ELECTRONIC SUPPLEMENTARY INFORMATION

Iridium catalysed synthesis of piperazines from diols

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General methods:
$[Cp^*IrCl_2]_2$ was purchased from Strem while all other chemicals were obtained from Aldrich and used as received. Toluene was distilled from sodium. NMR spectra were recorded on a Varian Mercury 300 spectrometer with residual solvent signals[1] or TMS as reference. Assignments were made based on one dimensional spectra as well as COSY and HSQC spectra. HRMS were obtained at the Department of Chemistry, University of Copenhagen (ionisation method: ESP+).

General procedure for *N*-heterocyclisation:
To 5 mL screw-top vial were added $[Cp^*IrCl_2]_2$, (8 mg, 10 μmol), diamine (2 mmol), diol (2 mmol), $NaHCO_3$ (10 mg, 0.12 mmol), and solvent (1 mL). The vial was flushed with argon, sealed, and heated to the indicated temperature overnight. After cooling to room temperature aqueous K_2CO_3 and CH_2Cl_2 were added. The phases were separated and the aqueous phase was extracted twice with CH_2Cl_2. The combined organic phases were dried (K_2CO_3) and concentrated. The residue was further purified by column chromatography (heptane/EtOAc or MeOH/CH_2Cl_2 mixtures).

(±)-*trans*-Decahydroquinoxaline
δ_H (300 MHz, $CDCl_3$): 2.98-2.78 (m, 4H), 2.25-2.10 (m, 2H), 1.80-1.10 (m, 10H, H1, H4, H6, H7, H8, H9); δ_C (75 MHz, $CDCl_3$): 61.4 (C5, C10), 47.1 (C2, C3), 32.1 (C6, C9), 25.0 (C7, C8); MS: *m/z* 140 [M^+].

(±)-(2*S*,4a*R*,8a*R*)-Decahydro-2-methylquinoxaline
δ_H (300 MHz, $CDCl_3$): 2.88 (dd, 1H, $J_{3eq\text{-}2}$ = 2.9 Hz, J_{3gem} = 11.6 Hz, H3eq), 2.83-2.73 (ddq, 1H, $J_{3eq\text{-}2}$ = 2.9 Hz, $J_{2\text{-}11}$ = 6.3 Hz, $J_{3ax\text{-}2}$ = 10.0 Hz, H2), 2.38 (dd, 1H, $J_{3ax\text{-}2}$ = 10.2 Hz, J_{3gem} = 11.6 Hz, H3ax), 2.26-2.05 (m, 2H, H5, H10), 1.75-1.55 (6H, H1, H4, H6, H9), 1.30-1.05 (m, 4H, H7, H8), 0.96 (d, 3H, $J_{2\text{-}11}$ = 6.3 Hz, H11); δ_C (75 MHz, $CDCl_3$): 61.7, 60.7 (C5, C10), 54.2, 52.2 (C2, C3), 32.2, 32.0 (C6, C9), 25.2, 25.0 (C7, C8), 20.0 (C11); HRMS calcd. for $C_9H_{19}N_2$ $[M+H]^+$ *m/z* 155.1548, found *m/z* 155.1556.
Minor isomer
δ_H (300 MHz, $CDCl_3$): 3.41 (tq, 1H, $J_{2\text{-}3}$ = 1.8 Hz, $J_{2\text{-}11}$ = 7.0 Hz, H2), 2.58-2.47 (m, 2H, H3ax, H3eq), 2.16-2.07 (m, 2H, H5, H10), 1.85-1.05 (m, 8H, H6, H7, H8, H9), 0.96 (d, 3H, $J_{2\text{-}11}$ = 6.6 Hz, H11); δ_C (75 MHz, $CDCl_3$): 62.9, 60.8, 56.5, 50.0, 32.3, 32.0, 25.1, 24.9, 18.3; MS: *m/z* 154 [M^+].

(±)-(2*R*,3*S*,4a*R*,8a*R*)-Decahydro-2,3-dimethylquinoxaline (major isomer)
δ_H (300 MHz, $CDCl_3$): 3.05, 2.88 (2×dq, 1H each, *J* = 3.6 Hz, *J* = 6.7 Hz, H2, H3), 2.44-2.15 (m, 2H, H5, H10), 1.67-1.50 (m, 6H, H1, H4, 2 × H6, 2 × H9), 1.30-1.15 (m, 4H, 2 × H7, 2 × H8), 1.08, 0.91 (2×d, 3H each, *J* = 6.7 Hz, H11, H12); δ_C (75 MHz, $CDCl_3$): 62.6, 54.4, 53.4, 52.1 (C2, C3, C5, C10), 31.2, 31.9 (C6, C9), 25.0, 24.9 (C7, C8), 19.2 (C11), 12.8 (C12); HRMS calcd. for $C_{10}H_{21}N_2$ $[M+H]^+$ *m/z* 169.1705, found *m/z* 169.1705.
Minor isomer
δ_C (75 MHz, $CDCl_3$): 61.3 (C5, C10), 57.9 (C2, C3), 31.7 (C6, C9), 19.0 (C11, C12).

1,4-Dibenzylpiperazine
δ_H (300 MHz, $CDCl_3$): 7.35-7.21 (m, 10H, Ar), 3.52 (s, 4H, Ph-CH_2-N), 2.49 (bs, 8H, N-CH_2-CH_2-N); δ_C (75 MHz, $CDCl_3$): 138.2 (C_{ipso}), 129.4, 128.3 (C_{ortho}, C_{meta}), 127.1 (C_{para}), 63.2 (Ph-CH_2-N), 53.2 (N-CH_2-CH_2-N); MS: *m/z* 266 [M^+].

(2*S*,3*S*)-2,3-Diphenylpiperazine

$[\alpha]_D^{25}$ = -102 (*c* 1.0, $CHCl_3$) (lit.[2] $[\alpha]_D^{25}$ = -104.6 (*c* 1.0, $CHCl_3$)); mp 93-95 ˚C (lit.[2] mp 94-96 ˚C); δ_H (300 MHz, $CDCl_3$): 7.20-7.05 (m, 10H, Ar), 3.71 (s, 2H, H2, H3), 3.14 (s, 4H, H5, H6), 2.01 (bs, 2H, H1, H4); δ_C (75 MHz, $CDCl_3$): 141.5 (C_{ipso}), 128.1, 127.9, 127.3 (Ar), 68.3 (C2, C3), 47.2 (C5, C6); MS: *m/z* 238 [M^+]. The starting material, (1*S*,2*S*)-1,2-diamino-1,2-diphenylethane, was prepared by resolution[3] and showed an optical rotation of $[\alpha]_D^{25}$ = -104 (*c* 1.5, MeOH) (lit.[3] $[\alpha]_D^{23}$ = -106 (*c* 1.1, MeOH)).

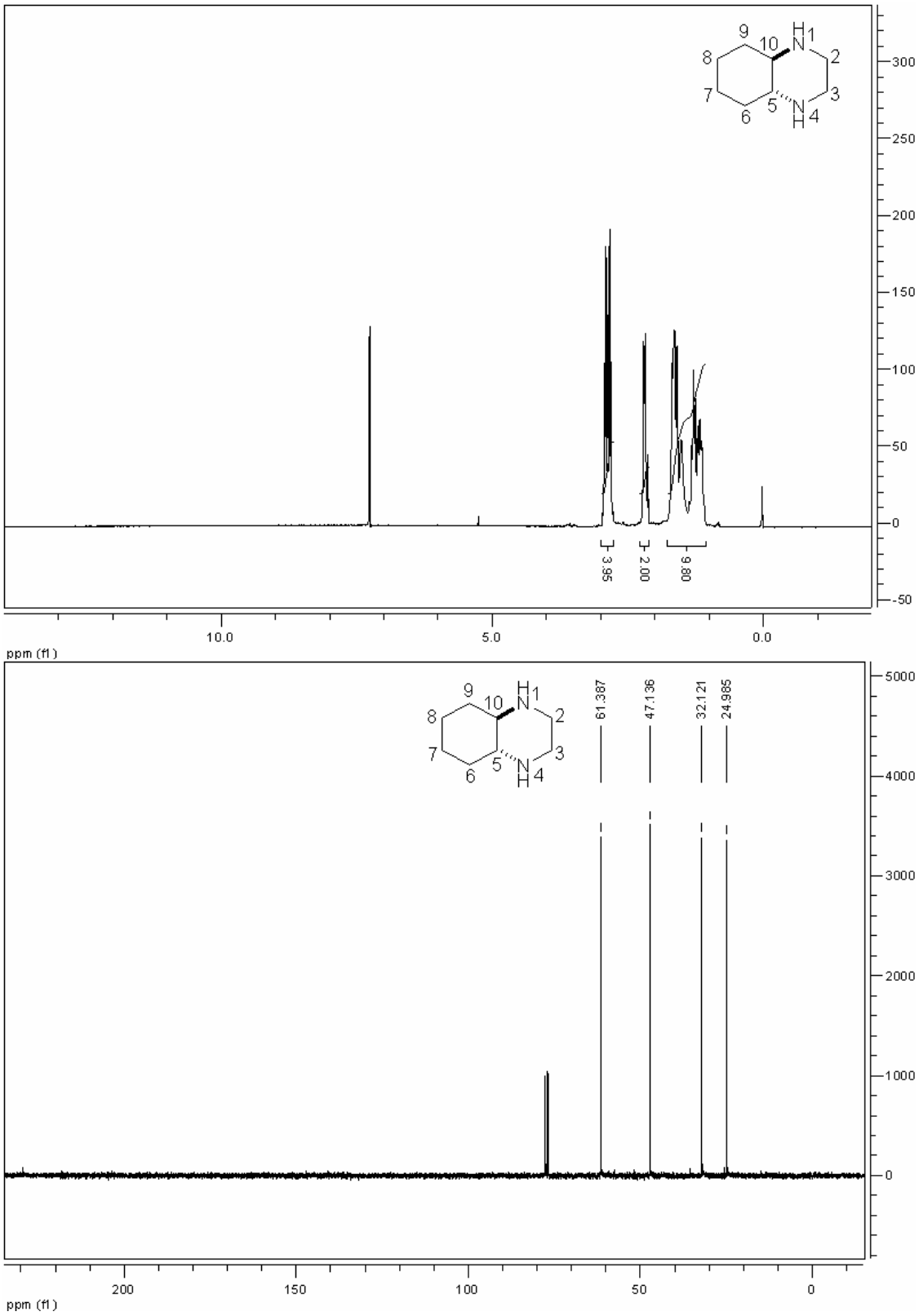
(±)-2-Phenylpiperazine
δ_H (300 MHz, $CDCl_3$): 7.40-7.20 (m, 5H, Ar), 3.73 (dd, 1H, $J_{2\text{-}3eq}$ = 2.8 Hz, $J_{2\text{-}3ax}$ = 10.2 Hz, H2), 3.11-2.80 (m, 5H, $H3_{eq}$, $H5_{ax}$, $H5_{eq}$, $H6_{ax}$, $H6_{eq}$), 2.69 (dd, 1H, $J_{2\text{-}3ax}$ = 10.2 Hz, J_{gem} = 11.9 Hz, $H3_{ax}$), 1.80 (bs, 2H, N-*H*); δ_C (75 MHz, $CDCl_3$): 142.8 (C_{ipso}), 128.5, 127.5, 126.9 (Ar), 62.1 (C2), 54.4, 47.9, 46.1 (C3, C4, C5); HRMS calcd. for $C_{10}H_{15}N_2$ $[M+H]^+$ *m/z* 163.1235, found *m/z* 163.0981.

(±)-1,4-Dibenzyl-2-phenylpiperazine
δ_H (300 MHz, $CDCl_3$): 7.45-7.10 (m, 15H, Ar), 3.71 (d, 1H, J_{gem} = 13.4 Hz, Ph-C*H*H'-N), 3.43 (s, 2H, Ph-CH_2-N), 3.36 (dd, 1H, $J_{2\text{-}3eq}$ = 3.0 Hz, $J_{2\text{-}3ax}$ = 10.3 Hz, H2), 2.85-2.67 (m, 4H, Ph-CH*H*'-N, H_{3eq}, H5, H6), 2.25-2.05 (m, 3H, H_{3ax}, H5', H6'); δ_C (75 MHz, $CDCl_3$): 142.3, 139.2, 138.0 (3 × C_{ipso}), 129.3, 128.9, 128.6, 128.3, 128.2, 127.5, 127.1, 126.8 (Ar), 67.4 (C2), 63.1 (N-*C*H_2-Ph), 62.1 (C4 or C5), 59.1 (N-*C*H_2-Ph), 53.3 (C4 or C5), 51.9 (C3); HRMS calcd. for $C_{24}H_{27}N_2$ $[M+H]^+$ *m/z* 343.2174, found *m/z* 343.2153.

(±)-1,4-Dibenzyl-2-methylpiperazine (contains a small impurity of (±)-1,4-dibenzyl-dimethylpiperazine according to mass spectrometry)
δ_H (300 MHz, $CDCl_3$): 7.35-7.20 (m, 10H, Ar), 4.05 (d, 1H, J_{gem} = 13.3 Hz, Ph-C*H*H'-N), 3.48 (s, 2H, Ph-CH_2-N), 3.19 (d, 1H, J_{gem} = 13.2 Hz, Ph-CH*H*'-N), 2.75-2.60 (m, 3H, H_{3eq}, H5, H6), 2.50 (dqd, 1H, $J_{2\text{-}3eq}$ = 3.0 Hz, $J_{2\text{-Me}}$ = 6.2 Hz, $J_{2\text{-}3ax}$ = 9.1 Hz, H2), 2.26-2.12 (m, 2H, H5', H6'), 2.02 (dd, 1H, *J* = 9.7 Hz, *J* = 10.5 Hz, H_{3ax}), 1.14 (d, 3H, $J_{2\text{-Me}}$ = 6.2 Hz, -CH_3); δ_C (75 MHz, C_6D_6): 140.1, 139.3 (2 × C_{ipso}), 129.2, 129.1, 128.5, 128.4 (2 × C_{ortho}, 2 × C_{meta}), 127.2, 127.0 (2 × C_{para}), 63.3, 61.1, 58.5, 55.7, 53.9, 51.5 (2 × Ph-*C*H_2-N, C2, C3, C5, C6), 16.7 (bs, -CH_3); HRMS calcd. for $C_{19}H_{25}N_2$ $[M+H]^+$ *m/z* 281.2018, found *m/z* 281.2026.

References

1) H. E. Gottlieb, V. Kotlyar and A. Nudelman, *J. Org. Chem.*, 1997, **62**, 7512-7515.
2) P. Vairaprakash and M. Periasamy, *J. Org. Chem.*, 2006, **71**, 3636-3638.
3) S. Pikul and E. J. Corey, *Org. Synth.*, 1993, **71**, 22-29.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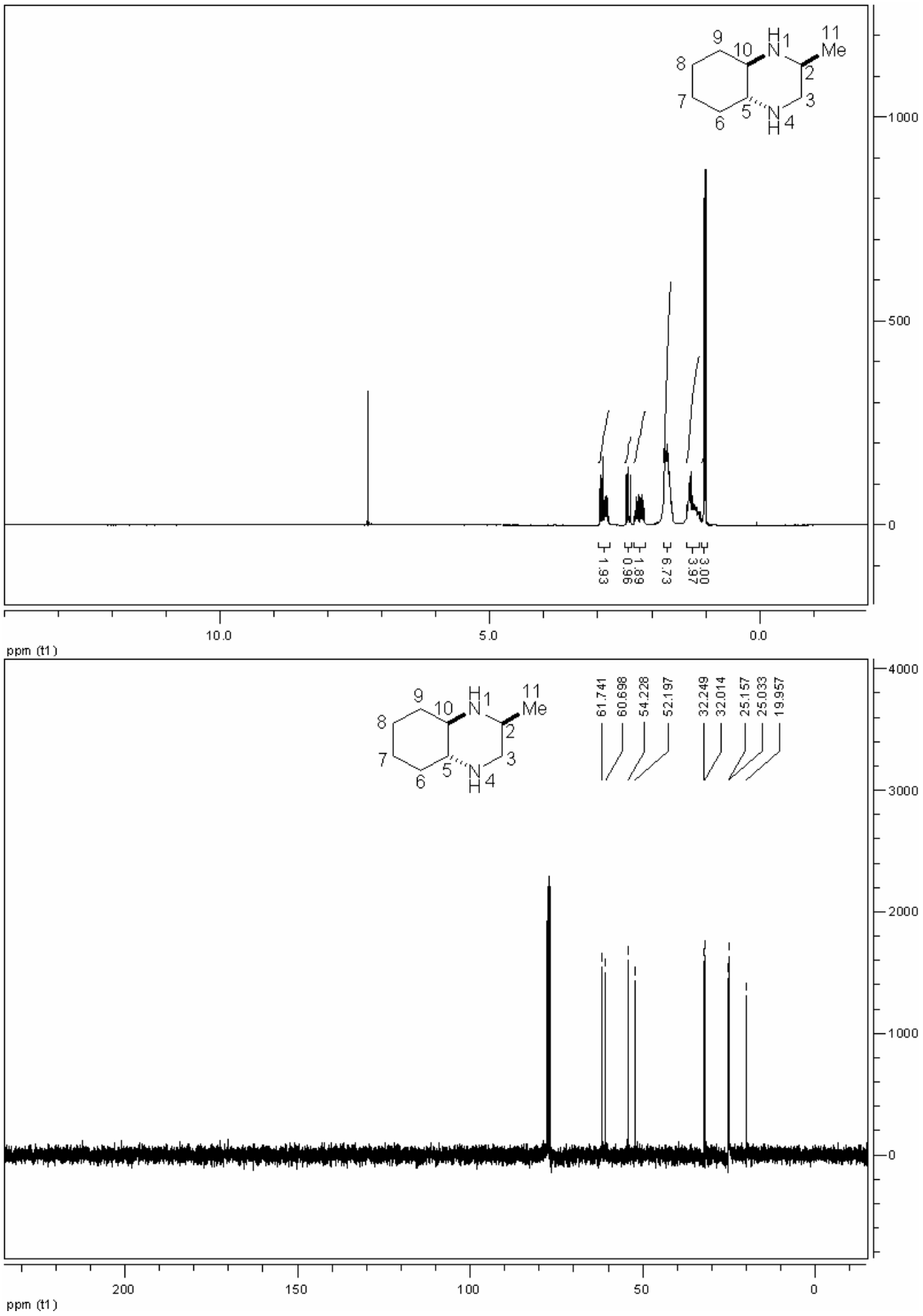
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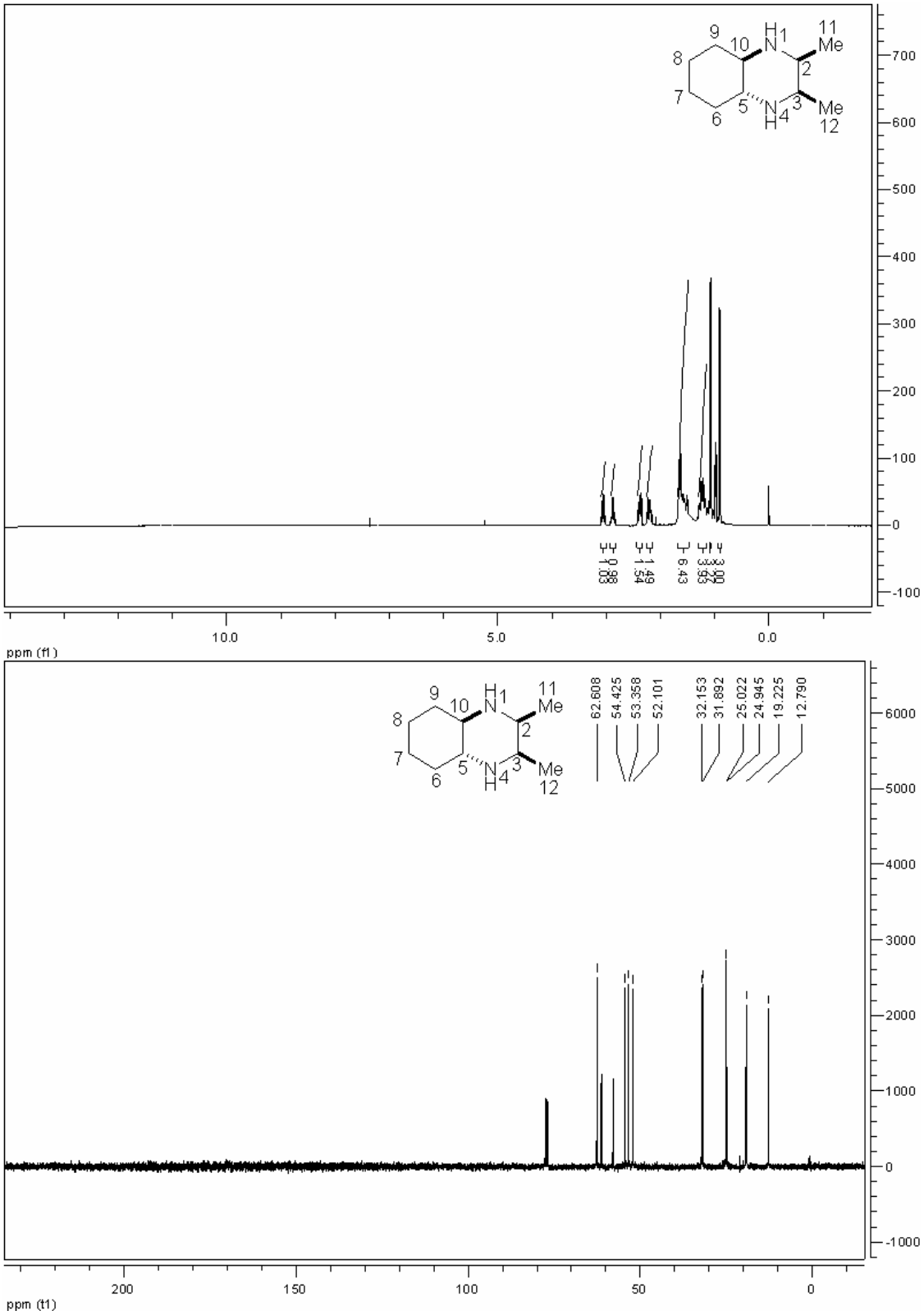
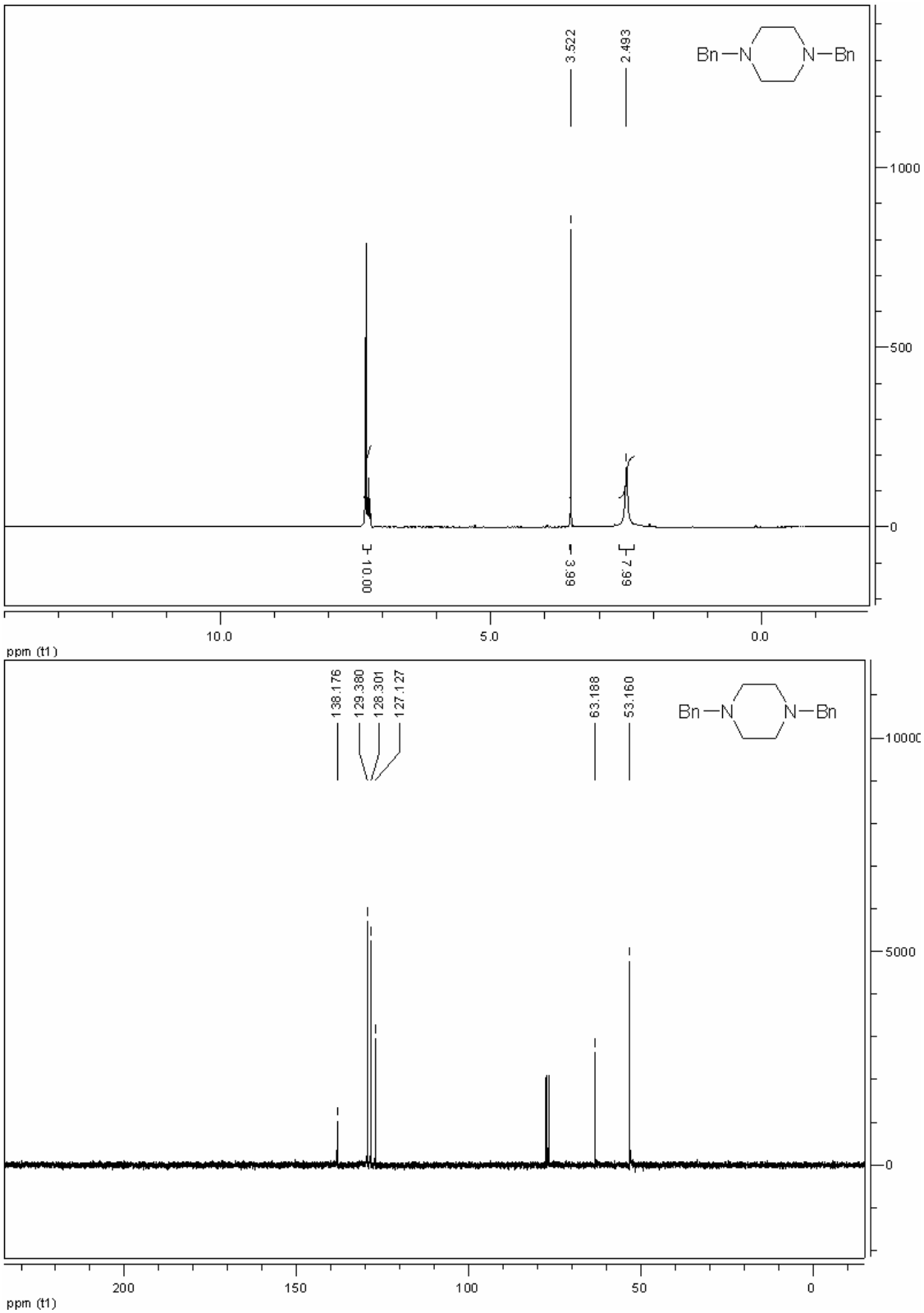


Minor isomer can be seen in spectra.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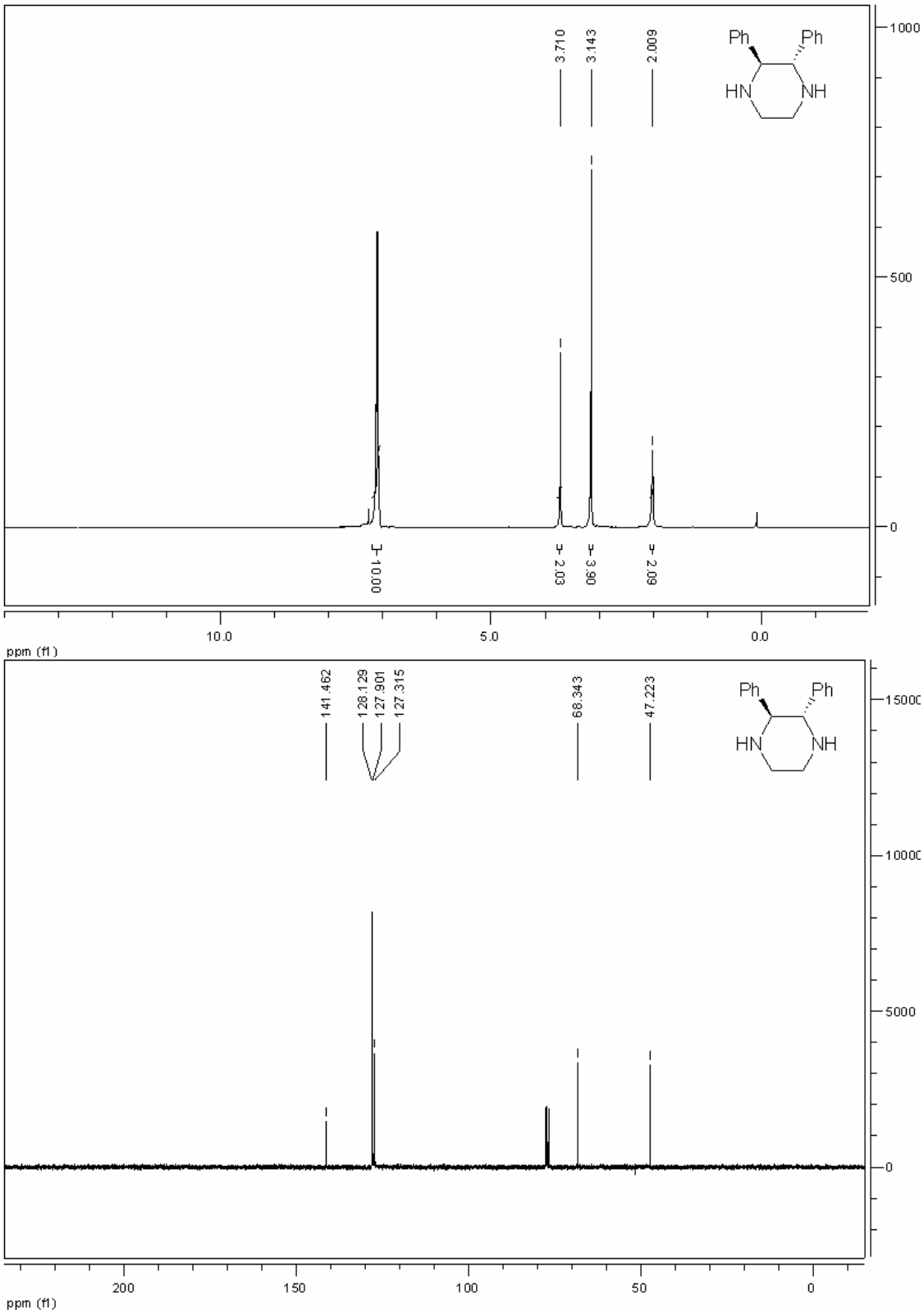
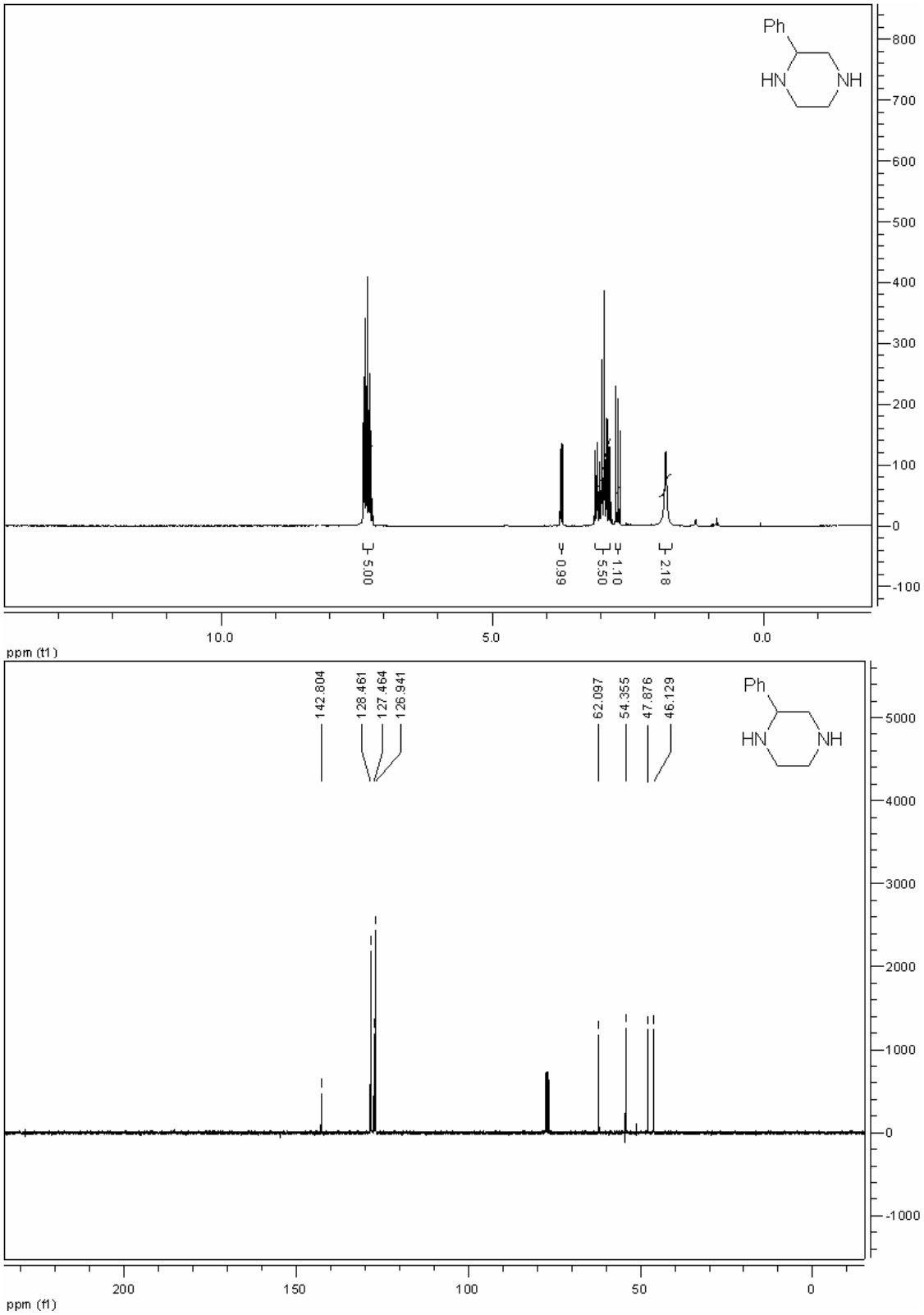


Artifact at 51 ppm



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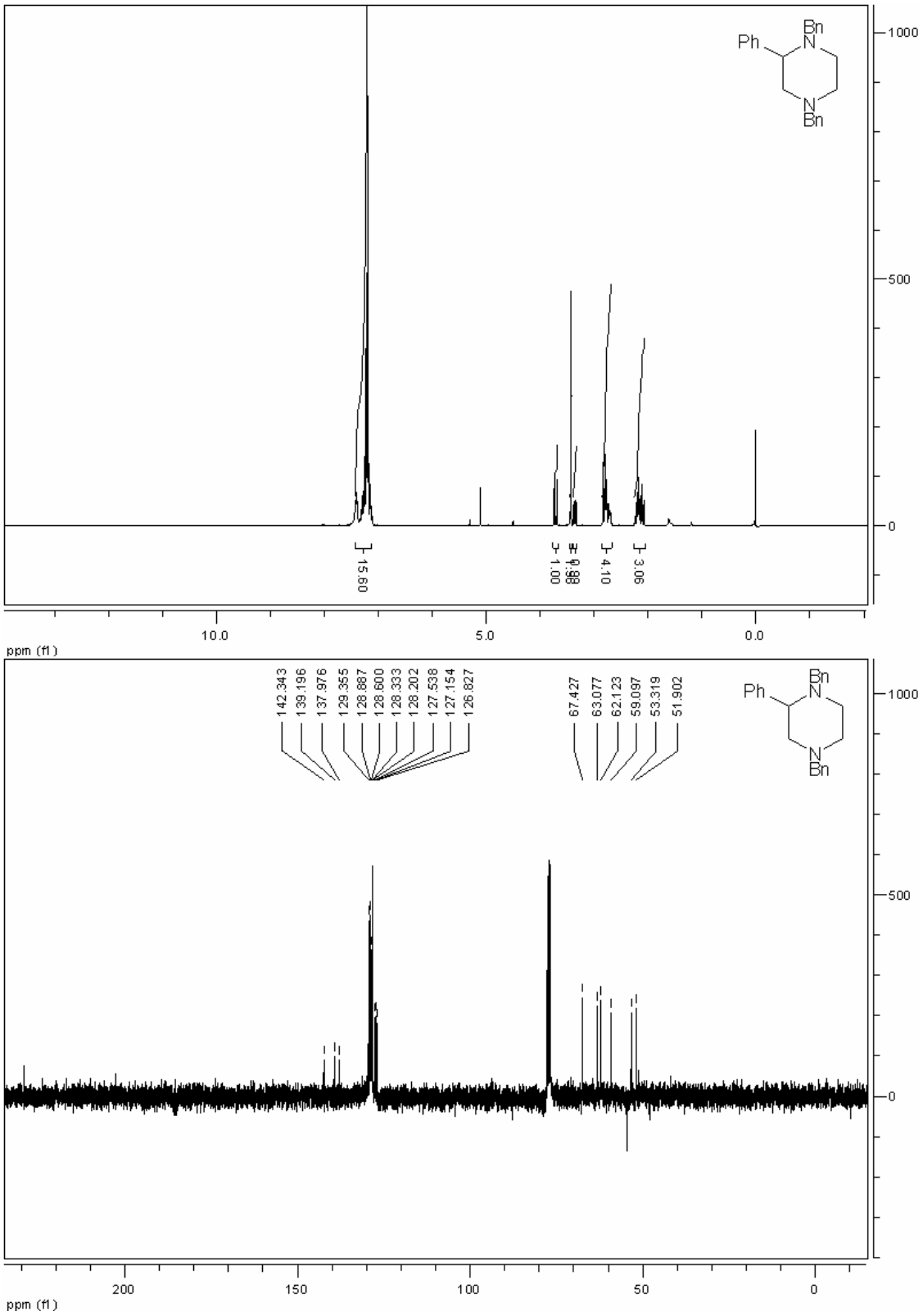
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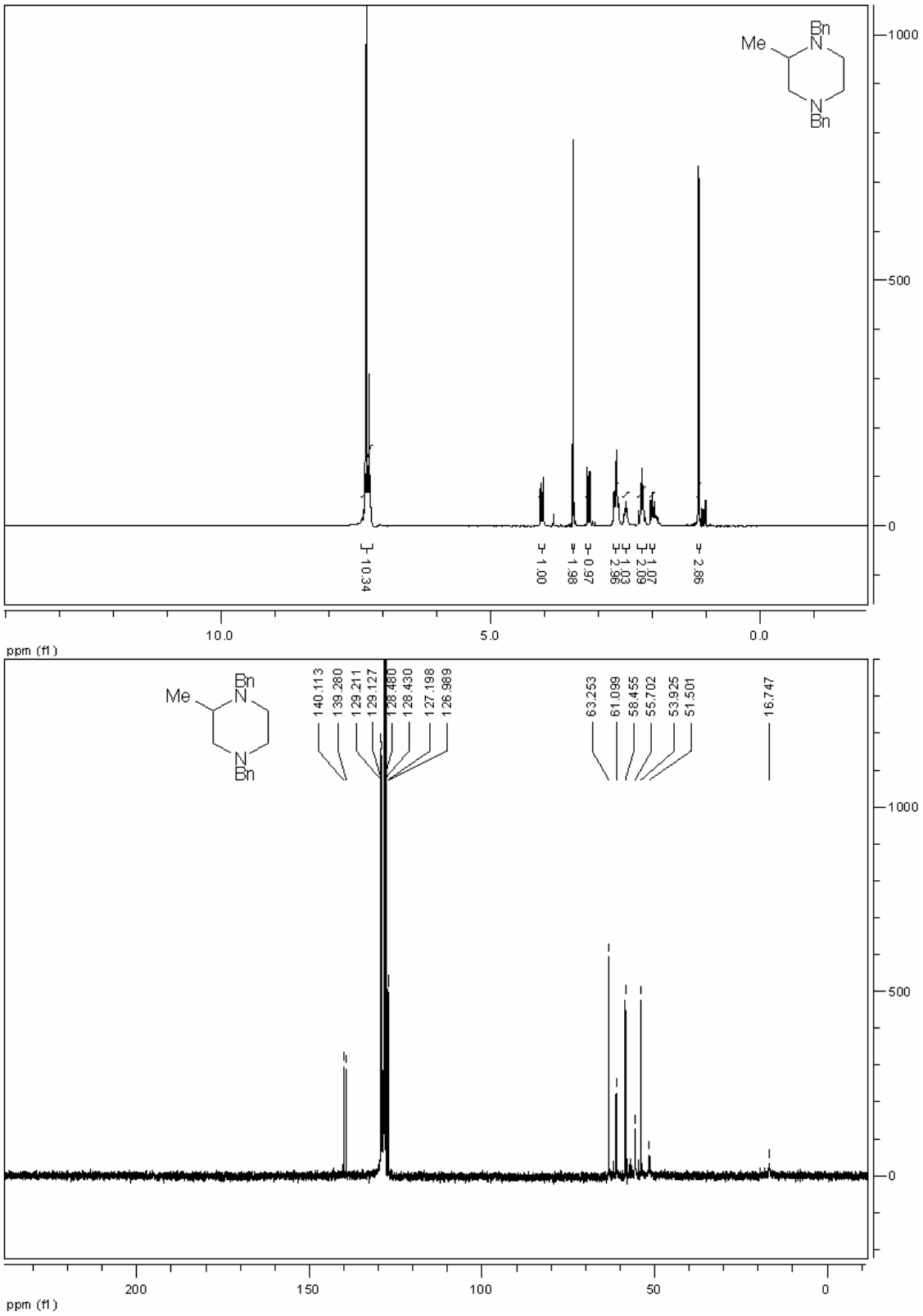
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200
150
100
50
0
ppm (f1)