Electronic Supplementary Material (ESI) for Photochemical & Photobiological Sciences

Supporting information

for

Photoinduced decarboxylation of 3-(*N*-phthalimido)adamantane-1-carboxylic acid and radical addition to electron deficient alkenes

By

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1. Experimental procedure

General: ^{1}H and ^{13}C NMR spectra were recorded on a spectrometer at 300 or 600 MHz, respectively. All NMR spectra were measured in $CDCl_3$ or d_6-DMSO using tetramethylsilane as a reference. For the assignation of the signals 2D homonuclear COSY and NOESY, and heteronuclear HSQC and HMBC correlation techniques were used. Melting points were uncorrected. Mass spectra and HRMS were obtained using MALDI-TOF technique. The laser wavelength was 337 nm (N_2 laser) and laser frequency amounted to 20 Hz. Calibrant and analyte spectra were obtained in positive ion mode. Internal calibration and elemental analysis were performed with software Data Explorer v. 4.0. The purity of samples were analyzed on a HPLC equipped with a diode array detector on a C18 column using CH_3OH/H_2O (20%) as a solvent. Silica gel was used for chromatographic purifications. Solvents were purified by distillation. The chemicals for synthesis were obtained from usual commercial sources.

3-(*N*-phthalimido)adamantane-1-carboxylic acid (1) A flask was charged with 3-aminoadamantane-1-carboxylic acid (1.40 g, 7.17 mmol), phthalic anhydride (2.12 g, 14.34 mmol) and DMF (3 mL) and refluxed over 2 days. After evaporation of DMF, the crude product was dissolved in CH_2Cl_2 (50 mL), washed with 0.2 M HCl (3 × 20 mL) and dried over anhydrous $MgSO_4$. The pure product **1** was isolated in 53% yield after column chromatography on sillica gel with $EtOAc/CH_3OH/CH_2Cl_2$ (0.5:0.95:8.55) as eluent and recrystallization from benzene/CH_2Cl_2 (5:1).

colorless crystals, mp 186-188 °C; ^{1}H NMR (DMSO-d_6, 600 MHz) δ/ppm 12.20 (br s, 1H, COOH), 7.81-7.79 (m, 2H), 7.78-7.76 (m, 2H), 2.41 (m, 4H), 2.21 (br s, 2H), 1.80 (d, 2H, J = 12.1 Hz), 1.77 (d, 2H, J = 12.1 Hz), 1.78 (d, 1H, J = 12.3 Hz), 1.67 (d, 1H, J = 12.3 Hz), one signal is covered by the signal of DMSO; ^{13}C NMR (DMSO-d_6, 75 MHz) δ/ppm 177.4 (s, COO), 169.1 (s, C=O), 134.4 (d, 2C), 131.2 (s, 2C), 122.5 (d, 2C), 59.4 (s), 41.8 (s), 40.7 (t), 38.8 (t, 2C), 37.4 (t, 2C), 34.7 (t), 28. 8 (d, 2C); IR (KBr) ν_{max}/cm^{-1} 3448.5, 2915.2, 2859.3, 1770.0, 1707.3, 1366.3, 1346, 1315.5, 1076.9; HRMS calcd for $C_{19}H_{19}NO_4+H^+$ 326.1387; obsd 326.1371.

Photochemistry of 3-(*N*-phthalimido)adamantane-1-carboxylic acid (1) in the presence of alkenes and arenes, general procedure: A solution of 3-(*N*-phthalimido)adamantane carboxylic acid (**1**) (100 mg, 0.307 mmol), K_2CO_3 (21 mg, 0.1535 mmol) and alkene or arene **4** (3.070 mmol) in 200 mL acetone-H_2O (3:1) was irradiated in a Rayonet reactor (8 lamps) over 2 h at 300 nm and continuously purged with argon and cooled with an internal cold finger condenser (tap water). After irradiation, most of the acetone was removed on a rotary evaporator and the residue extracted with CH_2Cl_2 (3×50 mL). After the extraction, aqueous phase was acidified to pH 3 by addition of HCl (0.1 M), and extraction with EtOAc was carried out (3×50 mL). Organic extracts were dried over anhydrous $MgSO_4$. After filtration and evaporation of the solvent photochemical products were obtained from the CH_2Cl_2 solution, whereas unreacted **1** was recovered from EtOAc. The ratio of the photoproducts **2** and **3** was determined by NMR.

Alternatively, after irradiation, the solvent (acetone and H_2O) was removed on a rotrary evaporator and the residue chromatographed on a column filled with silica gel using 0-10 % MeOH/CH_2Cl_2 as eluent. Pure photochemical products **3a-3d** were obtained by preparative TLC using CH_2Cl_2/Et_2O (9:1), or CH_2Cl_2-EtOAC-CH_3OH (8.5:1:0.5).

3-(*N*-phthalimido)-1-(2-cyanoethyl)adamantane (3a)

92 mg (89%); yellowish oil; ^{1}H NMR ($CDCl_3$, 600 MHz) δ/ppm 7.76-7.73 (m, 2H, H-b), 7.69-7.66 (m, 2H, H-a), 2.47 (d, 2H, J = 11.7 Hz, H-8 and H-9), 2.44 (d, 2H, J = 11.7 Hz, H-8 and H-9) 2.35-2.31 (m, 2H, H-B), 2.27-2.25 (m, 2H, H-5 and H-7), 2.24 (s, 2H, H-2), 1.79-1.74 (m, 1H, H-6), 1.63-1.58 (m, 3H, H-6, 2H-A), 1.56 (dd, 2H, J = 1.2 Hz, J = 12.2 Hz, H-4 and H-10), 1.49 (dd, 2H, J = 1.2 Hz, J = 12.2 Hz, H-4 and H-10); ^{13}C NMR ($CDCl_3$, 75 MHz) δ/ppm 169.5 (s, 2C, C=O), 133.6 (d, C-b), 131.7 (s, 2C, C-x), 122.4 (d, 2C, C-a), 120.3 (s, CN), 60.3 (s, C-1), 43.8 (t, C-2), 40.1 (t, 2C, C-4 and C-10), 39.2 (t, 2C, C-8 and C-9), 38.6 (t, C-A), 35.2 (t, C-6), 34.3 (s, C-3), 29.4 (d, 2C, C-5 and C-7), 11.0 (t, C-B); IR (KBr) ν_{max}/cm^{-1} 3457.6, 2911.5, 2852.9, 2245.4, 1769.1, 1706, 1368.8, 1314.4, 1078.6, 718.8; HRMS, calcd for $C_{21}H_{22}N_2O_2$+H^+ 335.1749; obsd 335.1749.

3-(*N*-phthalimido)-1-(3-methoxy-3-oxopropyl)adamantane (3b)

40 mg (33%); light yellow oil; ^{1}H NMR ($CDCl_3$, 600 MHz) δ/ppm 7.75-7.74 (m, 2H), 7.67-7.66 (m, 2H), 3.67 (s, 3H, OCH_3), 2.46-2.44 (m, 4H), 2.33-2.30 (m, 2H), 2.23 (br s, 4H), 1.73 (d, 1H, J = 12.4 Hz), 1.59 (d, 1H, J = 12.4 Hz), 1.56-1.53 (m, 4H), 1.45 (d, 2H, J = 12.2 Hz); ^{13}C NMR ($CDCl_3$, 150 MHz) δ/ppm 174.6 (s, COO), 169.6 (s, 2C, C=O), 133.5 (d, 2C), 131.8 (s, 2C), 122.4 (d, 2C), 60.7 (s), 51.4 (q, OCH_3), 44.2 (t), 40.4 (t, 2C), 39.5 (t, 2C), 38.1 (t), 35.4 (t), 34.2 (s), 29.6 (d, 2C), 27.8 (t); IR (KBr) ν_{max}/cm^{-1} 3452.2, 2913.3, 1718.3, 1447.5, 1356.3, 1312.1, 1172.3, 1076.1, 718.7; HRMS, calcd for $C_{22}H_{25}NO_4$+Na^+ 390.1676; obsd 390.1676.

3-(*N*-phthalimido)-1-(3-oxocyclohexyl)adamantane (3c)

36 mg (29%); colorless oil, ^{1}H NMR ($CDCl_3$, 300 MHz) δ/ppm 7.77-7.72 (m, 2H), 7.70-7.65 (m, 2H), 2.52-2.44 (m, 5H), 2.43-2.36 (m, 1H), 2.36-2.32 (m, 1H), 2.31-2.17 (m, 4H), 2.16-2.05 (m, 2H), 2.00 (d, 1H, J = 12.7 Hz), 1.76 (d, 1H, J = 12.5 Hz), 1.64-1.56 (m, 3H), 1.53-1.30 (m, 5H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ/ppm 212.6 (s, C=O), 169.6 (s, 2C, C=O), 133.6 (d, 2C), 131.7 (s, 2C), 122.4 (d, 2C), 61.0 (s), 49.0, (d), 42.0 (t), 41.8 (t), 41.3 (t), 39.7 (t), 39.6 (t), 38.3 (t), 37.6 (t), 36.9 (s), 35.6 (t), 29.6 (d), 29.6 (d), 25.4 (t), 24.6 (t); IR (KBr) ν_{max}/cm^{-1} 2909.8, 2854.7, 1769.3, 1702.1, 1466.9, 1450.9, 1702.1, 1364.6, 1313.7, 1076.4; HRMS, calcd for $C_{24}H_{27}NO_3$+Na^+ 400.1883; obsd 400.1866.

3-(*N*-phthalimido)-1-bromadamantane (3d)

10 mg (9 %); colorless oil; ^{1}H NMR ($CDCl_3$, 300 MHz) δ/ppm 7.80-7.73 (m, 2H), 7.71-7.64 (m, 2H), 2.51 (br s, 2H), 2.48-2.33 (m, 6H), 1.83-1.65 (m, 5H), 1.56 (ddd, 1H, J = 8.0 Hz, J = 10.7 Hz, J = 12.6 Hz); ^{13}C NMR ($CDCl_3$, 150 MHz) δ/ppm 169.4 (s, 2C, C=O), 133.7 (d, 2C), 131.7 (s, 2C), 122.6 (d, 2C), 69.2 (s), 68.2 (s), 47.8 (t), 43.8 (t, 2C), 38.8 (t, 2C), 34.6 (t), 30.7 (d, 2C); IR (KBr) ν_{max}/cm^{-1} 3447.4, 2915.1, 2855.6, 1769, 1704.3, 1354.8, 1308.7, 1121.3, 1100.2, 1077.5, 719.27; HRMS, calcd for $C_{18}H_{18}BrNO_2$+H^+ 360.0594; obsd 360.0594.

3-(*N*-phthalimido)-1-(2-cyano-2-deuterioethyl)adamantane (3a-D)

A solution of 3-(*N*-phthalimido)adamantane carboxylic acid (**1**) (10 mg, 0.031 mmol), K_2CO_3 (2.1 mg, 0.015 mmol) and acrylonitrile **4a** (20 μL, 0.31 mmol) in 20 mL acetone-D_2O (3:1) was irradiated in a Rayonet reactor (8 lamps) for 45 h at 300 nm and continuously purged with argon and cooled with an internal cold finger condenser (tap water). After irradiation, solvent was removed on a rotary evaporator and from the residue organic compound dissolved in $CDCl_3$ to record its NMR spectra.

yellowish oil, ^{1}H NMR ($CDCl_3$, 600 MHz) δ/ppm 7.76-7.73 (m, 2H), 7.69-7.66 (m, 2H), 2.47 (d, 2H, J=11.7 Hz), 2.44 (d, 2H, J=11.7 Hz) 2.33-2.29 (m, 1H), 2.27-2.25 (m, 2H), 2.24 (s, 2H), 1.80-1.76 (m, 1H), 1.61-1.59 (m, 3H), 1.56 (dd, 2H, J=1.2, J=12.2 Hz), 1.49 (dd, 2H, J=1.2 Hz, J=12.2 Hz); ^{13}C NMR ($CDCl_3$, 150 MHz) δ/ppm 169.6 (s, 2C), 133.6 (d, 2C), 131.8 (s, 2C), 122.3 (d, 2C), 120.3 (s, CN), 60.4 (s), 43.9 (t), 40.2 (t, 2C), 39.4 (t, 2C), 38.6 (t), 35.3 (t), 34.4 (s), 29.5 (d, 2C), 10.8 (dt, J_{HD}=20.1 Hz); MS (ESI, m/z), 337 (25, M+H$^+$), 336 (100, M+H$^+$).

Quantum yield of decarboxylation of 3-(*N*-phthalimido)adamantane-1-carboxylic acid (1)

Two quartz NMR tubes were charged with 1 mL of the solution (in CH_3CN−H_2O (3:1) or acetone−H_2O (3:1)), of 3-(*N*-phthalimido)adamantane-1-carboxylic acid (**1**) (3 mg, 0,009 mmol) and K_2CO_3 (0.62 mg, 0.0045 mmol), or 4-(*N*-phthalimidomethyl)cyclohexane-1-carboxylic acid (3 mg, 0,0105 mmol) and K_2CO_3 (0.73 mg, 0,0053 mmol). The solutions were purged with argon for 15 min and irradiated in a Rayonet reactor at the same time with 3 lamps at 300 nm for 0, 4 and 6 minutes. After each exposure to light, ^{1}H NMR spectra were taken. The conversion to the photodecarboxlyation product was determined from the spectra, and the quantum yield for the decarboxlation of **1** was calculated from the known quantum yield for the decarboxylation of 4-(*N*-phthalimidomethyl)cyclohexane-1-carboxylic acid (Φ_R = 0.30).

Irradiation of adamanane-1-carboxylic acid in the presence of *N*-methylphthalimide and acrylonitrile

In a quartz cuvette was dissolved adamantane-1-carboxylic acid (37 mg, 0.205 mmol), *N*-methylphthalimide (3.3 mg, 0.02 mmol), K_2CO_3 (14 mg, 0.102 mmol) and acrylonitrile (**4a**, 137 μL, 2.052 mmol) in acetone-H_2O (98:2, 20 mL). The solution was purged with argon for 15 minutes and irradiated in Rayonet reactor at 300 nm (8 lamps) for 19 hours. After irradiation, acetone was removed on a rotary evaporator and residue extracted with CH_2Cl_2 (3×15 mL). Organic layer was dried over anhydrous $MgSO_4$ and solvent was then removed on rotary evaporator. Product ratio was determined from ^{1}H-NMR and GC. Analysis indicated formatrion of adamantane in the yield of ~90%.

4-(*N*-phthalimido)phenyl acetic acid (5)

In a round bottom flask (50 mL) equipped with a stopper, phthalic anhydride (1.2 g, 8.1 mmol) was melted. To the melt a solution of 4-aminophenyl acetic acid (847 mg, 5.6 mmol) in CH_2Cl_2 (5 mL) was added. After the addition was complete, the reaction mixture was stirred at 180 °C for 10 minutes with the stopper and then 15 minutes without the stopper to remove H_2O. To the cooled reaction mixture CH_2Cl_2 (50 mL) was added and the solution washed with 10% acetic acid (3×50 mL) and extracted with 10% aqueous $NaHCO_3$ (3×50 mL). The basic aqueous layer was then acidified with 4M HCl to pH 2 and extracted with CH_2Cl_2 (3×50 mL). The organic layer was dried with anhydrous MgSO4, and after filtration solvent was removed on a rotary evaporator. The pure product **5** (450 mg, 28%) was obtained after crystallization from 50% hexane-CH_2Cl_2.

450 mg (28%), colorless crystals, mp 217-220 °C (lit. 218-220 °C); ^{1}H NMR ($CDCl_3$, 300 MHz) δ/ppm 7.98-7.92 (m, 2H), 7.83-7.77 (m, 2H), 7.48-7.40 (m, 4H), 3.72 (s, 2H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ/ppm 175.6 (s, COOH), 167.1 (s, 2C, CO), 134.3 (d, 2C), 133.1 (s, 2C), 131.6 (s, 1C), 130.8 (s, 1C), 130.0 (d, 2C), 126.6 (d, 2C), 123.7 (d, 2C), 40.8 (t, 1C).

Irradiation of 4-(*N*-phthalimido)phenyl acetic acid (5) in the presence of acrylonitrile

4-(*N*-phthalimido)phenyl acetic acid (**5**) (56 mg, 0.2 mmol), K_2CO_3 (13.8 mg, 0.1 mmol) and acrylonitrile **4a** (131 μL, 2 mmol) were disolved in acetone-H_2O (3:1, 20 mL) in a quartz cuvette. Solution was purged with argon for 15 min and then irradiated in a Rayonet reactor (8 lamps) for 4 h at 300. After irradiation, solvent was removed on a rotary evaporator and photoproducts **6** and **7** were isolated on a preparative TLC with 10% MeOH/CH_2Cl_2 and 60%Hexane/ 15% ethyl acetate/ 15% CH_2Cl_2 as eluens.

***N*-(4-methylphenyl)phthalimide (6)**

43 mg (77%), colorless crystals, mp 204-206 °C (lit. 204-205 °C); ^{1}H NMR ($CDCl_3$, 300 MHz) δ/ppm 7.96-7.90 (m, 2H), 7.80-7.75 (m, 2H), 7.32-7.29 (m, 4H), 2.40 (s, 3H);^{13}C NMR ($CDCl_3$, 75 MHz) δ/ppm 167.3 (s, 2C), 138.0 (s, 2C), 134.2 (d, 2C), 131.7 (s, 1C), 129.6 (d, 2C), 128.8 (s, 1C), 126.3 (d, 2C), 123.5 (d, 2C), 21.0 (q, 1C).

***N*-[4-(3-cyanopropyl)phenyl]phthalimide (7)** 8 mg (13%), colorless crystals, mp 145-147 °C; ^{1}H NMR (DMSO-d_6, 300 MHz) δ/ppm 7.99-7.89 (m, 4H), 7.40-7.34 (m, 4H), 2.75 (t, 2H, J = 7.9 Hz), 2.53 (t, 2H, J=7,1 Hz) 1.91 (dd, 2H, J = 7.1, J = 7.9 Hz); ^{13}C NMR (DMSO-d_6, 75 MHz) δ/ppm 167.1 (s, 2CO), 140.5 (s, 2C), 134.7 (d, 2C), 131.6 (s, 2C), 128.8 (d, 2C), 127.4 (d, 2C), 123.4 (d, 2C), 120.4 (s, CN), 33.6 (t), 26.4 (t), 16.0 (t); IR (KBr) ν_{max}/cm^{-1} 2933, 2856, 2244, 1717, 1516, 1395, 1121, 1099, 1083, 715; HRMS, calcd for $C_{18}H_{14}N_2O_2$+H^+ 291.1128; obsd 291.1135.

***N*-(3-deutero-1-adamantyl)phthalimide (D-2)**

A solution of 3-(*N*-phthalimido)adamantane carboxylic acid (**1**) (10 mg, 0.031 mmol) and K_2CO_3 (2.1 mg, 0.015 mmol) in 3 mL d_6-acetone/H_2O (3:1) was divided in three quartz NMR tubes. Each dolution was purged with argon and irradiated at the same time in a Rayonet reactor (8 lamps) for 7 minutes at 300 nm. After irradiation, samples were combined and solvent was removed on a rotary evaporator. Pure product was isolated on

preparative TLC with 5% MeOH-CH_2Cl_2 as eleunt and characterized by NMR and MS spectra.

5 mg, colorless crystals, ^{1}H NMR ($CDCl_3$, 300 MHz) δ/ppm 7.78-7.71 (m, 2H), 7.69-7.62 (m, 2H), 2.51 (s, 6H), 2.16 (s, 2H) 1.84-1.66 (m, 6H); MS (ESI, *m*/*z*), 283.2 (100, $M+H^+$), 284.2 (21).

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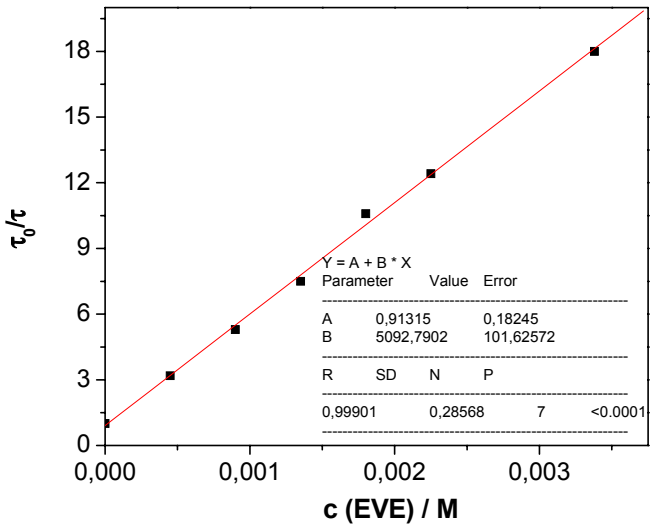
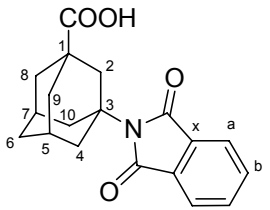
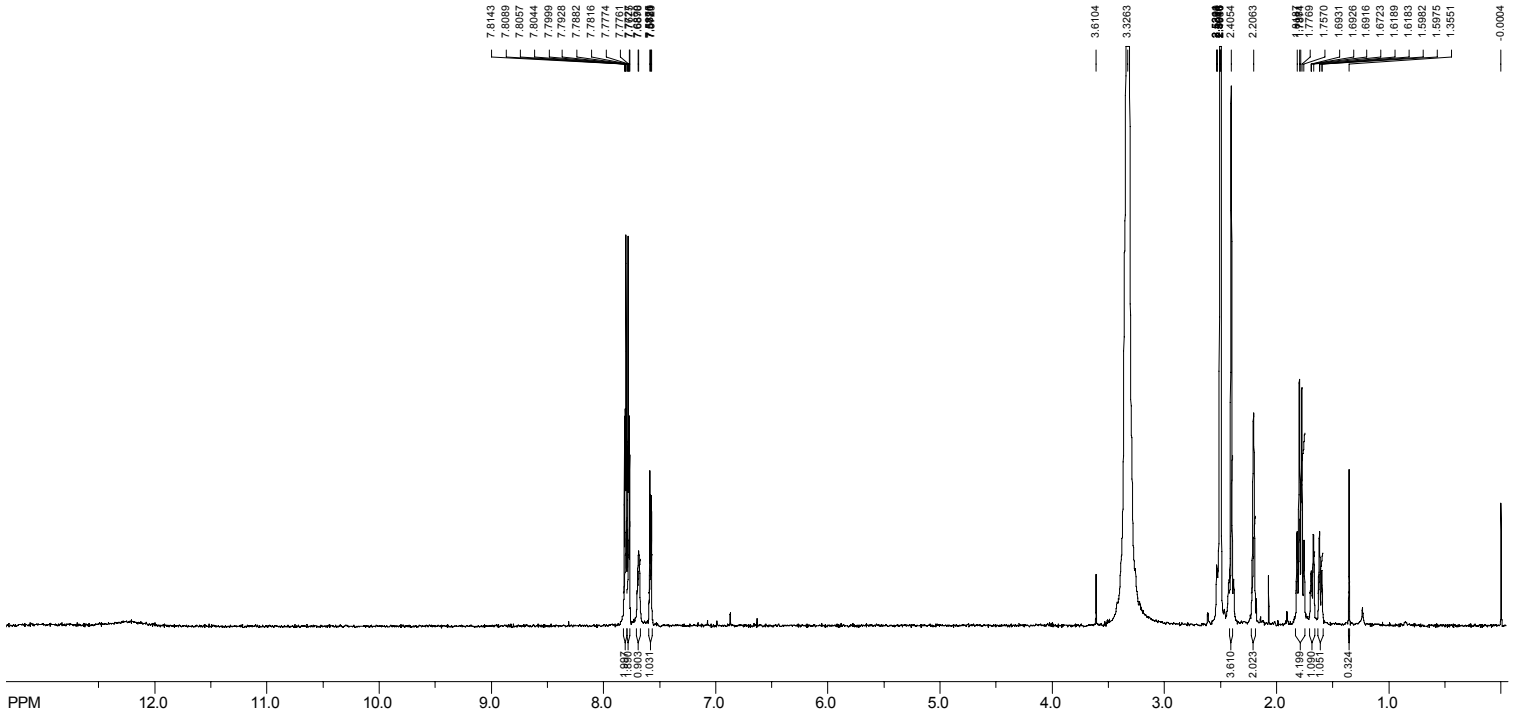
2. Stern-Volmer plot for the quenching of the triplet excited state of 1 with ethyl vinyl ether.



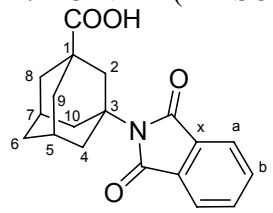
3. ^{1}H NMR (DMSO-d_6, 600 MHz) of **1**

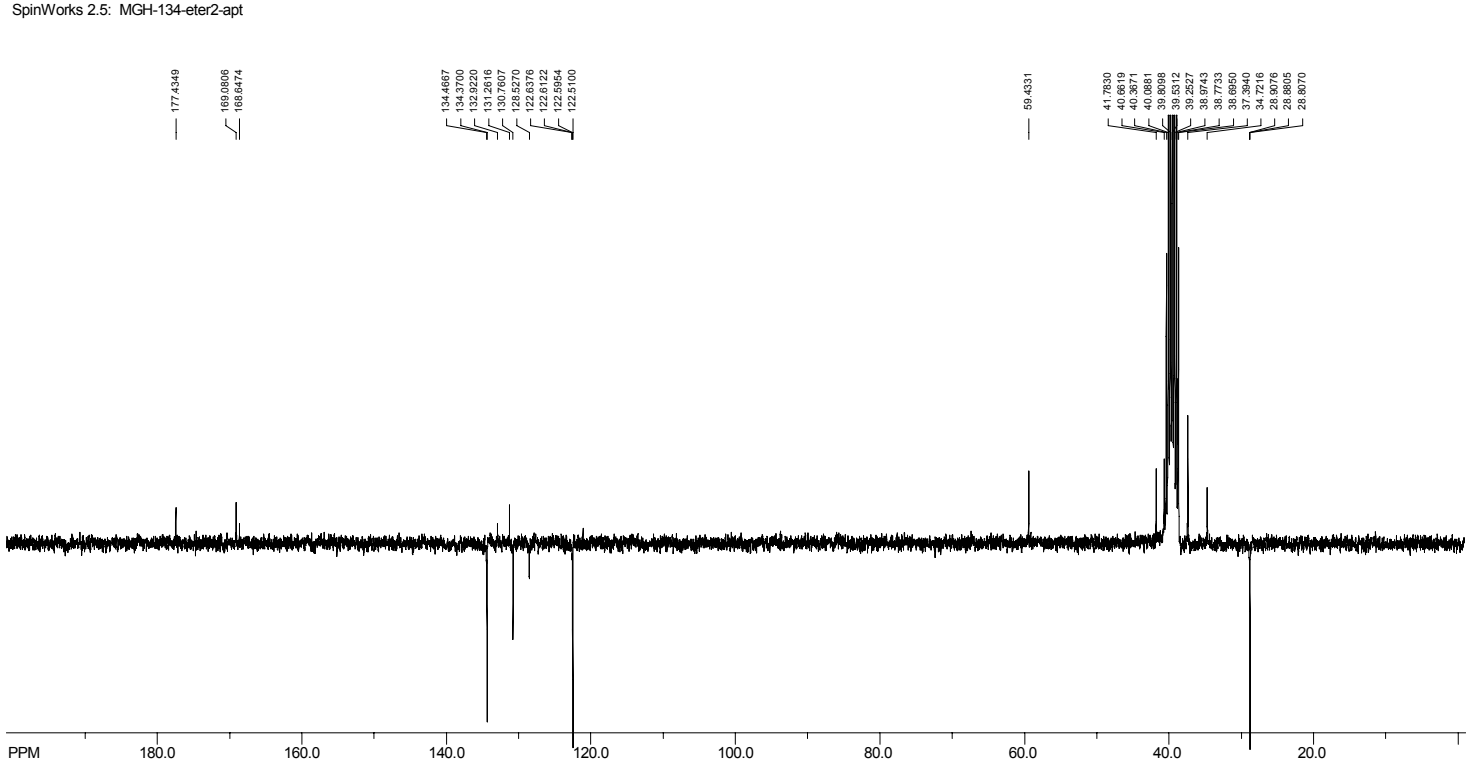


SpinWorks 2.5: MGH-134-ETER2

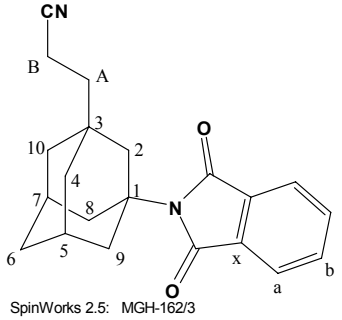


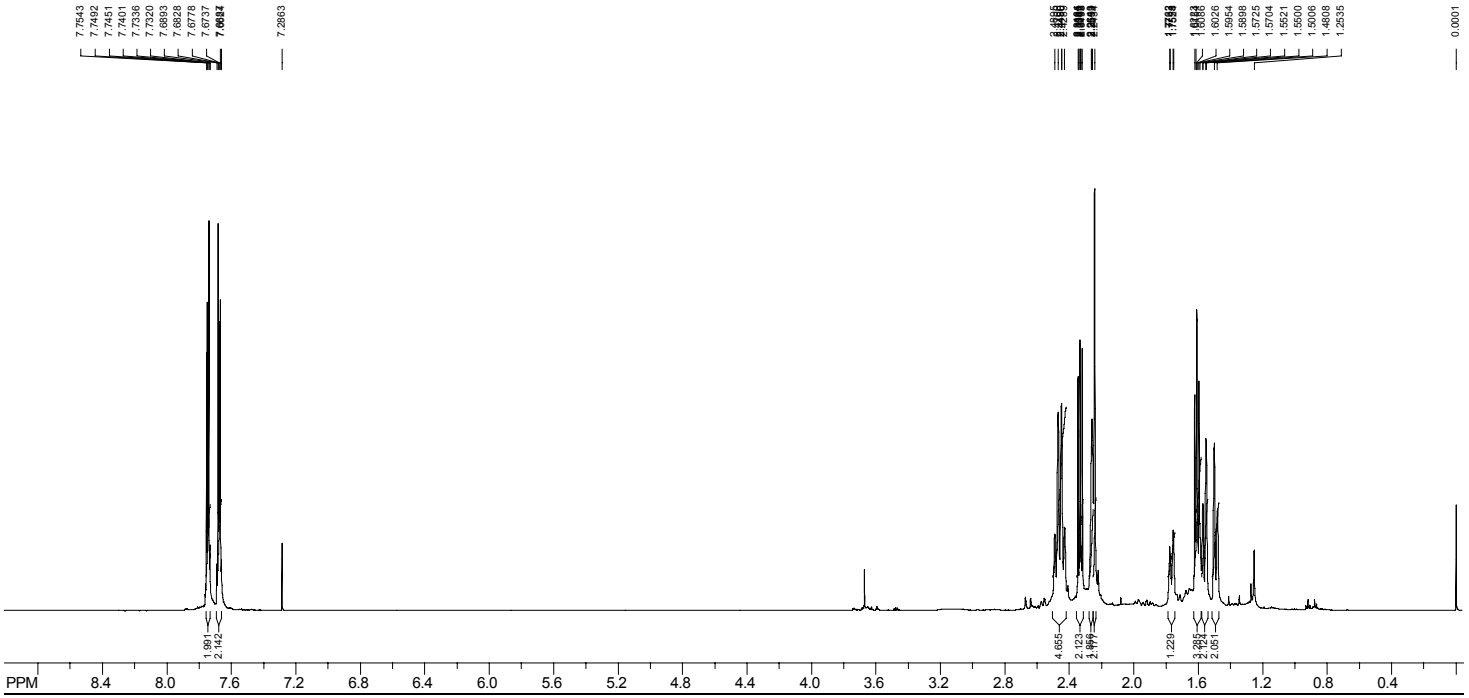
4. ^{13}C NMR (DMSO-d_6, 75 MHz, APT) of **1**



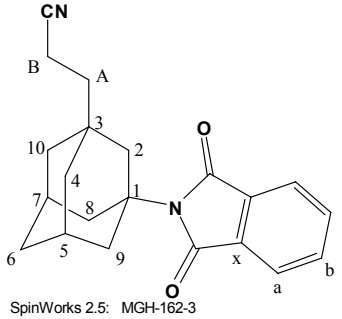


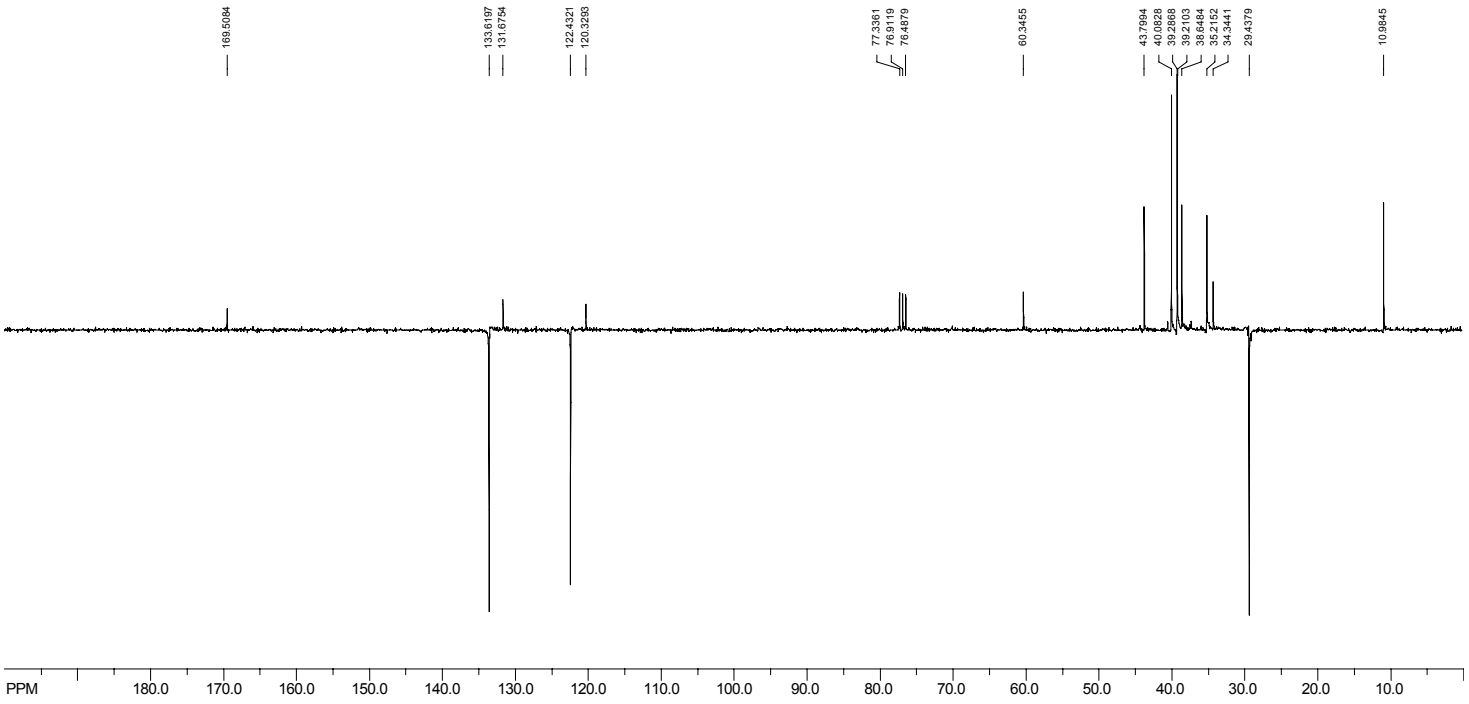
5. ^{1}H NMR ($CDCl_3$, 600 MHz) of **3a**



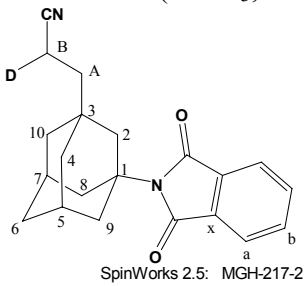


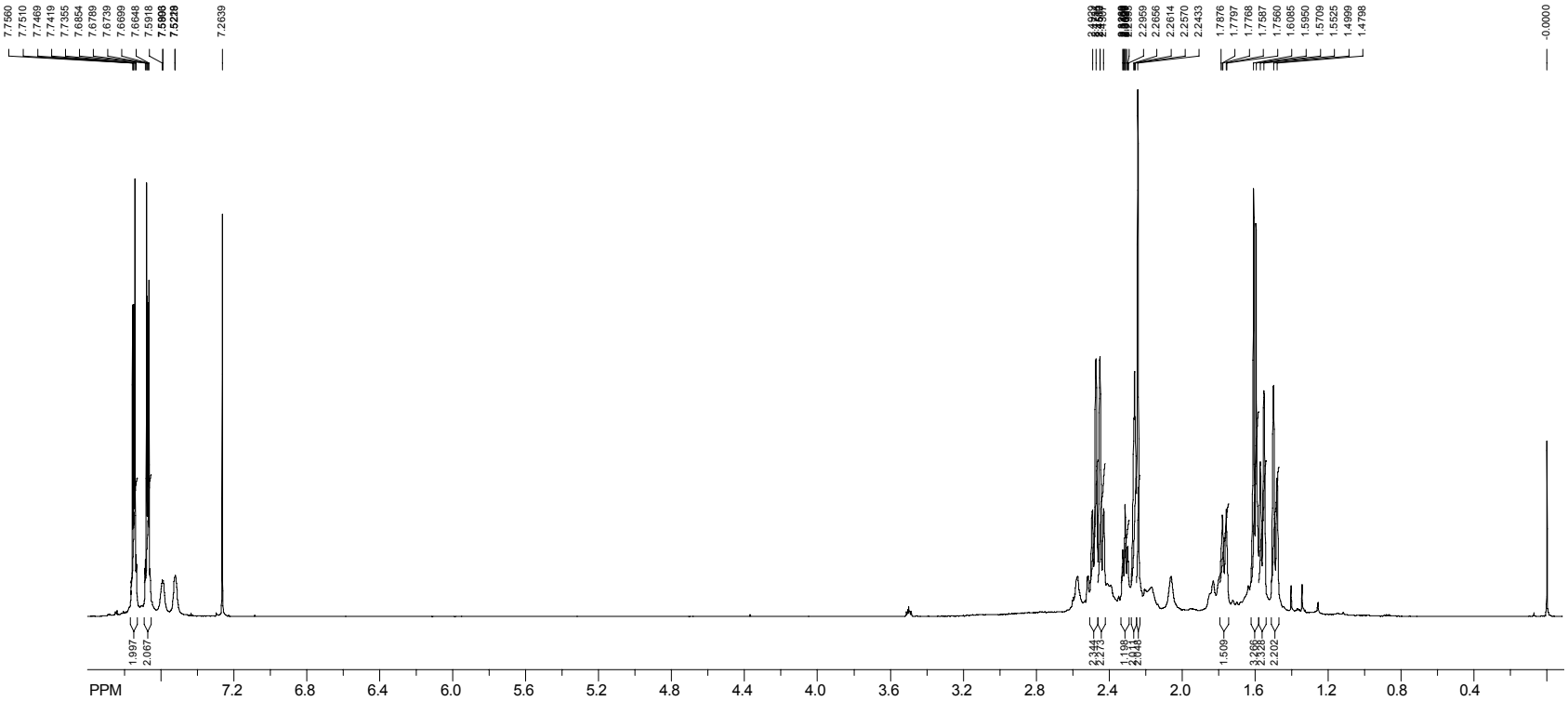
6. ^{13}C NMR ($CDCl_3$, 75 MHz, APT) of **3a**



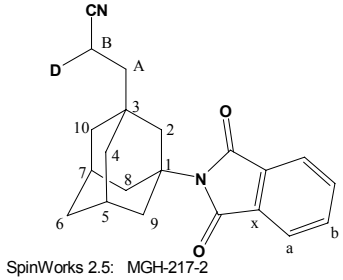


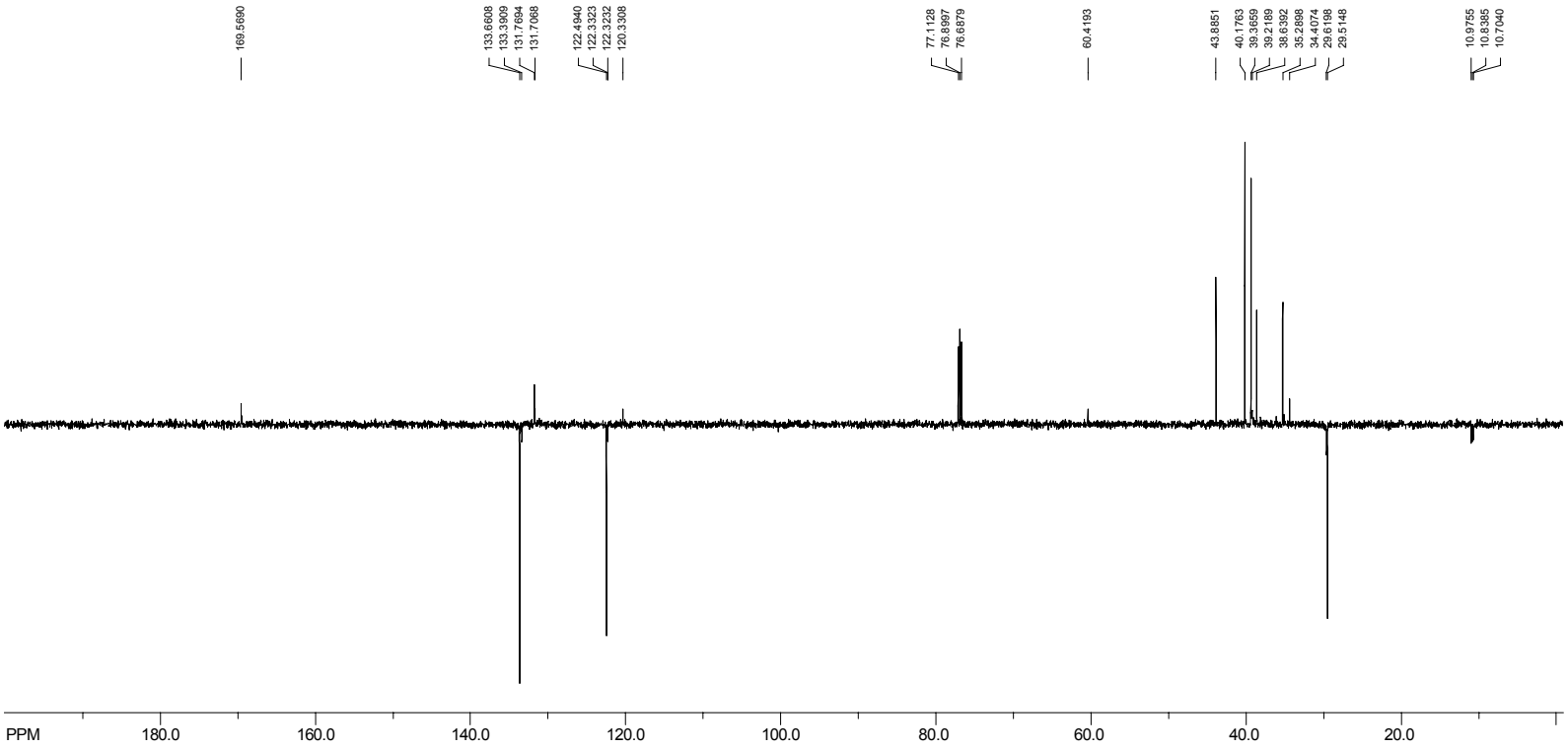
7. ^{1}H NMR ($CDCl_3$, 600 MHz) of **3a-D**



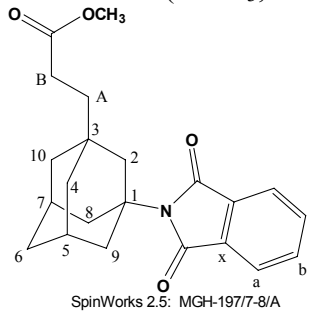


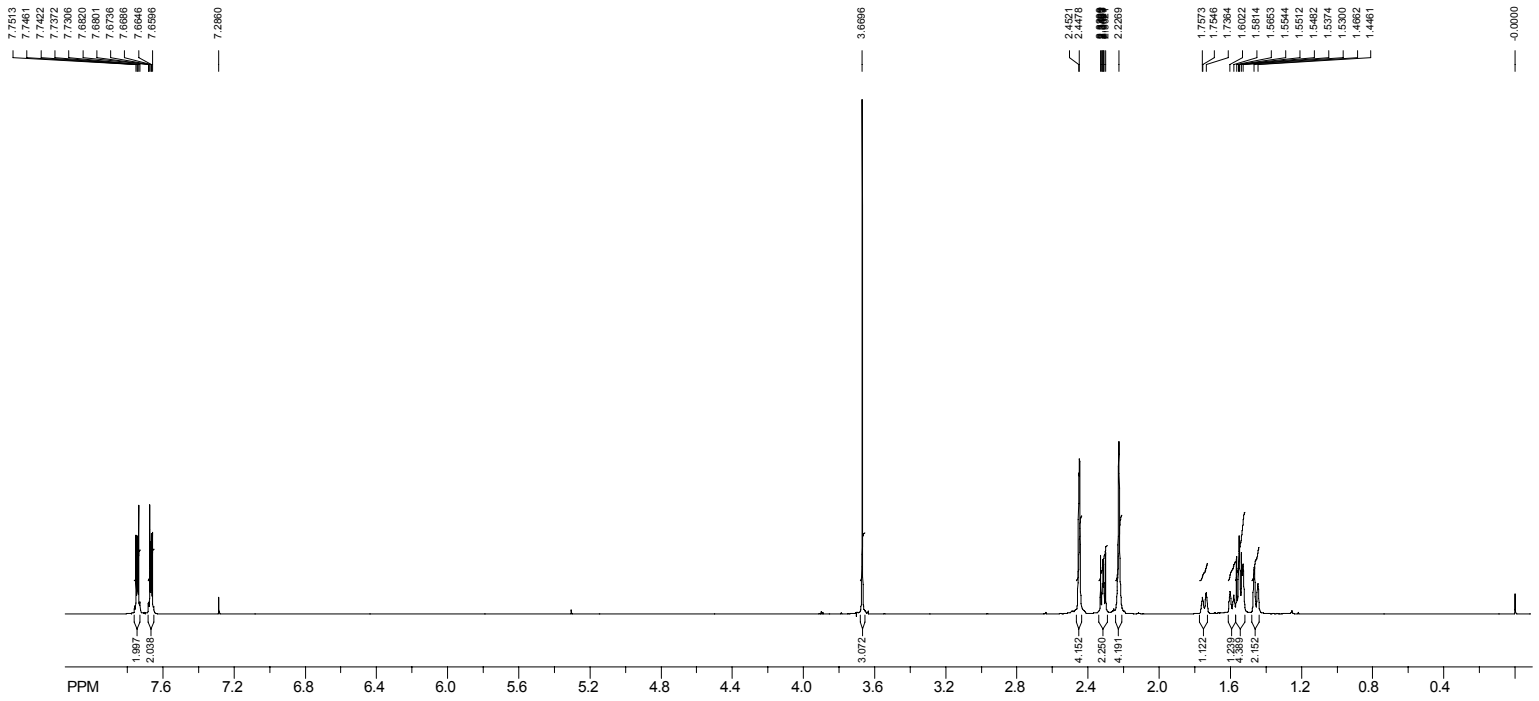
8. ^{13}C NMR ($CDCl_3$, 150 MHz, APT) of **3a-D**



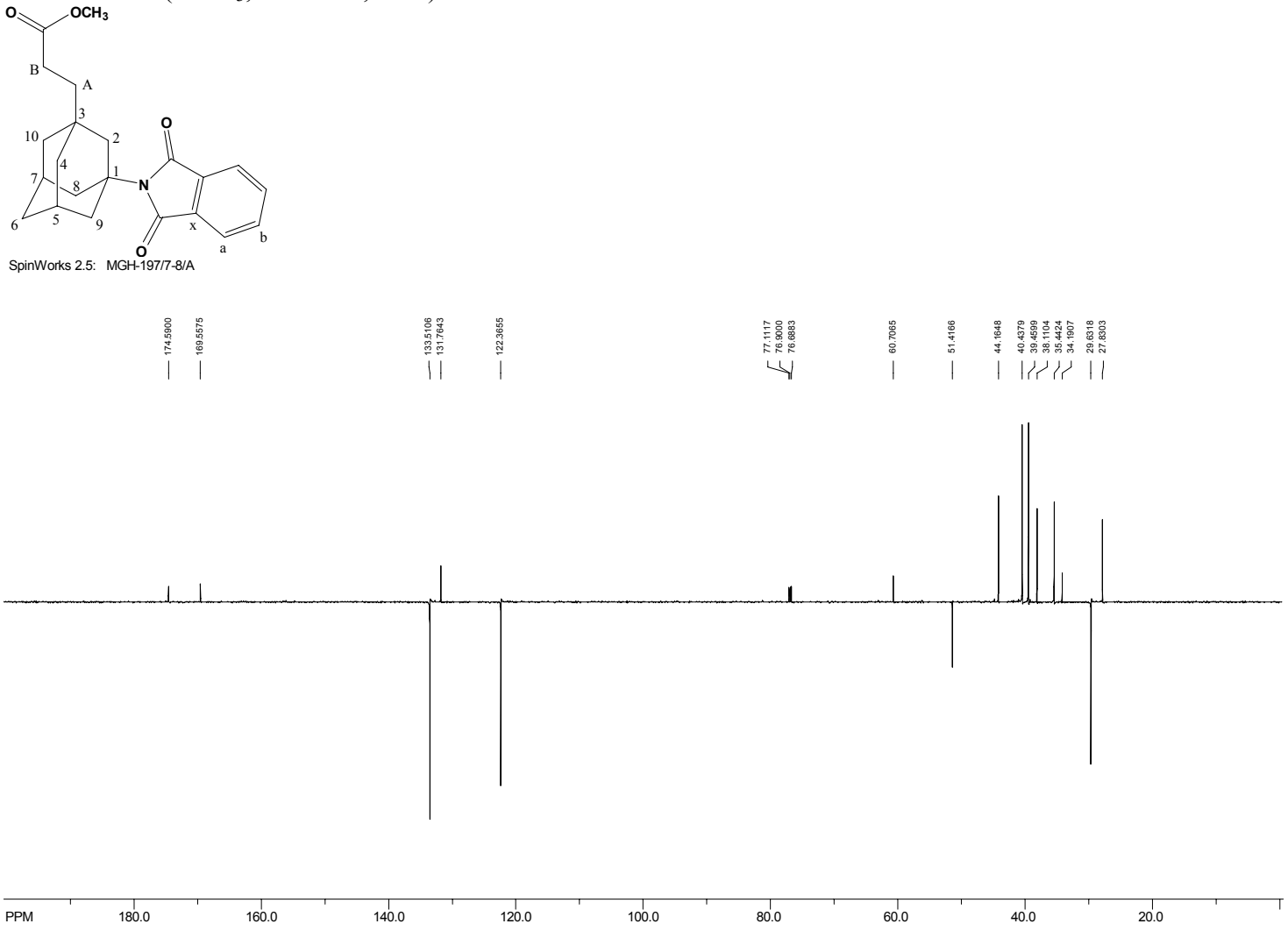


9. ^{1}H NMR ($CDCl_3$, 600 MHz) of **3b**

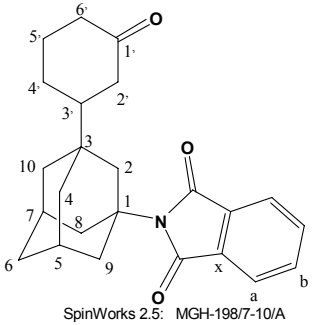


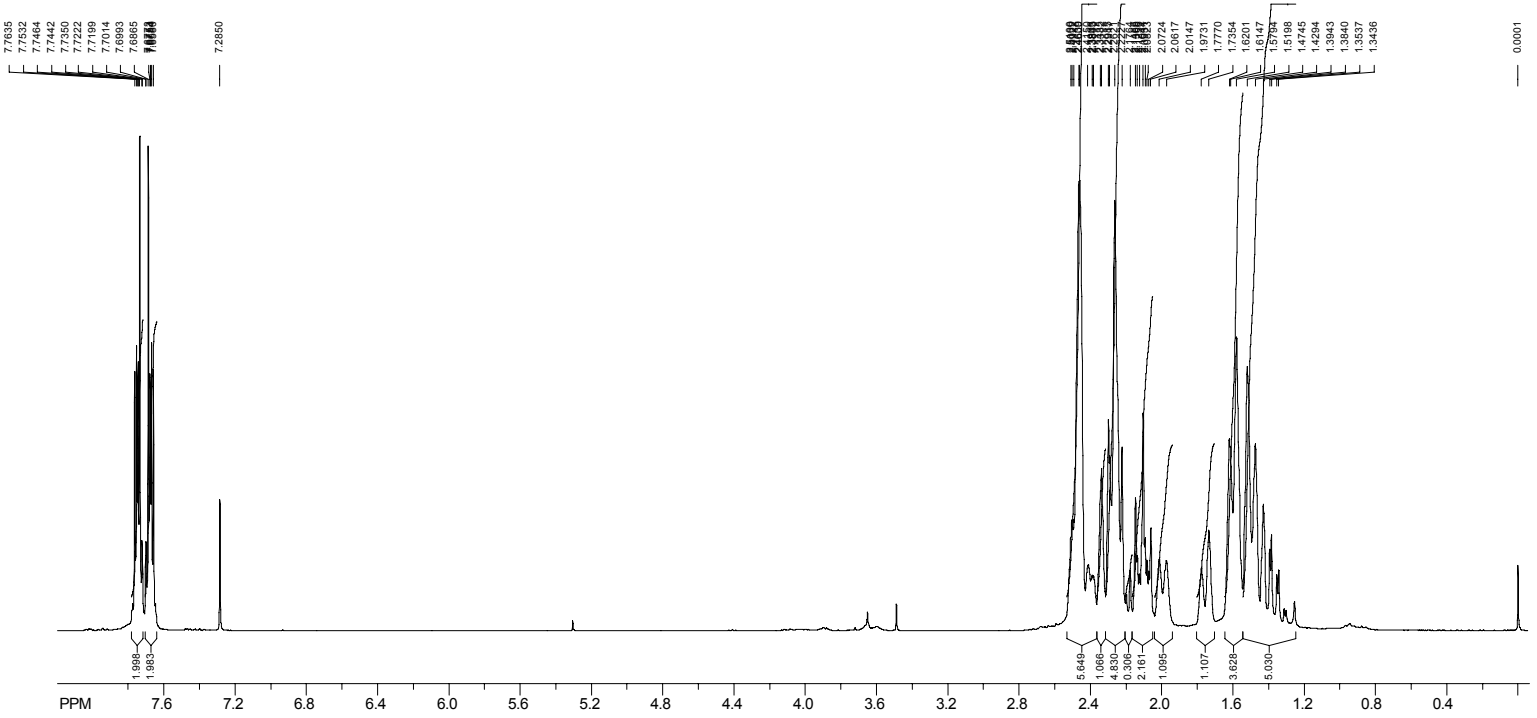


10. ^{13}C NMR ($CDCl_3$, 150 MHz, APT) of **3b**

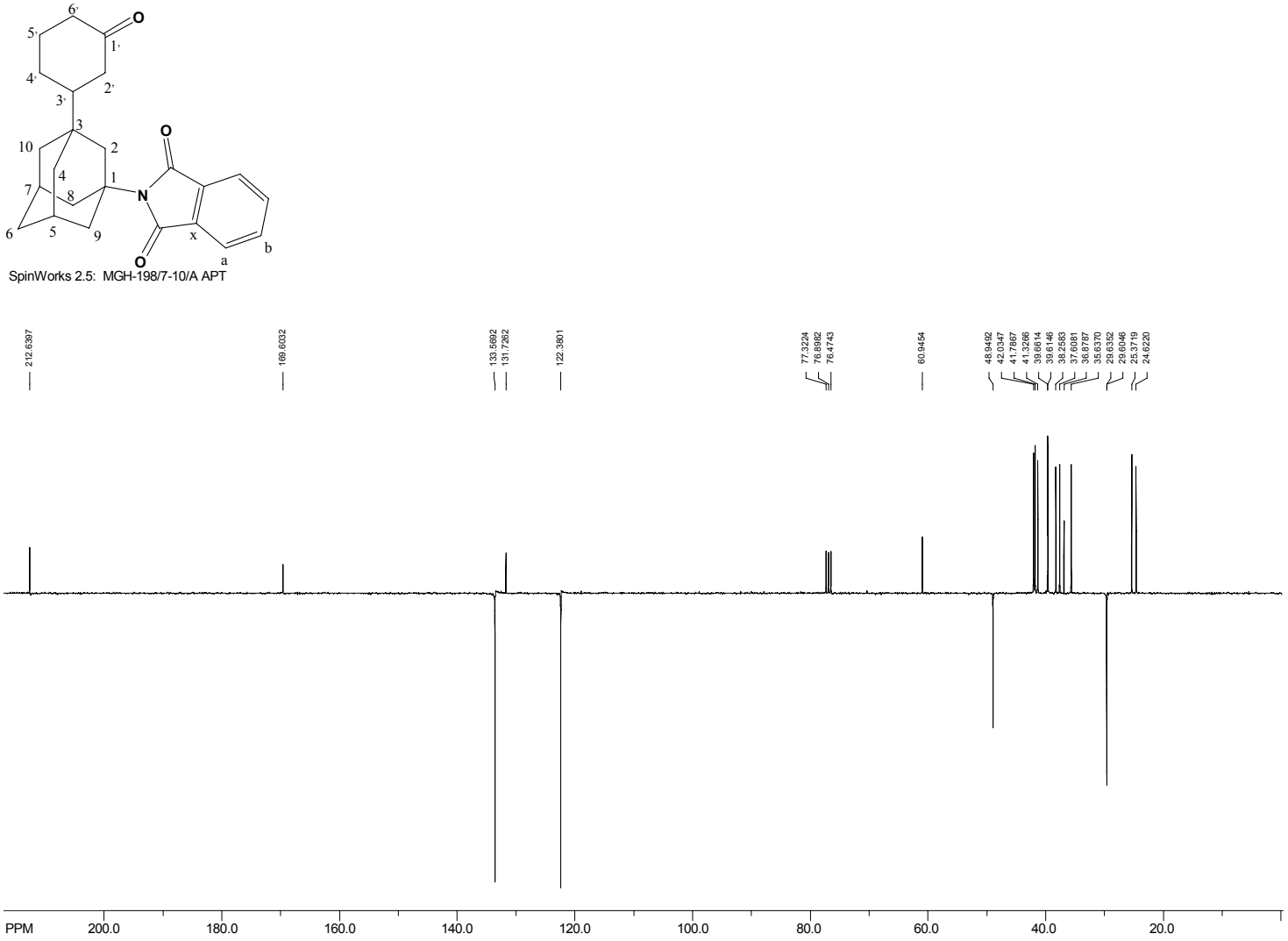


11. ^{1}H NMR ($CDCl_3$, 300 MHz) of **3c**

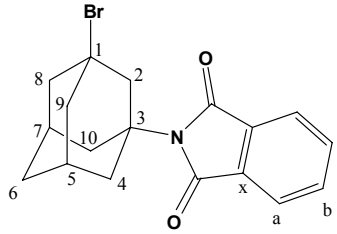


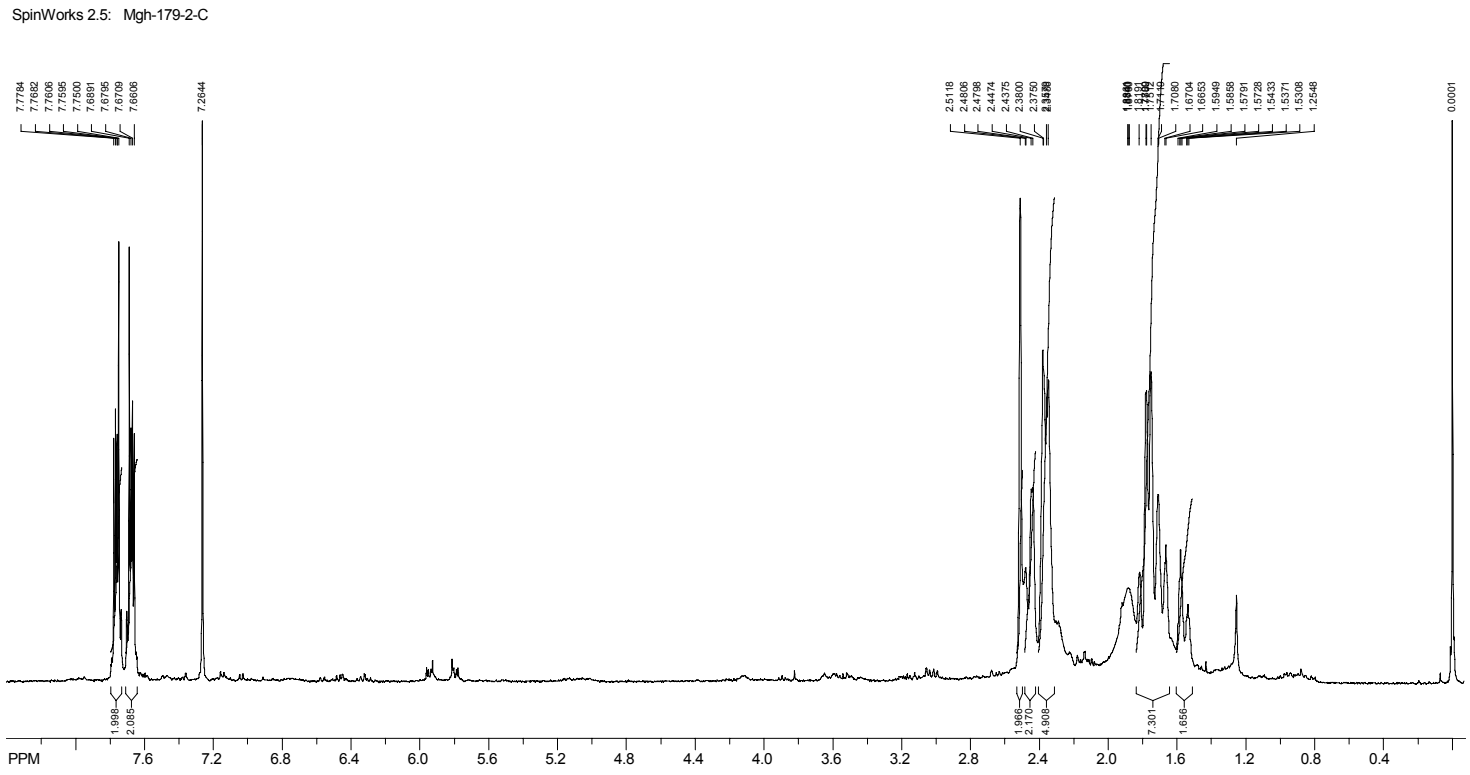


12. ^{13}C NMR ($CDCl_3$, 75 MHz, APT) of **3c**

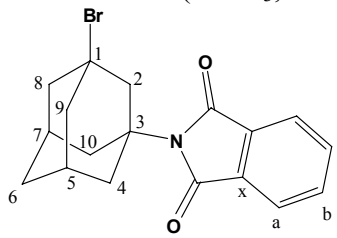


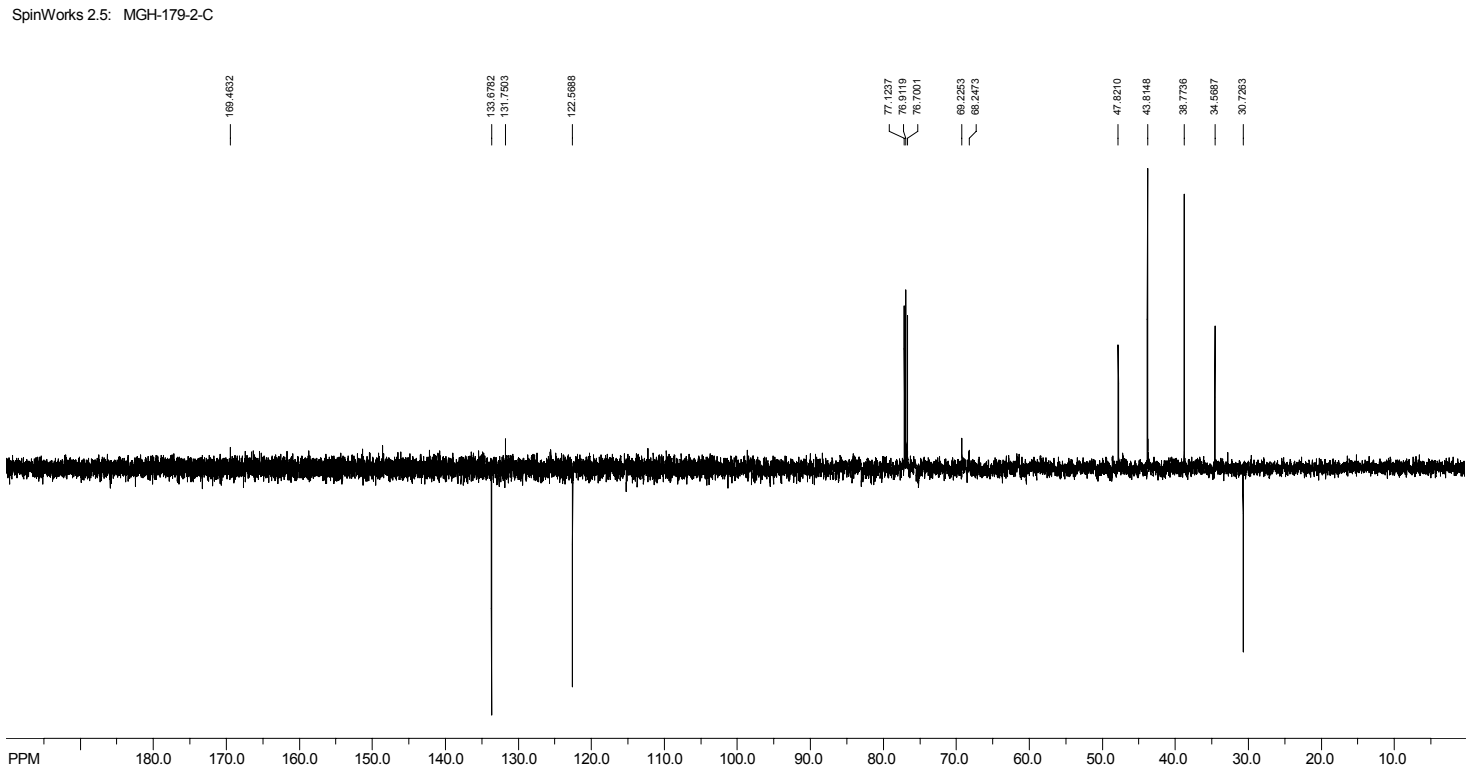
13. ^{1}H NMR ($CDCl_3$, 300 MHz) of **3d**



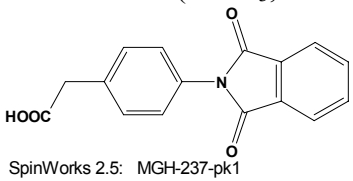


14. ^{13}C NMR ($CDCl_3$, 150 MHz, APT) of **3d**

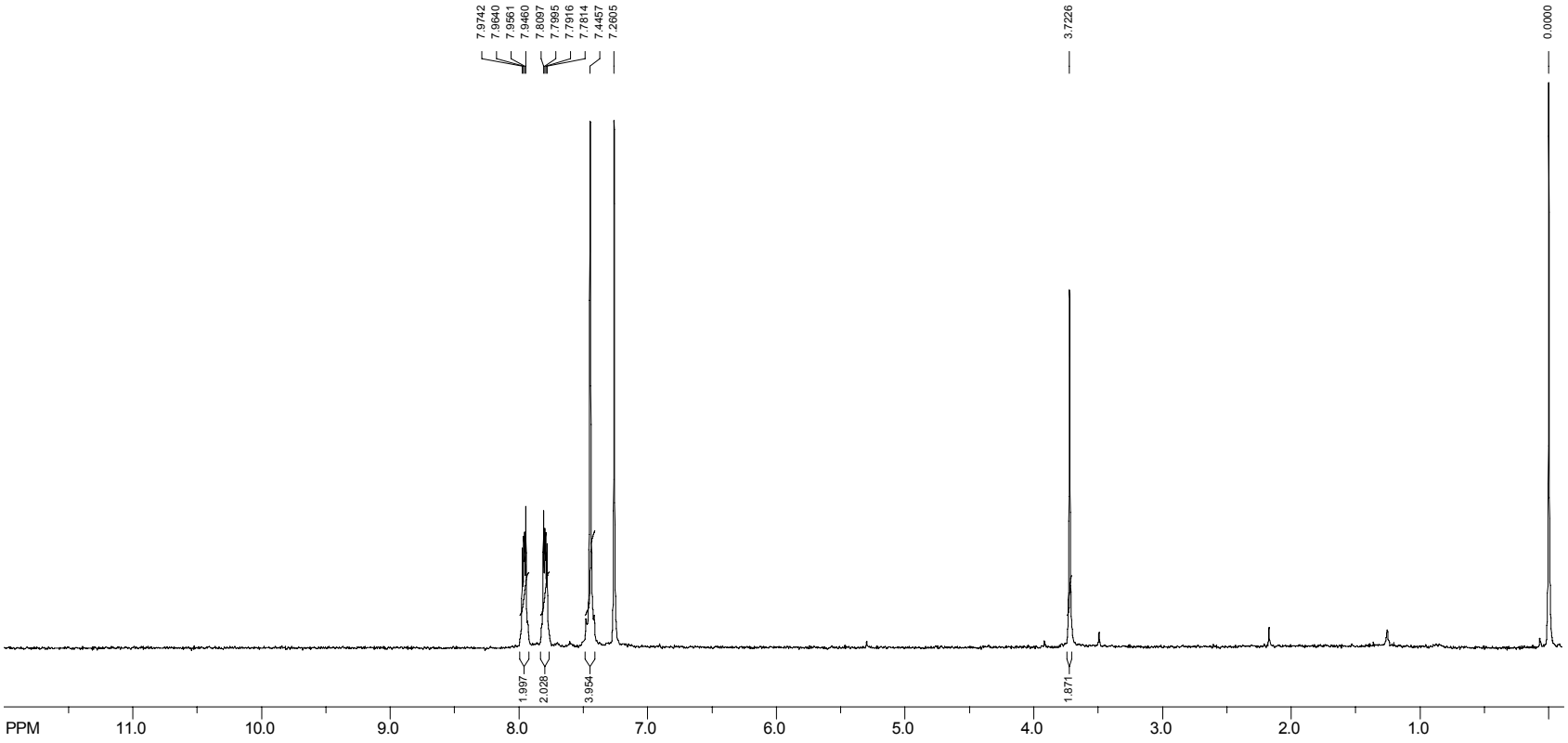




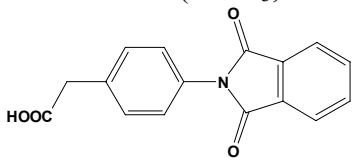
15. ^{1}H NMR ($CDCl_3$, 300 MHz) of **5**



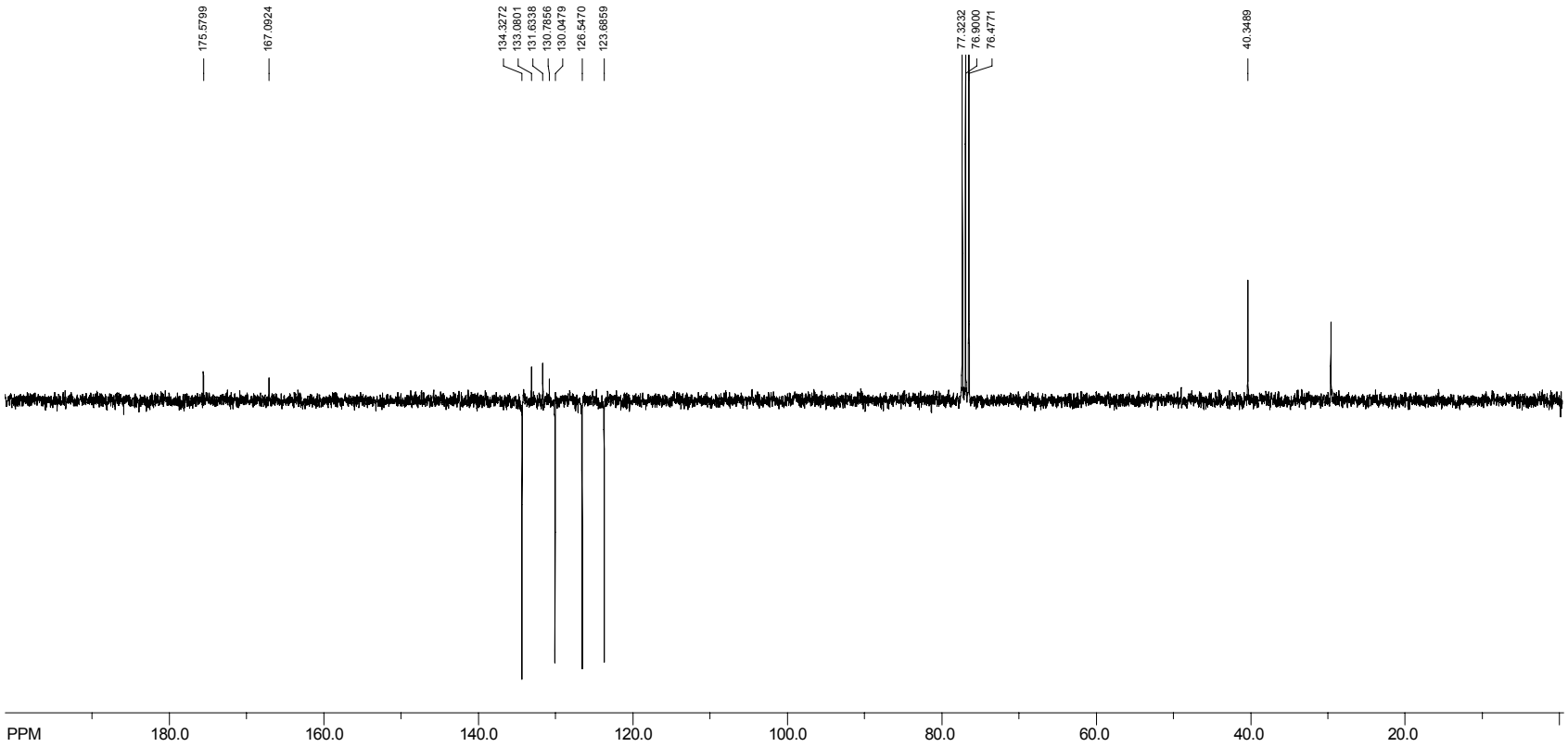
SpinWorks 2.5: MGH-237-pk1



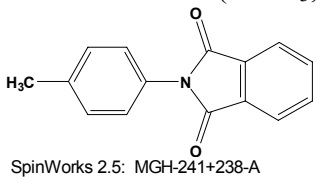
16. ^{13}C NMR ($CDCl_3$, 75 MHz, APT) of **5**



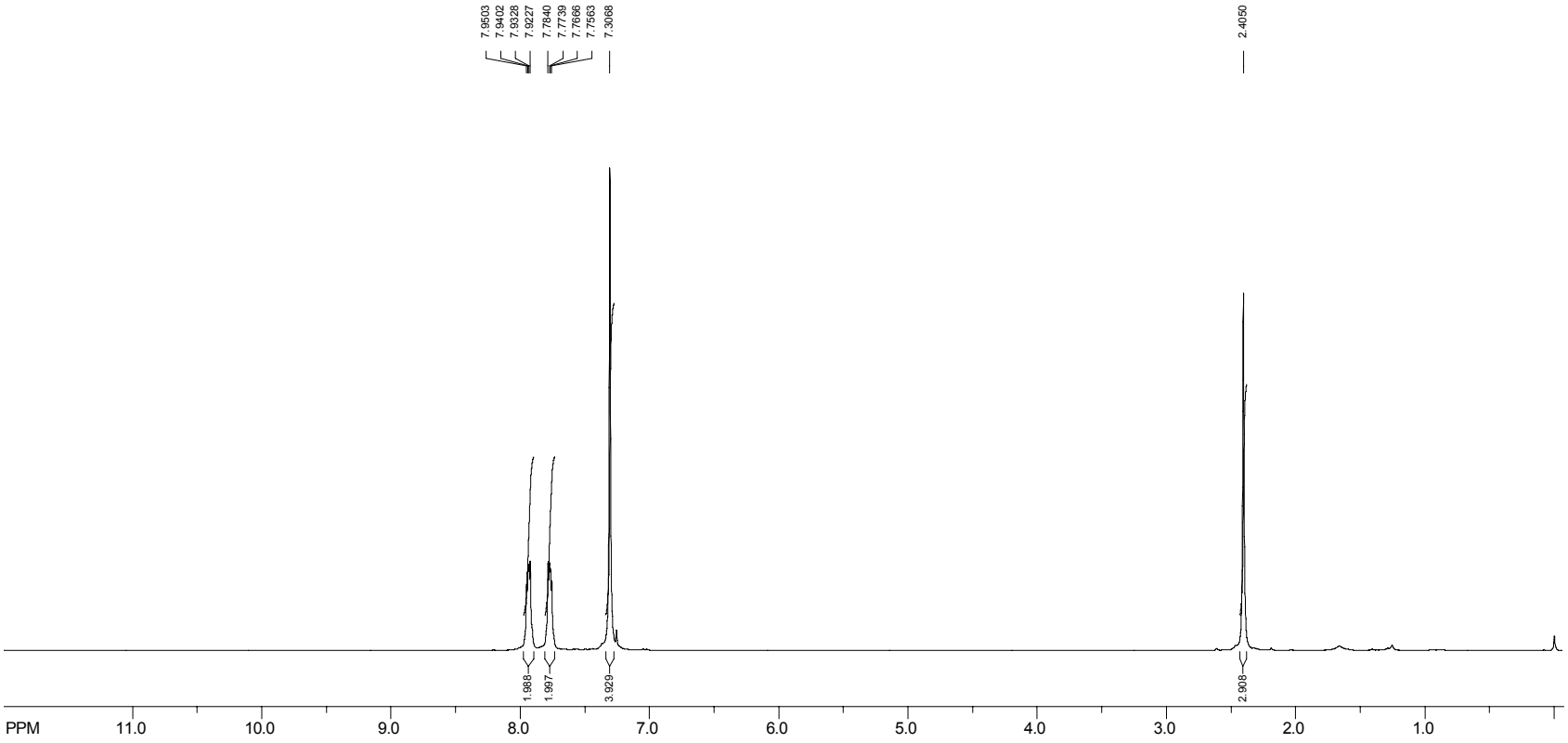
SpinWorks 2.5: MGH-237-pk2-APT



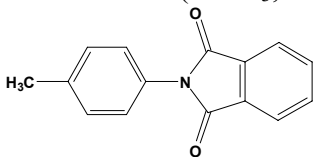
17. ^{1}H NMR ($CDCl_3$, 300 MHz) of **6**



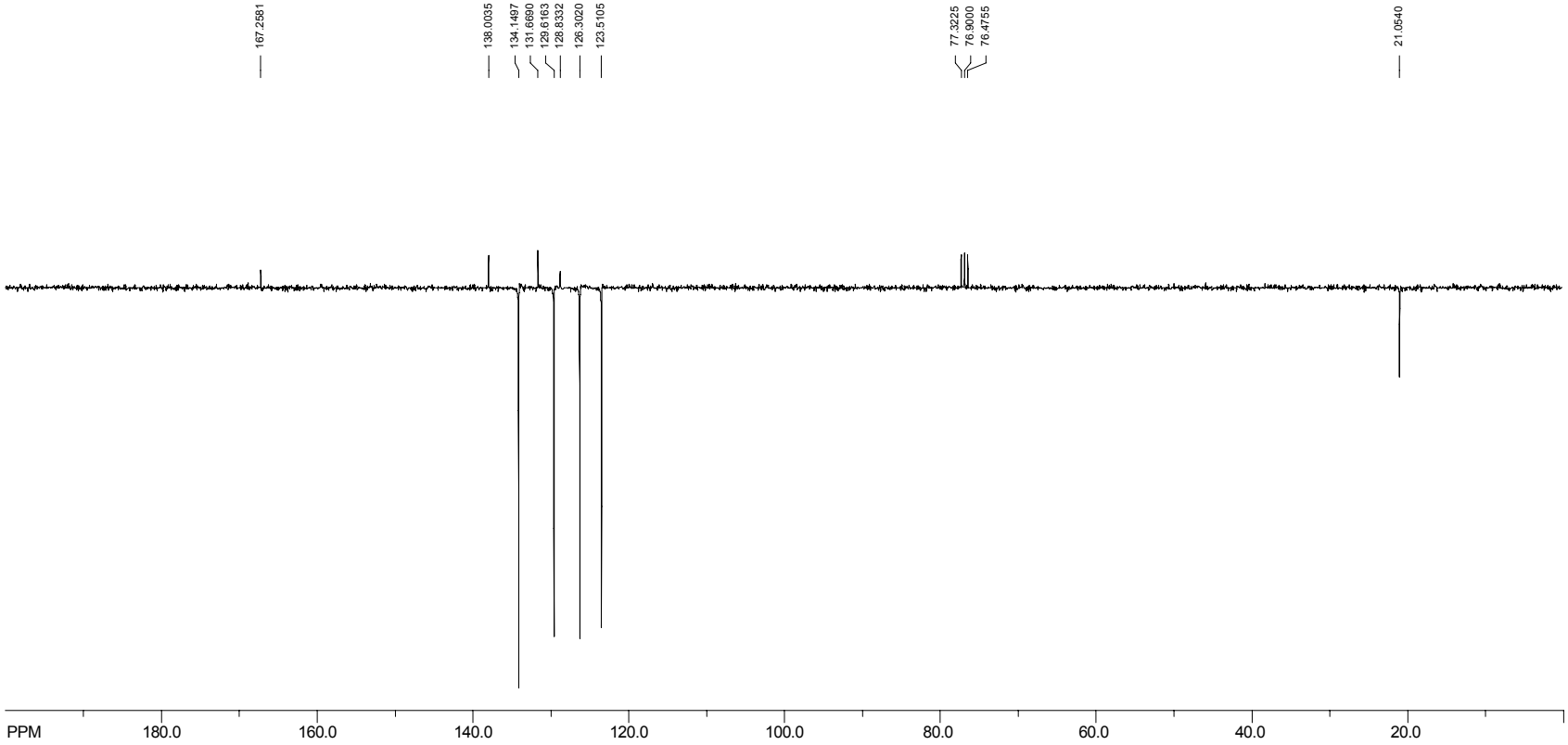
SpinWorks 2.5: MGH-241+238-A



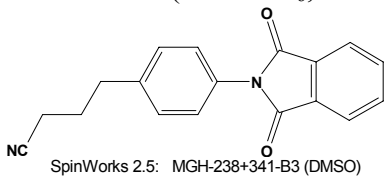
18. ^{13}C NMR ($CDCl_3$, 75 MHz, APT) of **6**



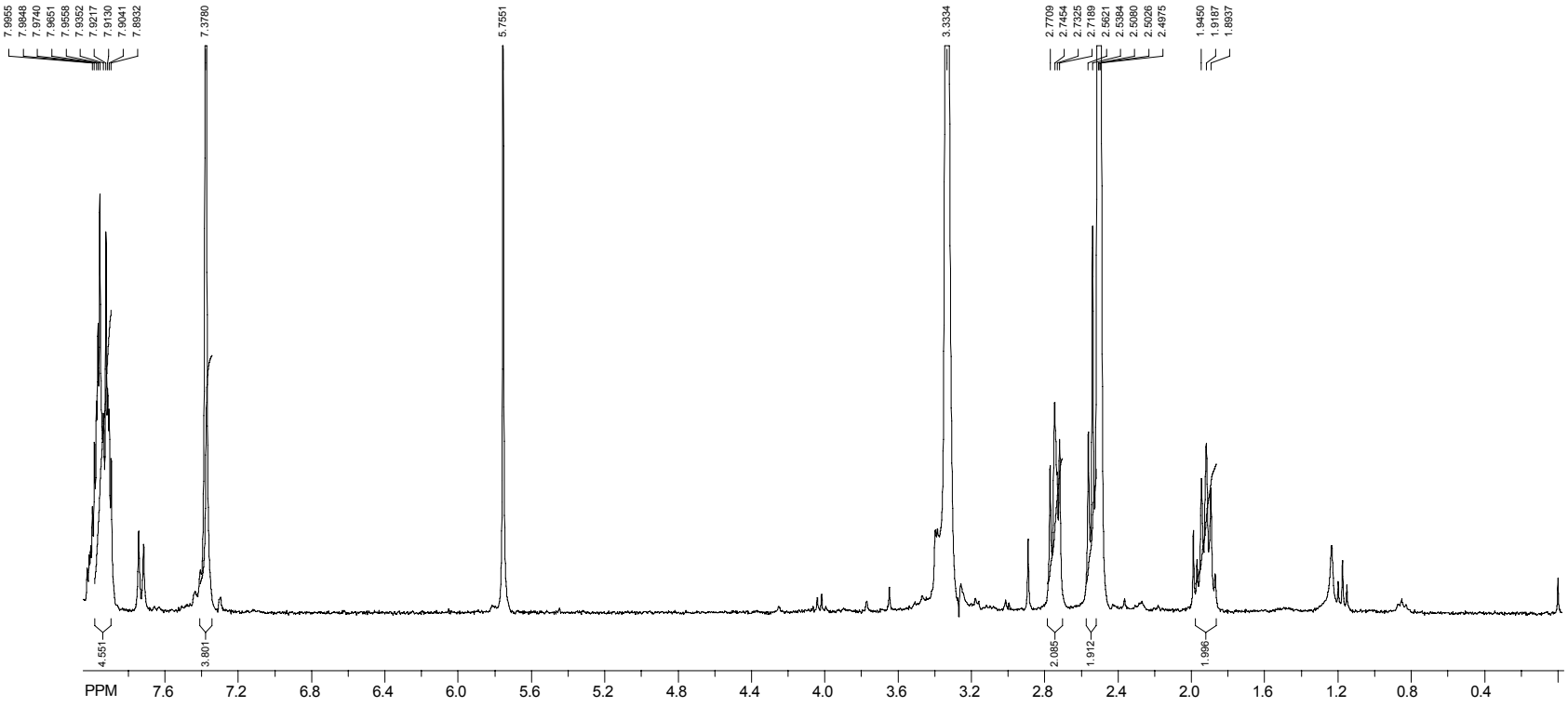
SpinWorks 2.5: MGH-238+241/A-APT



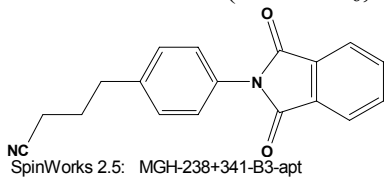
19. ^{1}H NMR (DMSO-d_6, 300 MHz) of **7**



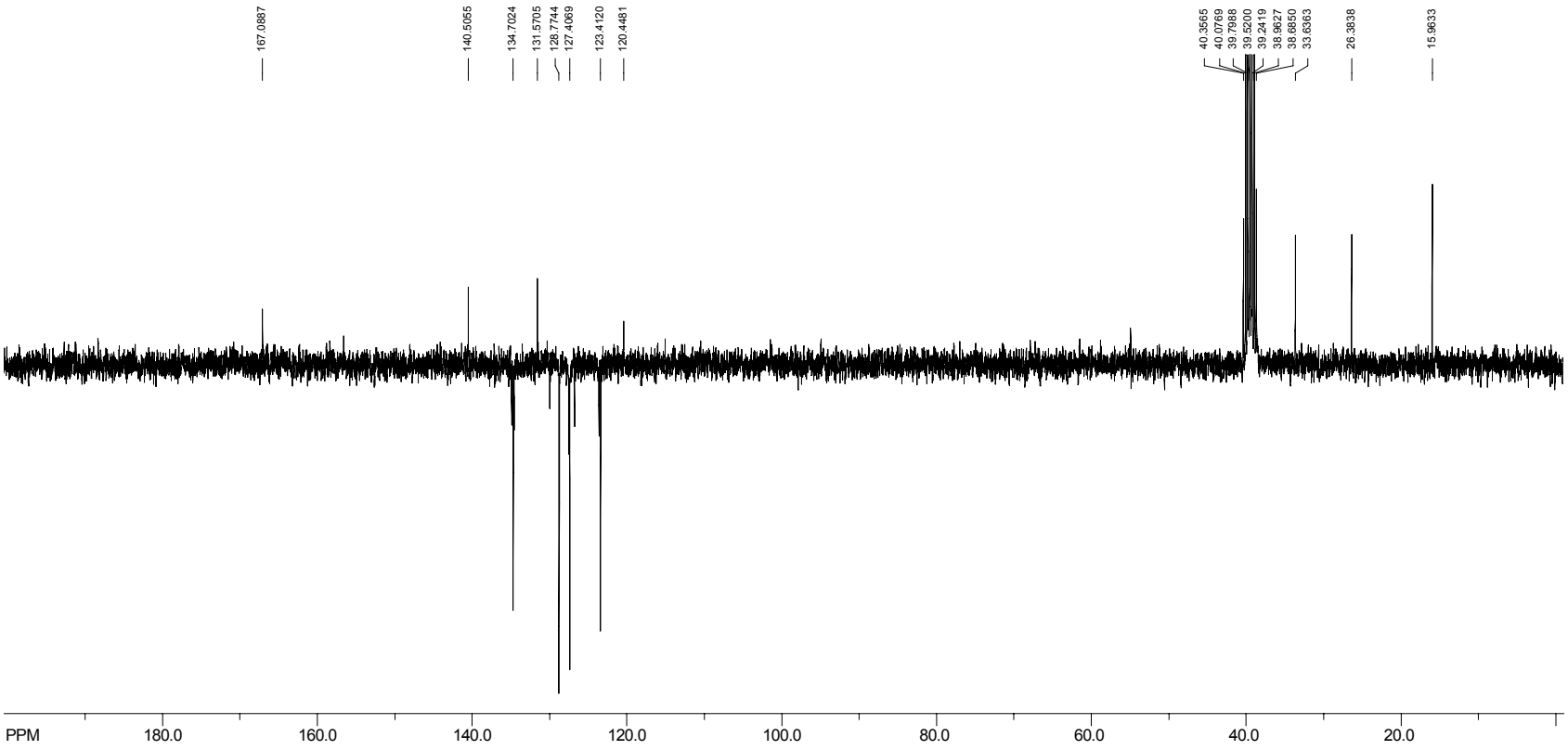
SpinWorks 2.5: MGH-238+341-B3 (DMSO)



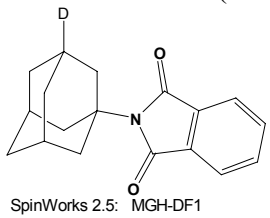
20. ^{13}C NMR (DMSO-d_6, 75 MHz, APT) of **7**



SpinWorks 2.5: MGH-238+341-B3-apt



21. ^{1}H NMR ($CDCl_3$, 300 MHz) of **D-2**



SpinWorks 2.5: MGH-DF1