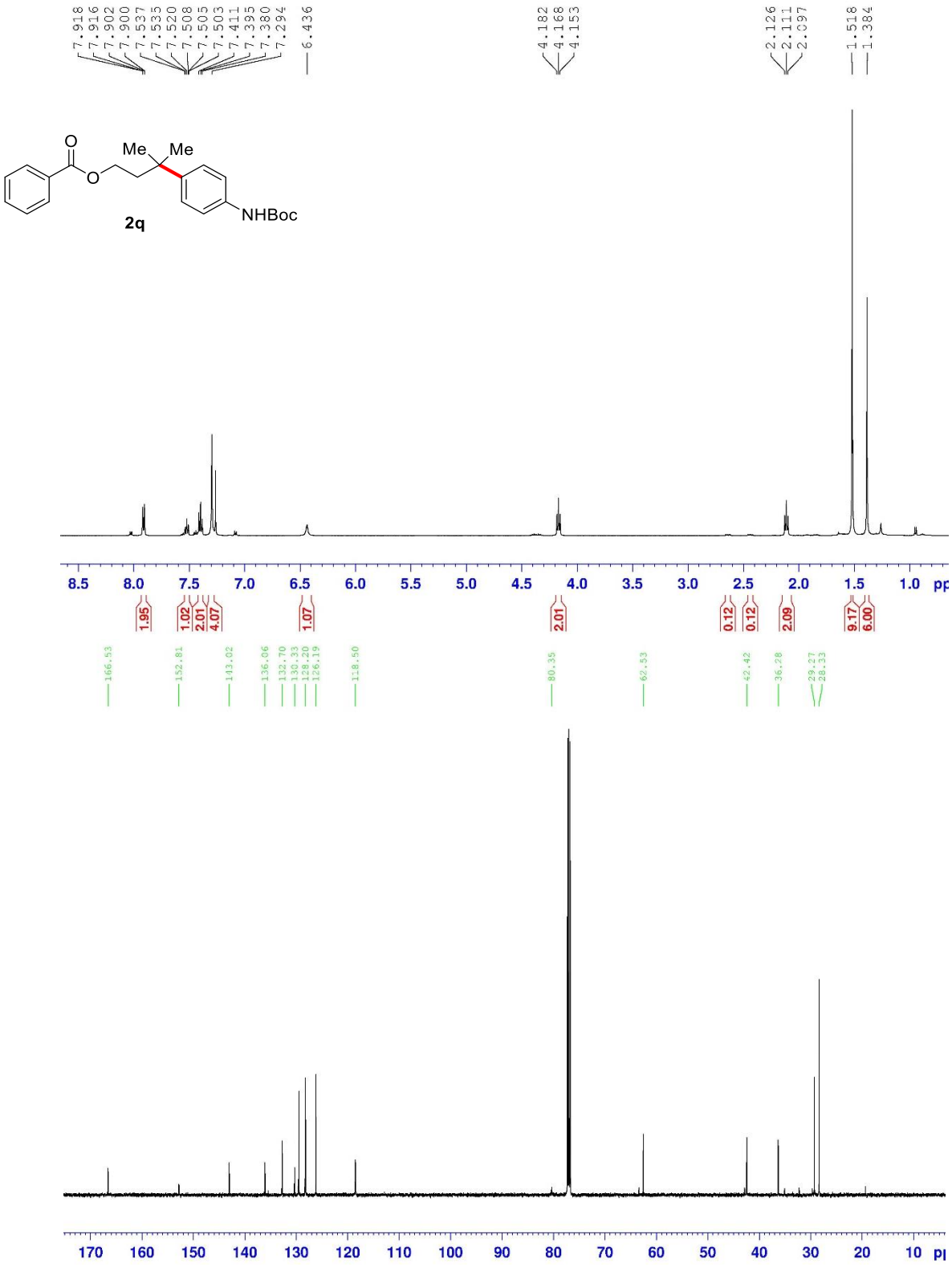
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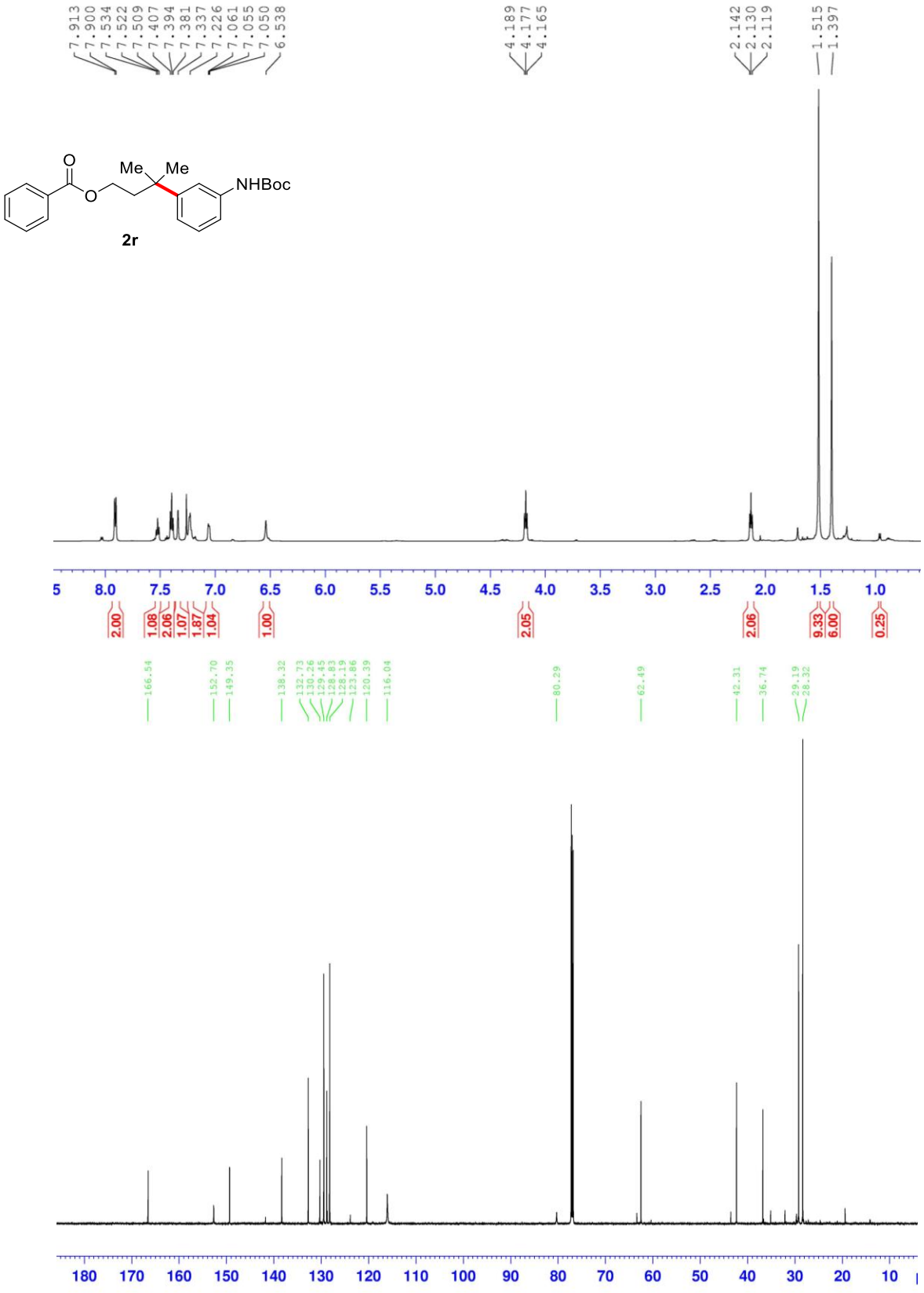
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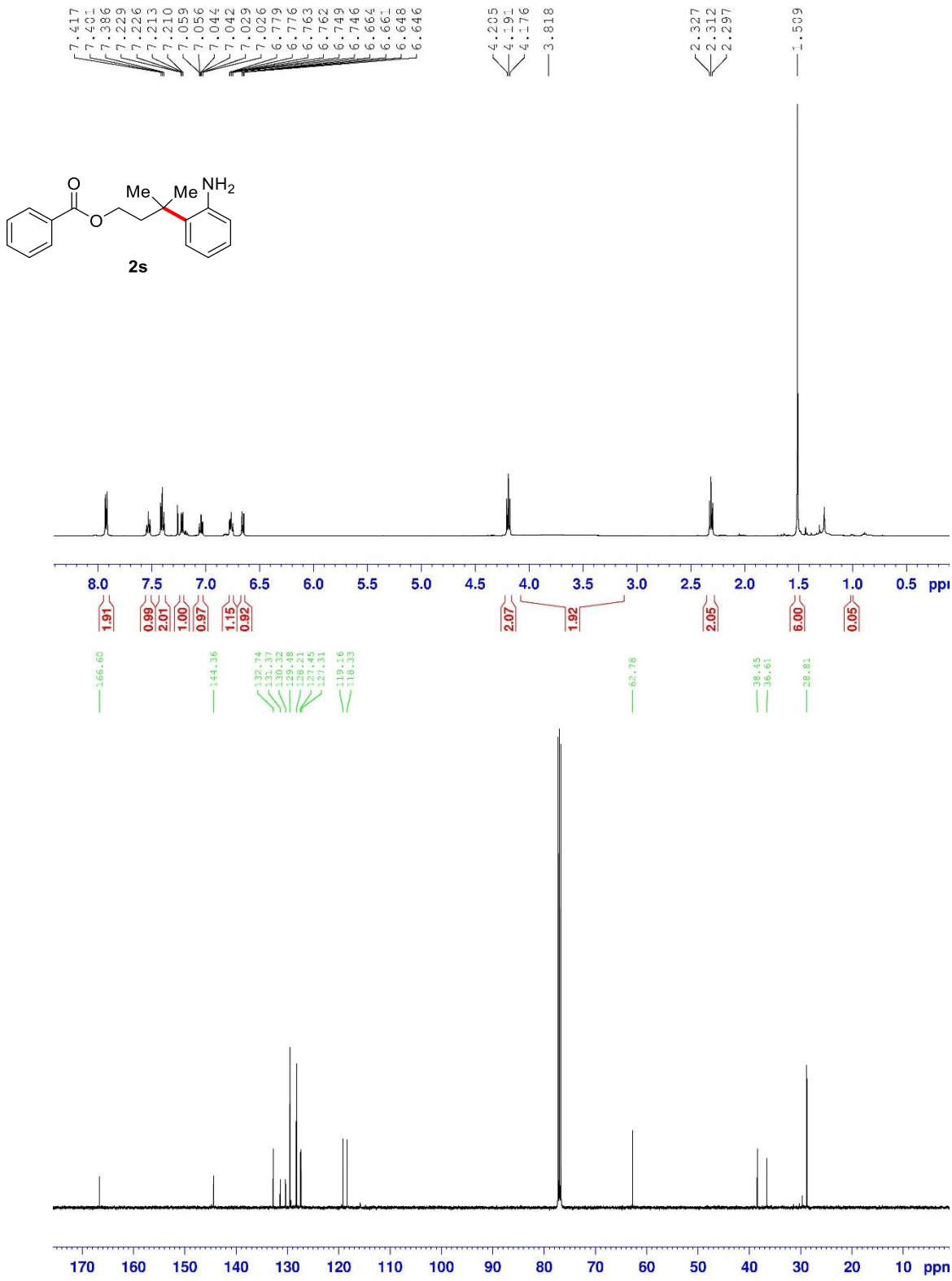
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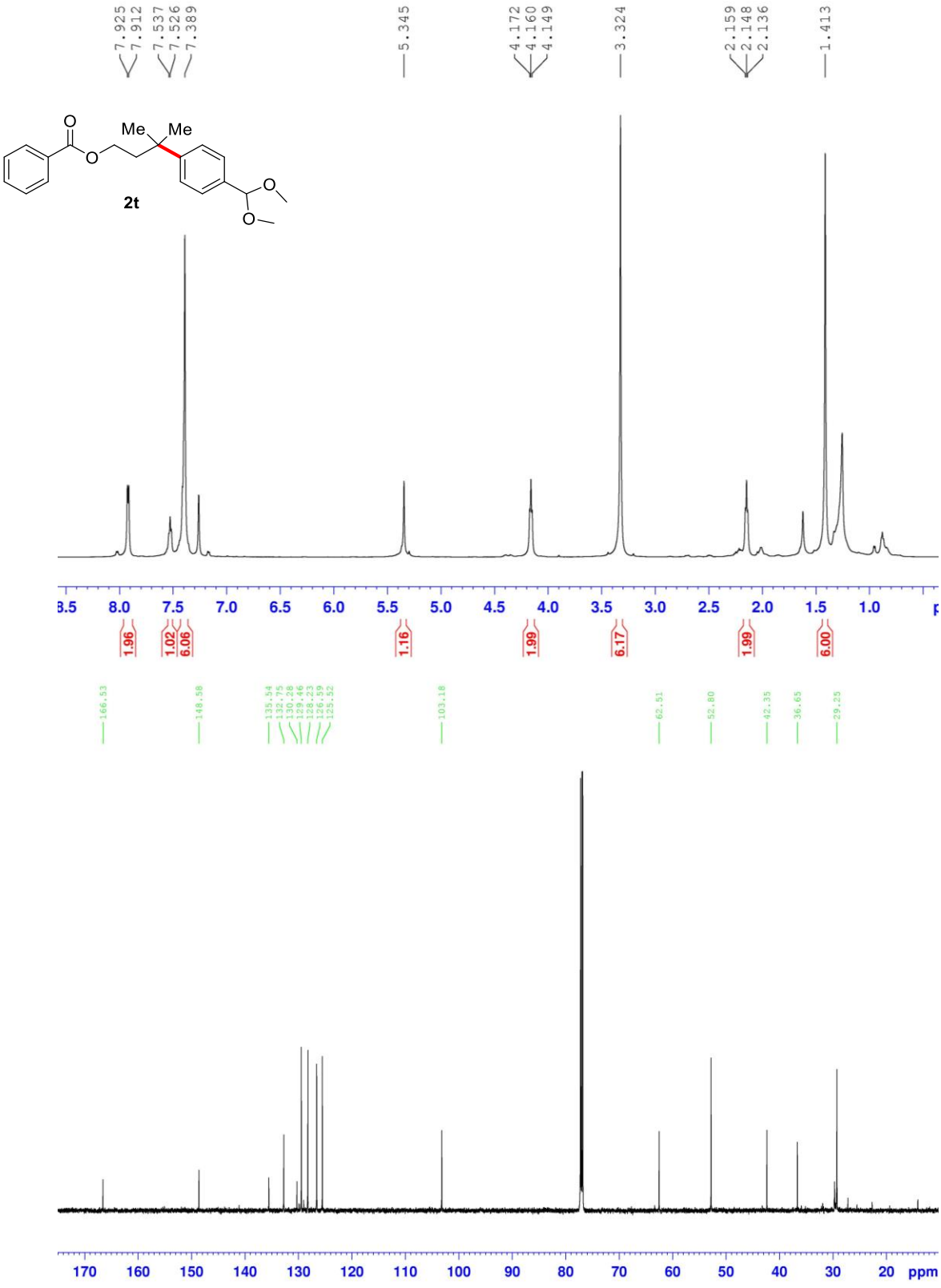
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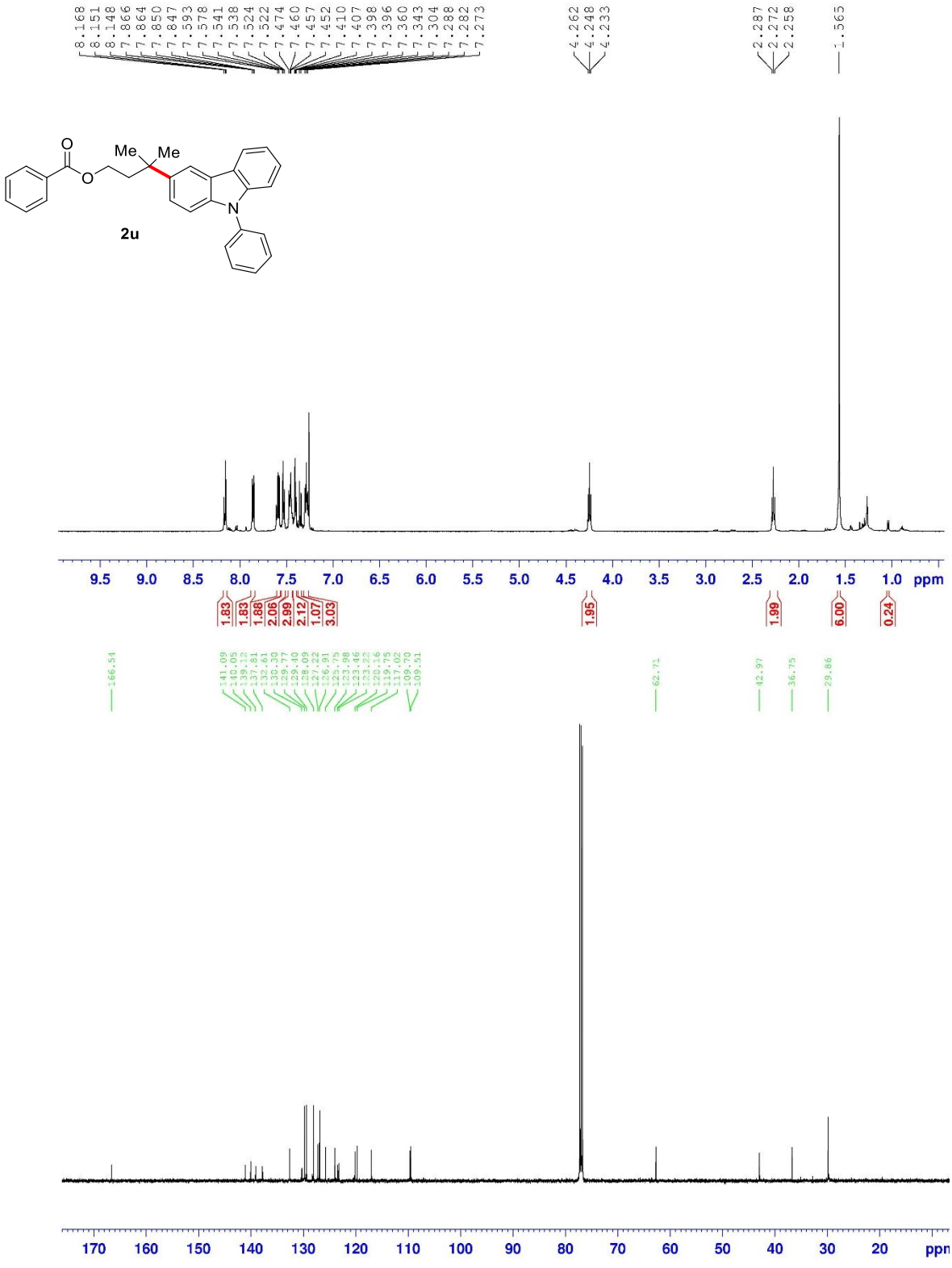
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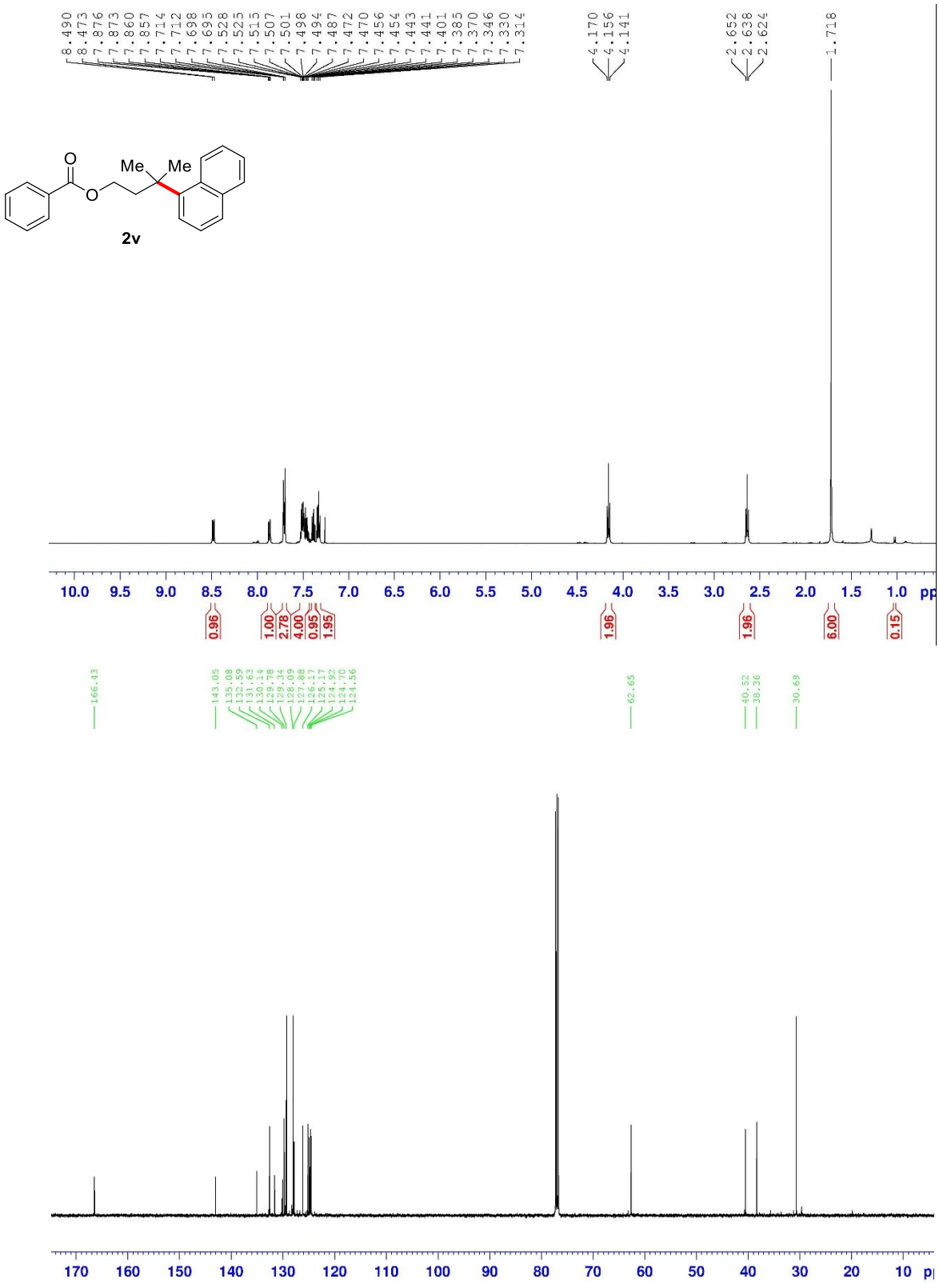
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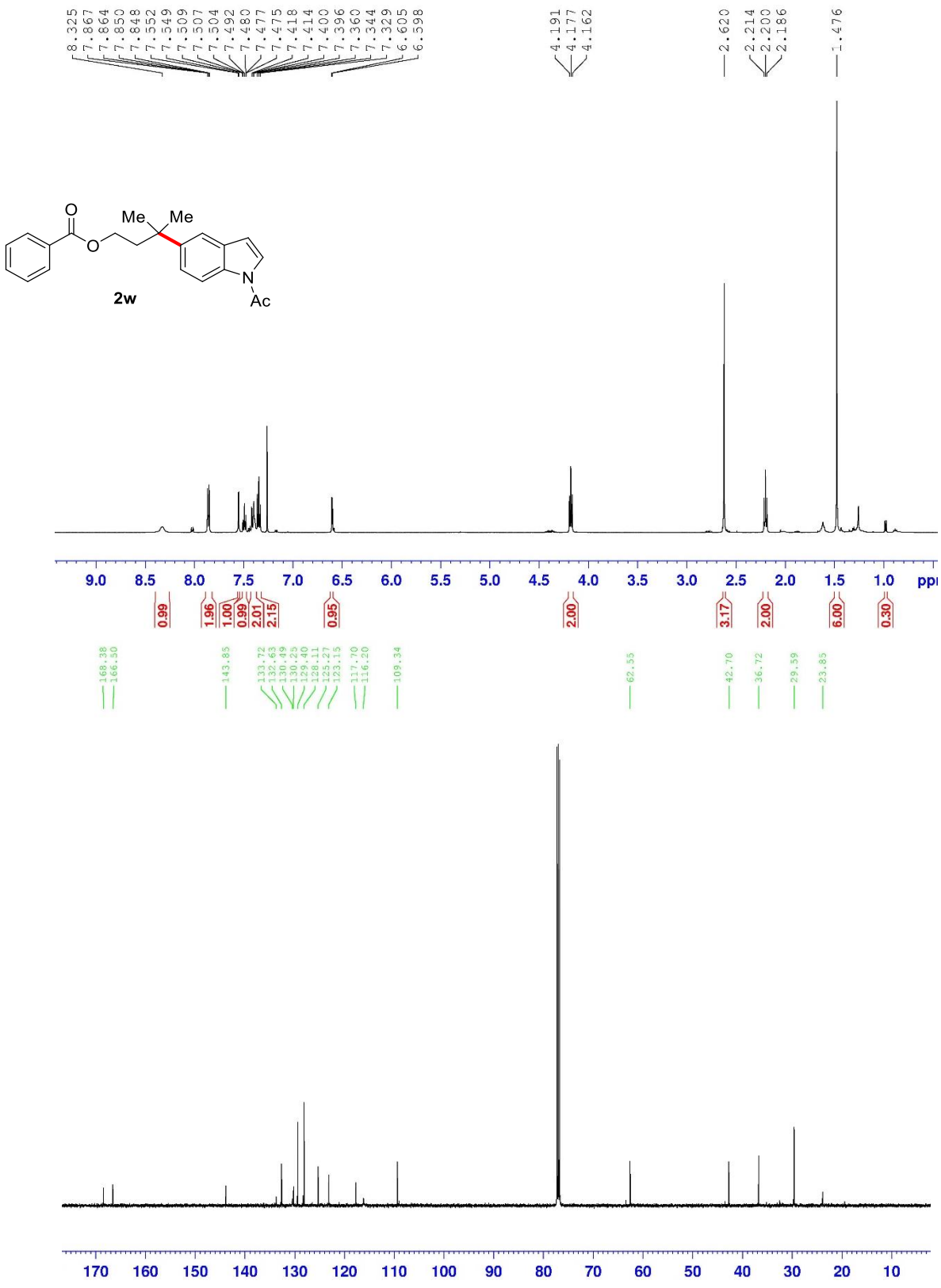
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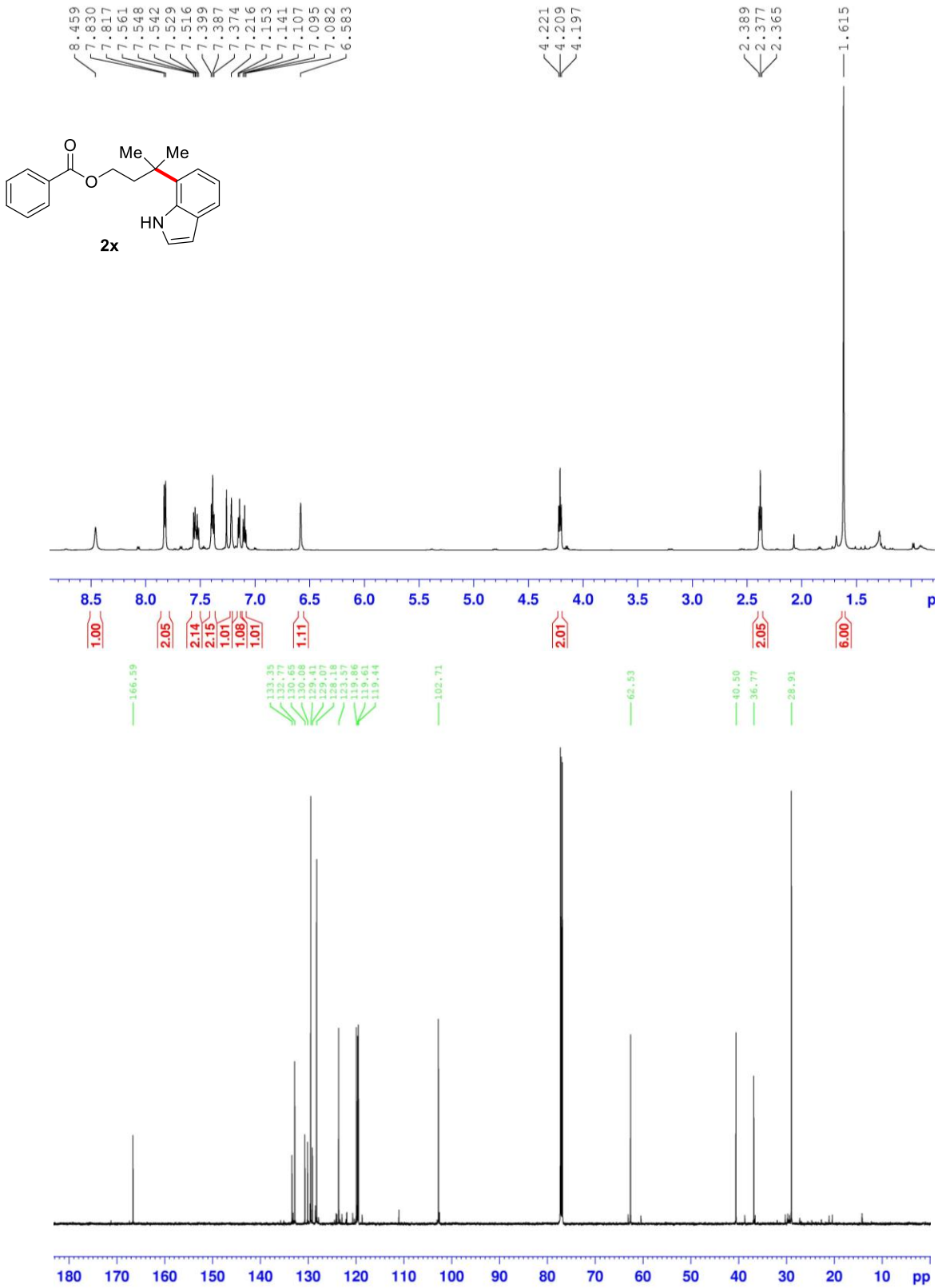
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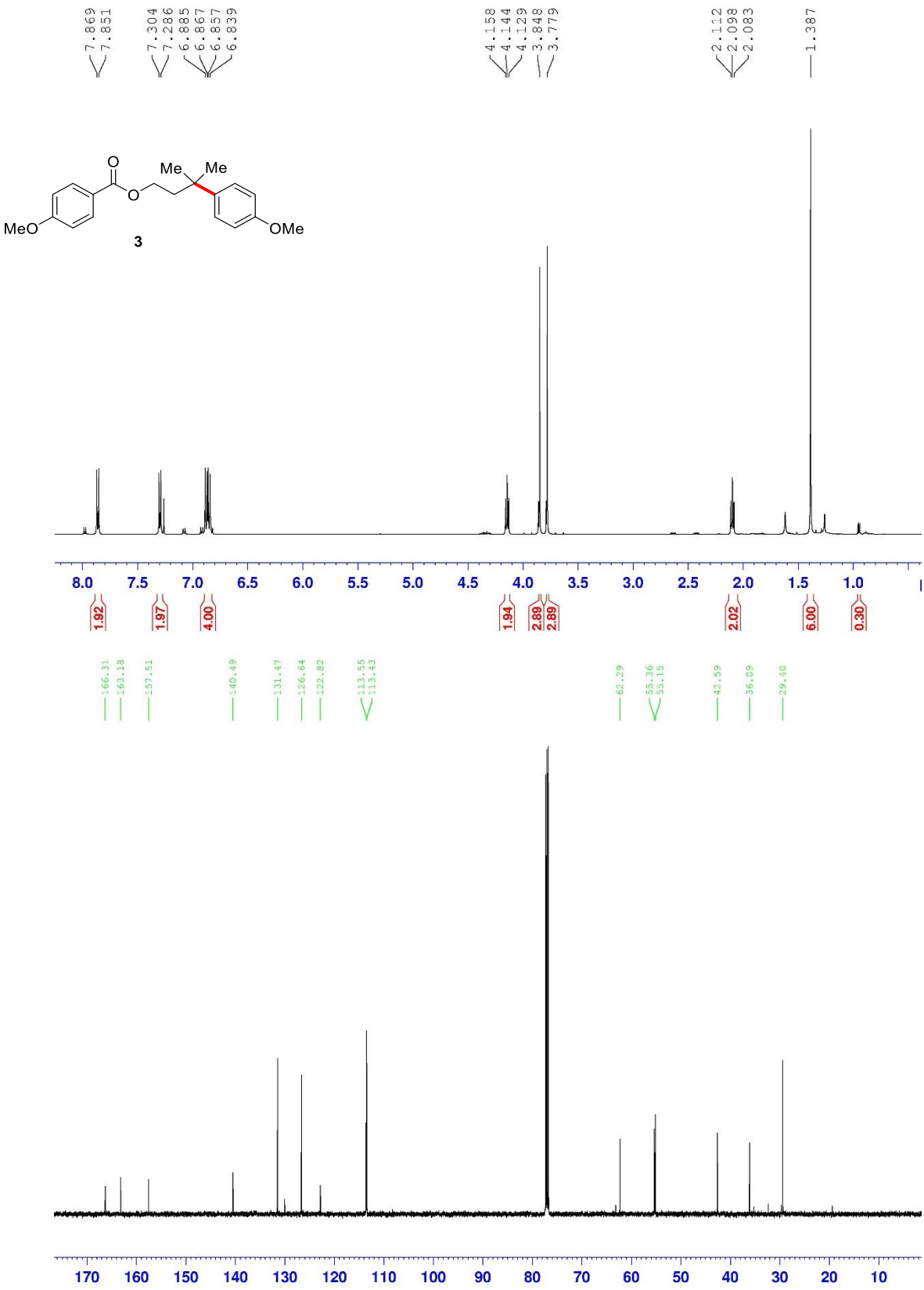
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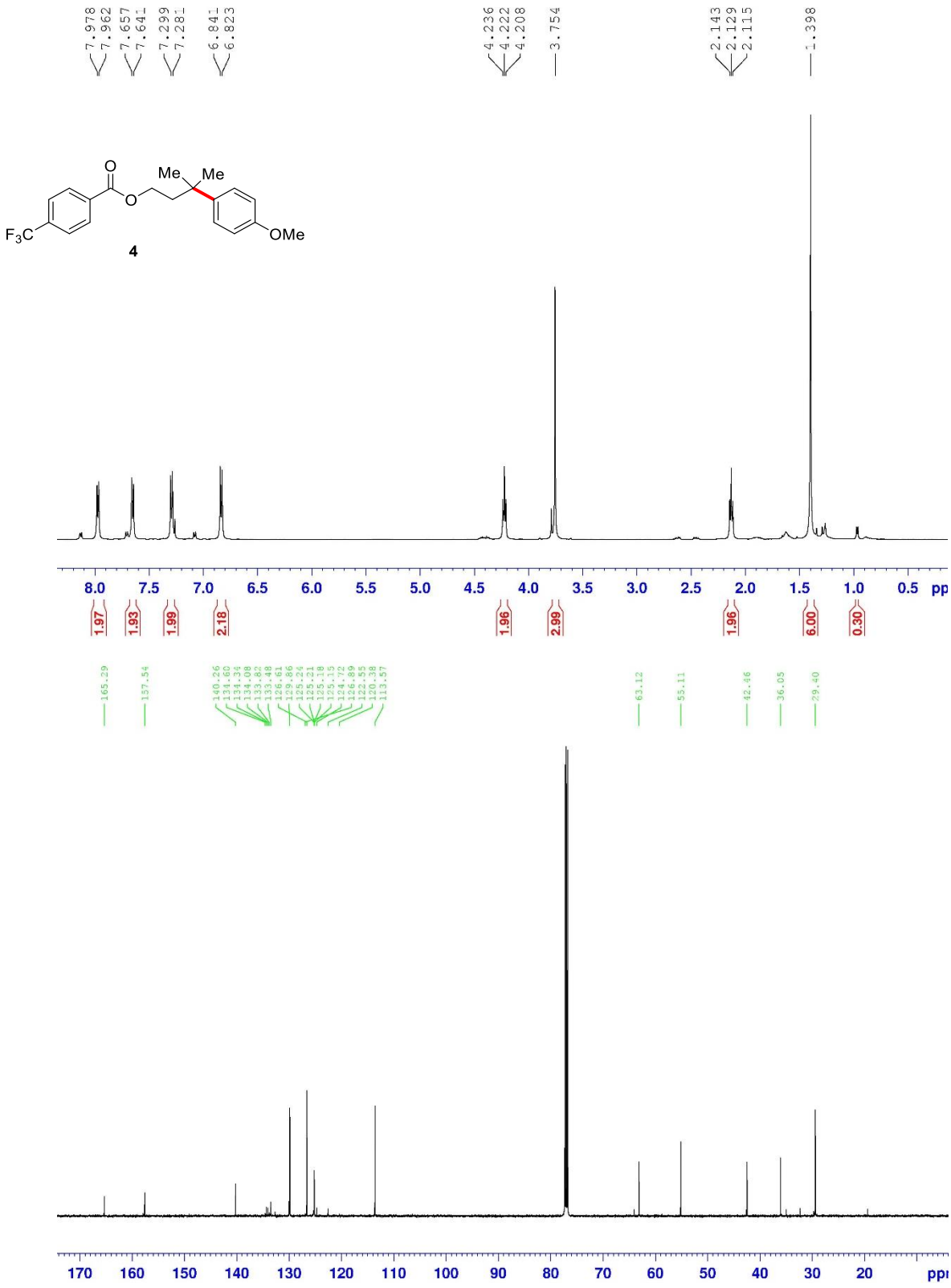
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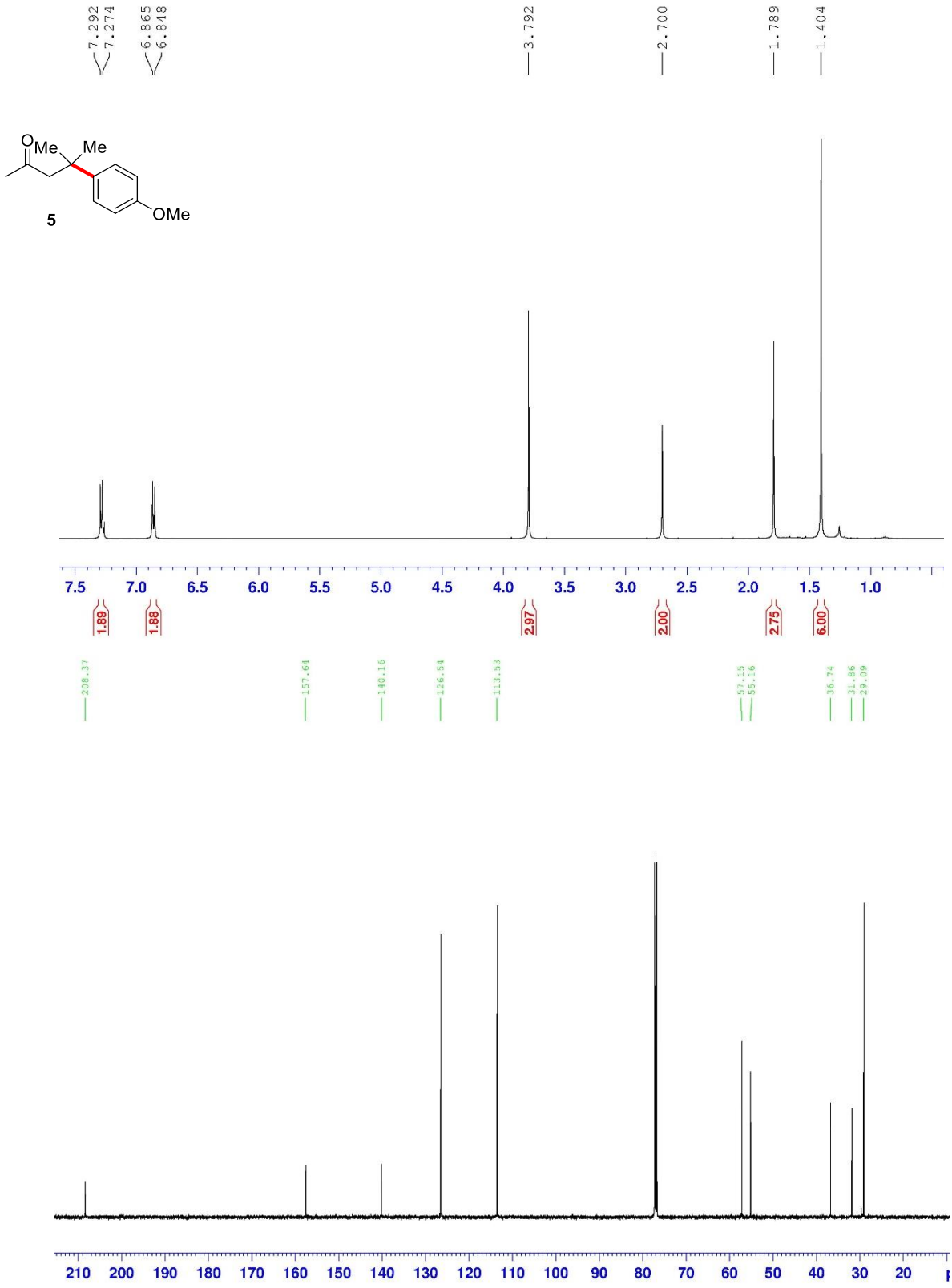
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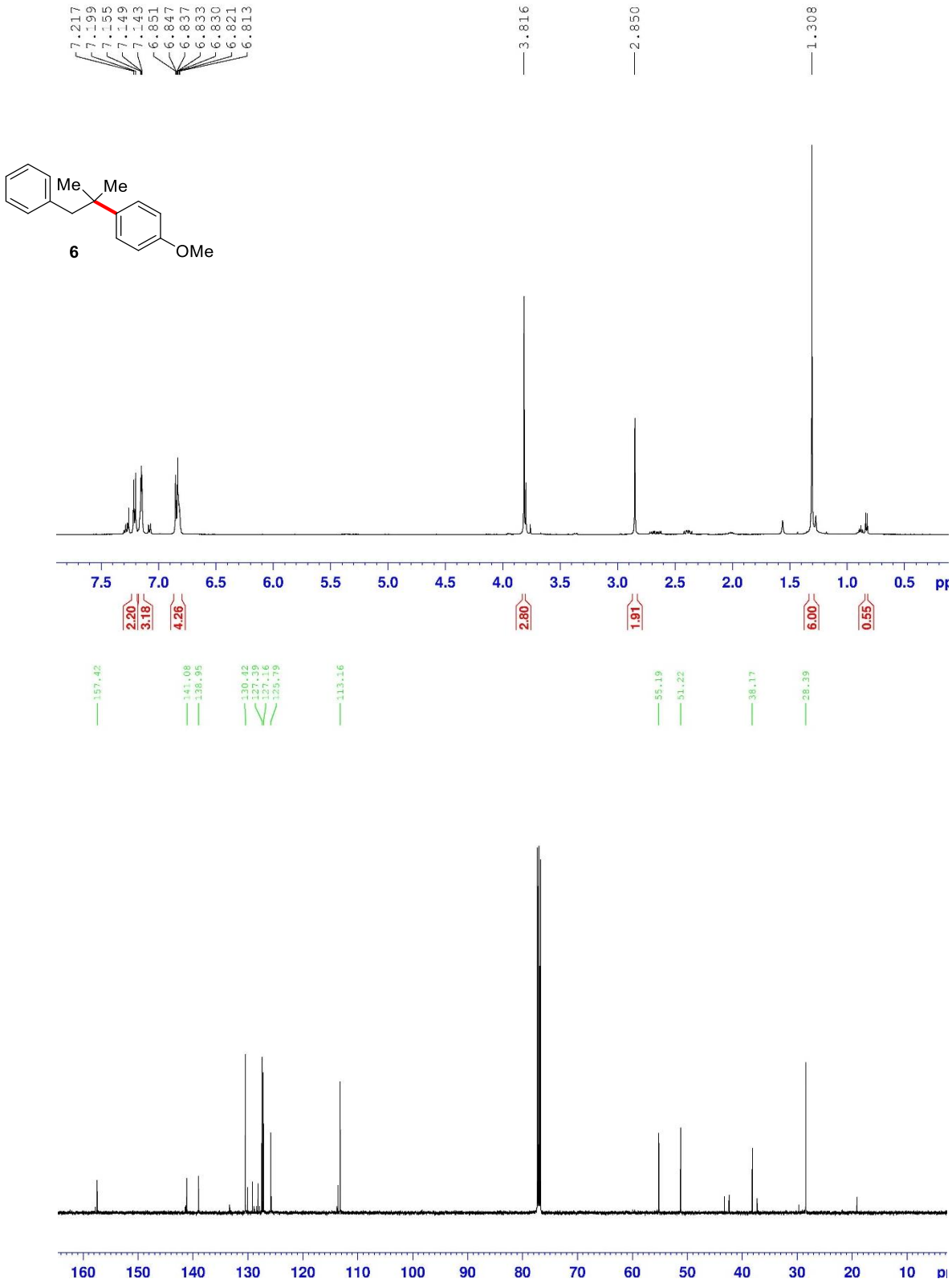
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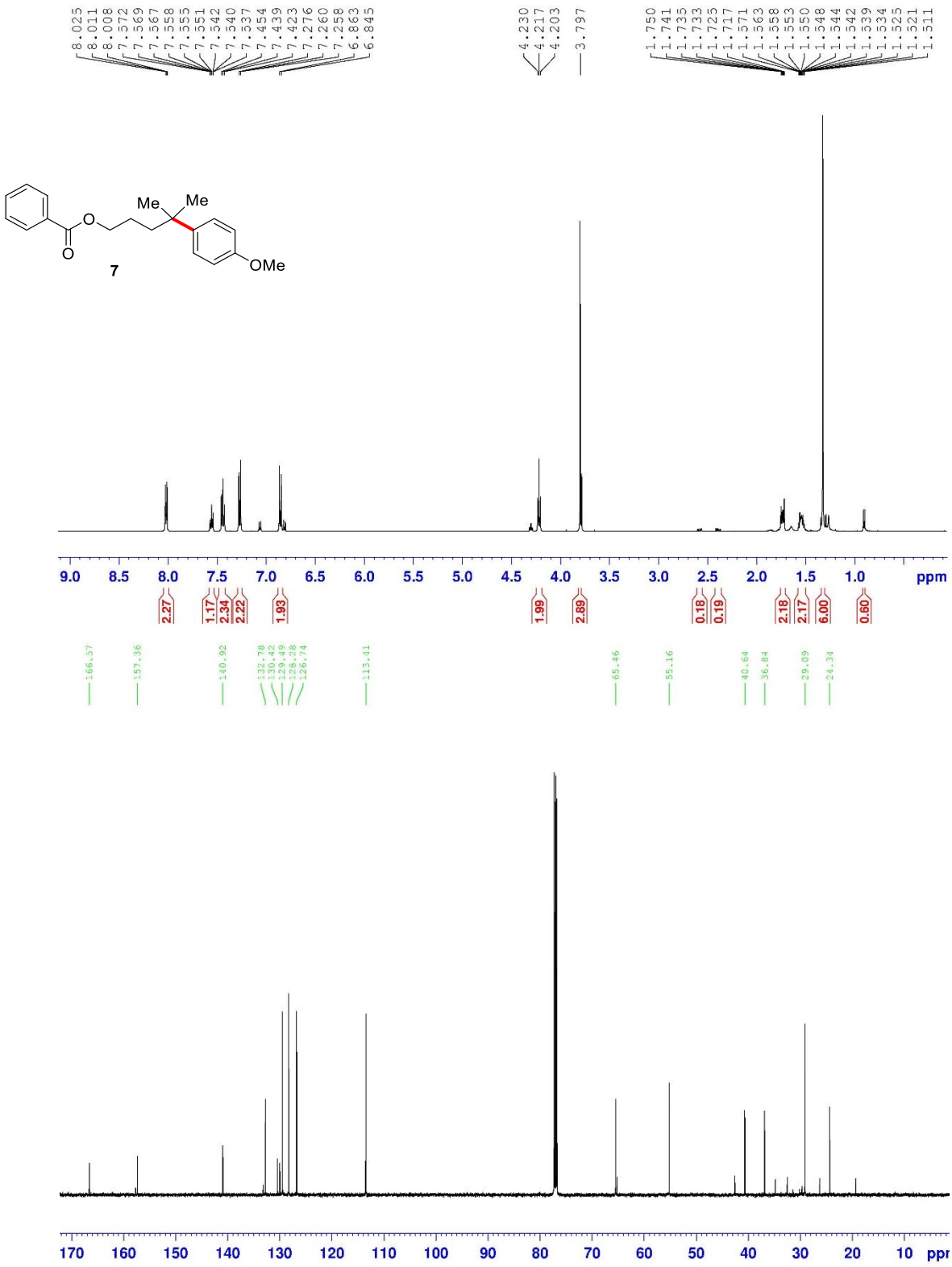
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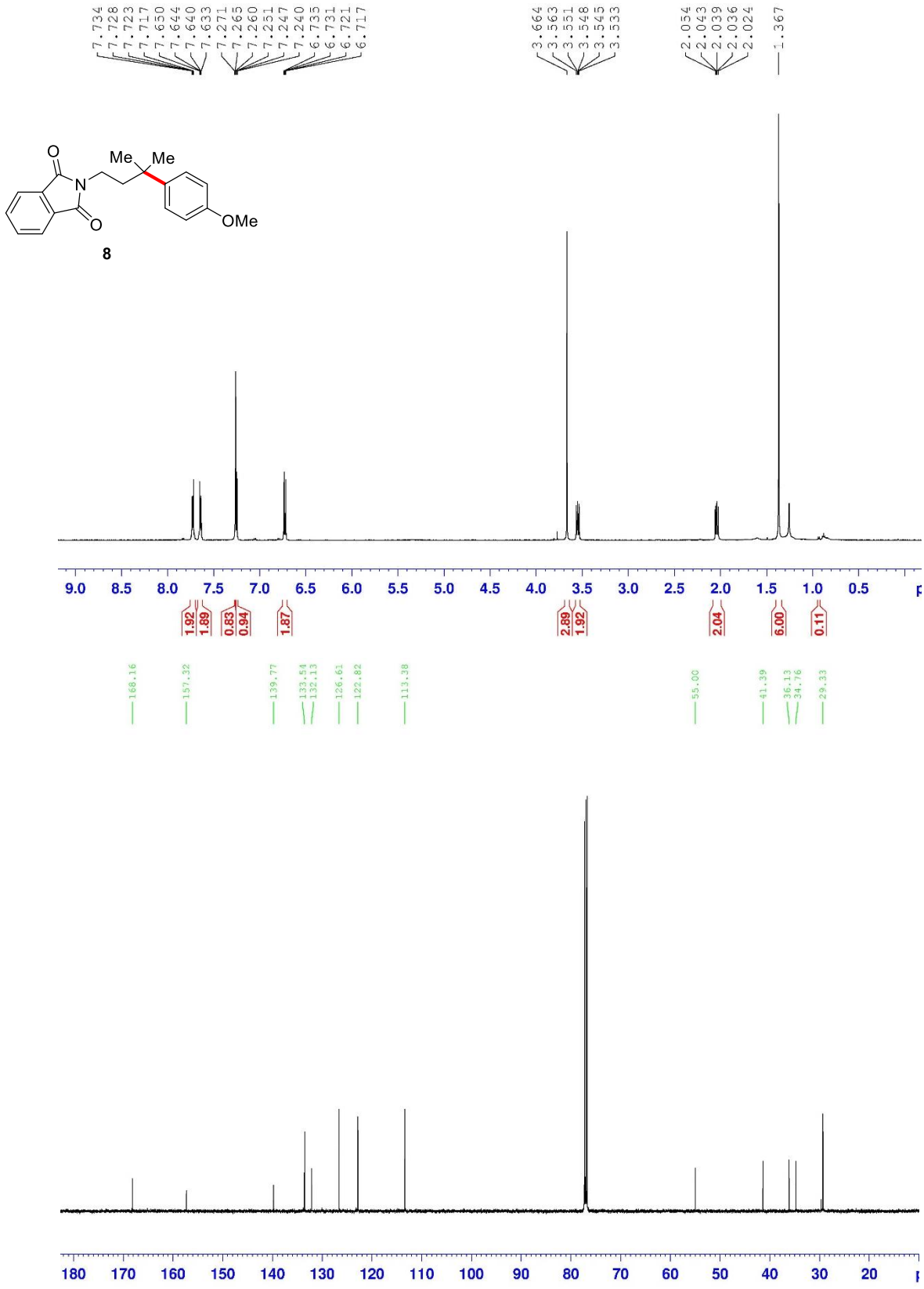
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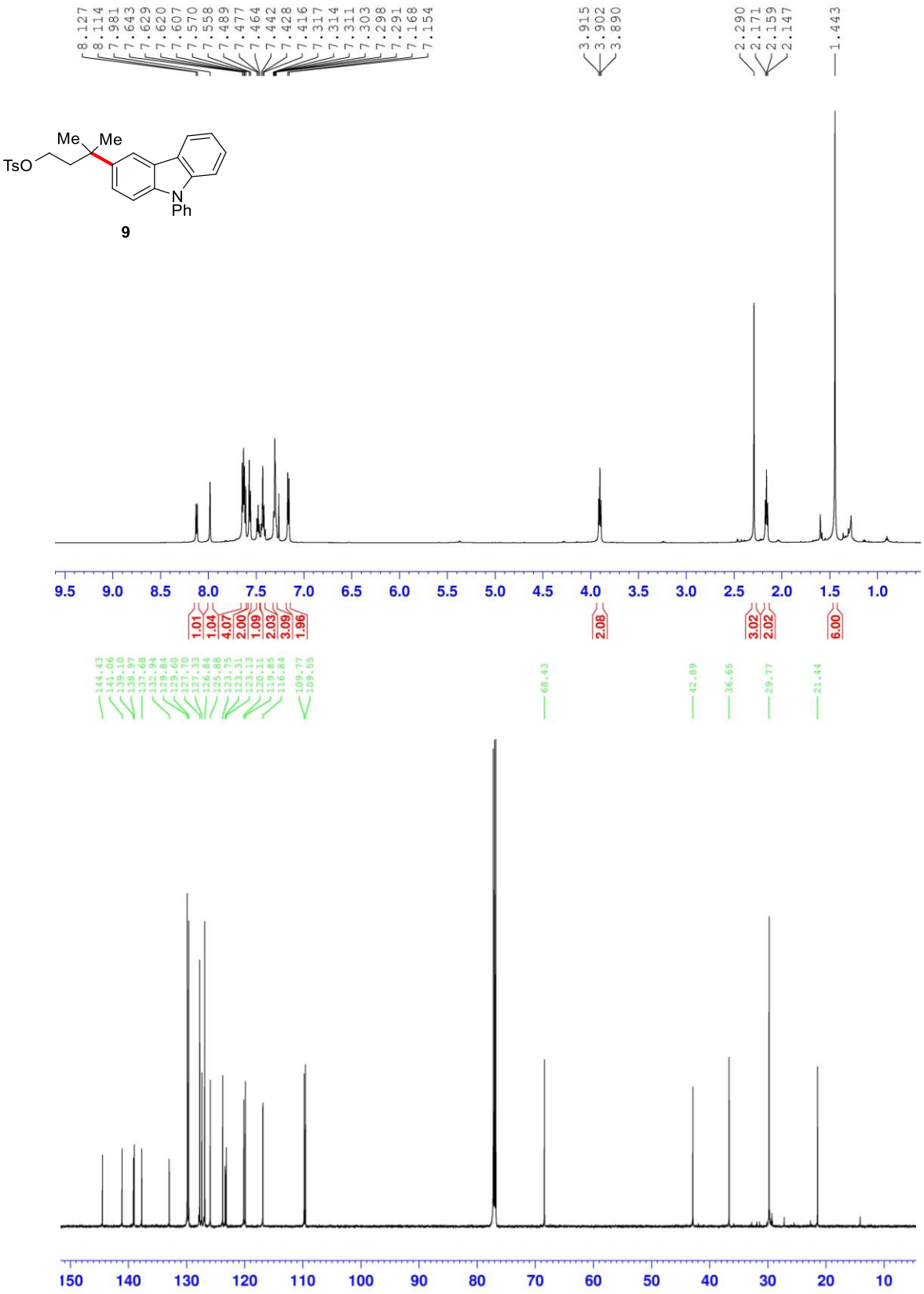
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Ph
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1.01
1.04
4.07
2.00
1.09
2.03
3.09
1.96
2.08
3.02
2.02
6.00
144.43
141.06
139.10
138.97
137.68
132.94
129.84
129.60
127.70
127.33
126.84
125.88
123.75
123.31
123.13
120.11
119.85
116.84
109.77
109.55
68.43
42.89
36.65
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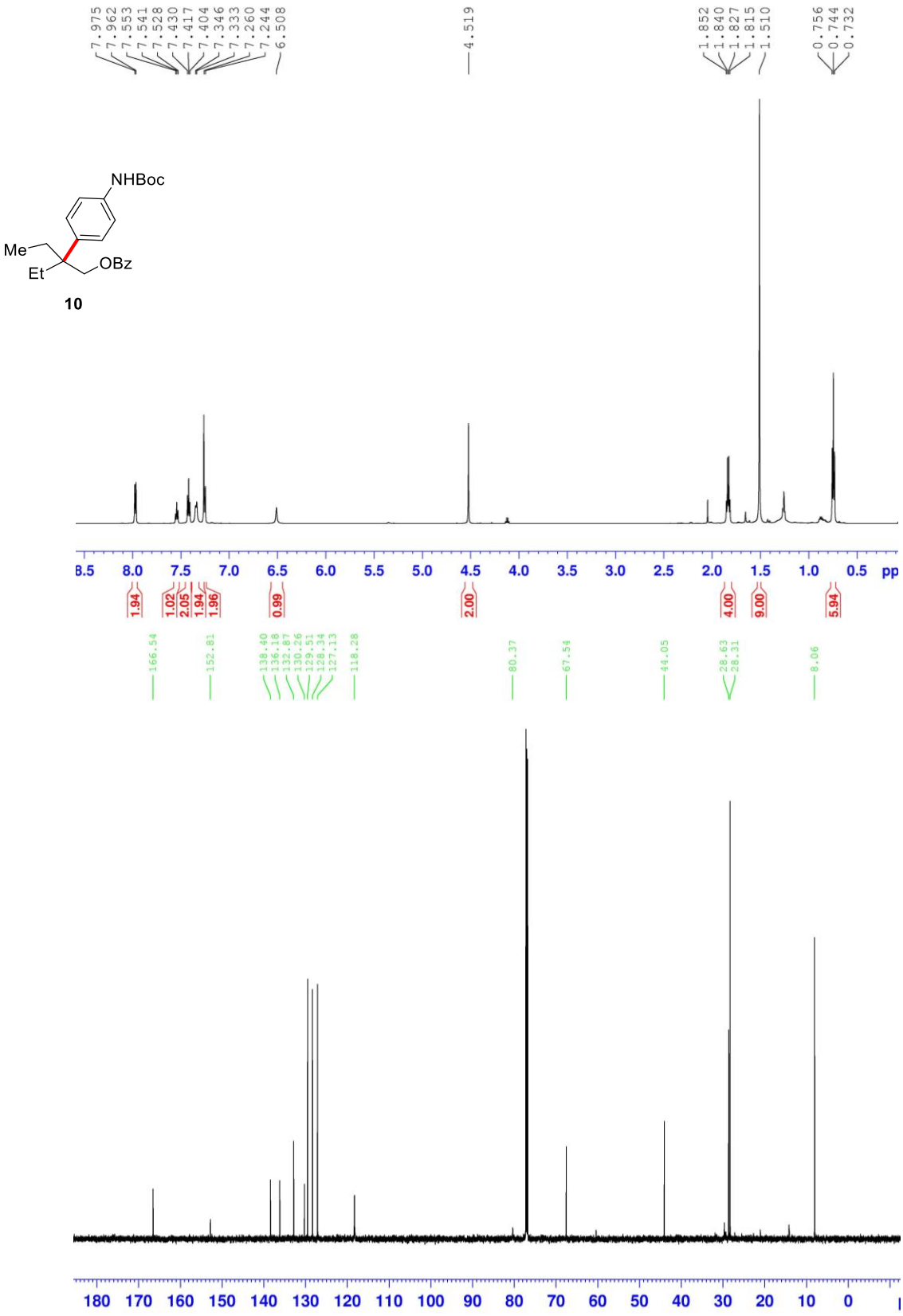
21.44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7.553
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7.528
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7.417
7.404
7.346
7.333
7.260
7.244
6.508
4.519
1.852
1.840
1.827
1.815
1.510
0.756
0.744
0.732
NHBoc
Me
Et
OBz
10
8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 ppm
1.94
1.02
2.05
1.94
1.96
0.99
2.00
4.00
9.00
5.94
166.54
152.81
138.40
136.18
132.87
130.26
129.51
128.34
127.13
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67.54
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28.63
28.31
8.06
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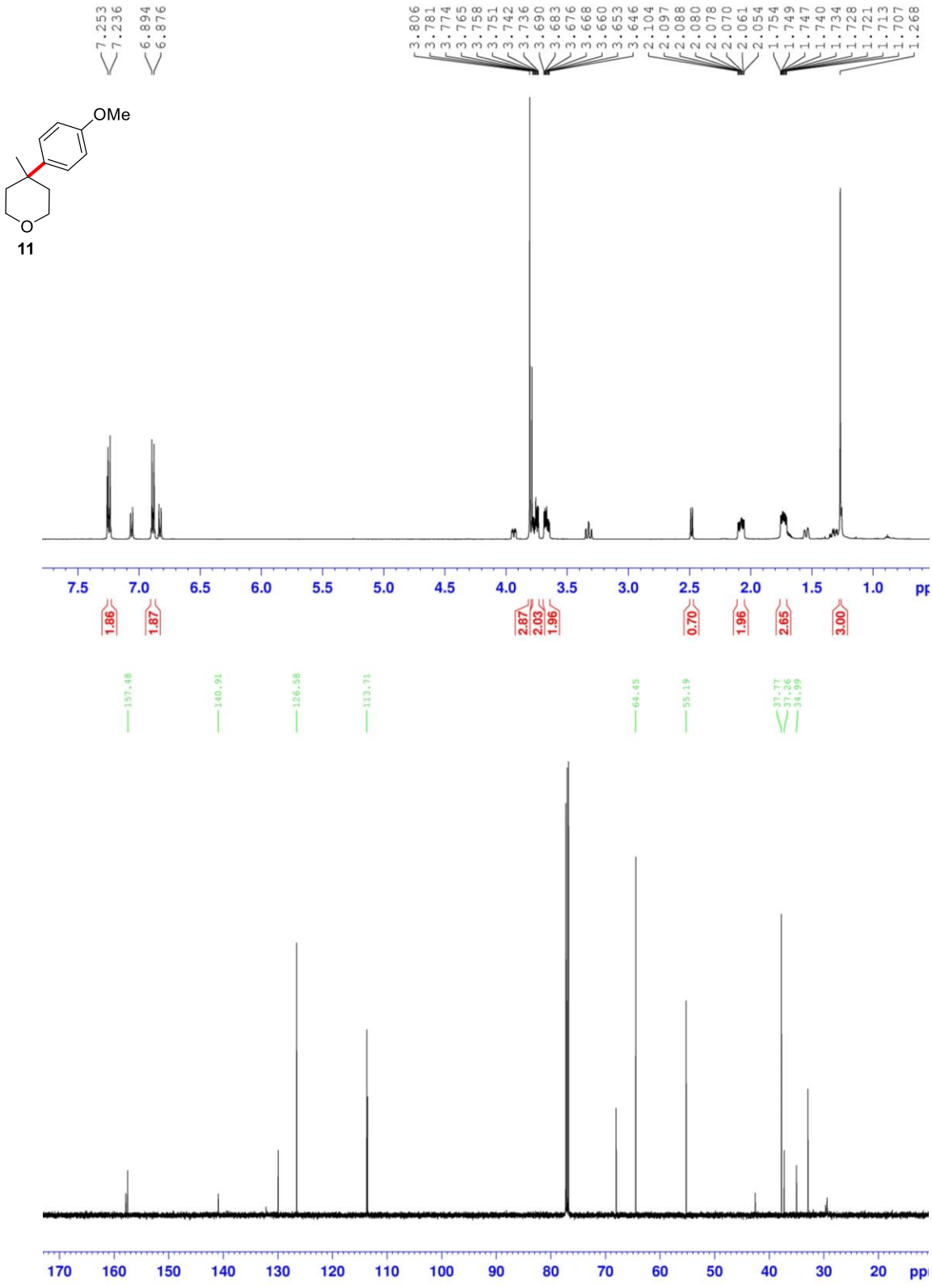
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3.774
3.765
3.758
3.751
3.742
3.736
3.690
3.683
3.676
3.668
3.660
3.653
3.646
2.104
2.097
2.088
2.080
2.078
2.070
2.061
2.054
1.754
1.749
1.747
1.740
1.734
1.728
1.721
1.713
1.707
1.268
OMe
O
11
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
1.86
1.87
2.87
2.03
1.96
0.70
1.96
2.65
3.00
157.48
140.91
126.58
113.71
64.45
55.19
37.77
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90
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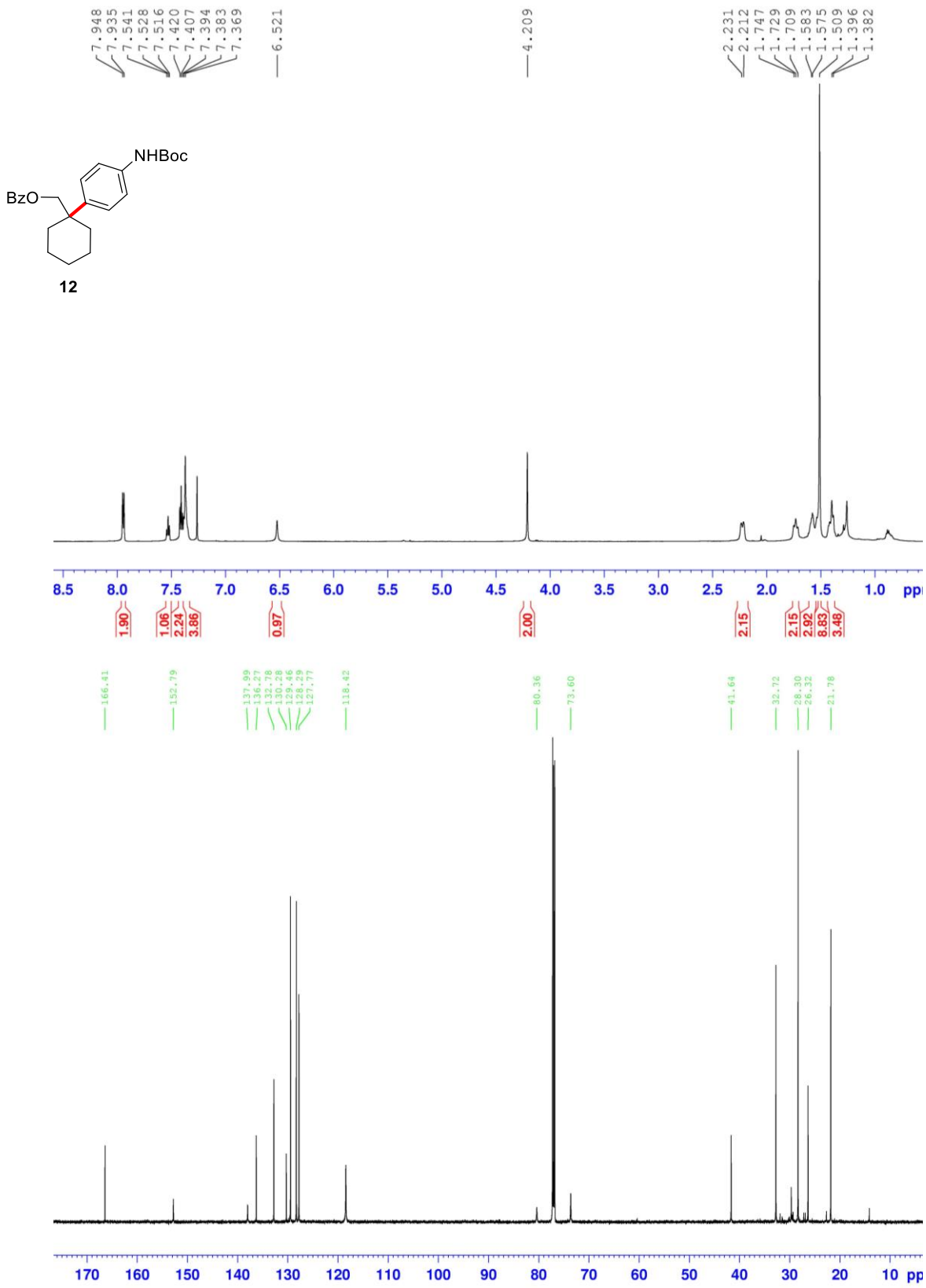
50
40
30
20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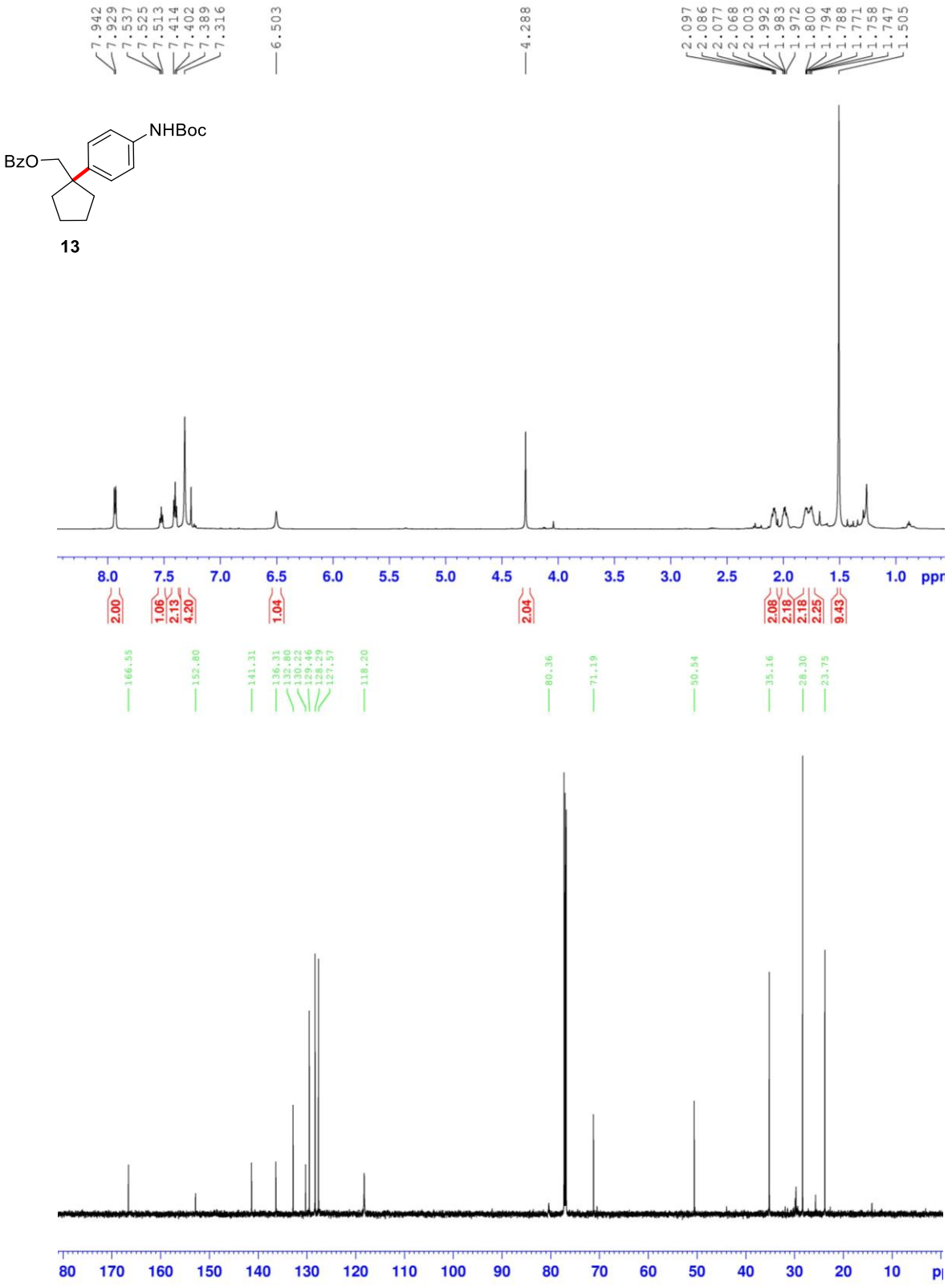
7.420
7.407
7.394
7.383
7.369
6.521
4.209
2.231
2.212
1.747
1.729
1.709
1.583
1.575
1.509
1.396
1.382
NHBoc
BzO
12
8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 ppm
1.90 1.06 2.24 3.86 0.97 2.00 2.15 2.15 2.92 8.83 3.48
166.41 152.79 137.99 136.27 132.78 130.28 129.46 128.29 127.77 118.42 80.36 73.60 41.64 32.72 28.30 26.32 21.78
170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 ppm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7.929
7.537
7.525
7.513
7.414
7.402
7.389
7.316
6.503
4.288
2.097
2.086
2.077
2.068
2.003
1.992
1.983
1.972
1.800
1.794
1.788
1.771
1.758
1.747
1.505
NHBoc
BzO
13
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
ppm
2.00
1.06
2.13
4.20
1.04
2.04
2.06
2.18
2.18
2.25
9.43
166.55
152.80
141.31
136.31
132.80
130.22
129.46
128.59
127.57
118.20
80.36
71.19
50.54
35.16
28.30
23.75
80
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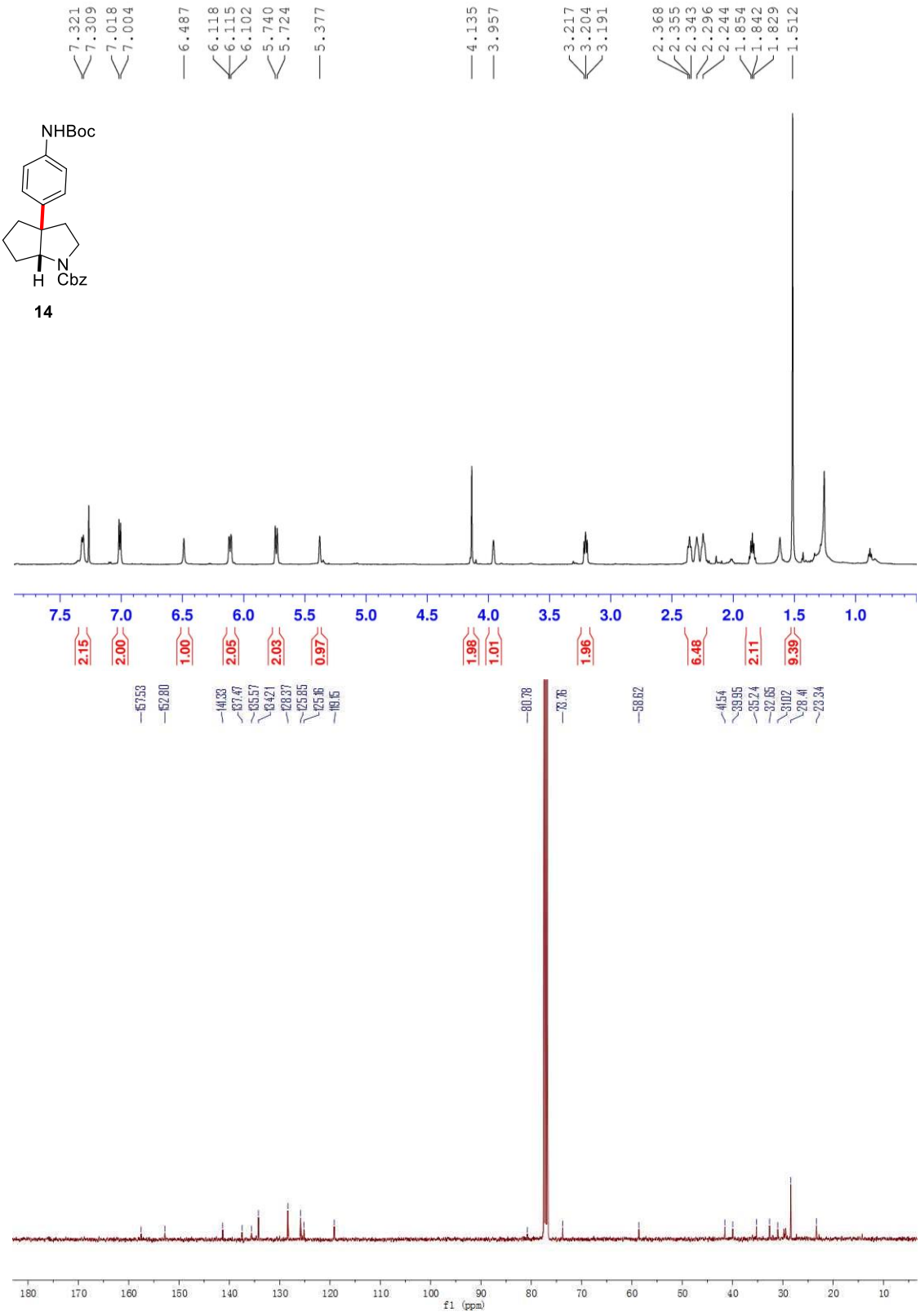
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10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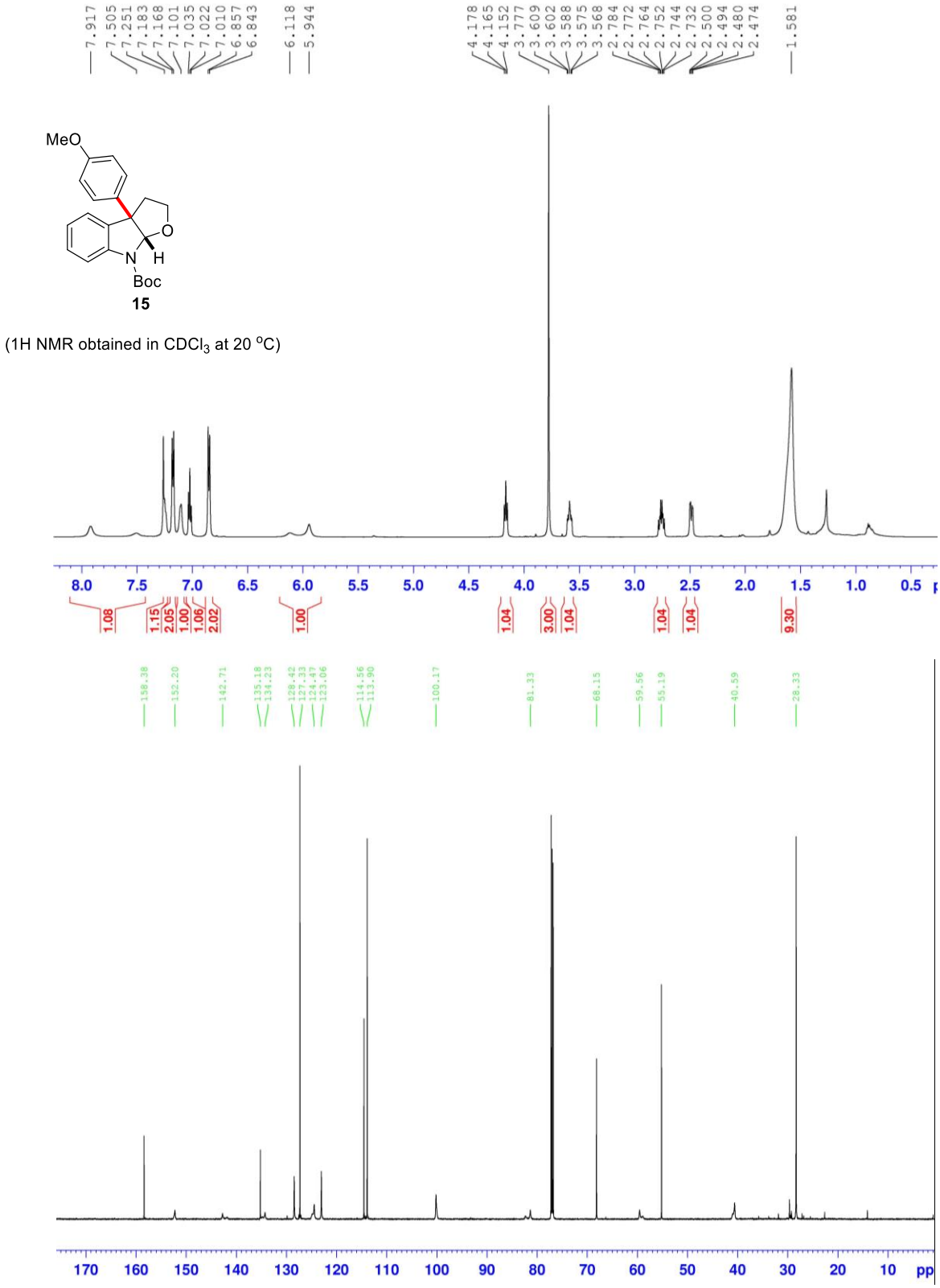
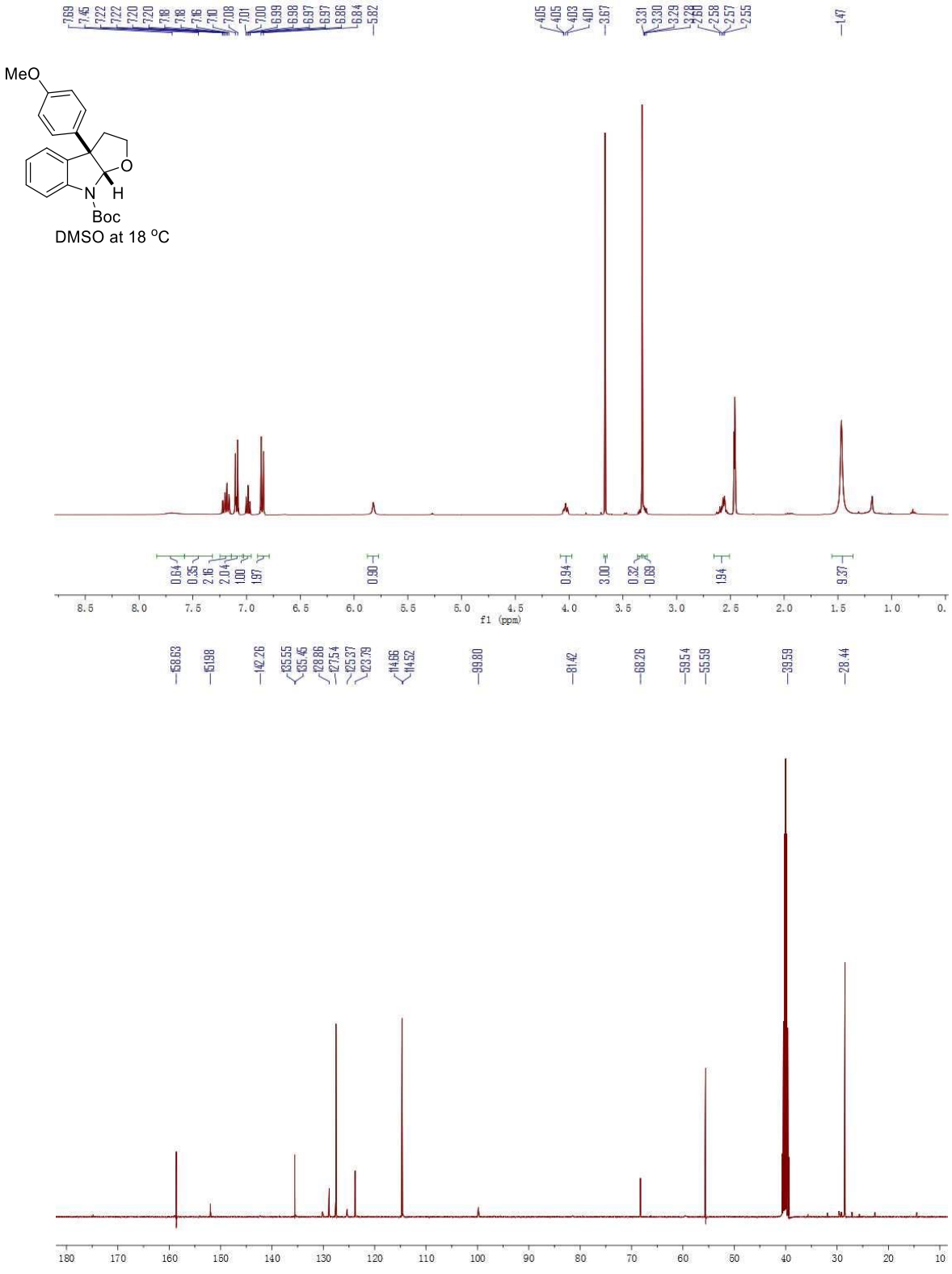
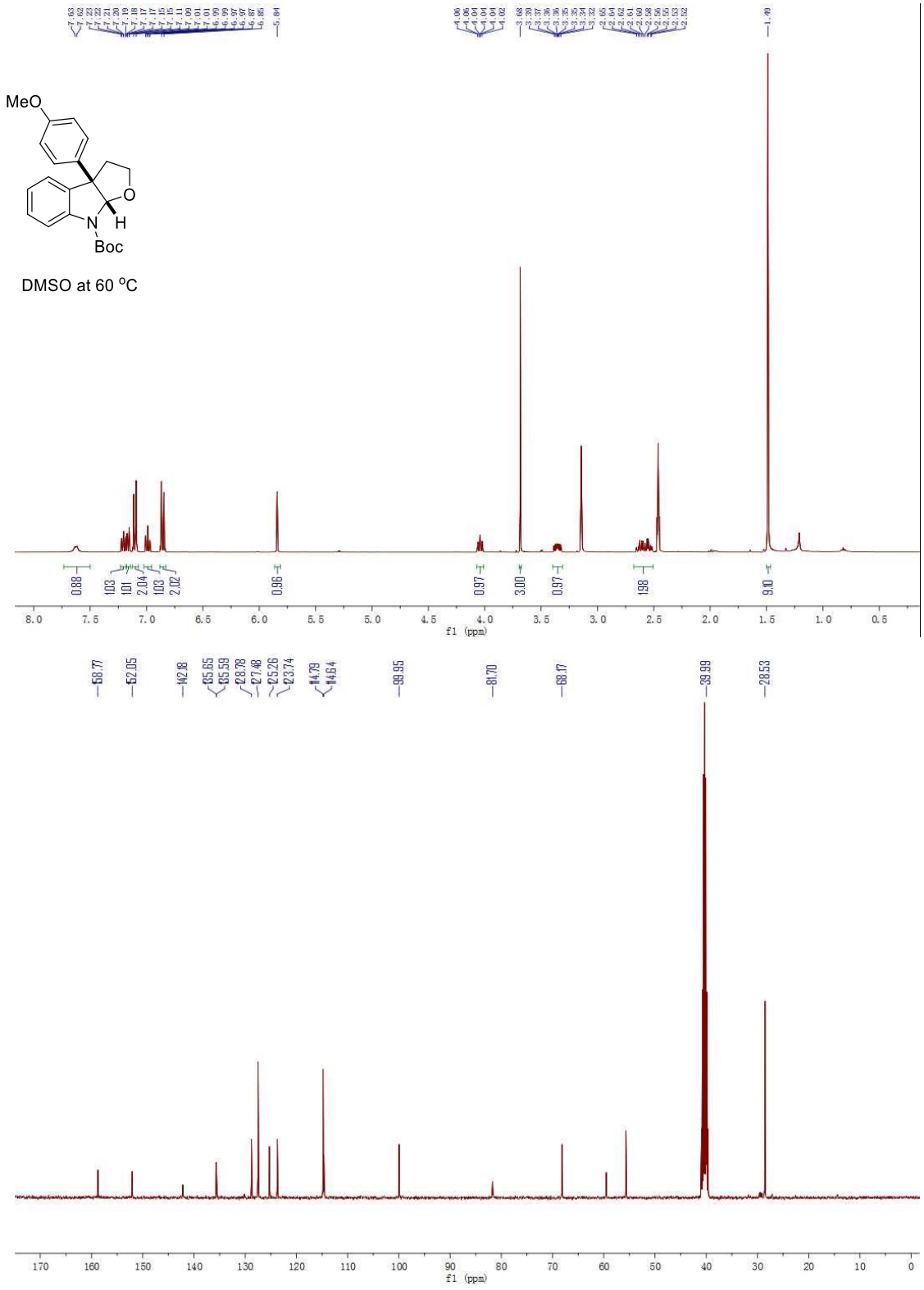
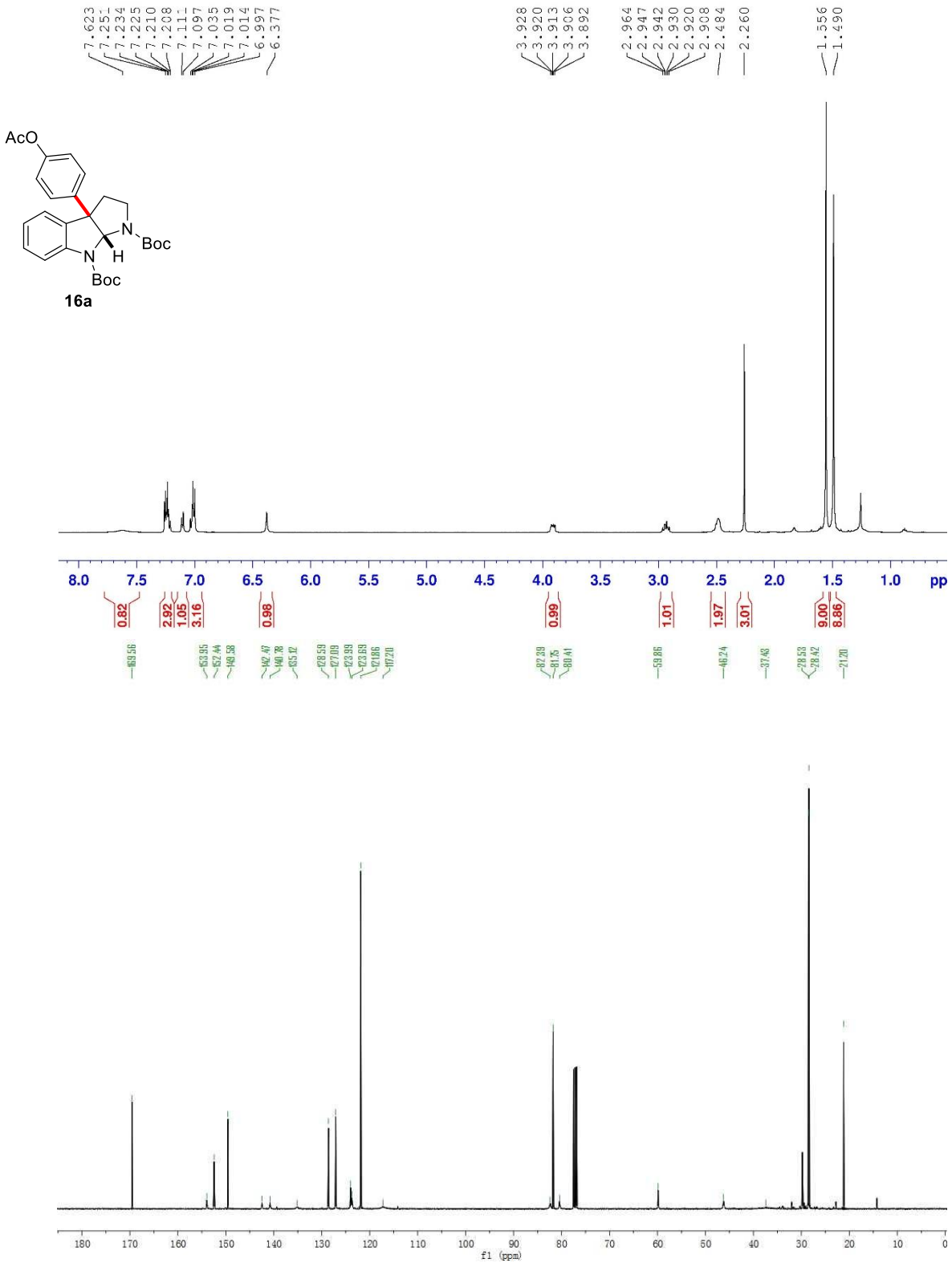
7.309
7.018
7.004
6.487
6.118
6.115
6.102
5.740
5.724
5.377
4.135
3.957
3.217
3.204
3.191
2.368
2.355
2.343
2.296
2.244
1.854
1.842
1.829
1.512
NHBoc
N
H Cbz
14
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
2.15
2.00
1.00
2.05
2.03
0.97
1.98
1.01
1.96
6.48
2.11
9.39
157.53
152.80
144.33
137.47
135.57
134.21
128.37
125.85
125.16
119.15
80.78
78.76
58.82
41.54
39.95
35.24
32.65
31.02
28.41
23.34
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)


7.917
7.505
7.251
7.183
7.168
7.101
7.035
7.022
7.010
6.857
6.843
6.118
5.944
4.178
4.165
4.152
3.777
3.609
3.602
3.588
3.575
3.568
2.784
2.772
2.764
2.752
2.744
2.732
2.500
2.494
2.480
2.474
1.581
MeO
O
N
H
Boc
15
(1H NMR obtained in CDCl3 at 20 °C)
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
1.08
1.15
2.05
1.00
1.06
2.02
1.00
1.04
3.00
1.04
1.04
1.04
9.30
158.38
152.20
142.71
135.18
134.23
128.42
127.33
124.47
123.06
114.56
113.90
100.17
81.33
68.15
59.56
55.19
40.59
28.33
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm


MeO
O
N
H
Boc
DMSO at 18 °C
f1 (ppm)


MeO
O
N
H
Boc
DMSO at 60 °C
f1 (ppm)
f1 (ppm)


AcO
N
Boc
N
H
Boc
16a
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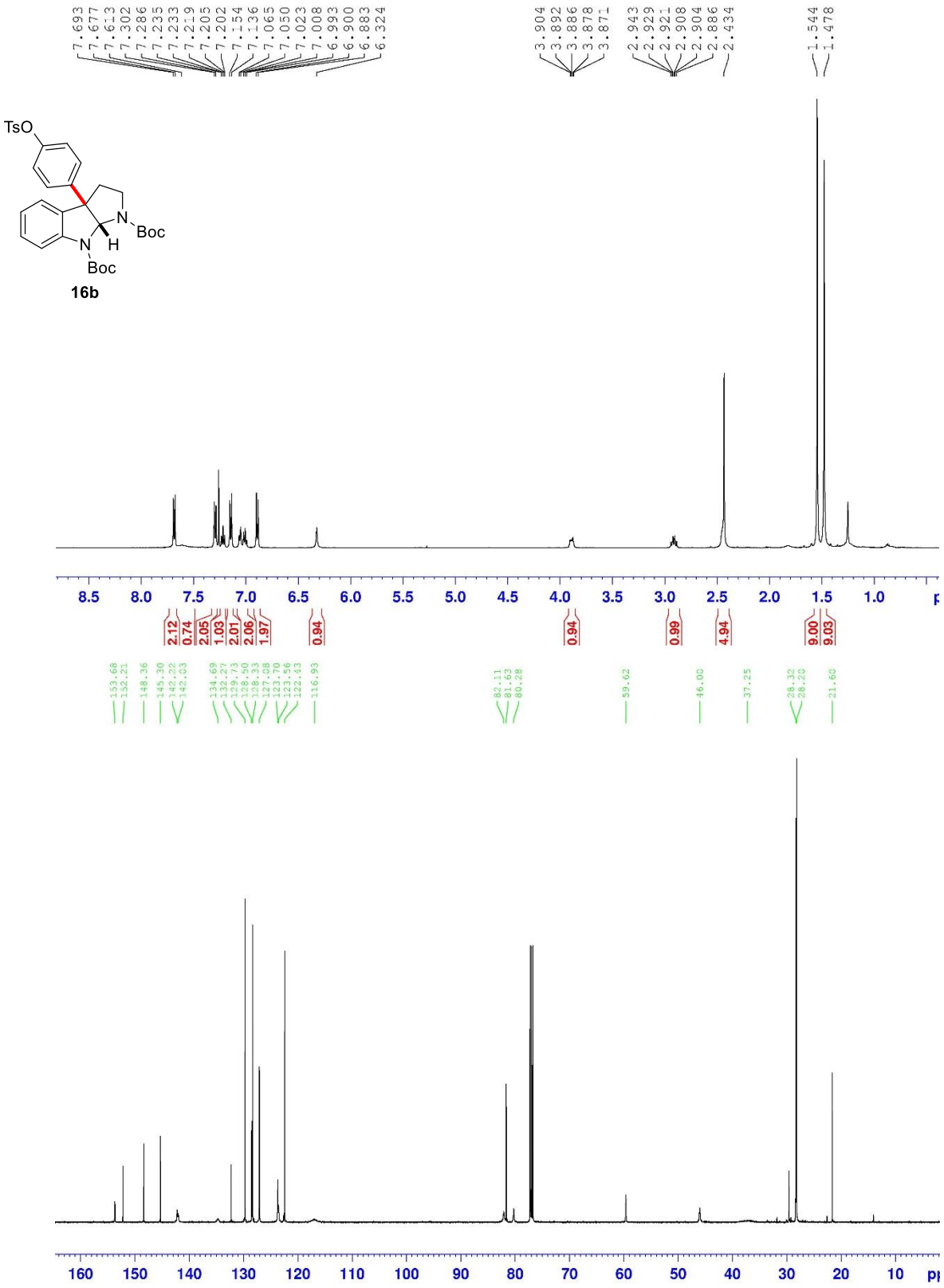
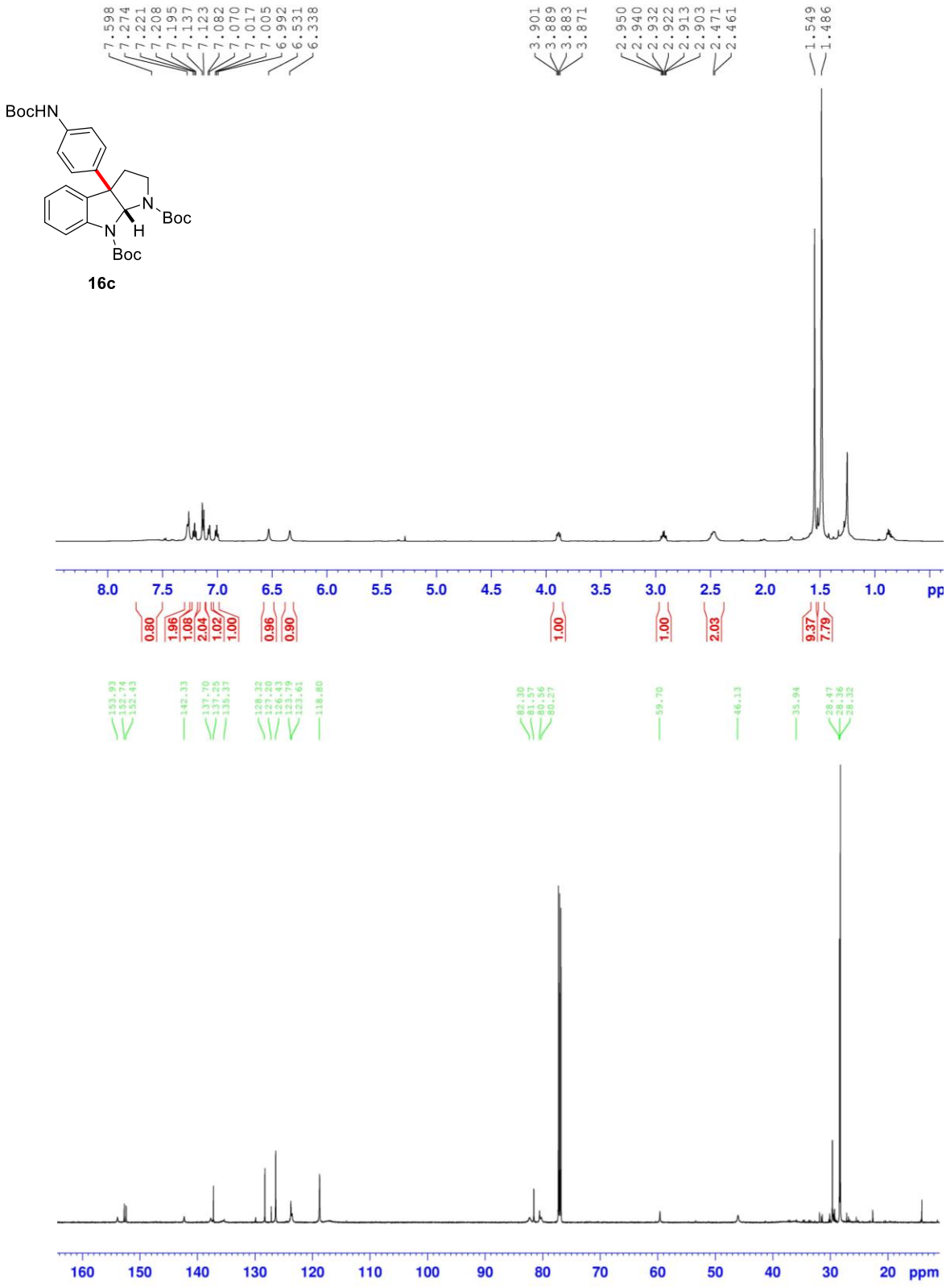
7.251
7.234
7.225
7.210
7.208
7.111
7.097
7.035
7.019
7.014
6.997
6.377
3.928
3.920
3.913
3.906
3.892
2.964
2.947
2.942
2.930
2.920
2.908
2.484
2.260
1.556
1.490
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
pp
0.82
2.92
1.05
3.16
0.98
0.99
1.01
1.97
3.01
9.00
8.86
169.56
153.95
152.44
148.58
142.47
140.78
135.12
128.59
127.09
123.99
123.69
121.86
107.20
82.39
81.75
60.41
59.86
46.24
37.48
28.53
28.42
21.20
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


TsO
N
Boc
N
H
Boc
16b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7.208
7.195
7.137
7.123
7.082
7.070
7.017
7.005
6.992
6.531
6.338
3.901
3.889
3.883
3.871
2.950
2.940
2.932
2.922
2.913
2.903
2.471
2.461
1.549
1.486
BocHN
N
Boc
N
H
Boc
16c
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.80
1.96
1.08
2.04
1.02
1.00
0.96
0.90
1.00
1.00
2.03
9.37
7.79
153.93
152.74
152.43
142.33
137.70
137.25
135.37
128.32
127.20
126.43
123.79
123.61
118.80
82.30
81.57
80.56
80.27
59.70
46.13
35.94
28.47
28.36
28.32
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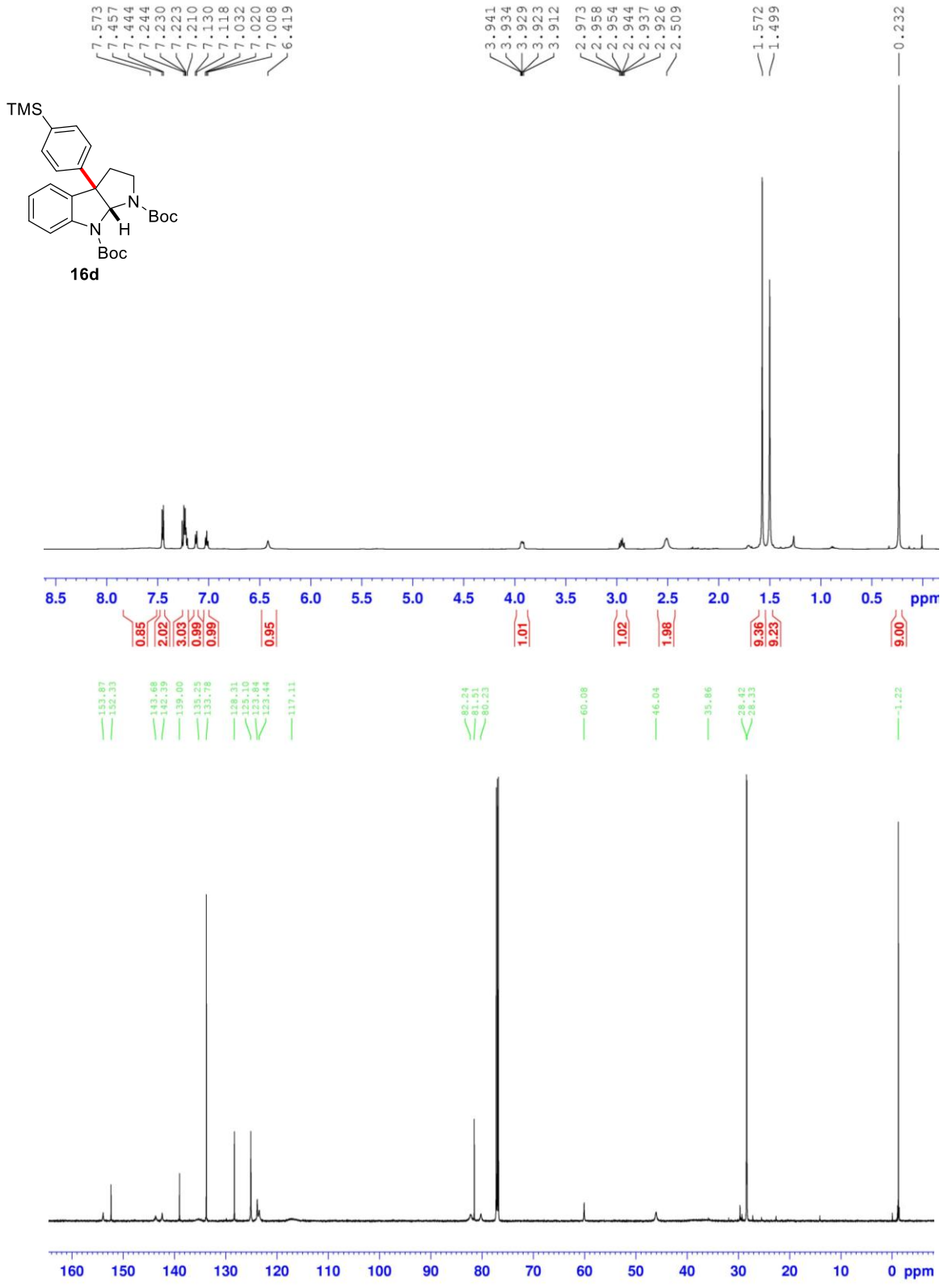
150
140
130
120
110
100
90
80
70
60
50
40
30
20
ppm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7.230
7.223
7.210
7.130
7.118
7.032
7.020
7.008
6.419
3.941
3.934
3.929
3.923
3.912
2.973
2.958
2.954
2.944
2.937
2.926
2.509
1.572
1.499
0.232
TMS
N
Boc
N
H
Boc
16d
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
ppm
0.85
2.02
3.03
0.99
0.99
0.95
1.01
1.02
1.98
9.36
9.23
9.00
153.87
152.33
143.68
142.39
139.00
135.25
133.78
128.31
125.10
123.84
123.44
117.11
82.24
81.51
80.23
60.08
46.04
35.86
28.42
28.33
-1.22
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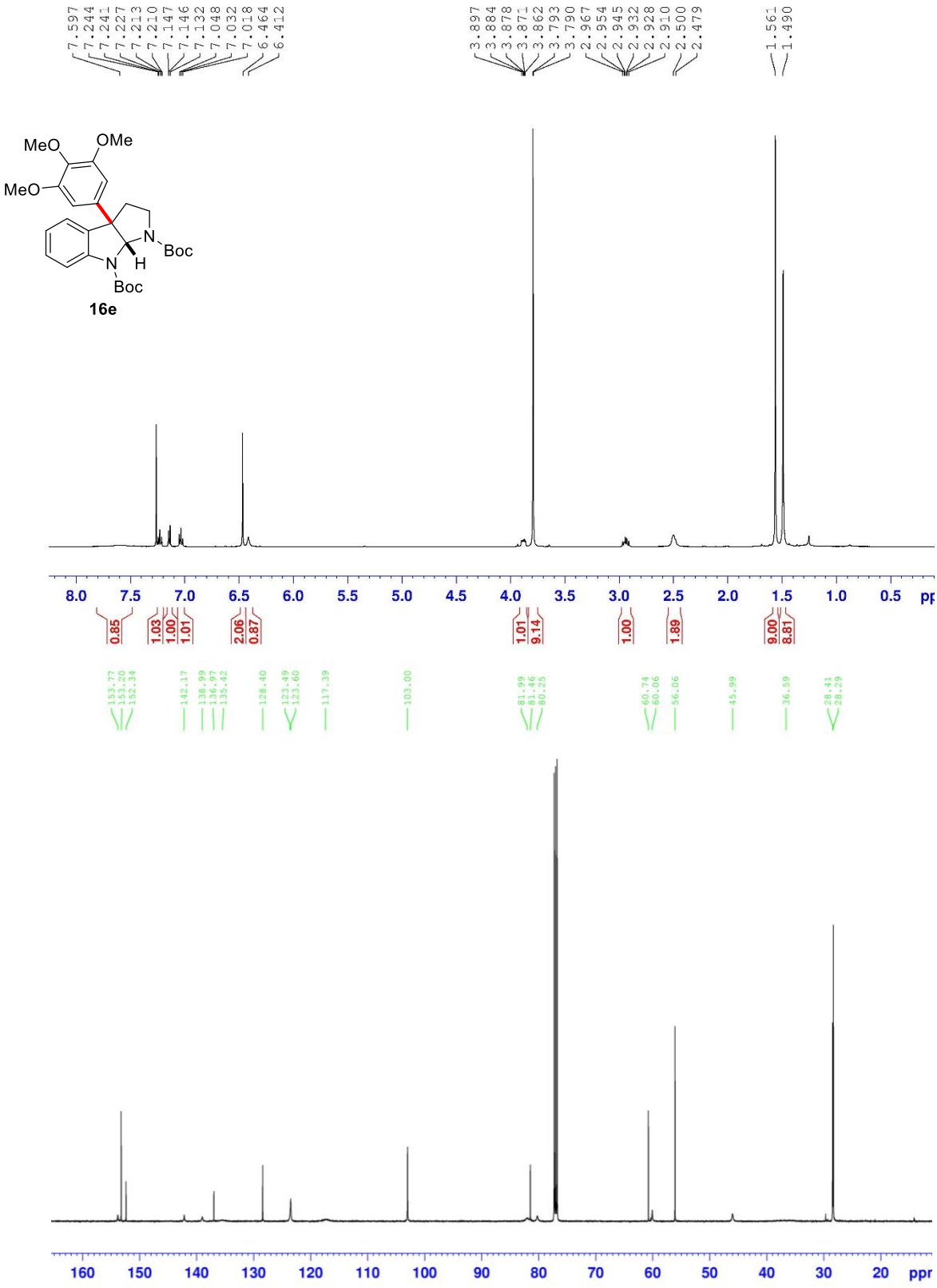
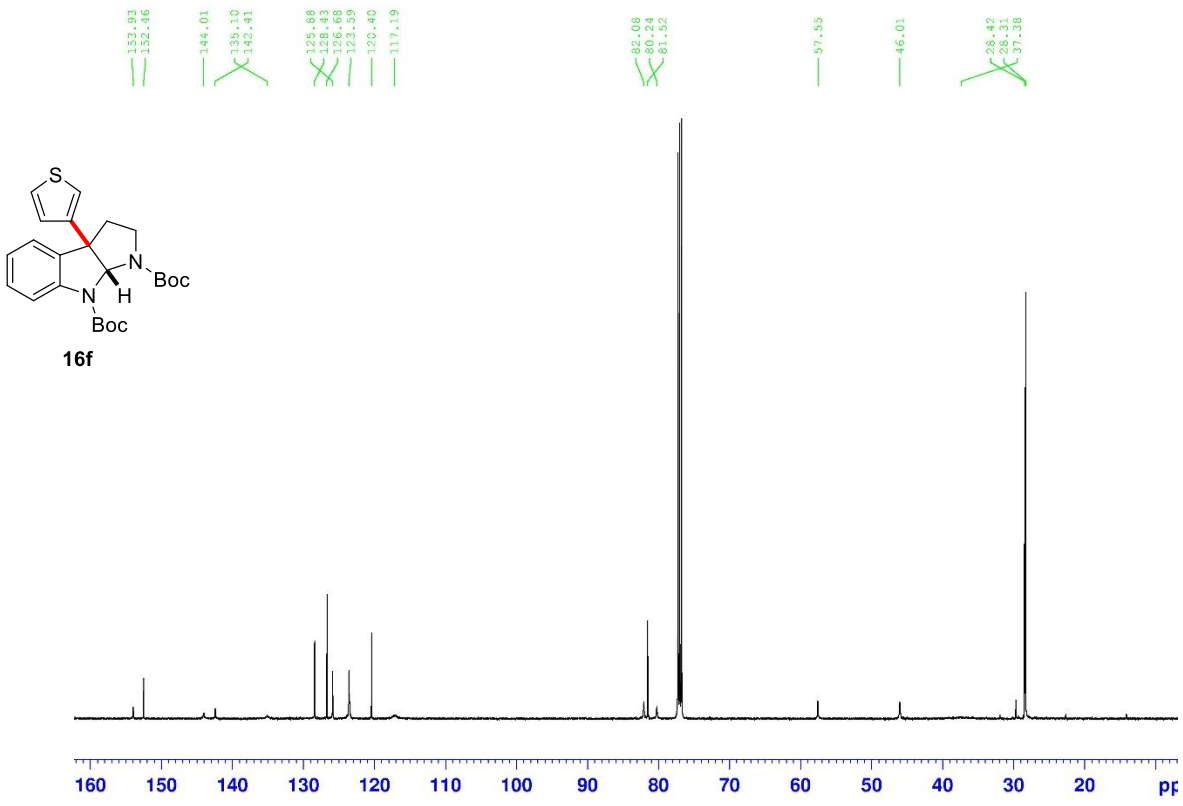
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0 ppm


MeO
OMe
MeO
N
Boc
N
H
Boc
16e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126.68
123.59
120.40
117.19
82.08
80.24
81.52
57.53
46.01
28.42
28.31
37.38
S
N
Boc
N
H
Boc
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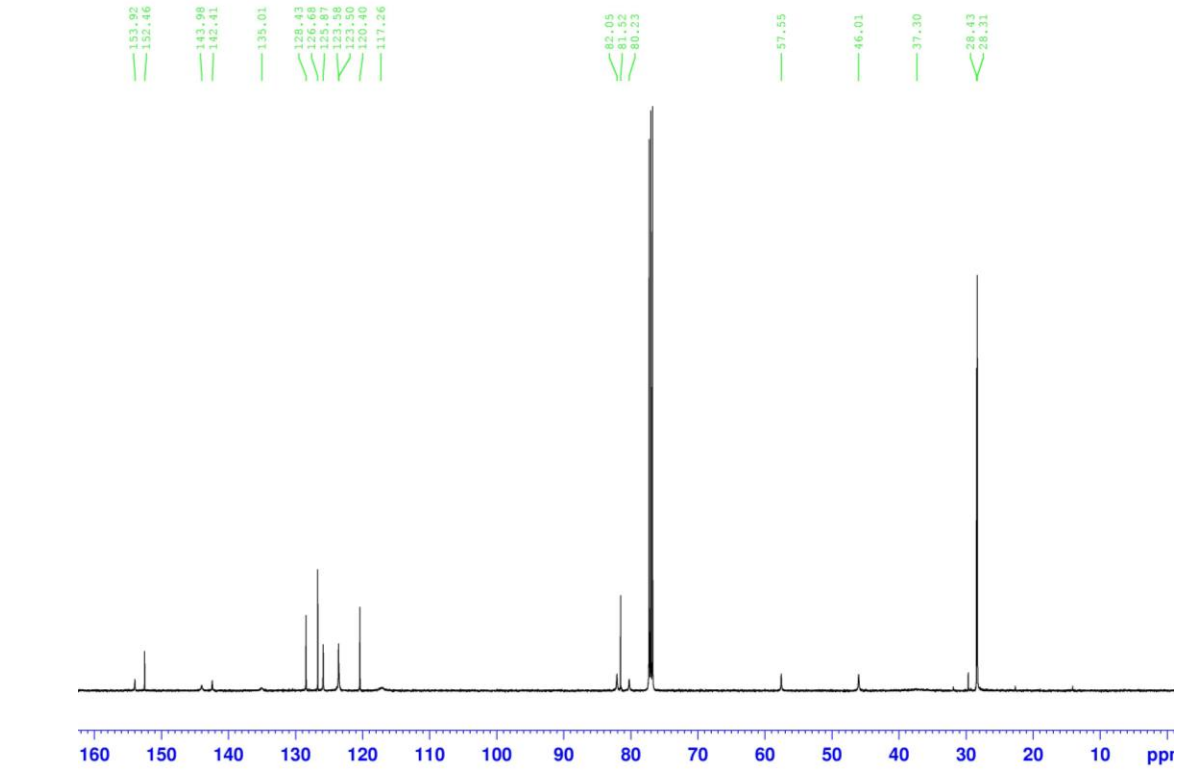
70
60
50
40
30
20
ppm

16f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123.50
120.40
117.26
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81.52
80.23
57.55
46.01
37.30
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150
140
130
120
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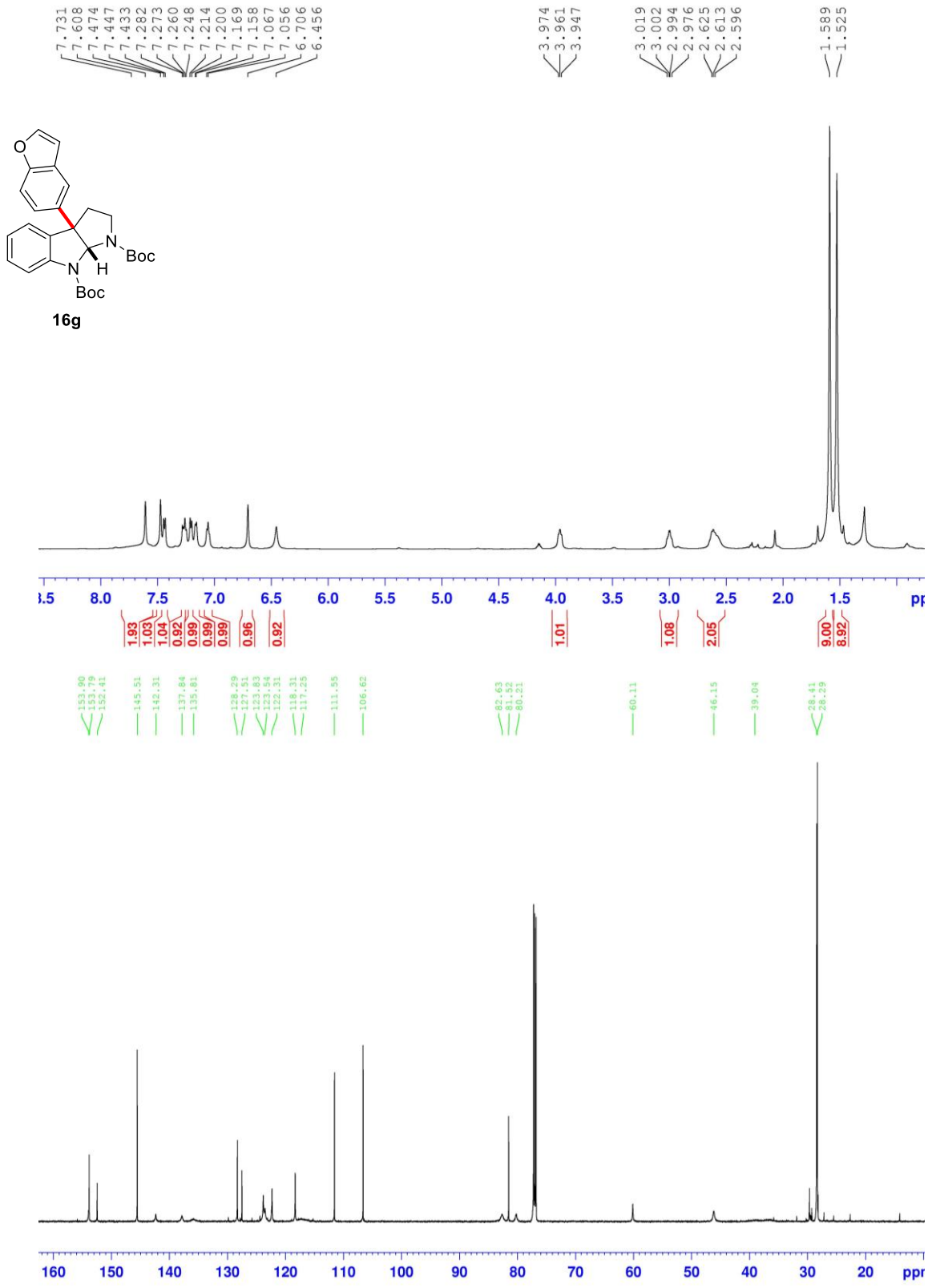
80
70
60
50
40
30
20
10
ppm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7.260
7.248
7.214
7.200
7.169
7.158
7.067
7.056
6.706
6.456
3.974
3.961
3.947
3.019
3.002
2.994
2.976
2.625
2.613
2.596
1.589
1.525
O
N
Boc
N
H
Boc
16g
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.93
1.03
1.04
0.92
0.99
0.99
0.99
0.96
0.92
1.01
1.08
2.05
9.00
8.92
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153.79
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123.83
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111.55
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80.21
60.11
46.15
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30
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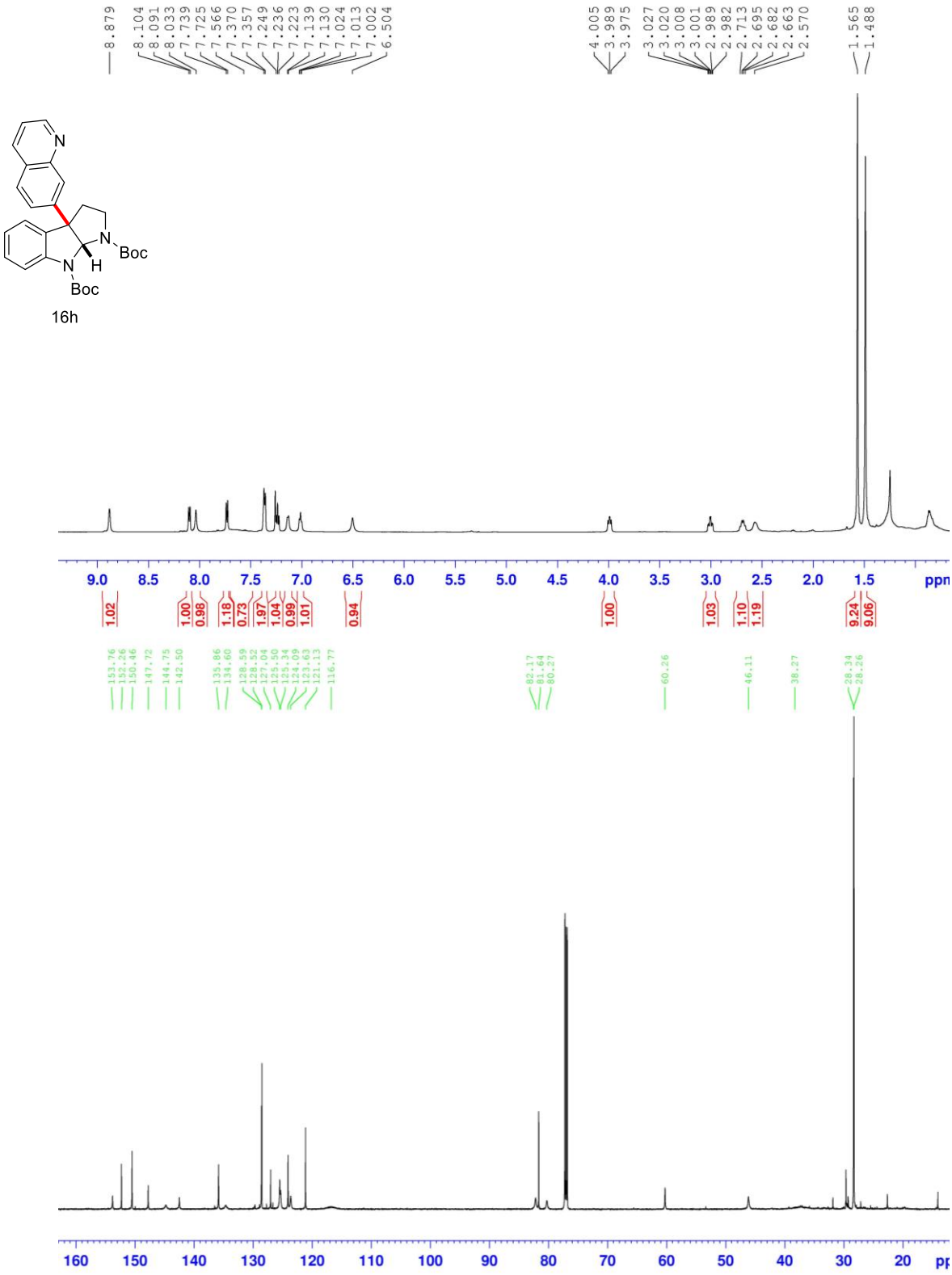
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7.725
7.566
7.370
7.357
7.249
7.236
7.223
7.139
7.130
7.024
7.013
7.002
6.504
4.005
3.989
3.975
3.027
3.020
3.008
3.001
2.989
2.982
2.713
2.695
2.682
2.663
2.570
1.565
1.488
N
N
Boc
N
H
Boc
16h
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
ppm
1.02
1.00
0.98
1.18
0.73
1.97
1.04
0.99
1.01
0.94
1.00
1.03
1.10
1.19
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9.06
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152.26
150.46
147.72
144.75
142.50
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134.60
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128.52
127.04
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125.14
124.09
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121.13
116.77
82.17
81.64
80.27
60.26
46.11
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90
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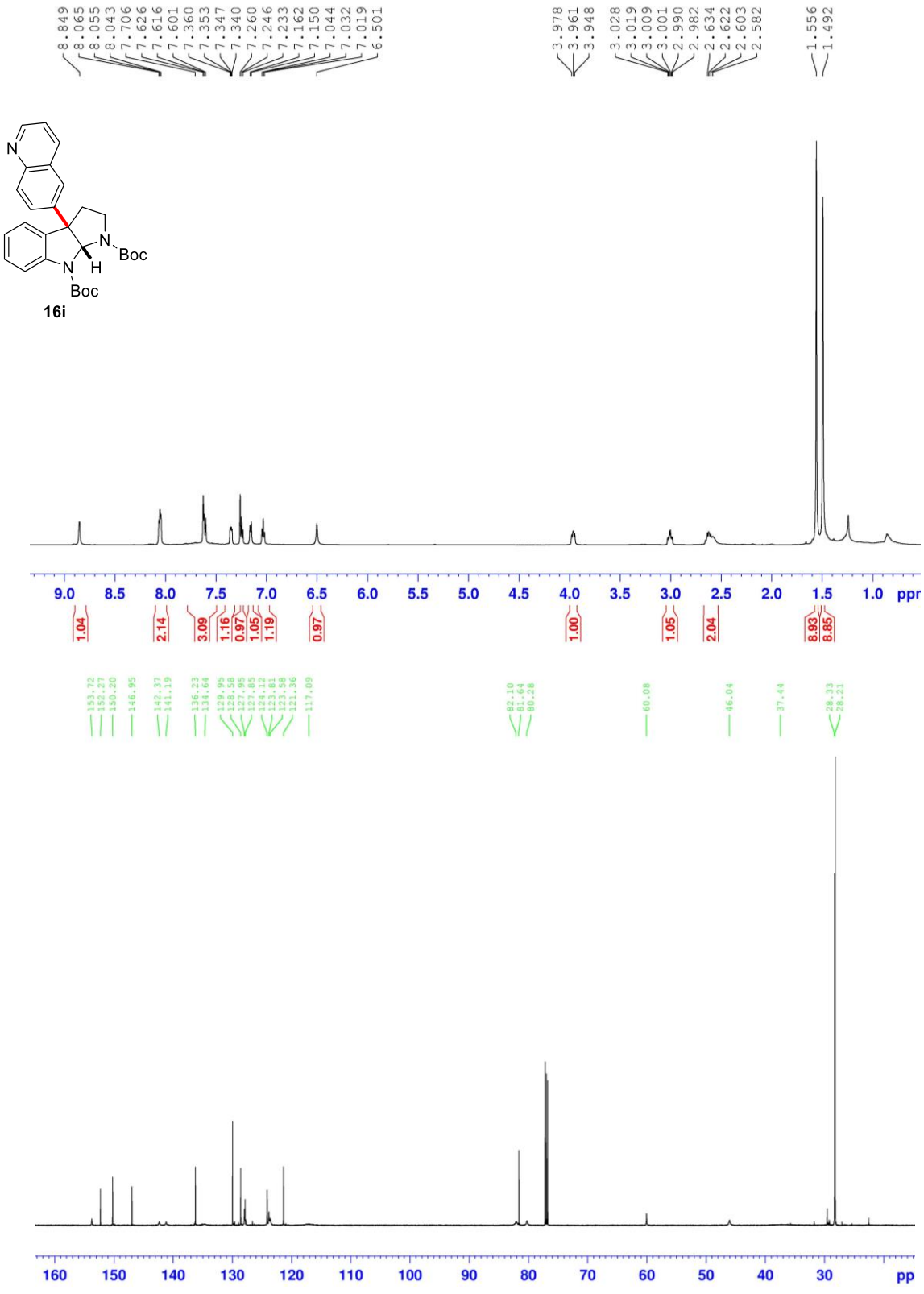
30
20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7.601
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7.347
7.340
7.260
7.246
7.233
7.162
7.150
7.044
7.032
7.019
6.501
3.978
3.961
3.948
3.028
3.019
3.009
3.001
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2.982
2.634
2.622
2.603
2.582
1.556
1.492
N
N
Boc
N
H
Boc
16i
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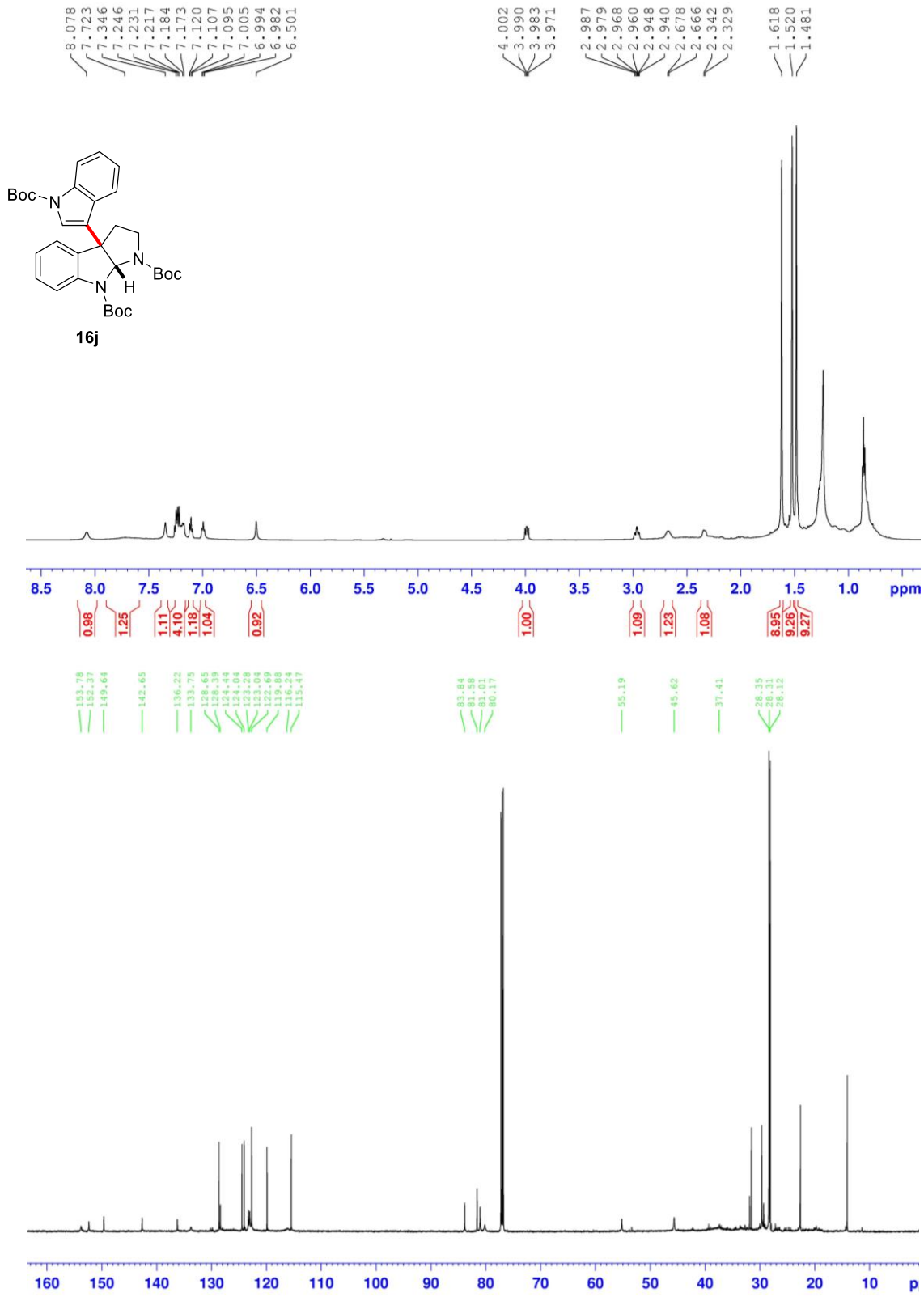
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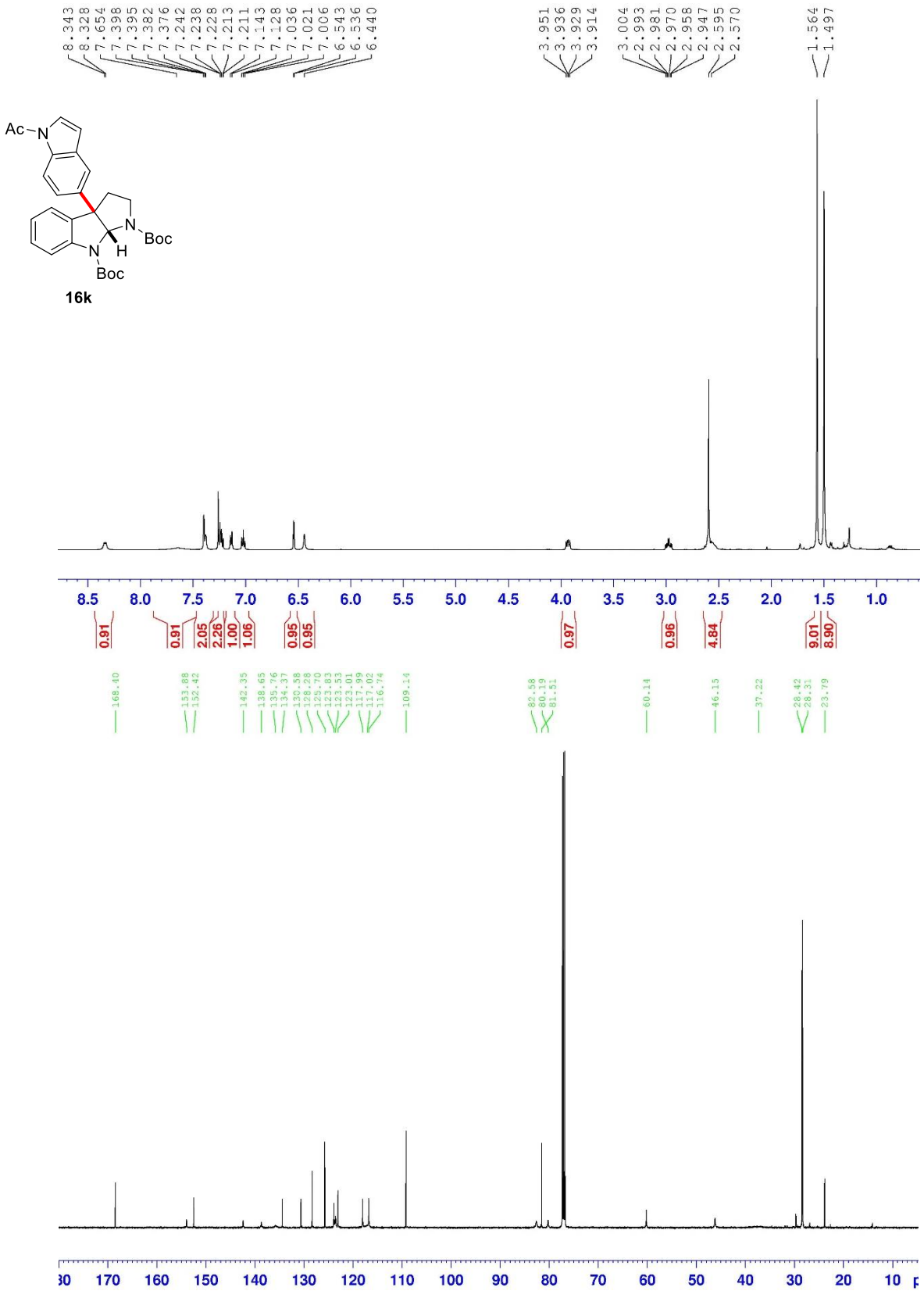
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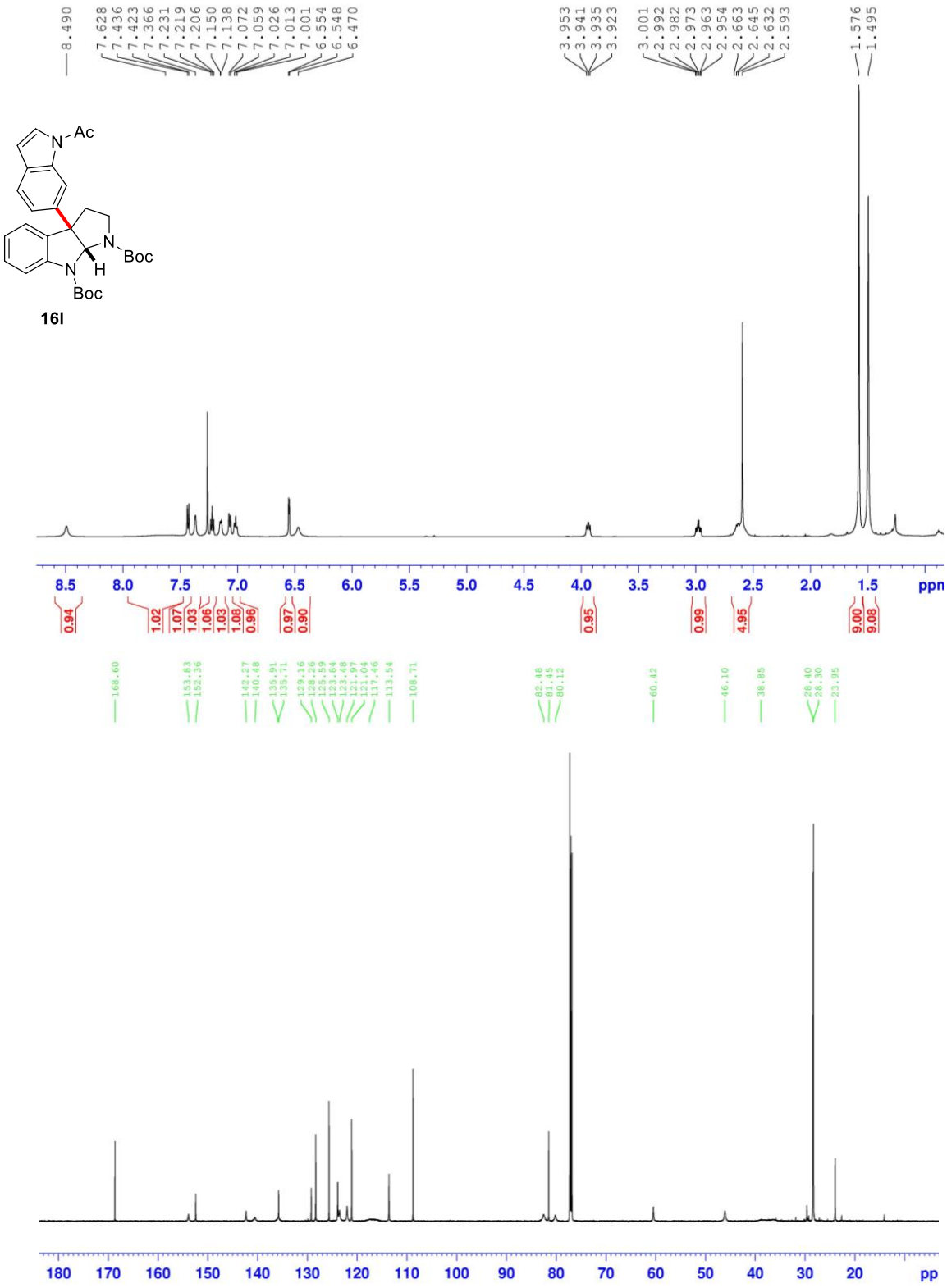
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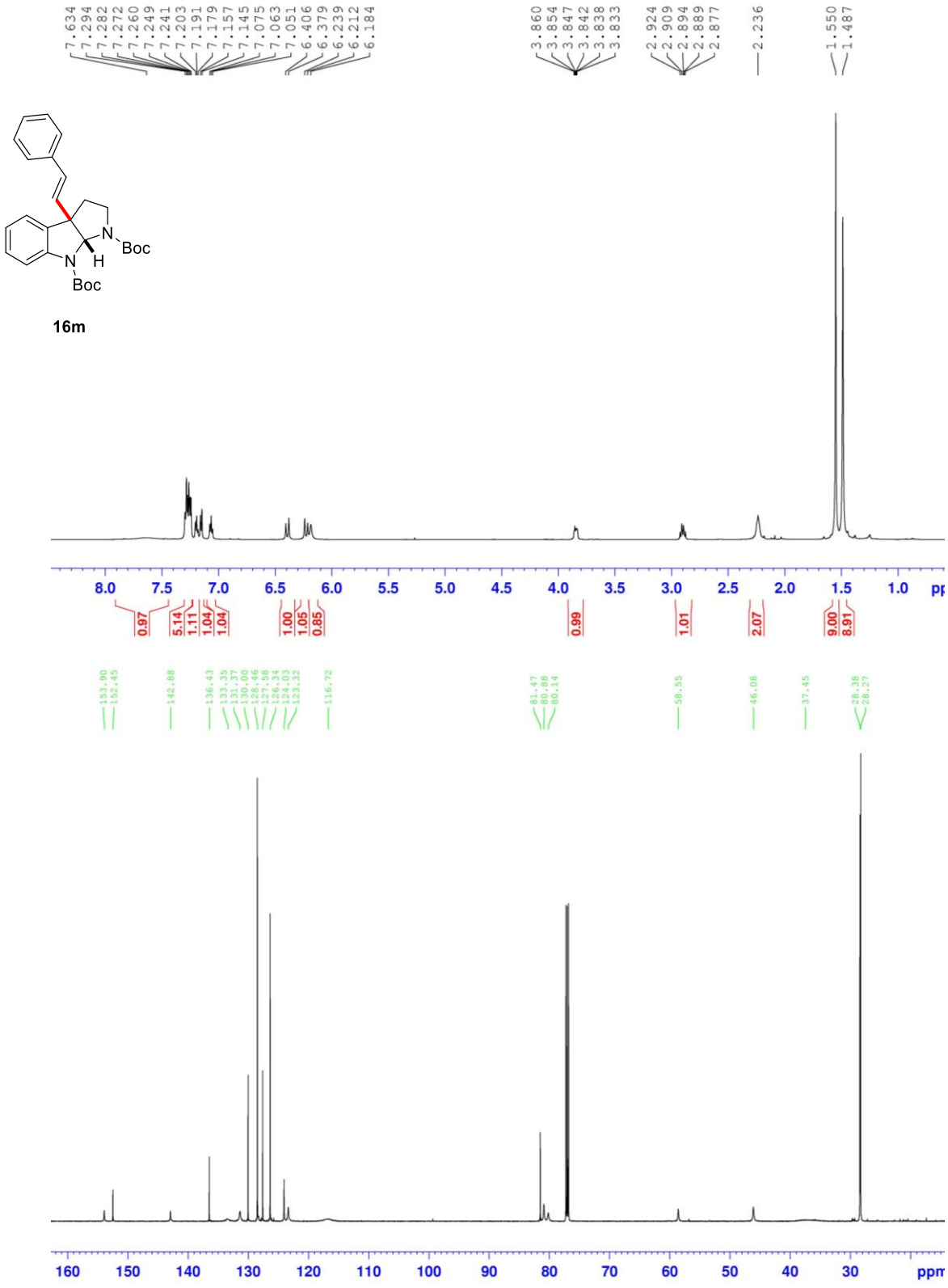
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Boc
N
H
Boc
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ppm

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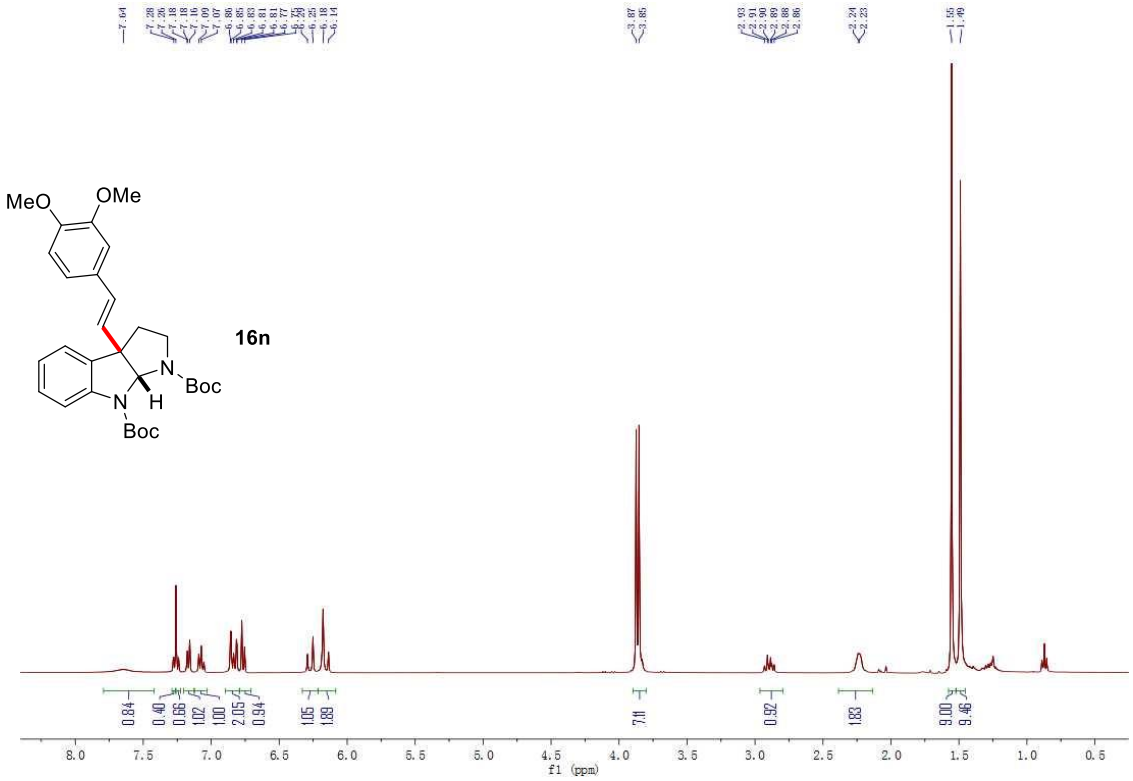

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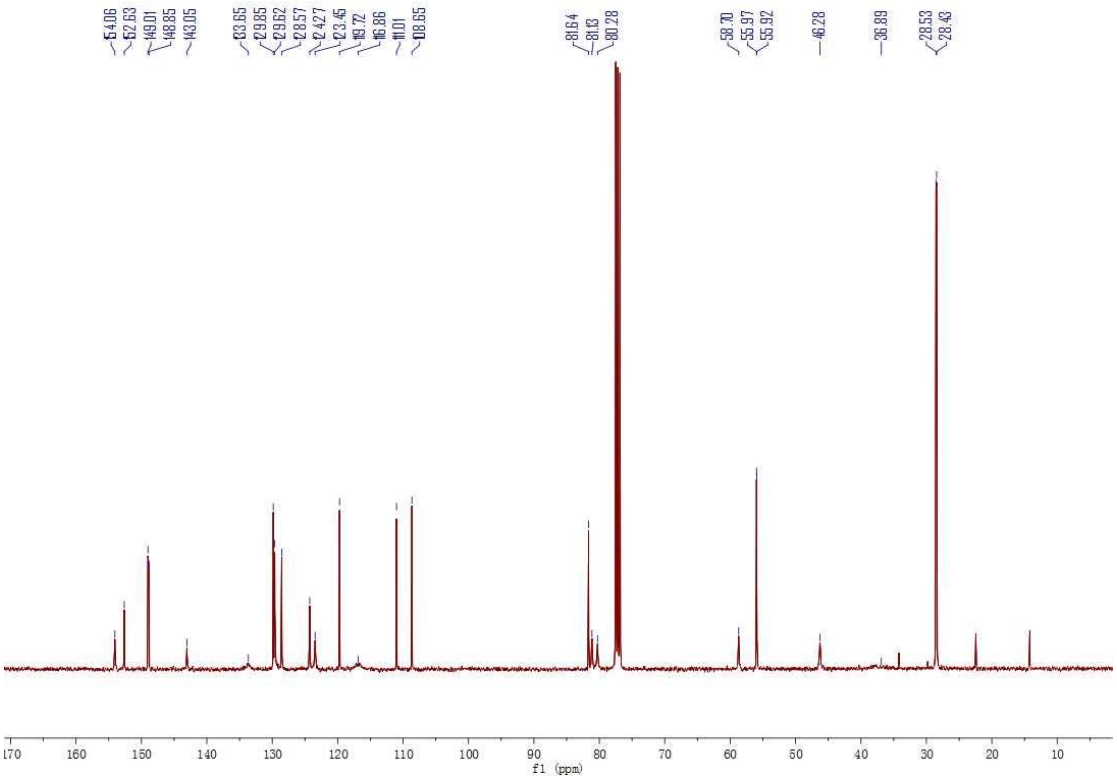

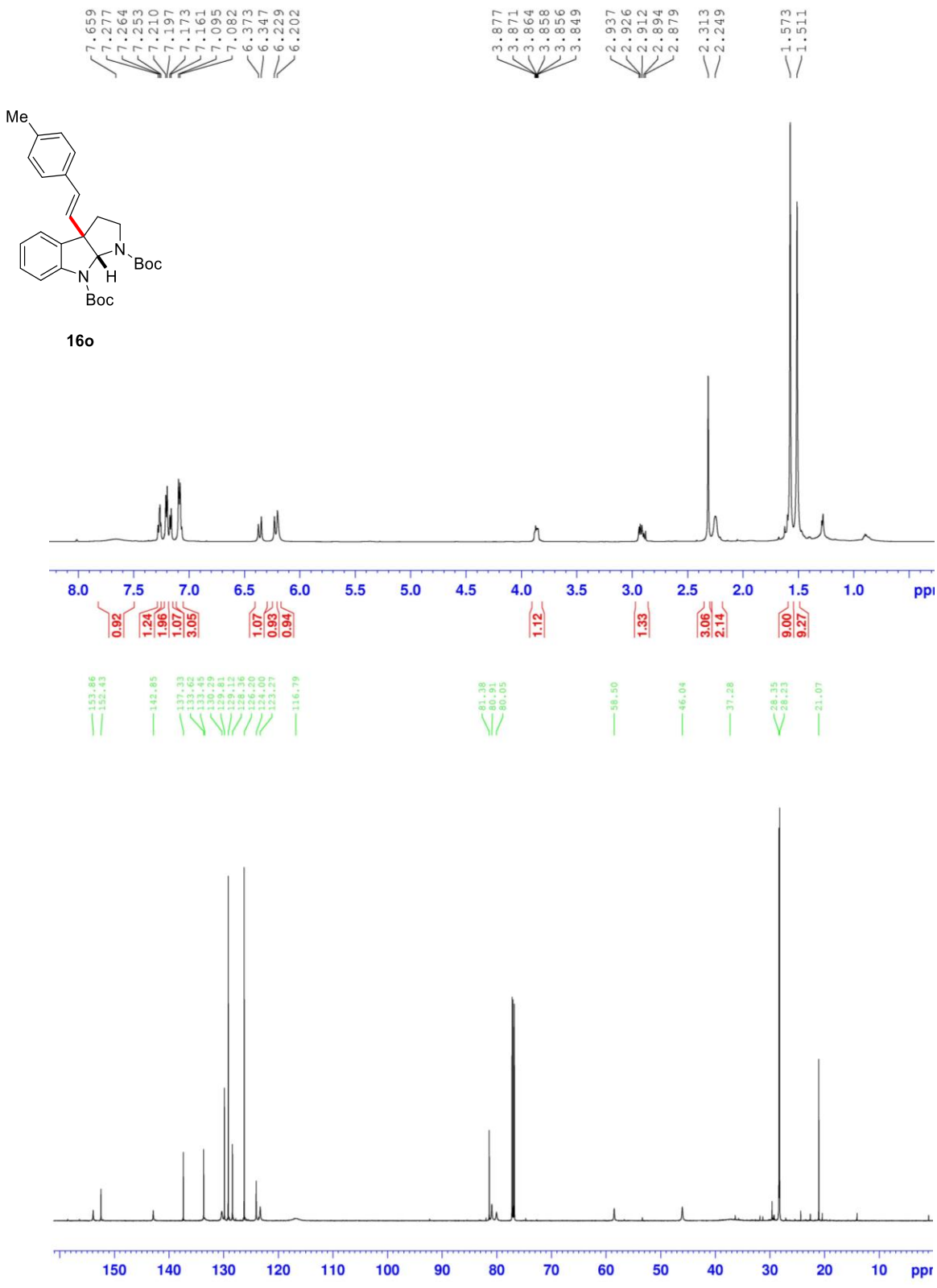
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H
Boc
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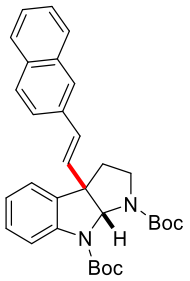
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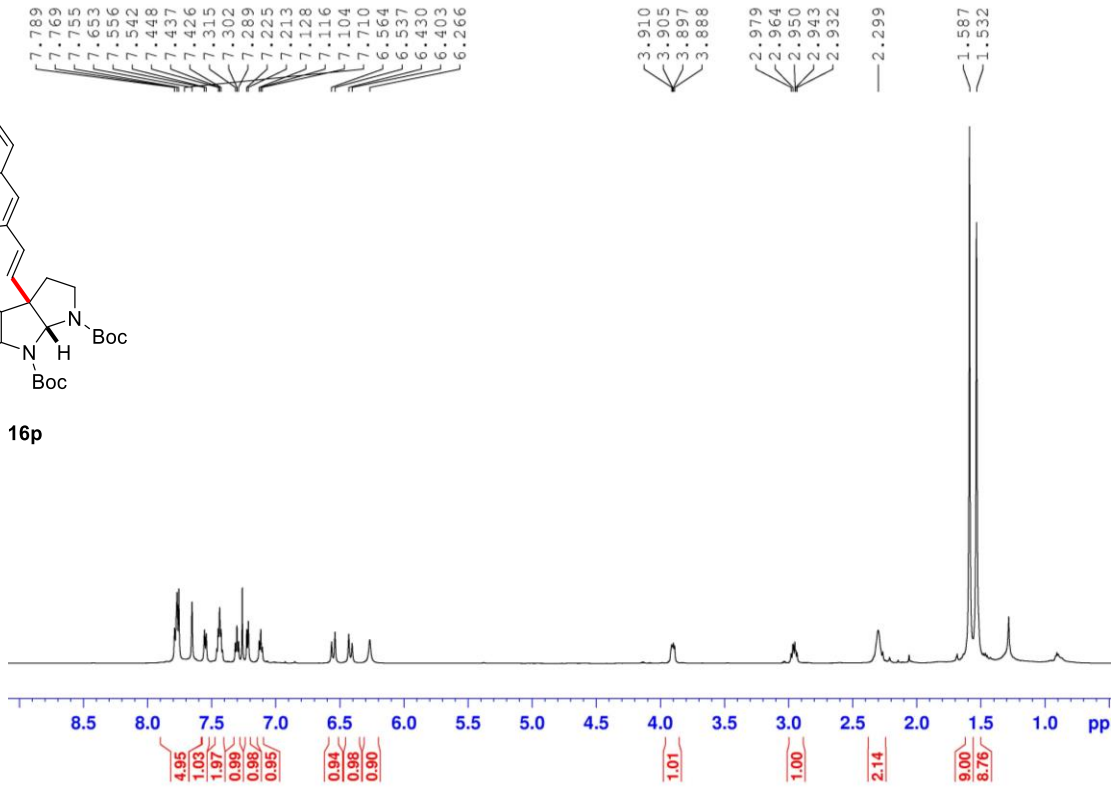
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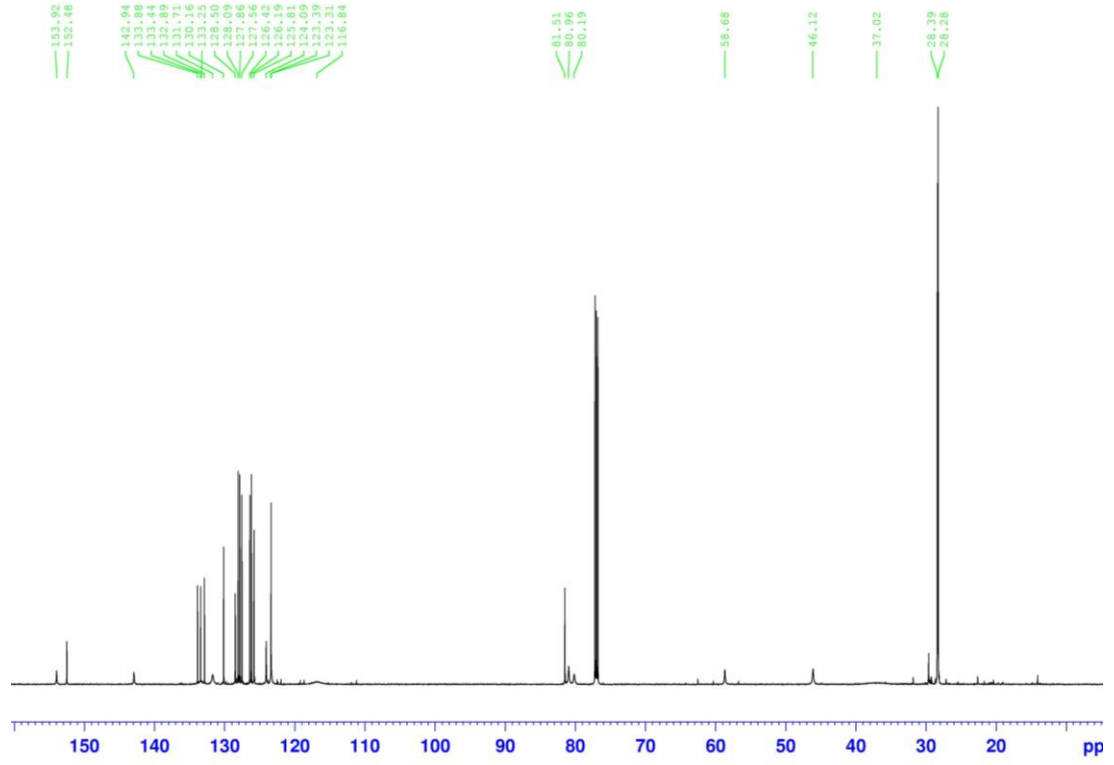
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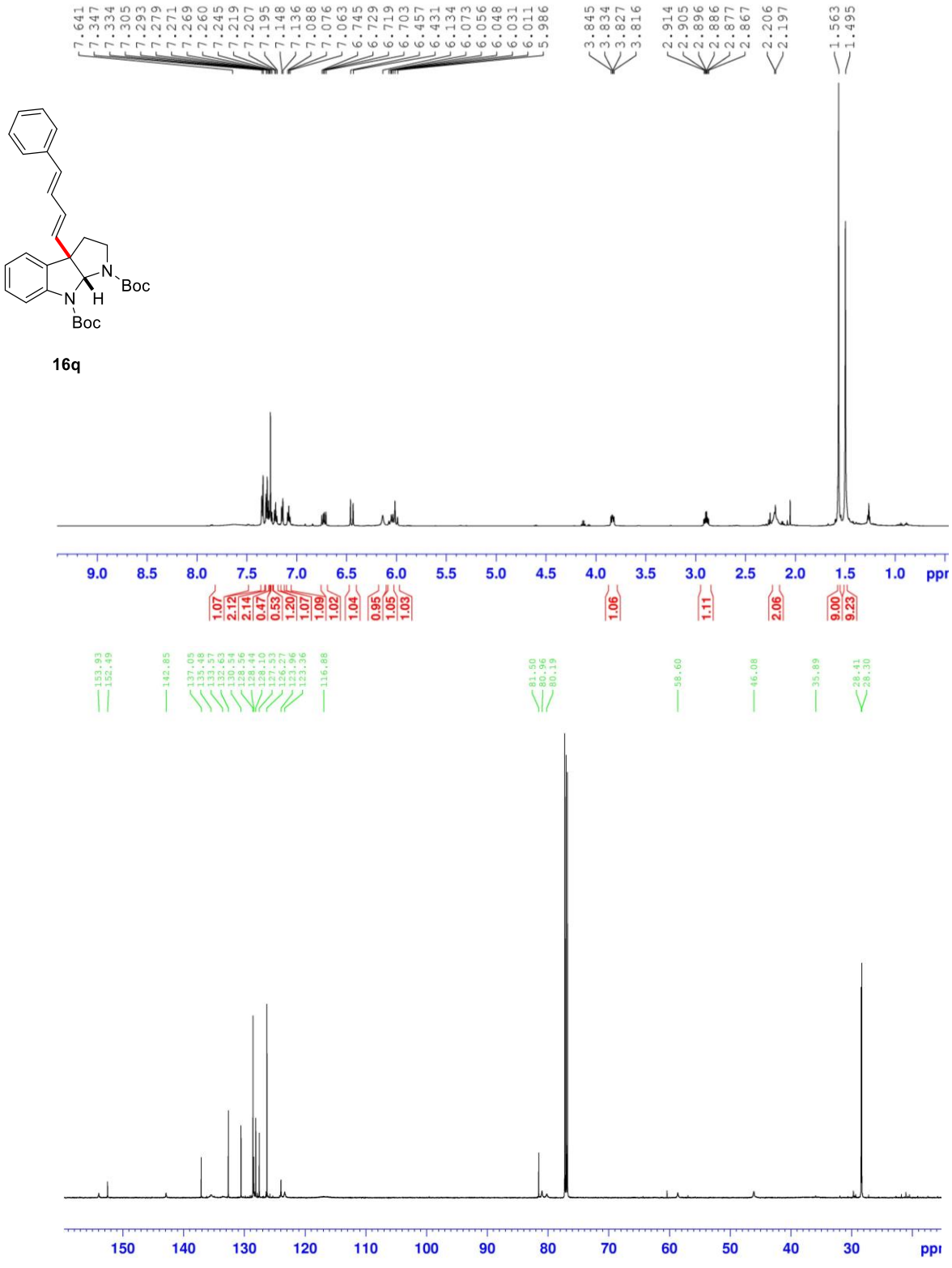
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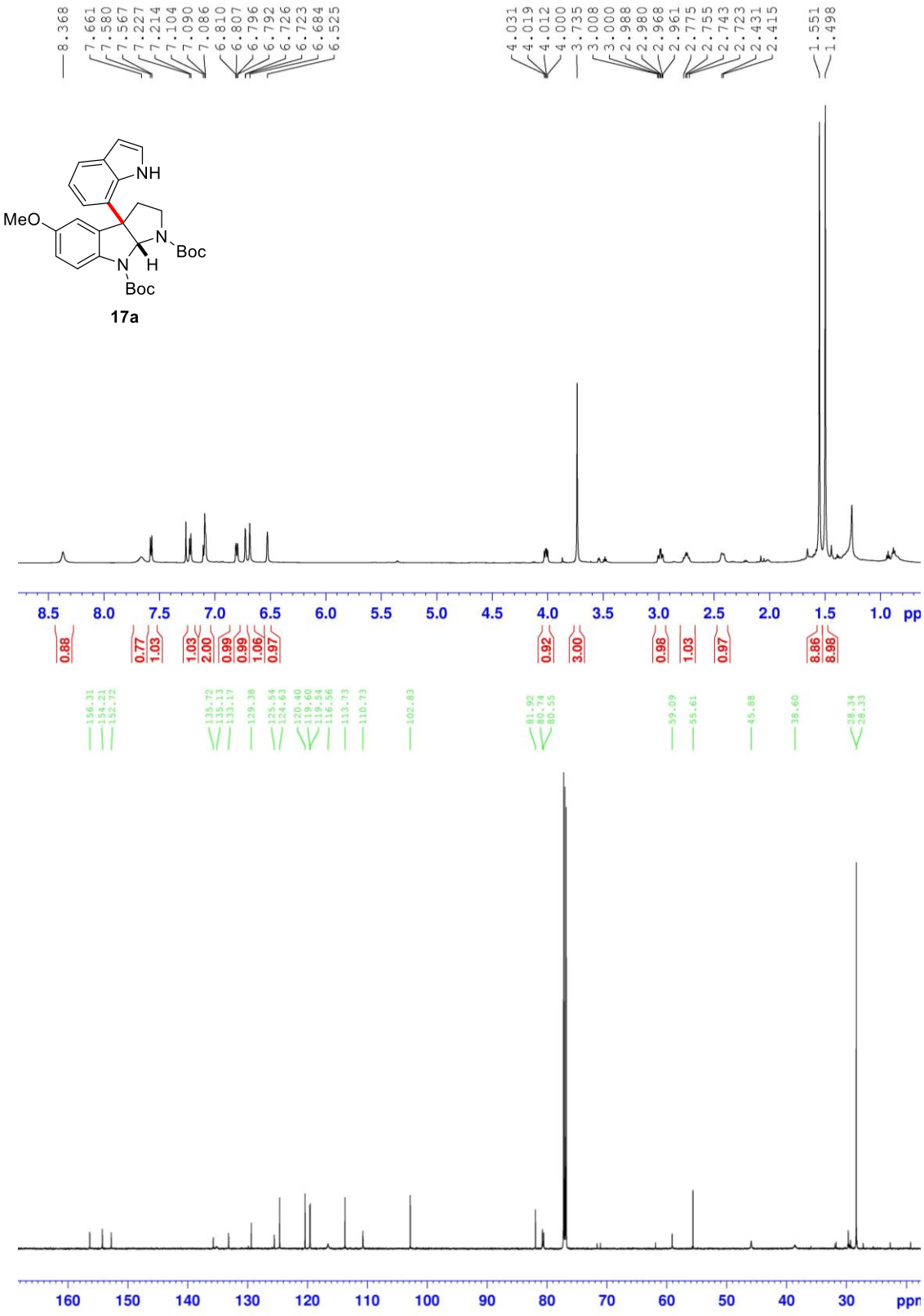
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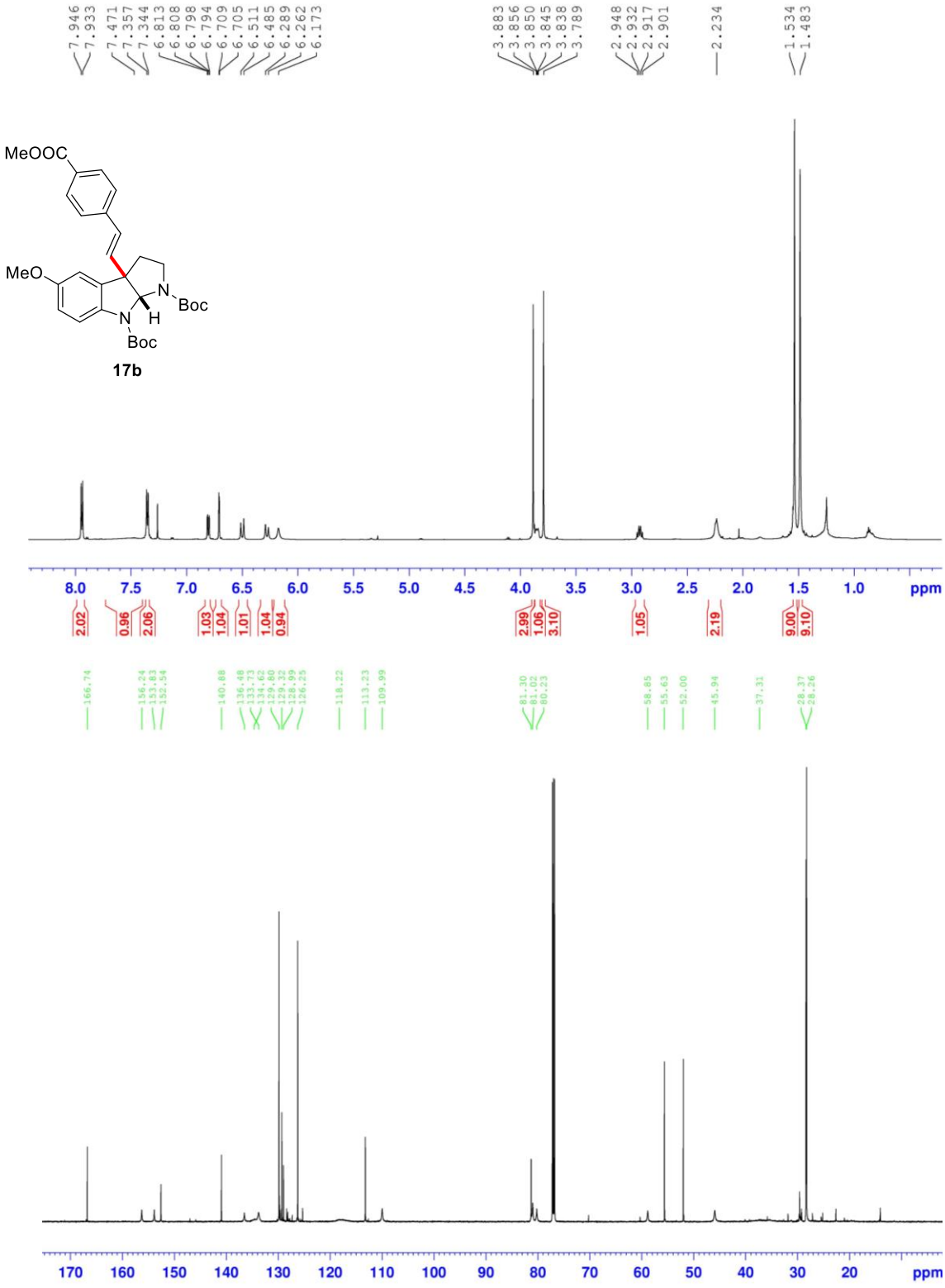
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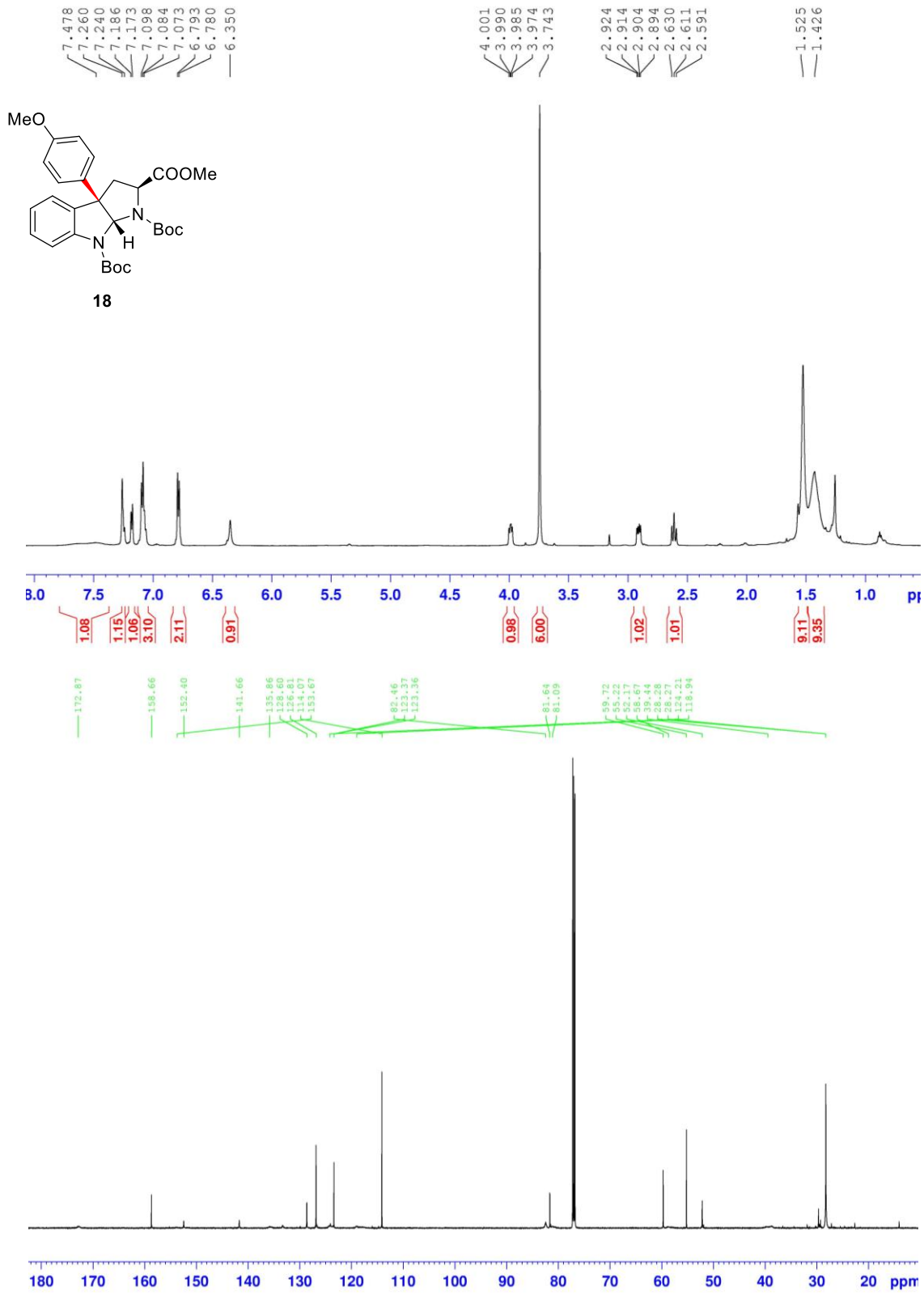
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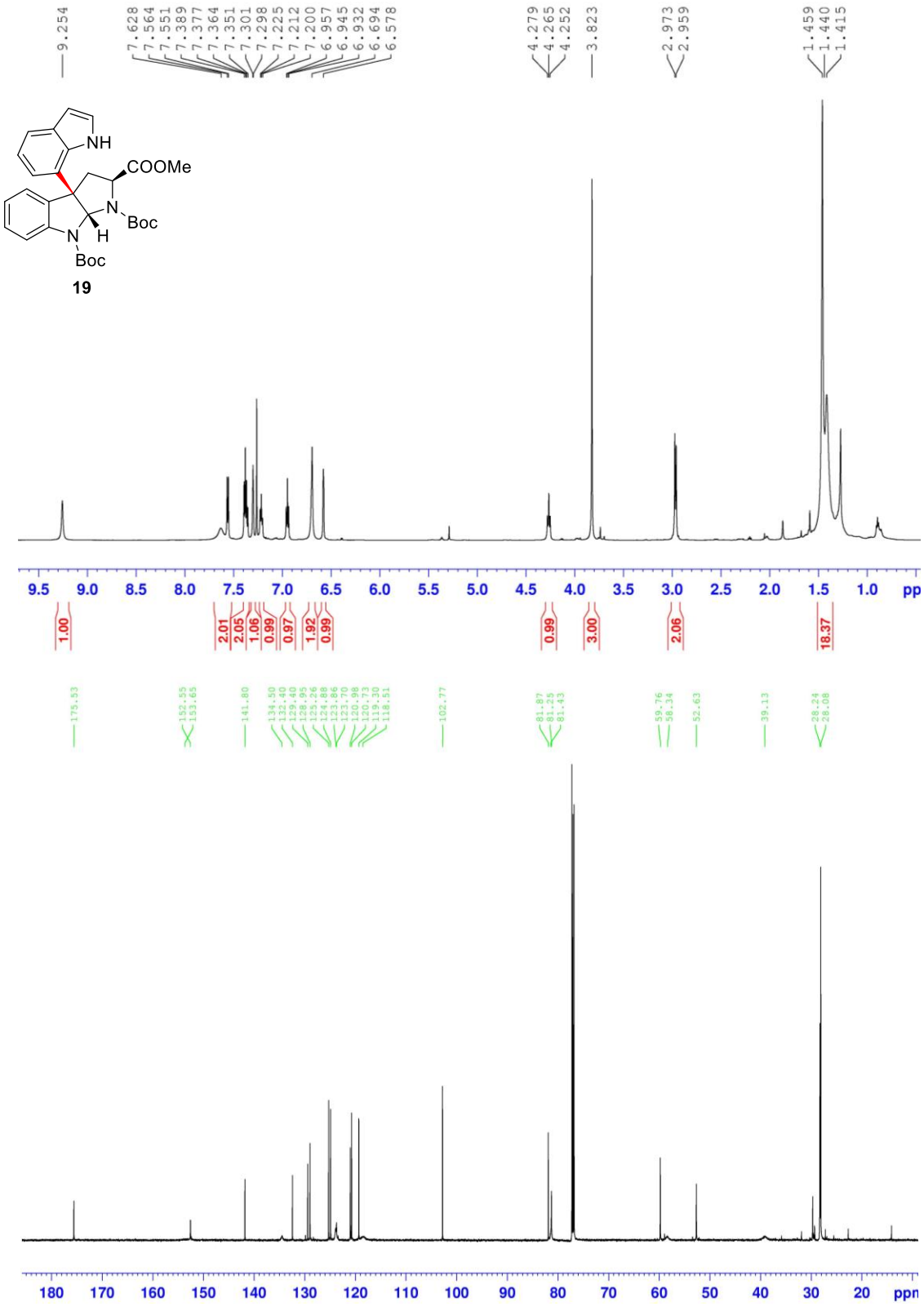
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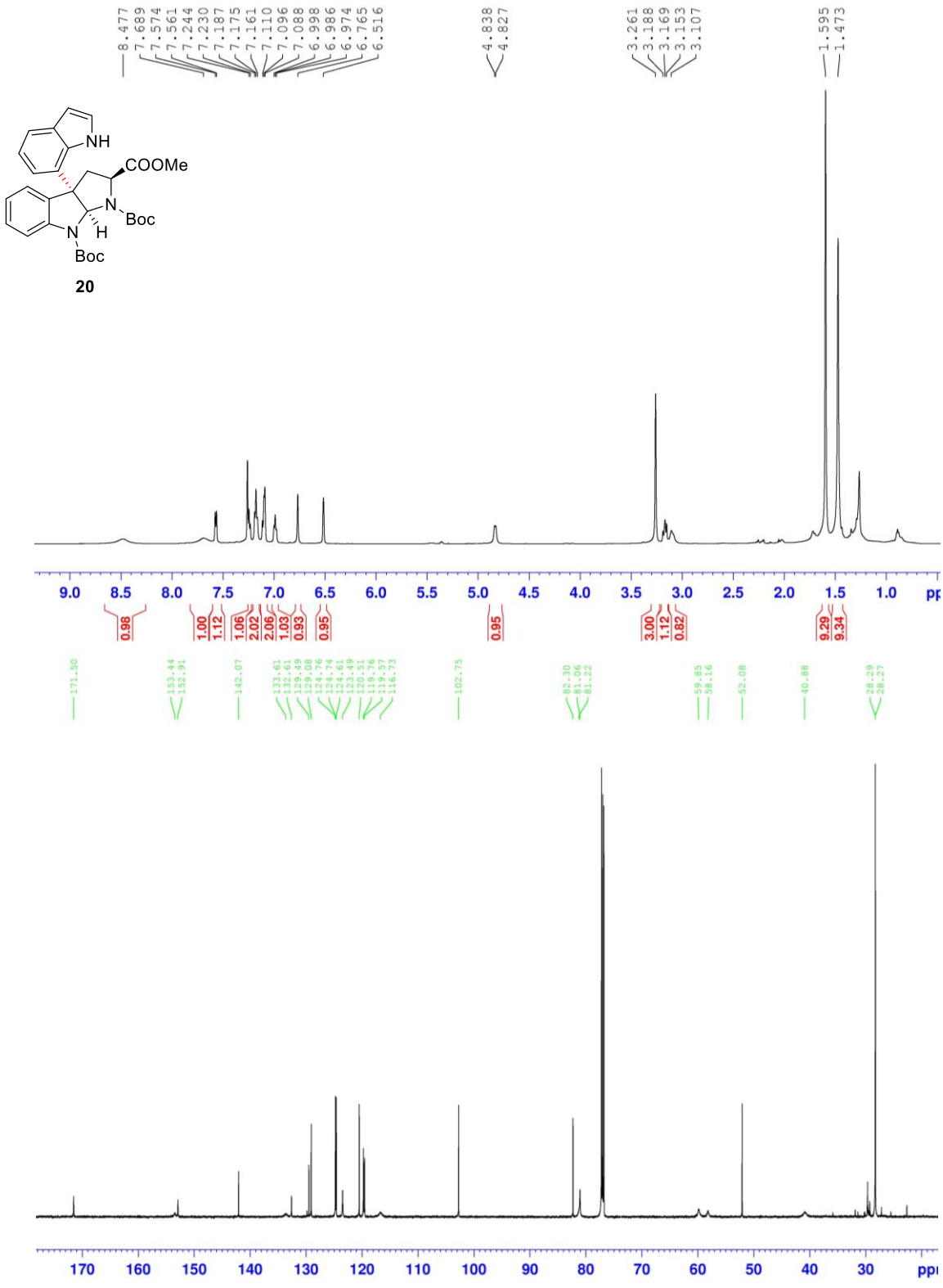
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82.30
81.66
81.22
59.85
58.16
52.08
40.88
28.29
28.27
170
160
150
140
130
120
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100
90
80
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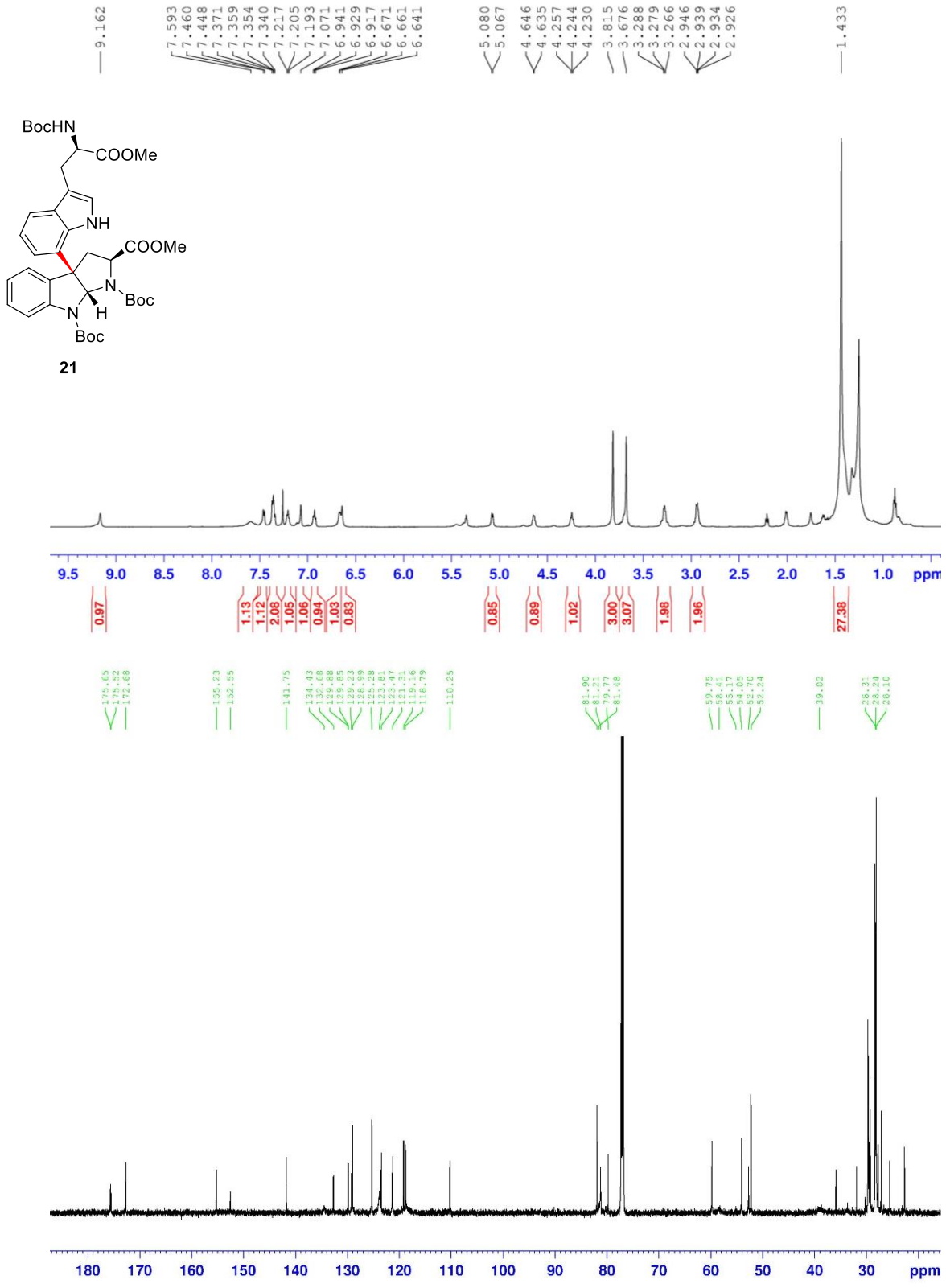
60
50
40
30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6.929
6.917
6.671
6.661
6.641
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5.067
4.646
4.635
4.257
4.244
4.230
3.815
3.676
3.288
3.279
3.266
2.946
2.939
2.934
2.926
1.433
BocHN
COOMe
NH
COOMe
N
Boc
N
H
Boc
21
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 ppm
0.97
1.13
1.12
2.08
1.05
1.06
0.94
1.03
0.83
0.85
0.89
1.02
3.00
3.07
1.98
1.96
27.38
175.65
175.52
172.68
155.23
152.55
141.75
134.43
132.68
129.88
129.85
129.23
128.99
125.28
123.81
123.47
121.31
119.16
118.79
110.25
81.90
81.21
79.77
81.48
59.75
58.41
55.17
54.55
54.70
52.24
39.02
26.31
26.24
26.10
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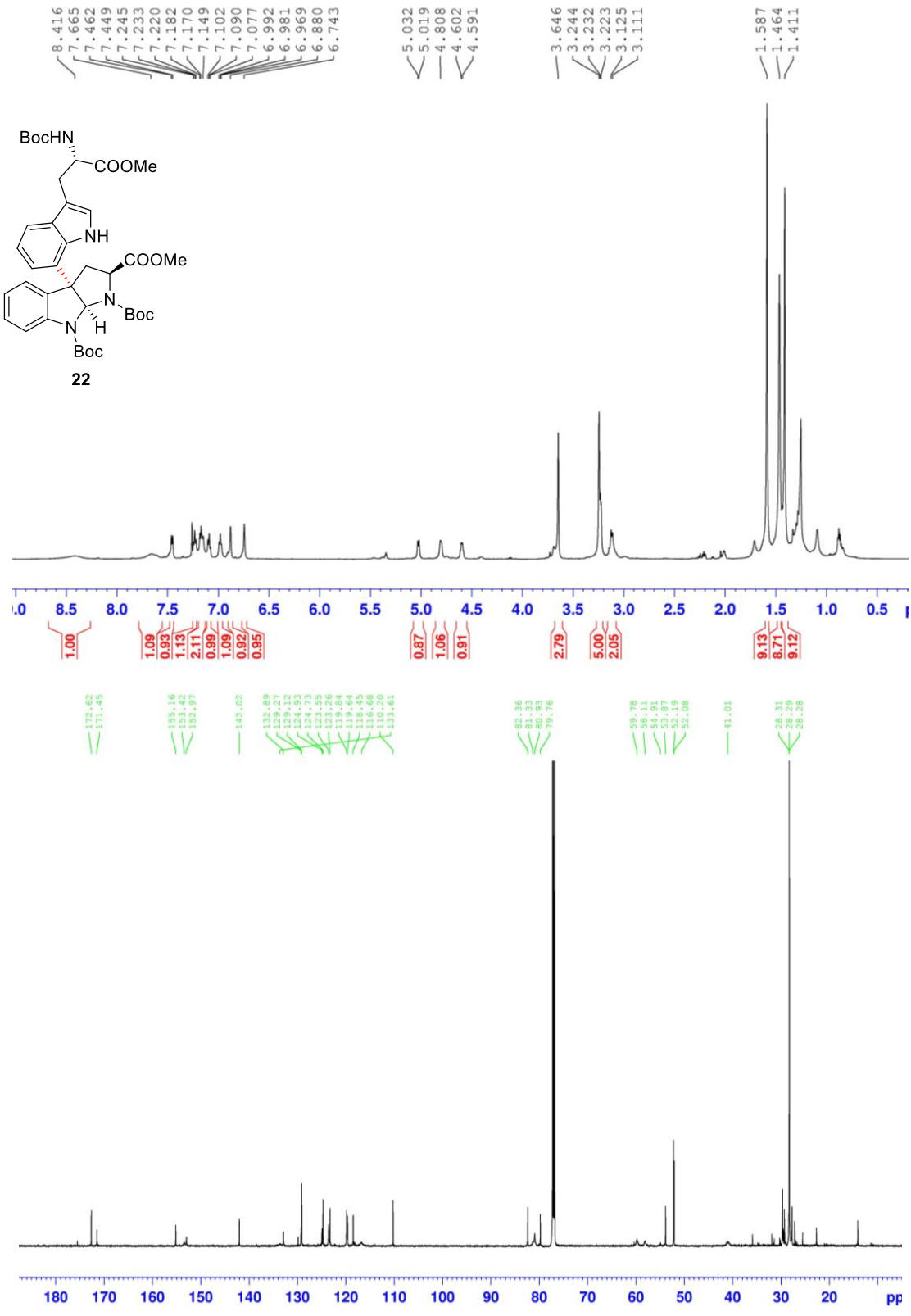
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7.149
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7.077
6.992
6.981
6.969
6.880
6.743
5.032
5.019
4.808
4.602
4.591
3.646
3.244
3.232
3.223
3.125
3.111
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1.464
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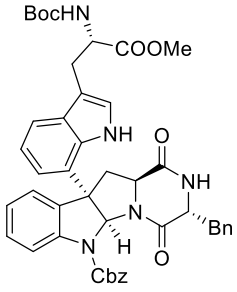
BocHN
COOMe
NH
COOMe
N
Boc
N
H
Boc
22



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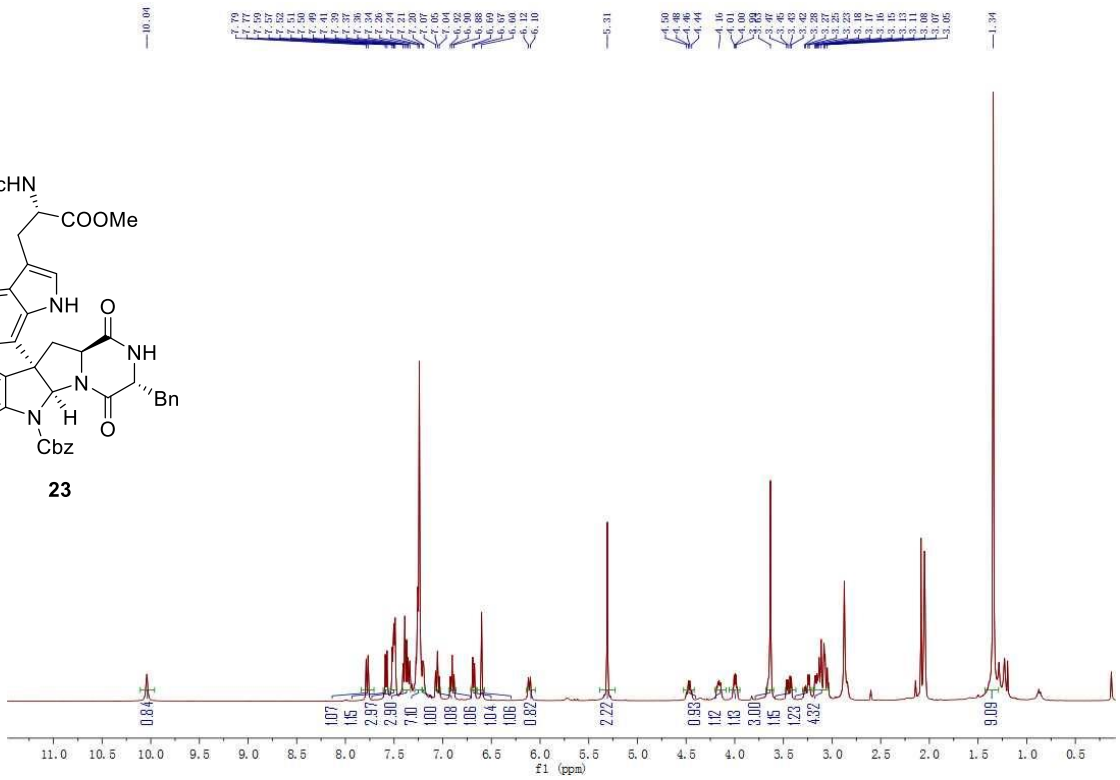

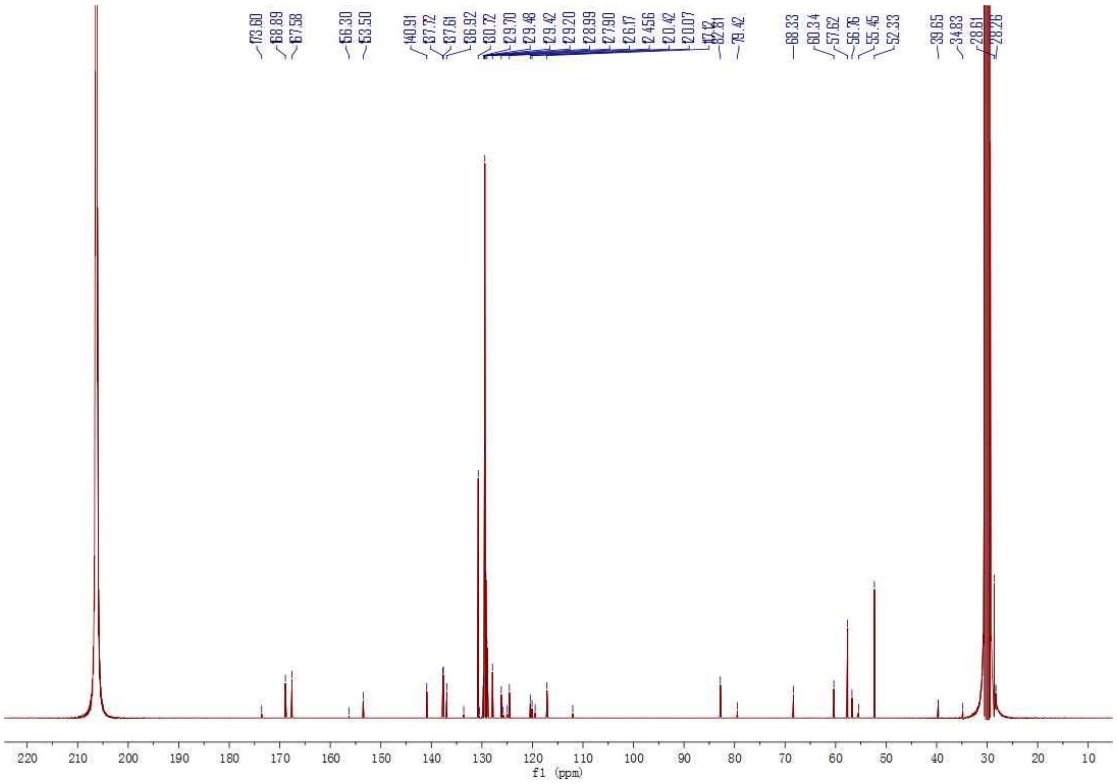

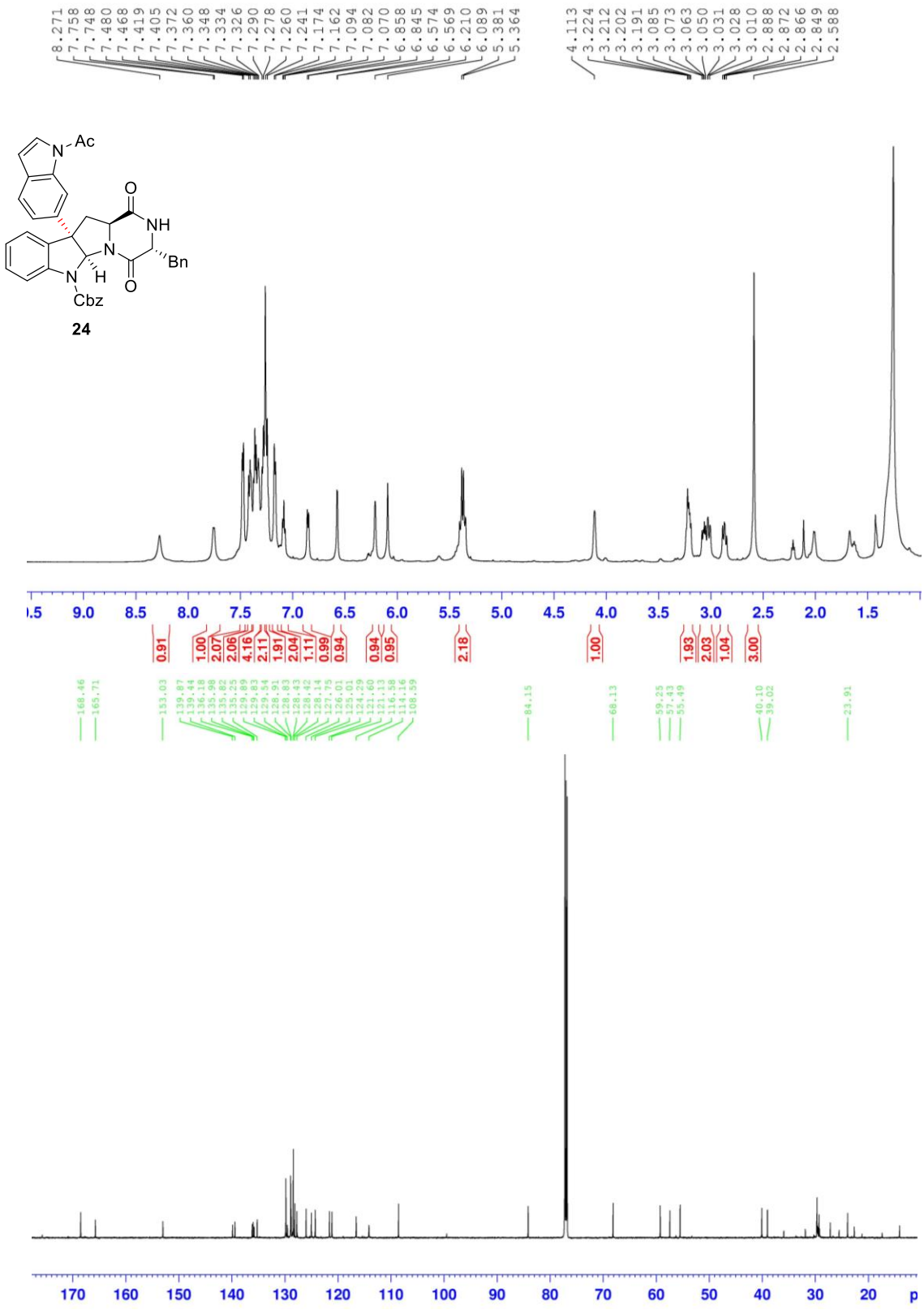
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7.278
7.260
7.241
7.174
7.162
7.094
7.082
7.070
6.858
6.845
6.574
6.569
6.210
6.089
5.381
5.364
4.113
3.224
3.212
3.202
3.191
3.085
3.073
3.063
3.050
3.031
3.028
3.010
2.888
2.872
2.866
2.849
2.588
N
Ac
O
NH
N
Bn
N
H
O
Cbz
24
0.91
1.00
2.07
2.06
4.16
2.11
1.91
2.04
1.11
0.99
0.94
0.94
0.95
2.18
1.00
1.93
2.03
1.04
3.00
168.46
165.71
153.03
139.87
139.44
136.18
135.98
133.82
133.25
129.89
129.83
129.54
128.91
128.83
128.43
128.42
128.14
127.75
126.01
125.01
124.29
121.60
121.13
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114.16
108.59
84.15
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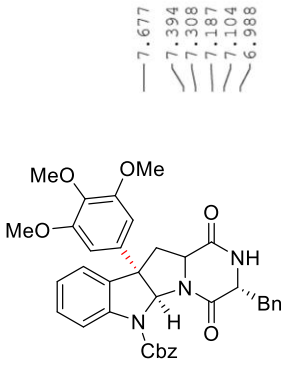
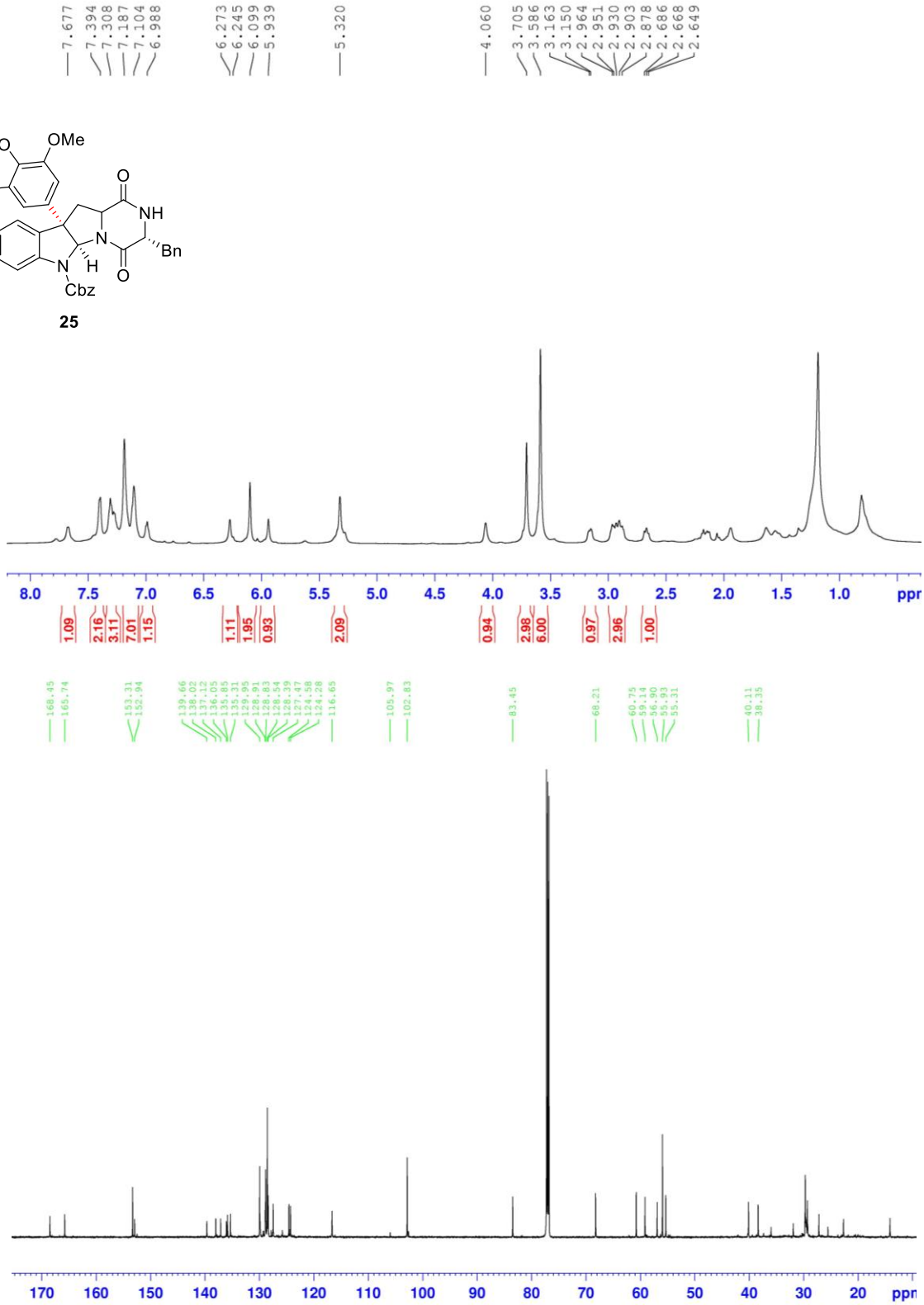
55.49
40.10
39.02
23.91


MeO
OMe
MeO
O
NH
N
Bn
N
H
O
Cbz

25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6.245
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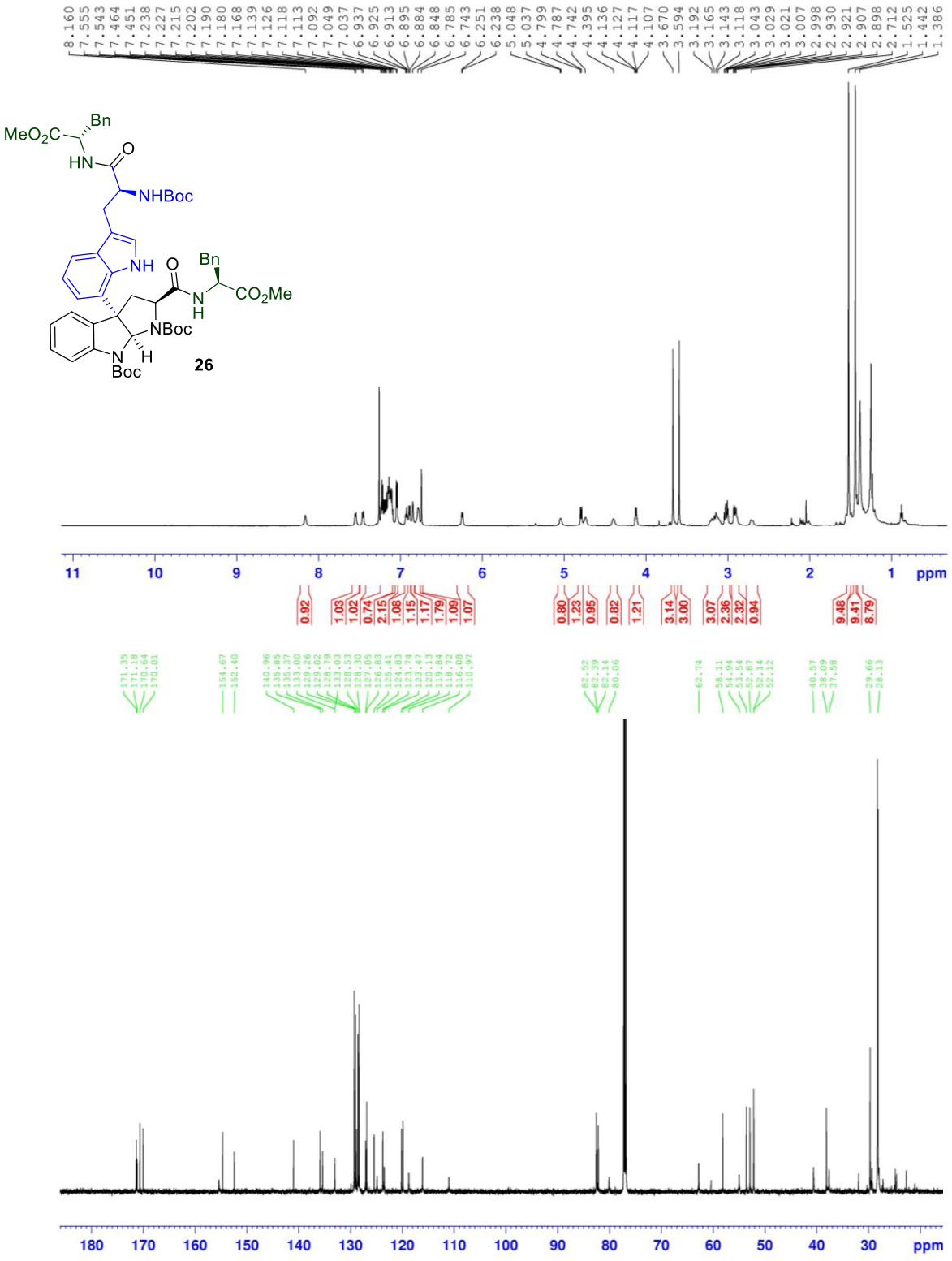
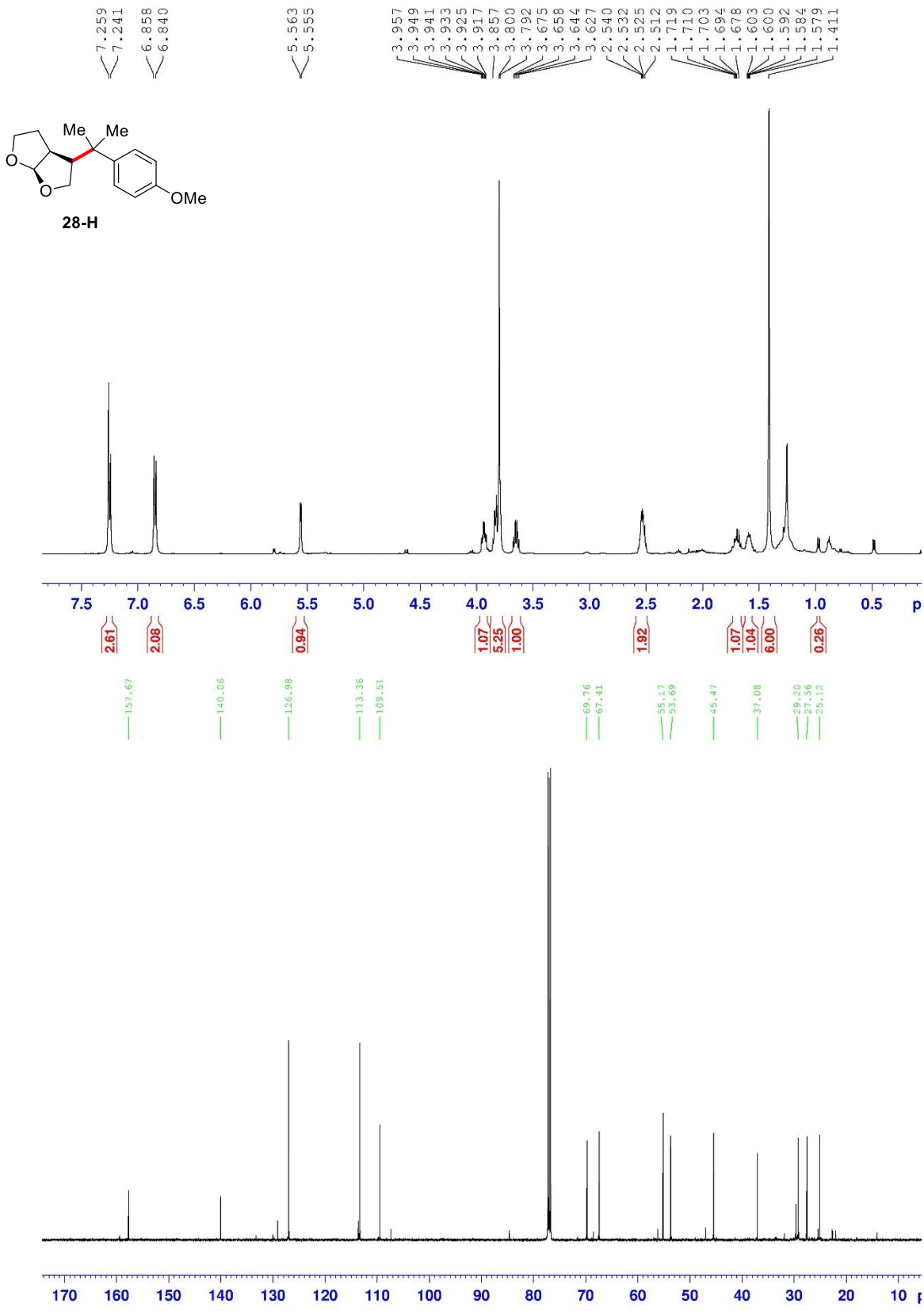
4.060
3.705
3.586
3.163
3.150
2.964
2.951
2.930
2.903
2.878
2.686
2.668
2.649
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
ppm
1.09
2.16
3.11
7.01
1.15
1.11
1.95
0.93
2.09
0.94
2.98
6.00
0.97
2.96
1.00
168.45
165.74
153.31
152.94
139.66
138.02
137.12
136.05
135.85
135.31
129.95
128.91
128.83
128.54
128.39
127.47
124.58
124.28
116.65
105.97
102.83
83.45
68.21
60.75
59.14
56.90
55.93
55.31
40.11
38.35
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
ppm


MeO2C
Bn
HN
O
NHBoc
NH
O
Bn
N
H
CO2Me
NBoc
N
H
Boc
26
ppm
ppm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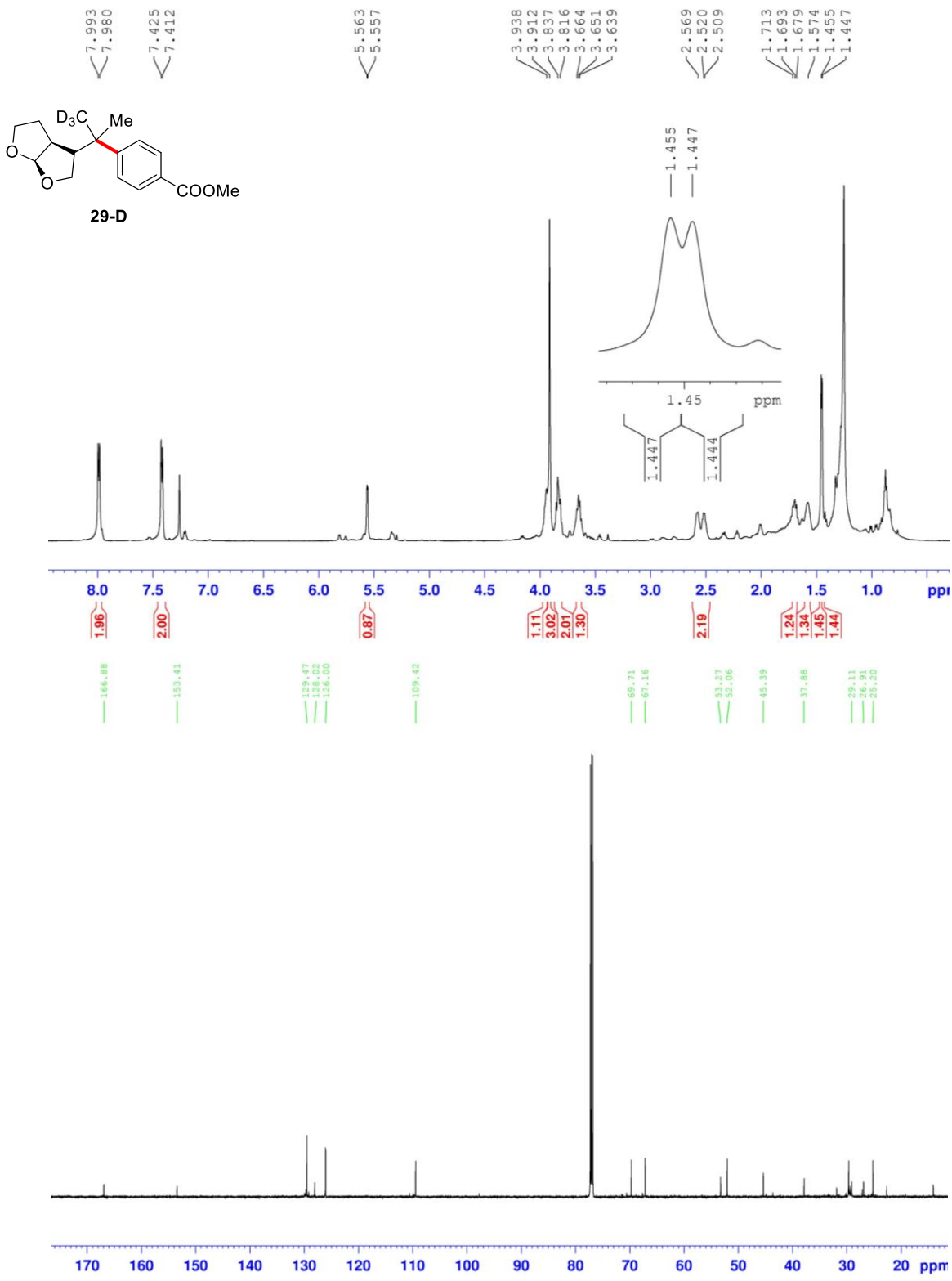
7.241
6.858
6.840
5.563
5.555
3.957
3.949
3.941
3.933
3.925
3.917
3.857
3.800
3.792
3.675
3.658
3.644
3.627
2.540
2.532
2.525
2.512
1.719
1.710
1.703
1.694
1.678
1.603
1.600
1.592
1.584
1.579
1.411
Me
Me
O
O
OMe
28-H
2.61
2.08
0.94
1.07
5.25
1.00
1.92
1.07
1.04
6.00
0.26
157.67
140.06
126.98
113.36
109.51
69.76
67.41
55.17
53.69
45.47
37.08
29.20
27.56
25.12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5.563
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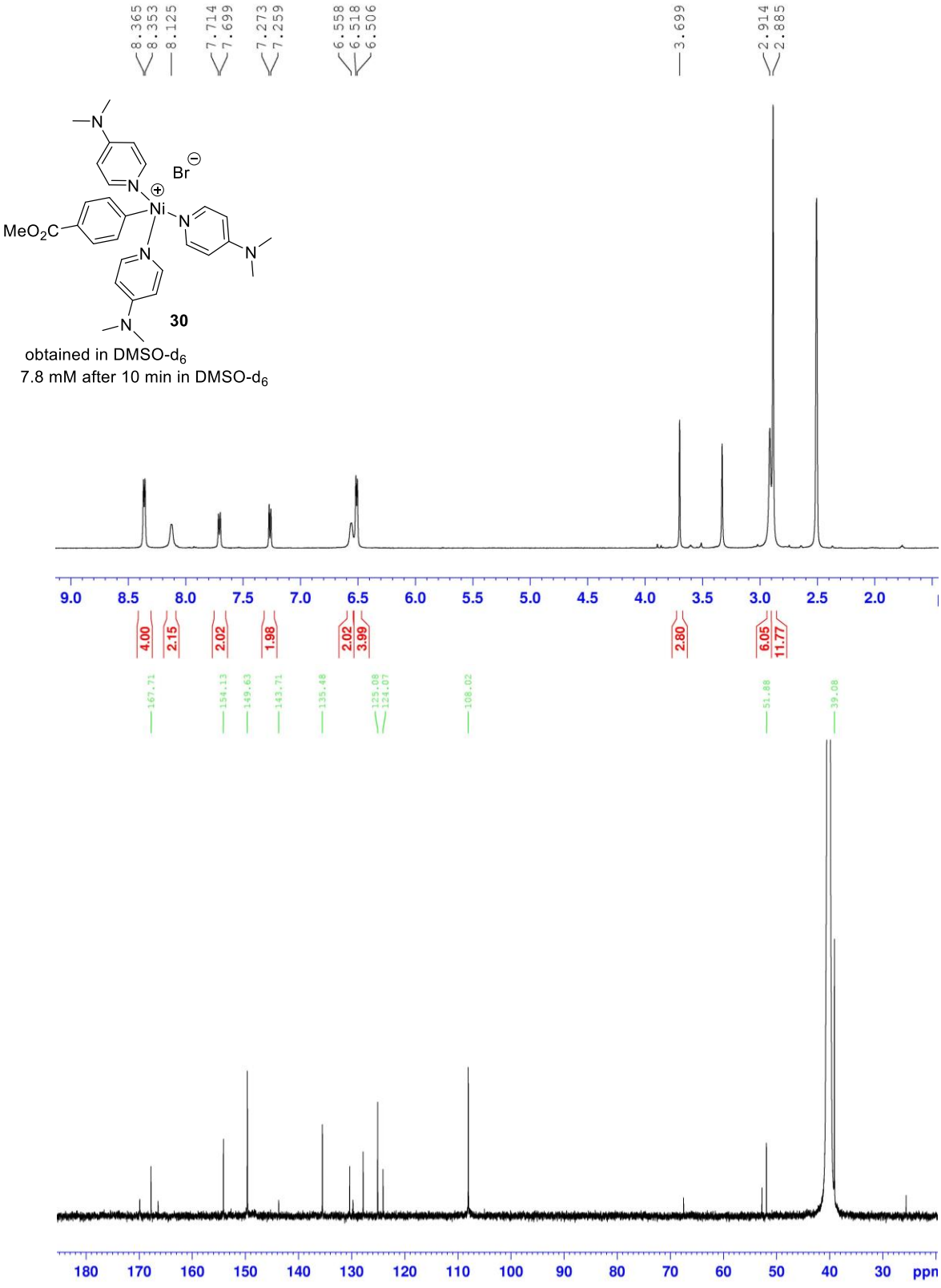
3.912
3.837
3.816
3.664
3.651
3.639
2.569
2.520
2.509
1.713
1.693
1.679
1.574
1.455
1.447
D3C
Me
O
O
COOMe
29-D
1.455
1.447
1.45
ppm
1.447
1.444
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
1.96
2.00
0.87
1.11
3.02
2.01
1.30
2.19
1.24
1.34
1.45
1.44
166.88
153.41
129.47
128.02
126.00
109.42
69.71
67.16
53.27
52.06
45.39
37.88
29.11
26.91
25.20
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
ppm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8.125
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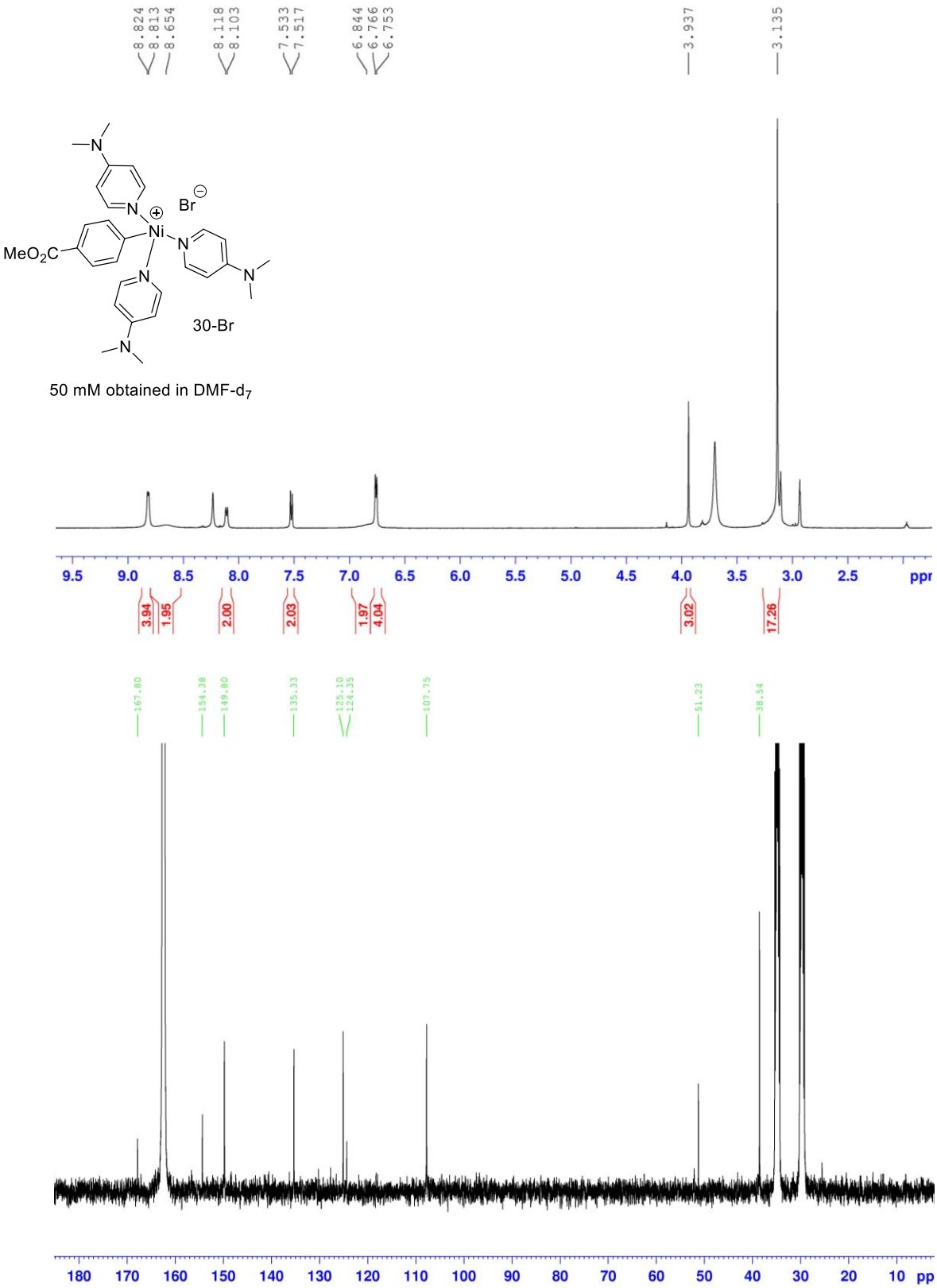
7.699
7.273
7.259
6.558
6.518
6.506
3.699
2.914
2.885
Br
Ni
MeO2C
30
obtained in DMSO-d6
7.8 mM after 10 min in DMSO-d6
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
4.00
2.15
2.02
1.98
2.02
3.99
2.80
6.05
11.77
167.71
154.13
149.63
143.71
135.48
125.08
124.07
108.02
51.88
39.08
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
ppm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8.103
7.533
7.517
6.844
6.766
6.753
3.937
3.135
Br
Ni
MeO2C
30-Br
50 mM obtained in DMF-d7
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
ppm
3.94
1.95
2.00
2.03
1.97
4.04
3.02
17.26
167.80
154.38
149.80
135.33
125.10
124.35
107.75
51.23
38.54
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm

8.440
8.430
7.799
7.786
7.284
7.271
6.501
6.490
3.693
2.863
MeO2C
Ni
I
30-I
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
ppm
4.00
1.76
1.95
1.99
5.72
2.83
17.48
170.24
168.15
154.83
154.55
150.04
148.82
135.92
125.53
124.91
108.45
108.16
52.32
39.52
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm

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