Nitrene Equivalents Mediated Metal-Free Ring Expansions of Alkylidenecyclopropanes and an Alkylidenecyclobutane

Yong Liang, Lei Jiao, Yuanyuan Wang, Yuanyuan Chen, Linge Ma, Jiaxi Xu, Shiwei Zhang, and Zhi-Xiang Yu*

Key Laboratory of Bioorganic Chemistry and Molecular Engineering of Ministry of Education, Beijing National Laboratory for Molecular Sciences, College of Chemistry, Peking University, Beijing 100871, China

yuzx@pku.edu.cn

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Experimental Details

General. *N*−aminophthalimide,[1] ACPs (**1**, **3**, **5**, **7**, **9**, **11**, **13**, and **15**),[2] and ACB **21**[3] were prepared according to literature procedures. Dichloromethane and acetonitrile were refluxed with CaH_2 and freshly distilled prior to use.

General Procedure for Metal−Free Ring Expansions of ACPs and ACBs. To a solution of ACP or ACB (1 mmol) in 20 mL CH_2Cl_2 was added *N*−aminophthalimide (1.5 mmol) and (diacetoxyiodo)benzene (1.5 mmol) successively. After stirred at room temperature for 2 hours, the reaction mixture was submitted to vacuum to remove the solvent. Column chromatography of the resulting crude mixture on silica gel afforded the corresponding products.

General Procedure for Copper−Catalyzed Ring Expansions of ACPs. To a solution of ACP (0.5 mmol) in 10 mL MeCN was added PhI=NTs (0.75 mmol) and $Cu(acac)_2$ (0.05 mmol) successively. After stirred at room temperature for 2 hours, the reaction mixture was submitted to vacuum to remove the solvent. Column chromatography of the resulting crude mixture on silica gel afforded the corresponding products.

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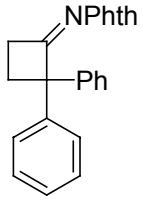
(1) Christine, T. S.; Picard, J.; Yudin, A. K. *J. Org. Chem.* **2005**, *70*, 932−937.

(2) Utimoto, K.; Tamura, M.; Sisido, K. *Tetrahedron* **1973**, *29*, 1169−1171. ACP **7** was prepared by acetylization of (*o*−Aminophenyl)phenylmethylenecyclopropane, which was obtained according to the literature method. Spectroscopic data for unknown substrates: ACP **7**: ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.21 (t, J = 7.8 Hz, 2H), 1.65 (t, J = 7.8 Hz, 2H), 1.78 (s, 3H), 6.98 (br, 1H), 7.14−7.47 (m, 8H), 8.22 (d, J = 8.4 Hz, 1H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 2.0, 5.6, 24.4, 121.5, 124.2, 126.3, 126.5, 127.5, 127.6, 128.2, 128.7, 130.4, 130.9, 135.6, 139.0, 168.0. ACP **11**: ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.15−1.37 (m, 7H), 2.34 (s, 3H), 2.57 (t, J = 7.8 Hz, 2H), 2.98 (t, J = 7.8 Hz, 2H), 4.12 (q, J = 7.2 Hz, 2H), 7.16 (d, J = 8.1 Hz, 2H), 7.49 (d, J = 8.1 Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 1.4, 4,3, 14.2, 21.0, 29.2, 33.2, 60.3, 120.3, 125.5, 125.7, 128.9, 136.3, 136.7, 173.5. ACP **15**: ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.04 (t, J = 7.2 Hz, 2H), 1.43 (t, J = 7.2 Hz, 2H), 1.86 (m, 2H), 2.63 (m, 2H), 2.83 (t, J = 6.3 Hz, 2H), 7.09 (m, 3H), 7.92 (d, J = 7.2 Hz, 1H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ –0.4, 5.3, 23.2, 30.5, 31.5, 116.7, 125.1, 125.7, 126.2, 128.9, 133.3, 135.1, 136.7.

(3) Graham, S. H.; Williams, A. J. S. *J. Chem. Soc.* **1959**, 4066−4073.

The Spectroscopic Data for the Products

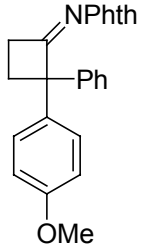
N−phthalyl−2, 2−diphenylcyclobutylidene hydrazine (2)



E−isomer (isolated yield: 21%): white solid (R_f = 0.18, PE/AcOEt = 5:1), m.p. 176−178 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.86 (t, J = 8.1 Hz, 2H), 3.04 (t, J = 8.1 Hz, 2H), 7.21−7.38 (m, 6H), 7.57−7.60 (m, 4H), 7.72−7.77 (m, 2H), 7.86−7.89 (m, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 29.5, 33.2, 64.6, 123.5, 126.8, 127.0, 128.5, 131.0, 134.2, 143.5, 163.7, 183.8. IR v (cm^{-1}): 1719, 1730. MS (EI) m/z: 366 (M^+, 26), 220 (47), 186 (65), 180 (76), 165 (100). Calcd for $C_{24}H_{18}N_2O_2$: C, 78.67; H, 4.95; N, 7.65. Found: C, 78.53; H, 4.96; N, 7.55.

Z−isomer[4] (isolated yield: 59%): white solid (R_f = 0.11, PE/AcOEt = 5:1), m.p. 177−179 °C. ^{1}H NMR (300 MHz, DMSO−*d*6): δ 2.71 (t, J = 8.1 Hz, 2H), 3.14 (t, J = 8.1 Hz, 2H), 7.04−7.20 (m, 10H), 7.53−7.56 (m, 2H), 7.66−7.69 (m, 2H). ^{13}C NMR (75.5 MHz, DMSO−*d*6): δ 28.7, 32.5, 69.6, 122.7, 126.8, 128.0, 128.2, 129.9, 134.1, 141.3, 162.9, 183.8. IR v (cm^{-1}): 1724. MS (EI) m/z: 366 (M^+, 34), 220 (37), 186 (72), 180 (95), 165 (69). Calcd for $C_{24}H_{18}N_2O_2$: 366.1368. Found: 366.1359.

N−phthalyl−2−(4−methoxyphenyl)−2−phenylcyclobutylidene hydrazine (4)



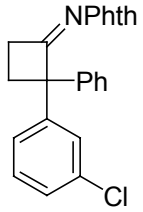
E−isomer (isolated yield: 43%): colorless oil (R_f = 0.13, PE/AcOEt = 5:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.81 (t, J = 8.4 Hz, 2H), 3.03 (t, J = 8.4 Hz, 2H), 3.77 (s, 3H), 6.86−6.89 (m, 2H), 7.22−7.57 (m, 7H), 7.70−7.74 (m, 2H), 7.84−7.87 (m, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 29.6, 33.1, 55.2, 64.0, 113.8, 123.4, 126.7, 127.0, 128.2, 128.4, 130.9, 134.1, 135.7, 143.8, 158.3, 163.7, 184.2. IR v (cm^{-1}): 1720. MS (EI) m/z: 396 (M^+, 13), 250 (100), 210 (80). Calcd for $C_{25}H_{20}N_2O_3$: 396.1474. Found: 396.1472.

Z−isomer (isolated yield: 55%): white solid (R_f = 0.06, PE/AcOEt = 5:1), m.p. 153−155 °C. ^{1}H NMR (300 MHz, DMSO−*d*6): δ 2.58−2.78 (m, 2H), 3.14 (t, J = 8.4 Hz, 2H), 3.58 (s, 3H),

(4) This compound is not stable in $CDCl_3$, and can be completely converted to *E*−isomer after 3 days.

6.63 (d, J = 9.0 Hz, 2H), 7.05−7.25 (m, 7H), 7.56−7.60 (m, 2H), 7.69−7.72 (m, 2H). ^{13}C NMR (75.5 MHz, DMSO−*d*6): δ 28.7, 32.5, 54.9, 69.1, 113.3, 122.6, 126.7, 128.0, 128.2, 129.3, 130.0, 132.8, 134.0, 141.8, 157.9, 162.8, 184.1. IR ν (cm^{-1}): 1724. MS (EI) m/z: 396 (M^+, 14), 250 (100), 210 (70). Calcd for $C_{25}H_{20}N_2O_3$: C, 75.74; H, 5.08; N, 7.07. Found: C, 75.75; H, 5.07; N, 7.04.

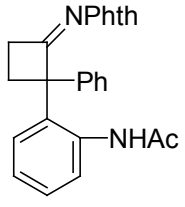
_N_−phthalyl−2−(3−chlorophenyl)−2−phenylcyclobutylidene hydrazine (6)



E−isomer (isolated yield: 36%): white solid (R_f = 0.17, PE/AcOEt = 5:1), m.p. 185−187 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.80−2.91 (m, 2H), 3.05 (t, J = 8.4 Hz, 2H), 7.20−7.59 (m, 9H), 7.72−7.75 (m, 2H), 7.86−7.89 (m, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 29.4, 33.2, 64.2, 123.5, 125.3, 126.9, 127.0, 127.08, 127.15 128.7, 129.8, 130.9, 134.2, 134.3, 142.8, 145.6, 163.6, 182.7. IR ν (cm^{-1}): 1718. MS (EI) m/z: 400 (M^+, 15), 254 (21), 214 (17), 186(100). Calcd for $C_{24}H_{17}ClN_2O_2$: C, 71.91; H, 4.27; N, 6.99. Found: C, 71.90; H, 4.26; N, 6.92.

Z−isomer (isolated yield: 52%): white solid (R_f = 0.10, PE/AcOEt = 5:1), m.p. 154−156 °C. ^{1}H NMR (300 MHz, DMSO−*d*6): δ 2.66 (m, 1H), 2.85 (m, 1H), 3.19 (t, J = 8.1 Hz, 2H), 7.13−7.27 (m, 9H), 7.59−7.62 (m, 2H), 7.71−7.74 (m, 2H). ^{13}C NMR (75.5 MHz, DMSO−*d*6): δ 28.7, 32.5, 69.0, 122.8, 126.8, 127.1, 128.1, 128.3, 129.8, 129.9, 132.9, 134.3, 141.1, 143.2, 162.9, 183.2. IR ν (cm^{-1}): 1717. MS (EI) m/z: 400 (M^+, 12), 254 (22), 214 (18), 186(100). Calcd for $C_{24}H_{17}ClN_2O_2$: C, 71.91; H, 4.27; N, 6.99. Found: C, 71.98; H, 4.24; N, 6.97.

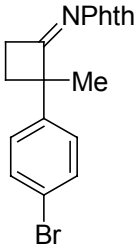
_N_−phthalyl−2−(2−acetamidophenyl)−2−phenylcyclobutylidene hydrazine (8)



White solid (R_f = 0.09, PE/AcOEt = 2:1), m.p. 205−207 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.87 (s, 3H), 2.50 (m, 1H), 3.03−3.27 (m, 3H), 7.20−7.38 (m, 7H), 7.60 (d, J = 7.8 Hz, 1H), 7.73 (d, J = 7.8 Hz, 1H), 7.77−7.80 (m, 2H), 7.89−7.92 (m, 2H), 9.62 (s, 1H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 23.8, 28.7, 32.7, 64.0, 123.8, 124.8, 126.0, 126.9, 127.0, 127.1 128.3, 128.6, 130.7, 134.1, 134.5, 136.3, 143.0, 163.4, 168.3, 184.5. IR ν (cm^{-1}): 1691, 1715. MS (EI) m/z: 423 (M^+, 17), 380 (38), 218 (56). Calcd for $C_{26}H_{21}N_3O_3$: C, 73.74; H, 5.00; N, 9.92. Found: C,

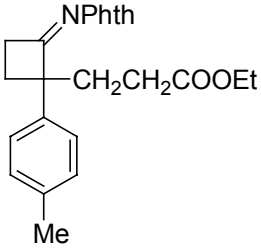
73.37; H, 5.01; N, 9.87.

_N_−phthalyl−2−(4−bromophenyl)−2−methylcyclobutylidene hydrazine (10)



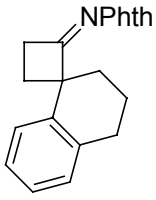
White solid (R_f = 0.18, PE/AcOEt = 5:1), m.p. 148−150 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.73 (s, 3H), 2.24 (m, 1H), 2.45 (m, 1H), 3.00 (t, J = 8.4 Hz, 2H), 7.44−7.52 (m, 4H), 7.74−7.77 (m, 2H), 7.87−7.90 (m, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 28.1, 29.6, 33.1, 56.5, 120.6, 123.5, 127.8, 130.9, 131.6, 134.2, 143.4, 163.8, 184.9. IR v (cm^{-1}): 1722. MS (EI) m/z: 382 (M^+, 6), 236 (12), 186 (100). Calcd for $C_{19}H_{15}BrN_2O_2$: C, 59.55; H, 3.95; N, 7.31. Found: C, 59.61; H, 3.97; N, 7.29.

_N_−phthalyl−2−(2−(ethoxycarbonyl)ethyl)−2−(4−methylphenyl)cyclobutylidene hydrazine (12)



Colorless oil (R_f = 0.12, PE/AcOEt = 5:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.20 (t, J = 7.2 Hz, 3H), 2.34 (s, 3H), 2.19−2.59 (m, 6H), 2.94 (t, J = 8.4 Hz, 2H), 4.06 (q, J = 7.2 Hz, 2H), 7.19 (d, J = 8.1 Hz, 2H), 7.45 (d, J = 8.1 Hz, 2H), 7.73−7.76 (m, 2H), 7.85−7.88 (m, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 14.1, 20.9, 27.7, 30.0, 32.5, 35.7, 59.5, 60.2, 123.4, 126.5, 129.1, 130.9, 134.1, 136.5, 138.4, 163.6, 173.2, 184.4. IR v (cm^{-1}): 1719. MS (EI) m/z: 404 (M^+, 6), 317 (24), 186 (65), 145 (100). Calcd for $C_{24}H_{24}N_2O_4$: 404.1736. Found: 404. 1730.

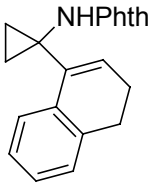
_N_−phthalylcyclobutylidene hydrazine derivative 16



White solid (R_f = 0.18, PE/AcOEt = 5:1), m.p. 186−188 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ

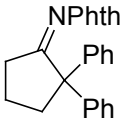
1.87 (m, 1H), 2.04 (m, 1H), 2.21 (m, 2H), 2.33 (m, 2H), 2.84 (m, 2H), 3.13 (t, J = 8.4 Hz, 2H), 7.07−7.27 (m, 3H), 7.50 (d, J = 7.8 Hz, 1H), 7.72−7.76 (m, 2H), 7.85−7.88 (m, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 19.6, 29.5, 32.0, 33.1, 34.4, 56.1, 123.4, 126.5, 126.8, 127.5, 129.0, 131.0, 134.1, 136.3, 138.4, 163.7, 188.5. IR ν (cm^{-1}): 1715. MS (EI) m/z: 330 (M^+, 20), 186 (38), 144 (81), 129 (100). Calcd for $C_{21}H_{18}N_2O_2$: C, 76.34; H, 5.49; N, 8.48. Found: C, 76.25; H, 5.45; N, 8.45.

_N_−aminophthalimide derivative 17



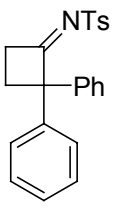
White solid (R_f = 0.22, PE/AcOEt = 5:1), m.p. 147−149 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.90 (dd, J = 4.5, 6.6 Hz, 2H), 1.49 (dd, J = 4.5, 6.6 Hz, 2H), 2.13 (m, 3H), 2.68 (t, J = 8.1 Hz, 2H), 5.93 (t, J = 4.8 Hz, 1H), 7.16−7.22 (m, 3H), 7.68−7.78 (m, 5H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 12.8, 22.9, 27.6, 44.0, 122.5, 123.1, 126.2, 126.9, 127.9, 128.9, 130.2, 133.9, 135.6, 137.0, 166.1. IR ν (cm^{-1}): 1721. MS (EI) m/z: 330 (M^+, 36), 169 (79), 128 (100). Calcd for $C_{21}H_{18}N_2O_2$: C, 76.34; H, 5.49; N, 8.48. Found: C, 76.30; H, 5.44; N, 8.45.

_N_−phthalyl−2, 2−diphenylcyclopentylidene hydrazine (22)



White solid (R_f = 0.20, PE/AcOEt = 5:1), m.p. 160−161 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.78 (m, 2H), 2.66 (t, J = 7.5 Hz, 2H), 2.73 (t, J = 6.6 Hz, 2H), 7.24−7.39 (m, 6H), 7.46−7.49 (m, 4H), 7.69−7.72 (m, 2H), 7.82−7.85 (m, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 20.2, 31.9, 40.7, 61.8, 123.3, 126.8, 128.2, 128.6, 131.2, 134.0, 142.5, 163.6, 194.1. IR ν (cm^{-1}): 1715. MS (EI) m/z: 380 (M^+, 20), 352 (22), 234 (28), 115 (100). Calcd for $C_{25}H_{20}N_2O_2$: C, 78.93; H, 5.30; N, 7.36. Found: C, 79.05; H, 5.33; N, 7.34.

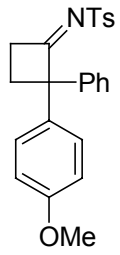
_N_−tosyl−2, 2−diphenylcyclobutanimine (23)



White solid (R_f = 0.30, PE/AcOEt = 5:1), m.p. 114−116 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ

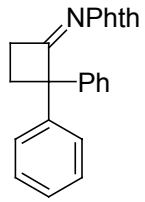
2.44 (s, 3H), 2.95 (t, J = 8.6 Hz, 2H), 3.52 (t, J = 8.6 Hz, 2H), 7.19−7.38 (m, 12H), 7.88 (d, J = 8.4 Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 21.6, 29.9, 36.5, 67.1, 126.5, 127.0, 127.4, 128.6, 129.6, 136.9, 142.5, 144.2, 195.5. IR v (cm^{-1}): 1659. MS (EI) m/z: 375 (M^+, 1), 220 (100), 91 (33). Calcd for $C_{23}H_{21}NO_2S$: C, 73.57; H, 5.64; N, 3.73. Found: C, 73.52; H, 5.65; N, 3.60.

_N_−tosyl−2−(4−methoxyphenyl)−2−phenylcyclobutanimine (24)

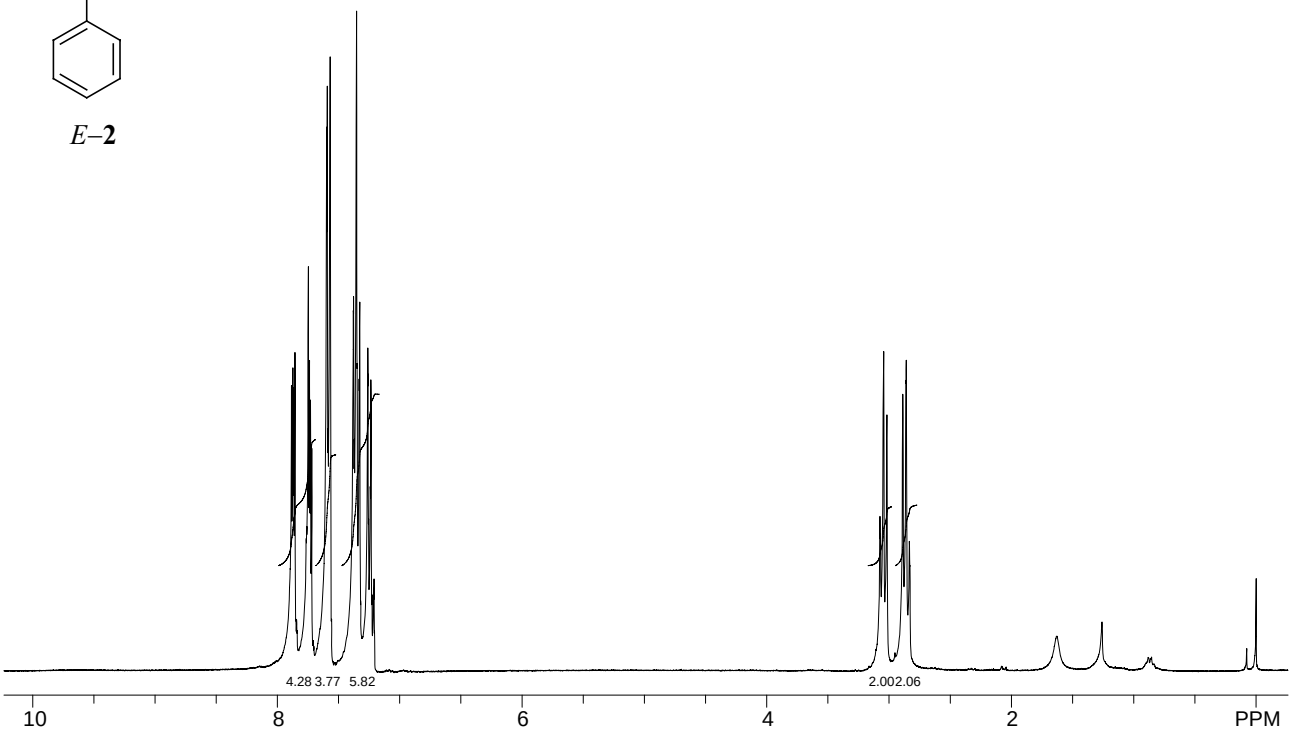


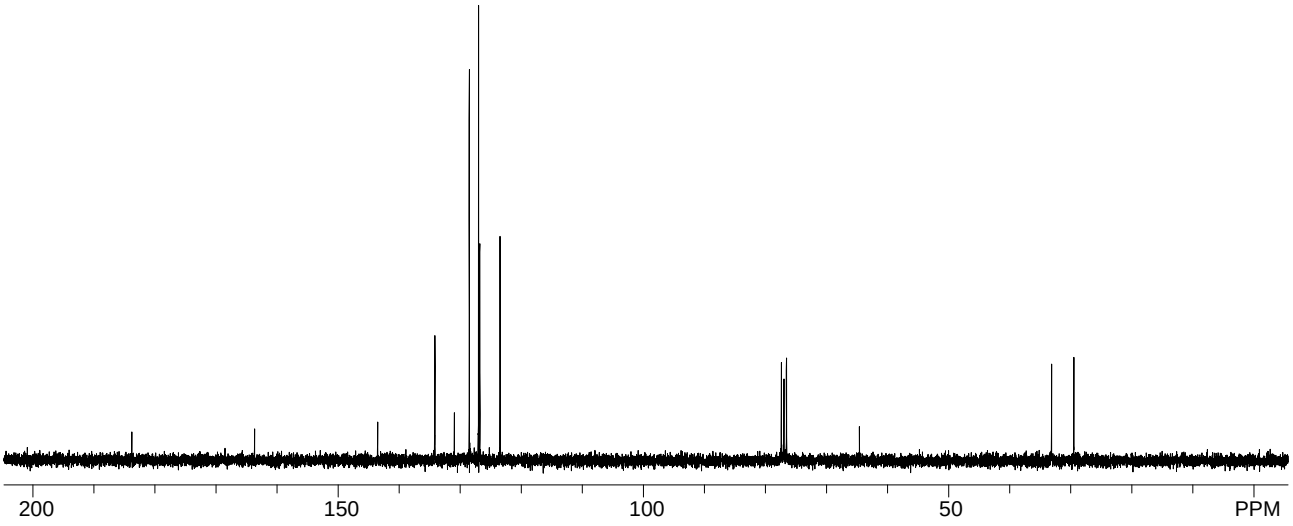
Colorless oil (R_f = 0.22, PE/AcOEt = 5:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.44 (s, 3H), 2.90 (t, J = 8.4 Hz, 2H), 3.51 (t, J = 8.4 Hz, 2H), 3.74 (s, 3H), 6.78−6.81 (m, 2H), 7.18−7.35 (m, 9H), 7.87 (d, J = 8.4 Hz, 2H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ 21.6, 30.0, 36.4, 55.2, 66.6, 113.9, 126.5, 126.9, 127.4, 127.7, 128.6, 129.6, 134.6, 136.9, 142.9, 144.2, 158.5, 195.8. IR v (cm^{-1}): 1658. MS (EI) m/z: 405 (M^+, 1), 250 (100), 210 (18). Calcd for $C_{24}H_{23}NO_3S$: 405.1399. Found: 405.1394.

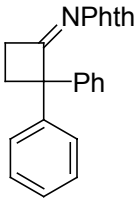
Copies of ^{1}H and ^{13}C NMR Spectra for the Products



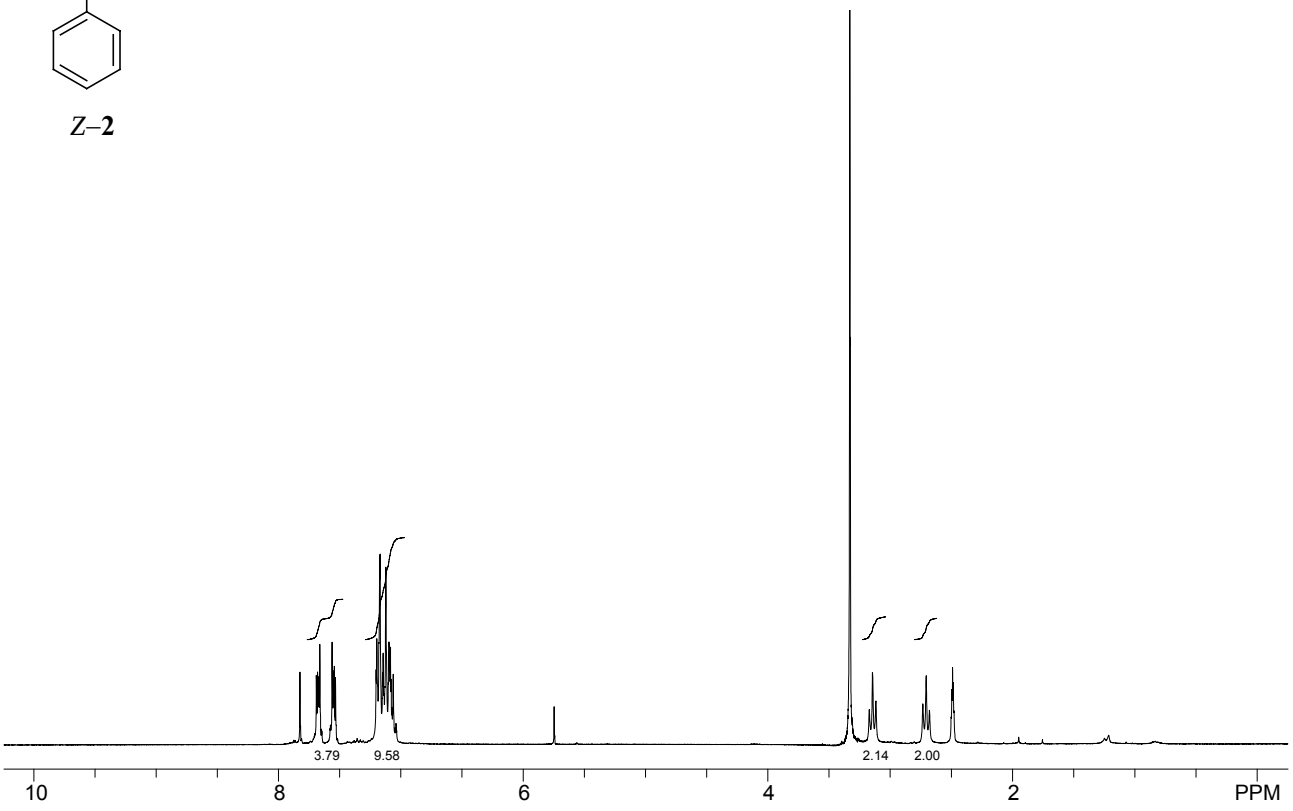
E–**2**

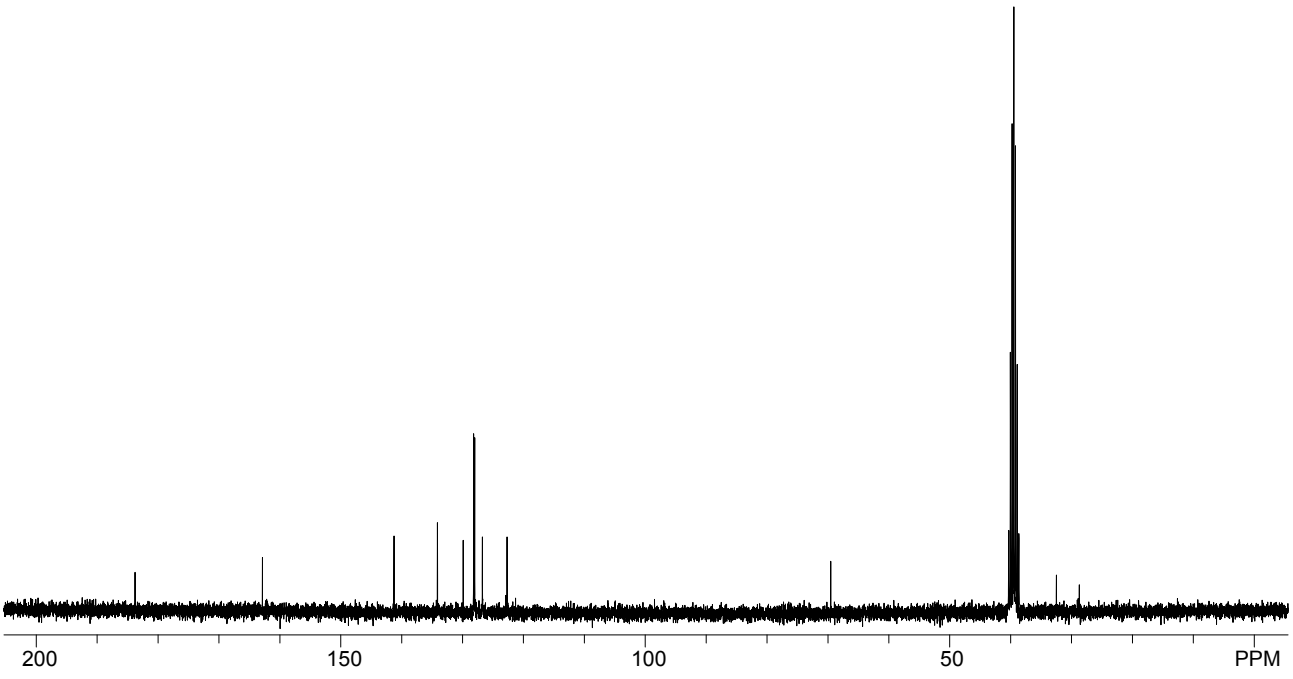


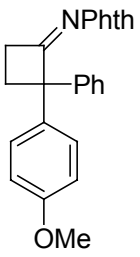




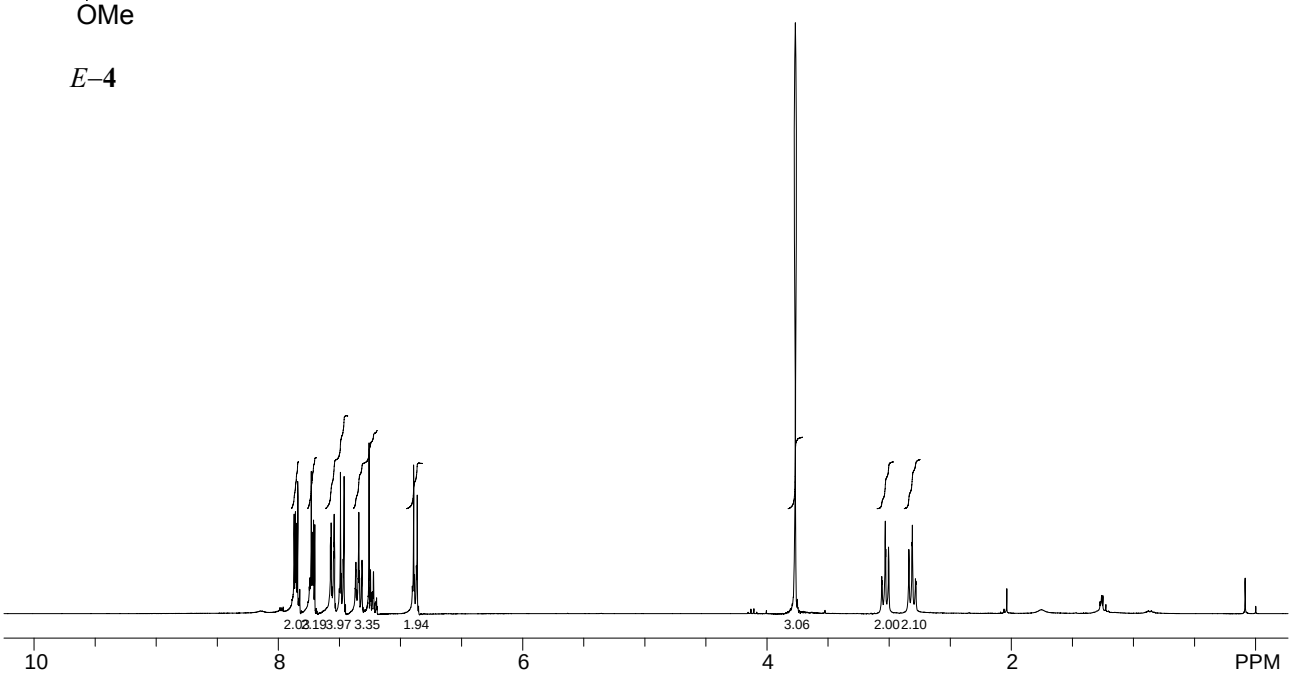
Z–**2**






NPhth
Ph
OMe

E–**4**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2.00
2.10
10
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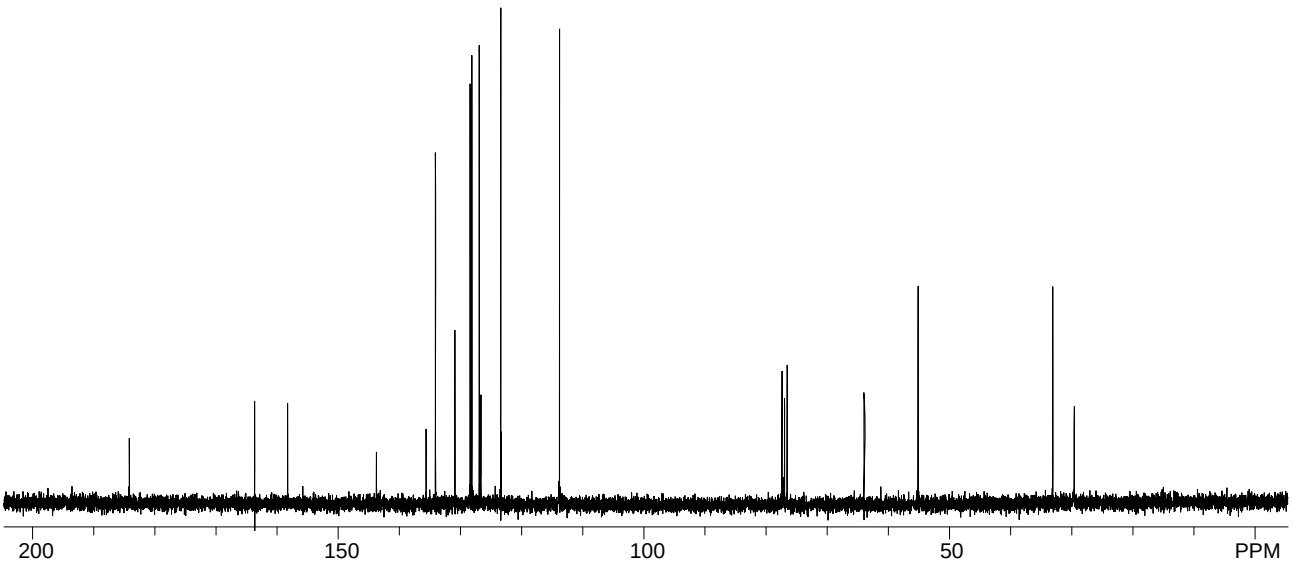
6
4
2
PPM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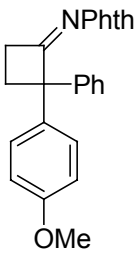
150
100
50
PPM



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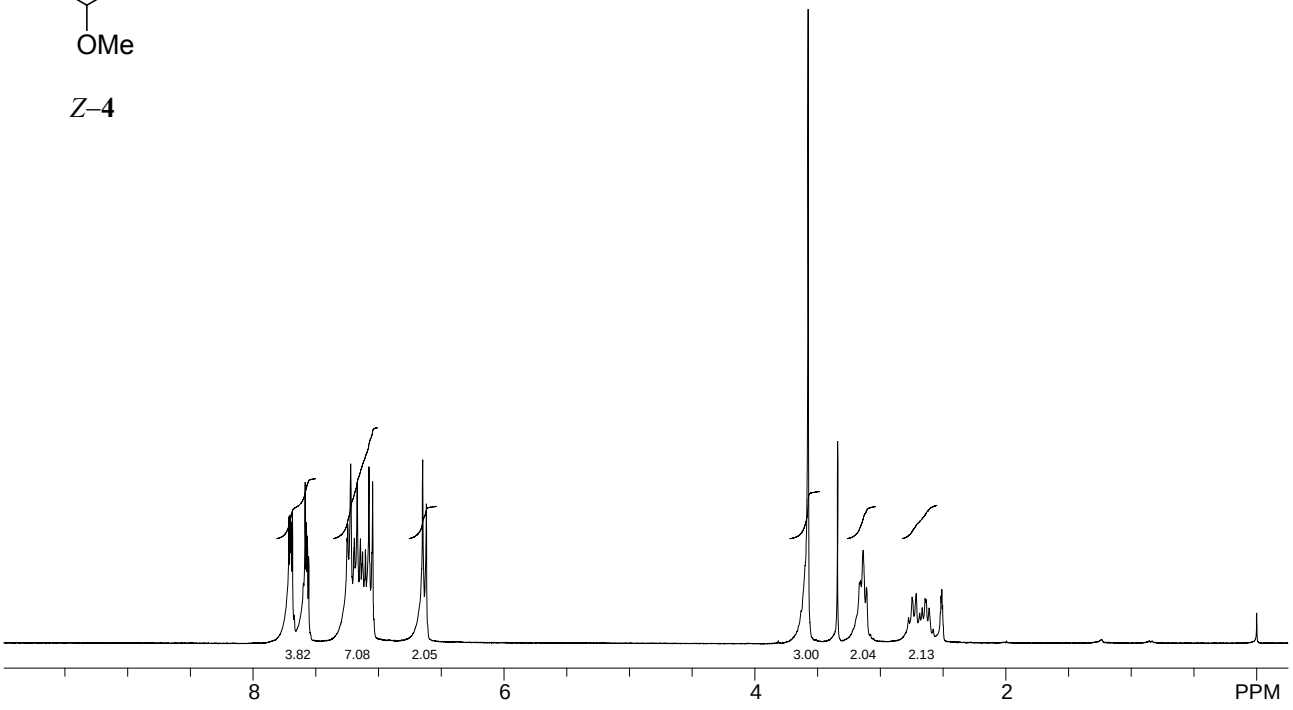

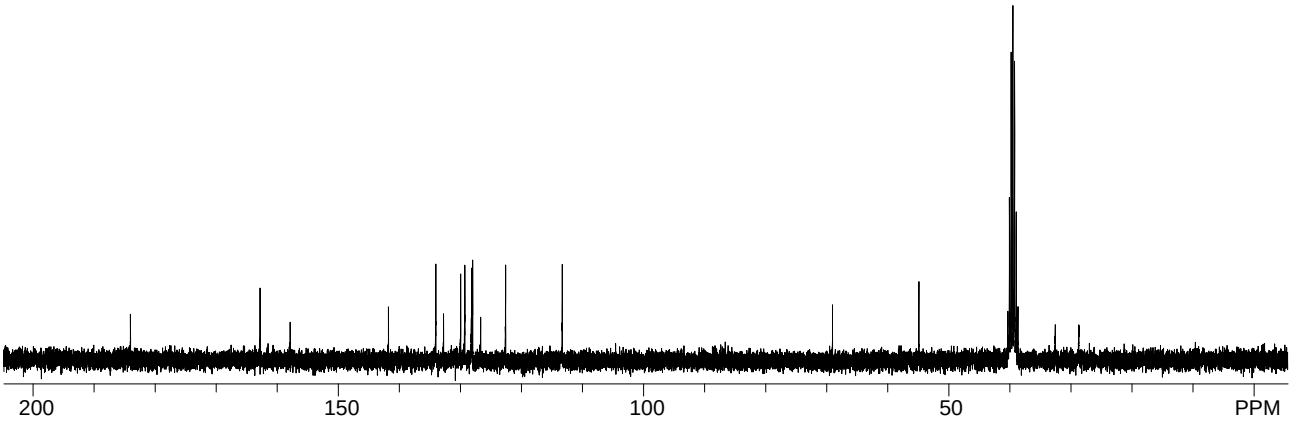

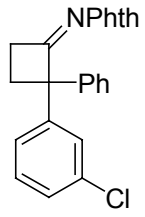

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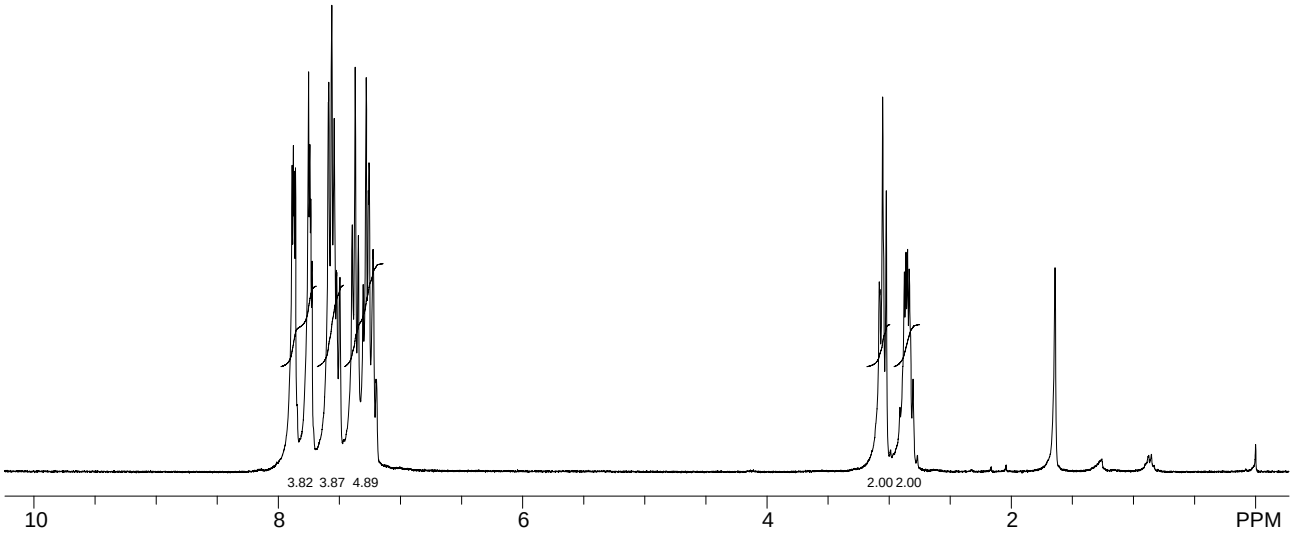
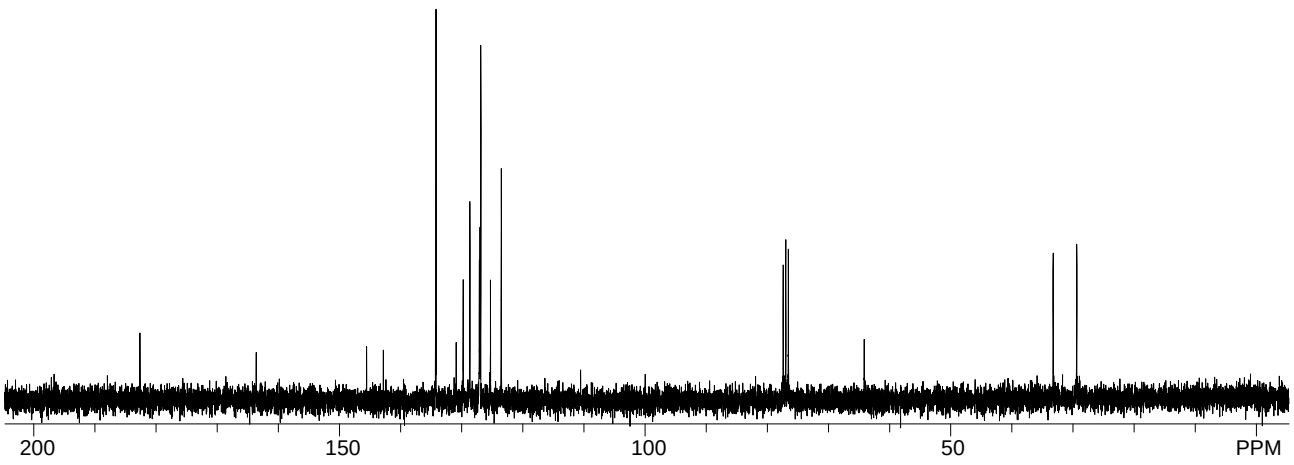
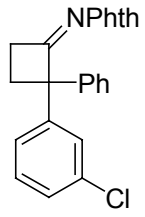
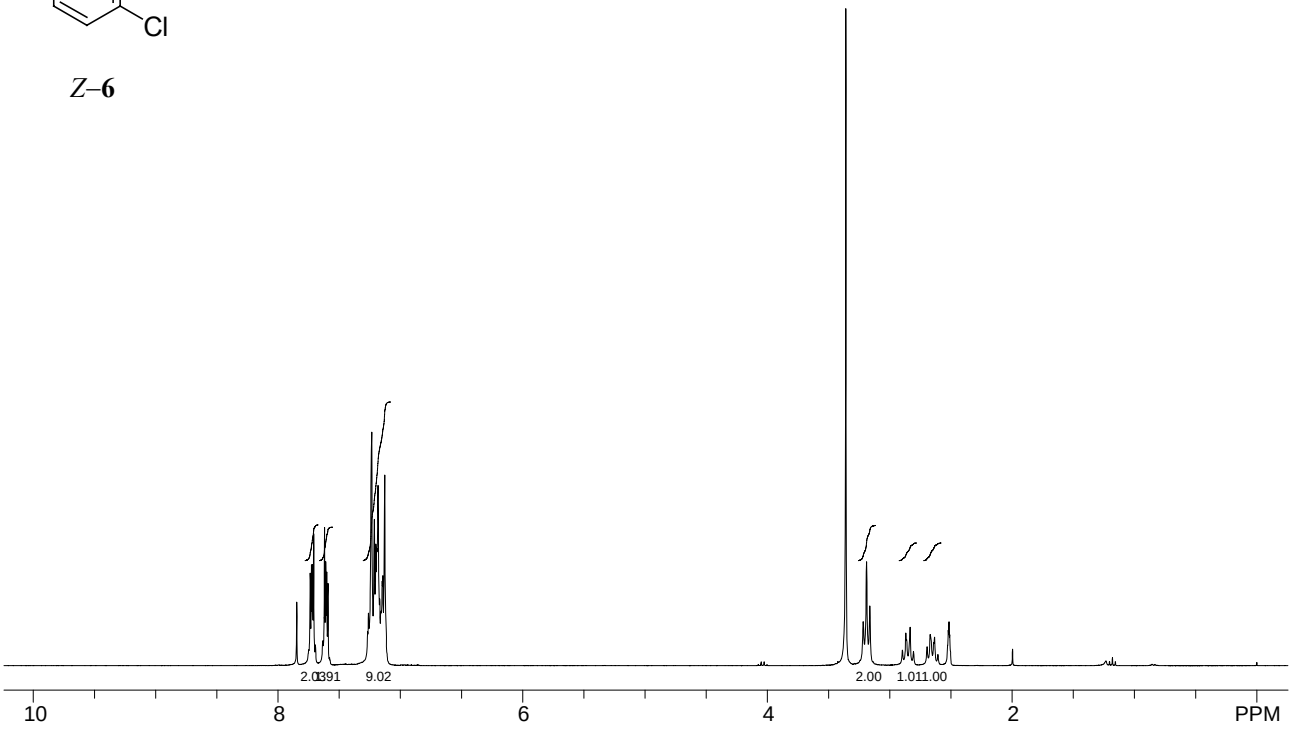





NPhth
Ph
Cl

Z–**6**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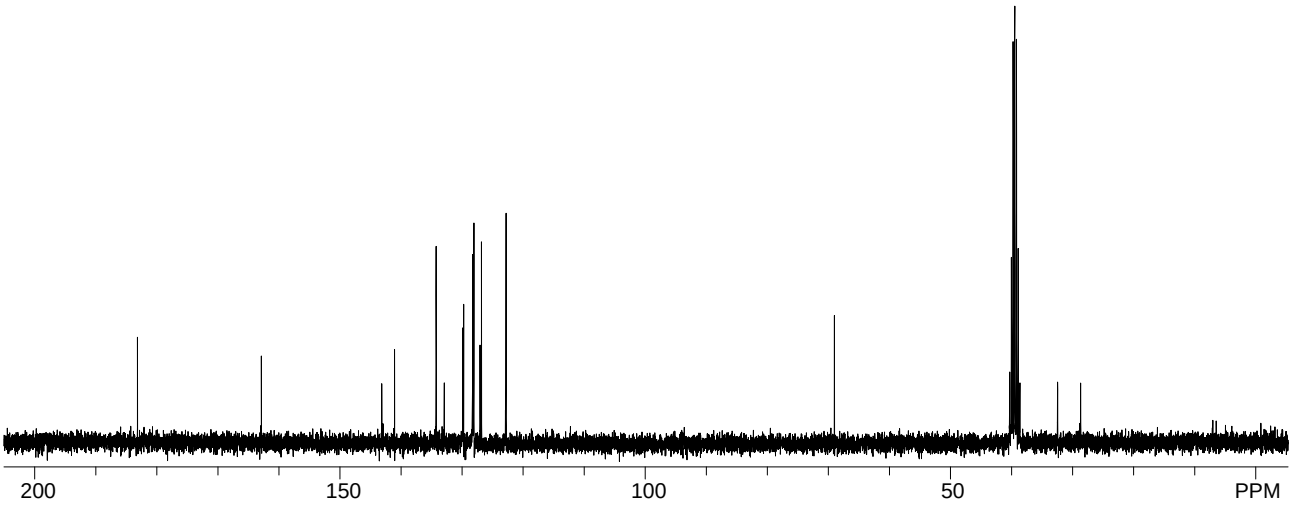
1.01
1.00
10
8
6
4
2
PPM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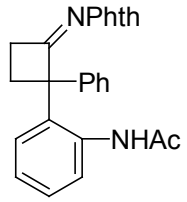
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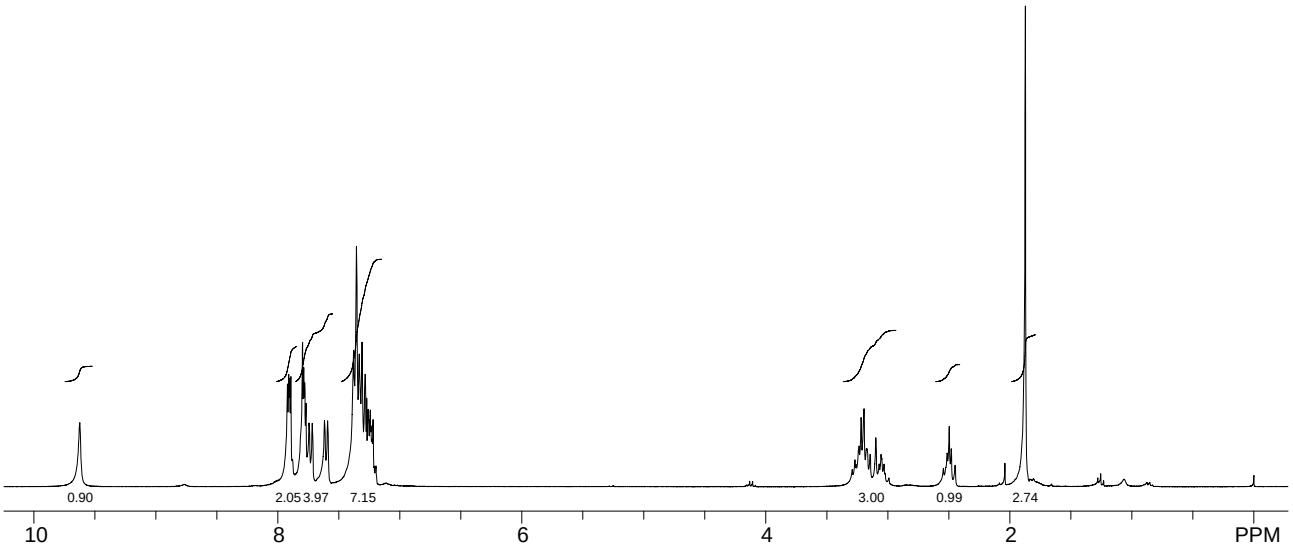
Ph
NHAc

8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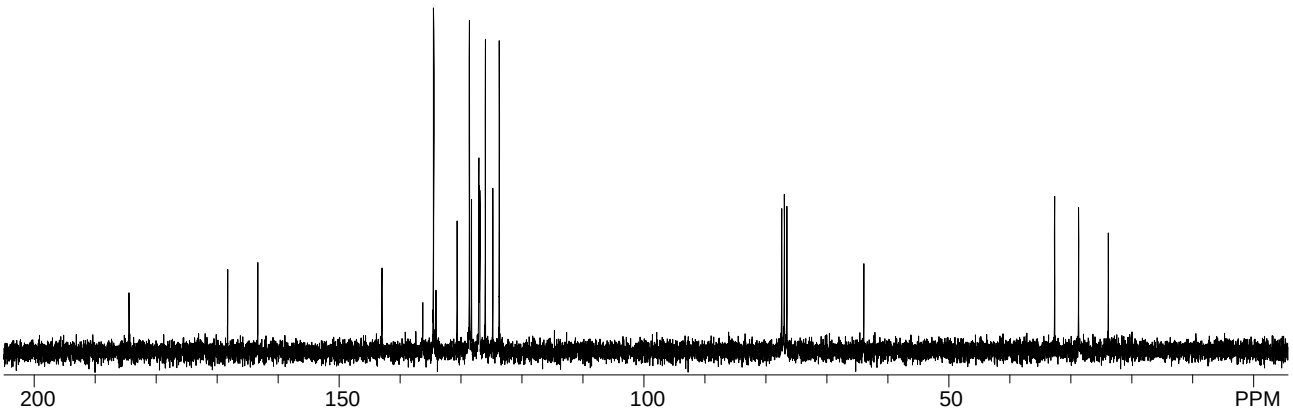
0.99
2.74
10
8
6
4
2
PPM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150
100
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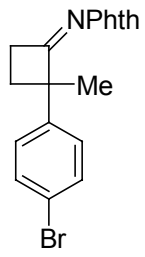
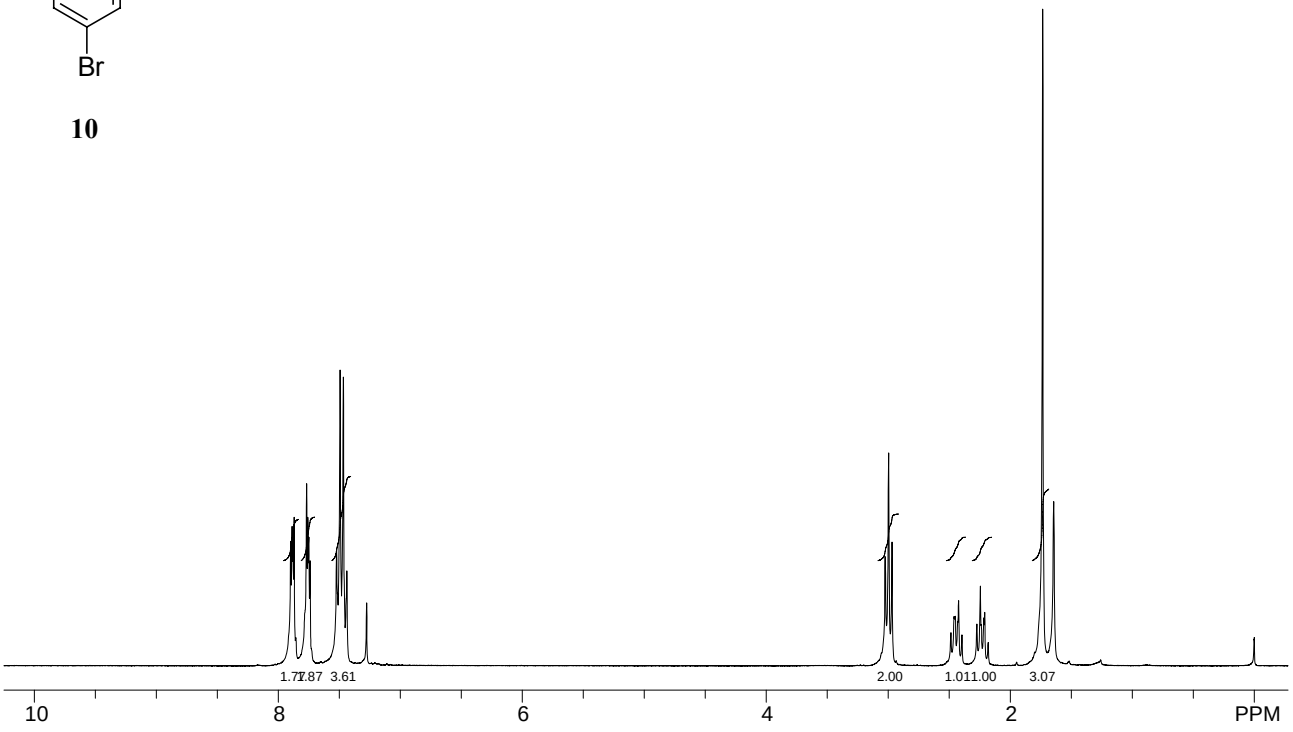

NPhth
Me
Br

10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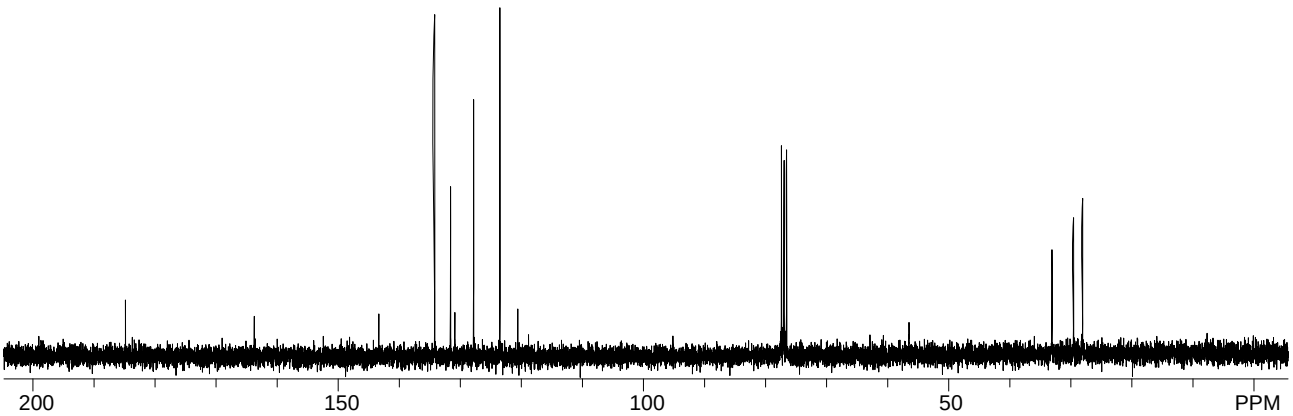
3.07
10
8
6
4
2
PPM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100
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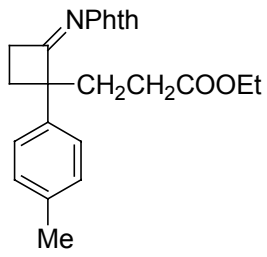
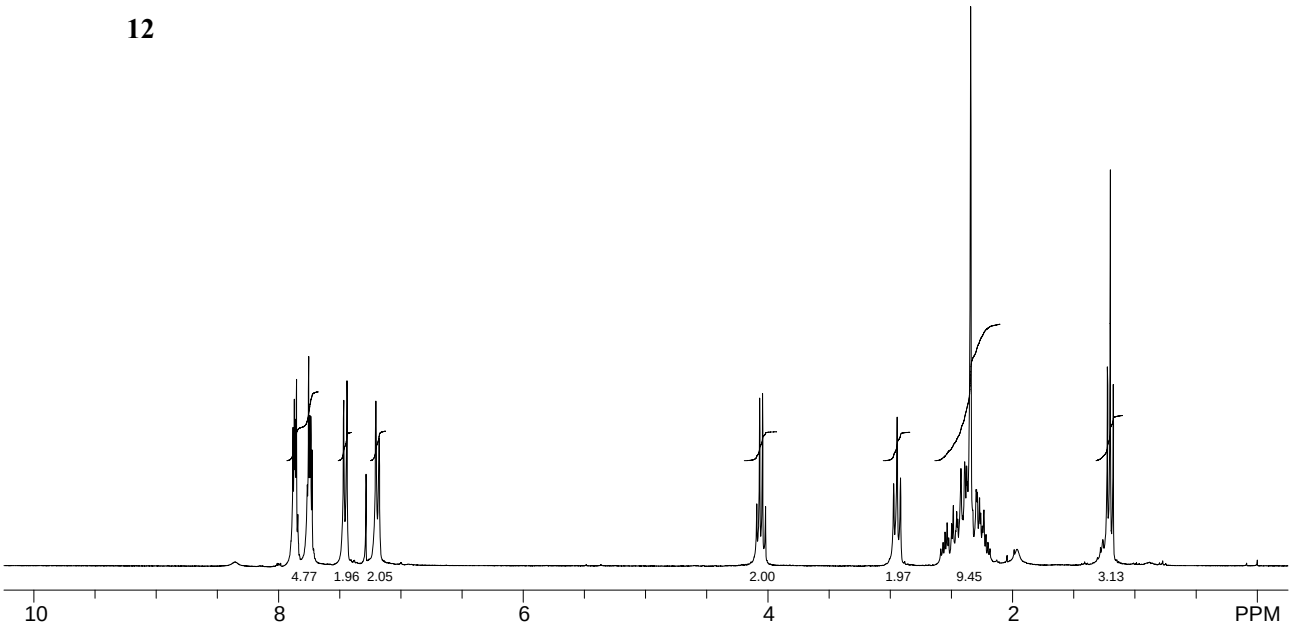
PPM


NPhth
CH2CH2COOEt
Me

12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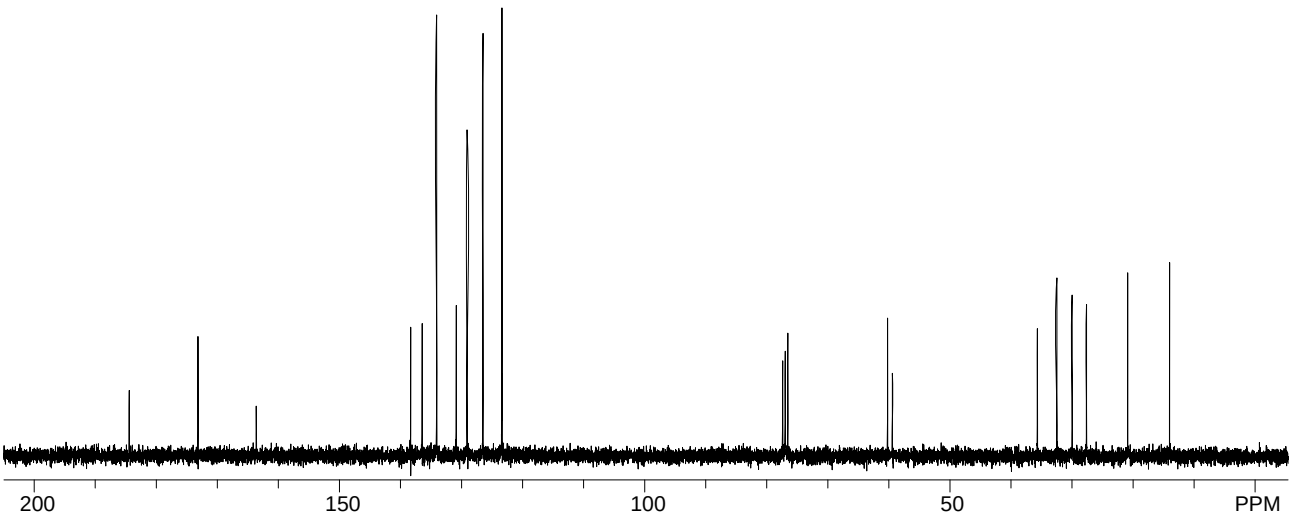
3.13
10
8
6
4
2
PPM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100
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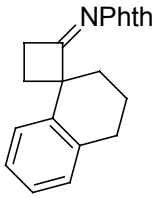
PPM



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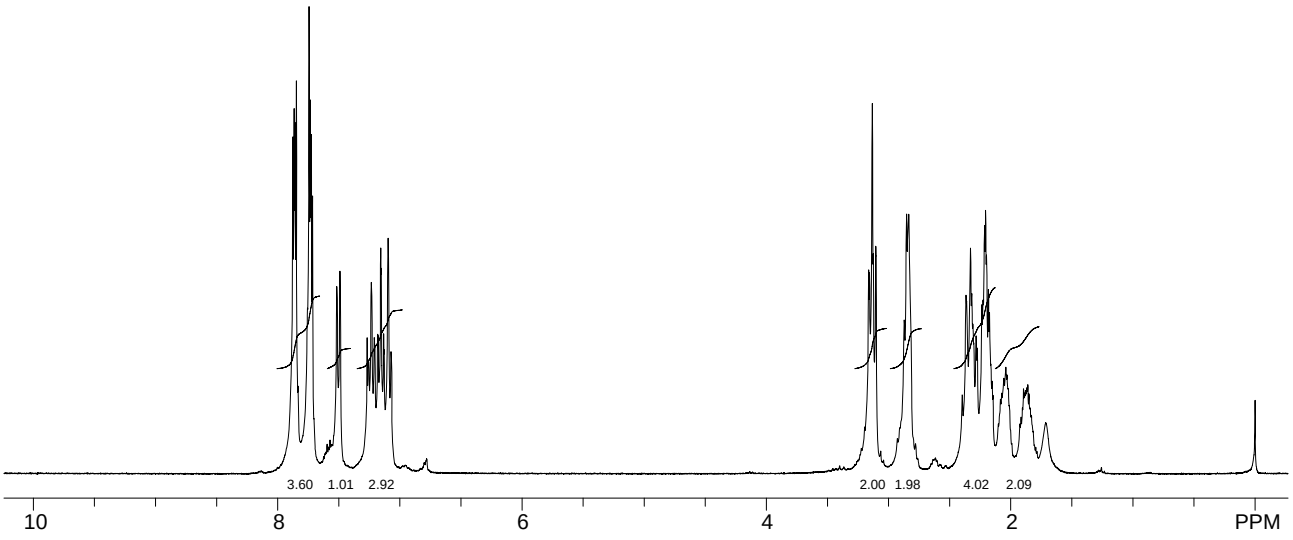
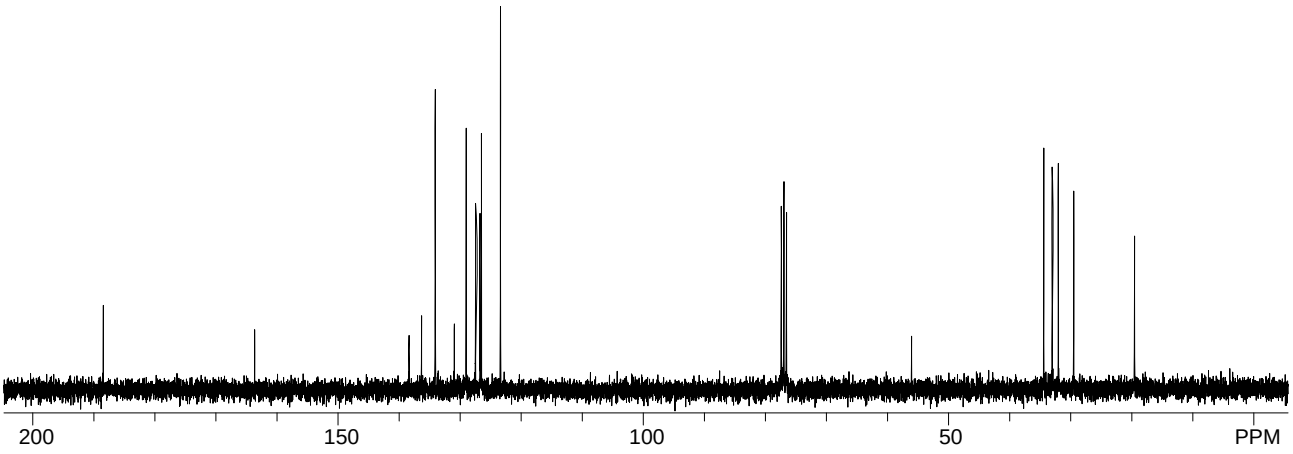
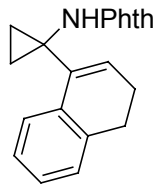
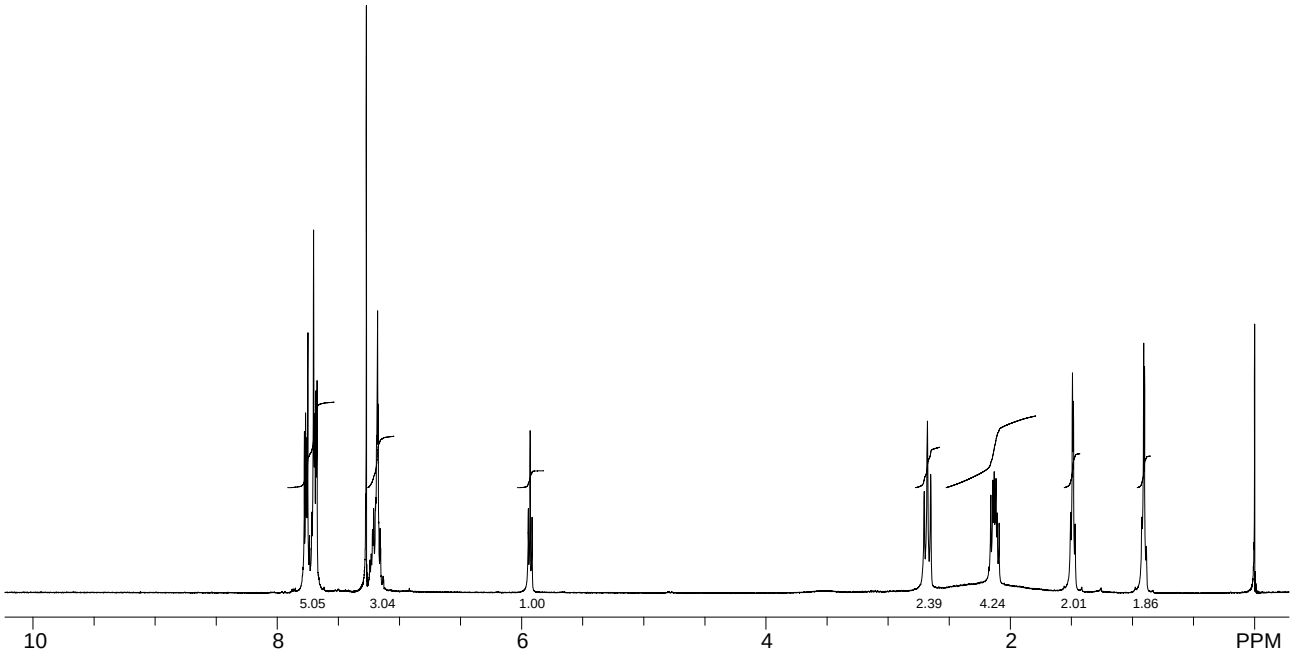





NHPhth

17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2.01
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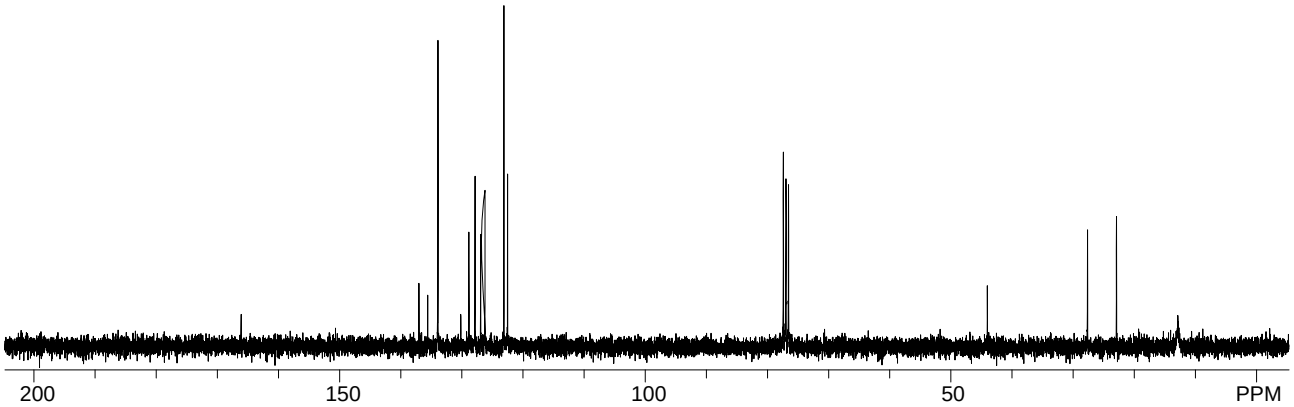
10
8
6
4
2
PPM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100
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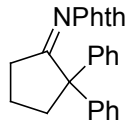
PPM



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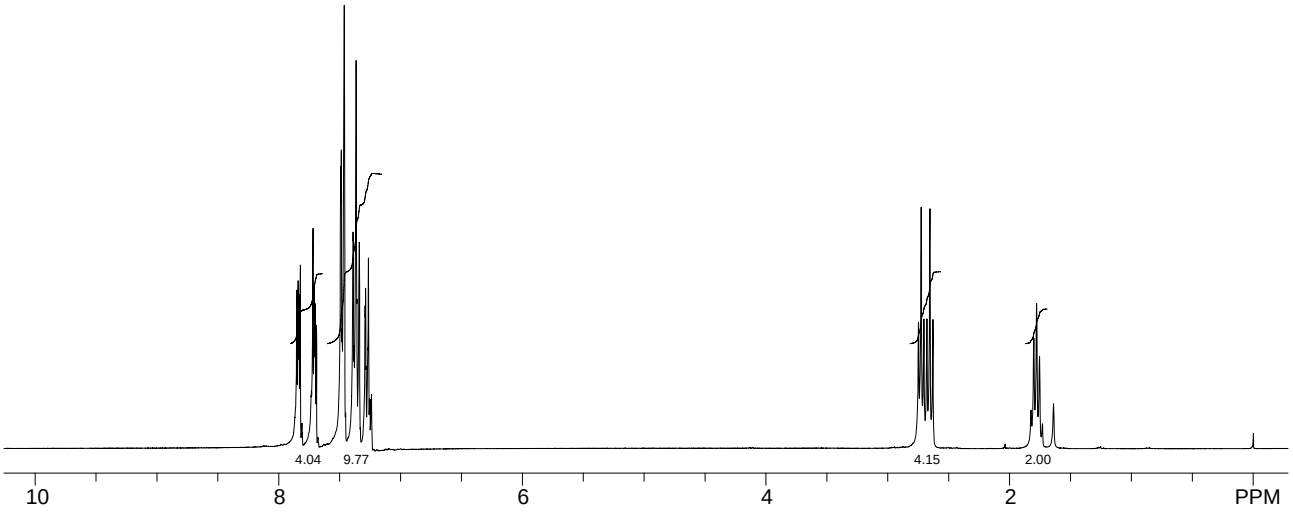

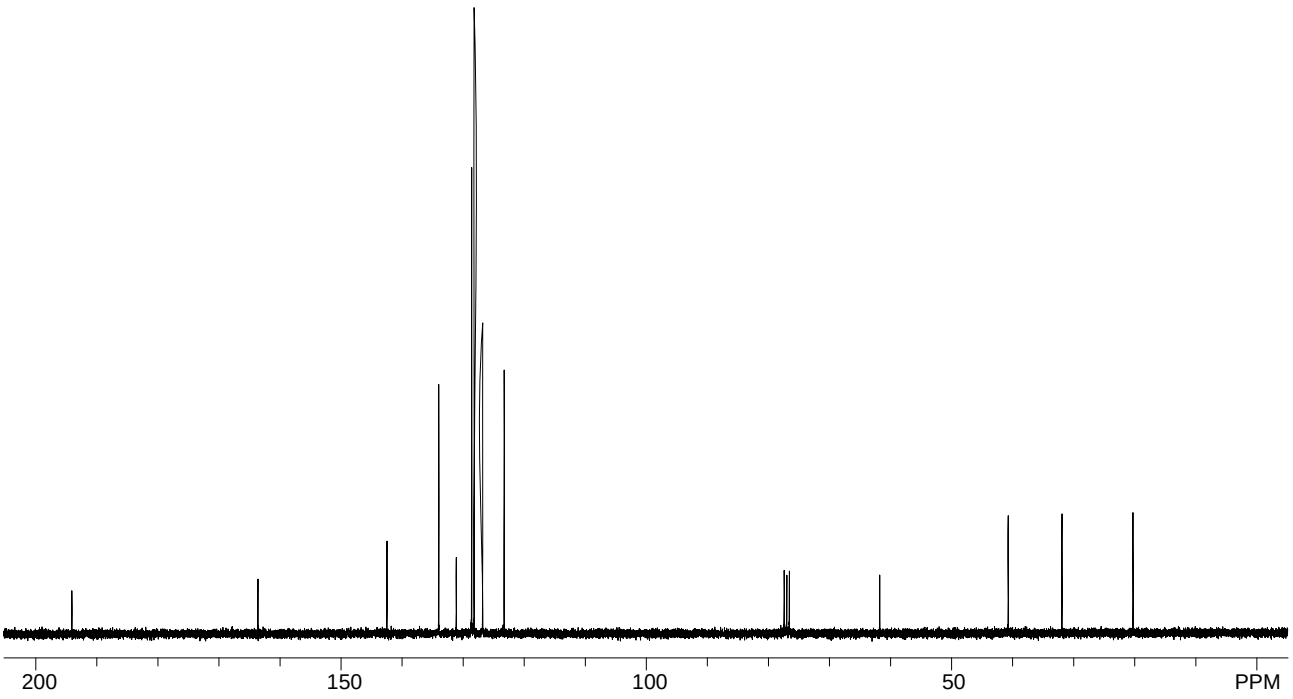

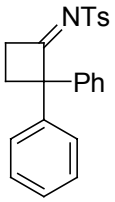

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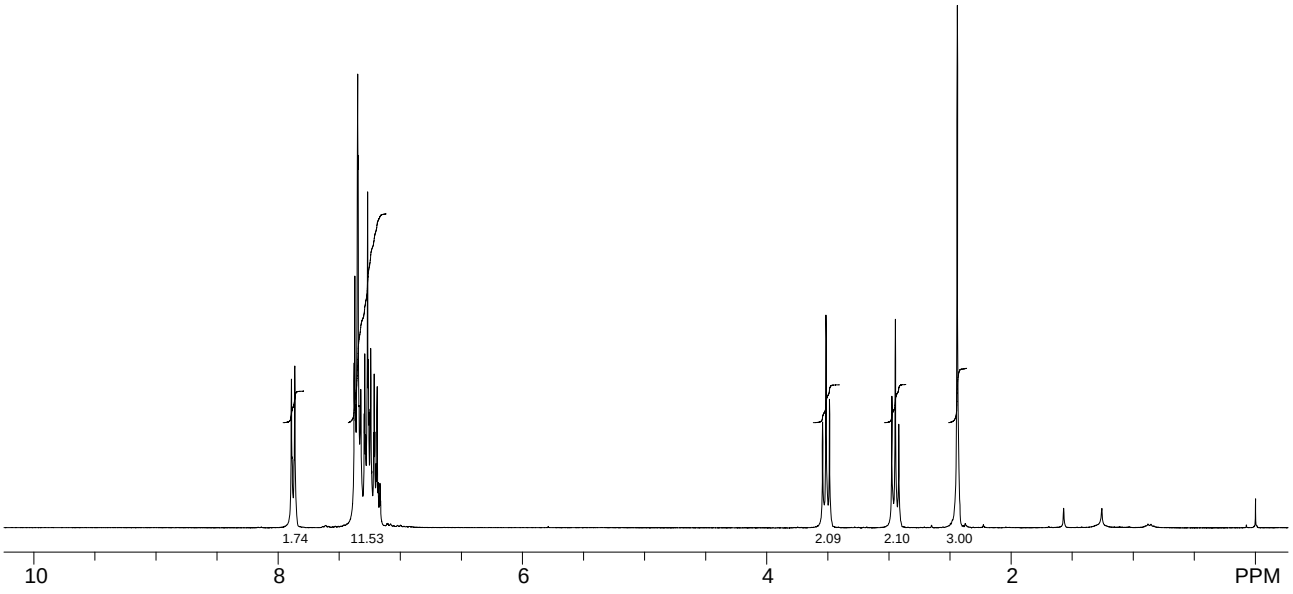
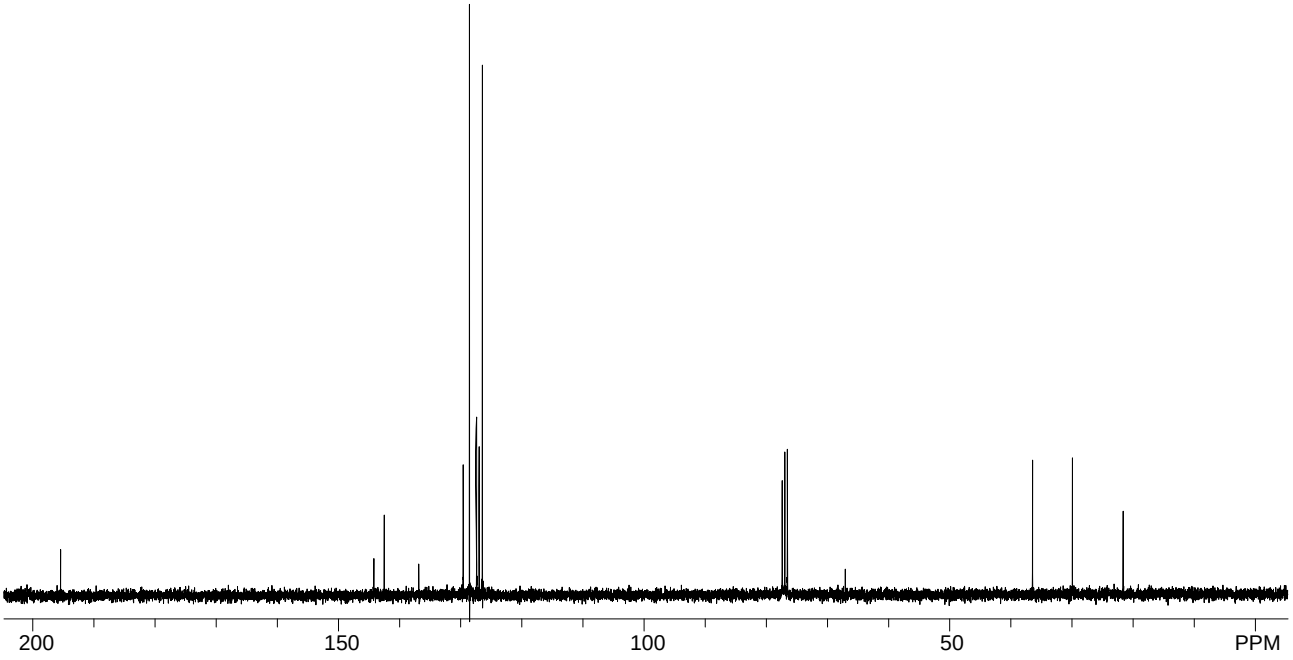
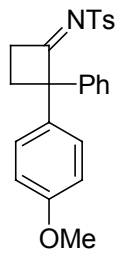
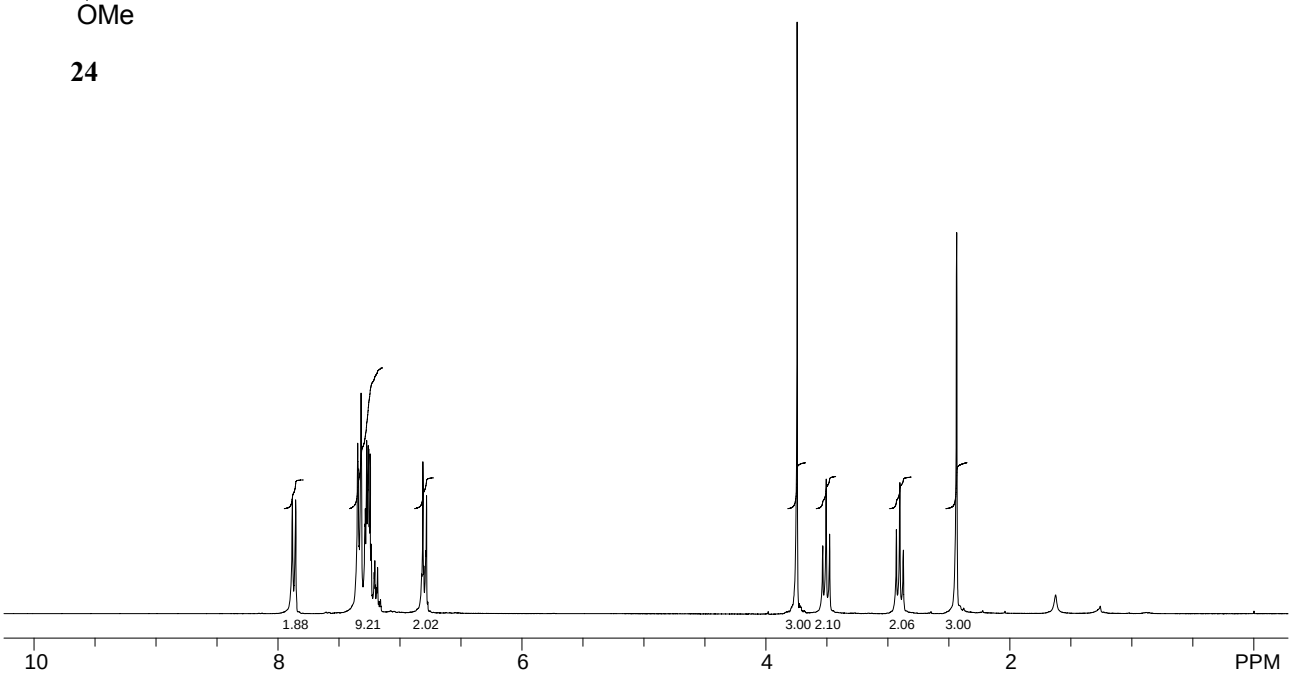





NTs
Ph
OMe

24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9.21
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3.00
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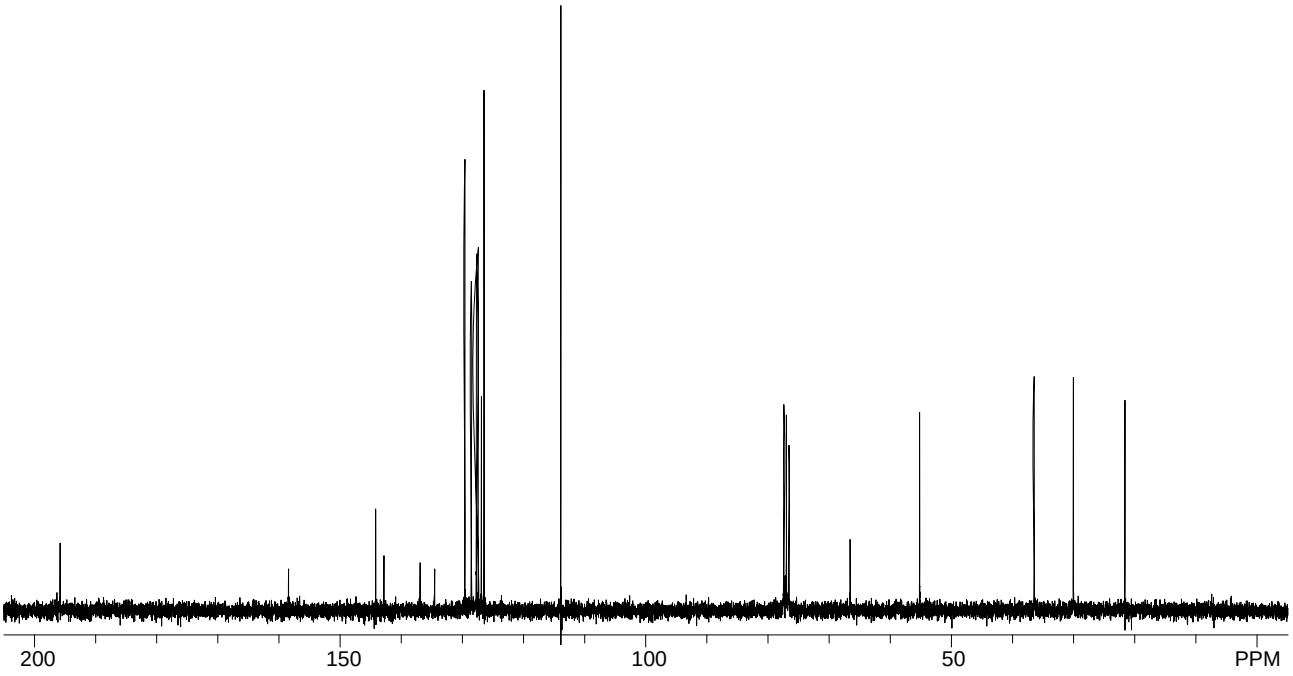
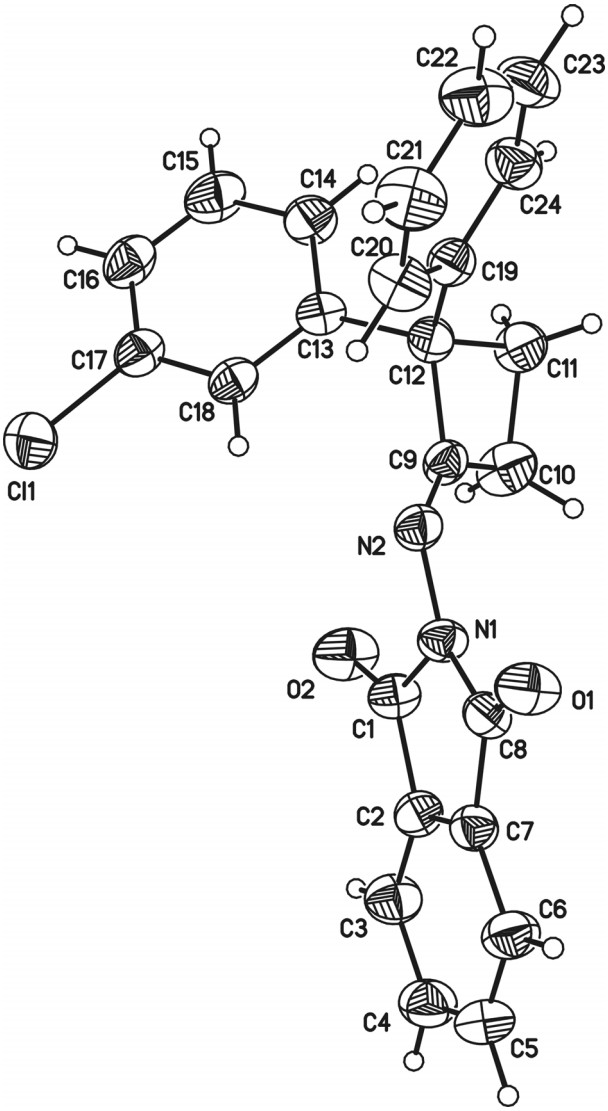
3.00
10
8
6
4
2
PPM


200
150
100
50
PPM

Crystal Structure of Compound *E*−6



CCDC 619410 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge via www.ccdc.cam.ac.uk/data_request/cif, by emailing data_request@ccdc.cam.ac.uk, or by contacting The Cambridge Crystallographic Data Centre, 12, Union Road, Cambridge CB2 1EZ, UK; fax: +44 1223 336033.