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Facile Organocatalytic Domino Oxidation of Diols to Lactones by In Situ-Generated TetMe-IBX

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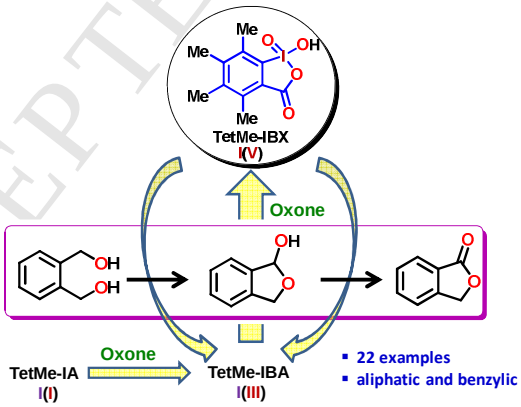
ABSTRACT

The domino oxidation of diols to lactones is an important transformation, and catalytic protocols that allow this conversion smoothly are scarce. Capitalizing on the established reactivity of tetramethyl-IBX (**TetMe-IBX**) and its in situ generation in the presence of a co-oxidant such as oxone, we have shown that a variety of diols can be converted to the corresponding lactones in respectable yields by employing the precursor of **TetMe-IBX**, namely, tetramethyl-*o*-iodobenzoic acid (**TetMe-IA**), as a catalyst in 5 mol% in the presence of 2 equiv of oxone.

KEYWORDS: Diols, Lactones, Modified IBX, Catalysis, Oxone, Cascade Reaction

GRAPHIC FOR TOC



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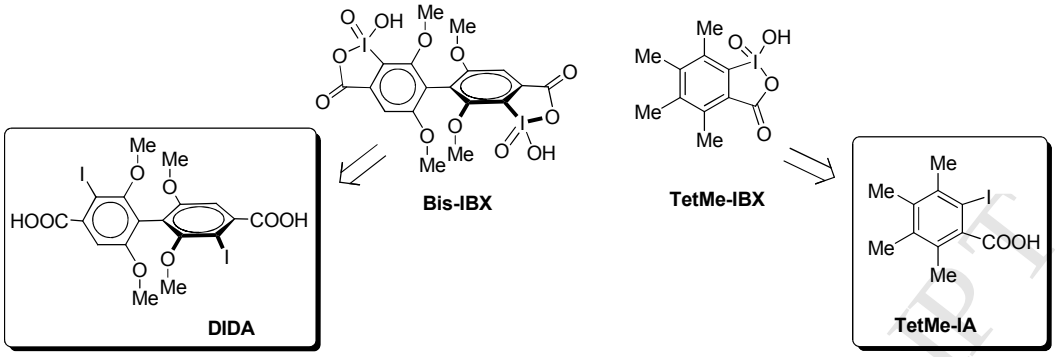
1. Introduction

Lactones are an important class of functional group compounds that are ubiquitous, and the lactone moiety constitutes an integral part of the structures of many biologically active natural products.[1] In principle, lactones may be considered as protected diols, which can be easily generated by treatment with hydride reagents. However, the protection-deprotection protocol of diols has seldom been employed in the synthesis of natural products due to lack of effective methodologies that permit conversion of diols to lactones under mild conditions. Thus, there is a need for facile methodologies that allow conversion of diols to lactones. The literature reveals that it was Fetizon and co-workers who first showed that lactones can be produced from diols using Ag_2CO_3 supported on celite;[2] this protocol, however, suffers from the impracticality associated with the usage of a large excess of silver salt. In the past decade or so, several improved methods for conversion of diols to lactones have been developed.[3] All of these methods are disadvantageous in terms of one consideration or the other that include harsh experimental conditions, use of the reagent in more than stoichiometric amounts, application of toxic metal complexes, etc.[3] A notable exception is the methodology reported by Kita and co-workers, which employs a green iodine reagent, i.e., hypervalent iodine (III), in the presence of catalytic amounts of KBr.[4] Incidentally, this method too suffers from the necessity of the hypervalent compound being employed in 3 equivalents.

Against the above background, we recently reported the results of a chance observation involving conversion of diols to lactones in nitromethane at r.t. with the precursor of a pentavalent iodine, i.e., a biphenyl-based diiodo diacid **DIDA** (Chart 1),[5] employed as a catalyst in the presence of oxone as a terminal oxidant; it is noteworthy that the application catalytically of the precursor of a hypervalent iodine compound in the presence of a co-oxidant such as oxone

is a new and recent dimension in hypervalent iodine-mediated oxidation chemistry, which obviates isolation of heat- and shock-sensitive IBX.[6,7] The diiodo-diacid **DIDA** was found to be a respectable reagent for conversion of activated diols to their corresponding lactones catalytically.[5] Presumably, the methoxy substituents attenuate reactivity of the in situ-generated **Bis-IBX** such that the conversion of diols to lactones occurs only when the former are activated; the methodology was found to be unsuccessful for aliphatic diols and led to poor yields or no reaction at all when the diols were electron-rich and deficient, respectively.[5] We were, therefore, motivated to develop a facile and catalytic protocol for the synthesis of lactones from a domino oxidation of diols based on an in situ-generated more reactive hypervalent iodine reagent. We surmised that the precursor of **TetMe-IBX**, i.e., **TetMe-IA**, which has been shown recently by us to be a remarkable catalyst for oxidation of alcohols to their corresponding oxidation products,[7] could be an effective catalyst for the oxidation of diols as well. The rationale for our conviction were the following: i) the little yet meaningful twisting introduced by steric relay between consecutive methyl groups has been shown to improve the solubility of IBX, and ii) the *o*-methyl group has been demonstrated to increase the rate of alcohol oxidation. Herein, we report that **TetMe-IA** does indeed work very nicely as a catalyst for conversion of a variety of diols to latones. Mechanistically, it is shown that it is the I(V)→I(III)→I(V) cycle that is involved in the cascade oxidation in the presence of oxone as a co-oxidant.



Scheme 1. The structures of **Bis-IBX** and **TetMe-IBX** and their precursor iodo-acids, namely, **DIDA** and **TetMe-IA**, respectively.

2. Results and Discussions

The syntheses of **TetMe-IA** and **TetMe-IBX** have previously been reported from our laboratory.[7] To begin with, the reactivity of **TetMe-IBX** was investigated to test if the latter indeed works for facile conversion of benzene-1,2-dimethanol into the corresponding lactone. Buoyed by the observation of the formation of lactone smoothly, catalytic reactivity of the precursor iodo-acid, i.e., **TetMe-IA**, was investigated in the presence of added oxone. Thus, the oxidation of benzene-1,2-dimethanol to its corresponding lactone was examined as a representative case in a variety of solvents that include nitromethane, THF, ethyl acetate, ethyl formate, choloroform, dichloromethane, acetone, DMSO, DMF, acetonitrile, H_2O, etc. As shown in Table 1, the reaction initially was found to occur smoothly at r.t. in nitromethane. We observed that addition of water in nitromethane expedites the reaction, due presumably to higher solubility of oxone in the aqueous medium, which seemingly facilitates formation rapidly of the active hypervalent iodine species. From a comprehensive set of screening experiments, acetonitrile-water (1:1, v/v) was determined to be the best solvent system for domino oxidation reaction. Further, a catalyst loading of just 5 mol% was found to be sufficient for completion of

the reactions, cf. Table 1. It is pertinent to note that although the reaction underwent smooth conversion in water, the choice of water as the solvent─a genuinely green medium─was not considered due to insolubility of some diols without the added organic solvent. Besides, the reaction time in water alone was found to be slower requiring approximately 2.5 times longer duration than that in a mixed solvent system involving equal volumes of acetonitrile and water.

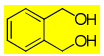
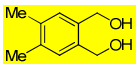
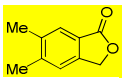
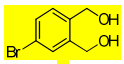
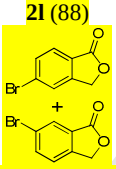
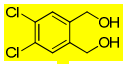
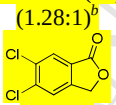
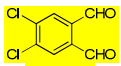
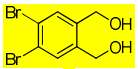
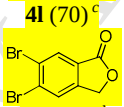
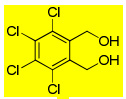
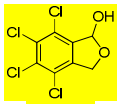
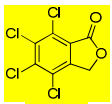
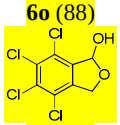
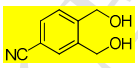
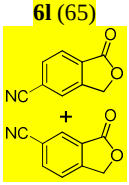
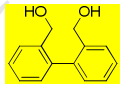
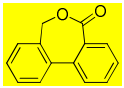
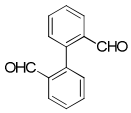
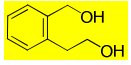
Table 1. Optimization of the Conditions for Oxidation of Benzene-1,2-dimethanol with **TetMe-IA** in the Presence of Oxone at Room Temperature.

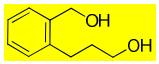
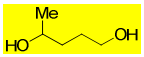
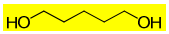
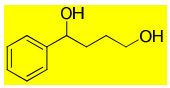
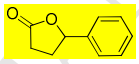
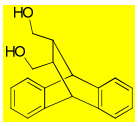
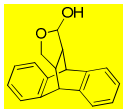
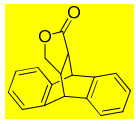
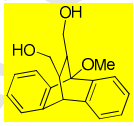
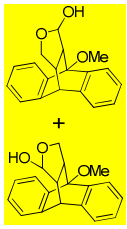
Entry	Solvent	Catalyst (mol%)	Oxone (equiv)	Time	Starting Material (%)[a]	Lactone (%)[a]	Dialdehyde (%)[a]
1	dry $MeNO_2$	10	2	35	-	96	-
2	dry DCM	10	2	36	25	44	-
3	dry THF	10	2	36	93	-	-
4	dry EtOAc	10	2	36	98	-	-
5	dry HCOOEt	10	2	36	42	48	-
6	dry $CHCl_3$	10	2	36	-	67	30
7	dry dioxane	10	2	36	99	-	-
8	dry DMF	10	2	36	98	-	-
9	dry DMSO	10	2	36	98	-	-
10	dry acetone	10	2	36	98	-	-
11	dry $MeNO_2$	10	1	36	37	60	-
12	dry $MeNO_2$	5	2	36	-	96	-
13	dry $MeNO_2$	5	1	36	55	41	-
14	dry MeCN	10	2	36	99	-	-
15	MeCN-H_2O	5	2	6.5	-	97	-
16	H_2O	5	2	15	-	96	-
17	$MeNO_2$-H_2O	10	2	16	-	94	-
18	$MeNO_2$-H_2O	5	2	27	-	94	-
19	DCM-H_2O	5	2	36	8	85	-
20	$CHCl_3$-H_2O	5	2	36	90	6	-

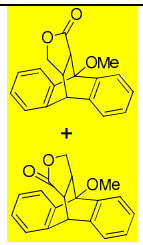
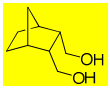
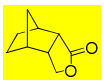
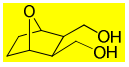
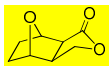
[a] The relative ratios of the products in the reaction mixture were determined by ^1H NMR analysis.

With the optimized reaction conditions, the oxidation of a variety of diols to their corresponding lactones at r.t. was investigated. The results of oxidations are summarized in Table 2.

Table 2. Catalytic Oxidation of Diols to Lactones Using **TetMe-IA**/Oxone.[a]

Entry	Substrate	Temp (°C)	Time (h)	Products (Yields, %) Lactone	Lactol	Dialdehyde
1	 **1**	30	6.5	 **1l** (97)		
2	 **2**	30	15	 **2l** (88)		
3	 **3**	30	10	 **3la** + **3lb** (79) (1.28:1)[b]		
4	 **4**	30	10	 **4l** (70)[c]		 **4d** (28)
5	 **5**	30	30	 **5l** (62)[c,d]		
6	 **6**	30	7		 **6o** (88)	
7		30	24	 **6l** (65)	 **6o** (30)	
8	 **7**	30	8	 **7la** + **7lb** (56)[e] (1:2.58)[b]		
9	 **8**	30	4	 **8l** (12)		 **8d** (76)
10	 **9**	30	4.5	 **9l** (72)		

11	 **10**	30	8		**10o** (65)
12	 **11**	45	15		**11l** (94)[f,g]
13	 **12**	45	18		**12l** (75)[f,g]
14	 **13**	60	24		**13l** (55)
15	 **14**	60	24		**14l** (25)[g,i]
16	 **15**	45	15		**15l** (15)[j]
17	 **16**	30	7		**16o** (96)
18		60	15		**16l** (82)
19	 **17**	30	19		**17oa** +**17ob** (98)

20		60	30	 **17la** + **17lb** (79) (1:1)[b]
21	 **18**	45	16	 **18l** (96)
22	 **19**	45	19.5	 **19l** (98)

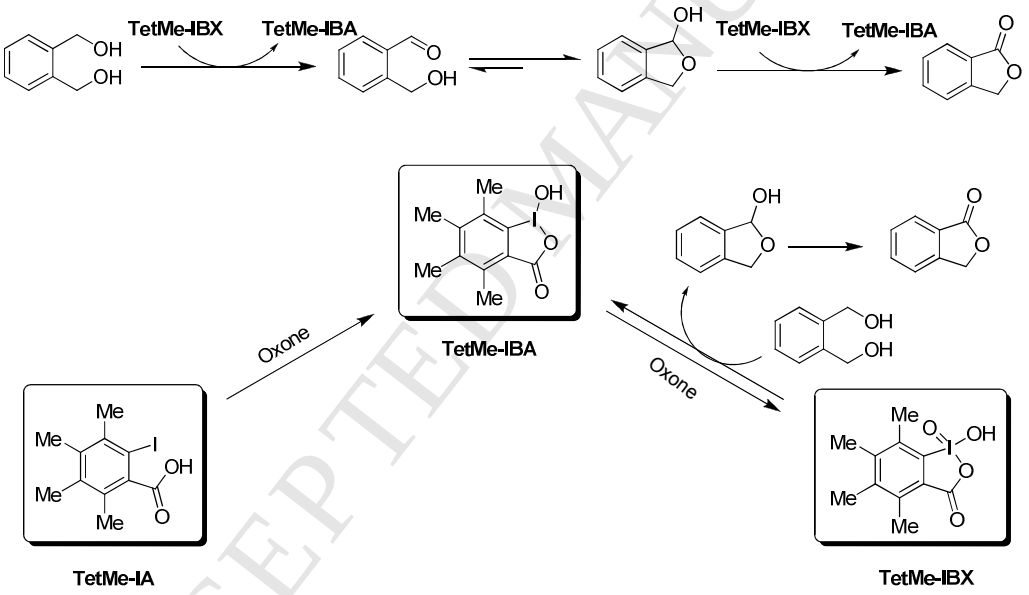
[a] Unless mentioned otherwise, all the reactions were carried out in CH_3CN/H_2O (1:1) mixture, and the yields refer to the isolated yields.
[b] Product mixtures were determined by ^1H NMR spectroscopy.
[c] Reaction was carried out in nitromethane as the solvent. Intriguingly, the same reaction in MeCN-H_2O produced a complex mixture of products.
[d] Starting material was recovered in 30% yield.
[e] The remainder corresponds to an intractable polar mixture.
[f] The reaction mixture was heated at 60 °C for two hours to ensure that the lactol was converted to lactone.
[g] Yield was determined by GC analysis using dodecane as an internal standard with response factors taken into consideration.
[h] The remainder was found to be a mixture of 5-hydroxypentanoic acid and glutaric acid.
[i] The remainder was found to be a mixture of 6-hydroxyhexanoic acid and adipic acid.
[j] 4-Hydroxy-1-phenylbutan-1-one was isolated in 55% yield. The remainder was found to be a complex mixture of polar material.

As can be perused from the results in Table 2, the catalytic protocol is effective for oxidation of a variety of both aliphatic and benzylic diols to their corresponding lactones. While the yield was found to be excellent for benzene-1,2-dimethanol (**1l**, entry 1), substitution as well as changes in the framework structure led to lesser yields (entries 2-11). The lactonization works well for diols substituted with electron-donating substituents (entry 2), and reasonably well for substrates with moderately electron-withdrawing substituents (entries 3-8). It is noteworthy that a highly electron deficient diol such as (perchloro-1,2-phenylene)dimethanol **6** yielded the corresponding

lactone **6l** in a respectable yield (entry 7), while the same was found to be inert to oxidation by **DIDA**/oxone.[5] Aliphatic 1,4-diols led to very good yields of lactones (entries 12 and 13). What is noteworthy is that the diol with a combination of primary and secondary hydroxyl groups, i.e., **12**, (entry 13) yielded predominantly the lactone **12l**, which attests to rapid oxidation of the primary hydroxyl group than the secondary one. The yields of lactones are found to drop with increasing chain length as revealed by oxidation of 1,5- and 1,6-diol **13** and **14** (entries 14 and 15). The oxidation of 1-phenyl-1,4-butandiol **15** led to the corresponding lactone **15l** in a very poor yield. In this instance, 4-hydroxy-1-phenylbutan-1-one was isolated in 55 % yield (entry 16); clearly, the benzylic oxidation is much faster. The fact that the lactol formation becomes progressively difficult with increasing chain length is clearly evident from the yields of lactones derived from butan-1,4-diol **11**, pentan-1,5-diol **13** and hexan-1,6-diol **14** (entries 12, 14 and 15). On the other hand, freezing of bond rotations in butan-1,4-diols improves the yields of domino oxidation products as is evident from the results of oxidation of conformationally locked cyclic diols (entries 18, 20, 21 and 22); the butyrolactones were accessed in very good isolated yields. In these cases, however, a relatively higher temperature (45 °C) was necessary to push the cyclization followed by oxidation to completion. Clearly, the results in Table 2 vindicate **TetMe-IA** as a powerful catalyst for sequential oxidation of the diols of a wider substrate scope to the corresponding lactones. The results of oxidation of tetrachlorobenzene-1,2-dimethanol **6** (entry 7, Table 2) and several aliphatic diols **11-19** (entries 12-22, Table 2) to their corresponding lactones establish superior reactivity of **TetMe-IA** as a catalyst over **DIDA**.

3. Mechanistic Considerations

The oxidation of diols to lactones may be readily envisaged to proceed in two steps: the first step involves oxidation of one of the two hydroxyl functionalities to the corresponding hydroxy-aldehyde that subsequently undergoes intramolecular nucleophilic attack by the alcohol to convert to lactol, Scheme 2; the second step constitutes oxidation of the lactol to a lactone. The isolation of lactol intermediate should constitute a direct proof to the reaction mechanism. Indeed, the lactol intermediates were readily isolated in at least four instances (entries 6, 11, 17, 19).

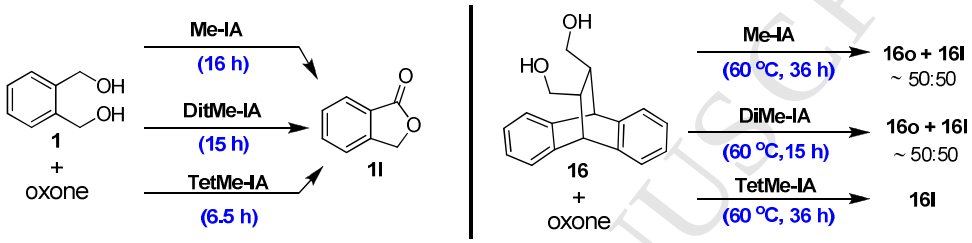


Scheme 2. Mechanism of domino oxidation of diols to the corresponding lactones.

To unequivocally establish which of the two hypervalent iodine species, i.e., I(III) and I(V), is responsible for the observed oxidations under the employed catalytic conditions, a comparative oxidation study was carried for the case of benzene-1,2-dimethanol **1** as a representative case. Thus, oxidation of the latter at r.t. was examined by employing 5 mol% of **TetMe-IA**, **TetMe-**

IBA and **TetMe-IBX** and 2 molar equivalents of oxone. The disappearance of dimethanol as monitored by TLC analysis was followed in each case. The durations for completion of the reaction with these reagents in each case were found to be 6.5, 5.0 and 4.0 h, respectively, which suggest that it is the I(V) species that is responsible for oxidations and that the catalytic cycle that is involved is I(V)→I(III)→I(V). Further, from an independent experiment, it was firmly established that the lactone formation is not observed when the reaction is run by employing two equivalents of I(III) reagent without the added oxone; the I(III) species was generated independently by reducing the I(V) reagent with a molar equivalent of *p*-bromobenzyl alcohol. The unique reactivity of **TetMe-IBX** for the cascade oxidation is compelling in light of the reported failure of the oxidation of diols to lactones with parent IBX at r.t. by Corey and co-workers long ago[8] and occurrence of the reaction only at a higher temperature in a combination of solvents, namely ethyl acetate and DMSO (9:1).[9] Indeed, when parent *o*-iodobenzoic acid was employed as the catalyst for the oxidation of benzene-1,2-dimethanol **1** under the same experimental conditions, the reaction was found to be highly sluggish. To establish the fact that the tetramethylation does indeed play a role, the oxidation of benzene-1,2-dimethanol **1** and 11,12-dihydrodibenzobarrelene-11,12-dimethanol **16**─two representative benzylic and aliphatic diols─was examined with 3-methyl-2-iodobenzoic acid (**Me-IA)**, 3,5-dimethyl-2-iodobenzoic acid (**DiMe-IA)** and **TetMe-IA** in the presence of oxone under identical conditions (Scheme 3). Although the yields of the lactone product **1l** were found to be similar for oxidation of the benzylic diol **1** with all the three reagents, the duration of reaction was found to be significantly longer (ca. 15-16 h) for **Me-IA** as well as **DiMe-IA** reagent. Further, for the case of aliphatic diol **16**, **TetMe-IA** produced the lactone **16l** cleanly at 60 °C after 15 h, while a mixture lactol **16l** and lactone **16o** in near equal amounts was obtained after 36 h when **Me-IA** and **DiMe-IA** were

employed as the catalysts in the presence of oxone under identical experimental conditions (Scheme 3). These results clearly attest to the superior oxidation capability of in situ-generated **TetMe-IBX**. The enhanced reactivity and better solubility evidently manifests in short reaction times when **TetMe-IA** is employed as the catalyst.



Scheme 3. Results of catalytic oxidation of diols with **Me-IA** and **DiMe-IA** in comparison with **TetMe-IA** in the presence of oxone under identical experimental conditions.

4. Conclusions

Environmentally-benign catalysts based on hypervalent iodine are appealing for facile conversion of diols to lactones, although several metal-catalyzed approaches are known.[3] We recently disclosed that the diiodo diacid based on diphenyl, namely **DIDA**, may accomplish this domino transformation, but with notable disadvantages that include poor yields in some benzylic cases and lack of oxidation with aliphatic diols.[5] We have shown in the present investigation that structurally *twisted* **TetMe-IBX**, generated in situ, can oxidize a variety of diols to lactones. The simple experimental conditions involving the use of acetonitrile-water medium and room temperature for a cascade reaction should constitute a leap forward in the catalytic reactions based on hypervalent I(V) reagents.

5. Experimental Section

5.1. General Aspects

Solvents were distilled prior to use and double distilled water was used for the reaction. Dry solvents used for the screening experiments were obtained following the standard drying techniques. Reactions were carried out in an open atmosphere without any precaution. Products of oxidation were isolated by column chromatography using silica gel of of 100−200 μm particle size. NMR spectra were recorded with JEOL 400 and 500 MHz spectrometers using $CDCl_3$ and CD_3OD as solvents with no internal standards added to them. The values of chemical shifts have been reported in ppm. In cases where the formation of two regioisomeric oxidation products was observed as expected, the relative ratio of the regioisomeric products was determined by integrations of the diagnostic signals in the ^1H NMR spectrum of the mixture.

5.2. General Procedure for Catalytic Oxidation of Diols to Lactones Using TetMe-IA via In situ-Generated TetMe-IBX. In a typical experiment, a round bottom flask containing 4-6 mL of acetonitrile-water mixture (1:1) was charged with 0.5-1.0 mmol of the diol, 5 mol% of **TetMe-IA**, and oxone (2 equiv). The resulting mixture was stirred at r.t. for benzylic diols and at 45 °C for aliphatic diols. At the end of the reaction, as judged from TLC analysis, little water was added to dissolve the inorganic salts, and the organic matter was extracted with EtOAc at least two times. The combined extract was dried over anhydrous Na_2SO_4, concentrated in vacuo to obtain the crude product, which was subjected to silica-gel column chromatography using ethyl acetate/ pet ether to isolate the pure product.

5.3. Characterization Data of All Products.

5.3.1. Isobenzofuran-1(3*H*)-one (**1l**).[10] Colorless solid; R_f (25% EtOAc/pet. ether) 0.55; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 5.33 (s, 2H), 7.49-7.56 (m, 2H), 7.67-7.71(m, 1H), 7.93 (d, J = 7.8 Hz, 1H).

5.3.2. 5,6-Dimethylisobenzofuran-1(3*H*)-one (**2l**).[11] Colorless solid; R_f (25% EtOAc/pet. ether) 0.58;^{1}H NMR ($CDCl_3$, 500 MHz) δ 2.36 (s, 3H), 2.39 (s, 3H), 5.24 (s, 2H), 7.24 (s, 1H), 7.67 (s, 1H).

5.3.3. 5-Bromoisobenzofuran-1(3*H*)-one (**3la**).[12] Colorless solid; R_f (25% EtOAc/pet. ether) 0.50;^{1}H NMR ($CDCl_3$, 400 MHz) δ 5.30 (s, 2H), 7.67 (s, 1H), 7.68 (d, J = 8.56 Hz, 1H), 7.79 (d, J = 8.56 Hz, 1H).

5.3.4. 6-Bromoisobenzofuran-1(3*H*)-one (**3lb**).[13] Colorless solid; R_f (25% EtOAc/pet. ether) 0.50; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 5.29 (s, 2H), 7.39 (d, J = 8.04 Hz, 1H), 7.80 (dd, J_1 = 8.04 Hz, J_2 = 1.72 Hz, 1H), 7.06 (d, J = 1.72 Hz, 1H).

5.3.5. 5,6-Dichloroisobenzofuran-1(3*H*)-one (**4l**).[14] Colorless solid; R_f (25% EtOAc/pet. ether) 0.40; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.29 (s, 2H), 7.63 (s, 1H), 8.00 (s, 1H).

5.3.6. 5,6-Dibromoisobenzofuran-1(3*H*)-one (**5l**).[5] Colorless solid; R_f (25% EtOAc/pet. ether) 0.40; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.26 (s, 2H), 7.82 (s, 1H), 8.16 (s, 1H).

5.3.7. 4,5,6,7-Tetrachloro-1,3-dihydroisobenzofuran-1-ol (**6o**). Colorless solid; R_f (50% EtOAc/pet. ether) 0.30; IR (KBr) cm^{-1} 3416, 2962, 1382.^{1}H NMR (CD_3OD, 500 MHz) δ 5.02 (d, J = 13.75 Hz, 1H), 5.22 (dd, J_1 = 13.75 Hz, J_2 = 2.10 Hz, 1H), 6.45 (d, J = 2.10 Hz, 1H). ^{13}C

NMR (CD_3OD, 125 MHz) δ 72.6, 102.9, 126.9, 129.0, 133.1, 134.0, 139.8, 140.9. ESI-MS^- m/z $[M+Cl]^-$ Calcd for $C_8H_4O_2Cl_5$: 306.8654, found: 306.8651.

5.3.8. 4,5,6,7-Tetrachloroisobenzofuran-1(3*H*)-one (**6l**). Colorless solid; R_f (25% EtOAc/pet. ether) 0.35; IR (KBr) cm^{-1} 1771, 1344, 1270.^{1}H NMR ($CDCl_3$, 400 MHz) δ 5.23 (s, 2H). ^{13}C NMR ($CDCl_3$, 125 MHz) δ 67.1, 122.9, 126.7, 131.6, 135.4, 138.9, 144.9, 165.7. ESI-MS^- m/z $[M-H]^-$ Calcd for $C_8HO_2Cl_4$: 268.8731, found: 268.8736.

5.3.9. 6-Cyanoisobenzofuran-1(3*H*)-one (**7lb**). Colorless solid; R_f (25% EtOAc/pet. ether) 0.45; IR (KBr) cm^{-1} 3055, 2235, 1761, 1485. ^{1}H NMR ($CDCl_3$, 400 MHz) δ 5.39 (s, 2H), 7.83 (s, 1H), 7.84 (d, J = 7.32 Hz, 1H), 8.05 (d, J = 7.32 Hz, 1H). ^{13}C NMR ($CDCl_3$, 125 MHz) δ 69.2, 117.4, 117.6, 126.3, 126.8, 129.5, 132.9, 146.6, 168.9. ESI-MS^- m/z $[M-H]^-$ Calcd for $C_9H_4O_2N$: 158.0242, found: 158.0241.

5.3.10. 5-Cyanoisobenzofuran-1(3*H*)-one (**7la**). Colorless solid; R_f (25% EtOAc/pet. ether) 0.45; IR (KBr) cm^{-1} 3092, 2236, 1762, 1428. ^{1}H NMR ($CDCl_3$, 400 MHz) δ 5.41 (s, 2H), 7.67 (d, J = 7.82 Hz, 1H), 7.96 (d, J = 7.82 Hz, 1H), 8.22 (s, 1H). ^{13}C NMR ($CDCl_3$, 125 MHz) δ 69.6, 113.8, 117.3, 123.5, 127.1, 130.0, 137.0, 150.3, 168.6. ESI-MS^- m/z $[M-H]^-$ Calcd for $C_9H_4O_2N$: 158.0242, found: 158.0241.

5.3.11. Dibenzo[c,e]oxepin-5(7*H*)-one (**8l**).[14] Colorless solid; R_f (25% EtOAc/pet. ether) 0.55; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 4.99 (s, 1H), 5.06 (s, 1H), 7.42-7.69 (m, 7H), 7.99 (d, J = 7.95 Hz, 1H).

5.3.12. Biphenyl-2,2'-dicarbaldehyde (**8d**).[15] Colorless solid; R_f (25% EtOAc/pet. ether) 0.30; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.36 (d, J = 7.72 Hz, 1H), 7.60 (t, J = 7.72 Hz, 1H), 7.67 (t, J = 6.6 Hz, 1H), 8.07 (d, J = 6.6 Hz, 1H), 9.84 (s, 1H).

5.3.13. Isochroman-1-one (**9l**).[16] Colorless solid; R_f (25% EtOAc/pet. ether) 0.45; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.07 (t, J = 5.98 Hz, 2H), 4.54 (t, J = 5.98 Hz, 1H), 7.40 (t, J = 5.4 Hz, 1H), 8.07 (d, J = 7.56 Hz, 1H), 7.54 (t, J = 7.44 Hz, 1H), 8.10 (d, J = 7.80 Hz, 1H).

5.3.14. 1,3,4,5-Tetrahydrobenzo[*c*]oxepin-1-ol (**10o**). Colorless gummy solid; R_f (25% EtOAc/pet. ether) 0.60; IR (KBr) cm^{-1} 3425, 2961, 2855, 1704, 1456.^{1}H NMR ($CDCl_3$, 500 MHz) δ 2.01 (pent, J = 6.85 Hz, 2H), 2.72 (t, J = 7.55 Hz, 2H), 4.21 (t, J = 6.62, 2H), 4.91 (s, 1H), 6.75 (d, J = 8.25 Hz, 1H), 6.87 (t, J = 7.32 Hz, 1H), 7.08-7.12 (m, 2H), 8.10 (s, 1H). ^{13}C NMR ($CDCl_3$, 125 MHz) δ 26.3, 28.5, 63.5, 115.3, 120.9, 127.0, 127.5, 130.4, 153.5, 161.2. ESI-MS$^+$ m/z $[M\text{-}OH]^+$ Calcd for $C_{10}H_{11}O$: 147.0810, found: 147.0802.

5.3.15. Dihydrofuran-2(3*H*)-one (**11l**).[17] Colorless liquid; R_f (10% EtOAc/pet. ether) 0.50; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.22–2.30 (m, 2H), 2.49 (t, J = 8.32 Hz, 2H), 4.35 (t, J = 7.08 Hz, 2H).

5.3.16. 5-Methyldihydrofuran-2(3*H*)-one (**12l**).[17] Colorless liquid; R_f (10% EtOAc/pet. ether) 0.50; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 1.41 (d, J = 6.4 Hz, 3H), 1.78-1.86 (m, 1H), 2.32-2.39 (m, 1H), 2.50-2.56 (m, 2H), 4.60-4.67 (m, 1H).

5.3.17. Tetrahydro-2*H*-pyran-2-one (**13l**).[17] Colorless liquid; R_f (10% EtOAc/pet. ether) 0.50; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 1.82-1.93 (m, 4H), 2.55 (t, J = 6.72 Hz, 2H), 4.34 (t, J = 5.58 Hz, 2H).

5.3.18. ε-Caprolactone (**14l**).[18] Colorless liquid; R_f (10% EtOAc/pet. ether) 0.50; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 1.75-1.85 (m, 6H), 2.61-2.63 (m, 2H), 4.20-4.22 (m, 2H).

5.3.19. 4-Hydroxy-1-phenylbutan-1-one.[19] Colorless solid; R_f (50% EtOAc/pet. ether) 0.40; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.02 (pent, J = 6.4 Hz, 2H), 3.14 (t, J = 6.88 Hz, 2H), 3.75 (t, J = 5.96 Hz, 2H), 7.44-7.48 (m, 2H), 7.55-7.59 (m, 1H), 7.94-7.99 (m, 2H).

5.3.20. 5-Phenyldihydrofuran-2(3*H*)-one (**15l**).[20] Colorless solid; R_f (25% EtOAc/pet. ether) 0.55; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.14-2.16 (m, 1H), 2.64-2.66 (m, 3H), 5.50-5.53 (m, 1H), 7.32-7.52 (m, 5H).

5.3.21. 4,9-benzo-1,3,3a,4,9,9a-hexahydronaphtho[2,3-c]furan-1-ol(**16o**). Colorless solid; R_f (50% EtOAc/pet. ether) 0.25; IR (KBr) cm^{-1} 3383, 2943, 1457. ^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.69-2.72 (m, 1H), 2.82-2.88 (m, 1H), 3.54 (dd, J_1 = 9.04 Hz, J_2 = 1.96 Hz, 1H), 4.02-4.06 (m, 1H), 4.18 (d, J = 3.2 Hz, 1H), 4.41 (d, J = 3.2 Hz, 1H), 4.96 (s, 1H), 7.11-7.16 (m, 4H), 7.23-7.30 (m, 4H). ^{13}C NMR ($CDCl_3$, 125 MHz) δ 45.0, 46.7, 48.4, 53.7, 69.8, 101.5, 123.9, 124.0, 124.7, 125.3, 126.3, 126.4, 126.5, 140.77, 140.80, 143.4, 143.7. ESI-MS$^+$ m/z $[M+Na]^+$ Calcd for $C_{18}H_{16}O_2Na$: 287.1048, found: 287.1040.

5.3.22. 4,9-Benzo-3a,4,9,9a-tetrahydronaphtho[2,3-c]furan-1(3H)-one (**16l**).[21] Colorless solid; R_f (25% EtOAc/pet. ether) 0.40; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.04-3.10 (m, 1H), 3.17-3.21 (m, 1H), 3.77-3.81 (m, 1H), 4.29 (d, J = 3.16 Hz), 4.33-4.37 (m, 1H), 4.71 (d, J = 3.44 Hz), 7.14-7.19 (m, 4H), 7.29-7.37 (m, 4H).

5.3.23. Endo-perhydro-4,7-methanoisobenzofuran-1-one (**18l**).[22] Colorless solid; R_f (25% EtOAc/pet. ether) 0.50; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 1.44-1.55 (m, 6H), 2.34 (s, 1H), 2.64 (s, 1H), 2.82-2.86 (m, 1H), 2.93-2.97 (m, 1H), 4.20-4.29 (m, 2H).

5.3.24. Exo-perhydro-4,7-epoxyisobenzofuran-1-one (**19l**).[23] Colorless solid; R_f (25% EtOAc/pet. ether) 0.40; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 1.47-1.60 (m, 2H), 1.73-1.85 (m, 2H),

2.70-2.74 (m, 1H), 2.78-2.80 (d, J = 8.25 Hz, 1H), 4.12 (dd, J_1 = 9.45 Hz, J_2 = 3.95 Hz, 1H), 4.43 (t, J = 9.2 Hz, 1H), 4.54 (d, J = 4.9 Hz, 1H), 4.88 (d, J = 4.85, 1H).

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Supporting Information Available. ^{1}H and ^{13}C NMR spectral reproductions for the intermediates, target compound and the products of oxidations.

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SUPPORTING INFORMATION

Facile Organocatalytic Domino Oxidation of Diols to Lactones by In Situ-Generated TetMe-IBX

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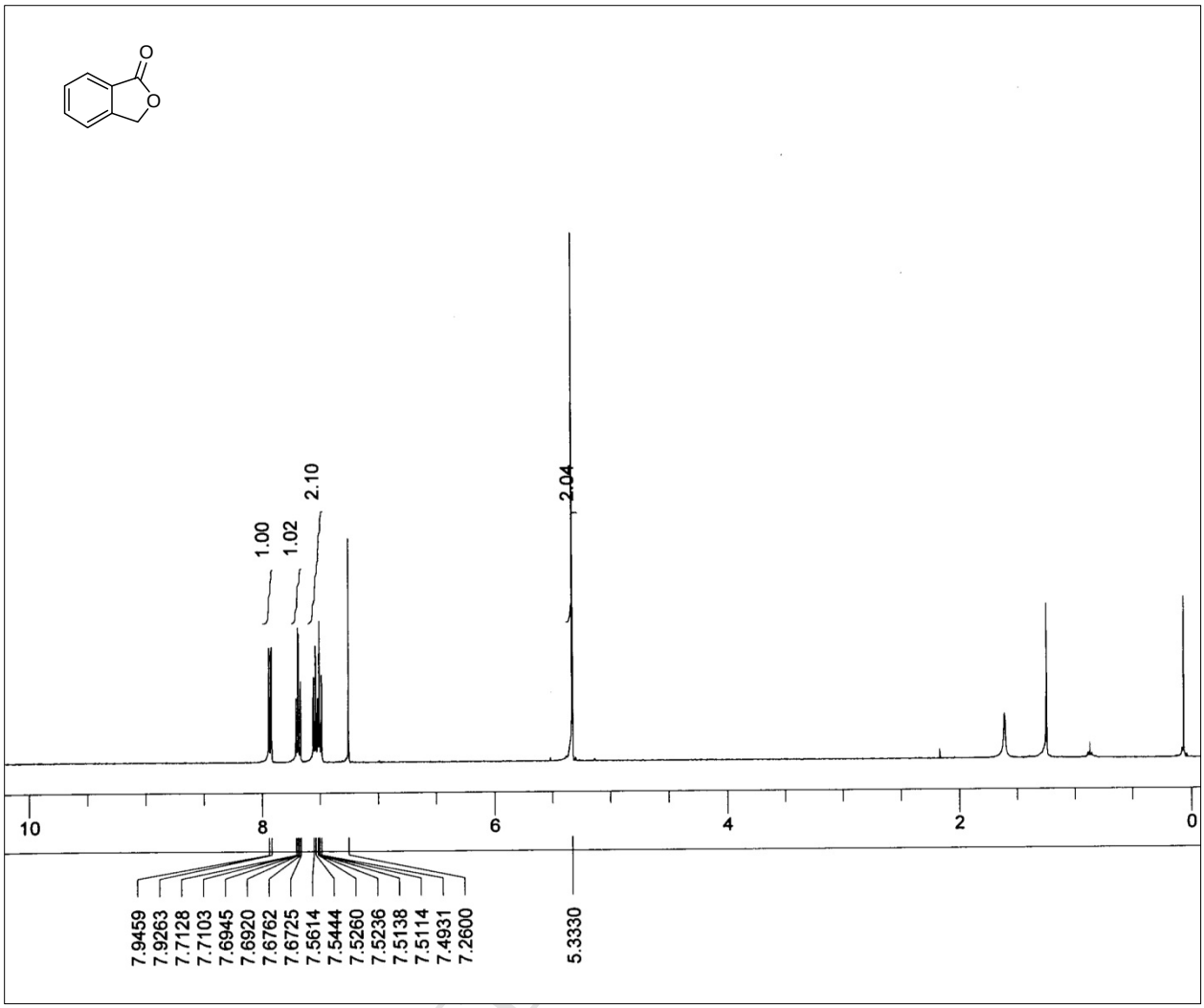


FIGURE S1. ^{1}H NMR (400 MHz) spectrum of isobenzofuran-1(3*H*)-one (**1l**)[1] in $CDCl_3$.

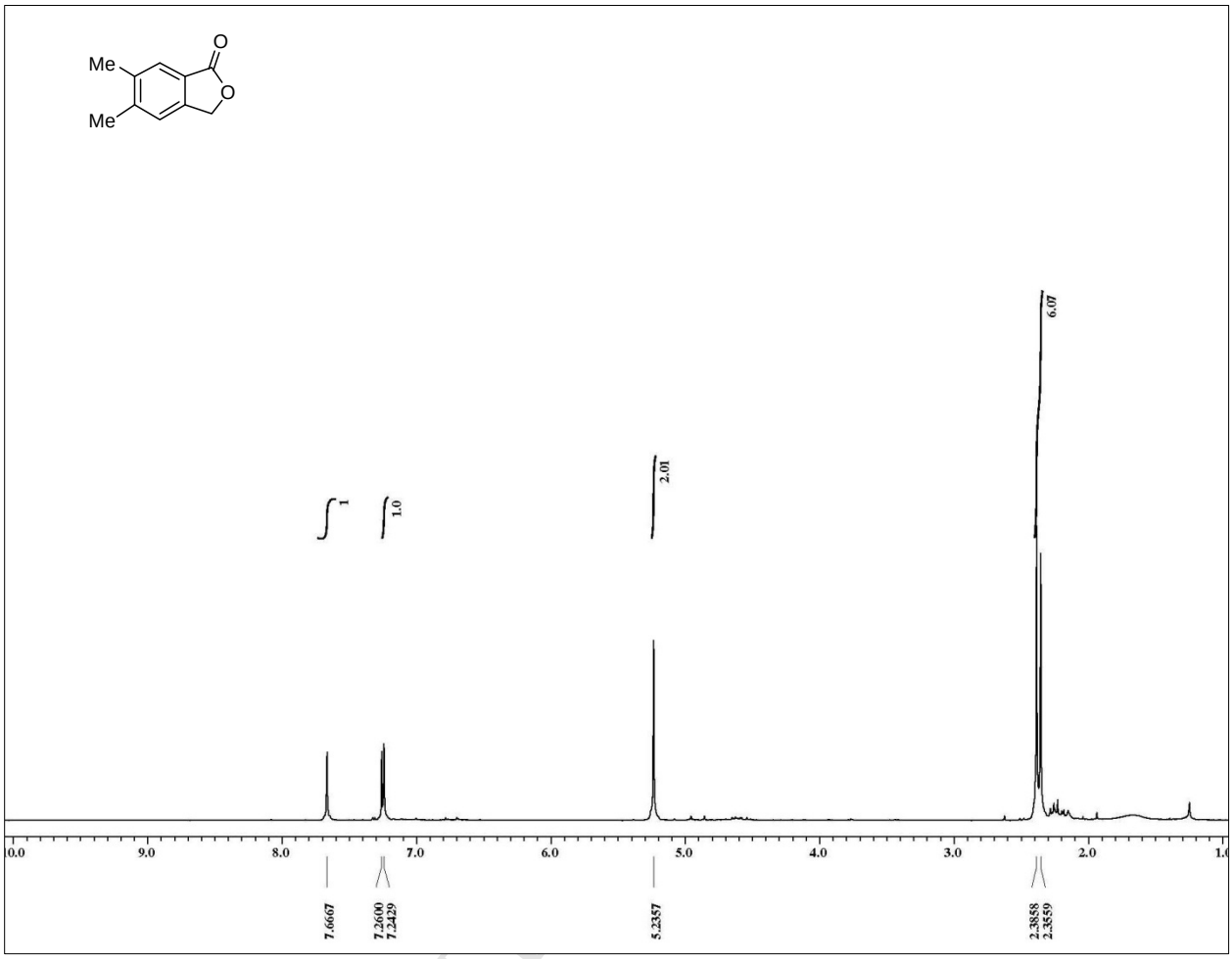


FIGURE S2. ^{1}H NMR (500 MHz) spectrum 5,6-dimethylisobenzofuran-1(3*H*)-one (**2l**)[2] in $CDCl_3$.

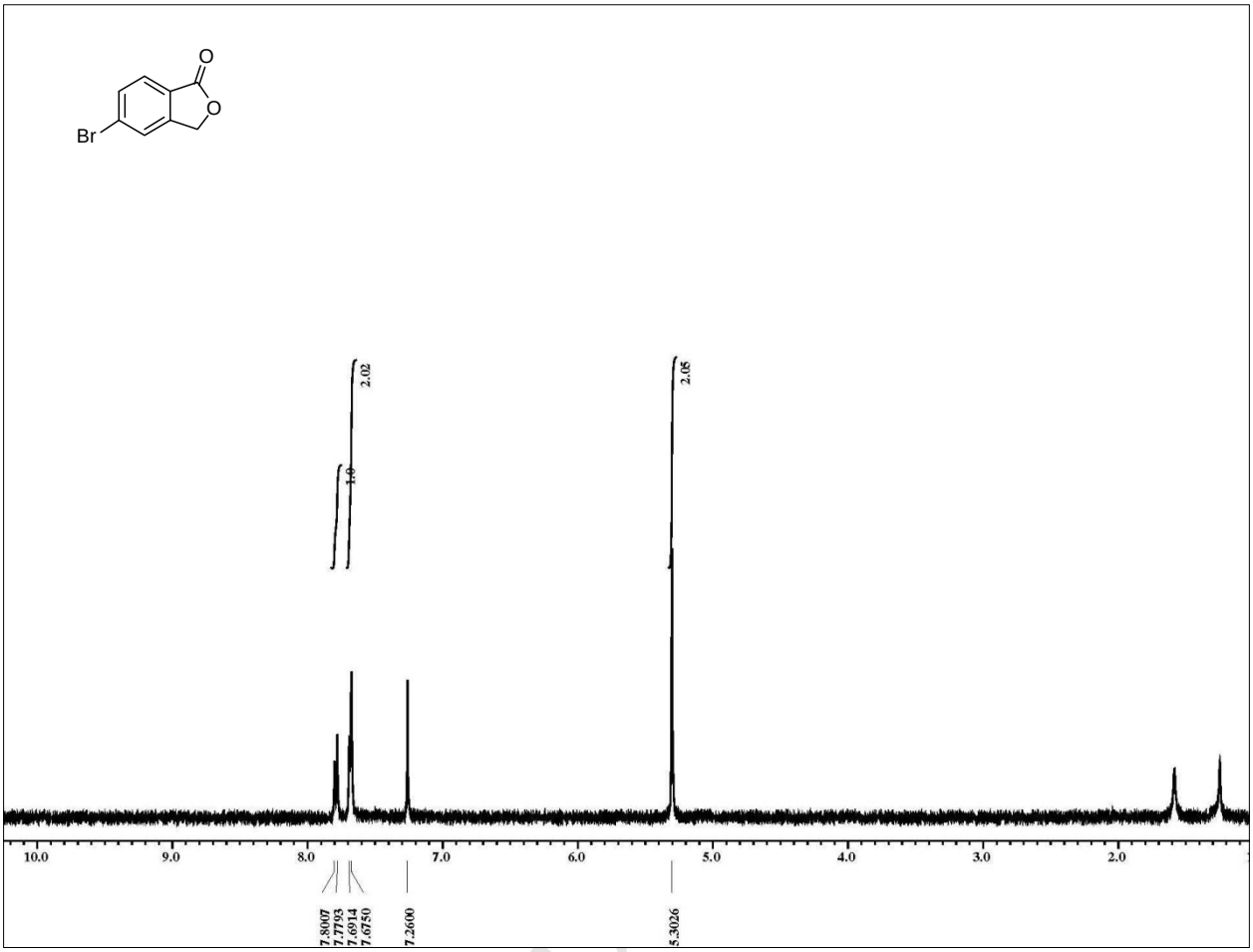


FIGURE S3. ^{1}H NMR (400 MHz) spectrum of 5-bromoisobenzofuran-1(3*H*)-one (**3la**)[3] in $CDCl_3$.

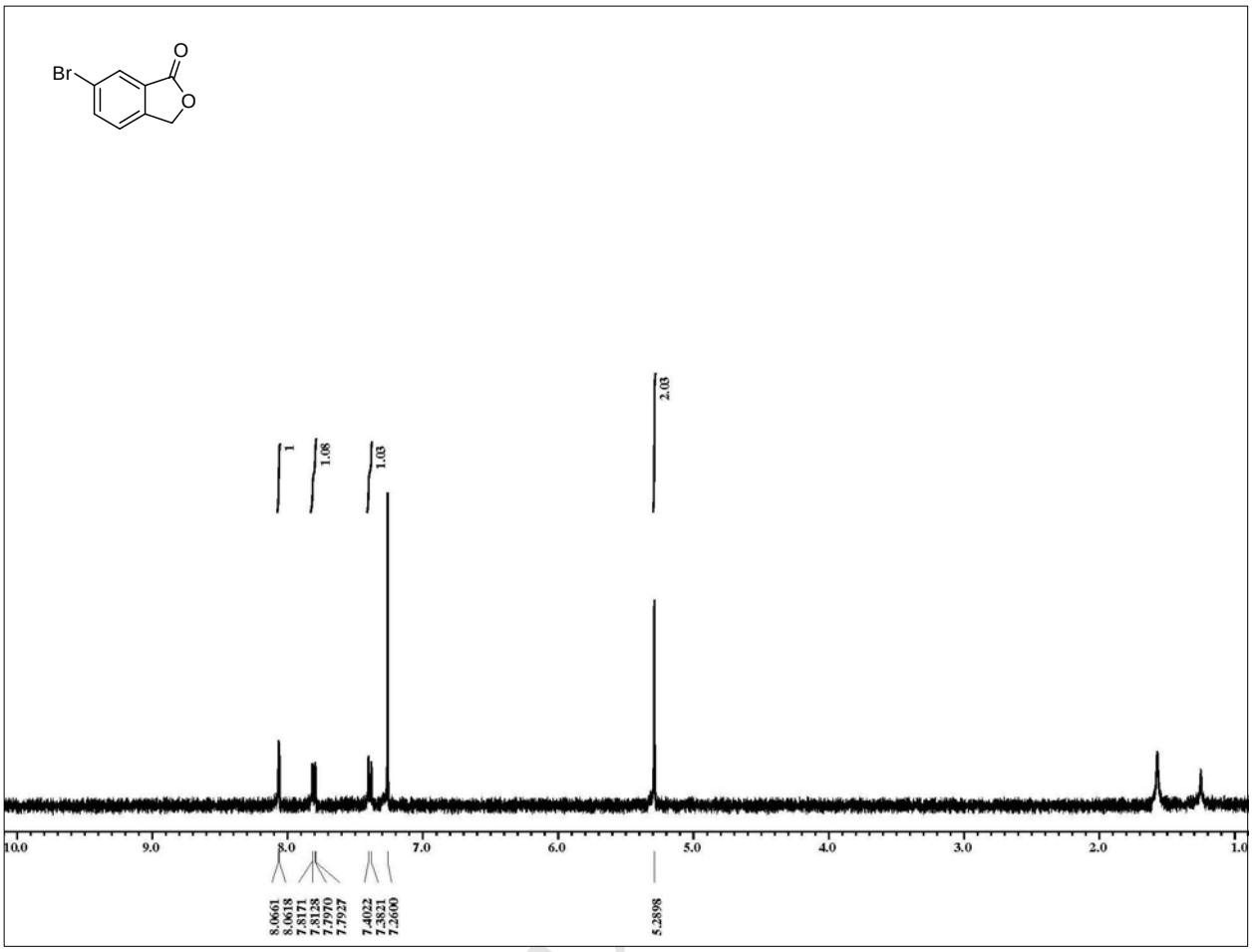


FIGURE S4. ^{1}H NMR (400 MHz) spectrum of 6-bromoisobenzofuran-1(3*H*)-one (**3lb**)[4] in $CDCl_3$.

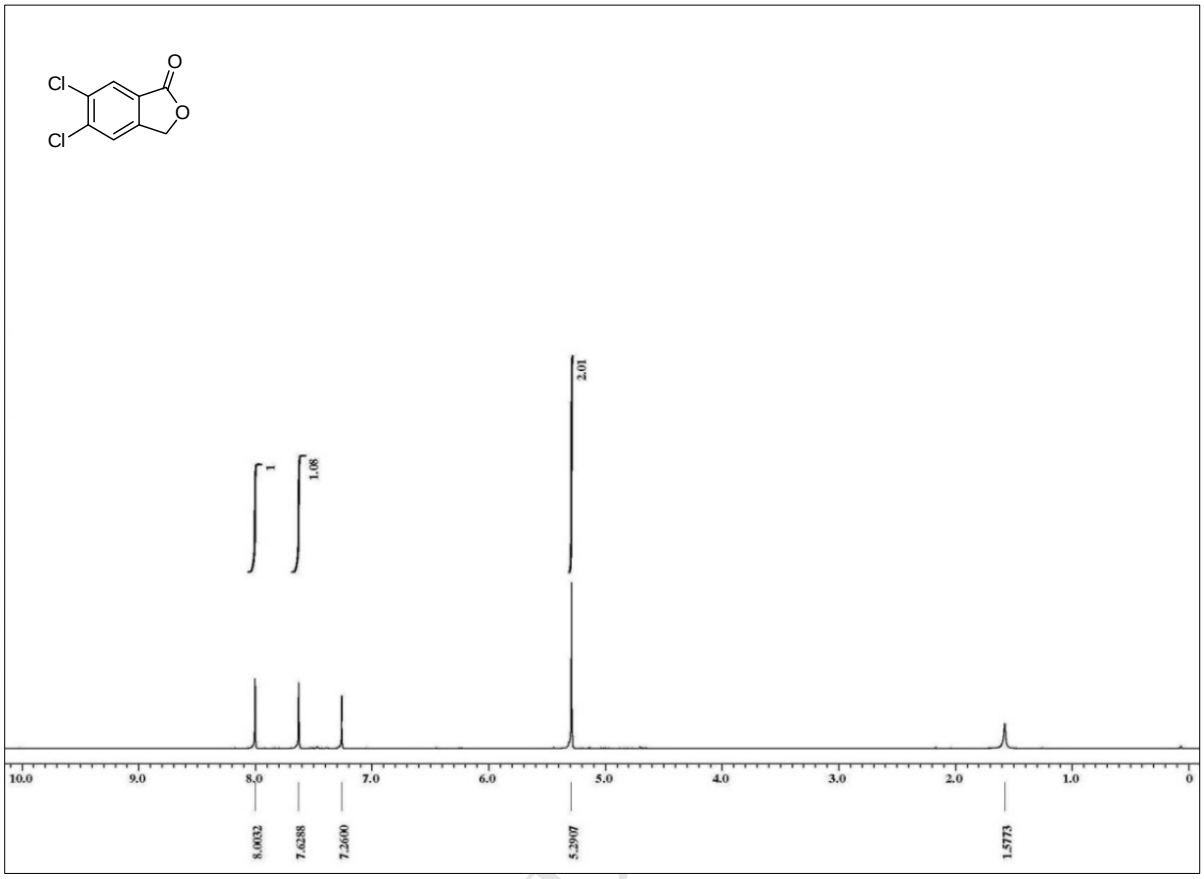


FIGURE S5. ^{1}H NMR (500 MHz) spectrum of 5,6-dichloroisobenzofuran-1(3*H*)-one (**4l**)[5] in $CDCl_3$.

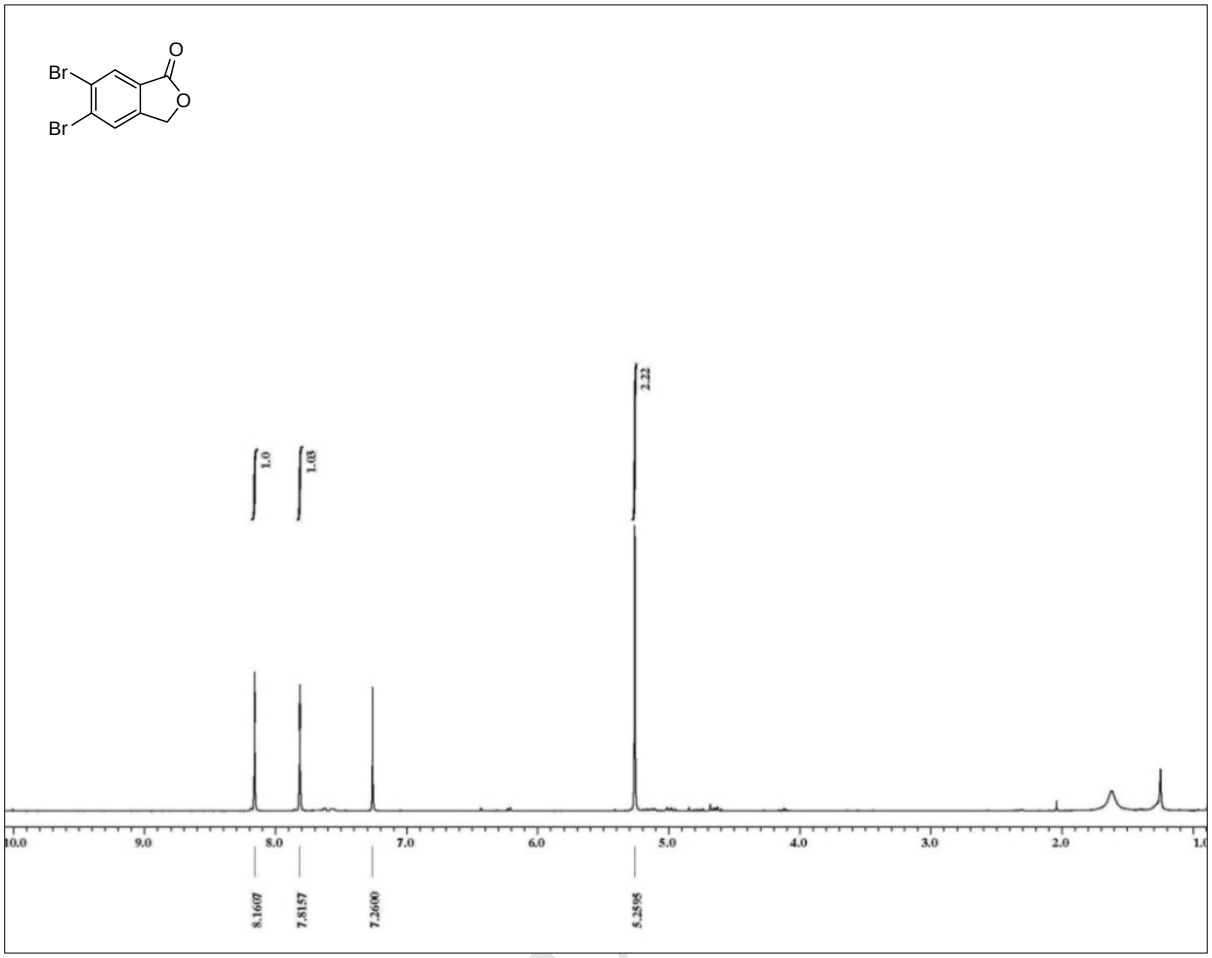


FIGURE S6. ^{1}H NMR (500 MHz) spectrum of 5,6-dibromoisobenzofuran-1(3*H*)-one (**5l**)[6] in $CDCl_3$.

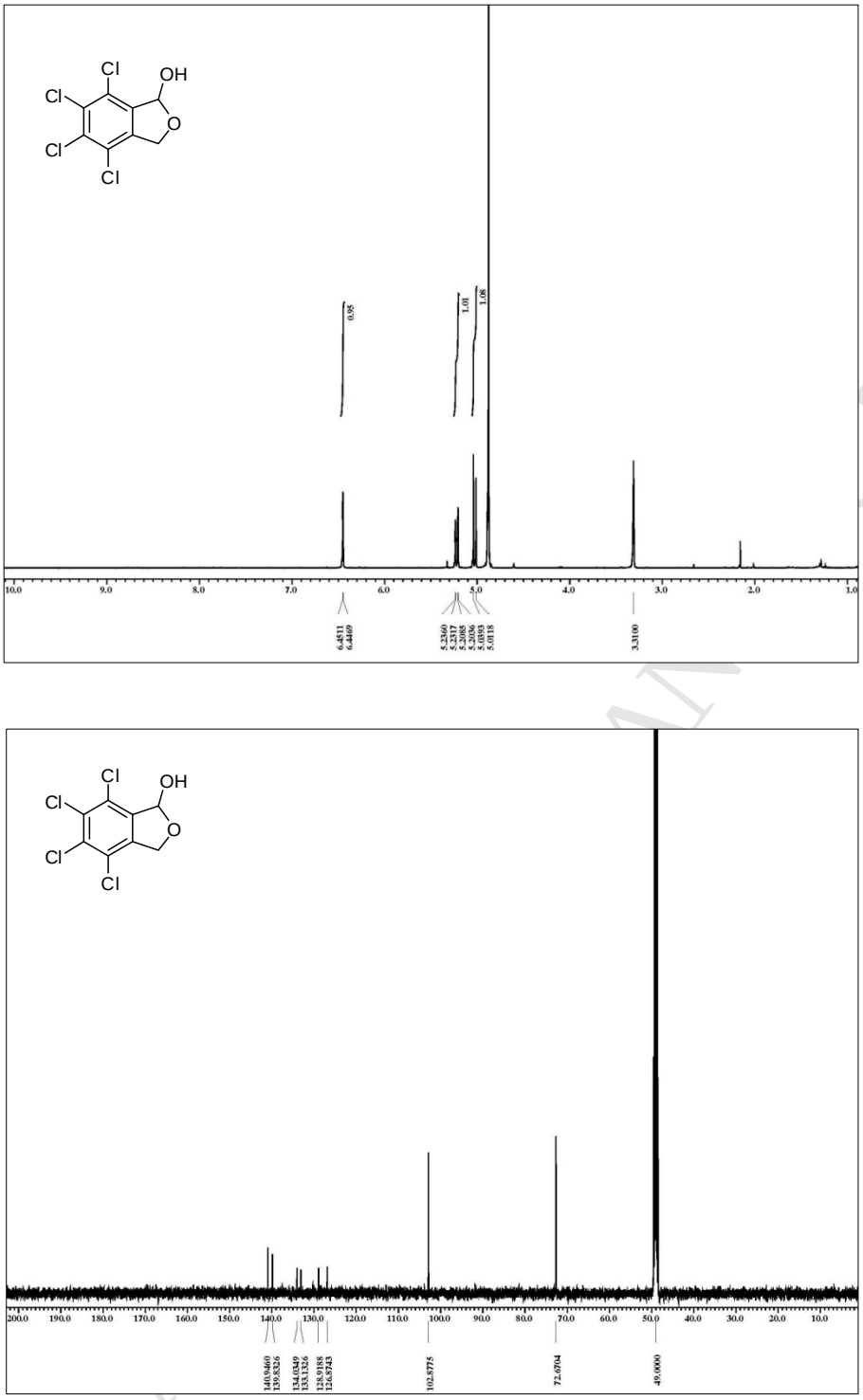
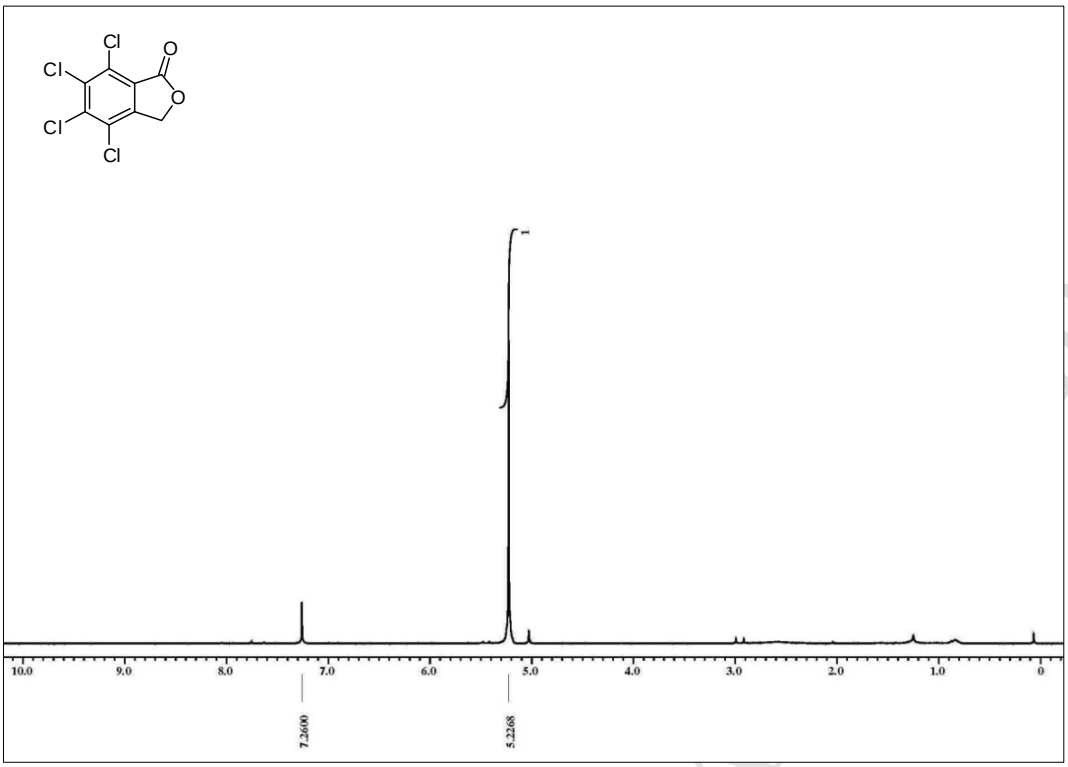


FIGURE S7. ^{1}H (500 MHz) and ^{13}C NMR (125 MHz) spectra of 4,5,6,7-tetrachloro-1,3-dihydroisobenzofuran-1-ol (**6o**) in CD_3OD.



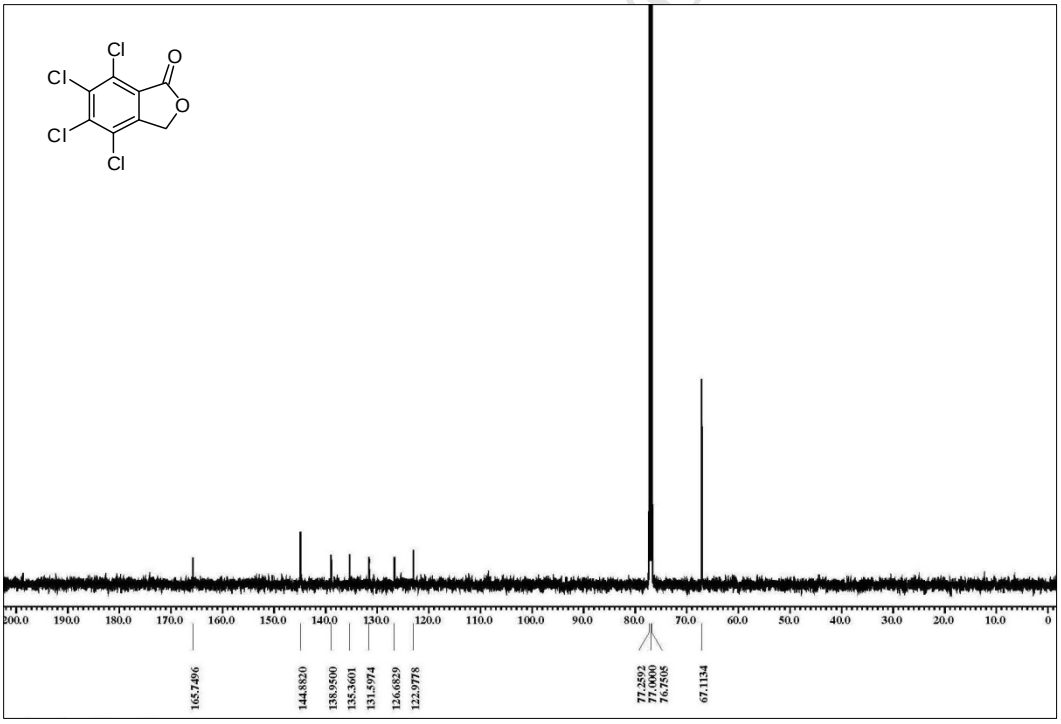
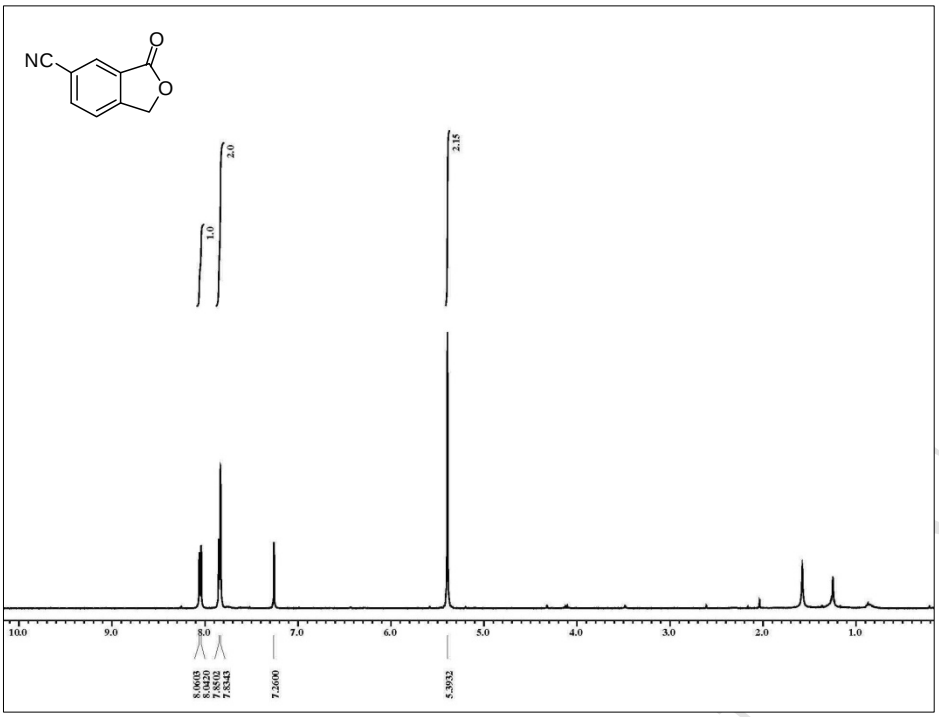


FIGURE S8. ^{1}H (400 MHz) and ^{13}C NMR (125 MHz) spectra of 4,5,6,7-tetrachloroisobenzofuran-1(3*H*)-one (**6l**) in $CDCl_3$.



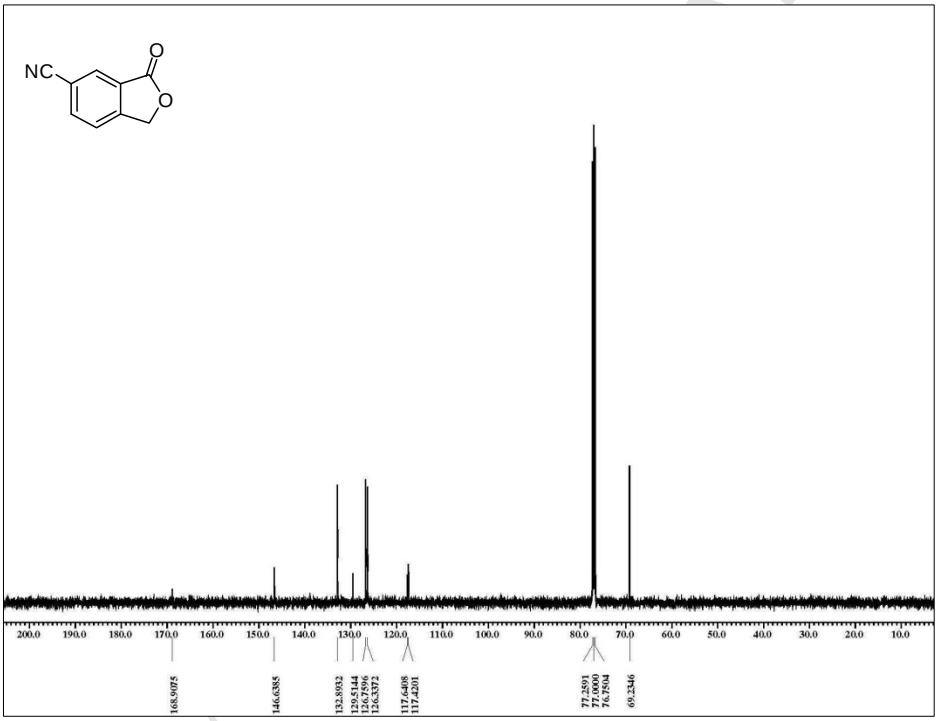


FIGURE S9. ^{1}H (400 MHz) and ^{13}C NMR (125 MHz) spectra of 6-cyanoisobenzofuran-1(3*H*)-one (**7lb**) in $CDCl_3$.

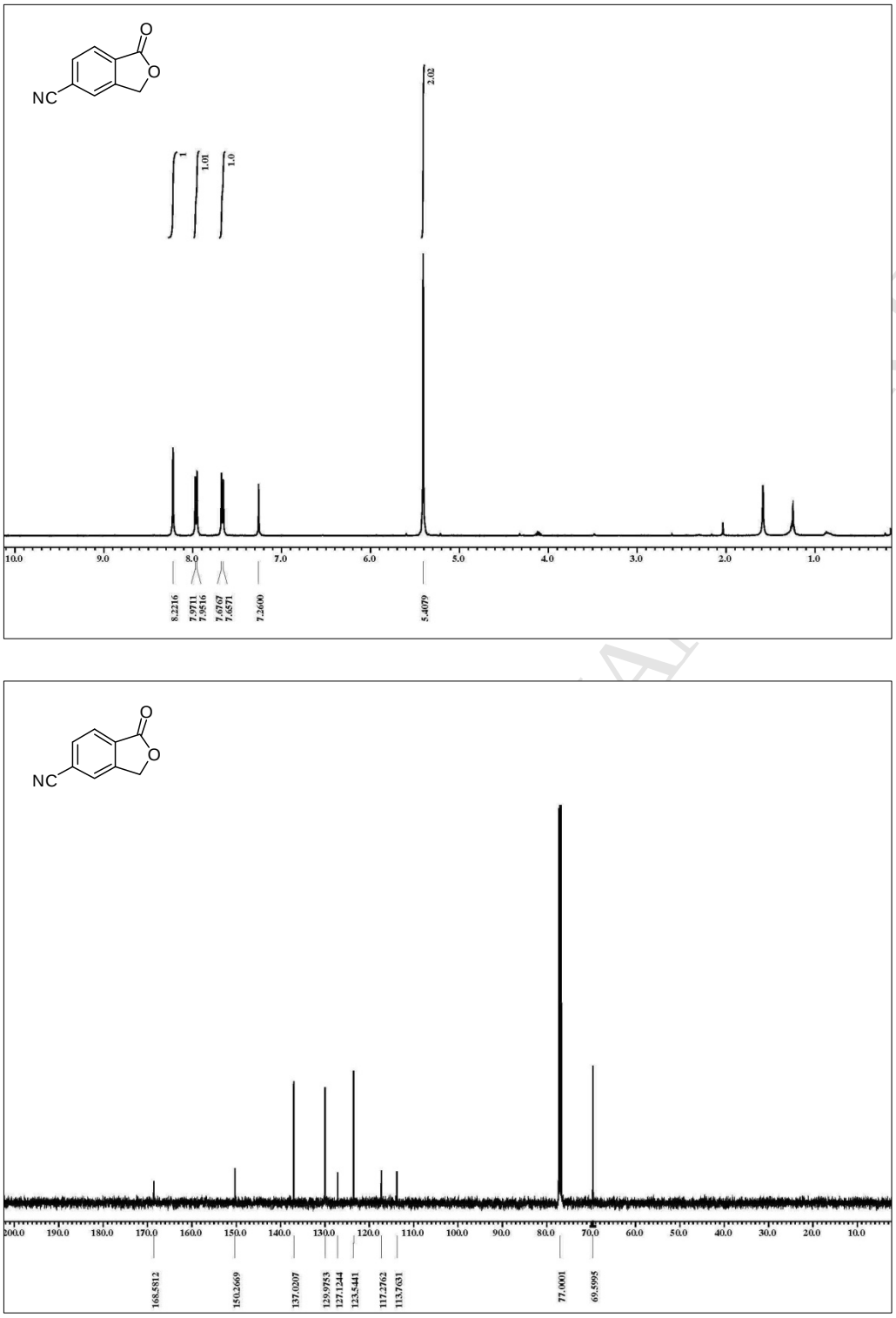


FIGURE S10. ^{1}H (400 MHz) and ^{13}C NMR (125 MHz) spectra of 5-cyanoisobenzofuran-1(3*H*)-one (**7la**) in $CDCl_3$.

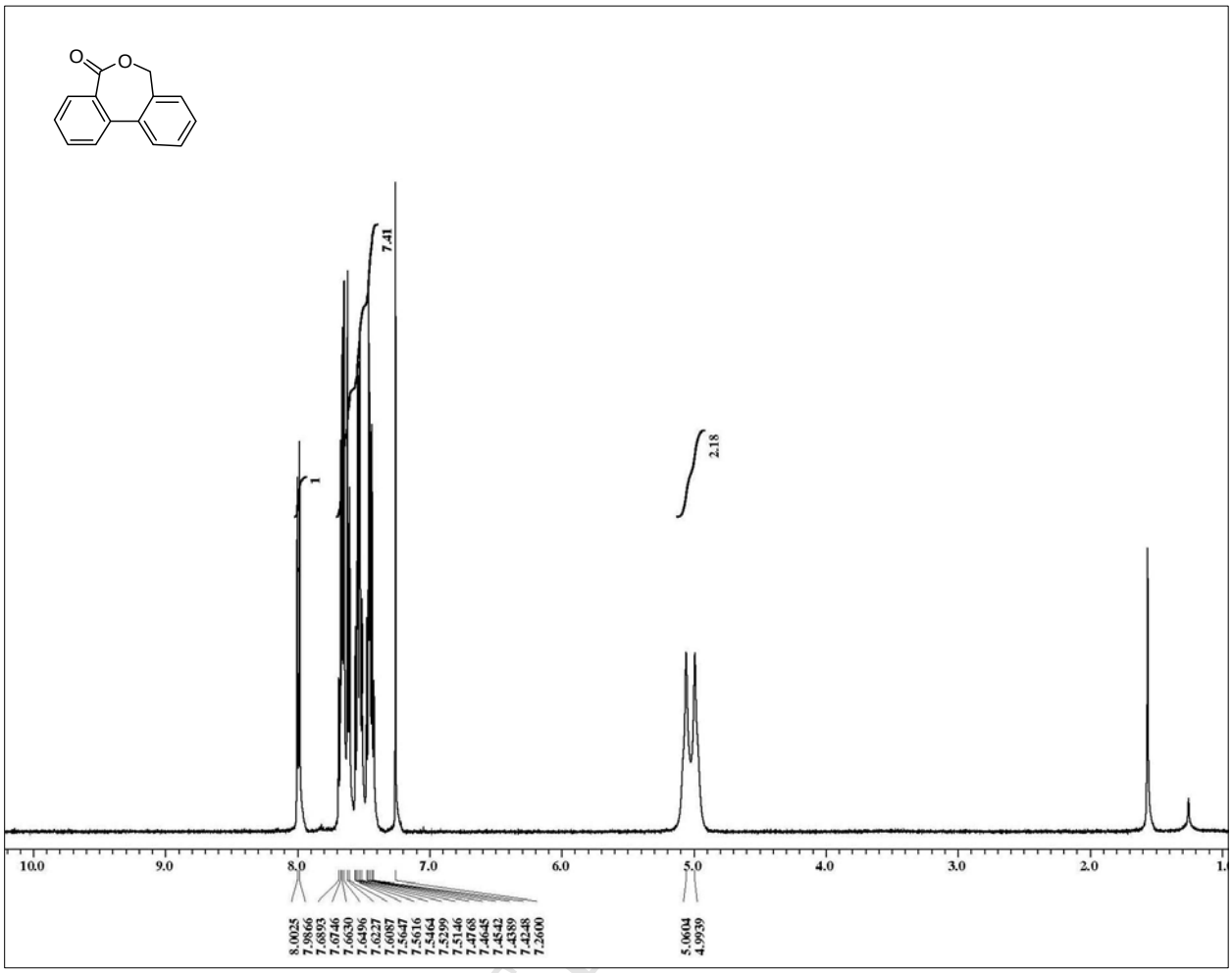


FIGURE S11. ^{1}H NMR (500 MHz) spectrum dibenzo[c,e]oxepin-5(7*H*)-one (**8l**)[5] in $CDCl_3$.

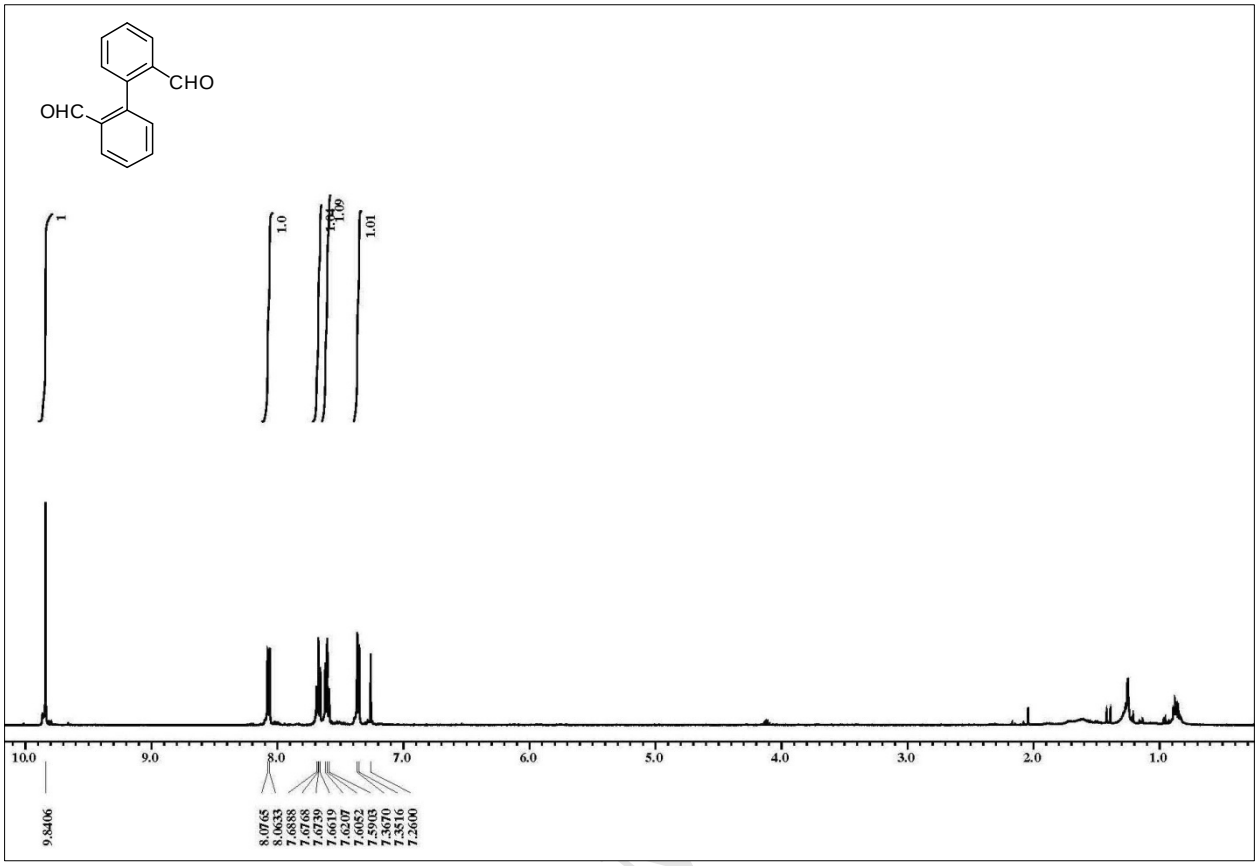


FIGURE S12. ^{1}H NMR (500 MHz) spectrum biphenyl-2,2'-dicarbaldehyde (**8d**)[7] in $CDCl_3$.

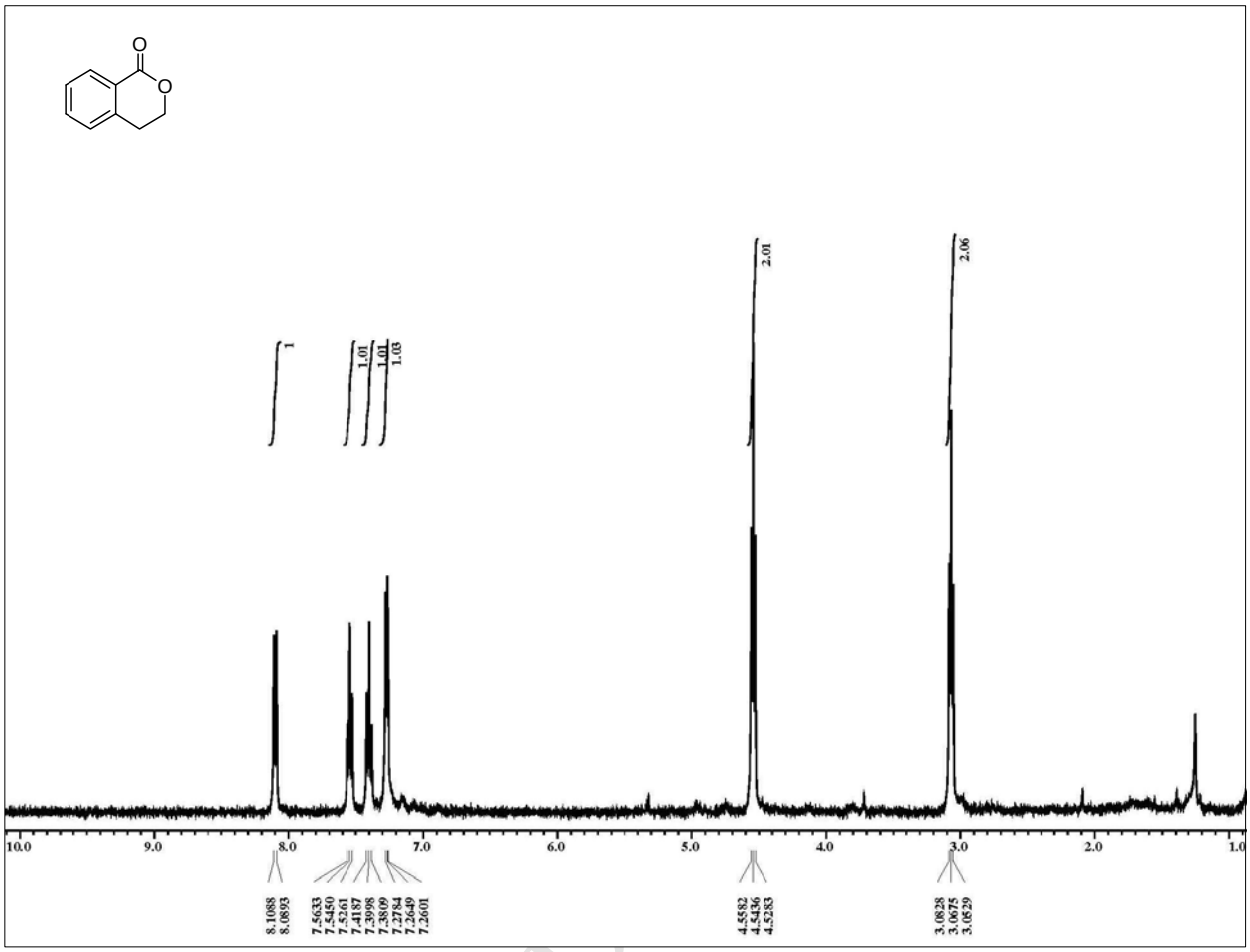


FIGURE S13. ^{1}H NMR (400 MHz) spectrum of isochroman-1-one (**9l**)[8] in $CDCl_3$.

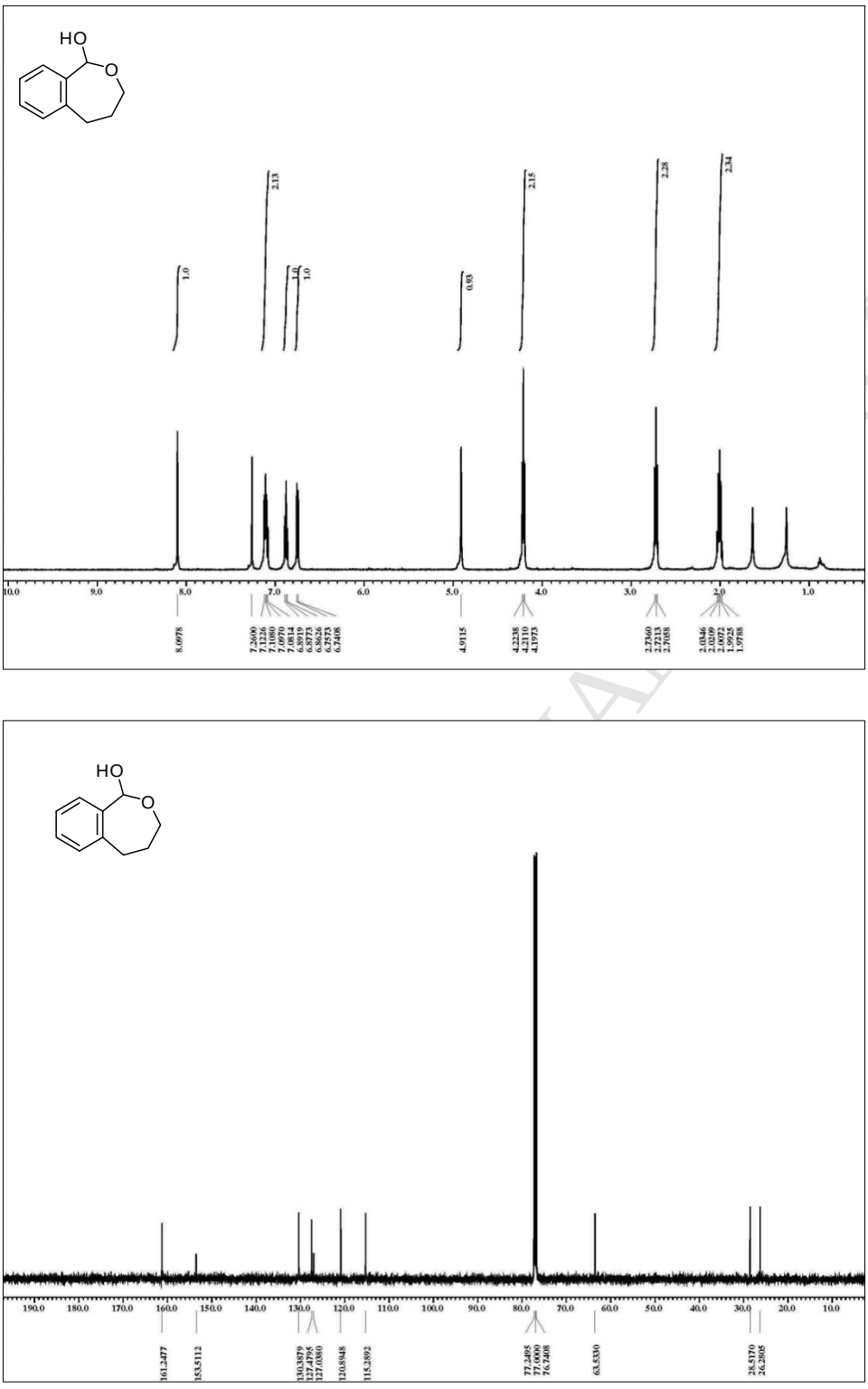


FIGURE S14. ^{1}H (500 MHz) and ^{13}C NMR (125 MHz) spectra of 1,3,4,5-tetrahydrobenzo[*c*]oxepin-1-ol (**10o**) in $CDCl_3$.

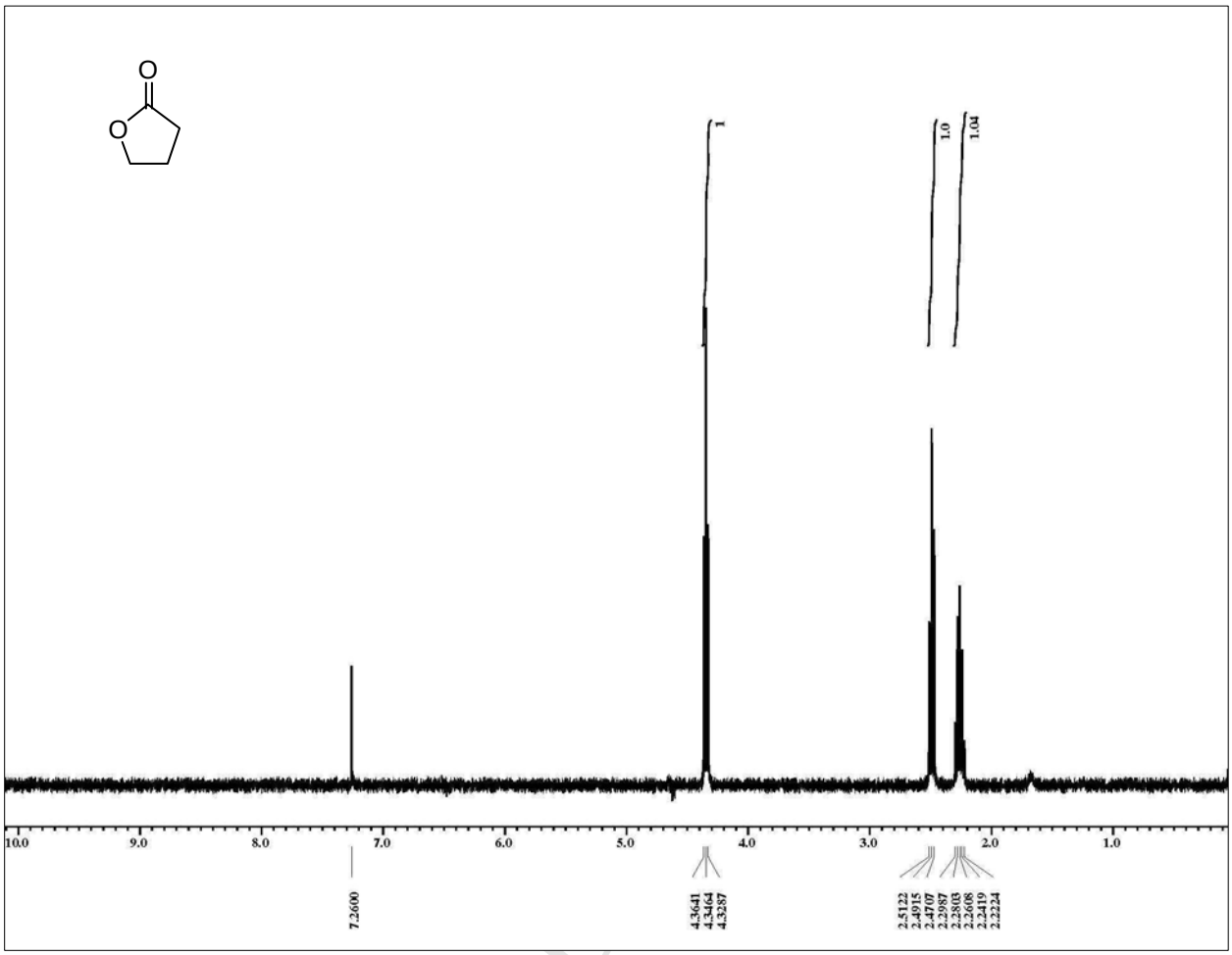


FIGURE S15. ^{1}H NMR (400 MHz) spectrum of dihydrofuran-2(3*H*)-one (**11l**)[9] in $CDCl_3$.

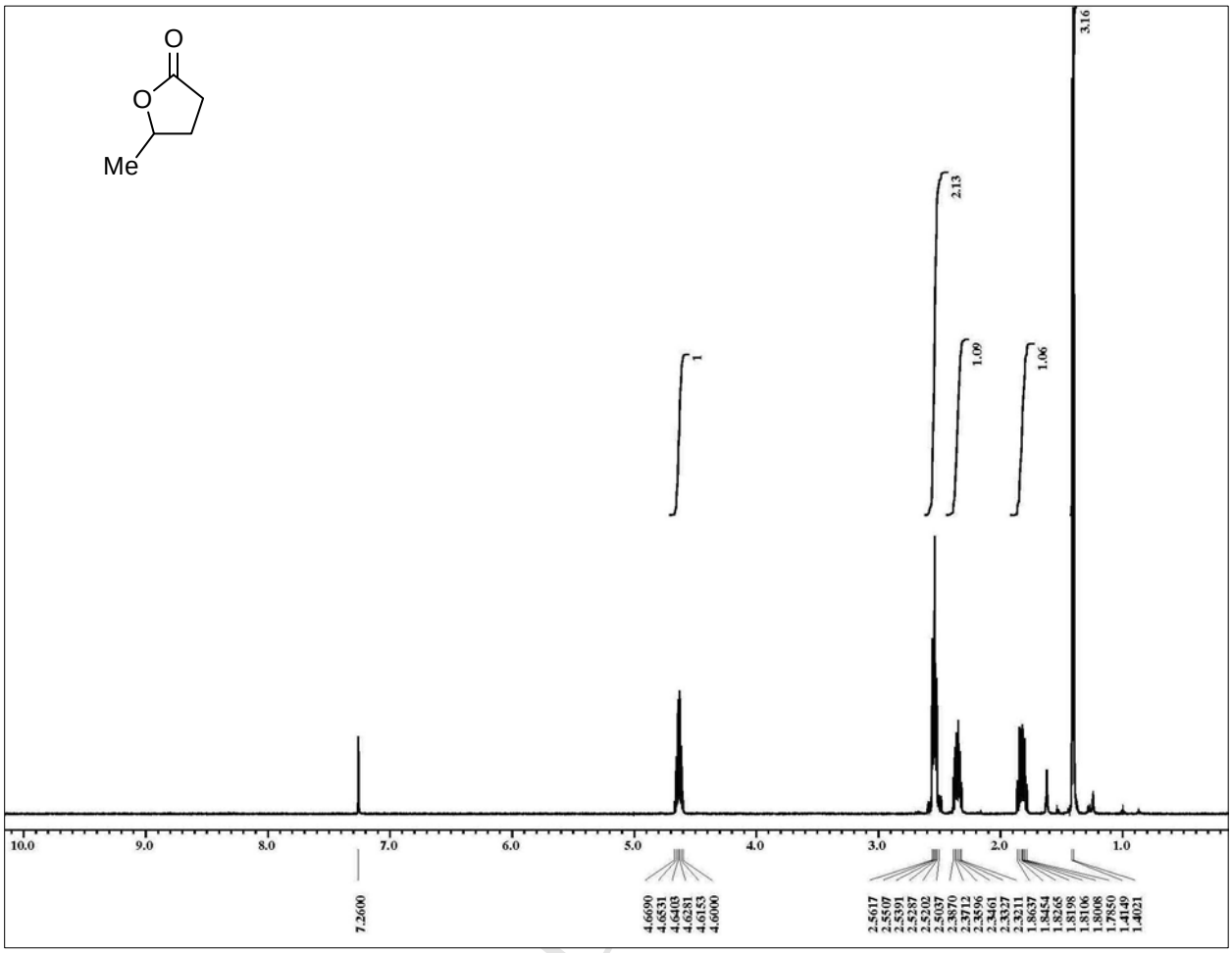


FIGURE S16. ^{1}H NMR (500 MHz) spectrum of 5-methyldihydrofuran-2(3*H*)-one (**12l**)[9] in $CDCl_3$.

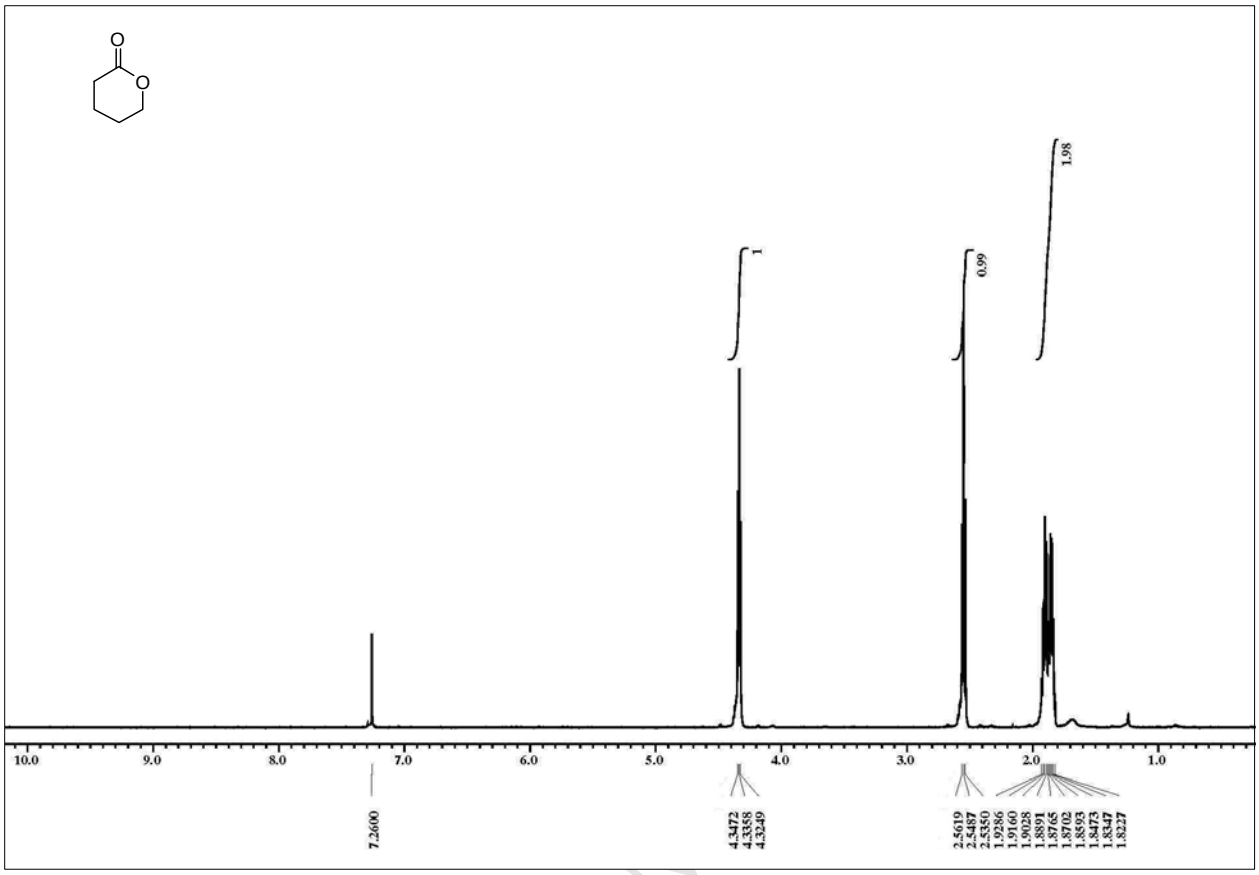


FIGURE S17. ^{1}H NMR (500 MHz) spectrum of tetrahydro-2*H*-pyran-2-one (**13l**)[9] in $CDCl_3$.

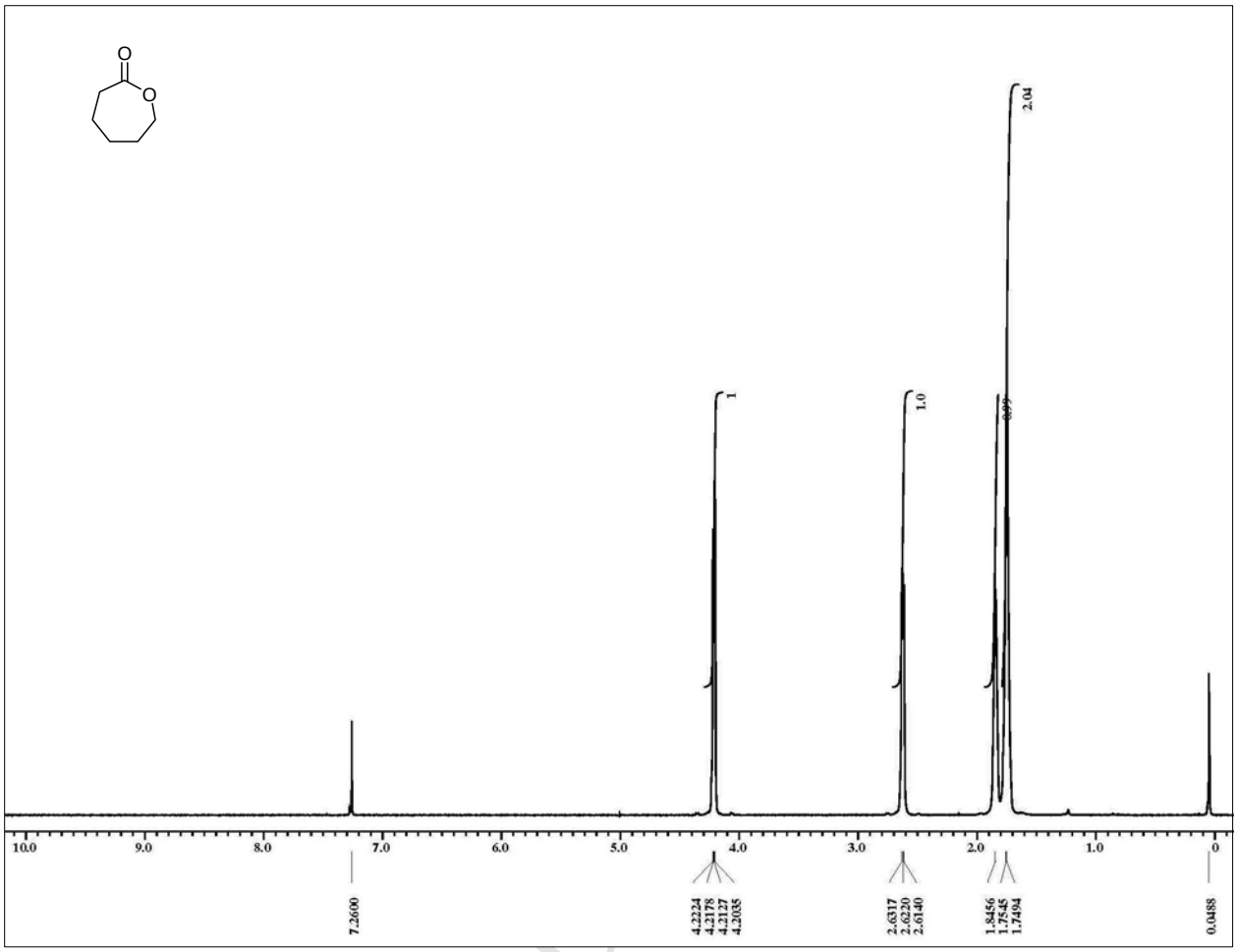


FIGURE S18. ^{1}H NMR (500 MHz) spectrum of ε-caprolactone (1**4l**)[10] in $CDCl_3$.

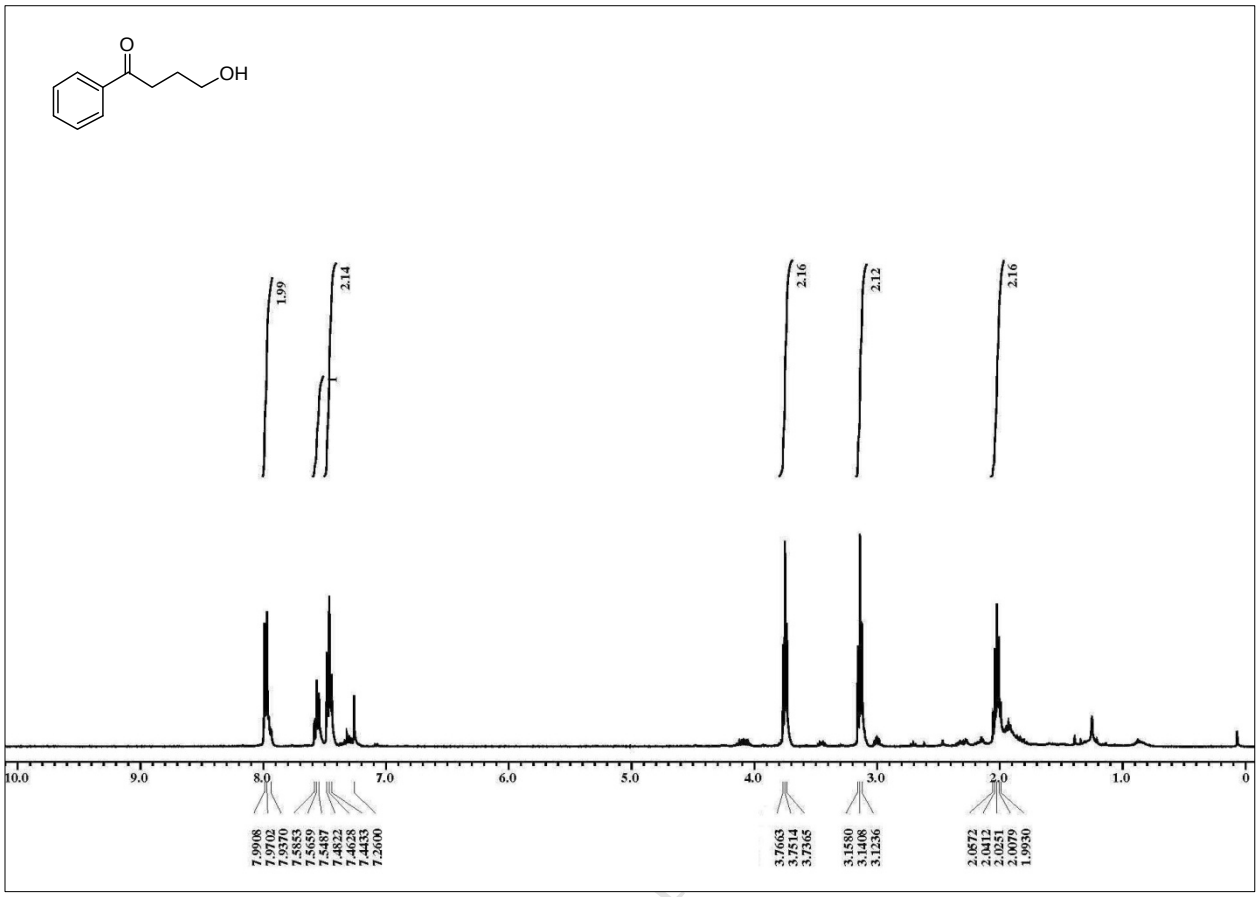


FIGURE S19. ^{1}H NMR (400 MHz) spectrum of 4-hydroxy-1-phenylbutan-1-one[11] in $CDCl_3$.

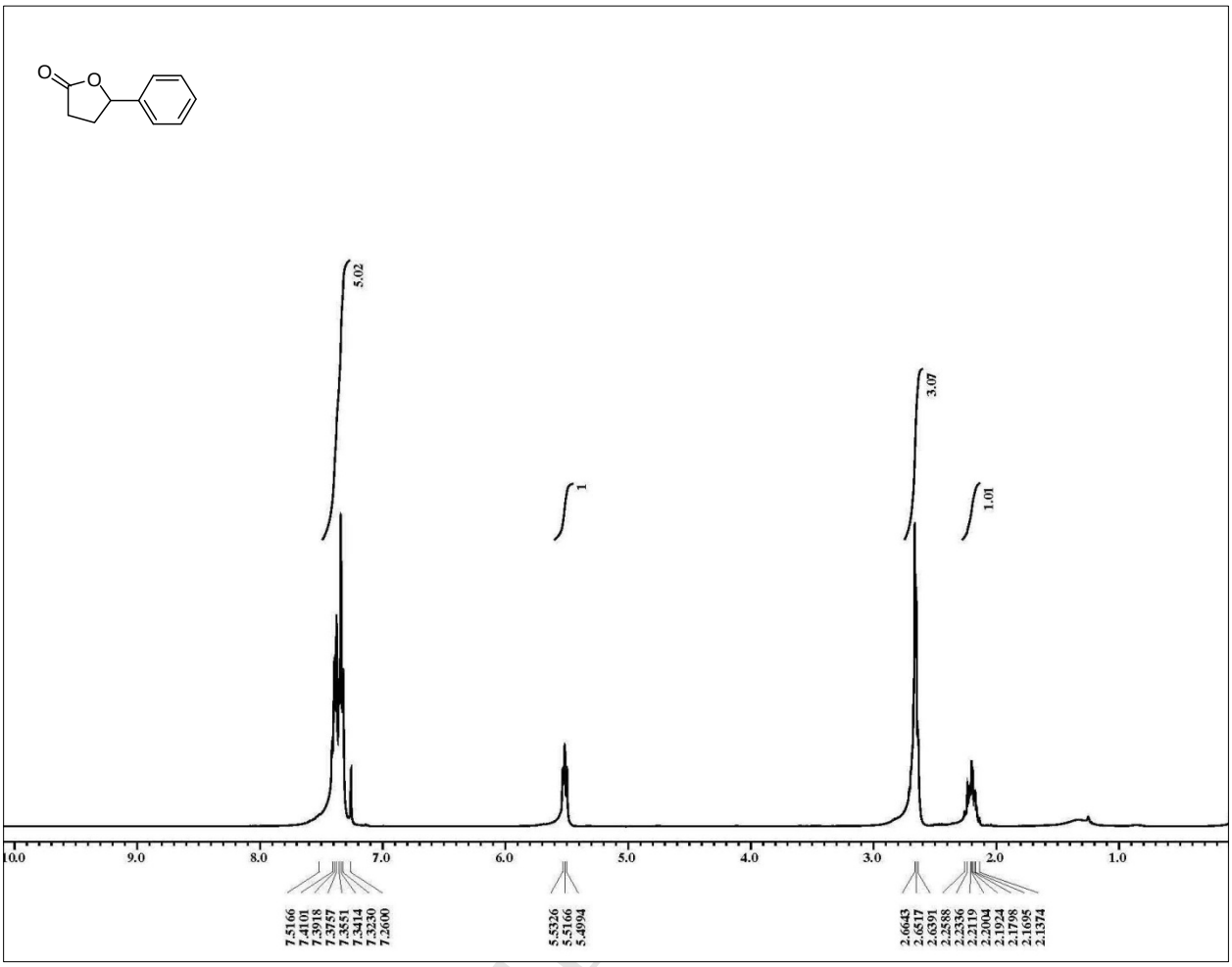


FIGURE S20. ^{1}H NMR (400 MHz) spectrum of 5-phenyldihydrofuran-2(3*H*)-one (**15l**)[12] in $CDCl_3$.

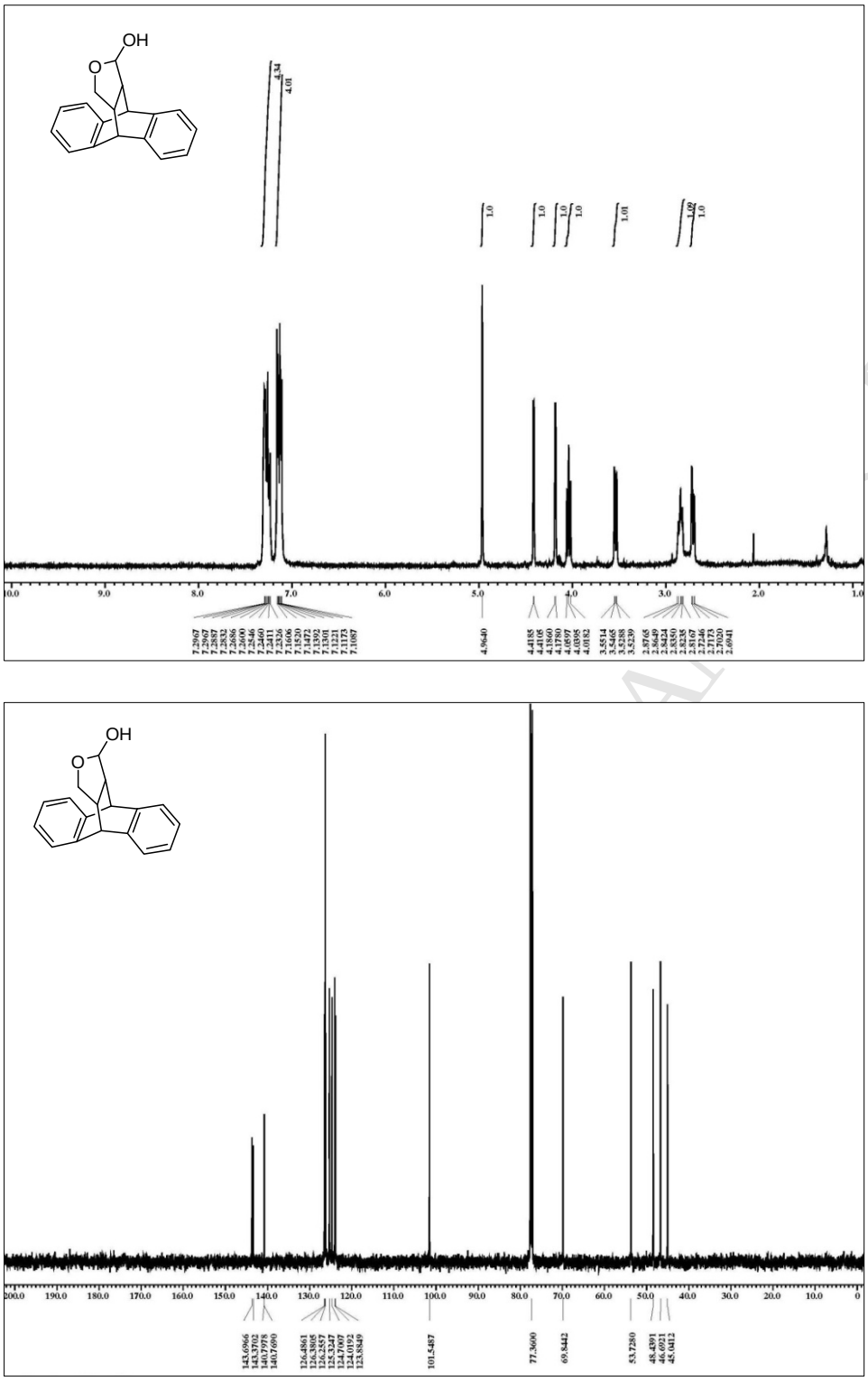


FIGURE S21. ^{1}H (400 MHz) and ^{13}C NMR (125 MHz) spectra of 4,9-benzo-1,3,3a,4,9,9a-hexahydronaphtho[2,3-c]furan-1-ol (**16o**) in $CDCl_3$.

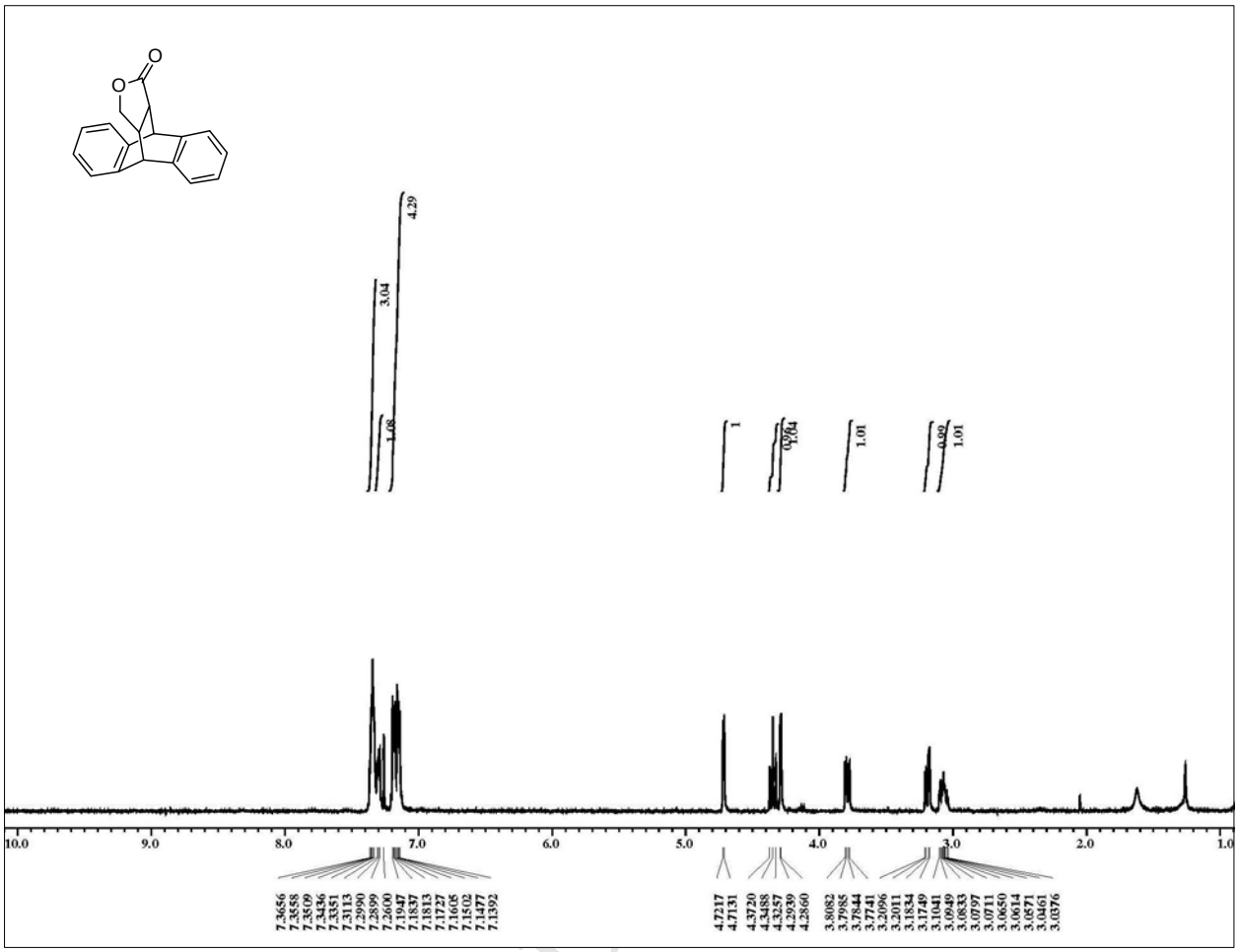


FIGURE S22. ^{1}H NMR (400 MHz) spectrum of 4,9-benzo-3a,4,9,9a-tetrahydronaphtho[2,3-c]furan-1(3H)-one (**16l**)[13] in $CDCl_3$.

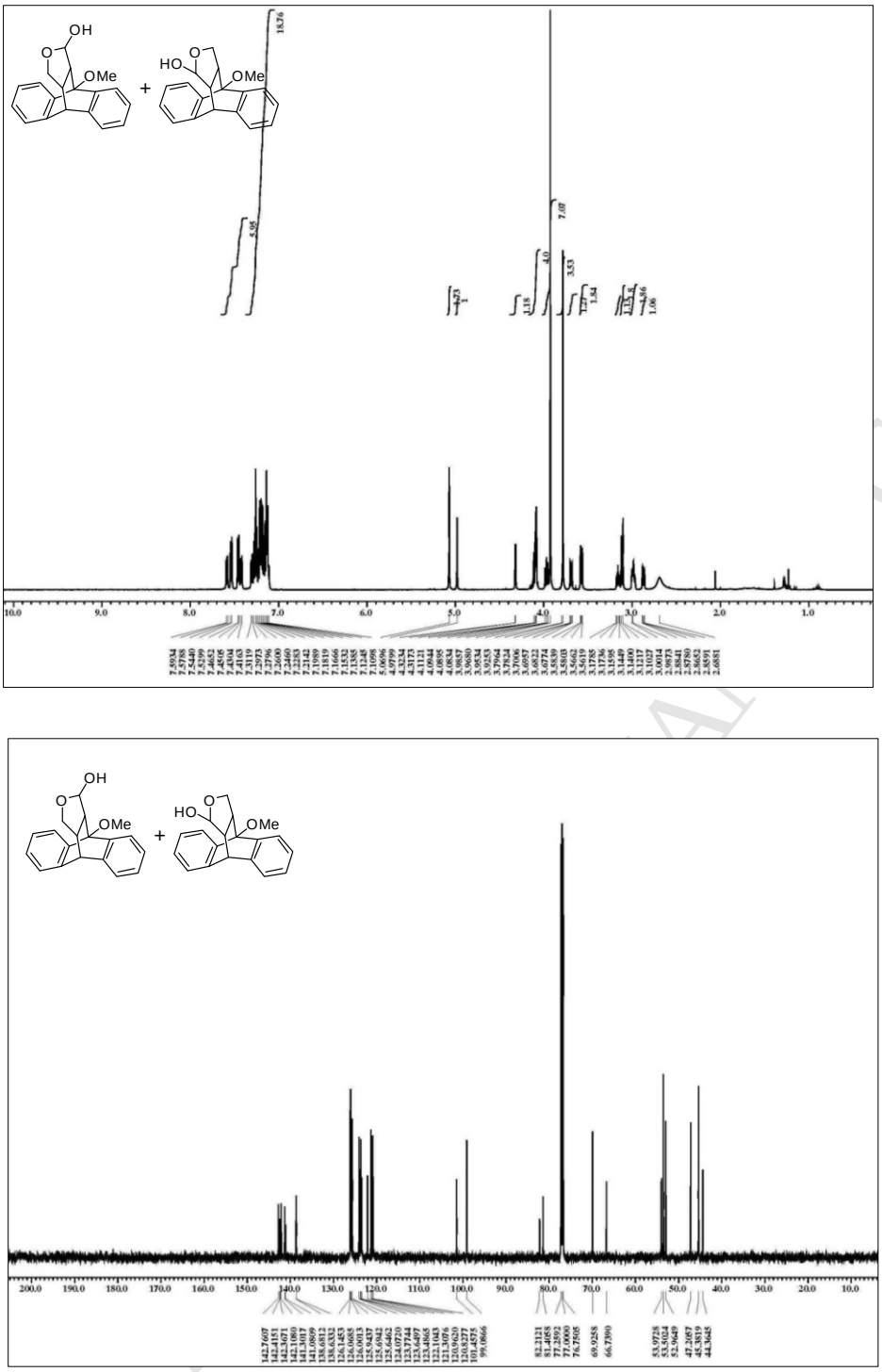


FIGURE S23. ^{1}H (500 MHz) and ^{13}C (125 MHz) NMR spectra of a mixture of two regioisomeric lactols (**17oa** and **17ob**) obtained from the oxidation of 5-methoxy-11,12-dihydrodibenzobarrelene-11,12-dimethanol in $CDCl_3$.

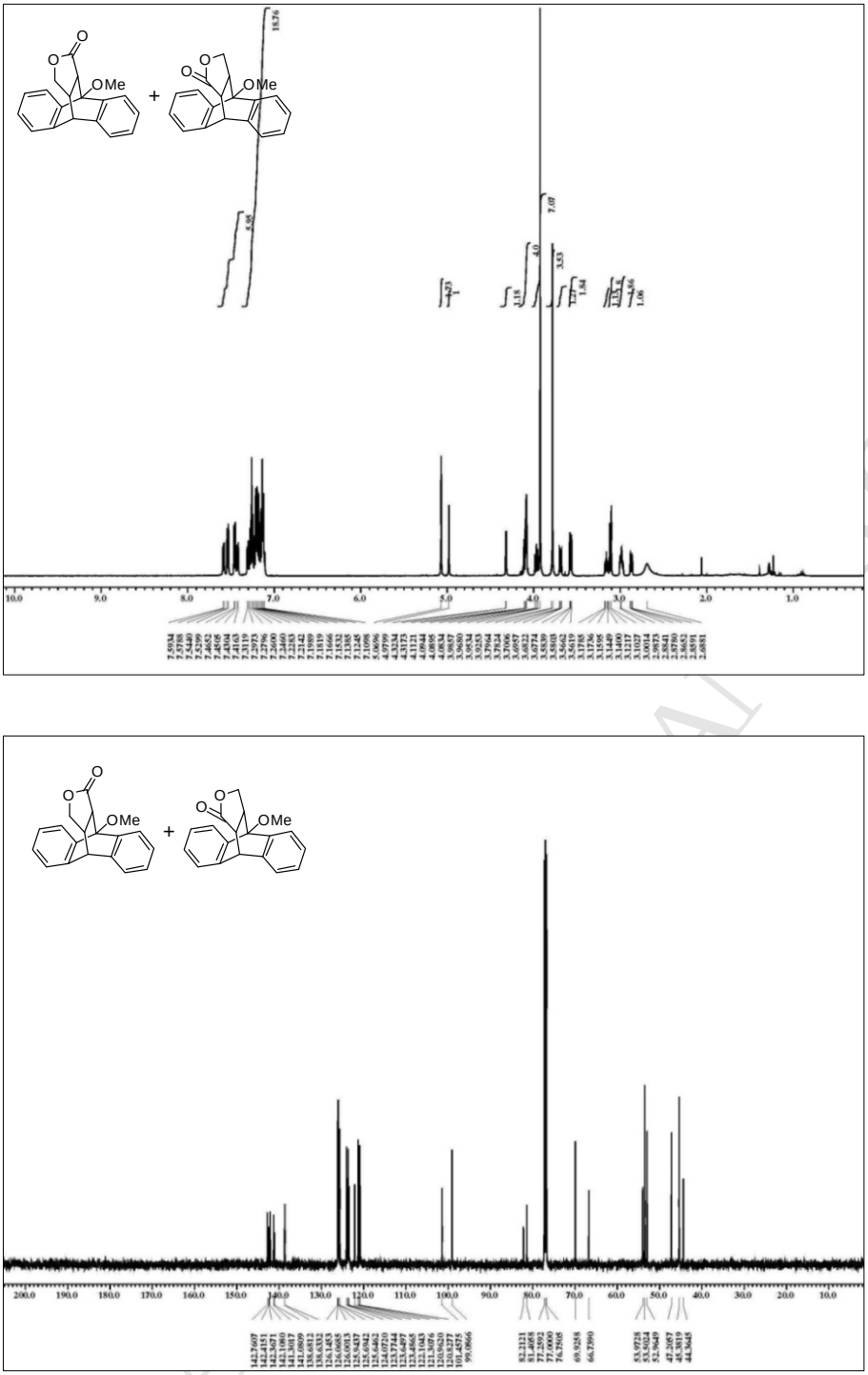


FIGURE S24. ^{1}H (500 MHz) and ^{13}C (125 MHz) NMR spectra of a mixture of two regioisomeric lactones (**17la** and **17lb**) obtained from the oxidation of 5-methoxy-11,12-dihydrodibenzobarrelene-11,12-dimethanol in $CDCl_3$.

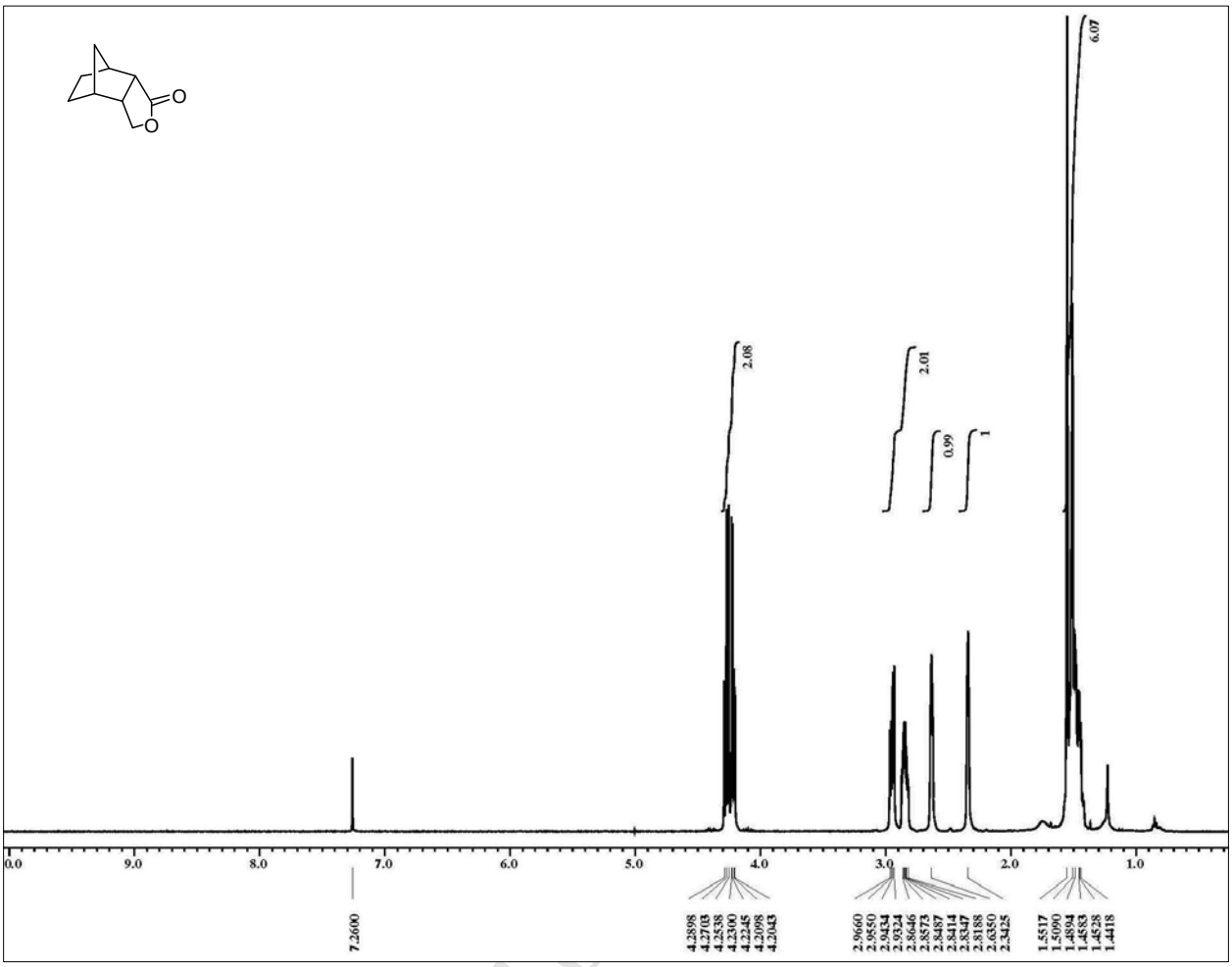


FIGURE S25. ^{1}H NMR (500 MHz) spectrum of Endo-perhydro-4,7-methanoisobenzofuran-1-one (**18l**)[14] in $CDCl_3$.

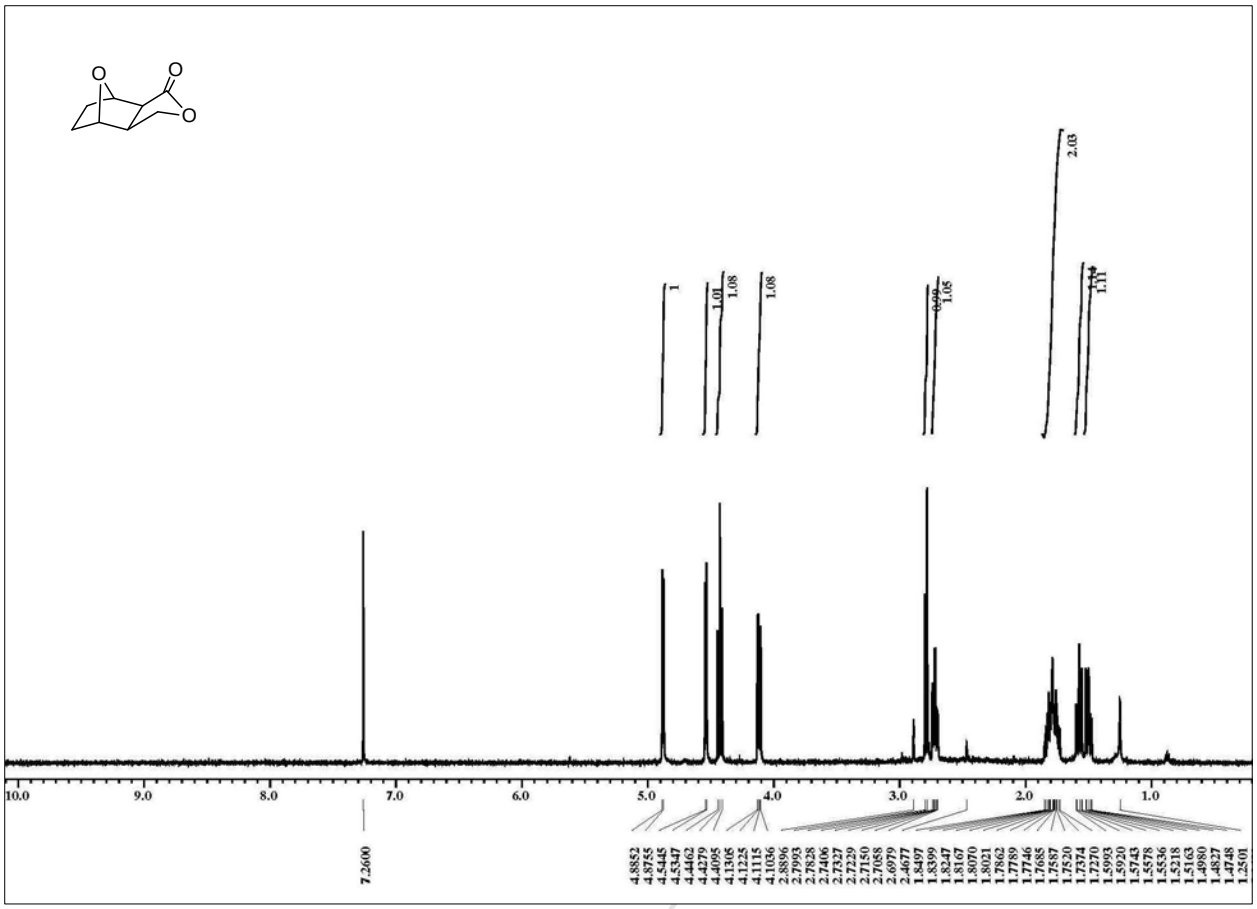


FIGURE S26. ^{1}H NMR (500 MHz) spectrum of exo-perhydro-4,7-epoxyisobenzofuranone (**19l**)[15] in $CDCl_3$.

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