Remote C-H Activation of Phenyl Substituted Alkenes by BH_3·THF: Mechanism and Applications

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Supporting Information

Preparation of starting materials

2,3,3-Trimethyl-1-1-diphenyl-1-butene (4)

Was prepared according literature methods[1].

2-Benzhydryl-3,3-dimethyl-1-butene (13)[2]

A solution of lithium *bis*-diphenylmethylcuprate was prepared by adding diphenymethyllithium (12 mmol, prepared by mixing phenylmethane (2.0 g) with 7.73 mL of a 1.56 M solution of *n*-BuLi in THF at 0°C) to a stirred slurry of CuBr (1.17 g, 8.18 mmol) in THF (10 mL) at 0 °C. 3,3-dimethyl-2-trifluoromethansulfonyloxy-1-butene[3] (1.0 g, 4.31 mmol) in THF (10 mL) was added, and the reaction mixture was stirred for 12 h at –15 °C. The reaction mixture was then diluted with hexane, filtered through a pad of celite, and concentrated on a rotary evaporator. Chromatography of the residue on silica gel using pentane as eluent afforded **13** in 80% yield.

^{1}H-NMR (300 MHz, $CDCl_3$) δ(ppm): 7.28-7.12 (m, 10H), 5.34 (s, 1H), 5.09 (s, 1H), 4.58 (s, 1H), 1.09 (s, 9H).

^{13}C-NMR, DEPT (75 MHz, $CDCl_3$) δ(ppm): 159.6 (C), 144.4 (2C), 129.2 (4CH), 128.1 (4CH), 125.9 (2CH), 113,6 (CH_2), 53.1 (CH), 37.0 (C), 29.9 ($3CH_3$).

MS m/z (%): 250 (M^+, 15), 193 (100), 167 (98), 159 (29), 115 (33).

HRMS for $C_{19}H_{22}$ calcd: 250.1721; found: 250.1721.

3,3-Dimethyl-1,1-diphenyl-1-butene (16)[4]

To a mixture of *n*-BuLi (7.22 mL, 11 mmol, 1.61 M) and THF (7 mL) at 0 °C was added dropwise a solution of diethylbenzhydrylphosphate (3.53 g, 11 mmol) in THF (14 mL). The ice bath was removed, and the mixture was stirred at room temperature for 1 h. To the resulting mixture was added dropwise a solution of (1.0 g, 11 mmol) of pivalaldehyde in THF (7 mL). The mixture was stirred for 2 h and treated with saturated aqueous NH_4Cl solution. The mixture was separated, and the aqueous layer was washed with ether. The combined organic layers were dried with $MgSO_4$, and the solvent was removed under reduced pressure. Purification by chromatography (pentane/ether 9/1) afforded 2.16g of **16** (79%).

^{1}H-NMR (300 MHz, $CDCl_3$) δ(ppm): 7.25-7.07 (m, 10H), 6.00 (s, 1H), 0.88 (s,3H).

^{13}C-NMR, DEPT (75 MHz, $CDCl_3$) δ(ppm): 144.1 (C), 140.8 (C), 140.1 (CH), 139.1 (C), 130.3 (2CH), 128.0 (2CH), 127.7 (2CH), 126.8 (2CH), 126.7 (CH), 126.5 (CH), 33.9 (C), 31.3 ($3CH_3$).

MS, m/z (%): 236 (M^+, 66), 221 (100), 191 (16), 178 (27), 165 (30), 143 (81), 128 (33), 91 (44).

IR (film KBr-disk): 2958, 1493, 1475, 1443, 702 cm^{-1}.

HRMS for $C_{18}H_{20}$ calcd: 236.1565; found: 236.1555.

(*E*)-3,3-Dimethyl-1-(4-methylphenyl)-1-phenyl-1-butene (*E*-18)

To a solution of 1-bromo-4-methylbenzene (0.79 g, 4.61 mmol) in THF (4 mL) at –78 °C was added *n*-BuLi (2.86 mL, 4.61 mmol, 1.61 M). After 1 h the solution was warmed to –45 °C and a solution of $ZnBr_2$ (3.35 mL, 5 mmol, 1.5 M) was added. After stirring at room temperature for 30 min a solution of $Pd(dba)_2$ (120 mg, 0.2 mmol), PPh_3 (0.20 g, 0.8 mmol) and (*E*)-1-(*tert*-butyl)-2-(4-methylphenyl)-1-ethenyl iodide (1.2 g, 4.19 mmol) (prepared by Sonogashira cross coupling between iodobenzene and 3,3-dimethyl-1-butyne[5] followed by treatment with DIBAL-H and iodide[6]) in THF (4 mL) was added. Stirring was mantained overnight. Saturated aqueous NH_4Cl (15 mL) was added and the mixture was extracted with ether, dried over $MgSO_4$ and concentrated under reduced pressure. Purification by chromatography of the residue on silica gel using pentane as eluent afforded 1 g (98% yield) of *E*-**18**.

^{1}H-NMR (300 MHz, $CDCl_3$) δ(ppm): 7.36-7.05 (m, 9H), 6.09 (s, 1H), 2.33 (s, 3H), 0.99 (s, 9H).

^{13}C-NMR, DEPT (75 MHz, $CDCl_3$) δ(ppm): 141.3 (C), 142.0 (C), 139.2 (CH), 138.8 (C), 136.2 (C), 130.3 (2CH), 128.7 (2CH), 127.7 (2CH), 126.7 (2CH), 126.6 (CH), 33.9 (C), 31.3 ($3CH_3$), 20.9 (CH_3).

MS, m/z (%): 250 (M^+, 61), 235 (100), 157 (42), 143 (50), 128 (20), 105 (28), 91 (25).

IR (film, KBr-disk): 2957, 1510, 816, 701 cm^{-1}.

HRMS for $C_{19}H_{22}$ calcd: 250.1721; found: 251.1752.

(*Z*)- 3,3-Dimethyl-1-(4-methylphenyl)-1-phenyl-1-butene (*Z*-18)

Analogous procedure as described for (*E*)-1-(4-methylphenyl)-1-phenyl-1-propene (*E*-18) from bromobenzene (0.47 g, 3 mmol), *n*-BuLi (1.86 mL, 3 mmol, 1.61 M), ZnBr (2.18 mL, 3.3 mmol, 1.5 M), $Pd(dba)_2$ (0.08 g, 0.14 mmol, 5%), PPh_3 (.128 g. 0.49 mmol, 18%) and (*Z*)-1-(tert-butyl)-2-phenyl-1-ethenyl iodide (0.82 g, 2.73 mmol) afforded Z-**18** (0.45 g, 67% yield).

^{1}H-NMR (300 MHz, $CDCl_3$) δ(ppm): 7.16-6.98 (m, 9H), 5.99 (s, 1H), 2.30 (s, 3H), 0.89 (s, 9H).

^{13}C-NMR, DEPT (75 MHz, $CDCl_3$) δ(ppm): 144.3 (C), 140.0 (CH), 139.1 (C), 137.7 (C), 136.2 (C), 130.2 (2CH), 128.4 (2CH), 127.9 (2CH), 126.8 (2CH), 126.4 (CH), 33.9 (C), 31.3 ($3CH_3$), 21.2 (CH_3).

MS, m/z (%): 250(M^+, 60), 235 (100), 157 (36), 143 (43), 128 (17),105 (22), 91 (19).

IR (film, KBr-disk): 2958, 1444, 737, 697 cm^{-1}.

HRMS for $C_{19}H_{21}$ calcd: 250.1721; found: 250.1703.

2-Methyl-3-phenylbicyclo[2.2.1]hept-2-ene (20)

n-BuLi (19.7 mL, 1.44 M, 28.4 mmol) was added dropwise to *i*-Pr_2NH (4.2 mL, 29.6 mmol) cooled to -78 ºC. THF (26 mL) was added and after stirring at room temperature for 30 min the mixture was cooled to 0 ºC. A solution of bicyclo[2.2.1]heptan-2-one (2.5 g, 22.7 mmol) in THF (10 mL) was then added dropwise. After 3 h, MeI (4.24 mL, 68.1 mmol) was added dropwise at 0 ºC and stirring was mantained for 3 h at room temperature. Aqueous HCl (20 mL, 1M) was added and the mixture was extracted with Et_2O. The combined organic layers were dried over anhydrous Na_2SO_4, filtered and concentrated under reduced pressure. Purification by chromatography of the residue (SiO_2; pentane/ether 9.4/6) afforded a mixture of *exo* and *endo* 3-methylbicyclo[2.2.1]heptan-2-one (2.15 g, 76%).

n-BuLi (5 mL, 1.58 M, 7.9 mmol) was added dropwise to *i*-Pr_2NH (1.15 mL, 8.2 mmol) cooled to -78 ºC. THF (3 mL) was added and after stirring at room temperature for 30 min the mixture was cooled to -78 ºC. A solution of 3-methylbicyclo[2.2.1]heptan-2-one (0.781 g, 6.3 mmol) in THF (3 mL) was then added dropwise. After 1 h, a solution of $PhNTf_2$ (2.36 g, 6.62 mmol) in THF (4 mL) was added dropwise at -78 ºC and stirring was mantained overnight at room temperature. Aqueous HCl (5 mL, 1M) was added and the mixture was extracted with Et_2O (2 X 10 mL). The combined organic layers were dried over anhydrous Na_2SO_4, filtered and concentrated under reduced pressure. Purification by chromatography of the residue (SiO_2; pentane) afforded 3-methylbicyclo[2.2.1]hept-2-en-2-yl trifluoromethanesulfonate (0.987 g, 61%).

A solution of $ZnBr_2$ (15.44 mL, 1.2 M, 18.5 mmol) was added dropwise to a solution of PhLi (9.64 mL, 1.76 M, 17.0 mmol) in THF (6 mL) cooled to -40 ºC. Stirring was mantained for 30 min at -40 ºC and 30 min at room temperature. A solution of 3-methylbicyclo[2.2.1]hept-2-en-2-yl trifluoromethanesulfonate

(0.987 g, 3.86 mmol), $Pd(PPh_3)_4$ (4%, 0.179 g, 0.154 mmol) in THF (8 mL) was then added dropwise. Stirring was mantained for 3 h at 50 ºC. Saturated aqueous NH_4Cl (14 mL) was added and the mixture was extracted with Et_2O. The combined organic layers were dried over anhydrous Na_2SO_4, filtered and concentrated under reduced pressure. Purification by chromatography of the residue (SiO_2; pentane) afforded **20** (0.683 g, 96%).

^{1}H-NMR (300 MHz, $CDCl_3$) δ(ppm): 7.48-7.41 (m, 4H), 7.30 (m, 1H), 3.29 (s, 1H), 2.92 (s, 1H), 2.07 (s, 3H), 196-1.86 (m, 2H), 1.68 (d, J=8 Hz, 1H), 1.50 (m, 1H), 1.34-1.28 (m, 2H).

^{13}C-NMR, DEPT (75 MHz, $CDCl_3$) δ(ppm): 139.66, 139.63, 137.6, 128.1, 126.6, 125.5, 49.5, 46.9, 46.4, 27.1, 25.8, 13.7.

IR (KBr-disk): 2958, 2870, 1682, 1497, 1447, 753, 700 cm^{-1}.

MS, m/z (%): 184(29), 156(100).

HRMS for $C_{14}H_{16}$, calcd: 184.1252, found: 184.1243.

2-Ethyl-3-phenylbicyclo[2.2.1]hept-2-ene (23)

Analogous procedure as described for **20** using 3-ethylbicyclo[2.2.1]hept-2-en-2-yl trifluoromethanesulfonate (0.416 g, 1.54 mmol), $ZnBr_2$ (6.2 mL, 1.2 M, 7.4 mmol), PhLi (3.9 mL, 1.76 M, 6.8 mmol), $Pd(PPh_3)_4$ (4%, 0.071 g, 0.062 mmol) afforded **23** (0.263g, 86% yield).

^{1}H-NMR (300 MHz, $CDCl_3$) δ(ppm): 7.19-7.10 (m, 4H), 7.02 (m, 1H), 2.99 (s, 1H), 2.78 (s, 1H), 2.25 (sextet –coalescence of dc-, J=15, 7.5 Hz, 1H), 2.06 (sextet –coalescence of dc-, J=15, 7.5 Hz, 1H), 1.68-1.59 (m, 2H), 1.37 (m, 1H), 1.21 (m, 1H), 1.06-1.03 (m, 2H), 1.01 (t, J=7.5 Hz, 3H).

^{13}C-NMR, DEPT (75 MHz, $CDCl_3$) δ(ppm): 145.6, 139.1, 137.7, 128.1, 126.7, 125.6, 47.2, 47.0, 46.5, 26.8, 26.3, 20.9, 13.2.

IR (KBr-disk): 2961, 2869, 1496, 698 cm^{-1}.

MS, m/z (%): 198(34), 170(90), 155(100).

HRMS for $C_{15}H_{18}$, calcd: 198.1409, found: 198.1390.

15-Ethyl-16-phenyltetracyclo[6.6.2.0^{2,7}.0^{9,14}]hexadeca-2(7),3,5,9(14),10,12,15-heptene (26)

To a solution of ethyliodide (0.37 g, 2.4 mmol) in ether (4 mL) at –78 °C a solution of *n*-BuLi (3.36 mL, 1.5 M) was added. After 0.5 h at –78 °C, the reaction solution was warmed to room temperature and kept at this temperature for 0.5 h. The solution was then cooled to 0 °C and 15-phenyl-16-(phenylsulfonyl)tetracyclo[6.6.2.0^{2,7}.0^{9,14}]hexadeca-2(7),3,5,9(14),10,12,15-heptaene[7] (0.84 g, 2 mmol) was added and heated at reflux for 6 h. The reaction was diluted with CH_2Cl_2 and washed with a saturated solution of NH_4Cl. The combined organic layers were dried over $MgSO_4$ and concentrated under vacuum. Purification by chromatography over silica gel using pentan/CH_2Cl_2 9/1 as eluent, afforded 168 mg (27% yield) of **26** and 470 mg of starting material were recovered.

^{1}H-NMR (300 MHz, $CDCl_3$) δ(ppm): 7.33-6.87 (m, 12H), 5.16 (s, 1H), 4.97 (s, 1H), 2.25 (q, J=7.5 Hz, 2H), 1.02 (t, J=7.5 Hz, 3H).

^{13}C-NMR, DEPT (75 MHz, $CDCl_3$) δ(ppm): 147.5 (C), 146.4 (C), 145.9 (C), 142.8 (C), 139.0 (C), 128.1 (2CH), 127.3 (2CH), 126.5 (CH), 124.6 (2CH), 124.5 (2CH), 122.6 (2CH), 122.5 (2CH).

MS m/z(%): 308 (M^+, 38), 279 (33), 178 (100).

Products of C-H activation

General Procedure: Preparation of 1-(2-hydroxyphenyl)-3,3-dimethyl-1-phenyl-2-butanol (17)

A solution of BH_3·THF (9 mL, 9 mmol, 3 equiv) was added to a solution of 3,3-dimethyl-1,1-diphenyl-1-butene (**16**) (0.71 g, 3 mmol) in THF (25 mL) at room temperature under argon atmosphere. After stirring at 50 °C for 24 h the resulting mixture was quenched by addition of 2M NaOH (12 mL) and 30% H_2O_2(12 mL). The resulting mixture was stirred at room temperature for 30 min and was then extracted with diethyl ether (10 mL). The combined organic layers were dried over $MgSO_4$, filtered and

concentrated under reduced pressure. Purification by chromatography of the residue on silica flash (elution with pentane/diethyl ether 7/3) afforded the product **17** as a white solid (478 mg, 60% yield).

2-[(2-Hydroxyphenyl)(phenyl)methyl]-3,3-dimethyl-1-butanol (6)

^{1}H-NMR (300 MHz, $CDCl_3$) δ(ppm): 7.22-7.01 (m, 7H), 6.77-6.73 (m, 2H), 4.29 (d, J=5.3 Hz, 1H), 3.73 (dd, J=11, 3.3 Hz, 1H), 3.52 (dd, J=11, 9.9 Hz, 1H), 2.3 (ddd, J=9.9, 5.3, 3.3 Hz, 1H), 0.91 (s, 9H).

^{13}C-NMR, DEPT (75 MHz, $CDCl_3$) δ(ppm): 154 (C), 142.1 (C), 131.1 (C), 130.9 (CH), 129.3 (2CH), 128.3 (2CH), 127.8 (CH), 126.1 (CH), 120.1 (CH), 117.2 (CH), 62.2 (CH_2), 53.9 (CH), 46.5 (CH), 34.4 (C), 28.7 ($3CH_3$).

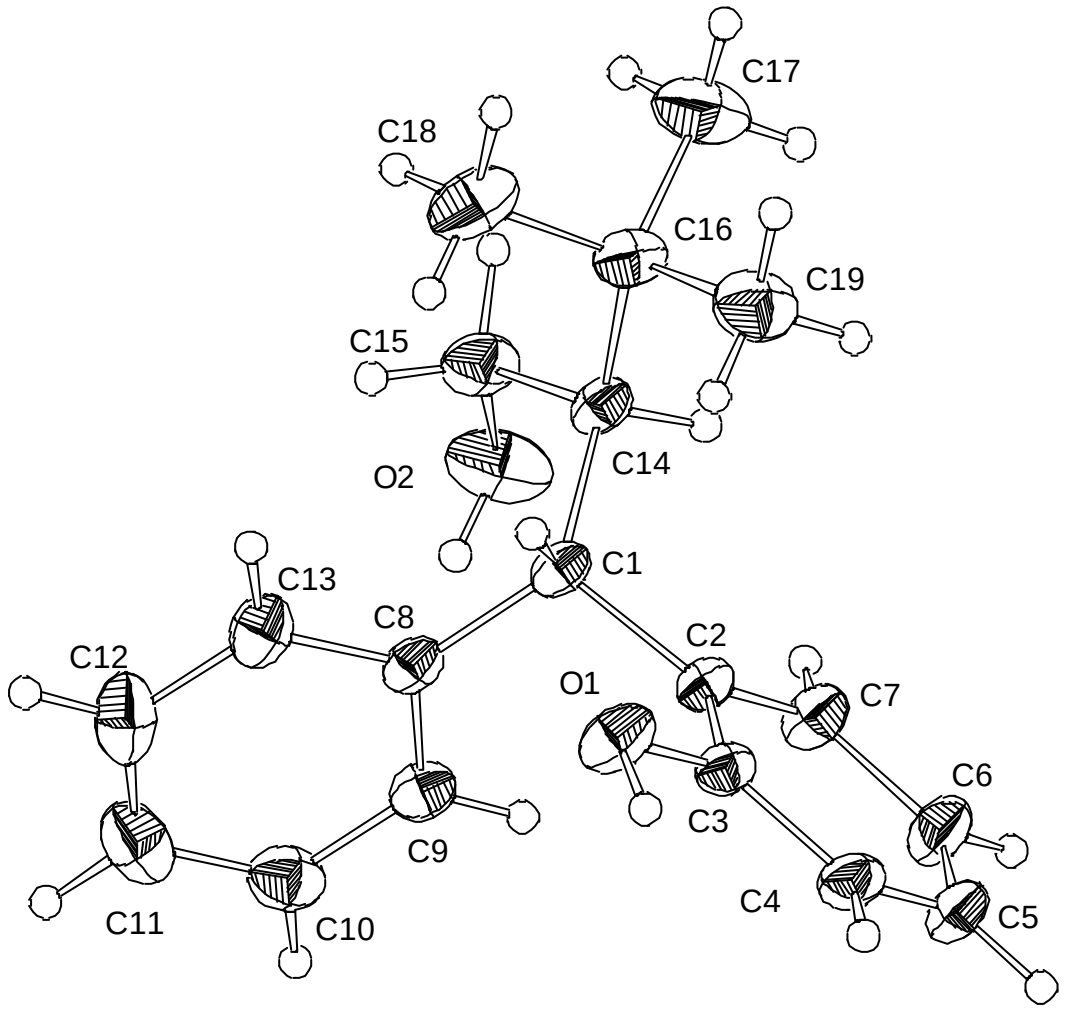
MS, m/z (%): 284 (M^+, 29), 183 (100).

IR (KBr): 3400, 3306, 2962, 1455, 1368, 1232, 752, 704 cm^{-1}.

HRMS for $C_{19}H_{24}O_2$, calcd: 284.1776; found: 284.1756.

X-ray

Crystallographic data (excluding structure factors) for the structure **6** has been deposited with the Cambridge Crystallographic Data Centre as supplementary publication no. CCDC-161451. Copies of the data can be obtained free of charge on application to CCDC, 12 Union Road, Cambridge CB21EZ, UK (fax: (+44)1223-336-033; E-mail: deposit@ccdc.cam.ac.uk).



2-Benzhydryl-3,3-dimethyl-1-butanol (14)

^{1}H-NMR (300 MHz, $CDCl_3$) δ(ppm): 7.4-7.1 (m, 10H), 4.20 (d, J=8.2 Hz, 1H), 3.74-3.61 (m, 2H), 234 (ddd, J=8, 5.3, 3.3 Hz, 1H), 0.91 (s, 9H).

^{13}C-NMR, DEPT (75 MHz, $CDCl_3$) δ(ppm): 146.1 (C), 144.0 (C), 129.1 (2CH), 128.7 (2CH), 128.6 (2CH), 128.4 (2CH), 126.3 (CH), 125.9 (CH), 62.6 (CH_2), 54.2 (CH), 52.1 (CH), 34.5 (C), 29.3 ($3CH_3$).

MS, m/z (%): 268 (M^+, 17), 167 (100).

1-(2-Hydroxyphenyl)- 2,3,3-trimethyl-1-phenyl-2-butanol (15)

^{1}H-NMR (300 MHz, $CDCl_3$) δ(ppm): 7.46-7.43 (m, 2H), 7.20-6.93 (m, 5H), 6.77-6.74 (m, 1H), 6.66-6.61 (m, 1H), 4.07 (s, 1H), 1.11 (s, 3H), 0.9 (s, 9H).

^{13}C-NMR, DEPT (75 MHz, $CDCl_3$) δ(ppm): 154.6 (C), 143.4 (C), 132.2 (CH), 130.2 (C), 129.3 (2CH), 128.5 (2CH), 128.1 (CH), 126.5 (CH), 120.0 (CH), 118.2 (CH), 81.3 (C), 59.5 (CH), 39.5 (C), 26.4 ($3CH_3$), 24.3 (CH_3).

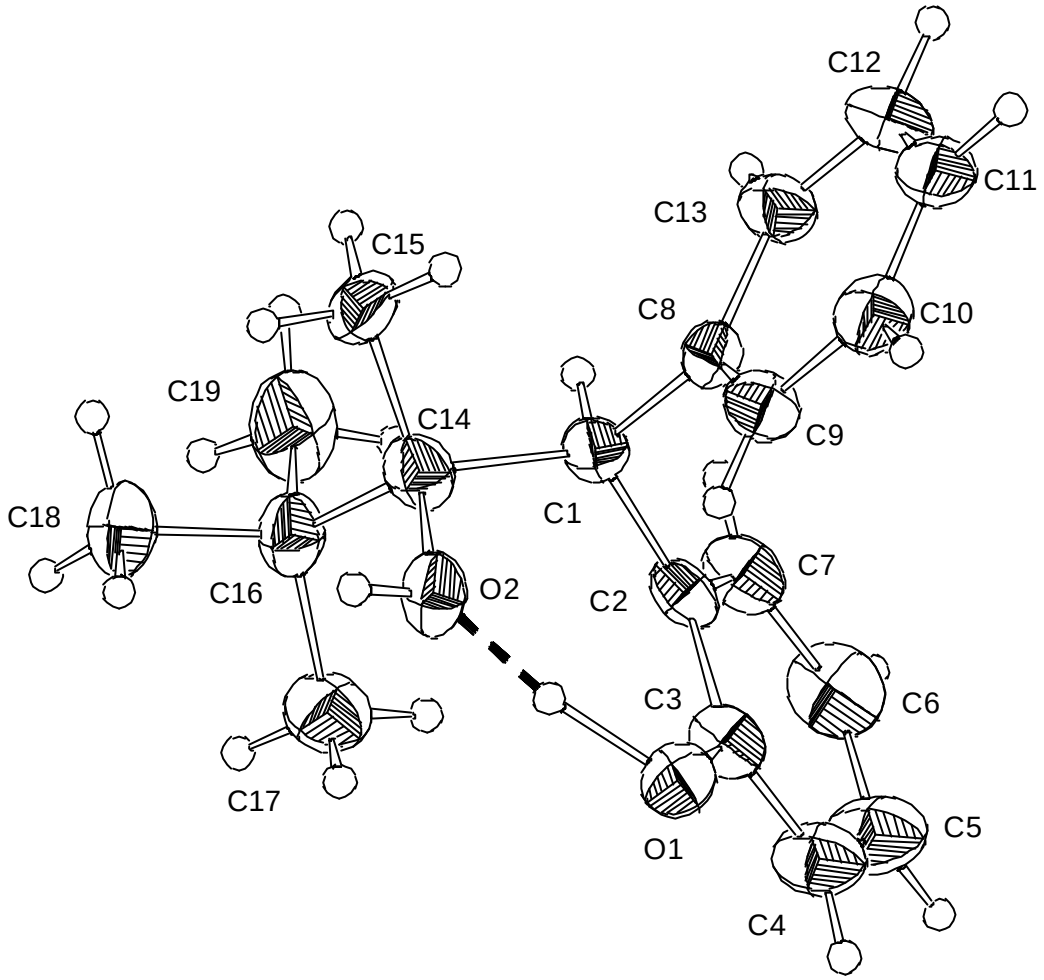
MS, m/z (%): 284 (M^+, 1), 209 (22), 184 (100), 165 (23), 101 (79), 83 (28).

IR (KBr): 3370, 2955, 1580, 1488, 1253, 752 cm^{-1}.

HRMS for $C_{19}H_{24}O_2$ calcd: 284.1776; found: 284.1750.

X-ray

Crystallographic data (excluding structure factors) for the structure **15** has been deposited with the Cambridge Crystallographic Data Centre as supplementary publication no. CCDC-161450. Copies of the data can be obtained free of charge on application to CCDC, 12 Union Road, Cambridge CB21EZ, UK (fax: (+44)1223-336-033; E-mail: deposit@ccdc.cam.ac.uk).



1-(2-Hydroxyphenyl)-3,3-dimethyl-1-phenyl-2-butanol (17)

^{1}H-NMR (300 MHz, $CDCl_3$) δ(ppm): 7.18-6.89 (m, 7H), 6.73-6.23 (m, 2H), 4.19 (d, J=2.9 Hz, 1H), 3.85 (d, J=2.9 Hz, 1H), 0.78 (s, 9H).

^{13}C-NMR, DEPT (75 MHz, $CDCl_3$) δ(ppm): 155.3 (C), 142.3 (C), 132.8 (CH), 128.6 (CH), 128.4 (2CH), 128.1 (2CH), 126.3 (C), 126.1 (CH), 120.0 (CH), 117.6 (CH), 83.4 (CH), 53.4 (CH), 35.9 (C), 26.3 ($3CH_3$).

MS m/z (%): 270 (M^+, 1), 184 (100), 165 (20), 106 (13).

IR (KBr): 3428, 2959, 1583, 1495, 1254, 751 cm^{-1}.

HRMS for $C_{18}H_{22}O_2$ calcd: 270.1620; found: 270.1611.

1-(2-Hydroxy-4-methylphenyl)-3,3-dimethyl-1-phenyl-2-butanol (19a)

^{1}H-NMR (300 MHz, $CDCl_3$) δ(ppm): 7.21-6.49 (m, 8H), 4.18 (d, J=3.1 Hz, 1H), 3.88 (d, J=3.1 Hz, 1H), 2.17 (s, 3H), 0.82 (s, 9H).

^{13}C-NMR, DEPT (75 MHz, $CDCl_3$) δ(ppm): 155.2 (C), 142.6 (C), 138.7 (C), 132.7 (CH), 128.5 (2CH), 128.1 (2CH), 126.2 (CH), 123.1 (C), 120.9 (CH), 118.4 (CH), 83.7 (CH), 53.3 (CH), 35.9 (C), 26.3 ($3CH_3$), 20.9 (CH_3).

MS m/z (%): 284 (M^+, 1), 198 (100), 183 (33), 165 (13), 120 (15).

IR (KBr): 3389, 2870, 1447, 1270, 718 cm^{-1}.

HRMS for $C_{15}H_{16}O_2$ calcd: 284.1776; found: 284.1796.

1-(2-Hydroxyphenyl)-3,3-dimethyl-1-(4-methylphenyl)-2-butanol (19b)

^{1}H-NMR (300 MHz, $CDCl_3$) δ(ppm): 7.24-6.51 (m, 8H), 4.2 (d, J=3.1 Hz, 1H), 3.91 (d, J=3.1 Hz, 1H), 2.19 (s, 3H), 0.83 (s, 9H).

^{13}C-NMR, DEPT (75 MHz, $CDCl_3$) δ(ppm): 155.5 (C), 139.2 (C), 135.8 (C), 132.8 (CH), 129.2 (2CH), 128.6 (CH), 128.0 (2CH), 126.4 (C), 120.0 (CH), 117.7 (CH), 83.8 (CH), 53.4 (CH), 35.9 (C), 26.3 ($3CH_3$), 20.8 (CH_3).

MS m/z (%): 284 (M^+, 1), 198 (100), 183 (39), 165 (13).

IR (KBr): 3412, 2957, 1488, 1250, 753 cm^{-1}.

HRMS for $C_{19}H_{24}O_2$ calcd: 284.1776; found: 284.1761.

(3-Phenylbicyclo[2.2.1]hept-2-yl)methanol (21)

^{1}H-NMR (300 MHz, $CDCl_3$) δ(ppm): 7.22-7.08 (m, 5H), 3.59 (dd, J=11.1, 5.8 Hz, 1H), 3.40 (dd, J=11.1, 8.9 Hz, 1H), 3.21 (dd, J=11.7, 2.8 Hz, 1H), 2.42-2.37 (m, 3H), 1.74 (dt, J=8.4, 2.7 Hz, 1H), 1.60-1.53 (m, 2H), 1.46-1.37 (m, 3H), 1.21 (s, 1H).

^{13}C-NMR, DEPT (75 MHz, $CDCl_3$) δ(ppm): 140.5, 129.6, 127.9, 125.8, 62.4, 47.4, 43.8, 42.6, 40.5, 39.5, 23.0, 22.7.

MS m/z (%):202(M^+, 16), 184(54), 91(100).

IR (KBr): 3338, 2961, 2879, 1494, 1446, 1023, 756, 704 cm^{-1}.

HRMS for $C_{14}H_{18}O$, calcd: 202.1357; found: 202.1343.

[3-(2-Hydroxyphenyl)bicyclo[2.2.1]hept-2-yl]methanol (22)

^{1}H-NMR (300 MHz, $CDCl_3$) δ(ppm): 7.32 (d, J=7.6 Hz, 1H), 7.08 (t, J=7.8 Hz, 1H), 6.89 (t, J=6.8 Hz, 1H), 6.73 (d, J=8.1 Hz, 1H), 3.51-3.39 (m, 2H), 3.28 (d, J=11.1 Hz, 1H), 2.62-2.55 (m, 2H), 2.49 (s, 1H), 1.94 (m, 1H), 1.70-1.62 (m, 2H), 1.49-1.34 (m, 3H).

^{13}C-NMR, DEPT (75 MHz, $CDCl_3$) δ(ppm): 154.4, 129.4, 129.0, 127.1, 120.5, 116.6, 63.9, 43.4, 42.9, 41.1, 40.5, 24.1, 22.7.

IR (KBr): 3536, 2954, 1630 cm^{-1}.

1-[3-(2-Hydroxyphenyl)bicyclo[2.2.1]hept-2-yl]-1-ethanol (24)

mp 173 ºC

^{1}H-NMR (300 MHz, $CDCl_3$:CD_3OD, 4:1) δ(ppm): 7.34 (dd, J=8.1, 1.5 Hz, 1H), 7.00 (td, J=8.1, 1.5 Hz, 1H), 6.81-6.74 (m, 2H), 3.81 (dc, J=10.3, 5.9 Hz, 1H), 3.56 (dd, J=11.8, 3.7 Hz, 1H), 2.34 (s, 1H), 2.27 (s, 1H) 2.06 (m, 1H), 1.92 (m, 1H), 1.58 (d, J=8.8 Hz, 1H), 1.52-1.39 (m, 4H), 1.07 (d, J=5.9 Hz, 3H).

^{13}C-NMR, DEPT (75 MHz, CD_3OD) δ(ppm): 156.8, 131.1, 129.5, 127.8, 120.2, 116.6, 67.7, 52.6, 44.3, 42.4, 42.1, 39.4, 24.6, 23.6, 23.5.

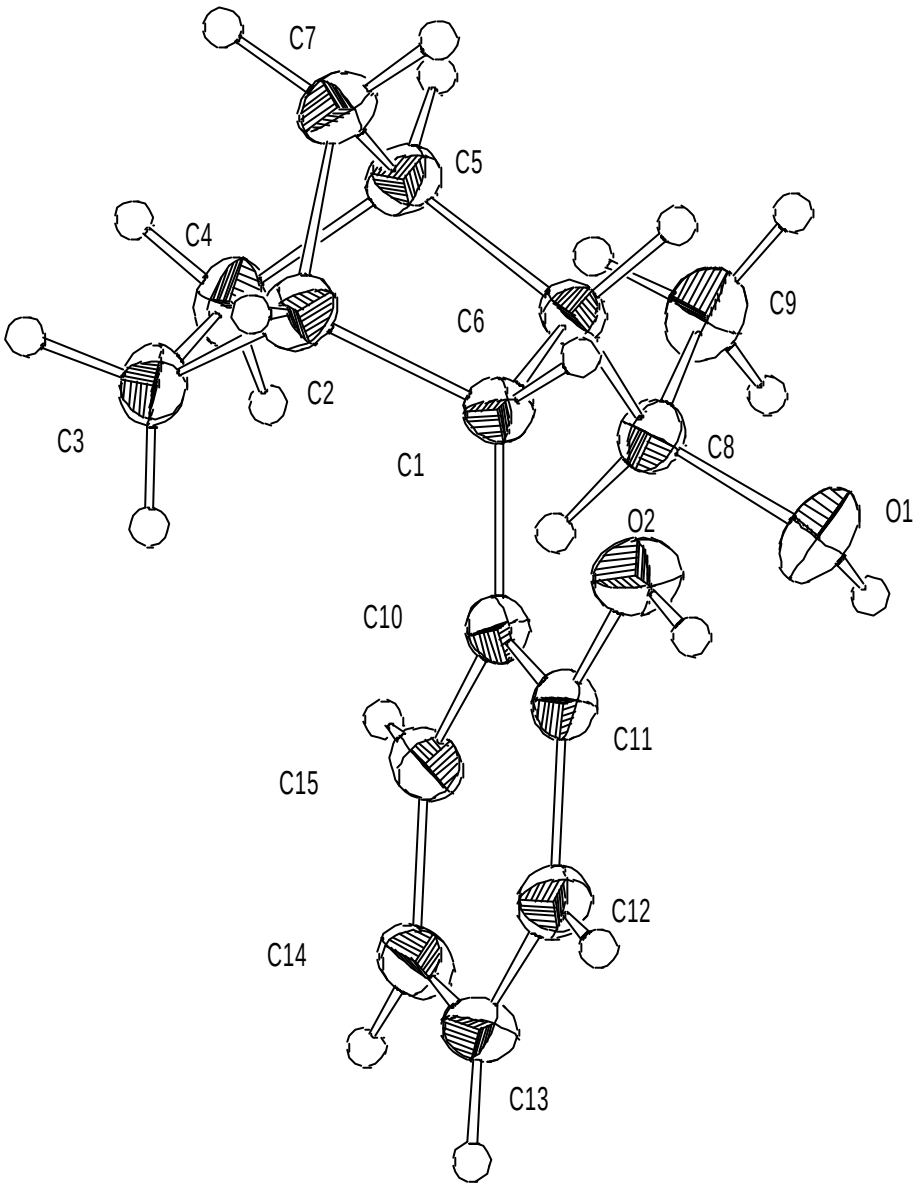
MS m/z (%):232(M^+, 22), 214(40), 186(75), 107(100).

IR (KBr): 3546, 3286, 2963, 2938, 1728, 1454 cm^{-1}.

HRMS for $C_{15}H_{20}O_2$, calcd: 232.1464; found: 232.1449.

X-ray

Crystallographic data (excluding structure factors) for the structure **24** has been deposited with the Cambridge Crystallographic Data Centre as supplementary publication no. CCDC-161449. Copies of the data can be obtained free of charge on application to CCDC, 12 Union Road, Cambridge CB21EZ, UK (fax: (+44)1223-336-033; E-mail: deposit@ccdc.cam.ac.uk).



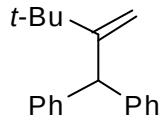
2-[16-(1-Hydroxyethyl)tetracyclo[6.6.2.0^{2,7}.0^{9,14}]hexadeca-2(7),3,5,9(14),10,12-hexaen-15-yl]phenol (27)

^{1}H-NMR (300 MHz, $CDCl_3$) δ(ppm): 7.33-6.41 (m, 8H), 4.23 (d, J=2.6 Hz, 1H), 4.22 (d, J=1.3 Hz, 1H), 3.73 (dd, J=9.9, 1.3 Hz, 1H), 2.9 (dc, J=9.9, 6.2 Hz, 1H), 2.26 (td, J=9.9, 2.6 Hz, 1H), 1.24 (d, J=6.2 Hz, 3H).

^{13}C-NMR, DEPT (75 MHz, $CDCl_3$) δ(ppm): 153.9 (C), 146.0 (C), 143,1 (C), 142.5 (C), 141.9 (C), 129.6 (C), 128.4 (CH), 127.7 (CH), 126.4 (CH), 125.9 (CH), 125.9 (CH), 125.7 (CH), 125.6 (CH), 124.6 (CH), 123.8 (CH), 122.7 (CH), 120.5 (CH), 115.8(CH), 69.3 (CH), 50.3 (2CH), 47.5 (CH), 38.7 (CH), 21.0 (CH_3).

References

[1] H. Laaziri, L. O. Bromm, F. Lhermitte, R. M. Gschwind, P. Knochel, *J. Am. Chem. Soc.* **1999**, *121*, 6940.
[2] J. E. McMurry, W. J. Scott, *Tetrhedron Letters* **1980**, *21*, 4313.
[3] P. J. Stang, W. Treptow, *Synthesis* **1980**, 283.
[4] C. Ha, J. H. Horner, M. Newcomb, T. R. Varick, *J. Org. Chem.* **1993**, *58*, 1194.
[5] P. J. Kropp, S. D. Crawford, *J. Org. Chem* **1994**, *11*, 3102.
[6] G. Zweifel, J. A. Miller, *Organic Reactions* **1984**, *32*, 430.
[7] M. Virgili, J. Belloch, A. Moyano, M. A. Pericàs, A. Riera, *Tetrahedron Lett.* **1991**, *32*, 4583.



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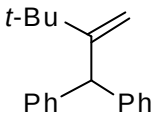

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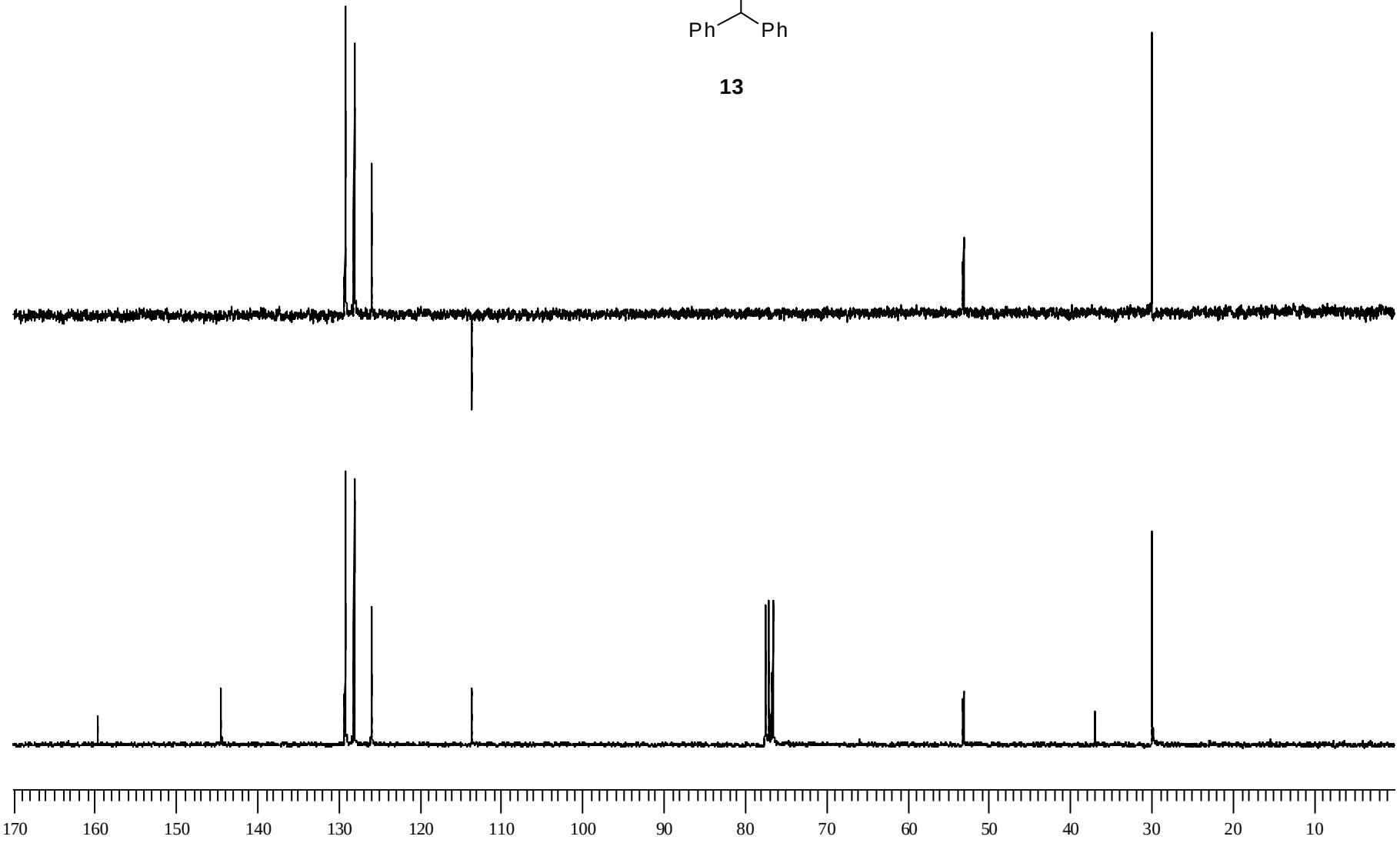

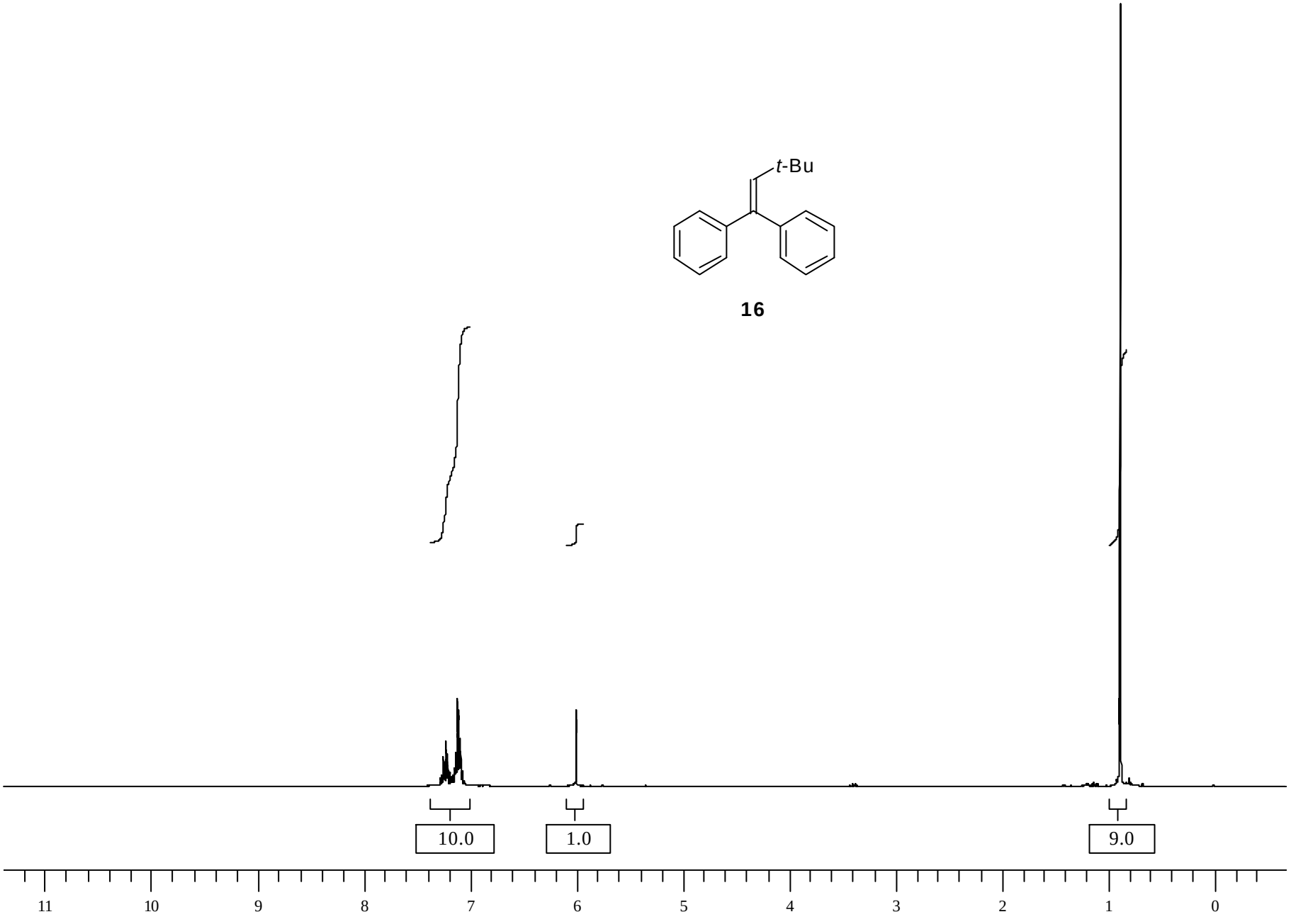
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10
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7
6
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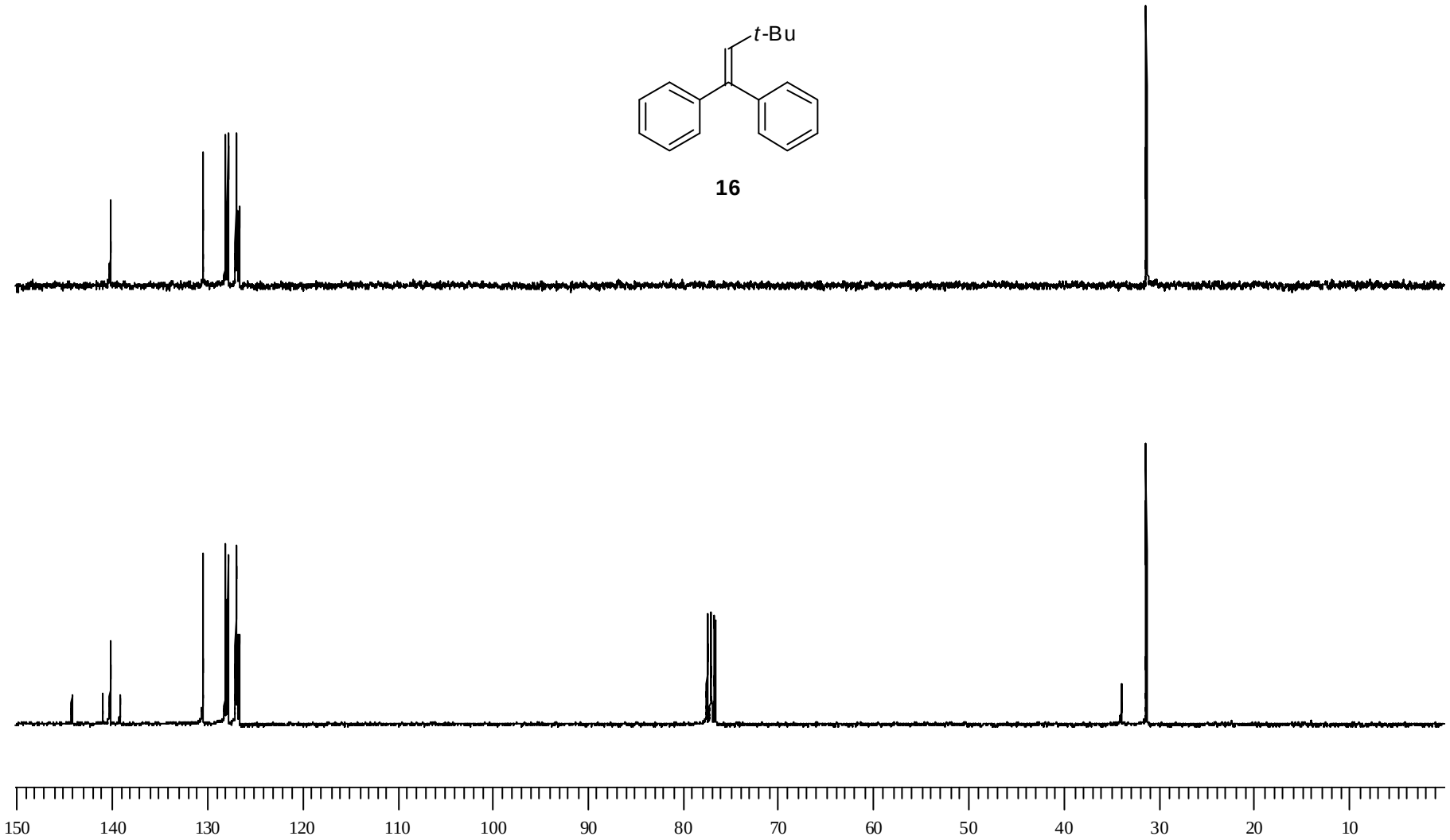
0



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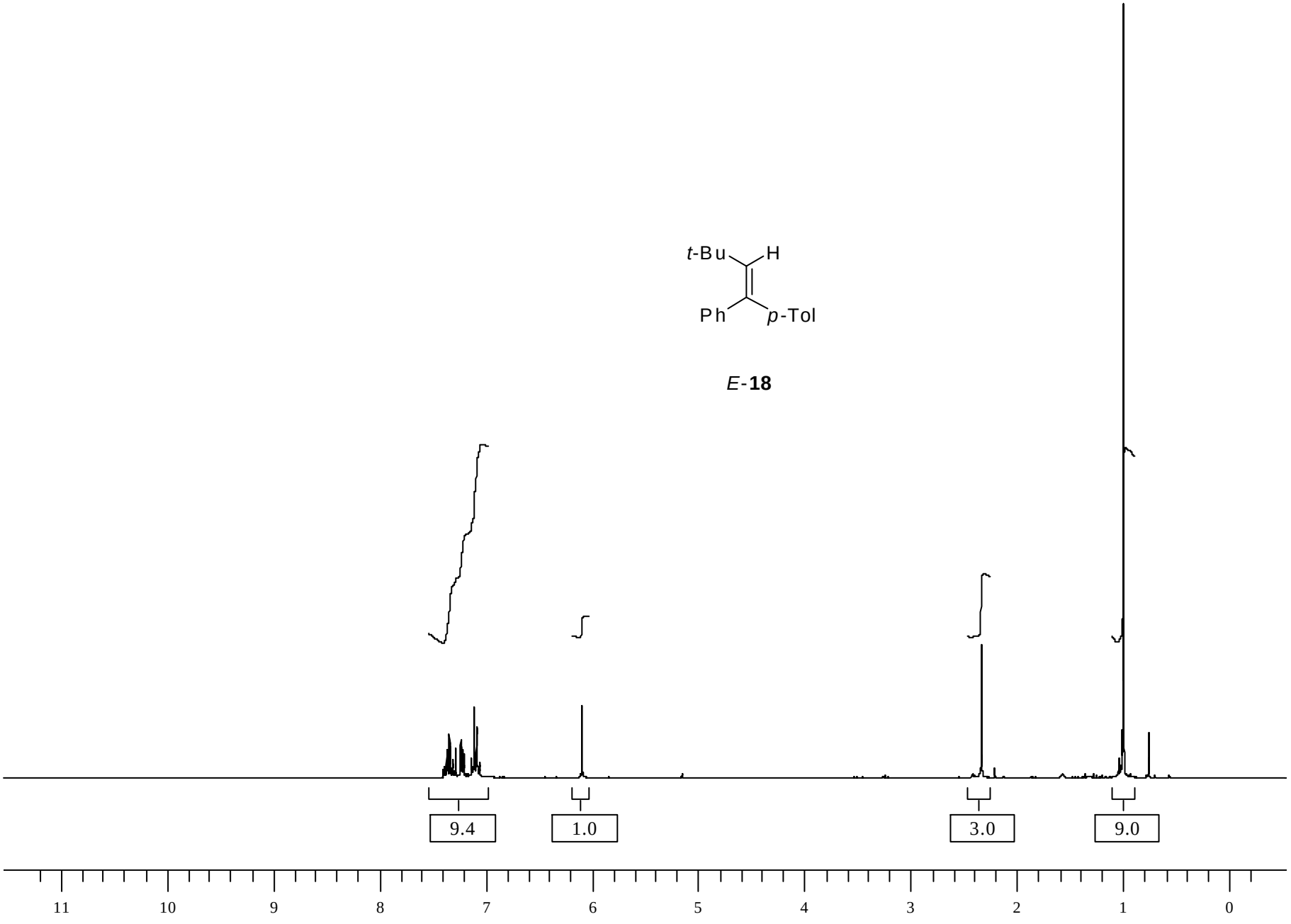
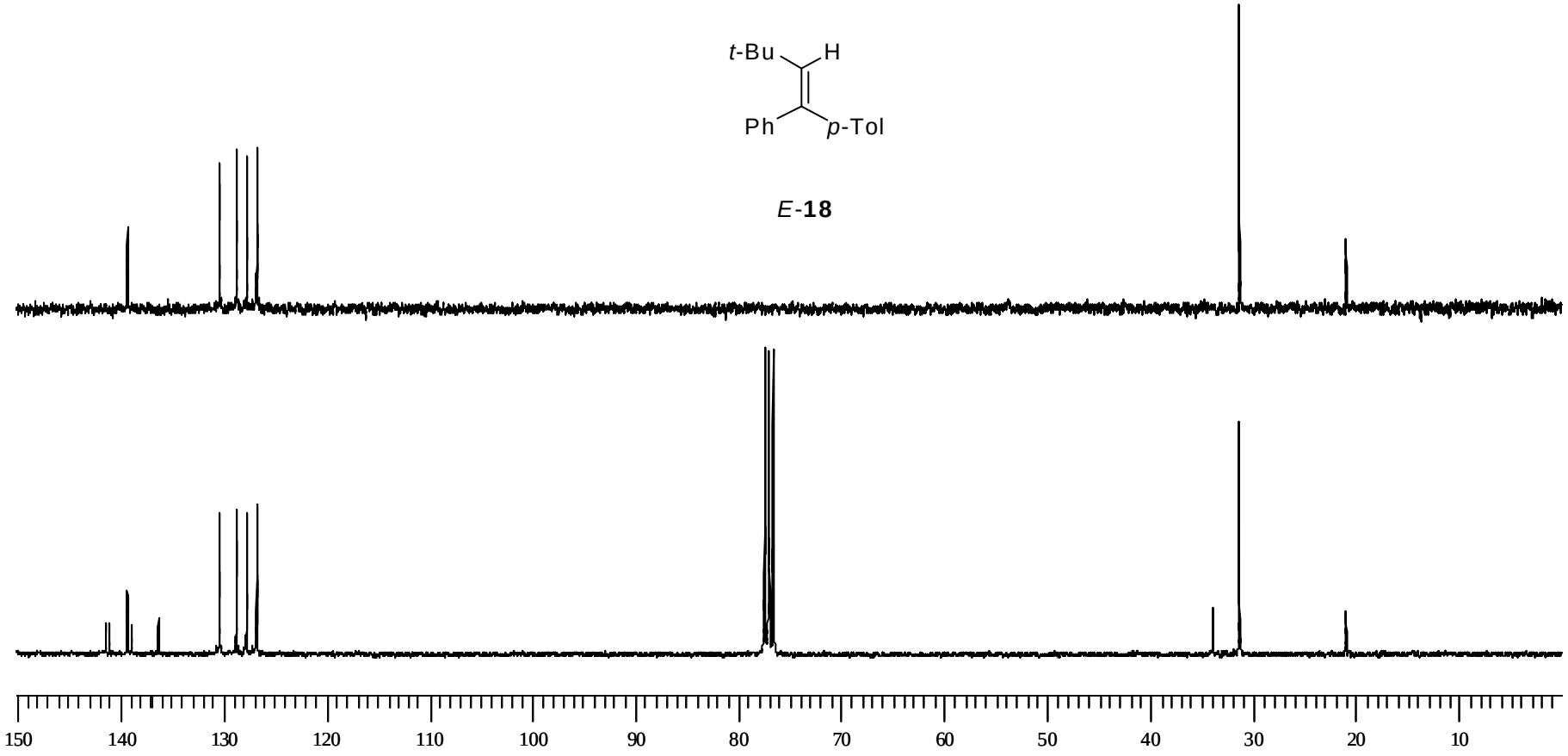
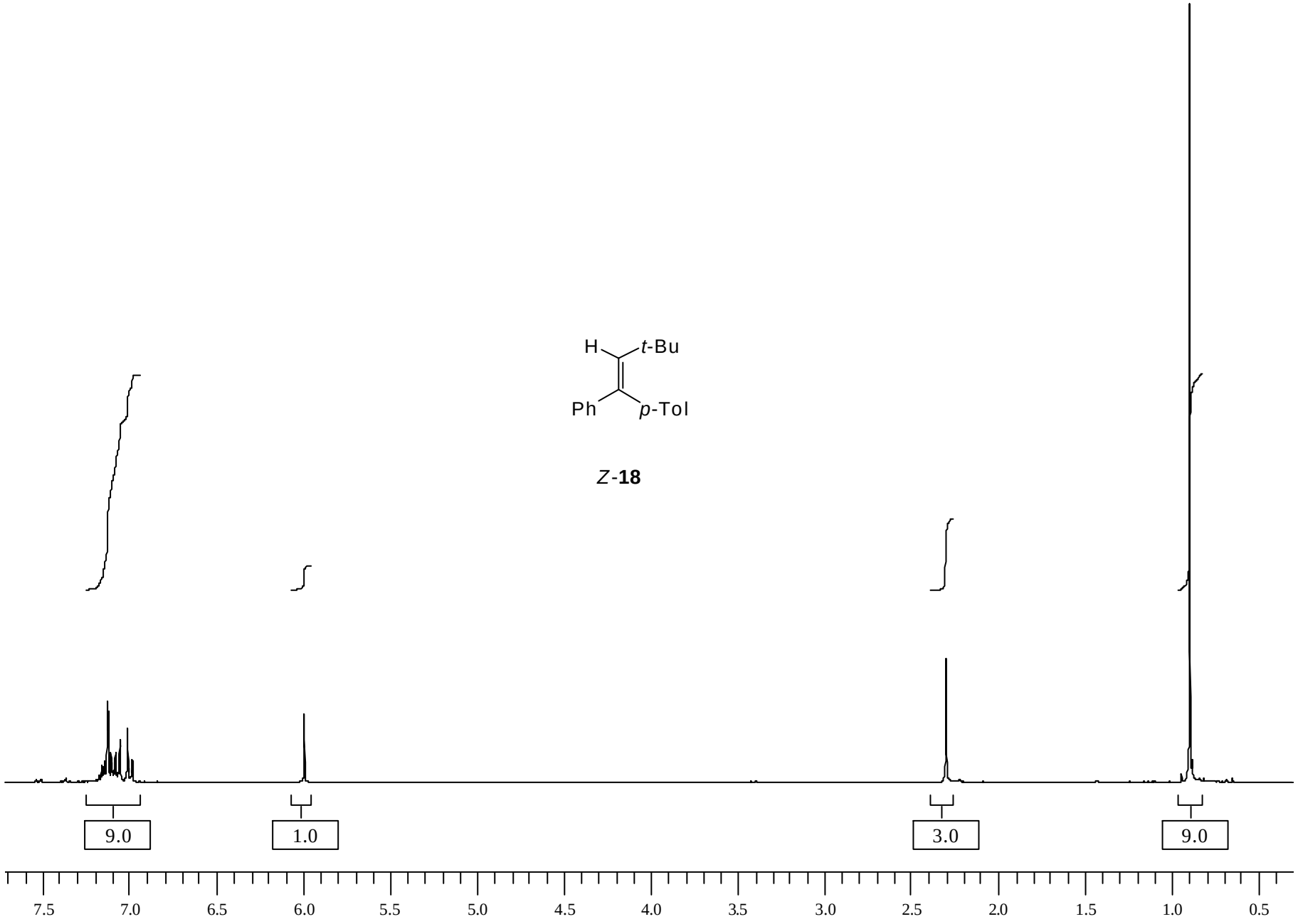


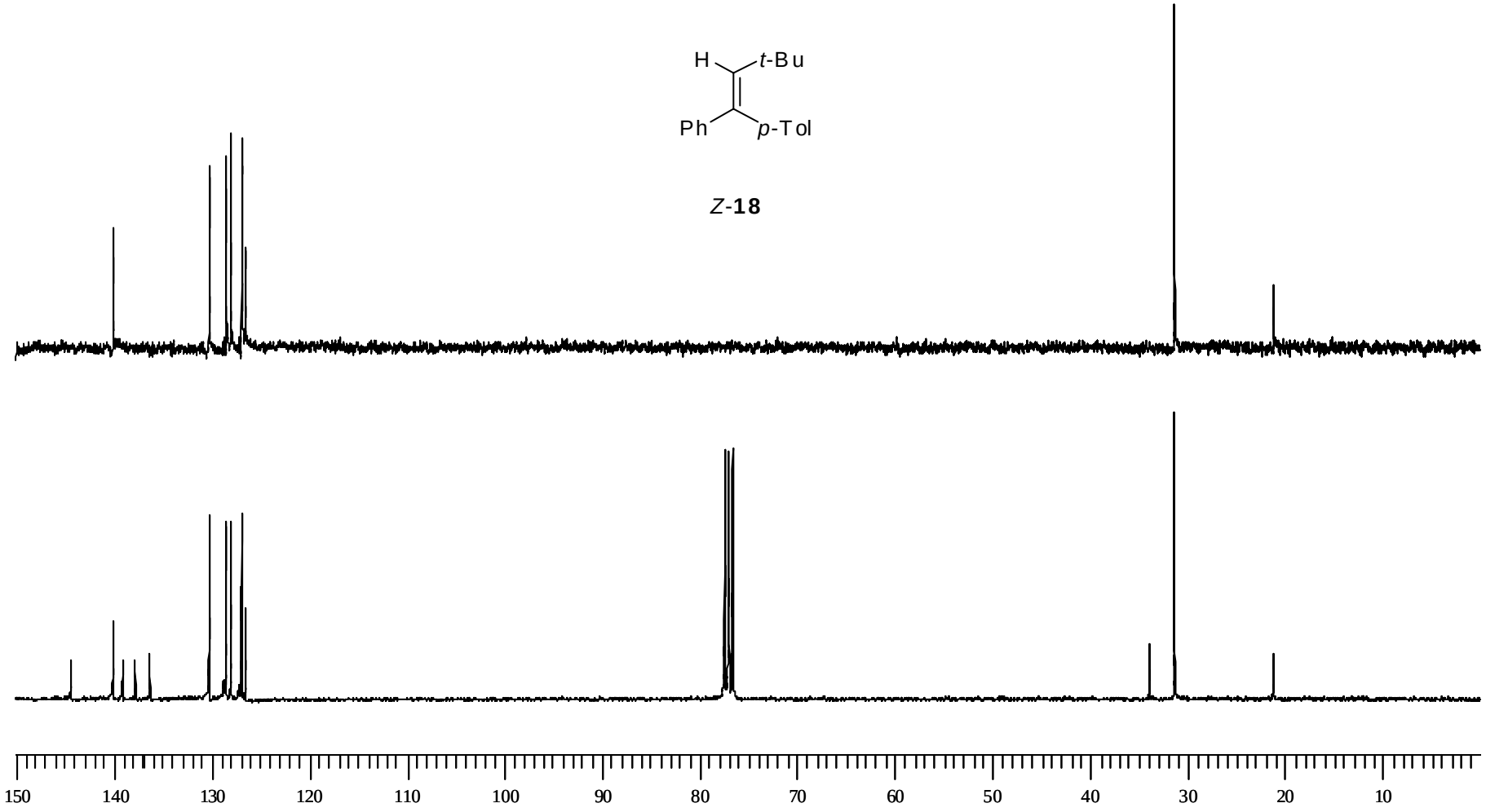
E-**18**



***E*-18**



Z-**18**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Z-18
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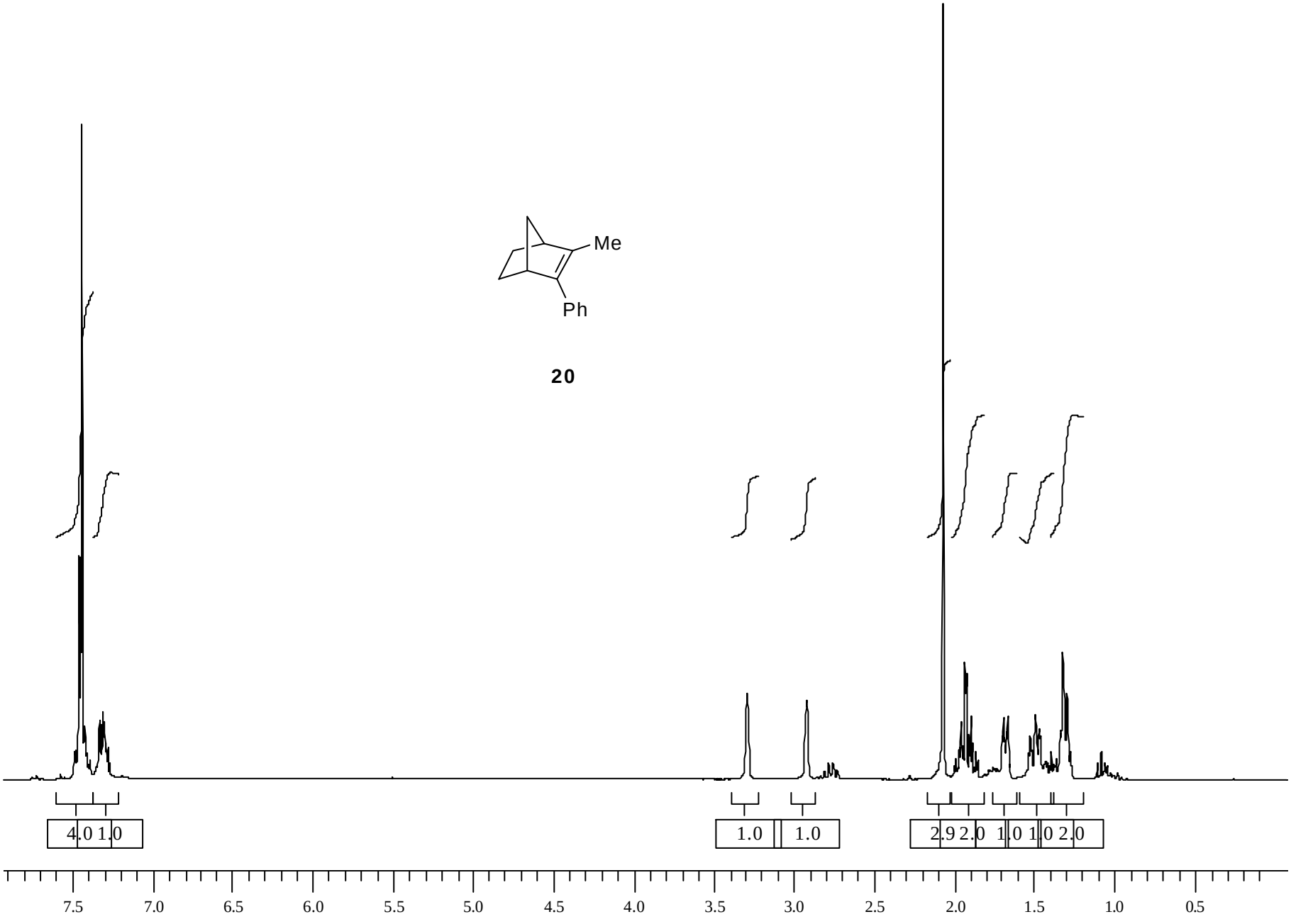
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2.9 2.0 1.0 1.0 2.0
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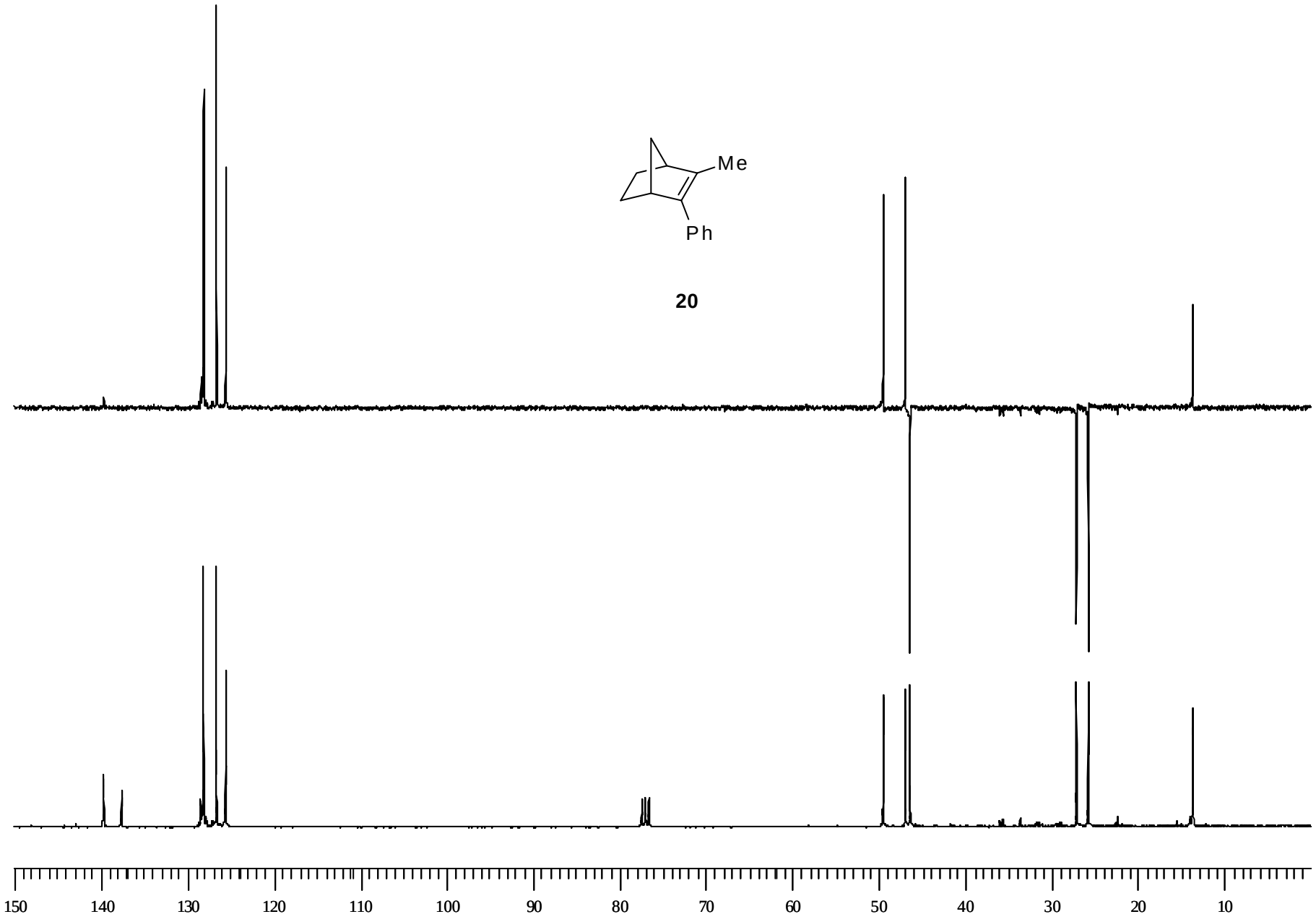
20



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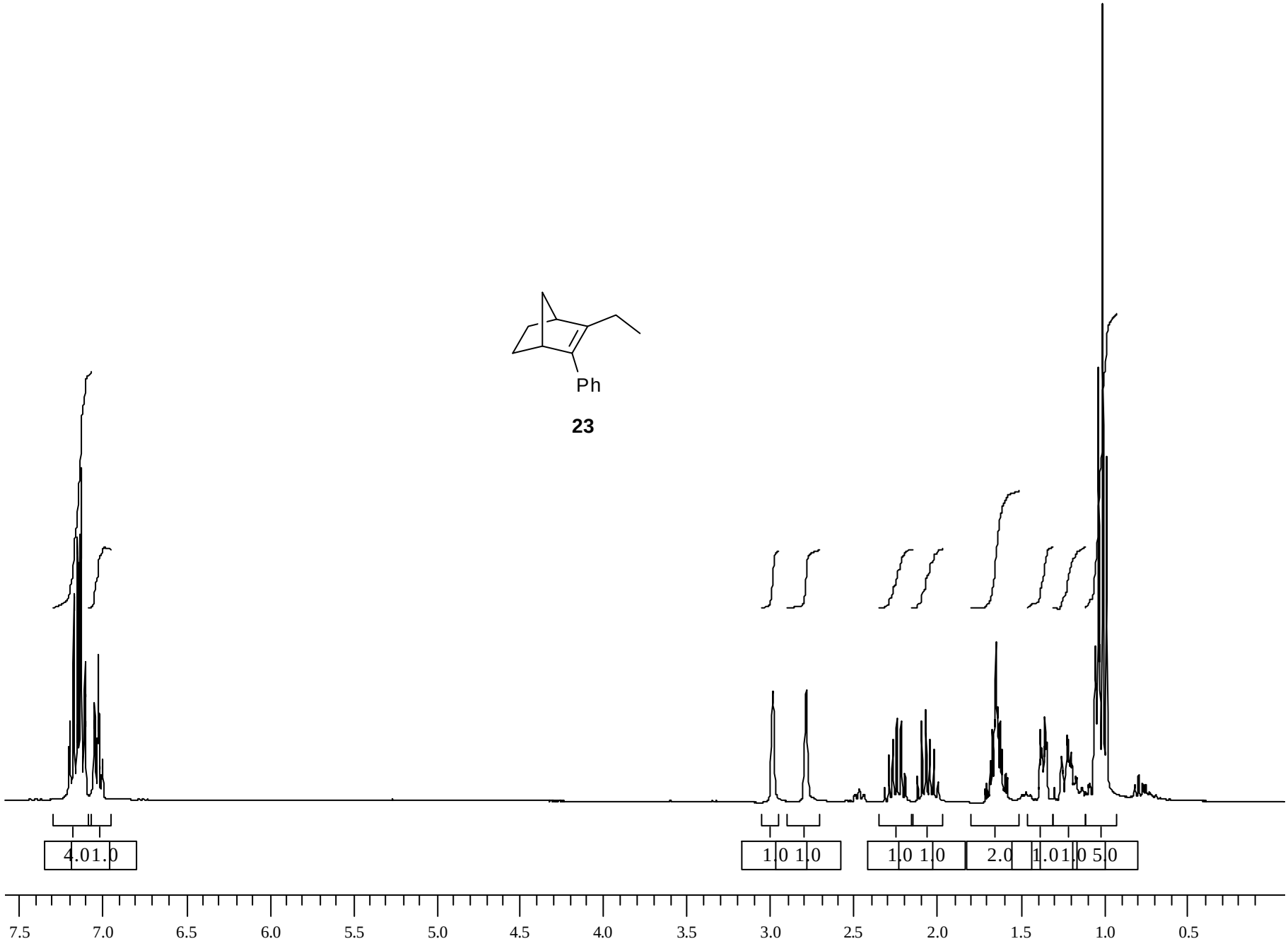
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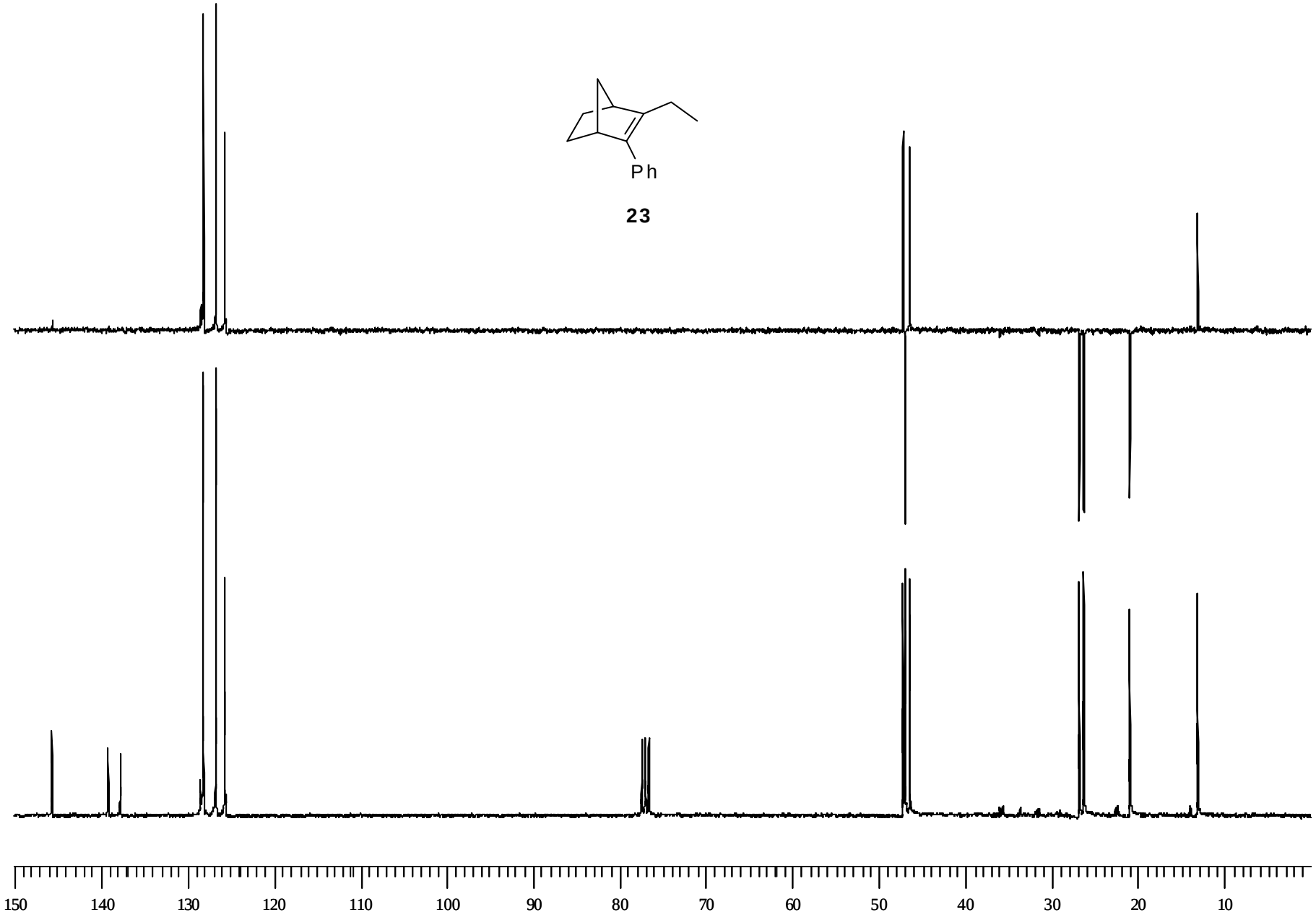
23



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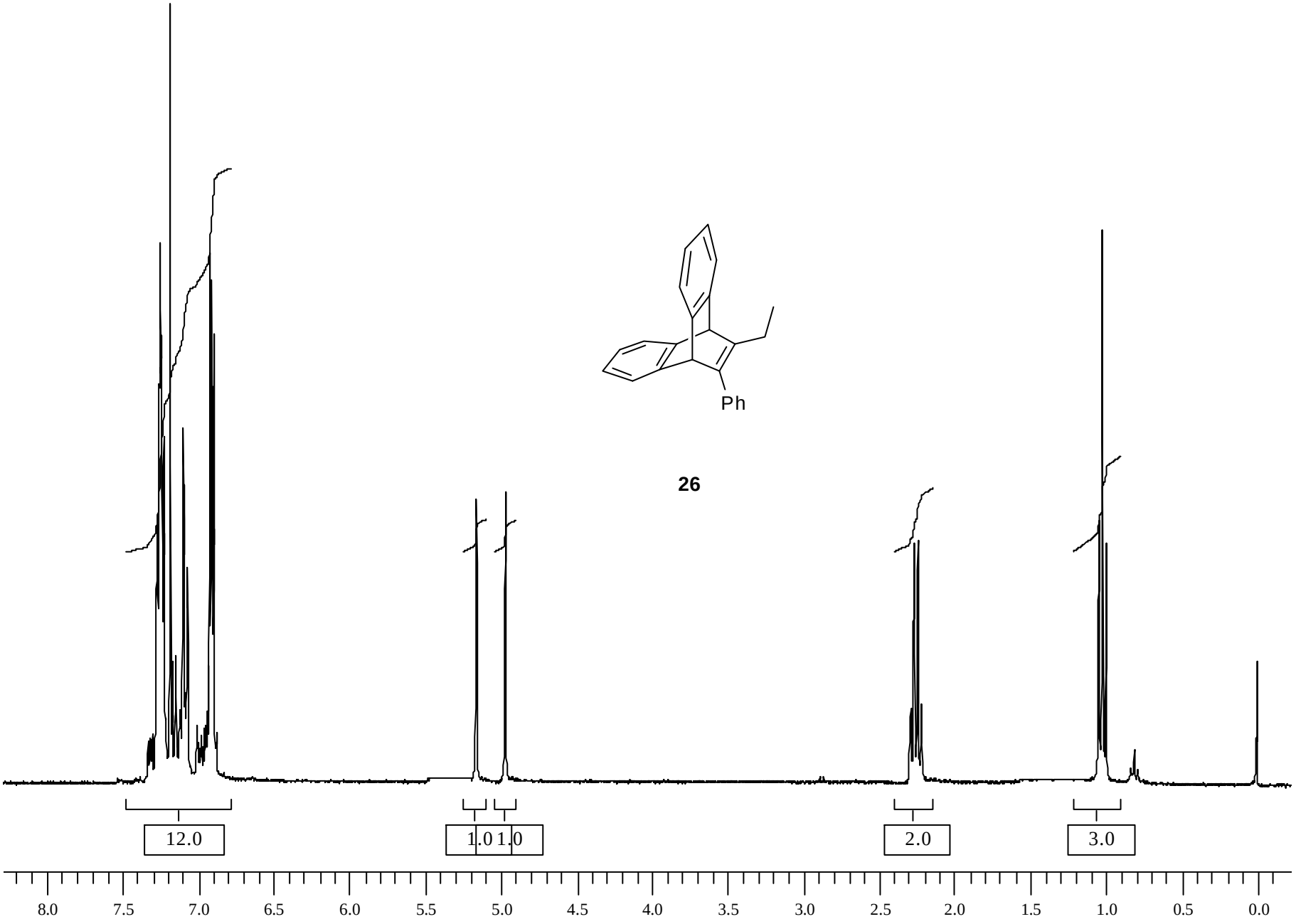

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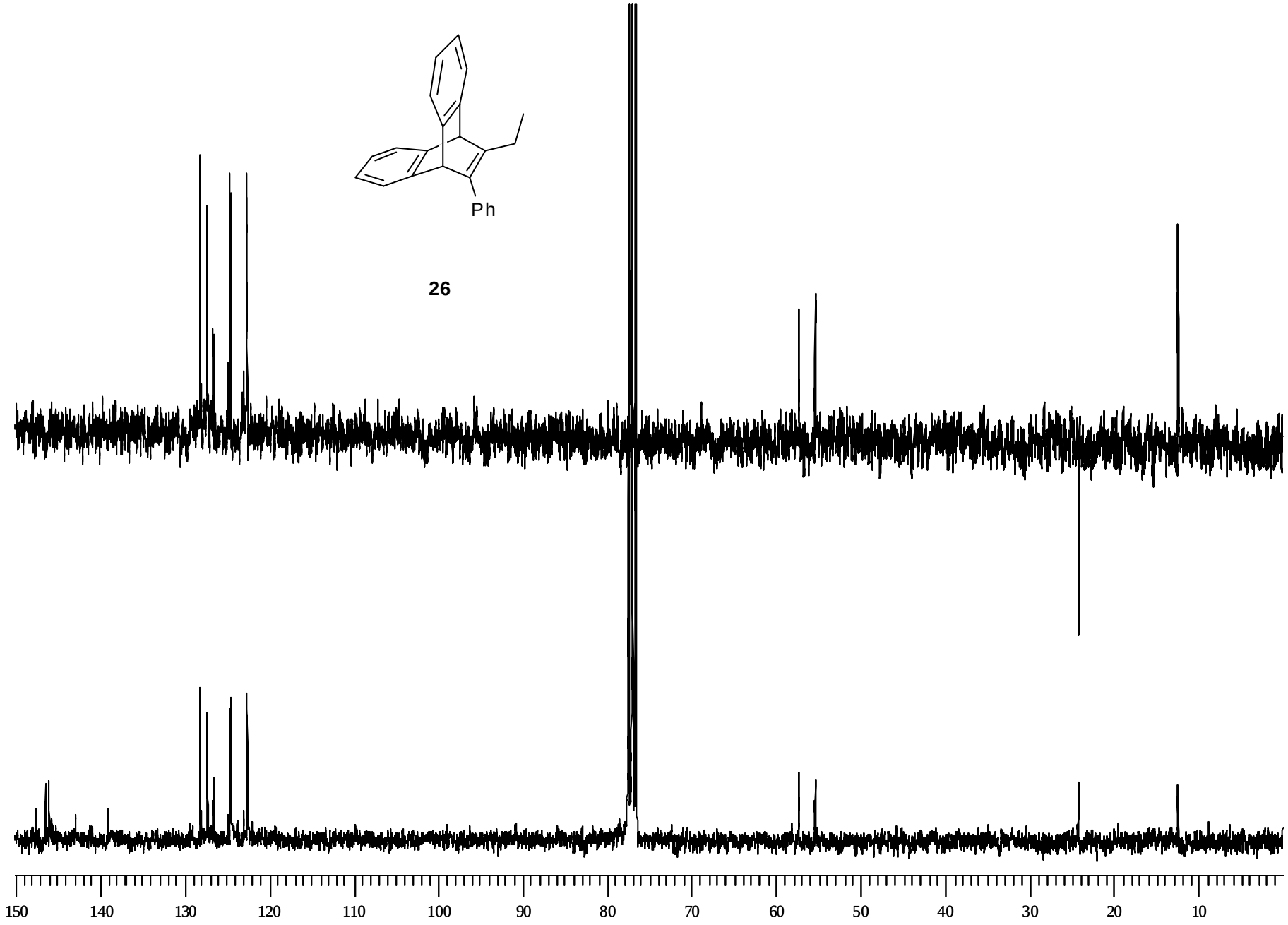

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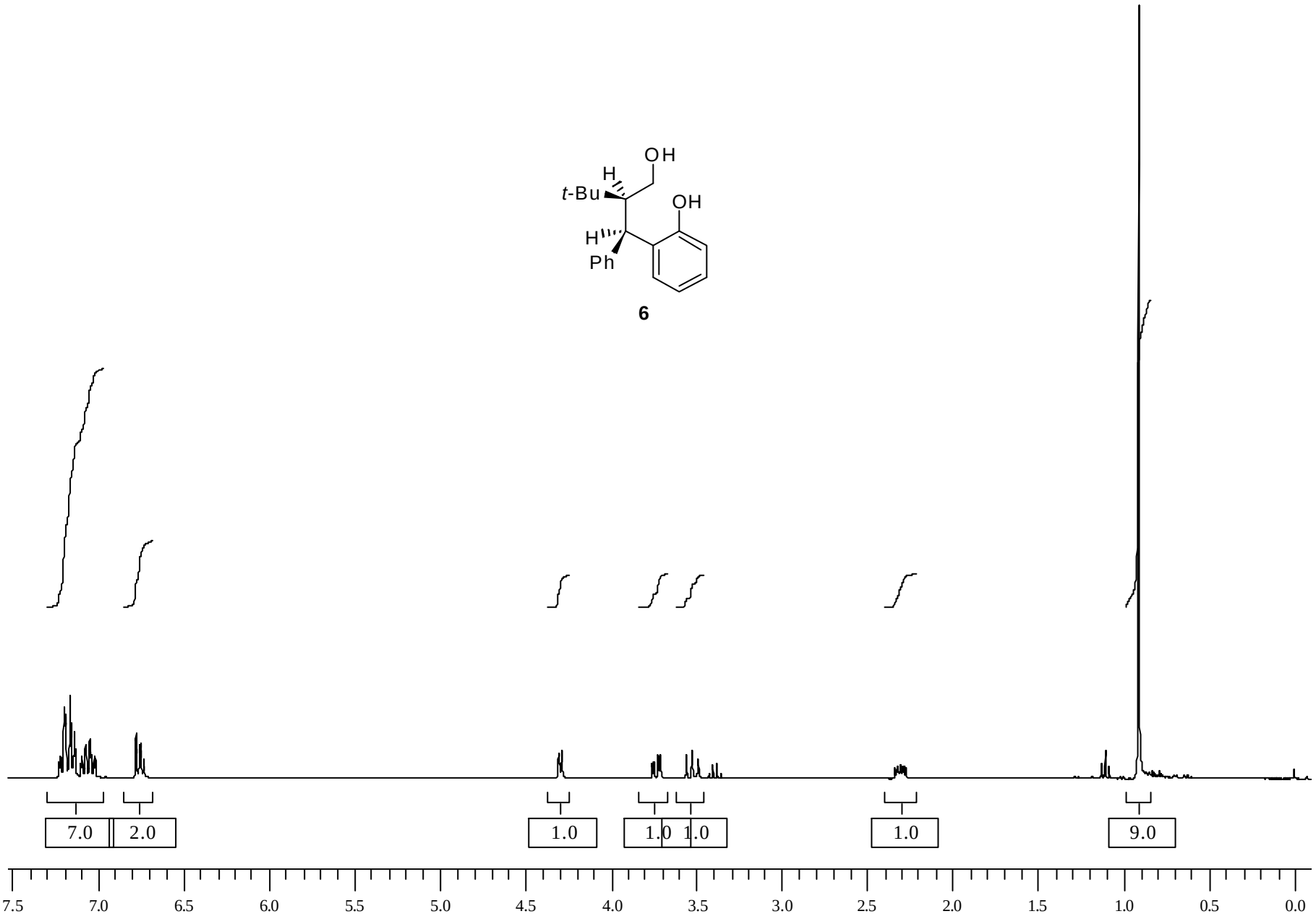
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H
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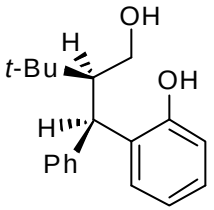
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t-Bu
OH
H
Ph

6

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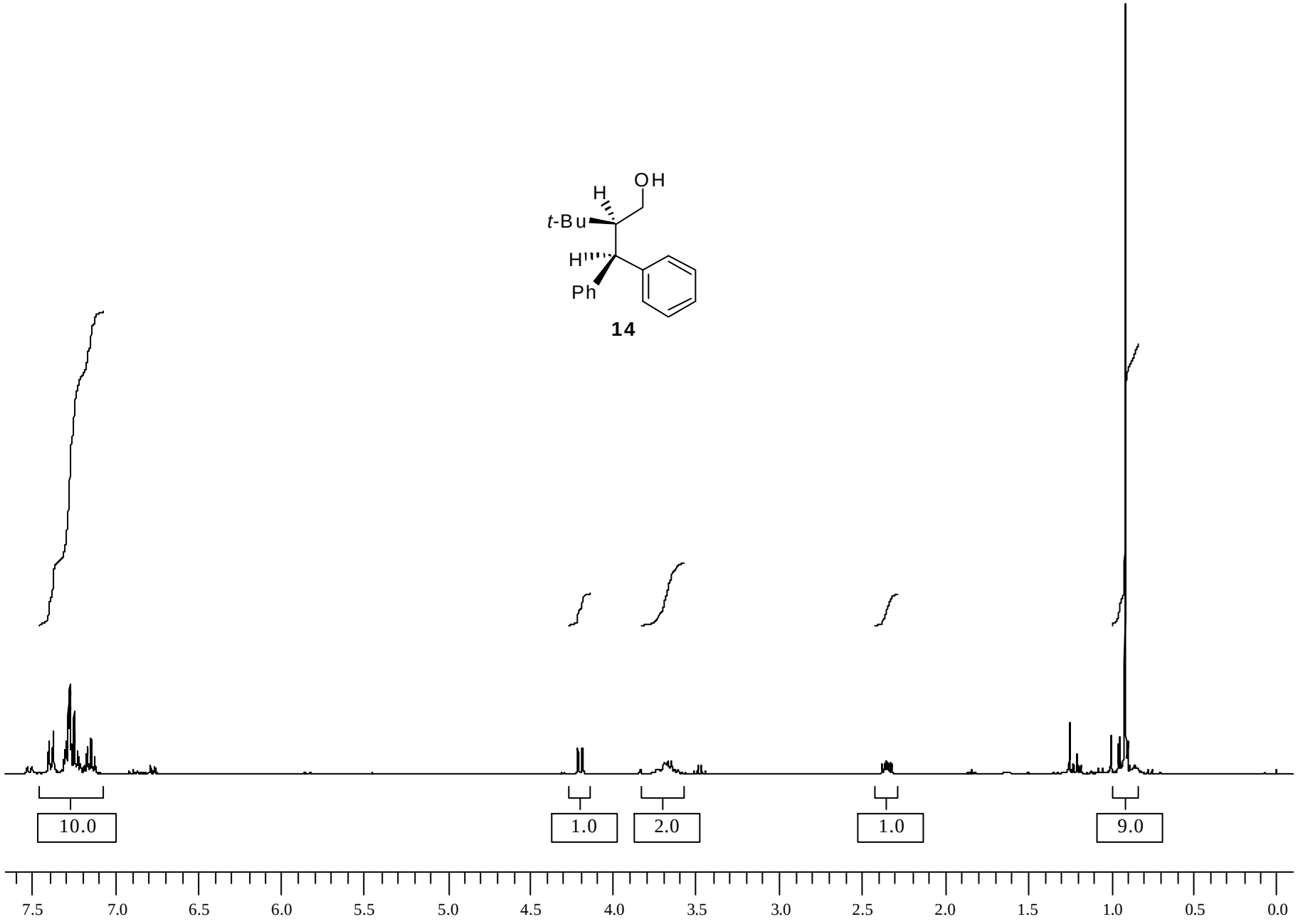
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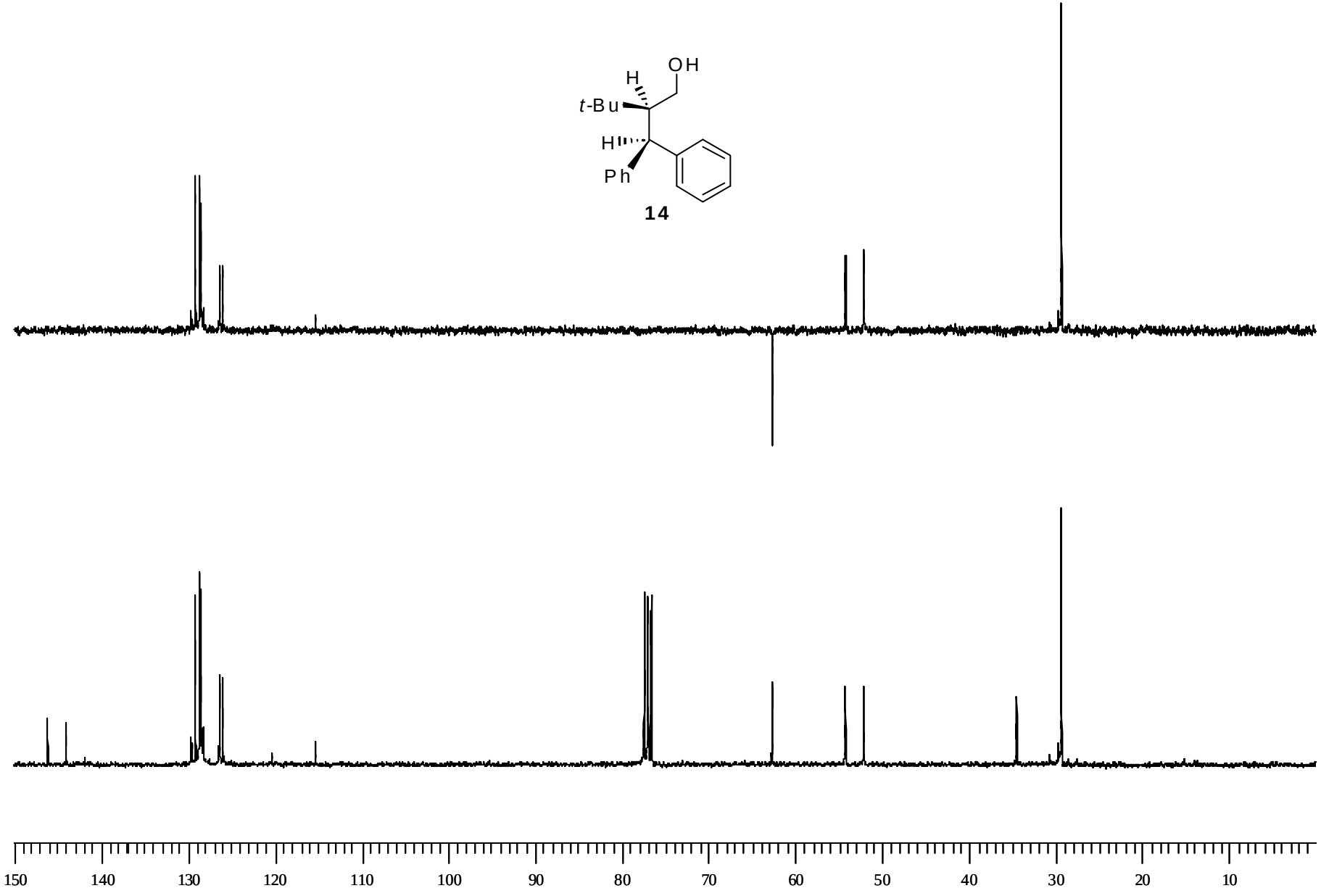
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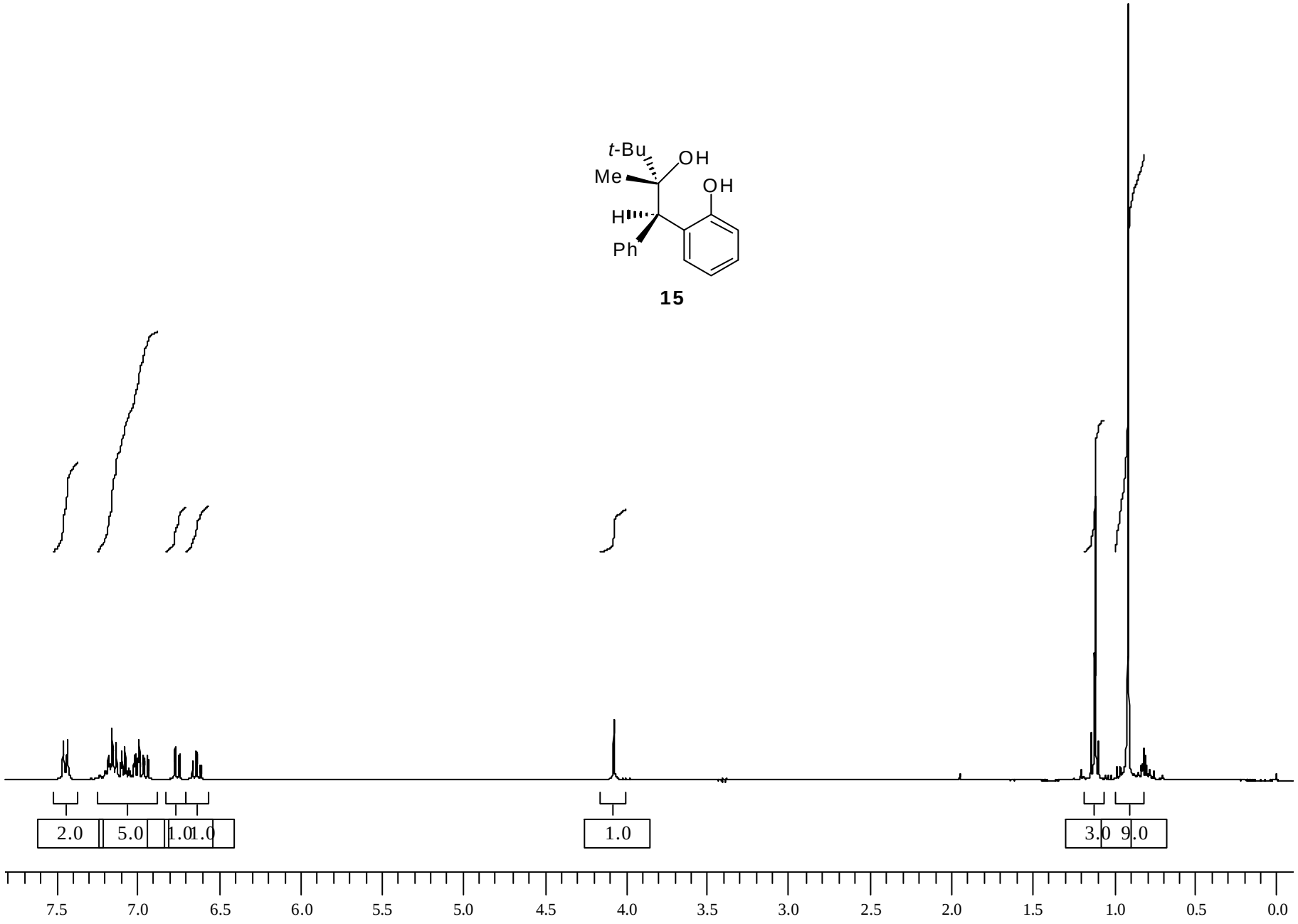
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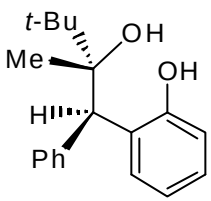
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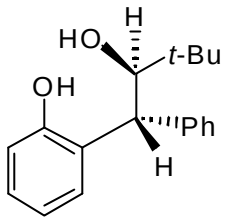
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Ph
H

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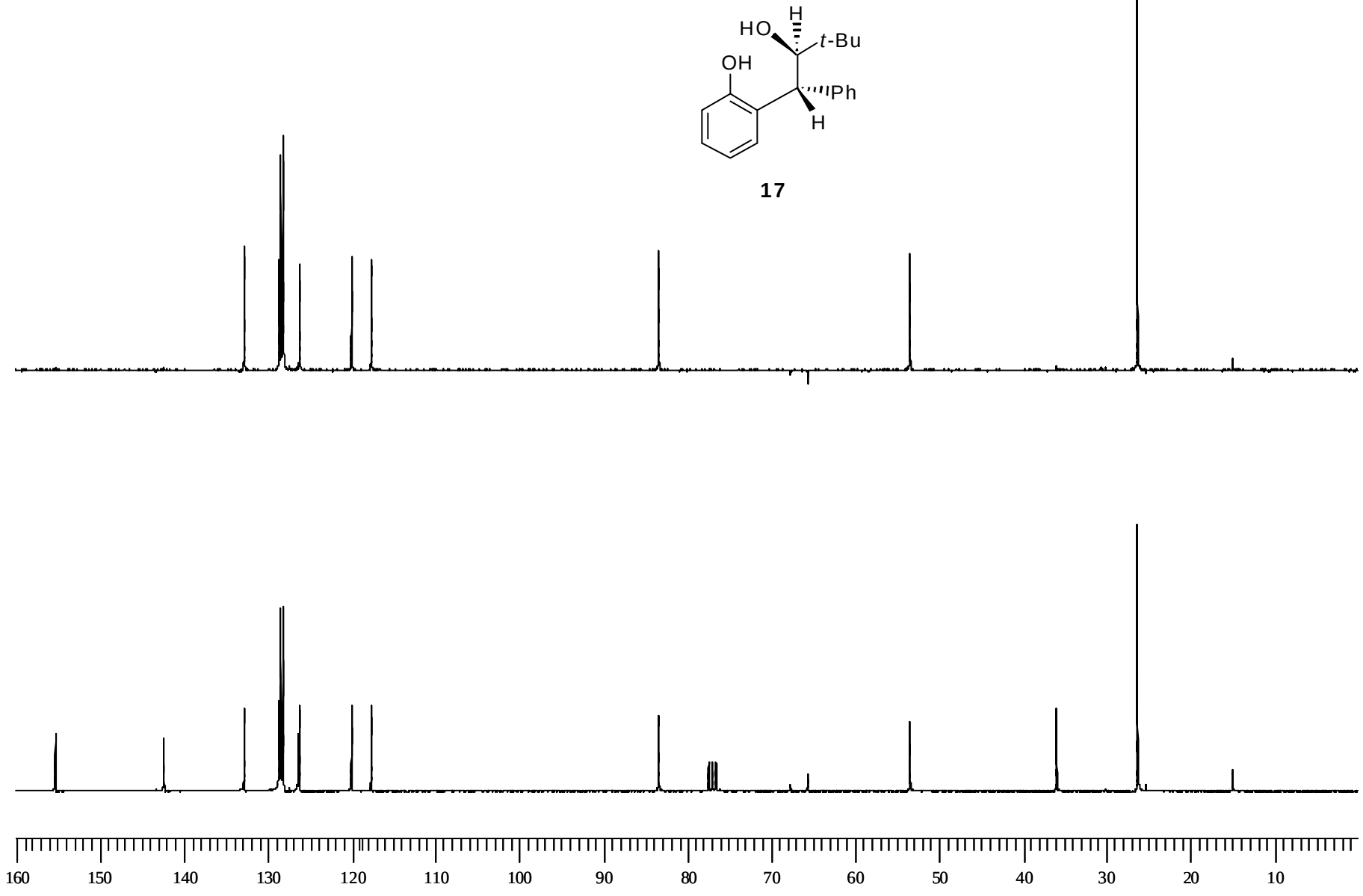
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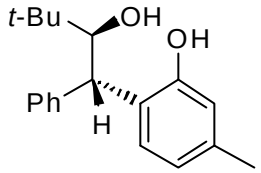
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Ph
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19a

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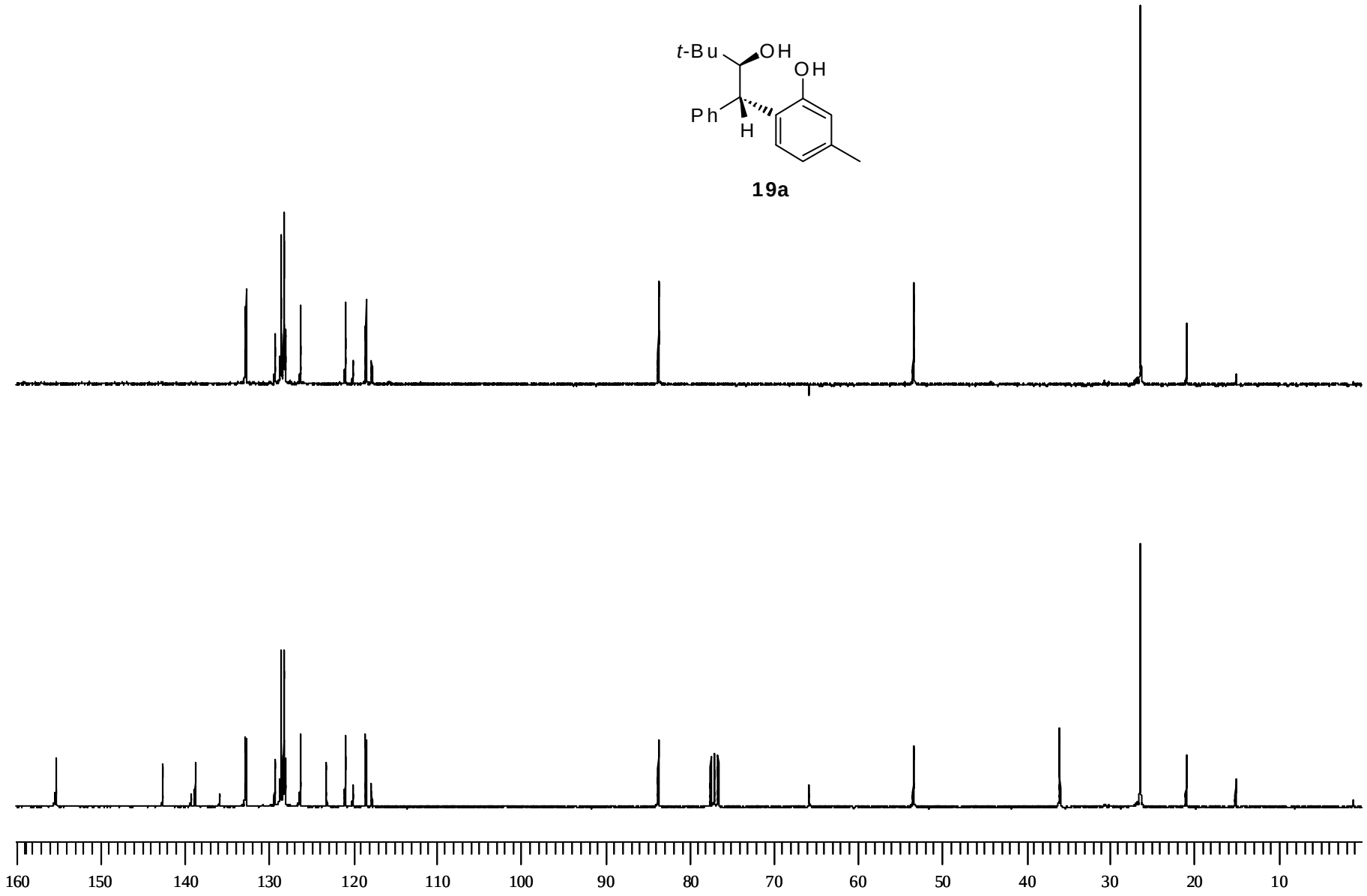

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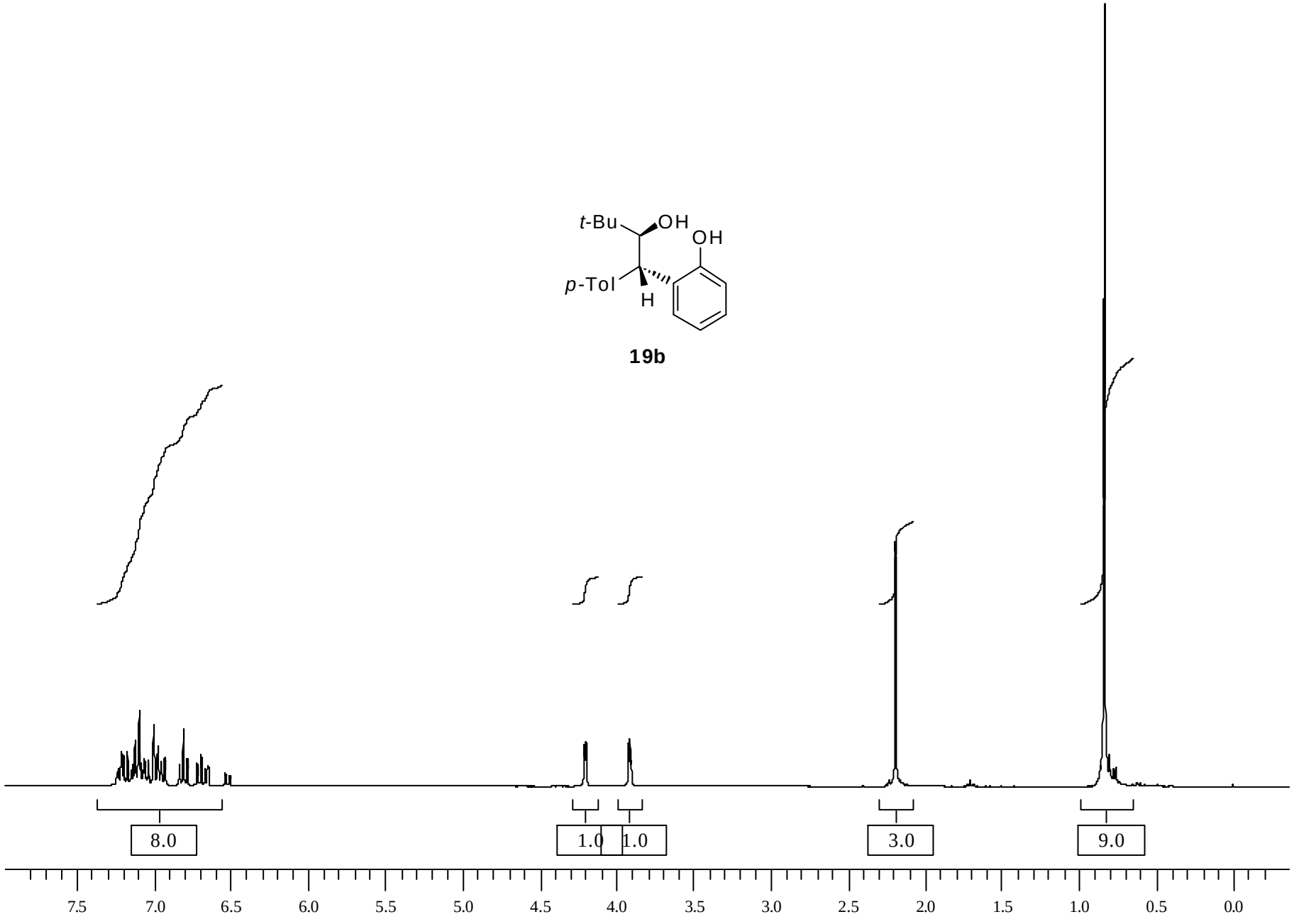
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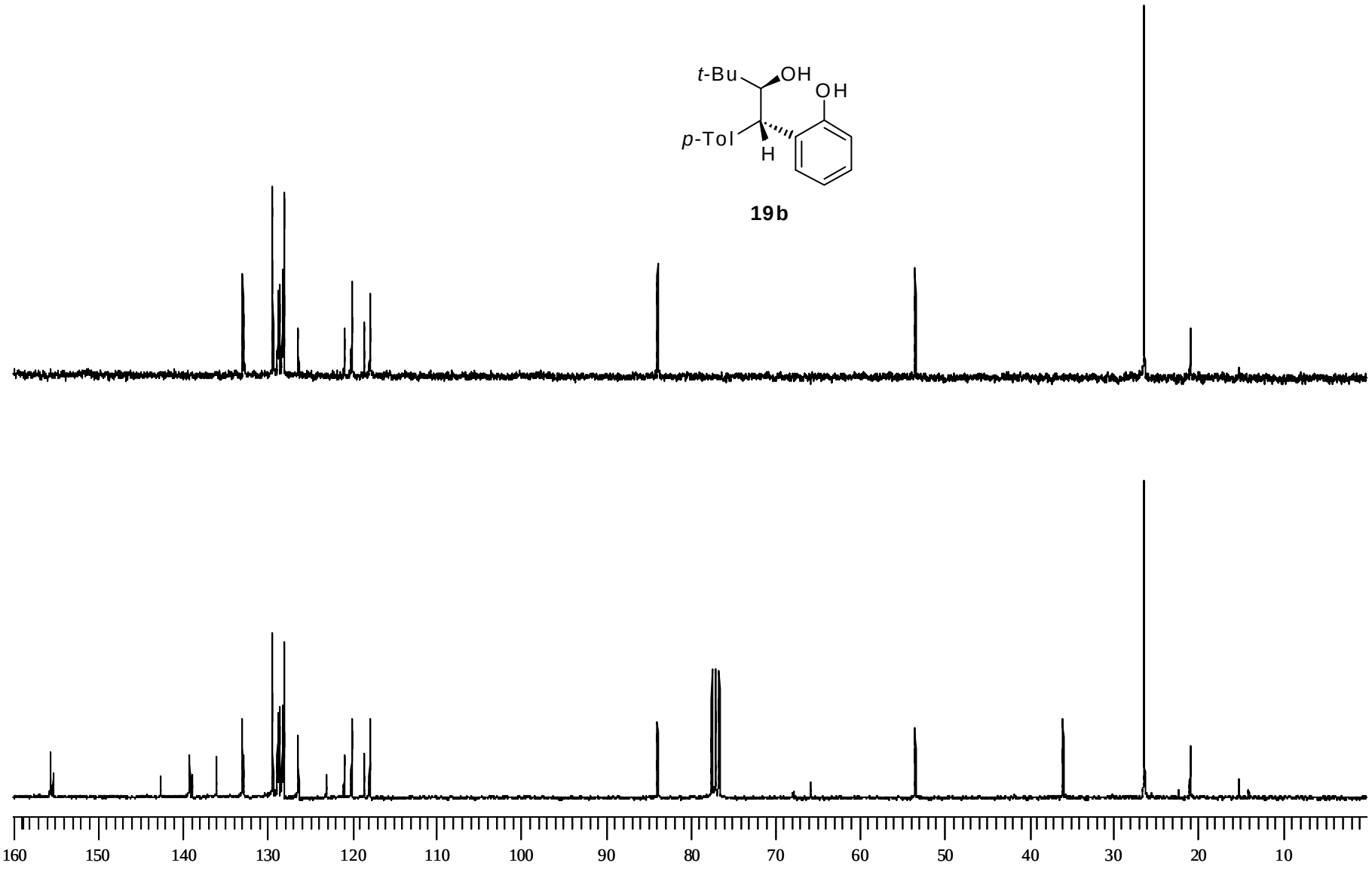
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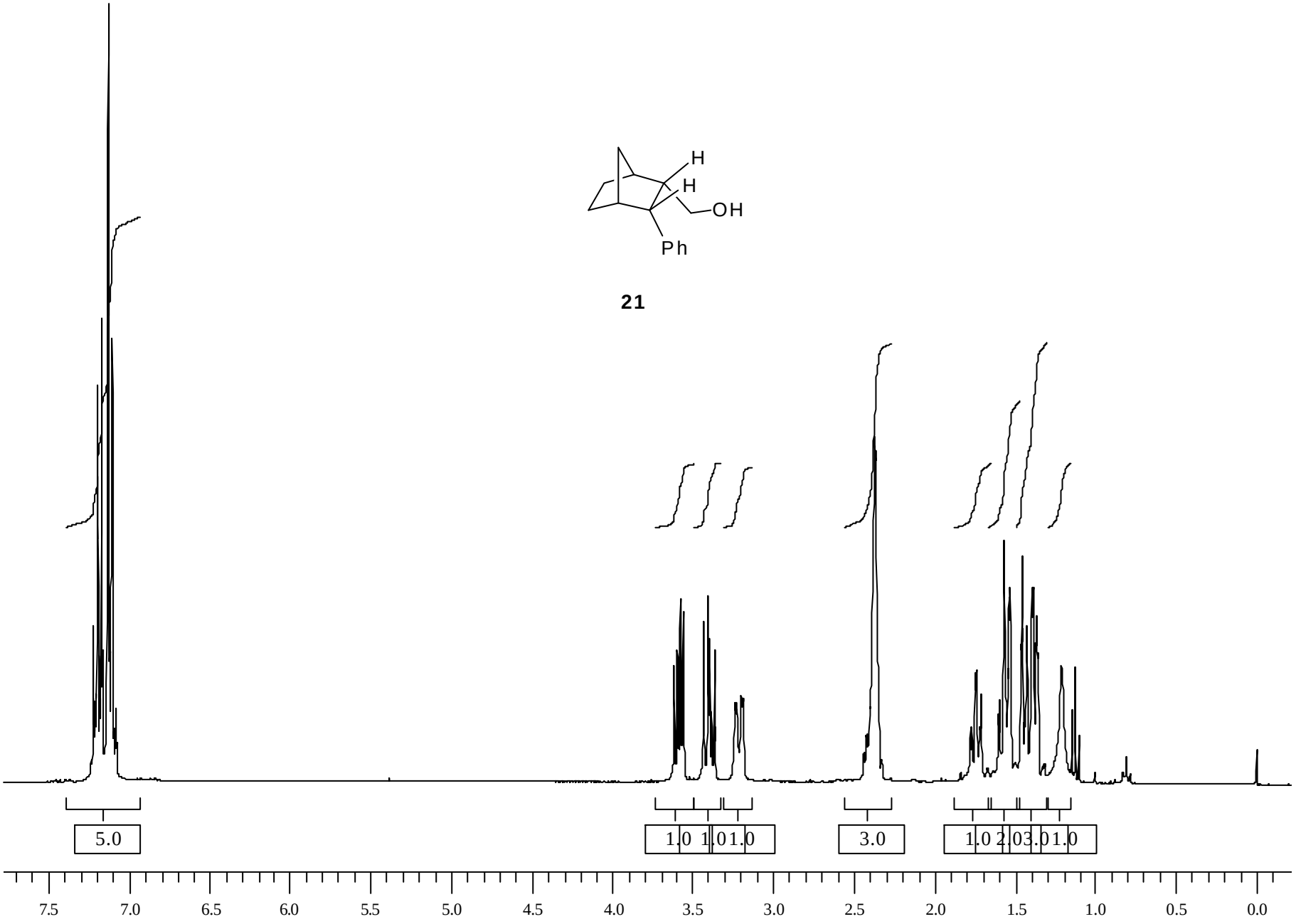
19b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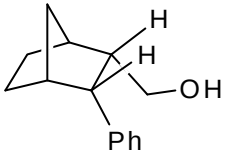

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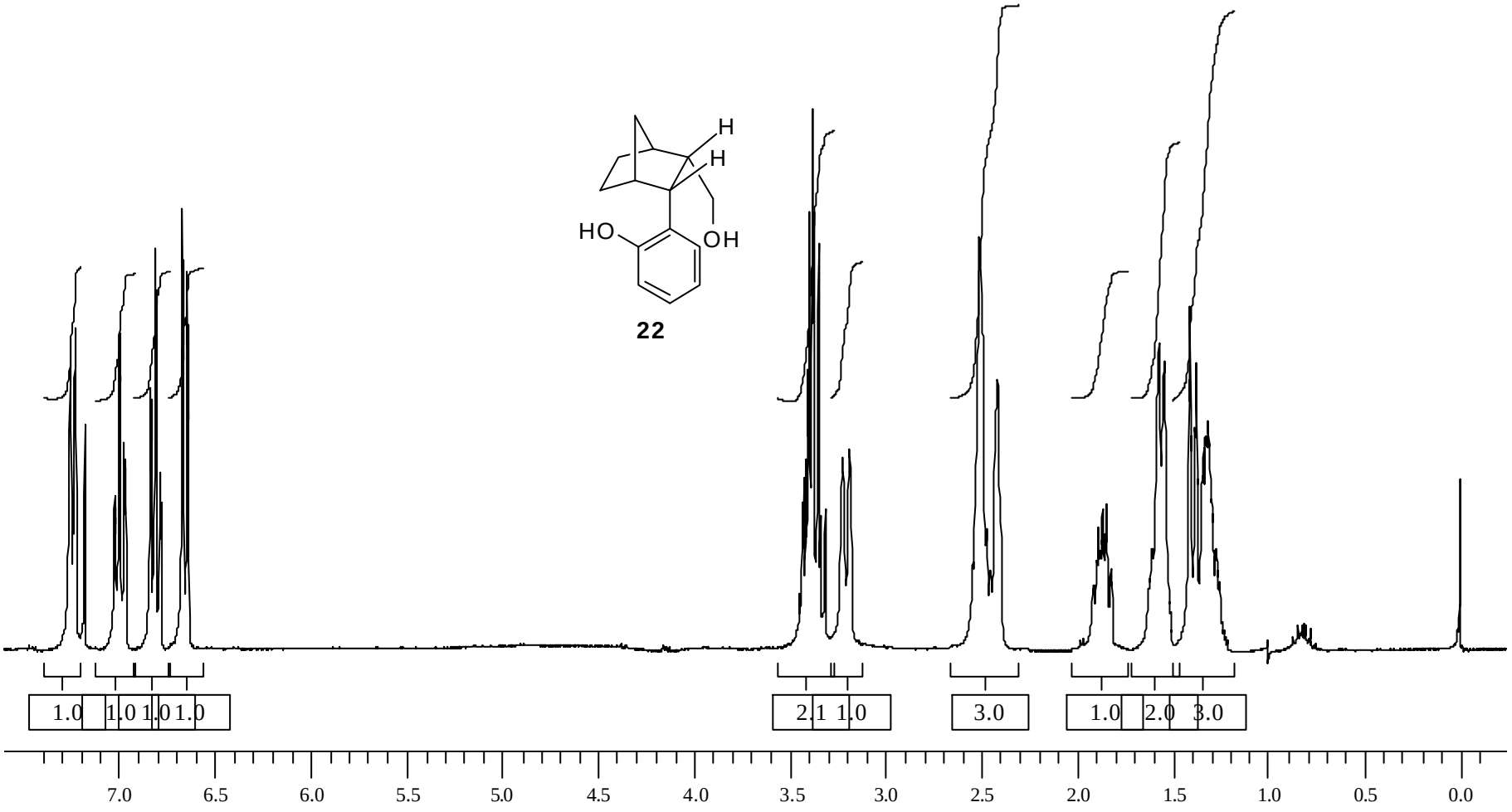
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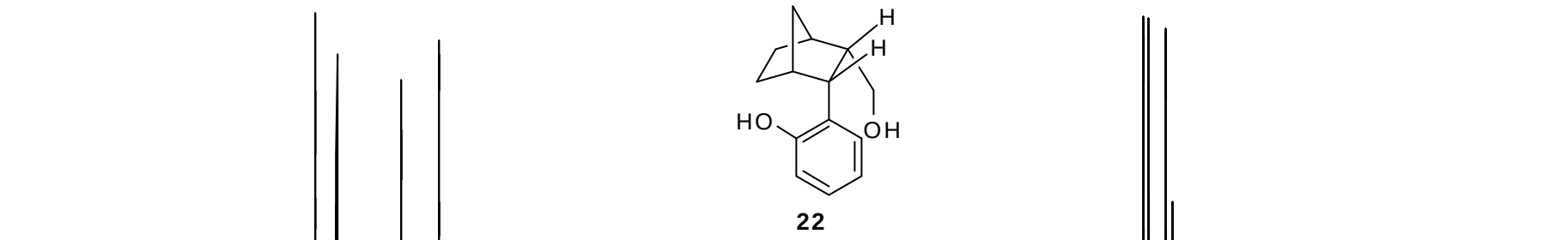
22



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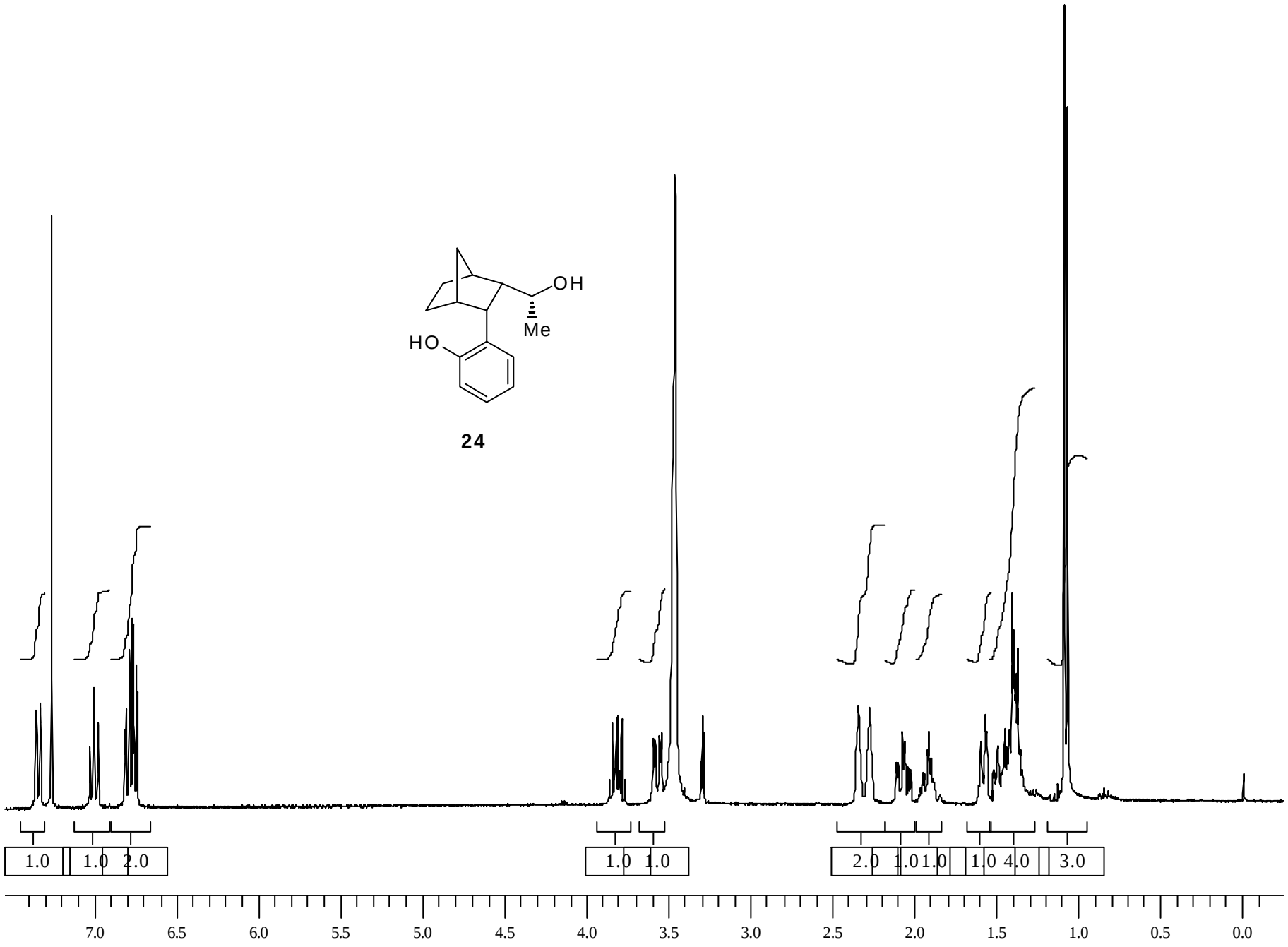
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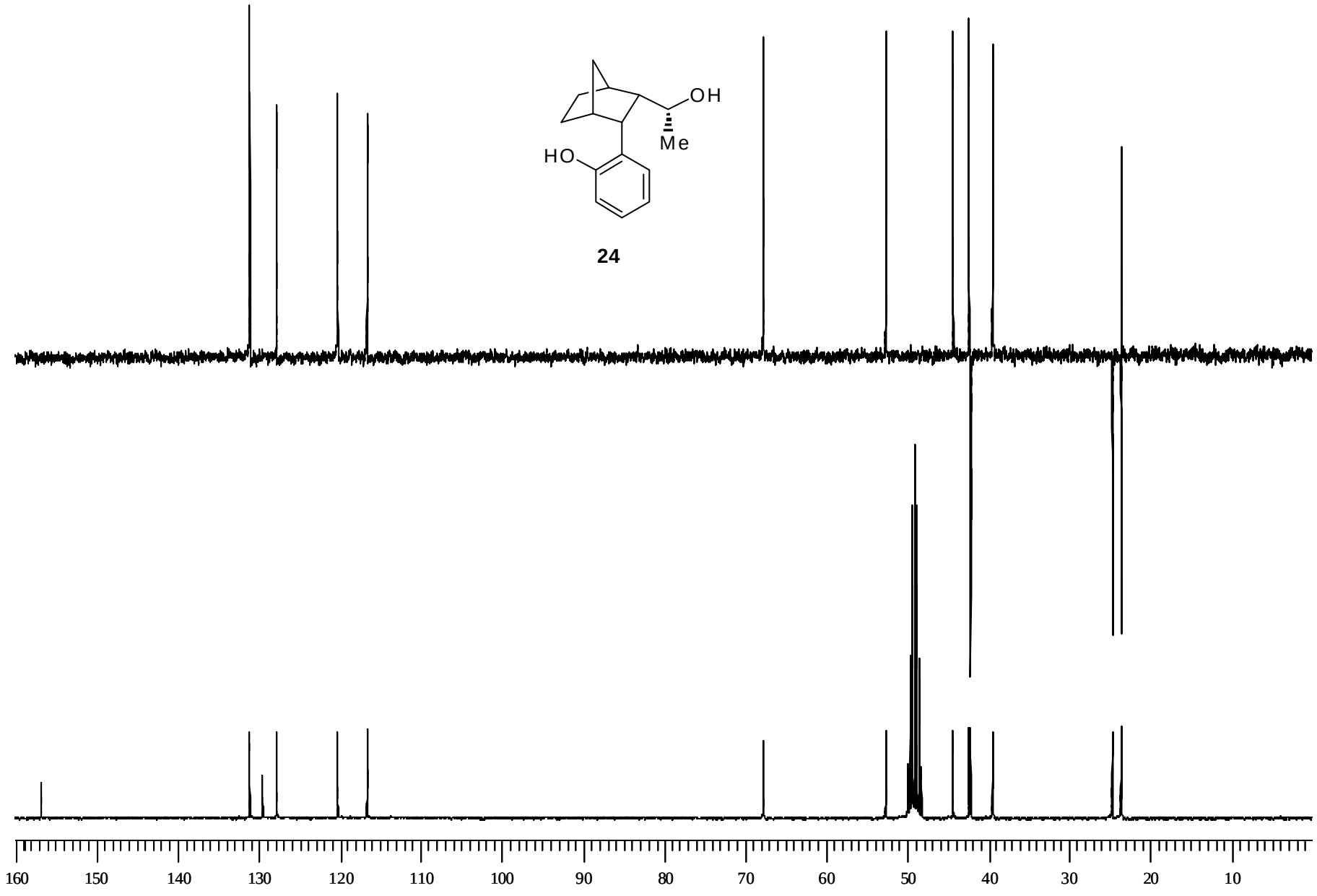
24



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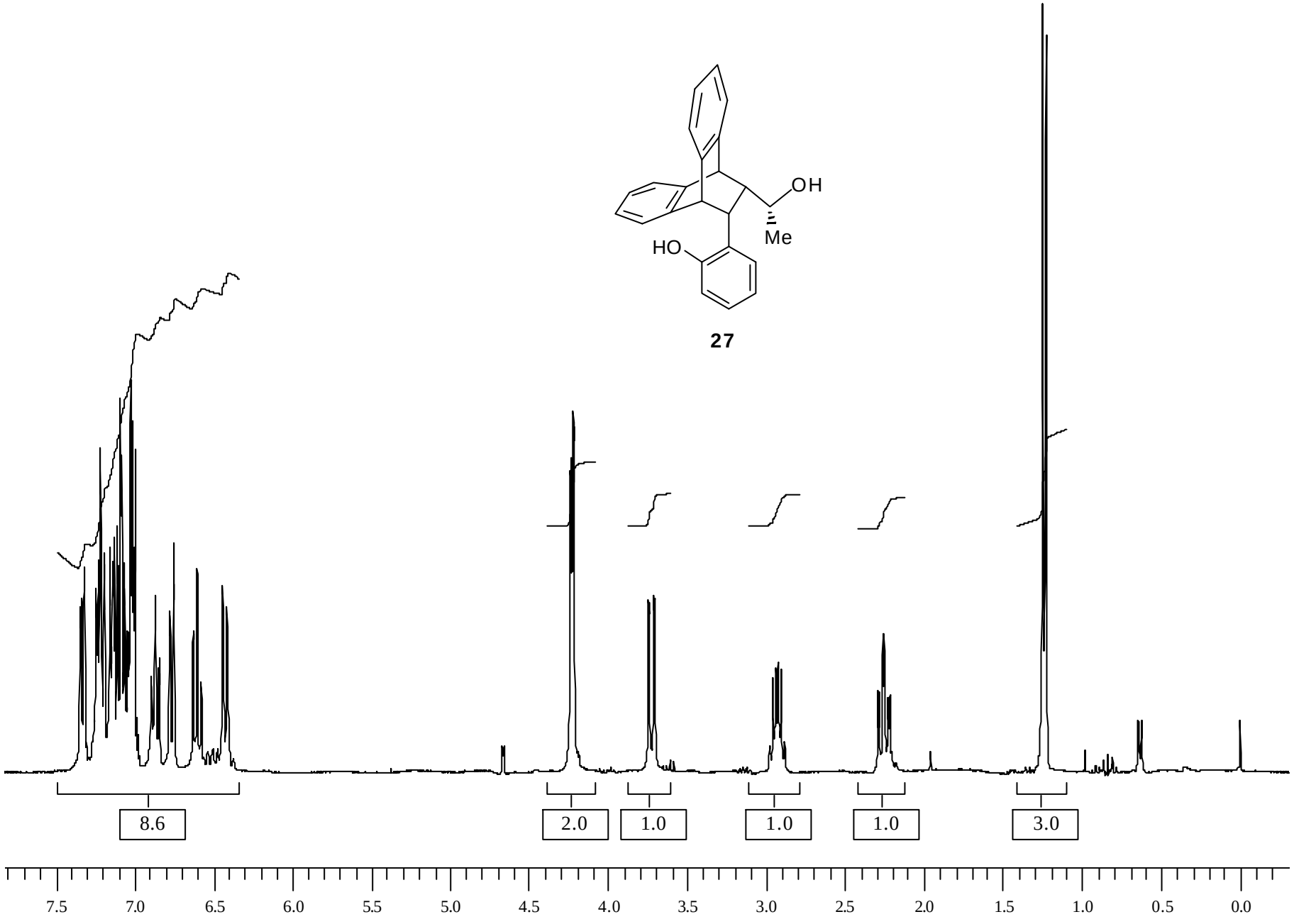
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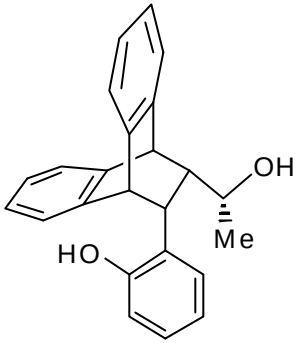
27



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