

## SUPPORTING INFORMATION

### DIHALOGENATIVE CYCLIZATION FOR THE SYNTHESIS OF 4-BROMO-1-BROMOALKYL-5-ARYL/ALKYL/ALKENYL PYRAZOLES

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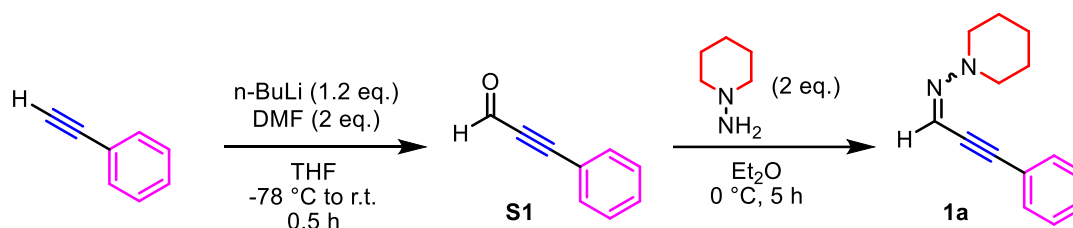
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General information.....	S2
Representative procedure for synthesis of Synthesis of alkynylhydrazones.....	S2
Representative procedure for synthesis of 4-bromo-1-bromoalkyl-5-aryl/alkyl/alkenyl pyrazoles...	S6
Transformation of <b>2a</b> .....	S11
Preliminary DFT calculations for activation energy of isomerization .....	S13
References.....	S38
NMR spectra.....	S39

### General information

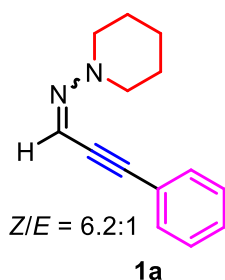
Infrared (IR) spectra were recorded on a Perkin-Elmer SpectrumOne Aspectsrometer using NaCl plates or KBr pellets.  $^1\text{H}$  NMR spectra were recorded at ambient temperature on 300 MHz Varian MERCURY plus spectrometer or 600 MHz Bruker AVANCE III HD 600. Chemical shifts are reported in parts per million from tetramethylsilane (0.00 ppm) resonance as the internal standard. Data are reported as follows: chemical shift, integration, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, dd = doublet of doublets, dt = doublet of triplets, dq = doublet of quartets, m = multiplet, br = broad), and coupling constants (Hz).  $^{13}\text{C}$  NMR spectra were recorded at ambient temperature on a 75 MHz Varian MERCURY plus spectrometer with complete proton decoupling. Chemical shifts are reported in ppm from the solvent resonance as the internal standard ( $\text{CDCl}_3$ ; 77.00 ppm). The high-resolution mass spectra (HRMS) were conducted on an FT-ESI mass analyzer. Melting points (uncorrected) were determined on BÜCHI M-565. Preparative Flash column chromatography was performed using KANTO CHEMICAL CO., INC. Silica Gel 60 N (spherical, neutral 40-50  $\mu\text{m}$ ). TLC separations (PTLC) were carried out on precoated silica gel plates (E. Merck 60F254). Unless otherwise stated, all the reagents and solvents were used as received from the manufacturer.

### Representative procedure for synthesis of Synthesis of alkynylhydrazones<sup>1</sup>



To a solution of phenylacetylene (4.2 mL, 40 mmol) in THF (100 mL) was added *n*-BuLi (2.6 M in hexane, 18.5 mL, 48 mmol) and DMF (6.2 mL, 80 mL) at -78 °C. The reaction mixture was warmed up to room temperature and stirred for 30 minutes. The mixture was transferred into Et<sub>2</sub>O (100 mL)-10% KH<sub>2</sub>PO<sub>4</sub> (220mL) at 0 °C. The mixture was extracted with ether three times. The organic layers were dried over Na<sub>2</sub>SO<sub>4</sub>, filtered and concentrated to afford crude aldehyde **S1** (4.80 g). The residue was used without further purification for a next step.

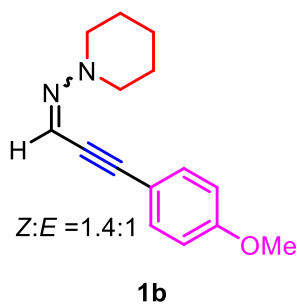
To a solution of crude **S1** (1.36 g) in Et<sub>2</sub>O (10 mL) was added 1-aminopiperidine (2.2 mL, 20.8 mmol) at 0 °C. The mixture was stirred at 0 °C for 5 h. Then, the mixture was quenched with water and extracted with ether three times. The organic layers were dried over MgSO<sub>4</sub>, filtered and concentrated. The residue was purified by silica gel column chromatography to afford **1a** (1.30 g, 54%, *Z/E* = 3:1). The mixture could be further purified by Preparative Thin-Layer Chromatography to afford **1a** (*Z/E* = 6.2 :1). Note: (*Z*)-**1a** was gradually isomerized to (*E*)-**1a** at 4 °C in several days.



$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ) (*Z*)-isomer:  $\delta$  7.50-7.41 (m, 2H), 7.38-7.32 (m, 3H), 6.85 (s, 1H), 3.48 (dd,  $J = 5.6, 5.6$  Hz, 4H), 1.78-1.68 (m, 4H), 1.59-1.40 (m, 2H); (*E*)-isomer:  $\delta$  7.51-7.40 (m, 2H), 7.33-7.28 (m, 3H), 6.82 (s, 1H), 3.17 (dd,  $J = 5.6, 5.6$  Hz, 4H), 1.78-1.68 (m, 4H), 1.59-1.40 (m, 2H);  $^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ ) (*Z*)-isomer:  $\delta$  131.5, 128.9, 128.4, 128.3, 120.6, 98.6, 83.8, 55.2, 25.4, 24.4;

IR (neat) = 2936, 2189, 1535, 1488  $\text{cm}^{-1}$

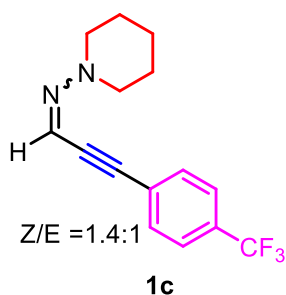
HRMS (ESI)  $m/z$  calcd for  $\text{C}_{14}\text{H}_{17}\text{N}_2$   $[\text{M}+\text{H}]^+$  213.1386, found 213.1282.



$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ) (*Z*)-isomer:  $\delta$  7.52-7.34 (m, 2H), 7.01-6.79 (m, 2H), 3.83 (s, 3H), 3.43 (dd,  $J = 5.5, 5.5$  Hz, 4H), 1.90-1.66 (m, 4H), 1.59-1.48 (m, 2H); (*E*)-isomer:  $\delta$  7.52-7.34 (m, 2H), 7.01-6.79 (m, 3H), 3.81 (s, 3H), 3.15 (dd,  $J = 5.6, 5.6$  Hz, 3H), 1.90-1.66 (m, 4H), 1.59-1.48 (m, 2H);  $^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ ) (*E/Z* mixture):  $\delta$  160.3, 159.6, 133.1, 133.0, 122.5, 116.3, 115.2, 116.1, 115.2, 114.3, 114.2, 113.9, 99.4, 90.1, 85.7, 82.8, 55.3, 55.3, 55.1, 51.5, 25.2, 24.9, 24.1, 23.9;

IR (neat) = 2936, 2182, 1604, 1507, 1442  $\text{cm}^{-1}$

HRMS (ESI)  $m/z$  calcd for  $\text{C}_{15}\text{H}_{19}\text{ON}_2$   $[\text{M}+\text{H}]^+$  243.1492, found 243.1493.

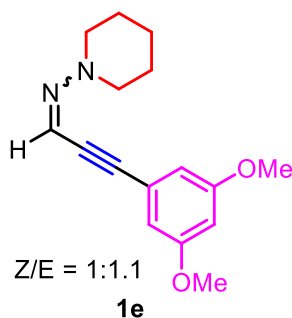


$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ) (*Z*)-isomer:  $\delta$  7.74-7.44 (m, 4H), 6.79 (s, 1H), 3.54 (dd,  $J = 5.5, 5.5$  Hz, 4H), 1.91-1.66 (m, 4H), 1.63-1.52 (m, 2H); (*E*)-isomer:  $\delta$  7.74-7.44 (m, 4H), 6.78 (s, 1H), 3.20 (dd,  $J = 5.6, 5.6$  Hz, 4H), 1.91-1.66 (m, 4H), 1.63-1.52 (m, 2H);

$^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ ) (*E/Z* mixture):  $\delta$  133.5, 131.7, 131.6, 130.8, 130.4, 129.9, 129.4, 127.1, 126.4, 125.8, 125.7, 125.5, 125.5, 125.3, 125.3, 117.7, 114.2, 96.4, 89.7, 88.5, 86.1, 55.0, 51.4, 25.2, 24.9, 24.1, 23.8;

IR (neat) = 2943, 2882, 1615, 1411, 1323  $\text{cm}^{-1}$

HRMS (ESI)  $m/z$  calcd for  $\text{C}_{15}\text{H}_{16}\text{N}_2\text{F}_3$   $[\text{M}+\text{H}]^+$  281.1260, found 281.1260.

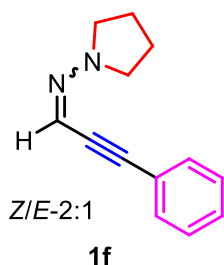


$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ) (*Z*)-isomer:  $\delta$  6.80 (s, 1H), 6.57 (d,  $J = 2.2$  Hz, 2H), 6.45 (t,  $J = 2.2$  Hz, 1H), 3.78 (s, 6H), 3.47 (t,  $J = 5.5$  Hz, 4H), 1.87-1.62 (m, 4H), 1.61-1.47 (2H); (*E*)-isomer:  $\delta$  6.78 (s, 1H), 6.63 (d,  $J = 2.2$  Hz, 2H), 6.41 (t,  $J = 2.2$  Hz, 1H), 3.75 (s, 6H), 3.16 (t,  $J = 5.6$  Hz, 4H), 1.87-1.62 (m, 4H), 1.61-1.47 (2H);

$^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ ) (*E/Z* mixture):  $\delta$  160.7, 160.5, 124.5, 123.7, 120.2, 115.3, 109.3, 109.3, 102.3, 101.9, 98.6, 90.0, 86.7, 55.5, 55.5, 55.1, 25.2, 24.9, 24.2, 23.9;

IR (neat) = 2938, 2193, 1588, 1537, 1451, 1420, 1352, 1340  $\text{cm}^{-1}$

HRMS (ESI)  $m/z$  calcd for  $\text{C}_{16}\text{H}_{21}\text{O}_2\text{N}_2$   $[\text{M}+\text{H}]^+$  273.1598, found 273.1599.

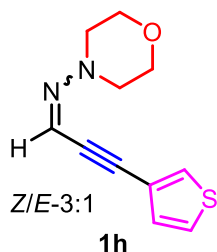


$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ) (*Z*)-isomer:  $\delta$  7.45-7.37 (m, 2H), 7.32-7.25 (m, 3H), 6.41 (s, 1H), 3.69-3.64 (m, 4H), 1.91-1.86 (m, 4H); (*E*)-isomer:  $\delta$  7.45-7.37 (m, 2H), 7.32-7.25 (m, 3H), 6.35 (t, 0.9 Hz, 1H), 3.37-3.33 (m, 4H), 1.98-1.93 (m, 4H);

$^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ ) (*E/Z* mixture):  $\delta$  131.1, 130.7, 128.3, 128.2, 128.0, 127.6, 123.3, 122.8, 112.4, 111.0, 94.5, 88.7, 87.6, 85.6, 54.4, 50.3, 24.1, 23.6;

IR (neat) = 2971, 2870, 2194, 1528, 1457  $\text{cm}^{-1}$

HRMS (ESI)  $m/z$  calcd for  $\text{C}_{13}\text{H}_{15}\text{N}_2$   $[\text{M}+\text{H}]^+$  199.1230, found 199.1229.

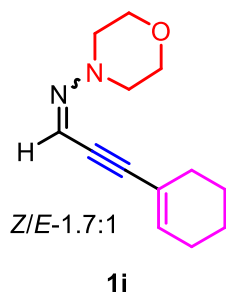


$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ) (*Z*)-isomer:  $\delta$  7.52 (dd,  $J = 1.2, 3.0$  Hz, 1H), 7.32 (dd, 3.0, 5.1 Hz, 1H), 7.12 (dd, 1.2, 5.1 Hz, 1H), 6.95 (s, 1H), 3.87-3.84 (m, 4H), 3.47-3.44 (m, 4H); (*E*)-isomer:  $\delta$  7.50 (dd,  $J = 1.2, 3.0$  Hz, 1H), 7.26 (dd,  $J = 3.0, 4.8$  Hz, 1H), 7.15 (dd,  $J = 1.2, 4.8$  Hz, 1H), 6.88 (s, 1H), 3.87-3.84 (m, 4H), 3.18-3.15 (m, 4H);

$^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ ) (*E/Z* mixture):  $\delta$  130.0, 129.7, 129.3, 129.1, 125.9, 125.3, 124.2, 121.7, 120.9, 117.8, 95.0, 86.0, 85.5, 82.7, 66.2, 66.1, 54.3, 51.0;

IR (neat) = 2964, 2856, 2188, 1552, 1450  $\text{cm}^{-1}$

HRMS (ESI)  $m/z$  calcd for  $\text{C}_{11}\text{H}_{13}\text{ON}_2\text{S}$   $[\text{M}+\text{H}]^+$  221.0743, found 221.0742.

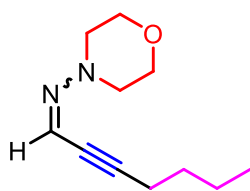


$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ) (*Z*)-isomer:  $\delta$  6.87 (s, 1H), 6.21-6.16 (m, 1H), 3.84-3.80 (m, 4H), 3.38-3.35 (m, 4H), 2.15-2.11 (m, 4H), 1.67-1.56 (m, 4H); (*E*)-isomer:  $\delta$  6.81 (s, 1H), 6.21-6.16 (m, 1H), 3.84-3.80 (m, 4H), 3.12-3.10 (m, 4H), 2.15-2.11 (m, 4H), 1.67-1.56 (m, 4H);

$^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ ) (*E/Z* mixture):  $\delta$  137.5, 135.8, 125.5, 120.1, 119.8, 118.5, 101.9, 92.7, 83.2, 80.7, 66.0, 65.9, 54.1, 51.0, 28.6, 28.2, 25.6, 25.5, 22.0, 21.8, 21.2, 21.0;

IR (neat) = 2931, 2858, 2179, 1549, 1450  $\text{cm}^{-1}$

HRMS (ESI)  $m/z$  calcd for  $\text{C}_{13}\text{H}_{19}\text{ON}_2$   $[\text{M}+\text{H}]^+$  219.1492, found 219.1489.



Z/E-1:1

**1j**

$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ) (*Z*)-isomer:  $\delta$  6.81 (t,  $J = 1.8$  Hz, 1H), 3.84-3.81 (m, 4H), 3.35-3.31 (m, 4H), 2.43-2.36 (m, 2H), 1.60-1.52 (m, 2H), 0.93(t,  $J = 7.2$  Hz, 3H); (*E*)-isomer:  $\delta$  6.72 (br s, 1H), 3.84-3.81 (m, 4H), 3.09 (br t,  $J = 5.1$  Hz, 4H), 2.43-2.36 (m, 2H), 1.60-1.52 (m, 4H), 1.50-1.37 (m, 2H), 0.91(t,  $J = 7.2$  Hz, 3H);

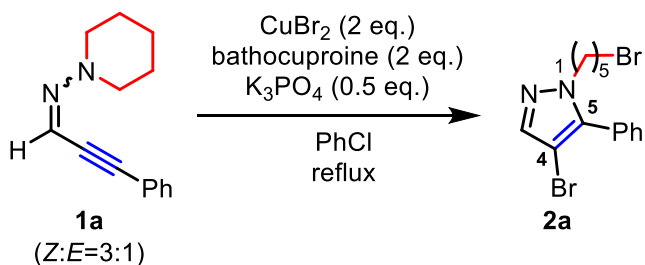
$^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ ) (*E/Z* mixture):  $\delta$  127.1, 118.9, 102.7, 92.2, 76.9, 74.9, 66.0, 65.9, 54.2, 51.0, 30.2, 29.8, 21.74, 21.71, 19.1, 18.9, 13.33, 13.25;

IR (neat) = 2960, 2859, 2204, 1556, 1452  $\text{cm}^{-1}$

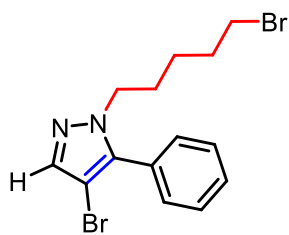
HRMS (ESI)  $m/z$  calcd for  $\text{C}_{11}\text{H}_{19}\text{ON}_2$   $[\text{M}+\text{H}]^+$  195.1492, found 195.1490.

**1g** and **1k** were identified with a previous report.<sup>1</sup>

#### Representative procedure for synthesis of 4-bromo-1-bromoalkyl-5-aryl/alkyl/alkenyl pyrazoles



To a solution of **1a** (46.8 mg, 0.22 mmol) in PhCl (2.2 mL) was added  $\text{CuBr}_2$  (98.3 mg, 0.44 mmol), bathocuproine (159 mg, 0.44 mmol) and  $\text{K}_3\text{PO}_4$  (23.3 mg, 0.11 mmol) at room temperature. The reaction mixture was stirred under reflux for 1 h. Then, the mixture was cooled to room temperature and quenched with sat. aq.  $\text{NaHCO}_3$ . The mixture was extracted with EtOAc three times. The organic layers were dried over  $\text{MgSO}_4$ , filtered and concentrated. The residue was purified by Preparative Thin-Layer Chromatography to afford 4-bromo-1-bromopentyl-5-phenylpyrazole **2a** (58.1 mg, 71%).



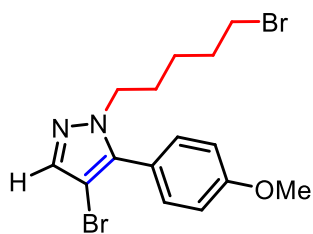
**2a**

$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ) :  $\delta$  7.55 (s, 1H), 7.53-7.43 (m, 3H), 7.42-7.30 (m, 2H), 4.05 (t,  $J = 7.1$  Hz, 2H), 3.29 (t,  $J = 6.6$  Hz, 2H), 1.83-1.66 (m, 4H), 1.42-1.19 (m, 2H);

$^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  141.5, 139.5, 130.2, 129.5, 129.1, 125.9, 93.8, 50.4, 33.5, 32.2, 29.4, 25.2;

IR (neat) = 2942, 2863, 1530, 1483, 1456  $\text{cm}^{-1}$

HRMS (ESI)  $m/z$  calcd for  $\text{C}_{14}\text{H}_{17}\text{N}_2\text{Br}_2$   $[\text{M}+\text{H}]^+$  372.9733, found 372.9734.



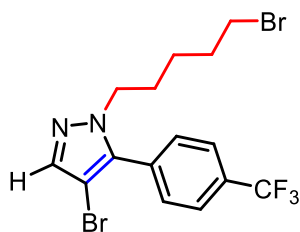
**2b**

$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  7.53 (s, 1H), 7.29 (d,  $J = 9.0$  Hz, 2H), 7.02 (d,  $J = 8.7$  Hz, 2H), 4.04 (t,  $J = 7.1$  Hz, 2H), 3.87 (s, 3H), 3.31 (t,  $J = 6.7$  Hz, 2H), 1.84-1.69 (m, 4H), 1.42-1.24 (m, 2H);

$^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  160.4, 141.2, 139.3, 131.3, 120.8, 114.4, 93.7, 55.5, 50.3, 33.4, 32.2, 29.4, 25.2;

IR (neat) = 2940, 2836, 1614, 1493  $\text{cm}^{-1}$

HRMS (ESI)  $m/z$  calcd for  $\text{C}_{15}\text{H}_{19}\text{ON}_2\text{Br}_2$   $[\text{M}+\text{H}]^+$  402.9838, found 402.9836.



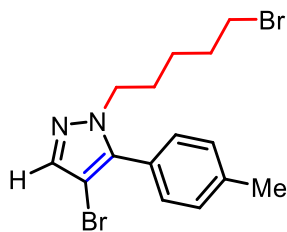
**2c**

$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  7.78 (d,  $J = 8.2$  Hz, 2H), 7.58 (s, 1H), 7.52 (d,  $J = 8.0$  Hz, 2H), 4.06 (t,  $J = 7.1$  Hz, 2H), 3.32 (t,  $J = 6.6$  Hz, 2H), 1.85-1.68 (m, 4H), 1.41-1.22 (m, 2H);

$^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  139.9, 139.7, 132.4, 131.7, 131.3, 130.5, 126.0, 126.0, 122.1, 94.2, 50.6, 33.3, 32.1, 29.4, 25.1;

IR (neat) = 2942, 2863, 1621, 1410, 1326  $\text{cm}^{-1}$

HRMS (ESI)  $m/z$  calcd for  $\text{C}_{15}\text{H}_{16}\text{N}_2\text{Br}_2\text{F}_3$   $[\text{M}+\text{H}]^+$  440.9607, found 440.9607.



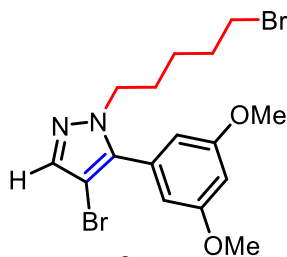
**2d**

$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  7.54 (s, 1H), 7.31 (d,  $J = 8.0$  Hz, 2H), 7.25 (d,  $J = 8.0$  Hz, 2H), 4.05 (t,  $J = 7.1$  Hz, 2H), 3.30 (t,  $J = 6.7$  Hz, 2H), 2.43 (s, 3H), 1.85-1.68 (m, 4H), 1.41-1.22 (m, 2H);

$^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  141.5, 139.6, 139.5, 130.0, 129.8, 125.8, 93.7, 50.4, 33.5, 32.3, 29.5, 25.2, 21.7;

IR (neat) = 2942, 2862, 1492, 1454  $\text{cm}^{-1}$

HRMS (ESI)  $m/z$  calcd for  $\text{C}_{15}\text{H}_{19}\text{N}_2\text{Br}_2$   $[\text{M}+\text{H}]^+$  386.9889, found 386.9888.



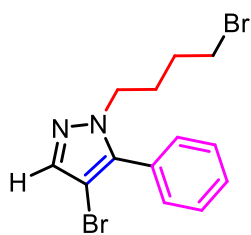
**2e**

$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  7.53 (s, 1H), 6.55 (t,  $J = 2.2$  Hz, 1H), 6.49 (d,  $J = 2.2$  Hz, 2H), 4.08 (t,  $J = 7.1$  Hz, 2H), 3.83 (s, 6H), 3.32 (t,  $J = 6.7$  Hz, 2H), 1.88-1.69 (m, 4H), 1.44-1.20 (m, 2H);

$^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  160.8, 141.0, 139.2, 130.1, 108.0, 101.2, 93.5, 55.7, 50.4, 33.6, 32.4, 29.5, 25.4

IR (neat) = 2940, 1594, 1457, 1422  $\text{cm}^{-1}$

HRMS (ESI)  $m/z$  calcd for  $\text{C}_{16}\text{H}_{21}\text{O}_2\text{N}_2\text{Br}_2$   $[\text{M}+\text{H}]^+$  432.9944, found 432.9943.



**2f**

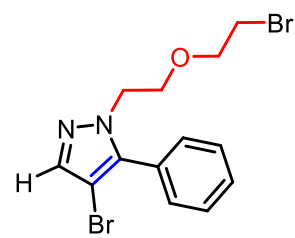
$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.89-7.86 (m, 2H), 7.49 (s, 1H), 7.46-7.33 (m, 3H), 4.17 (t,  $J = 6.9$  Hz,

$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.59 (s, 1H), 7.55-7.43 (m, 5H), 4.21 (t,  $J = 5.5$  Hz, 2H), 3.88 (t,  $J =$

5.4 Hz, 2H), 3.65 (t,  $J = 6.0$  Hz, 2H), 3.35 (t,  $J = 6.0$  Hz, 2H);

$^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ ):  $\delta$  148.6, 132.0, 131.0, 128.3, 128.1, 127.5, 91.5, 51.9, 32.7, 29.5, 28.8.

IR (neat) = 2937, 1449, 1328, 1255  $\text{cm}^{-1}$



**2g**

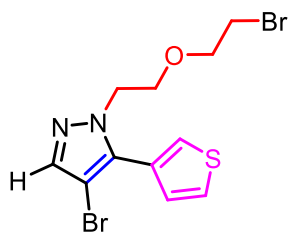
$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.59 (s, 1H), 7.55-7.43 (m, 5H), 4.21 (t,  $J = 5.5$  Hz, 2H), 3.88 (t,  $J =$

5.4 Hz, 2H), 3.65 (t,  $J = 6.0$  Hz, 2H), 3.35 (t,  $J = 6.0$  Hz, 2H);

$^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ ):  $\delta$  142.3, 139.9, 130.4, 129.3, 128.7, 128.3, 93.6, 71.1, 69.4, 50.2, 30.2;

IR (neat) = 2917, 1456, 1401, 1278  $\text{cm}^{-1}$

HRMS (ESI)  $m/z$  calcd for  $\text{C}_{13}\text{H}_{15}\text{ON}_2\text{Br}_2$   $[\text{M}+\text{H}]^+$  374.9525, found 374.9531



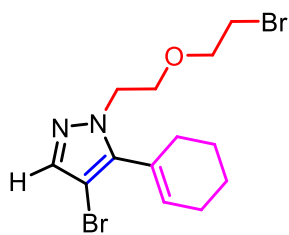
**2h**

$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.69 (dd,  $J = 1.2, 3.0$  Hz, 1H), 7.57 (s, 1H), 7.46 (dd,  $J = 3.0, 5.1$  Hz, 1H), 7.35 (dd,  $J = 1.2, 5.1$  Hz, 1H), 4.27 (t,  $J = 5.4$  Hz, 2H), 3.93 (t,  $J = 5.4$  Hz, 2H), 3.69 (t,  $J = 5.7$  Hz, 2H), 3.37 (t,  $J = 5.7$  Hz, 2H);

$^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ ):  $\delta$  139.8, 137.8, 128.5, 127.9, 127.0, 126.0, 93.5, 71.1, 69.5, 50.1, 30.1.;

IR (neat) = 2948, 1455, 1357, 1297  $\text{cm}^{-1}$

HRMS (ESI)  $m/z$  calcd for  $\text{C}_{11}\text{H}_{13}\text{ON}_2\text{Br}_2\text{S}$   $[\text{M}+\text{H}]^+$  378.9110, found 378.9112.

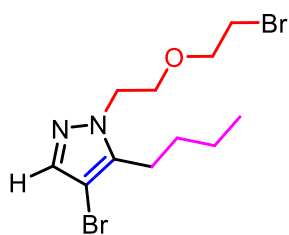


**2i**

$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.41 (s, 1H), 5.88-5.85 (m, 1H), 4.20 (t,  $J = 5.7$  Hz, 2H), 3.86 (t,  $J = 5.7$  Hz, 2H), 3.68 (t,  $J = 5.7$  Hz, 2H), 3.36 (t,  $J = 6.0$  Hz, 2H), 2.25-2.21 (m, 4H), 1.80-1.66 (m, 4H);  
 $^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ ):  $\delta$  139.1, 133.3, 127.1, 126.7, 92.0, 71.1, 69.5, 49.7, 30.3, 28.6, 25.6, 22.7, 21.8.;

IR (neat) = 2932, 1434, 1397, 1297  $\text{cm}^{-1}$

HRMS (ESI)  $m/z$  calcd for  $\text{C}_{13}\text{H}_{19}\text{ON}_2\text{Br}_2$   $[\text{M}+\text{H}]^+$  376.9859, found 376.9859.



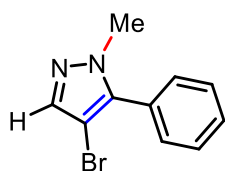
**2j**

$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.60 (s, 1H), 3.86 (t,  $J = 4.8$  Hz, 4H), 3.19 (t,  $J = 4.8$  Hz, 4H), 2.89 (t,  $J = 7.5$  Hz, 1H), 1.66-1.57 (m, 2H), 1.45-1.33 (m, 2H), 0.95 (t,  $J = 7.2$  Hz, 3H);

$^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ ):  $\delta$  132.5, 126.6, 116.3, 69.4, 66.3, 51.6, 41.4, 29.9, 21.9, 18.7, 14.3;

IR (neat) = 2960, 1450, 1373, 1272  $\text{cm}^{-1}$

HRMS (ESI)  $m/z$  calcd for  $\text{C}_{11}\text{H}_{19}\text{ON}_2\text{Br}_2$   $[\text{M}+\text{H}]^+$  352.9859, found 352.9862.



**2k**

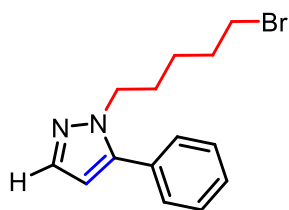
$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ):  $\delta$  7.54 (s, 1H), 7.54-7.45 (m, 3H), 7.45 (m, 2H), 3.82 (s, 3H);

$^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ ):  $\delta$  141.3, 139.3, 129.9, 129.3, 128.8, 128.5, 93.5;

IR (neat) = 3060, 2953, 1484, 1439, 1388  $\text{cm}^{-1}$

HRMS (ESI)  $m/z$  calcd for  $\text{C}_{10}\text{H}_{10}\text{N}_2\text{Br}$   $[\text{M}+\text{H}]^+$  237.0022, found 237.0027.

The spectra data of **2k** was matched with reported data.<sup>2</sup>



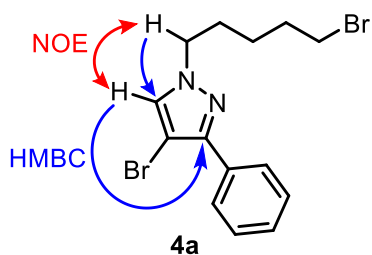
**3a**

<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) δ 7.53 (d, *J* = 2.0 Hz, 1H), 7.46-7.33 (m, 5H), 6.27 (d, *J* = 2.0 Hz, 1H), 4.14 (t, *J* = 7.0 Hz, 2H), 3.32 (t, *J* = 6.8 Hz, 2H), 1.89-1.72 (m, 4H), 1.41-1.29 (m, 2H);

<sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) δ 138.6, 128.9, 128.7, 128.5, 106.1, 49.4, 33.7, 32.4, 29.8, 25.5;

IR (neat) = 2931, 2855, 1734, 1563, 1460 cm<sup>-1</sup>

HRMS (ESI) *m/z* calcd C<sub>14</sub>H<sub>18</sub>N<sub>2</sub>Br [M+H]<sup>+</sup> 293.0648, found 293.0649.



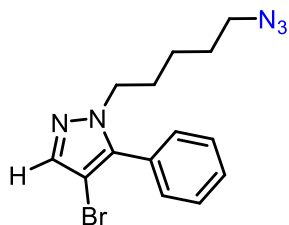
**4a**

<sup>1</sup>H NMR (600 MHz, CDCl<sub>3</sub>) δ 7.90 (d, *J* = 7.0 Hz, 2H), 7.50 (s, 1H), 7.45 (t, *J* = 7.7 Hz, 2H), 7.38 (t, *J* = 7.5 Hz, 1H), 4.16 (t, *J* = 7.2 Hz, 2H), 3.43 (t, *J* = 6.8 Hz, 2H), 1.99-1.90 (m, 4H), 1.31-1.25 (m, 2H);

<sup>13</sup>C NMR (150 MHz, CDCl<sub>3</sub>) δ 148.6, 132.2, 131.2, 128.3, 128.0, 127.5, 91.4, 52.7, 33.3, 32.1, 29.5, 25.2

HRMS (ESI) *m/z* calcd for C<sub>14</sub>H<sub>17</sub>N<sub>2</sub>Br<sub>2</sub> [M+H]<sup>+</sup> 372.9745, found 372.9733.

### Transformation of **2a**



**5**

To a solution of **2a** (34.7 mg, 0.0933 mmol) in DMF (1 mL) was added NaN<sub>3</sub> (12.6 mg, 0.194 mmol). The mixture was stirred at 50 °C for 5 h. Then, the mixture was quenched with water, extracted with

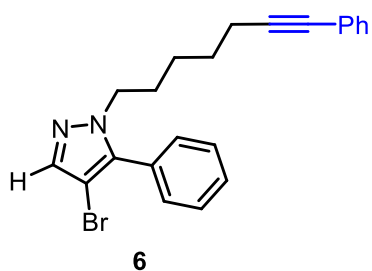
ether three times. The organic layers were washed with water and brine, dried over Na<sub>2</sub>SO<sub>4</sub>, and concentrated. The residue was purified by Preparative Thin-Layer Chromatography (15% EtOAc/Hexane) to afford azide **5** (28.2 mg, 90%);

<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>): δ 7.55 (s, 1H), 7.54-7.46 (m, 3H), 7.41-7.33 (m, 2H), 4.06 (t, *J* = 7.1 Hz, 2H), 3.18 (t, *J* = 6.7 Hz, 2H), 1.84-1.69 (m, 2H), 1.55-1.38 (m, 2H), 1.34-1.16 (m, 2H);

<sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) δ 139.2, 131.0, 129.8, 129.2, 128.8, 127.5, 93.6, 51.3, 50.4, 29.9, 28.6, 23.9;

IR (neat) = 2942, 2865, 2097, 1453, 1396 cm<sup>-1</sup>

HRMS (ESI) *m/z* calcd C<sub>14</sub>H<sub>17</sub>N<sub>5</sub>Br [M+H]<sup>+</sup> 334.0662, found 334.0664.



To a solution of ethynylbenzene (18.7 μL, 0.170 mmol) in THF (500 μL) was added *n*-BuLi (1.6 M in hexane, 94 μL) at -78 °C. The mixture was warmed up to room temperature and stirred for 30 minutes. Then, to the solution added mixture of HMPA (26.1 μL, 0.150 mmol) and **2a** (36.8 mg, 0.0989 mmol) in THF (1.5 mL) at -78 °C. The mixture was warmed up to room temperature and stirred overnight. Then, the mixture was quenched with water, extracted with ether three times. The collected organic layers were dried over Na<sub>2</sub>SO<sub>4</sub>, filtered and concentrated. The residue was purified by Preparative Thin-Layer Chromatography (10% EtOAc/Hexane, twice) to afford alkyne **6** (19.1 mg, 49%);

<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>): δ 7.55 (s, 1H), 7.52-7.43 (m, 3H), 7.40-7.30 (m, 4H), 7.30-7.20 (m, 3H), 4.08 (t, *J* = 7.3 Hz, 2H), 2.34 (t, *J* = 7.0 Hz, 2H), 1.87-1.72 (m, 2H), 1.58-1.45 (m, 2H), 1.41-1.26 (m, 2H);

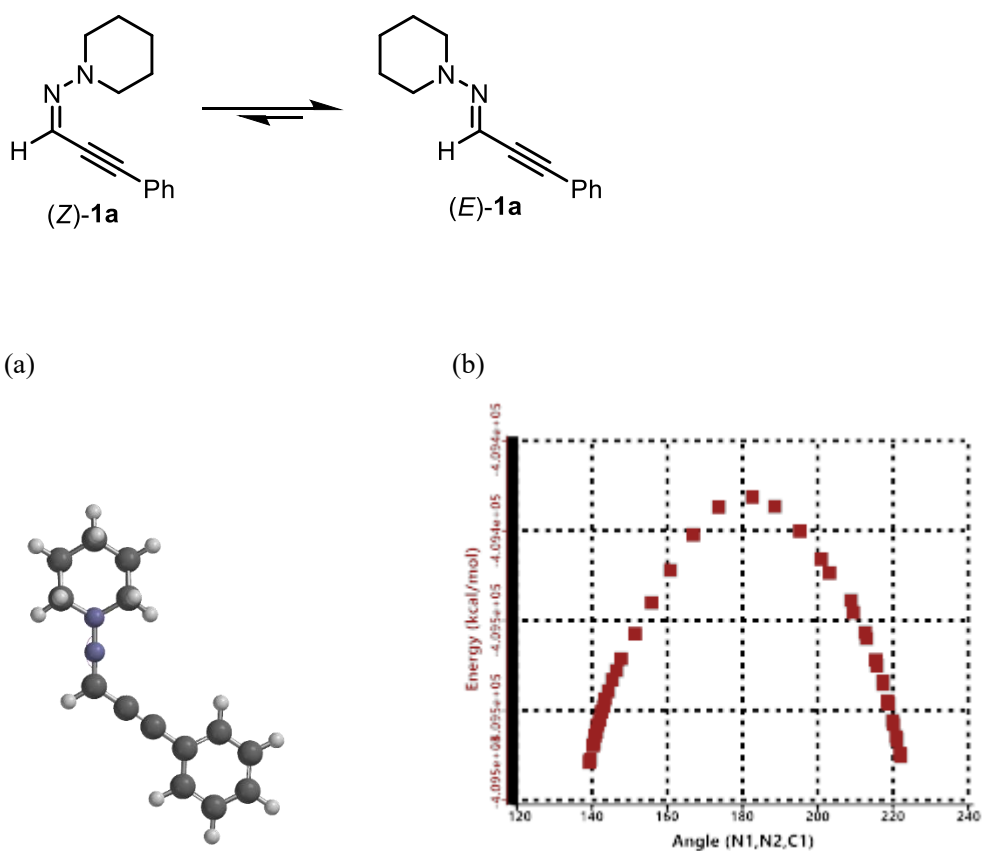
<sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) δ 139.2, 131.5, 129.8, 129.2, 128.7, 128.1, 127.5, 123.9, 93.5, 89.8, 81.0, 69.6, 50.8, 30.0, 28.3, 25.9, 19.2;

IR (neat) = 3425, 3058, 2939, 2860, 2225, 1598, 1490, 1441 cm<sup>-1</sup>

HRMS (ESI) *m/z* calcd C<sub>22</sub>H<sub>22</sub>N<sub>2</sub>Br [M+H]<sup>+</sup> 393.0961, found 393.0960.

### Preliminary DFT calculations for activation energy of isomerization

All calculations were performed with the program package Spartan '18 (Wavefunction, Inc., Irvine, CA). Structures of ground states (*Z*)-**1a** and (*E*)-**1a** were optimized and subjected to frequency analysis with the B3LYP/6-31G\* method, followed by single point B3LYP/6-31G\* calculation. The calculation of transition state **TS-1** was first performed using density functional theory (DFT) methods at the B3LYP/6-31G(d) level. Once the stationary points were obtained, the harmonic vibrational frequencies were calculated at the same level to estimate the Gibbs free energy. All of the Gibbs free energy values reported in this paper were calculated for a temperature of 298.15 K. In addition, intrinsic reaction coordinate (IRC) calculations were performed at the same level to connect all the transition states with the corresponding reactants and products. As the results, the calculated activation energy of (*E*)-**1a** is 30.43 kcal/mol and (*Z*)-**1a** is 28.30 kcal/mol, respectively. Moreover, (*Z*)-**1g** and (*E*)-**1g** were also calculated by the same procedure to give 32.29 kcal/mol of the activation energy for (*E*)-**1g** and 30.29 kcal/mol for (*Z*)-**1g**. These results suggest that interconversion between (*E*)-isomer and (*Z*)-isomer can proceed under heating condition, but isomerization maybe also involved in copper species.



**Figure S1.** (a) Structure of **TS-1**; (b) IRC calculations for **TS-1** (B3LYP/6-31G(d) level)

SPARTAN '18 (Win/64b) Release 1.4.2

Name: M0001

Formula: C<sub>14</sub>H<sub>16</sub>N<sub>2</sub>

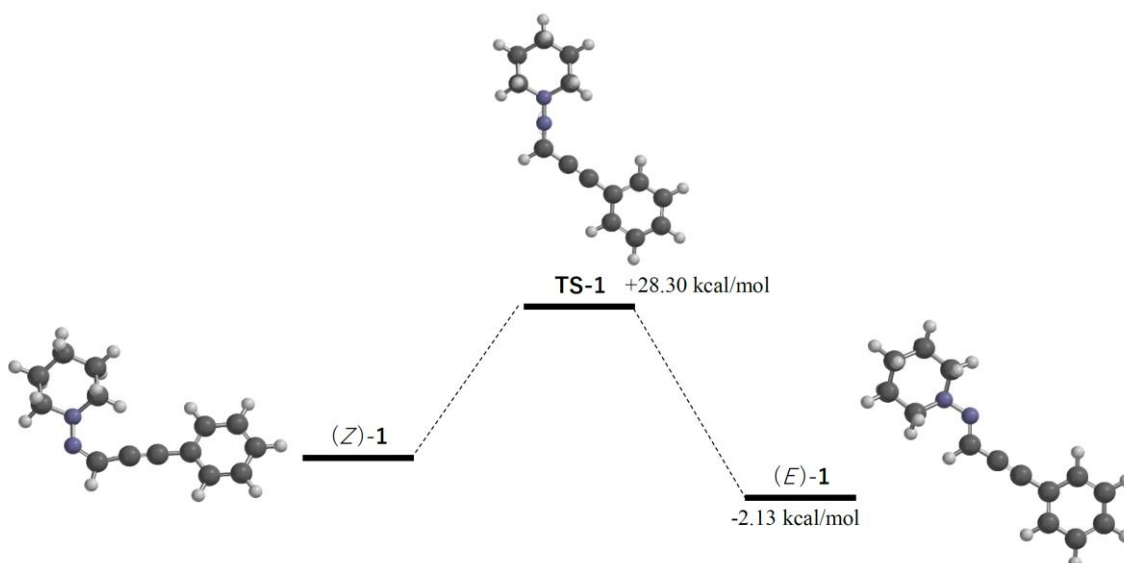
Job type: Transition State Geometry

Method: B3LYP

Basis set: 6-31G\*

With Options: IRC GRADIENTTOLERANCE=0.0001

Energy: -652.488613 hartrees



**Figure S2.** Energy diagram for isomerization of **1a**

### Thermodynamic Properties at 298.15 K

Zero Point Energy : 676.03 kJ/mol (ZPE)

Temperature Correction : 36.53 kJ/mol (vibration + gas law + rotation + translation)

Enthalpy Correction : 712.55 kJ/mol (ZPE + temperature correction)

Enthalpy : -652.217216 au (Electronic Energy + Enthalpy Correction)

Entropy : 527.46 J/mol•K

Gibbs Energy : -652.277114 au (Enthalpy - T\*Entropy)

Cv : 247.65 J/mol•K

### Raman/IR Table

	Uncorrected $\text{cm}^{-1}$	Corrected	Intensity
1	-417	-397	39.04
2	10	9	0.19
3	34	32	0.28
4	54	52	0.57
5	73	70	1.31
6	121	115	0.85
7	135	128	0.26
8	207	197	1.27
9	235	223	12.50
10	270	257	0.70
11	311	296	8.01
12	324	309	5.01
13	368	351	2.27
14	392	373	14.88
15	414	394	0.01
16	425	405	3.12
17	449	427	0.86
18	465	443	0.50
19	501	477	4.93
20	534	508	0.26
21	548	522	4.29
22	600	571	35.83
23	637	607	0.50
24	704	670	18.84
25	732	697	1.55
26	738	703	4.58
27	771	734	38.21
28	813	774	0.21
29	847	807	7.68
30	853	812	0.24
31	857	816	0.05
32	873	831	27.96

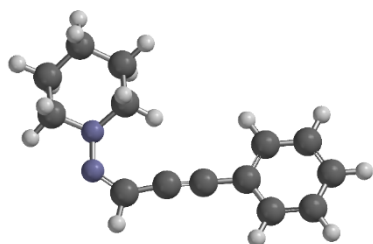
33	917	873	2.90
34	921	877	2.98
35	964	918	0.00
36	969	923	7.95
37	986	938	1.80
38	991	944	0.11
39	1015	966	0.55
40	1024	975	7.14
41	1047	997	12.06
42	1057	1006	2.52
43	1081	1029	0.78
44	1108	1055	3.56
45	1113	1060	4.79
46	1129	1075	79.65
47	1185	1128	0.71
48	1193	1136	0.01
49	1203	1145	5.49
50	1210	1152	1.83
51	1263	1203	2.58
52	1297	1235	54.93
53	1304	1242	17.04
54	1307	1244	7.95
55	1326	1262	0.04
56	1342	1277	14.39
57	1364	1298	0.06
58	1366	1300	0.72
59	1400	1333	17.15
60	1402	1334	2.74
61	1405	1338	37.20
62	1411	1344	55.44
63	1462	1392	67.67
64	1488	1417	2.66
65	1509	1437	1.27
66	1517	1444	19.37
67	1520	1447	9.47

68	1522	1449	9.56
69	1536	1463	3.01
70	1541	1467	43.94
71	1624	1546	1.87
72	1658	1578	36.06
73	1850	1761	220.38
74	2294	2184	25.25
75	2985	2842	14.24
76	2989	2845	100.00
77	2994	2850	116.62
78	3026	2881	31.77
79	3044	2898	29.33
80	3047	2900	22.66
81	3083	2935	73.39
82	3086	2938	31.35
83	3092	2943	63.52
84	3126	2976	18.81
85	3133	2982	12.09
86	3181	3028	3.06
87	3189	3036	8.96
88	3202	3048	30.47
89	3210	3056	28.97
90	3215	3060	11.14

**Cartesian coordinates**

C	4.233002	1.084757	-2.022186
H	5.323360	0.974684	-1.986797
C	3.634037	0.141658	-3.074211
H	3.917343	-0.893971	-2.843695
H	4.029164	0.370145	-4.071895
C	2.106933	0.246656	-3.107184
H	1.663318	-0.517188	-3.750231
H	1.803137	1.234066	-3.495005
C	-1.640717	-0.731708	-0.343803
C	-2.305100	-0.700993	0.677116

C	-3.068846	-0.656327	1.878347
C	-4.575022	-0.562626	4.253635
C	-4.420012	-1.059951	1.889924
C	-2.488241	-0.205281	3.081925
C	-3.236794	-0.160454	4.254604
C	-5.161247	-1.011599	3.067320
H	-4.873771	-1.407752	0.966820
H	-1.448010	0.106342	3.079796
H	-2.774336	0.189400	5.174026
H	-6.201935	-1.325552	3.059788
H	-5.156872	-0.526773	5.170731
H	4.028350	2.127507	-2.307552
C	3.619717	0.803851	-0.644158
H	4.005373	1.506504	0.104967
H	3.900119	-0.205691	-0.315038
C	2.093383	0.907953	-0.687703
H	1.789297	1.954662	-0.860002
H	1.636040	0.576720	0.247143
N	1.527223	0.055167	-1.758062
C	-0.875115	-0.770802	-1.560236
H	-1.395037	-1.210027	-2.426599
N	0.311259	-0.333377	-1.651784



**(Z)-1a**

SPARTAN '18 (Win/64b) Release 1.4.2

Name: M0001

Formula: C<sub>14</sub>H<sub>16</sub>N<sub>2</sub>

Job type: Energy

Method: B3LYP

Basis set: 6-31G\*

Energy: -652.533708 hartrees

### Thermodynamic Properties at 298.15K

Zero Point Energy : 680.73 kJ/mol (ZPE)

Temperature Correction : 35.60 kJ/mol (vibration + gas law + rotation + translation)

Enthalpy Correction : 716.33 kJ/mol (ZPE + temperature correction)

Enthalpy : 652.260874 au (Electronic Energy + Enthalpy Correction)

Entropy : 527.61 J/mol•K

Gibbs Energy : 652.320789 au (Enthalpy -T\* Entropy)

Cv : 242.36 J/mol•K

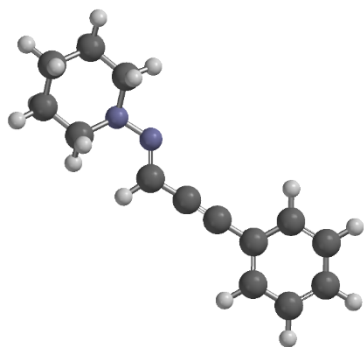
### Raman/IR Table

	Uncorrected cm <sup>-1</sup>		Corrected	Intensity
1	18	17	0.18	
2	33	32	0.24	
3	40	38	0.17	
4	76	73	0.11	
5	110	105	2.04	
6	123	117	1.12	
7	204	195	0.05	
8	241	229	2.76	
9	255	242	3.03	
10	263	251	21.31	
11	313	298	7.57	
12	376	358	10.70	
13	393	374	6.18	
14	412	392	0.00	
15	421	401	1.27	
16	452	430	0.41	
17	463	441	2.04	
18	524	499	1.19	
19	536	510	3.83	

20	551	525	2.06
21	599	571	21.11

**Cartesian coordinates**

N	0.968139	1.188819	-1.906437
C	2.168208	-1.092104	-3.262339
H	2.100955	-1.942420	-3.951367
C	1.878668	0.224407	-3.992775
H	0.889835	0.174123	-4.466707
H	2.612965	0.400350	-4.788060
C	1.904371	1.402790	-3.018144
H	1.609007	2.334971	-3.502567
H	2.928049	1.540078	-2.626565
N	0.626042	2.354133	-1.327042
C	0.002846	2.498311	-0.195560
H	-0.193992	3.543936	0.041154
C	-0.511840	1.574152	0.753449
C	-1.037447	0.905223	1.628029
C	-1.640744	0.101554	2.635813
C	-2.837332	-1.476715	4.631909
C	-2.132238	0.690292	3.819457
C	-1.762504	-1.293746	2.471947
C	-2.355070	-2.070814	3.462810
C	-2.723223	-0.095049	4.804649
H	-2.041552	1.764029	3.951343
H	-1.390448	-1.754510	1.561845
H	-2.442663	-3.144793	3.322087
H	-3.096759	0.372834	5.711546
H	-3.300018	-2.086594	5.402918
H	3.197509	-1.077094	-2.875903
C	1.188937	-1.266976	-2.096225
H	1.431652	-2.163824	-1.512711
H	0.172036	-1.401081	-2.487014
C	1.198077	-0.054369	-1.156866
H	2.166737	0.010162	-0.629696
H	0.421797	-0.160079	-0.402978



**(E)-1a**

SPARTAN '18 (Win/64b) Release 1.4.2

Name: M0001

Formula: C<sub>14</sub>H<sub>16</sub>N<sub>2</sub>

Job type: Energy

Method: B3LYP

Basis set: 6-31G\*

Energy: 652.537114 hartrees

**Thermodynamic Properties at 298.15 K**

Zero Point Energy : 679.89 kJ/mol (ZPE)

Temperature Correction : 35.79 kJ/mol (vibration + gas law + rotation + translation)

Enthalpy Correction : 715.68 kJ/mol (ZPE + temperature correction)

Enthalpy : 652.264527 au (Electronic Energy + Enthalpy Correction)

Entropy : 530.62 J/mol•K

Gibbs Energy : 652.324784 au (Enthalpy - T\*Entropy)

Cv : 243.17 J/mol•K

**Raman/IR Table**

	Uncorrected cm <sup>-1</sup>	Corrected	Intensity
1	17	16	0.15
2	33	31	1.26
3	35	34	0.73
4	77	73	0.64

5	120	115	0.07
6	151	143	0.79
7	192	183	0.79
8	199	189	12.84
9	230	219	10.99
10	280	267	9.39
11	316	301	1.95
12	350	333	5.21
13	365	348	19.08
14	412	392	0.01
15	431	411	0.12
16	454	432	0.25
17	486	463	8.35
18	496	472	6.19
19	523	498	2.42
20	545	519	8.87
21	558	531	3.78
22	636	605	8.54
23	640	609	35.76
24	704	670	18.94
25	752	716	1.48
26	772	735	38.92
27	809	770	5.19
28	825	785	1.29
29	853	812	0.02
30	871	829	9.81
31	872	830	17.02
32	889	847	30.05
33	924	879	2.86
34	930	885	5.64
35	964	918	0.00
36	983	936	1.20
37	993	946	0.12
38	1015	966	1.31
39	1019	970	68.26
40	1048	997	3.18

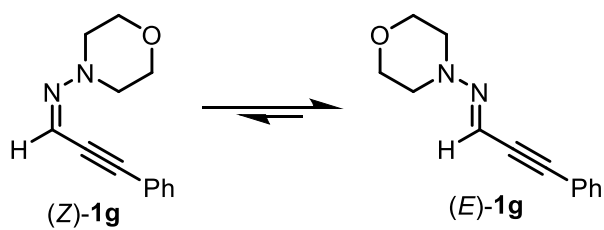
41	1054	1003	7.32
42	1076	1024	3.54
43	1091	1039	6.49
44	1110	1057	3.78
45	1134	1079	268.96
46	1154	1098	12.65
47	1188	1131	13.98
48	1194	1137	0.01
49	1208	1150	94.55
50	1212	1154	12.75
51	1284	1222	44.80
52	1301	1238	32.91
53	1311	1248	8.52
54	1324	1261	11.32
55	1328	1264	0.12
56	1347	1283	4.05
57	1365	1299	0.13
58	1370	1304	4.50
59	1400	1332	0.34
60	1402	1335	73.11
61	1410	1342	48.67
62	1419	1351	155.30
63	1432	1363	12.92
64	1489	1418	3.61
65	1507	1434	1.91
66	1514	1441	13.82
67	1519	1446	44.31
68	1522	1449	4.66
69	1536	1463	28.70
70	1540	1467	43.45
71	1620	1543	113.72
72	1625	1547	6.69
73	1660	1581	5.68
74	2306	2196	19.87
75	2961	2819	26.08
76	2967	2825	105.69

77	3030	2884	30.87
78	3046	2900	23.36
79	3048	2901	25.65
80	3083	2935	78.69
81	3089	2941	34.62
82	3094	2945	36.14
83	3098	2949	39.89
84	3121	2971	50.78
85	3131	2981	15.59
86	3184	3031	3.98
87	3192	3039	8.95
88	3205	3051	26.78
89	3213	3058	27.48
90	3217	3063	12.68

**Cartesian coordinates**

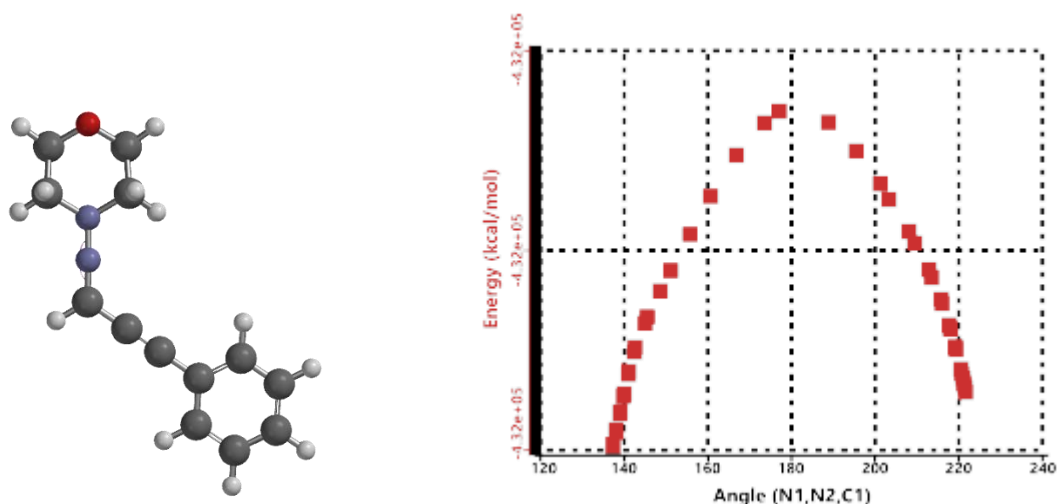
C	-0.019157	0.551512	0.455075
H	0.153915	1.446370	1.057543
N	-0.009365	0.541416	-0.843875
N	0.167918	1.667464	-1.567429
C	0.658330	2.904824	-0.958368
H	1.712953	2.784827	-0.648794
H	0.075748	3.103469	-0.054003
C	0.500758	4.096014	-1.913827
H	0.974942	4.973887	-1.458456
H	-0.568565	4.323720	-2.013475
C	1.086069	3.810025	-3.301449
H	2.176631	3.687284	-3.227917
H	0.907844	4.660952	-3.969728
C	0.464202	2.530584	-3.871229
H	0.905952	2.279675	-4.843256
H	-0.611710	2.680681	-4.031285
C	0.674719	1.360450	-2.911298
H	1.750536	1.113589	-2.860216
H	0.149568	0.461965	-3.242564
C	-0.268812	-0.649744	1.164048

C	-0.466798	-1.656677	1.819308
C	-0.692042	-2.856714	2.550267
C	-1.129276	-5.237708	3.981777
C	-0.808539	-4.090085	1.875884
C	-0.800185	-2.840146	3.955885
C	-1.016740	-4.021299	4.659957
C	-1.024169	-5.265644	2.588727
H	-0.725391	-4.107685	0.793617
H	-0.712129	-1.894061	4.481412
H	-1.098583	-3.992828	5.743345
H	-1.111004	-6.208502	2.055105
H	-1.297619	-6.157614	4.535223



(a)

(b)



**Figure S3.** (a) Structure of TS-2; (b) IRC calculations for TS-2 (B3LYP/6-31G(d) level)

Name: M0001

Formula: C<sub>13</sub>H<sub>14</sub>N<sub>2</sub>O

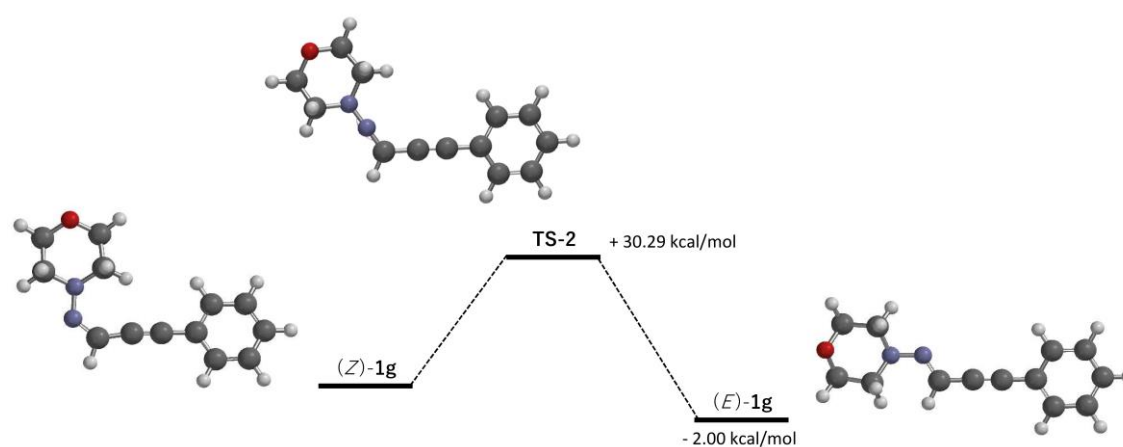
Job type: Transition State Geometry

Method: B3LYP

Basis set: 6-31G\*

With Options: IRC GRADIENTTOLERANCE=0.0001 OPTCYCLES=10000

Energy: -688.376329 hartrees



**Figure S4.** Energy diagram for isomerization of **1g**

#### **Thermodynamic Properties at 298.15K**

Zero Point Energy: 615.84 kJ/mol (ZPE)

Temperature Correction: 35.87 kJ/mol (vibration + gas law + rotation + translation)

Enthalpy Correction: 651.71 kJ/mol (ZPE + temperature correction)

Enthalpy: -688.128106 au (Electronic Energy + Enthalpy Correction)

Entropy: 518.66 J/mol•K

Gibbs Energy: -688.187005 au (Enthalpy - T\*Entropy)

Cv: 240.44 J/mol•K

#### **Raman/IR Table**

Uncorrected cm <sup>-1</sup>	Corrected Intensity		
1	-423	-403	38.29
2	21	20	0.04
3	33	31	0.14

4	46	44	0.12
5	74	71	1.80
6	121	115	1.17
7	137	131	0.39
8	219	208	3.10
9	244	232	26.30
10	268	255	0.77
11	311	296	11.87
12	320	304	5.64
13	383	364	10.83
14	412	392	4.02
15	414	394	0.15
16	427	406	0.97
17	456	434	0.70
18	486	463	0.47
19	505	481	4.83
20	549	523	4.27
21	562	535	6.00
22	624	594	51.44
23	638	607	2.72
24	705	671	18.36
25	733	698	1.29
26	748	712	4.01
27	772	735	38.94
28	843	803	5.19
29	855	814	0.00
30	859	817	3.07
31	878	835	11.31
32	923	879	3.02
33	925	880	3.17
34	966	919	0.01
35	973	926	14.51
36	994	946	0.10
37	1015	967	0.91
38	1021	972	7.15
39	1043	993	33.83

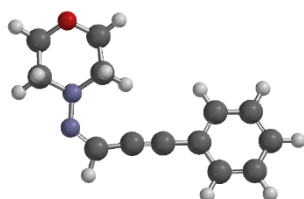
40	1058	1007	7.90
41	1102	1049	4.99
42	1109	1056	3.70
43	1130	1076	61.28
44	1138	1083	67.23
45	1182	1125	24.51
46	1193	1136	39.24
47	1194	1136	0.15
48	1211	1152	0.97
49	1240	1180	0.56
50	1298	1236	12.13
51	1302	1239	53.56
52	1327	1263	0.04
53	1332	1268	15.30
54	1344	1279	1.42
55	1364	1299	0.10
56	1370	1304	1.09
57	1403	1336	85.39
58	1410	1343	20.36
59	1441	1371	9.88
60	1462	1391	60.94
61	1489	1417	2.83
62	1508	1435	0.48
63	1513	1441	1.28
64	1516	1443	38.49
65	1528	1455	3.35
66	1542	1468	41.69
67	1625	1547	1.80
68	1658	1578	29.87
69	1854	1765	187.36
70	2296	2185	13.08
71	2995	2851	21.85
72	2997	2853	116.24
73	3000	2856	60.59
74	3014	2869	8.49
75	3017	2873	123.78

76	3113	2964	45.53
77	3116	2966	42.77
78	3127	2977	15.87
79	3132	2982	11.56
80	3182	3030	2.54
81	3191	3038	8.16
82	3203	3049	29.50
83	3212	3058	29.10
84	3216	3061	10.56

Cartesian coordinates

C	3.950506	0.289430	-3.131800
H	4.256319	-0.745384	-2.904677
H	4.407240	0.587138	-4.080521
C	2.426597	0.369370	-3.226353
H	2.033817	-0.397247	-3.899620
H	2.126341	1.359194	-3.604738
C	-1.360229	-0.596221	-0.504504
C	-2.023139	-0.576883	0.517327
C	-2.782225	-0.542993	1.722014
C	-4.276544	-0.467454	4.104537
C	-4.101315	-1.039452	1.759138
C	-2.227152	-0.008883	2.903332
C	-2.969948	0.026925	4.079857
C	-4.836936	-0.999789	2.940394
H	-4.534966	-1.452513	0.853349
H	-1.211633	0.374953	2.881148
H	-2.527870	0.442393	4.981891
H	-5.852853	-1.386023	2.953068
H	-4.854007	-0.438331	5.024584
C	3.948272	0.837326	-0.857735
H	4.409105	1.530017	-0.147201
H	4.246504	-0.190388	-0.591624
C	2.426462	0.959276	-0.813957
H	2.131262	2.013124	-0.938032
H	2.025716	0.593056	0.134612

N	1.829713	0.143495	-1.892854
C	-0.594082	-0.622074	-1.720774
H	-1.121654	-1.026542	-2.599027
N	0.602035	-0.210757	-1.799499
O	4.454664	1.175240	-2.142337



**(Z)-1g**

SPARTAN '18 (Win/64b) Release 1.4.2

Name: M0001

Formula: C<sub>13</sub>H<sub>14</sub>N<sub>2</sub>O

Job type: Equilibrium Geometry

Method: B3LYP

Basis set: 6-31G\*

With Options: FREQ=B3LYP,6-31G\*

Energy: -688.422563 hartrees

**Thermodynamic Properties at 298.15K**

Zero Point Energy: 620.60 kJ/mol (ZPE)

Temperature Correction: 34.90 kJ/mol (vibration + gas law + rotation + translation)

Enthalpy Correction: 655.50 kJ/mol (ZPE + temperature correction)

Enthalpy: -688.172898 au (Electronic Energy + Enthalpy Correction)

Entropy: 519.43 J/mol•K

Gibbs Energy: -688.231883 au (Enthalpy - T\*Entropy)

Cv: 234.88 J/mol•K

**Raman/IR Table**

	Uncorrected $\text{cm}^{-1}$	Corrected	Intensity
1	21	20	0.05
2	35	34	0.11
3	48	45	0.40
4	80	76	0.71
5	114	108	2.10
6	123	117	0.69
7	214	204	0.11
8	242	231	3.60
9	261	248	3.58
10	277	264	41.96
11	315	300	4.78
12	392	373	6.39
13	409	389	4.94
14	413	393	0.01
15	422	402	0.10
16	460	438	3.54
17	486	462	0.29
18	524	499	2.27
19	543	517	3.13
20	583	555	8.52
21	620	590	27.08
22	637	606	0.25
23	696	663	35.43
24	703	669	18.77
25	752	716	13.52
26	772	735	37.68
27	820	781	24.70
28	852	811	5.24
29	854	813	4.12
30	867	825	2.80
31	881	839	14.05
32	926	881	2.24
33	953	908	0.87
34	967	920	0.05

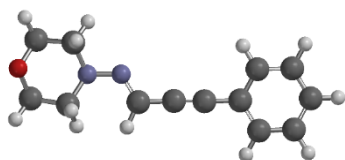
35	993	945	55.90
36	997	949	0.05
37	1016	967	4.09
38	1031	981	14.71
39	1040	990	76.10
40	1060	1009	10.39
41	1104	1051	6.60
42	1111	1058	3.79
43	1129	1075	111.22
44	1152	1097	127.49
45	1173	1116	111.20
46	1195	1137	0.00
47	1212	1154	0.62
48	1226	1167	8.85
49	1244	1184	3.37
50	1299	1237	33.92
51	1312	1249	14.73
52	1328	1264	0.11
53	1334	1270	7.83
54	1349	1284	1.77
55	1365	1300	0.28
56	1374	1308	11.29
57	1407	1339	29.45
58	1412	1344	121.52
59	1438	1369	26.46
60	1442	1373	18.25
61	1489	1417	3.54
62	1508	1435	3.44
63	1512	1440	4.47
64	1520	1447	34.97
65	1531	1457	7.41
66	1540	1466	35.00
67	1625	1547	11.15
68	1629	1550	90.77
69	1661	1581	4.19
70	2282	2172	4.91

71	2988	2844	19.59
72	2993	2850	65.06
73	3001	2857	3.16
74	3006	2862	153.25
75	3114	2964	30.88
76	3117	2967	50.73
77	3133	2983	17.14
78	3152	3001	14.89
79	3170	3018	4.17
80	3186	3033	2.70
81	3194	3041	5.04
82	3204	3051	23.60
83	3212	3058	25.57
84	3218	3063	12.46

**Cartesian coordinates**

N	1.047310	1.129143	-2.151609
C	2.012194	0.094602	-4.146689
H	1.026294	-0.062635	-4.614687
H	2.761966	0.204394	-4.935610
C	1.973879	1.341750	-3.268933
H	1.622477	2.209242	-3.832467
H	2.988171	1.557593	-2.893871
N	0.682206	2.296787	-1.584544
C	0.070393	2.426894	-0.446451
H	-0.154668	3.466558	-0.208855
C	-0.401197	1.486062	0.509072
C	-0.889068	0.795229	1.388117
C	-1.449169	-0.028183	2.405516
C	-2.559807	-1.641633	4.421580
C	-1.881453	0.538821	3.622244
C	-1.585967	-1.419103	2.218295
C	-2.136288	-2.214049	3.219441
C	-2.430175	-0.264246	4.617621
H	-1.778581	1.609229	3.771451
H	-1.260583	-1.862910	1.282165

H	-2.236594	-3.284467	3.061046
H	-2.758037	0.186014	5.550703
H	-2.989267	-2.265332	5.200730
C	1.453376	-1.277146	-2.342735
H	1.802486	-2.161823	-1.801912
H	0.455723	-1.491450	-2.760691
C	1.355550	-0.086739	-1.386736
H	2.307552	0.041980	-0.843979
H	0.568649	-0.273290	-0.657373
O	2.382628	-1.051291	-3.390838



**(E)-1g**

SPARTAN '18 (Win/64b) Release 1.4.2

Name: M0001

Formula: C<sub>13</sub>H<sub>14</sub>N<sub>2</sub>O

Job type: Equilibrium Geometry

Method: B3LYP

Basis set: 6-31G\*

With Options: FREQ=B3LYP,6-31G\*

Energy: -688.425747 hartrees

**Thermodynamic Properties at 298.15K**

Zero Point Energy: 620.10 kJ/mol (ZPE)

Temperature Correction: 35.06 kJ/mol (vibration + gas law + rotation + translation)

Enthalpy Correction: 655.17 kJ/mol (ZPE + temperature correction)

Enthalpy: -688.176208 au (Electronic Energy + Enthalpy Correction)

Entropy: 523.36 J/mol•K

Gibbs Energy: -688.235640 au (Enthalpy - T\*Entropy)

Cv : 235.58 J/mol•K

**Raman/IR Table**

	Uncorrected $\text{cm}^{-1}$	Corrected	Intensity
1	19	18	0.11
2	35	33	0.43
3	37	35	0.42
4	84	80	0.98
5	122	116	0.24
6	155	148	0.58
7	191	182	0.28
8	209	199	21.31
9	246	234	16.97
10	284	270	16.45
11	315	300	2.38
12	354	337	19.00
13	405	385	3.56
14	412	392	0.00
15	434	413	2.29
16	480	457	3.82
17	488	464	2.34
18	500	476	6.45
19	539	513	9.42
20	557	530	4.36
21	570	542	1.39
22	637	606	0.02
23	660	629	62.89
24	704	670	19.21
25	758	722	1.53
26	772	735	38.75
27	821	782	8.56
28	853	812	0.01
29	871	829	2.32
30	890	848	11.86
31	893	850	23.63
32	925	881	2.76
33	946	900	6.06
34	965	919	0.00

35	994	947	0.11
36	1015	966	0.10
37	1030	981	28.45
38	1037	987	101.51
39	1051	1000	4.67
40	1076	1024	9.05
41	1105	1052	2.53
42	1111	1057	3.71
43	1135	1081	143.90
44	1152	1097	125.57
45	1186	1129	199.28
46	1194	1137	0.01
47	1212	1154	1.38
48	1229	1170	5.20
49	1248	1188	5.48
50	1307	1245	56.99
51	1324	1260	9.72
52	1328	1265	0.13
53	1337	1273	6.71
54	1352	1287	2.02
55	1365	1299	0.19
56	1380	1314	14.29
57	1407	1340	118.77
58	1414	1346	99.14
59	1431	1363	16.82
60	1446	1376	14.54
61	1490	1418	3.88
62	1509	1437	0.46
63	1513	1440	0.86
64	1518	1445	66.59
65	1528	1455	15.18
66	1540	1466	45.46
67	1624	1546	22.19
68	1626	1548	72.51
69	1661	1581	3.18
70	2308	2198	6.10

71	2982	2839	37.54
72	2994	2850	65.16
73	2999	2855	23.16
74	3008	2864	110.02
75	3097	2948	16.72
76	3118	2968	39.56
77	3122	2972	45.26
78	3123	2973	50.88
79	3129	2979	16.57
80	3185	3032	3.60
81	3193	3039	8.35
82	3206	3052	25.30
83	3213	3059	26.69
84	3217	3063	12.54

**Cartesian coordinates**

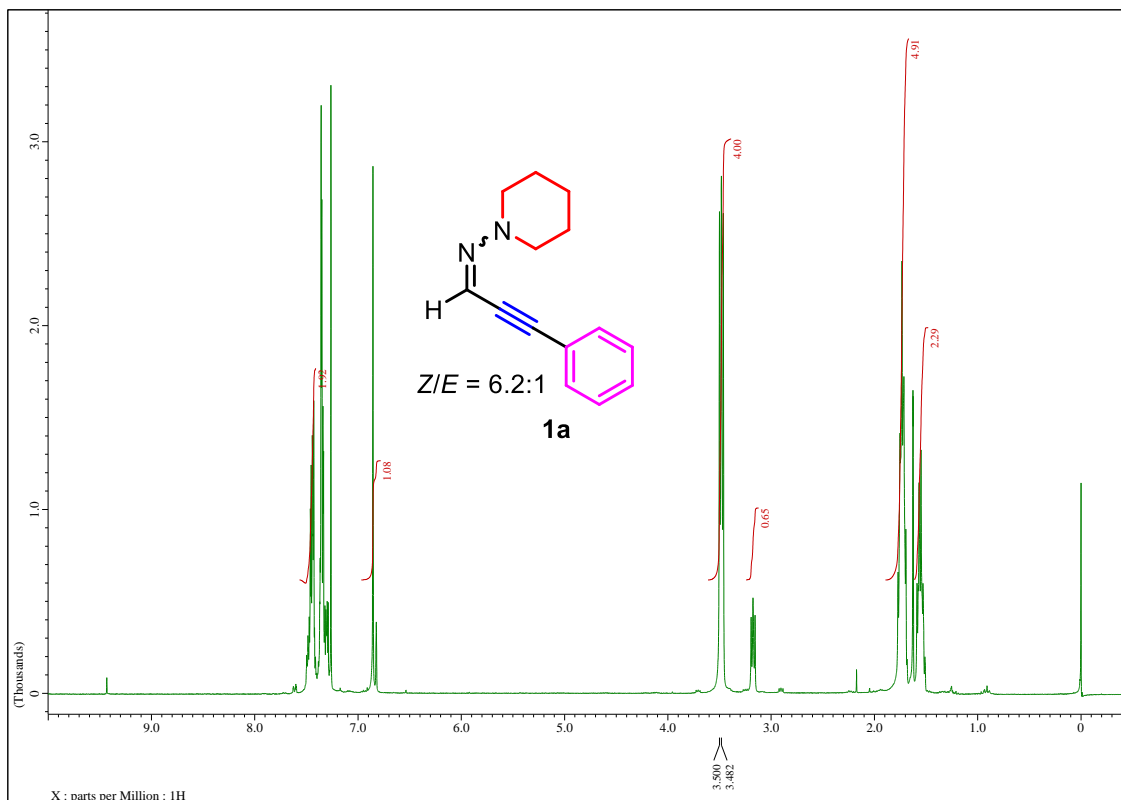
C	0.815065	-0.058299	0.207418
H	1.717430	-0.214517	0.802768
N	0.798997	-0.070775	-1.089948
N	1.934239	-0.230655	-1.808618
C	3.167169	-0.736131	-1.205212
H	3.040461	-1.783683	-0.880543
H	3.415061	-0.135728	-0.323890
C	4.321124	-0.613304	-2.206273
H	5.206246	-1.126755	-1.819684
H	4.566306	0.452399	-2.346626
C	2.879902	-0.583153	-4.038428
H	2.719669	-1.063781	-5.007647
H	3.080899	0.488213	-4.202879
C	1.654677	-0.754700	-3.148422
H	1.388811	-1.823546	-3.097530
H	0.795031	-0.206681	-3.542769
C	-0.384897	0.175894	0.923315
C	-1.390091	0.364014	1.583619
C	-2.590633	0.581815	2.316394
C	-4.971164	1.008099	3.749252

C	-3.824682	0.691603	1.642358
C	-2.572575	0.690198	3.721928
C	-3.753897	0.901589	4.426934
C	-5.000381	0.901936	2.356144
H	-3.842909	0.607571	0.560164
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H	-5.944210	0.983573	1.823510
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O	4.016271	-1.209341	-3.455492

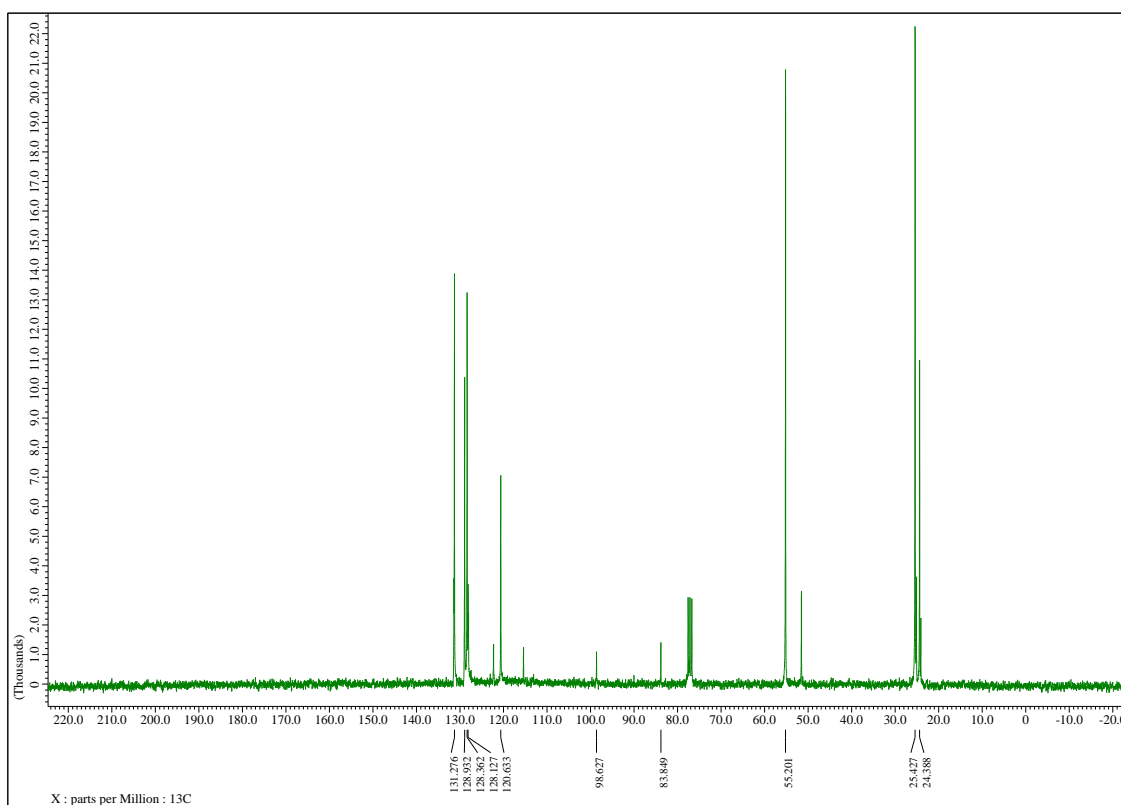
### References

- (1) I. Nakamura, N. Shirakawa, R. Kanazawa, and M. Terada, *Org. Lett.* 2010, **12**, 4198.
- (2) K. Kano, D. Scarretti, J. C. Warner, and J.-P. Anselme, *Can. J. Chem.* 1986, **64**, 2211.

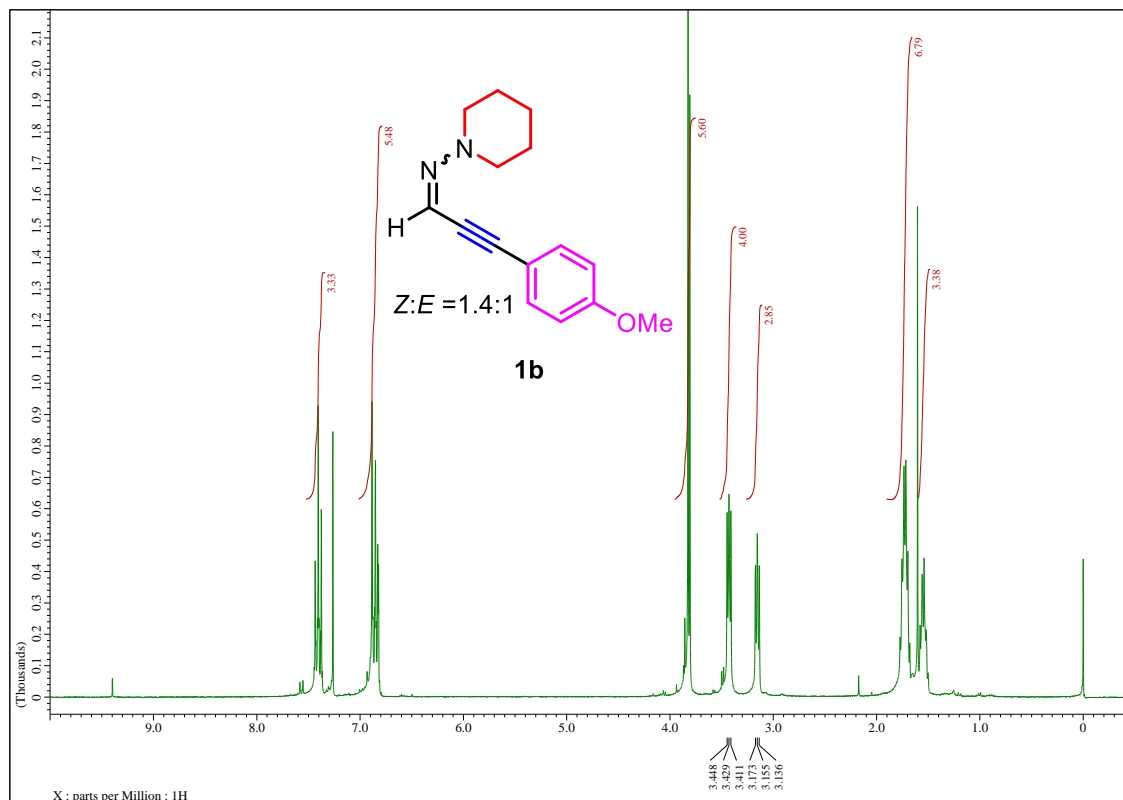
<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) of **1a**



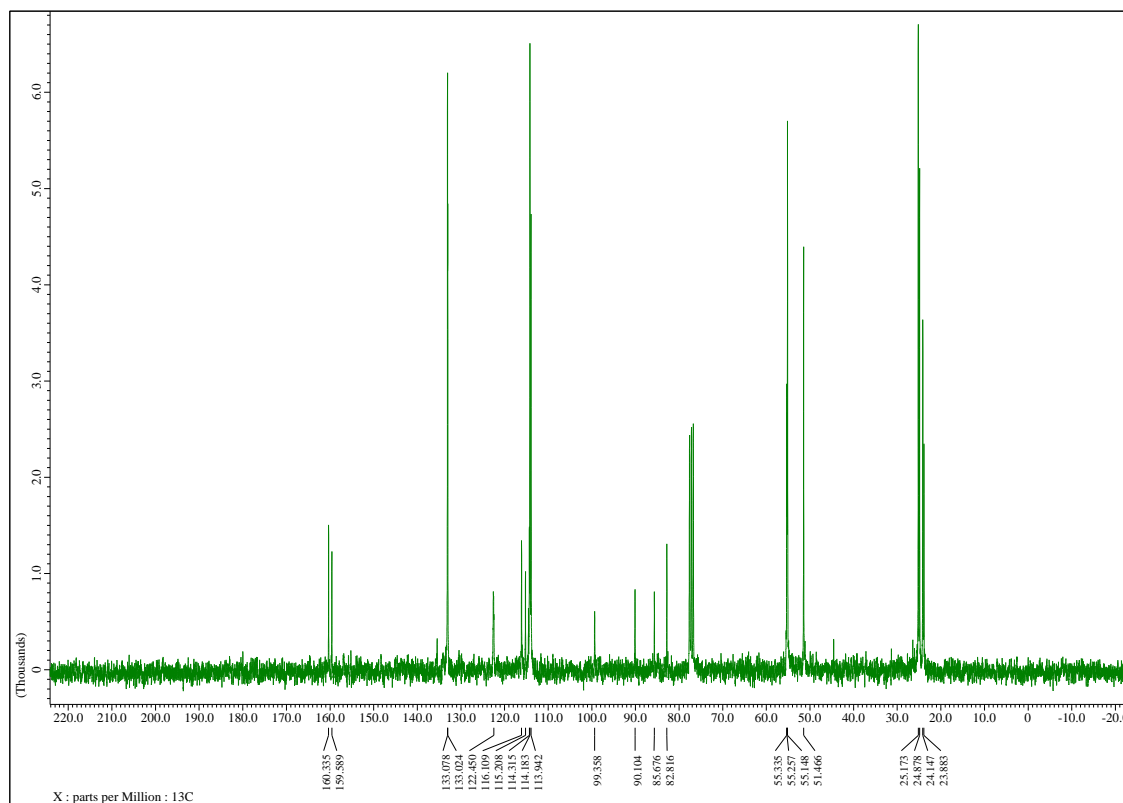
<sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) of **1a**



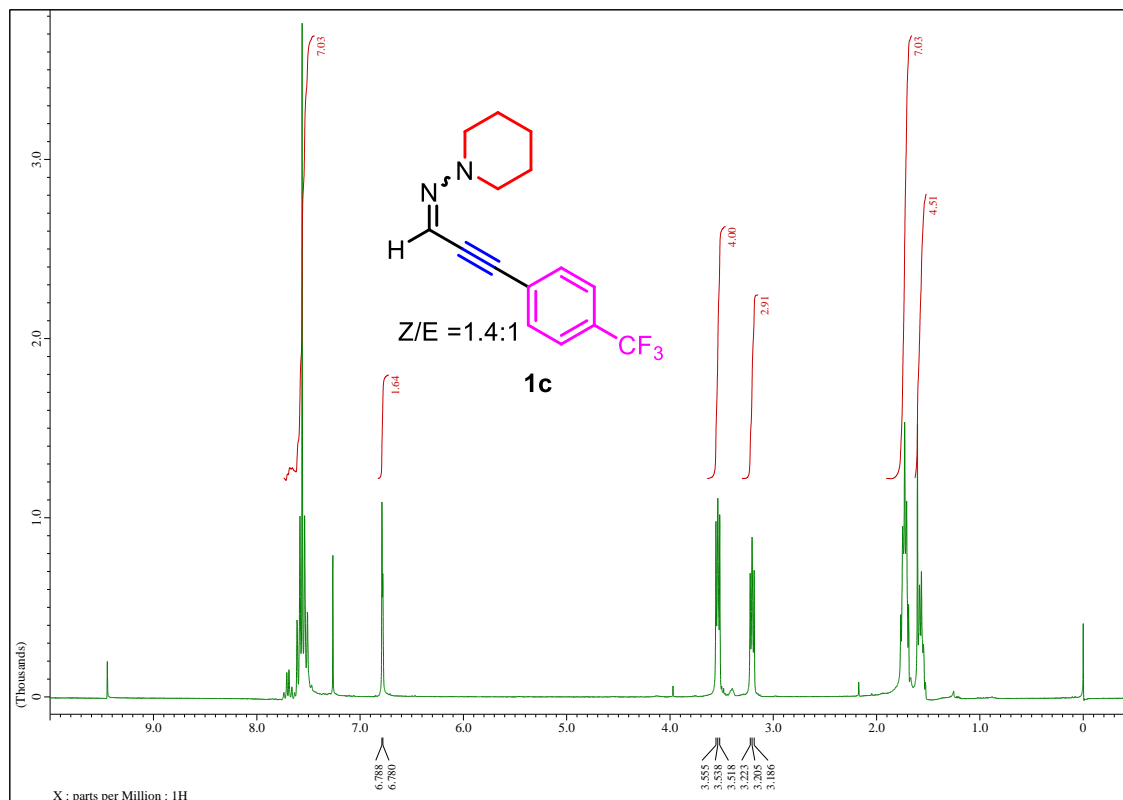
<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) of **1b**



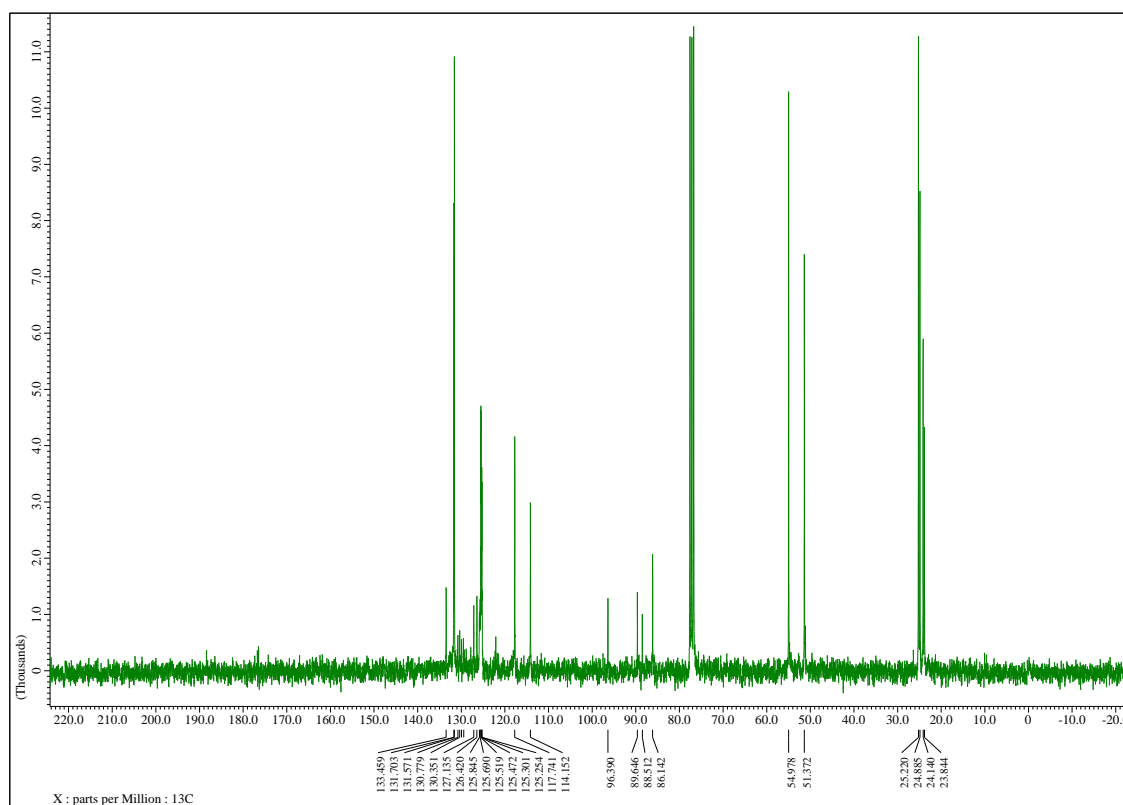
<sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) of **1b**



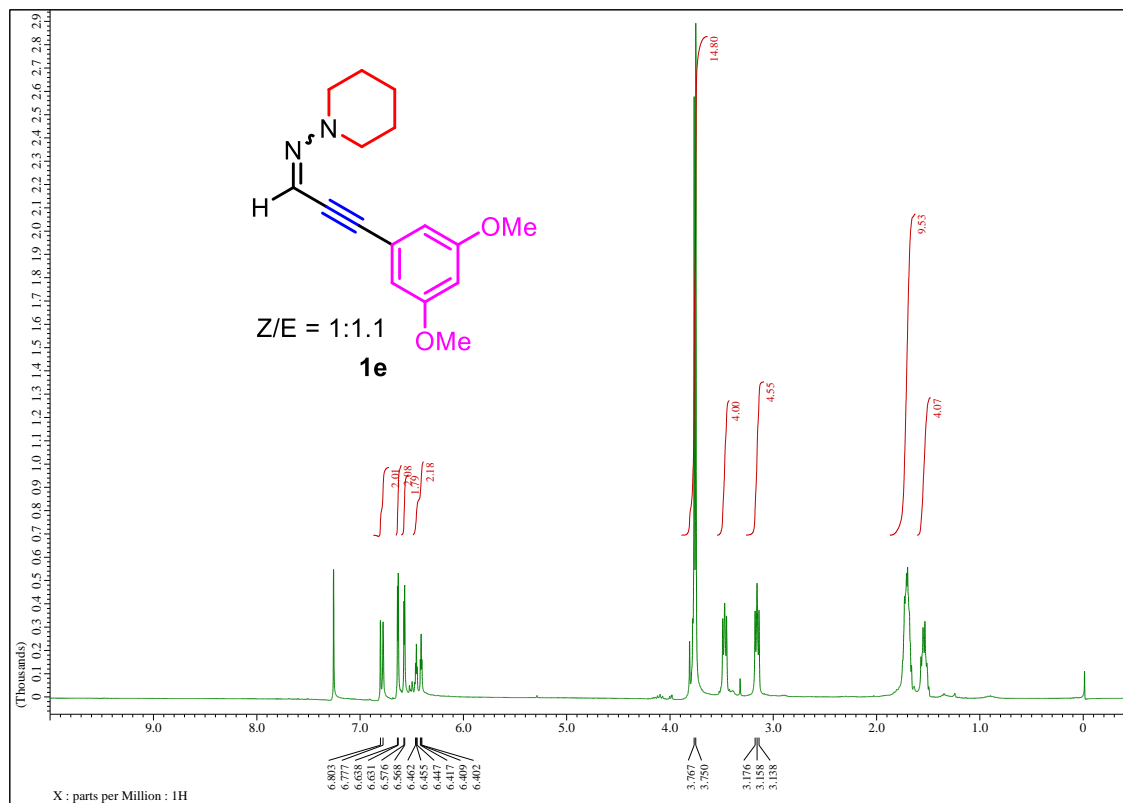
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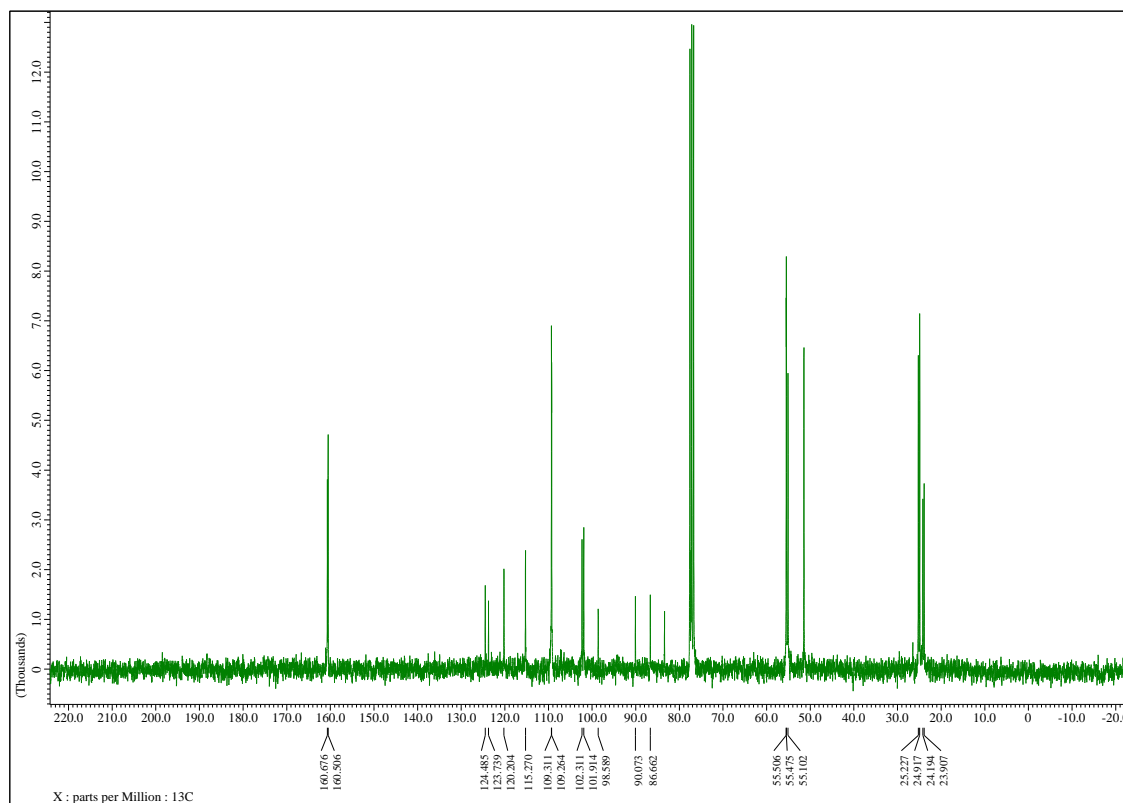
<sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) of **1c**



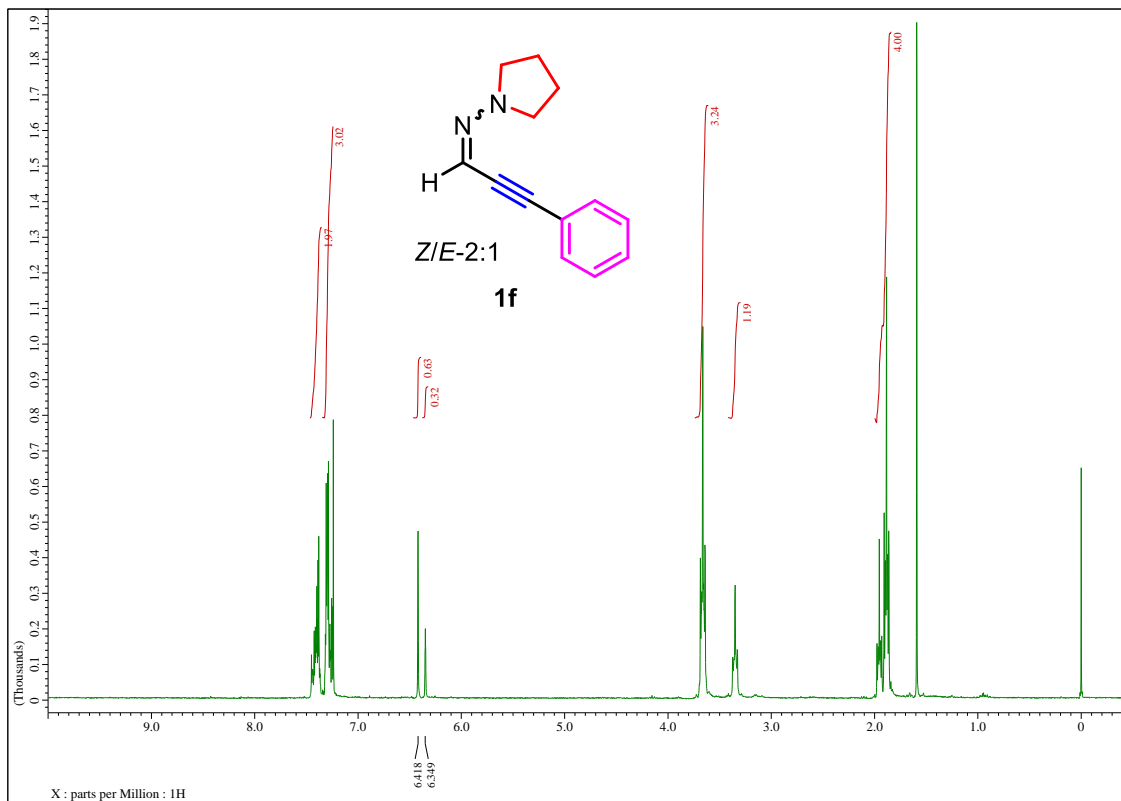
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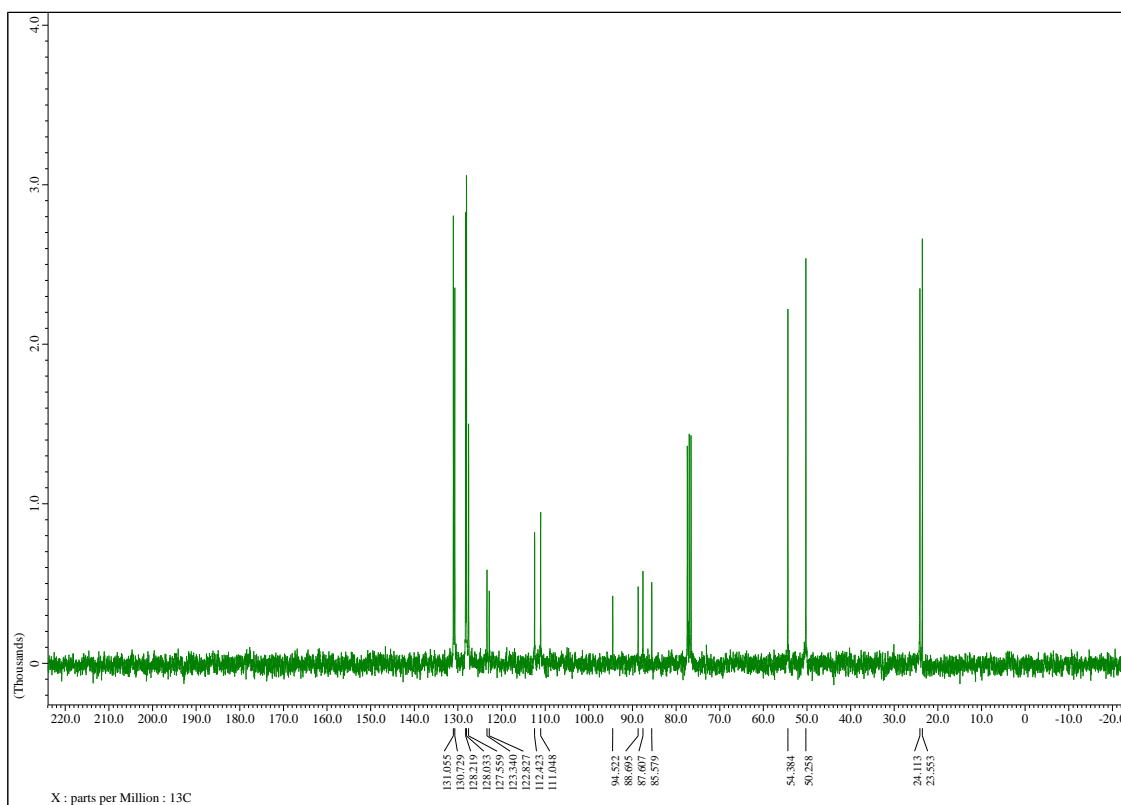
<sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) of **1e**



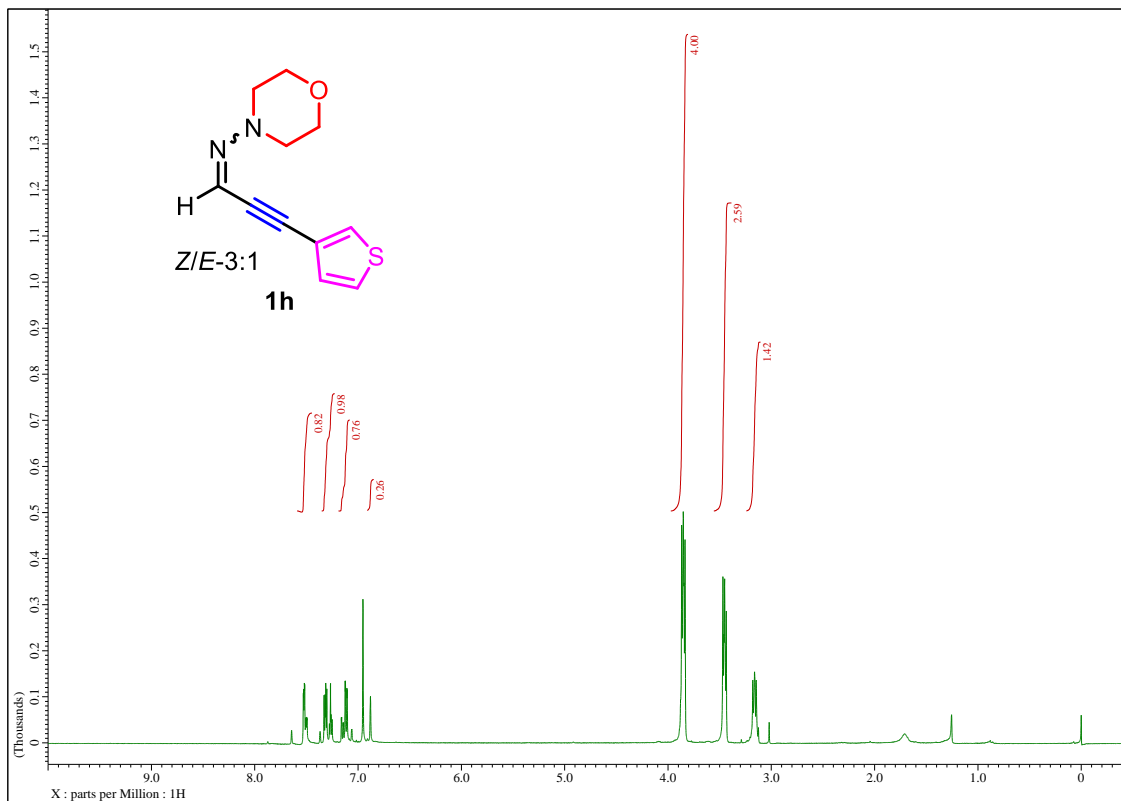
<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) of **1f**



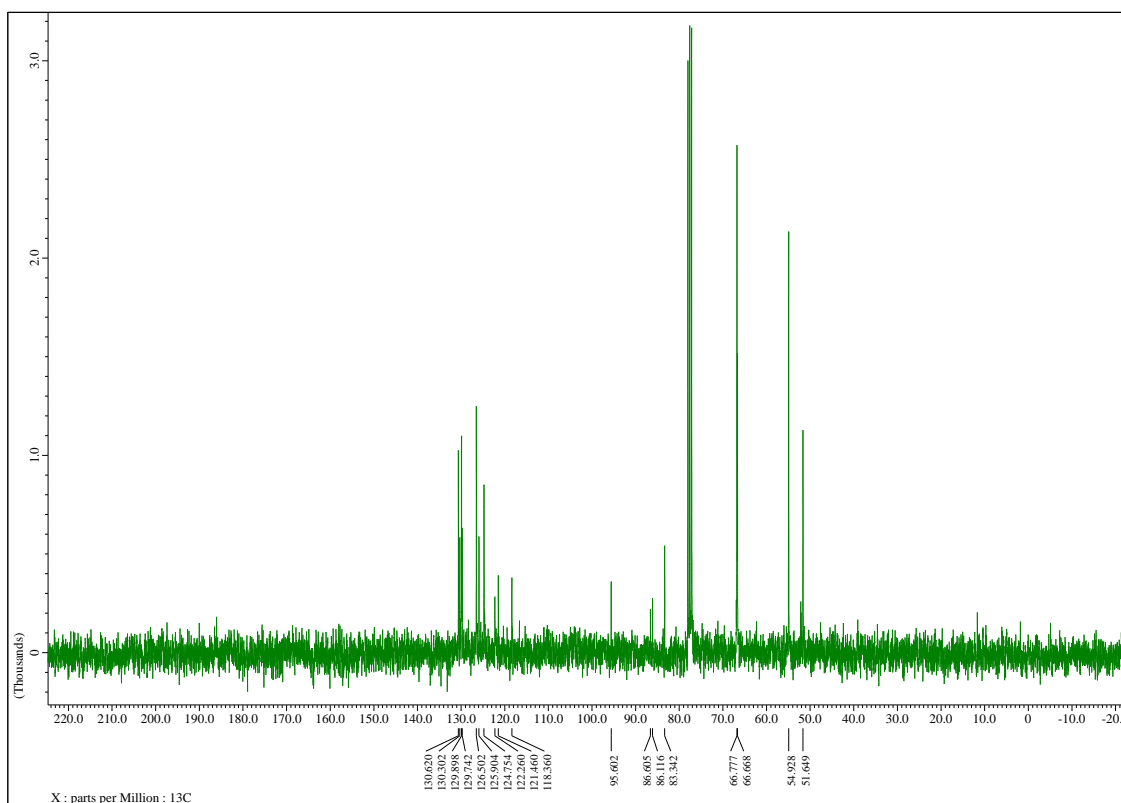
<sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) of **1f**



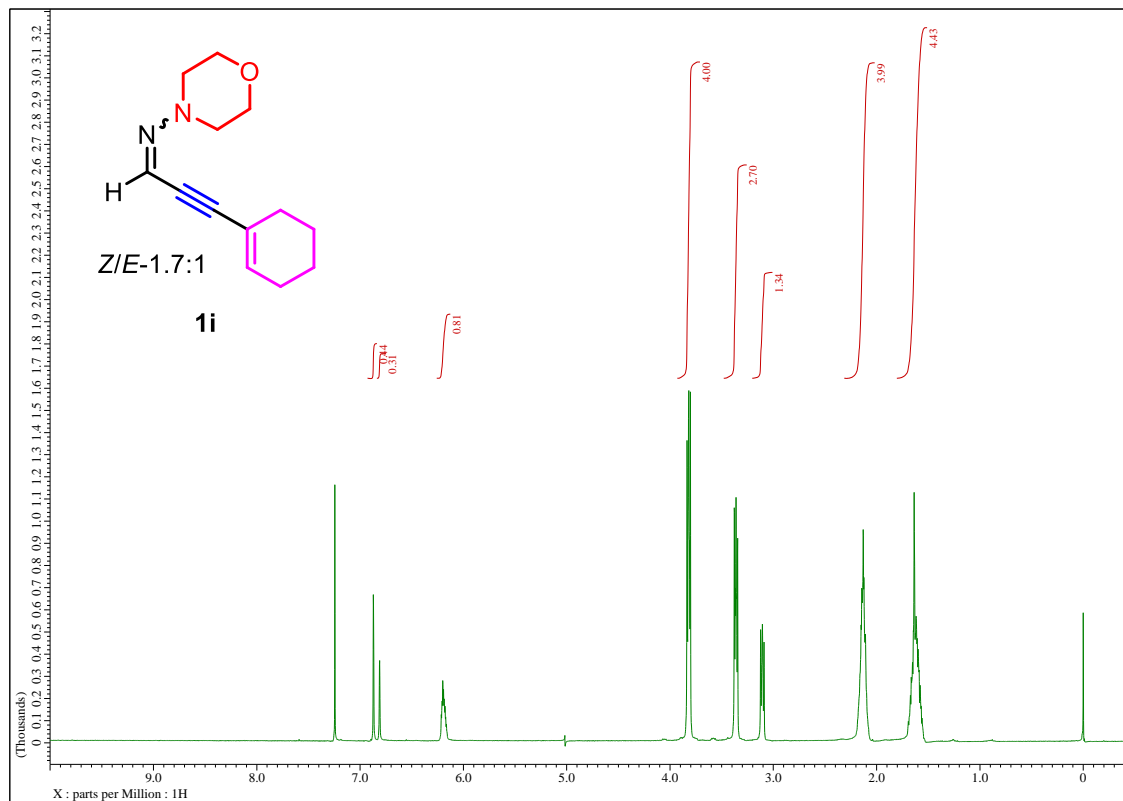
$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ) of **1h**



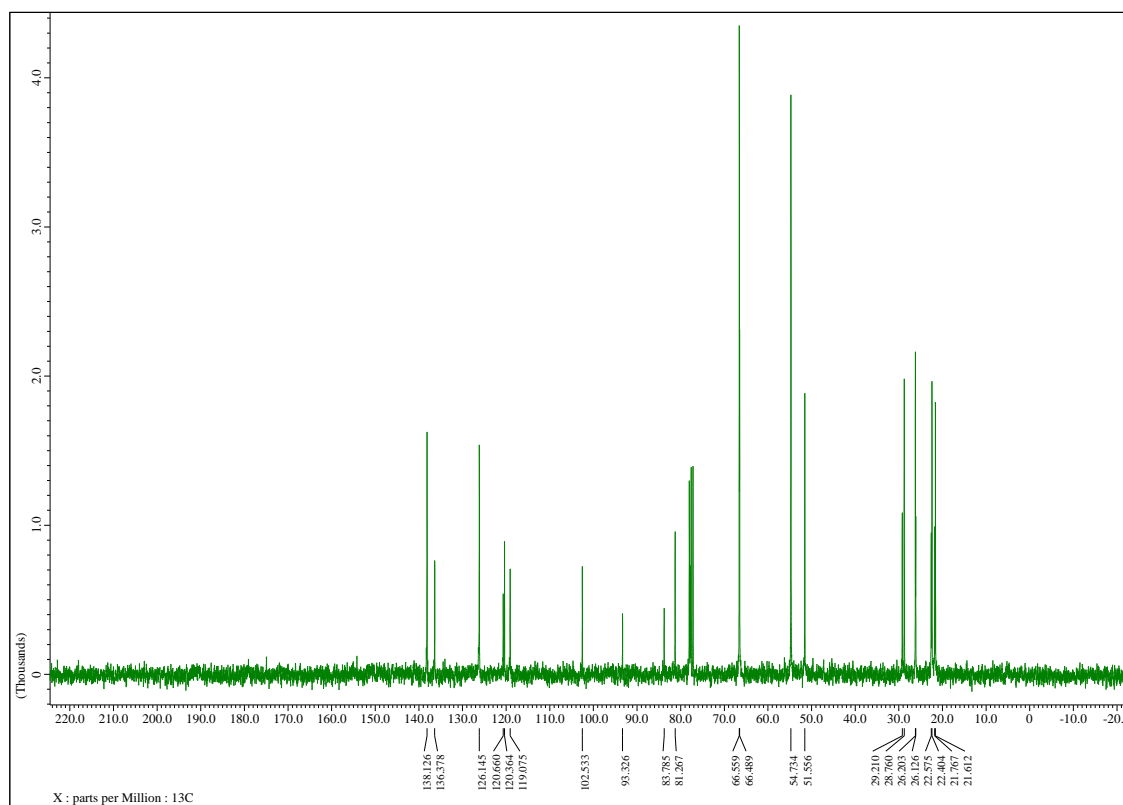
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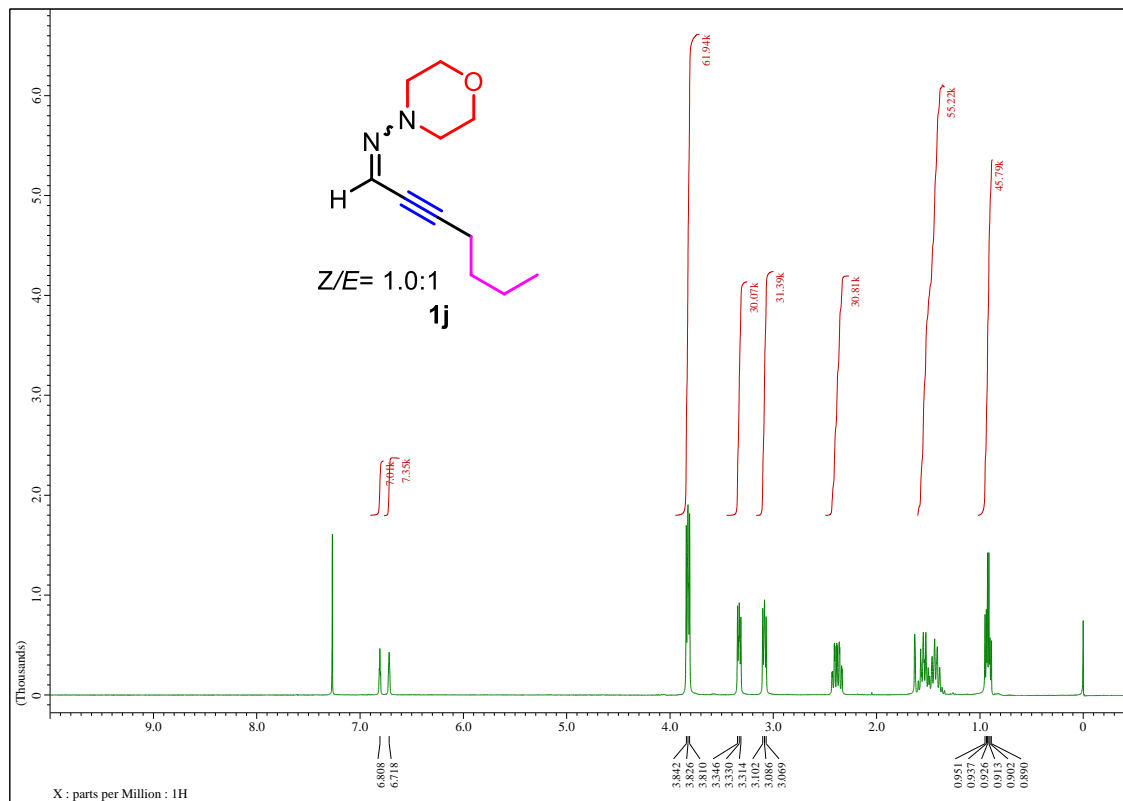
$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ) of **1i**



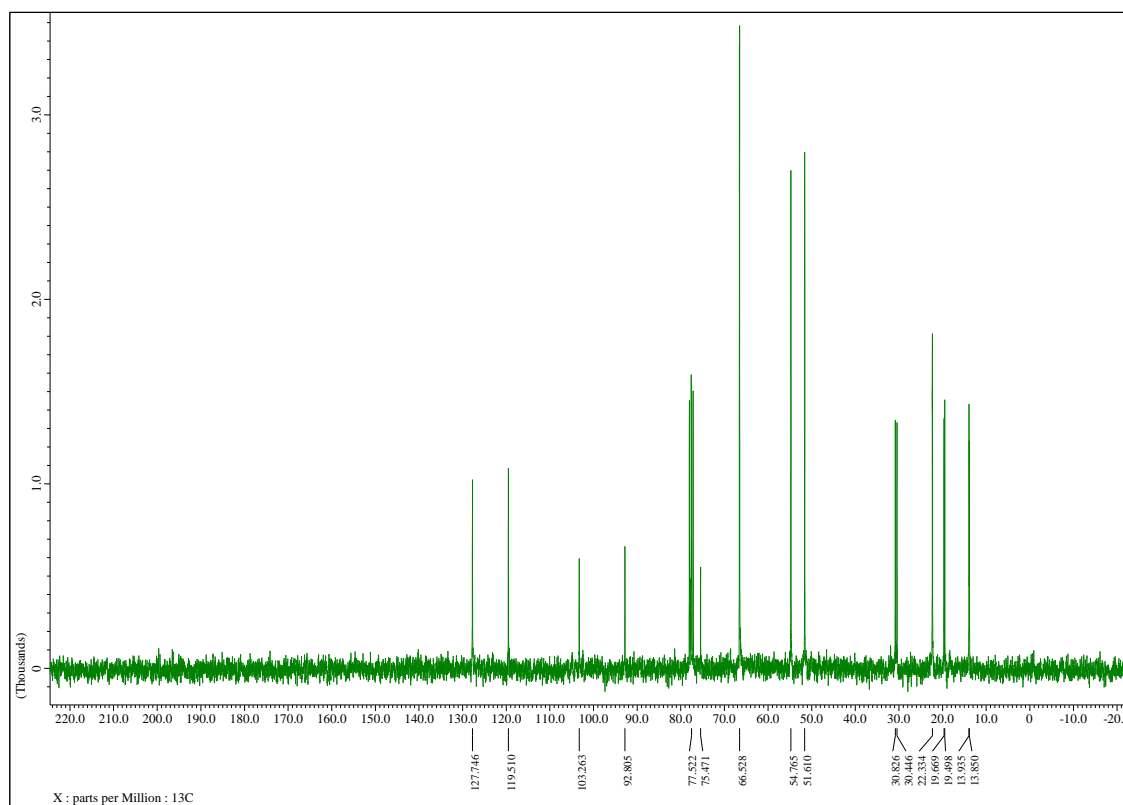
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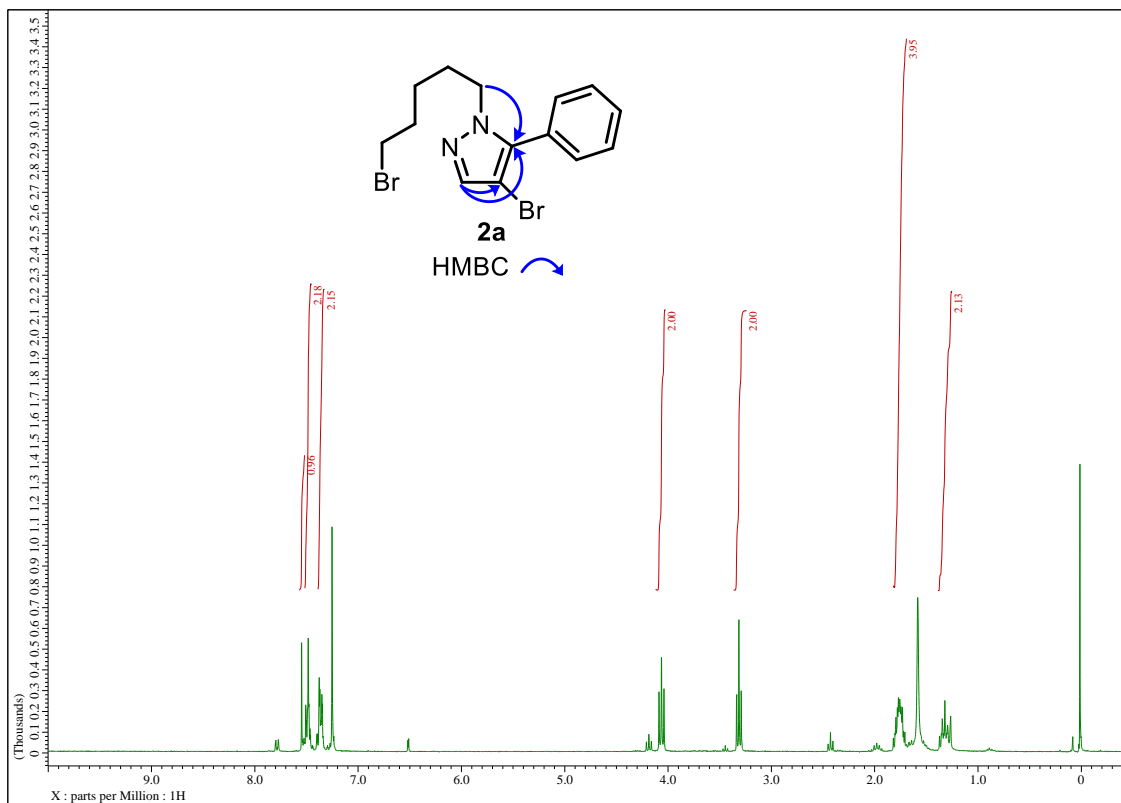
<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) of **1j**



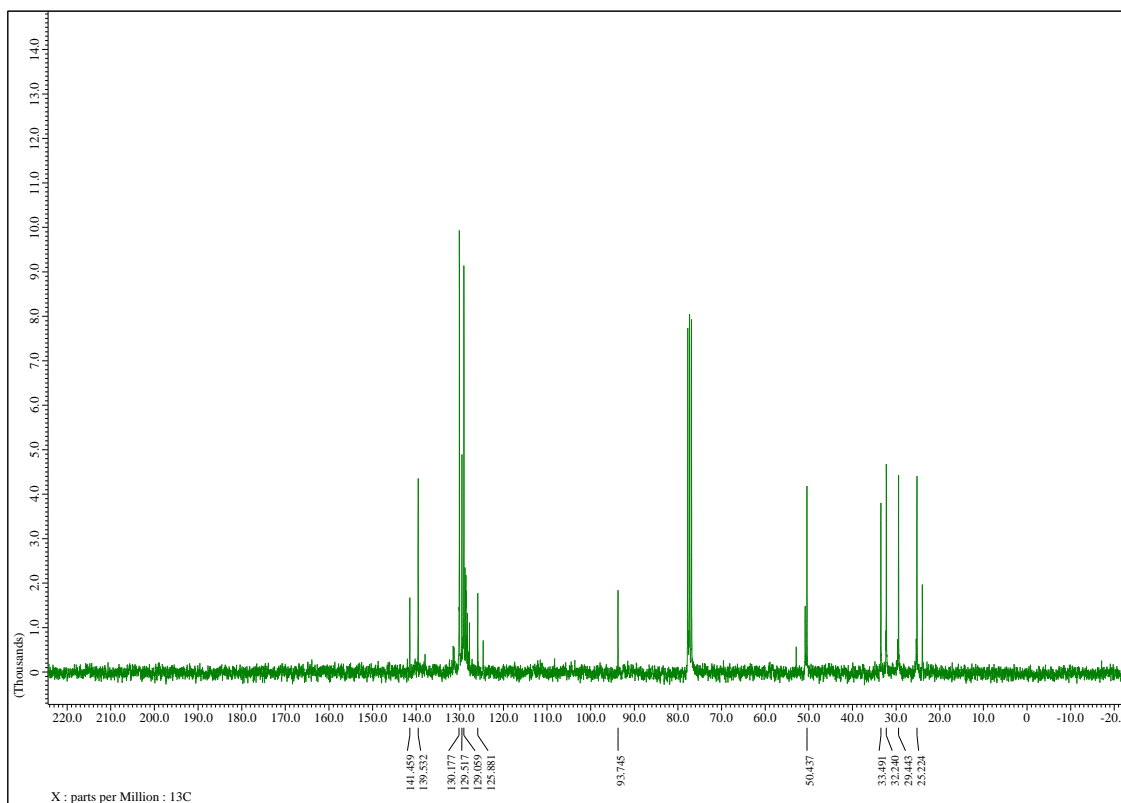
<sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) of **1j**



$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ) of **2a**



$^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ ) of **2a**



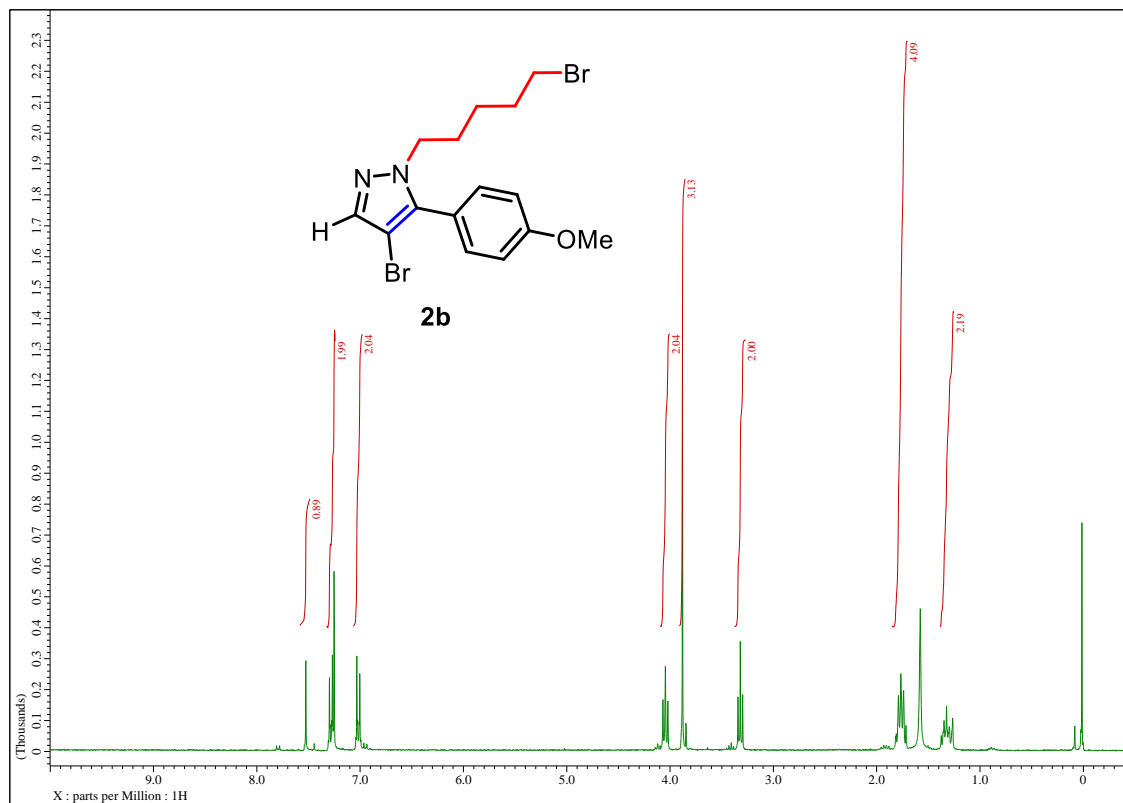




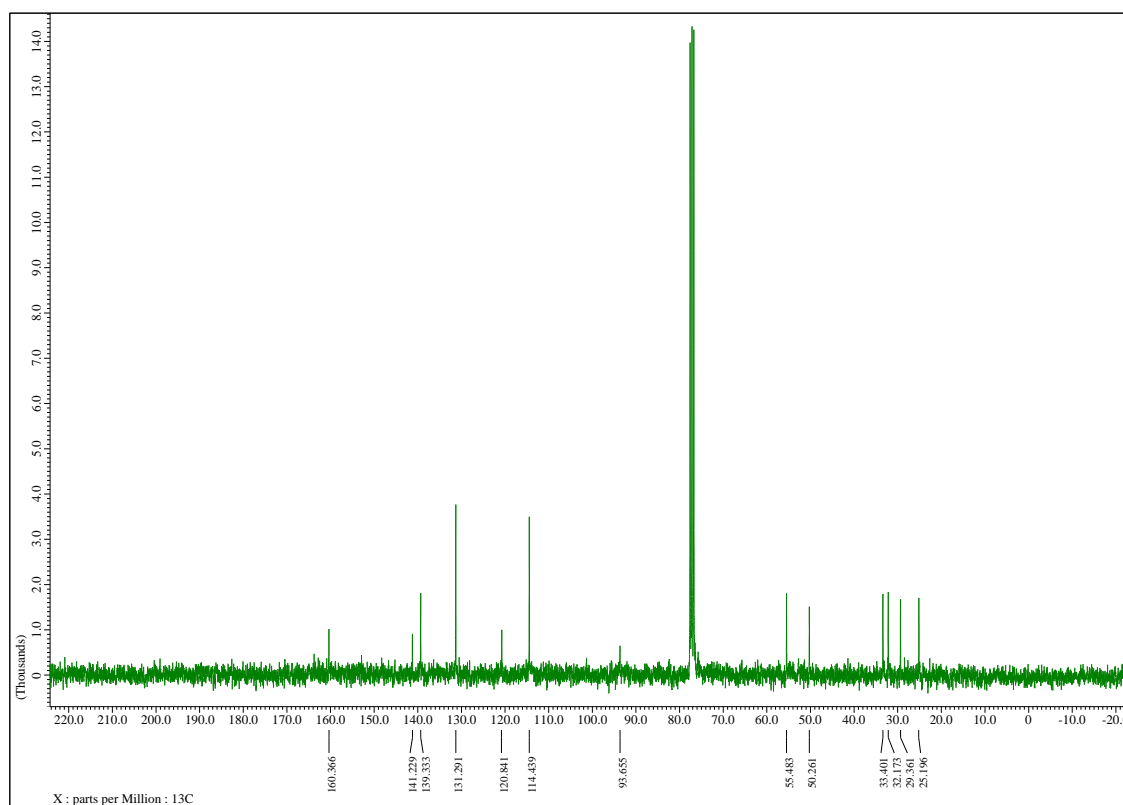




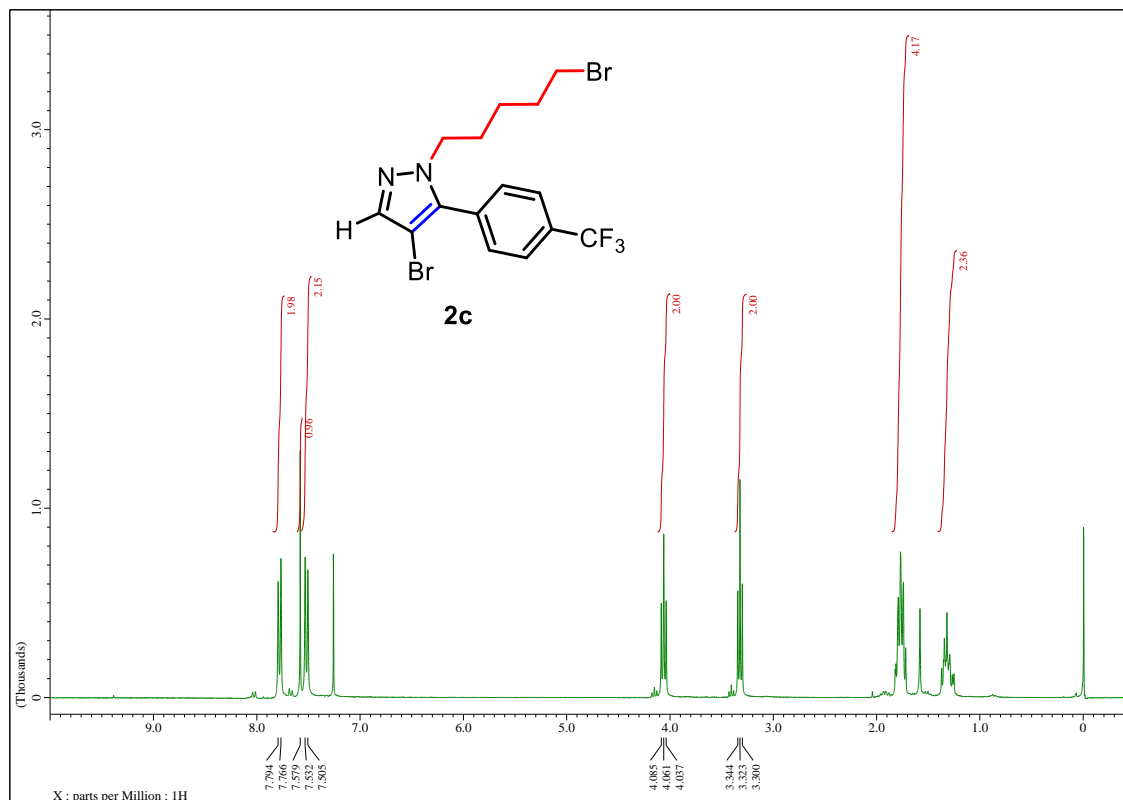
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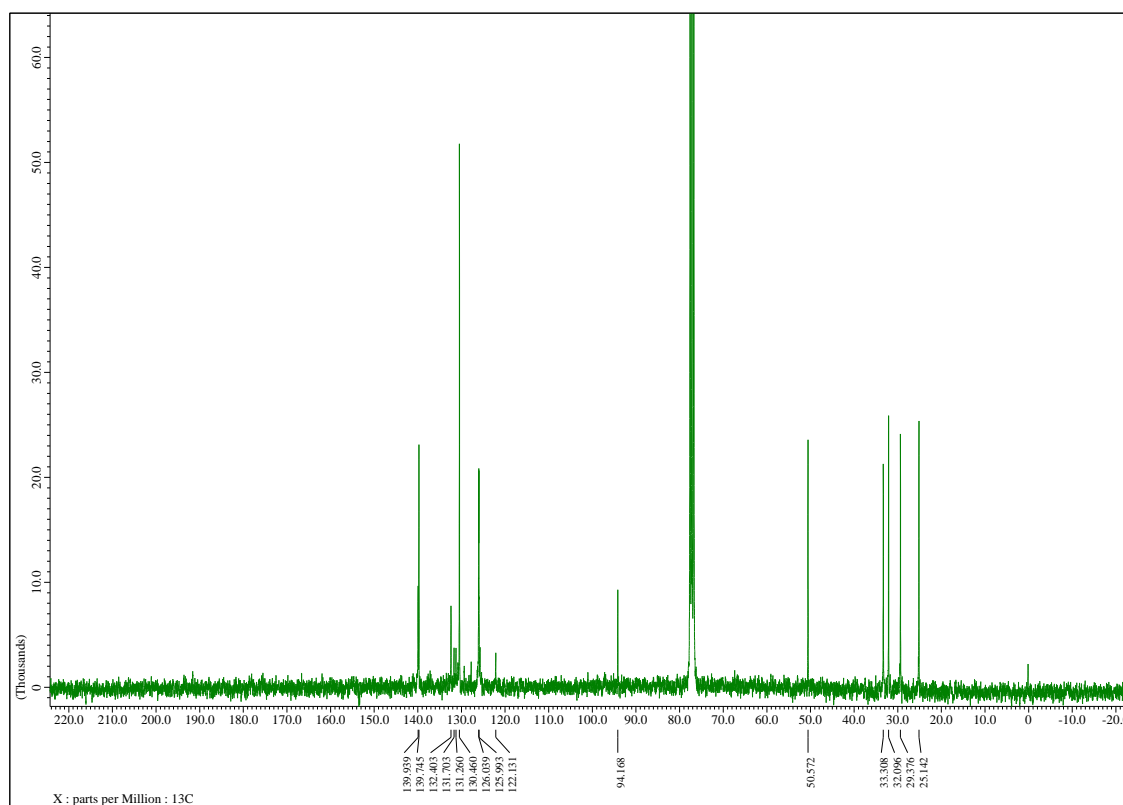
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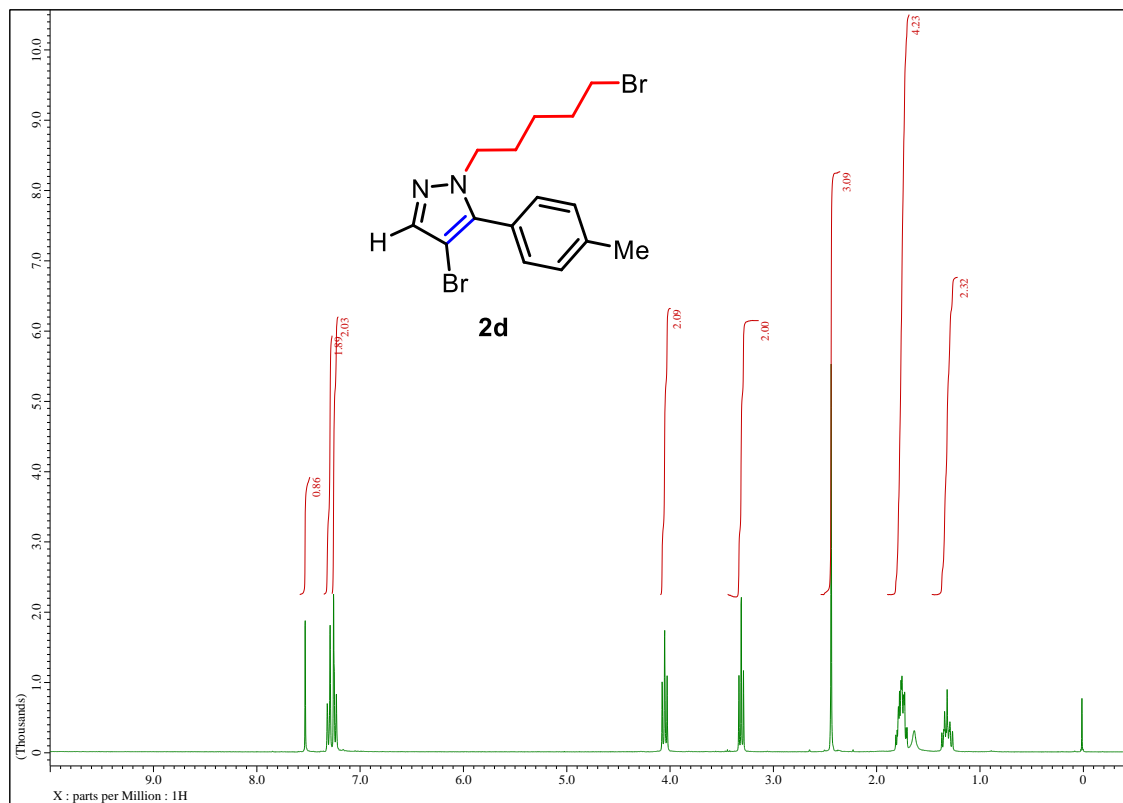
<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) of **2c**



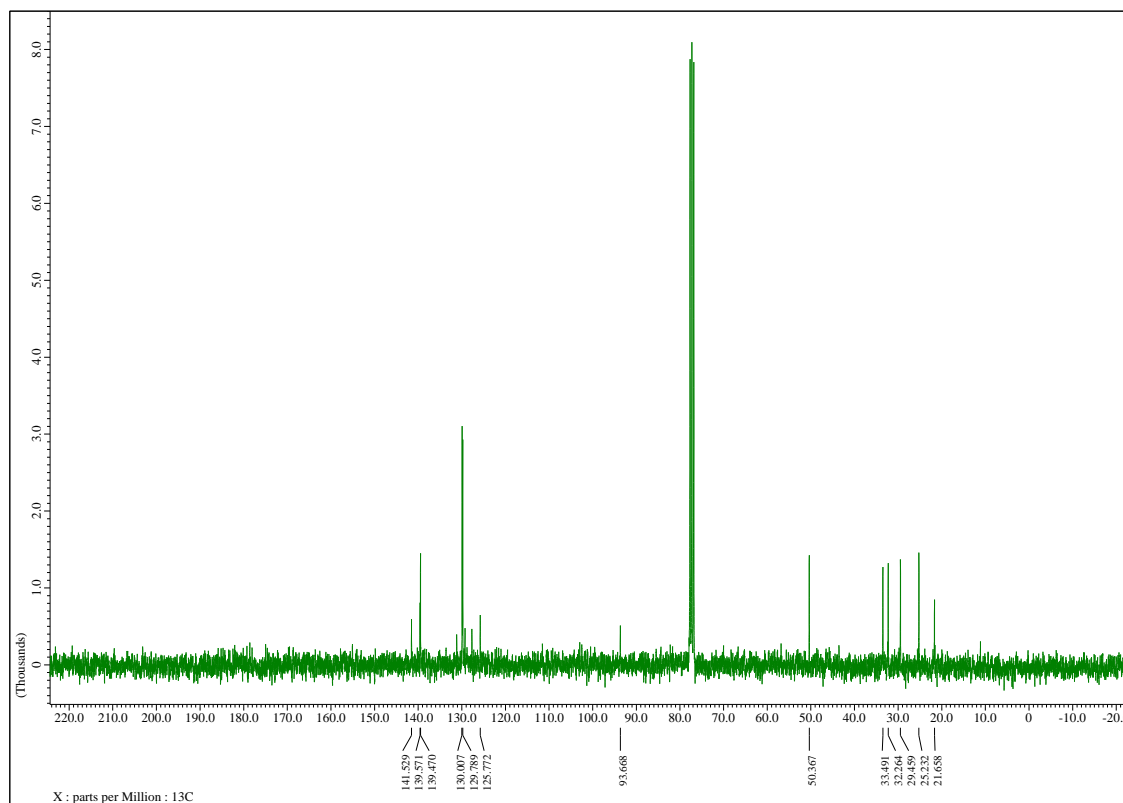
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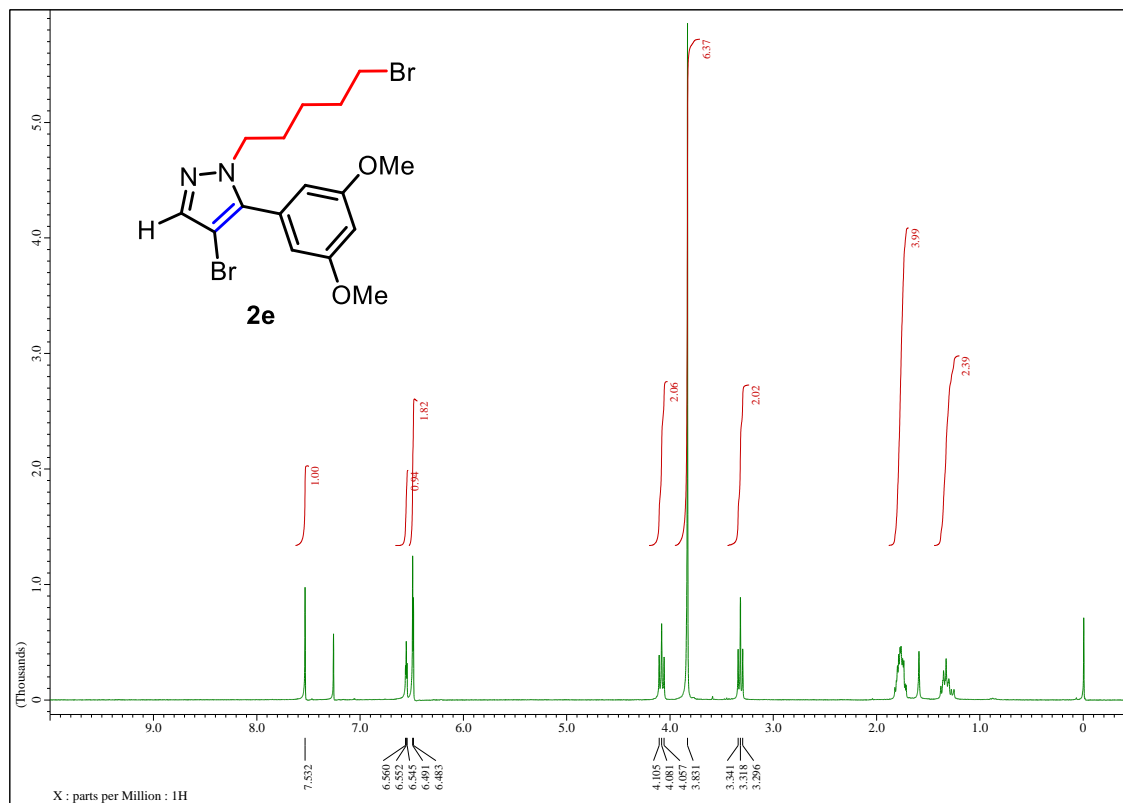
<sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) of **2d**



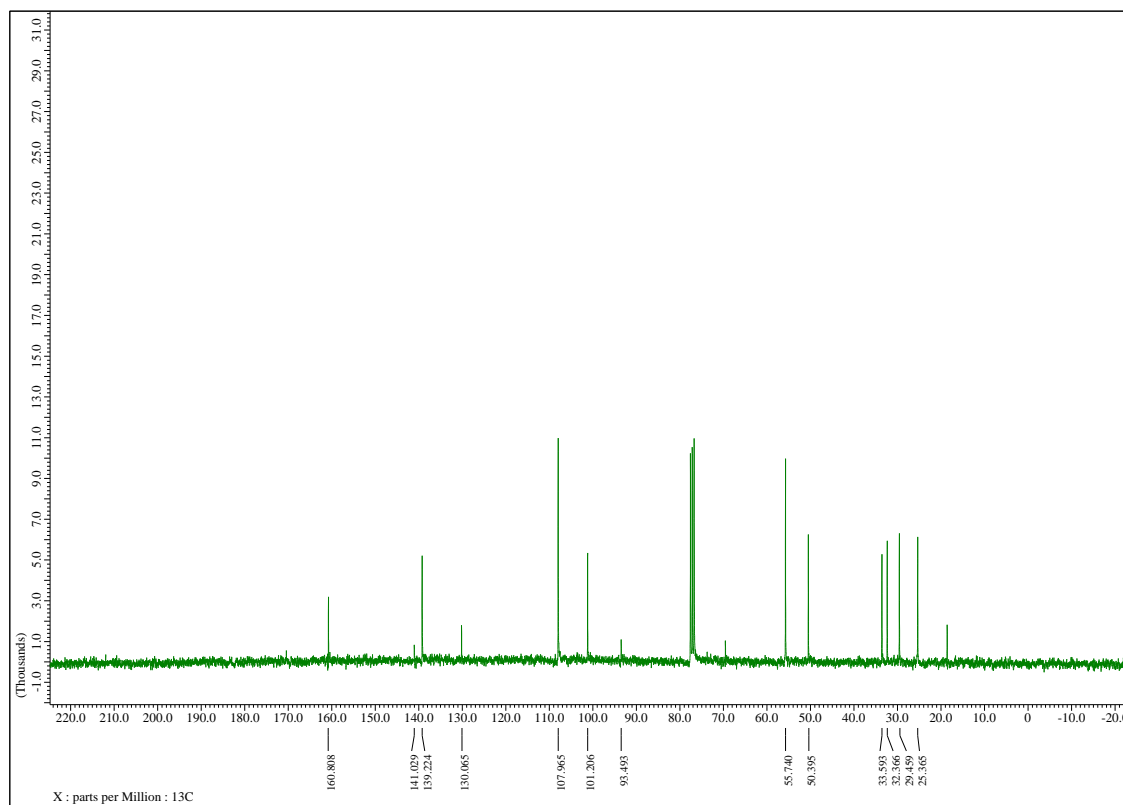
<sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) of **2d**



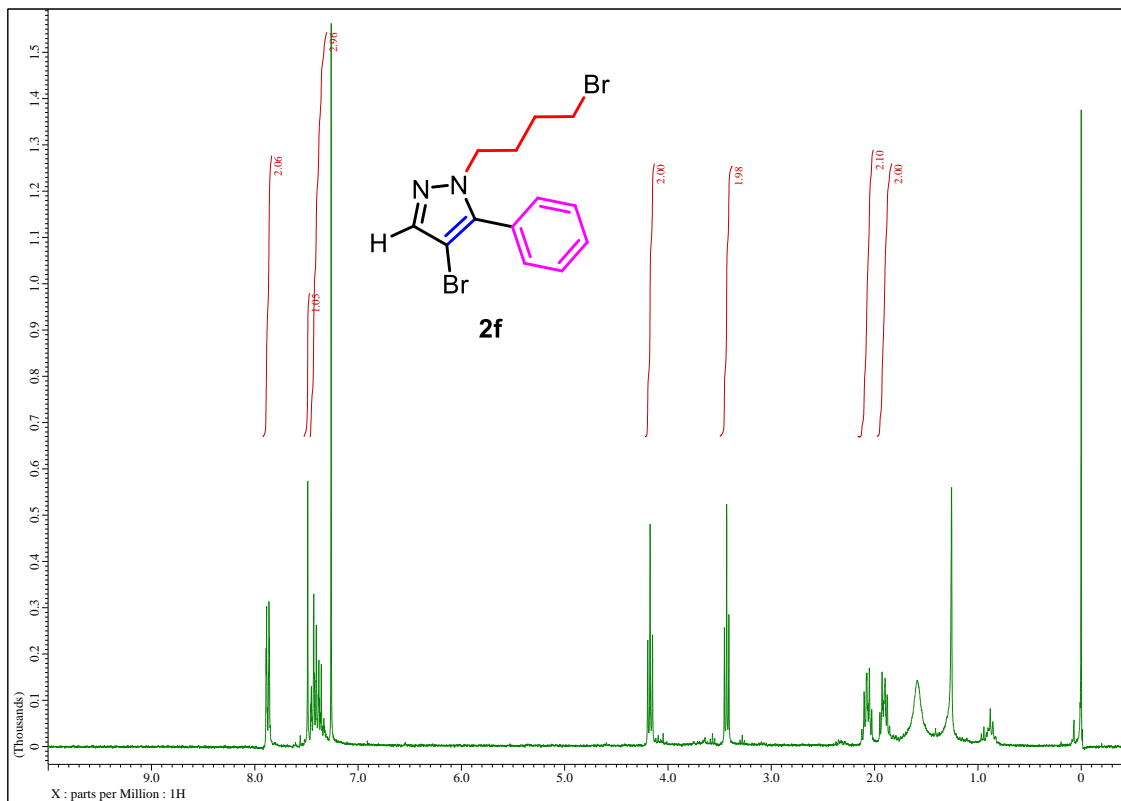
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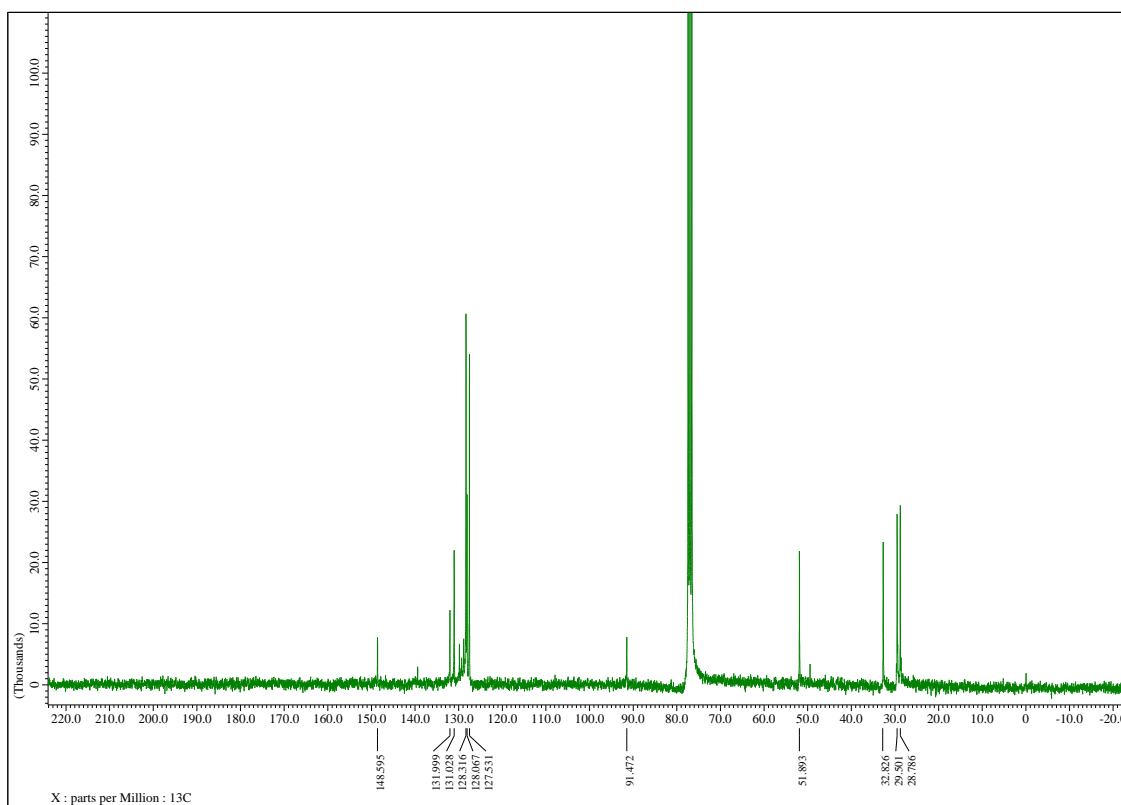
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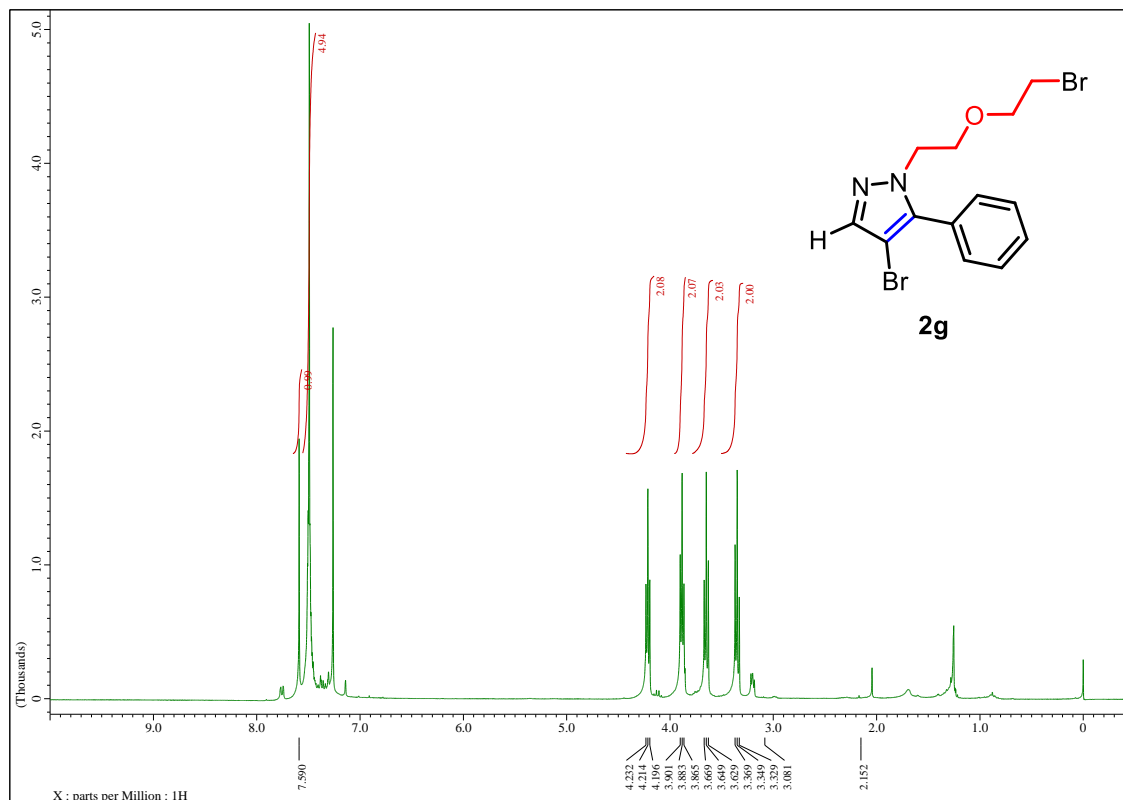
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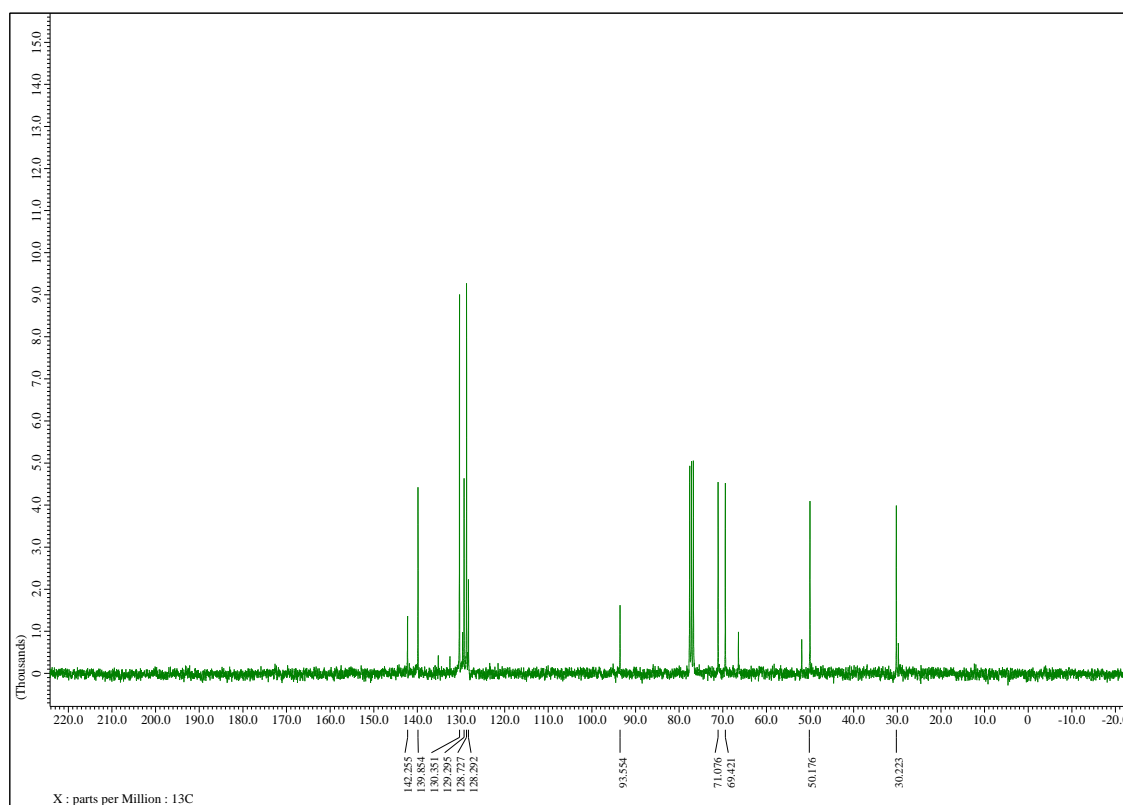
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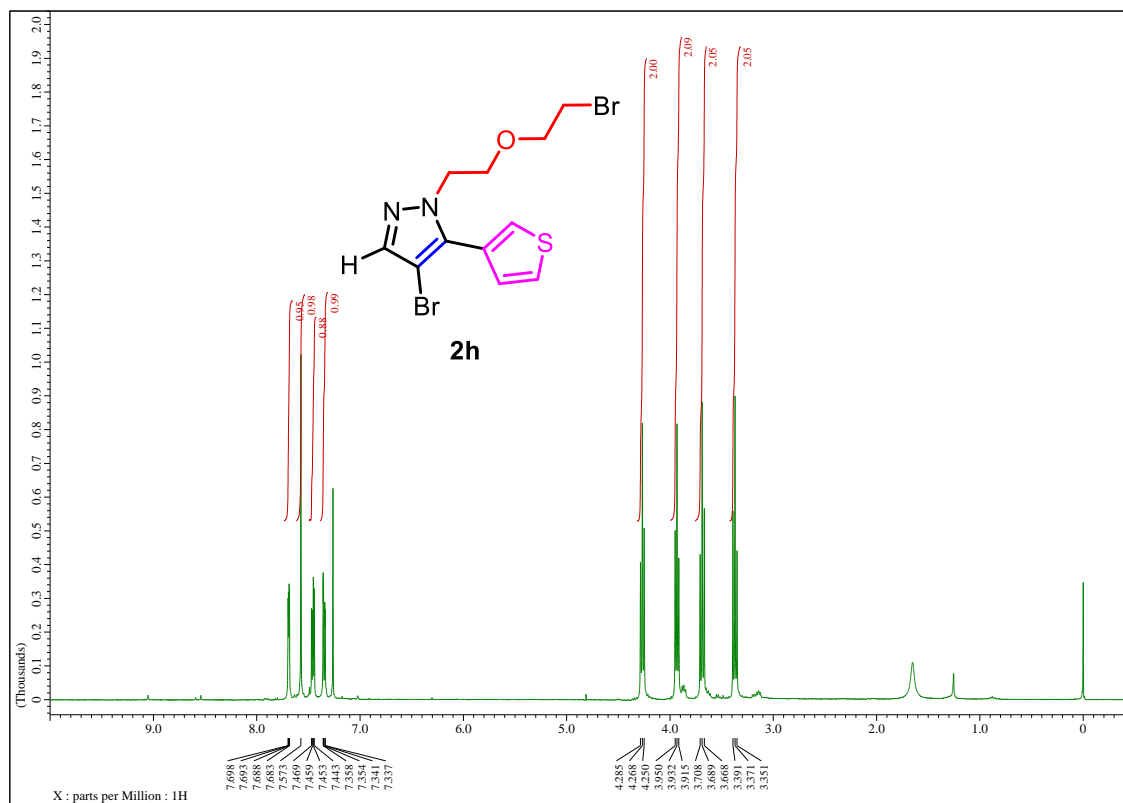
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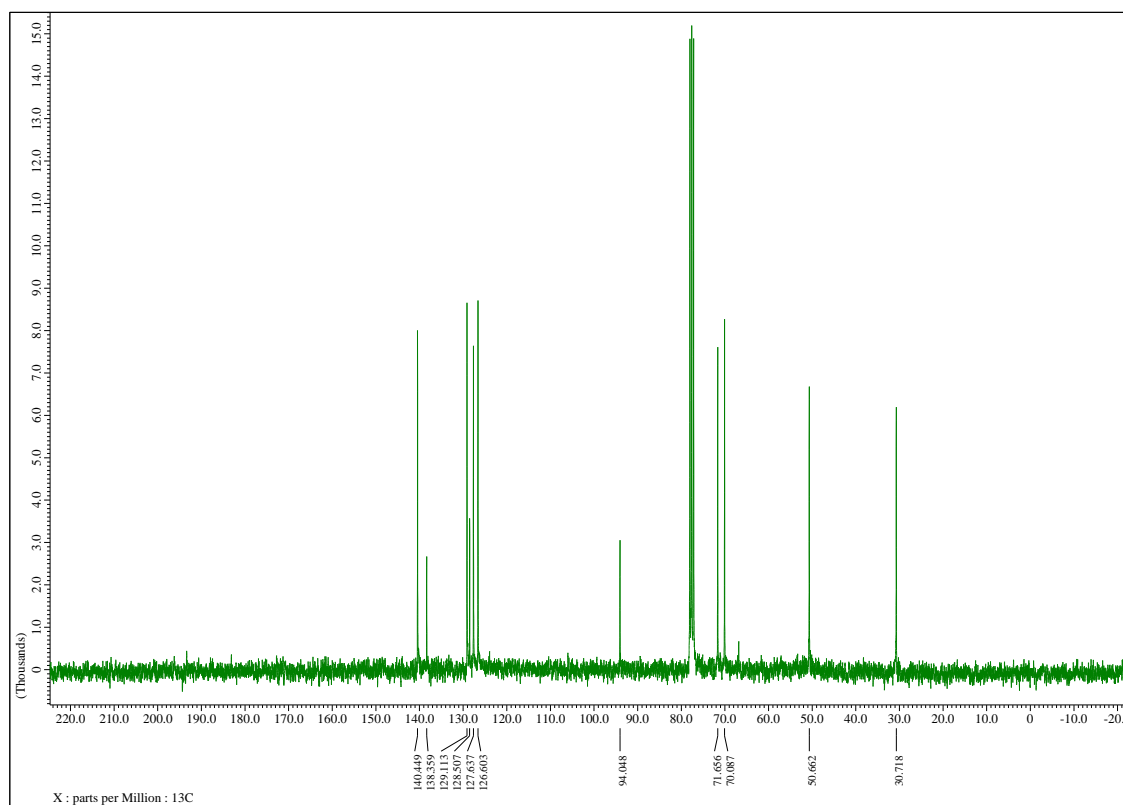
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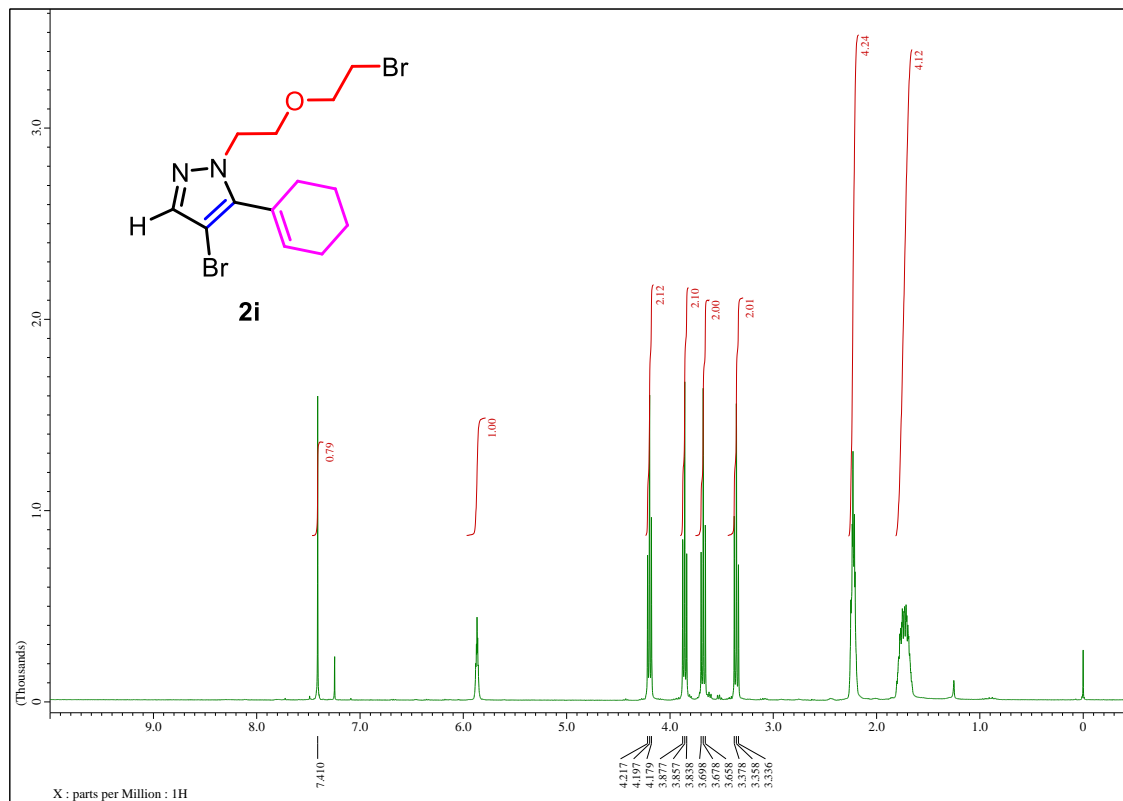
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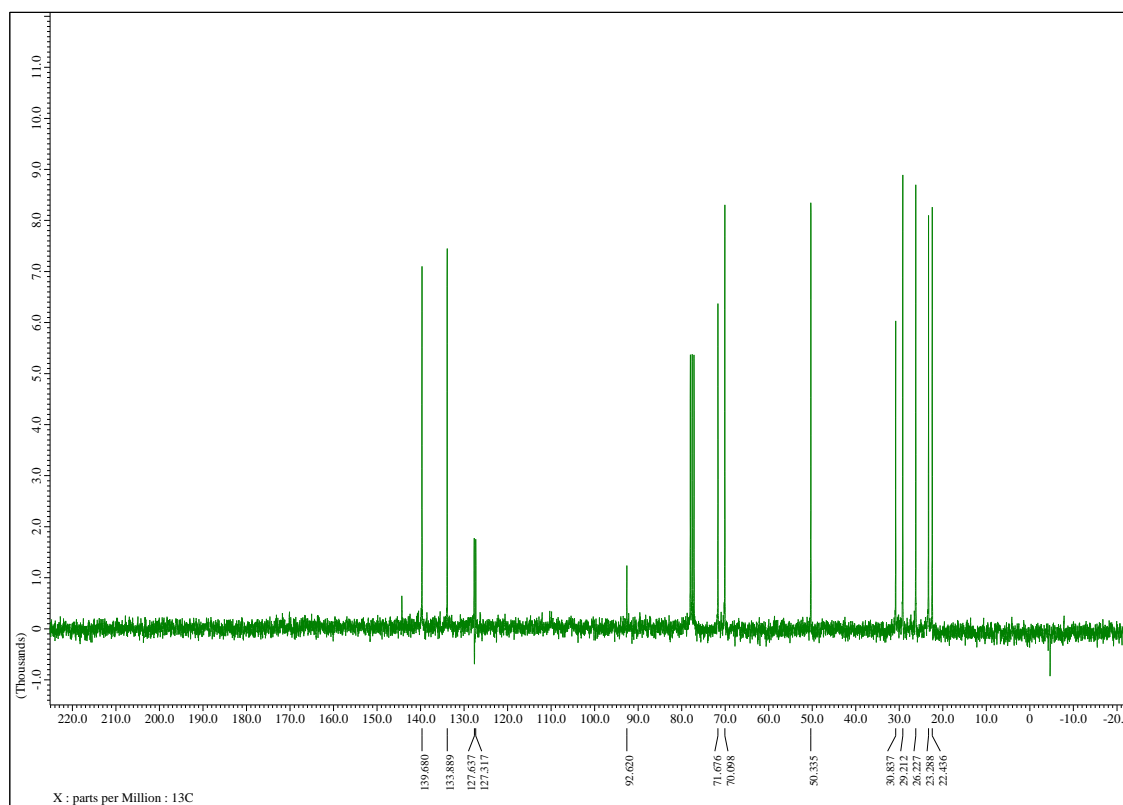
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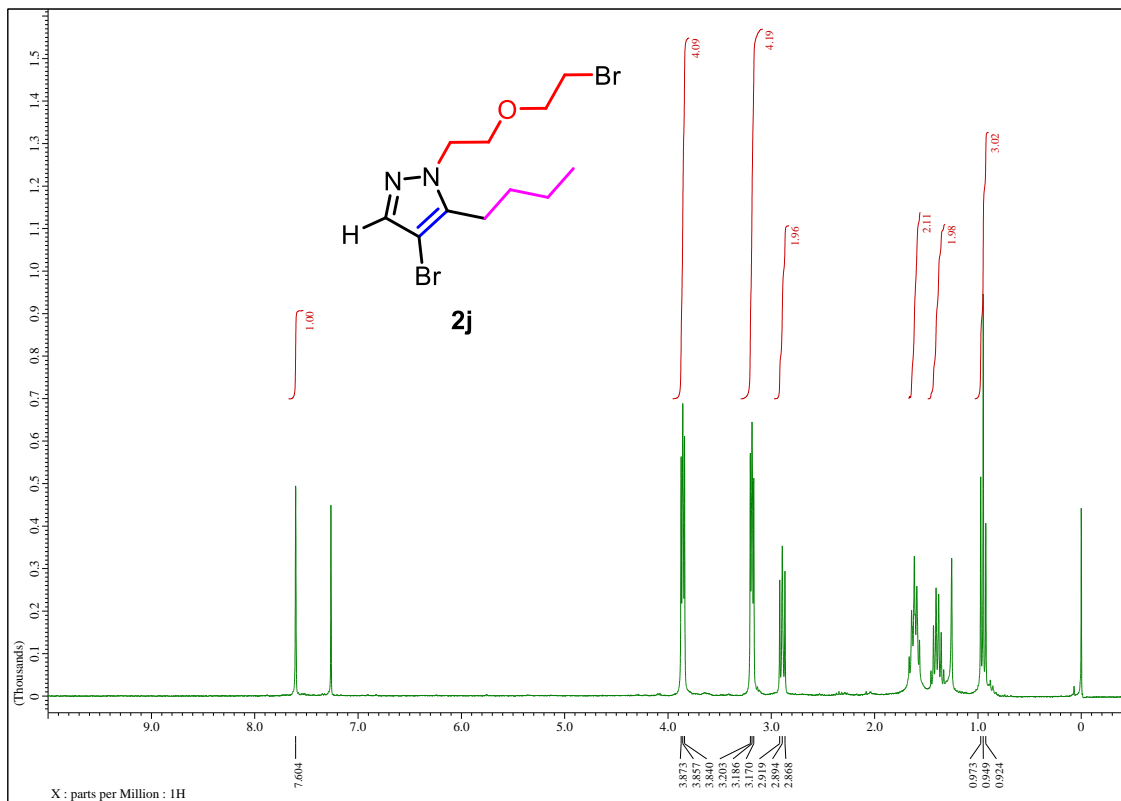
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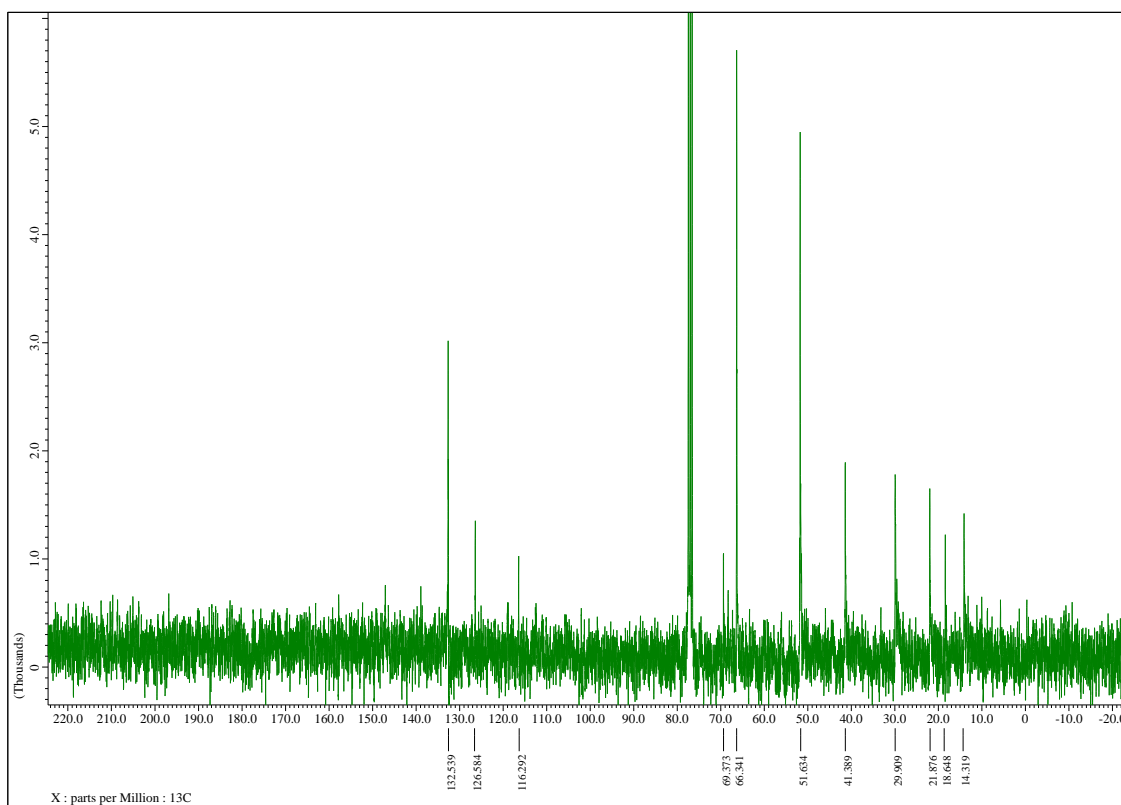
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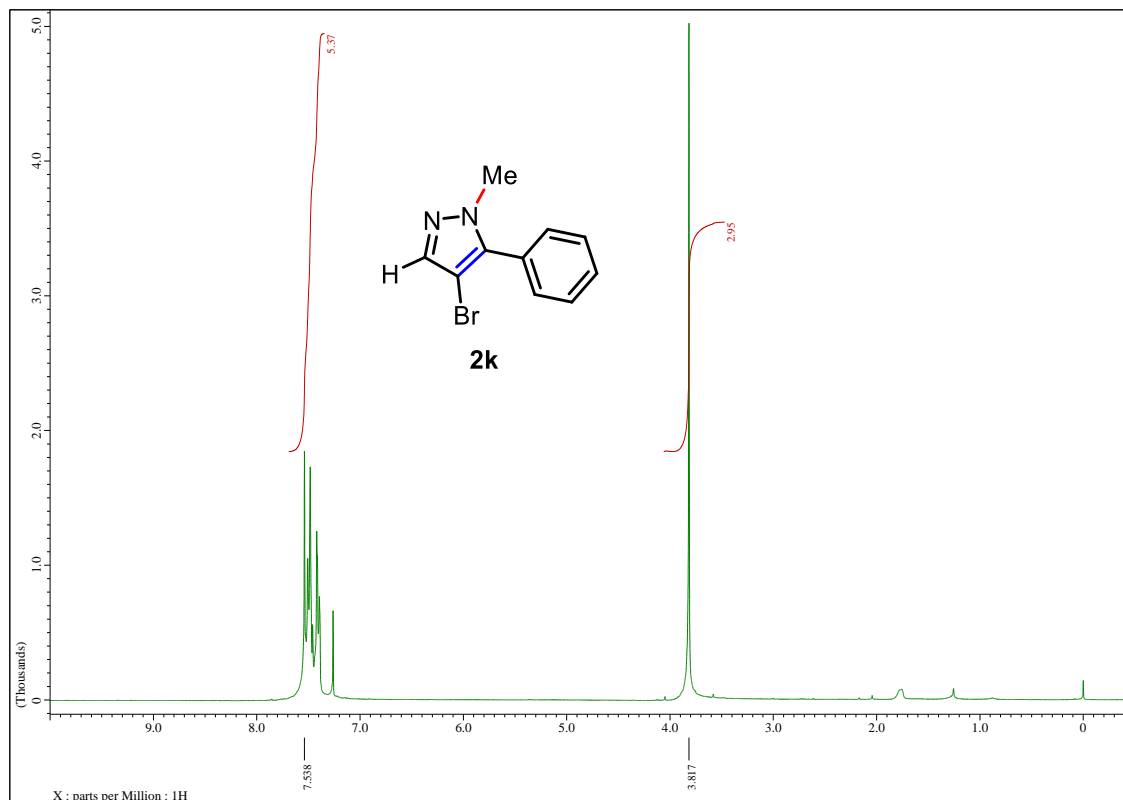
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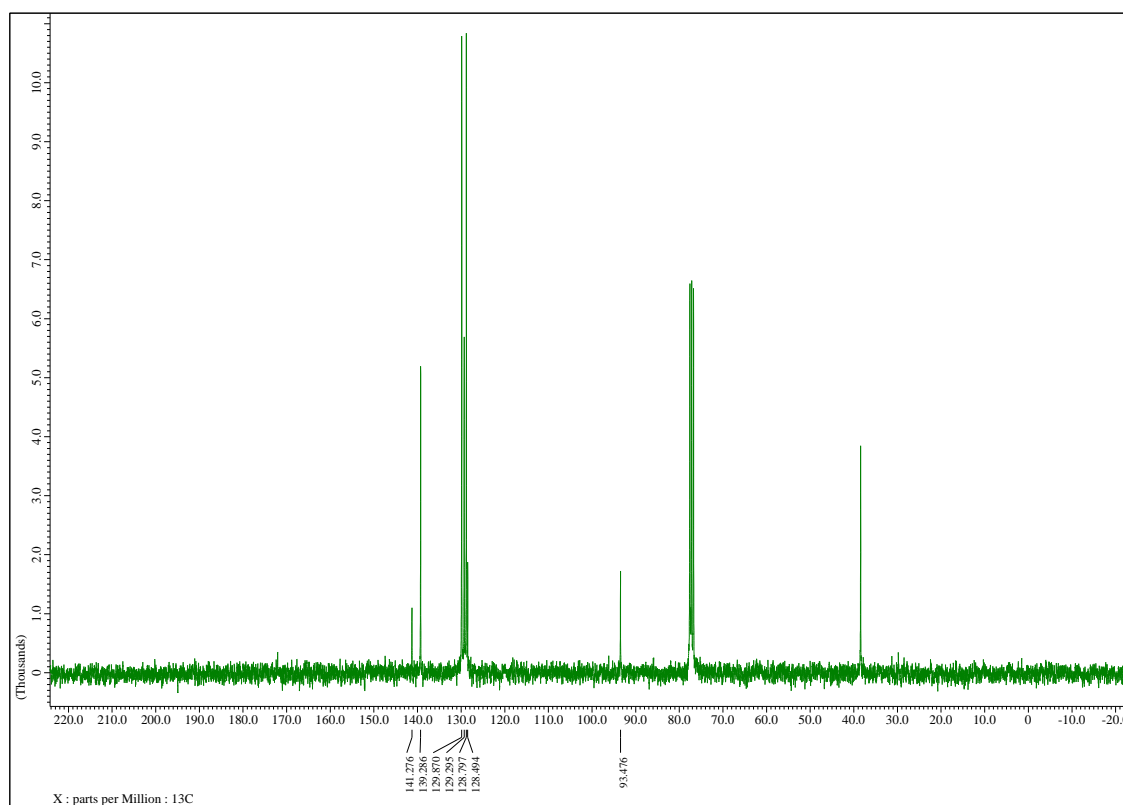
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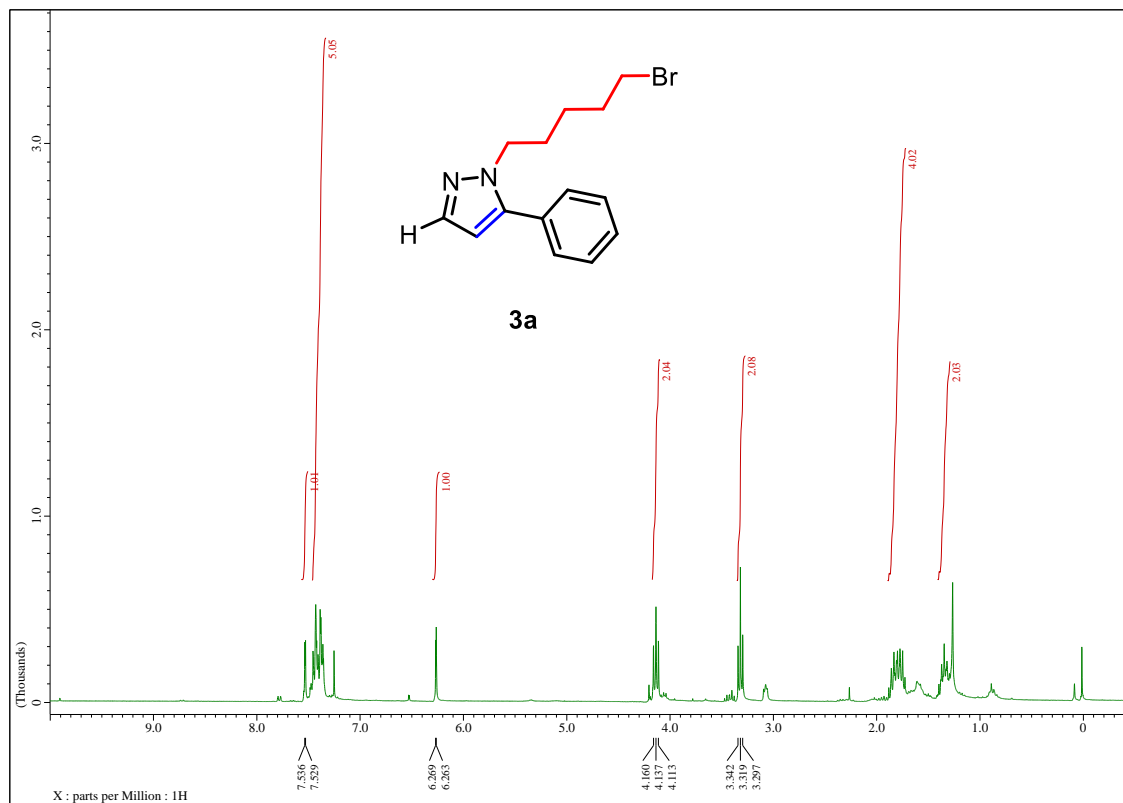
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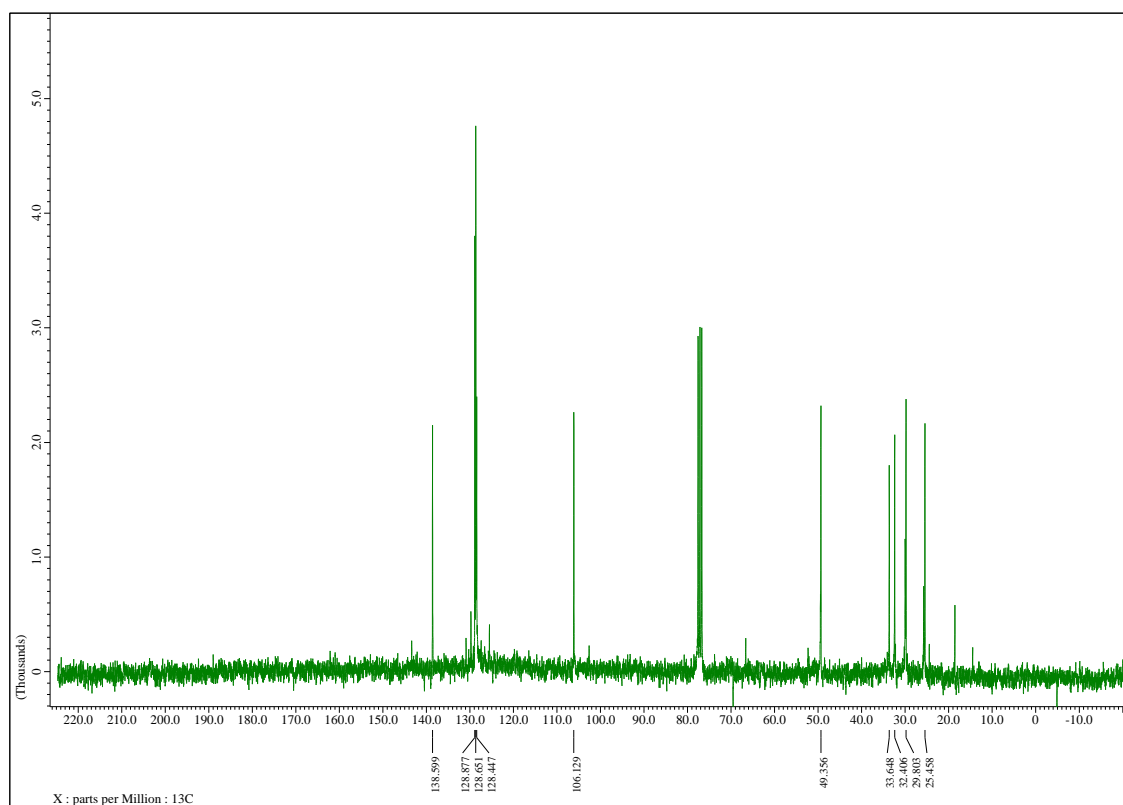
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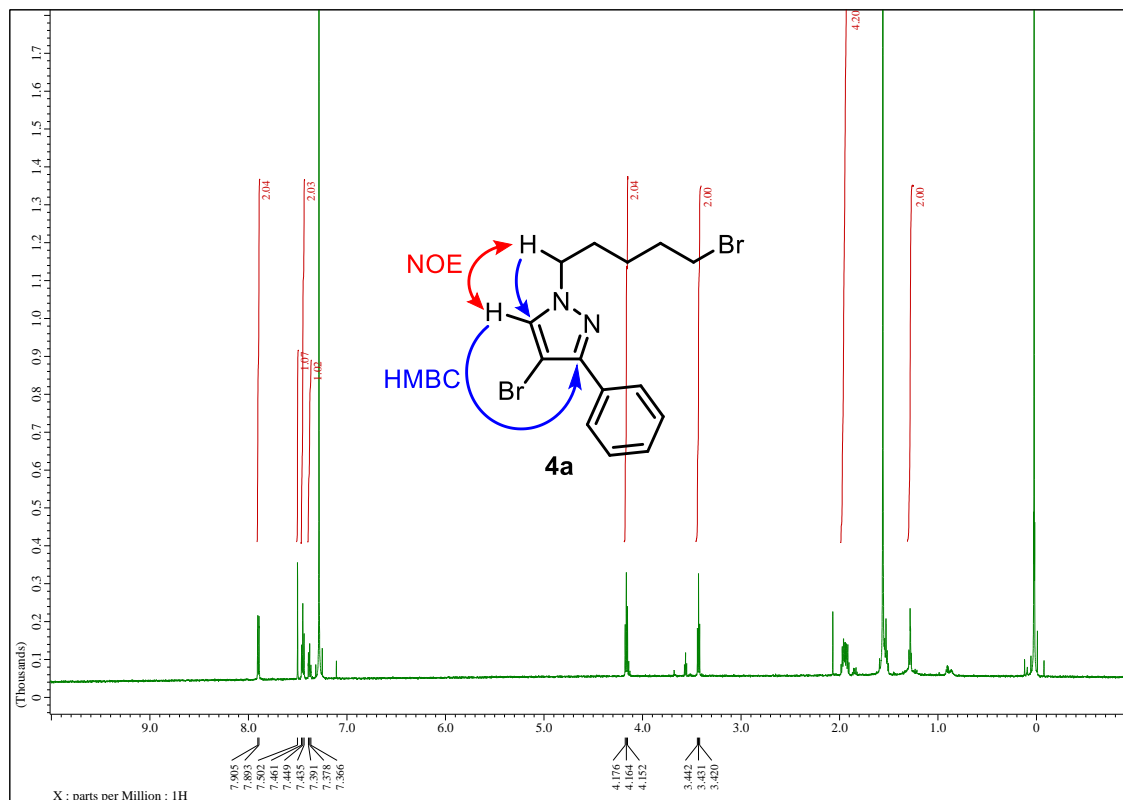
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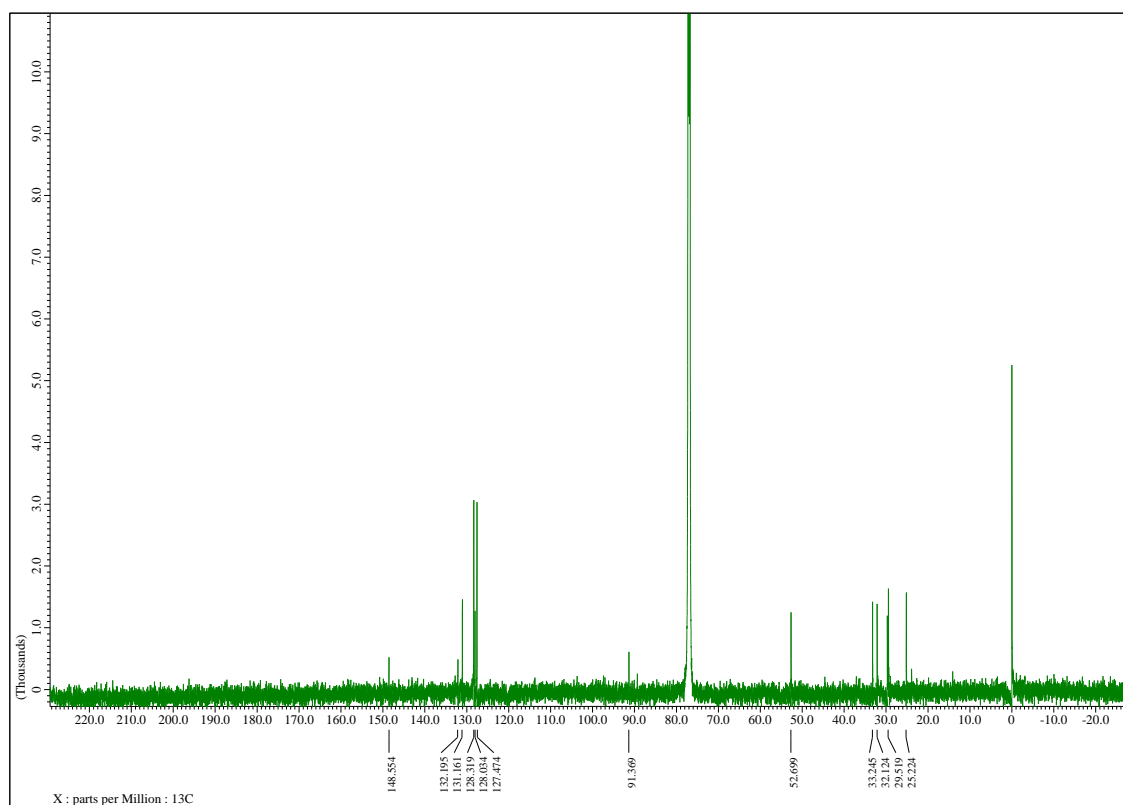
<sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) of **3a**



<sup>1</sup>H NMR (600 MHz, CDCl<sub>3</sub>) of **4a**



<sup>13</sup>C NMR (150 MHz, CDCl<sub>3</sub>) of **4a**



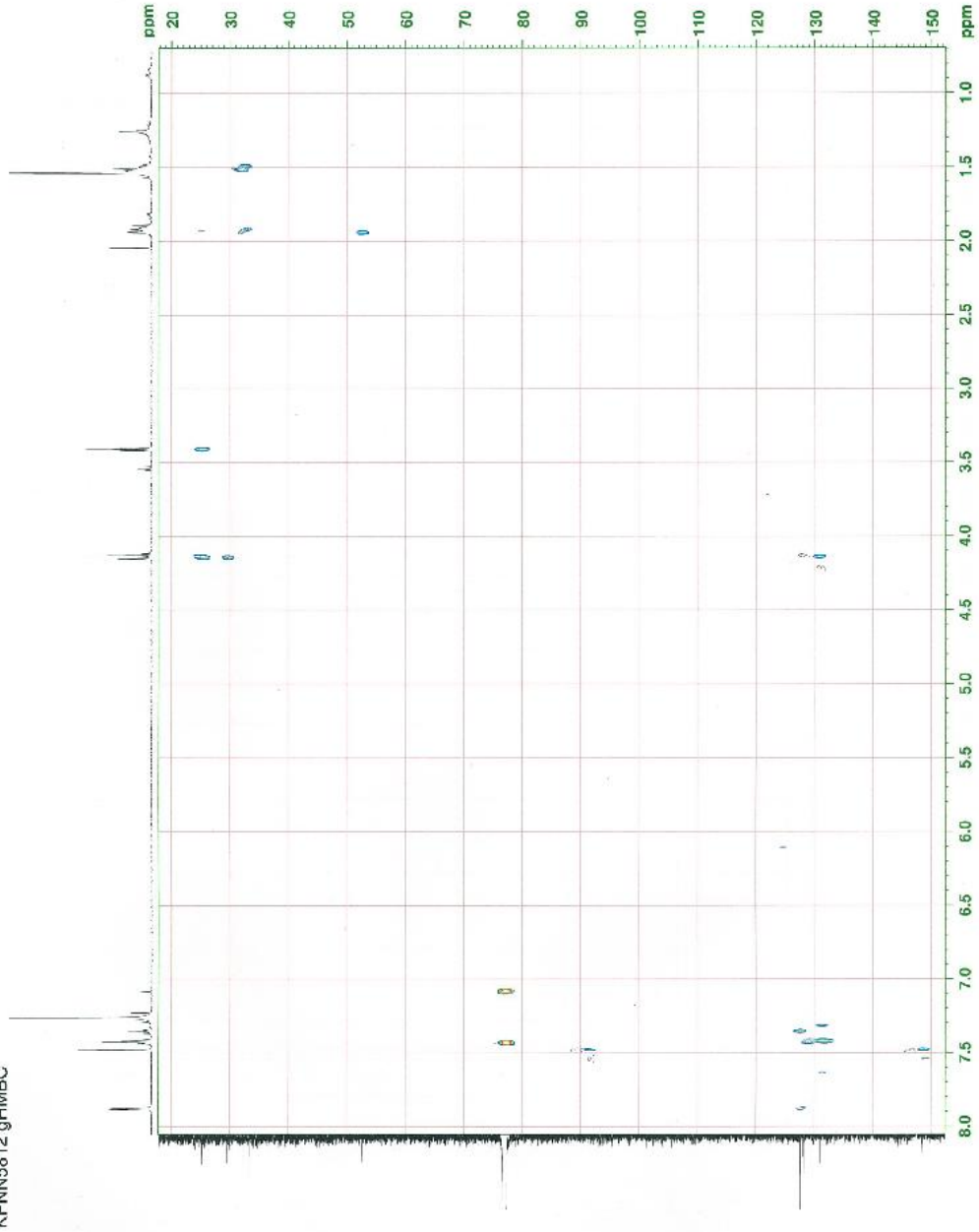




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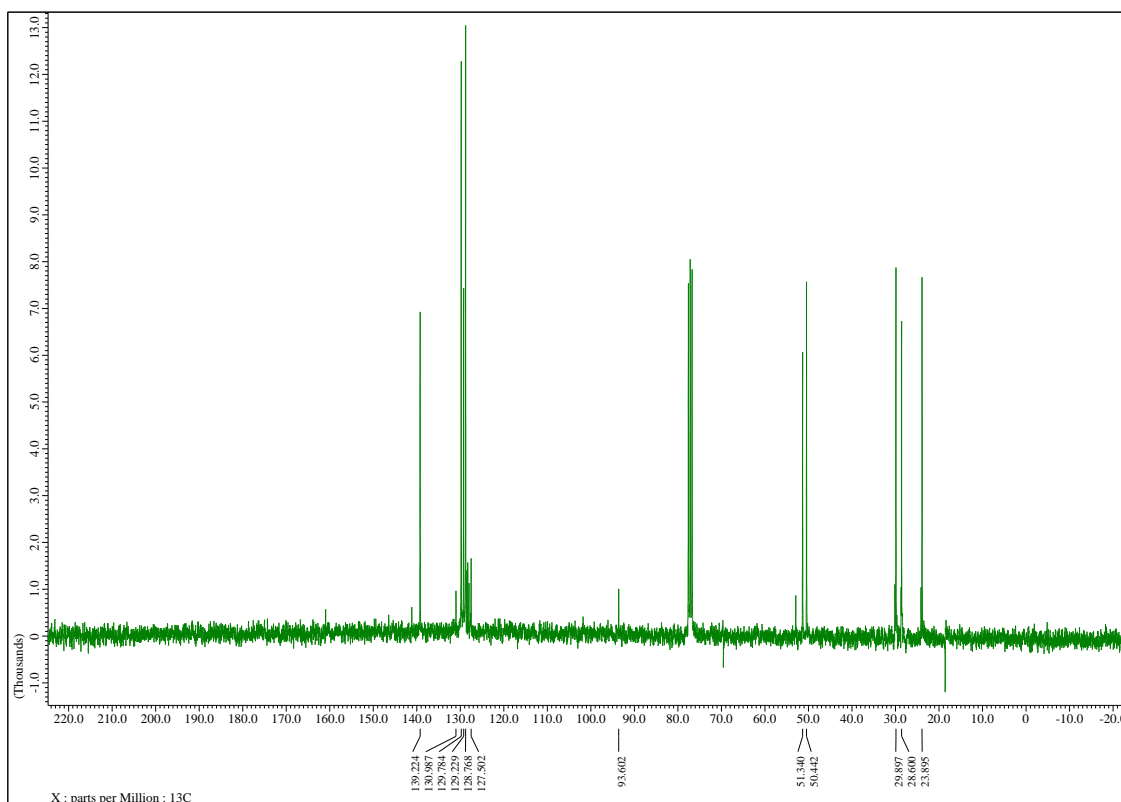
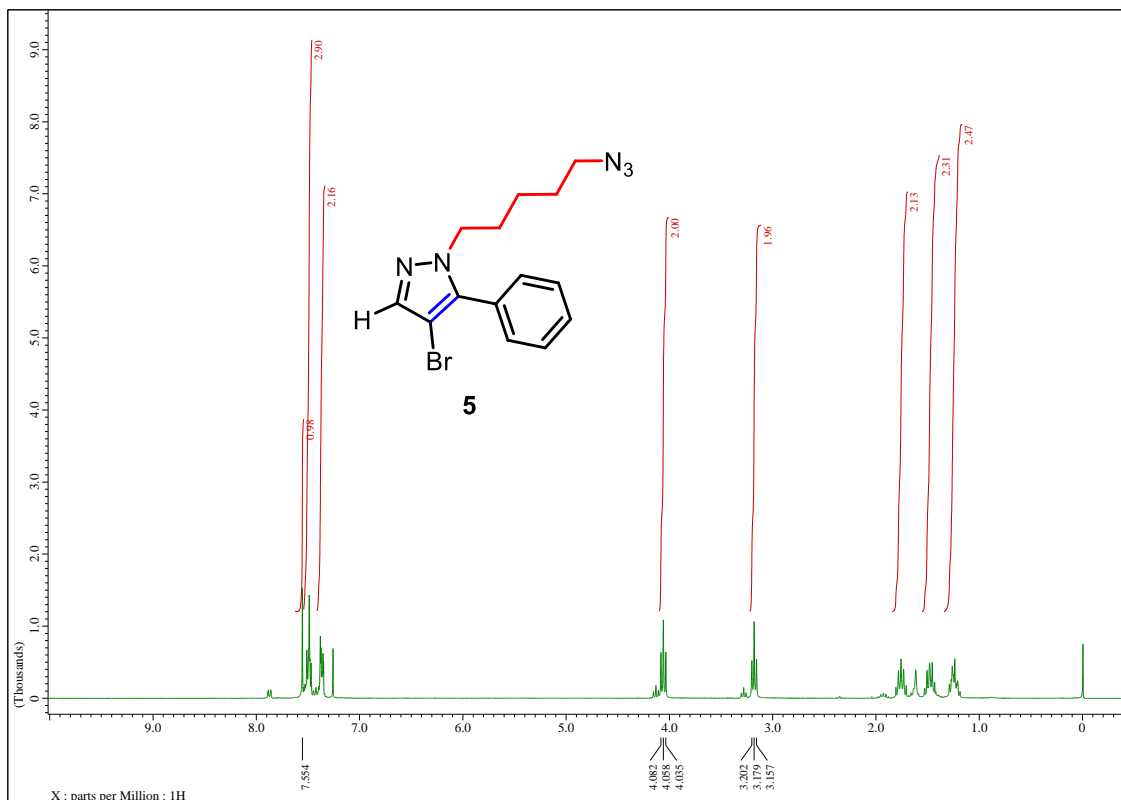
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$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ) of **5**



$^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ) of **6**

