"Synthesis of benzofurans from norbornyl α– diketones"

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Roll No - CY12M1020

Under the supervision of Prof. Faiz Ahmed Khan.

A Dissertation Submitted to Indian Institute of Technology Hyderabad

In Partial Fulfillment of the Requirements for The Degree of Master of Science.

भारतीय प्रौद्योगिकी संस्थान हैदराबाद
Indian Institute of Technology Hyderabad

Department of Chemistry

Indian Institute of Technology Hyderabad

Declaration

I declare that this written submission represents my ideas in my own words, and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the Institute and can also evoke penal action from the sources that have thus not been properly cited, or from whom proper permission has not been taken when needed.

Susanta Mandal

(Signature)

Susanta Mandal

(– Student Name –)

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Approval Sheet

This thesis entitled "L-Proline catalyzed aldol reaction of acetone and norbornyl α–diketones and exploration of resultant acyloins for the synthesis of highly substituted benzofurans" by Susanta Mandal is approved for the degree of Master of Science from IIT Hyderabad.

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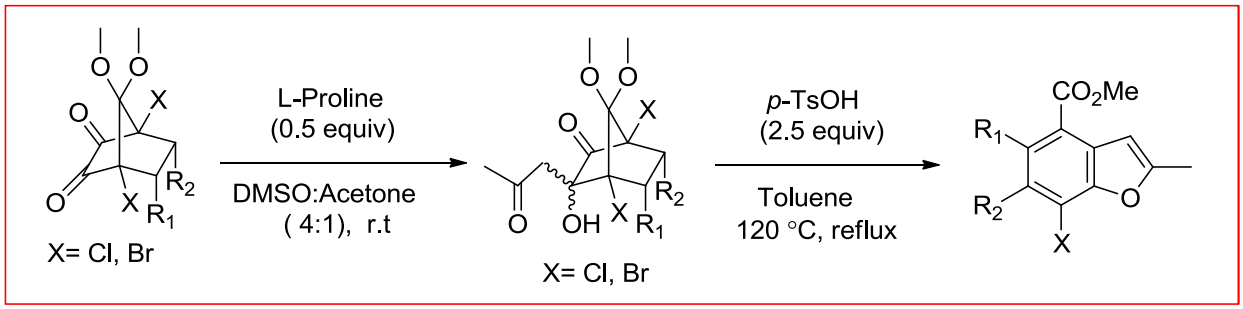
I acknowledge my supervisor **Prof. F. A. Khan** for his constant support and encouragement. I also thank to IIT Hyderabad for providing us with the best facilities and equipment's to work. I am grateful to all the faculty members in the department of chemistry at IIT Hyderabad for their guidance. I sincerely thank my group members for their constant help and for giving a good working atmosphere.

Dedicated to

My family

Content:

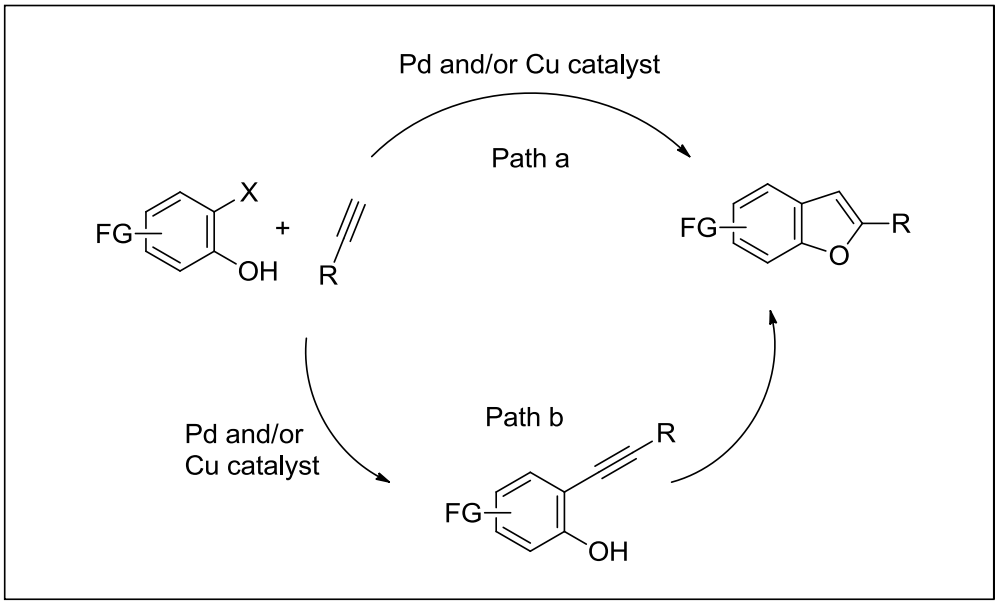
Abstract: 2-substituted benzofuran were synthesized by two steps, 1st step involves the proline catalyzed aldol reaction of norbornyl α– diketones[1] with acetone and the 2nd step is an acid mediated fragmentation of the resultant acyloins which further cyclized to produce highly substituted benzofuran .



Introduction:

The benzofuran moiety is largely defuse in nature and present in various natural products and pharmaceutically active compounds. An important access to these heterocyclic compound is first made by the hetero annulation of 2-halophenols with alkynes as first demonstrated by Castro and coworkers in 1966.[2] And development of Sonogashira coupling made this as a novel pathway to get this heterocyclic compounds. The interest of this method is the evidenced by the large no of reports in recent years, generally starting from 2-iodo-phenol [3-4] (Scheme 1 path a) in one pot procedure or with the separation of 2-alkenylphenol (Scheme 1 path b).

Scheme 1. Metal-Catalyzed Synthesis of 2-Substituted Benzofurans from 2-Halophenols (FG = Functional Group)

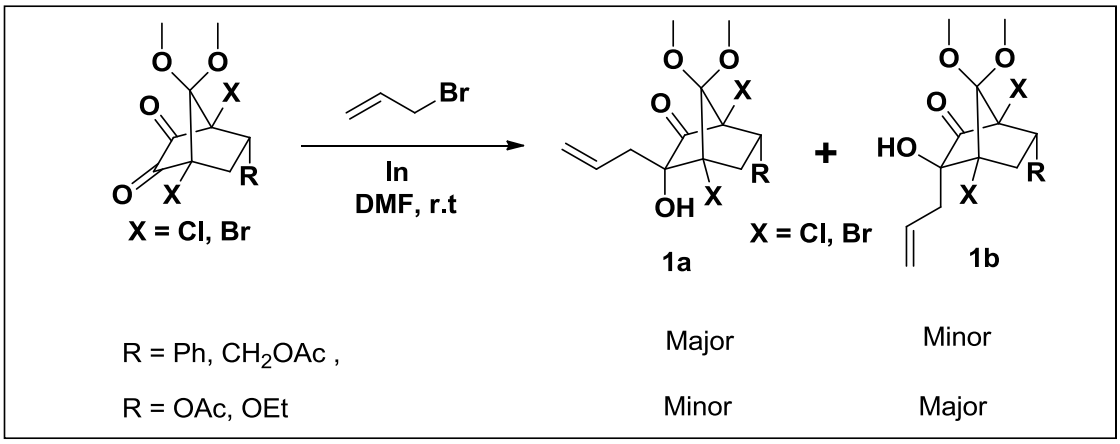


Whereas people are using extreme Pd and Cu catalyzed coupling reactions to get the desired benzofuran, but in our laboratory we have efficiently developed method to prepare highly aromatic substituted benzofuran from norbornyl α–diketones.

Previous Work from our Lab :

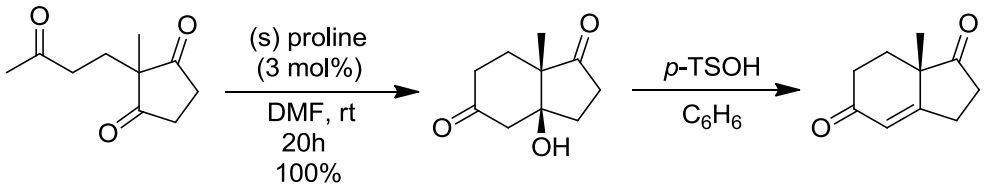
The reaction, particularly for mono substituted α–diketones was found to be diastereoselective, producing two diastereomers, endo (1a, Scheme 2) and exo (1b, Scheme 2) alcohols. The reactions are highly regioselective. In all the cases the allyl group is transferred to the less congested carbonyl group diagonal to the endo substituent. The diastereoselectivity depends on the endo substituent. and the nucleophilic attack mainly facilitating from the exo face which producing endo alcohol as major product. But in case of ethoxy (R= OEt, Scheme 2) and acetoxy (R = OAc, Scheme 2) substituent it is the reverse, the nucleophilic addition is taking place from endo face which producing exo alcohol as major product.

Scheme 2: Allyindium addition to the mono substituted norbornyl α–diketones: [5-6]



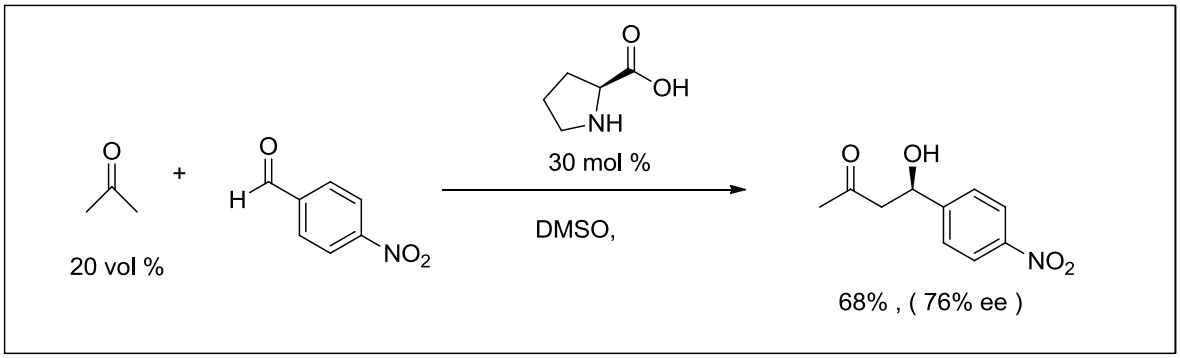
Literature Report:

Asymmetric enamine catalysis was first realized with the discovery of proline catalyzed asymmetric intermolecular aldol reaction in 1970 named as **Hajos-Parris-Eder-Sauer-Wiechert** reaction. The reaction was used in several steroid and natural product syntheses.



First Proline catalyzed enentioselective direct intermolecular aldol reaction was reported by Benjamine List in 2000. The reaction of acetone with aromatic aldehyde which gave 76% ee aldol product with 68% yield.

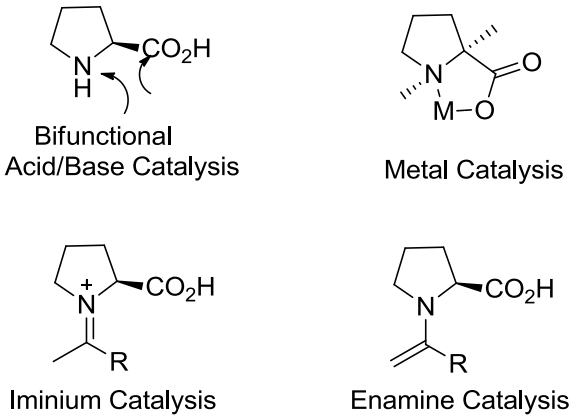
Scheme 3: Proline catalyzed direct asymmetric aldol reaction.[7-8]



Proline as an organocatalyst:

Nowadays proline is used enormously in chemical transformation in organic synthesis as an organocatalyst, and large no of literature report is coming for proline catalyzed Aldol and Mannich reactions used in total synthesis. There are several reasons why proline has become of so much importance in asymmetric catalysis. Proline is an abundant natural molecule which is inexpensive and available in both enantiomeric forms. Additionally there are many chemical reasons which contribute to proline as catalyst**.**

Proline can be a ligand in asymmetric transition-metal catalysis, a chiral molecule in heterogeneously catalyzed hydrogenation and most importantly proline itself can act as an organocatalyst in several powerful asymmetric transformations, such as the Aldols, Mannich and Micheal addition.



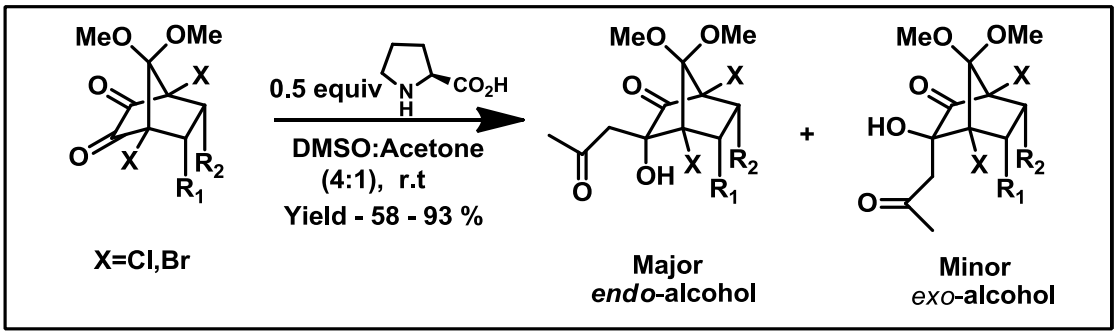
Proline is bifunctional which contain carboxylic acid group and an amine group this both functional groups can act as an acid and bases and can also facilitate chemical transformation like an enzyme catalysis reactions. In addition proline is a chiral bidentate ligand which can form catalytically active metal complexes.

While all of these criteria applied to all amino acid, proline is a secondary, cyclic, pyrrolidine based amino acid. Its pKa is higher than other amino acids. The most important difference of proline with other amino acids is proline's effective aminocatalysis a Lewis-acid-base catalysis that facilitate iminium and enamine base transformation. The carboxylate contributes to proline's aminocatalysis by acting as a general Bronsted acid.

Results and Discussions:

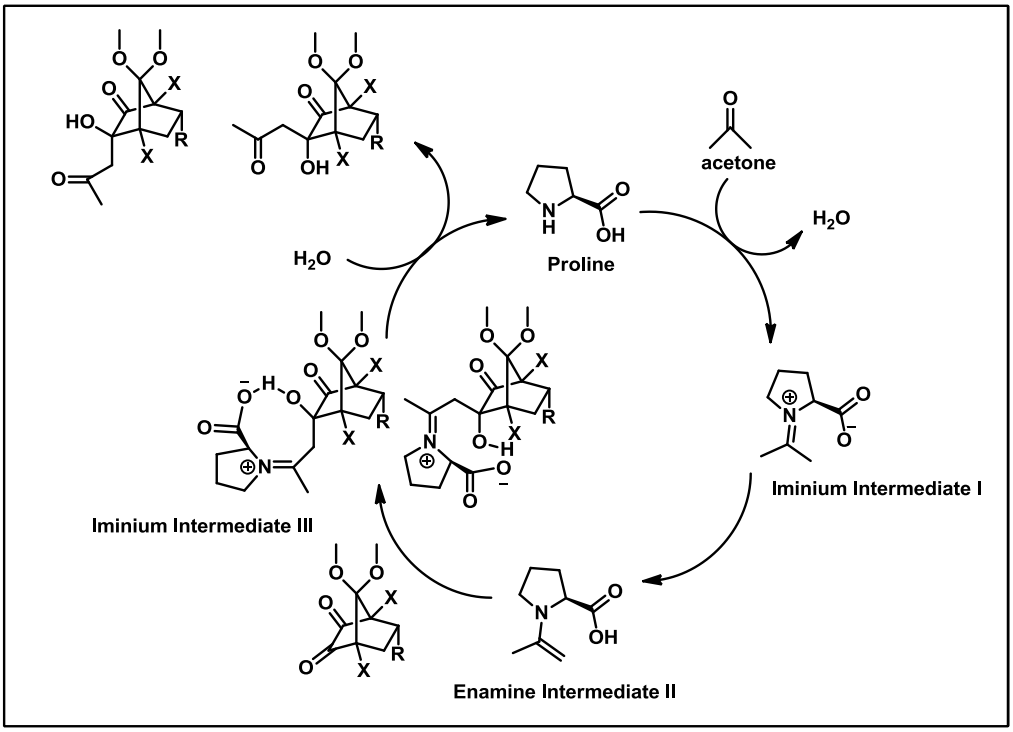
The encouraging result of Indium mediated efficient reduction of norbornyl α–diketones with high regio and diastereoselectivity, and the recent development of proline catalyzed aldol reactions with ketone to aromatic aldehydes driven us to study the proline catalyzed aldol addition reaction of acetone to the mono substituted and di substituted norbornyl α–diketones. Here in this case we are using acetone as one of the reactant and as well as solvent.

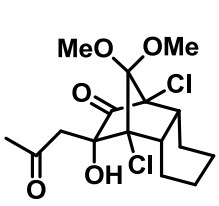
Scheme 4: Proline catalyzed aldol reaction of acetone with norbornyl α–diketones.



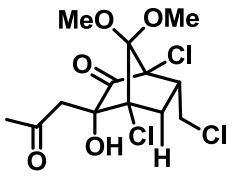
In this reaction, Proline acting as a bifunctional catalyst, it content both $–CO_2H$ and $–NH_2$ group, the carboxylic group here acting like a Bronsted acid. The reaction undergoes via two intermediate , eminium ion and enamine intermediate . The secondary amine group present in proline forming an enamine (II) with acetone and the carboxylic acid group donating a proton to the acceptor keto group, (one of the keto group of the a-diketones) . Now the enamine (II) act as a nucleophile to the keto group of diketones and reducing one of the keto group to the corresponding alcohol , followed by hydrolisation of the forming iminium intermediate (III) produce the acetone addition product.

Scheme 5 : Plausible mechanism of the proline catalyzed aldol reaction.[9]

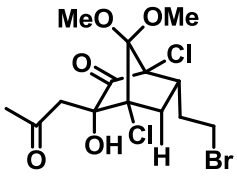




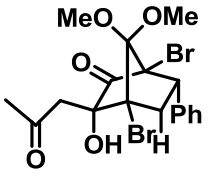
2a , 12h, 66%



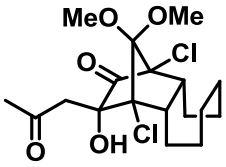
2b, 3.5h, 64%



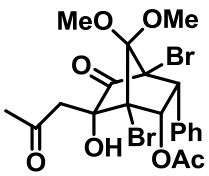
2c, 4.5h, 72%



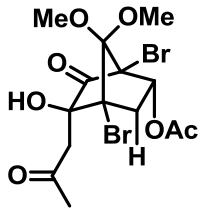
2d, 3h, 90%



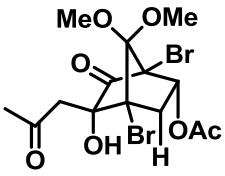
2e, 3h, 93%



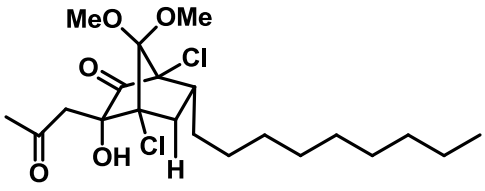
2f , 20h, 48%



2g, 6h, 49%



3g, 6h, 40%

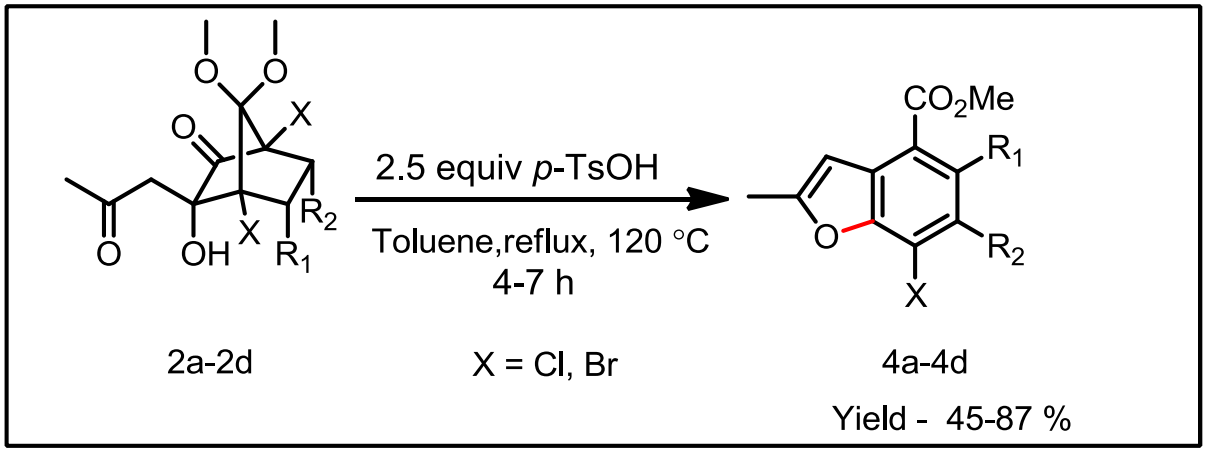


2h, 3h, 89%

Figure 1: Examples of the acetone addition products with the reaction time, and yield of the products.

After successfull synthesis of the aldol products 2a-2d we further used this compounds for the preparation of benzofuran derivatives. We treated the acyloins 2a-2d with *p*-toluene sulphonic acid , refluxed at 120^{o}C in toluene, facilitating the fragmentation of the norbornyl system followed by cyclisation of the 1,4 diketones leading to the formation of benzofuran .

Scheme 6: Acid mediated fragmentation of the resultant acyloins 2a-2d to benzofuran 4a-4d.



p-toluene sulphonic acid is used for the fragmentation of the acyloins to prepare the benzofuran derivative 4a-4d (scheme-6) . By this method we can prepare highly substituted benzofuran which are present in many natural products. And we can functionalize the compound by using the halogen and ester group presents in the compounds 4a-4d (scheme-6).

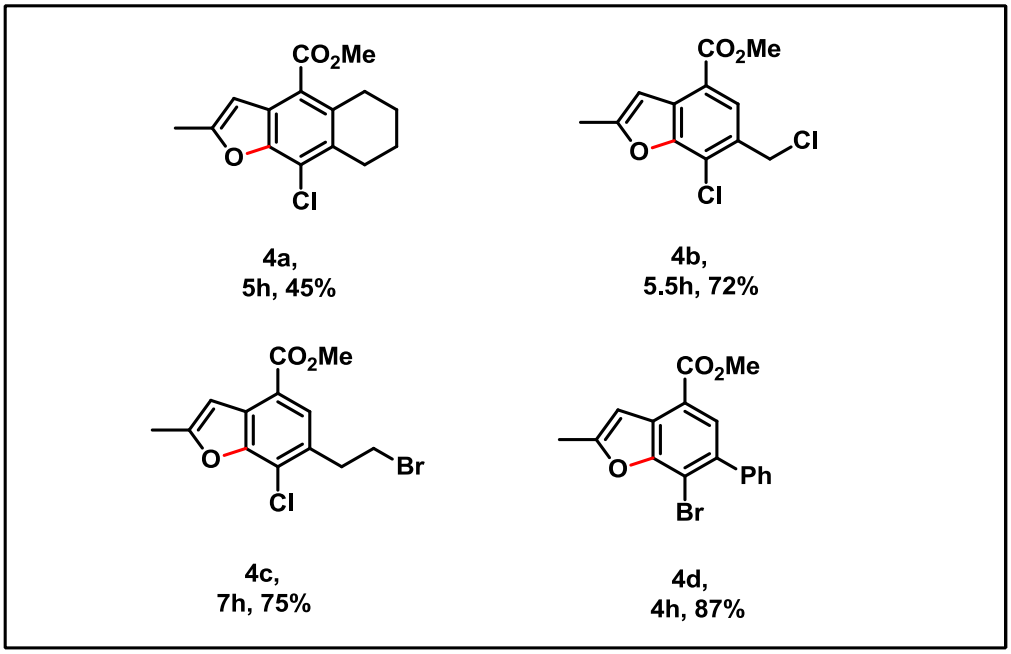
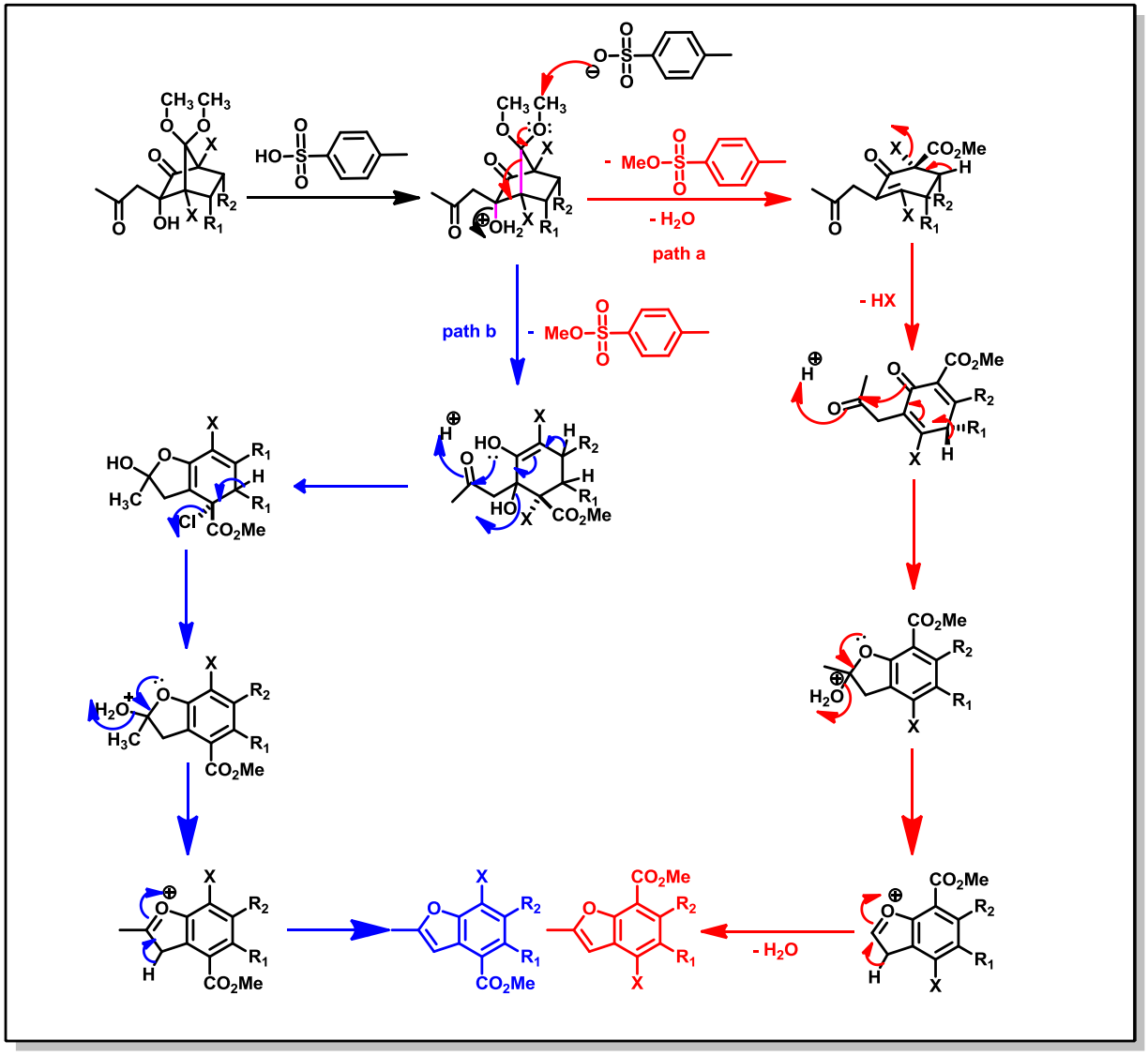


Figure 2: Examples of the benzofuran 4a-4d prepared from acyloins 2a-2d

Scheme 7: Plausible mechanism for the fragmentation of the acyloins by *p*-toluene sulphonic acid .[11]



Previously our group reported a similar kind of fragmentation of norbornyl α–diketones using *p*-toluene sulphonic acid , where we have demonstrated the mechanism in details.[11] Here aromatization of the benzene ring is the driving force for the for the cyclisation .

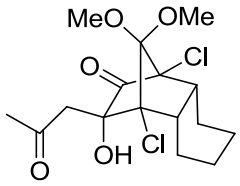
Conclusion:

In conclusion we found that the proline catalyzed aldol addition of acetone to norbornyl α–diketones are highly diastereoselective and regio selective with excellent yields. We have successfully synthesized benzofuran moiety by acid mediated fragmentation of acyloins with quantitative yield which was present in many biological active natural products.

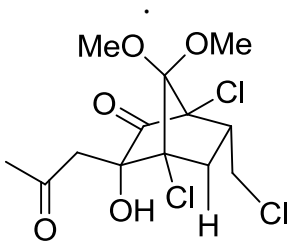
Experimental Section:

In this section the preparation of all the compounds that have been made in the course of synthesis of Benzofuran has written. For experiment all the starting material and the reagents are purchased from standard commercial source or were prepared in laboratory. All the glass wares were cleaned with soap water followed by acetone and the dried in hot air oven at 140^{o}C for 2hours. Solvents were dried and distilled using standard procedure. For evaporation of solvent Buchi rotary vapor machine was used. NMR data was taken using Bruker 400MHZ machine, IR data was collected using Bruker machine.

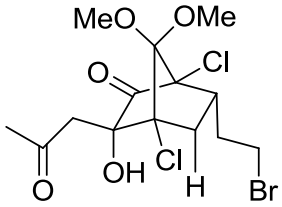
General procedure for the proline catalyzed acetone addition to the norbornyl a-diketones: proline (50 mol%) was added to a stirred solution of diketones (0.1 mmol) in 2 ml solvent combination of DMSO:acetone (4:1) .The reaction was carried in room temperature. After completion of the reaction (monitored by TLC) the reaction mixture was quenched with 1ml of saturated ammonium chloride solution. Now the organic part was extracted with 15 ml Ethyl acetate and washed with 5ml of brine solution and dried over anhydrous Na_2SO_4 .



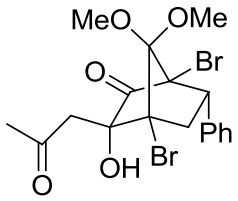
Compound 2a, Colorless crystalline solid, Mp 57 ^{o}C Yield 66% ^{1}H NMR (400 MHz $CDCl_3$) δ ppm 1.10 - 1.40 (m, 3 H) 1.51 - 1.81 (m, 4 H) 2. 28 (s, 3 H) 2.37 (s, 1 H) 2.37 - 2.47 (m, 1 H) 2.52 (td, *J* = 13.08, 5.14 Hz, 1 H) 2.91 - 3.02 (m, 1 H) 3.02 - 3.13 (m, 2 H) 3.60 (s, 3 H) 3.68 (s, 3 H) 6.63 (s, 1 H) ^{13}C NMR (100 MHz, $CDCl_3$) δ ppm 19.08 , 20.06 , 20.67, 20.85, 32.39 , 42.87, 43.76, 44.30, 51.63, 51.77, 80.53, 84.70 , 103.43 , 201.36 , 212.60. IR(MIR-ATR, 4000-600 cm^{-1}) 3310, 2946, 2866, 1778, 1694, 1421, 1360, 1325, 1222, 1189, 1102, 1024, 979, 897, 791, 733 cm^{-1}.



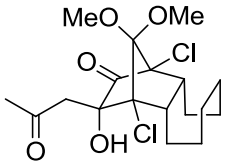
Compound 2b, colorless crystalline solid, mp 105 ^{o}C, yield 64%, ^{1}H NMR (400 MHZ, $CDCl_3$) δ ppm 2.30 (s, 3 H) 2.42 - 2.62 (m, 1 H) 2.72 - 2.87 (m, 2 H) 2.87 - 3.12 (m, 2 H) 3.34 (t, *J* = 11.25 Hz, 1 H) 3.54 (dd, *J* = 10.76, 3.91 Hz, 1 H) 3.61 (s, 3 H) 3.69 (s, 3 H) 6.81 (s, 1 H) ^{13}C NMR (100 MHz, $CDCl_3$) δ ppm 32.3, 34.1, 42.6, 42.7, 45.2, 51.7, 51.9, 74.2, 76.3, 76.69, 76.88, 79.0, 81.5, 103.3, 200.0, 212.0. IR(MIR-ATR, 4000-600 cm^{-1}) 3311, 2954, 2845, 1779, 1697, 1439, 1417, 1362, 1202, 1105, 1056, 976, 887, 803 cm^{-1} .



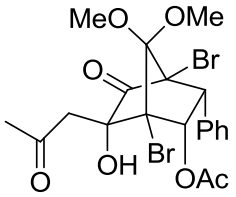
Compound 2c, Colorless crystalline solid, Mp 110 ^{o}C, yield 54%, ^{1}H NMR (400 MHz, $CDCl_3$) δ ppm 1.72 - 1.88 (m, 1 H) 1.92 - 2.05 (m, 1 H) 2.30 (s, 3 H) 2.40 - 2.62 (m, 2 H) 2.65 - 2.79 (m, 1 H) 2.9-3.1 (m, 2H) 3.34 (td, *J* = 9.66, 5.62 Hz, 1 H) 3.40 - 3.54 (m, 1 H) 3.62 (s, 3 H) 3.70 (s, 3 H) 6.75 (s, 1 H) . ^{13}C NMR (100 MHz, $CDCl_3$) δ ppm 30.90, 31.80, 32.36, 34.58, 41.02 , 42.75, 51.61, 51.94, 74.39, 79.85, 81.43, 103.23, 200.82, 212.15. IR (MIR-ATR, 4000-600 cm^{-1}) 3308, 2952, 2845, 1778, 1695, 1447, 1417, 1361, 1326, 1201, 1102, 1059, 973, 885, 772, 732 cm^{-1} .



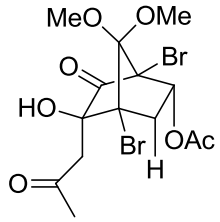
Compound 2d , colorless crystalline solid, Mp 110 ^{o}C yield 90 ^{1}H NMR (400 MHz, $CDCl_3$) δ ppm 2.30 (s, 3 H) 2.73 (t, *J* = 12.72 Hz, 1 H) 3.01-3.13 (m, 2 H) 3.18 - 3.22 (m, 6 H) 3.69-3.77 (m, 6 H) 7.03 (s, 1 H), 7.23-7.30 (m, 4 H) 7.42 (d, *J* = 6.85 Hz, 1 H) ^{13}C NMR (100 MHz, $CDCl_3$) δ ppm 32.4, 36.3, 43.0, 48.2, 51.6, 51.8, 74.1, 81.6, 81.8, 103.5, 127.8, 127.7, 128.3, 128.8, 129.4, 135.5, 200.8, 212.1. IR(MIR-ATR, 4000-600 cm^{-1}) 3301, 3062, 2951, 2845, 1772, 1695, 1498, 1448, 1418, 1360, 1326, 1269, 1180, 1104, 1044, 960, 763, 733, 699 cm^{-1} .HRMS (ESI): m/z calcd for $([C_{18}H_{20}Br_2O_5]+Na)^+$ 498.9538, found 498.96.



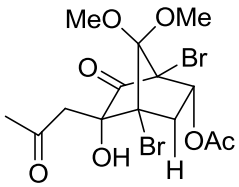
Compound 2e , colorless crystalline solid, Mp 132 ^{o}C yield 93%, ^{1}H NMR (400 MHz, $CDCl_3$) d ppm 1.46 - 1.90 (m, 6H) 2.03 - 2.20 (m, 1H) 2.26 (s, 3H) 2.54 (dt, *J* = 11.86, 6.05 Hz, 1H) 2.73 (t, *J* = 11.25 Hz, 1H) 2.92 - 3.09 (m, 2H) 3.58 (s, 3H) 3.69 (s, 3H) 6.47 (s, 1H) ^{13}C NMR (100 MHz, $CDCl_3$) δ ppm 14.0, 21.1, 23.7, 25.0, 25.6, 29.6, 30.7, 31.7, 32.2, 44.0, 48.4, 49.5, 51.6, 51.8, 78.0, 81.0, 84.5, 102.6, 200.6, 212.4. IR (MIR-ATR, 4000-600 cm^{-1}) 3316, 2992, 2921, 2850, 1780, 1695, 1466, 1445, 1360, 1327, 1213, 1194, 1095, 1034, 926, 892, 785, 737 cm^{-1}. HRMS (ESI): m/z calcd for $([C_{13}H_{26}Cl_2O_5]+Na)^+$ 415.1055, found 415.1041.



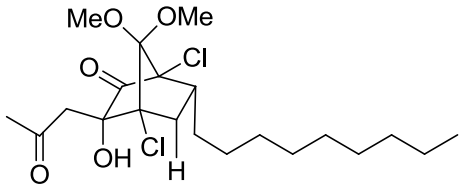
Compound 2f , colorless crystalline solid , Mp 190 ^{o}C , Yield 48% ^{1}H NMR (400 MHz, $CDCl_3$) δ ppm 1.78 (s, 3 H) 2.32 (s, 3 H) 3.06 - 3.10 (d, 1 H), 3.13-3.17(d,1H) 3.73 (s, 3H) 3.84 (s,3H) 4.14-4.17 (d, 1H) 6.04 (d, 1H) , 6.80 (s, 1H) 7.21 - 7.30 (m, 3H) 7.39 (dd, *J* = 6.60, 3.18 Hz, 2H) ^{13}C NMR (100 MHz, $CDCl_3$) δ ppm 20.52, 32.54, 46.62, 52.03, 52.55, 55.22, 68.47, 74.74, 83.95, 101.92, 127.95, 128.15, 130.51, 131.43, 170.10, 199.71, 211.05. IR(MIR-ATR, 4000-600 cm^{-1}) 3308, 3067, 2994, 2953, 2924, 2850, 1775,1742,1697,1500, 1455, 1432, 1362, 1229, 1189, 1127, 1070, 958, 702 cm^{-1} . HRMS (ESI): m/z calcd for $([C_{20}H_{22}Br_2O_5]+Na)^+$ 556.9610, found 556.9587.



Compound 2g , Colorless crystalline solid , Mp 158 ^{o}C, Yield 40%, ^{1}H NMR (400 MHz, $CDCl_3$) δ ppm 2.07 (s, 3H) , 2.38 (s, 3H) 2.34-2.35 (d, 1 H) 2.89 (d, 1H)) 3.12 (d, *J* = 10.27 Hz, 3 H) 3.08 (d, *J* = 10.27 Hz, 3 H) 3.73 (s, 3H) 3.69 (s, 3H) 4.81 (s, 1H) 5.46 (dd, *J* = 10.27, 1.92 Hz, 1H) ^{13}C NMR (100 MHz, $CDCl_3$) δ ppm 20.68, 32.78, 40.78, 41.11, 52.22, 52.70, 65.40, 71.57, 105.35, 169.29, 198.07, 207.02. IR (MIR-ATR, 4000-600 cm^{-1}), 3306, 3006, 2954, 2848, 1778, 1751, 1691, 1447, 1370, 1211, 1186 , 1081, 1045, 828cm^{-1} .



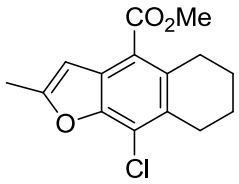
Compound 3g , colorless crystalline solid , Mp 90 ^{o}C ,yield 49% , ^{1}H NMR (400 MHz, $CDCl_3$) δ ppm 2.05 (s, 3H) 2.31 (s, 3H) 2.83 – 2.96 (m, 3H) 3.02 - 3.19 (d, 1H) 3.66 (s, 3 H) 3.73 (s, 3H) 5.33 (d, *J* = 9.29 Hz, 1H) 6.79 (s, 1H) ^{13}C NMR (100 MHz, $CDCl_3$) δ ppm 20.73 , 32.48, 39.36, 44.87, 51.83, 52.24, 66.80, 71.85,81.57, 103.07, 170.14, 197.65, 211.75. IR (MIR-ATR, 4000-600 cm^{-1}) 3313, 2987, 2953, 2846, 1782, 1748, 1695, 1435, 1369, 1327, 1267, 1222, 1187, 1122, 1050, 974, 863,737 cm^{-1}.



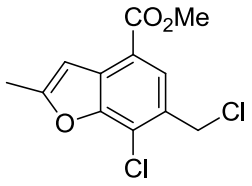
Compound 2h , colorless viscous liquid, yield 89%, ^{1}H NMR (400 MHz, $CDCl_3$) δ ppm 0.88 (t, *J* = 6.85 Hz, 3 H) 1.05 - 1.39 (m, 16 H) 2.30 (s, 3 H) 2.36 - 2.44 (m, 2 H) 2.50 - 2.64 (m, 1 H) 2.94 (d, *J* = 17.12 Hz, 1 H) 3.05 (d, *J* = 16.63 Hz, 1 H) 3.60 (s, 3 H) , 3.67 (s, 3H) 6.65 (s, 1 H) ^{13}C NMR (100 MHz, $CDCl_3$) δ ppm 14.07 , 22.63, 27.48, 28.50, 29.24, 29.28, 29.40, 29.45, 31.84, 32.34, 35.16, 42.74, 42.91, 51.46, 51.77, 74.63, 80.65, 81.40, 103.24, 201.11, 212.11, IR (MIR-ATR, 4000-600 cm^{-1}) 3318, 2924, 2853, 1778, 1697, 1453, 1419, 1360, 1325, 1283, 1199, 1099, 1059, 1025, 975, 885, 802, 724 cm^{-1}

General Procedure for the acid mediated fragmentation of the acylions :

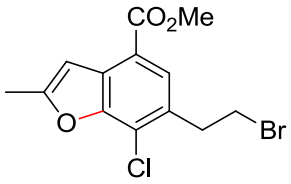
p-Toluenesulphonic acid,(2.5equiv) was added to a stirred solution of the resultant acyloins (3aa-3ah ,) of (0.1mmol) in toluene (3ml) and the mixture was heated for 3- 7h . After completion of the reaction the solvent was removed by reduced pressure . The residue was dissolved in Ethyl acetate (20ml) and washed with $NaHCO_3$ and dried over anhydrous Na_2SO_4 .After evaporation of the solvent the crude reaction mixture was purified by silica gel column chromatography to afford the colorless compound with quantitative yield.



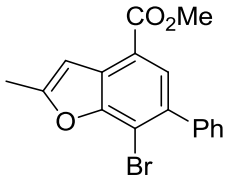
Compound 4a, colorless crystalline solid, Mp 56 ^{0}C , yield 45% ^{1}H NMR (400 MHz, $CDCl_3$) δ ppm 1.73 - 1.85 (m, 4H) 2.47 (s, 3H) 2.90 (t, *J* = 6.36 Hz, 3H) 3.08 (t, *J* = 6.11 Hz, 2H) 3.94 (s, 3H) 6.60 (s, 1H) ^{13}C NMR (100 MHz, $CDCl_3$) δ ppm 14.0, 22.2, 22.7, 27.5, 28.5, 51.7, 104.3, 119.7, 120.1, 128.3, 130.8, 135.1, 149.1, 156.9, 167.8 . IR (MIR-ATR, 4000-600 cm^{-1}) 2932, 2860, 1713, 1599, 1563, 1429, 1395, 1305, 1275, 1234, 1159, 1099, 1030, 898, 808, 737 cm^{-1} . HRMS (ESI): m/z calcd for $([C_{15}H_{15}ClO_3]+Na)^+$, found 415.1041.



Compound 4b, colorless crystalline solid , Mp 92 ^{0}C , yield 72% , ^{1}H NMR :(400 MHz, $CDCl_3$) δ ppm 2.55 (s, 1H) , 3.96 (s, 3H), 4.83 (s, 2H) 7.01 (s, 1H) , 8.01 (s, 1H) ^{13}C NMR (100 MHz, $CDCl_3$) δ ppm 14.2, 43.1, 52.1, 104.9, 120.1, 121.1, 127.5, 128.5, 129.6, 131.3, 151.3, 159.9, 166 . IR (MIR-ATR, 4000-600 cm^{-1}) 2948, 2922, 2840, 1712, 1602, 1431, 1395, 1225, 1150, 1040, 930, 815 cm^{-1} .



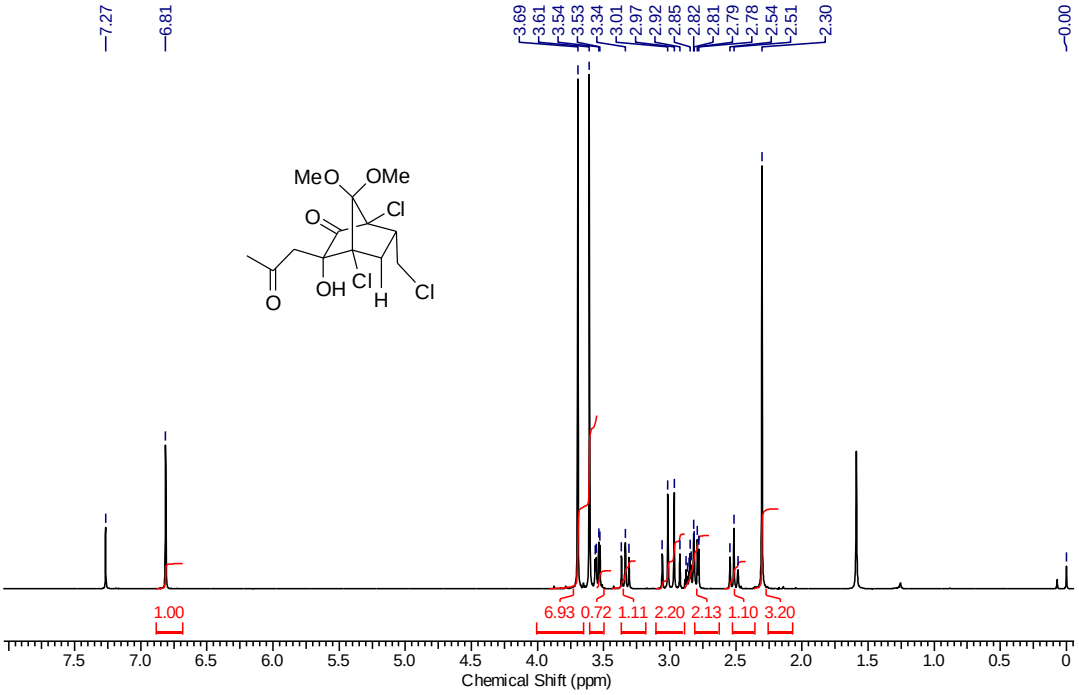
Compound 4c, colorless crystalline solid , Mp 98 ^{0}C yield 75% ^{1}H NMR (400 MHz, $CDCl_3$) δ ppm 2.54 (s, 3H) 3.41 (t, *J*=7.34 Hz, 2H) 3.61 (t, *J*=7.58 Hz, 2 H) 3.96 (s, 1H) 6.97 (s, 1H) 7.82 (m, 11H) ^{13}C NMR (100 MHz, $CDCl_3$) δ ppm 14.2, 30.9, 36.2, 52 , 104.3 , 119.81, 120.7, 127.3, 129.3, 131.0, 151.3, 158.8, 166.3 .IR (MIR-ATR, 4000-600 cm^{-1}) 2950, 2921, 2847, 1712, 1600, 1575, 1433, 1396, 1335, 1288, 1224, 1149, 1039, 932, 817 cm^{-1}. HRMS (ESI): m/z calcd for $([C_{13}H_{12}ClBrO_3]+H)^+$ 332.5975, found 332.9708.

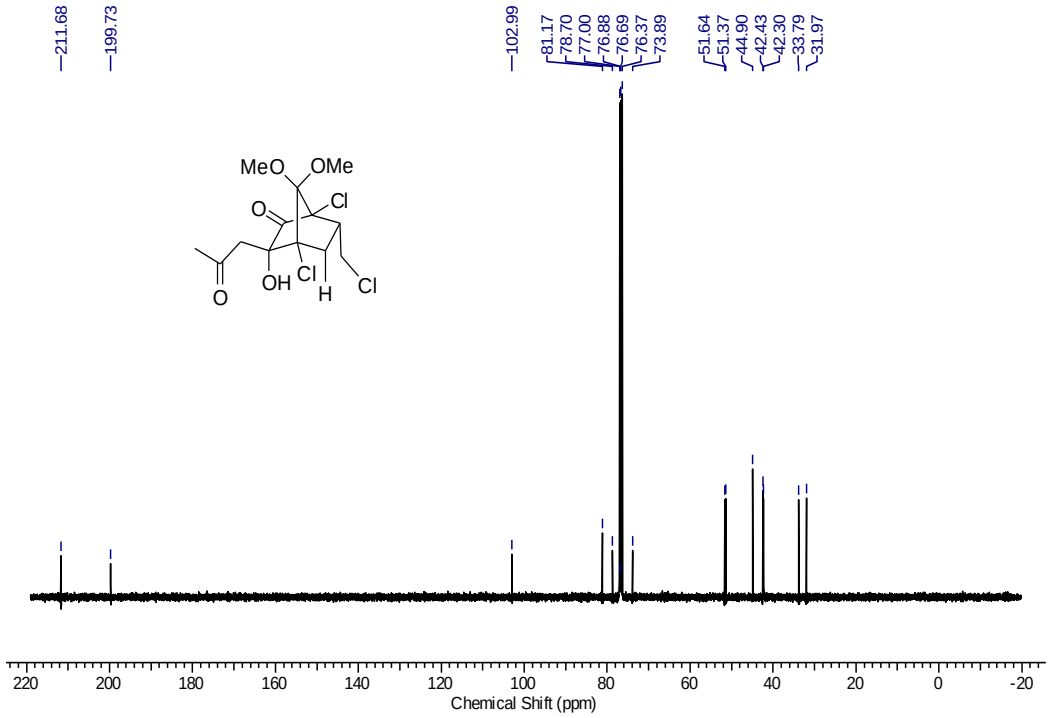


Compound 4d, colorless crystalline solid , mp 85 ^{0}C yield 87% ^{1}H NMR :(400 MHz, $CDCl_3$) δ ppm 2.48 (s, 3H), 3.87 (m, 21 H) 6.96 (s, 1H) 7.16 - 7.43 (m, 5 H) 7.86 (s, 1 H) ^{13}C NMR (100 MHz, $CDCl_3$) δ ppm 14.2, 22.7, 29.7, 37.3, 52.0, 104.8, 119.7, 127.7, 127.9, 128.1, 129.8, 129.9, 135.2, 138.2, 151.6, 159.0, 166.4 . IR (MIR-ATR, 4000-600 cm^{-1}) 3058, 3024, 2950, 2922, 2851, 1717, 1600, 1434, 1392, 1338, 1293, 1244, 1190, 1148, 1034, 923, 817, 769, 742, 699 cm^{-1} .

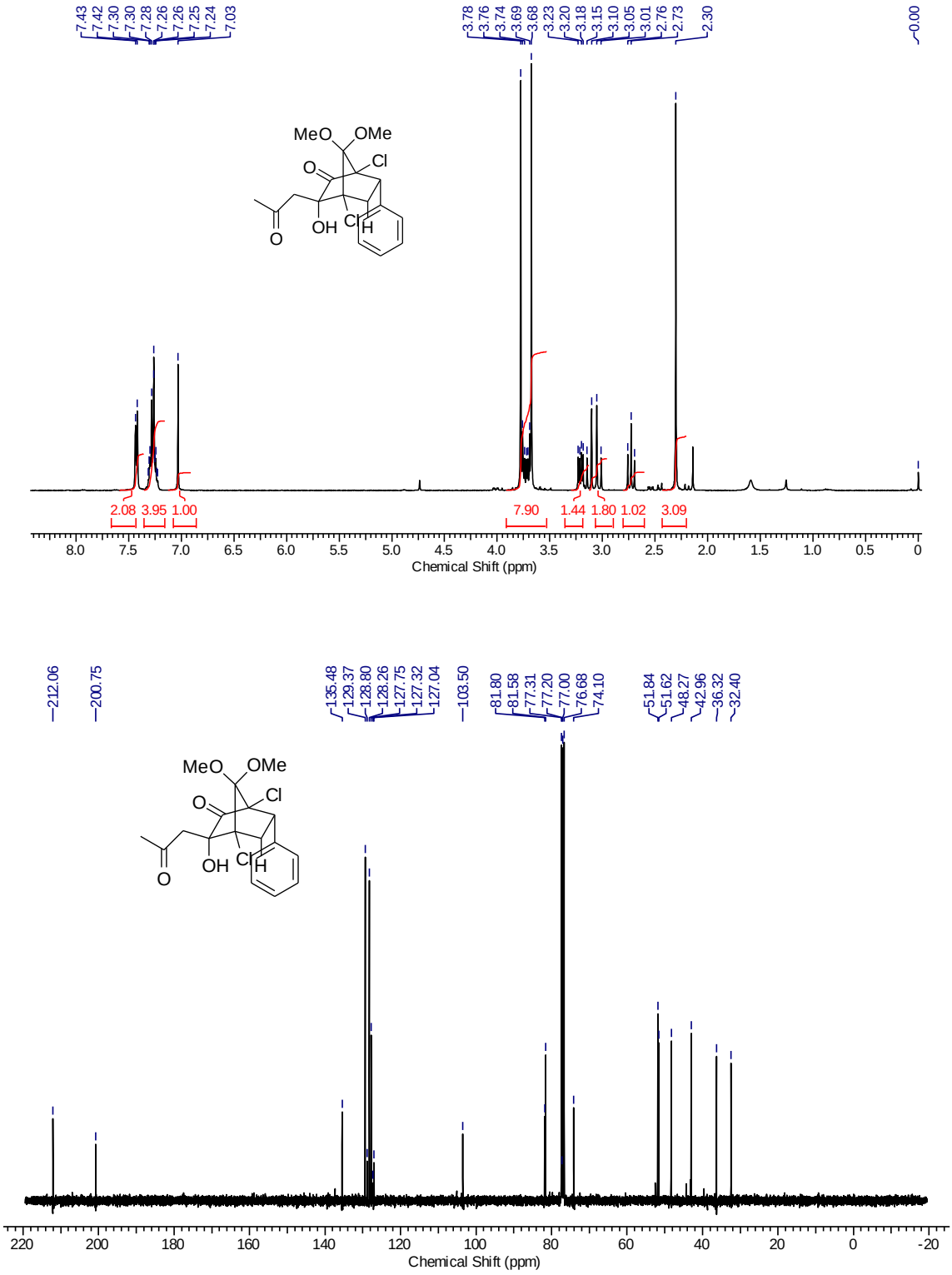
Spectral data

^{1}H NMR (400 MHZ) and ^{13}C NMR (100) MHZ of 2b in $CDCl_3$.

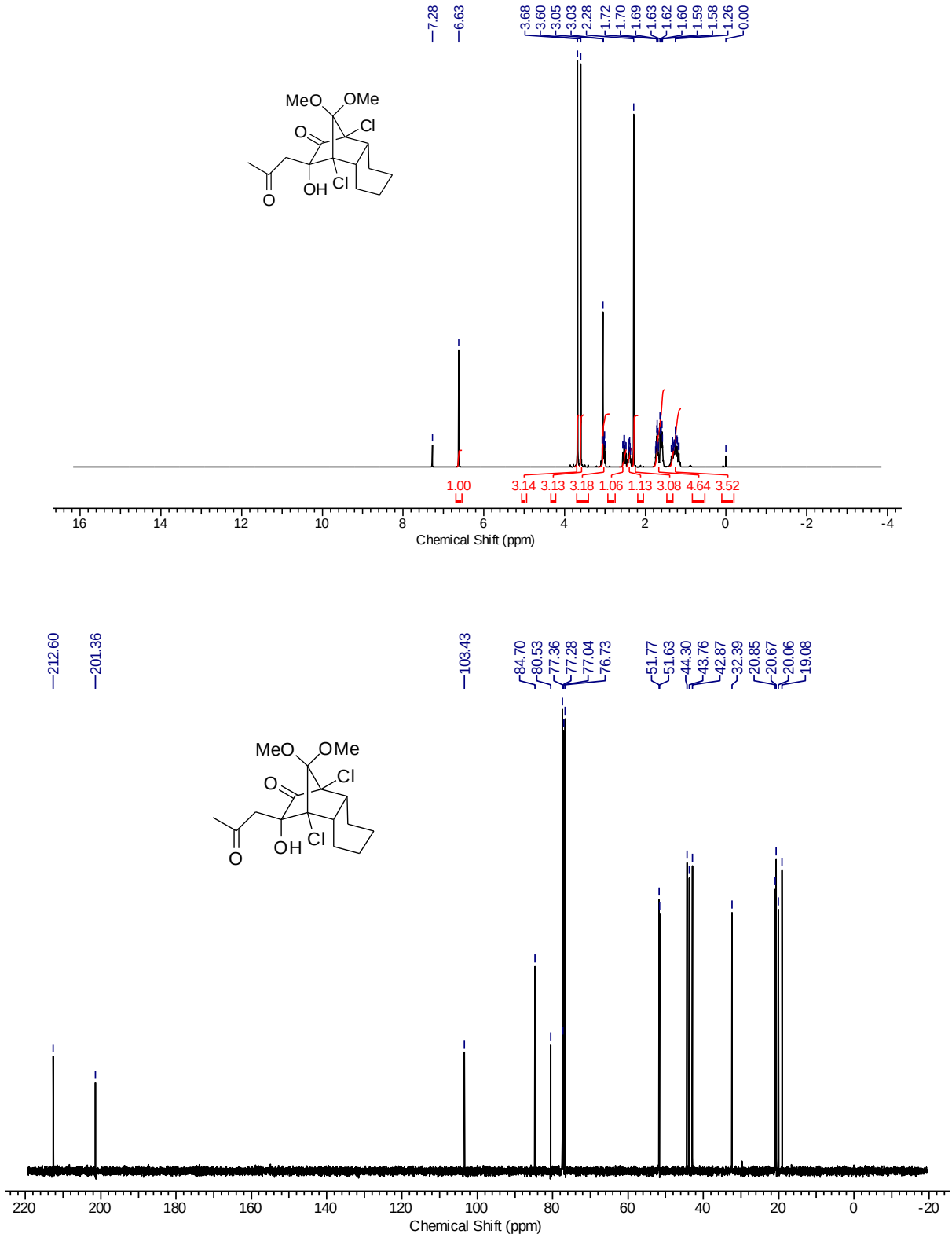




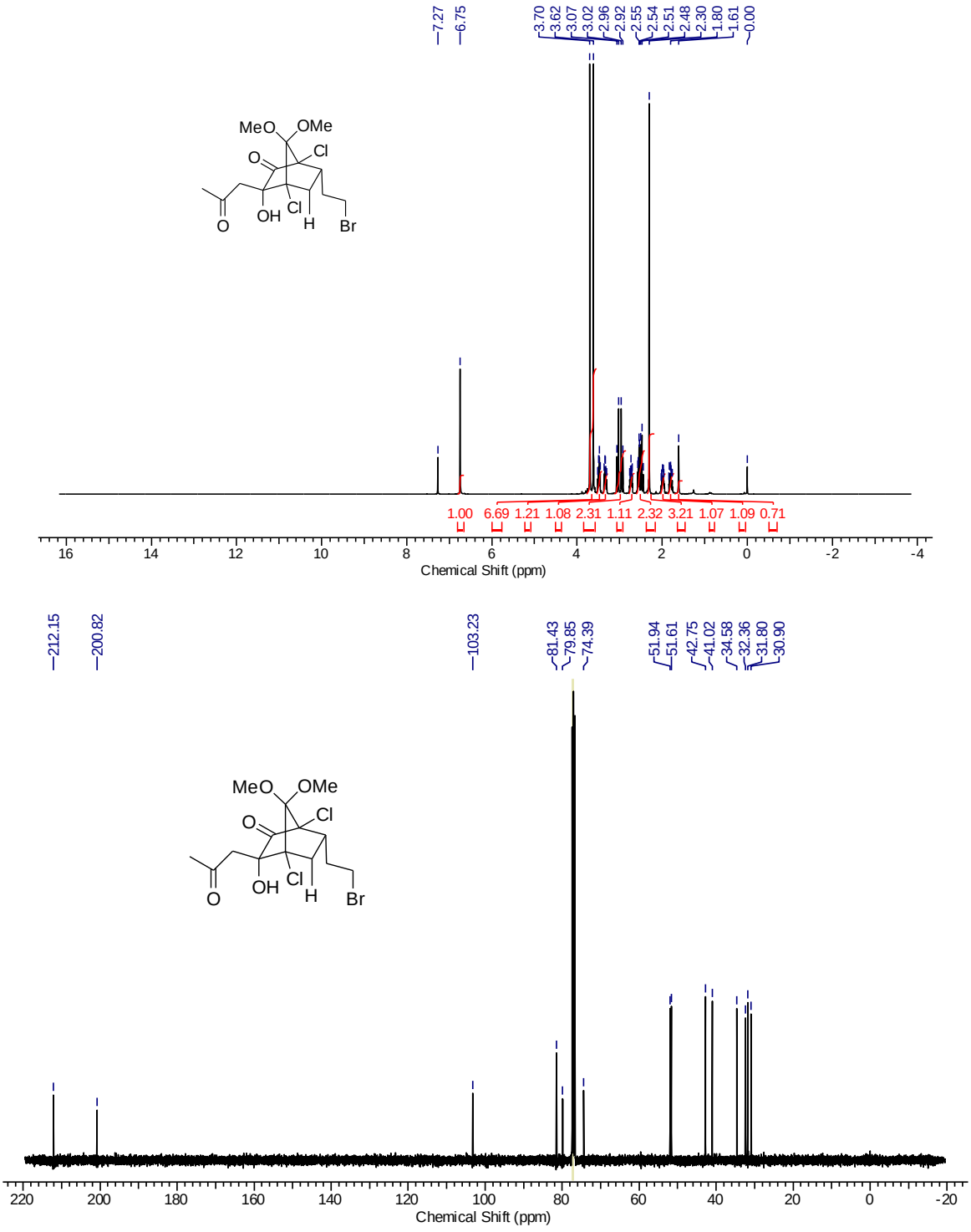
^{1}H NMR (400 MHZ) and ^{13}C NMR (100) MHZ of 2d in $CDCl_3$.



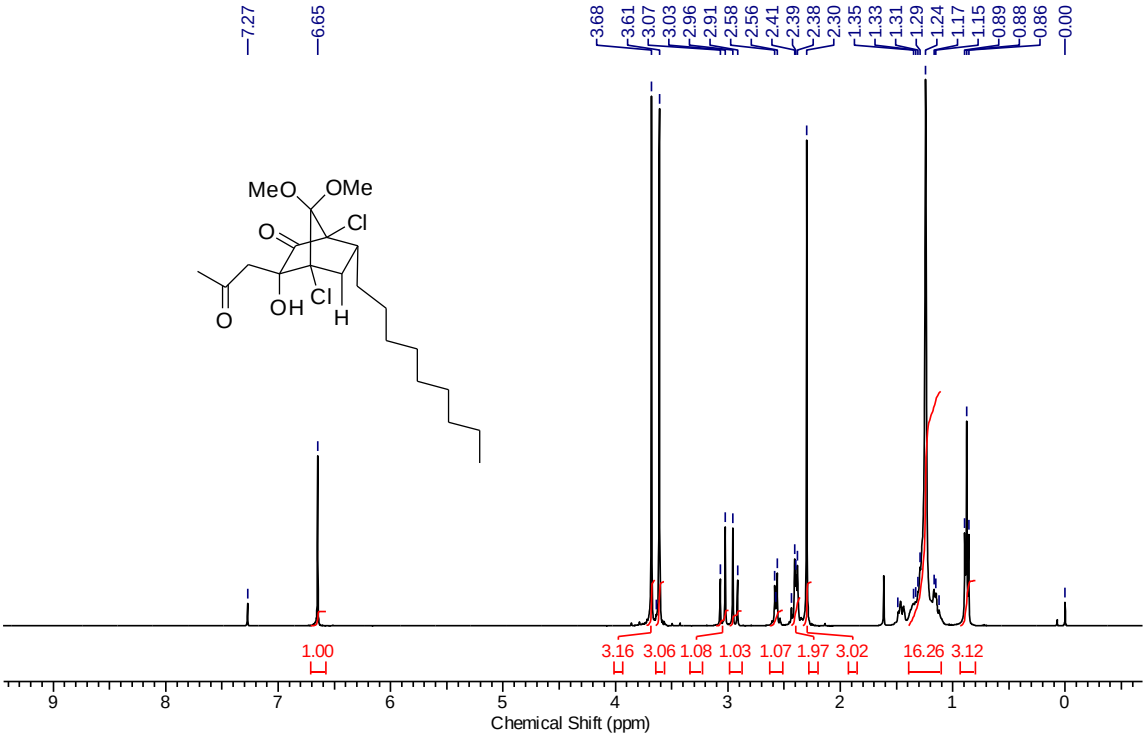
^{1}H NMR (400 MHZ) and ^{13}C NMR (100) MHZ of 2a in $CDCl_3$.

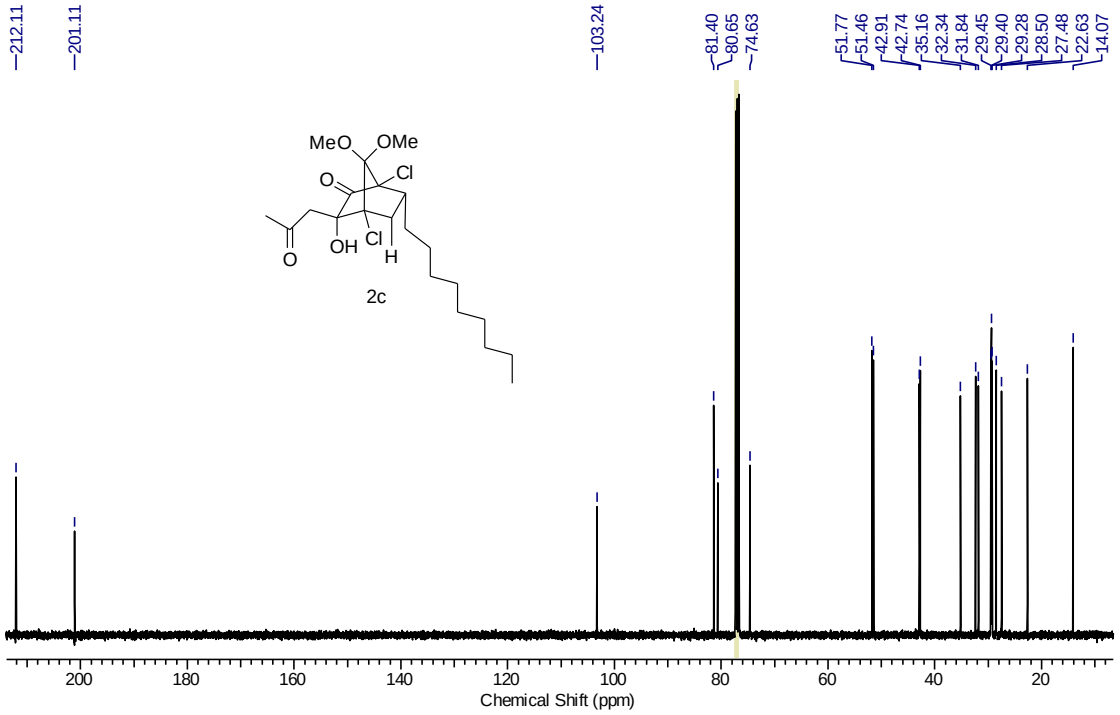


^{1}H NMR (400 MHZ) and ^{13}C NMR (100) MHZ of 2c in $CDCl_3$.

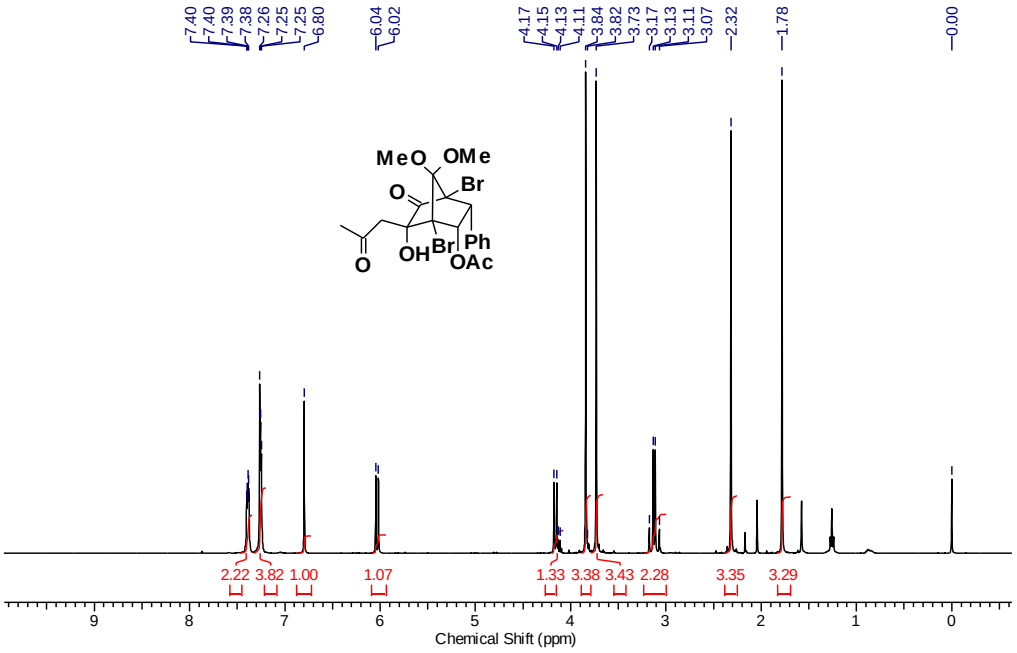


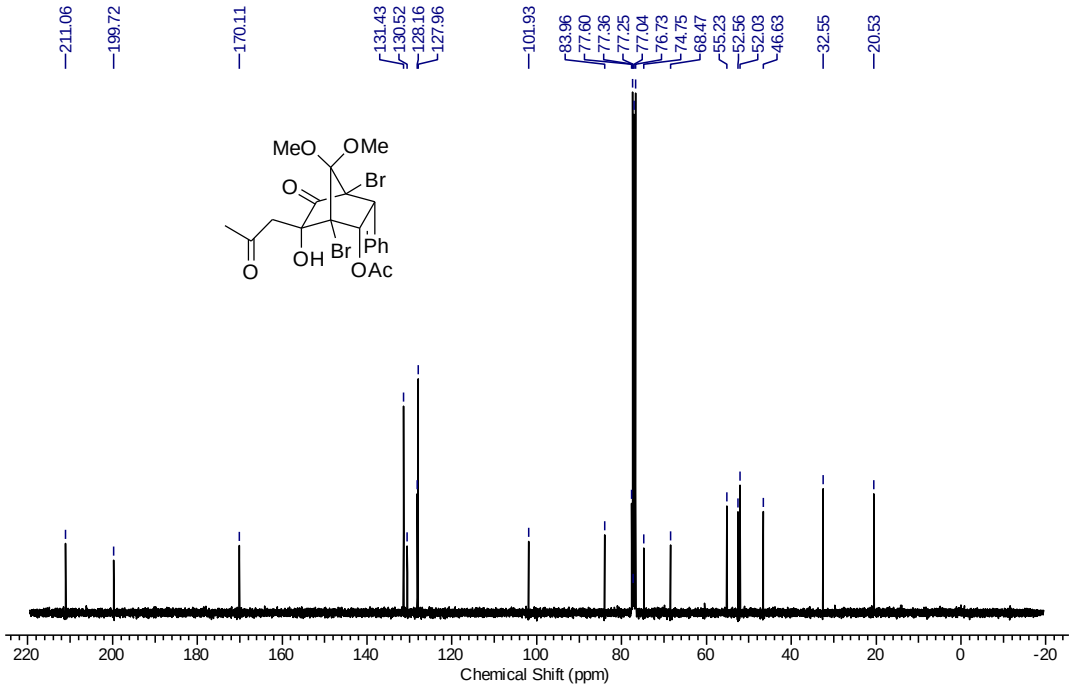
^{1}H NMR (400 MHZ) and ^{13}C NMR (100) MHZ of 2b in $CDCl_3$.



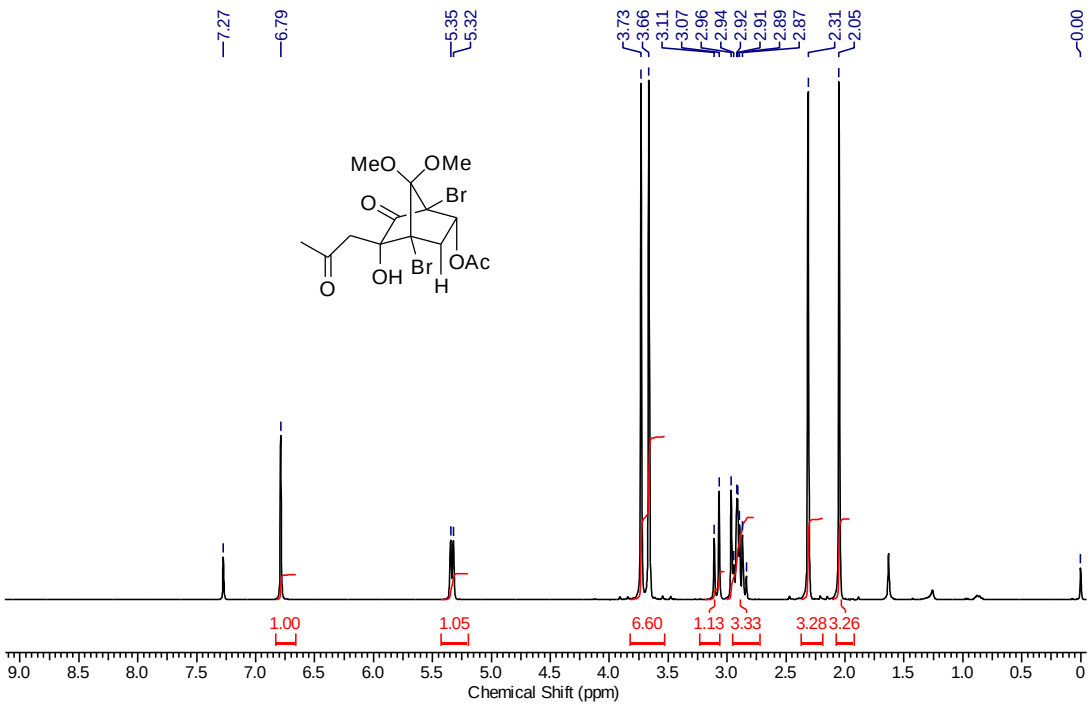


^{1}H NMR (400 MHZ) and ^{13}C NMR (100) MHZ of 2f in $CDCl_3$.





^{1}H NMR (400 MHZ) and ^{13}C NMR (100) MHZ of 2g in $CDCl_3$.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2.87
2.31
2.05
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OMe
O
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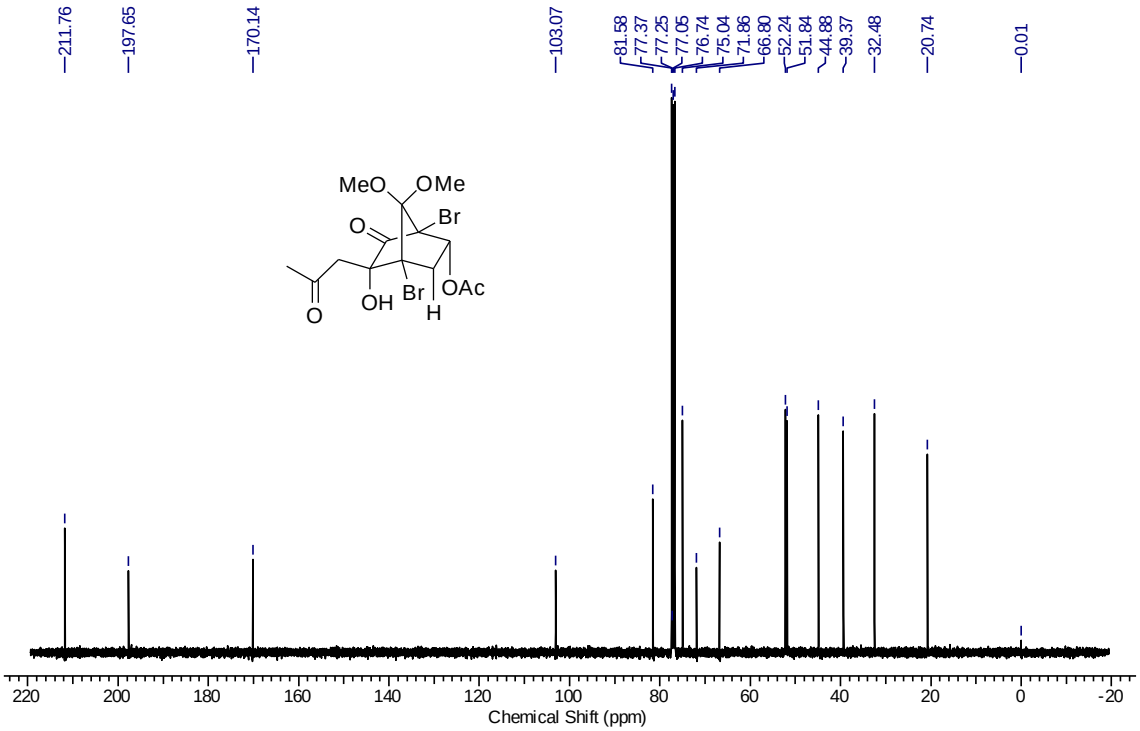
3.26
Chemical Shift (ppm)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44.88
39.37
32.48
20.74
0.01
MeO
OMe
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OH
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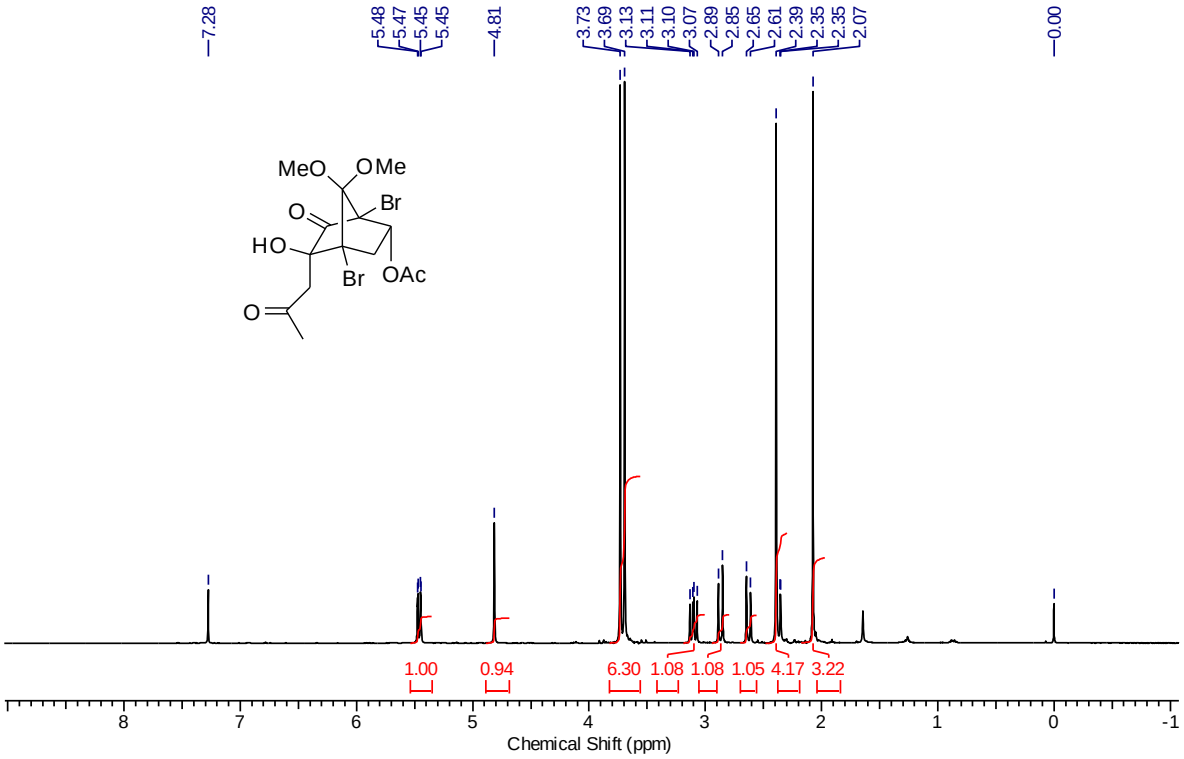
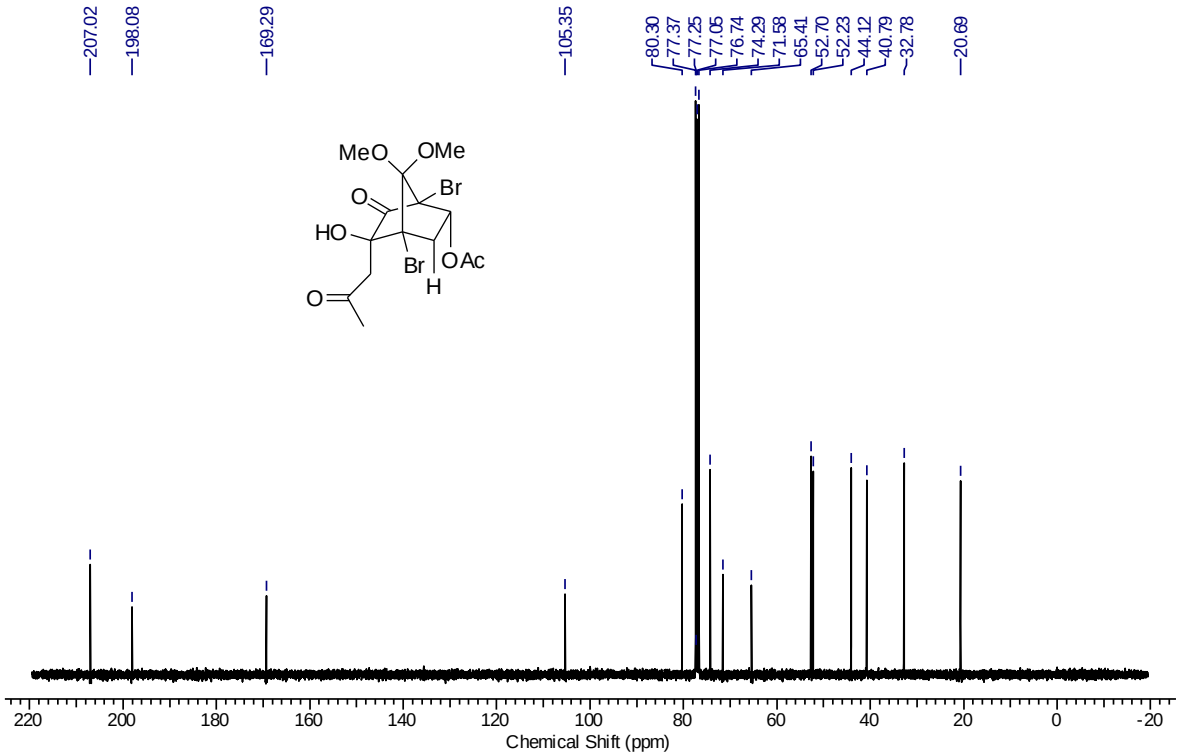
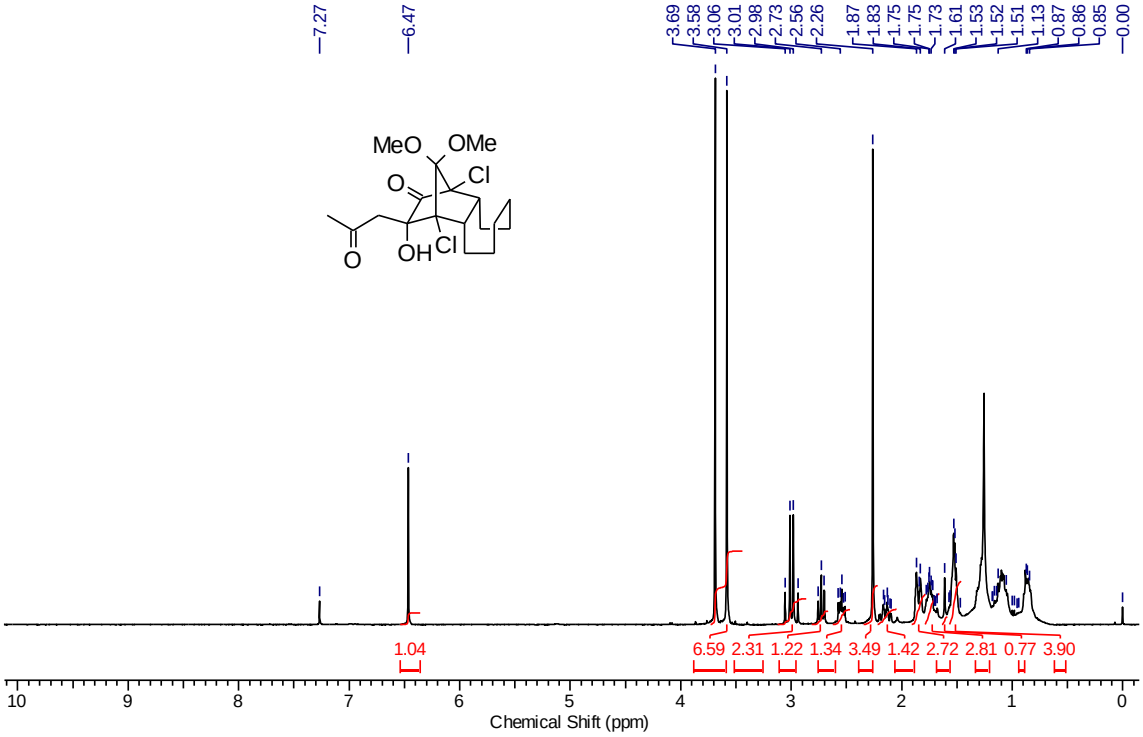
H
O
Chemical Shift (ppm)

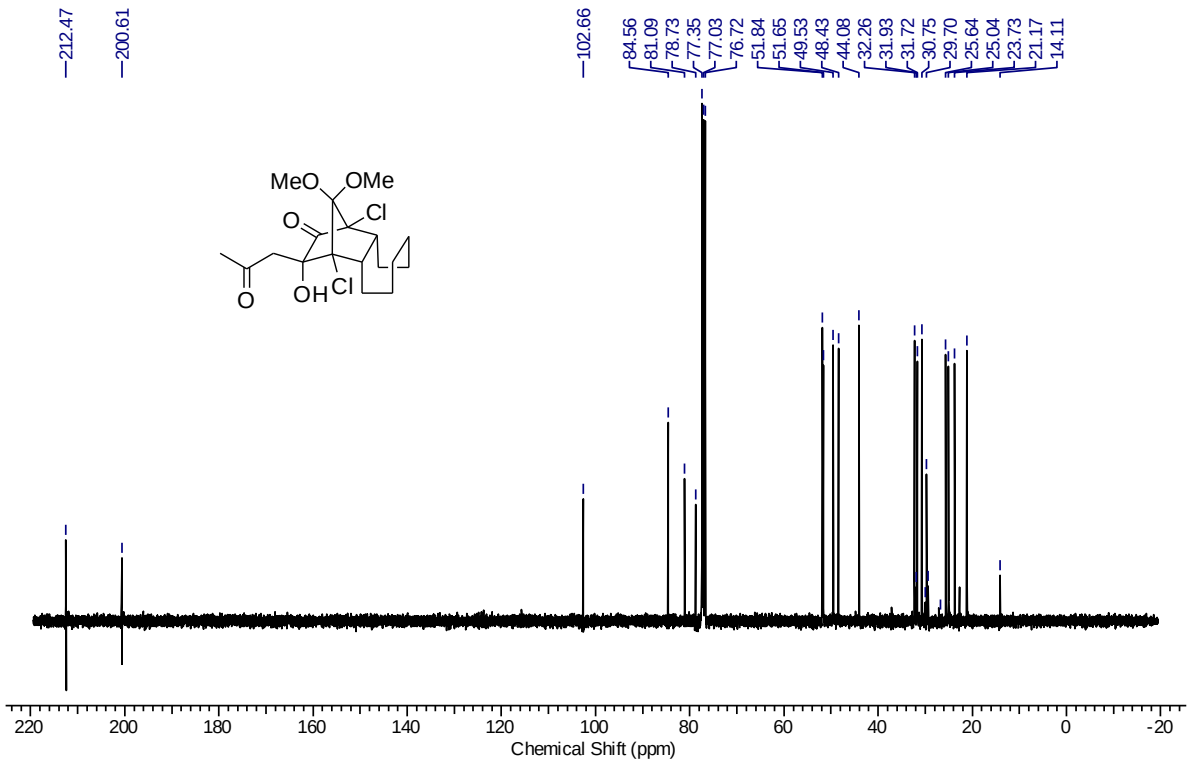
^{1}H NMR (400 MHZ) and ^{13}C NMR (100) MHZ of 3g in $CDCl_3$.



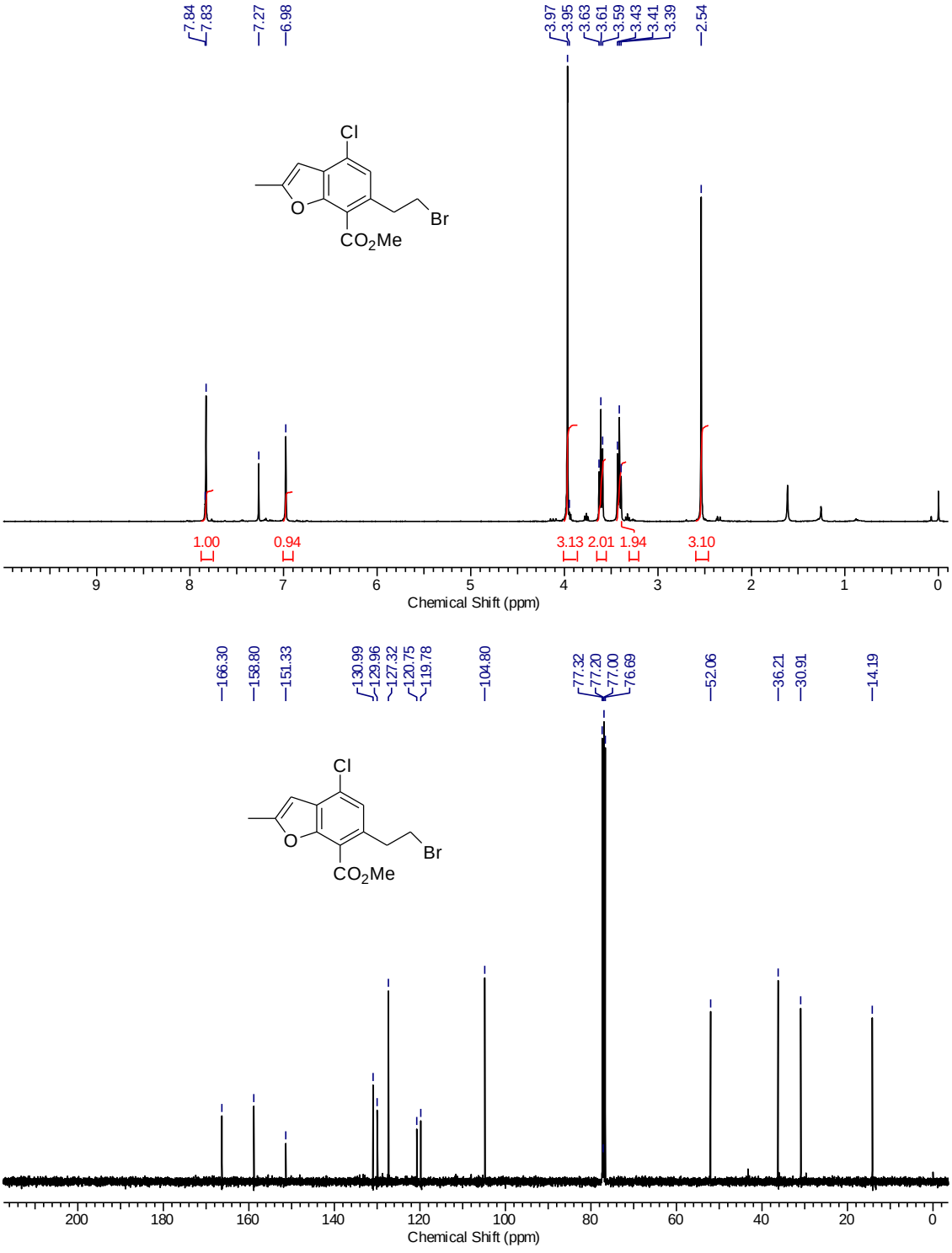


^{1}H NMR (400 MHZ) and ^{13}C NMR (100) MHZ of 2e in $CDCl_3$.

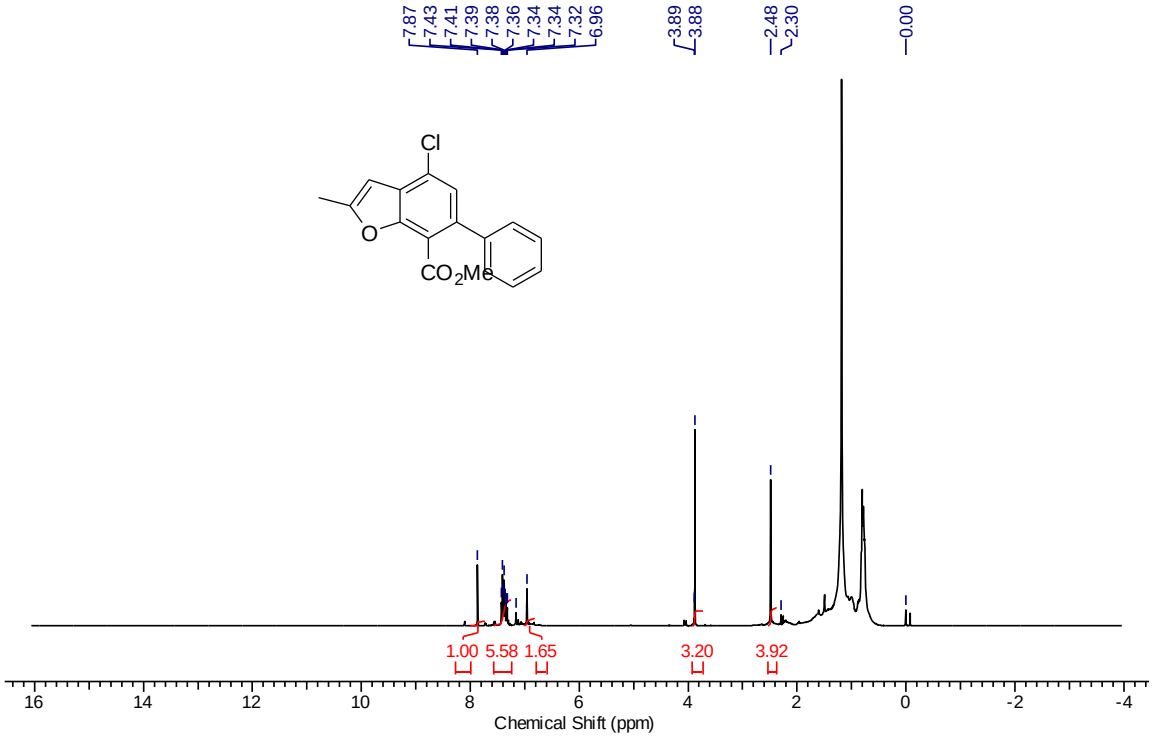


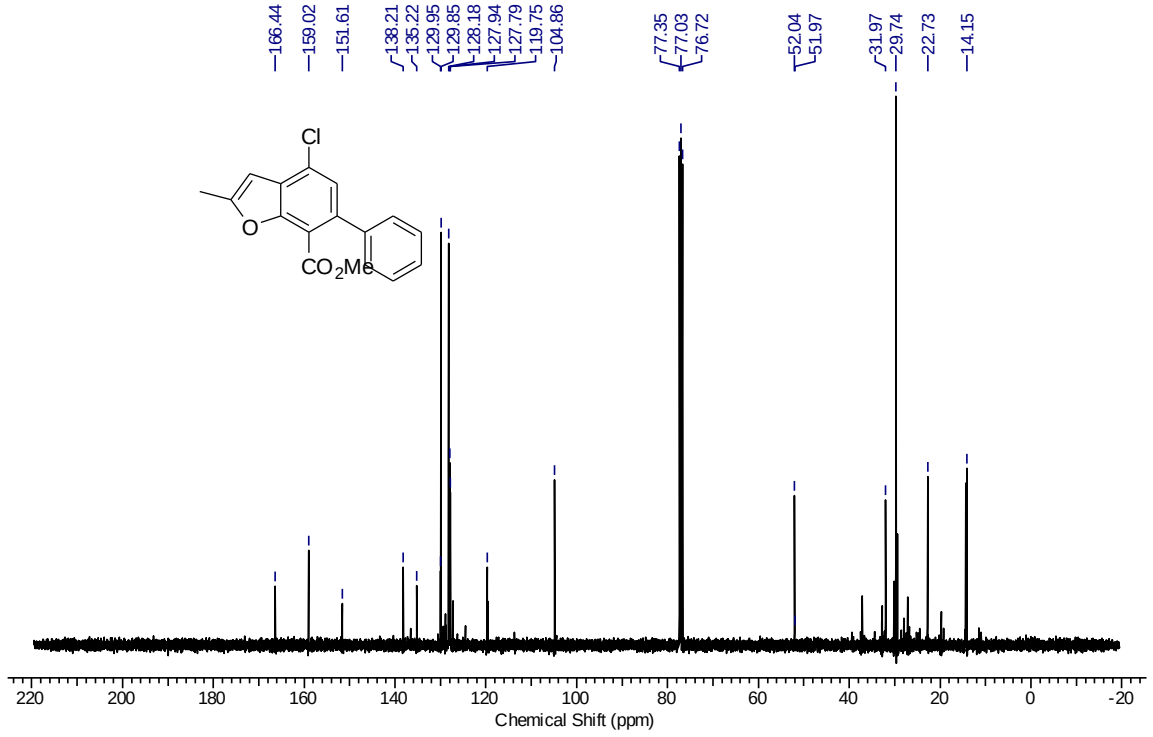


^{1}H NMR (400 MHZ) and ^{13}C NMR (100) MHZ of 4c in $CDCl_3$.

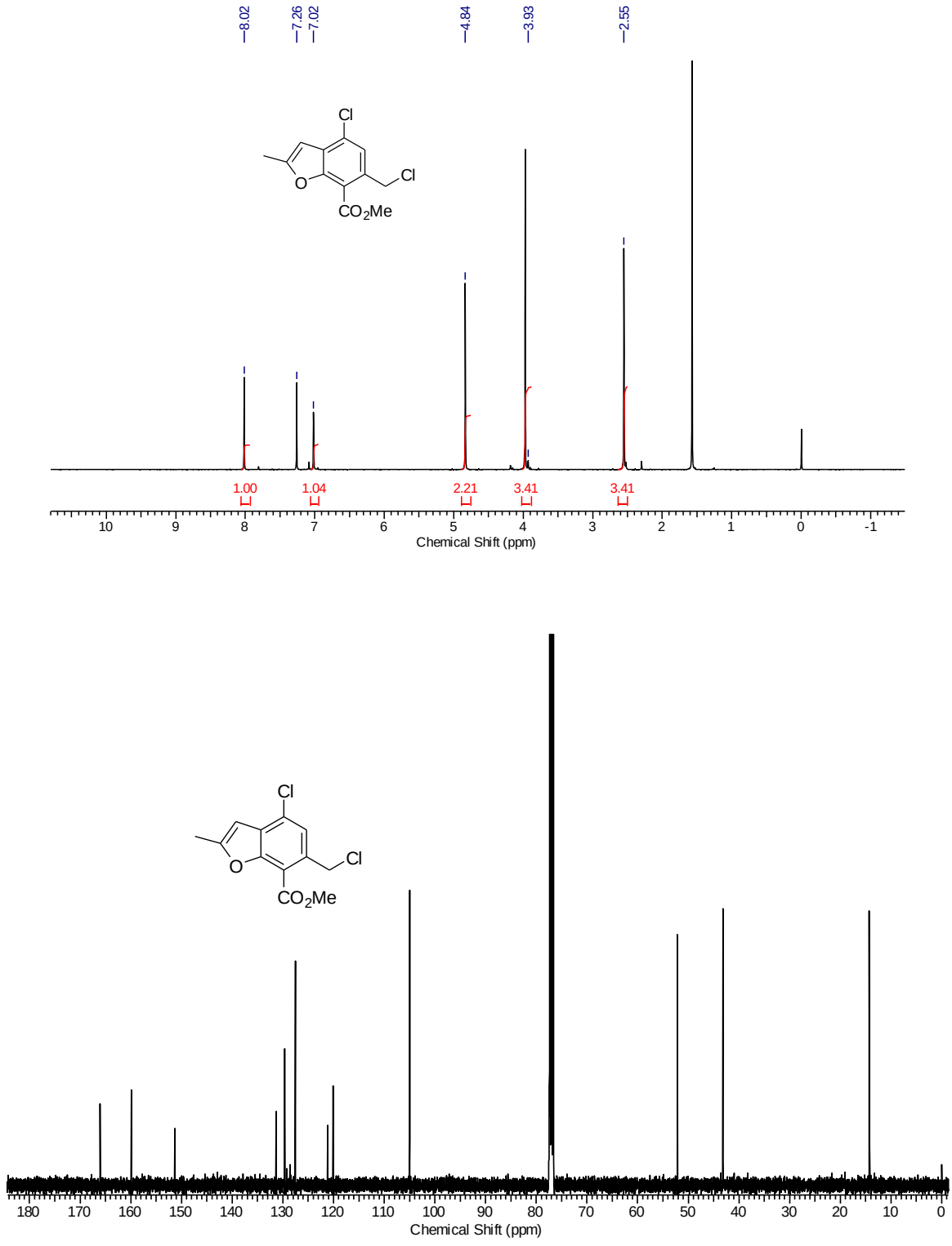


^{1}H NMR (400 MHZ) and ^{13}C NMR (100) MHZ of 4d in $CDCl_3$.

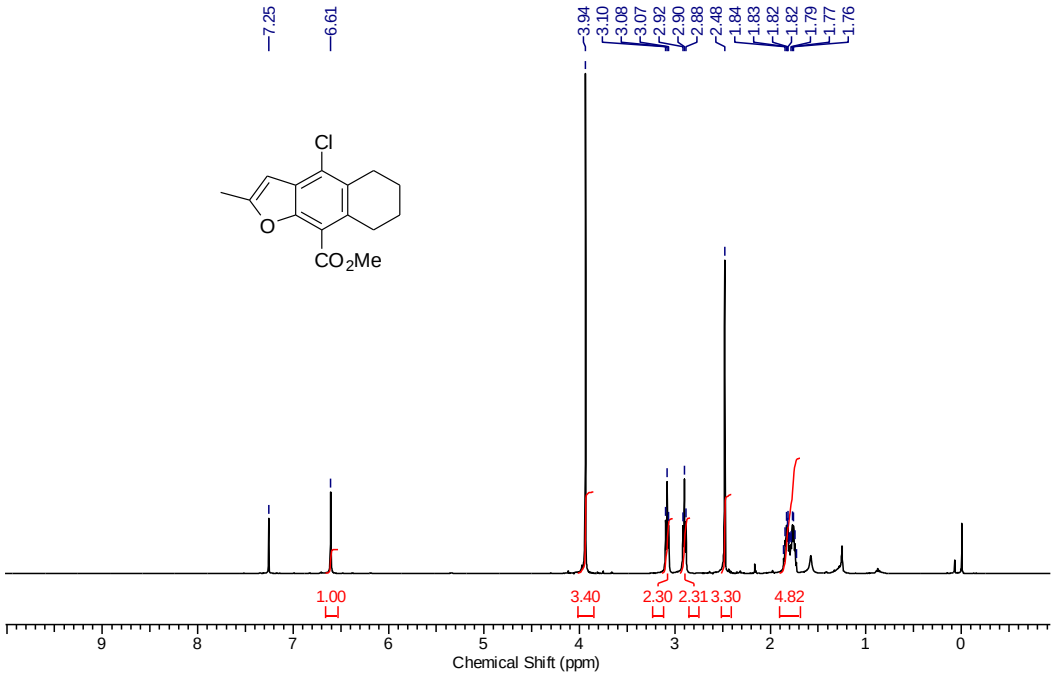




^{1}H NMR (400 MHZ) and ^{13}C NMR (100) MHZ of 4b in $CDCl_3$.



^{1}H NMR (400 MHZ) and ^{13}C NMR (100) MHZ of 4a in $CDCl_3$.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1.82
1.79
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Cl
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CO2Me
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2.31
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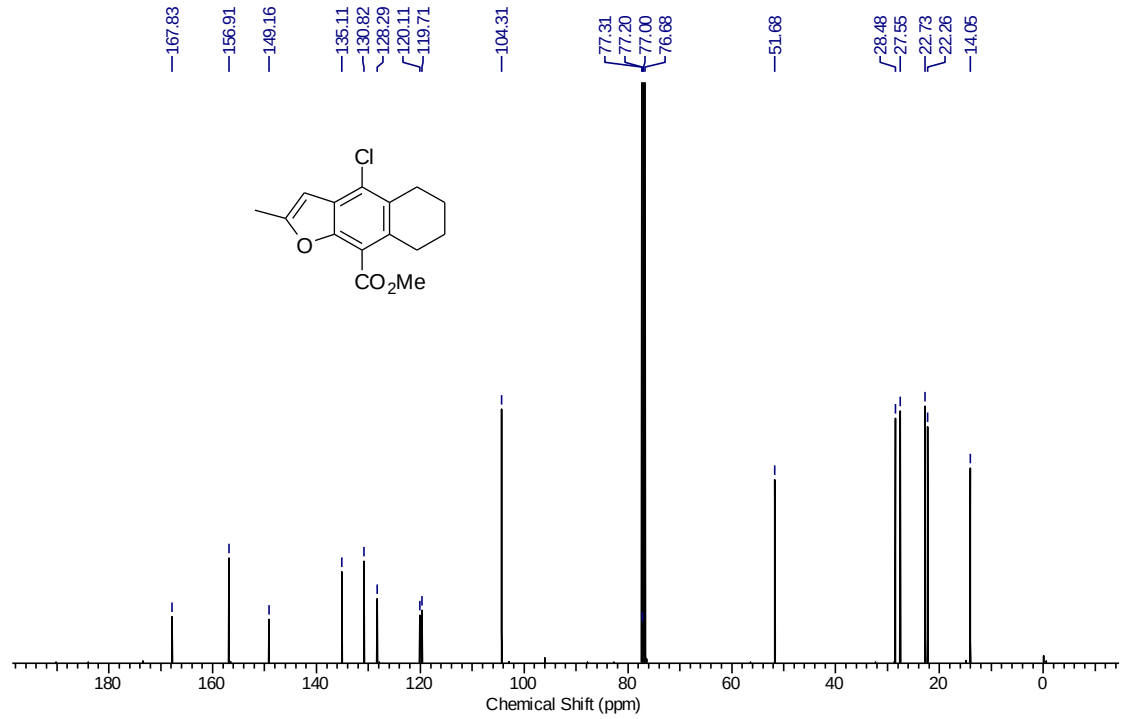
4.82
Chemical Shift (ppm)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77.00
76.68
51.68
28.48
27.55
22.73
22.26
14.05
Cl
O
CO2Me
Chemical Shift (ppm)

References

1) a) F. A. Khan, B. Prabhudas, J. Dash and N. Sahu. A Ruthenium-Catalyzed, Novel and Facile Procedure for the Conversion of Vicinal Di halo alkenes to a-Diketones. J. Am. Chem. Soc. 122, (2000**)** 9558-9559

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