Electronic Supplementary Material (ESI) for ChemComm.
This journal is © The Royal Society of Chemistry 2019

Supporting Information

Palladium-Catalyzed Highly Diastereoselective Cascade Dihalogenation of Alkyne-tethered Cylcohexadienones *via* Umpolung of Palladium Enolate

Anurag Singh, Rahul K.Shukla and Chandra M. R. Volla*

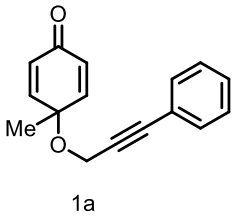
Department of Chemistry, Indian Institute of Technology Bombay,
Powai, Mumbai 400076, India
E–mail: chandra.volla@chem.iitb.ac.in

Table of Contents:

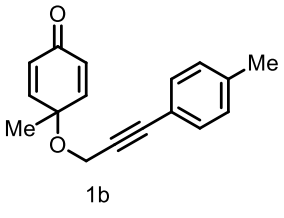
1: Methods:

All reactions were carried out under nitrogen atmosphere in screw cap reaction tubes and the workups were performed under air. All the solvents used for the reactions were dried by following the reported procedures. Unless otherwise noted, all materials were purchased from commercial suppliers and used as received. All alkyne-tethered Cyclohexadienone were prepared in lab usingconventional procedure. Reactions were monitored using thin-layer chromatography (SiO_2). Agradient elution using petroleum ether and ethyl acetate was performed based on Merckaluminium TLC sheets (silica gel 60F254). TLC plates were visualized with UV light (254 nm) or KMnO4 stain or Anisaldehyde stain. For column chromatography, silica gel (100–200 mesh)from SRL Co. was used. NMR studies were performedon Bruker Advance DPX at 400 MHz(^{1}H) or 500 MHz (^{1}H) and at 100 MHz (^{13}C) or 125 MHz (^{13}C), respectively. Chemical shifts (δ) are reported in ppm, using the residual solvent peak in $CDCl_3$ (δH = 7.26 and δC = 77.16) ppm as internal standards, and coupling constants (*J*) are given in Hz. HRMS were recorded with BrukerMaXis impact mass spectrometer using ESI-TOF techniques. Melting points were measured with Buchi Melting Point B-545. FTIR measurements were performed on an Agilent Cary 630 FTIR Spectrometer.

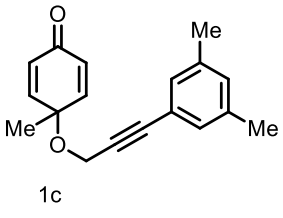
Alkyne tethered cyclohexadienone:



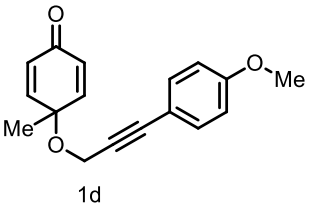
1a



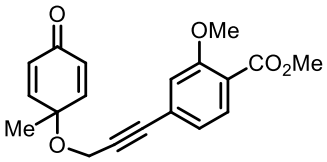
1b



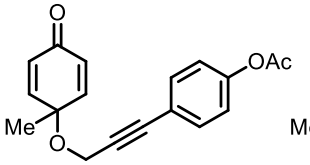
1c



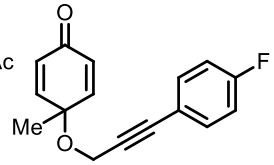
1d



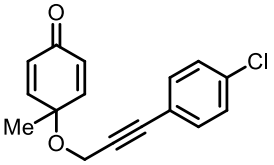
1e



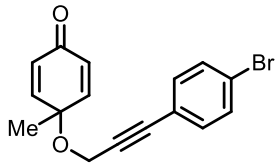
1f



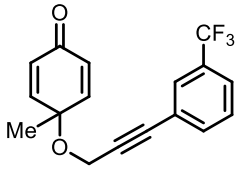
1g



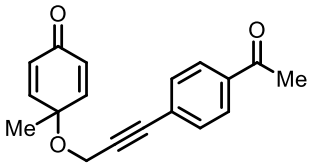
1h



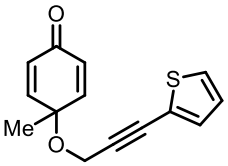
1i



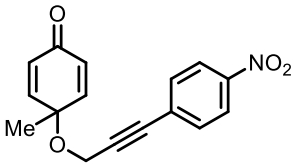
1j



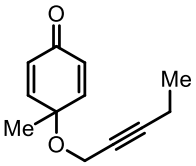
1k



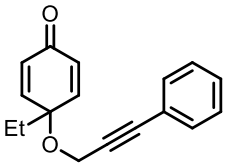
1l



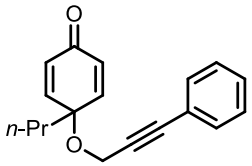
1m



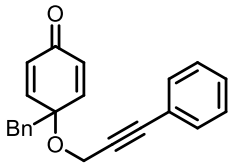
1n



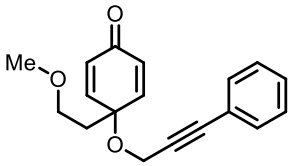
1o



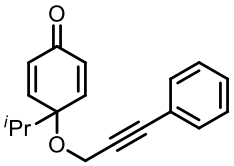
1p



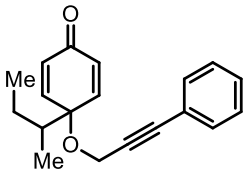
1q



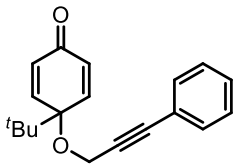
1r



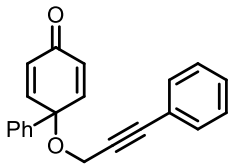
1s



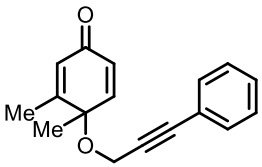
1t



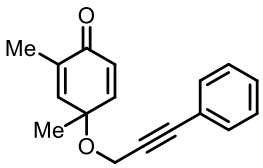
1u



1v



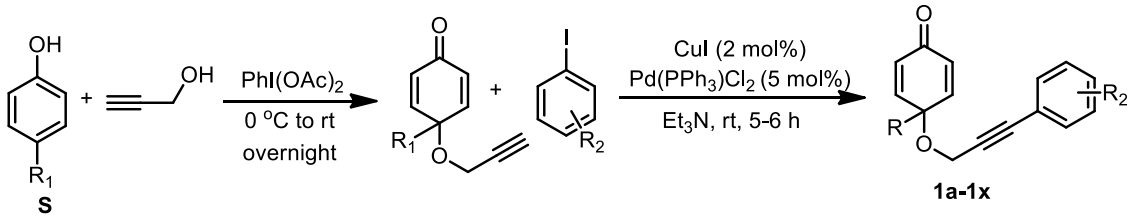
1w



1x

2) Experimental procedures and analytical data

General procedure for the synthesis of *O*-tethered alkynes:



a) General procedure for the dearomatization of substituted Phenols:

To a stirred solution of 4-substituted phenol S (1.0 mmol) in 1 mL of propargyl alcohol was added phenyliodine(III)diacetate (1.5 mmol) in several portions at 0^{o}C. The resulting reaction mixture was stirred at room temperature for overnight. Then the reaction mixture was diluted with water (10 mL) and extracted with ethyl acetate (15 mL × 3). The combined organic solvent was washed with brine (15 mL), dried (Na_2SO_4), filtered, and concentrated in vacuo. The crude reaction mixture was purified by column chromatography (EtOAc/hexane) to give the desired products.

b) General procedure for the Sonogashira coupling of 1a-1x.[1,2]

To a solution of *O*-tethered alkyne **1a**(10.0 mmol) in degassed Et_3N (1 M, 10 mL) was added$Pd(PPh_3)_2Cl_2$ (3 mol%), CuI (1.5 mol%) and aryl iodide (12 mmol). The mixture was stirred at roomtemperature for 3-5 hours. The reaction was cooled to room temperature, water (50 mL) was added, and the mixture was extracted with EtOAc (3 × 40 mL). Thecombined organic solvent was washed with 10% aqueous HCl (20 mL), dried (Na_2SO_4), filtered, andconcentrated *in vacuo*. The mixture was purified by column chromatography (EtOAc/hexane) to givearyl substituted alkynes **1a-1x** inhigh yields.

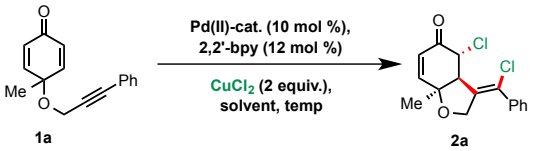
References:

1) Gollapelli, K. K.; Donikela, S.; Manjula, N.; Chegondi, R. *ACS Catal*. **2018**, *8*, 1440−1447.

2) He, Z.-T.; Tian, B.; Fukui, Y.; Tong, X.; Tian, P. Lin, G.-Q. *Angew. Chem., Int. Ed.***2013**, *52*, 5314−5318.

Optimization of reaction condition[a] :

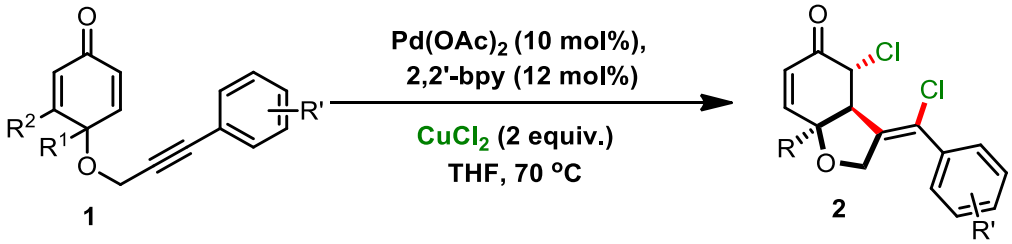
Table 1: Optimization of reaction conditions[a]



entry	Pd(II)-cat.	Solvent	temp (^oC)	yield (%)[b]
1	$Pd(OAc)_2$	DCE	Rt	0[c]
2	$Pd(OAc)_2$	DCE	50	18[c]
3	$Pd(OAc)_2$	DCE	50	45
4	$Pd(OAc)_2$	DCE	70	65 (60)[d]
5	$Pd(OAc)_2$	DCE	100	57
6	$Pd(OAc)_2$	1,4-dioxane	70	40
7	$Pd(OAc)_2$	CH_3CN	70	trace
8	$Pd(OAc)_2$	DMF	70	19
9	$Pd(OAc)_2$	Toluene	70	32
10	$Pd(OAc)_2$	DME	70	82
11	**$Pd(OAc)_2$**	**THF**	**70**	**93 (91)[d]**
12	$PdCl_2$	THF	70	90
13	$Pd(CH_3CN)_2Cl_2$	THF	70	88
14	$Pd(OAc)_2$	THF	70	54[e]
15	$Pd(OAc)_2$	THF	70	68[f]
16	$Pd(OAc)_2$	THF	70	0[g]
17	-	THF	70	10

Reaction conditions: [a] **1a** (0.2 mmol), $CuCl_2$ (2 equiv.), Pd(II)-catalyst (10 mol%), 2,2'-bpy (12 mol%);[b] yield is based on **1a**, determined by ^1H NMR using 1,3,5 trimethoxybenzene as the internal standard;[c] without using 2,2'-bpy; [d] yield in parenthesis refers to isolated yield; [e] 5 mol% Pd(II)-catalyst and 6 mol% of 2,2'-bpy; [f]1,10-Phenanthroline was used instead of 2,2'bpy;[g]LiCl was used instead of $CuCl_2$.

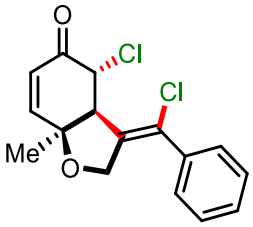
c) General procedure for palladium catalysed dichlorination of alkyne-tethered cyclohexadienones



A dried reaction tube was charged with $Pd(OAc)_2$ (4.49 mg, 10 mol%), 2,2'- bpy (3.56 mg, 12 mol%), $CuCl_2$ (68 mg, 2equiv) , and **1** (.2 mmol, 1 equiv) and anhydrous THF (2 mL, .2M) under nitrogen atmosphere. After that mixture was stirred at room temperature for 10 min, reaction mixture was kept at 70 ^oC for 8-12 hour. After the completion of reaction as observed by TLC, solvent was evaporated under reduced pressure. The residue was purified by silica gel (100-200 mesh, hexane/ethylacetate) column chromatography to afford the desired product.

Characterization Data:

2a.



(*E*)-4-chloro-3-(chloro(phenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

56.03 mg, 91% yield, colorless liquid.

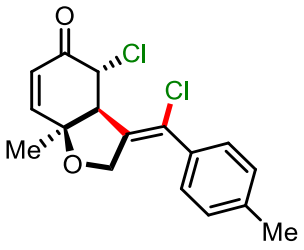
I.R. ($CHCl_3$): *v* 3016, 2995, 2985, 1690, 1467, 1586, 1210, 1098, 1084, 668 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$):δ 7.41 – 7.32 (m, 3H), 7.33 – 7.20 (m, 2H), 6.54 (dd, J = 10.4, 1.3 Hz, 1H), 6.21 (dd, J = 10.4, 1.1 Hz, 1H), 5.05 (dd, J = 2.8, 1.1 Hz, 1H), 4.22 (dd, J = 12.9, 2.1 Hz, 1H), 4.13 (d, J = 12.9 Hz, 1H), 3.62 (t, J = 3.0 Hz, 1H), 1.72 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$):δ 190.61, 149.50, 137.17, 135.82, 129.72, 129.64, 128.53, 127.98, 127.15, 79.36, 68.53, 55.90, 54.07, 25.99.

HRMS (ESI):$C_{16}H_{14}Cl_2NaO_2[M+Na]^+$, calculated = 331.0263, found = 331.0265.

2b.



(*E*)-4-chloro-3-(chloro(p-tolyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one.

57.96 mg, 90 % yield, white solid.

Melting point: 131-133 ^{o}C.

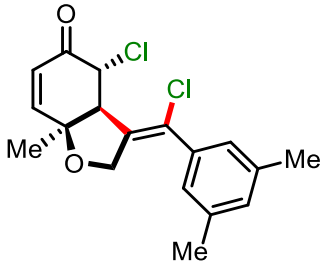
I.R. (Solid): *v* 3018, 2975, 2854, 1687, 1445, 1559, 1215, 1095, 1065, 689 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.15 (s, 4H), 6.54 (d, J = 10.3 Hz, 1H), 6.21 (d, J = 10.4 Hz, 1H), 4.95 (d, J = 77.9 Hz, 1H), 4.21 (d, J = 12.6 Hz, 1H), 4.13 (d, J = 12.8 Hz, 1H), 3.61 (s, 1H), 2.35 (s, 3H), 1.72 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 190.75, 149.57, 139.87, 135.08, 134.41, 129.97, 129.21, 127.93, 127.18, 79.38, 68.62, 55.92, 54.12, 26.03, 21.42.

HRMS (ESI): $C_{17}H_{16}Cl_2NaO_2$ $[M+ Na]^+$, Calculated = 345.0420, Found = 345.0421.

2c.



(*E*)-4-chloro-3-(chloro(3,5-dimethylphenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

66.61 mg, 91% yield, colorless liquid.

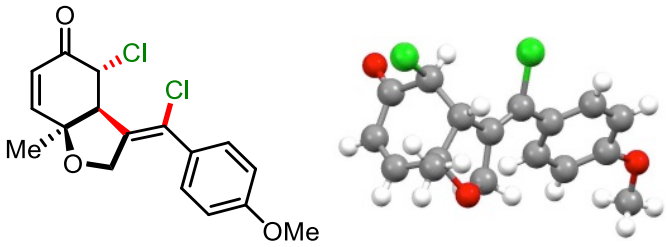
I.R. ($CHCl_3$): *v* 3015, 2993, 2881, 1693, 1207, 1446, 1556, 1216, 1088, 1098,669 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ 6.98 (s, J = 0.6 Hz, 1H), 6.86 (s, 2H), 6.53 (dd, J = 10.4, 1.4 Hz, 1H), 6.21 (dd, J = 10.4, 1.2 Hz, 1H), 5.05 (dd, J = 2.8, 1.2 Hz, 1H), 4.18 (dd, J = 12.9, 2.1 Hz, 1H), 4.12 (d, J = 12.8 Hz, 1H), 3.66 – 3.55 (m, 1H), 2.30 (d, J = 0.5 Hz, 6H), 1.71 (s, 3H).

^{13}CNMR (125 MHz, $CDCl_3$):δ190.76, 149.55, 138.20, 137.18, 135.27, 131.32, 130.06, 127.16, 125.76, 79.35, 68.59, 55.83, 54.14, 26.03, 21.33.

HRMS (ESI):$C_{18}H_{18}Cl_2NaO_2[M+Na]^+$, Calculated= 359.0576, found = 359.0574.

2d.



(*E*)-4-chloro-3-(chloro(4-methoxyphenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one)

60.72 mg, 92% yield, white solid.

Melting Point:126-128 ^{o}C.

I.R. (Solid): *v* 3018, 2975, 2984, 1687, 1454, 1556, 1215, 1115, 1098, 678 cm^{-1}.

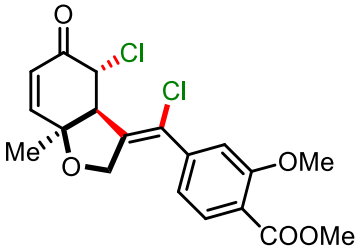
^{1}H NMR (400 MHz, $CDCl_3$):δ 7.22 – 7.15 (m, 2H), 6.91 – 6.82 (m, 2H), 6.54 (dd, *J* = 10.4, 1.4 Hz, 1H), 6.20 (dd, *J* = 10.4, 1.2 Hz, 1H), 5.04 (dd, *J* = 2.8, 1.2 Hz, 1H), 4.20 (dd, *J* = 12.7, 2.1 Hz, 1H), 4.13 (d, *J* = 12.7 Hz, 1H), 3.82 (s, 3H), 3.61 (t, *J* = 3.0 Hz, 1H), 1.72 (s, 3H)..

^{13}C NMR (100 MHz, $CDCl_3$):δ 190.80, 163.59, 160.53, 149.57, 146.92, 134.35, 129.78, 129.49, 127.17, 113.87, 79.39, 68.64, 55.93, 55.52, 54.15, 26.03.

HRMS (ESI): $C_{17}H_{16}Cl_2KO_3[M+K]^+$, Calculated = 377.0108, Found = 377.0109.

Crystal structure of this compound is reported (CCDC: 1913347).

2e.



(*E*)-chloro((3aS,4R,7aS)-4-chloro-7a-methyl-5-oxo-4,5-dihydrobenzofuran-3(2H,3aH,7a*H*)-ylidene)methyl)-2- methoxybenzoate

70.31 mg, 89% yield, white solid.

Melting Point: 115-117 ^{o}C.

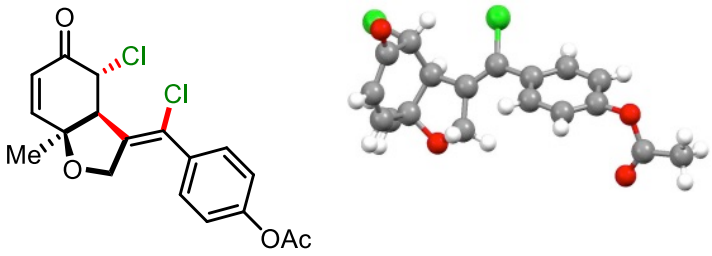
I.R. (Solid):*v* 3021, 2988, 2884, 1775, 1755, 1695, 1586, 1453, 1209, 1075, 1031, 669 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$):*δ* 7.67 (d, *J* = 2.5 Hz, 1H), 7.38 (dd, *J* = 8.7, 2.5 Hz, 1H), 6.95 (d, *J* = 8.8 Hz, 1H), 6.54 (dd, *J* = 10.4, 1.3 Hz, 1H), 6.21 (dd, *J* = 10.4, 1.1 Hz, 1H), 5.02 (dd, *J* = 2.8, 1.1 Hz, 1H), 4.20 (dd, *J* = 12.8, 2.1 Hz, 1H), 4.11 (d, *J* = 12.8 Hz, 1H), 3.92 (s, 3H), 3.89 (s, 3H), 3.60 (t, *J* = 3.0 Hz, 1H), 1.71 (s, 3H).

^{13}CNMR (100 MHz, $CDCl_3$): *δ* 190.70, 149.07, 133.48, 131.76, 127.19, 112.02, 79.26, 68.61, 57.62, 56.34, 52.41, 43.45, 25.78.

HRMS (ESI): $C_{19}H_{18}Cl_2NaO_5[M+Na]^+$, Calculated = 419.0424; Found = 419.0426.

2f.



(*E*)-chloro((3aS,4R,7aS)-4-chloro-7a-methyl-5-oxo-4,5-dihydrobenzofuran-3(2H,3aH,7a*H*)-ylidene)methyl)phenyl acetate

64.80 mg, 90% yield, white solid.

Melting Point:115-117 ^{o}C.

I.R. (Solid):*v* 3019, 2998, 2886, 1771, 1751, 1697, 1458, 1589, 1215, 1078, 1035, 669 cm^{-1}.

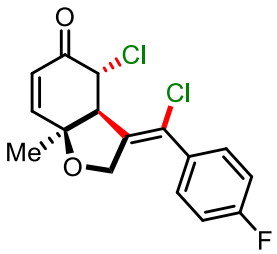
^{1}H NMR (400 MHz, $CDCl_3$):*δ* 7.31 – 7.27 (m, 2H), 7.13 – 7.07 (m, 2H), 6.54 (dd, *J* = 10.4, 1.4 Hz, 1H), 6.21 (dd, *J* = 10.4, 1.1 Hz, 1H), 5.03 (dd, *J* = 2.9, 1.2 Hz, 1H), 4.21 (dd, *J* = 12.9, 2.0 Hz, 1H), 4.15 (d, *J* = 12.9 Hz, 1H), 3.62 (dt, *J* = 3.0, 1.7 Hz, 1H), 2.30 (s, 3H), 1.72 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$):*δ* 190.58, 169.18, 151.43, 149.48, 136.19, 134.68, 129.23, 128.81, 127.19, 121.77, 79.40, 68.49, 55.96, 54.04, 29.82, 25.99, 21.25.

HRMS (ESI): $C_{18}H_{16}Cl_2NaO_4[M+Na]^+$, Calculated = 389.0318; Found = 389.0314.

Crystal structure of this compound is reported (CCDC: 1913321).

2g.



(*E*)-4-chloro-3-(chloro(4-fluorophenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one.

55.16 mg, 85% yield, colorless liquid

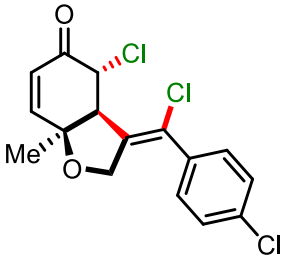
I.R. ($CHCl_3$): *v* 3016, 2915, 2816, 1698, 1467, 1598, 1219, 1091, 1076, 662 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$):δ 7.33 – 7.22 (m, 2H), 7.04 (t, J = 8.5 Hz, 2H), 6.54 (d, J = 10.4 Hz, 1H), 6.21 (d, J = 10.4 Hz, 1H), 5.02 (d, J = 2.6 Hz, 1H), 4.19 (dd, J = 12.8, 1.8 Hz, 1H), 4.10 (d, J = 12.8 Hz, 1H), 3.60 (s, 1H), 1.72 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 190.45 (s), 163.07 (d, J = 250.5 Hz), 149.30 (s), 135.91 (s), 133.21 (s), 129.92 (s), 129.84 (s), 128.53 (s), 127.09 (s), 115.67 (s), 115.46 (s), 79.35 (s), 68.34 (s), 55.79 (s), 53.88 (s), 25.87 (s).

HRMS (ESI): $C_{16}H_{13}Cl_2FKO_2[M+K]^+$, Calculated = 364.9908, Found = 364.9905.

2h.



(E)-4-chloro-3-(chloro(4-chlorophenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-on

57.27 mg, 83% yield,White solid.

Melting point:136-138 ^oC.

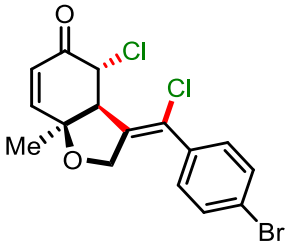
I.R. (Solid): *v* 3019, 2926, 2876, 1697, 1456, 1578, 1210, 1094, 1081, 668 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$):δ 7.36 – 7.30 (m, 2H), 7.22 – 7.16 (m, 2H), 6.54 (dd, J = 10.4, 1.3 Hz, 1H), 6.21 (dd, J = 10.4, 1.1 Hz, 1H), 5.02 (dd, J = 2.8, 1.1 Hz, 1H), 4.19 (dd, J = 12.9, 2.1 Hz, 1H), 4.10 (d, J = 12.9 Hz, 1H), 3.61 (t, J = 3.0 Hz, 1H), 1.72 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 190.53, 149.42, 136.58, 135.72, 135.62, 129.33, 128.86, 128.56, 127.25, 79.47, 68.45, 55.98, 53.96, 26.01

HRMS (ESI):$C_{16}H_{13}Cl_3NaO_2[M+ Na]^+$, Calculated = 364.9873, Found = 364.9870.

2i.



(*E*)-3-((4-bromophenyl)chloromethylene)-4-chloro-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one.

67.13 mg, 87% yield, white solid

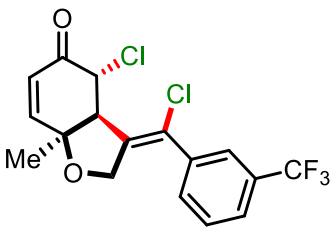
Melting Point: 171 ^{o}C.

^{1}H NMR (500 MHz, $CDCl_3$):δ 7.51 (d, J = 8.3 Hz, 2H), 7.16 (d, J = 8.3 Hz, 2H), 6.56 (d, J = 10.4 Hz, 1H), 6.23 (d, J = 10.4 Hz, 1H), 5.02 (d, J = 21.8 Hz, 1H), 4.21 (d, J = 12.9 Hz, 1H), 4.13 (d, J = 12.9 Hz, 1H), 3.62 (s, 1H), 1.74 (s, 3H)..

^{13}C NMR (125 MHz, $CDCl_3$):δ 190.46, 149.39, 136.63, 136.03, 131.78, 129.52, 128.54, 127.21, 123.92, 79.42, 68.40, 55.95, 53.90.

HRMS (ESI):$C_{16}H_{14}BrCl_2NaO_2[M+ Na]^+$, Calculated = 408.9368, Found = 408.9364.

2j.



(*E*)-4-chloro-3-(chloro(3-(trifluoromethyl)phenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one.

56.94 mg, 78% yield, yellow liquid.

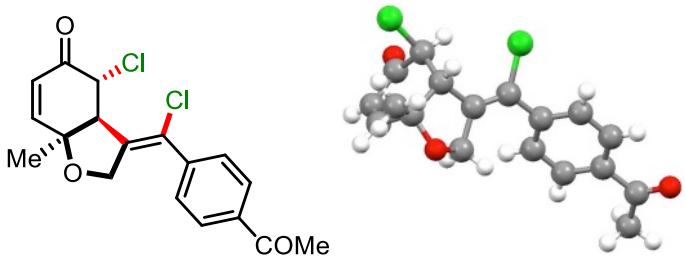
I.R. ($CHCl_3$): *v* 3019, 2976, 2954, 1687, 1498, 1567, 1216, 1123, 1055, 669 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$):δ 7.62 (d, *J* = 7.7 Hz, 1H), 7.51 (dd, *J* = 16.9, 9.0 Hz, 2H), 7.43 (d, *J* = 7.8 Hz, 1H), 6.55 (d, *J* = 10.5 Hz, 1H), 6.23 (d, *J* = 10.5 Hz, 1H), 5.04 – 5.02 (m, 1H), 4.22 (dd, *J* = 13.0, 1.7 Hz, 1H), 4.10 (d, *J* = 12.9 Hz, 1H), 3.63 (s, 1H), 1.72 (s, 3H)..

^{13}C NMR (125 MHz, $CDCl_3$): δ 190.41, 149.36, 137.97, 137.76, 131.26, 129.24, 128.00, 127.31, 126.38, 126.35, 124.86, 124.83, 122.64, 115.20, 79.53, 68.32, 56.05, 53.93, 26.00.

HRMS (ESI): $C_{17}H_{13}Cl_2F_3NaO_2$ $[M+ Na]^+$, Calculated = 399.0137, Found = 399.0139.

2k.



(*E*)-3-((4-acetylphenyl)chloromethylene)-4-chloro-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one.

49.56 mg, 84% yield, white solid.

Meting Point:116-118 ^oC.

I.R. (Solid): *v* 3019, 2975, 2852, 1686, 1697, 1445, 1556, 1216, 1098, 1084, 668 cm^{-1}.

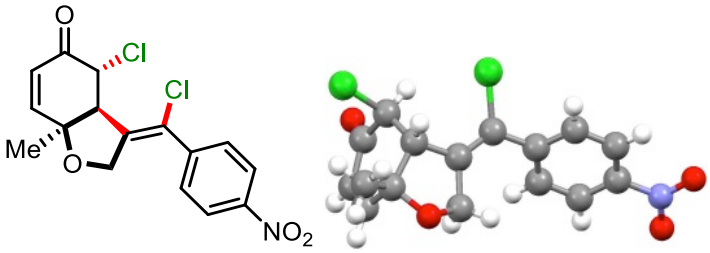
^{1}H NMR (400 MHz, $CDCl_3$):δ 7.93 (d, *J* = 7.2 Hz, 2H), 7.36 (d, *J* = 7.2 Hz, 2H), 6.55 (d, *J* = 10.4 Hz, 1H), 6.22 (d, *J* = 10.4 Hz, 1H), 5.03 – 5.02 (m, 1H), 4.23 (d, *J* = 13.0 Hz, 1H), 4.12 (dd, *J* = 13.0, 1.2 Hz, 1H), 3.63 (s, 1H), 2.60 (d, *J* = 1.4 Hz, 3H), 1.72 (d, *J* = 1.2 Hz, 3H)..

^{13}C NMR (100 MHz, $CDCl_3$): δ 197.27, 190.45, 149.39, 141.36, 137.84, 128.52, 128.29, 127.29, 79.45, 68.44, 56.09, 53.92, 26.82, 26.00.

HRMS (ESI): $C_{18}H_{16}Cl_2NaO_3[M+Na]^+$**,** Calculated = 373.0369, Found = 373.0370.

Crystal structure of this compound is reported (CCDC: 1922350).

2l.



(*E*)-4-chloro-3-(chloro(4-nitrophenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

44.88 mg, 68% yield, white solid.

Melting point:149-150 ^{o}C.

I.R. (Solid): *v* 2954, 2926, 1689, 1522, 1454, 1578, 1348, 1215, 1095, 1013, 699 cm^{-1}.

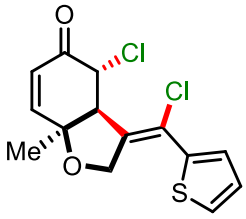
^{1}H NMR (400 MHz, $CDCl_3$):δ 8.26 – 8.18 (m, 2H), 7.48 – 7.38 (m, 2H), 6.55 (dd, J = 10.5, 1.3 Hz, 1H), 6.22 (dd, J = 10.4, 1.1 Hz, 1H), 5.00 (dd, J = 2.8, 1.1 Hz, 1H), 4.23 (dd, J = 13.1, 2.1 Hz, 1H), 4.10 (d, J = 13.0 Hz, 1H), 3.63 (t, J = 3.1 Hz, 1H), 1.72 (s, J = 3.7 Hz, 3H).

^{13}C NMR (100 MHz, $CDCl_3$):δ190.25, 149.24, 143.06, 139.44, 129.06, 127.39, 127.26, 123.90, 79.57, 68.33, 56.22, 53.79, 26.00.

HRMS (ESI): $C_{16}H_{13}Cl_2NNaO_4$**[**M+ Na$]^{+}$, Calculated = 376.0114, Found = 376.0111.

Crystal structure of this compound is reported (CCDC: 1913363).

2m.



(*E*)-4-chloro-3-(chloro(thiophen-2-yl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

44.53 mg, 73% yield, white solid.

Melting Point:137-139 ^{o}C

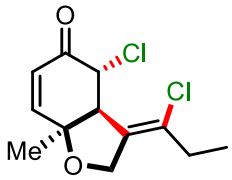
I.R. (Solid): *v* 3020, 2930, 2880, 1698, 1456, 1576, 1217, 1110, 1087, 699 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$):δ 7.38 (dd, *J* = 4.6, 1.7 Hz, 1H), 7.06 – 6.98 (m, 2H), 6.56 (dd, *J* = 10.4, 1.3 Hz, 1H), 6.21 – 6.17 (m, 1H), 5.04 (dd, *J* = 3.1, 1.1 Hz, 1H), 4.52 (d, *J* = 13.2 Hz, 1H), 4.25 (dd, *J* = 13.2, 2.4 Hz, 1H), 3.67 – 3.63 (m, 1H), 1.72 (s, 3H).

^{13}C NMR (125 MHz, $CDCl_3$): δ190.52, 149.48, 139.92, 134.93, 128.29, 127.95, 127.49, 127.15, 123.12, 79.40, 68.87, 56.35, 54.23, 25.97.

HRMS (ESI): $C_{14}H_{12}Cl_2O_2KS$ $[M+ K]^+$, Calculated = 352.9567, Found = 352.9562.

2n.



(*E*)-4-chloro-3-(1-chloropropylidene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

38.45 mg, 74% yield, yellow liquid.

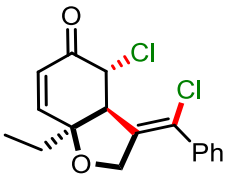
I.R. ($CHCl_3$): *v* 3037, 2935, 2872, 1691, 1474, 1576, 1211, 1095, 668 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$):δ6.49 (dd, *J* = 10.4, 1.3 Hz, 1H), 6.11 (dd, *J* = 10.4, 1.1 Hz, 1H), 5.02 (dd, *J* = 3.0, 1.1 Hz, 1H), 4.35 (d, *J* = 12.4 Hz, 1H), 4.00 (dd, *J* = 13.3, 1.0 Hz, 1H), 3.41 (s, *J* = 21.6 Hz, 1H), 2.23 (q, *J* = 7.3 Hz, 2H), 1.68 (s, 3H), 1.09 (t, *J* = 7.4 Hz, 3H).

^{13}C NMR (100 MHz, $CDCl_3$):δ 190.72, 149.56, 132.95, 132.37, 126.94, 79.77, 77.48, 54.75, 54.28, 30.84, 25.99, 12.09.

HRMS (ESI):$C_{12}H_{14}Cl_2NaO_2$ $[M+Na]^+$, Calculated = 283.0263, Found = 283.0265.

2o.



(*E*)-4-chloro-3-(chloro(phenyl)methylene)-7a-ethyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

54.12 mg, 82% yield, white solid.

Melting Point:118-120 ^{o}C.

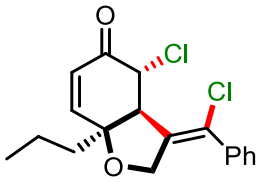
I.R. (Solid): *v* 3015, 2925, 2884, 1695, 1476, 1556, 1120, 1095, 665 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$):δ 7.39 – 7.31 (m, 3H), 7.30 – 7.23 (m, 2H), 6.63 (dd, *J* = 10.5, 1.2 Hz, 1H), 6.24 (dd, *J* = 10.5, 1.0 Hz, 1H), 5.04 (dd, *J* = 3.2, 1.0 Hz, 1H), 4.25 (dd, *J* = 12.9, 2.1 Hz, 1H), 4.14 (d, *J* = 12.9 Hz, 1H), 3.73 – 3.69 (m, 1H), 2.03 (qq, *J* = 14.7, 7.4 Hz, 2H), 1.08 (t, *J* = 7.5 Hz, 3H).

^{13}CNMR (100 MHz, $CDCl_3$):δ 190.97, 148.81, 137.22, 136.04, 129.64, 128.55, 128.04, 127.61, 81.65, 68.47, 54.48, 53.20, 31.31, 7.66.

HRMS (ESI): $C_{17}H_{16}Cl_2NaO_2$ $[M+ Na]^+$, Calculated = 345.0420, Found = 345.0417.

2p.



(*E*)-4-chloro-3-(chloro(phenyl)methylene)-7a-propyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

57.59 mg, 79% yield, white solid.

Melting Point:132-134 ^{o}C.

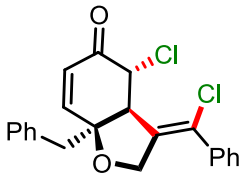
I.R. ($CHCl_3$): *v* 3024, 2928, 2884, 1695, 1487, 1568, 1217, 1095, 669 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$):δ 7.38 – 7.31 (m, 3H), 7.29 – 7.23 (m, 2H), 6.62 (dd, *J* = 10.5, 1.2 Hz, 1H), 6.22 (dd, *J* = 10.5, 1.0 Hz, 1H), 5.03 (dd, *J* = 3.0, 1.0 Hz, 1H), 4.23 (dd, *J* = 12.9, 2.0 Hz, 1H), 4.13 (d, *J* = 12.9 Hz, 1H), 3.71 (s, 1H), 2.08 – 1.84 (m, 2H), 1.63 – 1.49 (m, 2H), 0.99 (t, *J* = 7.3 Hz, 3H).

^{13}C NMR (100 MHz, CDCl3):δ 190.85, 148.88, 137.17, 135.99, 129.59, 128.50, 127.99, 127.41, 81.48, 68.41, 54.39, 53.73, 40.72, 16.71, 14.55.

HRMS (ESI):$C_{18}H_{18}Cl_2NaO_2[M+ Na]^+$, Calculated =359.0576, Found =359.0572.

2q.



(*E*)-7a-benzyl-4-chloro-3-(chloro(phenyl)methylene)-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

60.08 mg, 78% yield, white solid.

Melting Point: 142-145 ^oC.

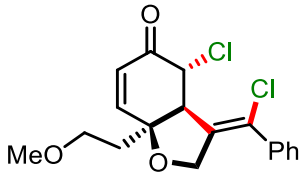
I.R. ($CHCl_3$): *v* 3028, 2923, 2881, 1694, 1458, 1567, 1214, 1095, 669 cm^{-1}.

^1H NMR (500 MHz, $CDCl_3$):δ 7.46 – 7.10 (m, 10H), 6.53 (dd, J = 10.5, 0.9 Hz, 1H), 6.26 (d, J = 10.5 Hz, 1H), 5.11 (dd, J = 6.6, 4.0 Hz, 1H), 4.25 (dd, J = 12.9, 1.9 Hz, 1H), 4.18 (d, J = 12.9 Hz, 1H), 3.72 (d, J = 10.6 Hz, 1H), 3.42 (d, J = 14.2 Hz, 1H), 3.28 (d, J = 14.2 Hz, 1H).

^{13}C NMR (125 MHz, $CDCl_3$):δ 190.79, 148.16, 137.15, 135.56, 135.22, 131.18, 129.61, 128.49, 128.42, 128.00, 127.48, 127.22, 81.34, 68.49, 54.53, 53.47, 44.52.

HRMS (ESI):$C_{22}H_{19}Cl_2O_2[M+ H]^+$, Calculated = 407.0576, Found = 407.0578.

2r.



(*E*)-4-chloro-3-(chloro(phenyl)methylene)-7a-(3-methoxypropyl)-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

48.49 mg, 71% yield, yellow liquid**.**

I.R. ($CHCl_3$): *v* 3023, 2923, 2889, 1695, 1554, 1598, 1217, 1195, 1095, 669 cm^{-1}.

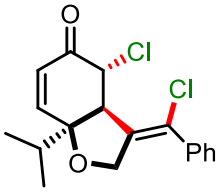
^1H NMR (400 MHz, $CDCl_3$):δ 7.39 – 7.32 (m, 3H), 7.30 – 7.21 (m, 2H), 6.70 (dd, J = 10.5, 1.3 Hz, 1H), 6.22 (dd, J = 10.5, 1.1 Hz, 1H), 5.03 (dd, J = 3.2, 1.1 Hz, 1H), 4.24 (dt, J = 12.6,

4.0 Hz, 1H), 4.15 (d, *J* = 12.9 Hz, 1H), 3.85 – 3.79 (m, 1H), 3.72 – 3.58 (m, 2H), 3.35 (s, 3H), 2.41 – 2.29 (m, 1H), 2.23 (dt, *J* = 14.8, 5.9 Hz, 1H).

^{13}C NMR (100 MHz, $CDCl_3$): *δ*190.76, 148.58, 135.62, 129.65, 128.55, 128.02, 127.27, 80.57, 68.51, 67.78, 58.75, 54.69, 38.43.

HRMS (ESI): $C_{18}H_{19}Cl_2O_3$ $[M+H]^+$, Calculated =353.0706, Found = 353.0705.

2s.



(*E*)-4-chloro-3-(chloro(phenyl)methylene)-7a-isopropyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

40.34 mg, 63% yield, yellow liquid.

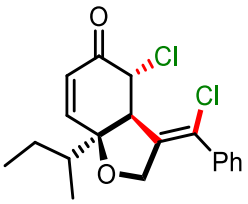
I.R. ($CHCl_3$): *v* 3036, 2924, 2887, 1698, 1413, 1518, 1216. 1123, 1087, 669 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$):*δ* 7.40 – 7.34 (m, 3H), 7.32 – 7.27 (m, 2H), 6.73 (d, *J* = 10.6 Hz, 1H), 6.28 (d, *J* = 10.6 Hz, 1H), 4.91 (d, *J* = 4.6 Hz, 1H), 4.34 (dd, *J* = 13.0, 1.7 Hz, 1H), 4.19 (d, *J* = 13.0 Hz, 1H), 3.86 (d, *J* = 3.7 Hz, 1H), 2.22 – 2.08 (m, 1H), 1.08 (d, *J* = 6.9 Hz, 3H), 1.05 (d, *J* = 6.9 Hz, 3H).

^{13}C NMR (125 MHz, $CDCl_3$): *δ* 190.88, 147.65, 137.11, 136.59, 129.58, 129.26, 128.53, 128.31, 128.08, 83.80, 68.12, 56.23, 52.24, 34.70, 17.44, 16.99.

HRMS (ESI): $C_{18}H_{18}Cl_2NaO_2$$[M+Na]^+$, Calculated = 359.0576, Found = 359.0576.

2t.



(*E*)-7a-((S)-sec-butyl)-4-chloro-3-(chloro(phenyl)methylene)-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

35.70 mg, 51% yield, yellow liquid.

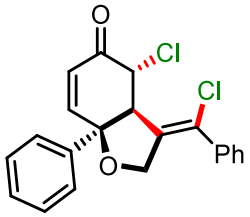
I.R. ($CHCl_3$): *v* 3020, 2926, 2876, 1691, 1456, 1587, 1216, 1095, 668 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$):δ 7.39 – 7.34 (m, 3H), 7.32 – 7.28 (m, 2H), 6.69 (ddd, *J* = 10.5, 4.1, 0.7 Hz, 1H), 6.28 (ddd, *J* = 10.5, 3.4, 0.7 Hz, 1H), 4.89 – 4.85 (m, 1H), 4.35 (ddd, *J* = 13.0, 4.9, 1.7 Hz, 1H), 4.19 (dd, *J* = 13.0, 0.9 Hz, 1H), 3.87 (d, *J* = 4.7 Hz, 1H), 1.86 – 1.75 (m, 1H), 1.74 – 1.64 (m, 1H), 1.19 – 1.09 (m, 1H), 1.04 (dd, *J* = 17.2, 6.9 Hz, 3H), 0.96 (td, *J* = 7.3, 1.4 Hz, 3H).

^{13}C NMR (100 MHz, $CDCl_3$):δ 190.92, 147.82, 147.72, 137.09, 136.78, 136.72, 129.58, 129.21, 128.53, 128.34, 128.16, 128.10, 84.14, 84.09, 67.97, 67.89, 56.53, 52.46, 52.34, 42.03, 41.80, 24.14, 23.95, 13.84, 13.41, 12.73, 12.58.

HRMS (ESI): $C_{19}H_{20}Cl_2NaO_2[M+ Na]^+$, Calculated = 373.0733; Found = 373.0731.

2v.



(*E*)-4-chloro-3-(chloro(phenyl)methylene)-7a-phenyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

48.10 mg, 65% yield, white solid.

Melting Point:151-153 ^oC.

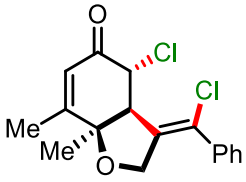
I.R. (Solid): *v* 3034, 2923, 2921, 1697, 1445, 1554, 1216, 1184, 1091, 669 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$):δ 7.52 (dd, *J* = 6.8, 1.6 Hz, 1H), 7.44 – 7.32 (m, 6H), 7.31 – 7.25 (m, 3H), 6.78 (dd, *J* = 10.4, 2.0 Hz, 1H), 6.45 (dd, *J* = 10.4, 2.1 Hz, 1H), 5.03 (d, *J* = 3.7 Hz, 1H), 4.53 (d, *J* = 12.9 Hz, 1H), 4.41 (dd, *J* = 12.9, 2.9 Hz, 1H), 4.02 (s, 1H).

^{13}C NMR (125 MHz, $CDCl_3$):δ 184.26, 146.55, 141.65, 137.15, 132.75, 132.03, 129.81, 129.15, 128.59, 128.32, 125.02, 123.19, 82.84, 72.19, 63.30.

HRMS (ESI): $C_{21}H_{16}Cl_2NaO_2$ [M+ Na]$^+$, Calculated = 393.0420, Found = 393.0419.

2w.



(*E*)-4-chloro-3-(chloro(phenyl)methylene)-7,7a-dimethyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

47.91 mg, 75% yield, white solid.

Melting point:145-147 ^{o}C.

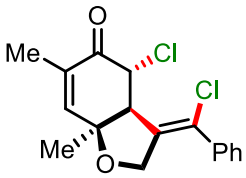
I.R. ($CHCl_3$): *v* 3024, 2925, 2882, 1691, 1444, 1556, 1211, 1095, 668 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$):δ 7.39 – 7.30 (m, 3H), 7.30 – 7.23 (m, 2H), 6.10 (d, J = 0.9 Hz, 1H), 5.14 – 5.11 (m, 1H), 4.08 (s, J = 12.0 Hz, 2H), 3.60 (s, 1H), 2.04 (s, 3H), 1.73 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$):δ190.22, 160.25, 137.34, 135.87, 129.59, 128.52, 128.00, 126.15, 81.72, 68.77, 56.98, 54.14, 24.75, 18.67.

HRMS (ESI):$C_{17}H_{16}Cl_2NaO_2$[M+ Na]$^{+}$, Calculated = 345.0420, Found = 345.0418.

2x.



(*E*)-4-chloro-3-(chloro(phenyl)methylene)-6,7a-dimethyl-2,3,3a,4 tetrahydrobenzofuran-5(7a*H*)-one

46.80 mg, 46% yield, colorless liquid.

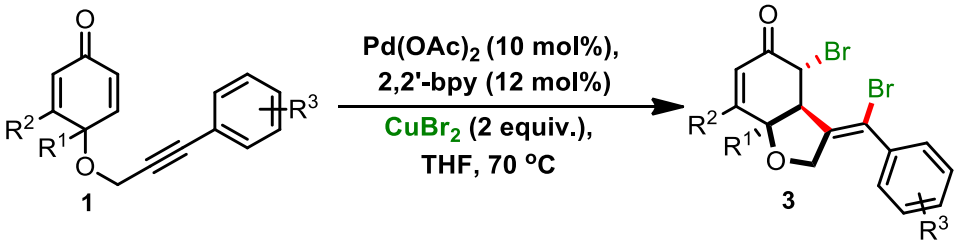
I.R. ($CHCl_3$): *v* 3029, 2936, 2878, 1697, 1449, 1558, 1216, 1090, 665 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$):δ 7.37 – 7.34 (m, 3H), 7.29 – 7.25 (m, 2H), 6.32 (s, 1H), 5.07 (d, J = 2.9 Hz, 1H), 4.19 (dd, J = 12.8, 1.9 Hz, 1H), 4.12 (d, J = 12.8 Hz, 1H), 3.61 (s, 1H), 1.95 (d, J = 1.0 Hz, 3H), 1.70 (s, 3H).

^{13}C NMR (125 MHz, $CDCl_3$):δ 191.48, 144.65, 137.24, 136.25, 134.40, 129.57, 129.49, 128.51, 128.02, 79.74, 77.41, 77.16, 76.91, 68.35, 56.06, 54.69, 26.43, 16.17.

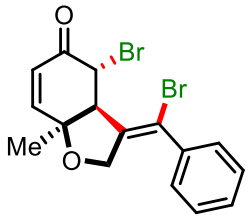
HRMS (ESI):$C_{17}H_{16}Cl_2NaO_2$ [M+ Na]$^{+}$, Calculated = 345.0420, Found = 345.0419.

d) General Procedure for palladium catalyzed dibromination of alkyne-tethered cyclohexadienones:



A dried reaction tube was charged with $Pd(OAc)_2$ (4.49 mg, 10 mol%), 2,2'- bpy (3.56 mg, 10 mol%), $CuBr_2$ (89.34 mg, 2equiv) , and **1** (.2 mmol, 1 equiv) and anhydrous THF (2 mL, .2M) under nitrogen atmosphere. After that mixture was stirred at room temperature for 10 min, then reaction mixture was kept at 70 ^oC for 8-12 hour. After the completion of reaction as observed by TLC, solvent was evaporated under reduced pressure. The residue was purified by silica gel (100-200 mesh, hexane/ethylacetate) column chromatography to afford the desired product.

3a.



(*E*)-4-bromo-3-(bromo(phenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

69.39 mg, 89% yield, white solid.

Melting Point:136-138 ^oC.

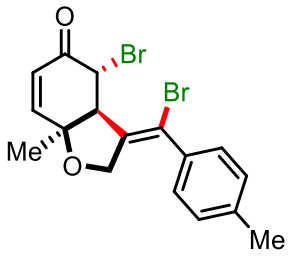
I.R. (liquid): *v* 3014, 2996, 2874, 1692, 1476, 1567, 1216, 1087, 699 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$):δ 7.38 – 7.30 (m, 3H), 7.30 – 7.18 (m, 2H), 6.48 (dd, J = 10.4, 1.2 Hz, 1H), 6.22 (dd, J = 10.4, 1.1 Hz, 1H), 5.18 (dd, J = 2.1, 1.2 Hz, 1H), 4.13 – 4.08 (m, 1H), 4.05 (d, J = 12.7 Hz, 1H), 3.56 (d, J = 1.6 Hz, 1H), 1.75 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$):δ 190.63, 148.95, 139.69, 138.70, 129.47, 128.43, 128.33, 127.03, 120.95, 79.12, 68.56, 57.46, 43.41, 25.67.

HRMS (ESI): $C_{16}H_{14}Br_2NaO_2$ $[M+Na]^+$, Calculated = 418.9253, Found = 418.9256.

3b.



(*E*)-4-bromo-3-(bromo(p-tolyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

72.11 mg, 84% yield, white solid.

Melting point:138-140 ^{o}C.

I.R. (Solid): *v* 3019, 2976, 2854, 1687, 1215, 1084, 1055, 669 cm^{-1}.

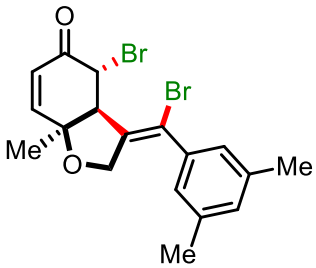
^{1}H NMR (400 MHz, $CDCl_3$):δ 7.13 (s, 4H), 6.48 (dd, J = 10.4, 1.3 Hz, 1H), 6.21 (dd, J = 10.4, 1.1 Hz, 1H), 5.18 (dd, J = 2.1, 1.3 Hz, 1H), 4.10 (dd, J = 12.7, 1.8 Hz, 1H), 4.05 (d, J = 12.7 Hz, 1H), 3.55 (d, J = 1.7 Hz, 1H), 2.35 (s, 3H), 1.74 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$):δ 190.82, 149.12, 139.83, 139.15, 136.05, 129.22, 128.39, 127.16, 121.39, 79.24, 68.75, 57.62, 43.66, 25.82, 21.40.

HRMS (ESI): $C_{17}H_{16}Br_2NaO_2$ $[M+Na]^+$, Calculated = 432.9409, Found = 432.9407.

Crystal structure of this compound is reported (CCDC:1934494).

3c.



(*E*)-4-bromo-3-(bromo(3,5-dimethylphenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

74.46 mg, 86% yield, white semi-solid.

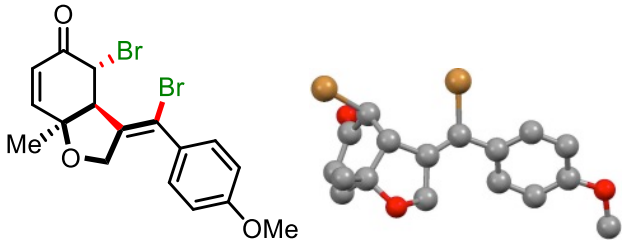
I.R. ($CHCl_3$): *v*3022, 2965, 2935, 1689, 1456, 1556, 1215, 1113, 1058, 660 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ 6.95 (s, J = 0.6 Hz, 1H), 6.84 (s, 2H), 6.47 (dd, J = 10.4, 1.4 Hz, 1H), 6.22 (dd, J = 10.4, 1.3 Hz, 1H), 5.18 (dd, J = 2.3, 1.3 Hz, 1H), 4.06 (d, J= 2.2 Hz, 2H), 3.66 – 3.42 (m, 1H), 2.29 (d, J = 0.5 Hz, 6H), 1.74 (s, J = 32.0 Hz, 3H).

^{13}C NMR (100 MHz, $CDCl_3$): δ190.79, 149.08, 139.24, 138.77, 138.18, 131.26, 127.10, 126.14, 121.40, 79.18, 68.70, 57.47, 43.65, 25.79, 21.28.

HRMS (ESI): $C_{18}H_{18}O_2Br_2NaO_2[M+Na]^+$, Calculated = 446.9566, Found = 446.9568.

3d.



(*E*)-4-bromo-3-(bromo(4-methoxyphenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

68.88 mg, 82% yield, white solid.

Melting Point: 130-132 ^oC.

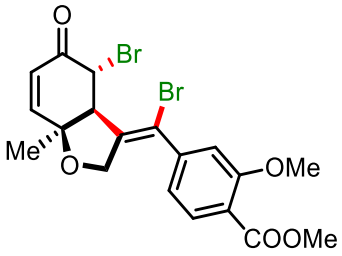
I.R. (Solid): ν 3016, 2975, 2984, 1697, 1498, 1538, 1216, 1089, 665 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.21 – 7.13 (m, 2H), 6.87 – 6.81 (m, 2H), 6.48 (dd, J = 10.4, 1.4 Hz, 1H), 6.21 (dd, J = 10.4, 1.2 Hz, 1H), 5.17 (dd, J = 2.2, 1.3 Hz, 1H), 4.10 (dd, J = 12.6, 1.8 Hz, 1H), 4.05 (d, J = 12.6 Hz, 1H), 3.81 (s, 3H), 3.55 (dd, J = 3.5, 1.7 Hz, 1H), 1.74 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 190.88, 160.47, 149.12, 138.52, 131.25, 130.54, 129.96, 127.14, 121.29, 94.60, 79.24, 68.76, 57.63, 55.52, 43.72, 25.80.

HRMS (ESI): $C_{17}H_{16}Br_2NaO_3$ $[M+Na]^+$,Calculated = 448.9358, Found = 448.9358.***Crystal structure of this compound is reported (CCDC: 1922346).***

3e.



Methyl 4-((*E*)-bromo-4-bromo-7a-methyl-5-oxo-4,5-dihydrobenzofuran-3(2*H*,3a*H*,7a*H*) ylidene)methyl)-2-methoxybenzoate

79.92 mg, 83% yield, white solid.

Melting Point: 115-117 ^{o}C.

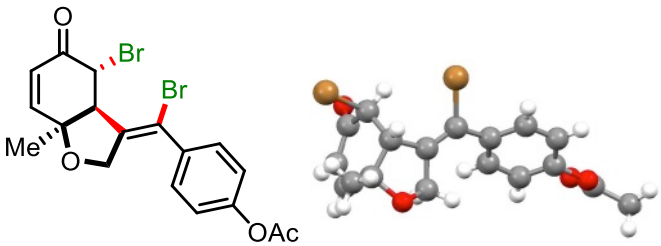
I.R. (Solid): *v*3024, 2924, 1726, 1695, 1486, 1584, 1216, 1097, 1076, 699 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$):δ 7.64 (d, J = 2.2 Hz, 1H), 7.36 (dd, J = 8.7, 2.3 Hz, 1H), 6.93 (d, J = 8.7 Hz, 1H), 6.48 (d, J = 10.4 Hz, 1H), 6.21 (d, J = 10.4 Hz, 1H), 5.14 (s, 1H), 4.09 (d, J = 14.0 Hz, 1H), 4.03 (d, J = 12.7 Hz, 1H), 3.91 (s, 3H), 3.88 (s, 3H), 3.53 (s, 1H), 1.74 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$):δ 190.70, 165.87, 159.73, 149.07, 139.72, 133.48, 131.76, 130.75, 127.19, 120.03, 119.76, 112.02, 79.26, 68.61, 57.62, 56.34, 52.41, 43.45, 25.78.

HRMS (ESI): $C_{19}H_{18}Br_2NaO_5[M+ Na]^+$, Calculated =506.9413, Found = 506.9413.

3f.



4-((*E*)-bromo-4-bromo-7a-methyl-5-oxo-4,5-dihydrobenzofuran-3(2*H*,3a*H*,7a*H*)-ylidene)methyl)phenyl acetate

73.8 mg, 82% yield, white solid.

Melting Point:142-143 ^{o}C.

I.R. (Solid): *v*3017, 2984, 2884, 1773, 1750, 1695, 1498, 1598, 1216, 1084, 664 cm^{-1}.

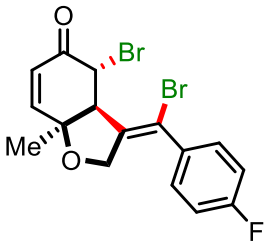
^{1}H NMR (400 MHz, $CDCl_3$):δ 7.33 – 7.11 (m, 2H), 7.19 – 6.85 (m, 2H), 6.48 (dd, J = 10.4, 1.3 Hz, 1H), 6.21 (dd, J = 10.4, 1.2 Hz, 1H), 5.16 (dd, J = 2.2, 1.2 Hz, 1H), 4.08 (s, 2H), 3.57 (t, J = 14.2 Hz, 1H), 2.30 (s, 3H), 1.75 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$):δ 190.69, 169.17, 151.37, 149.06, 140.24, 136.30, 129.68, 127.17, 121.75, 120.00, 79.26, 68.64, 57.63, 43.45, 29.83, 25.79, 21.25.

HRMS (ESI): $C_{18}H_{16}Br_2NaO_4$ $[M+ Na]^+$, Calculated = 476.9308, Found = 476.9307.

Crystal structure of this compound is reported (CCDC: 1913346).

3g.



(*E*)-4-bromo-3-(bromo(4-fluorophenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

66.22 mg, 80% yield, colorless semi-solid.

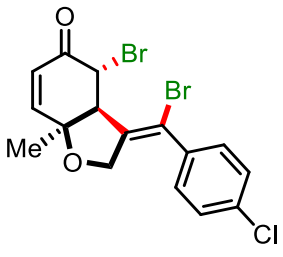
I.R. (Solid): ν 3016, 2915, 2875, 1698, 1478, 1567, 1216, 1091, 1076, 662 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$):δ 7.27 – 7.18 (m, 2H), 7.06 – 6.98 (m, 2H), 6.48 (dd, J = 10.4, 1.3 Hz, 1H), 6.21 (dd, J = 10.4, 1.1 Hz, 1H), 5.15 (dd, J = 2.1, 1.2 Hz, 1H), 4.08 (dd, J = 12.7, 1.8 Hz, 1H), 4.02 (d, J = 12.7 Hz, 1H), 3.54 (d, J = 1.6 Hz, 1H), 1.75 (s, 3H).

^{13}C NMR (100 MHz, CDCl3):δ 190.53, 164.25, 161.76, 148.86, 140.00, 134.85, 130.34, 130.26, 127.07, 119.66, 115.66, 115.44, 79.21, 68.47, 57.46, 43.29, 25.67.

HRMS (ESI):$C_{16}H_{13}Br_2FKO_2$ $[M+K]^+$, Calculated = 452.8898, found =452.8894.

3h.



(*E*)-4-chloro-3-(chloro(4-chlorophenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

69.88 mg, 80% yield, white solid

Melting point: 128-130 ^{o}C.

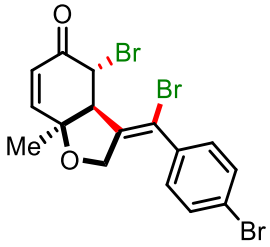
I.R. (Solid): *v* 3018, 2925, 2882, 1696, 1455, 1555, 1217, 1076, 1093, 665 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$):δ 7.31 (d, J = 8.5 Hz, 2H), 7.18 (d, J = 8.5 Hz, 2H), 6.48 (d, J = 10.4 Hz, 1H), 6.21 (d, J = 10.4 Hz, 1H), 5.14 (s, 1H), 4.08 (dd, J = 12.8, 1.7 Hz, 1H), 4.03 (d, J = 12.8 Hz, 1H), 3.54 (d, J = 1.3 Hz, 1H), 1.75 (s, 3H).

^{13}C NMR (125 MHz, $CDCl_3$):δ 190.63, 148.99, 140.61, 137.27, 135.66, 131.53, 129.79, 128.86, 127.23, 119.65, 79.34, 68.60, 57.65, 43.34, 25.81.

HRMS (ESI): $C_{16}H_{13}Br_2ClNaO_2$[M+ Na]$^{+}$, Calculated = 452.8863, Found = 452.8865.

3i.



(*E*)-4-bromo-3-(bromo(4-bromophenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

76.46 mg, 81% yield, white solid

Melting Point:161-171 ^{o}C.

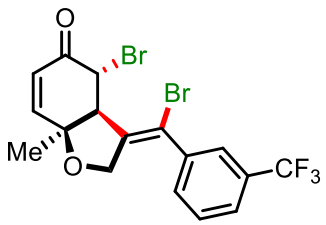
I.R. (Solid): *v* 3013, 2927, 2886, 1694, 1217, 1087, 1067, 669 cm^{-1}

^{1}H NMR (500 MHz, $CDCl_3$):δ 7.47 (d, J = 8.5 Hz, 2H), 7.11 (d, J = 8.5 Hz, 2H), 6.48 (dd, J = 10.4, 1.2 Hz, 1H), 6.21 (dd, J = 10.4, 1.0 Hz, 1H), 5.13 (dd, J = 2.0, 1.2 Hz, 1H), 4.08 (dd, J = 12.8, 1.8 Hz, 1H), 4.03 (d, J = 12.8 Hz, 1H), 3.53 (d, J = 1.4 Hz, 1H), 1.74 (s, 3H)..

^{13}CNMR (125 MHz, CDCl3):δ 190.59, 148.97, 140.63, 137.70, 131.80, 129.99, 127.21, 123.88, 119.65, 79.31, 68.56, 57.63, 43.28, 25.78.

HRMS (ESI):$C_{16}H_{13}Br_3KO_2$ [M+K]$^{+}$, Calculated = 512.8097, found = 512.8092.

3j.



(*E*)-4-bromo-3-(bromo(3-(trifluoromethyl)phenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

59 mg, 65% yield, colorless liquid.

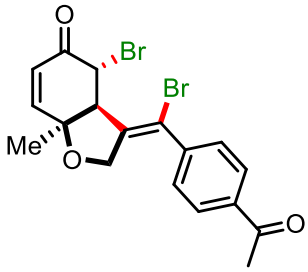
I.R. ($CHCl_3$): *v*3034, 2955, 2858, 1694, 1464, 1543, 1216, 1085, 668 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$):δ 7.60 (d, J = 7.7 Hz, 1H), 7.49 (dd, J = 15.3, 7.4 Hz, 2H), 7.41 (d, J = 7.6 Hz, 1H), 6.49 (d, J = 10.4 Hz, 1H), 6.23 (d, J = 10.4 Hz, 1H), 5.15 (d, J = 1.0 Hz, 1H), 4.10 (d, J = 12.8 Hz, 1H), 4.02 (d, J = 12.7 Hz, 1H), 3.57 (s, 1H), 1.76 (s, J = 11.2 Hz, 3H).

^{13}C NMR (125 MHz, $CDCl_3$):δ 190.53, 148.95, 141.71, 139.61, 131.71, 129.27, 128.32, 127.31, 126.34, 125.30, 79.40, 68.48, 57.70, 43.19, 25.82

HRMS (ESI): $C_{17}H_{13}Br_2F_3NaO_2[M+ Na]^+$,Calculated = 486.9127, Found = 486.9123.

3k.



(*E*)-3-((4-acetylphenyl)bromomethylene)-4-bromo-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one.

63.99 mg, 81% yield, white solid.

I.R. (Solid): *v* 3014, 2975, 2984, 1705, 1685, 1485, 1565, 1216, 1089, 1065, 665, cm^{-1}.

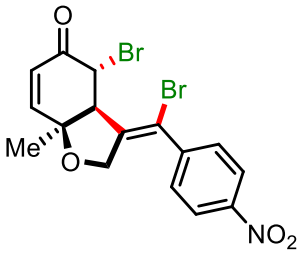
^{1}H NMR (400 MHz, $CDCl_3$):δ7.91 (d, J = 8.5 Hz, 2H), 7.34 (d, J = 8.5 Hz, 2H), 6.49 (dd, J = 10.4, 1.3 Hz, 1H), 6.22 (dd, J = 10.4, 1.2 Hz, 1H), 5.15 (dd, J = 2.2, 1.2 Hz, 1H), 4.11 (dd,

J = 12.9, 2.0 Hz, 1H), 4.03 (d, *J* = 12.8 Hz, 1H), 3.57 (dd, *J* = 3.5, 2.0 Hz, 1H), 2.60 (s, *J* = 3.8 Hz, 3H), 1.75 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$):δ 197.23, 190.55, 148.96, 143.01, 141.63, 137.64, 128.78, 128.53, 127.26, 119.53, 79.31, 68.58, 57.72, 43.22, 26.81, 25.79.

HRMS (ESI): $C_{18}H_{17}Br_2O_3$ $[M+H]^+$, Calculated = 438.9539, Found = 438.9539.

3l.



(*E*)-4-bromo-3-(bromo(4-nitrophenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

46.98 mg, 54% yield, white solid.

Melting point: 118-119 ^{o}C.

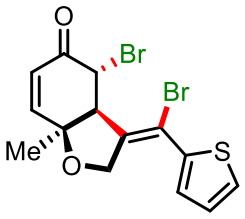
I.R. (Solid): *v* 2952, 2926, 1690, 1520, 1346, 1498, 1520, 1216, 1095, 839, 668 cm^{-1}

^{1}H NMR (400 MHz, $CDCl_3$):δ 8.24 – 8.18 (m, 2H), 7.46 – 7.41 (m, 2H), 6.50 (dd, *J* = 10.5, 1.3 Hz, 1H), 6.24 (dd, *J* = 10.4, 1.2 Hz, 1H), 5.13 (dd, *J* = 2.2, 1.2 Hz, 1H), 4.12 (dd, *J* = 12.9, 2.0 Hz, 1H), 4.04 (d, *J* = 12.9 Hz, 1H), 3.74 – 3.26 (m, 1H), 1.77 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$):δ 189.33, 149.66, 144.41, 142.86, 129.49, 127.13, 124.61, 81.89, 72.66, 54.80, 42.36, 25.61.

HRMS (ESI): $C_{16}H_{13}Br_2NNaO_4$ $[M+ Na]^+$, Calculated = 463.9104, Found = 463.9104.

3m.



(*E*)-4-bromo-3-(bromo(thiophen-2-yl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

53.72 mg, 68% yield, white solid.

Melting Point:142-144^{o}C.

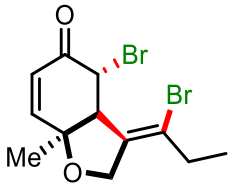
I.R. (Solid): *v* 3024, 2945, 2848, 1684, 1454, 1533, 1216, 1095, 665 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$):δ7.45 (dd, *J* = 5.1, 0.8 Hz, 1H), 7.20 (d, *J* = 3.1 Hz, 1H), 7.05 (ddd, *J* = 14.2, 7.2, 4.6 Hz, 1H), 6.51 (dd, *J* = 10.5, 1.3 Hz, 1H), 6.09 (dd, *J* = 10.4, 0.8 Hz, 1H), 4.55 (d, *J* = 14.6 Hz, 1H), 4.18 (d, *J* = 1.2 Hz, 1H), 4.10 (dd, *J* = 14.6, 2.6 Hz, 1H), 3.72 (s, *J* = 12.8 Hz, 1H), 1.75 (s, 3H).

^{13}C NMR (125 MHz, $CDCl_3$):δ 189.86, 149.85, 141.31, 139.53, 129.46, 128.45, 127.71, 127.06, 109.98, 81.48, 72.54, 55.11, 42.23, 25.72.

HRMS (ESI): $C_{14}H_{12}Br_2NaO_2S$ $[M+ Na]^+$, Calculated = 424.8817, Found = 424.8819.

3n.



(*E*)-4-bromo-3-(1-bromopropylidene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

47.9 mg, 69% yield, yellow liquid**.**

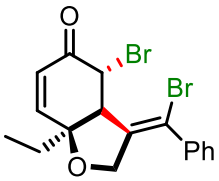
I.R. (Solid): *v*3025, 2975, 2974, 1696, 1437, 1554, 1215, 1090, 1073, 665 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$):δ 6.43 (dd, *J* = 10.4, 1.1 Hz, 1H), 6.13 (dd, *J* = 10.4, 0.9 Hz, 1H), 5.14 (d, *J* = 1.0 Hz, 1H), 4.35 (d, *J* = 12.2 Hz, 1H), 3.91 (d, *J* = 12.3 Hz, 1H), 3.35 (s, *J* = 21.4 Hz, 1H), 2.38 – 2.32 (m, 2H), 1.69 (d, *J* = 15.6 Hz, 3H), 1.09 (t, *J* = 7.4 Hz, 3H).

^{13}C NMR (100 MHz, $CDCl_3$):δ 190.82, 149.14, 136.31, 126.94, 125.99, 79.45, 67.36, 56.48, 43.83, 32.98, 25.84, 13.02.

HRMS (ESI):$C_{12}H_{14}Br_2NaO_2$ [M+Na], Calculated = 370.9253, found = 370.9258.

3o.



(*E*)-4-bromo-3-(bromo(phenyl)methylene)-7a-ethyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

60.35 mg, 71% yield, white semi-solid.

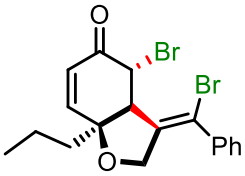
I.R. ($CHCl_3$): *v* 3054, 2955, 2868, 1684, 1474, 1573, 1215, 1096, 666 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$):δ 7.39 – 7.32 (m, 3H), 7.30 – 7.24 (m, 2H), 6.63 (dd, *J* = 10.5, 1.2 Hz, 1H), 6.24 (dd, *J* = 10.5, 1.0 Hz, 1H), 5.04 (dd, *J* = 3.2, 1.0 Hz, 1H), 4.25 (dd, *J* = 12.9, 2.1 Hz, 1H), 4.14 (d, *J* = 12.9 Hz, 1H), 3.73 – 3.67 (m, 1H), 2.12 – 1.94 (m, 2H), 1.08 (t, *J* = 7.5 Hz, 3H).

^{13}CNMR (100 MHz, $CDCl_3$):δ 190.91, 149.82, 138.21, 135.06, 128.56, 129.54, 128.03, 127.61, 82.65, 67.47, 53.48, 52.20, 30.31, 8.1.

HRMS (ESI): $C_{17}H_{17}Br_2O_2$ $[M+H]^+$,Calculated = 410.9590, Found = 410.9592.

3p.



(*E*)-4-bromo-3-(bromo(phenyl)methylene)-7a-propyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

52.129 mg, 70% yield, white solid.

Melting Point:141-143 ^oC.

I.R. (Solid): *v* 3018, 2975, 2988, 1699, 1434, 1553,1216, 1083, 1073, 668 $cm^{-1.}$

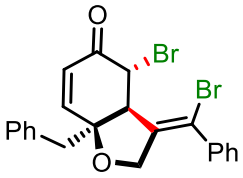
^{1}H NMR (400 MHz, $CDCl_3$):δ 7.37 – 7.30 (m, 3H), 7.28 – 7.20 (m, 2H), 6.57 (dd, *J* = 10.5, 1.2 Hz, 1H), 6.23 (dd, *J* = 10.5, 1.1 Hz, 1H), 5.17 (dd, *J* = 2.2, 1.2 Hz, 1H), 4.10 (dd, *J* =

12.8, 1.8 Hz, 1H), 4.05 (d, *J* = 12.7 Hz, 1H), 3.65 (d, *J*= 1.5 Hz, 1H), 2.11 – 1.92 (m, 2H), 1.66 – 1.51 (m, 2H), 1.00 (t, *J* = 7.3 Hz, 3H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 191.01, 148.51, 140.02, 138.83, 129.56, 128.54, 128.48, 127.34, 120.91, 81.34, 68.57, 55.37, 43.75, 40.45, 16.57, 14.58.

HRMS (ESI): $C_{18}H_{19}Br_2NaO_2$ $[M+Na]^+$, Calculated = 446.9566, Found = 446.9566.

3q.



(*E*)-7a-benzyl-4-bromo-3-(bromo(phenyl)methylene)-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

61.41 mg, 65% yield, white semi-solid.

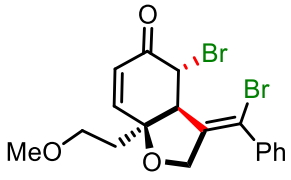
I.R. ($CHCl_3$): *v* 3013, 2972, 2982, 1695, 1432, 1552, 1216, 1085, 1073, 665 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.42 – 7.27 (m, 8H), 7.25 – 7.14 (m, 2H), 6.43 (dd, *J* = 10.5, 1.1 Hz, 1H), 6.23 (dd, *J* = 10.5, 1.0 Hz, 1H), 5.21 (s, *J* = 1.1 Hz, 1H), 4.07 (s, 2H), 3.63 (s, 1H), 3.47 (d, *J* = 14.2 Hz, 1H), 3.29 (d, *J* = 14.2 Hz, 1H).

^{13}C NMR (100 MHz, CDCl3): δ 190.95, 147.61, 139.60, 138.76, 135.21, 131.19, 129.57, 128.51, 128.47, 128.40, 127.38, 127.24, 120.96, 81.07, 68.53, 55.23, 44.28, 43.92.

HRMS (ESI): $C_{22}H_{18}Br_2NaO_2$ $[M+Na]^+$, Calculated = 494.9566, Found = 494.9561.

3r.



(*E*)-4-bromo-3-(bromo(phenyl)methylene)-7a-(2-methoxyethyl)-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

53.07 mg, 61% yield, white liquid.

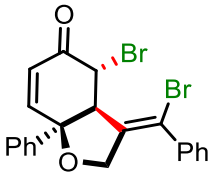
I.R. ($CHCl_3$): *v*3023, 2995, 2938, 1694, 1474, 1563,1216, 1063, 1053, 665 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$):δ 7.36 – 7.30 (m, 3H), 7.28 – 7.17 (m, 2H), 6.64 (dd, J = 10.5, 1.3 Hz, 1H), 6.23 (dd, J = 10.5, 1.2 Hz, 1H), 5.16 (dd, J = 2.4, 1.2 Hz, 1H), 4.12 (dd, J = 12.8, 1.8 Hz, 1H), 4.07 (d, J = 12.7 Hz, 1H), 3.77 (dd, J = 3.5, 1.7 Hz, 1H), 3.71 – 3.62 (m, 2H), 3.36 (s, 3H), 2.47 – 2.37 (m, 1H), 2.33 – 2.24 (m, 1H)..

^{13}C NMR (100 MHz, $CDCl_3$):δ 190.83, 148.15, 139.66, 138.80, 129.59, 128.54, 128.47, 127.18, 120.97, 80.36, 68.61, 67.67, 58.76, 56.30, 43.65, 38.18.

HRMS (ESI): $C_{18}H_{18}Br_2KO_3[M+K]^+$, Calculated = 478.9254, Found = 478.9256.

3s.



(*E*)-4-bromo-3-(bromo(phenyl)methylene)-7a-phenyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

45.91 mg, 51% yield, white semi-solid.

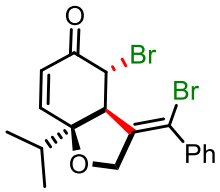
I.R. ($CHCl_3$): *v* 3034, 2985, 2848, 1694, 1454, 1533, 1214, 1094, 664 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$):δ 7.58 (d, *J* = 7.2 Hz, 2H), 7.46 – 7.34 (m, 6H), 7.31 – 7.27 (m, 2H), 6.79 (d, *J* = 10.4 Hz, 1H), 6.50 (d, *J* = 10.4 Hz, 1H), 5.16 (d, *J* = 2.2 Hz, 1H), 4.34 (s, 2H), 3.91 (d, *J* = 1.8 Hz, 1H).

^{13}C NMR (125 MHz, $CDCl_3$): δ 190.52, 146.75, 141.13, 139.38, 138.60, 129.57, 128.71, 128.63, 128.56, 128.49, 128.43, 126.29, 120.84, 82.20, 77.30, 77.04, 76.79, 68.96, 59.55, 43.85, 22.64.

HRMS (ESI): $C_{21}H_{16}Br_2NaO_2$ $[M+Na]^+$, Calculated = 480.9409, Found = 480.9403.

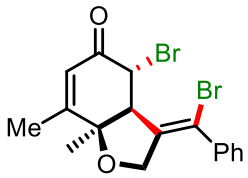
3t.



52 mg mixture of **3t** and starting material**1s.**

Mole ratio of **3t** and **1s** = (1.15:1). **3t** was found in 36 % yield.

3v.



(*E*)-4-bromo-3-(bromo(phenyl)methylene)-7,7a-dimethyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

56.44 mg, 69% yield, white solid

Melting Point: 126-128 ^{o}C**.**

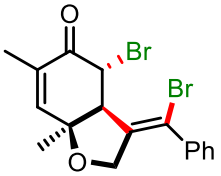
I.R. (Solid): *v* 3016, 2975, 2984, 1698, 1435, 1556, 1214, 1089, 1073, 665, cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$):δ 7.35 – 7.28 (m, 3H), 7.26 – 7.19 (m, 2H), 6.12 – 6.11 (m, 1H), 5.26 (dd, *J* = 2.1, 1.2 Hz, 1H), 3.99 (d, *J* = 2.4 Hz, 2H), 3.54 (s, 1H), 2.04 (d, *J* = 1.2 Hz, 3H), 1.76 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$):δ 190.37 (s), 159.78 (s), 139.42 (d, J = 83.1 Hz), 128.21 (dd, J = 169.9, 164.0 Hz), 120.83 (s), 81.66 (s), 69.01 (s), 58.69 (s), 43.77 (s), 24.54 (s), 18.68 (s).

HRMS (ESI):$C_{17}H_{16}Br_2NaO_2[M+Na]^+$, Calculated = 432.9409, found = 432.9408.

3w.



(*E*)-4-bromo-3-(bromo(phenyl)methylene)-6,7a-dimethyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

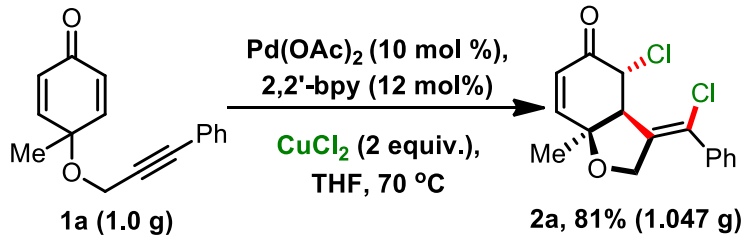
31 mg, 38% yield, colorless liquid

^{1}H NMR (500 MHz, $CDCl_3$):δ7.39 – 7.32 (m, 3H), 7.31 – 7.21 (m, 2H), 6.27 (s, 1H), 5.21 (d, *J* = 2.2 Hz, 1H), 4.09 (dd, *J* = 12.7, 1.6 Hz, 1H), 4.05 (d, *J* = 12.7 Hz, 1H), 3.59 (d, *J* = 26.9 Hz, 1H), 1.98 (s, 3H), 1.74 (s, 3H).

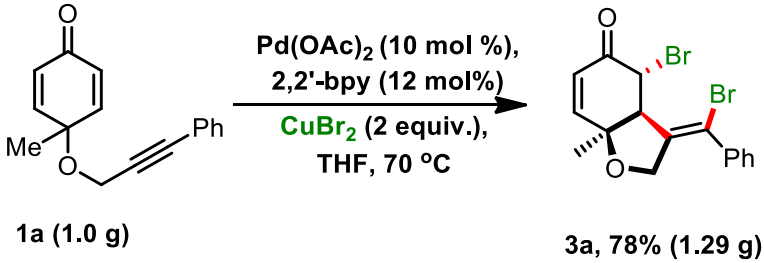
^{13}C NMR (125 MHz, $CDCl_3$): δ 191.52, 144.26, 140.24, 138.87, 134.35, 129.53, 128.52, 128.49, 120.83, 79.63, 77.41, 77.16, 76.91, 68.46, 57.76, 44.25, 26.21, 16.29.

HRMS (ESI): $C_{17}H_{16}Br_2NaO_2[M+Na]^+$, Calculated = 432.9409, found = 432.9407.

3) Procedure for gram scale synthesis:

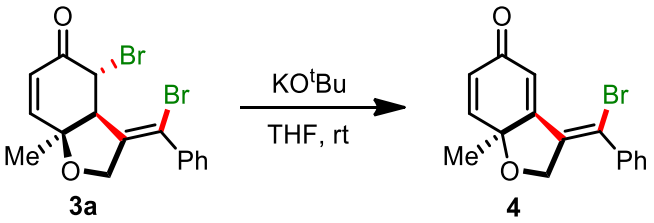


A dried reaction tube was charged with $Pd(OAc)_2$ (94.21 mg, 10 mol%), 2,2'- bpy (65.6 mg, 10 mol%), $CuCl_2.2H_2O$ (1.4 g, 2 equiv.) , and **1a** (1 g, 4.13 mmol) and anhydrous THF (20 mL, .2M) under nitrogen atmosphere. After that mixture was stirred at room temperature for 10 min, reaction mixture was kept at 70 ^oC for 8-12 hour. After the completion of reaction as observed by TLC, solvent was evaporated under reduced pressure. The residue was purified by silica gel (100-200 mesh, hexane/ethylacetate) column chromatography to afford the desired product**2a** (1.047 g, 81% yield).



A dried reaction tube was charged with $Pd(OAc)_2$ (94.21 mg, 10 mol%), 2,2'- bpy (65.6 mg, 10 mol%), $CuBr_2$ (1.84 g, 2 equiv.) and **1a** (1 g, 4.13 mmol) and anhydrous THF (20 L, .2M) under nitrogen atmosphere. After that mixture was stirred at room temperature for 10 min, reaction mixture was kept at 70 ^oC for 8-12 hour. After the completion of reaction as observed by TLC, solvent was evaporated under reduced pressure. The residue was purified by silica gel (100-200 mesh, hexane/ethylacetate) column chromatography to afford the desired product**3a** (1.29 g, 78% yield).

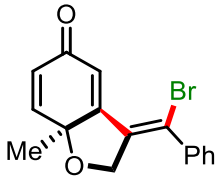
5. Functionalization:



3a **4**

To a solution of **3a**(100 mg, 0.25 mmol) in dry THF (5 mL) was added KO^{t}Bu (28 mg mg, 1 equiv.) at room temperature. After 2 h, solvent was removed in vacuo and the resulting mixture was extracted with diethyl ether. The combined organic layer was washed with brine and dried over anhydrous sodium sulfate. Evaporation of the solvent followed by purification by flash chromatography (PE/EA = 85/15) on silica gel to give product **4**(67.86 mg, 85%yield).

4.



(E)-3-(bromo(phenyl)methylene)-7a-methyl-2,3-dihydrobenzofuran-5(7aH)-one

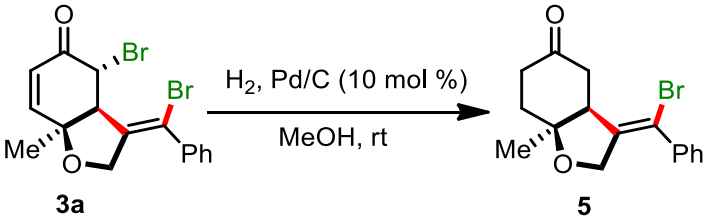
33.93 mg, 85% yield, colorless liquid.

I.R.($CHCl_3$): *v* 3021, 2955, 2944, 1697, 1455, 1576, 1215, 1086, 1063 cm-1.

^{1}H NMR (400 MHz, $CDCl_3$):δ 7.45 – 7.33 (m, 5H), 7.21 (d, J = 1.1 Hz, 1H), 7.13 (d, J = 9.9 Hz, 1H), 6.19 (dd, J = 9.9, 1.4 Hz, 1H), 4.54 (dd, J = 34.6, 13.5 Hz, 2H), 1.47 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$):δ 186.80, 160.51, 148.21, 140.21, 134.16, 129.78, 128.91, 127.90, 127.82, 121.32, 80.73, 70.81, 26.66.

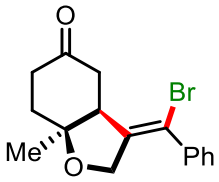
HRMS (ESI):$C_{16}H_{13}BrNaO_2[M+Na]^+$, Calculated = 338.9991, found = 338.9996.



3a **5**

To a solution of **3a**(100 mg, 0.25mmol) in MeOH (5 mL) was added Pd/C (10 wt.%, 50 mg, 0.0267mmol) and H_2 gas was bubbled from a balloon at room temperature. After 2 h, mixture was filtered through a pad of celite and washed with EtOAc (10 mL) anddiethyl ether (10 mL). The combined organic phase was dried with Na_2SO_4. After removal of thesolvent under reduced pressure, the residue was purified by column chromatography (silica gel mesh100-200; hexane: ethyl acetate; 80:20) to give the product **5** (71.13 mg, 91%yield).

5.



(*E*)-4-bromo-3-(bromo(phenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7a*H*)-one

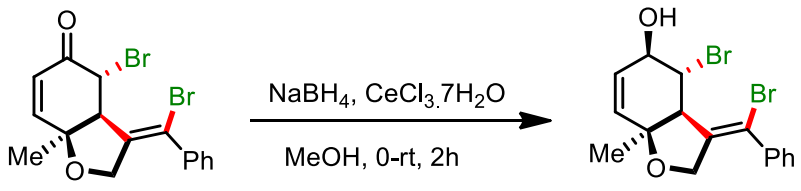
78.08 mg, 91% yield, colorless liquid.

I.R. ($CHCl_3$): *v* 3015, 2965, 2974, 1710, 1455, 1576, 1216, 1089, 1073 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$):δ 7.40 – 7.30 (m, 5H), 4.52 (d, J = 14.1 Hz, 1H), 4.34 (d, J = 14.1 Hz, 1H), 3.23 (t, J = 7.6 Hz, 1H), 2.86 (dd, J = 15.0, 7.4 Hz, 1H), 2.63 – 2.51 (m, 2H), 2.24 (ddt, J = 20.3, 10.2, 5.2 Hz, 2H), 2.17 – 2.10 (m, 1H), 1.34 (s, 3H).

^{13}C NMR (126 MHz, $CDCl_3$):δ 211.42, 144.44, 139.28, 128.88, 128.60, 128.26, 114.64, 81.04, 68.52, 52.54, 40.29, 35.69, 33.46, 25.69.

HRMS (ESI):$C_{16}H_{17}BrNaO_2$ $[M+Na]^+$, Calculated = 343.0304, found = 343.0307.

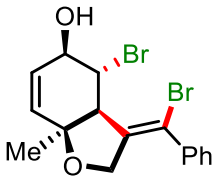


3a **6**,

To a solution of **3a**(100 mg, 0.25mmol) in MeOH (5 mL) was added $CeCl_3.7H_2O$ (9.4 mg, 10 mol%) and $NaBH_4$(9.5 mg 1 equiv) at 0 ^oC temperature. After that, reaction mixture was allowed to run at room temperature for 2 h. After that, reaction mixture was filtered through

a pad of celiteand washed with EtOAc (10 mL) anddiethyl ether (10 mL). The combined organic phase was dried with Na_2SO_4. After removal of thesolvent under reduced pressure, the residue was purified by column chromatography (silica gel mesh100-200; PE/EA = 70:30) to give the product **6** (92.46 mg, 92%yield).

6.



(*E*)-4-bromo-3-(bromo(phenyl)methylene)-7a-methyl-2,3,3a,4,5,7a-hexahydrobenzofuran-5-ol

46.23 mg, 92% yield, semi solid.

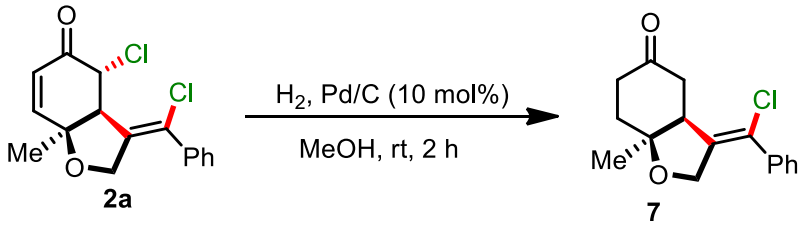
I.R. ($CHCl_3$): *v* 3347, 3021, 2959, 2843, 1485, 1586, 1215, 1096, 1063, 699 cm^{-1}.

^{1}H NMR (400 MHz, $CDCl_3$):δ 7.38 – 7.23 (m, 5H), 5.83 (d, J = 10.3 Hz, 1H), 5.58 (dd, J = 10.2, 1.5 Hz, 1H), 5.39 (s, 1H), 4.29 (s, 1H), 4.20 (dd, J = 12.6, 1.5 Hz, 1H), 4.04 (t, J = 16.7 Hz, 1H), 3.52 (d, J = 3.5 Hz, 1H), 1.59 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$):δ 141.24 (s), 139.08 (s), 131.58 (s), 131.09 (s), 129.33 (s), 128.52 (s), 128.43 (s), 119.07 (s), 80.12 (s), 68.55 (s), 65.74 (s), 58.24 (s), 56.31 (s), 27.55 (s).

HRMS (ESI):$C_{16}H_{16}Br_2NaO_2[M+Na]^+$, Calculated = 420.9409, found = 420.9407.

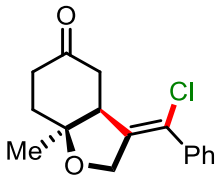
7.



To a solution of **2a**(100 mg, 0.327mmol) in MeOH (5 mL) was added Pd/C (10 wt.%, 50 mg, 0.0035mmol) and H_2 gas was bubbled from a balloon at room temperature. After 2 h, the reaction mixture was filtered through a pad of celite and washed with EtOAc (10 mL) and diethyl ether (10 mL). The combined organic phase was dried over Na_2SO_4. After removal of

thesolvent under reduced pressure, the residue was purified by column chromatography (silica gel,mesh100-200; hexane: ethyl acetate; 80:20) to give the product **7**(94.50 mg, 91%yield).

7.



(*E*)-3-(chloro(phenyl)methylene)-7a-methylhexahydrobenzofuran-5(6*H*)-one

81.4 mg, 91% yield, colorless liquid.

I.R. ($CHCl_3$): *v* 3029, 2979, 2883, 1698, 1485, 1586, 1215, 1076, 1083cm^{-1}.

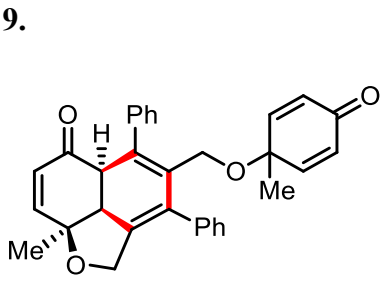
^{1}H NMR (400 MHz, $CDCl_3$):δ 7.46 – 7.29 (m, 5H), 4.67 – 4.56 (m, 1H), 4.41 (d, J = 14.1 Hz, 1H), 3.35 – 3.02 (m, 1H), 2.82 (dd, J = 15.0, 7.4 Hz, 1H), 2.66 – 2.39 (m, 2H), 2.33 – 2.05 (m, 3H), 1.31 (s, 3H).

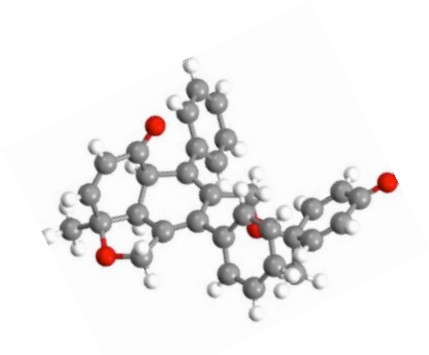
^{13}C NMR (100 MHz, $CDCl_3$):δ 211.55 (s), 141.32 (s), 137.63 (s), 128.92 (s), 128.58 (s), 127.87 (s), 124.46 (s), 81.19 (s), 68.46 (s), 50.37 (s), 40.41 (s), 35.67 (s), 33.39 (s), 25.76 (s).

HRMS (ESI):$C_{16}H_{17}ClNaO_2$ $[M+Na]^+$, Calculated = 299.0809, found = 299.0811.

6. Mechanistic study:

9.





(8a-methyl-4-(((1-methyl-4-oxocyclohexa ,5-dien-1-yl)oxy)methyl)-3,5-diphenyl-5a,8a-dihydro-2*H*-naphtho[1,8-bc]furan-6(2a1*H*)-one

36.9 mg, 40% yield, white solid.

I.R. (Solid):*v*3016, 2975, 2984, 1698, 1694, 1556, 1435, 1216, 1120, 1089, 1073 cm^{-1}.

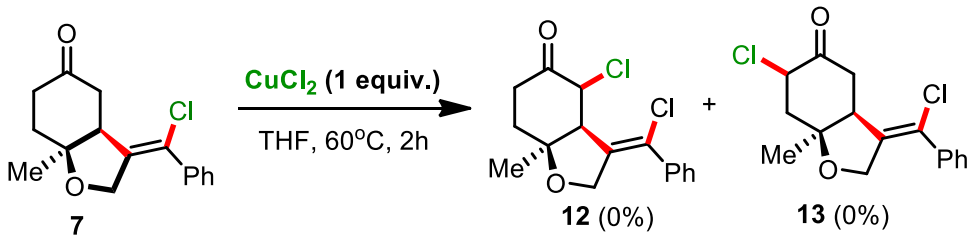
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.54 – 7.46 (m, 2H), 7.41 – 7.27 (m, 6H), 7.13 (s, 2H), 6.59 – 6.48 (m, 1H), 6.37 (dd, J = 10.2, 3.1 Hz, 1H), 6.17 – 6.04 (m, 1H), 6.04 – 5.90 (m, 1H), 5.88 – 5.67 (m, 1H), 5.46 – 5.10 (m, 1H), 4.90 – 4.62 (m, 1H), 3.97 (dd, J = 15.4, 3.1 Hz, 1H), 3.83 (d, J = 9.9 Hz, 1H), 3.63 (d, J = 9.9 Hz, 1H), 3.51 – 3.41 (m, 1H), 3.34 (t, J = 7.6 Hz, 1H), 1.59 (s, 3H), 1.22 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 199.32 (s), 185.11 (s), 151.64 (s), 151.35 (s), 150.08 (s), 141.17 (s), 140.62 (s), 138.27 (s), 137.87 (s), 132.20 (s), 132.11 (s), 130.72 (s), 129.85 (s), 129.76 (s), 128.95 (s), 128.82 (s), 128.35 (s), 128.33 (s), 127.73 (s), 127.51 (s), 79.83 (s), 72.27 (s), 67.94 (s), 62.40 (s), 49.66 (s), 49.22 (s), 26.41 (s), 24.46 (s).

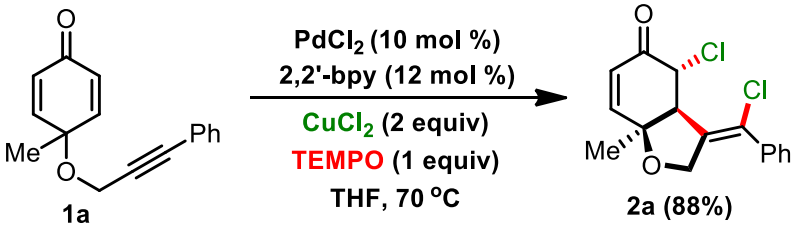
HRMS (ESI): $C_{32}H_{28}NaO_4[M+Na]^+$, Calculated = 499.1880, found = 499.1881.

Crystal structure of this compound is reported (CCDC: 1922338).

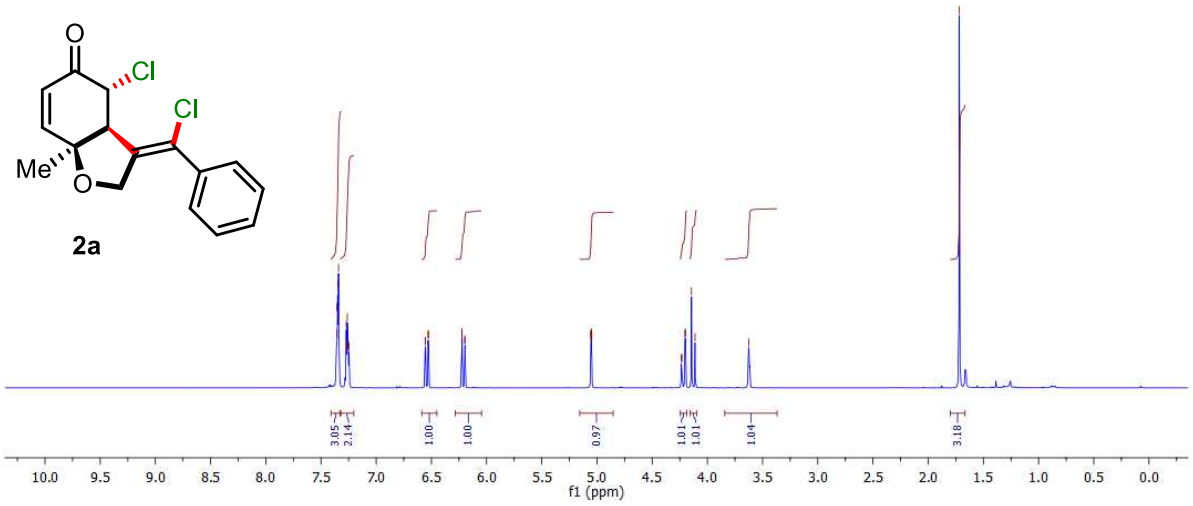
(e) A dried reaction tube was charged with compound **7**(55.35 mg, 0.2 mmol), $CuCl_2$ (26 mg, 1 equiv.) and anhydrous THF (2mL,) under nitrogen atmosphere. After that, mixture was stirred at room temperature for 10 min. After 10 minute, when TLC was observed, no new product formation was observed. Thereafter, the reaction temperature was increased to 60 ^oC and reaction was monitored after 1 and 2 hoursby TLC. Starting material was found to be un-reactedas per the NMR analysis. This experiment excludes the possibility of any alpha chlorination of **7,**failing to provide anyof thechlorinated products**12** or **13**with $CuCl_2$acting as the Cl_2 source.

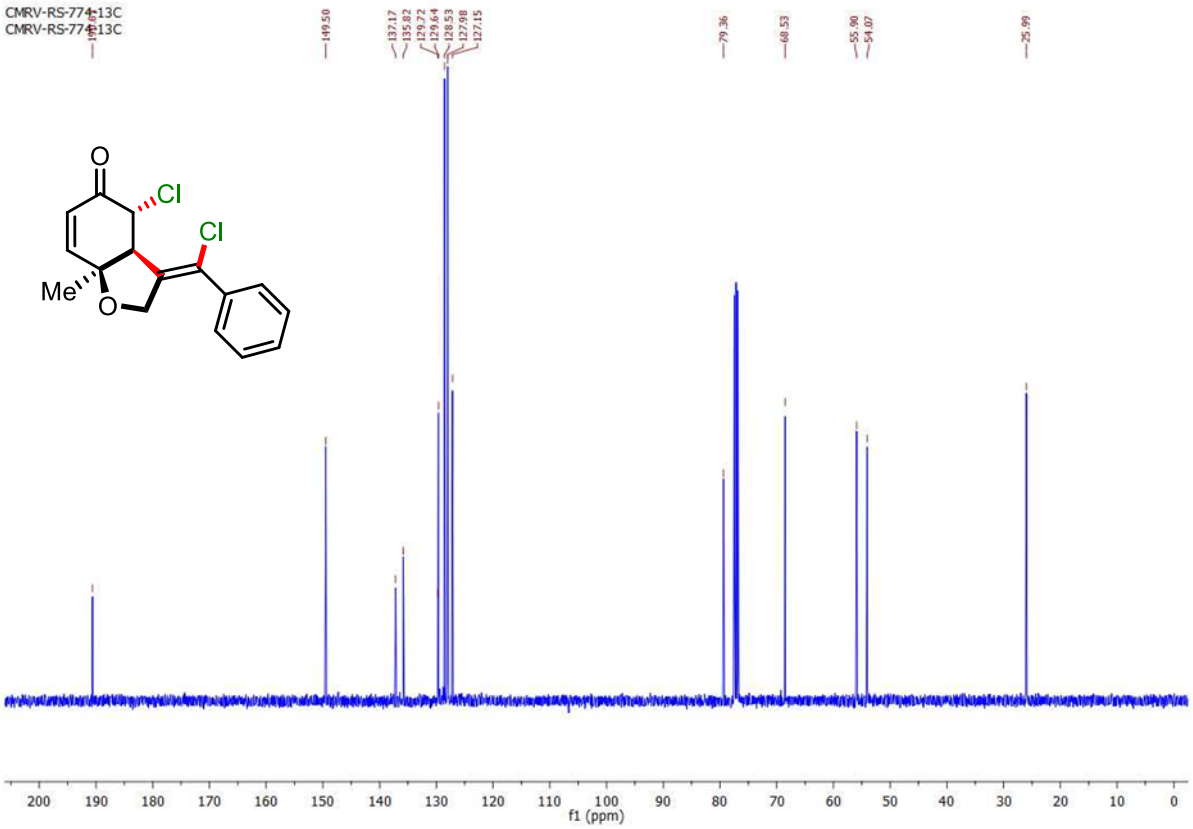


(f)A dried reaction tube was charged with $Pd(OAc)_2$(2.23 mg, 10 mol%), compound **1a** (23.8 mg, 0.1 mmol), $CuCl_2$ (26.8 mg, 2equiv.), 2,2,6,6-tetramethylpiperidyl-1-oxyl (TEMPO) (15.6 mg, 1 equiv.) and anhydrous THF (1mL,) under nitrogen atmosphere and reaction mixture was stirred at 60 ^oC for 2 h. Thereafter, NMR of crude reaction mixture was studied, suggesting the absence of radical intermediated since formation of 2a was observed in 88% yield.

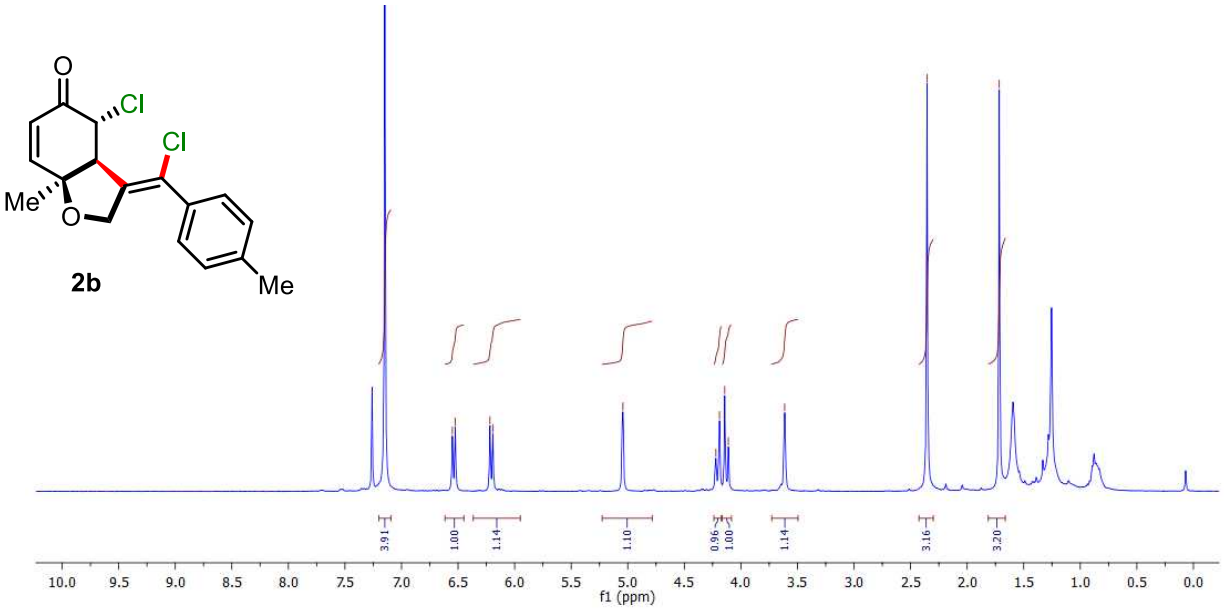

O
Me
O
Ph
1a
PdCl2 (10 mol %)
2,2'-bpy (12 mol %)
CuCl2 (2 equiv)
TEMPO (1 equiv)
THF, 70 °C
O
Cl
Cl
Me
O
Ph
2a (88%)

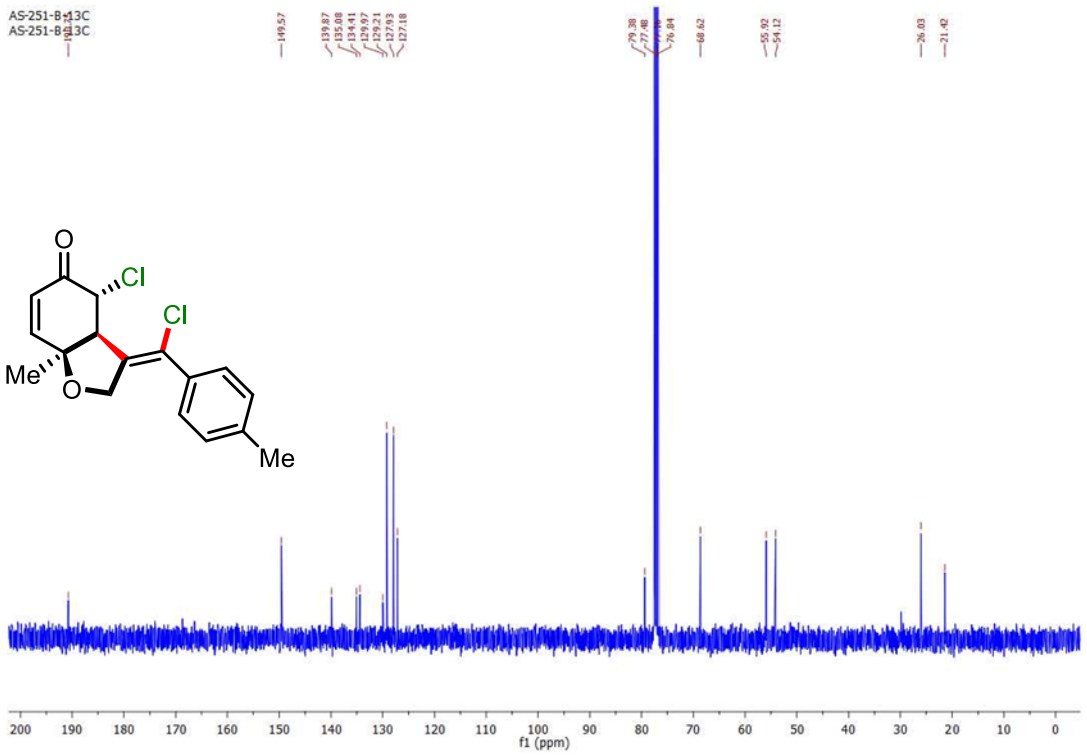
(E)-3-((4-acetylphenyl)chloromethylene)-4-chloro-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one





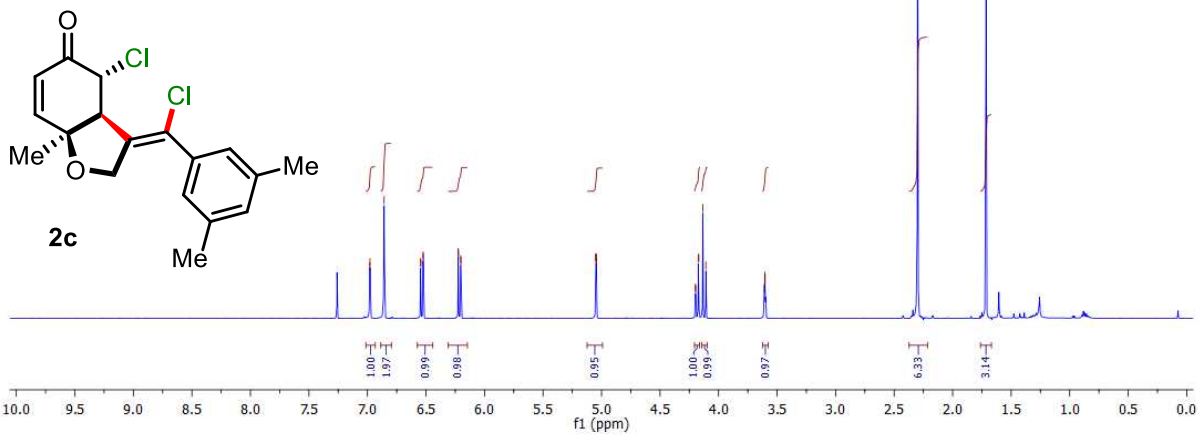
(E)-4-chloro-3-(chloro(p-tolyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one



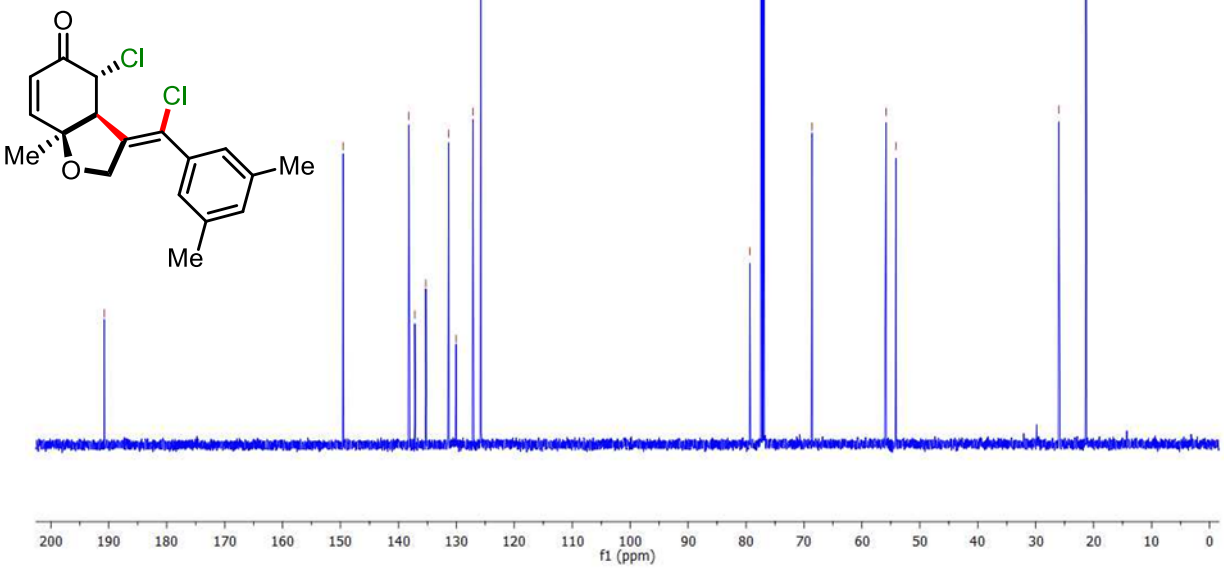


CMRV-RS-699-1H
CMRV-RS-699-1H

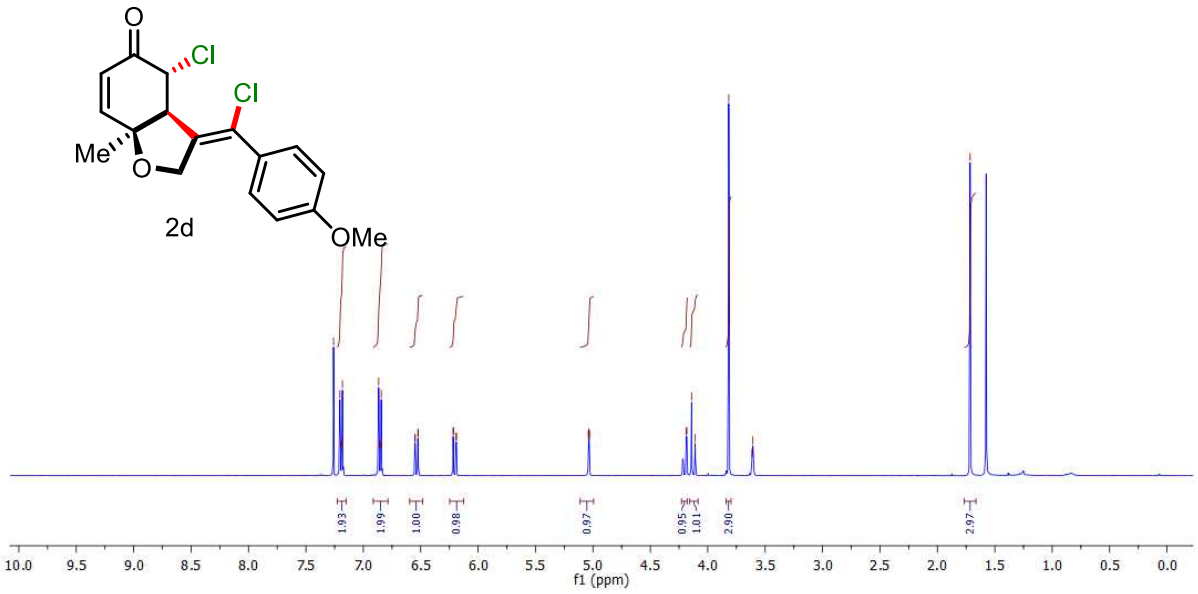
(E)-4-chloro-3-(chloro(3,5-dimethylphenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one

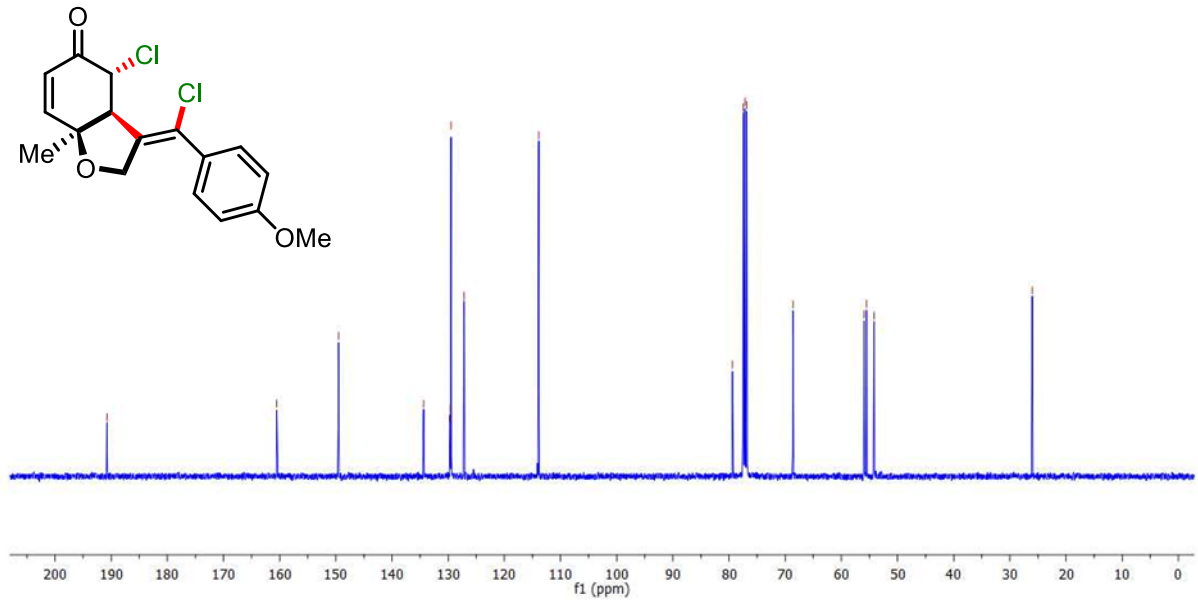


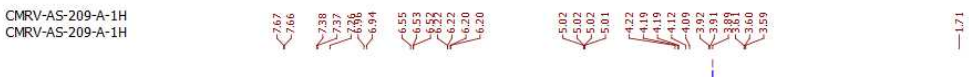
CMRV-RS-699-13C
CMRV-RS-699-13C



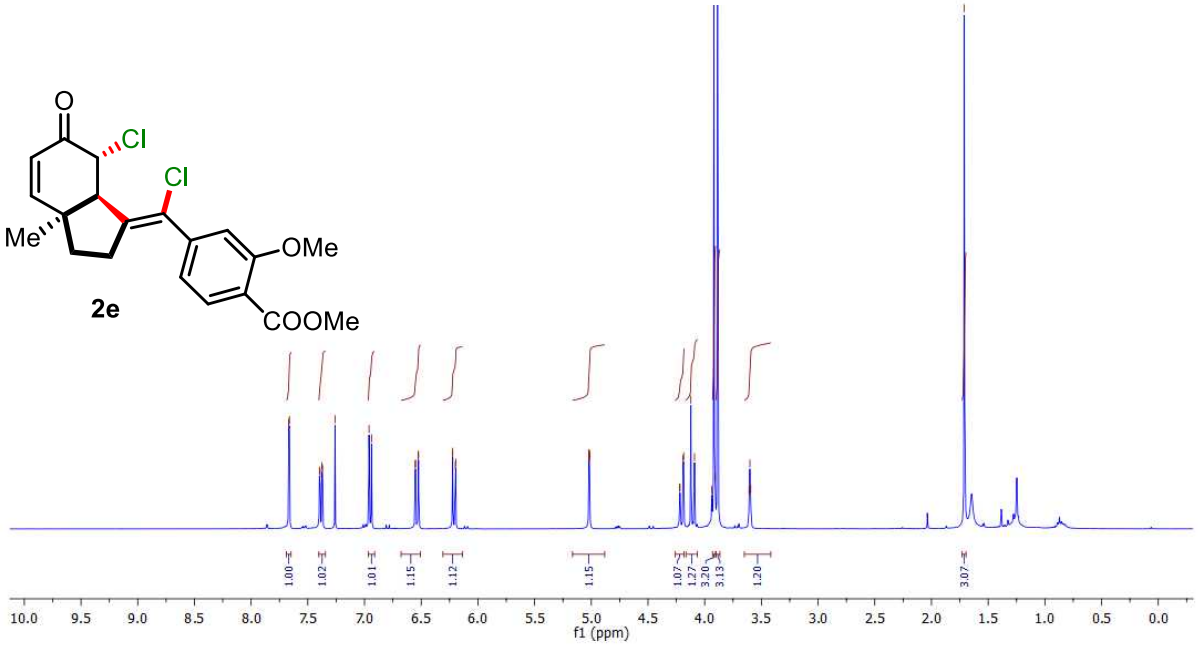
(E)-4-chloro-3-(chloro(4-methoxyphenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one

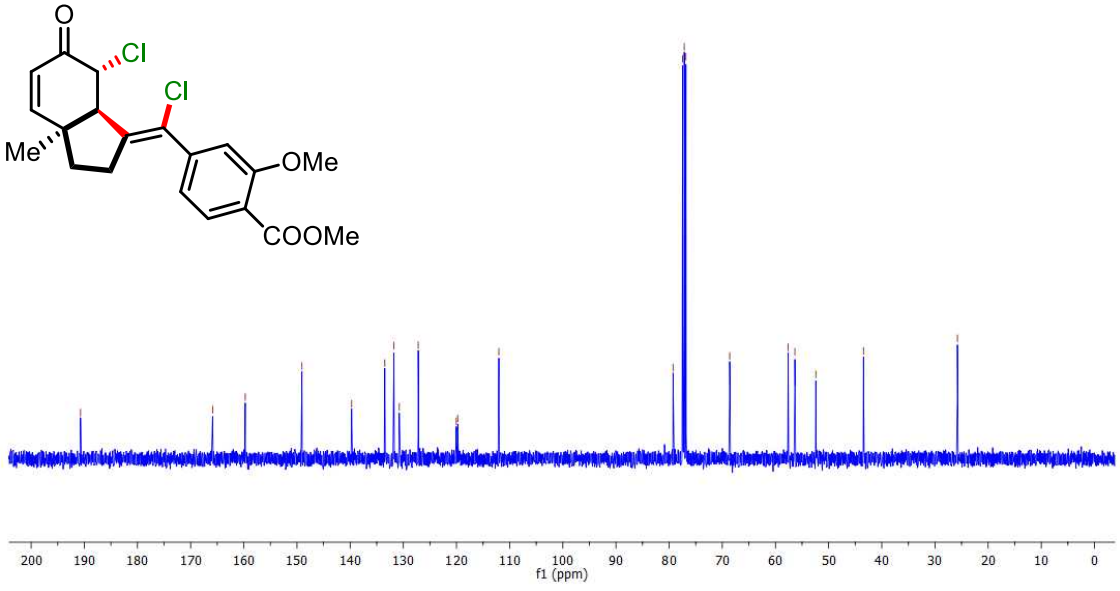


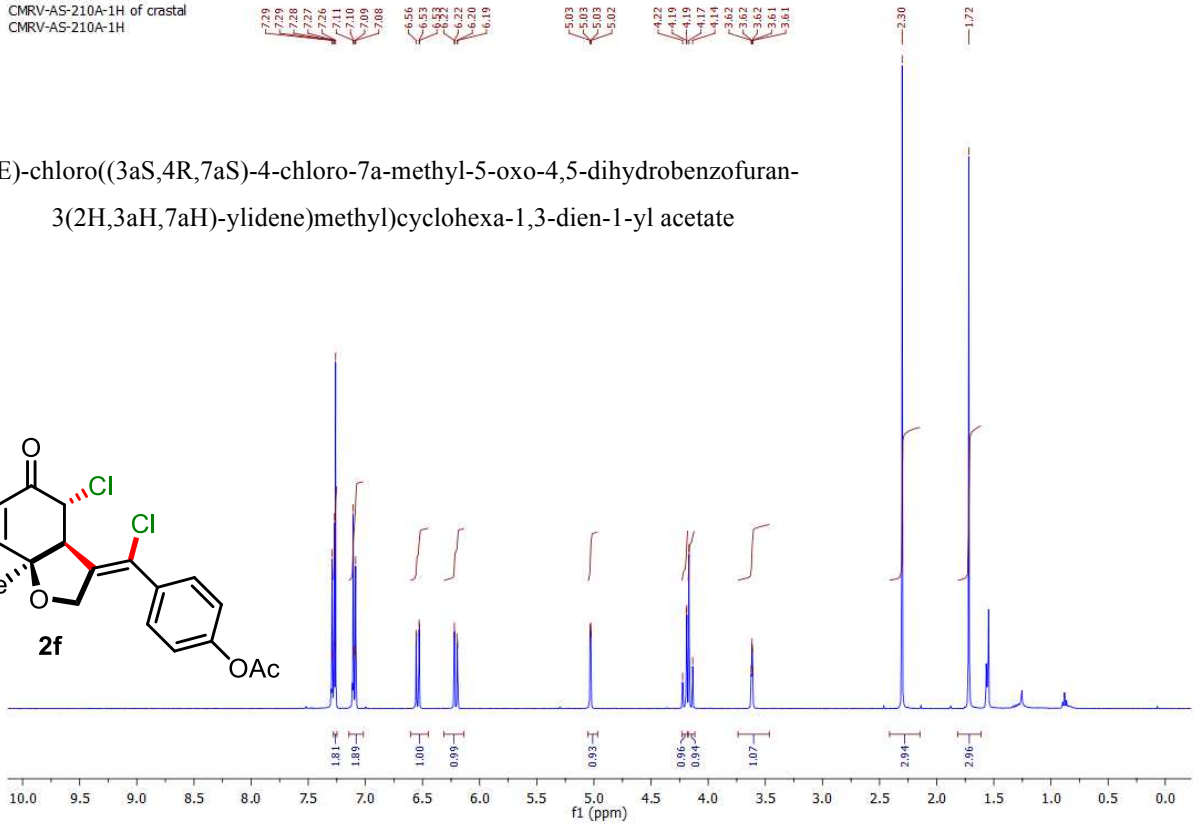




(Z)-methyl 4-(chloro(7-chloro-3a-methyl-6-oxo-2,3,3a,6,7,7a-hexahydro-1H-inden-1-ylidene)methyl)-2-methoxybenzoate

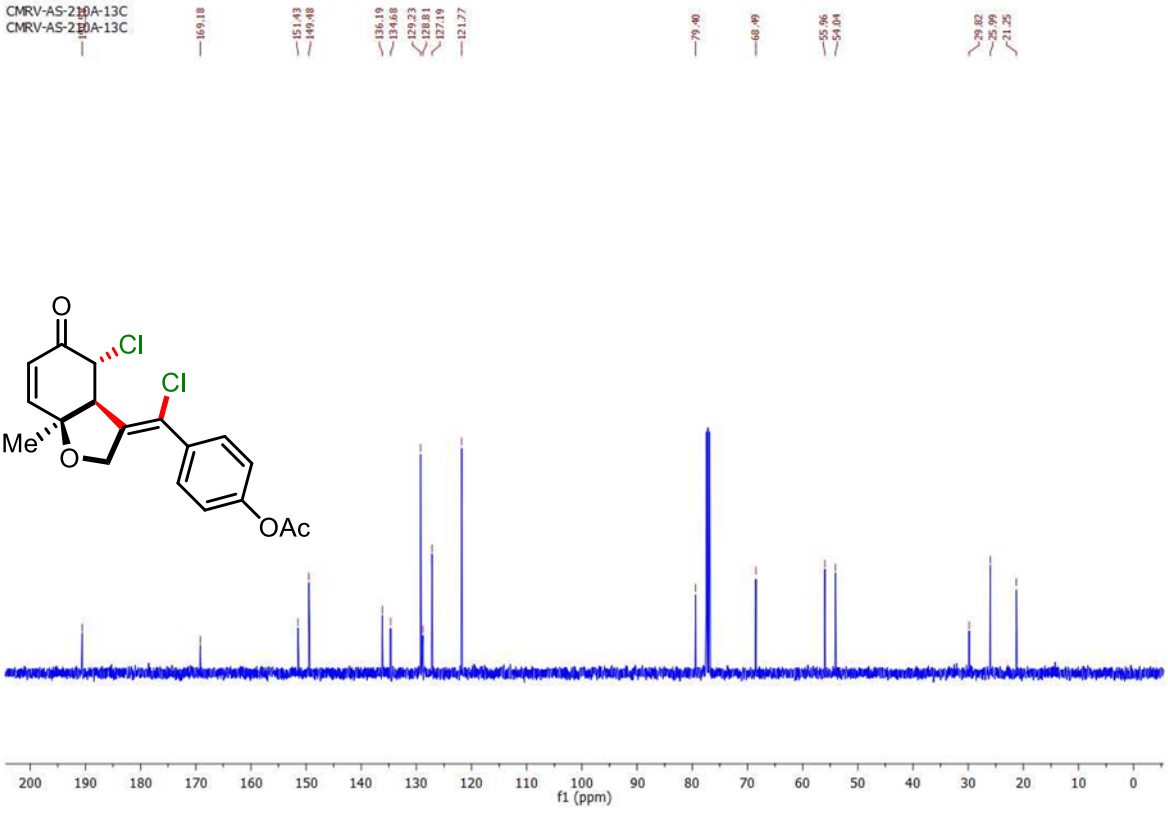






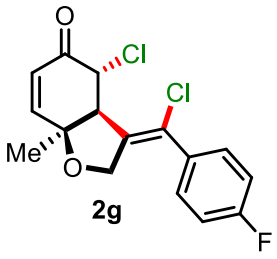
(E)-chloro((3aS,4R,7aS)-4-chloro-7a-methyl-5-oxo-4,5-dihydrobenzofuran-3(2H,3aH,7aH)-ylidene)methyl)cyclohexa-1,3-dien-1-yl acetate

2f



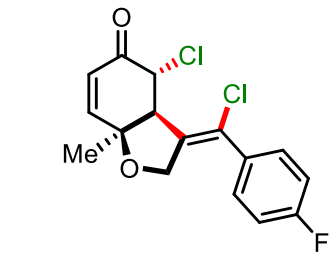
CMRV-AS-533-RE-1H
CMRV-AS-533-RE-1H

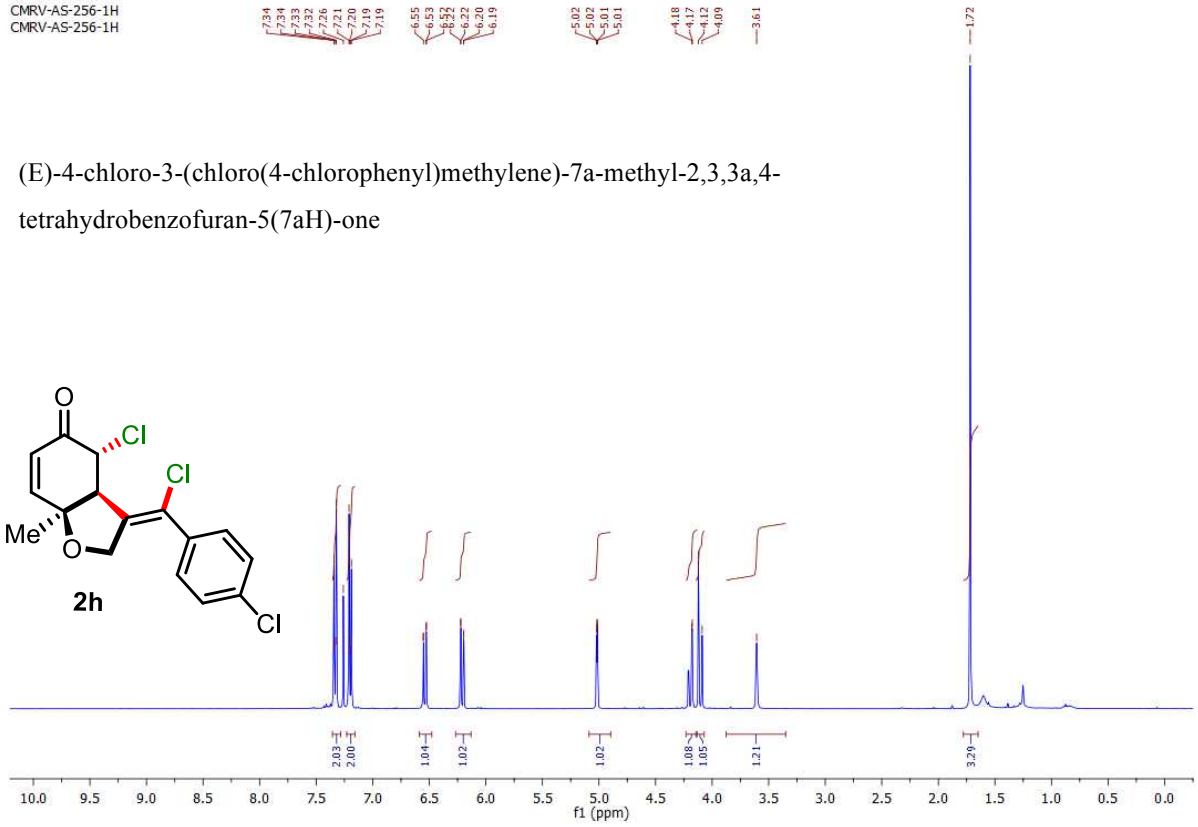
(E)-4-chloro-3-(chloro(4-fluorophenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one



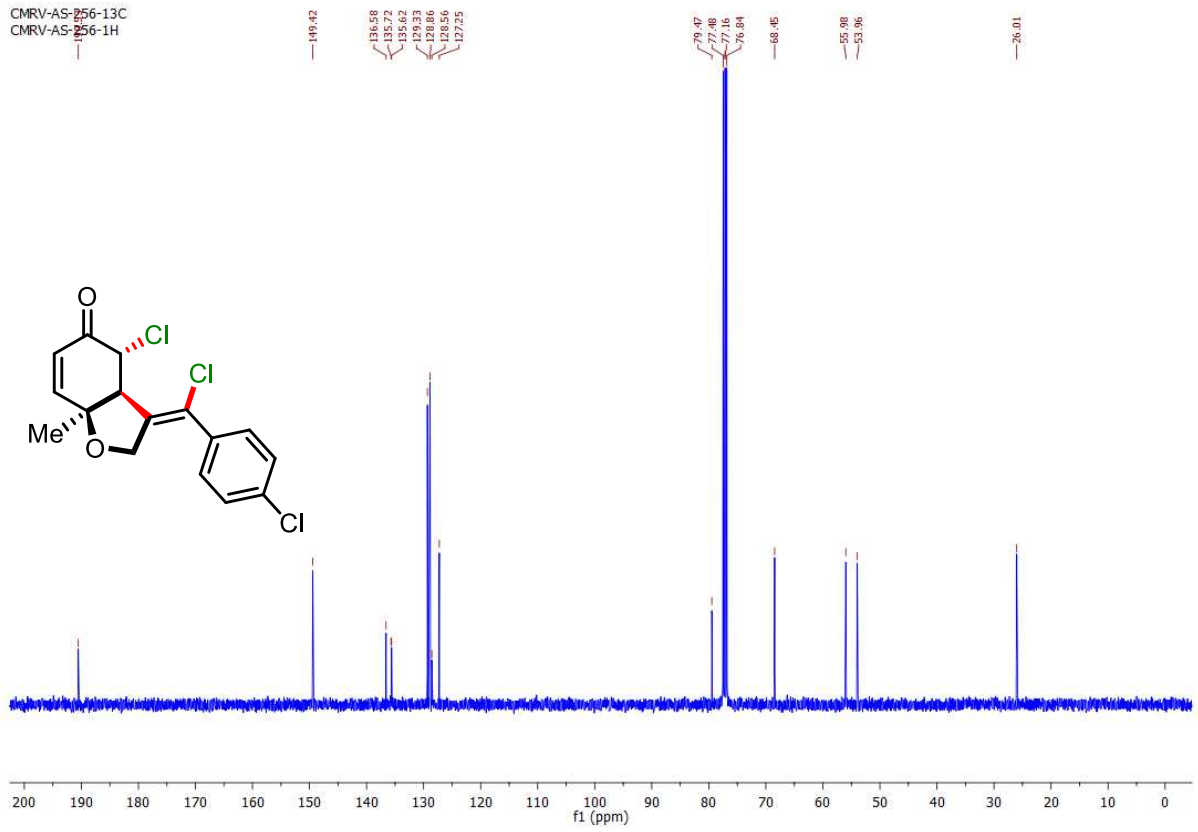
2g

CMRV-AS-533-RE-13C
CMRV-AS-533-RE-13C

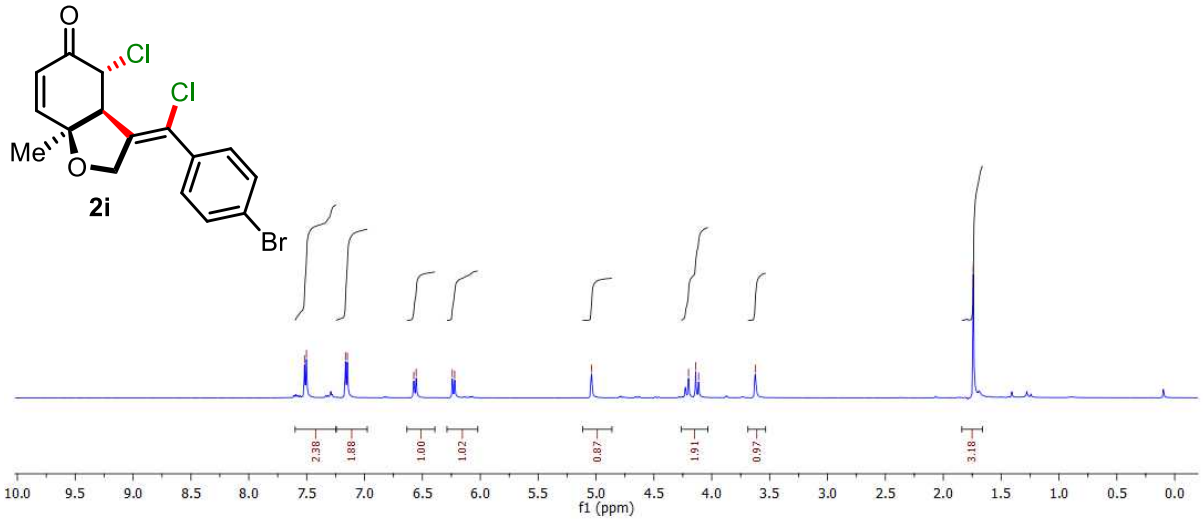


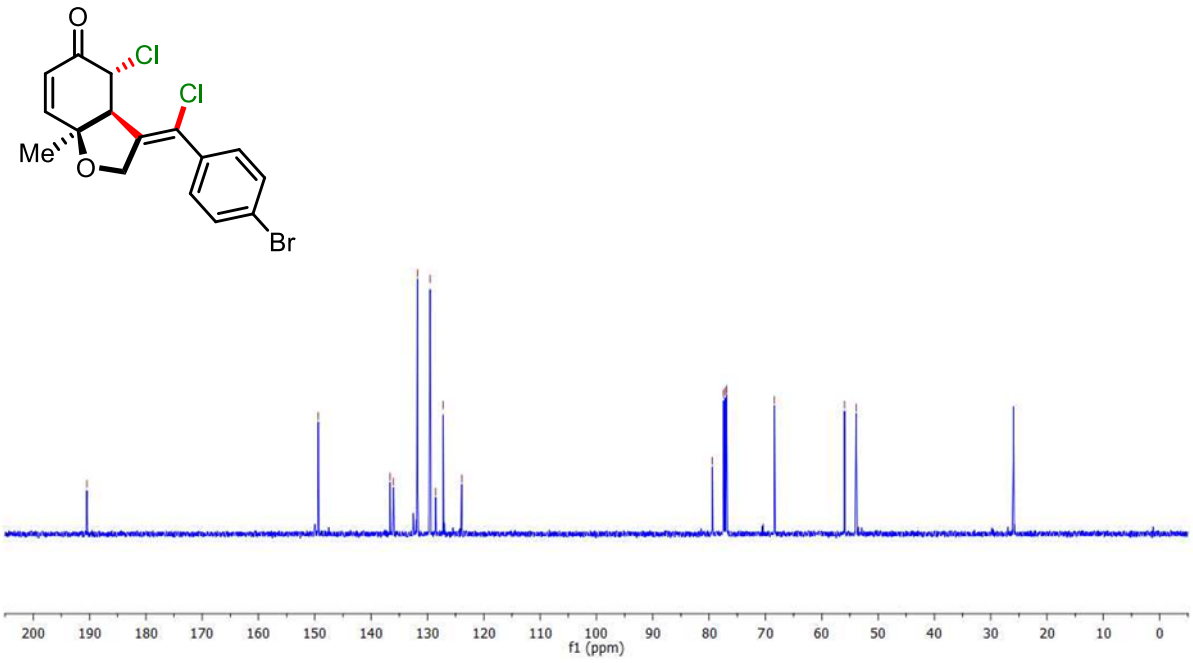


(E)-4-chloro-3-(chloro(4-chlorophenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one

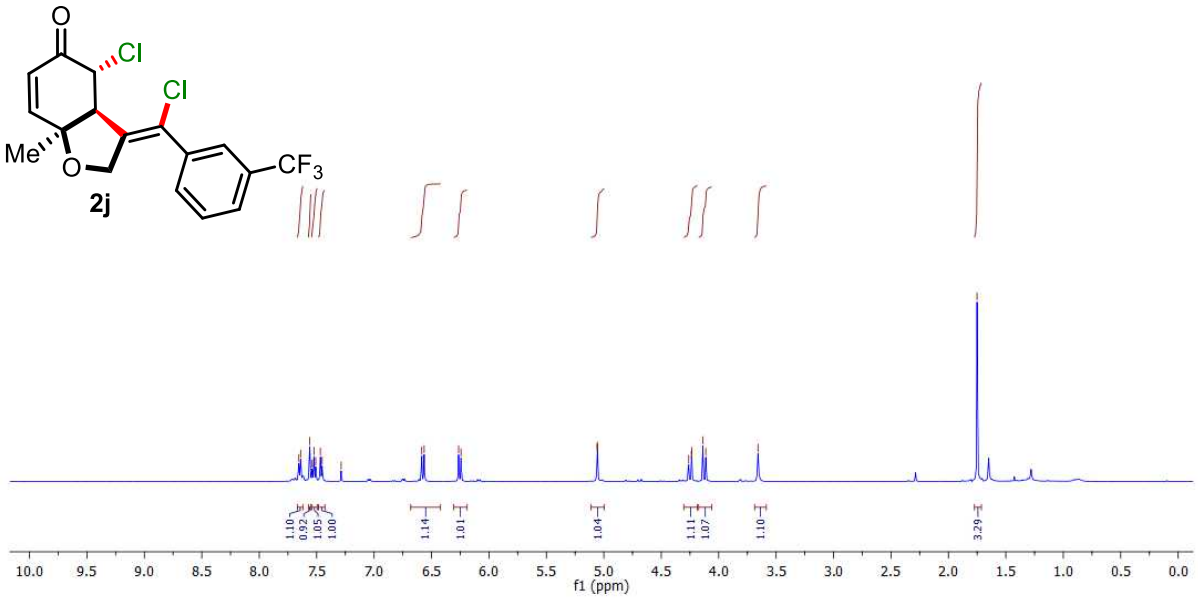


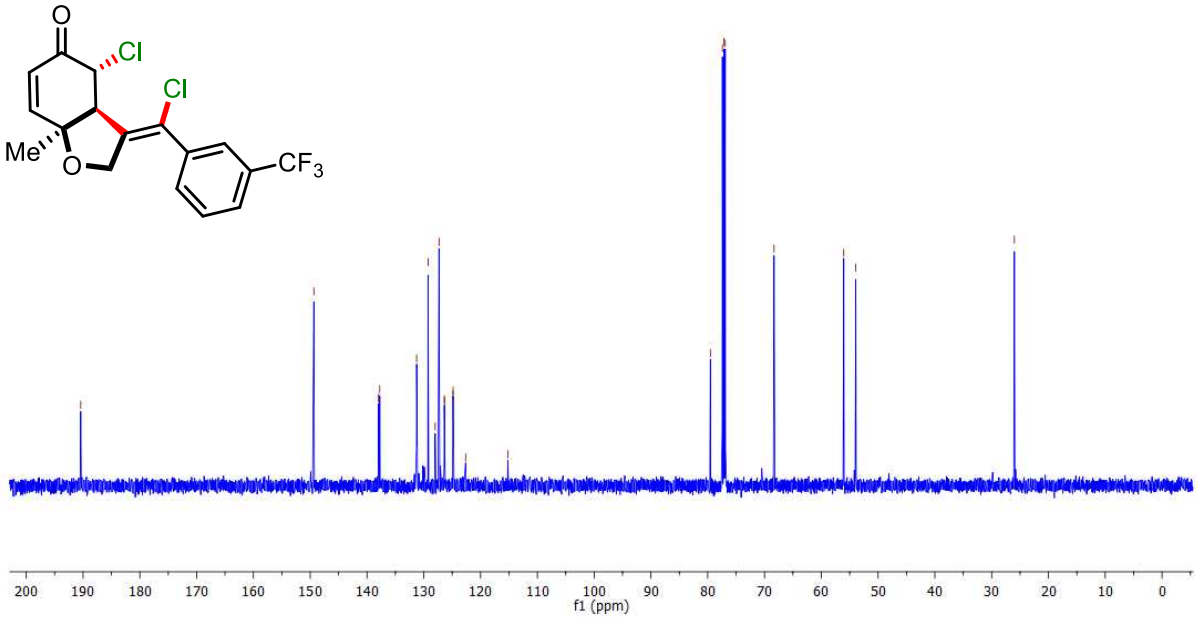
(3aS,4R,7aS,E)-3-((4-bromophenyl)chloromethylene)-4-chloro-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one

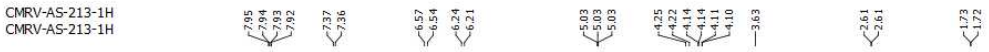




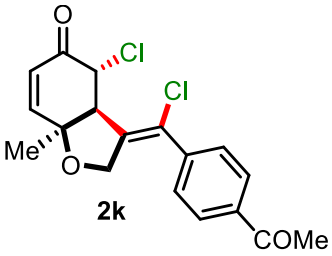
(E)-4-chloro-3-(chloro(3-(trifluoromethyl)phenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one



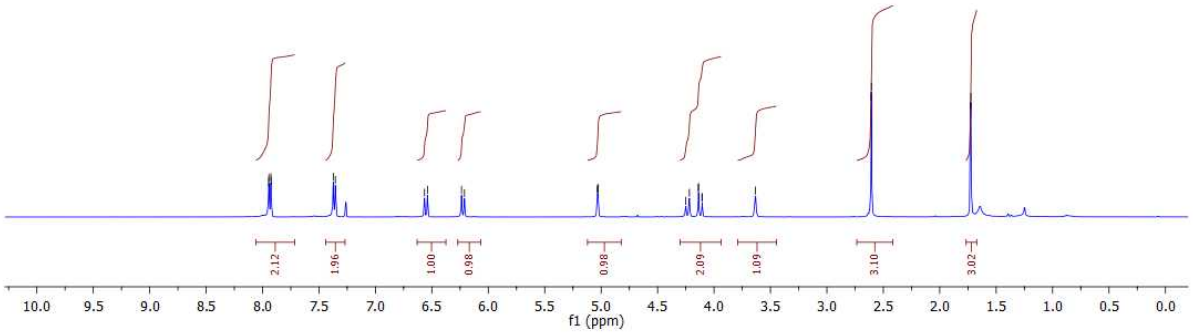


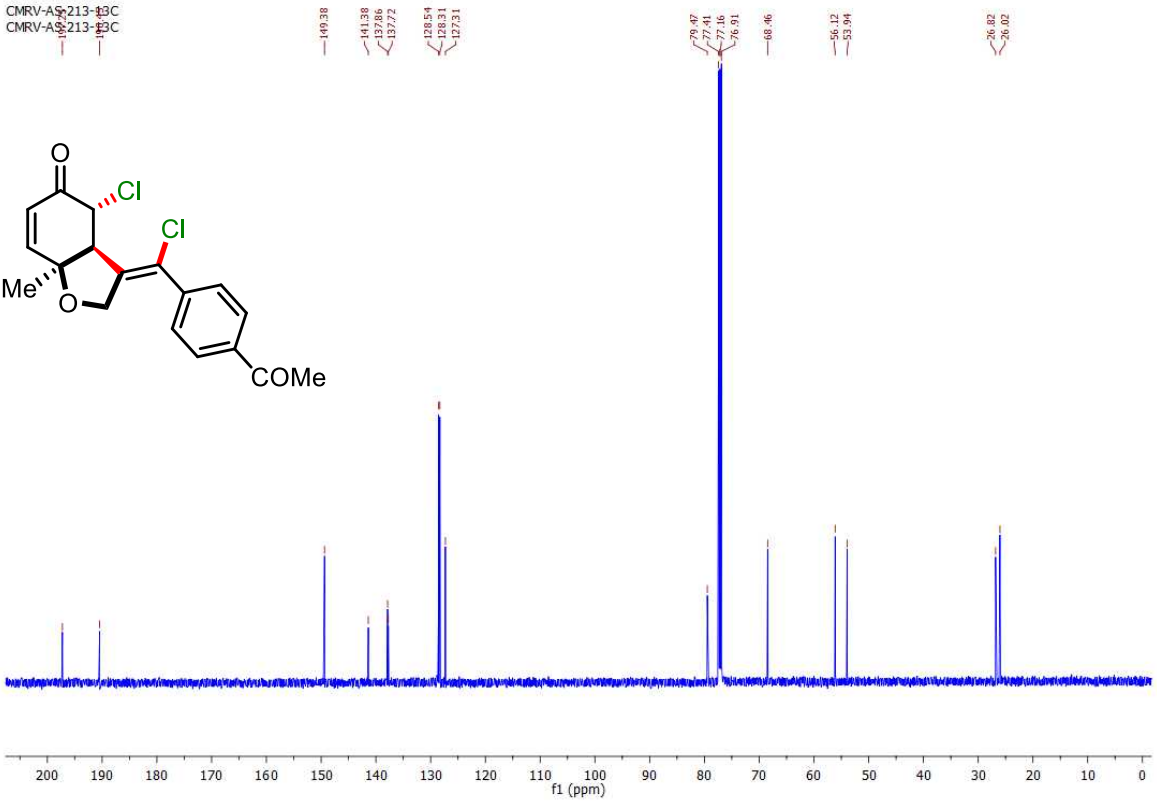


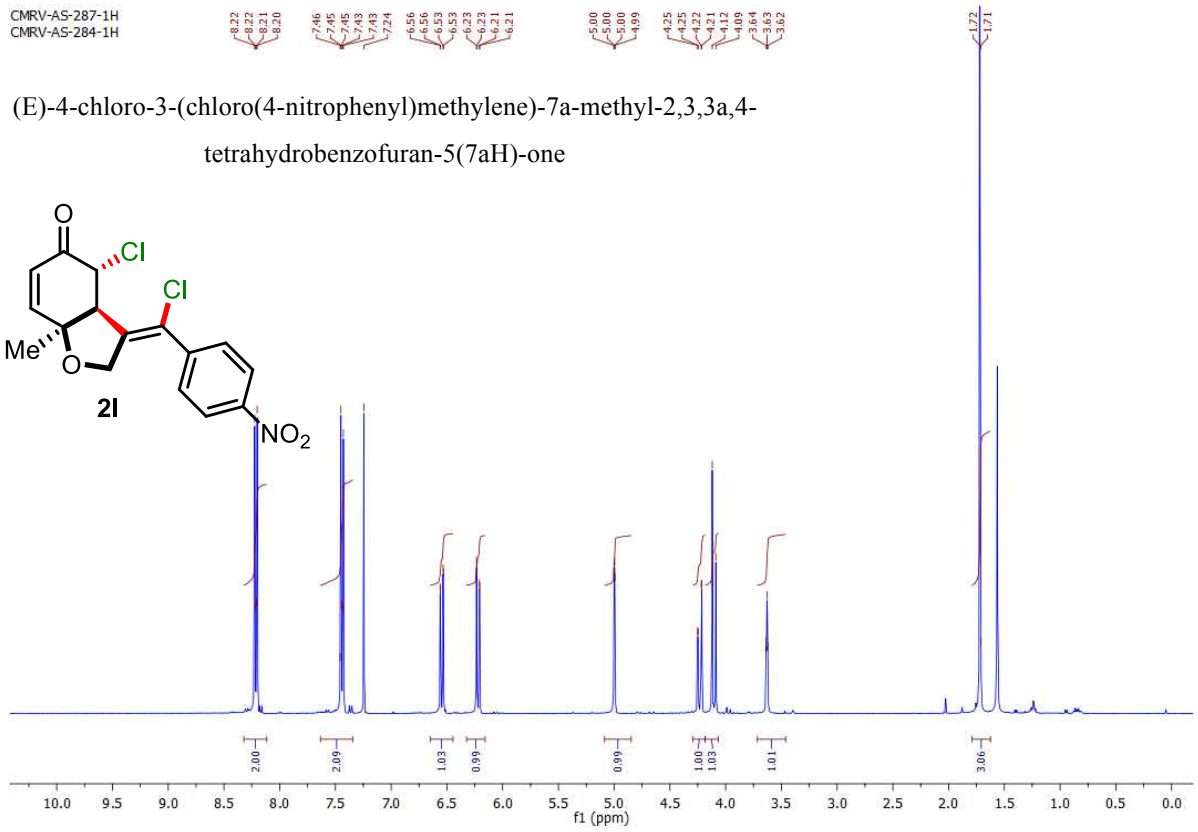
(E)-3-((4-acetylphenyl)chloromethylene)-4-chloro-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one



2k

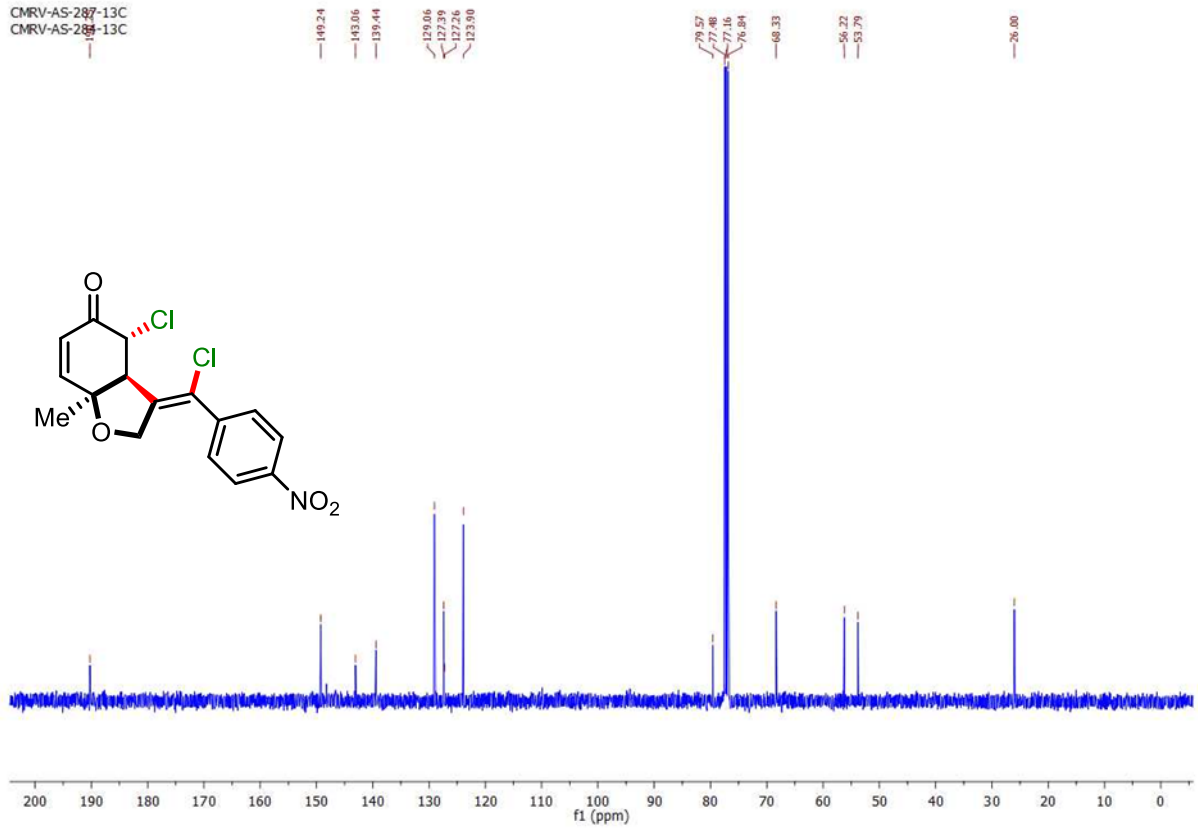




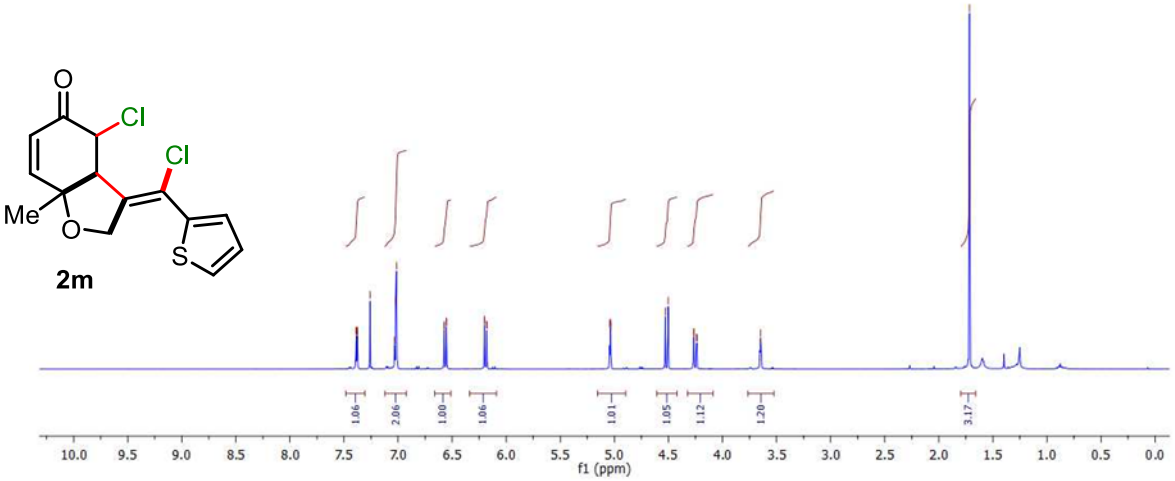


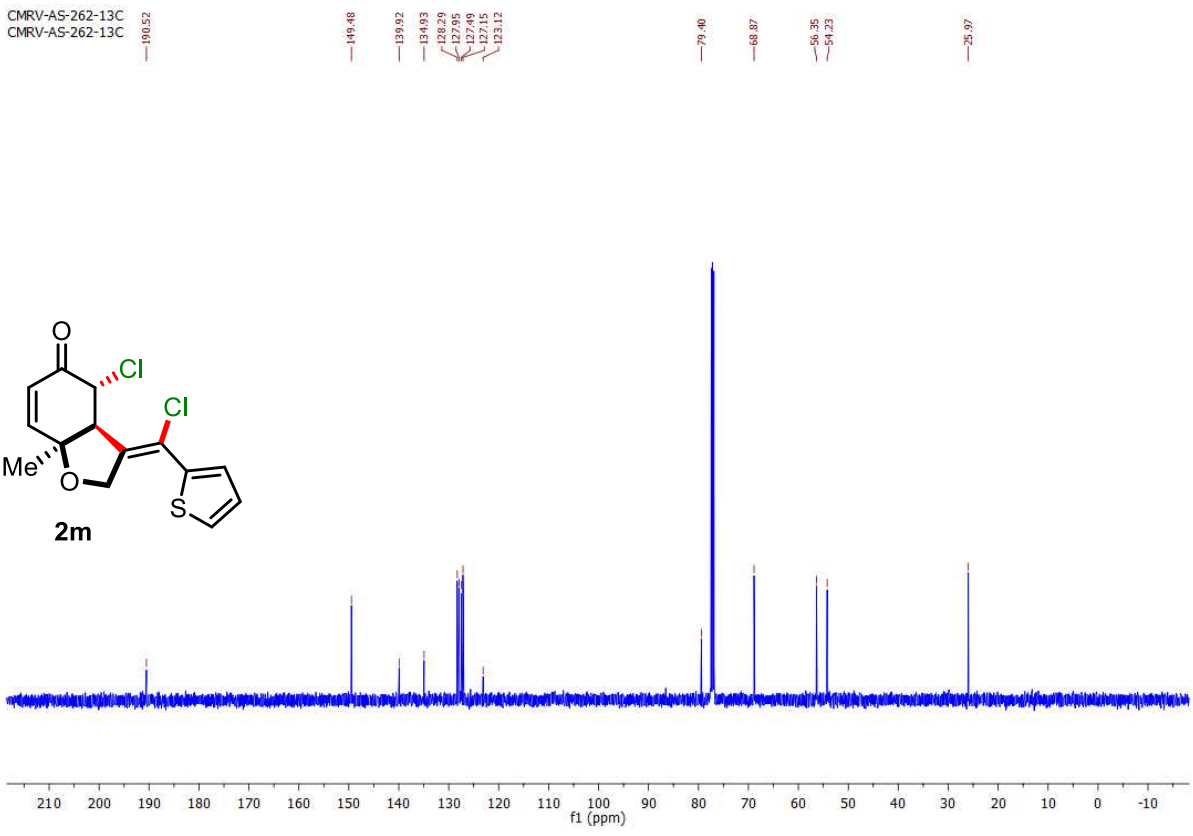
(E)-4-chloro-3-(chloro(4-nitrophenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one

2l

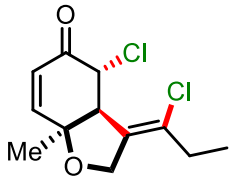


(E)-4-chloro-3-(chloro(thiophen-2-yl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one

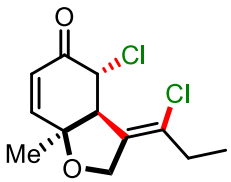




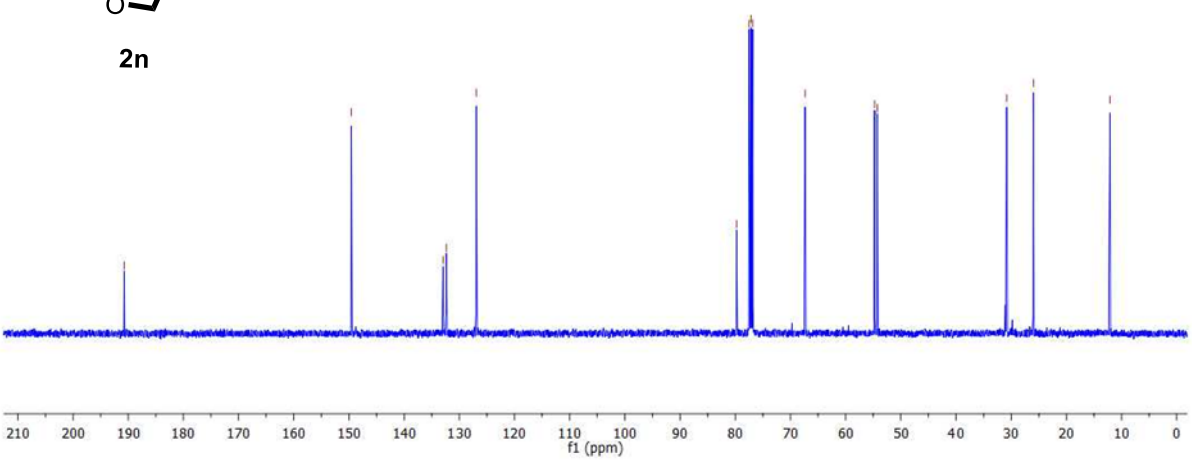
(E)-4-chloro-3-(1-chloropropylidene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one



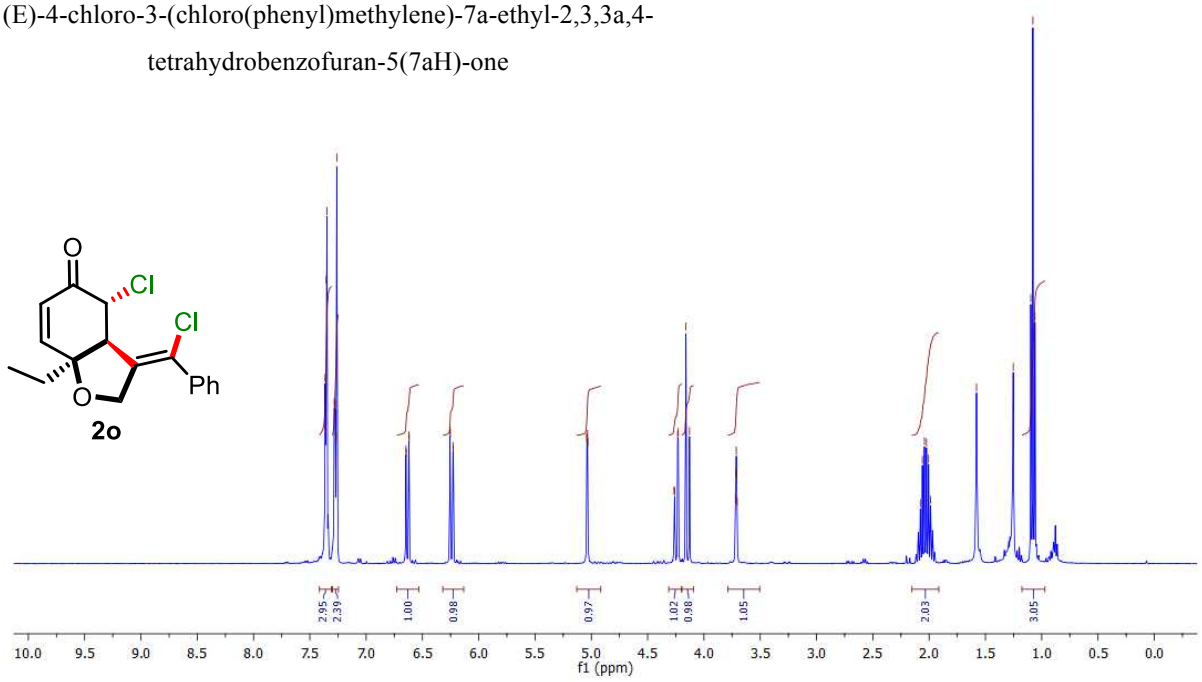
2n

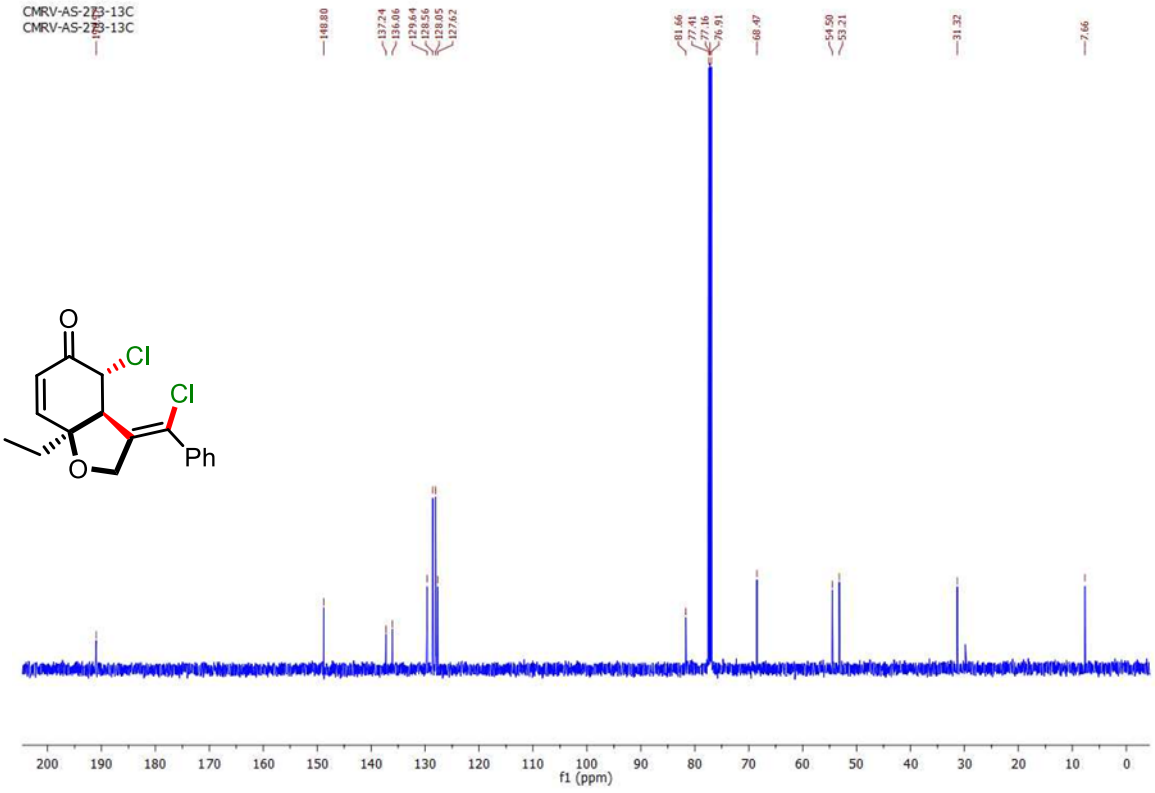


2n



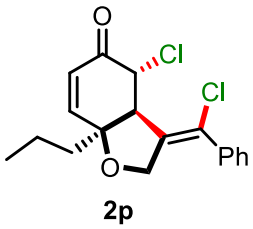
(E)-4-chloro-3-(chloro(phenyl)methylene)-7a-ethyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one





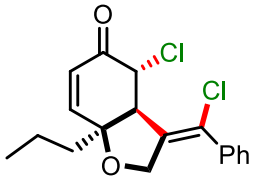
CMRV-AS-525-13C
CMRV-AS-525-13C

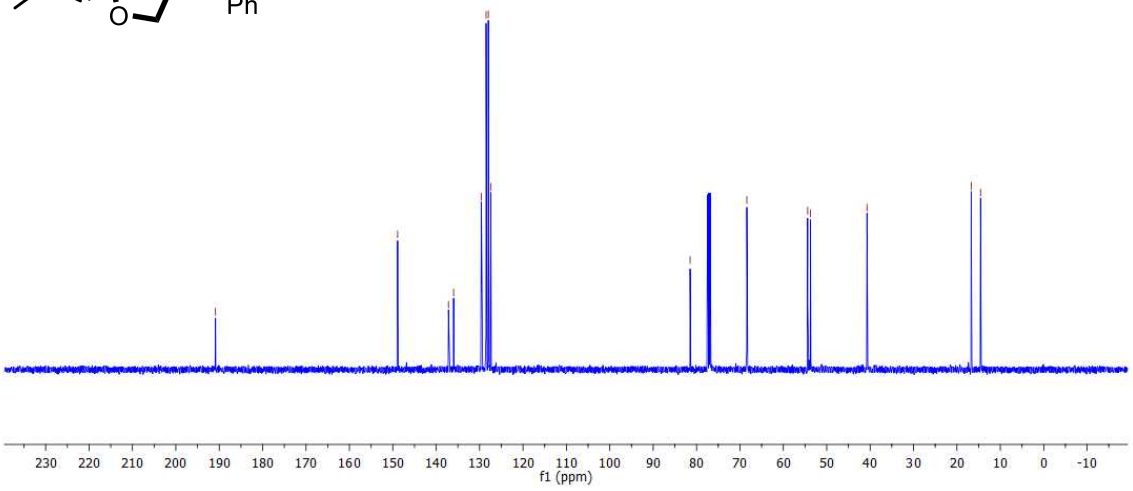
(E)-4-chloro-3-(chloro(phenyl)methylene)-7a-propyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one

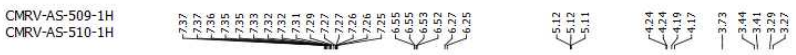


2p

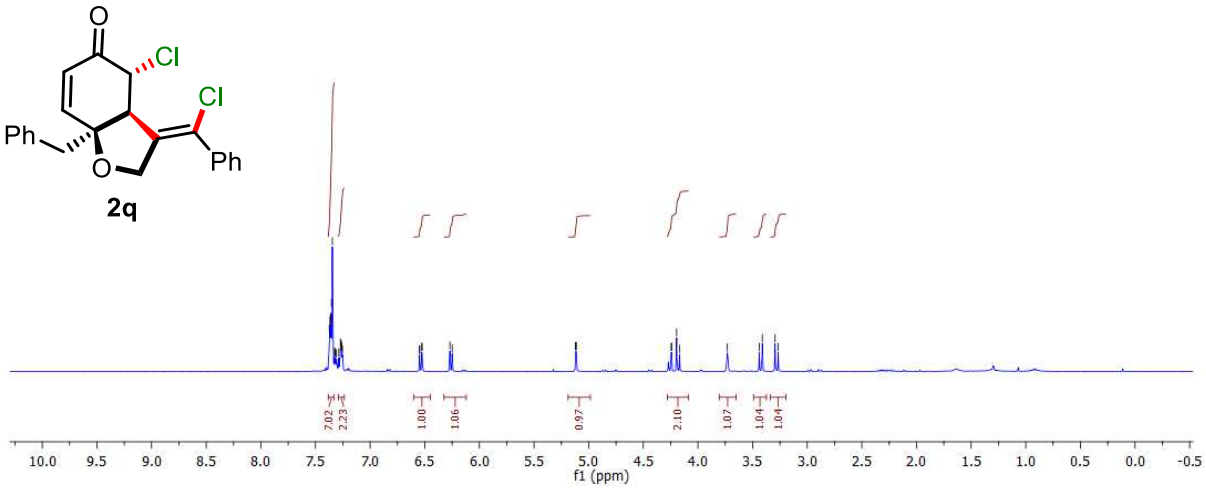
CMRV-AS-525-13C-RE
CMRV-AS-525-13C-RE

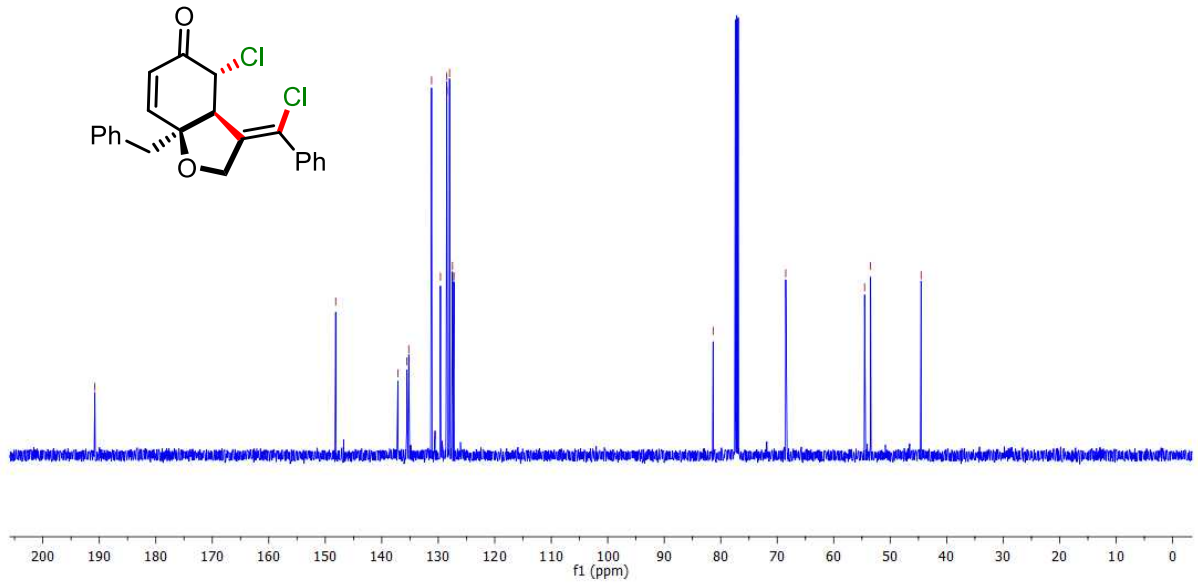




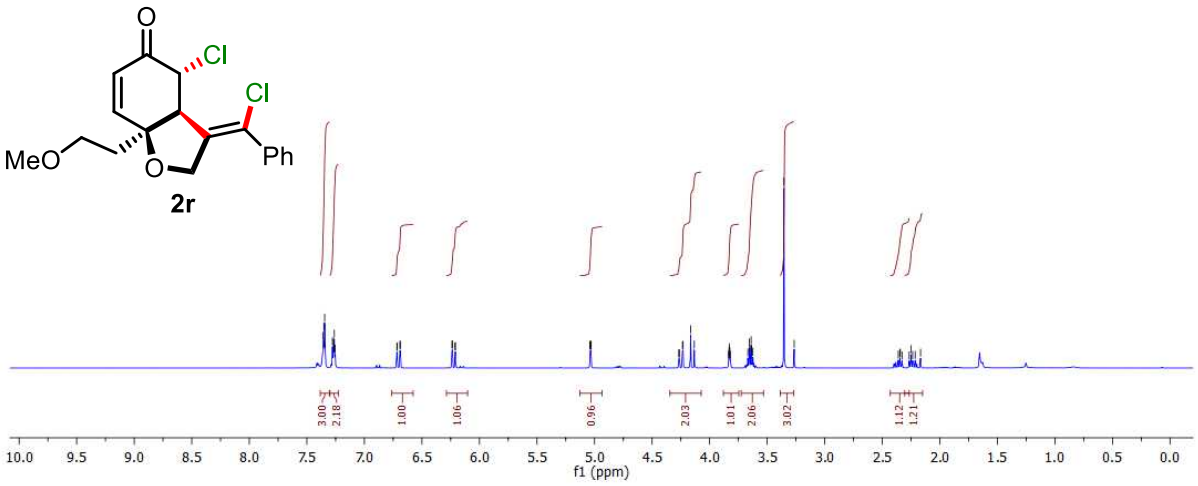


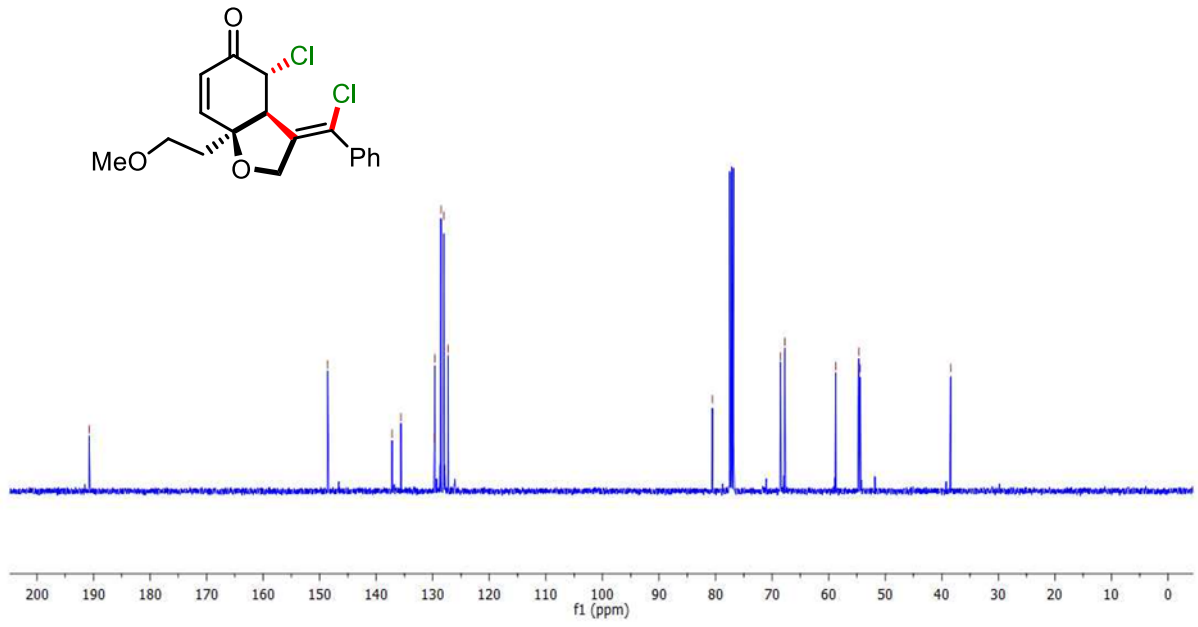
(E)-7a-benzyl-4-chloro-3-(chloro(phenyl)methylene)-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one



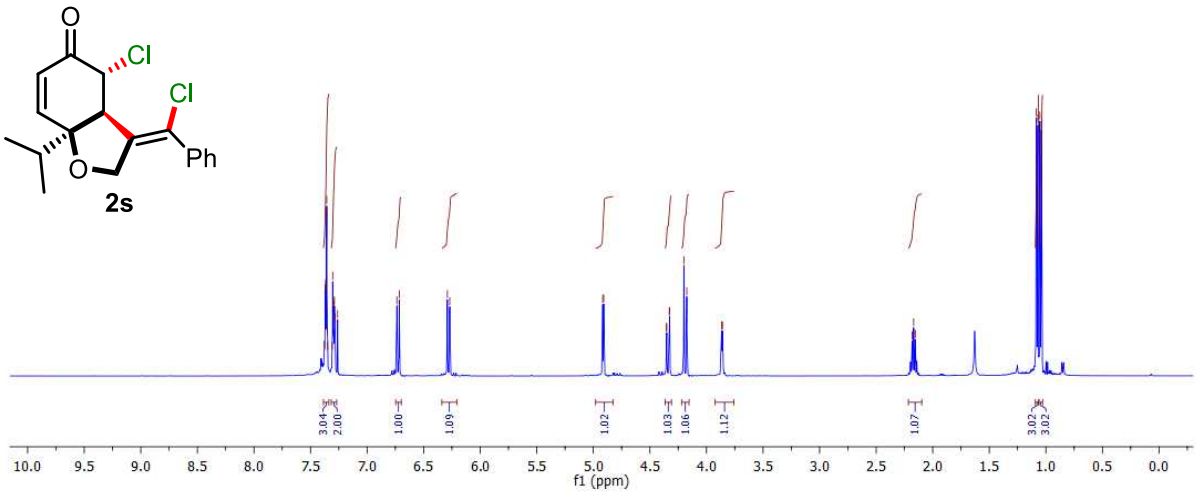


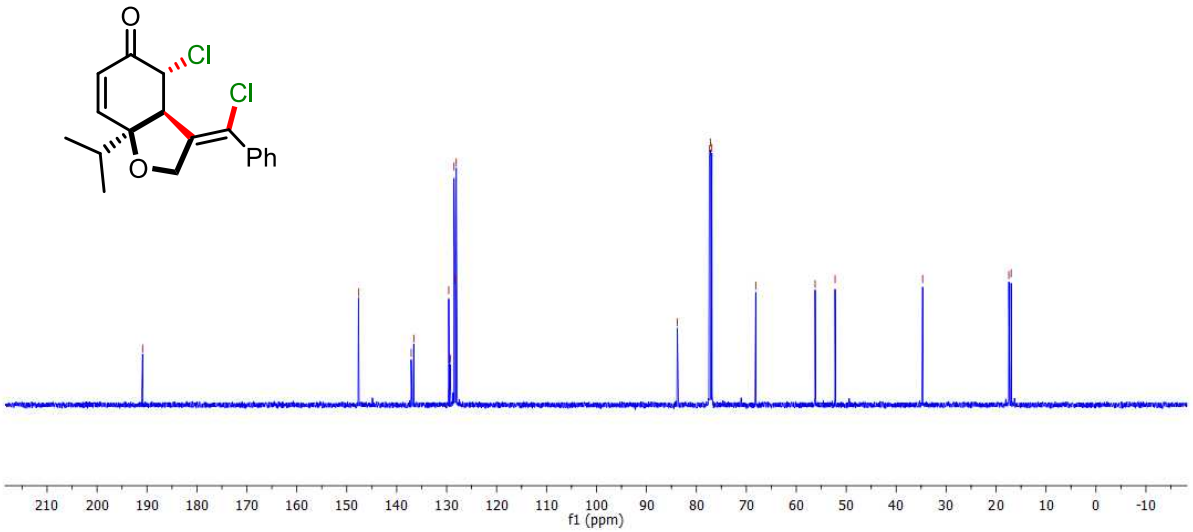
(E)-4-chloro-3-(chloro(phenyl)methylene)-7a-(2-methoxyethyl)-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one



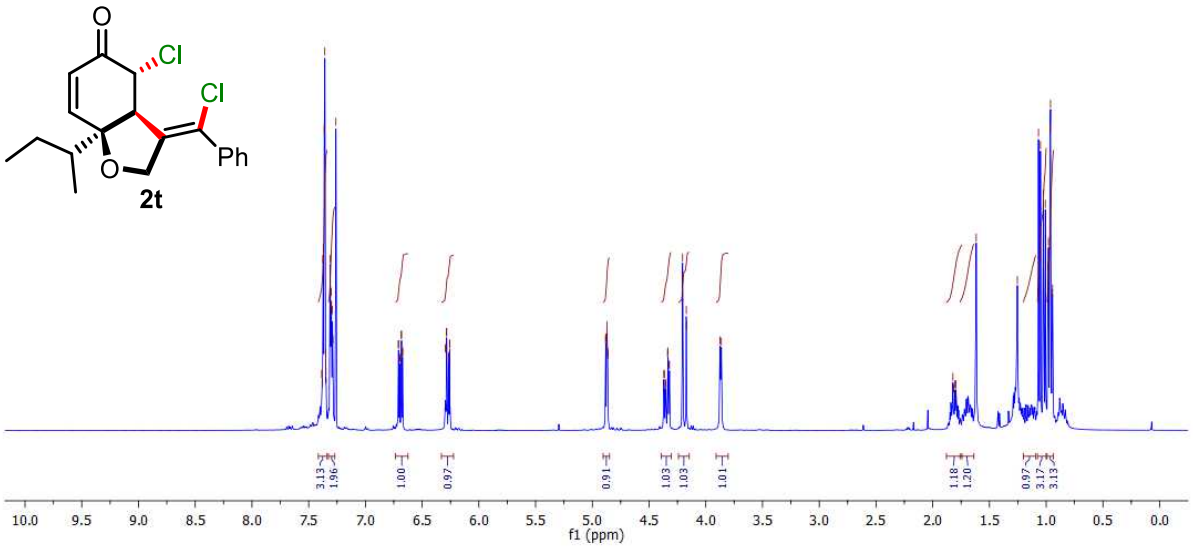


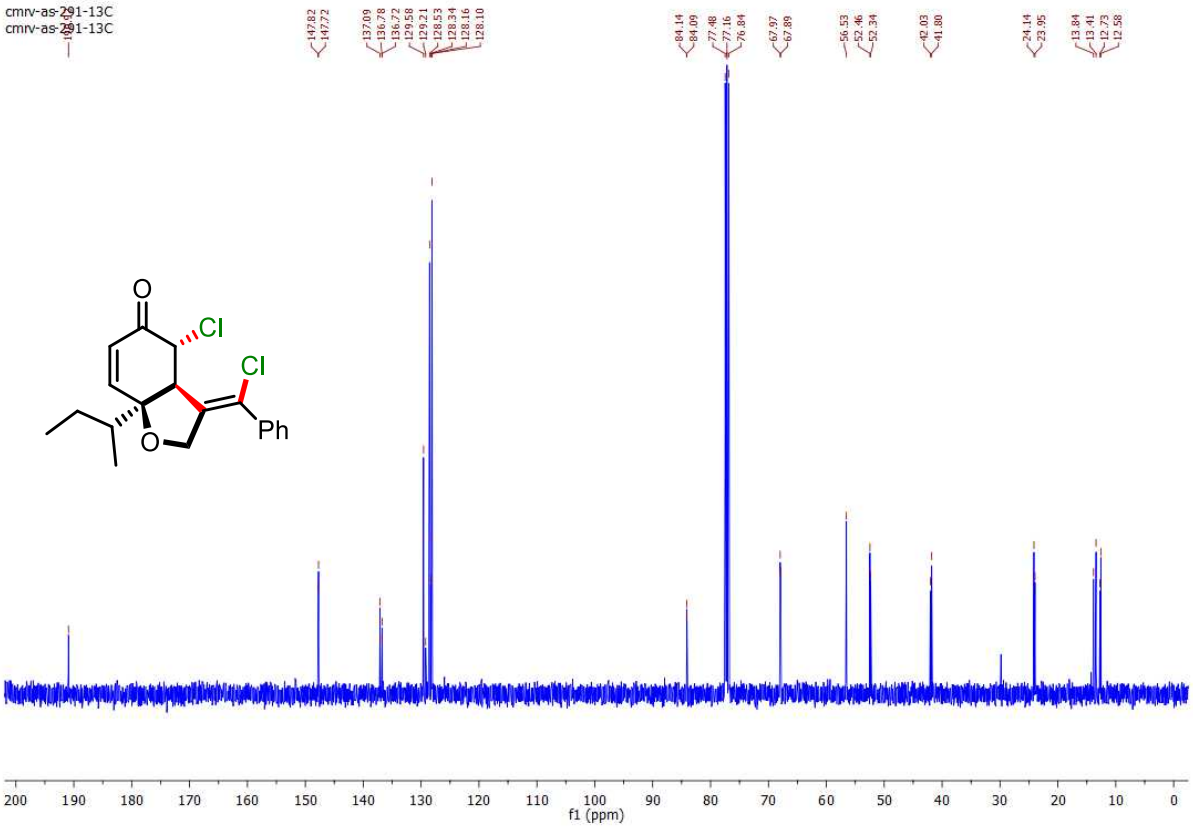
(E)-4-chloro-3-(chloro(phenyl)methylene)-7a-isopropyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one





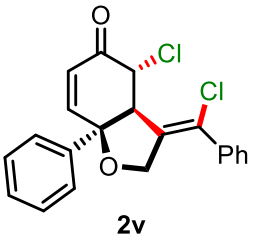
(E)-7a-((S)-sec-butyl)-4-chloro-3-(chloro(phenyl)methylene)-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one





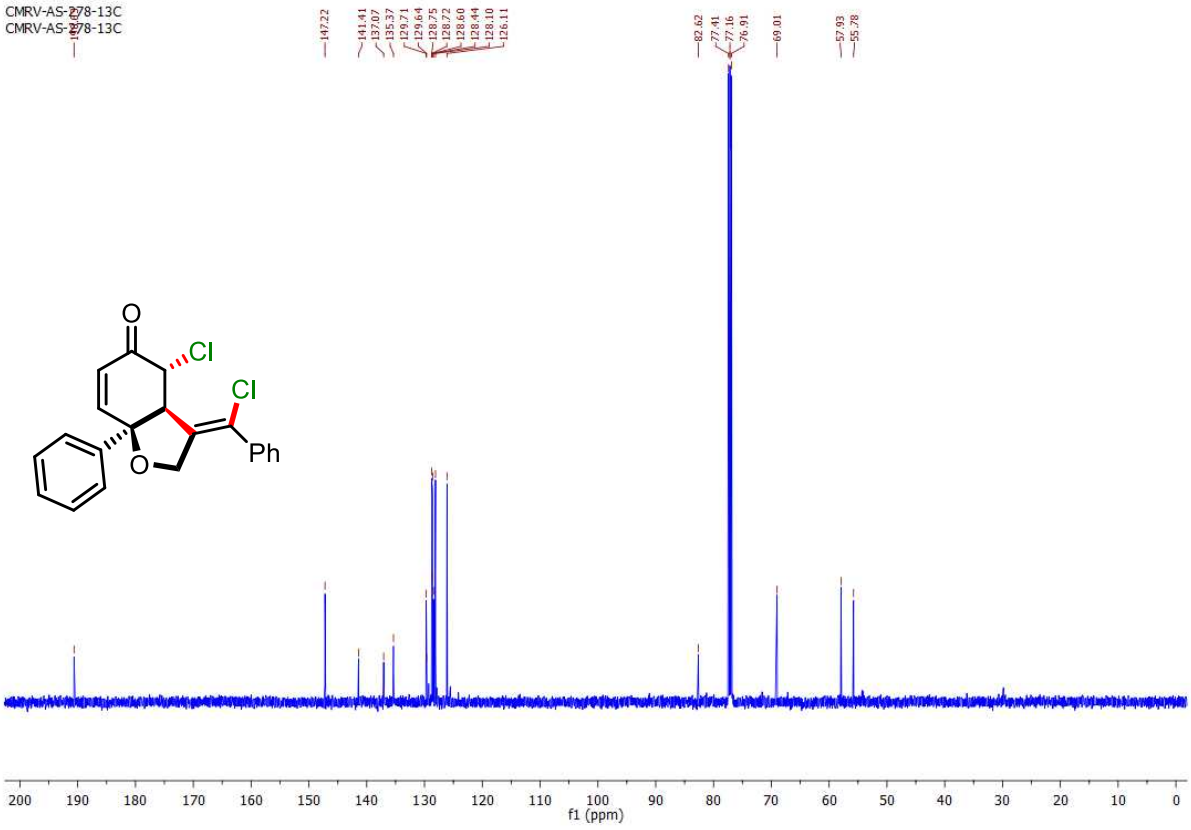
CMRV-AS-278-1H
CMRV-AS-278-1H

(E)-4-chloro-3-(chloro(phenyl)methylene)-7a-phenyl-2,3,3a,7a-tetrahydrobenzofuran-5(4H)-one



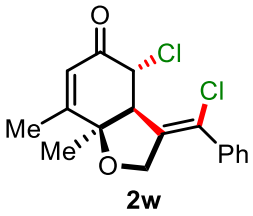
2v

CMRV-AS-278-13C
CMRV-AS-278-13C

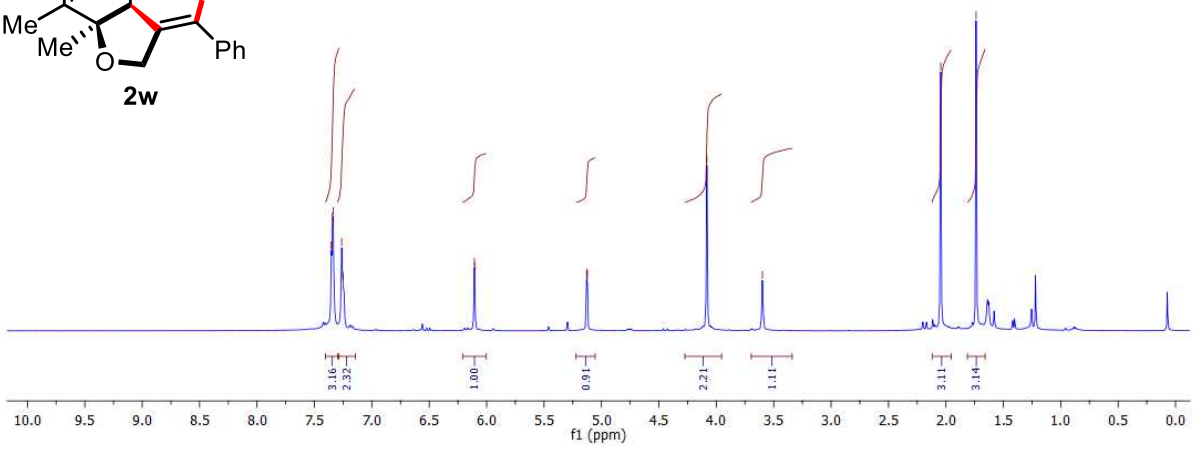


CMRV-AS-540-1H
CMRV-AS-540-1H

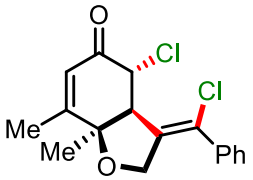
(3aS,4R,7aR,E)-4-chloro-3-(chloro(phenyl)methylene)-7,7a-dimethyl-2,3,3a,7a-tetrahydrobenzofuran-5(4H)-one

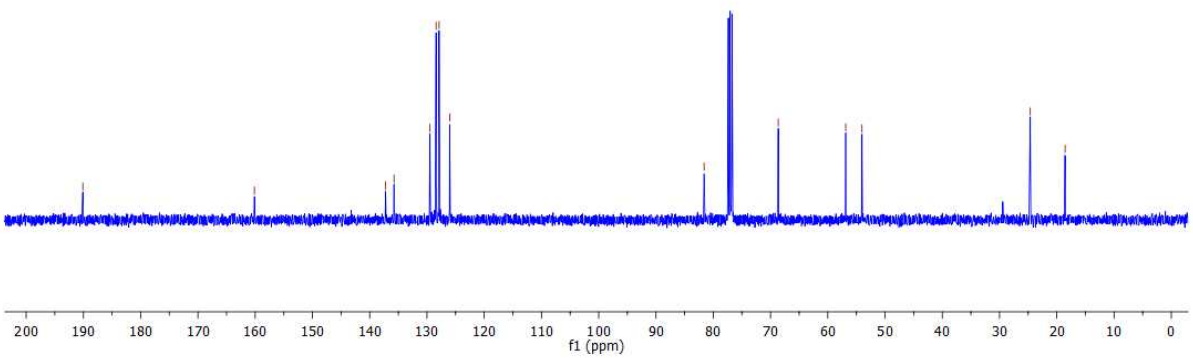


2w

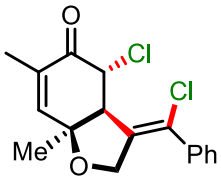


CMRV-AS-540-13C
CMRV-AS-540-13C

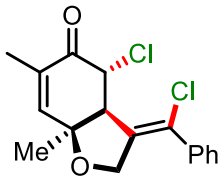


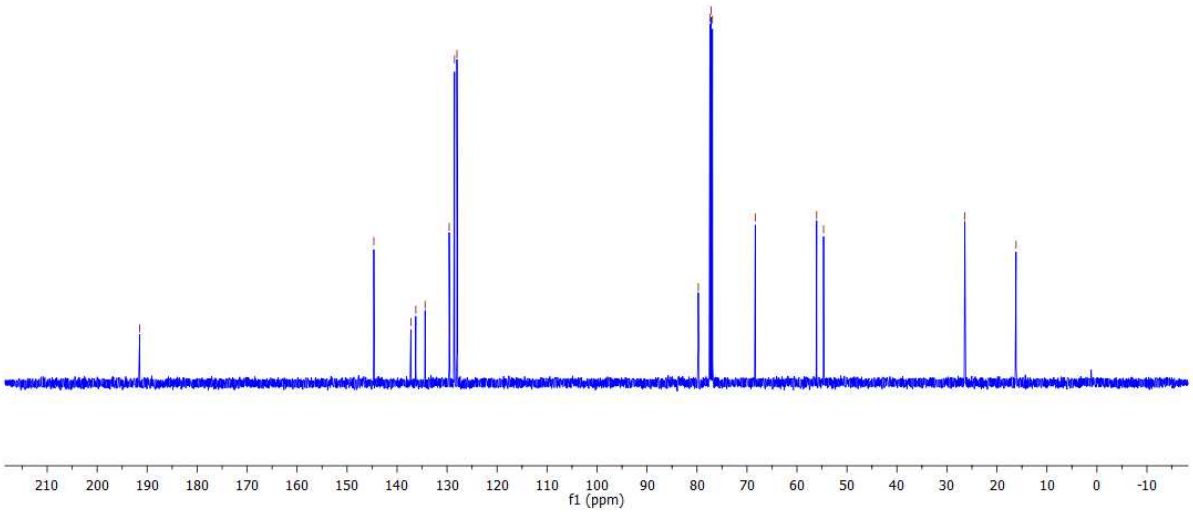


CMRV-AS-559-1H
CMRV-AS-559-1H

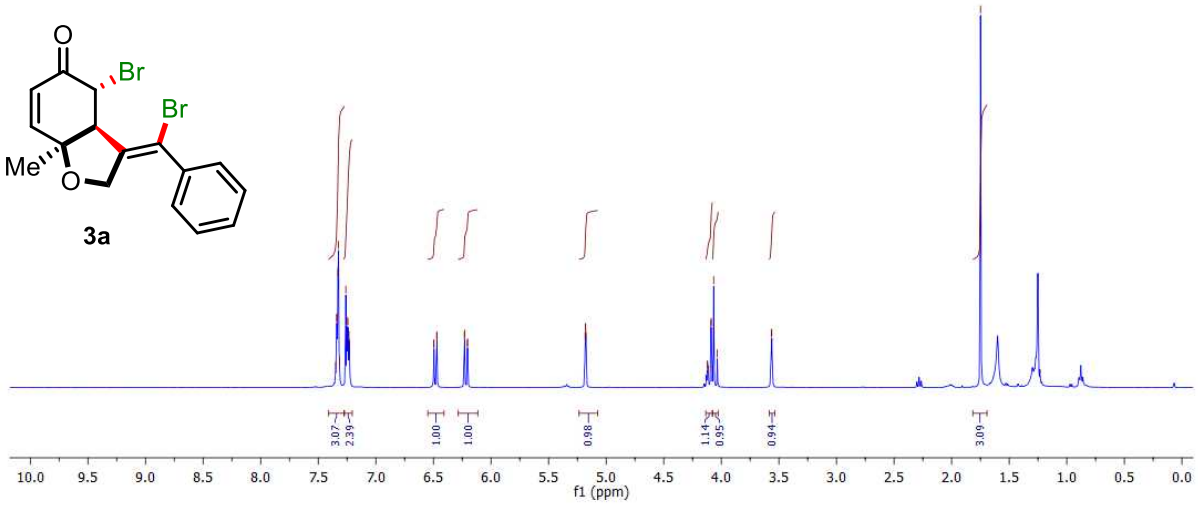


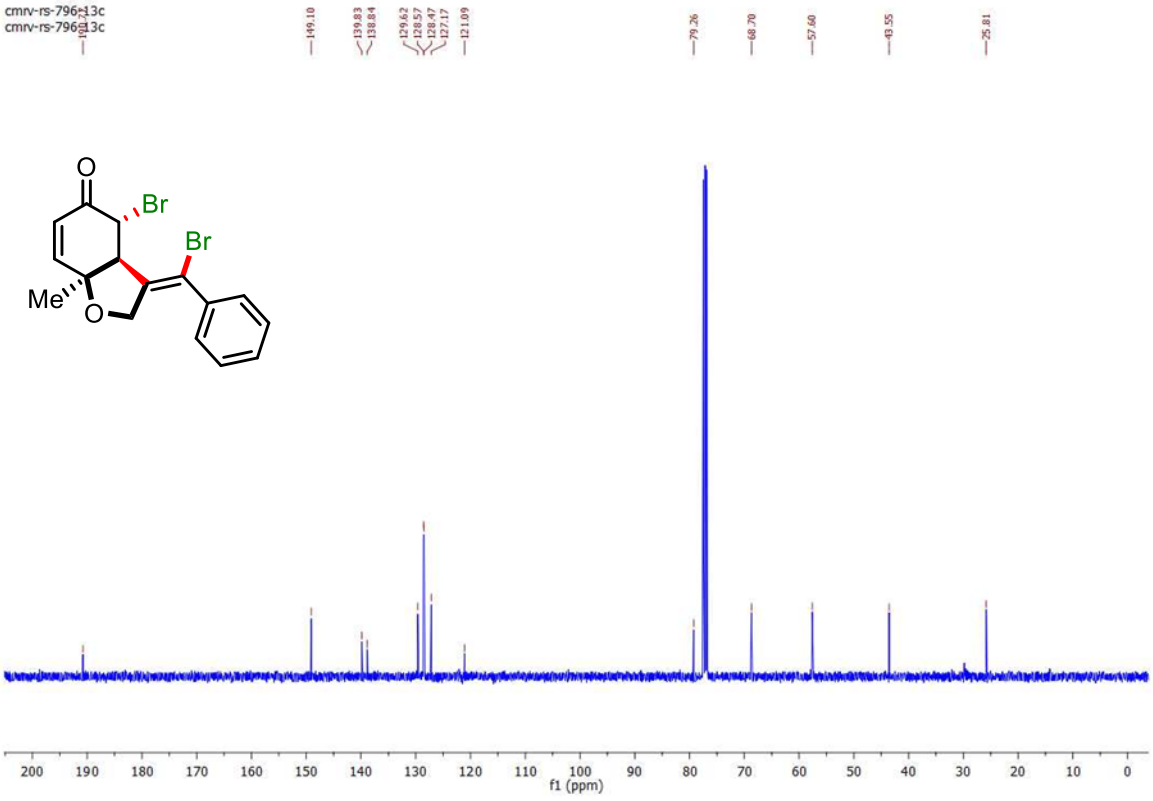
CMRV-AS-559-13C
CMRV-AS-559-13C





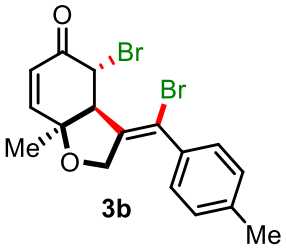
(E)-4-bromo-3-(bromo(phenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one





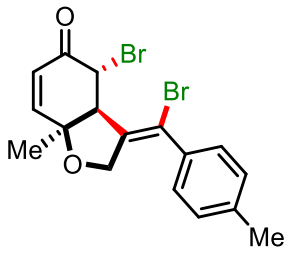
CMRV-AS-252-1H
CMRV-AS-252-1H

(E)-4-bromo-3-(bromo(p-tolyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one

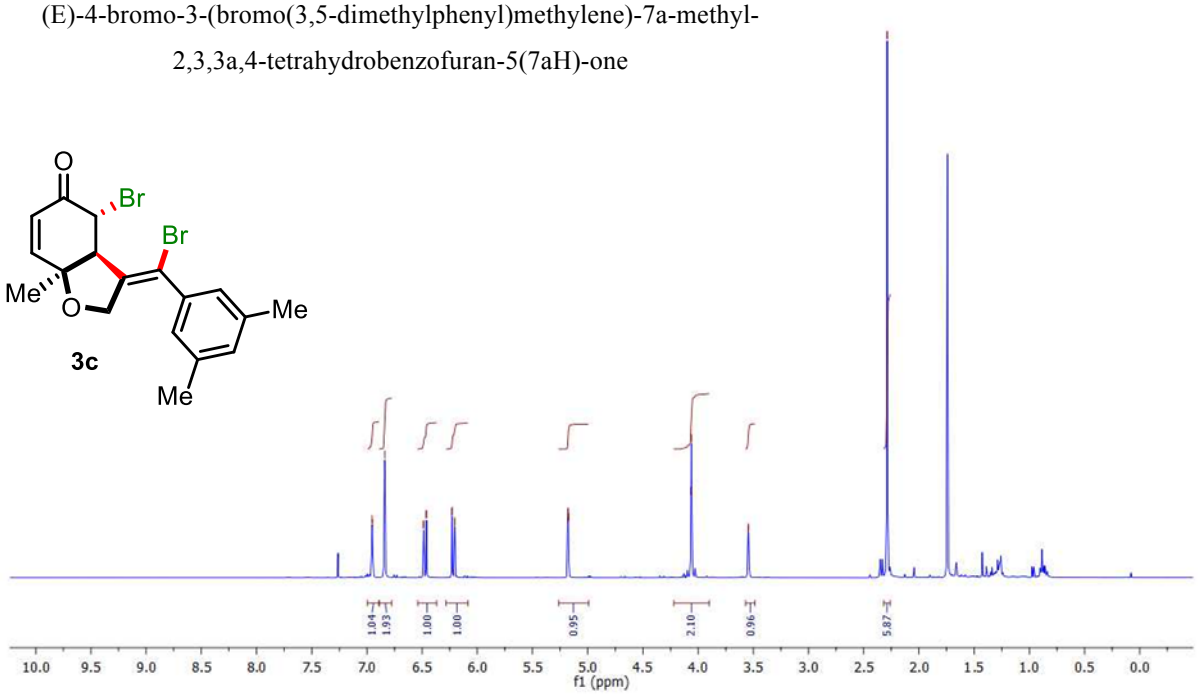


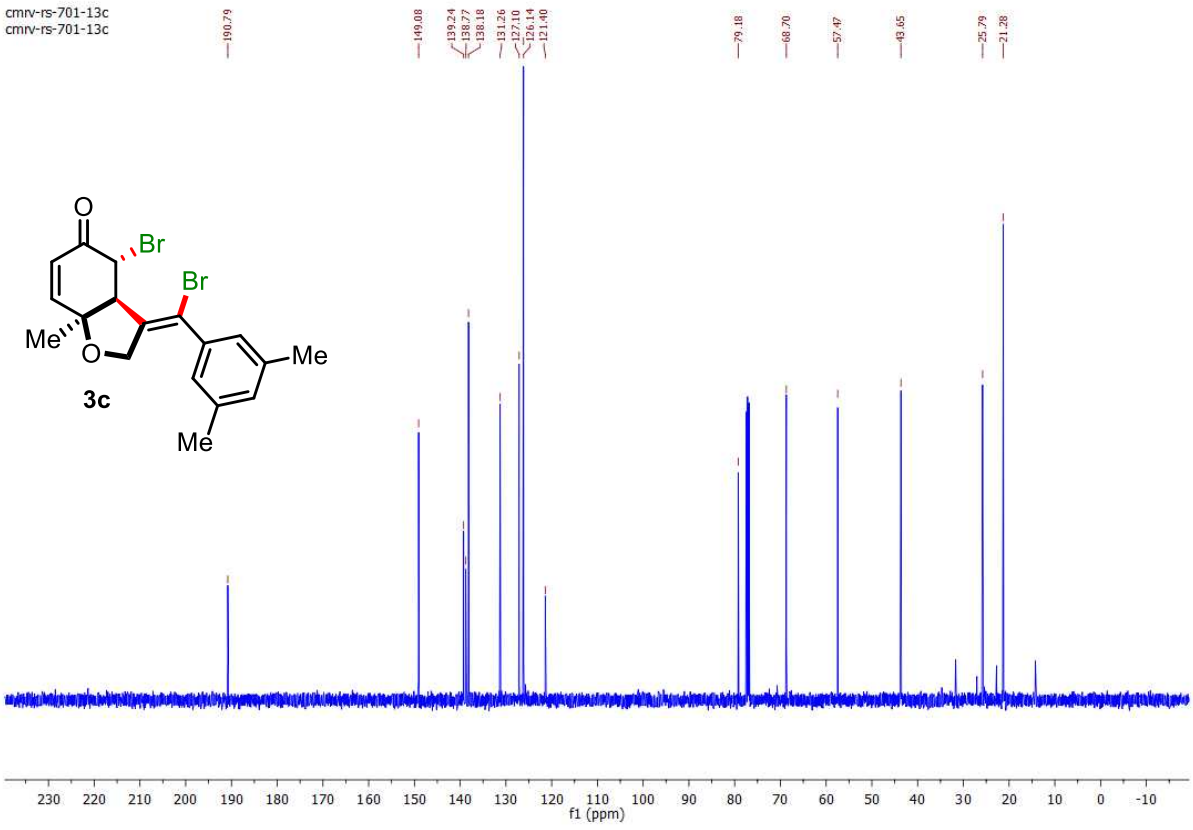
3b

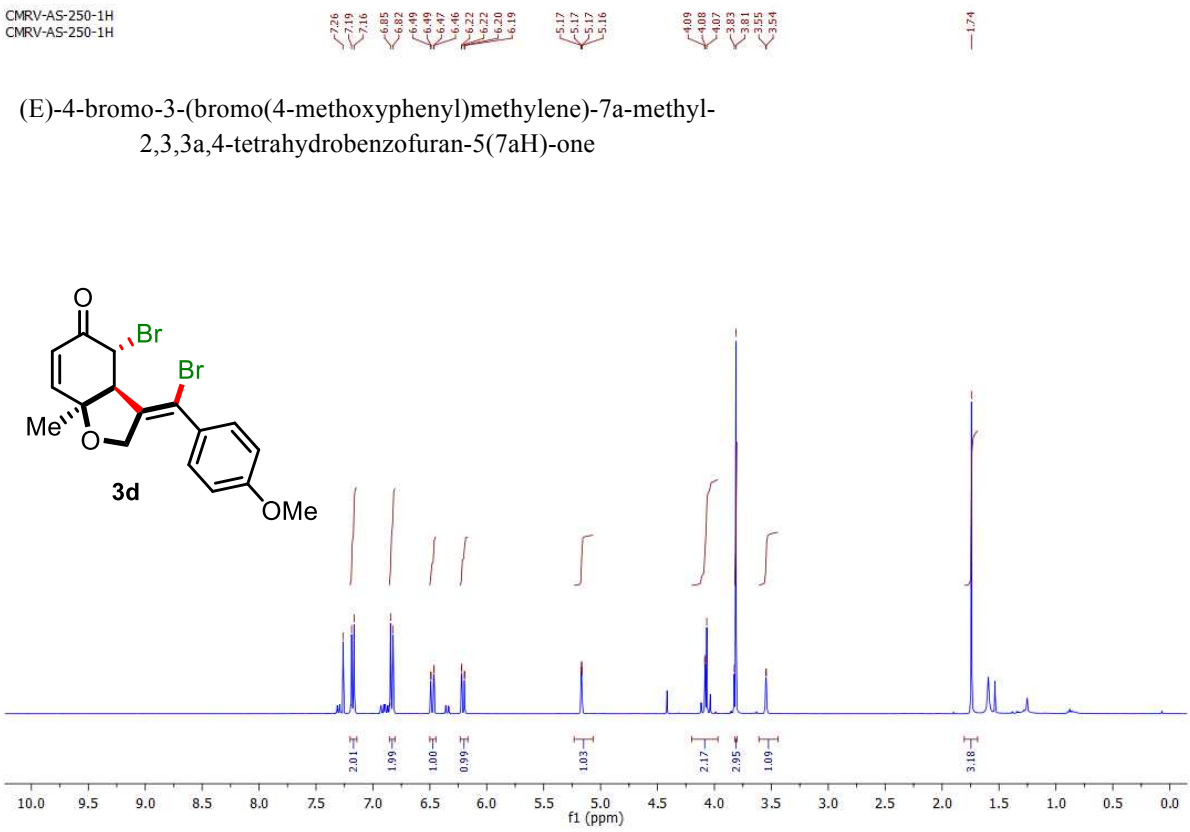
CMRV-AS-252-13C
CMRV-AS-252-13C



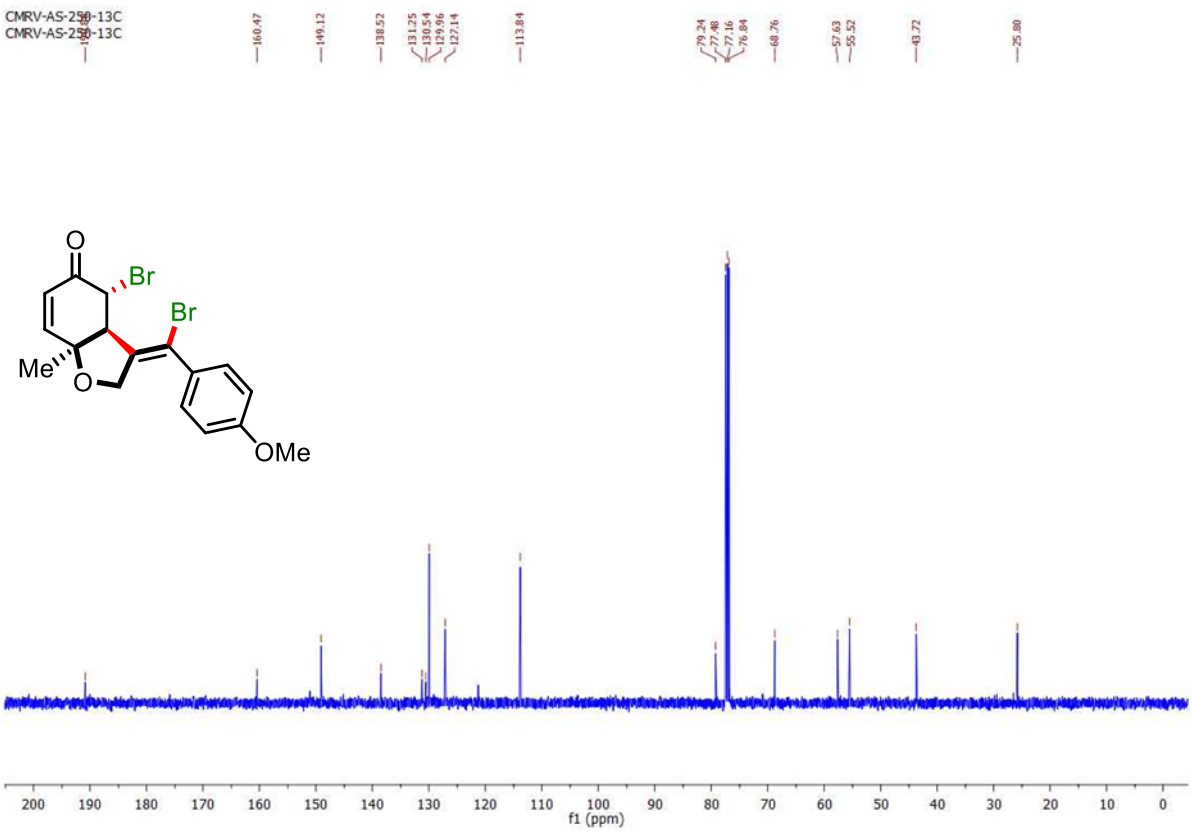
(E)-4-bromo-3-(bromo(3,5-dimethylphenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one





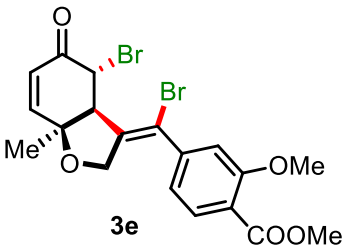


(E)-4-bromo-3-(bromo(4-methoxyphenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one



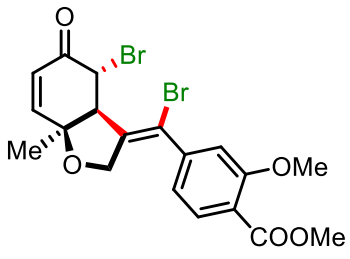
CMRV-AS-209-B-1H
CMRV-AS-209-B-1H

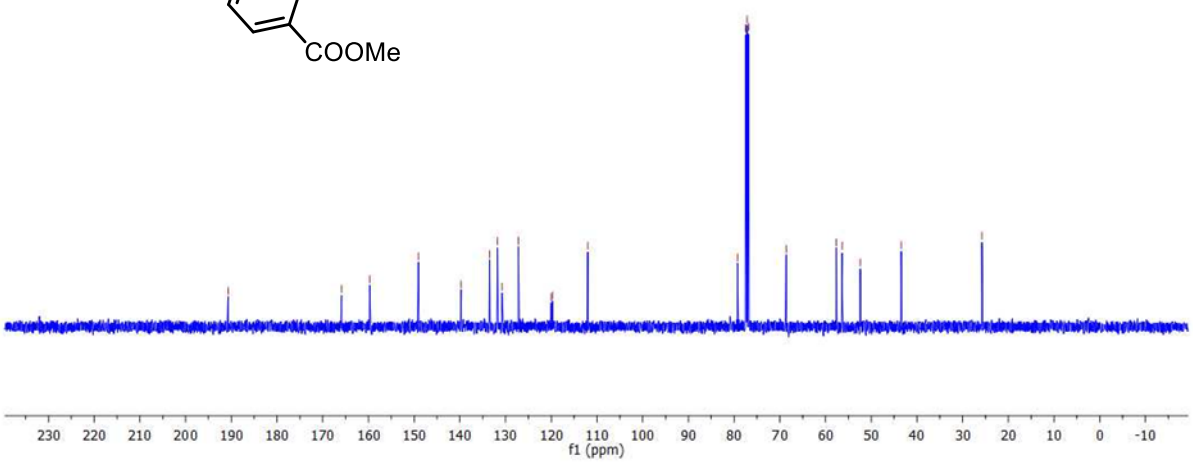
(E)-methyl 4-(bromo(4-bromo-7a-methyl-5-oxo-4,5-dihydrobenzofuran-3(2H,3aH,7aH)-ylidene)methyl)-2-methoxybenzoate



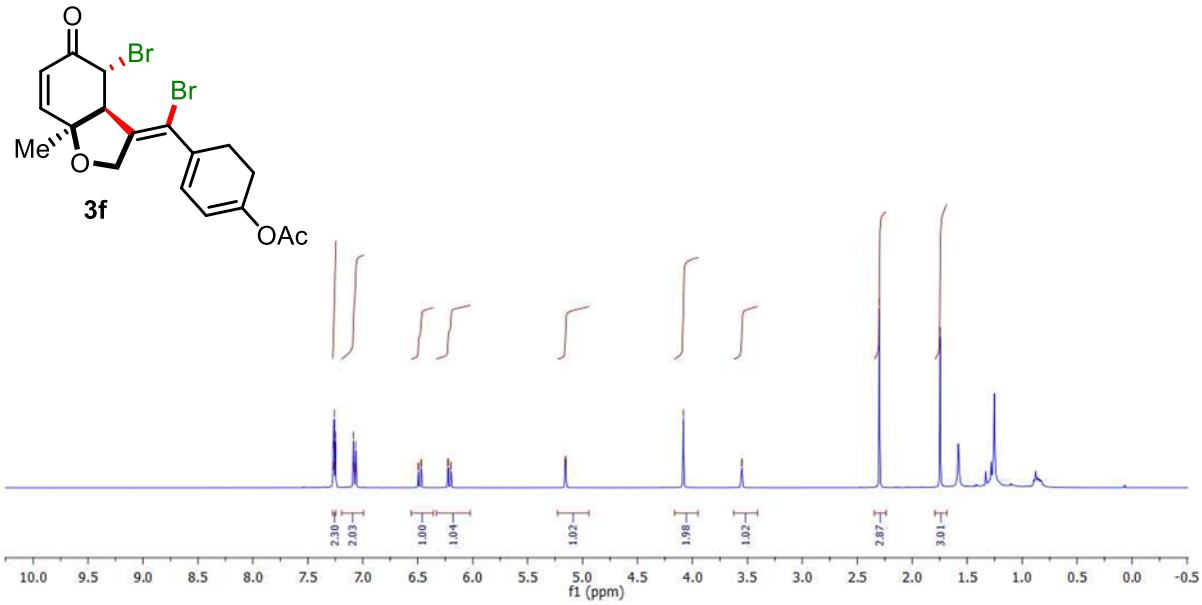
3e

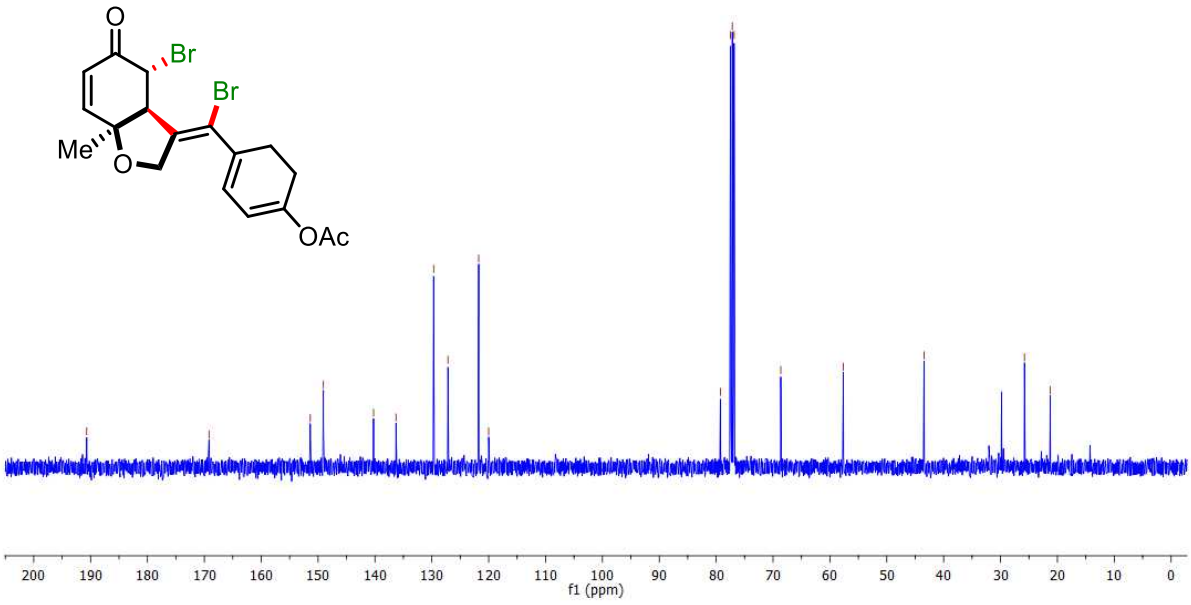
CMRV-AS-209-B-13C
CMRV-AS-209-B-13C





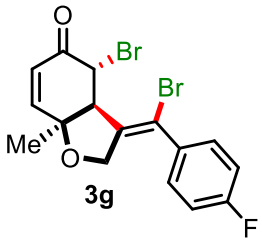
4-((E)-bromo-4-bromo-7a-methyl-5-oxo-4,5-dihydrobenzofuran-3(2H,3aH,7aH)-ylidene)methyl)phenyl acetate





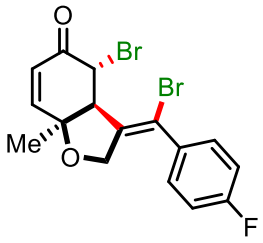
CMRV-AS-535-1H
CMRV-AS-535-1H

(E)-4-bromo-3-(bromo(4-fluorophenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one



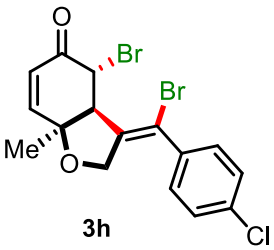
3g

CMRV-AS-535-13C
CMRV-AS-535-13C



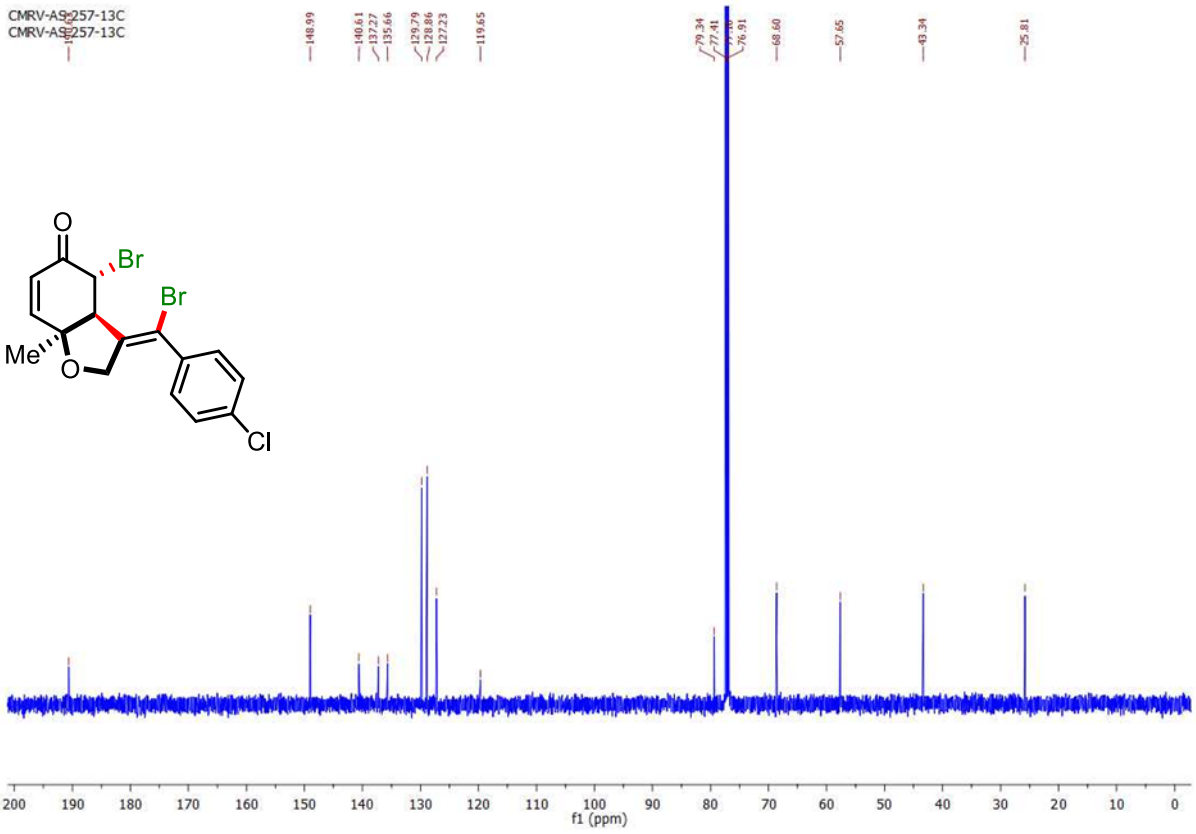
CMRV-AS-257-1RE
CMRV-AS-257-1HRE

(E)-4-bromo-3-(bromo(4-chlorophenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one

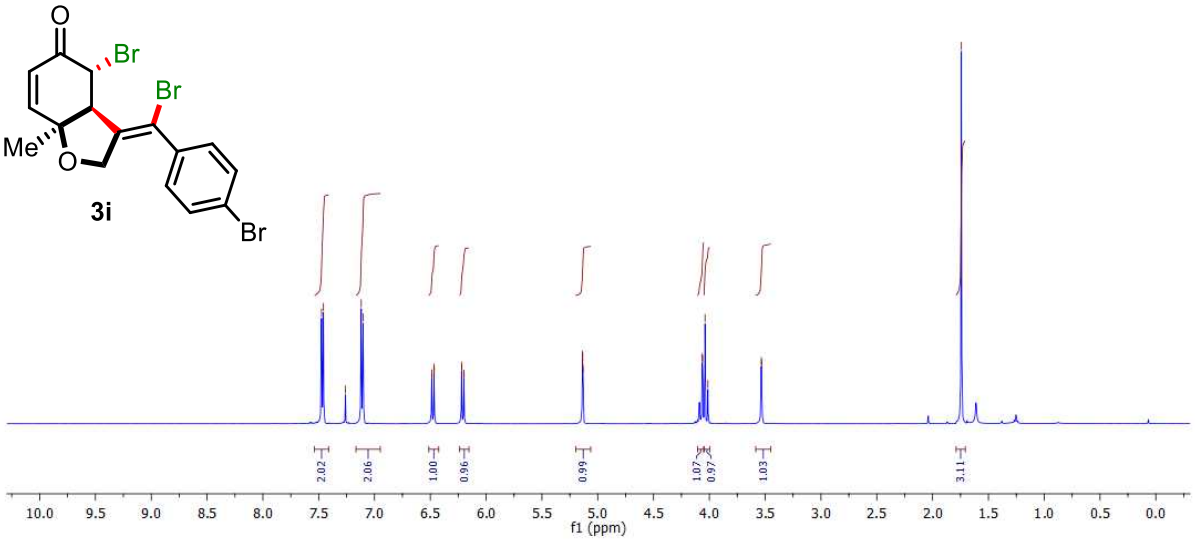


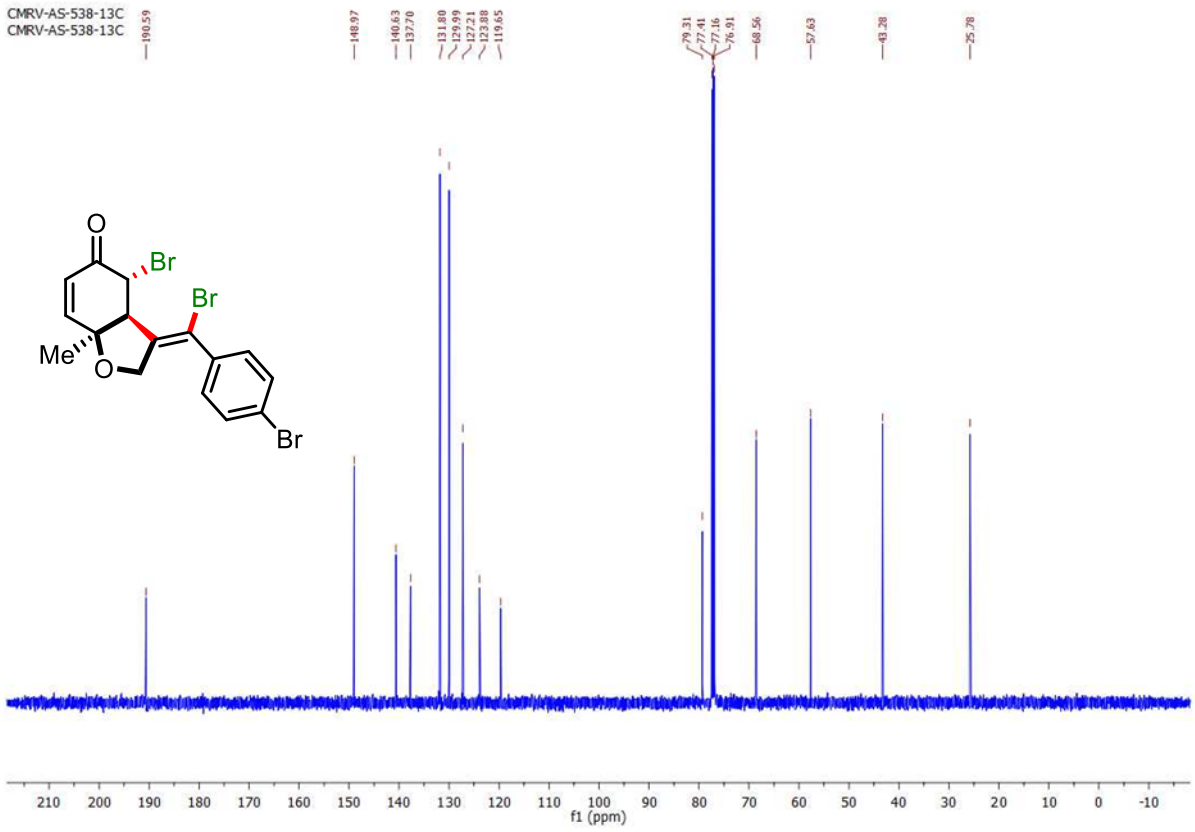
3h

CMRV-AS-257-13C
CMRV-AS-257-13C

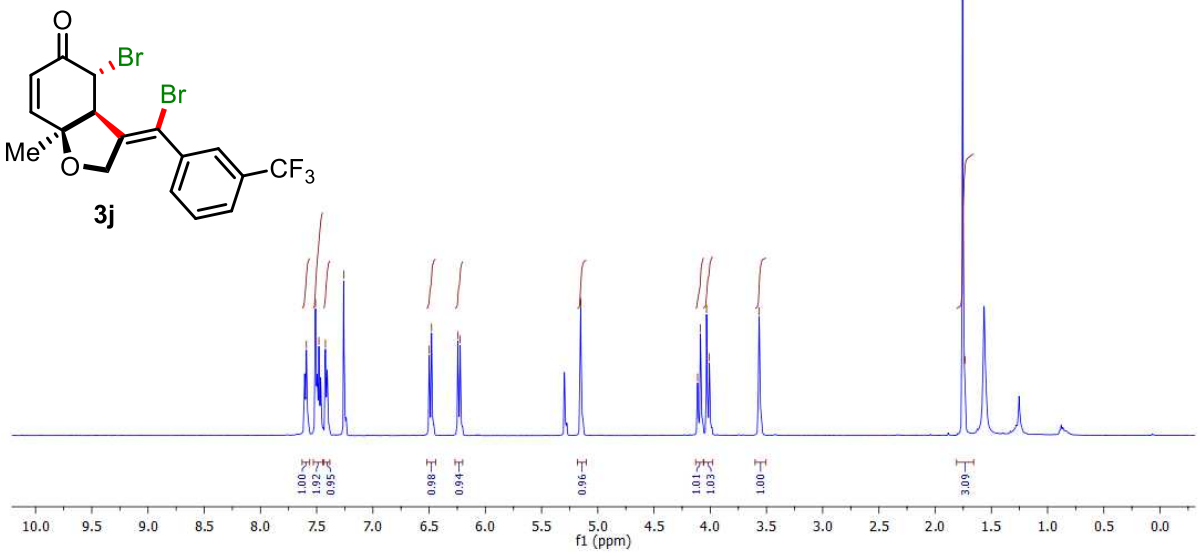


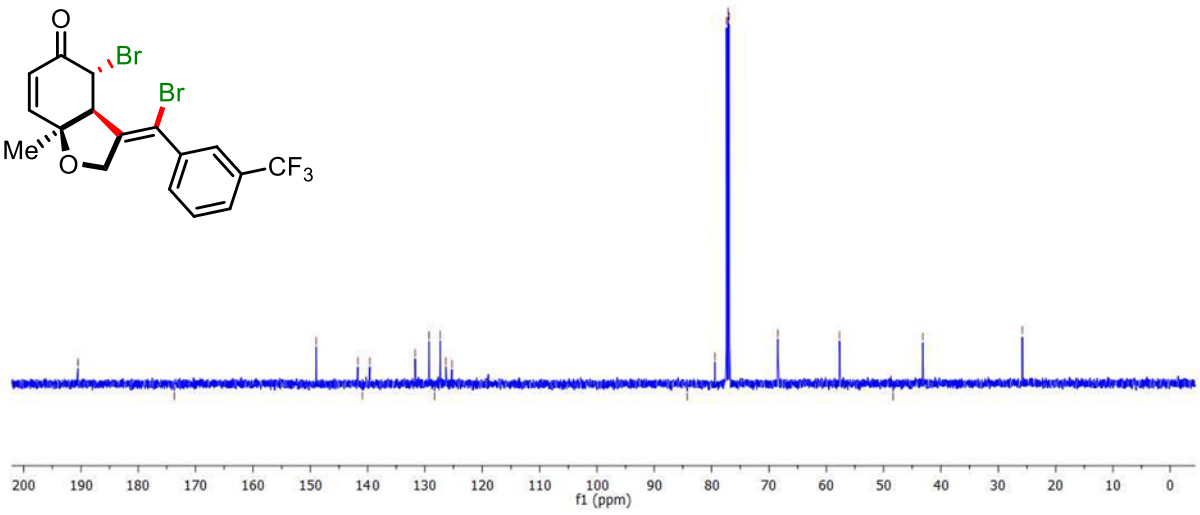
(E)-4-bromo-3-(bromo(4-bromophenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one



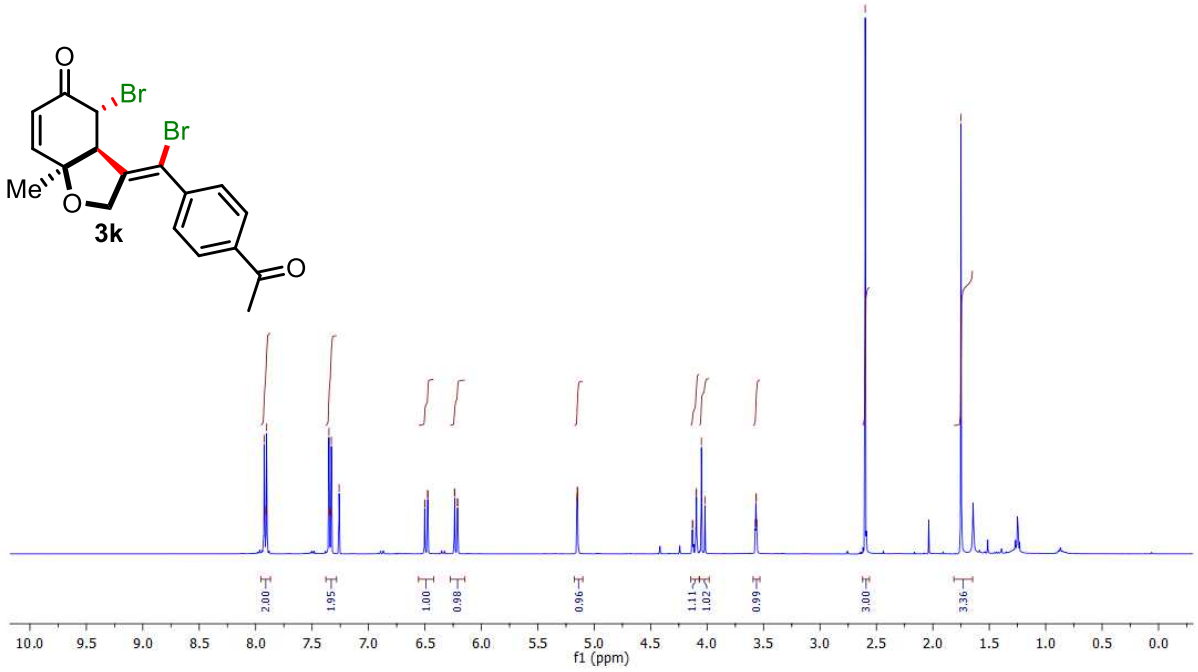


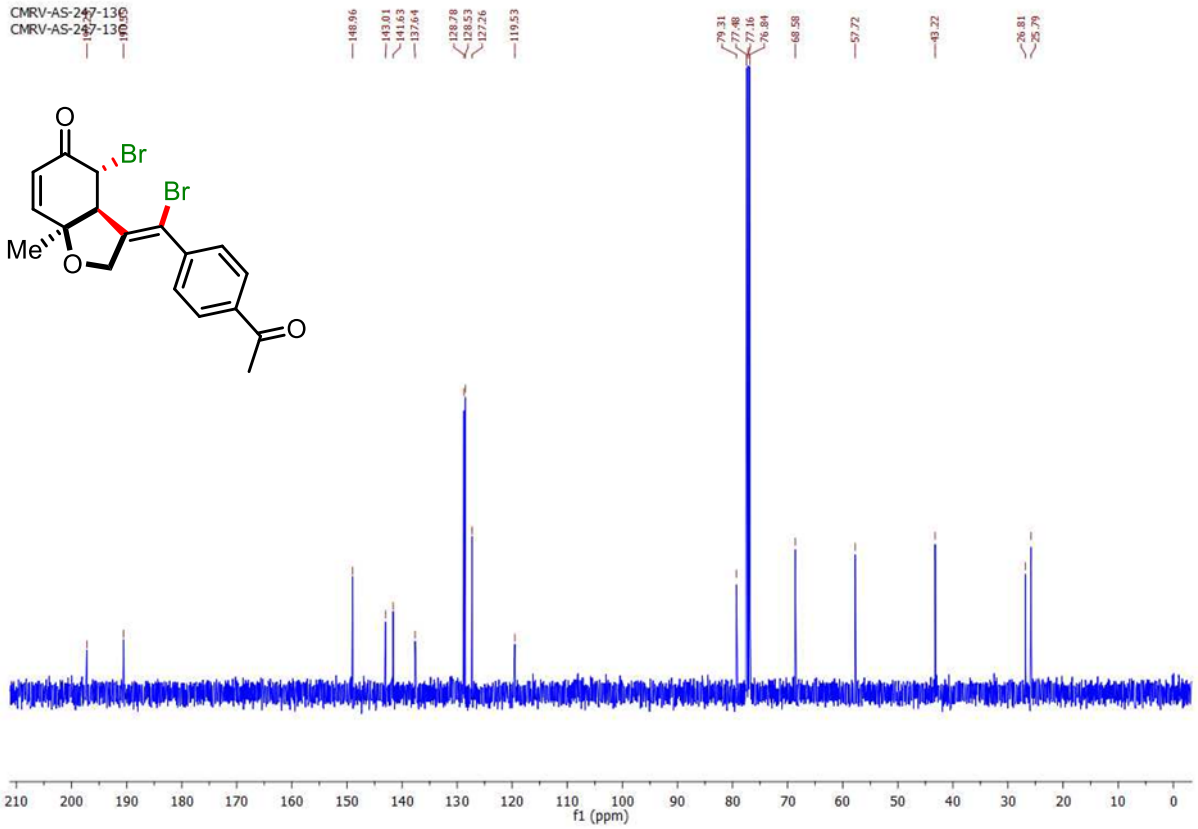
(E)-4-bromo-3-(bromo(3-(trifluoromethyl)phenyl)methylene)-7a-methy
2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one



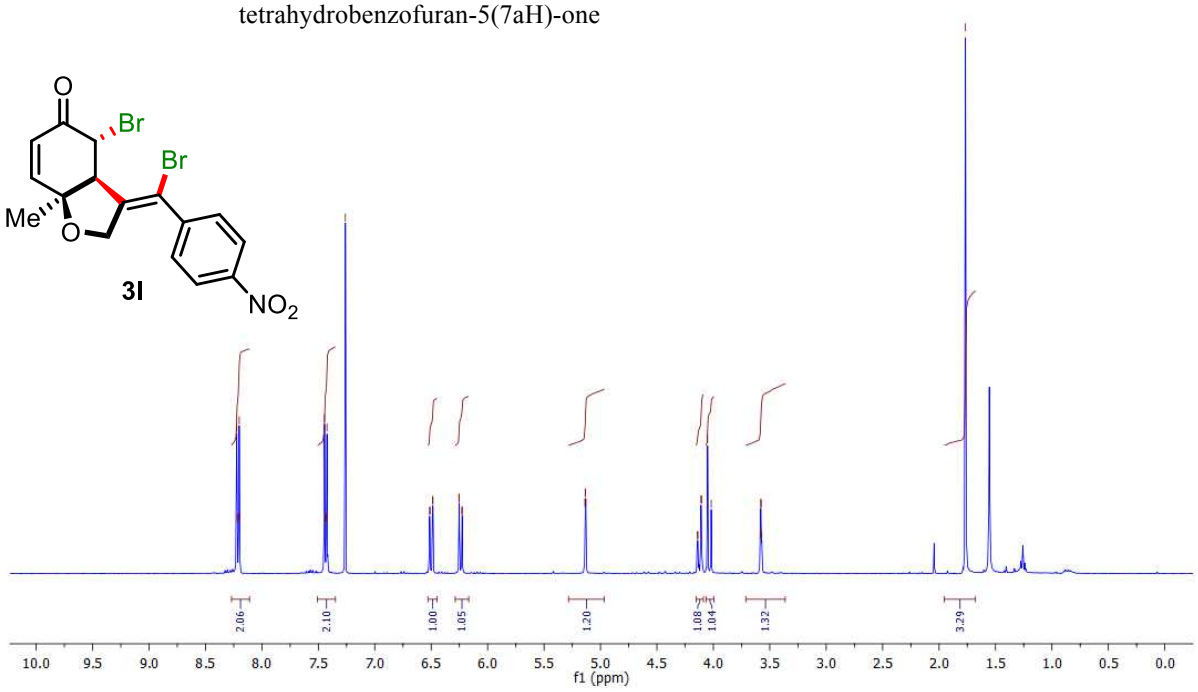


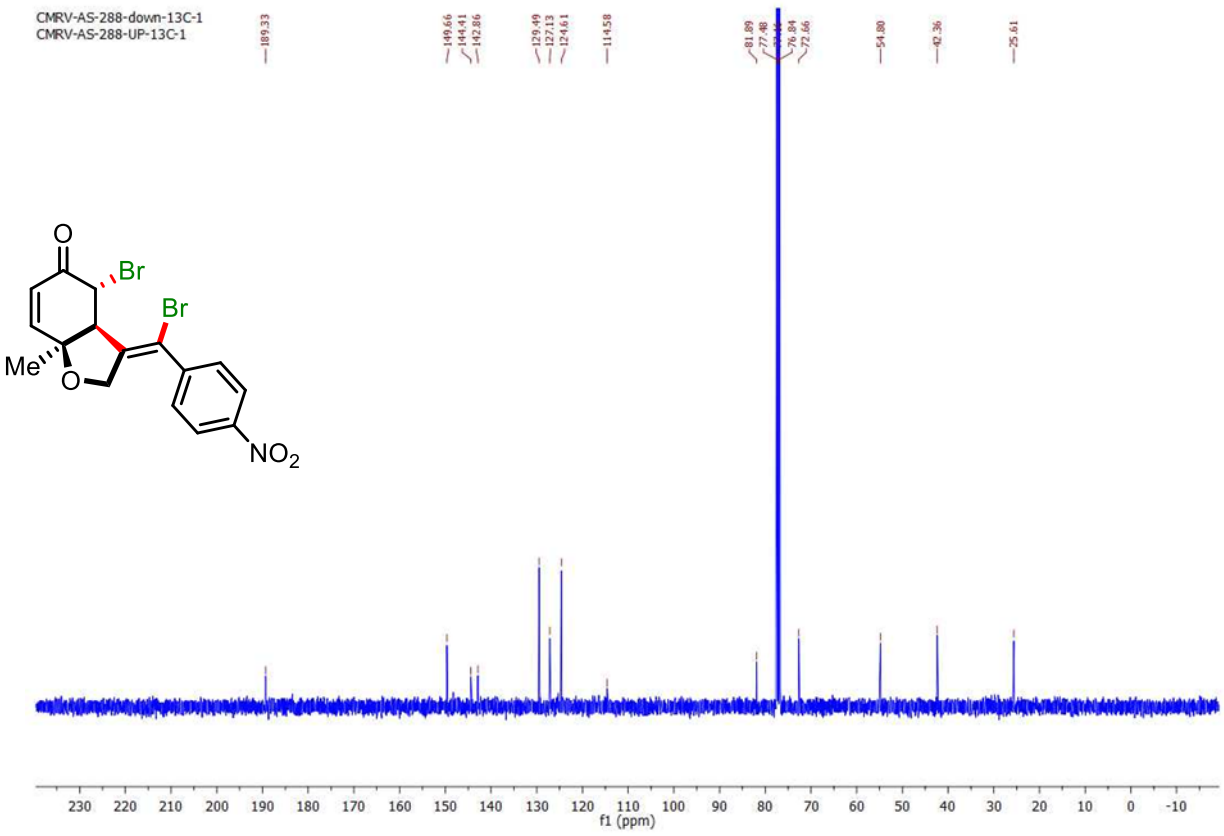
(E)-3-((4-acetylphenyl)bromomethylene)-4-bromo-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one



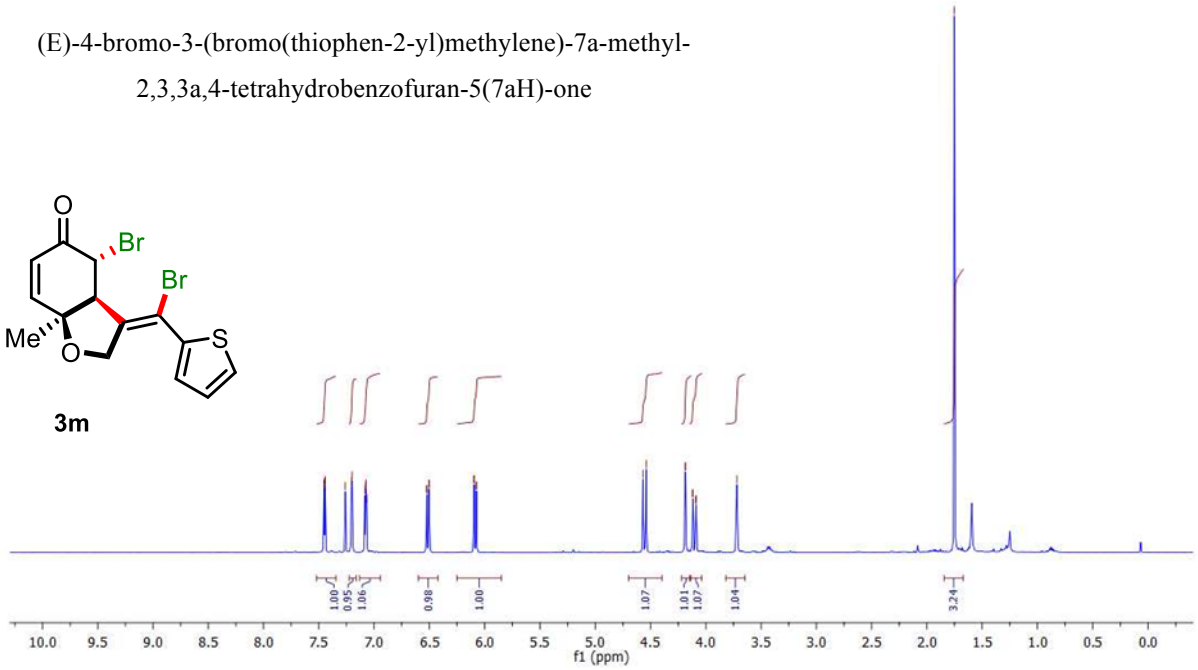


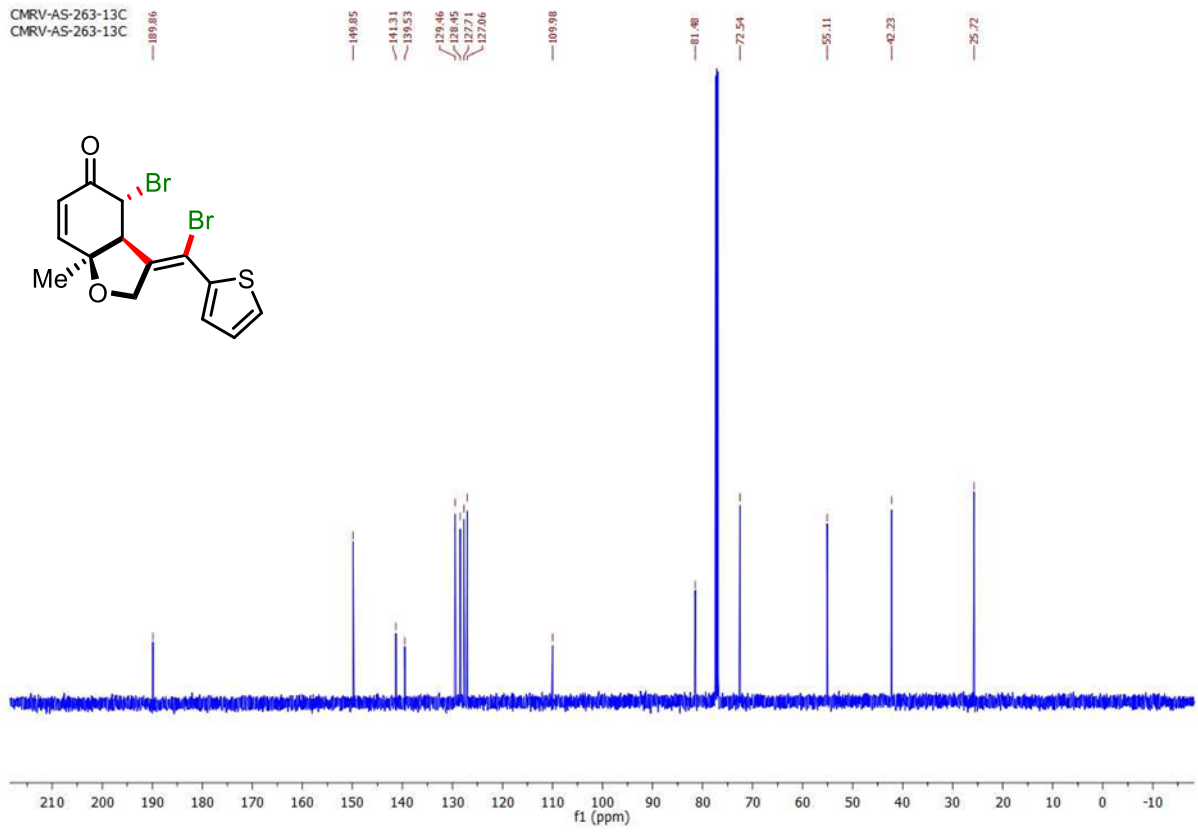
(E)-4-bromo-3-(bromo(4-nitrophenyl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one



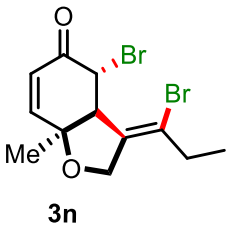


(E)-4-bromo-3-(bromo(thiophen-2-yl)methylene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one

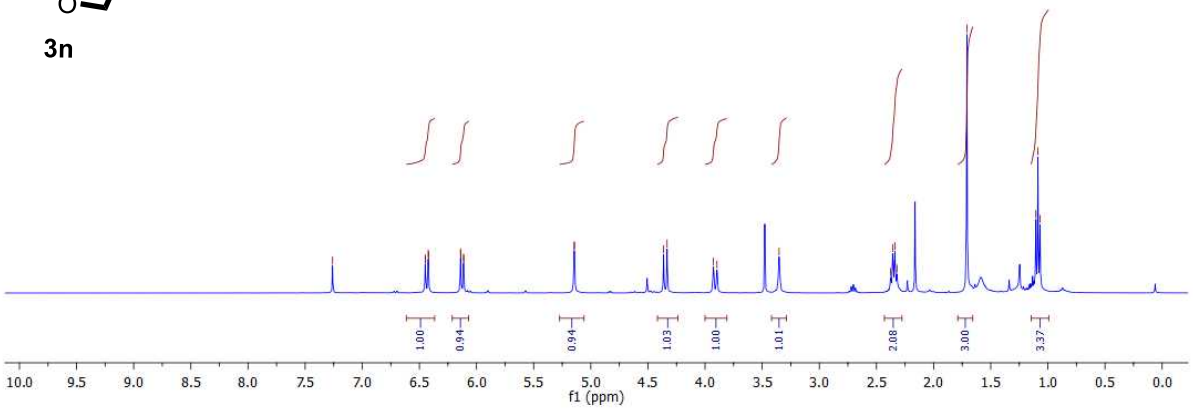


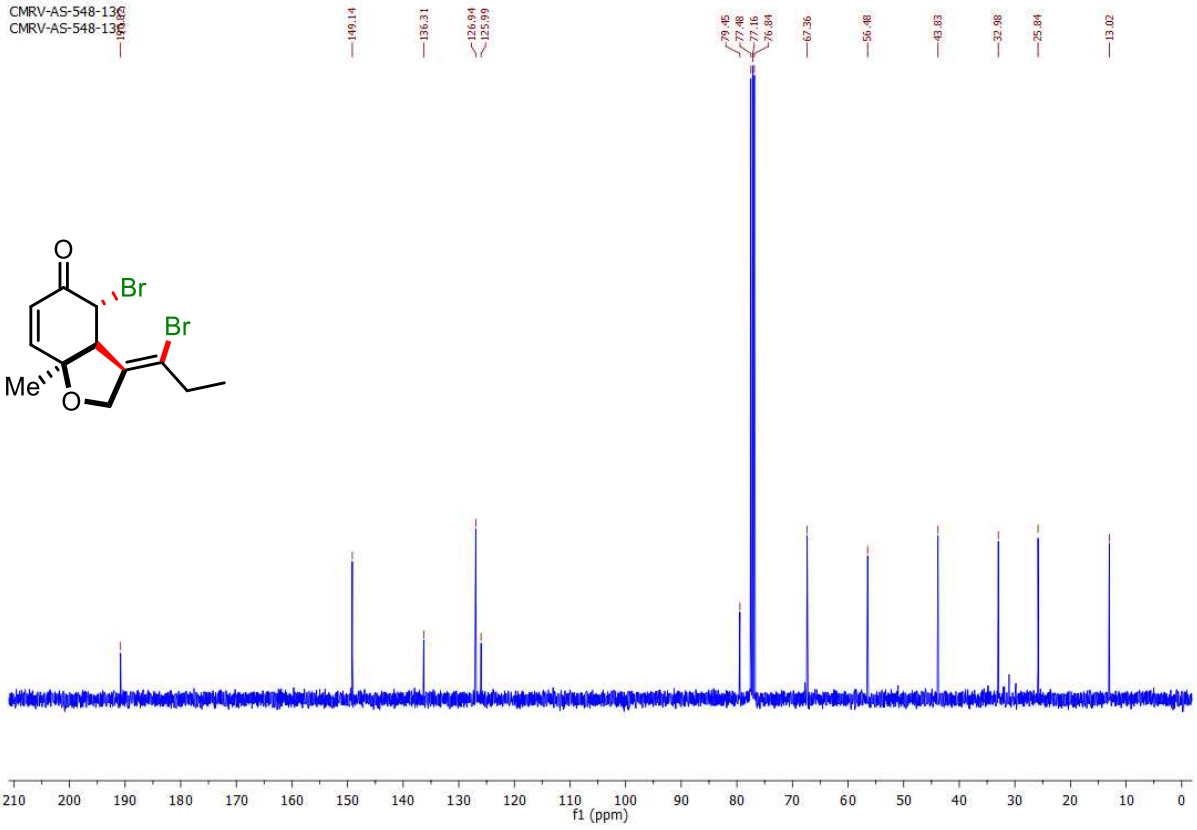


(3aS,4R,7aS,E)-4-bromo-3-(1-bromopropylidene)-7a-methyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one

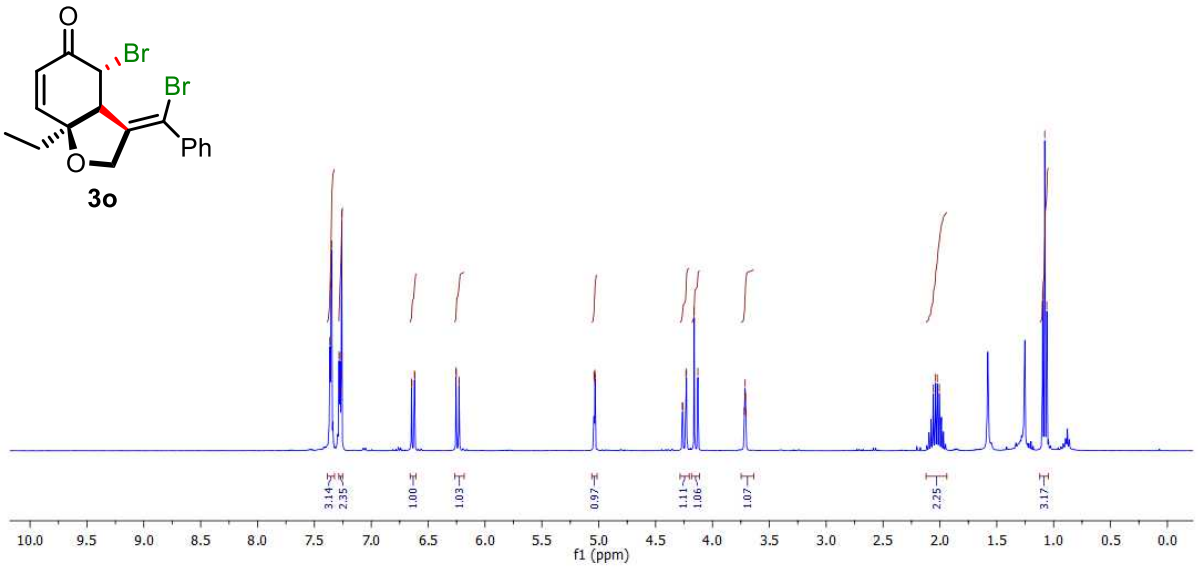


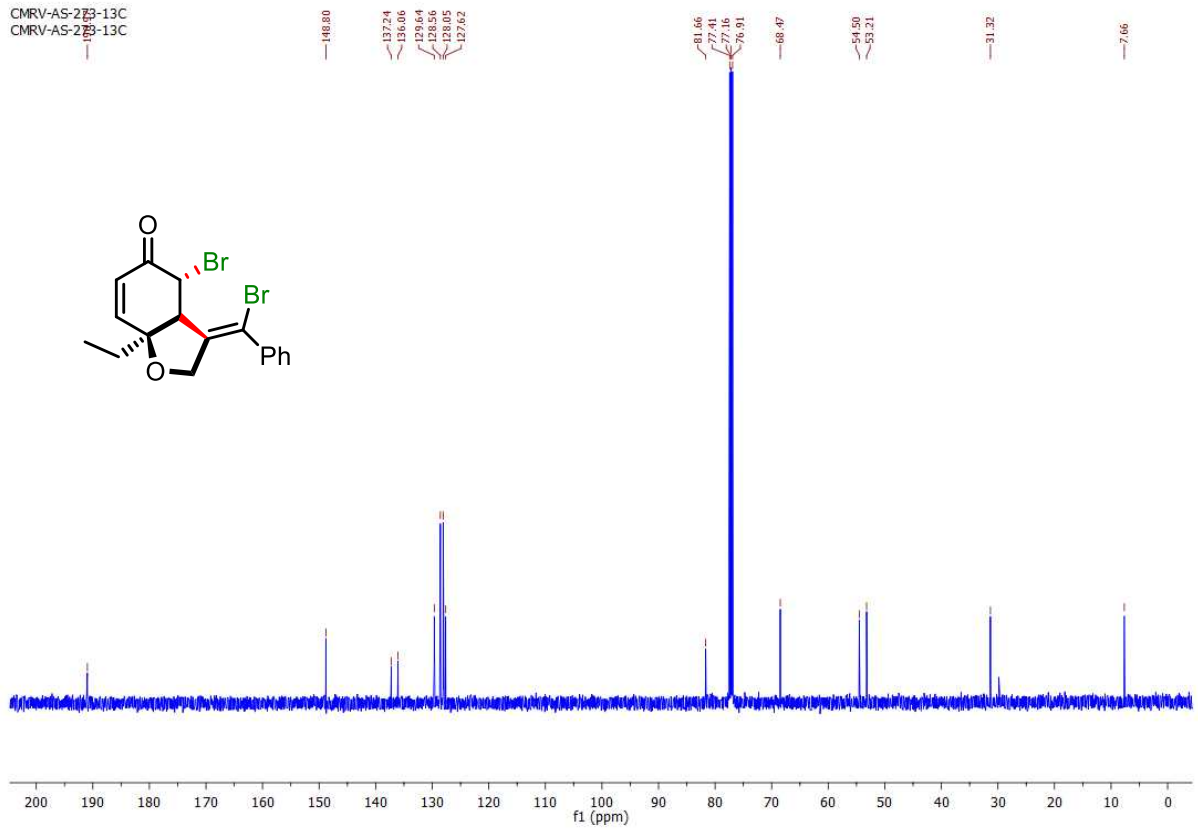
3n

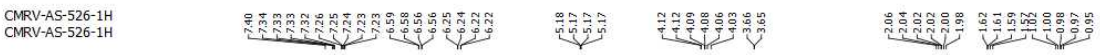




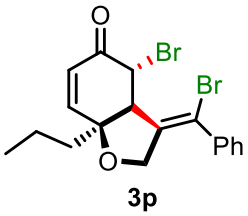
(E)-4-bromo-3-(bromo(phenyl)methylene)-7a-ethyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one



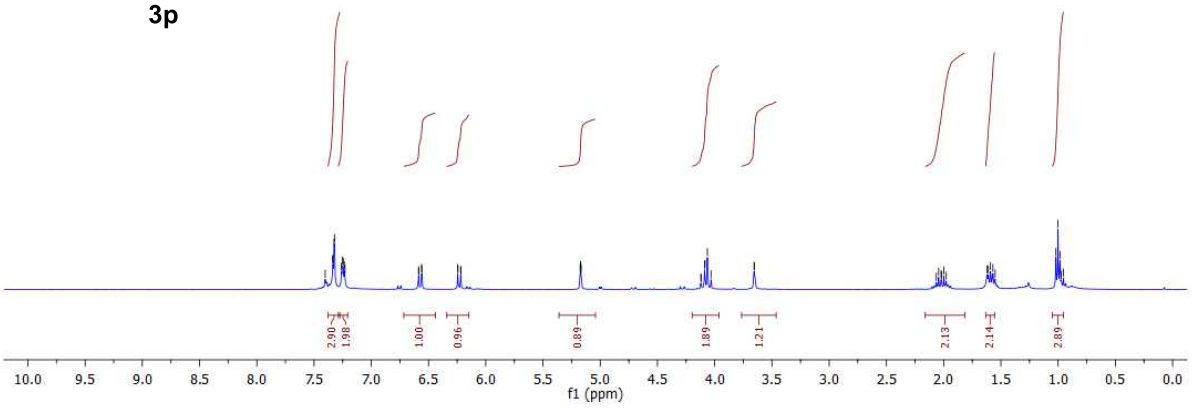


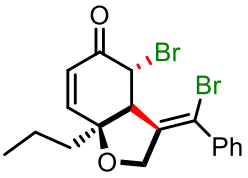


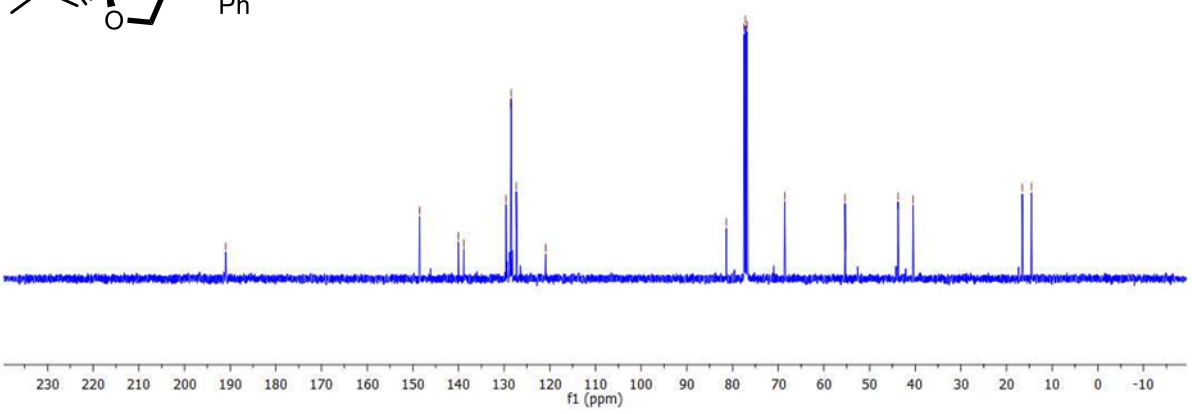
(3aS,4R,7aS,E)-4-bromo-3-(bromo(phenyl)methylene)-7a-propyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one



3p

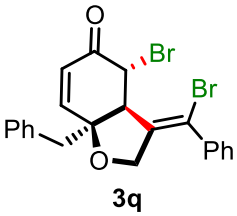




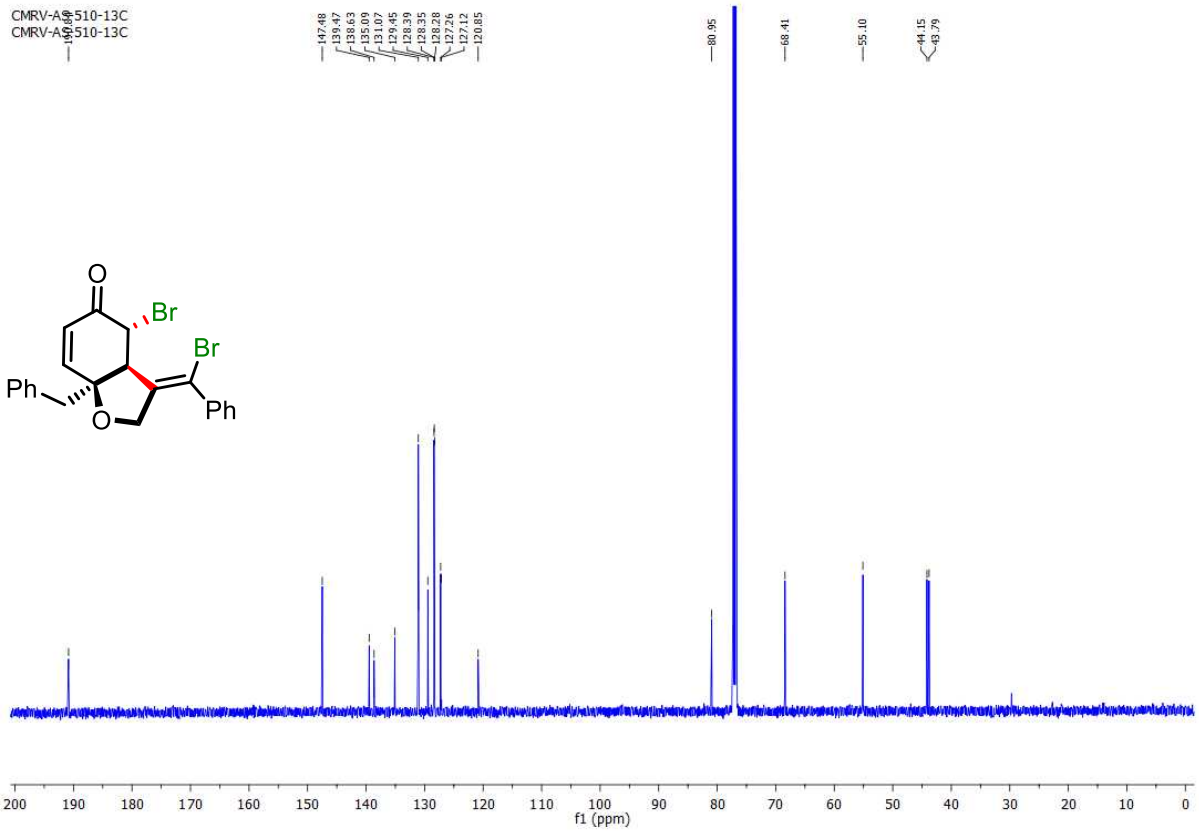


CMRV-AS-510-1H
CMRV-AS-510-1H

(E)-7a-benzyl-4-bromo-3-(bromo(phenyl)methylene)-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one

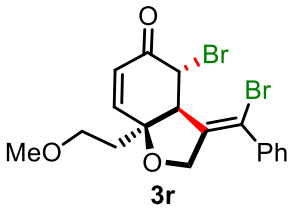


3q



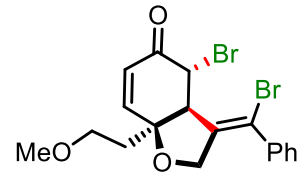
CMRV-AS-286-A-1H
CMRV-AS-286-A-1H

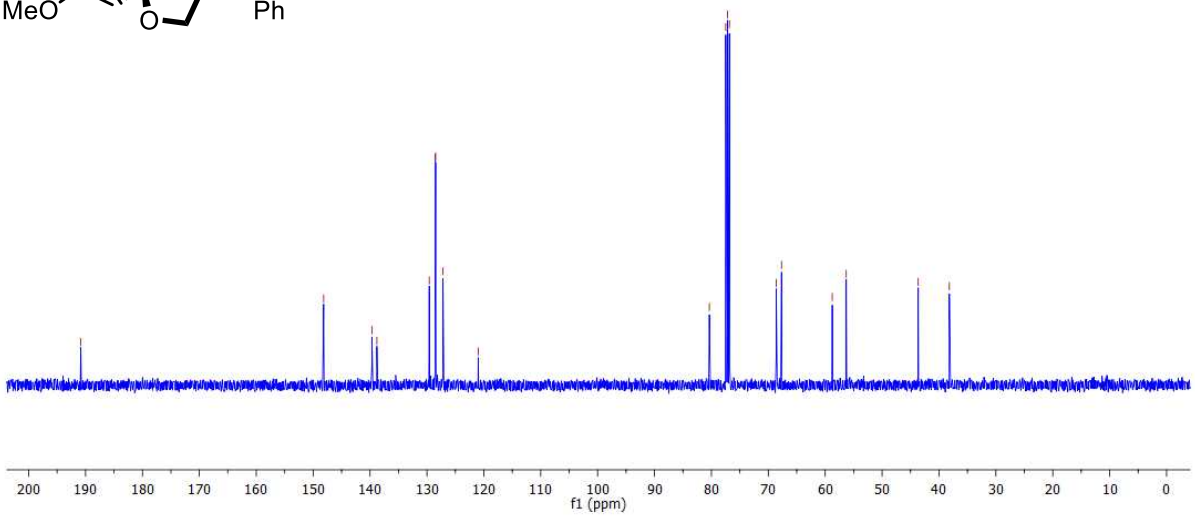
(E)-4-bromo-3-(bromo(phenyl)methylene)-7a-(2-methoxyethyl)-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one



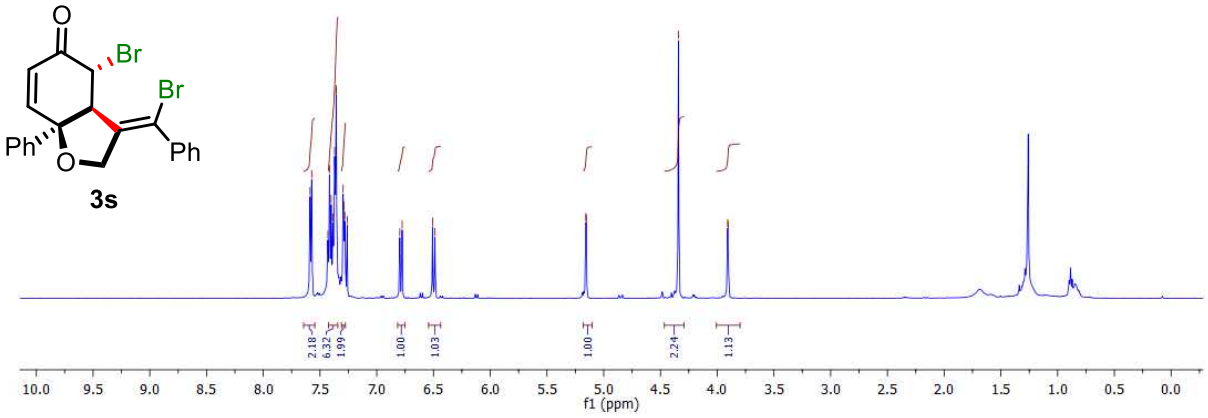
3r

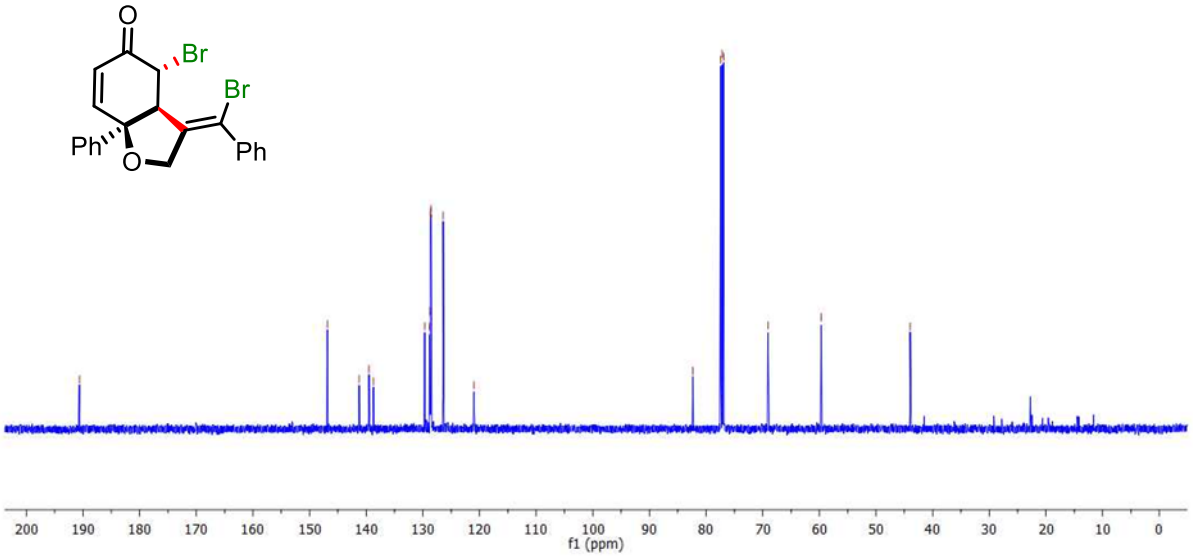
CMRV-AS-286-A-13C-2
CMRV-AS-286-A-13C-2



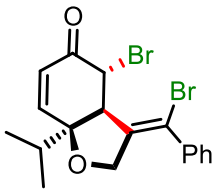


(E)-4-bromo-3-(bromo(phenyl)methylene)-7a-phenyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one



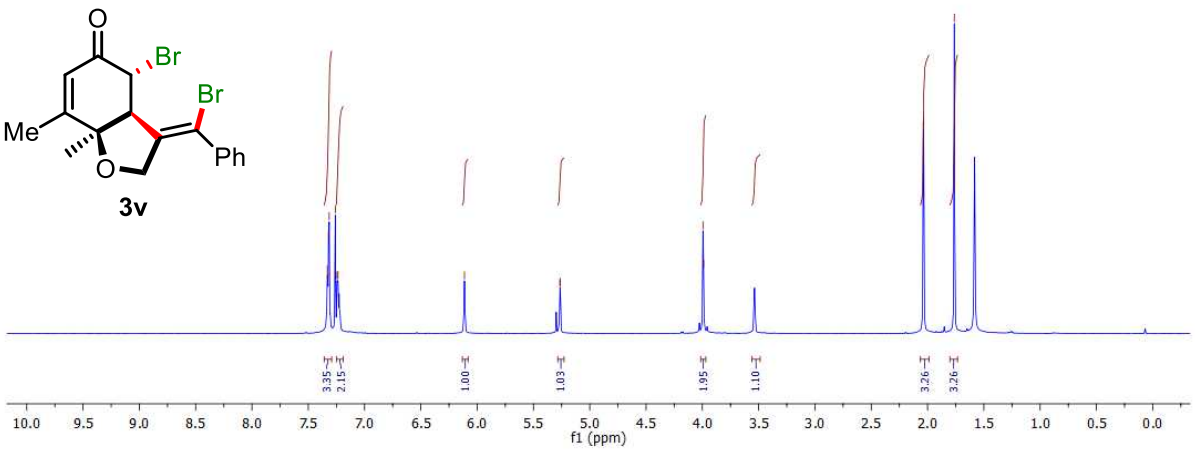


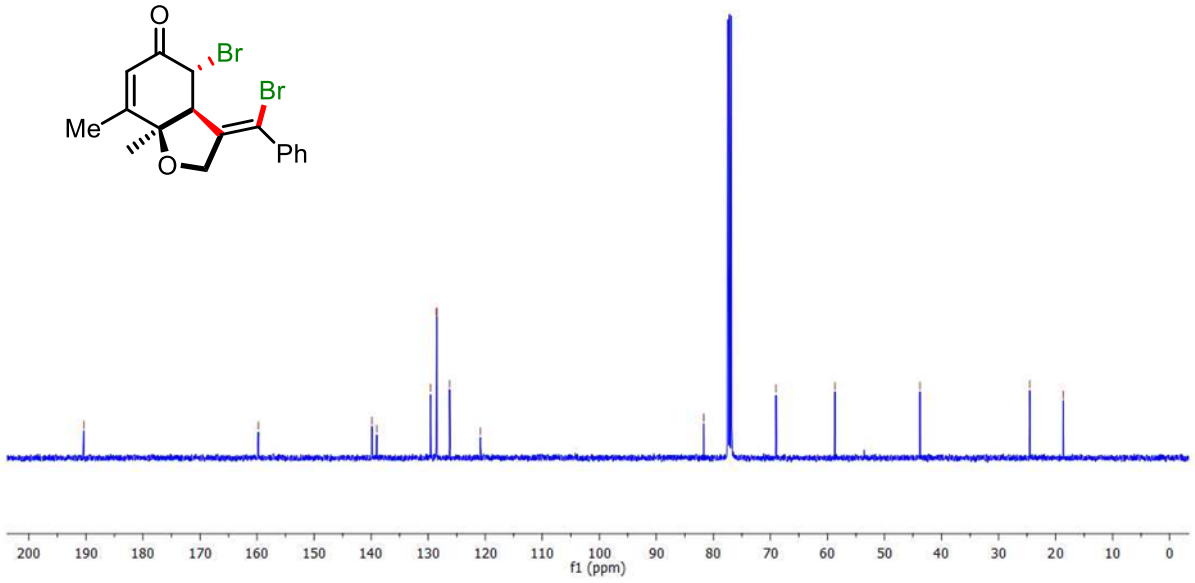
CMRV-AS-284-1H
CMRV-AS-284-1H

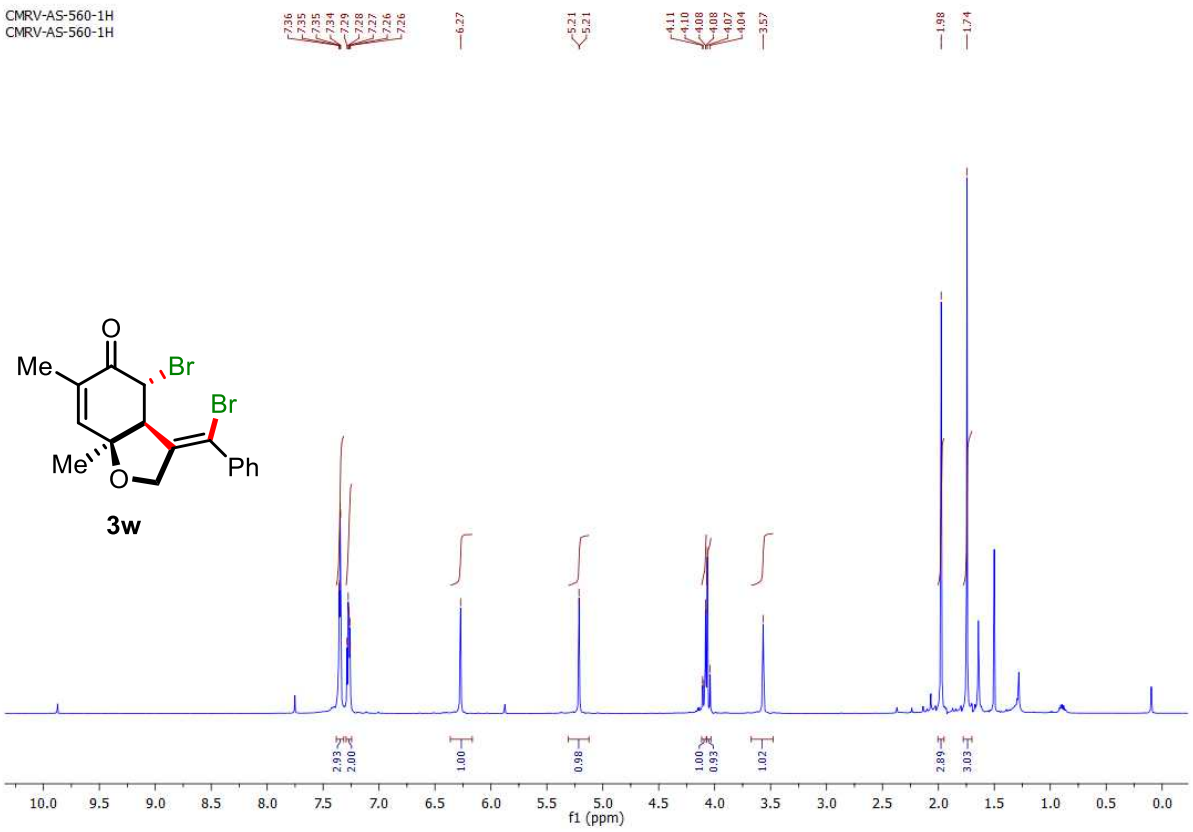


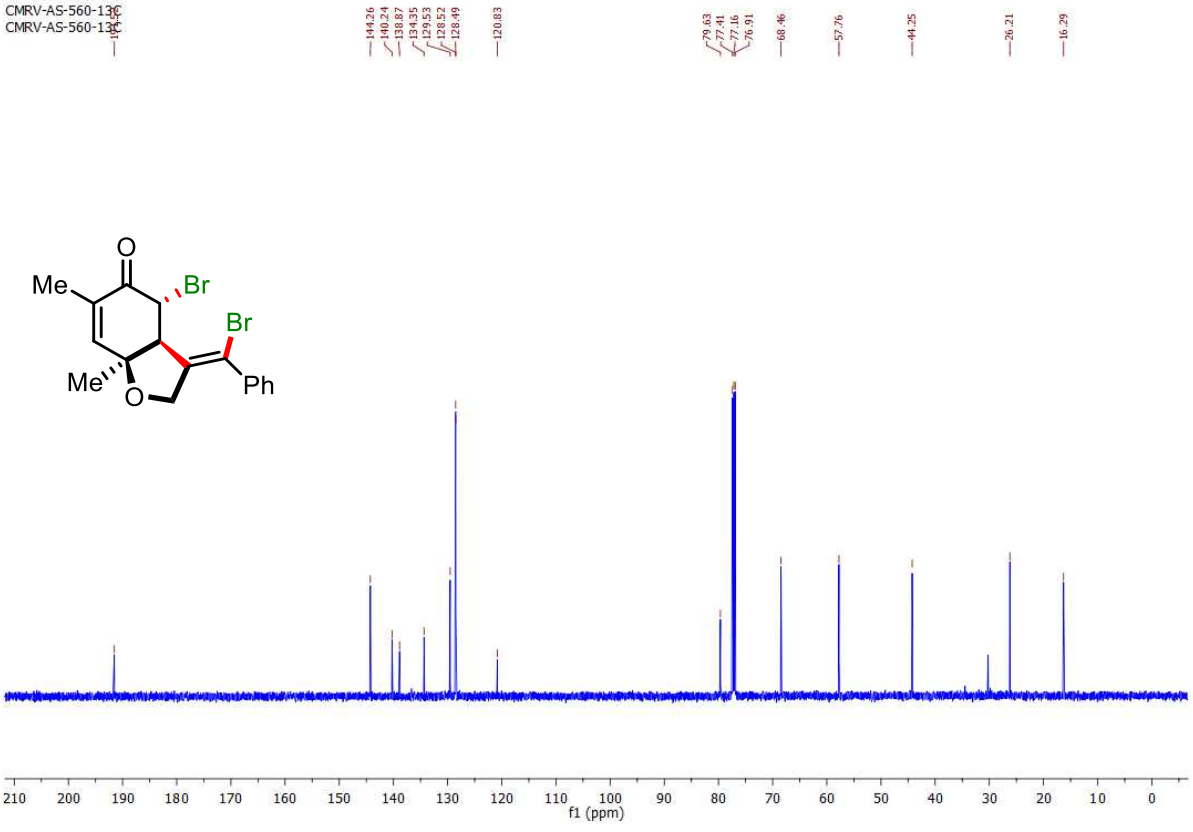
3t

(E)-4-bromo-3-(bromo(phenyl)methylene)-7,7a-dimethyl-2,3,3a,4-tetrahydrobenzofuran-5(7aH)-one



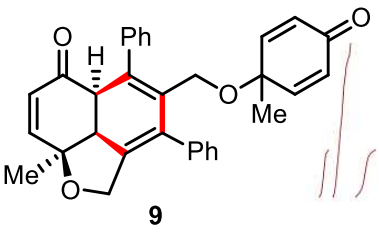



CMRV-AS-560-1H
CMRV-AS-560-1H
Me
Br
Br
Me
O
Ph
3w
f1 (ppm)


CMRV-AS-560-13C
CMRV-AS-560-13C
Me
Br
Br
Me
O
Ph
f1 (ppm)

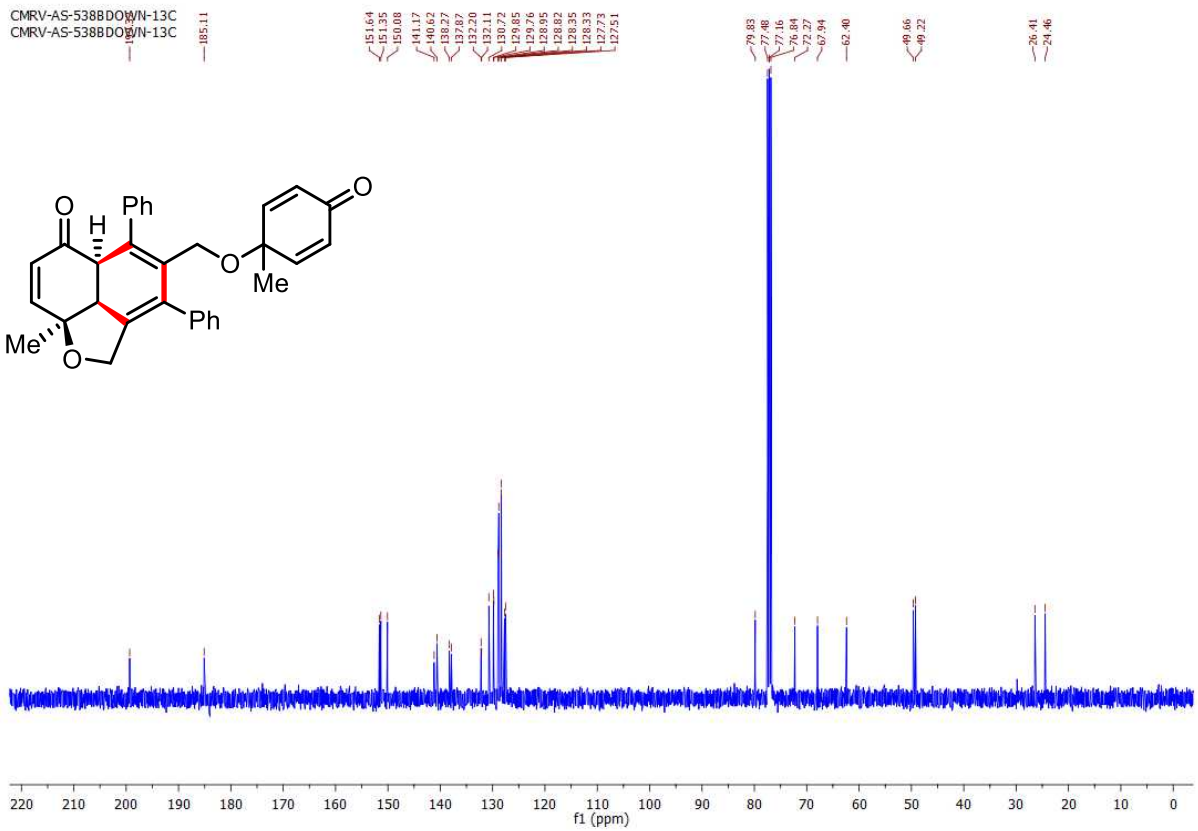
CMRV-AS-538BDOWN-1H
CMRV-AS-538BDOWN-1H

8a-methyl-4-(((1-methyl-4-oxocyclohexa-2,5-dien-1-yl)oxy)methyl)-3,5-diphenyl-5a,8a-dihydro-2H-naphtho[1,8-bc]furan-6(2a1H)-one

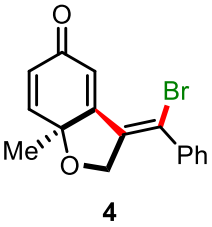


9

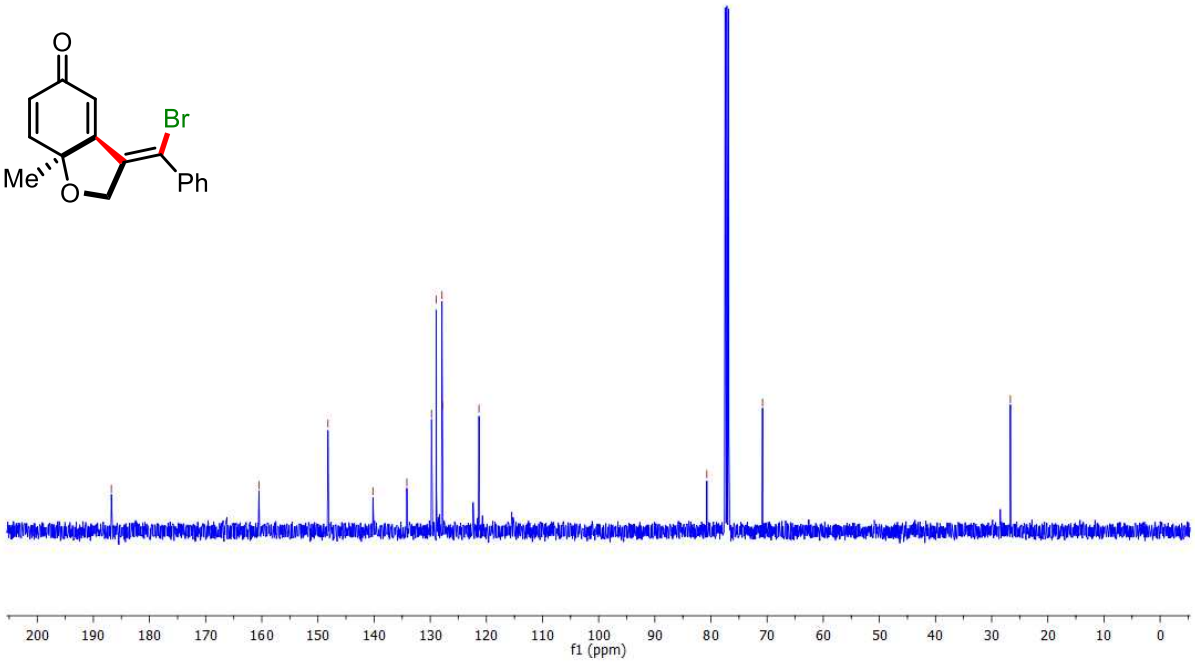
CMRV-AS-538BDOWN-13C
CMRV-AS-538BDOWN-13C



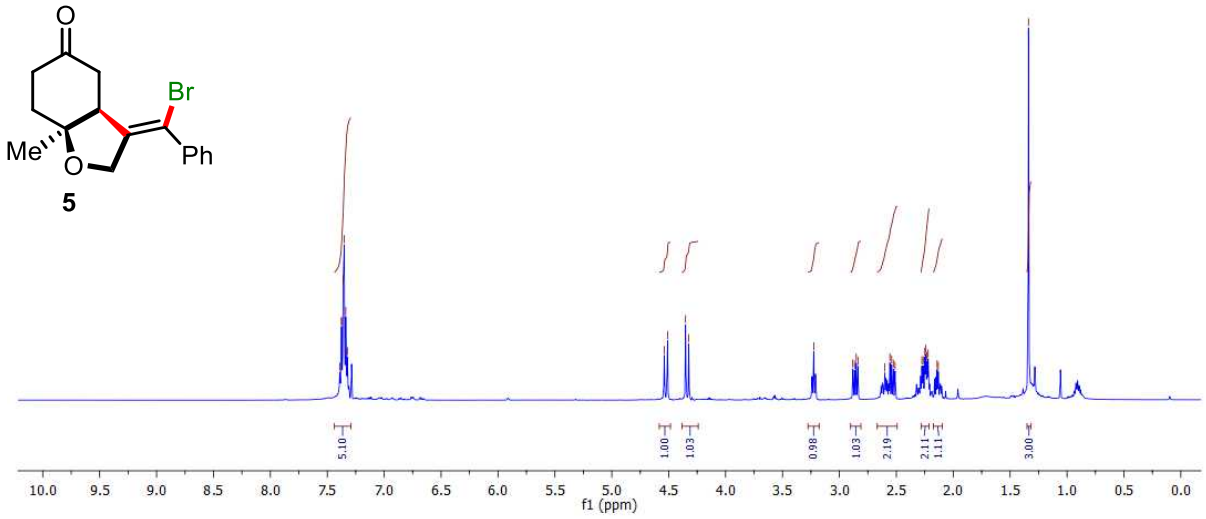
(E)-3-(bromo(phenyl)methylene)-7a-methyl-2,3-dihydrobenzofuran-5(7aH)-one

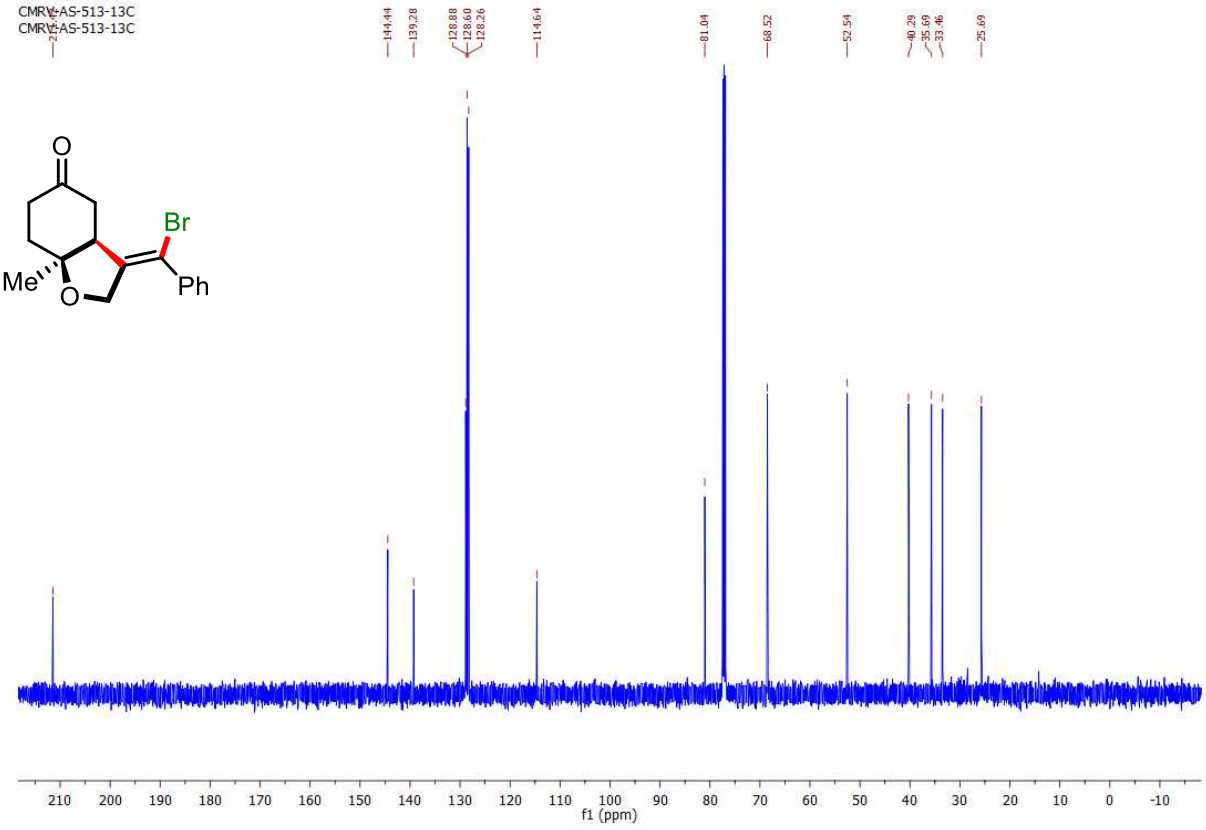


4



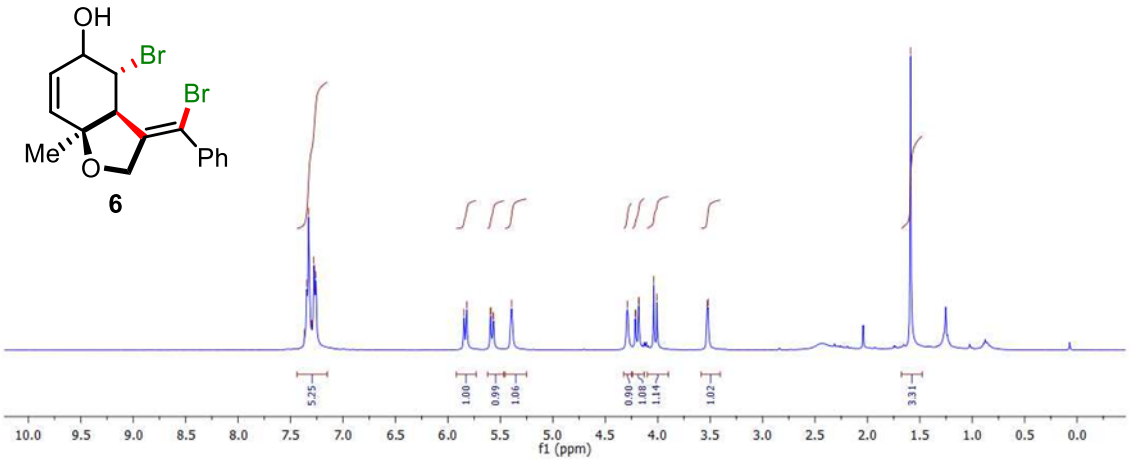
(E)-3-(bromo(phenyl)methylene)-7a-methylhexahydrobenzofuran-5(6H)-one



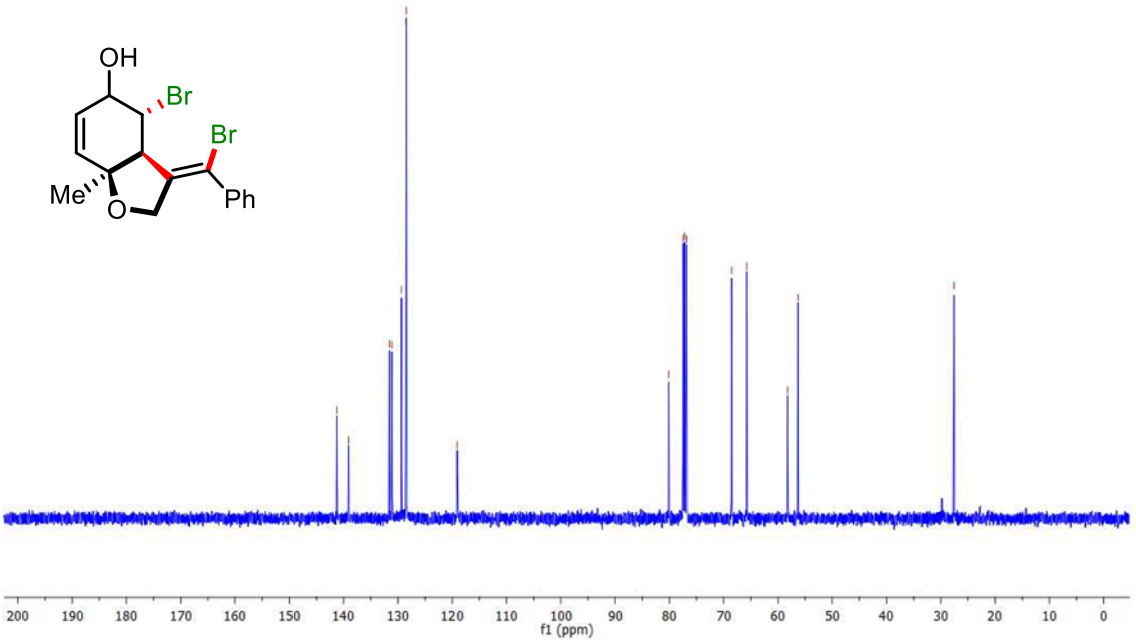


CMRV-AS-REDUCTION-1H
CMRV-AS-REDUCTION-1H

(3aS,4R,7aS,E)-4-bromo-3-(bromo(phenyl)methylene)-7a-methyl-2,3,3a,4,5,7a-hexahydrobenzofuran-5-ol



CMRV-AS-REDUCTION-13C
CMRV-AS-REDUCTION-13C



(E)-3-(chloro(phenyl)methylene)-7a-methylhexahydrobenzofuran-5(6H)-one