Supporting Information

Total synthesis of the isoquinoline alkaloid decumbenine B *via* Ru(III)-catalyzed C-H activation

Yong Zhang, Zhongzhen Yang, Lingmei Guo, Weijian Li, Xu Cheng, Xiaolong Wang, Qiantao Wang, Li Hai,* Yong Wu*

Key Laboratory of Drug Targeting and Drug Delivery System of Education Ministry, Department of Medicinal Chemistry, West China School of Pharmacy, Sichuan University, No.17, 3th Section, South Renmin Road, Chengdu, 610041, P. R. China.

Table of Contents

1. Computational study.....S2

2. Supplementary Experimental Section.....S2

2.1 General Information.....S2

2.2 Experimental Procedures and Characterizations.....S3

3. The ratio of compound 3a and 3a'.....S6

4. NMR spectrums of Compounds.....S7

5. Cartesian Coordinates, Structures, and Computed Gibbs Free Energies for Optimized Structures and Transition States.....S17

6. Reference.....S26

1. Computational study

After the careful analysis of Ding's work, we wondered whether or not the valence of ruthenium would play a crucial role in the hydroxymethylation process of compound **1a**. So we performed a computational study using a model system to explore the activation energy barrier of the two regioisomers (**3a** and **3a'**) in the presence of both Ru(II) and Ru(III) (Fig. S1). Considering the computational cost, our calculation was limited to the most important formaldehyde insertion step. In the presence of Ru(II), the calculation suggested that the activation energy barrier for **M-1** was 3.9 kcal/mol higher than **O-1**. To our delight, such activation energy barrier for **M-1** is 1.7 kcal/mol lower than **O-1** when the metal was changed to Ru(III). In other words, it might be possible to increase the yield of **3a** by replacing Ru(II) with Ru(III).

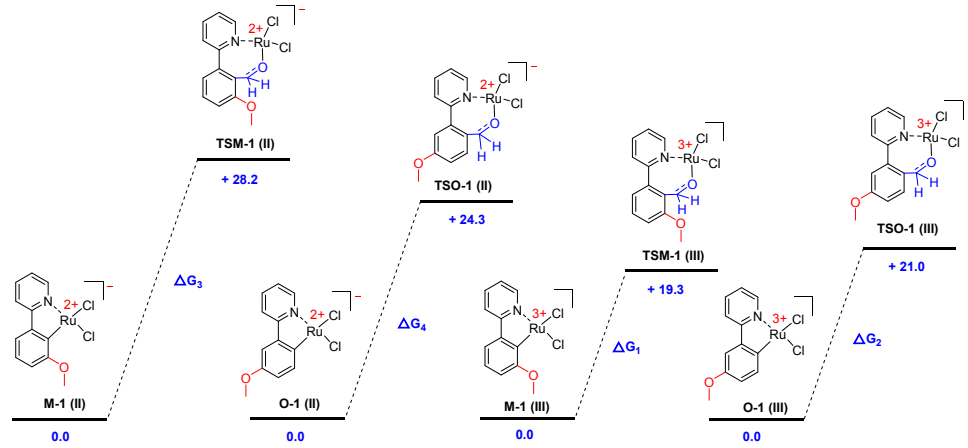


Figure S1. Computed reaction profile of the insertion of formaldehyde catalyzed by Ru(II) and Ru(III). Relative energies (ZPVE included) are given in kcal/mol. All structures were optimized at the B3LYP/6-31G*/LANL2DZ ECP level of theory, followed by the frequency calculation at the same level. The final energy was further corrected using M06/6-311G+(d,p)/SRSC 1997 ECP energy with the COSMO solvation model.[S1] All calculations were done in NWChem6.6.[S2] Similar methods have been effectively used in reaction energy calculations of similar systems.[S3]

2. Supplementary Experimental Section

2.1 General Information

All reagents and solvents were used as received from Sigma-Aldrich or other commercial sources. All the reactions were monitored by thin-layer chromatography (TLC) and were visualized using UV light. The product purification was done using silica gel column chromatography. Thin layer chromatography (TLC) characterization was performed with precoated silica gel GF254 (0.2mm), while column chromatography characterization was performed with silica gel (100-200 mesh). ^{1}H and ^{13}C NMR spectra were recorded with tetramethylsilane as the internal standard. ^{1}H NMR spectra were recorded at 400 or 600 MHz and ^{13}C NMR spectra were recorded at 100 or 150 MHz. Chemical shifts (δ) were reported as parts per million

(ppm) downfield from tetramethylsilane and the following abbreviations were used to identify the multiplicities: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br = broad and all combinations thereof can be explained by their integral parts. Melting points were determined using the X-4 micro melting point apparatus. ESI-HRMS data were obtained with a Waters SYNAPT G2 mass spectrometer.

2.2 Experimental Procedures and Characterizations

General procedure for the synthesis of 3. To a 15 ml oven-dried tube was added $ZnBr_2$ (0.3 mmol, 67.6 mg), $RuCl_3 \cdot xH_2O$ (0.06 mmol, 10 mol%, 15.3 mg), THF (2.0 mL), compound **1** (0.6 mmol), paraformaldehyde **2a** (3.0 mmol, 90.1 mg) and $ZnMe_2$ (2.1 mmol, 1.0 M in toluene, 2.1 mL) sequentially under argon. The tube was sealed and stirred at 60 °C for 24h. After completion, the reaction mixture was diluted with saturated. aq NH_4Cl (10 mL) and extracted with ethyl acetate (10 mL×3). Then the oganic layer was dried with anhydrous sodium sulfate, concentrated in vacuo and purified by silica gel column chromatography (10:1 PE/EtOAc) to provide pure product **3**.

(2-methoxy-6-(pyridin-2-yl)phenyl)methanol (3a). Compound **3a** and **3a'** are inseparable mixture.[S4] compound **3a**: pale yellow oil, Yield 66.7%, ^{1}H NMR (400 MHz, DMSO-d_6) δ 8.66 (d, J = 4.0 Hz, 1H), 7.96-7.91 (m, 1H), 7.73 (d, J = 8.0 Hz, 1H), 7.49-7.41 (m, 1H), 7.38 (t, J = 8.0 Hz, 1H), 7.10 (d, J = 8.0 Hz, 2H), 5.10 (t, J = 6.4 Hz, 1H), 4.38 (d, J = 6.4 Hz, 2H), 3.85 (s, 3H). Spectroscopic data were in agreement with literature values.[S4]

(4-methoxy-2-(pyridin-2-yl)phenyl)methanol (3a'). Pale yellow oil, yield 24.3%, ^{1}H NMR (400 MHz, DMSO-d_6) δ 8.66 (d, J = 4.0 Hz, 1H), 7.93-7.89 (m, 1H), 7.69 (d, J = 8.0 Hz, 1H), 7.49-7.40 (m, 2H), 7.05-6.96 (m, 2H), 5.29 (t, J = 6.4 Hz, 1H), 4.40 (d, J = 6.4 Hz, 2H), 3.80 (s, 3H). Spectroscopic data were in agreement with literature values.[S4]

(5-(pyridin-2-yl)benzo[d][1,3]dioxol-4-yl)methanol (3b). Pale yellow oil, yield 63%, ^{1}H NMR (600 MHz, DMSO-d_6) δ 8.63 (d, J = 4.8 Hz, 1H), 7.91 (t, J = 7.8 Hz, 1H), 7.71 (d, J = 8.4 Hz, 1H), 7.35-7.40 (m, 1H), 7.10 (d, J = 8.4 Hz, 1H), 6.97 (d, J = 8.4 Hz, 1H), 6.11 (s, 2H), 5.64 (t, J = 6.0 Hz, 1H), 4.37 (d, J = 6.6 Hz, 2H). ^{13}C NMR (150 MHz, DMSO-d_6) δ 157.78, 148.50, 147.32, 146.52, 137.54, 134.29, 123.89, 123.81, 122.18, 121.42, 107.58, 101.35, 55.15.

(6-(pyridin-2-yl)benzo[d][1,3]dioxol-5-yl)methanol (3b'). Pale yellow oil, yield 16%, ^{1}H NMR (600 MHz, DMSO-d_6) δ 8.62 (d, J = 4.8 Hz, 1H), 7.88 (t, J = 7.8 Hz, 1H), 7.60 (d, J = 7.8 Hz, 1H), 7.39-7.34 (m, 1H), 7.10 (s, 1H), 7.05 (s, 1H), 6.06 (s, 2H), 5.37 (s, 1H), 4.38 (s, 2H).^{13}C NMR (150 MHz, DMSO-d_6) δ 157.92, 148.66, 147.37, 146.21, 137.02, 134.78, 132.58, 123.98, 122.06, 109.51, 108.77, 101.24, 61.31.

2-bromo-3,4-dihydroxybenzaldehyde (5). To a stirred suspension of 2-bromo-3-hydroxy-4-methoxybenzaldehyd (**4**, 5.78 g, 25 mmol) in 100 mL of dry CH_2Cl_2 under argon was added anhydrous $AlCl_3$ (3.68 g, 27.5 mmol) gradually over a period of 5 min. Anhydrous pyridine (freshly distilled after being stored over NaOH pellets; 8.7 g, 8.86 mL, 110 mmol) was then added dropwise to the vigorously stirred mixture.

The clear, homogeneous, orange solution was then refluxed under Ar for 30 h. After cooling, the mixture was acidified to pH~1 with 6N HCl and filtered. The precipitate was mostly the product and was dissolved in a minimum volume of acetone. The aqueous layer of the filtrate was separated (from the organic layer which contained traces of starting material and was discarded) and extracted twice with Et_2O. The Et_2O extracts were combined with the acetone solution of the precipitate, and the resulting mixture was diluted with 200 mL of Et_2O, washed with brine (3 x 25 mL), dried (anhydrous Na_2SO_4), and then evaporated in vacuo to dryness to give crude product, after recrystallization from EtOAc-hexane pure **5** was obtained (5.21 g, 96%). Gray solid, mp 181-182°C (Lit.[S5] 181-183 °C), ^{1}H NMR (400 MHz, DMSO-d_6) δ 11.04 (brs, 1H), 10.06 (s, 1H), 9.62 (brs, 1H), 7.31 (d, J = 8.4 Hz, 1H), 6.92 (d, J = 8.4 Hz, 1H). Spectroscopic data were in agreement with literature values.[S5]

4-bromobenzo[*d*][1,3]dioxole-5-carbaldehyde (6). To a stirred solution of compound **5** (2.17 g, 10 mmol) in 30 mL of dry DMF under Ar atmosphere was added anhydrous KF (2.9 g, 50 mmol). After 15 min, CH_2Br_2 (1.92 g, 0.77 mL, 11 mmol) was added, and the mixture was heated at 115 °C with stirring for 2 h. The mixture was then evaporated in vacuo to dryness, and the residue was placed on a sintered-glass funnel and washed exhaustively with Et_2O. The combined Et_2O solutions were washed with water and brine, dried (anhydrous Na_2SO_4), and then evaporated in vacuo to dryness to give crude product, after recrystallization from benzene-hexane pure **6** was obtained (1.95 g, 86%). White solid, mp 130-132°C (Lit.[S5] 131-133°C), ^{1}H NMR (400 MHz, DMSO-d_6) δ 9.99 (s, 1H), 7.51 (d, J = 8.0 Hz, 1H), 7.12 (d, J = 8.0 Hz, 1H), 6.28 (s, 2H). Spectroscopic data were in agreement with literature values.[S5]

4-(benzo[*d*][1,3]dioxol-5-ylethynyl)benzo[*d*][1,3]dioxole-5-carbaldehyde (8). To a mixture of dichlorobis(triphenylphosphine)palladium (5 mol %) and compound **6** (1g, 4.37 mmol) in 20 mL THF was added triethyl amine (1.33 g, 1.82 mL, 13.11 mmol). After being stirred for 10 min at room temperature, 5-ethynylbenzo[*d*][1,3]dioxole (**7**, 958 mg, 6.66 mmol) and copper iodide (41.6 mg, 0.219 mmol) were added to the mixture. The resulting mixture was stirred at 70 °C for 3h. The reaction mixture was quenched with saturated aq. NH_4Cl, extracted with EtOAc three times, and washed with brine. The organic layers were dried over Na_2SO_4 and concentrated under reduced pressure after filtration. After silica-gel column chromatography pure compound **8** was obtained (913 mg, 71%). Yellow solid, mp 168-170 °C, ^{1}H NMR (400 MHz, DMSO-d_6) δ 10.19 (s, 1H), 7.52 (d, J = 8.4 Hz, 1H), 7.18-7.10 (m, 3H), 7.00 (d, J = 8.4 Hz, 1H), 6.29 (s, 2H), 6.11 (s, 2H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 189.26, 152.10, 149.47, 148.50, 147.47, 129.69, 126.66, 125.72, 114.71, 111.03, 108.88, 108.51, 105.36, 103.09, 101.70, 98.87, 78.37. HRMS (ESI): m/z calcd for $C_{17}H_{10}O_5Na$ $[M + Na]^+$: 317.0420; found: 317.0422.

8-(benzo[*d*][1,3]dioxol-5-yl)-[1,3]dioxolo[4,5-f]isoquinoline (9). *t*-BuOH (10 mL) was added to a mixture of $AgNO_3$ (57.8 mg, 0.34 mmol), ammonium acetate (393.1 mg, 5.1 mmol) and compound **8** (1.0 g, 3.4 mmol) under Ar atmosphere. The resulting mixture was stirred at room temperature and the reaction was monitored by TLC. After completion, the reaction was quenched by the addition of $NaHCO_3$ (1.14 g, 13.6 mmol) at room temperature and stirring was continued for additional 4 h. The

mixture was then filtered through a cotton plug, washed with EtOAc (10 mL) and dried over anhydrous Na_2SO_4. The filtrate was evaporated under reduced pressure and the residue was purified through silica gel column chromatography (EtOAc in hexane) to obtain the pure compound **9** (650 mg, 65.2%). Yellow solid, mp 160-162 ^oC, ^1H NMR (400 MHz, DMSO-d_6) δ 9.27 (s, 1H), 7.98 (s, 1H), 7.82-7.73 (m, 3H), 7.44 (d, J = 8.4 Hz, 1H), 7.03 (d, J = 8.4 Hz, 1H), 6.33 (s, 2H), 6.09 (s, 2H). ^{13}C NMR (150 MHz, DMSO-d_6) δ 152.59, 149.20, 147.94, 147.89, 146.93, 139.88, 132.96, 123.57, 122.96, 121.74, 120.71, 111.48, 108.44, 106.69, 106.51, 102.43, 101.27. HRMS (ESI): m/z calcd for $C_{17}H_{12}NO_4$ $[M + H]^+$: 294.0761; found: 294.0763.

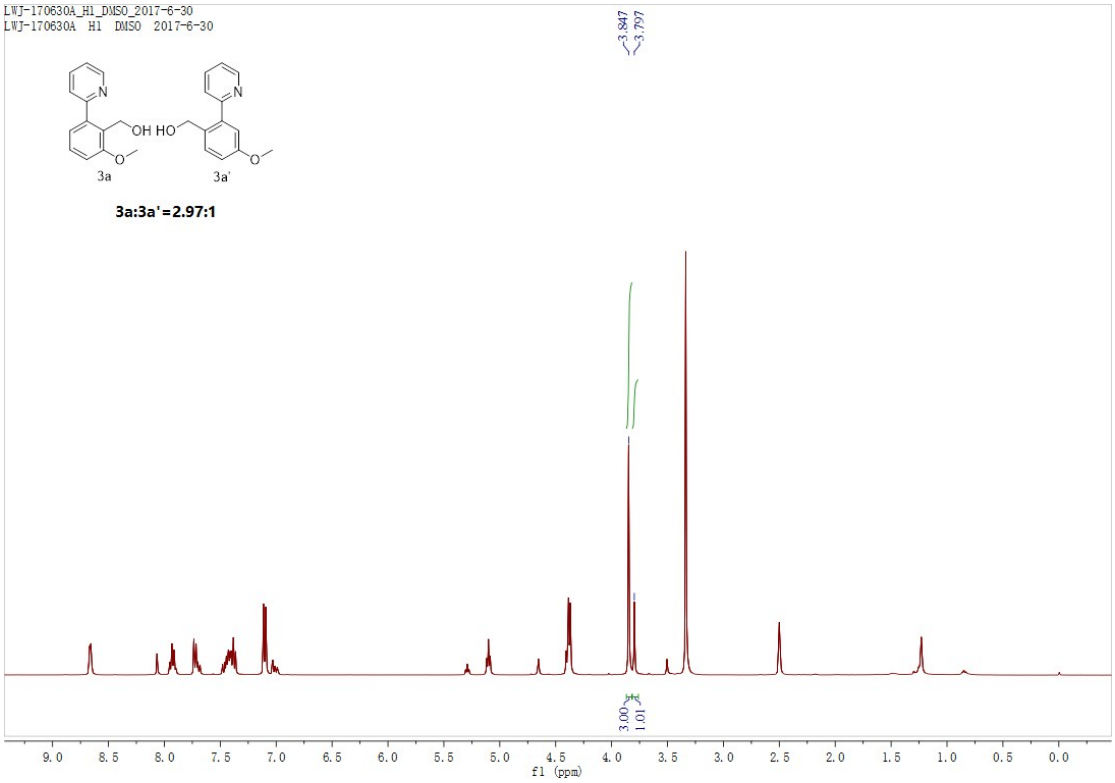
Procedure for the synthesis of 3c and 3c'. To a 15 ml oven-dried tube was added $ZnBr_2$ (0.085 mmol, 19.2 mg), $RuCl_3 \cdot xH_2O$ (0.017 mmol, 10 mol%, 4.3 mg), THF (1.0 mL), compound **9** (0.17 mmol, 50 mg), paraformaldehyde **2a** (0.85 mmol, 25.6 mg) and $ZnMe_2$ (0.60 mmol, 1.0 M in toluene, 0.6 mL) sequentially under argon. The tube was sealed and stirred at 60 ^oC for 24 h. After completion, the reaction mixture was diluted with saturated. aq NH_4Cl (10 mL) and extracted with ethyl acetate (3 x 10 mL). Then the oganic layer was dried with anhydrous sodium sulfate, concentrated in vacuo and purified by silica gel column chromatography (5:1 PE/DCM to 200:1 DCM/MeOH) to provide pure product **3c** and **3c'**.

Decumbenine B (3c). 37.6 mg, yield 68.4%, white solid, mp 224-226 ^oC, ^1H NMR (400 MHz, DMSO-d_6) δ 9.30 (s, 1H), 7.88 (s, 1H), 7.81 (d, J = 8.6 Hz, 1H), 7.50 (d, J = 8.6 Hz, 1H), 7.20 (d, J = 8.0 Hz, 1H), 6.98 (d, J = 8.0 Hz, 1H), 6.33 (s, 2H), 6.12 (s, 2H), 5.52 (t, J = 5.6 Hz, 1H), 4.42 (d, J = 5.6 Hz, 2H). ^{13}C NMR (100 MHz, DMSO-d_6) δ 152.1, 151.0, 147.2, 147.1, 146.6, 139.8, 134.5, 124.0, 123.2, 123.2, 121.6, 121.3, 119.1, 111.1, 107.6, 102.6, 101.3, 55.0. HRMS (ESI): m/z calcd for $C_{18}H_{13}NO_5Na$ $[M + Na]^+$: 346.0686; found: 346.0688.

(6-**([1,3]dioxolo[4,5-f]isoquinolin-8-yl)benzo[d][1,3]dioxol-5-yl)methanol (3c')**. 6.38 mg, yield 11.6%, pale pink solid, mp 202-204 ^oC, ^1H NMR (400 MHz, DMSO-d6) δ 9.28 (s, 1H), 7.81 (d, J = 8.4 Hz, 1H), 7.76 (s, 1H), 7.51 (d, J = 8.4 Hz, 1H), 7.16 (s, 1H), 7.11 (s, 1H), 6.33 (s, 2H), 6.08 (s, 2H), 5.34 (brs, 1H), 4.43 (brs, 2H). ^{13}C NMR (150 MHz, DMSO-d6) δ 152.07, 151.22, 147.21, 147.08, 146.21, 139.85, 134.59, 124.02, 123.20, 123.04, 121.57, 121.35, 111.95, 111.08, 107.62, 102.55, 101.17, 55.18. HRMS (ESI): m/z calcd for C18H13NO5Na [M + Na]+: 346.0686; found: 346.0688.

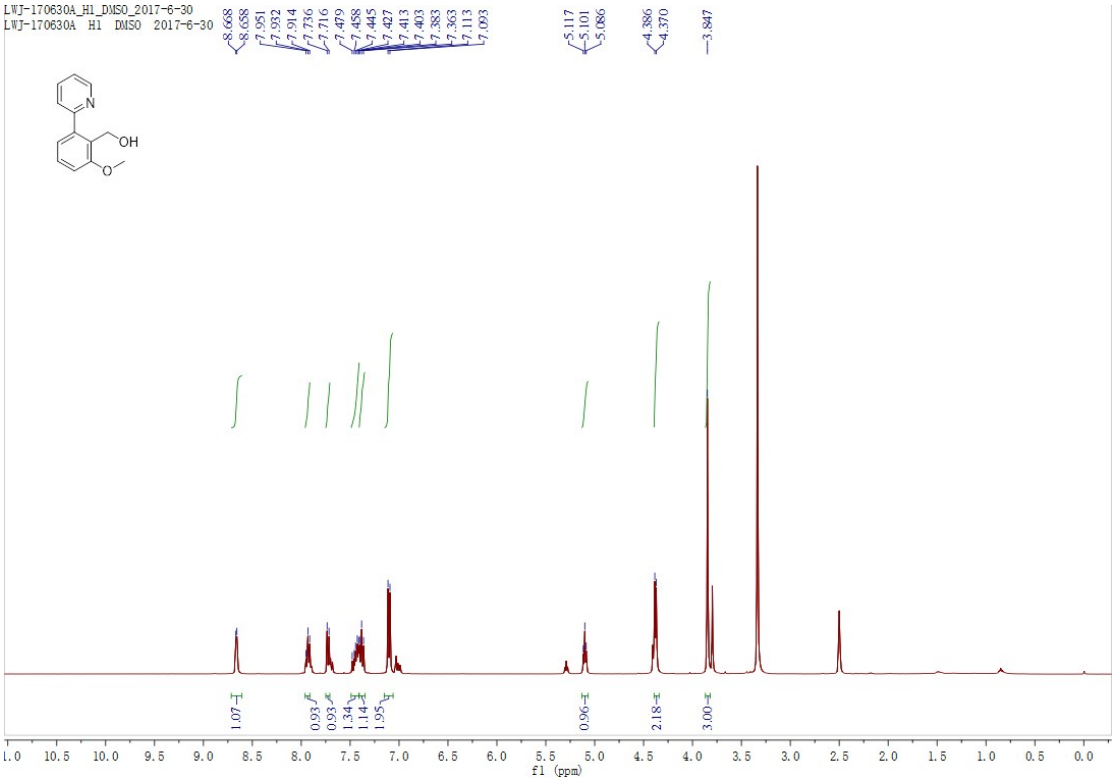
3. The ratio of compound 3a and 3a’

The ratio of compound **3a** and **3a’** is 2.97:1.

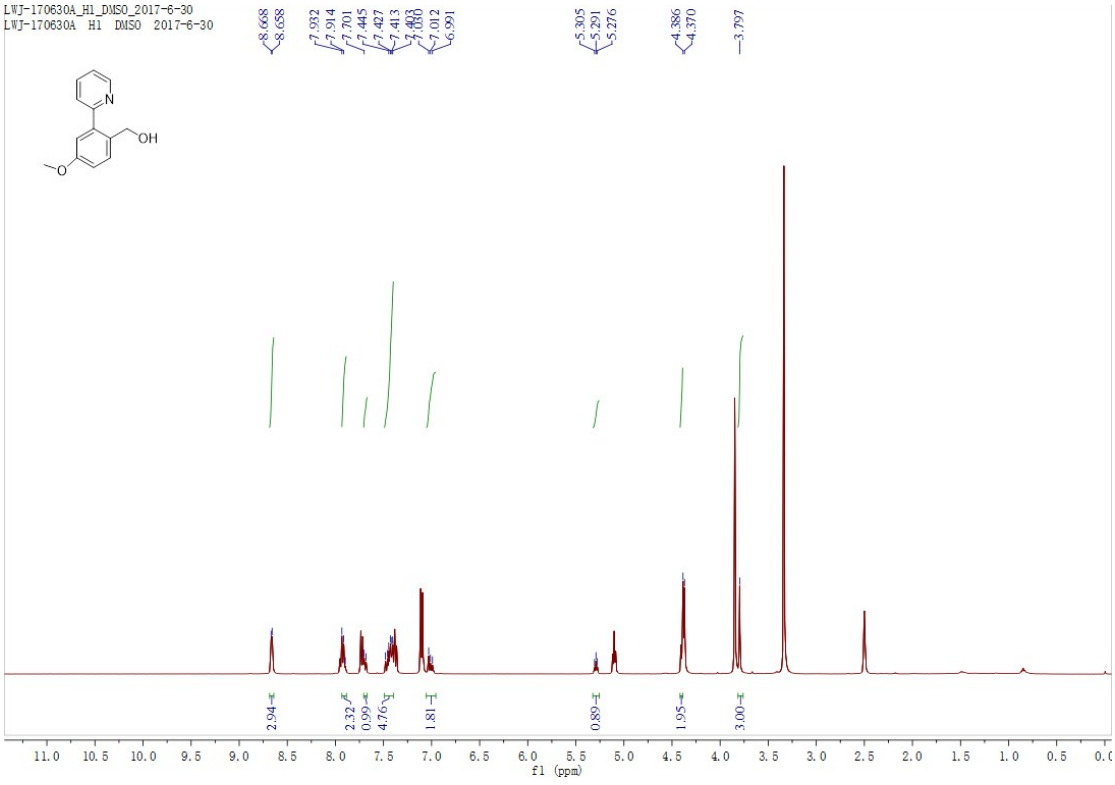


4. NMR spectrums of Compounds

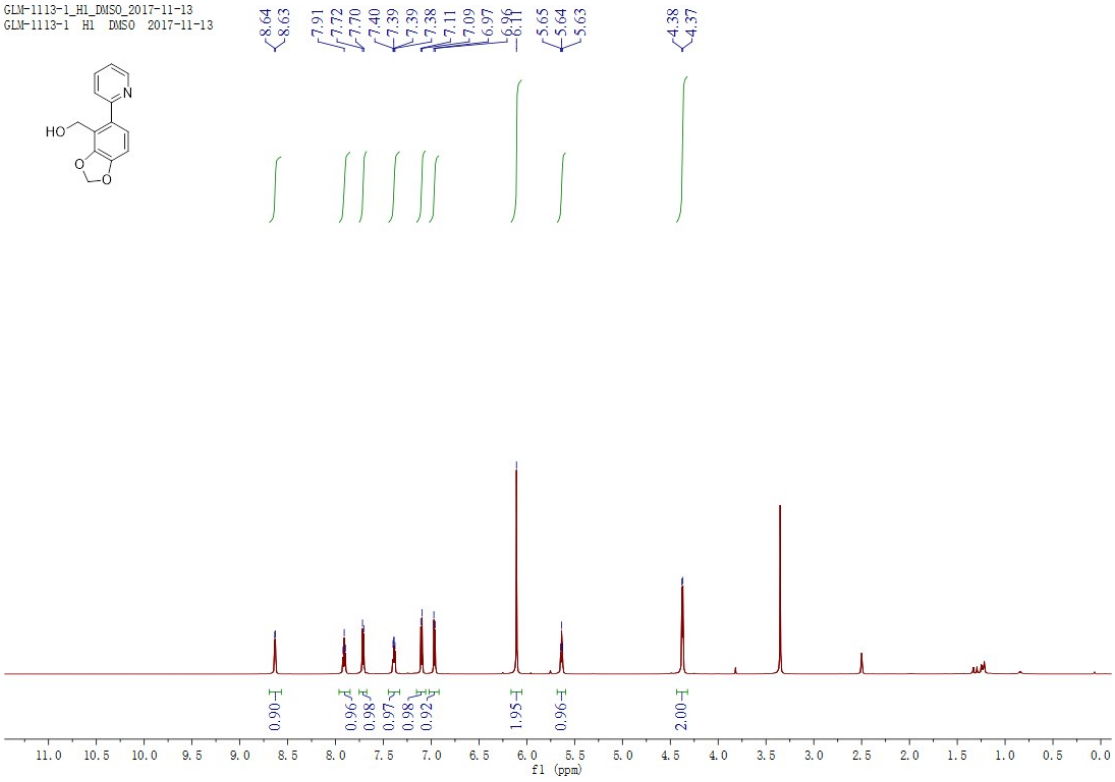
^{1}H NMR of compound **3a**



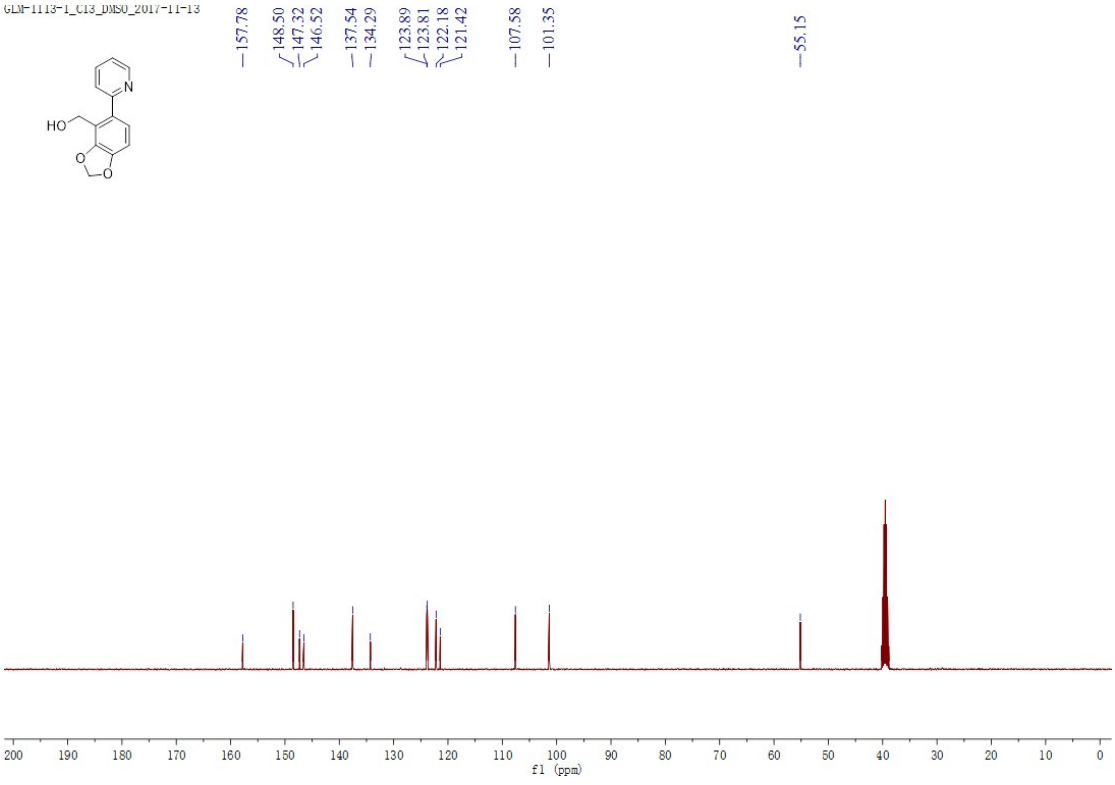
^{1}H NMR of compound **3a'**



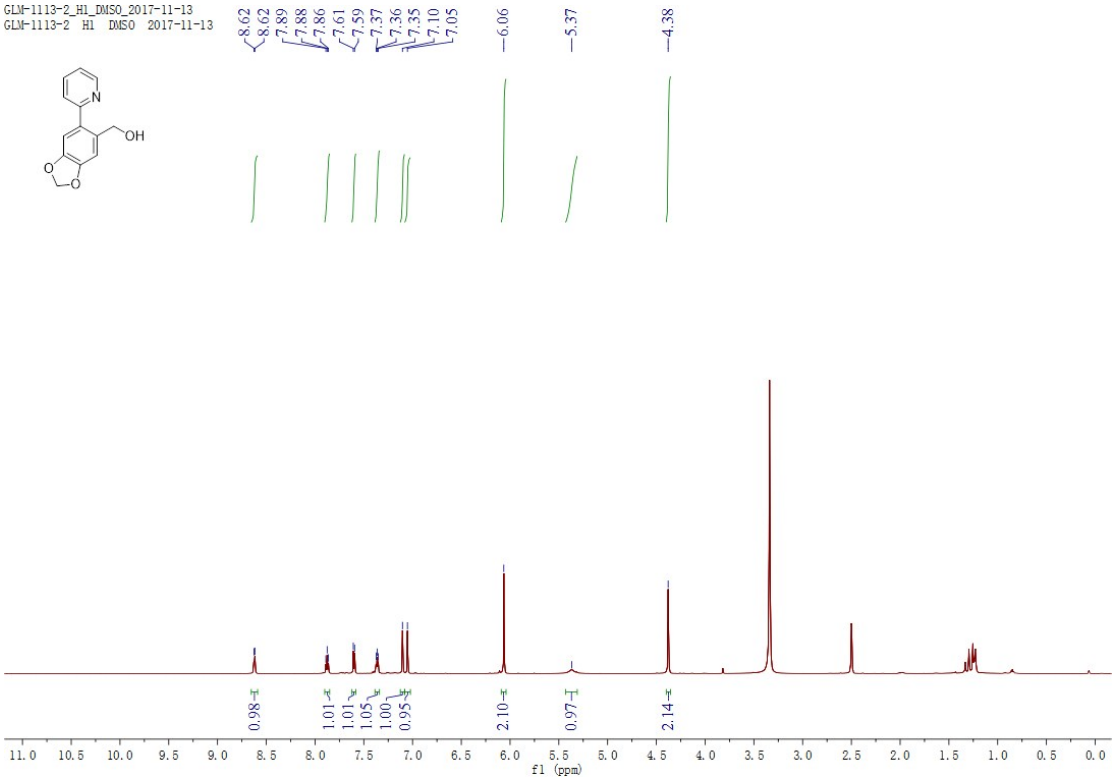
^{1}H NMR of compound **3b**



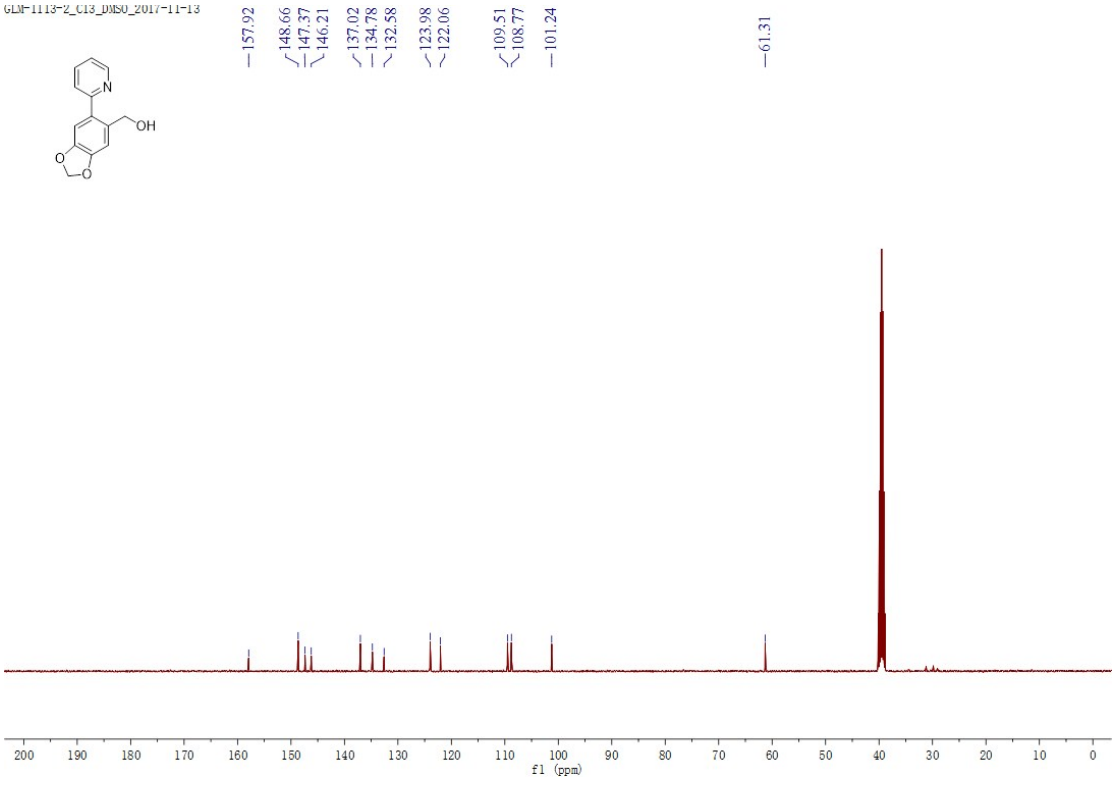
^{13}C NMR of compound **3b**



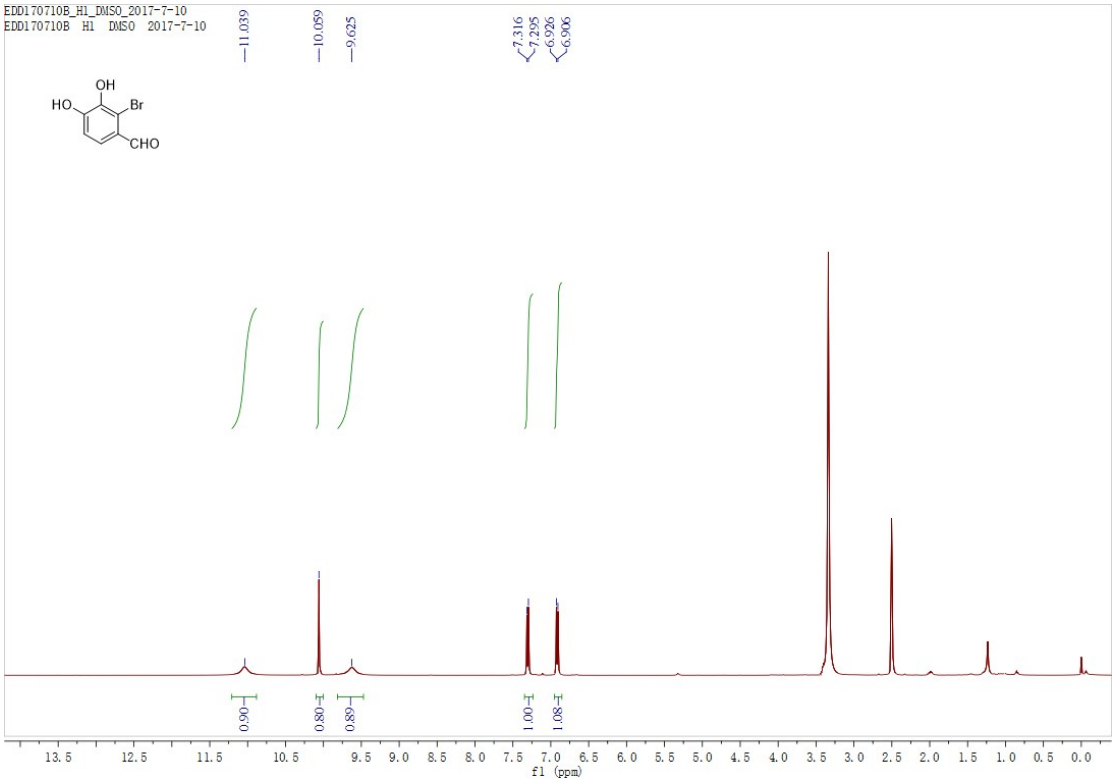
^{1}H NMR of compound **3b'**



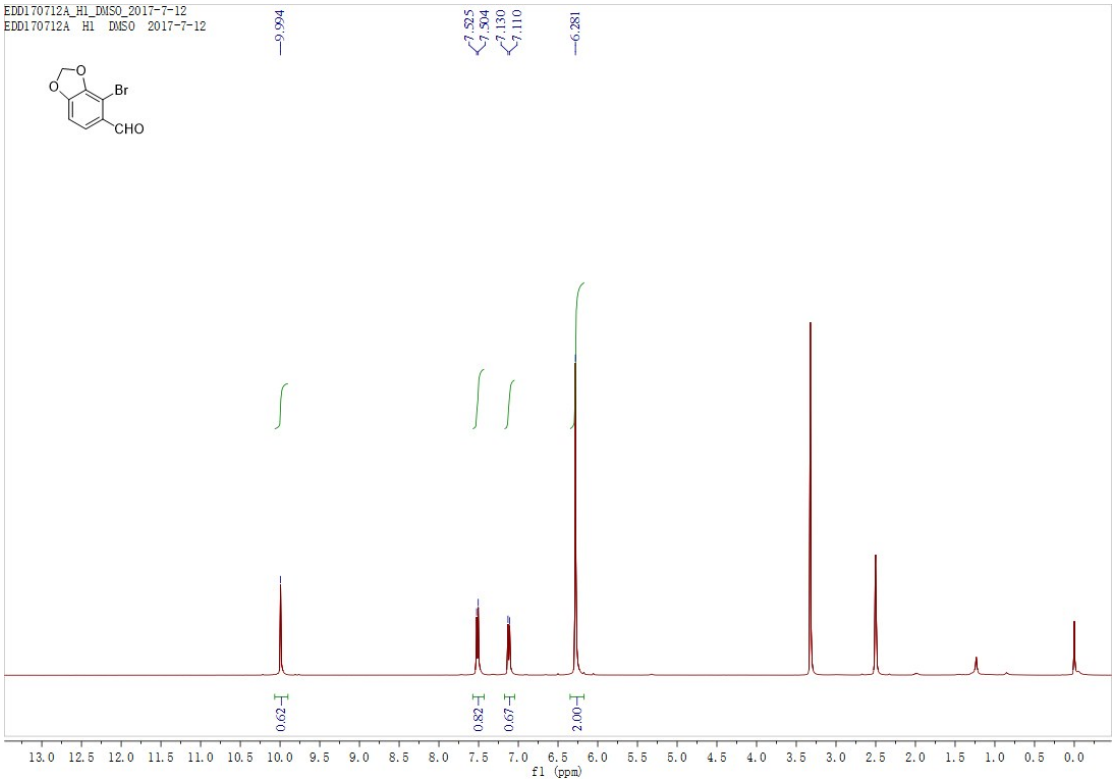
^{13}C NMR of compound **3b'**



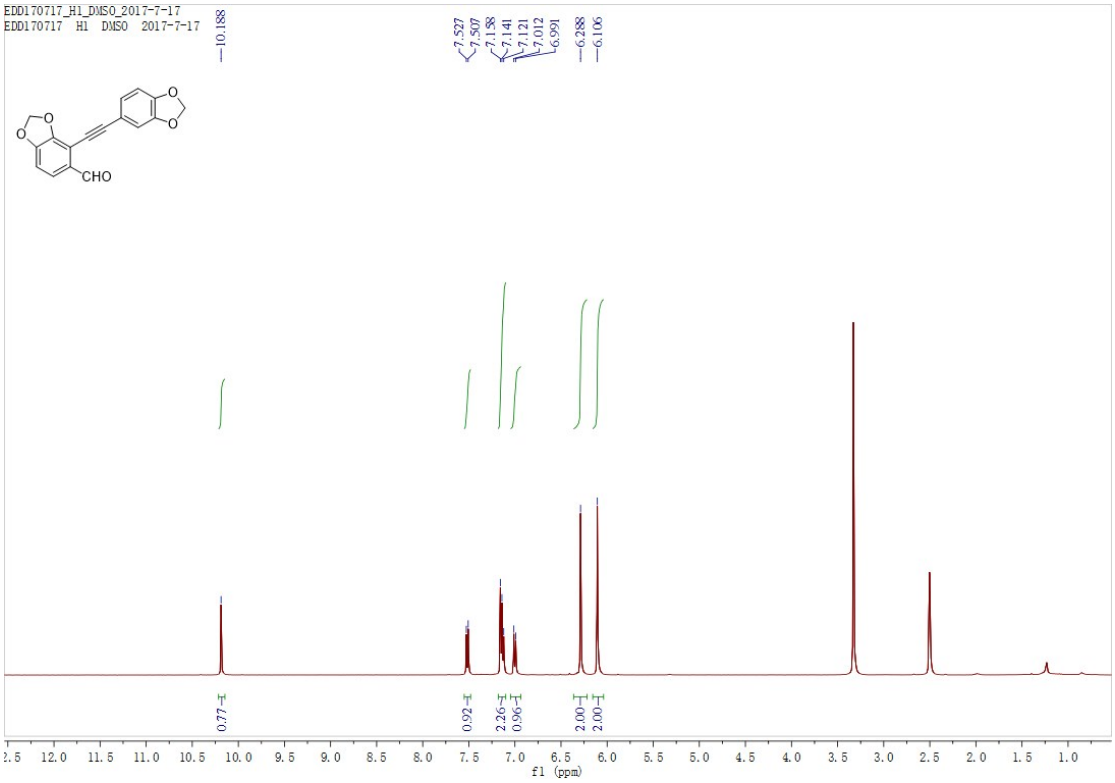
^{1}H NMR of compound **5**



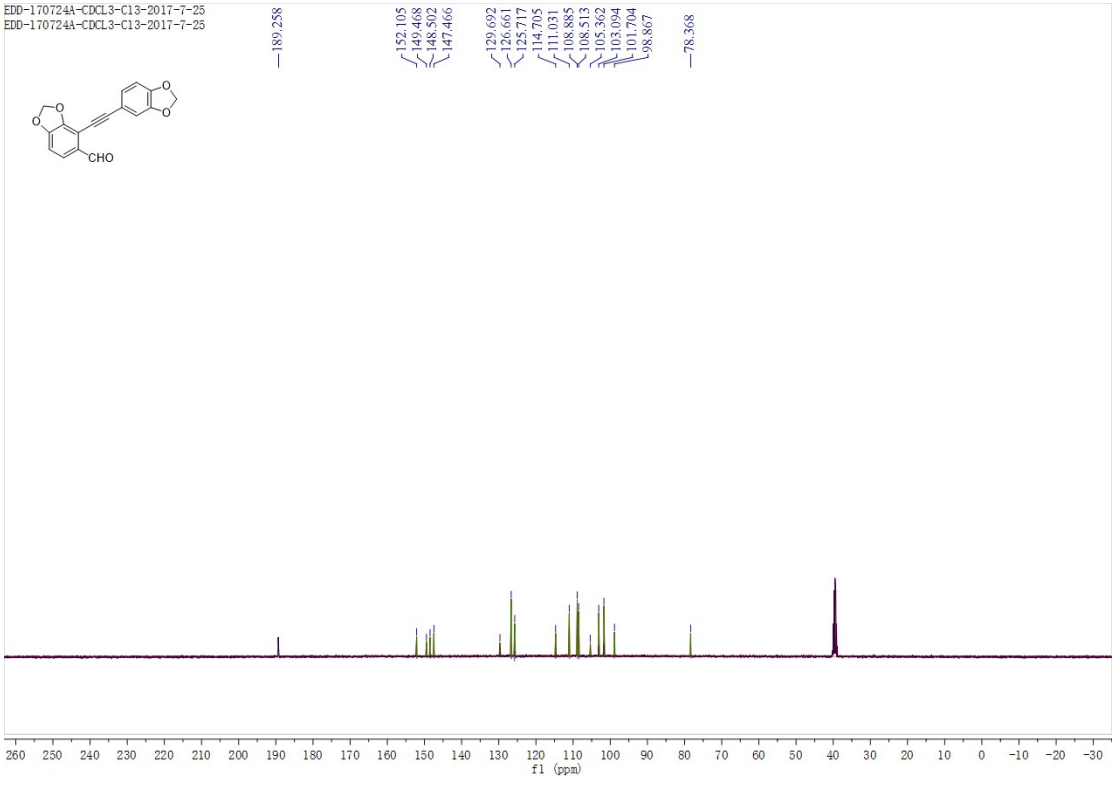
^{1}H NMR of compound **6**



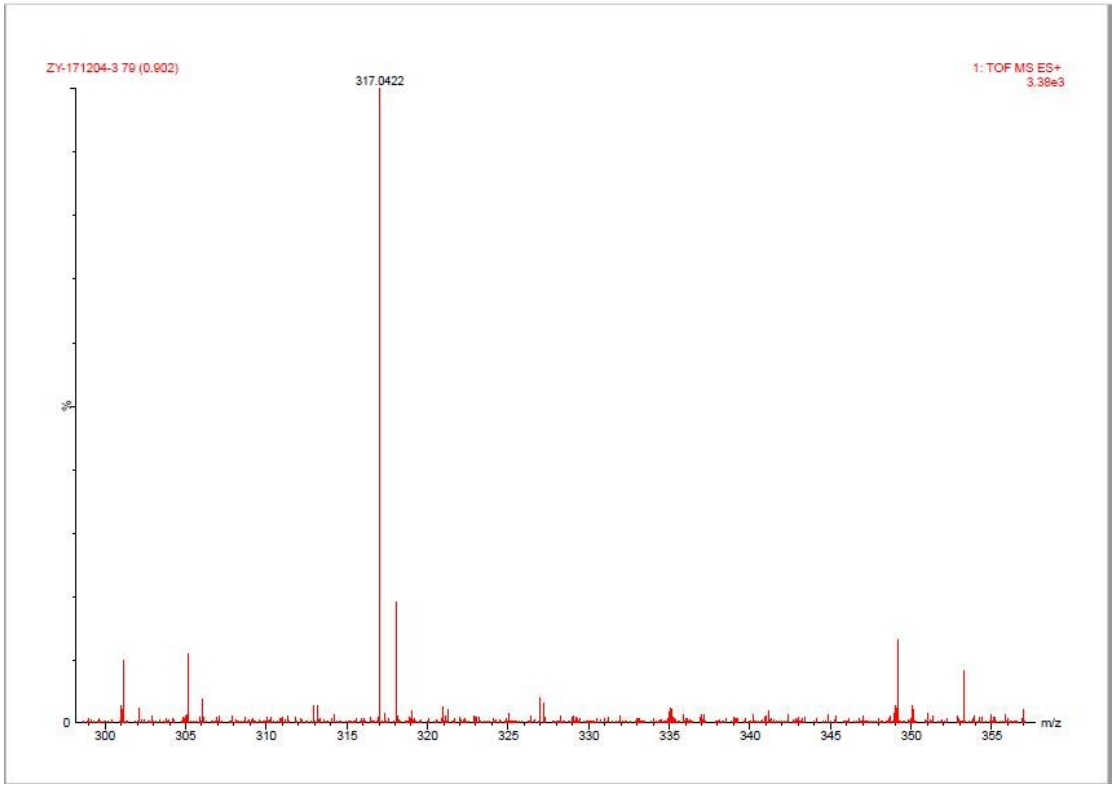
^{1}H NMR of compound **8**



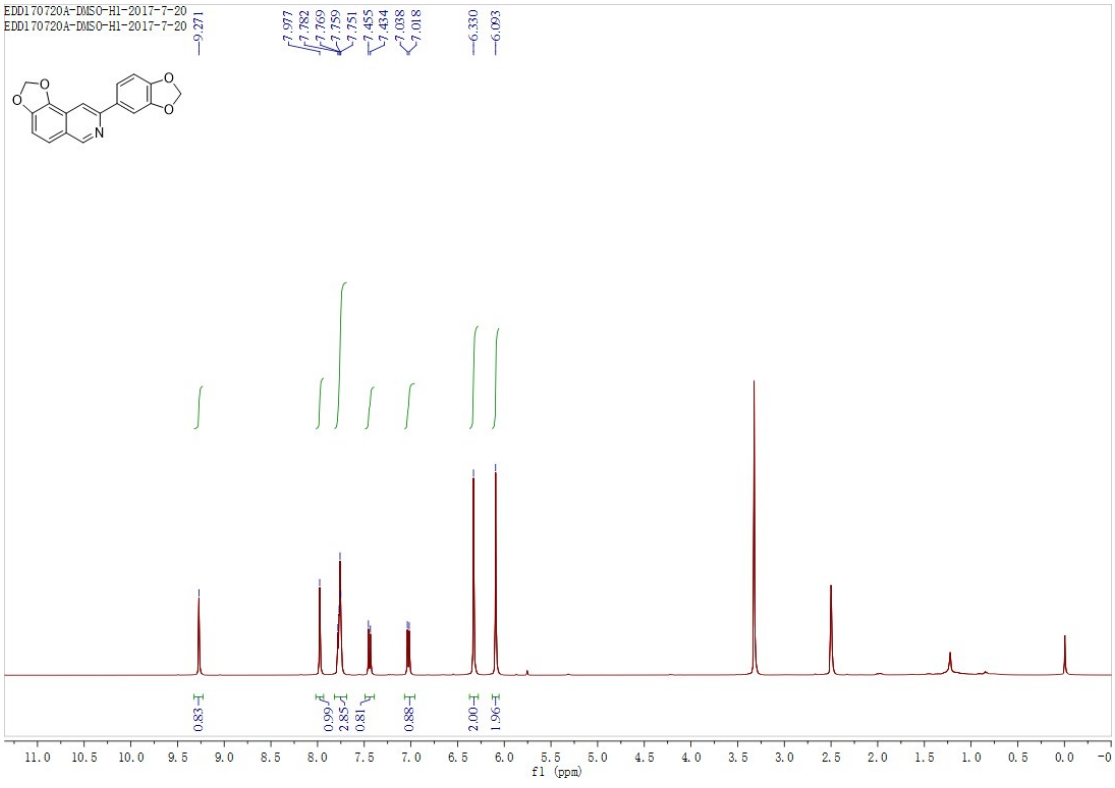
^{13}C NMR of compound **8**



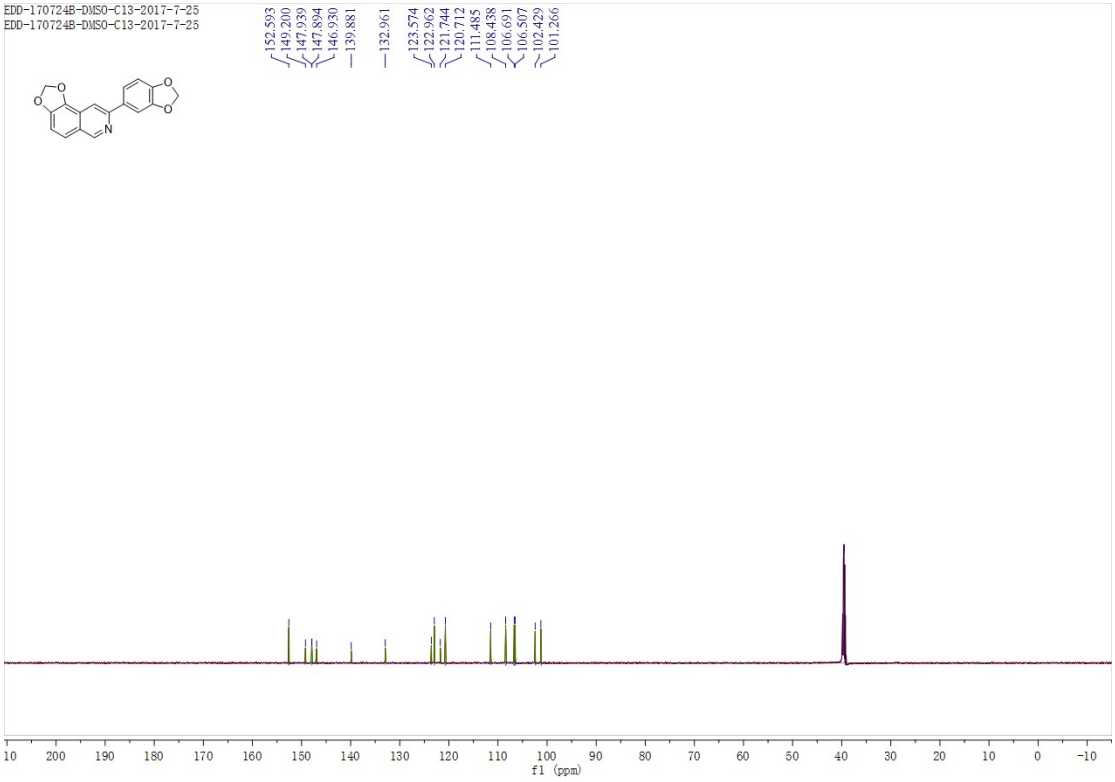
HRMS of compound **8**



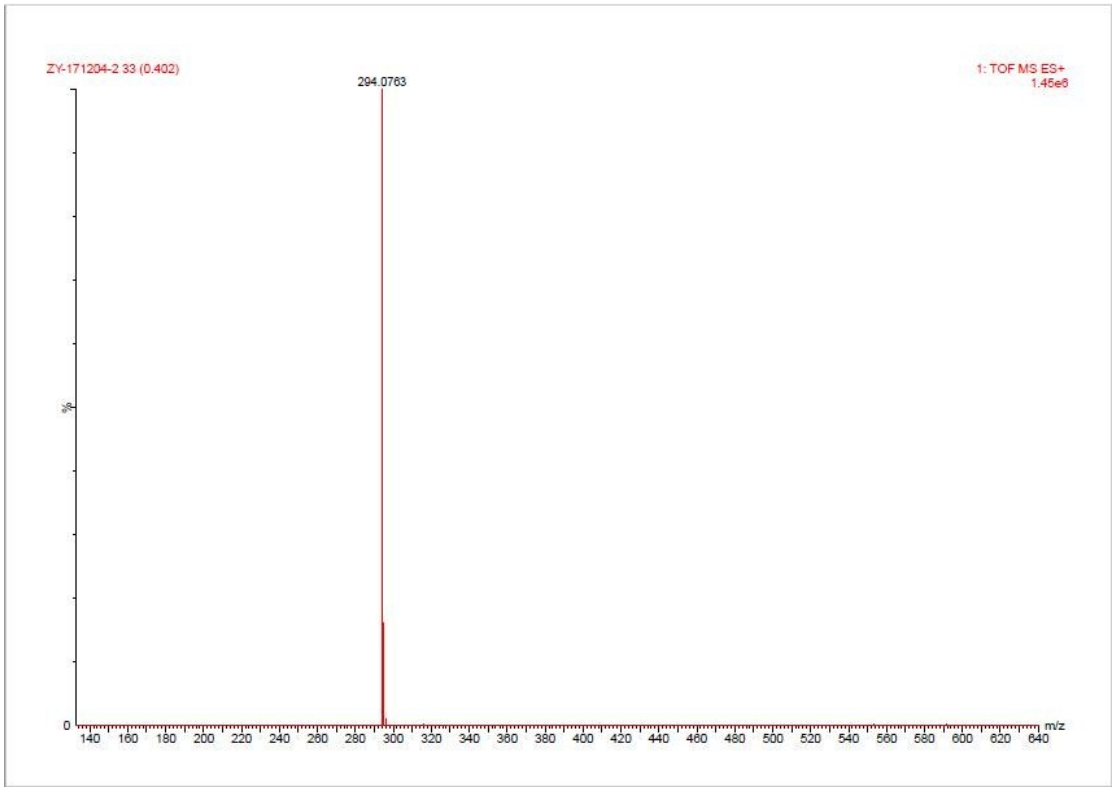
^{1}H NMR of compound **9**



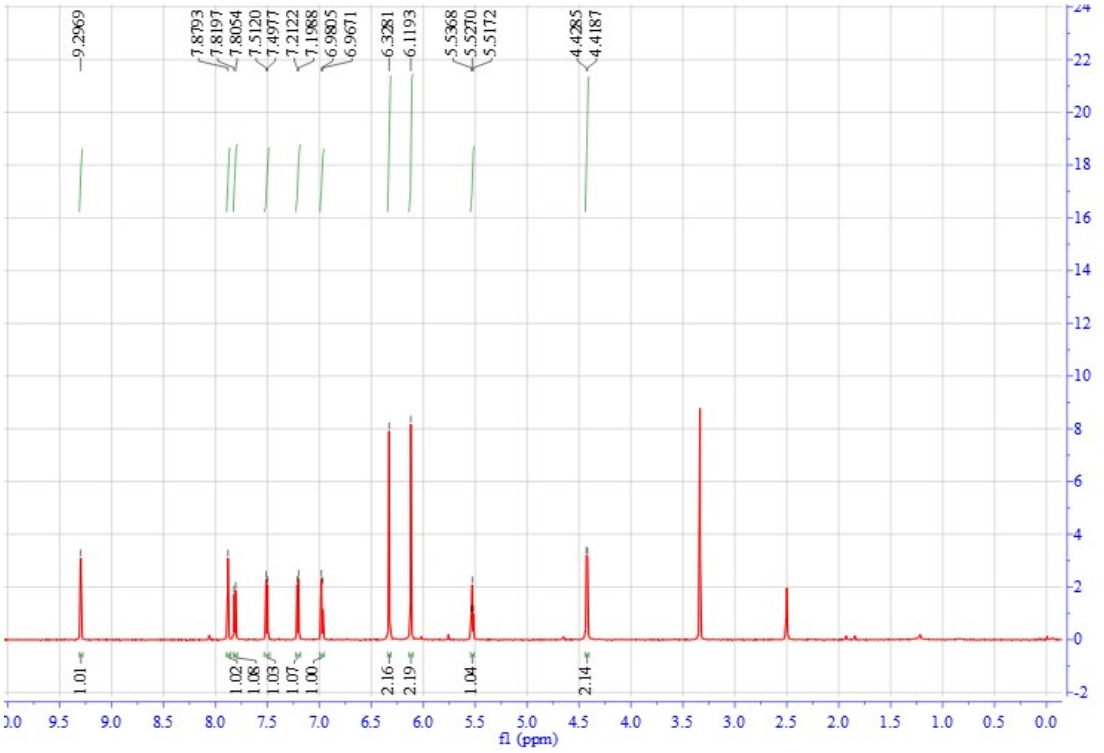
^{13}C NMR of compound **9**



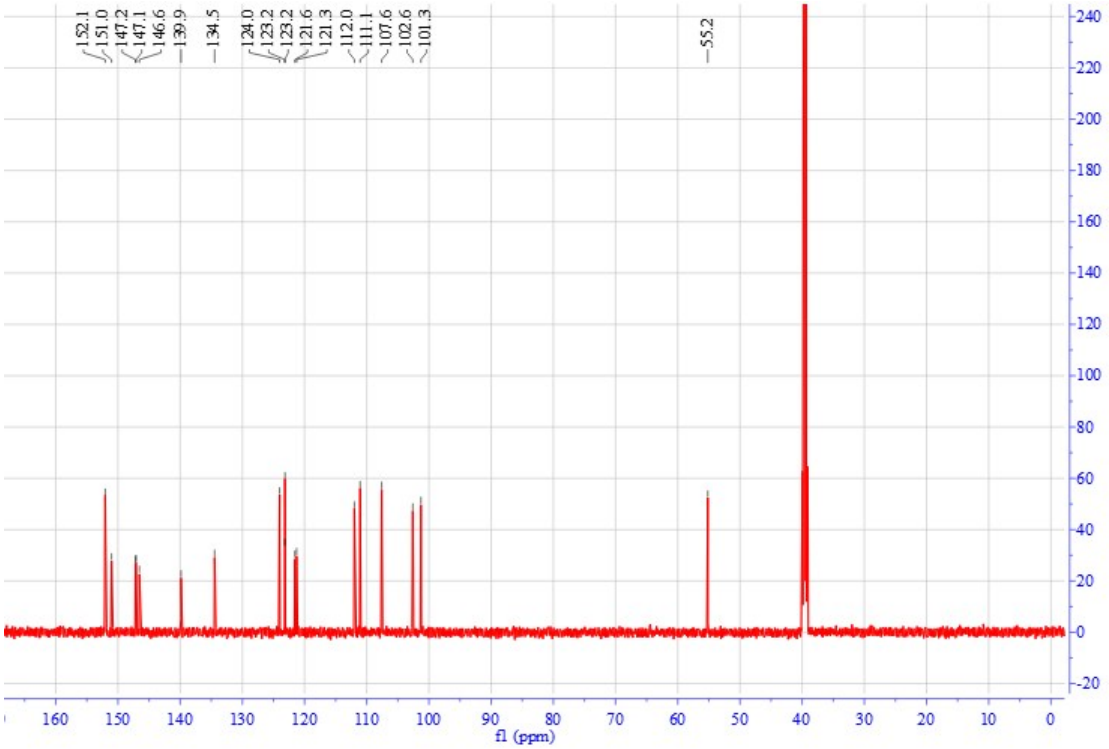
HRMS of compound **9**



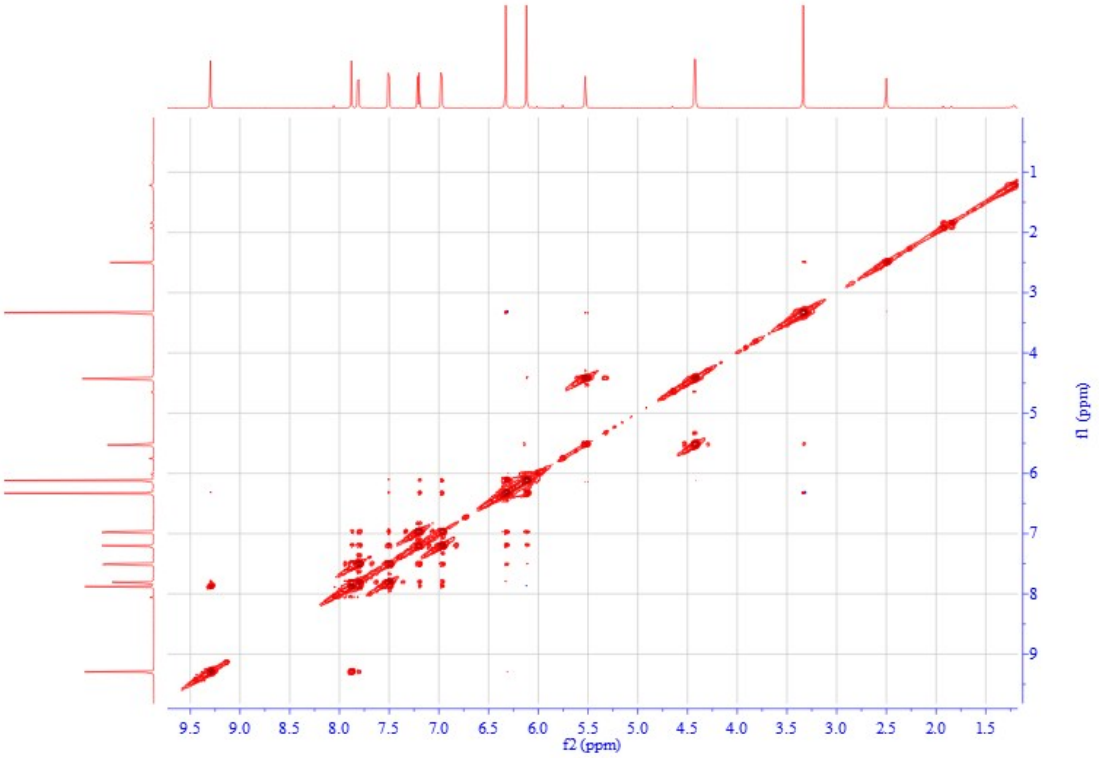
^{1}H NMR of decumbenine B.



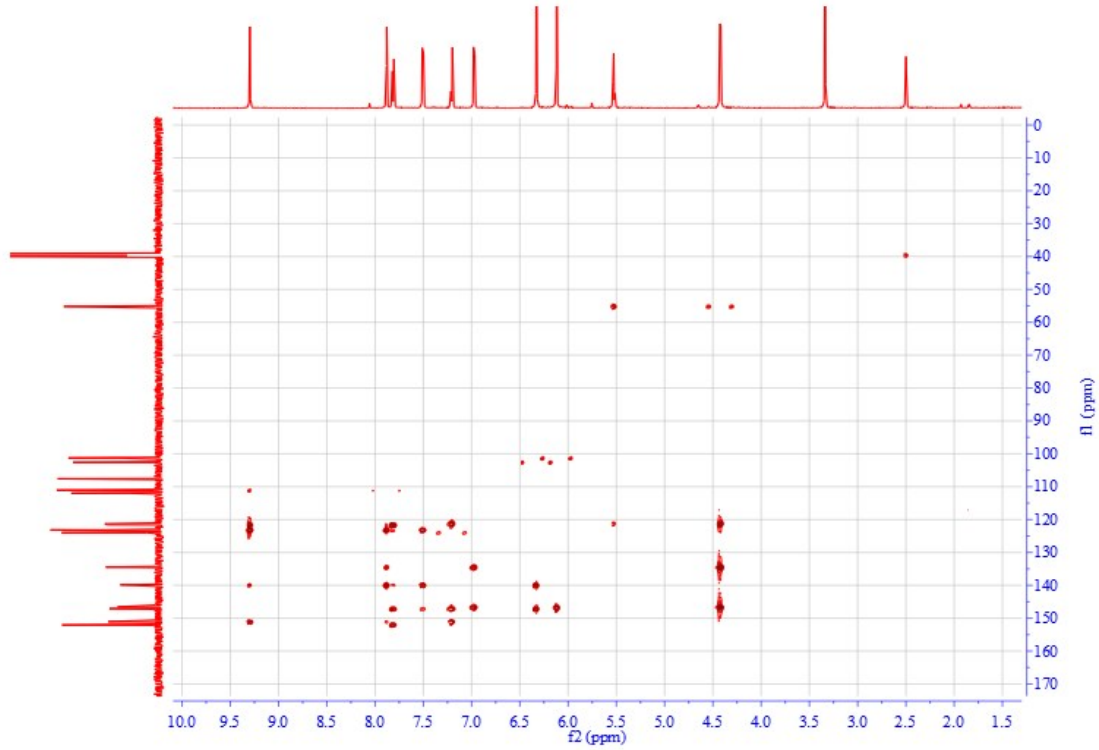
^{13}C NMR of decumbenine B.



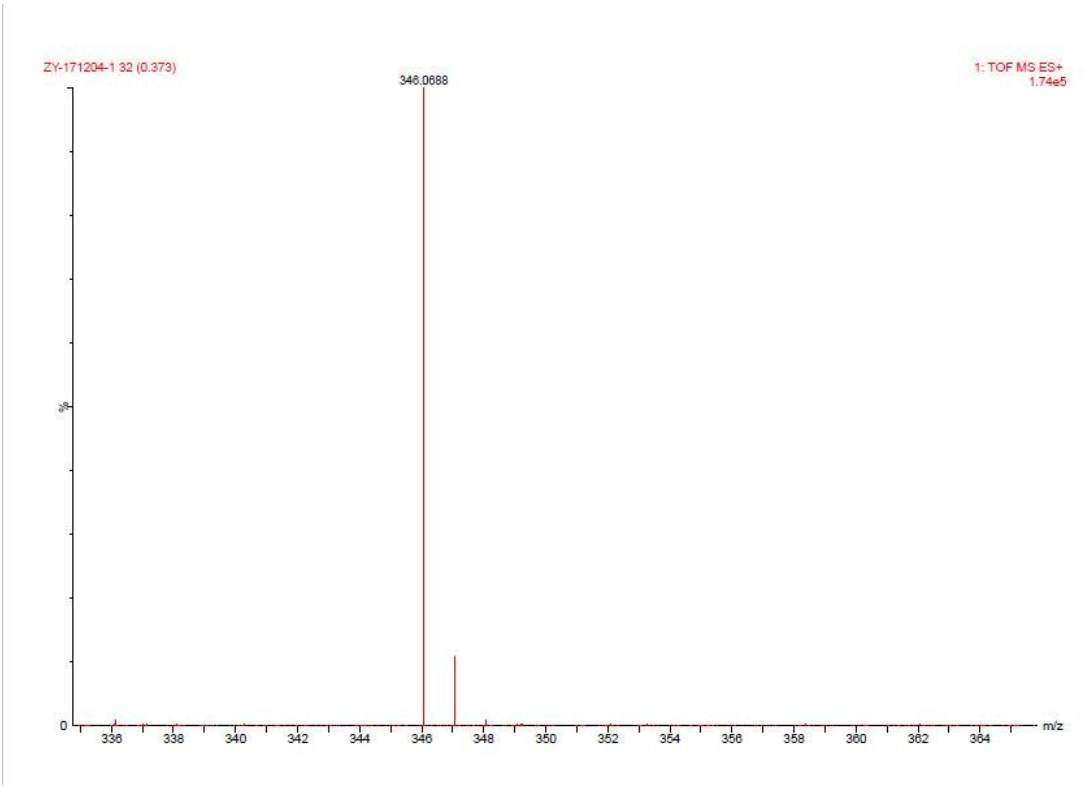
^{1}H-^{1}H COSY of decumbenine B.



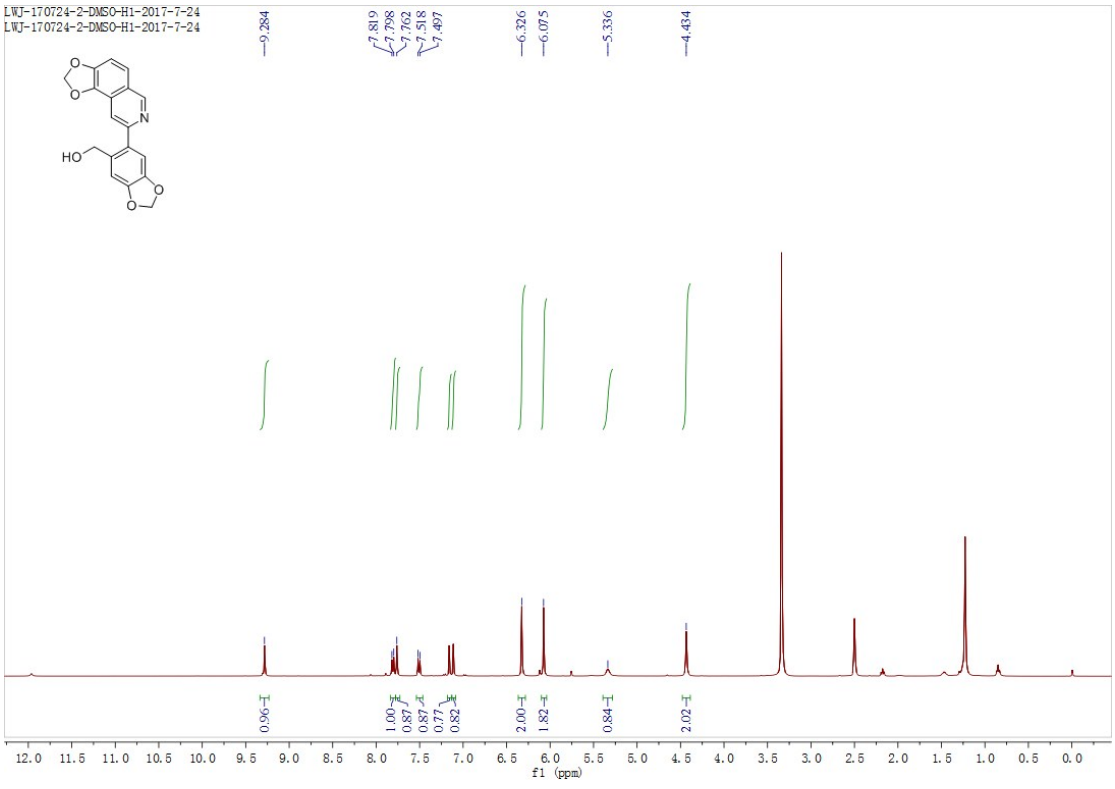
HMBC spectrum of decumbenine B.



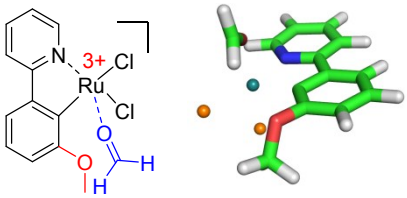
HRMS of decumbenine B



^{1}H NMR of compound **3c'**



5. Cartesian Coordinates, Structures, and Computed Gibbs Free Energies for Optimized Structures and Transition States



M-1 (III)

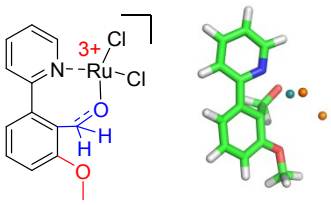
Charge: 0, Multiplicity: 2

Ru	-0.94644764	-0.21633212	0.16707308
Cl	-1.65668704	-2.44742048	0.58086223
Cl	-1.50290581	-0.28225423	-2.08892059
N	-0.72140709	1.86007523	-0.02967133
C	1.54146486	1.27320554	-0.30386004
C	2.91003353	1.51082760	-0.50127724
C	3.80775097	0.45098983	-0.44483143
C	3.34209920	-0.83722244	-0.17666500
C	1.97771004	-1.08461209	0.01779696
C	1.04642194	-0.03535212	-0.06569326
C	0.53150143	2.32360446	-0.28550817
C	-1.76182245	2.70814405	0.03019242
C	-1.61232989	4.07540829	-0.14847892
C	-0.33213907	4.57301359	-0.41263519
C	0.74153464	3.69608915	-0.48236068
C	1.36902412	-3.24500478	-0.74030026
O	1.59344196	-2.35935267	0.36699029
H	4.86949006	0.62564224	-0.59272919
H	4.03154579	-1.67330578	-0.09683212
H	3.27512349	2.51628604	-0.68993233
H	-2.73152450	2.25687202	0.21490605
H	-2.47686220	4.72755237	-0.09283477
H	-0.17706249	5.63695930	-0.56671878
H	1.73941604	4.06468255	-0.69070230
H	1.06938238	-4.20092537	-0.30920749
H	0.56634855	-2.87085211	-1.38238637
H	2.29158437	-3.37076113	-1.32296288
C	-0.19473051	-0.94724372	2.95766965
O	-0.71336923	-0.07363114	2.26197207
H	0.26596770	-1.83424240	2.51089755
H	-0.20064836	-0.82115207	4.04840031

T = 298.15 K

M06 gas phase (au) -1722.832487 TC to enthalpy (au) 0.24595

M06 sol phase (au)	-1722.859303	Entropy (cal/mol*K)	145.817
B3LYP gas phase(au)	-1722.14657	Cv (cal/mol*K)	70.422
ZPC to energy (au)	0.225502	H (kcal/mol)	-1080956.244
TC to energy (au)	0.245007	G (kcal/mol)	-1080999.719



TSM-1 (III)

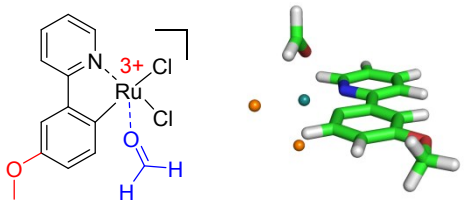
Charge: 0, Multiplicity: 2

Ru	-1.16091071	-0.12805191	0.14111551
Cl	-2.29254287	-2.17525378	0.20827522
Cl	-1.57762250	0.24922737	-2.15221926
N	-0.33659503	1.84493575	0.17907860
C	1.68063199	0.64081497	-0.10851200
C	2.94142900	0.52948218	-0.68448555
C	3.47137029	-0.74074493	-0.93217913
C	2.76822689	-1.89389311	-0.60111504
C	1.50374049	-1.79523792	0.00228891
C	0.92164421	-0.51606887	0.27658555
C	1.01036982	1.93506850	0.06523925
C	-1.07795570	2.95239788	0.31520593
C	-0.50955808	4.22057156	0.35519052
C	0.87814442	4.33268221	0.25006578
C	1.64568171	3.18221517	0.10502237
C	1.24056497	-4.17990041	0.09242450
O	0.80178601	-2.85960182	0.40575090
H	4.44674117	-0.83193769	-1.40196963
H	3.20032567	-2.86429721	-0.81425951
H	3.48985474	1.41123428	-0.99951334
H	-2.14975094	2.80044207	0.38584607
H	-1.14262517	5.09395742	0.46710649
H	1.35648368	5.30708864	0.28354523
H	2.72589046	3.24354527	0.03431807
H	0.45548079	-4.83591448	0.46699137
H	1.34097788	-4.30923568	-0.99050495
H	2.19090210	-4.41270088	0.58830461
C	0.38519964	-0.47597539	2.08399467
O	-0.85939610	-0.05580457	2.15048727
H	0.54560335	-1.53870979	2.29680783

H	1.14971997	0.19022848	2.51039856

T = 298.15 K

M06 gas phase (au)	-1722.793029	TC to enthalpy(au)	0.245397
M06 sol phase (au)	-1722.830289	Entropy (cal/mol*K)	141.037
B3LYP gas phase(au)	-1722.109907	Cv (cal/mol*K)	67.327
ZPC to energy(au)	0.226034	H (kcal/mol)	-1080938.384
TC to energy(au)	0.244454	G (kcal/mol)	-1080980.435



O-1 (III)

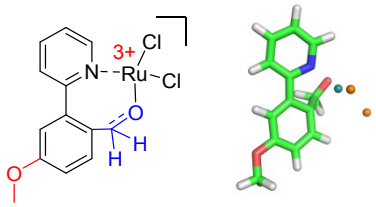
Charge: 0, Multiplicity: 2

Ru	-0.45602709	1.32033485	0.20463618
Cl	-2.75225839	1.76035865	0.68190148
Cl	-0.52528601	1.90973153	-2.03557983
N	1.61018530	0.97811210	0.00121132
C	0.86846573	-1.26070951	-0.09216263
C	-0.41188153	-0.66047288	0.02585405
C	-1.54344959	-1.48165620	0.00880813
C	-1.41608691	-2.86924365	-0.10771670
C	-0.14539206	-3.45527103	-0.21382560
C	0.99613630	-2.64696553	-0.20690916
C	1.98987981	-0.32610491	-0.10462532
C	2.53333630	1.95343115	-0.02016610
C	3.89102199	1.68773855	-0.13193331
C	4.30100132	0.35486493	-0.23102456
C	3.34750013	-0.65448942	-0.21863011
C	-1.03330158	-5.66929083	-0.38549163
O	0.08454254	-4.79558546	-0.32995363
H	-2.53105986	-1.03851867	0.07670334
H	-2.31121948	-3.48116673	-0.12193817
H	1.96247745	-3.13239820	-0.30278258
H	2.15237005	2.96741528	0.04449884
H	4.60344471	2.50519959	-0.14835952
H	5.35484857	0.10830945	-0.32243882
H	3.64423188	-1.69399308	-0.30128936
H	-0.62085437	-6.67389300	-0.49410682
H	-1.63035209	-5.62072800	0.53471646
H	-1.67709851	-5.44607239	-1.24603373

C	-0.93308227	0.81960079	3.13921937
O	-0.15304527	1.25434563	2.29310351
H	-1.87052141	0.33069621	2.85503692
H	-0.68330392	0.94186045	4.20111019

T = 298.15 K

M06 gas phase (au)	-1722.835516	TC to enthalpy(au)	0.24611
M06 sol phase (au)	-1722.865408	Entropy (cal/mol*K)	146.371
B3LYP gas phase(au)	-1722.15339	Cv (cal/mol*K)	70.432
ZPC to energy(au)	0.225649	H (kcal/mol)	-1080959.974
TC to energy(au)	0.245166	G (kcal/mol)I	-1081003.615



TSO-1 (III)

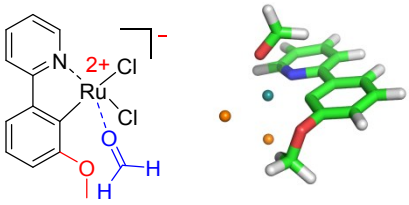
Charge: 0, Multiplicity: 2

Ru	-0.62963743	1.40089307	0.09026326
Cl	-2.95149733	1.73354411	0.28632134
Cl	-0.55474335	1.58252647	-2.25993209
N	1.48619745	1.08489864	0.01998047
C	0.79595515	-1.17039253	0.25861115
C	0.94869755	-2.51122543	-0.04969331
C	-0.17533418	-3.36070007	-0.08120935
C	-1.45915017	-2.84879948	0.18243000
C	-1.60342869	-1.50883810	0.50937587
C	-0.49471353	-0.63227240	0.59362372
C	1.89660720	-0.20108292	0.16206188
C	2.38848598	2.06497992	-0.12145421
C	3.75714937	1.81766364	-0.11357102
C	4.19687276	0.50274163	0.04556792
C	3.25965827	-0.51584439	0.18381620
H	-2.33409933	-3.48560373	0.12826334
H	1.90701893	-2.93444029	-0.33259474
H	1.98710231	3.06454844	-0.24878277
H	4.45545521	2.63946818	-0.22839636
H	5.25835603	0.27409201	0.06258986
H	3.57584768	-1.54462980	0.31645054
C	-0.53762854	0.19414098	2.27867219
O	-0.32707555	1.47992339	2.09901427
H	-1.55091840	-0.08874910	2.58852743

H	0.24940017	-0.37051237	2.79881003
C	-0.99747796	-5.56523000	-0.52055507
O	0.08702463	-4.64498058	-0.39491124
H	-2.59099847	-1.10938510	0.71845016
H	-0.54213307	-6.51772868	-0.79300392
H	-1.53603107	-5.67400694	0.42798346
H	-1.69235337	-5.25105732	-1.30750130

T = 298.15 K

M06 gas phase (au)	-1722.797292	TC to enthalpy(au)	0.245456
M06 sol phase (au)	-1722.833684	Entropy (cal/mol*K)	141.223
B3LYP gas phase(au)	-1722.114805	Cv (cal/mol*K)	67.297
ZPC to energy(au)	0.226108	H (kcal/mol)	-1080940.478
TC to energy(au)	0.244512	G (kcal/mol)	-1080982.583



M-1 (II)

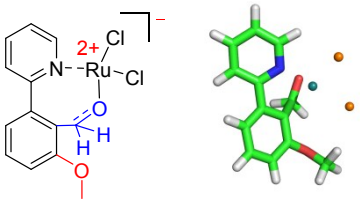
Charge: -1, Multiplicity: 1

Ru	-0.86231390	-0.27605824	0.42328191
Cl	-2.51096043	-1.97475697	1.07967190
Cl	-1.58569480	-0.31696211	-1.89450645
N	0.11006627	1.48973540	0.01337884
C	2.00675457	0.09753154	-0.03538327
C	3.38253081	-0.19363270	-0.11649625
C	3.81297987	-1.50775662	-0.02027444
C	2.86292355	-2.52643547	0.13642778
C	1.49789934	-2.24473504	0.21853309
C	1.01311632	-0.91154532	0.16218187
C	1.47030656	1.44560258	-0.13917059
C	-0.52992465	2.66751424	-0.12288922
C	0.13135167	3.86072771	-0.37478812
C	1.52596584	3.83867611	-0.50002969
C	2.19103541	2.62550976	-0.38476755
C	-0.13619681	-3.69503771	-0.69202805
O	0.67058116	-3.32406372	0.43073065
H	4.87211665	-1.74959636	-0.07544479
H	3.16880834	-3.56762276	0.20971527
H	4.10953167	0.60491997	-0.25114272
H	-1.60974135	2.61916033	-0.02702462

H	-0.43519036	4.78137629	-0.47524429
H	2.08072896	4.75330956	-0.69475252
H	3.26947975	2.57833752	-0.49712885
H	-0.83385965	-4.45227780	-0.32953430
H	-0.70386921	-2.84707099	-1.08151275
H	0.49963955	-4.12102826	-1.48598312
C	0.44049860	0.22295147	3.11573946
O	-0.56386449	-0.05803336	2.45371167
H	1.42592769	0.34600698	2.65126566
H	0.34702562	0.34053693	4.20378022

T = 298.15 K

M06 gas phase (au)	-1722.912228	TC to enthalpy(au)	0.243844
M06 sol phase (au)	-1723.008572	Entropy (cal/mol*K)	147.27
B3LYP gas phase(au)	-1722.219436	Cv (cal/mol*K)	71.011
ZPC to energy(au)	0.223167	H (kcal/mol)	-1081051.233
TC to energy(au)	0.2429	G (kcal/mol)	-1081095.142



TSM-1 (II)

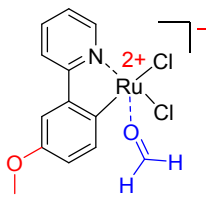
Charge: -1, Multiplicity: 1

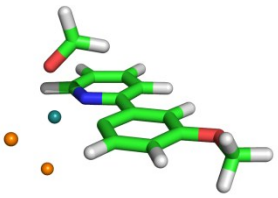
Ru	1.06406665	0.01379611	0.01687335
Cl	2.30052858	2.12228911	0.17052446
Cl	2.87784929	-0.98080245	-1.19641582
N	0.00422914	-1.78180695	-0.07151215
C	-1.91331912	-0.36735735	-0.09817686
C	-3.14193899	-0.18389223	-0.73883846
C	-3.60829696	1.09934774	-1.02066395
C	-2.83657013	2.19897274	-0.65017237
C	-1.60941474	2.03171404	-0.00085719
C	-1.08835879	0.73938696	0.28817510
C	-1.35373459	-1.71712760	0.03802452
C	0.59691484	-2.99351011	-0.02756188
C	-0.11746164	-4.17568213	0.12003962
C	-1.50807525	-4.11935409	0.24769790
C	-2.12509020	-2.87404074	0.20822136
C	-0.42067986	4.02440765	-0.53490116
C	-0.27354255	0.70105112	1.84490829
O	-0.96644096	3.15554942	0.46100248

O	0.73273378	-0.18638382	1.99853305
H	-4.56201546	1.24148133	-1.52309420
H	-3.19025021	3.20978615	-0.83628914
H	-3.70732950	-1.05024637	-1.07265951
H	1.67548812	-2.97477598	-0.13003404
H	0.41646156	-5.12098584	0.15059349
H	-2.09518444	-5.02358740	0.38740204
H	-3.20032409	-2.78127079	0.32506675
H	-0.01484840	4.88204628	0.00655825
H	0.39304422	3.52566484	-1.06744543
H	-1.19809930	4.37127675	-1.23191980
H	0.00019498	1.75008414	1.99067351
H	-1.16554433	0.42396070	2.43222871

T = 298.15 K

M06 gas phase (au)	-1722.874758	TC to enthalpy(au)	0.243975
M06 sol phase (au)	-1722.967727	Entropy (cal/mol*K)	139.042
B3LYP gas phase(au)	-1722.182396	Cv (cal/mol*K)	67.293
ZPC to energy(au)	0.224829	H (kcal/mol)	-1081025.521
TC to energy(au)	0.243031	G (kcal/mol)	-1081066.976





O-1 (II)

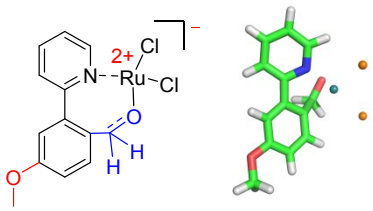
Charge: -1, Multiplicity: 1

Ru	-0.55578498	1.31456705	0.11983450
Cl	-2.92043150	1.95587263	0.33121126
Cl	-0.46057302	1.93656333	-2.21744729
N	1.46342703	0.86918840	0.00273350
C	0.63448399	-1.33847069	-0.08259502
C	-0.61443883	-0.65256567	-0.02060302
C	-1.77758341	-1.44623468	-0.04044644
C	-1.71329599	-2.83839948	-0.11013032
C	-0.46838752	-3.48965737	-0.16234687
C	0.70257479	-2.74036426	-0.14835534
C	1.79552357	-0.46091211	-0.08115280
C	2.44686085	1.78904442	-0.03118758
C	3.79247582	1.45866224	-0.11441288
C	4.14700596	0.10565250	-0.17496670
C	3.14079460	-0.85140631	-0.16145357

C	-1.47005495	-5.65663537	-0.28797854
O	-0.30585340	-4.86508715	-0.22643339
H	-2.74362972	-0.95249286	-0.00171166
H	-2.63676654	-3.40988344	-0.12306831
H	1.65052500	-3.27075550	-0.19732561
H	2.11396938	2.82133139	0.00223779
H	4.54096105	2.24491945	-0.13746168
H	5.19020513	-0.19357515	-0.24112355
H	3.38463072	-1.90736000	-0.22354680
H	-1.13084010	-6.69457729	-0.35422678
H	-2.09715196	-5.54318667	0.60924168
H	-2.08285415	-5.42308327	-1.17117746
C	0.00396849	0.45986382	2.96150674
O	-0.52614764	1.25139501	2.16919289
H	0.50971745	-0.45004092	2.61909730
H	-0.03796970	0.67270277	4.03754816

T = 298.15 K

M06 gas phase (au)	-1722.912049	TC to enthalpy(au)	0.244037
M06 sol phase (au)	-1723.011118	Entropy (cal/mol*K)	148.493
B3LYP gas phase(au)	-1722.222671	Cv (cal/mol*K)	70.907
ZPC to energy(au)	0.223374	H (kcal/mol)	-1081052.71
TC to energy(au)	0.243094	G (kcal/mol)	-1081096.983



TSO-1 (II)

Charge: -1, Multiplicity: 1

Ru	-0.34468997	1.42980075	0.25043873
Cl	-2.72393679	1.88385098	0.67839452
Cl	-0.07985184	3.37852739	-1.13774273
N	1.62937652	0.84689206	-0.10474644
C	0.77958581	-1.34906976	0.26464724
C	-0.41139207	-0.75931949	0.79144845
C	-1.58830854	-1.52968640	0.73171173
C	-1.60387187	-2.82679152	0.22124227
C	-0.41212850	-3.40212086	-0.23786833
C	0.77078944	-2.65186992	-0.22913006
C	1.94386049	-0.47134289	0.08596278
C	2.63396292	1.71576410	-0.34667476

C	3.96612904	1.32712571	-0.41391284
C	4.29747640	-0.01548534	-0.21075930
C	3.26937062	-0.91740354	0.04272984
C	-1.48425408	-5.44274522	-0.85871441
O	-0.30254089	-4.67616609	-0.74629669
H	-2.51039832	-1.07876333	1.08629976
H	-2.54065785	-3.37274814	0.18115334
H	1.65685583	-3.08986943	-0.67996211
H	2.31714783	2.74123492	-0.49907238
H	4.72951152	2.07493352	-0.60842836
H	5.33191740	-0.34836272	-0.23839675
H	3.48008744	-1.96719385	0.22299877
H	-1.18538740	-6.39820242	-1.29748931
H	-1.94837205	-5.62665054	0.12085337
H	-2.22346376	-4.96005214	-1.51327601
C	-0.33536623	0.16922886	2.24720259
O	0.24552018	1.38525349	2.18300247
H	-1.38439082	0.17343923	2.57988366
H	0.25834592	-0.54684455	2.84257983

T = 298.15 K

M06 gas phase (au)	-1722.8803530928	TC to enthalpy(au)	0.244251
M06 sol phase (au)	-1722.977123	Entropy (cal/mol*K)	139.04
B3LYP gas phase(au)	-1722.190423	Cv (cal/mol*K)	66.974
ZPC to energy(au)	0.225228	H (kcal/mol)	-1081031.243
TC to energy(au)	0.243307	G (kcal/mol)I	-1081072.698

6. Reference

S1. (a) A. Klamt, G. J. Schuurmann, *Chem. Soc. Perk. T.* 1993, **2**, 799-805. (b) D. M. York, M. J. Karplus, *Phys. Chem. A.* 1999, **103**, 11060-11079.

S2. M. Valiev, E. J. Bylaska, N.Govind, K. Kowalski, T. P. Straatsma, H. J. J. van Dam, D. Wang, J. Nieplocha, E. Apra, T. L. Windus, W. A. de Jong, *Comput. Phys. Commun.* 2010, **181**, 1477.

S3. (a) Y. Park, K. T. Park, J. G. Kim, S. Chang, *J. Am. Chem. Soc.* 2015, **137**, 4534-4542. (b) M. Zhou, D. Balcells, A. R. Parent, R. H. Crabtree, O. Eisenstein, *ACS Catal.* 2011, **2**, 208. (c) P. Liu, X. Xu, X. Dong, B. K. Keitz, M. B. Herbert, R. H. Grubbs, K. N. Houk, *J. Am. Chem. Soc.* 2012, **134**, 146.

S4. Y. X. Wu, ; B. Zhou, *ACS Catal.* 2017, **7**, 2213-2217.

S5. A. Sinhababu, ; R. J. Borchardt, *Org. Chem.* 1983, **48**, 2356-2360.