Microwave-Assisted [3+2] Cycloaddition Reactions of Dicyanoepoxide with Benzylidene Meldrum's Acid

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Experimental Section

General procedures. Microwave reactions were performed using a "Monowave 300" single-mode microwave reactor from Anton Paar GmbH (Graz, Austria)[1]. Flash chromatography was performed using silica gel 60 (230-400 mesh) from Merck. Thin layer chromatography was performed on glass plates precoated with 0.25 mm Kieselgel 60 F254 (Merck).

Materials. Meldrum's acid, Malononitrile, Sodium hypochlorite, Sulfuric acid, Aldehydes, and all solvents were purchased from Merck, Sigma Alderich, Daejung, and Ambeed. Alkylidene Meldrum's acids[2] and dicyano epoxides[3-7] were prepared in accordance with previously published synthetic strategies.

Instrumentation.

Proton nuclear magnetic resonance (^{1}H NMR) spectra and carbon nuclear magnetic resonance (^{13}C NMR) spectra were recorded on a Bruker DRX-600 (600 MHz) spectrometers. Chemical shifts for protons (δ scale) are reported in parts per million (ppm) downfield from tetramethylsilane and are referenced to residual protium in the NMR solvent (DMSO: δ 2.50, $CDCl_3$: δ 7.26). Chemical shifts for carbon are reported in parts per million downfield from tetramethylsilane and are referenced to the carbon resonances of the solvent (DMSO: δ 39.51, $CDCl_3$: δ 77.23). Data represented as follows: chemical shift, multiplicity (br = broad, s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet), coupling constants (*J* value) in Hertz (Hz), and number of protons.

High-resolution mass spectra (HRMS) were obtained on an Agilent technologies 6530 Q-TOF-LC-MS. The mass accuracy performance verification was achieved using G1969-85001 ES-TOF reference mass solution kit.

Microwave irradiation reactor. The experiment was performed using a "Monowave 300" single-mode microwave reactor from Anton Paar GmbH (Graz, Austria).116 The instrument utilizes a maximum of 850 W magnetron output power. The vessels used were sealed and made of borosilicate glass rated to withstand the pressure up to 30 bar at a temperature up to 300 °C with a volume range of 0.5−20 ml. The measurement of the reaction temperature is achieved using an external infrared (IR) sensor housed in the side walls of the microwave cavity measuring the surface temperature of the reaction vessel. The temperature−time profile was monitored using the IR sensor for reaction temperature control from the instrument.

Crystal Data

X-ray Crystallography

Crystal data are summarized in Table S1. Single crystals of **3ai** and **3bb** were mounted on a MiTeGen loop with grease and examined on a Bruker D8 Venture APEX diffractometer equipped with Photon 100 CCD area detector at 296 (2) K using graphite mono-chromatized Mo-K_α radiation (λ = 0.71073Å). Data were collected using the APEX 4 software,[8] integrated using SAINT [9] and corrected for absorption using a multi-scan approach (SADABS).[10] Final cell constants were determined from full least squares refinement of all observed reflections. The structure was solved using intrinsic phasing (SHELXT).[11] All non-H atoms were located in subsequent difference maps and refined anisotropically. H-atoms were added at calculated positions and refined with a riding model.

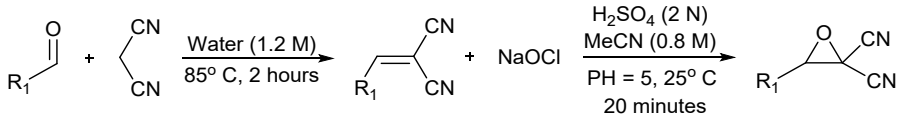
Table S1: Crystal data for ATR_360

Compounds	**3ai**	**3bb**
Chemical formula	C_{25} H_{20} N_2 O_5	C_{24} H_{19} Cl N_2 O_6
Mr	428.43	466.86
Crystal system, space group	Triclinic, P-1	Monoclinic, P21/n
Temperature (K)	296	296
a (Å)	10.7433(4)	8.8296(4)
b (Å)	11.4423(5)	23.8348(13)
c (Å)	11.6498(5)	12.1335(7)
α (°)	115.4180(10)	90
β (°)	104.594(2)	109.541(2)
γ (°)	105.643(2)	90
V (Å^3)	1128.76(8)	2406.4(2)
Z	2	4
Radiation type	MoK_α	MoK_α
μ (mm^{-1})	0.09	0.2
Absorption correction	Multi-scan, SADABS	Multi-scan, SADABS
T_{min}, T_{max}	0.6747, 0.7454	0.6914, 0.7454

No. of measured, independent and observed [$I > 2\sigma(I)$] reflections	34982, 4609, 3071	41089, 4905, 3322
R_{int}	0.0580	0.0756
$(\sin\theta/\lambda)_{max}$ ($Å^{-1}$)	0.626	0.625
$R[F^2 > 2\sigma(F^2)]$, $wR(F^2)$, S	0.0605, 0.2278, 1.130	0.0676, 0.1804, 1.065
No. of reflections	4609	4905
No. of parameters	292	324
$\Delta\rho_{max}$, $\Delta\rho_{min}$ ($eÅ^{-3}$)	0.313, -0.251	0.268, -0.260
CCDC	2390548	2390547

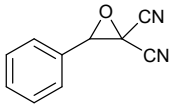
General procedure for the synthesis of dicyanoepoxides (1a-h).

GP 3

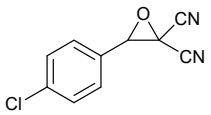


Aldehyde (1.0 equiv.) and Malononitrile (1.0 equiv.) were suspended in water (1.2 M) and stirred at 85 °C for 2 hours. Then the solid was filtered and the filtrate without further purification was used in next step.

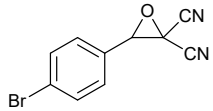
The olefin (1.0 equiv.) was dissolved in acetonitrile (1.5 ml/mmol) and 2 N H_2SO_4 (0.06 ml) was added. The solution was stirred vigorously and the NaClO (2.5 N, 2.6 ml/mmol) solution was added gradually and immediately the pH of the reaction mixture was adjusted to about 5 with 2 N H_2SO_4. Then vigorous stirring was continued for 20 min at pH 5. After adding water (30 ml/mmol) and cooling, the corresponding epoxide was obtained. Generally, the product, washed with water, is pure enough to be used without further recrystallization.



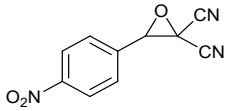
3-phenyloxirane-2,2-dicarbonitrile (1a).[3,6] Filtered to afford the title compound as white solid; 81% yield; mp 52-53 °C. ^1H NMR (600 MHz, $CDCl_3$) δ_H 7.52 – 7.56 (m, 3H), 7.44 – 7.40 (m, 2H), 4.73 (s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 131.4, 129.2, 127.5, 126.8, 111.7, 110.18, 65.8, 41.7.



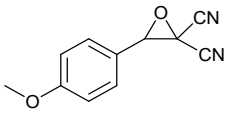
3-(4-chlorophenyl)oxirane-2,2-dicarbonitrile (1b).[3,6] Filtered to afford the title compound as white solid; 80% yield; mp 124-126 °C. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.53 – 7.48 (m, 2H), 7.42 – 7.39 (m, 2H), 4.72 (s, 1H)); ^{13}C NMR (150 MHz, $CDCl_3$) δ 137.8, 129.6, 128.1, 125.1, 111.3, 109.1, 65.1, 41.7.



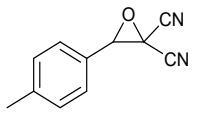
3-(4-bromophenyl)oxirane-2,2-dicarbonitrile (1c).[4,7] Filtered to afford the title compound as white solid; 75% yield; mp 117-119 °C. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.69 – 7.63 (m, 2H), 7.36 – 7.29 (m, 2H), 4.71 (s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 132.5, 128.3, 126.5, 126.1, 111.3, 109.9, 65.2, 41.5.



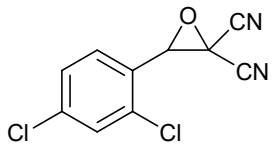
3-(4-nitrophenyl)oxirane-2,2-dicarbonitrile (1d).[5,6] Filtered to afford the title compound as yellow solid; 74% yield; mp 152-153 °C. ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.30 (d, J = 9.0 Hz, 2H), 7.59 (d, J = 8.9 Hz, 2H), 4.78 (s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ149.7, 134.1, 128.1, 124.4, 110.8, 109.5, 64.3, 41.5.



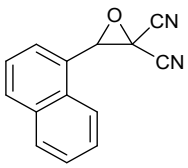
3-(4-methoxyphenyl)oxirane-2,2-dicarbonitrile (1e).[3,5] Filtered to afford the title compound as pale yellow solid; 82% yield; mp 80-82 °C. ^{1}H NMR (600 MHz, Chloroform-*d*) δ 7.38 (d, J = 8.4 Hz, 2H), 7.01 (d, J = 8.4 Hz, 2H), 4.69 (s, 1H), 3.87 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 161.9, 128.3, 119.0, 114.6, 111.7, 110.4, 66.0, 55.4, 41.8.



3-(p-tolyl)oxirane-2,2-dicarbonitrile (1f).[6,7] Filtered to afford the title compound as white solid; 84% yield; mp 58-60 °C. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.32 (q, J = 8.1 Hz, 4H), 4.70 (s, 1H), 2.43 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 141.9, 129.9, 126.7, 124.4, 111.7, 110.3, 77.3, 66.0, 41.8, 21.5.

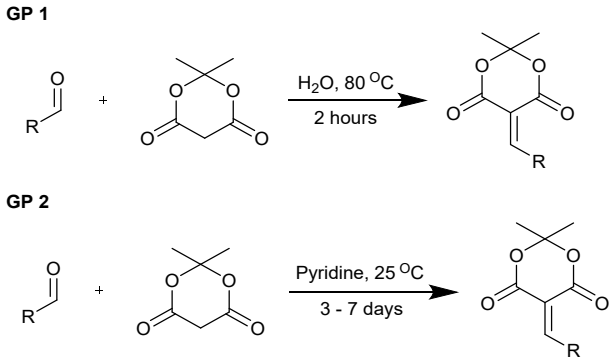


3-(2,4-dichlorophenyl)oxirane-2,2-dicarbonitrile (1g). Filtered to afford the title compound as pale yellow solid; 73% yield; mp 90-92 °C.^{1}H NMR (600 MHz, $CDCl_3$) δ_H 7.56 (d, J = 2.0 Hz, 1H), 7.41 (dd, J = 8.4, 2.0 Hz, 1H), 7.29 (d, J = 8.4 Hz, 1H), 4.95 (s, 1H); ^{13}C (150 MHz, $CDCl_3$) δ 138.1, 134.7, 130.1, 128.2, 128.1, 125.1, 110.1, 109.6, 63.2, 41.0; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{10}H_5Cl_2N_2O^+$ 238.9774, Found 238.9766.



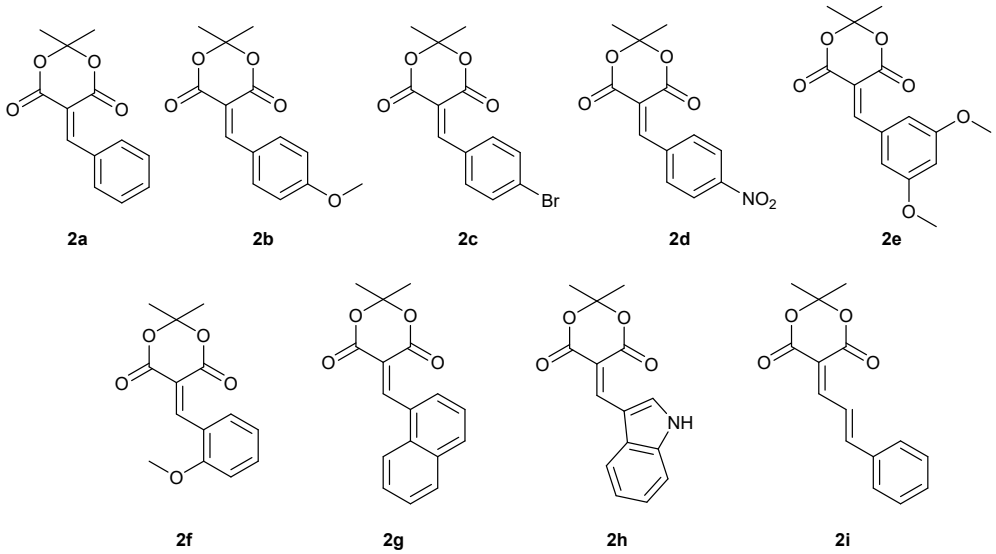
3-(naphthalen-1-yl)oxirane-2,2-dicarbonitrile (1h). Filtered to afford the title compound as white solid; 70% yield; mp 120-122 °C. ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.06 – 7.96 (m, 3H), 7.72 (t, *J* = 8.1 Hz, 1H), 7.66 (t, *J* = 8.1 Hz, 1H), 7.60 – 7.54 (m, 2H), 5.33 (s, 1H); ^{13}C (150 MHz, $CDCl_3$) δ 133.3, 131.6, 130.6, 129.4, 127.9, 126.9, 125.1, 124.3, 123.7, 121.3, 111.6, 110.0, 64.4, 41.4; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{14}H_9N_2O^+$ 221.0709, Found 221.0728.

General procedure for the synthesis of alkylidyne Meldrum's

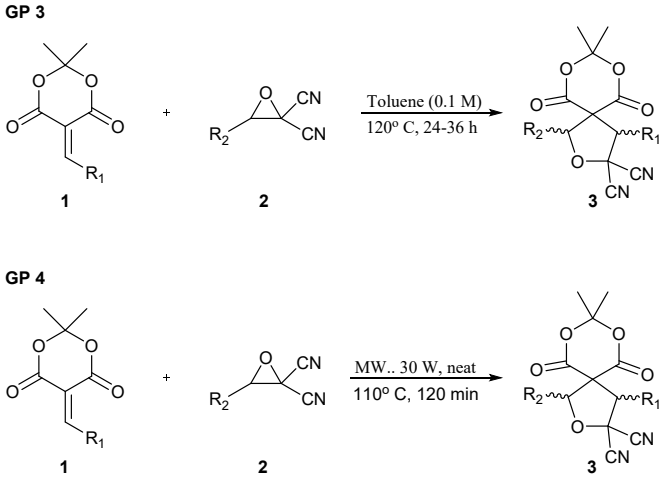


GP 1. Aldehyde (1.0 equiv.) and Meldrum's acid (1.0 equiv.) were suspended in water (0.5 M) and stirred at 80 °C for 2 hours. The mixture was then diluted with water (8ml/mmol) and extracted with ethyl acetate (10 ml/mmol). The organic phase was dried with magnesium sulfate, and the solvent was evaporated. The resulting residue was recrystallized in methanol to yield the pure product.

GP 2. Aldehyde (1.0 equiv.) and Meldrum's acid (1.0 equiv.) were disolved in pyridine (0.5M) and stirred at 25 °C for 3 – 7 days. After that solvent was evaporated. The resulting residue was recrystallized in methanol to yield the pure product.

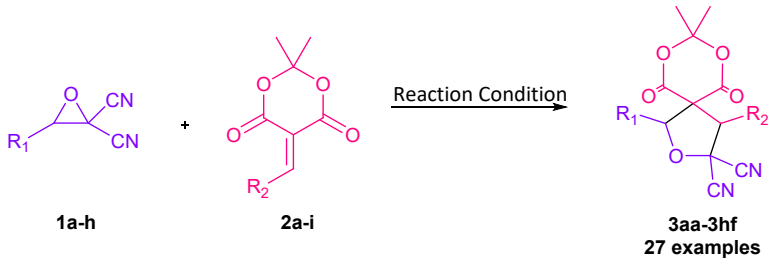


General Procedure for the Preparation of Final Products:



Classical Heating. A pressure vessel was charged with stir bar, corresponding alkylidyne Meldrum's (0.2 mmol, 1 equiv.), dicyano-epoxides (0.3 mmol, 1.5 equiv.) and 2 ml of toluene. The mixture was allowed to stir for 30 hours at reflux. After that the solvent was evaporated and the residue was purified by column chromatography (*n*-hexane/ethyl acetate 100:0 → 80:20).

Microwave Irradiation. A microwave vial was charged with stir bar, corresponding alkylidyne Meldrum's (0.2 mmol, 1 equiv.) and dicyano-epoxides (0.3 mmol, 1.5 equiv.). Then the mixture was heated to 110° C by 20 w power allowed to stir for 120 minutes at same conditions. After that the residue was purified by column chromatography (*n*-hexane/ethyl acetate 100:0 → 80:20).

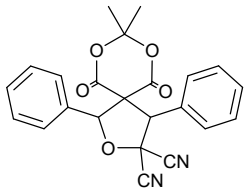


1a-h **2a-i** **3aa-3hf**
27 examples

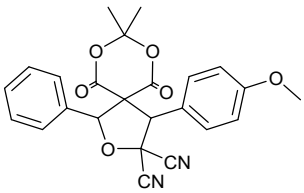
Table S2: Comparision of product yields and diastereoselectivies in classical heating versus microwave irradiation.

Compounds	Condition A: toluene, reflux, 30 h	Condition B: MW 30 W, neat, 110 °C, 120 min
3aa	Isolated Yield: 51% Diastereomeric ratio: 89/11	Isolated Yield: 78% Diastereomeric ratio: 84/16
3ab	Isolated Yield: 67% Diastereomeric ratio: 90/10	Isolated Yield: 84% Diastereomeric ratio: 87/13
3ac	Isolated Yield: 60% Diastereomeric ratio: 93/7	Isolated Yield: 84% Diastereomeric ratio: 89/11
3ad	Isolated Yield: 41% Diastereomeric ratio: 76/24	Isolated Yield: 58% Diastereomeric ratio: 74/26
3ae	Isolated Yield: 71% Diastereomeric ratio: 82/18	Isolated Yield: 81% Diastereomeric ratio: 80/20
3af	Isolated Yield: 66% Diastereomeric ratio: 85/15	Isolated Yield: 79% Diastereomeric ratio: 82/18
3ag	Isolated Yield: 53% Diastereomeric ratio: 76/24	Isolated Yield: 54% Diastereomeric ratio: 75/25
3ah	Isolated Yield: 81% Diastereomeric ratio: 95/5	Isolated Yield: 85% Diastereomeric ratio: 93/7
3ai	Isolated Yield: 63% Diastereomeric ratio: 90/10	Isolated Yield: 71% Diastereomeric ratio: 91/9
3bb	Isolated Yield: 59% Diastereomeric ratio: 90/10	Isolated Yield: 86% Diastereomeric ratio: 88/12
3bc	Isolated Yield: 88% Diastereomeric ratio: 85/15	Isolated Yield: 91% Diastereomeric ratio: 86/14
3bd	Isolated Yield: 28% Diastereomeric ratio: 81/19	Isolated Yield: 55% Diastereomeric ratio: 78/22
3bf	Isolated Yield: 59% Diastereomeric ratio: 85/15	Isolated Yield: 76% Diastereomeric ratio: 82/18

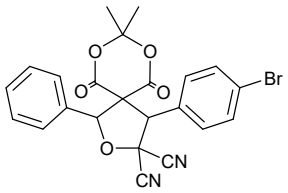
3bg	Isolated Yield: 65% Diastereomeric ratio: 80/20	Isolated Yield: 66% Diastereomeric ratio: 76/24
3bh	Isolated Yield: 59% Diastereomeric ratio: 91/9	Isolated Yield: 73% Diastereomeric ratio: 90/10
3cb	Isolated Yield: 81% Diastereomeric ratio: 90/10	Isolated Yield: 89% Diastereomeric ratio: 87/13
3db	Isolated Yield: 62% Diastereomeric ratio: 81/19	Isolated Yield: 66% Diastereomeric ratio: 78/22
3dc	Isolated Yield: 64% Diastereomeric ratio: 86/14	Isolated Yield: 70% Diastereomeric ratio: 84/16
3eb	Isolated Yield: 69% Diastereomeric ratio: 75/25	Isolated Yield: 81% Diastereomeric ratio: 72/28
3ec	Isolated Yield: 80% Diastereomeric ratio: 82/18	Isolated Yield: 89% Diastereomeric ratio: 81/19
3ed	Isolated Yield: 53% Diastereomeric ratio: 89/11	Isolated Yield: 72% Diastereomeric ratio: 86/14
3ee	Isolated Yield: 69% Diastereomeric ratio: 74/26	Isolated Yield: 79% Diastereomeric ratio: 70/30
3fb	Isolated Yield: 67% Diastereomeric ratio: 77/23	Isolated Yield: 77% Diastereomeric ratio: 75/25
3gc	Isolated Yield: 81% Diastereomeric ratio: 86/14	Isolated Yield: 87% Diastereomeric ratio: 86/14
3ge	Isolated Yield: 69% Diastereomeric ratio: 88/12	Isolated Yield: 80% Diastereomeric ratio: 84/16
3he	Isolated Yield: 49% Diastereomeric ratio: 76/24	Isolated Yield: 68% Diastereomeric ratio: 76/24
3hf	Isolated Yield: 43% Diastereomeric ratio: 75/25	Isolated Yield: 62% Diastereomeric ratio: 72/28



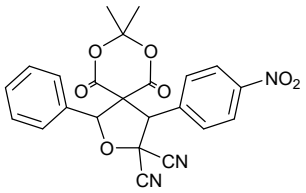
8,8-dimethyl-6,10-dioxo-1,4-diphenyl-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3aa). white solid, mp: 173-175; Yield 78% (62 mg); major isomer ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.61 (s, 1H), 7.84 (d, *J* = 2.8 Hz, 1H), 7.53 (d, *J* = 8.1, 1H), 7.44 – 7.37 (m, 3H), 7.32 – 7.25 (m, 3H), 7.19 (dd, *J* = 8.1, 7.0, 1H), 6.20 (s, 1H), 5.45 (s, 1H), 1.46 (s, 3H), 0.91 (s, 3H); ^{13}C NMR (150 MHz, Chloroform-*d*) δ 166.7, 166.3, 136.2, 134.6, 129.0, 127.7, 123.6, 121.5, 116.8, 112.1, 111.9, 106.3, 100.7, 91.9, 73.0, 64.6, 56.4, 29.7, 27.8; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{23}H_{19}N_2O_5^+$ 403.1288, Found 403.1281.



4-(4-methoxyphenyl)-8,8-dimethyl-6,10-dioxo-1-phenyl-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3ab). Clear oil, Yield 84% (72 mg); major isomer ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.59 – 7.55 (m, 2H), 7.41 – 7.37 (m, 3H), 7.31 (dd, J = 6.7, 3.0 Hz, 2H), 6.98 – 6.92 (m, 2H), 6.20 (s, 1H), 4.86 (s, 1H), 3.81 (s, 3H), 1.50 (s, 3H), 1.09 (s, 3H); ^{13}C NMR (150 MHz, Chloroform-d) δ 166.3, 165.7, 161.4, 132.4, 132.0, 130.1, 128.7, 126.2, 118.1, 115.1, 112.1, 111.7, 106.2, 92.7, 72.4, 64.7, 64.2, 55.3, 30.0, 27.9; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{24}H_{21}N_2O_6^+$ 433.1394, Found 433.1389.

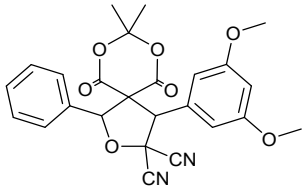


4-(4-bromophenyl)-8,8-dimethyl-6,10-dioxo-1-phenyl-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3ac). white solid, mp: 181-183; Yield 84% (80 mg); major isomer ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.59 (dq, J = 8.6, 2.3, 1.7 Hz, 2H), 7.55 – 7.51 (m, 2H), 7.40 (dd, J = 5.1, 2.0 Hz, 3H), 7.33 – 7.29 (m, 2H), 6.13 (s, 1H), 4.89 (s, 1H), 1.49 (s, 3H), 1.13 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 165.9, 165.4, 133.0, 132.4, 131.5, 130.3, 128.8, 126.4, 125.8, 125.6, 111.8, 111.5, 106.3, 92.9, 71.8, 64.5, 63.6, 30.2, 27.8; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{23}H_{18}BrN_2O_5^+$ 481.0393, Found 481.0391.

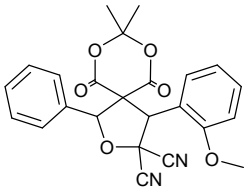


8,8-dimethyl-4-(4-nitrophenyl)-6,10-dioxo-1-phenyl-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3ad). Yellow oil; Yield 58% (51 mg); major isomer ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.31 (dd, *J* = 8.9, 2.2 Hz, 2H), 7.89 (d, *J* = 8.8 Hz, 2H), 7.44 – 7.42 (m, 3H), 7.34 – 7.32 (m, 2H), 6.10 (s, 1H), 5.10 (s, 1H), 1.48 (s, 3H), 1.16 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ

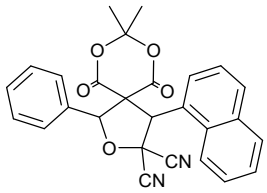
165.5, 165.1, 149.2, 133.6, 132.1, 130.9, 130.7, 128.9, 126.68, 124.6, 111.5, 111.3, 106.6, 93.2, 71.4, 64.7, 62.9, 30.4, 27.8; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{23}H_{18}N_3O_7^+$ 448.1139, Found 448.1158.



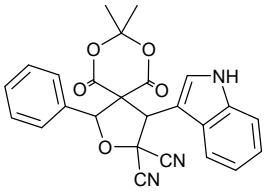
4-(3,5-dimethoxyphenyl)-8,8-dimethyl-6,10-dioxo-1-phenyl-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3ae). white solid, mp: 151-153; Yield 81% (75 mg); major isomer ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.41 – 7.38 (m, 3H), 7.32 – 7.28 (m, 2H), 6.77 (d, J = 2.2 Hz, 2H), 6.51 (t, J = 2.3 Hz, 1H), 6.19 (s, 1H), 4.80 (s, 1H), 3.79 (s, 6H), 1.51 (s, 3H), 1.17 (s, 3H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 166.1, 165.7, 161.4, 131.9, 130.1, 128.7, 128.3, 126.2, 111.9, 111.8, 108.6, 106.3, 102.9, 92.8, 72.05, 64.5, 64.4, 55.5, 30.0, 27.9; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{25}H_{23}N_2O_7^+$ 463.1499, Found 463.1492.



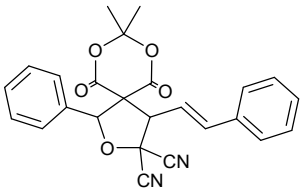
4-(2-methoxyphenyl)-8,8-dimethyl-6,10-dioxo-1-phenyl-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3af). white solid, mp: 179-181; Yield 79% (68 mg); major isomer ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.98 (d, *J* = 7.9 Hz, 1H), 7.44 – 7.34 (m, 6H), 7.11 (t, *J* = 7.7 Hz, 1H), 6.91 (d, *J* = 8.3 Hz, 1H), 6.08 (s, 1H), 5.59 (s, 1H), 3.79 (s, 3H), 1.39 (s, 3H), 1.26 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 165.3, 165.1, 157.1, 131.6, 131.3, 130.2, 129.9, 129.0, 128.6, 127.0, 121.8, 112.2, 111.9, 111.0, 106.1, 92.2, 70.9, 63.2, 56.1, 55.6, 29.1, 28.4; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{24}H_{21}N_2O_6^+$ 433.1394, Found 433.1408.



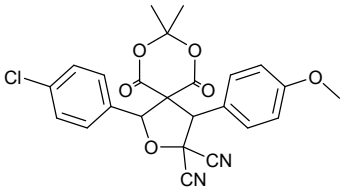
8,8-dimethyl-4-(naphthalen-1-yl)-6,10-dioxo-1-phenyl-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3ag). Pale yellow oil; Yield 54% (48 mg); major isomer ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.41 (dd, *J* = 7.5, 1.0 Hz, 1H), 8.00 (d, *J* = 8.7 Hz, 1H), 7.96 (d, *J* = 8.2 Hz, 1H), 7.90 (dd, *J* = 8.2, 1.3 Hz, 1H), 7.64 – 7.59 (m, 2H), 7.53 (dd, *J* = 8.0, 6.5 Hz, 1H), 7.42 (q, *J* = 2.9 Hz, 3H), 7.38 (dd, *J* = 6.9, 2.9 Hz, 2H), 6.36 (s, 1H), 6.00 (s, 1H), 1.41 (s, 3H), 0.63 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 166.5, 165.6, 133.9, 132.2, 131.8, 131.4, 130.1, 129.8, 129.7, 128.7, 128.4, 126.5, 126.2, 125.6, 122.0, 121.06, 112.0, 111.8, 106.2, 93.1, 72.1, 64.6, 56.9, 29.4, 27.8; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{27}H_{21}N_2O_5^+$ 453.1444, Found 453.1441.



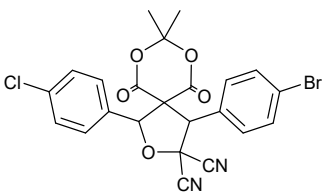
4-(1H-indol-3-yl)-8,8-dimethyl-6,10-dioxo-1-phenyl-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3ah). Clear oil; Yield 85% (75 mg); major isomer ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.70 (s, 1H), 7.85 (d, J = 2.9 Hz, 1H), 7.55 (d, J = 8.0 Hz, 1H), 7.44 – 7.40 (m, 4H), 7.36 (dd, J = 6.9, 2.9 Hz, 2H), 7.26 – 7.23 (m, 1H), 7.18 (ddd, J = 8.0, 7.0, 0.9 Hz, 1H), 6.23 (s, 1H), 5.50 (s, 1H), 1.45 (s, 3H), 0.91 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 166.8, 166.5, 134.7, 131.8, 130.1, 128.7, 127.4, 126.8, 126.2, 123.5, 121.4, 116.9, 112.3, 112.1, 111.7, 106.3, 100.8, 92.7, 73.0, 64.8, 56.4, 29.7, 27.7; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{25}H_{20}N_3O_5^+$ 442.1397, Found 442.1397.



(E)-8,8-dimethyl-6,10-dioxo-1-phenyl-4-styryl-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3ai). Pale yellow oil; Yield 71% (60 mg); major isomer, ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.45 (dd, *J* = 7.7, 1.9 Hz, 2H), 7.41 – 7.38 (m, 3H), 7.38 – 7.35 (m, 3H), 7.31 – 7.29 (m, 2H), 6.82 (d, *J* = 15.6 Hz, 1H), 6.47 (dd, *J* = 15.6, 10.2 Hz, 1H), 5.95 (s, 1H), 4.46 (dd, *J* = 10.2, 0.6 Hz, 1H), 1.51 (s, 3H), 1.46 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 166.2, 164.8, 141.3, 134.2, 130.9, 130.3, 129.7, 128.9, 128.8, 127.4, 126.3, 116.1, 111.8, 110.7, 106.4, 92.7, 72.5, 63.7, 62.2, 31.0, 27.5; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{25}H_{21}N_2O_5^+$ 429.1444, Found 429.1443.

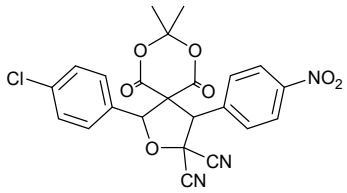


1-(4-chlorophenyl)-4-(4-methoxyphenyl)-8,8-dimethyl-6,10-dioxo-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3bb). white solid, mp: 184-186; Yield 86% (80 mg); major isomer ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.52 – 7.49 (m, 2H), 7.33 – 7.31 (m, 2H), 7.21 – 7.19 (m, 2H), 6.91 – 6.89 (m, 2H), 6.13 (s, 1H), 4.76 (s, 1H), 3.76 (s, 3H), 1.46 (s, 3H), 1.04 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 166.3, 165.5, 161.5, 136.1, 132.4, 130.4, 129.0, 127.6, 117.9, 115.2, 111.9, 111.6, 106.3, 91.9, 72.4, 64.5, 64.4, 55.3, 30.0, 27.9; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{24}H_{20}ClN_2O_6^+$ 467.1004, Found 467.1002.

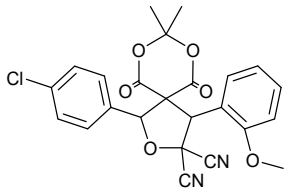


4-(4-bromophenyl)-1-(4-chlorophenyl)-8,8-dimethyl-6,10-dioxo-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3bc). Colorless oil; Yield 91% (93 mg); major isomer ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.62

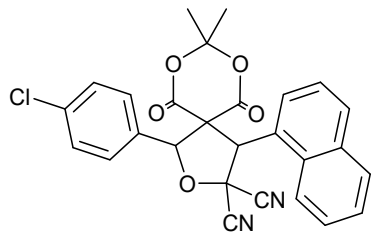
– 7.59 (m, 2H), 7.52 – 7.50 (m, 2H), 7.40 – 7.38 (m, 2H), 7.26 – 7.24 (m, 2H), 6.12 (s, 1H), 4.85 (s, 1H), 1.51 (s, 3H), 1.13 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 166.0, 165.2, 136.5, 133.1, 132.4, 129.9, 129.1, 127.8, 126.0, 125.4, 111.6, 111.3, 106.5, 92.2, 71.9, 64.3, 63.8, 30.2, 27.9; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{23}H_{17}BrClN_2O_5^+$ 515.0003, Found 515.0017.



1-(4-chlorophenyl)-8,8-dimethyl-4-(4-nitrophenyl)-6,10-dioxo-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3bd). yellow solid, mp: 189-191; Yield 55% (53 mg); major isomer ^{1}H NMR (600 MHz, Chloroform-*d*) δ 8.33 – 8.29 (m, 2H), 7.90 – 7.85 (m, 2H), 7.43 – 7.39 (m, 2H), 7.29 – 7.26 (m, 2H), 6.09 (s, 1H), 5.05 (s, 1H), 1.51 (s, 3H), 1.16 (s, 3H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 165.6, 165.0, 149.3, 136.9, 133.4, 132.1, 129.4, 129.2, 128.0, 124.6, 111.3, 111.1, 106.7, 92.4, 71.4, 64.5, 63.0, 30.4, 27.9; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{23}H_{17}ClN_3O_7^+$ 482.0749, Found 482.0748.

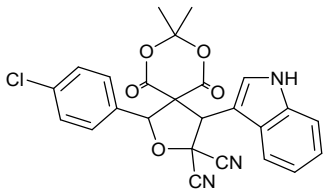


1-(4-chlorophenyl)-4-(2-methoxyphenyl)-8,8-dimethyl-6,10-dioxo-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3bf). Colorless oil; Yield 76% (70 mg); major isomer ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.96 (dd, *J* = 7.9, 1.5 Hz, 1H), 7.41 (ddd, *J* = 8.3, 7.5, 1.6 Hz, 1H), 7.38 – 7.36 (m, 2H), 7.32 – 7.29 (m, 2H), 7.10 (td, *J* = 7.7, 1.2 Hz, 1H), 6.91 (dd, *J* = 8.4, 1.1 Hz, 1H), 6.08 (s, 1H), 5.58 (s, 1H), 3.80 (s, 3H), 1.43 (s, 3H), 1.24 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 165.3, 165.0, 157.2, 136.3, 131.5, 130.1, 130.1, 128.9, 128.3, 121.8, 116.1, 112.1, 111.8, 111.1, 106.2, 91.4, 71.0, 63.1, 55.9, 55.7, 29.1, 28.5; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{24}H_{20}ClN_2O_6^+$ 467.1004, Found 467.1002.

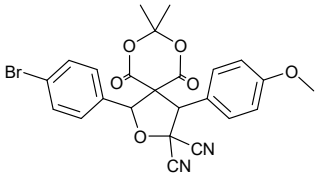


1-(4-chlorophenyl)-8,8-dimethyl-4-(naphthalen-1-yl)-6,10-dioxo-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3bg). Pale yellow oil; Yield 66% (64 mg); major isomer ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.38 (dd, *J* = 7.5, 1.1 Hz, 1H), 7.99 – 7.95 (m, 2H), 7.90 (dd, *J* = 8.2, 1.4 Hz, 1H), 7.64 – 7.60 (m, 2H), 7.54 (ddd, *J* = 8.0, 5.9, 0.9 Hz, 1H), 7.43 – 7.39 (m, 2H), 7.34 – 7.31 (m, 2H), 6.33 (s, 1H), 5.96 (s, 1H), 1.42 (s,

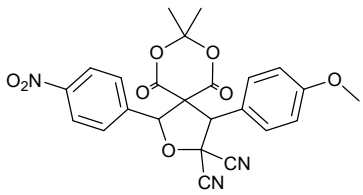
3H), 0.62 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 166.6, 165.5, 136.2, 133.9, 132.2, 131.5, 130.3, 129.9, 129.8, 129.1, 128.5, 127.6, 126.6, 125.6, 121.8, 120.9, 111.8, 111.6, 106.4, 92.4, 72.2, 64.5, 57.0, 29.3, 27.9. HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{27}H_{20}ClN_2O_5^+$ 487.1054, Found 487.1066.



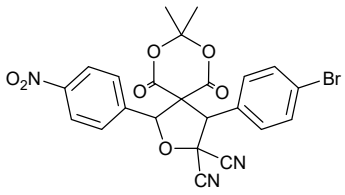
1-(4-chlorophenyl)-4-(1H-indol-3-yl)-8,8-dimethyl-6,10-dioxo-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3bh). White solid, mp: 170-173, yield 73% (69 mg); major isomer ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.62 (s, 1H), 7.84 (d, *J* = 2.9 Hz, 1H), 7.53 (d, *J* = 8.0 Hz, 1H), 7.42 – 7.38 (m, 3H), 7.31 – 7.28 (m, 2H), 7.26 (dd, *J* = 7.1, 1.1 Hz, 1H), 7.21 – 7.18 (m, 1H), 6.20 (s, 1H), 5.45 (s, 1H), 1.46 (s, 3H), 0.91 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 166.8, 166.3, 136.2, 134.7, 130.4, 129.1, 127.7, 127.3, 126.8, 123.7, 121.5, 116.9, 112.1, 112.0, 111.7, 106.4, 100.7, 92.0, 73.0, 64.7, 56.5, 29.8, 27.8; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{25}H_{19}ClN_3O_5^+$ 476.1007, Found 476.1021.



1-(4-bromophenyl)-4-(4-methoxyphenyl)-8,8-dimethyl-6,10-dioxo-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3cb). Colorless oil; Yield 89% (90 mg); major isomer ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.61 – 7.56 (m, 4H), 7.25 – 7.21 (m, 2H), 7.02 – 6.98 (m, 2H), 6.21 (s, 1H), 4.85 (s, 1H), 3.86 (s, 3H), 1.56 (s, 3H), 1.13 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 166.3, 165.5, 161.6, 132.5, 132.0, 131.0, 127.8, 124.4, 117.9, 115.2, 111.9, 111.6, 106.4, 91.9, 72.4, 64.4, 64.4, 55.4, 30.0, 27.9. HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{24}H_{20}BrN_2O_6^+$ 511.0499, Found 511.0498.

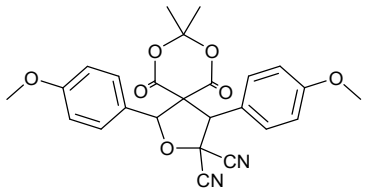


4-(4-methoxyphenyl)-8,8-dimethyl-1-(4-nitrophenyl)-6,10-dioxo-2,7,9-trioxaspiro[4.5] decane-3,3-dicarbonitrile (3db). Pale yellow solid, mp: 177-179, yield 66% (62 mg); major isomer ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.26 (d, *J* = 8.8 Hz, 2H), 7.57 – 7.54 (m, 2H), 7.51 – 7.49 (m, 2H), 6.97 (d, *J* = 8.8 Hz, 2H), 6.33 (s, 1H), 4.77 (s, 1H), 3.862 (s, 3H), 1.54 (s, 3H), 1.08 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 166.1, 165.2, 161.8, 148.7, 138.9, 132.5,

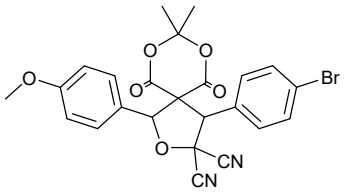


127.1, 124.0, 115.4, 111.6, 111.3, 106.7, 91.0, 72.7, 64.9, 64.3, 55.4, 30.0, 28.0; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{24}H_{20}N_3O_8^+$ 478.1244, Found 478.1241.

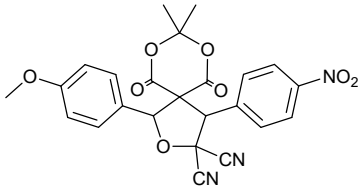
4-(4-bromophenyl)-8,8-dimethyl-1-(4-nitrophenyl)-6,10-dioxo-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3dc). Pale yellow oil; yield 70% (73 mg); major isomer ^{1}H NMR (600 MHz, Chloroform-*d*) δ 8.29 – 8.25 (m, 2H), 7.62 (d, *J* = 8.6 Hz, 2H), 7.51 (dd, *J* = 10.2, 8.7 Hz, 4H), 6.28 (s, 1H), 4.80 (s, 1H), 1.55 (s, 3H), 1.12 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 165.9, 164.9, 148.9, 138.4, 133.3, 132.5, 127.3, 126.4, 125.0, 124.0, 111.4, 111.0, 106.8, 91.3, 72.3, 64.2, 64.1, 30.2, 28.0; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{23}H_{17}BrN_3O_7^+$ 526.0244, Found 526.0243.



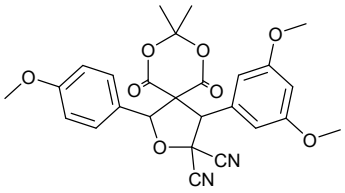
1,4-bis(4-methoxyphenyl)-8,8-dimethyl-6,10-dioxo-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3eb). Colorless oil; yield 81% (74 mg); major isomer ^{1}H NMR (600 MHz, Chloroform-*d*) δ 7.57 – 7.55 (m, 2H), 7.25 – 7.23 (m, 2H), 6.95 – 6.93 (m, 2H), 6.90 – 6.88 (m, 2H), 6.12 (s, 1H), 4.87 (s, 1H), 3.82 (s, 3H), 3.80 (s, 3H), 1.48 (s, 3H), 1.11 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 166.5, 165.8, 161.4, 160.9, 132.4, 132.0, 128.00, 127.9, 115.1, 114.1, 112.2, 111.9, 106.1, 92.9, 72.2, 64.9, 64.1, 55.4, 55.3, 30.0, 28.0; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{25}H_{23}N_2O_7^+$ 463.1499, Found 463.1512.



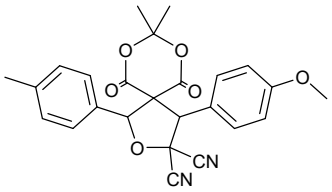
4-(4-bromophenyl)-1-(4-methoxyphenyl)-8,8-dimethyl-6,10-dioxo-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3ec). Pale yellow solid, mp: 182-184; Yield 89% (90 mg); major isomer ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.60 – 7.57 (m, 2H), 7.54 – 7.51 (m, 2H), 7.25 – 7.23 (m, 2H), 6.92 – 6.88 (m, 2H), 6.06 (s, 1H), 4.92 (s, 1H), 3.80 (s, 3H), 1.48 (s, 3H), 1.15 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 166.1, 165.5, 161.0, 133.0, 132.4, 128.2, 125.7, 125.7, 123.1, 114.1, 111.8, 111.6, 106.3, 93.1, 71.6, 64.6, 63.4, 55.3, 30.2, 27.9; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{24}H_{20}BrN_2O_6^+$ 511.0499, Found 511.0496.



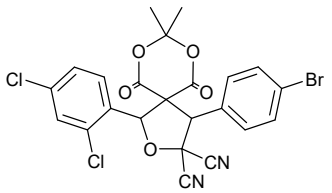
1-(4-methoxyphenyl)-8,8-dimethyl-4-(4-nitrophenyl)-6,10-dioxo-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3ed). yellow solid, mp: 191-193, yield 72% (68 mg); major isomer ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.30 (d, J = 8.8 Hz, 2H), 7.90 – 7.85 (m, 2H), 7.28 – 7.25 (m, 2H), 6.93 – 6.90 (m, 2H), 6.02 (s, 1H), 5.13 (s, 1H), 3.81 (s, 3H), 1.47 (s, 3H), 1.19 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 165.7, 165.3, 161.3, 149.2, 133.9, 131.9, 128.5, 124.6, 122.7, 114.3, 111.6, 111.4, 106.6, 93.3, 71.1, 64.8, 62.7, 55.4, 30.3, 28.0; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{24}H_{20}N_3O_8^+$ 478.1244, Found 478.1255.



4-(3,5-dimethoxyphenyl)-1-(4-methoxyphenyl)-8,8-dimethyl-6,10-dioxo-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3ee). Pale yellow solid, mp: 197-199, yield 79% (78 mg); major isomer ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.24 (dd, J = 8.9, 2H), 6.89 (dd, J = 8.9, 2.3 Hz, 2H), 6.76 (d, J = 2.2 Hz, 2H), 6.51 – 6.49 (m, 1H), 6.11 (s, 1H), 4.82 (s, 1H), 3.80 (s, 3H), 3.79 (s, 6H), 1.49 (s, 3H), 1.18 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 166.3, 165.8, 161.4, 160.9, 128.5, 128.1, 123.6, 114.1, 112.1, 112.0, 108.5, 106.2, 102.8, 93.1, 71.8, 64.6, 64.3, 55.5, 55.3, 30.0, 28.0; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{26}H_{25}N_2O_8^+$ 493.1605, Found 493.1603.

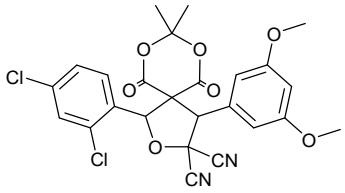


4-(4-methoxyphenyl)-8,8-dimethyl-6,10-dioxo-1-(p-tolyl)-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3fb). Colorless oil; yield 77% (68 mg); major isomer ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.64 – 7.58 (m, 2H), 7.23 (s, 4H), 7.02 – 6.97 (m, 2H), 6.20 (s, 1H), 4.90 (s, 1H), 3.85 (s, 3H), 2.39 (s, 3H), 1.54 (s, 3H), 1.14 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 166.4, 165.8, 161.4, 140.2, 132.4, 129.4, 129.0, 126.2, 118.2, 115.1, 112.1, 111.8, 106.1, 92.9, 72.3, 64.8, 64.1, 55.3, 30.0, 27.9, 21.3. HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{25}H_{23}N_2O_6^+$ 447.1551, Found 447.1552.

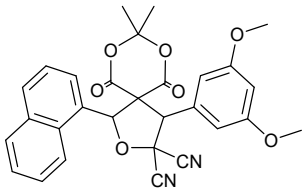


4-(4-bromophenyl)-1-(2,4-dichlorophenyl)-8,8-dimethyl-6,10-dioxo-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3gc). White solid, mp: 195-198; Yield 87% (95 mg); major isomer ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.61 (dd, J = 8.9, 2.4 Hz, 2H), 7.56 (d, J = 9.0 Hz, 1H), 7.53 – 7.50 (m, 2H), 7.38 (dt, J = 5.1, 2.7 Hz, 2H), 6.41 (s, 1H), 4.73 (s, 1H), 1.60 (s, 3H),

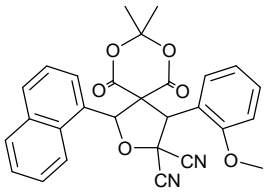
0.94 (s, 3H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 165.7, 165.0, 136.7, 133.4, 132.3, 131.5, 130.2, 129.8, 129.2, 127.9, 126.3, 124.7, 111.7, 111.1, 107.2, 89.2, 71.6, 64.1, 62.8, 30.2, 27.3; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{23}H_{16}BrCl_2N_2O_5^+$ 548.9614, Found 548.9632.



1-(2,4-dichlorophenyl)-4-(3,5-dimethoxyphenyl)-8,8-dimethyl-6,10-dioxo-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3ge). White solid, mp: 178-180; Yield 80% (84 mg); major isomer ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.61 (d, *J* = 8.5 Hz, 1H), 7.42 (d, *J* = 8.7 Hz, 2H), 6.79 (d, *J* = 9.9 Hz, 2H), 6.57 (s, 1H), 6.47 (s, 1H), 4.67 (s, 1H), 3.82 (s, 6H), 1.65 (s, 3H), 1.02 (s, 3H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 165.7, 165.3, 161.7, 136.5, 131.4, 130.2, 130.1, 129.1, 127.8, 127.4, 111.9, 111.6, 108.4, 107.1, 103.3, 89.2, 71.8, 64.8, 62.8, 55.5, 29.9, 27.4; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{25}H_{21}Cl_2N_2O_7^+$ 531.0720, Found 531.0718.



4-(3,5-dimethoxyphenyl)-8,8-dimethyl-1-(naphthalen-1-yl)-6,10-dioxo-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3he). Yellow solid, mp: 180-182, yield 68% (69 mg); major isomer ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.91 – 7.88 (m, 2H), 7.81 (dt, *J* = 7.3, 1.0 Hz, 1H), 7.60 – 7.54 (m, 2H), 7.54 – 7.47 (m, 2H), 6.92 (s, 1H), 6.82 (d, *J* = 2.2 Hz, 2H), 6.52 (t, *J* = 2.2 Hz, 1H), 4.88 (s, 1H), 3.80 (s, 6H), 1.16 (s, 3H), 0.98 (s, 3H); ^{13}C NMR (151 MHz, $CDCl_3$) δ 166.4, 165.7, 161.5, 133.4, 130.5, 129.6, 129.2, 128.0, 127.8, 127.1, 126.4, 126.0, 125.4, 121.6, 112.1, 112.0, 108.5, 106.6, 103.0, 90.0, 71.6, 64.3, 64.2, 55.5, 29.9, 26.9; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{29}H_{25}N_2O_7^+$ 513.1656, Found 513.1666.

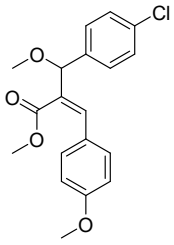


4-(2-methoxyphenyl)-8,8-dimethyl-1-(naphthalen-1-yl)-6,10-dioxo-2,7,9-trioxaspiro[4.5]decane-3,3-dicarbonitrile (3hi). White solid, mp: 171-174, yield 62% (60 mg); major isomer ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.93 (d, *J* = 8.0 Hz, 3H), 7.64 (d, *J* = 8.9 Hz, 2H), 7.62 – 7.60 (m, 2H), 7.57 – 7.50 (m, 2H), 7.00 (d, *J* = 9.0 Hz, 2H), 6.96 (s, 1H), 4.98 (s, 1H), 3.85 (s, 3H), 1.19 (s, 3H), 0.93 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 166.4, 165.8, 161.5, 133.4, 132.3, 130.4, 129.5, 129.3, 129.2, 127.9, 127.1, 126.4, 126.1, 126.0, 125.4, 121.6, 117.7, 115.2, 112.2, 111.9, 106.5, 89.9,

71.9, 64.3, 64.1, 55.4, 29.9, 26.9; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{28}H_{23}N_2O_6^+$ 483.1550, Found 483.1551.

General Procedure for the Preparation of Product 4:

The spiro compound **3bb** (0.1 mmol) was dissolved in 1 ml of methanol and 1 ml of 2 N HCl was added. The solution was stirred at 60 °C for 6h. Afterward, the mixture was then diluted with water and extracted with ethyl acetate. The organic layer was dried over magnesium sulfate, and the solvent was evaporated. The resulting residue was purified using column chromatography on silicagel with *n*-Hexane/Ethyl acetate = 4/1.



methyl (Z)-2-((4-chlorophenyl)(methoxy)methyl)-3-(4-methoxyphenyl)acrylate (4). Yellow oil; Yield 67% (23 mg); ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.45 – 7.40 (m, 2H), 7.27 (d, *J* = 8.5 Hz, 2H), 7.10 – 7.05 (m, 2H), 6.96 – 6.91 (m, 2H), 6.50 (d, *J* = 1.7 Hz, 1H), 4.89 (d, *J* = 1.8 Hz, 1H), 3.84 (s, 3H), 3.75 (s, 3H), 3.63 (s, 3H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 172.3, 168.4, 159.3, 137.0, 134.2, 133.0, 130.3, 129.7, 128.1, 114.3, 55.3, 54.5, 52.5, 51.8; HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{19}H_{20}ClO_4^+$ 347.1044, Found 347.1071.

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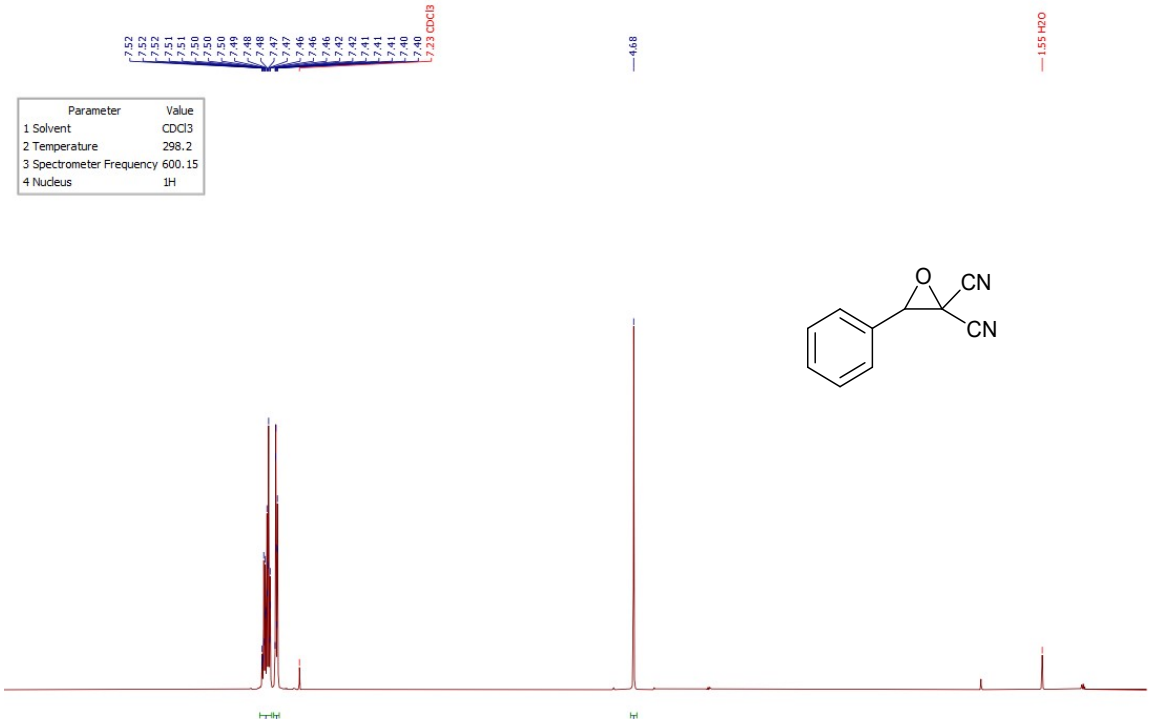
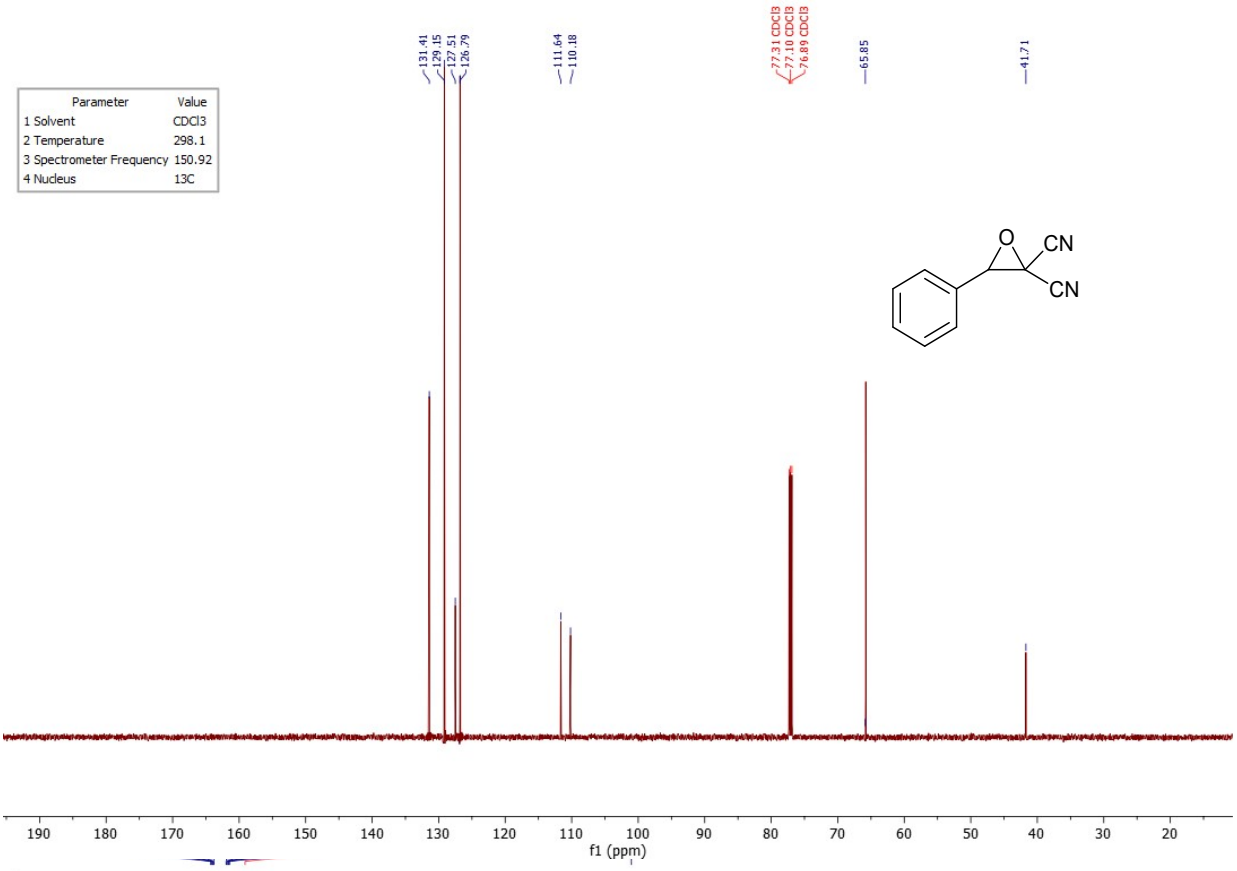
Copy of spectra

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127.51
126.79
111.64
110.18
77.31 CDCl3
77.10 CDCl3
76.89 CDCl3
65.85
41.71
Parameter Value
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4 Nucleus 13C
O
CN
CN
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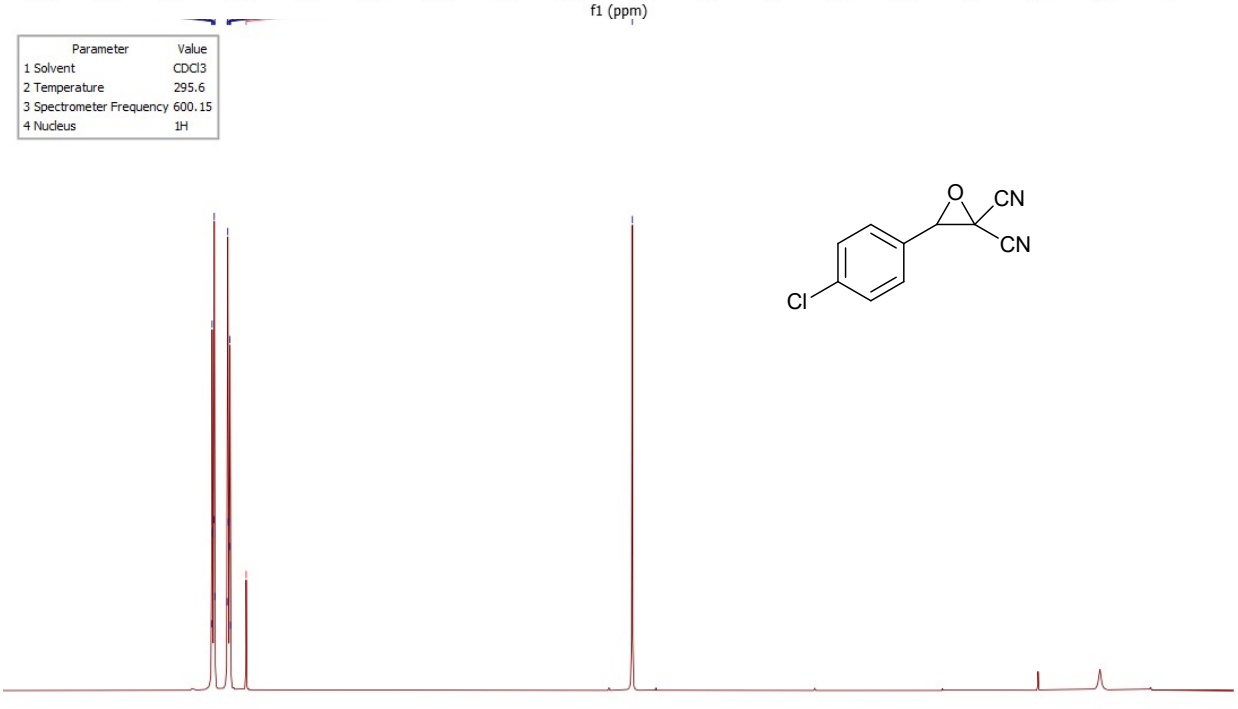
f1 (ppm)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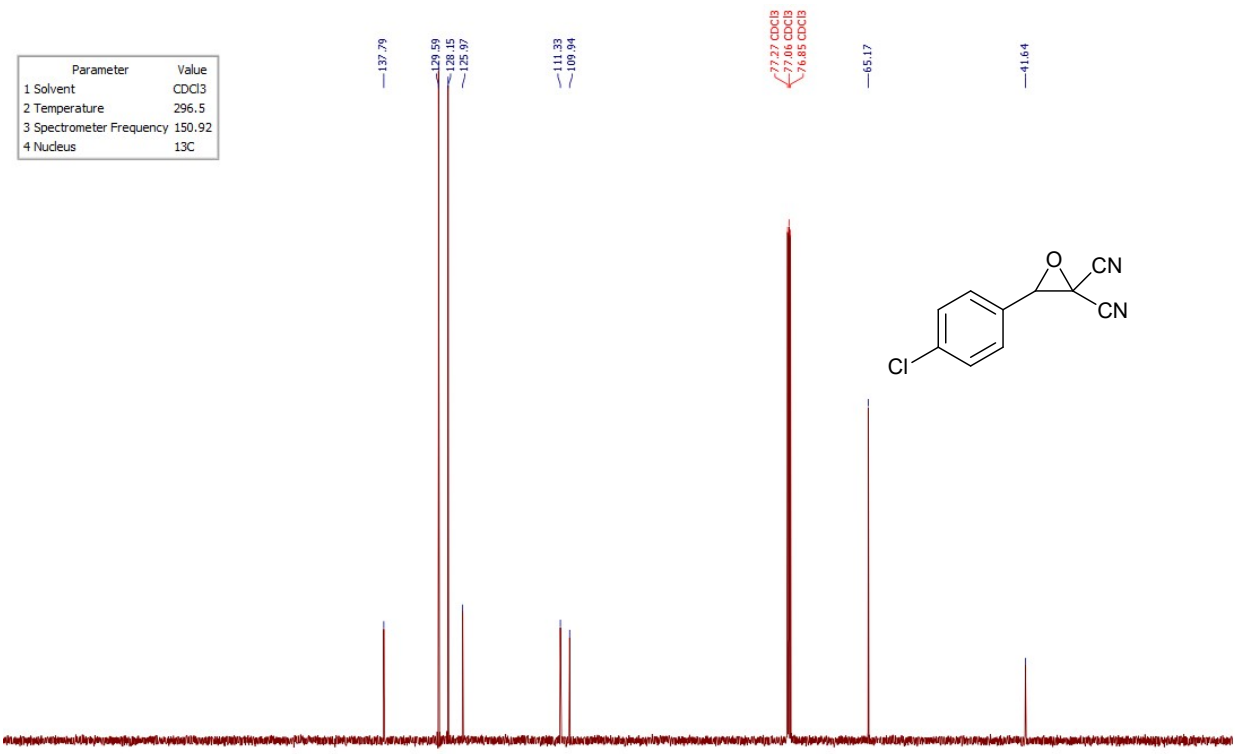
Cl


Parameter Value
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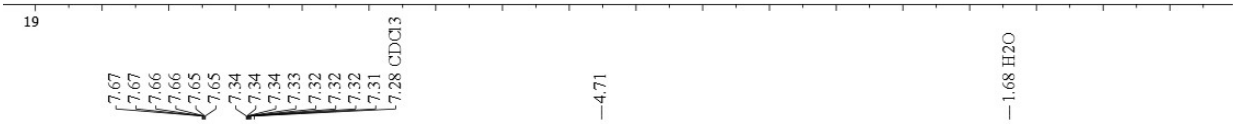
O
CN
CN
Cl


19
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7.67
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7.32
7.32
7.31
7.28 CDCl3
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Parameter Value
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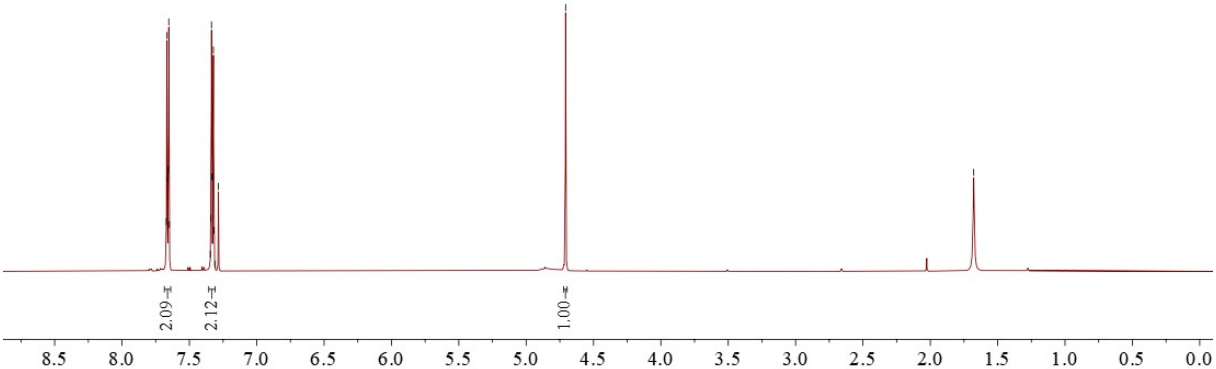
O
CN
CN
Br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1.5
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0.0

Parameter	Value
1 Solvent	CDCl3
2 Temperature	297.0
3 Spectrometer Frequency	150.92
4 Nucleus	13C

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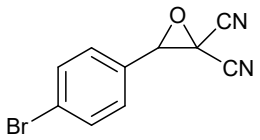

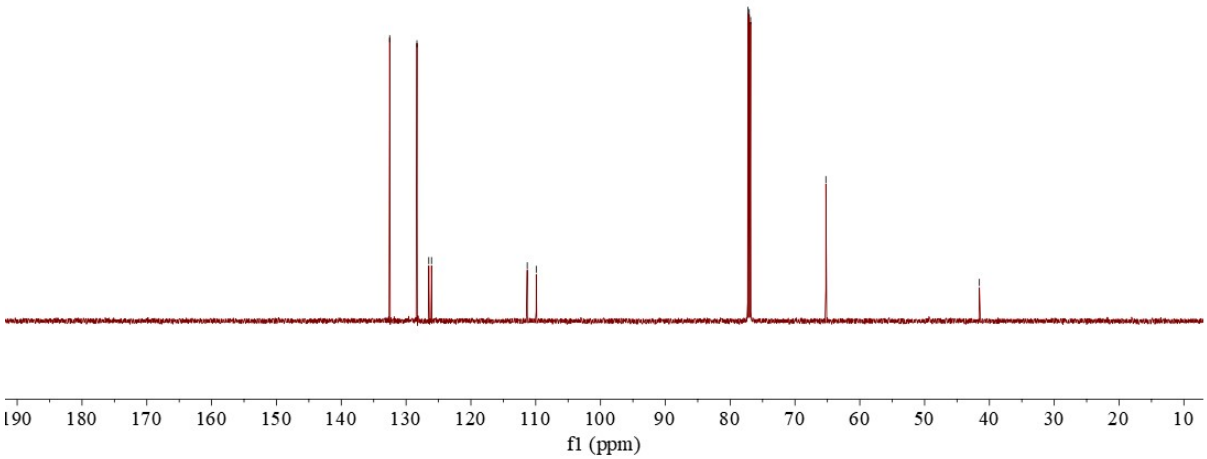

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Parameter	Value
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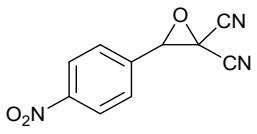

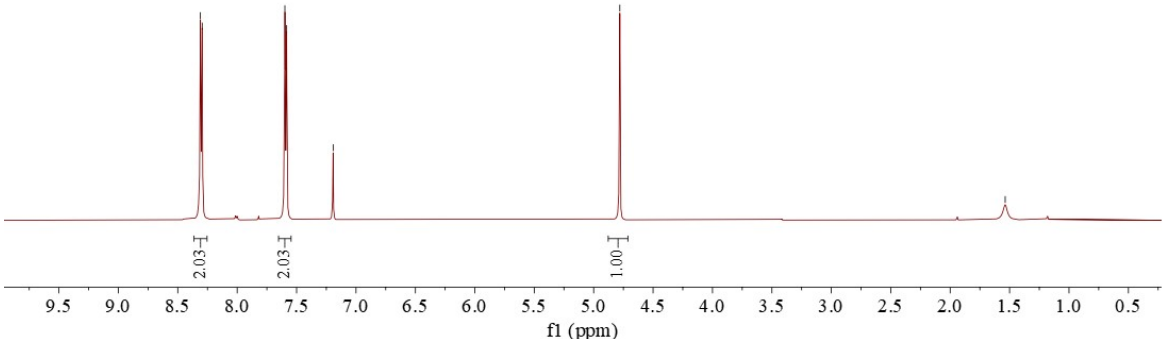

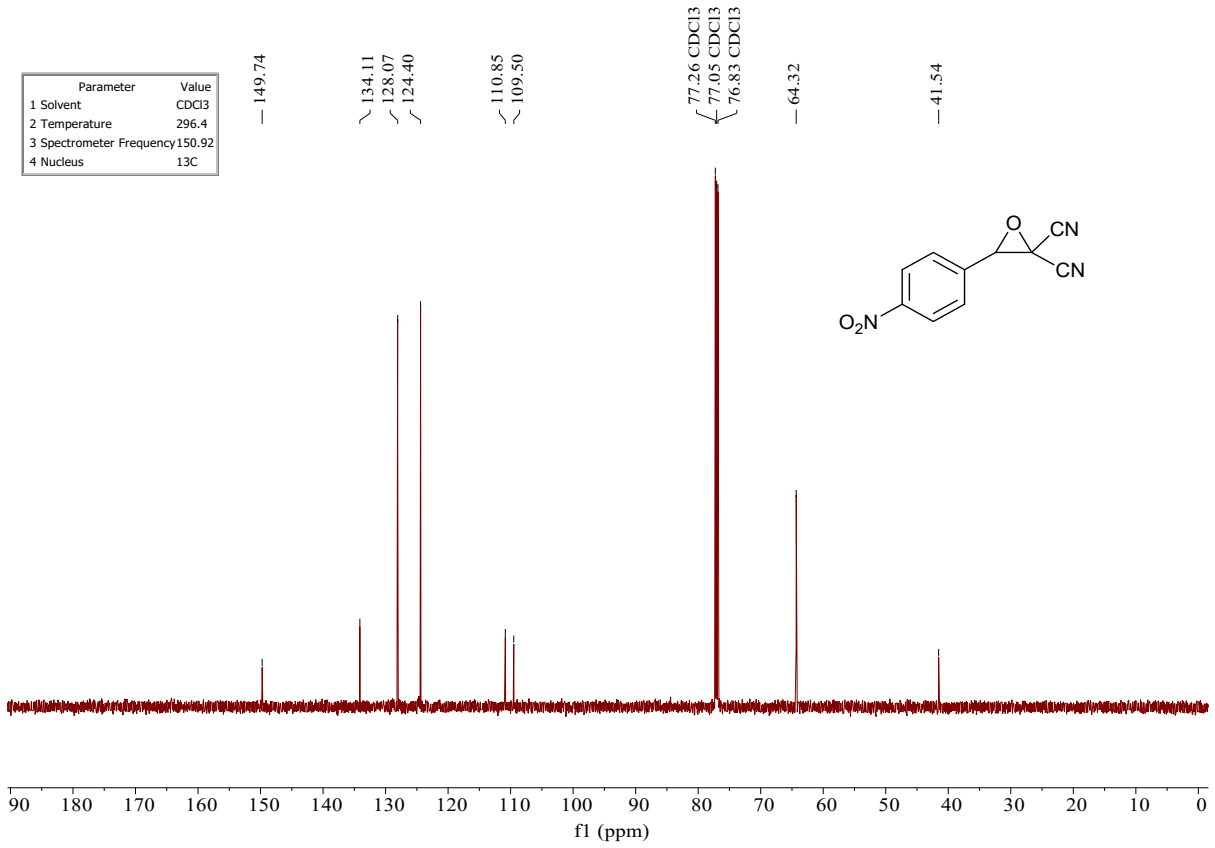
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77.05 CDCl3
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41.54
O
CN
CN
O2N
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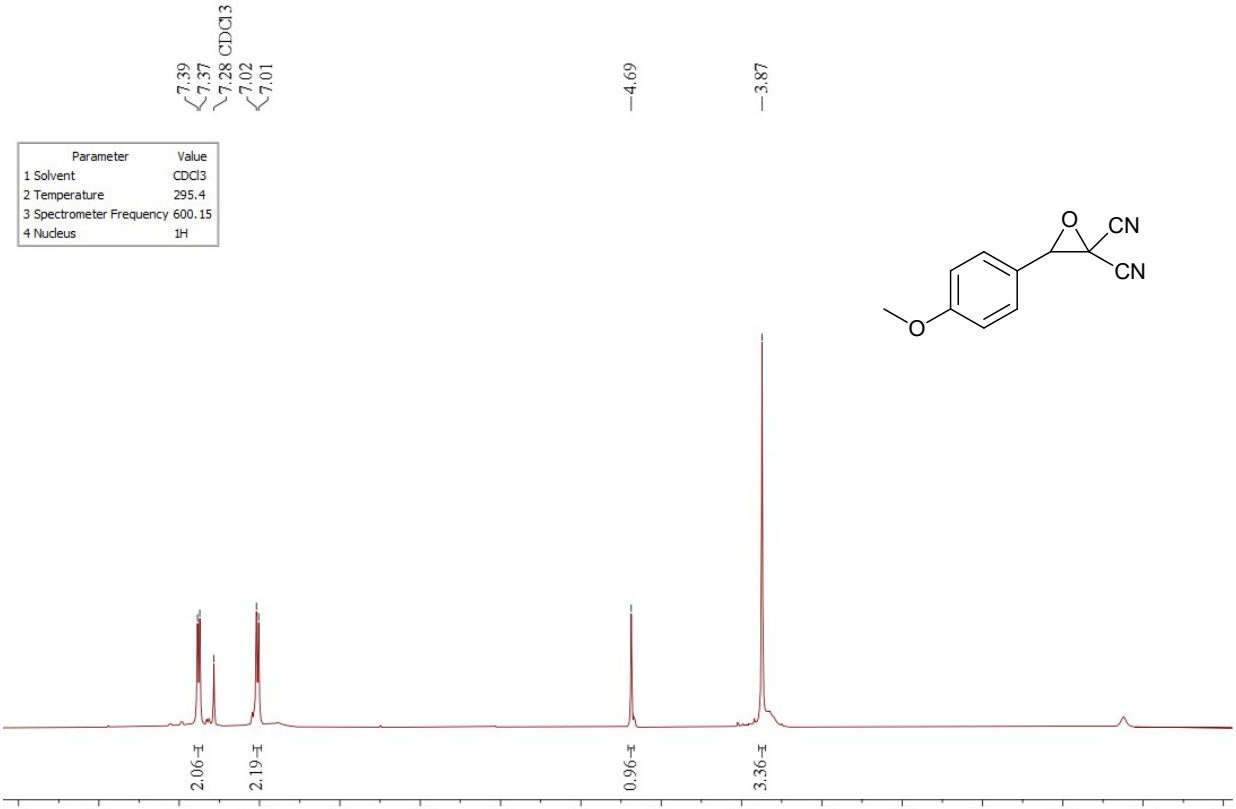
f1 (ppm)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7.37
7.28 CDCl3
7.02
7.01
4.69
3.87
Parameter Value
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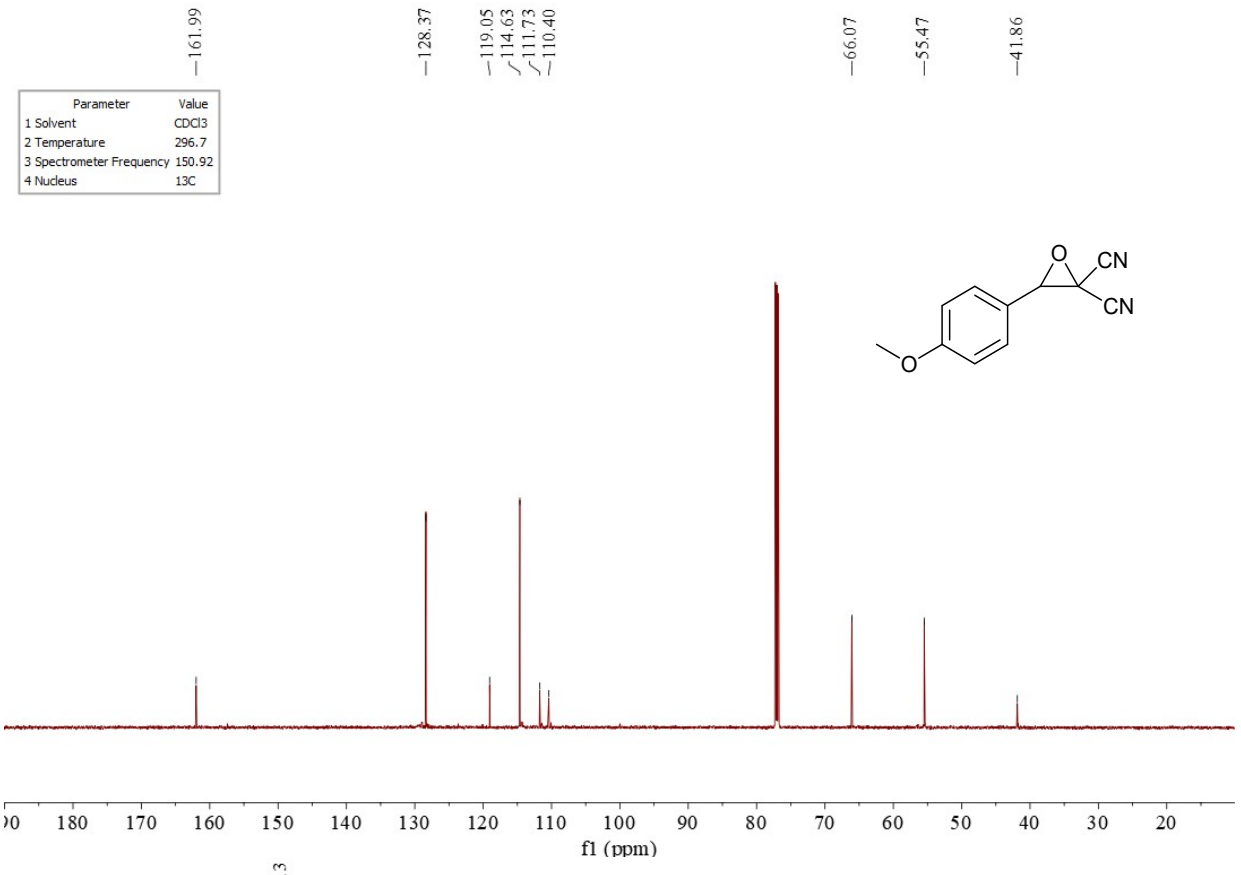
3 Spectrometer Frequency 600.15
4 Nucleus 1H
O
CN
CN
O
2.06
2.19
0.96
3.36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111.73
110.40
66.07
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3 Spectrometer Frequency 150.92
4 Nucleus 13C
O
CN
CN
O
f1 (ppm)


7.34
7.33
7.32
7.30
7.28 CDCl3
4.70
2.43
Parameter Value
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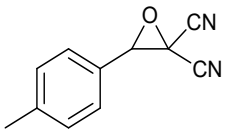
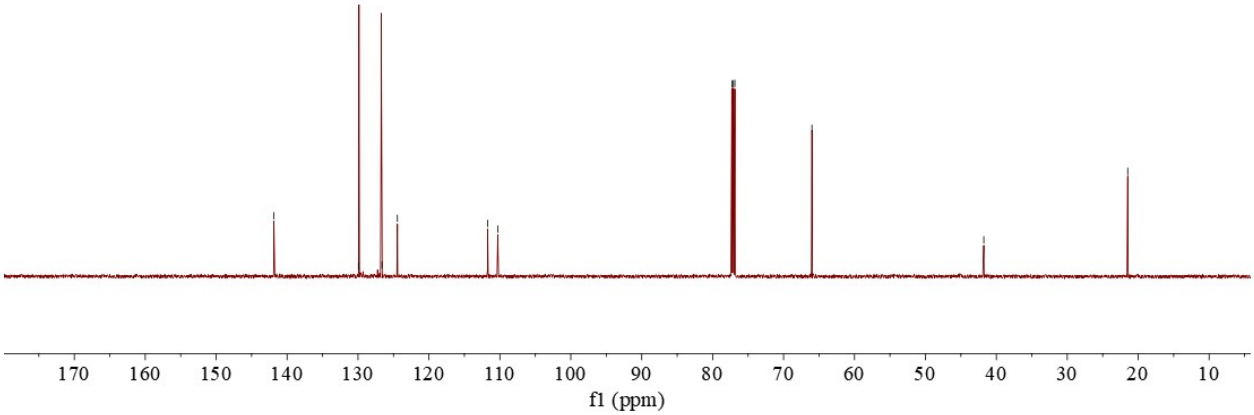
2 Temperature 296.0
3 Spectrometer Frequency 600.15
4 Nucleus 1H
O
CN
CN
4.37
1.00
3.40

Parameter	Value
1 Solvent	CDCl3
2 Temperature	297.1
3 Spectrometer Frequency	150.92
4 Nucleus	13C

141.86
129.94
126.62
124.44
111.72
110.30
77.29 CDCl3
77.08 CDCl3
76.86 CDCl3
66.00
41.77
21.48

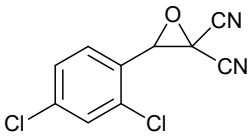


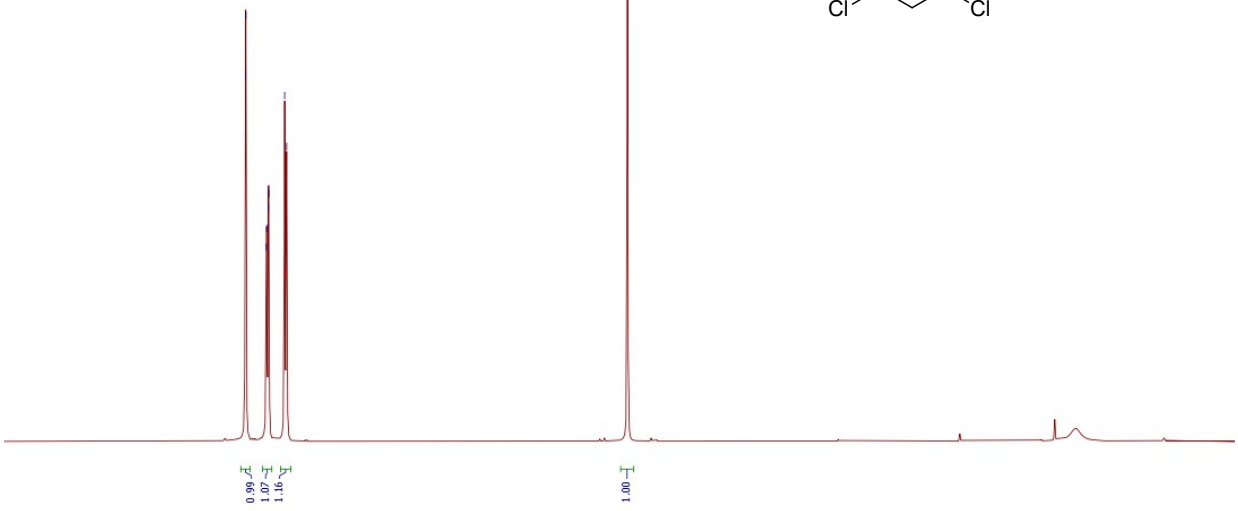


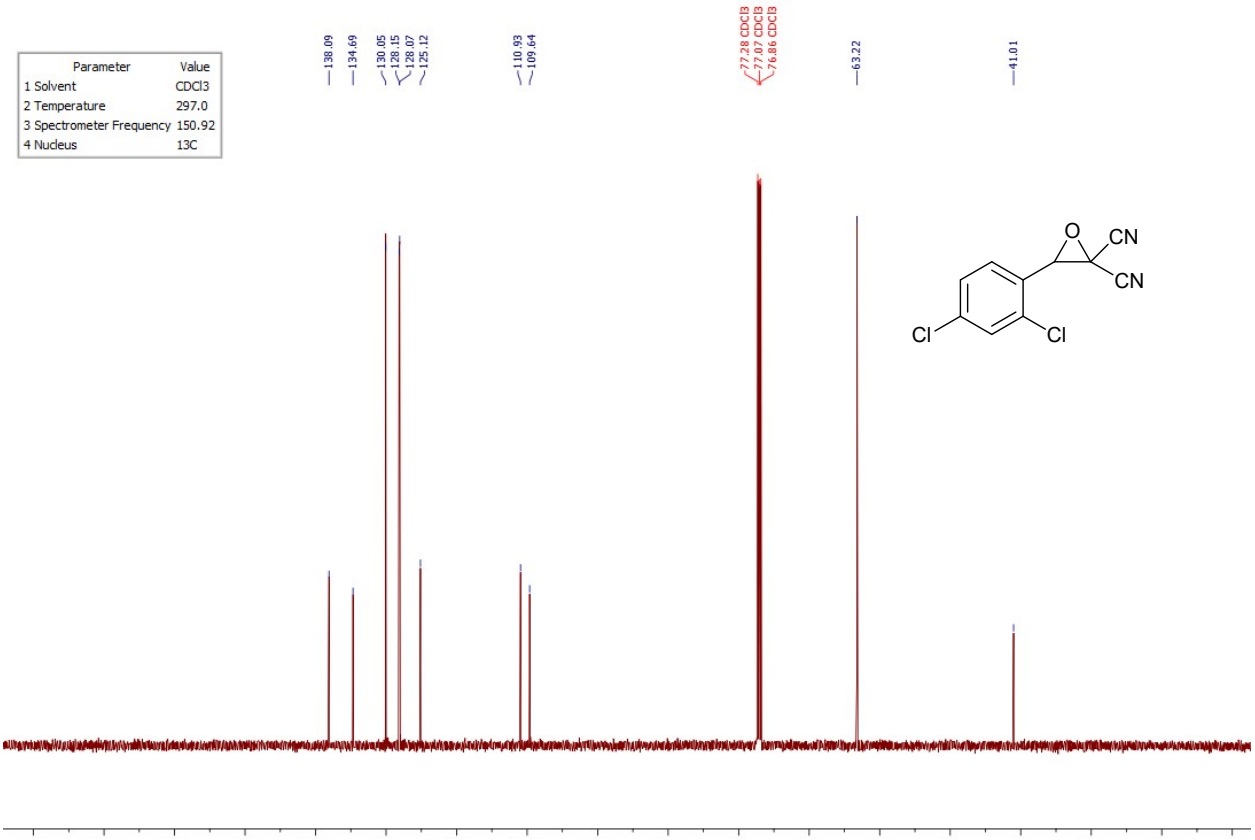
7.56
7.56
7.42
7.42
7.41
7.40
7.30
7.29 CDCl3
7.28

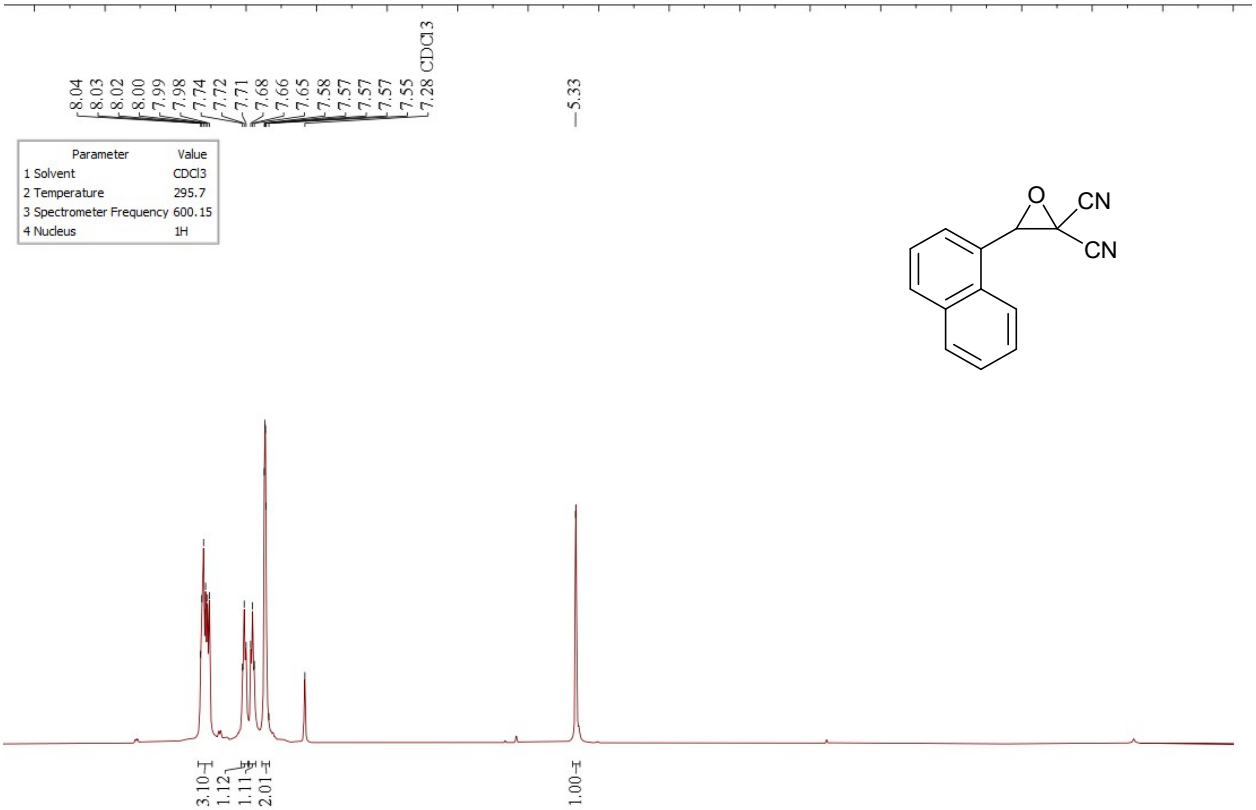
4.95

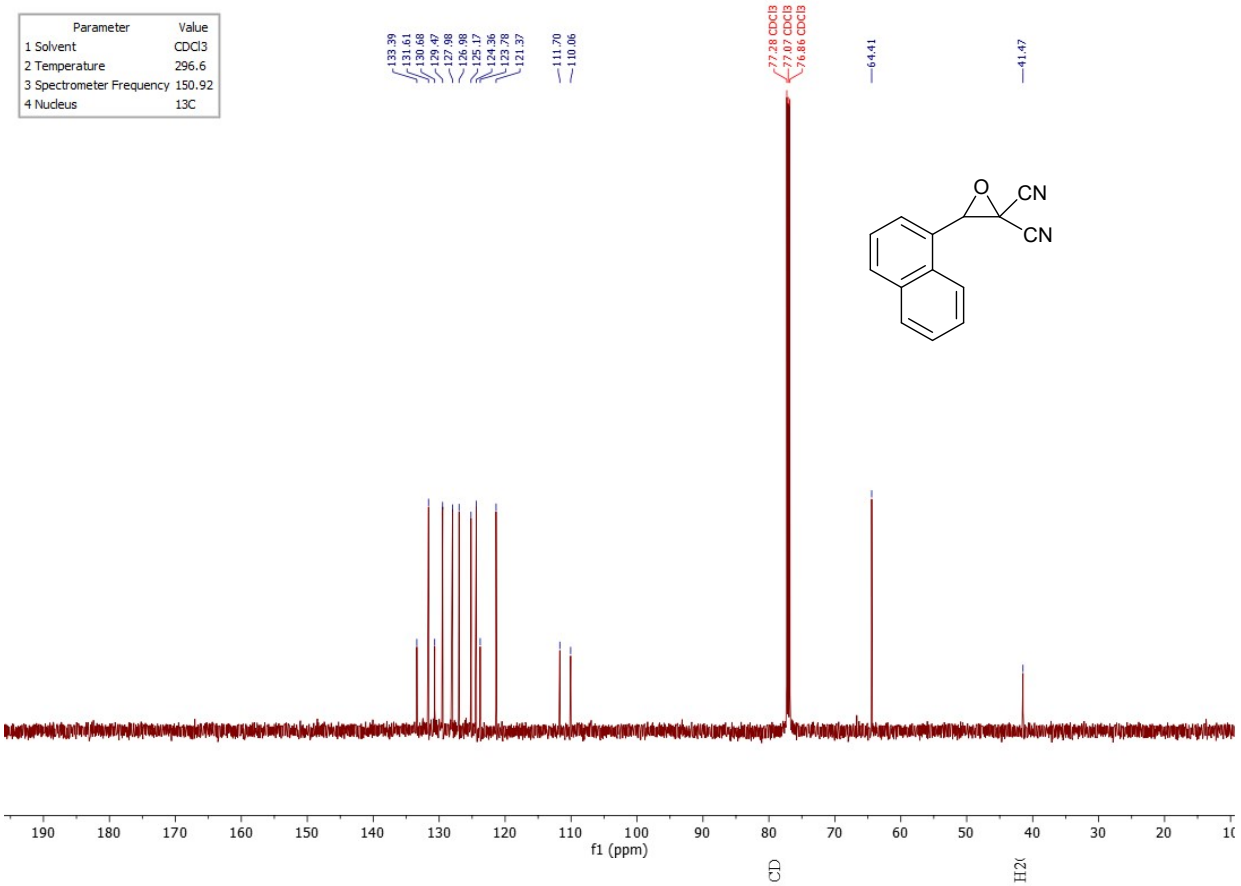
Parameter	Value
1 Solvent	CDCl3
2 Temperature	296.0
3 Spectrometer Frequency	600.15
4 Nucleus	1H

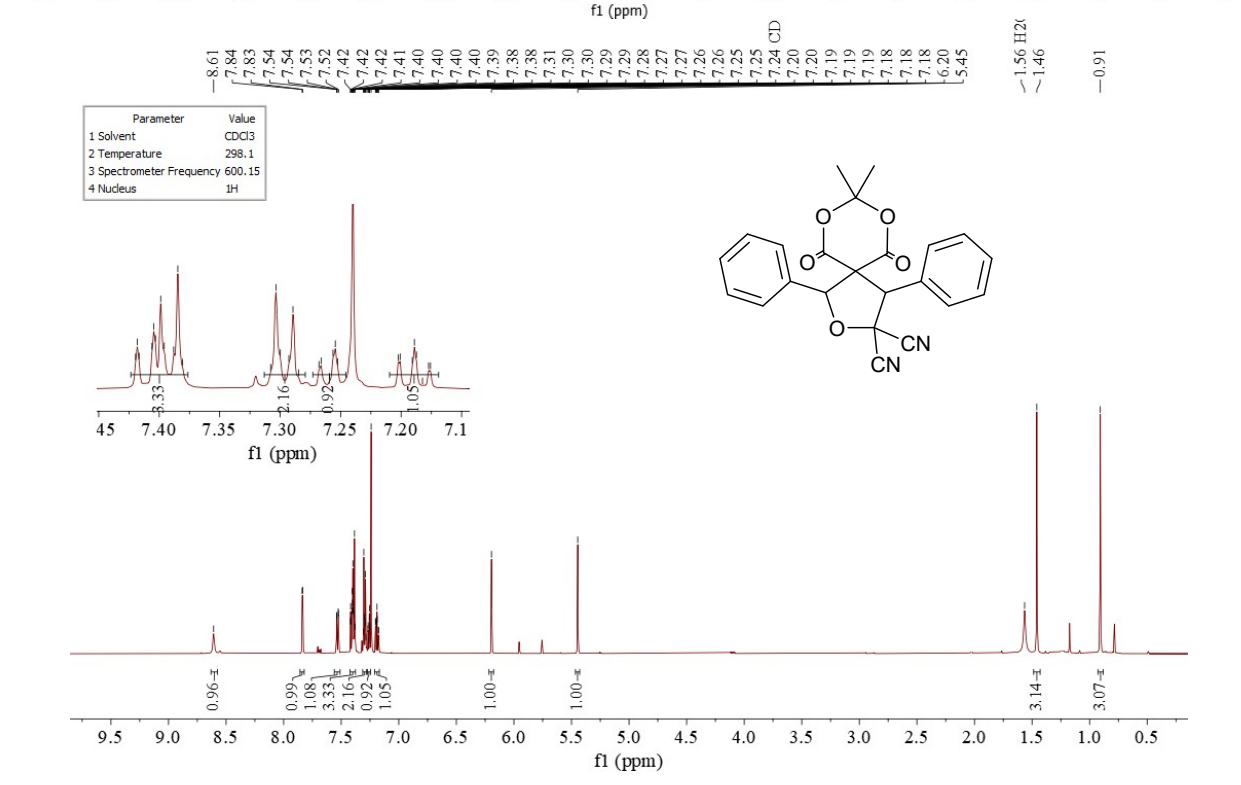





Parameter Value
1 Solvent CDCl3
2 Temperature 297.0
3 Spectrometer Frequency 150.92
4 Nucleus 13C
138.09
134.69
130.05
128.15
128.07
125.12
110.93
109.64
77.28 CDCl3
77.07 CDCl3
76.86 CDCl3
63.22
41.01
O
CN
CN
Cl
Cl


8.04
8.03
8.02
8.00
7.99
7.98
7.74
7.72
7.71
7.68
7.66
7.65
7.58
7.57
7.57
7.57
7.55
7.28 CDCl3
5.33
Parameter Value
1 Solvent CDCl3
2 Temperature 295.7
3 Spectrometer Frequency 600.15
4 Nucleus 1H
O
CN
CN
3.10
1.12
1.11
2.01
1.00


Parameter Value
1 Solvent CDCl3
2 Temperature 296.6
3 Spectrometer Frequency 150.92
4 Nucleus 13C
133.39
131.61
130.68
129.47
127.98
126.98
125.17
124.36
123.78
121.37
111.70
110.06
77.28 CDCl3
77.07 CDCl3
76.86 CDCl3
64.41
41.47
O
CN
CN
f1 (ppm)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7.42
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7.42
7.41
7.40
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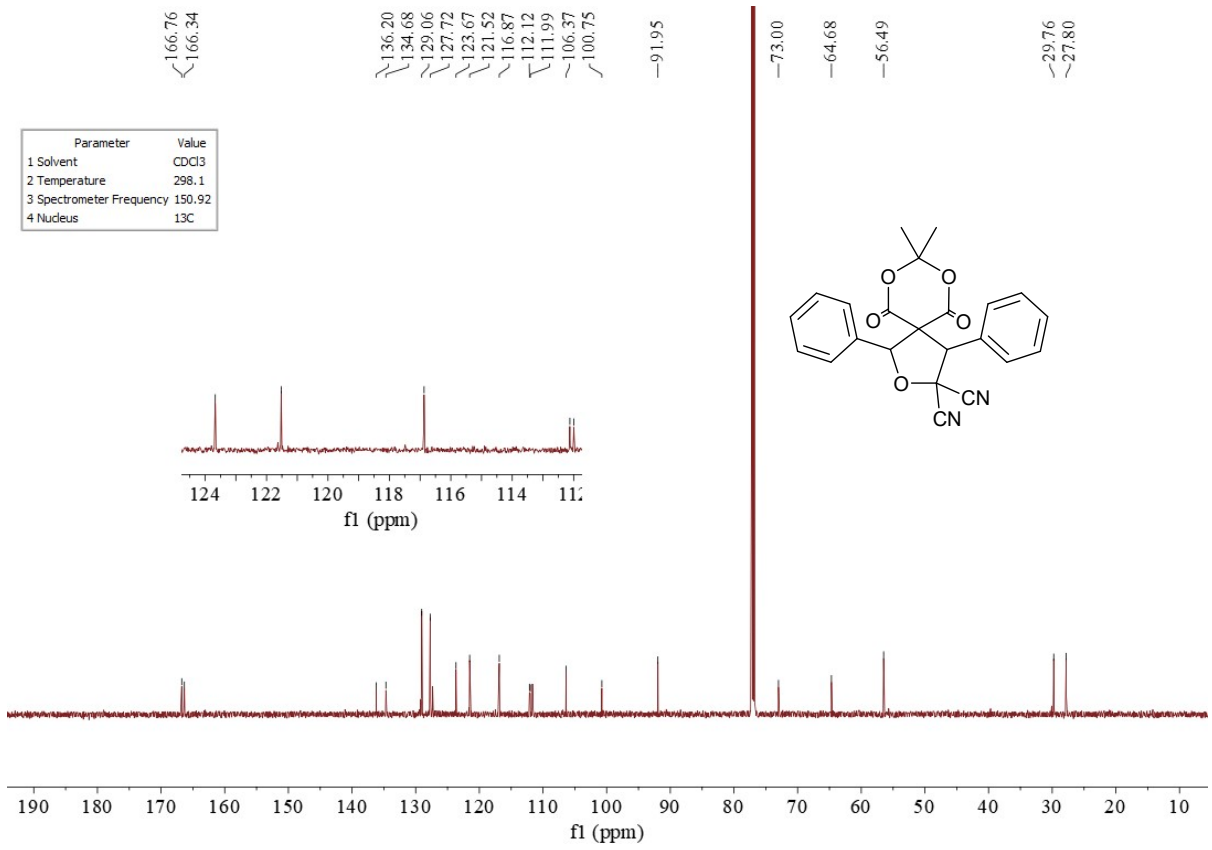
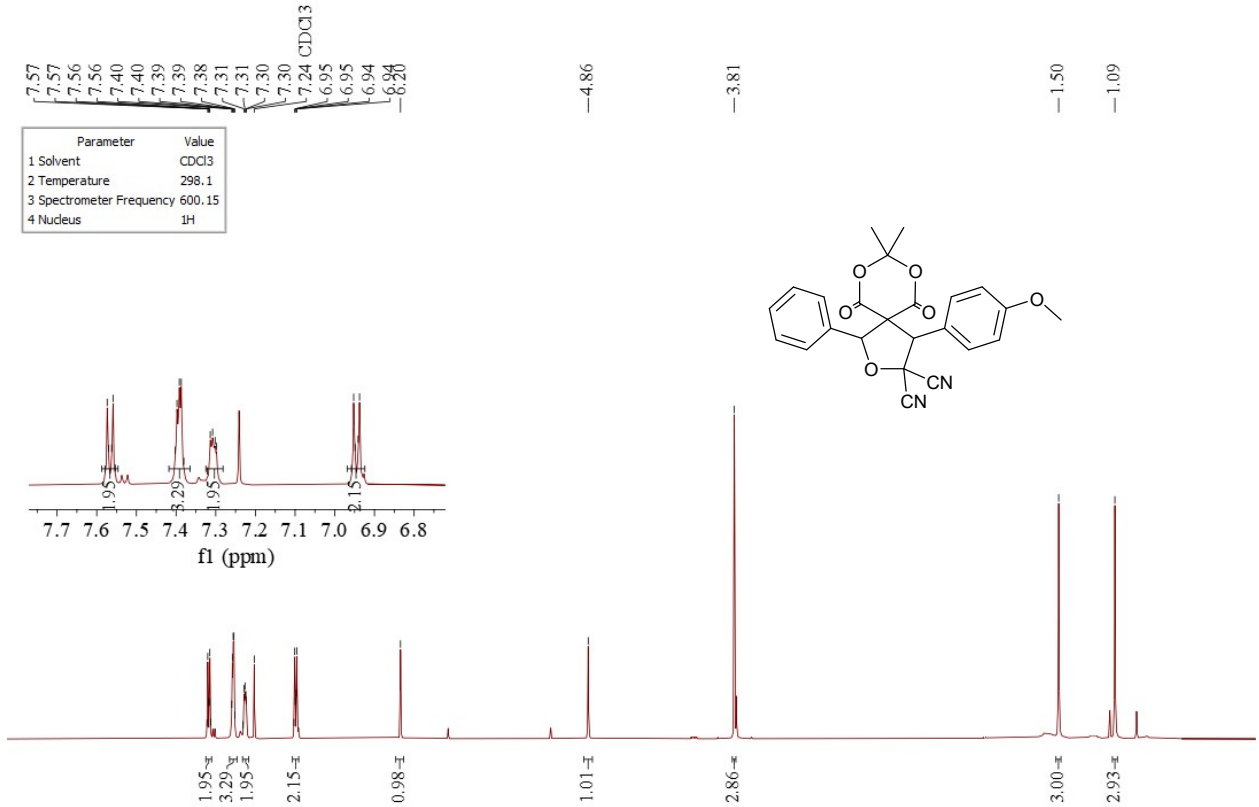
7.40
7.40
7.39
7.38
7.38
7.31
7.30
7.30
7.29
7.29
7.28
7.27
7.27
7.26
7.26
7.25
7.25
7.24 CD
7.20
7.20
7.19
7.19
7.19
7.18
7.18
6.20
5.45
1.56 H2(
1.46
0.91
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 600.15
4 Nucleus 1H
O
O
O
O
O
CN
CN
0.96
0.99
1.08
3.33
2.16
0.92
1.05
1.00
1.00
3.14
3.07
f1 (ppm)


166.76
166.34
136.20
134.68
129.06
127.72
123.67
121.52
116.87
112.12
111.99
106.37
100.75
91.95
73.00
64.68
56.49
29.76
27.80
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 150.92
4 Nucleus 13C
O
O
O
O
O
O
CN
CN
124 122 120 118 116 114
f1 (ppm)
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)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7.56
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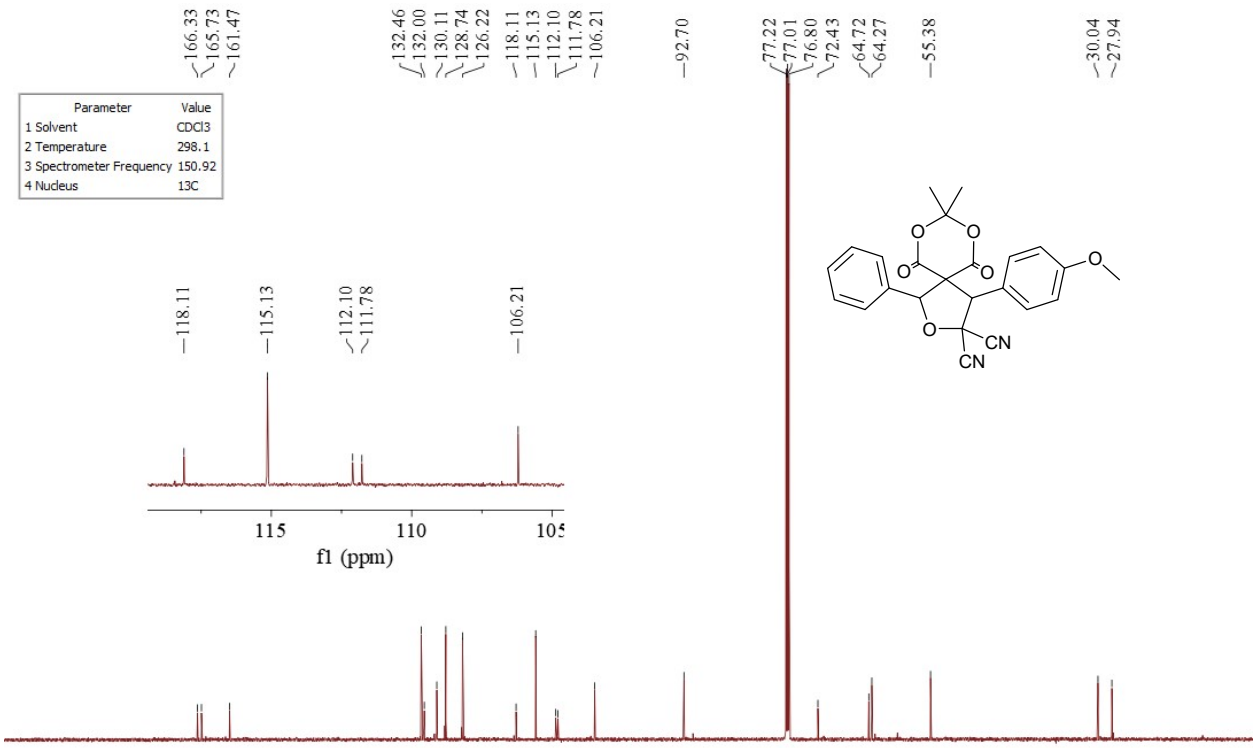
7.40
7.39
7.39
7.38
7.31
7.31
7.30
7.30
7.24 CDCl3
6.95
6.95
6.94
6.94
6.20
4.86
3.81
1.50
1.09
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 600.15
4 Nucleus 1H
O
O
O
O
O
O
CN
CN
1.95
3.29
1.95
2.15
7.7 7.6 7.5 7.4 7.3 7.2 7.1 7.0 6.9 6.8
f1 (ppm)
1.95
3.29
1.95
2.15
0.98
1.01
2.86
3.00
2.93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165.73
161.47
132.46
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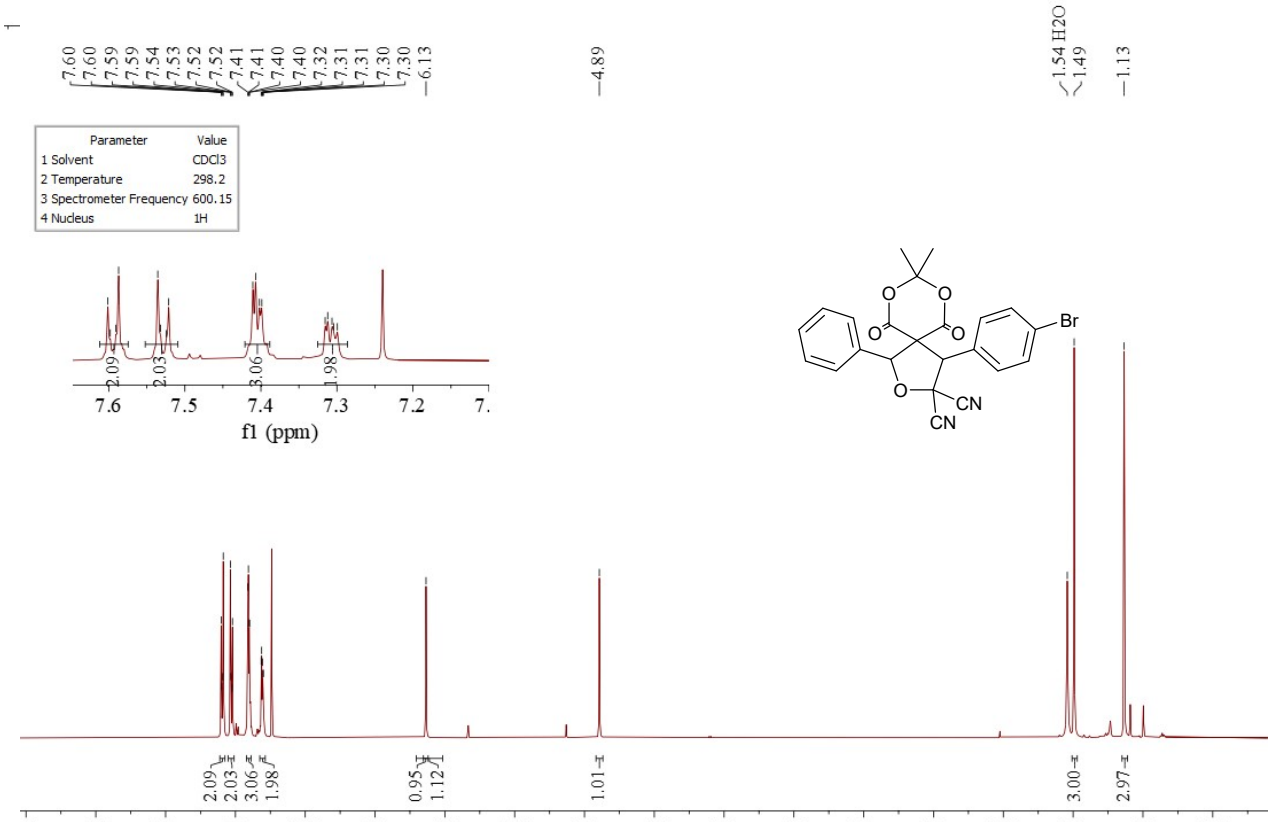
130.11
128.74
126.22
118.11
115.13
112.10
111.78
106.21
92.70
77.22
77.01
76.80
72.43
64.72
64.27
55.38
30.04
27.94
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 150.92
4 Nucleus 13C
O
O
O
O
O
O
CN
CN
f1 (ppm)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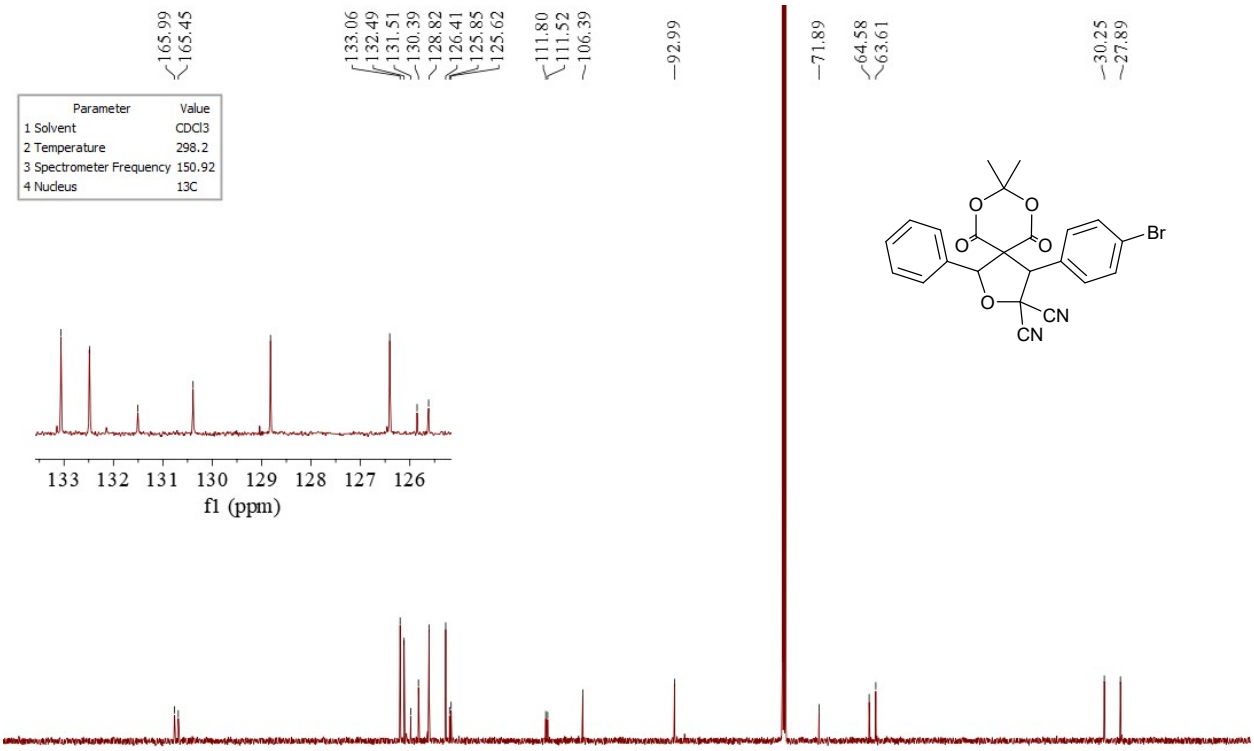
7.59
7.59
7.54
7.53
7.52
7.52
7.41
7.41
7.40
7.40
7.32
7.31
7.31
7.30
7.30
6.13
4.89
1.54 H2O
1.49
1.13
Parameter Value
1 Solvent CDCl3
2 Temperature 298.2
3 Spectrometer Frequency 600.15
4 Nucleus 1H
2.09
2.03
3.06
1.98
f1 (ppm)
O
O
O
O
O
Br
CN
CN
0.95
1.12
1.01
3.00
2.97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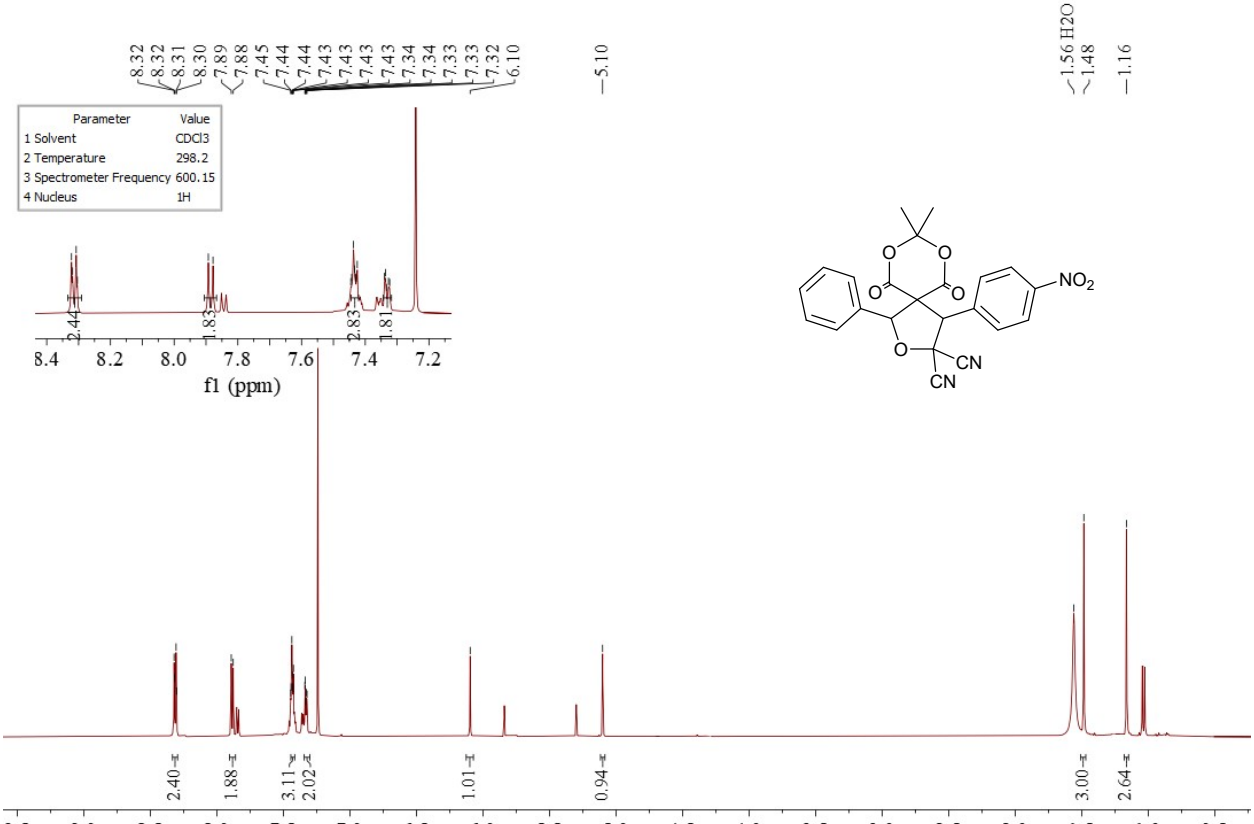
165.45
133.06
132.49
131.51
130.39
128.82
126.41
125.85
125.62
111.80
111.52
106.39
92.99
71.89
64.58
63.61
30.25
27.89
Parameter Value
1 Solvent CDCl3
2 Temperature 298.2
3 Spectrometer Frequency 150.92
4 Nucleus 13C
Br
CN
CN
133 132 131 130 129 128 127 126
f1 (ppm)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8.31
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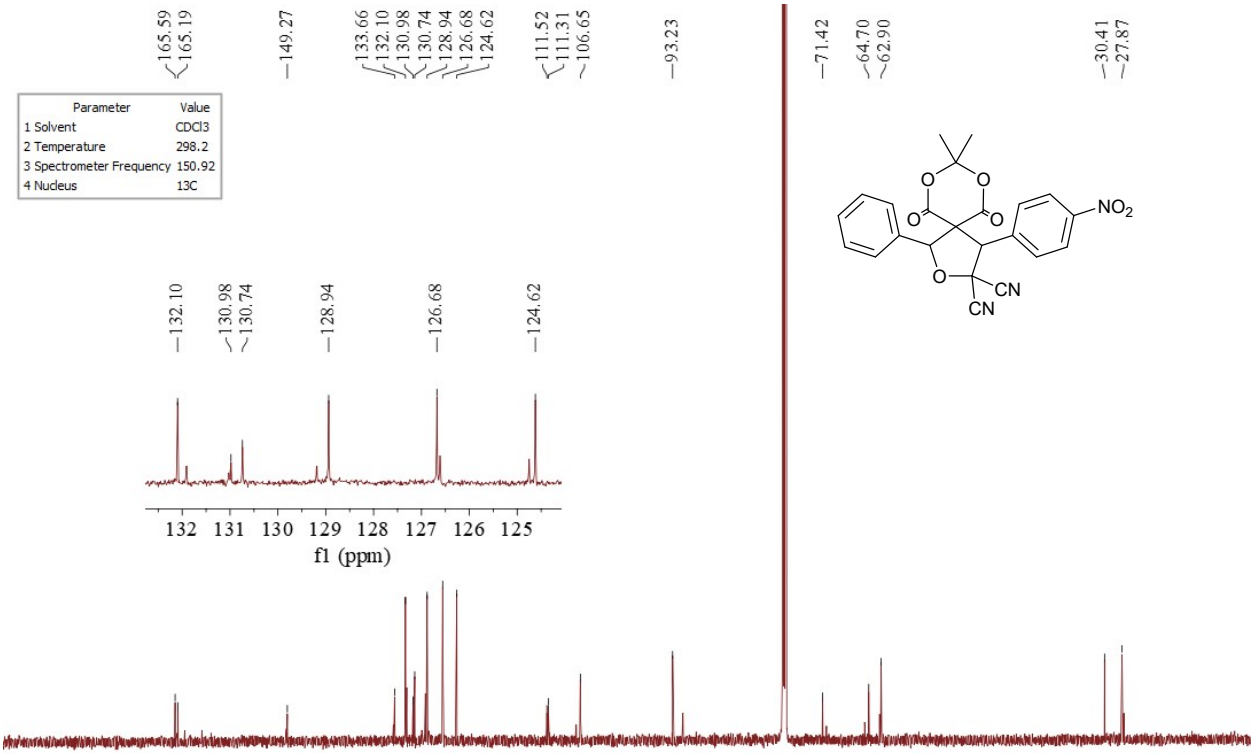
7.88
7.45
7.44
7.44
7.43
7.43
7.43
7.43
7.34
7.33
7.33
7.32
6.10
5.10
1.56 H2O
1.48
1.16
Parameter Value
1 Solvent CDCl3
2 Temperature 298.2
3 Spectrometer Frequency 600.15
4 Nucleus 1H
NO2
CN
CN
2.44
1.83
2.83
1.81
8.4 8.2 8.0 7.8 7.6 7.4 7.2
f1 (ppm)
2.40
1.88
3.11
2.02
1.01
0.94
3.00
2.64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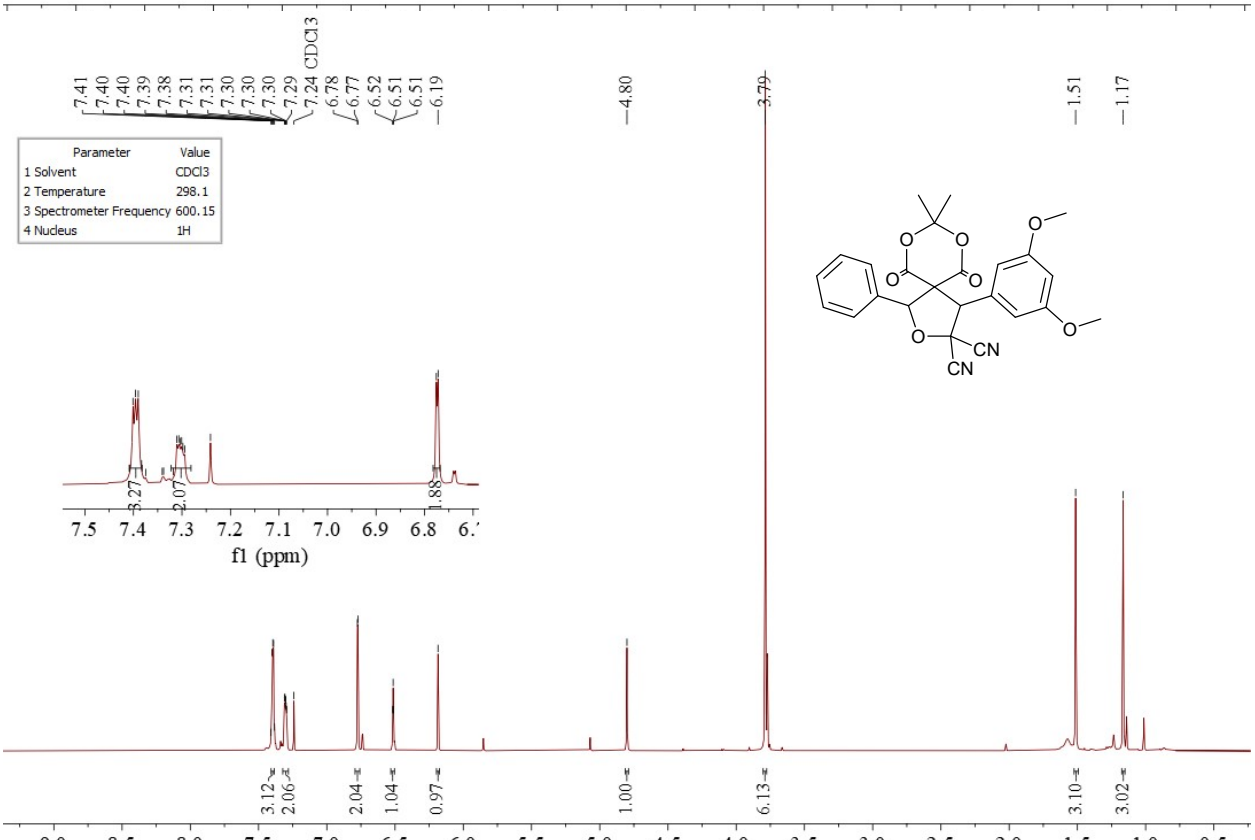
165.19
149.27
133.66
132.10
130.98
130.74
128.94
126.68
124.62
111.52
111.31
106.65
93.23
71.42
64.70
62.90
30.41
27.87
Parameter Value
1 Solvent CDCl3
2 Temperature 298.2
3 Spectrometer Frequency 150.92
4 Nucleus 13C
NO2
CN
CN
132.10
130.98
130.74
128.94
126.68
124.62
132 131 130 129 128 127 126 125
f1 (ppm)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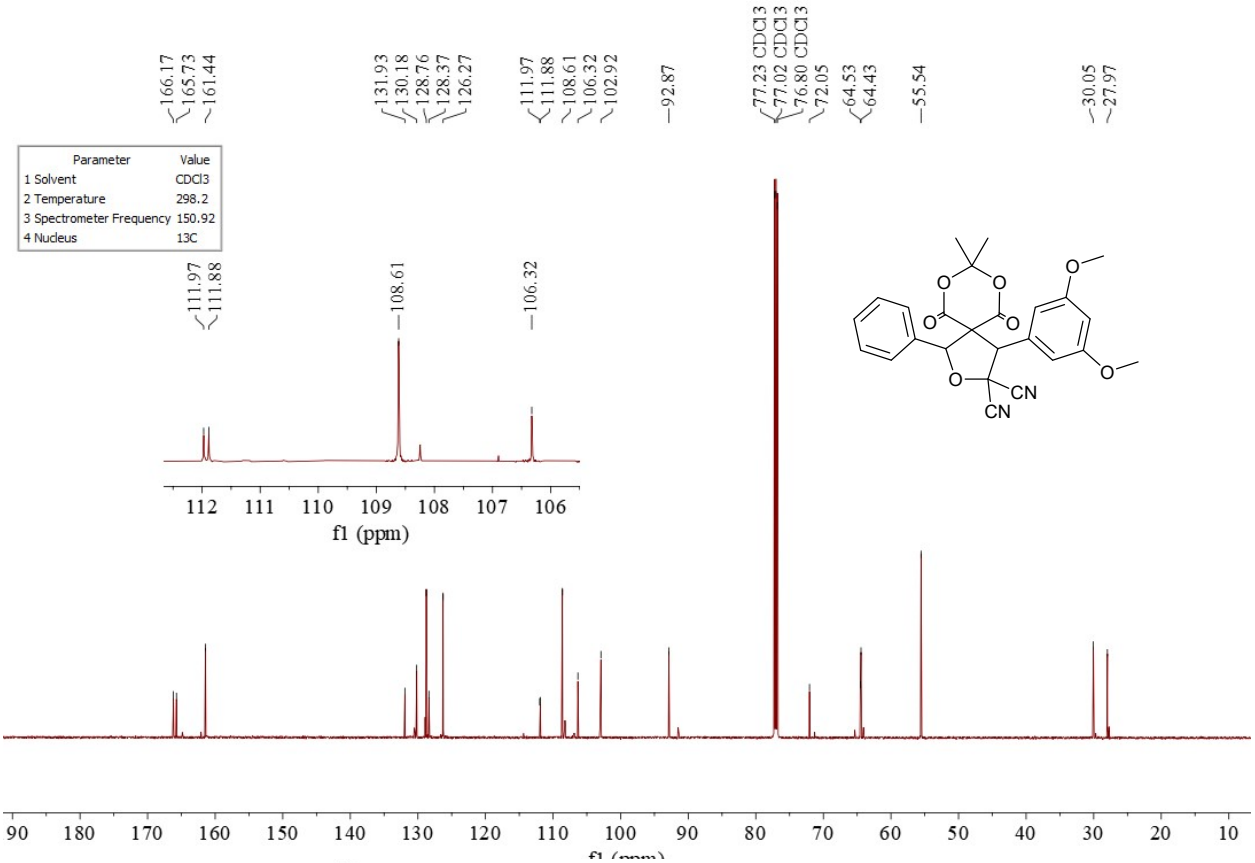
7.39
7.38
7.31
7.31
7.30
7.30
7.30
7.29
CDCl3
6.78
6.77
6.52
6.51
6.51
6.19
4.80
3.79
1.51
1.17
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 600.15
4 Nucleus 1H
CN
CN
3.27
2.07
1.88
7.5 7.4 7.3 7.2 7.1 7.0 6.9 6.8
f1 (ppm)
3.12
2.06
2.04
1.04
0.97
1.00
6.13
3.10
3.02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165.73
161.44
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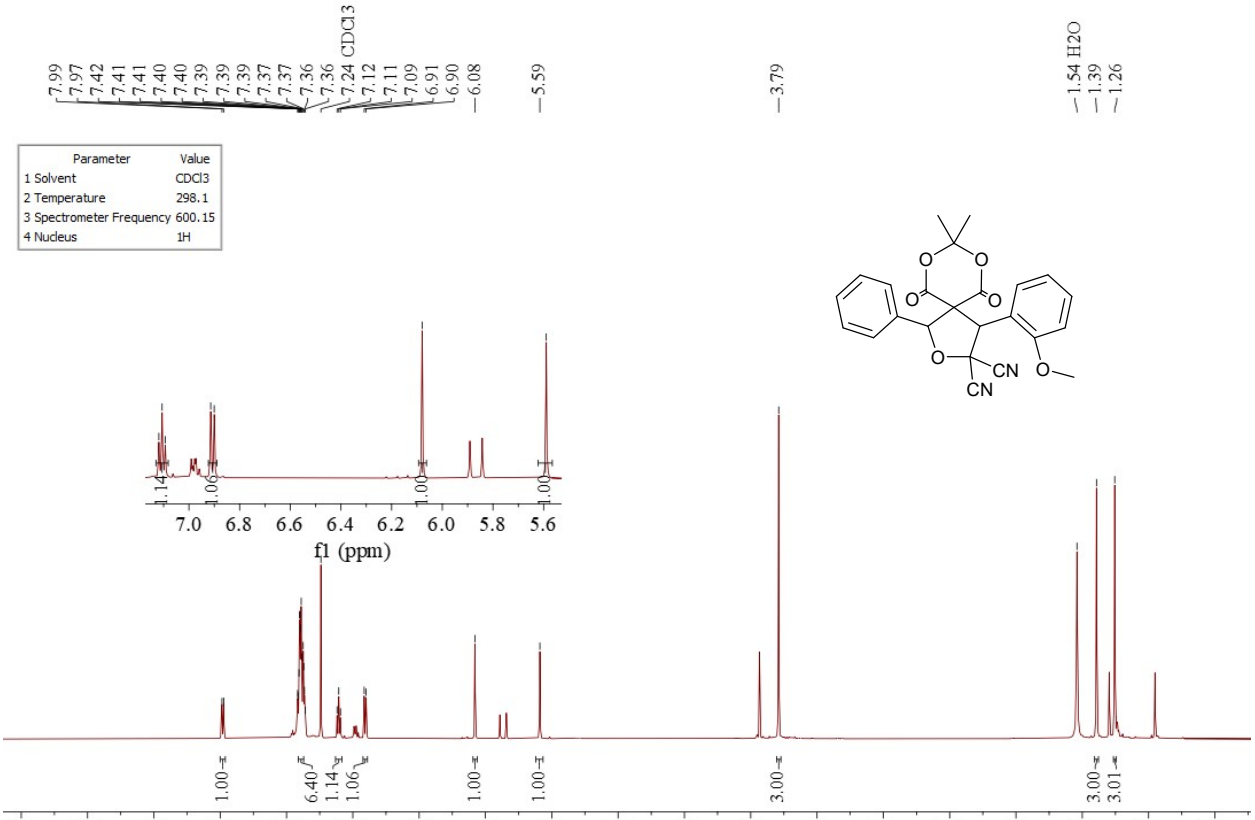
130.18
128.76
128.37
126.27
111.97
111.88
108.61
106.32
102.92
92.87
77.23 CDCl3
77.02 CDCl3
76.80 CDCl3
72.05
64.53
64.43
55.54
30.05
27.97
Parameter Value
1 Solvent CDCl3
2 Temperature 298.2
3 Spectrometer Frequency 150.92
4 Nucleus 13C
f1 (ppm)
f1 (ppm)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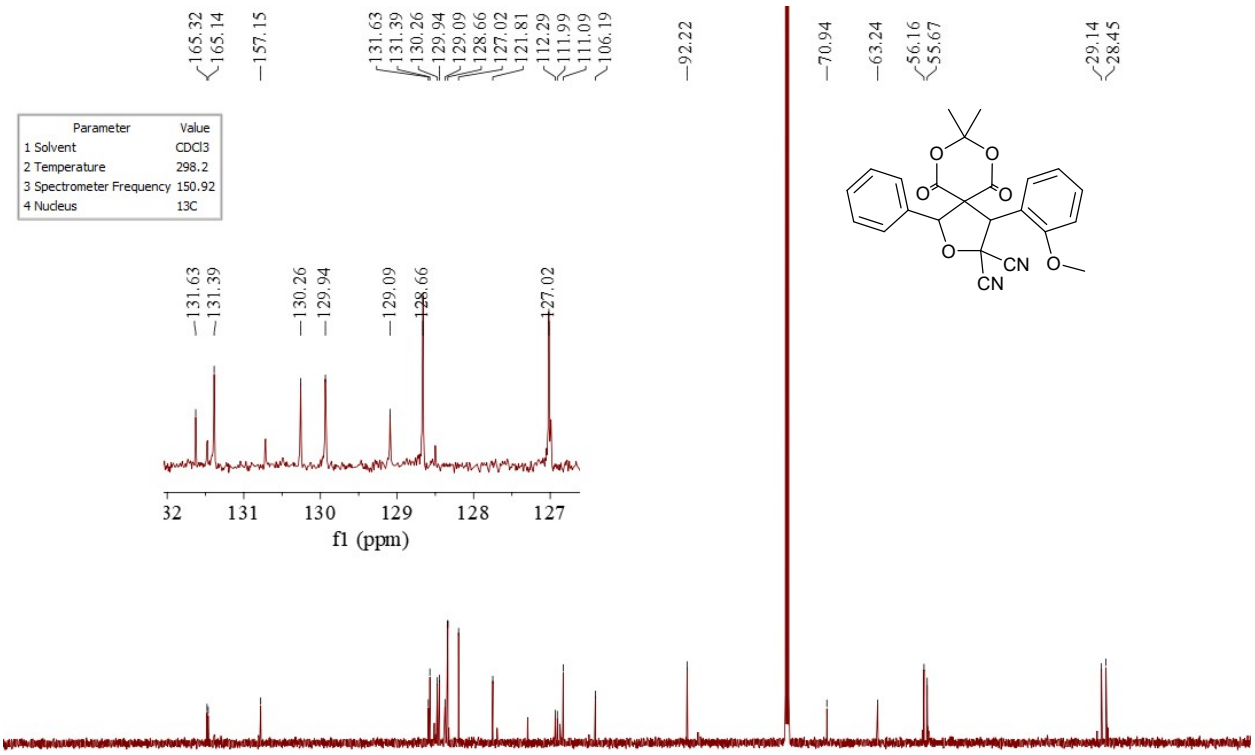
7.40
7.39
7.39
7.39
7.37
7.37
7.36
7.36
7.24 CDCl3
7.12
7.11
7.09
6.91
6.90
6.08
5.59
3.79
1.54 H2O
1.39
1.26
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 600.15
4 Nucleus 1H
1.14
1.06
1.00
1.00
f1 (ppm)
1.00
6.40
1.14
1.06
1.00
1.00
3.00
3.00
3.01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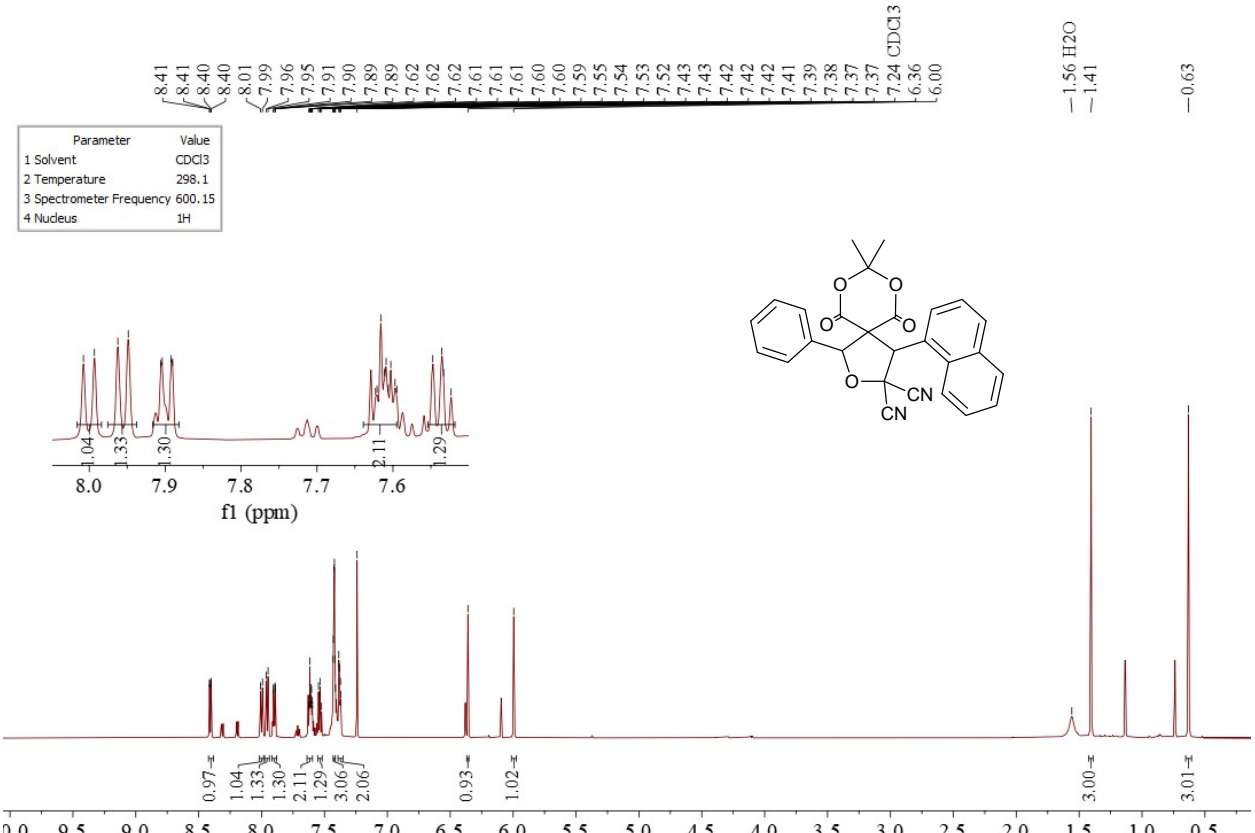
128.66
127.02
121.81
112.29
111.99
111.09
106.19
92.22
70.94
63.24
56.16
55.67
29.14
28.45
Parameter Value
1 Solvent CDCl3
2 Temperature 298.2
3 Spectrometer Frequency 150.92
4 Nucleus 13C
CN
CN
O
f1 (ppm)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7.96
7.95
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7.89
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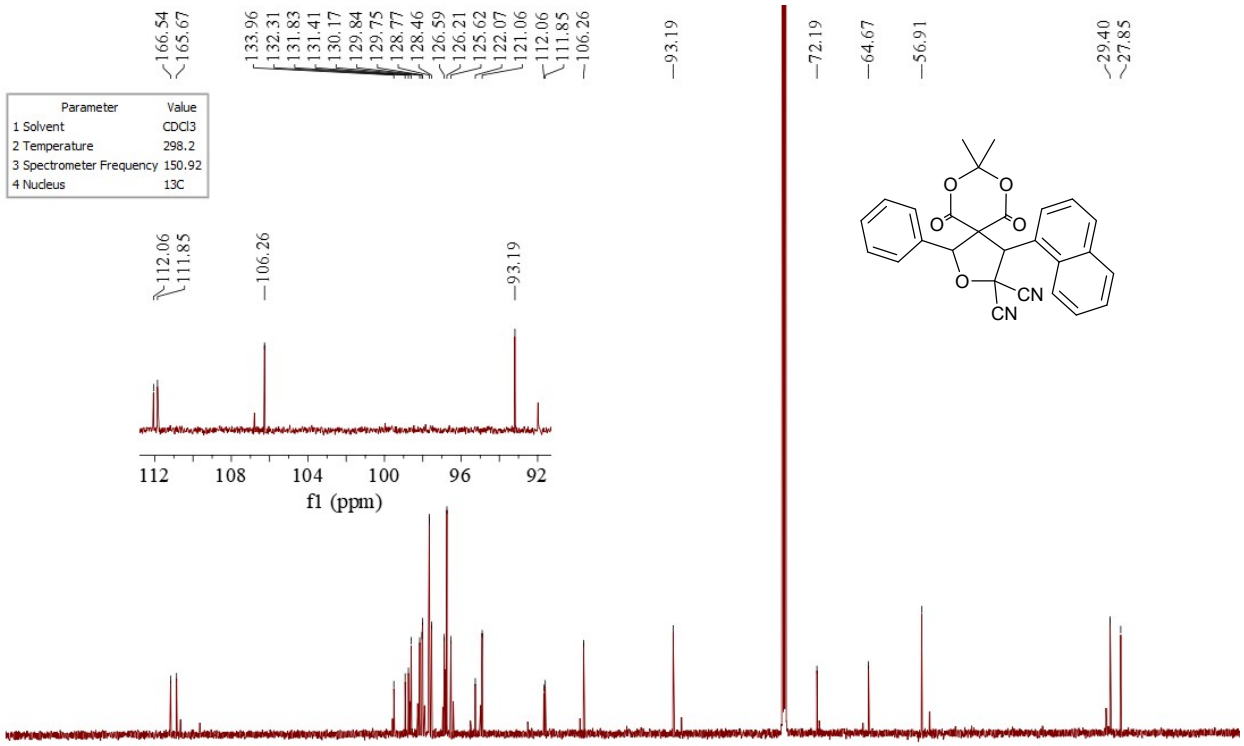
7.62
7.62
7.62
7.61
7.61
7.61
7.60
7.60
7.59
7.55
7.54
7.53
7.52
7.43
7.43
7.42
7.42
7.42
7.41
7.39
7.38
7.37
7.37
7.24 CDCl3
6.36
6.00
1.56 H2O
1.41
0.63
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 600.15
4 Nucleus 1H
CN
CN
f1 (ppm)
0.97
1.04
1.33
1.30
2.11
1.29
3.06
2.06
0.93
1.02
3.00
3.01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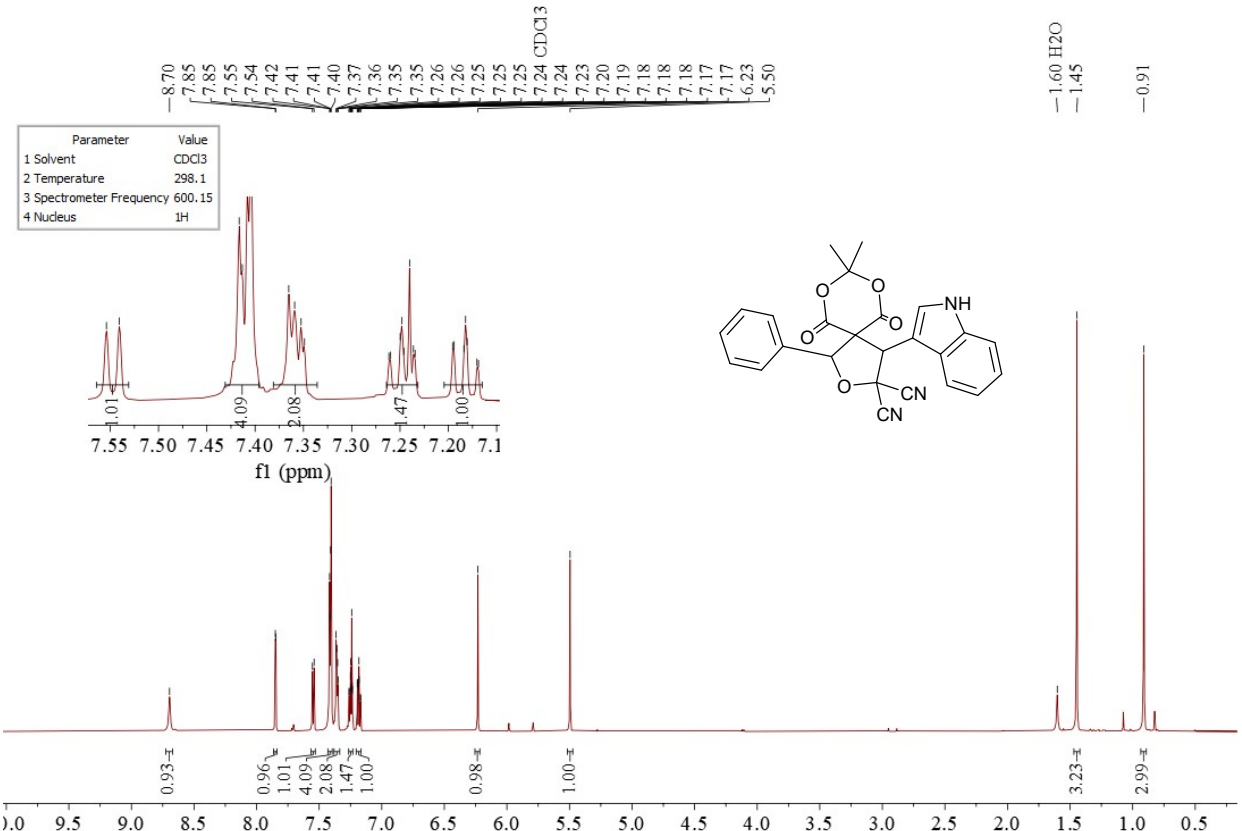
128.46
126.59
126.21
125.62
122.07
121.06
112.06
111.85
106.26
93.19
72.19
64.67
56.91
29.40
27.85
Parameter Value
1 Solvent CDCl3
2 Temperature 298.2
3 Spectrometer Frequency 150.92
4 Nucleus 13C
112.06
111.85
106.26
93.19
112 108 104 100 96 92
f1 (ppm)
O
O
O
O
O
CN
CN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7.85
7.55
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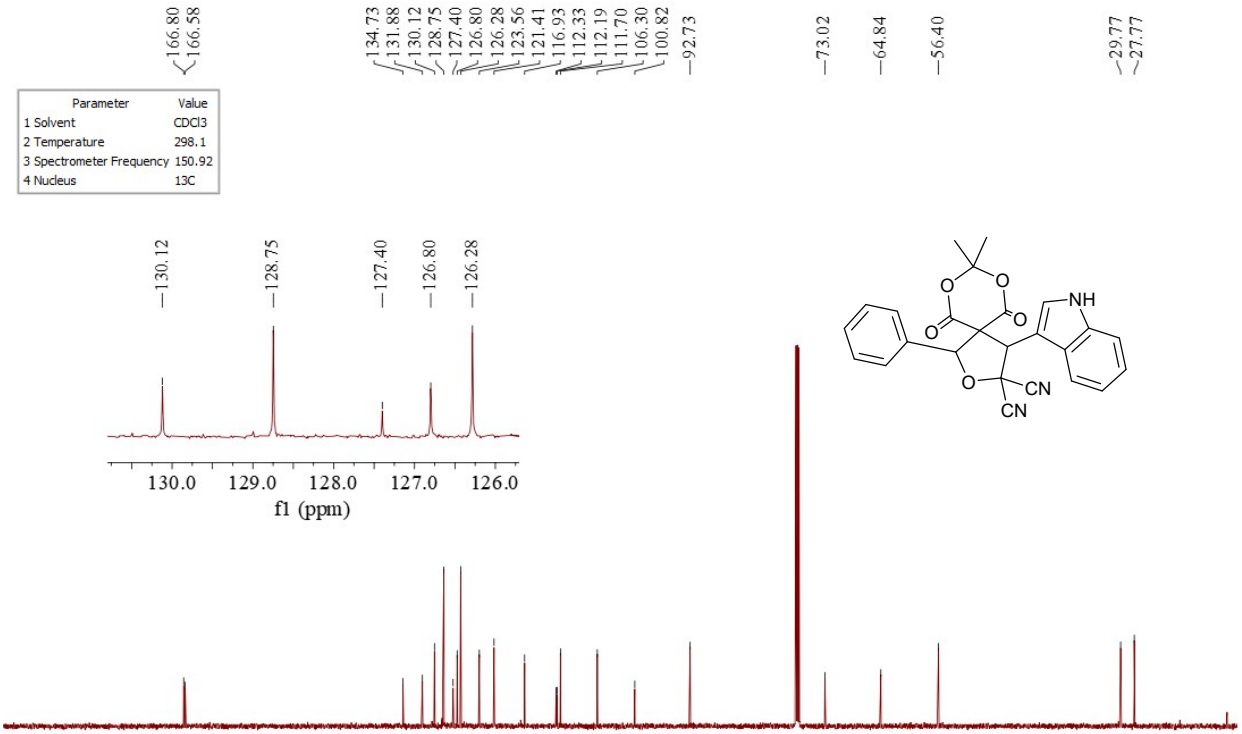
7.41
7.41
7.40
7.37
7.36
7.35
7.35
7.26
7.25
7.25
7.25
CDCl3
7.24
7.24
7.23
7.20
7.19
7.18
7.18
7.18
7.17
7.17
6.23
5.50
1.60 H2O
1.45
0.91
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 600.15
4 Nucleus 1H
1.01
4.09
2.08
1.47
1.00
7.55 7.50 7.45 7.40 7.35 7.30 7.25 7.20 7.1
f1 (ppm)
NH
O
O
O
O
O
CN
CN
0.93
0.96
1.01
4.09
2.08
1.47
1.00
0.98
1.00
3.23
2.99
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5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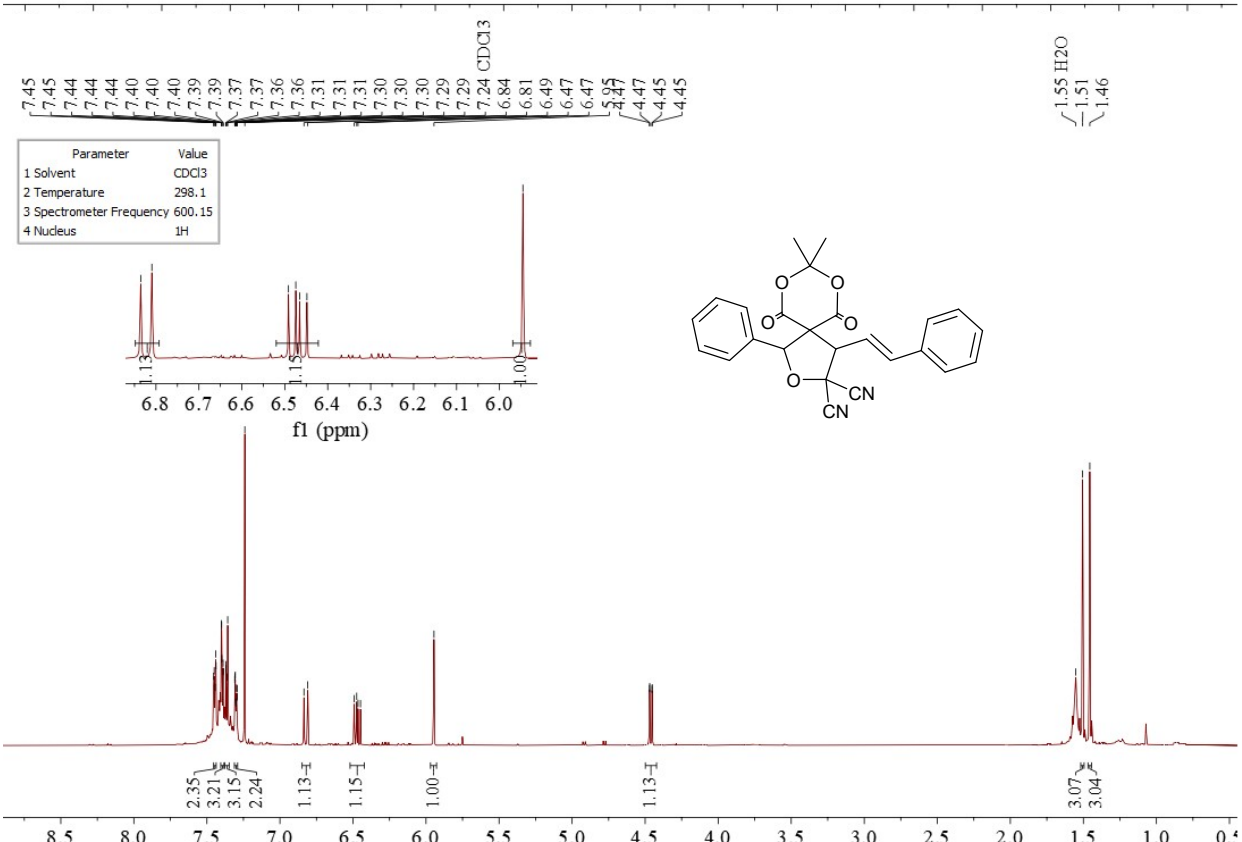
116.93
112.33
112.19
111.70
106.30
100.82
92.73
73.02
64.84
56.40
29.77
27.77
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 150.92
4 Nucleus 13C
130.12
128.75
127.40
126.80
126.28
130.0 129.0 128.0 127.0 126.0
f1 (ppm)
NH
O
CN
CN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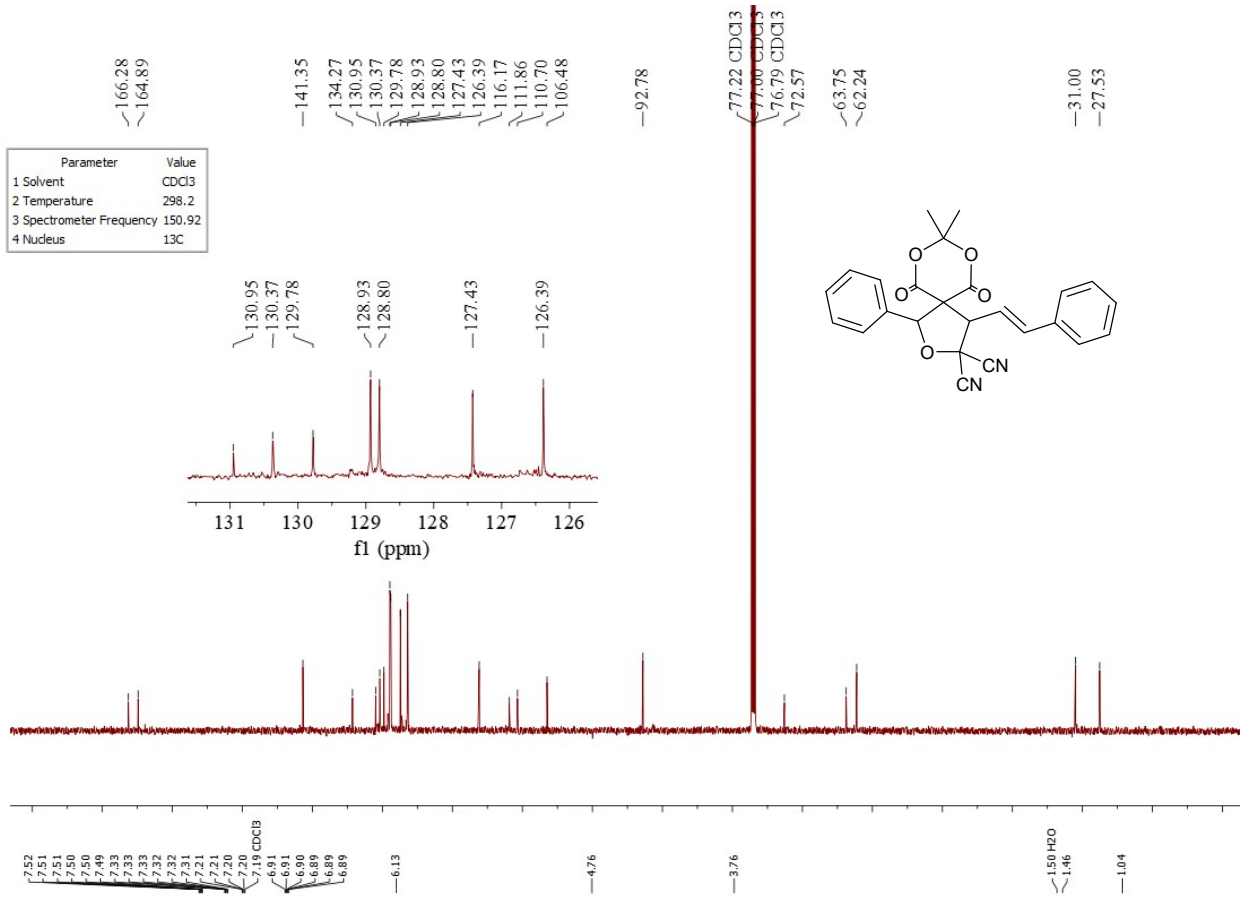
7.36
7.36
7.31
7.31
7.31
7.30
7.30
7.30
7.29
7.29
7.24 CDCl3
6.84
6.81
6.49
6.47
6.47
5.95
4.47
4.47
4.45
4.45
1.55 H2O
1.51
1.46
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 600.15
4 Nucleus 1H
1.13
1.15
1.00
6.8 6.7 6.6 6.5 6.4 6.3 6.2 6.1 6.0
f1 (ppm)
O
CN
CN
2.35
3.21
3.15
2.24
1.13
1.15
1.00
1.13
3.07
3.04
8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5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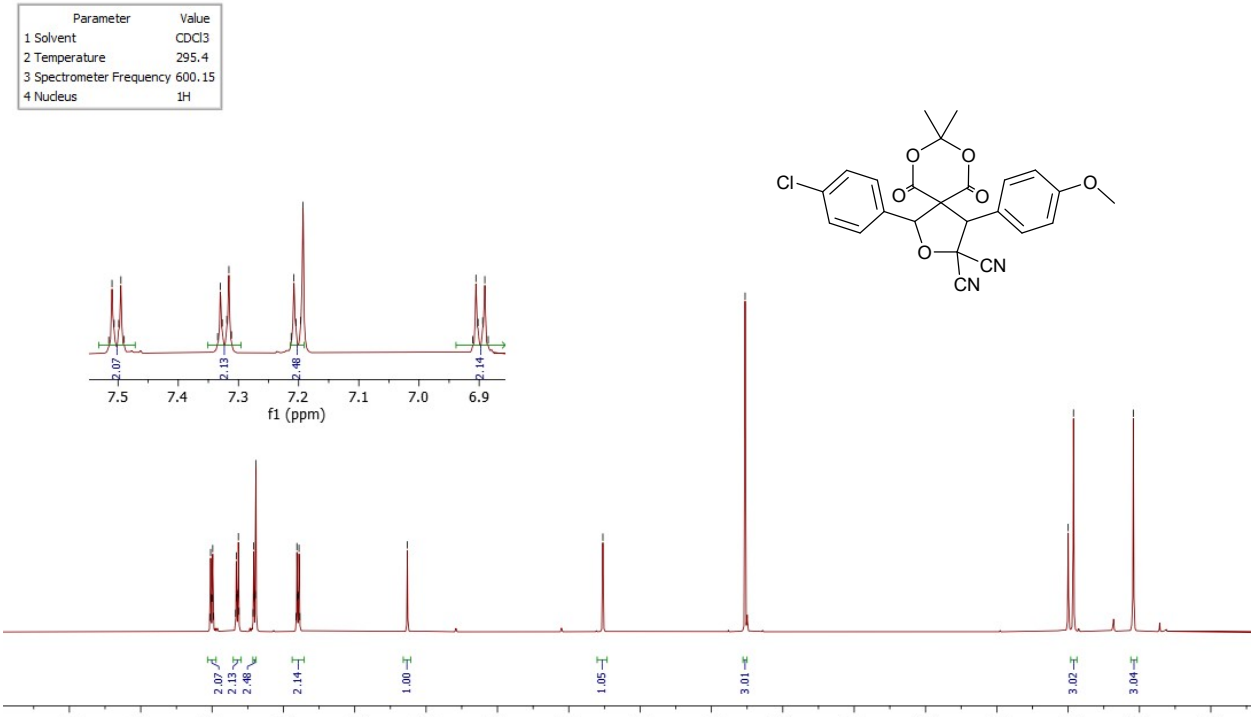
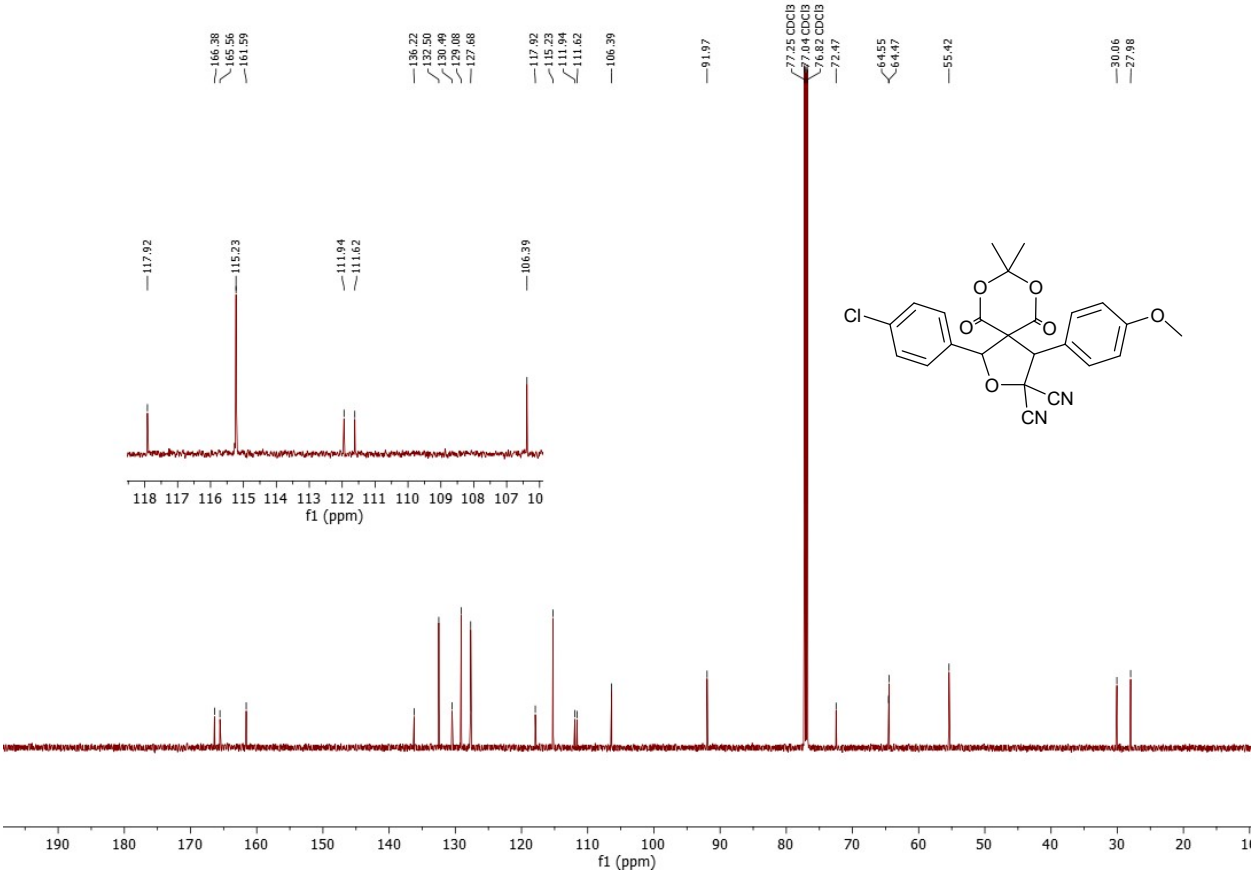
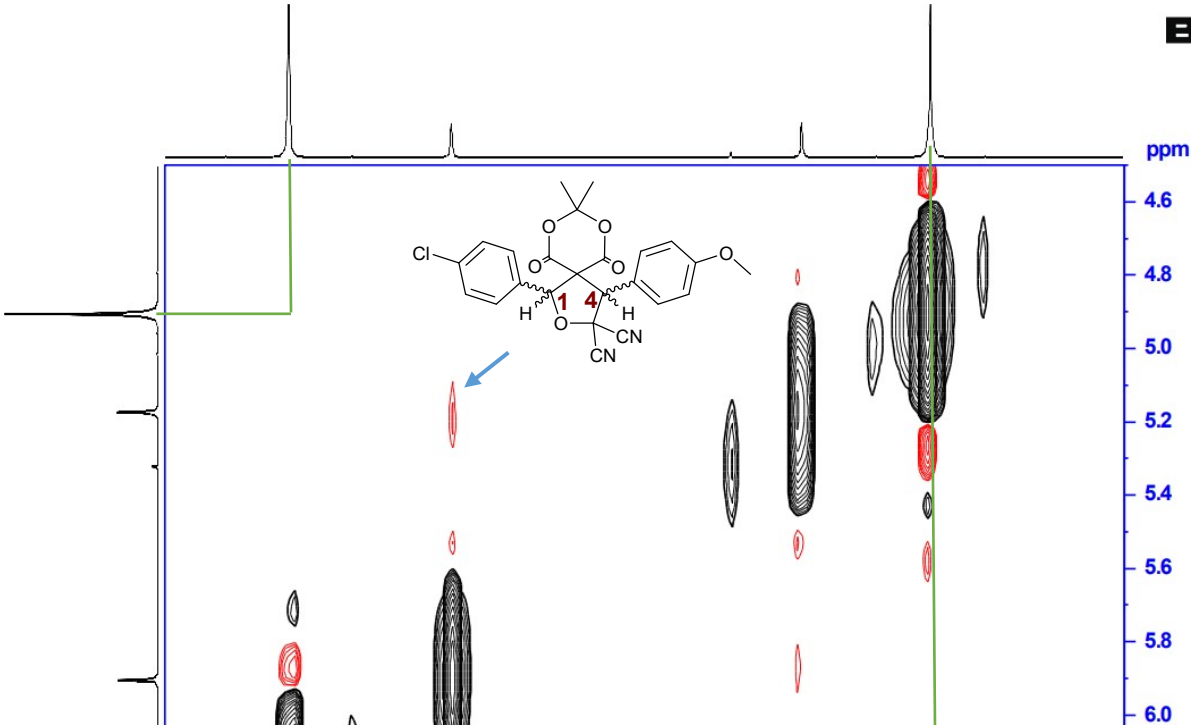
134.27
130.95
130.37
129.78
128.93
128.80
127.43
126.39
116.17
111.86
110.70
106.48
92.78
77.22 CDCl3
77.00 CDCl3
76.79 CDCl3
72.57
63.75
62.24
31.00
27.53
Parameter Value
1 Solvent CDCl3
2 Temperature 298.2
3 Spectrometer Frequency 150.92
4 Nucleus 13C
130.95
130.37
129.78
128.93
128.80
127.43
126.39
131 130 129 128 127 126
f1 (ppm)
CN
CN
7.52
7.51
7.51
7.50
7.49
7.33
7.33
7.32
7.32
7.31
7.21
7.21
7.20
7.19 CDCl3
6.91
6.91
6.90
6.89
6.89
6.89
6.13
4.76
3.76
1.50 H2O
1.46
1.04

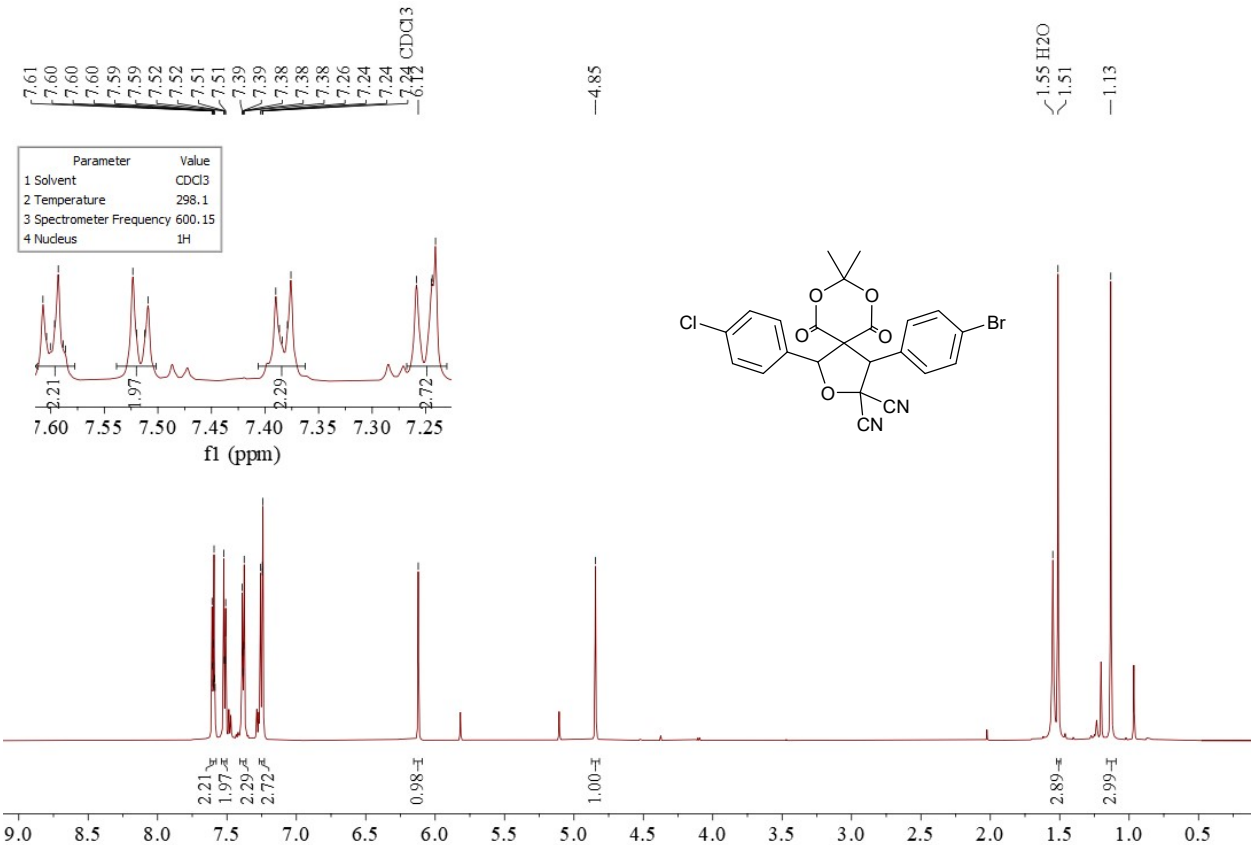

Parameter Value
1 Solvent CDCl3
2 Temperature 295.4
3 Spectrometer Frequency 600.15
4 Nucleus 1H
Cl
O
CN
CN
2.07
2.13
2.48
2.14
7.5 7.4 7.3 7.2 7.1 7.0 6.9
f1 (ppm)
2.07
2.13
2.48
2.14
1.00
1.05
3.01
3.02
3.04

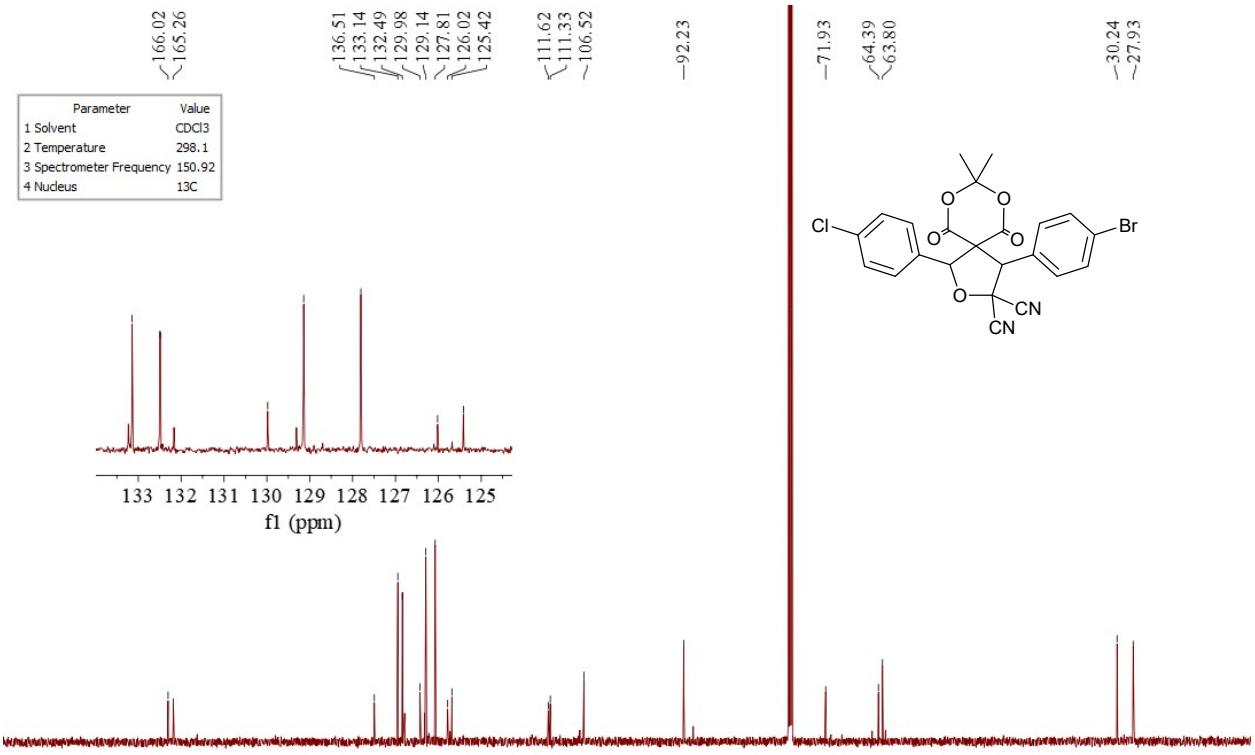

166.38
165.56
161.59
136.22
132.50
130.49
129.08
127.68
117.92
115.23
111.94
111.62
106.39
91.97
77.25 CDCl3
77.04 CDCl3
76.82 CDCl3
72.47
64.55
64.47
55.42
30.06
27.98
Cl
O
CN
CN
f1 (ppm)


ppm
4.6
4.8
5.0
5.2
5.4
5.6
5.8
6.0
Cl
O
H
1
4
CN
CN

NOESYPHSW of **3bb** in $CDCl_3$ (600 MHz)

(The correlation between H1 and H4 in minor isomer (*cis*) is shown with a blue arrow; there is no correlation between these hydrogens in major product (*trans*)).

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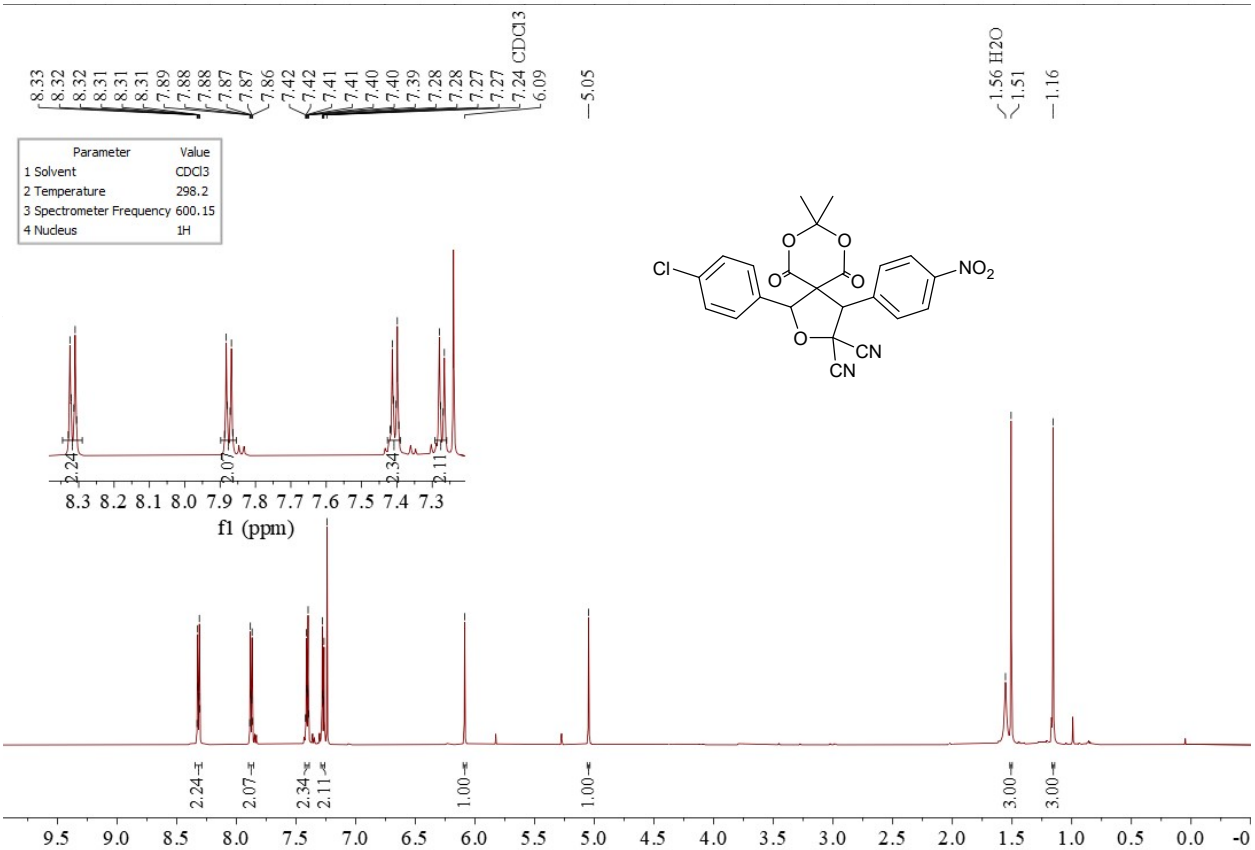
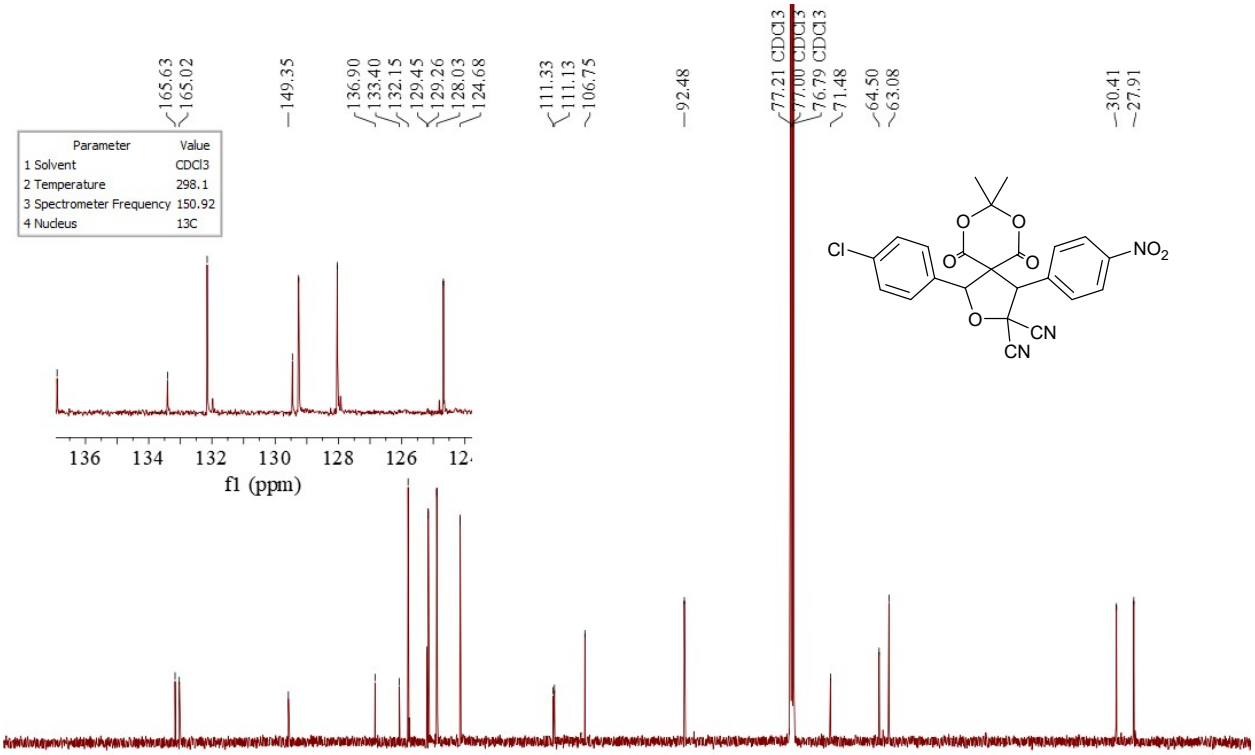
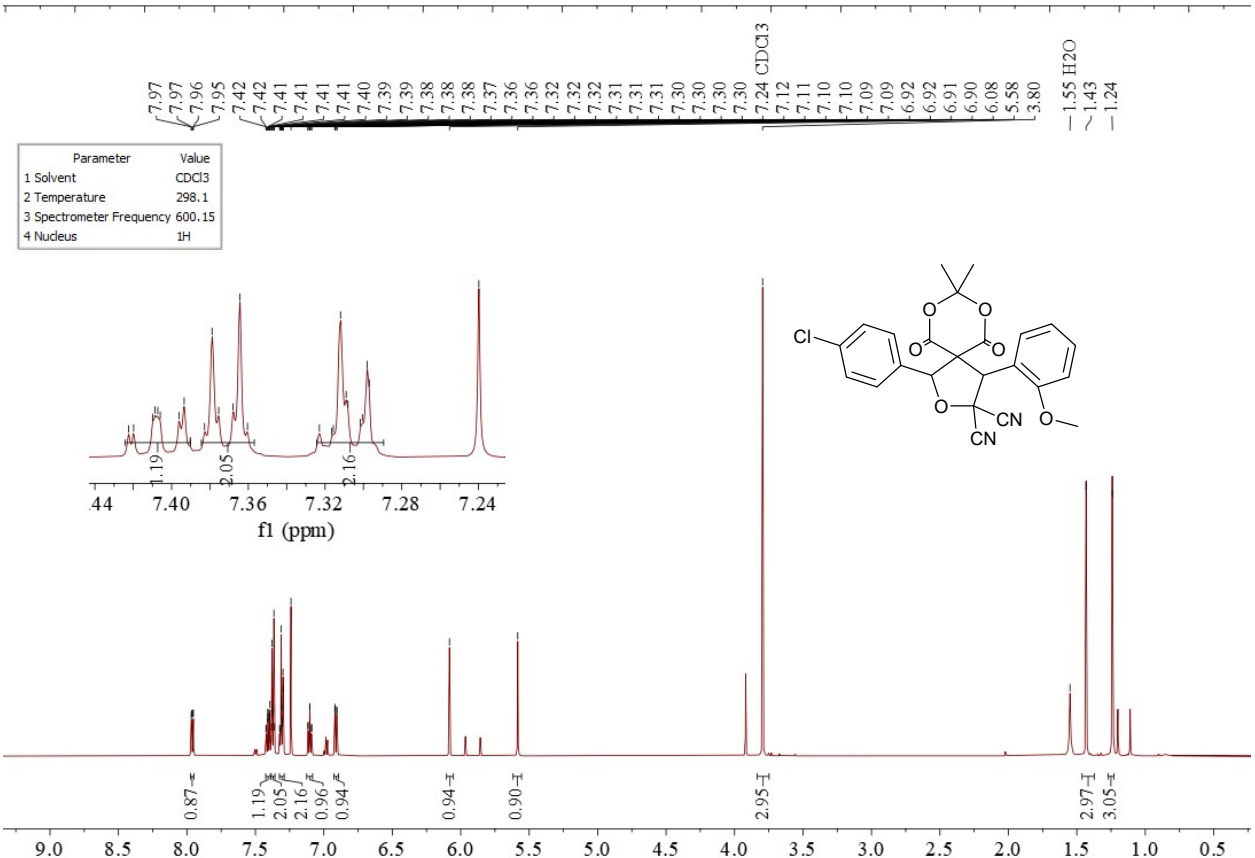
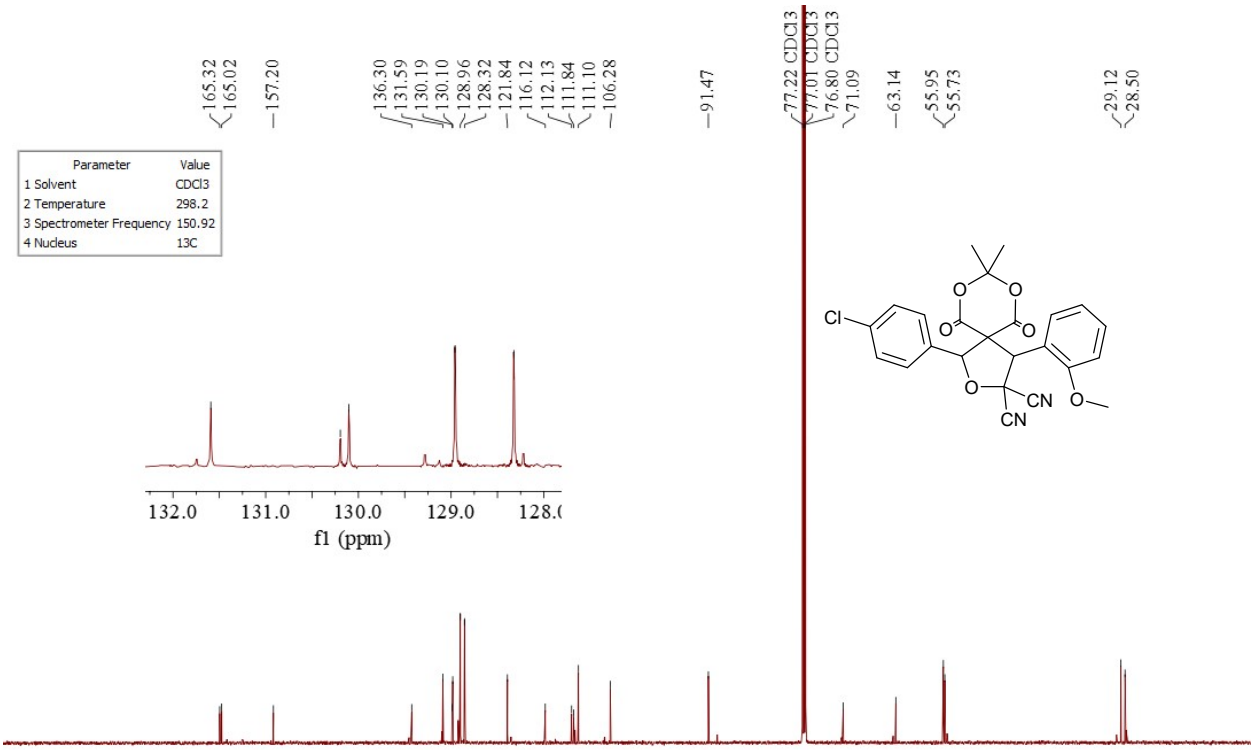
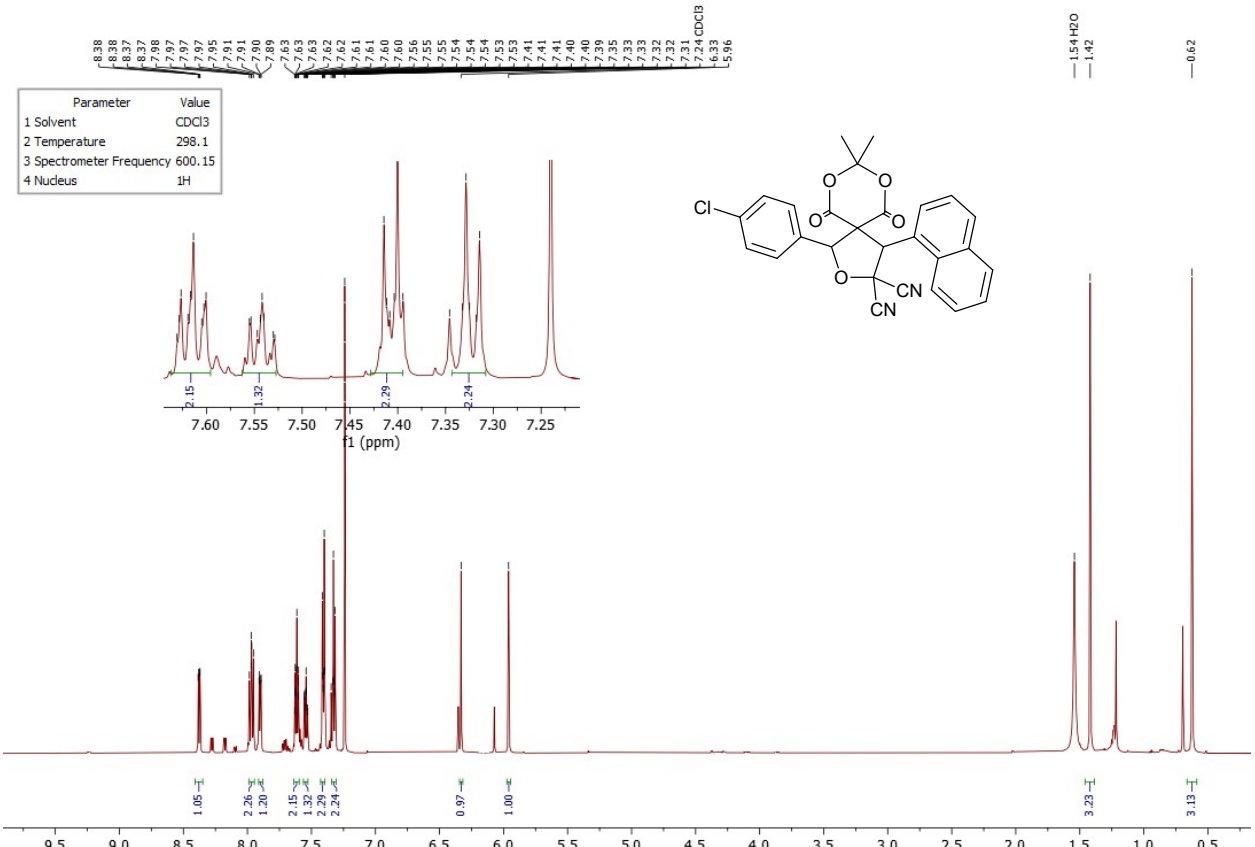
165.26
136.51
133.14
132.49
129.98
129.14
127.81
126.02
125.42
111.62
111.33
106.52
92.23
71.93
64.39
63.80
30.24
27.93
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 150.92
4 Nucleus 13C
Cl
Br
O
CN
CN
133 132 131 130 129 128 127 126 125
f1 (ppm)


8.33
8.32
8.32
8.31
8.31
8.31
7.89
7.88
7.88
7.87
7.87
7.86
7.42
7.42
7.41
7.41
7.40
7.40
7.39
7.28
7.28
7.27
7.27
7.24 CDCl3
6.09
5.05
1.56 H2O
1.51
1.16
Parameter Value
1 Solvent CDCl3
2 Temperature 298.2
3 Spectrometer Frequency 600.15
4 Nucleus 1H
Cl
NO2
O
CN
CN
2.24
2.07
2.34
2.11
8.3 8.2 8.1 8.0 7.9 7.8 7.7 7.6 7.5 7.4 7.3
f1 (ppm)
2.24
2.07
2.34
2.11
1.00
1.00
3.00
3.00
9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0


165.63
165.02
149.35
136.90
133.40
132.15
129.45
129.26
128.03
124.68
111.33
111.13
106.75
92.48
77.21 CDCl3
77.00 CDCl3
76.79 CDCl3
71.48
64.50
63.08
30.41
27.91
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 150.92
4 Nucleus 13C
f1 (ppm)
Cl
NO2
CN
CN


7.97
7.97
7.96
7.95
7.42
7.42
7.41
7.41
7.41
7.41
7.40
7.39
7.39
7.38
7.38
7.38
7.37
7.36
7.36
7.32
7.32
7.32
7.31
7.31
7.31
7.30
7.30
7.30
7.30
7.24 CDCl3
7.12
7.11
7.10
7.10
7.09
7.09
6.92
6.92
6.91
6.90
6.08
5.58
3.80
1.55 H2O
1.43
1.24
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 600.15
4 Nucleus 1H
1.19
2.05
2.16
f1 (ppm)
Cl
CN
CN
O
0.87
1.19
2.05
2.16
0.96
0.94
0.94
0.90
2.95
2.97
3.05


165.32
165.02
157.20
136.30
131.59
130.19
130.10
128.96
128.32
121.84
116.12
112.13
111.84
111.10
106.28
91.47
77.22 CDCl3
77.01 CDCl3
76.80 CDCl3
71.09
63.14
55.95
55.73
29.12
28.50
Parameter Value
1 Solvent CDCl3
2 Temperature 298.2
3 Spectrometer Frequency 150.92
4 Nucleus 13C
Cl
O
CN
CN
132.0
131.0
130.0
129.0
f1 (ppm)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8.38
8.37
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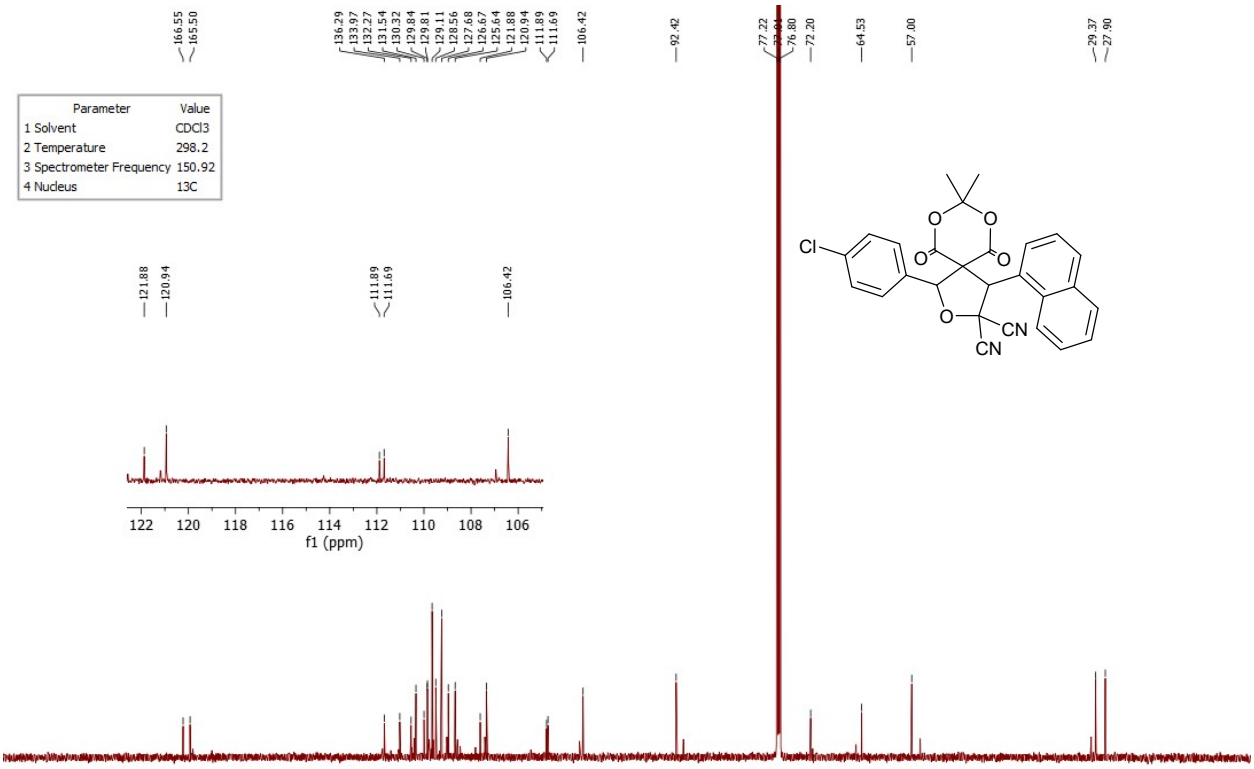
8.37
8.37
7.98
7.97
7.97
7.97
7.95
7.91
7.91
7.90
7.89
7.63
7.63
7.63
7.62
7.62
7.62
7.61
7.61
7.60
7.60
7.60
7.56
7.55
7.55
7.54
7.54
7.54
7.53
7.53
7.41
7.41
7.41
7.40
7.40
7.40
7.39
7.35
7.33
7.33
7.32
7.32
7.31
7.24 CDCl3
6.33
5.96
1.54 H2O
1.42
0.62
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 600.15
4 Nucleus 1H
Cl
O
CN
CN
2.15
1.32
2.29
2.24
7.60
7.55
7.50
7.45
7.40
7.35
7.30
7.25
f1 (ppm)
1.05
2.26
1.20
2.15
1.32
2.29
2.24
0.97
1.00
3.23
3.13
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5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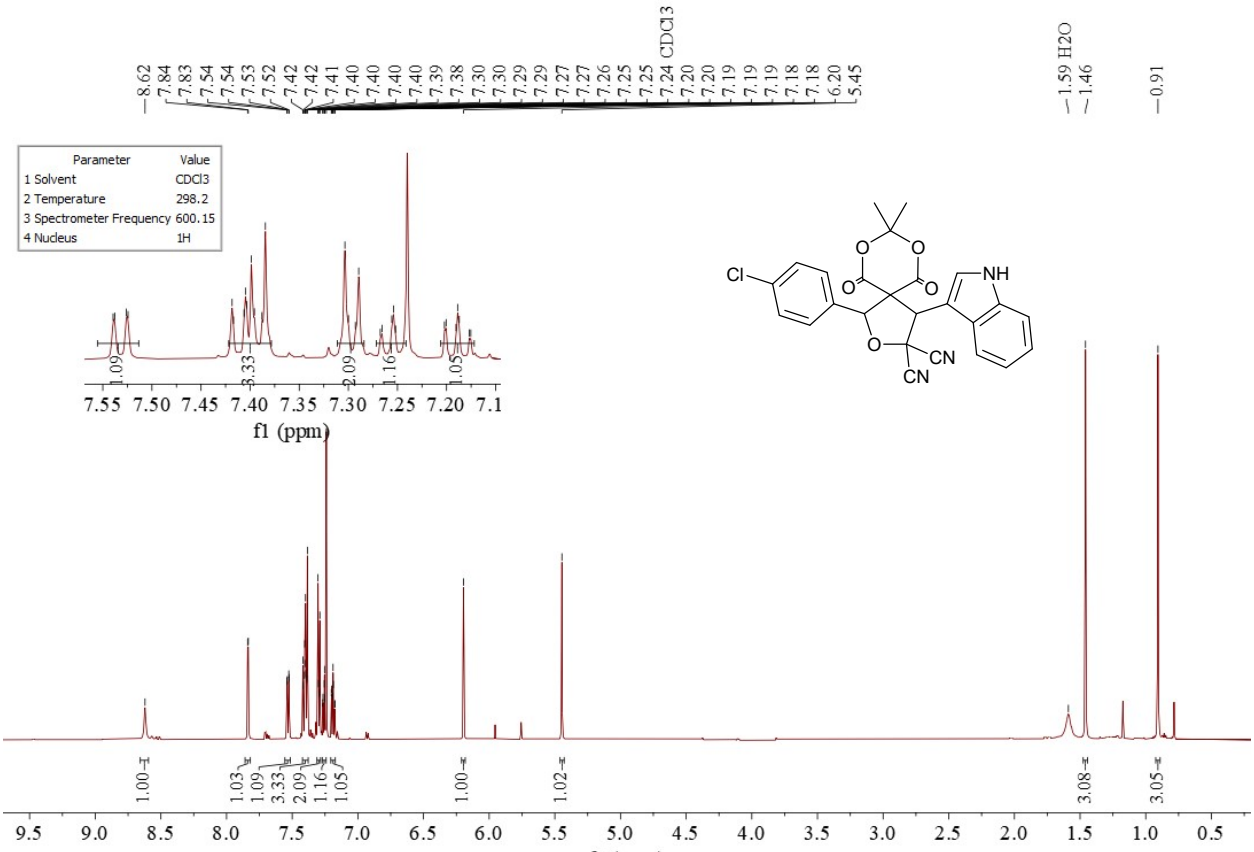
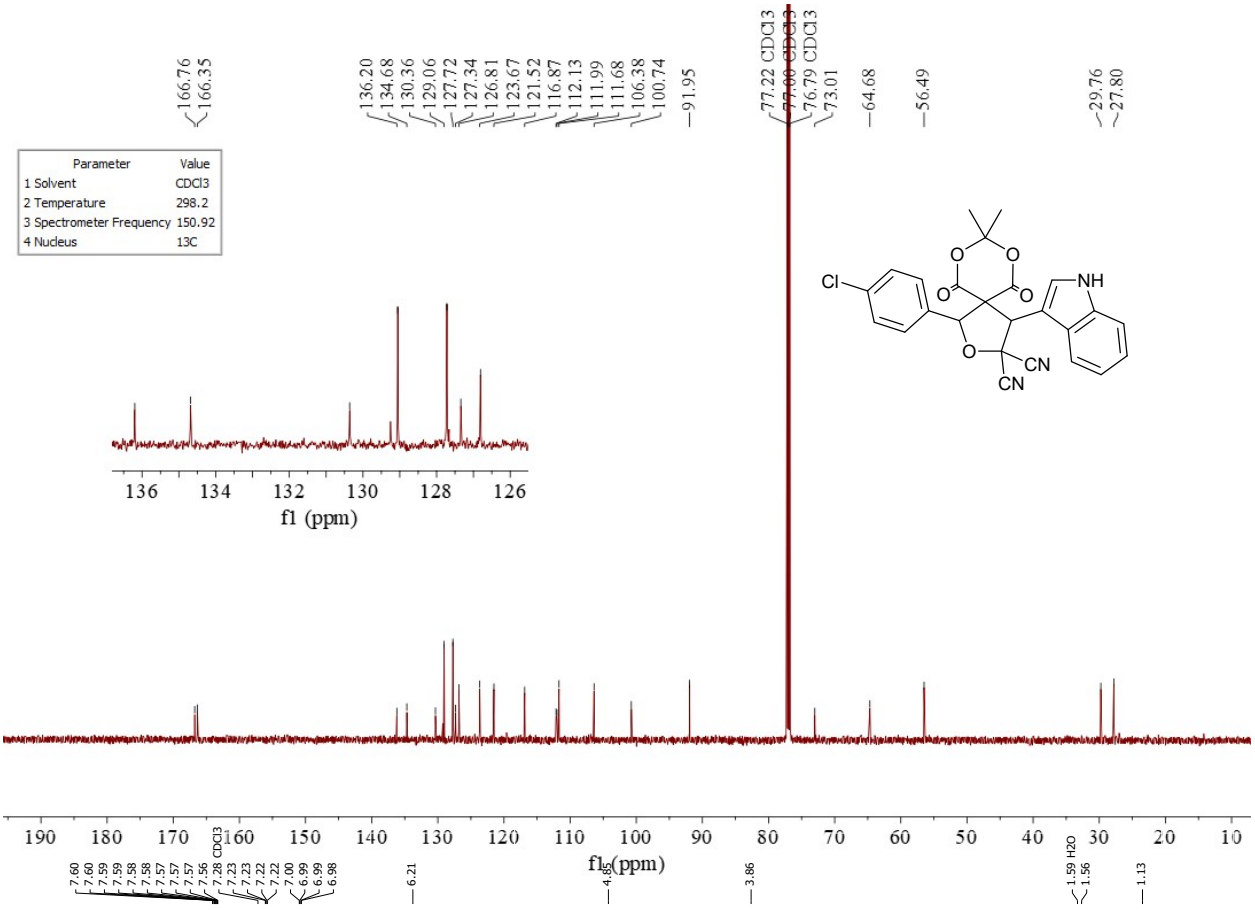
165.50
136.29
133.97
132.27
131.54
130.32
129.84
129.81
129.11
128.56
127.68
126.67
125.64
121.88
120.94
111.89
111.69
106.42
92.42
77.22
76.80
72.20
64.53
57.00
29.37
27.90
Parameter Value
1 Solvent CDCl3
2 Temperature 298.2
3 Spectrometer Frequency 150.92
4 Nucleus 13C
Cl
O
CN
f1 (ppm)


8.62
7.84
7.83
7.54
7.54
7.53
7.52
7.42
7.42
7.41
7.40
7.40
7.40
7.40
7.39
7.38
7.30
7.30
7.29
7.29
7.27
7.27
7.26
7.25
7.25
7.24 CDCl3
7.20
7.20
7.19
7.19
7.19
7.18
7.18
6.20
5.45
1.59 H2O
1.46
0.91
Parameter Value
1 Solvent CDCl3
2 Temperature 298.2
3 Spectrometer Frequency 600.15
4 Nucleus 1H
1.09
3.33
2.09
1.16
1.05
f1 (ppm)
Cl
NH
CN
1.00
1.03
1.09
3.33
2.09
1.16
1.05
1.00
1.02
3.08
3.05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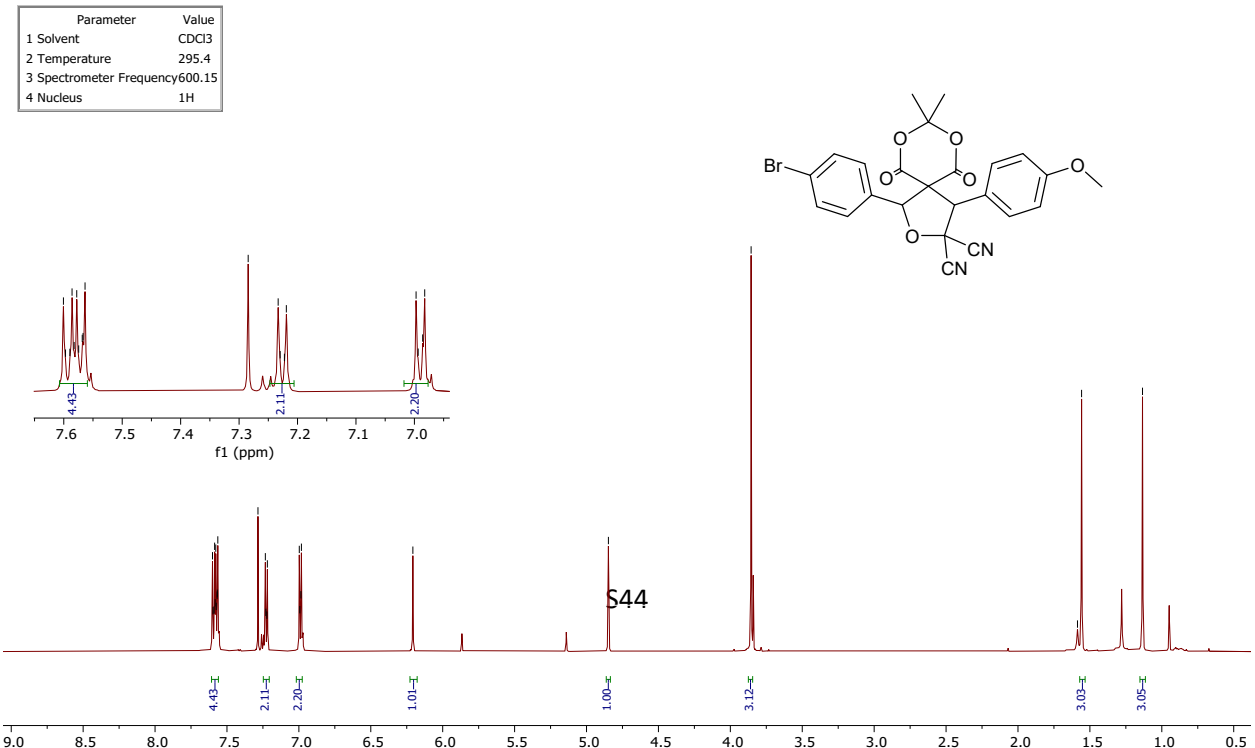
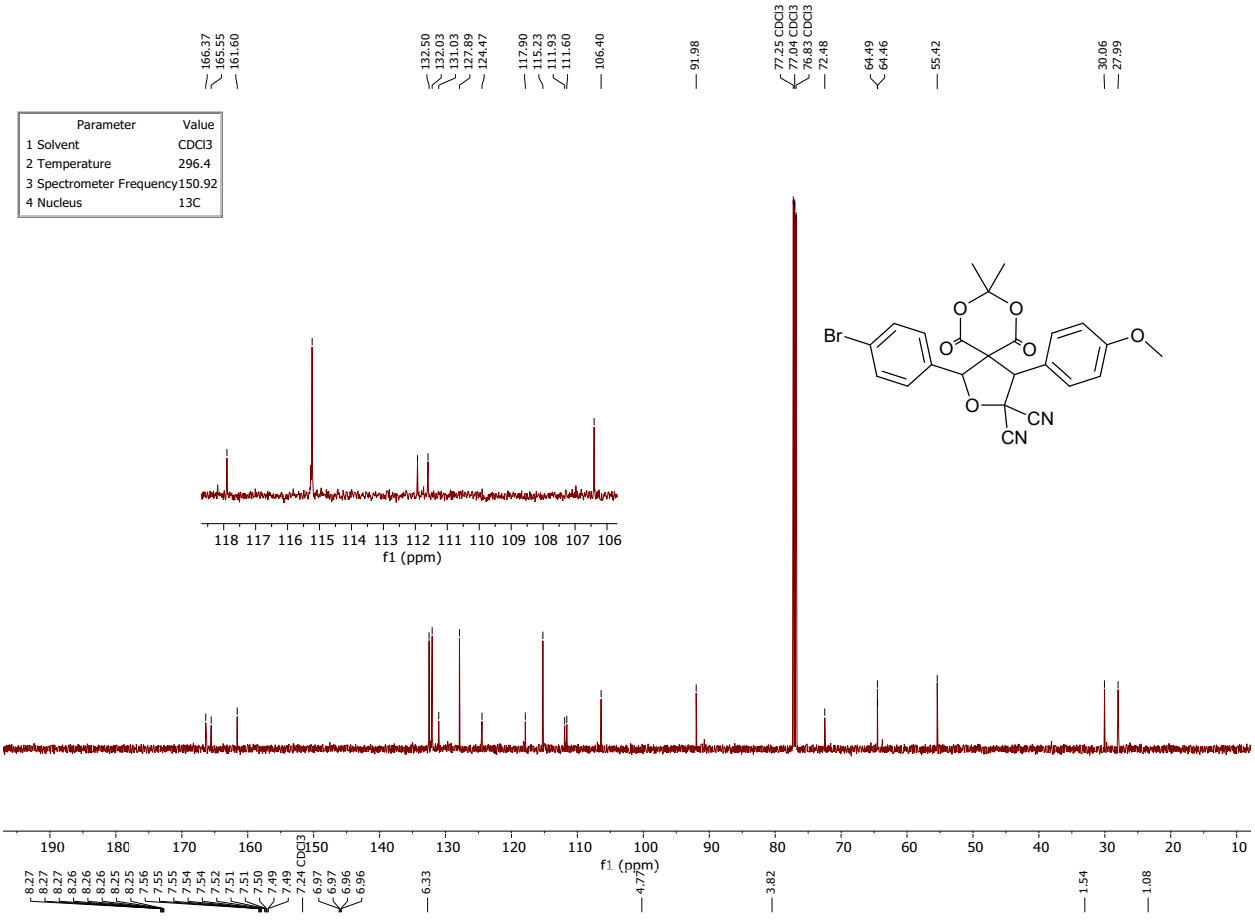
136.20
134.68
130.36
129.06
127.72
127.34
126.81
123.67
121.52
116.87
112.13
111.99
111.68
106.38
100.74
91.95
77.22 CDCl3
77.00 CDCl3
76.79 CDCl3
73.01
64.68
56.49
29.76
27.80
Parameter Value
1 Solvent CDCl3
2 Temperature 298.2
3 Spectrometer Frequency 150.92
4 Nucleus 13C
Cl
NH
O
CN
CN
136 134 132 130 128 126
f1 (ppm)
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)
CDCl3
7.60 7.60 7.59 7.59 7.58 7.58 7.57 7.57 7.57 7.56 7.28 7.23 7.23 7.22 7.22 7.00 6.99 6.99 6.98
6.21
4.85
3.86
1.59 H2O
1.56
1.13


Parameter Value
1 Solvent CDCl3
2 Temperature 295.4
3 Spectrometer Frequency 600.15
4 Nucleus 1H
Br
O
CN
CN
4.43
2.11
2.20
7.6 7.5 7.4 7.3 7.2 7.1 7.0
f1 (ppm)
4.43
2.11
2.20
1.01
1.00
3.12
3.03
3.05
9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5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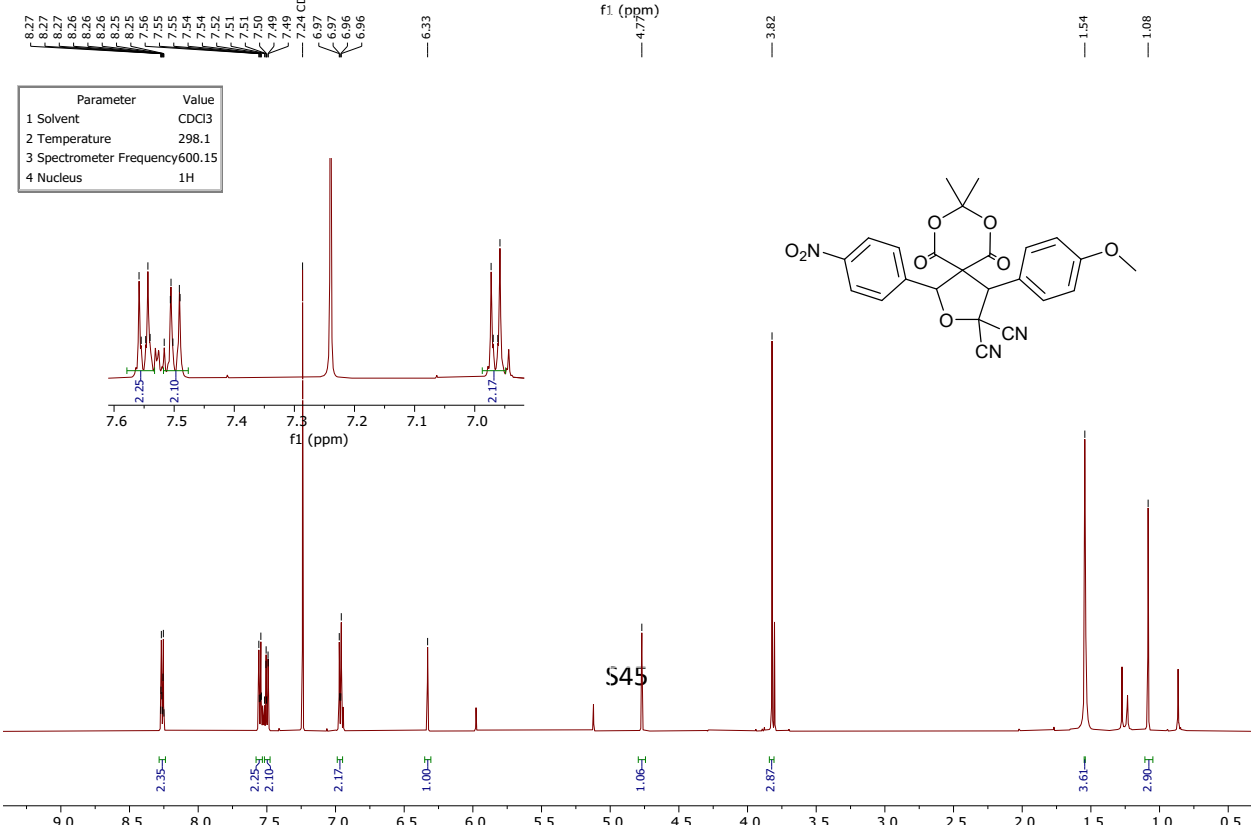
132.50
132.03
131.03
127.89
124.47
117.90
115.23
111.93
111.60
106.40
91.98
77.25 CDCl3
77.04 CDCl3
76.83 CDCl3
72.48
64.49
64.46
55.42
30.06
27.99
Parameter Value
1 Solvent CDCl3
2 Temperature 296.4
3 Spectrometer Frequency 150.92
4 Nucleus 13C
Br
O
O
O
O
O
O
CN
CN
118 117 116 115 114 113 112 111 110 109 108 107 106
f1 (ppm)
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)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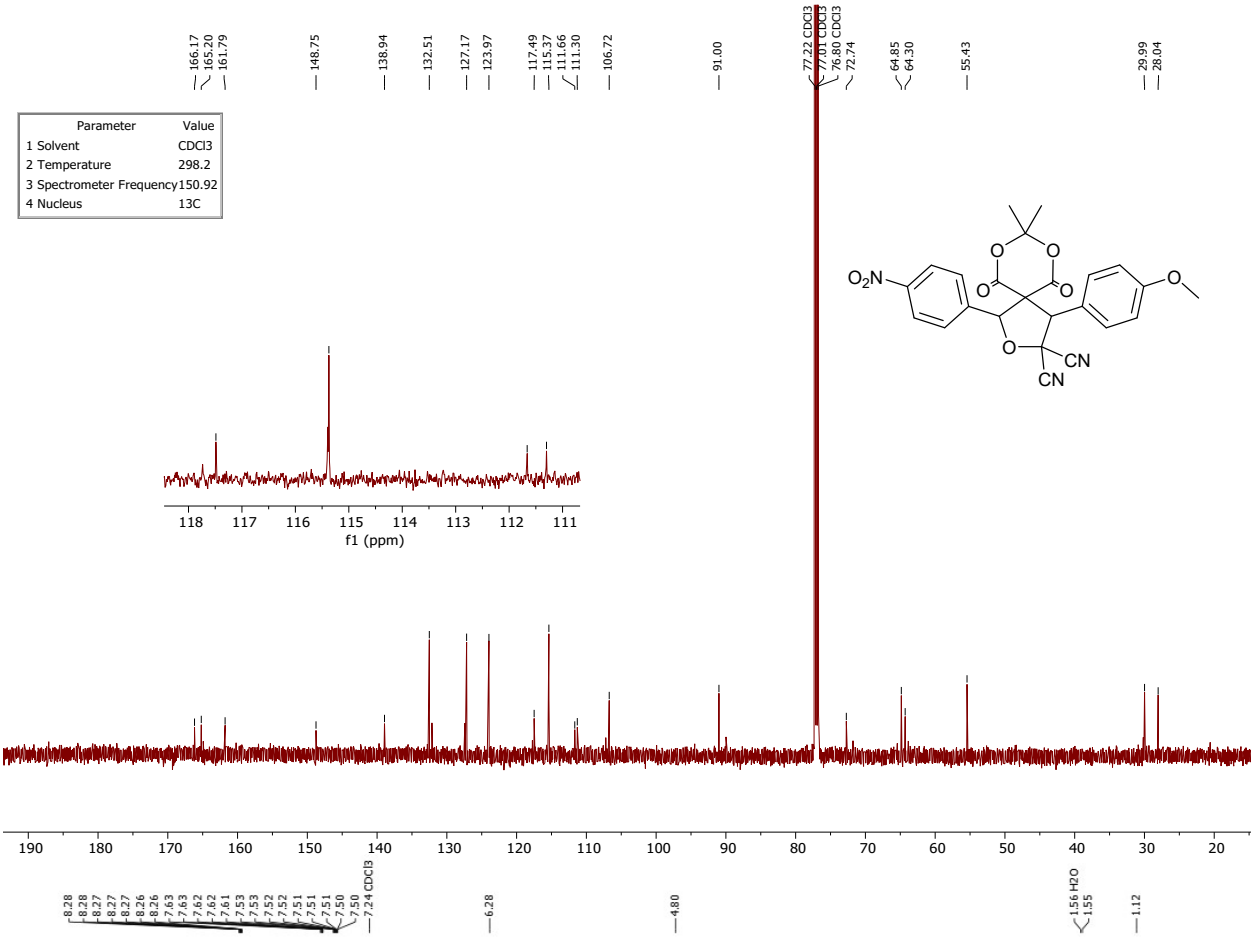
8.25
7.56
7.55
7.55
7.54
7.54
7.52
7.51
7.51
7.50
7.49
7.49
7.24 CDCl3
6.97
6.97
6.96
6.96
6.33
4.77
3.82
1.54
1.08
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 600.15
4 Nucleus 1H
O2N
O
O
O
O
O
O
CN
CN
2.25
2.10
2.17
7.6 7.5 7.4 7.3 7.2 7.1 7.0
f1 (ppm)
2.35
2.25
2.10
2.17
1.00
1.06
2.87
3.61
2.90
9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5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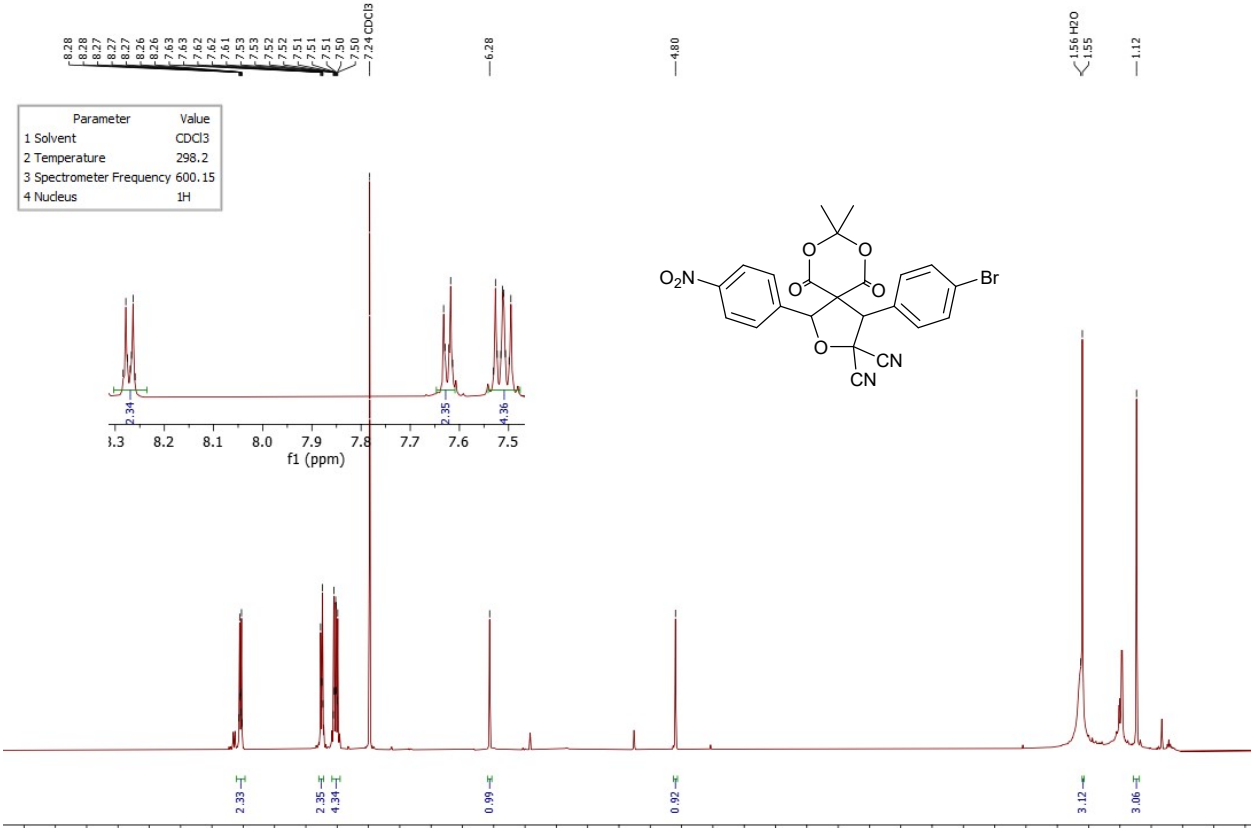
161.79
148.75
138.94
132.51
127.17
123.97
117.49
115.37
111.66
111.30
106.72
91.00
77.22 CDCl3
77.01 CDCl3
76.80 CDCl3
72.74
64.85
64.30
55.43
29.99
28.04
Parameter Value
1 Solvent CDCl3
2 Temperature 298.2
3 Spectrometer Frequency 150.92
4 Nucleus 13C
O2N
O
CN
CN
118 117 116 115 114 113 112 111
f1 (ppm)
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20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8.26
7.63
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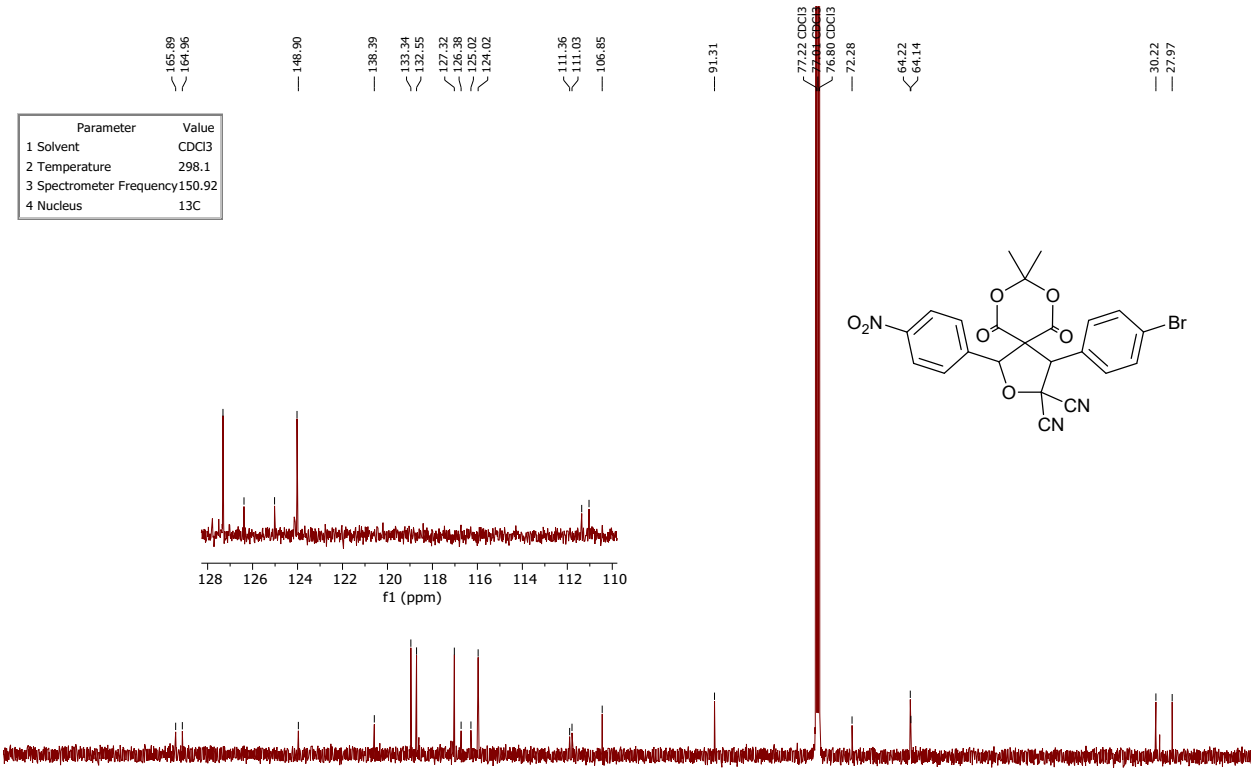
7.62
7.61
7.53
7.53
7.52
7.52
7.51
7.51
7.51
7.50
7.50
7.24 CDCl3
6.28
4.80
1.56 H2O
1.55
1.12
Parameter Value
1 Solvent CDCl3
2 Temperature 298.2
3 Spectrometer Frequency 600.15
4 Nucleus 1H
O2N
Br
O
CN
CN
2.34
2.35
4.36
8.2 8.1 8.0 7.9 7.8 7.7 7.6 7.5
f1 (ppm)
2.33
2.35
4.34
0.99
0.92
3.12
3.06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138.39
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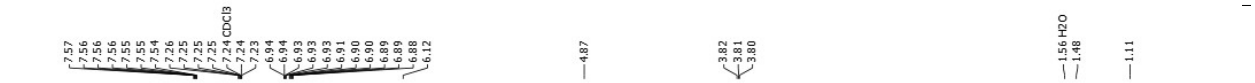
132.55
127.32
126.38
125.02
124.02
111.36
111.03
106.85
91.31
77.22 CDCl3
76.80 CDCl3
72.28
64.22
64.14
30.22
27.97
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 150.92
4 Nucleus 13C
O2N
Br
O
CN
CN
128 126 124 122 120 118 116 114 112 110
f1 (ppm)


7.57
7.56
7.56
7.56
7.55
7.55
7.54
7.26
7.25
7.25
7.25
7.24 CDCl3
7.24
7.23
6.94
6.94
6.93
6.93
6.93
6.91
6.90
6.90
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6.88
6.12
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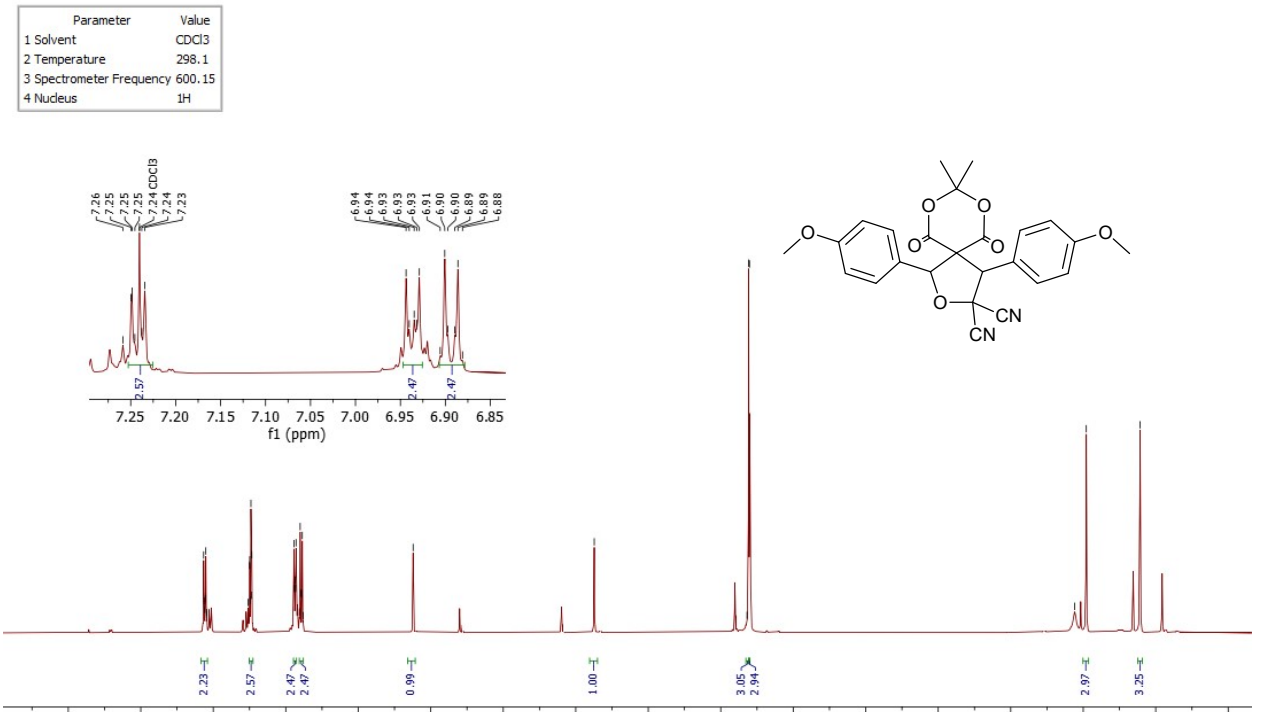
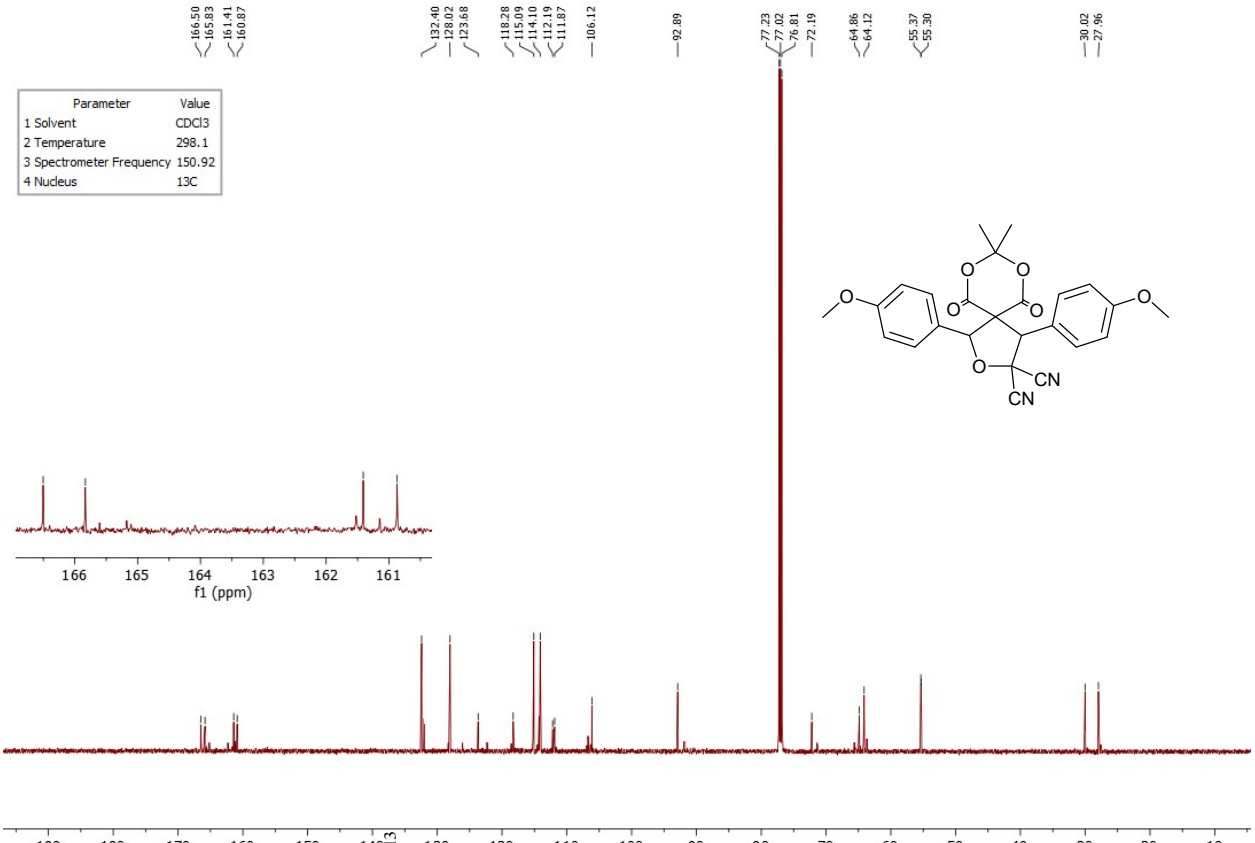
3.81
3.80
1.56 H2O
1.48
1.11


Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 600.15
4 Nucleus 1H
7.26
7.25
7.25
7.25
7.24 CDCl3
7.24
7.23
6.94
6.94
6.93
6.93
6.93
6.91
6.90
6.90
6.89
6.89
6.88
2.57
2.47
2.47
7.25 7.20 7.15 7.10 7.05 7.00 6.95 6.90 6.85
f1 (ppm)
O
O
O
O
O
O
O
CN
CN
2.23
2.57
2.47
2.47
0.99
1.00
3.05
2.94
2.97
3.25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165.83
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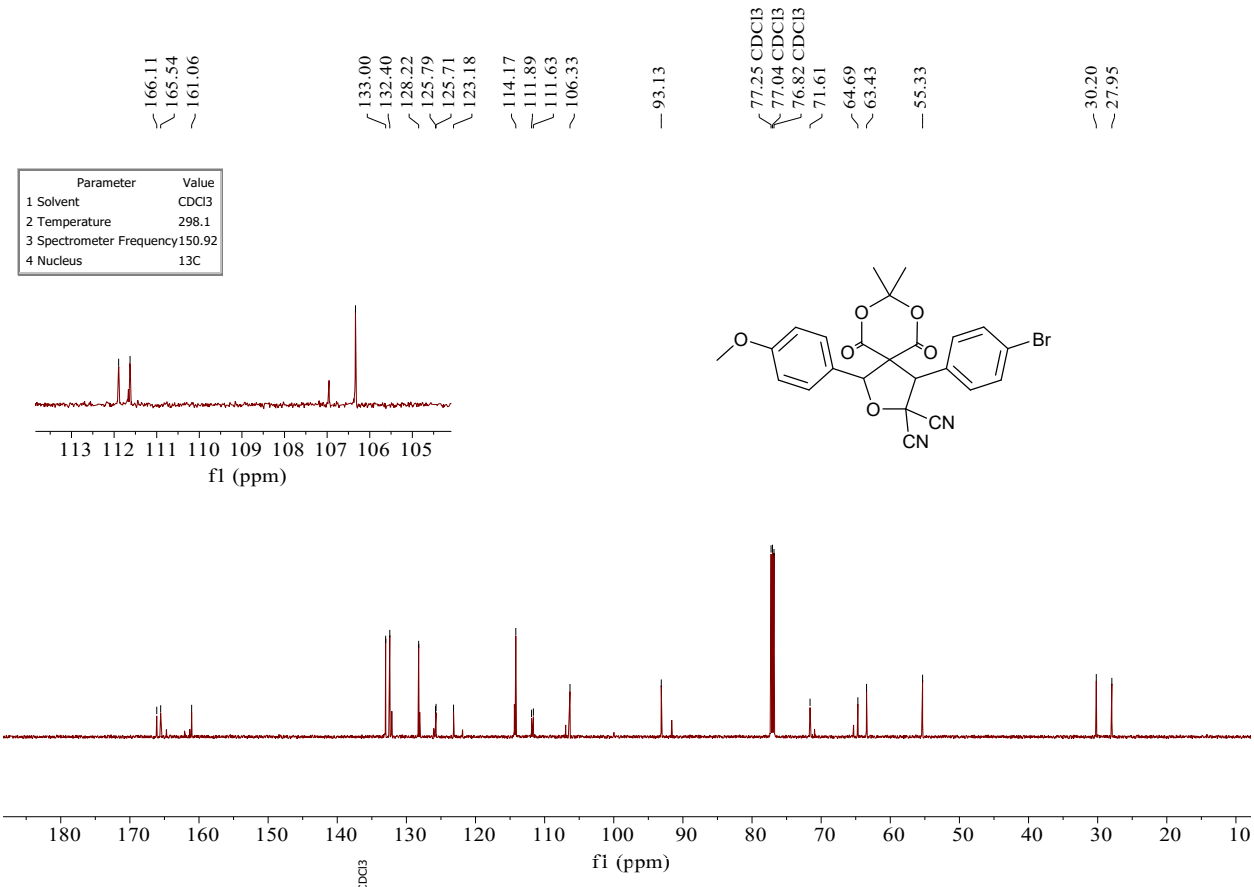
160.87
132.40
128.02
123.68
118.28
115.09
114.10
112.19
111.87
106.12
92.89
77.23
77.02
76.81
72.19
64.86
64.12
55.37
55.30
30.02
27.96
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 150.92
4 Nucleus 13C
O
O
O
O
O
O
O
CN
CN
166 165 164 163 162 161
f1 (ppm)
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)

7.59
7.59
7.59
7.58
7.58
7.57
7.57
7.53
7.53
7.52
7.52
7.51
7.51
7.26
7.26
7.25
7.25
7.24 CDCl3
7.24
7.23
6.92
6.91
6.91
6.90
6.90
6.90
6.89
6.89
6.06
4.92
3.80
1.58 H2O
1.48
1.15
Parameter Value
1 Solvent CDCl3
2 Temperature 298.2
3 Spectrometer Frequency 600.15
4 Nucleus 1H
O
O
O
O
O
O
Br
CN
CN
2.66
2.12
2.17
2.77
1.01
1.00
3.08
3.07
3.07
7.6 7.5 7.4 7.3 7.2 7.1 7.0 6.9
f1 (ppm)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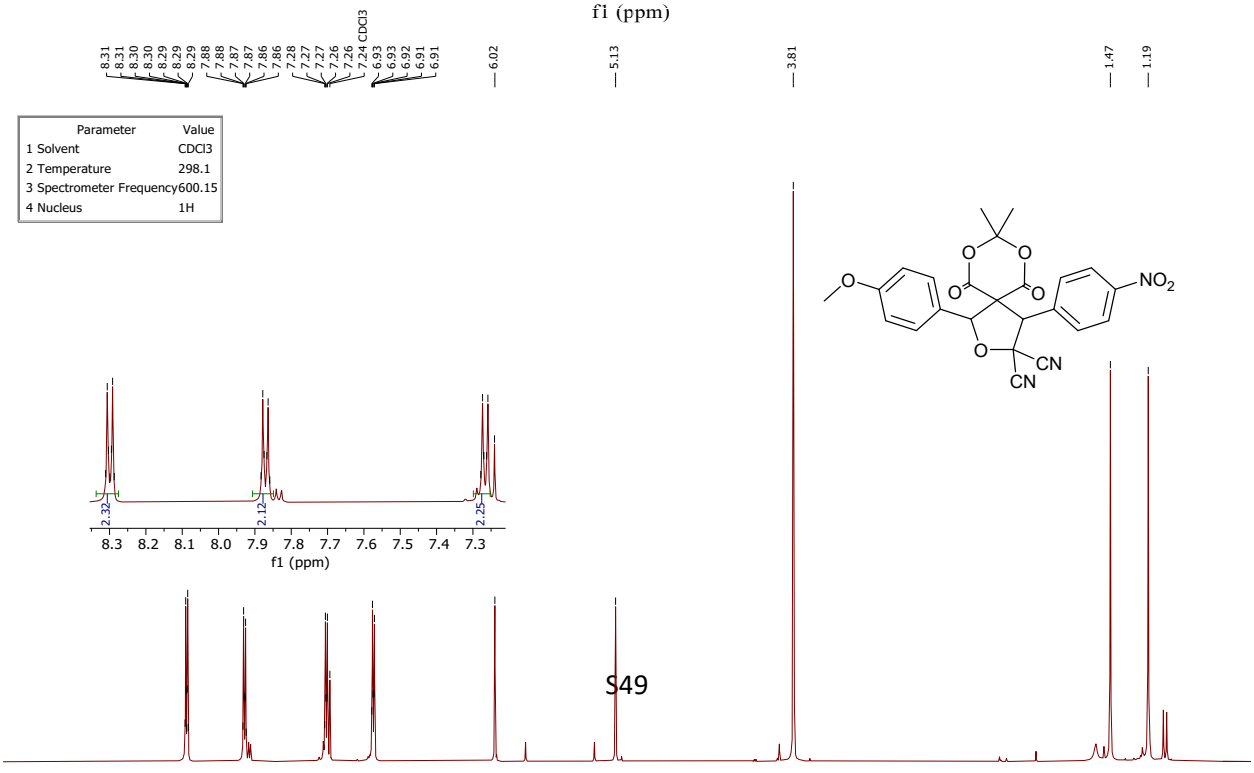
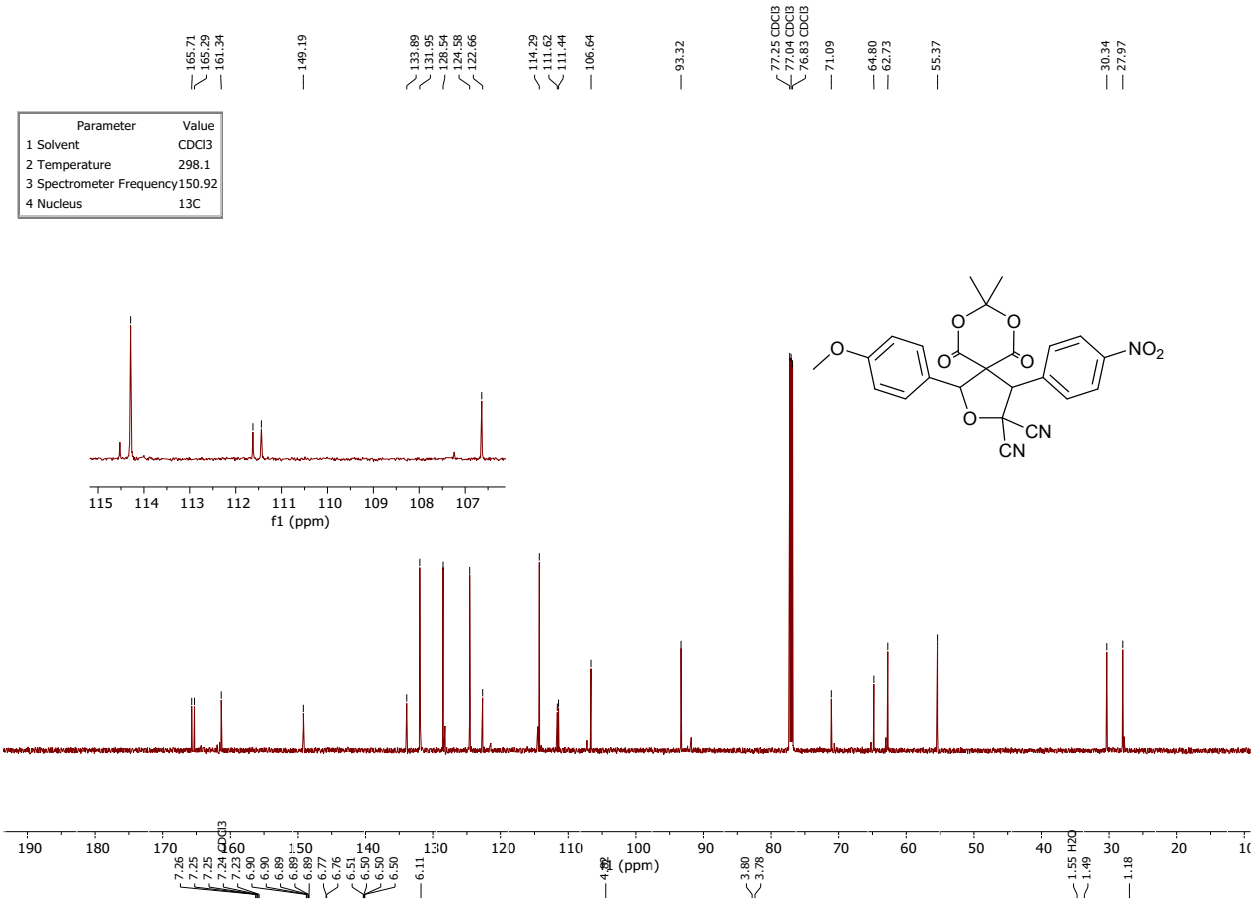
165.54
161.06
133.00
132.40
128.22
125.79
125.71
123.18
114.17
111.89
111.63
106.33
93.13
77.25 CDCl3
77.04 CDCl3
76.82 CDCl3
71.61
64.69
63.43
55.33
30.20
27.95
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 150.92
4 Nucleus 13C
113 112 111 110 109 108 107 106 105
f1 (ppm)
O
O
O
O
O
O
Br
O
CN
CN
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)


8.31
8.31
8.30
8.30
8.29
8.29
8.29
7.88
7.88
7.87
7.87
7.86
7.86
7.28
7.27
7.27
7.26
7.26
7.24 CDCl3
6.93
6.93
6.92
6.91
6.91
6.02
5.13
3.81
1.47
1.19
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 600.15
4 Nucleus 1H
2.32
2.12
2.25
8.3 8.2 8.1 8.0 7.9 7.8 7.7 7.6 7.5 7.4 7.3
f1 (ppm)
O
O
O
O
O
O
NO2
O
CN
CN
2.32
2.12
2.25
2.34
1.03
1.00
3.19
3.12
3.12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165.29
161.34
149.19
133.89
131.95
128.54
124.58
122.66
114.29
111.62
111.44
106.64
93.32
77.25 CDCl3
77.04 CDCl3
76.83 CDCl3
71.09
64.80
62.73
55.37
30.34
27.97
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 150.92
4 Nucleus 13C
O
O
O
O
O
O
CN
CN
NO2
115 114 113 112 111 110 109 108 107
f1 (ppm)
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)
7.26
7.25
7.25
7.24
7.23
CDCl3
6.90
6.90
6.89
6.89
6.89
6.77
6.76
6.51
6.50
6.50
6.50
6.11
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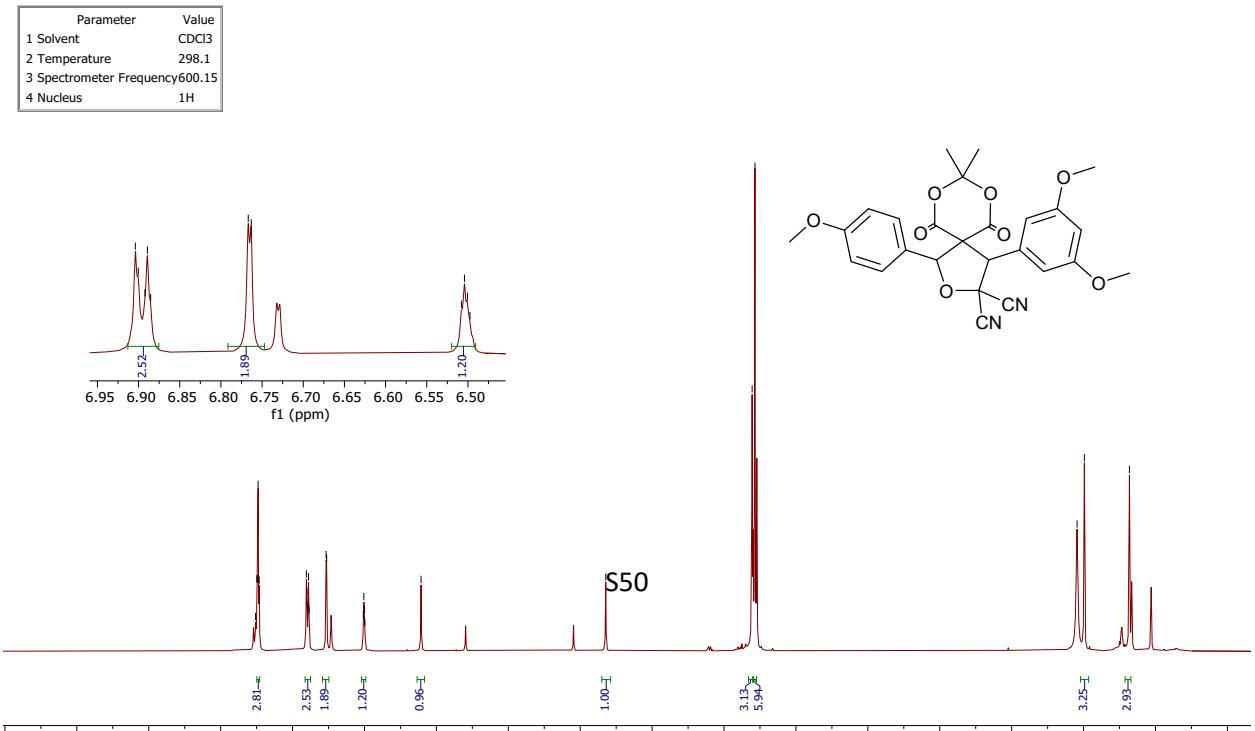
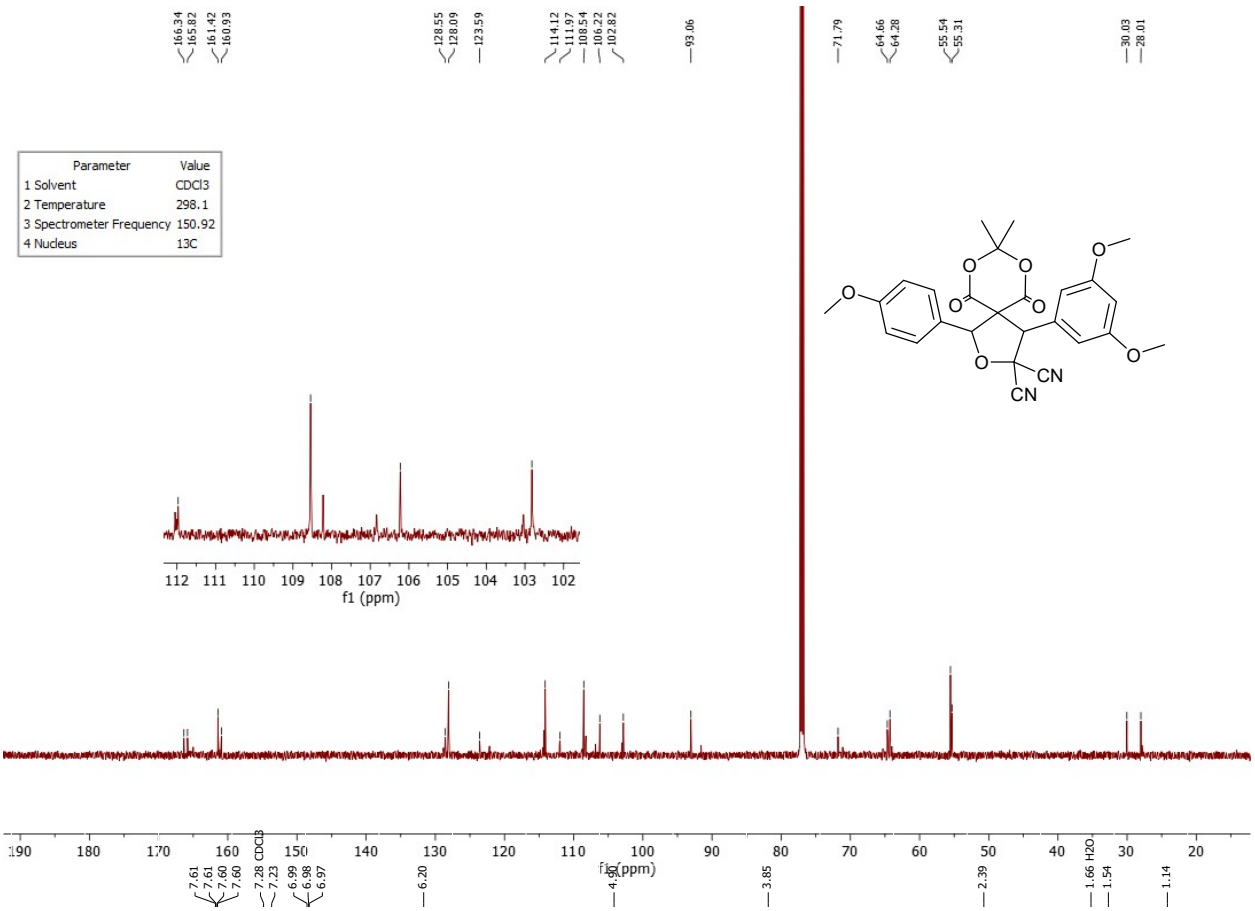
3.80
3.78
1.55 H2O
1.49
1.18


Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 600.15
4 Nucleus 1H
O
O
O
O
O
O
CN
CN
2.52
1.89
1.20
6.95 6.90 6.85 6.80 6.75 6.70 6.65 6.60 6.55 6.50
f1 (ppm)
2.81
2.53
1.89
1.20
0.96
1.00
3.13
5.94
3.25
2.93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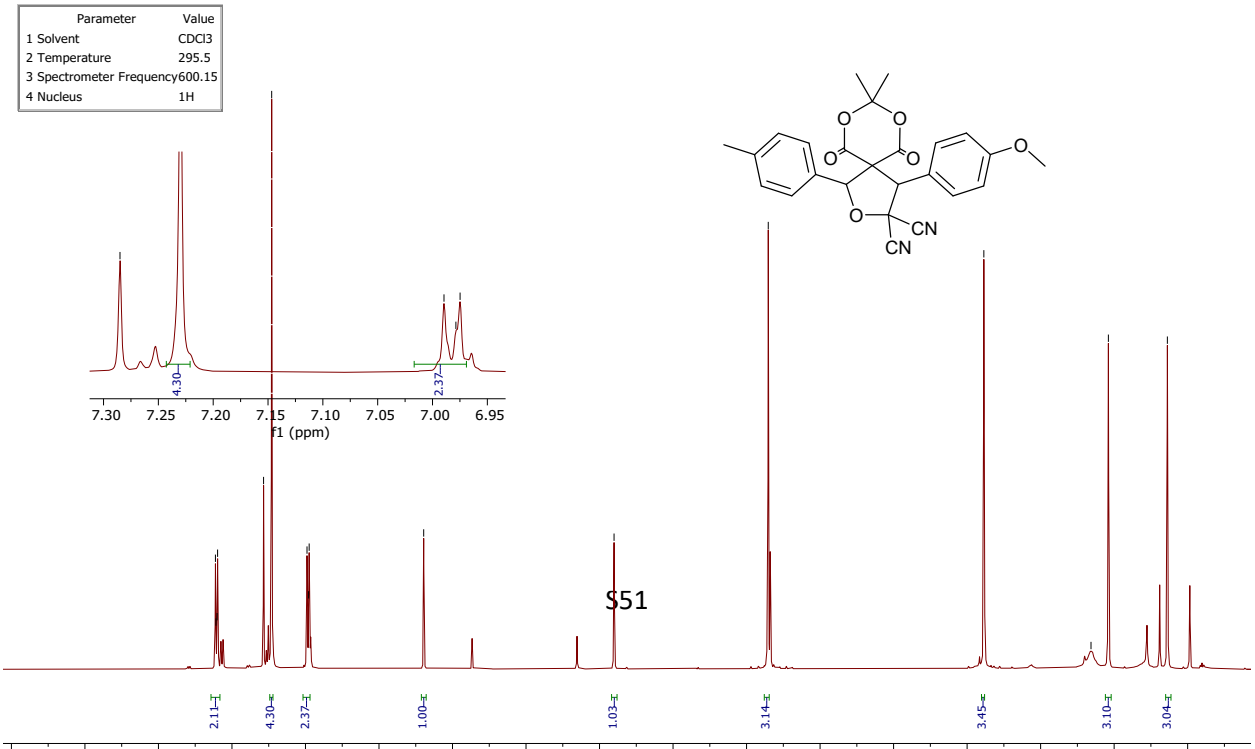
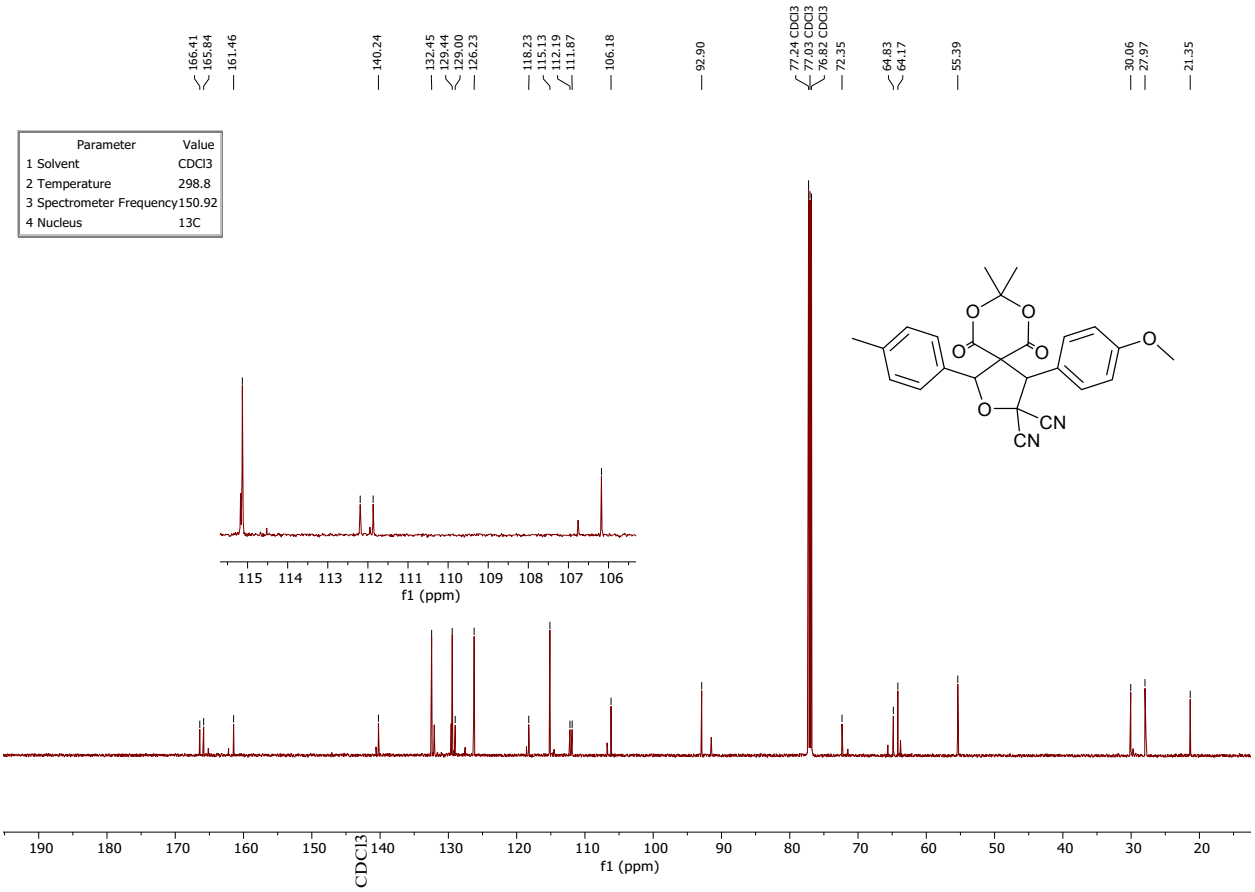
165.82
161.42
160.93
128.55
128.09
123.59
114.12
111.97
108.54
106.22
102.82
93.06
71.79
64.66
64.28
55.54
55.31
30.03
28.01
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 150.92
4 Nucleus 13C
CN
CN
112 111 110 109 108 107 106 105 104 103 102
f1 (ppm)
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20
f1 (ppm)
7.61
7.61
7.60
7.60
7.28 CDCl3
7.23
6.99
6.98
6.97
6.20
4.30
3.85
2.39
1.66 H2O
1.54
1.14


Parameter Value
1 Solvent CDCl3
2 Temperature 295.5
3 Spectrometer Frequency 600.15
4 Nucleus 1H
CN
CN
4.30
2.37
7.30 7.25 7.20 7.15 7.10 7.05 7.00 6.95
f1 (ppm)
2.11
4.30
2.37
1.00
1.03
3.14
3.45
3.10
3.04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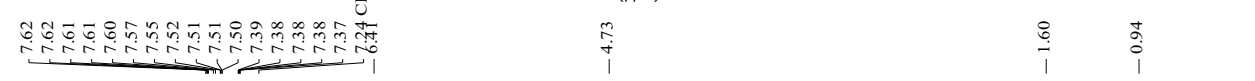
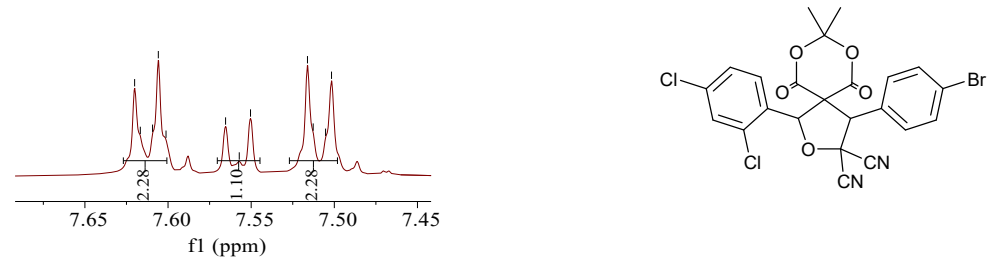
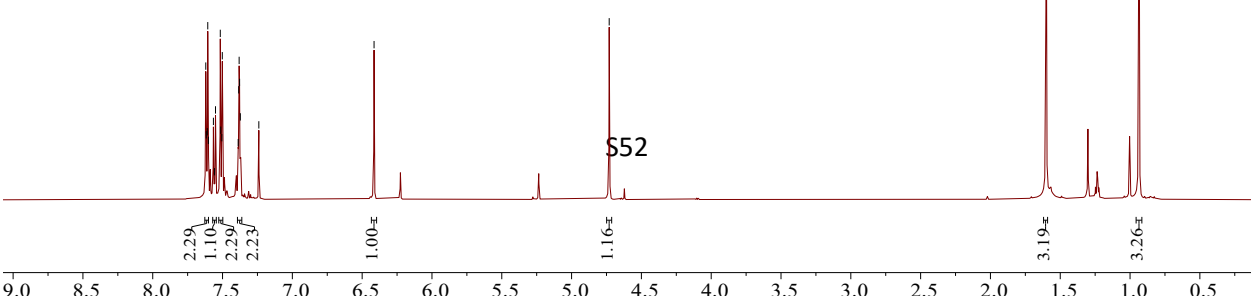
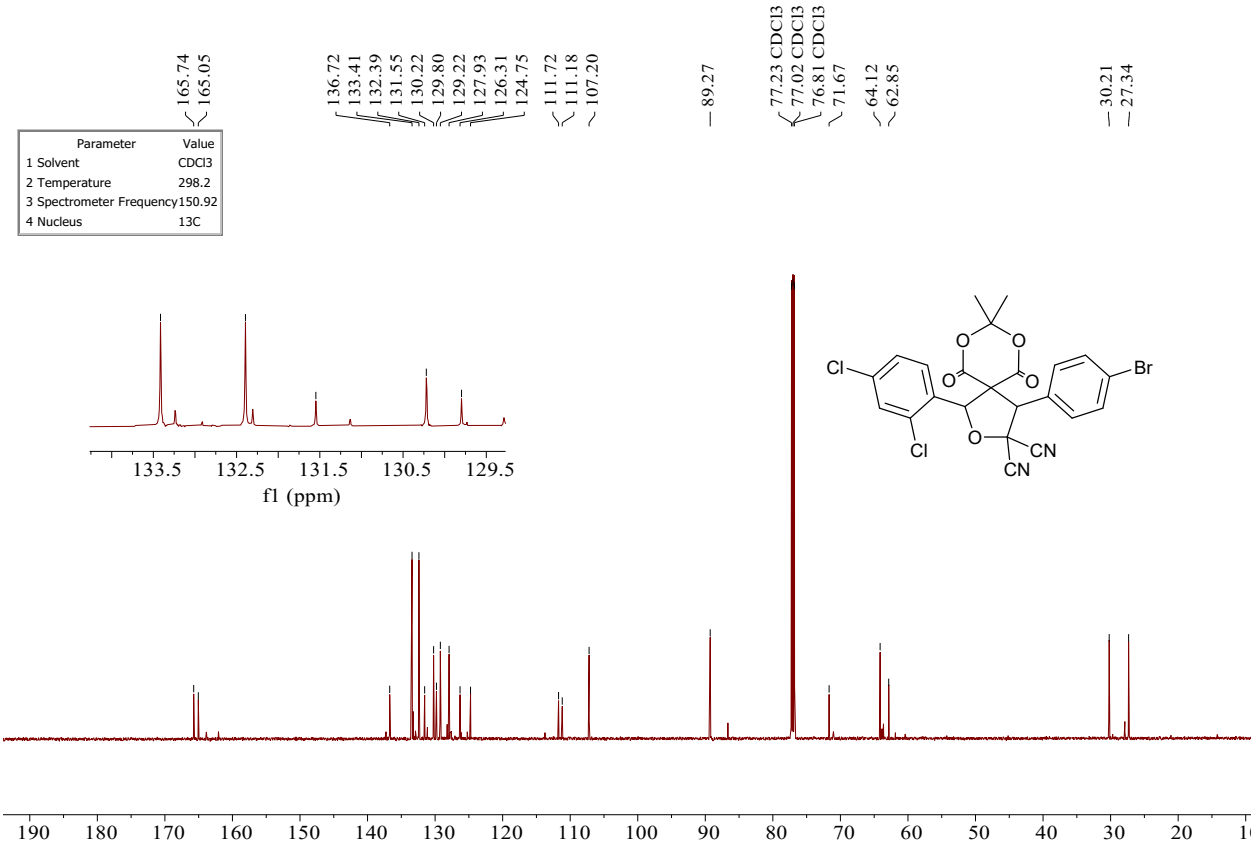
165.84
161.46
140.24
132.45
129.44
129.00
126.23
118.23
115.13
112.19
111.87
106.18
92.90
77.24 CDCl3
77.03 CDCl3
76.82 CDCl3
72.35
64.83
64.17
55.39
30.06
27.97
21.35
Parameter Value
1 Solvent CDCl3
2 Temperature 298.8
3 Spectrometer Frequency 150.92
4 Nucleus 13C
CN
CN
f1 (ppm)

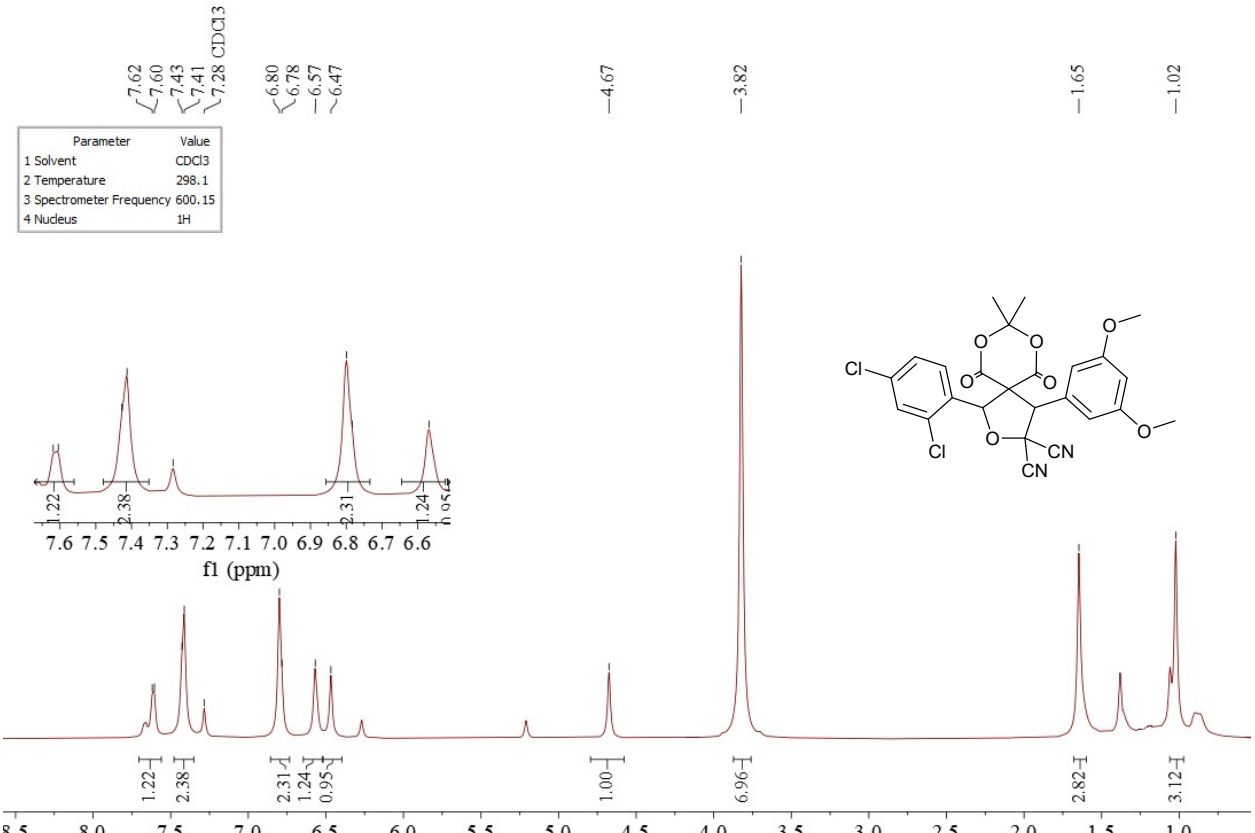

f1 (ppm)

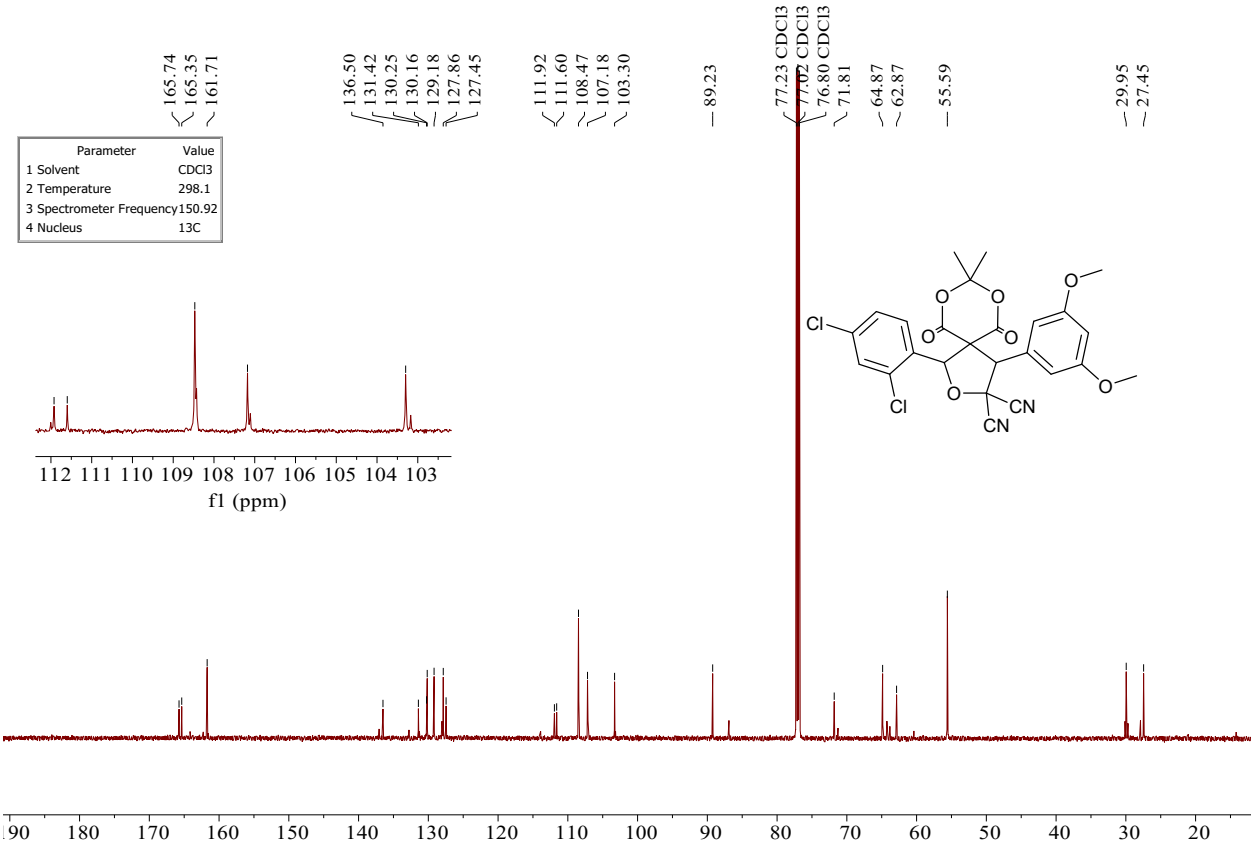
7.62
7.62
7.61
7.61
7.60
7.57
7.55
7.52
7.51
7.51
7.50
7.39
7.38
7.38
7.38
7.37
7.24 CDCl3
6.41
4.73
1.60
0.94

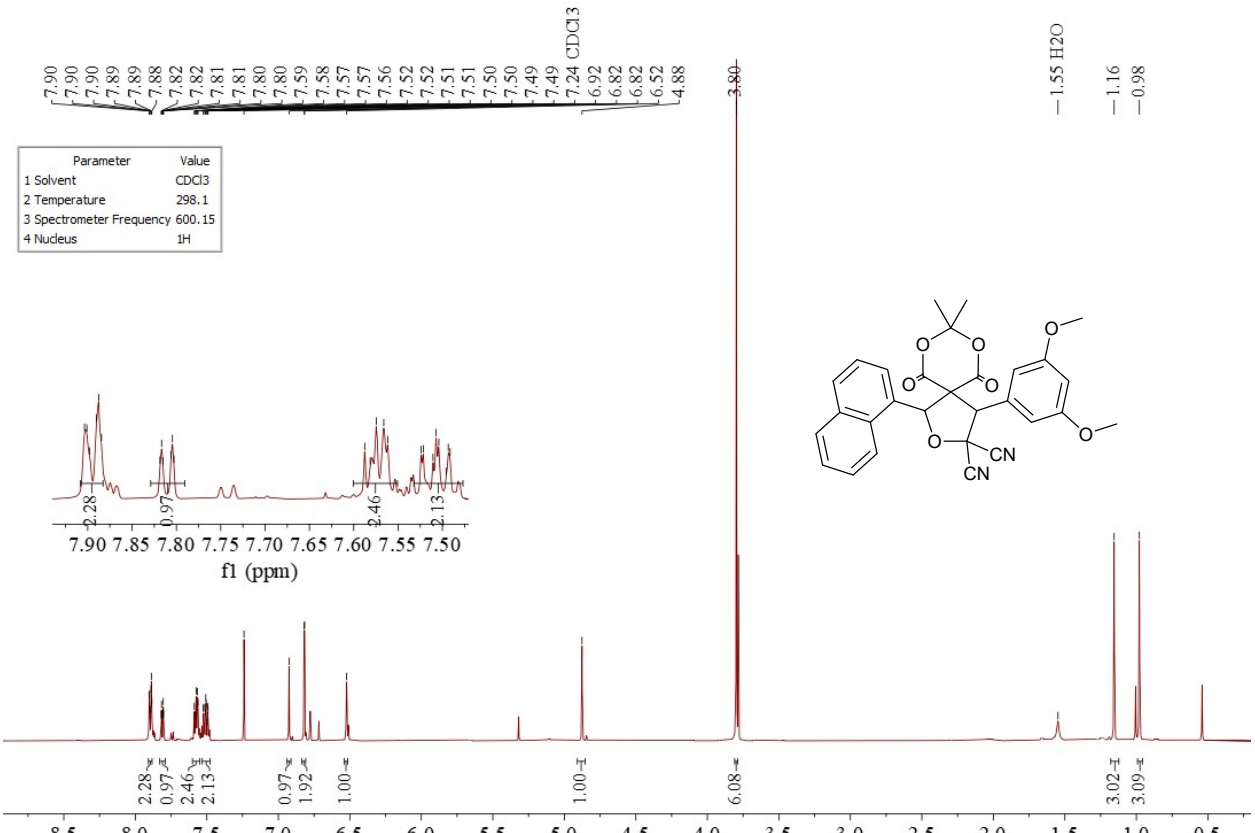

Cl
Br
Cl
CN
CN
2.28
1.10
2.28
f1 (ppm)

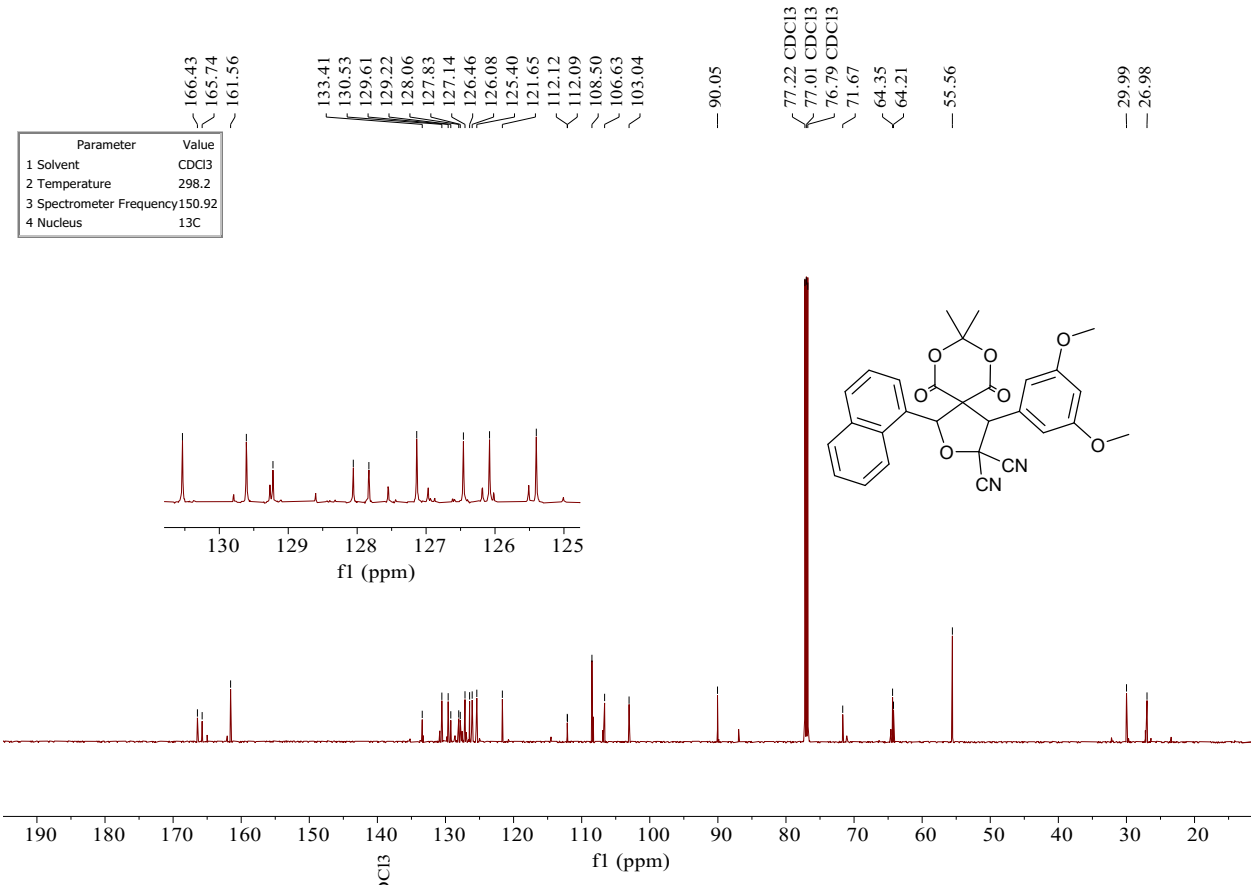

2.29
1.10
2.29
2.23
1.00
1.16
3.19
3.26
f1 (ppm)


165.74
165.05
136.72
133.41
132.39
131.55
130.22
129.80
129.22
127.93
126.31
124.75
111.72
111.18
107.20
89.27
77.23 CDCl3
77.02 CDCl3
76.81 CDCl3
71.67
64.12
62.85
30.21
27.34
Parameter Value
1 Solvent CDCl3
2 Temperature 298.2
3 Spectrometer Frequency 150.92
4 Nucleus 13C
133.5 132.5 131.5 130.5 129.5
f1 (ppm)
Cl
Br
Cl
O
O
O
O
O
O
CN
CN
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20


7.62
7.60
7.43
7.41
7.28 CDCl3
6.80
6.78
6.57
6.47
4.67
3.82
1.65
1.02
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 600.15
4 Nucleus 1H
1.22
2.38
2.31
1.24
7.6 7.5 7.4 7.3 7.2 7.1 7.0 6.9 6.8 6.7 6.6
f1 (ppm)
Cl
Cl
O
O
O
O
O
O
O
CN
CN
1.22
2.38
2.31
1.24
0.95
1.00
6.96
2.82
3.12
8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0


165.74
165.35
161.71
136.50
131.42
130.25
130.16
129.18
127.86
127.45
111.92
111.60
108.47
107.18
103.30
89.23
77.23 CDCl3
77.02 CDCl3
76.80 CDCl3
71.81
64.87
62.87
55.59
29.95
27.45
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 150.92
4 Nucleus 13C
112 111 110 109 108 107 106 105 104 103
f1 (ppm)
Cl
Cl
O
O
O
O
O
O
O
CN
CN
90 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20


7.90 7.90 7.90 7.89 7.89 7.88 7.82 7.82 7.81 7.81 7.80 7.80 7.59 7.58 7.57 7.57 7.56 7.52 7.52 7.51 7.51 7.50 7.50 7.49 7.49
7.24 CDCl3
6.92 6.82 6.82 6.52 4.88
3.80
1.55 H2O
1.16
0.98
Parameter Value
1 Solvent CDCl3
2 Temperature 298.1
3 Spectrometer Frequency 600.15
4 Nucleus 1H
2.28 0.97 2.46 2.13
7.90 7.85 7.80 7.75 7.70 7.65 7.60 7.55 7.50
f1 (ppm)
O
O
O
O
O
O
O
CN
CN
2.28 0.97 2.46 2.13 0.97 1.92 1.00 1.00 6.08 3.02 3.09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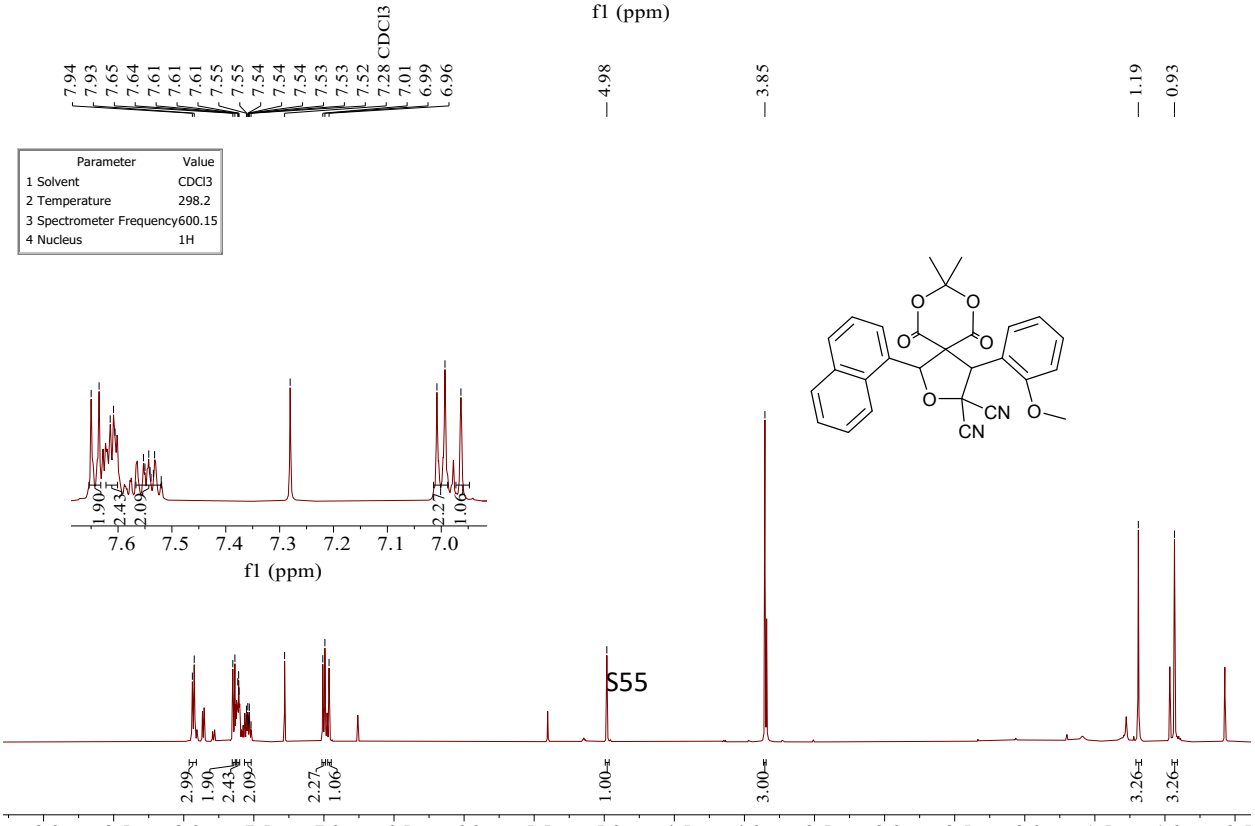
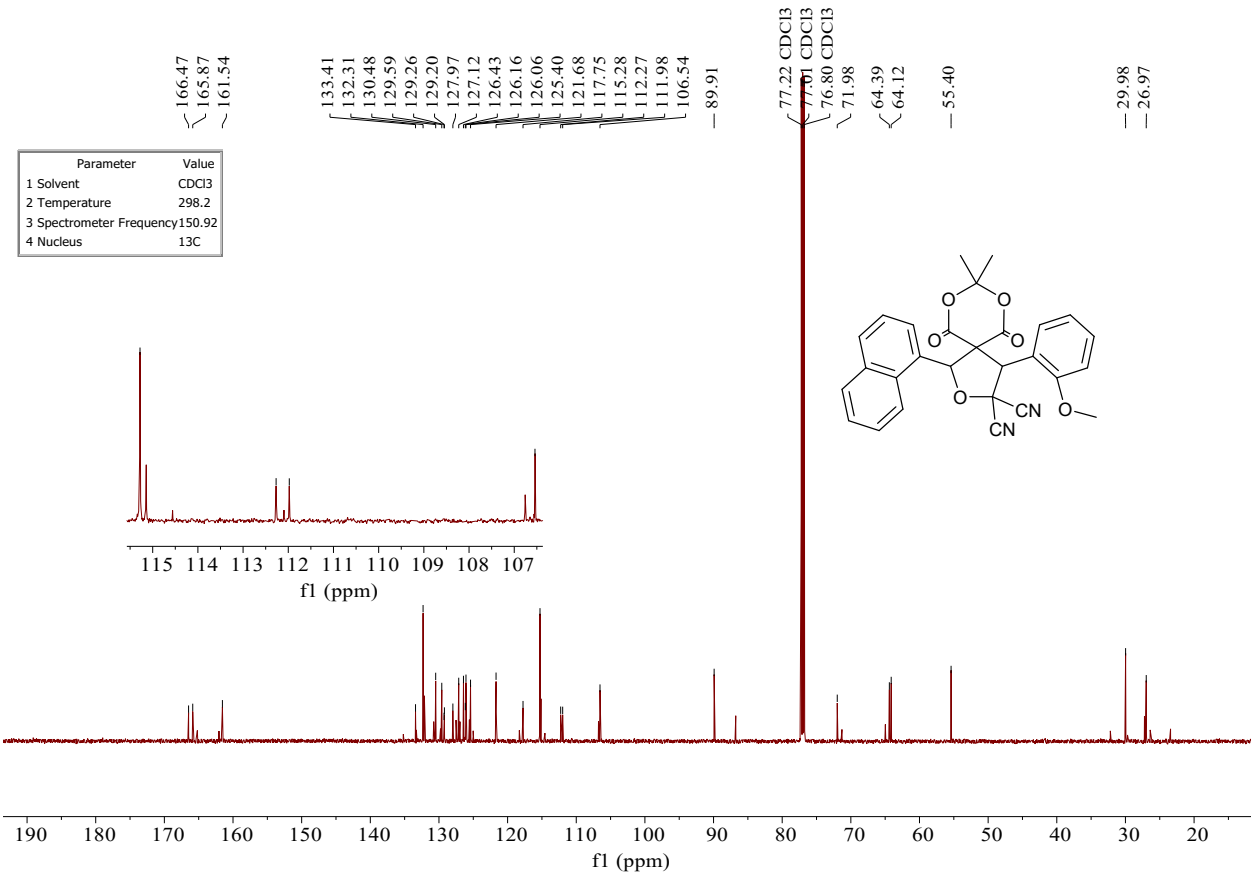
165.74
161.56
133.41
130.53
129.61
129.22
128.06
127.83
127.14
126.46
126.08
125.40
121.65
112.12
112.09
108.50
106.63
103.04
90.05
77.22 CDCl3
77.01 CDCl3
76.79 CDCl3
71.67
64.35
64.21
55.56
29.99
26.98
Parameter Value
1 Solvent CDCl3
2 Temperature 298.2
3 Spectrometer Frequency 150.92
4 Nucleus 13C
CN
CN
130 129 128 127 126 125
f1 (ppm)
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20
f1 (ppm)


7.94
7.93
7.65
7.64
7.61
7.61
7.61
7.55
7.55
7.54
7.54
7.54
7.53
7.53
7.52
7.28 CDCl3
7.01
6.99
6.96
4.98
3.85
1.19
0.93
Parameter Value
1 Solvent CDCl3
2 Temperature 298.2
3 Spectrometer Frequency 600.15
4 Nucleus 1H
CN
CN
1.90
2.43
2.09
2.27
1.06
7.6 7.5 7.4 7.3 7.2 7.1 7.0
f1 (ppm)
S55
2.99
1.90
2.43
2.09
2.27
1.06
1.00
3.00
3.26
3.26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161.54
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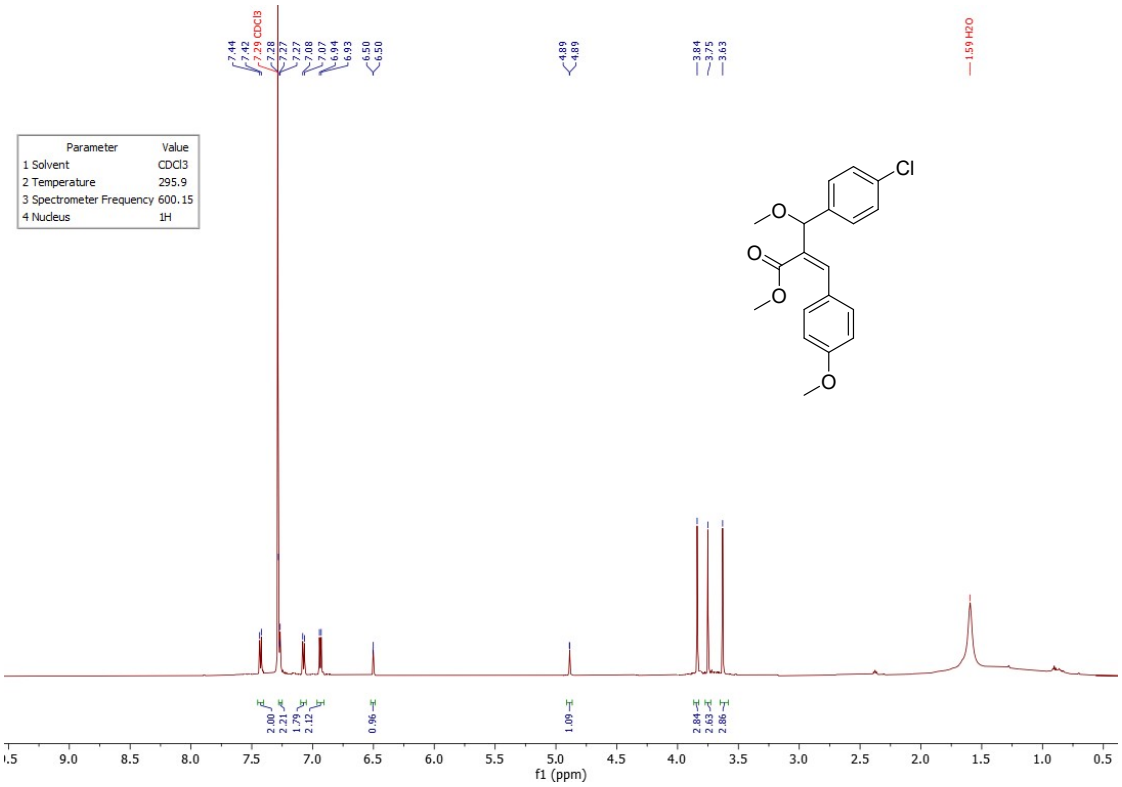
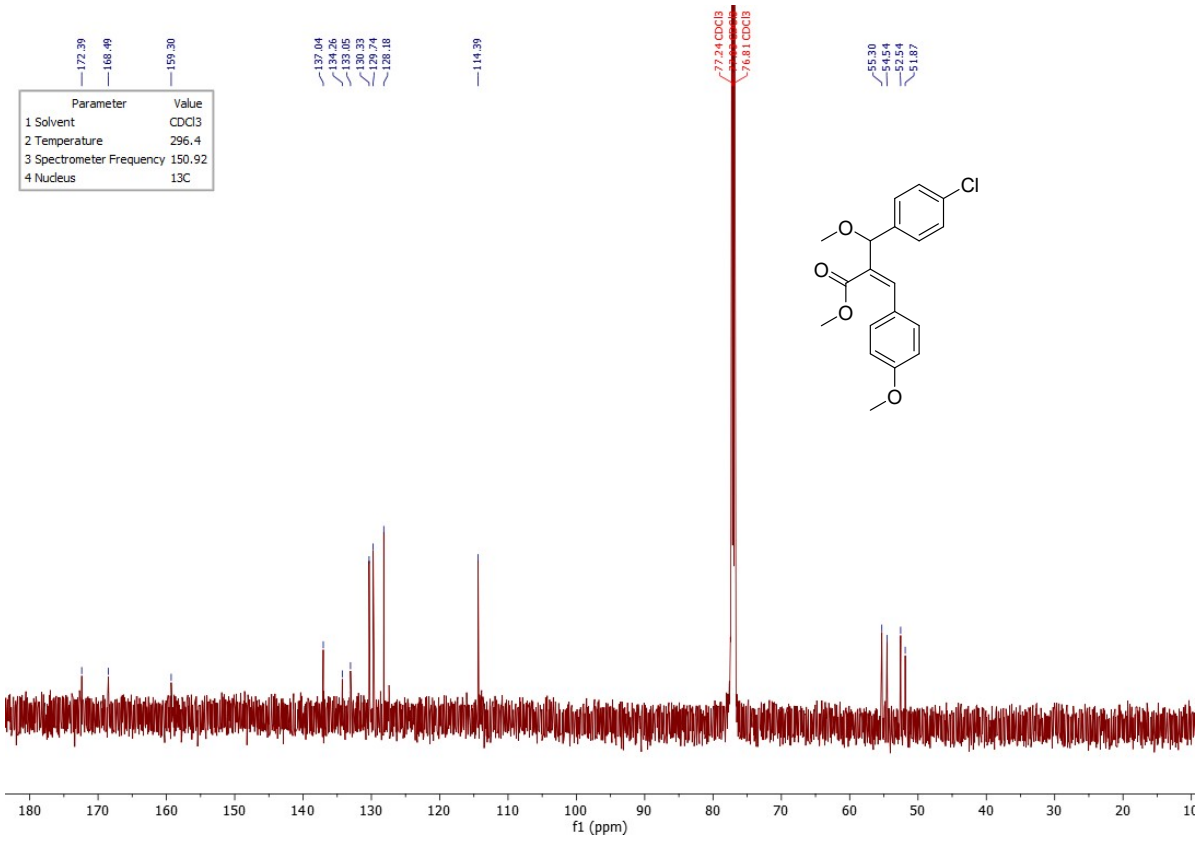
132.31
130.48
129.59
129.26
129.20
127.97
127.12
126.43
126.16
126.06
125.40
121.68
117.75
115.28
112.27
111.98
106.54
89.91
77.22 CDCl3
77.01 CDCl3
76.80 CDCl3
71.98
64.39
64.12
55.40
29.98
26.97
Parameter Value
1 Solvent CDCl3
2 Temperature 298.2
3 Spectrometer Frequency 150.92
4 Nucleus 13C
O
O
O
O
O
CN
CN
O
115 114 113 112 111 110 109 108 107
f1 (ppm)
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20
f1 (ppm)


7.44
7.42
7.29 CDCl3
7.28
7.27
7.27
7.08
7.07
6.94
6.93
6.50
6.50
4.89
4.89
3.84
3.75
3.63
1.59 H2O
Parameter Value
1 Solvent CDCl3
2 Temperature 295.9
3 Spectrometer Frequency 600.15
4 Nucleus 1H
Cl
O
O
O
O
2.00
2.21
1.79
2.12
0.96
1.09
2.84
2.63
2.86
f1 (ppm)


172.39
168.49
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134.26
133.05
130.33
129.74
128.18
114.39
77.24 CDCl3
76.81 CDCl3
55.30
54.54
52.54
51.87
Parameter Value
1 Solvent CDCl3
2 Temperature 296.4
3 Spectrometer Frequency 150.92
4 Nucleus 13C
Cl
O
O
O
O
f1 (ppm)