Supporting Information for:

A Versatile Catalyst System for Enantioselective Synthesis of 2-Substituted 1,4-Benzodioxanes

Eugene Chong,*[a] Bo Qu,*[a] Yongda Zhang,*[a] Zachary P. Cannone,[a] Joyce C. Leung,[a] Sergei Tcyrulnikov,[b] Khoa D. Nguyen,[a] Nizar Haddad,[a] Soumik Biswas,[a] Xiaowen Hou,[a] Katarzyna Kaczanowska,[c] Michał Chwalba,[c] Andrzej Tracz,[c] Stefan Czarnocki,[c] Jinhua J. Song,[a] Marisa C. Kozlowski*[b] and Chris H. Senanayake[a,d]

[a] Chemical Development US, Boehringer Ingelheim Pharmaceuticals, Inc. 900 Ridgebury Road, Ridgefield, CT 06877, USA

[b] Department of Chemistry, University of Pennsylvania, Philadelphia, PA 19104, USA

[c] Aperion Synthesis S. A. Wroclaw Technology Park ul. Duńska 9, 54-427 Wrocław, Poland

[d] Astatech BioPharmaceutical Corporation, 488 Kelin West Road, Wenjiang Dist., Chengdu, Sichuan 611130, P. R. China

Table of Contents

I. General Information

General:

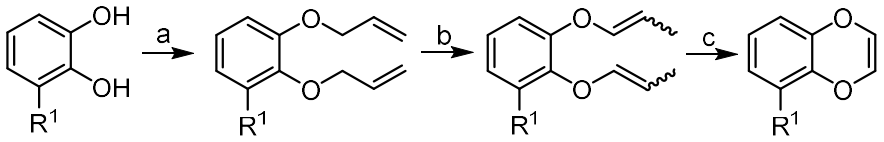
Unless stated otherwise, reactions were conducted under an atmosphere of nitrogen using standard Schlenk or glove box techniques. NMR Spectra (^{1}H, ^{13}C, ^{19}F) were recorded on Bruker DPX-400, Bruker DRX-500, or Bruker AVANCE 600 NMR spectrometer. All ^{13}C NMR data presented are proton-decoupled ^{13}C NMR spectra, unless noted otherwise. Chemical shifts (δ) are reported in parts per million (ppm) and coupling constants (J) are given in Hertz (Hz) and referenced relative to TMS (0 ppm). The following abbreviations are used to indicate signal multiplicity: s = singlet, d = doublet, t = triplet, q = quartet, p = pentet, dd = doublet of doublets, dq = doublet of quartets, td = triplet of doublets, qd = quartet of doublets, ddt = doublet of doublet of triplets, m = multiplet, app = apparent, and br = broad resonance. High-resolution mass spectrometry (HRMS) data were obtained on Thermo LTQ FT Ultra mass spectrometer at 100,000 resolving power using direct analysis in real time (DART) source ionization or Thermo Scientific Exactive mass spectrometer at 120,000 resolving power using Heated Electrospray Source Ionization (HESI) in the positive ion mode. Flash chromatography was performed using a Teledyne CombiFlash Rf (visualizing at 254 & 280 nm) with Silicycle SiliaSep Flash Cartridges (60Å porosity, 40-63 μm). Chiral SFC and HPLC analyses were conducted on Agilent 1260 Infinity system. Specific rotation was measured on Rudolph Research Analytical Autopol III S2 polarimeter.

The absolute configuration of product **6f**[1] and **6z**[2] were determined by comparison of analytical data with the literature. The absolute configurations of other compounds were assigned by analogy.

All commercial reagents were used as received. All anhydrous solvents were purchased from Sigma Aldrich in a Sure-Seal bottle and degassed by sparging with nitrogen for 15 min before use. $[RuClH(CO)(PPh_3)_3]$, nitro-Grela AS2032, and SnatchCat AS1033 were synthesized in house by Aperion Synthesis. $[Ir(cod)Cl]_2$ was purchased from Strem. Compounds **5f**,[1] **5h**,[1] **5z**,[2] **L1–L5**[3] are known compounds and were prepared according to reported procedures.

[1] Wang, Y.; Xia, J.; Yang, G.; Zhang, W. *Tetrahedron* **2018**, *74*, 477.
[2] Yin, X.; Huang, Y.; Chen, Z.; Hu, Y.; Tao, L.; Zhao, Q.; Dong, X.-Q.; Zhang, X. *Org. Lett.* **2018**, *20*, 4173.
[3] (a) Luo, R. S.; Li, K.; Hu, Y.; Tang, W. *Adv. Synth. Catal.* **2013**, *355*, 1297. (b) Liu, G.; Liu, X.; Cai, Z.; Jiao, G.; Xu, G.; Tang, W. *Angew. Chem., Int. Ed.* **2013**, *52*, 4235. (c) Huang, L.; Zhu, J.; Jiao, G.; Wang, Z.; Yu, X.; Deng, W.-P.; Tang, W. *Angew. Chem., Int. Ed.* **2016**, *55*, 4527.

II. Synthesis of 1,4-Benzodioxines 4a and 4b Using Nitro-Grela Catalyst

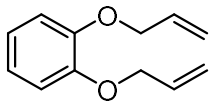


1a: R^1 = H **2a**: R^1 = H **3a**: R^1 = H **4a**: R^1 = H
1b: R^1 = CO_2Me **2b**: R^1 = CO_2Me **3b**: R^1 = CO_2Me **4b**: R^1 = CO_2Me

a: allyl bromide, K_2CO_3, MeCN; b: $RuClH(CO)(PPh_3)_3$ (3.0 mol%); c: Nitro-Grela (300 ppm)

Alkylation of catechols **1** with allyl bromide afforded bis(allyloxy)benzoates **2**, which were then catalytically isomerized to obtain bis(prop-1-en-1-yloxy)benzenes **3** as a mixture of E/Z isomers. In the final step, **3** gave ring closing metathesis product **4** catalyzed by nitro-Grela catalyst.

1,2-Bis(allyloxy)benzene (2a)



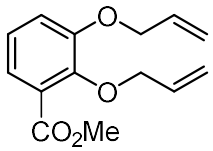
2a

1,2-Dihydroxybenzene (31.6 g, 287 mmol) was dissolved in DMF (270 mL) in 500 mL round-bottom flask equipped with reflux condenser. Flask was placed in water bath (reaction is exothermic) and sodium iodide (4.30 g, 29 mmol), allyl bromide (62.0 mL, 717 mmol) followed by potassium carbonate (119.0 g, 861 mmol) were added. The mixture was stirred at room temperature for 2 h. Acetonitrile (270 mL) was added and solids were filtered off. The mixture was concentrated in vacuo and the product (colorless oil, 45.5 g, 83% yield, 97% GC purity) was isolated by vacuum distillation (100 °C, 0.001 mbar). NMR spectral data match literature data.[4]

^{1}H NMR (601 MHz, $CDCl_3$) δ 6.93–6.86 (m, 4H), 6.08 (ddt, J = 17.3, 10.5, 5.3 Hz, 2H), 5.41 (dq, J = 17.3, 1.6 Hz, 2H), 5.26 (dq, J = 10.5, 1.4 Hz, 2H), 4.60 (dt, J = 5.3, 1.6 Hz, 4H).

^{13}C NMR (151 MHz, $CDCl_3$) δ 148.6, 133.5, 121.2, 117.4, 114.3, 69.9.

Methyl 2,3-bis(allyloxy)benzoate (2b)



2b

Methyl 2,3-dihydroxybenzoate (20.0 g, 120 mmol) was dissolved in acetonitrile (80 mL), allyl bromide (26.0 mL, 300 mmol, 2.5 eq) followed by potassium carbonate (49.9 g, 360 mmol, 3.0 eq) were added

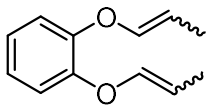
[4] Morgans, G. L.; Ngidi, E. L.; Madeley, L. G.; Khanye, S. D.; Michael, J. P.; de Koning, C. B.; van Otterlo, W. A. L. *Tetrahedron* **2009**, *65*, 10650.

and the mixture was stirred at 80 °C for 1 h. The solids were filtered off, the mixture concentrated in vacuo and the product (pale yellow oil, 29.6 g, 94% yield, 98% GC purity) was isolated by vacuum distillation (140 °C, 0.0043 mbar). NMR spectral data match literature data.[5]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.34–7.31 (m, 1H), 7.05–7.04 (m, 2H), 6.17–6.02 (m, 2H), 5.45–5.40 (m, 1H), 5.39–5.34 (m, 1H), 5.30–5.27 (m, 1H), 5.24–5.20 (m, 1H), 4.60–4.57 (m, 4H), 3.88 (s, 3H).

^{13}C NMR (126 MHz, $CDCl_3$) δ 166.9, 152.7, 148.4, 134.4, 133.2, 126.8, 123.9, 122.7, 118.0, 117.7, 117.7, 74.9, 70.1, 52.3.

1,2-Bis(1-propenyloxy)benzene (3a)



3a

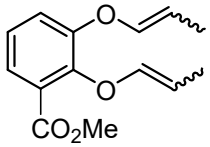
A mixture of methyl 1,2-bis(allyloxy)benzene (12.4 g, 65 mmol) in toluene (65 mL) was purged with argon. The mixture was equilibrated at 80 °C for 30 minutes. [$RuClH(CO)(PPh_3)_3$] (0.621 g, 1.0 mol%) was then added in one portion, a reflux condenser was mounted and the reaction mixture was stirred at 80 °C for 7 h. The mixture was allowed to cool to rt, copper chloride was added (0.29 g, 4.5 mol%) and the mixture was stirred at rt for 30 min. The suspension was filtered via an aluminum oxide pad, the solvents were removed in vacuo and the product (colorless oil, 10.5 g, 85% yield, >99% GC purity) was isolated by vacuum distillation (75-95 °C, 0.001 mbar). NMR spectral data match

literature data.[4]

^{1}H NMR (601 MHz, $CDCl_3$): δ 7.05–6.94 (m, 4H), 6.44–6.27 (m, 2H), 5.41–5.28 (m, 0.4H), 4.94–4.82 (m, 1.5H), 1.81–1.69 (m, 4.7H), 1.69–1.61 (s, 1.4H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 147.8, 147.7, 143.1, 141.9, 141.6, 123.4, 123.2, 123.2, 123.1, 118.1, 117.6, 117.4, 117.2, 108.1, 107.8, 107.6, 107.3, 77.2, 12.3, 9.6, 9.5.

Methyl 2,3-bis(1-propenyloxy)benzoate (3b)



3b

A mixture of methyl 2,3-bis(allyloxy)benzoate (14.9 g, 60 mmol) in toluene (16 mL) was degassed and purged with argon. The mixture was equilibrated at 60 °C for 30 minutes. [$RuClH(CO)(PPh_3)_3$] (1.72 g, 3 mol%) was then added in one portion, a reflux condenser was mounted and the reaction mixture was

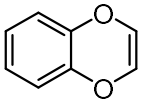
[5] Aristegui, S. R.; El-Murr, M. D.; Golding, B. T.; Griffin, R. J.; Hardcastle, I. R. *Org. Lett.* **2006**, *8*, 5927.

stirred at 60 °C for 20 h followed by 3 h at 130 °C. The mixture was allowed to cool to rt, copper chloride was added (0.54 g, 9 mol%) and the mixture was stirred at rt for 30 min. The suspension was filtered via an aluminum oxide pad, the solvents were removed in vacuo and the product (colorless oil, 13.0 g, 87% yield, 97% GC purity) was isolated by vacuum distillation (135-150 °C, 0.25 mbar).

^{1}H NMR (601 MHz, $CDCl_3$): δ 7.47–7.44 (m, 1H), 7.18–7.15 (m, 1H), 7.12–7.09 (m, 1H), 6.34 (dq, J = 12.0, 1.2 Hz, 0.2H), 6.31 (dq, J = 6.0, 1.8 Hz, 0.8H), 6.18 (dq, J = 6.0, 1.8 Hz, 0.7H), 6.14 (dq, J = 6.0, 1.2 Hz, 0.2H), 5.33 (dq, J = 12.0, 7.2 Hz, 0.2H), 4.90 (dq, J = 6.6, 6.0 Hz, 0.8H), 4.68–4.63 (m, 0.9H), 3.89 (s, 2.4H), 3.88 (s, 0.6H), 1.77 (dd, J = 7.2, 1.8 Hz, 2.6H), 1.75 (d, J = 1.8 Hz, 0.3H), 1.71 (dd, J = 6.6, 1.8 Hz, 2.4H), 1.64–1.63 (m, 0.7H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 166.4, 150.6, 150.3, 146.9, 145.0, 144.9, 142.5, 141.1, 126.2, 126.1, 124.9, 124.5, 124.5, 124.5, 121.6, 120.4, 108.6, 108.3, 103.6, 103.5, 52.4, 12.3, 9.5, 9.3.

1,4-Benzodioxine (4a)



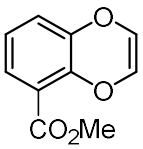
4a

A dry three-neck round-bottom flask equipped in a reflux condenser, flushed with argon, was charged with a solution of 1,2-bis(1-propenyloxy)benzene (77.2 g, 406 mmol) in toluene 406 mL) and the solution was equilibrated at 70 °C for 30 min with a steady argon flow through the mixture. A solution of nitro-Grela AS2032 catalyst (0.041 g, 0.061 mmol, 150 ppm) in toluene (3 mL), was added in 5 portions in 15 min increments (90% of product was observed by GC after second 30 ppm portion). The mixture was stirred at 70 °C for additional 1 h under steady flow of argon. Next the mixture was cooled to rt, 0.1 M dichloromethane solution of SnatchCat AS1033 (3.65 mL, 0.365 mmol) was added and stirring continued for 20 minutes at rt. Silica gel (8.2 g) was added and the suspension was stirred for 30 minutes at rt. The solids were removed by filtration through a silica gel pad (8.2 g), which was then washed with cyclohexane (150 mL). The crude mixture was concentrated in vacuo and the product (colorless oil, 44.0 g, 81% yield, >99% GC purity) was isolated by vacuum distillation (75-80 °C, 0.001 mbar). NMR spectral data match literature data.[4]

^{1}H NMR (601 MHz, $CDCl_3$): δ 6.85–6.75 (m, 2H), 6.66–6.57 (m, 2H), 5.86 (s, 2H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 142.9, 126.9, 124.3, 116.4, 77.2.

Methyl 1,4-benzodioxine-5-carboxylate (4b)



4b

A dry three-neck round-bottom flask equipped in a reflux condenser flushed with argon was charged with a solution of methyl 2,3-bis(1-propenyloxy)benzoate (6.79 g, 27.3 mmol) in toluene (12 mL) and the solution was equilibrated at 70 °C for 30 min with a steady argon flow through the mixture. nitro-Grela AS2032 catalyst (0.030 g, 0.045 mmol) was dissolved in toluene (14.8 mL) in a separate dry and argon flushed flask. Argon flow through the mixture was increased, the catalyst solution was added to the substrate mixture with a syringe pump (300 ppm, 2.7 mL, 30 uL/min) over 90 min and the mixture was stirred at 70 °C for additional 30 min. After the mixture reached rt, dichloromethane solution of SnachCat AS1033 (0.03 mmol, 0.25 mL, 0.1 M) was added and stirring continued for 20 minutes at rt. Silica gel (1.6 g) was added and the suspension was stirred for 30 minutes at rt. The solids were removed by filtration through a silica gel pad (3.2 g), which was then rinsed with *tert*-butyl methyl ether (20 mL). The crude mixture was concentrated in vacuo and the product (colorless oil, 4.5 g, 87% yield, 97.6% GC purity) was isolated by vacuum distillation (124 °C, 0.005 mbar). The product solidified when stored at 4 °C. The solid was recrystallized from diethyl ether/pentane/cyclohexane (99% GC purity).

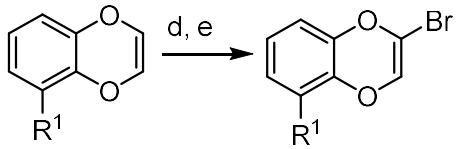
^{1}H NMR (601 MHz, $CDCl_3$): δ 7.32 (dd, J = 8.0, 1.5 Hz, 1H), 6.82 (t, J = 8.0 Hz, 1H), 6.74 (dd, J = 8.0, 1.5 Hz, 1H), 5.98 (d, J = 3,6 Hz, 1H), 5.91 (d, J = 3,6 Hz, 1H), 3.86 (s, 3H).

^{13}C NMR (151 MHz, $CDCl_3$): δ 165.1, 143.3, 143.2, 127.2, 126.9, 126.0, 123.2, 120.0, 119.2, 52.2.

HRMS (HESI): *m/z* calcd for $C_{10}H_9O_4$ $[M+H]^+$: 193.04954. Found: 193.04952.

III. Synthesis of Substrates 5a–5ae

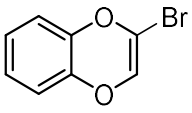
Preparation of 2-bromo-1,4-benzodioxine derivatives



4a: R^1 = H **SI-1:** R^1 = H
4b: R^1 = CO_2Me **SI-2:** R^1 = CO_2Me

d: NBS; e: base

2-bromo-1,4-benzodioxine (SI-1)



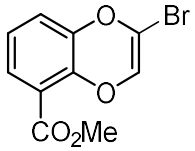
SI-1

A flask was charged 1,4-benzodioxine (6.96 g, 51.9 mmol, 1 equiv), LiBr (6.76 g, 86.8 mmol, 1.5 equiv) and CH_3CN (30 mL). A solution of N-Bromosuccinimide (9.70 g, 54.5 mmol, 1.05 equiv) in CH_3CN (70 mL) was added to the flask while maintaining the internal temperature at 20-25 °C. After 15 min, 5% sodium hydrogen sulfite in 8 mL of water was added. Acetonitrile was removed in vacuo. Water (100 mL)

was added to the crude residue and extracted three times with MTBE (3 × 150 mL). Combined organic extracts were dried over $MgSO_4$, filtered through a short pad of silica gel, and concentrated in vacuo. The resulting light brown solid was stirred in toluene (45 mL), and the resulting slurry was added to a stirred slurry of NaO*t*Bu (15.0 g, 156 mmol, 3 equiv) in *t*BuOH (150 mL) at rt. After 1 h, water (100 mL) was added and extracted with CH_2Cl_2 (3 × 100 mL). Combined organic extracts were dried over $MgSO_4$, filtered, and concentrated in vacuo. The product was purified by column chromatography (100% hexanes) to yield a colorless oil (6.70 g, 61% yield). NMR spectral data match literature data.[6]

^{1}H NMR (400 MHz, $CDCl_3$): δ 6.93–6.85 (multiple peaks, 2H), 6.75–6.65 (multiple peaks, 2H), 6.03 (s, 1H).

methyl 2-bromo-1,4-benzodioxine-5-carboxylate (SI-2)



SI-2

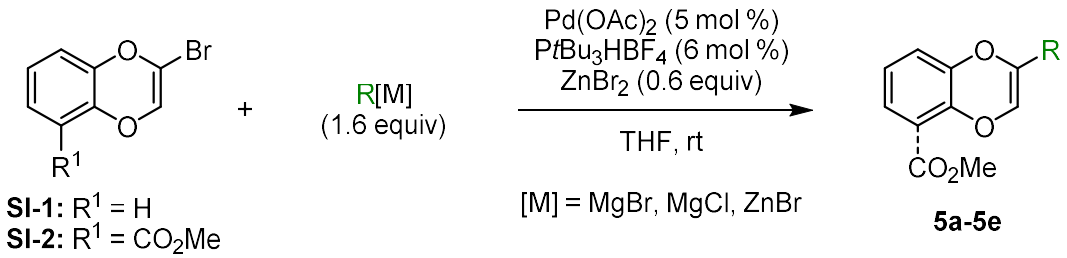
SI-2 was prepared in a related procedure to the synthesis of **SI-1**. After the NBS step d, methyl 2,3-dibromo-2,3-dihydro-1,4-benzodioxine-5-carboxylate (22.5 g, 63.9 mmol, 1 equiv) and MeOH (200 mL) were charged into a flask and placed in a pre-heated oil bath at 75 °C. NaOMe (0.5 M in MeOH, 511 mL, 256 mmol, 4 equiv) was added. After 90 minutes at 75 °C, the reaction mixture was cooled to room temperature and then treated with 90 g of silica. The solvent was evaporated and the dry silica is split in two portions for purification. Each portion was purified by Isolera (340g KP-Sil Biotage column, 0–15% EtOAc/Heptane). A total of 6.20 g of the desired product was obtained with 36 % yield.

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.44 (dd, J = 7.6, 2.0 Hz, 1H), 6.93–6.86 (multiple peaks, 2H), 6.14 (s, 1H), 3.87 (s, 3H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 164.7, 143.2, 142.2, 127.2, 124.8, 123.5, 120.2, 119.4, 118.5, 52.3.

HRMS (HESI): *m/z* calcd for $C_{10}H_8O_4Br$ $[M+H]^+$: 270.96005. Found: 270.95983.

General Procedure 1 (GP1) for the Synthesis of Substrates 5a–5e



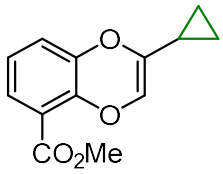
SI-1: R^1 = H
SI-2: R^1 = CO_2Me

5a-5e

[6] Lee, T. V.; Leigh, A. J.; Chapleo, C. B. *Tetrahedron* **1990**, *46*, 921.

A representative procedure is given for the synthesis of 2-alkyl-substituted 1,4-benzodioxines: synthesis of **5a**. To a suspension of methyl 2-bromo-1,4-benzodioxine-5-carboxylate **SI-2** (5.00 g, 18.4 mmol, 1 equiv) and tBu$_3$PHBF$_4$ (321 mg, 1.10 mmol, 0.06 equiv) in THF (30 mL), Pd(OAc)$_2$ (207 mg, 0.922 mmol, 0.05 equiv) and a solution of ZnBr$_2$ (~30 wt% solution, 2.49 g, 11.1 mmol, 0.6 equiv) was added. Cyclopropylmagnesium bromide (59.0 ml, 0.5 M in THF, 29.5 mmol, 1.6 equiv) was added dropwise over 1 h using a syringe pump while maintaining the temperature at 20–25 °C. Reaction was monitored by HPLC. Once starting material was consumed (total reaction time within 2 h), reaction was quenched with water (10 mL) and saturated aqueous ammonium chloride solution (50 mL) was added. The organic layer was extracted with EtOAc (3 × 50 mL). The combined organic extracts were dried over MgSO$_4$, filtered through a short pad of silica gel, followed by copious EtOAc washes, and concentrated in vacuo. Purification by column chromatography (elution gradient from 0–5% EtOAc in hexanes) yielded the title compound as an off-white solid (2.42 g, 57% yield).

Methyl 2-cyclopropyl-1,4-benzodioxine-5-carboxylate (5a)



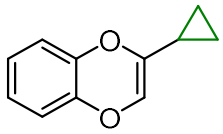
5a

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.33 (dd, J = 7.7, 2.0 Hz, 1H), 6.82–6.76 (multiple peaks, 2H), 5.89 (s, 1H), 3.85 (s, 3H), 1.30 (m, 1H), 0.69–0.61 (multiple peaks, 4H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 165.3, 143.41, 143.39, 139.3, 125.8, 122.6, 121.6, 119.8, 118.7, 52.1, 9.3, 3.3.

HRMS (DART): *m/z* calcd for $C_{13}H_{13}O_4$ $[M+H]^+$: 233.08084. Found: 233.08077.

2-Cyclopropyl-1,4-benzodioxine (5b)



5b

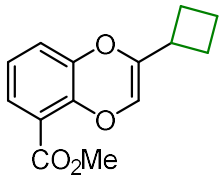
The compound was synthesized using **GP1** with 2-bromo-1,4-benzodioxine (700 mg, 3.29 mmol, 1 equiv). Purification by column chromatography using hexanes yielded the title compound as a colorless liquid (364 mg, 64% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 6.81–6.76 (multiple peaks, 2H), 6.65–6.59 (multiple peaks, 2H), 5.78 (s, 1H), 1.29 (m, 1H), 0.66–0.61 (multiple peaks, 4H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 142.7, 142.6, 138.8, 123.8, 123,6, 121.4, 116.0, 115.8, 9.5, 3.2.

HRMS (DART): *m/z* calcd for $C_{11}H_{11}O_2$ $[M+H]^+$: 175.07536. Found: 175.07513.

Methyl 2-cyclobutyl-1,4-benzodioxine-5-carboxylate (5c)



5c

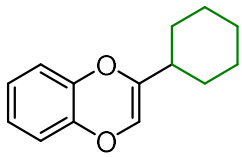
The compound was synthesized using **GP1** with methyl 2-bromo-1,4-benzodioxine-5-carboxylate (2.00 g, 7.38 mmol, 1 equiv). Instead of the Grignard reagent, cyclobutylzinc bromide (20.7 mL, 0.5 M in THF, 10.3 mmol, 1.4 equiv) was used without $ZnBr_2$. Purification by column chromatography (elution gradient 0–5% EtOAc in hexanes) yielded the title compound as a colorless oil (682 mg, 38% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.33 (m, 1H), 6.84–6.80 (multiple peaks, 2H), 5.86 (s, 1H), 3.85 (s, 3H, 2.86 (p, J = 8.4 Hz, 1H), 2.16–2.02 (multiple peaks, 4H), 1.96–1.79 (multiple peaks, 2H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 165.4, 143.7, 143.4, 140.3, 125.7, 122.7, 121.1, 119.8, 118.7, 52.1, 34.2, 25.1, 18.4.

HRMS (DART): *m/z* calcd for $C_{14}H_{15}O_4$ $[M+H]^+$: 247.09649. Found: 247.09660.

2-Cyclohexyl-1,4-benzodioxine (5d)



5d

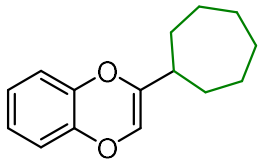
The compound was synthesized using **GP1** with 2-bromo-1,4-benzodioxine (700 mg, 3.29 mmol, 1 equiv) and cyclohexylmagnesium chloride (5.3 mL, 1.0 M in 2-MeTHF, 5.3 mmol, 1.6 equiv). Purification by column chromatography using hexanes yielded the title compound as a white solid (230 mg, 32% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 6.80–6.76 (multiple peaks, 2H), 6.65–6.59 (multiple peaks, 2H), 5.69 (s, 1H), 1.91-1.66 (multiple peaks, 6H), 1.31–1.13 (multiple peaks, 5H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 143.2, 142.8, 142.4, 123.6, 123.5, 120.7, 116.0, 115.7, 38.4, 29.6, 26.0, 25.6.

HRMS (DART): *m/z* calcd for $C_{14}H_{17}O_2$ $[M+H]^+$: 217.12231. Found: 217.12216.

2-Cycloheptyl-1,4-benzodioxine (5e)



5e

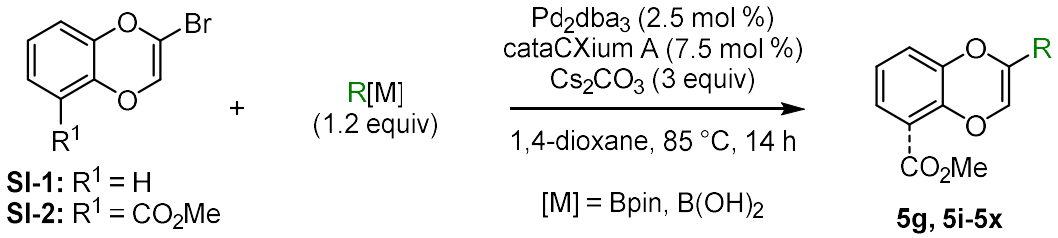
The compound was synthesized using **GP1** with 2-bromo-1,4-benzodioxine (1.00 g, 4.69 mmol, 1 equiv) and cycloheptylmagnesium bromide (3.8 mL, 2.0 M in Et_2O, 7.5 mmol, 1.6 equiv). Purification by column chromatography using hexanes yielded the title compound as a colorless liquid (202 mg, 19% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 6.80–6.75 (multiple peaks, 2H), 6.66–6.59 (multiple peaks, 2H), 5.73 (s, 1H), 2.05 (m, 1H), 1.85-1.40 (multiple peaks, 12H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 143.2, 143.1, 142.8, 123.6, 123.5, 120.4, 116.0, 115.7, 40.3, 31.5, 28.3, 26.4.

HRMS (DART): *m/z* calcd for $C_{15}H_{19}O_2$ $[M+H]^+$: 231.13796. Found: 231.13808.

General Procedure 2 (GP2) for the Synthesis of Substrates 5g, 5i–5x

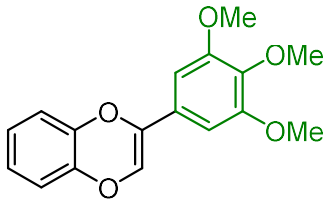


SI-1: R^1 = H
SI-2: R^1 = CO_2Me

5g, 5i-5x

A representative procedure is given for the synthesis of 2-aryl- or 2-heteroaryl-substituted 1,4-benzodioxines: synthesis of **5g**. A 20 mL tube was charged with 2-bromo-1,4-benzodioxine **SI-1** (700 mg, 3.29 mmol, 1 equiv), (3,4,5-trimethoxyphenyl)boronic acid (836 mg, 3.94 mmol, 1.2 equiv), Pd_2dba_3 (75.2 mg, 0.0822 mmol, 0.025 equiv), cataCXium A (88.4 mg, 0.246 mmol, 0.075 equiv), Cs_2CO_3 (3.21 g, 9.86 mmol, 3 equiv), and 1,4-dioxane (14 mL). The tube was sealed and heated to 85 °C for 14 h. The reaction was diluted with EtOAc, filtered through a short pad of Celite, followed by copious EtOAc washes, and concentrated in vacuo. Purification by column chromatography (elution gradient from 0–10% EtOAc in hexanes) yielded the title compound as an off-white solid (615 mg, 62% yield).

2-(3,4,5-Trimethoxyphenyl)-1,4-benzodioxine (5g)



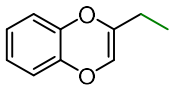
5g

^{1}H NMR (500 MHz, $CDCl_3$): δ 6.90–6.81 (multiple peaks, 3H), 6.71 (m, 1H), 6.68 (s, 2H), 6.39 (s, 1H), 3.89 (s, 6H), 3.86 (s, 3H).

^{13}C NMR (100 MHz, d_6-DMSO): δ 153.5, 142.5, 142.0, 138.1, 136.1, 126.6, 124.98, 124.91, 124.4, 116.9, 116.4, 101.0, 60.5, 56.5.

HRMS (DART): *m/z* calcd for $C_{17}H_{17}O_5$ $[M+H]^+$: 301.10705. Found: 301.10716.

2-Ethylbenzo[*b*][1,4]dioxine (5h)



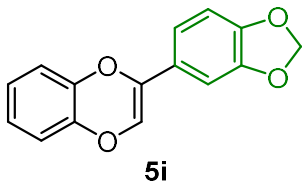
5h

The compound was synthesized using **GP1** with 2-bromo-1,4-benzodioxine (1g, 4.69 mmol, 1 equiv) and ethylmagnesium bromide (7.5 mL, 1.0 M in THF, 1.6 equiv). Purification by column chromatography using hexanes yielded the title compound as colorless oil (699 mg, 86 wt% containing des-Br impurity, net weight 601 mg, 3.71 mmol, 79% yield). The mixture was directly applied for the reduction. NMR spectra were run by collecting the earlier pure fractions, and match those reported.[1]

^{1}H NMR (400 MHz, CD_2Cl_2): δ 6.83–6.78 (multiple peaks, 2H), 6.68–6.59 (multiple peaks, 2H), 5.74 (t, J = 1.2 Hz, 1H), 2.00 (qd, J = 7.4, 1.2 Hz, 1H), 1.06 (t, J = 7.4 Hz, 3H).

^{13}C NMR (100 MHz, CD_2Cl_2): δ 143.3, 143.0, 139.9, 124.2, 124.0, 121.2, 116.3, 116.1, 23.0, 10.9.

2-(Benzo[*d*][1,3]dioxol-5-yl)benzo[*b*][1,4]dioxine (5i)



5i

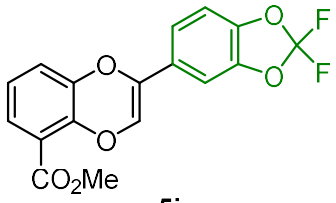
The compound was synthesized using **GP2** with 2-bromo-1,4-benzodioxine (700 mg, 3.29 mmol, 1 equiv) and (3,4-methylenedioxyphenyl)boronic acid (654 mg, 3.94 mmol, 1.2 equiv). Purification by column chromatography using hexanes yielded the title compound as a white solid (743 mg, 89% yield).

^{1}H NMR (500 MHz, DMSO-d_6): δ 7.12 (m, 1H), 7.05 (dd, J = 8.5, 1.3 Hz, 1H), 6.98 (s, 1H), 6.96–6.90 (multiple peaks, 4H), 6.81 (m, 1H), 6.04 (s, 2H).

^{13}C NMR (126 MHz, DMSO-d_6): δ 147.6, 147.3, 141.9, 141.5, 135.6, 124.5, 124.5, 124.4, 123.1, 116.7, 116.4, 115.9, 108.2, 103.3, 101.2.

HRMS (DART): *m/z* calcd for $C_{15}H_{11}O_4$ $[M+H]^+$: 255.06519. Found: 255.06516.

Methyl 2-(2,2-difluorobenzo[*d*][1,3]dioxol-5-yl)benzo[*b*][1,4]dioxine-5-carboxylate (5j)



5j

The compound was synthesized using **GP2** with methyl 2-bromo-1,4-benzodioxine-5-carboxylate (800 mg, 2.95 mmol, 1 equiv) and 2,2-difluorobenzo[1,3]dioxole-5-boronic acid (775 mg, 3.84 mmol, 1.3 equiv). Purification by column chromatography using gradient 0–30% EtOAc in hexanes, followed by recrystallization from CH_2Cl_2/hexanes, yielded the title compound **1i** as a white crystalline solid (480 mg, 44% yield).

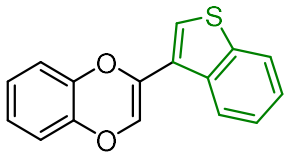
^{1}H NMR (500 MHz, $CDCl_3$): δ 7.41 (dd, J = 7.8, 1.9 Hz, 1H), 7.20–7.16 (m, 2H), 7.05 (d, J = 8.4 Hz, 1H), 6.96–6.89 (m, 2H), 6.52 (s, 1H), 3.89 (s, 3H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 165.1, 144.2, 143.8, 143.2, 142.7, 136.4, 131.8 (t, J_{CF} = 260 Hz), 127.2, 126.5, 123.6, 123.5, 120.3, 119.2, 118.9, 109.6, 105.1, 52.4.

^{19}F NMR (471 MHz, $CDCl_3$): δ -50.1.

HRMS (DART): *m/z* calcd for $C_{17}H_{11}O_6F_2$ $[M+H]^+$: 349.05182. Found: 349.05192.

2-(benzo[*b*]thiophen-3-yl)benzo[*b*][1,4]dioxine (5k)



5k

The compound was synthesized using **GP2** with 2-bromo-1,4-benzodioxine (300 mg, 1.41 mmol, 1 equiv) and thianaphthene-3-boronic acid (301 mg, 1.69 mmol, 1.2 equiv). Purification by column

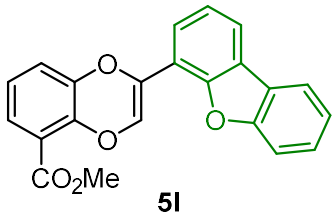
chromatography (elution gradient from 0–5% CH_2Cl_2 in hexanes) yielded the title compound as a white solid (364 mg, 97% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.98 (d, J = 7.7 Hz, 1H), 7.86 (d, J = 7.7 Hz, 1H), 7.58 (s, 1H), 7.44–7.35 (multiple peaks, 2H), 6.91–6.86 (multiple peaks, 2H), 6.81 (m, 1H), 6.74 (m, 1H), 6.46 (s, 1H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 142.8, 142.3, 140.4, 136.2, 133.8, 127.4, 124.8, 124.7, 124.6, 124.3, 124.23, 124.22, 123.1, 123.0, 116.4, 116.1.

HRMS (DART): *m/z* calcd for $C_{16}H_{11}O_2S$ $[M+H]^+$: 267.04743. Found: 267.04758.

Methyl 2-(dibenzo[*b,d*]furan-4-yl)benzo[*b*][1,4]dioxine-5-carboxylate (5l)



5l

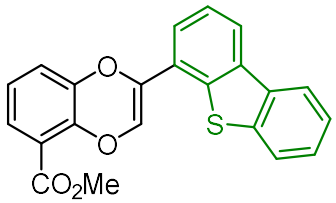
The compound was synthesized using **GP2** with methyl 2-bromo-1,4-benzodioxine-5-carboxylate (1.00 g, 3.69 mmol, 1 equiv) and 4-dibenzofuranylboronic acid (1.01 g, 4.80 mmol, 1.3 equiv). Purification by column chromatography (elution gradient from 10–100% EtOAc in hexanes) yielded the title compound as a white solid (696 mg, 53% yield).

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.95 (d, J = 7.6 Hz, 1H), 7.88 (dd, J = 7.7, 0.9 Hz, 1H), 7.72 (dd, J = 7.7, 0.7 Hz, 1H), 7.63 (s, 1H), 7.58 (d, J = 8.2 Hz, 1H), 7.50–7.46 (m, 1H), 7.43 (dd, J = 8.1, 1.6 Hz, 1H), 7.40–7.35 (m, 2H), 7.02 (dd, J = 7.8, 1.6 Hz, 1H), 6.93 (t, J = 7.9 Hz, 1H), 3.93 (s, 3H).

^{13}CNMR (125 MHz, $CDCl_3$): δ 165.2, 155.8, 150.9, 143.5, 142.9, 132.8, 128.4, 127.4, 126.1, 124.5, 123.8, 123.3, 123.2, 122.8, 122.1, 120.7, 120.1, 119.9, 119.0, 115.7, 111.8, 52.3.

HRMS (DART): *m/z* calcd for $C_{22}H_{15}O_5$ $[M+H]^+$: 359.09140. Found: 359.09129.

Methyl 2-(dibenzo[*b,d*]thiophen-4-yl)benzo[*b*][1,4]dioxine-5-carboxylate (5m)



5m

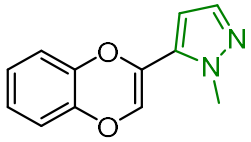
The compound was synthesized using **GP2** with methyl 2-bromo-1,4-benzodioxine-5-carboxylate (1.00 g, 3.69 mmol, 1 equiv) and 4-dibenzothienylboronic acid (1.09 g, 4.80 mmol, 1.3 equiv). Purification by column chromatography (elution gradient from 0–100% EtOAc in hexanes) yielded the title compound as a white solid (459 mg, 33% yield).

^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.16–8.13 (m, 2H), 7.88–7.86 (m, 1H), 7.59 (dd, J = 8.2, 2.1 Hz, 1H), 7.50–7.44 (m, 4H), 7.07 (dd, J = 8.0, 1.6 Hz, 1H), 6.95 (t, J = 8.0 Hz, 1H), 6.82 (s, 1H), 3.91 (s, 1H).

^{13}CNMR (125 MHz, $CDCl_3$): δ 165.1, 143.4, 143.0, 139.4, 137.0, 136.7, 135.6, 135.0, 127.1, 126.3, 125.9, 124.6, 124.6, 123.5, 123.4, 123.4, 122.5, 121.9, 121.6, 120.3, 119.1, 52.3.

HRMS (DART): *m/z* calcd for $C_{22}H_{15}O_4S$ $[M+H]^+$: 375.06856. Found: 375.06781.

5-(Benzo[*b*][1,4]dioxin-2-yl)-1-methyl-1*H*-pyrazole (5n)



5n

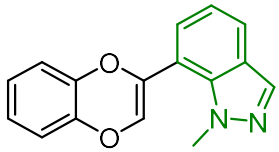
The compound was synthesized using **GP2** with 2-bromo-1,4-benzodioxine (700 mg, 3.29 mmol, 1 equiv) and 1-methyl-1*H*-pyrazole-5-boronic acid pinacol ester (820 mg, 3.94 mmol, 1.2 equiv). Increased catalyst loading was used: Pd_2dba_3 (150 mg, 0.164 mmol, 0.05 equiv) and cataCXium A (177 mg, 0.493 mmol, 0.15 equiv). Purification by column chromatography (elution gradient from 5–15% EtOAc in hexanes) yielded the title compound as an orange oil (545 mg, 77% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.42 (d, J = 1.8 Hz, 1H), 6.91–6.86 (multiple peaks, 2H), 6.75–6.70 (multiple peaks, 2H), 6.29 (d, J = 1.8 Hz, 1H), 6.21 (s, 1H), 3.97 (s, 3H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 142.3, 141.8, 138.3, 133,7, 128.7, 126.5, 124.60, 124.55, 116.34, 116.28, 106.33, 38.1.

HRMS (DART): *m/z* calcd for $C_{12}H_{11}O_2N_2$ $[M+H]^+$: 215.08150. Found: 215.08131.

7-(Benzo[*b*][1,4]dioxin-2-yl)-1-methyl-1*H*-indazole (5o)



5o

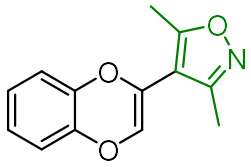
The compound was synthesized using **GP2** with 2-bromo-1,4-benzodioxine (700 mg, 3.29 mmol, 1 equiv) and 1-methylindazole-4-boronic acid (694 mg, 3.94 mmol, 1.2 equiv). Increased catalyst loading was used: Pd_2dba_3 (150 mg, 0.164 mmol, 0.05 equiv) and cataCXium A (177 mg, 0.493 mmol, 0.15 equiv). Purification by column chromatography (elution gradient from 5–15% EtOAc in hexanes) yielded the title compound as an off-white solid (739 mg, 85% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 8.16 (s, 1H), 7.38–7.33 (multiple peaks, 2H), 7.27 (dd, J = 6.2, 1.8 Hz, 1H), 6.93–6.85 (multiple peaks, 3H), 6.75 (dd, J = 7.2, 1.8 Hz, 1H), 6.63 (s, 1H), 4.08 (s, 3H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 142.8, 142.2, 140.3, 136.6, 132.4, 126.0, 125.5, 124.8, 124.3, 124.2, 119.9, 116.4, 116.2, 116.1, 109.9, 35.6.

HRMS (DART): *m/z* calcd for $C_{16}H_{13}O_2N_2$ $[M+H]^+$: 265.09715. Found: 265.09733.

4-(Benzo[*b*][1,4]dioxin-2-yl)-3,5-dimethylisoxazole (5p)



5p

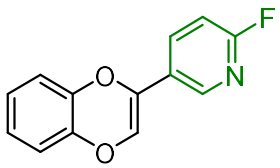
The compound was synthesized using **GP2** with 2-bromo-1,4-benzodioxine (700 mg, 3.29 mmol, 1 equiv) and 3,5-dimethyl-4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)isoxazole (880 mg, 3.94 mmol, 1.2 equiv). Purification by column chromatography (elution gradient from 0–10% EtOAc in hexanes) yielded the title compound as an off-white solid (562 mg, 75% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 6.89–6.85 (multiple peaks, 2H), 6.72–6.68 (multiple peaks, 2H), 5.98 (s, 1H), 2.47 (s, 3H), 2.31 (s, 3H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 167.2, 158.5, 142.4, 142.0, 128.9, 125.7, 124.5, 124.3, 116.2, 116.1, 108.0, 12.0, 11.0.

HRMS (DART): *m/z* calcd for $C_{13}H_{12}O_3N$ $[M+H]^+$: 230.08117. Found: 230.08123.

5-(Benzo[*b*][1,4]dioxin-2-yl)-2-fluoropyridine (5q)



5q

The compound was synthesized using **GP2** with 2-bromo-1,4-benzodioxine (700 mg, 3.29 mmol, 1 equiv) and 2-fluoropyridine-5-boronic acid (556 mg, 3.94 mmol, 1.2 equiv). Purification by column chromatography (elution gradient from 0–5% EtOAc in hexanes) yielded the title compound as a white solid (643 mg, 85% yield).

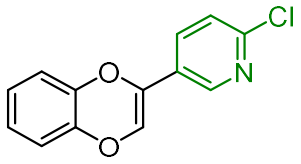
^{1}H NMR (500 MHz, $CDCl_3$): δ 8.33 (s, 1H), 7.85 (app t, J = 8.0 Hz, 1H), 6.95–6.86 (multiple peaks, 3H), 6.81 (m, 1H), 6.72 (m, 1H), 6.46 (s, 1H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 163.2 (d, J_{CF} = 240 Hz), 142.6 (d, J_{CF} = 15.2 Hz), 142.2, 141.8, 136.0 (d, J_{CF} = 7.9 Hz), 133.8, 125.5 (d, J_{CF} = 4.8 Hz), 124.53, 124.49, 123.9 (d, J_{CF} = 1.8 Hz), 116.4, 116.2, 109.4 (d, J_{CF} = 37.9 Hz).

^{19}F NMR (376 MHz, $CDCl_3$): δ -68.3.

HRMS (DART): *m/z* calcd for $C_{13}H_9O_2NF$ $[M+H]^+$: 230.06118. Found: 230.06112.

5-(Benzo[*b*][1,4]dioxin-2-yl)-2-chloropyridine (5r)



5r

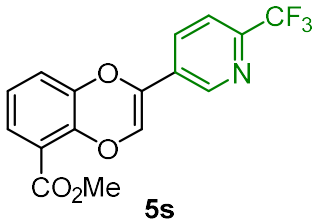
The compound was synthesized using **GP2** with 2-bromo-1,4-benzodioxine (700 mg, 3.29 mmol, 1 equiv) and 2-chloropyridine-5-boronic acid (543 mg, 3.45 mmol, 1.05 equiv). Purification by column chromatography (elution gradient from 50–60% CH_2Cl_2 in hexanes) yielded the title compound as an off-white solid (609 mg, 75% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 8.48 (s, 1H), 7.70 (d, J = 8.4 Hz, 1H), 7.31 (d, J = 8.4 Hz, 1H), 6.92–6.86 (multiple peaks, 2H), 6.81 (m, 1H), 6.73 (m, 1H), 6.52 (s, 1H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 150.6, 144.3, 142.1, 141.7, 133.6, 133.0, 126.4, 124.60, 124.58, 124.56, 124.0, 116.40, 116.2.

HRMS (DART): *m/z* calcd for $C_{13}H_9O_2NCl$ $[M+H]^+$: 246.03163. Found: 246.03136.

Bethyl 2-(6-(trifluoromethyl)pyridin-3-yl)benzo[*b*][1,4]dioxine-5-carboxylate (5s)



5s

The compound was synthesized using **GP2** with methyl 2-bromo-1,4-benzodioxine-5-carboxylate (1.00 g, 3.69 mmol, 1 equiv) and (6-(trifluoromethyl)pyridin-3-yl)boronic acid (916 mg, 4.80 mmol, 1.3 equiv). Purification by column chromatography (elution gradient from 0–20% EtOAc in hexanes) yielded the title compound as a white solid (842 mg, 68% yield).

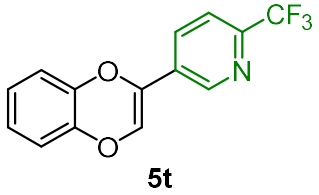
^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.80 (d, J = 1.5 Hz, 1H), 7.92 (dd, J = 8.2, 1.7 Hz, 1H), 7.68 (d, J = 8.2 Hz, 1H), 7.45 (dd, J = 7.7, 1.9 Hz, 1H), 7.00–6.94 (m, 2H), 6.77 (s, 1H), 3.90 (s, 3H).

^{13}CNMR (125 MHz, $CDCl_3$): δ 164.8, 147.4 (q, J_{CF} = 35 Hz), 144.5, 142.7, 142.0, 133.9, 131.3, 129.6 (q, J_{CF} = 1.1 Hz), 126.7, 125.8, 123.9, 121.4 (q, J_{CF} = 272 Hz), 120.3, 120.2 (q, J_{CF} = 2.8 Hz), 119.4, 52.4.

^{19}FNMR (471 MHz, $CDCl_3$): δ -67.9.

HRMS (DART): *m/z* calcd for $C_{16}H_{11}O_4NF_3$ $[M+H]^+$: 338.06347. Found: 338.06309.

5-(Benzo[*b*][1,4]dioxin-2-yl)-2-(trifluoromethyl)pyridine (5t)



5t

The compound was synthesized using **GP2** with 2-bromo-1,4-benzodioxine (500 mg, 2.35 mmol, 1 equiv) and 2-trifluoromethylpyridin-5-ylboronic acid HCl (640 mg, 2.82 mmol, 1.2 equiv). Purification by column chromatography (elution gradient from 0–10% EtOAc in hexanes) yielded the title compound as a white solid (587 mg, 90% yield).

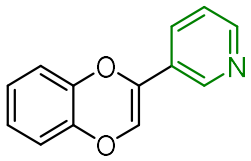
^{1}H NMR (500 MHz, $CDCl_3$): δ 8.79 (s, 1H), 7.92 (d, J = 8.1 Hz, 1H), 7.67 (d, J = 8.1 Hz, 1H), 6.93–6.88 (multiple peaks, 2H), 6.83 (m, 1H), 6.74 (m, 1H), 6.66 (s, 1H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 147.0 (q, J_{CF} = 35.0 Hz), 144.3, 142.0, 141.5, 133.4, 131.1, 130.2 (q, J_{CF} = 1.0 Hz), 126.0, 124.8, 124.7, 121.5 (q, J_{CF} = 274 Hz), 120.2 (q, J_{CF} = 2.8 Hz), 116.5, 116.3.

^{19}F NMR (376 MHz, $CDCl_3$): δ -67.82.

HRMS (DART): *m/z* calcd for $C_{14}H_9O_2NF_3$ $[M+H]^+$: 280.05799. Found: 280.05799.

3-(Benzo[*b*][1,4]dioxin-2-yl)pyridine (5u)



5u

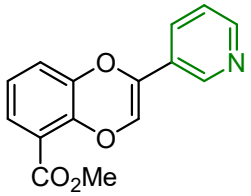
The compound was synthesized using **GP2** with 2-bromo-1,4-benzodioxine (700 mg, 3.29 mmol, 1 equiv) and 3-pyridylboronic acid (485 mg, 3.94 mmol, 1.2 equiv). Increased catalyst loading was used: Pd_2dba_3 (150 mg, 0.164 mmol, 0.05 equiv) and tBu$_2$PFcHBF$_4$ (143 mg, 0.493 mmol, 0.15 equiv). Purification by column chromatography (elution gradient from 10–30% EtOAc in hexanes) yielded the title compound as an off-white solid (163 mg, 24% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 8.72 (d, J = 2.0 Hz, 1H), 8.53 (dd, J = 4.5, 1.4 Hz, 1H), 7.76 (app dt, J = 8.0, 2.0 Hz, 1H), 7.28 (dd, J = 8.0, 4.5 Hz, 1H), 6.92–6.86 (multiple peaks, 2H), 6.82 (m, 1H), 6.73 (m, 1H), 6.53 (s, 1H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 149.1, 144.6, 142.4, 141.9, 134.4, 130.4, 127.4, 124.44, 124.41, 124.3, 123.2, 116.4, 116.1.

HRMS (DART): *m/z* calcd for $C_{13}H_{10}O_2N$ $[M+H]^+$: 212.07061. Found: 212.07058.

Methyl 2-(3-pyridyl)-1,4-benzodioxine-5-carboxylate (5v)



5v

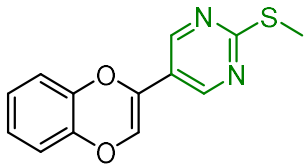
The compound was synthesized using **GP2** with methyl 2-bromo-1,4-benzodioxine-5-carboxylate (1.00 g, 3.69 mmol, 1 equiv) and 3-pyridinylboronic acid (574 mg, 4.80 mmol, 1.3 equiv). Purification by column chromatography (elution gradient from 0–80% EtOAc in hexanes) yielded the title compound as a white solid (590 mg, 58% yield).

^{1}H-NMR (500 MHz, $CDCl_3$): δ 8.72 (d, J = 2.0 Hz, 1H), 8.56 (dd, J = 4.8, 1.4 Hz, 1H), 7.75 (dt, J = 7.9, 1.8 Hz, 1H), 7.42 (dd, J = 7.8, 1.8 Hz, 1H), 7.31–7.29 (m, 1H), 6.98–6.91 (m, 2H), 6.64 (s, 1H), 3.89 (s, 3H).

^{13}CNMR (125 MHz, $CDCl_3$): δ 165.0, 149.4, 144.7, 143.0, 142.5, 134.9, 130.4, 126.8, 126.4, 124.1, 123.5, 123.5, 123.3, 120.2, 120.2, 119.1, 52.3.

HRMS (DART): *m/z* calcd for C_{22} $H_{15}O_5$ $[M+H]^+$: 359.09169. Found: 359.09140.

5-(Benzo[*b*][1,4]dioxin-2-yl)-2-(methylthio)pyrimidine (5w)



5w

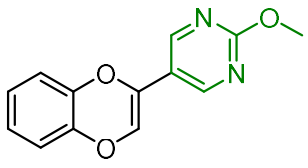
The compound was synthesized using **GP2** with 2-bromo-1,4-benzodioxine (700 mg, 3.29 mmol, 1 equiv) and 2-(methylthio)pyrimidinyl-5-boronic acid pinacol ester (994 mg, 3.94 mmol, 1.2 equiv). Increased catalyst loading was used: Pd_2dba_3 (150 mg, 0.164 mmol, 0.05 equiv) and cataCXium A (177 mg, 0.493 mmol, 0.15 equiv). Purification by column chromatography (elution gradient from 70–80% CH_2Cl_2 in hexanes) yielded the title compound as a white solid (574 mg, 68% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 8.60 (s, 2H), 6.92–6.86 (multiple peaks, 2H), 6.80 (m, 1H), 6.73 (m, 1H), 6.47 (s, 1H), 2.58 (s, 3H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 172.0, 151.7, 142.0, 141.7, 132.4, 124.62, 124.60, 123.9, 120.6, 116.4, 116.2, 14.2.

HRMS (DART): *m/z* calcd for $C_{13}H_{11}O_2N_2S$ $[M+H]^+$: 259.05357. Found: 259.05333.

5-(Benzo[*b*][1,4]dioxin-2-yl)-2-methoxypyrimidine (5x)



5x

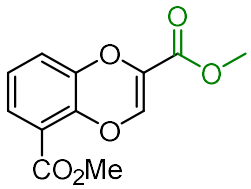
The compound was synthesized using **GP2** with 2-bromo-1,4-benzodioxine (700 mg, 3.29 mmol, 1 equiv) and 2-methoxypyrimidinyl-5-boronic acid (607 mg, 3.94 mmol, 1.2 equiv). Increased catalyst loading was used: Pd_2dba_3 (150 mg, 0.164 mmol, 0.05 equiv) and cataCXium A (177 mg, 0.493 mmol, 0.15 equiv). Purification by column chromatography (elution gradient from 10–15% EtOAc in hexanes) yielded the title compound as an off-white solid (170 mg, 21% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 8.60 (s, 2H), 6.92–6.86 (multiple peaks, 2H), 6.80 (m, 1H), 6.72 (m, 1H), 6.41 (s, 1H), 4.04 (s, 3H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 165.3, 154.4, 142.1, 141.8, 132.5, 124.6, 124.5, 123.2, 119.5, 116.5, 116.2, 55.1.

HRMS (DART): *m/z* calcd for $C_{13}H_{11}O_3N_2$ $[M+H]^+$: 243.07642. Found: 243.07622.

Mimethyl 1,4-benzodioxine-2,5-dicarboxylate (5y)



5y

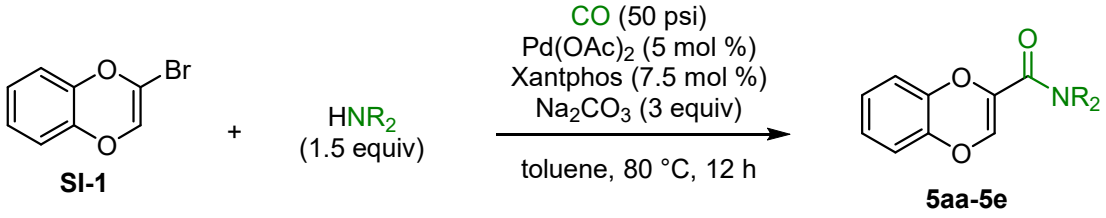
A tube containing methyl 2-bromo-1,4-benzodioxine-5-carboxylate (500 mg, 1.84 mmol, 1 equiv), $Pd(OAc)_2$ (10.4 mg, 0.0461 mmol, 0.025 equiv), cataCXium A (49.6 mg, 0.138 mmol, 0.075 equiv) in MeOH (3 mL) was heated to 80 °C under CO (100 psi) for 16 h in Biotage Endeavor reactor. At the end of the reaction, the reaction was concentrated in vacuo and extracted with EtOAc (30 mL). The residual solid was filtered and washed with EtOAc (3 × 5 mL). The combined EtOAc extracts were concentrated in vacuo. Purification by column chromatography (elution gradient 10–20% EtOAc in hexanes) yielded the title compound as a white solid (310 mg, 67% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.38 (dd, J = Hz, 1H), 7.01 (s, 1H), 6.97–6.90 (multiple peaks, 2H), 3.87 (s, 3H), 3.82 (s, 3H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 164.6, 161.2, 142.8, 140.9, 135.6, 129.3, 126.4, 124.6, 120.6, 119.7, 52.4, 52.2.

HRMS (DART): *m/z* calcd for $C_{12}H_{11}O_6$ $[M+H]^+$: 251.05501. Found: 251.05514.

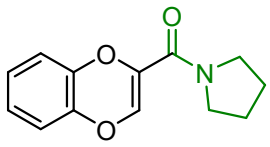
General Procedure 3 (GP3) for the Synthesis of Amides 5aa–5ae



SI-1 **5aa-5e**

A representative procedure is given for the synthesis of 2-amide-substituted 1,4-benzodioxines: synthesis of **5aa**. A reaction tube was charged with $Pd(OAc)_2$ (52.8 mg, 0.235 mmol, 0.05 equiv), Xantphos (203.53 mg, 0.35 mmol, 0.075 equiv), 2-bromo-1,4-benzodioxine (1.00 g, 4.69 mmol, 1 equiv), Na_2CO_3 (1.49 g, 14.1 mmol, 3 equiv), pyrrolidine (501 mg, 7.04 mmol, 1.5 equiv), and toluene (4 mL). The reaction was heated to 80 °C under CO (50 psi) for 12 h in Biotage Endeavor reactor. The reaction was then diluted with EtOAc (20 mL), filtered through a short pad of Celite, concentrated in vacuo, and purified by column chromatography (elution gradient 10–20% EtOAc in hexanes) yielded the title compound as a colorless solid (481 mg, 44% yield).

Benzo[*b*][1,4]dioxin-2-yl(pyrrolidin-1-yl)methanone (5aa)



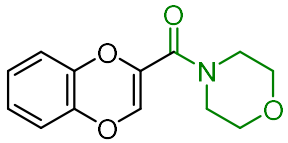
5aa

^{1}H NMR (500 MHz, $CDCl_3$): δ 6.87–6.84 (multiple peaks, 2H), 6.78 (s, 1H), 6.71–6.66 (multiple peaks, 2H), 3.72 (br s, 2H), 3.54 (br s, 2H), 1.91 (br s, 2H), 1.88 (br s, 2H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 160.5, 142.2, 141.6, 133.4, 133.0, 124.8, 124.6, 116.5, 116.2, 47.7, 47.2, 26.6, 23.5.

HRMS (DART): *m/z* calcd for $C_{13}H_{14}O_3N$ $[M+H]^+$: 232.09682. Found: 232.09684.

Benzo[*b*][1,4]dioxin-2-yl(morpholino)methanone (5ab)



5ab

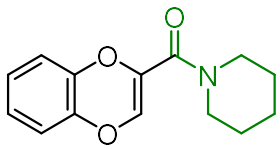
The compound was synthesized using **GP3** with 2-bromo-1,4-benzodioxine (1.00 g, 4.69 mmol, 1 equiv) and morpholine (613 mg, 7.04 mmol, 1.5 equiv). Purification by column chromatography (elution gradient 10–30% EtOAc in hexanes) yielded the title compound as a colorless solid (409 mg, 37% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 6.89–6.86 (multiple peaks, 2H), 6.73–6.66 (multiple peaks, 2H), 6.64 (s, 1H), 3.73–3.66 (multiple peaks, 8H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 161.6, 141.8, 141.5, 133.1, 132.7, 124.94, 124.88, 116.6, 116.3, 66.9, 42.3.

HRMS (DART): *m/z* calcd for $C_{13}H_{14}O_4N$ $[M+H]^+$: 248.09173. Found: 248.09180.

Benzo[*b*][1,4]dioxin-2-yl(piperidin-1-yl)methanone (5ac)



5ac

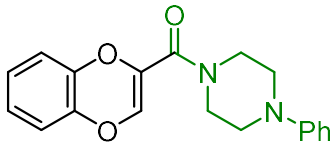
The compound was synthesized using **GP3** with 2-bromo-1,4-benzodioxine (426 mg, 2.00 mmol, 1 equiv) and piperidine (255 mg, 3.00 mmol, 1.5 equiv). Purification by column chromatography (elution gradient 10–20% EtOAc in hexanes) yielded the title compound as a yellow oil (234 mg, 48% yield). NMR spectral data match literature data.[7]

^{1}H NMR (500 MHz, $CDCl_3$): δ 6.88–6.85 (multiple peaks, 2H), 6.71–6.67 (multiple peaks, 2H), 6.54 (s, 1H), 3.56 (m, 4H), 1.70–1.58 (multiple peaks, 6H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 161.5, 142.1, 141.7, 133.2, 131.9, 124.7, 124.6, 116.5, 116.4, 45.9, 26.1, 24.6.

HRMS (DART): *m/z* calcd for $C_{14}H_{16}O_3N$ $[M+H]^+$: 246.11247. Found: 246.11253.

Benzo[*b*][1,4]dioxin-2-yl(4-phenylpiperazin-1-yl)methanone (5ad)



5ad

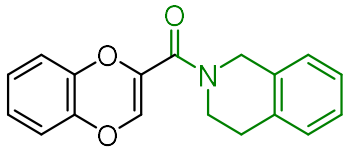
The compound was synthesized using **GP3** with 2-bromo-1,4-benzodioxine (500mg, 2.35mmol, 1 equiv) and 1-phenylpiperazine (571 mg, 3.52 mmol,1.5 equiv). Purification by column chromatography (elution gradient 10–25% EtOAc in hexanes) yielded the title compound as an off white solid (500 mg, 17% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.29 (t, J = 7.8 Hz, 2H), 6.96–6.86 (multiple peaks, 5H), 6.73–6.69 (multiple peaks, 2H), 6.65 (s, 1H), 3.82 (t, J = 5.0 Hz, 4H), 3.23 (t, J = 5.0 Hz, 4H)

^{13}C NMR (126 MHz, $CDCl_3$): δ 161.6, 150.9, 141.9, 141.6, 133.0, 132.8, 129.3, 124.92, 124.85, 120.6, 116.7, 116.6, 116.4, 49.7, 44.6.

HRMS (HESI): *m/z* calcd for $C_{19}H_{19}O_3N_2$ $[M+H]^+$: 323.13902. Found: 323.13881.

Benzo[*b*][1,4]dioxin-2-yl(3,4-dihydroisoquinolin-2(1*H*)-yl)methanone (5ae)



5ae

The compound was synthesized using **GP3** with 2-bromo-1,4-benzodioxine (1.00 g, 4.69 mmol, 1 equiv) and tetrahydroisoquinoline (938 mg, 7.04 mmol, 1.5 equiv). Purification by column chromatography

[7] Bozzo, C.; Pujol, M. D.; Solans, X.; Font-Bardia, M. *Tetrahedron* **2003**, *59*, 1227.

(elution gradient 10–20% EtOAc in hexanes) yielded the title compound as a colorless solid (283 mg, 21% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.23–7.11 (multiple peaks, 4H), 6.91–6.86 (m, 2H), 6.74–6.70 (m, 2H), 6.65 (s, 1H), 4.76 (s, 2H), 3.86 (t, J = 5.8 Hz, 2H), 2.96 (t, J = 5.8 Hz, 2H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 161.0, 141.0, 140.6, 133.4, 132.0, 131.8, 131.7, 127.7, 125.7, 124.4, 124.3, 123.9, 123.8, 115.5, 115.4, 45.6, 42.2, 28.0.

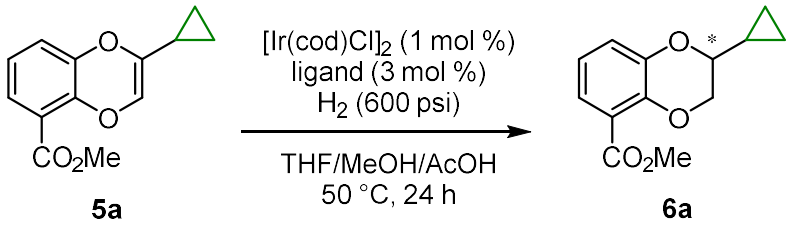
HRMS (DART): *m/z* calcd for $C_{18}H_{16}O_3N$ $[M+H]^+$: 294.11247. Found: 294.11248.

IV. Ligand Screening and Synthesis of 6a

General Procedure 4 (GP4) for Ligand Screening and Synthesis of 6a

A catalyst solution was prepared in a vial by mixing $[Ir(cod)Cl]_2$ (0.7 mg, 0.001 mmol, 0.01 equiv) and ligand (0.003 mmol, 0.03 equiv) in THF (0.2 mL) for 5 min. Substrate **5a** (23.2 mg, 0.100 mmol, 1 equiv), MeOH (0.2 mL), and AcOH (0.23 mL, 4.0 mmol, 40 equiv) were added to the vial. The mixture was purged with N_2 three times, followed by H_2 three times. The reaction was heated to 50 °C under 600 psi H_2 and stirred for 24 h. Upon completion, the reactor was vented and purged with N_2 twice. Percentage conversions were determined by HPLC, and enantiomeric ratios were determined by chiral SFC.

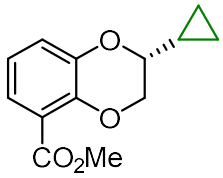
Table S1. Ligand Screening of Ir-Catalyzed Asymmetric Hydrogenation



5a **6a**

entry	ligand	conv (%)	*er*
1	(S)-Phanephos	91	88:12
2	(R)-Ph-Garphos	79	76:24
3	(R)-MeO-BIPHEP	88	76:24
4	(R)-TriOMe-BIPHEP	86	84:16
5	(R)-3,5-t-Bu-MeOBIPHEP	93	81:19
6	(S,S)-Et-FerroTANE	79	55:45
7	(R)-C_3-TunePhos	83	77:23
8	(S)-SEGPHOS	67	16:84
9	(R)-DM-SEGPHOS	90	82:18
10	(S)-DTBM-SEGPHOS	83	26:74
11	(R)-MP_2-SEGPHOS	79	45:55
12	(R)-BINAP	92	81:19
13	(R)-H_8-BINAP	95	73:27
14	(R)-Tol-BINAP	94	82:18
15	(R,R)-DIPAMP	0	nd
16	(R,R,S,S)-DuanPhos	63	41:59
17	(S)-SYNPHOS	88	25:75
18	(R)-Difluorophos	88	75:25
19	Josiphos SL-J002-1	74	87:13
20	Josiphos SL-J009-1	75	56:44
21	(S,S)-NORPHOS	5	nd
22	(S)-BINAPINE	92	51:49
23	H-BIBOP (**L1**)	68	47:53
24	MeO-BIBOP (**L2**)	94	59:41
25	Ph-BIBOP (**L3**)	>98	66:34
26	WingPhos (**L4**)	>98	95:5
27	BIDIME-dimer (**L5**)	>98	97:3

Methyl (*R*)-2-cyclopropyl-2,3-dihydrobenzo[*b*][1,4]dioxine-5-carboxylate (6a)



6a
97:3 *er*
98% yield

For isolation of Table S1, entry 27, the reaction was concentrated in vacuo, loaded onto silica gel cartridge, and purified by column chromatography (elution gradient 0–10% EtOAc in hexanes) yielded the title compound as a colorless oil (23.0 mg, 98% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.38 (dd, J = 8.0, 1.6 Hz, 1H), 7.05 (dd, J = 8.0, 1.6 Hz, 1H), 6.85 (t, J = 8.0 Hz, 1H), 4.48 (dd, J = 11.4, 2.3 Hz, 1H), 4.05 (dd, J = 11.4, 8.5 Hz, 1H), 3.88 (s, 3H), 3.45 (td, J = 8.5, 2.3 Hz, 1H), 1.00 (m, 1H), 0.73 (m, 1H), 0.64 (m, 1H), 0.57 (m, 1H), 0.39 (m, 1H).

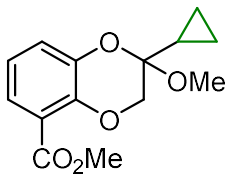
^{13}C NMR (126 MHz, $CDCl_3$): δ 166.1, 144.2, 143.8, 123.5, 121.4, 120.5, 119.7, 77.2, 68.2, 52.0, 11.2, 3.0, 1.7.

HRMS (DART): *m/z* calcd for $C_{13}H_{15}O_4$ $[M+H]^+$: 235.09649. Found: 235.09626.

$[\alpha]_D^{24}$ = +109.0 (c = 1.15 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on Phenomenex Lux Cellulose-4 column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 4.1 min (minor), 4.23 min (major); *er* 97.0:3.0.

Methyl 2-cyclopropyl-2-methoxy-2,3-dihydrobenzo[b][1,4]dioxine-5-carboxylate (7)



7

When the reaction (**GP4**) was run in the absence of acetic acid, a side product **7** was formed. The ratio of **6a** to **7** was 69:31. Compound **7** was isolated as a colorless oil (5.6 mg, 21% yield) after purification by column chromatography (elution gradient 0–10% EtOAc in hexanes).

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.44 (dd, J = 8.0, 1.6 Hz, 1H), 7.00 (dd, J = 8.0, 1.6 Hz, 1H), 6.86 (t, J = 8.0 Hz, 1H), 4.38 (d, J = 11.2 Hz, 1H), 3.91 (d, J = 11.2 Hz, 1H), 3.87 (s, 3H), 3.39 (s, 3H), 1.09 (m, 1H), 1.00 (m, 1H), 0.68 (m, 1H), 0.52 (m, 1H), 0.30 (m, 1H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 166.1, 143.8, 141.7, 124.4, 121.6, 120.4, 119.6, 94.4, 69.6, 52.0, 49.8, 12.7, 0.6, 0.2.

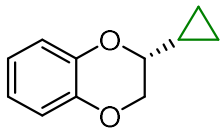
HRMS (DART): *m/z* calcd for $C_{14}H_{17}O_5$ $[M+H]^+$: 265.10705. Found: 265.10717.

V. Synthesis of 6b–6ae Using Asymmetric Hydrogenation

General Procedure 5 (GP5) for Asymmetric Hydrogenation

A catalyst solution was prepared in a vial by mixing $[Ir(cod)Cl]_2$ (1.3 mg, 0.0020 mmol, 0.01 equiv) and **L5** ligand (4.3 mg, 91.6 wt%, 0.0060 mmol, 0.03 equiv) in THF (0.3 mL) for 5 min. Substrate **5** (0.200 mmol, 1 equiv), MeOH (0.3 mL), and AcOH (0.46 mL, 8.0 mmol, 40 equiv) were added to the vial. The mixture was purged with N_2 three times, followed by H_2 three times. The reaction was heated to 50 °C or 70 °C under 600 psi H_2 and stirred for 24 h. Upon completion, the reactor was vented and purged with N_2 twice. The reaction was concentrated in vacuo, loaded onto silica gel cartridge, and purified by column chromatography. Enantiomeric ratios were determined by chiral SFC or chiral HPLC.

(*R*)-2-Cyclopropyl-2,3-dihydrobenzo[*b*][1,4]dioxine (6b)



6b
94:6 *er*
92% yield

The compound was synthesized using **GP5** with **5b** (34.8 mg, 0.200 mmol, 1 equiv) at 50 °C. Purification by column chromatography (elution gradient 0–2% EtOAc in hexanes) yielded the title compound as a white solid (32.4 mg, 92% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 6.91–6.78 (multiple peaks, 4H), 4.32 (dd, J = 11.2, 2.2 Hz, 1H), 4.00 (dd, J = 11.2, 8.4 Hz, 1H), 3.42 (td, J = 8.4, 2.2 Hz, 1H), 1.00 (m, 1H), 0.72 (m, 1H), 0.63 (m, 1H), 0.57 (m, 1H), 0.39 (m, 1H).

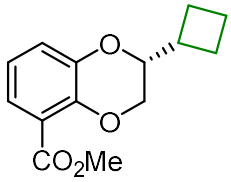
^{13}C NMR (126 MHz, $CDCl_3$): δ 143.6, 143.2, 121.5, 121.2, 117.3, 117.0, 77.5, 68.0, 11.4, 3.0, 1.7.

HRMS (DART): *m/z* calcd for $C_{11}H_{13}O_2$ $[M+H]^+$: 177.09101. Found: 177.09109.

$[\alpha]_D^{23}$ = +77.2 (c = 0.16 in $CDCl_3$)

The enantiomeric excess was determined by chiral HPLC on CHIRALCEL OJ-3 column, 4.6 mm ID x 150 mm L, 3 um particle size. The compounds were eluted with 99.8% heptane/0.2% isopropanol. Column temperature 20 ºC; Flow rate 1.3 mL/min; UV detection at 220 nm; t_R= 5.94 min (minor), 7.06 min (major); *er* 94.3:5.6

Methyl (*R*)-2-cyclobutyl-2,3-dihydrobenzo[*b*][1,4]dioxine-5-carboxylate (6c)



6c
94:6 *er*
93% yield

The compound was synthesized using **GP5** with **5c** (49.3 mg, 0.200 mmol, 1 equiv) at 50 °C. Purification by column chromatography (5% EtOAc in hexanes) yielded the title compound as a colorless oil (46.3 mg, 93% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.38 (dd, J = 8.0, 1.6 Hz, 1H), 7.04 (dd, J = 8.0, 1.6 Hz, 1H), 6.85 (t, J = 8.0 Hz, 1H), 4.32 (dd, J = 11.3, 2.2 Hz, 1H), 4.09 (td, J = 8.0, 2.2 Hz, 1H), 3.88 (s, 3H), 3.82 (dd, J = 11.3, 8.0 Hz, 1H), 2.55 (m, 1H), 2.16–1.87 (multiple peaks, 6H).

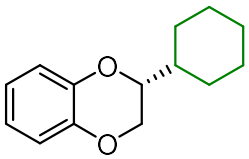
^{13}C NMR (126 MHz, $CDCl_3$): δ 166.1, 144.3, 143.9, 123.4, 121.3, 120.4, 119.7, 75.8, 66.4, 52.0, 35.5, 24.1, 23.5, 18.7.

HRMS (DART): *m/z* calcd for $C_{14}H_{17}O_4$ $[M+H]^+$: 249.11214. Found: 249.11218.

$[\alpha]_D^{22}$ = +107.8 (*c* = 0.21 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on Phenomenex Lux Cellulose-3 column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 2.02 min (minor), 1.80 min (major); *er* 94.4:5.6

(*R*)-2-cyclohexyl-2,3-dihydrobenzo[*b*][1,4]dioxine (6d)



6d
95:5 *er*
99% yield

The compound was synthesized using **GP5** with **5d** (43.3 mg, 0.200 mmol, 1 equiv) at 50 °C. Purification by column chromatography (elution gradient 0–2% EtOAc in hexanes) yielded the title compound as a white crystalline solid (43.2 mg, 99% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 6.88–6.77 (multiple peaks, 4H), 4.26 (dd, J = 11.2, 2.0 Hz, 1H), 3.98 (dd, J = 11.2, 7.7 Hz, 1H), 3.85 (td, J = 7.7, 2.0 Hz, 1H), 2.01 (m, 1H), 1.80–1.61 (multiple peaks, 5H), 1.33–1.10 (multiple peaks, 5H).

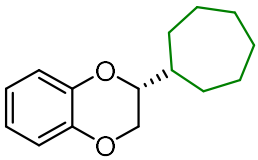
^{13}C NMR (126 MHz, $CDCl_3$): δ 143.8, 143.5, 121.3, 121.0, 117.3, 116.9, 77.1, 66.3, 38.9, 28.5, 28.4, 26.3, 25.9, 25.8.

HRMS (DART): *m/z* calcd for $C_{14}H_{18}O_2$ $[M]^{+\cdot}$: 218.13013. Found: 218.13026.

$[\alpha]_D^{22}$ = +44.5 (c = 0.20 in $CDCl_3$)

The enantiomeric excess was determined by chiral HPLC on CHIRALCEL OJ-3 column, 4.6 mm ID x 150 mm L, 3 um particle size. The compounds were eluted with 99.8% heptane/0.2% isopropanol. Column temperature 20 ºC; Flow rate 1.3 mL/min; UV detection at 220 nm; t_R= 4.13 min (minor), 4.41 min (major); *er* 94.9:5.1

(*R*)-2-cycloheptyl-2,3-dihydrobenzo[*b*][1,4]dioxine (6e)



6e
93:7 *er*
95% yield

The compound was synthesized using **GP5** with **5e** (52.0 mg, 0.227 mmol, 1 equiv) at 50 °C. Purification by column chromatography (elution gradient 0–2% EtOAc in hexanes) yielded the title compound as a colorless oil (49.8 mg, 95% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 6.88–6.77 (multiple peaks, 4H), 4.27 (m, 1H), 3.98–3.89 (multiple peaks, 2H), 1.91–1.42 (multiple peaks, 12H), 1.34 (m, 1H).

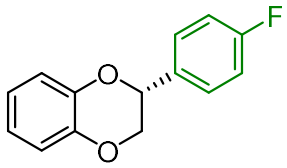
^{13}C NMR (126 MHz, $CDCl_3$): δ 143.9, 143.5, 121.3, 121.0, 117.3, 116.8, 77.3, 66.2, 40.5, 29.7, 29.2, 28.5, 28.4, 26.7, 26.5.

HRMS (DART): *m/z* calcd for $C_{15}H_{21}O_2$ $[M+H]^+$: 233.15361. Found: 233.15382.

$[\alpha]_D^{22}$ = +39.9 (*c* = 0.23 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on Phenomenex Lux Cellulose-3 column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 1.31 min (minor), 1.42 min (major); *er* 93.2:6.8.

(*R*)-2-(4-fluorophenyl)-2,3-dihydrobenzo[*b*][1,4]dioxine (6f)



6f
98:2 *er*
95% yield

The compound was synthesized using **GP5** with **5f** (45.6 mg, 0.200 mmol, 1 equiv) at 50 °C. Purification by column chromatography (elution gradient 0–2% EtOAc in hexanes) yielded the title compound as a colorless oil (43.7 mg, 95% yield). NMR spectral data match literature data.[1]

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.40 (m, 2H), 7.11 (m, 2H), 7.00–6.87 (multiple peaks, 4H), 5.11(dd, *J* = 8.8, 2.4 Hz, 1H), 4.33 (dd, *J* = 11.5, 2.4 Hz, 1H), 4.00 (dd, *J* = 11.5, 8.8 Hz, 1H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 162.9 (d, J_{CF}= 247 Hz), 143.7, 143.0, 132.3 (d, J_{CF} = 3.2 Hz), 128.3 (d, J_{CF} = 8.3 Hz), 121.71, 121.67, 117.5, 117.2, 115.8 (d, J_{CF} =21.7 Hz), 74.5, 69.3.

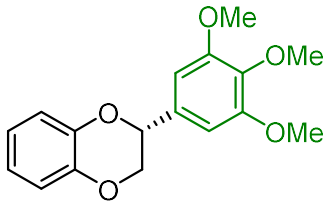
^{19}F NMR (471 MHz, $CDCl_3$): δ -112.9.

HRMS (DART): *m/z* calcd for $C_{14}H_{11}O_2F$ $[M]^{+\cdot}$: 230.07376. Found: 230.07393.

$[\alpha]_D^{24}$ = -76.6 (*c* = 0.21 in $CDCl_3$); [lit[1] $[\alpha]_D^{25}$ = -46.72 (*c* = 1.0, $CHCl_3$) for 83% ee, (*R*)-isomer]

The enantiomeric excess was determined by chiral SFC on Phenomenex Lux Cellulose-3 column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 1.83 min (minor), 2.05 min (major); *er* 97.9:2.1

(*R*)-2-(3,4,5-trimethoxyphenyl)-2,3-dihydrobenzo[*b*][1,4]dioxine (6g)



6g
>99:1 *er*
90% yield

The compound was synthesized using **GP5** with **1g** (60.1 mg, 0.200 mmol, 1 equiv) at 50 °C. Purification by column chromatography (elution gradient 0–10% EtOAc in hexanes) yielded the title compound as a white solid (54.2 mg, 90% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.00 (m, 1H), 6.94 (m, 1H), 6.91–6.87 (multiple peaks, 2H), 6.64 (s, 2H), 5.05 (dd, J = 9.0, 2.2 Hz, 1H), 4.35 (dd, J = 11.4, 2.2 Hz, 1H), 4.03 (dd, J = 11.4, 9.0 Hz, 1H), 3.89 (s, 6H), 3.86 (s, 3H).

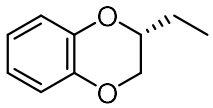
^{13}C NMR (126 MHz, $CDCl_3$): δ 153.6, 143.8, 143.0, 148.4, 142.0, 121.7, 121.6, 117.6, 117.2, 103.6, 75.2, 69.4, 60.9, 56.2.

HRMS (DART): *m/z* calcd for $C_{17}H_{19}O_5$ $[M+H]^+$: 303.12270. Found: 303.12278.

$[\alpha]_D^{22}$ = -59.4 (c = 0.16 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on ChromegaChiral CCA column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 3.98 min (minor), 4.33 min (major); *er* 99.2:0.8

(*R*)-2-ethyl-2,3-dihydrobenzo[*b*][1,4]dioxine (6h)



6h
90.1:9.9 *er*
92% yield

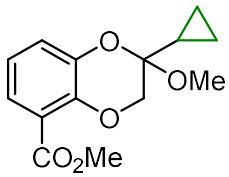
The title compound was synthesized using **GP5** with **5h** (191 mg, 86wt%, net weight 164 mg, 1.0 mmol, 1 equiv). The reaction was run with $[Ir(cod)Cl]_2$ (6.5 mg, 0.01 mmol, 0.01 equiv) and **L5** ligand (21.5 mg, 91.6 wt%, 0.03 mmol, 0.03 equiv) in THF (1.0 mL) and MeOH (1.0 mL) at 25 °C and 600 psi H_2 for 24 h. Product was purified on silica with hexanes to yield colorless liquid after dryness, 151 mg, 92% yield. NMR spectral data match literature data.[1]

^{1}H NMR (400 MHz, CD_2Cl_2): δ 6.91–6.80 (multiple peaks, 4H), 4.25 (dd, J = 11.2, 2.1 Hz, 1H), 4.05 (m, 1H), 3.89 (dd, J = 11.2, 7.9 Hz, 1H), 1.81–1.60 (multiple peaks, 2H), 1.10 (t, J = 7.5 Hz, 3H).

^{13}C NMR (100 MHz, CD_2Cl_2): δ 144.1, 143.9, 121.7, 121.4, 117.6, 117.3, 74.8, 68.3, 24.6, 9.6.

The enantiomeric excess was determined by chiral HPLC on CHIRALCEL OJ-3 column, 4.6 mm ID x 150 mm L, 3 um particle size. The product was purified with 100% heptane (des-Br impurty elutes later than the product). Column temperature 20 ºC; Flow rate 1.3 mL/min; UV detection at 220 nm; t_R= 5.67 min (major), 6.56 min (major); *er* 90.1:9.9

Methyl 2-cyclopropyl-2-methoxy-2,3-dihydrobenzo[b][1,4]dioxine-5-carboxylate (7)



7

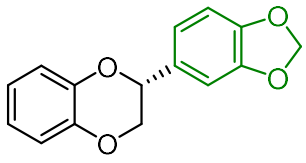
When the reaction (**GP4**) was run in the absence of acetic acid, a side product **7** was formed. The ratio of **6a** to **7** was 69:31. Compound **7** was isolated as a colorless oil (5.6 mg, 21% yield) after purification by column chromatography (elution gradient 0–10% EtOAc in hexanes).

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.44 (dd, J = 8.0, 1.6 Hz, 1H), 7.00 (dd, J = 8.0, 1.6 Hz, 1H), 6.86 (t, J = 8.0 Hz, 1H), 4.38 (d, J = 11.2 Hz, 1H), 3.91 (d, J = 11.2 Hz, 1H), 3.87 (s, 3H), 3.39 (s, 3H), 1.09 (m, 1H), 1.00 (m, 1H), 0.68 (m, 1H), 0.52 (m, 1H), 0.30 (m, 1H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 166.1, 143.8, 141.7, 124.4, 121.6, 120.4, 119.6, 94.4, 69.6, 52.0, 49.8, 12.7, 0.6, 0.2.

HRMS (DART): *m/z* calcd for $C_{14}H_{17}O_5$ $[M+H]^+$: 265.10705. Found: 265.10717.

(*R*)-2-(benzo[*d*][1,3]dioxol-5-yl)-2,3-dihydrobenzo[*b*][1,4]dioxine (6i)



6i
98:2 *er*
96% yield

The compound was synthesized using **GP5** with **5i** (50.8 mg, 0.200 mmol, 1 equiv) at 50 °C. Purification by column chromatography (elution gradient 0–5% EtOAc in hexanes) yielded the title compound as a colorless oil (49.1 mg, 96% yield).

^{1}H NMR (500 MHz, CD_3CN): δ 6.96–6.85 (multiple peaks, 7H), 5.98 (s, 2H), 5.08 (dd, J = 8.5, 2.3 Hz, 1H), 4.33 (dd, J = 11.5, 2.3 Hz, 1H), 4.03 (dd, J = 11.5, 8.5 Hz, 1H).

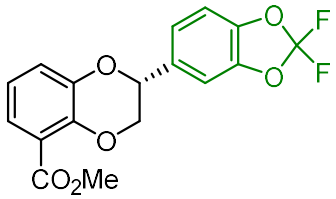
^{13}C NMR (126 MHz, CD_3CN): δ 149.1, 149.0, 145.0, 144.2, 131.7, 122.5, 122.5, 121.5, 118.3, 118.0, 198.2, 108.0, 102.7, 75.7, 69.8.

HRMS (DART): *m/z* calcd for $C_{15}H_{13}O_4$ $[M+H]^+$: 257.08084. Found: 257.08090.

$[\alpha]_D^{26}$ = -67.1 (c = 0.16 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on Phenomenex Lux Cellulose-3 column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 2.69 min (minor), 2.86 min (major); *er* 97.7:2.3.

Methyl (*R*)-2-(2,2-difluorobenzo[*d*][1,3]dioxol-5-yl)-2,3-dihydrobenzo[*b*][1,4]dioxine-5-carboxylate (6j)



6j
94:6 *er*
90% yield

The compound was synthesized using **GP5** with **5j** (69.7 mg, 0.200 mmol, 1 equiv) at 50 °C. Purification by column chromatography (elution gradient 0–5% EtOAc in hexanes) yielded the title compound as a white solid (63.1 mg, 90% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.47 (dd, J = 7.8, 1.4 Hz, 1H), 7.17–7.10 (m, 4H), 6.92 (t, J = 7.8 Hz, 1H), 5.16 (dd, J = 8.9, 2.3 Hz, 1H), 4.51 (dd, J = 11.5, 2.3 Hz, 1H), 4.00 (dd, J = 11.5, 8.9 Hz, 1H), 3.90 (s, 3H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 165.9, 144.2, 144.1, 144.0, 143.3, 132.2, 131.7 (t, J_{CF} = 18 Hz), 124.2, 122.0, 121.6, 120.8, 120.0, 109.7, 107.9, 74.0, 69.4, 52.1.

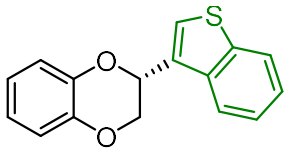
^{19}F NMR (471 MHz, $CDCl_3$): δ -49.85, -49.89.

HRMS (DART): *m/z* calcd for $C_{17}H_{13}O_6F$ $[M+H]^+$: 351.06747. Found: 351.06749.

$[\alpha]_D^{26}$ = -2.5 (c = 0.20 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on Phenomenex Lux Cellulose-3 column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 2.02 min (minor), 1.80 min (major); *er* 94.4:5.6.

(*R*)-2-(benzo[*b*]thiophen-3-yl)-2,3-dihydrobenzo[*b*][1,4]dioxine (6k)



6k
99:1 *er*
95% yield

The compound was synthesized using **GP5** with **5k** (53.3 mg, 0.200 mmol, 1 equiv) at 50 °C. Purification by column chromatography (elution gradient 0–5% EtOAc in hexanes) yielded the title compound as a white solid (51.0 mg, 95% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.91–7.86 (multiple peaks, 2H), 7.57 (s, 1H), 7.45–7.37 (multiple peaks, 2H), 7.01–6.95 (multiple peaks, 2H), 6.93–6.88 (multiple peaks, 2H), 5.57 (dd, J = 8.3, 2.5 Hz, 1H), 4.54 (dd, J = 11.5, 2.5 Hz, 1H), 4.26 (dd, J = 11.5, 8.3 Hz, 1H).

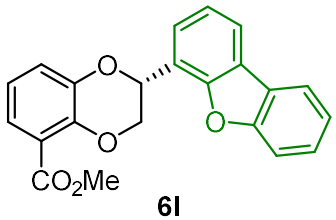
^{13}C NMR (126 MHz, $CDCl_3$): δ 143.6, 143.1, 140.7, 137.0, 131.3, 124.82, 124.79, 124.5, 123.1, 121.8, 121.8, 121.7, 117.6, 117.2, 71.1, 68.1.

HRMS (DART): *m/z* calcd for $C_{16}H_{13}O_2S$ $[M+H]^+$: 269.06308. Found: 269.06327.

$[\alpha]_D^{25}$ = -68.0 (*c* = 0.20 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on Phenomenex Lux Cellulose-3 column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 4.54 min (minor), 5.34 min (major); *er* 99.1:0.9

Methyl (*R*)-2-(dibenzo[*b,d*]furan-4-yl)-2,3-dihydrobenzo[*b*][1,4]dioxine-5-carboxylate (6l)



6l
>99:1 *er*
91% yield

The compound was synthesized using **GP5** with **5l** (71.7 mg, 0.200 mmol, 1 equiv) at 70 °C. Purification by column chromatography (8% EtOAc in hexanes) yielded the title compound as a white solid (65.7 mg, 91% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 8.19–8.17 (m, 2H), 7.89–7.86 (m, 1H), 7.56–7.46 (m, 5H), 7.24 (dd, J = 8.1, 1.4 Hz, 1H), 6.96 (t, J = 8.0 Hz, 1H), 5.55 (dd, J = 9.1, 2.4 Hz, 1H), 4.70 (dd, J = 11.6, 2.6 Hz, 1H), 4.27 (dd, J = 11.6, 9.2 Hz, 1H), 3.93 (s, 3H).

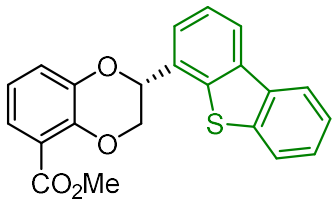
^{13}C NMR (125 MHz, $CDCl_3$): δ 166.0, 144.1, 143.6, 139.3, 137.3, 136.7, 135.2, 130.3, 125.0, 124.7, 124.6, 124.2, 122.8, 122.1, 121.7, 120.8, 120.0, 74.2, 67.7, 52.2.

HRMS (DART): *m/z* calcd for $C_{22}H_{17}O_5$ $[M+H]^+$: 361.10705. Found: 361.10700.

$[\alpha]_D^{22}$ = -116.0 (c = 0.10 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on Phenomenex Lux Cellulose-3 column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 5.74 min (minor), 5.98 min (major); *er* 99.5:0.5

Methyl (*R*)-2-(dibenzo[*b,d*]thiophen-4-yl)-2,3-dihydrobenzo[*b*][1,4]dioxine-5-carboxylate (6m)



6m
>99:1 *er*
91% yield

The compound was synthesized using **GP5** with **5m** (74.9 mg, 0.200 mmol, 1 equiv) at 70 °C. Purification by column chromatography (6% EtOAc in hexanes) yielded the title compound as a white solid (68.4 mg, 91% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.97 (d, J = 7.7 Hz, 2H), 7.61–7.57 (m, 2H), 7.50–7.47 (m, 2H), 7.41 (t, J = 7.6 Hz, 1H), 7.37 (t, J = 7.4 Hz, 1H), 7.24 (1d, J = 8.0, 1.4 Hz, 1H), 6.94 (t, J = 7.9 Hz, 1H), 5.85 (dd, J = 8.7, 2.4 Hz, 1H), 4. 83 (dd, J = 11.5, 2.4 Hz, 1H), 4.29 (dd, J = 11.4, 8.8 Hz, 1H), 3.92 (s, 3H).

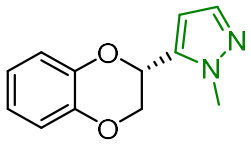
^{13}C NMR (125 MHz, $CDCl_3$): δ 166.1, 156.1, 153.0, 144.4, 143.7, 127.6, 124.63, 124.60, 124.0, 123.9, 123.2, 123.1, 121.7, 121.0, 120.8, 120.6, 120.1, 120.0, 111.9, 70.5, 68.2, 52.1.

HRMS (DART): *m/z* calcd for $C_{22}H_{17}O_4S$ $[M+H]^+$: 377.08421. Found: 377.08442.

$[\alpha]_D^{22}$ = -125.0 (c = 0.10 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on ChromegaChiral CCC column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 6.75 min (minor), 7.52 min (major); *er* 99.5:0.5

(*R*)-5-(2,3-dihydrobenzo[*b*][1,4]dioxin-2-yl)-1-methyl-1*H*-pyrazole (6n)



6n
98:2 *er*
93% yield

The compound was synthesized using **GP5** with **5n** (42.8 mg, 0.200 mmol, 1 equiv) at 70 °C. Purification by column chromatography (20% EtOAc in hexanes) yielded the title compound as a white solid (40.3 mg, 93% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.46 (d, J = 2.0 Hz, 1H), 6.95–6.85 (multiple peaks, 4H), 6.32 (d, J = 2.0 Hz, 1H), 5.27 (dd, J = 7.6, 2.5 Hz, 1H), 4.47 (dd, J = 11.5, 2.5 Hz, 1H), 4.34 (dd, J = 11.5, 7.6 Hz, 1H), 4.00 (s, 3H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 142.8, 142.6, 138.5, 137.0, 122.1, 121.9, 117.5, 117.3, 105.1, 66.8, 66.2, 37.2.

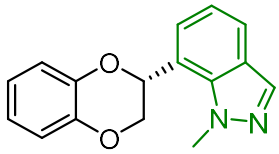
HRMS (DART): *m/z* calcd for $C_{12}H_{13}O_2N_2$ $[M+H]^+$: 217.09715. Found: 217.09717.

$[\alpha]_D^{23}$ = +111.6 (c = 0.18 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on Phenomenex Lux Cellulose-2 column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC;

SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 4.04 min (minor), 4.76 min (major); *er* 97.6:2.4

(*R*)-7-(2,3-Dihydrobenzo[*b*][1,4]dioxin-2-yl)-1-methyl-1*H*-indazole (6o)



6o
98:2 *er*
96% yield

The compound was synthesized using **GP5** with **5o** (52.9 mg, 0.200 mmol, 1 equiv) at 70 °C. Purification by column chromatography (10% EtOAc in hexanes) yielded the title compound as a white solid (51.2 mg, 96% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 8.12 (s, 1H), 7.45–7.40 (multiple peaks, 2H), 7.24 (m, 1H), 7.04 (m, 1H), 6.97 (m, 1H), 6.94–6.90 (multiple peaks, 2H), 5.54 (dd, J = 8.9, 2.0 Hz, 1H), 4.47 (dd, J = 11.5, 2.0 Hz, 1H), 4.23 (dd, J = 11.5, 8.9 Hz, 1H), 4.11 (s, 3H).

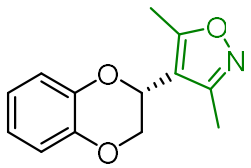
^{13}C NMR (126 MHz, $CDCl_3$): δ 143.7, 143.2, 140.3, 131.3, 129.6, 126.3, 121.79, 121.78, 121.75, 118.4, 117.6, 117.2, 109.5, 74.4, 68.8, 35.7.

HRMS (DART): *m/z* calcd for $C_{16}H_{15}O_2N_2$ $[M+H]^+$: 267.11280. Found: 267.11278.

$[\alpha]_D^{24}$ = -117.3 (c = 0.21 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on ChromegaChiral CCA column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 5.06 min (minor), 5.44 min (major); *er* 98.3:1.7

(*R*)-4-(2,3-Dihydrobenzo[*b*][1,4]dioxin-2-yl)-3,5-dimethylisoxazole (6p)



6p
98:2 *er*
72% yield

The compound was synthesized using **GP5** with **5p** (45.8 mg, 0.200 mmol, 1 equiv) at 50 °C. Purification by column chromatography (5% EtOAc in hexanes) yielded the title compound as a white solid (33.5 mg, 72% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 6.96–6.86 (multiple peaks, 4H), 5.05 (dd, J = 9.4, 2.6 Hz, 1H), 4.23 (dd, J = 11.5, 2.6 Hz, 1H), 4.15 (dd, J = 11.5, 9.4 Hz, 1H), 2.45 (s, 3H), 2.31 (s, 3H).

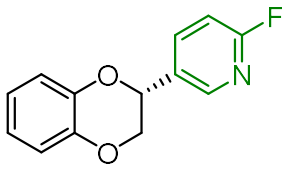
^{13}C NMR (126 MHz, $CDCl_3$): δ 167.6, 158.6, 143.3, 142.7, 122.0, 121.9, 117.4, 117.3, 109.8, 67.9, 66.9, 11.7, 10.7.

HRMS (DART): *m/z* calcd for $C_{13}H_{14}O_3N$ $[M+H]^+$: 232.09682. Found: 232.09691.

$[\alpha]_D^{23}$ = -49.0 (c = 0.21 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on Phenomenex Lux Cellulose-4 column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 2.97 min (minor), 2.77 min (major); *er* 97.7:2.3

(*R*)-5-(2,3-Dihydrobenzo[*b*][1,4]dioxin-2-yl)-2-fluoropyridine (6q)



6q
98:2 *er*
82% yield

The compound was synthesized using **GP5** with **5q** (45.8 mg, 0.200 mmol, 1 equiv) at 50 °C. Purification by column chromatography (elution gradient 0–10% EtOAc in hexanes) yielded the title compound as a white solid (38.0 mg, 82% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 8.47 (d, J = 2.3 Hz, 1H), 7.74 (dd, J = 8.3, 2.3 Hz, 1H), 7.39 (d, J = 8.3 Hz, 1H), 7.00–6.88 (multiple peaks, 4H), 5.19 (dd, J = 8.5, 2.3 Hz, 1H), 4.37 (dd, J = 11.5, 2.3 Hz, 1H), 4.04 (dd, J = 11.5, 8.5 Hz, 1H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 163.8 (d, J_{CF} = 241 Hz), 146.2 (d, J_{CF} = 15.3 Hz), 143.2, 142.8, 139.5 (d, J_{CF} = 8.2 Hz), 130.1 (d, J_{CF} = 4.6 Hz), 122.1, 121.9, 117.5, 117.3, 109.9 (d, J_{CF} = 37.6 Hz), 72.3 (d, J_{CF} = 1.5 Hz), 68.7 (d, J_{CF} = 1.2 Hz).

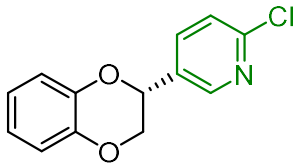
^{19}F NMR (471 MHz, $CDCl_3$): δ -67.6.

HRMS (DART): *m/z* calcd for $C_{13}H_{11}O_2NF$ $[M+H]^+$: 232.07683. Found: 232.07688.

$[\alpha]_D^{23}$ = -81.8 (*c* = 0.24 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on Phenomenex Lux Cellulose-3 column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 2.26 min (minor), 2.48 min (major); *er* 98.1:1.9.

(*R*)-2-Chloro-5-(2,3-dihydrobenzo[*b*][1,4]dioxin-2-yl)pyridine (6r)



6r
99:1 *er*
94% yield

The compound was synthesized using **GP5** with **5r** (49.1 mg, 0.200 mmol, 1 equiv) at 70 °C. Purification by column chromatography (elution gradient 0–10% EtOAc in hexanes) yielded the title compound as a white solid (46.4 mg, 94% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 8.47 (d, *J* = 2.3 Hz, 1H), 7.74 (dd, *J* = 8.3, 2.3 Hz, 1H), 7.39 (d, *J* = 8.3 Hz, 1H), 7.00–6.88 (multiple peaks, 4H), 5.19 (dd, *J* = 8.5, 2.3 Hz, 1H), 4.37 (dd, *J* = 11.5, 2.3 Hz, 1H), 4.04 (dd, *J* = 11.5, 8.5 Hz, 1H).

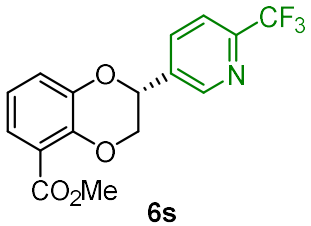
^{13}C NMR (126 MHz, $CDCl_3$): δ 152.0, 148.0, 143.1, 142.8, 137.0, 131.3, 124.5, 122.1, 121.9, 117.5, 117.3, 72.3, 68.6.

HRMS (DART): *m/z* calcd for $C_{13}H_{11}O_2NCl$ $[M+H]^+$: 248.04728. Found: 248.04731.

$[\alpha]_D^{24}$ = -85.6 (*c* = 0.22 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on ChromegaChiral CCA column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 4.79 min (minor), 5.56 min (major); *er* 98.8:1.2.

Methyl (*R*)-2-(6-(trifluoromethyl)pyridin-3-yl)-2,3-dihydrobenzo[*b*][1,4]dioxine-5-carboxylate (6s)



6s
99:1 *er*
99% yield

The compound was synthesized using **GP5** with **5s** (67.5 mg, 0.200 mmol, 1 equiv) at 70 °C. Purification by column chromatography (15% EtOAc in hexanes) yielded the title compound as a white solid (quantitative yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 8.80 (s, 1H), 7.97 (dd, J = 8.3, 1.7 Hz, 1H), 7.77 (d, J = 8.1 Hz, 1H), 7.50 (dd, J = 7.8, 1.4 Hz, 1H), 7.17 (dd, J = 8.1, 1.4 Hz, 1H), 6.95 (t, J = 7.9 Hz, 1H), 5.34 (dd, J = 8.5, 1.9 Hz, 1H), 4.59 (dd, J = 11.6, 2.4 Hz, 1H), 4.11 (dd, J = 11.6, 8.5 Hz, 1H), 3.91 (s, 3H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 165.7, 148.7 (q, J_{CF} = 36.6 Hz), 148.2, 143.5, 143.2, 135.5, 135.0 (q, J_{CF} = 0.96 Hz), 124.6, 121.6, 121.3 (q, J_{CF} = 273 Hz), 121.0, 120.6 (q, J_{CF} = 2.7 Hz), 120.2, 72.1, 68.7, 52.2.

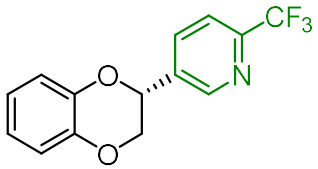
^{19}FNMR (471 MHz, $CDCl_3$): δ -68.0.

HRMS (DART): *m/z* calcd for $C_{16}H_{13}O_4NF_3$ $[M+H]^+$: 340.07912. Found: 340.07913.

$[\alpha]_D^{24}$ = -17.5 (c = 0.10 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on Phenomenex Lux Cellulose-4 column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 5.06 min (minor), 5.35 min (major); *er* 99.1:0.9

(*R*)-5-(2,3-Dihydrobenzo[*b*][1,4]dioxin-2-yl)-2-(trifluoromethyl)pyridine (6t)



6t
99:1 *er*
96% yield

The compound was synthesized using **GP5** with **5t** (55.8 mg, 0.200 mmol, 1 equiv) at 70 °C. Purification by column chromatography (elution gradient 0–8% EtOAc in hexanes) yielded the title compound as a white solid (54.2 mg, 96% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 8.80 (s, 1H), 7.97 (d, J = 7.8 Hz, 1H), 7.75 (d, J = 8.1 Hz, 1H), 7.02–6.90 (multiple peaks, 4H), 5.30 (dd, J = 8.3, 2.1 Hz, 1H), 4.42 (dd, J = 11.6, 2.1 Hz, 1H), 4.07 (dd, J = 11.6, 8.3 Hz, 1H).

^{13}C NMR (126 MHz, $CDCl_3$): δ 148.5 (q, J_{CF} = 35.0 Hz), 148.3, 143.0, 142.8, 135.5 (two overlapping peaks), 122.2, 122.1, 121.4 (q, J_{CF} = 274 Hz), 120.5 (q, J_{CF} = 2.7 Hz), 117.5, 117.4, 72.5, 68.5.

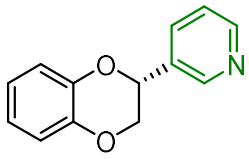
^{19}FNMR (471 MHz, $CDCl_3$): δ -68.0.

HRMS (DART): *m/z* calcd for $C_{14}H_{11}O_2NF_3$ $[M+H]^+$: 282.07364. Found: 282.07362.

$[\alpha]_D^{24}$ = -91.3 (*c* = 0.27 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on Phenomenex Lux Cellulose-4 column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 3.04 min (minor), 2.65 min (major); *er* 98.6:1.4

(*R*)-3-(2,3-Dihydrobenzo[*b*][1,4]dioxin-2-yl)pyridine (6u)



6u
98:2 *er*
70% yield

The compound was synthesized using **GP5** with **5u** (42.2 mg, 0.200 mmol, 1 equiv) at 70 °C. Purification by column chromatography (30% EtOAc in hexanes) yielded the title compound as a colorless oil (30.0 mg, 70% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 8.69 (d, J = 1.8 Hz, 1H), 8.64 (dd, J = 4.8, 1.8 Hz, 1H), 7.76 (m, 1H), 7.36 (dd, J = 7.8, 4.8 Hz, 1H), 7.01–6.88 (multiple peaks, 4H), 5.19 (dd, J = 8.7, 2.3 Hz, 1H), 4.38 (dd, J = 11.5, 2.3 Hz, 1H), 4.06 (dd, J = 11.5, 8.7 Hz, 1H).

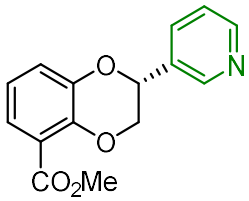
^{13}C NMR (126 MHz, $CDCl_3$): δ 150.2, 148.2, 143.4, 142.9, 134.2, 132.2, 123.7, 121.9, 121.8, 117.5, 117.3, 73.0, 68.9.

HRMS (DART): *m/z* calcd for for $C_{13}H_{12}O_2N$ $[M+H]^+$: 214.08626. Found: 214.08645.

$[\alpha]_D^{23}$ = -95.6 (*c* = 0.60 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on ChromegaChiral CCA column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 4.64 min (minor), 4.94 min (major); *er* 98.3:1.6.

Methyl (*R*)-2-(pyridin-3-yl)-2,3-dihydrobenzo[*b*][1,4]dioxine-5-carboxylate (6v)



6v
99:1 *er*
85% yield

The compound was synthesized using **GP5** with **5v** (53.9 mg, 0.200 mmol, 1 equiv), 2 mol % $[Ir(cod)Cl]_2$ and 6 mol % ligand at 70 °C. Purification by column chromatography (60% EtOAc in hexanes) yielded the title compound as a white solid (45.9 mg, 85% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 8.69 (s, 1H), 8.66 (d, *J* = 4.8 Hz, 1H), 7.76 (d, *J* = 7.9 Hz, 1H), 7.48 (d, *J* = 7.9 Hz, 1H), 7.38 (dd, *J* = 7.9, 4.8 Hz, 1H), 7.15 (d, *J* = 7.9 Hz, 1H), 6.93 (t, *J* = 7.9 Hz, 1H), 5.23 (app d, *J* = 7.4 Hz, 1H), 4.56 (dd, *J* = 11.5, 1.9 Hz, 1H), 4.09 (dd, *J* = 11.5, 9.1 Hz, 1H), 3.91 (s, 3H).

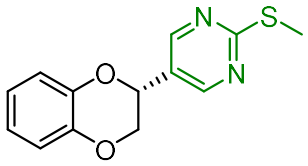
^{13}C NMR (126 MHz, $CDCl_3$): δ 165.9, 150.3, 148.1, 144.0, 143.3, 134.1, 131.7, 124.3, 123.7, 121.6, 120.8, 120.1, 72.7, 69.1, 52.1.

HRMS (DART): *m/z* calcd for $C_{15}H_{14}O_4N$ $[M+H]^+$: 272.09173. Found: 272.09174.

$[\alpha]_D^{24}$ = -4.58 (*c* = 0.12 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on Phenomenex Lux Cellulose-3 column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 4.57 min (minor), 4.16 min (major); *er* 99.0:1.0

(*R*)-5-(2,3-Dihydrobenzo[*b*][1,4]dioxin-2-yl)-2-(methylthio)pyrimidine (6w)



6w
98:2 *er*
86% yield

The compound was synthesized using **GP5** with **5w** (51.7 mg, 0.200 mmol, 1 equiv), 2 mol % $[Ir(cod)Cl]_2$ and 6 mol % ligand at 70 °C. Purification by column chromatography (8% EtOAc in hexanes) yielded the title compound as a white solid (44.8 mg, 86% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 8.58 (s, 2H), 6.98–6.88 (multiple peaks, 4H), 5.14 (dd, J = 8.2, 2.3 Hz, 1H), 4.37 (dd, J = 11.5, 2.3 Hz, 1H), 4.09 (dd, J = 11.5, 8.2 Hz, 1H), 2.58 (s, 3H).

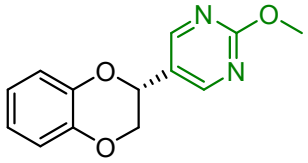
^{13}C NMR (126 MHz, $CDCl_3$): δ 173.6, 155.6, 143.0, 142.7, 124.9, 122.2, 122.0, 117.6, 117.3, 71.2, 68.2, 14.2.

HRMS (DART): *m/z* calcd for $C_{13}H_{13}O_2N_2S$ $[M+H]^+$: 261.06922. Found: 261.06927.

$[\alpha]_D^{23}$ = -66.8 (c = 0.19 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on Phenomenex Lux Cellulose-3 column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 4.70 min (minor), 5.12 min (major); *er* 98.2:1.8

(*R*)-5-(2,3-Dihydrobenzo[*b*][1,4]dioxin-2-yl)-2-methoxypyrimidine (6x)



6x
98:2 *er*
50% yield

The compound was synthesized using **GP5** with **5x** (48.4 mg, 0.200 mmol, 1 equiv), 2 mol % $[Ir(cod)Cl]_2$ and 6 mol % ligand at 50 °C. Purification by column chromatography (15% EtOAc in hexanes) yielded the title compound as a white solid (24.4 mg, 50% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 8.58 (s, 2H), 6.98–6.88 (multiple peaks, 4H), 5.15 (dd, J = 8.3, 2.1 Hz, 1H), 4.36 (dd, J = 11.5, 2.1 Hz, 1H), 4.10 (dd, J = 11.5, 8.3 Hz, 1H), 4.04 (s, 3H).

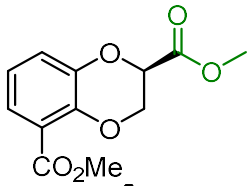
^{13}C NMR (126 MHz, $CDCl_3$): δ 166.0, 158.0, 143.1, 142.7, 123.5, 122.1, 122.0, 117.5, 117.3, 71.1, 68.3, 55.2.

HRMS (DART): *m/z* calcd for $C_{13}H_{13}O_3N_2$ $[M+H]^+$: 245.09207. Found: 245.09225.

$[\alpha]_D^{22}$ = -59.0 (*c* = 0.26 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on Phenomenex Lux Cellulose-3 column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 3.10 min (minor), 3.67 min (major); *er* 97.7:2.3

Dimethyl (*R*)-2,3-dihydrobenzo[*b*][1,4]dioxine-2,5-dicarboxylate (6y)



6y
>99:1 *er*
97% yield

The compound was synthesized using **GP5** with **5y** (50.0 mg, 0.200 mmol, 1 equiv) at 50 °C. Purification by column chromatography (20% EtOAc in hexanes) yielded the title compound as a colorless oil (49.1 mg, 97% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.44 (dd, *J* = 8.0, 1.0 Hz, 1H), 7.17 (dd, *J* = 8.0, 1.0 Hz, 1H), 6.91 (t, *J* = 8.0 Hz, 1H), 4.87 (dd, *J* = 5.1, 3.0 Hz, 1H), 4.52–4.43 (multiple peaks, 2H), 3.88(s, 3H), 3.82 (s, 3H).

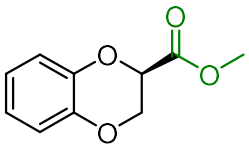
^{13}C NMR (126 MHz, $CDCl_3$): δ 167.9, 165.7, 143.4, 142.7, 124.3, 121.5, 121.1, 120.0, 71.5, 65.0, 52.9, 52.1.

HRMS (DART): *m/z* calcd for $C_{12}H_{13}O_6$ $[M+H]^+$: 253.07066. Found: 253.07074.

$[\alpha]_D^{24}$ = +11.2 (*c* = 0.20 in $CDCl_3$)

The enantiomeric excess was determined by chiral HPLC on Phenomenex Lux Cellulose-3 column, 4.6 mm ID x 150 mm L, 3 um particle size. The compounds were eluted with 0.1% (v/v) $HClO_4$ in water (mobile phase A) and acetonitrile (mobile phase B) using an isocratic condition 80% A/20% B. Column temperature 25 ºC; Flow rate 1.5 mL/min; UV detection at 220 nm; t_R= 12.7 min (minor), 11.3 min (major); *er* 99.9:0.1

Methyl (*R*)-2,3-dihydrobenzo[*b*][1,4]dioxine-2-carboxylate (6z)



6z
95:5 *er*
95% yield

The compound was synthesized using **GP5** with **5z** (38.4 mg, 0.200 mmol, 1 equiv) at 50 °C. Purification by column chromatography (elution gradient 5–15% EtOAc in hexanes) yielded the title compound as a white solid (36.8 mg, 95% yield). NMR spectral data match literature data.[2]

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.00 (m, 1H), 6.92–6.86 (multiple peaks, 3H), 4.85 (t, J = 3.9 Hz, 1H), 4.39 (d, J = 3.9 Hz, 2H), 3.82 (s, 3H).

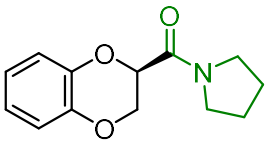
^{13}C NMR (126 MHz, $CDCl_3$): δ 168.5, 142.9, 142.3, 122.2, 121.9, 117.4, 117.3, 72.0, 64.9, 52.8.

HRMS (HESI): *m/z* calcd for $C_{10}H_{10}O_4$ $[M]^{+\cdot}$: 194.05736. Found: 194.05742.

$[\alpha]_D^{24}$ = +39.5 (c = 0.10 in $CDCl_3$); [lit[2] $[\alpha]_D^{20}$ = +55.1 (c = 1.0, $CHCl_3$) for 99% ee, (*R*)-isomer]

The enantiomeric excess was determined by chiral SFC on Phenomenex Lux Cellulose-2 column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 2.91 min (minor), 2.36 min (major); *er* 95.4:4.6

(*R*)-(2,3-Dihydrobenzo[*b*][1,4]dioxin-2-yl)(pyrrolidin-1-yl)methanone (6aa)



6aa
93:7 *er*
93% yield

The compound was synthesized using **GP5** with **5aa** (46.3 mg, 0.200 mmol, 1 equiv) at 50 °C. Purification by column chromatography (elution gradient 10–30% EtOAc in hexanes) yielded the title compound as a colorless oil (43.3 mg, 93% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 6.95–6.83 (multiple peaks, 4H), 4.76 (dd, J = 8.1, 2.5 Hz, 1H), 4.47 (dd, J = 11.7, 2.5 Hz, 1H), 4.33 (dd, J = 11.7, 8.1 Hz, 1H), 3.76 (m, 1H), 3.62–3.52 (multiple peaks, 3H), 2.07–1.85 (multiple peaks, 4H).

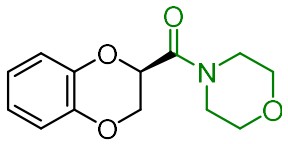
^{13}C NMR (126 MHz, $CDCl_3$): δ 165.0, 143.3, 142.8, 122.0, 121.5, 117.3, 117.3, 72.3, 65.1, 46.7, 46.4, 26.3, 23.8.

HRMS (DART): *m/z* calcd for $C_{13}H_{16}O_3N$ $[M+H]^+$: 234.11247. Found: 234.11250.

$[\alpha]_D^{24}$ = +65.9 (*c* = 0.17 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on ChromegaChiral CCC column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 6.78 min (minor), 5.33 min (major); *er* 92.8:7.2.

(*R*)-(2,3-Dihydrobenzo[*b*][1,4]dioxin-2-yl)(morpholino)methanone (6ab)



6ab
98:2 *er*
93% yield

The compound was synthesized using **GP5** with **5ab** (49.5 mg, 0.200 mmol, 1 equiv) at 50 °C. Purification by column chromatography (elution gradient 10–30% EtOAc in hexanes) yielded the title compound as a colorless oil (46.5 mg, 93% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 6.93–6.83 (multiple peaks, 4H), 4.81 (dd, *J* = 8.0, 2.4 Hz, 1H), 4.49 (dd, *J* = 11.8, 2.5 Hz, 1H), 4.34 (dd, *J* = 11.8, 8.0 Hz, 1H), 3.83–3.67 (multiple peaks, 6H), 3.63–3.54 (multiple peaks, 2H).

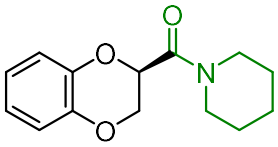
^{13}C NMR (126 MHz, $CDCl_3$): δ 165.0, 143.3, 142.4, 122.4, 121.6, 117.5, 117.2, 70.6, 66.84, 66.77, 65.1, 46.3, 42.5.

HRMS (DART): *m/z* calcd for $C_{13}H_{16}O_4N$ $[M+H]^+$: 250.10738. Found: 250.10742.

$[\alpha]_D^{24}$ = +95.0 (*c* = 0.16 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on Phenomenex Lux Cellulose-4 column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 5.74 min (minor), 5.08 min (major); *er* 98.2:1.8

(*R*)-(2,3-Dihydrobenzo[*b*][1,4]dioxin-2-yl)(piperidin-1-yl)methanone (6ac)



6ac
97:3 *er*
90% yield

The compound was synthesized using **GP5** with **5ac** (49.1 mg, 0.200 mmol, 1 equiv) at 50 °C. Purification by column chromatography (elution gradient 5–20% EtOAc in hexanes) yielded the title compound as a colorless oil (44.4 mg, 90% yield). NMR spectral data match literature data.[7]

^{1}H NMR (500 MHz, $CDCl_3$): δ 6.93–6.83 (multiple peaks, 4H), 4.83 (dd, J = 8.2, 2.5 Hz, 1H), 4.48 (dd, J = 12.0, 2.5 Hz, 1H), 4.31 (dd, J = 12.0, 8.2 Hz, 1H), 3.75–3.66 (multiple peaks, 2H), 3.53–3.44 (multiple peaks, 2H), 1.76–1.58 (multiple peaks, 6H).

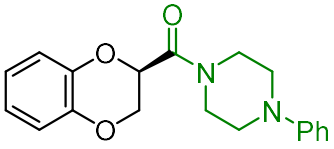
^{13}C NMR (126 MHz, $CDCl_3$): δ 164.6, 143.4, 142.8, 122.1, 121.4, 117.3, 117.3, 70.7, 65.4, 46.8, 43.2, 26.6, 25.5, 24.5.

HRMS (DART): *m/z* calcd for $C_{14}H_{18}O_3N$ $[M+H]^+$: 248.12812. Found: 248.12821.

$[\alpha]_D^{24}$ = +73.4 (c = 0.16 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on Phenomenex Lux Cellulose-2 column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 7.15 min (minor), 5.20 min (major); *er* 97.5:2.5

(*R*)-(2,3-Dihydrobenzo[*b*][1,4]dioxin-2-yl)(4-phenylpiperazin-1-yl)methanone (6ad)



6ad
98:2 *er*
84% yield

The compound was synthesized using **GP5** with **5ad** (64.5 mg, 0.200 mmol, 1 equiv) at 50 °C. Purification by column chromatography (elution gradient 5–15% EtOAc in hexanes) yielded the title compound as a colorless oil (54.6 mg, 84% yield).

^{1}H NMR (500 MHz, $CDCl_3$): δ 7.30 (m, 2H), 6.97–6.83 (multiple peaks, 7H), 4.88 (dd, J = 8.1, 2.5 Hz, 1H), 4.52 (dd, J = 11.9, 2.5 Hz, 1H), 4.36 (dd, J = 11.9, 8.1 Hz, 1H), 3.98–3.90 (multiple peaks, 2H), 3.80–3.67 (multiple peaks, 2H), 3.32–3.12 (multiple peaks,4H).

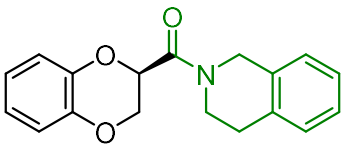
^{13}C NMR (126 MHz, $CDCl_3$): δ 164.9, 150.9, 143.3, 142.5, 129.3, 122.3, 121.6, 120.8, 117.5, 117.3, 116.8, 70.7, 65.2, 50.0, 49.3, 45.7, 42.1.

HRMS (HESI): *m/z* calcd for $C_{19}H_{21}O_3N_2$ $[M+H]^+$: 325.15467. Found: 325.15435.

$[\alpha]_D^{24}$ = +46.0 (c = 0.10 in $CDCl_3$)

The enantiomeric excess was determined by chiral SFC on ChromegaChiral CCC column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 7.48 min (minor), 6.63 min (major); *er* 98.0:2.0

(*R*)-(2,3-Dihydrobenzo[*b*][1,4]dioxin-2-yl)(3,4-dihydroisoquinolin-2(1*H*)-yl)methanone (6ae)



6ae
97:3 *er*
82% yield

The compound was synthesized using **GP5** with **5ae** (58.7 mg, 0.200 mmol, 1 equiv) at 50 °C. Purification by column chromatography (elution gradient 5–20% EtOAc in hexanes) yielded the title compound as a tan oil (48.5 mg, 82% yield).

Two sets of peaks were observed with about 3:2 ratio in ^{1}H and ^{13}C NMR spectrum at 300 K. At 350 K two sets of ^{1}H peaks start to coalesce, which indicates the presence of two rotamers at 300 K.

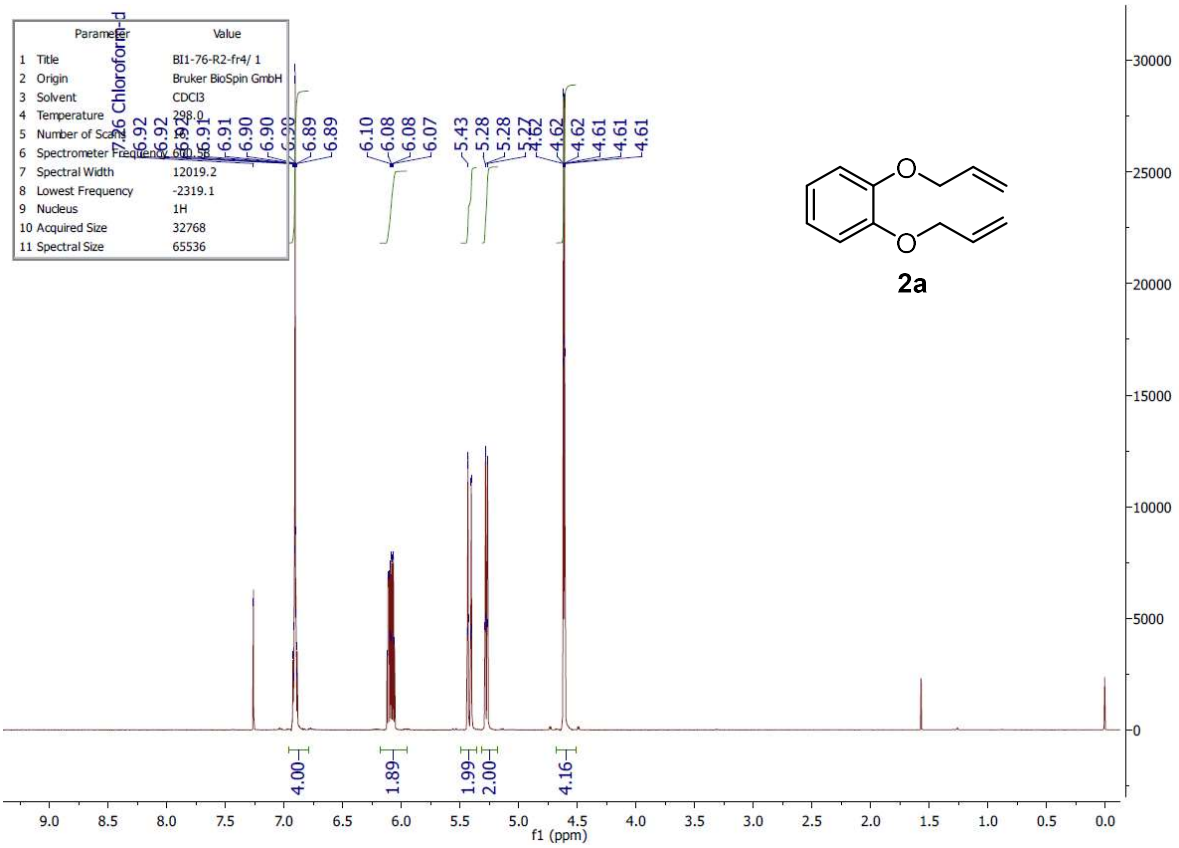
^{1}H NMR (600.04 MHz, DMSO-d_6): δ 7.23–7.17 (m, 4H, rotamer 1+2), 6.96-6.91 (m, 0.6H, rotamer 1), 6.91-6.82 (m, 3.4H, rotamer 1+2), 5.33 (dd, J = 6.4, 2.4 Hz, 0.4H, rotamer 2), 5.30 (dd, J = 6.4, 2.3 Hz, 0.6H, rotamer 1), 4.86 (d, J = 16.3 Hz, 0.4H, rotamer 2), 4.81 (d, J = 16.3 Hz, 0.4H, rotamer 2), 4.68 (d, J = 16.8 Hz, 0.6H, rotamer 1), 4.59 (d, J = 16.8 Hz, 0.6H, rotamer 1), 4.44-4.39 (m, 1H, rotamer 1+2), 4.24-4.18 (m, 1H, rotamer 1+2), 3.93-3.87 (m, 0.6H, rotamer 2), 3.83-3.77 (m, 0.6H, rotamer 2), 3.75-3.65 (m, 0.8H, rotamer 1), 2.94 (t, J = 6.0 Hz, 1.2H, rotamer 2), 2.81 (t, J = 6.0 Hz, 0.8H, rotamer 1).

^{13}C NMR (150.88 MHz, DMSO-d_6): δ rotamer 1: 165.3, 143.0, 142.8, 134.3, 132.9, 128.5, 126.5, 126.5, 126.2, 121.5, 121.4, 117.0, 116.9, 69.8, 64.7, 43.9, 42.7, 28.8; rotamer 2: 165.2, 142.9, 142.8, 134.6, 133.3, 128.5, 126.6, 126.2, 126.2, 121.4, 121.4, 117.0, 116.8, 69.8, 64.6, 46.3, 40.0, 27.6.

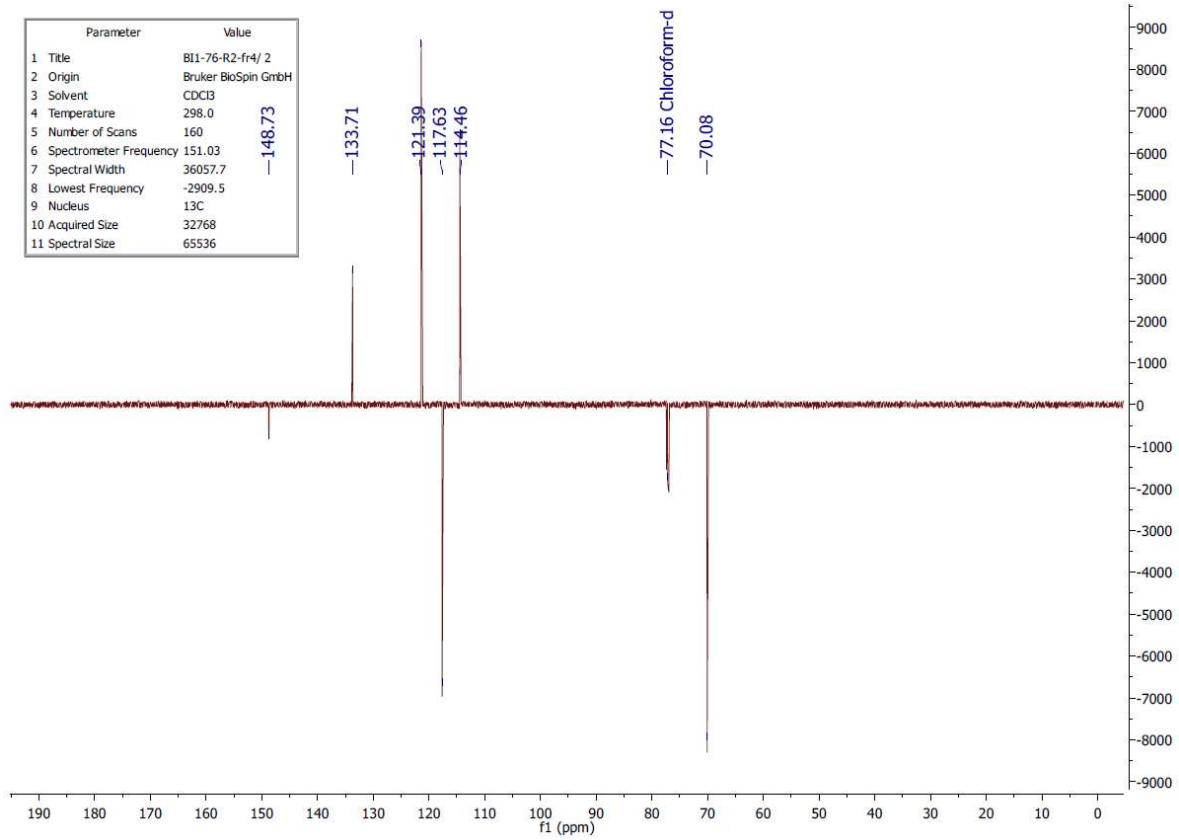
HRMS (DART): *m/z* calcd for $C_{18}H_{18}O_3N$ $[M+H]^+$: 296.12812. Found: 296.12814.

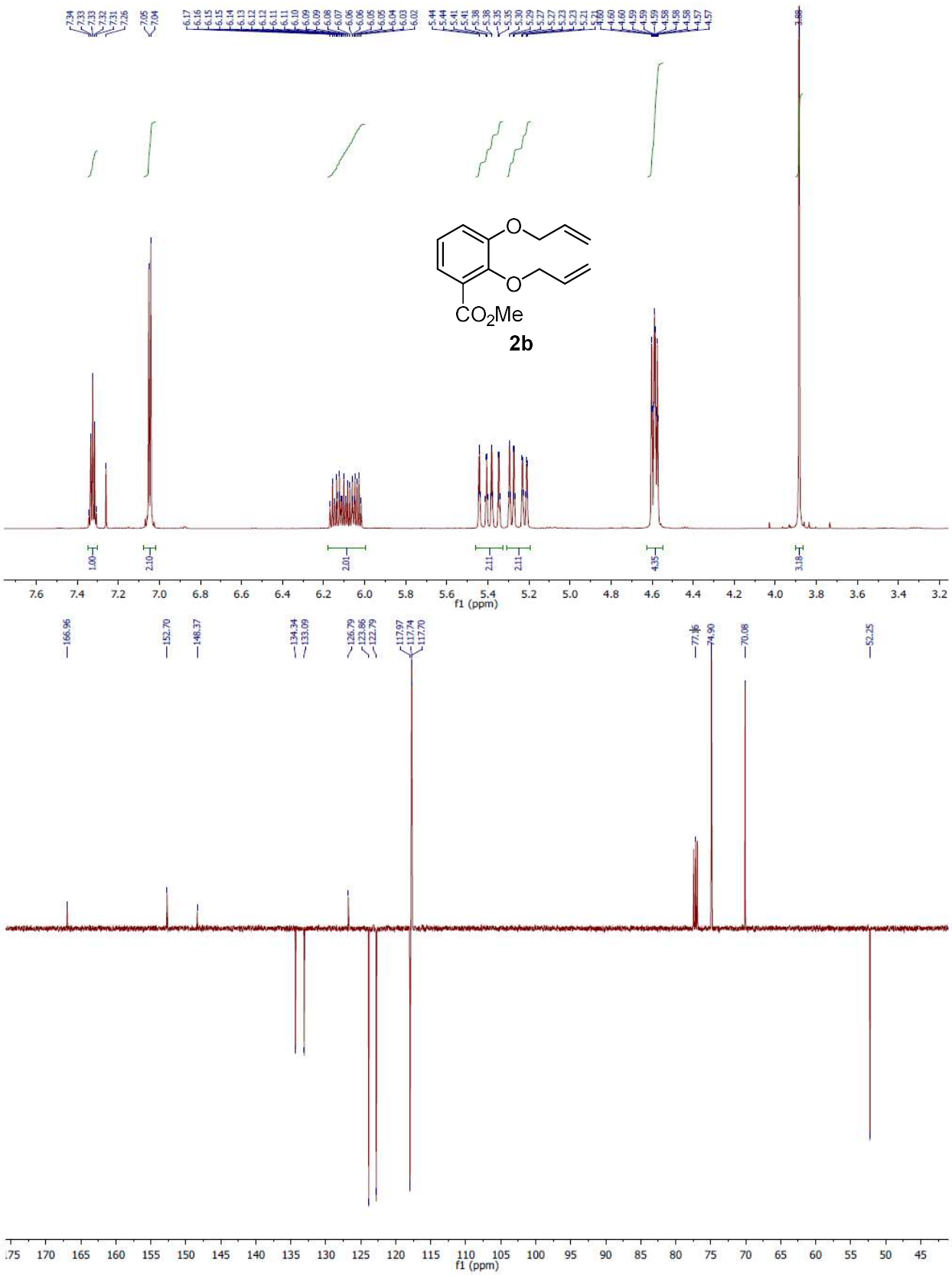
$[\alpha]_D^{26} = +34.2$ ($c = 0.18$ in $CDCl_3$)

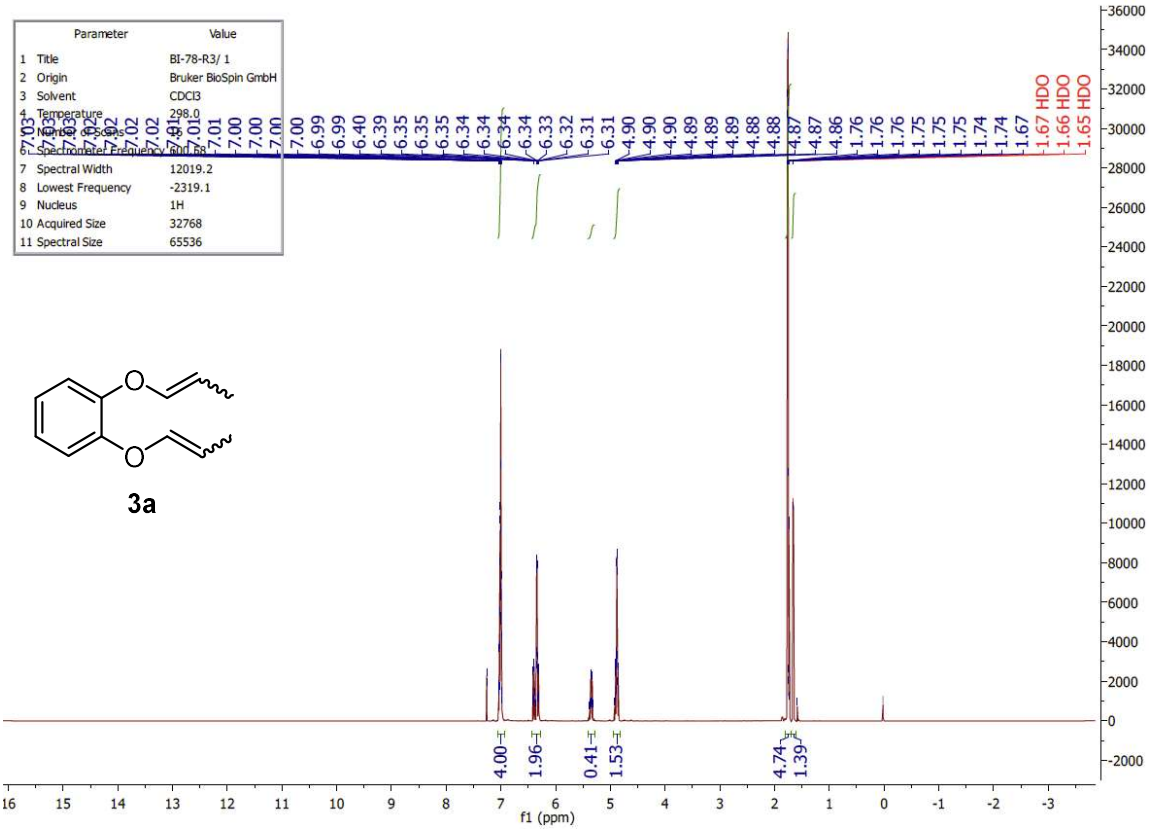
The enantiomeric excess was determined by chiral SFC on Phenomenex Lux Cellulose-3 column, 4.6 mm ID x 100 mm L, 5 um particle size. The compounds were eluted with CO_2 (mobile phase A) and methanol (mobile phase B) using a gradient. The gradient used was 1%B to 3%B in 3 min, 3%B to 50%B in 5 min, hold at 50%B for 1 min, then to 1%B in 1 min (analysis time 10 minutes). Column temperature 35 ºC; SFC back pressure 150 bar; Flow rate 3.0 mL/min; UV detection at 220 nm; t_R= 4.93 min (minor), 5.47 min (major); *er* 97.5:2.5.


Parameter Value
1 Title BI1-76-R2-fr4/ 1
2 Origin Bruker BioSpin GmbH
3 Solvent CDCl3
4 Temperature 298.0
5 Number of Scans 16
6 Spectrometer Frequency 600.58
7 Spectral Width 12019.2
8 Lowest Frequency -2319.1
9 Nucleus 1H
10 Acquired Size 32768
11 Spectral Size 65536
7.26 Chloroform-d
6.92
6.92
6.91
6.91
6.90
6.90
6.89
6.89
6.10
6.08
6.08
6.07
5.43
5.28
5.28
5.27
4.62
4.62
4.61
4.61
4.61
4.00
1.89
1.99
2.00
4.16
f1 (ppm)

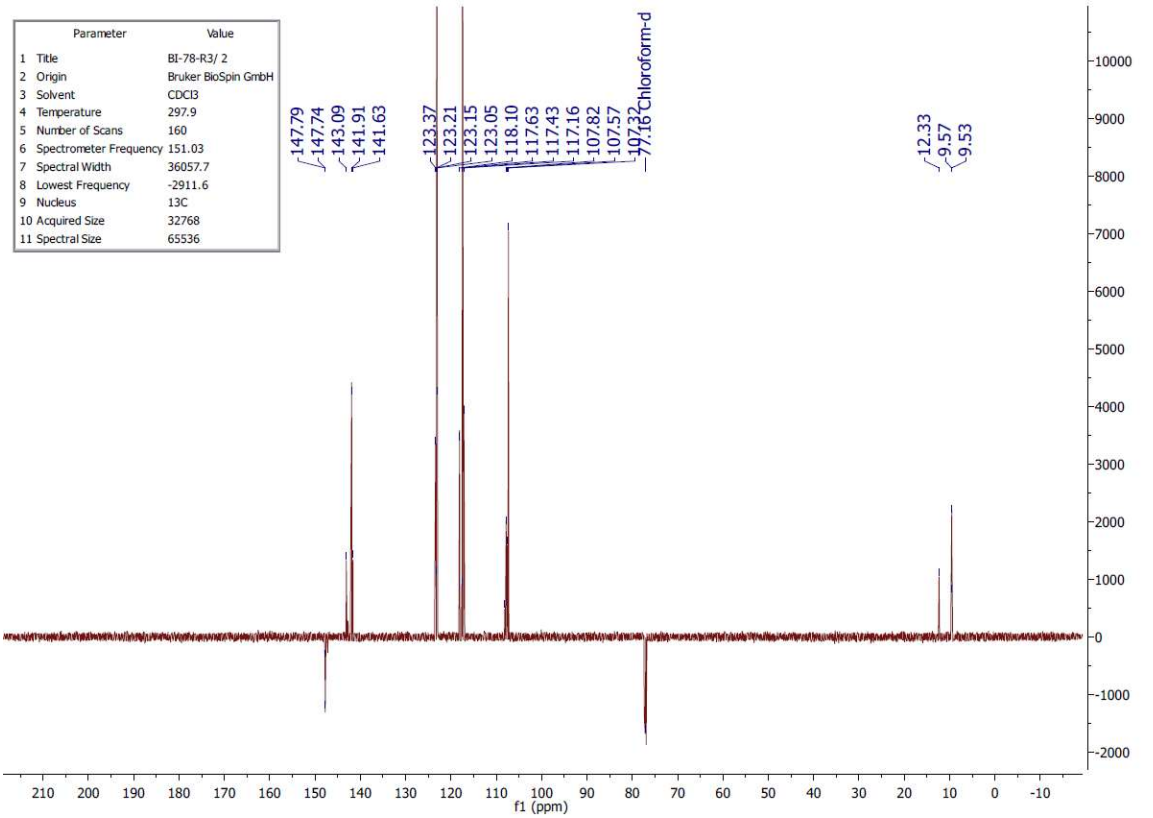
2a

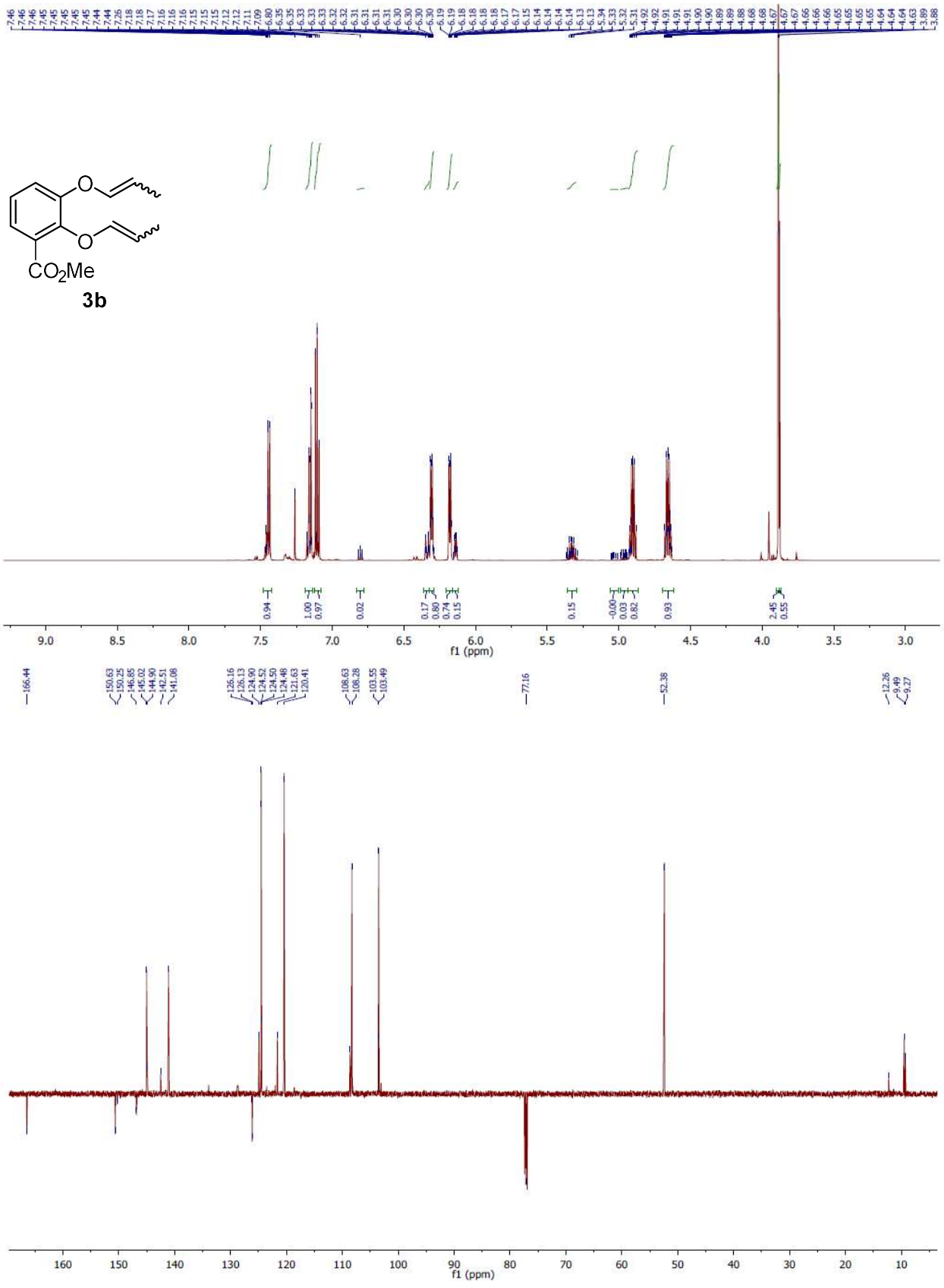

Parameter Value
1 Title BI1-76-R2-fr4/ 2
2 Origin Bruker BioSpin GmbH
3 Solvent CDCl3
4 Temperature 298.0
5 Number of Scans 160
6 Spectrometer Frequency 151.03
7 Spectral Width 36057.7
8 Lowest Frequency -2909.5
9 Nucleus 13C
10 Acquired Size 32768
11 Spectral Size 65536
148.73
133.71
121.39
117.63
114.46
77.16 Chloroform-d
70.08
f1 (ppm)

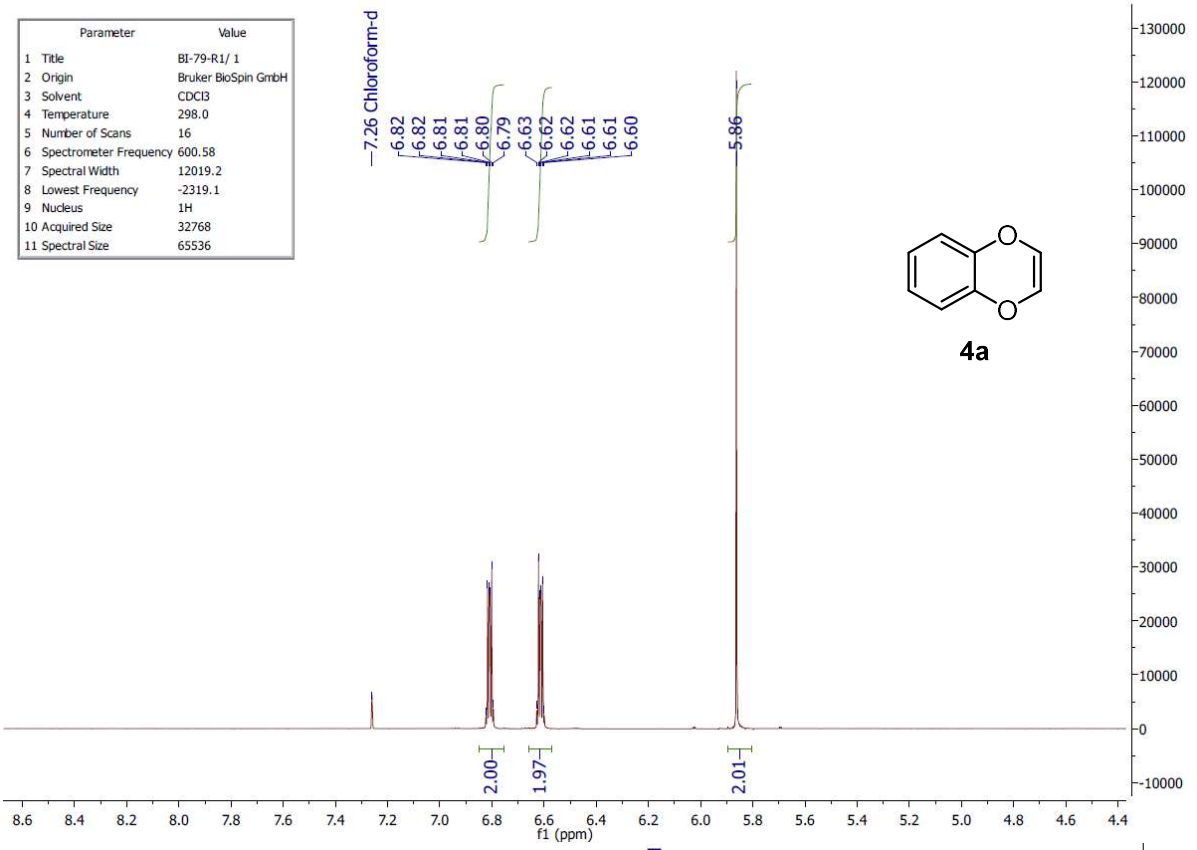

CO2Me
2b
f1 (ppm)
f1 (ppm)


Parameter Value
1 Title BI-78-R3/ 1
2 Origin Bruker BioSpin GmbH
3 Solvent CDCl3
4 Temperature 298.0
5 Number of Scans 8
6 Spectrometer Frequency 600.58
7 Spectral Width 12019.2
8 Lowest Frequency -2319.1
9 Nucleus 1H
10 Acquired Size 32768
11 Spectral Size 65536
1.67 HDO
1.66 HDO
1.65 HDO
4.00
1.96
0.41
1.53
4.74
1.39
f1 (ppm)

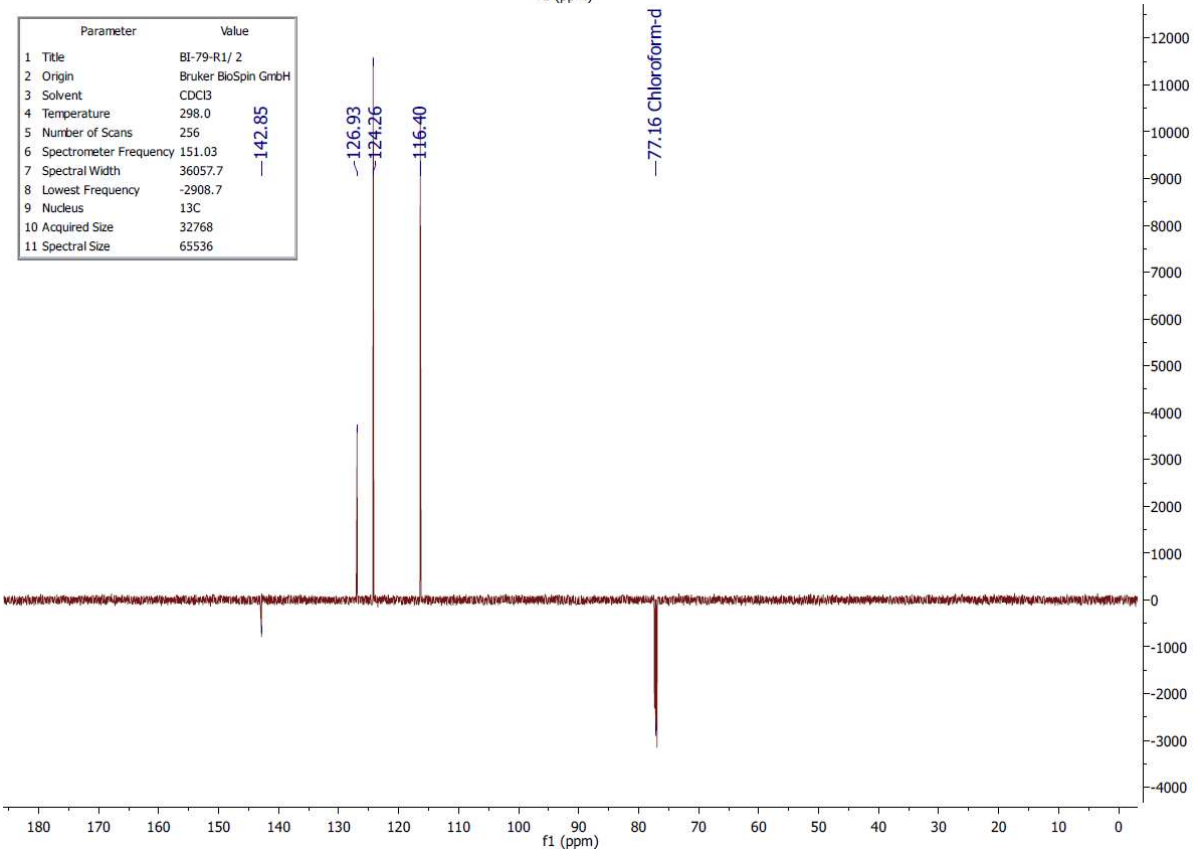
3a


Parameter Value
1 Title BI-78-R3/ 2
2 Origin Bruker BioSpin GmbH
3 Solvent CDCl3
4 Temperature 297.9
5 Number of Scans 160
6 Spectrometer Frequency 151.03
7 Spectral Width 36057.7
8 Lowest Frequency -2911.6
9 Nucleus 13C
10 Acquired Size 32768
11 Spectral Size 65536
147.79
147.74
143.09
141.91
141.63
123.37
123.21
123.15
123.05
118.10
117.63
117.43
117.16
107.82
107.57
107.32
77.16 Chloroform-d
12.33
9.57
9.53
f1 (ppm)

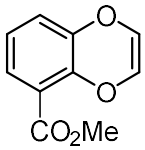

CO2Me
3b
f1 (ppm)
f1 (ppm)


Parameter Value
1 Title BI-79-R1/ 1
2 Origin Bruker BioSpin GmbH
3 Solvent CDCl3
4 Temperature 298.0
5 Number of Scans 16
6 Spectrometer Frequency 600.58
7 Spectral Width 12019.2
8 Lowest Frequency -2319.1
9 Nucleus 1H
10 Acquired Size 32768
11 Spectral Size 65536
7.26 Chloroform-d
6.82
6.82
6.81
6.81
6.80
6.79
6.63
6.62
6.62
6.61
6.61
6.60
5.86
2.00
1.97
2.01
f1 (ppm)

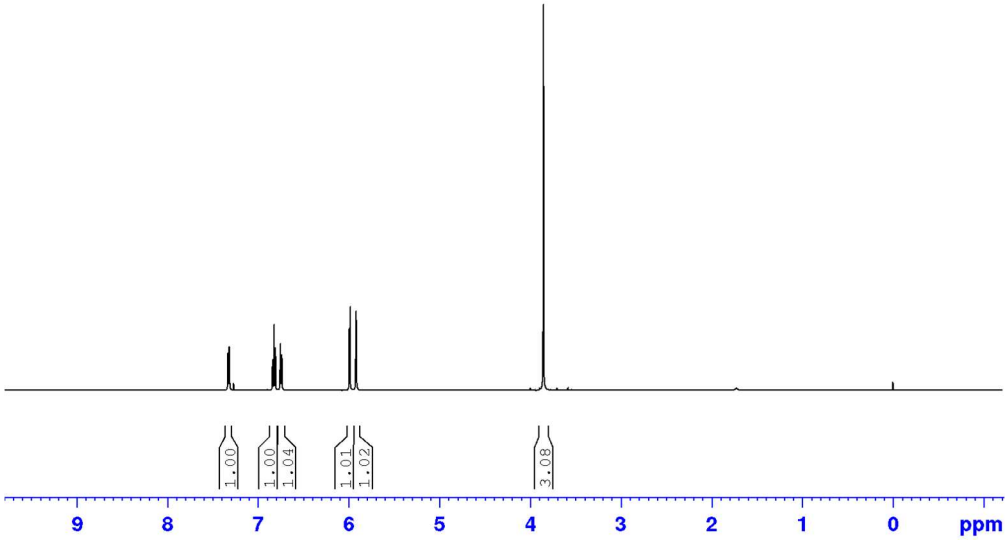
4a

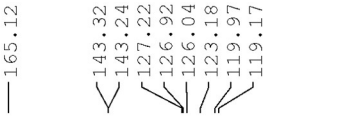

Parameter Value
1 Title BI-79-R1/ 2
2 Origin Bruker BioSpin GmbH
3 Solvent CDCl3
4 Temperature 298.0
5 Number of Scans 256
6 Spectrometer Frequency 151.03
7 Spectral Width 36057.7
8 Lowest Frequency -2908.7
9 Nucleus 13C
10 Acquired Size 32768
11 Spectral Size 65536
142.85
126.93
124.26
116.40
77.16 Chloroform-d
f1 (ppm)

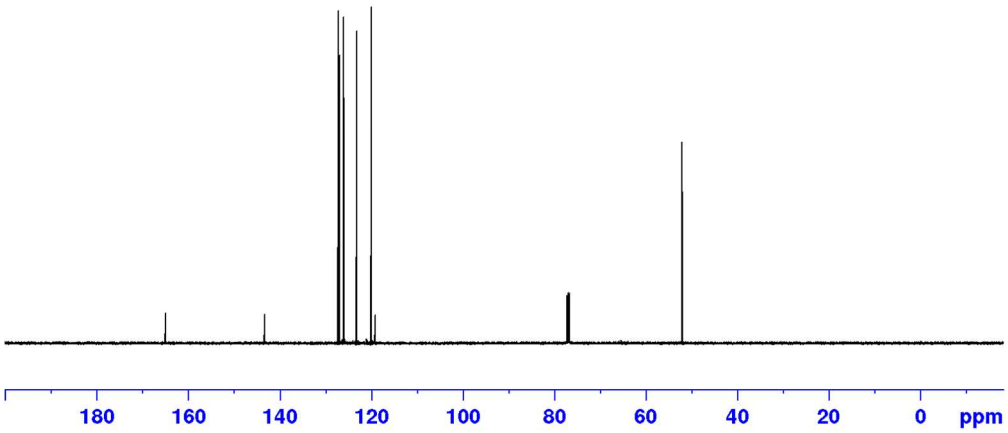

7.34
7.33
7.32
7.32
6.84
6.82
6.80
6.75
6.75
6.74
6.73
5.99
5.98
5.92
5.91
3.86
0.00

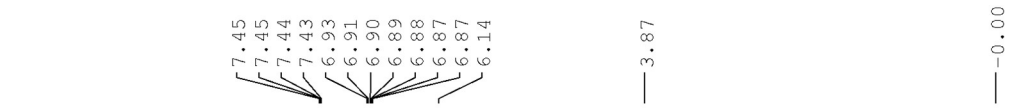

O
O
CO2Me

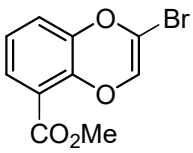
4b


1.00
1.00
1.04
1.01
1.02
3.08
9
8
7
6
5
4
3
2
1
0
ppm

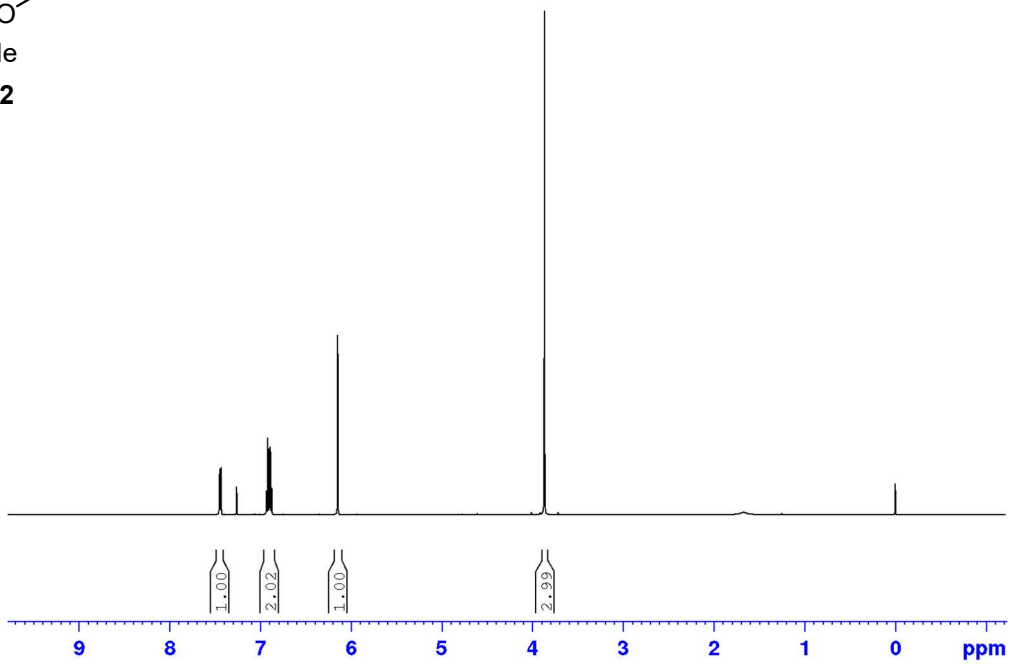

165.12
143.32
143.24
127.22
126.92
126.04
123.18
119.97
119.17
77.32
77.06
76.81
52.16

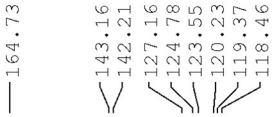

180
160
140
120
100
80
60
40
20
0
ppm

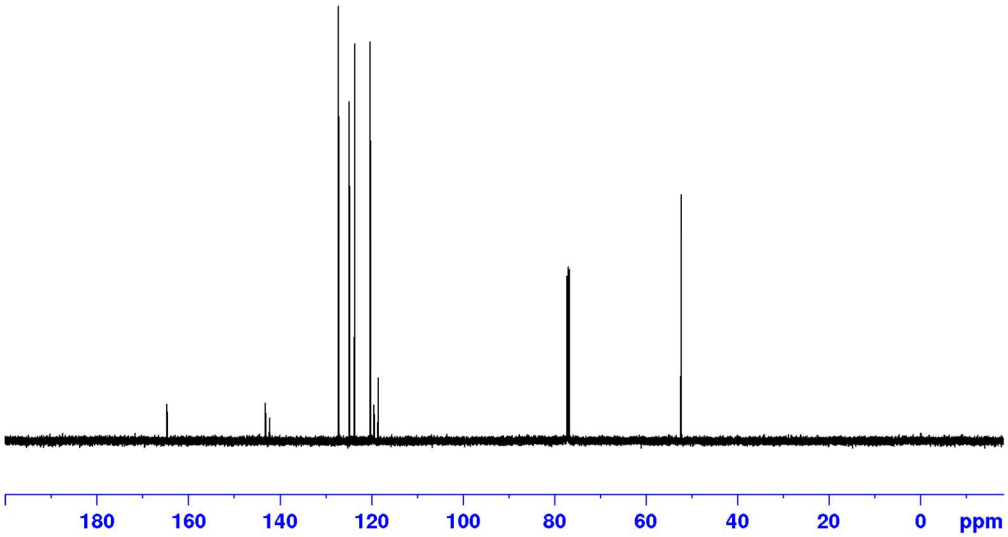

7.45
7.45
7.44
7.43
6.93
6.91
6.90
6.89
6.88
6.87
6.87
6.14
3.87
0.00

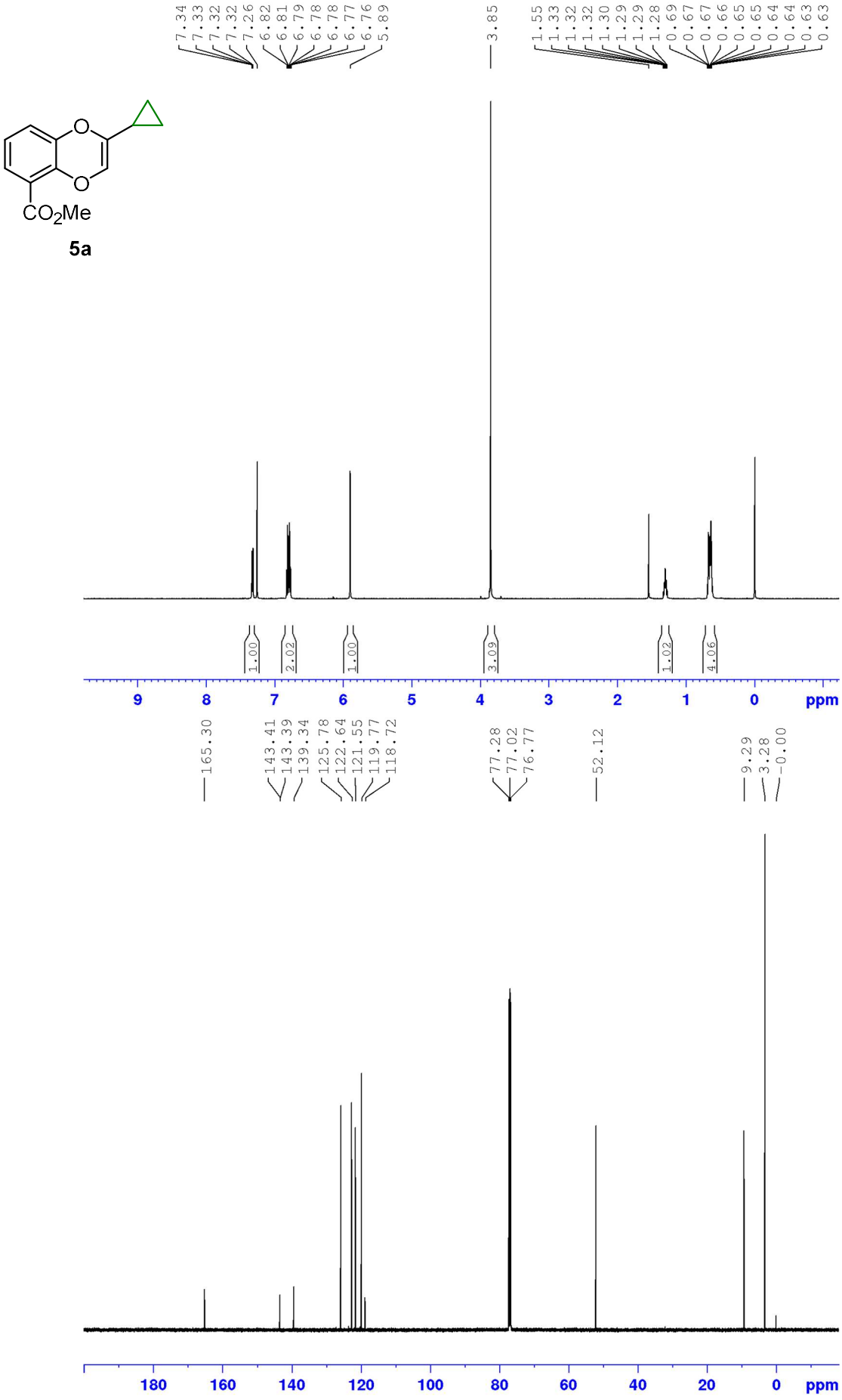

O
Br
O
CO2Me

SI-2


1.00
2.02
1.00
2.99
9
8
7
6
5
4
3
2
1
0
ppm

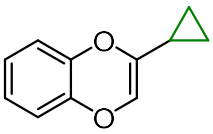

164.73
143.16
142.21
127.16
124.78
123.55
120.23
119.37
118.46
77.28
77.03
76.77
52.31


180
160
140
120
100
80
60
40
20
0
ppm

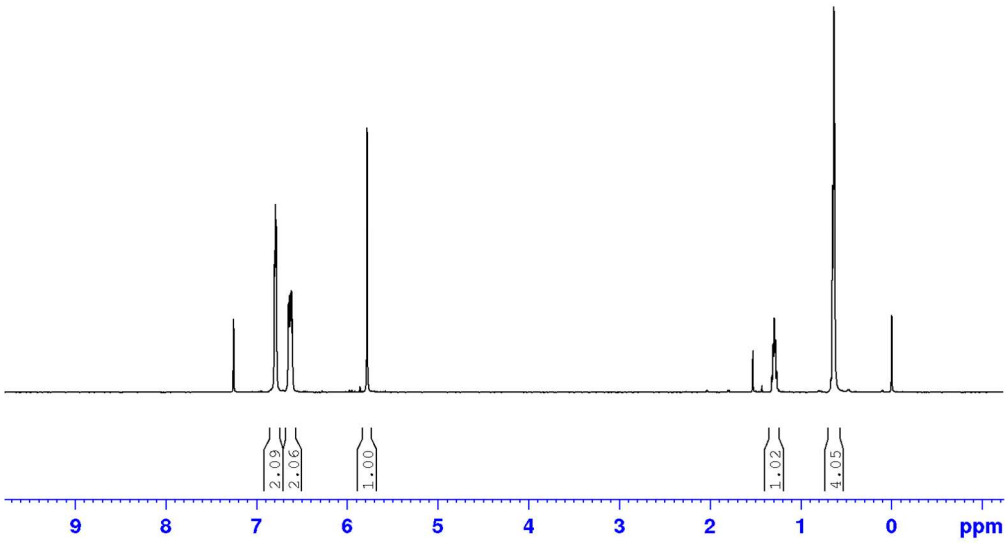

7.34
7.33
7.32
7.32
7.26
6.82
6.81
6.79
6.78
6.78
6.77
6.76
5.89
3.85
1.55
1.33
1.32
1.32
1.30
1.29
1.29
1.28
0.69
0.67
0.67
0.66
0.65
0.65
0.64
0.64
0.63
0.63
O
O
CO2Me
1.00
2.02
1.00
3.09
1.02
4.06
9
8
7
6
5
4
3
2
1
0
ppm
165.30
143.41
143.39
139.34
125.78
122.64
121.55
119.77
118.72
77.28
77.02
76.77
52.12
9.29
3.28
-0.00
180
160
140
120
100
80
60
40
20
0
ppm

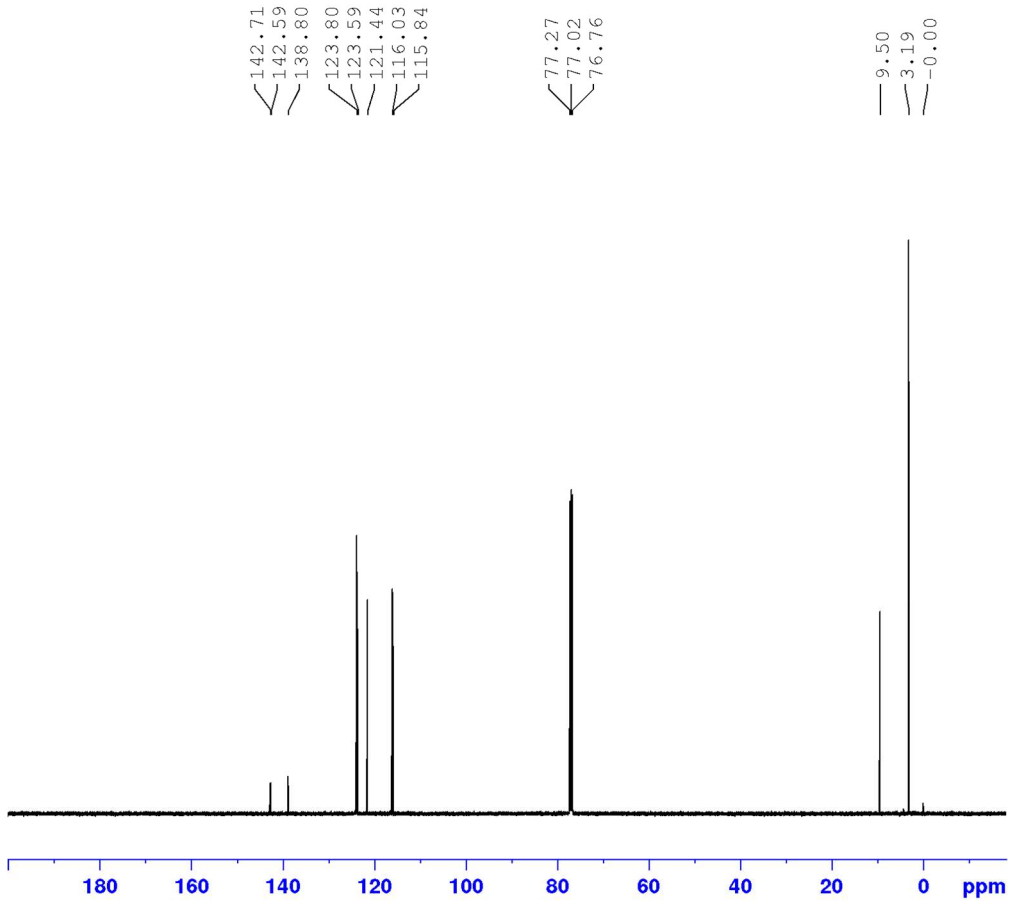
5a

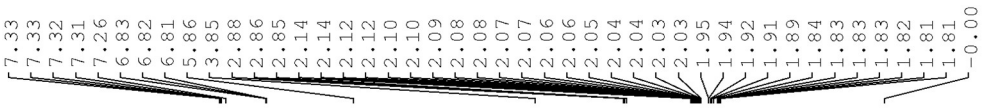

7.26
6.80
6.79
6.78
6.64
6.64
6.63
6.62
6.61
6.60
5.78
1.32
1.31
1.29
1.28
1.27
0.65
0.64
0.00

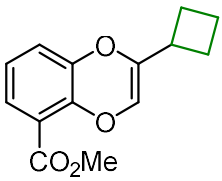


5b

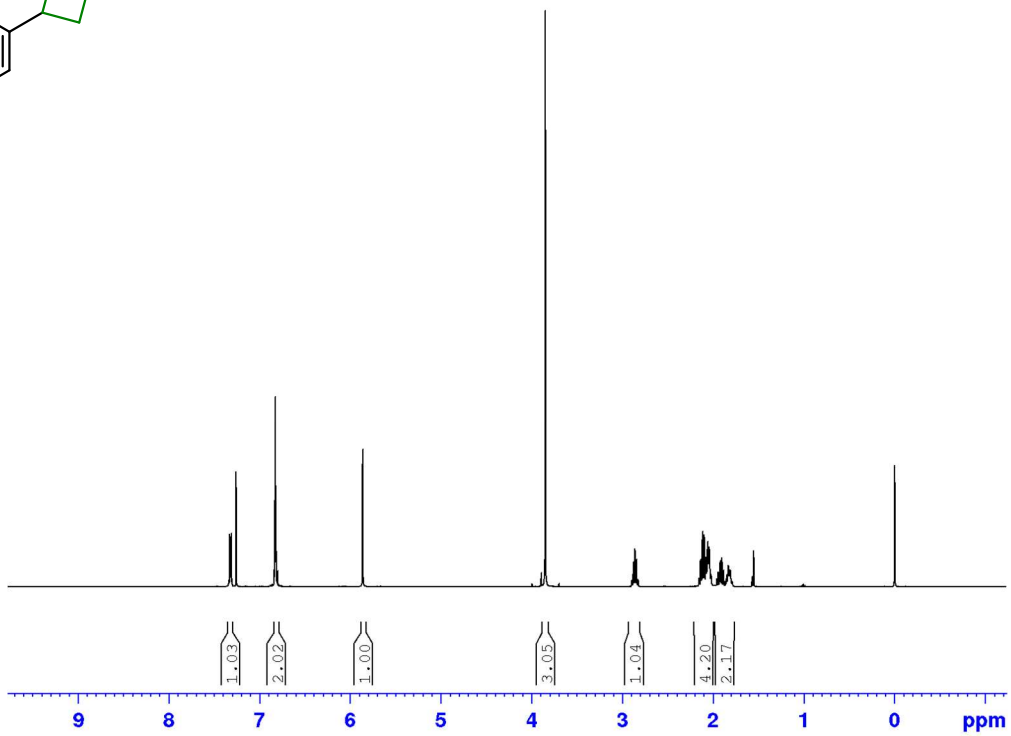

2.09
2.06
1.00
1.02
4.05
9
8
7
6
5
4
3
2
1
0
ppm

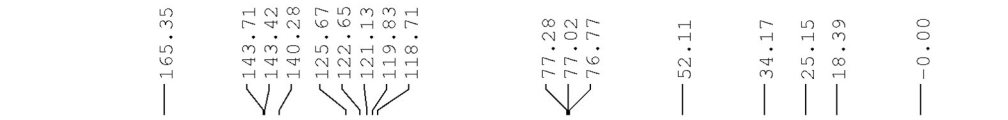

142.71
142.59
138.80
123.80
123.59
121.44
116.03
115.84
77.27
77.02
76.76
9.50
3.19
0.00
180
160
140
120
100
80
60
40
20
0
ppm

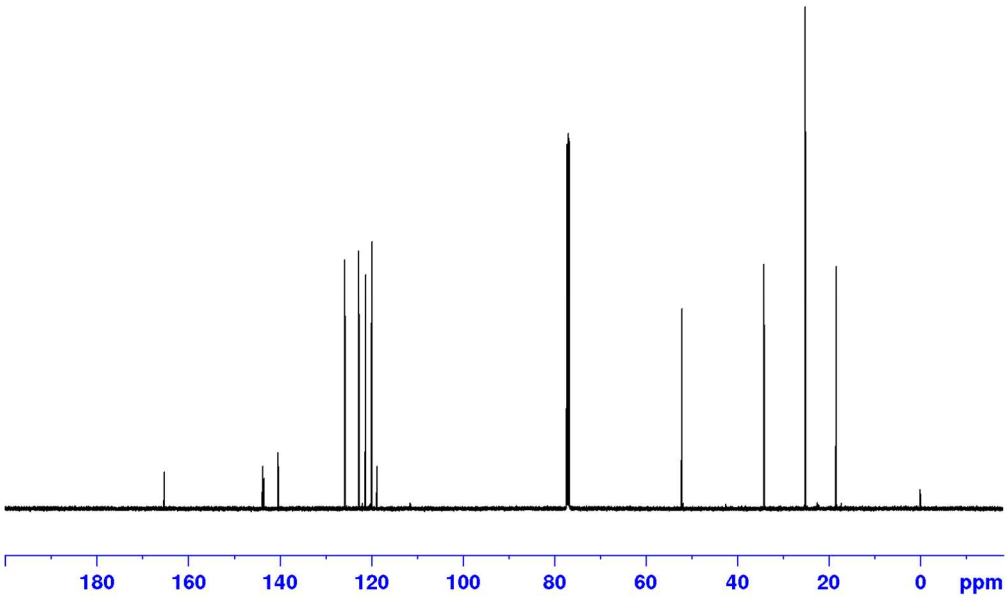

7.33
7.33
7.32
7.31
7.26
6.83
6.82
6.81
5.86
3.85
2.88
2.86
2.85
2.14
2.14
2.12
2.12
2.10
2.10
2.09
2.08
2.08
2.07
2.07
2.06
2.06
2.05
2.04
2.04
2.03
2.03
1.95
1.94
1.92
1.91
1.89
1.84
1.83
1.83
1.83
1.82
1.81
1.81
0.00

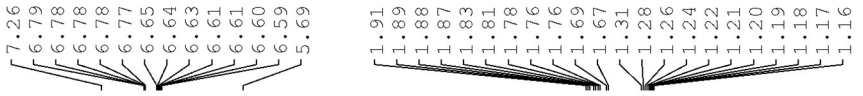

O
O
CO2Me

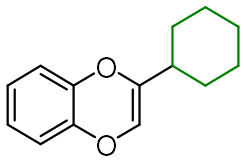
5c


1.03
2.02
1.00
3.05
1.04
4.20
2.17
9
8
7
6
5
4
3
2
1
0
ppm

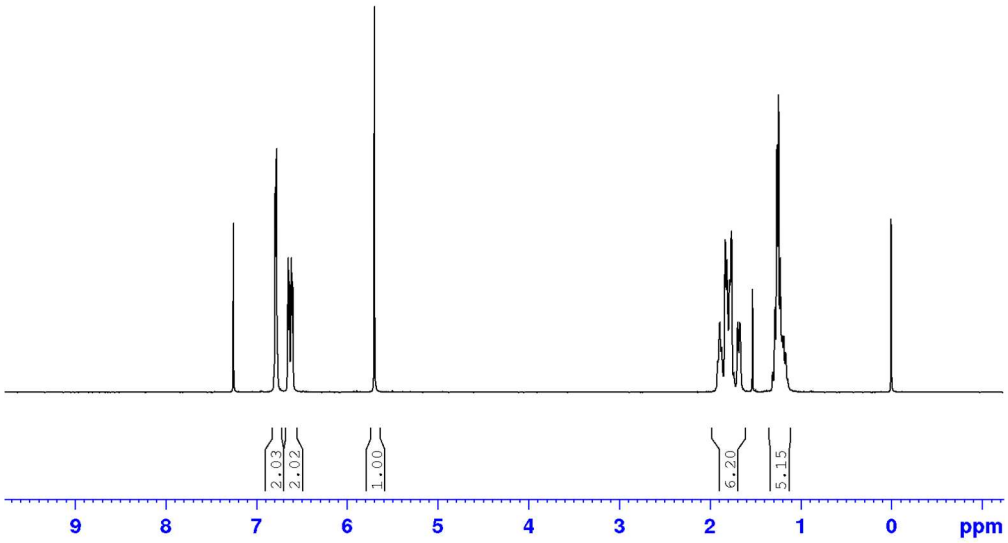

165.35
143.71
143.42
140.28
125.67
122.65
121.13
119.83
118.71
77.28
77.02
76.77
52.11
34.17
25.15
18.39
0.00

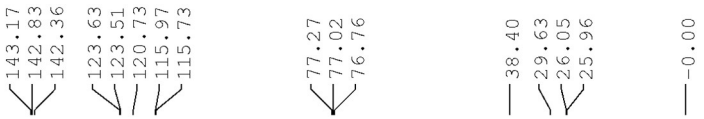

180
160
140
120
100
80
60
40
20
0
ppm

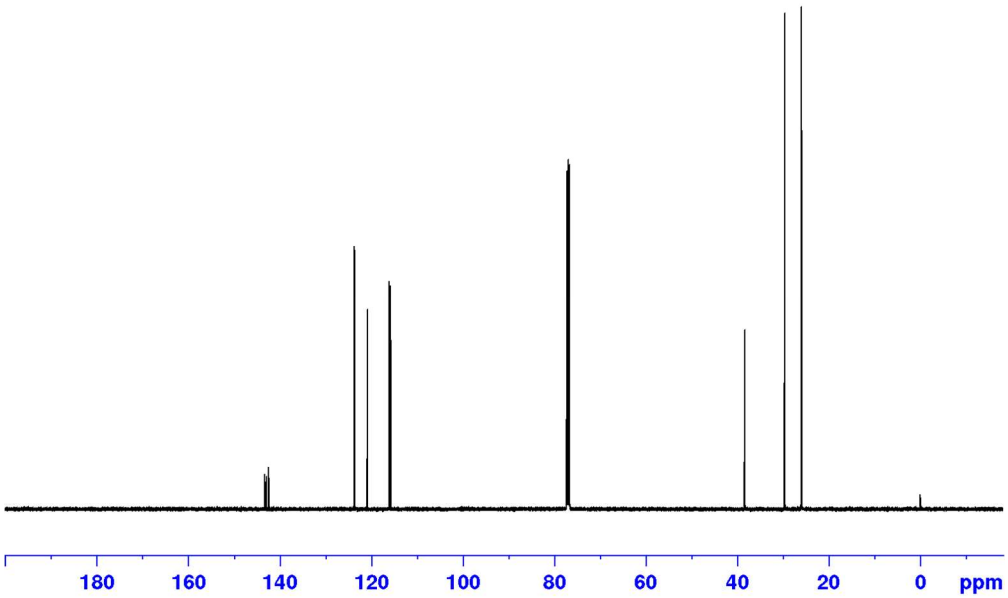

7.26
6.79
6.78
6.78
6.78
6.77
6.65
6.64
6.63
6.61
6.61
6.60
6.59
5.69
1.91
1.89
1.88
1.87
1.83
1.81
1.78
1.76
1.76
1.69
1.67
1.31
1.28
1.26
1.24
1.22
1.21
1.20
1.19
1.18
1.17
1.16

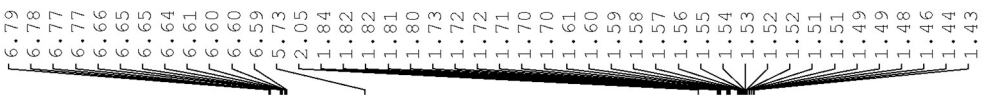


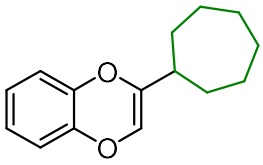
5d


2.03
2.02
1.00
6.20
5.15
9
8
7
6
5
4
3
2
1
0
ppm

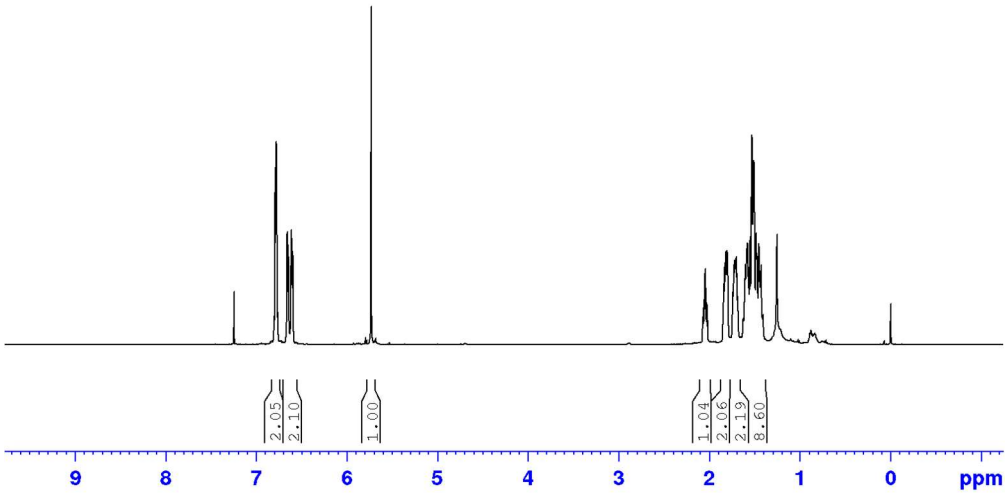

143.17
142.83
142.36
123.63
123.51
120.73
115.97
115.73
77.27
77.02
76.76
38.40
29.63
26.05
25.96
0.00

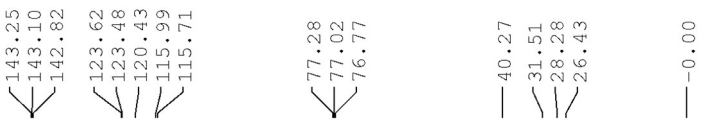

180
160
140
120
100
80
60
40
20
0
ppm

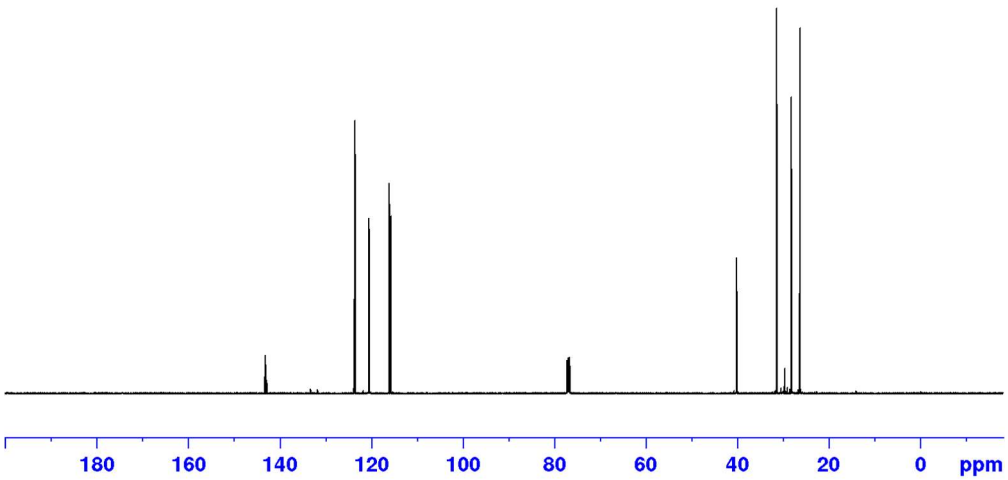

6.79
6.78
6.77
6.77
6.66
6.65
6.65
6.64
6.61
6.60
6.60
6.59
5.73
2.05
1.84
1.82
1.82
1.81
1.80
1.73
1.72
1.72
1.71
1.70
1.70
1.61
1.60
1.59
1.58
1.57
1.56
1.55
1.54
1.53
1.52
1.52
1.51
1.51
1.49
1.49
1.48
1.46
1.44
1.43

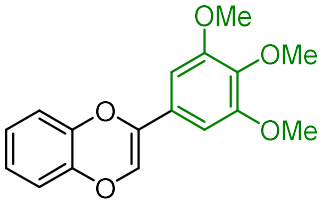


5e

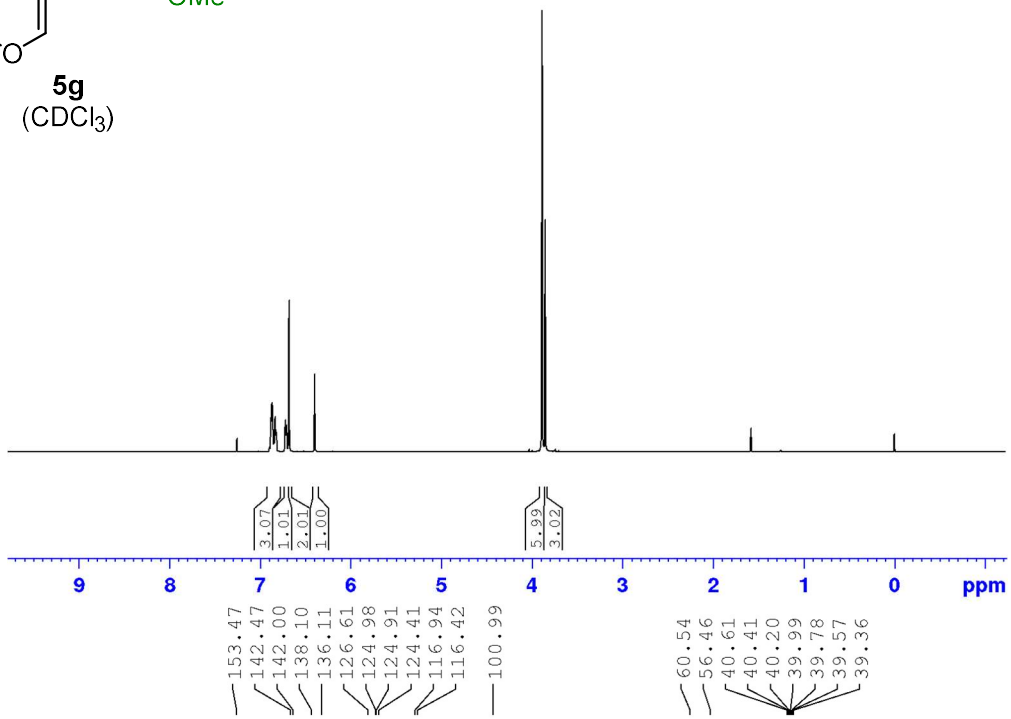

2.05
2.10
1.00
1.04
2.06
2.19
8.60
9
8
7
6
5
4
3
2
1
0
ppm

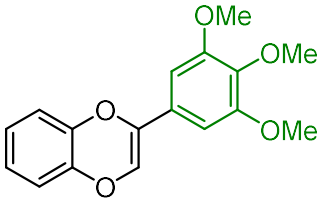

143.25
143.10
142.82
123.62
123.48
120.43
115.99
115.71
77.28
77.02
76.77
40.27
31.51
28.28
26.43
-0.00


180
160
140
120
100
80
60
40
20
0
ppm

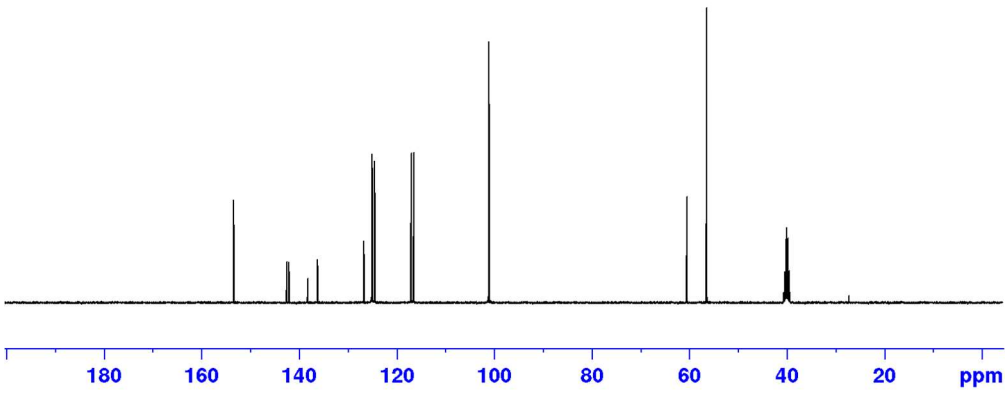


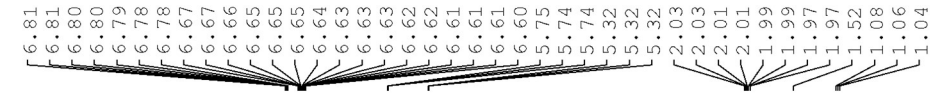
5g
($CDCl_3$)

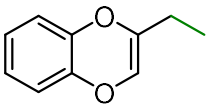




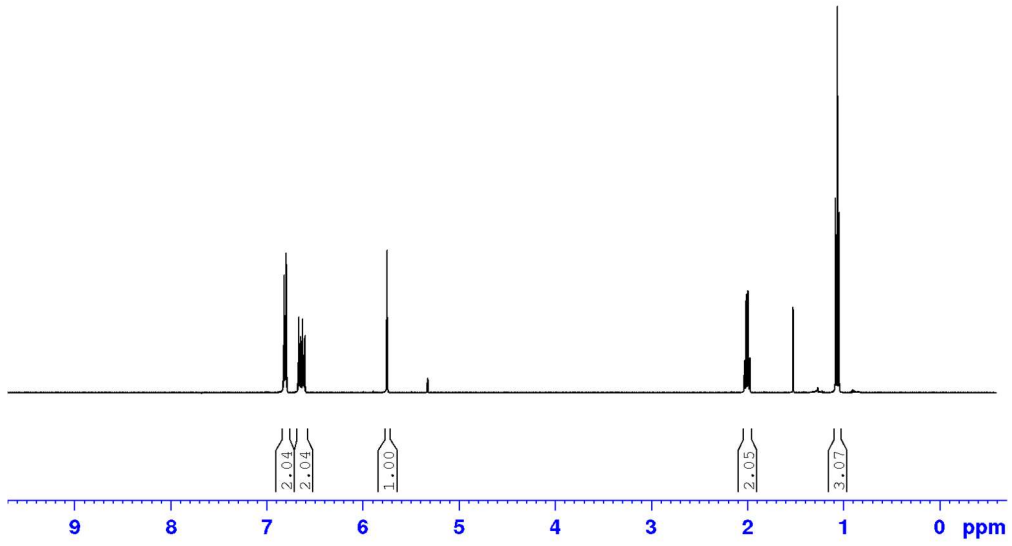
5g
(d_6-DMSO)



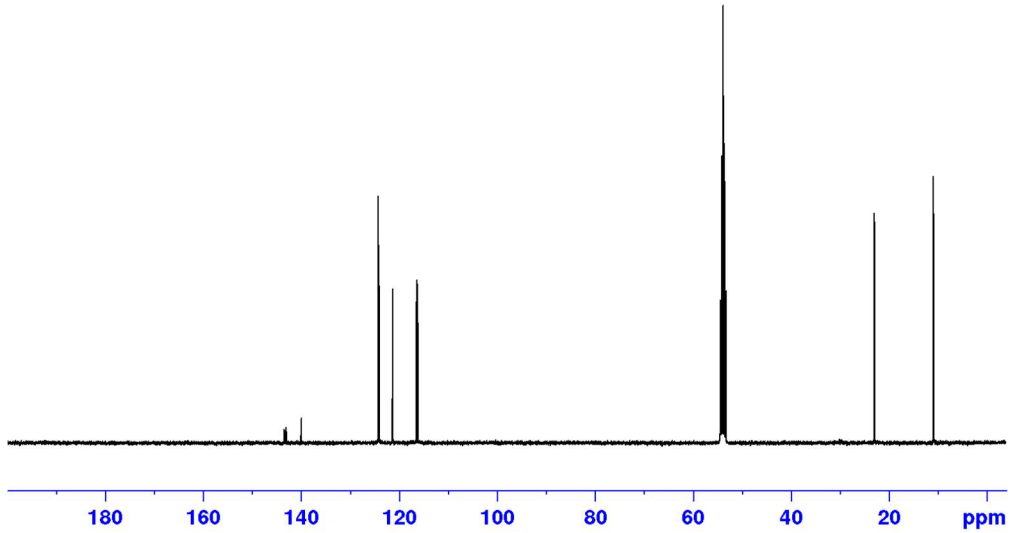

6.81
6.81
6.80
6.80
6.79
6.78
6.78
6.67
6.67
6.66
6.65
6.65
6.65
6.64
6.63
6.63
6.63
6.62
6.62
6.61
6.61
6.61
6.60
5.75
5.74
5.74
5.32
5.32
5.32
2.03
2.03
2.01
2.01
1.99
1.99
1.97
1.97
1.52
1.08
1.06
1.04

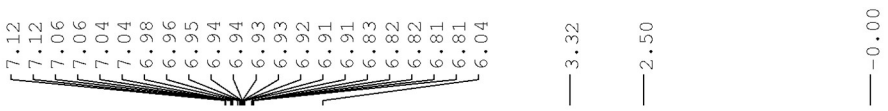


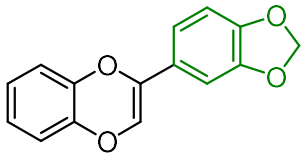
5h


2.04
2.04
1.00
2.05
3.07
9
8
7
6
5
4
3
2
1
0
ppm

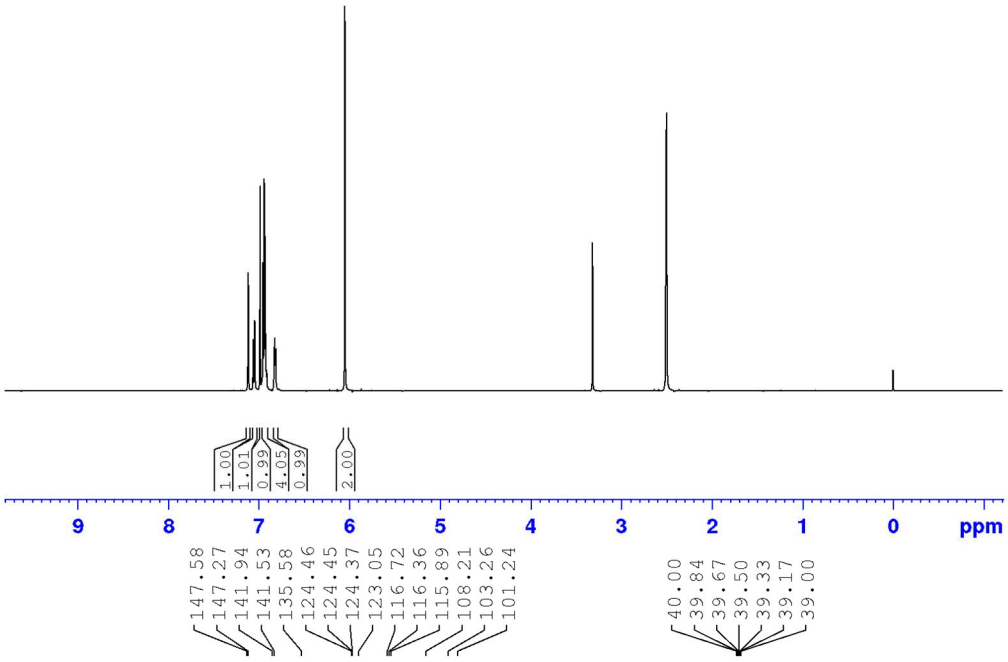

143.32
142.98
139.89
124.17
124.00
121.23
116.34
116.12
54.38
54.11
53.84
53.57
53.30
22.95
10.89


180
160
140
120
100
80
60
40
20
ppm

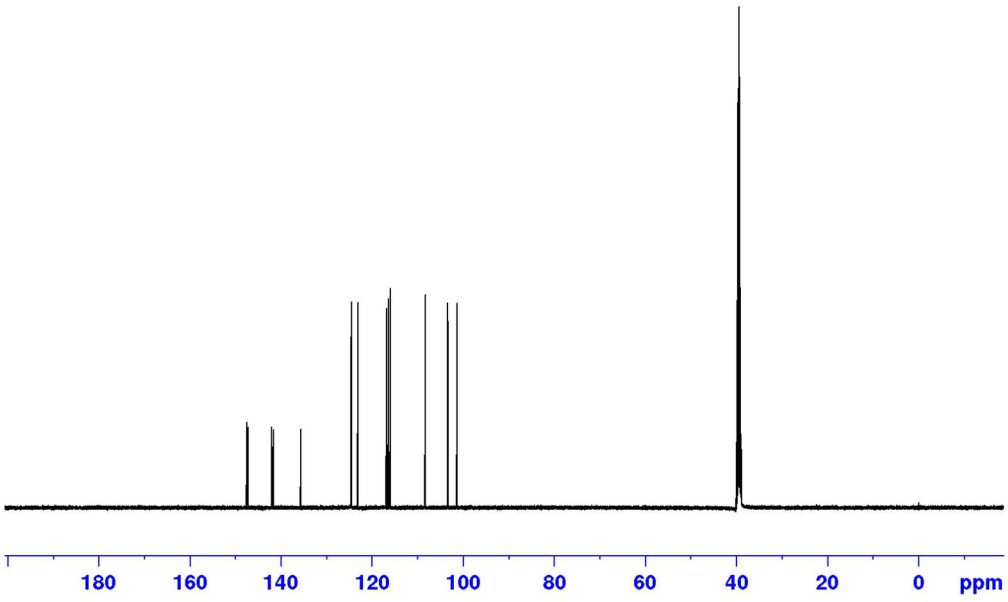

7.12
7.12
7.06
7.06
7.04
7.04
6.98
6.96
6.95
6.94
6.94
6.93
6.93
6.92
6.91
6.91
6.83
6.82
6.82
6.81
6.81
6.04
3.32
2.50
0.00

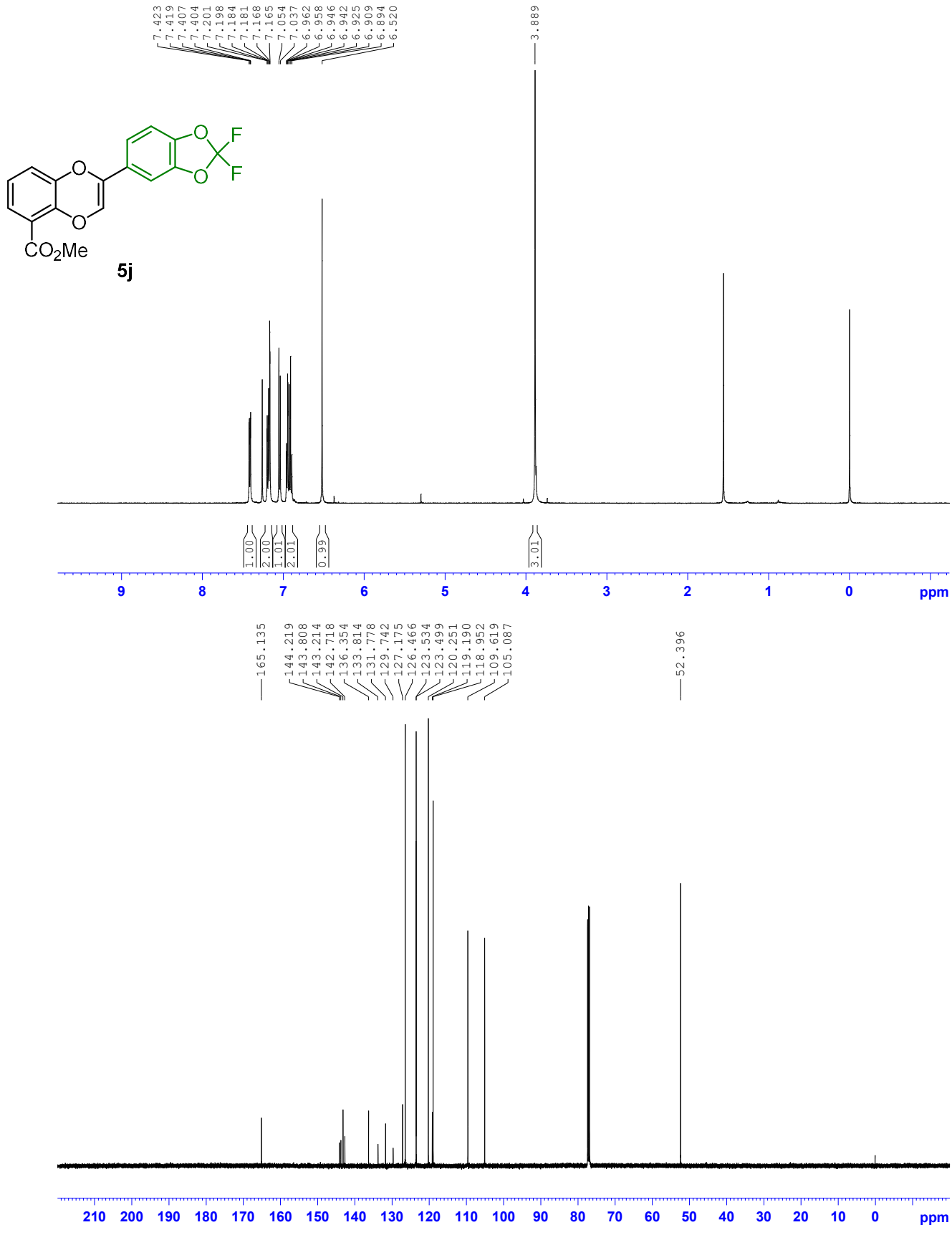


5i

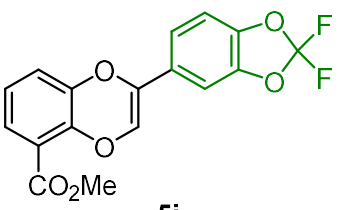

1.00
1.01
0.99
4.05
0.99
2.00
9
8
7
6
5
4
3
2
1
0
ppm

147.58
147.27
141.94
141.53
135.58
124.46
124.45
124.37
123.05
116.72
116.36
115.89
108.21
103.26
101.24
40.00
39.84
39.67
39.50
39.33
39.17
39.00

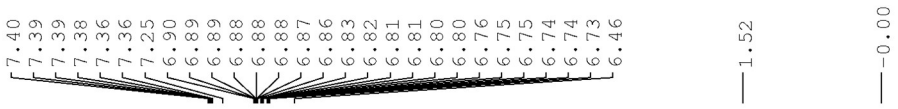

180
160
140
120
100
80
60
40
20
0
ppm

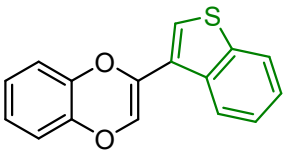

7.423
7.419
7.407
7.404
7.201
7.198
7.184
7.181
7.168
7.165
7.054
7.037
6.962
6.958
6.946
6.942
6.925
6.909
6.894
6.520
3.889
O
F
F
O
O
O
CO2Me
1.00
2.00
1.01
2.01
0.99
3.01
9
8
7
6
5
4
3
2
1
0
ppm
165.135
144.219
143.808
143.214
142.718
136.354
133.814
131.778
129.742
127.175
126.466
123.534
123.499
120.251
119.190
118.952
109.619
105.087
52.396
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

5j

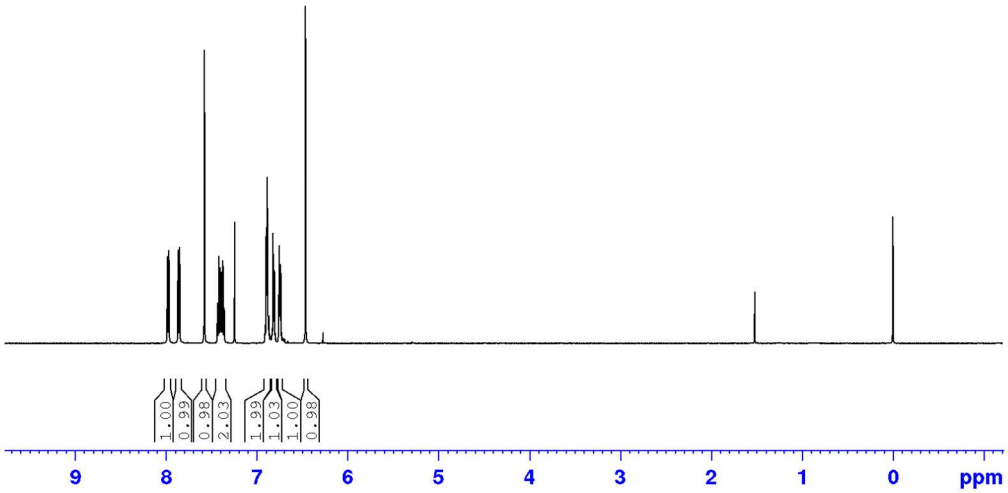


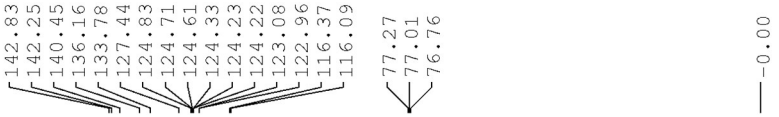
5j

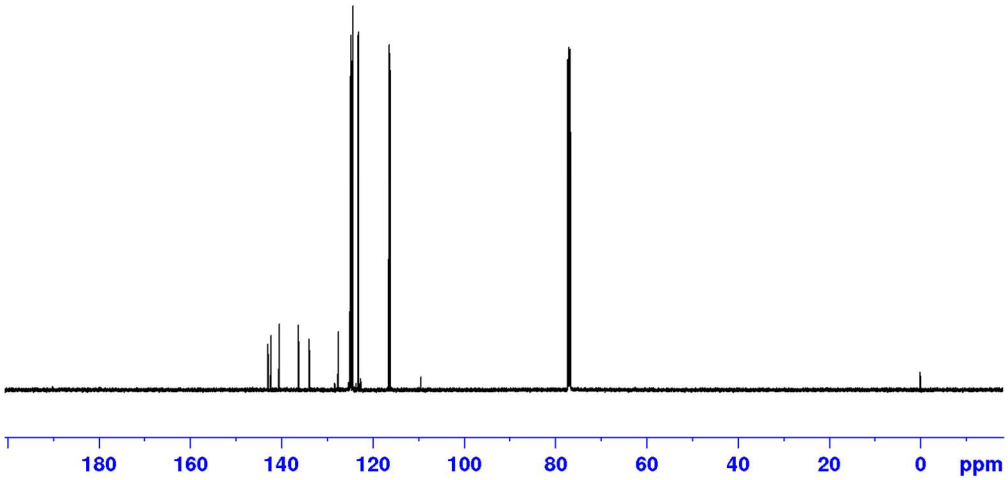

7.40
7.39
7.39
7.38
7.36
7.36
7.25
6.90
6.89
6.89
6.88
6.88
6.88
6.87
6.86
6.83
6.82
6.81
6.81
6.80
6.80
6.76
6.75
6.75
6.74
6.74
6.73
6.46
1.52
0.00

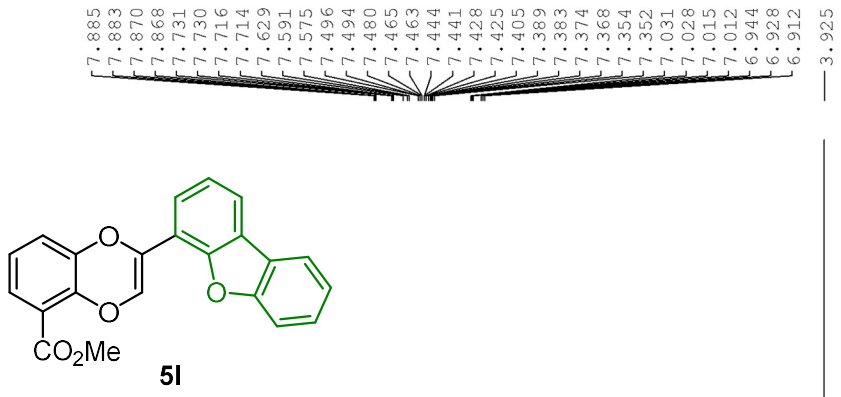


5k


1.00
0.99
0.98
2.03
1.99
1.03
1.00
0.98
9
8
7
6
5
4
3
2
1
0
ppm


142.83
142.25
140.45
136.16
133.78
127.44
124.83
124.71
124.61
124.33
124.23
124.22
123.08
122.96
116.37
116.09
77.27
77.01
76.76
0.00

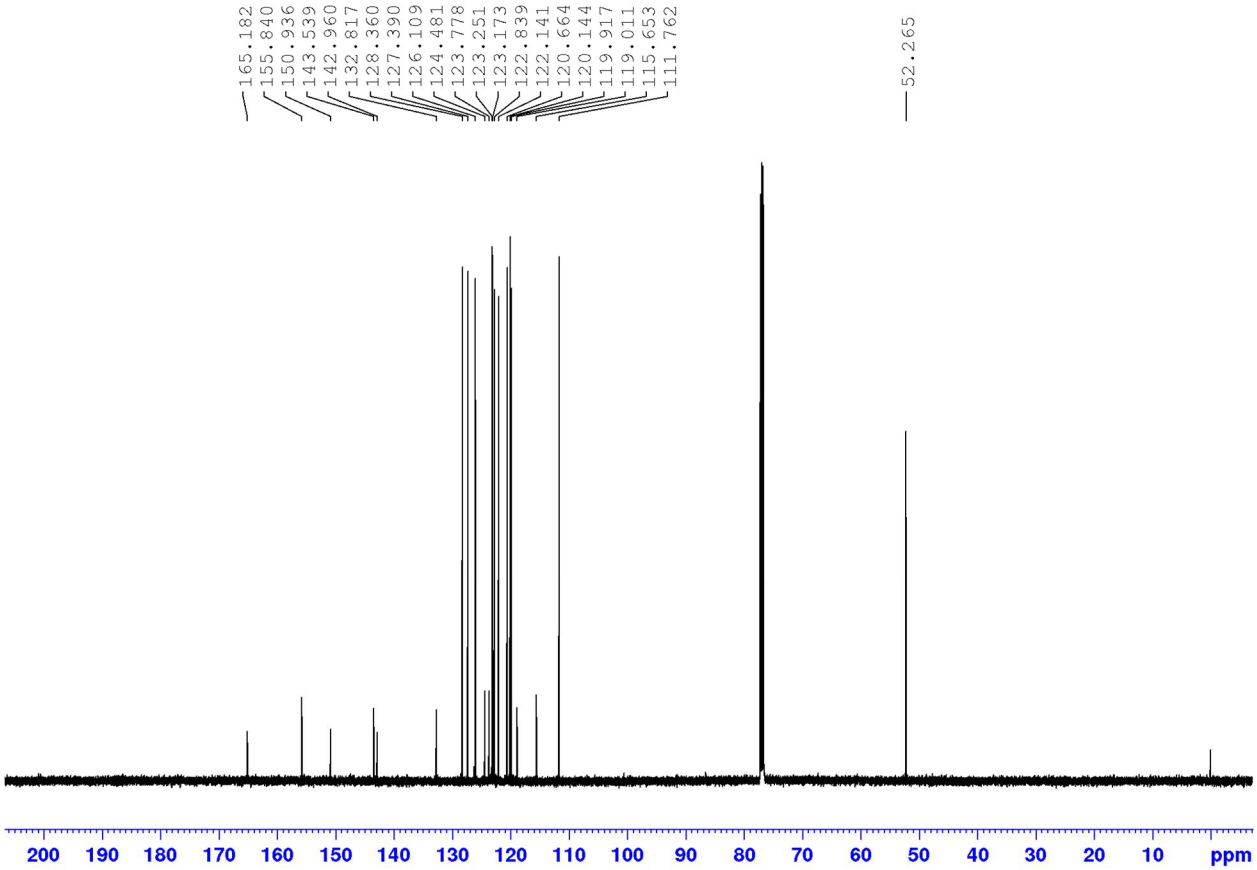

180
160
140
120
100
80
60
40
20
0
ppm

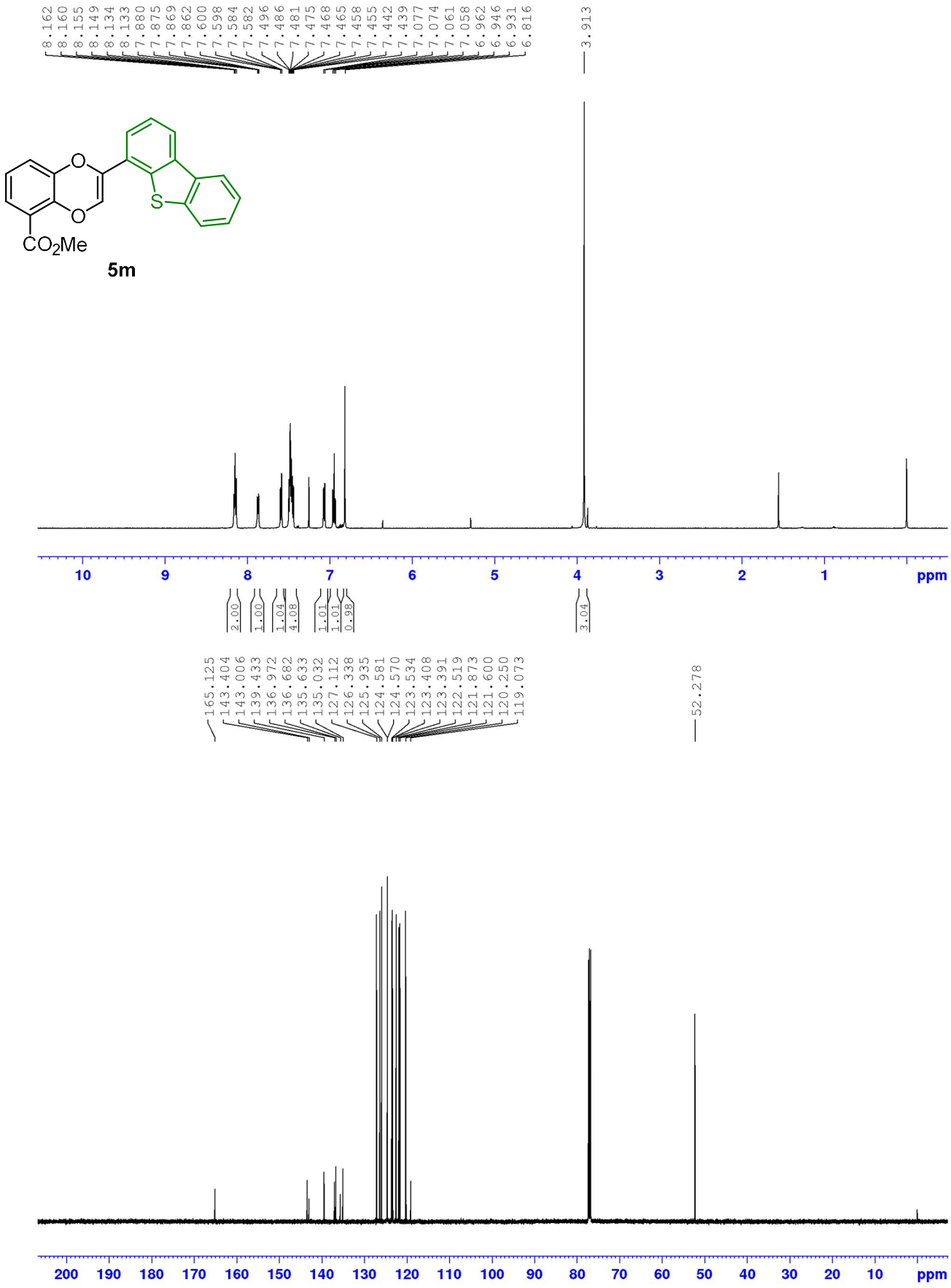

7.885
7.883
7.870
7.868
7.731
7.730
7.716
7.714
7.629
7.591
7.575
7.496
7.494
7.480
7.465
7.463
7.444
7.441
7.428
7.425
7.405
7.389
7.383
7.374
7.368
7.354
7.352
7.031
7.028
7.015
7.012
6.944
6.928
6.912
3.925

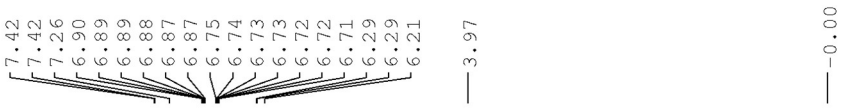
O
O
O
CO2Me

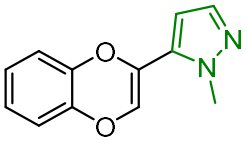
5l

10
9
8
7
6
5
4
3
2
1
ppm
1.00
1.01
1.01
0.97
1.05
1.03
1.04
2.11
1.01
1.02
3.01

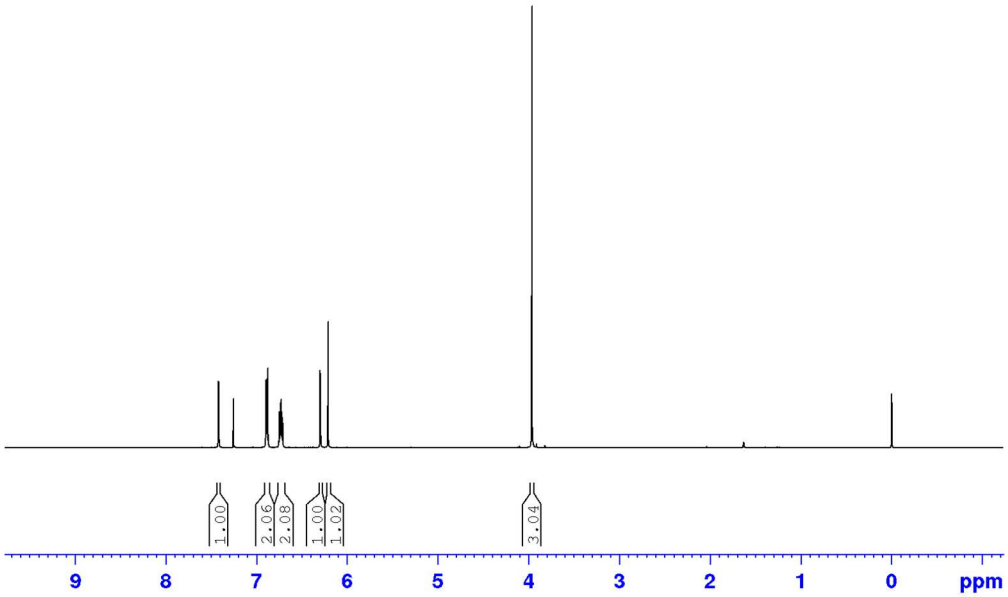

165.182
155.840
150.936
143.539
142.960
132.817
128.360
127.390
126.109
124.481
123.778
123.251
123.173
122.839
122.141
120.664
120.144
119.917
119.011
115.653
111.762
52.265
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm

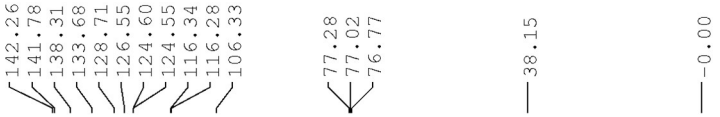

8.162
8.160
8.155
8.149
8.134
8.133
7.880
7.875
7.869
7.862
7.600
7.598
7.584
7.582
7.496
7.486
7.481
7.475
7.468
7.465
7.458
7.455
7.442
7.439
7.077
7.074
7.061
7.058
6.962
6.946
6.931
6.816
3.913
O
O
S
CO2Me
5m
10
9
8
7
6
5
4
3
2
1
ppm
2.00
1.00
1.04
4.08
1.01
1.01
0.98
3.04
165.125
143.404
143.006
139.433
136.972
136.682
135.633
135.032
127.112
126.338
125.935
124.581
124.570
123.534
123.408
123.391
122.519
121.873
121.600
120.250
119.073
52.278
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm

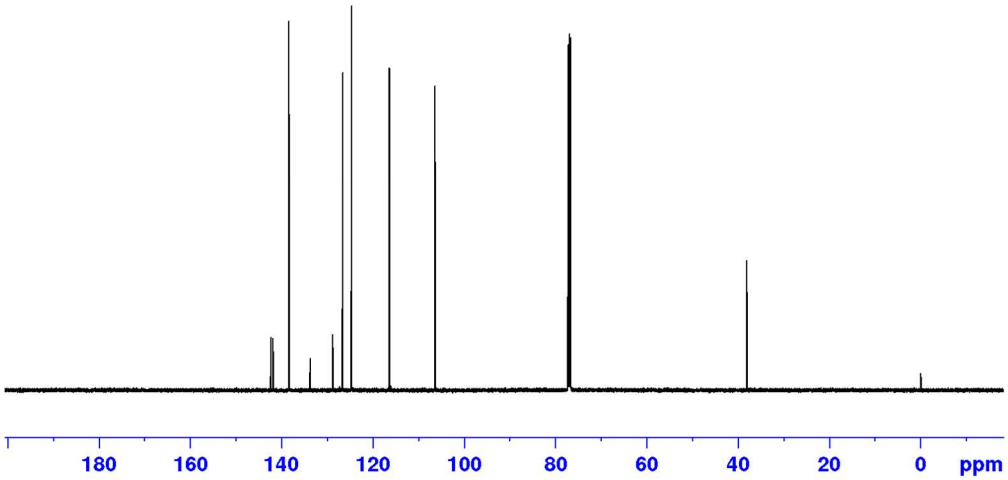

7.42
7.42
7.26
6.90
6.89
6.89
6.88
6.87
6.87
6.75
6.74
6.73
6.73
6.72
6.72
6.71
6.29
6.29
6.21
3.97
0.00

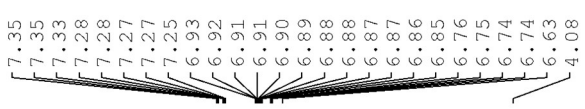


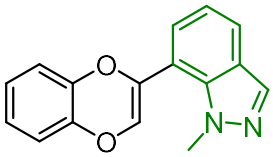
5n


1.00
2.06
2.08
1.00
1.02
3.04
9
8
7
6
5
4
3
2
1
0
ppm

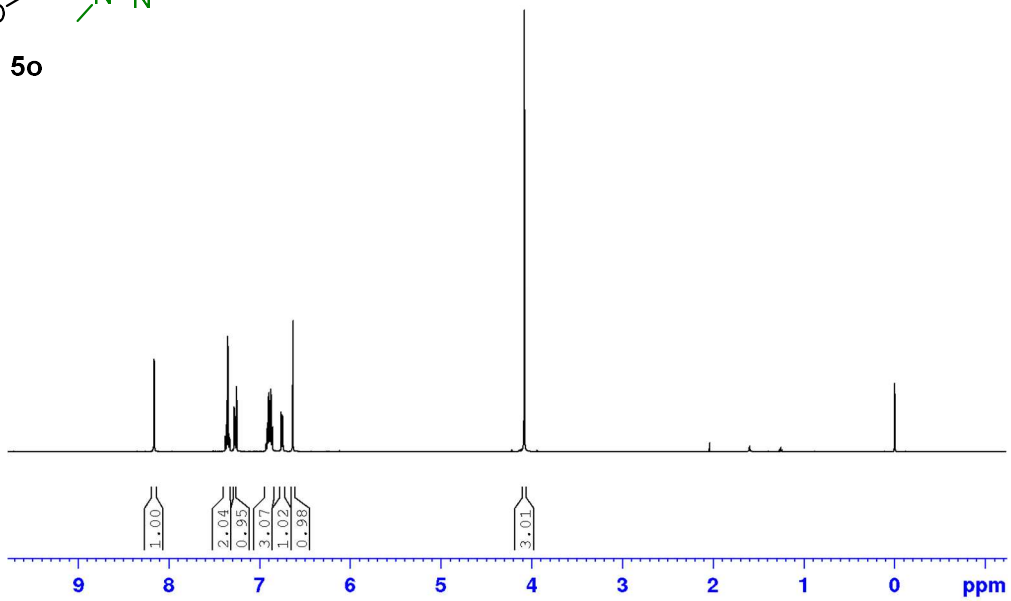

142.26
141.78
138.31
133.68
128.71
126.55
124.60
124.55
116.34
116.28
106.33
77.28
77.02
76.77
38.15
0.00

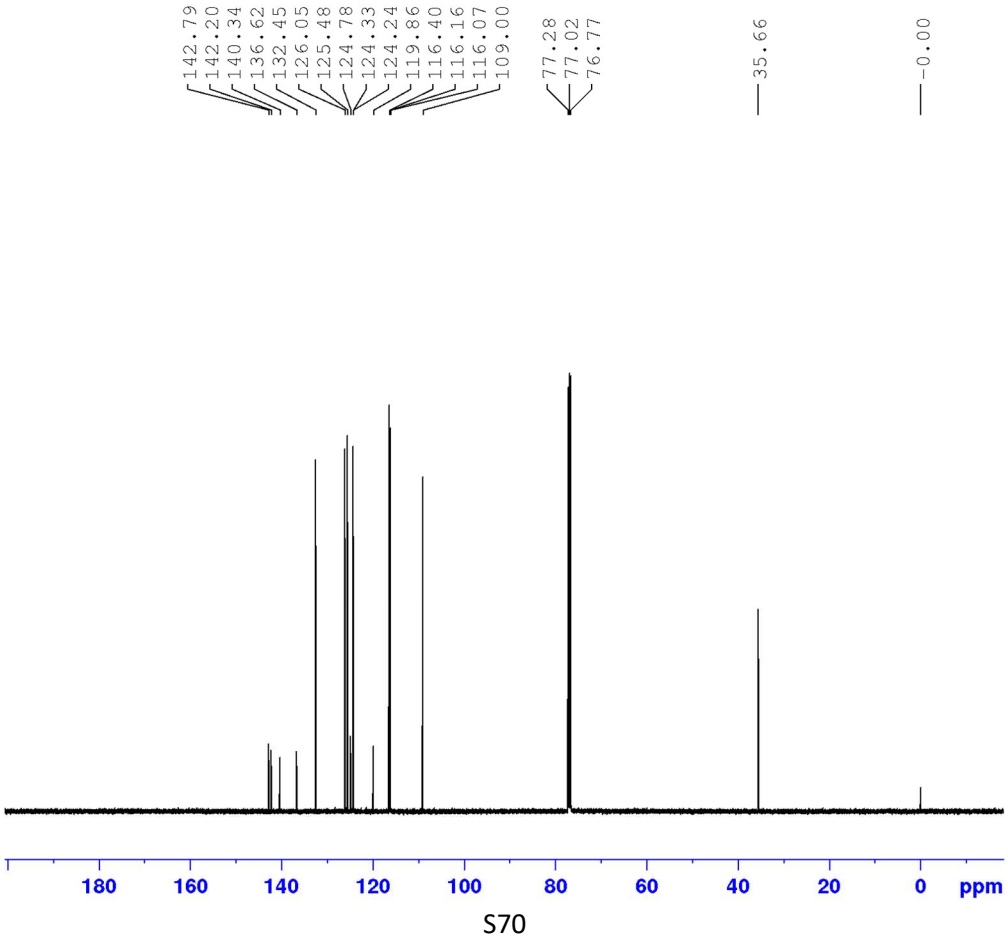

180
160
140
120
100
80
60
40
20
0
ppm

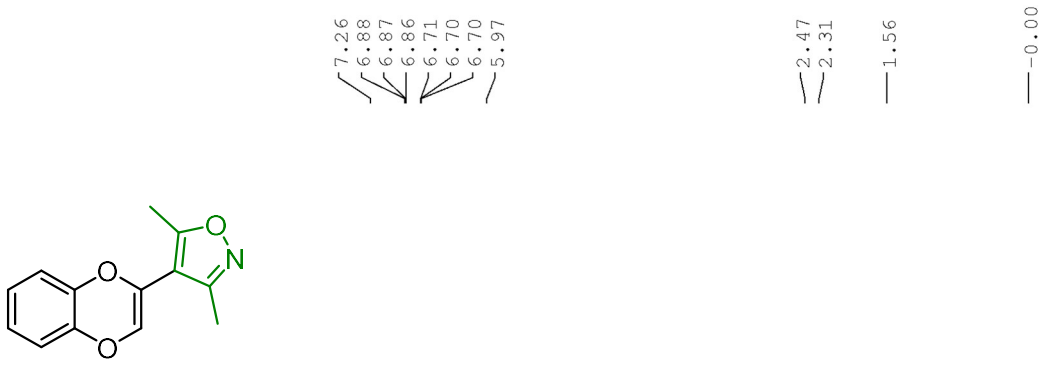

7.35
7.35
7.33
7.28
7.28
7.27
7.27
7.25
6.93
6.92
6.91
6.91
6.90
6.89
6.88
6.88
6.87
6.87
6.86
6.85
6.76
6.75
6.74
6.74
6.63
4.08
0.00



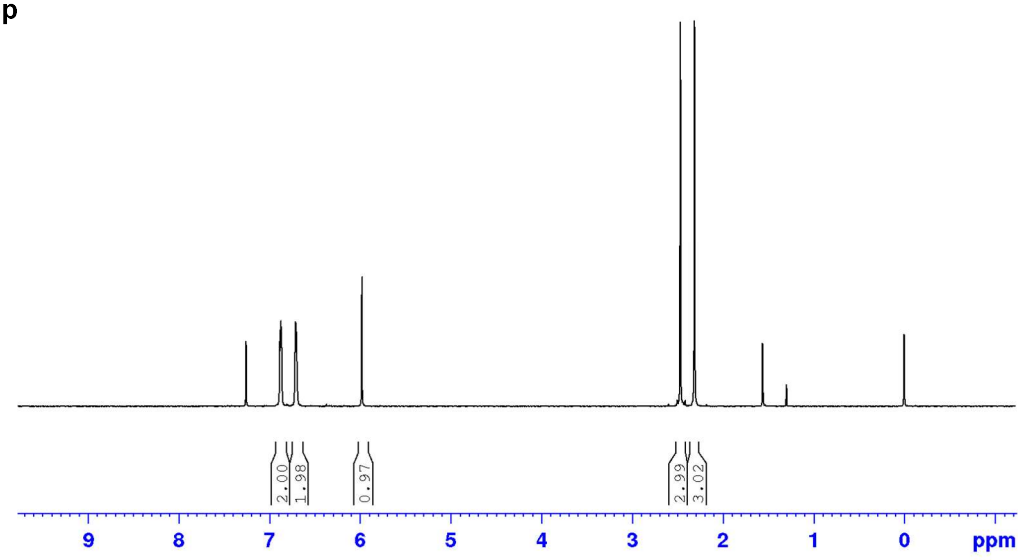
5o

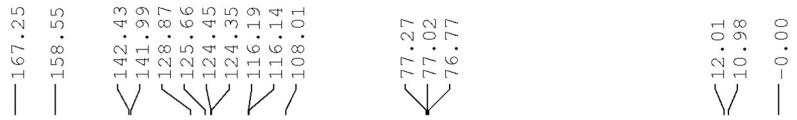

1.00
2.04
0.95
3.07
1.02
0.98
3.01
9
8
7
6
5
4
3
2
1
0
ppm

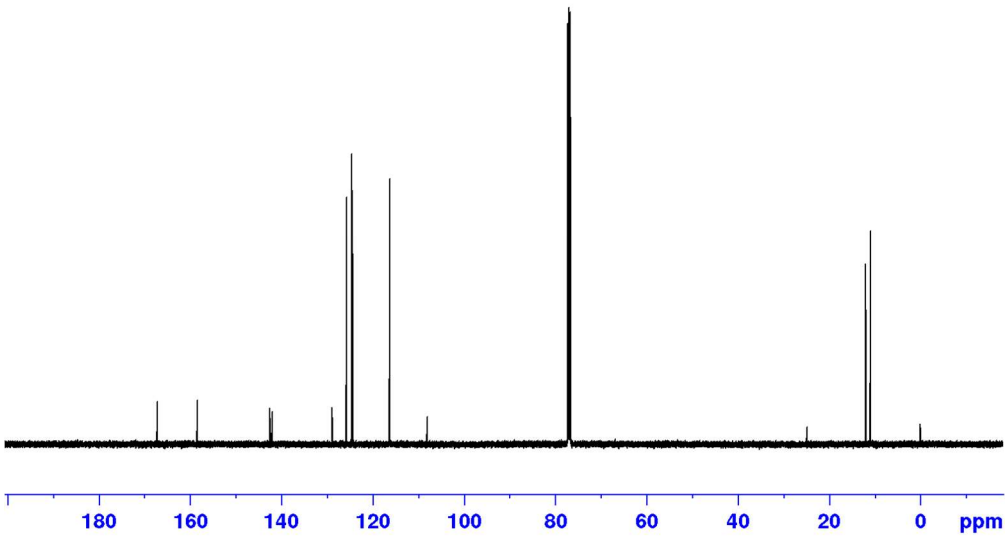

142.79
142.20
140.34
136.62
132.45
126.05
125.48
124.78
124.33
124.24
119.86
116.40
116.16
116.07
109.00
77.28
77.02
76.77
35.66
0.00
180
160
140
120
100
80
60
40
20
0
ppm

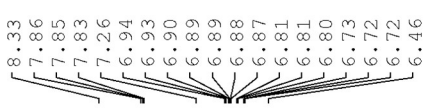

7.26
6.88
6.87
6.86
6.71
6.70
6.70
5.97
2.47
2.31
1.56
0.00

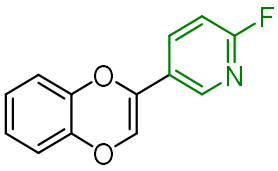
5p


2.00
1.98
0.97
2.99
3.02
9
8
7
6
5
4
3
2
1
0
ppm

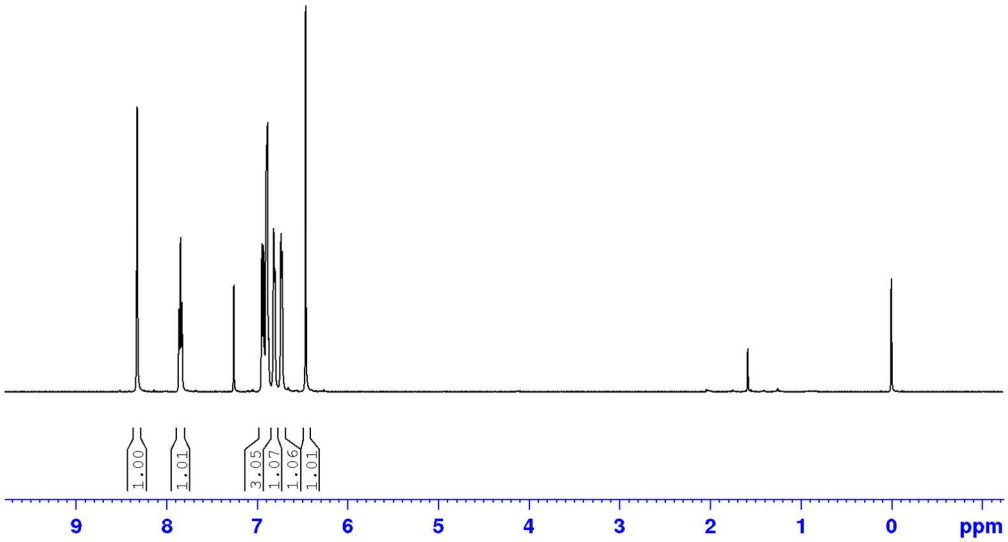

167.25
158.55
142.43
141.99
128.87
125.66
124.45
124.35
116.19
116.14
108.01
77.27
77.02
76.77
12.01
10.98
0.00

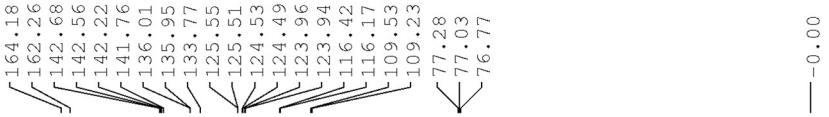

180
160
140
120
100
80
60
40
20
0
ppm

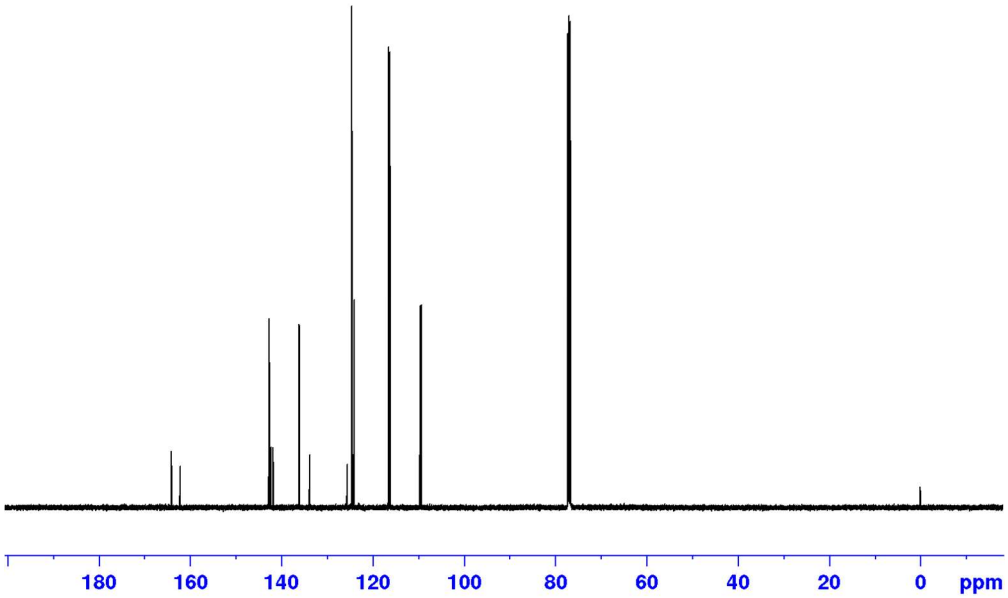

8.33
7.86
7.85
7.83
7.26
6.94
6.93
6.90
6.89
6.89
6.88
6.87
6.81
6.81
6.80
6.73
6.72
6.72
6.46
1.58
0.00

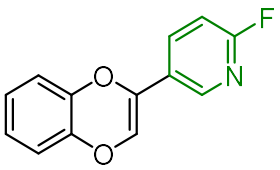

F
N
O
O

5q

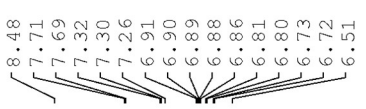

1.00
1.01
3.05
1.07
1.06
1.01
9
8
7
6
5
4
3
2
1
0
ppm

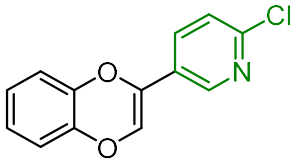

164.18
162.26
142.68
142.56
142.22
141.76
136.01
135.95
133.77
125.55
125.51
124.53
124.49
123.96
123.94
116.42
116.17
109.53
109.23
77.28
77.03
76.77
0.00


180
160
140
120
100
80
60
40
20
0
ppm

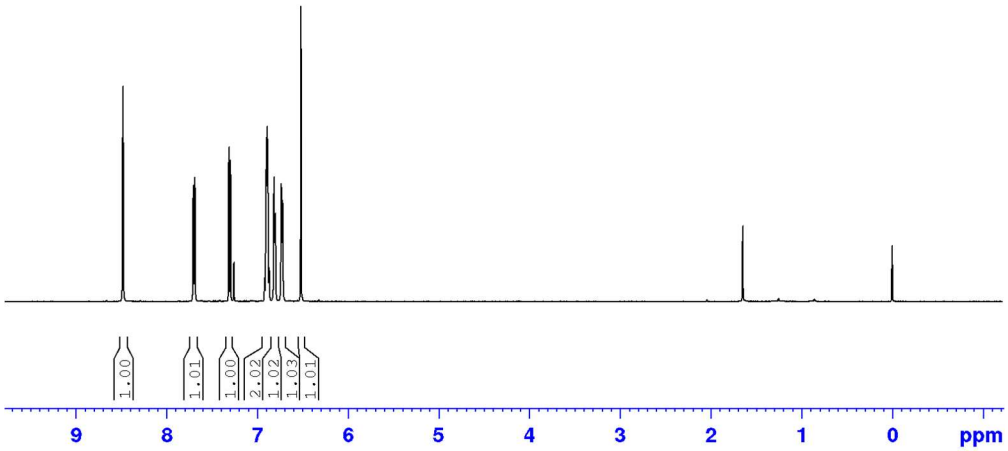


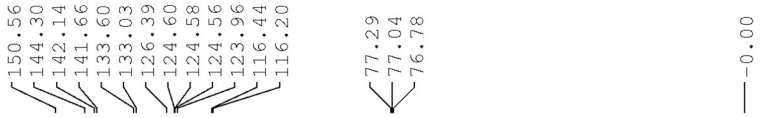
5q

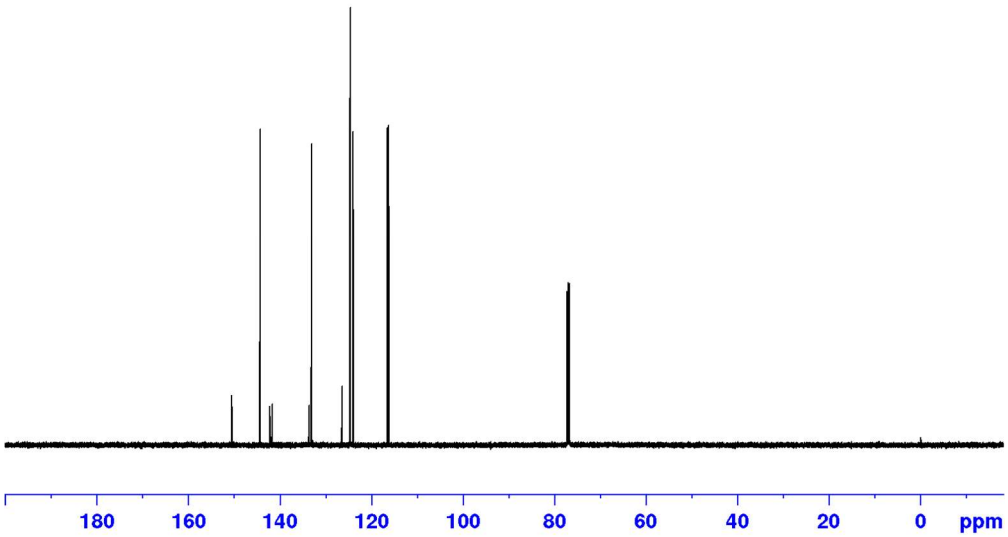

8.48
7.71
7.69
7.32
7.30
7.26
6.91
6.90
6.89
6.88
6.86
6.81
6.80
6.73
6.72
6.51
1.65
0.00

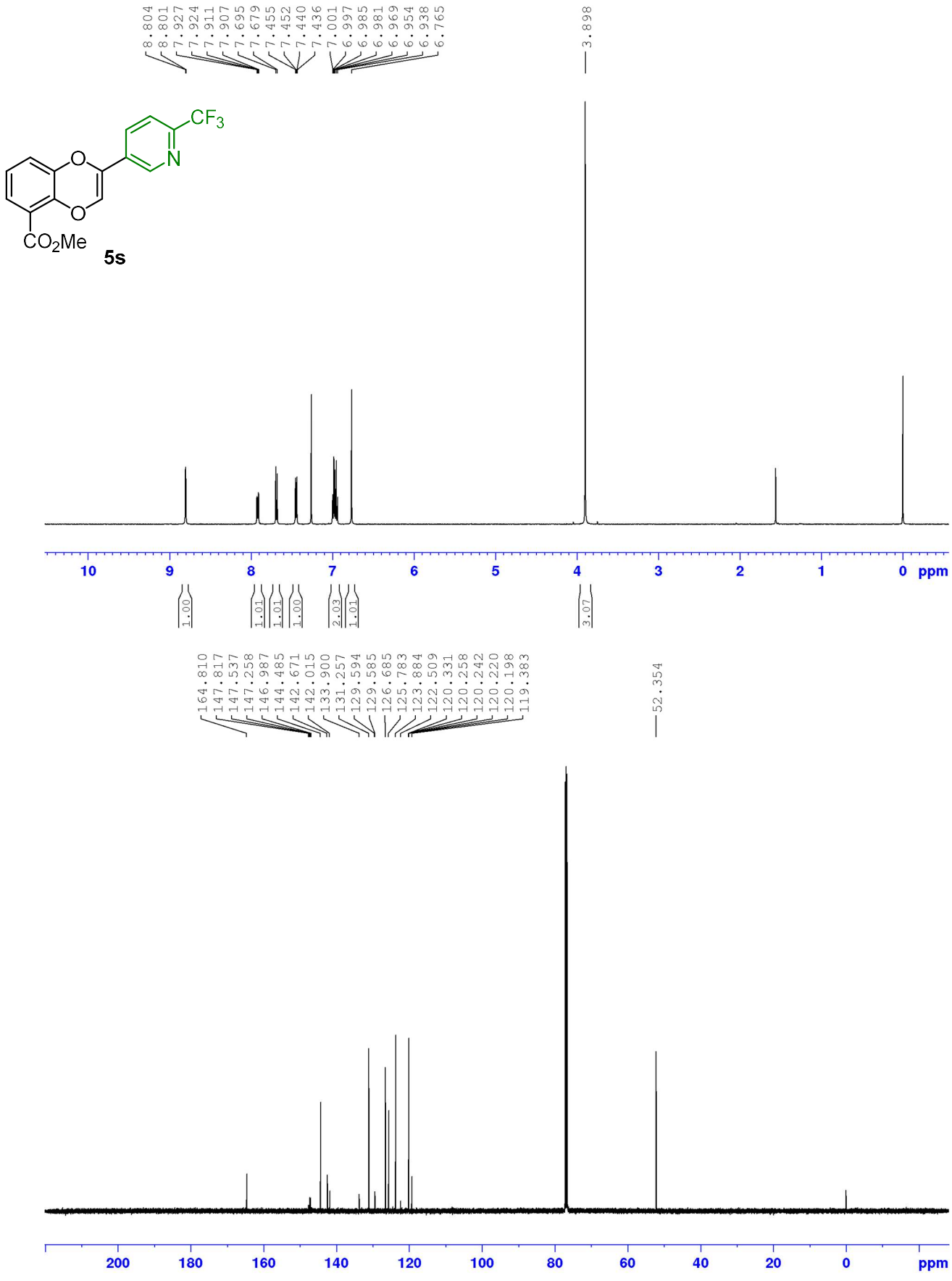

Cl
N
O
O

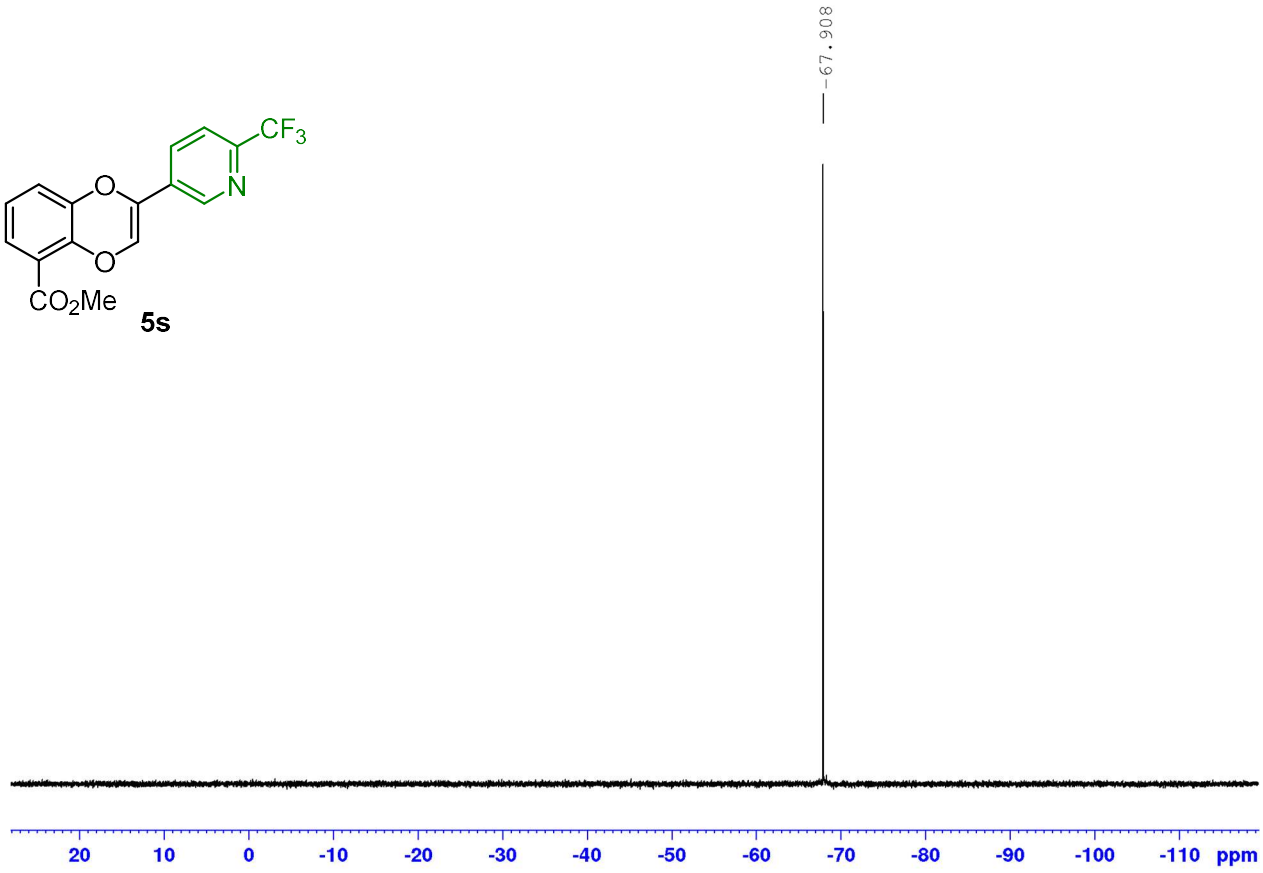
5r


1.00
1.01
1.00
2.02
1.02
1.03
1.01
9
8
7
6
5
4
3
2
1
0
ppm

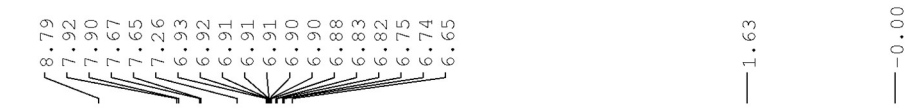

150.56
144.30
142.14
141.66
133.60
133.03
126.39
124.60
124.58
124.56
123.96
116.44
116.20
77.29
77.04
76.78
0.00

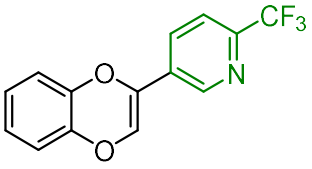

180
160
140
120
100
80
60
40
20
0
ppm


8.804
8.801
7.927
7.924
7.911
7.907
7.695
7.679
7.455
7.452
7.440
7.436
7.001
6.997
6.985
6.981
6.969
6.954
6.938
6.765
3.898
CF3
N
O
O
CO2Me
5s
10
9
8
7
6
5
4
3
2
1
0 ppm
1.00
1.01
1.01
1.00
2.03
1.01
3.07
164.810
147.817
147.537
147.258
146.987
144.485
142.671
142.015
133.900
131.257
129.594
129.585
126.685
125.783
123.884
122.509
120.331
120.258
120.242
120.220
120.198
119.383
52.354
200
180
160
140
120
100
80
60
40
20
0
ppm

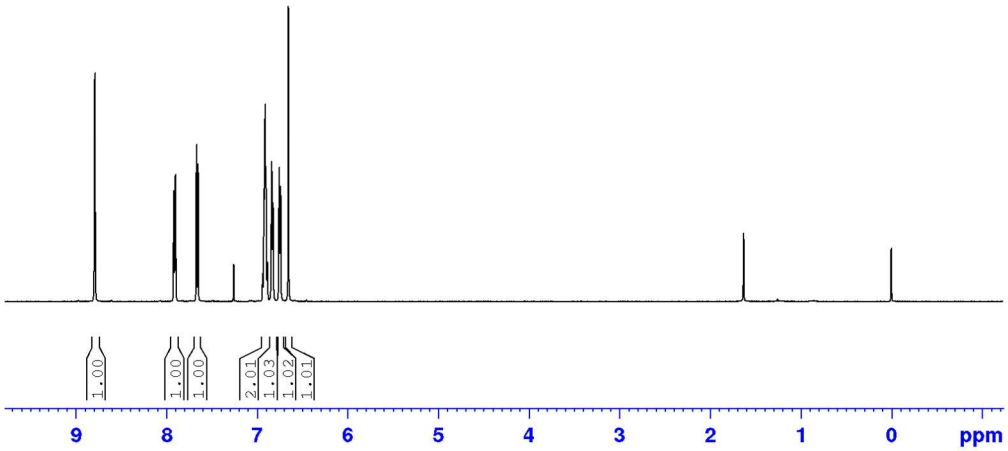


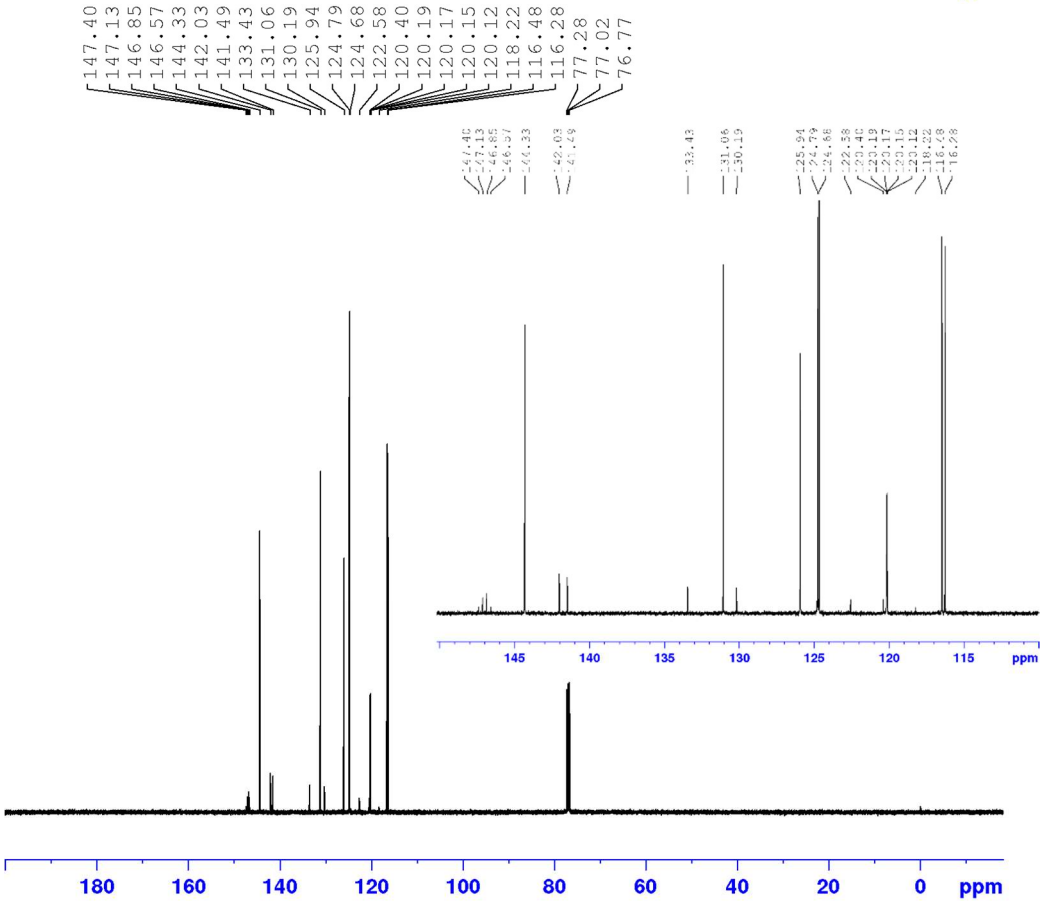
5s

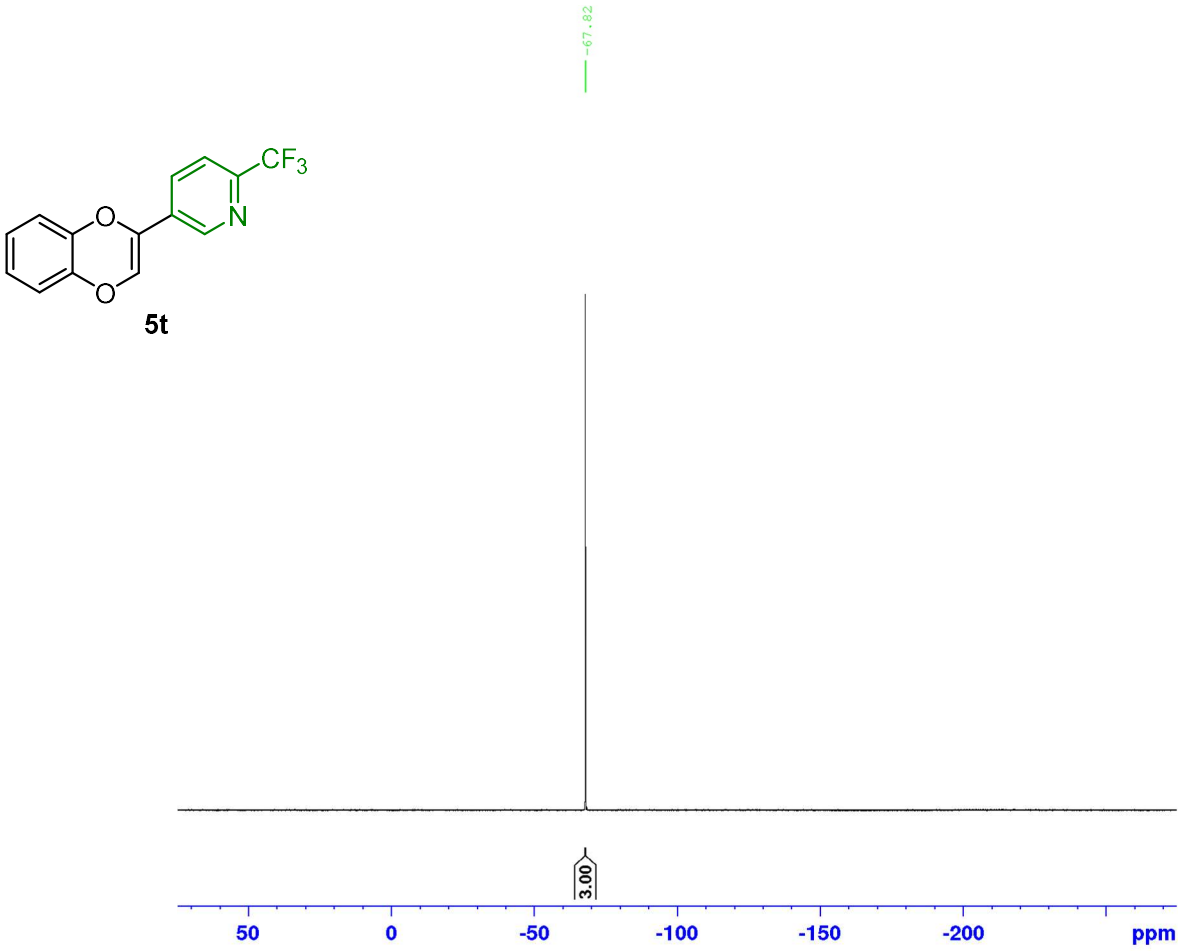

8.79
7.92
7.90
7.67
7.65
7.26
6.93
6.92
6.91
6.91
6.91
6.90
6.90
6.88
6.83
6.82
6.75
6.74
6.65
1.63
0.00

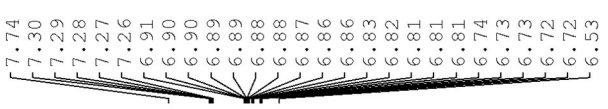

CF3
N
O
O

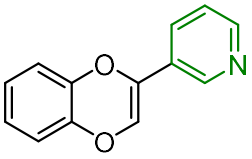
5t


1.00
1.00
1.00
2.01
1.03
1.02
1.01
9
8
7
6
5
4
3
2
1
0
ppm

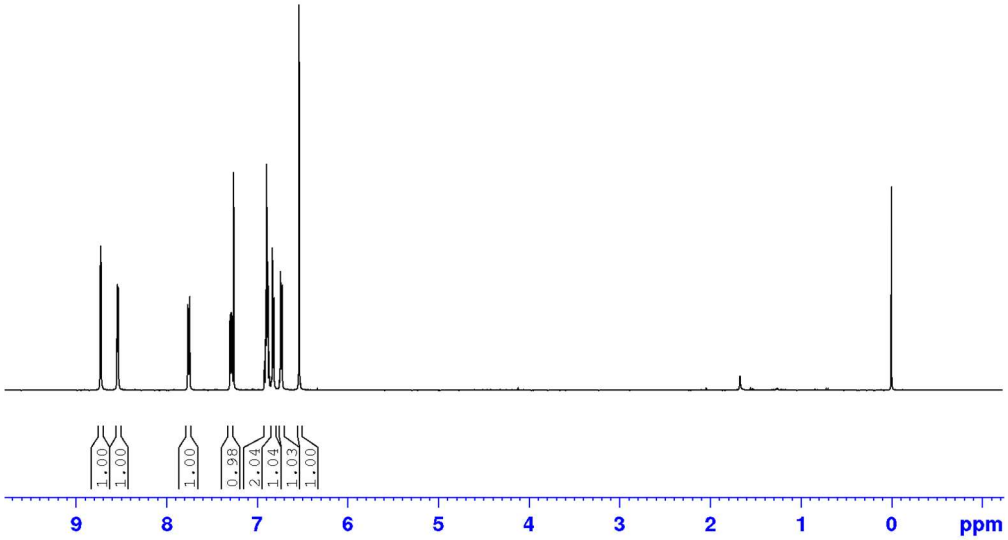

147.40
147.13
146.85
146.57
144.33
142.03
141.49
133.43
131.06
130.19
125.94
124.79
124.68
122.58
120.40
120.19
120.17
120.15
120.12
118.22
116.48
116.28
77.28
77.02
76.77
145
140
135
130
125
120
115
ppm
180
160
140
120
100
80
60
40
20
0
ppm

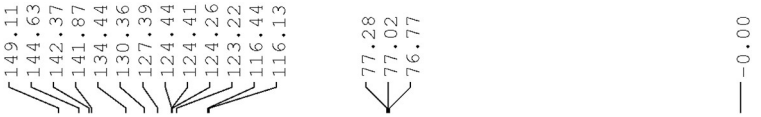

-67.82
CF3
N
O
O
5t
3.00
50
0
-50
-100
-150
-200
ppm

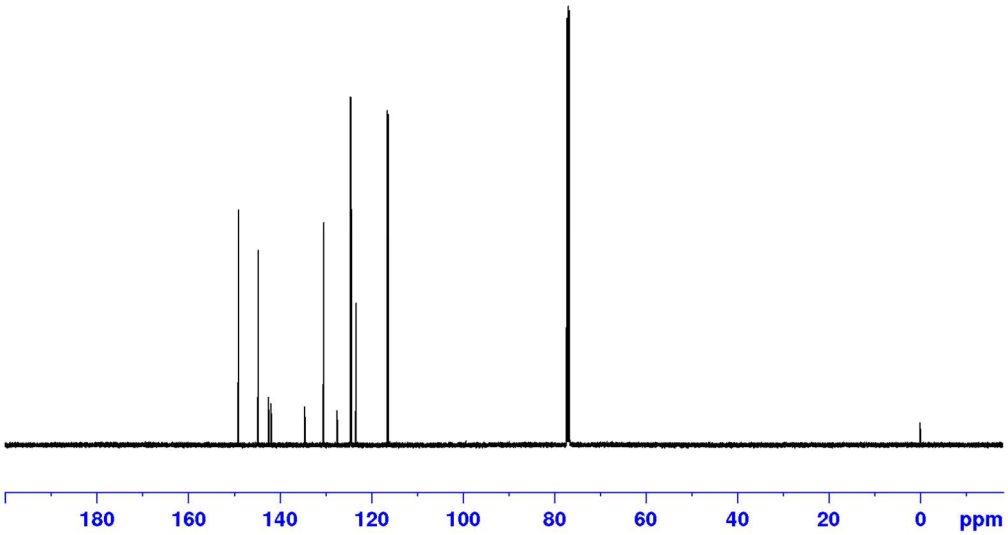

7.74
7.30
7.29
7.28
7.27
7.26
6.91
6.90
6.90
6.89
6.89
6.88
6.88
6.87
6.86
6.86
6.83
6.82
6.81
6.81
6.81
6.74
6.73
6.73
6.72
6.72
6.53
0.00

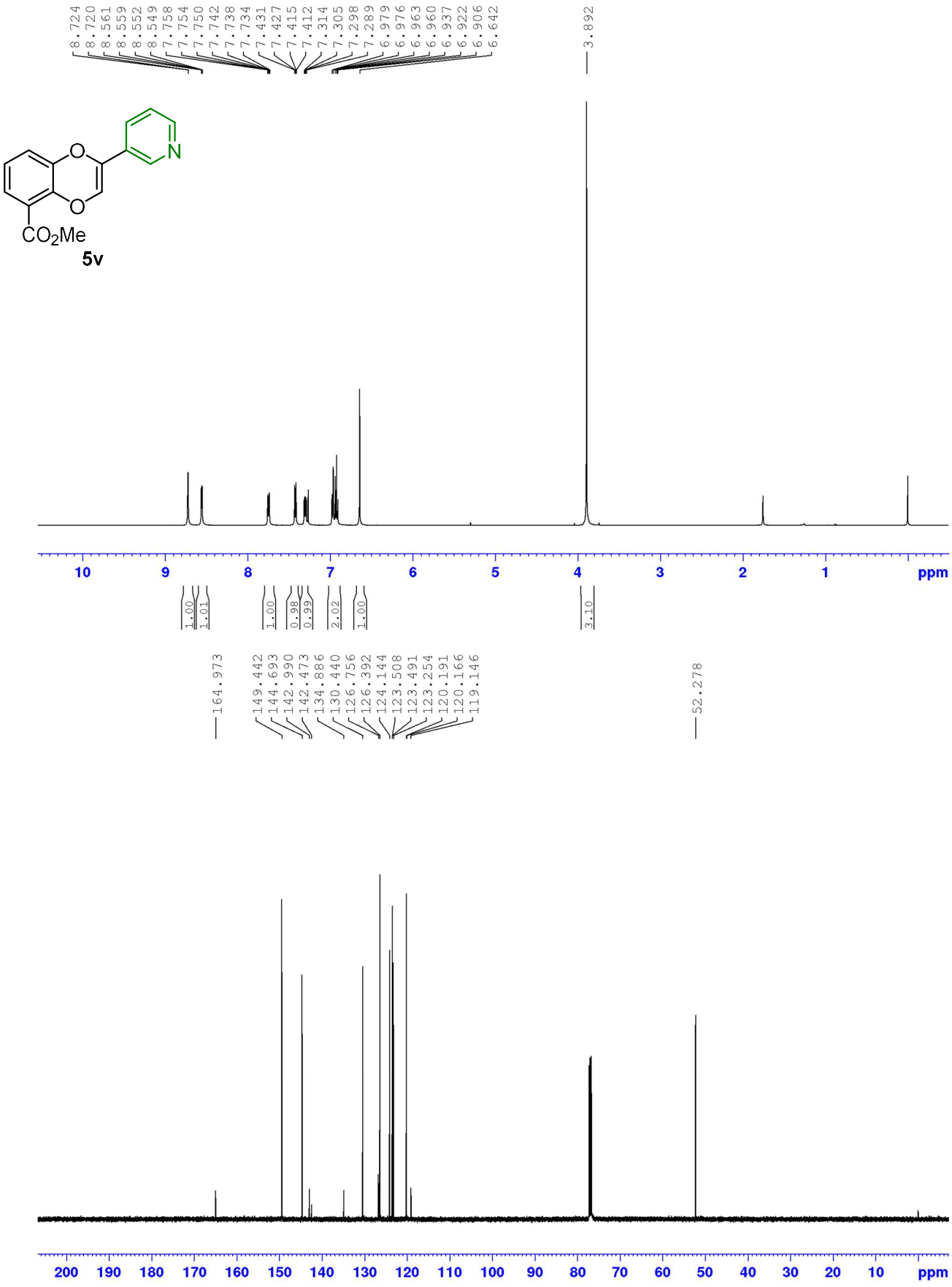

O
O
N

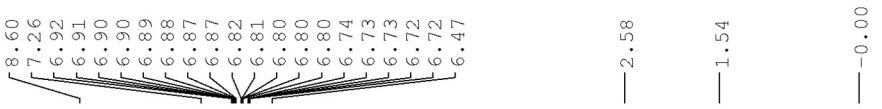
5u

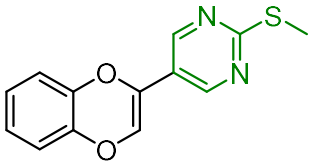

1.00
1.00
1.00
0.98
2.04
1.04
1.03
1.00
9
8
7
6
5
4
3
2
1
0
ppm


149.11
144.63
142.37
141.87
134.44
130.36
127.39
124.44
124.41
124.26
123.22
116.44
116.13
77.28
77.02
76.77
0.00

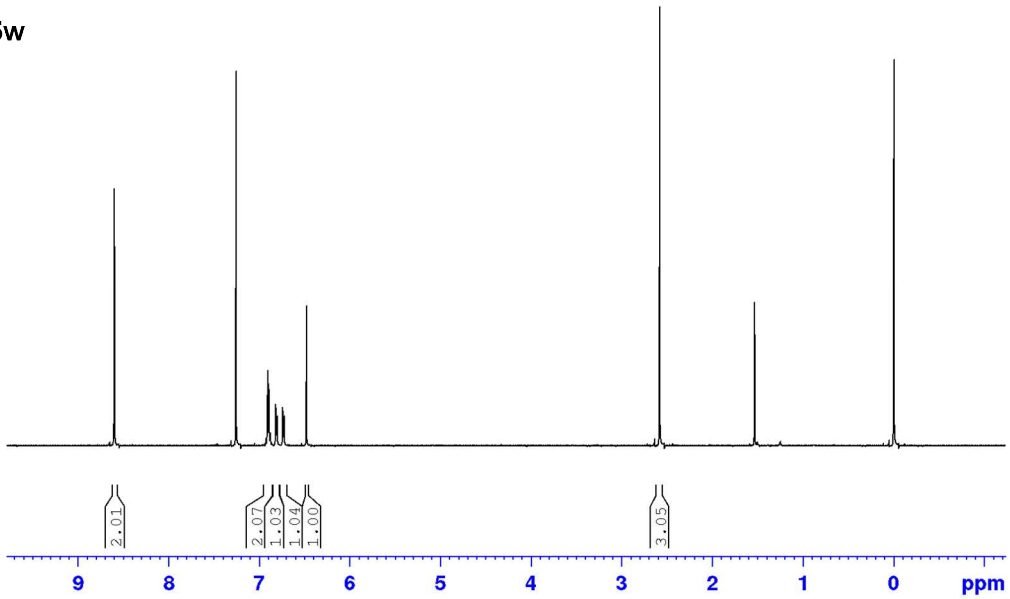

180
160
140
120
100
80
60
40
20
0
ppm

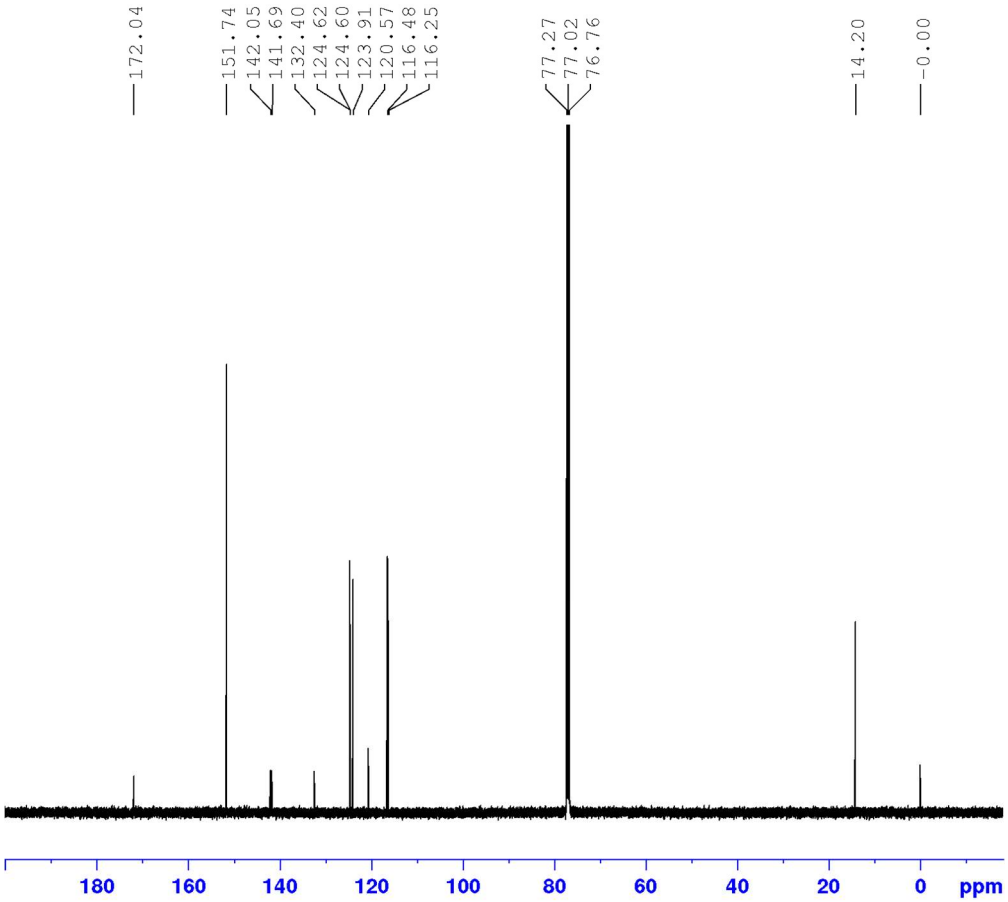

8.724
8.720
8.561
8.559
8.552
8.549
7.758
7.754
7.750
7.742
7.738
7.734
7.431
7.427
7.415
7.412
7.314
7.305
7.298
7.289
6.979
6.976
6.963
6.960
6.937
6.922
6.906
6.642
3.892
O
O
N
CO2Me
5v
10
9
8
7
6
5
4
3
2
1
ppm
1.00
1.01
1.00
0.98
0.99
2.02
1.00
3.10
164.973
149.442
144.693
142.990
142.473
134.886
130.440
126.756
126.392
124.144
123.508
123.491
123.254
120.191
120.166
119.146
52.278
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm

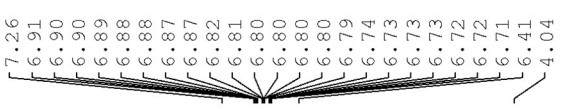

8.60
7.26
6.92
6.91
6.90
6.90
6.89
6.88
6.87
6.87
6.82
6.81
6.80
6.80
6.80
6.74
6.73
6.73
6.72
6.72
6.47
2.58
1.54
0.00

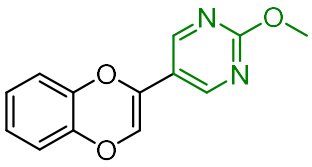

N
S
N
O
O

5w

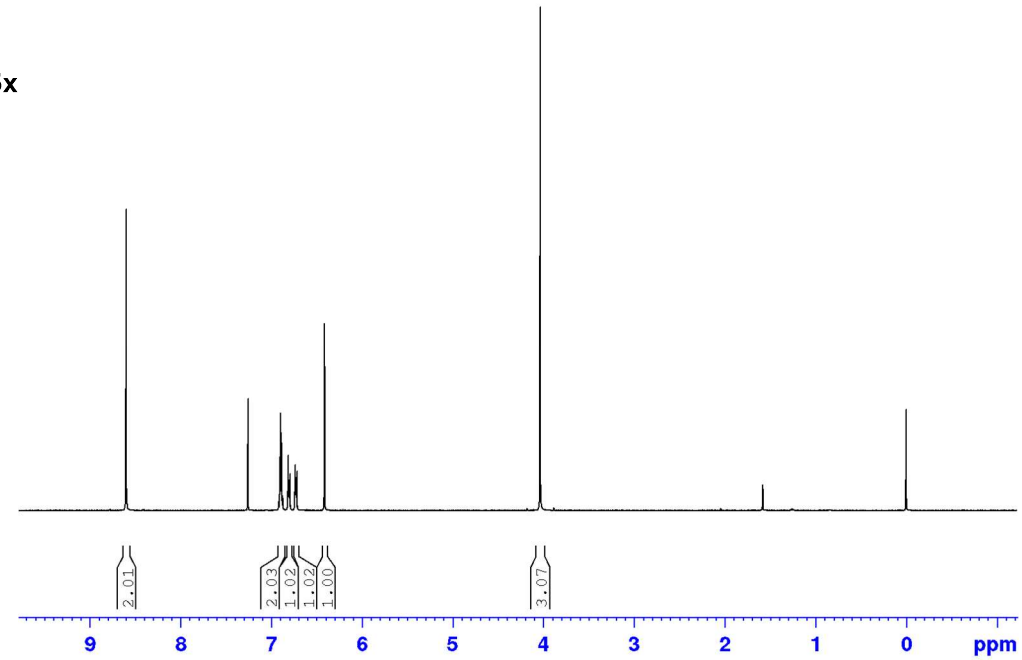

2.01
2.07
1.03
1.04
1.00
3.05
9
8
7
6
5
4
3
2
1
0
ppm

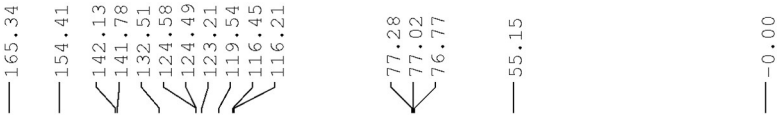

172.04
151.74
142.05
141.69
132.40
124.62
124.60
123.91
120.57
116.48
116.25
77.27
77.02
76.76
14.20
0.00
180
160
140
120
100
80
60
40
20
0
ppm

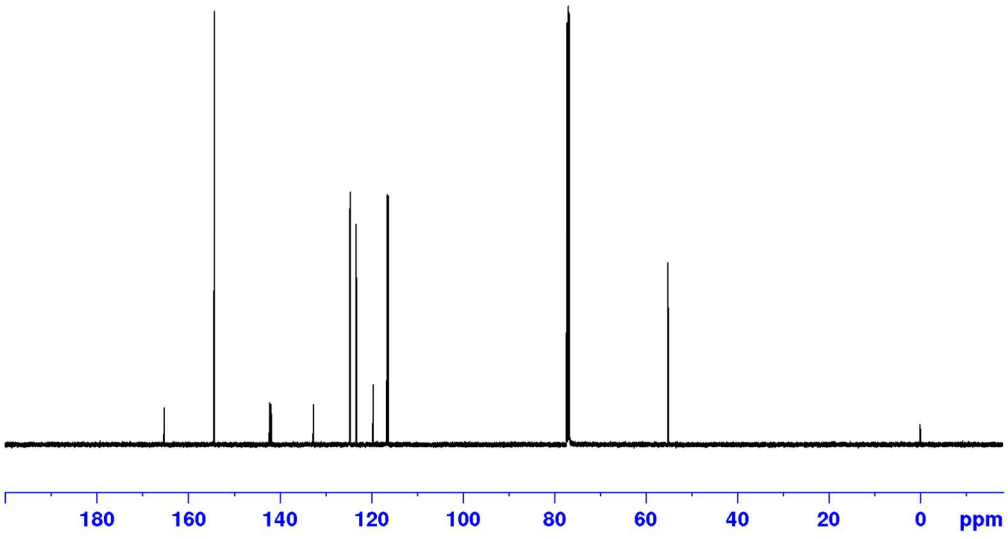

7.26
6.91
6.90
6.90
6.89
6.88
6.88
6.87
6.87
6.82
6.81
6.80
6.80
6.80
6.80
6.79
6.74
6.73
6.73
6.73
6.72
6.72
6.71
6.41
4.04
1.58
0.00



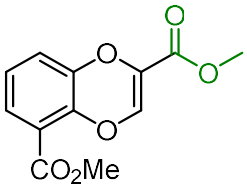
5x


2.01
2.03
1.02
1.02
1.00
3.07
9
8
7
6
5
4
3
2
1
0
ppm

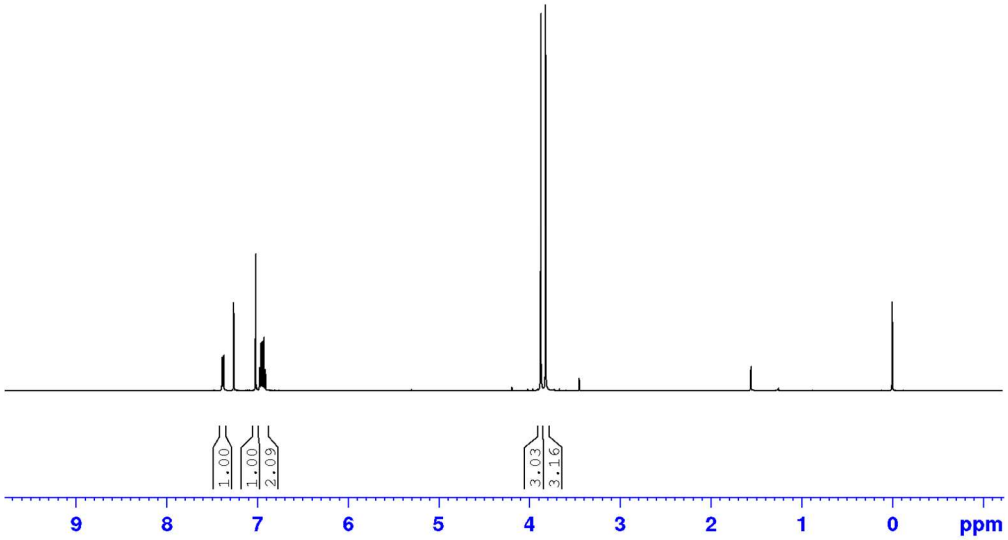

165.34
154.41
142.13
141.78
132.51
124.58
124.49
123.21
119.54
116.45
116.21
77.28
77.02
76.77
55.15
0.00

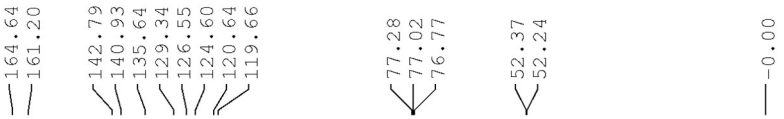

180
160
140
120
100
80
60
40
20
0
ppm

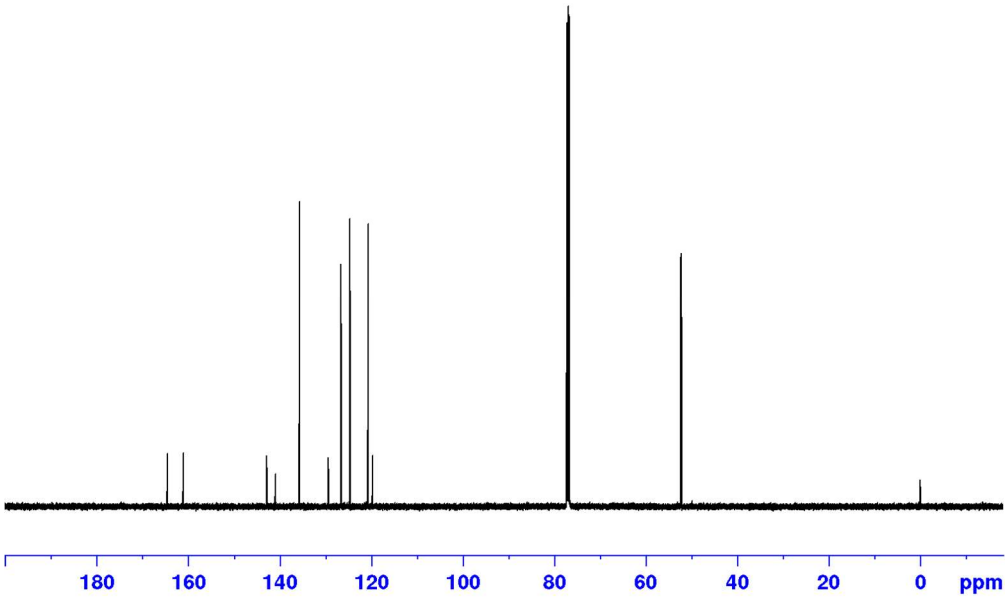

7.39
7.39
7.38
7.37
7.26
7.01
6.97
6.96
6.95
6.94
6.92
6.91
3.87
3.82
1.56
0.00

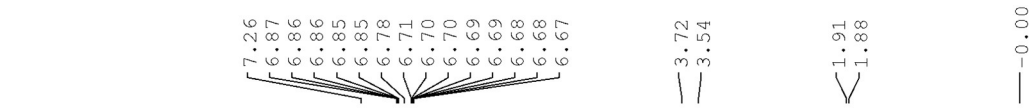

O
O
O
O
CO2Me

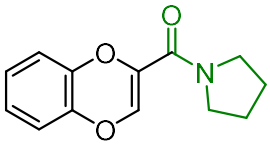
5y


1.00
1.00
2.09
3.03
3.16
9
8
7
6
5
4
3
2
1
0
ppm

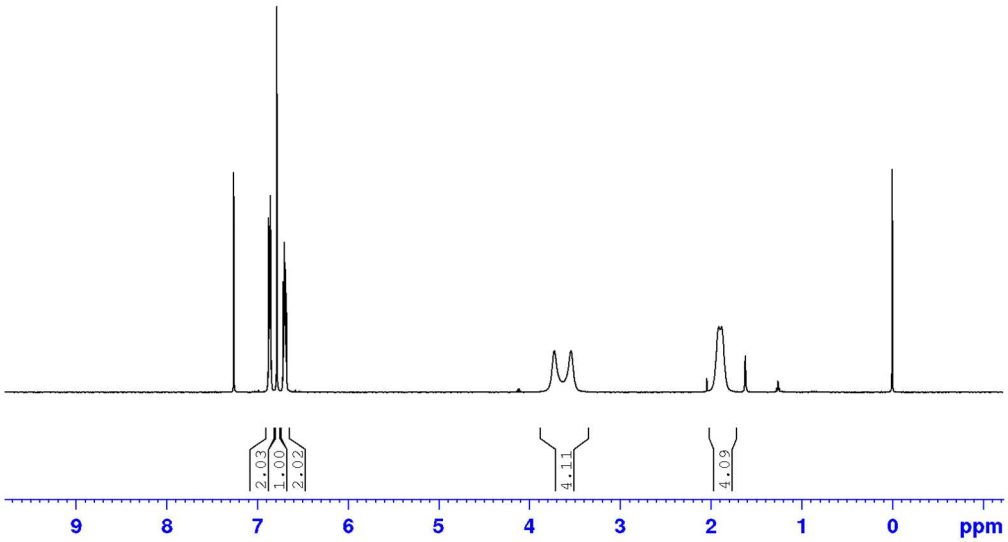

164.64
161.20
142.79
140.93
135.64
129.34
126.55
124.60
120.64
119.66
77.28
77.02
76.77
52.37
52.24
0.00

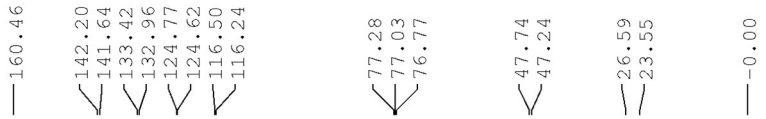

180
160
140
120
100
80
60
40
20
0
ppm

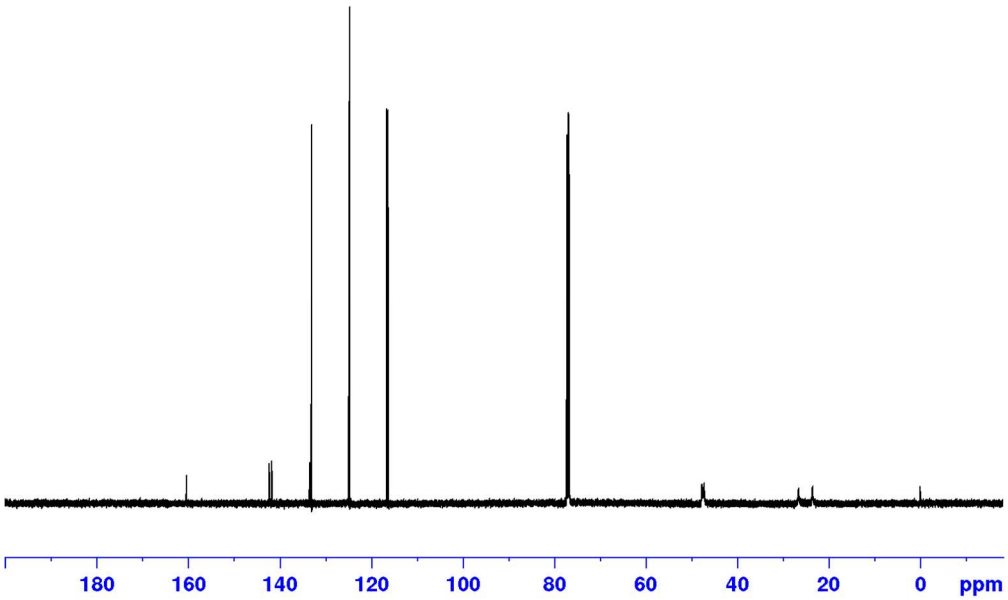

7.26
6.87
6.86
6.86
6.85
6.85
6.78
6.71
6.70
6.70
6.69
6.69
6.68
6.68
6.67
3.72
3.54
1.91
1.88
0.00

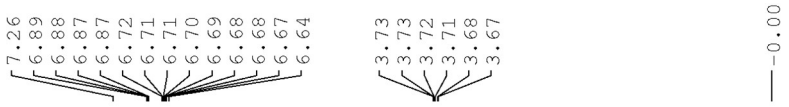


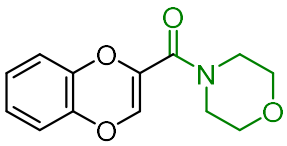
5aa


2.03
1.00
2.02
4.11
4.09
9
8
7
6
5
4
3
2
1
0
ppm

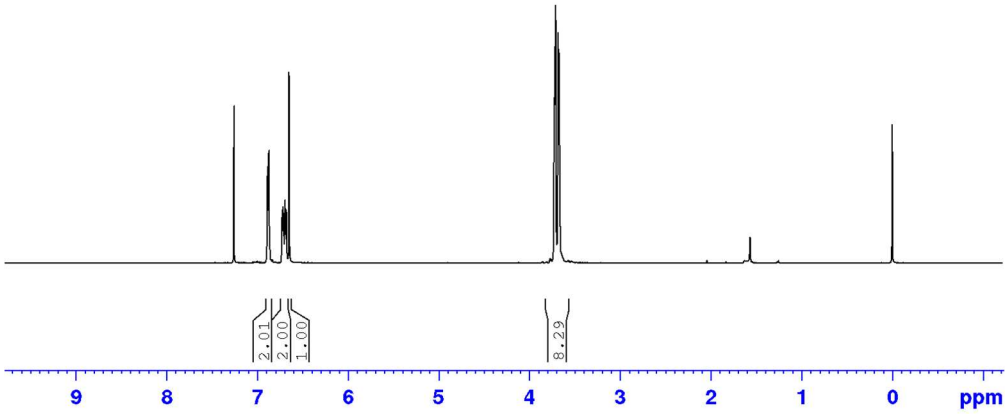

160.46
142.20
141.64
133.42
132.96
124.77
124.62
116.50
116.24
77.28
77.03
76.77
47.74
47.24
26.59
23.55
0.00

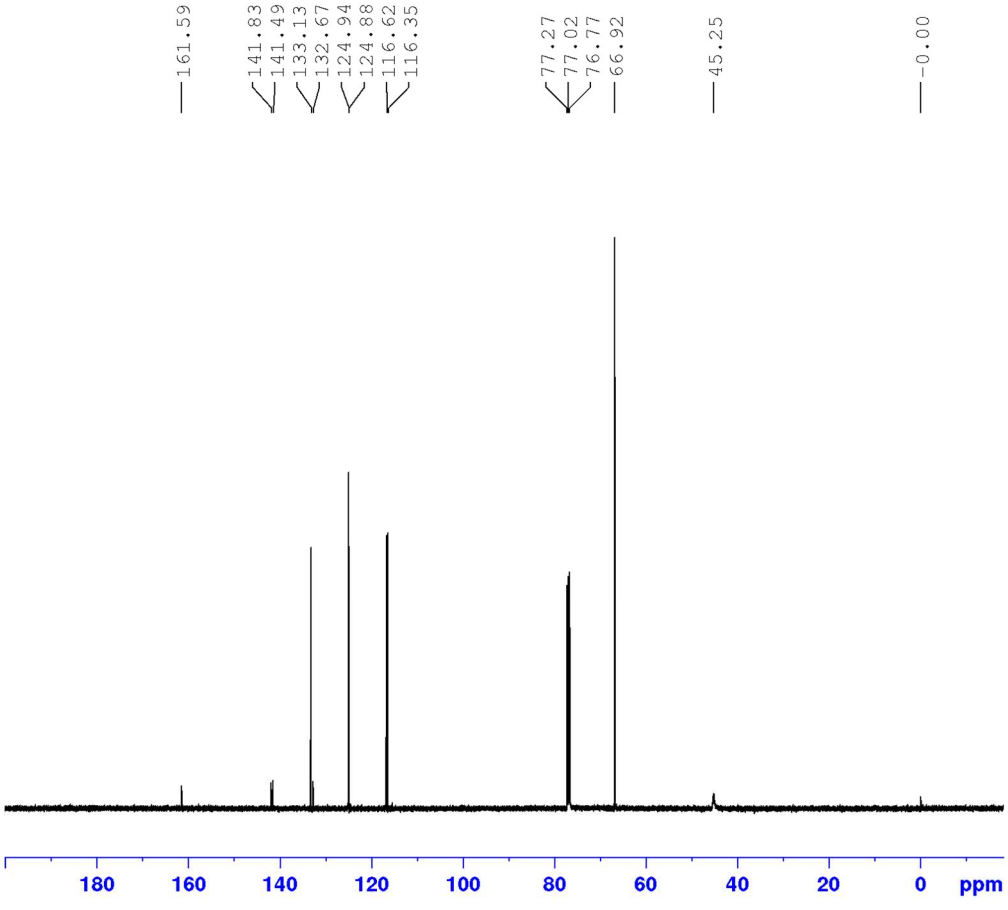

180
160
140
120
100
80
60
40
20
0
ppm


7.26
6.89
6.88
6.87
6.87
6.72
6.71
6.71
6.70
6.69
6.68
6.68
6.67
6.64
3.73
3.73
3.72
3.71
3.68
3.67
0.00

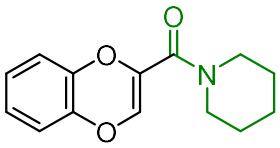


5ab

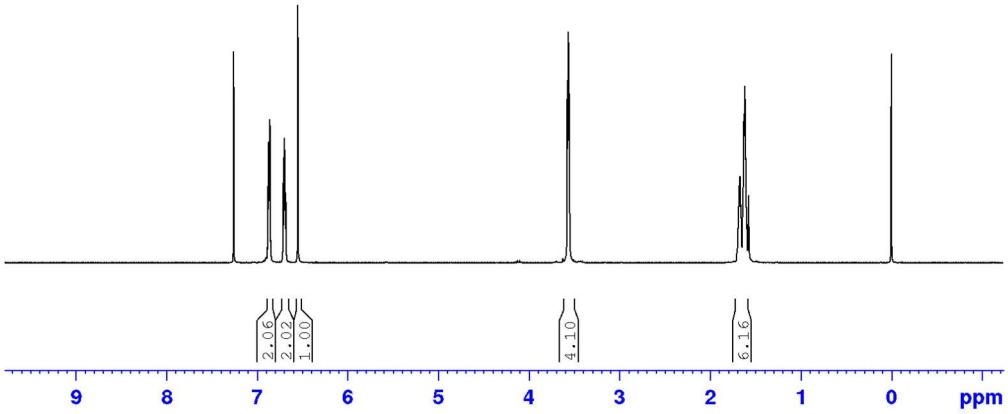

2.01
2.00
1.00
8.29
9
8
7
6
5
4
3
2
1
0
ppm

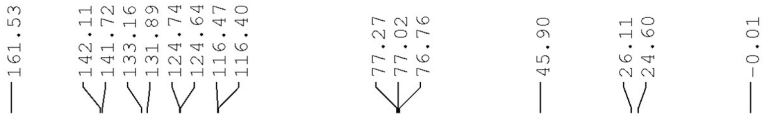

161.59
141.83
141.49
133.13
132.67
124.94
124.88
116.62
116.35
77.27
77.02
76.77
66.92
45.25
0.00
180
160
140
120
100
80
60
40
20
0
ppm

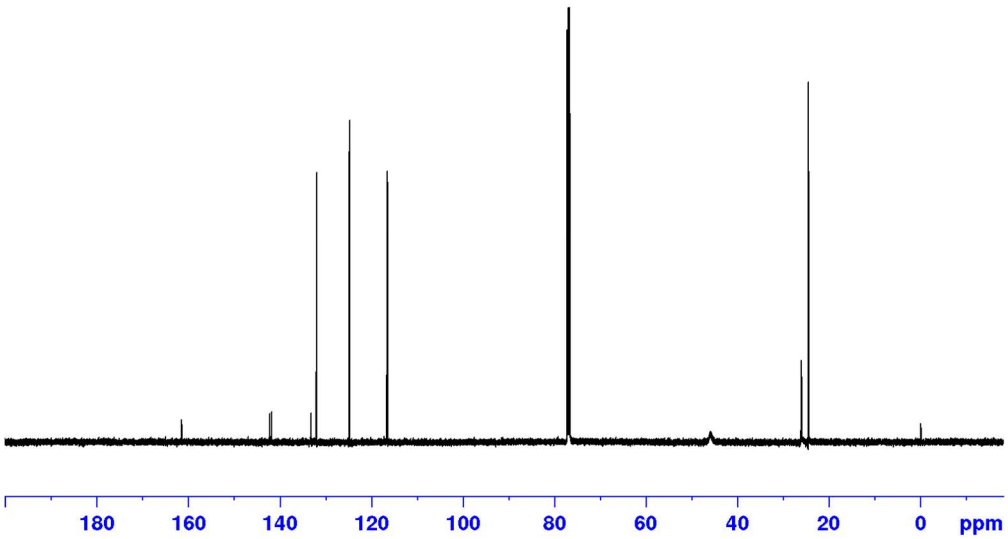

7.26
6.87
6.87
6.86
6.85
6.71
6.70
6.69
6.68
6.54
3.58
3.56
3.55
1.69
1.68
1.67
1.66
1.63
1.62
1.59
1.57
0.00



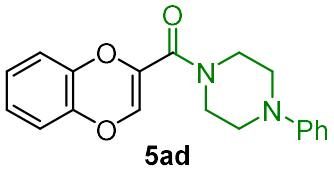
5ac


2.06
2.02
1.00
4.10
6.16
9
8
7
6
5
4
3
2
1
0
ppm

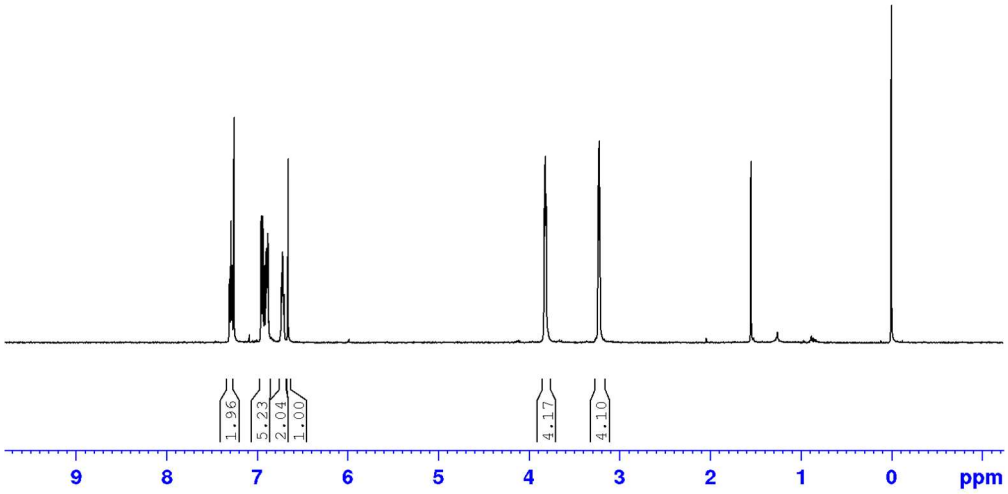

161.53
142.11
141.72
133.16
131.89
124.74
124.64
116.47
116.40
77.27
77.02
76.76
45.90
26.11
24.60
0.01

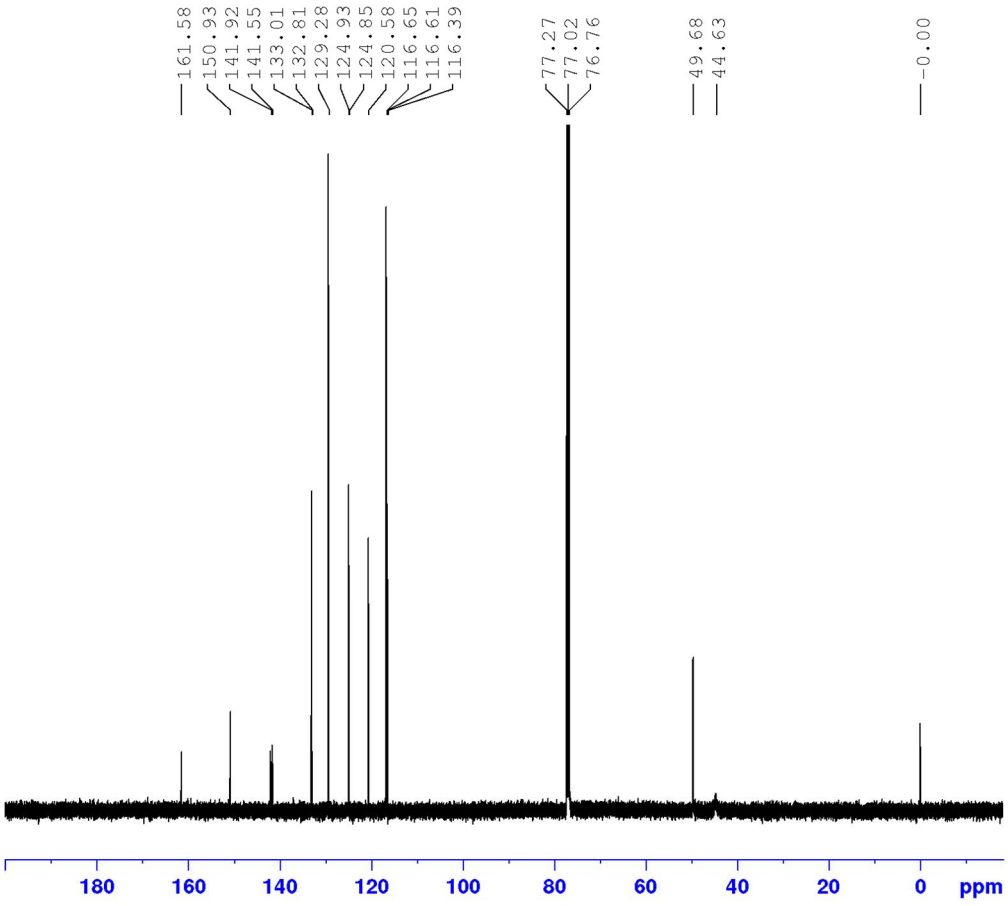

180
160
140
120
100
80
60
40
20
0
ppm

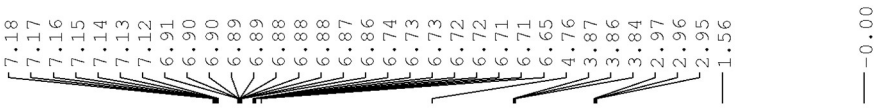

7.31
7.29
7.28
7.26
6.95
6.93
6.91
6.89
6.88
6.87
6.73
6.72
6.71
6.70
6.65
3.83
3.82
3.81
3.24
3.23
3.22
0.00

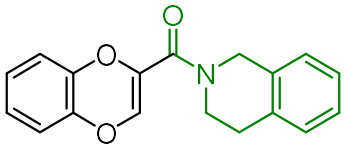

O
O
O
N
N
Ph

5ad

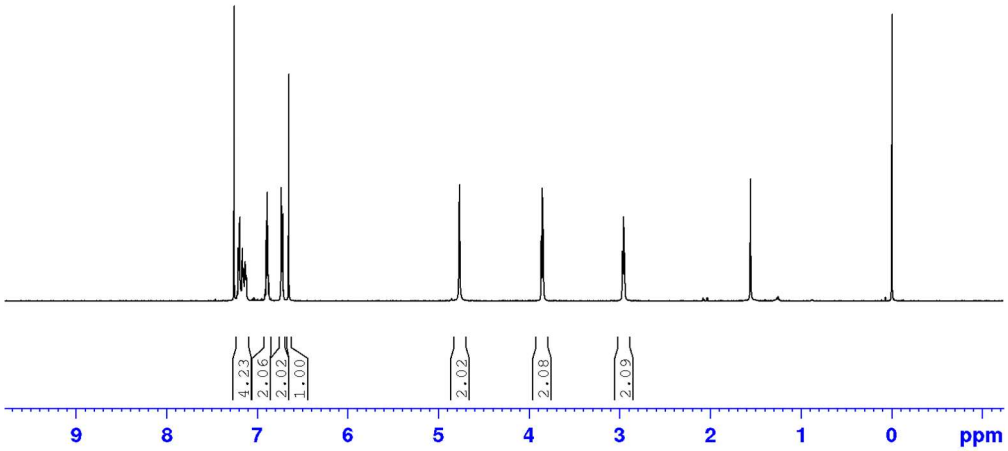

1.96
5.23
2.04
1.00
4.17
4.10
9
8
7
6
5
4
3
2
1
0
ppm

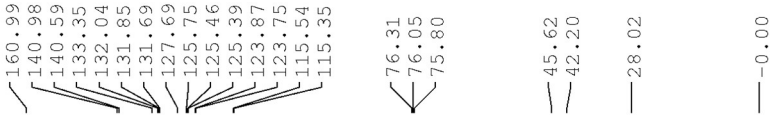

161.58
150.93
141.92
141.55
133.01
132.81
129.28
124.93
124.85
120.58
116.65
116.61
116.39
77.27
77.02
76.76
49.68
44.63
0.00
180
160
140
120
100
80
60
40
20
0
ppm

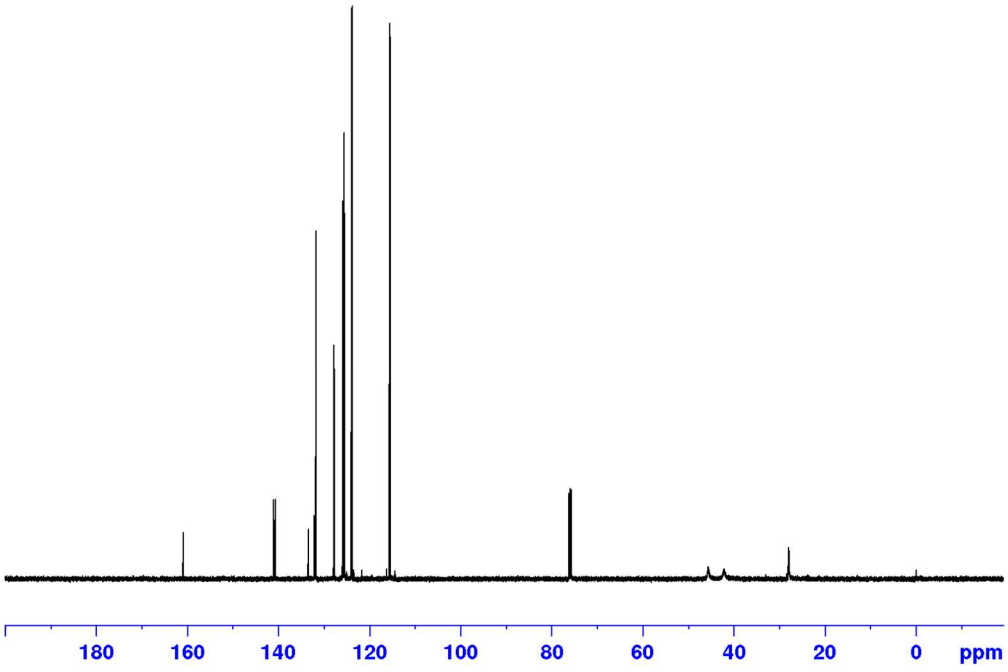

7.18
7.17
7.16
7.15
7.14
7.13
7.12
6.91
6.90
6.90
6.89
6.89
6.88
6.88
6.88
6.87
6.86
6.74
6.73
6.73
6.72
6.72
6.71
6.71
6.65
4.76
3.87
3.86
3.84
2.97
2.96
2.95
1.56
0.00

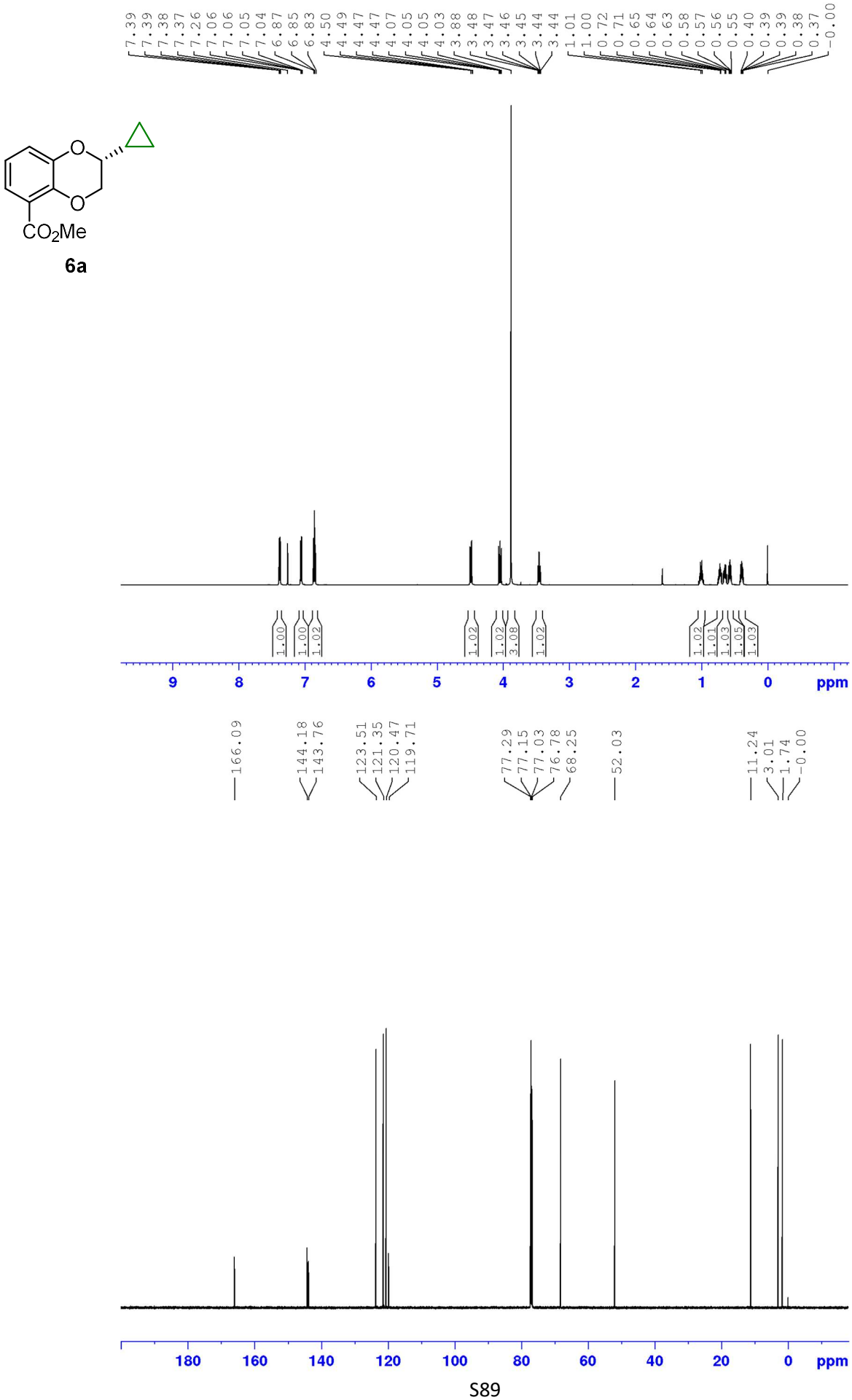


5ae

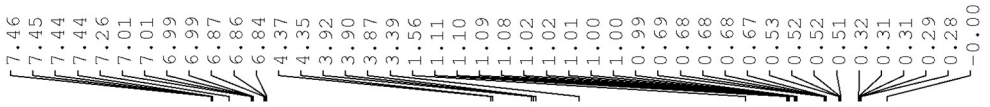

4.23
2.06
2.02
1.00
2.02
2.08
2.09
9
8
7
6
5
4
3
2
1
0
ppm

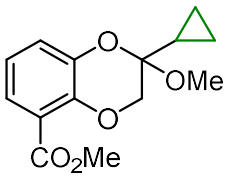

160.99
140.98
140.59
133.35
132.04
131.85
131.69
127.69
125.75
125.46
125.39
123.87
123.75
115.54
115.35
76.31
76.05
75.80
45.62
42.20
28.02
0.00


180
160
140
120
100
80
60
40
20
0
ppm

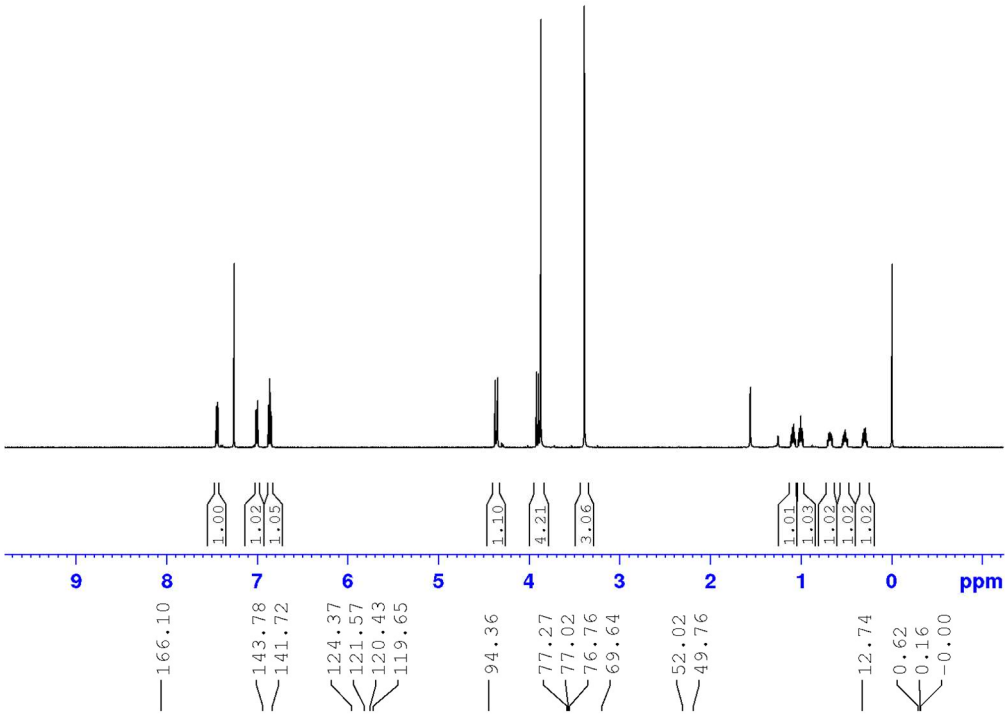

7.39
7.39
7.38
7.37
7.26
7.06
7.06
7.05
7.04
6.87
6.85
6.83
4.50
4.49
4.47
4.47
4.07
4.05
4.05
4.03
3.88
3.48
3.47
3.46
3.45
3.44
3.44
1.01
1.00
0.72
0.71
0.65
0.64
0.63
0.58
0.57
0.56
0.55
0.40
0.39
0.39
0.38
0.37
-0.00
O
O
CO2Me
1.00
1.00
1.02
1.02
1.02
3.08
1.02
1.02
1.01
1.03
1.05
1.03
9
8
7
6
5
4
3
2
1
0
ppm
166.09
144.18
143.76
123.51
121.35
120.47
119.71
77.29
77.15
77.03
76.78
68.25
52.03
11.24
3.01
1.74
-0.00
180
160
140
120
100
80
60
40
20
0
ppm

6a

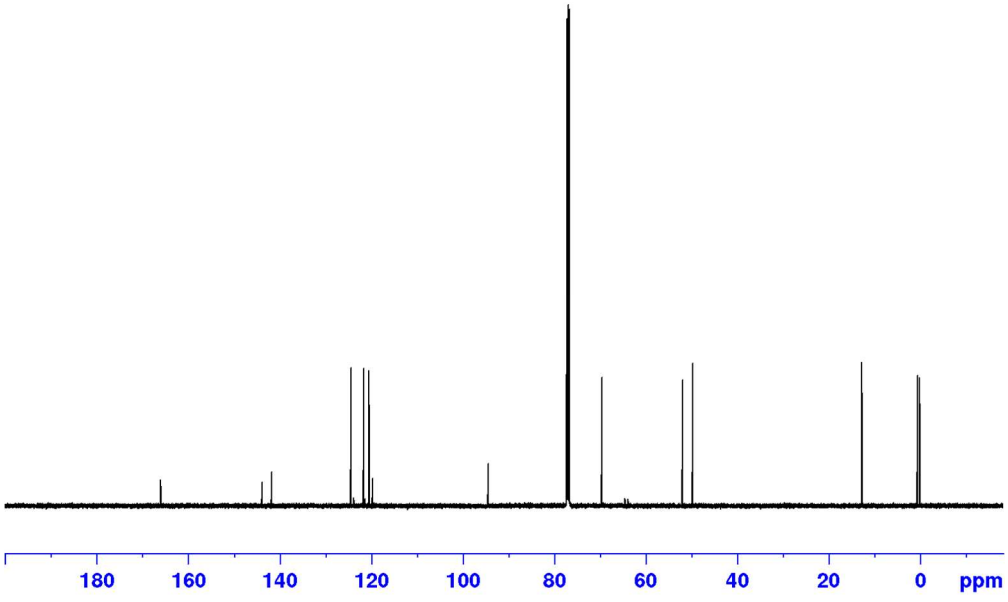

7.46
7.45
7.44
7.44
7.26
7.01
7.01
6.99
6.99
6.87
6.86
6.84
4.37
4.35
3.92
3.90
3.87
3.39
1.56
1.11
1.10
1.09
1.08
1.02
1.02
1.01
1.00
1.00
0.99
0.69
0.68
0.68
0.67
0.53
0.52
0.52
0.51
0.32
0.31
0.31
0.29
0.28
0.00

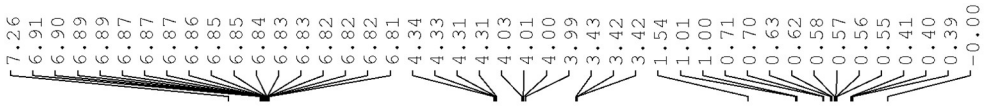

O
OMe
O
CO2Me

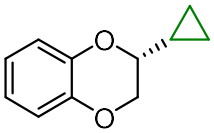
7


1.00
1.02
1.05
1.10
4.21
3.06
1.01
1.03
1.02
1.02
1.02
9
8
7
6
5
4
3
2
1
0
ppm

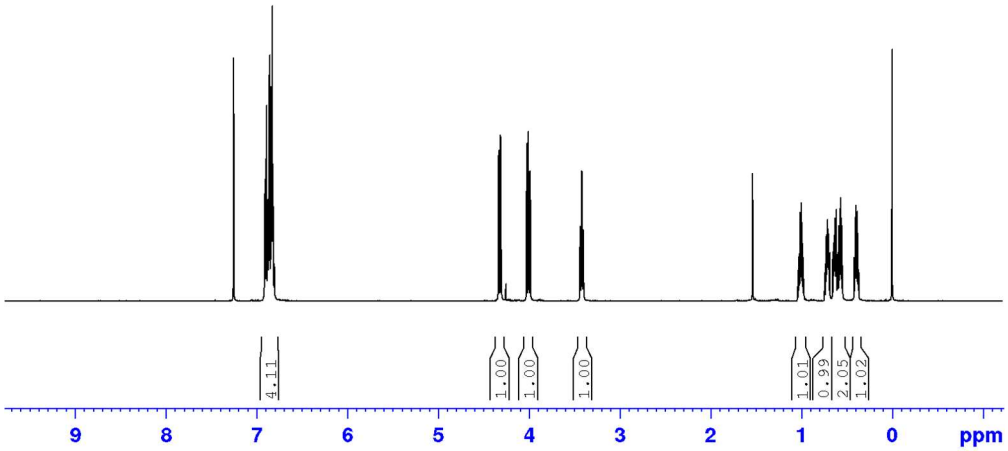
166.10
143.78
141.72
124.37
121.57
120.43
119.65
94.36
77.27
77.02
76.76
69.64
52.02
49.76
12.74
0.62
0.16
0.00

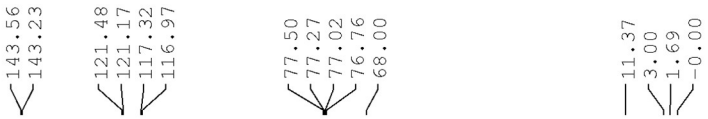

180
160
140
120
100
80
60
40
20
0
ppm

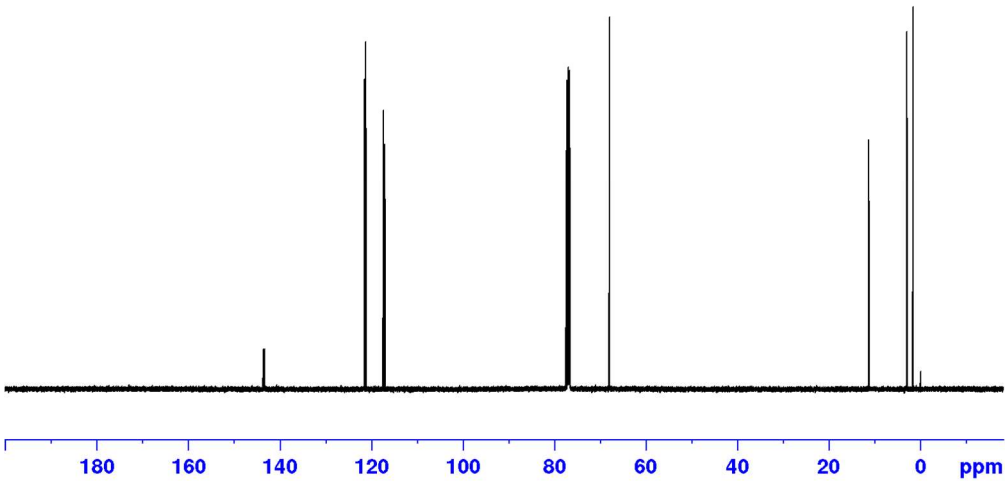

7.26
6.91
6.90
6.89
6.89
6.87
6.87
6.87
6.86
6.85
6.85
6.84
6.83
6.83
6.82
6.82
6.82
6.81
4.34
4.33
4.31
4.31
4.03
4.01
4.00
3.99
3.43
3.42
3.42
1.54
1.01
1.00
0.71
0.70
0.63
0.62
0.58
0.57
0.56
0.55
0.41
0.40
0.39
-0.00

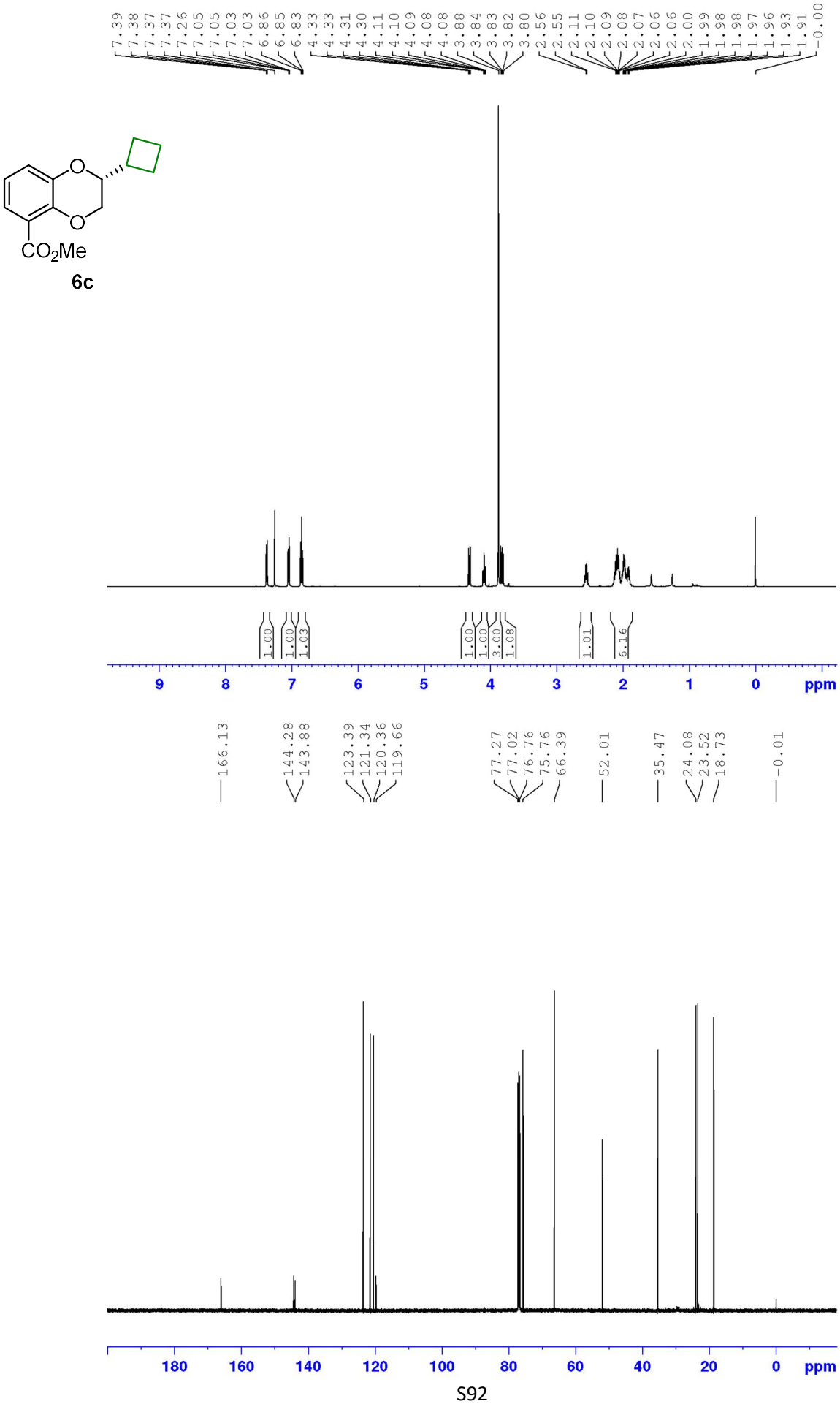


6b

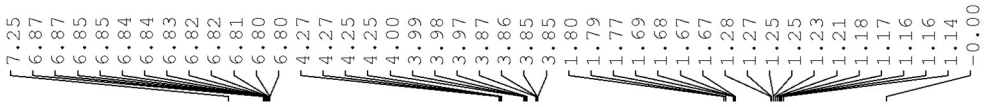

4.11
1.00
1.00
1.00
1.01
0.99
2.05
1.02
9
8
7
6
5
4
3
2
1
0
ppm

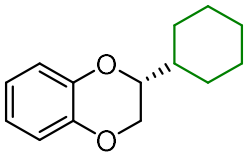

143.56
143.23
121.48
121.17
117.32
116.97
77.50
77.27
77.02
76.76
68.00
11.37
3.00
1.69
-0.00


180
160
140
120
100
80
60
40
20
0
ppm

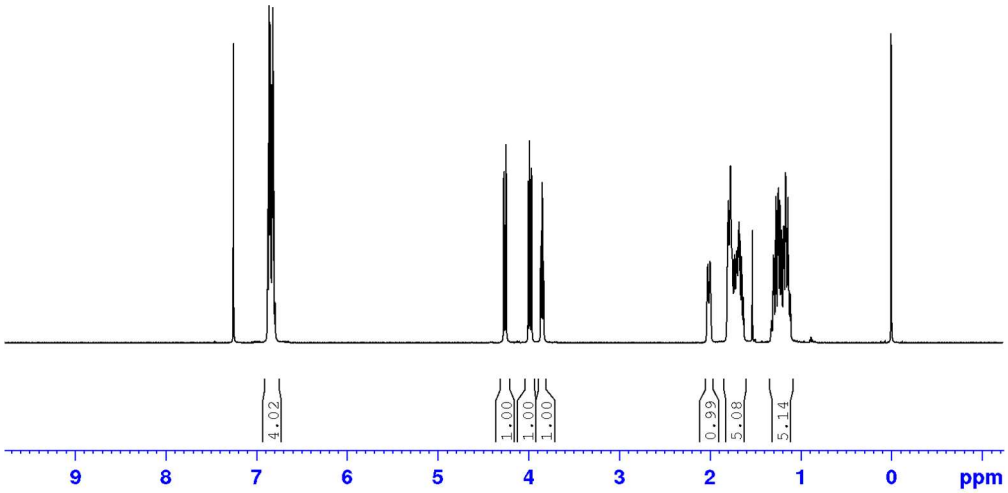

7.39
7.38
7.37
7.37
7.26
7.05
7.05
7.03
7.03
6.86
6.85
6.83
4.33
4.31
4.30
4.11
4.10
4.09
4.08
4.08
3.88
3.84
3.83
3.82
3.80
2.56
2.55
2.11
2.10
2.09
2.08
2.07
2.06
2.06
2.00
1.99
1.98
1.98
1.97
1.96
1.93
1.91
0.00
O
O
O
CO2Me
1.00
1.00
1.03
1.00
1.00
3.00
1.08
1.01
6.16
9
8
7
6
5
4
3
2
1
0
ppm
166.13
144.28
143.88
123.39
121.34
120.36
119.66
77.27
77.02
76.76
75.76
66.39
52.01
35.47
24.08
23.52
18.73
0.01
180
160
140
120
100
80
60
40
20
0
ppm

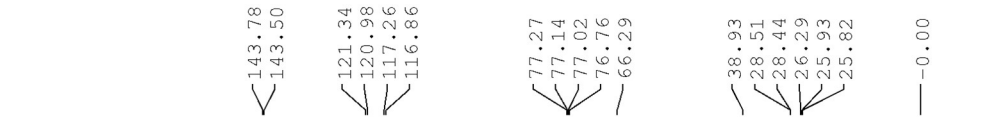
6c

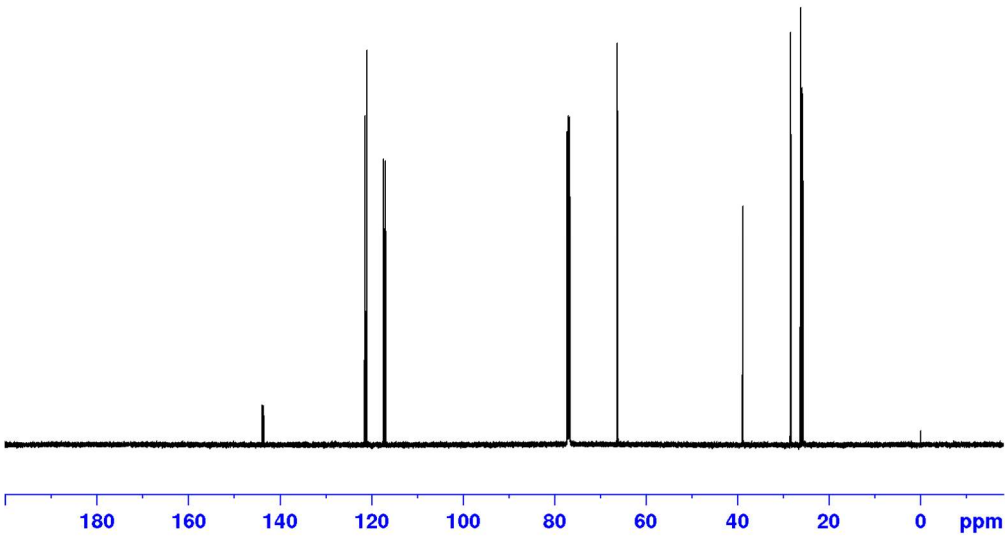

7.25
6.87
6.87
6.85
6.85
6.84
6.84
6.83
6.82
6.82
6.81
6.80
6.80
4.27
4.27
4.25
4.25
4.00
3.99
3.98
3.97
3.87
3.86
3.85
3.85
1.80
1.79
1.77
1.69
1.68
1.67
1.67
1.28
1.27
1.25
1.25
1.23
1.21
1.18
1.17
1.16
1.16
1.14
0.00

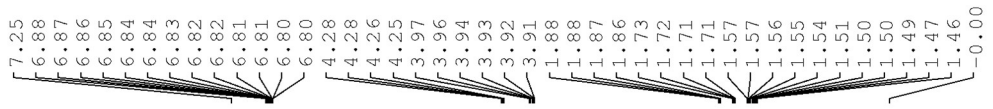


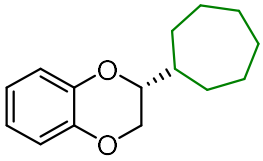
6d


4.02
1.00
1.00
1.00
0.99
5.08
5.14
9
8
7
6
5
4
3
2
1
0
ppm

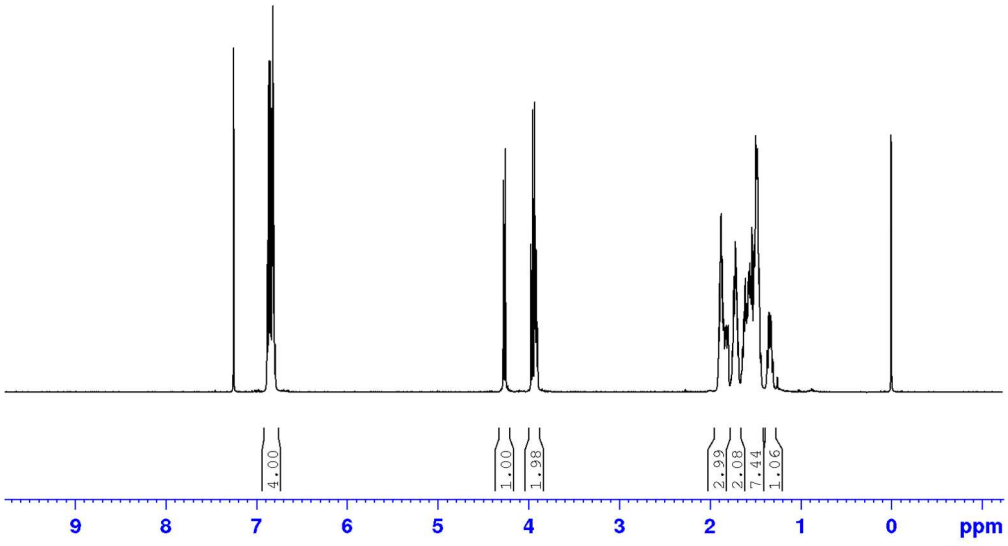

143.78
143.50
121.34
120.98
117.26
116.86
77.27
77.14
77.02
76.76
66.29
38.93
28.51
28.44
26.29
25.93
25.82
0.00

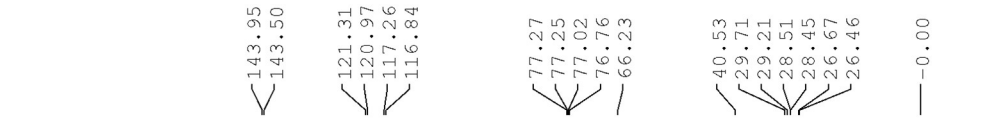

180
160
140
120
100
80
60
40
20
0
ppm

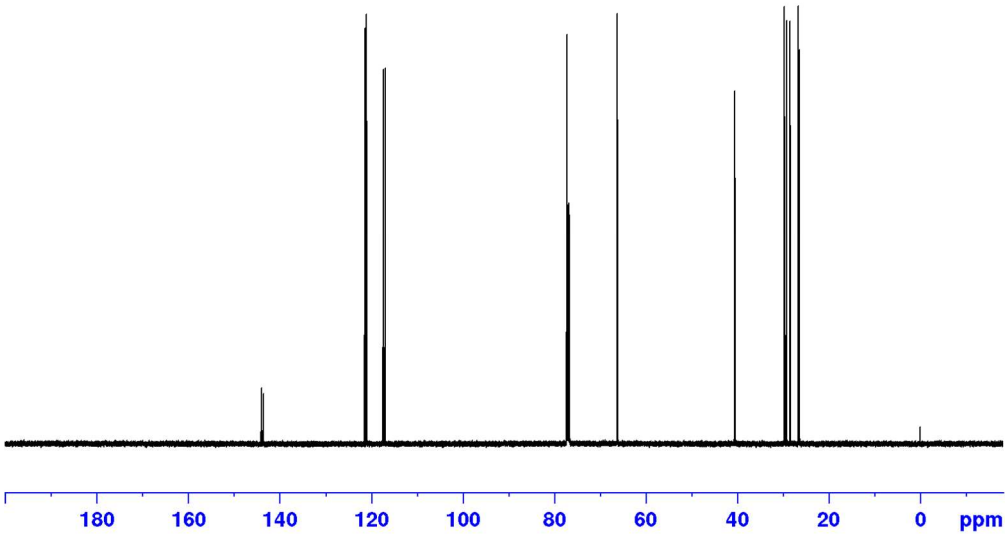

7.25
6.88
6.87
6.86
6.85
6.84
6.84
6.83
6.82
6.82
6.81
6.81
6.80
6.80
4.28
4.28
4.26
4.25
3.97
3.96
3.94
3.93
3.92
3.91
1.88
1.88
1.87
1.86
1.73
1.72
1.71
1.71
1.57
1.57
1.56
1.55
1.54
1.51
1.50
1.50
1.49
1.47
1.46
0.00

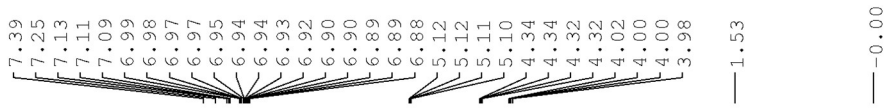


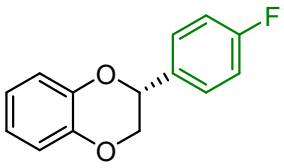
6e


4.00
1.00
1.98
2.99
2.08
7.44
1.06
9
8
7
6
5
4
3
2
1
0
ppm

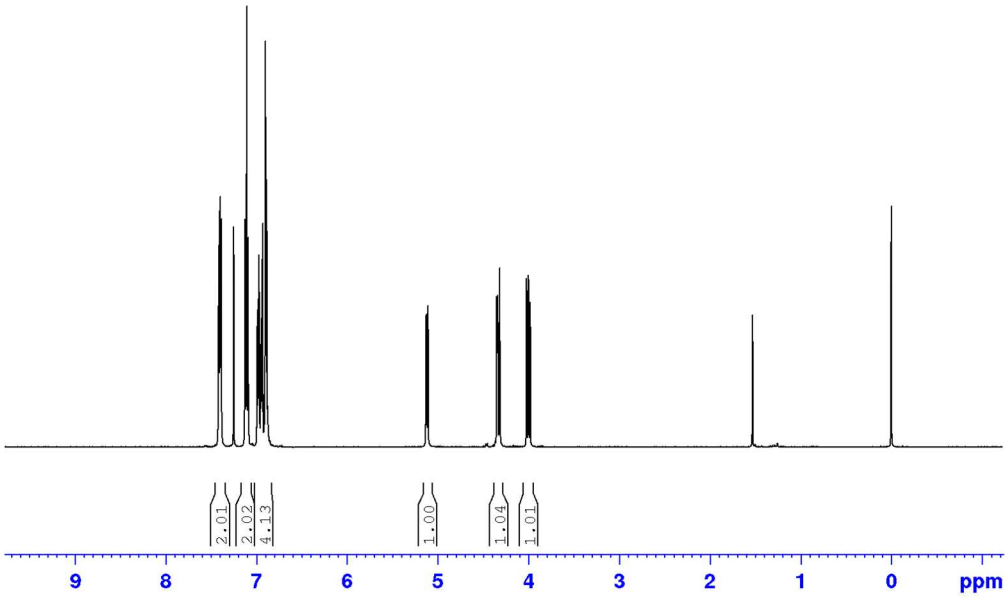

143.95
143.50
121.31
120.97
117.26
116.84
77.27
77.25
77.02
76.76
66.23
40.53
29.71
29.21
28.51
28.45
26.67
26.46
0.00

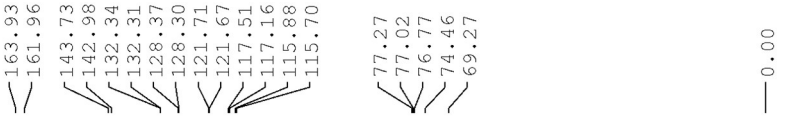

180
160
140
120
100
80
60
40
20
0
ppm

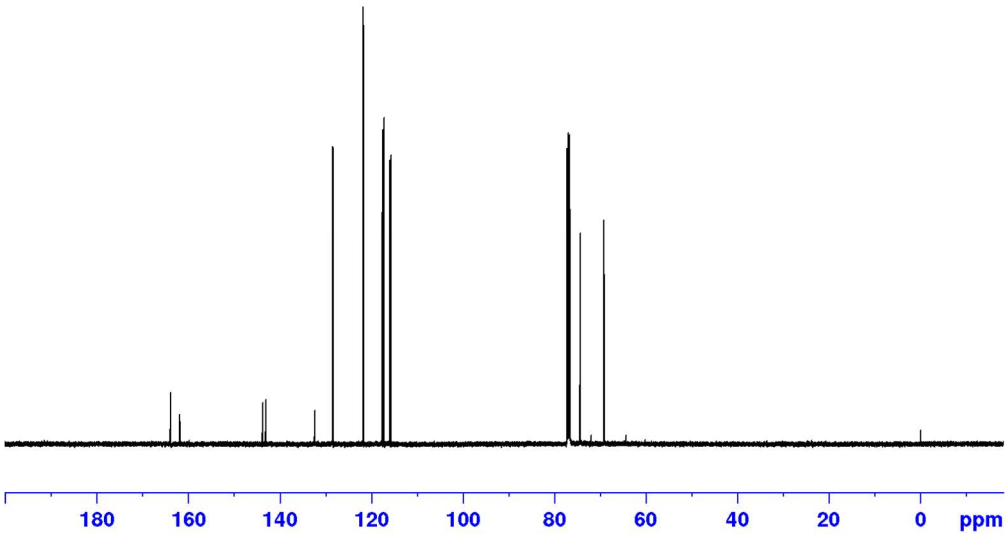

7.39
7.25
7.13
7.11
7.09
6.99
6.98
6.97
6.97
6.95
6.94
6.94
6.93
6.92
6.90
6.90
6.89
6.89
6.88
5.12
5.11
5.10
4.34
4.34
4.32
4.32
4.02
4.00
4.00
3.98
1.53
0.00

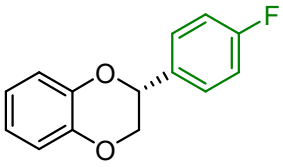

O
O
F

6f

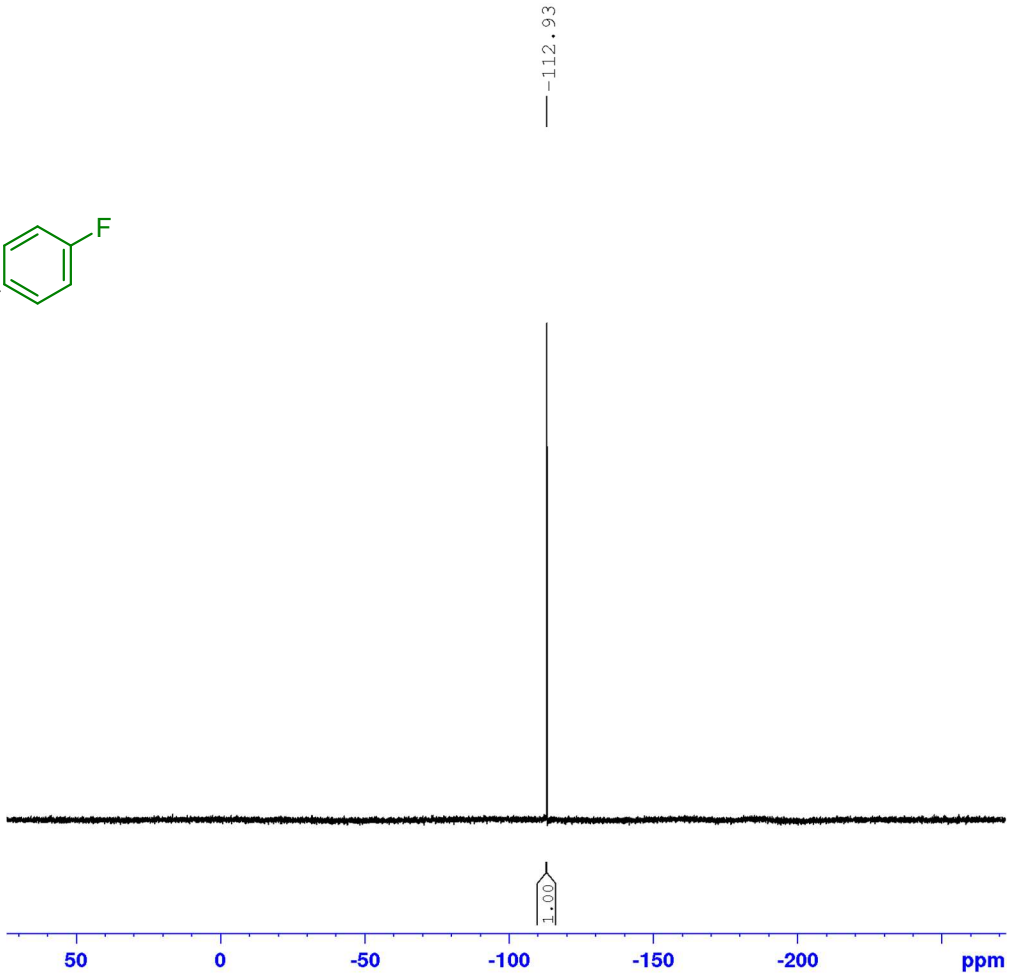

2.01
2.02
4.13
1.00
1.04
1.01
9
8
7
6
5
4
3
2
1
0
ppm

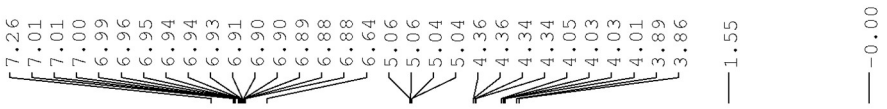

163.93
161.96
143.73
142.98
132.34
132.31
128.37
128.30
121.71
121.67
117.51
117.16
115.88
115.70
77.27
77.02
76.77
74.46
69.27
0.00

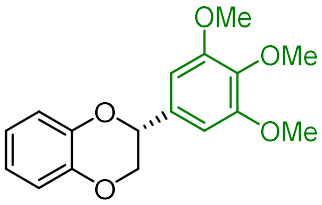

180
160
140
120
100
80
60
40
20
0
ppm



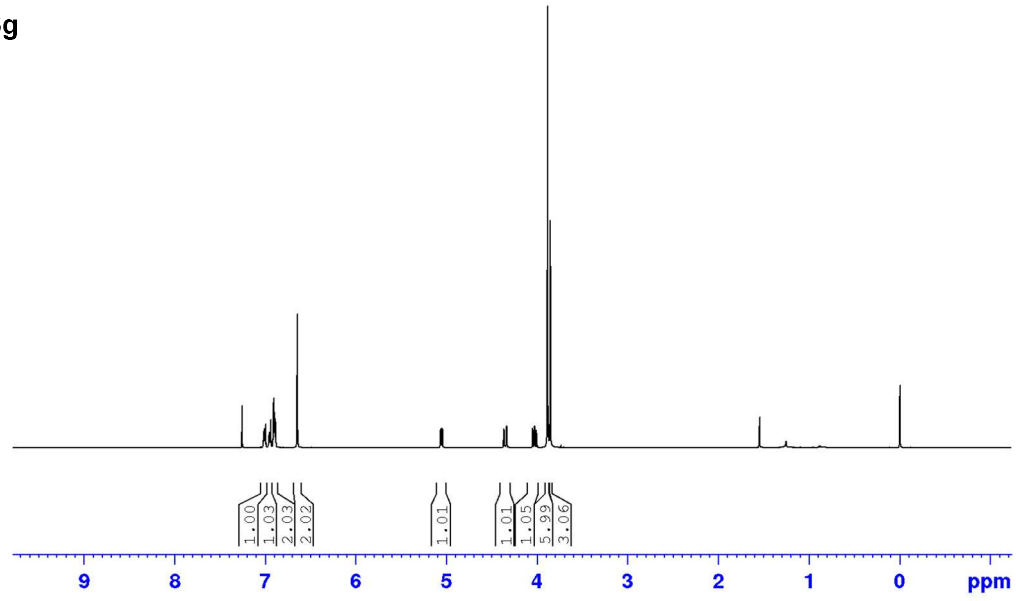
6f

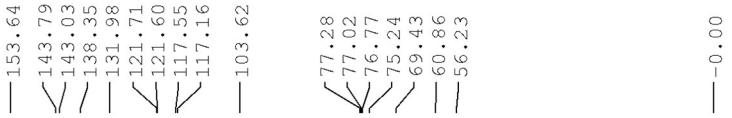


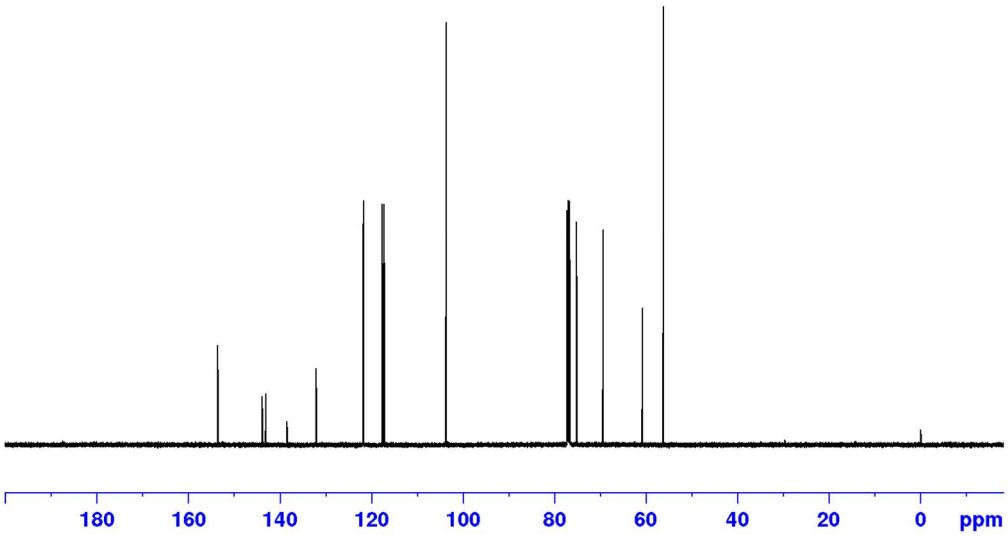

7.26
7.01
7.01
7.00
6.99
6.96
6.95
6.94
6.94
6.93
6.91
6.90
6.90
6.89
6.88
6.88
6.64
5.06
5.06
5.04
5.04
4.36
4.36
4.34
4.34
4.05
4.03
4.03
4.01
3.89
3.86
1.55
0.00

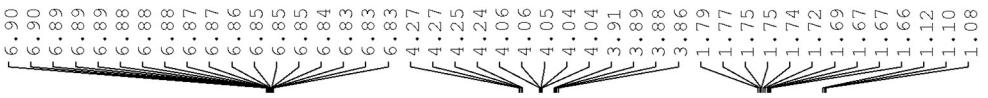

OMe
OMe
OMe
O
O

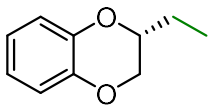
6g


1.00
1.03
2.03
2.02
1.01
1.01
1.05
5.99
3.06
9
8
7
6
5
4
3
2
1
0
ppm

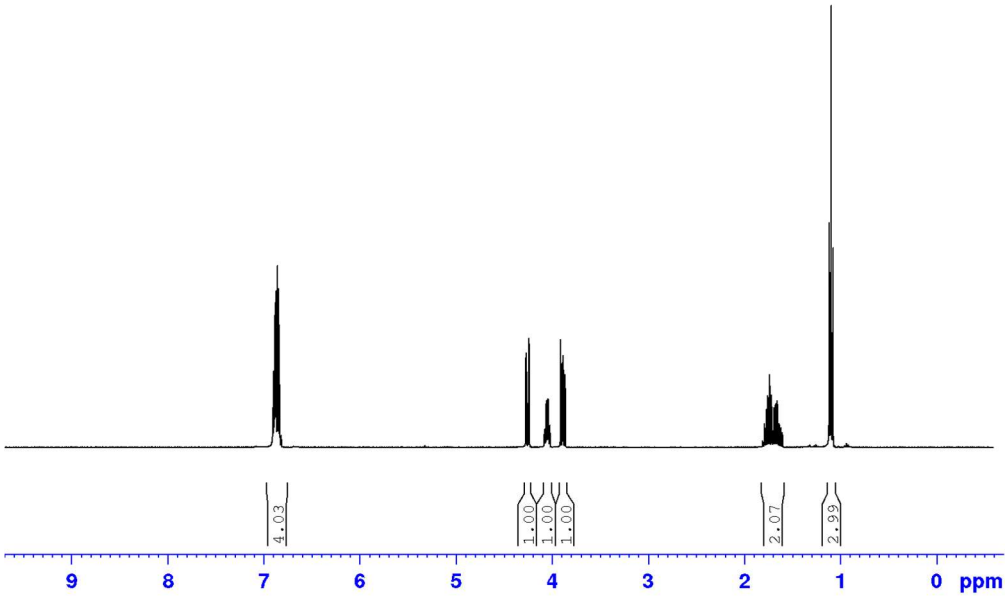

153.64
143.79
143.03
138.35
131.98
121.71
121.60
117.55
117.16
103.62
77.28
77.02
76.77
75.24
69.43
60.86
56.23
0.00


180
160
140
120
100
80
60
40
20
0
ppm

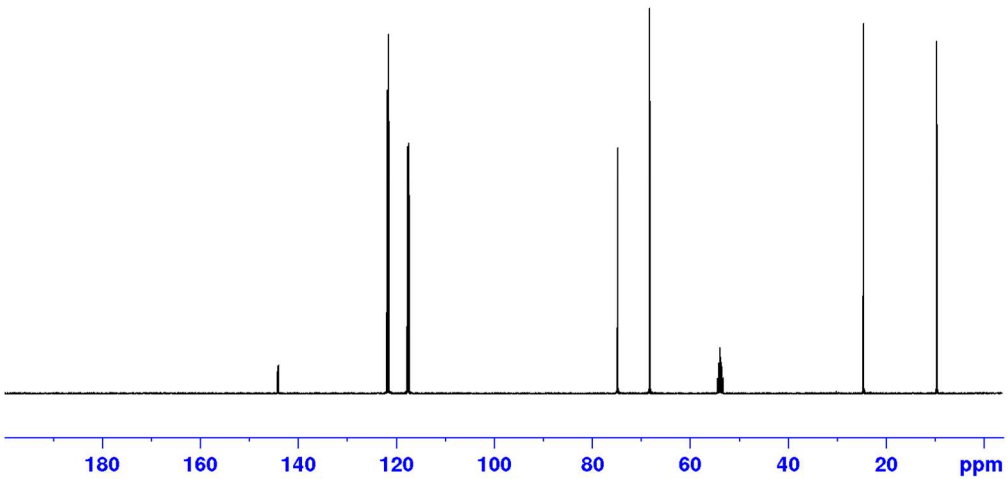

6.90
6.90
6.89
6.89
6.89
6.88
6.88
6.88
6.87
6.87
6.86
6.85
6.85
6.84
6.83
6.83
6.83
4.27
4.27
4.25
4.24
4.06
4.05
4.04
4.04
3.91
3.89
3.88
3.86
1.79
1.77
1.75
1.75
1.74
1.72
1.69
1.67
1.67
1.66
1.12
1.10
1.08

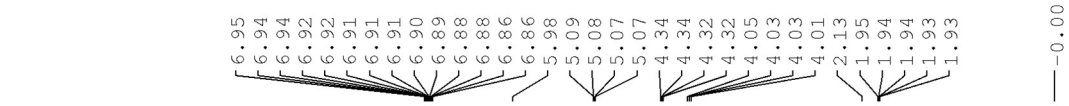


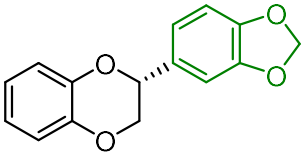
6h


4.03
1.00
1.00
1.00
2.07
2.99
9
8
7
6
5
4
3
2
1
0
ppm

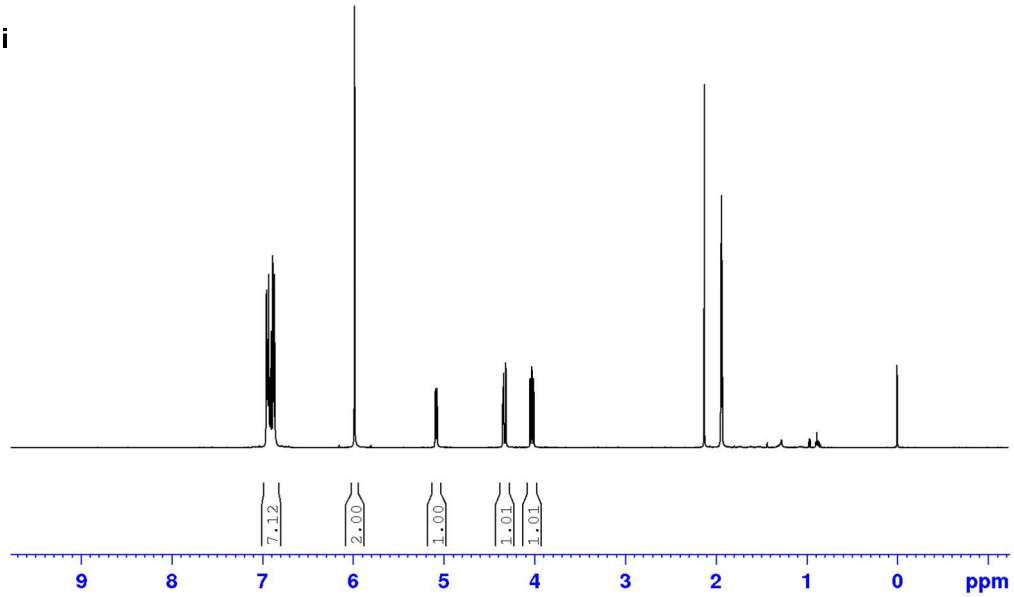

144.09
143.90
121.72
121.44
117.58
117.26
74.77
68.25
54.38
54.11
53.84
53.57
53.30
24.57
9.61

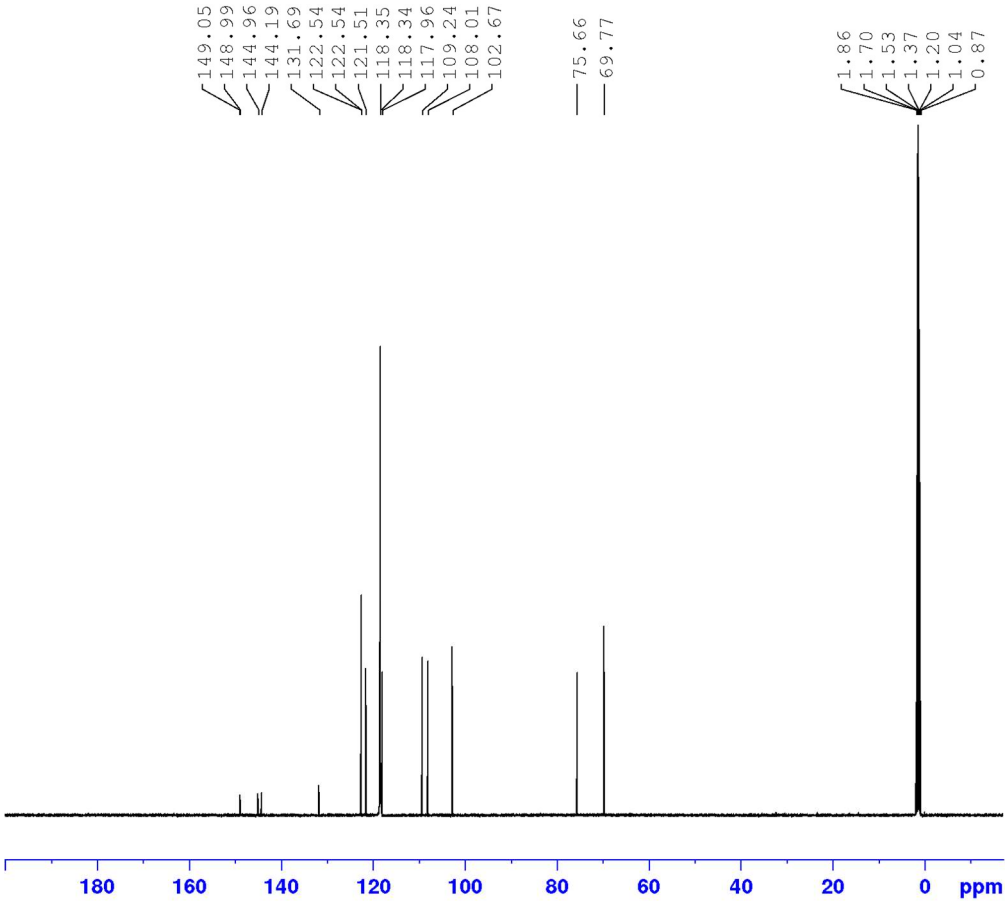

180
160
140
120
100
80
60
40
20
ppm

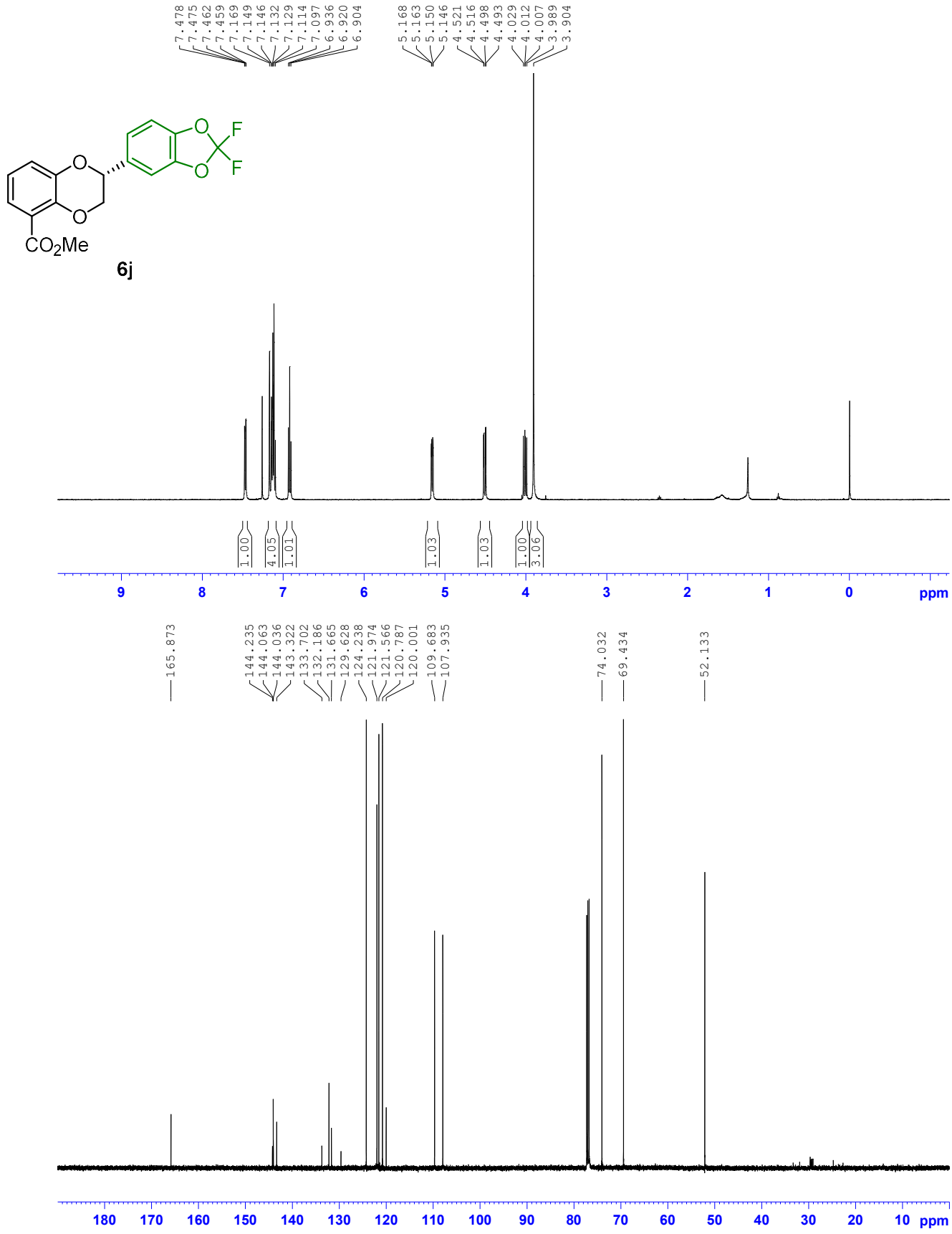

6.95
6.94
6.94
6.92
6.92
6.91
6.91
6.91
6.90
6.89
6.88
6.88
6.86
5.98
5.09
5.08
5.07
4.34
4.34
4.32
4.32
4.05
4.03
4.03
4.01
2.13
1.95
1.94
1.94
1.93
1.93
0.00

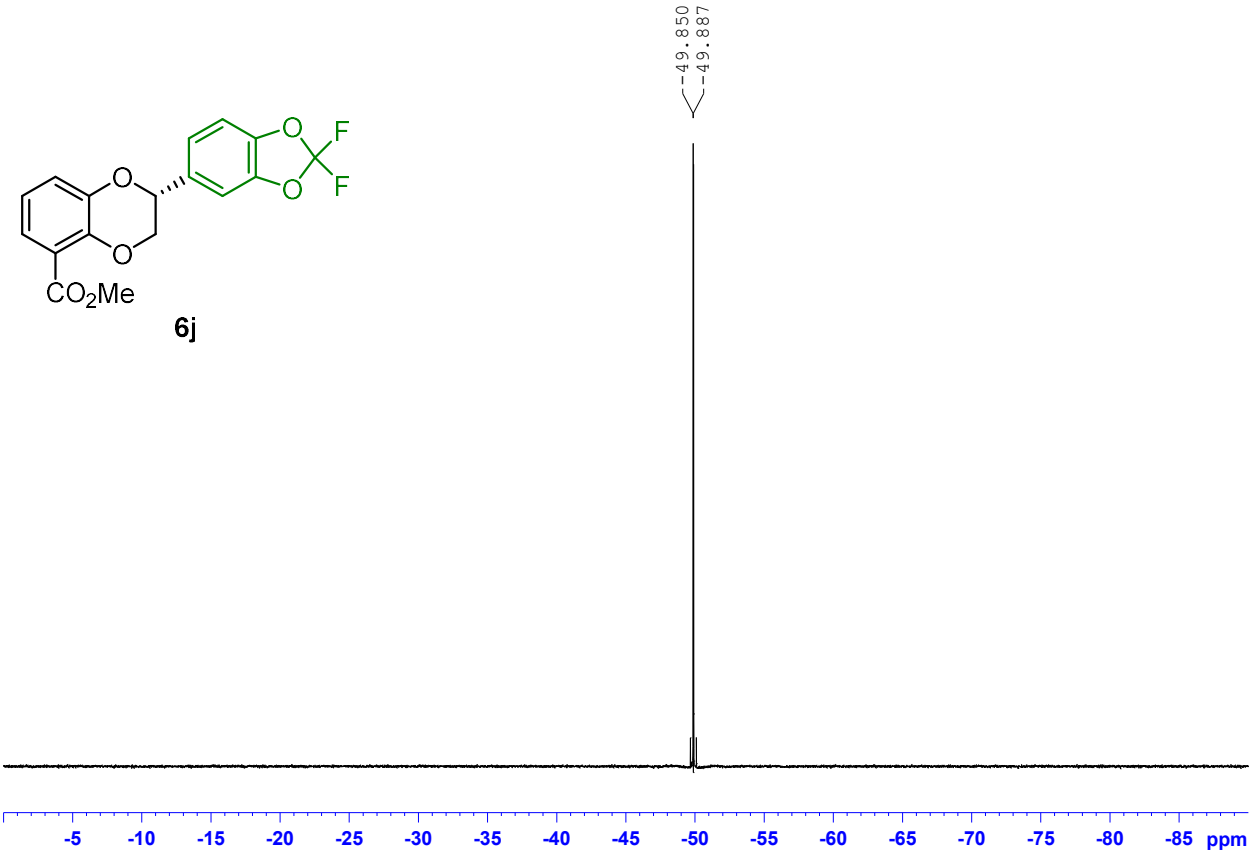


6i

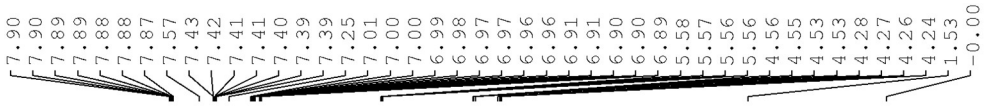

7.12
2.00
1.00
1.01
1.01
9
8
7
6
5
4
3
2
1
0
ppm

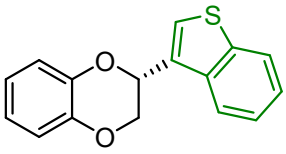

149.05
148.99
144.96
144.19
131.69
122.54
122.54
121.51
118.35
118.34
117.96
109.24
108.01
102.67
75.66
69.77
1.86
1.70
1.53
1.37
1.20
1.04
0.87
180
160
140
120
100
80
60
40
20
0
ppm


7.478
7.475
7.462
7.459
7.169
7.149
7.146
7.132
7.129
7.114
7.097
6.936
6.920
6.904
5.168
5.163
5.150
5.146
4.521
4.516
4.498
4.493
4.029
4.012
4.007
3.989
3.904
O
F
F
O
O
O
CO2Me
6j
1.00
4.05
1.01
1.03
1.03
1.00
3.06
9
8
7
6
5
4
3
2
1
0
ppm
165.873
144.235
144.063
144.036
143.322
133.702
132.186
131.665
129.628
124.238
121.974
121.566
120.787
120.001
109.683
107.935
74.032
69.434
52.133
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm

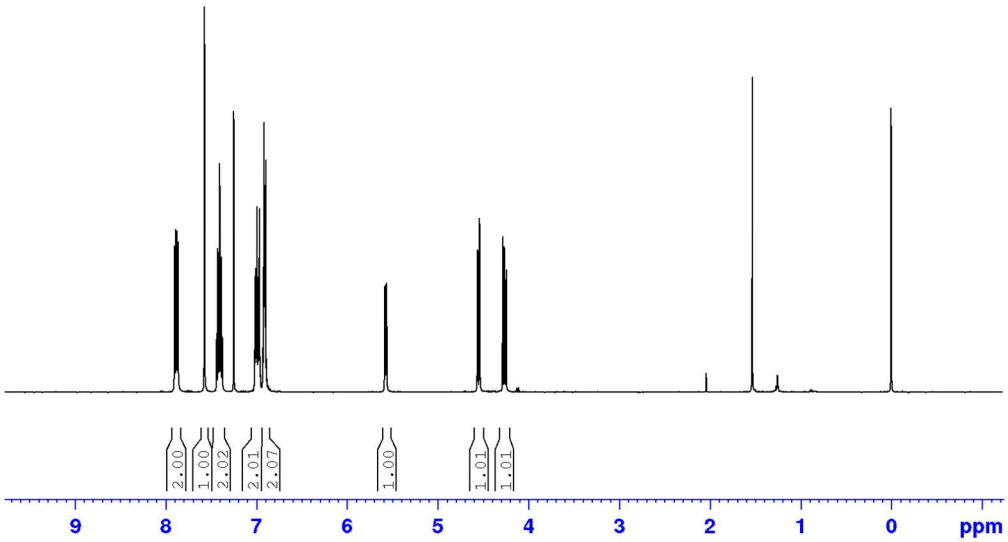

-49.850
-49.887
O
F
F
O
O
O
CO2Me
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
ppm

6j

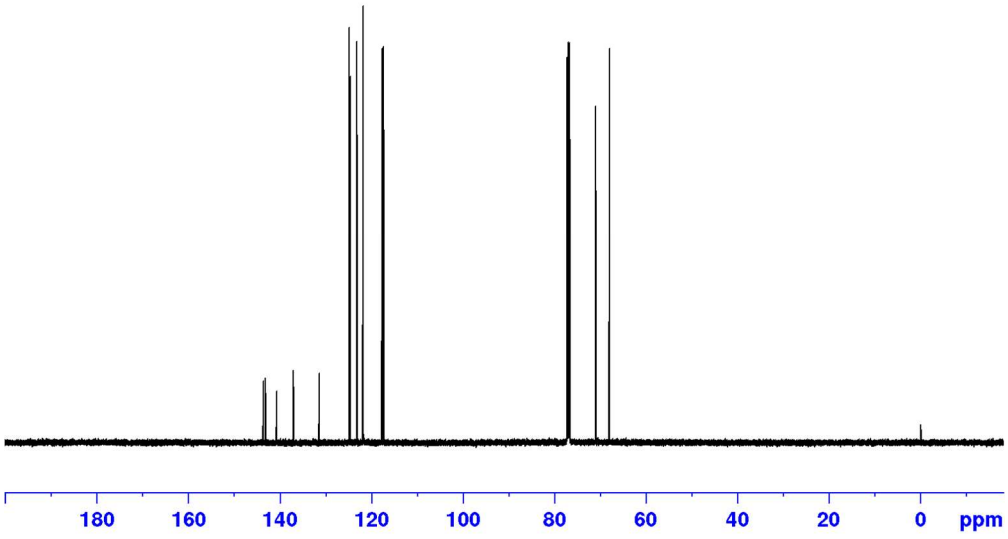

7.90
7.90
7.89
7.89
7.88
7.88
7.87
7.57
7.43
7.42
7.41
7.41
7.40
7.39
7.39
7.25
7.01
7.00
7.00
6.99
6.98
6.97
6.97
6.96
6.96
6.91
6.91
6.90
6.90
6.89
5.58
5.57
5.56
5.56
4.56
4.55
4.53
4.53
4.28
4.27
4.26
4.24
1.53
0.00

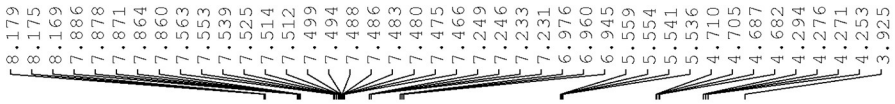

S
O
O

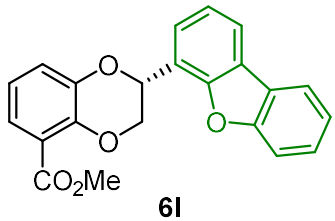
6k


2.00
1.00
2.02
2.01
2.07
1.00
1.01
1.01
9
8
7
6
5
4
3
2
1
0
ppm


143.56
143.12
140.69
136.96
131.34
124.82
124.79
124.53
123.08
121.79
121.75
121.70
117.62
117.24
77.28
77.02
76.77
71.07
68.08
0.01

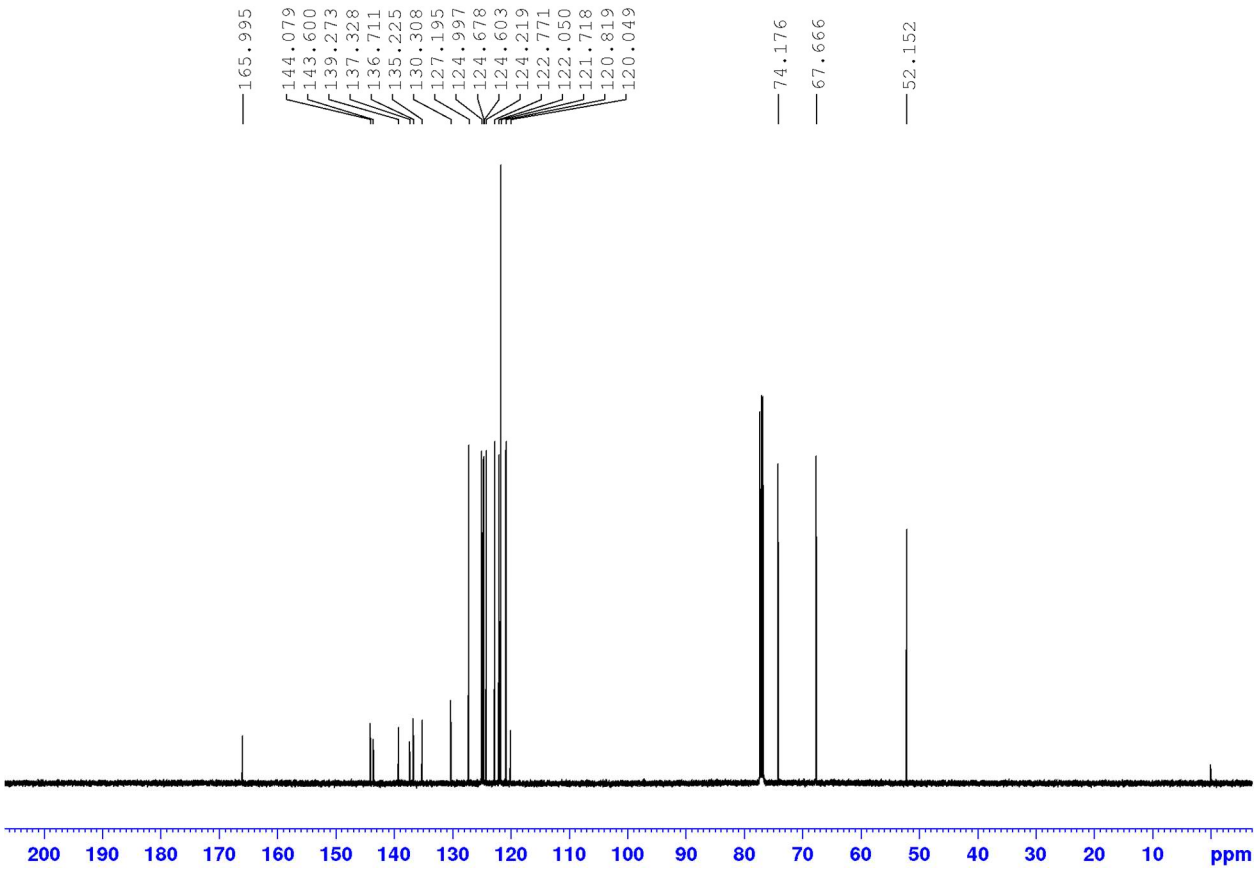

180
160
140
120
100
80
60
40
20
0
ppm

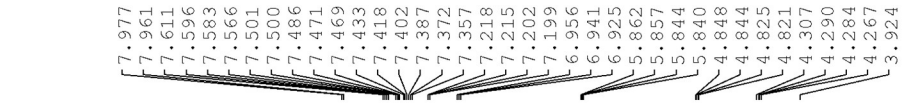

8.179
8.175
8.169
7.886
7.878
7.871
7.864
7.860
7.563
7.553
7.539
7.525
7.514
7.512
7.499
7.494
7.488
7.486
7.483
7.480
7.475
7.466
7.249
7.246
7.233
7.231
6.976
6.960
6.945
5.559
5.554
5.541
5.536
4.710
4.705
4.687
4.682
4.294
4.276
4.271
4.253
3.925

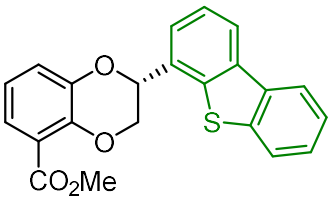

O
O
O
CO2Me

6l

10
9
8
7
6
5
4
3
2
1
ppm
2.00
0.99
5.03
1.07
1.00
1.00
1.00
1.00
3.03

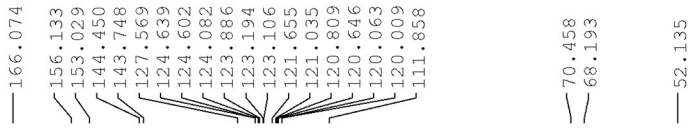

165.995
144.079
143.600
139.273
137.328
136.711
135.225
130.308
127.195
124.997
124.678
124.603
124.219
122.771
122.050
121.718
120.819
120.049
74.176
67.666
52.152
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm

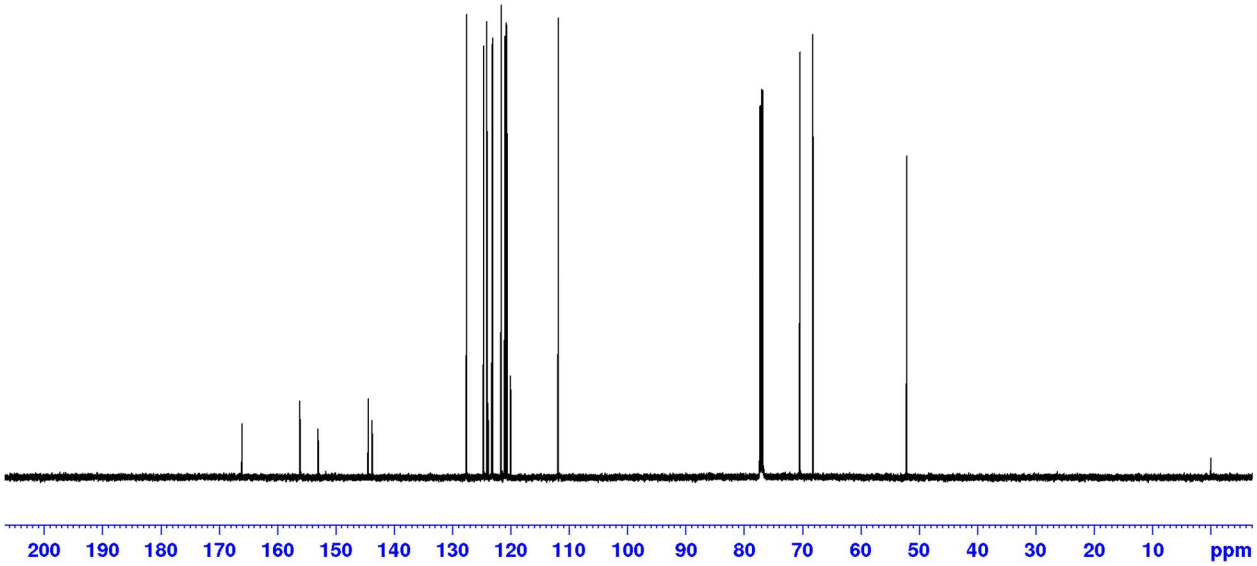

7.977
7.961
7.611
7.596
7.583
7.566
7.501
7.500
7.486
7.471
7.469
7.433
7.418
7.402
7.387
7.372
7.357
7.218
7.215
7.202
7.199
6.956
6.941
6.925
5.862
5.857
5.844
5.840
4.848
4.844
4.825
4.821
4.307
4.290
4.284
4.267
3.924

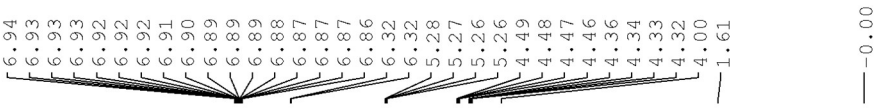

O
O
S
CO2Me

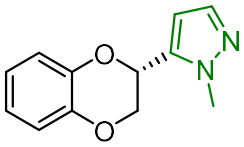
6m

10
9
8
7
6
5
4
3
2
1
ppm
2.00
2.07
2.02
1.03
1.00
1.00
1.00
1.01
1.01
3.05


166.074
156.133
153.029
144.450
143.748
127.569
124.639
124.602
124.082
123.886
123.194
123.106
121.655
121.035
120.809
120.646
120.063
120.009
111.858
70.458
68.193
52.135

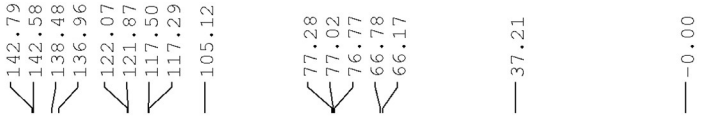

200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm

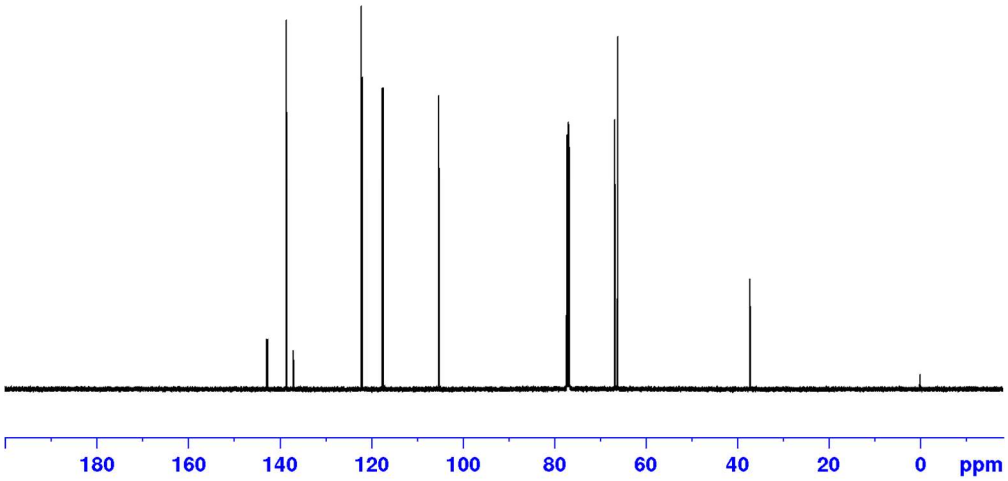

6.94
6.93
6.93
6.93
6.92
6.92
6.92
6.91
6.90
6.89
6.89
6.89
6.88
6.87
6.87
6.87
6.86
6.32
6.32
5.28
5.27
5.26
5.26
4.49
4.48
4.47
4.46
4.36
4.34
4.33
4.32
4.00
1.61
0.00

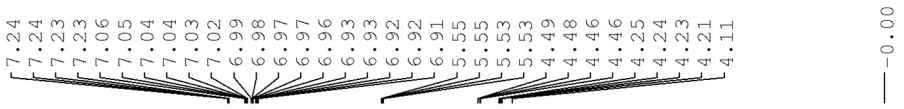


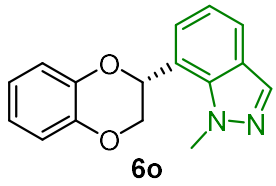
6n

1.00
4.11
1.00
1.00
1.02
1.02
3.05
9
8
7
6
5
4
3
2
1
0
ppm


142.79
142.58
138.48
136.96
122.07
121.87
117.50
117.29
105.12
77.28
77.02
76.77
66.78
66.17
37.21
0.00

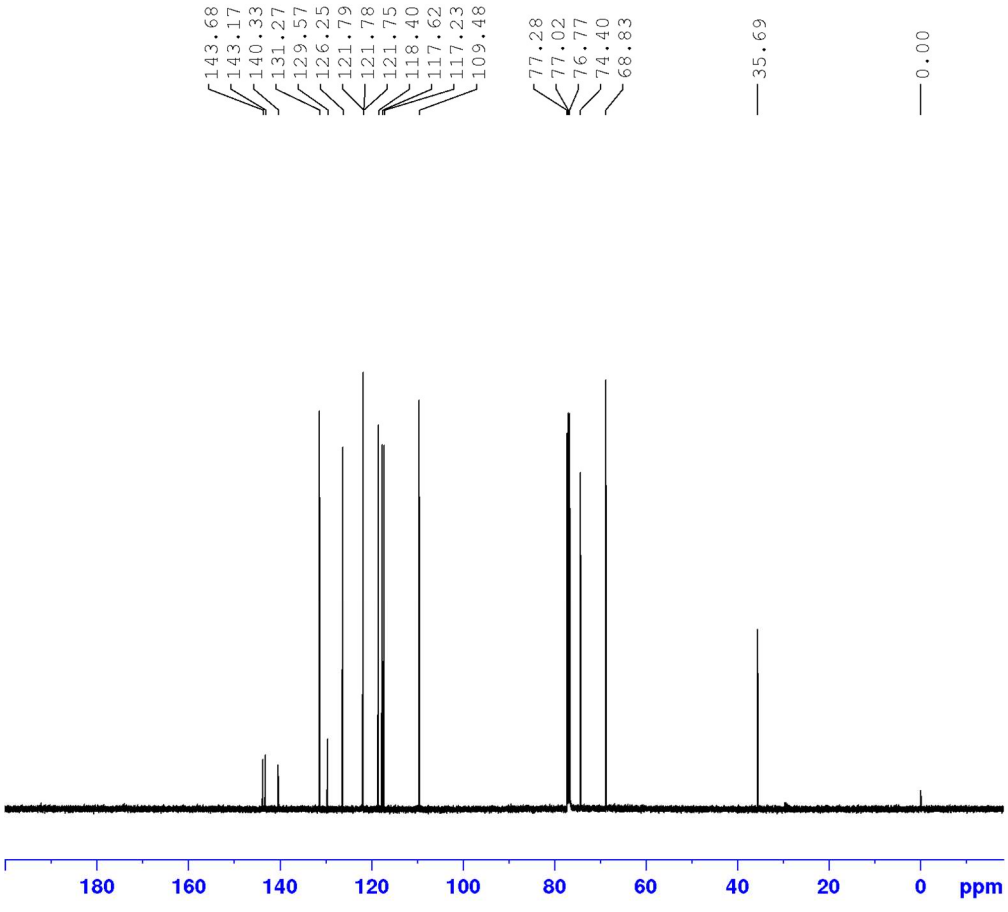

180
160
140
120
100
80
60
40
20
0
ppm

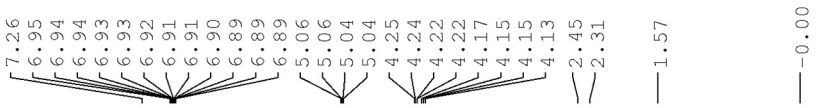

7.24
7.24
7.23
7.23
7.06
7.05
7.04
7.04
7.03
7.02
6.99
6.98
6.97
6.97
6.96
6.93
6.93
6.92
6.92
6.91
5.55
5.55
5.53
5.53
4.49
4.48
4.46
4.46
4.25
4.24
4.23
4.21
4.11
0.00

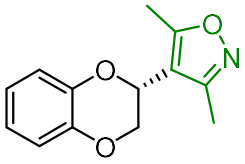

O
O
N–N

6o

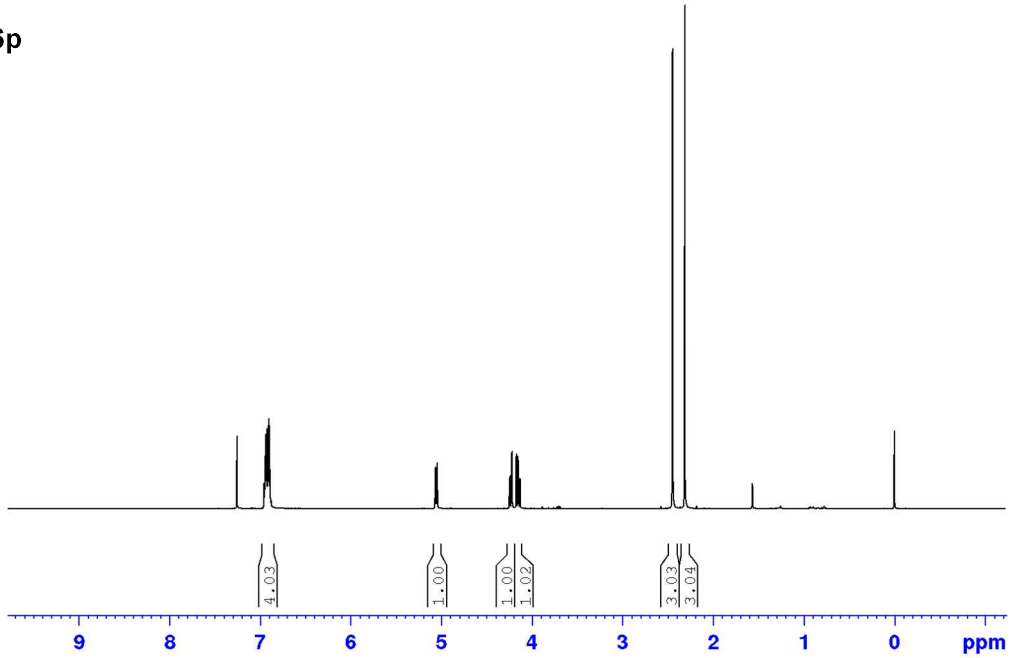
0.99
2.02
1.01
1.01
1.02
2.04
1.00
1.00
1.02
3.05
9
8
7
6
5
4
3
2
1
0
ppm

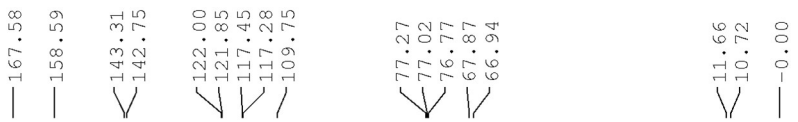

143.68
143.17
140.33
131.27
129.57
126.25
121.79
121.78
121.75
118.40
117.62
117.23
109.48
77.28
77.02
76.77
74.40
68.83
35.69
0.00
180
160
140
120
100
80
60
40
20
0
ppm

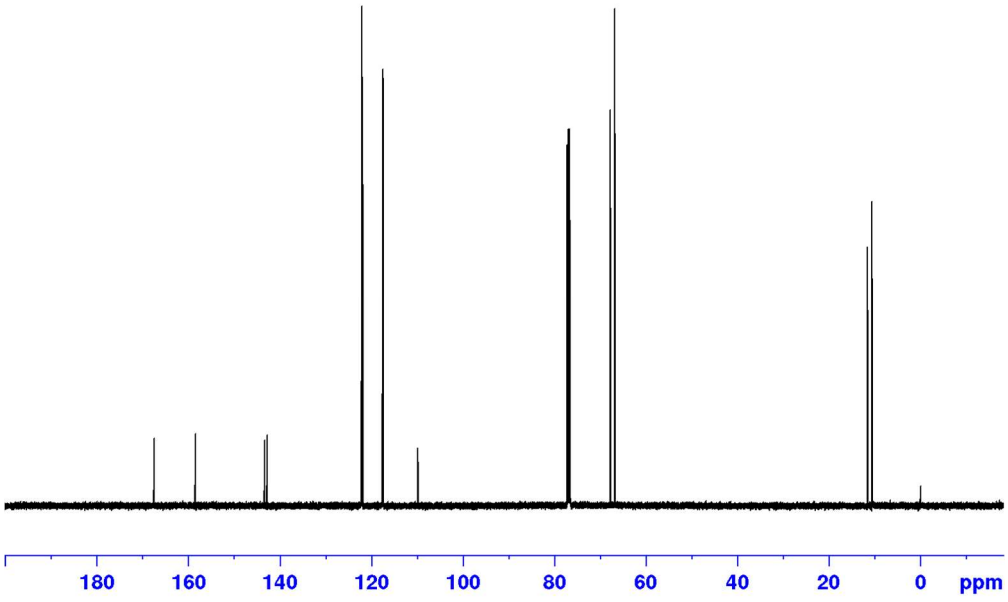

7.26
6.95
6.94
6.94
6.93
6.93
6.92
6.91
6.91
6.90
6.89
6.89
6.89
5.06
5.06
5.04
5.04
4.25
4.24
4.22
4.22
4.17
4.15
4.15
4.13
2.45
2.31
1.57
0.00

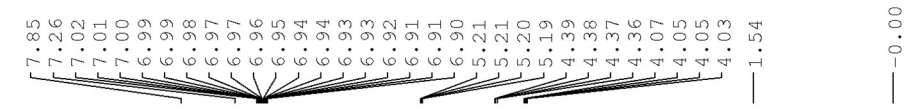


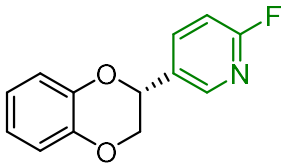
6p


4.03
1.00
1.00
1.02
3.03
3.04
9
8
7
6
5
4
3
2
1
0
ppm

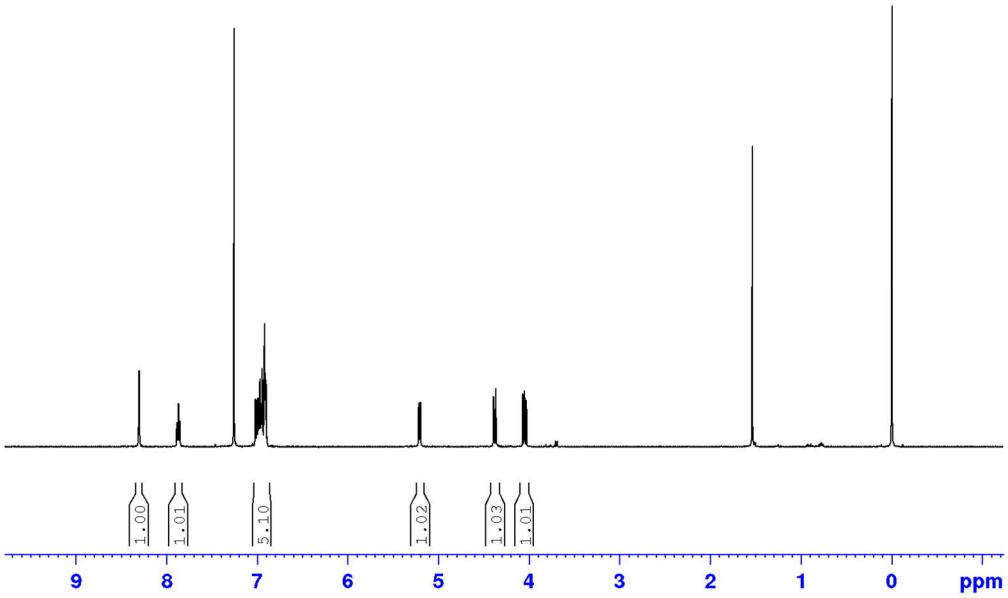

167.58
158.59
143.31
142.75
122.00
121.85
117.45
117.28
109.75
77.27
77.02
76.77
67.87
66.94
11.66
10.72
0.00

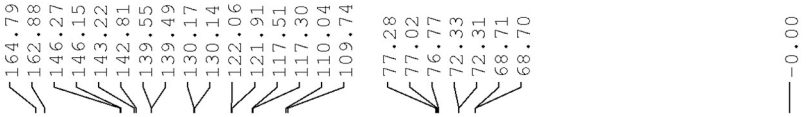

180
160
140
120
100
80
60
40
20
0
ppm

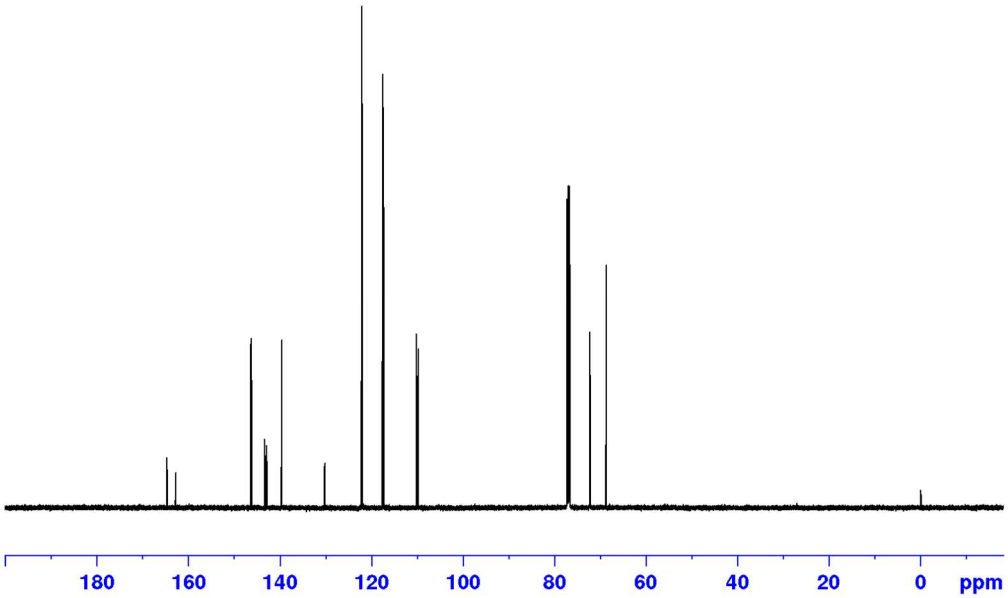

7.85
7.26
7.02
7.01
7.00
6.99
6.99
6.98
6.97
6.97
6.96
6.95
6.94
6.94
6.93
6.93
6.92
6.91
6.91
6.90
5.21
5.20
5.19
4.39
4.38
4.37
4.36
4.07
4.05
4.05
4.03
1.54
0.00

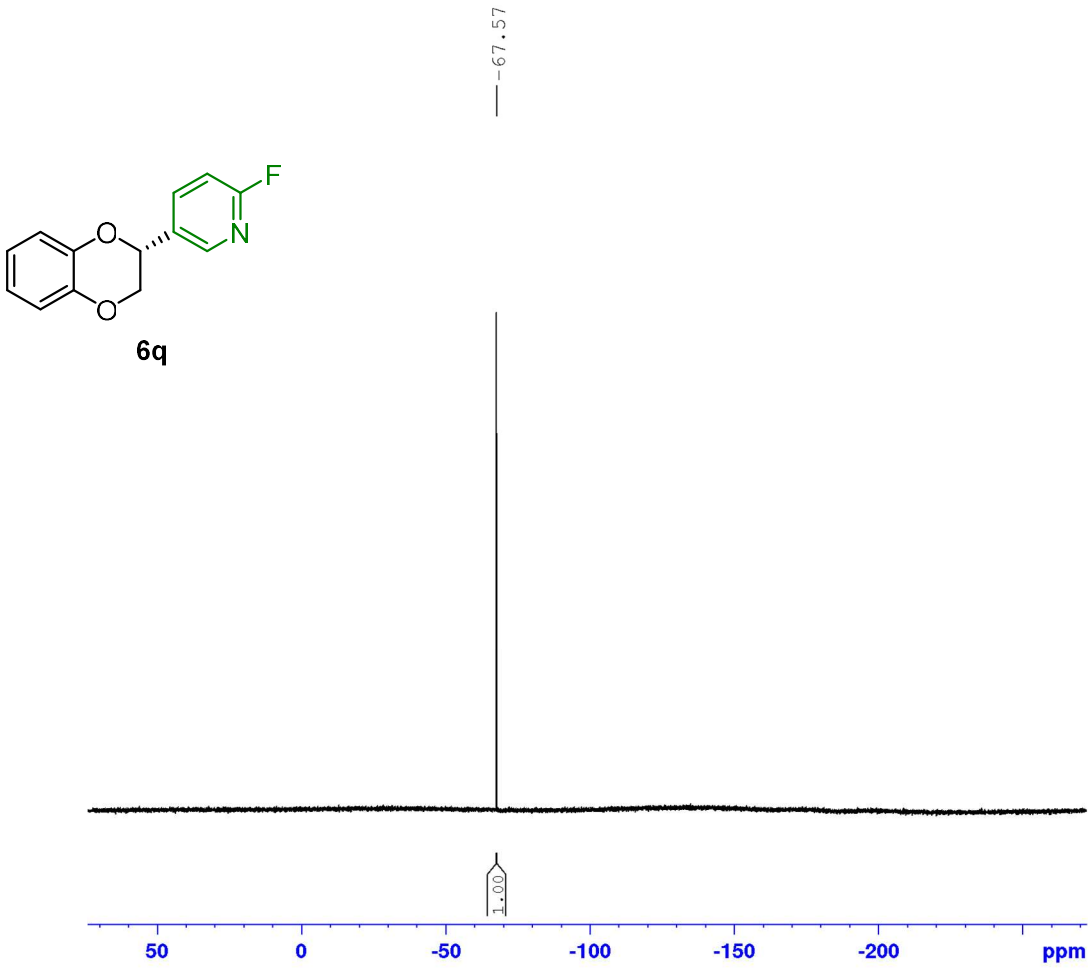

F
N
O
O

6q

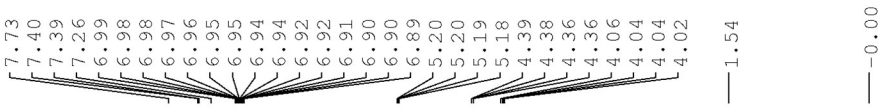

1.00
1.01
5.10
1.02
1.03
1.01
9
8
7
6
5
4
3
2
1
0
ppm

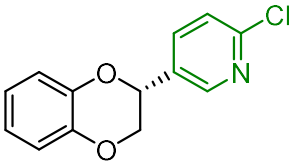

164.79
162.88
146.27
146.15
143.22
142.81
139.55
139.49
130.17
130.14
122.06
121.91
117.51
117.30
110.04
109.74
77.28
77.02
76.77
72.33
72.31
68.71
68.70
0.00


180
160
140
120
100
80
60
40
20
0
ppm

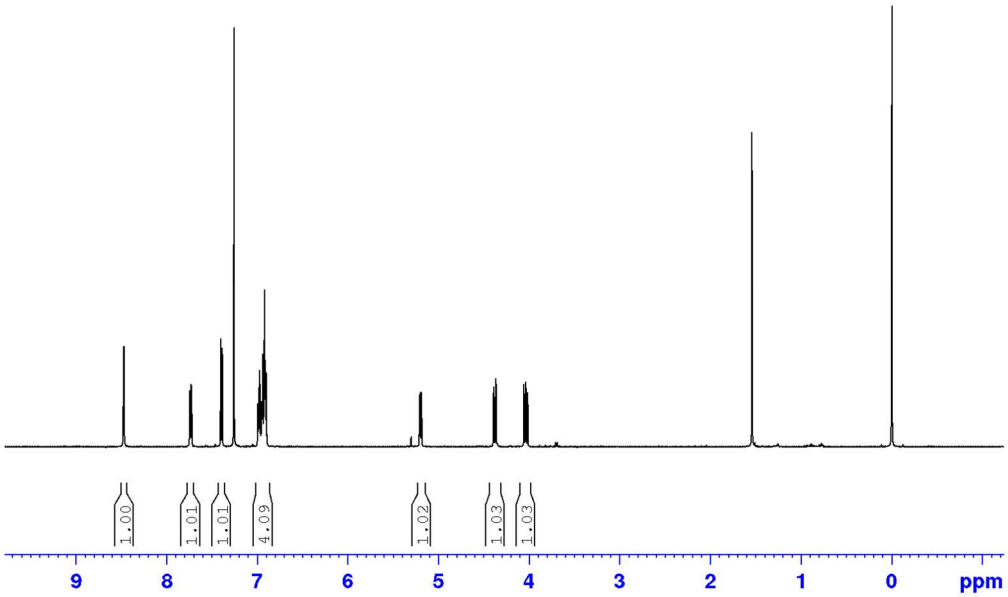


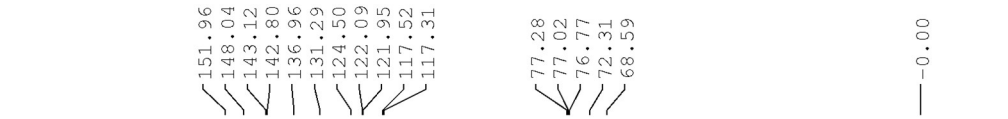
6q

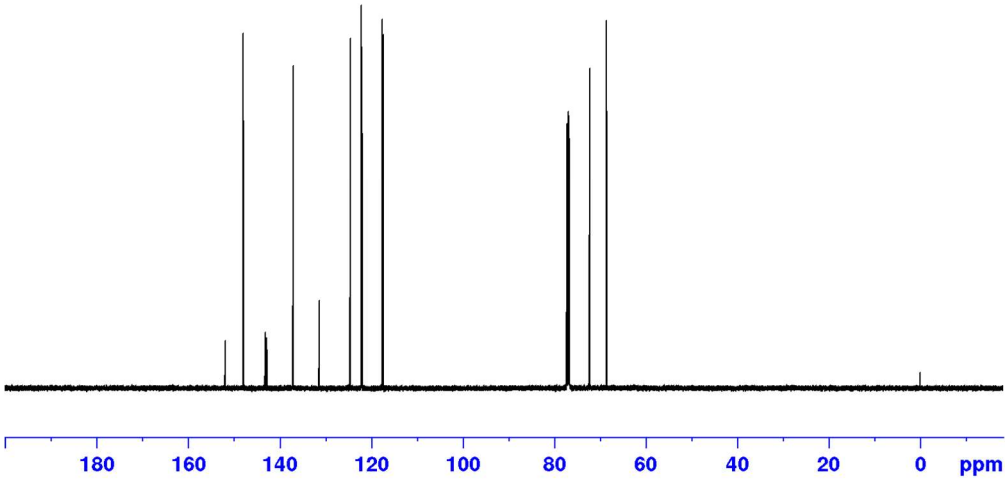

7.73
7.40
7.39
7.26
6.99
6.98
6.98
6.97
6.96
6.95
6.95
6.94
6.94
6.92
6.92
6.91
6.90
6.90
6.89
5.20
5.20
5.19
5.18
4.39
4.38
4.36
4.36
4.06
4.04
4.04
4.02
1.54
0.00

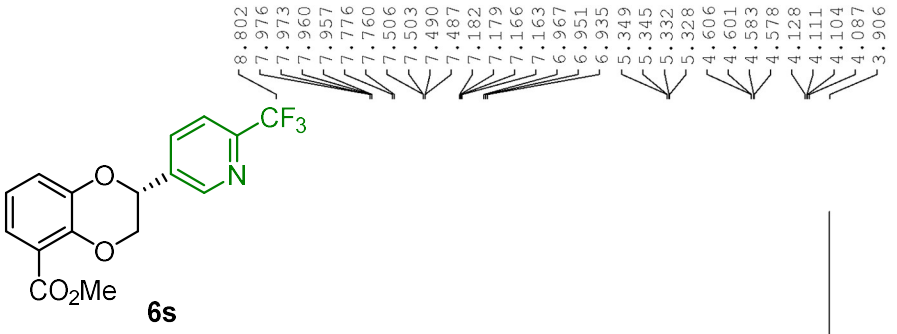

Cl
N
O
O

6r

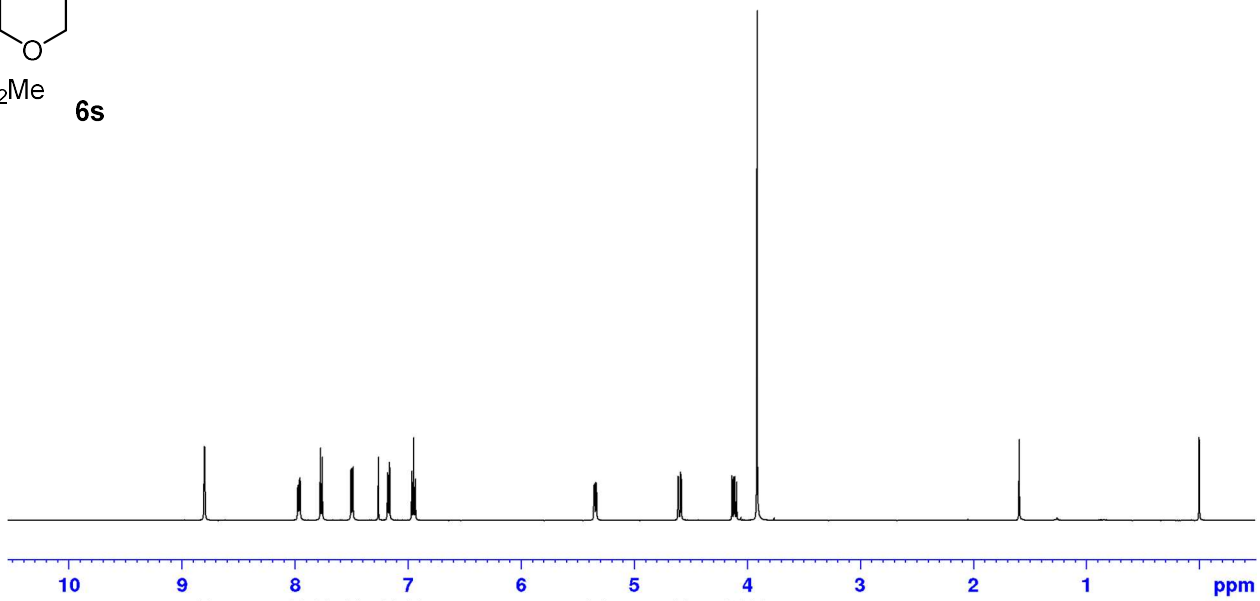

1.00
1.01
1.01
4.09
1.02
1.03
1.03
9
8
7
6
5
4
3
2
1
0
ppm

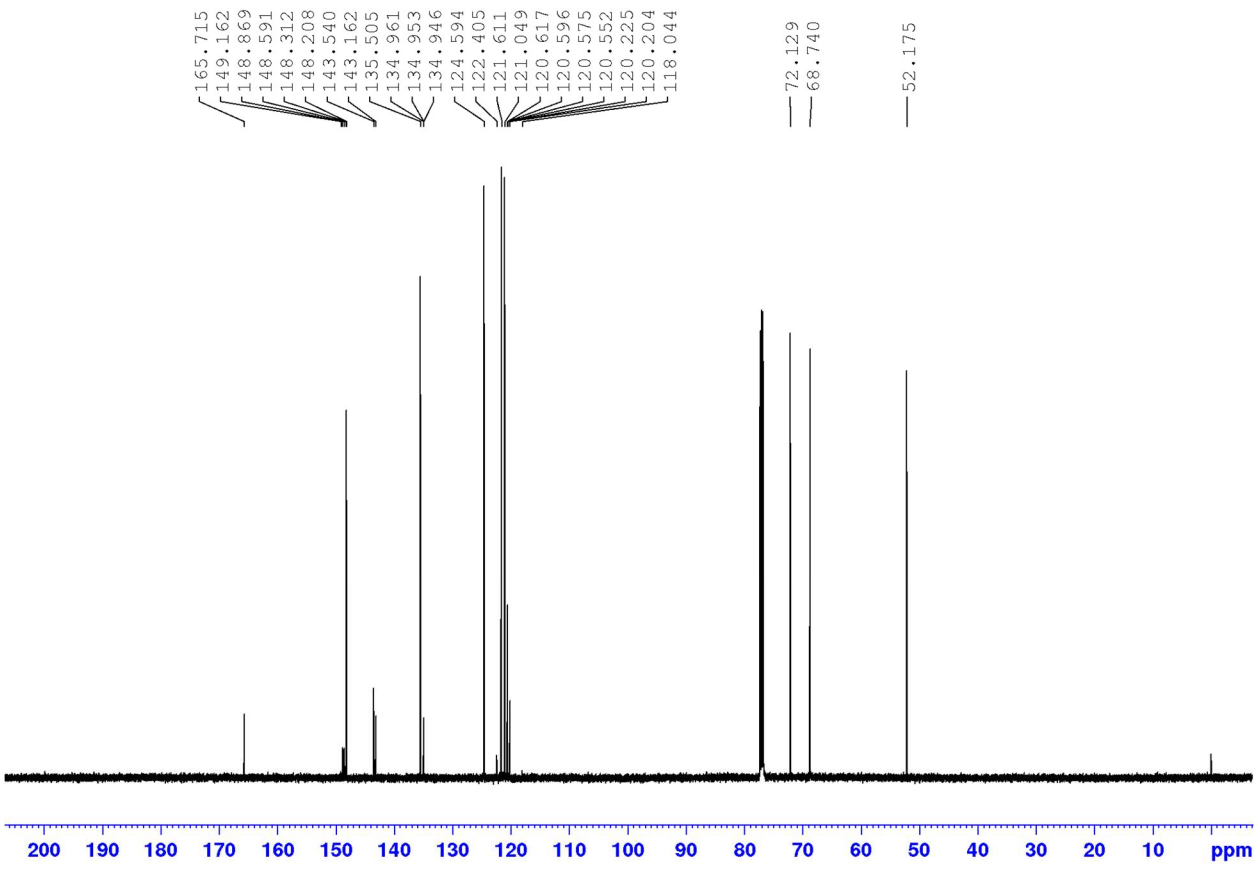

151.96
148.04
143.12
142.80
136.96
131.29
124.50
122.09
121.95
117.52
117.31
77.28
77.02
76.77
72.31
68.59
0.00

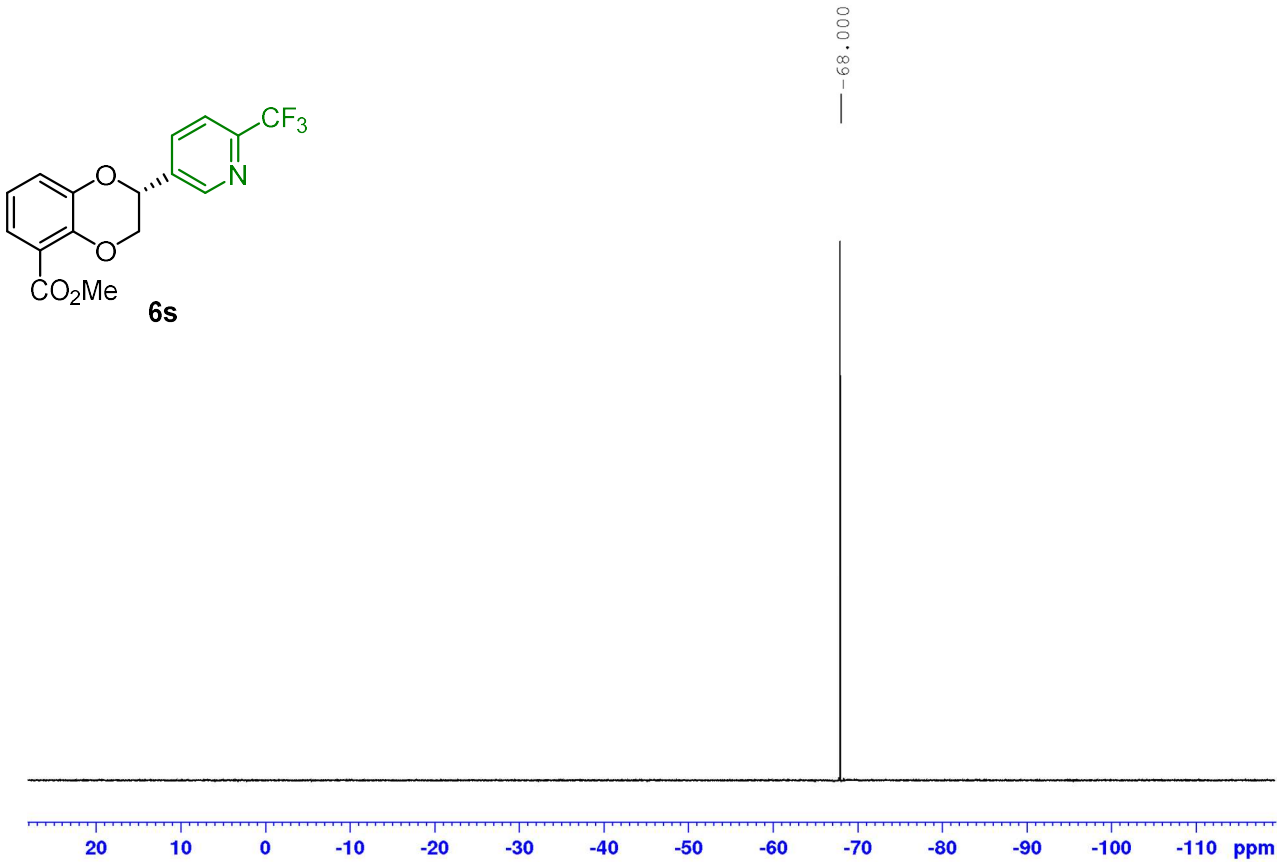

180
160
140
120
100
80
60
40
20
0
ppm


8.802
7.976
7.973
7.960
7.957
7.776
7.760
7.506
7.503
7.490
7.487
7.182
7.179
7.166
7.163
6.967
6.951
6.935
5.349
5.345
5.332
5.328
4.606
4.601
4.583
4.578
4.128
4.111
4.104
4.087
3.906
CF3
N
O
O
O
CO2Me

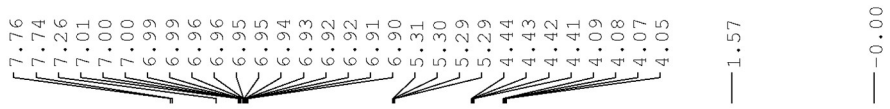
6s

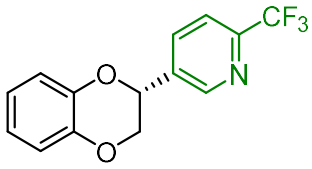

10
9
8
7
6
5
4
3
2
1
ppm
1.00
1.00
1.01
1.01
1.00
0.99
1.01
1.00
1.01
3.02


165.715
149.162
148.869
148.591
148.312
148.208
143.540
143.162
135.505
134.961
134.953
134.946
124.594
122.405
121.611
121.049
120.617
120.596
120.575
120.552
120.225
120.204
118.044
72.129
68.740
52.175
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm

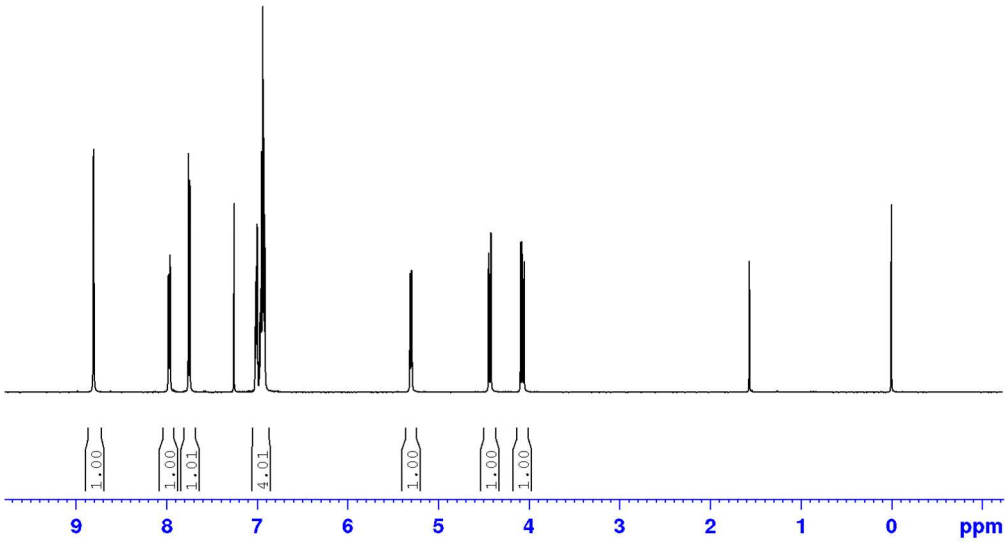


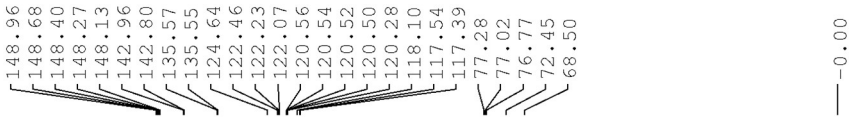
6s

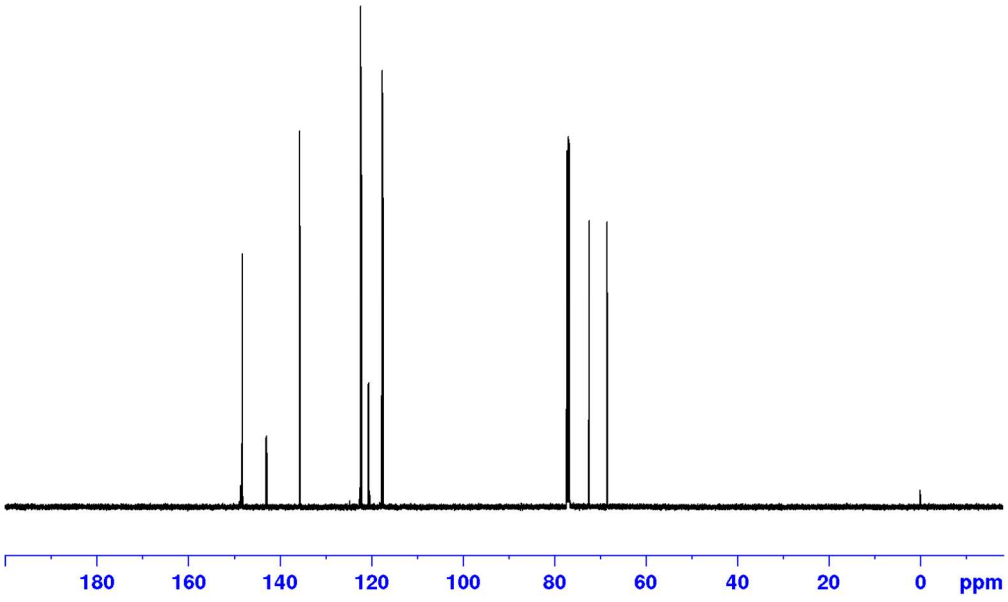

7.76
7.74
7.26
7.01
7.00
7.00
6.99
6.99
6.96
6.96
6.95
6.95
6.94
6.93
6.92
6.92
6.91
6.90
5.31
5.30
5.29
5.29
4.44
4.43
4.42
4.41
4.09
4.08
4.07
4.05
1.57
0.00

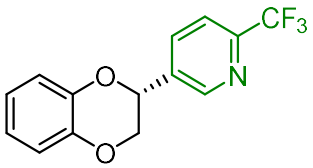

CF3
N
O
O

6t

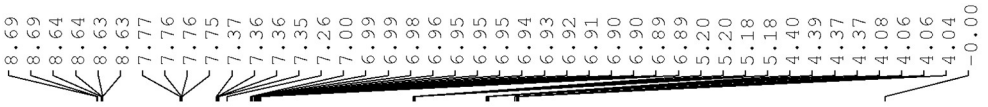

1.00
1.00
1.01
4.01
1.00
1.00
1.00
9
8
7
6
5
4
3
2
1
0
ppm

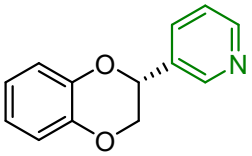

148.96
148.68
148.40
148.27
148.13
142.96
142.80
135.57
135.55
124.64
122.46
122.23
122.07
120.56
120.54
120.52
120.50
120.28
118.10
117.54
117.39
77.28
77.02
76.77
72.45
68.50
0.00


180
160
140
120
100
80
60
40
20
0
ppm

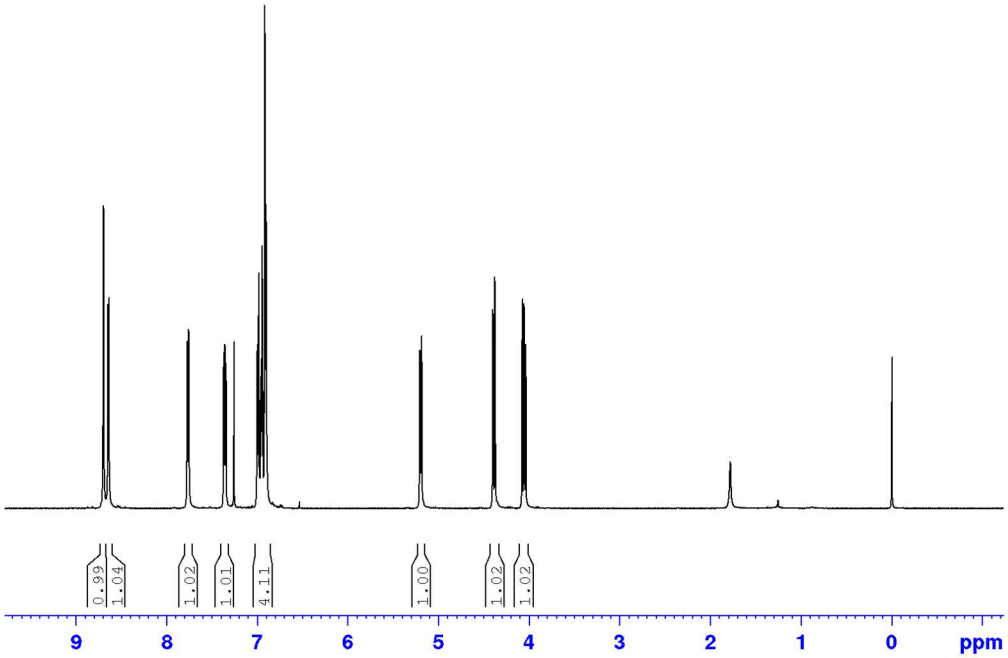


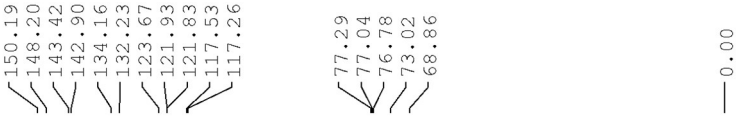
6t

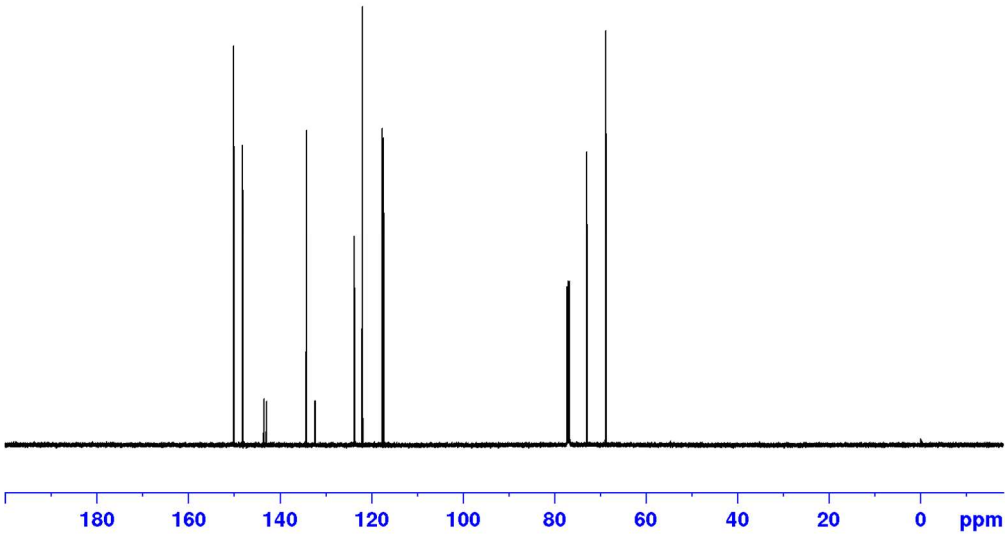

8.69
8.69
8.64
8.64
8.63
8.63
7.77
7.76
7.76
7.75
7.37
7.36
7.36
7.35
7.26
7.00
6.99
6.99
6.98
6.96
6.95
6.95
6.95
6.94
6.93
6.92
6.91
6.90
6.90
6.89
6.89
5.20
5.20
5.18
5.18
4.40
4.39
4.37
4.37
4.08
4.06
4.06
4.04
0.00

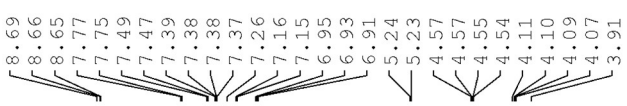


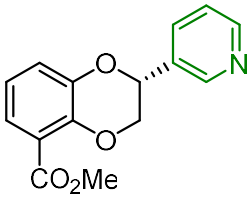
6u


0.99
1.04
1.02
1.01
4.11
1.00
1.02
1.02
9
8
7
6
5
4
3
2
1
0
ppm

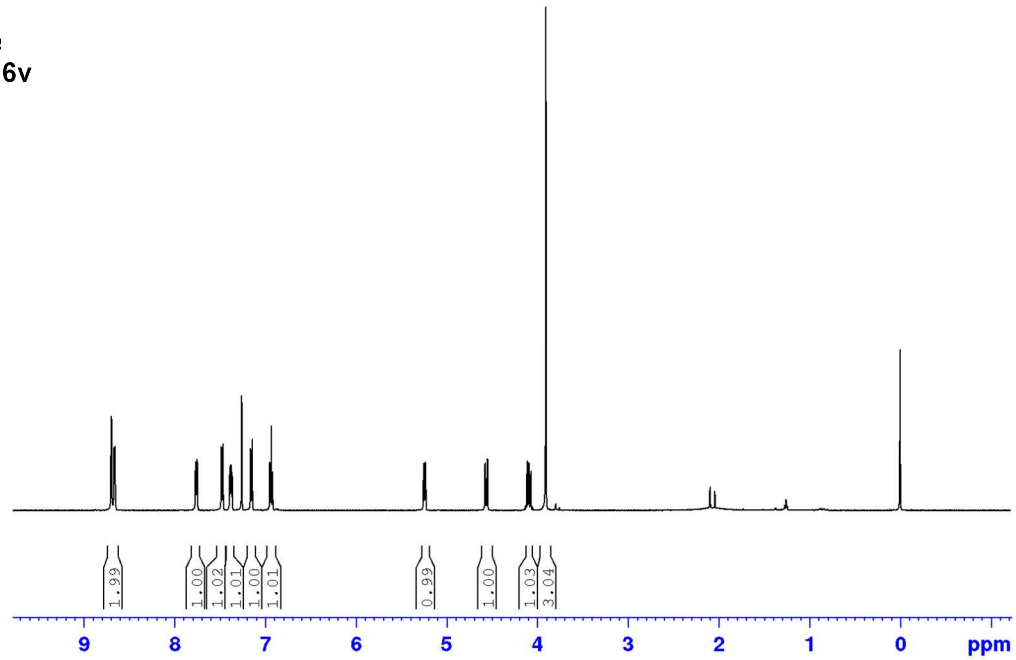

150.19
148.20
143.42
142.90
134.16
132.23
123.67
121.93
121.83
117.53
117.26
77.29
77.04
76.78
73.02
68.86
0.00


180
160
140
120
100
80
60
40
20
0
ppm

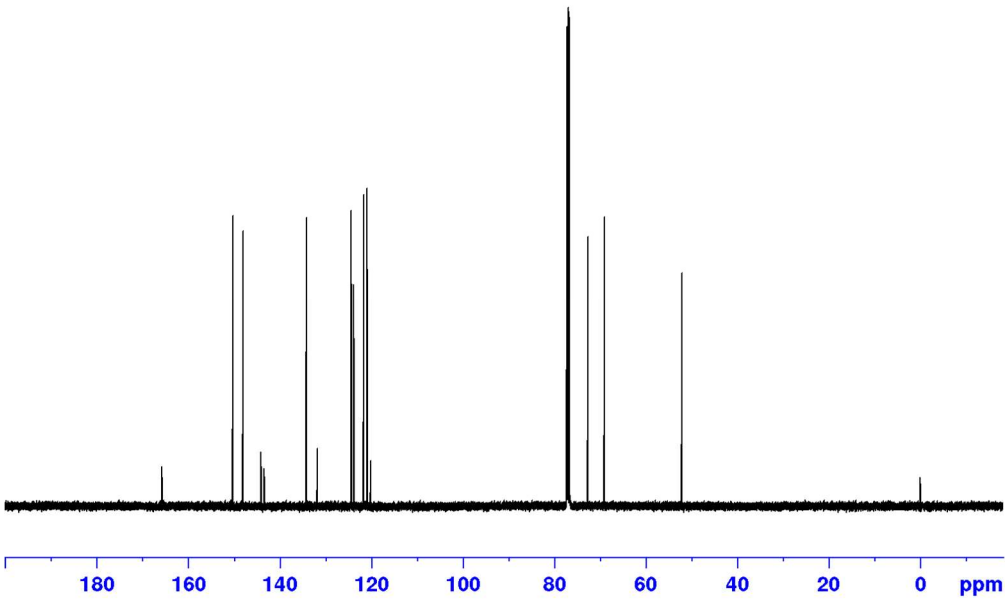

8.69
8.66
8.65
7.77
7.75
7.49
7.47
7.39
7.38
7.38
7.37
7.26
7.16
7.15
6.95
6.93
6.91
5.24
5.23
4.57
4.57
4.55
4.54
4.11
4.10
4.09
4.07
3.91
0.00

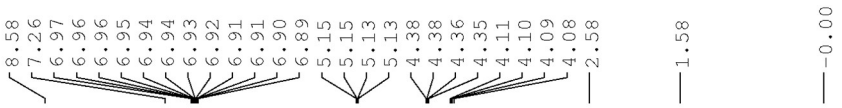

O
O
N
CO2Me

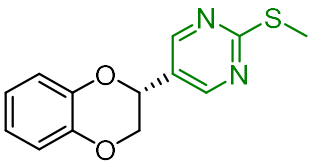
6v


1.99
1.00
1.02
1.01
1.00
1.01
0.99
1.00
1.03
3.04
9
8
7
6
5
4
3
2
1
0
ppm

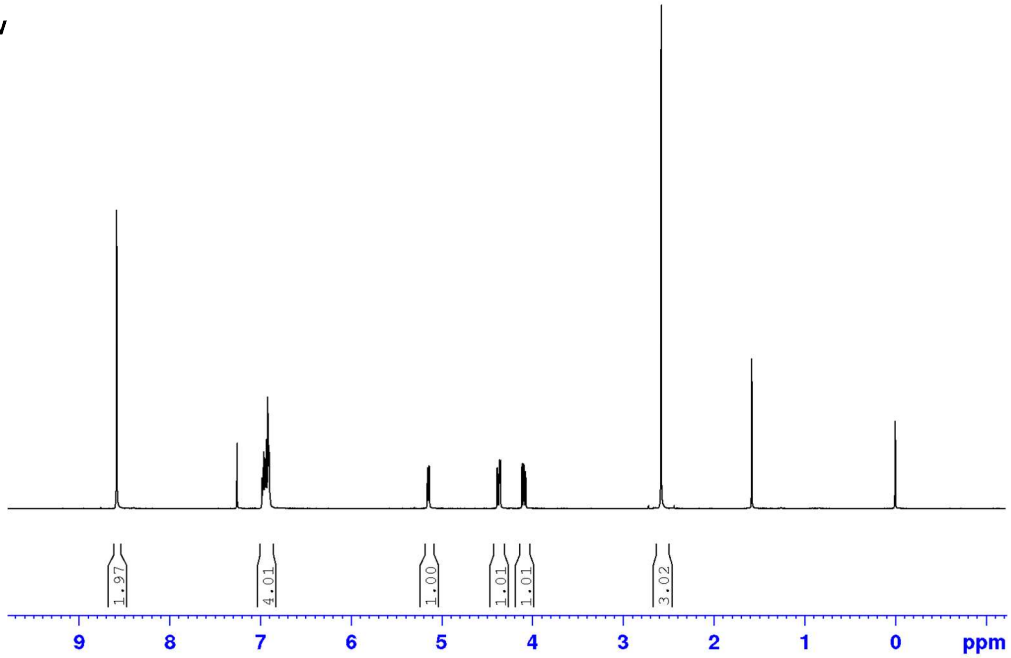

165.88
150.35
148.11
144.02
143.32
134.13
131.72
124.31
123.74
121.60
120.83
120.07
77.28
77.02
76.77
72.68
69.09
52.15
0.00

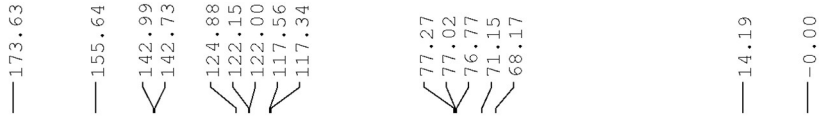

180
160
140
120
100
80
60
40
20
0
ppm

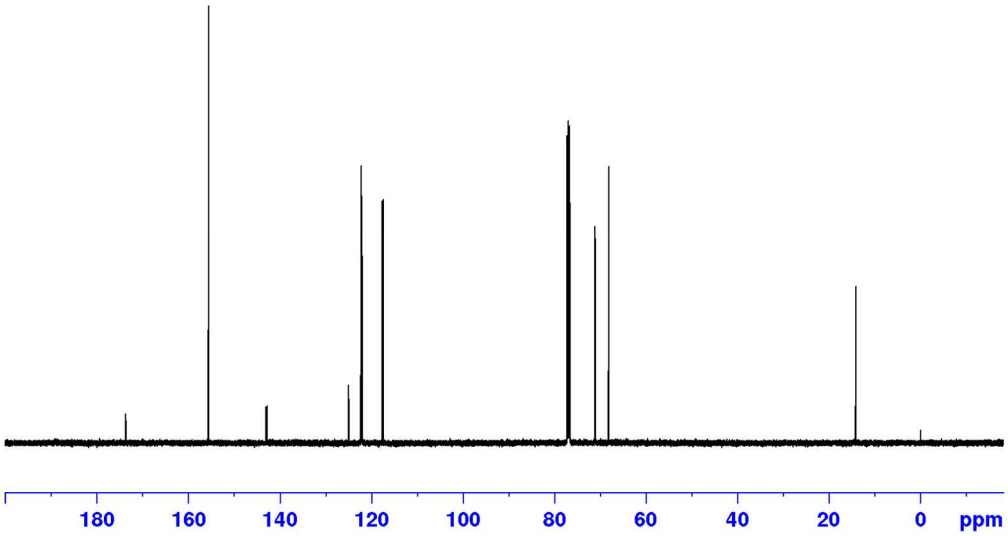

8.58
7.26
6.97
6.96
6.96
6.95
6.94
6.94
6.93
6.92
6.91
6.91
6.90
6.89
5.15
5.15
5.13
5.13
4.38
4.38
4.36
4.35
4.11
4.10
4.09
4.08
2.58
1.58
0.00

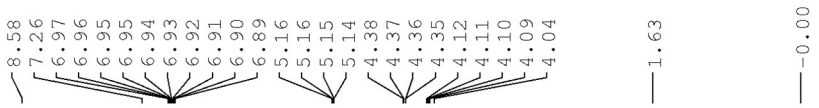

N
S
N
O
O

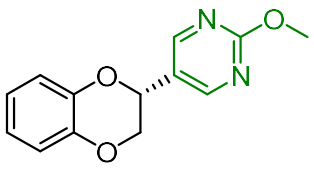
6w


1.97
4.01
1.00
1.01
1.01
3.02
9
8
7
6
5
4
3
2
1
0
ppm

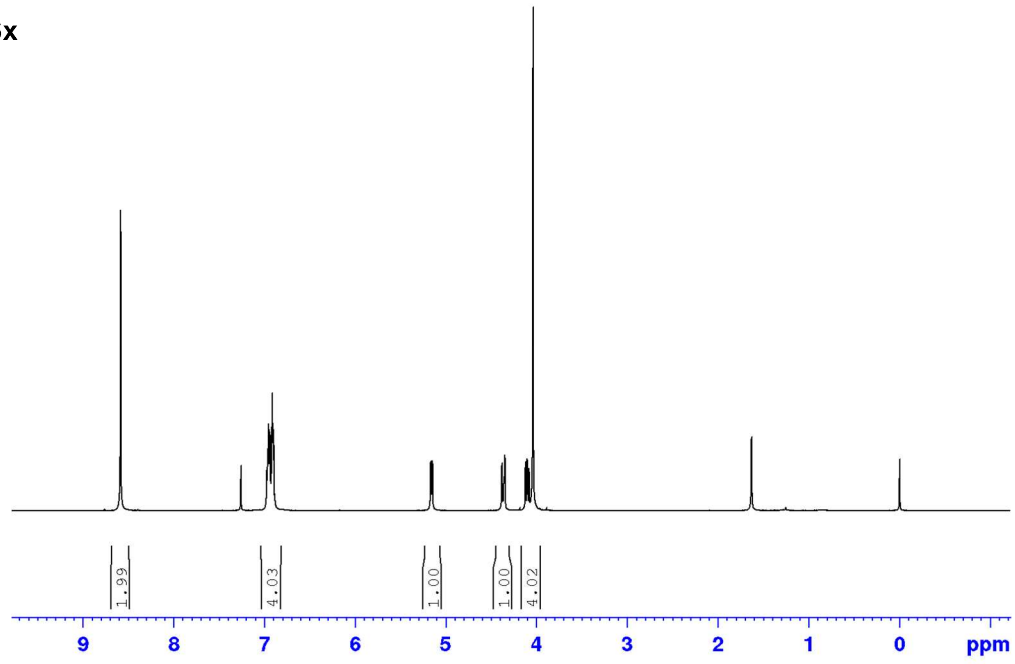

173.63
155.64
142.99
142.73
124.88
122.15
122.00
117.56
117.34
77.27
77.02
76.77
71.15
68.17
14.19
0.00

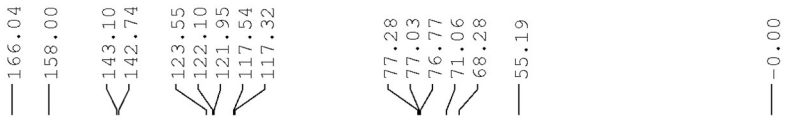

180
160
140
120
100
80
60
40
20
0
ppm

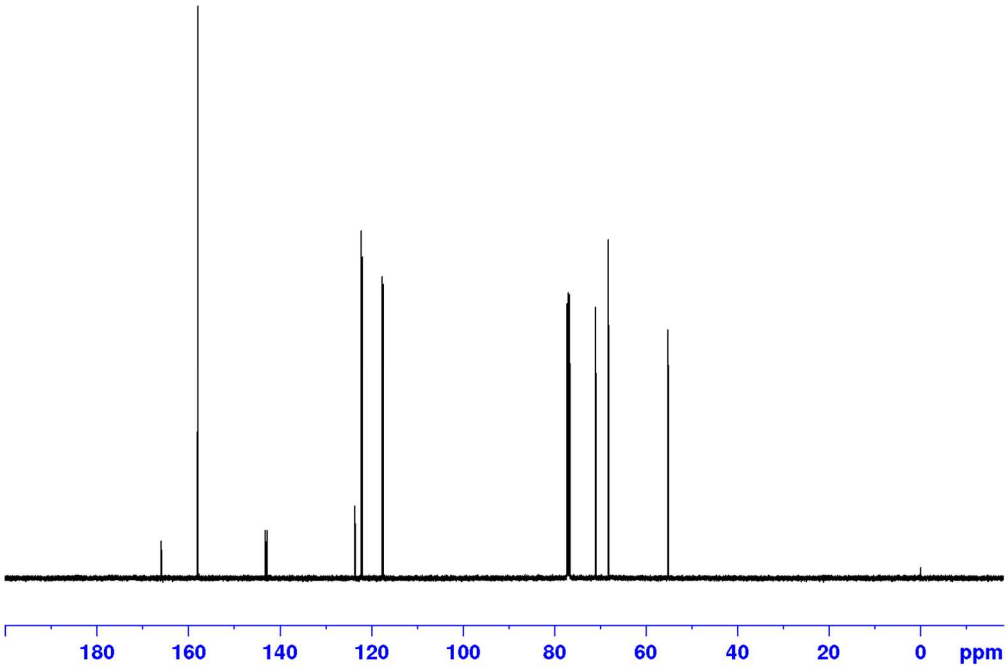

8.58
7.26
6.97
6.96
6.95
6.95
6.94
6.93
6.92
6.91
6.90
6.89
5.16
5.15
5.14
4.38
4.37
4.36
4.35
4.12
4.11
4.10
4.09
4.04
1.63
0.00

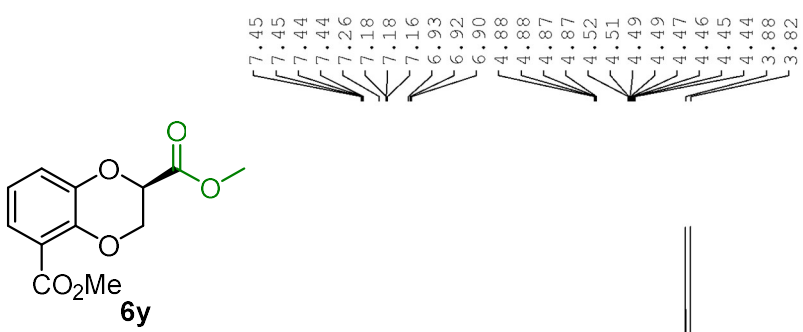


6x


1.99
4.03
1.00
1.00
4.02
9
8
7
6
5
4
3
2
1
0
ppm

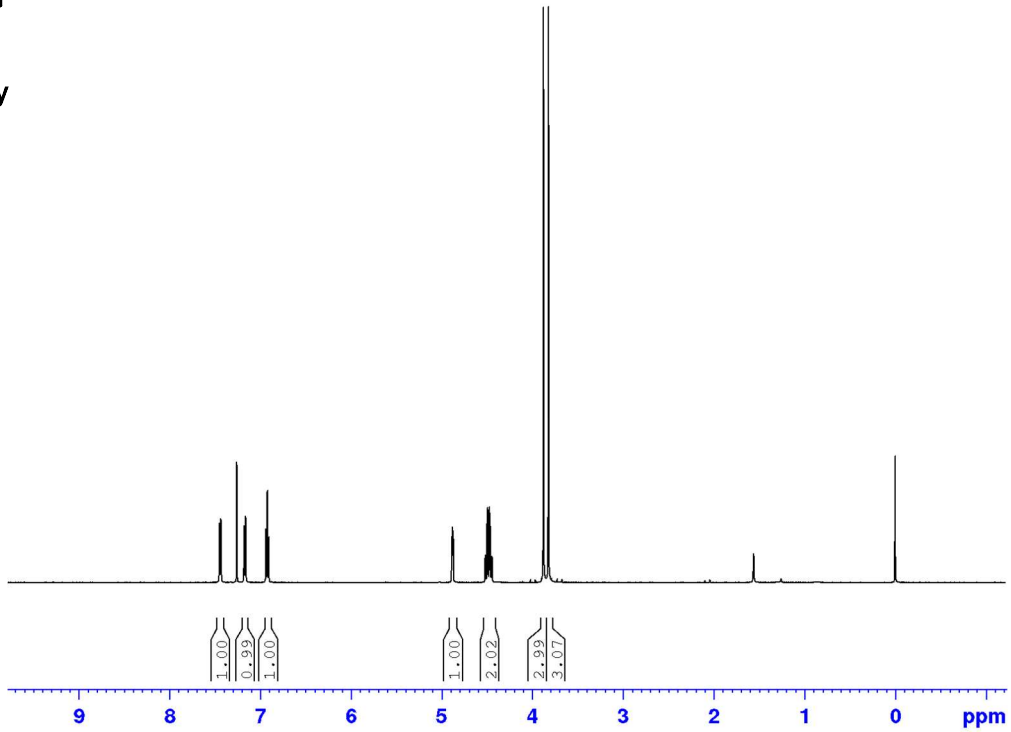

166.04
158.00
143.10
142.74
123.55
122.10
121.95
117.54
117.32
77.28
77.03
76.77
71.06
68.28
55.19
0.00

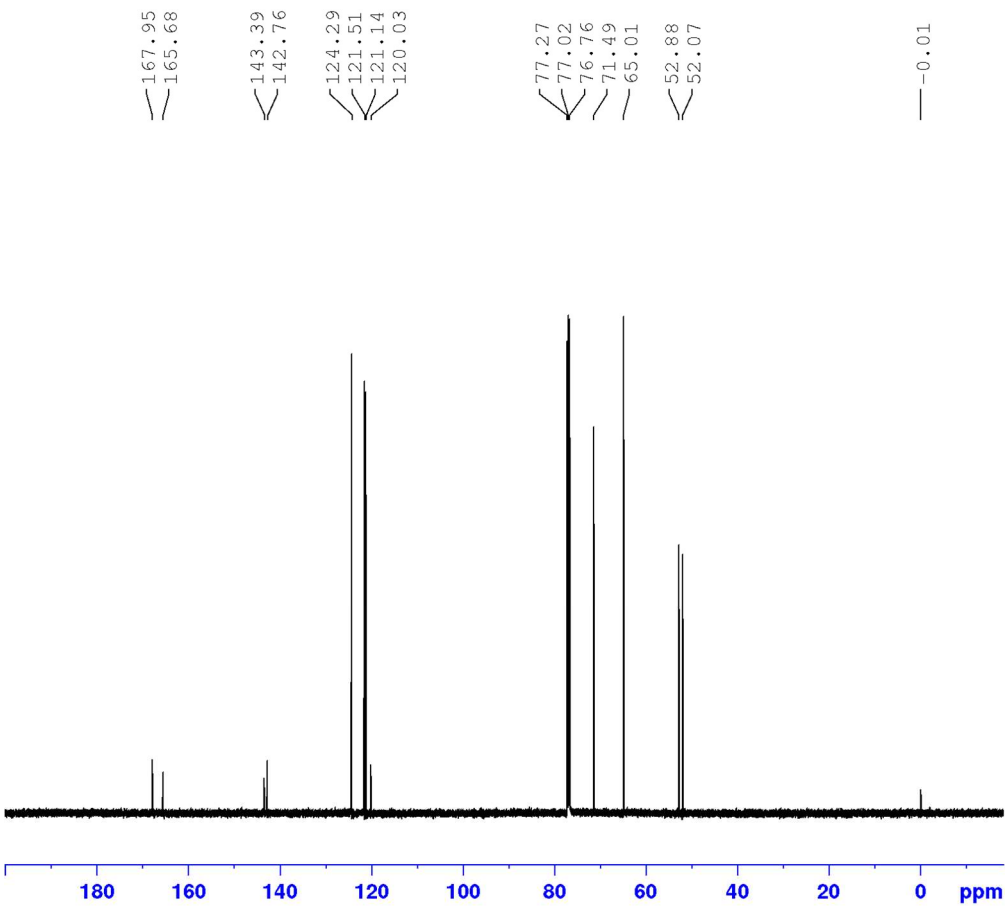

180
160
140
120
100
80
60
40
20
0
ppm

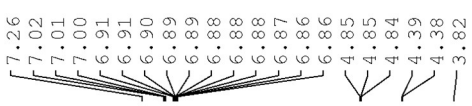

7.45
7.45
7.44
7.44
7.26
7.18
7.18
7.16
6.93
6.92
6.90
4.88
4.88
4.87
4.87
4.52
4.51
4.49
4.49
4.47
4.46
4.45
4.44
3.88
3.82
1.56
0.00

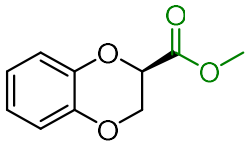
O
O
O
O
CO2Me

6y

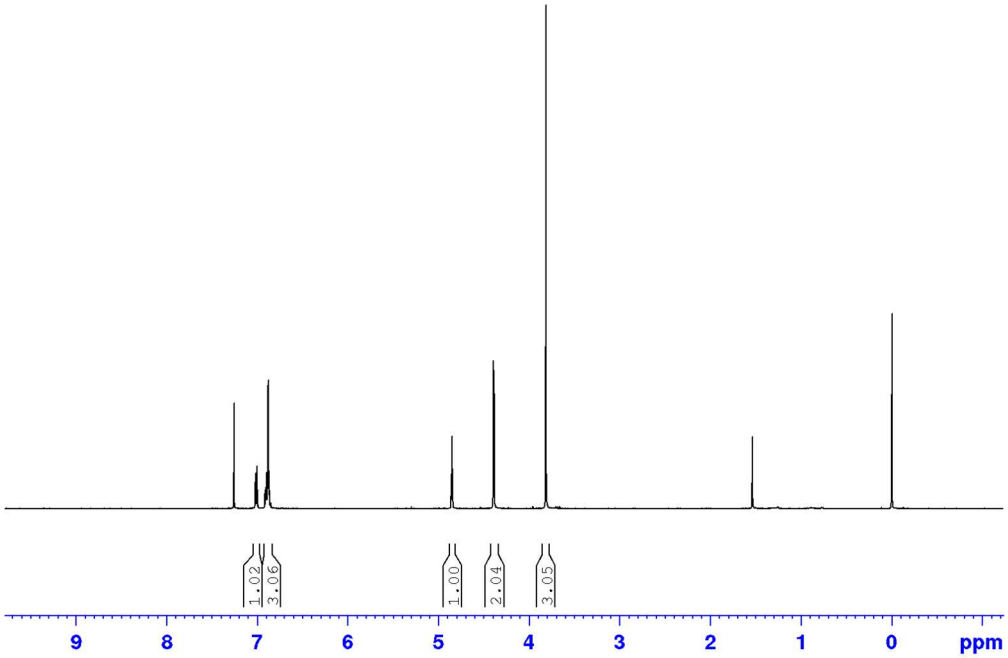

1.00
0.99
1.00
1.00
2.02
2.99
3.07
9
8
7
6
5
4
3
2
1
0
ppm

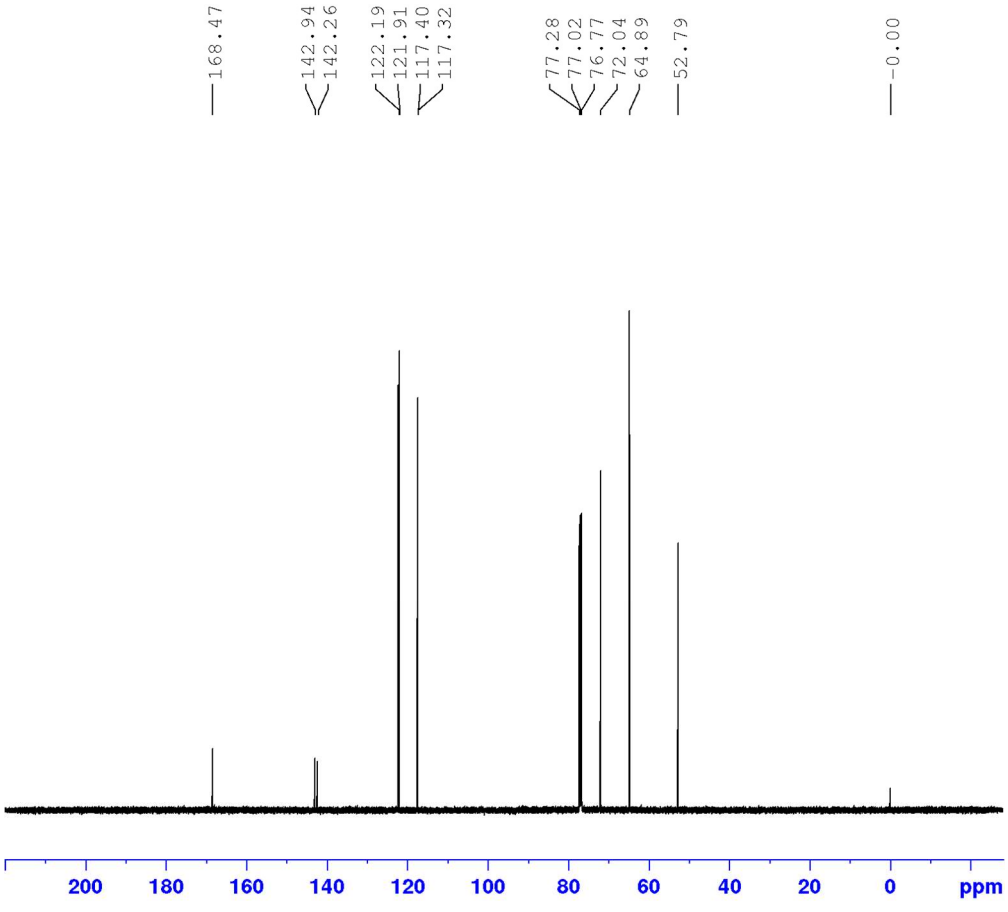

167.95
165.68
143.39
142.76
124.29
121.51
121.14
120.03
77.27
77.02
76.76
71.49
65.01
52.88
52.07
0.01
180
160
140
120
100
80
60
40
20
0
ppm

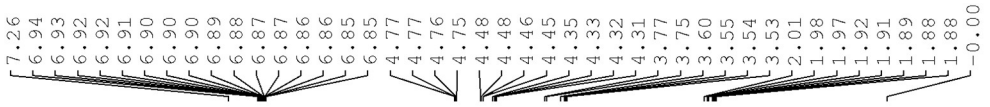

7.26
7.02
7.01
7.00
6.91
6.91
6.90
6.89
6.89
6.88
6.88
6.88
6.87
6.86
6.86
4.85
4.85
4.84
4.39
4.38
3.82
0.00

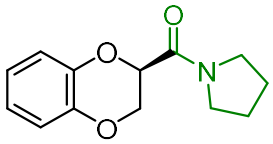


6z

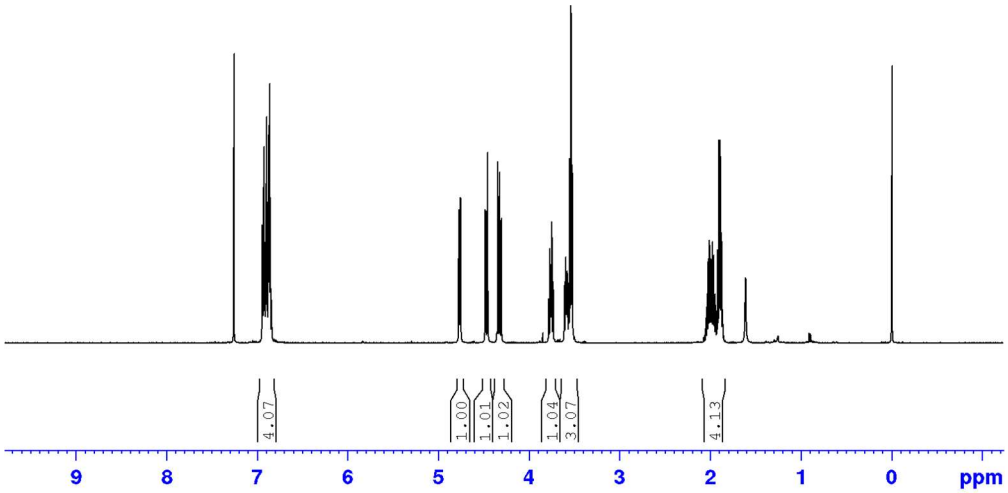

1.02
3.06
1.00
2.04
3.05
9
8
7
6
5
4
3
2
1
0
ppm

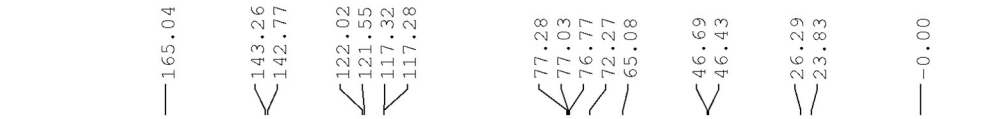

168.47
142.94
142.26
122.19
121.91
117.40
117.32
77.28
77.02
76.77
72.04
64.89
52.79
0.00
200
180
160
140
120
100
80
60
40
20
0
ppm

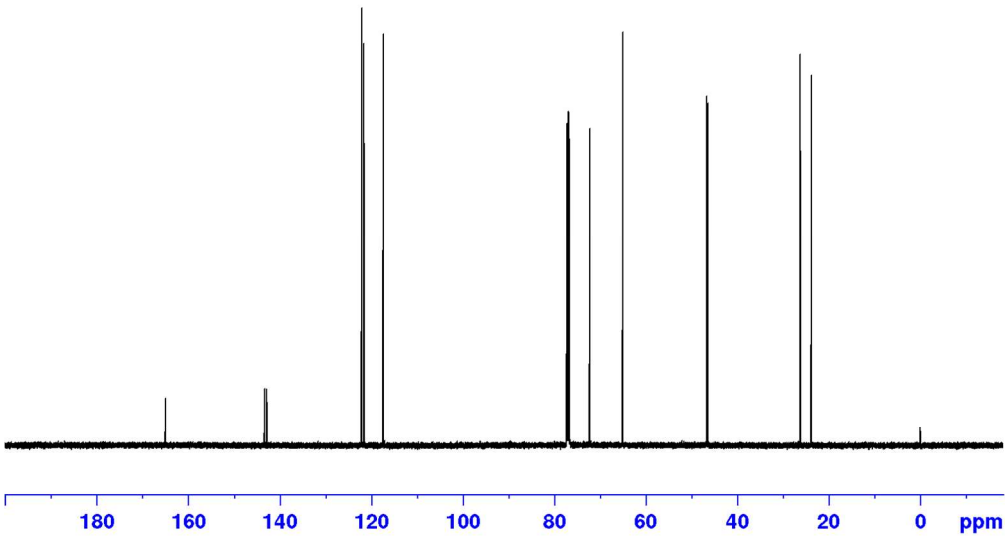

7.26
6.94
6.93
6.92
6.92
6.91
6.90
6.90
6.90
6.89
6.88
6.87
6.87
6.86
6.86
6.85
6.85
4.77
4.77
4.76
4.75
4.48
4.48
4.46
4.45
4.35
4.33
4.32
4.31
3.77
3.75
3.60
3.55
3.54
3.53
2.01
1.98
1.97
1.92
1.91
1.89
1.88
0.00

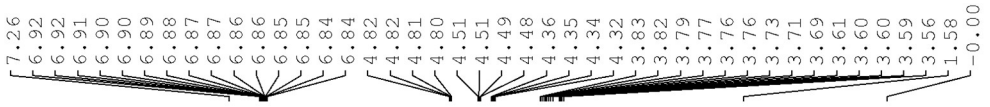

O
O
O
N

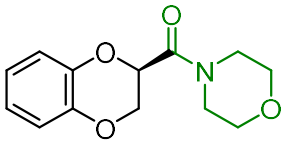
6aa


4.07
1.00
1.01
1.02
1.04
3.07
4.13
9
8
7
6
5
4
3
2
1
0
ppm

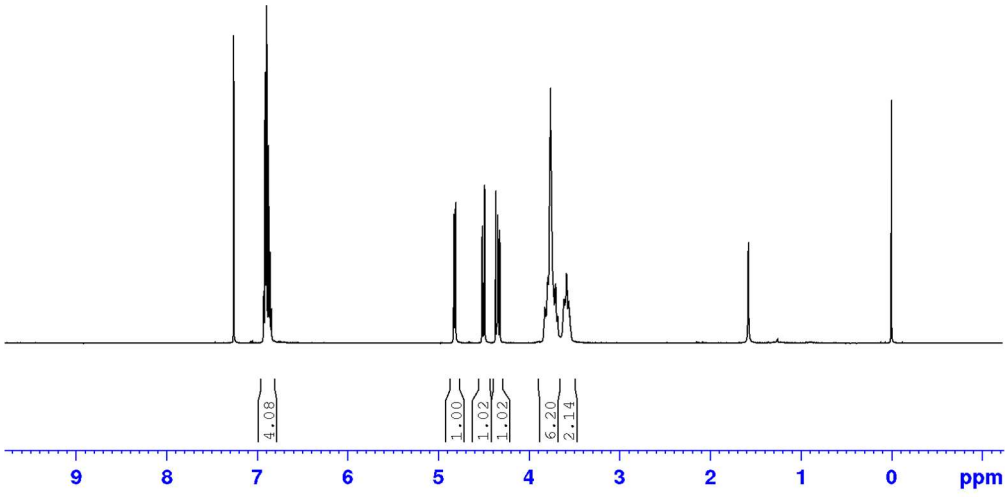

165.04
143.26
142.77
122.02
121.55
117.32
117.28
77.28
77.03
76.77
72.27
65.08
46.69
46.43
26.29
23.83
0.00

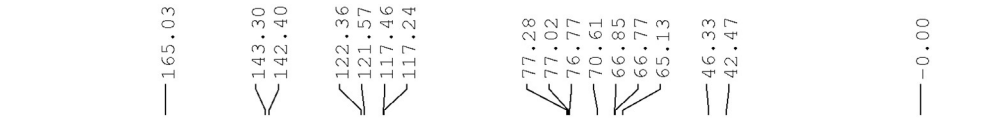

180
160
140
120
100
80
60
40
20
0
ppm

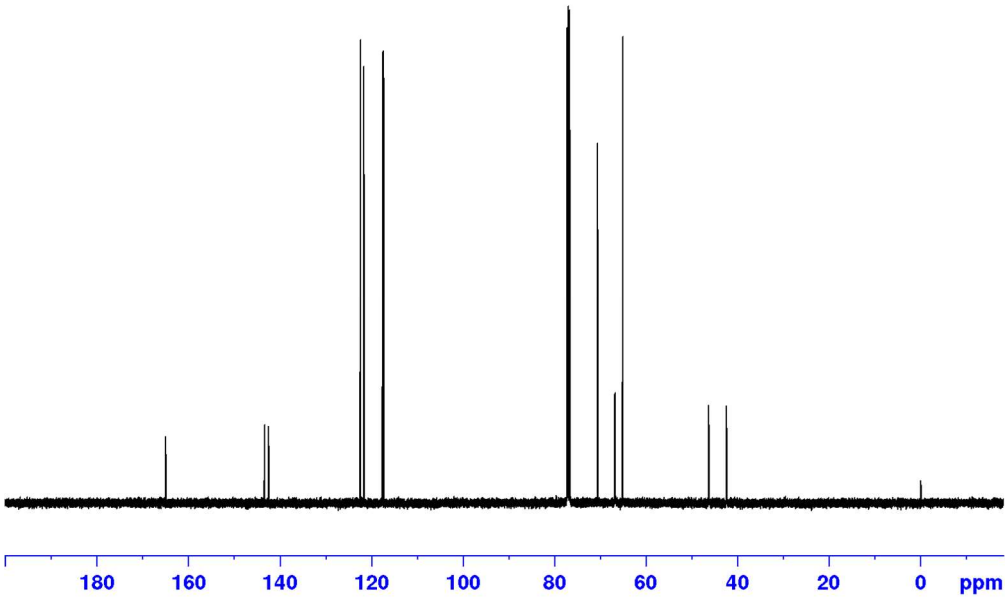

7.26
6.92
6.92
6.91
6.90
6.90
6.89
6.88
6.87
6.87
6.86
6.86
6.85
6.85
6.84
6.84
4.82
4.82
4.81
4.80
4.51
4.51
4.49
4.48
4.36
4.35
4.34
4.32
3.83
3.82
3.79
3.77
3.76
3.76
3.73
3.71
3.69
3.61
3.60
3.60
3.59
3.56
1.58
0.00

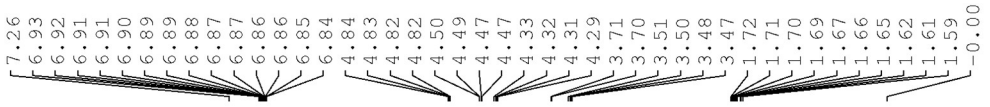


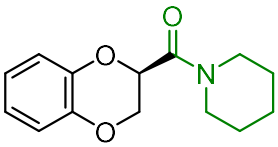
6ab


4.08
1.00
1.02
1.02
6.20
2.14
9
8
7
6
5
4
3
2
1
0
ppm

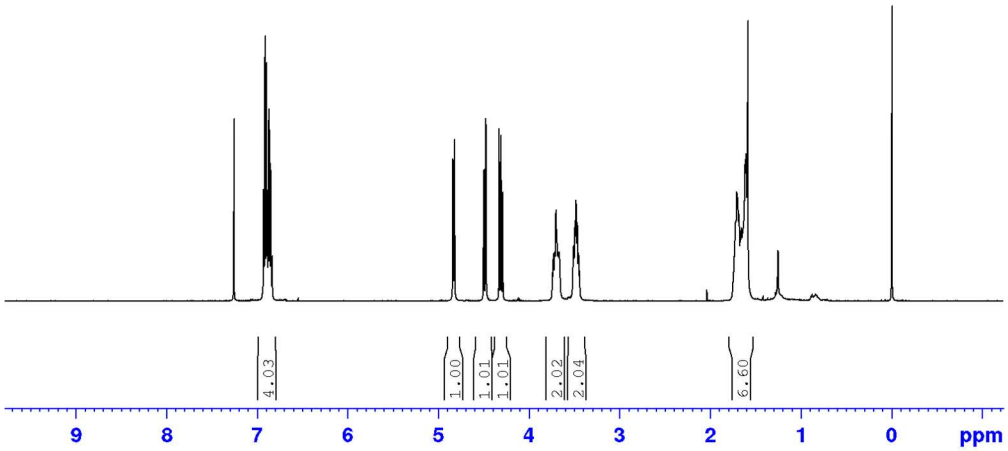

165.03
143.30
142.40
122.36
121.57
117.46
117.24
77.28
77.02
76.77
70.61
66.85
66.77
65.13
46.33
42.47
0.00

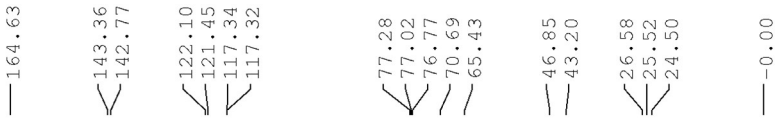

180
160
140
120
100
80
60
40
20
0
ppm

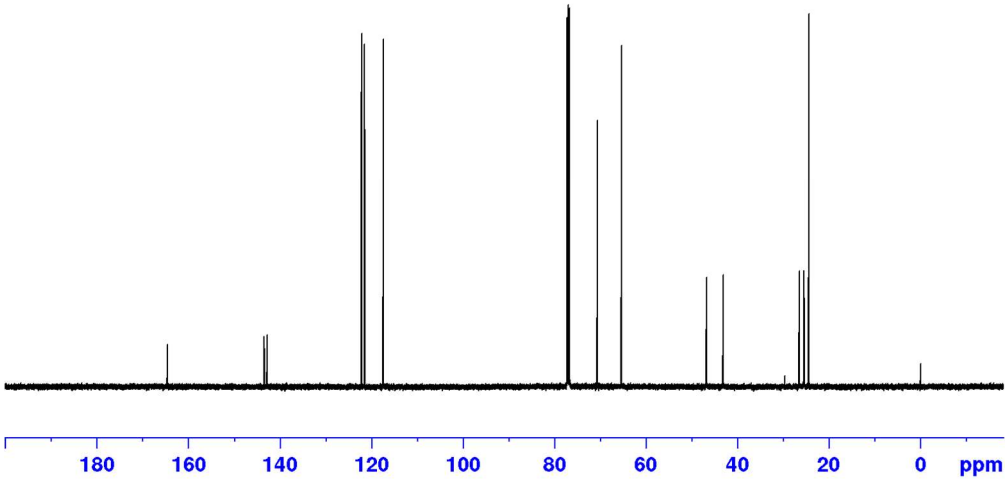

7.26
6.93
6.92
6.91
6.91
6.90
6.89
6.89
6.88
6.87
6.87
6.86
6.86
6.85
6.84
4.84
4.83
4.82
4.82
4.50
4.49
4.47
4.47
4.33
4.32
4.31
4.29
3.71
3.70
3.51
3.50
3.48
3.47
1.72
1.71
1.70
1.69
1.67
1.66
1.65
1.62
1.61
1.59
0.00

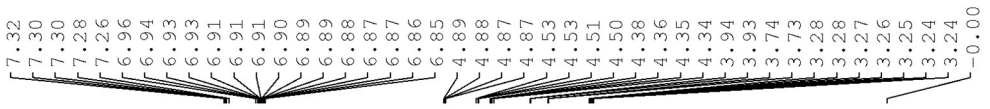


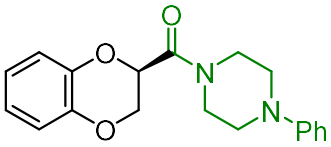
6ac


4.03
1.00
1.01
1.01
2.02
2.04
6.60
9
8
7
6
5
4
3
2
1
0
ppm

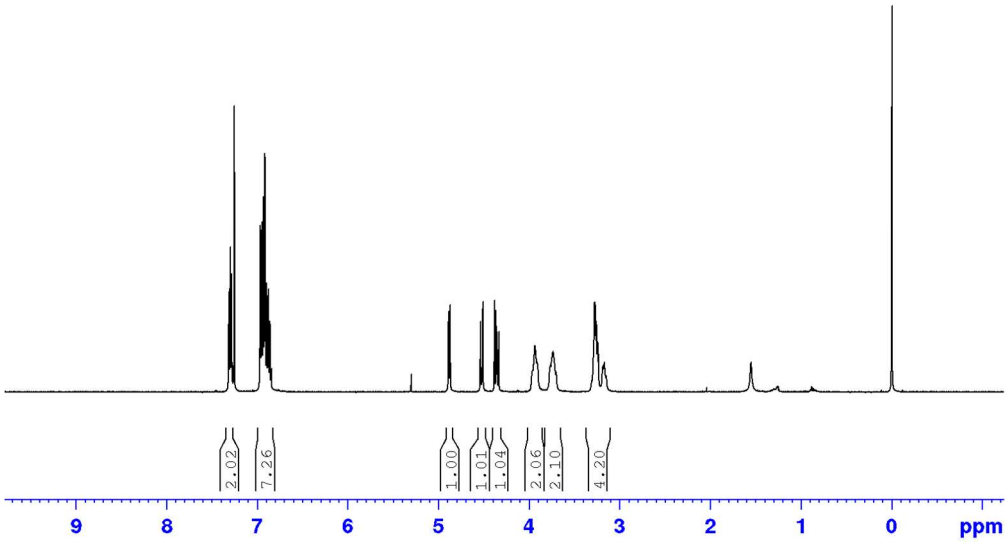

164.63
143.36
142.77
122.10
121.45
117.34
117.32
77.28
77.02
76.77
70.69
65.43
46.85
43.20
26.58
25.52
24.50
0.00

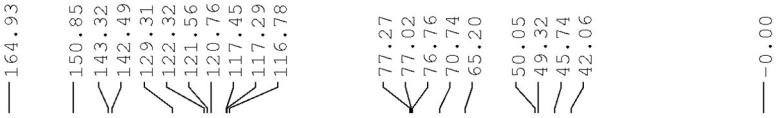

180
160
140
120
100
80
60
40
20
0
ppm

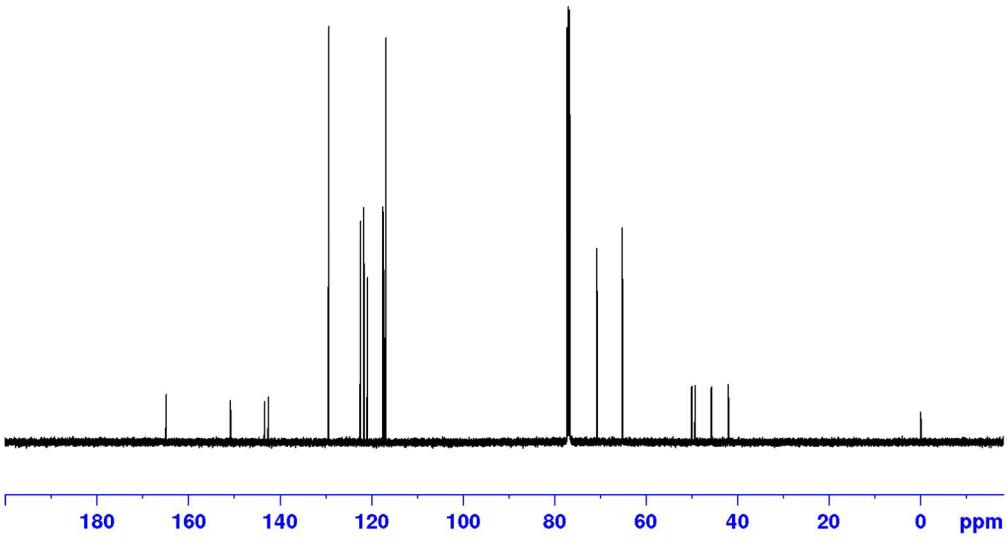

7.32
7.30
7.30
7.28
7.26
6.96
6.94
6.93
6.93
6.91
6.91
6.91
6.90
6.89
6.89
6.88
6.87
6.87
6.86
6.85
4.89
4.88
4.87
4.87
4.53
4.53
4.51
4.50
4.38
4.36
4.35
4.34
3.94
3.93
3.74
3.73
3.28
3.27
3.26
3.25
3.24
0.00


O
O
O
N
N
Ph

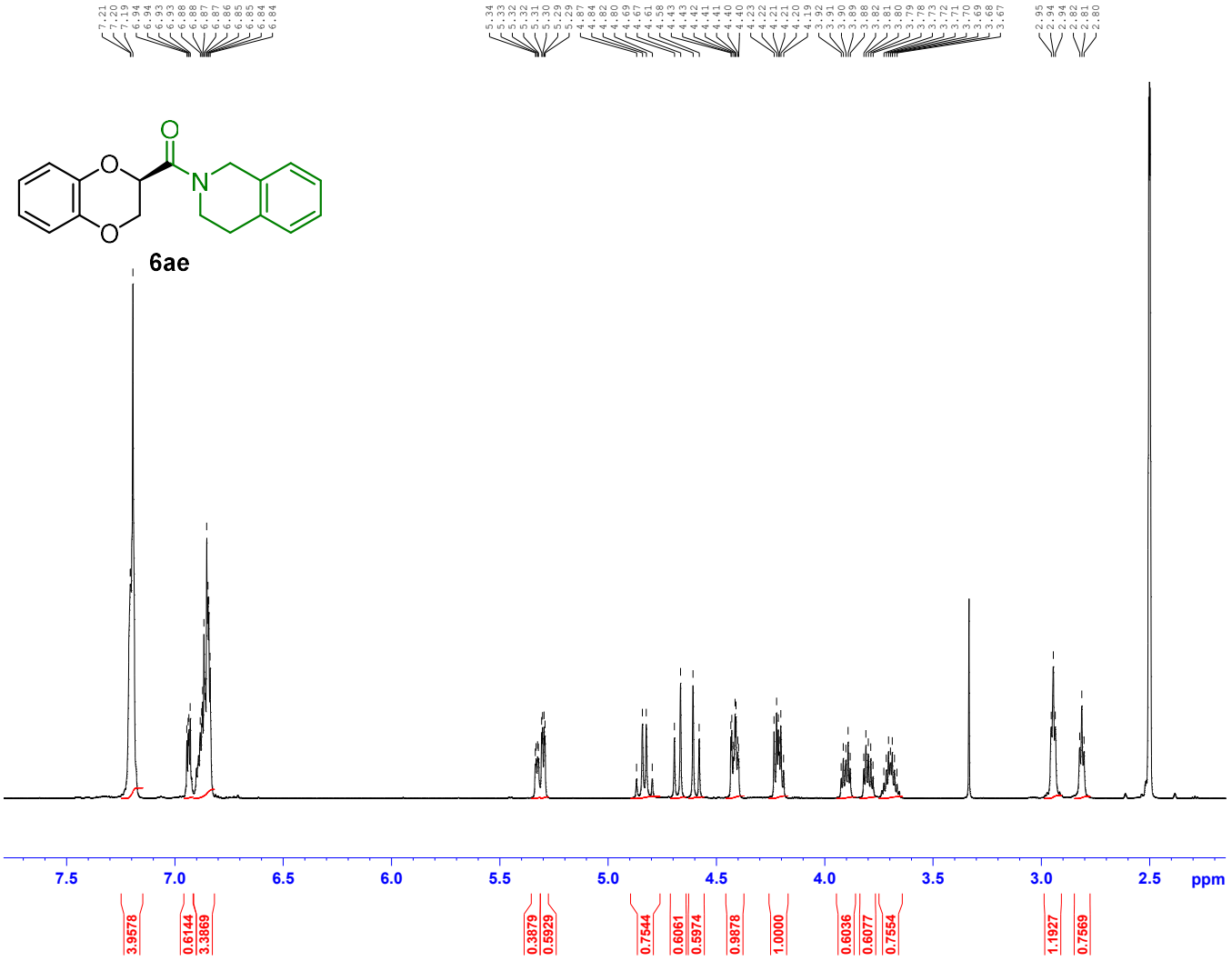
6ad


2.02
7.26
1.00
1.01
1.04
2.06
2.10
4.20
9
8
7
6
5
4
3
2
1
0
ppm

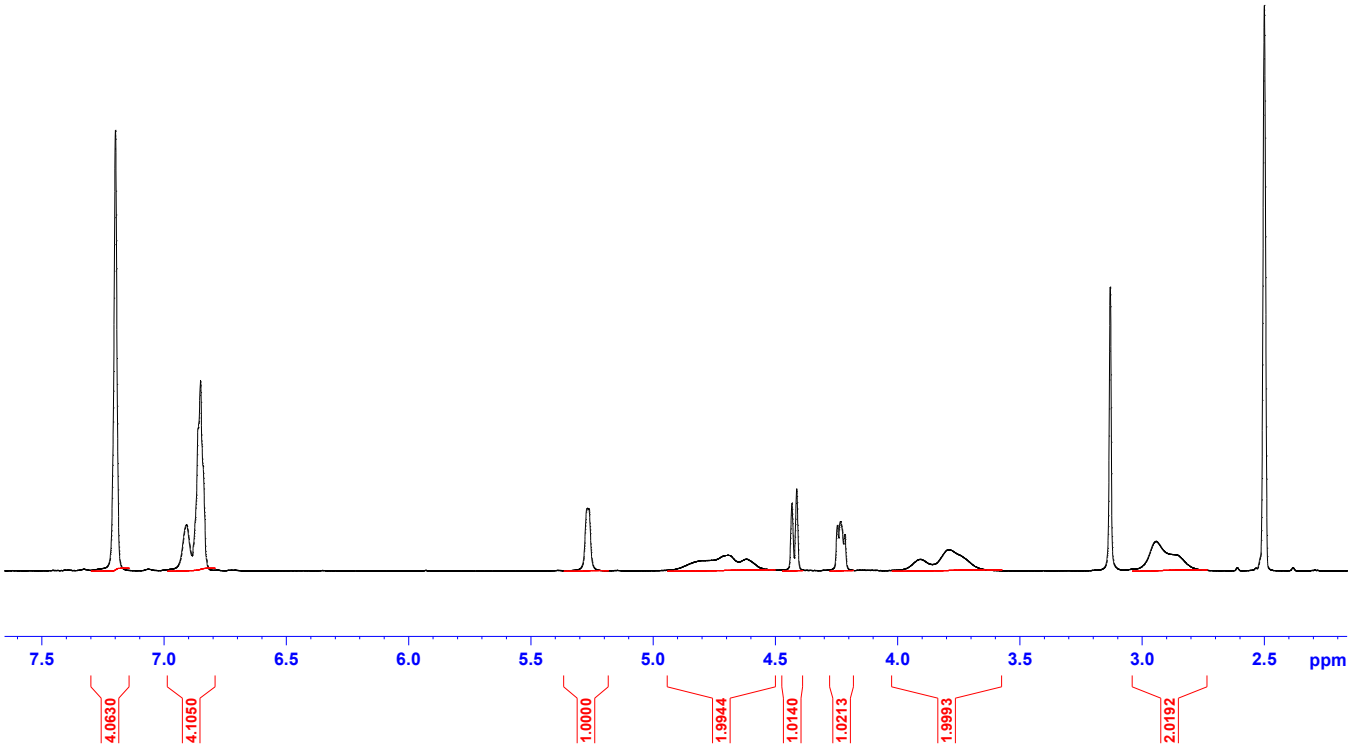

164.93
150.85
143.32
142.49
129.31
122.32
121.56
120.76
117.45
117.29
116.78
77.27
77.02
76.76
70.74
65.20
50.05
49.32
45.74
42.06
0.00


180
160
140
120
100
80
60
40
20
0
ppm

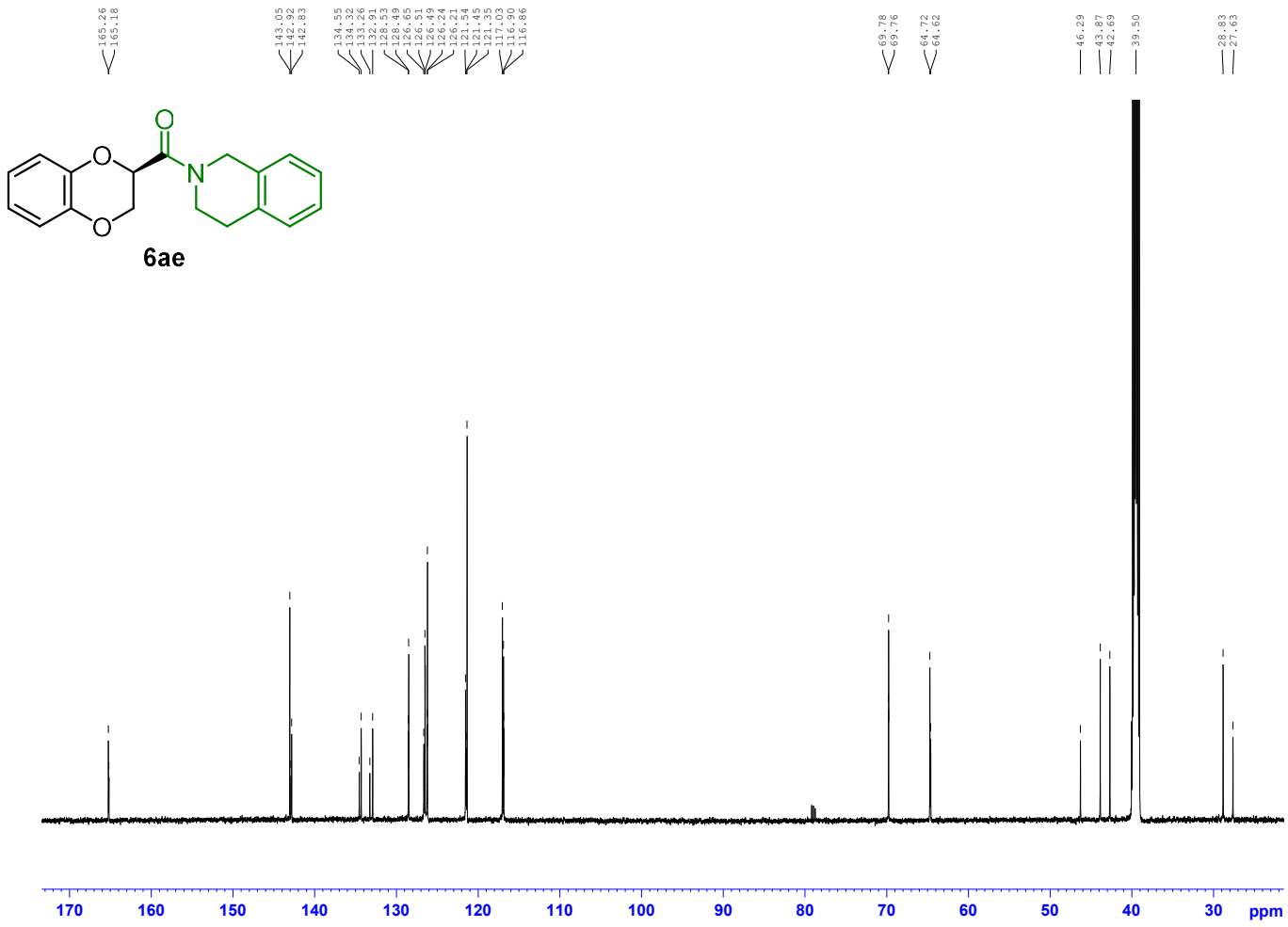
^{1}H NMR (300 K)



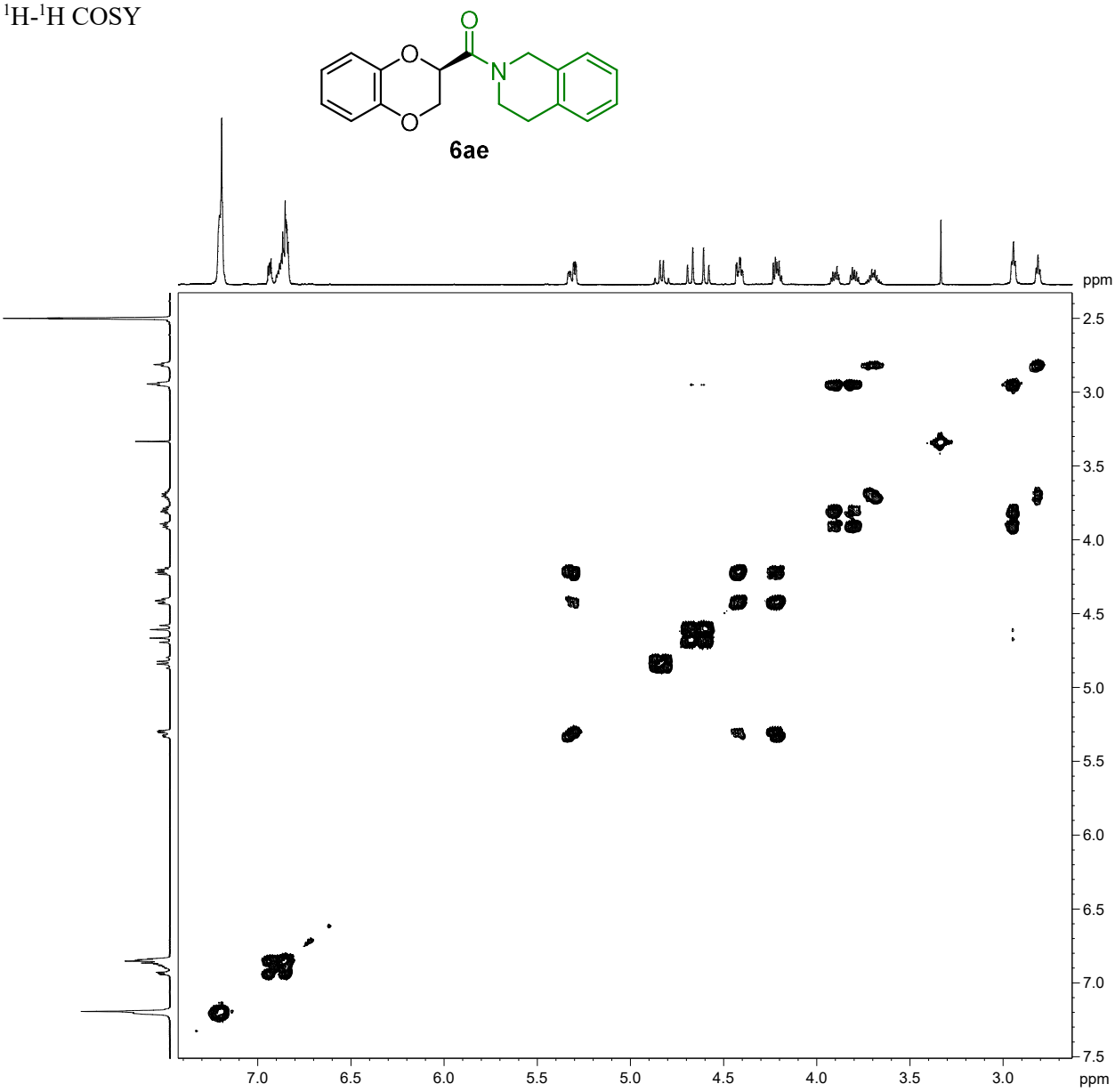
^{1}H NMR (350 K)



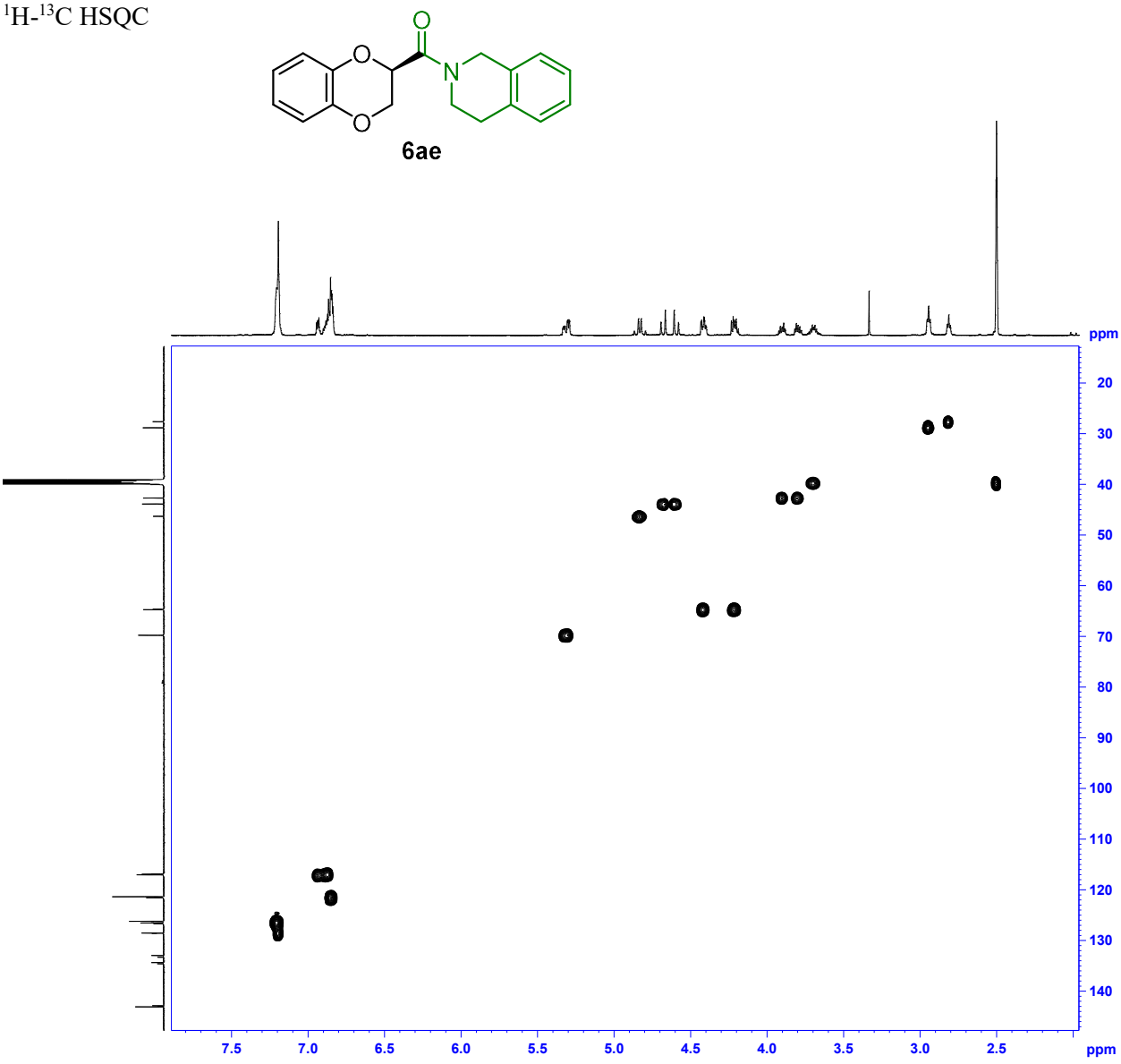
^{13}C NMR


165.26
165.18
143.05
142.32
142.83
134.55
134.32
133.26
132.91
128.53
128.49
126.45
126.51
126.49
126.24
126.21
121.54
121.45
117.03
116.90
116.86
69.78
69.76
64.72
64.62
46.29
43.87
42.69
39.50
28.83
27.63
O
O
O
N
6ae
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
ppm

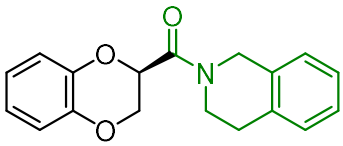
^{1}H-^{1}H COSY


O
O
N
O
6ae
ppm
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
ppm

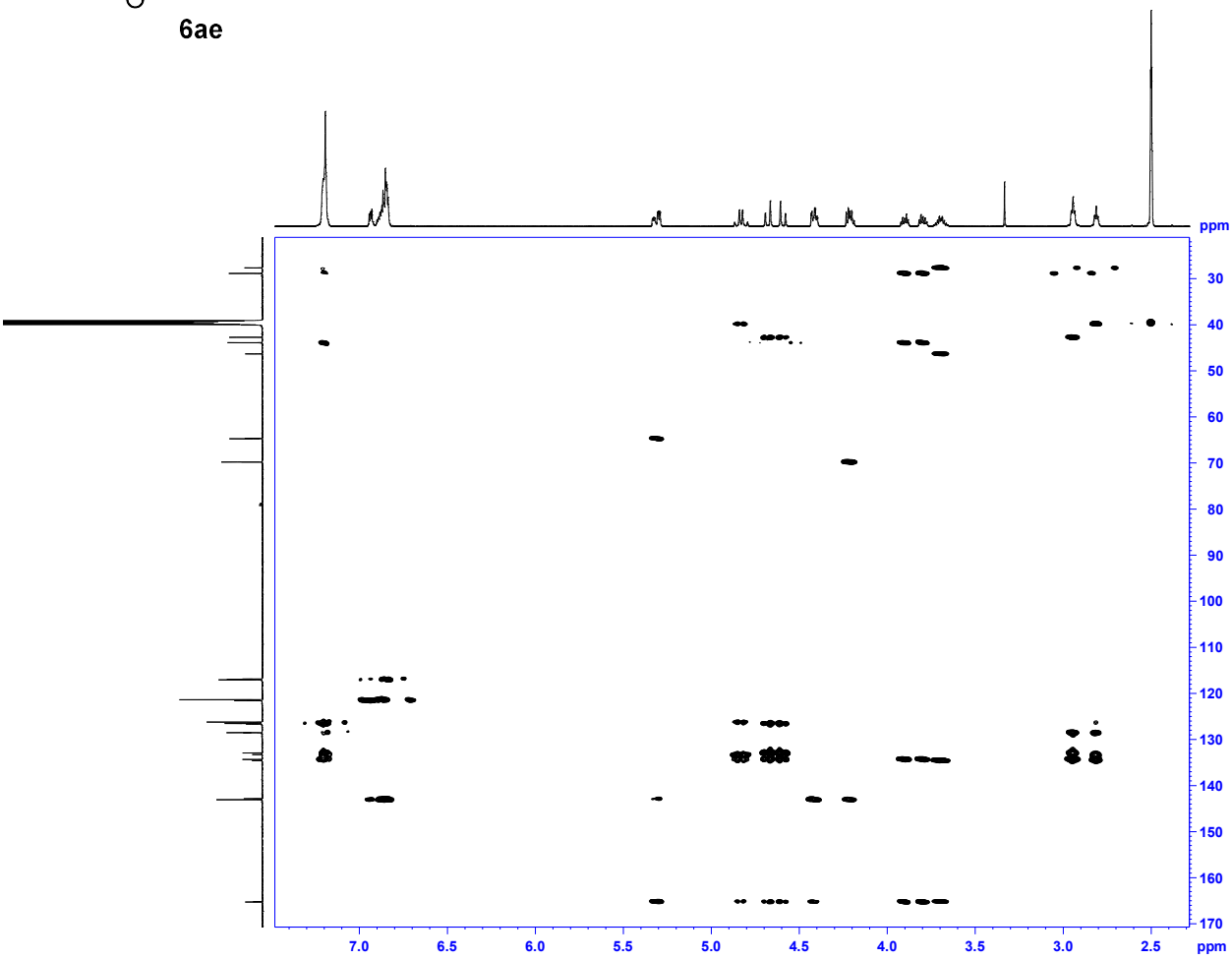
^{1}H-^{13}C HSQC


O
O
N
O
6ae
ppm
20
30
40
50
60
70
80
90
100
110
120
130
140
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
ppm

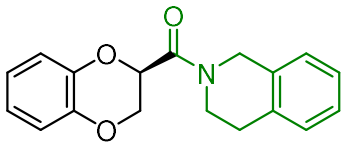
^{1}H-^{13}C HMBC



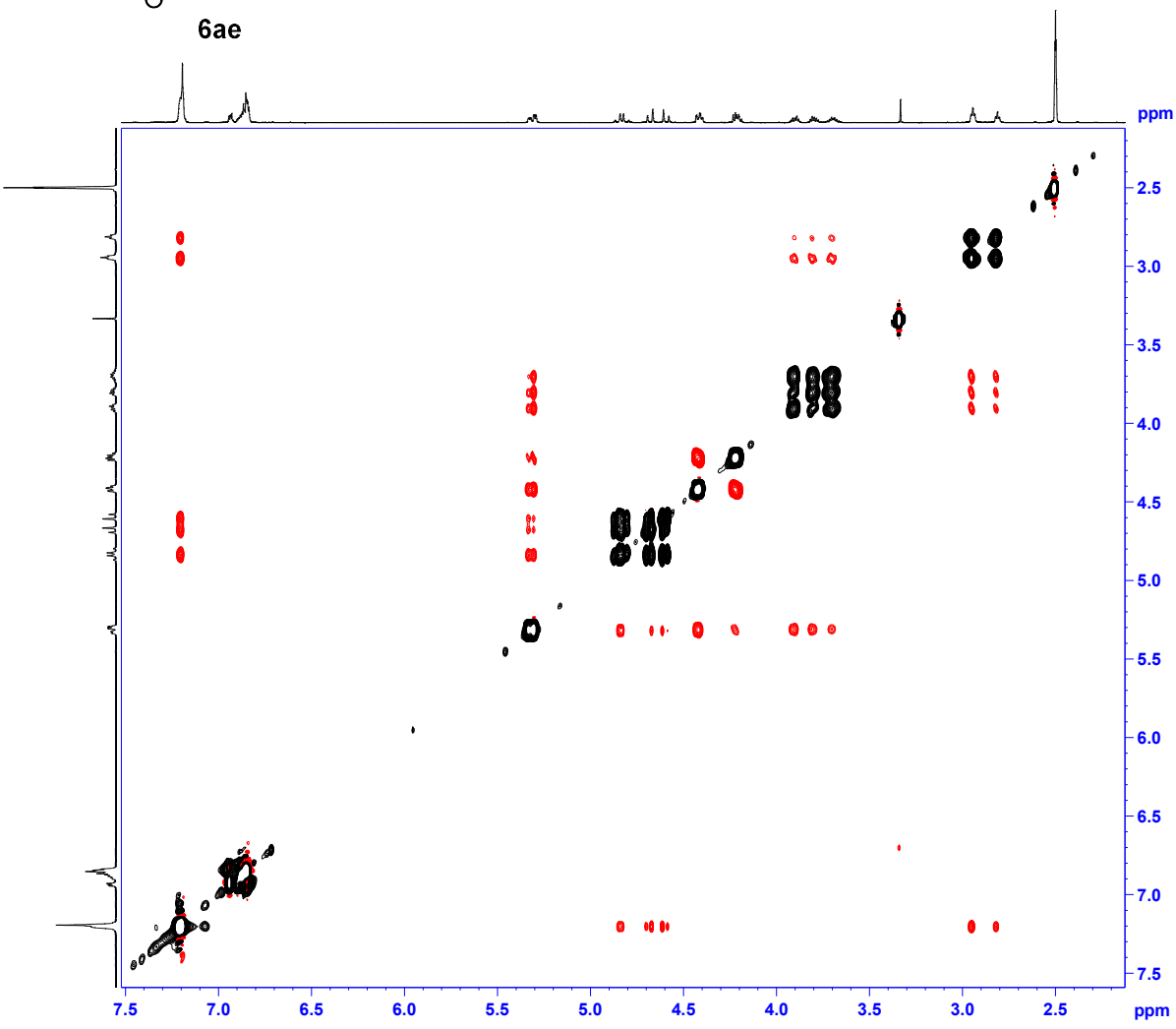
6ae



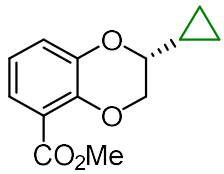
^{1}H-^{1}H ROESY



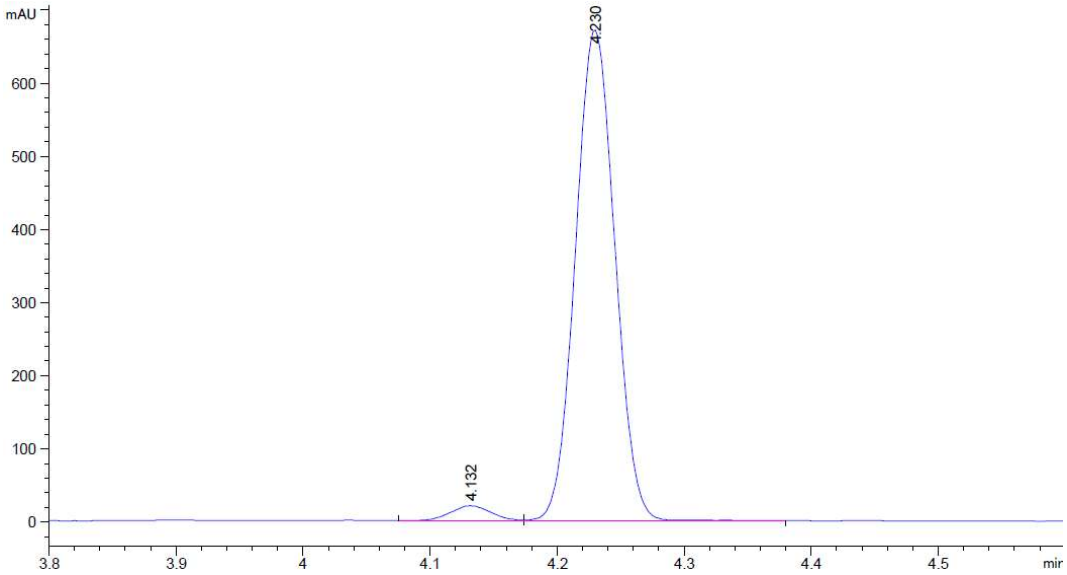
6ae

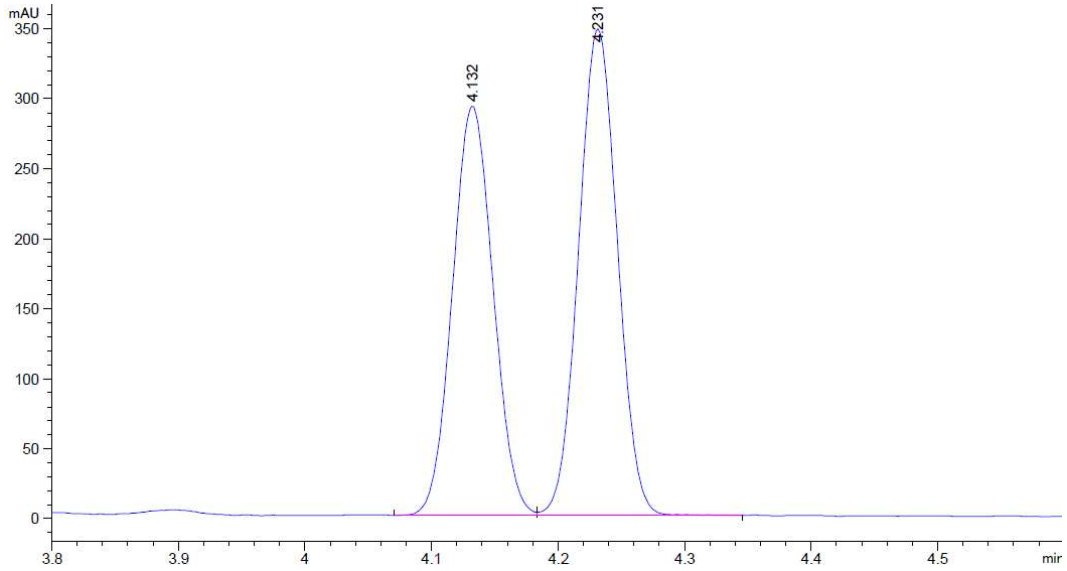


VII. Chiral HPLC/SFC Data

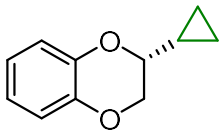


6a

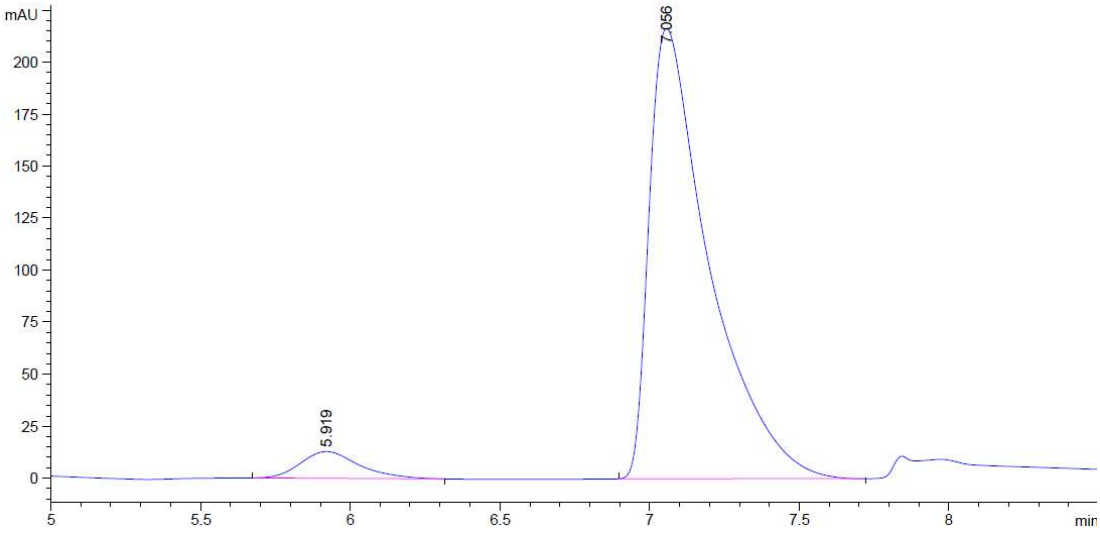


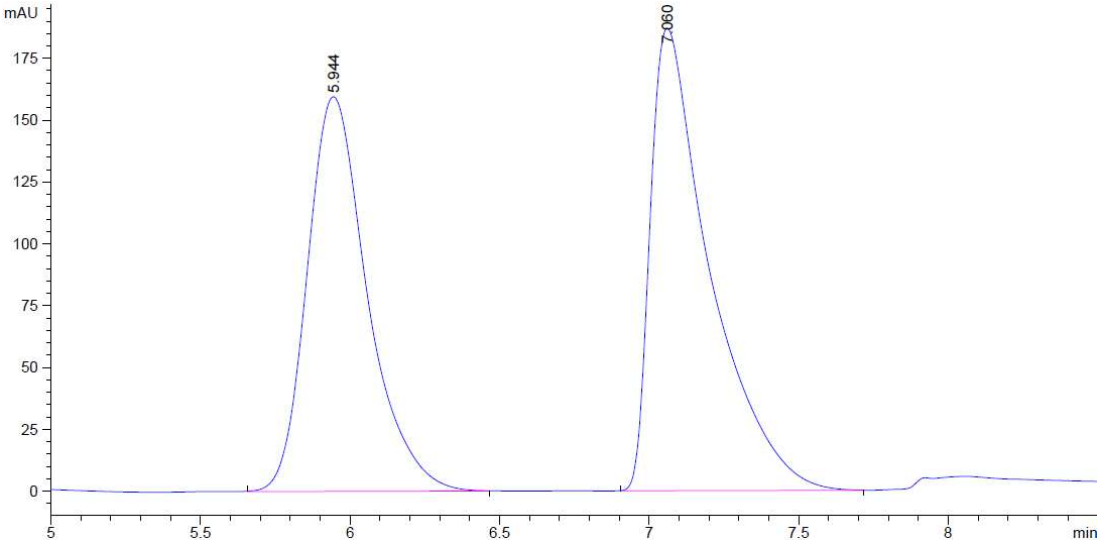


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	4.132	BV	0.0342	44.74331	20.31365	2.9985
2	4.230	VV R	0.0337	1447.44556	670.84180	97.0015

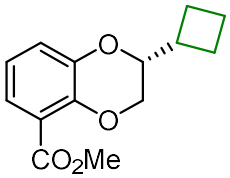


6b

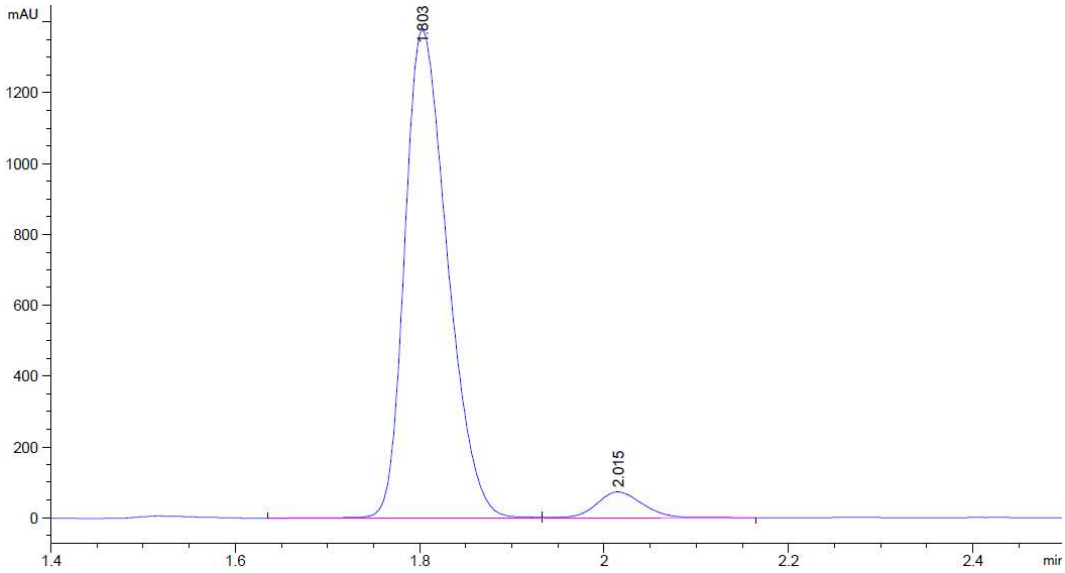


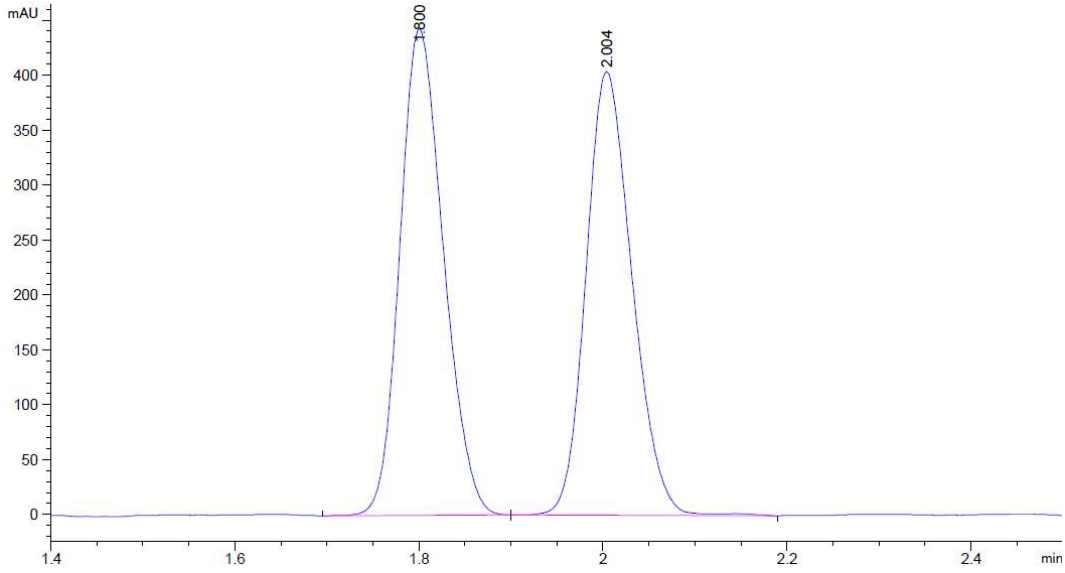


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.919	BB	0.2117	180.68475	13.03613	5.6383
2	7.056	BB	0.2027	3023.92603	216.77681	94.3617

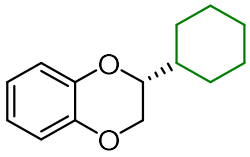


6c

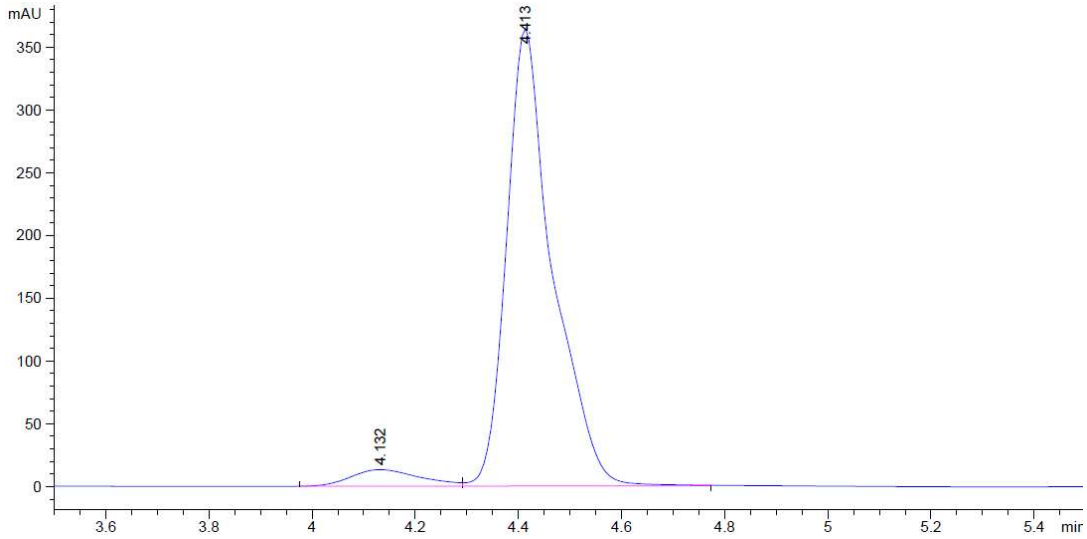


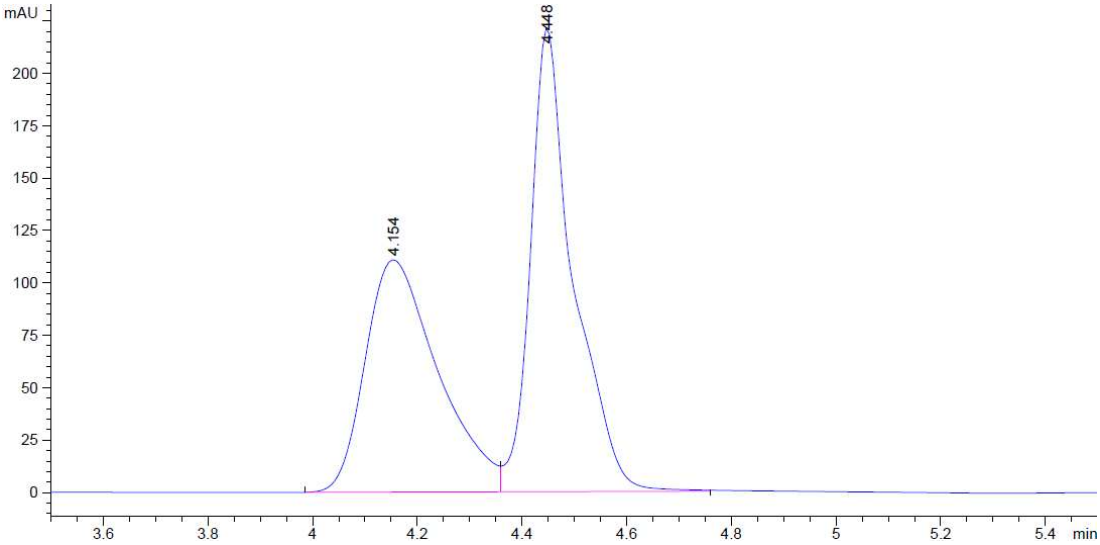


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	1.803	VV R	0.0495	4432.75342	1378.77051	94.4080
2	2.015	VV R	0.0546	262.56332	73.63523	5.5920

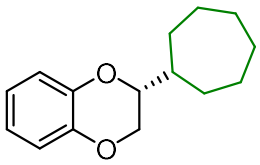


6d

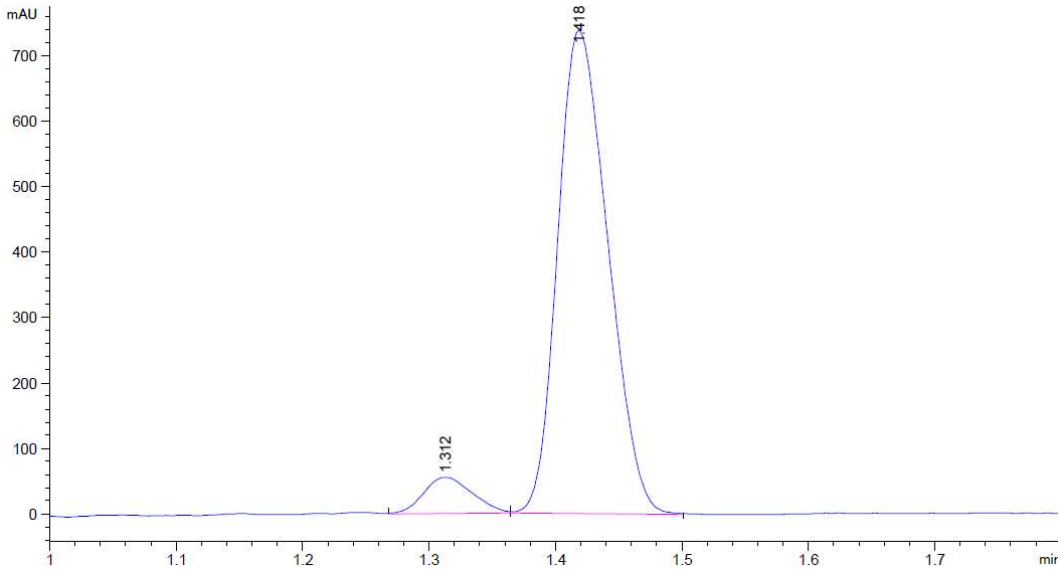


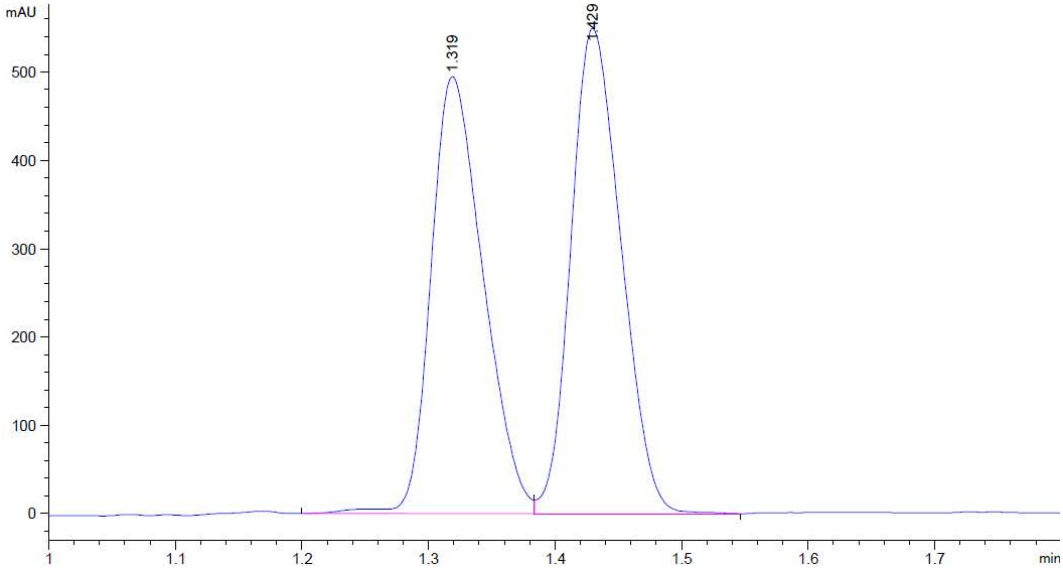


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	4.132	BV	0.1401	121.99075	13.16288	5.1110
2	4.413	VB	0.0885	2264.85010	364.51703	94.8890

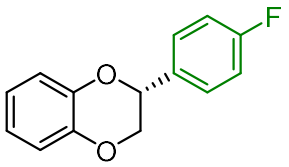


6e

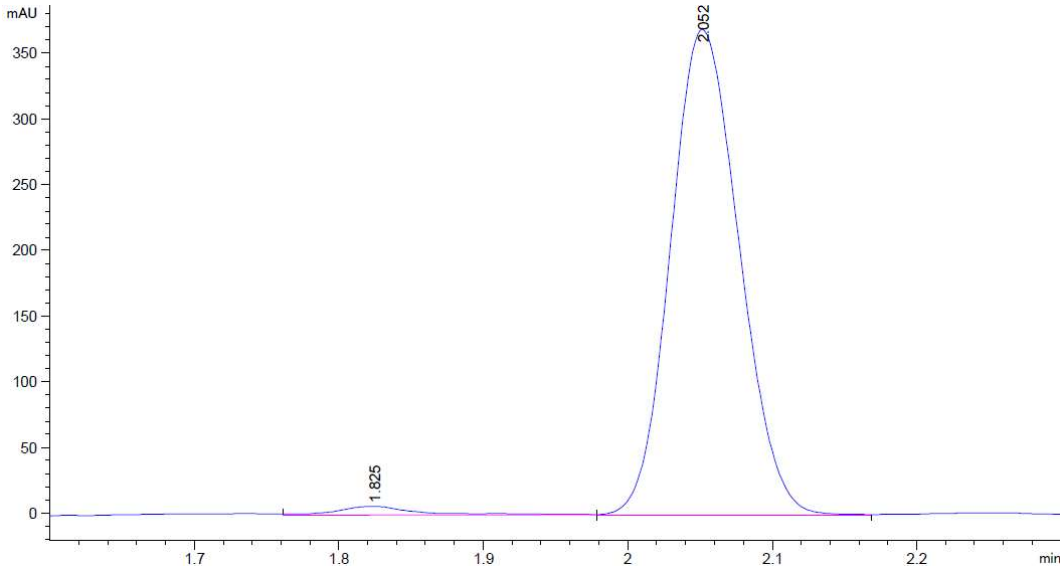


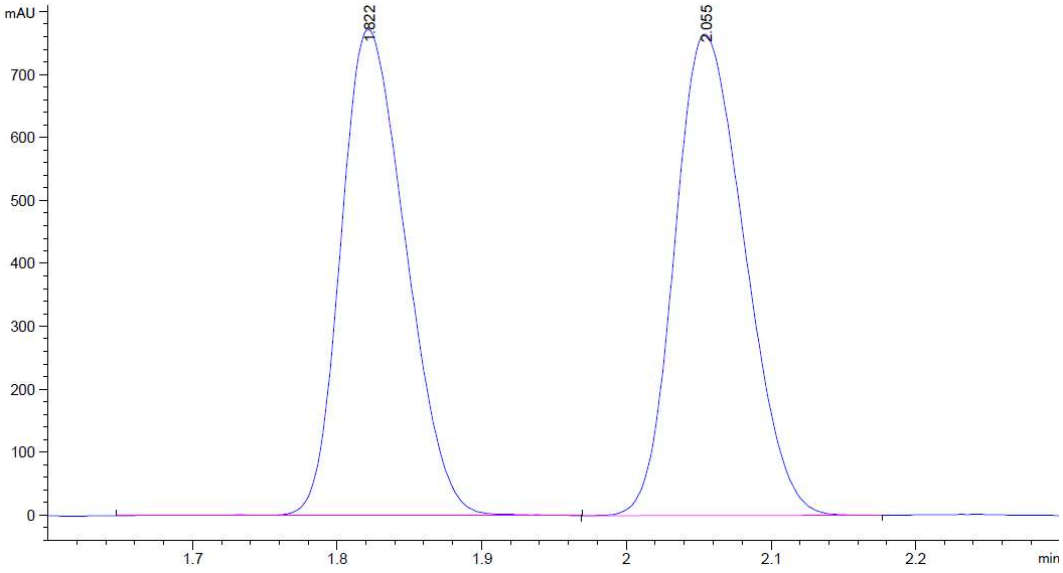


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	1.312	MM	0.0445	148.10214	55.41978	6.7733
2	1.418	MM	0.0460	2038.46729	738.60114	93.2267

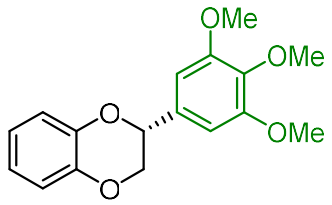


6f

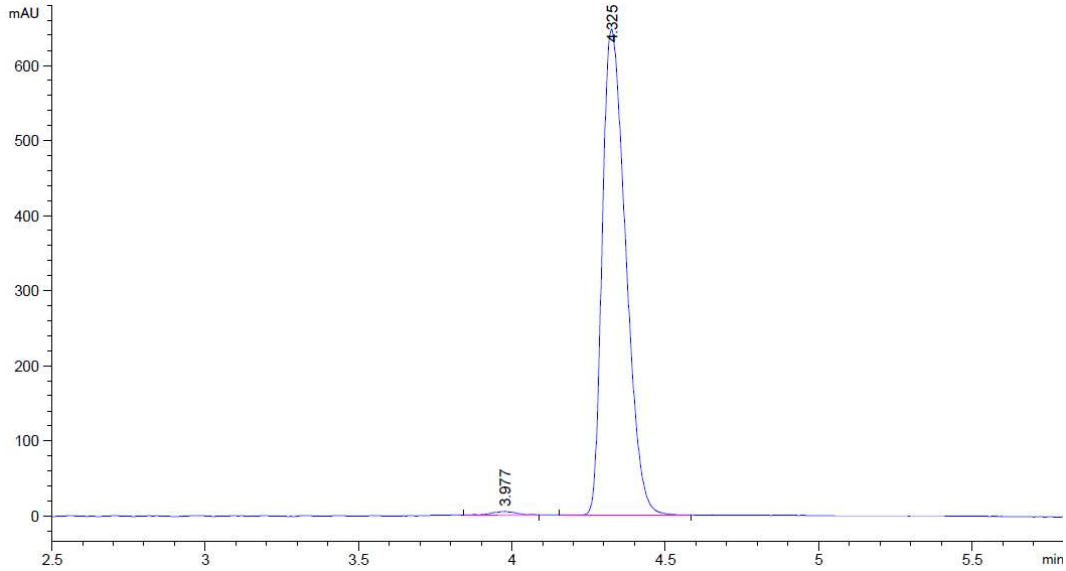


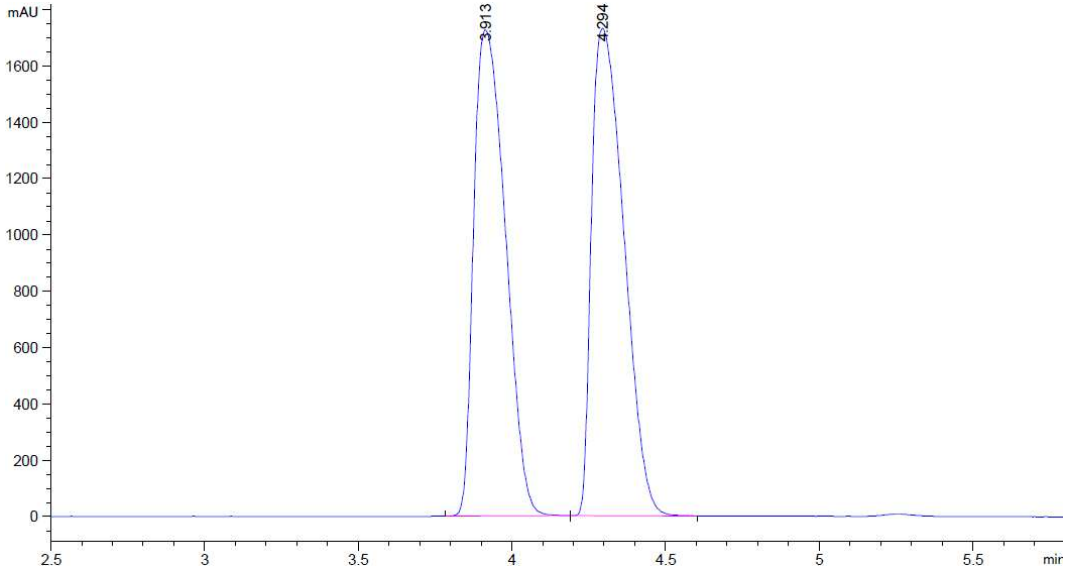


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	1.825	VV R	0.0558	26.18029	6.66611	2.1089
2	2.052	BV R	0.0514	1215.23779	369.34103	97.8911

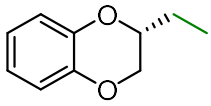


6g

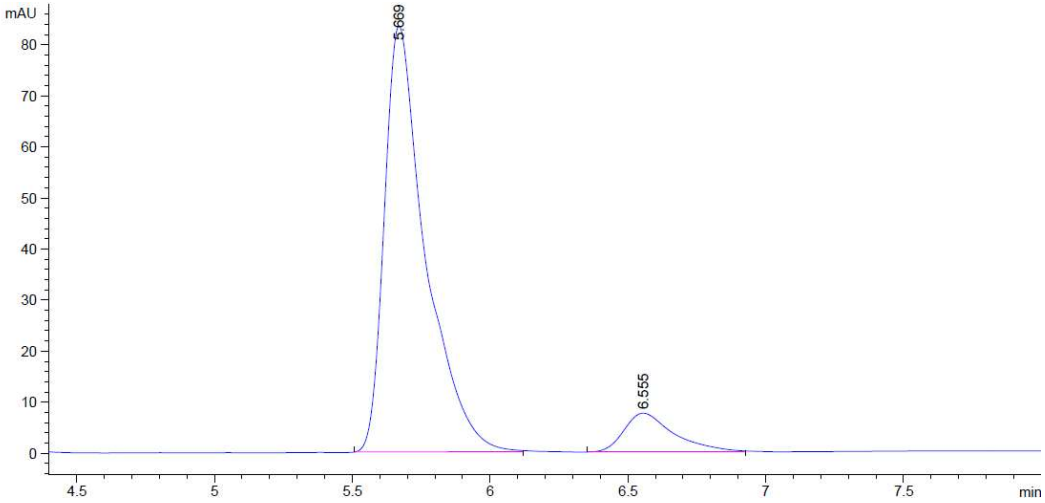


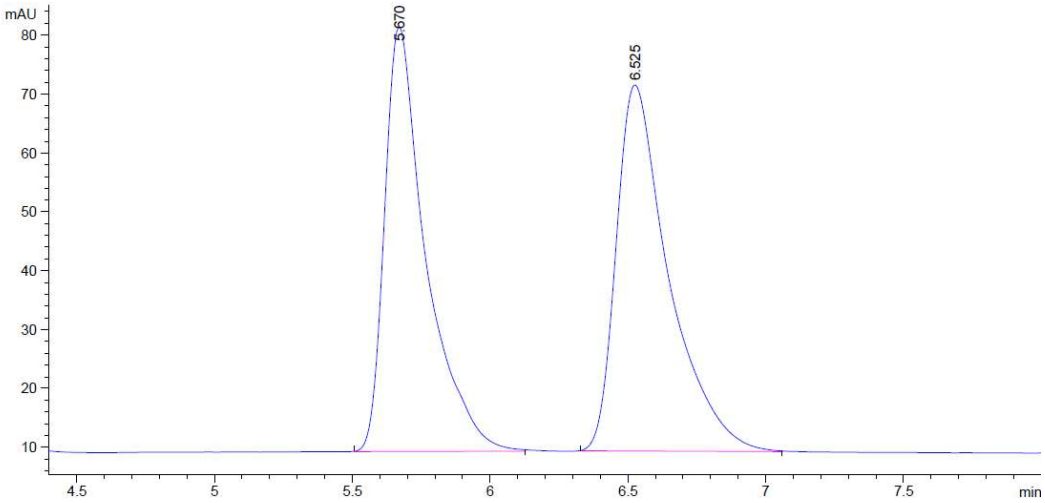


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	3.977	VV R	0.0690	27.32773	4.94515	0.7906
2	4.325	VV R	0.0838	3429.44873	646.94293	99.2094

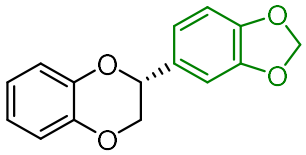


6h

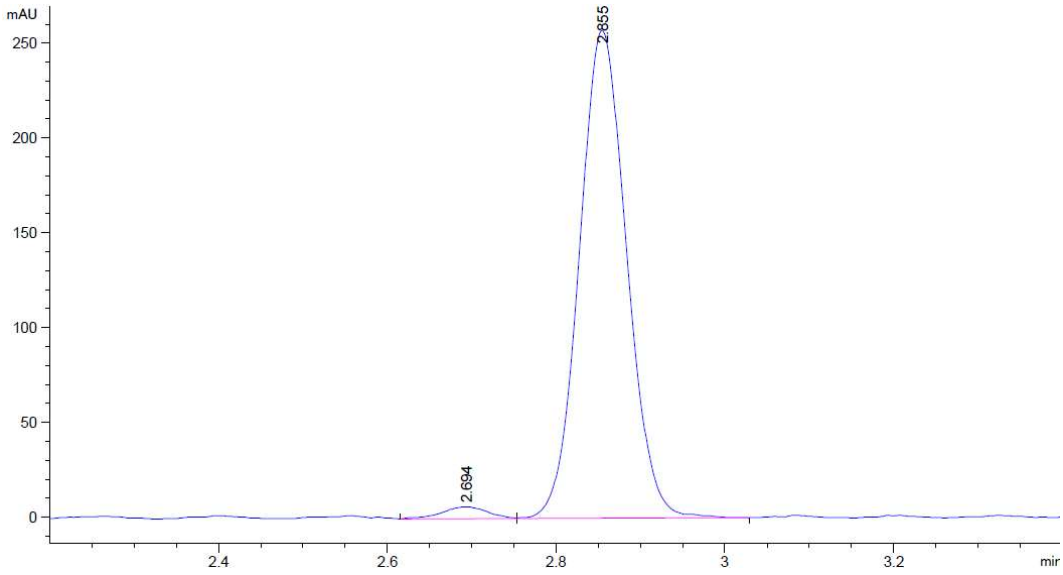


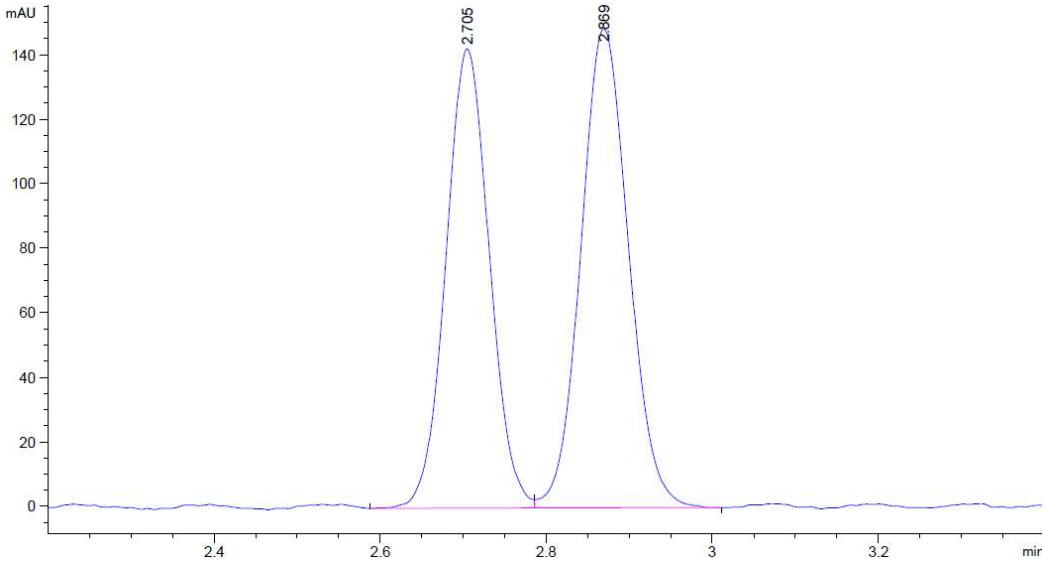


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.669	BB	0.1507	865.03510	83.63120	90.0672
2	6.555	BB	0.1844	95.39750	7.60194	9.9328

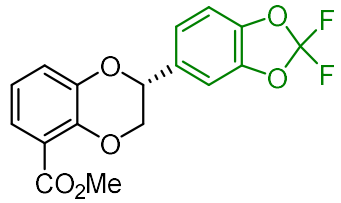


6i

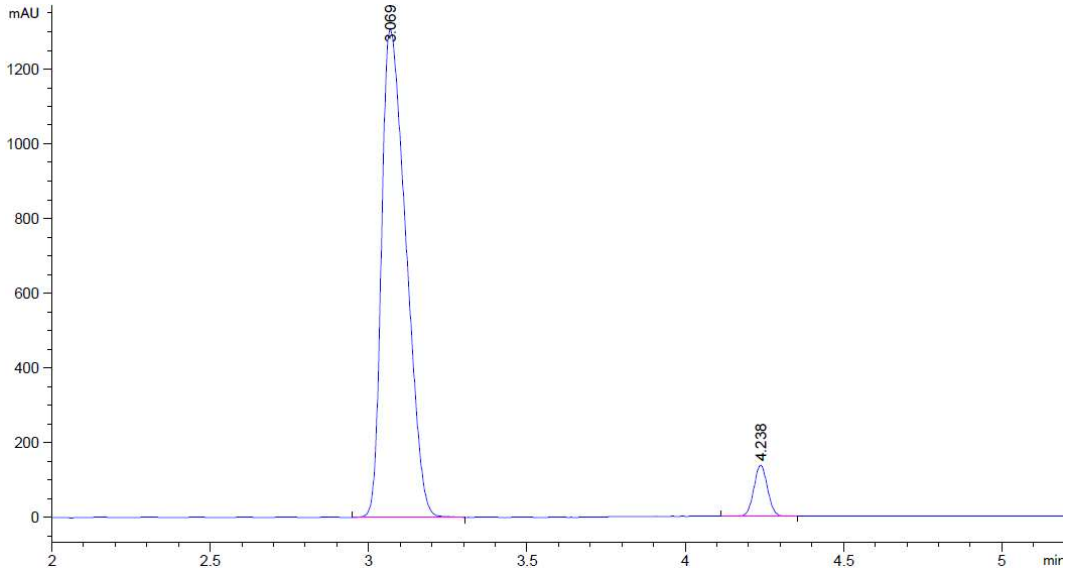


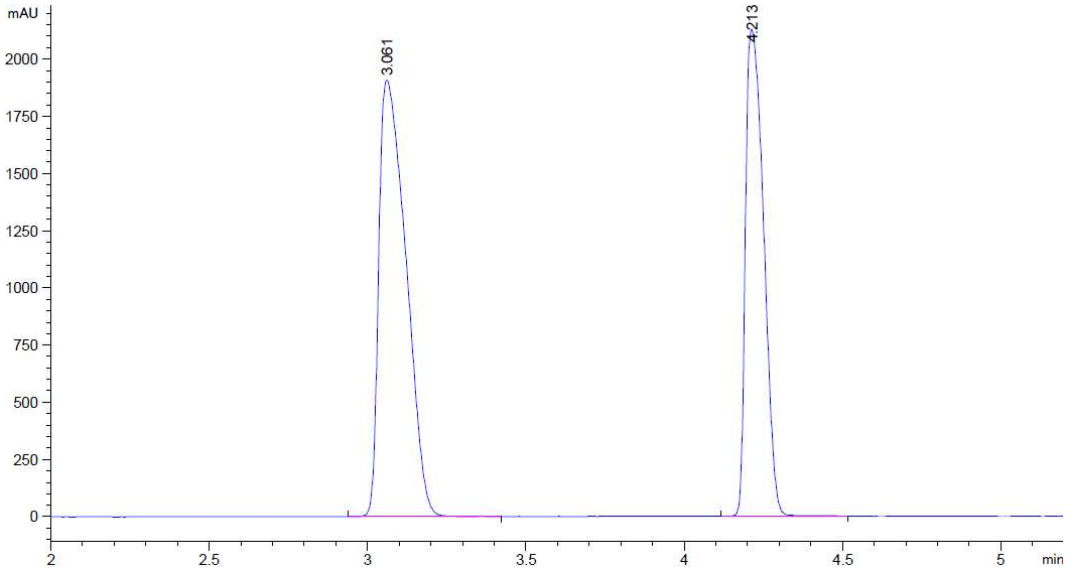


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	2.694	BV	0.0548	23.19637	6.18534	2.2624
2	2.855	VV R	0.0604	1002.11853	257.42316	97.7376

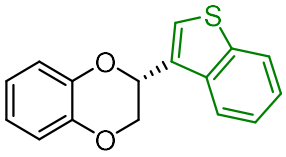


6j

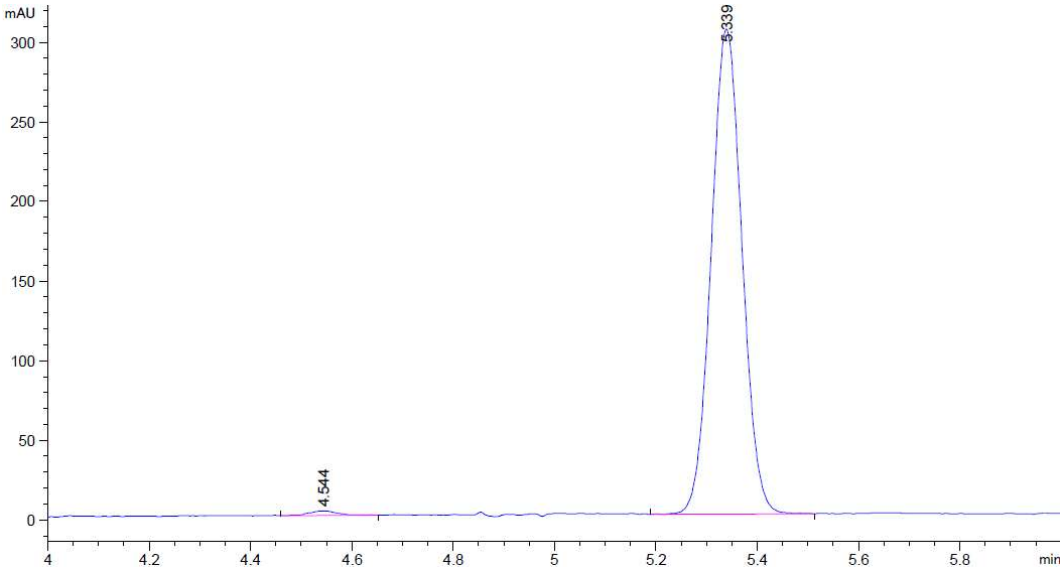


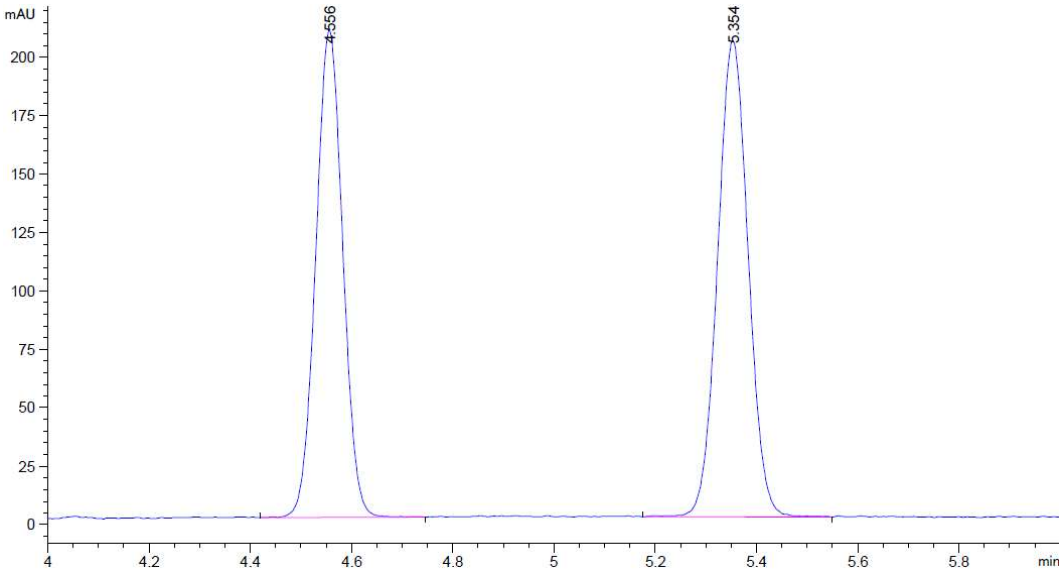


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	3.069	BV R	0.0863	6978.27295	1306.50940	94.4355
2	4.238	VV R	0.0470	411.18750	137.01413	5.5645

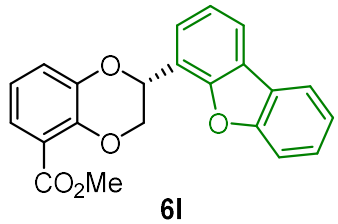


6k

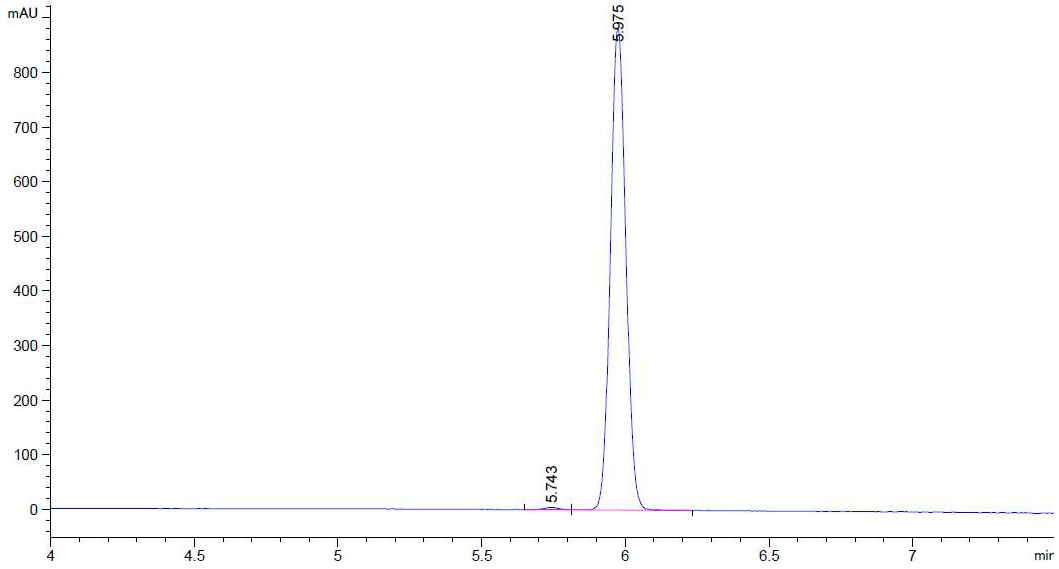


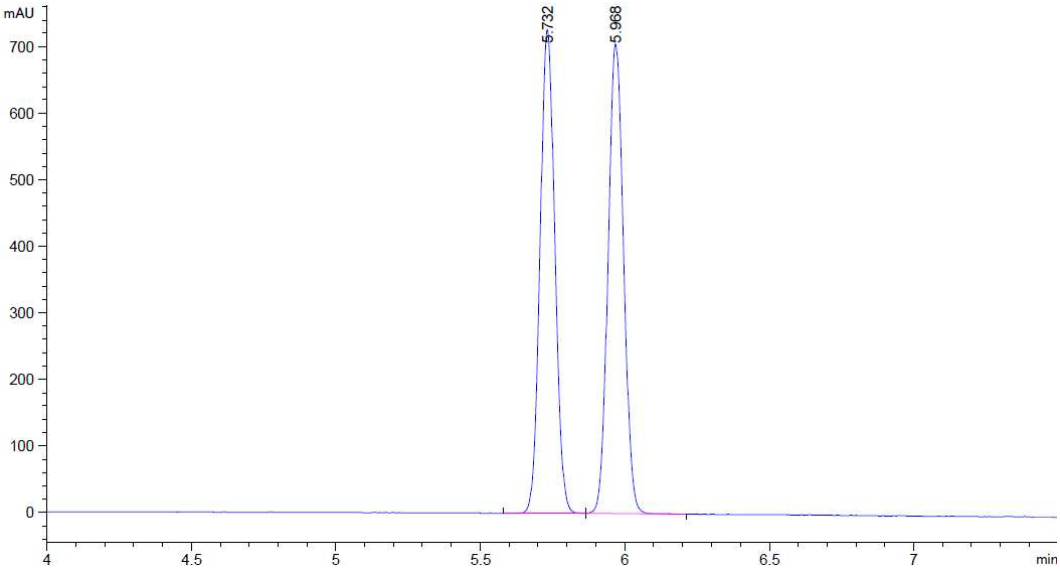


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	4.544	VV R	0.0545	11.69475	2.84489	0.9008
2	5.339	VV R	0.0658	1286.58459	304.60342	99.0992

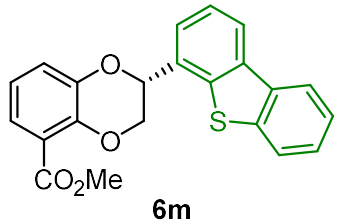


6l

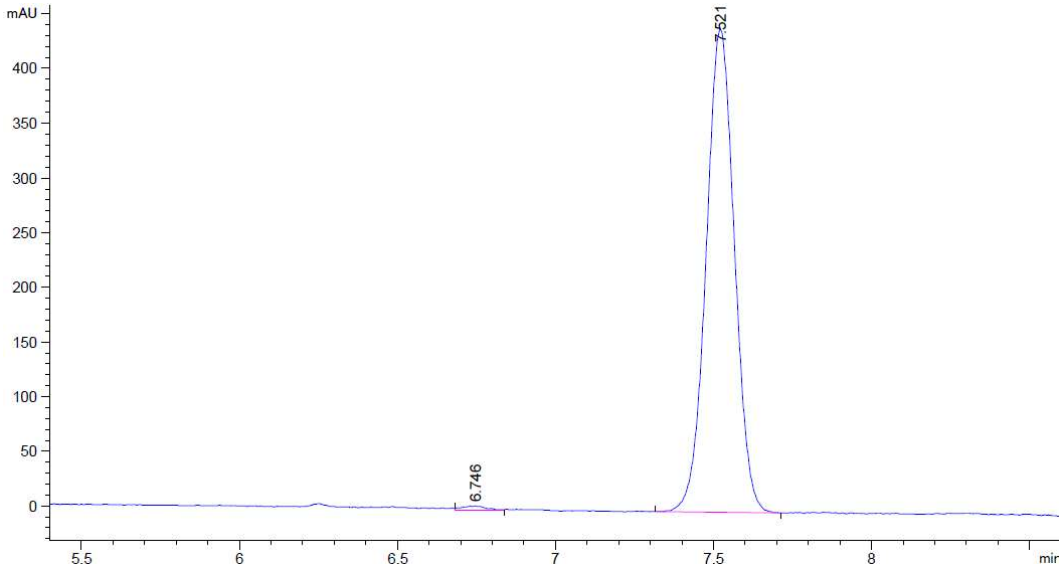


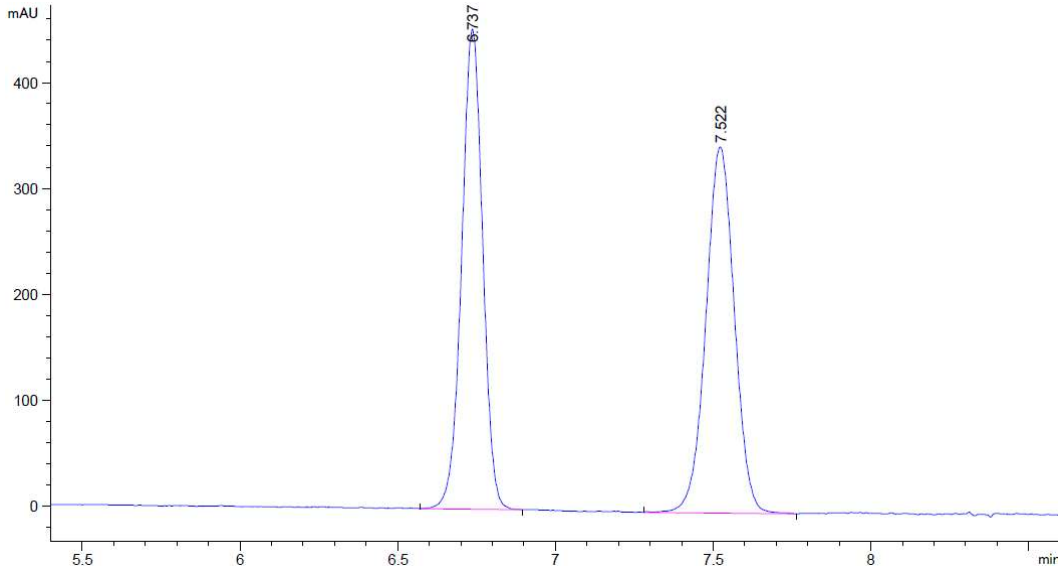


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.743	VB R	0.0487	16.10260	4.56140	0.4874
2	5.975	VV R	0.0586	3287.74731	880.61395	99.5126

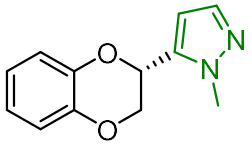


6m

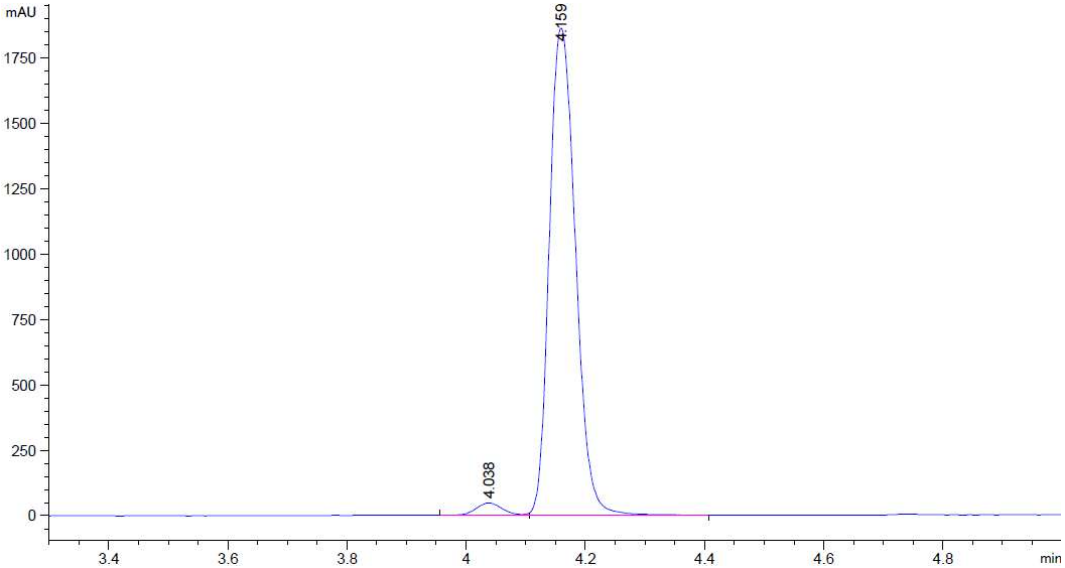


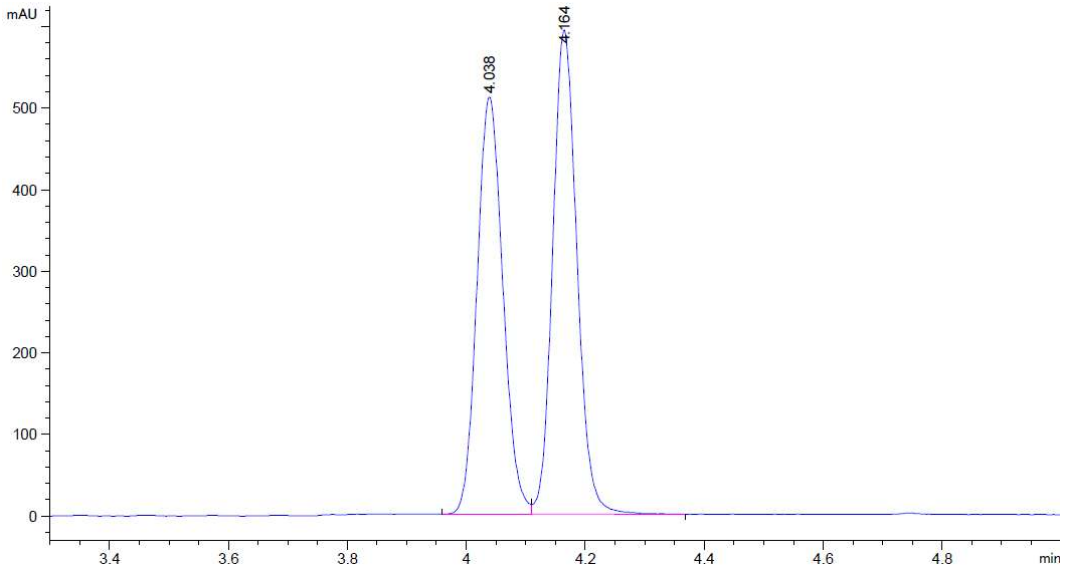


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.746	MM	0.0803	14.87096	3.08540	0.5372
2	7.521	VB R	0.0967	2753.31616	441.66220	99.4628

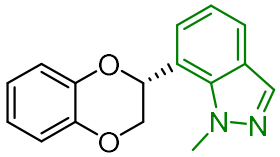


6n

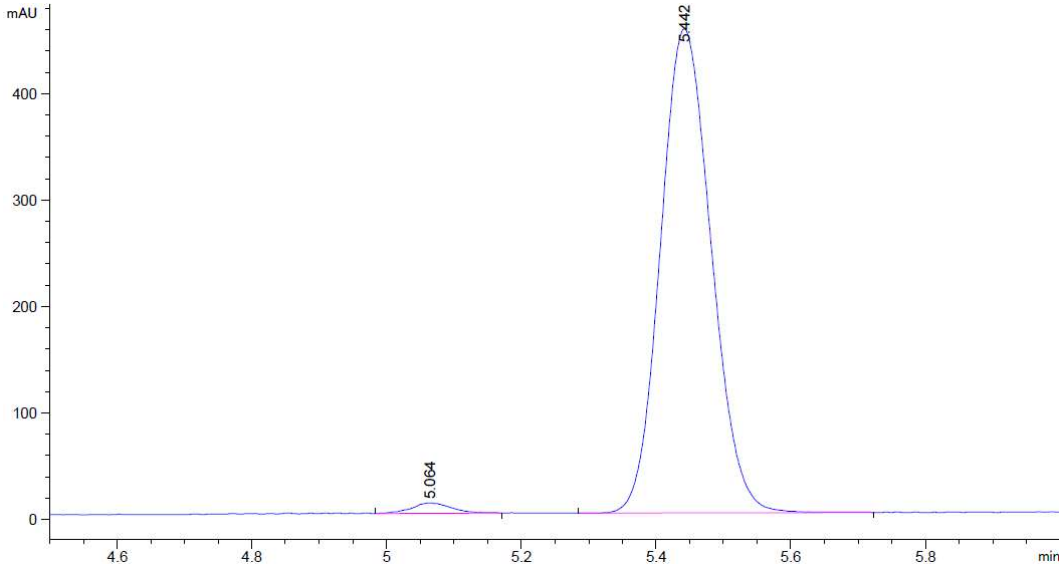


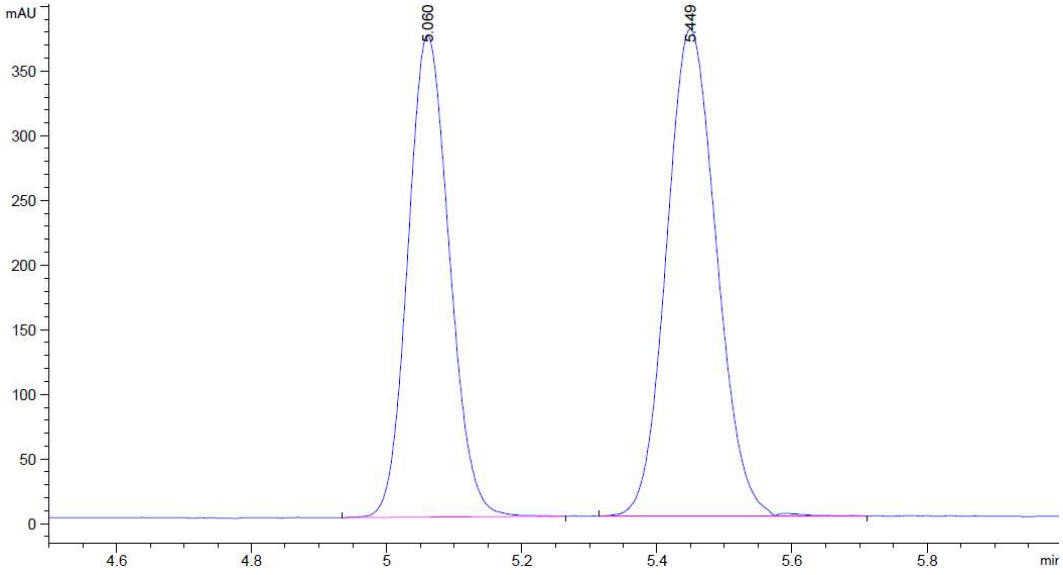


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	4.038	BV E	0.0471	141.52544	47.02908	2.4352
2	4.159	VV R	0.0485	5670.10840	1861.90784	97.5648

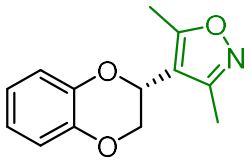


6o

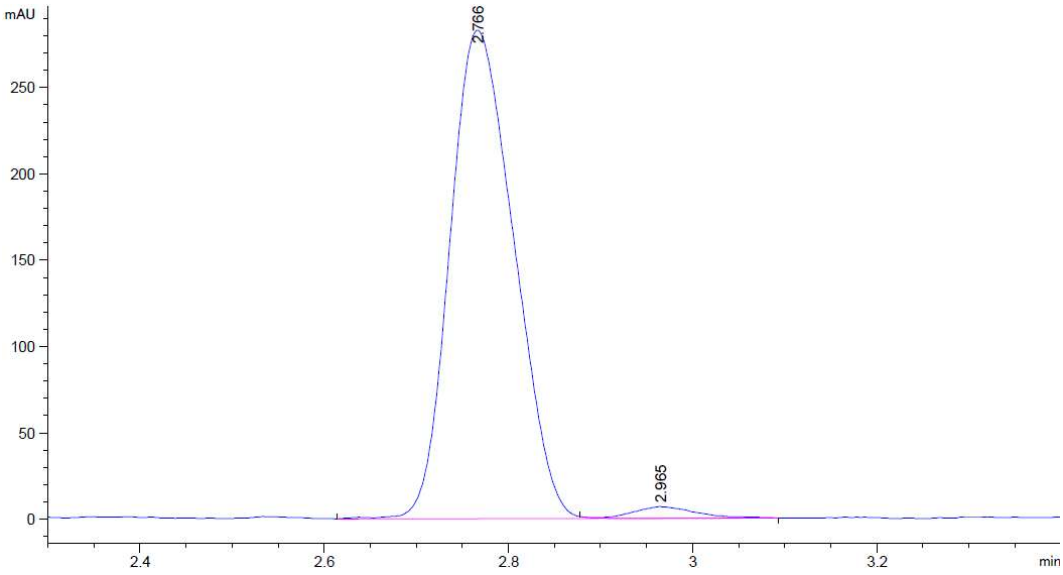


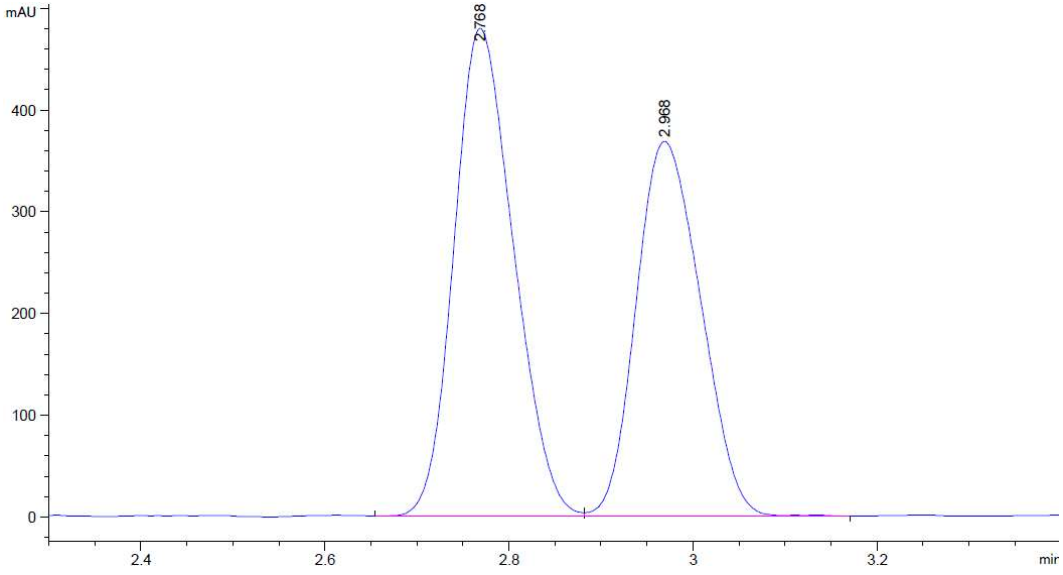


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.064	BV R	0.0595	40.43837	9.73639	1.6685
2	5.442	VV R	0.0826	2383.20703	454.81406	98.3315

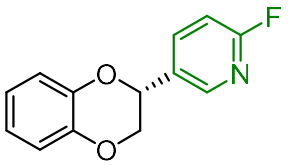


6p

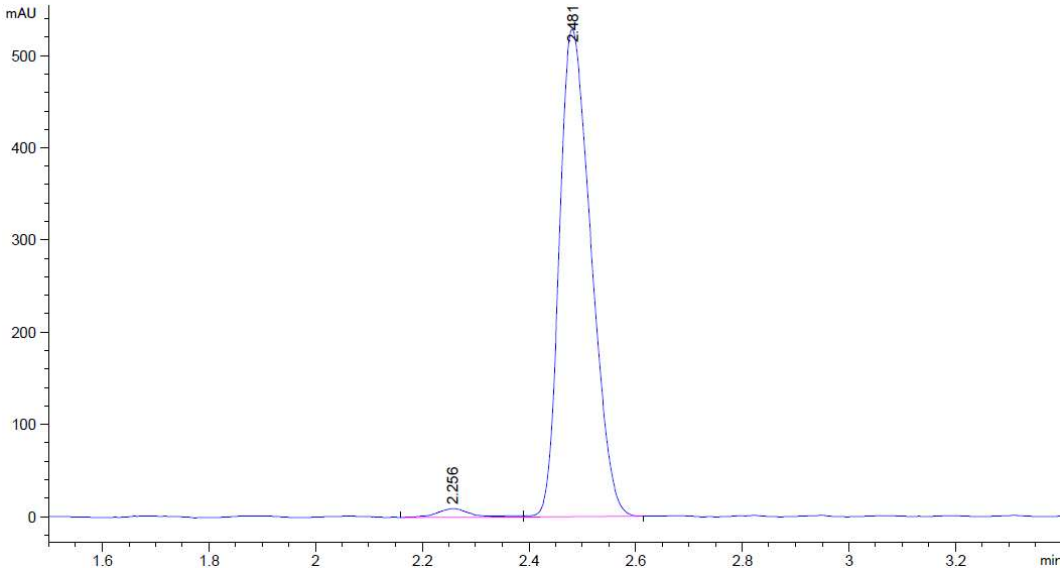


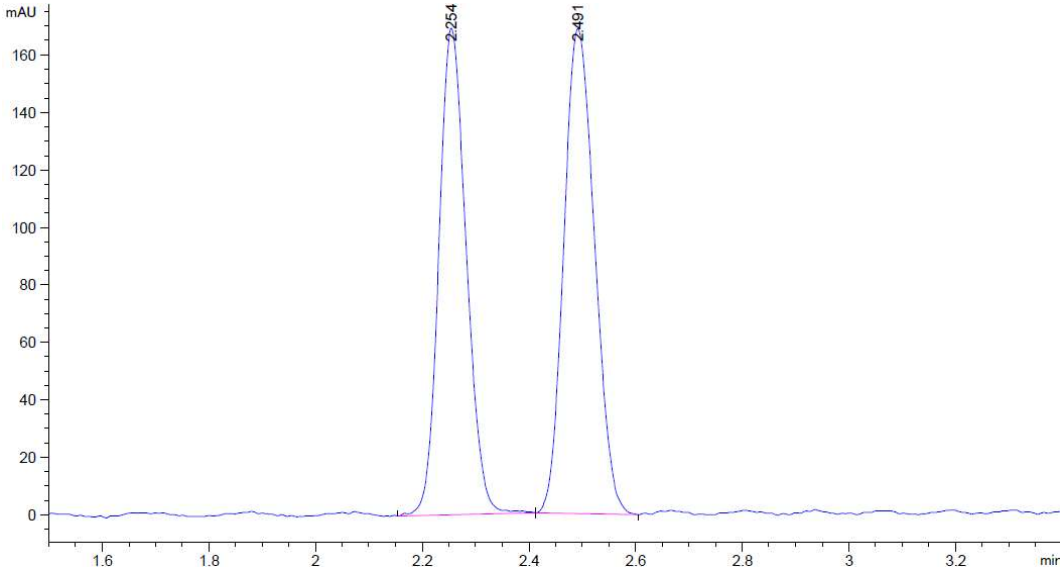


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	2.766	VV R	0.0742	1361.65125	282.82779	97.7153
2	2.965	VB E	0.0628	31.83715	6.71283	2.2847

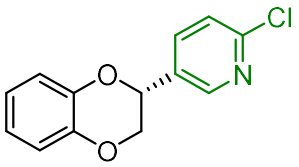


6q

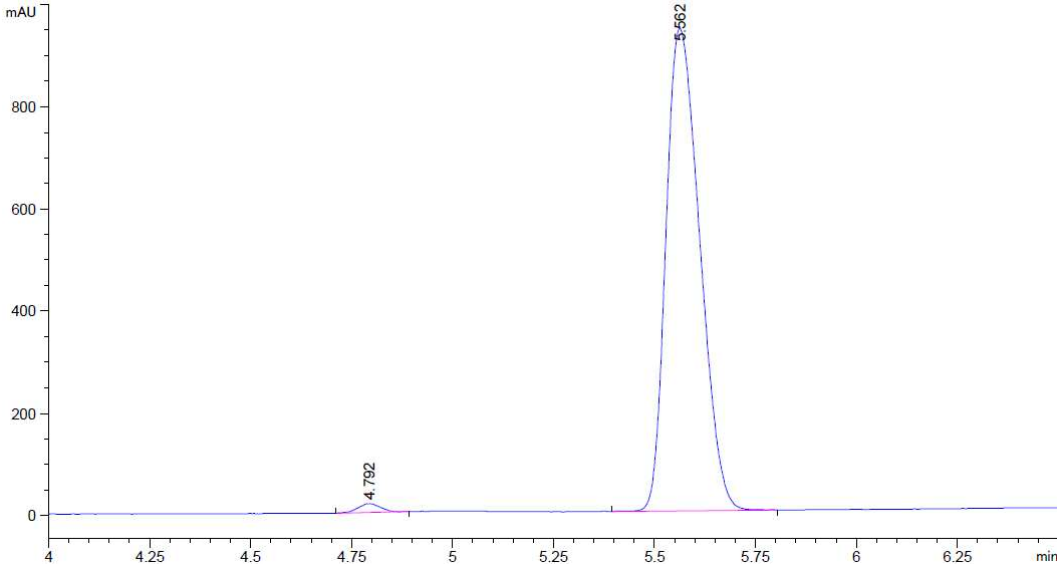


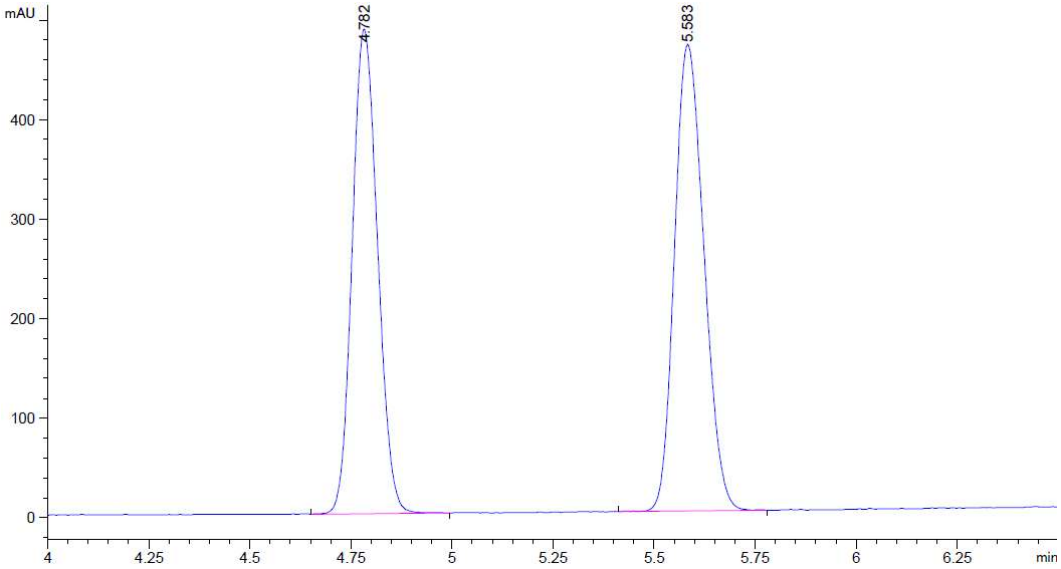


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	2.256	BV R	0.0602	41.45049	9.35714	1.8693
2	2.481	VB	0.0650	2175.95947	528.83002	98.1307

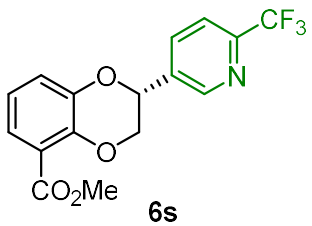


6r

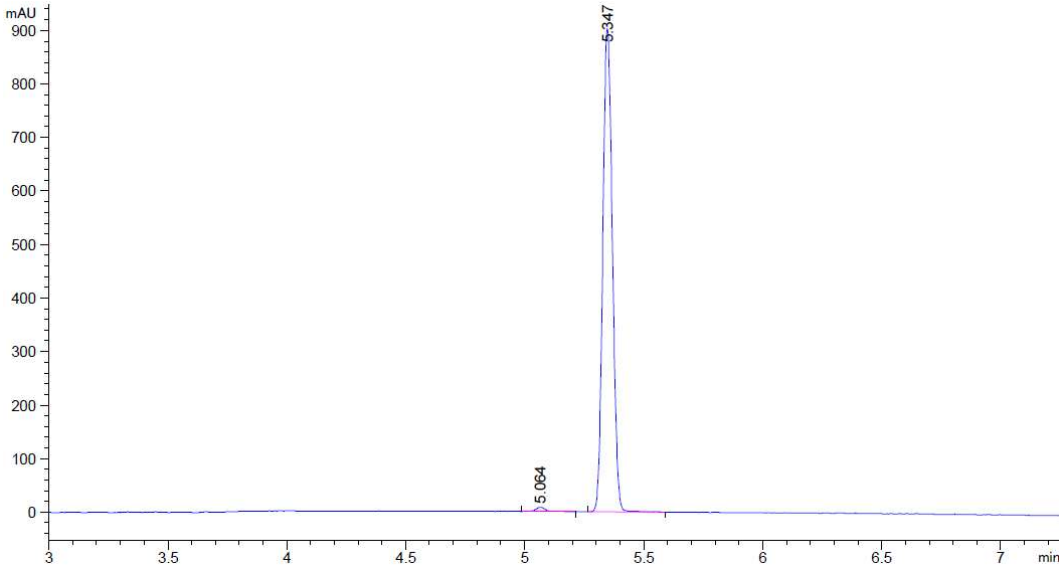


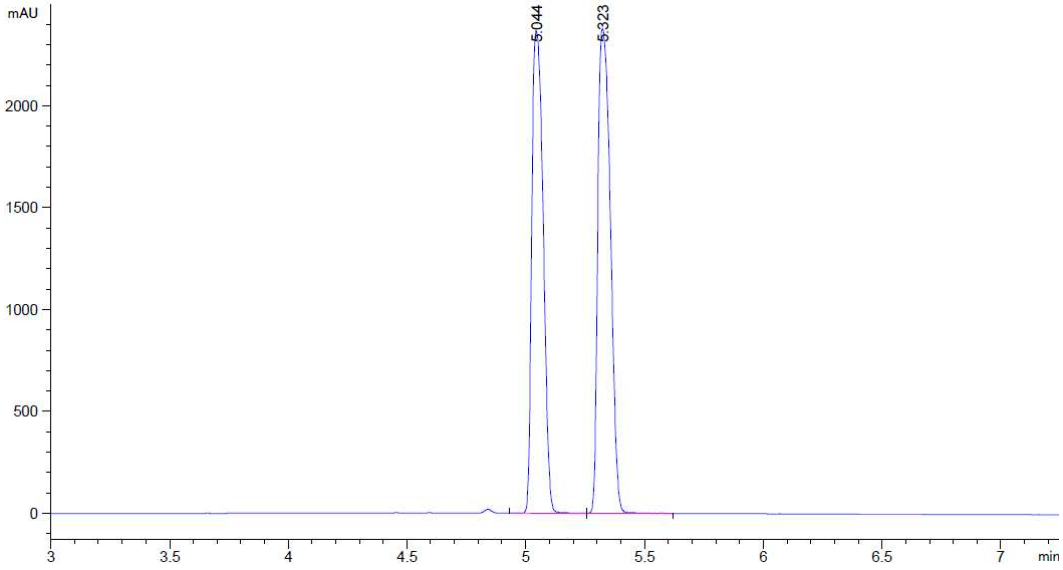


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	4.792	BV R	0.0582	66.86068	17.27545	1.2048
2	5.562	VV R	0.0917	5482.57568	944.47418	98.7952

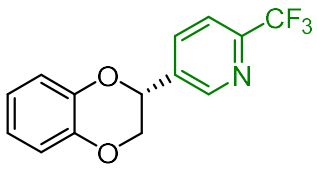


6s

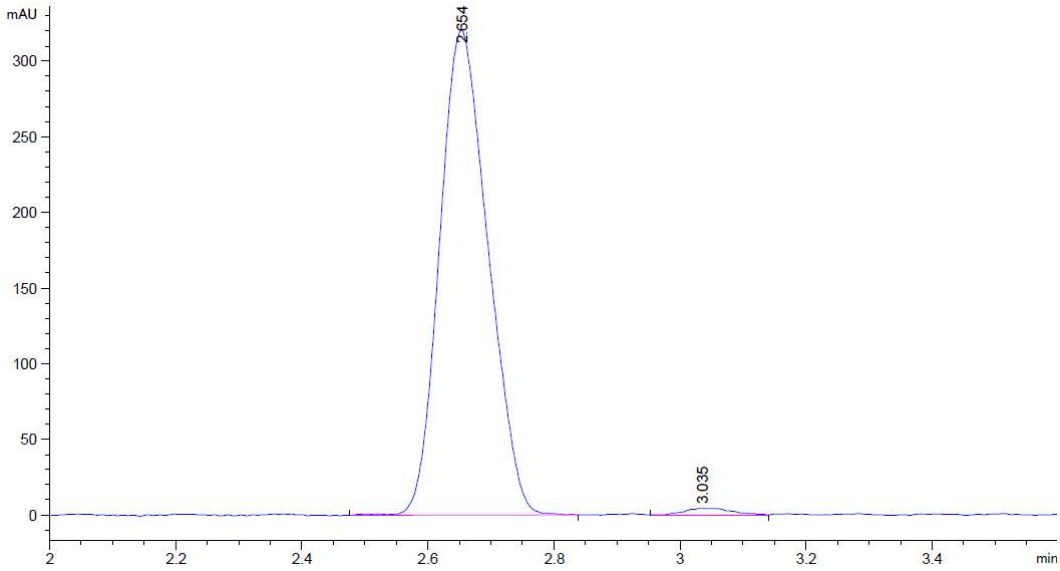


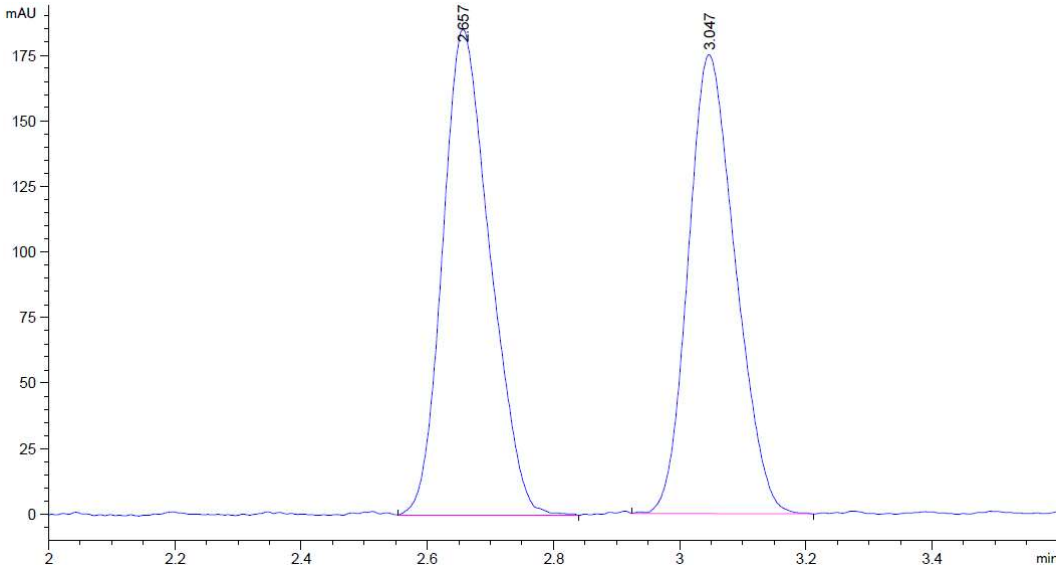


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.064	BV R	0.0435	22.50614	7.72511	0.8858
2	5.347	BV R	0.0441	2518.16260	901.88599	99.1142

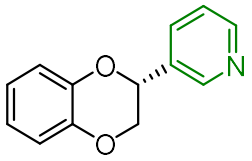


6t

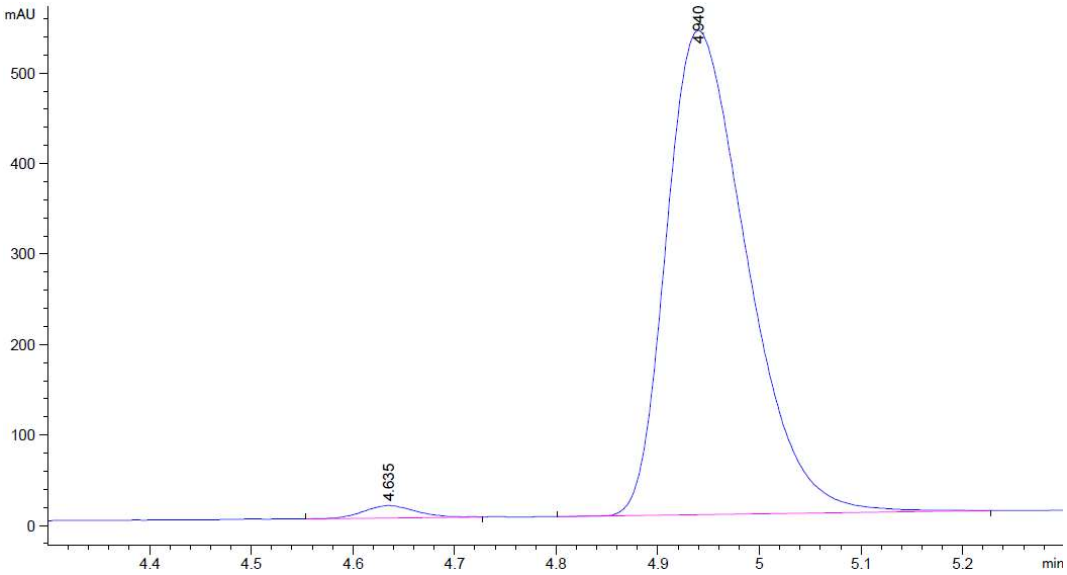


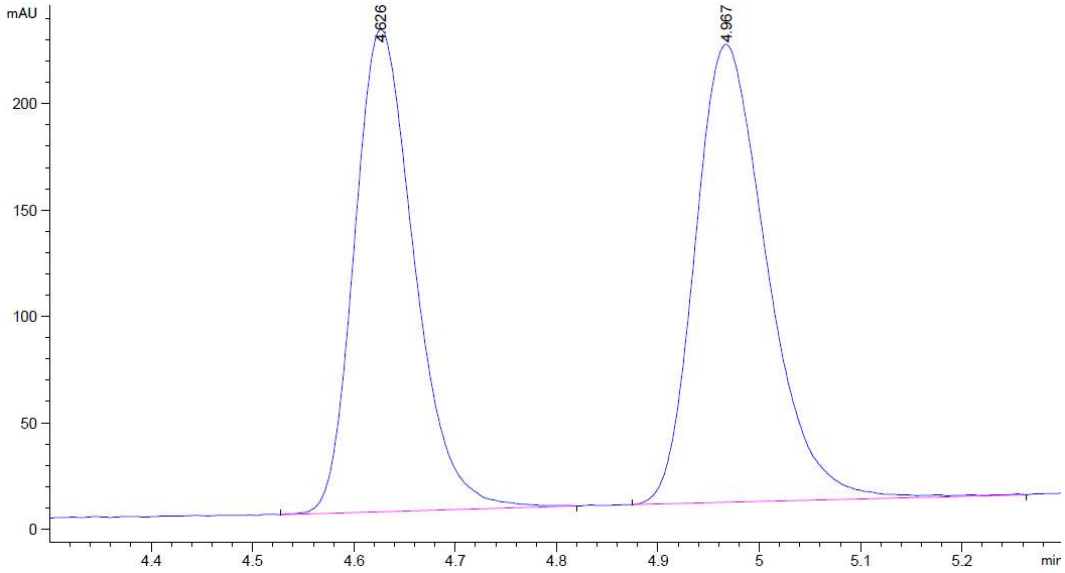


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	2.654	VV R	0.0829	1713.59778	320.61575	98.6465
2	3.035	BV R	0.0625	23.51180	4.61036	1.3535

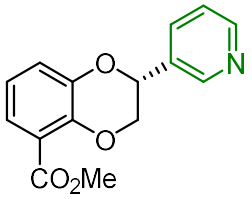


6u

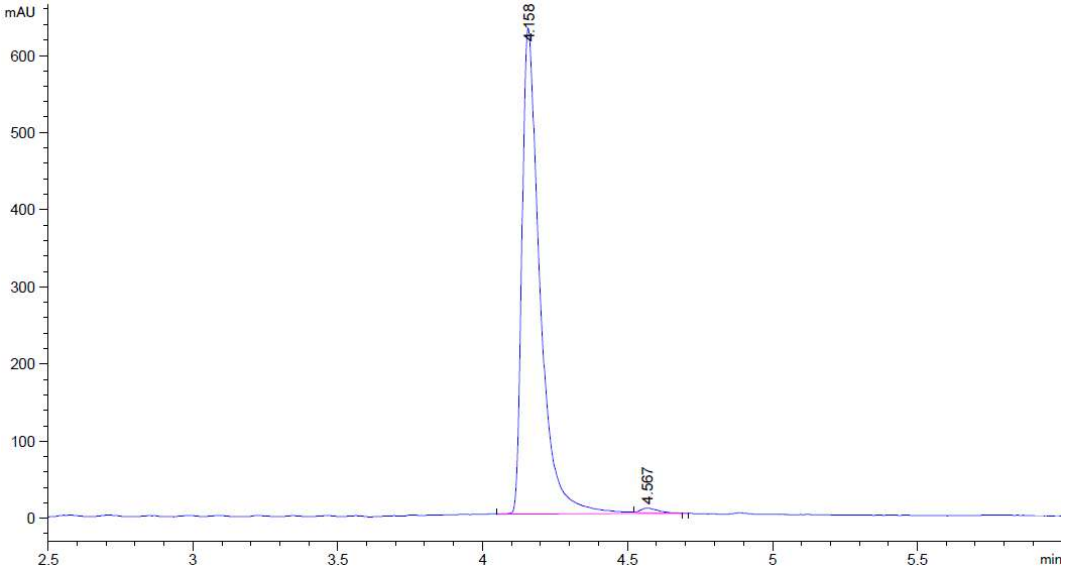


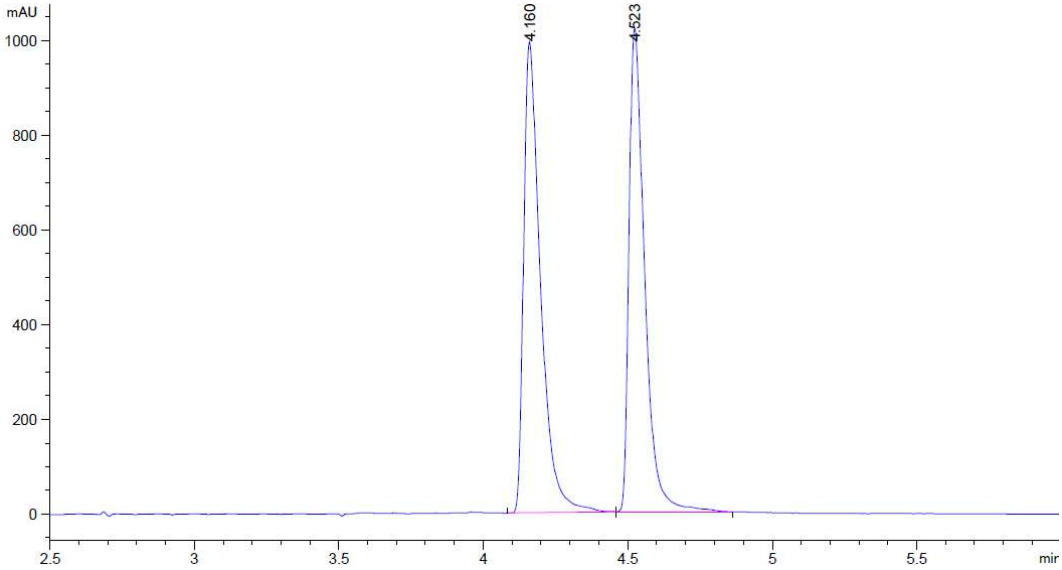


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	4.635	BV R	0.0557	48.27862	13.68087	1.6114
2	4.940	BV R	0.0852	2947.83423	535.42896	98.3886

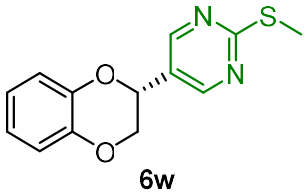


6v

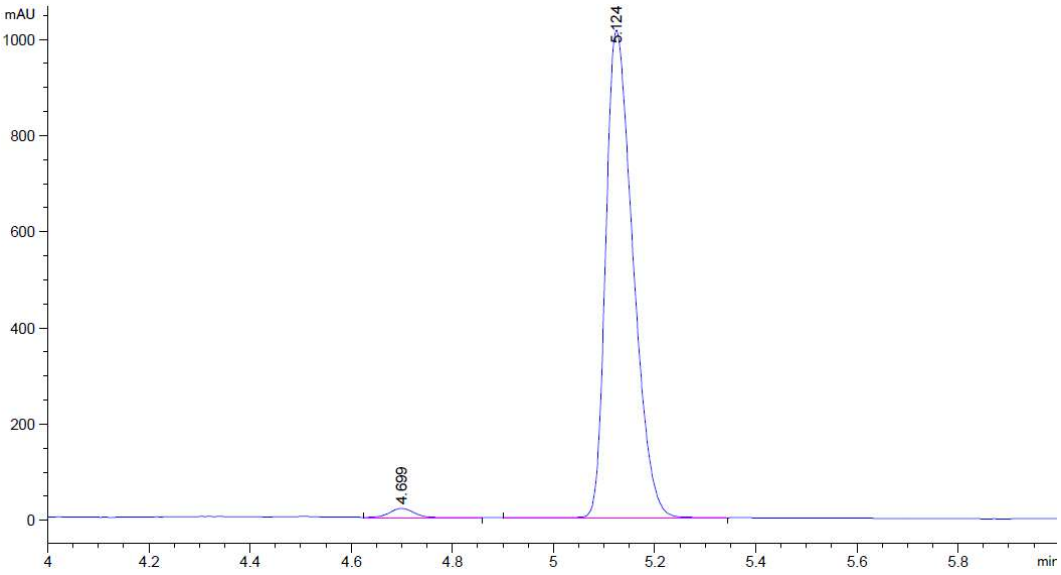


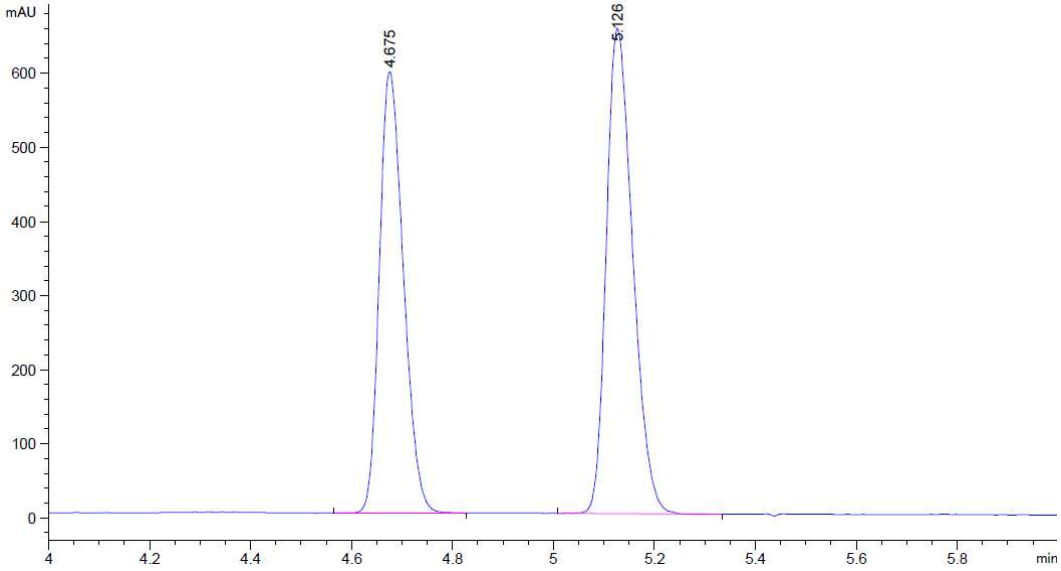


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	4.158	BV R	0.0636	2731.02612	629.32831	99.0469
2	4.567	VV E	0.0608	26.28027	6.09497	0.9531

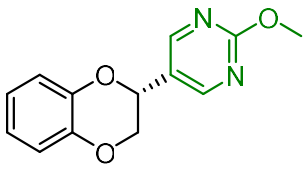


6w

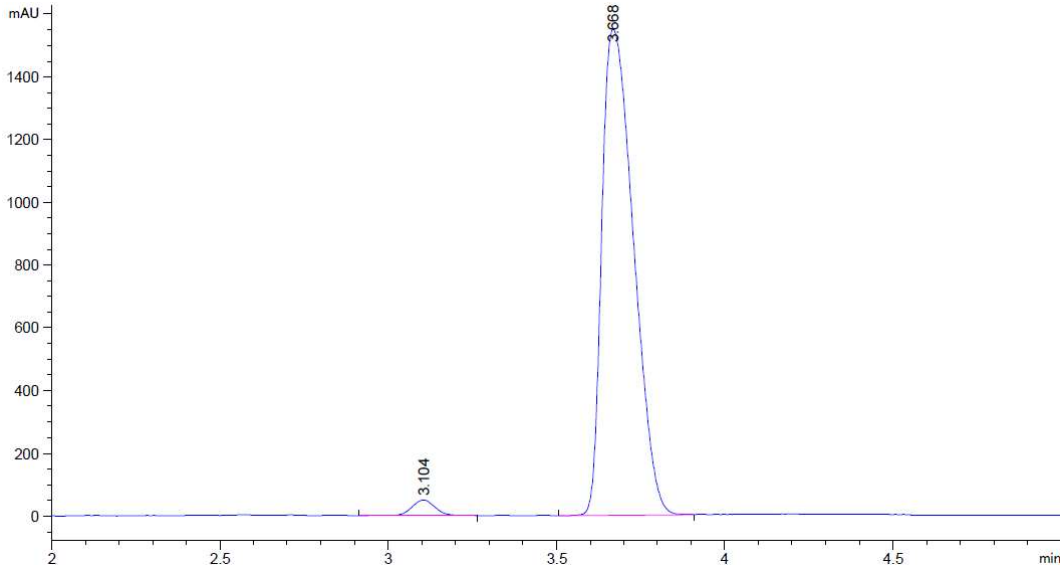


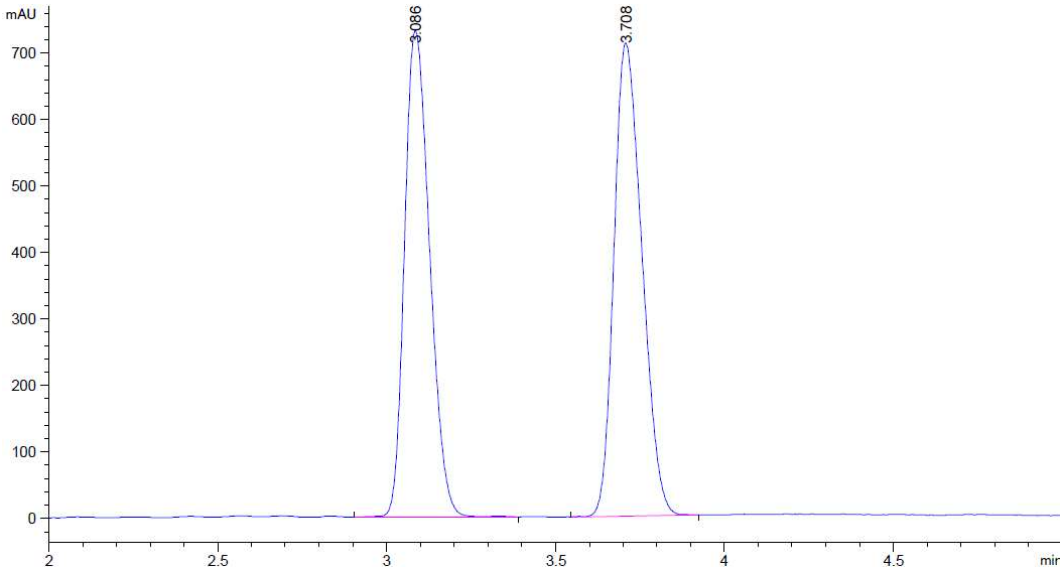


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	4.699	BV R	0.0527	67.68853	19.17303	1.7596
2	5.124	VV R	0.0580	3779.03931	1013.38159	98.2404

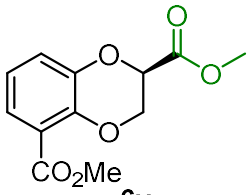


6x

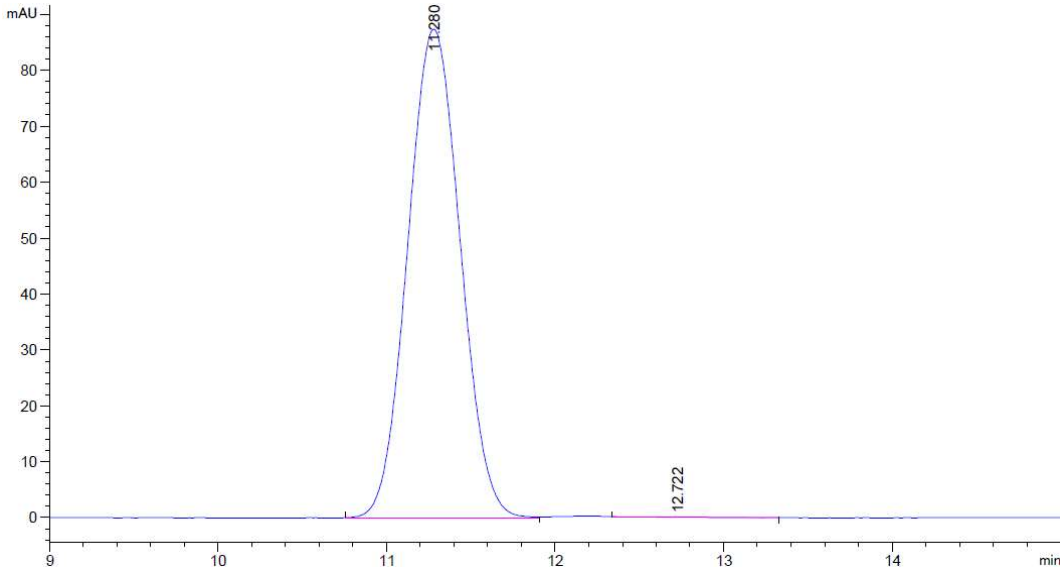


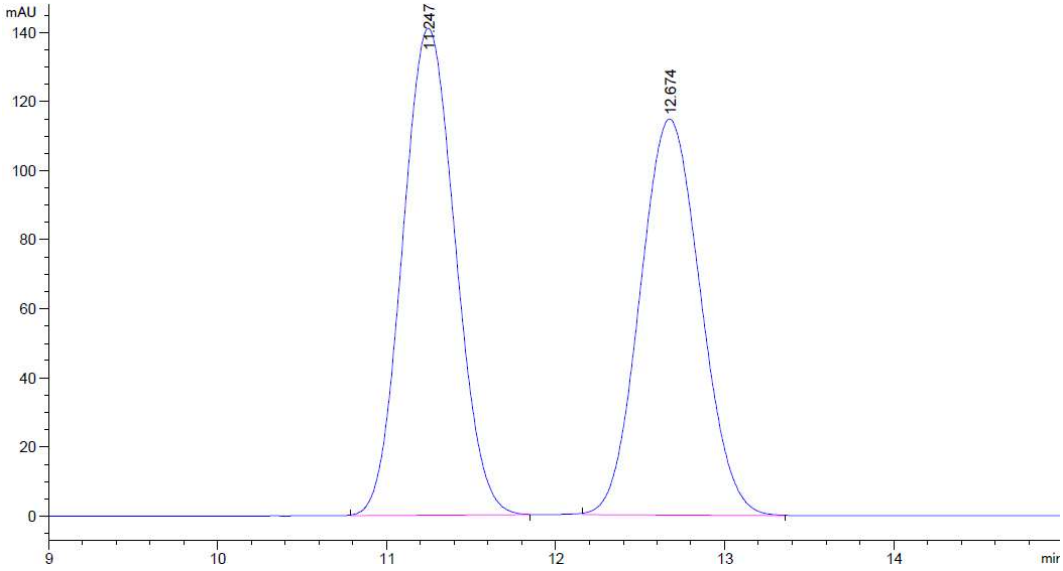


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	3.104	VB R	0.0771	240.69904	49.61906	2.3265
2	3.668	BB	0.1036	1.01054e4	1549.13367	97.6735

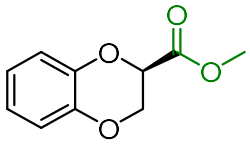


6y

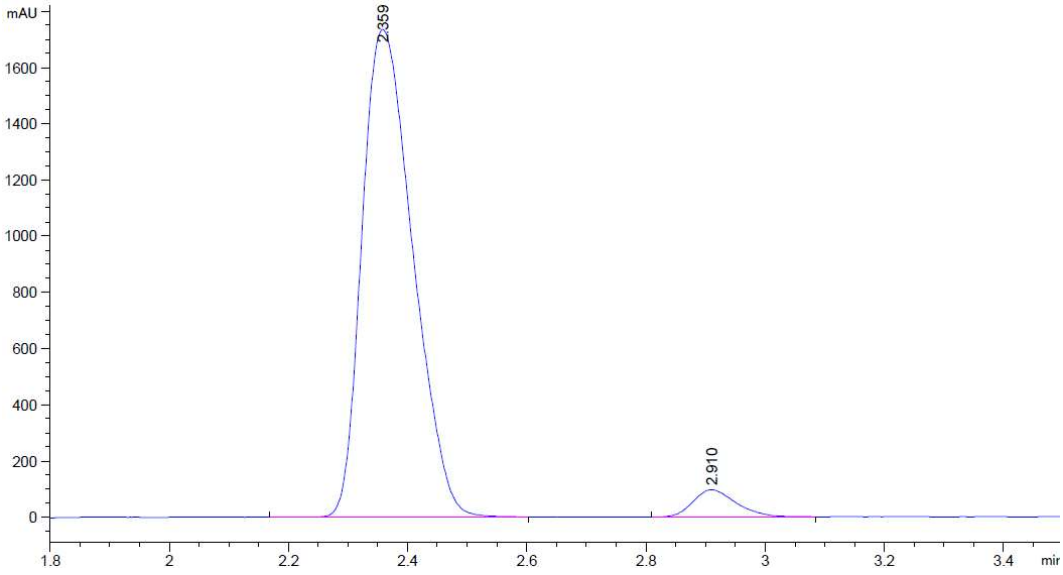


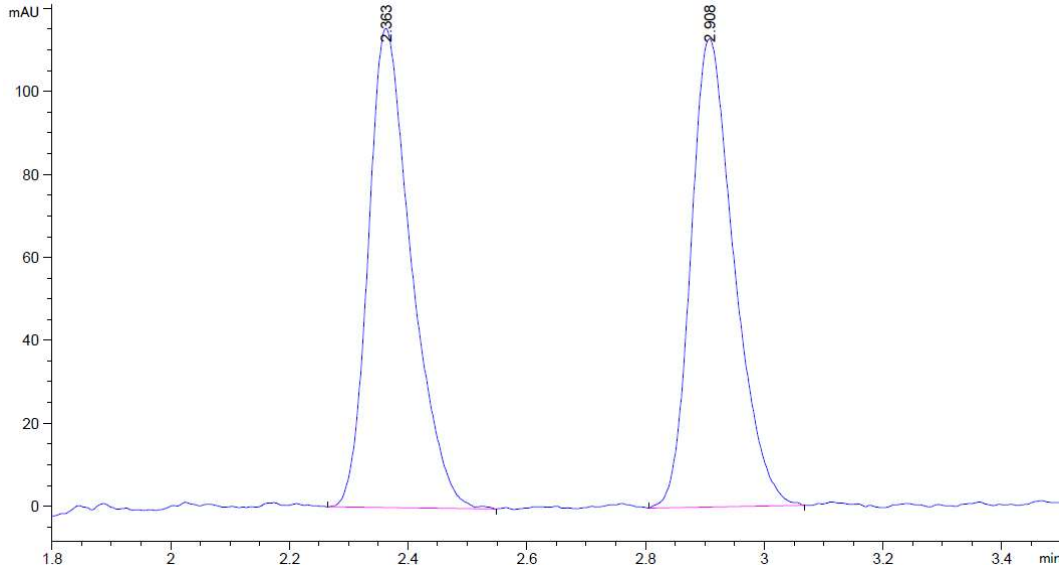


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	11.280	BV	0.3406	1890.86792	87.32867	99.8730
2	12.722	MM	0.3859	2.40366	1.03808e-1	0.1270

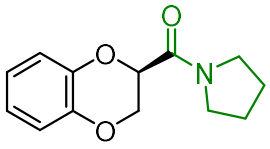


6z

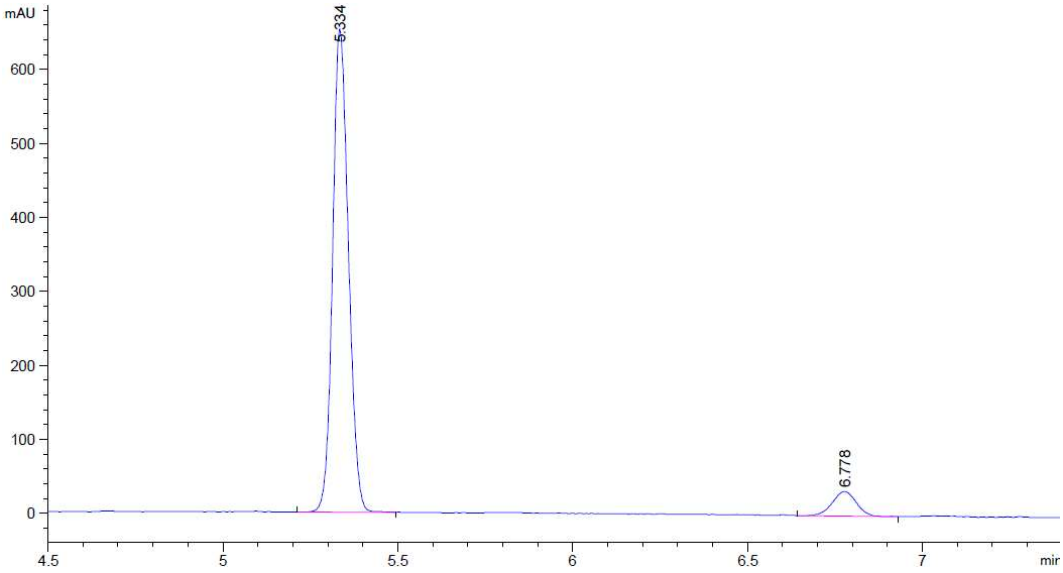


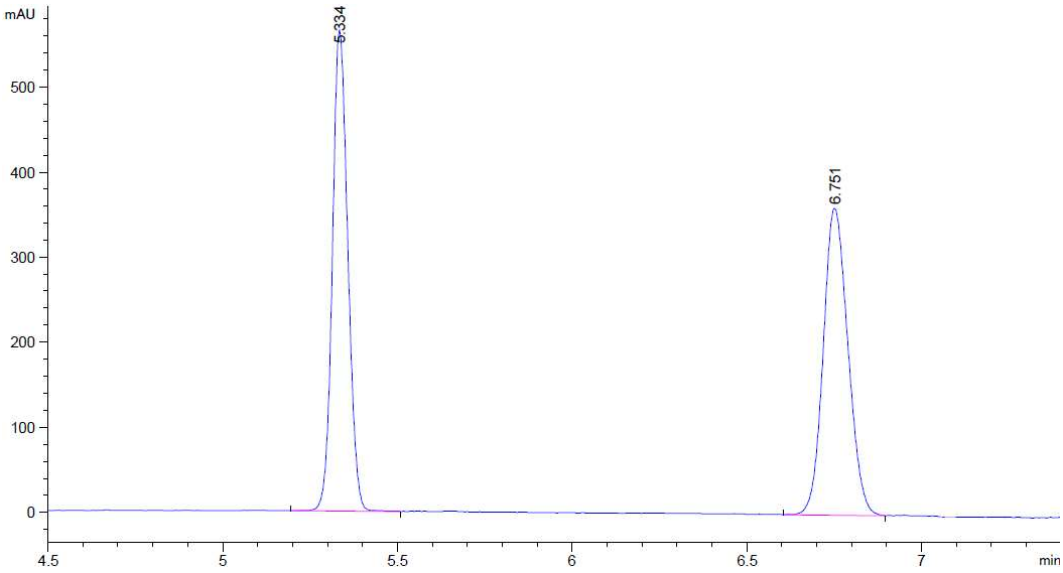


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	2.359	VB R	0.0920	1.02609e4	1735.24243	95.4334
2	2.910	BV R	0.0780	491.00027	97.13327	4.5666

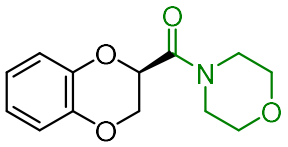


6aa

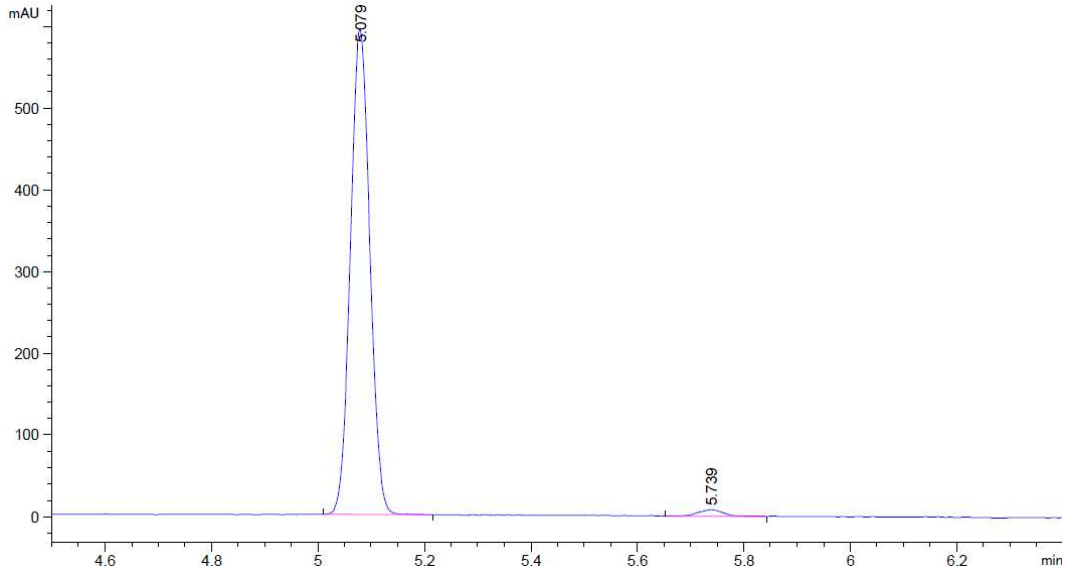


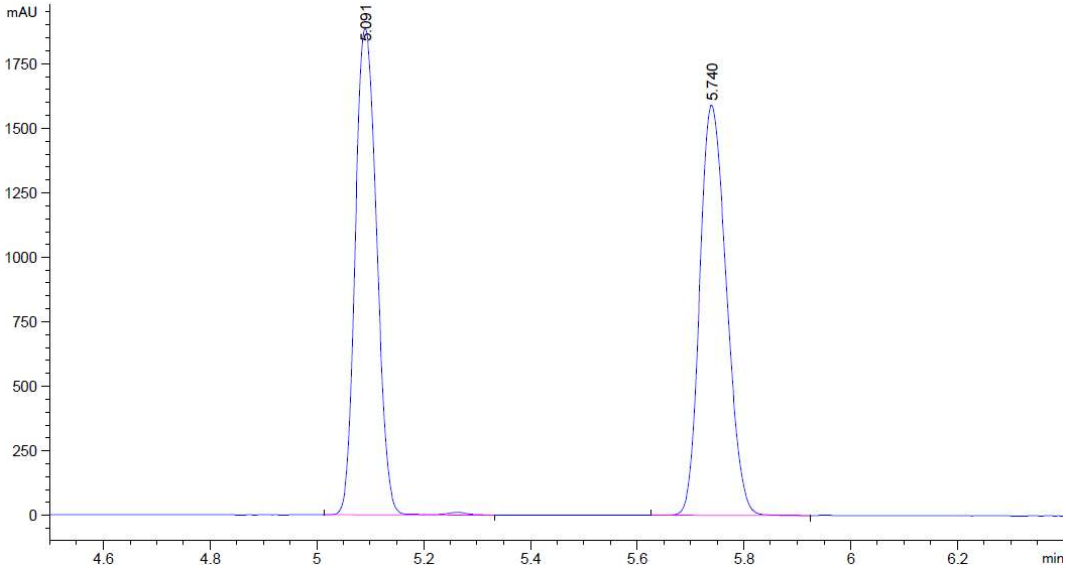


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.334	BV R	0.0486	2048.73975	652.91919	92.8136
2	6.778	BV R	0.0692	158.63075	33.21504	7.1864

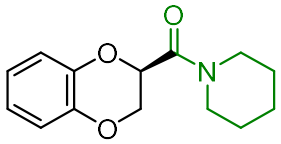


6ab

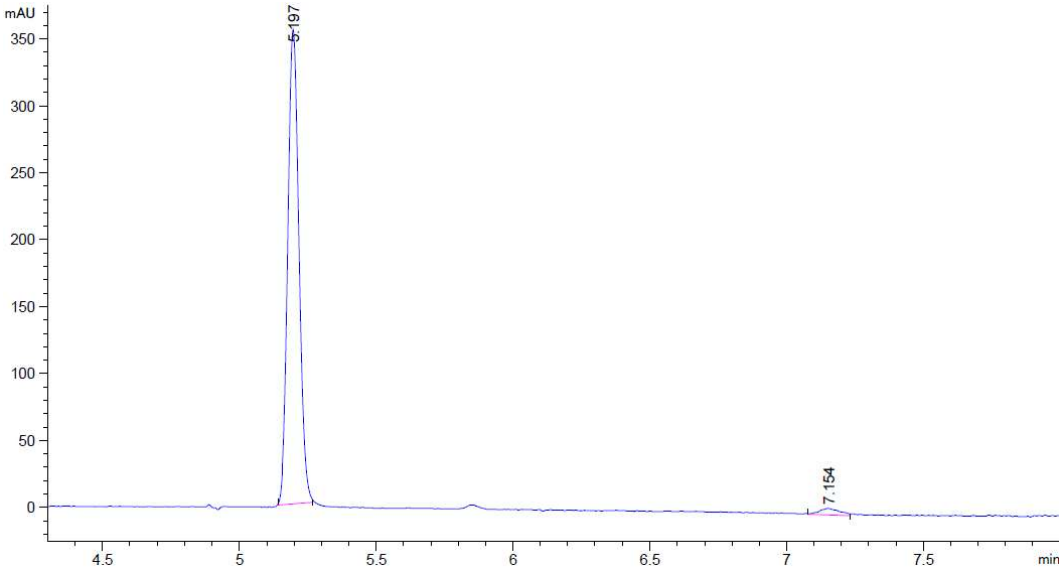


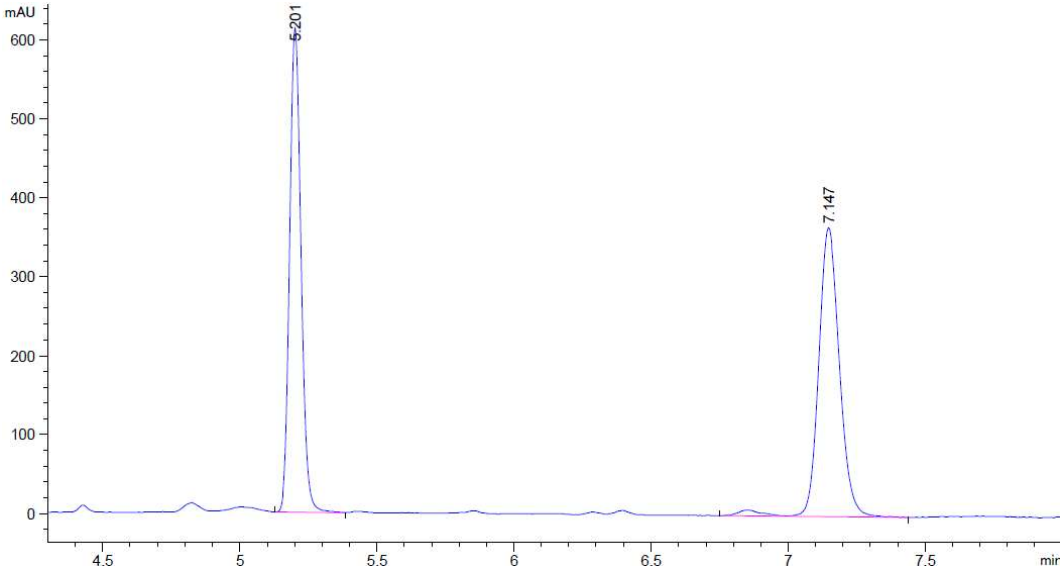


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.079	BV R	0.0396	1508.83118	594.37537	98.2450
2	5.739	VV R	0.0481	26.95242	7.94723	1.7550

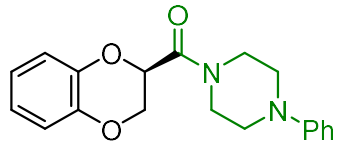


6ac

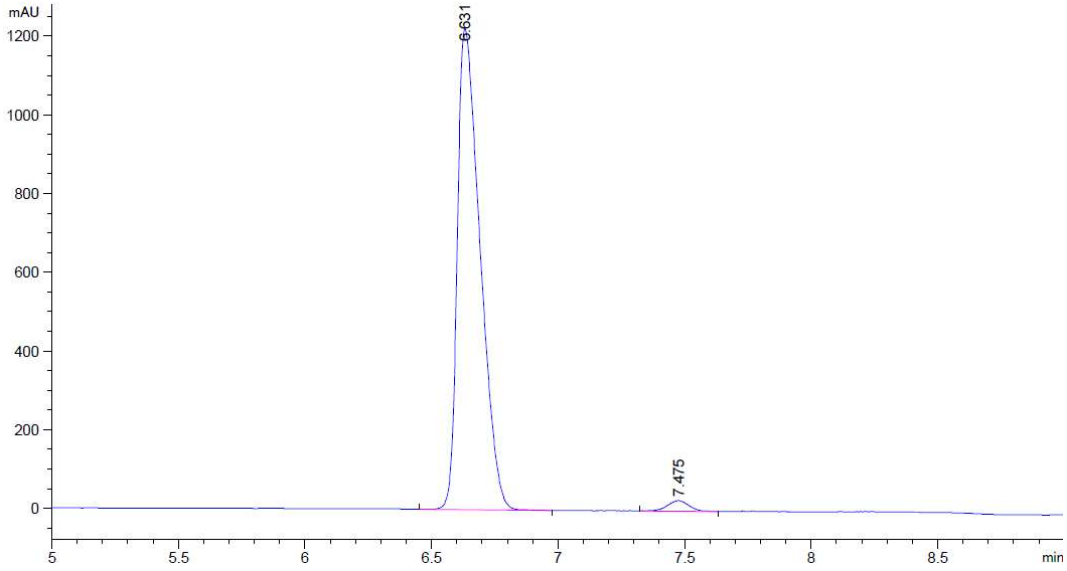


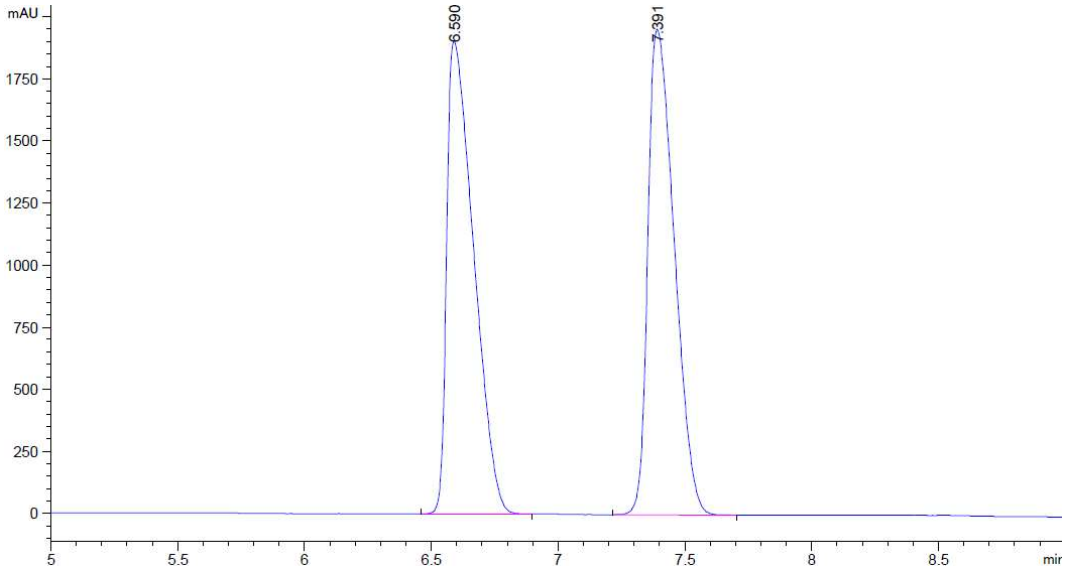


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	5.197	MM	0.0469	998.12708	354.61432	97.4998
2	7.154	MM	0.0886	25.59502	4.81550	2.5002

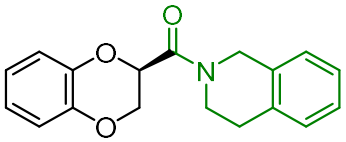


6ad

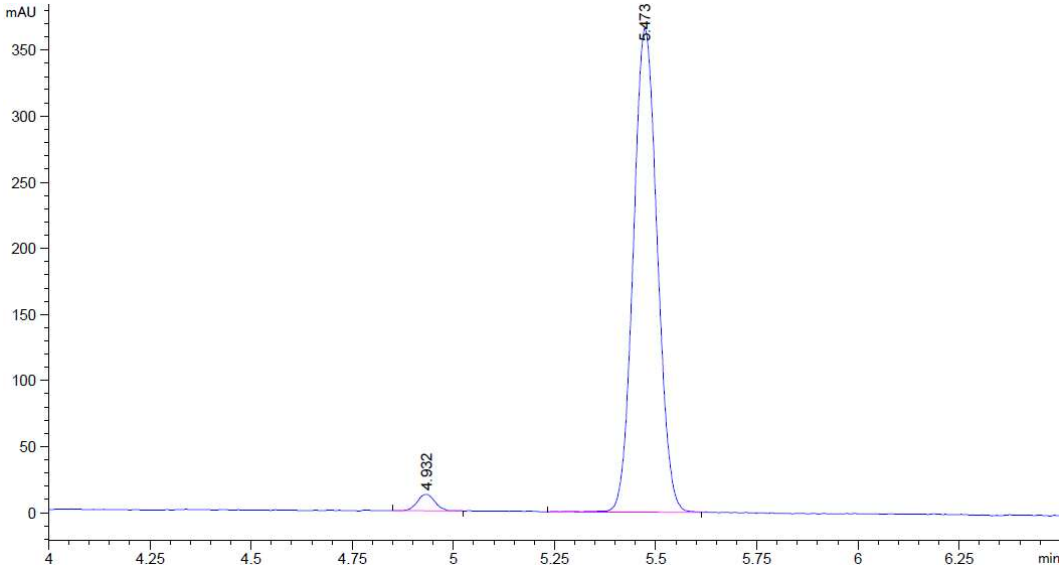


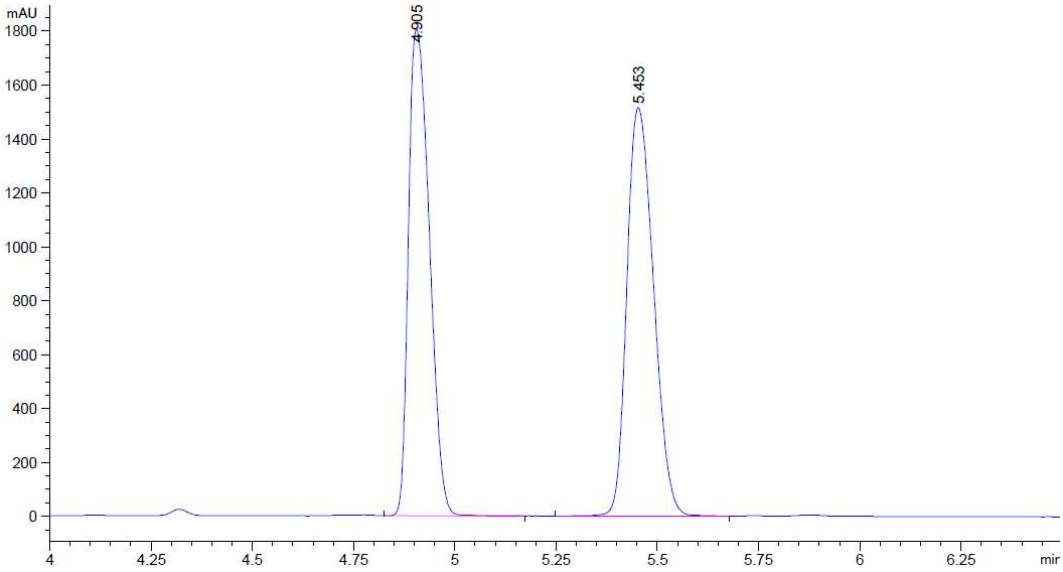


Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	6.631	VV R	0.0952	7620.18848	1222.85583	97.9781
2	7.475	VB R	0.0722	157.25119	27.09343	2.0219



6ae





Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	4.932	VV R	0.0481	38.43156	12.59318	2.4863
2	5.473	VB R	0.0640	1507.27795	366.21469	97.5137

VIII. Details of Computational Studies

Optimizations of intermediates and transition states were performed using Gaussian 09[8] software with spin-restricted DFT using PBE[9] functional and split basis set (6-31G(d) for C, P, O, H, Cl and LANL2DZ for Ir) in the gas phase. For all species, vibrational frequencies were also computed at the specified level of theory to obtain thermal Gibbs Free Energy corrections (at 298 K) and to characterize the stationary points as transition states (one and only one imaginary frequency) or minima (zero imaginary frequencies). Single point energy calculations were performed on optimized geometries in methanol solvent using the IEFPCM -solvation model[10], PBE functional including Grimme dispersion correction D2[11], and split basis set (6-311+G(d,p) for C, P, O, H, Cl and LANL2DZ (f) for Ir).[12] Obtained single-point energies were converted to the enthalpies and Gibbs free energies using corrections from gas-phase frequency analysis. Conformational analysis of the transition states was performed manually.

Example of the input file specifying basis set used in single-point:

rpbepbe/gen pseudo=read extrabasis empiricaldispersion=gd2 scrf=(iefpcm,solvent=methanol)

name

0 1
COORDINATES

C H O P Cl 0
6-311G(d,p)
****
Ir 0
lanl2dz
****

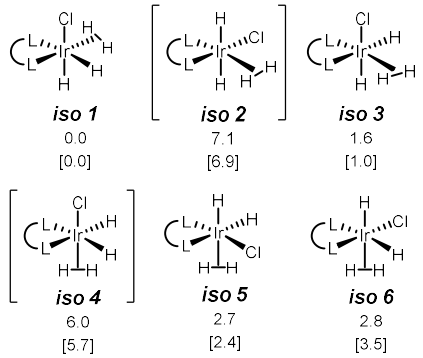
Ir 0
F 1 1.0
0.938 1.0
****

Ir 0
Lanl2dz

[8] Gaussian 09, Revision D.01, M. J. Frisch, G. W. Trucks, H. B. Schlegel, G. E. Scuseria, M. A. Robb, J. R. Cheeseman, G. Scalmani, V. Barone, B. Mennucci, G. A. Petersson, H. Nakatsuji, M. Caricato, X. Li, H. P. Hratchian, A. F. Izmaylov, J. Bloino, G. Zheng, J. L. Sonnenberg, M. Hada, M. Ehara, K. Toyota, R. Fukuda, J. Hasegawa, M. Ishida, T. Nakajima, Y. Honda, O. Kitao, H. Nakai, T. Vreven, J. A. Montgomery, Jr., J. E. Peralta, F. Ogliaro, M. Bearpark, J. J. Heyd, E. Brothers, K. N. Kudin, V. N. Staroverov, T. Keith, R. Kobayashi, J. Normand, K. Raghavachari, A. Rendell, J. C. Burant, S. S. Iyengar, J. Tomasi, M. Cossi, N. Rega, J. M. Millam, M. Klene, J. E. Knox, J. B. Cross, V. Bakken, C. Adamo, J. Jaramillo, R. Gomperts, R. E. Stratmann, O. Yazyev, A. J. Austin, R. Cammi, C. Pomelli, J. W. Ochterski, R. L. Martin, K. Morokuma, V. G. Zakrzewski, G. A. Voth, P. Salvador, J. J. Dannenberg, S. Dapprich, A. D. Daniels, O. Farkas, J. B. Foresman, J. V. Ortiz, J. Cioslowski, and D. J. Fox, Gaussian, Inc., Wallingford CT, 2013.
[9] Perdew, J. P., Burke, K., Ernzerhof, M. *Phys. Rev. Lett.,* **1996***, 77,* 3865*;* [9] Perdew, J. P., Burke, K., Ernzerhof, M. *Phys. Rev. Lett.,* **1997***, 78,* 1396*;*
[10] Tomasi, J., Mennucci,B., Cammi, R. Chem. Rev., 2005, 105, 2999.
[11] Grimme, S. *J. Comp. Chem.*, **2006**, *27*, 1787.
[12] Hopmann, K. H. *Organometallics*, **2016**, *35*, 3795.

Coordinates and thermochemical data for computed intermediates and transition states

Analysis of the isomeric Ir complexes identified the most stable complexes that likely define the selectivity of the protonation step. Out of six possible isomeric structures, diastereomers iso 1 and iso 3 are the most stable, with hydrogen coordinated at the equatorial position. When coordinated to the same orbital as the chloride (iso 2 and iso 4), dihydrogen undergoes addition to the metal center, resulting in the formation of Ir(V) intermediate. We focused on the analysis of the reactivity of the isomers 1 and 3.



Relative free energies and enthalpies (in brackets), kcal/mol are shown.

Iso1

Zero-point correction= 0.635112 (Hartree/Particle)
Thermal correction to Energy= 0.676086
Thermal correction to Enthalpy= 0.677030
Thermal correction to Gibbs Free Energy= 0.563341
Sum of electronic and zero-point Energies= -2714.757921
Sum of electronic and thermal Energies= -2714.716946
Sum of electronic and thermal Enthalpies= -2714.716002
Sum of electronic and thermal Free Energies= -2714.829691
Electronic energy -2716.02587636

C	-4.97105500	-1.02666700	-1.99393700
C	-4.12141900	-0.40318000	-1.05496300
C	-2.93341400	-1.06956300	-0.66467100
C	-2.62294800	-2.30717700	-1.27026500
C	-3.45465700	-2.91404300	-2.22097200
C	-4.64008300	-2.26084300	-2.57057700
H	-5.89007100	-0.51152700	-2.28919200
H	-3.16993700	-3.87642300	-2.65450800
H	-5.31196900	-2.71598700	-3.30527000
O	-1.45658800	-2.93633400	-0.92090800
C	-0.82851400	-2.35091300	0.23871000
P	-1.60557000	-0.62933500	0.54218400
C	-2.34218800	-0.75238800	2.30353000
C	-2.77698900	0.66861600	2.71777700
H	-3.17884800	0.63154100	3.74771700
H	-3.56701900	1.07440000	2.06441100
H	-1.91256700	1.35488400	2.71538100
C	-3.53087600	-1.72634200	2.34844500
H	-3.88870200	-1.80899700	3.39162900
H	-3.25450800	-2.74205000	2.01239600
H	-4.37283500	-1.38060300	1.72611100
C	-1.21623400	-1.22180700	3.25046800
H	-0.33733600	-0.55723200	3.19298400
H	-0.89319000	-2.25851900	3.05373000
H	-1.60257200	-1.19139400	4.28649400
Ir	0.01127700	0.99575300	-0.08636100
H	-1.04088600	-3.00652900	1.10326300
H	-0.64015100	2.64540400	-0.01956600
H	-1.27141900	2.17451000	0.36636200
H	-0.53120100	0.92011400	-1.60018400
H	1.17538600	1.96468300	-0.69691600
C	0.68367100	-2.35674600	0.01517600
H	0.91398800	-3.13047800	-0.74314300
C	2.85519600	-1.00803600	0.62407700
C	2.52840200	-2.11837900	1.43243900
C	4.10062800	-0.35956400	0.81702700
C	3.39191100	-2.61247100	2.41785200
C	4.97924500	-0.87850000	1.79031900
C	4.62583100	-1.97858300	2.58501300
H	3.09158600	-3.47464600	3.01892100
H	5.94275700	-0.38201600	1.93841700
H	5.32287100	-2.34550700	3.34523800
O	1.31781100	-2.73920600	1.24780700
C	2.00343400	-0.97044200	-2.32528900
C	2.50642400	0.35865300	-2.92024400
H	2.76033000	0.19228100	-3.98370400
H	1.72743300	1.13569800	-2.86445600
H	3.40680500	0.73248800	-2.40902800
C	0.76679400	-1.43944900	-3.12081600
H	0.38428700	-2.41873000	-2.78756200
H	-0.05701000	-0.70890200	-3.05432200
H	1.05036700	-1.53653900	-4.18485800
C	3.11519000	-2.03513100	-2.38119600
H	3.37912400	-2.21847300	-3.43890500
H	4.02481600	-1.70282200	-1.85526700
H	2.80249000	-3.00124700	-1.94714100
P	1.45717300	-0.69077900	-0.52183200
Cl	0.91800300	1.49221400	2.21237200
C	4.54552700	0.83293400	0.04001300
C	5.71125400	0.75781600	-0.75270400
C	3.85459000	2.05870800	0.13323800
C	6.15920600	1.87670400	-1.46848200
H	6.25783900	-0.19015500	-0.81438300
C	4.31308400	3.17654700	-0.57866000
H	2.97343200	2.12805800	0.78158600
C	5.45728700	3.08905700	-1.38569900
H	7.05802000	1.80113000	-2.08976500
H	3.77121600	4.12452900	-0.49428900
H	5.80732500	3.96472900	-1.94259800
C	-4.52202200	0.93822000	-0.54038600
C	-3.73964400	2.07643700	-0.82217300
C	-5.73070400	1.10166700	0.16828900
C	-4.14385600	3.34449000	-0.38178900
H	-2.82027500	1.95623800	-1.40361700
C	-6.13012600	2.36953800	0.61392200
H	-6.35069300	0.22328100	0.37854000
C	-5.33542800	3.49356200	0.34395700
H	-3.52957200	4.22101900	-0.61465300
H	-7.06474500	2.47903100	1.17384800
H	-5.64785800	4.48386400	0.69068300

Iso2

Zero-point correction= 0.634963 (Hartree/Particle)
Thermal correction to Energy= 0.675850
Thermal correction to Enthalpy= 0.676794
Thermal correction to Gibbs Free Energy= 0.563421
Sum of electronic and zero-point Energies= -2714.750441
Sum of electronic and thermal Energies= -2714.709554
Sum of electronic and thermal Enthalpies= -2714.708610
Sum of electronic and thermal Free Energies= -2714.821983
Electronic energy -2716.01470181

C	5.26197800	-0.93266600	1.57989400
C	4.32525200	-0.37890400	0.67999900
C	3.05039800	-0.98935500	0.57973100
C	2.75742800	-2.10184300	1.40119000
C	3.67925500	-2.62910700	2.31305000
C	4.94033800	-2.03014900	2.39056800
H	6.24972700	-0.46806000	1.65384500
H	3.40475300	-3.49260500	2.92459500
H	5.68434100	-2.42545500	3.08943000
O	1.51597000	-2.68162200	1.30031100
C	0.85124100	-2.31032900	0.07587000
P	1.53738500	-0.59460600	-0.39233200
C	1.88605700	-0.69120400	-2.26225900
C	2.29562300	0.70031000	-2.78218500
H	2.40326100	0.64456000	-3.88125900
H	3.25519600	1.03947800	-2.36372200
H	1.52607300	1.45461800	-2.55101000
C	2.99247200	-1.71955600	-2.55946500
H	3.13326700	-1.78271700	-3.65421600
H	2.73977000	-2.73338400	-2.20239800
H	3.95541700	-1.42608100	-2.11073400
C	0.56265200	-1.10452400	-2.93807700
H	-0.25640500	-0.41511100	-2.67212200
H	0.25387500	-2.13070600	-2.67836900
H	0.69518800	-1.06395000	-4.03469400
Ir	0.13665600	0.96251600	0.46992100
H	1.11757500	-3.05446700	-0.70033000
H	1.34332900	1.58015400	1.37177600
H	0.88042800	2.17514700	-0.31830100
H	0.37970300	0.32227100	1.99137500
C	-0.65961100	-2.39841800	0.31168300
H	-0.80631200	-3.04010000	1.19915800
C	-2.70932900	-1.15603800	-0.81491000
C	-2.31935300	-2.40229300	-1.35916400
C	-3.84091600	-0.49384000	-1.37295100
C	-2.97820200	-3.00601000	-2.43778700
C	-4.49669400	-1.11235400	-2.46304200
C	-4.07316500	-2.33844700	-2.98997900
H	-2.62842300	-3.97124700	-2.81302900
H	-5.34897200	-0.59518000	-2.91247900
H	-4.60410200	-2.77722200	-3.84084200
O	-1.25140600	-3.06828100	-0.81648400
C	-2.55517600	-1.05364800	2.20550500
C	-3.48890800	0.14663600	2.46168500
H	-3.94222800	0.02604400	3.46364100
H	-2.93758900	1.10168100	2.43788300
H	-4.30672900	0.19630500	1.72542200
C	-1.53444400	-1.15891500	3.35460800
H	-0.76076800	-1.92919500	3.18277900
H	-1.02844400	-0.19512500	3.52545600
H	-2.07587900	-1.42997700	4.27952700
C	-3.38452500	-2.34750500	2.09440700
H	-3.97495000	-2.46384100	3.02180100
H	-4.09120100	-2.31119600	1.24866500
H	-2.76464300	-3.25550000	1.98929400
P	-1.58190300	-0.74361300	0.58693200
C	-4.42289900	0.78338600	-0.87574000
C	-5.82548400	0.87245100	-0.70484600
C	-3.63834400	1.92142100	-0.60413300
C	-6.42106500	2.06288800	-0.27314100
H	-6.44486900	-0.01246700	-0.88706500
C	-4.23849400	3.11362100	-0.17509800
H	-2.55257800	1.88639700	-0.71866600
C	-5.62757400	3.19100800	-0.01027800
H	-7.50651200	2.10650100	-0.13347000
H	-3.59883200	3.97304200	0.04487600
H	-6.09139900	4.12218000	0.33166300
C	4.75229000	0.80564500	-0.12091000
C	4.11345300	2.05522400	0.01257900
C	5.86317500	0.70057000	-0.98617300
C	4.56159000	3.16536100	-0.71660200
H	3.26533400	2.15734700	0.69390200
C	6.30370200	1.80938600	-1.72169600
H	6.37298100	-0.26405900	-1.08705300
C	5.65220200	3.04513600	-1.59034400
H	4.05406300	4.12801100	-0.59648500
H	7.15896400	1.70720200	-2.39790900
H	5.99734900	3.91229200	-2.16274300
H	-0.57562600	1.31846000	-0.99020300
Cl	-1.13852600	2.77865100	1.54979800

Iso3

Zero-point correction= 0.635600 (Hartree/Particle)
Thermal correction to Energy= 0.676384
Thermal correction to Enthalpy= 0.677328
Thermal correction to Gibbs Free Energy= 0.564604
Sum of electronic and zero-point Energies= -2714.756637
Sum of electronic and thermal Energies= -2714.715853
Sum of electronic and thermal Enthalpies= -2714.714909
Sum of electronic and thermal Free Energies= -2714.827634
Electronic energy -2716.02465240

C	-5.00990400	0.59652400	1.96249500
C	-4.14810900	0.22491200	0.90887400
C	-2.91227200	0.90260800	0.77733200
C	-2.56611600	1.88145400	1.73370300
C	-3.40930800	2.22923600	2.79565000
C	-4.64223200	1.57678000	2.89483100
H	-5.96795800	0.07730000	2.06065200
H	-3.09741300	2.99780900	3.50767900
H	-5.32422000	1.83226600	3.71210600
O	-1.35314900	2.51514300	1.61426300
C	-0.75916400	2.31219000	0.31969100
P	-1.53364600	0.73405500	-0.43236600
C	-2.14297600	1.29927300	-2.15595300
C	-2.65537100	0.06071200	-2.91794300
H	-2.94232900	0.36496600	-3.94187300
H	-3.53697600	-0.39476500	-2.44049600
H	-1.86554600	-0.70505900	-3.00282100
C	-3.25591200	2.35471200	-2.04231300
H	-3.56729100	2.66444500	-3.05717800
H	-2.92282500	3.26347900	-1.51019600
H	-4.14215700	1.95990000	-1.51882300
C	-0.92624700	1.87099500	-2.91204700
H	-0.10546300	1.13581800	-2.96470900
H	-0.52905800	2.79311000	-2.45574200
H	-1.23366400	2.11452200	-3.94590300
Ir	0.09482500	-0.98517400	-0.25204000
H	-1.01058700	3.18486800	-0.31421300
H	-0.46216700	-2.52337200	-0.94942300
H	-1.15704200	-2.00125400	-1.06079300

H	1.32025000	-2.04266100	-0.04771100
C	0.75843500	2.28728400	0.48754300
H	1.01520000	2.84691700	1.40688300
C	2.87925300	1.14740000	-0.57779300
C	2.51692400	2.42668200	-1.05588500
C	4.10158400	0.57816400	-1.01920600
C	3.31034600	3.15441300	-1.95268000
C	4.90997800	1.32560100	-1.90261200
C	4.51676400	2.58768600	-2.37000300
H	2.98021000	4.14062600	-2.28954200
H	5.85466400	0.88706300	-2.23749800
H	5.16115900	3.13557200	-3.06493600
O	1.33861100	2.98471200	-0.63163600
C	2.25598800	0.39489900	2.32382200
C	2.72639800	-1.05698100	2.54304000
H	3.10132000	-1.14633300	3.57976400
H	1.88868400	-1.76143100	2.41419100
H	3.54414200	-1.33978800	1.86128800
C	1.11394500	0.71270900	3.31316500
H	0.77210500	1.75987100	3.25492900
H	0.25066600	0.04475100	3.15529700
H	1.49379000	0.54649800	4.33842900
C	3.42492500	1.37954200	2.51198600
H	3.76222200	1.32264600	3.56320800
H	4.28297700	1.13251600	1.86578100
H	3.13745600	2.42795700	2.31531500
P	1.55569400	0.54859300	0.55962700
C	4.61198900	-0.75851100	-0.59369200
C	5.83581200	-0.84597800	0.10481100
C	3.93883000	-1.94781400	-0.93760000
C	6.35607000	-2.09169800	0.48139600
H	6.37178900	0.07428000	0.36263400
C	4.46436200	-3.19278000	-0.56456400
H	3.00092400	-1.89155100	-1.49581500
C	5.66852800	-3.26898000	0.15065600
H	7.29941700	-2.14181400	1.03522800
H	3.92668800	-4.10721600	-0.83572200
H	6.07252100	-4.24284200	0.44592200
C	-4.58712300	-0.86284300	-0.01228100
C	-3.85869300	-2.06804300	-0.10028100
C	-5.77255600	-0.72013100	-0.76419900
C	-4.30125400	-3.09568900	-0.94585400
H	-2.96740200	-2.19836700	0.52701900
C	-6.20481500	-1.74742800	-1.61504900
H	-6.34733600	0.20965400	-0.68708500
C	-5.46692500	-2.93691400	-1.71120900
H	-3.73702600	-4.03356700	-0.99471500
H	-7.12023400	-1.61844700	-2.20226900
H	-5.80611200	-3.74151700	-2.37213100
H	0.70964100	-0.64937500	-1.70243200
Cl	-0.83799500	-1.88338600	1.90446400

Iso4

Zero-point correction= 0.634931 (Hartree/Particle)
Thermal correction to Energy= 0.675977
Thermal correction to Enthalpy= 0.676921
Thermal correction to Gibbs Free Energy= 0.563778
Sum of electronic and zero-point Energies= -2714.751780
Sum of electronic and thermal Energies= -2714.710734
Sum of electronic and thermal Enthalpies= -2714.709790
Sum of electronic and thermal Free Energies= -2714.822933
Electronic energy -2716.01669581

C	-4.95994100	-1.40019600	-1.87227900
C	-4.17694500	-0.62297100	-0.98913200
C	-2.93177700	-1.14367300	-0.55347000
C	-2.52230500	-2.40636300	-1.03692000
C	-3.28961500	-3.16433200	-1.92968000
C	-4.51981900	-2.64403800	-2.34335500
H	-5.92144700	-0.99779300	-2.20504800
H	-2.92533700	-4.13861300	-2.26636200
H	-5.14455800	-3.21584000	-3.03689900
O	-1.31739000	-2.91030000	-0.61420900
C	-0.80364100	-2.21019600	0.53821900
P	-1.61040900	-0.46809600	0.55009400
C	-2.32373500	-0.29544800	2.31935400
C	-2.77782100	1.16740500	2.50035200
H	-3.11929700	1.30410100	3.54354900
H	-3.61284700	1.43286700	1.83367300
H	-1.94100900	1.86217500	2.31889300
C	-3.49732000	-1.26380800	2.54396500
H	-3.83581400	-1.17498700	3.59323600
H	-3.21345900	-2.31842200	2.37747900
H	-4.35499600	-1.03424600	1.89093000
C	-1.18763100	-0.58886200	3.32320600
H	-0.32488800	0.07845000	3.16332700
H	-0.83814300	-1.63395300	3.28528000
H	-1.57694300	-0.40810300	4.34286300
Ir	-0.03343700	1.04383200	-0.44776500
H	-1.10720100	-2.77019700	1.44409100
H	-0.92573200	2.36603400	-0.11794300
H	0.99874900	2.04874900	-1.19947900
C	0.72220000	-2.25619100	0.44986700
H	0.99817800	-3.18079400	-0.09507600
C	2.86261900	-0.81150700	0.91798600
C	2.44974100	-1.70887500	1.92709500
C	4.10287600	-0.13945100	1.05597600
C	3.22261200	-1.96685000	3.06548100
C	4.89009800	-0.42446100	2.19182300
C	4.45212900	-1.31244300	3.18430100
H	2.86018600	-2.67088400	3.81896800
H	5.84846100	0.09136900	2.30232500
H	5.07905900	-1.49677200	4.06255200
O	1.24732300	-2.35524400	1.78514700
C	2.27161500	-1.44849900	-2.02290100
C	2.84443100	-0.27656300	-2.84453700
H	3.14902200	-0.65694300	-3.83732400
H	2.09139000	0.51579100	-2.99215000
H	3.72650300	0.17496700	-2.36627700
C	1.11363300	-2.09338200	-2.81133000
H	0.65890200	-2.95238200	-2.29126900
H	0.31086900	-1.36914000	-3.03361000
H	1.51029000	-2.45369100	-3.77818800
C	3.36628200	-2.49381100	-1.74076800
H	3.72953900	-2.89893000	-2.70326900
H	4.22587000	-2.05280100	-1.21082700
H	2.99402300	-3.34511700	-1.14363900
P	1.57040600	-0.75681700	-0.38257500
Cl	0.90663600	1.84503900	1.69245200
C	4.63548900	0.83112300	0.05793000
C	5.89842600	0.60264600	-0.53159300
C	3.92467900	2.00210900	-0.27792600
C	6.42697800	1.50975600	-1.46002200
H	6.45699600	-0.30280100	-0.26839200
C	4.46241900	2.90991100	-1.20113700
H	2.96251100	2.20351000	0.20440900
C	5.70742200	2.66588400	-1.79962100
H	7.40170700	1.31221800	-1.91872900
H	3.90101600	3.81702500	-1.44845400

H	6.11999400	3.37643500	-2.52367100
C	-4.73580000	0.69038000	-0.55401100
C	-4.06566300	1.90323600	-0.81043900
C	-5.99900200	0.73715100	0.07568800
C	-4.63205400	3.12736100	-0.42985800
H	-3.09619300	1.88444200	-1.31325200
C	-6.56139400	1.96095400	0.46288300
H	-6.53205400	-0.19939200	0.27357700
C	-5.87810300	3.16055200	0.21318400
H	-4.09434600	4.05796400	-0.63890900
H	-7.53583700	1.97650000	0.96229900
H	-6.31663900	4.11705300	0.51555500
H	-0.18704200	0.24542400	-1.85254100
H	-1.04353500	1.58475200	-1.57574300

Iso5

Zero-point correction= 0.635843 (Hartree/Particle)
Thermal correction to Energy= 0.676692
Thermal correction to Enthalpy= 0.677636
Thermal correction to Gibbs Free Energy= 0.564530
Sum of electronic and zero-point Energies= -2714.755468
Sum of electronic and thermal Energies= -2714.714619
Sum of electronic and thermal Enthalpies= -2714.713675
Sum of electronic and thermal Free Energies= -2714.826781
Electronic energy -2716.02269951

C	5.27127000	-1.03293500	1.47105800
C	4.31508600	-0.42788200	0.62646600
C	3.04419500	-1.04434400	0.49882900
C	2.77771600	-2.21632300	1.24387300
C	3.71993500	-2.79701500	2.10196100
C	4.97527500	-2.19056700	2.20447800
H	6.25517300	-0.56325600	1.56235000
H	3.46350300	-3.70570000	2.65295900
H	5.73453300	-2.62643800	2.86162100
O	1.54202300	-2.80142600	1.12681100
C	0.83128100	-2.34157200	-0.04347700
P	1.51269100	-0.59880200	-0.42757200
C	1.82897800	-0.58464700	-2.30378500
C	2.24687600	0.83511600	-2.73395000
H	2.31652900	0.86116000	-3.83728300
H	3.22699100	1.12244300	-2.32378800
H	1.50437800	1.58484100	-2.41482500
C	2.91605600	-1.60442600	-2.68813800
H	3.04772600	-1.58907800	-3.78576600
H	2.64989400	-2.63785900	-2.40403600
H	3.88710900	-1.36011400	-2.22718600
C	0.48689600	-0.94234000	-2.97638600
H	-0.31675200	-0.24986600	-2.67238900
H	0.16067700	-1.97219200	-2.75240600
H	0.60520200	-0.86171100	-4.07252900
Ir	0.14801600	0.93565500	0.49904300
H	1.05563100	-3.03720300	-0.87508000
H	1.22081500	2.10081000	0.15798800
C	-0.66959700	-2.43043100	0.25533700
H	-0.77803400	-3.08703200	1.13736800
C	-2.72032400	-1.14008100	-0.80277100
C	-2.37087900	-2.38896500	-1.36925100
C	-3.84497200	-0.44928700	-1.33956300
C	-3.06409000	-2.96909900	-2.43954500
C	-4.53746900	-1.04260900	-2.42136100
C	-4.15480600	-2.27420000	-2.96534800
H	-2.74220800	-3.93856200	-2.82875700
H	-5.38424900	-0.49963700	-2.85029800
H	-4.71204800	-2.69423100	-3.80886800
O	-1.30968200	-3.08593500	-0.85477600
C	-2.54998200	-1.14454300	2.20370500
C	-3.46802700	0.06297600	2.48385500
H	-3.92766000	-0.06494900	3.48222600
H	-2.90509800	1.01252400	2.47504900
H	-4.28200900	0.13878000	1.74521700
C	-1.52279200	-1.27582900	3.34493800
H	-0.75621900	-2.04977300	3.15567100
H	-1.01155800	-0.31632400	3.53032500
H	-2.05320300	-1.55505300	4.27376600
C	-3.38656500	-2.42982200	2.07571100
H	-3.96874600	-2.57124000	3.00532600
H	-4.10074200	-2.36950100	1.23761600
H	-2.76922600	-3.33520400	1.93747400
P	-1.57033700	-0.77197100	0.60227800
C	-4.38263400	0.84446100	-0.83572800
C	-5.77794100	0.97597600	-0.63622800
C	-3.56079100	1.96259000	-0.59881100
C	-6.33000300	2.19006000	-0.21258000
H	-6.42576800	0.10667900	-0.79327200
C	-4.11643600	3.17877300	-0.17757500
H	-2.47957000	1.89072800	-0.73696200
C	-5.49915600	3.29903900	0.01369900
H	-7.41063300	2.26771800	-0.05170000
H	-3.44843900	4.02298900	0.01473500
H	-5.92881400	4.24929500	0.34774000
C	4.72189000	0.81427300	-0.09413200
C	4.09857300	2.05224100	0.16072400
C	5.80167500	0.77074600	-1.00276200
C	4.52731600	3.21291600	-0.49804800
H	3.27302800	2.10419400	0.87496800
C	6.22442600	1.93119600	-1.66553900
H	6.30062600	-0.18559100	-1.19520500
C	5.58545400	3.15541000	-1.41693000
H	4.02871300	4.16478300	-0.28864400
H	7.05511500	1.87817900	-2.37710300
H	5.91532900	4.06247200	-1.93380300
H	0.56005400	0.39953700	2.24285700
H	1.13539900	0.99234700	2.04851500
Cl	-1.08719600	2.77738900	1.55420800
H	-0.40296600	1.35732800	-0.93493800

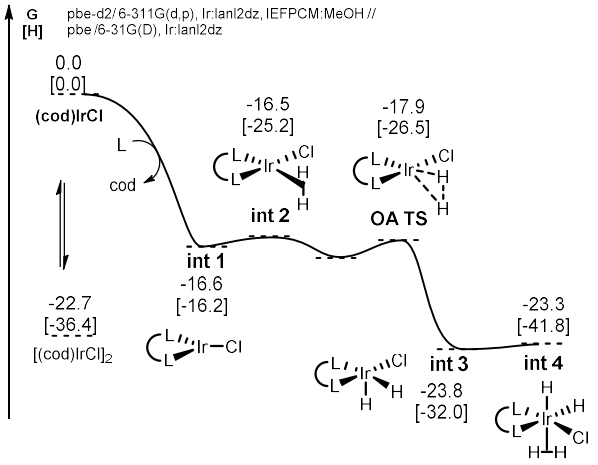
Iso6

Zero-point correction= 0.635463 (Hartree/Particle)
Thermal correction to Energy= 0.676662
Thermal correction to Enthalpy= 0.677606
Thermal correction to Gibbs Free Energy= 0.562726
Sum of electronic and zero-point Energies= -2714.755607
Sum of electronic and thermal Energies= -2714.714408
Sum of electronic and thermal Enthalpies= -2714.713464
Sum of electronic and thermal Free Energies= -2714.828344
Electronic energy -2716.02086309

C	-4.97706800	-1.39085300	-1.85578500
C	-4.17928900	-0.66955200	-0.93712500
C	-2.90227100	-1.19156100	-0.59814700
C	-2.49300100	-2.40370100	-1.20181500

C	-3.27782600	-3.10294600	-2.12576600
C	-4.53268000	-2.57835300	-2.44890200
H	-5.95639200	-0.98169200	-2.12065500
H	-2.90655000	-4.03814200	-2.55327700
H	-5.17192100	-3.10180800	-3.16702600
O	-1.26626800	-2.92173300	-0.86874600
C	-0.72587900	-2.32010100	0.32359300
P	-1.53297500	-0.58357200	0.49800900
C	-2.13856600	-0.55921000	2.31309900
C	-2.73117900	0.83249300	2.61429800
H	-2.89789600	0.91407500	3.70495200
H	-3.69841800	0.98622600	2.11244600
H	-2.05279300	1.64425600	2.30094100
C	-3.18638600	-1.65334800	2.57747400
H	-3.49055700	-1.60742200	3.63975200
H	-2.80165900	-2.67179100	2.39108100
H	-4.08918100	-1.50891900	1.96126300
C	-0.89503200	-0.77004000	3.20204200
H	-0.13553800	0.00956400	3.02305300
H	-0.41873800	-1.75462300	3.05895200
H	-1.20666200	-0.69994100	4.26055200
Ir	0.16366200	0.98315100	-0.23779000
H	-1.01168700	-2.94917700	1.18954600
C	0.79319600	-2.36647100	0.18901900
H	1.04334100	-3.19640500	-0.49919900
C	2.91702700	-0.96171400	0.84650300
C	2.54213800	-2.01915400	1.70586300
C	4.13661400	-0.28133200	1.10107100
C	3.32365900	-2.42661400	2.79496000
C	4.93307800	-0.71172900	2.18417900
C	4.52995900	-1.76043700	3.02271400
H	2.98314100	-3.25188700	3.42587400
H	5.87520500	-0.18937400	2.37499500
H	5.16463600	-2.06055900	3.86262100
O	1.36041400	-2.67638900	1.47540400
C	2.31414500	-1.20746800	-2.14151000
C	2.94800800	0.04757500	-2.77530200
H	3.27025600	-0.19883300	-3.80419700
H	2.23008300	0.88238200	-2.83099000
H	3.83081600	0.39591100	-2.21736500
C	1.13950800	-1.68028400	-3.02393100
H	0.63661200	-2.57910000	-2.62998000
H	0.37655400	-0.89353500	-3.14477100
H	1.52866300	-1.92526100	-4.02919100
C	3.36984900	-2.32083700	-2.01290900
H	3.75619400	-2.56613900	-3.01934000
H	4.22232100	-2.00483400	-1.38956800
H	2.95929300	-3.25230200	-1.58494200
P	1.59947800	-0.74806700	-0.43056100
C	4.65471800	0.85878000	0.28878000
C	5.88315300	0.72639200	-0.39460500
C	3.98497700	2.09796600	0.25212300
C	6.41095500	1.79820900	-1.12767600
H	6.41647200	-0.23005600	-0.35603500
C	4.51765000	3.17003600	-0.47762900
H	3.04687300	2.21943800	0.79907900
C	5.72611000	3.02206000	-1.17422200
H	7.35910800	1.67678200	-1.66208000
H	3.98234700	4.12482900	-0.49639700
H	6.13766300	3.86028500	-1.74598900
C	-4.75453600	0.58486300	-0.37991300
C	-4.05620800	1.80585600	-0.43749700
C	-6.05588300	0.57094500	0.17253200
C	-4.63916100	2.98307400	0.05086800
H	-3.04372500	1.85169700	-0.84705600
C	-6.63474900	1.74768800	0.66402000
H	-6.60296000	-0.37649100	0.23196600
C	-5.92783700	2.95937100	0.60164300
H	-4.06367000	3.91251800	0.00602800
H	-7.63843400	1.71708100	1.10138700
H	-6.38014400	3.87940100	0.98660300
H	-0.07627800	1.30097100	-2.03978600
H	-0.75259700	0.82863700	-1.86493000
H	0.69351500	1.14401400	1.25459900
Cl	-0.99802000	3.10498400	0.15188700
H	1.39318800	1.98482100	-0.57244900

Formation of the active catalyst:



Formation of isomer 5 (int 4 on the diagram) is shown here as an example; Using relative energies of the other isomers, one can estimate thermochemistry of their formation.

$[(cod)IrCl]_2$

Zero-point correction= 0.362136 (Hartree/Particle)
Thermal correction to Energy= 0.383354
Thermal correction to Enthalpy= 0.384298
Thermal correction to Gibbs Free Energy= 0.311515
Sum of electronic and zero-point Energies= -1752.503706
Sum of electronic and thermal Energies= -1752.482488
Sum of electronic and thermal Enthalpies= -1752.481543
Sum of electronic and thermal Free Energies= -1752.554327
Electronic energy -1753.19669720

C	4.42244300	-0.34707500	-0.68969000
H	4.64920600	-1.42804900	-0.68614700
H	5.22270600	0.13709700	-1.28679800
C	2.76745000	2.34288600	-0.70827600
H	3.87071200	2.38583500	-0.71687300
H	2.42502300	3.20220700	-1.31063700
C	2.06086300	1.11396800	1.40230400
H	1.33999000	1.11182300	2.23348000
C	3.03676300	0.05129900	1.40552500
H	2.96838000	-0.66294800	2.23873100
C	3.06988000	-0.17355000	-1.36404000
H	2.89742700	-0.85940000	-2.20744400
C	2.29280800	1.04167300	-1.35836100
H	1.57995300	1.16451300	-2.18628600
C	4.42373200	0.17369700	0.76783700
H	4.76278500	1.22401900	0.80981800
H	5.15140600	-0.40361300	1.36370100
C	2.22399500	2.46857600	0.73213700
H	1.22200500	2.93413100	0.69937500

H	2.86165700	3.13922000	1.34429700
Ir	1.49397500	-0.36208000	0.01502600
Cl	0.01643600	-1.41745100	-1.65525700
Cl	-0.01629700	-1.41725000	1.65528800
Ir	-1.49399800	-0.36199900	-0.01507600
C	-3.06966000	-0.17345000	1.36419500
C	-2.29259100	1.04181600	1.35822700
C	-2.06121600	1.11378000	-1.40258000
C	-3.03707800	0.05107500	-1.40533300
H	-2.89700700	-0.85910600	2.20772100
C	-4.42227100	-0.34731300	0.69009100
H	-1.57972500	1.16472200	2.18614300
C	-2.76722700	2.34303600	0.70811600
C	-2.22414200	2.46845100	-0.73246300
H	-1.34055700	1.11153400	-2.23394000
C	-4.42391100	0.17364300	-0.76732900
H	-2.96887600	-0.66332700	-2.23842700
H	-4.64864300	-1.42837600	0.68641700
H	-5.22263700	0.13647500	1.28737600
H	-3.87048100	2.38622400	0.71709500
H	-2.42439200	3.20235700	1.31023900
H	-1.22209200	2.93391000	-0.69999200
H	-2.86186600	3.13911500	-1.34453700
H	-4.76275500	1.22404000	-0.80905200
H	-5.15183400	-0.40344300	-1.36310400

[(cod)IrCl]

Zero-point correction= 0.180027 (Hartree/Particle)
Thermal correction to Energy= 0.189933
Thermal correction to Enthalpy= 0.190877
Thermal correction to Gibbs Free Energy= 0.143506
Sum of electronic and zero-point Energies= -876.212259
Sum of electronic and thermal Energies= -876.202352
Sum of electronic and thermal Enthalpies= -876.201408
Sum of electronic and thermal Free Energies= -876.248779
Electronic energy -876.56803677

Cl	-2.71119700	0.13362100	0.38355300
Ir	-0.49803300	-0.14281000	-0.28110000
C	1.24817500	-1.19440000	-0.82025000
C	1.33217000	0.14267300	-1.34357600
C	0.32056400	1.30692900	0.94185600
C	0.47691500	-0.02075700	1.54437100
H	0.97985100	-1.98578700	-1.54077700
C	2.00252800	-1.69760100	0.40471100
H	1.10474600	0.26840100	-2.41327600
C	2.22511900	1.22717500	-0.73545600
C	1.43155500	2.09325700	0.27186400
H	-0.48484000	1.93035900	1.36032700
C	1.81577800	-0.76093700	1.62194900
H	-0.23786100	-0.26585900	2.34414300
H	1.60107900	-2.69584000	0.65247300
H	3.07807800	-1.84148500	0.17800900
H	3.10155200	0.76416900	-0.24865300
H	2.62758700	1.86833100	-1.53813000
H	0.95880100	2.93831700	-0.25912200
H	2.10012400	2.54152000	1.03558100
H	2.63824900	-0.02652400	1.68635800
H	1.85469200	-1.34880400	2.55452100

L

Zero-point correction= 0.598749 (Hartree/Particle)
Thermal correction to Energy= 0.635265
Thermal correction to Enthalpy= 0.636210
Thermal correction to Gibbs Free Energy= 0.530311
Sum of electronic and zero-point Energies= -2147.642174
Sum of electronic and thermal Energies= -2147.605657
Sum of electronic and thermal Enthalpies= -2147.604713
Sum of electronic and thermal Free Energies= -2147.710611
Electronic energy -2148.74009364

C	-3.10573000	-2.69799300	1.05540500
C	-3.32286000	-1.44506300	0.43742700
C	-2.33818400	-0.43958400	0.59628900
C	-1.16290700	-0.73385800	1.32197800
C	-0.94497600	-1.97888000	1.92579900
C	-1.93843700	-2.95529300	1.78679100
H	-3.85070400	-3.48835500	0.92213400
H	-0.01802100	-2.16619900	2.47406200
H	-1.78958900	-3.94139800	2.23879600
O	-0.22456200	0.25532500	1.45408900
C	-0.49763100	1.38306700	0.58310000
P	-2.31054300	1.30533400	-0.00066200
C	-3.19913200	2.26597900	1.41595200
C	-4.70898000	2.02174900	1.22554400
H	-5.27902500	2.63710200	1.94757100
H	-4.97685700	0.96608700	1.39792600
H	-5.04539100	2.29265300	0.20952100
C	-2.77842600	1.85434600	2.83476300
H	-3.34974000	2.44200200	3.57899000
H	-1.70618500	2.03314300	3.02447600
H	-2.98134800	0.78658800	3.02112000
C	-2.89022700	3.75627400	1.17188300
H	-3.18368900	4.07270700	0.15531100
H	-1.81869700	3.99103700	1.30646100
H	-3.45204300	4.37730300	1.89472400
H	-0.32432700	2.29882800	1.17740300
C	0.49764500	1.38310800	-0.58305700
H	0.32433500	2.29890500	-1.17730300
C	2.33820600	-0.43953400	-0.59633100
C	1.16293800	-0.73377100	-1.32205100
C	3.32287300	-1.44502700	-0.43749600
C	0.94501300	-1.97876100	-1.92593700
C	3.10574700	-2.69792600	-1.05553900
C	1.93846800	-2.95518600	-1.78696000
H	0.01806400	-2.16605200	-2.47422000
H	3.85071400	-3.48829900	-0.92229000
H	1.78962300	-3.94126800	-2.23901300
O	0.22459100	0.25541800	-1.45411600
C	3.19913300	2.26607300	-1.41587500
C	4.70900800	2.02217400	-1.22525600
H	5.27901600	2.63760200	-1.94724800
H	5.04522900	2.29321300	-0.20920700
H	4.97713100	0.96655800	-1.39753600
C	2.88988200	3.75632000	-1.17196000
H	1.81831500	3.99084000	-1.30667400
H	3.18316100	4.07289800	-0.15538100
H	3.45164300	4.37741300	-1.89478900
C	2.77869500	1.85424500	-2.83470900
H	3.34998300	2.44196400	-3.57890600
H	2.98186500	0.78651500	-3.02096100
H	1.70644300	2.03280400	-3.02457700
P	2.31055700	1.30535800	0.00070000
C	4.56739400	-1.24087200	0.35493100
C	5.81211600	-1.67348800	-0.15269100

C	4.53580400	-0.65320900	1.63832200
C	6.98854600	-1.51249000	0.59049200
H	5.85357800	-2.12063200	-1.15185600
C	5.71237600	-0.49533600	2.38164100
H	3.57761300	-0.33464000	2.05930800
C	6.94353900	-0.92056000	1.86086600
H	7.94420500	-1.84603500	0.17223400
H	5.66461400	-0.04396400	3.37832400
H	7.86221500	-0.79333700	2.44292200
C	-4.56740000	-1.24085600	-0.35495700
C	-4.53583800	-0.65312700	-1.63831900
C	-5.81211400	-1.67348000	0.15267800
C	-5.71242800	-0.49520200	-2.38159800
H	-3.57765500	-0.33454900	-2.05931500
C	-6.98856300	-1.51242900	-0.59046400
H	-5.85355400	-2.12067300	1.15182300
C	-6.94358300	-0.92043600	-1.86081000
H	-5.66468900	-0.04377900	-3.37825800
H	-7.94421400	-1.84598200	-0.17219600
H	-7.86227300	-0.79317100	-2.44283400

cod

Zero-point correction= 0.176198 (Hartree/Particle)
Thermal correction to Energy= 0.183843
Thermal correction to Enthalpy= 0.184787
Thermal correction to Gibbs Free Energy= 0.144486
Sum of electronic and zero-point Energies= -311.416010
Sum of electronic and thermal Energies= -311.408365
Sum of electronic and thermal Enthalpies= -311.407421
Sum of electronic and thermal Free Energies= -311.447722
Electronic energy -311.69286879

C	-1.92767400	0.01050900	0.02778400
H	-2.43555800	-0.43399400	0.90734200
H	-2.75358100	0.31661600	-0.64901500
C	1.10003700	1.09375700	-0.66895700
H	0.67520900	0.70507400	-1.60800200
H	1.80231700	1.89185600	-0.97172200
C	1.20354100	-1.24787300	0.49740800
H	1.80427100	-1.86657700	1.18009300
C	-0.03267200	-1.70534600	0.21467900
H	-0.33003600	-2.63758600	0.71488100
C	-1.20340800	1.24792600	0.49749200
H	-1.80411100	1.86667600	1.18019400
C	0.03275200	1.70543700	0.21456800
H	0.33015900	2.63767600	0.71473400
C	-1.10026400	-1.09405400	-0.66877500
H	-0.67580300	-0.70574100	-1.60808000
H	-1.80259500	-1.89228100	-0.97098100
C	1.92777200	-0.01036500	0.02779600
H	2.43532200	0.43447900	0.90739000
H	2.75390900	-0.31614500	-0.64880500

Int 1

Zero-point correction= 0.601839 (Hartree/Particle)
Thermal correction to Energy= 0.641737
Thermal correction to Enthalpy= 0.642681
Thermal correction to Gibbs Free Energy= 0.529018
Sum of electronic and zero-point Energies= -2712.429732
Sum of electronic and thermal Energies= -2712.389833
Sum of electronic and thermal Enthalpies= -2712.388889
Sum of electronic and thermal Free Energies= -2712.502553
Electronic energy -2713.64138941

C	-5.16730000	-1.30454500	-0.94564200
C	-4.07428200	-0.57462000	-0.42930000
C	-2.88122800	-1.27958000	-0.12725000
C	-2.81705300	-2.66954000	-0.36895000
C	-3.90217700	-3.38736100	-0.89089600
C	-5.07883700	-2.68558700	-1.17282900
H	-6.08476600	-0.76636700	-1.20174900
H	-3.81065100	-4.46355500	-1.06022400
H	-5.93874000	-3.22191200	-1.58697700
O	-1.66682900	-3.34867500	-0.05153700
C	-0.60125900	-2.47629100	0.38138900
P	-1.30368500	-0.72705000	0.64158300
C	-1.62278300	-0.60358600	2.52312800
C	-2.27333100	0.76526200	2.80386800
H	-2.40067800	0.88899400	3.89570500
H	-3.26491100	0.86334900	2.33257500
H	-1.63470600	1.58905000	2.43871200
C	-2.53222700	-1.74567300	3.00647300
H	-2.66891300	-1.66294800	4.10089900
H	-2.10293000	-2.74260500	2.80215200
H	-3.52887300	-1.70177500	2.53669600
C	-0.25120600	-0.65924800	3.22363500
H	0.41339400	0.14055400	2.85506700
H	0.26424100	-1.62591500	3.08342400
H	-0.39370900	-0.51973300	4.31152800
Ir	-0.09534300	0.87987700	-0.26484200
H	-0.21250600	-2.88555000	1.32925900
C	0.54569600	-2.45339500	-0.63737400
H	0.16603600	-2.78578100	-1.61764400
C	2.72202200	-1.30547500	0.26781100
C	2.63915000	-2.71649800	0.35730900
C	3.84303500	-0.64558500	0.84293100
C	3.61300700	-3.49354800	0.99819600
C	4.81677300	-1.43934900	1.49261800
C	4.70493200	-2.83367800	1.56826000
H	3.49812300	-4.58005700	1.03721400
H	5.66251900	-0.93714100	1.97088600
H	5.47541000	-3.41202600	2.08840200
O	1.58858600	-3.36688600	-0.24598000
C	1.98768600	-0.57619900	-2.55074000
C	2.86589100	0.68652400	-2.64065900
H	3.22002800	0.79889000	-3.68245000
H	2.30460600	1.59588800	-2.36841500
H	3.75221700	0.61744900	-1.98817000
C	0.77727300	-0.44421700	-3.49474600
H	0.12197000	-1.33325200	-3.46611400
H	0.16656200	0.43722200	-3.23635300
H	1.14078900	-0.33243900	-4.53344100
C	2.81985800	-1.82373700	-2.90425800
H	3.18324000	-1.71830500	-3.94323400
H	3.70097900	-1.92958900	-2.24992600
H	2.23518400	-2.75803100	-2.85084200
P	1.30715100	-0.70969600	-0.76969200
C	4.07179000	0.82452000	0.79935600
C	5.36540100	1.31651400	0.50488600
C	3.04975400	1.75183600	1.08493300
C	5.62368700	2.69200600	0.49238200
H	6.16498300	0.60954000	0.25829200
C	3.30988500	3.12846400	1.07089400
H	2.03341000	1.39661300	1.30018200
C	4.59548400	3.60378500	0.77843600
H	6.62861400	3.05276300	0.24870700

H	2.49189700	3.82640700	1.27281200
H	4.79489200	4.68037200	0.76367300
C	-4.22057400	0.88962300	-0.21736900
C	-3.24583500	1.80153000	-0.67707900
C	-5.36533000	1.39998500	0.43463600
C	-3.39232200	3.17895700	-0.46285400
H	-2.37591300	1.42716800	-1.23966500
C	-5.51402900	2.77735100	0.64333000
H	-6.12659100	0.70377500	0.80335800
C	-4.52610200	3.67081800	0.19920900
H	-2.60860300	3.85601800	-0.81725000
H	-6.40081000	3.15318800	1.16469000
H	-4.64137600	4.74630800	0.36926500
Cl	0.31636800	3.07657800	-0.94993100

Int 2

Zero-point correction= 0.617007 (Hartree/Particle)
Thermal correction to Energy= 0.657648
Thermal correction to Enthalpy= 0.658592
Thermal correction to Gibbs Free Energy= 0.544629
Sum of electronic and zero-point Energies= -2713.583915
Sum of electronic and thermal Energies= -2713.543275
Sum of electronic and thermal Enthalpies= -2713.542330
Sum of electronic and thermal Free Energies= -2713.656293
Electronic energy -2714.82446122

C	-5.12002300	-1.42597000	-0.97175500
C	-4.06264400	-0.62749400	-0.48092100
C	-2.86389500	-1.27230300	-0.08384600
C	-2.75401200	-2.67428500	-0.23805700
C	-3.80140200	-3.46070500	-0.73583800
C	-4.99166300	-2.81718200	-1.09091600
H	-6.04027900	-0.93199200	-1.29786500
H	-3.66979200	-4.54146300	-0.83571600
H	-5.82534200	-3.40604600	-1.48693400
O	-1.58722100	-3.28965300	0.15004100
C	-0.54606400	-2.32218700	0.40745300
P	-1.34757600	-0.65720200	0.78395600
C	-1.79740000	-0.74115500	2.64425800
C	-2.73898600	0.43692000	2.96129000
H	-2.99717400	0.41513300	4.03635900
H	-3.67947700	0.38305400	2.38733900
H	-2.26578500	1.41134900	2.75412100
C	-2.48841700	-2.06501800	3.01787100
H	-2.70722900	-2.06112000	4.10199100
H	-1.85781100	-2.94557700	2.80931600
H	-3.44471500	-2.19424600	2.48408700
C	-0.47737800	-0.58073500	3.42248300
H	0.05107500	0.33949300	3.11906100
H	0.20769100	-1.43239800	3.26102500
H	-0.69217000	-0.52890900	4.50619700
Ir	-0.09758500	1.03901100	0.05968400
H	0.02787400	-2.68537000	1.27609600
H	-1.36651200	2.18700300	0.42948800
H	-0.83959500	2.14227400	1.17569100
C	0.39609200	-2.22056200	-0.80333500
H	-0.17806800	-2.38984300	-1.72901300
C	2.71266100	-1.37670700	-0.00012700
C	2.53634100	-2.77929100	-0.11934000
C	3.90670800	-0.88155100	0.58952800
C	3.49456800	-3.70250400	0.31732700
C	4.86363600	-1.82492500	1.03336300
C	4.66553300	-3.20419000	0.89576800
H	3.30551100	-4.77302000	0.20269000
H	5.76688700	-1.45419100	1.52590400
H	5.42740900	-3.90057900	1.26074300
O	1.39719100	-3.25434400	-0.72338200
C	1.84958800	-0.33278400	-2.66715100
C	3.00600900	0.68771600	-2.68030600
H	3.30158200	0.87077700	-3.73062200
H	2.70687100	1.64826100	-2.23015600
H	3.89077900	0.30517600	-2.14368800
C	0.63423700	0.21973000	-3.43755200
H	-0.22757200	-0.47166400	-3.40560700
H	0.31474600	1.19353600	-3.03131200
H	0.91283100	0.35562200	-4.49938100
C	2.32312800	-1.66038700	-3.28695300
H	2.66643900	-1.45706300	-4.31820900
H	3.17158900	-2.09689300	-2.73411300
H	1.52270300	-2.41705500	-3.34747000
P	1.29409500	-0.55256700	-0.85554800
C	4.22098000	0.55937400	0.77933900
C	5.52746600	1.02762400	0.50490500
C	3.27004000	1.47013500	1.27900900
C	5.86899300	2.36616900	0.72574600
H	6.26978100	0.33633800	0.09116700
C	3.61405400	2.81033600	1.49881600
H	2.24509200	1.13384400	1.48368400
C	4.91260900	3.26195000	1.22917700
H	6.88181900	2.71306000	0.49505300
H	2.85116000	3.50387800	1.86451000
H	5.17681400	4.31113600	1.39763900
C	-4.25929300	0.84882900	-0.43985900
C	-3.35981400	1.71982800	-1.09121500
C	-5.39713400	1.39803800	0.19013300
C	-3.58422900	3.10456500	-1.09476500
H	-2.47978100	1.30828900	-1.59791100
C	-5.61726000	2.78206600	0.19014400
H	-6.10342600	0.72981500	0.69550500
C	-4.71008600	3.63964600	-0.45139500
H	-2.86939200	3.76119500	-1.60160000
H	-6.49861300	3.19132000	0.69506100
H	-4.88242000	4.72090700	-0.45297800
Cl	0.96266600	3.00250900	-0.86028800

OA TS

Zero-point correction= 0.615090 (Hartree/Particle)
Thermal correction to Energy= 0.655634
Thermal correction to Enthalpy= 0.656578
Thermal correction to Gibbs Free Energy= 0.542554
Sum of electronic and zero-point Energies= -2713.585444
Sum of electronic and thermal Energies= -2713.544900
Sum of electronic and thermal Enthalpies= -2713.543956
Sum of electronic and thermal Free Energies= -2713.657981
Electronic energy -2714.82455219

C	5.10801600	1.47009000	-0.98322700
C	4.06314000	0.65633300	-0.49042500
C	2.85631700	1.28423100	-0.08930100
C	2.72946000	2.68562700	-0.23866500
C	3.76459200	3.48674500	-0.73843100
C	4.96158100	2.85961100	-1.09966100
H	6.03375300	0.98860700	-1.31243600
H	3.61836400	4.56595200	-0.83455000
H	5.78618500	3.45988500	-1.49754000

O	1.55807200	3.28714000	0.15762000
C	0.52804500	2.30752300	0.41201400
P	1.35061100	0.65017900	0.78422200
C	1.80500300	0.73559500	2.64197900
C	2.75585600	-0.43700700	2.95239400
H	3.01319500	-0.41906400	4.02772700
H	3.69609700	-0.37116900	2.37929200
H	2.29143300	-1.41406600	2.73760900
C	2.48845000	2.06366200	3.01510900
H	2.71323500	2.05834100	4.09793500
H	1.85037200	2.94024100	2.81243600
H	3.44084800	2.20113900	2.47648300
C	0.48923000	0.56618700	3.42579500
H	-0.03543100	-0.35699900	3.12533500
H	-0.20142000	1.41420600	3.26883200
H	0.71000800	0.51486100	4.50827400
Ir	0.11371400	-1.06371500	0.07100600
H	-0.04866700	2.66137100	1.28277100
H	1.37461300	-2.13373200	0.36276000
H	0.76077200	-2.06220800	1.23649500
C	-0.41428700	2.20874300	-0.80037300
H	0.16218600	2.37559600	-1.72515700
C	-2.73531300	1.38000800	-0.00274900
C	-2.55089900	2.78202900	-0.11810200
C	-3.92968800	0.88716600	0.58738100
C	-3.50517500	3.70767600	0.32196000
C	-4.88241700	1.83326600	1.03399400
C	-4.67800800	3.21203200	0.89946800
H	-3.31222700	4.77786100	0.21111300
H	-5.78689300	1.46535600	1.52640400
H	-5.43656600	3.91071100	1.26694400
O	-1.40869600	3.25046300	-0.72033200
C	-1.86994700	0.33032600	-2.66978200
C	-3.00475400	-0.71423500	-2.68189100
H	-3.29477200	-0.90784600	-3.73187200
H	-2.68572700	-1.66669400	-2.22722800
H	-3.89822600	-0.34891900	-2.14768100
C	-0.64116200	-0.20165900	-3.43384100
H	0.20486800	0.50929800	-3.40816300
H	-0.29989200	-1.16551000	-3.02036600
H	-0.91457700	-0.35379500	-4.49472800
C	-2.36452500	1.64914000	-3.28994600
H	-2.70106900	1.44308800	-4.32292700
H	-3.22184400	2.06930500	-2.73793700
H	-1.57691500	2.41966700	-3.34465800
P	-1.32385000	0.54933600	-0.85729300
C	-4.24502300	-0.55386100	0.77269800
C	-5.55252400	-1.02046200	0.50045000
C	-3.29198300	-1.46779000	1.26296900
C	-5.89265100	-2.36062600	0.71372600
H	-6.29659400	-0.32668500	0.09414800
C	-3.63424000	-2.80975400	1.47430500
H	-2.26747900	-1.13297800	1.47104100
C	-4.93380400	-3.25972800	1.20643900
H	-6.90638200	-2.70621700	0.48509900
H	-2.86929800	-3.50512100	1.83191300
H	-5.19690600	-4.31020100	1.36833400
C	4.28434100	-0.81657700	-0.45031000
C	3.40088600	-1.70261500	-1.10255800
C	5.43158400	-1.34587000	0.17981100
C	3.64936000	-3.08303700	-1.10669000
H	2.51490900	-1.30607700	-1.60987000
C	5.67602000	-2.72573700	0.17897700
H	6.12569300	-0.66557900	0.68595400
C	4.78415400	-3.59853300	-0.46340300
H	2.94584400	-3.75204600	-1.61290100
H	6.56422000	-3.11979800	0.68398500
H	4.97507700	-4.67666500	-0.46506600
Cl	-0.94594000	-3.03015200	-0.83754200

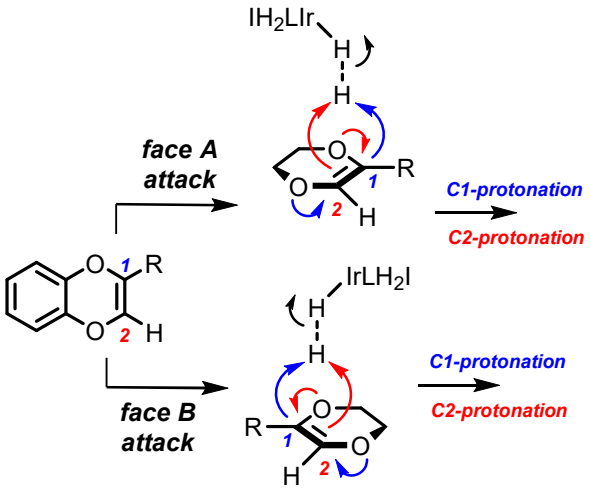
Int 3

Zero-point correction=	0.618839 (Hartree/Particle)
Thermal correction to Energy=	0.659417
Thermal correction to Enthalpy=	0.660361
Thermal correction to Gibbs Free Energy=	0.545736
Sum of electronic and zero-point Energies=	-2713.601388
Sum of electronic and thermal Energies=	-2713.560810
Sum of electronic and thermal Enthalpies=	-2713.559866
Sum of electronic and thermal Free Energies=	-2713.674491
Electronic energy	-2714.83716257

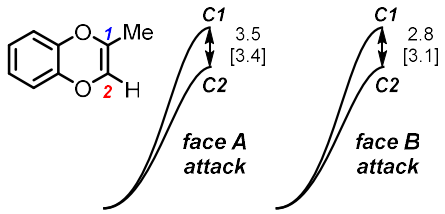
C	-4.87309700	-0.60105800	-1.97379400
C	-4.00855500	-0.21231200	-0.92935700
C	-2.82149600	-0.96584400	-0.72330700
C	-2.53335100	-2.03725500	-1.60080500
C	-3.38366400	-2.40052900	-2.65371600
C	-4.56259300	-1.67178000	-2.82548000
H	-5.79005700	-0.02515500	-2.12939700
H	-3.11448400	-3.23843100	-3.30214000
H	-5.24778000	-1.93547600	-3.63750100
O	-1.37917500	-2.75366200	-1.42301400
C	-0.71447300	-2.46130400	-0.17826500
P	-1.46517100	-0.84018600	0.51364500
C	-2.11126200	-1.31502300	2.24075800
C	-2.68119900	-0.05937300	2.92896200
H	-2.97787300	-0.32546100	3.96062300
H	-3.56957900	0.33322100	2.40934100
H	-1.92965200	0.74515900	2.97975800
C	-3.20041200	-2.39858600	2.12610300
H	-3.55314400	-2.66018100	3.14053100
H	-2.83217600	-3.32873400	1.65840000
H	-4.06801200	-2.04406400	1.54537500
C	-0.90903900	-1.83603000	3.05538000
H	-0.12635600	-1.06530200	3.15883700
H	-0.44300100	-2.73552300	2.61753800
H	-1.25702600	-2.09967200	4.07091800
Ir	-0.09768800	0.86425100	0.18684200
H	-0.91968800	-3.29670100	0.51696900
H	-1.13800000	1.84713100	0.95664800
C	0.79048000	-2.41888200	-0.44410300
H	0.97749400	-3.00612600	-1.36181700
C	2.87535900	-1.15152400	0.53988500
C	2.59826900	-2.43639400	1.05719400
C	4.02227300	-0.45793100	1.00714800
C	3.43522900	-3.07668300	1.98023500
C	4.87030300	-1.11311100	1.92852200
C	4.58207000	-2.39849000	2.40527400
H	3.18207700	-4.07739700	2.34028200
H	5.75104700	-0.57911600	2.29714300
H	5.25391500	-2.87357500	3.12738800
O	1.45831900	-3.08198400	0.64925400
C	2.24467800	-0.70114600	-2.41446100
C	2.99085200	0.62545100	-2.66378300
H	3.28393400	0.67041800	-3.72994900
H	2.35141400	1.49606400	-2.44343500
H	3.90786200	0.70207300	-2.05803300
C	1.00793000	-0.76890500	-3.33547600
H	0.43153000	-1.70262900	-3.20908100

H	0.33097900	0.08384700	-3.15136800
H	1.33938900	-0.72070400	-4.38932000
C	3.19113900	-1.88816800	-2.65601800
H	3.58665100	-1.82992900	-3.68745100
H	4.04993500	-1.86954900	-1.96364000
H	2.69106100	-2.86781900	-2.55621300
P	1.54254500	-0.66503500	-0.63876600
C	4.37512000	0.92623400	0.58983800
C	5.69619300	1.23046600	0.19102400
C	3.42369500	1.96599200	0.61907400
C	6.04614100	2.53327000	-0.18582900
H	6.44231600	0.42917600	0.15287800
C	3.77321400	3.26769500	0.23903600
H	2.39800800	1.75610300	0.94505900
C	5.08460000	3.55564400	-0.16550300
H	7.07156300	2.74849000	-0.50470100
H	3.00894100	4.05085500	0.25316900
H	5.35725900	4.57259400	-0.46613800
C	-4.40785200	0.96790700	-0.10962200
C	-3.63471800	2.14663800	-0.10426300
C	-5.62147400	0.94176200	0.61174900
C	-4.05522500	3.26325500	0.63195600
H	-2.70584300	2.19178200	-0.68004100
C	-6.03506800	2.05797600	1.35146000
H	-6.23250800	0.03218500	0.59888100
C	-5.24956900	3.22115700	1.36550900
H	-3.44058800	4.16913600	0.62580900
H	-6.97220100	2.01862900	1.91677900
H	-5.57249000	4.09431800	1.94209700
Cl	0.27142900	2.73980200	-1.25589500
H	0.36201800	0.48121100	1.65411700

Regioselectivity of the protonation



R=Me



R=Me, face A, C1 TS

Zero-point correction=	0.779446 (Hartree/Particle)
Thermal correction to Energy=	0.830617
Thermal correction to Enthalpy=	0.831561
Thermal correction to Gibbs Free Energy=	0.694714
Sum of electronic and zero-point Energies=	-3212.173961
Sum of electronic and thermal Energies=	-3212.122790
Sum of electronic and thermal Enthalpies=	-3212.121846
Sum of electronic and thermal Free Energies=	-3212.258693
Electronic energy	-3213.73835870

C	0.82429000	3.23686400	-1.64745100
C	-0.54253900	3.47008200	-1.92627600
C	0.60353300	4.62722000	0.25966500
C	-0.79321800	4.57845400	0.11543600
H	0.72892800	2.12032400	-1.00523500
C	-4.97408200	-2.19040800	-1.68562800
C	-4.14331600	-1.45965500	-0.80817300
C	-2.89470900	-2.01887900	-0.43725800
C	-2.52120100	-3.26504300	-0.98977000
C	-3.33516200	-3.97378700	-1.88228400
C	-4.57231200	-3.42083200	-2.22295900
H	-5.93871700	-1.75822300	-1.96812900
H	-2.99604500	-4.93532500	-2.27680000
H	-5.23214000	-3.95374100	-2.91523600
O	-1.31298300	-3.80849900	-0.63683700
C	-0.73647000	-3.16535300	0.51613300
P	-1.52798300	-1.42578500	0.65468200
C	-2.16456600	-1.35462100	2.45609800
C	-2.72628800	0.05298000	2.73783200
H	-3.00349700	0.11459900	3.80715300
H	-3.62492300	0.27203800	2.14052000
H	-1.97290200	0.82886900	2.52548000
C	-3.25388700	-2.41599700	2.69475500
H	-3.56640700	-2.37727000	3.75483700
H	-2.90029700	-3.44281200	2.49369200
H	-4.14452900	-2.23432000	2.07094700
C	-0.95989300	-1.60105800	3.38840100
H	-0.16122400	-0.85998800	3.21649400
H	-0.52165300	-2.60653500	3.27352100
H	-1.29905300	-1.50120200	4.43630700
Ir	-0.01824500	0.15085100	-0.04247800
H	1.16619900	1.34484300	-0.20163000
H	0.46529900	0.31388600	1.47602400
H	-1.08591600	1.32075800	0.36351200
H	-0.99776300	-3.76953200	1.40708600
C	-4.65307800	-0.14595800	-0.32139300
C	-5.89798200	-0.08253600	0.34266000
C	-3.95343200	1.05099800	-0.57780700
C	-6.42390600	1.14721700	0.76108700
H	-6.44727800	-1.01013300	0.53945500

C	-4.49215400	2.27964600	-0.17043500
H	-3.00071400	1.00928700	-1.11680500
C	-5.72136400	2.33412700	0.50326100
H	-7.38489100	1.17799800	1.28569000
H	-3.94441100	3.20051500	-0.39672400
H	-6.13574800	3.29710300	0.82106400
Cl	-0.86102900	0.38869200	-2.41430800
O	-1.37509500	4.02286300	-1.04494500
O	1.45213400	4.11271200	-0.69182800
C	1.14204300	5.24117200	1.39542400
H	2.22993200	5.27556900	1.50343500
C	-1.64983500	5.11131900	1.07453400
H	-2.73021600	5.04237100	0.92021700
C	-1.10283500	5.71901800	2.21632000
H	-1.76642200	6.13542500	2.97893000
C	0.28872500	5.78743900	2.36754500
H	0.72230300	6.25999400	3.25392600
C	0.78080300	-3.18873400	0.35817600
H	1.03692400	-4.02915800	-0.31439600
P	1.57448800	-1.56991700	-0.30526700
C	2.30909500	-2.13123000	-1.98529300
C	1.13848200	-2.68276200	-2.82734200
H	0.71031200	-3.61134200	-2.41295200
H	0.32886500	-1.93974300	-2.92558500
H	1.51453300	-2.91711700	-3.84131000
C	2.87173600	-0.87888100	-2.68646100
H	3.22802700	-1.16122100	-3.69544500
H	2.08602500	-0.11451400	-2.80202200
H	3.72118000	-0.43831700	-2.13954500
C	3.40755600	-3.19338200	-1.81955600
H	3.76847900	-3.50085100	-2.81922000
H	4.27006900	-2.80867500	-1.25008800
H	3.04319600	-4.10323900	-1.30943500
C	2.90714000	-1.78197200	0.97170700
C	4.13733600	-1.11528400	1.20297100
C	2.53834900	-2.82035700	1.85735200
C	4.94753700	-1.53339300	2.28300300
C	3.33013400	-3.21756100	2.94299000
C	4.54709300	-2.56191600	3.14551700
H	5.89701500	-1.01604300	2.45091300
H	2.99029500	-4.03115400	3.58954800
H	5.19043400	-2.85515800	3.98139700
O	1.35113700	-3.47162900	1.65255300
C	4.66044200	0.01368400	0.37889500
C	5.90112600	-0.11740400	-0.28239600
C	3.99294000	1.25327300	0.32664100
C	6.44935600	0.95628800	-0.99720700
H	6.43004100	-1.07585000	-0.23807400
C	4.54949300	2.33166900	-0.37674300
H	3.03986600	1.36915400	0.85048800
C	5.77481400	2.18543400	-1.04513400
H	7.40703500	0.83296900	-1.51402300
H	4.01677700	3.28799900	-0.39864900
H	6.20590300	3.02807500	-1.59606700
H	-1.05324200	3.01906800	-2.77811500
C	1.76593100	2.95007700	-2.79773500
H	2.67684400	2.46125900	-2.41933400
H	1.27335900	2.26537800	-3.50546800
H	2.04905200	3.88291500	-3.31366100

R=Me, face A, C2 TS

Zero-point correction=	0.778944 (Hartree/Particle)
Thermal correction to Energy=	0.830152
Thermal correction to Enthalpy=	0.831096
Thermal correction to Gibbs Free Energy=	0.694059
Sum of electronic and zero-point Energies=	-3212.177535
Sum of electronic and thermal Energies=	-3212.126327
Sum of electronic and thermal Enthalpies=	-3212.125382
Sum of electronic and thermal Free Energies=	-3212.262419
Electronic energy	-3213.74334272

C	-1.56680900	3.02982000	-1.53027600
C	-0.82472100	3.95559100	-0.79162800
C	-3.42751900	3.41362000	-0.14330100
C	-2.62889600	4.23233000	0.67360300
H	-1.06249000	1.75436900	-1.16101400
C	5.22437900	1.04063200	2.04635600
C	4.42506000	0.68554500	0.93830000
C	3.41175800	-0.28889500	1.11813200
C	3.22230700	-0.83593700	2.40667000
C	3.99731300	-0.46030800	3.51120300
C	5.00641300	0.48594400	3.31475000
H	6.00844400	1.79038000	1.90348900
H	3.80736800	-0.91857800	4.48536300
H	5.63169400	0.79475500	4.15870500
O	2.24304900	-1.77821500	2.58429500
C	1.79410500	-2.33652900	1.33457600
P	2.17389000	-1.04446800	-0.02848300
C	3.09641400	-2.04893600	-1.36505600
C	3.34239600	-1.14545300	-2.58937600
H	3.77259400	-1.75940700	-3.40296900
H	4.04773400	-0.32896500	-2.37090000
H	2.39913200	-0.70053200	-2.94659300
C	4.43168600	-2.59103900	-0.82404000
H	4.91793600	-3.19771100	-1.61042600
H	4.29933100	-3.24110100	0.05912300
H	5.12111000	-1.77701100	-0.54628300
C	2.17530400	-3.21329200	-1.78725100
H	1.20375100	-2.84311000	-2.15539500
H	1.98304600	-3.92941900	-0.97031900
H	2.66229700	-3.76802000	-2.61053500
Ir	0.25346200	0.06204300	-0.57701400
H	-1.25251000	0.72056100	-1.06519900
H	0.04257800	-0.88259700	-1.85755700
H	1.09208300	0.98260300	-1.64111000
H	2.37674100	-3.25934300	1.14486100
H	-1.31366300	2.92125200	-2.59139700
C	0.55792800	4.35994400	-1.16123300
H	1.02758400	3.56511200	-1.76177300
H	1.16201500	4.52606500	-0.25756900
H	0.53529300	5.29239700	-1.75845600
C	4.71050000	1.35734100	-0.36015000
C	6.00543300	1.29116400	-0.91858700
C	3.71901900	2.11384400	-1.01707500
C	6.29769300	1.94410100	-2.12373100
H	6.77942600	0.70867100	-0.40641100
C	4.01934600	2.77096000	-2.21856500
H	2.72309900	2.18166200	-0.56600800
C	5.30268000	2.68507800	-2.77891900
H	7.30322800	1.87270700	-2.55187800
H	3.24469400	3.35852500	-2.72358400
H	5.52866000	3.19679400	-3.72041900
Cl	0.55232700	1.90978800	1.10821900
O	-1.32261400	4.57931000	0.29300800
O	-2.96851900	2.91955500	-1.34515700
C	-4.73079900	3.10977500	0.26289200
H	-5.33452700	2.45510700	-0.37183800
C	-3.10406300	4.73872200	1.88034000
H	-2.44120200	5.36263800	2.48631900
C	-4.41470500	4.43432000	2.28427500

H	-4.79466600	4.82895800	3.23074800
C	-5.22162700	3.62462500	1.47426600
H	-6.24150400	3.37865900	1.78513500
C	0.32706600	-2.72678800	1.49893100
H	0.12933200	-2.83089300	2.58130700
P	-0.93507000	-1.49921500	0.73992100
C	-2.02700800	-1.01534700	2.24057000
C	-1.09592100	-0.43851500	3.32829800
H	-0.41867500	-1.19484200	3.76205400
H	-0.48741200	0.39471500	2.93761500
H	-1.72230200	-0.05099200	4.15402100
C	-2.98038400	0.09934000	1.76684800
H	-3.59851200	0.43492800	2.62085900
H	-2.40966900	0.96819200	1.39962500
H	-3.66244400	-0.23838000	0.96901000
C	-2.81886300	-2.21551400	2.78341400
H	-3.39112100	-1.89863700	3.67572900
H	-3.53410800	-2.60690200	2.04110600
H	-2.16154300	-3.04867400	3.09163800
C	-1.77170800	-2.94650300	-0.07050400
C	-2.96777500	-3.06944700	-0.82487600
C	-1.01816600	-4.11768000	0.17232000
C	-3.36221600	-4.35121300	-1.27170100
C	-1.39875700	-5.38451600	-0.29177000
C	-2.58789100	-5.49003300	-1.01617100
H	-4.28437600	-4.43623900	-1.85432200
H	-0.77201600	-6.25171100	-0.06701100
H	-2.91429800	-6.46680000	-1.38757000
O	0.13908800	-4.02357800	0.89634600
C	-3.86565100	-1.93906700	-1.20186800
C	-5.23084900	-1.98149800	-0.84175700
C	-3.41169200	-0.88097600	-2.01448900
C	-6.11809200	-0.98760300	-1.27573400
H	-5.59092900	-2.80306500	-0.21276700
C	-4.30348800	0.10524300	-2.45843100
H	-2.35783000	-0.84565100	-2.30585700
C	-5.65691900	0.05659200	-2.09177700
H	-7.17231000	-1.03407600	-0.98227300
H	-3.93908700	0.91772100	-3.09386000
H	-6.35211300	0.82418100	-2.44940600

R=Me, face B, C1 TS

Zero-point correction= 0.778569 (Hartree/Particle)
Thermal correction to Energy= 0.829915
Thermal correction to Enthalpy= 0.830859
Thermal correction to Gibbs Free Energy= 0.693106
Sum of electronic and zero-point Energies= -3212.174337
Sum of electronic and thermal Energies= -3212.122991
Sum of electronic and thermal Enthalpies= -3212.122047
Sum of electronic and thermal Free Energies= -3212.259800
Electronic energy -3213.73832121

C	1.50287200	-3.17592700	-1.10147900
C	0.99222300	-3.90653700	-0.02106000
C	3.63184800	-3.26260500	-0.04458700
C	3.04923300	-3.88797600	1.07157700
H	1.05504100	-1.89241900	-0.82362800
C	-5.37097300	-1.16561700	1.92195400
C	-4.50684100	-0.84469800	0.85309900
C	-3.53975100	0.17266300	1.04824400
C	-3.44956200	0.78982500	2.31572300
C	-4.28885400	0.44788500	3.38370800
C	-5.25703500	-0.53685300	3.16961600
H	-6.12034500	-1.94806200	1.76867900
H	-4.17750800	0.95866400	4.34379600
H	-5.93050200	-0.82028000	3.98491000
O	-2.50235800	1.76105800	2.50983200
C	-1.96760800	2.26163300	1.26877000
P	-2.25517300	0.90604000	-0.05419500
C	-3.11495800	1.83107900	-1.48514200
C	-3.27194500	0.86827900	-2.67839100
H	-3.68613600	1.43102200	-3.53610300
H	-3.95619000	0.03478700	-2.45581000
H	-2.29812900	0.44520700	-2.97417000
C	-4.48967600	2.36811700	-1.04793500
H	-4.93669600	2.93641700	-1.88462800
H	-4.42187000	3.05286800	-0.18415200
H	-5.18140900	1.55222700	-0.78168200
C	-2.19179900	2.99485200	-1.90441200
H	-1.19095700	2.63108800	-2.19230400
H	-2.06850000	3.75346100	-1.11260100
H	-2.63575900	3.50019300	-2.78190800
Ir	-0.28964400	-0.17845300	-0.46698000
H	1.22788600	-0.81665400	-0.93049800
H	-0.09010400	0.69415100	-1.79617900
H	-1.06955100	-1.17904900	-1.49513800
H	-2.53576200	3.17303000	0.99774300
C	-4.66904600	-1.60315700	-0.41956700
C	-5.91120000	-1.60440600	-1.09010700
C	-3.61168800	-2.38018200	-0.93545200
C	-6.08603000	-2.34390600	-2.26791700
H	-6.73705500	-1.00721700	-0.68747800
C	-3.79433900	-3.12323900	-2.10997300
H	-2.65767900	-2.39846600	-0.39828300
C	-5.02522100	-3.10443600	-2.78294600
H	-7.05174200	-2.32490100	-2.78417700
H	-2.96723900	-3.72613000	-2.50168600
H	-5.16006700	-3.68371900	-3.70250600
Cl	-0.63992900	-1.90457800	1.32530900
O	1.70102400	-4.27502800	1.05597600
O	2.92130400	-3.00809800	-1.19664300
C	4.98385800	-2.90661700	0.00965700
H	5.42319700	-2.40069000	-0.85392700
C	3.78302300	-4.15473500	2.22491600
H	3.28035700	-4.63800600	3.06743200
C	5.14058800	-3.79768400	2.27278200
H	5.72392400	-4.00414400	3.17443500
C	5.73413100	-3.17715200	1.16555100
H	6.78934200	-2.88933700	1.19642500
C	-0.51262500	2.67403800	1.51057000
H	-0.37221500	2.74403700	2.60398800
P	0.81892000	1.50107600	0.77524500
C	1.96936500	1.16509500	2.27371700
C	1.12030000	0.50069100	3.37712900
H	0.34093700	1.17037700	3.78108700
H	0.62995700	-0.41837900	3.01521700
H	1.78589400	0.23246200	4.21953400
C	3.04564600	0.16639500	1.80461800
H	3.68774400	-0.10719800	2.66305300
H	2.58530100	-0.75834500	1.41934800
H	3.69470700	0.58573500	1.01836700
C	2.62165000	2.45501600	2.79882000
H	3.23658800	2.21411900	3.68638500
H	3.27825700	2.92423300	2.04748400
H	1.87389000	3.20588200	3.11181500
C	1.56407300	2.96336500	-0.09363300
C	2.72079000	3.11827300	-0.90485400
C	0.79412000	4.11548900	0.18821600

C	3.05653700	4.41157600	-1.36782700
C	1.12070700	5.39347000	-0.28745400
C	2.26868700	5.53048200	-1.06928900
H	3.94369000	4.52168100	-1.99844000
H	0.48312400	6.24331300	-0.02939600
H	2.55134100	6.51560500	-1.45423100
O	-0.32428500	3.99732300	0.96633900
C	3.63802500	2.01933600	-1.32775600
C	5.02483500	2.13957900	-1.08336400
C	3.17847200	0.91722800	-2.07634700
C	5.92614800	1.18507900	-1.57230100
H	5.39140500	2.99213400	-0.50117900
C	4.08213200	-0.03354300	-2.57075600
H	2.10919100	0.81540000	-2.27993800
C	5.45700400	0.09787800	-2.32514500
H	6.99691700	1.29535800	-1.37015100
H	3.70782400	-0.88121300	-3.15314600
H	6.16206700	-0.63843100	-2.72689200
C	0.89834100	-3.33762900	-2.48005200
H	1.30868200	-4.22747100	-2.98787800
H	-0.19605600	-3.42947000	-2.39782700
H	1.10940500	-2.44276400	-3.08900000
H	-0.04819100	-4.22369200	0.02711000

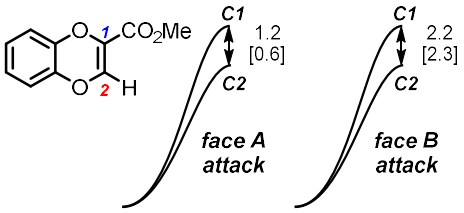
R=Me, face B, C2 TS

Zero-point correction= 0.778973 (Hartree/Particle)
Thermal correction to Energy= 0.830333
Thermal correction to Enthalpy= 0.831277
Thermal correction to Gibbs Free Energy= 0.694069
Sum of electronic and zero-point Energies= -3212.178663
Sum of electronic and thermal Energies= -3212.127303
Sum of electronic and thermal Enthalpies= -3212.126359
Sum of electronic and thermal Free Energies= -3212.263566
Electronic energy -3213.74374185

C	-0.68262100	3.57702400	0.90032900
C	0.25273300	3.71023800	1.92977100
C	0.84212000	4.51221000	-0.62716200
C	1.83703000	4.44705500	0.36373800
H	-0.63732800	2.22395300	0.48166500
C	4.47230000	-2.66966600	1.88437500
C	3.72969600	-2.03770400	0.86392700
C	2.37506200	-2.41483100	0.68403500
C	1.81685500	-3.37949800	1.55181600
C	2.54915300	-3.98418600	2.58126800
C	3.88884500	-3.61760500	2.73633000
H	5.51884800	-2.38096300	2.02052300
H	2.06833100	-4.72682200	3.22350000
H	4.48707100	-4.07645800	3.53023300
O	0.50504100	-3.74169700	1.38052100
C	-0.02360500	-3.31096100	0.11126900
P	1.06949700	-1.85593100	-0.49194600
C	1.55683300	-2.35742200	-2.26891600
C	2.34554800	-1.20630600	-2.92308100
H	2.53200300	-1.46389500	-3.98276300
H	3.31868100	-1.03795500	-2.43708000
H	1.77436600	-0.26455100	-2.88599900
C	2.40393800	-3.64313700	-2.26108800
H	2.63758700	-3.92339900	-3.30490700
H	1.87784800	-4.49829200	-1.80131300
H	3.35691100	-3.50071700	-1.72567000
C	0.25023600	-2.57795100	-3.06026900
H	-0.37220500	-1.66733700	-3.06789000
H	-0.36091600	-3.40587600	-2.66260500
H	0.50842800	-2.82374300	-4.10697400
Ir	-0.02489900	0.10971300	-0.15939900
H	-0.87785000	1.58850800	-0.27434800
H	-0.52423900	0.05904300	-1.68409100
H	1.23589400	0.93180000	-0.78770000
H	0.05644500	-4.15820200	-0.59745600
H	-1.74413500	3.61423400	1.16846100
C	-0.05087700	3.51865800	3.37602000
H	-0.98916800	2.96096600	3.50701800
H	-0.15587200	4.51062800	3.85897300
H	0.76084500	2.96796700	3.87272700
C	4.42672800	-1.02563600	0.02141400
C	5.59865300	-1.38693800	-0.67874200
C	3.96663400	0.30509800	-0.05271200
C	6.28068700	-0.44624500	-1.46221900
H	5.96183800	-2.41911400	-0.61741400
C	4.65476300	1.24340400	-0.83529700
H	3.07538600	0.59621500	0.51337000
C	5.80640000	0.87191400	-1.54525400
H	7.18055100	-0.74487400	-2.01075900
H	4.28193700	2.27175800	-0.88985900
H	6.33600700	1.60767700	-2.16019900
Cl	0.93926200	0.63584700	2.10218600
O	1.52093900	4.10132000	1.68754200
O	-0.47437700	4.22408200	-0.35031300
C	1.19467000	4.90716500	-1.92147400
H	0.41261600	4.94976500	-2.68482200
C	3.16363700	4.76339700	0.08110400
H	3.90267500	4.69760800	0.88467700
C	3.51443900	5.15911700	-1.22139300
H	4.55427800	5.40955900	-1.44967200
C	2.52904400	5.23155400	-2.21507200
H	2.79406600	5.53651900	-3.23180900
C	-1.50548900	-2.99483800	0.30715100
H	-1.84501300	-3.53886800	1.20779500
P	-1.92700700	-1.13064000	0.48428400
C	-2.72779200	-1.03835100	2.22615300
C	-1.69785400	-1.59774000	3.23068900
H	-1.52174100	-2.68006000	3.10689800
H	-0.73074200	-1.07326400	3.14459100
H	-2.08566100	-1.44448800	4.25585500
C	-2.95802300	0.45421800	2.53813800
H	-3.37818000	0.55051400	3.55751900
H	-1.99863700	0.99846900	2.50674200
H	-3.66367400	0.92682700	1.83504900
C	-4.04875900	-1.81914500	2.30692300
H	-4.43507100	-1.77584400	3.34306800
H	-4.81938200	-1.39955800	1.63897300
H	-3.92271000	-2.88575700	2.04776600
C	-3.31607800	-1.39193200	-0.71535200
C	-4.36051100	-0.54595100	-1.16712800
C	-3.24796300	-2.70440700	-1.23402900
C	-5.30807000	-1.06166200	-2.07929000
C	-4.17359900	-3.20745900	-2.15847900
C	-5.21259300	-2.36981100	-2.57240000
H	-6.11325200	-0.40442000	-2.42148000
H	-4.07236800	-4.23410500	-2.52062800
H	-5.95422900	-2.73792300	-3.28866800
O	-2.23293000	-3.52545500	-0.82131100
C	-4.53055800	0.87852100	-0.75499800
C	-5.72045400	1.29533500	-0.11986900
C	-3.56371900	1.84918700	-1.08557900
C	-5.92836200	2.64475800	0.19801000
H	-6.48207600	0.54836200	0.12993900
C	-3.77976000	3.20183000	-0.78243500

H	-2.64783900	1.53718400	-1.59551500
C	-4.95844000	3.60278700	-0.13387500
H	-6.85302000	2.94844700	0.70021400
H	-3.02366100	3.94203400	-1.06571100
H	-5.12583300	4.65921800	0.10162500

R=CO_2Me



R=CO_2Me, face A, C1 TS

Zero-point correction= 0.793125 (Hartree/Particle)
Thermal correction to Energy= 0.847468
Thermal correction to Enthalpy= 0.848412
Thermal correction to Gibbs Free Energy= 0.704605
Sum of electronic and zero-point Energies= -3400.526680
Sum of electronic and thermal Energies= -3400.472337
Sum of electronic and thermal Enthalpies= -3400.471393
Sum of electronic and thermal Free Energies= -3400.615200
Electronic energy -3402.16459362

C	0.22966300	3.43719700	0.46586300
C	1.01167600	3.22024800	1.62429900
C	2.22046800	4.01013800	-0.68816100
C	2.96594300	3.80779800	0.48529200
H	-0.30860900	2.13769600	0.10984900
C	4.44189100	-2.75661500	1.95845600
C	3.66822600	-2.24966700	0.89214400
C	2.28468100	-2.55286000	0.86060700
C	1.72798900	-3.30767500	1.91741700
C	2.49288000	-3.78310600	2.98940000
C	3.86226300	-3.50164500	2.99459700
H	5.51196900	-2.52917700	1.97879700
H	2.01335800	-4.36577300	3.78034500
H	4.48630900	-3.86682200	3.81666500
O	0.38368100	-3.58228800	1.89096500
C	-0.18018000	-3.39032700	0.57804600
P	0.93283700	-2.11350600	-0.31317600
C	1.27790500	-2.88738900	-2.02291600
C	2.04215500	-1.87115300	-2.89420300
H	2.15586200	-2.29403600	-3.91007300
H	3.04729600	-1.65728800	-2.49964000
H	1.49191400	-0.91917400	-2.97148800
C	2.09552800	-4.18407600	-1.87982600
H	2.22960600	-4.63340600	-2.88123400
H	1.59513000	-4.93678600	-1.24553100
H	3.09519700	-3.99047800	-1.45792900
C	-0.08704400	-3.18201800	-2.68015800
H	-0.69914100	-2.26852900	-2.77062300
H	-0.67418900	-3.93714800	-2.13098200
H	0.08989900	-3.57198200	-3.69949800
Ir	-0.04596300	-0.06328000	-0.20818400
H	-0.81926500	1.45865800	-0.44748900
H	-0.58113700	-0.26931900	-1.70213500
H	1.24739100	0.56552100	-0.97010100
H	-0.14412500	-4.36005700	0.04397800
C	4.36149300	-1.43233500	-0.14349800
C	5.43866800	-1.98459000	-0.86996300
C	3.99674000	-0.09011600	-0.37421800
C	6.11668000	-1.22140400	-1.83042800
H	5.73101800	-3.02456600	-0.68588800
C	4.68006600	0.67175000	-1.33289500
H	3.18274800	0.34952000	0.21041100
C	5.73479200	0.10813500	-2.06658000
H	6.94184400	-1.66715900	-2.39618900
H	4.38588900	1.71212300	-1.50391400
H	6.26230200	0.70580500	-2.81767900
Cl	1.01416000	0.61099600	1.95460600
O	2.34215500	3.38766400	1.66785800
O	0.87248400	3.76457300	-0.75448500
C	2.87790800	4.46216100	-1.83895700
H	2.28808000	4.61543900	-2.74698700
C	4.33790000	4.04881500	0.52990300
H	4.87247600	3.87450800	1.46785400
C	4.99278800	4.50192600	-0.62653400
H	6.06979000	4.68910300	-0.60110500
C	4.26015200	4.70586800	-1.80503100
H	4.76304000	5.05673500	-2.71129400
C	-1.64600700	-2.99524700	0.75200400
H	-1.96057800	-3.33745900	1.75458400
P	-2.02856800	-1.12038300	0.57992500
C	-2.92942100	-0.74606300	2.23314900
C	-1.93059300	-1.02711300	3.37483800
H	-1.62725700	-2.08713200	3.43159900
H	-1.01753700	-0.41781800	3.27137900
H	-2.41342300	-0.77197400	4.33723500
C	-3.28187900	0.75359900	2.23488500
H	-3.72230200	1.01878400	3.21531500
H	-2.38473400	1.37653300	2.08365600
H	-4.01815200	1.00772500	1.45471500
C	-4.20027000	-1.59466700	2.39944400
H	-4.67189500	-1.35668300	3.37171700
H	-4.93714100	-1.39301200	1.60426400
H	-3.98693600	-2.67853500	2.39734600
C	-3.36806500	-1.55965900	-0.63047800
C	-4.34922700	-0.78199700	-1.30145700
C	-3.35951000	-2.95533100	-0.85468800
C	-5.27896600	-1.43866800	-2.13976900
C	-4.27007900	-3.60111500	-1.70268200
C	-5.23710100	-2.82380900	-2.34339400
H	-6.02796400	-0.83225300	-2.65759800
H	-4.21078300	-4.68507200	-1.83262100
H	-5.96329200	-3.29970800	-3.01023100
O	-2.42326600	-3.72518800	-0.21850500
C	-4.48795500	0.69932900	-1.19464600
C	-5.72946900	1.25728500	-0.81622200
C	-3.44093800	1.56692900	-1.56545300
C	-5.91339300	2.64639300	-0.79286700
H	-6.55005300	0.58925500	-0.53196400
C	-3.62768300	2.95609400	-1.55058100
H	-2.48170000	1.14529300	-1.87862300
C	-4.86224100	3.49993200	-1.16181400
H	-6.88113400	3.06099400	-0.49049500
H	-2.80582400	3.61913100	-1.83635700
H	-5.00357500	4.58600600	-1.15652300
H	0.54901100	3.16960800	2.60710400
C	-1.04007900	4.22197900	0.64396100
O	-1.47596900	5.02283400	-0.16777600
O	-1.65510100	3.88173100	1.81140500
C	-2.91171100	4.55592400	2.04465900
H	-3.64749200	4.26626700	1.27785500
H	-3.23663000	4.22024100	3.03864500
H	-2.77258700	5.64867000	2.02656400

R=CO_2Me, face A, C2 TS

Zero-point correction= 0.792316 (Hartree/Particle)
Thermal correction to Energy= 0.846861
Thermal correction to Enthalpy= 0.847805
Thermal correction to Gibbs Free Energy= 0.703092
Sum of electronic and zero-point Energies= -3400.528464
Sum of electronic and thermal Energies= -3400.473919
Sum of electronic and thermal Enthalpies= -3400.472975
Sum of electronic and thermal Free Energies= -3400.617688
Electronic energy -3402.16499004

C	-1.26367300	3.01045600	-1.33127600
C	-0.54679400	3.79180300	-0.41051700
C	-3.23344000	3.45187400	-0.11339200
C	-2.47008100	4.10995500	0.86703200
H	-0.91737400	1.69281100	-1.06850100
C	5.29898100	0.16594100	2.01473400
C	4.44570000	-0.07841500	0.91676500
C	3.31167600	-0.90434200	1.11600000
C	3.06188500	-1.41625100	2.40929900
C	3.89370700	-1.14577100	3.50291000
C	5.02145600	-0.34867200	3.28846800
H	6.17754100	0.79923500	1.85893900
H	3.65437200	-1.56870100	4.48211900
H	5.69326800	-0.12555100	4.12364400
O	1.96131100	-2.21094600	2.60046900
C	1.43087100	-2.71041500	1.35736700
P	1.96717000	-1.47797500	-0.00745000
C	2.69682500	-2.58377400	-1.38133700
C	3.03298200	-1.70801600	-2.60437200
H	3.36110100	-2.36632300	-3.43058600
H	3.84470600	-0.99497500	-2.39347200
H	2.15128500	-1.13775600	-2.93930500
C	3.95973600	-3.31195900	-0.88630800
H	4.33558600	-3.96523100	-1.69551100
H	3.76600000	-3.95427200	-0.00908200
H	4.76161600	-2.60351700	-0.62183200
C	1.60722300	-3.60241000	-1.77524900
H	0.68420200	-3.09792400	-2.10820000
H	1.34647500	-4.29030100	-0.95315400
H	1.98210400	-4.21421000	-2.61655300
Ir	0.19202600	-0.11934800	-0.51209200
H	-1.21680700	0.63544100	-1.09814200
H	-0.10049100	-1.02991700	-1.79987400
H	1.15049000	0.69132800	-1.55341000
H	1.88857400	-3.70083400	1.16502600
H	-0.88808700	3.01318100	-2.36064300
C	4.79957800	0.55193900	-0.38572800
C	6.06087800	0.30524800	-0.97063400
C	3.91892600	1.45463100	-1.01554400
C	6.42195100	0.92750800	-2.17367100
H	6.75191600	-0.39022100	-0.48094000
C	4.28784800	2.08514900	-2.21270300
H	2.94743900	1.66600500	-0.55886000
C	5.53524600	1.81908100	-2.79748300
H	7.39816100	0.71570500	-2.62310500
H	3.58722600	2.78914800	-2.67143600
H	5.81939900	2.30804800	-3.73552200
Cl	0.71821900	1.64305300	1.17292300
O	-1.10316300	4.35183200	0.68306000
O	-2.67665100	3.00757200	-1.29671200
C	-4.60026500	3.25598700	0.10307600
H	-5.17643800	2.72399100	-0.65884300
C	-3.04867500	4.56207500	2.05083100
H	-2.41306700	5.06322300	2.78619500
C	-4.42329400	4.36528000	2.26511000
H	-4.88234500	4.71948400	3.19239300
C	-5.19298700	3.71638800	1.29129400
H	-6.26313900	3.55495300	1.45220000
C	-0.07314200	-2.91428000	1.54016100
H	-0.26605700	-2.96393400	2.62683300
P	-1.19084800	-1.56286900	0.76474900
C	-2.26325800	-0.99533600	2.24764700
C	-1.30642300	-0.47690400	3.34208700
H	-0.67981100	-1.27433200	3.77875300
H	-0.64096600	0.31448000	2.95770700
H	-1.91236600	-0.05136700	4.16414500
C	-3.12781700	0.17708800	1.74625700
H	-3.72718400	0.57745200	2.58536500
H	-2.49165500	0.99267700	1.36563700
H	-3.82497700	-0.12453400	0.94671400
C	-3.14645800	-2.12993200	2.79026100
H	-3.71908100	-1.75869700	3.66104200
H	-3.86647300	-2.48859000	2.03609800
H	-2.55475300	-2.99791400	3.13299000
C	-2.15387400	-2.91105000	-0.07326200
C	-3.32421900	-2.89998300	-0.87728200
C	-1.56113700	-4.16112400	0.21809300
C	-3.85813100	-4.13312300	-1.31648900
C	-2.07994600	-5.38103300	-0.23776000
C	-3.24481600	-5.35379800	-1.00694900
H	-4.75836700	-4.11593000	-1.93795400
H	-1.57422000	-6.31389600	0.02549300
H	-3.67689900	-6.29036600	-1.37387900
O	-0.42568700	-4.19648900	0.98093700
C	-4.05499100	-1.67831400	-1.32611100
C	-5.42996700	-1.54154900	-1.03326400
C	-3.44116800	-0.71932200	-2.15719200
C	-6.17120200	-0.47208000	-1.55294000
H	-5.91495800	-2.28574000	-0.39204200
C	-4.18607500	0.34485700	-2.68376200
H	-2.38032700	-0.82373000	-2.40187800
C	-5.55165500	0.47116700	-2.38715900
H	-7.23616900	-0.38180100	-1.31359400
H	-3.69677800	1.07687500	-3.33346200
H	-6.13316100	1.29626900	-2.81307800
C	0.88132500	4.09240400	-0.68116000
O	1.44301500	3.70820400	-1.70536200
O	1.42965400	4.87717200	0.27000100
C	2.82636100	5.17039300	0.05973000
H	2.98012300	5.65108500	-0.92011600
H	3.10399900	5.84959100	0.87667600
H	3.41998800	4.24317400	0.10435500

R=CO_2Me, face B, C1 TS

Zero-point correction= 0.793372 (Hartree/Particle)
Thermal correction to Energy= 0.847635
Thermal correction to Enthalpy= 0.848579
Thermal correction to Gibbs Free Energy= 0.704766
Sum of electronic and zero-point Energies= -3400.527839
Sum of electronic and thermal Energies= -3400.473576
Sum of electronic and thermal Enthalpies= -3400.472632
Sum of electronic and thermal Free Energies= -3400.616445
Electronic energy -3402.16557714

C	1.34150800	-3.09859400	-0.45586200

C	0.71575400	-3.63666600	0.69657500
C	3.38179200	-3.07113300	0.75435100
C	2.71420200	-3.55149200	1.89349800
H	0.93374700	-1.75835200	-0.52862900
C	-5.29443300	-0.74612300	2.22085400
C	-4.46761800	-0.55496500	1.09264000
C	-3.51252300	0.49127200	1.13010500
C	-3.39185800	1.26608000	2.30522400
C	-4.19360000	1.05321700	3.43326300
C	-5.15286500	0.03765000	3.37427900
H	-6.03662000	-1.54952200	2.19165900
H	-4.06300600	1.68247800	4.31759600
H	-5.79761800	-0.14740100	4.23955900
O	-2.44820800	2.26180600	2.34256700
C	-1.96965600	2.60960600	1.02736900
P	-2.25871200	1.07812500	-0.08506800
C	-3.13316200	1.78341400	-1.62866800
C	-3.30926400	0.65715800	-2.66679400
H	-3.72245400	1.09472700	-3.59509600
H	-4.00283700	-0.12419100	-2.31992300
H	-2.34376300	0.18124400	-2.90392800
C	-4.50350300	2.38064600	-1.26046700
H	-4.96803300	2.79931900	-2.17246300
H	-4.42909000	3.20075800	-0.52475100
H	-5.18472400	1.61616600	-0.85234900
C	-2.21240600	2.87070400	-2.22057300
H	-1.22589000	2.46012700	-2.49559000
H	-2.05185600	3.71784700	-1.53262500
H	-2.68140600	3.27021600	-3.13885400
Ir	-0.27305100	-0.04181900	-0.34320000
H	1.24660800	-0.68766300	-0.72361000
H	-0.07688500	0.66587400	-1.76258100
H	-1.05553300	-1.15211100	-1.24736500
H	-2.57274000	3.46324000	0.66053100
C	-4.65303700	-1.46598500	-0.07244400
C	-5.91319800	-1.56032800	-0.70233900
C	-3.59981700	-2.28552400	-0.52702300
C	-6.10524100	-2.43234400	-1.78289800
H	-6.73826500	-0.93200100	-0.34801400
C	-3.79462500	-3.15898400	-1.60638300
H	-2.63010400	-2.23926300	-0.02306600
C	-5.04451800	-3.23019000	-2.23979800
H	-7.08492800	-2.48608700	-2.26996200
H	-2.95642300	-3.77523700	-1.94639900
H	-5.19538900	-3.90966000	-3.08559400
Cl	-0.58931100	-1.55191700	1.64077000
O	1.37199200	-3.95189500	1.81840100
O	2.76220800	-2.95426700	-0.46749100
C	4.73095700	-2.71252700	0.86335500
H	5.23767300	-2.31833700	-0.02138700
C	3.35747000	-3.67416300	3.12293600
H	2.78914600	-4.04935900	3.97862500
C	4.71118400	-3.31664900	3.22587800
H	5.22570400	-3.41043900	4.18621300
C	5.39038400	-2.83971000	2.09588200
H	6.44391600	-2.55311900	2.16873400
C	-0.52094600	3.08311700	1.16429100
H	-0.37161600	3.37367000	2.21995200
P	0.81716600	1.80271200	0.66266400
C	1.91476700	1.70296300	2.22932200
C	1.01501800	1.22685400	3.38883400
H	0.23452000	1.96042700	3.65546700
H	0.52081300	0.27042600	3.14995000
H	1.64533400	1.07753900	4.28569700
C	2.99626700	0.63693400	1.96489000
H	3.60914200	0.50581900	2.87644600
H	2.53962100	-0.33629900	1.72232000
H	3.67194800	0.91905000	1.14070700
C	2.56470800	3.05552100	2.56393600
H	3.15541500	2.95313100	3.49377400
H	3.24455000	3.39461300	1.76466800
H	1.81898300	3.85258700	2.73522200
C	1.58732200	3.09631800	-0.41957400
C	2.77031400	3.10980800	-1.20589100
C	0.79910000	4.26871200	-0.37924700
C	3.12093400	4.30165400	-1.87991300
C	1.13893500	5.44228200	-1.06683700
C	2.31746800	5.44750400	-1.81614100
H	4.03145800	4.30570200	-2.48655100
H	0.48945100	6.31866900	-0.99287300
H	2.61130900	6.35064100	-2.36069600
O	-0.35241800	4.27152300	0.36204800
C	3.68917500	1.94873100	-1.39429600
C	5.06283900	2.08552900	-1.09416000
C	3.24199100	0.74576800	-1.97625600
C	5.96074800	1.04274300	-1.35813500
H	5.42096200	3.01861200	-0.64528700
C	4.13990600	-0.29773000	-2.24092200
H	2.18459500	0.63487400	-2.22956400
C	5.50165700	-0.15120400	-1.93600300
H	7.02180700	1.16545100	-1.11576900
H	3.76592000	-1.22869500	-2.67871400
H	6.20586600	-0.96144500	-2.15597600
H	-0.28684200	-4.05546000	0.63501600
C	0.74464800	-3.53497200	-1.75738500
O	-0.40610600	-3.94156500	-1.87404300
O	1.60344800	-3.33954700	-2.78746800
C	1.04457600	-3.65420000	-4.08198500
H	0.72429100	-4.70754800	-4.12067000
H	0.17896700	-3.00620800	-4.29266100
H	1.85522000	-3.46740400	-4.79886400

R=CO_2Me, face B, C2 TS

Zero-point correction= 0.793336 (Hartree/Particle)
Thermal correction to Energy= 0.847653
Thermal correction to Enthalpy= 0.848597
Thermal correction to Gibbs Free Energy= 0.705018
Sum of electronic and zero-point Energies= -3400.530718
Sum of electronic and thermal Energies= -3400.476400
Sum of electronic and thermal Enthalpies= -3400.475456
Sum of electronic and thermal Free Energies= -3400.619035
Electronic energy -3402.16930060

C	-1.05523100	3.00458600	0.18925900
C	-0.10268400	3.59977100	1.03449000
C	0.06399700	3.90474800	-1.67135100
C	1.14537600	4.23584200	-0.83308200
H	-0.70746500	1.71821600	0.05081400
C	4.73322100	-1.97127600	2.19104100
C	3.97741700	-1.59979600	1.05848400
C	2.67251400	-2.13552300	0.92100800
C	2.16537000	-2.98045600	1.93296400
C	2.90999100	-3.32505100	3.06693100
C	4.20496700	-2.80997800	3.18233900
H	5.74223200	-1.56253100	2.30006800
H	2.47528300	-3.98629300	3.82106800
H	4.81123900	-3.06466500	4.05758200
O	0.89365900	-3.47947500	1.79748400
C	0.38995400	-3.33688300	0.45602300
P	1.37299000	-1.91204300	-0.35561100

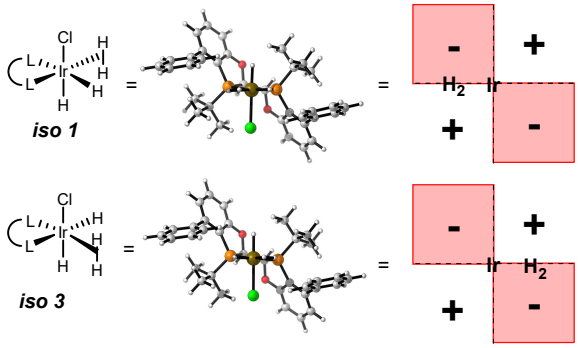
C	1.97485500	-2.62853800	-2.02386100
C	2.62292200	-1.50163600	-2.85135700
H	2.89428500	-1.90597200	-3.84446600
H	3.53700900	-1.11052400	-2.38020200
H	1.92411300	-0.66123300	-2.99547400
C	2.98803800	-3.76224700	-1.77822100
H	3.27914200	-4.19689500	-2.75221900
H	2.57163100	-4.57899000	-1.16271400
H	3.90140800	-3.39340200	-1.28416800
C	0.75069800	-3.16893100	-2.79125500
H	-0.00085700	-2.38194200	-2.97312200
H	0.24855700	-4.00424500	-2.27623200
H	1.09321100	-3.53634800	-3.77607200
Ir	-0.01870400	0.00387200	-0.39541400
H	-0.99220000	0.87329600	-1.35927200
H	-0.35352500	-0.64975900	-1.83454200
H	1.13152600	0.85802800	-1.16309300
H	0.58949000	-4.28221700	-0.08698100
H	-2.05963400	2.88550400	0.60839600
C	4.60217900	-0.68112500	0.06522600
C	5.83747300	-1.02440300	-0.52692400
C	4.00316200	0.55226900	-0.26577600
C	6.44673800	-0.16693300	-1.45308600
H	6.30860000	-1.97917400	-0.26744400
C	4.61901400	1.40857600	-1.18961700
H	3.06336500	0.83883600	0.21713700
C	5.83558900	1.05088700	-1.78979700
H	7.39804800	-0.45259500	-1.91465000
H	4.13703400	2.35935300	-1.44183200
H	6.30981700	1.71999600	-2.51578700
Cl	0.96912400	0.76787100	1.74373300
O	1.05438300	4.12675400	0.55516800
O	-1.12732900	3.42715200	-1.16610300
C	0.19033600	4.07665600	-3.05268100
H	-0.65805900	3.81000700	-3.68975200
C	2.33694800	4.73165100	-1.36347200
H	3.14868100	4.98474500	-0.67512500
C	2.46055300	4.90136800	-2.75294200
H	3.39377000	5.29132700	-3.16952500
C	1.38642100	4.57816300	-3.59255700
H	1.47331200	4.70845300	-4.67538400
C	-1.12634200	-3.15401100	0.53258800
H	-1.47377000	-3.65972800	1.45353100
P	-1.77829900	-1.34407200	0.50710000
C	-2.58643300	-1.16937800	2.23732300
C	-1.49268100	-1.46286600	3.28663100
H	-1.14894300	-2.51088800	3.26895200
H	-0.61668800	-0.80715200	3.14901200
H	-1.91378500	-1.26924600	4.29114600
C	-3.06022700	0.28687300	2.40921800
H	-3.51114400	0.39341300	3.41386900
H	-2.22407700	1.00103300	2.35165500
H	-3.82724100	0.56862200	1.67024900
C	-3.77235900	-2.13480900	2.40306300
H	-4.17608400	-2.03103700	3.42767400
H	-4.58579800	-1.91187000	1.69300800
H	-3.48560600	-3.19323900	2.26974200
C	-3.09774000	-1.90575000	-0.66796400
C	-4.25485200	-1.27001500	-1.18622400
C	-2.81025200	-3.22190200	-1.09471700
C	-5.07351600	-1.98415800	-2.08993100
C	-3.61026100	-3.92003000	-2.00837800
C	-4.75189700	-3.28360500	-2.50307900
H	-5.96753900	-1.48976000	-2.48157500
H	-3.33815000	-4.93870500	-2.29758600
H	-5.40020200	-3.80636900	-3.21357300
O	-1.69693800	-3.84759900	-0.59595600
C	-4.69933000	0.11010900	-0.82673600
C	-5.94378800	0.29562000	-0.18642000
C	-3.95038900	1.24739600	-1.18865400
C	-6.41169300	1.58282700	0.11199100
H	-6.53860300	-0.58261500	0.08775100
C	-4.42548600	2.53564000	-0.90251100
H	-2.99776500	1.11996900	-1.71033300
C	-5.65257500	2.70727700	-0.24430000
H	-7.37255300	1.70650100	0.62254900
H	-3.83054300	3.40375500	-1.20517800
H	-6.01852900	3.71347800	-0.01541500
C	-0.29872000	3.61590400	2.49626100
O	0.76539600	4.15358300	3.14579500
O	-1.33621100	3.24272900	3.04263900
C	0.62313900	4.16837300	4.57812500
H	1.53139100	4.65810500	4.95486400
H	-0.27749100	4.72895600	4.87766800
H	0.54769100	3.13901700	4.96543200

Stereoselectivity of the C2 protonations.

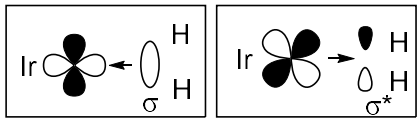
R=Me

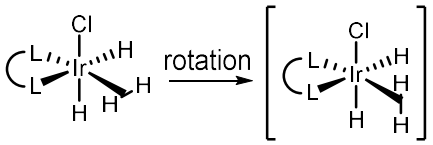
Conformational analysis of the transition states

Due to C_2 symmetry of the ligand, there are two quadrants across which the substrate can be positioned:



This contributes to **2** TS conformations with different substrate orientation. For each of those, there **2** distinct ways of interaction with the hydrogen. This is because H_2 in reactive conformation is positioned perpendicular to the L_2IrH plane:



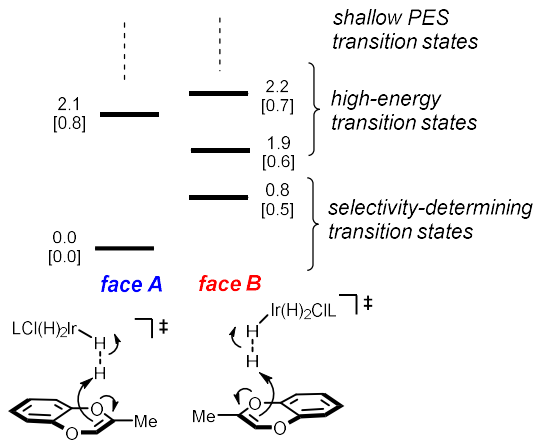


no back donation
σ* is open for attack

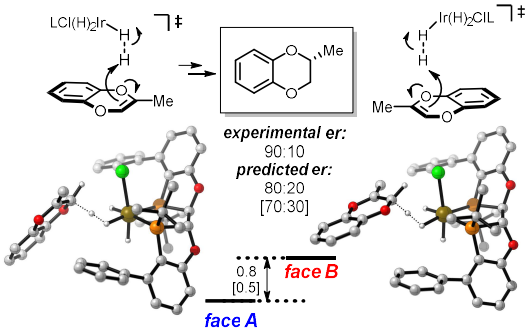
This opens the σ* orbital of the H_2 for the attack by incoming nucleophile (substrate). Such orientation creates the possibility of the attack on the top or bottom hydrogen atom, producing 2 possibilities mentioned above. Finally, the substrate can attack with **2** different faces.

This gives a total of 2^3=**8** conformations for each Ir complex isomer, bringing the overall number of conformations for given substrate to **16**.

This formal analysis accounts for some transition states where approach of the substrate is not optimal. Such transition states quickly converged to other, more stable transition states, during optimization, reducing the total number of available conformers. Finally, some transition states proved to be very hard to converge and, despite our best efforts, didn't allow us to locate stationary points. This suggests very shallow PES around TS region. For those TSs we estimated free energies by analyzing the structures with frozen TS core. Importantly, most of these structures satisfy the single negative frequency requirement. The analysis produced the following energy-level diagram:



According to this, two conformations control the selectivity of the overall process:



R=Me, face A, lowest energy TS

Optimization of this TS structure proved to be unsuccessful with various algorithms, grid sizes and step sizes. This suggests very shallow PES around TS. Located structure satisfies single negative frequency requirement.

Zero-point correction= 0.778518 (Hartree/Particle)
Thermal correction to Energy= 0.829965
Thermal correction to Enthalpy= 0.830909
Thermal correction to Gibbs Free Energy= 0.691747
Sum of electronic and zero-point Energies= -3212.180928
Sum of electronic and thermal Energies= -3212.129481
Sum of electronic and thermal Enthalpies= -3212.128537
Sum of electronic and thermal Free Energies= -3212.267699
Electronic energy -3213.74437624

C	1.41422800	2.87856900	-1.18498700
C	2.62066400	2.90516400	-1.86460900
C	2.31190100	4.24158800	0.49684400
C	3.57540700	4.13994800	-0.11297700
H	1.41665400	1.53558500	-0.72249900
C	-5.55073100	0.39634500	-1.70717600
C	-4.48056700	0.62852700	-0.81693800
C	-3.65208200	-0.46548100	-0.45990200
C	-3.90719800	-1.72951600	-1.03558200
C	-4.95312800	-1.94968900	-1.94087200
C	-5.77601200	-0.86841300	-2.26810300
H	-6.19151200	1.23954000	-1.98220000
H	-5.10882500	-2.94886300	-2.35624300
H	-6.60379100	-1.01189000	-2.97013500
O	-3.10248000	-2.78692800	-0.69325800
C	-2.29656800	-2.51259200	0.46904400
P	-2.18682100	-0.60893500	0.64923700
C	-2.73132200	-0.29079000	2.45395300
C	-2.55586200	1.20451400	2.78514800
H	-2.79371000	1.35793500	3.85468100
H	-3.22667400	1.84533600	2.19240200
H	-1.51848400	1.53183800	2.60695400
C	-4.19934200	-0.70766600	2.65992700
H	-4.47002700	-0.55352500	3.72111900
H	-4.37701300	-1.77225800	2.42635100
H	-4.88475200	-0.10360700	2.04294200
C	-1.80280600	-1.11340800	3.37198100
H	-0.74317300	-0.85401500	3.20828500
H	-1.91309100	-2.20226900	3.23475300
H	-2.05225600	-0.88185900	4.42406400
Ir	-0.13419700	0.10475100	-0.02656000
H	1.48594000	0.53874300	-0.38257300
H	0.38691200	0.03601000	1.48662300
H	-0.58606500	1.60981600	0.41828600
H	-2.81205600	-2.94450300	1.34871300
H	0.49377500	2.65748200	-1.74923700
C	2.85275800	2.13999700	-3.11874900
H	3.29178500	2.79461600	-3.89295500
H	1.90419000	1.71373900	-3.48188800
H	3.56611900	1.31455100	-2.93556200
C	-4.29339600	2.01129000	-0.29467700
C	-5.35291600	2.66524400	0.37141500
C	-3.08139200	2.70241000	-0.49670100
C	-5.19345300	3.97215800	0.85230800
H	-6.29896100	2.13380400	0.52517000
C	-2.92701900	4.00982800	-0.01514000
H	-2.27389400	2.20747800	-1.04618900
C	-3.97671800	4.64625400	0.66415800
H	-6.01961600	4.46284300	1.37805700
H	-1.97493600	4.52887100	-0.17151200
H	-3.85090000	5.66658900	1.04213900
Cl	-0.75501900	0.66097600	-2.43485300
O	3.74494400	3.46128700	-1.33478800
O	1.17927300	3.69374400	-0.06629400
C	2.19308200	4.93211400	1.70693100
H	1.20452200	4.99991000	2.17004100
C	4.70579000	4.70978300	0.46837100

H	5.66849000	4.60657300	-0.04077200
C	4.58182700	5.40349300	1.68392300
H	5.46683000	5.85243700	2.14326700
C	3.32698600	5.51401800	2.29655000
H	3.22203500	6.05106300	3.24385700
C	-0.96248600	-3.23772200	0.30325100
H	-1.12337300	-4.08188700	-0.39355900
P	0.49004200	-2.15087600	-0.31865600
C	0.93310900	-2.94404800	-2.00577800
C	-0.34678500	-2.94295100	-2.86988700
H	-1.13990500	-3.59599200	-2.46792100
H	-0.75489500	-1.92437700	-2.98331000
H	-0.08700800	-3.32262400	-3.87623100
C	1.97758400	-2.03057900	-2.67934500
H	2.19181800	-2.41763500	-3.69370200
H	1.58198200	-1.00552400	-2.77730500
H	2.92832800	-1.99921000	-2.12276500
C	1.47955000	-4.37188100	-1.84774600
H	1.67695300	-4.79719100	-2.84985200
H	2.42389700	-4.39195800	-1.27854000
H	0.76390100	-5.04355900	-1.34044900
C	1.55952600	-2.94929500	0.96657400
C	2.95116900	-2.88614200	1.22768200
C	0.75222000	-3.73269000	1.82174200
C	3.47601300	-3.63032700	2.30731800
C	1.26992500	-4.45119600	2.90801700
C	2.64689500	-4.39397300	3.13999900
H	4.55208700	-3.58152700	2.49984700
H	0.59762100	-5.04439800	3.53378200
H	3.07938700	-4.95072400	3.97756200
O	-0.59545200	-3.79256300	1.58426900
C	3.91900400	-2.08042500	0.42542600
C	4.96262500	-2.72457700	-0.27343900
C	3.86776200	-0.67211300	0.41958800
C	5.91288500	-1.98143900	-0.98718800
H	5.01659700	-3.81873800	-0.26111400
C	4.82591700	0.07090000	-0.28534900
H	3.07691700	-0.16613800	0.98102400
C	5.84544400	-0.58015200	-0.99692900
H	6.70862000	-2.49850100	-1.53378400
H	4.78268600	1.16522900	-0.27161200
H	6.59185500	0.00274500	-1.54694800

R=Me, face B, lowest energy TS

Zero-point correction= 0.777427 (Hartree/Particle)
Thermal correction to Energy= 0.829117
Thermal correction to Enthalpy= 0.830061
Thermal correction to Gibbs Free Energy= 0.691418
Sum of electronic and zero-point Energies= -3212.181346
Sum of electronic and thermal Energies= -3212.129656
Sum of electronic and thermal Enthalpies= -3212.128712
Sum of electronic and thermal Free Energies= -3212.267354
Electronic energy -3213.74275520

C	2.30392200	-2.39774500	0.96160300
C	2.12030400	-3.58695700	0.23949000
C	4.64266100	-2.65303100	0.73734900
C	4.43552800	-3.76455900	-0.09799700
H	1.72122000	-1.47731400	0.21076900
C	-5.43231300	-1.60941700	1.79461900
C	-4.47847300	-1.40961200	0.77328400
C	-3.75401300	-0.19184200	0.75241100
C	-3.98858200	0.75283900	1.77614700
C	-4.91381100	0.53906400	2.80574300
C	-5.63767800	-0.65610300	2.80133100
H	-5.99383600	-2.54846300	1.80638000
H	-5.05661100	1.30573800	3.57188500
H	-6.37125800	-0.84807600	3.59102100
O	-3.28616300	1.92951400	1.76034500
C	-2.65951200	2.17280300	0.48597900
P	-2.44726200	0.47127900	-0.37169000
C	-3.19679100	0.74483400	-2.10797400
C	-2.96935900	-0.52132300	-2.95622600
H	-3.30692600	-0.32135400	-3.99065600
H	-3.53489300	-1.38539600	-2.57454900
H	-1.90122900	-0.79180300	-2.98219800
C	-4.70066900	1.06102600	-2.01615500
H	-5.09160800	1.24811700	-3.03363400
H	-4.90900600	1.96185700	-1.41209600
H	-5.26865900	0.22160000	-1.58246700
C	-2.43864300	1.92210800	-2.75688300
H	-1.35474100	1.72301200	-2.80876200
H	-2.58700100	2.87586700	-2.22240800
H	-2.81009100	2.05665100	-3.78970700
Ir	-0.26240800	-0.18612900	-0.19958800
H	1.40190200	-0.54124500	-0.31526900
H	0.01754400	0.36395300	-1.67664400
H	-0.61690500	-1.57105700	-1.00025000
H	-3.34164700	2.80693200	-0.11335900
H	1.57033700	-2.21160500	1.77714300
C	0.76905000	-4.09908100	-0.07896000
H	0.11643000	-4.04675000	0.80897800
H	0.82179900	-5.12169800	-0.48245000
H	0.29480700	-3.42082000	-0.82435600
C	-4.30363400	-2.49846800	-0.22859600
C	-5.41226500	-2.95137700	-0.97609200
C	-3.05654000	-3.13318500	-0.40045000
C	-5.27397600	-4.00010600	-1.89540600
H	-6.38387000	-2.46327900	-0.84017700
C	-2.92622200	-4.18776600	-1.31515000
H	-2.20474600	-2.79598500	0.19961800
C	-4.02770800	-4.62092300	-2.06834600
H	-6.14049900	-4.33212700	-2.47715100
H	-1.95498700	-4.67925500	-1.43925000
H	-3.91746600	-5.44244700	-2.78413500
Cl	-0.62104600	-1.45553200	1.97018400
O	3.13332800	-4.23030700	-0.37476900
O	3.60694000	-1.95839700	1.30894800
C	5.95554800	-2.24701200	1.00550600
H	6.10571700	-1.38042900	1.65516600
C	5.49919200	-4.46040600	-0.66690000
H	5.28413900	-5.31997300	-1.30818100
C	6.81406600	-4.04445400	-0.39919900
H	7.65459500	-4.58498300	-0.84279500
C	7.03540000	-2.94272600	0.43824000
H	8.05626200	-2.61451200	0.65609100
C	-1.37719000	2.96645300	0.73797400
H	-1.46310000	3.41994400	1.74191600
P	0.25252000	1.95532700	0.63733800
C	1.06446600	2.30536700	2.34013400
C	0.09474300	1.78838100	3.42336400
H	-0.85533200	2.34980900	3.45229000
H	-0.14185700	0.72100100	3.27603300
H	0.57481300	1.90684500	4.41329500
C	2.36984400	1.48926400	2.41068000
H	2.82922800	1.63076000	3.40745300
H	2.17333800	0.41274400	2.27961300
H	3.10538900	1.80380700	1.65246800
C	1.35678400	3.80174300	2.54067500
H	1.78832000	3.95515100	3.54780300
H	2.07664400	4.18583900	1.79875500

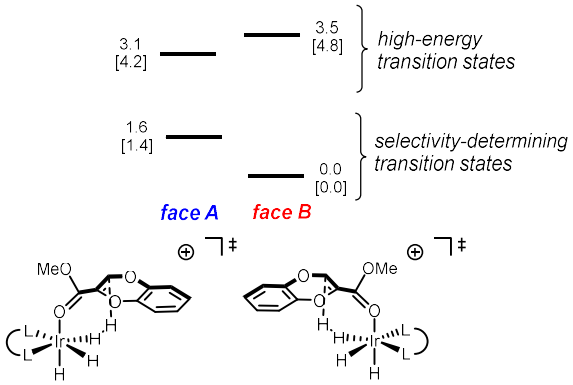
H	0.44376500	4.42070200	2.47819000
C	0.92253400	3.24726600	-0.51649000
C	2.19427300	3.43125800	-1.11990200
C	-0.08268600	4.20509200	-0.78194000
C	2.40644200	4.57208200	-1.92667700
C	0.12291600	5.32413500	-1.60124800
C	1.38617700	5.50093000	-2.16937300
H	3.38903100	4.70492400	-2.38922400
H	-0.69609000	6.02950900	-1.76576000
H	1.57791100	6.36760400	-2.81026400
O	-1.32002000	4.04359400	-0.22027300
C	3.35196100	2.50000600	-0.97904700
C	4.58063000	2.98035100	-0.47575600
C	3.28424800	1.17287700	-1.44766500
C	5.70875000	2.15009800	-0.42661400
H	4.64210400	4.01360100	-0.11647100
C	4.41618900	0.34753200	-1.40617900
H	2.34075500	0.79691200	-1.85241800
C	5.63021000	0.83033800	-0.89539300
H	6.65153200	2.53812200	-0.02616600
H	4.35210900	-0.67823800	-1.78503200
H	6.50967100	0.17896500	-0.86611800

R=CO_2Me

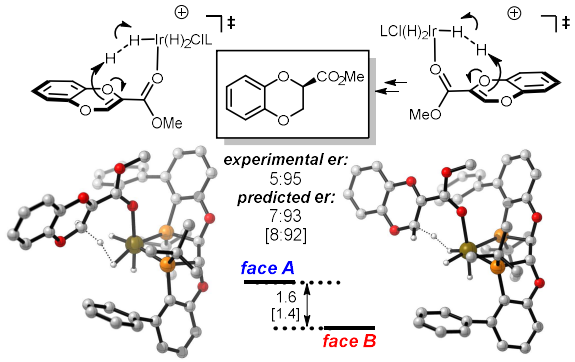
Conformational analysis of the transition states

Due to the intramolecular nature of the transition states with carboxymethyl substrate, the available number of conformations goes down from 16 to **4**. Thus, quadrant positioning of the substrate cannot be altered. Also, the reaction can only proceed with the hydrogen atom of the H_2 fragment that is pointing towards the substrate.

This leaves the conformations that correspond to face A and face B reactivity of the iso 1 and iso 2 Ir complexes, giving the following energy diagram:



Two conformations control the selectivity of the process:



R=CO_2Me, face A, lowest energy TS

Zero-point correction=	0.793150 (Hartree/Particle)
Thermal correction to Energy=	0.845467
Thermal correction to Enthalpy=	0.846411
Thermal correction to Gibbs Free Energy=	0.706520
Sum of electronic and zero-point Energies=	-2940.308714
Sum of electronic and thermal Energies=	-2940.256397
Sum of electronic and thermal Enthalpies=	-2940.255453
Sum of electronic and thermal Free Energies=	-2940.395344
Electronic energy	-2941.93118781

C	1.76382100	-2.44891200	-0.95740600
C	1.58172000	-2.95958600	0.36852600
C	3.94281600	-3.39967300	-0.92217200
C	3.73761400	-3.86416800	0.38439300
H	1.47871600	-1.22026700	-0.90198500
C	-4.82293400	-1.90298400	1.89940400
C	-4.13939100	-1.41015200	0.76557400
C	-3.42468700	-0.18894000	0.89611700
C	-3.40445700	0.46358600	2.15256200
C	-4.06267200	-0.04607600	3.27869700
C	-4.77712200	-1.23913800	3.13505400
H	-5.38757900	-2.83484100	1.80112400
H	-4.02833400	0.50380800	4.22273400
H	-5.31377000	-1.65432500	3.99377000
O	-2.71661500	1.64210100	2.27069000
C	-2.37775000	2.22007300	0.99635500
P	-2.41501100	0.79646500	-0.27913100
C	-3.45245300	1.44227500	-1.73905900
C	-3.43069900	0.41044200	-2.88380200
H	-3.95508500	0.84675400	-3.75330700
H	-3.94242400	-0.52559500	-2.61450100
H	-2.39934000	0.16857300	-3.18875400
C	-4.89888800	1.69743000	-1.27333600
H	-5.47395700	2.10483700	-2.12417300
H	-4.96188600	2.43433700	-0.45372400
H	-5.39444000	0.76980600	-0.94374700
C	-2.80432400	2.75441500	-2.23024000
H	-1.76535500	2.60044500	-2.56816000
H	-2.80272300	3.54954600	-1.46701500
H	-3.38465900	3.12042300	-3.09608500
Ir	-0.21969100	0.08378000	-0.66756000
H	1.27806900	0.11449600	-1.37106200
H	-0.28106600	1.10184400	-1.88029500
H	-0.67137000	-0.97308000	-1.83173800
H	-3.15247000	2.96894100	0.74014000
H	0.94228500	-2.69342300	-1.65368500
C	-4.24362100	-2.19221900	-0.49821500
C	-5.51894400	-2.50045300	-1.02143600
C	-3.10119200	-2.68964000	-1.15791300
C	-5.64500000	-3.26572800	-2.18818200
H	-6.41282400	-2.12057400	-0.51510300
C	-3.23047200	-3.46288900	-2.31948600
H	-2.10981500	-2.46307100	-0.75688200
C	-4.50060800	-3.74959700	-2.84060900
H	-6.63987600	-3.48443300	-2.58861100
H	-2.33438300	-3.84411600	-2.82034900
H	-4.59955400	-4.35036000	-3.75000500
O	2.54990500	-3.55101000	1.07984900
O	3.00556700	-2.62961100	-1.59135400
C	5.13085200	-3.72488500	-1.57919000
H	5.28254600	-3.36640100	-2.60126900
C	4.68645000	-4.63631900	1.04920100
H	4.47918400	-4.97529800	2.06796200
C	5.88453500	-4.95546000	0.38791800

H	6.64009700	-5.55704700	0.89944600
C	6.10154100	-4.49928400	-0.91844200
H	7.03283600	-4.74258600	-1.43739900
C	-1.04099000	2.94130100	1.15764200
H	-0.97043000	3.29747000	2.20375000
P	0.49921800	1.89440400	0.72489600
C	1.39891300	1.63827400	2.39200500
C	0.38594600	0.99144900	3.36031400
H	0.91229500	0.72062400	4.29405300
H	-0.44027500	1.66942600	3.62992100
H	-0.05483900	0.07320800	2.93649900
C	2.56797500	0.66076700	2.15347400
H	3.05569900	0.44094700	3.12102600
H	2.21347600	-0.29467300	1.72909800
H	3.33076500	1.07579200	1.47721300
C	1.91731400	2.96658400	2.96723400
H	2.38709300	2.77700900	3.94995600
H	2.67458900	3.42766800	2.31306500
H	1.10883100	3.70170400	3.12578800
C	1.19766100	3.36490700	-0.13875100
C	2.47303900	3.63102400	-0.69971700
C	0.19161200	4.35209400	-0.24280000
C	2.68709300	4.88048300	-1.31825600
C	0.40064900	5.58308900	-0.87474500
C	1.66586300	5.83702700	-1.41218400
H	3.67344200	5.08975200	-1.74234700
H	-0.40984200	6.31494200	-0.92183900
H	1.86108000	6.79356500	-1.90638000
O	-1.04814300	4.08606300	0.28956300
C	3.62058700	2.67522300	-0.65277700
C	4.74901900	2.97112100	0.14152800
C	3.63817800	1.51194500	-1.44824300
C	5.84644000	2.09887700	0.17712200
H	4.75884300	3.89021600	0.73742300
C	4.73697700	0.64105900	-1.41387900
H	2.79764600	1.30985100	-2.11903900
C	5.83857600	0.92630300	-0.59342800
H	6.71081900	2.33944500	0.80428900
H	4.73410400	-0.25582200	-2.04185200
H	6.69653400	0.24689200	-0.56817700
C	0.37974500	-2.59138000	1.11866200
O	-0.25167800	-1.53115000	0.89024500
O	0.07219700	-3.42727600	2.10974400
C	-1.05507800	-3.04984200	2.94715600
H	-1.94873300	-2.86922700	2.33008300
H	-1.20214400	-3.90599100	3.61665000
H	-0.81045300	-2.14279200	3.52121200

R=CO_2Me, face B, lowest energy TS

Zero-point correction= 0.792777 (Hartree/Particle)
Thermal correction to Energy= 0.845211
Thermal correction to Enthalpy= 0.846156
Thermal correction to Gibbs Free Energy= 0.706072
Sum of electronic and zero-point Energies= -2940.309698
Sum of electronic and thermal Energies= -2940.257264
Sum of electronic and thermal Enthalpies= -2940.256319
Sum of electronic and thermal Free Energies= -2940.396403
Electronic energy -2941.93321561

C	1.89534900	2.57052600	-0.00304700
C	2.59198700	1.95919500	1.08109200
C	3.96306600	3.51456400	-0.68747900
C	4.62185800	2.86930200	0.36854300
H	1.28074800	1.59951400	-0.59389400
C	-5.89171600	0.69572600	-1.81128900
C	-4.77803000	0.94958000	-0.98478600
C	-3.98893500	-0.15604000	-0.56907000
C	-4.33825500	-1.45313700	-1.01303900
C	-5.43216200	-1.69420000	-1.85313200
C	-6.20802800	-0.60072600	-2.24505000
H	-6.50519000	1.54307100	-2.13062600
H	-5.66201100	-2.71577400	-2.16615500
H	-7.07371800	-0.75847500	-2.89548400
O	-3.57576500	-2.52044200	-0.60818400
C	-2.67429200	-2.19032700	0.45940000
P	-2.52318400	-0.28781500	0.52113100
C	-2.97891800	0.20223900	2.31698900
C	-2.72269700	1.70961600	2.50785600
H	-2.95860500	1.97382300	3.55519500
H	-3.35247300	2.33052500	1.85242000
H	-1.66736500	1.96697800	2.31799900
C	-4.45493900	-0.13470300	2.59165400
H	-4.67778600	0.09611400	3.64951300
H	-4.68459400	-1.20286500	2.43357400
H	-5.13593100	0.46112900	1.96311800
C	-2.04792000	-0.59848100	3.25006100
H	-0.98784600	-0.44187100	2.99040200
H	-2.24799500	-1.68249100	3.23344200
H	-2.20691100	-0.24796000	4.28650300
Ir	-0.43987900	0.36152600	-0.31186500
H	0.65704400	0.77534600	-1.50139400
H	-0.89524200	1.92246800	-0.16167500
H	-3.12057300	-2.54886100	1.40647300
H	0.95742700	3.07974300	0.27357900
C	-4.52172500	2.36337900	-0.58473000
C	-5.50237900	3.06860800	0.14696500
C	-3.35430000	3.04170000	-0.98856400
C	-5.30374700	4.41173100	0.49487500
H	-6.42087200	2.55318100	0.44844900
C	-3.16351600	4.38822400	-0.64832200
H	-2.60131600	2.51288100	-1.57825500
C	-4.13177000	5.07443800	0.09966700
H	-6.06898900	4.94262900	1.06999400
H	-2.25853300	4.90659700	-0.98240700
H	-3.98058800	6.12602300	0.36320000
O	3.92331700	1.98923300	1.22194300
O	2.61121400	3.32913800	-0.93982100
C	4.68392900	4.37536600	-1.51623900
H	4.16244000	4.87560500	-2.33699400
C	5.97863000	3.06050400	0.61324700
H	6.44852900	2.53425200	1.44860300
C	6.70427200	3.92349000	-0.22606200
H	7.77141900	4.07848900	-0.04804500
C	6.05725400	4.57425800	-1.28383200
H	6.61766300	5.24328800	-1.94270700
C	-1.36297700	-2.94424100	0.24592300
H	-1.58516500	-3.86447800	-0.32827800
P	0.04954700	-1.96967200	-0.60484400
C	0.15277800	-2.75448800	-2.34539000
C	-1.24591600	-2.60789400	-2.98282700
H	-2.02657700	-3.17730500	-2.45310500
H	-1.56323200	-1.55153900	-3.03160300
H	-1.19931800	-2.99002300	-4.01840500
C	1.16611900	-1.97741200	-3.20812800
H	1.11034400	-2.36128400	-4.24314700
H	0.93309000	-0.89918600	-3.23589700
H	2.20109900	-2.10405600	-2.85785800
C	0.56118700	-4.23566000	-2.25749200
H	0.57134100	-4.66440000	-3.27611100
H	1.56994800	-4.35729600	-1.82975400

H	-0.14124400	-4.83934200	-1.65706800
C	1.23464700	-2.78288600	0.55530500
C	2.65301200	-2.83862600	0.60572800
C	0.49286100	-3.39757900	1.59105700
C	3.25601900	-3.52578700	1.68514500
C	1.09550600	-4.06534300	2.66461400
C	2.49316800	-4.12391100	2.69735800
H	4.34799500	-3.56854000	1.73189100
H	0.47349700	-4.53859400	3.42885400
H	2.99403800	-4.64627800	3.51834800
O	-0.87639800	-3.32869500	1.54583000
C	3.55099800	-2.22687600	-0.41186100
C	4.63693200	-2.96591500	-0.93186100
C	3.37925000	-0.89665300	-0.84454300
C	5.51650300	-2.39052500	-1.85795400
H	4.77615100	-4.00636300	-0.62030100
C	4.26243600	-0.31718100	-1.76508500
H	2.52970800	-0.32294200	-0.46198100
C	5.33501200	-1.06315400	-2.27527300
H	6.34402500	-2.98388800	-2.25930500
H	4.10969800	0.71706800	-2.09152700
H	6.02308200	-0.61457400	-2.99843700
H	-1.24696300	0.43149000	-1.66808400
C	1.88511100	1.00494800	1.94161900
O	0.82768700	0.43007200	1.58977900
O	2.52358500	0.74600100	3.08155600
C	1.98335500	-0.31844200	3.90856300
H	1.94553000	-1.26080800	3.34078600
H	2.68007600	-0.39475800	4.75236800
H	0.97614400	-0.04712500	4.26064200