Electronic Supplementary Information

Ir(III)-Catalyzed [4+2] Cyclization of Azobenzene and Diazotized Meldrum's Acid for the Synthesis of Cinnolin-3(2*H*)-one

Gongutri Borah[a,b,] and Pitambar Patel[a,b,]*

[a] Chemical Science and Technology Division, CSIR-North East Institute of Science and Technology, Jorhat, India-785006.

[b] Academy of Scientific and Innovative Research (AcSIR), CSIR-North East Institute of Science and Technology, Jorhat, India-785006.

Email: patel.pitambar@gmail.com

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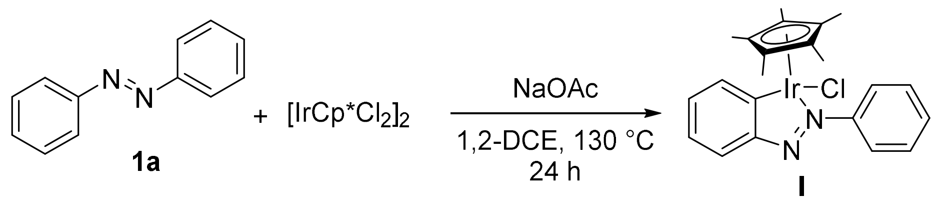
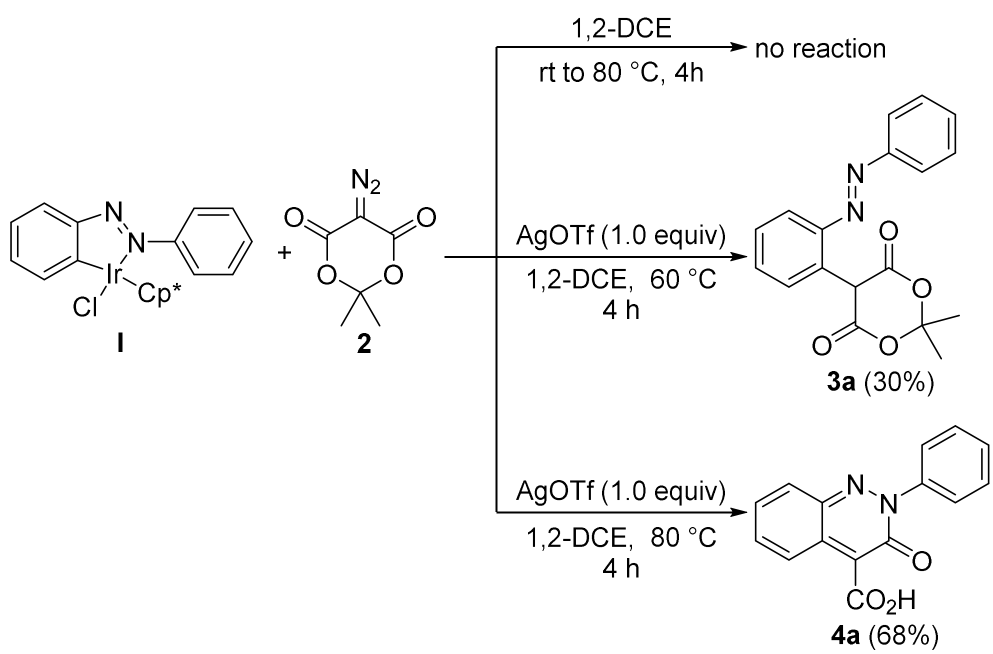
1. Mechanistic Studies

1.1.1. Preparation for Iridacyclic Intermediate I.



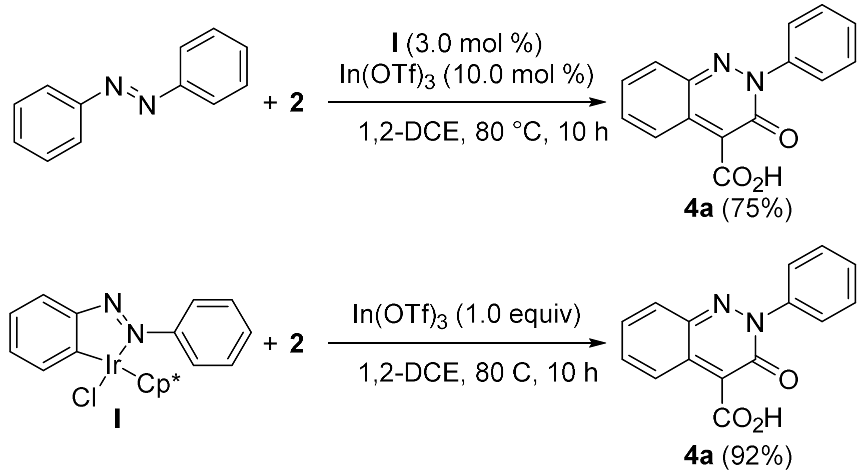
Azobenzene (73.0 mg, 0.4 mmol), [Cp*IrCl_2]$_2$ (160 mg, 0.2 mmol), and NaOAc (66.0 mg, 0.8 mmol) was taken in a 15 mL sealed tube and DCE (5 mL) was added under nitrogen atmosphere. Then the tube was sealed and the mixture was stirred at 130 °C for 24 h. After completion, the reaction mixture was cooled to room temperature and filtered over a pad of celite, followed by washing of the celite pad with CH_2Cl_2 (5 mL x 2). The combined organic phase was concentrated under reduced pressure and the residue was purified by column chromatography to afford 140 mg (64%) of iridacyclic complex **I** as a dark greenish solid. ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.26 (dd, *J* = 7.8, 1.2 Hz, 1H), 8.01 – 7.73 (m, 3H), 7.52 – 7.46 (m, 2H), 7.45 – 7.39 (m, 1H), 7.25 (dt, *J* = 7.5, 1.9 Hz, 1H), 7.21 – 7.15 (m, 1H), 1.55 (s, 15H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 168.0, 165.4, 154.9, 134.3, 132.4, 129.7, 129.4, 128.7, 123.4, 123.3, 92.6, 8.8 ppm. HRMS (ESI+): calcd. for $C_{22}H_{25}ClIrN_2$ $[M+H]^+$: 545.1336, found: 545.1332.

1.1.2. Reaction of I with diazocompounds



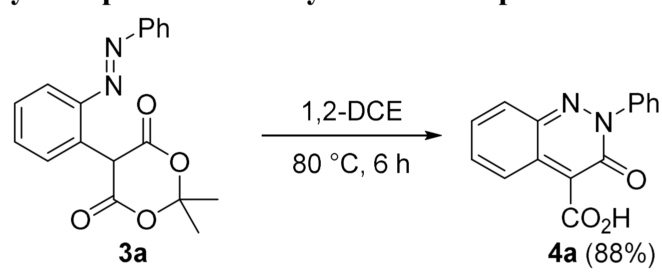
Scheme S1. Initial study using stoichiometric amount of iridacyclic complex **I** and diazo compound **2**. All the reactions were carried using **I** (20 mg), **2** (7 mg, 1.1 equiv) and additive (1 equiv) in 1,2-DCE (0.5 mL).

1.1.2. Annulation of azobenzene using complex I both as catalyst and substrate



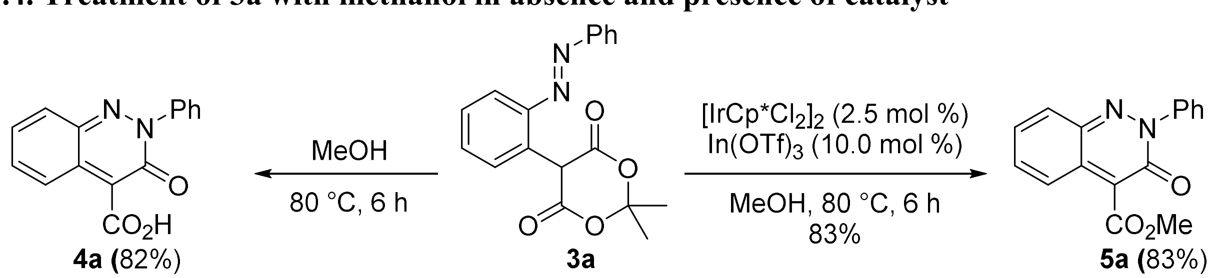
Scheme S2. Synthesis of cinnolin-3(2*H*)-one-4-carboxylic acid derivative **4a** using iridacyclic complex **I** as catalyst and substrate.

1.2. Conversion of alkylated product 3a to cyclic acid compound 4a



To an oven dried reaction vial, alkylated compound **3a** (20.0 mg) was added followed by 1,2-dichloroethane (1 mL) under atmospheric conditions and the reaction vial was stirred at 80 °C in a preheated heating block for 6 hours. Next, the reaction mixture was cooled to room temperature and the solvent was removed under reduced pressure and the residue was purified by column chromatography to obtain the annulated product **4a** (14.5 mg, 88%) as orange solid.

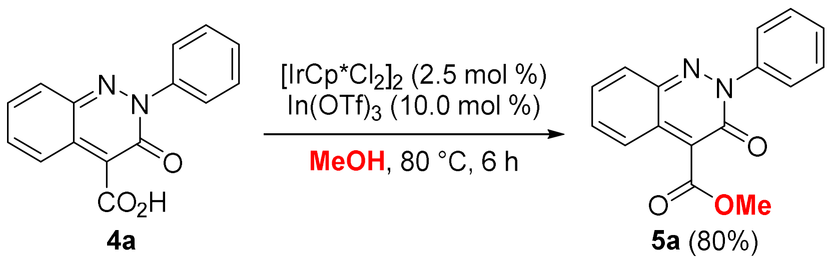
1.4. Treatment of 3a with methanol in absence and presence of catalyst



In absence of catalyst: To an oven dried reaction vial, alkylated compound **3a** (20.0 mg) was added followed by methanol (1 mL) under atmospheric conditions and the reaction vial was stirred at 80 °C in a preheated heating block for 6 hours. Next, the reaction mixture was cooled to room temperature and the solvent was removed under reduced pressure and the residue was purified by column chromatography to obtain the annulated product **4a** (13.5 mg, 82%) as orange solid.

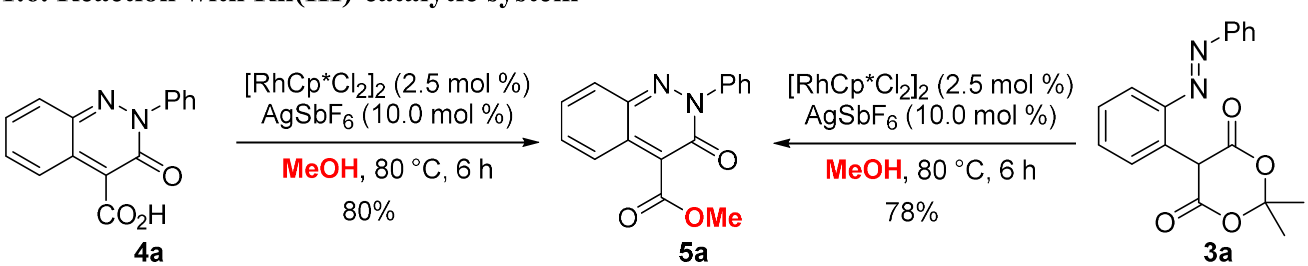
In presence of catalyst: To an oven dried reaction vial, alkylated product **3a** (25.0 mg, 0.08 mmol) was added along with $[IrCp^*Cl_2]_2$ (1.5 mg, 2.5 mol%), $In(OTf)_3$ (4.3 mg, 10.0 mol %), and methanol (1 mL) under atmospheric conditions and the reaction vial was stirred at 80 °C in a preheated heating block for 6 hour. Next, the reaction mixture was cooled to room temperature and filtered through a celite pad followed by washing of the celite pad with ethyl acetate (5 mL x 3). The filtrate was concentrated under reduce pressure and the residue was purified by column chromatography to obtain the methyl ester product **5a** (18.0 mg, 83%) as orange solid.

1.5. Conversion of carboxylic acid 4a to its methyl ester 5a under Ir(III)-catalytic conditions using methanol as solvent.



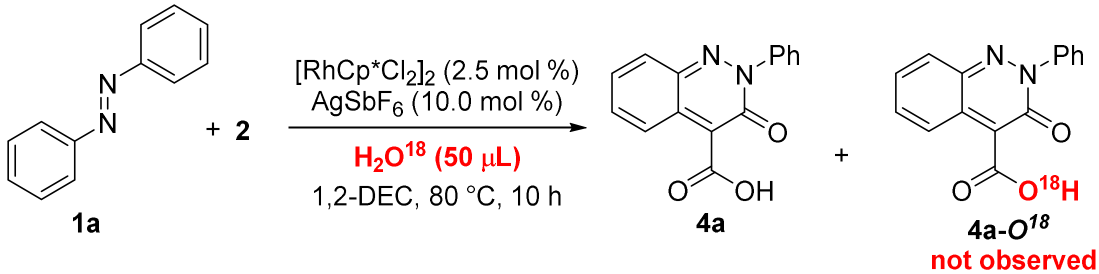
To an oven dried reaction vial, acid compound **4a** (26.7 mg, 0.1 mmol) was added along with $[IrCp^*Cl_2]_2$ (2.0 mg, 2.5 mol%), $In(OTf)_3$ (5.6 mg, 10.0 mol%), and methanol (1 mL) under atmospheric conditions and the reaction vial was stirred at 80 °C in a preheated heating block for 6 hour. Next, the reaction mixture was cooled to room temperature and filtered through a celite pad followed by washing of the celite pad with ethyl acetate (5 mL x 3). The filtrate was concentrated under reduce pressure and the residue was purified by column chromatography to obtain the methyl ester product **5a** (22.5 mg, 80%) as orange solid. The spectral data were well agreement with the previously synthesized compound.

1.6. Reaction with Rh(III)-catalytic system



Similar observation were observed with Rh(III)-catalytic system. Both alkylated product **3a** and carboxylic acid **4a** converted to the ester derivative **5a** under previously reported Rh(III)-catalytic conditions.

1.7. Reaction in presence of H_2O^{18}

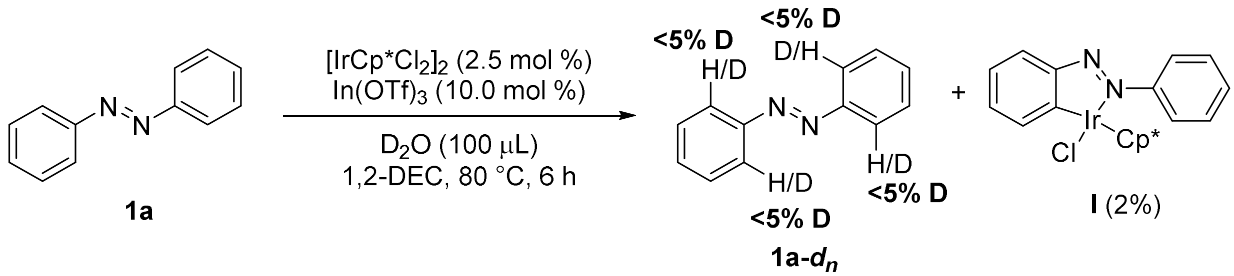


Azobenzene **1a** (18.3 mg, 0.1 mmol) was taken in an oven dried 3mL reaction vial along with diazotized Meldrum's acid (**2**, 18.8 mg, 0.11 mmol), $[IrCp^*Cl_2]_2$ (2.0 mg, 2.5 mol%), $In(OTf)_3$ (5.6 mg, 10.0 mol%), H_2O^{18} (50 μL) and 1,2-dichloroethane (1 mL) under atmospheric conditions and the reaction vial was stirred at 80 °C in a preheated heating block for 10 hour. Next the reaction mixture was cooled to room temperature and filtered through a celite pad followed by washing of the celite pad with ethyl acetate (5 mL x 3). The combined filtrate was concentrated under reduced pressure and the residue was purified by column chromatography to obtain **4a-O¹⁸**. The HRMS spectra of the compound did not shows any O^{18} incorporation.

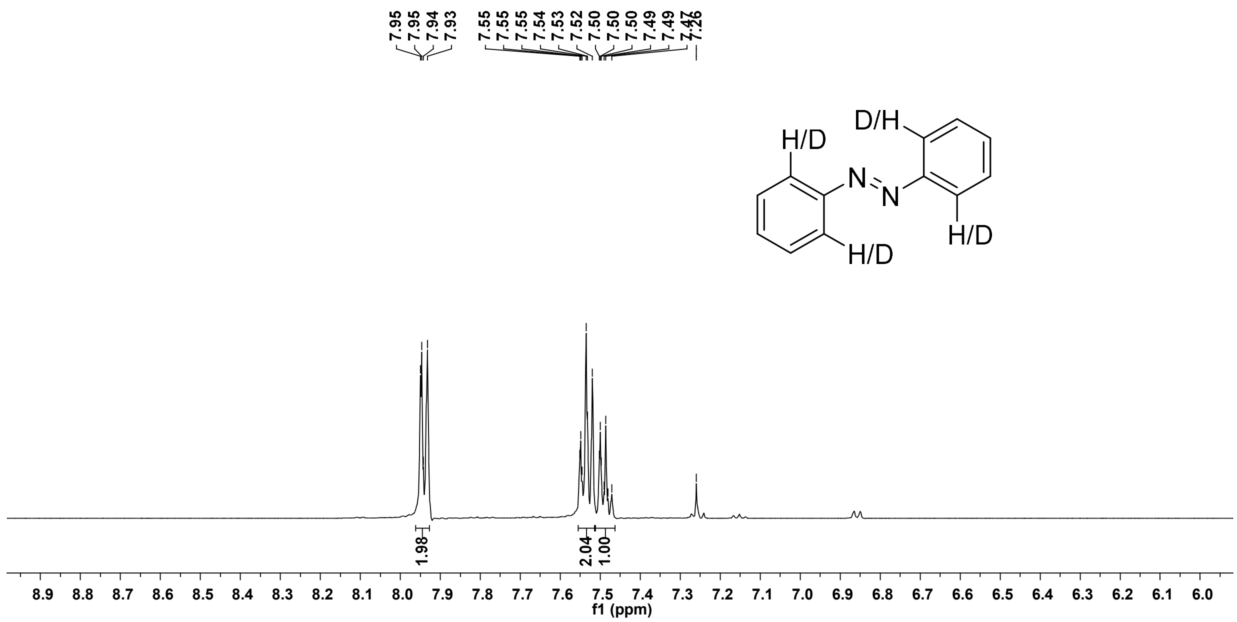
HRMS spectra of compound **5a-O¹⁸**

1.8. Deuterium Scrambling Experiments

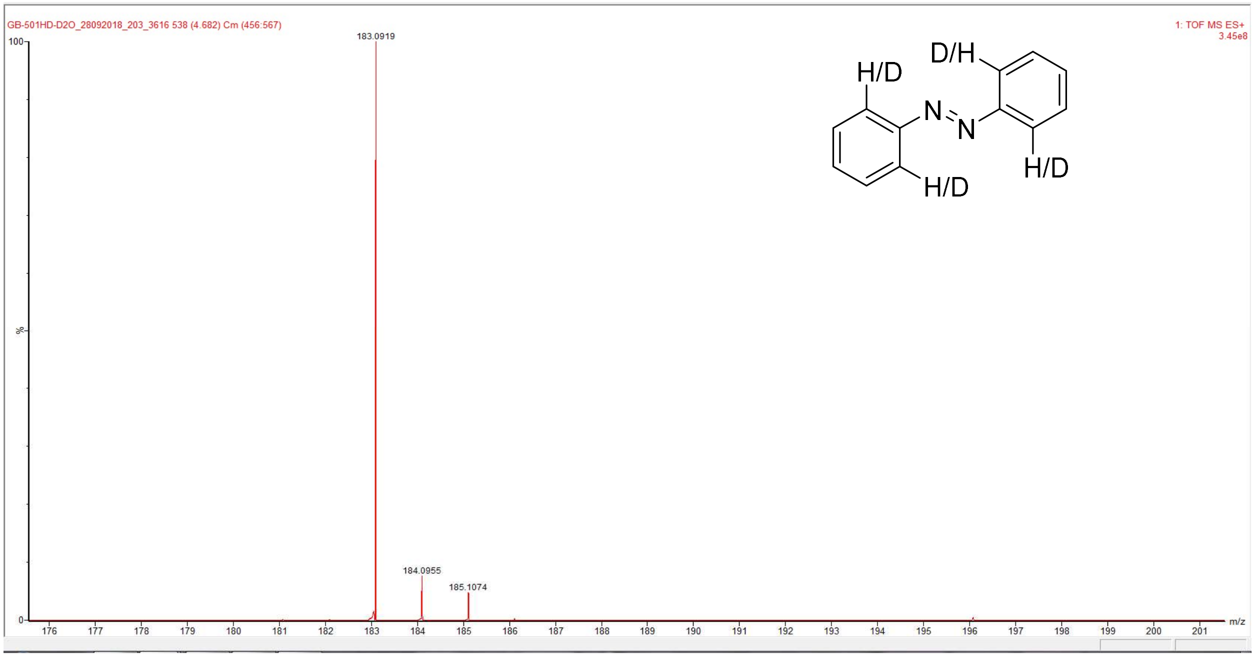
1.8.1. Deuterium scrambling in absence of diazo compound



Azobenzene **1a** (18.3 mg, 0.1 mmol) was taken in an oven dried 3mL reaction vial along with $[IrCp^*Cl_2]_2$ (2.0 mg, 2.5 mol%), $In(OTf)_3$ (5.6 mg, 10.0 mol%), D_2O (100 μL) and 1,2-dichloroethane (0.75 mL) under atmospheric conditions and the reaction vial was stirred at 80 °C in a preheated heating block for 6 hour. Next, the reaction mixture was cooled to room temperature and filtered through a celite pad followed by washing of the celite pad with ethyl acetate (5 mL x 3). The filtrate was concentrated under reduced pressure and the residue was purified by column chromatography before analyzing with ^{1}H NMR, which shows <5% deuterium scrambling at *ortho*-position of **1a**, suggesting irreversible C–H activation.

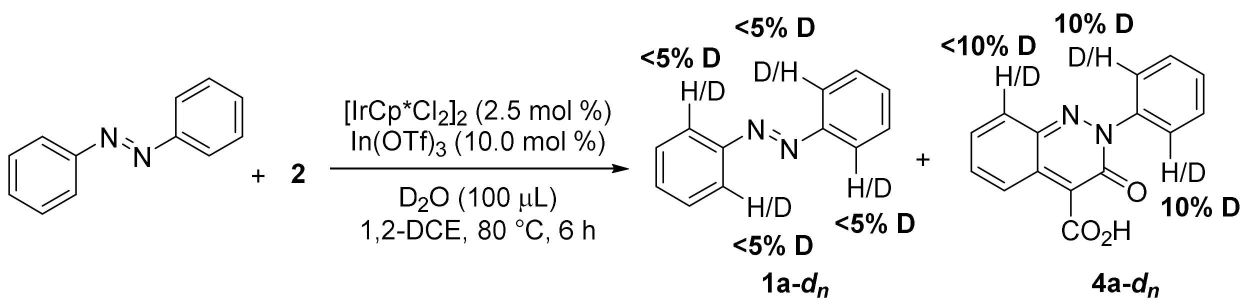


^{1}H NMR of **1a-*d*$_n$** in $CDCl_3$

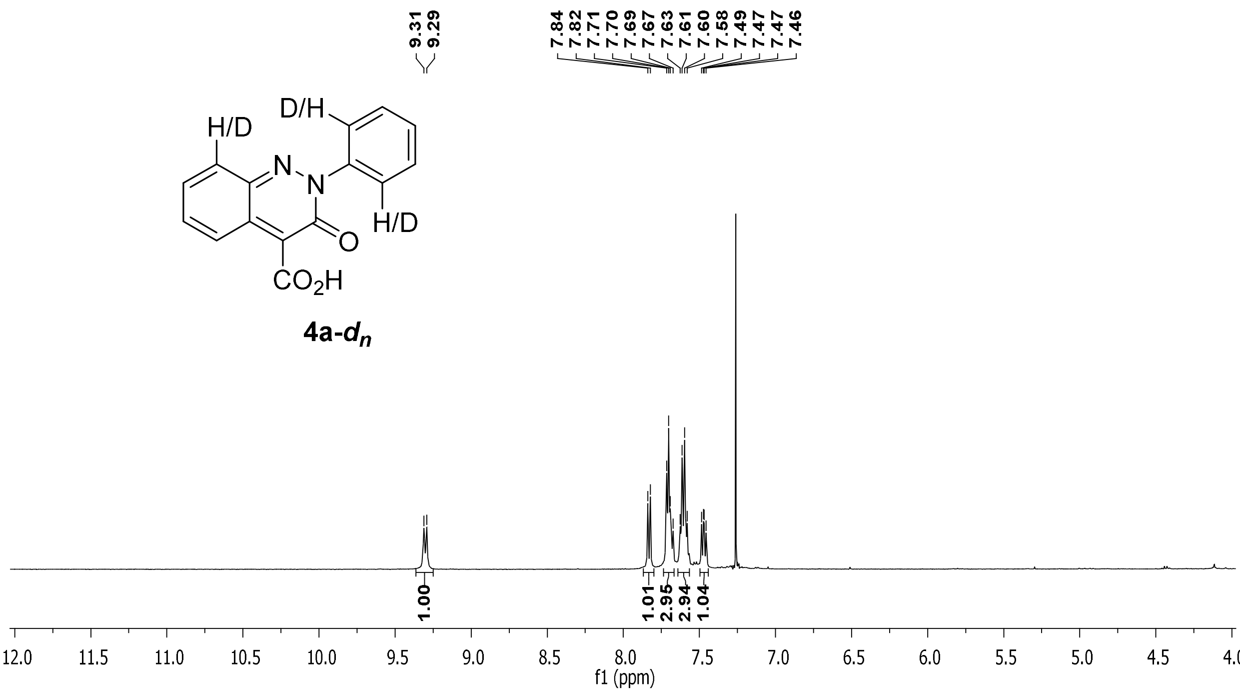


Mass (ESI) spectra of compound **1a-*dn***

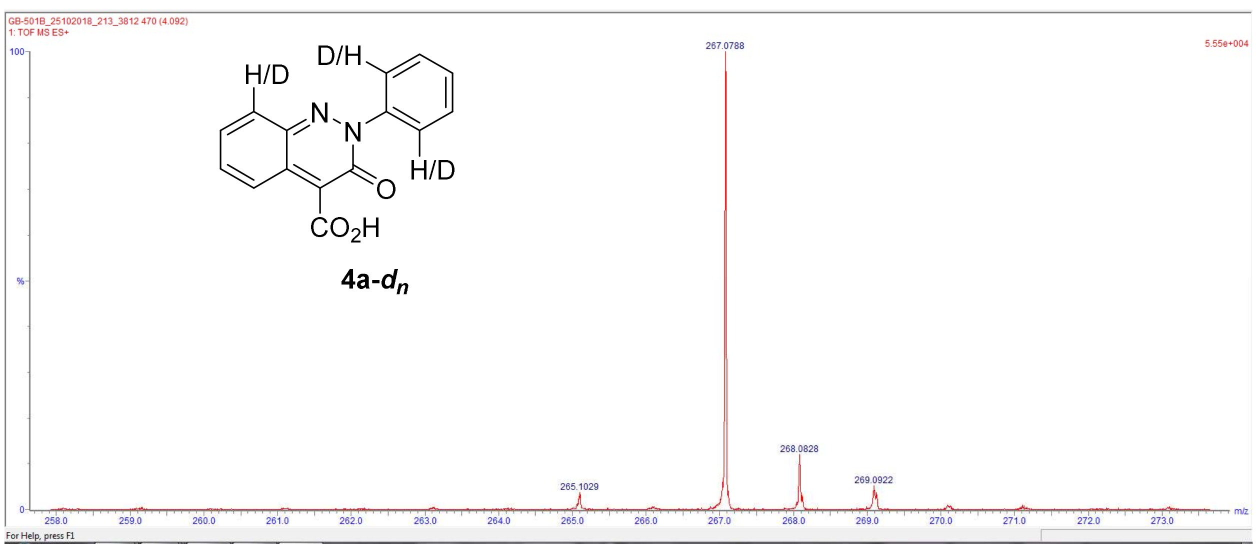
1.8.2. Deuterium scrambling in presence of diazo compound



Azobenzene **1a** (18.3 mg, 0.1 mmol) was taken in an oven dried 3mL reaction vial along with diazotized Meldrum's acid (**2**, 18.7 mg, 0.11 mmol), $[IrCp^*Cl_2]_2$ (2.0 mg, 2.5 mol%), $In(OTf)_3$ (5.6 mg, 10.0 mol%), D_2O (0.1 mL) and 1,2-DCE (1 mL) under atmospheric conditions and the reaction vial was stirred at 80 °C in a preheated heating block for 6 hour. The reaction mixture was cooled to room temperature and filtered through a celite pad followed by washing of the celite pad with ethyl acetate (5 mL x 3). The combined filtrate was concentrated under reduced pressure and the residue was purified by column chromatography to obtain the pure **1a-*dn*** and **4a-*dn***. The ^1H NMR spectra and HRMS spectra shows <10% of deuterium scrambling, which indicate irreversible C–H bond cleavage.

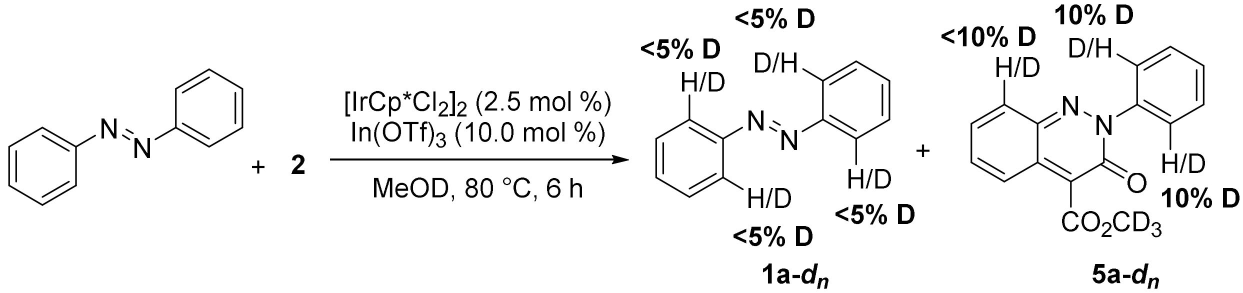


^{1}H NMR of **4a-*d*$_n$** in $CDCl_3$

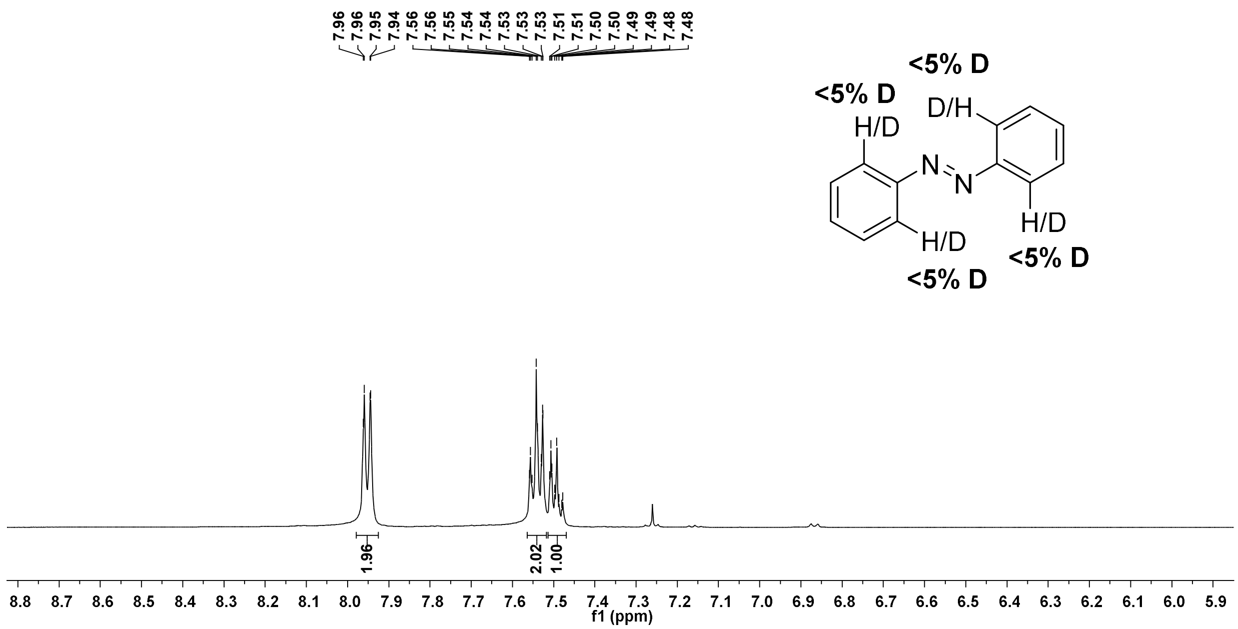


Mass (ESI) spectra of compound **4a-*d*$_n$**

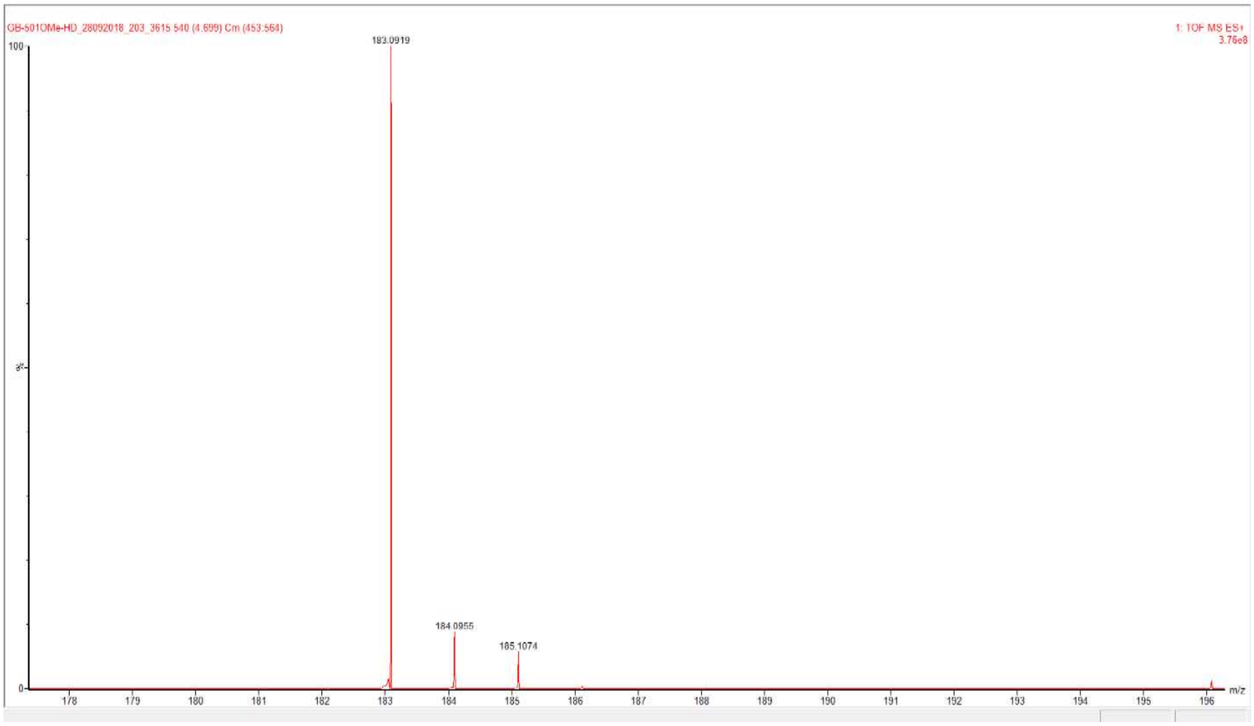
1.8.3. Deuterium scrambling in presence of diazo compound in CD_3OD



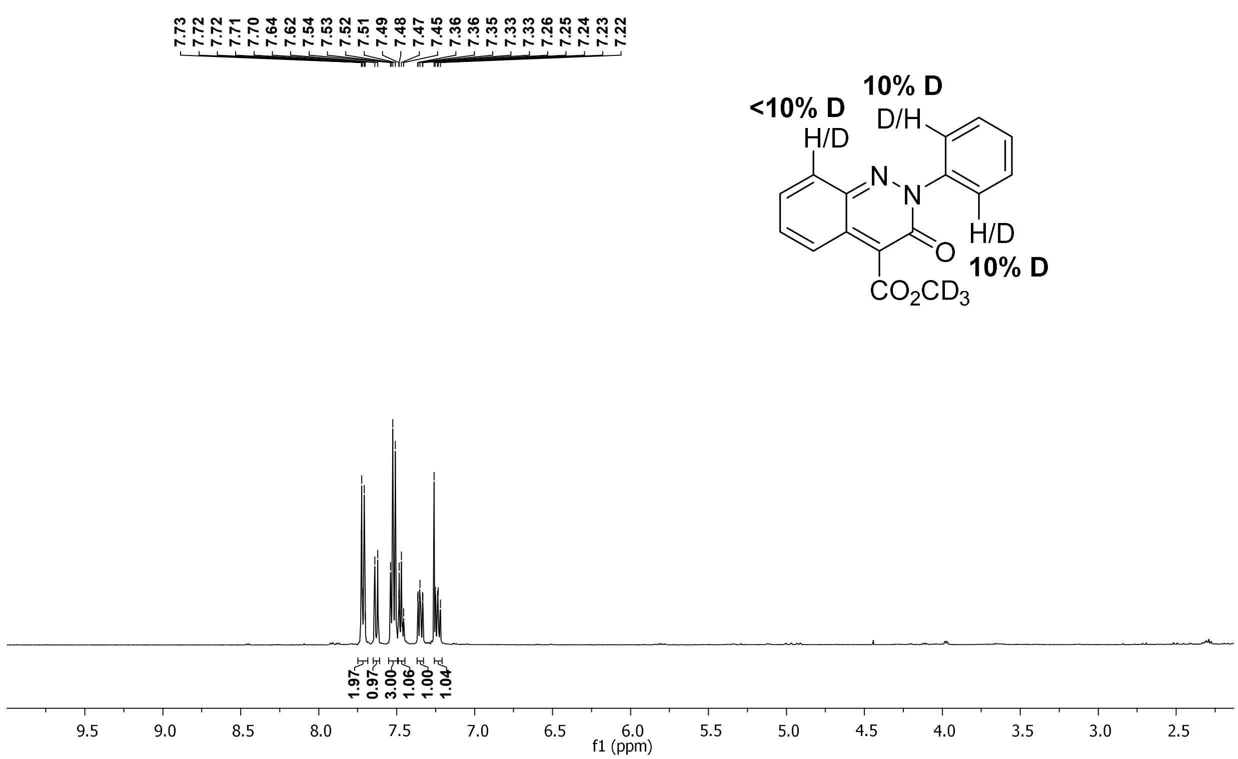
Azobenzene **1a** (18.3 mg, 0.1 mmol) was taken in an oven dried 3mL reaction vial along with diazotized Meldrum's acid (**2**, 18.7 mg, 0.11 mmol), $[IrCp^*Cl_2]_2$ (2.0 mg, 2.5 mol%), $In(OTf)_3$ (5.6 mg, 10.0 mol%), CD_3OD (1 mL) under atmospheric conditions and the reaction vial was stirred at 80 °C in a preheated heating block for 6 hour. The reaction mixture was cooled to room temperature and filtered through a celite pad followed by washing of the celite pad with ethyl acetate (5 mL x 3). The combined filtrate was concentrated under reduced pressure and the residue was purified by column chromatography to obtain the pure **1a-*d*$_n$** and **5a-*d*$_n$**. The ^1H NMR spectra of both the shows <5% of deuterium scrambling, which indicate irreversible C–H bond cleavage.



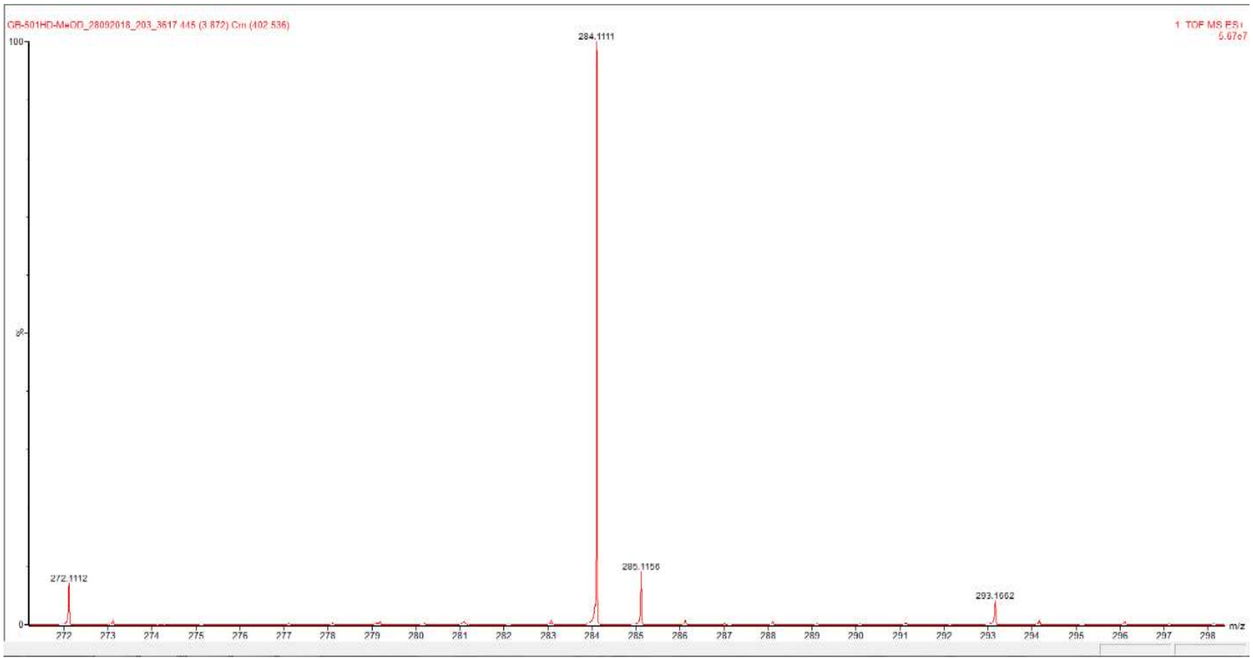
^1H NMR of **1a-*d*$_n$** in $CDCl_3$



Mass (ESI) spectra of compound **1a-*d*$_n$**

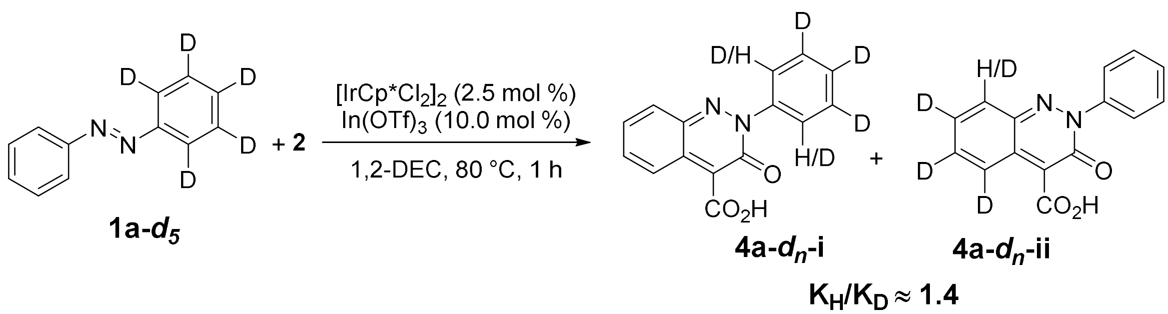


[1]H NMR of **5a-*d*$_n$** in $CDCl_3$

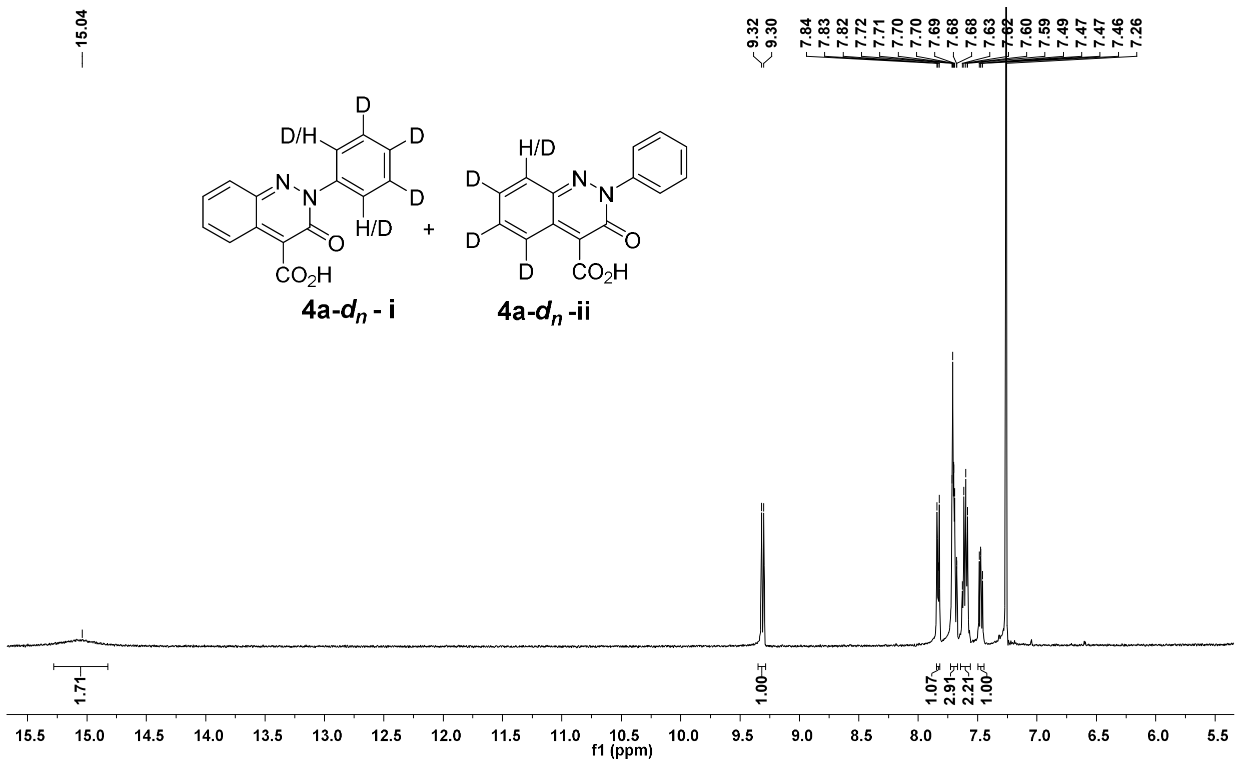


Mass (ESI) spectra of compound **5a-*dn***

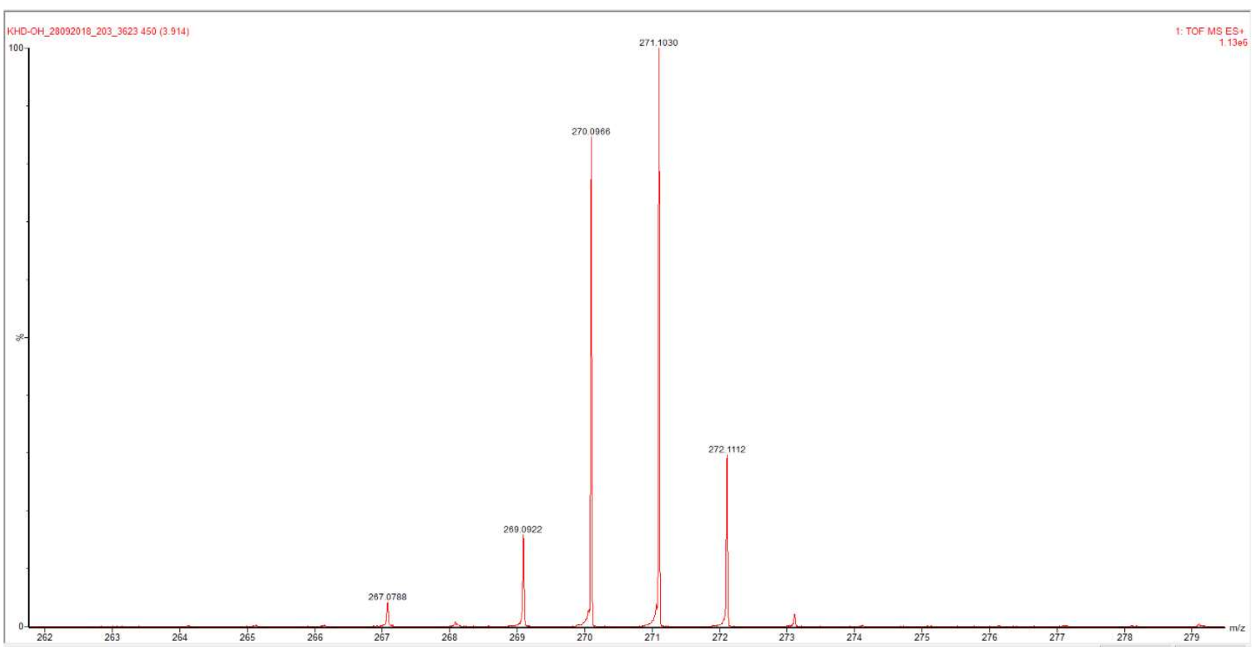
1.9. Intramolecular Kinetic Isotope Effect Studies



Azobenzene **1a-*d5*** (19.0 mg, 0.1 mmol) was taken in an oven dried 3 mL reaction vial along with diazotized Meldrum's acid (**2**, 18.7 mg, 0.11 mmol), $[IrCp^*Cl_2]_2$ (2.0 mg, 2.5 mol%), $In(OTf)_3$ (5.6 mg, 10.0 mol%) and 1,2-dichloroethane (1 mL) under atmospheric conditions and the reaction vial was stirred at 90 °C in a preheated heating block for 1 hour. Next, the reaction mixture was cooled to room temperature and filtered through a celite pad followed by washing of the celite pad with ethyl acetate (5 mL x 3). The combined filtrate was concentrated under reduce pressure and the residue was purified by column chromatography to obtain the 8 mg of pure **4a-*dn***. The ^{1}H NMR analysis of the compound shows $\boldsymbol{K_H/K_D \approx 1.4}$.



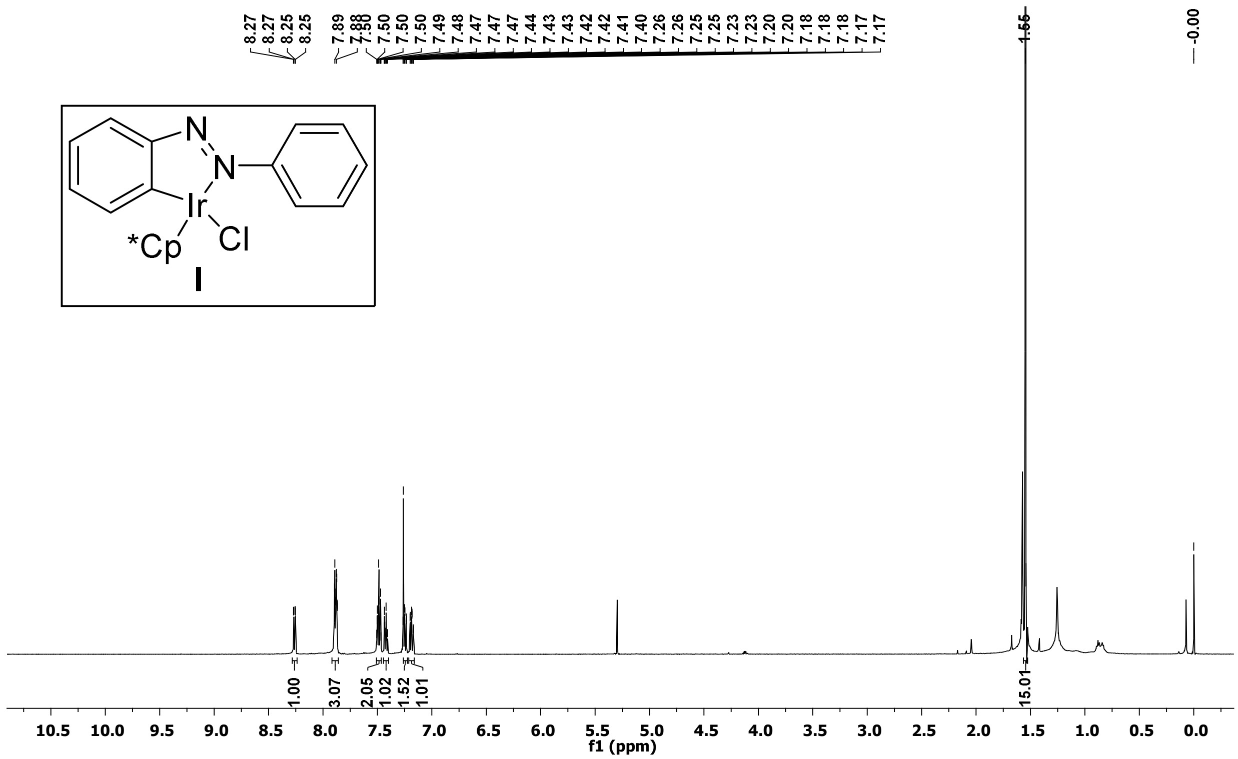
[1]H spectra for **4a-*d*$_n$** in $CDCl_3$

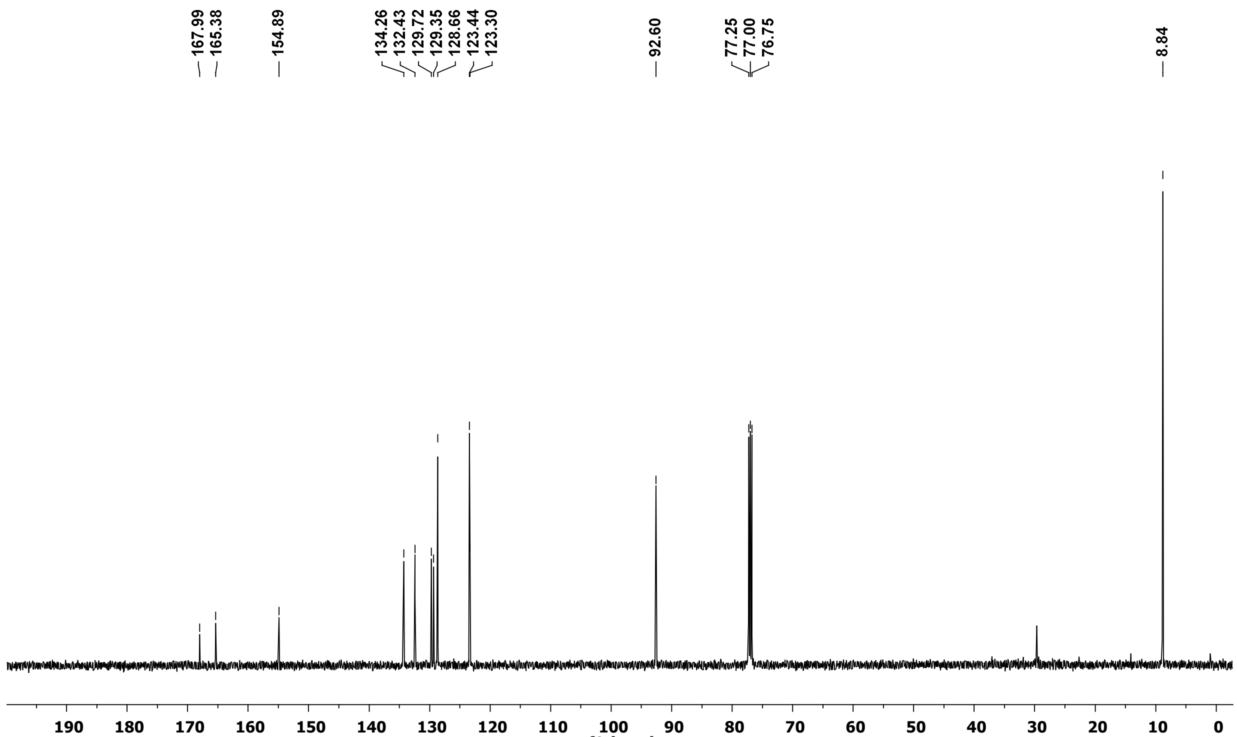


Mass (ESI) spectra of compound **4a-*d*$_n$**

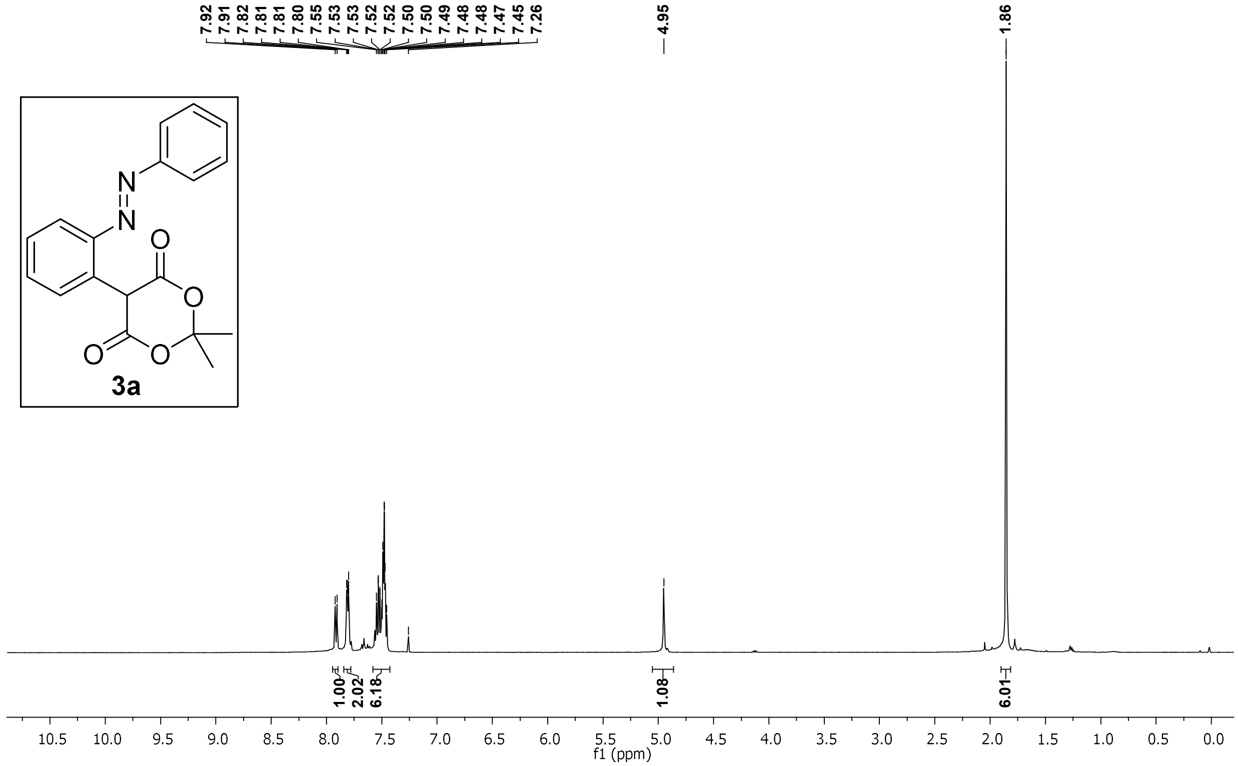
^{1}H and ^{13}C Spectra of all compounds

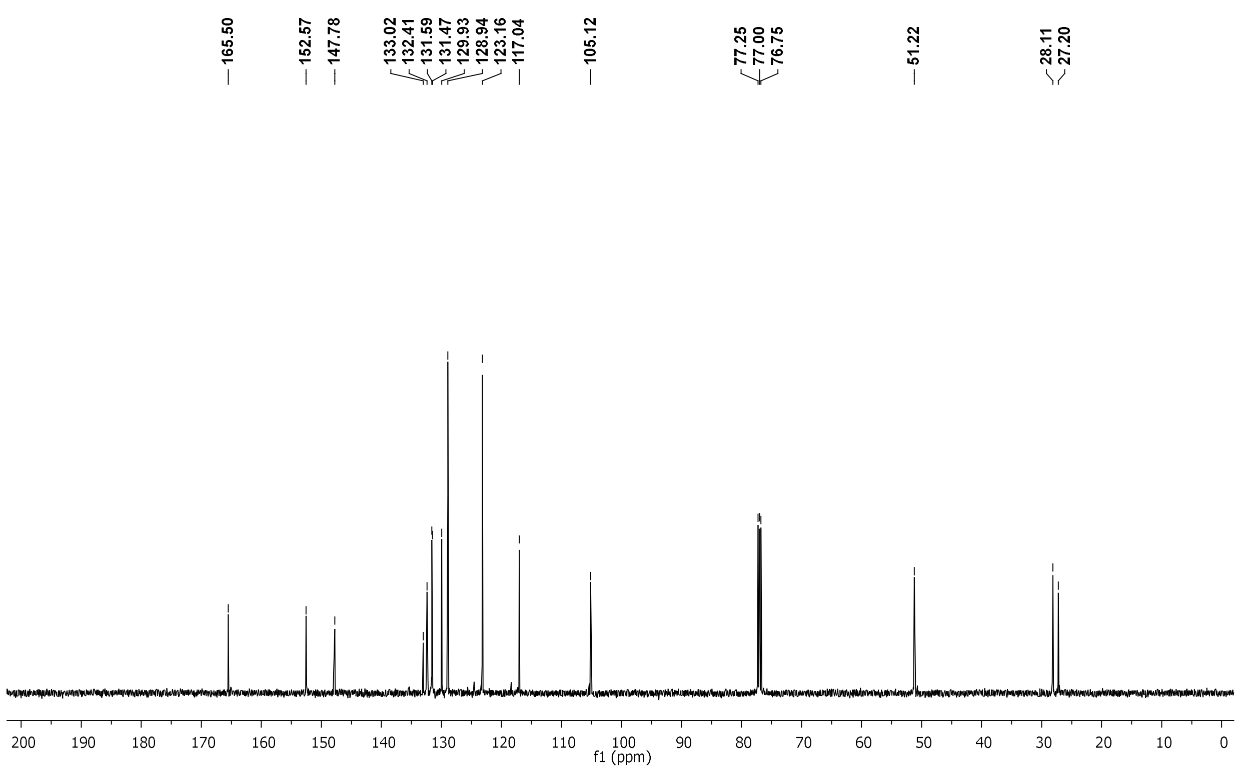
^{1}H and ^{13}C NMR of Iridacyclic complex I in $CDCl_3$



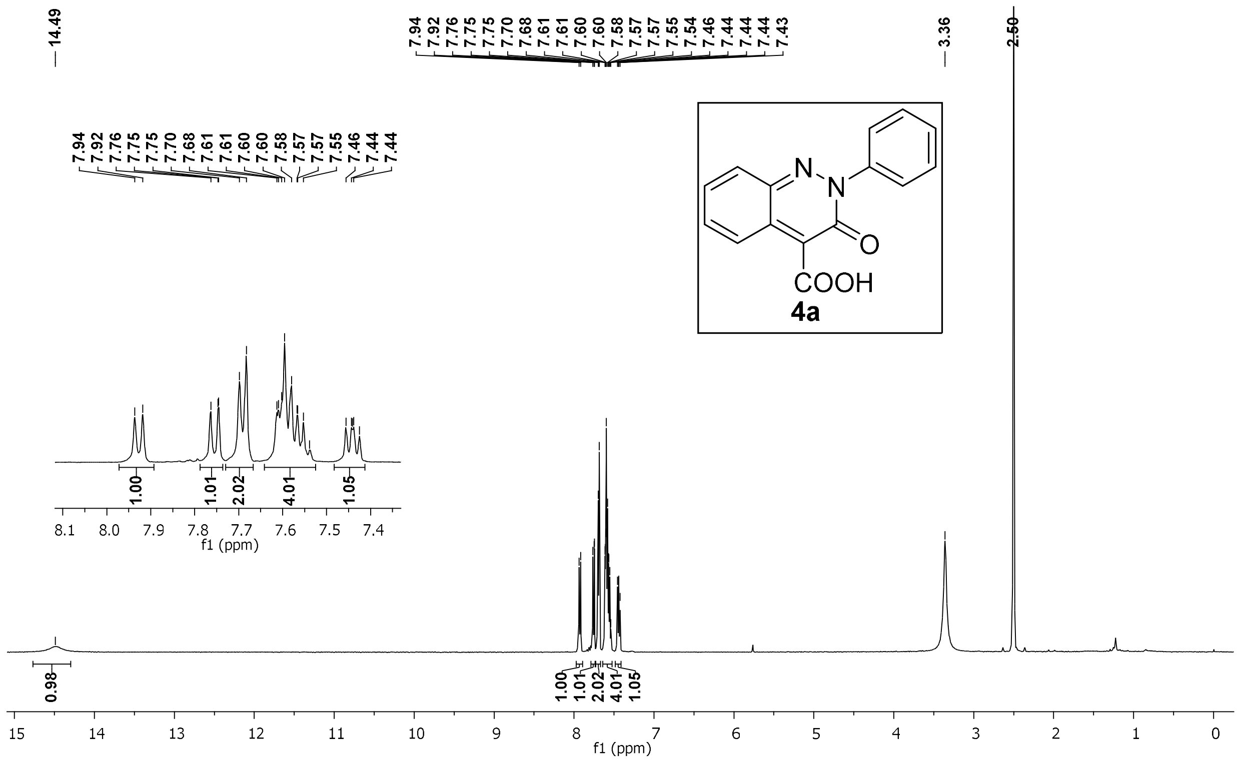


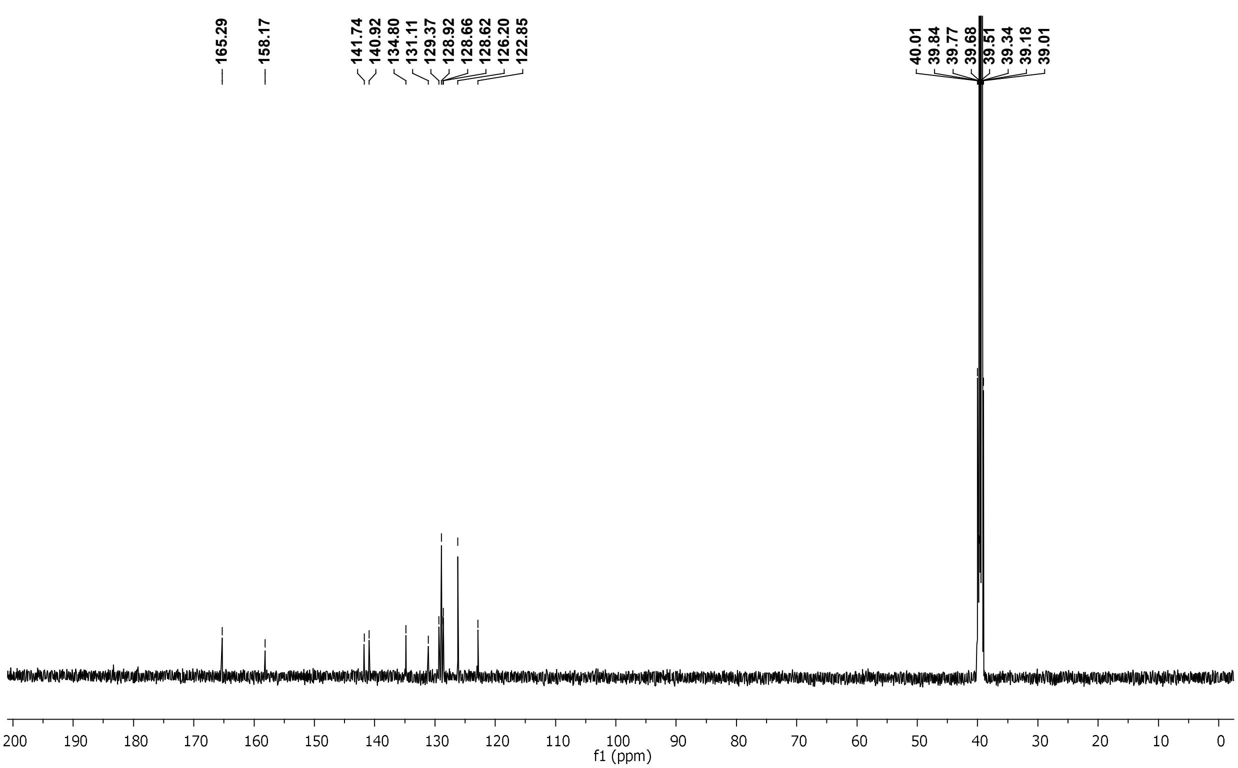
^{1}H and ^{13}C NMR of Compound 3a in $CDCl_3$



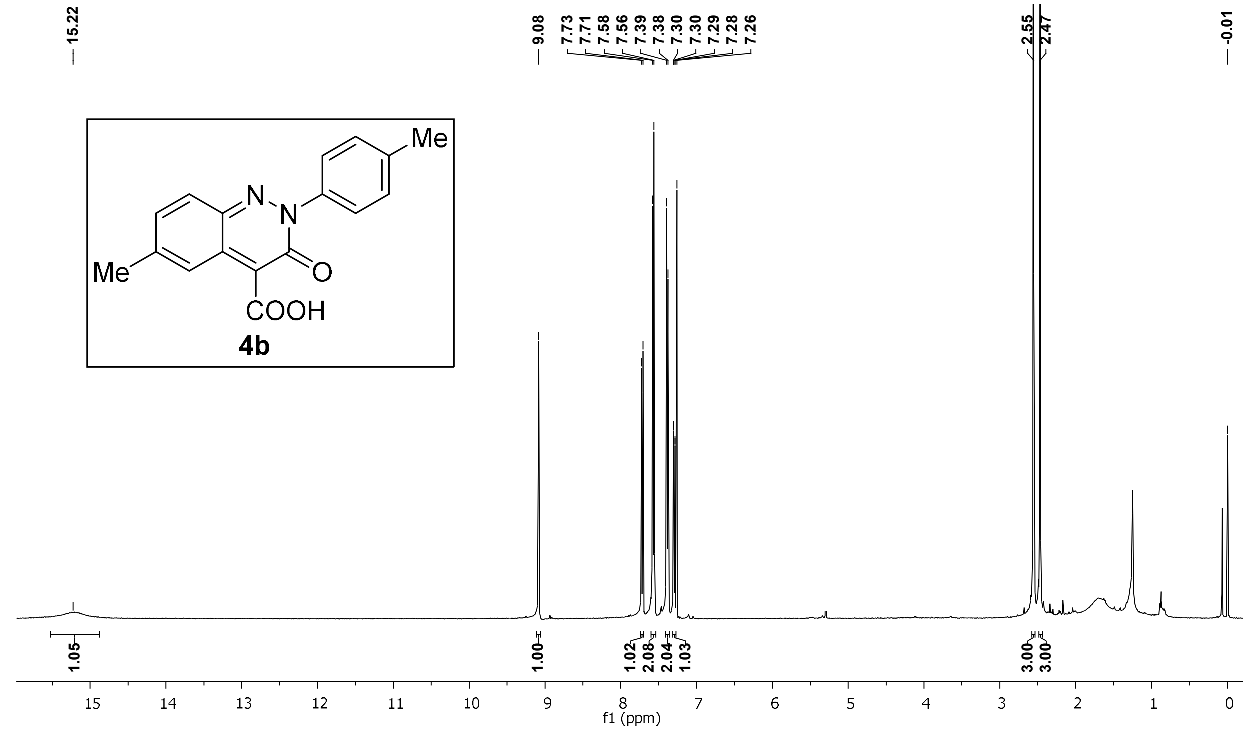


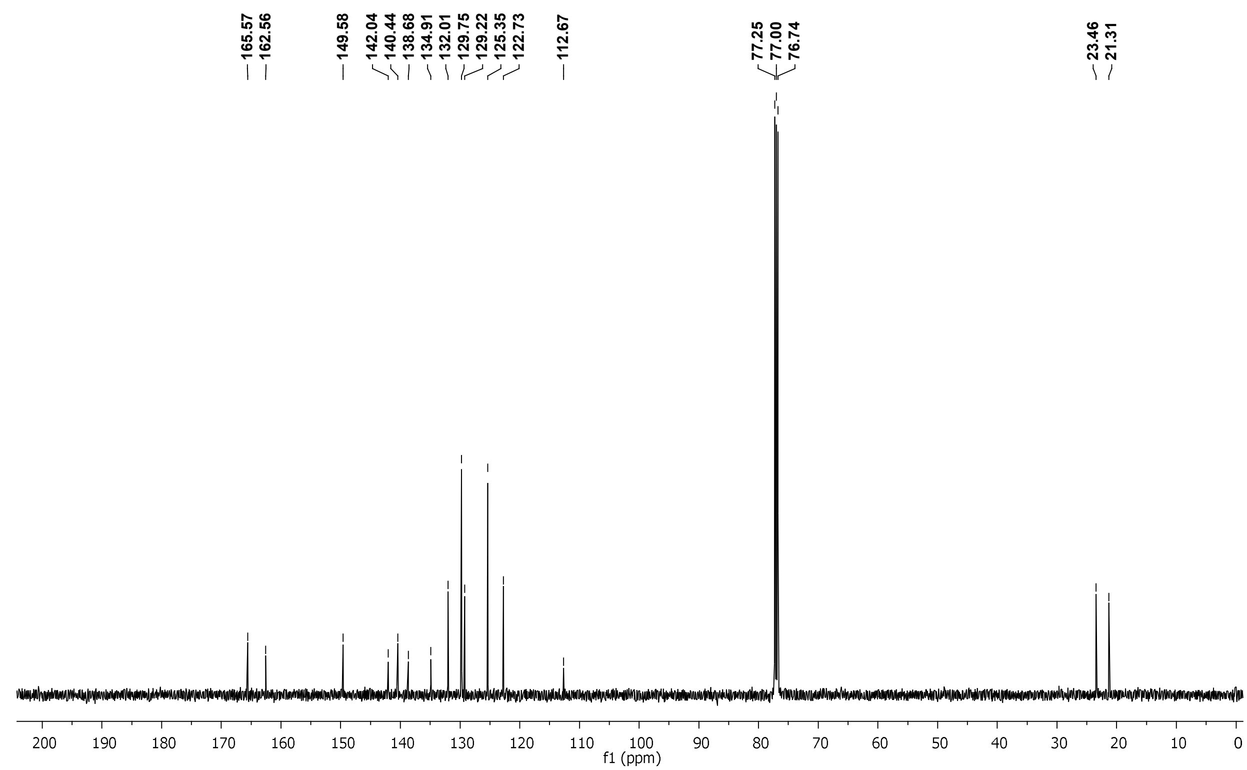
^{1}H and ^{13}C NMR of Compound 4a in DMSO-d_6



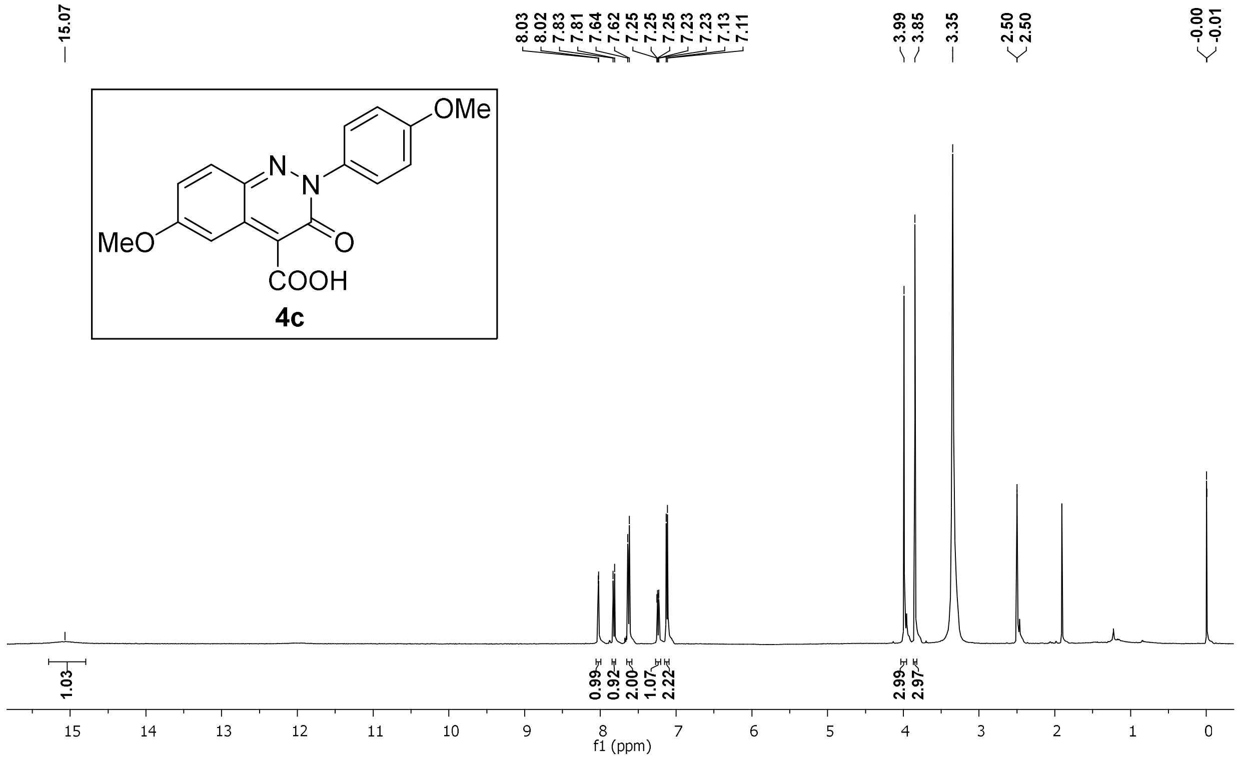


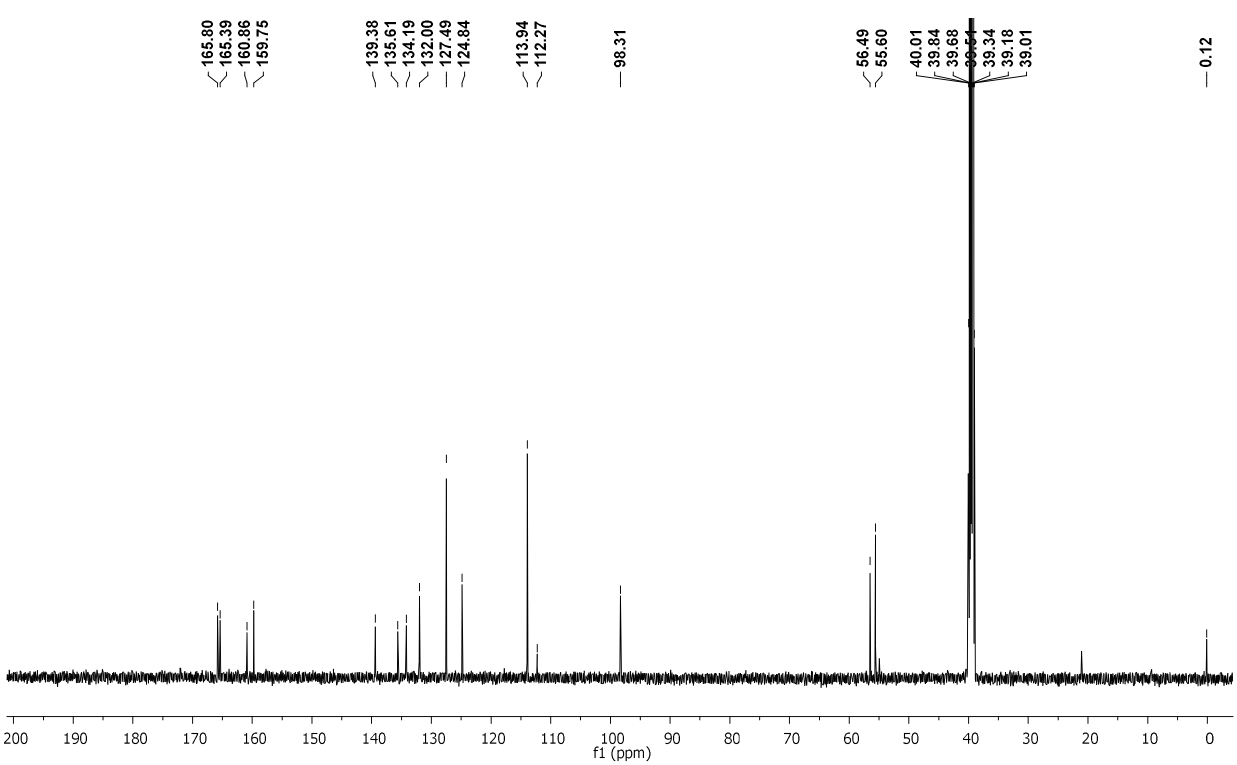
^{1}H and ^{13}C NMR of Compound 4b in $CDCl_3$



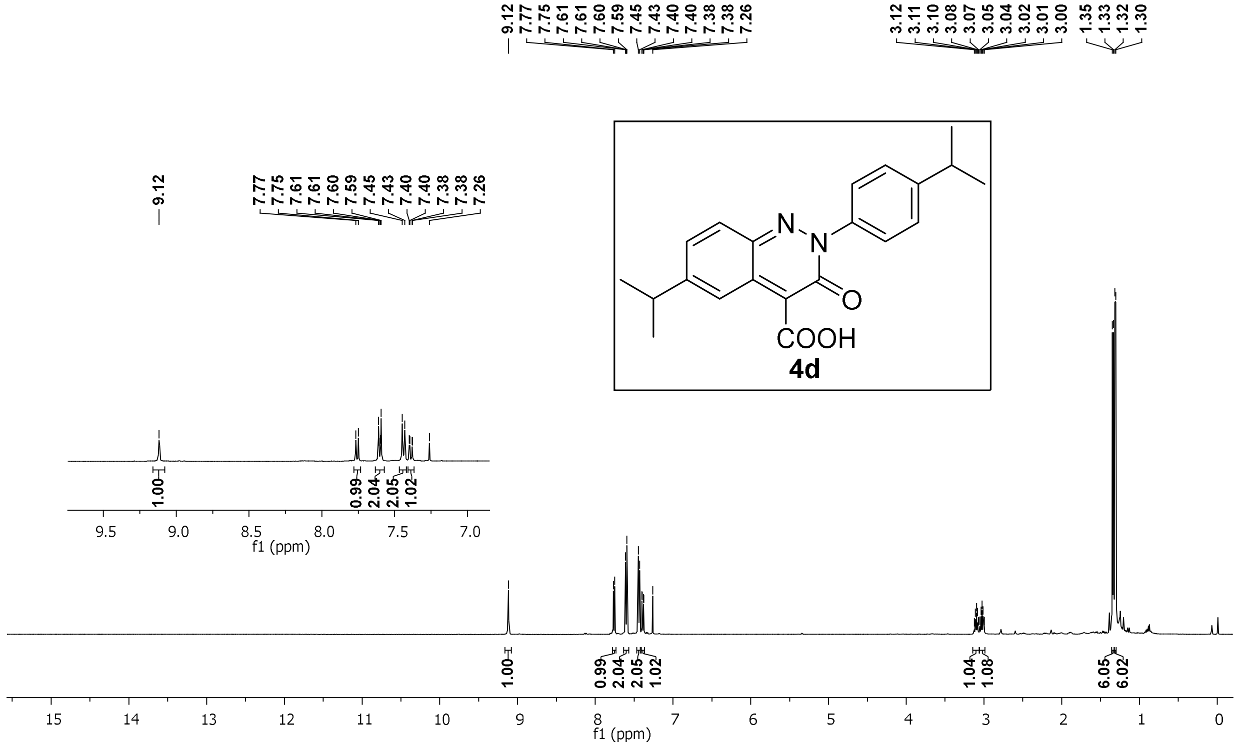


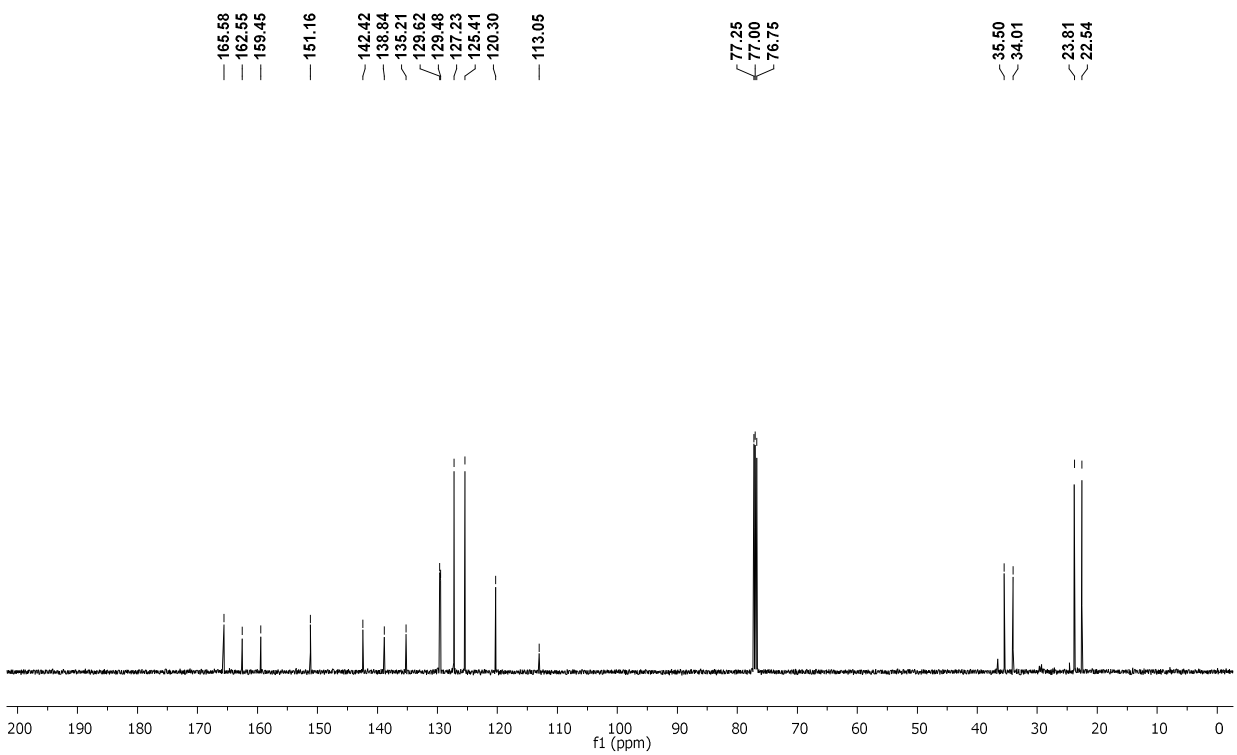
[1]H and [13]C NMR of Compound 4c in DMSO-*d*$_6$



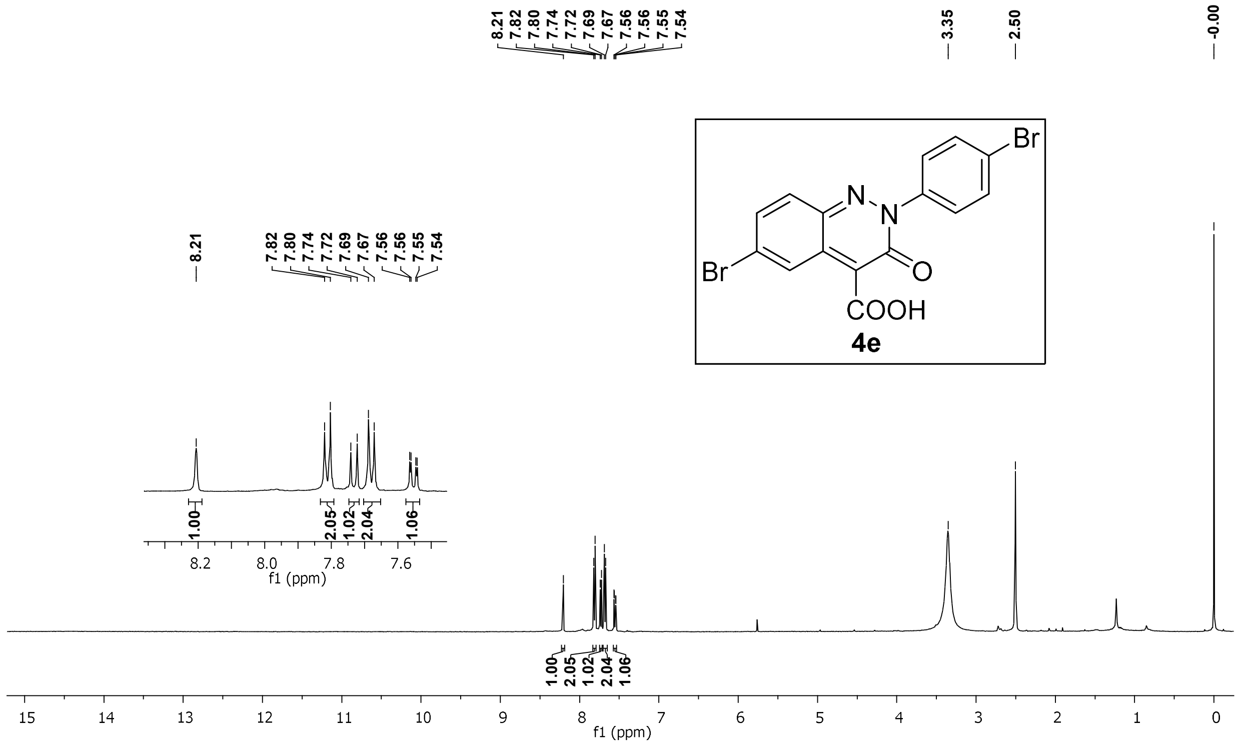


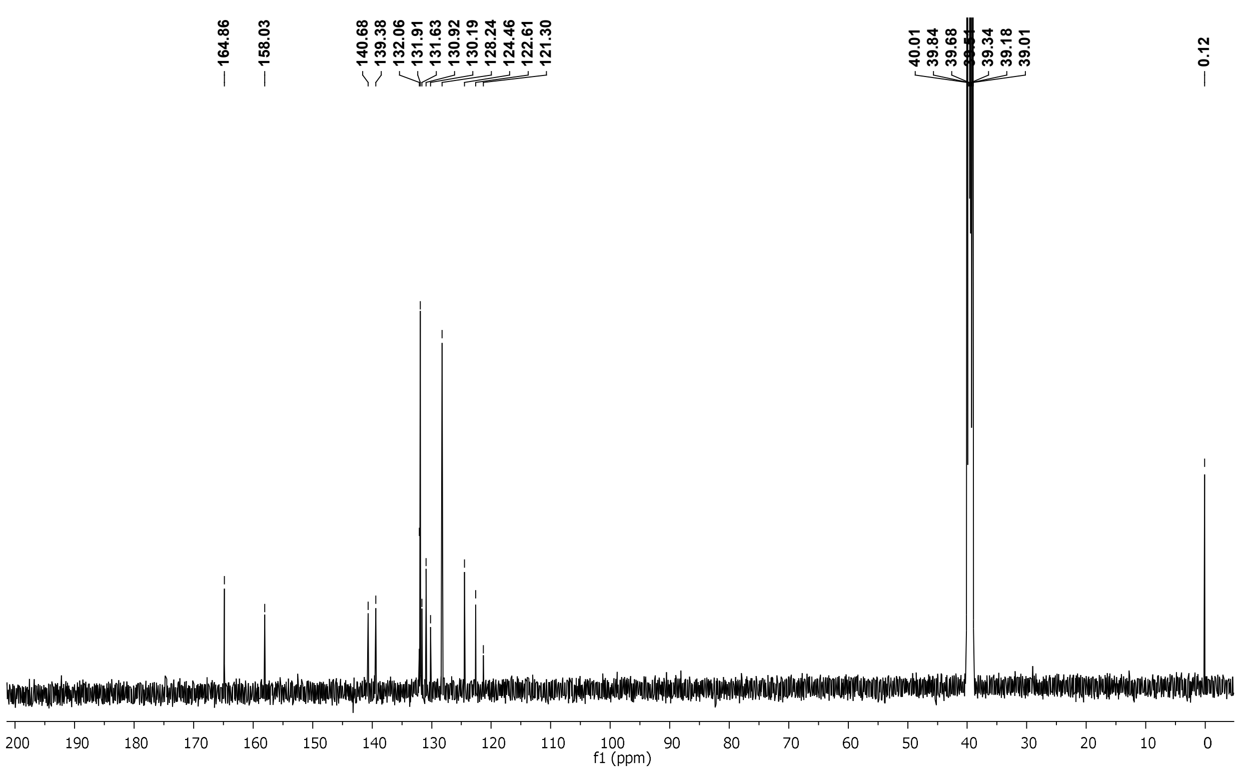
[1]H and [13]C NMR of Compound 4d in $CDCl_3$



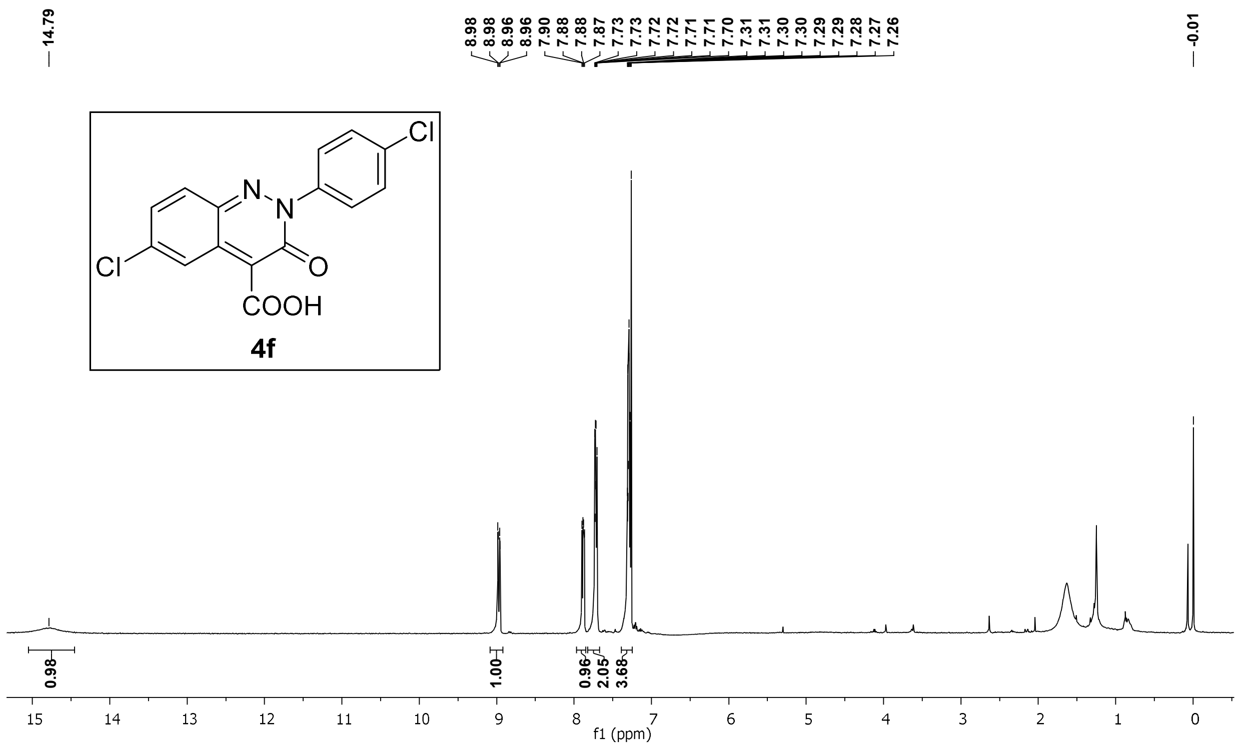


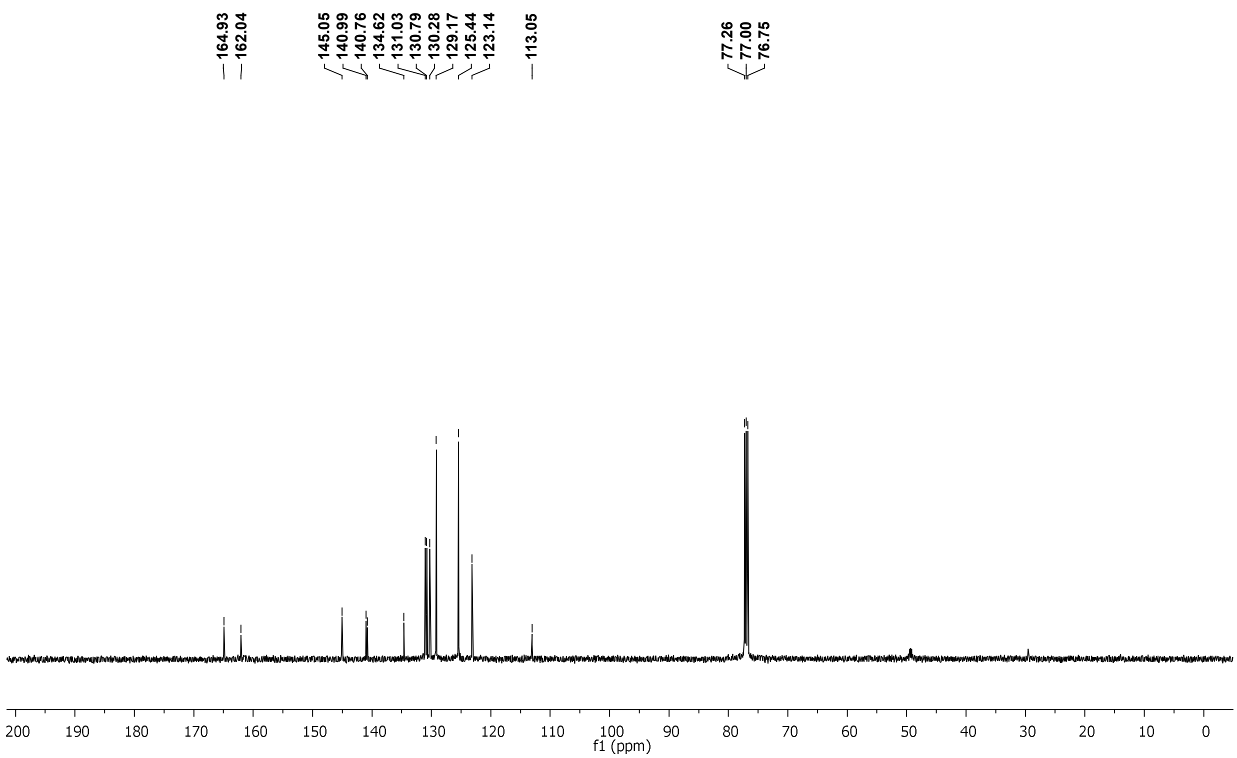
^{1}H and ^{13}C NMR of Compound 4e in DMSO-d_6



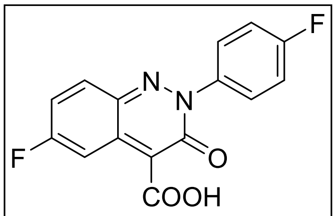


^{1}H and ^{13}C NMR of Compound 4f in $CDCl_3$

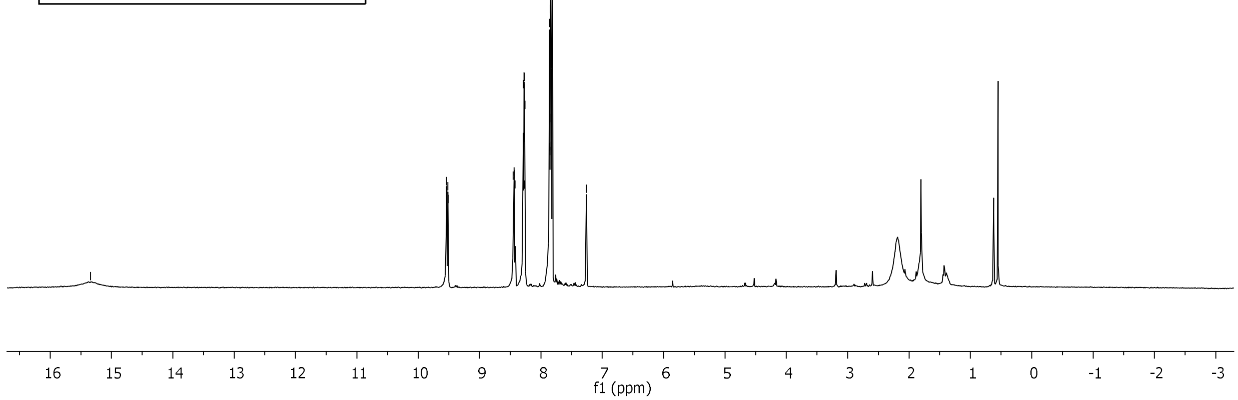


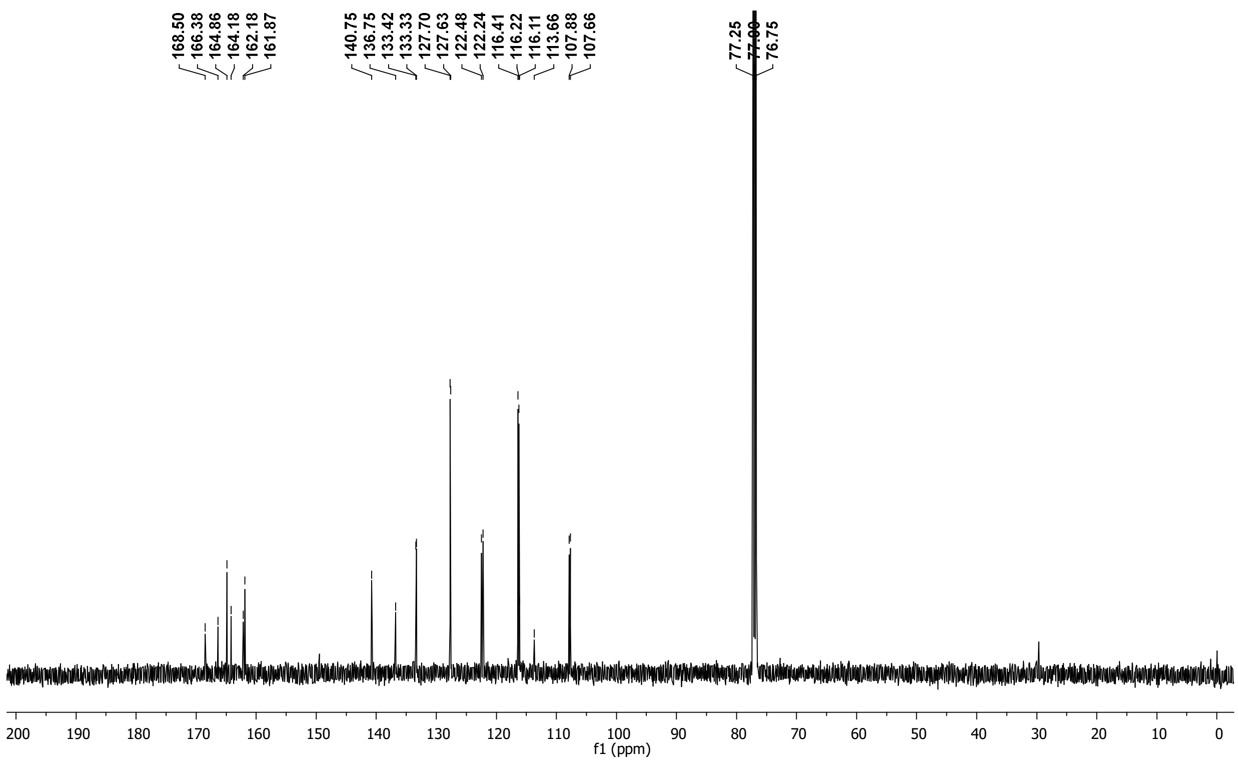


^{1}H and ^{13}C NMR of Compound 4g in $CDCl_3$

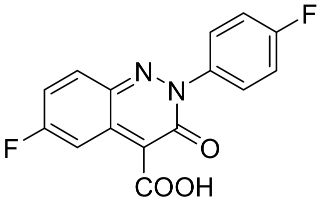


4g

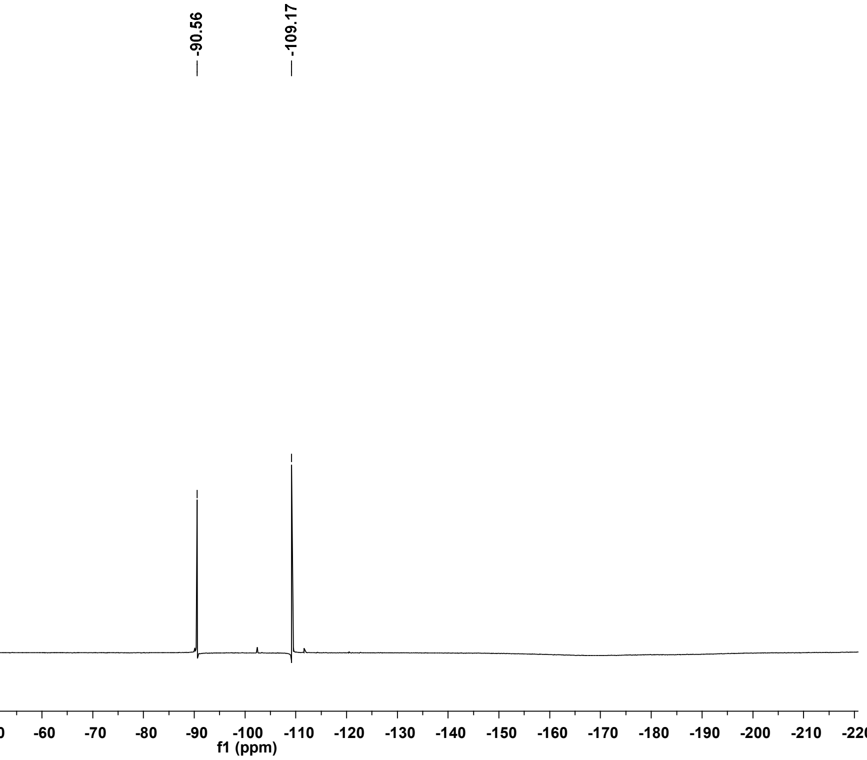




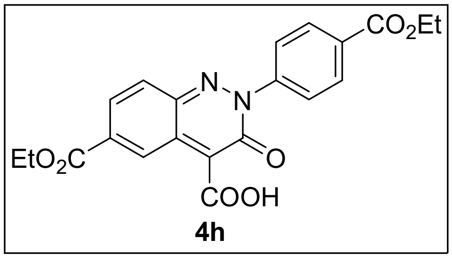
^{19}F NMR of Compound 4g in $CDCl_3$

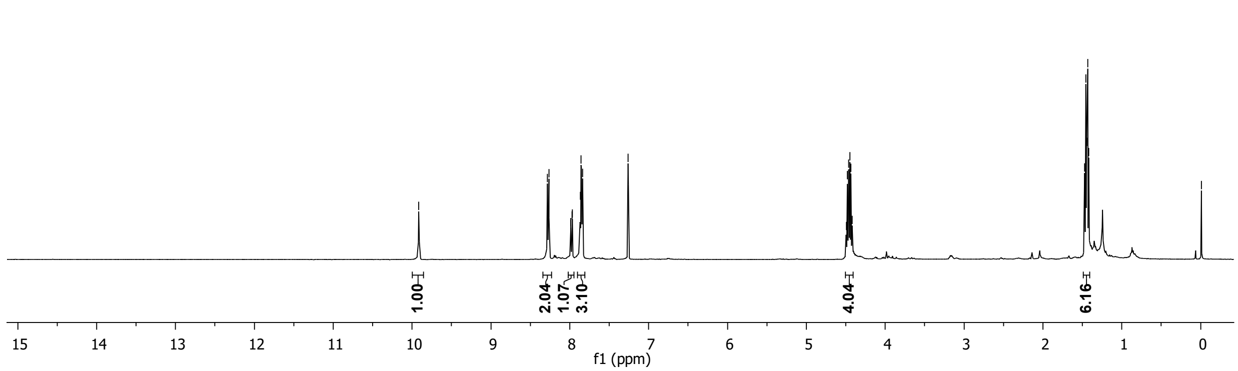


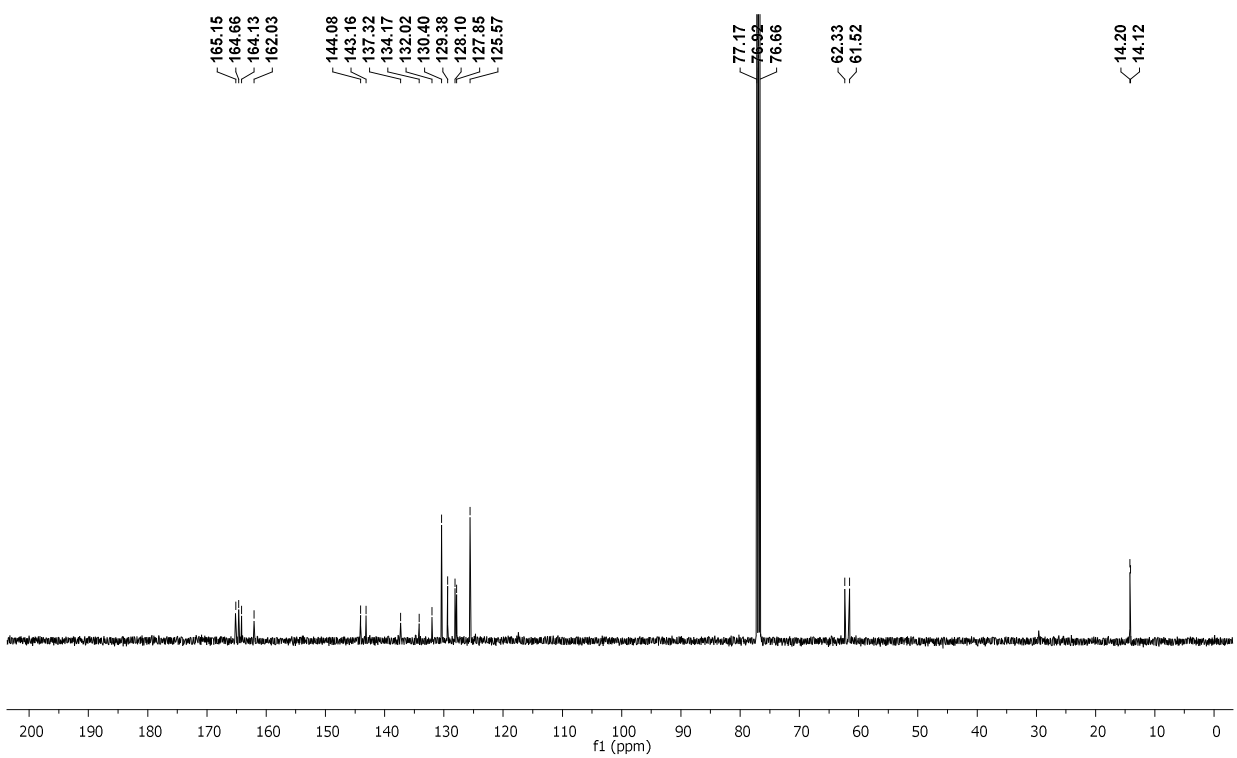
4g



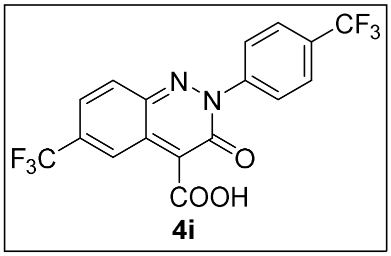
[1]H and [13]C NMR of Compound 4h in $CDCl_3$

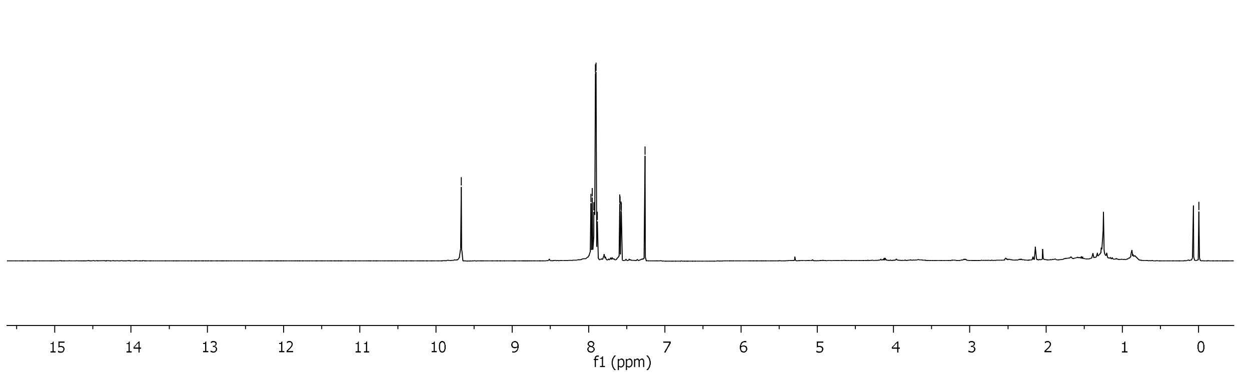


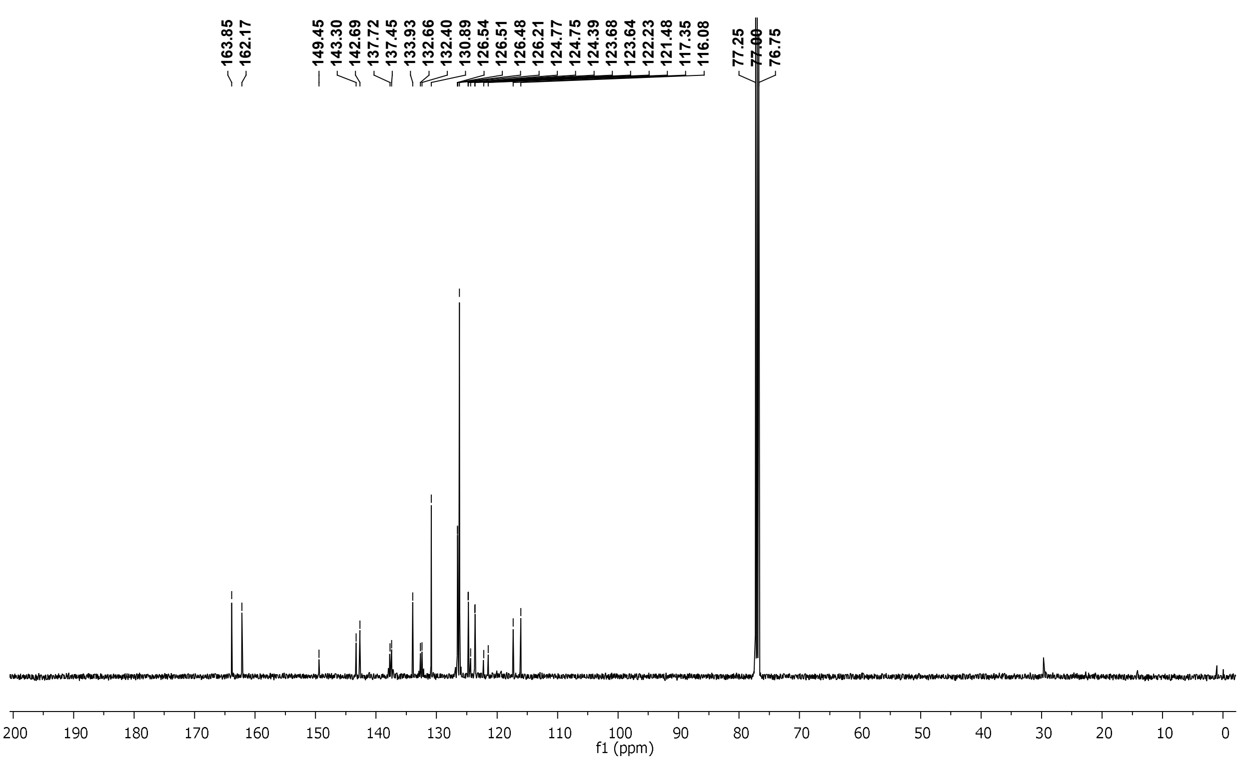




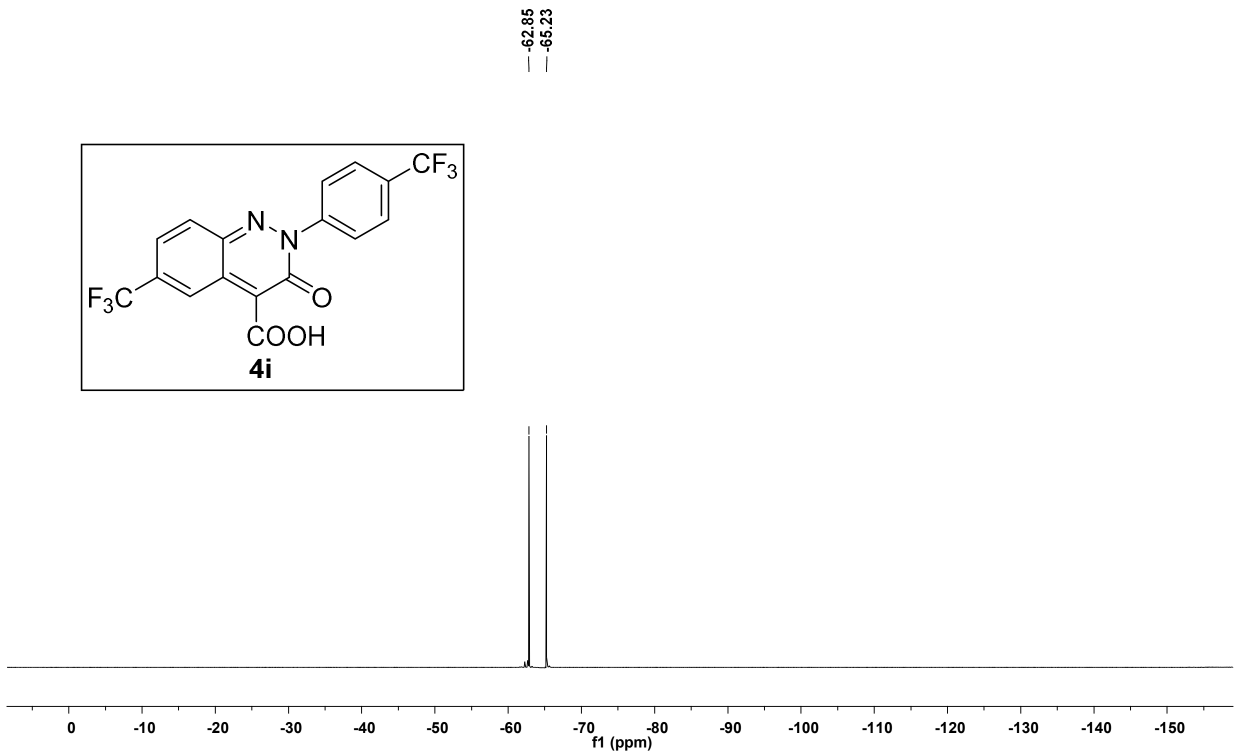
^{1}H and ^{13}C NMR of Compound 4i in $CDCl_3$



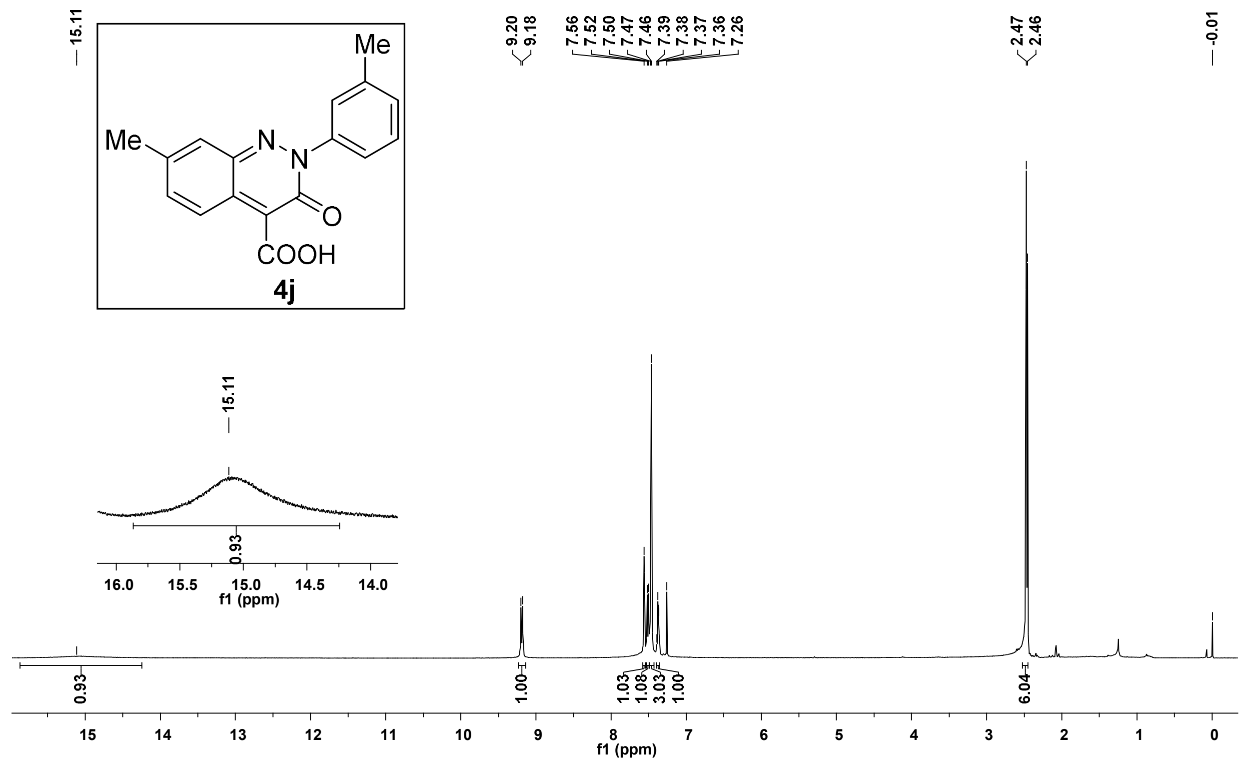


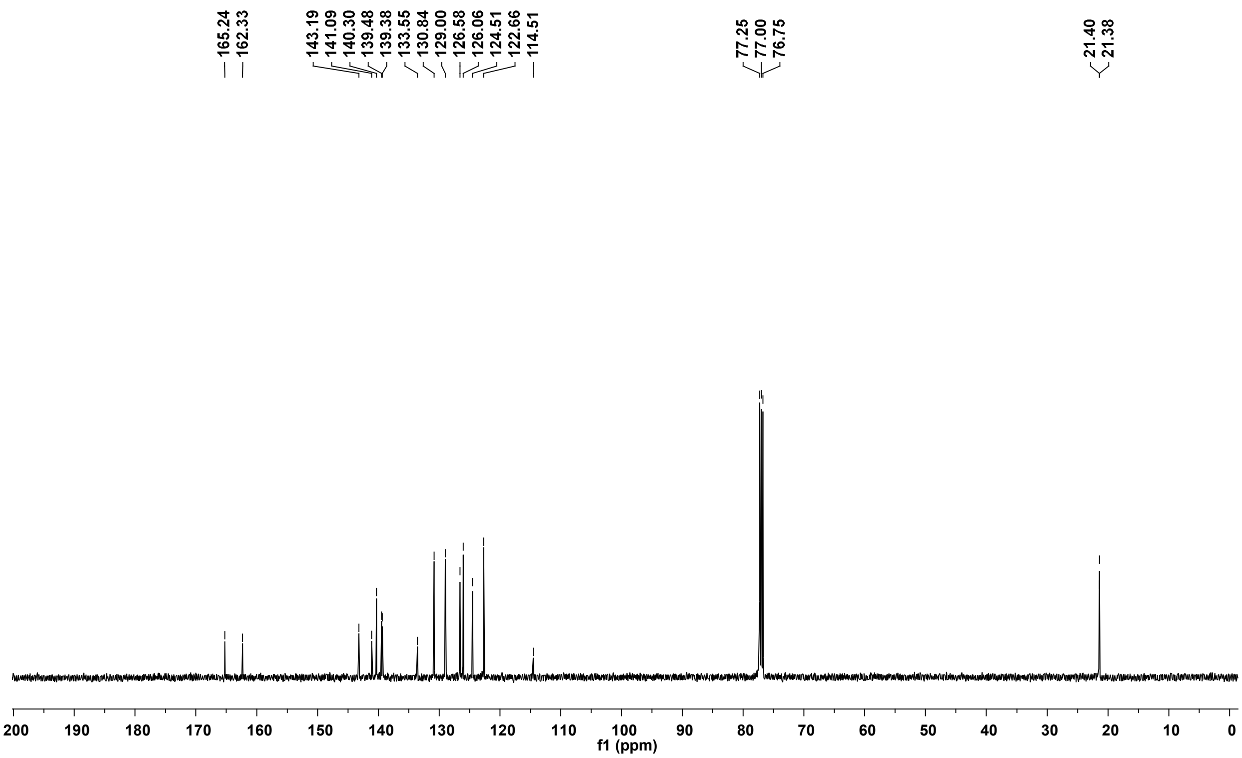


^{19}F NMR of Compound 4i in CDCl$_3$

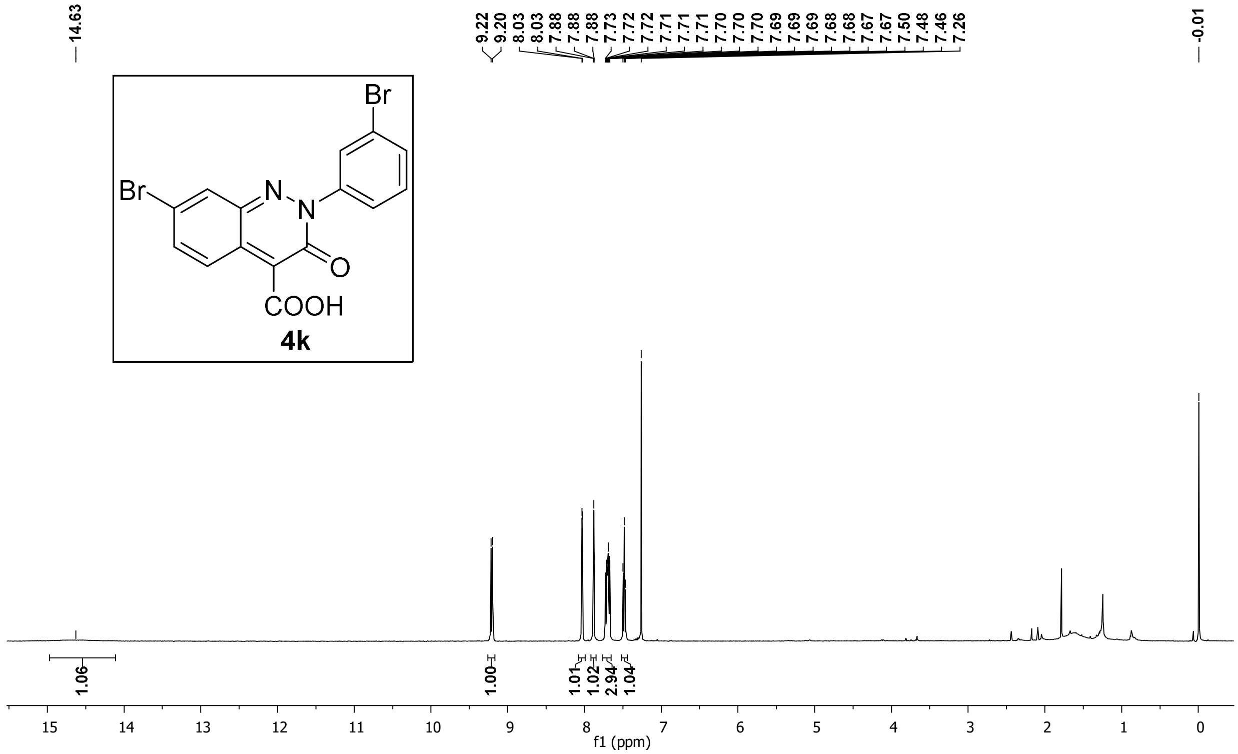


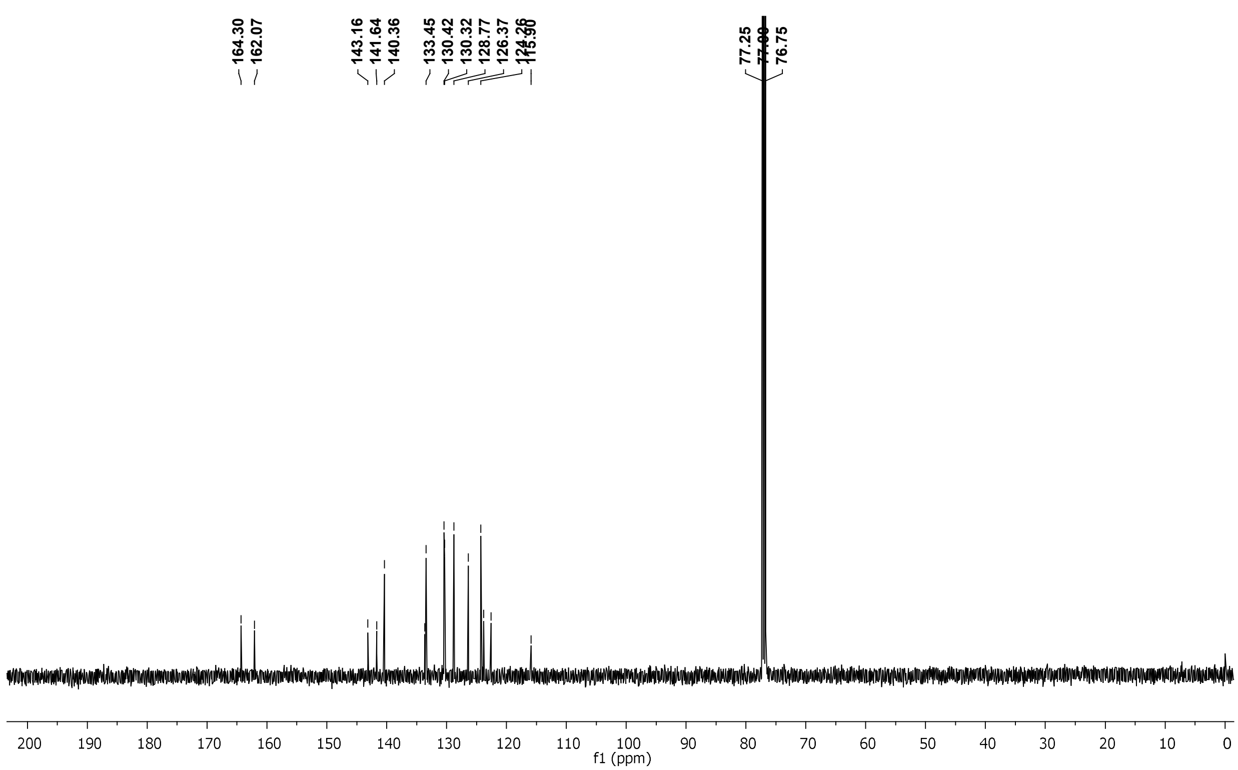
^{1}H and ^{13}C NMR of Compound 4j in $CDCl_3$



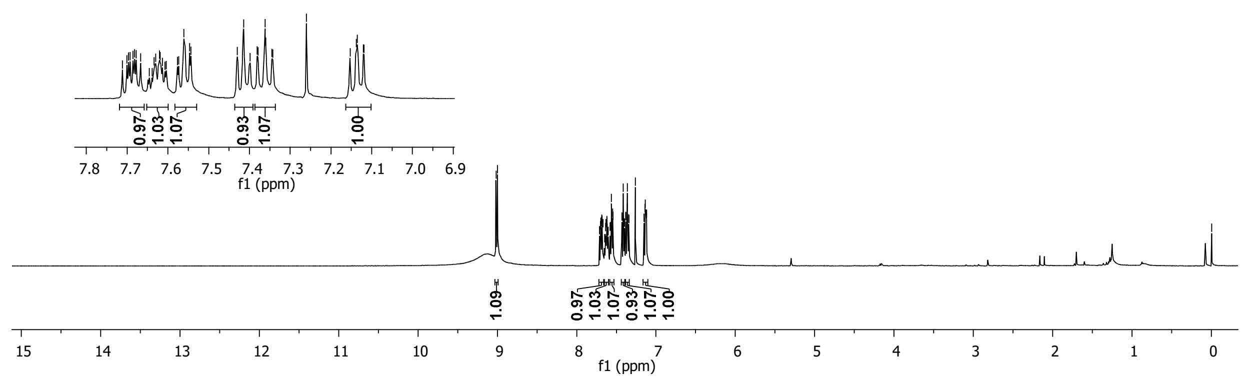


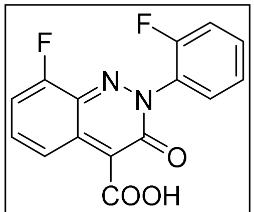
^{1}H and ^{13}C NMR of Compound 4k in $CDCl_3$



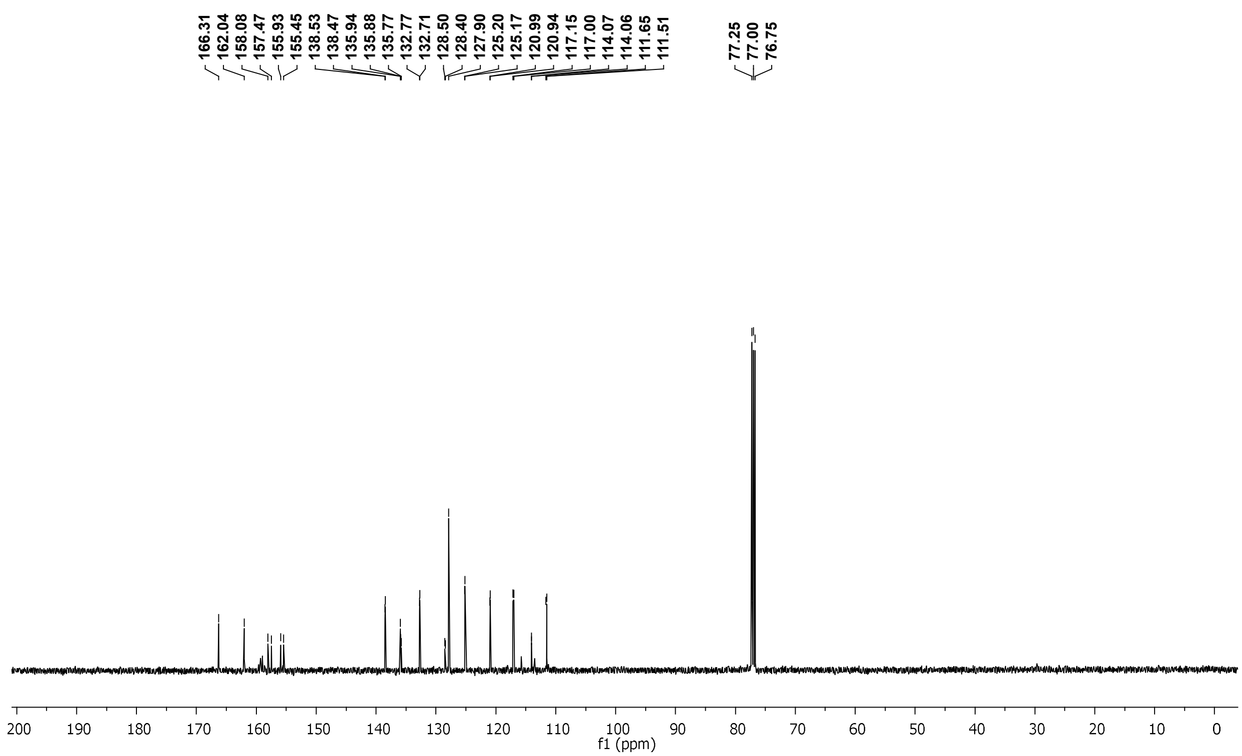


^{1}H and ^{13}C NMR of Compound 4l in $CDCl_3$ (1 drop TFAA)

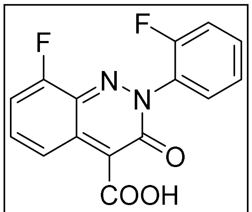




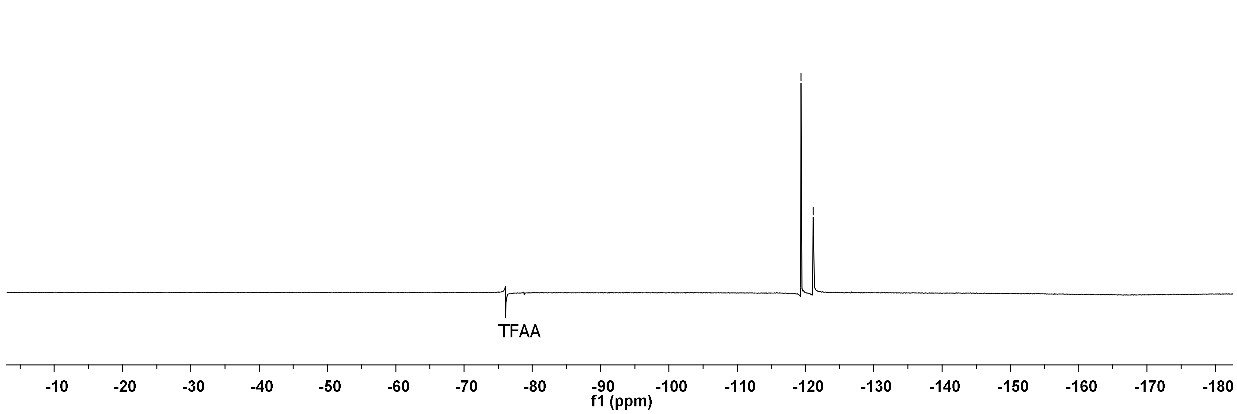
4l



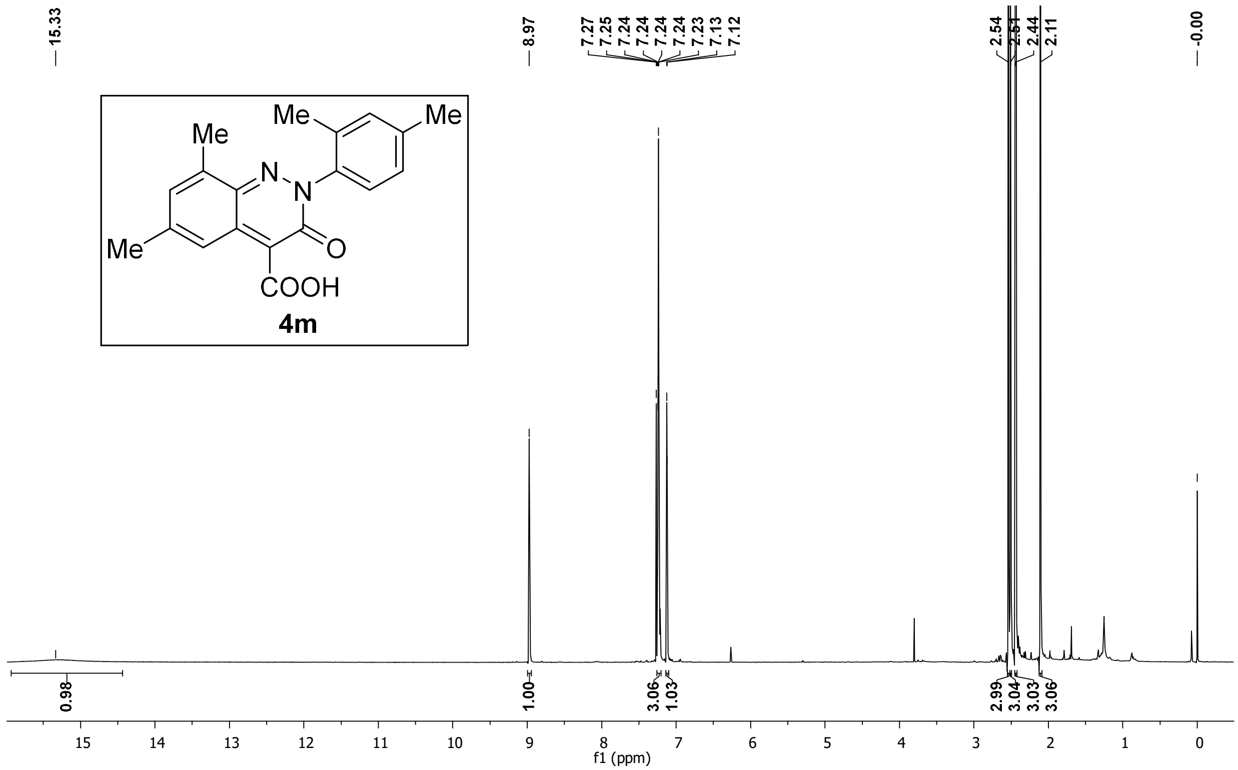
^{19}F NMR of Compound 4l in $CDCl_3$ (1 drop TFAA)

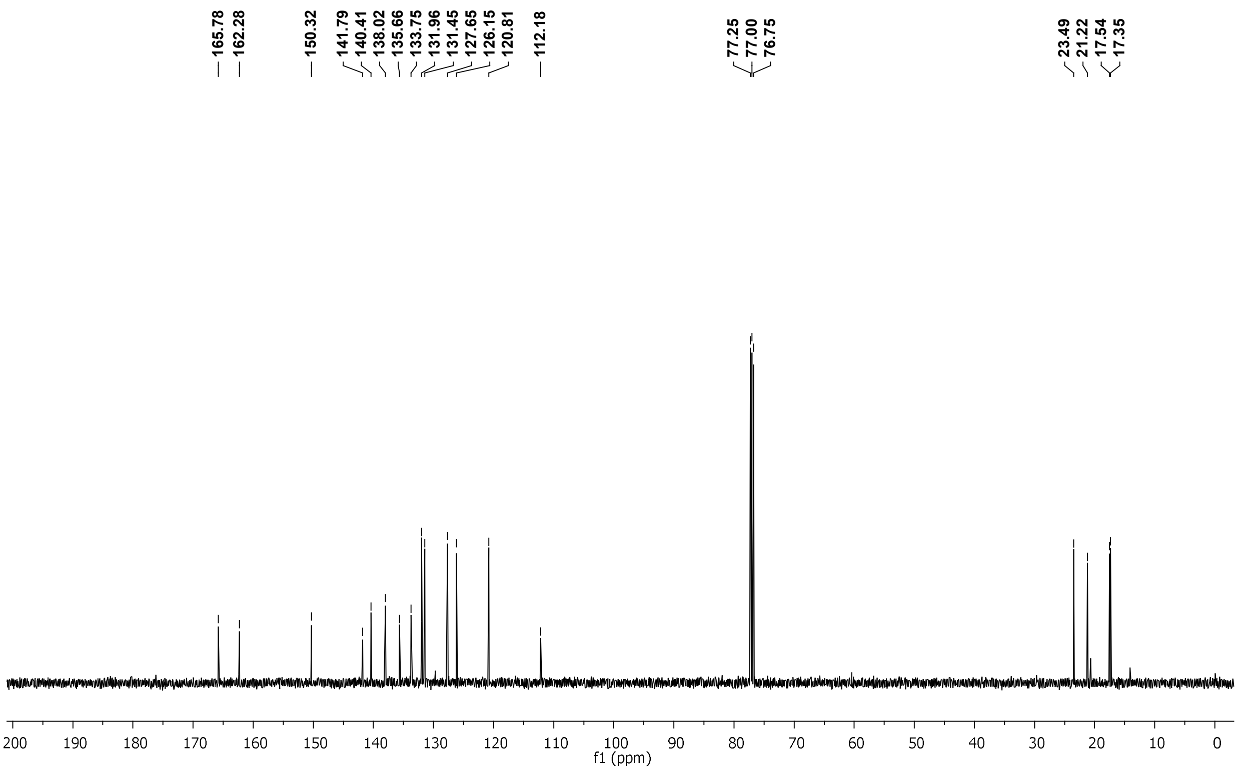


4l

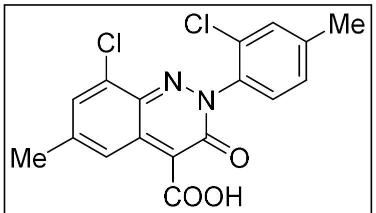


[1]H and [13]C NMR of Compound 4m in CDCl₃

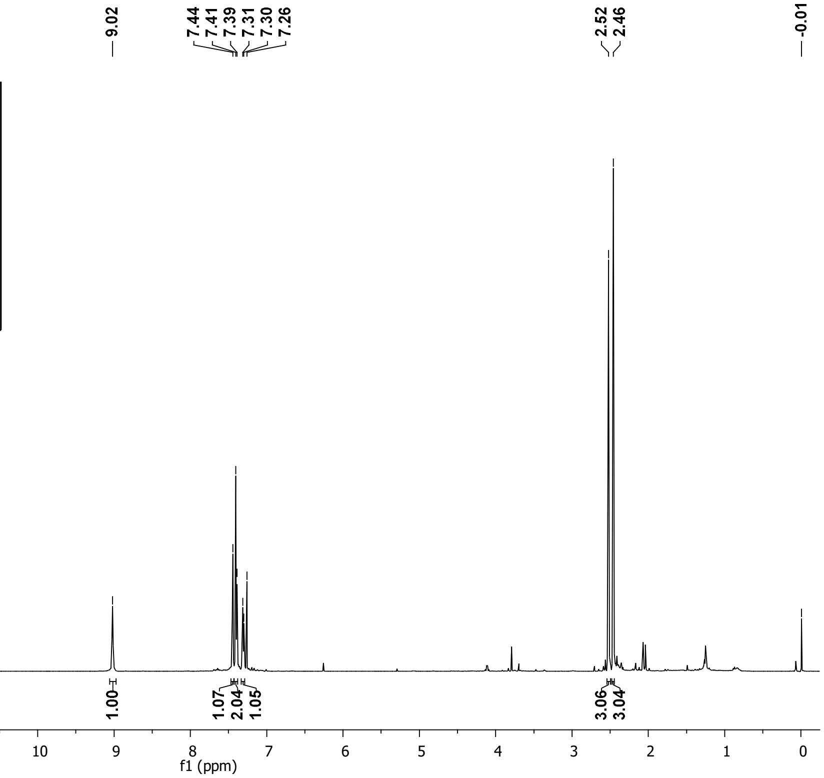


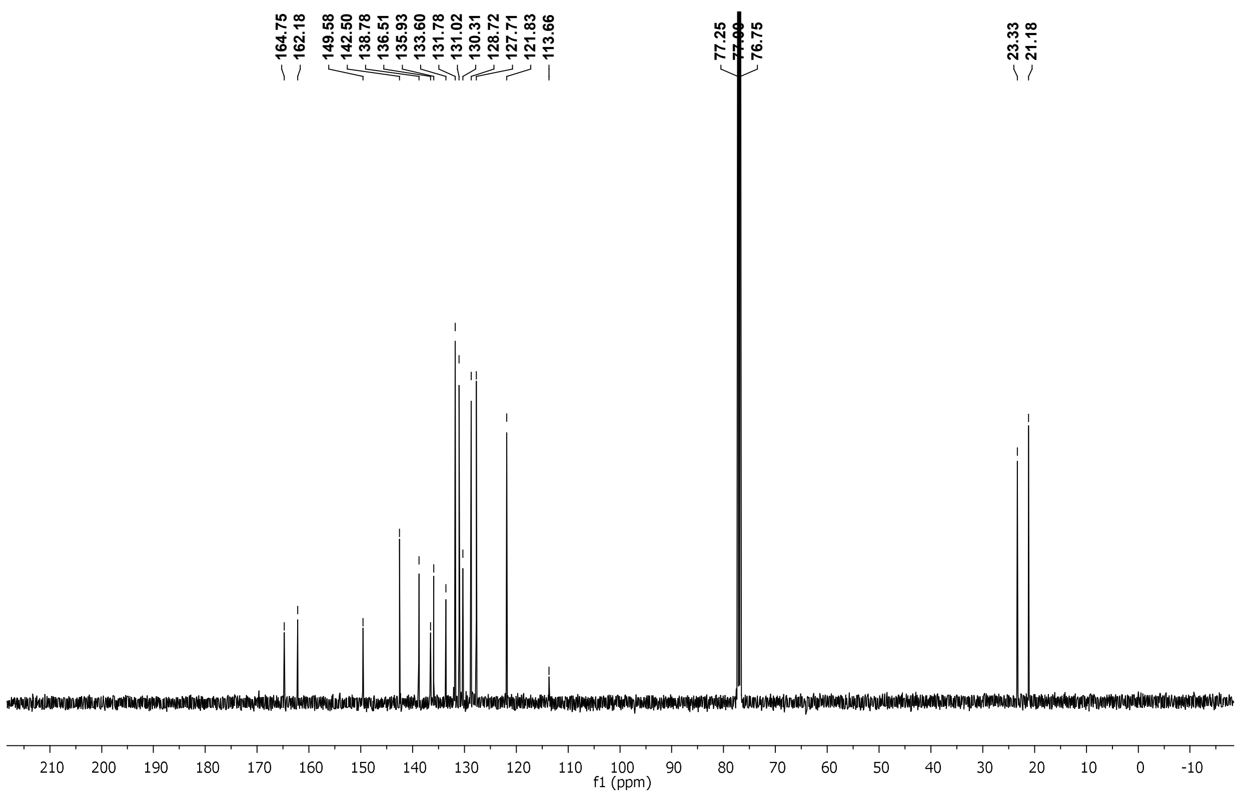


^{1}H and ^{13}C NMR of Compound 4n in $CDCl_3$

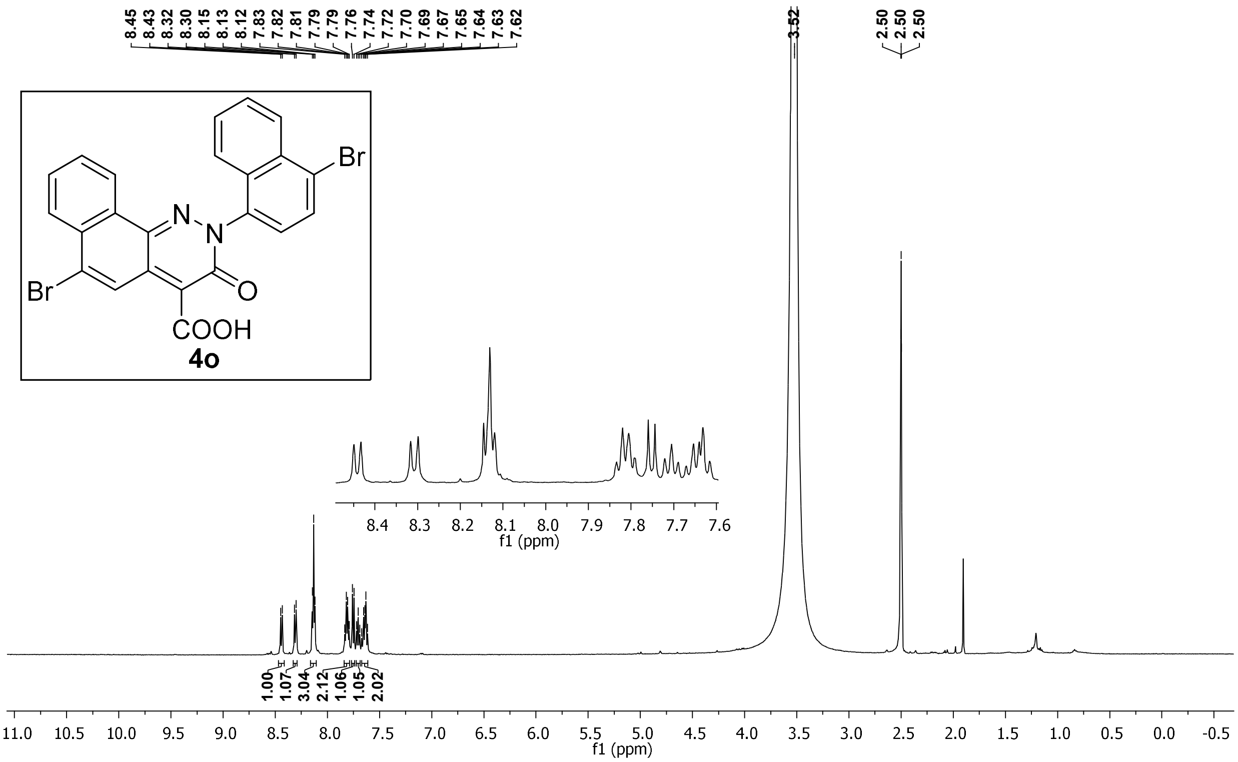


4n

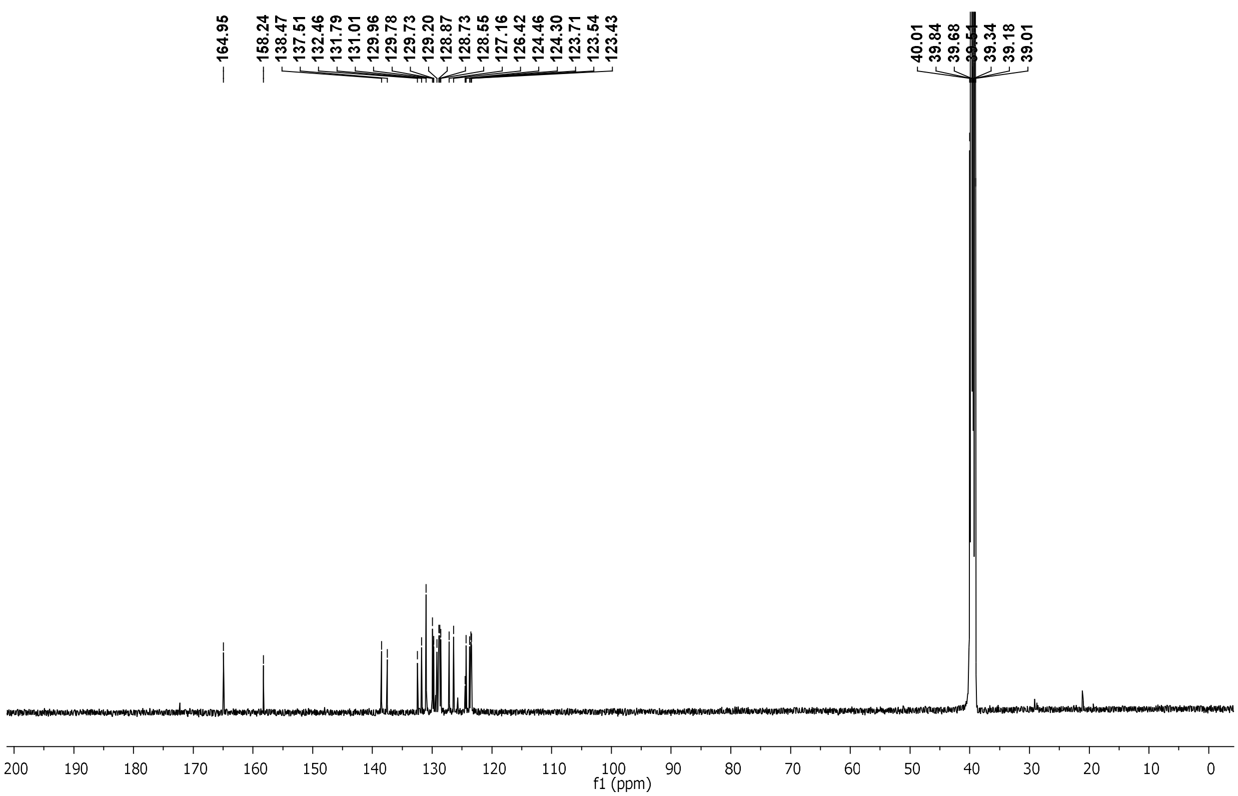




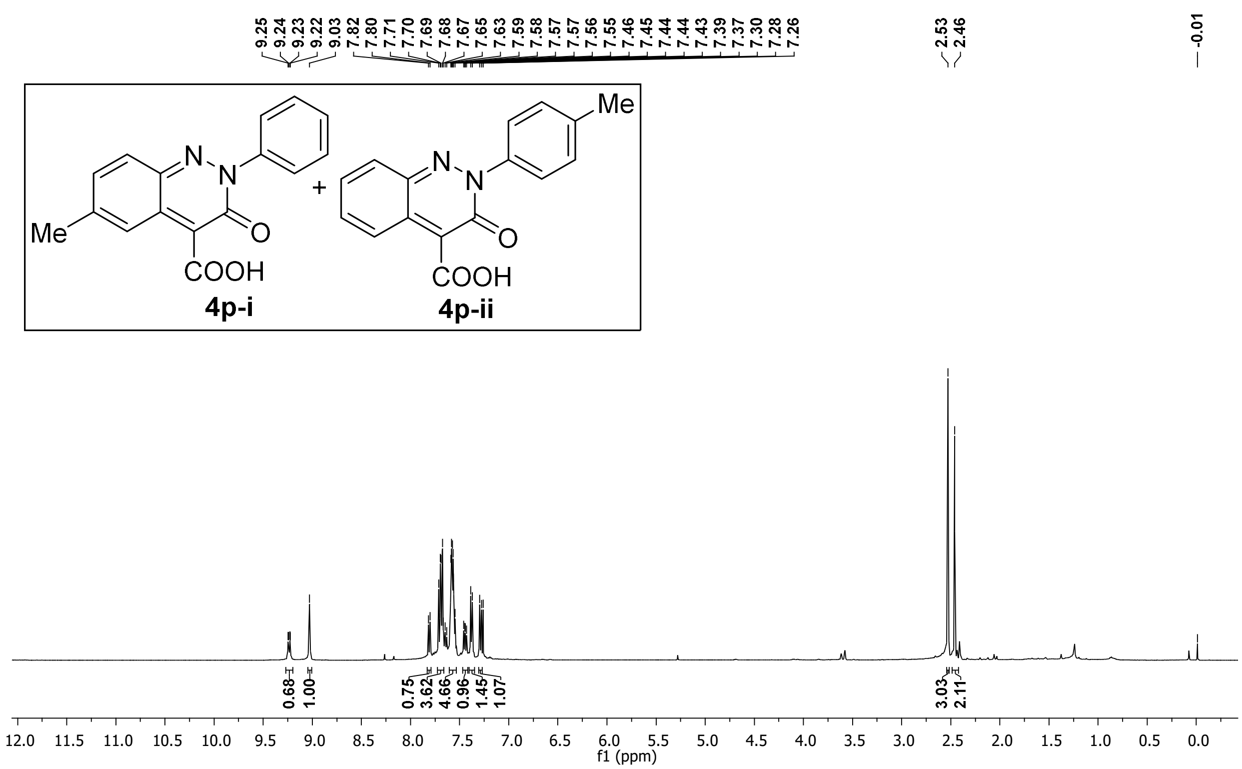
^{1}H and ^{13}C NMR of Compound 4o in DMSO-d_6

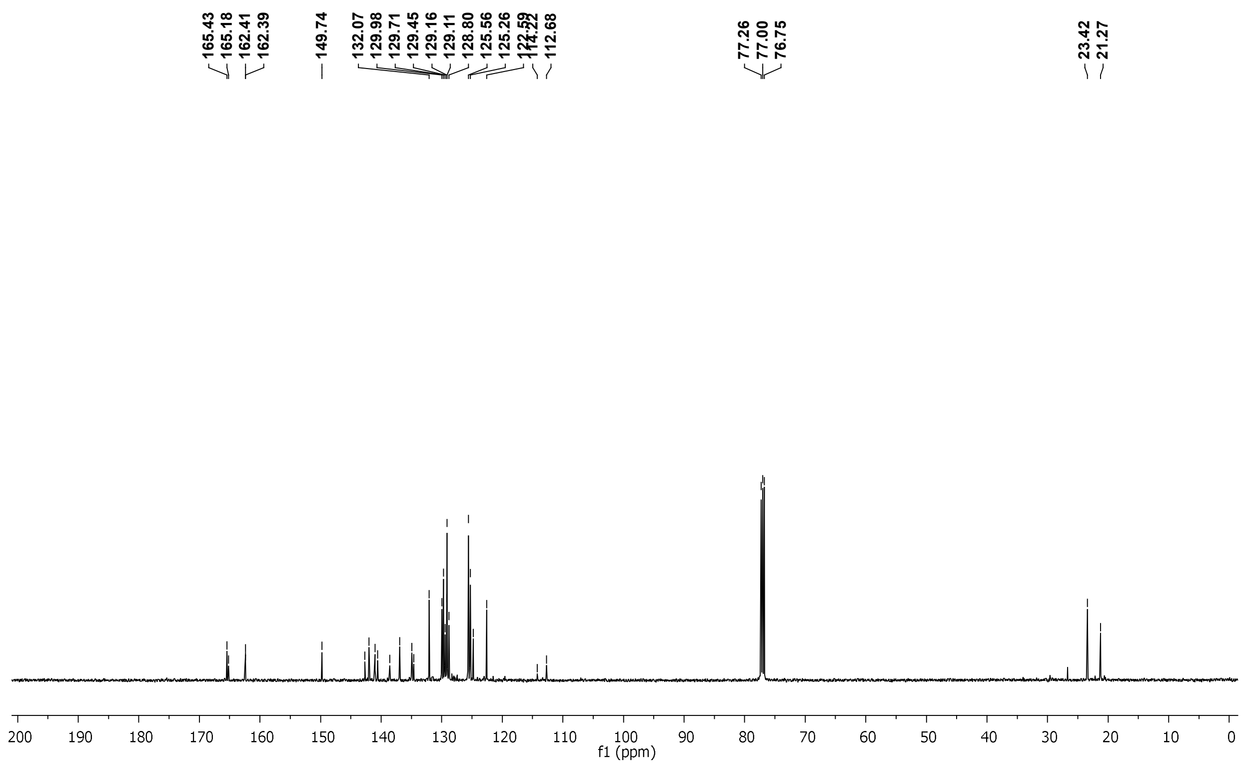


4o

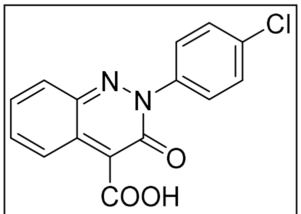


^{1}H and ^{13}C NMR of Compound 4p-i + 4p-ii in $CDCl_3$

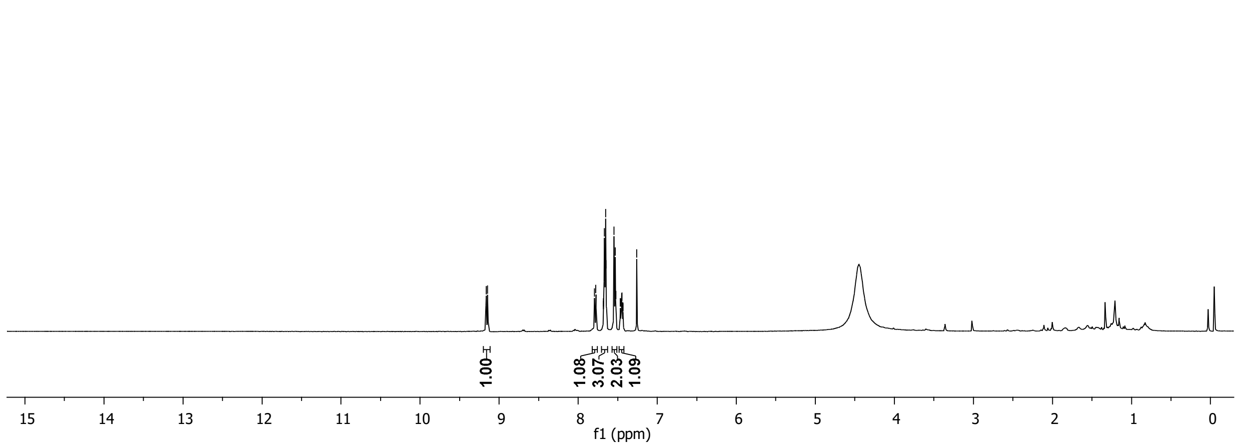


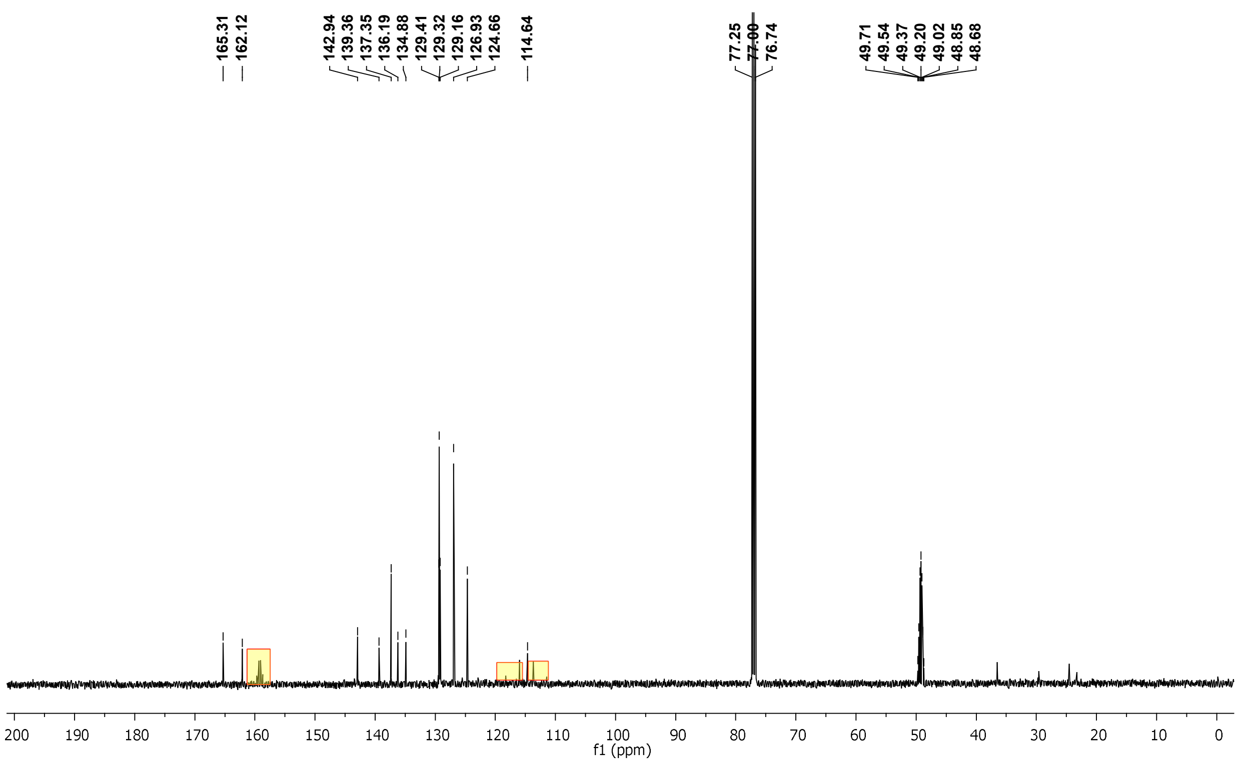


[1]H and [13]C NMR of Compound 4q-i in $CDCl_3$ + CD_3OD + 1 drop CF_3COOH



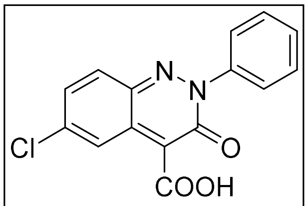
4q-i



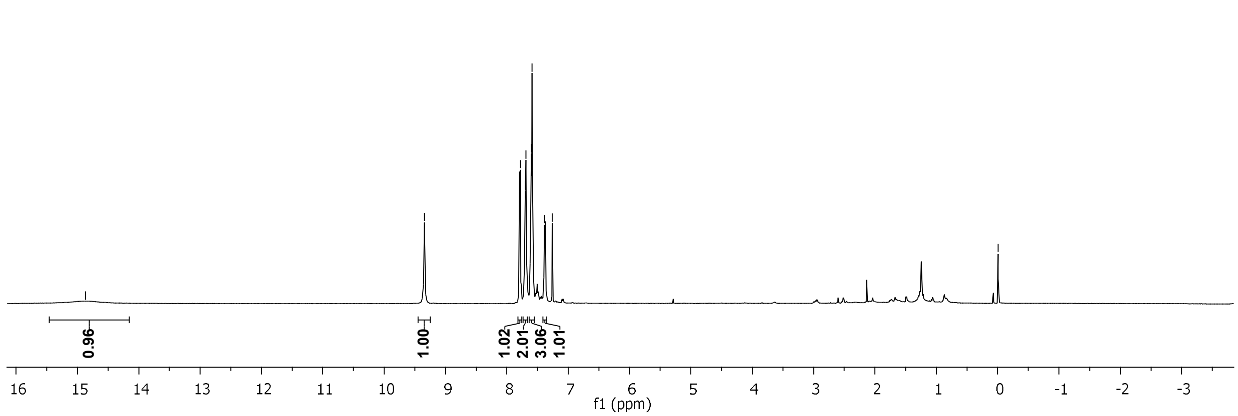


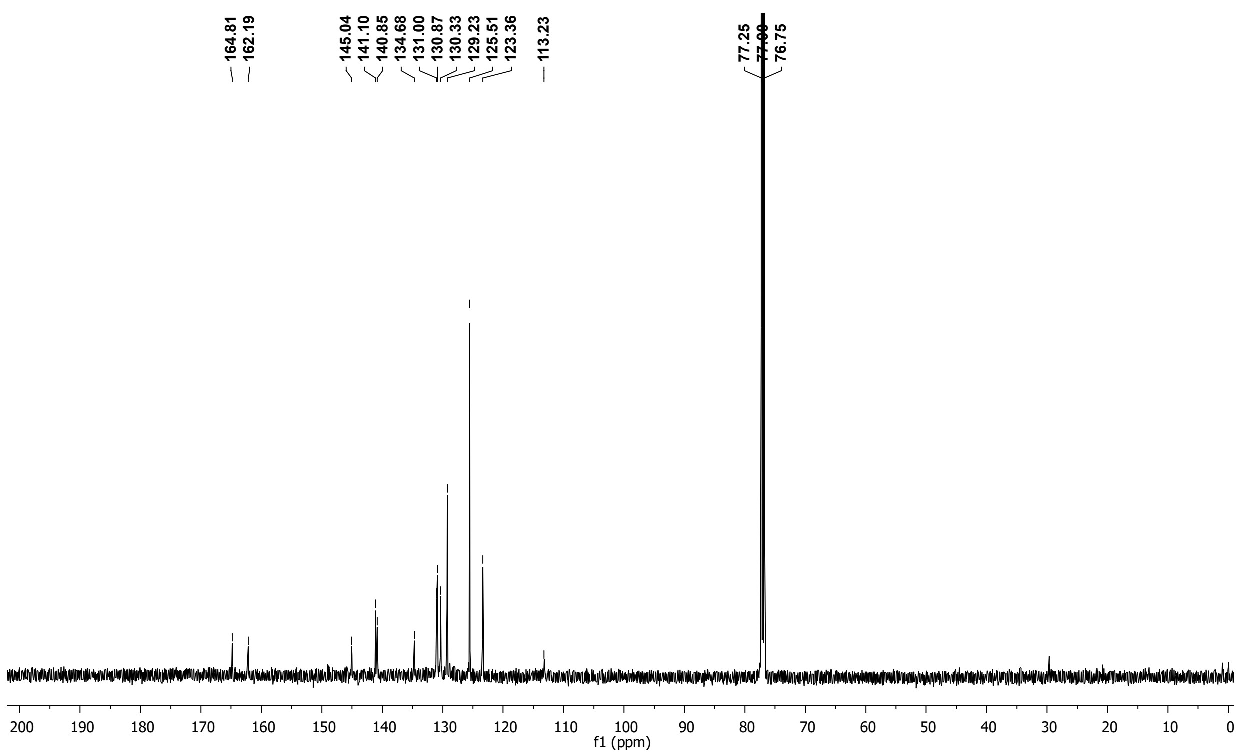
*** Highlighted peaks belong to CF_3COOH used to make the compound soluble in the solvent.**

[1]H and [13]C NMR of Compound 4q-ii in $CDCl_3$

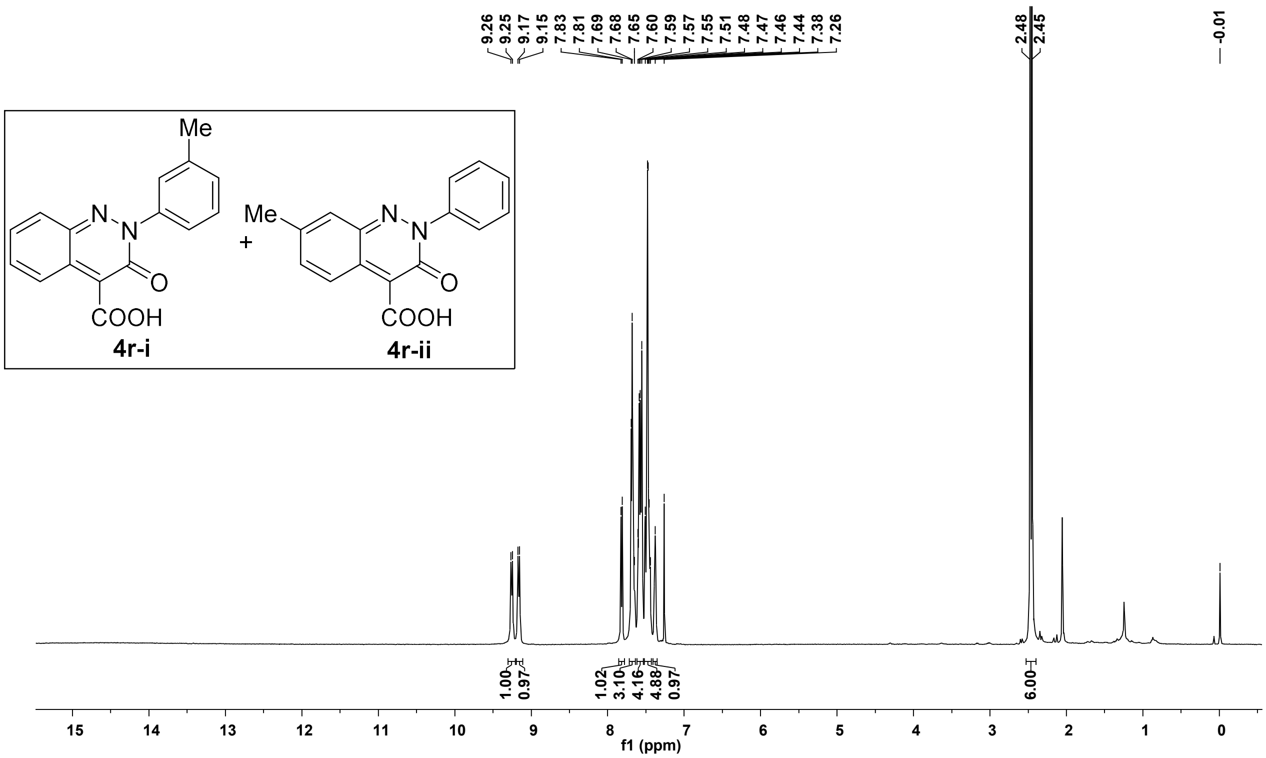


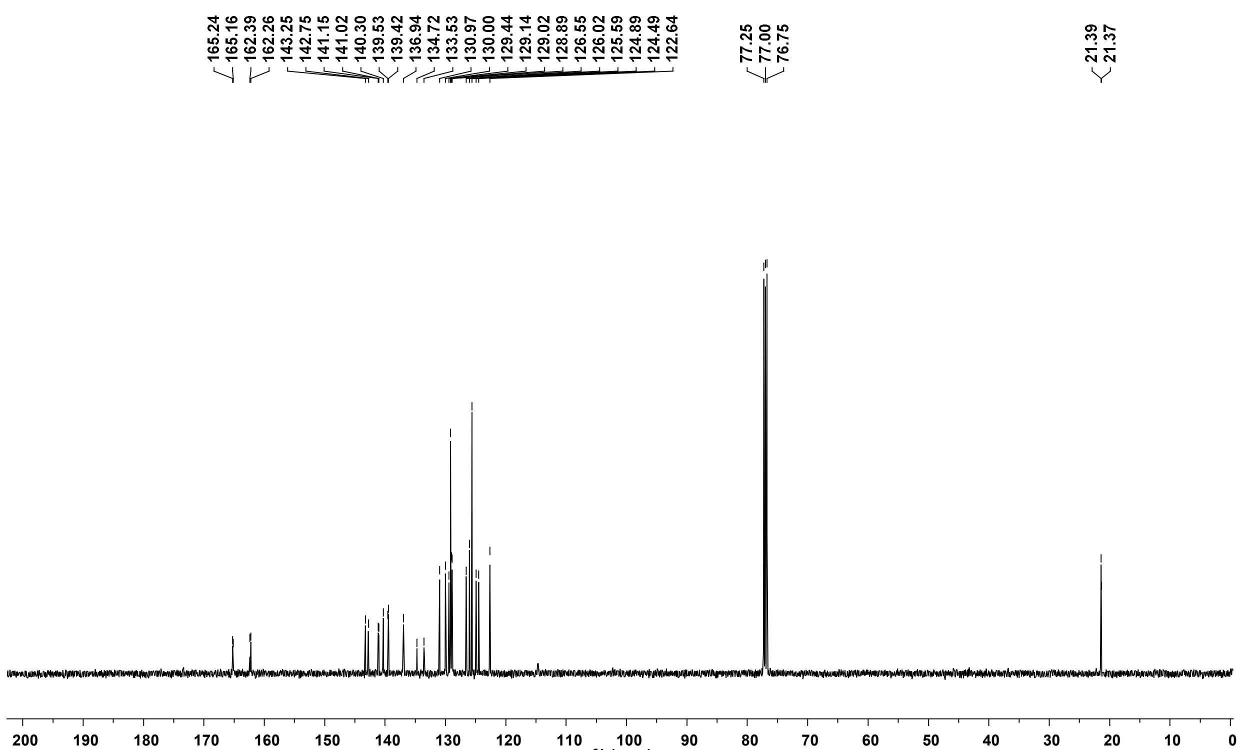
4q-ii



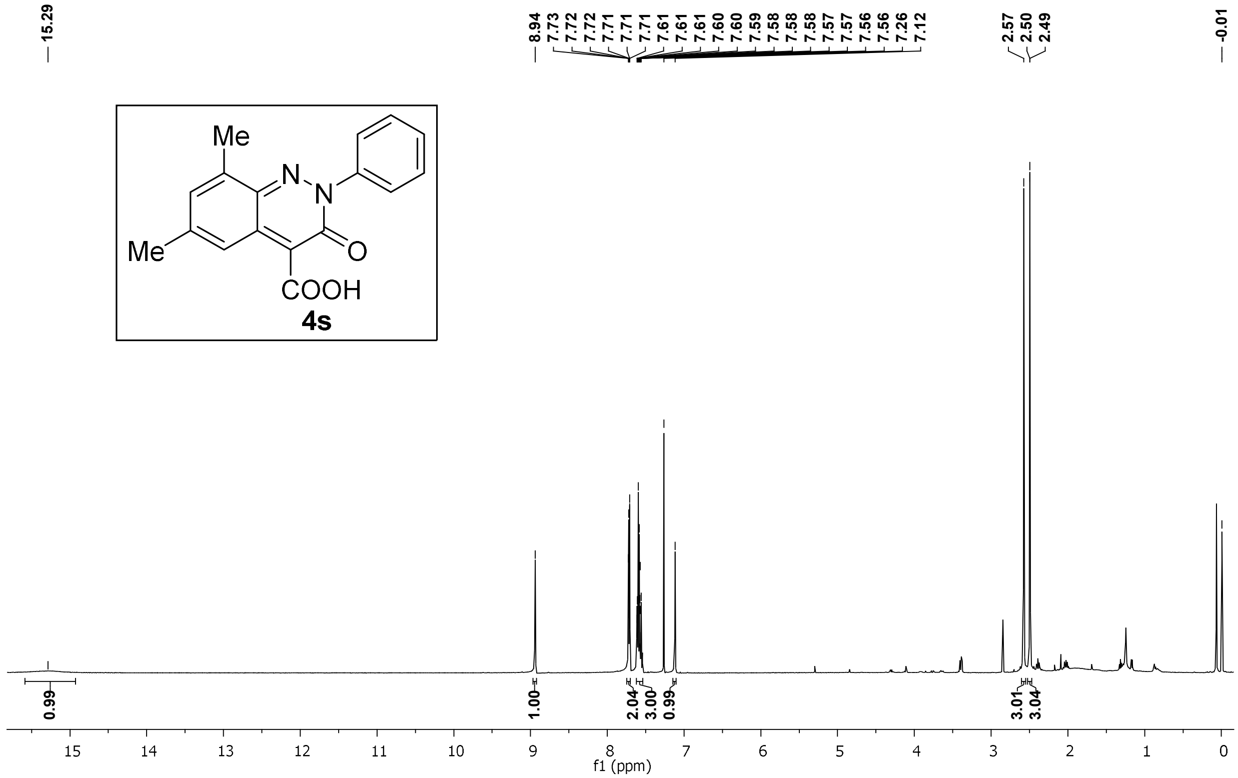


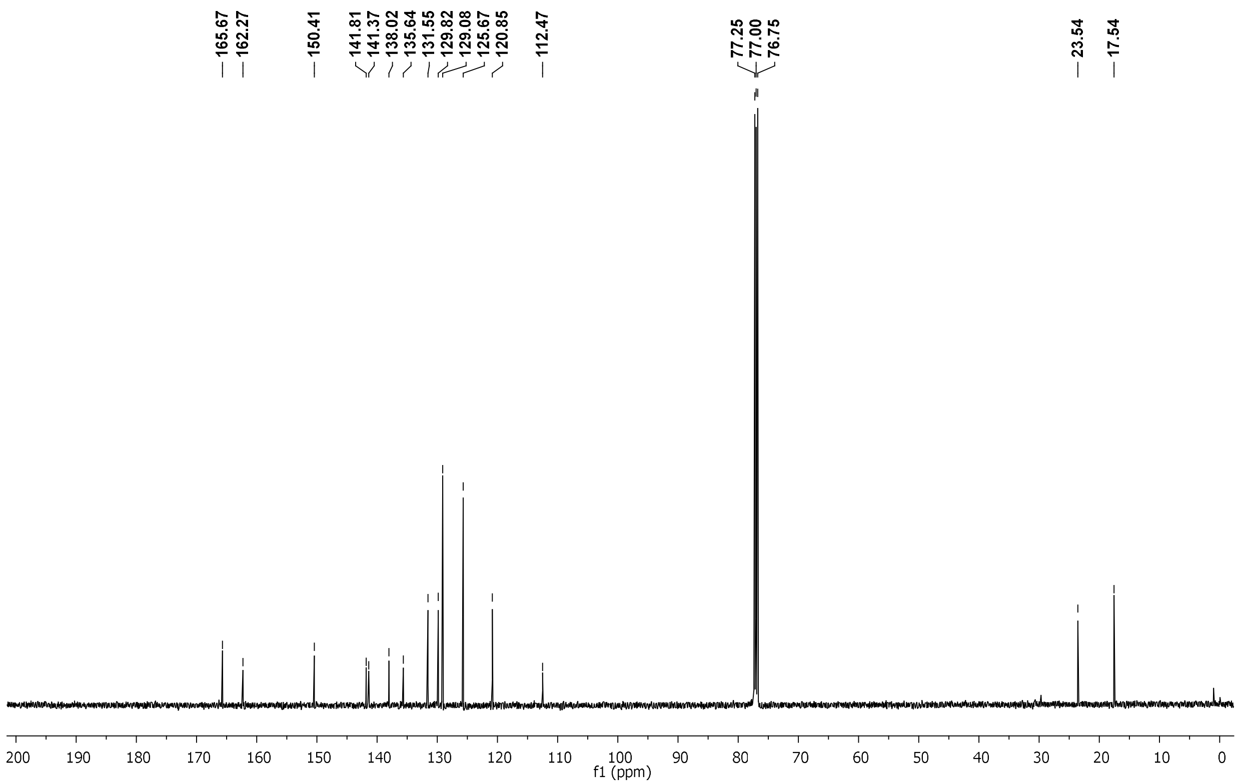
^{1}H and ^{13}C NMR of Compound 4r-i + 4r-ii in $CDCl_3$



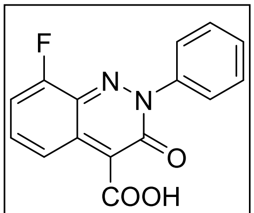


[1]H and [13]C NMR of Compound 4s in $CDCl_3$

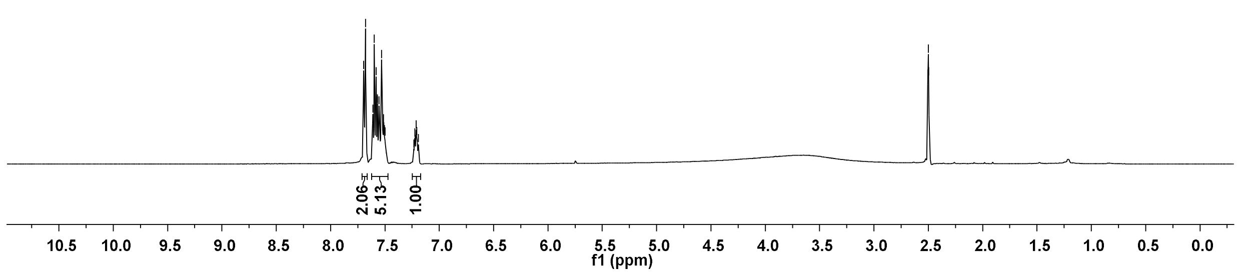


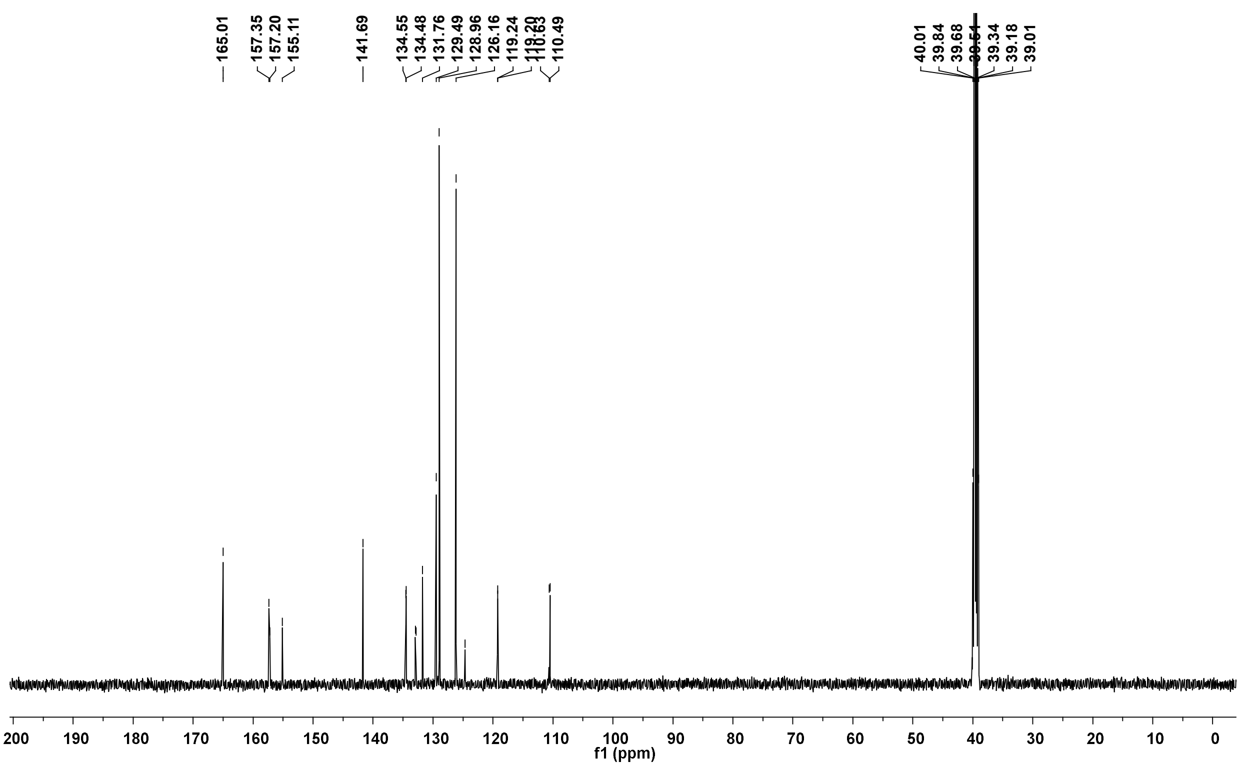


^{1}H and ^{13}C NMR of Compound 4t-i in DMSO-d_6

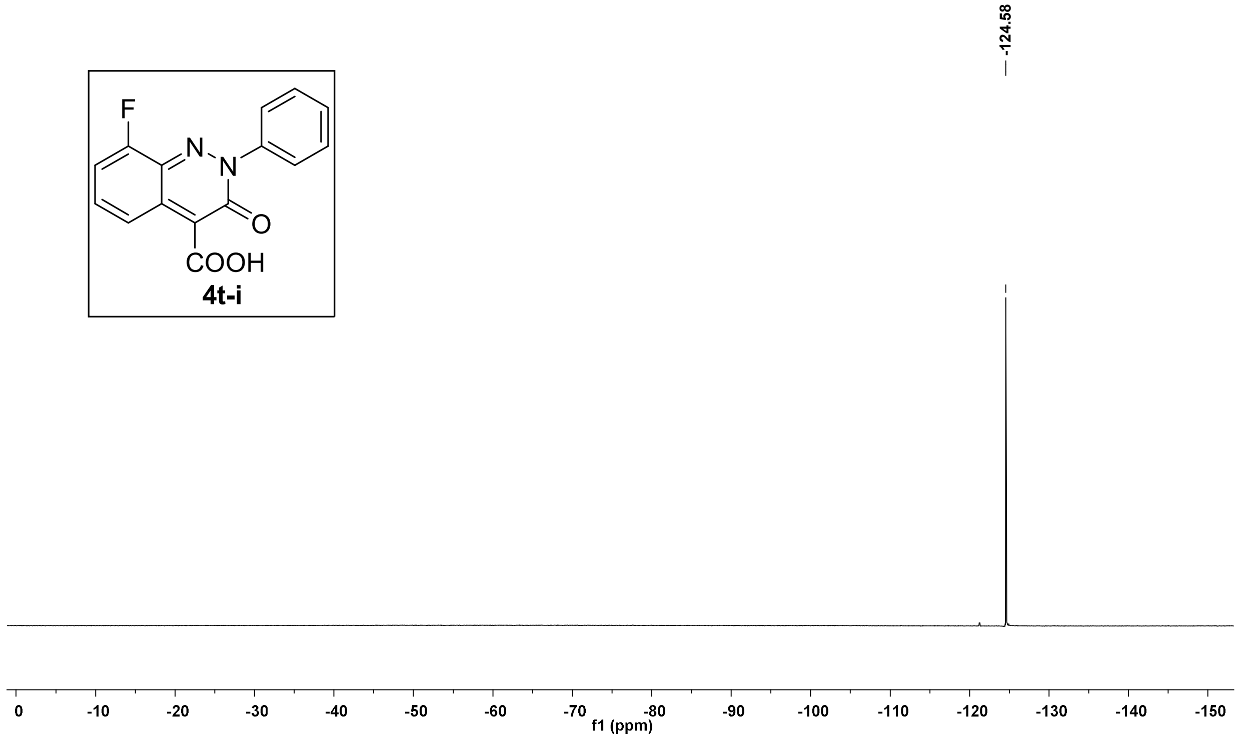


4t-i

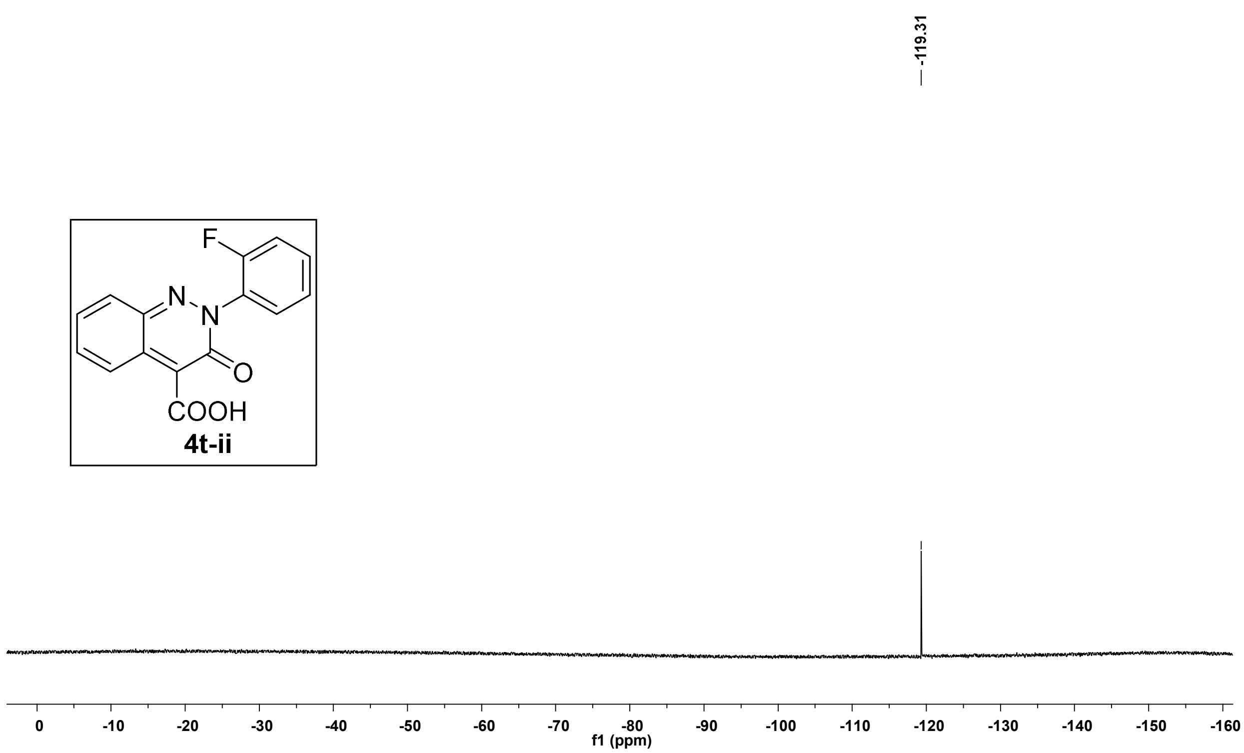




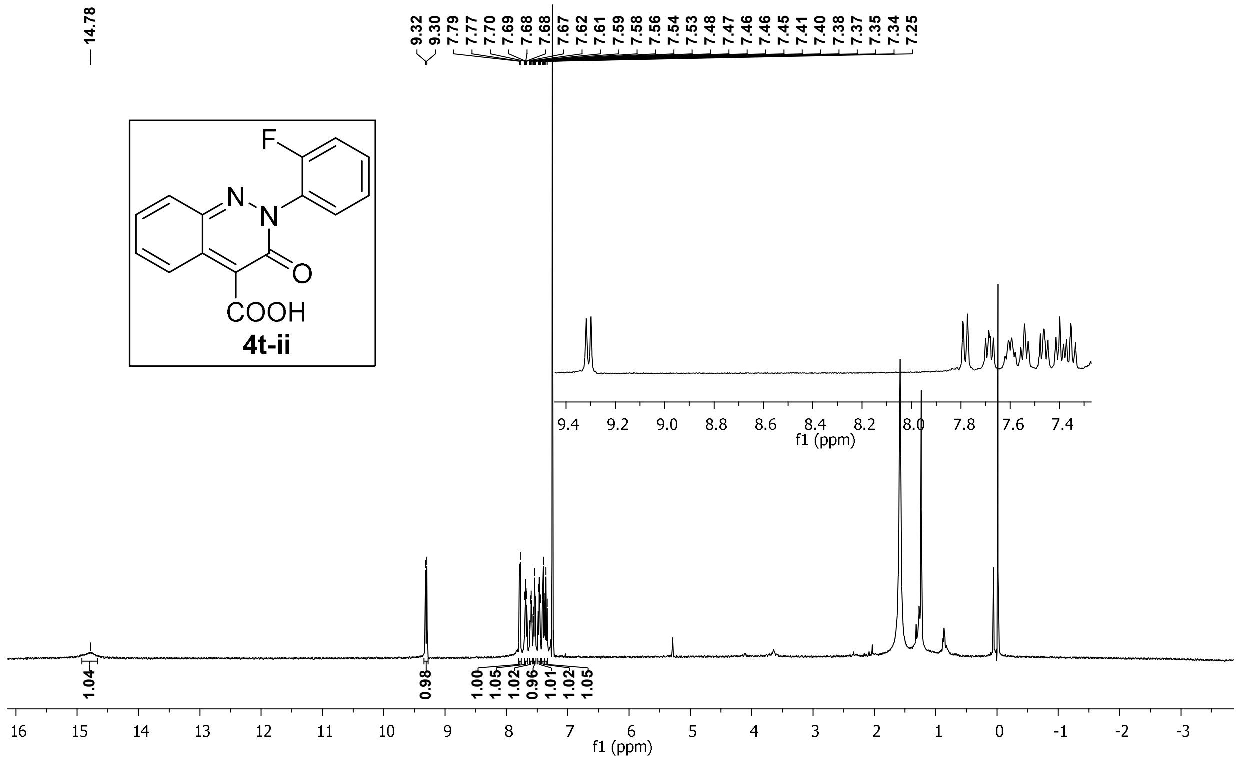
^{19}F NMR of Compound 4t-i in DMSO-d_6

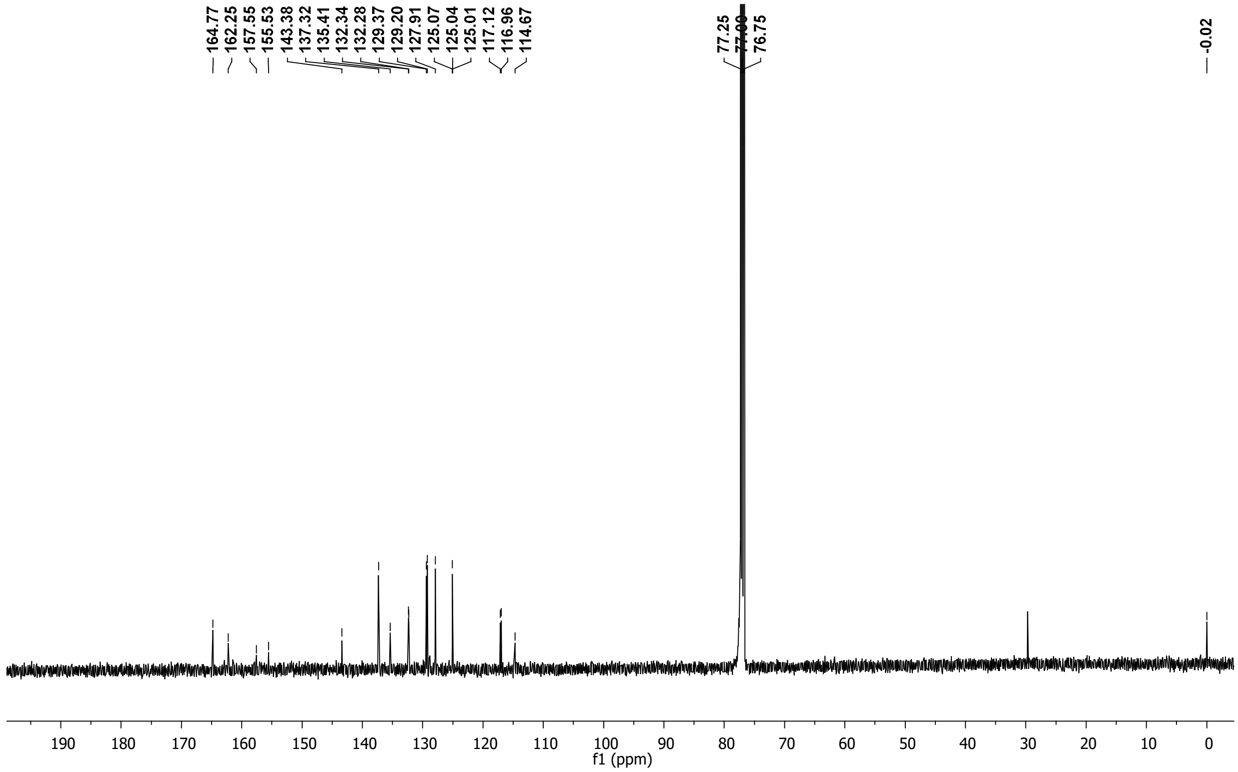


^{19}F NMR of Compound 4t-ii in $CDCl_3$

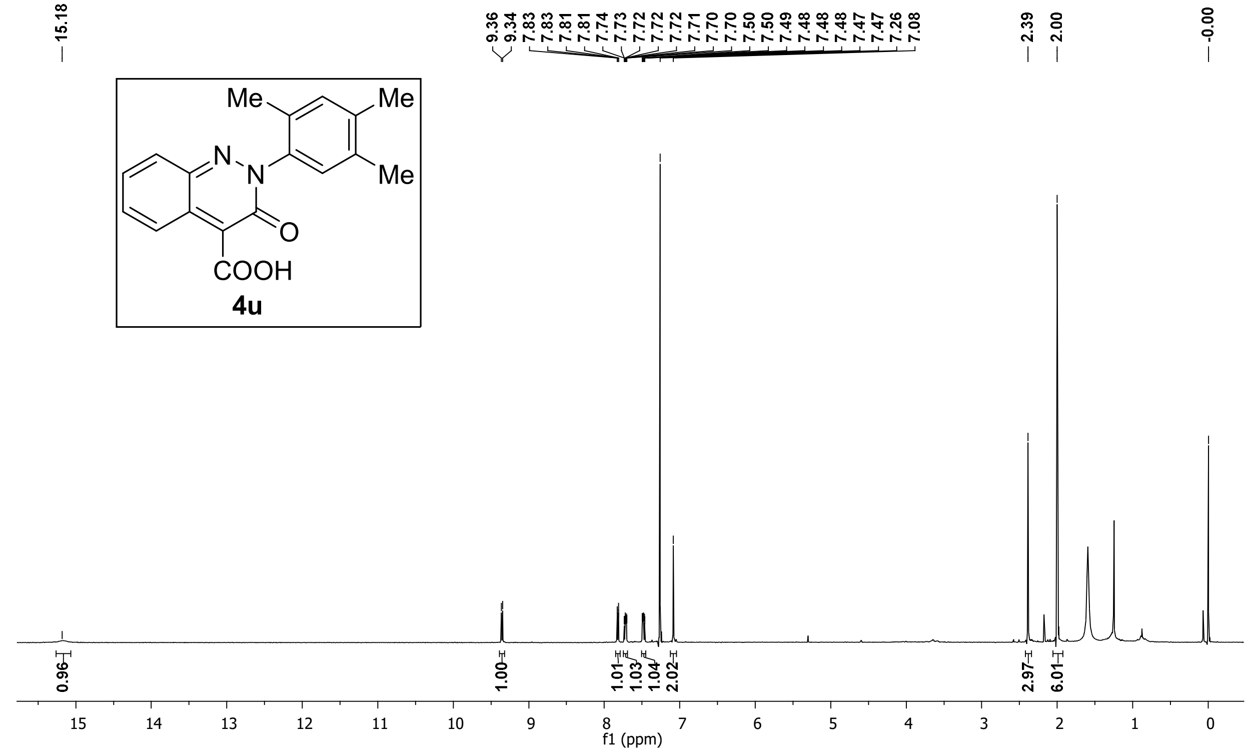


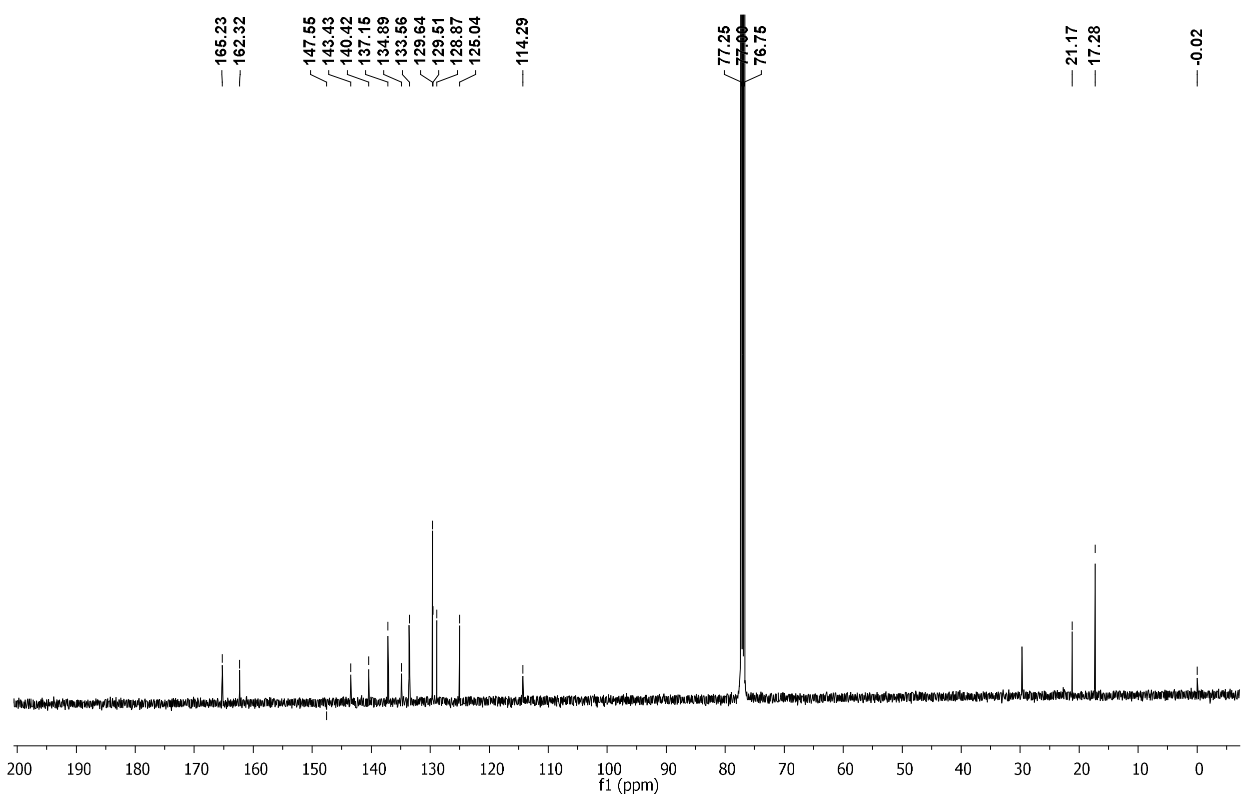
[1]H and [13]C NMR of Compound 4t-ii in $CDCl_3$



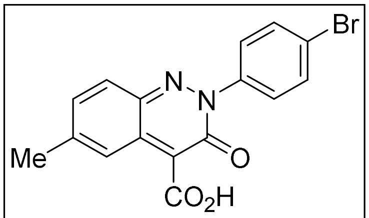


^{1}H and ^{13}C NMR of Compound 4u in $CDCl_3$

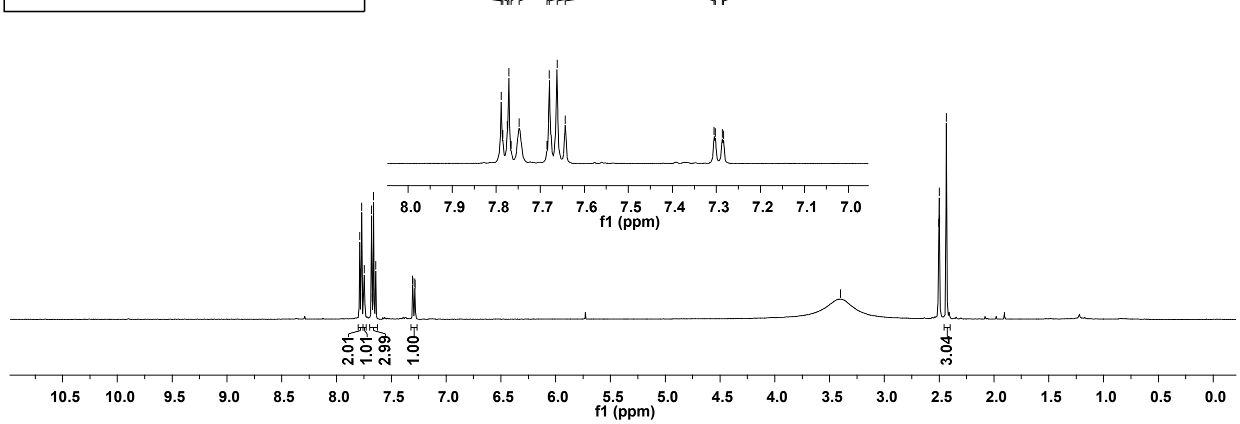


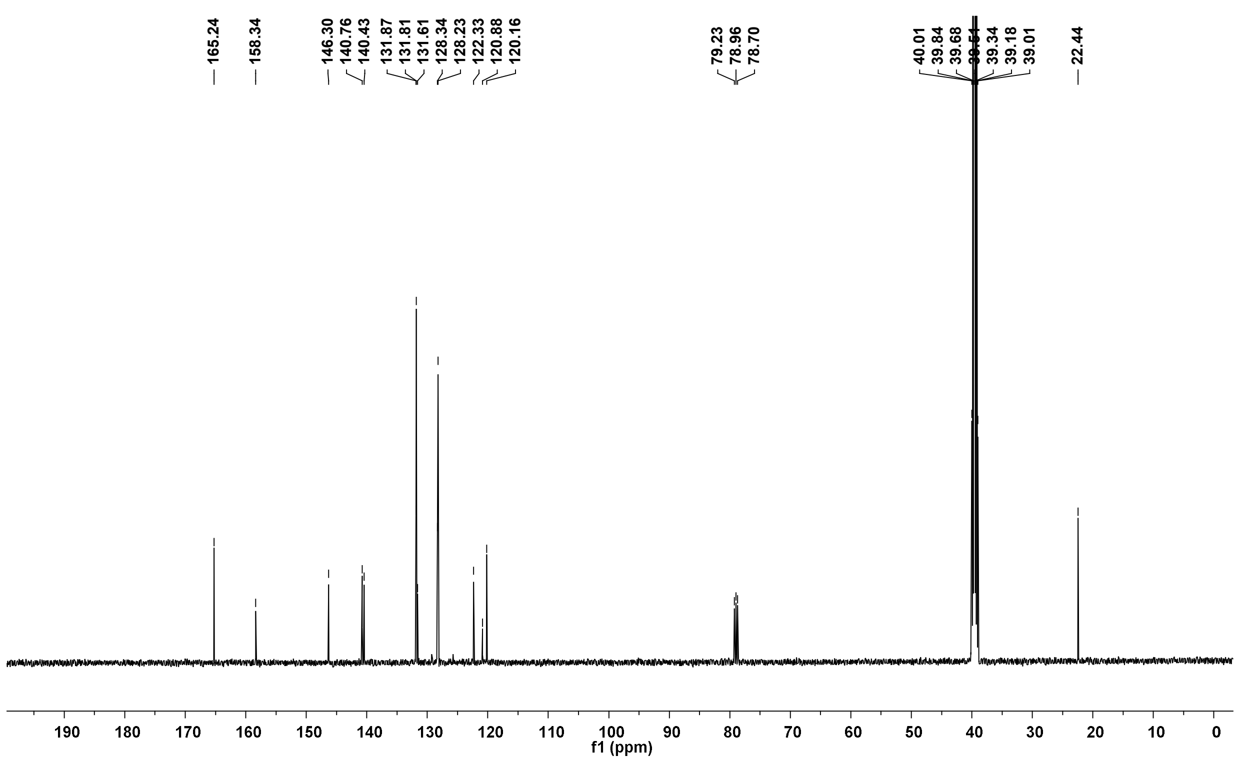


^{1}H and ^{13}C NMR of Compound 4v-i in DMSO-d_6 (1 drop $CDCl_3$)

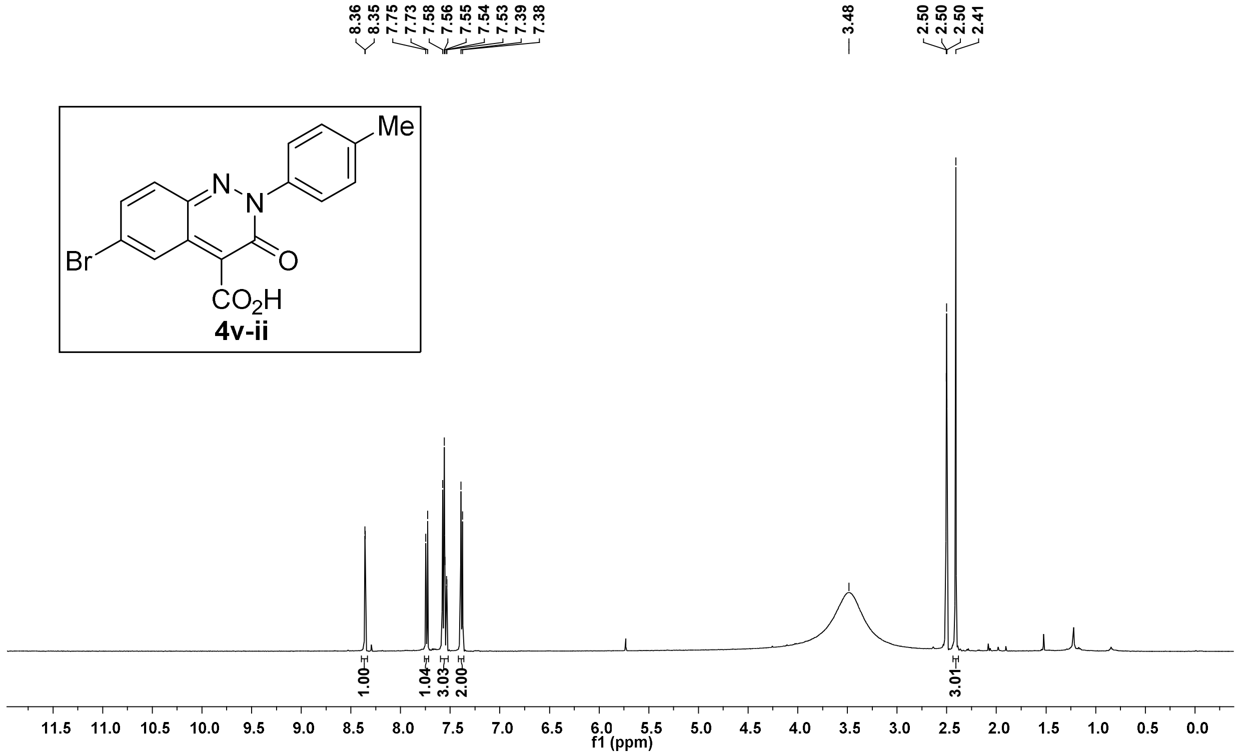


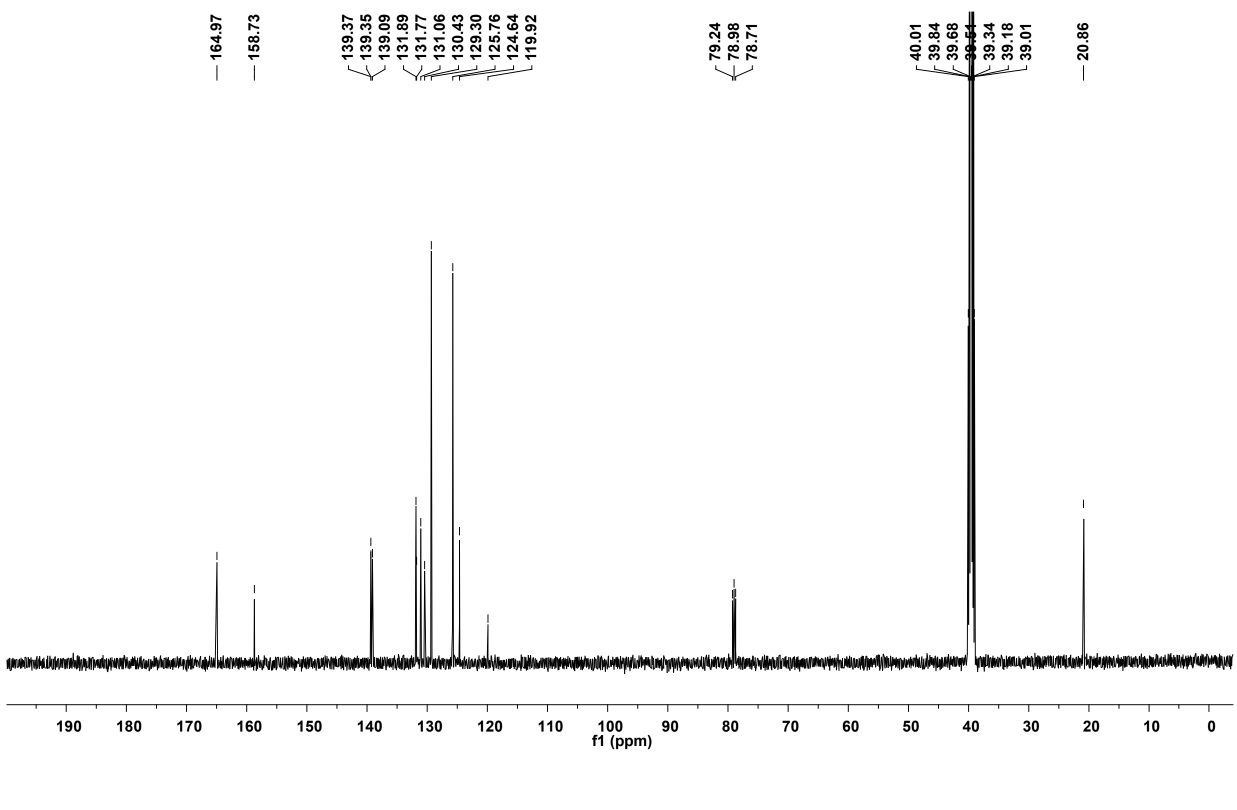
4v-i



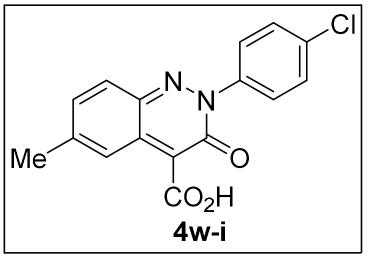


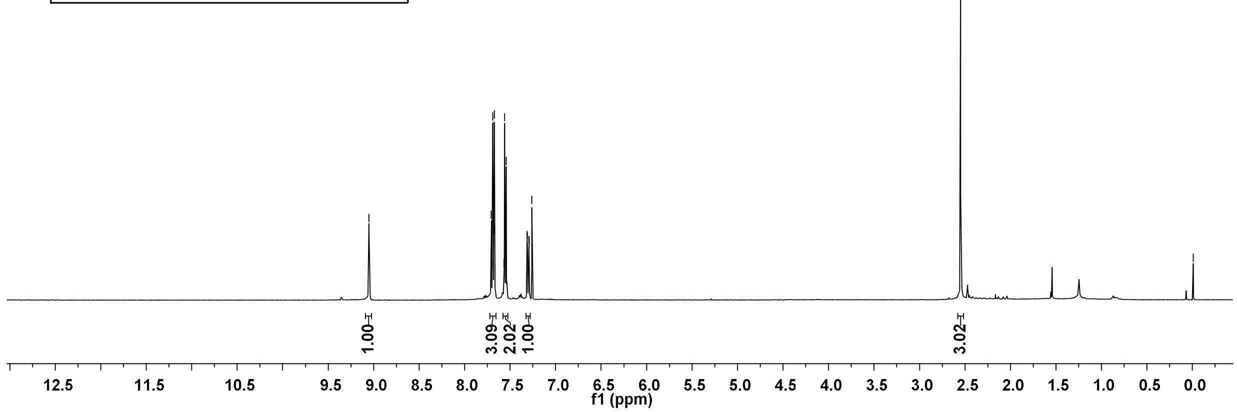
^{1}H and ^{13}C NMR of Compound 4v-ii in DMSO-*d_6* (1 drop $CDCl_3$)

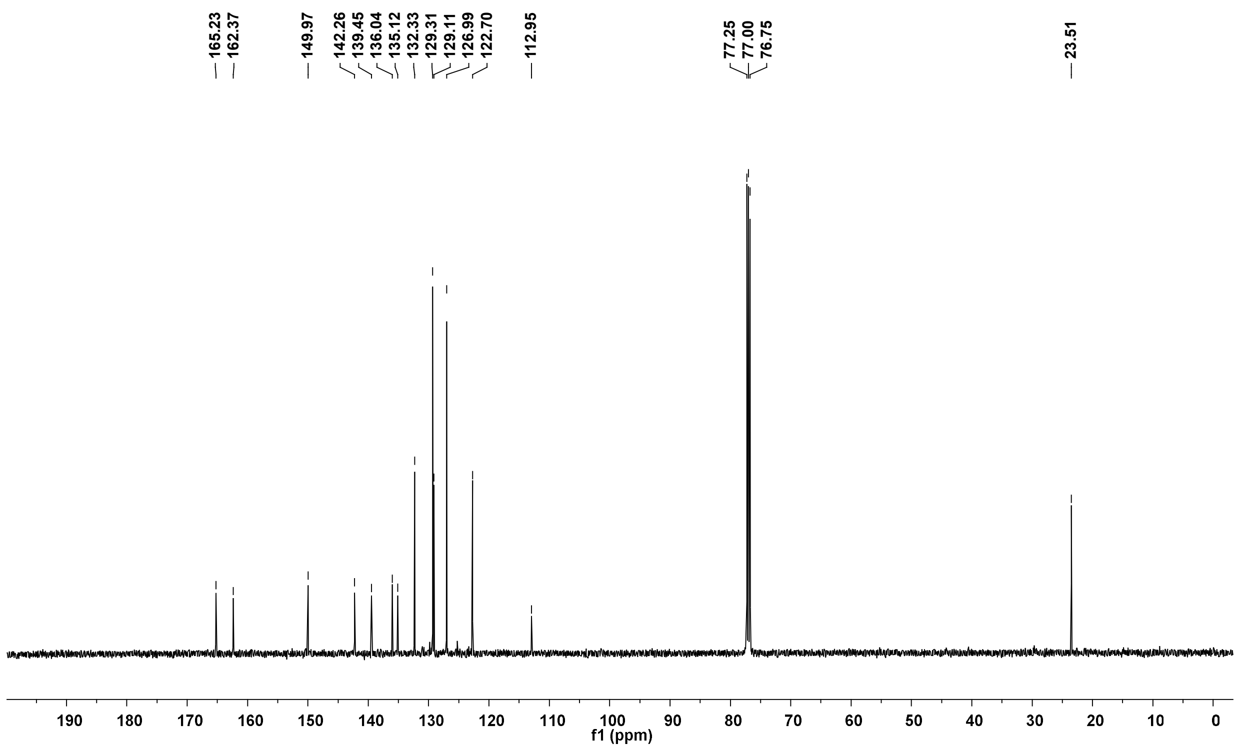




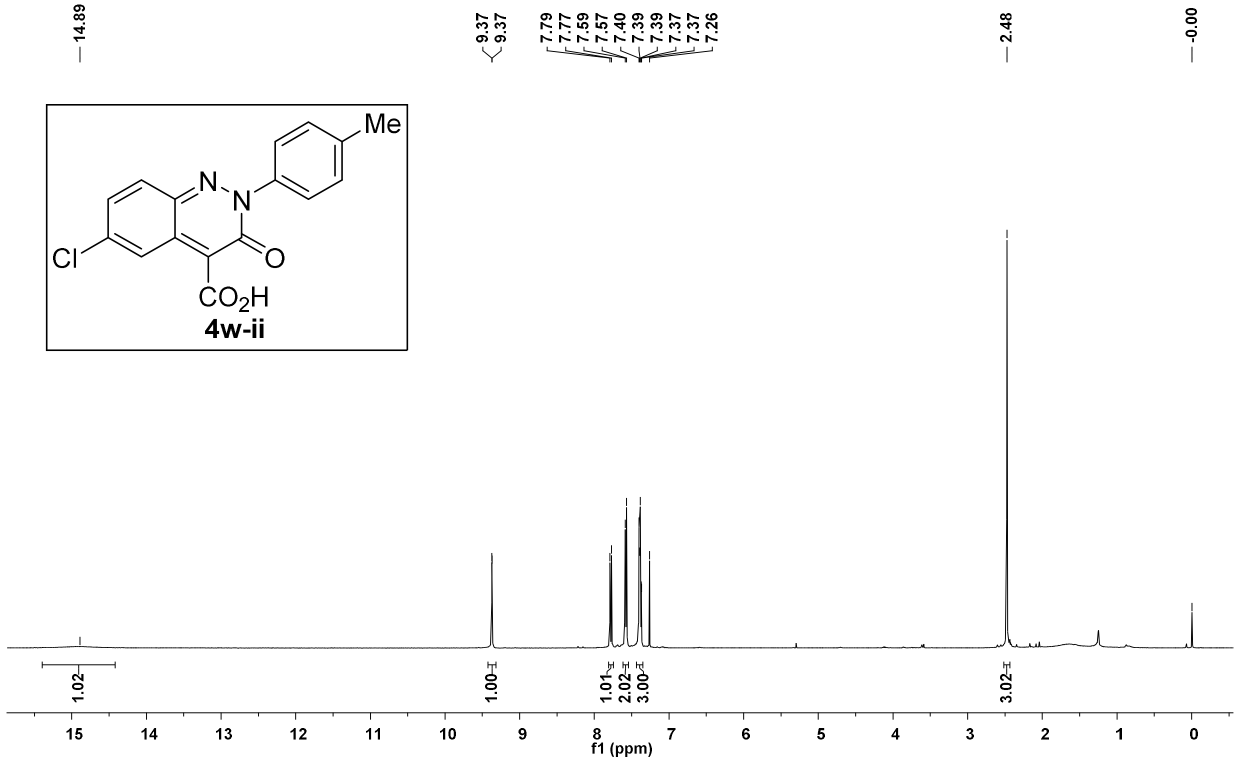
[1]H and [13]C NMR of Compound 4w-i in $CDCl_3$

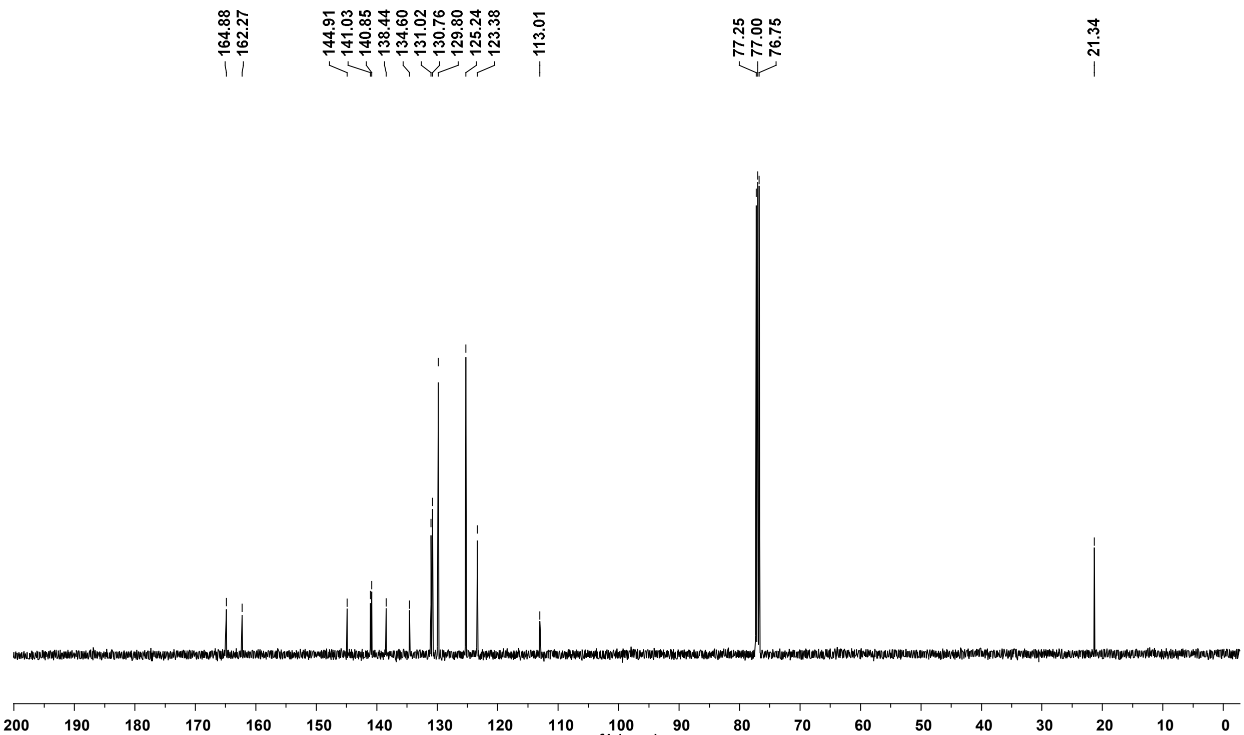




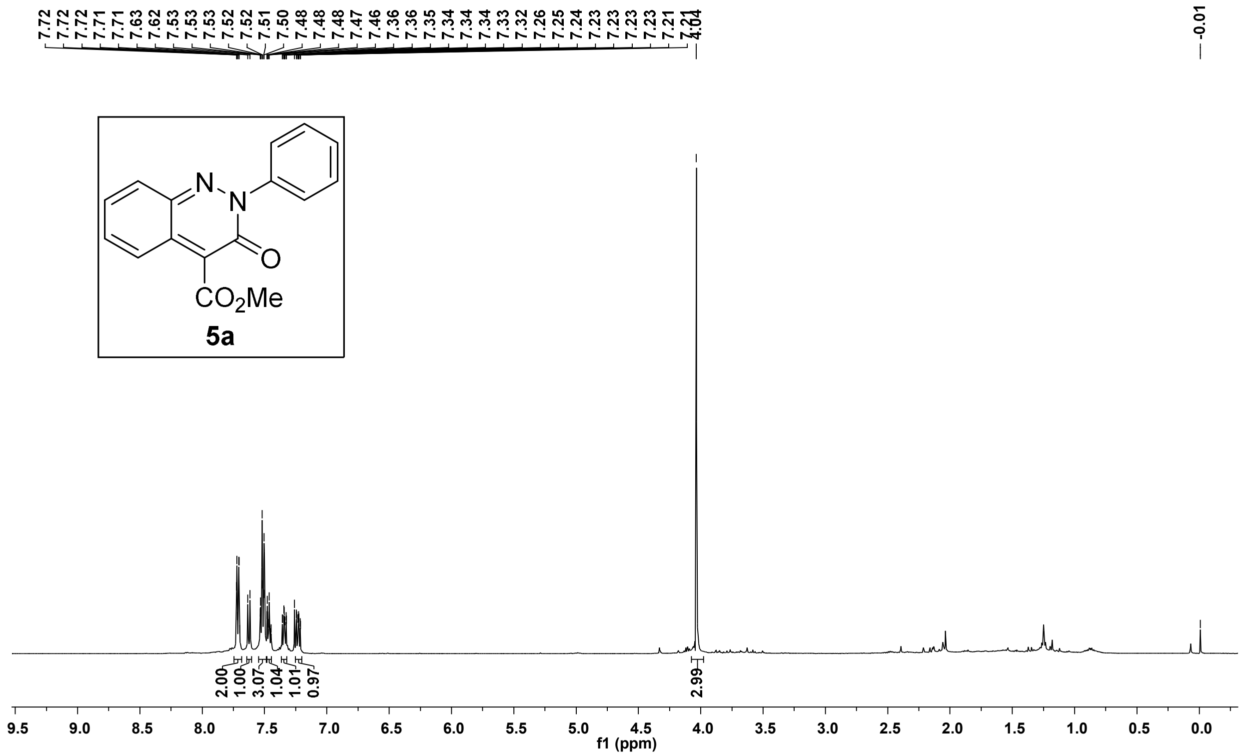


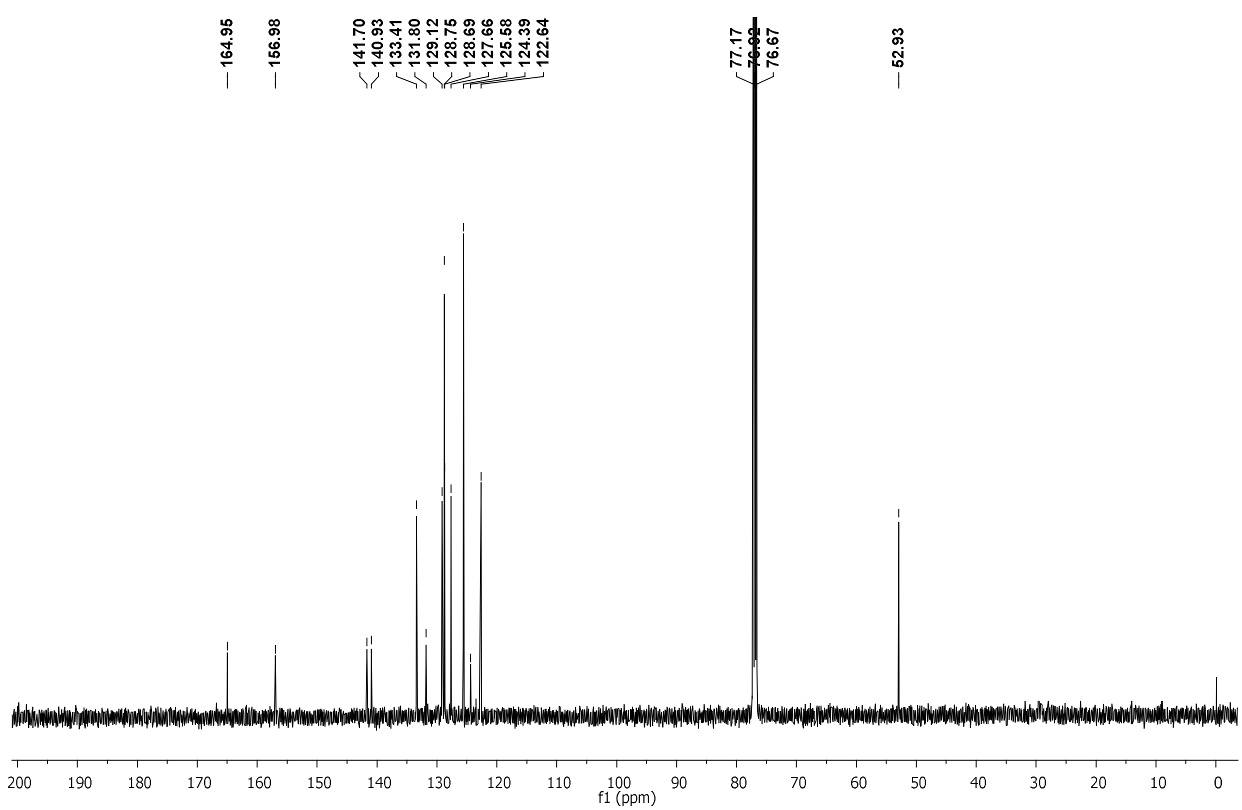
^{1}H and ^{13}C NMR of Compound 4w-ii in $CDCl_3$



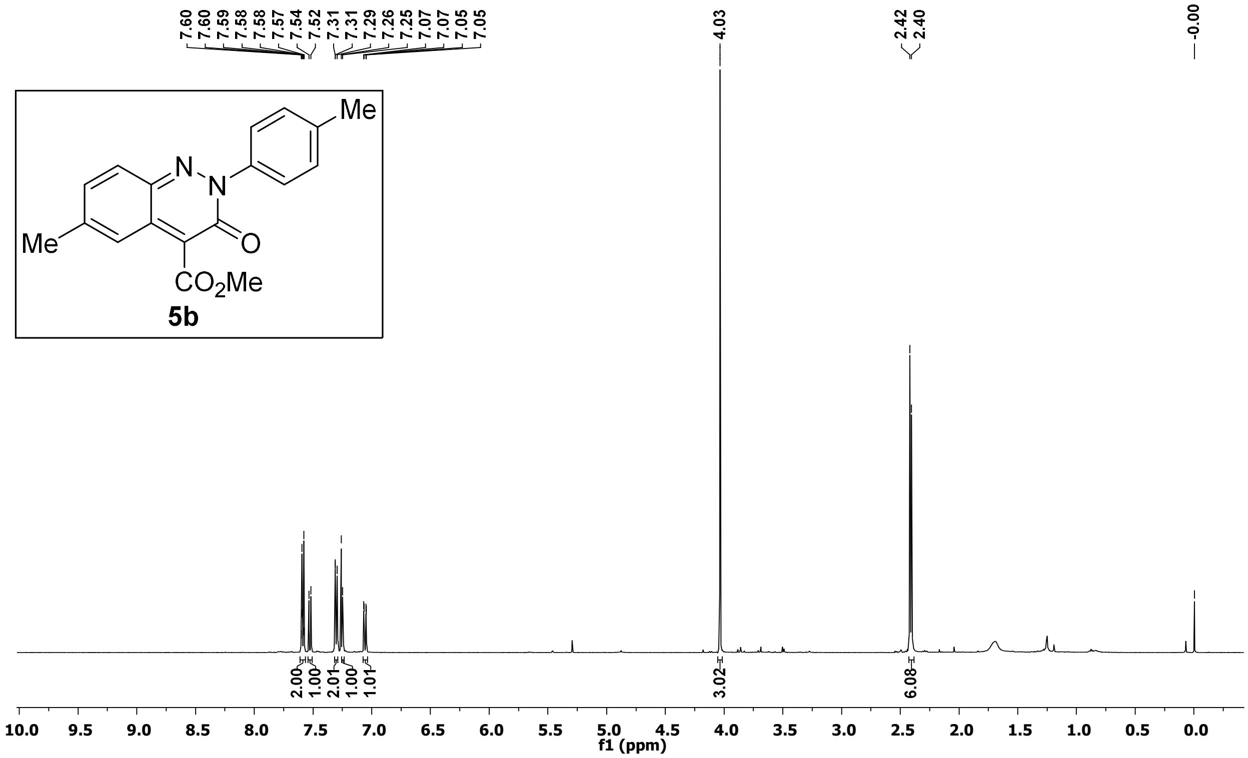


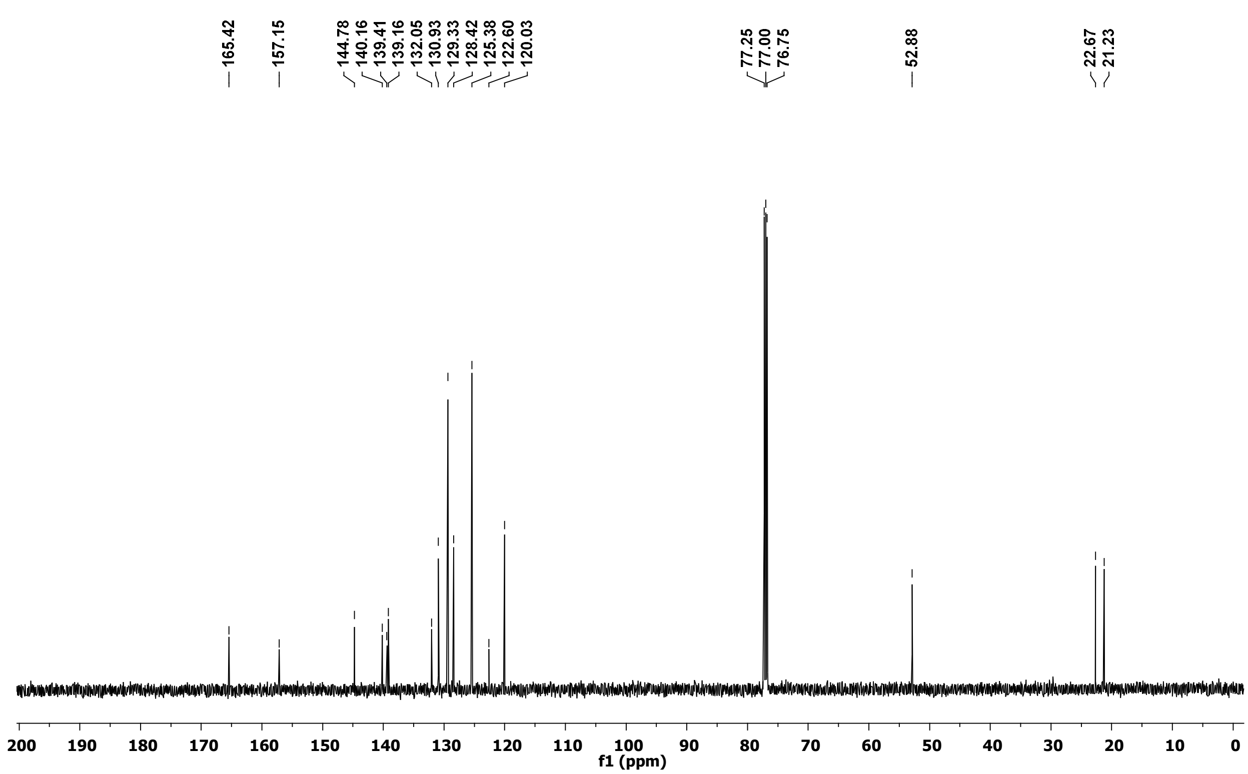
^{1}H and ^{13}C NMR of Compound 5a in $CDCl_3$



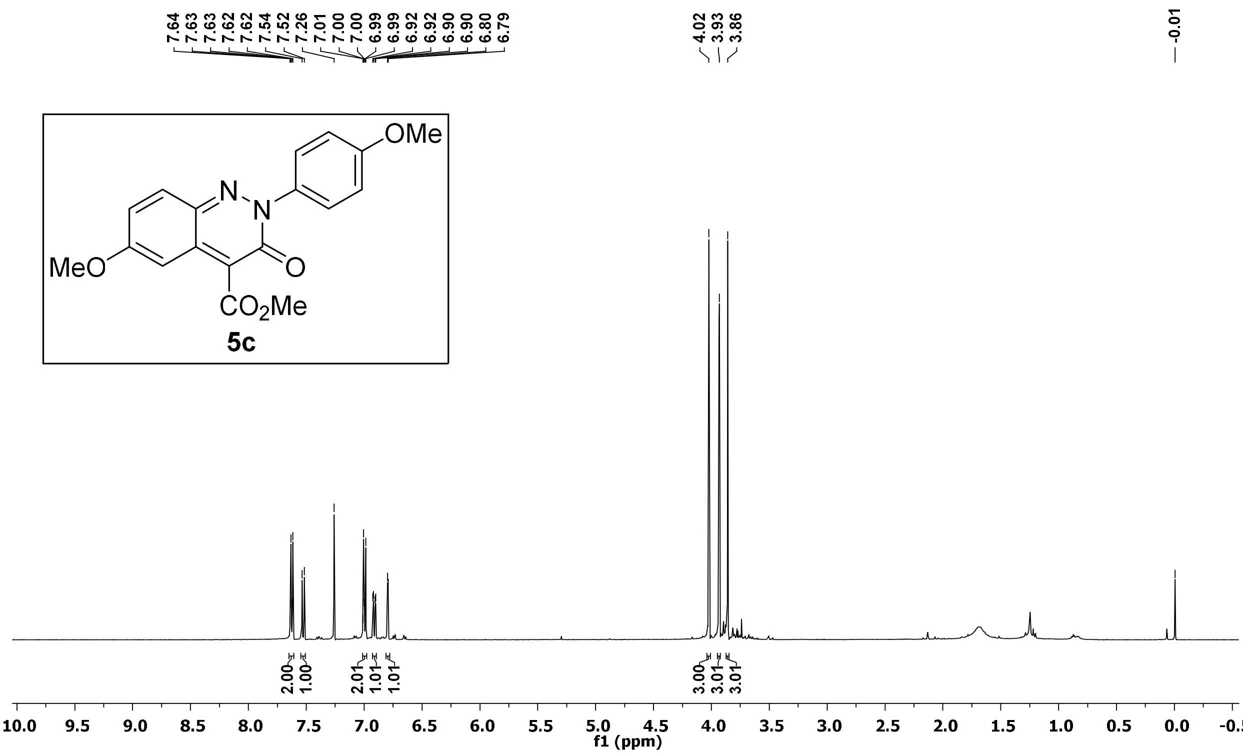


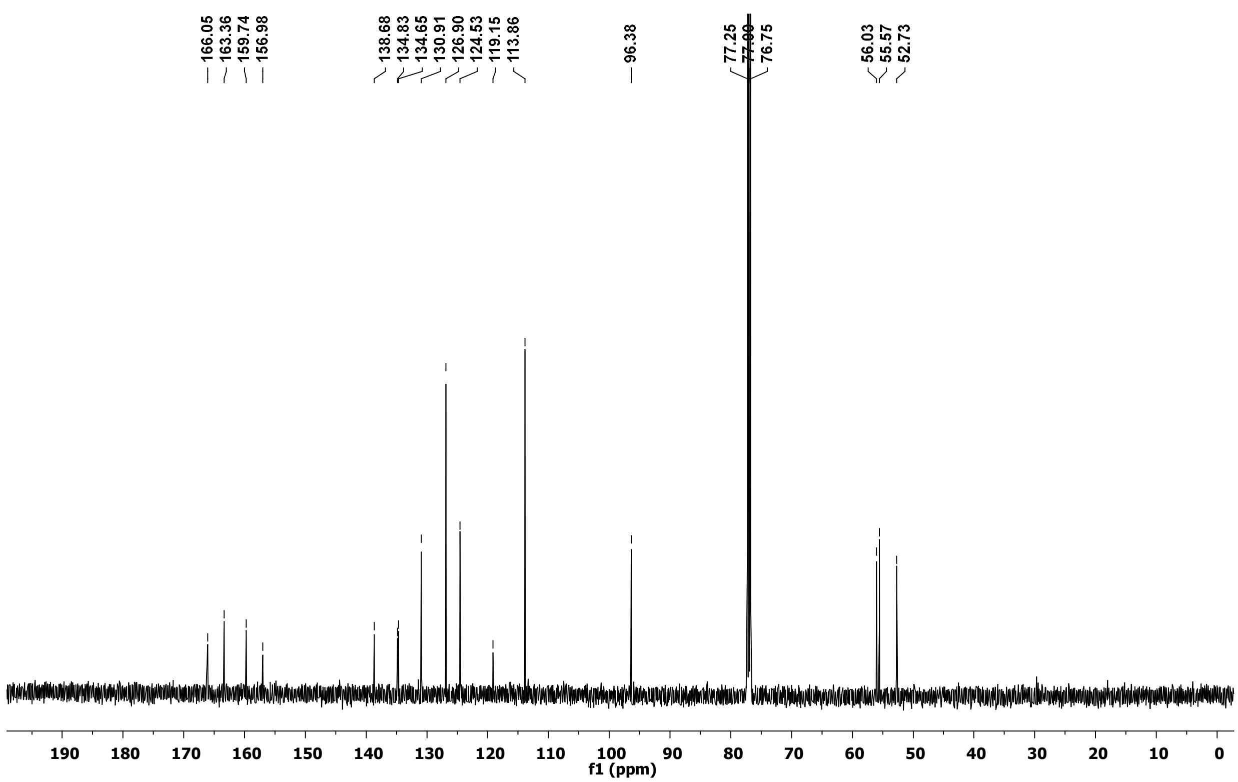
^{1}H and ^{13}C NMR of Compound 5b in $CDCl_3$



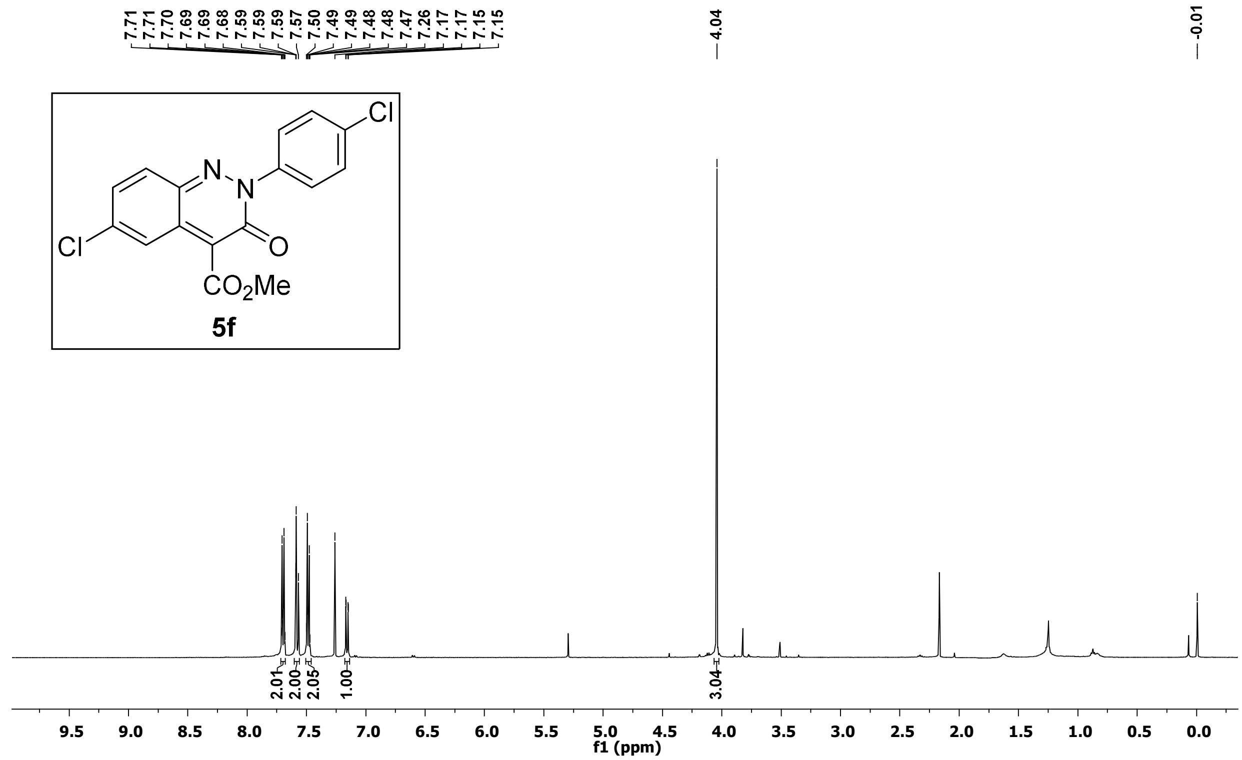


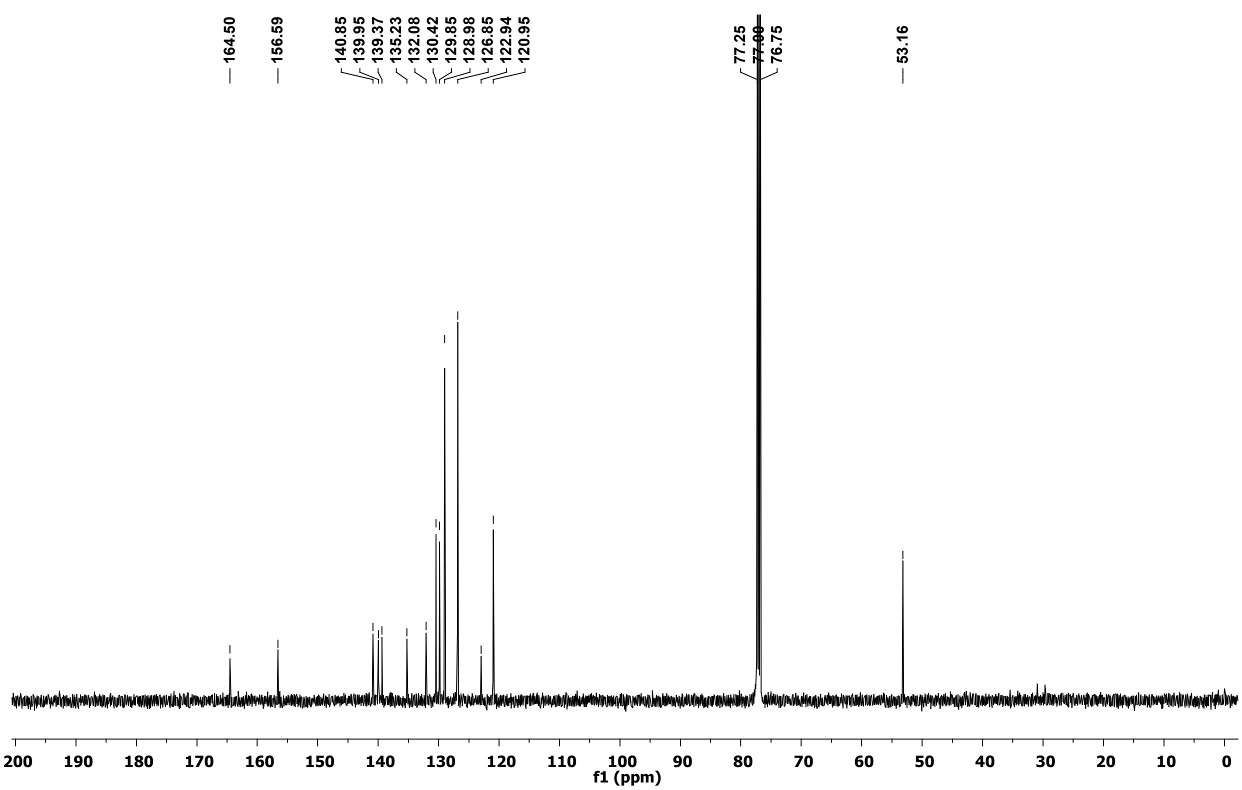
^{1}H and ^{13}C NMR of Compound 5c in $CDCl_3$



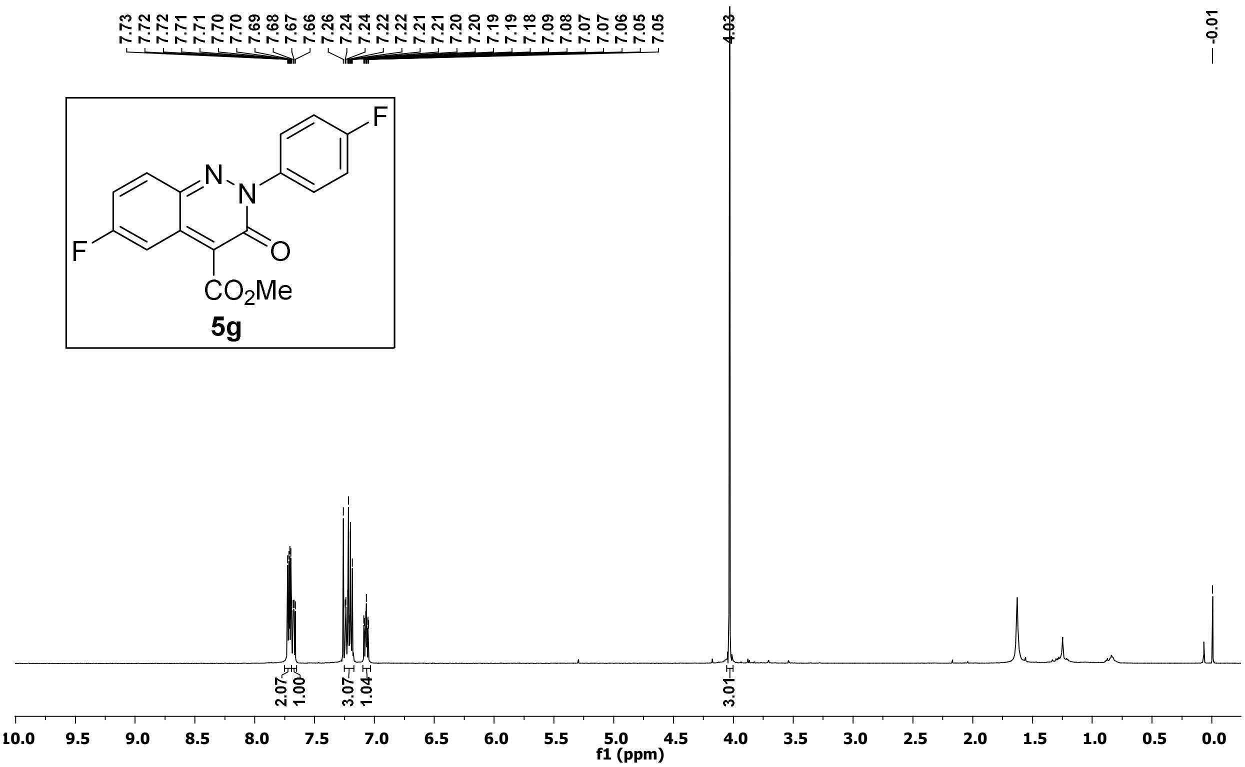


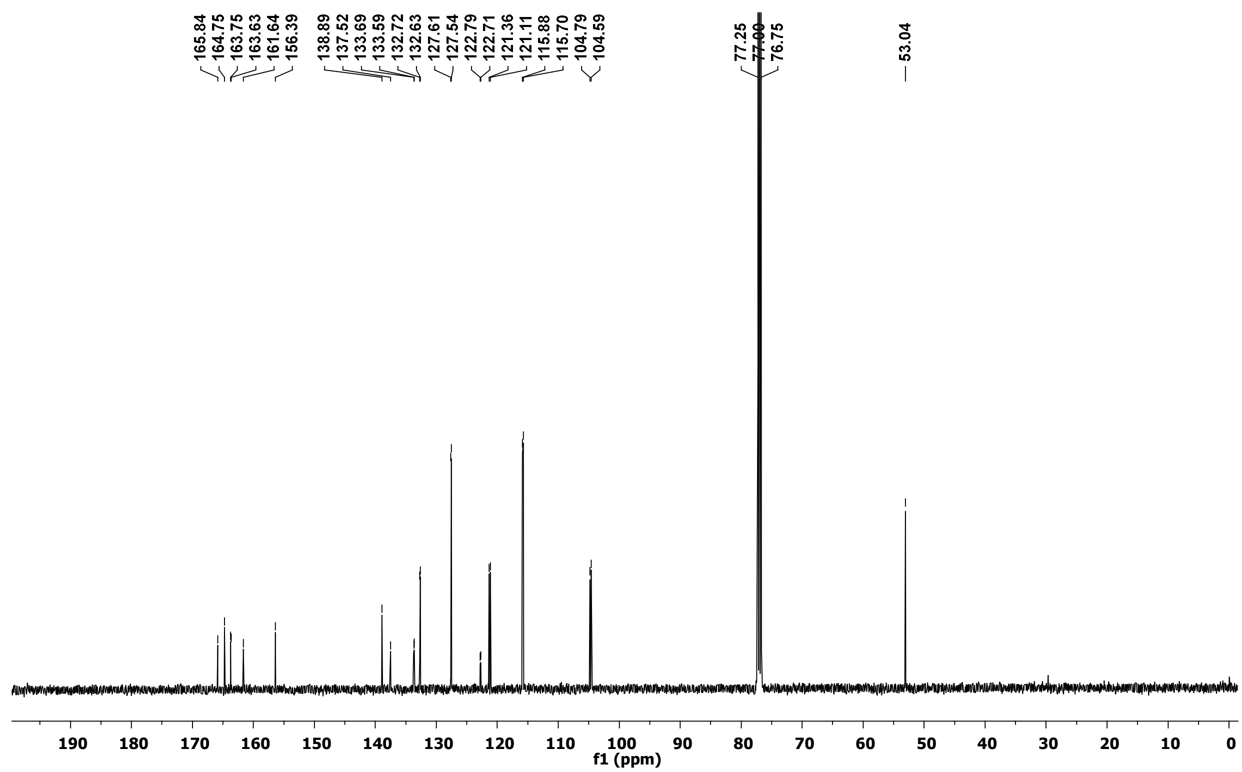
[1]H and [13]C NMR of Compound 5f in $CDCl_3$



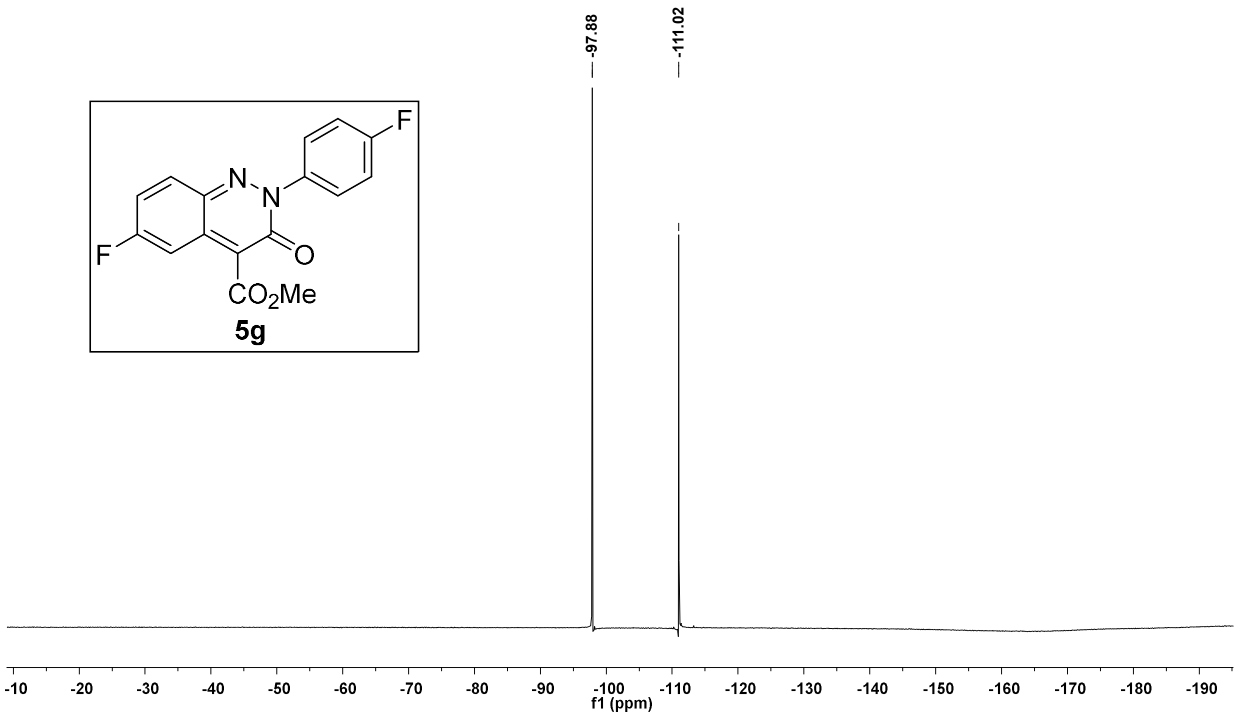


^{1}H and ^{13}C NMR of Compound 5g in $CDCl_3$

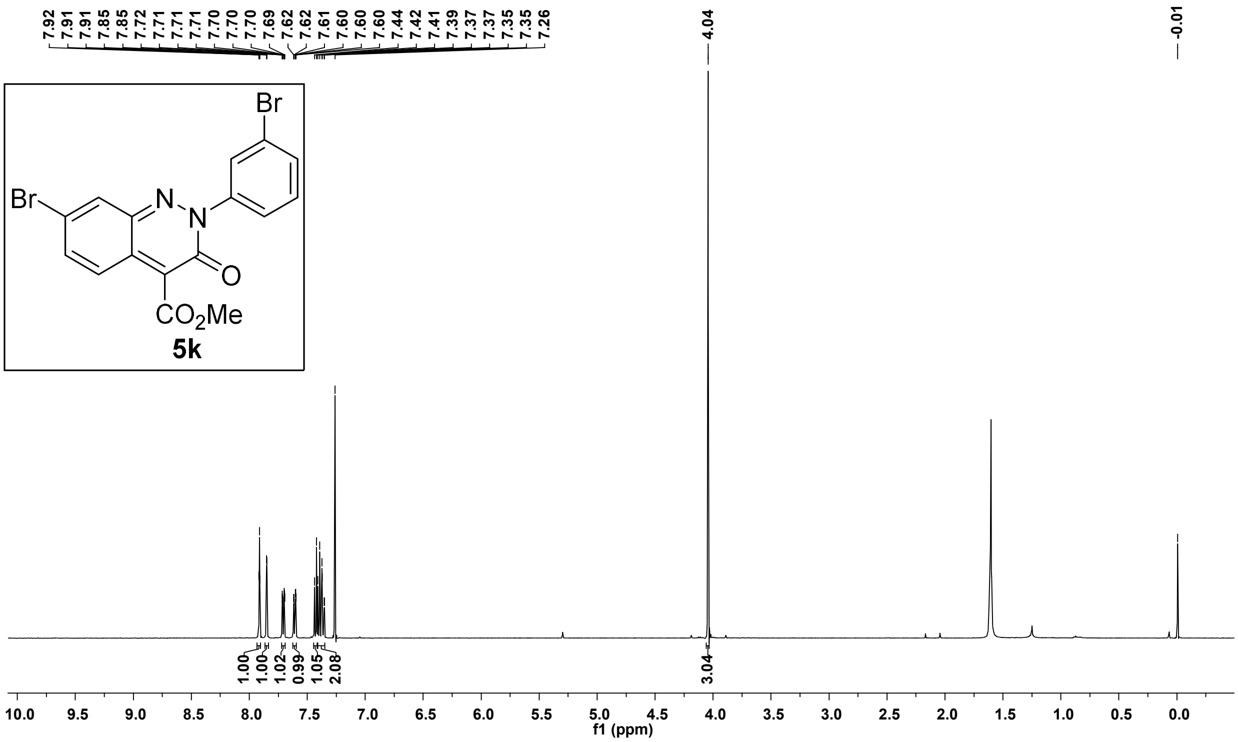


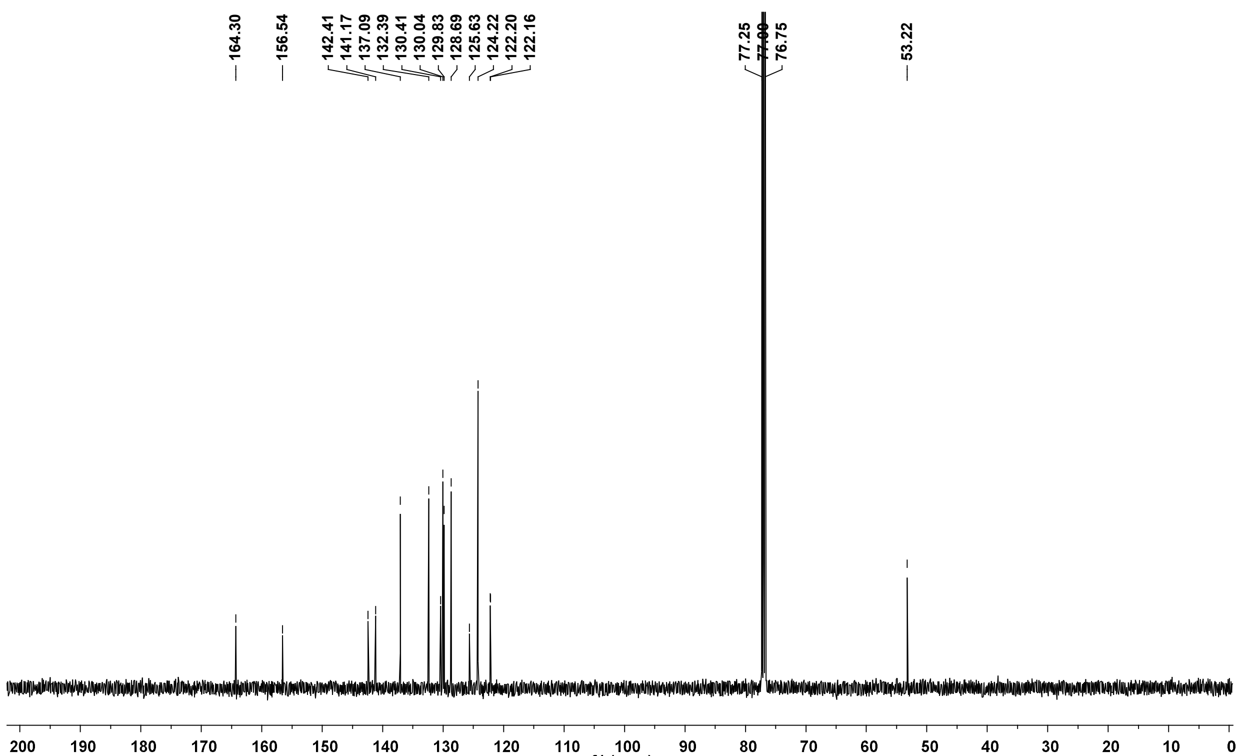


[19]F NMR of Compound 5g in CDCl₃

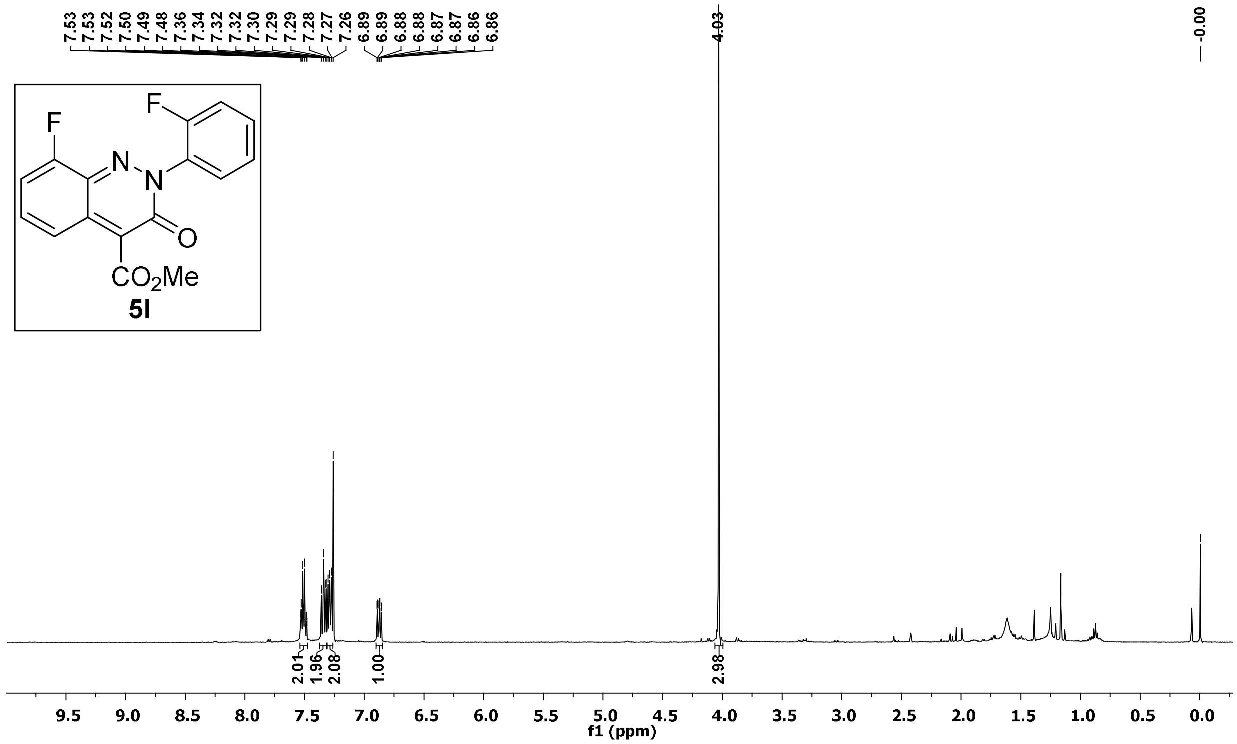


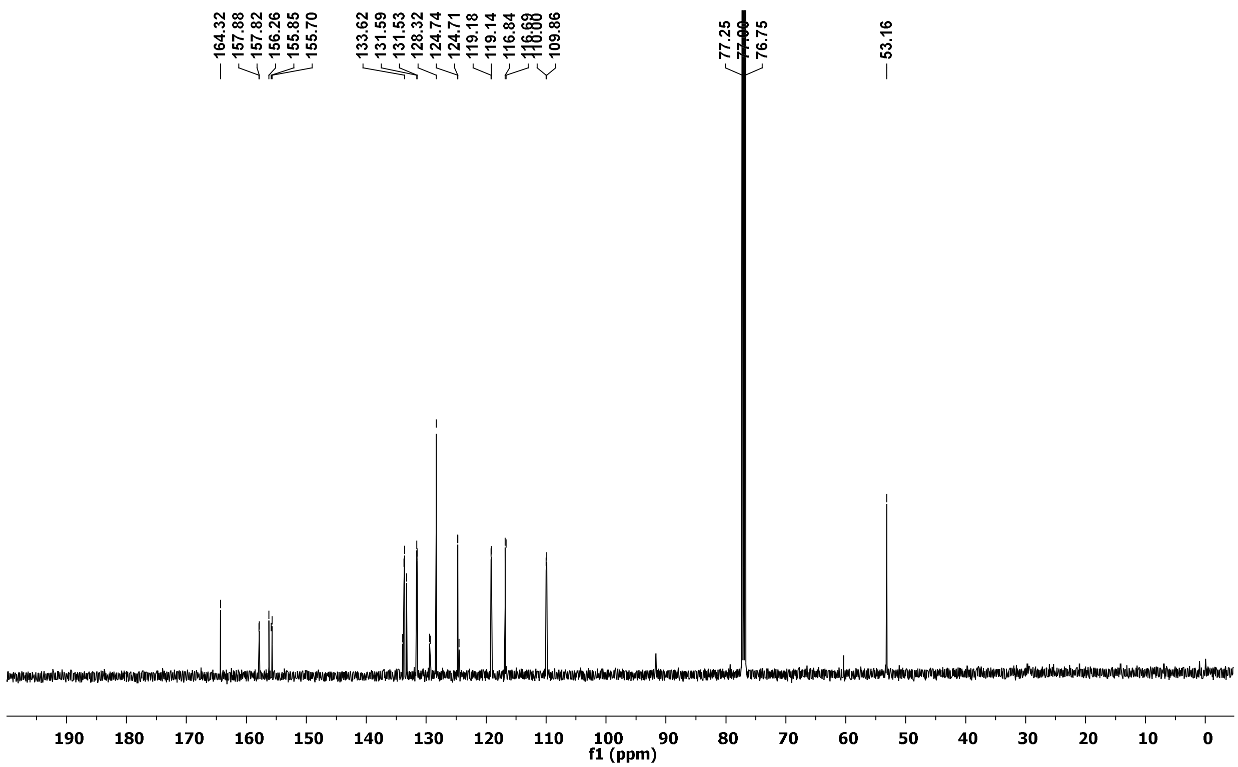
[1]H and [13]C NMR of Compound 5k in $CDCl_3$



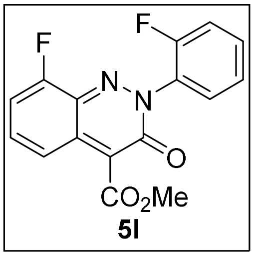


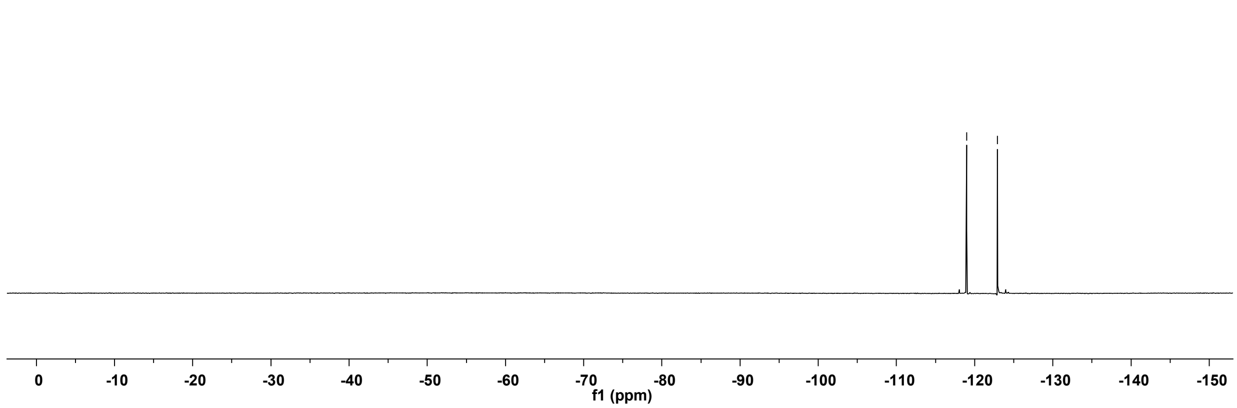
^{1}H and ^{13}C NMR of Compound 5l in CDCl$_3$



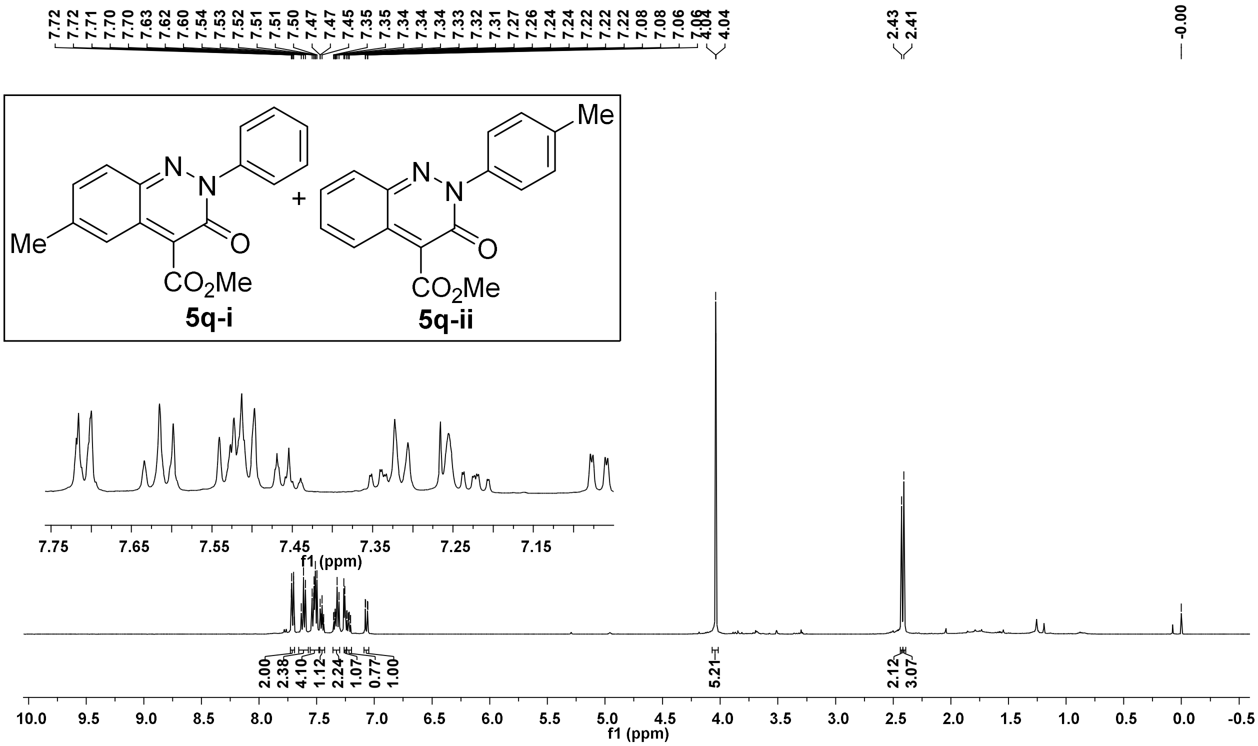


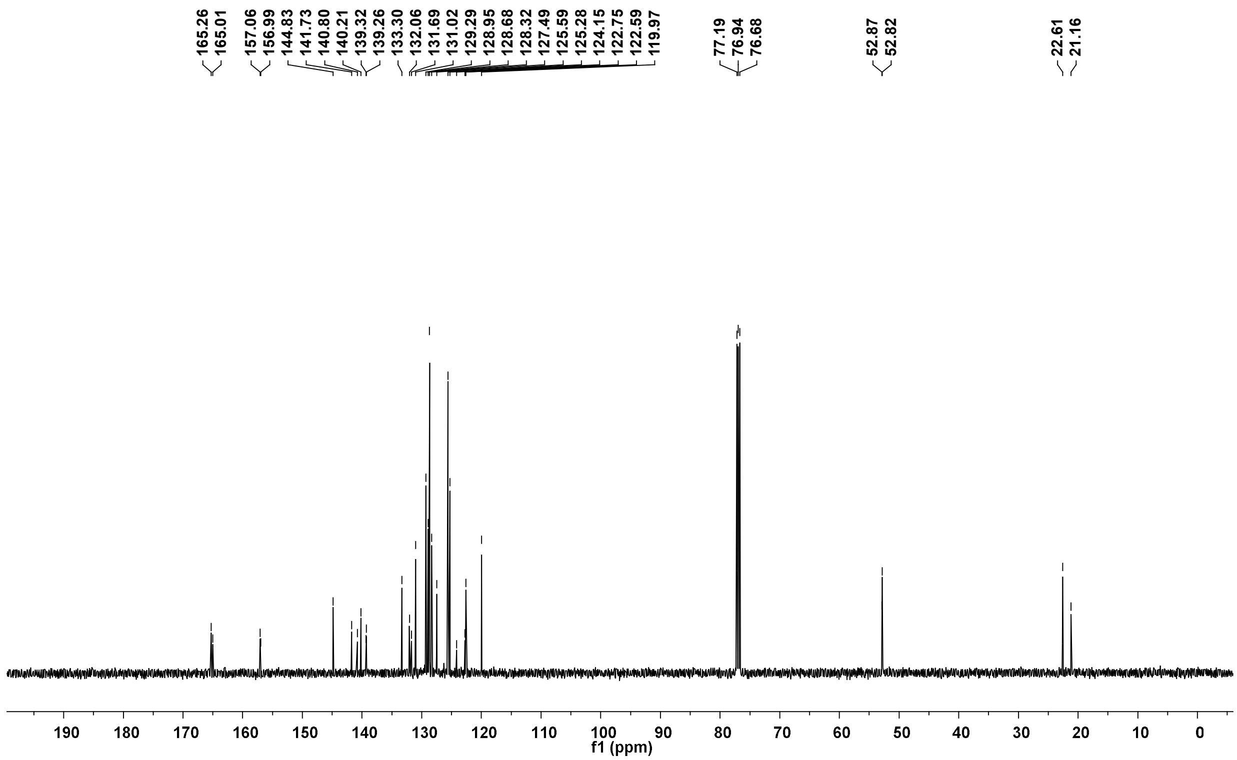
[19]F NMR of Compound 5l in $CDCl_3$



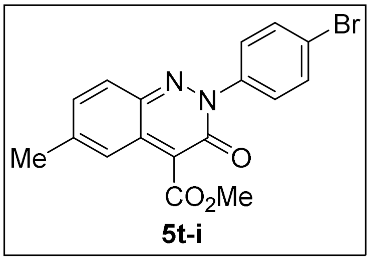


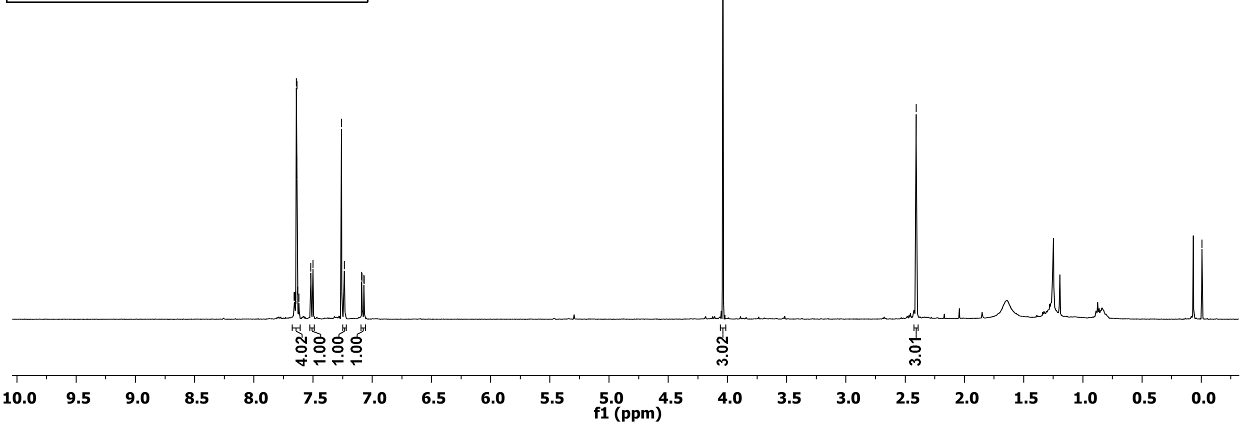
[1]H and [13]C NMR of Compound 5q-i + 5q-ii in $CDCl_3$

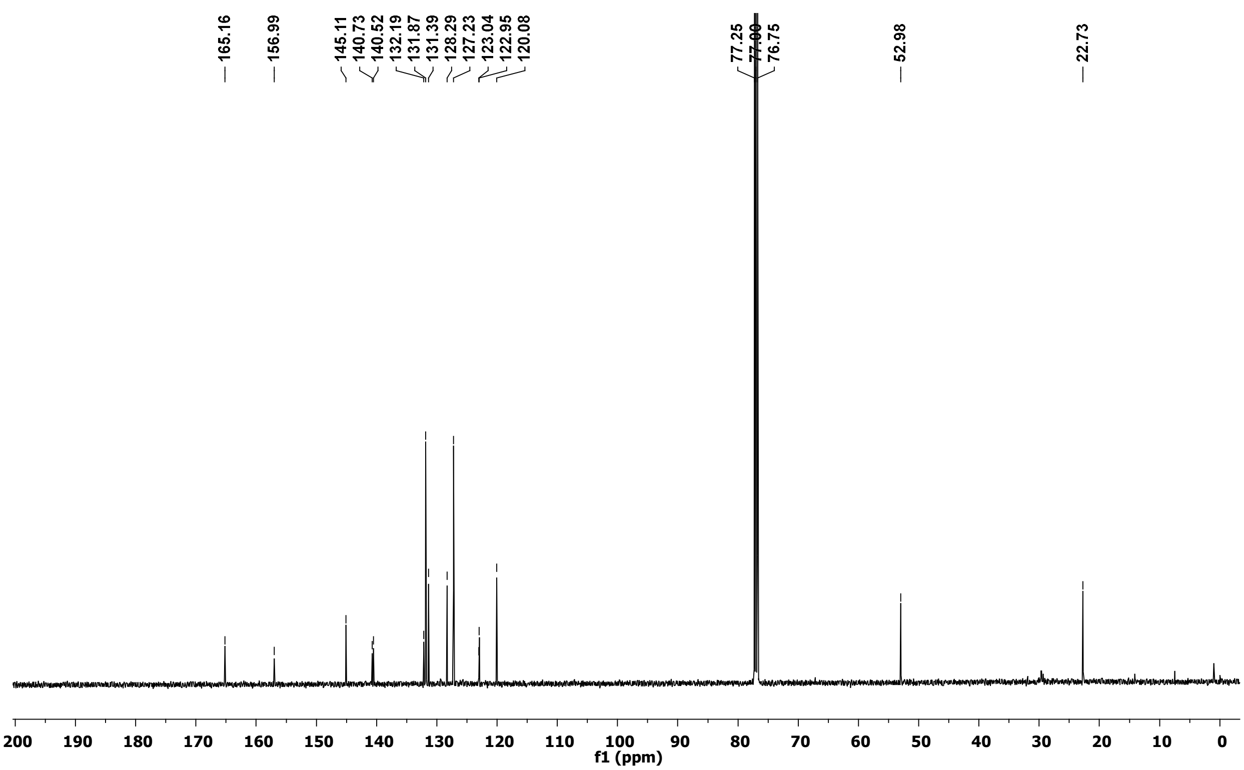




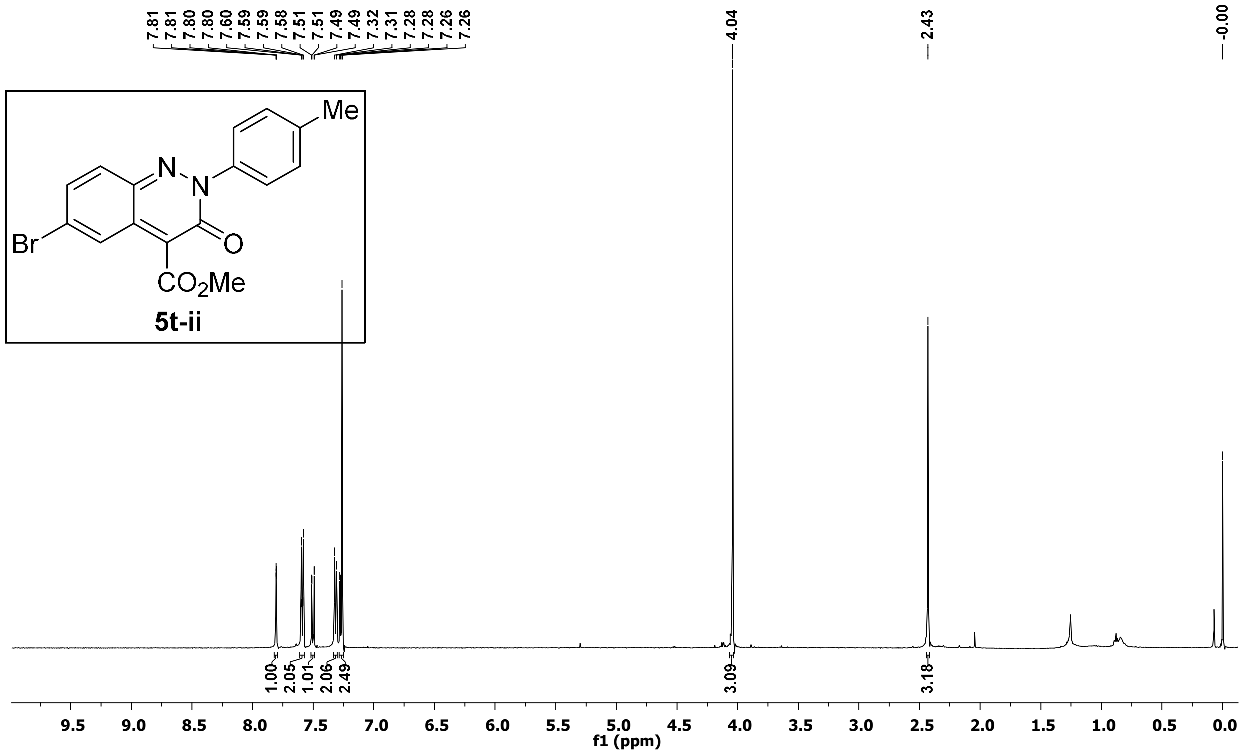
[1]H and [13]C NMR of Compound 5t-i in $CDCl_3$

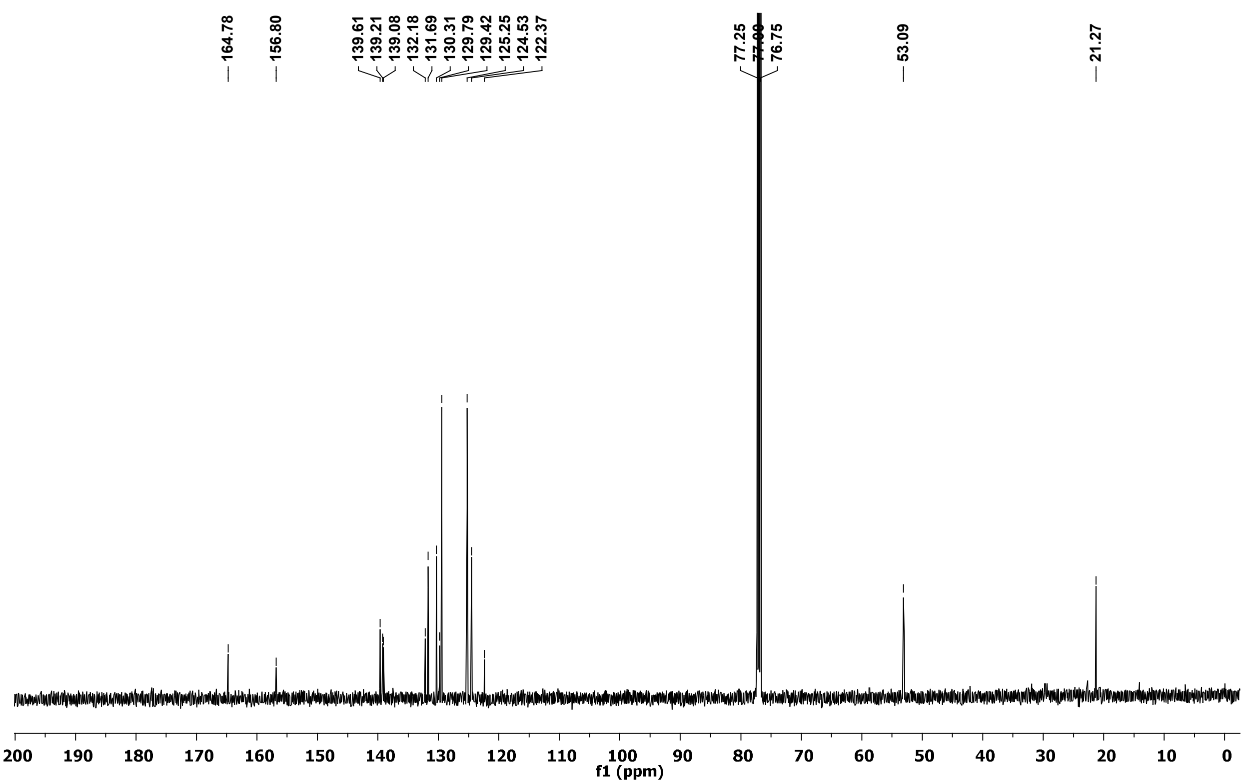




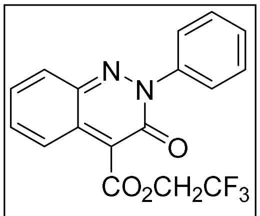


^{1}H and ^{13}C NMR of Compound 5t-ii in $CDCl_3$

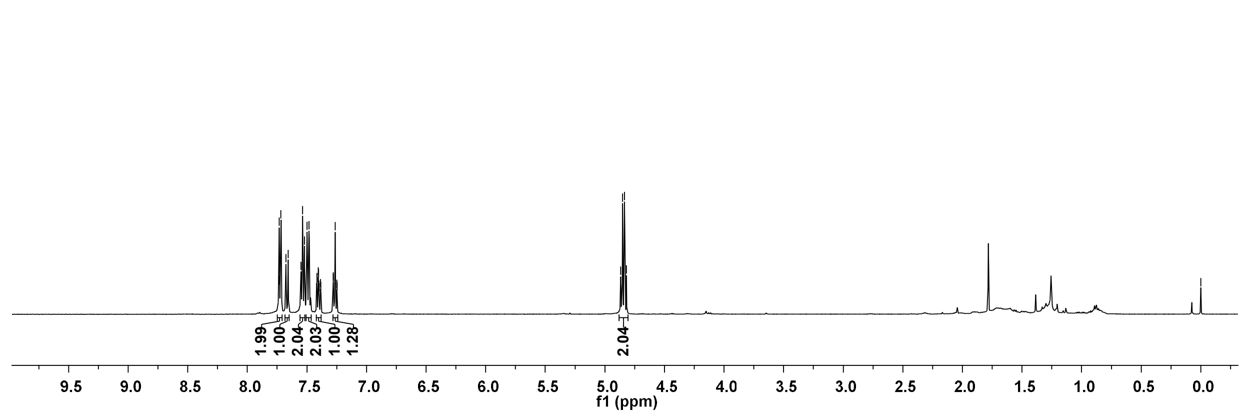


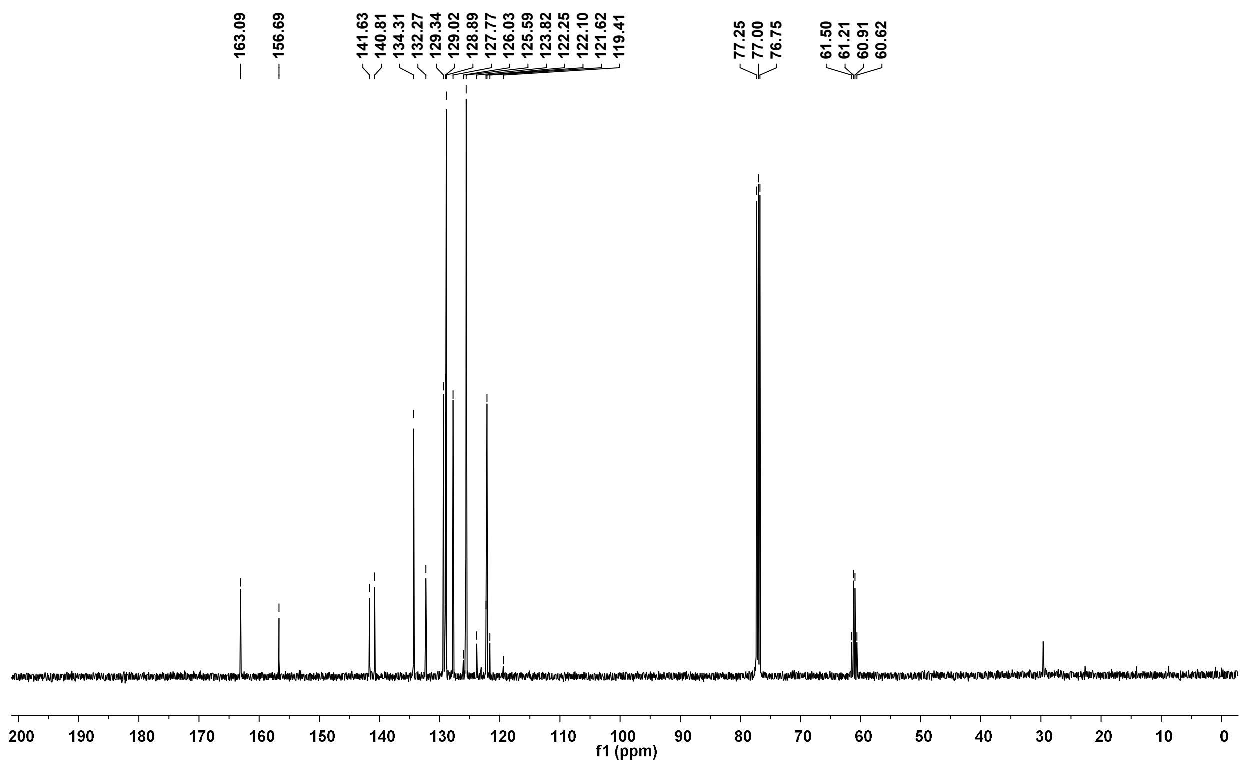


[1]H and [13]C NMR of 6a in $CDCl_3$

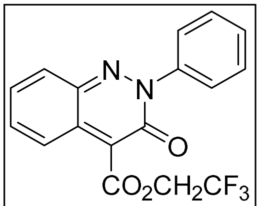


6a

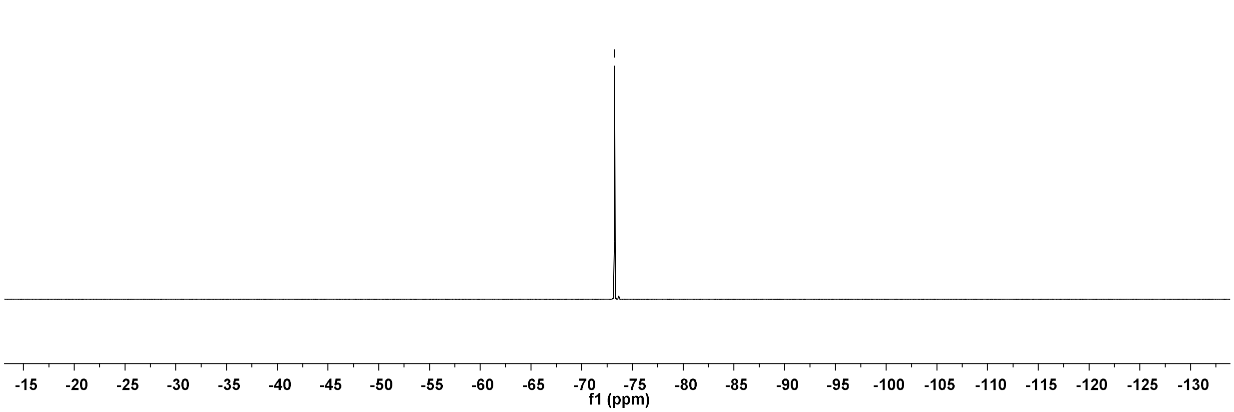




[19]F NMR of 6a in $CDCl_3$



6a



[1]H and [13]C NMR of compound 7 in $CDCl_3$