Electronic Supplementary Material (ESI) for Chemical Communications
This journal is © The Royal Society of Chemistry 2013

Nickel-catalyzed regio- and diastereoselective intermolecular three-component coupling of oxabicyclic alkenes with alkynes and organoboronic acids

*Subramaniyan Mannathan and Chien-Hong Cheng**

Department of Chemistry, National Tsing Hua University, Hsinchu 30013, Taiwan

chcheng@mx.nthu.edu.tw

Supporting Information

Table of Contents

Page 2	Experimental section
Page 3 – 4	Optimization studies
Page 4 – 16	Spectral data
Page 16	NOE data of compound **4a**
Page 16 – 38	Copies of ^{1}H and ^{13}C NMR spectra of all compounds

Experimental section

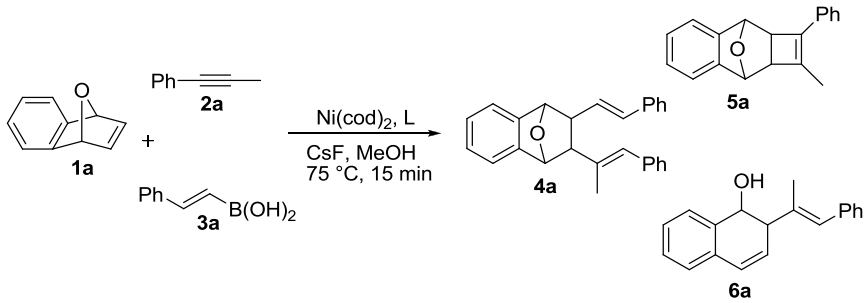
General: All reactions were conducted under nitrogen atmosphere on a dual-manifold Schlenk line unless otherwise mentioned and in oven-dried glass wares. All solvents were dried according to known methods and distilled prior to use.[1] Starting materials 1-methoxy-4-(pent-1-ynyl)benzene (**2d**), (3-methoxyprop-1-ynyl)benzene (**2f**) and 4-phenylbut-3-yn-1-ol (**2g**) were prepared according to the literature procedure. Others were commercially available and used as purchased.

References:

1. D. D. Perrin, W. L. F. Armarego, *In Purification of Laboratory Chemicals*, 3rd ed.; Pergamon Press: New York, 1988.
2. C. Molinaro, T. F. Jamison, *J. Am. Chem. Soc*., 2003, **125**, 8076.
3. M. Krause, X. Ligneau, H. Stark, M. Garbarg, J.-C. Schwartz, W. Schunack, *J. Med. Chem.*, 1998, **41**, 4171.

General procedure for nickel-catalyzed three-component coupling reaction of oxanorbornenes (1) and alkynes (2) with organoboronic acids (3): A sealed tube (20 mL) fitted with a septum containing oxanorbornene (**1**) (1.50 mmol) and boronic acid **(3)** (1.00 mmol) was evacuated and purged with nitrogen. Then, $Ni(cod)_2$ (0.100 mmol, 10 mol %), and CsF (1.00 mmol) were added inside the glove box. Freshly distilled toluene (0.5 mL), methanol (1.50 mL), and $P(t\text{-Bu})_3$ (tri-(*t*-butyl)phosphine) (0.100 mmol, 10 mol %) were sequentially added and the mixture was stirred until the solution became yellow at room temperature. The reaction mixture was heated to 75 ℃ in a preheated oil bath, followed by dropwise addition of alkyne (**2**) (1.50 mmol) via syringe. The resulting mixture was stirred well for 15-30 min and was then cooled to room temperature, filtered through a short Celite pad and washed with ethyl acetate/hexane (v/v = 70:30). The filtrate was concentrated and the residue was purified on a silica gel column using ethyl acetate/hexane as eluent to afford **4a-v**.

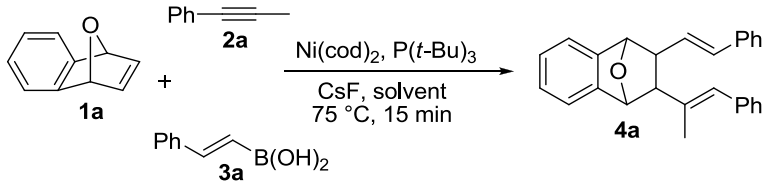
Table 1: Optimization studies for the nickel-catalyzed three component coupling reaction of oxabenzonorbornadiene (**1a**) and 1-phenyl-1-propyne (**2a**) with (*E*)-styrylboronic acid (**3a**)[a]



Entry	Ligand (10 mol%)	Additive (1 equiv.)	4a (%)[b]	5a (%)[b]	6a (%)[b]
1	-	-	54	22	10
2	PBu_3	-	50	12	12
3	PCy_3	-	46	14	9
4	PPh_3	-	38	57	12
5	P(*t*-Bu)$_3$	-	62	trace	<10
6	**P(*t*-Bu)$_3$**	**CsF**	**82**	**trace**	**10**
7	P(*t*-Bu)$_3$	K_2CO_3	45	-	trace
8	P(*t*-Bu)$_3$	K_3PO_4	54	-	<10
9	P(*t*-Bu)$_3$	Cs_2CO_3	17	-	trace
10	dppe	CsF	trace	-	25
11	dppp	CsF	trace	-	-

[a]Reaction conditions: oxabenzonorbornadiene (**1a**) (1.00 mmol), 1-phenyl-1-propyne (**2a**) (1.00 mmol), *E*-styryl boronic acid (**3a**) (1.00 mmol) $Ni(cod)_2$ (0.10 mmol, 10 mol %), ligand (0.10 mmol, 10 mol %), additive (1.00 mmol) and methanol (1.50 mL) at 75 °C for 15 min. [b]Yields were measured from the crude products by the ^{1}H NMR integration method using mesitylene as an internal standard.

Table 2: Effect of solvents[a]

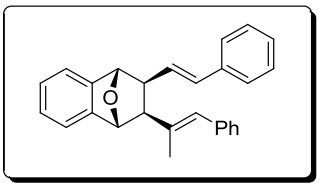


Entry	Solvents	4a (%)[b]
1	Toluene	-
2	THF	-
3	CH_3CN	-
4	DCE	-
5	Toluene/MeOH (1:1)	70
6	THF/MeOH (1:1)	62
7	Dioxane/MeOH (1:1)	55
8	CH_3CN/MeOH (1:1)	25
9	DCE/MeOH (1:1)	59
11	**Toluene/MeOH (1:3)**	**86**

[a]Reaction conditions: oxabenzonorbornadiene (**1a**) (1.00 mmol), 1-phenyl-1-propyne (**2a**) (1.00 mmol), *E*-styryl boronic acid (**3a**) (1.00 mmol) $Ni(cod)_2$ (0.10 mmol, 10 mol %), $P(t\text{-}Bu)_3$ (0.10 mmol, 10 mol %), CsF (1.00 mmol) and solvent (2.00 mL), at 75 °C for 15 min. [b]Yields were measured from the crude products by the ^1H NMR integration method using mesitylene as an internal standard.

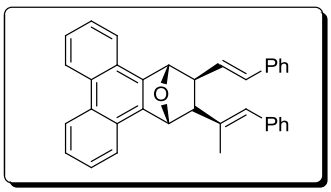
The spectral data and copies of ^{1}H and ^{13}C NMR spectra of all compounds are listed below.

(1*R,8*S**,9*S**,10*S**)-9-[(*E*)-2-Phenylethenyl]-10-[(1*E*)-1-phenylprop-1-en-2-yl]-11-oxatricyclo[6.2.1.0^{2,7}]undeca-2,4,6-triene (4a)**



White solid: mp: 82 – 84 ºC; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.42 – 7.15 (m, 14 H), 6.68 (s, 1 H), 6.44 (d, J = 15.6 Hz, 1 H), 6.38 (dd, J_{dd} = 8.8 Hz, J_d = 16.0 Hz, 1 H), 5.61 (s, 1 H), 5.25(s, 1 H), 2.86 (t, J = 8.4 Hz, 1 H), 2.69 (d, J = 8.4 Hz, 1 H), 1.79 (d, J = 1.2 Hz, 3 H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 146.9, 145.6, 138.5, 137.8, 137.6, 131.2, 130.4, 129.1, 128.8, 128.8, 128.3, 127.3, 127.1, 127.0, 126.3, 119.7, 119.2, 84.8, 83.1, 53.9, 48.7, 19.9; **HRMS**: calcd for $C_{27}H_{24}O$ 364.1827, found 364.1822.

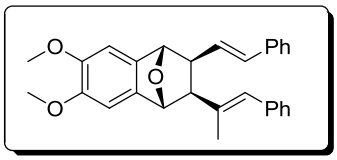
(1*R,16*S**,17*S**,18*S**)-17-[(*E*)-2-Phenylethenyl]-18-[(1*E*)-1-phenylprop-1-en-2-yl]-19-oxapentacyclo[14.2.1.0^{2,15}.0^{3,8}.0^{9,14}]nonadeca-2,4,6,8,10,12,14-heptaene (4b)**



White solid; mp: 150 – 152 ºC;**^{1}H NMR** (400 MHz, $CDCl_3$): δ 8.77 – 8.75 (m, 2 H), 8.02 – 8.00 (m, 1 H), 7.97 – 7.95 (m, 1 H), 7.69 – 7.67 (m, 4 H), 7.35 – 7.28 (m, 10 H), 6.77 (s, 1 H), 6.50 (dd, J_{dd} = 9.6 H_Z, J_d = 15.6 Hz, 1 H), 6.41 (d, J = 16.0 Hz, 1 H), 6.17 (s, 1 H), 5.81 (s,1 H), 2.84 (t, J = 8.4 Hz,1 H), 2.63 (d, J = 8.0 Hz,1 H), 1.78 (s, 3 H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 141.7, 140.6, 138.2, 137.7, 137.3, 131.1, 130.3, 130.2, 130.1, 128.9, 128.5, 128.0, 127.1, 127.0, 127.0, 126.8, 126.3, 126.1, 125.9, 125.5, 124.2,

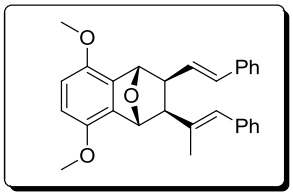
123.6, 84.1, 82.4, 53.7, 48.6, 19.7; **HRMS**: calcd for $C_{35}H_{28}O$ 464.2140, found 464.2137.

(1*R,8*S**,9*S**,10*S**)-4,5-Dimethoxy-9-[(*E*)-2-phenylethenyl]-10-[(1*E*)-1-phenylprop-1-en-2-yl]-11-oxatricyclo[6.2.1.0^{2,7}]undeca-2,4,6-triene (4c)**



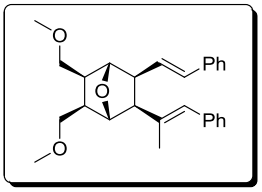
White solid: mp: 160 – 164 ºC; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.32 – 7.15 (m, 10 H), 6.94 (s, 2 H), 6.65 (s, 1 H), 6.41 (d, J = 15.6 Hz, 1 H), 6.35 (dd, J_{dd} = 8.8 Hz, J_d = 15.6 Hz, 1 H), 5.54 (s, 1 H), 5.18 (s, 1 H), 3.90 (s, 6 H), 2.79 (t, J = 8.4 Hz, 1 H), 2.60 (d, J = 8.4 Hz, 1 H), 1.76 (s, 3 H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 147.9, 147.9, 138.2, 137.6, 137.4, 137.3, 130.8, 130.3, 128.8, 128.4, 127.9, 127.0, 126.5, 125.9, 125.9, 104.0, 103.5, 84.7, 83.0, 56.2, 54.1, 48.9, 19.6; **HRMS**: calcd for $C_{29}H_{28}O_3$ 424.2038, found 424.2041.

(1*R,8*S**,9*S**,10*S**)-3,6-Dimethoxy-9-[(*E*)-2-phenylethenyl]-10-[(1*E*)-1-phenylprop-1-en-2-yl]-11-oxatricyclo[6.2.1.0^{2,7}]undeca-2,4,6-triene (4d)**



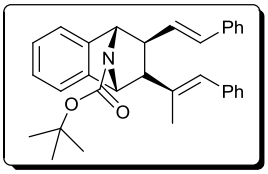
Colorless highly viscous liquid; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.32 – 7.15 (m, 10 H), 6.69 (d, J = 1.2 Hz, 2 H), 6.65 (s, 1 H), 6.44 (d, J = 15.6 Hz, 1 H), 6.36 (dd, J_{dd} = 9.2 Hz, J_d = 16.0 Hz, 1 H), 5.76 (s, 1 H), 5.40 (s, 1 H), 3.83 (s, 3 H), 3.82 (s, 3 H), 2.87 (t, J_t = 8.4 Hz, 1 H), 2.69 (d, J = 8.4 Hz, 1 H),1.77 (d, J = 1.2 Hz, 3 H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 146.8, 146.3, 138.3, 137.5, 137.4, 135.7, 134.5, 130.9, 130.2, 128.9, 128.4, 128.4, 127.9, 127.0, 126.6, 126.0, 125.9, 111.2, 82.4, 80.6, 56.0, 53.1, 47.9, 19.5; **HRMS**: calcd for $C_{29}H_{28}O_3$ 424.2038, found 424.2040.

(1*R,2*R**,3*S**,4*S**,5*S**,6*S**)-2,3-Bis(methoxymethyl)-5-[(*E*)-2-phenylethenyl]-6-[(1*E*)-1-phenylprop-1-en-2-yl]-7-oxabicyclo[2.2.1]heptane (4e)**



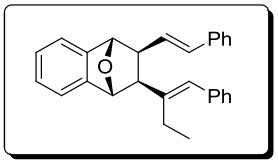
Colorless highly viscous oil: **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.27 – 7.20 (m, 6 H), 7.17 – 7.11(m, 4 H), 6.52 (s, 1 H), 6.32 (d, J = 16.0 Hz, 1 H), 6.18 (dd, J_{dd} = 10.0 Hz, J_d = 16.0 Hz, 1 H), 4.67 (s, 1 H), 4.27 (s, 1 H), 3.40 – 3.23(m, 4 H), 3.36 (s, 3 H), 3.33 (s, 3 H), 2.90 (t, J = 9.2 Hz, 1 H), 2.72 (d, J = 9.2H_Z, 1 H), 2.30 – 2.22 (m, 2 H), 1.70 (d, J = 1.2 Hz, 3 H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 138.3, 137.4, 137.4, 130.0, 129.9, 128.8, 128.4, 127.9, 126.8, 126.3, 125.9, 125.8, 84.2, 82.5, 71.0, 70.9, 58.8, 58.7, 56.1, 51.8, 46.2, 45.1, 19.3; **HRMS**: calcd for $C_{27}H_{32}O_3$ 404.2351, found 404.2345.

***Tert*-butyl (1*R**,8*S**,9*S**)-9-[(*E*)-2-phenylethenyl]-10-[(1*E*)-1-phenylprop-1-en-2-yl]-11-azatricyclo[6.2.1.0^{2,7}]undeca-2,4,6-triene-11-carboxylate (4f)**



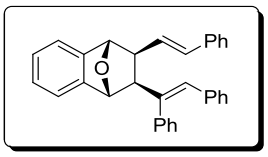
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.32 – 7.15 (m, 14 H), 6.67 (s, 1 H), 6.42 (d, J = 16.0 Hz, 1 H), 6.31 (dd, J_{dd} =9.6 Hz, J =16.0 Hz, 1 H), 5.29 (s, br, 1 H), 4.98 (s, br, 1 H), 2.73 (t, J = 9.2 Hz, 1 H), 2.53 (d, J = 8.8 Hz, 1 H), 1.72 (s, 3 H), 1.35 (s, 9 H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 155.5, 138.3, 137.4, 130.9, 130.0, 128.9, 128.5, 128.0, 127.1, 126.6, 126.5, 126.3, 126.1, 126.0, 119.9, 80.1, 66.4, 65.1, 53.6, 48.1, 28.3, 19.4; **HRMS**: calcd for $C_{33}H_{33}NO_2$ 463.2511, found 463.2501.

(1*S,8*R**,9*S**,10*S**)-9-[(1*E*)-1-Phenylbut-1-en-2-yl]-10-[(*E*)-2-phenylethenyl]-11-oxatricyclo[6.2.1.0^{2,7}]undeca-2,4,6-triene (4g)**



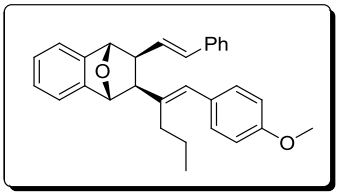
White solid; mp: 97 – 99 ºC; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.36 – 7.17 (m, 14 H), 6.78 (s, 1 H), 6.42 (d, *J* = 16.0 Hz, 1 H), 6.36 (d, *J* = 14.8 Hz, 1 H), 5.58 (s, 1 H), 5.22 (s, 1 H), 2.84 (t, *J* = 8.0 Hz, 1 H), 2.74 (d, *J* = 8.4 Hz, 1 H), 2.42 – 2.33 (m, 1 H), 1.85 – 1.75 (m,1 H), 0.99 (t, *J* = 7.2 Hz, 3 H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 146.8, 145.3,143.1, 138.3, 137.3, 131.0, 130.5, 128.5, 128.4, 128.0, 127.0, 126.8, 126.6, 126.3, 126.0, 119.4, 118.8, 84.8, 83.7, 49.3, 48.5, 25.9, 12.5; **HRMS**: calcd for $C_{28}H_{26}O$ 378.1984, found 378.1992.

(1*S,8*R**,9*S**,10*S**)-9-[(*Z*)-1,2-diphenylethenyl]-10-[(*E*)-2-phenylethenyl]-11-oxatricyclo[6.2.1.0^{2,7}]undeca-2,4,6-triene (4h)**



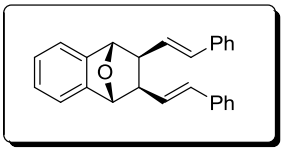
Colorless highly viscous oil; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.35 – 7.15 (m, 11 H), 7.07 – 6.98 (m, 9 H), 6.48 (dd, J_{dd} =11.2 Hz, *J* =16.0 Hz, 1 H), 6.23 (d, *J* = 15.6 Hz, 1 H), 5.70 (s, 1 H), 5.24 (s, 1 H), 3.01 (d, *J* = 8.0 Hz, 1 H), 2.81 (t, *J* = 9.6 Hz, 1 H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 146.6, 145.2,142.0, 141.3, 137.4, 137.3, 131.0, 130.8, 129.2, 129.0, 128.5, 128.1, 128.0, 127.8, 127.0, 126.8, 126.7, 126.2, 126.1, 119.5, 118.9, 85.0, 84.6,53.0, 48.6; **HRMS**: calcd for $C_{32}H_{26}O$ 426.1984, found 426.1980.

(1*S,8*R**,9*S**,10*S**)-9-[(1*E*)-1-(4-Methoxyphenyl)pent-1-en-2-yl]-10-[(*E*)-2-phenylethenyl]-11-oxatricyclo[6.2.1.0^{2,7}]undeca-2,4,6-triene (4i)**



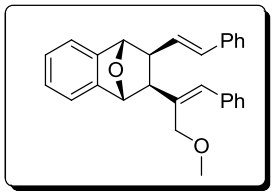
Colorless highly viscous oil; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.32 – 7.13 (m, 11 H), 6.83 (dd, J_{dd} = 2.4 Hz, J_d = 6.4 Hz, 2 H), 6.68 (s, 1 H), 6.35 – 6.33 (m, 2 H), 5.53 (s, 1 H), 5.17 (s, 1 H), 3.78 (3, H), 2.81 – 2.77 (m, 1 H), 2.67 (d, *J* = 8.4 Hz, 1 H), 2.35 – 2.40 (m, 1 H), 1.71 – 1.65 (m, 1 H), 1.52 – 1.26 (m, 2 H), 0.77 (t, *J* = 7.2 Hz, 3 H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 157.8, 146.9, 145.3, 140.6, 137.4, 131.2, 130.8, 130.3, 129.6, 128.4, 127.0, 126.7, 126.6, 126.0, 119.4, 118.8, 113.5, 84.6, 84.8, 55.1, 49.9, 48.4, 35.2, 21.1, 14.3; **HRMS**: calcd for $C_{30}H_{30}O_2$ 422.2246, found 422.2254.

(1*R,8*S**,9*S**,10*R**)-9,10-Bis[(*E*)-2-phenylethenyl]-11-oxatricyclo[6.2.1.0^{2,7}] undeca-2,4,6-triene (4j)**



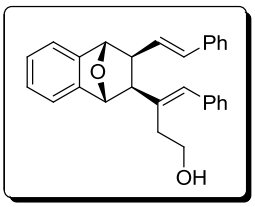
Yellow solid; mp: 145 – 147 ºC;**^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.32 (d, *J* = 6.8 Hz, 3 H), 7.25 (t, J_t = 7.2 Hz, 2 H), 7.22 – 7.15 (m, 2 H), 6.42 (d, *J* = 15.6 Hz, 1 H), 6.32 (dd, J_{dd} = 8.8 Hz, J_d = 15.6 Hz, 1 H), 5.27 (s, 1 H), 2.83 – 2.78 (m, 1 H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 145.3, 137.2, 131.5, 130.0, 128.4, 127.1, 126.8, 126.1, 119.2, 84.5, 49.4; **HRMS**: calcd for $C_{26}H_{22}O$ 350.1671, found 350.1667.

(1*S,8*R**,9*S**,10S*)-9-[(1*Z*)-3-Methoxy-1-phenylprop-1-en-2-yl]-10-[(*E*)-2-phenylethenyl]-11-oxatricyclo[6.2.1.0^{2,7}]undeca-2,4,6-triene (4k)**



White solid; mp: 98 – 100 ºC;**^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.32 – 7.19 (m, 14 H), 6.98 (s, 1 H), 6.41 (d *J* = 16.0 Hz, 1 H) 6.32 (dd, J_{dd} = 9.6 Hz, J_d = 16.0 H_Z, 1 H), 5.66 (s, 1 H), 5.23 (s, 1 H), 4.08 (d, *J* = 10.4 Hz, 1 H), 3.58 (d, *J* = 10.4 Hz, 1 H), 3.25 (s, 3 H), 3.06 (d, *J* = 8.4 Hz, 1 H), 2.88(t, *J* = 8.8 Hz, 1 H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 146.5, 145.3, 137.9, 137.2, 137.0, 130.8, 130.7, 129.6, 128.7, 128.5, 128.1, 127.1, 126.8, 126.7, 126.6,126.0, 119.3, 119.1, 84.7, 83.1, 71.5, 58.1, 48.5, 47.7; **HRMS**: calcd for $C_{28}H_{26}O_2$ 394.1933, found 394.1927.

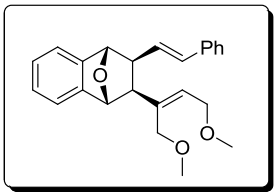
(3*E*)-4-Phenyl-3-[(1*S,8*R**,9*S**,10*S**)-10-[(*E*)-2-phenylethenyl]-11-oxatricyclo[6.2.1.0^{2,7}]undeca-2,4,6-trien-9-yl]but-3-en-1-ol (4l)**



Colorless highly viscous oil; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.32 – 7.19 (m, 14 H), 6.92 (s, 1 H), 6.40 - 6.38 (m, 2 H), 5.58 (s, 1 H), 5.19 (s, 1 H), 3.59 (t, *J* = 6.4 Hz, 2 H), 2.83 – 2.81 (m, 1 H), 2.71 (d, *J* = 8.4 Hz, 1 H), 2.61 – 2.54 (m, 1 H), 2.17 – 2.11 (m, 1 H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 146.5, 145.1, 137.8, 137.7, 136.9, 130.7, 129.5, 128.5,128.5, 128.1, 127.2, 126.8, 126.7, 126.3,126.0, 119.4, 118.9, 84.7, 83.6, 60.5, 50.2, 48.6, 36.2;

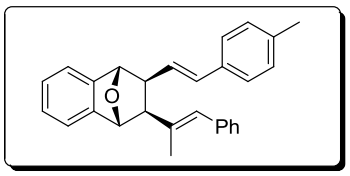
HRMS: calcd for $C_{28}H_{26}O_2$ 394.1933, found 394.1943.

(1*S,8*R**,9*S**,10*S**)-9-[(2*Z*)-1,4-Dimethoxybut-2-en-2-yl]-10-[(*E*)-2-phenylethenyl]-11-oxatricyclo[6.2.1.0^{2,7}]undeca-2,4,6-triene (4m)**



Colorless highly viscous oil; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.32 – 7.51 (m, 5 H), 7.22 – 7.15 (m, 4 H), 6.34 (d, J = 16.0 Hz, 1 H), 6.18 (dd, J_{dd} =10.0 Hz, J_d =16.0 Hz, 1 H), 5.95 (t, J = 6.4 Hz, 1 H), 5.48 (s, 1 H), 5.15 (s, 1 H), 4.05 – 4.02 (m, 2 H), 3.98 (d, J = 11.6 Hz, 1 H), 3.52 (d, J = 11.6 Hz, 1 H), 3.29 (s, 3 H), 3.21 (s, 3 H), 2.83 (d, J = 8.4 Hz, 1 H), 2.76 (t, J = 9.2 Hz, 1 H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 146.4, 145.2, 138.8, 137.3, 130.9, 130.7, 128.5, 127.4, 127.1, 126.7, 126.6, 126.0, 119.3, 119.0, 84.6, 82.8, 70.5, 68.2, 58.2, 57.9, 48.2, 48.0; **HRMS**: calcd for $C_{24}H_{26}O_3$ 362.1882, found 362.1872.

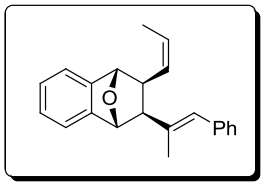
(1*R,8*S**,9*S**,10*S**)-9-[(*E*)-2-(4-Methylphenyl)ethenyl]-10-[(1*E*)-1-phenylprop-1-en-2-yl]-11-oxatricyclo[6.2.1.0^{2,7}]undeca-2,4,6-triene (4n)**



Colorless highly viscous oil; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.36 – 7.31 (m, 4 H), 7.27 – 7.19 (m, 7 H), 7.12 (d, J = 7.6 Hz, 2 H), 6.70 (s, 1 H), 6.42 (d, J = 16.0 Hz, 1 H), 6.35 (dd, J_{dd} = 9.2 Hz, J_d = 16.0 Hz, 1 H), 5.62 (s, 1 H), 5.26 (s, 1 H), 2.86 (t, J = 8.8 Hz, 1 H), 2.69 (d, J = 8.4 Hz, 1 H), 2.35 (s, 3 H), 1.80 (d, J = 0.8 Hz, 3 H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 146.6, 145.3, 138.2, 137.5, 136.8, 134.5, 130.7,129.1, 129.0, 128.8, 127.9,

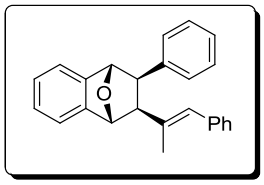
126.7, 126.6, 125.9, 125.9, 119.3, 118.8; **HRMS**: calcd for $C_{28}H_{26}O$ 378.1984, found 378.1981.

(1*S,8*R**,9*S**,10*S**)-9-[(1*E*)-1-Phenylprop-1-en-2-yl]-10-[(1*Z*)-prop-1-en-1-yl]-11-oxatricyclo[6.2.1.0^{2,7}]undeca-2,4,6-triene (4o)**



Colorless highly viscous oil; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.35 – 7.29 (m, 4 H), 7.28 – 7.24 (m, 2 H), 7.21 – 7.14 (m, 3 H), 6.46 (s, 1 H), 5.58 – 5.51 (m, 2 H), 5.49 (s, 1 H), 5.09 (s, 1 H), 2.99 (t, *J* = 8.8 Hz, 1 H), 2.67 (d, *J* = 8.4 Hz, 1 H), 1.78 (d, *J* = 1.2 Hz, 3 H), 1.58 (d, *J* = 5.2 Hz, 3 H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 146.5, 145.7, 138.3, 138.0, 130.4, 128.8, 127.9, 126.6, 126.5, 125.9, 124.7, 119.2, 118.8, 84.2, 82.5, 53.6, 42.4, 18.6, 13.1; **HRMS**: calcd for $C_{22}H_{22}O$ 302.1671, found 302.1663.

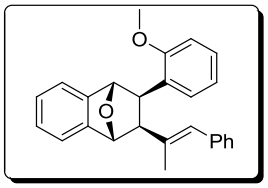
(1*R,8*S**,9*R**,10*S**)-9-Phenyl-10-[(1*E*)-1-phenylprop-1-en-2-yl]-11-oxatricyclo[6.2.1.0^{2,7}]undeca-2,4,6-triene (4p)**



Colorless highly viscous oil; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.38 – 7.31 (m, 4 H), 7.25 – 7.17 (m, 7 H), 7.14 – 7.11 (m, 1 H), 6.89 (d, *J* = 7.2 Hz, 2 H), 6.52 (s, 1 H), 5.62 (s, 1 H), 5.57 (s, 1 H), 3.32 (d, *J* = 7.2 Hz, 1 H), 2.90 (d, *J* = 7.2 Hz, 1 H), 1.28 (d, *J* = 1.2 Hz, 3 H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 146.7, 146.5, 140.7, 138.2, 137.8, 129.7, 128.6,

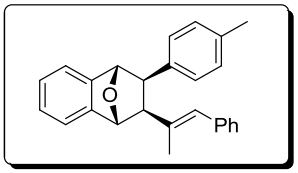
127.8, 127.5, 127.4, 126.7, 126.6, 126.2, 125.8, 119.1, 85.0, 82.3, 54.6, 50.6, 18.8; **HRMS**: calcd for $C_{25}H_{22}O$ 338.1671, found 338.1676.

(1*R,8*S**,9*R**,10*S**)-9-(2-Methoxyphenyl)-10-[(1*E*)-1-phenylprop-1-en-2-yl]-11-oxatricyclo[6.2.1.0^{2,7}]undeca-2,4,6-triene (4q)**



Colorless semisolid:**^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.65 (dd, J_{dd} = 1.2 Hz, J_d = 7.2 Hz, 1 H), 7.36 – 7.34 (m, 1 H), 7.31 – 7.29 (m, 1 H), 7.23 – 7.16 (m, 5 H), 7.09 (t, *J* = 7.2 Hz, 1 H), 6.94 (dt, J_d = 0.8 Hz, J_t = 8.4 Hz, 1 H), 6.84 (d, *J* = 6.8 Hz, 2 H), 6.73 (d, *J* = 8.0 Hz, 1 H), 6.38 (s, 1 H), 5.54 (s, 1 H), 5.52 (s, 1 H), 3.76 (d, *J* = 8.8 Hz, 1 H), 3.65 (s, 3 H), 2.95 (d, *J* = 8.8 Hz, 1 H), 1.36 (d, *J* = 1.2 Hz, 3 H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 157.1, 147.1, 146.8, 138.5, 137.9, 129.2, 129.0, 128.7, 127.7, 127.5, 127.2, 126.6, 126.5, 125.6, 120.1, 119.1, 119.1, 109.3, 83.7, 82.8, 54.8, 54.0, 43.3, 17.4; **HRMS**: calcd for $C_{26}H_{24}O_2$ 368.1776, found 368.1786.

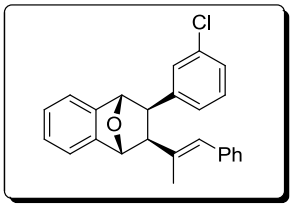
(1*R,8*S**,9*R**,10*S**)-9-(4-Methylphenyl)-10-[(1*E*)-1-phenylprop-1-en-2-yl]-11-oxatricyclo[6.2.1.0^{2,7}]undeca-2,4,6-triene (4r)**



Colorless highly viscous oil; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.38 – 7.36 (m, 1 H), 7.33 – 7.31 (m, 1 H), 7.26 – 7.22 (m, 6 H), 7.16 – 7.12 (m, 1 H), 7.06 (d, *J* = 7.2 Hz, 2 H), 6.93 (d, *J* = 8.0 Hz, 2 H), 6.53 (s, 1 H), 5.62 (s, 1 H), 5. 48 (s, 1 H), 3.30 (d, *J* = 8.6 Hz, 1 H), 2.89 (d, *J* = 8.8 Hz, 1 H), 2.32 (s, 3 H), 1.31 (s, 3 H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ

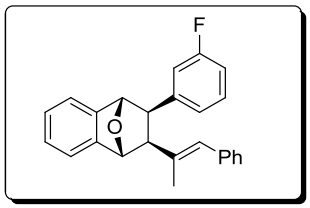
146.7, 146.6, 138.3, 138.0, 137.5,135.6 129.5, 128.7, 128.1, 127.8, 127.3, 126.7, 126.6, 125.8, 119.1, 85.2, 82.3, 54.5, 50.2, 21.0, 18.9; **HRMS**: calcd for $C_{26}H_{24}O$ 352.1827, found 352.1824.

(1*R,8*S**,9*R**,10*S**)-9-(3-Chlorophenyl)-10-[(1*E*)-1-phenylprop-1-en-2-yl]-11-oxatricyclo[6.2.1.0^{2,7}]undeca-2,4,6-triene (4s)**



Colorless highly viscous oil; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.40 – 7.39 (m, 1 H), 7.37 – 7.35 (m, 1 H), 7.33 – 7.31 (m, 1 H), 7.25 – 7.19 (m, 5 H), 7.17 – 7.13 (m, 3 H), 6.96 (d, *J* = 7.2 Hz, 2 H), 6.59 (s, 1 H), 5.61 (s, 1 H), 5.44 (s, 1 H), 3.27 (d, *J* = 8.8 Hz, 1 H), 2.89 (d, *J* = 8.8 Hz, 1 H), 1.28 (d, *J* = 1.2 Hz, 3 H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 146.6, 146.1, 142.9, 138.0, 137.3, 133.4, 129.8, 128.7, 128.5, 128.0, 127.9, 127.9, 126.9, 126.8, 126.4, 126.0, 119.2, 84.9, 82.3, 54.6, 50.3, 19.0; **HRMS**: calcd for $C_{25}H_{21}ClO$ 372.1281, found 372.1275.

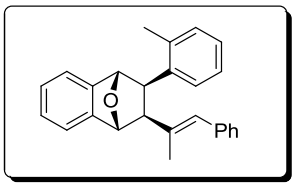
(1*R,8*S**,9*R**,10*S**)-9-(3-Fluorophenyl)-10-[(1*E*)-1-phenylprop-1-en-2-yl]-11-oxatricyclo[6.2.1.0^{2,7}]undeca-2,4,6-triene (4t)**



Colorless highly viscous oil; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.36 – 7.34 (m, 1 H), 7.33 – 7.29 (m, 1 H), 7.24 – 7.20 (m, 4 H), 7.19 – 7.12 (m, 2 H), 7.10 – 7.07 (m, 2 H), 6.92 (d, *J* = 7.2 Hz, 1 H), 6.89 – 6.84 (m, 2 H), 6.52 (s, 1 H), 5.60 (s, 1 H), 5.45 (s, 1 H), 3.29 (d, *J*

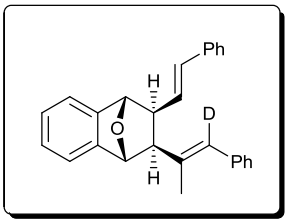
= 9.2 Hz, 1 H), 2.89 (d, J = 9.2 Hz, 1 H), 1.29 (d, J = 0.8 Hz, 3 H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 162.4 (d, $J_{C\text{-}F}$ = 243.1 Hz), 146.7, 146.1, 143.5 (d, $J_{C\text{-}F}$ = 7.3 Hz) 138.1, 137.3, 128.7, 128.6, 127.9, 127.9, 126.9, 126.8, 125.9, 125.5, 119.2 (d, $J_{C\text{-}F}$ = 2.9 Hz), 116.6 (d, $J_{C\text{-}F}$ = 22.0 Hz), 113.1 (d, $J_{C\text{-}F}$ = 21.2 Hz), 84.9, 82.3,54.7, 50.4, 18.9; **HRMS**: calcd for $C_{25}H_{21}FO$ 356.1576, found 356.1568.

(1*R,8*S**,9*R**,10*S**)-9-(2-Methylphenyl)-10-[(1*E*)-1-phenylprop-1-en-2-yl]-11-oxatricyclo[6.2.1.0^{2,7}]undeca-2,4,6-triene (4u)**



Colorless highly viscous oil; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.68 (d, J = 7.6 Hz, 1 H), 7.43 – 7.41 (m, 1 H), 7.36 – 7.34 (m, 1 H), 7.29 – 7.22 (m, 5 H), 7.19 – 7.17 (m, 2 H), 7.11 (d, J = 7.6 Hz, 1 H), 6.92 (d, J = 7.6 Hz, 2 H), 6.50 (s, 1 H), 5.63 (s, 1 H), 5.59 (s, 1 H), 3.51 (d, J = 8.8 Hz, 1 H), 3.05 (d, J = 8.8 Hz, 1 H), 2.25 (s, 3 H), 1.40 (s, 3 H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 147.1, 146.7, 138.8, 138.1, 137.8, 136.5, 129.5, 128.7, 128.5, 128.0, 127.8, 126.6, 126.6, 126.2, 125.8, 125.5, 119.2, 119.0, 84.3, 82.7, 54.4, 46.7, 20.5, 17.3; **HRMS**: calcd for $C_{26}H_{24}O$ 352.1827, found 352.1820.

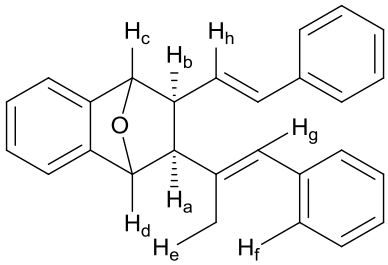
(1*S,8*R**,9*S**,10*S**)-9-[(1*E*)-1-phenyl(1-^{2}H)prop-1-en-2-yl]-10-[(*E*)-2-phenylethenyl]-11-oxatricyclo[6.2.1.0^{2,7}]undeca-2,4,6-triene (4a-d$_1$)**



White solid: mp: 88 – 92 ºC; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.33 – 7.15 (m, 14 H), 6.41

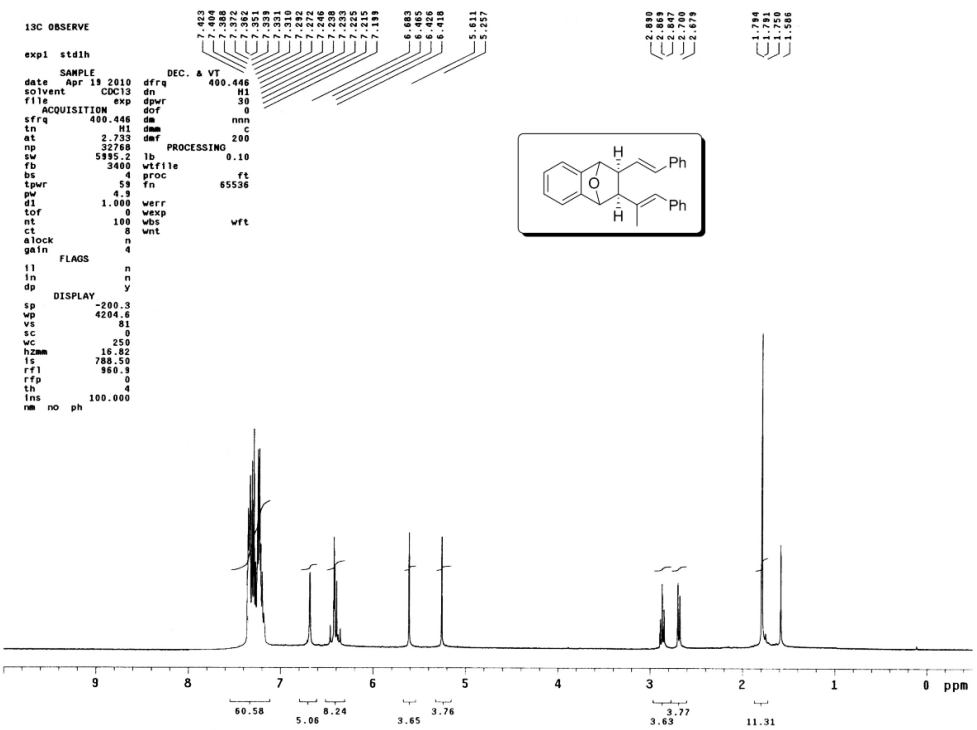
(d, J = 16.0 Hz, 1 H), 6.35 (dd, J_{dd} = 8.8 Hz, J_d = 16.0 Hz, 1 H), 5.57 (s, 1 H), 5.22 (s, 1 H), 2.83 (t, J = 8.4 Hz, 1 H), 2.65 (d, J = 8.4 Hz, 1 H), 1.76 (s, 3 H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 146.6, 145.3, 138.1, 137.4, 137.3, 130.9, 130.1, 128.9, 128.5, 128.0, 127.1, 126.8, 126.7, 126.0, 126.0, 119.4, 118.9, 84.6, 82.8, 53.6, 48.5, 19.6; **HRMS**: calcd for $C_{27}H_{23}DO$ 365.1890, found 365.1882.

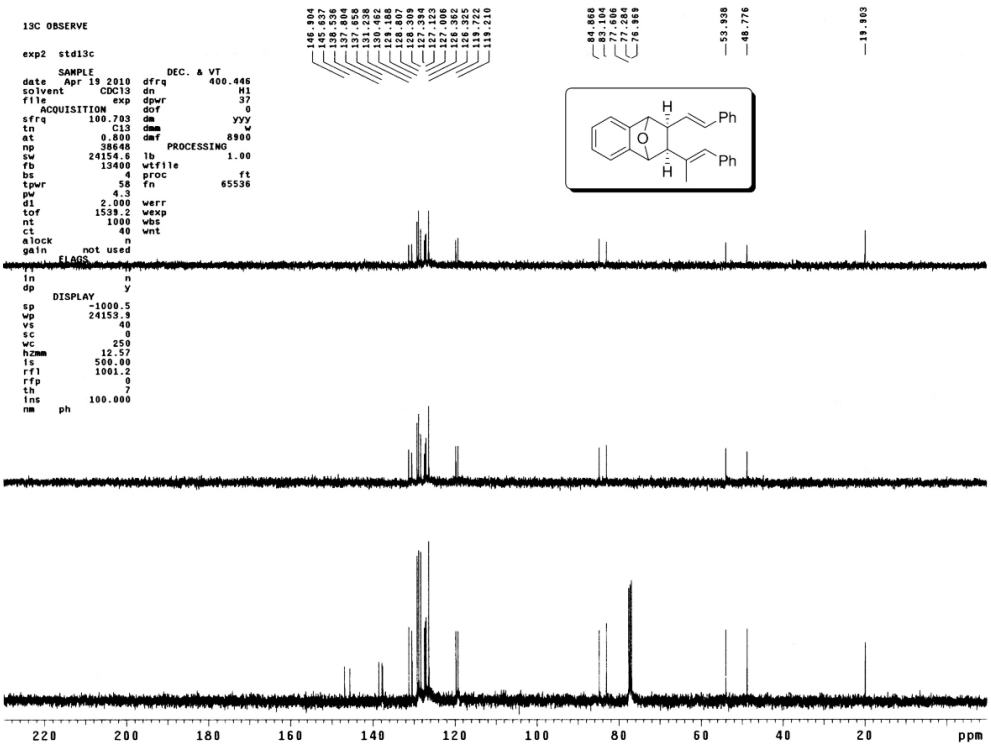
4.7 NOE for the compound 4a



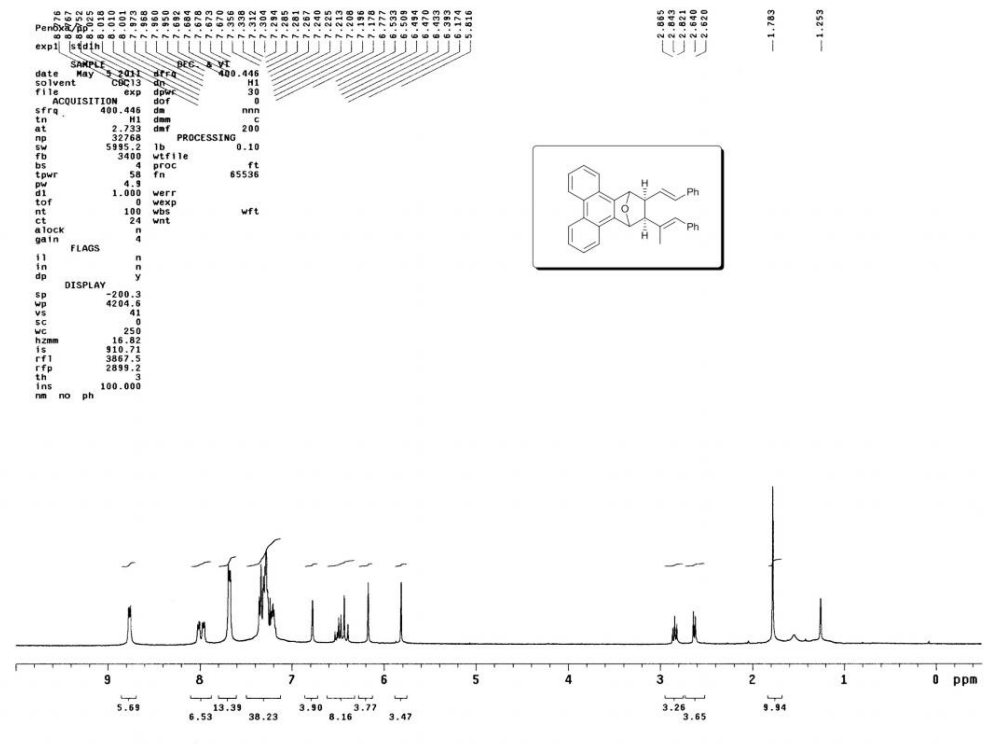
Irradiation at	Observed enhancement (%)
H_e	H_a (0.85), H_d (0.68), H_f (0.76), No NOE for H_g
H_a	H_e (2.40), H_b (0.46), H_d (1.28), H_g (1.59)
H_b	H_c (1.1.6), H_h (3.93), H_a (0.80)
H_g	H_d (4.08), H_a (1.53), No NOE for H_e

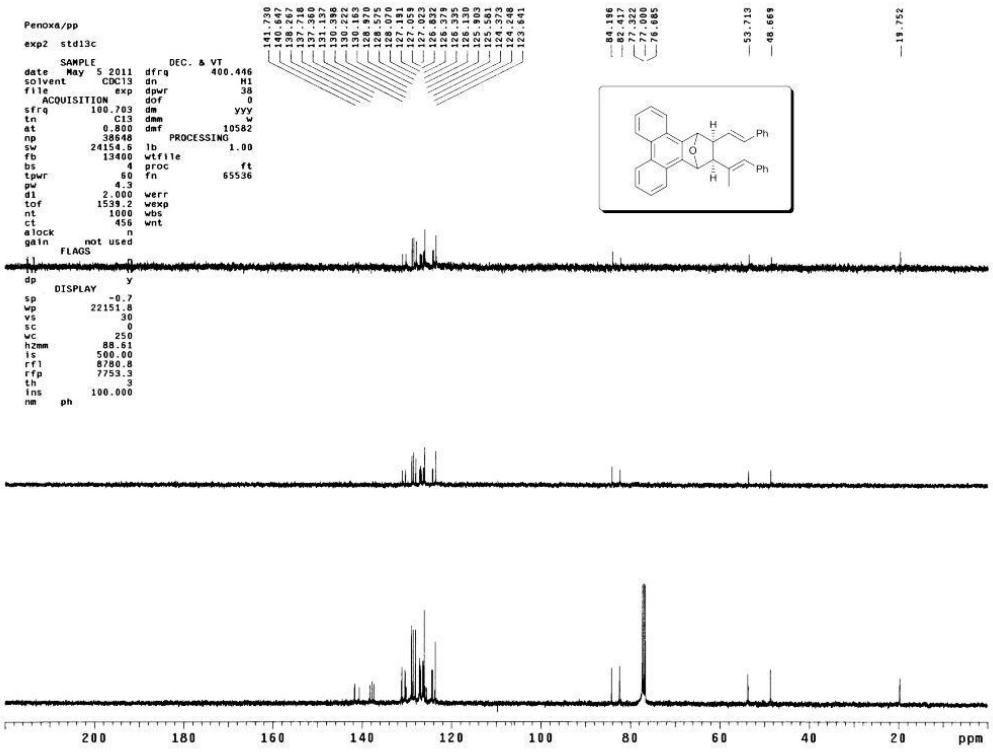
^{1}H and ^{13}C NMR spectra of compound **4a**



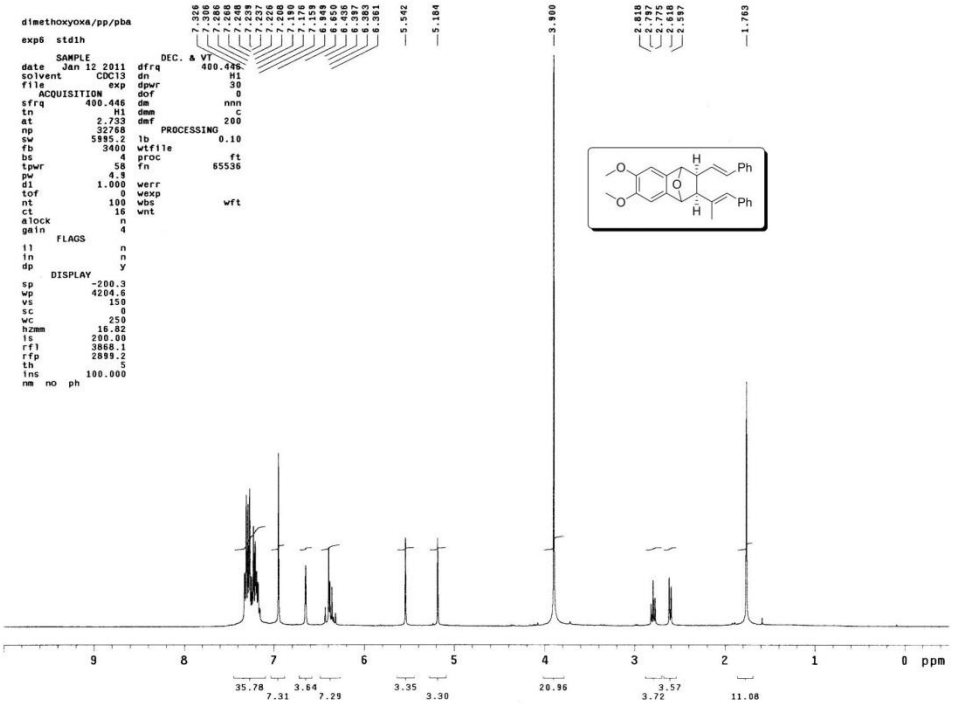


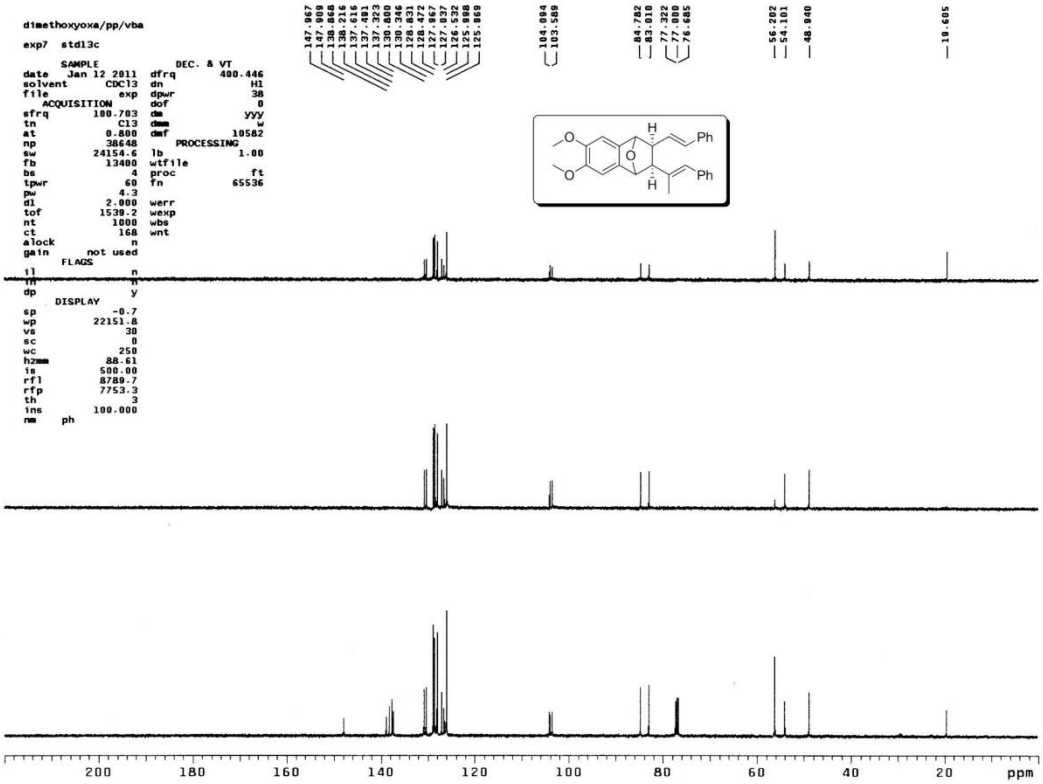
^{1}H and ^{13}C NMR spectra of compound **4b**



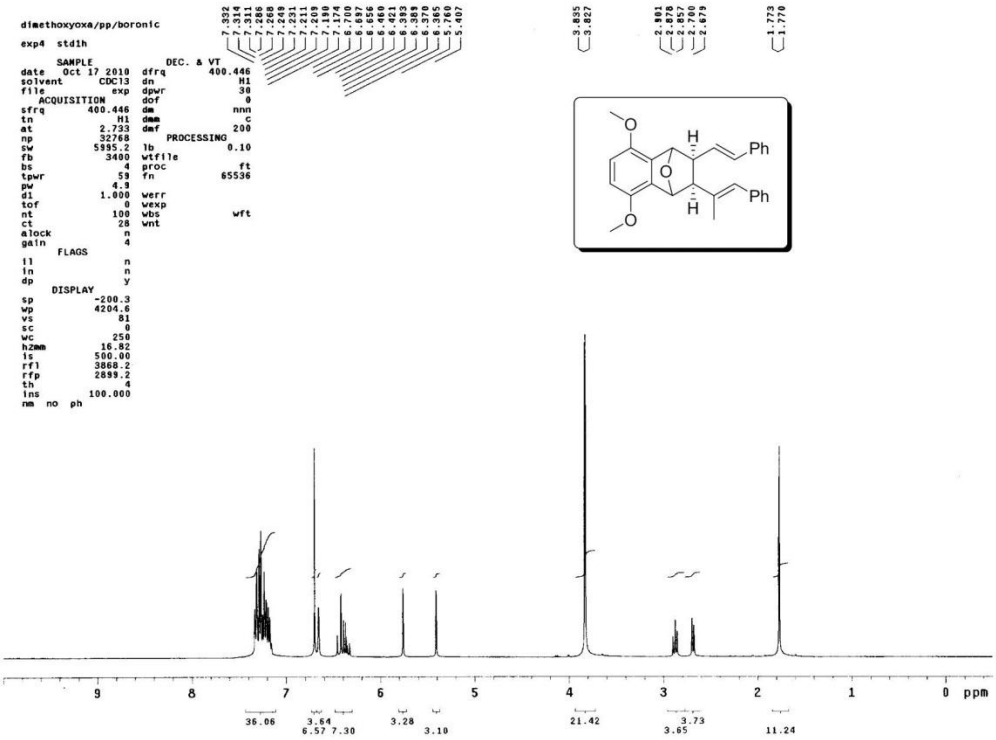


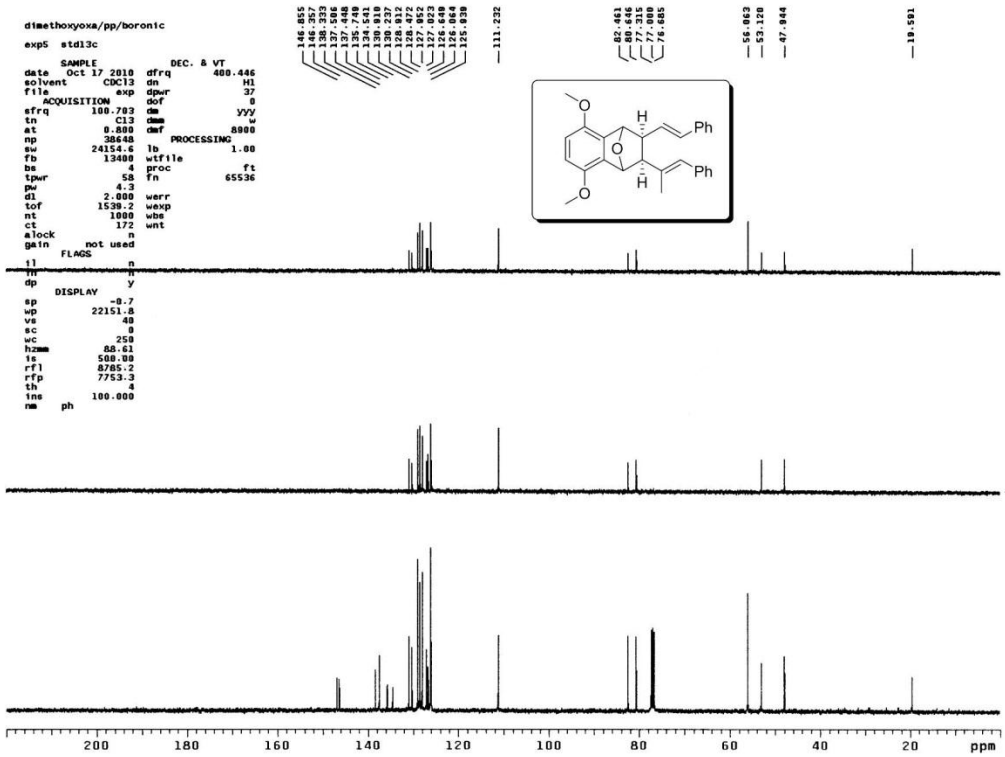
^{1}H and ^{13}C NMR spectra of compound **4c**



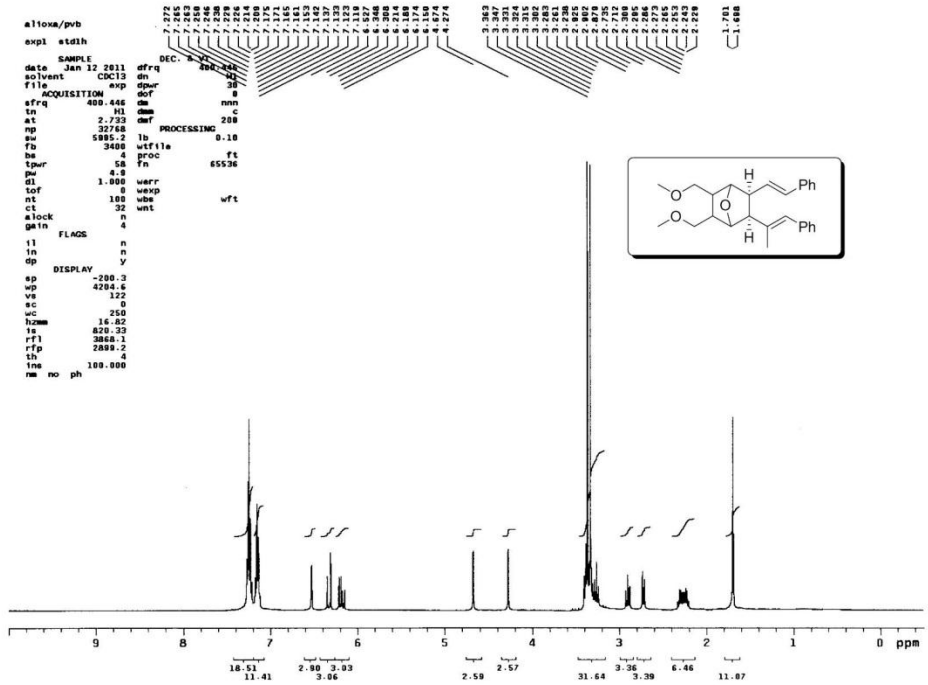


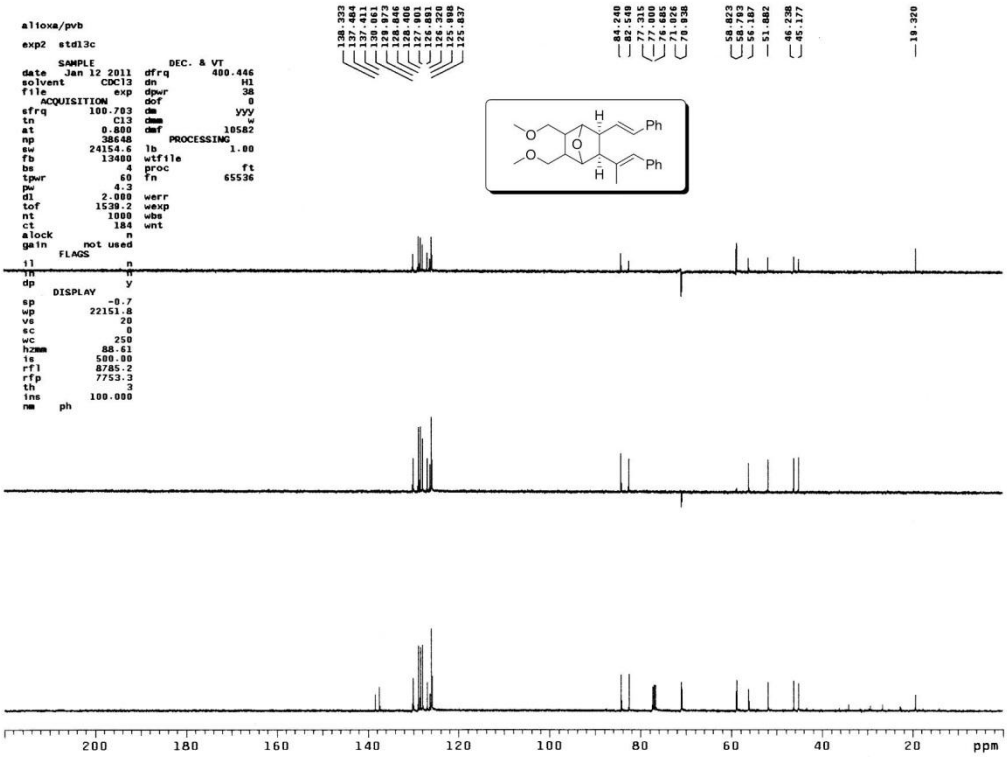
^{1}H and ^{13}C NMR spectra of compound **4d**



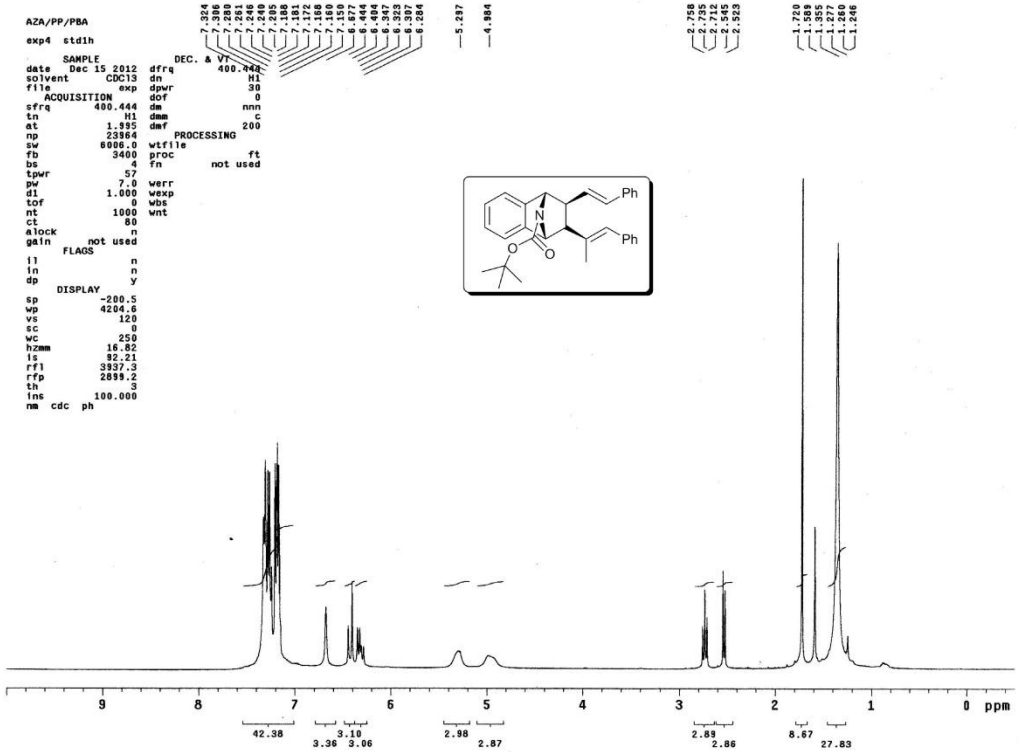


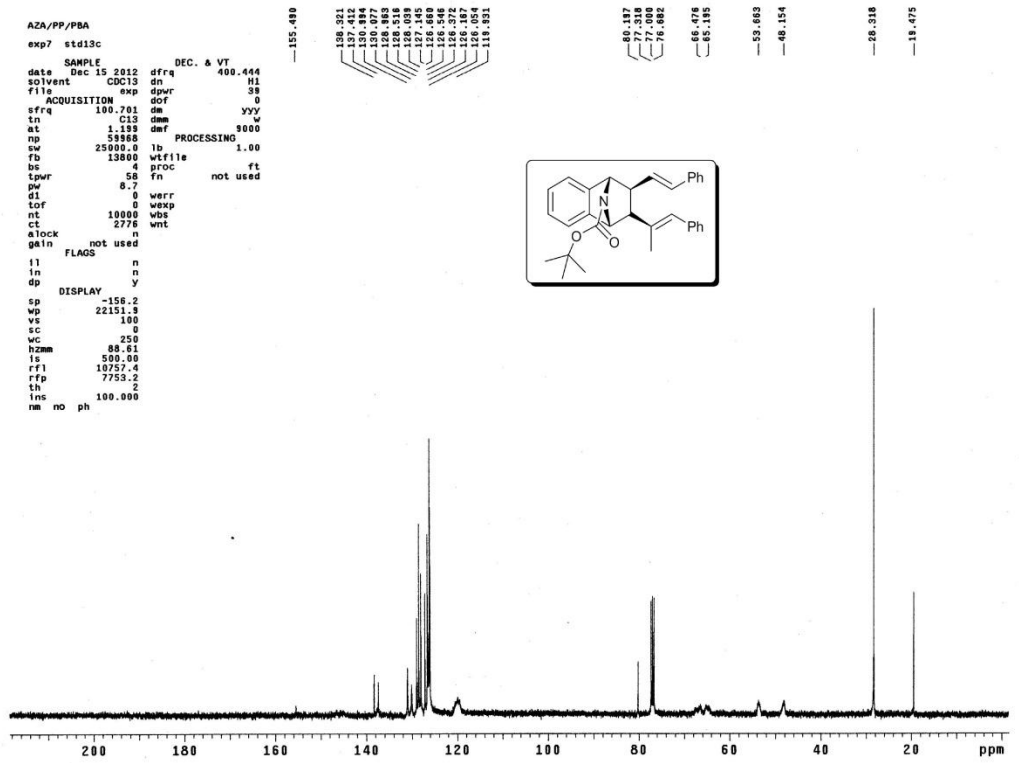
^{1}H and ^{13}C NMR spectra of compound **4e**



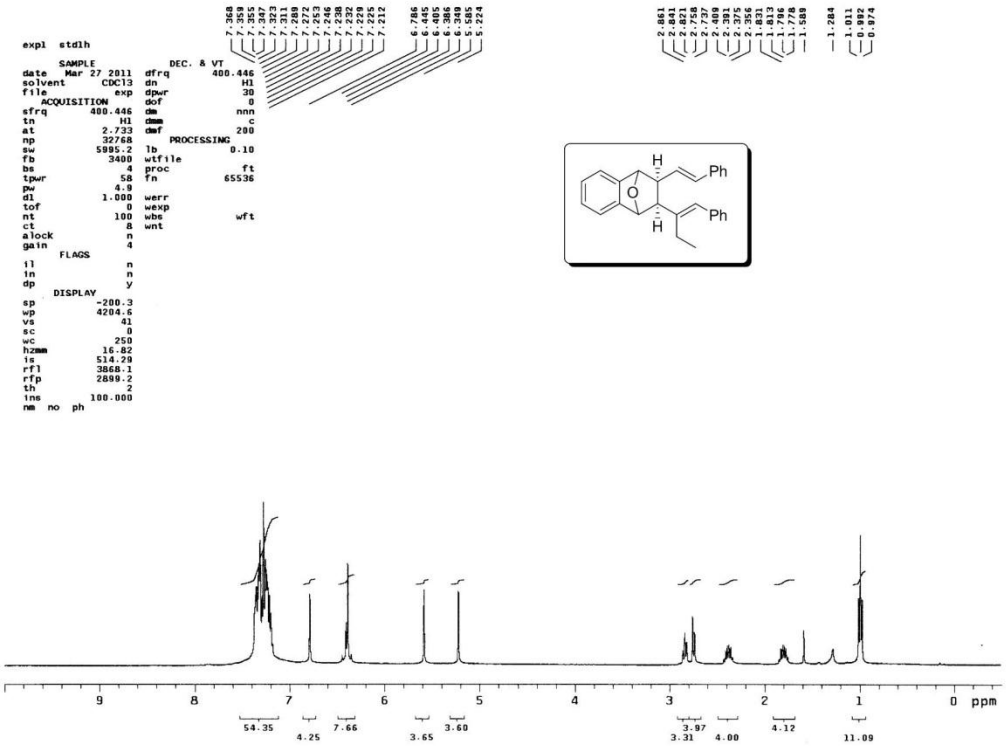


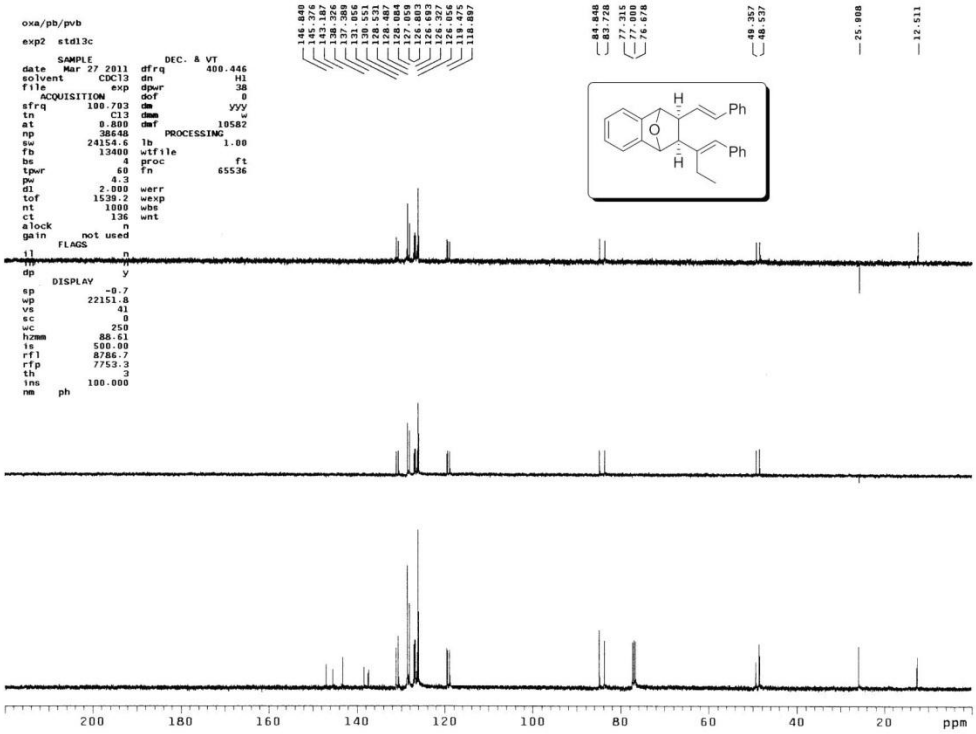
^{1}H and ^{13}C NMR spectra of compound **4f**



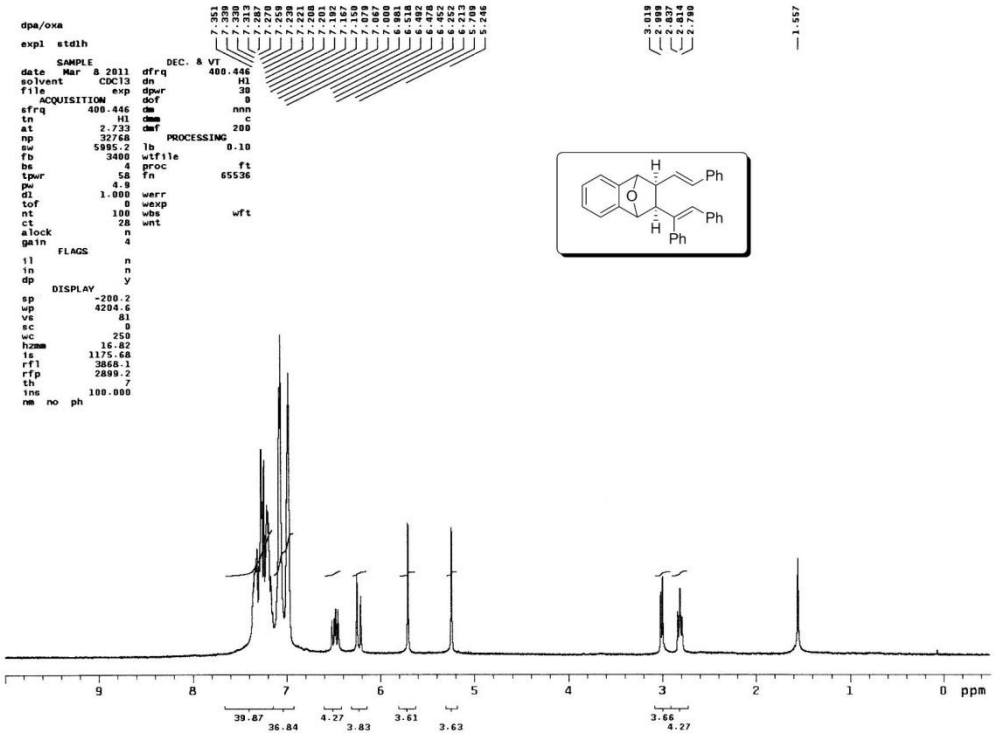


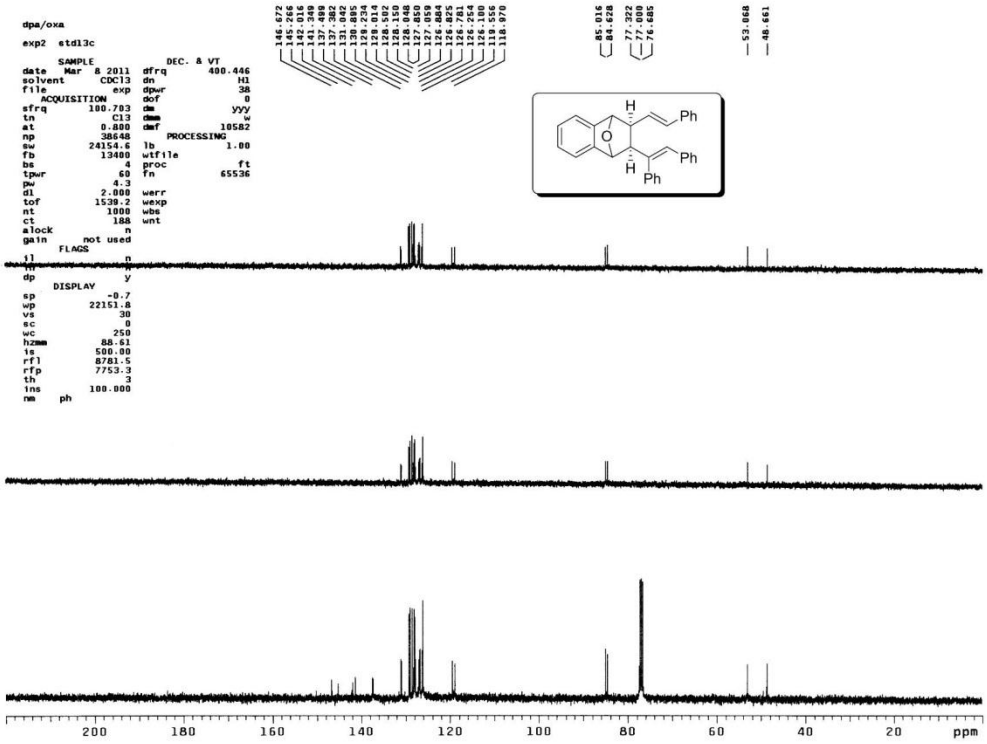
^{1}H and ^{13}C NMR spectra of compound **4g**



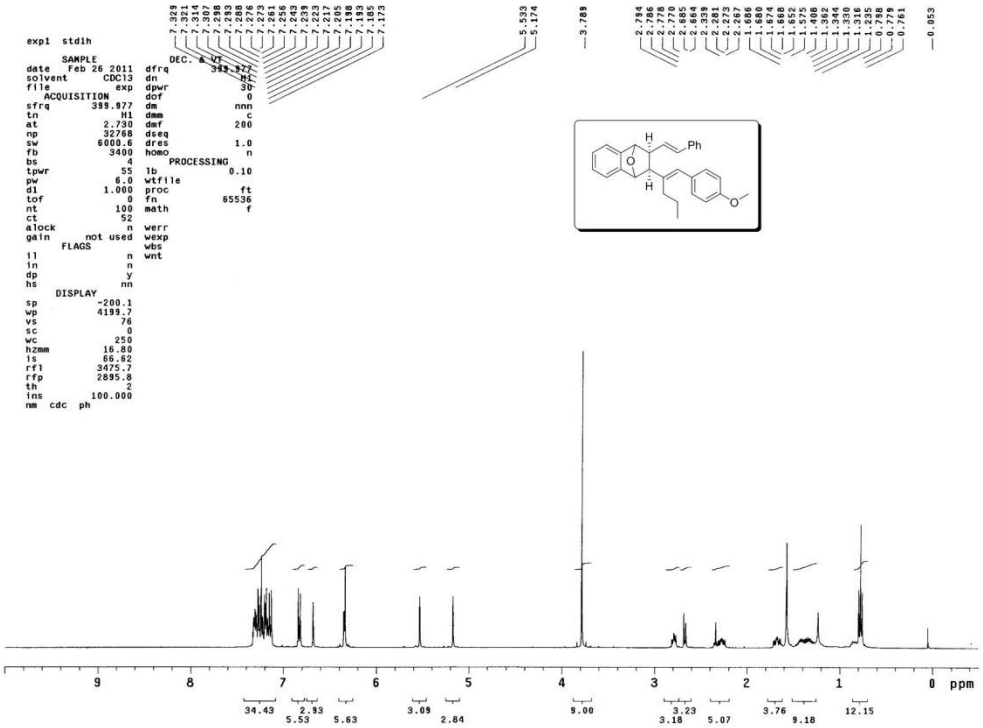


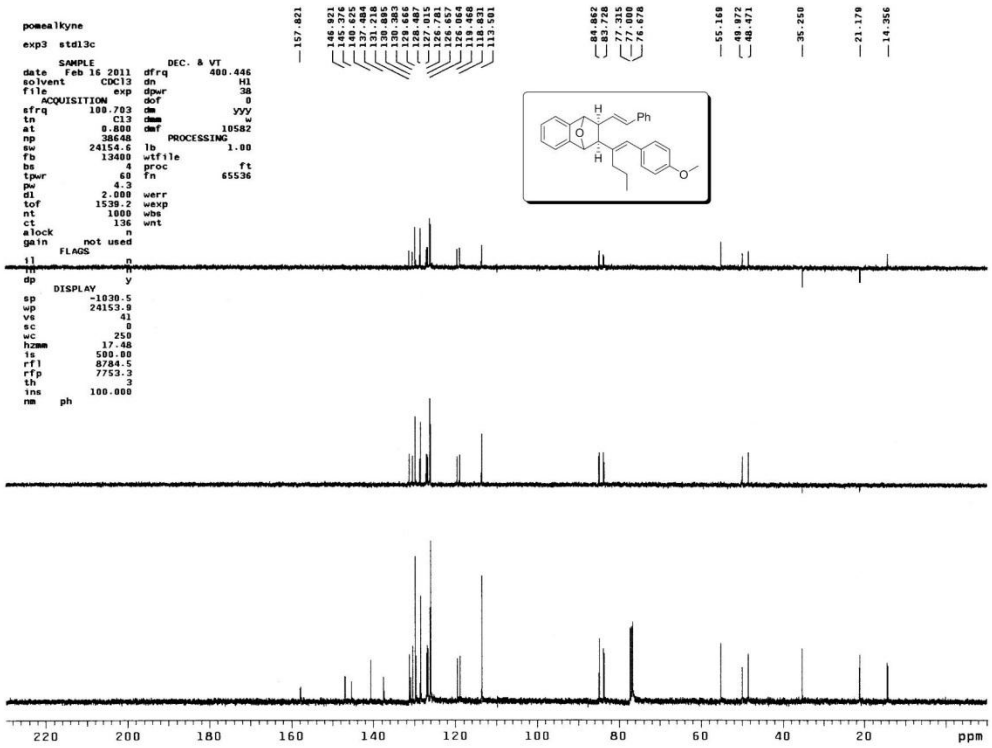
^{1}H and ^{13}C NMR spectra of compound **4h**



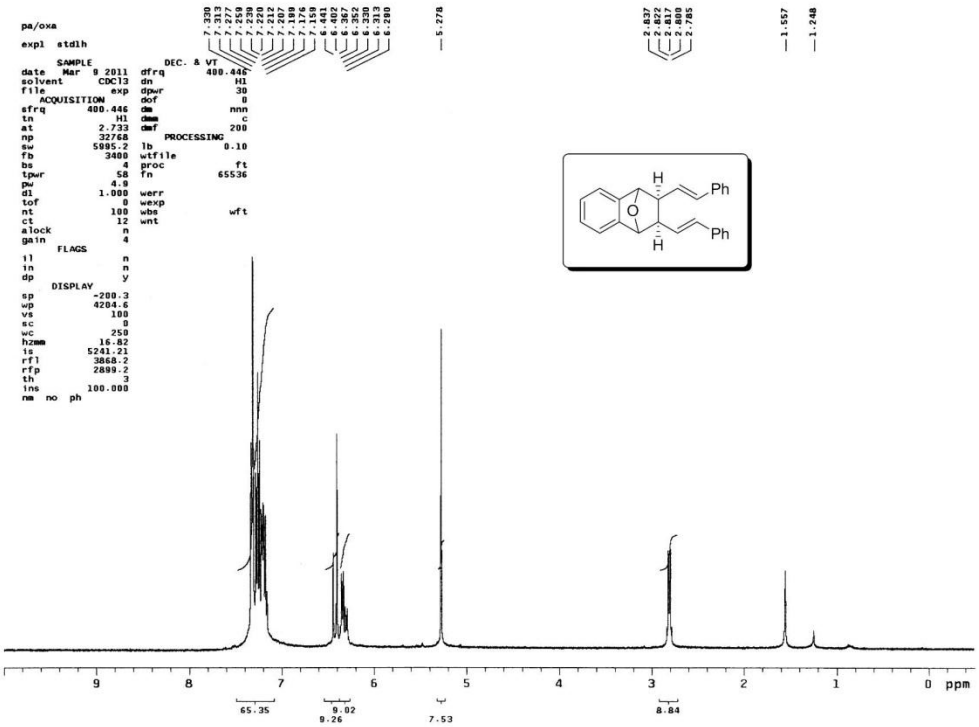


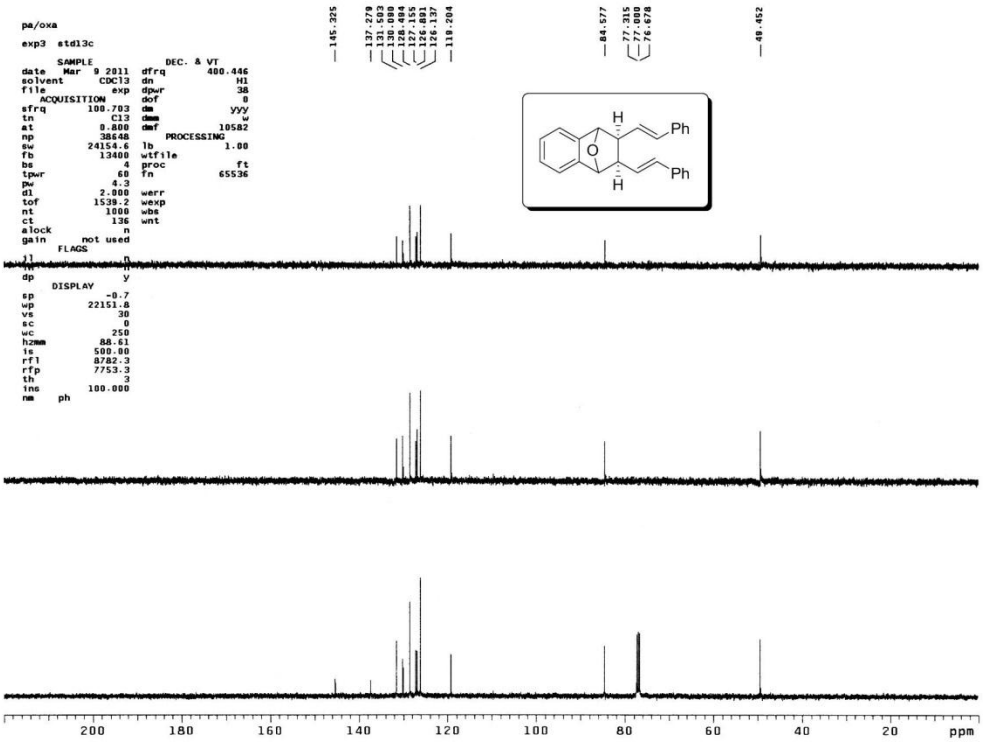
^{1}H and ^{13}C NMR spectra of compound **4i**



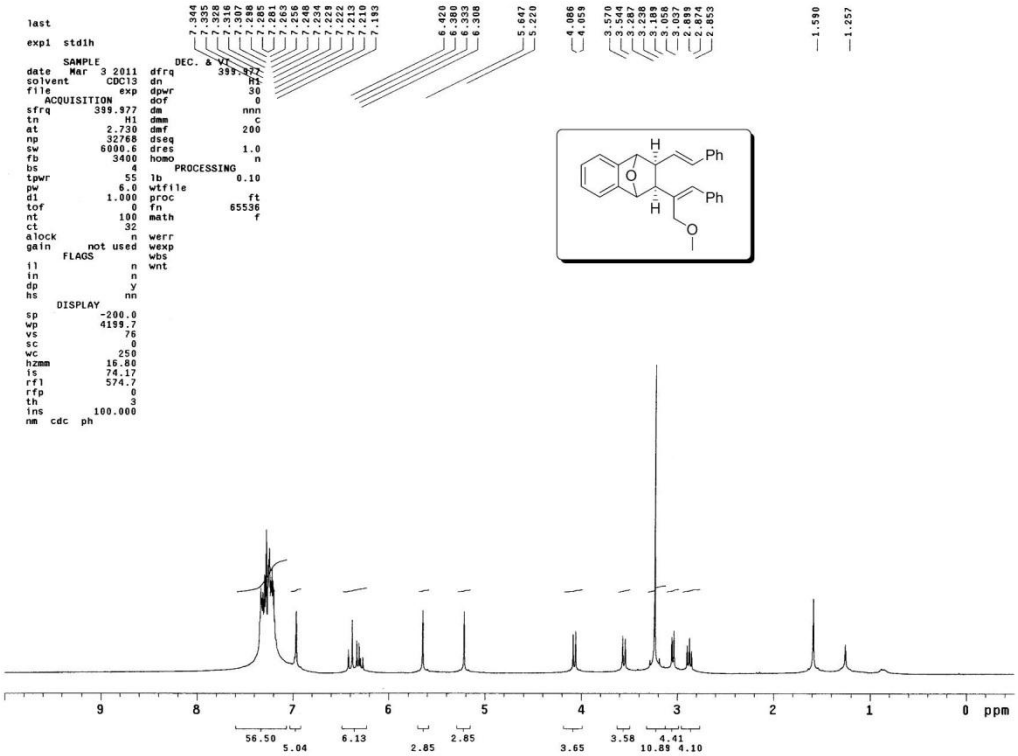


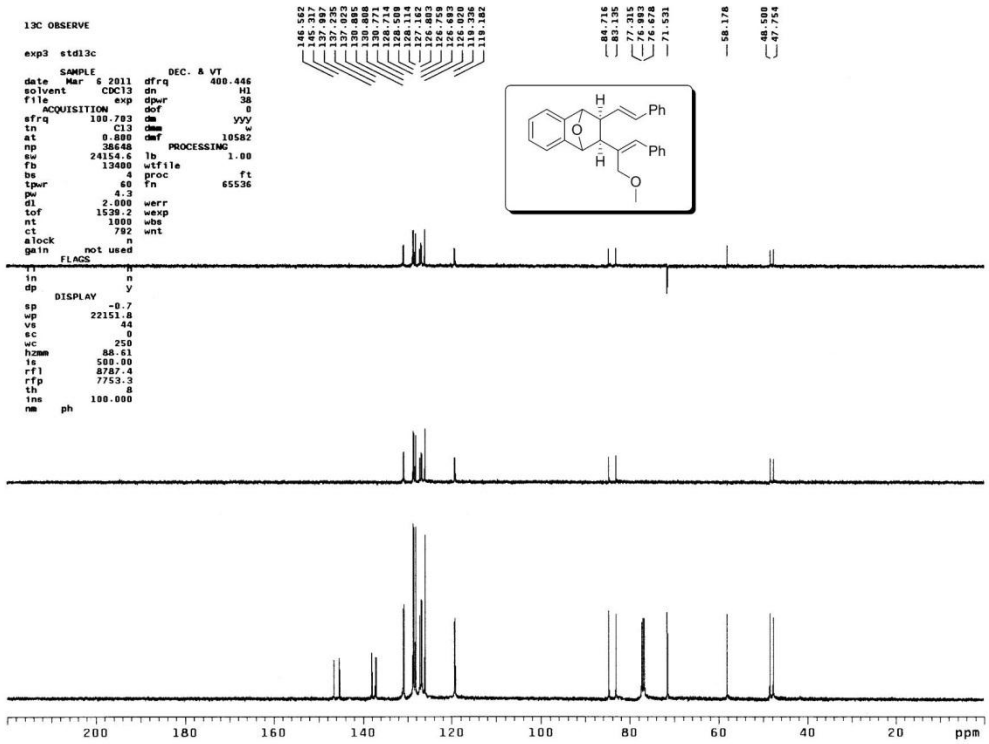
^{1}H and ^{13}C NMR spectra of compound **4j**



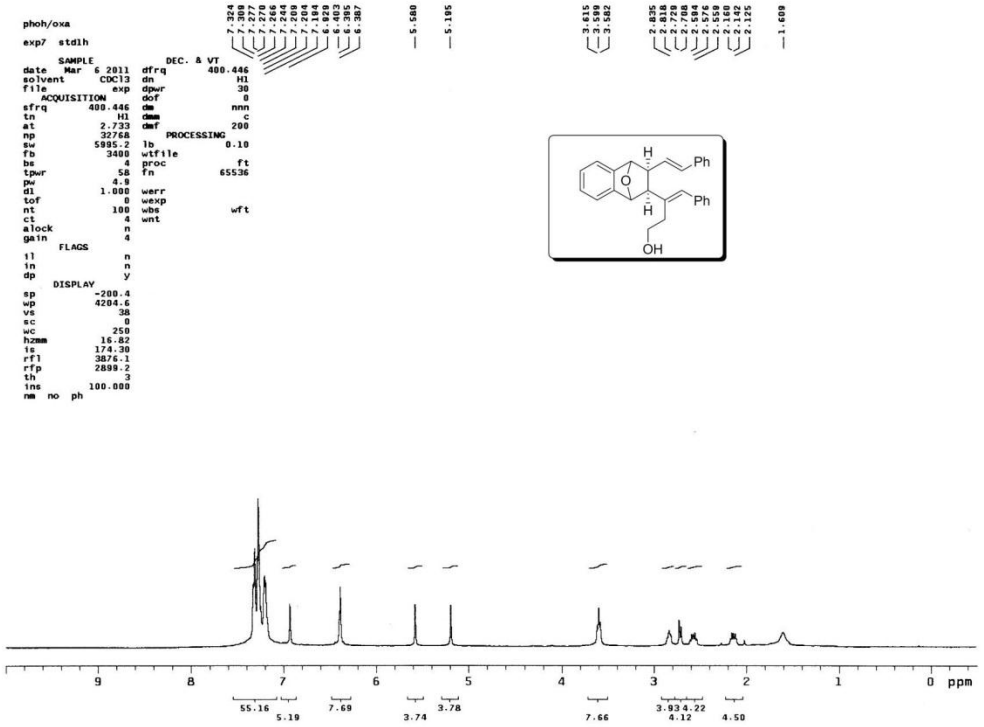


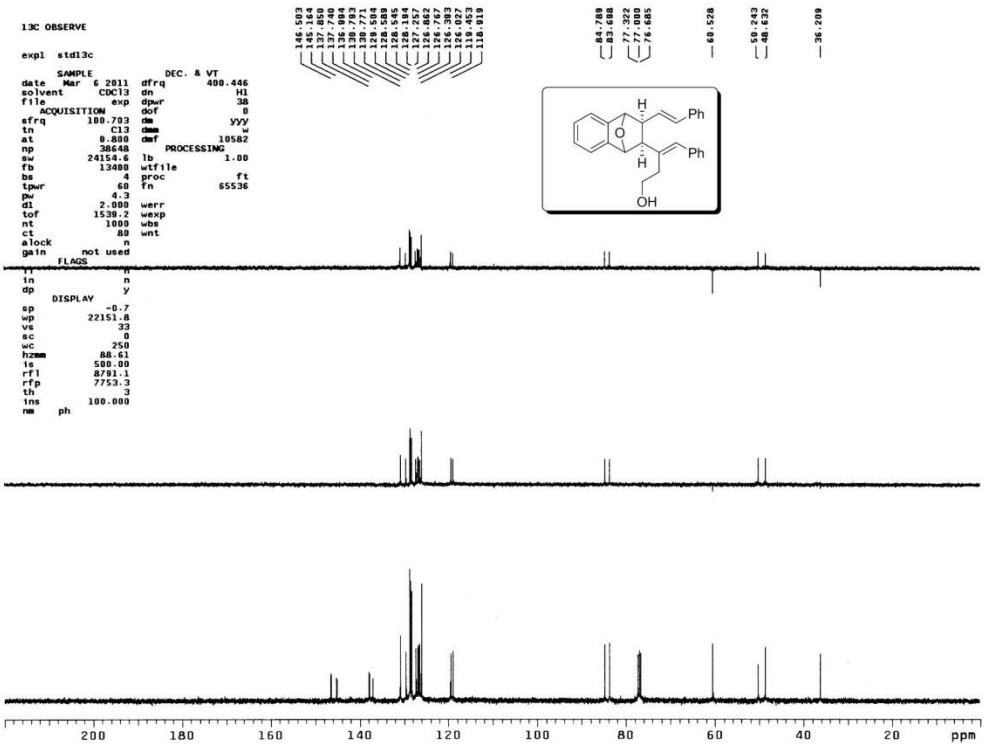
^{1}H and ^{13}C NMR spectra of compound **4k**



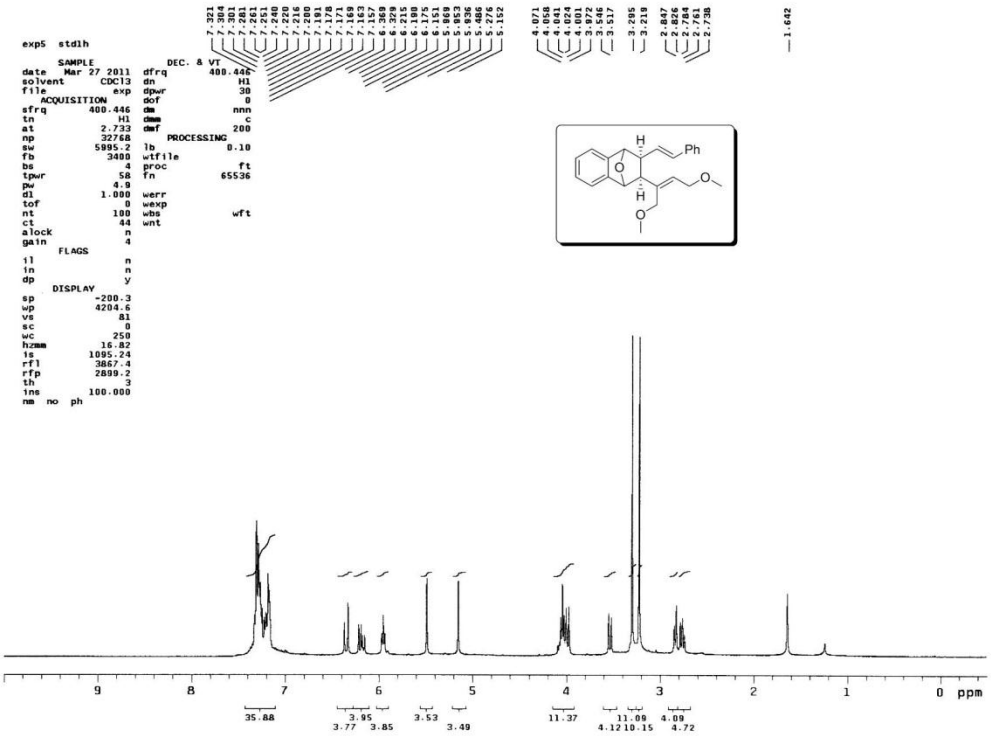


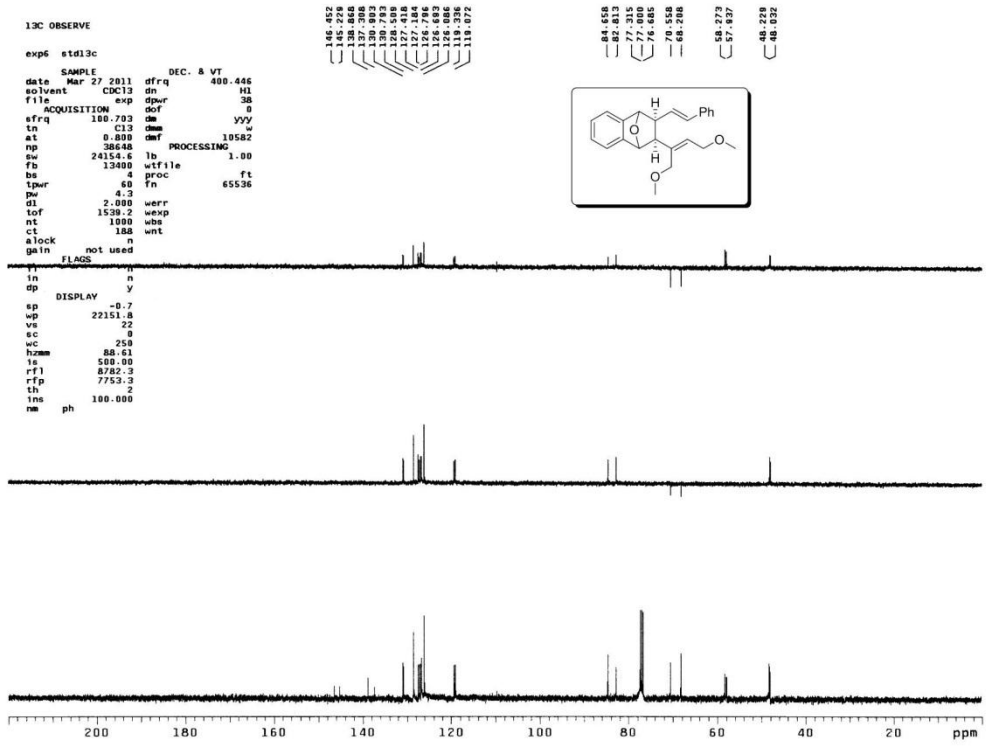
^{1}H and ^{13}C NMR spectra of compound **4l**



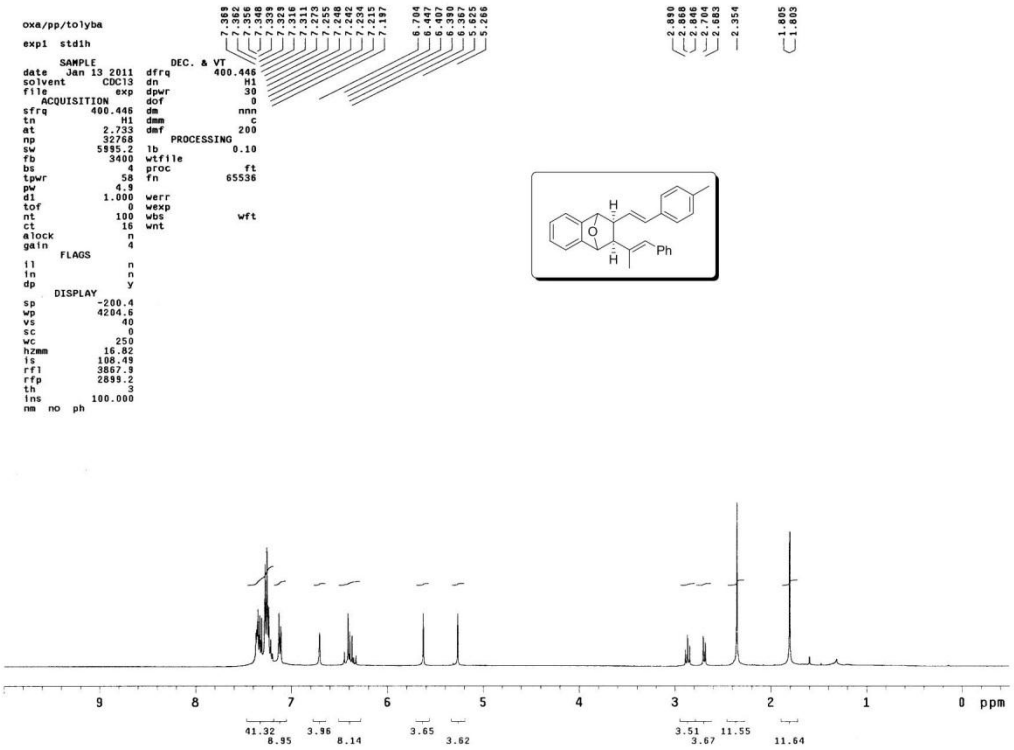


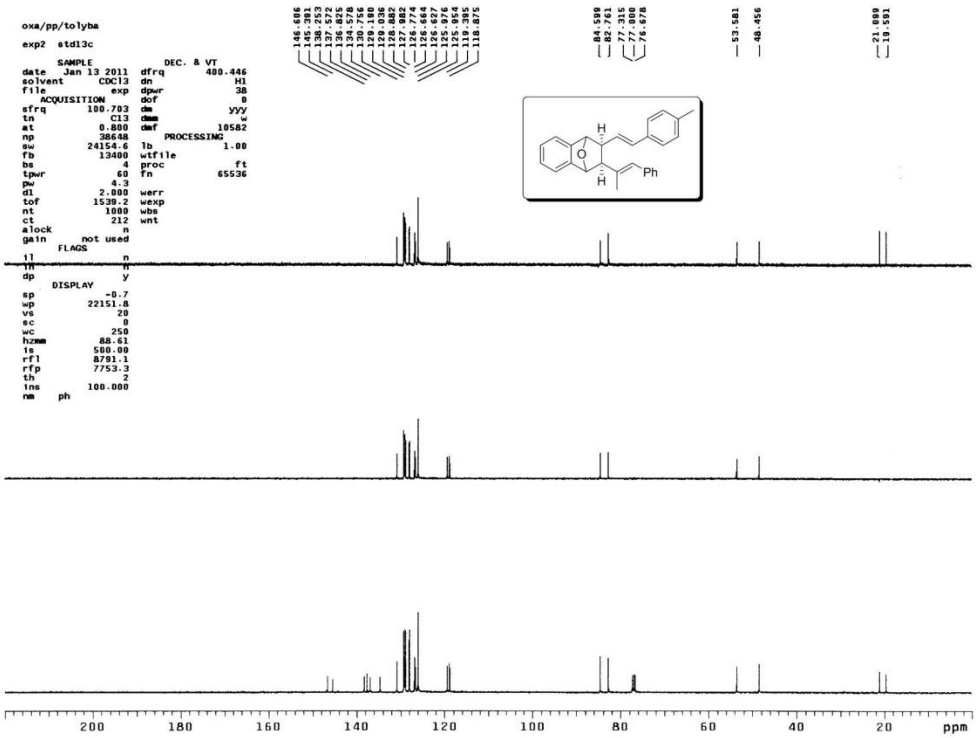
^{1}H and ^{13}C NMR spectra of compound **4m**



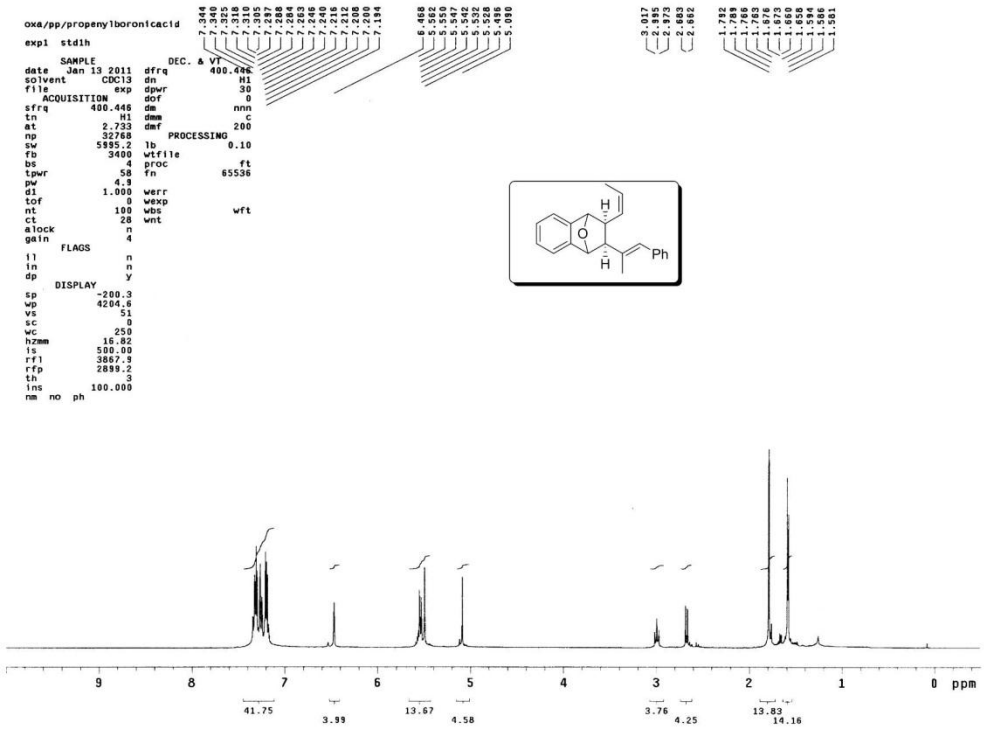


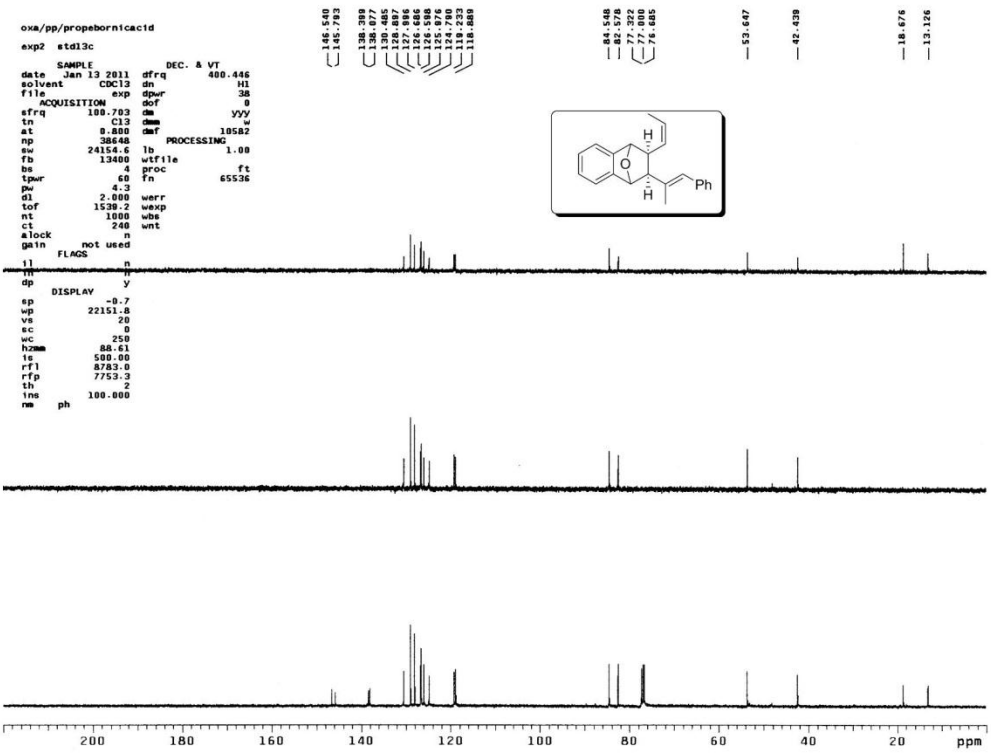
^{1}H and ^{13}C NMR spectra of compound **4n**



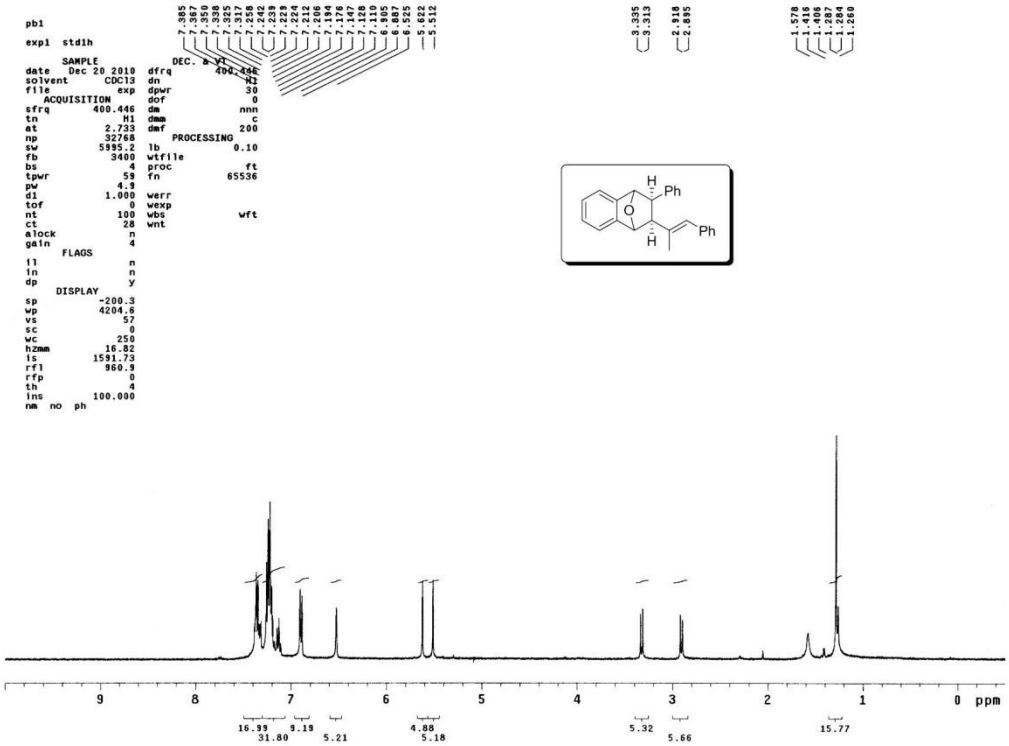


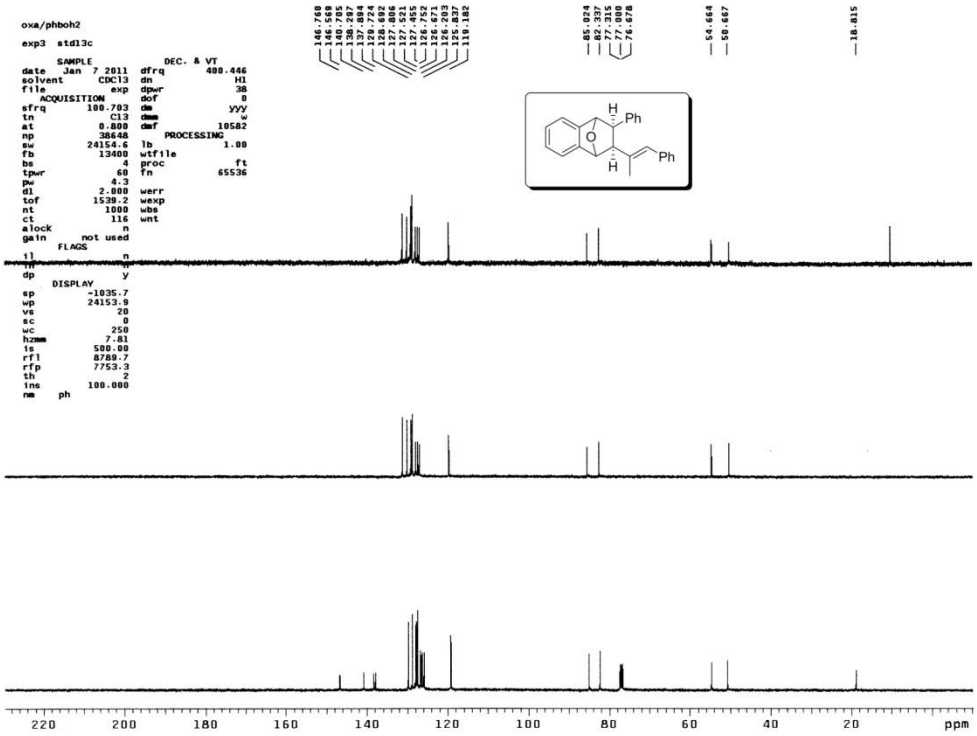
^{1}H and ^{13}C NMR spectra of compound **4o**



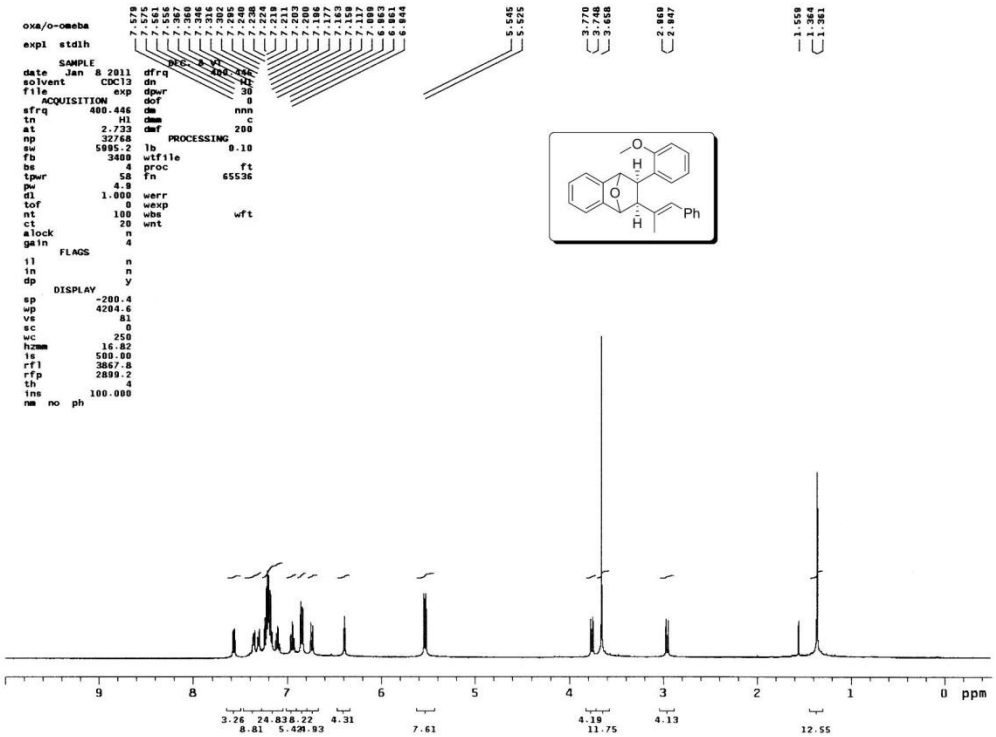


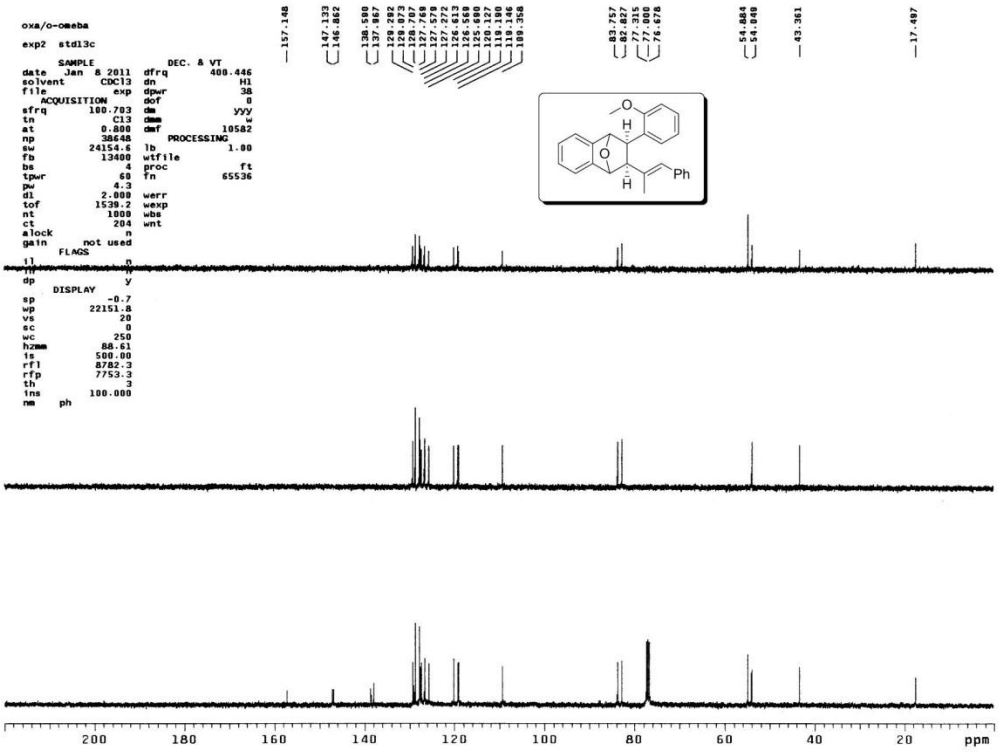
^{1}H and ^{13}C NMR spectra of compound **4p**



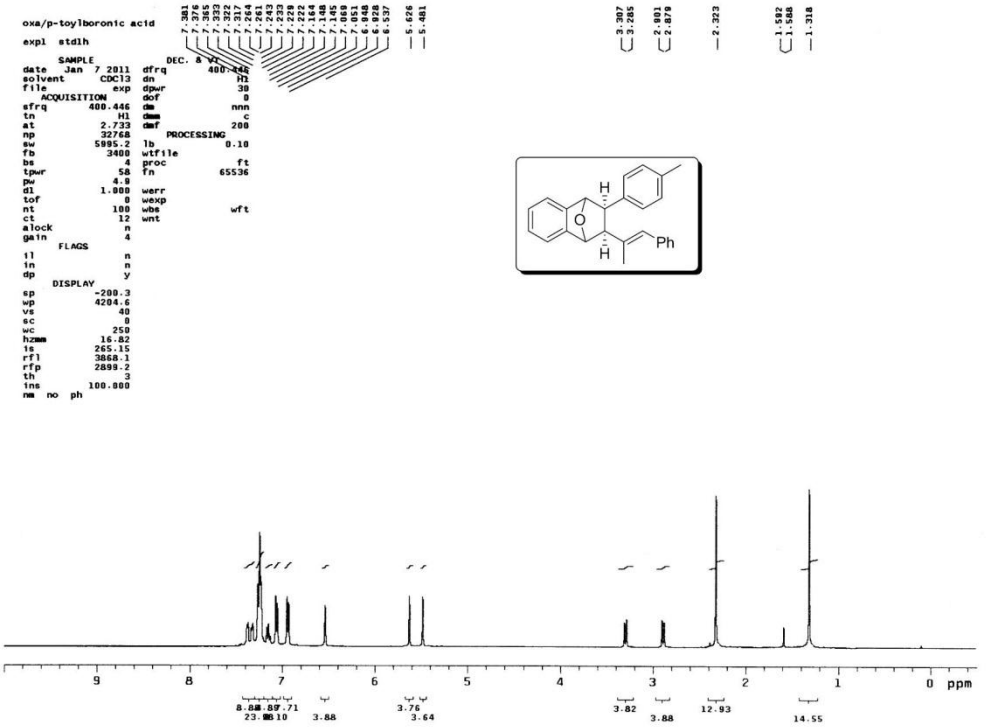


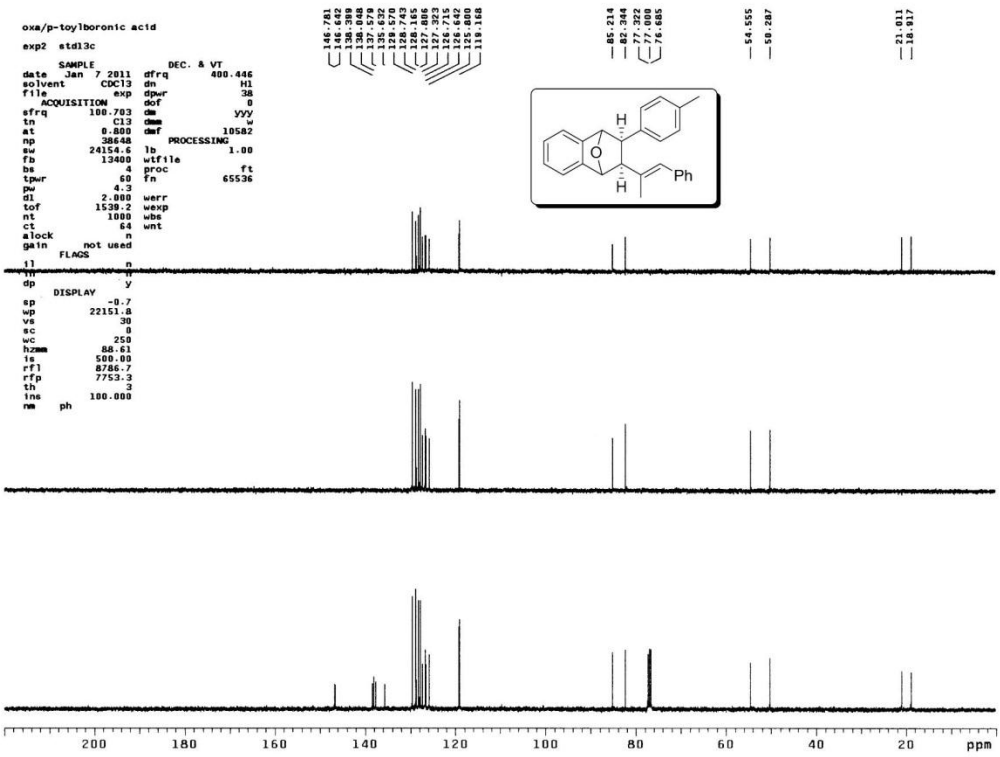
^{1}H and ^{13}C NMR spectra of compound **4q**



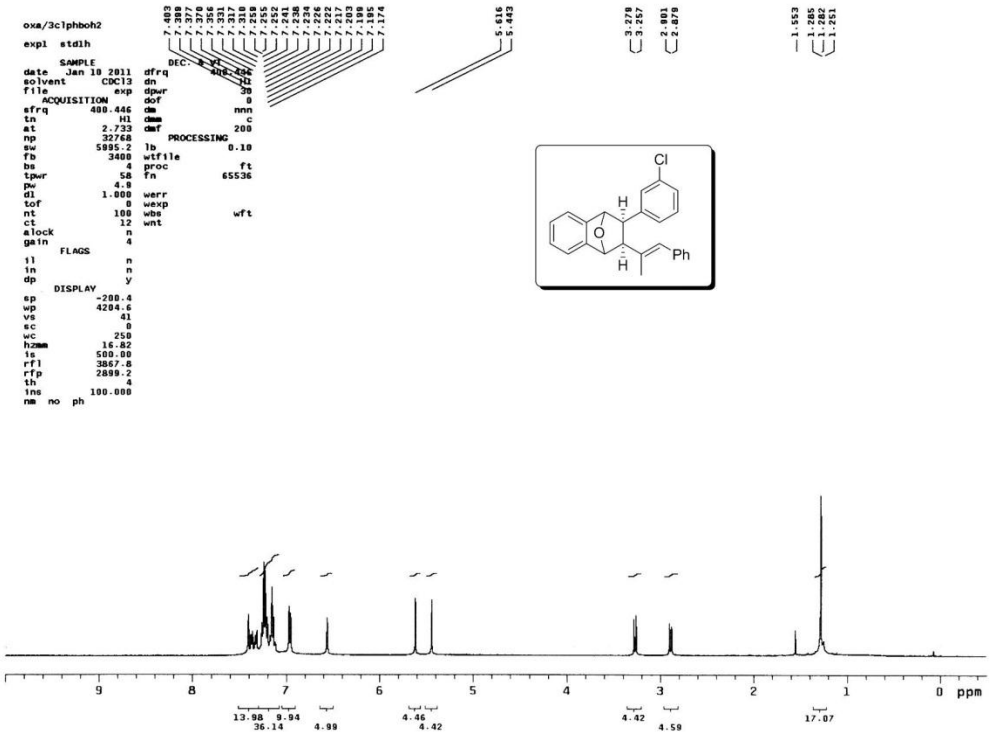


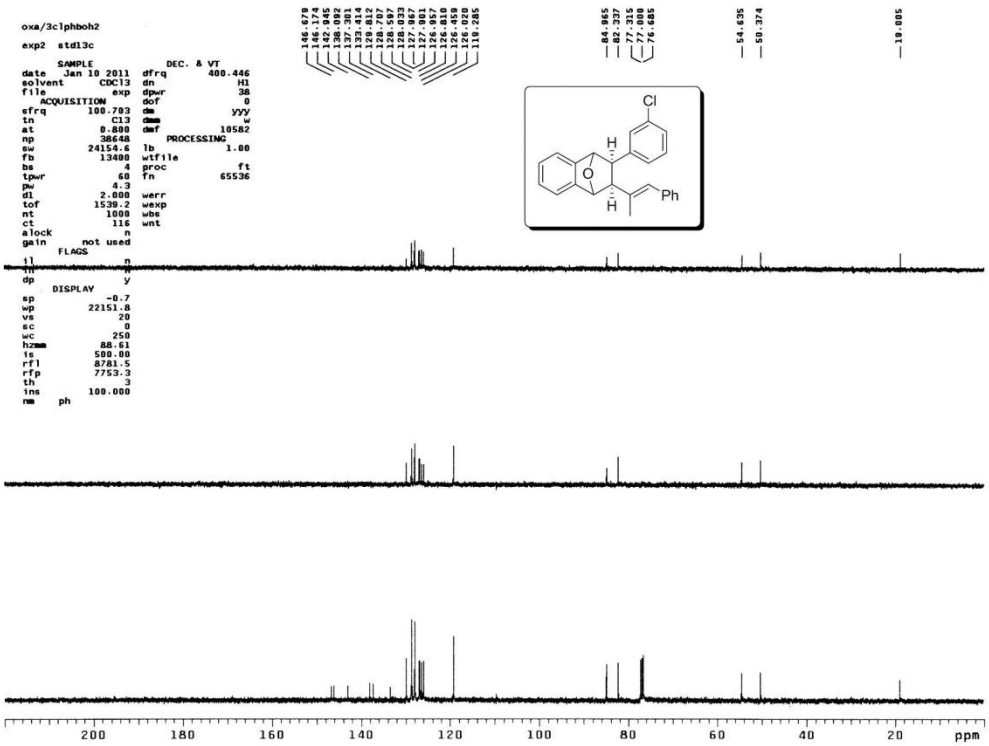
^{1}H and ^{13}C NMR spectra of compound **4r**



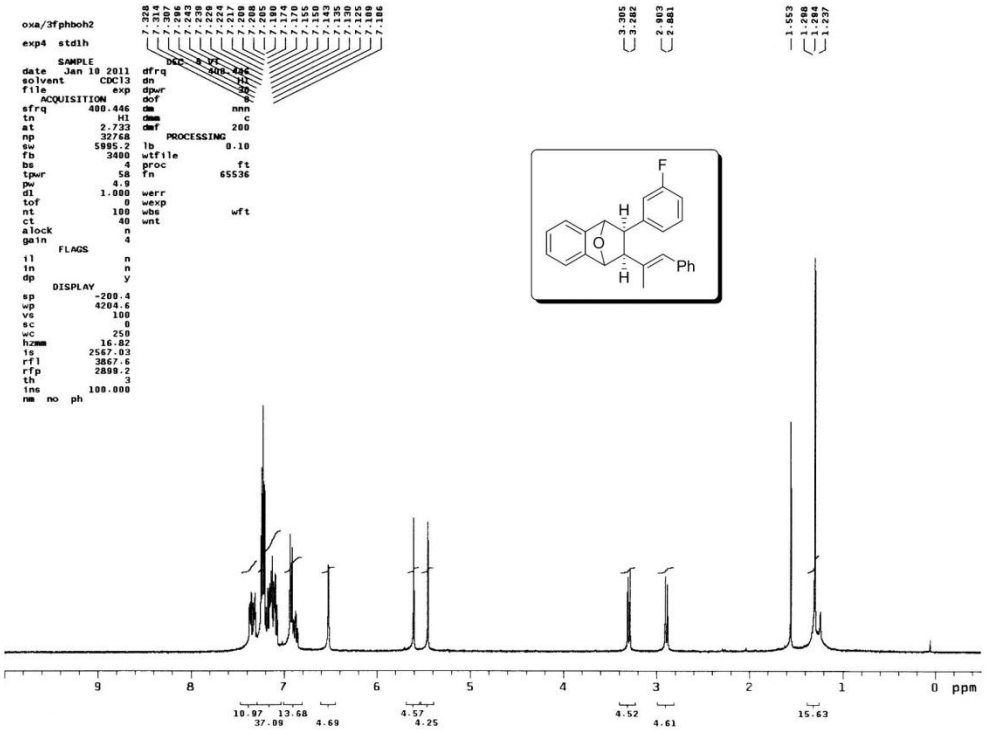


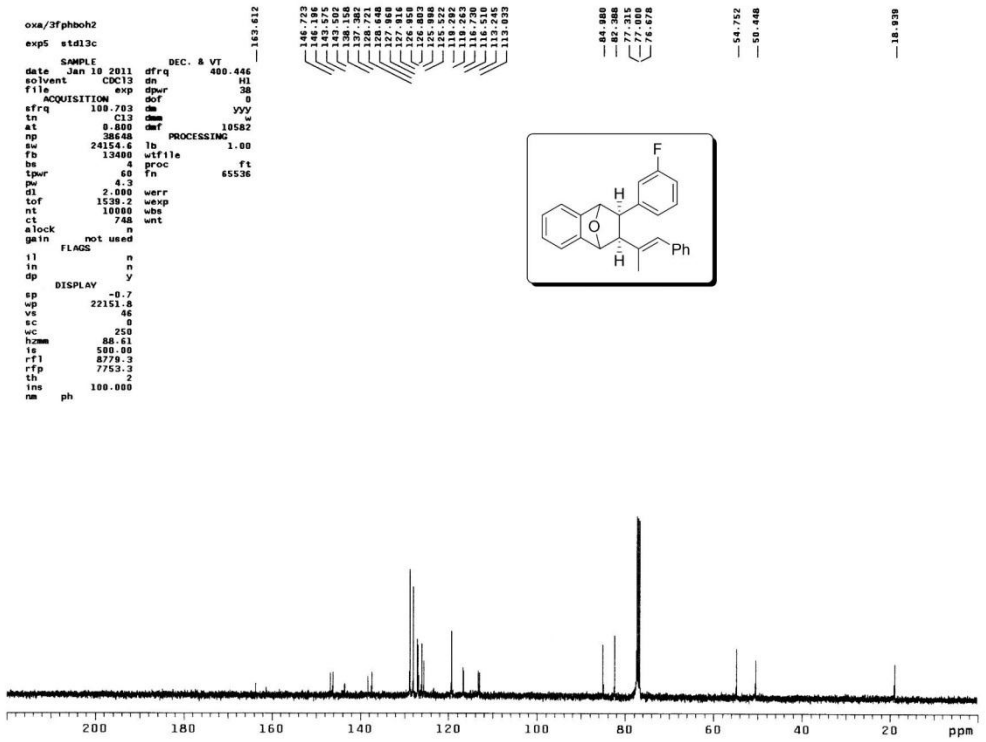
^{1}H and ^{13}C NMR spectra of compound **4s**



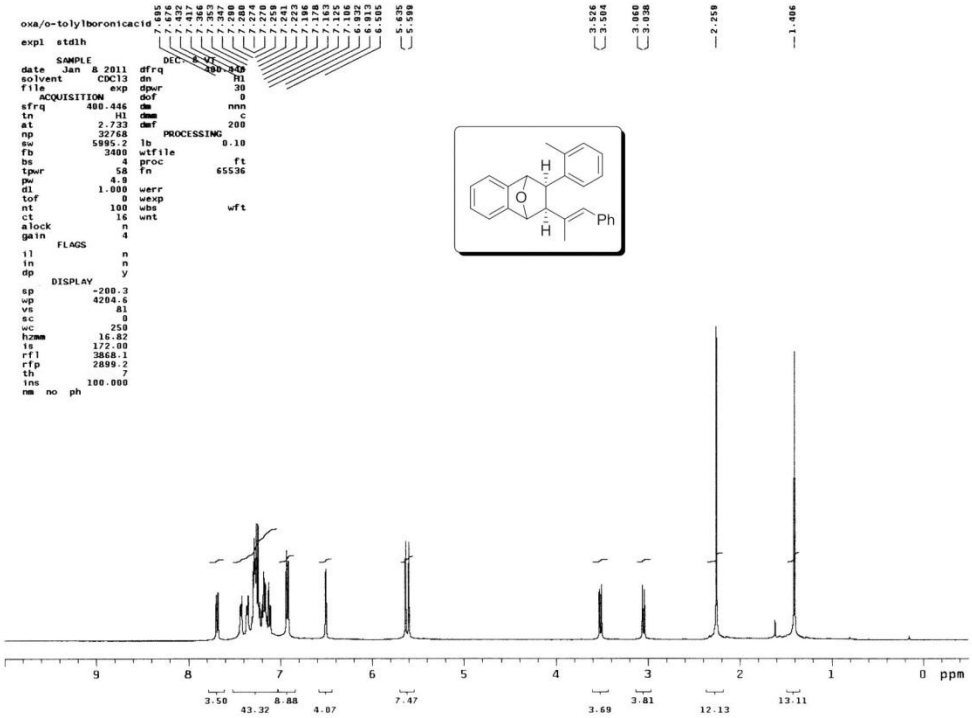


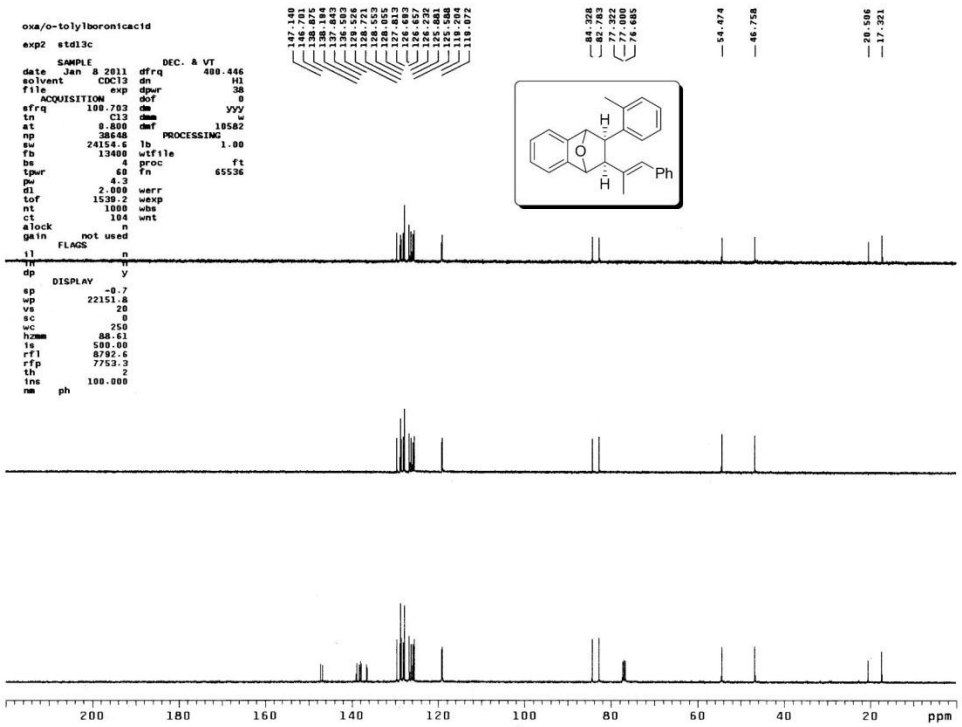
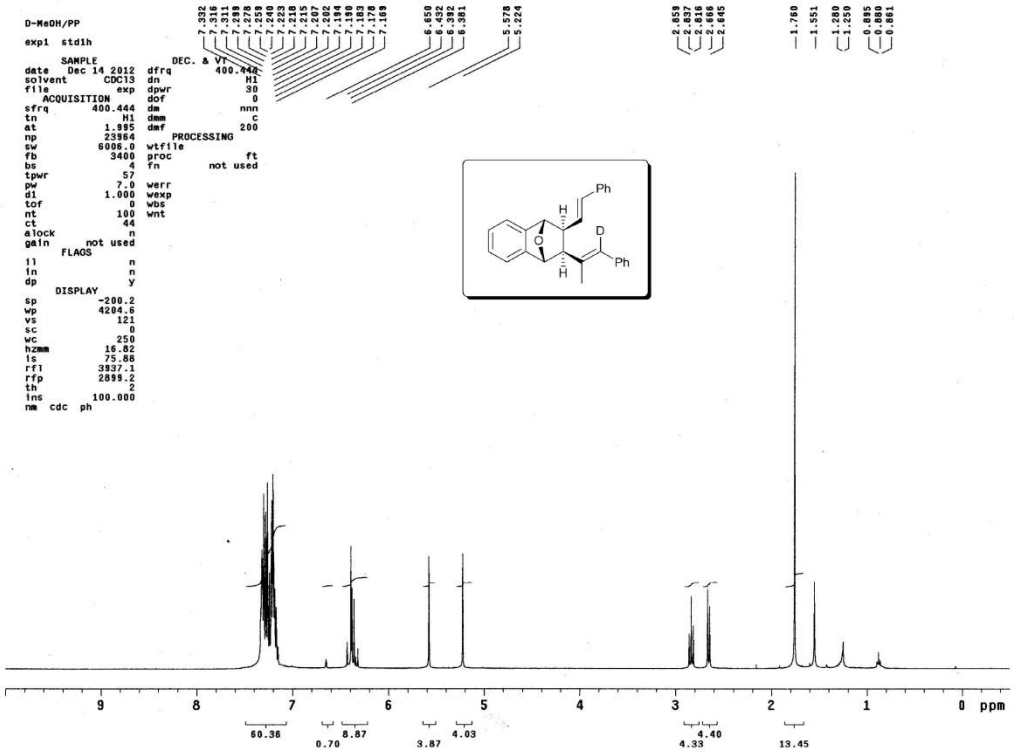
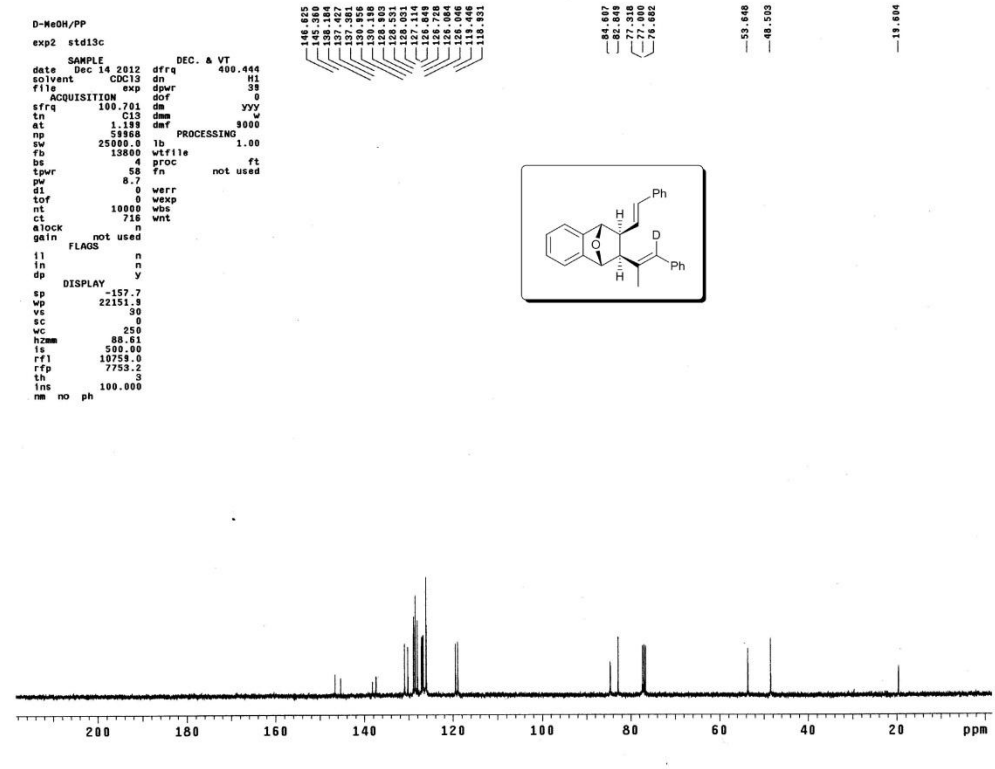
^{1}H and ^{13}C NMR spectra of compound **4t**





^{1}H and ^{13}C NMR spectra of compound **4u**





^{1}H and ^{13}C NMR spectra of compound **4a-d$_1$**