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Gold-catalyzed intermolecular reaction of 2-(1-alknyl)-2-alken-1-ones with diarylethenes to construct polysubstituted cyclopeta[*c*]furans through a cascade heterocyclization/[3+2] cycloaddition sequence

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1. General Remarks

Column chromatography was carried out on silica gel. Unless noted ^{1}H NMR spectra were recorded on 400 MHz and ^{13}C NMR spectra were recorded on 100 MHz in $CDCl_3$ using TMS as internal standard. IR spectra were recorded on a FT-IR spectrometer and only major peaks are reported in cm^{-1}. All new compounds were further characterized by (ESI)HRMS, HRMS was obtained using a Q-TOF instrument equipped with APCI. Copies of their ^{1}H NMR and ^{13}C NMR spectra are provided. Commercially available reagents and solvents were used without further purification. THF was distilled from Na/benzophenone and used immediately.

2. Typical procedure for the preparation of 2-(1-alkynyl)-2-alken-1-one 1a-1r according to references 1-3.

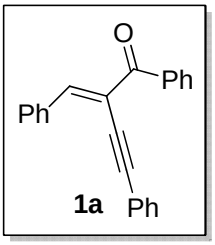
References:

(1) F. Liu, Y.-H. Yu, J.-L. Zhang, *Angew. Chem. Int. Ed*. 2009, **48**, 5505.

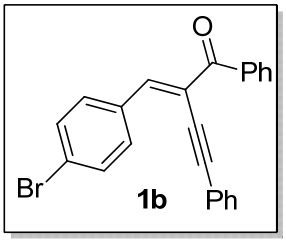
(2) F. Liu, D.- Y. Qian, L. Li, X.-L. Zhao, J.-L. Zhang, *Angew. Chem. Int. Ed*. 2010, **49**, 6669.

(3) T. He, P. Gao, S.-C. Zhao, Y.-D. Shi, X.-Y. Liu, Y.-M. Liang, *Adv. Synth. Catal*. 2013, **355**, 365.

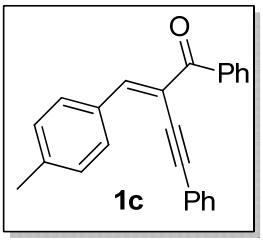
3. Characterization data of 2-(1-alkynyl)-2-alken-1-ones 1a-1r



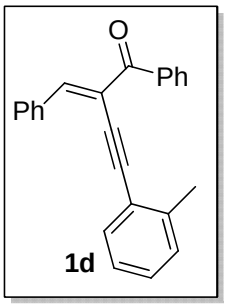
1a: ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.13-8.11 (m, 2H), 8.02-7.99 (dd, J_1 = 8.0 Hz, J_2 = 1.2 Hz, 2H), 7.63 (s, 1H), 7.58-7.56 (m, 1H), 7.50-7.43 (m, 5H), 7.41-7.38 (m, 2H), 7.34-7.32 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.4, 145.0, 137.2, 134.8, 132.5, 131.3, 130.6, 130.4, 129.7, 128.8, 128.6, 128.4, 128.1, 122.9, 120.9, 100.8, 87.2; IR (neat, cm^{-1}) 3435.2, 3059.0, 2922.5, 2197.2, 1663.2, 1594.2, 1489.3, 1445.3, 1262.2, 1070.6, 755.4, 689.9.



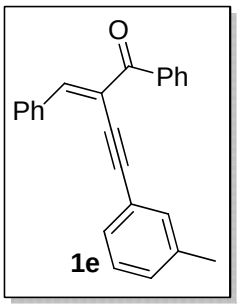
1b: ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.03-7.99 (m, 3H), 7.81-7.72 (m, 1H), 7.62-7.57 (m, 4H), 7.52-7.48 (m, 3H), 7.41-7.35 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.0, 143.3, 138.0, 136.9, 133.7, 132.6, 132.0, 131.9, 131.8, 131.6, 131.3, 129.7, 129.5, 129.0, 128.5, 128.1, 124.8, 122.6, 121.5; IR (neat, cm^{-1}) 3432.7, 3058.8, 2923.3, 2194.0, 1624.7, 1580.1, 1485.0, 1384.1, 1260.4, 1171.3, 1083.3, 962.5, 816.9, 755.0, 690.2.



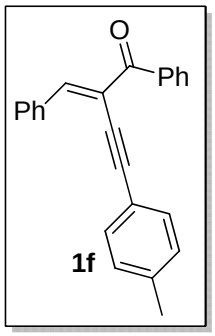
1c: Compound **1c** was prepared according to the method B. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.03-7.97 (dd, J_1 = 17.2 Hz, J_2 = 7.6 Hz, 4H), 7.63 (s, 1H), 7.57-7.54 (m, 1H), 7.48-7.44 (m, 2H), 7.39-7.38 (m, 2H), 7.32-7.31 (m, 3H), 7.26-7.24 (m, 2H), 2.40 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.4, 145.4, 141.2, 137.3, 132.3, 132.1, 131.2, 130.4, 129.6, 129.3, 128.7, 128.4, 128.0, 123.0, 119.7, 100.6, 87.4, 21.6; IR (neat, cm^{-1}) 3393.4, 3057.4, 3027.7, 2920.6, 2851.5, 2198.7, 1624.5, 1598.1, 1578.8, 1445.0, 1319.1, 1275.3, 1180.6, 1095.8, 755.5, 691.5.



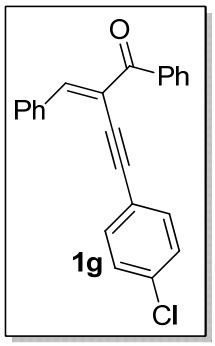
1d: Compound **1d** was prepared according to the method A. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.14-8.11 (d, J = 5.6 Hz, 2H), 8.00-7.98 (d, J = 7.6 Hz, 2H), 7.61 (s, 1H), 7.58-7.54 (m, 1H), 7.48-7.43 (m, 5H), 7.34-7.33 (d, J = 7.6 Hz, 1H), 7.23-7.11 (m, 3H), 2.28 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.7, 144.3, 140.3, 137.3, 134.9, 132.4, 131.9, 130.5, 130.3, 129.7, 129.6, 128.8, 128.6, 128.1, 125.6, 122.6, 121.2, 100.4, 90.7, 20.5; IR (neat, cm^{-1}) 3441.4, 3060.0, 2921.6, 2362.0, 2190.2, 1612.7, 1598.0, 1447.6, 1263.2, 1206.0, 1070.5, 785.6, 718.3, 690.4.



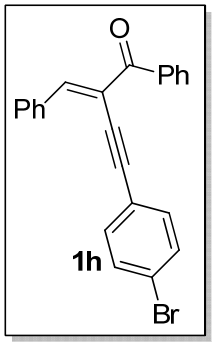
1e: Compound **1e** was prepared according to the method A. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.13-8.11 (m, 2H), 8.01-7.99 (d, J = 8.0 Hz, 2H), 7.61-7.56 (m, 2H), 7.50-7.43 (m, 5H), 7.21-7.20 (m, 3H), 7.16-7.14 (m, 1H), 2.33 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.4, 144.9, 138.1, 137.2, 134.9, 132.5, 131.9, 130.5, 130.4, 129.7, 128.6, 128.4, 128.3, 128.0, 122.7, 121.0, 101.1, 86.8, 21.2; IR (neat, cm^{-1}) 3395.6, 3058.0, 2921.3, 2361.8, 2197.2, 1621.5, 1595.9, 1446.7, 1384.1, 1250.7, 1071.1, 1026.8, 783.6, 719.1, 693.7, 670.0.



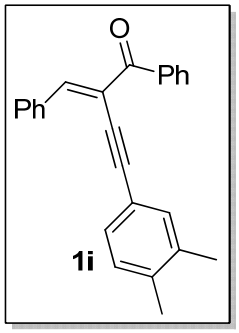
1f: ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.11-8.10 (m, 2H), 8.00-7.98 (m, 2H), 7.59 (s, 1H), 7.57-7.54 (m, 1H), 7.47-7.40 (m, 5H), 7.29-7.27 (d, J = 8.0 Hz, 2H), 7.13-7.11 (d, J = 8.0 Hz, 2H), 2.33 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.4, 144.5, 139.1, 137.1, 134.9, 132.4, 131.2, 130.4, 130.3, 129.7, 129.2, 128.5, 128.0, 125.6, 121.0, 119.8, 101.2, 86.6, 21.5; IR (neat, cm^{-1}) 3334.6, 3058.4, 2921.6, 2194.8, 1662.4, 1594.2, 1446.3, 1262.9, 1178.8, 1097.0, 1026.2, 962.1, 815.1, 753.8, 690.5.



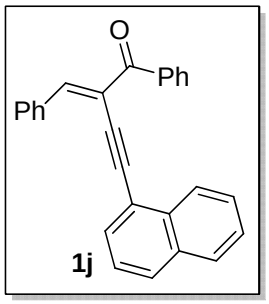
1g: ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.07-7.97 (m, 4H), 7.63-7.57 (m, 2H), 7.50-7.45 (m, 5H), 7.31-7.25 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.2, 145.5, 137.1, 134.9, 134.7, 132.5, 130.7, 130.3, 129.7, 128.8, 128.6, 128.1, 121.3, 120.7, 99.5, 88.0; IR (neat, cm^{-1}) 3402.0, 3064.4, 2923.7, 1663.7, 1595.7, 1488.8, 1383.6, 1263.8, 1157.3, 1018.8, 962.6, 826.6, 691.3.



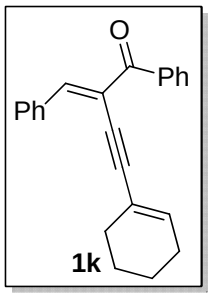
1h: ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.08-8.07 (m, 2H), 7.98-7.96 (m, 2H), 7.63 (s, 1H), 7.61-7.57 (m, 1H), 7.50-7.45 (m, 7H), 7.25-7.23 (d, J = 8.0 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.2, 145.6, 137.1, 134.7, 132.7, 132.6, 131.8, 130.7, 130.3, 129.7, 128.6, 128.1, 123.2, 121.8, 120.6, 99.5, 88.2; IR (neat, cm^{-1}) 3383.1, 2923.0, 1662.6, 1594.6, 1484.9, 1384.7, 1263.3, 1069.2, 1017.5, 822.9, 756.9, 691.4.



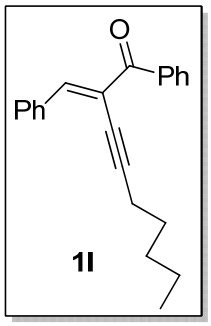
1i: ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.12-8.10 (m, 2H), 8.00-7.98 (m, 2H), 7.62-7.54 (m, 2H), 7.48-7.40 (m, 5H), 7.16-7.13 (m, 2H), 7.08-7.06 (m, 1H), 2.24 (s, 3H), 2.21 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.4, 144.4, 137.9, 137.1, 136.7, 134.9, 132.4, 130.4, 130.3, 129.9, 129.7, 129.3, 128.9, 128.5, 128.0, 121.0, 120.0, 101.4, 86.4, 19.7, 19.6; IR (neat, cm^{-1}) 3310.3, 2920.1, 2196.0, 1634.8, 1594.4, 1495.9, 1447.2, 1317.8, 1263.6, 1207.1, 1071.9, 1024.2, 819.4, 754.5, 691.8.



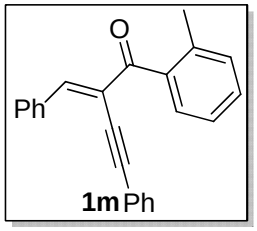
1j: ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.22-8.21 (m, 2H), 8.07-7.05 (d, J = 8.8 Hz, 2H), 8.00-7.96 (m, 1H), 7.84-7.82 (d, J = 8.4 Hz, 2H), 7.71-7.70 (m, 1H), 7.64-7.59 (m, 2H), 7.53-7.47 (m, 6H), 7.45-7.40 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.7, 144.9, 137.5, 134.9, 133.2, 133.1, 132.5, 130.6, 130.5, 130.4, 129.7, 129.3, 128.6, 128.2, 126.9, 126.5, 126.2, 125.2, 121.3, 120.6, 99.6, 91.8; IR (neat, cm^{-1}) 3403.5, 2923.0, 1660.6, 1590.2, 1449.8, 1383.6, 1256.4, 1152.3, 1066.9, 1017.5, 800.1, 771.7, 691.6.



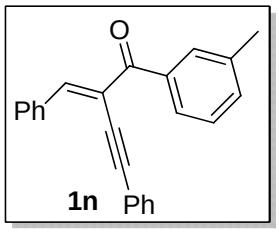
1k: ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.06-8.04 (m, 2H), 7.95-7.94 (d, J = 7.6 Hz, 2H), 7.80-7.76 (m, 1H), 7.58-7.38 (m, 6H), 6.12 (s, 1H), 2.14-2.11 (m, 4H), 1.67-1.56 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.6, 143.6, 137.1, 136.4, 135.0, 132.3, 130.2, 130.1, 129.6, 128.4, 127.9, 121.2, 120.7, 103.1, 84.7, 28.3, 25.8, 22.1, 21.3; IR (neat, cm^{-1}) 3394.1, 3058.9, 2929.6, 2859.4, 2182.6, 1643.7, 1594.4, 1446.3, 1316.5, 1258.8, 1178.3, 1069.1, 755.8, 691.8.



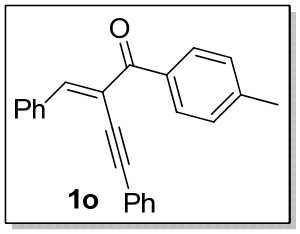
1l: ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.05-8.03 (m, 2H), 7.92-7.90 (m, 2H), 7.55-7.51 (m, 1H), 7.45-7.37 (m, 6H), 2.46-2.42 (t, J = 7.2 Hz, 2H), 1.59-1.52 (m, 2H), 1.36-1.26 (m, 4H), 0.89-0.85 (t, J = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 194.1, 143.8, 137.2, 134.8, 132.2, 130.1, 129.9, 129.6, 128.3, 127.9, 121.7, 103.2, 78.0, 31.0, 27.8, 22.1, 19.9, 13.9; IR (neat, cm^{-1}) 3060.2, 2955.8, 2930.4, 2860.6, 2216.5, 1624.3, 1594.2, 1447.6, 1319.0, 1284.7, 1210.4, 1179.7, 1015.8, 932.4, 757.3, 721.5, 692.0.



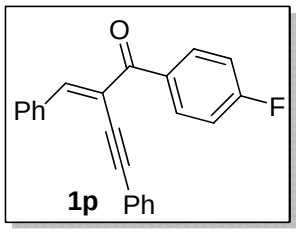
1m: ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.10-8.08 (m, 2H), 7.63 (s, 1H), 7.48-7.46 (m, 1H), 7.43-7.42 (m, 3H), 7.39-7.34 (m, 3H), 7.31-7.29 (m, 3H), 7.27-7.25 (m, 2H), 2.43 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.2, 145.9, 138.6, 136.3, 134.5, 131.4, 130.9, 130.7, 130.5, 130.1, 128.7, 128.5, 128.3, 128.0, 125.1, 122.8, 121.9, 100.3, 86.4, 19.8; IR (neat, cm^{-1}) 3059.6, 3023.8, 2924.7, 2200.1, 1624.5, 1595.9, 1489.2, 1446.4, 1290.1, 1264.8, 1070.9, 931.3, 793.4, 661.2.



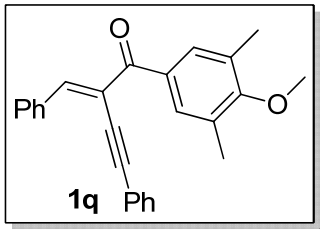
1n: ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.10-8.09 (d, J = 6.8 Hz, 2H), 7.80 (s, 2H), 7.61 (s, 1H), 7.45-7.35 (m, 7H), 7.33-7.28 (m, 3H), 2.39 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.3, 144.8, 137.7, 137.0, 134.7, 133.2, 131.2, 130.4, 130.2, 130.1, 128.7, 128.4, 128.3, 127.8, 126.8, 122.8, 120.9, 100.6, 87.1, 21.2; IR (neat, cm^{-1}) 3057.9, 3014.0, 2921.0, 2195.1, 1618.4, 1598.6, 1489.2, 1445.1, 1297.4, 1178.8, 1071.9, 793.5, 673.9.



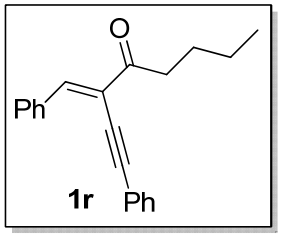
1o: ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.11-8.09 (d, J = 7.6 Hz, 2H), 7.95-7.93 (d, J = 8.0 Hz, 2H), 7.58 (s, 1H), 7.44-7.40 (m, 5H), 7.33-7.31 (m, 3H), 7.28-7.26 (d, J = 8.0 Hz, 2H), 2.42 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.9, 144.6, 143.3, 134.9,134.3, 131.3, 130.4, 130.2, 130.0, 128.8, 128.4, 122.9, 121.1, 100.6, 87.2, 21.7; IR (neat, cm^{-1}) 3440.1, 3057.6, 2921.5, 2196.7, 1674.8, 1604.0, 1489.8, 1445.1, 1275.9, 1179.3, 1095.7, 960.5, 754.3, 689.4.



1p: ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.11-8.04 (m, 4H), 7.62 (s, 1H), 7.44-7.38 (m, 5H), 7.32-7.31 (m, 3H), 7.15-7.11 (t, J = 8.8 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.6, 166.6, 164.1, 145.0, 134.7, 133.2, 133.1, 132.4, 132.3, 131.2, 130.6, 130.3, 128.9, 128.4, 122.6, 120.4, 115.2, 115.0, 101.0, 87.0; IR (neat, cm^{-1}) 3395.3, 3060.3, 2195.9, 1663.1, 1597.4, 1503.9, 1384.6, 1262.4, 1231.6, 1155.5, 1093.3, 847.9, 757.5, 689.2.

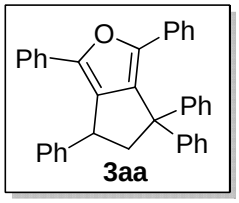


1q: ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.11-8.10 (d, J = 4.8 Hz, 2H), 7.72 (s, 2H), 7.57 (s, 1H), 7.43-7.34 (m, 8H), 3.78 (s, 3H), 2.34 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.6, 160.9, 144.4, 134.9, 132.4, 131.3, 130.9, 130.7, 130.4, 130.2, 128.7, 128.5, 128.4, 122.9, 121.1, 100.6, 87.3, 59.7, 16.2, 16.1; IR (neat, cm^{-1}) 3439.8, 2925.3, 2360.7, 1658.8, 1595.1, 1486.7, 1382.6, 1280.7, 1180.9, 1010.6, 756.4, 689.8.

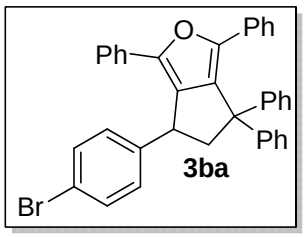


1r: ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.10-8.08 (m, 2H), 7.84 (s, 1H), 7.55-7.53 (m, 2H), 7.43-7.38 (m, 6H), 3.02-2.99 (t, J = 7.6 Hz, 2H), 1.76-1.69 (m, 2H), 1.47-1.38 (m, 2H), 0.98-0.94 (t, J = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.5, 142.7, 134.6, 131.3, 130.7, 130.6, 128.8, 128.6, 128.5, 122.9, 119.8, 99.0, 86.9, 40.0, 26.4, 22.4, 13.9; IR (neat, cm^{-1}) 3371.7, 2957.4, 2929.1, 2869.3, 2360.9, 1680.4, 1563.6, 1489.7, 1446.2, 1381.8, 1140.7, 1069.9, 1031.3, 779.2, 683.8.

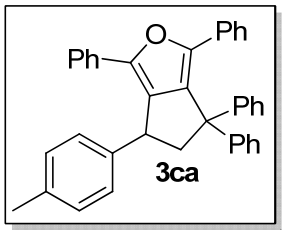
4. Characterization data of highly substituted 4*H*-cyclopenta[*c*]furans 3aa-3ra, 3ab-3af



3aa: The reaction mixture was chromatographed using 100:1 hexane/EtOAc to afford 87.8 mg (90%) of the indicated compound after 1 h. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.40-7.38 (m, 2H), 7.28-7.20 (m, 7H), 7.17-7.14 (t, J = 6.0 Hz, 4H), 7.11-7.02 (m, 8H), 7.01-6.98 (m, 4H), 4.26-4.22 (t, J = 7.2 Hz, 1H), 3.63-3.58 (dd, J_1 = 13.2 Hz, J_2 = 7.2 Hz, 1H), 3.18-3.12 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.1, 144.4, 143.7, 143.0, 142.1, 138.1, 132.6, 130.2, 130.1, 128.9, 128.5, 128.4, 128.1, 128.1, 127.8, 126.8, 126.6, 126.5, 126.4, 126.3, 125.0, 124.8, 64.4, 57.1, 43.4; IR (neat, cm^{-1}) 3401.3, 3057.5, 2923.6, 1663.2, 1598.1, 1489.8, 1446.3, 1383.2, 1068.4, 1026.4, 761.1, 693.5; (ESI)HRMS: Found: m/z 489.2217. Calcd for $C_{37}H_{29}O$: $M+H^+$: 489.2213.



3ba: The reaction mixture was chromatographed using 100:1 hexane/EtOAc to afford 107.5 mg (95%) of the indicated compound after 1 h. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.78-7.76 (d, J = 8.0 Hz, 0.5H), 7.68-7.66 (d, J = 8.4 Hz, 0.5H), 7.54-7.51 (m, 1H), 7.48-7.41 (m, 3H), 7.33-7.30 (m, 4H), 7.27-7.22 (m, 6H), 7.19-7.10 (m, 5H), 7.05-7.03 (m, 4H), 4.32-4.28 (t, J = 7.6 Hz, 1H), 3.68-3.63 (dd, J_1 = 12.8 Hz, J_2 = 7.2 Hz, 1H), 3.19-3.13 (dd, J_1 = 12.4 Hz, J_2 = 7.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 144.5, 143.8, 143.1, 141.1, 138.0, 132.0, 131.9, 131.8, 131.5, 130.1, 130.0, 129.5, 129.4, 128.8, 128.5, 128.4, 128.3, 128.1, 128.0, 126.8, 126.7, 126.4, 125.0, 124.7, 120.1, 64.0, 57.1, 42.8; IR (neat, cm^{-1}) 3395.1， 2969.2， 2924.8， 2360.2， 1744.6， 1660.8， 1595.8， 1448.4， 1383.5， 1260.7， 1070.4， 1027.8， 810.9， 775.7， 698.7; (ESI)HRMS: Found: m/z 567.1311. Calcd for $C_{37}H_{28}BrO$: $M+H^+$: 567.1318.



3ca: The reaction mixture was chromatographed using 100:1 hexane/EtOAc to afford 88.4 mg (88%) of the indicated compound after 2 h. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.48-7.46 (m, 2H), 7.35-7.28 (m, 9H), 7.25-7.23 (m, 7H), 7.20-7.04 (m, 4H), 7.00-6.98 (m, 2H), 4.29-4.26 (m, 1H), 3.68-3.63 (m, 1H), 3.22-3.16 (m, 1H), 2.25 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.3, 144.3, 143.7, 143.0, 139.1, 138.2, 135.9,

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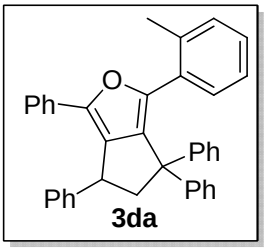
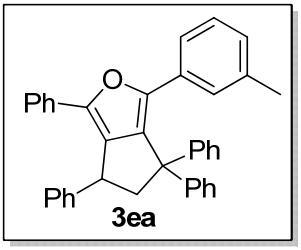
132.8, 130.3, 130.2, 129.2, 128.9, 128.5, 128.3, 128.1, 128.0, 127.9, 127.6, 126.7, 126.6, 126.5, 126.2, 125.0, 124.8, 64.5, 57.1, 43.0, 21.0; IR (neat, cm^{-1}) 3421.8, 3056.5, 2924.2, 2359.6, 1598.5, 1490.1, 1445.2, 1383.6, 1067.9, 1025.3, 793.7, 694.2; (ESI)HRMS: Found: m/z 503.2358. Calcd for $C_{38}H_{31}O$: $M+H^+$: 503.2369.



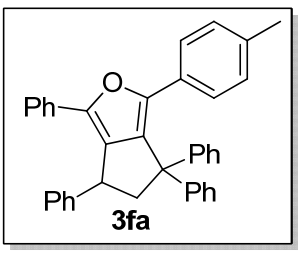
3da

3da: The reaction mixture was chromatographed using 100:1 hexane/EtOAc to afford 94.4 mg (94%) of the indicated compound after 2 h. ^1H NMR (400 MHz, $CDCl_3$): δ 7.34-7.14 (m, 14H), 7.10-7.01 (m, 8H), 6.73-6.67 (m, 1H), 6.61-6.56 (m, 1H), 4.36-4.30 (m, 1H), 3.53-3.46 (m, 1H), 3.37-3.29 (m, 1H), 2.40-2.38 (d, J = 12.0 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.7, 145.6, 145.2, 143.8, 142.4, 138.2, 137.1, 131.0, 130.4, 130.3, 129.8, 129.7, 128.6, 128.5, 128.1, 127.9, 127.7, 126.5, 126.4, 126.3, 126.0, 124.8, 124.6, 62.8, 56.3, 43.2, 21.2; IR (neat, cm^{-1}) 3385.2, 3058.8, 2926.6, 1599.3, 1490.5, 1447.1, 1384.1, 1069.3, 1027.9, 758.6, 697.6; (ESI)HRMS: Found: m/z 503.2358. Calcd for $C_{38}H_{31}O$: $M+H^+$: 503.2369.



3ea

3ea: The reaction mixture was chromatographed using 100:1 hexane/EtOAc to afford 89.4 mg (89%) of the indicated compound after 2 h. ^1H NMR (400 MHz, $CDCl_3$): δ 7.45 (s, 2H), 7.30-7.21 (m, 7H), 7.16-7.05 (m, 12H), 7.01-6.97 (m, 1H), 6.91-6.86 (m, 2H), 4.30 (s, 1H), 3.70-3.66 (dd, J_1 = 12.4 Hz, J_2 = 6.8 Hz, 1H), 3.25-3.20 (t, J = 12.0 Hz, 1H), 2.04(s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.3, 144.5, 143.6, 142.1, 138.0, 137.5, 132.5, 130.3, 130.1, 128.9, 128.6, 128.5, 128.4, 128.1, 127.9, 127.8, 127.5, 126.7, 126.5, 126.4, 126.2, 125.8, 124.8, 122.1, 64.1, 57.1, 43.4, 21.2; IR (neat, cm^{-1}) 3436.5, 2924.0, 2360.9, 1601.6, 1490.9, 1447.3, 1383.7, 1093.3, 1068.2, 757.9, 697.0; (ESI)HRMS: Found: m/z 503.2358. Calcd for $C_{38}H_{31}O$: $M+H^+$: 503.2369.



3fa

3fa: The reaction mixture was chromatographed using 100:1 hexane/EtOAc to afford

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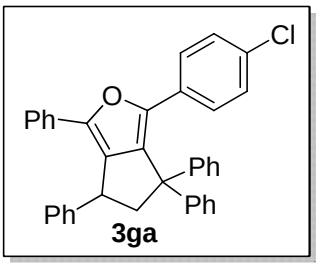
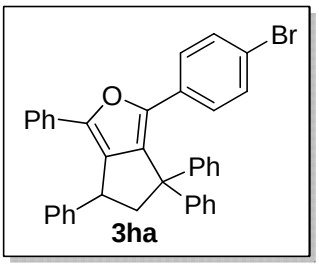
86.5 mg (86%) of the indicated compound after 2 h. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.47-7.45 (d, J = 7.2 Hz, 2H), 7.36-7.31 (m, 8H), 7.29-7.26 (t, J = 7.2 Hz, 2H), 7.24-7.13 (m, 9H), 7.08-7.04 (m, 1H), 6.89-6.87 (d, J = 8.0 Hz, 2H), 4.33-4.29 (t, J = 8.0 Hz, 1H), 3.70-3.65 (dd, J_1 = 12.8 Hz, J_2 = 7.2 Hz, 1H), 3.24-3.18 (dd, J_1 = 12.8 Hz, J_2 = 8.8 Hz, 1H), 2.23(s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.4, 144.7, 143.4, 142.3, 137.4, 136.6, 132.6, 130.4, 129.0, 128.8, 128.6, 128.4, 128.2, 128.1, 127.9, 127.6, 126.8, 126.5, 126.3, 125.0, 124.8, 64.4, 57.2, 43.5, 21.2; IR (neat, cm^{-1}) 3403.6, 2922.6, 2359.0, 1659.6, 1600.0, 1490.8, 1447.6, 1383.2, 1068.4, 1026.3, 757.4, 697.0; (ESI)HRMS: Found: m/z 503.2358. Calcd for $C_{38}H_{31}O$: M+H$^+$: 503.2369.



3ga

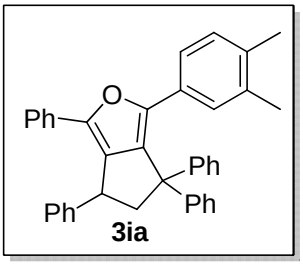
3ga: The reaction mixture was chromatographed using 100:1 hexane/EtOAc to afford 29.3 mg (28%) of the indicated compound after 1 h at 0°C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.82-7.80 (m, 2H), 7.62-7.57 (m, 1H), 7.50-7.46 (m, 2H), 7.44-7.42 (m, 2H), 7.35-7.25 (m, 7H), 7.21-7.12 (m, 8H), 7.04-7.02 (d, J = 8.8 Hz, 2H), 4.33-4.30 (m, 1H), 3.71-3.66 (dd, J_1 = 13.2 Hz, J_2 = 6.8 Hz, 1H), 3.25-3.20 (dd, J_1 = 13.2 Hz, J_2 = 8.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 144.9, 144.1, 143.4, 142.7, 141.9, 138.7, 137.6, 132.7, 132.4, 130.0, 128.8, 128.6, 128.5, 128.4, 128.3, 128.2, 128.1, 127.8, 126.9, 126.8, 126.5, 126.4, 126.1, 124.8, 64.3, 57.1, 43.4; IR (neat, cm^{-1}) 3419.0, 2958.0, 2924.4, 2360.0, 1659.5, 1449.0, 1383.6, 1260.1, 1091.6, 1070.9, 1026.3, 801.3, 699.0; (ESI)HRMS: Found: m/z 523.1809. Calcd for $C_{37}H_{28}ClO$: M+H$^+$: 523.1823.



3ha

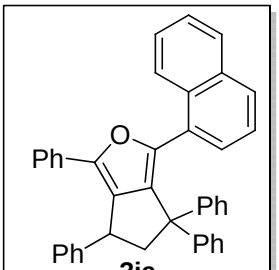
3ha: The reaction mixture was chromatographed using 100:1 hexane/EtOAc to afford 39.6 mg (35%) of the indicated compound after 1 h at 0°C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.82-7.80 (d, J = 7.2 Hz, 1H), 7.59-7.55 (m, 1H), 7.50-7.46 (m, 2H), 7.44-7.42 (m, 2H), 7.37-7.29 (m, 2H), 7.27-7.23 (m, 4H), 7.21-7.17 (m, 7H), 7.14-7.11 (m, 3H), 7.08-7.06 (m, 2H), 4.34-4.30 (t, J = 8.0Hz, 1H), 3.71-3.66 (dd, J_1 = 13.2 Hz, J_2 = 7.2 Hz, 1H), 3.25-3.19 (dd, J_1 = 13.2 Hz, J_2 = 8.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 144.9, 144.1, 143.4, 142.7, 141.9, 138.9, 137.6, 132.7, 132.4, 131.2, 130.0, 128.8, 128.6, 128.5, 128.4, 128.3, 128.2, 128.1, 127.8, 126.9, 126.8, 126.5, 126.4, 124.8, 120.6, 64.2, 57.1, 43.4; IR (neat, cm^{-1}) 3397.0, 2969.2, 2924.2, 2360.2, 1657.9, 1448.4, 1383.5, 1260.7, 1087.7, 1070.4, 1027.1, 801.9, 713.7, 698.7;

(ESI)HRMS: Found: m/z 567.1311. Calcd for $C_{37}H_{28}BrO$: $M+H^+$: 567.1318.



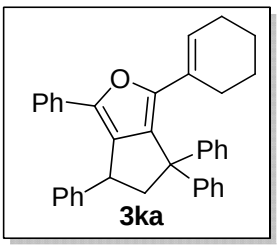
3ia

3ia: The reaction mixture was chromatographed using 100:1 hexane/EtOAc to afford 81.5 mg (79%) of the indicated compound after 1 h. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.47-7.45 (m, 3H), 7.41-7.28 (m, 7H), 7.23-7.04 (m, 11H), 6.88-6.86 (m, 2H), 4.32-4.28 (t, J = 7.2Hz, 1H), 3.70-3.65 (dd, J_1 = 12.8 Hz, J_2 = 7.2 Hz, 1H), 3.24-3.19 (dd, J_1 = 12.4 Hz, J_2 = 9.6 Hz, 1H), 2.13 (s, 3H), 1.94 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.5, 144.7, 143.2, 142.2, 137.3, 136.1, 135.2, 132.5, 130.4, 130.0, 129.9, 129.4, 129.3, 128.9, 128.6, 128.5, 128.4, 128.3, 128.2, 128.1, 127.9, 127.8, 126.7, 126.4, 126.2, 124.7, 122.5, 64.1, 57.1, 43.4, 19.5, 19.4; IR (neat, cm^{-1}) 3420.7, 3058.8, 2922.3, 2360.4, 1660.0, 1599.2, 1492.2, 1447.7, 1383.7, 1068.1, 1022.9, 757.2, 697.2; (ESI)HRMS: Found: m/z 517.2529. Calcd for $C_{39}H_{33}O$: $M+H^+$: 517.2526.



3ja

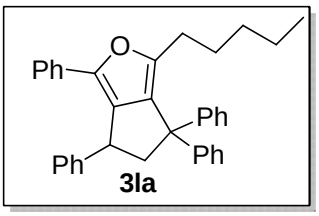
3ja: The reaction mixture was chromatographed using 100:1 hexane/EtOAc to afford 98.6 mg (92%) of the indicated compound after 12 h. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.26-8.25 (d, J = 5.6Hz, 1H), 7.78-7.76 (d, J = 7.6Hz, 1H), 7.65-7.63 (d, J = 8.4Hz, 1H), 7.47-7.44 (t, J = 6.4Hz, 2H), 7.34-7.05 (m, 17H), 7.00-6.99 (m, 4H), 6.68-6.67 (m, 1H), 4.41-4.39 (m, 1H), 3.58-3.53 (m, 1H), 3.45-3.40 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.7, 145.2, 145.0, 144.4, 142.4, 139.5, 133.6, 132.2, 131.2, 130.4, 128.7, 128.6, 128.5, 128.2, 128.1, 128.0, 127.9, 127.7, 126.6, 126.5, 126.4, 126.3, 126.2, 126.0, 125.6, 124.8, 124.6, 62.7, 56.3, 43.3; IR (neat, cm^{-1}) 3405.2, 3057.8, 2930.3, 1949.6, 1598.1, 1491.5, 1446.4, 1385.5, 1216.7, 1069.7, 1023.9, 795.6, 687.9; (ESI)HRMS: Found: m/z 539.2379. Calcd for $C_{41}H_{31}O$: $M+H^+$: 539.2369.



3ka

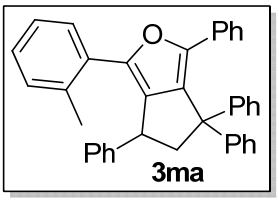
3ka: The reaction mixture was chromatographed using 100:1 hexane/EtOAc to afford 38.4 mg (39%) of the indicated compound after 1 h. ^{1}H NMR (400 MHz, $CDCl_3$): δ

7.44-7.39 (m, 4H), 7.33-7.31 (m, 1H), 7.28-7.26 (m, 2H), 7.24-7.22 (m, 7H), 7.19-7.09 (m, 5H), 7.06-7.03 (m, 1H), 5.63-5.61 (t, J = 4.0Hz, 1H), 4.28-4.24 (t, J = 7.6Hz, 1H), 3.63-3.58 (dd, J_1 = 13.2 Hz, J_2 = 7.2 Hz, 1H), 3.24-3.19 (dd, J_1 = 12.8 Hz, J_2 = 8.8 Hz, 1H), 2.07-2.04 (m, 2H), 1.53-1.38 (m, 4H), 1.30-1.27 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 147.0, 145.5, 143.7, 142.4, 142.2, 136.2, 132.0, 130.6, 129.1, 128.6, 128.4, 128.1, 128.0, 127.8, 127.7, 127.4, 126.5, 126.3, 126.2, 126.0, 124.5, 64.7, 56.8, 43.3, 25.4, 22.4, 21.8; IR (neat, cm^{-1}) 3421.6, 3025.5, 2930.8, 1659.1, 1599.3, 1491.7, 1447.0, 1217.6, 1070.9, 754.7, 698.5; (ESI)HRMS: Found: m/z 493.2524. Calcd for $C_{37}H_{33}O$: M+H$^+$: 493.2526.



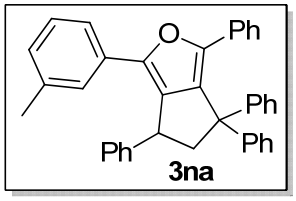
3la

3la: The reaction mixture was chromatographed using 100:1 hexane/EtOAc to afford 55.9 mg (58%) of the indicated compound after 3 h at 50°C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.34-7.33 (m, 4H), 7.24-7.19 (m, 9H), 7.17-7.13 (m, 4H), 7.09-7.01 (m, 2H), 7.00-6.98 (m, 1H), 4.36-4.32 (t, J = 8.0Hz, 1H), 3.53-3.48 (dd, J_1 = 13.2 Hz, J_2 = 7.2 Hz, 1H), 3.16-3.10 (dd, J_1 = 13.2 Hz, J_2 = 9.2 Hz, 1H), 2.35-2.31 (t, J = 7.6Hz, 2H), 1.52-1.47 (m, 2H), 1.22-1.16 (m, 4H), 0.85-0.82 (t, J = 6.8Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 147.3, 146.5, 145.8, 142.7, 142.6, 135.9, 130.8, 130.0, 128.5, 128.4, 128.2, 128.1, 128.0, 127.9, 127.8, 126.4, 126.3, 126.0, 125.8, 124.2, 62.0, 55.5, 43.6, 31.6, 27.6, 27.2, 22.3, 14.0; IR (neat, cm^{-1}) 3058.8, 2928.5, 2863.7, 1600.5, 1491.8, 1447.4, 1382.9, 1217.9, 1069.6, 758.4, 697.3; (ESI)HRMS: Found: m/z 483.2684. Calcd for $C_{36}H_{35}O$: M+H$^+$: 483.2682.

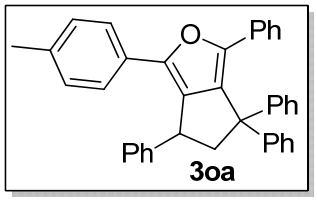


3ma

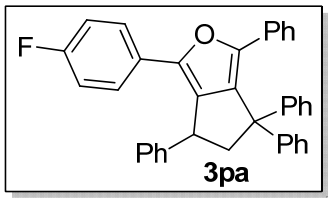
3ma: The reaction mixture was chromatographed using 100:1 hexane/EtOAc to afford 86.3 mg (86%) of the indicated compound after 5 h at 50°C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.52-7.51 (m, 2H), 7.39-7.35 (m, 2H), 7.32-7.28 (m, 3H), 7.20-7.15 (m, 5H), 7.10-7.00 (m, 11H), 6.91-6.88 (m, 1H), 4.25-4.21 (m, 1H), 3.66-3.61 (dd, J_1 = 12.8 Hz, J_2 = 6.4 Hz, 1H), 3.18-3.12 (m, 1H), 2.49 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.4, 144.9, 144.8, 142.7, 141.7, 137.2, 135.4, 133.3, 130.7, 130.3, 129.6, 129.0, 128.7, 128.5, 128.4, 128.1, 128.0, 127.9, 127.6, 127.3, 126.8, 126.5, 126.2, 125.1, 124.8, 64.2, 57.1, 43.6, 21.6; IR (neat, cm^{-1}) 3434.4, 3053.2, 2926.8, 1600.1, 1489.1, 1447.5, 1383.8, 1099.0, 1068.7, 1026.0, 758.9, 697.5; (ESI)HRMS: Found: m/z 503.2358. Calcd for $C_{38}H_{31}O$: M+H$^+$: 503.2369.



3na: The reaction mixture was chromatographed using 100:1 hexane/EtOAc to afford 84.3mg (84%) of the indicated compound after 3 h. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.49-7.47 (d, J = 7.6Hz, 2H), 7.36-7.31 (m, 5H), 7.29-7.24 (m, 4H), 7.21-7.15 (m, 6H), 7.12-7.10 (m, 1H), 7.05-7.01-6.88 (m, 5H), 6.88-6.86 (d, J = 7.6Hz, 1H), 4.30-4.26 (t, J = 8.8Hz, 1H), 3.70-3.65 (dd, J_1 = 13.2 Hz, J_2 = 6.8 Hz, 1H), 3.24-3.19 (dd, J_1 = 12.8 Hz, J_2 = 9.6 Hz, 1H), 2.10 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.3, 144.2, 143.8, 142.8, 142.3, 138.0, 137.6, 132.6, 130.2, 130.1, 128.9, 128.5, 128.4, 128.3, 128.1, 128.0, 127.9, 127.4, 126.8, 126.6, 126.5, 126.3, 125.7, 125.0, 121.8, 64.4, 57.1, 43.5, 21.2; IR (neat, cm^{-1}) 3397.0, 3058.3, 2923.2, 1663.6, 1600.7, 1489.5, 1446.8, 1383.4, 1070.8, 743.9, 692.7; (ESI)HRMS: Found: m/z 503.2358. Calcd for $C_{38}H_{31}O$: M+H$^+$: 503.2369.



3oa: The reaction mixture was chromatographed using 100:1 hexane/EtOAc to afford 86.3mg (86%) of the indicated compound after 1 h. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.49-7.46 (m, 2H), 7.34-7.27 (m, 5H), 7.23-7.09 (m, 12H), 7.06-7.04 (m, 3H), 6.96-6.93 (m, 2H), 4.33-4.28 (m, 1H), 3.71-3.65 (m, 1H), 3.25-3.18 (m, 1H), 2.23 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.2, 144.0, 143.0, 142.3, 138.1, 136.4, 131.8, 130.3, 128.9, 128.5, 128.3, 128.1, 128.0, 127.8, 127.6, 126.7, 126.5, 126.4, 126.2, 124.9, 124.7, 64.4, 57.1, 43.4, 21.2; IR (neat, cm^{-1}) 3402.0, 3032.3, 2877.2, 1663.6, 1519.2, 1489.5, 1446.8, 1383.4, 1107.2, 1070.8, 757.9, 676.8; (ESI)HRMS: Found: m/z 503.2358. Calcd for $C_{38}H_{31}O$: M+H$^+$: 503.2369.



3pa: The reaction mixture was chromatographed using 100:1 hexane/EtOAc to afford 74.9 mg (74%) of the indicated compound after 1 h. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.49-7.47 (m, 2H), 7.37-7.31 (m, 2H), 7.29-7.14 (m, 15H), 7.12-7.06 (m, 3H), 6.84-6.79 (m, 2H), 4.29-4.25 (t, J = 8.4 Hz, 1H), 3.70-3.65 (dd, J_1 = 13.2 Hz, J_2 = 6.8 Hz, 1H), 3.23-3.18 (dd, J_1 = 12.8 Hz, J_2 = 5.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.8, 160.3, 145.2, 144.4, 142.9, 142.7, 141.9, 138.1, 132.2, 130.1, 128.9, 128.6, 128.4, 128.1, 128.0, 127.8, 126.8, 126.6, 126.5, 126.3, 125.0, 115.2, 115.1, 64.4, 57.1, 43.3, 43.2; IR (neat, cm^{-1}) 3401.9, 3059.2, 2931.1, 1662.3, 1599.7, 1496.8, 1447.0, 1383.9, 1231.0, 1156.6, 1092.1, 1029.9, 834.9, 784.2, 697.4; (ESI)HRMS: Found:

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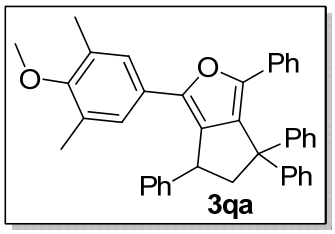
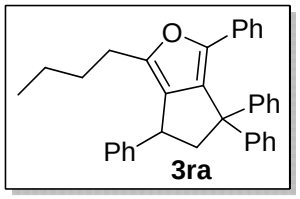
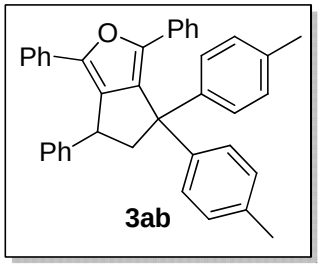
m/z 507.2098. Calcd for $C_{37}H_{28}FO$: $M+H^+$: 507.2119.



3qa: The reaction mixture was chromatographed using 50:1 hexane/EtOAc to afford 74.2 mg (68%) of the indicated compound after 1 h. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.49-7.47 (m, 2H), 7.36-7.11 (m, 15H), 7.06-7.04 (m, 3H), 6.91 (s, 2H), 4.24-4.20 (m, 1H), 3.69-3.62 (m, 4H), 3.24-3.18 (dd, J_1 = 12.8 Hz, J_2 = 9.2 Hz, 1H), 2.26(s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.9, 145.5, 143.9, 143.7, 142.6, 142.5, 137.9, 132.0, 130.5, 130.3, 129.0, 128.6, 128.4, 128.3, 128.1, 128.0, 127.9, 126.8, 126.5, 126.4, 126.2, 125.8, 124.9, 64.4, 59.7, 57.1, 43.6, 15.9, 15.9; IR (neat, cm^{-1}) 3396.2, 2927.4, 1657.5, 1599.4, 1487.3, 1447.3, 1395.3, 1238.0, 1078.9, 1016.9, 759.6, 697.4; (ESI)HRMS: Found: m/z 547.2614. Calcd for $C_{40}H_{35}O_2$: $M+H^+$: 547.2632.

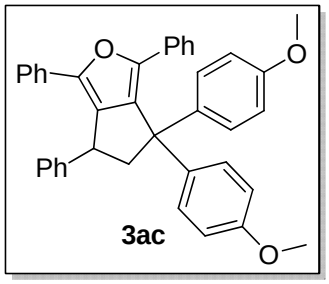


3ra: The reaction mixture was chromatographed using 100:1 hexane/EtOAc to afford 45.9 mg (49%) of the indicated compound after 12 h at 80°C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.50-7.48 (m, J = 8.0 Hz, 2H), 7.39-7.32 (m, 2H), 7.30-7.26 (m, 5H), 7.24-7.22 (m, 3H), 7.21-6.15 (m, 2H), 7.12-7.09 (m, 3H), 7.02-7.00 (m, 3H), 3.97-3.92 (dd, J_1 = 10.4 Hz, J_2 = 6.4 Hz, 1H), 3.55-3.50 (dd, J_1 = 12.8 Hz, J_2 = 6.4 Hz, 1H), 3.13-3.07 (t, J = 12.0 Hz, 1H), 2.33-2.16 (m, 2H), 1.51-1.41 (m, 2H), 1.26-1.14 (m, 2H), 0.79-0.75 (t, J = 7.6Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 146.6, 146.2, 143.2, 142.6, 142.4, 135.7, 131.8, 130.7, 129.1, 128.4, 128.3, 128.1, 127.9, 126.7, 126.5, 126.1, 125.9, 124.4, 63.7, 57.3, 42.2, 30.2, 26.4, 22.2, 13.7; IR (neat, cm^{-1}) 3058.9, 2956.3, 2869.2, 1600.6, 1491.2, 1447.9, 1381.7, 1071.1, 762.2, 739.2, 697.3; (ESI)HRMS: Found: m/z 469.2527. Calcd for $C_{35}H_{33}O$: $M+H^+$: 469.2526.

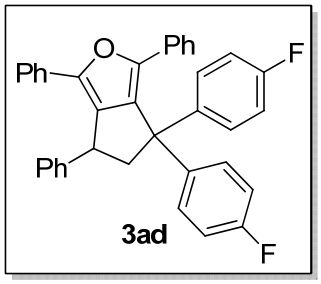


3ab: The reaction mixture was chromatographed using 100:1 hexane/EtOAc to afford 99.1 mg (96%) of the indicated compound after 2 h. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.37-7.34 (m, 2H), 7.30-7.23 (m, 6H), 7.20-7.10 (m, 9H), 7.07-7.06 (m, 4H), 6.99-6.97 (m, 2H), 4.31-4.27 (t, J = 6.8 Hz, 1H), 3.66-3.60 (m, 1H), 3.19-3.12 (m,

1H), 2.35 (s, 3H), 2,24(s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 144.2, 143.6, 142.5, 142.3, 140.0, 138.4, 136.3, 135.7, 132.7, 130.3, 129.0, 128.8, 128.7, 128.5, 128.3, 128.1, 128.0, 127.8, 126.5, 126.4, 125.0, 124.8, 64.5, 56.4, 43.4, 21.0, 20.8; IR (neat, cm^{-1}) 3436.4, 3025.8, 2921.2, 1672.4, 1598.9, 1489.5, 1448.4, 1382.9, 1261.9, 1225.7, 1179.9, 1023.8, 821.2, 762.3, 697.5; (ESI)HRMS: Found: m/z 517.2529. Calcd for $C_{39}H_{33}O$: $M+H^+$: 517.2526.



3ac: The reaction mixture was chromatographed using 50:1 hexane/EtOAc to afford 100.8 mg (92%) of the indicated compound after 2 h. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.38-7.36 (d, J = 7.2 Hz, 2H), 7.31-7.28 (m, 4H), 7.23-7.16 (m, 6H), 7.13-7.06 (m, 7H), 6.87-6.86 (d, J = 7.2 Hz, 2H), 6.72-6.70 (d, J = 7.2 Hz, 2H), 4.30-4.27 (t, J = 7.2 Hz, 1H), 3.77 (s, 3H), 3.70 (s, 3H), 3.61-3.57 (dd, J_1 = 11.6 Hz, J_2 = 6.8 Hz, 1H), 3.16-3.11 (t, J = 9.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 158.2, 157.9, 144.1, 143.6, 142.2, 138.5, 137.6, 135.1, 132.6, 130.2, 129.8, 129.4, 128.5, 128.1, 128.0, 127.8, 126.5, 126.4, 125.0, 124.8, 113.6, 113.4, 64.4, 55.8, 55.2, 43.3; IR (neat, cm^{-1}) 3058.6, 2932.5, 2835.0, 1604.1, 1510.3, 1486.3, 1446.8, 1295.6, 1242.7, 1180.1, 1035.3, 828.1, 764.1, 693.9; (ESI)HRMS: Found: m/z 549.2413. Calcd for $C_{39}H_{33}O_3$: $M+H^+$: 549.2424.



3ad: The reaction mixture was chromatographed using 100:1 hexane/EtOAc to afford 102.7 mg (98%) of the indicated compound after 2 h. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.40-7.38 (m, 2H), 7.34-7.32 (m, 2H), 7.24-7.21 (m, 4H), 7.18-7.14 (m, 4H), 7.13-7.06 (m, 7H), 7.03-6.99 (t, J = 8.4 Hz, 2H), 6.87-6.82 (t, J = 8.8 Hz, 2H), 4.34-4.30 (t, J = 7.6 Hz, 1H), 3.62-3.57 (dd, J_1 = 12.8 Hz, J_2 = 6.8 Hz, 1H), 3.20-3.14 (dd, J_1 = 13.2 Hz, J_2 = 8.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.9, 162.6, 160.4, 160.1, 144.3, 144.0, 141.7, 140.4, 140.3, 138.8, 137.7, 132.1, 130.4, 130.3, 130.1, 130.0, 129.9, 128.5, 128.2, 128.1, 127.7, 126.9, 126.8, 126.6, 124.9, 124.8, 115.3, 115.1, 115.0, 114.8, 64.5, 56.0, 43.2; IR (neat, cm^{-1}) 3397.7, 2925.4, 1600.1, 1512.4, 1447.7, 1383.9, 1232.1, 1161.2, 1068.0, 1022.2, 831.7, 762.7, 693.3; (ESI)HRMS: Found: m/z 525.2024. Calcd for $C_{37}H_{27}F_2O$: $M+H^+$: 525.2013.

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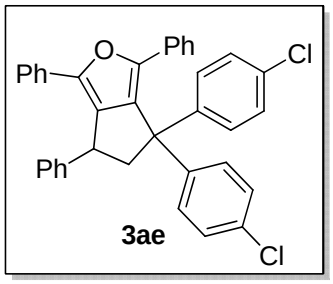
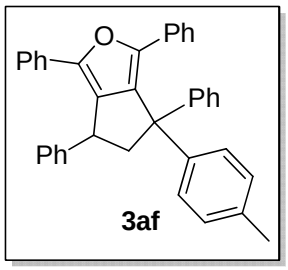


3ae

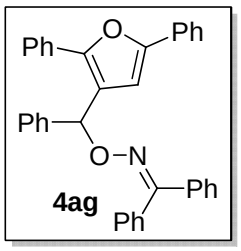
3ae: The reaction mixture was chromatographed using 50:1 hexane/EtOAc to afford 109.0 mg (98%) of the indicated compound after 2 h. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.26-7.19 (m, 6H), 7.14-7.07 (m, 8H), 7.05-7.01 (m, 9H), 4.24-4.23 (d, J = 5.2 Hz, 1H), 3.51-3.46 (m, 1H), 3.08-3.03 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 144.4, 144.1, 143.0, 141.6, 141.4, 137.1, 132.9, 132.4, 132.1, 130.1, 130.0, 129.8, 128.6, 128.3, 128.2, 127.7, 127.0, 126.8, 126.6, 124.9, 124.8, 64.4, 56.2, 43.2; IR (neat, cm^{-1}) 3416.2, 3062.1, 2924.8, 1674.4, 1596.7, 1490.2, 1449.3, 1384.7, 1227.7, 1091.5, 1016.0, 830.6, 745.7, 699.2; (ESI)HRMS: Found: m/z 557.1433. Calcd for $C_{37}H_{27}Cl_2O$: M+H$^+$: 557.1407.



3af

3af: The reaction mixture was chromatographed using 50:1 hexane/EtOAc to afford 95.4 mg (95%) of the indicated compound after 1 h. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.58-7.56 (d, J = 7.2 Hz, 1H), 7.48-7.15 (m, 22H), 7.09-7.07 (d, J = 7.6 Hz, 1H), 4.30-4.29 (t, J = 8.0 Hz, 1H), 3.79-3.74 (dd, J_1 = 12.8 Hz, J_2 = 6.8 Hz, 1H), 3.33-3.26 (m, 1H), 2.45-2.34 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.4, 144.3, 143.7, 143.3, 142.2, 139.8, 138.2, 136.4, 135.7, 132.7, 130.2, 129.1, 128.8, 128.7, 128.5, 128.4, 128.3, 128.1, 128.0, 127.8, 126.7, 126.6, 126.5, 126.4, 125.1, 124.8, 64.4, 56.8, 43.3, 20.8; IR (neat, cm^{-1}) 3398.1, 2923.1, 1599.1, 1490.0, 1446.5, 1383.7, 1070.9, 1025.7, 760.2, 694.0; (ESI)HRMS: Found: m/z 503.2358. Calcd for $C_{38}H_{31}O$: M+H$^+$: 503.2369.

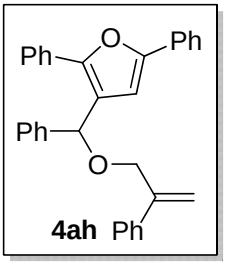
5. Characterization data of trisubstituted furans 4ag, 4ah



4ag

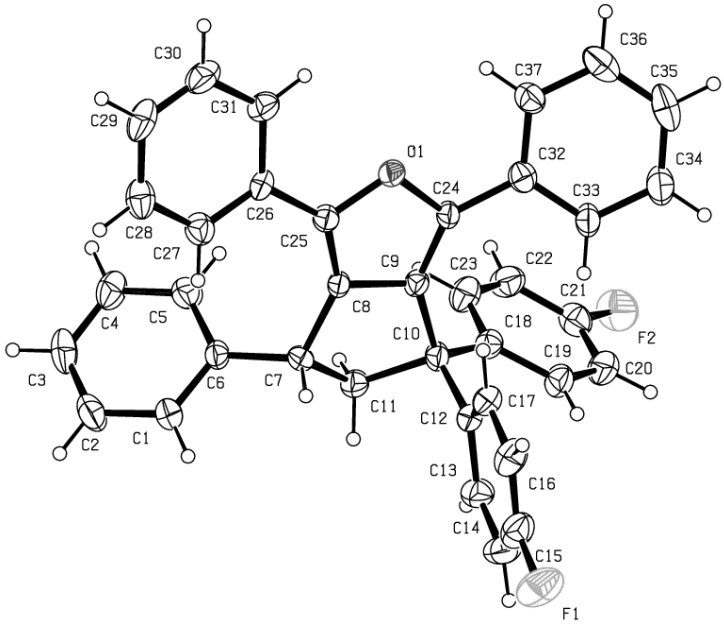
4ag: The reaction mixture was chromatographed using 50:1 hexane/EtOAc to afford 75.8 mg (75%) of the indicated compound after 1 h. ^{1}H NMR (400 MHz, $CDCl_3$):

δ7.84-7.82 (d, J = 8.4 Hz, 2H), 7.65-7.63 (d, J = 8.0 Hz, 2H), 7.44-7.38 (m, 11H), 7.36-7.30 (m, 5H), 7.29-7.19 (m, 5H), 6.66 (s, 1H), 6.48 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 157.5, 152.3, 150.2, 140.8, 136.4, 133.4, 130.8, 130.6, 129.3, 129.2, 128.7, 128.6, 128.5, 128.3, 128.1, 128.0, 127.9, 127.7, 127.5, 127.3, 127.1, 126.6, 123.7, 123.5, 108.0, 79.9; IR (neat, cm^{-1}) 3388.6, 3059.8, 2923.2, 2347.3, 1953.8, 1596.4, 1489.6, 1446.2, 1384.6, 1165.4, 1025.4, 966.0, 906.5, 763.8, 689.2; (ESI)HRMS: Found: m/z 528.1934. Calcd for $C_{36}H_{27}NNaO_2$: M+Na$^+$: 528.1956.



4ah: The reaction mixture was chromatographed using 50:1 hexane/EtOAc to afford 49.5 mg (56%) of the indicated compound after 1 h. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.72-7.70 (d, J = 8.4 Hz, 2H), 7.65-7.63 (d, J = 8.0 Hz, 2H), 7.43-7.33 (m, 7H), 7.32-7.23 (m, 9H), 6.75 (s, 1H), 5.79 (s, 1H), 5.45 (s, 1H), 5.23 (s, 1H), 4.51-4.48 (d, J = 12.8 Hz, 1H), 4.34-4.31 (d, J = 12.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 152.9, 150.4, 144.0, 140.9, 138.8, 130.8, 130.5, 128.7, 128.6, 128.4, 128.3, 127.8, 127.7, 127.6, 127.5, 127.2, 126.5, 126.2, 123.8, 123.6, 114.9, 107.3, 74.6, 70.4; IR (neat, cm^{-1}) 3435.2, 3058.6, 2923.6, 2358.2, 1951.2, 1597.8, 1489.8, 1448.2, 1384.0, 1261.0, 1082.9, 1027.0, 911.3, 793.6, 684.3; (ESI)HRMS: Found: m/z 465.1825. Calcd for $C_{32}H_{26}NaO_2$: M+Na$^+$: 465.1847.

6. Crystal structure of 3ad



X-ray structure of **3ad**

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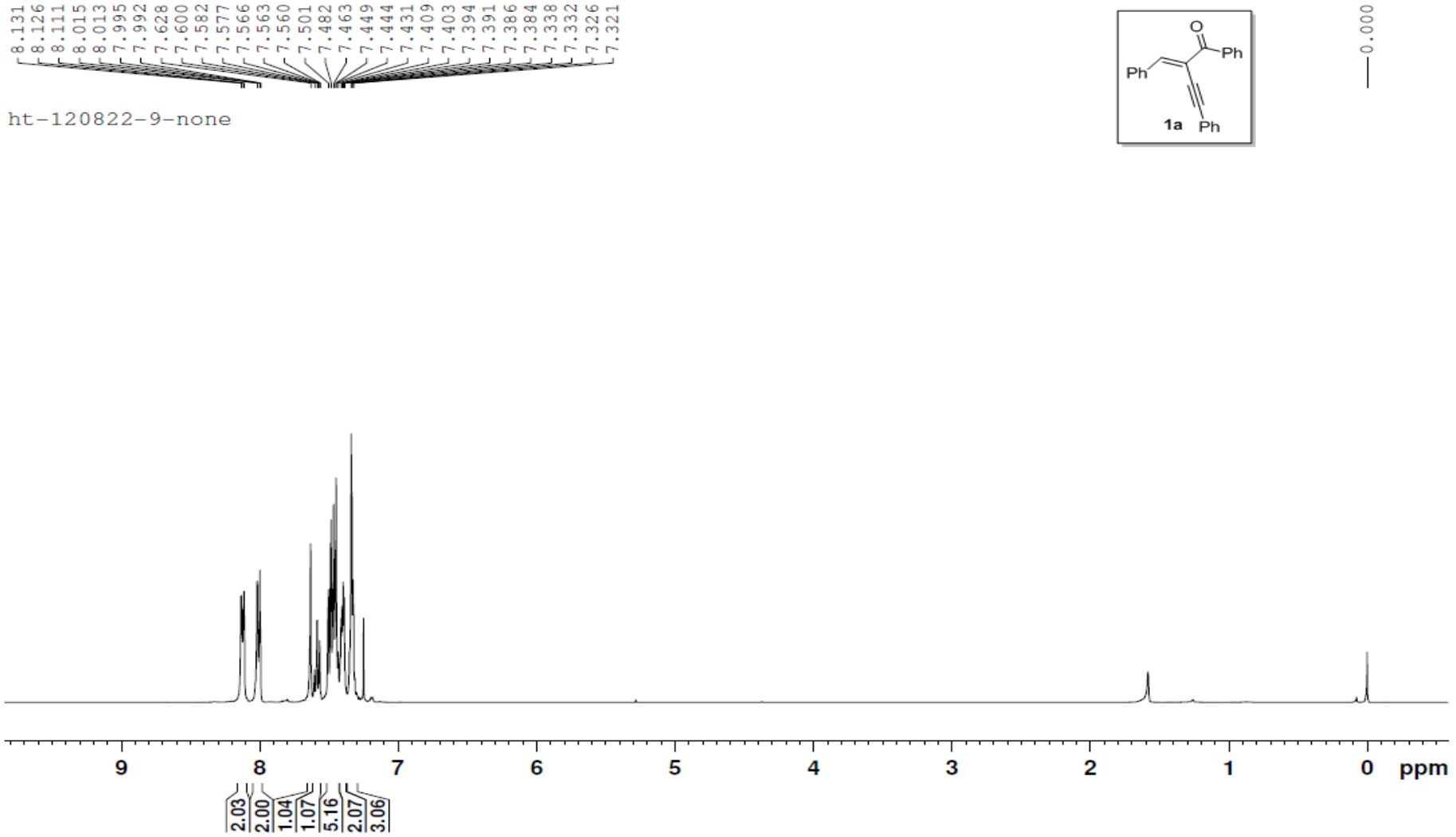
7. ^{1}H NMR and ^{13}C NMR spectra for compounds 1a-1r



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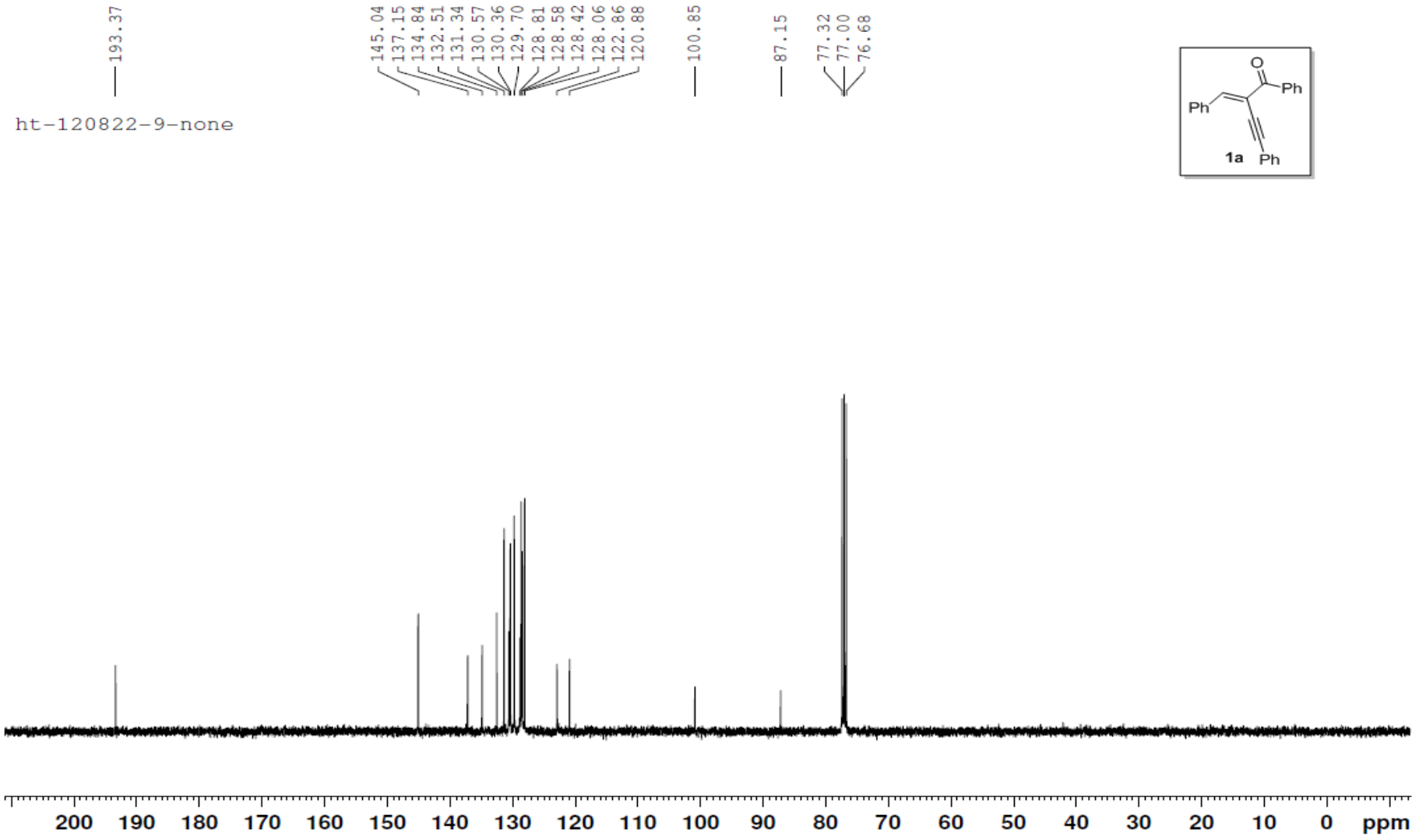

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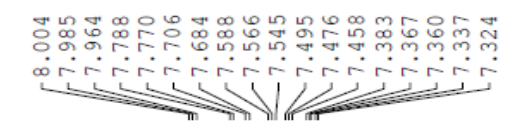

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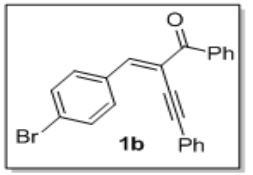

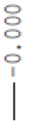

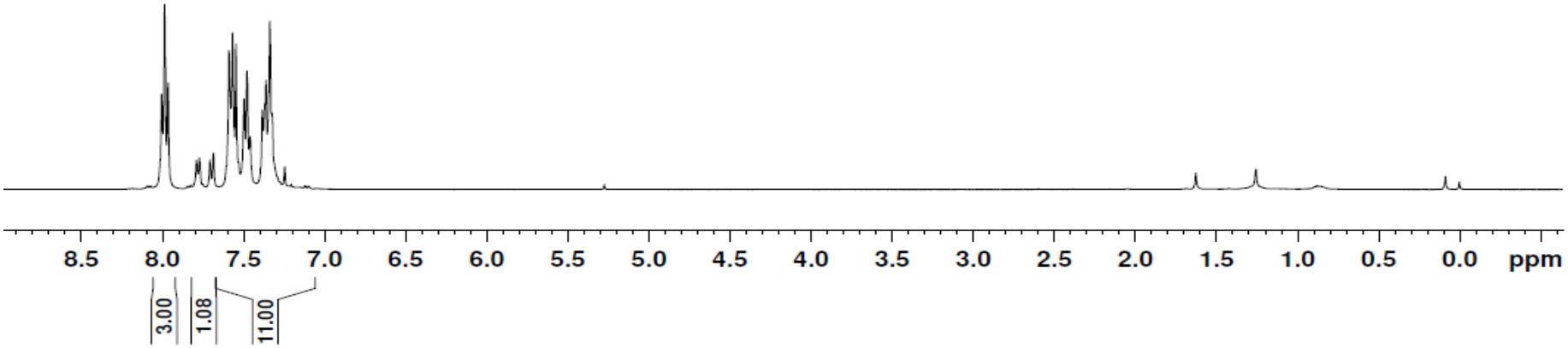

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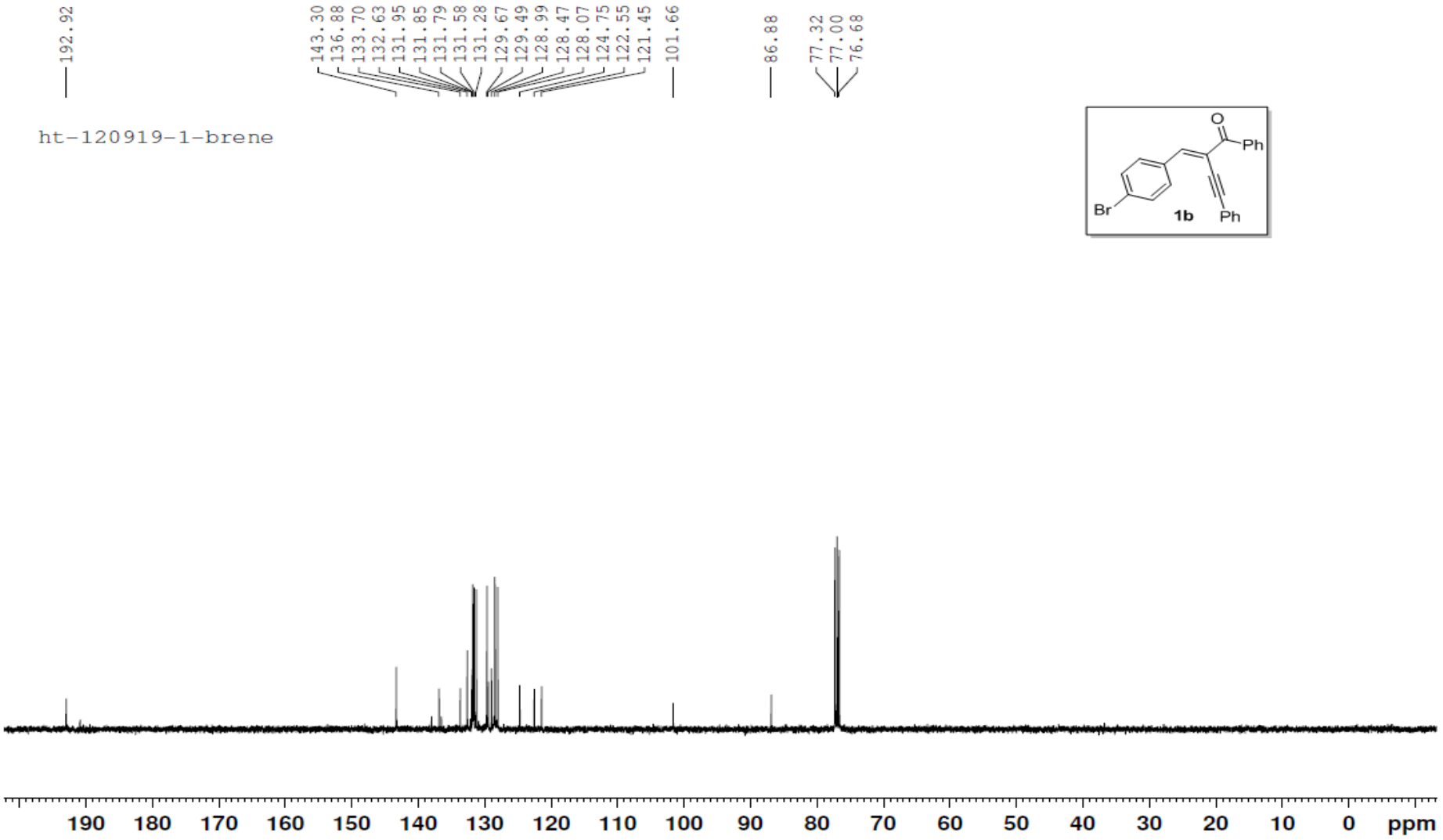

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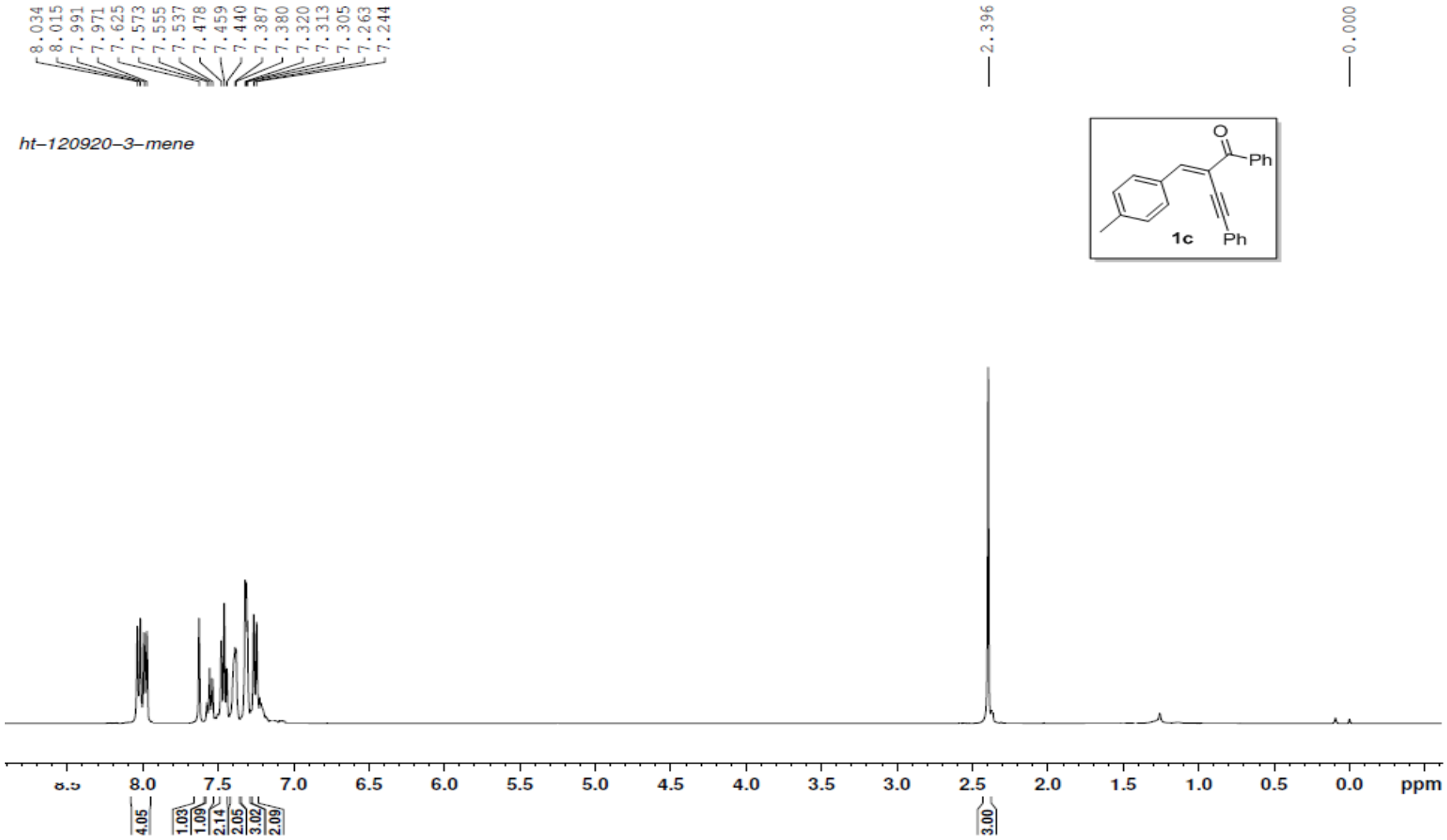

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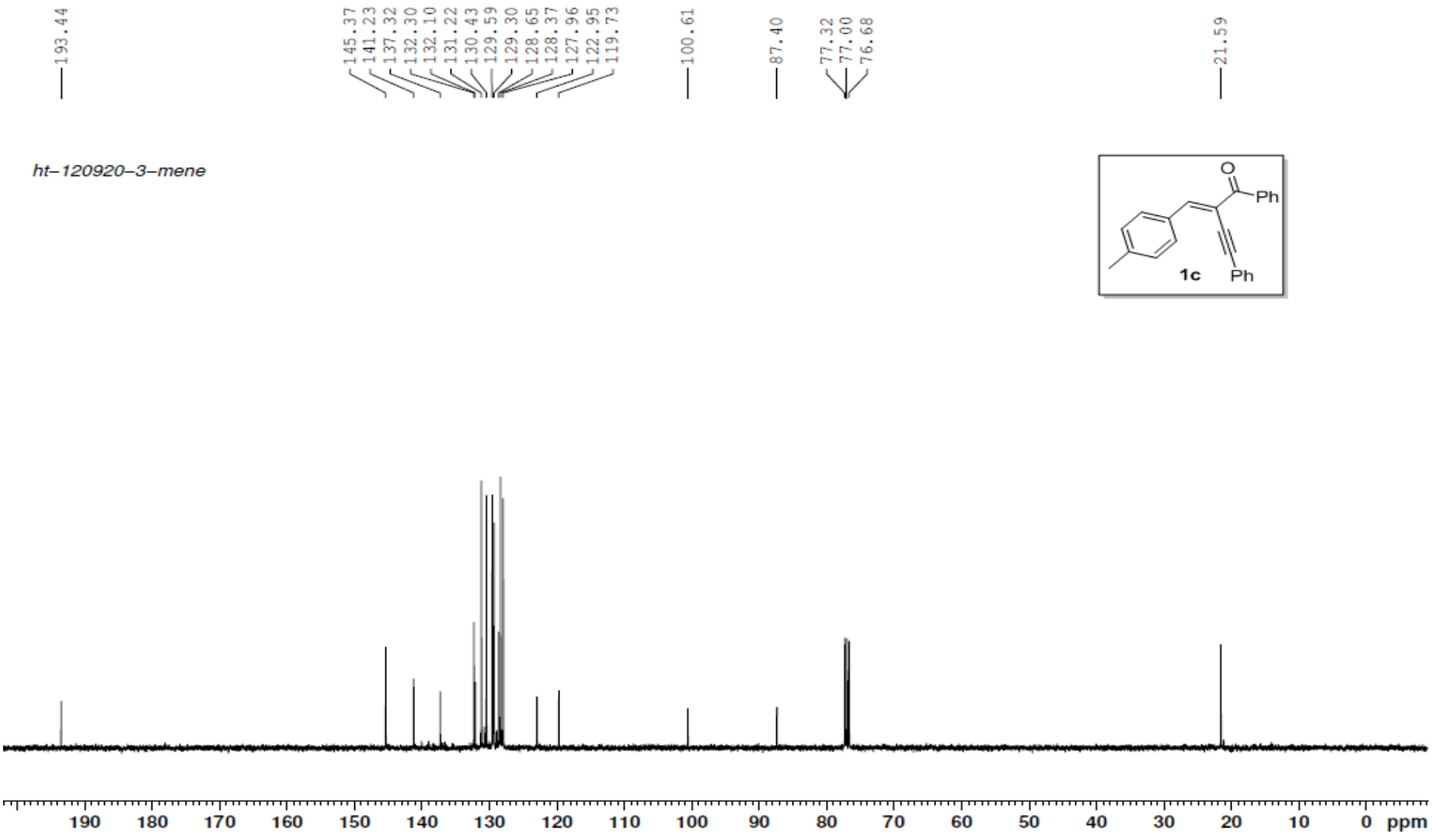

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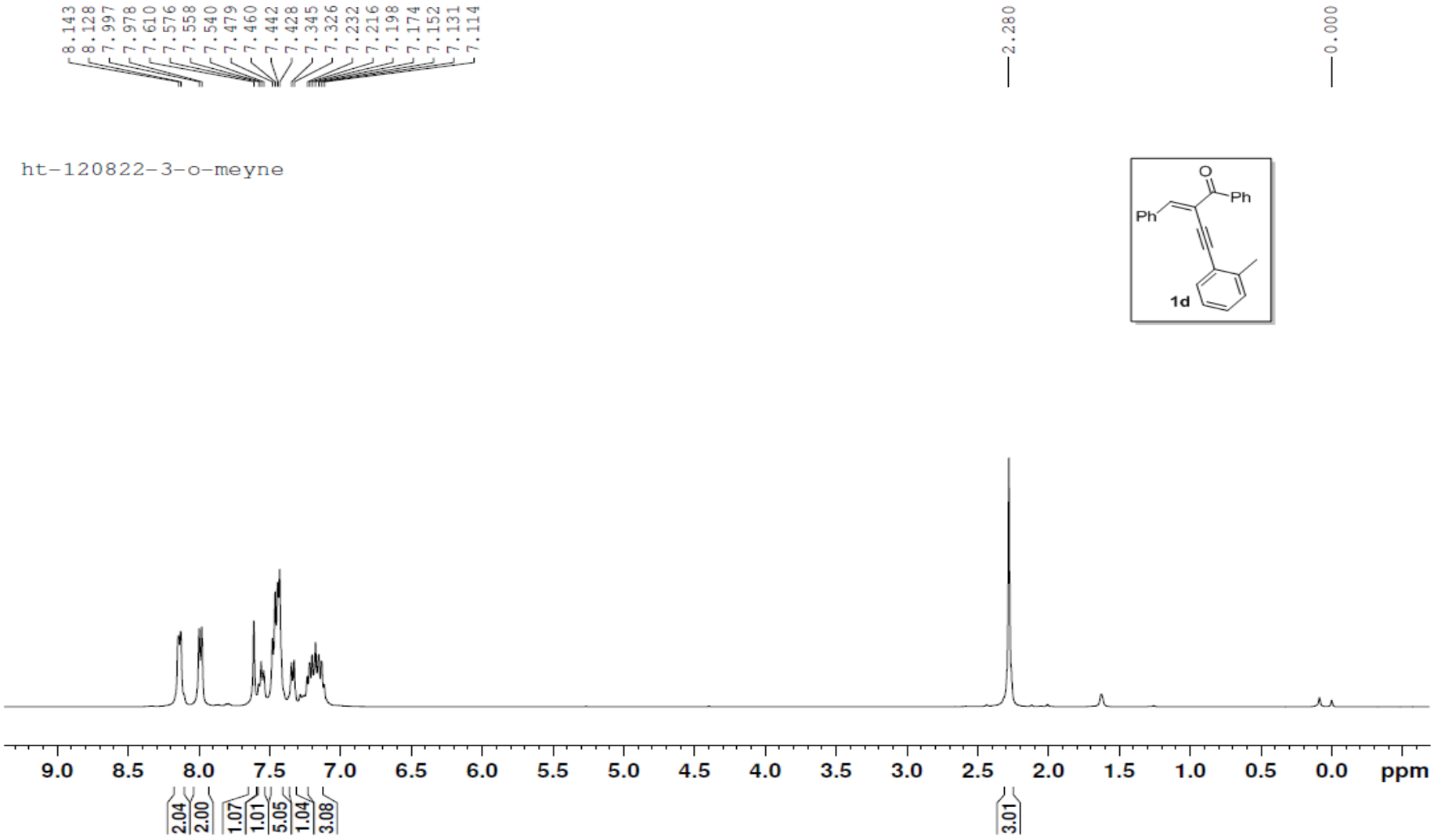

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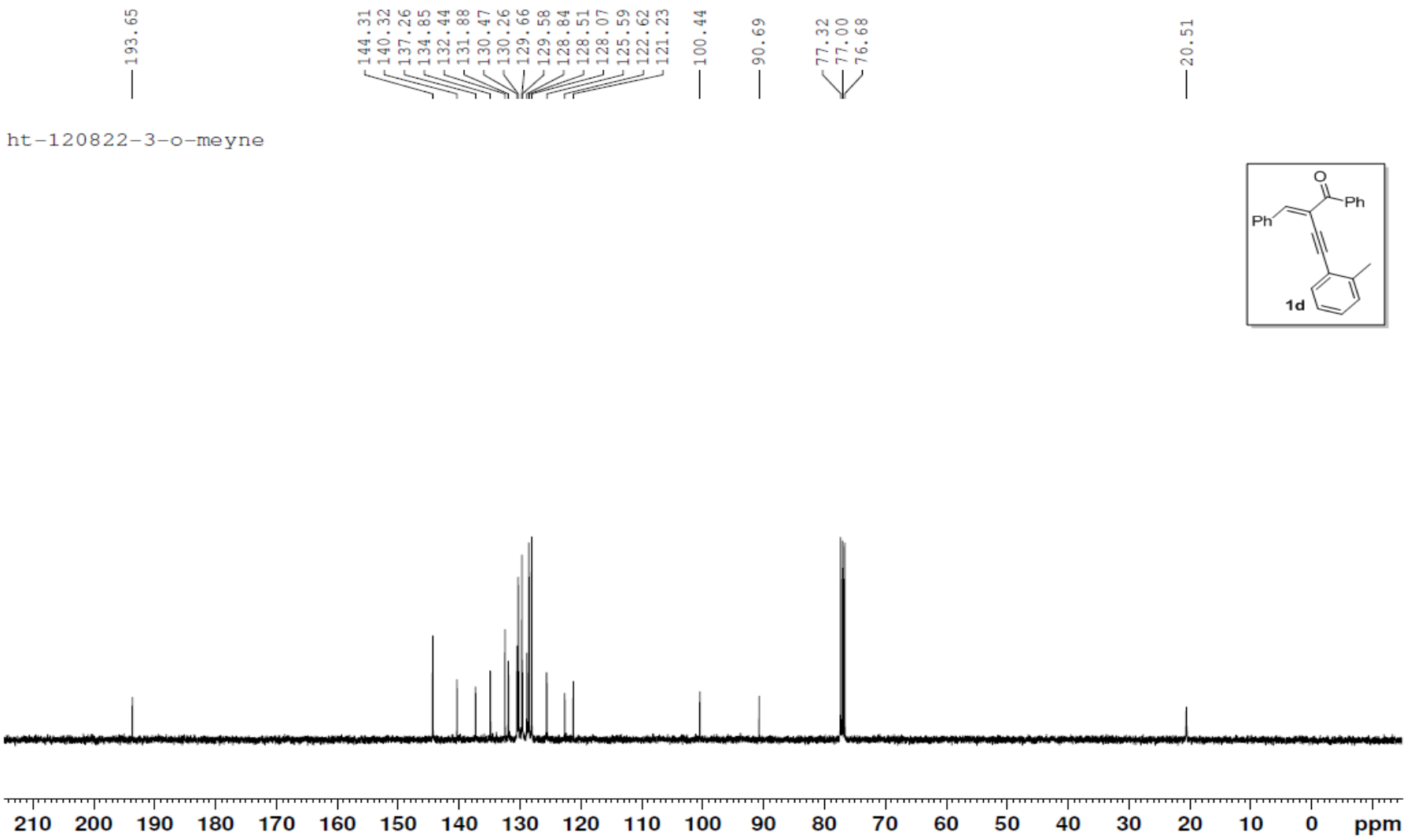

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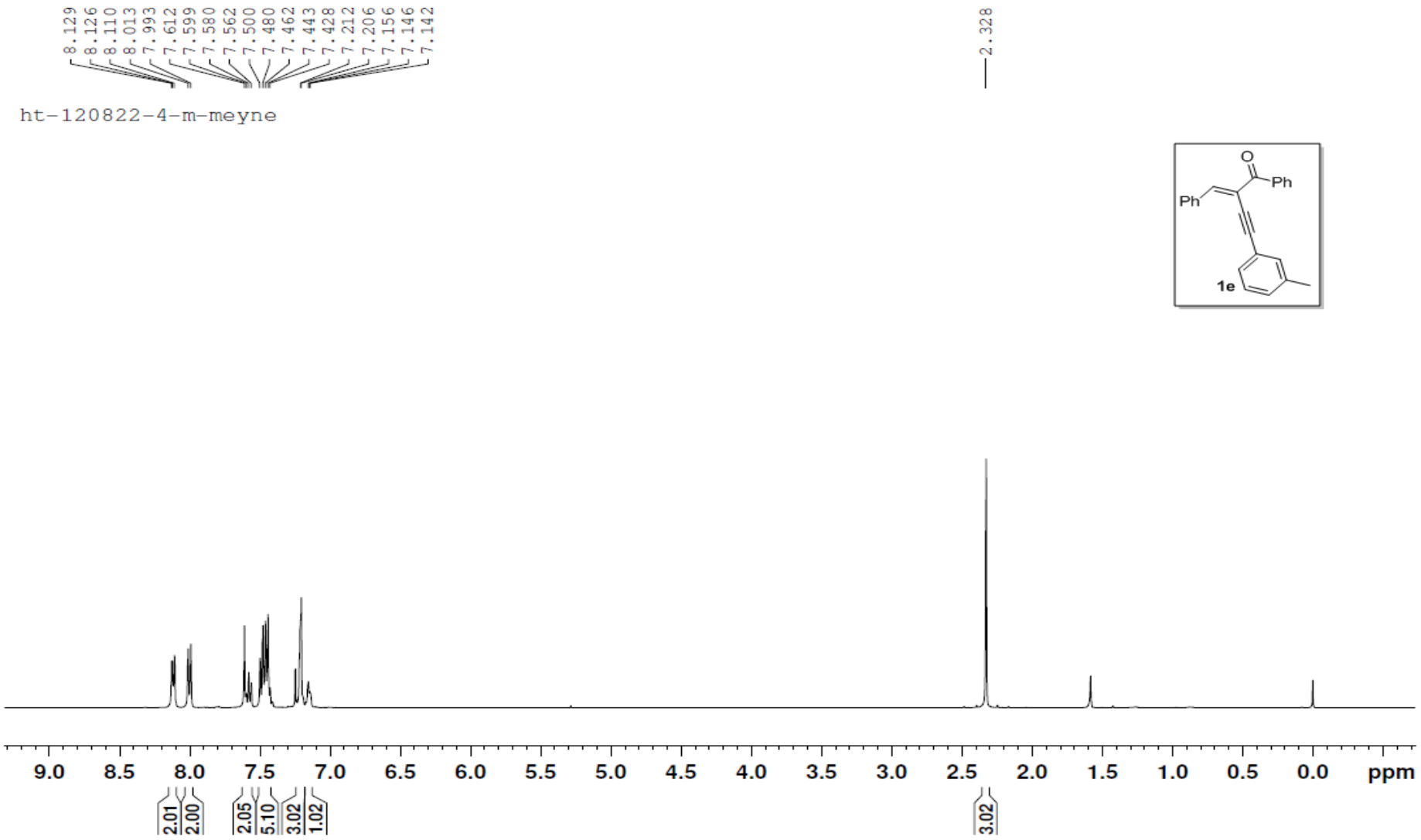

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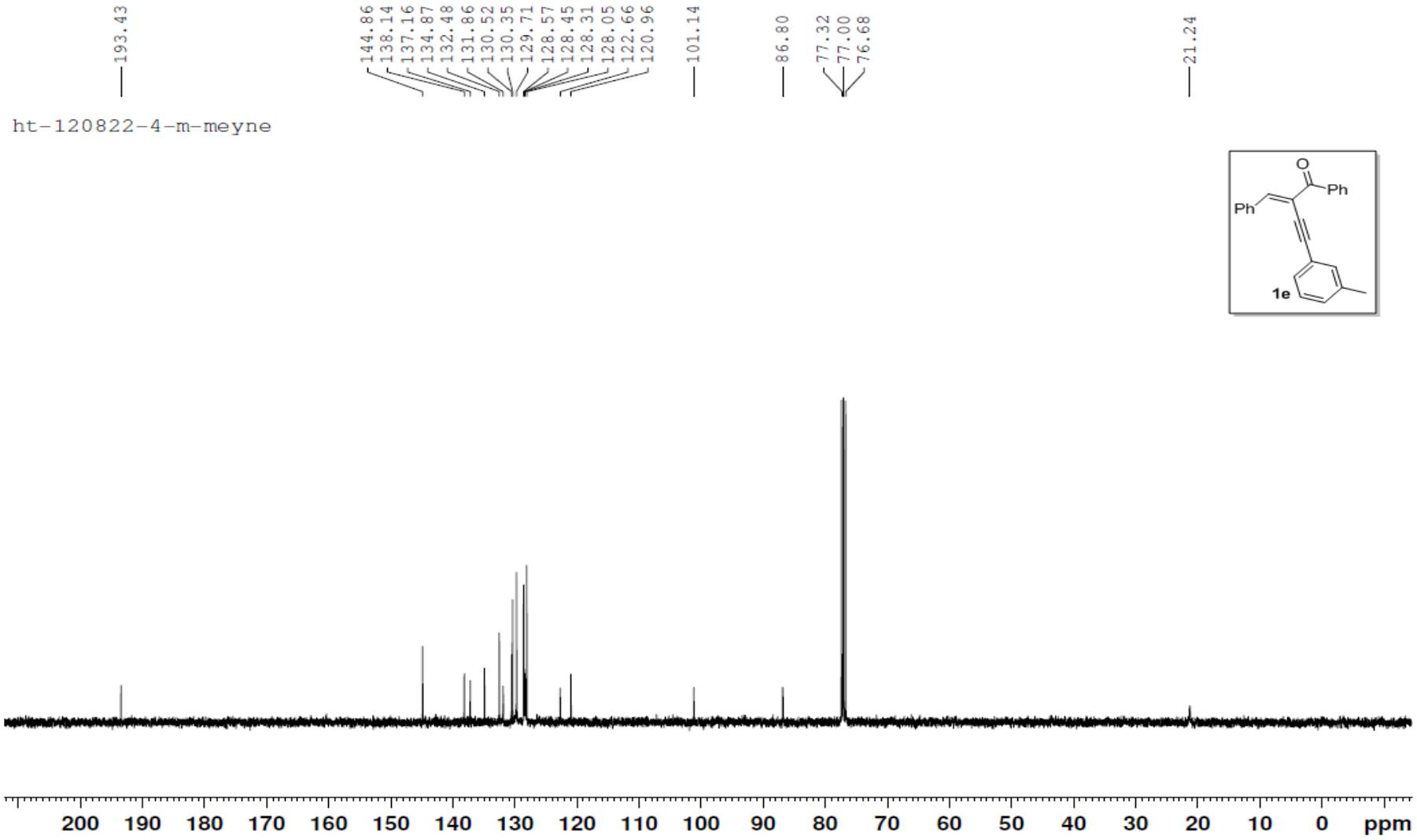

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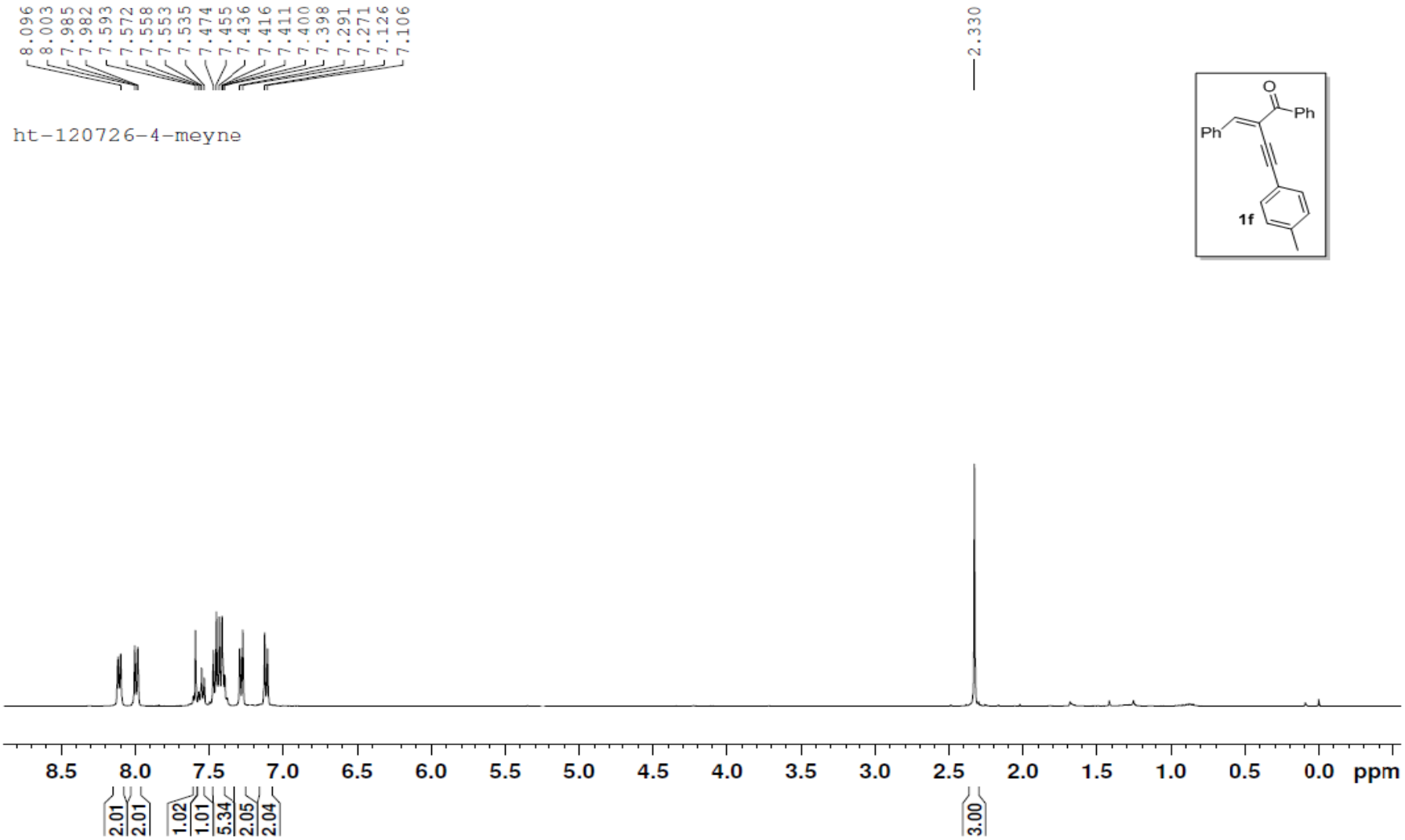

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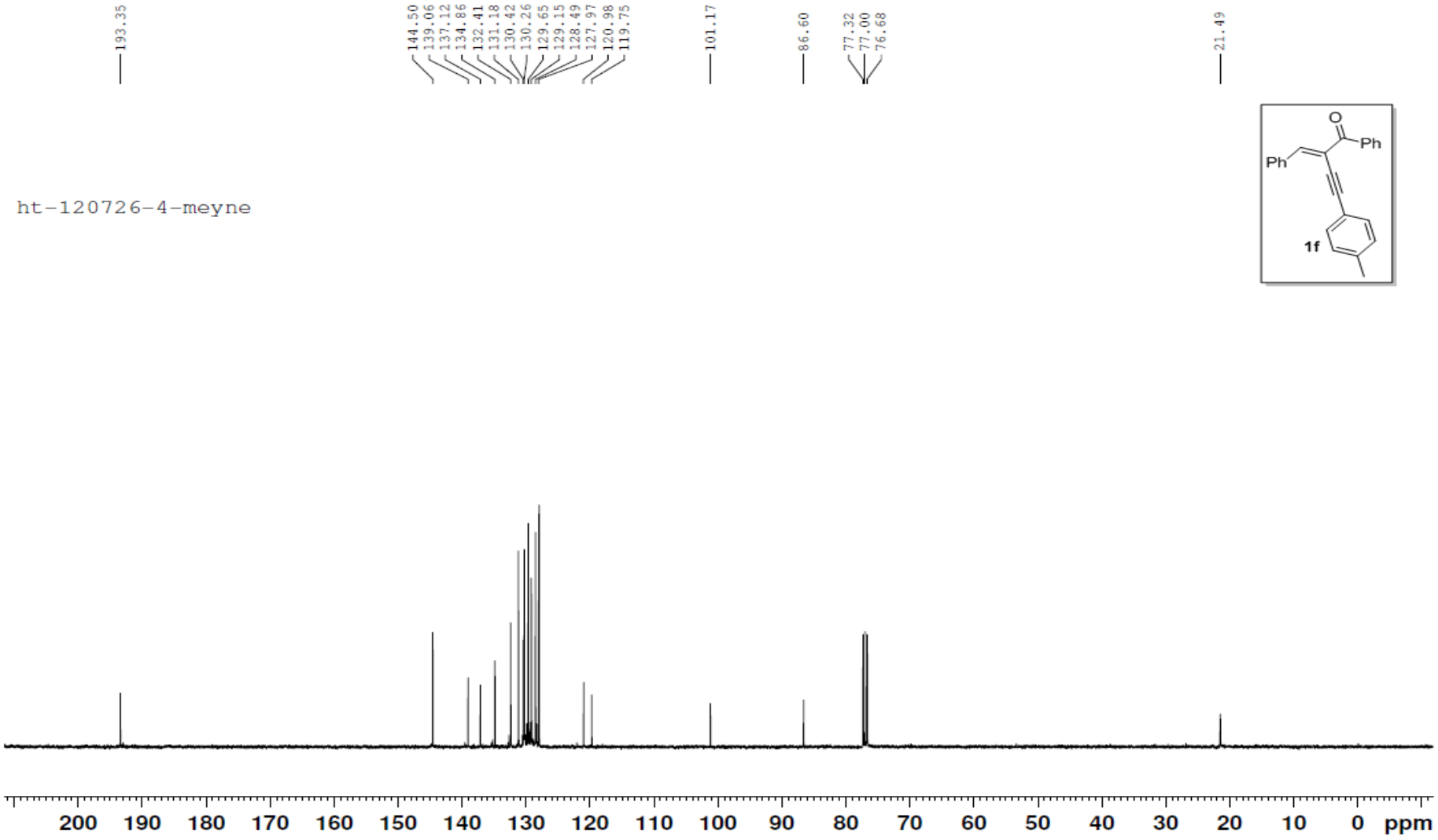

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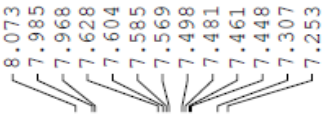

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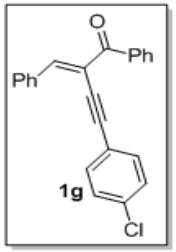

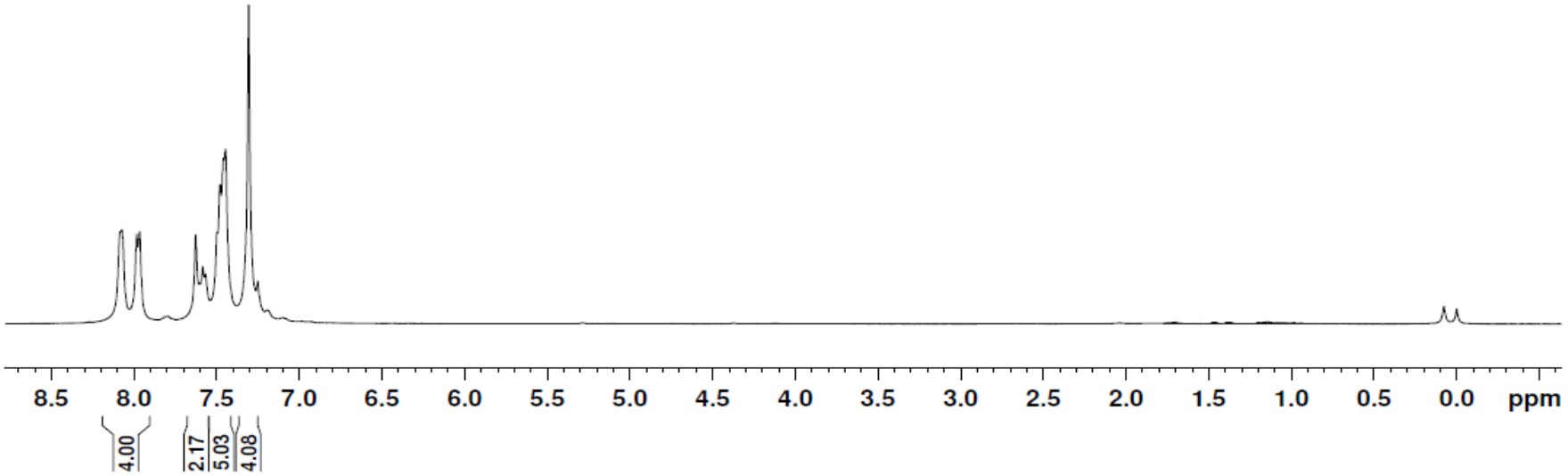

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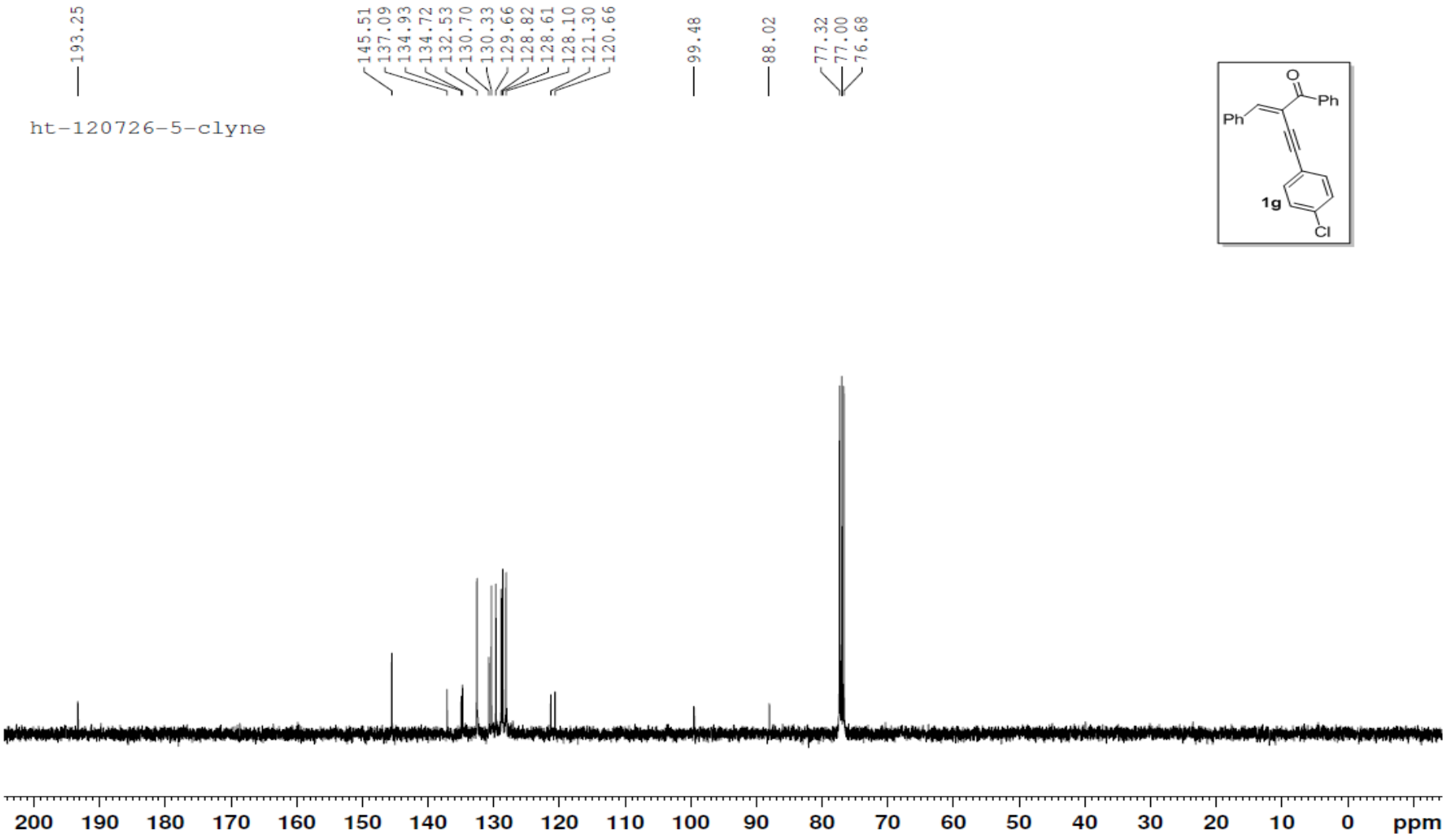

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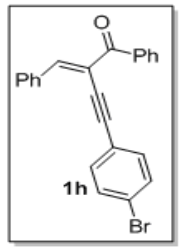

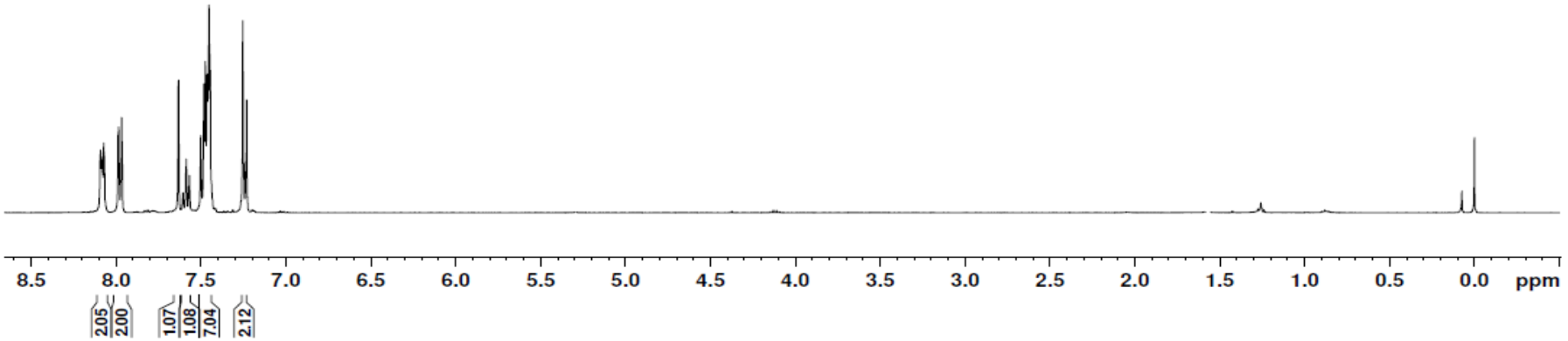

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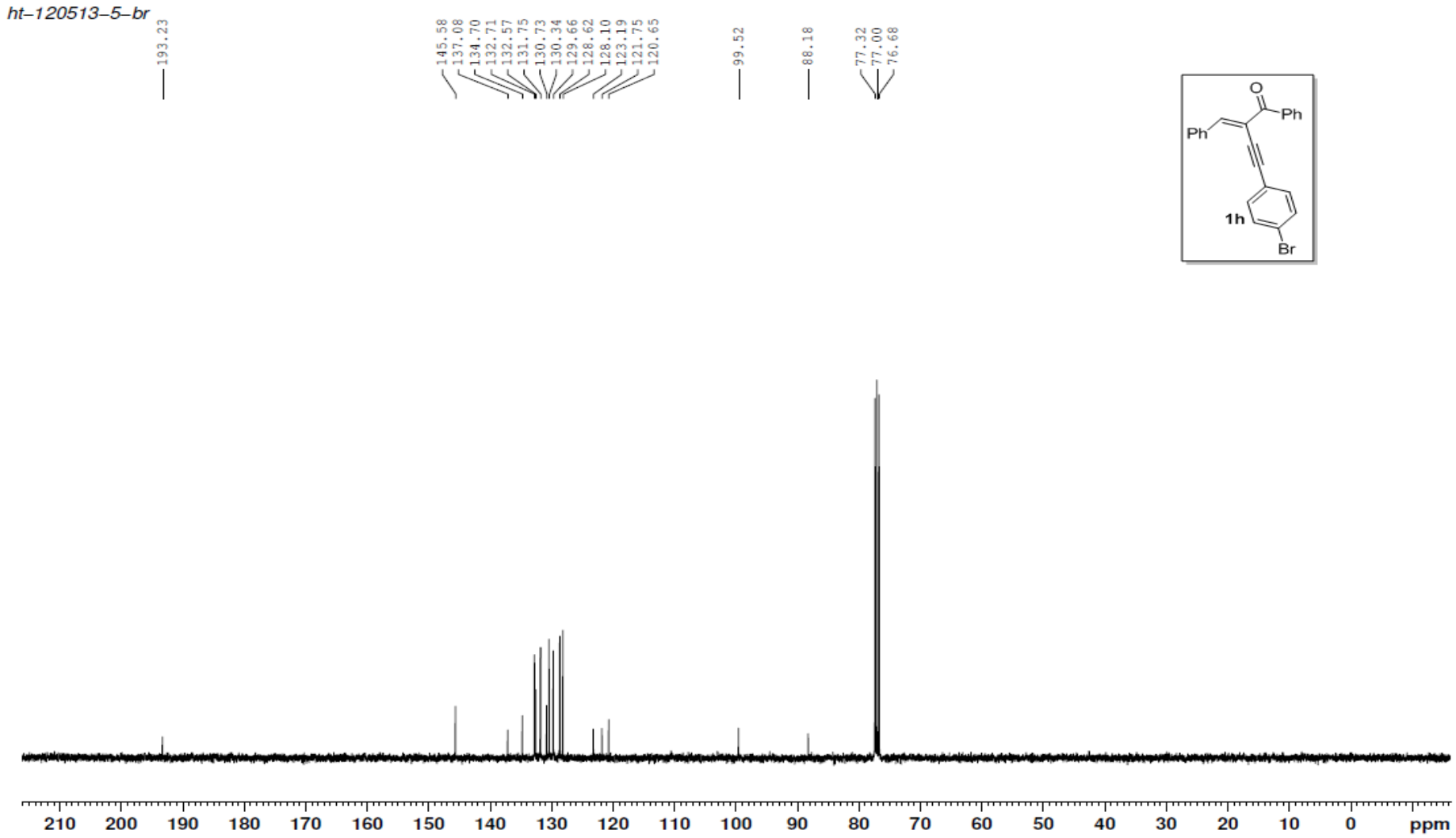

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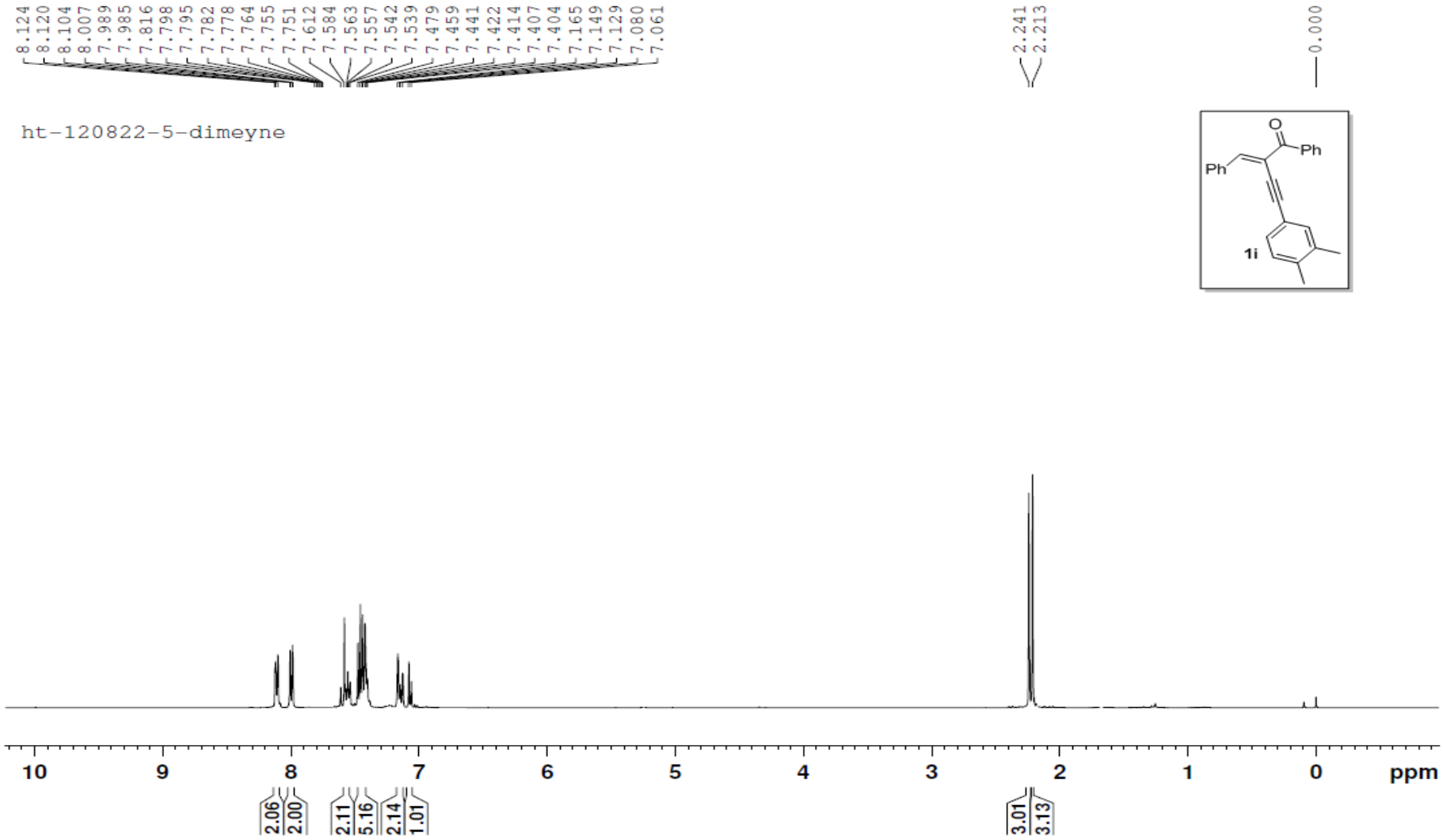

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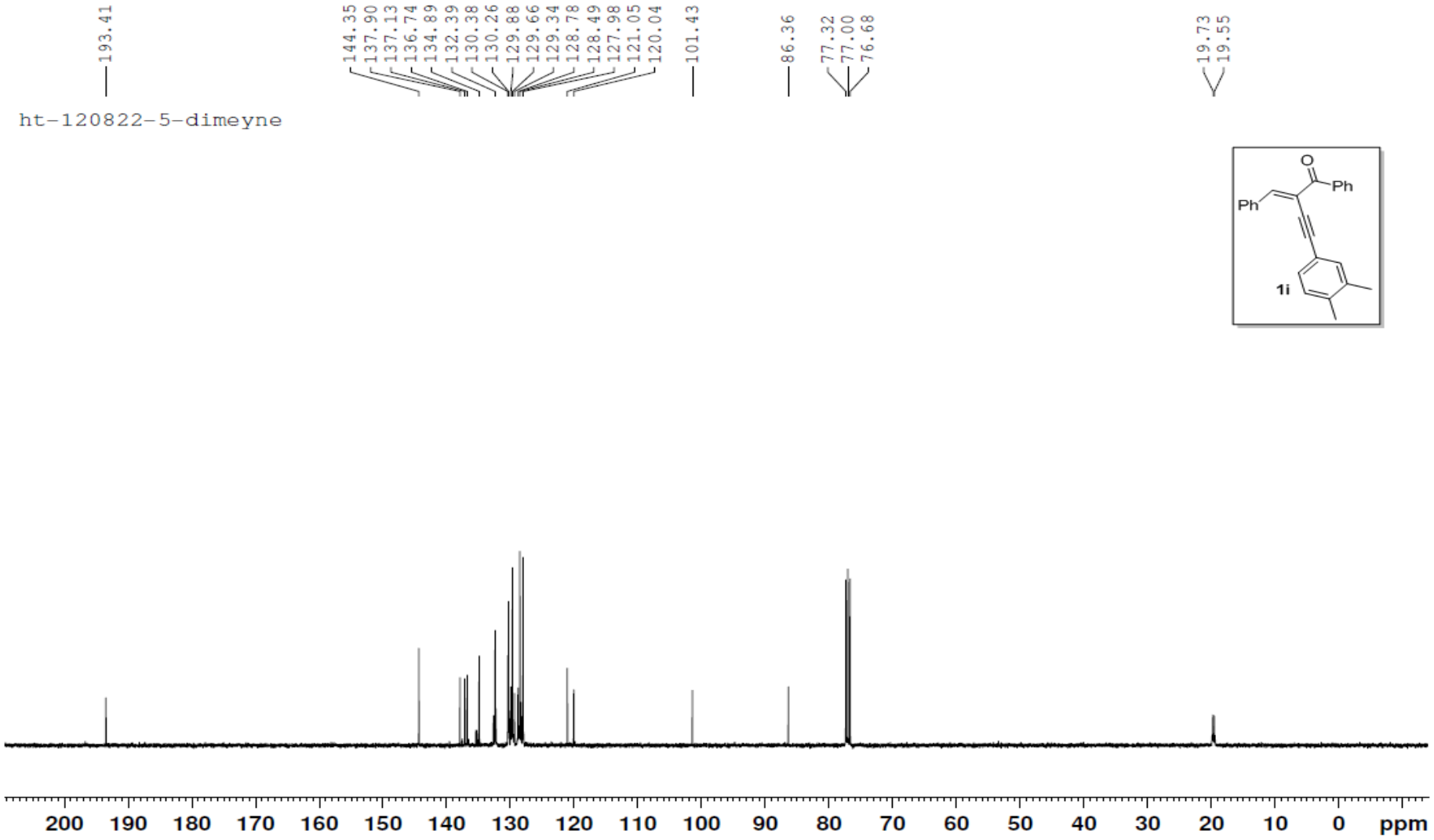

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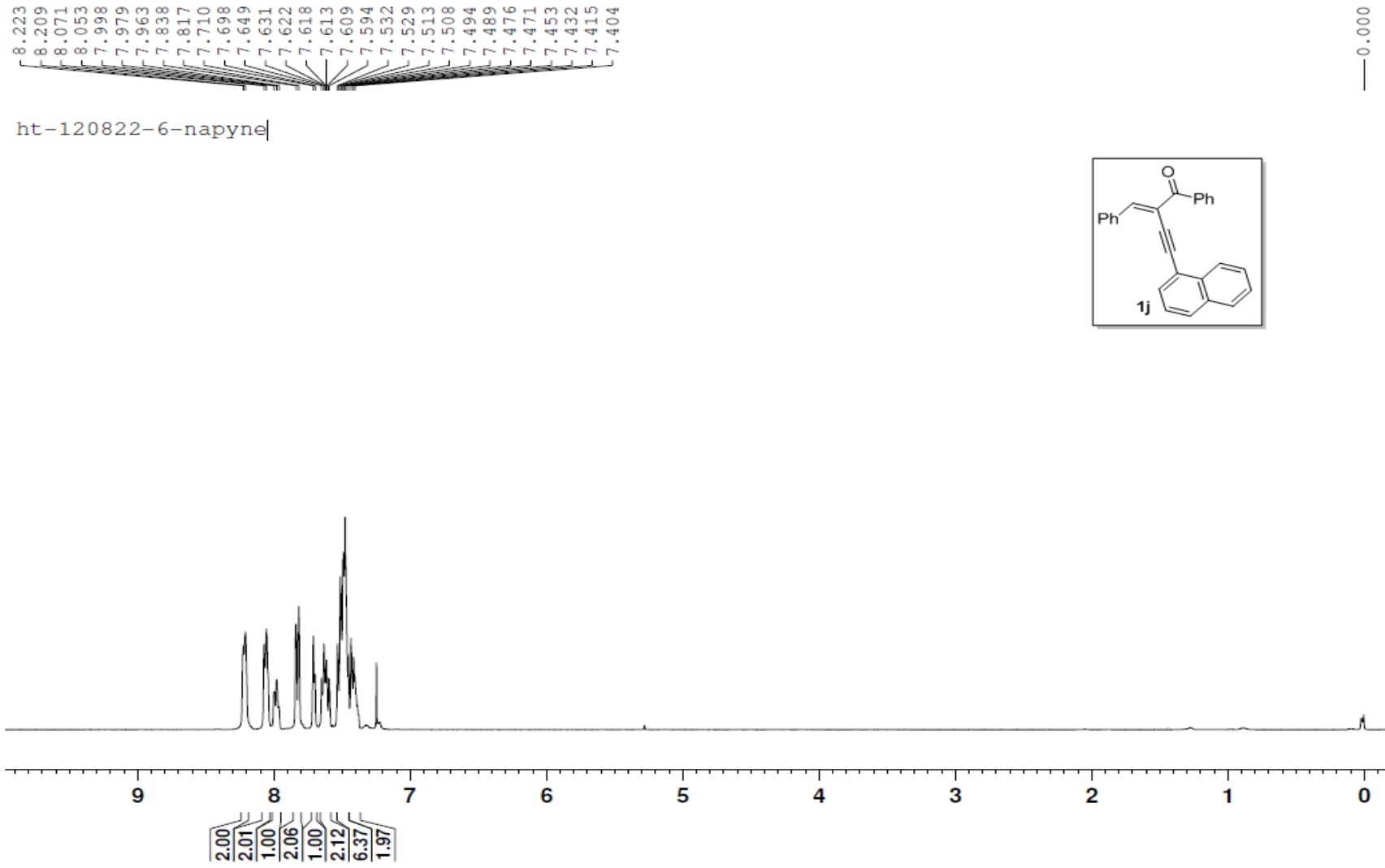

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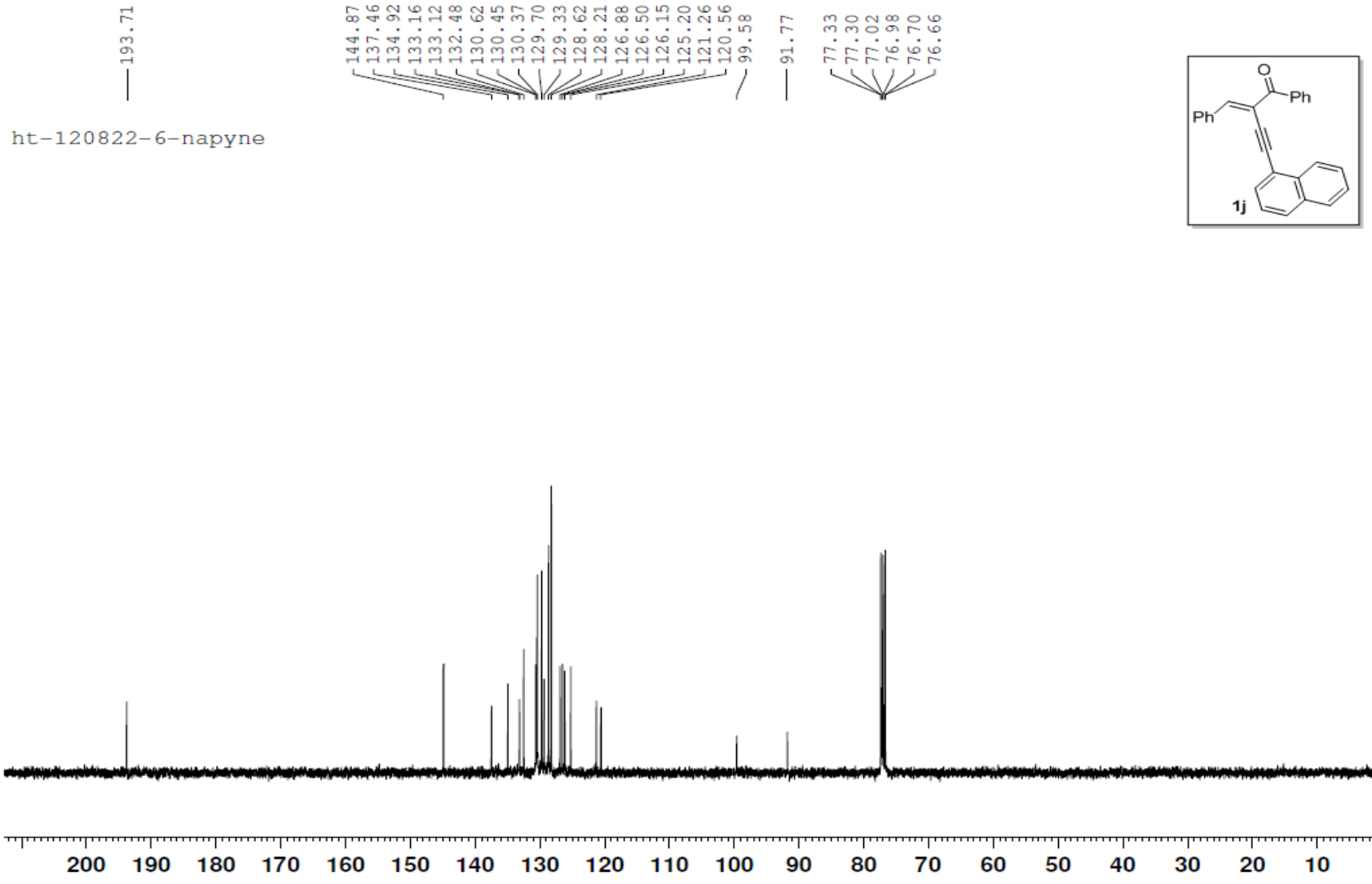

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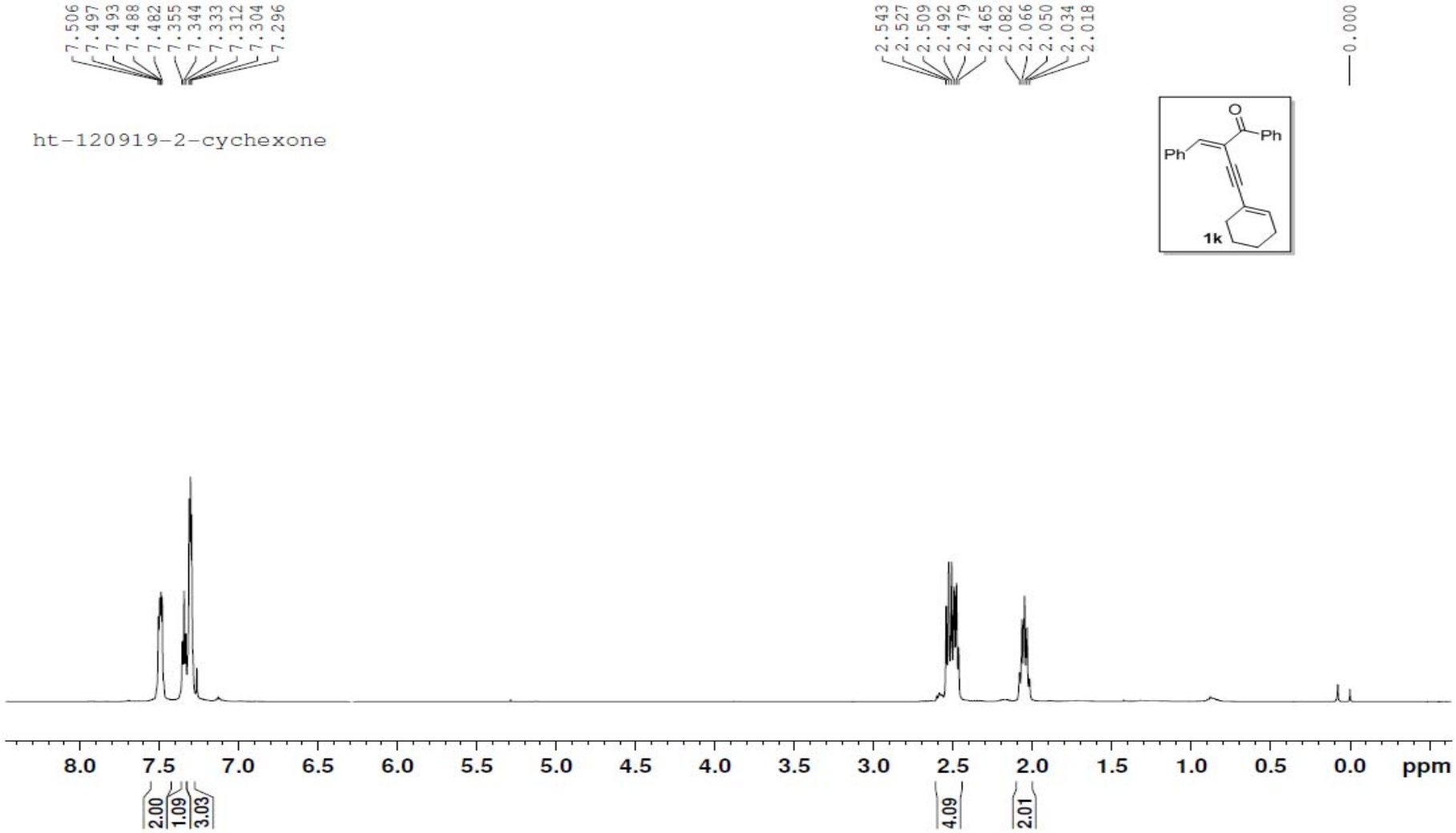

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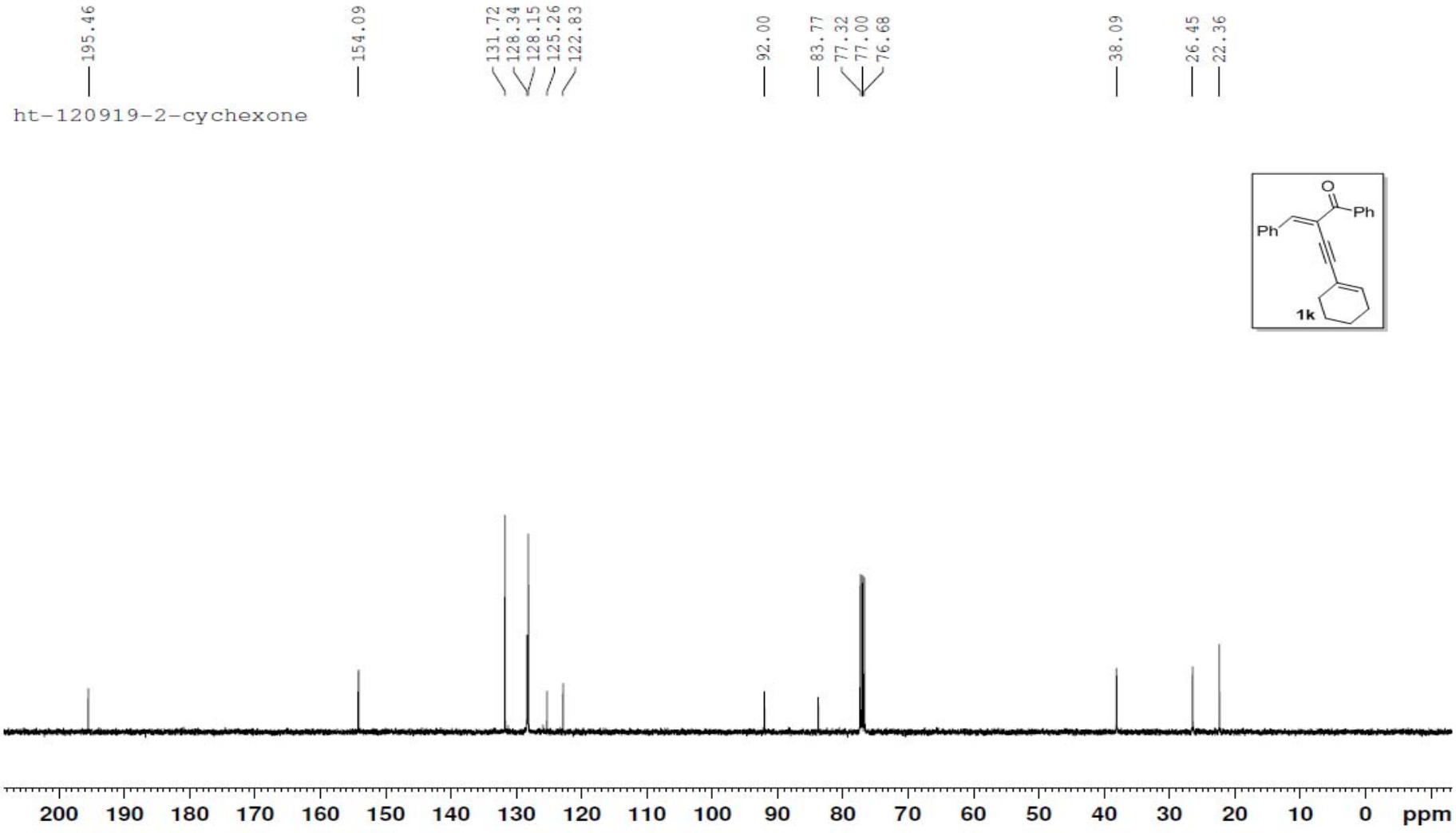

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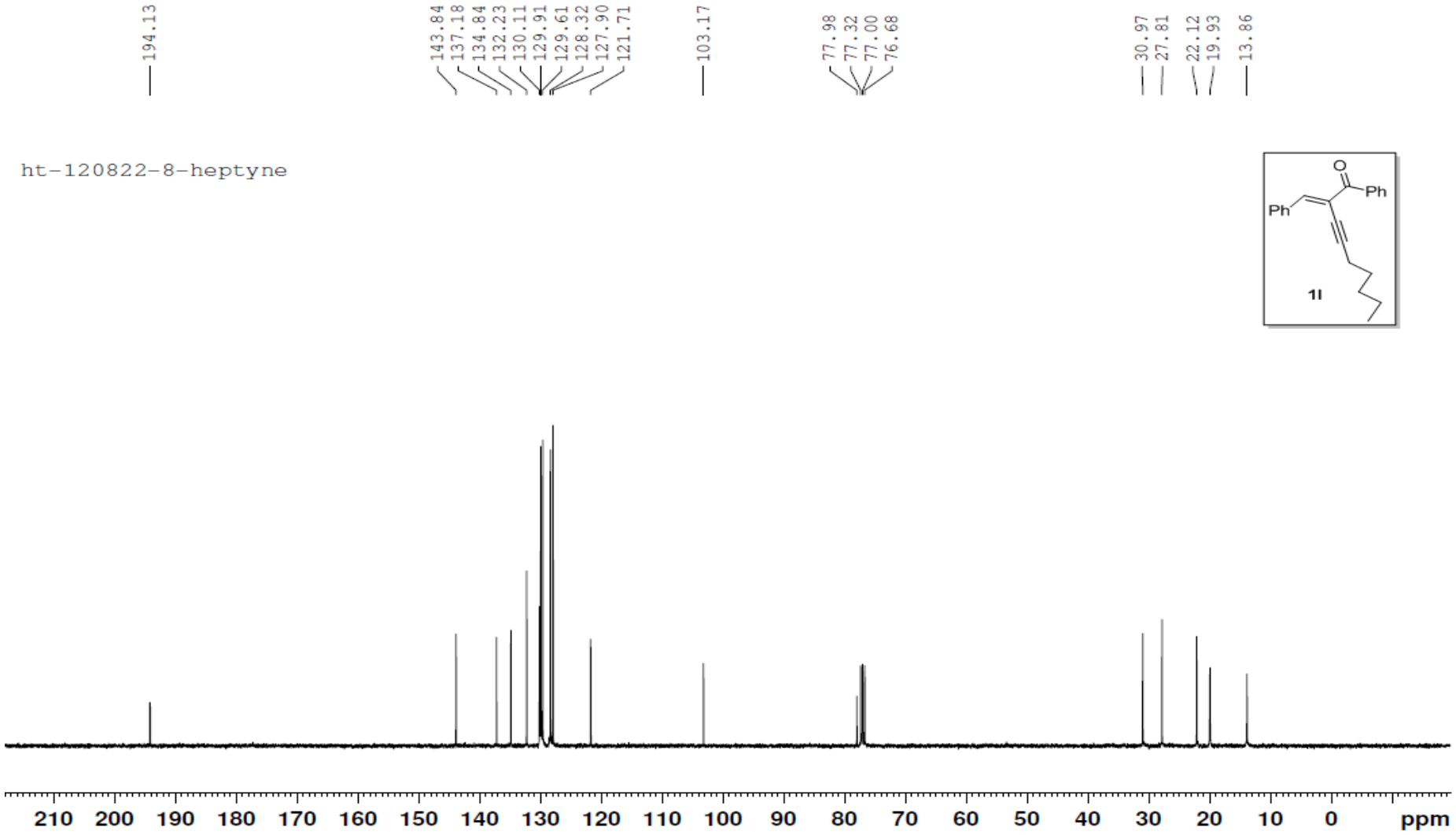

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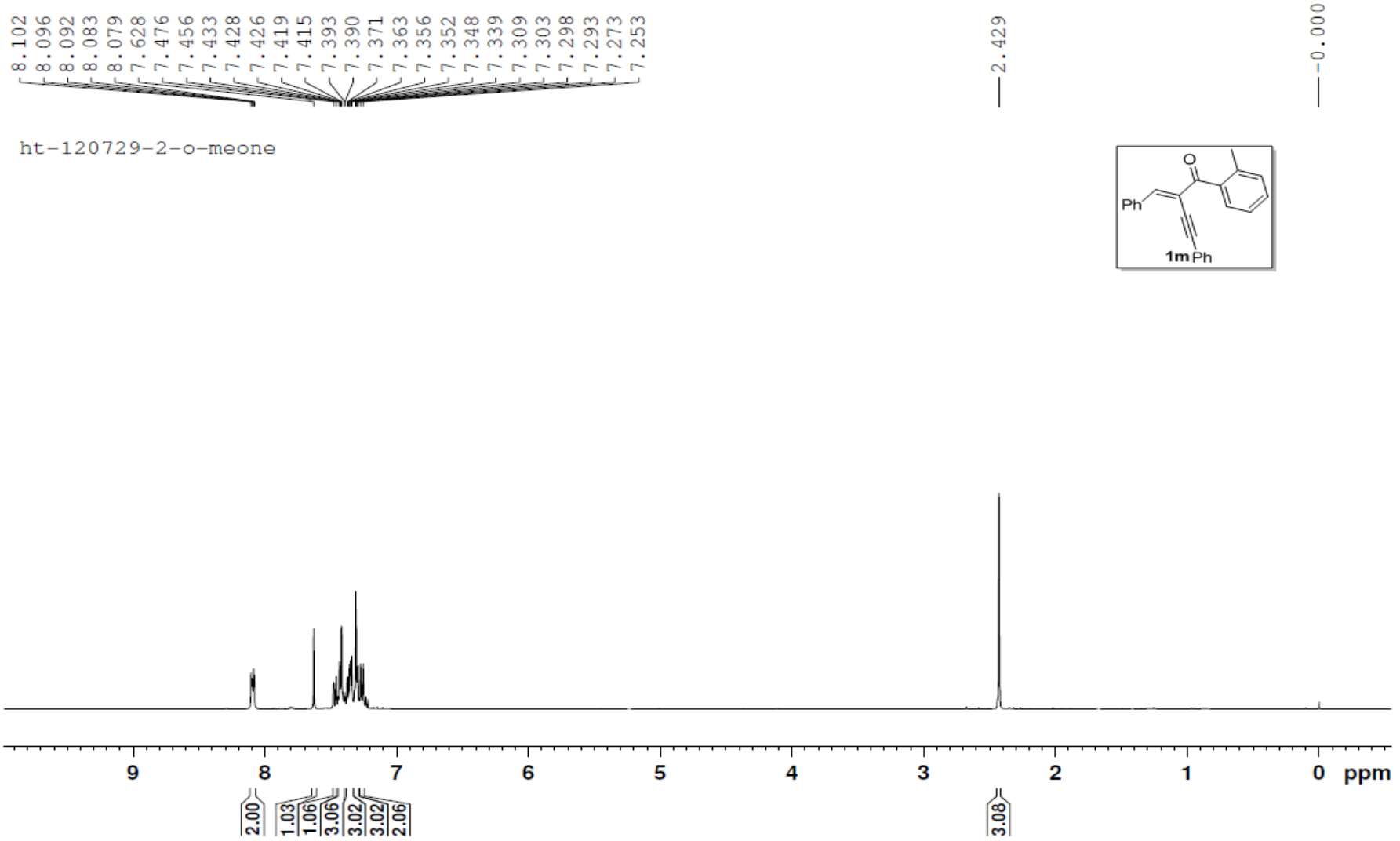

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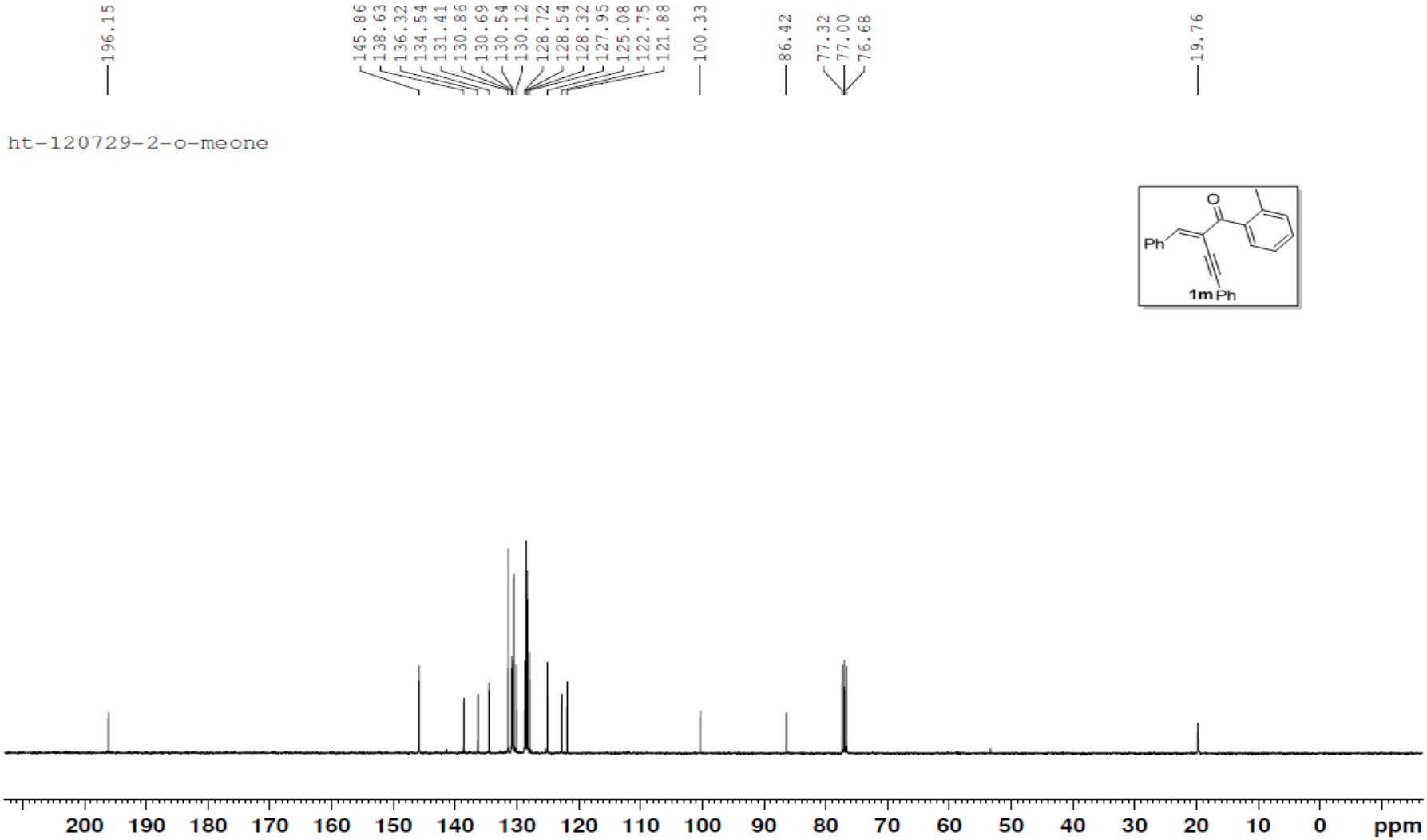

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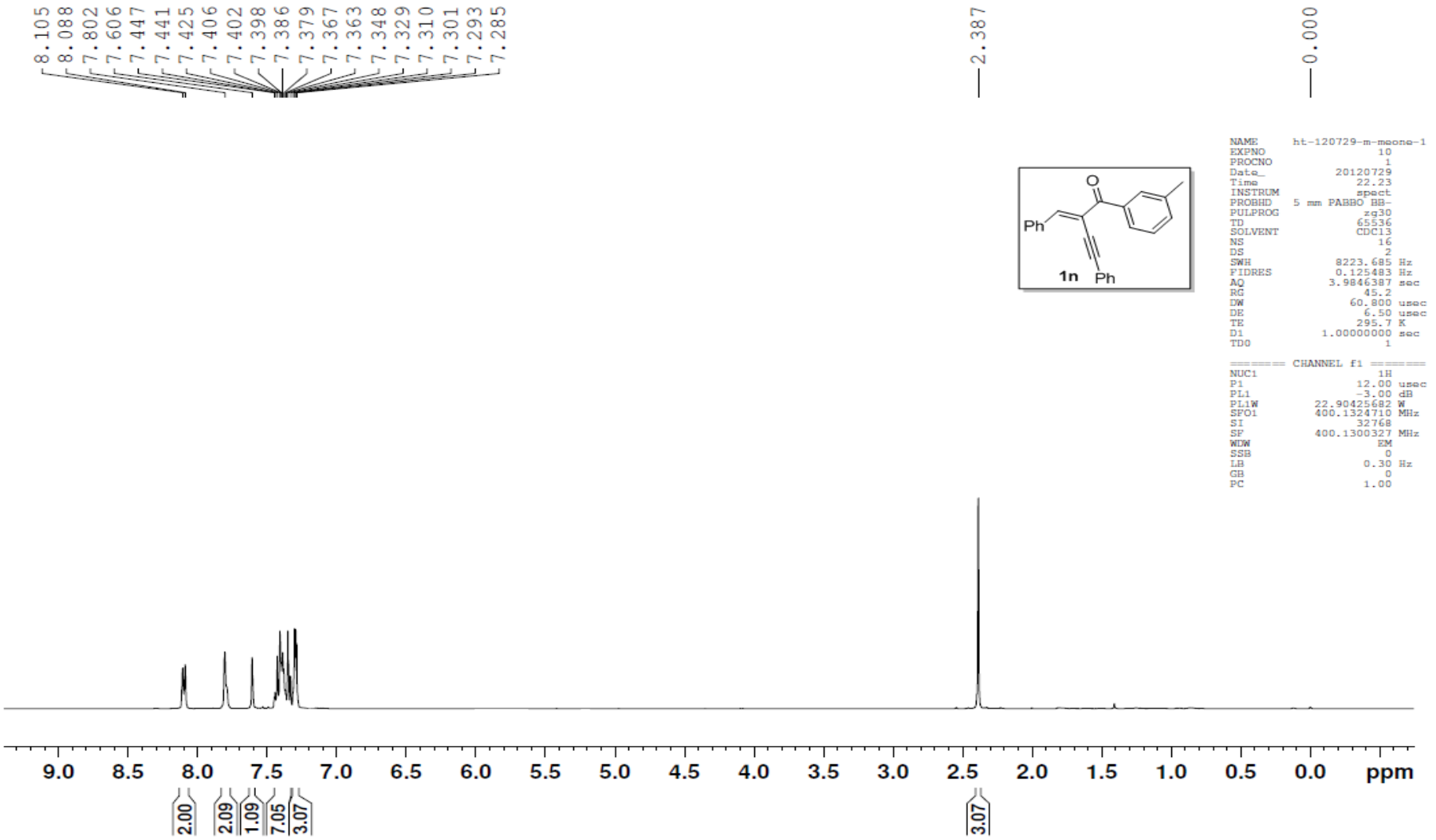

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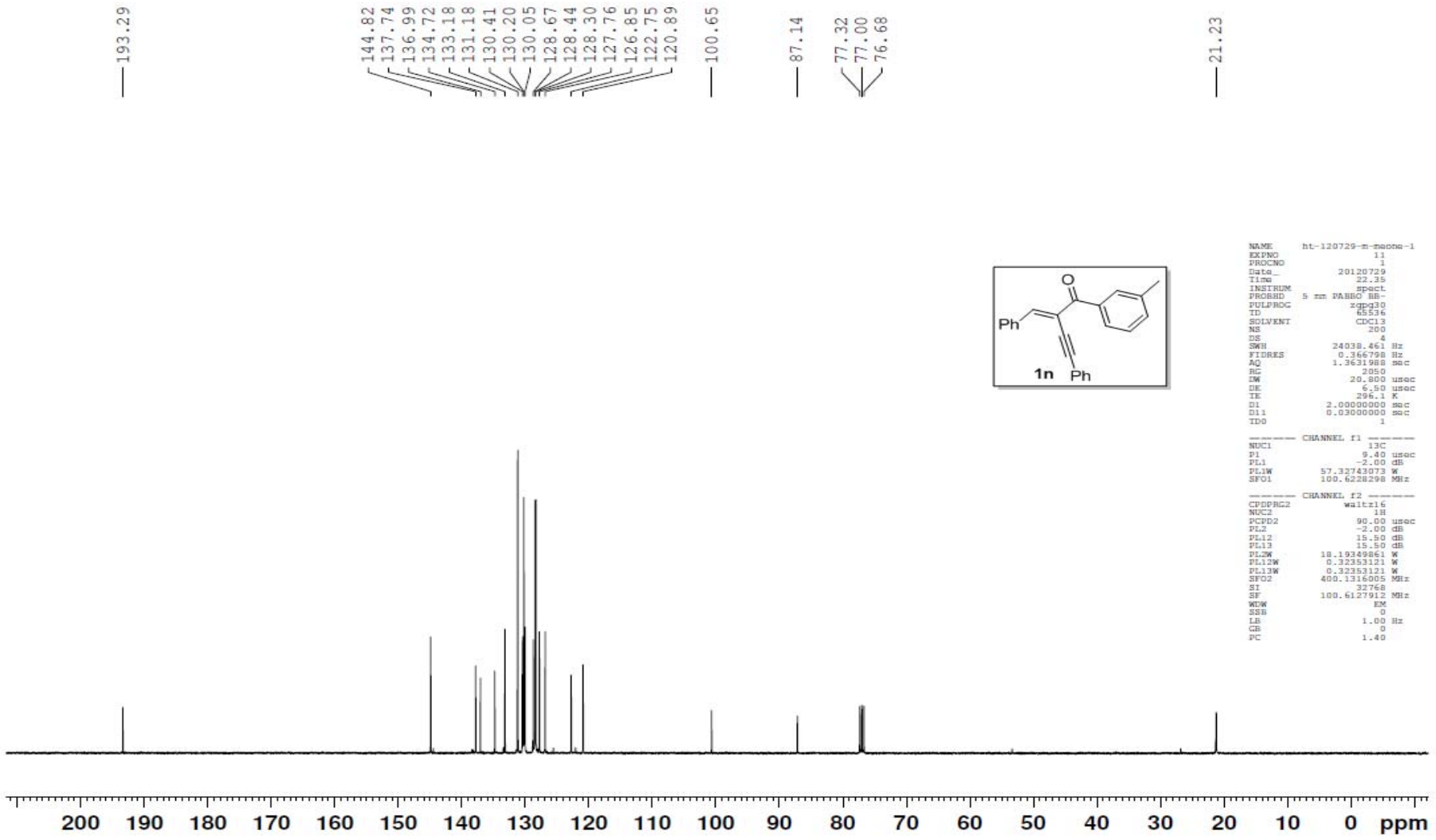

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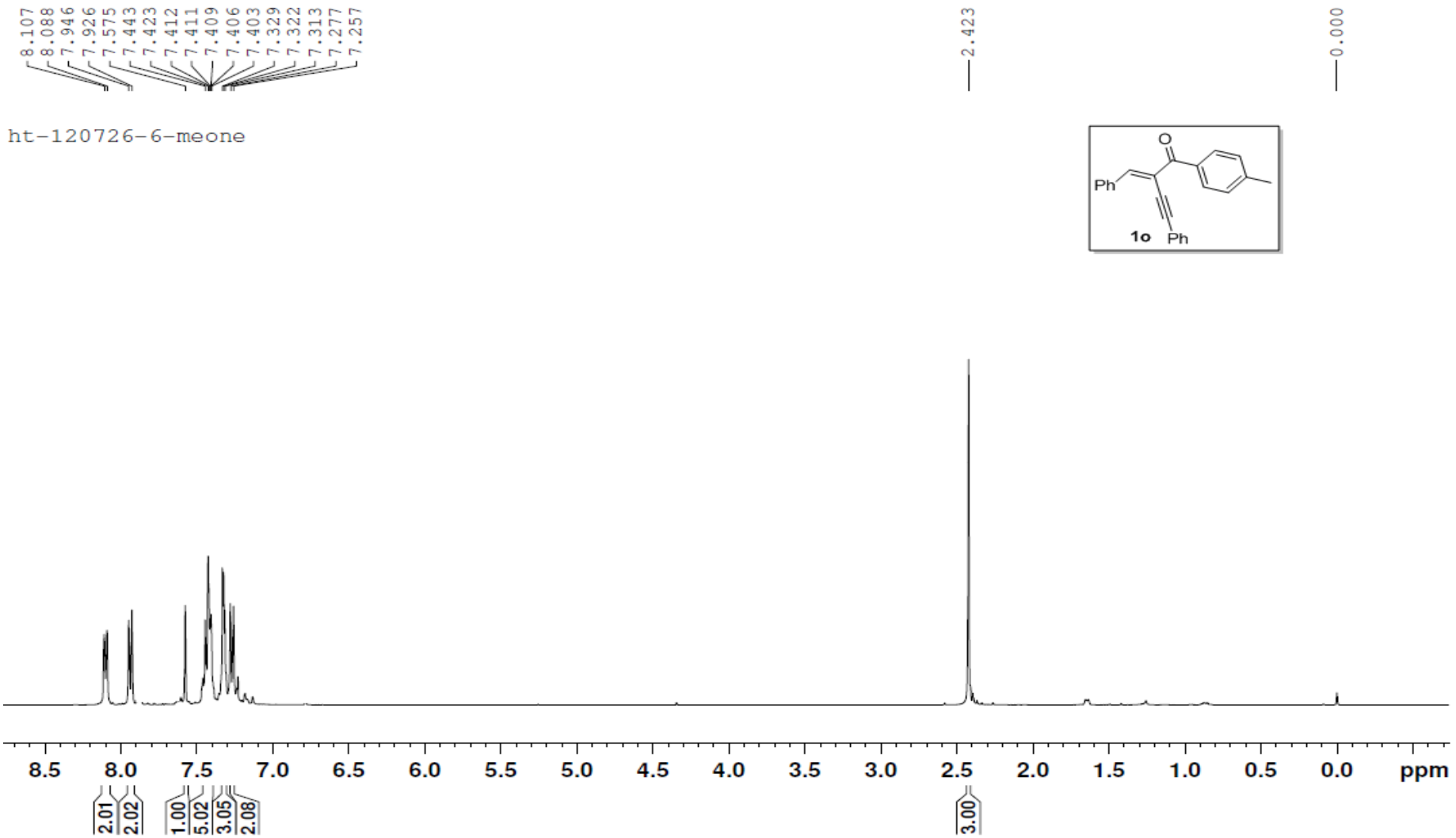

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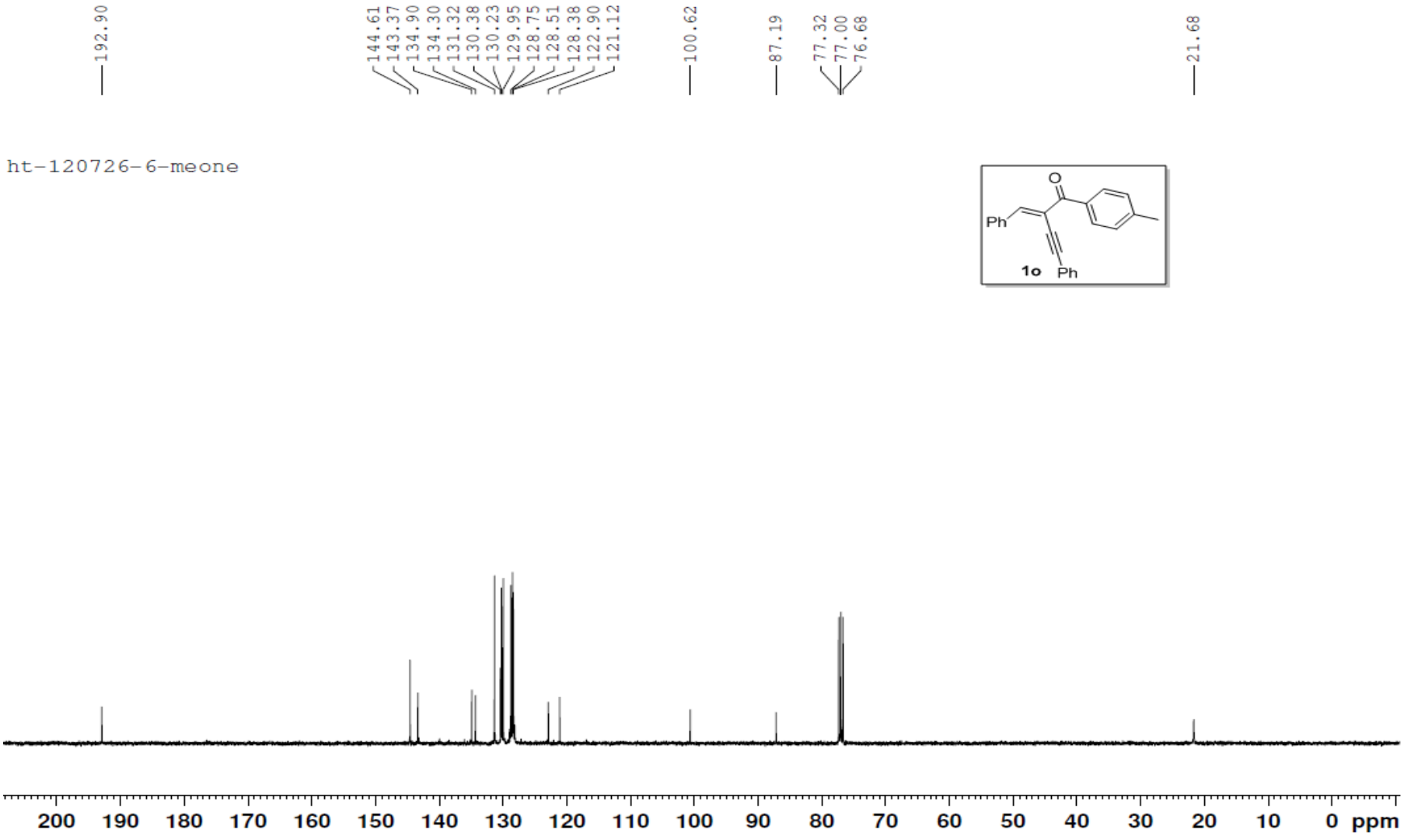

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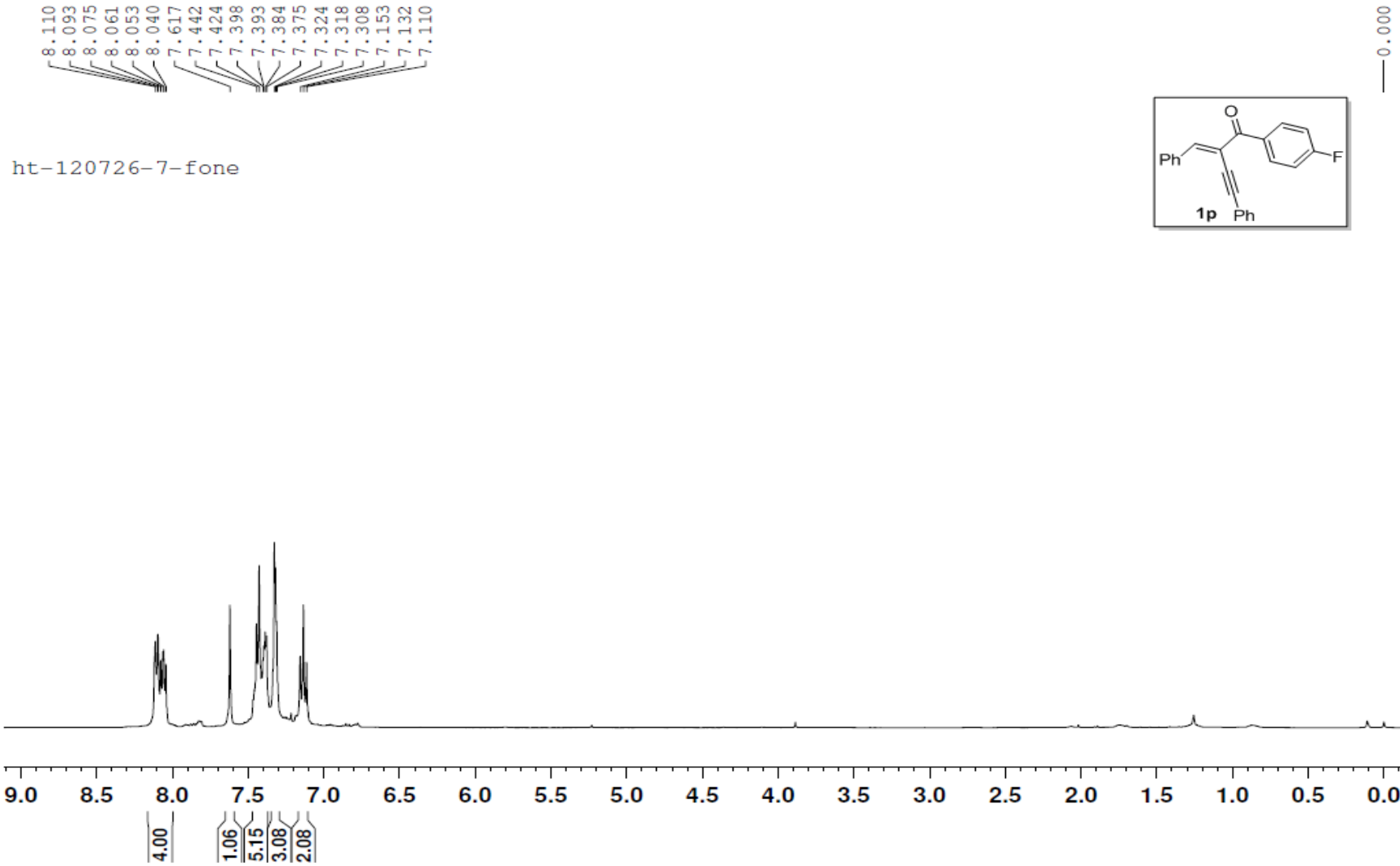

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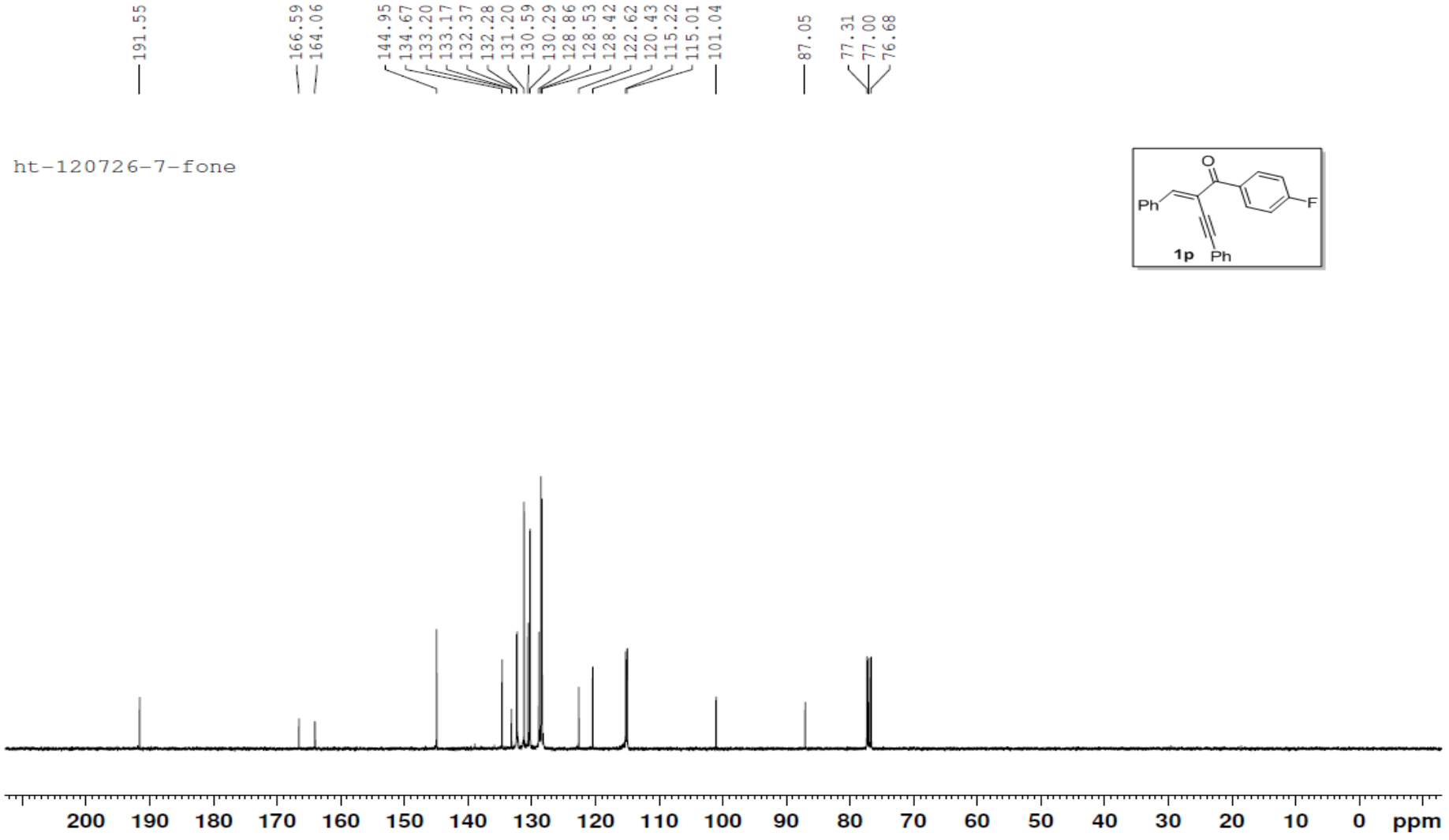

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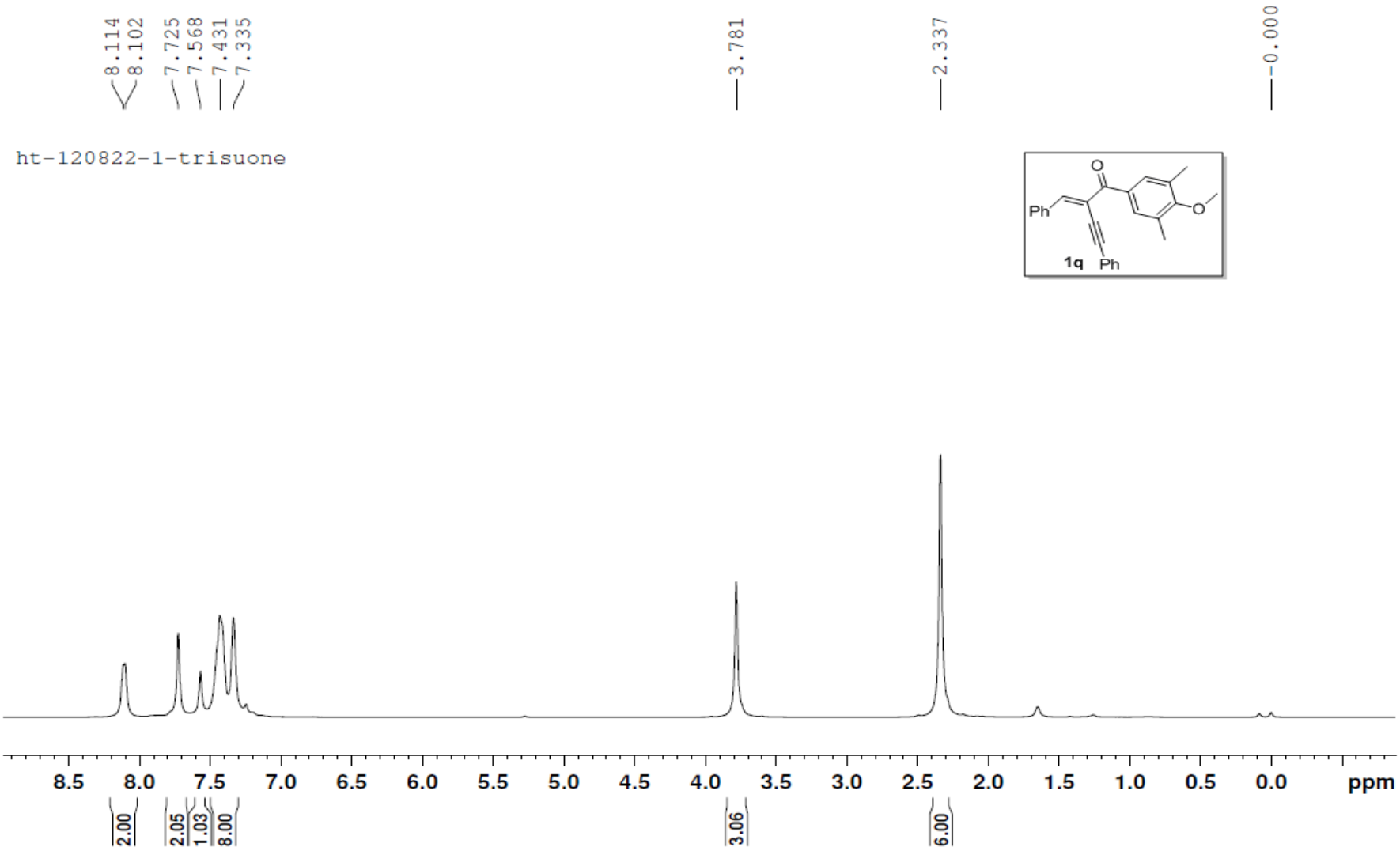

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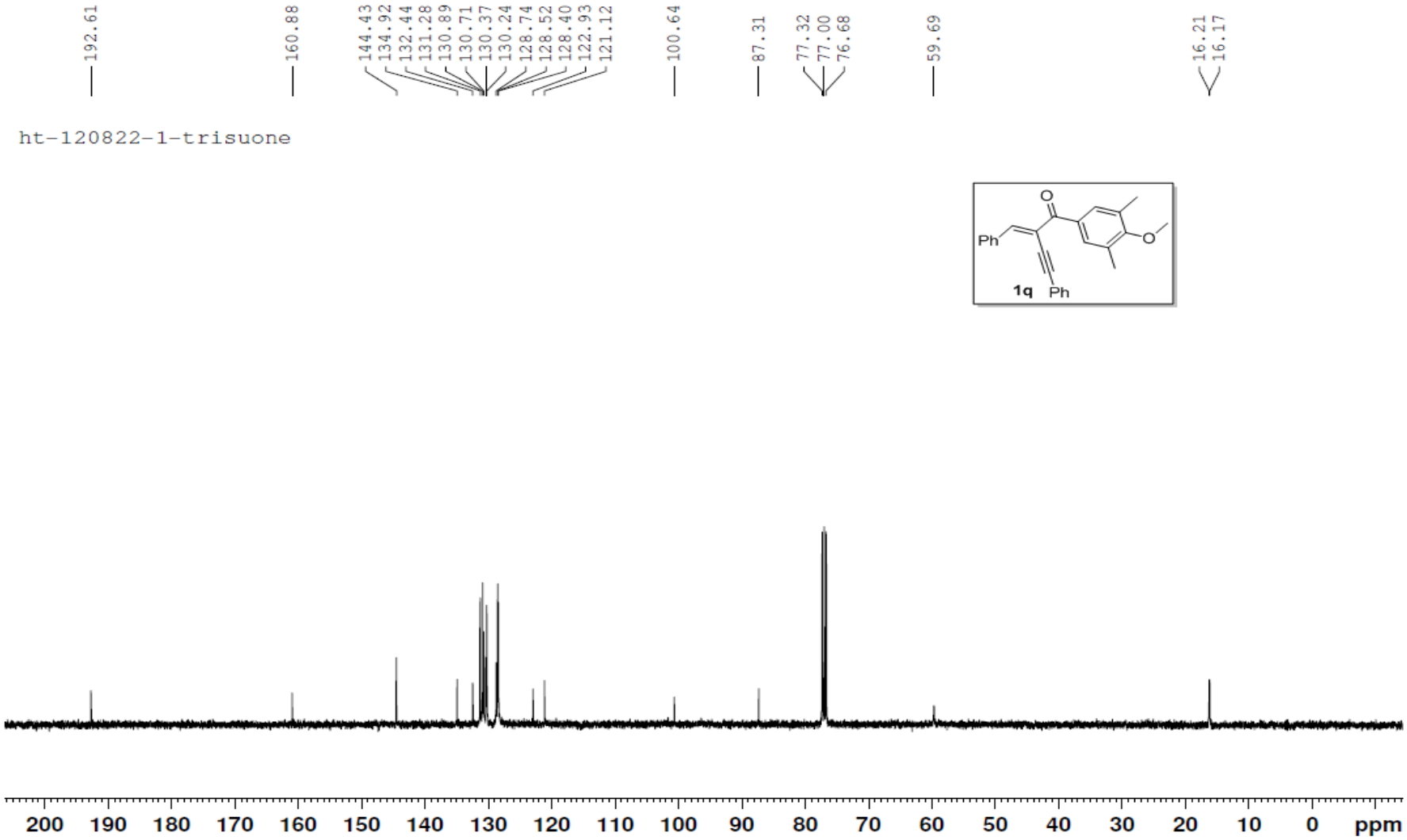

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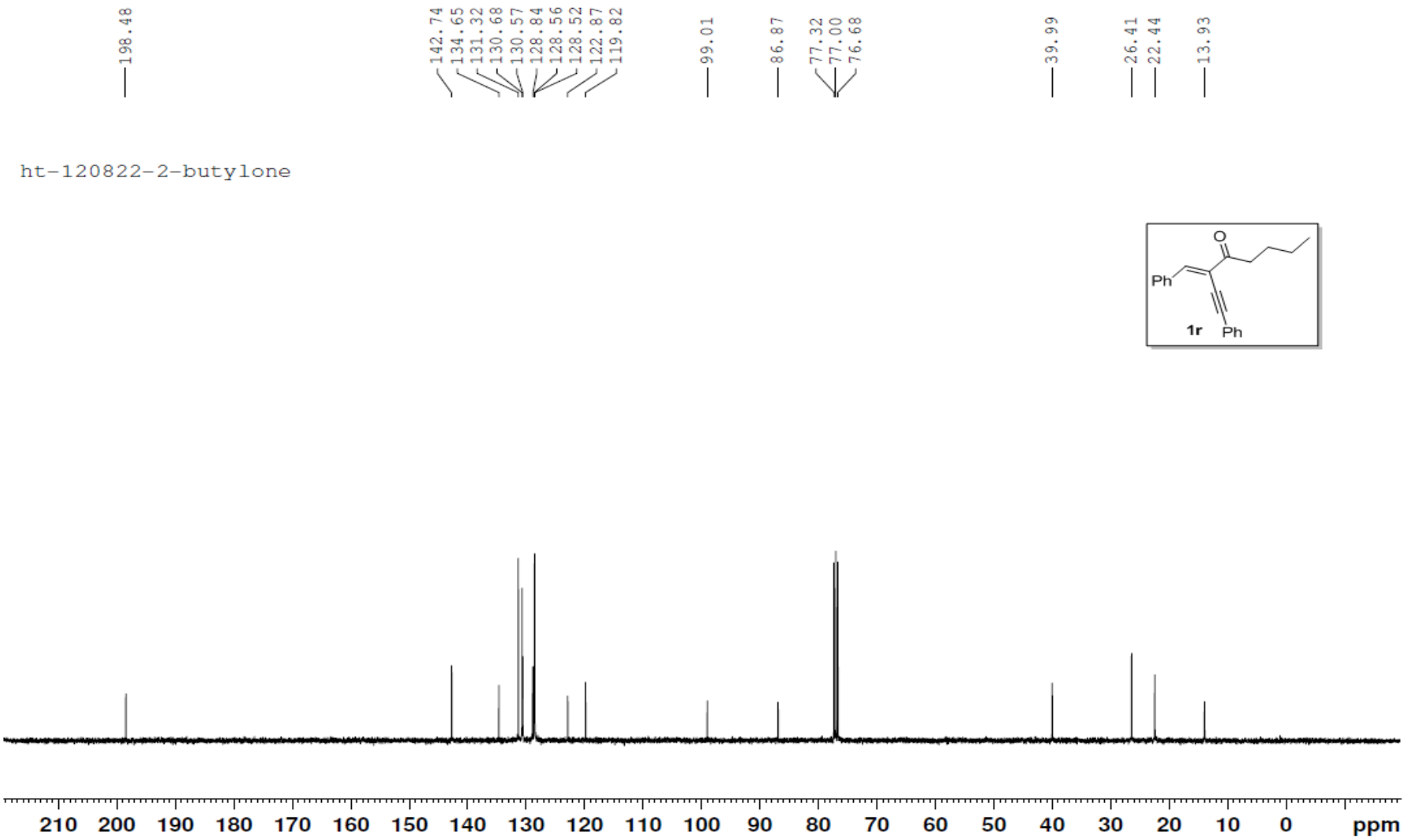
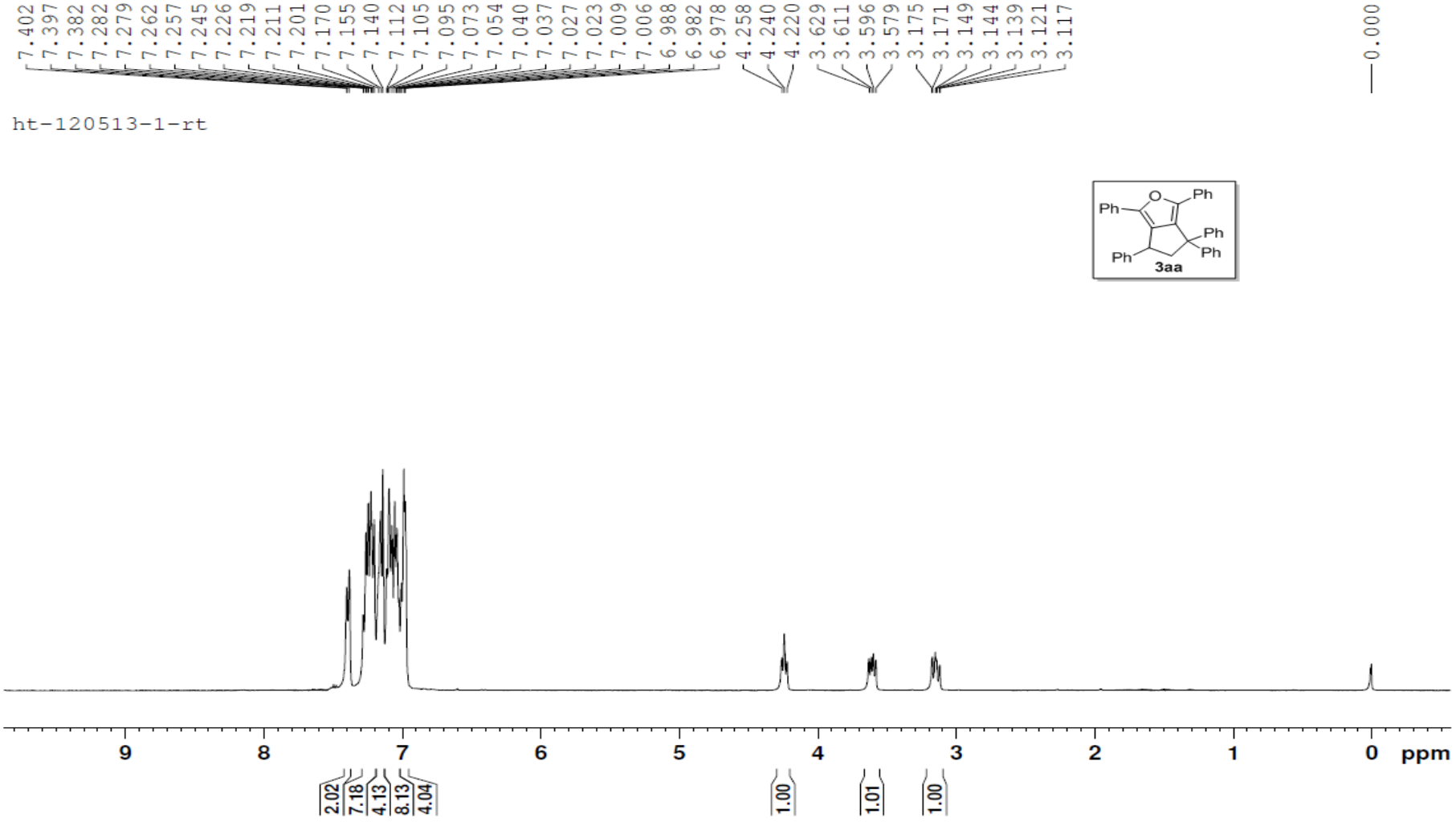


8. ^{1}H NMR and ^{13}C NMR spectra for compounds 3aa-3ra, 3ab-3af



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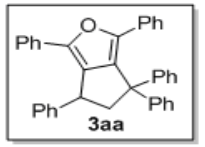

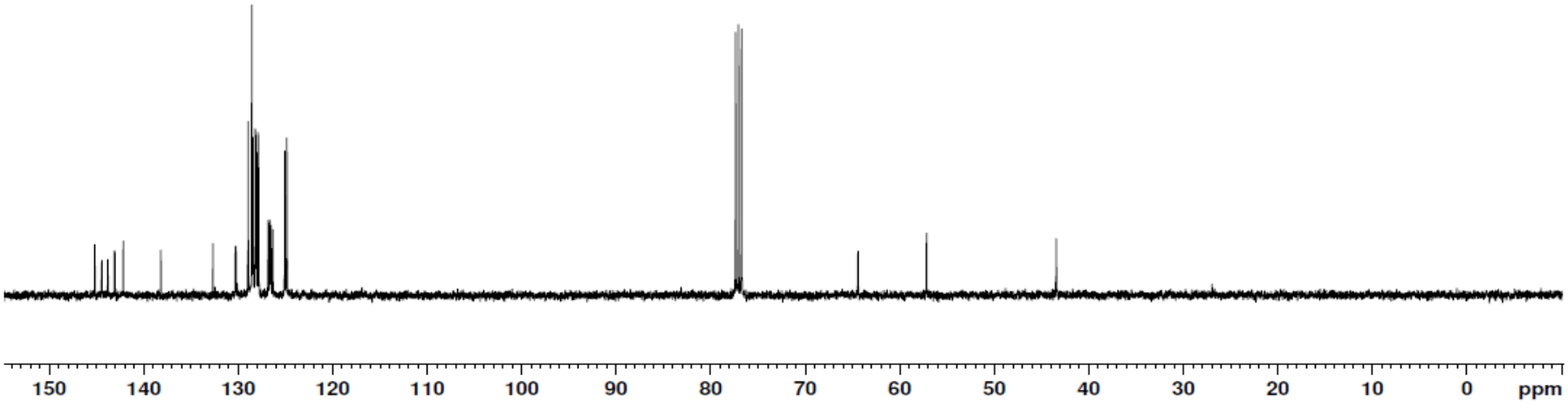

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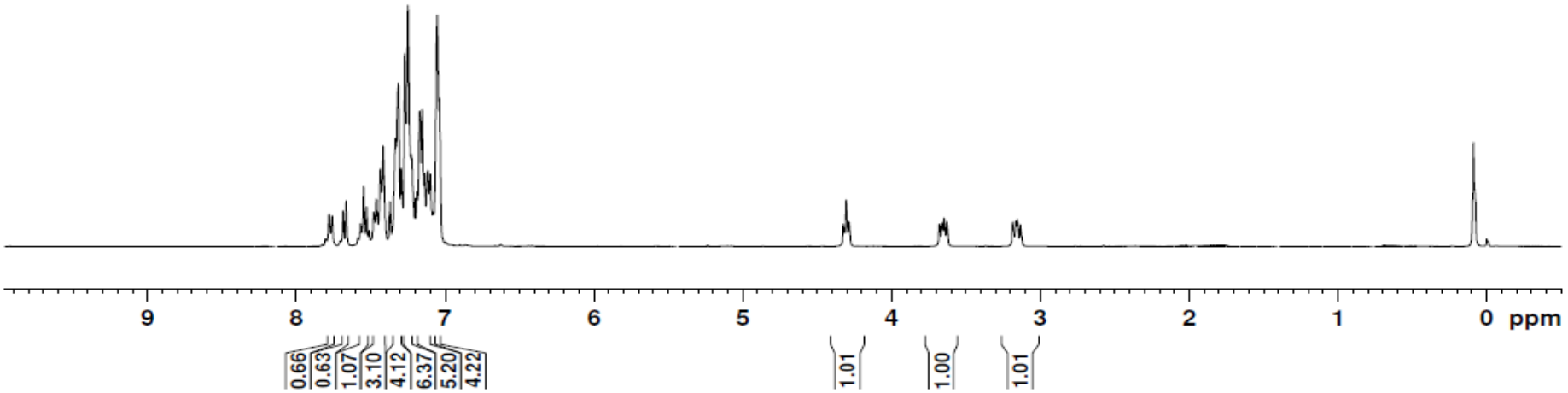

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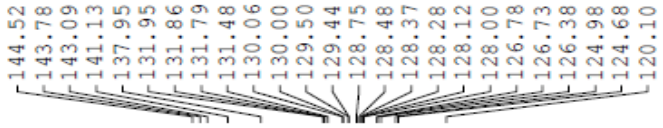

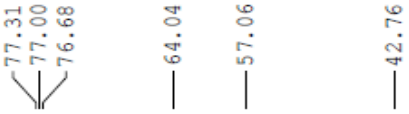

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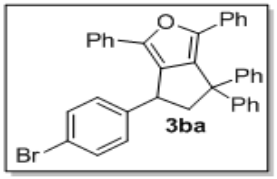

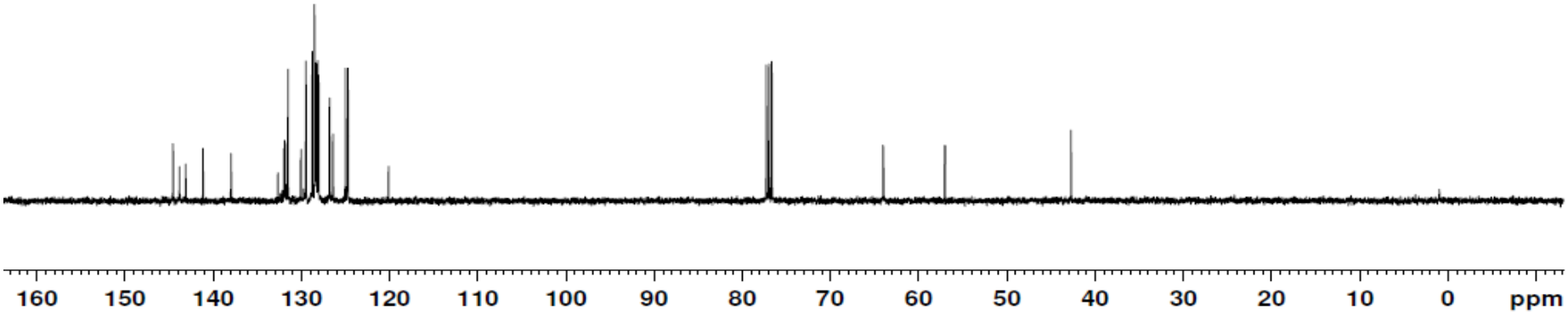

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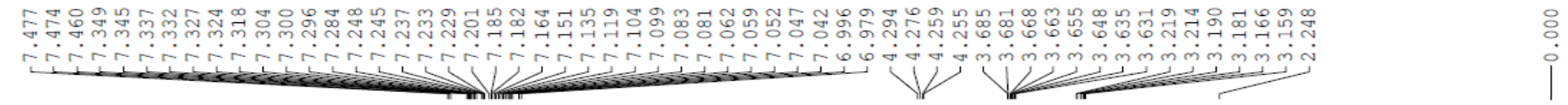

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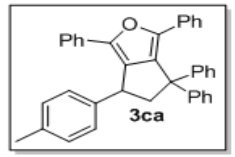

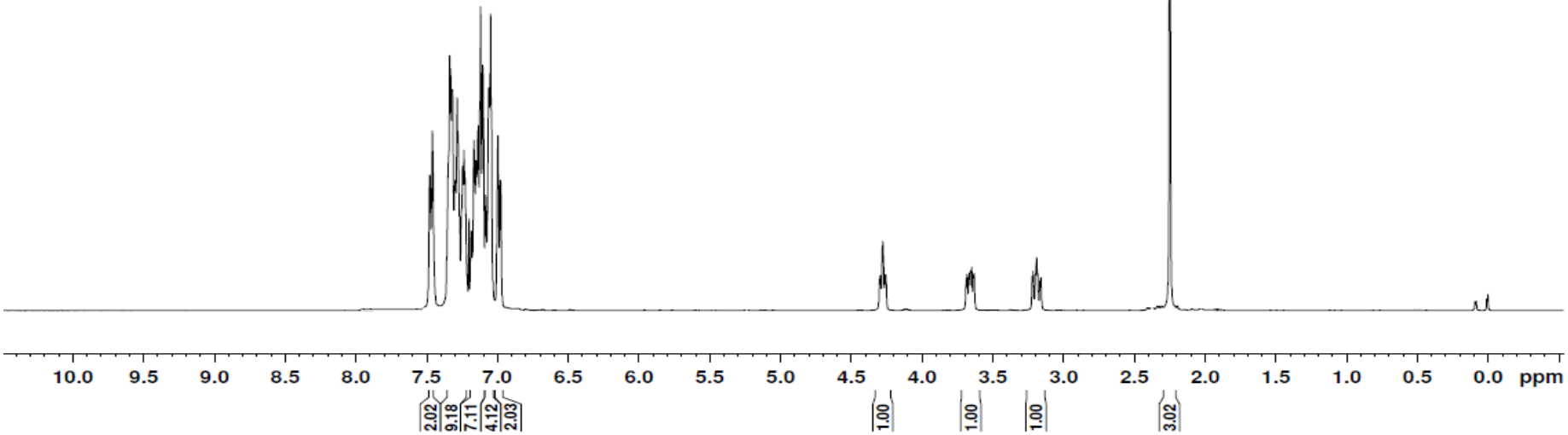

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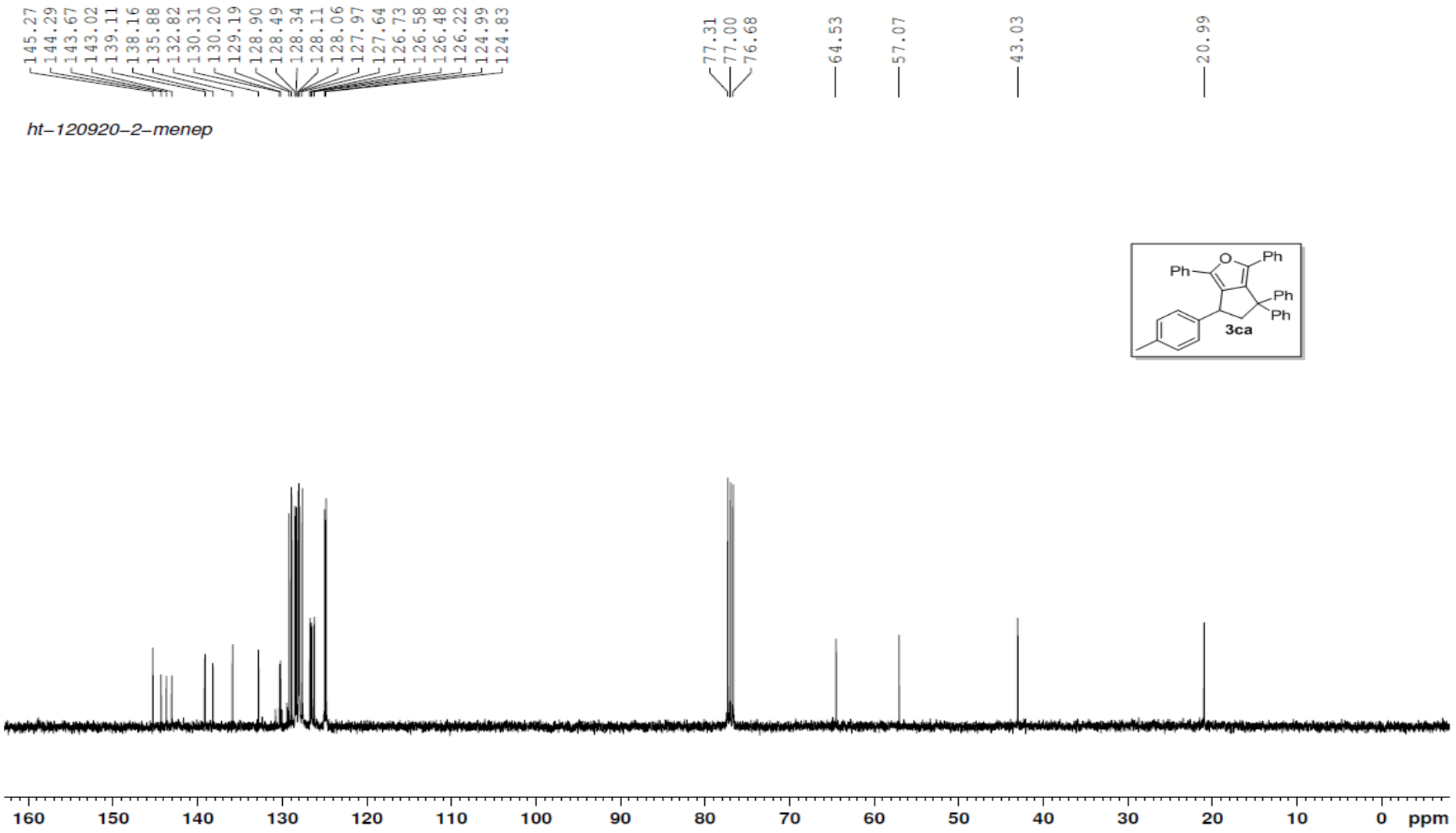

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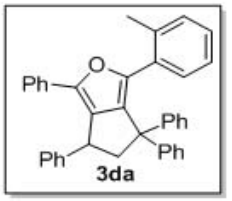

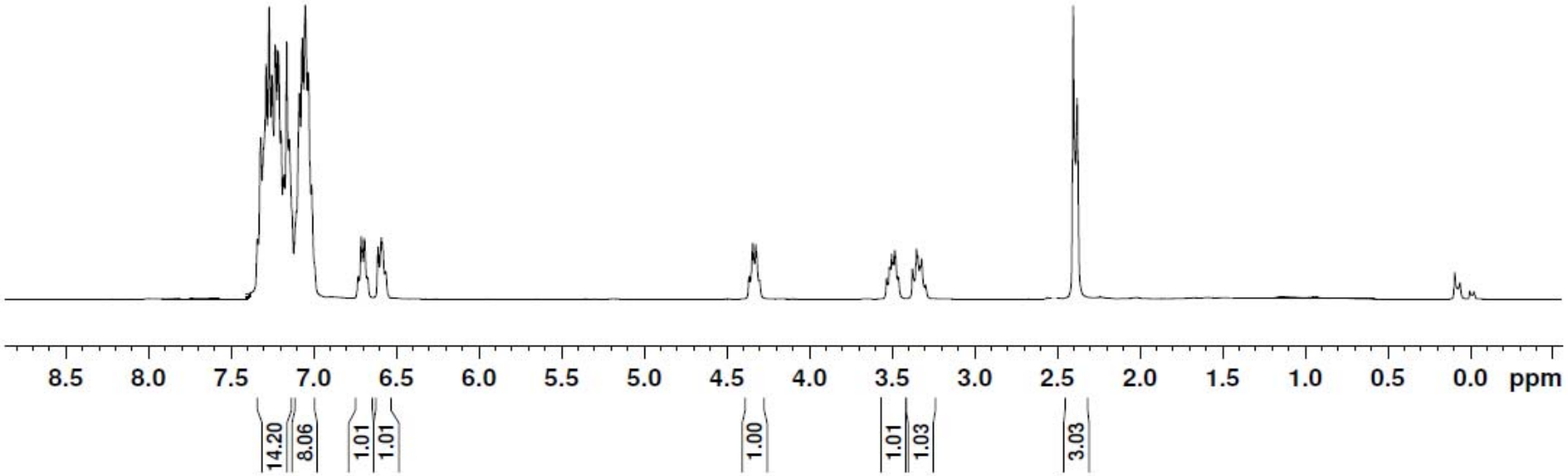

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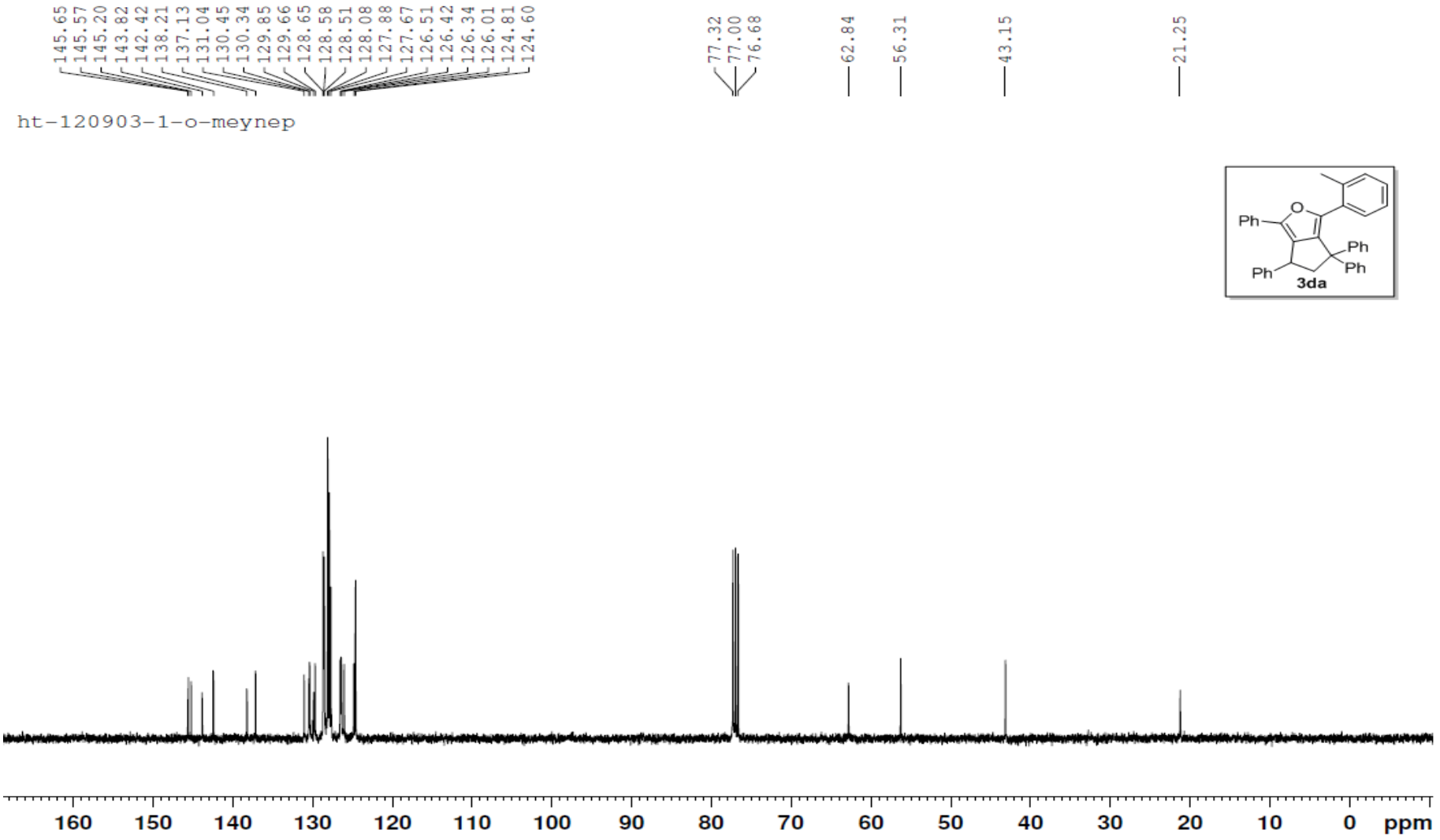

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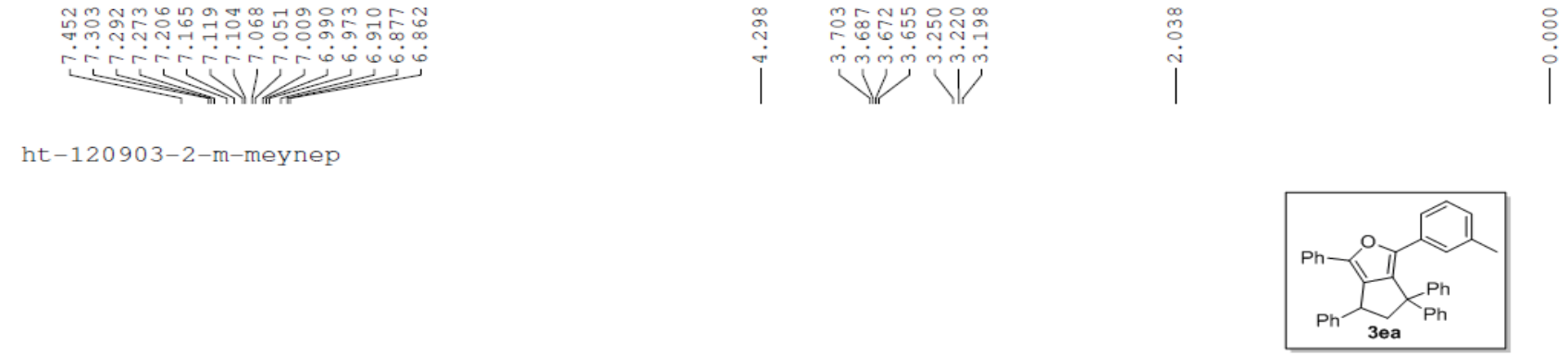

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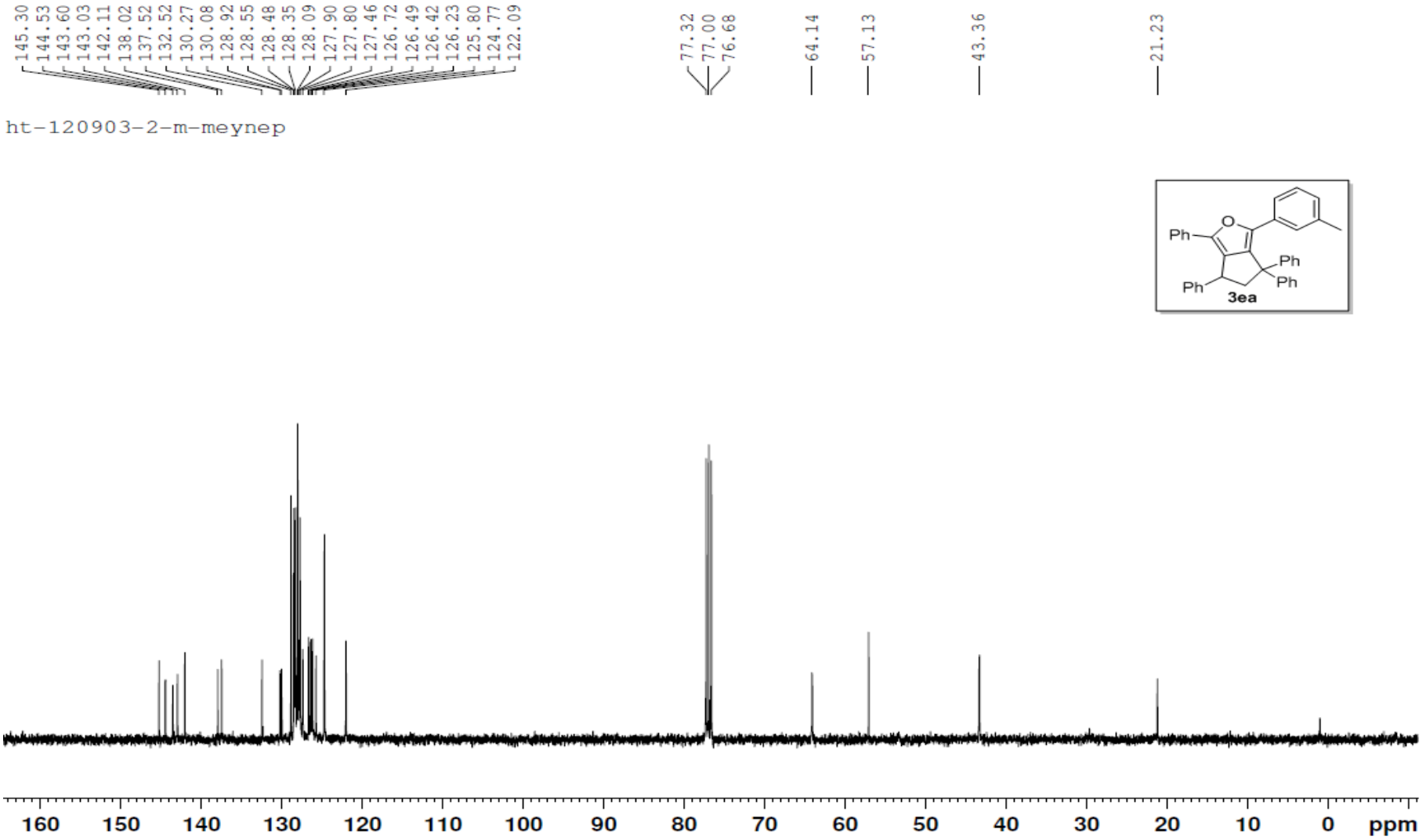

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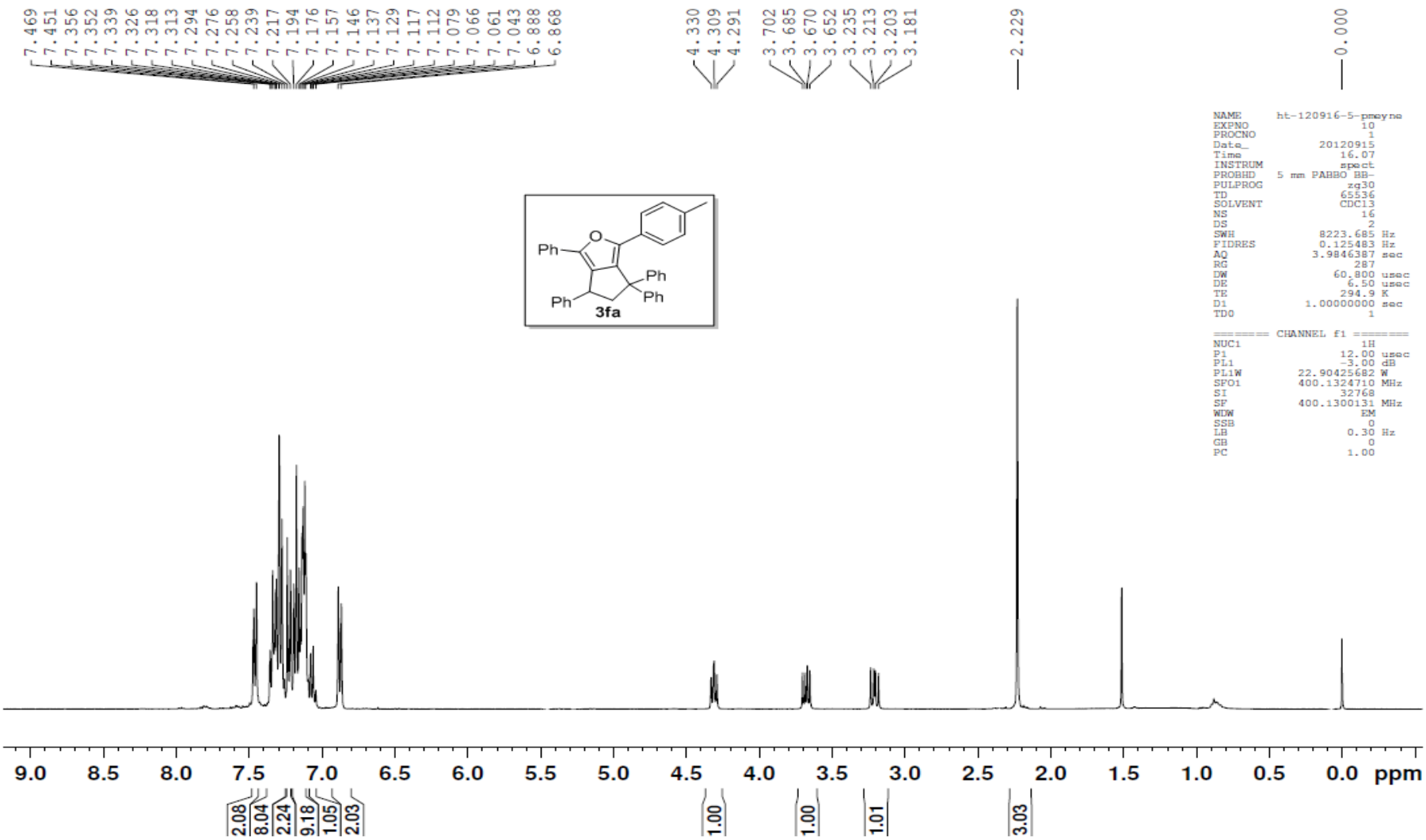

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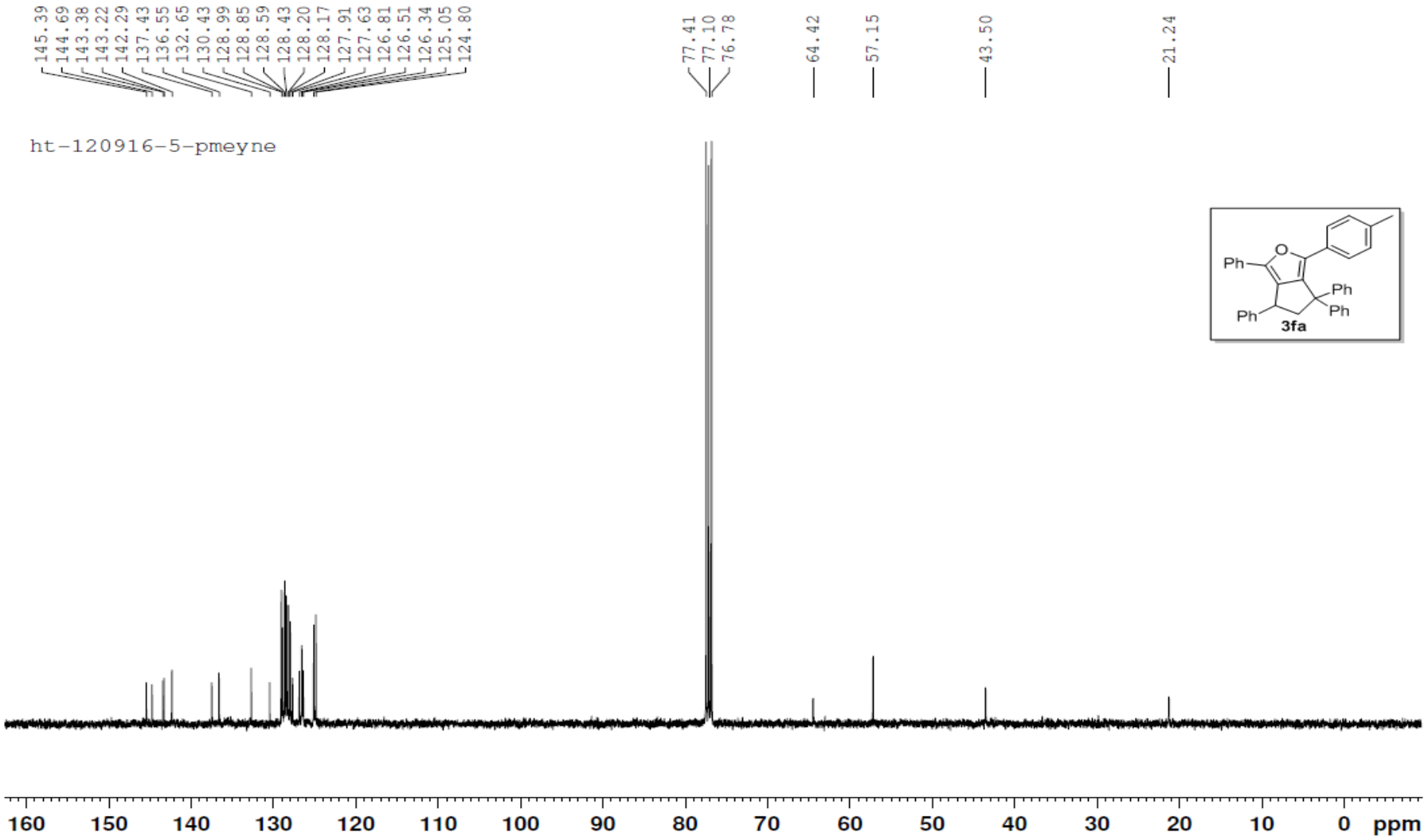

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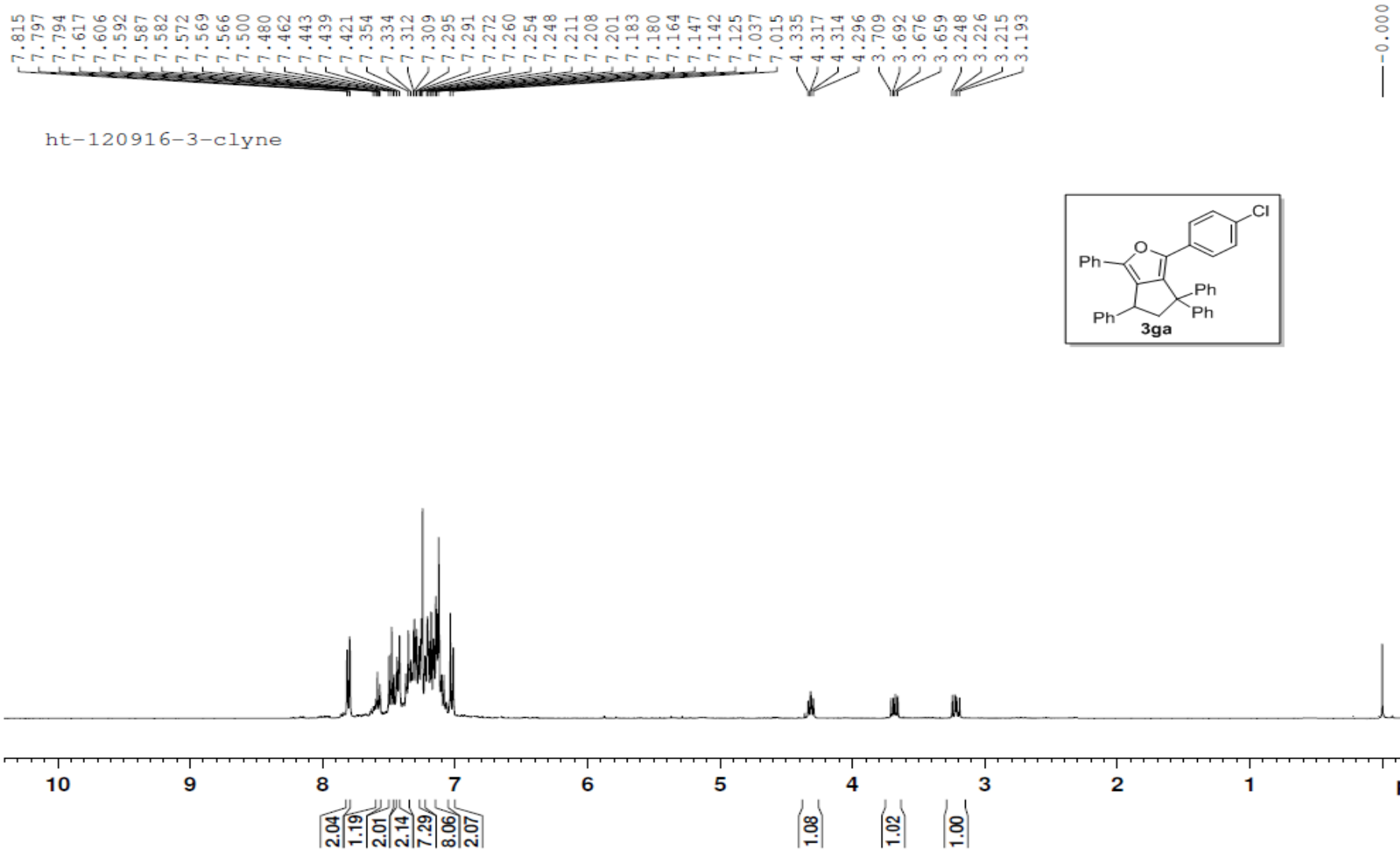

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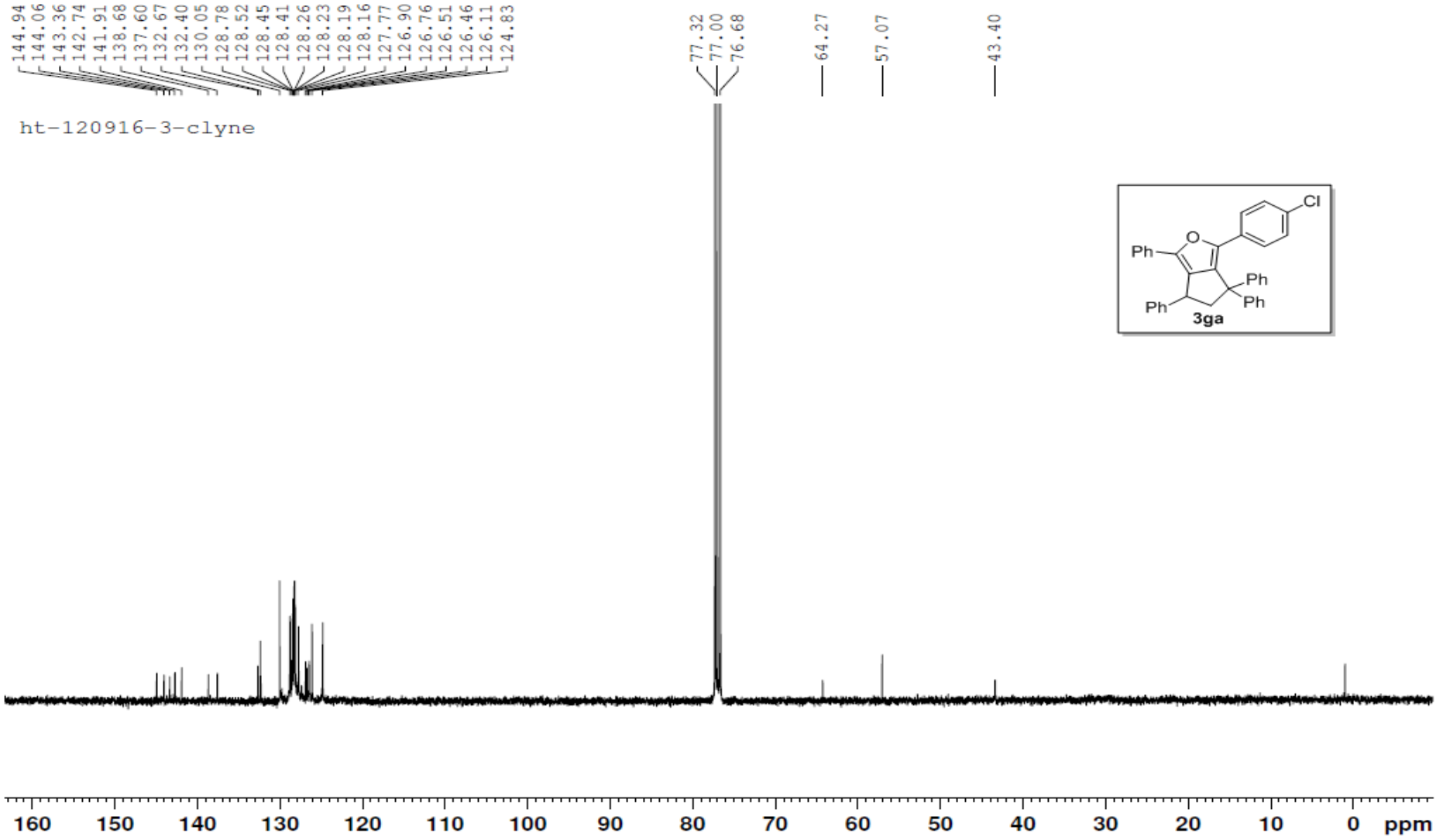

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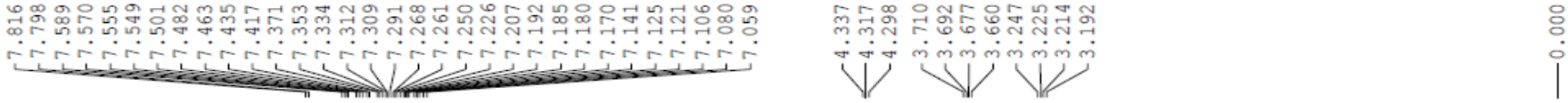

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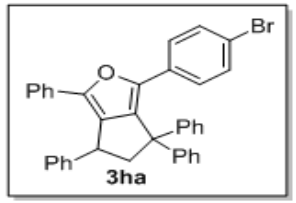

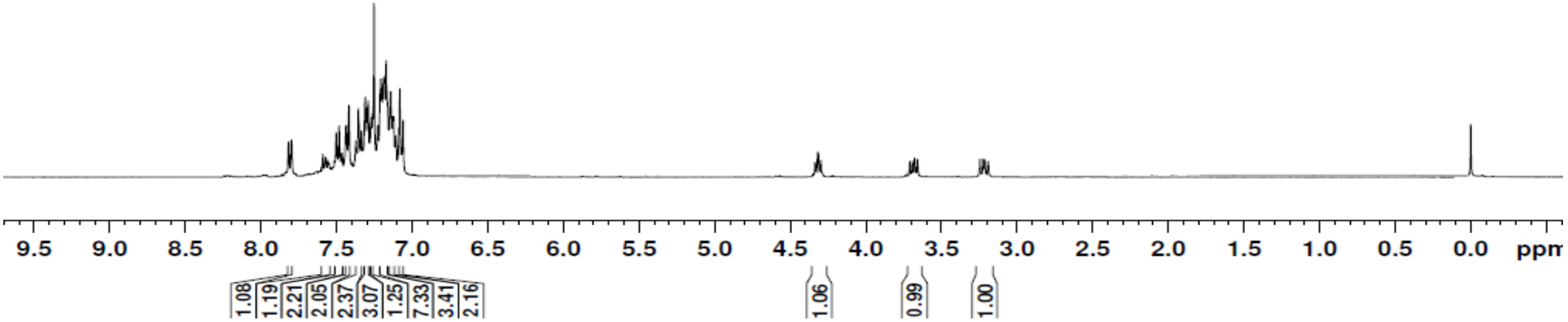

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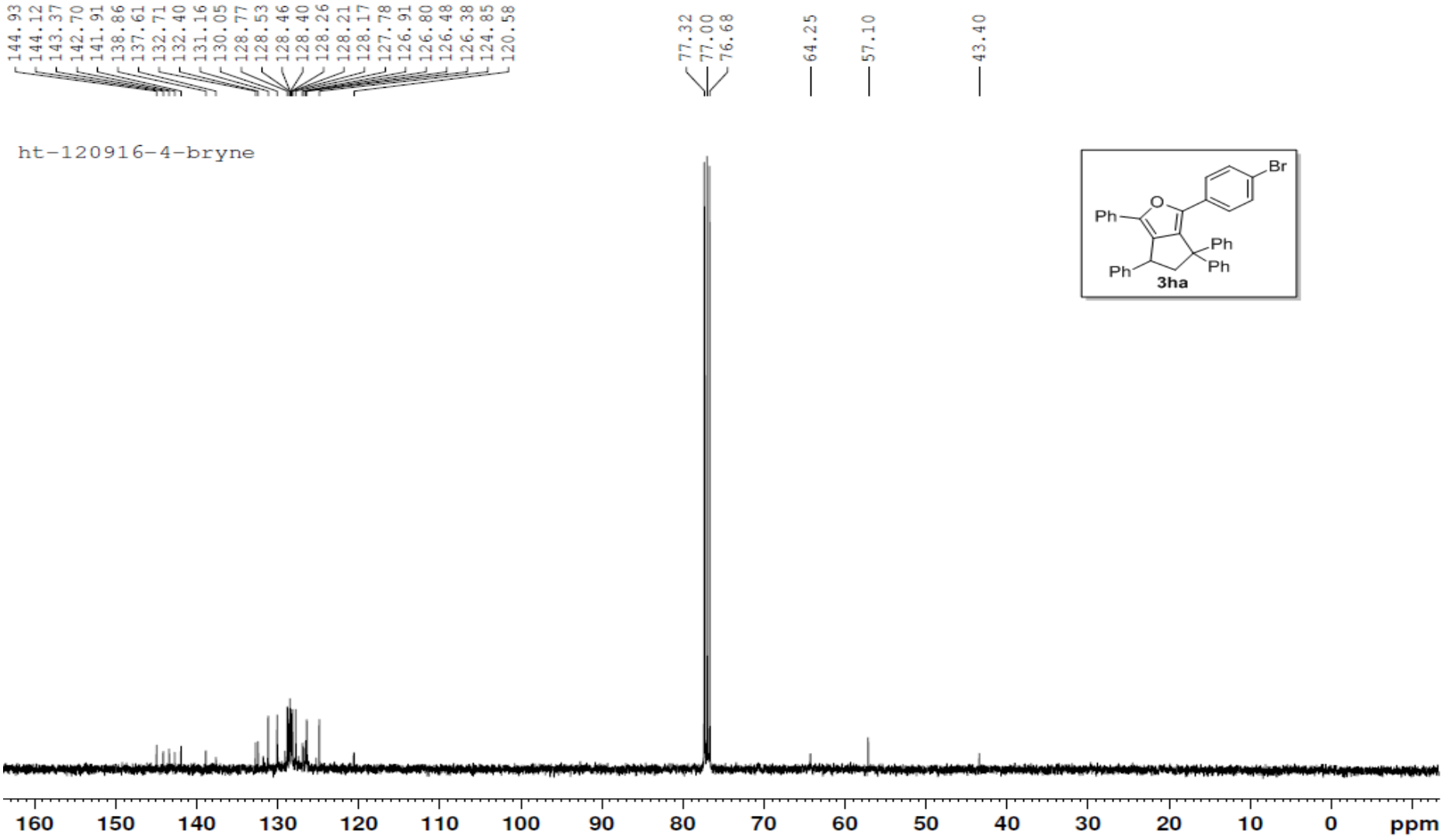

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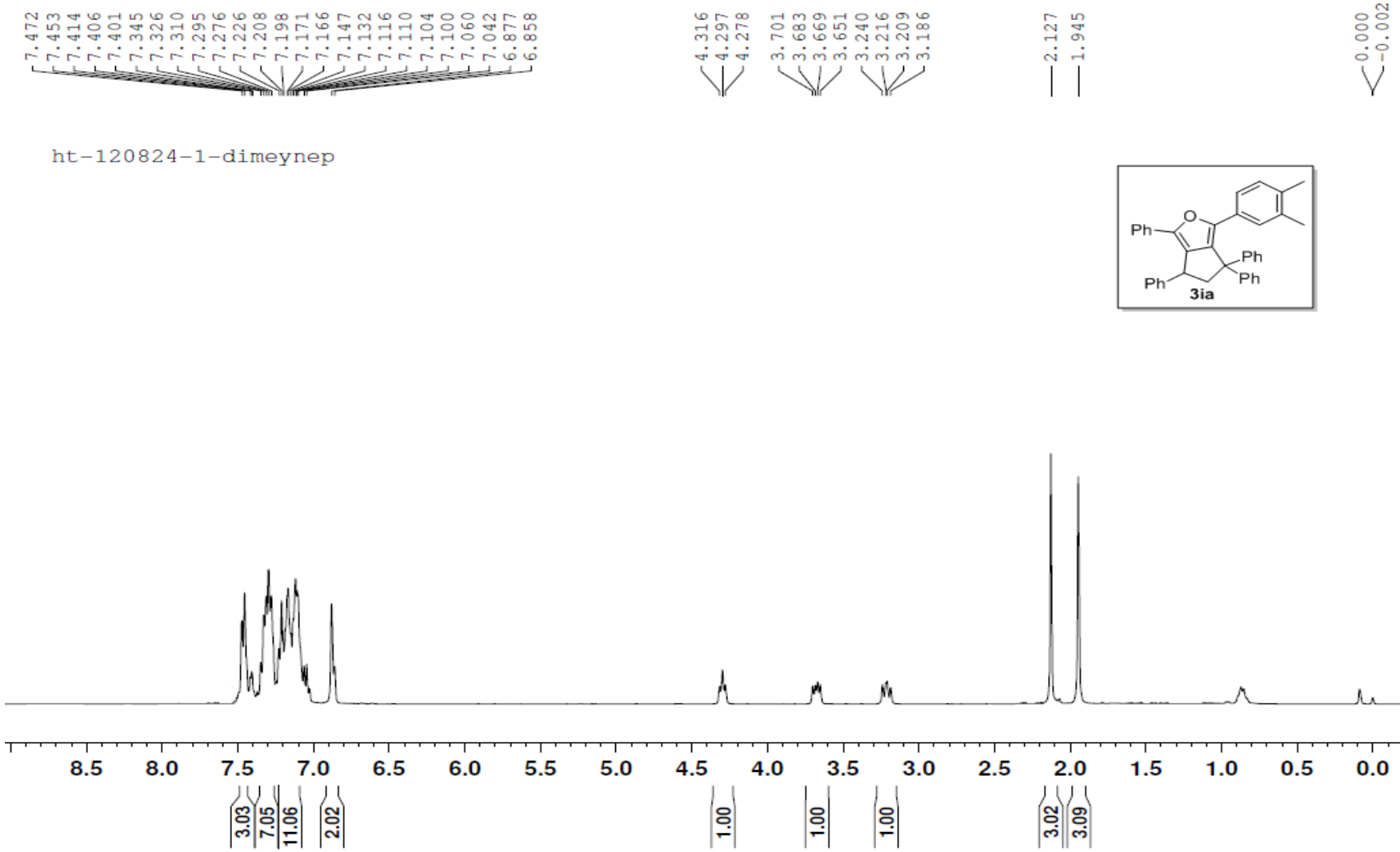

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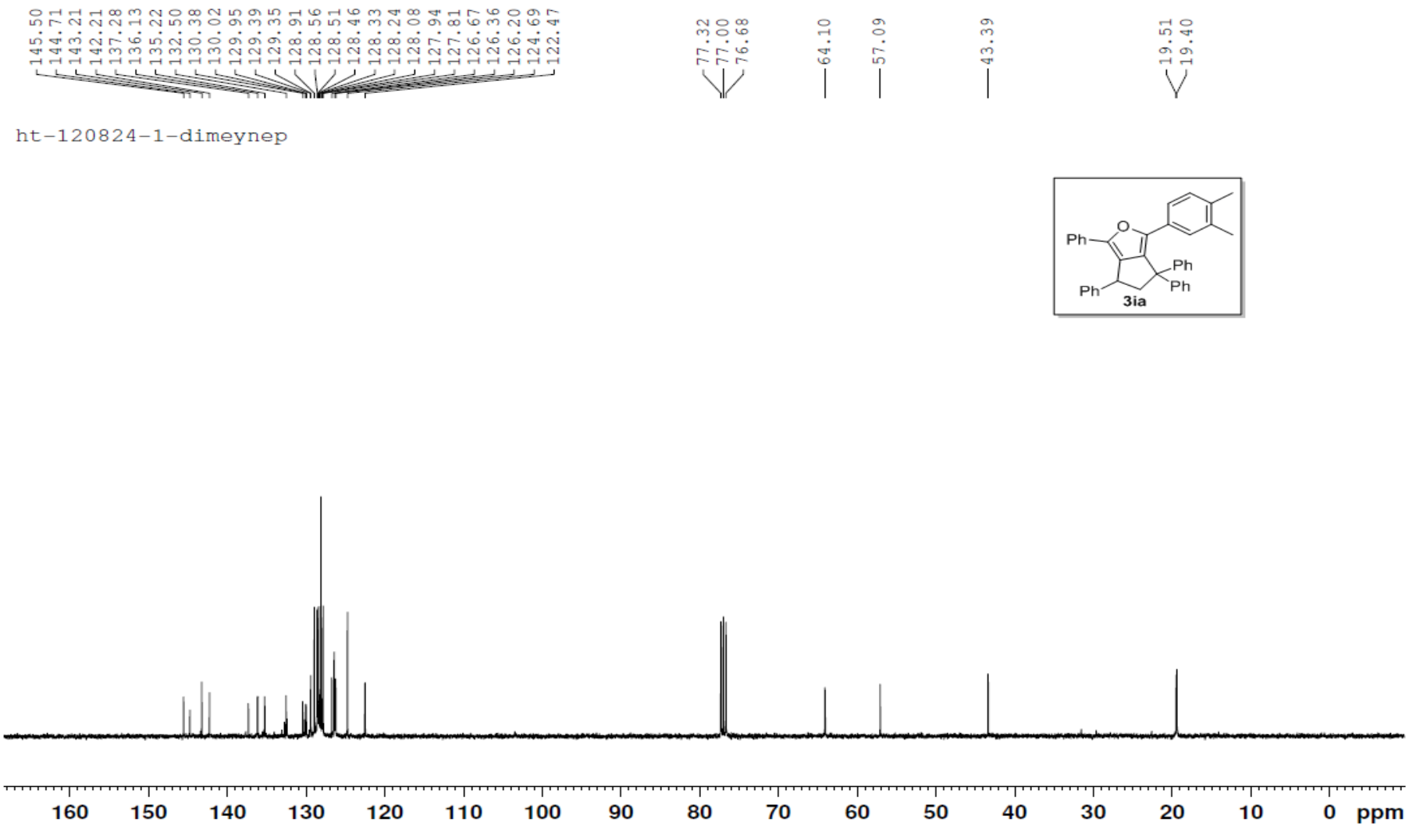

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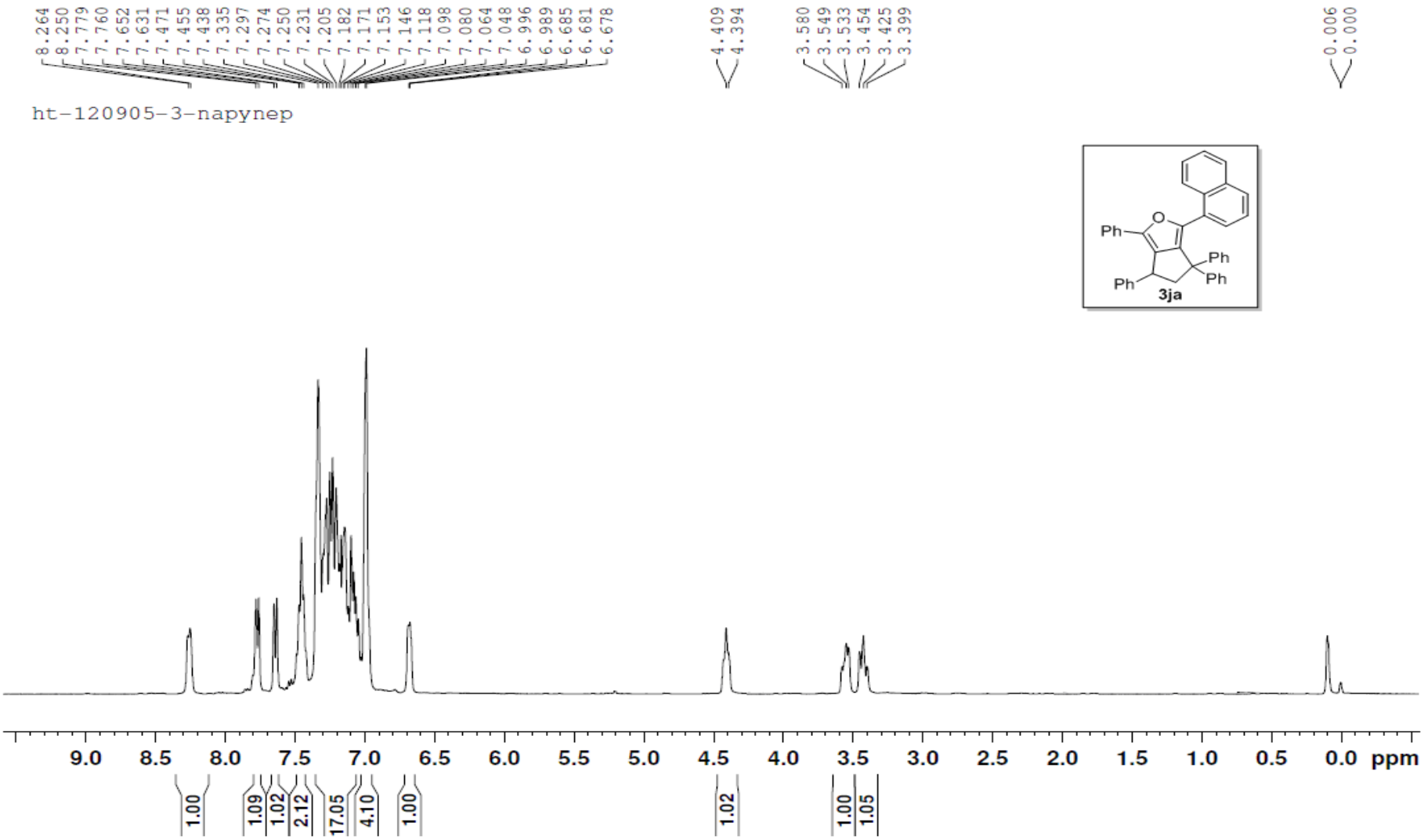

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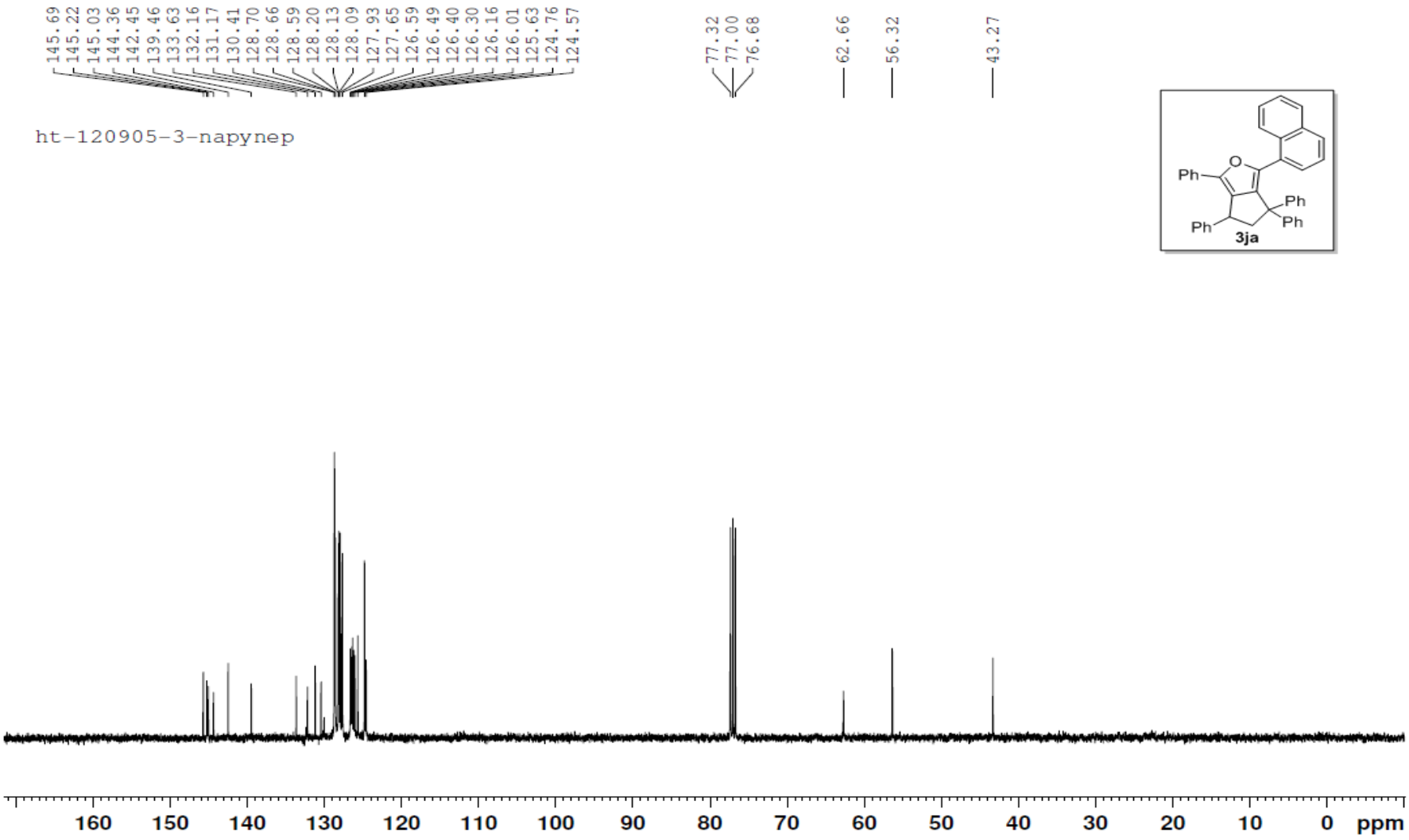

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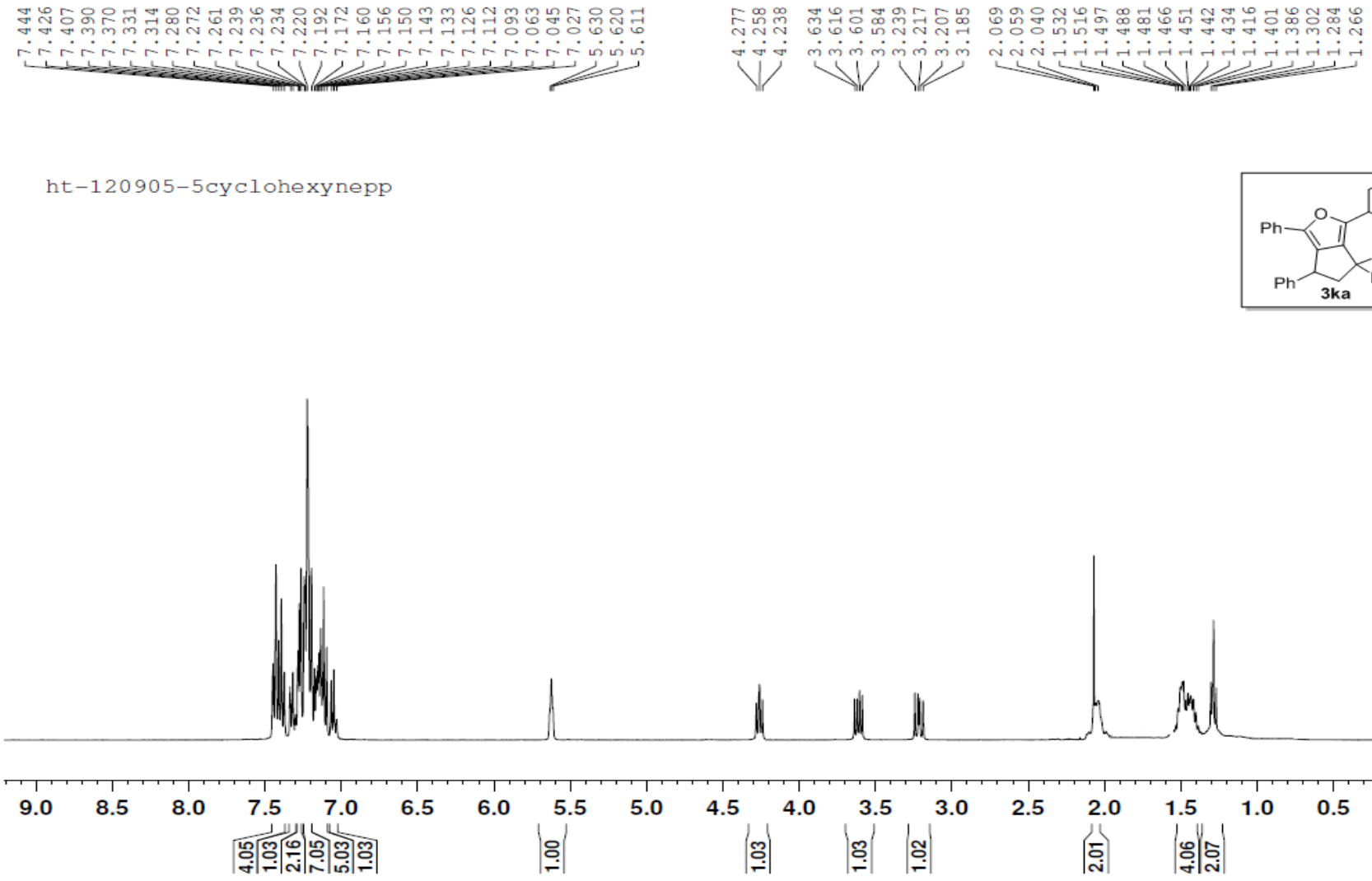

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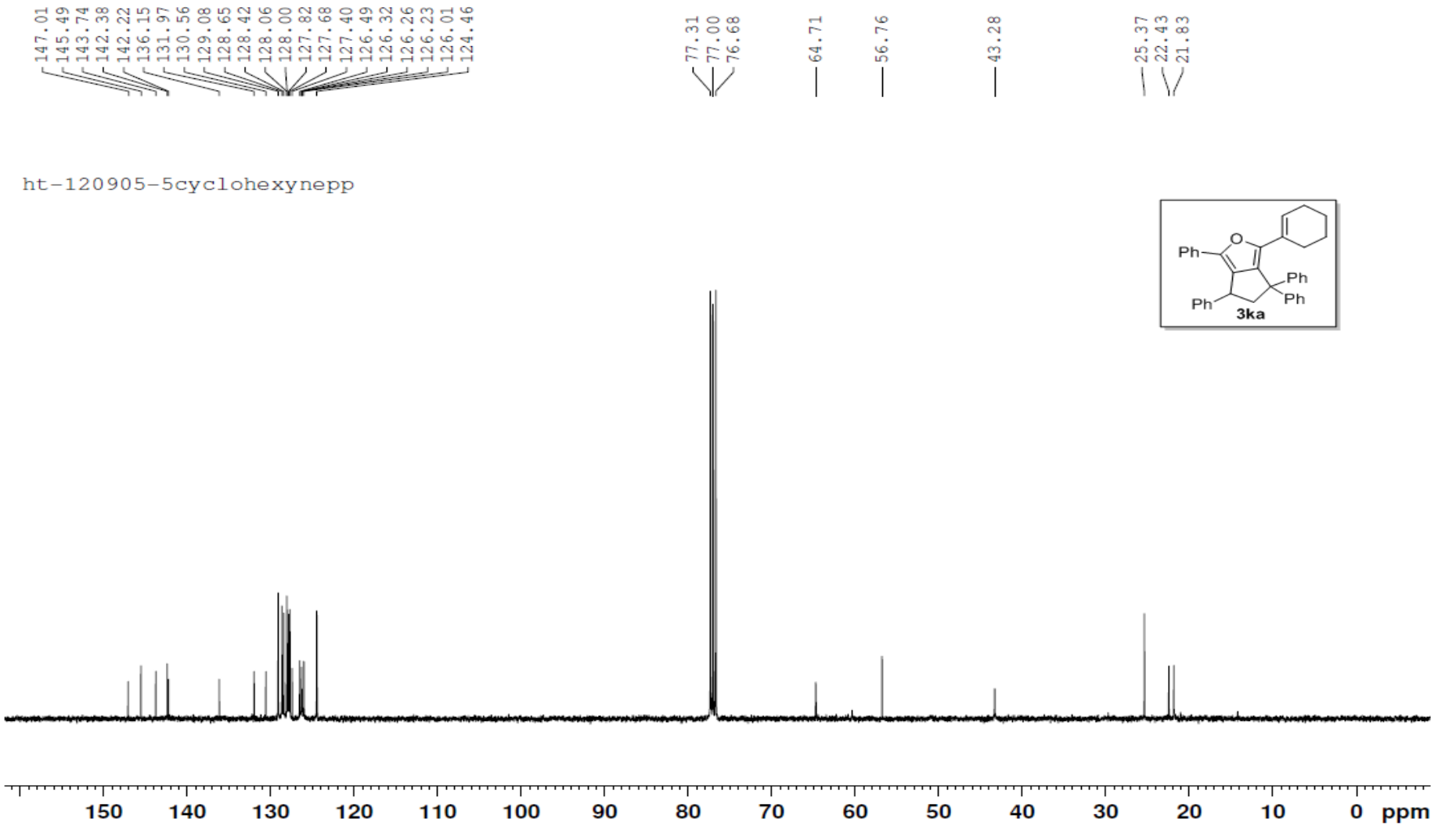

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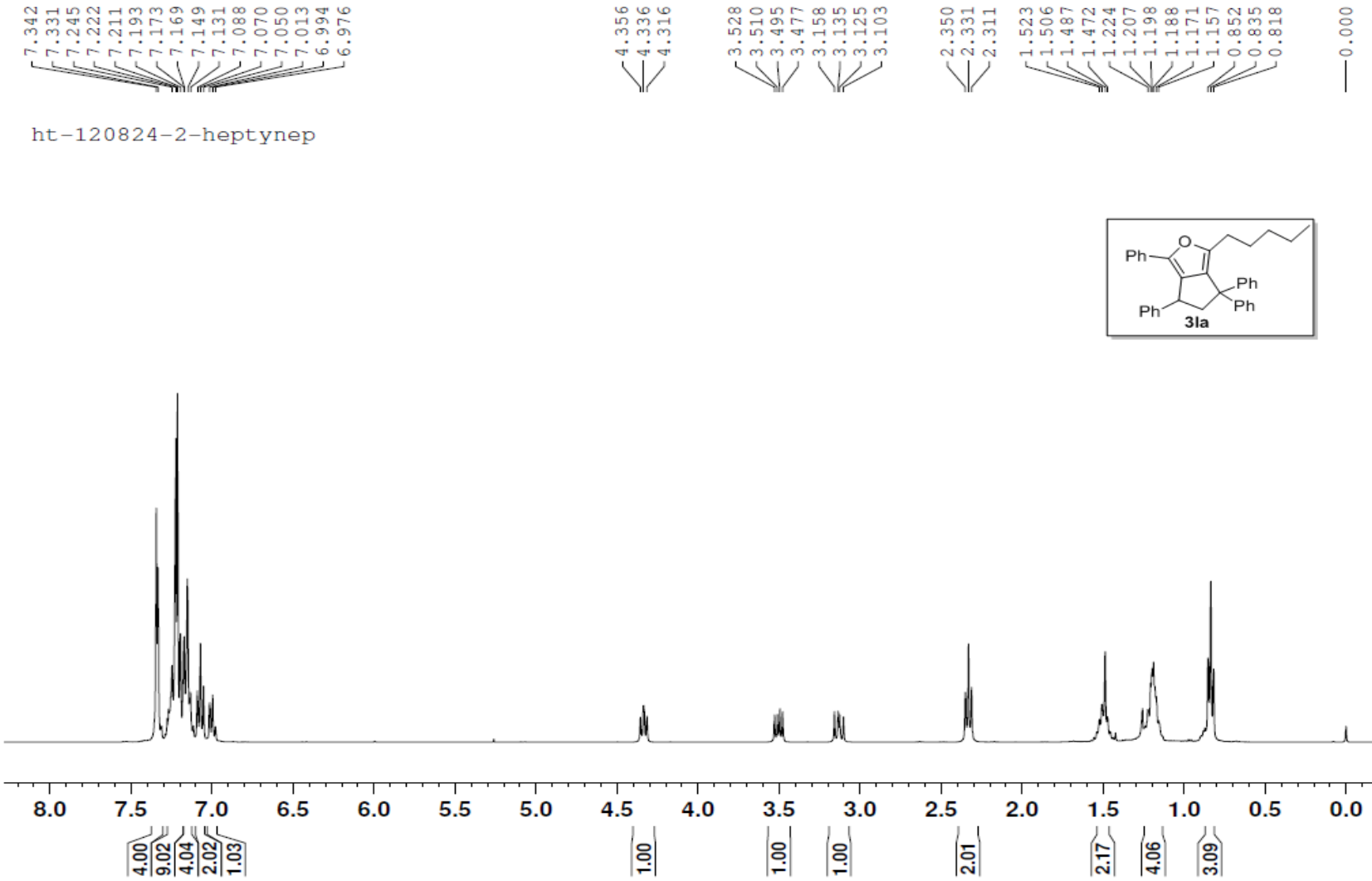

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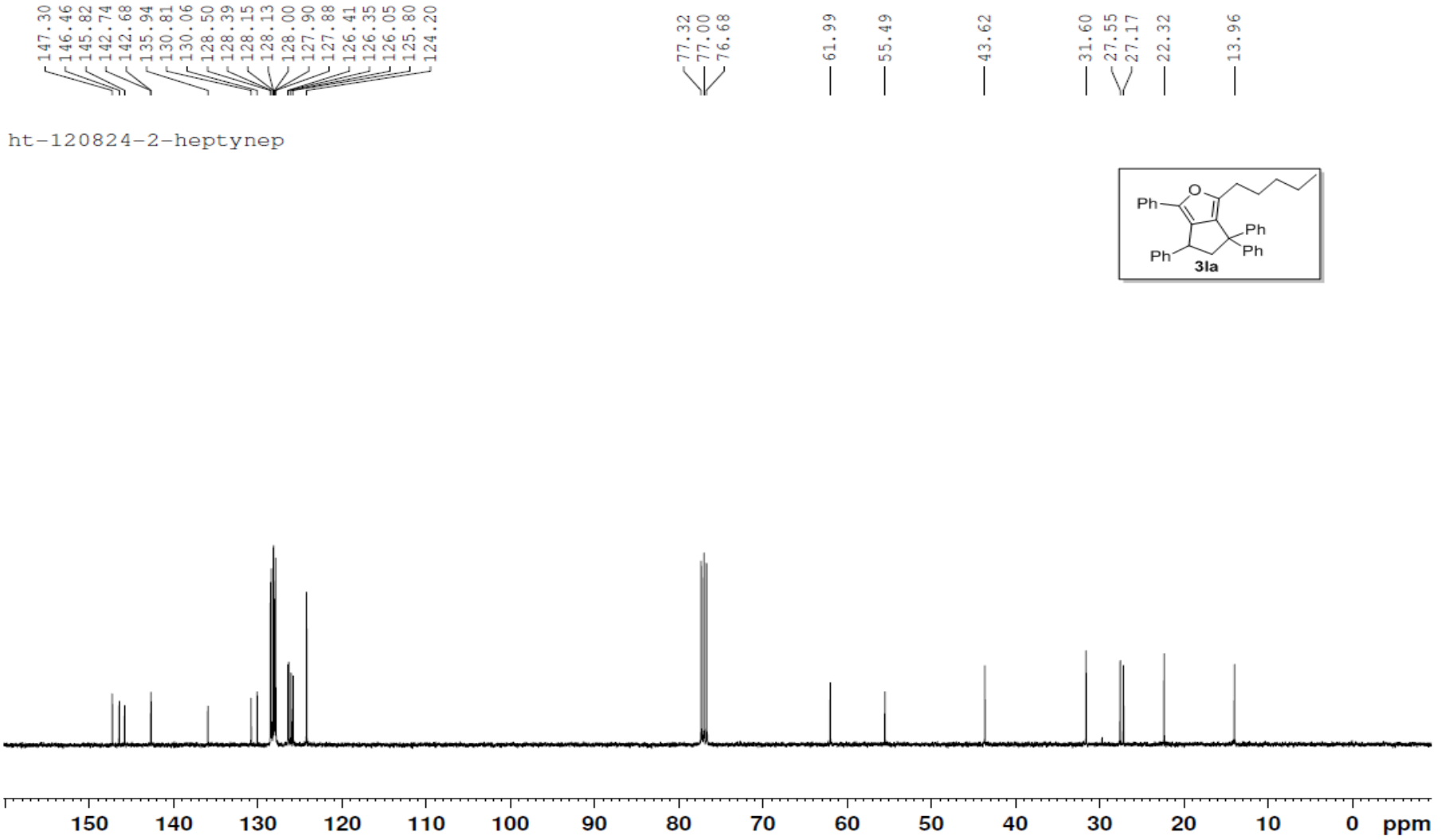

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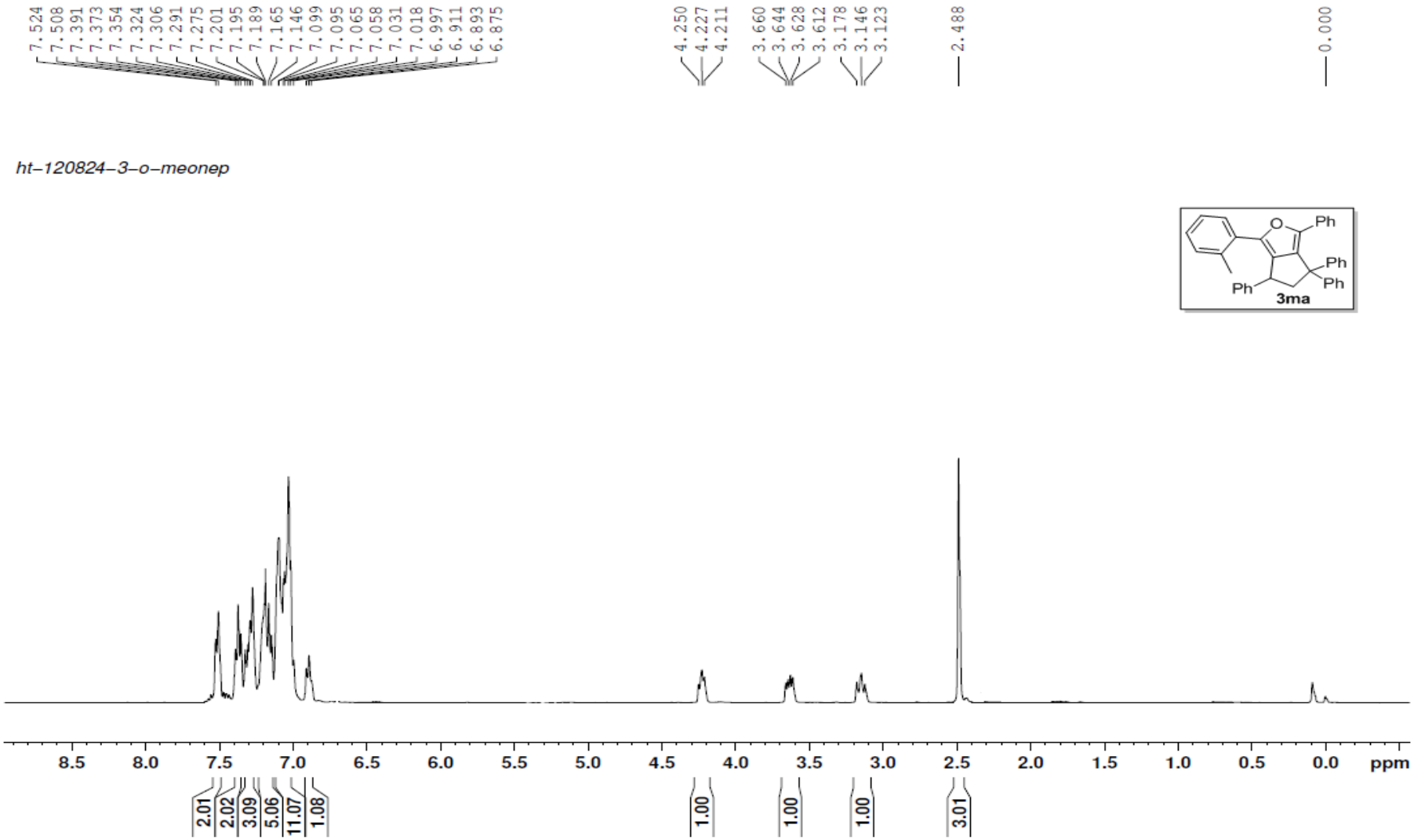

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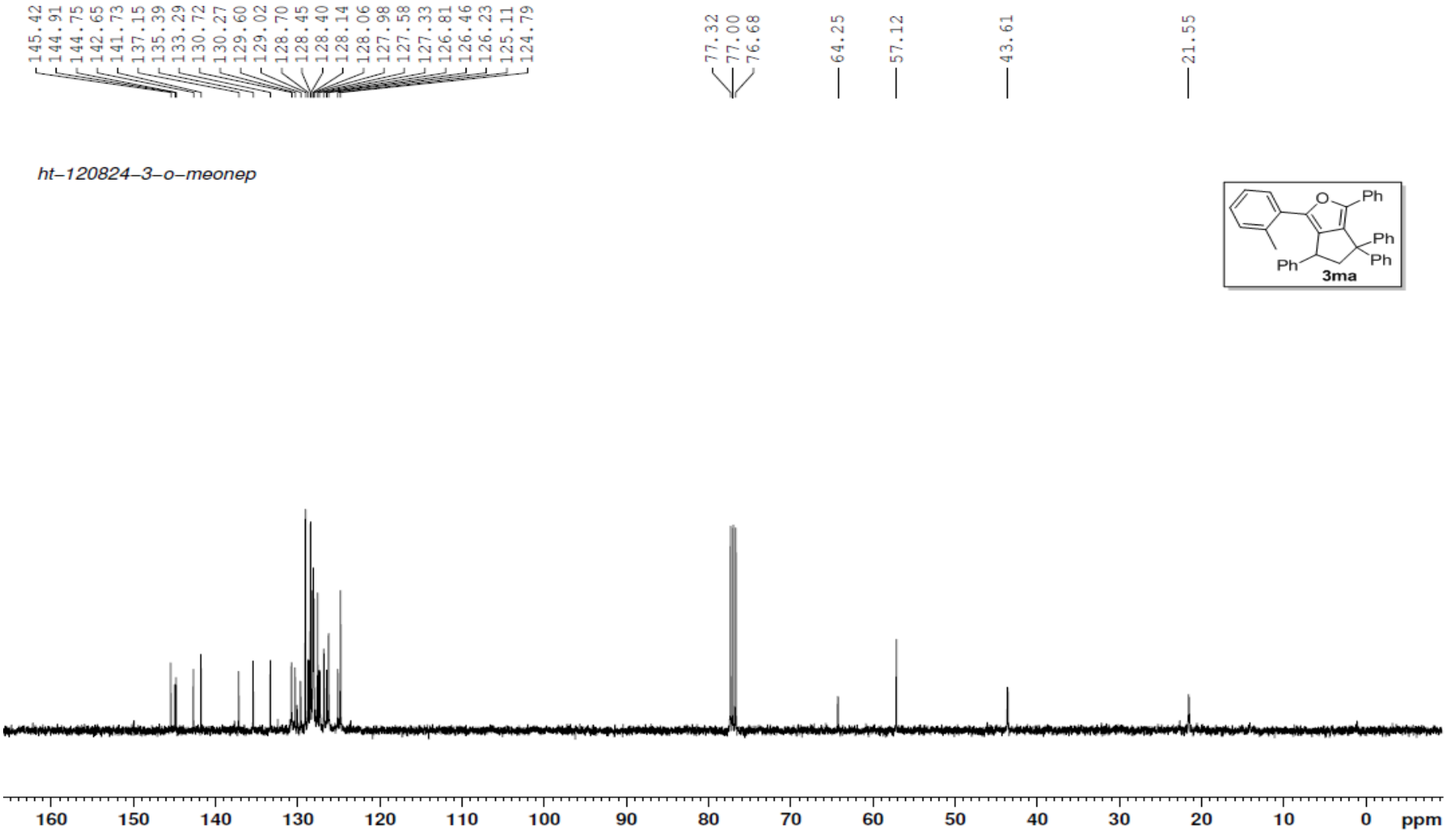

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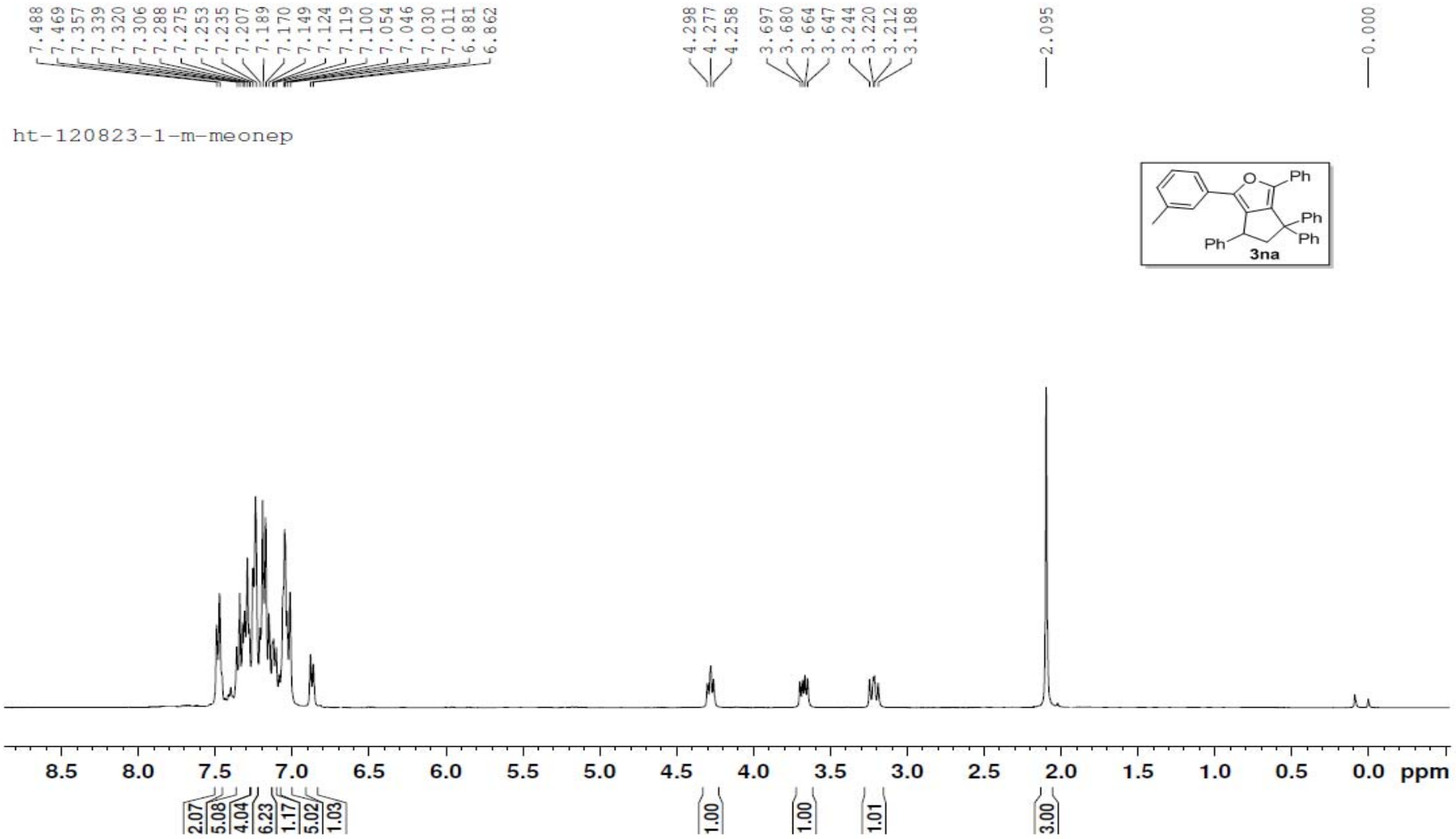

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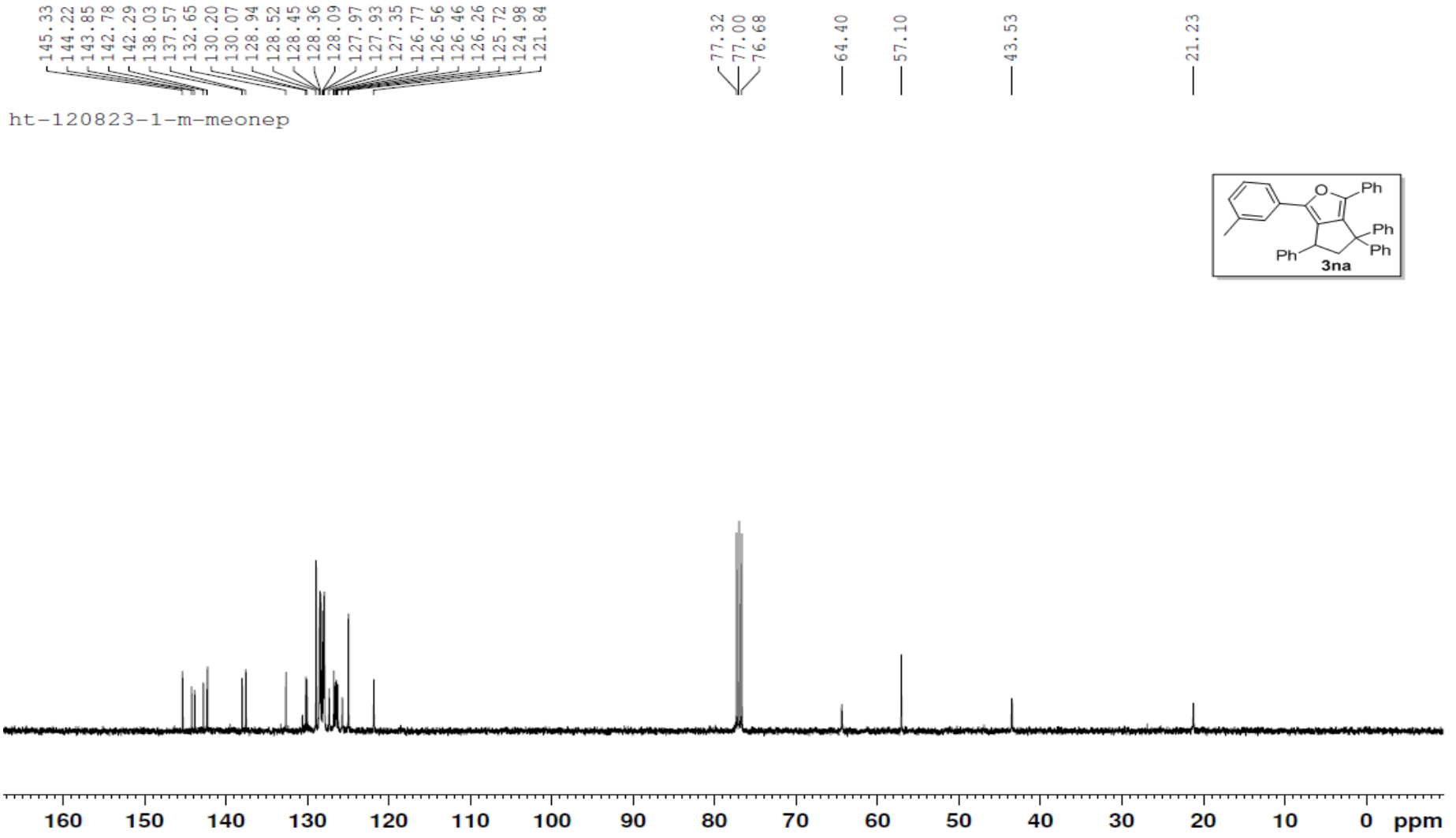

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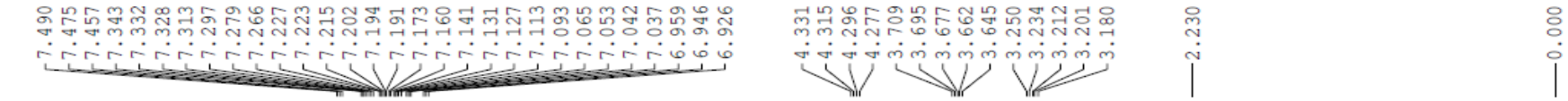

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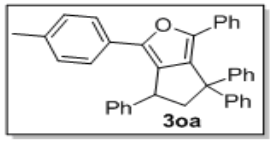

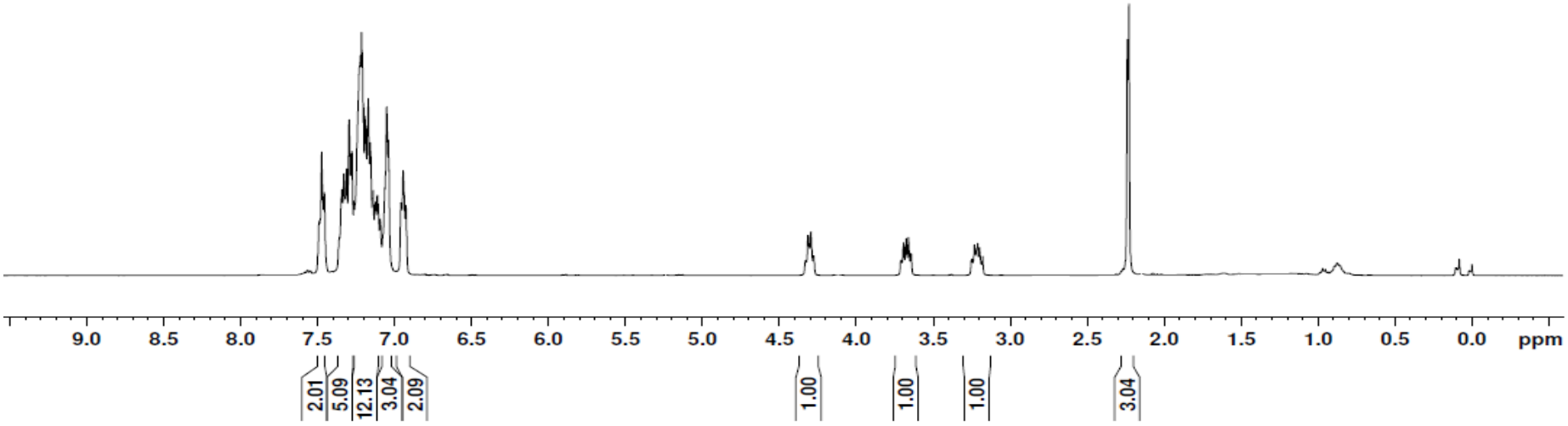

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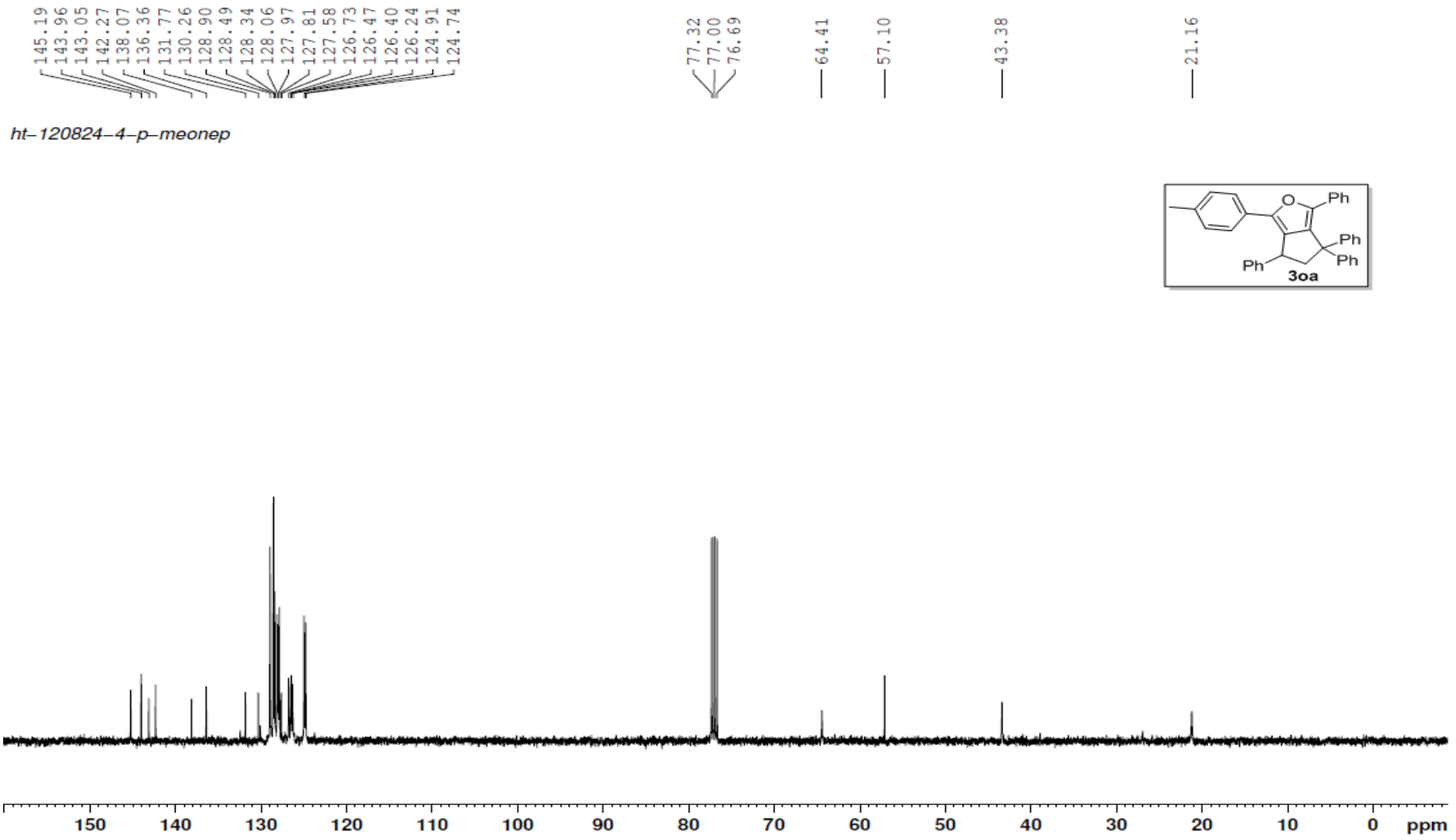

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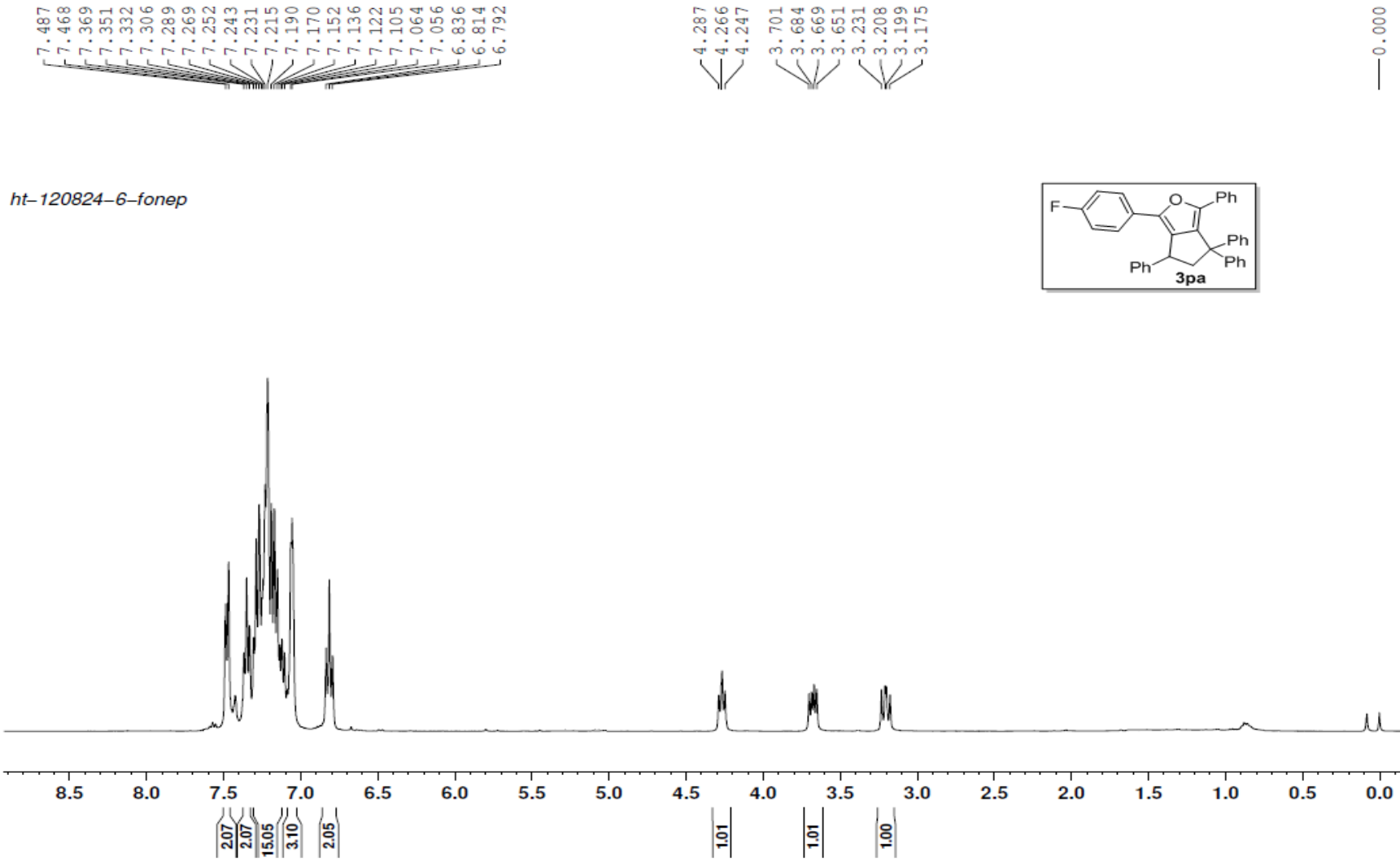

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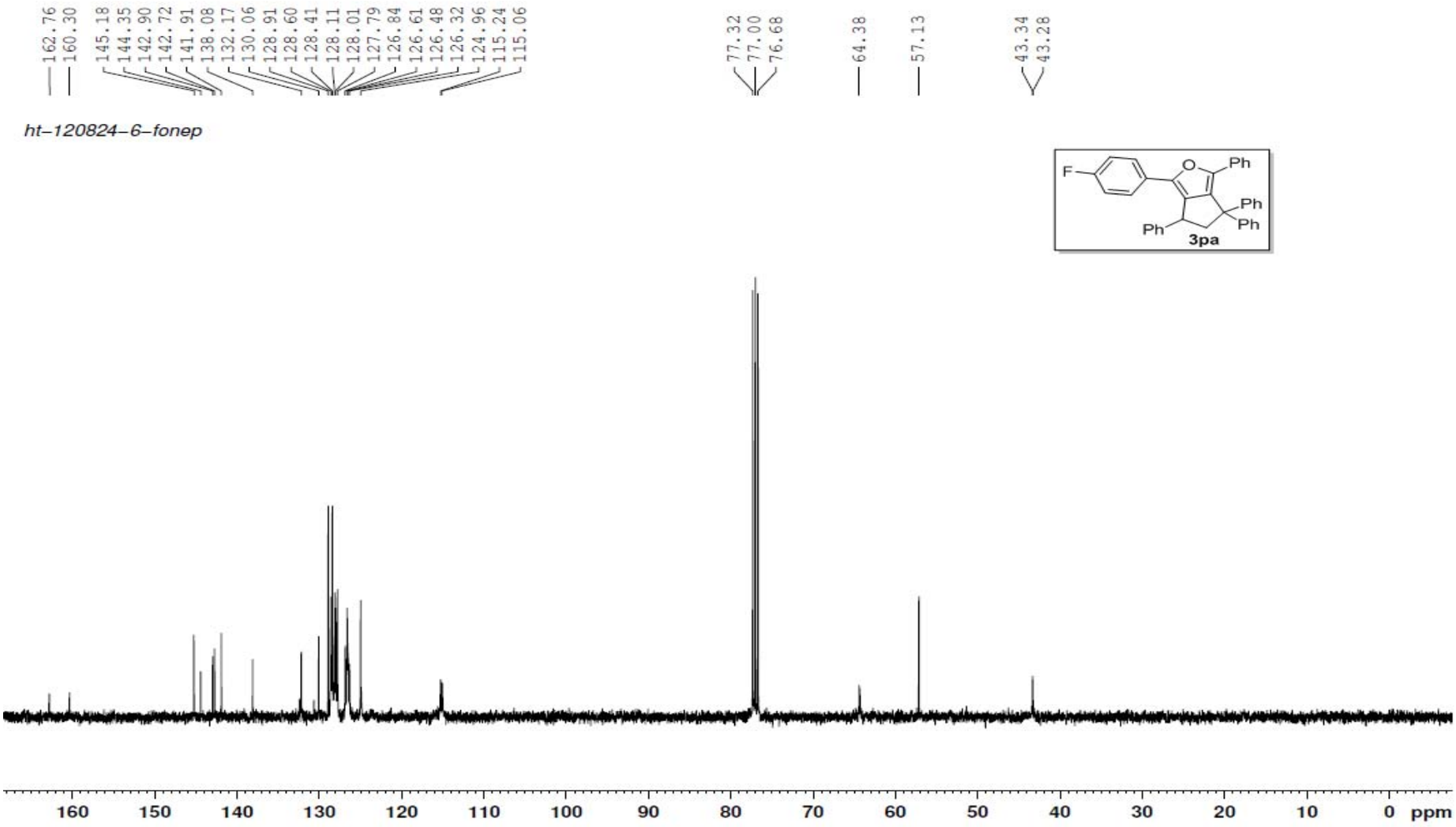

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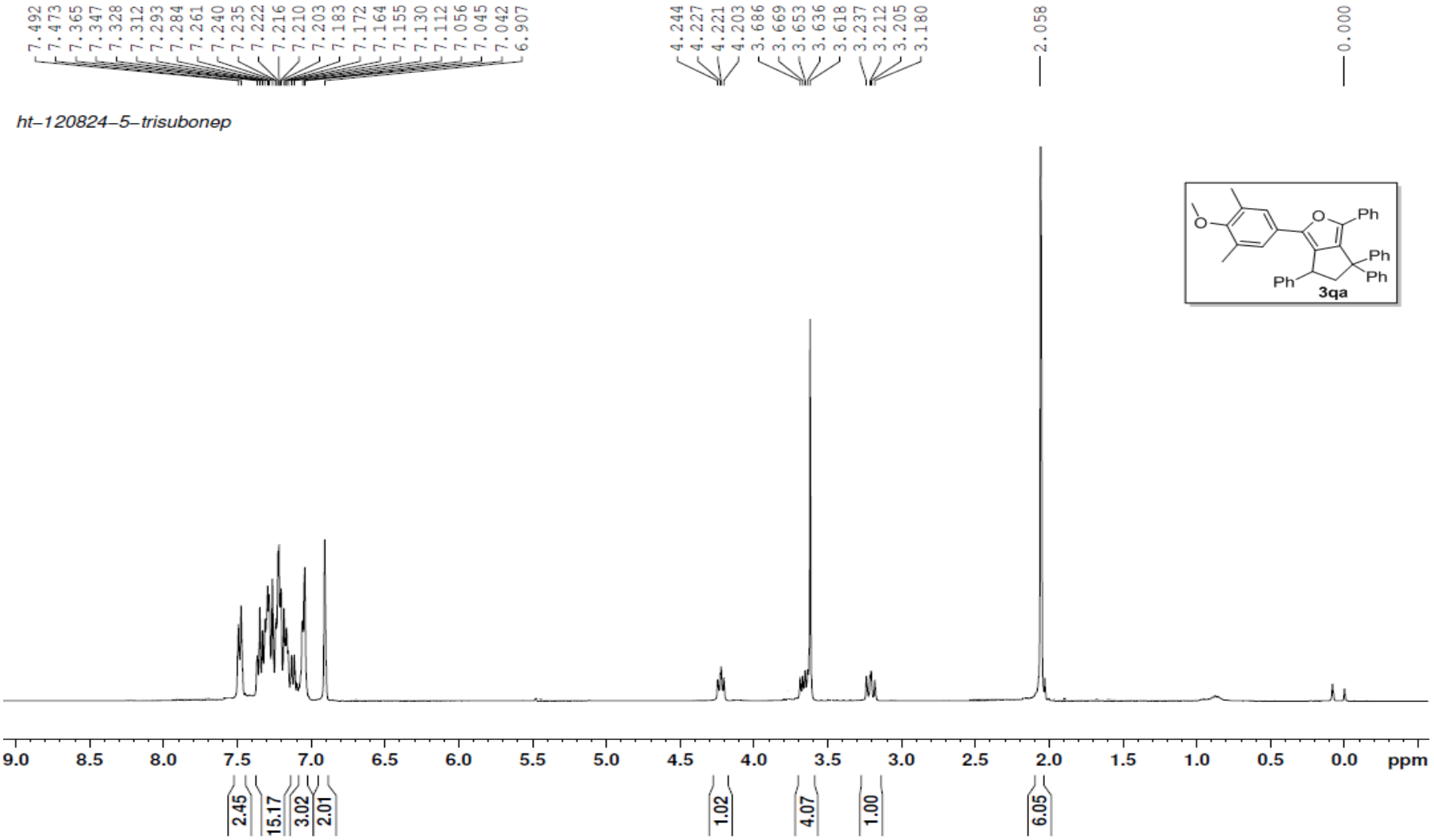

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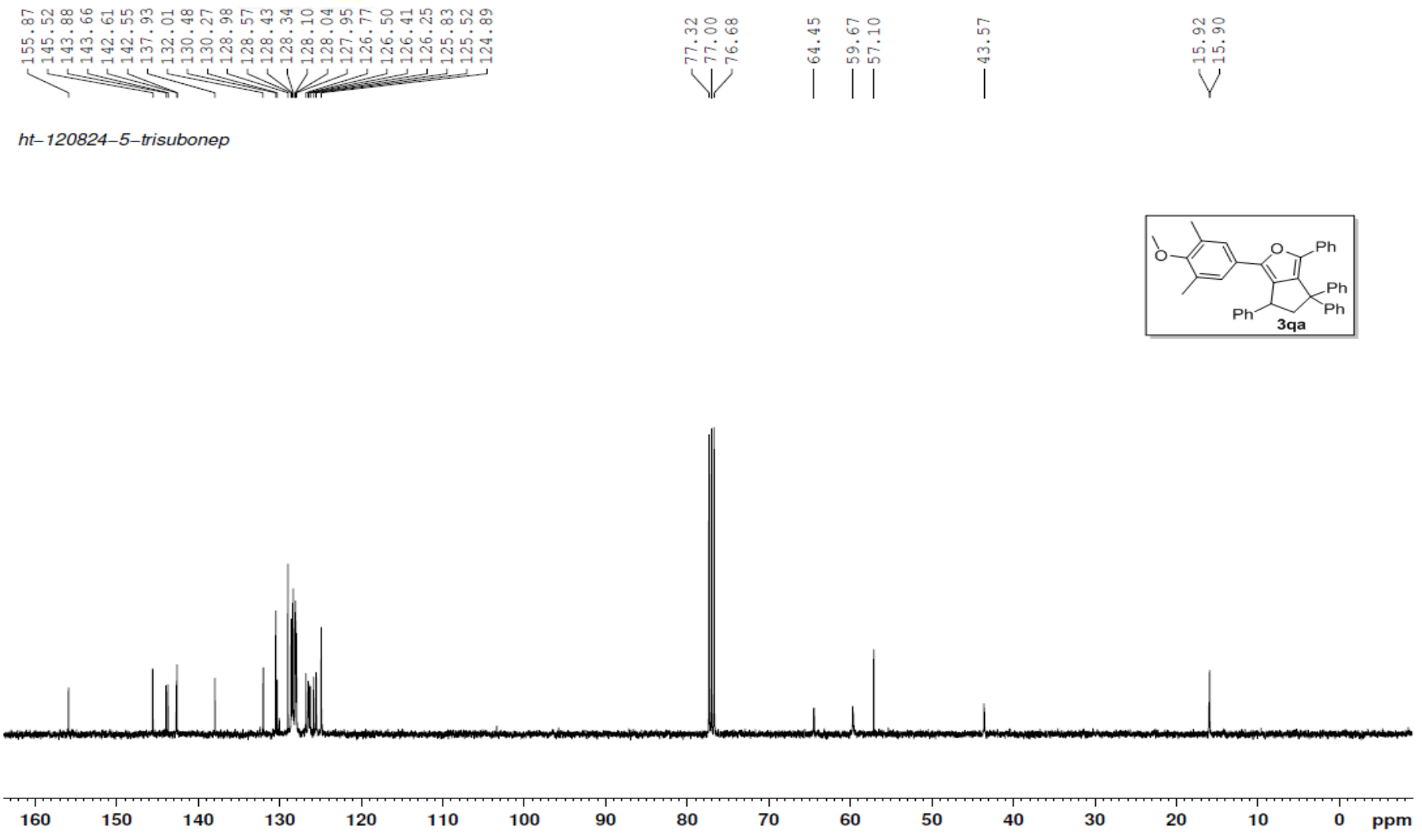

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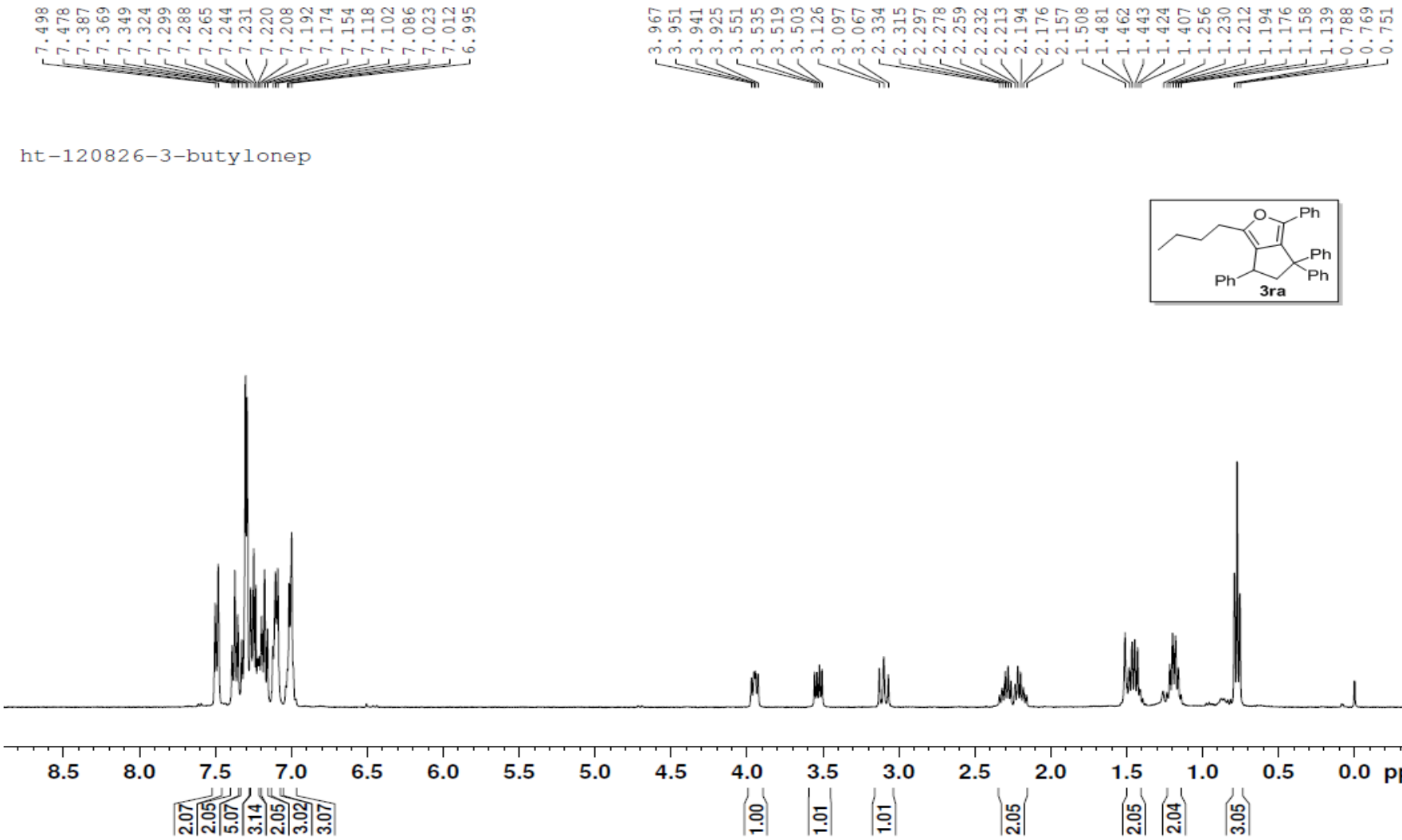

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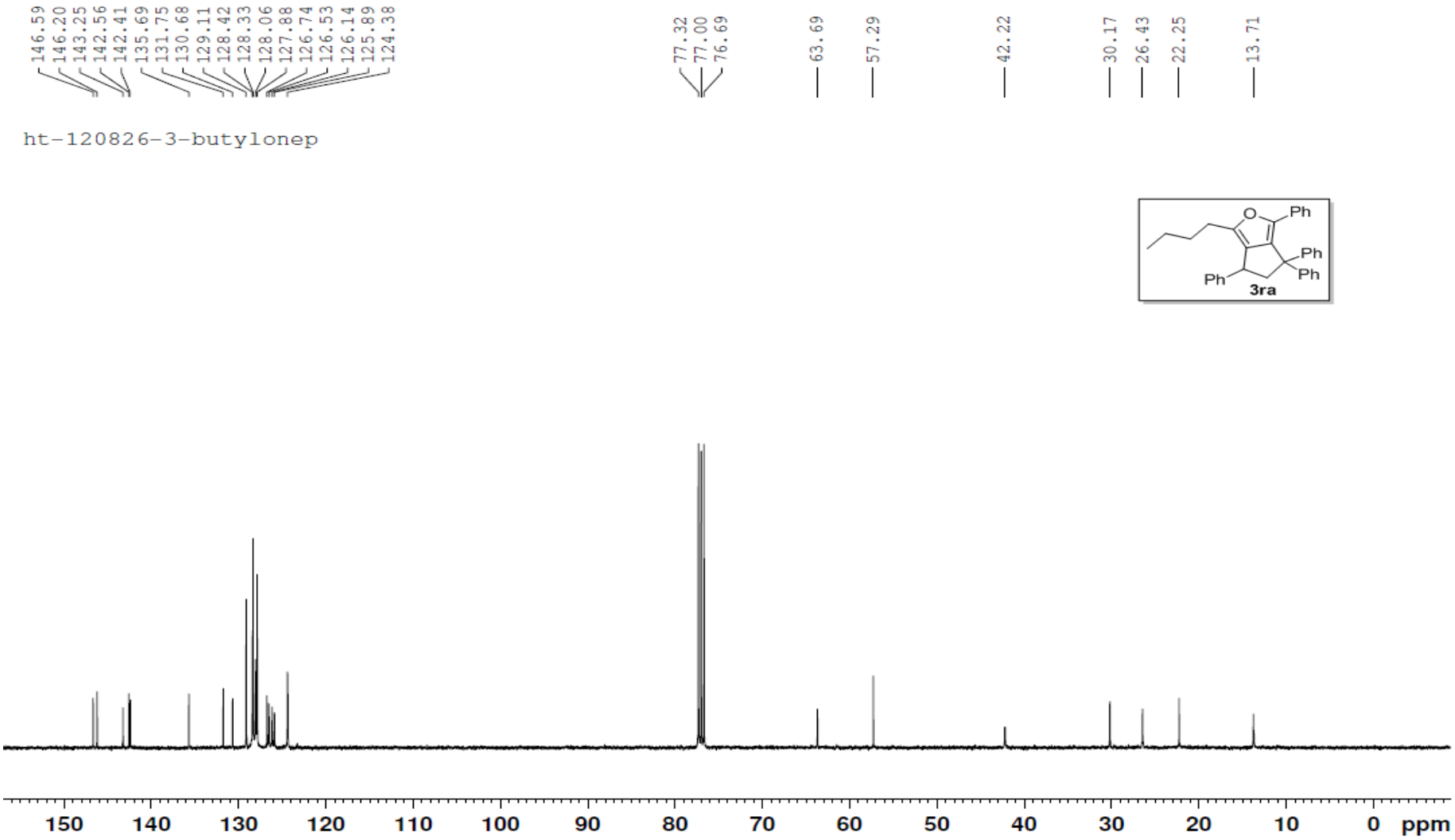

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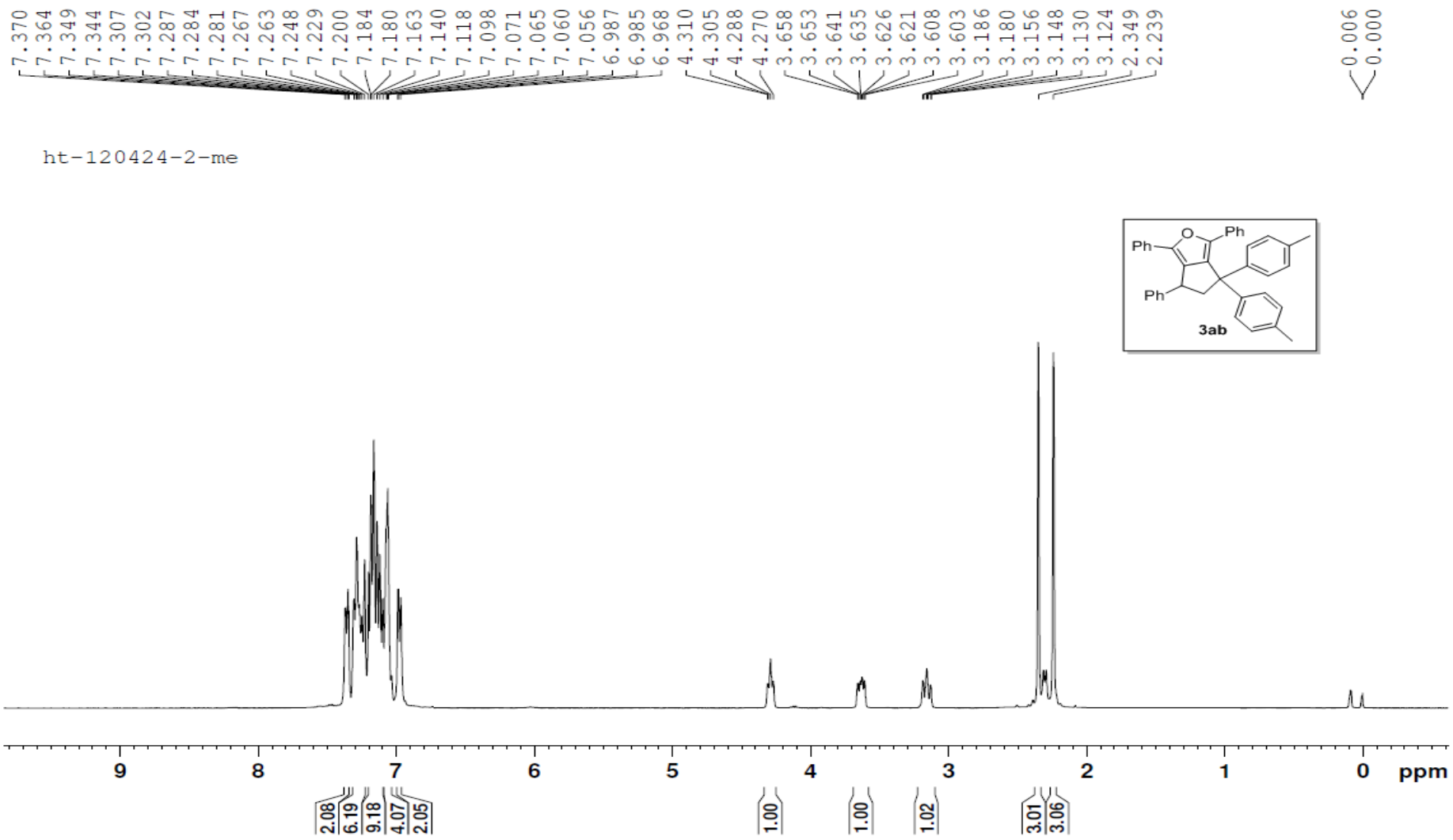

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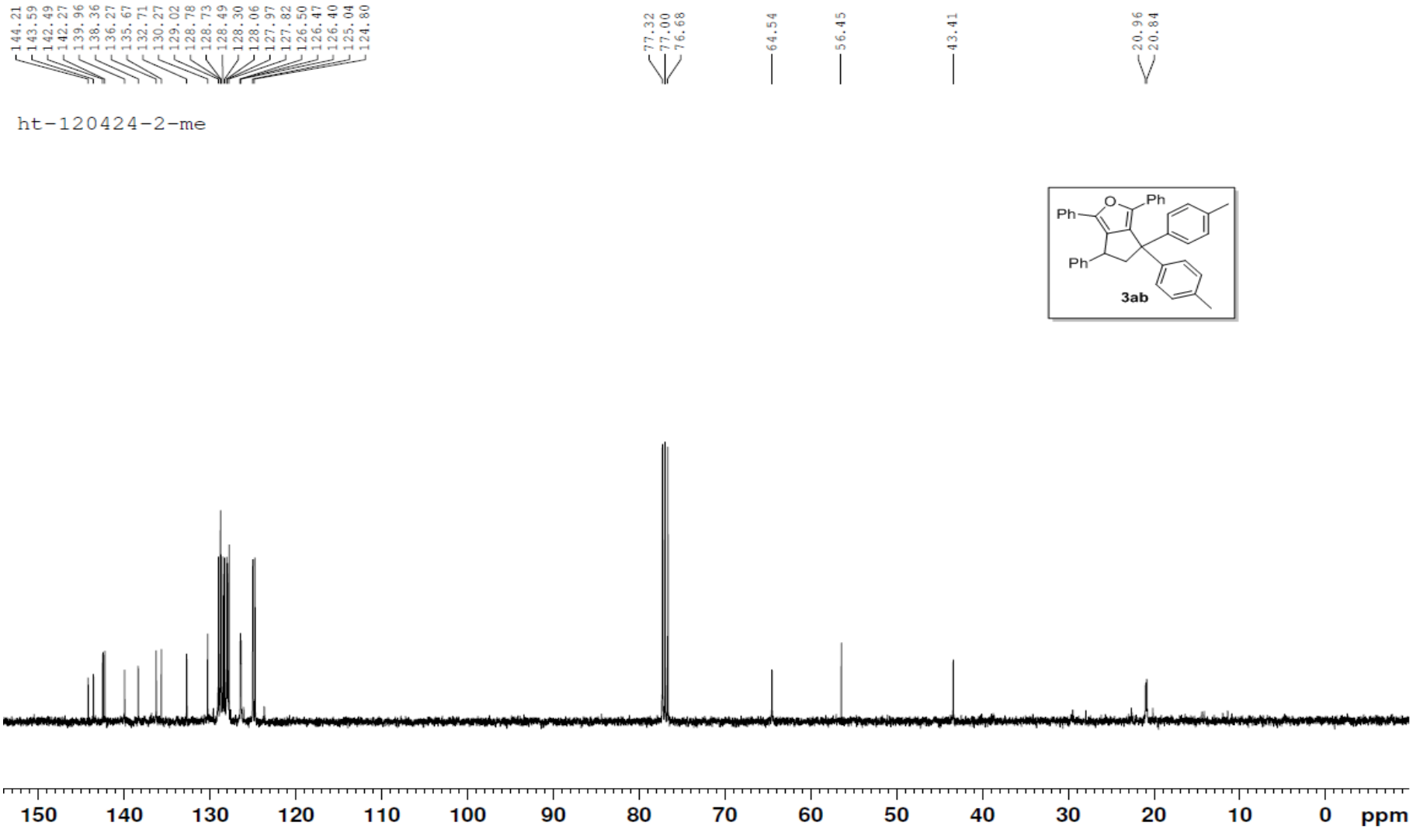

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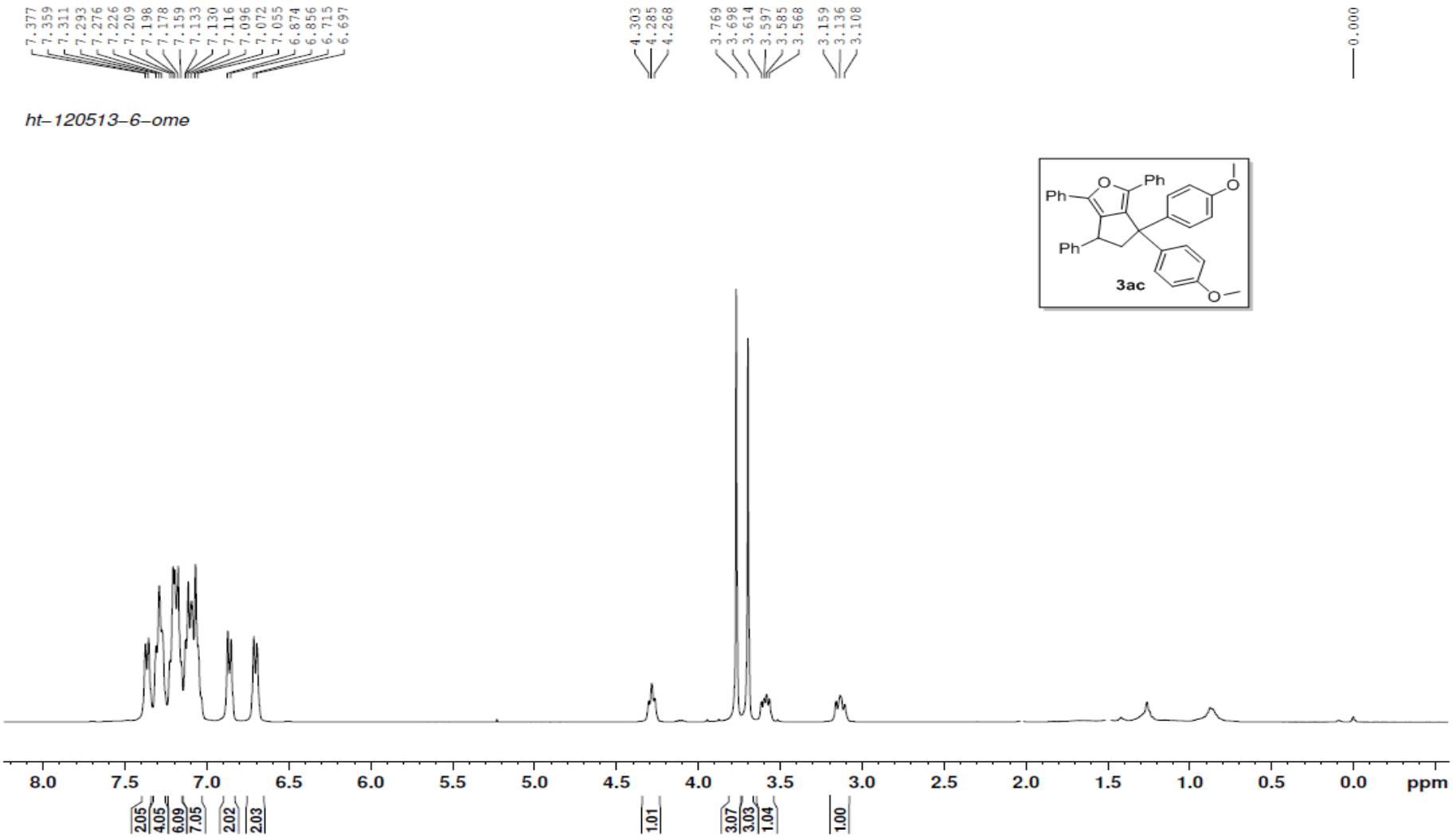

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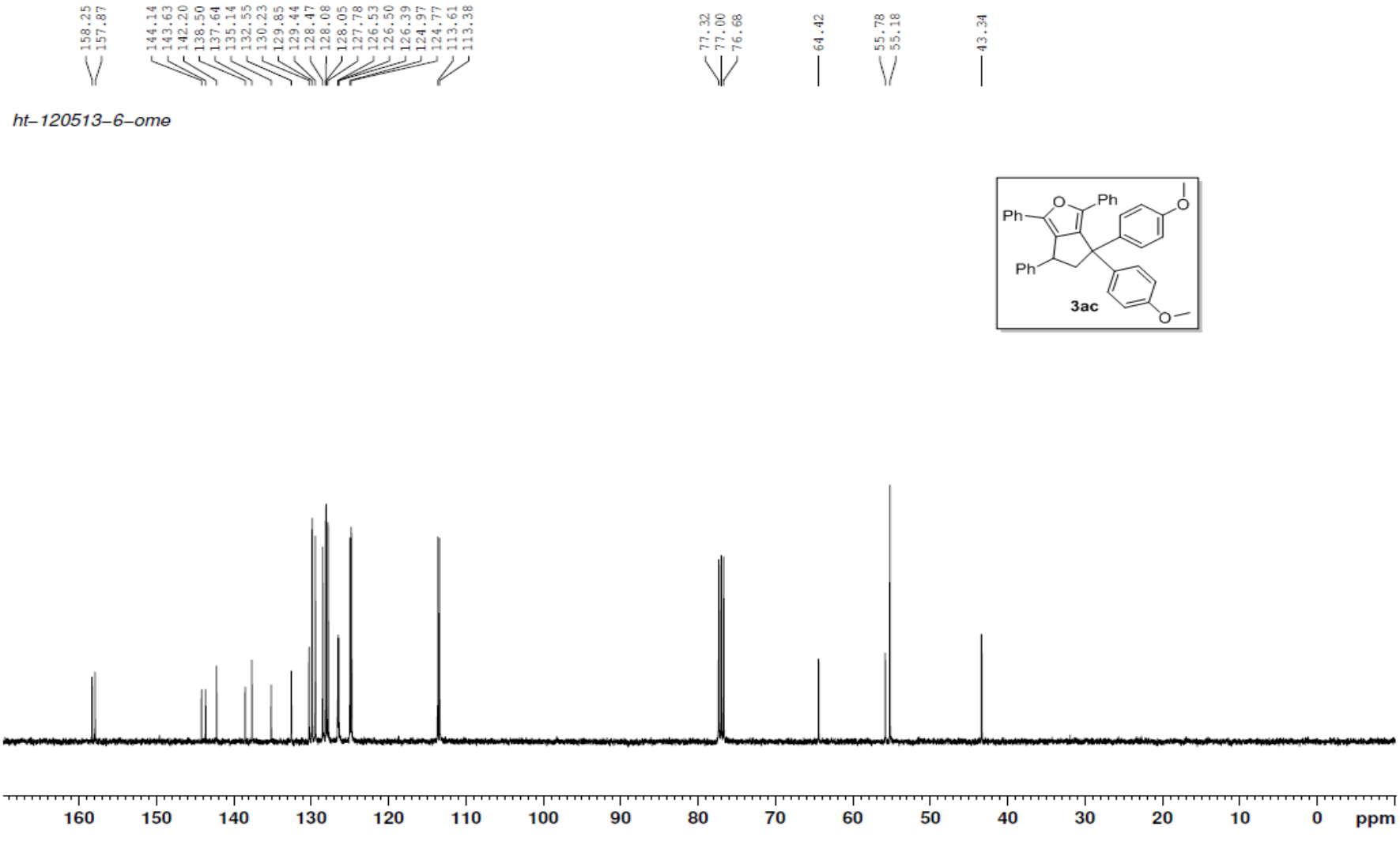

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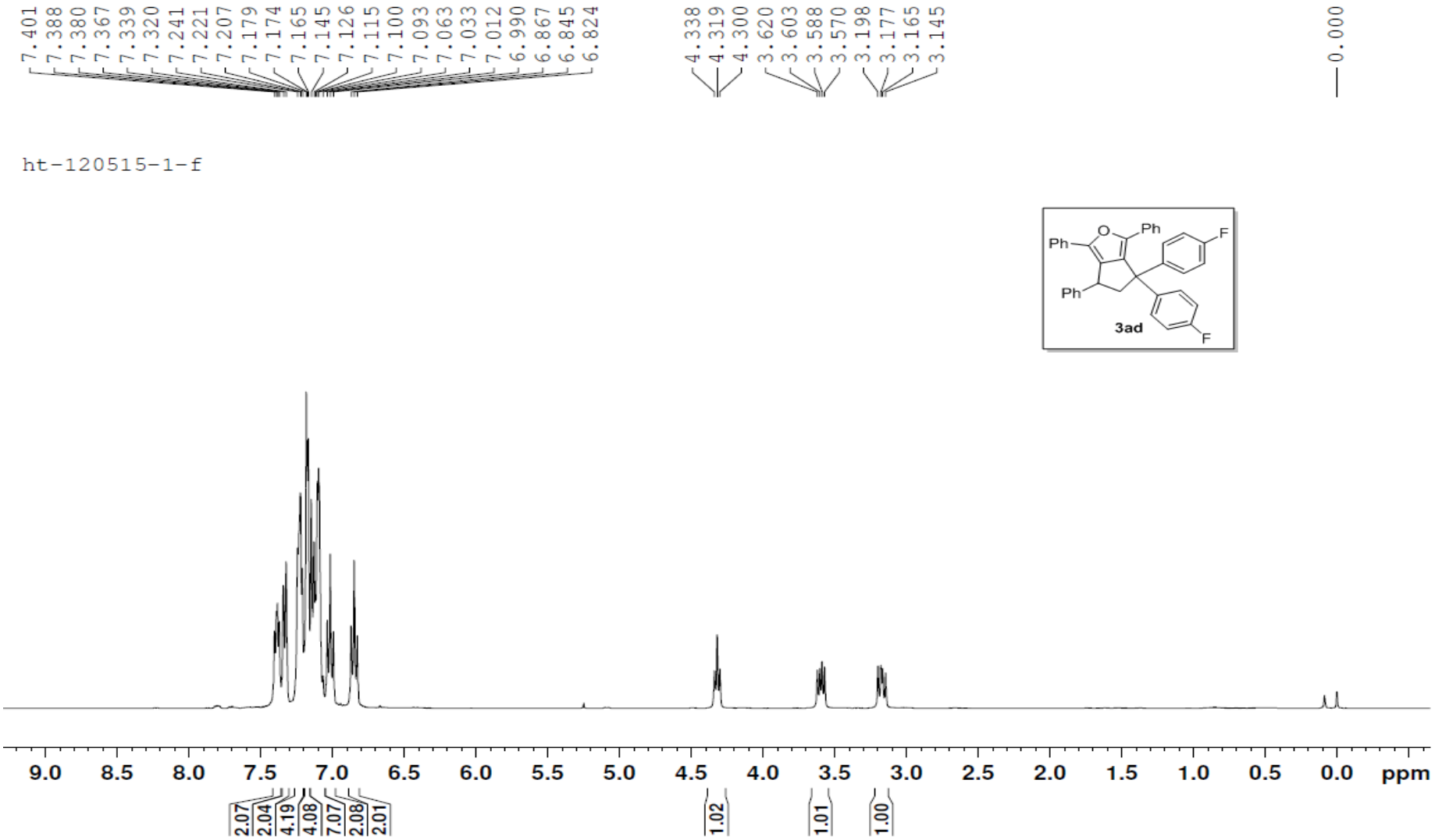

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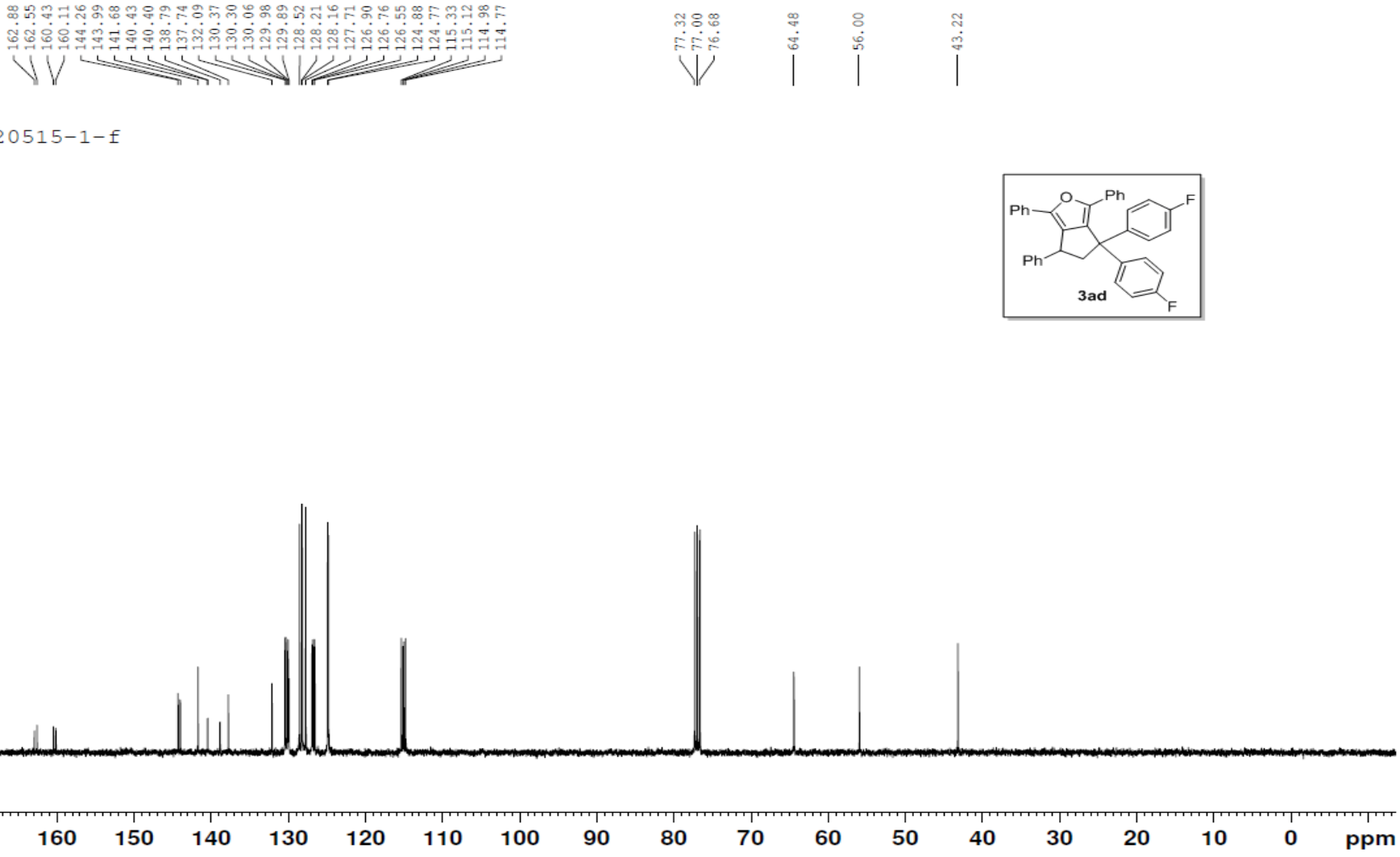

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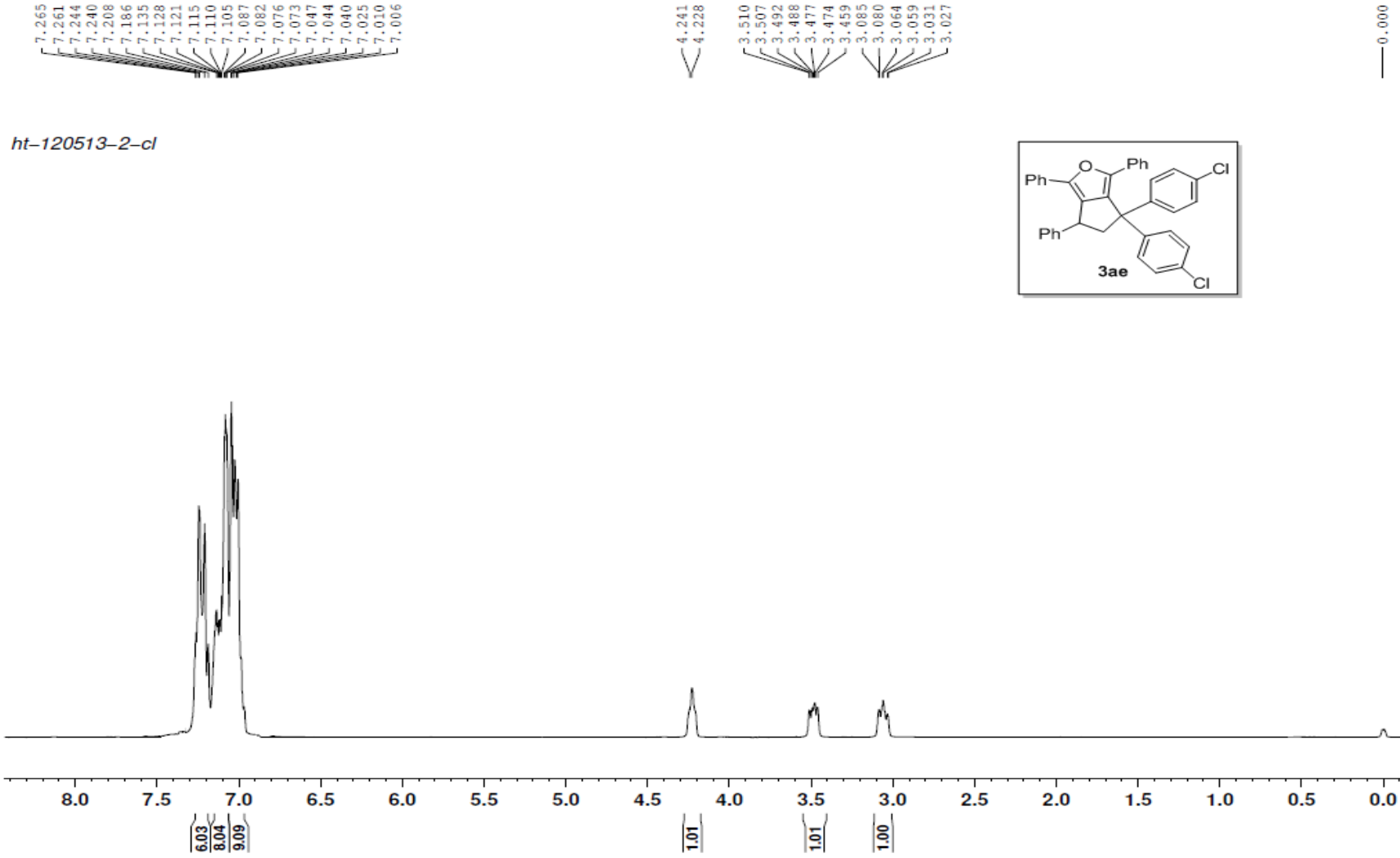

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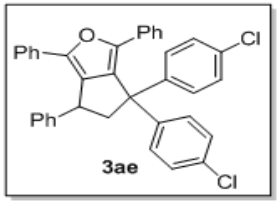

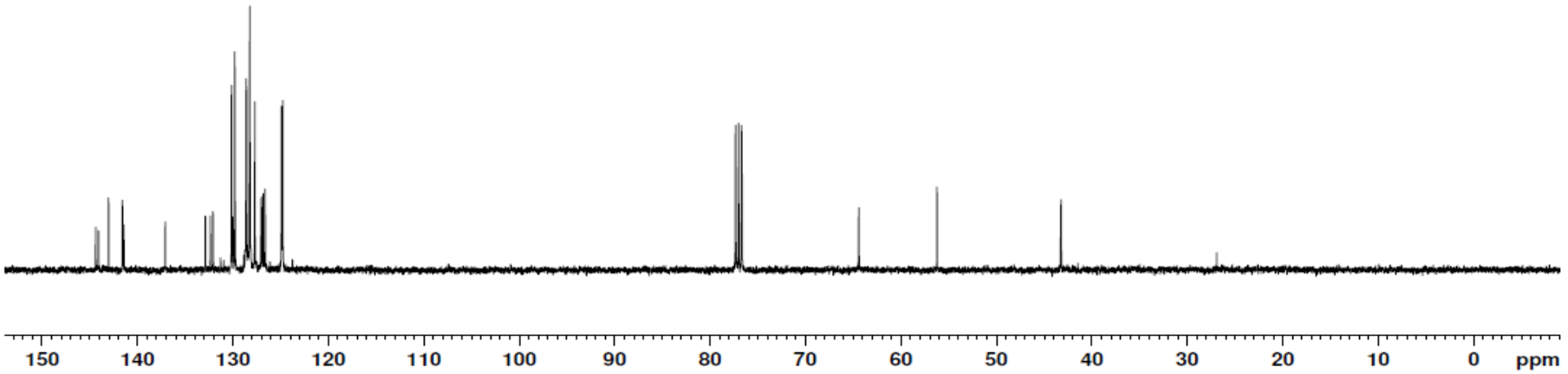

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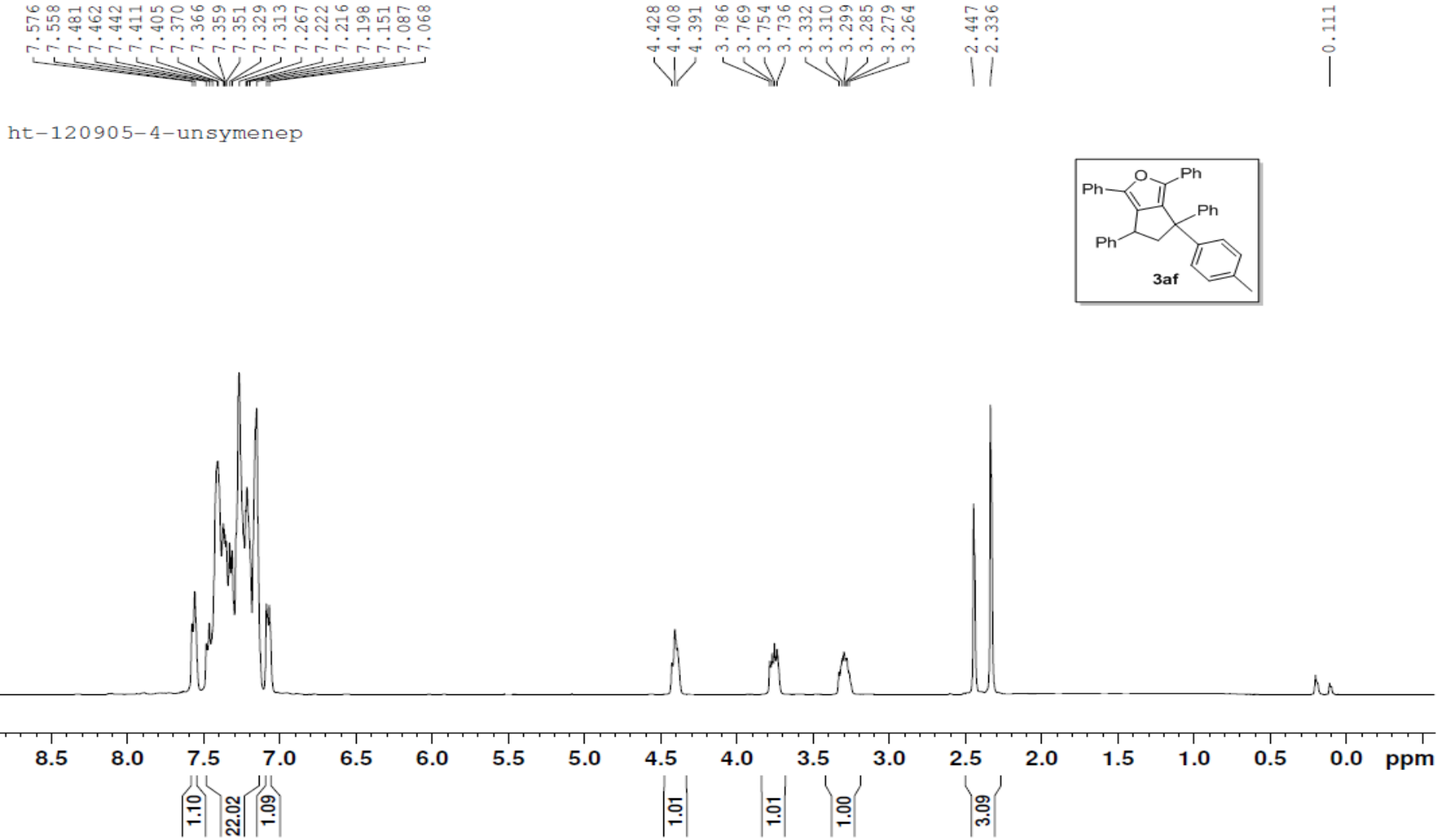

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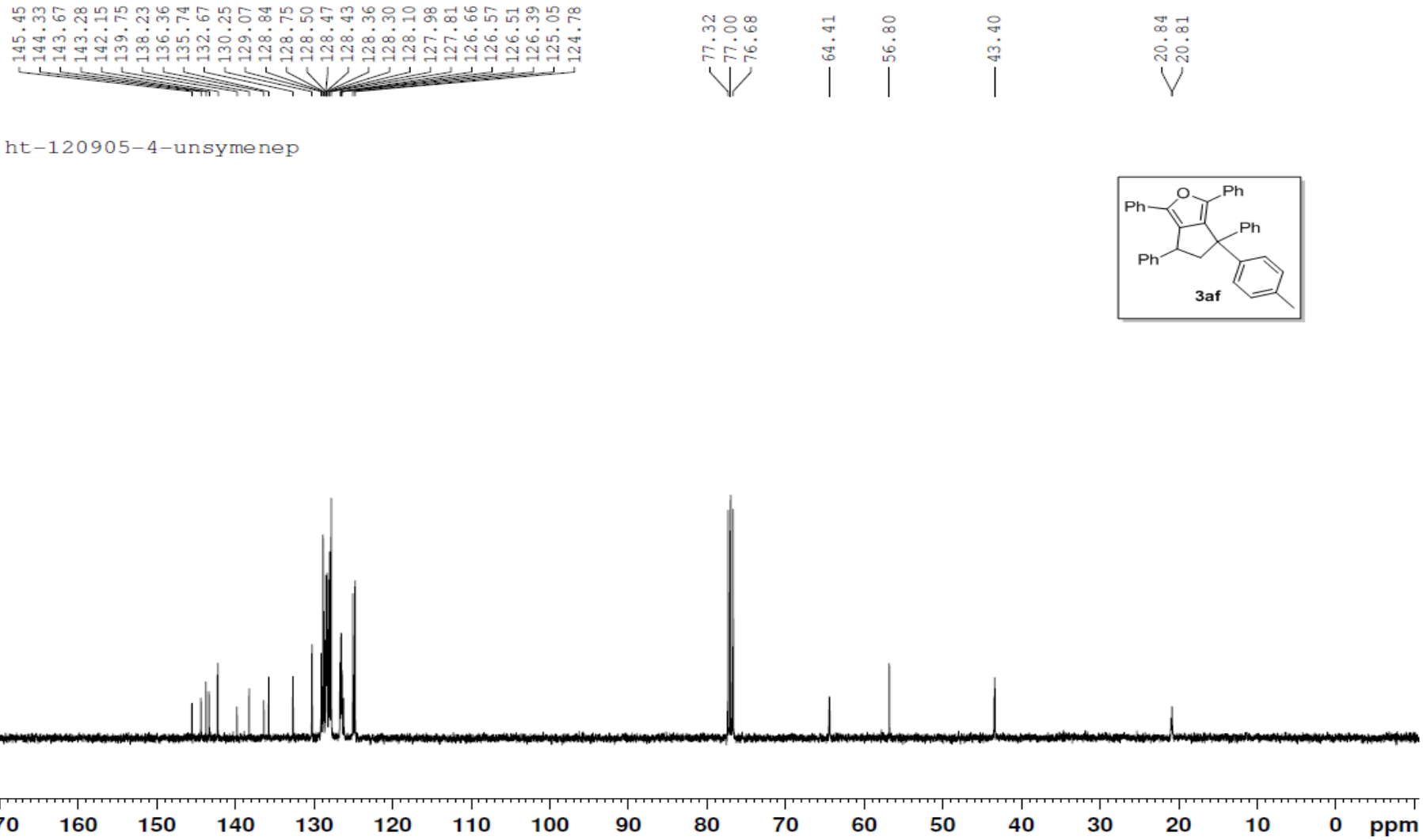
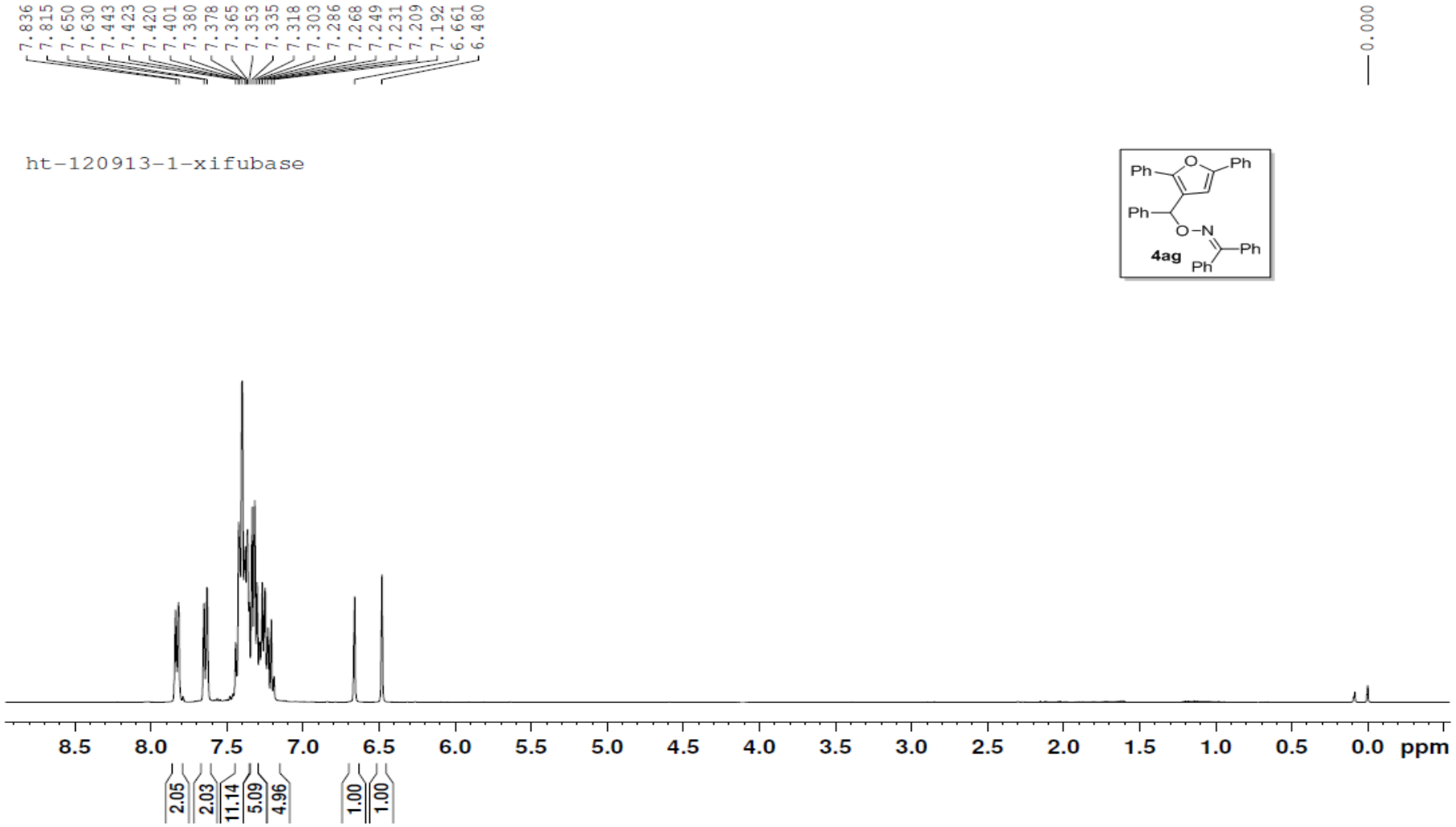


9. ^{1}H NMR and ^{13}C NMR spectra for compounds 4ag, 4ah



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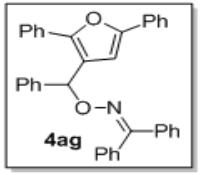

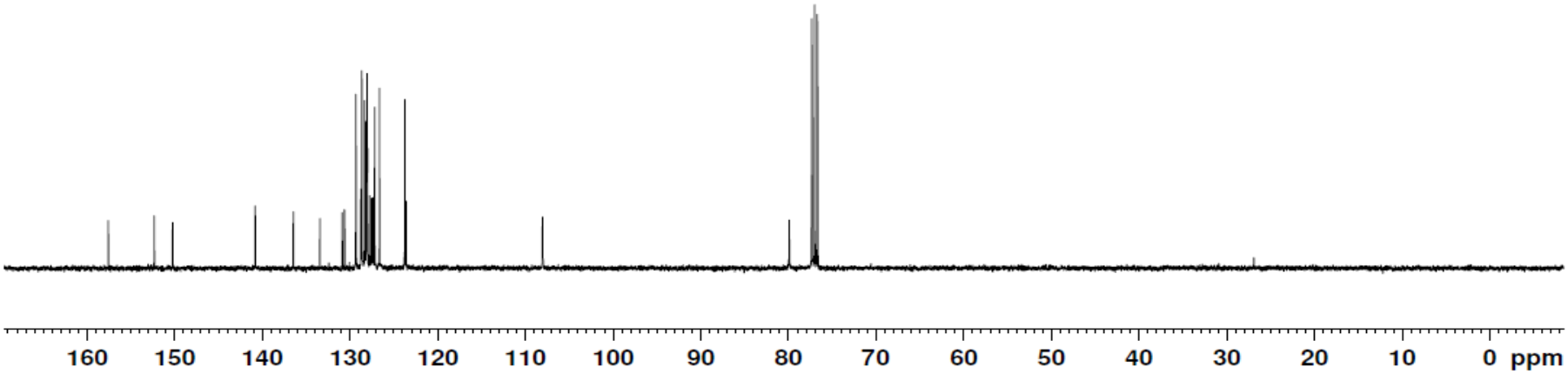

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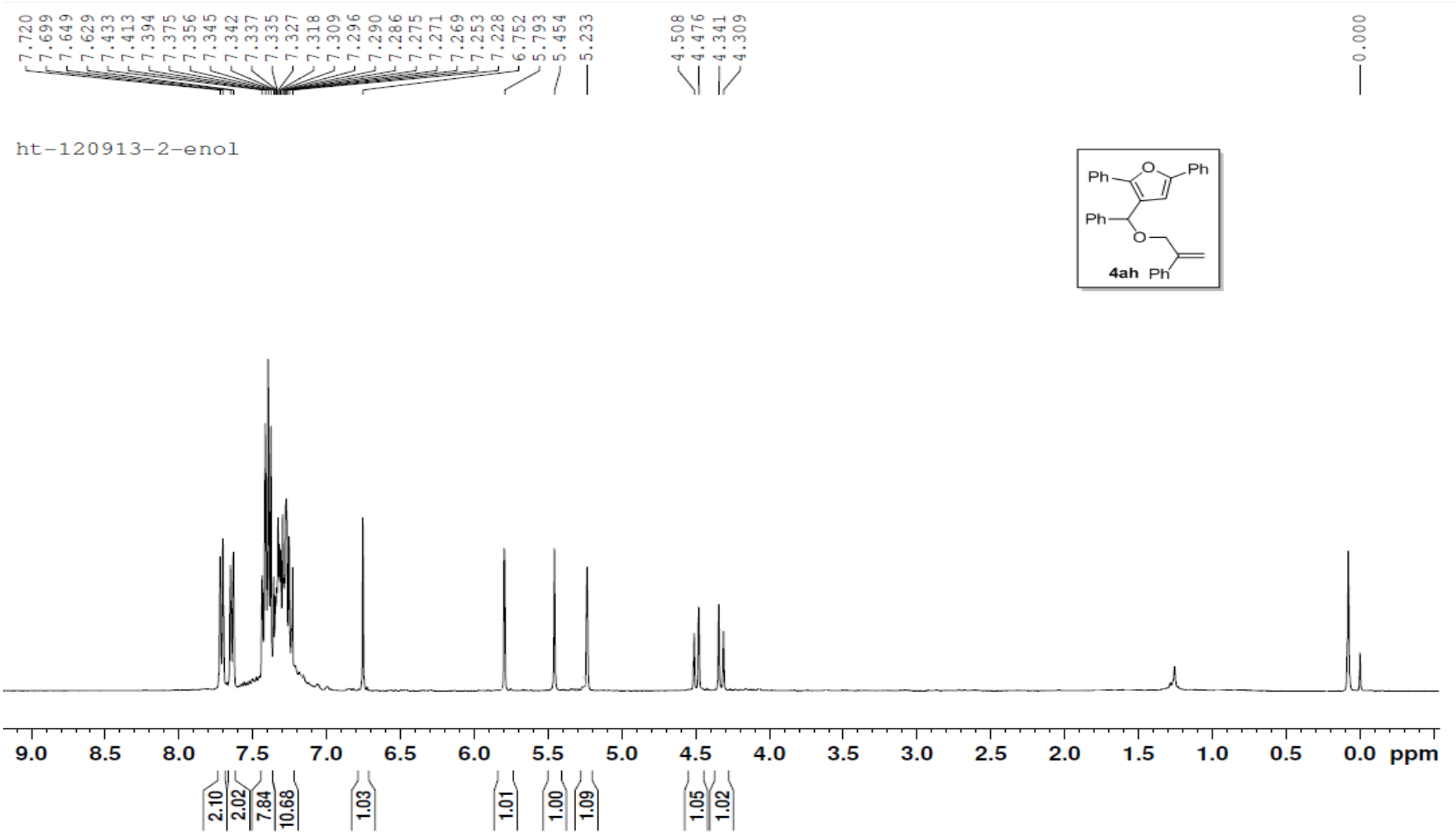

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