Alternative Method to Baeyer-Villiger Oxidation of Cyclobutenones using I_2/DMSO Catalytic Systems

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Supporting Information

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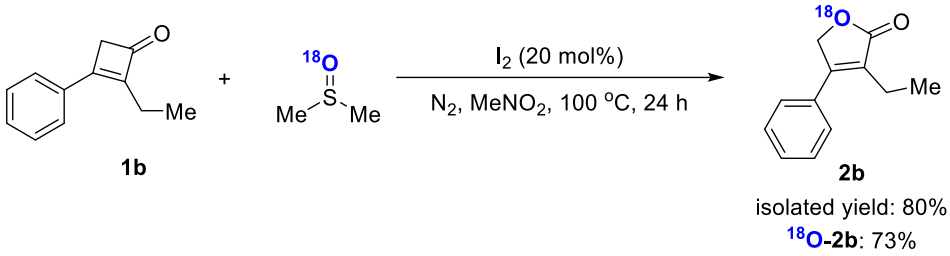
1. General remarks

All commercially available compounds were purchased from Sigma-Aldrich, J&K Chemicals, Bide Pharmatech, Shanghai Macklin Biochemical Technology Co., Ltd. Unless otherwise noted, materials obtained from commercial suppliers were used without further purification. Products were purified by flash chromatography on silica gel. ^{1}H-NMR spectra were recorded on Bruker AVANCE III-400 spectrometers. Chemical shifts (in ppm) were referenced with TMS in $CDCl_3$ (0 ppm). ^{13}C-NMR spectra were obtained by using the same NMR spectrometers and were calibrated with $CDCl_3$ (δ = 77.00 ppm). High resolution mass spectra were obtained with a Bruker APEX IV Fourier transform ion cyclotron resonance mass spectrometer.

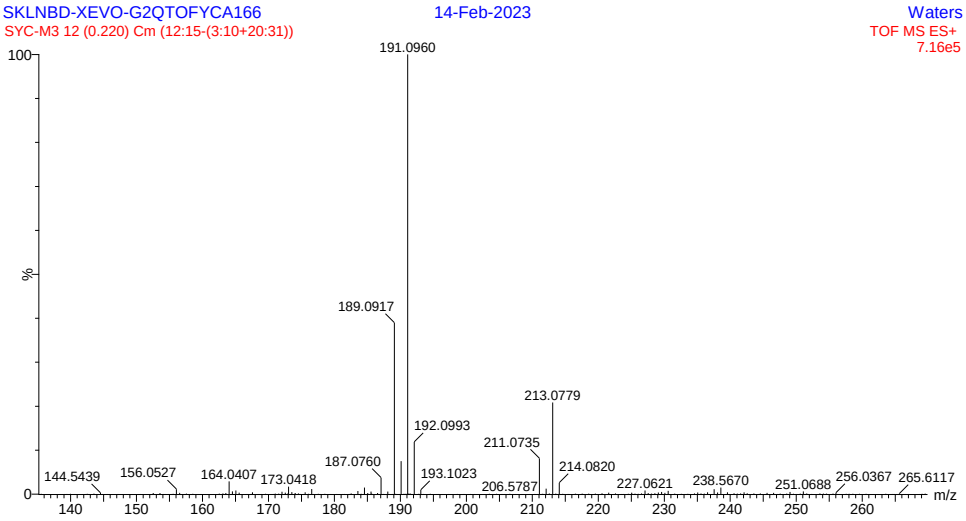
2. ^{18}O-Labeling Experiments



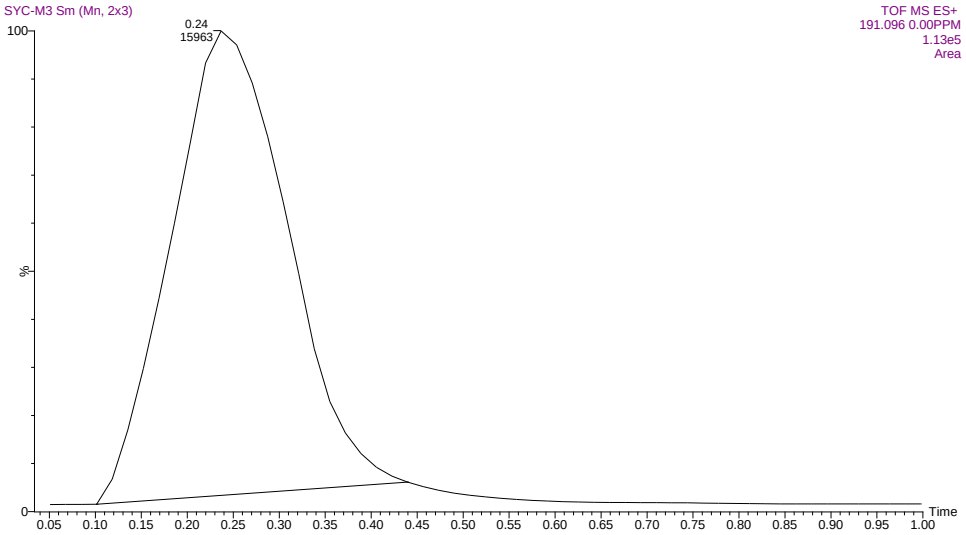
isolated yield: 80%

^{18}O-**2b**: 73%

A 25 mL Schlenk tube was equipped with a rubber septum and magnetic stir bar and was charged with 2-ethyl-3-phenylcyclobut-2-en-1-one **1b** (17.1 mg, 0.1 mmol) and I_2 (0.02 mmol, 5.0 mg, 0.2 equiv). The tube was evacuated and backfilled with N_2 for 3 times. ^{18}O-DMSO (40.0 mg, 0.5 mmol, 5.0 equiv) and $MeNO_2$ (1.0 mL)were added respectively with syringe under nitrogen. The mixture was stirred at 100 ºC under nitrogen for 24 hours. The mixture was quenched with a saturated solution of $Na_2S_2O_4$, and extracted with ethyl acetate (3 × 5 mL). The combined organic extracts were washed with a saturated solution of NaCl (20 mL), dried over sodium sulfate, and evaporated in vacuo. The residue was purified by chromatography on silica gel (PE/EA = 10:1), afforded 12.2 mg (80%) of ^{18}O-**2b** as yellow oil. In addition, 73% of ^{18}O-**2b** was determined by HRMS (Fig S1a-S1c). HRMS (ESI) ([M+H]$^+$) Calcd. for $C_{12}H_{13}O^{18}O$: 191.0958, Found: 191.0960.



(a)



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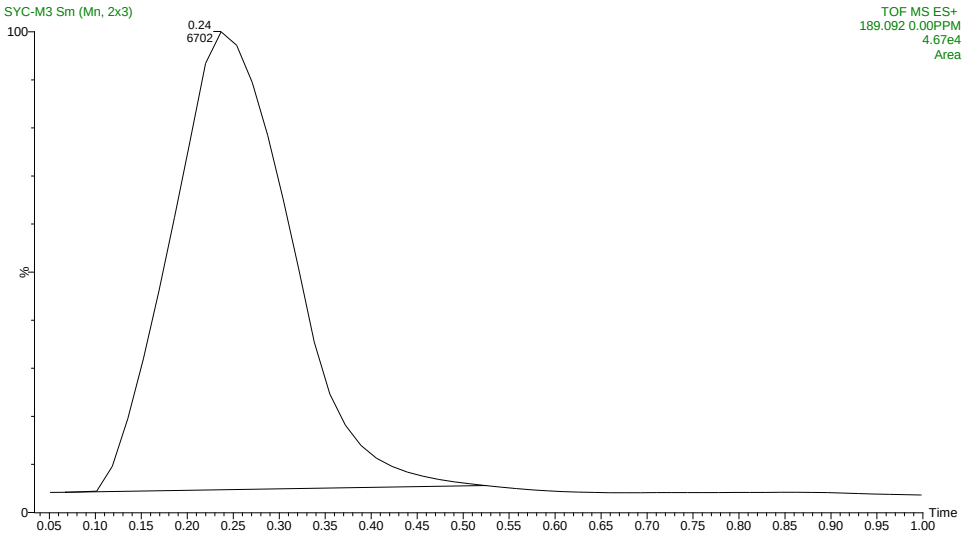
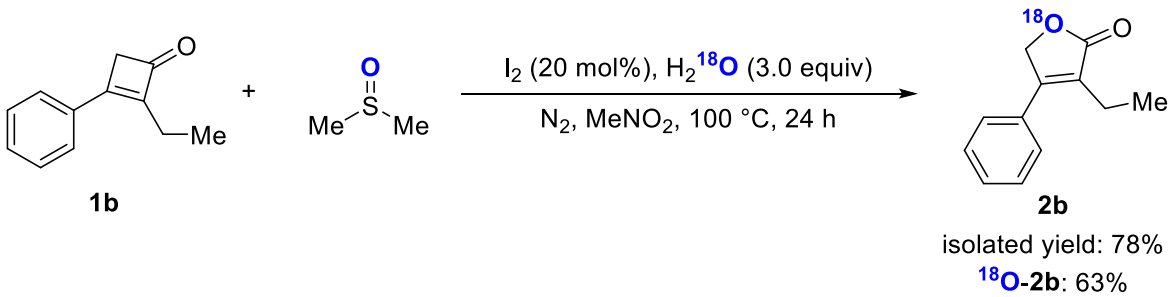


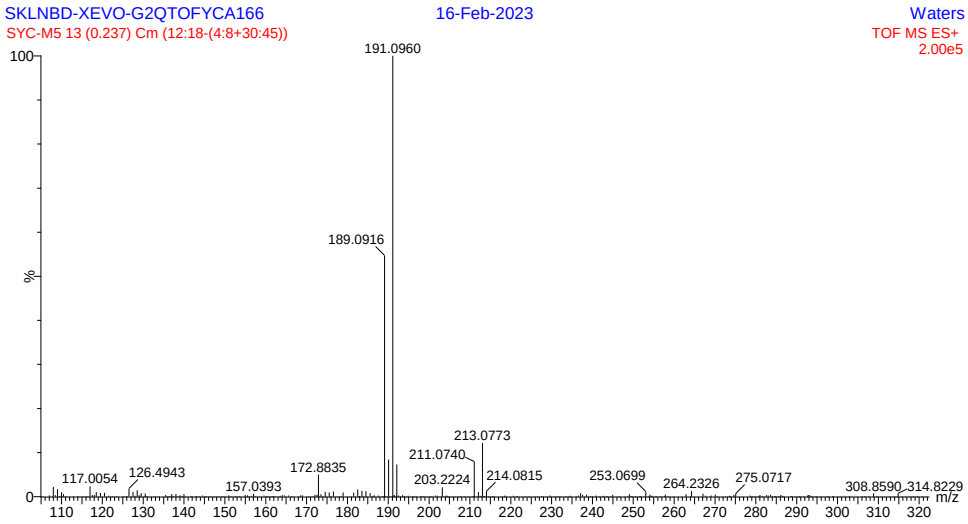
(c)

Fig S1. The HRMS of ^{18}O-2b under the condition of ^{18}O-DMSO

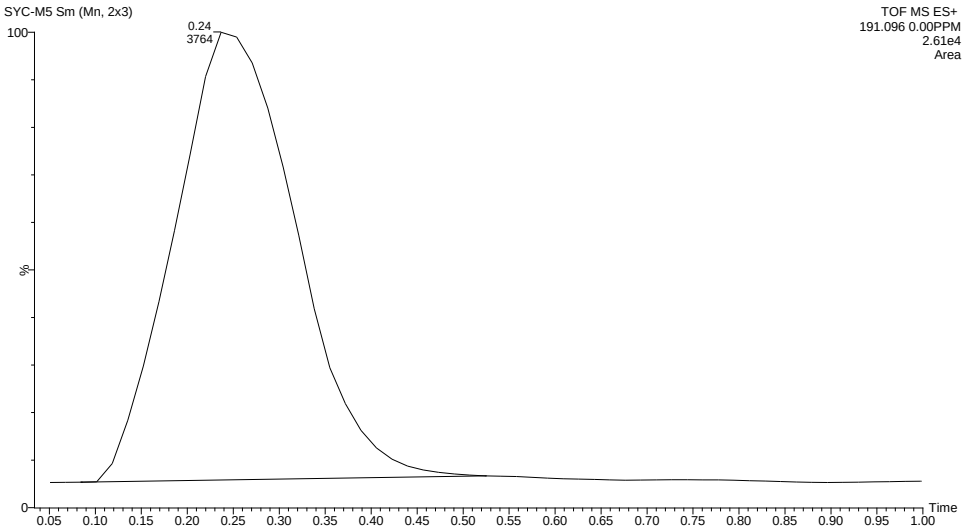


A 25 mL Schlenk tube was equipped with a rubber septum and magnetic stir bar and

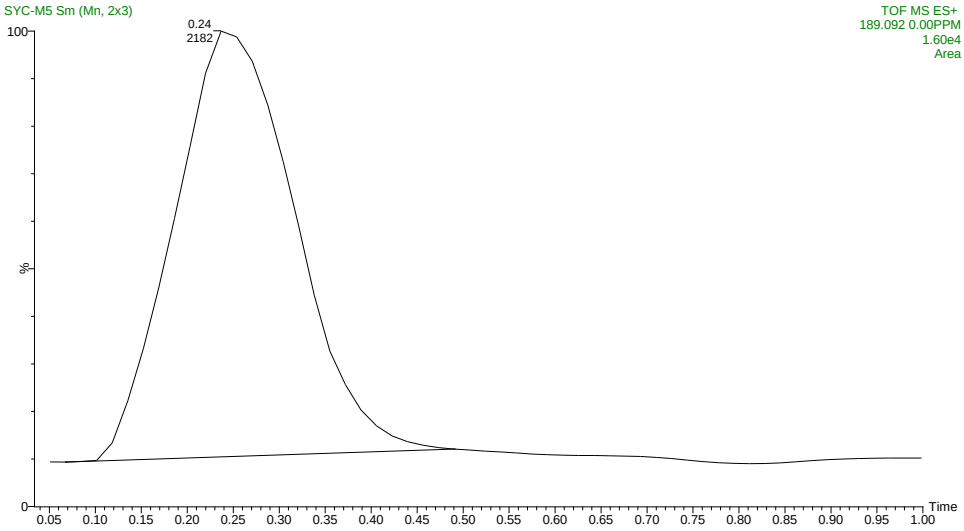
was charged with 2-ethyl-3-phenylcyclobut-2-en-1-one **1b** (34.2 mg, 0.2 mmol) and I_2 (10.1 mg, 0.04 mmol, 0.2 equiv). The tube was evacuated and backfilled with N_2 for 3 times. DMSO (78.0 mg, 1.0 mmol, 5.0 equiv), $H_2{}^{18}O$ (11.0 mL, 0.6 mmol, 3.0 equiv) and $MeNO_2$ (1.0 mL) were added respectively with syringe under nitrogen. The mixture was stirred at 100 ºC under nitrogen for 24 hours. The mixture was quenched with a saturated solution of $Na_2S_2O_4$, and extracted with ethyl acetate (3 × 5 mL). The combined organic extracts were washed with a saturated solution of NaCl (20 mL), dried over sodium sulfate, and evaporated in vacuo. The residue was purified by chromatography on silica gel (PE/EA = 10:1), afforded 24.0 mg (78%) of ^{18}O-**2b** as yellow oil. In addition, 63% of ^{18}O-**2b** was determined by HRMS (Fig S2a-S2c). HRMS (ESI) ($[M+H]^+$) Calcd. for $C_{12}H_{13}O^{18}O$: 191.0958, Found: 191.0960.



(a)



(b)



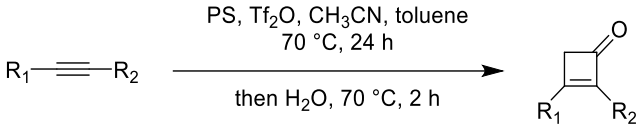
(c)

Fig S2. The HRMS of ^{18}O-2b under the condition of $H_2{}^{18}O$

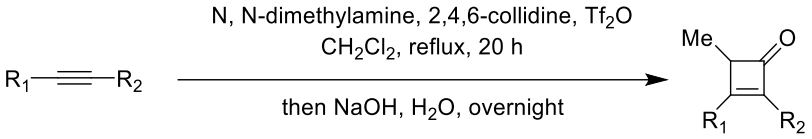
3. Experimental Procedure and Characterization Data of Products

3.1 Experimental Procedure

The cyclobutenones **1** were prepared according to literature procedures.[1-5]

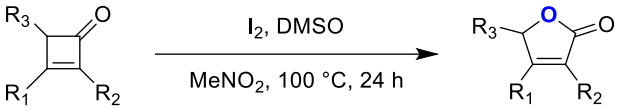


General procedure A: A 25 mL Schlenk tube was equipped with a rubber septum and magnetic stir bar and was charged with Proton Sponge (27.5 mg, 25 mol%). The tube was evacuated and backfilled with N_2 for 3 times. Alkyne (0.5 mmol, 1.0 equiv), CH_3CN (2.5 mL), toluene (2.5 mL), Tf_2O (190 μL, 3.0 equiv) were added respectively with syringe under nitrogen. The mixture was stirred at 70 ºC under nitrogen for 24 hours, then 0.3 mL H_2O was added with syringe and the mixture was stirred at 70 ºC for another 2 hours. The mixture was diluted with water (10 mL) and extracted with ethyl acetate (3 × 10 mL). The combined organic extracts were washed with a saturated solution of NaCl (15 mL), dried over sodium sulfate, and evaporated in vacuo. The residue was purified by chromatography on silica gel (PE/EA = 30:1) to afford the cyclobutenones.



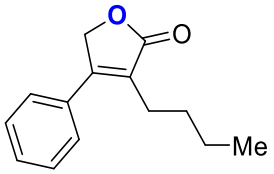
General procedure B: Alkyne (2.0 mmol, 1 equiv.), N, N-dimethyl propionamide (2.5 mmol, 1.25 equiv., 0.25 g, 0.28 mL) and 2, 4, 6-collidine (3.0 mmol, 1.5 equiv, 392 mg, 0.4 mL) were dissolved in 20 mL dichloromethane in a flame-dried flask and the solution was heated to reflux. Triflic anhydride (3.0 mmol, 1.5 equiv, 0.5 mL) was added into the refluxing reaction solution over 20 hours. Then the solution was directly concentrated under vacuum to evaporate all the solvent. Water (10 mL) were added to the same flask and form a heterogeneous mixture and NaOH (100 mg) was added to hydrolyze the [2+2] product, after which the reaction solution was stirred at RT

overnight. The reaction mixture was then extracted with dichloromethane (15 mL × 3), washed with brine, and dried over sodium sulfate. Then the solution was filtered, concentrated under vacuum and purified by column chromatography on silica gel (PE/EA = 30:1) to afford the cyclobutenones.

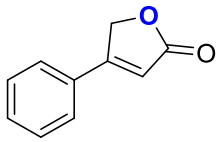


General procedure C: A 25 mL Schlenk tube was equipped with a rubber septum and magnetic stir bar and was charged with cyclobutenones (0.2 mmol, 1.0 equiv) and I_2 (0.04 mmol, 10.1 mg, 0.2 equiv). The tube was evacuated and backfilled with N_2 for 3 times. DMSO (1.0 mmol, 5.0 equiv) and $MeNO_2$ (1.0 mL) were added respectively with syringe under nitrogen. The mixture was stirred at 100 ºC under nitrogen for 24 h. The mixture was quenched with a saturated solution of $Na_2S_2O_4$, and extracted with ethyl acetate (3 × 5 mL). The combined organic extracts were washed with a saturated solution of NaCl (20 mL), dried over sodium sulfate, and evaporated in vacuo. The residue was purified by chromatography on silica gel (PE/EA = 10:1) to afford the furan-2(5H)-ones.

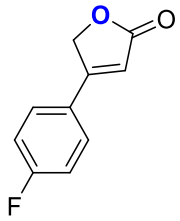
3.2 Characterization Data of Products



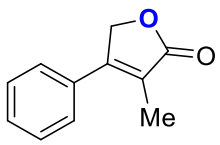
3-Butyl-4-phenylfuran-2(5H)-one (2a). The reaction of 2-butyl-3-phenylcyclobut-2-en-1-one **1a** (40.5 mg, 0.2 mmol), I_2 (10.1 mg, 0.04 mmol) and DMSO (78.0 mg, 1.0 mmol) in $MeNO_2$ (1.0 mL) under N_2 for 24 hours, afforded 36.3 mg (84%) of **2a** as yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.56–7.46 (m, 3H), 7.44 (d, J = 7.2 Hz, 2H), 5.04 (d, J = 2.4 Hz, 2H), 2.54 (t, J = 8.0 Hz, 2H), 1.59 (dt, J = 8.8, 6.4 Hz, 2H), 1.41 (hd, J = 7.2, 2.0 Hz, 2H), 0.93 (td, J = 7.2, 2.4 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 175.1, 155.1, 131.5, 130.1, 129.2, 127.8, 127.1, 70.7, 30.0, 24.3, 22.8, 13.8. HRMS (ESI) ($[M+H]^+$) Calcd. for $C_{14}H_{17}O_2$: 217.1229, Found: 217.1232.



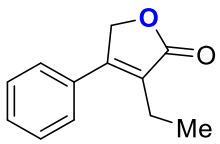
4-phenylfuran-2(5H)-one (2b): According to general procedure C, a solution of **1b** (0.2 mmol, 31.6 mg), I_2 (0.04 mmol, 6.4 mg), DMSO (1.0 mmol, 71 uL) in $MeNO_2$ (2.0 mL) were stirred at 100 ºC under N_2 for 24 h to afforded **2b** (15.4 mg, 44%) as white solid after purification on silica gel (PE:EA=10:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.73 – 7.41 (m, 5H), 6.41 (t, *J* = 1.8 Hz, 1H), 5.26 (d, *J* = 1.8 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.9, 163.9, 131.8, 129.7, 129.3, 126.5, 113.1, 71.0. HRMS (ESI) ($[M+H]^+$) Calcd. for $C_{10}H_9O_2$: 161.0603; found: 161.0603.



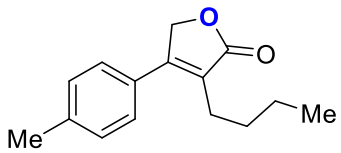
4-(4-fluorophenyl)furan-2(5H)-one (2c). The reaction of 3-(4-fluorophenyl)cyclobut-2-en-1-one **1c** (32.3 mg, 0.2 mmol), I_2 (10.1 mg, 0.04 mmol) and DMSO (78.0 mg, 1.0 mmol) in $MeNO_2$ (1 mL), under N_2 for 24 hours, afforded 19.6 mg (55%) of **2c** as white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.54 (ddd, *J* = 11.6, 6.8, 4.4 Hz, 2H), 7.19 (t, *J* = 8.4 Hz, 2H), 6.35 (s, 1H), 5.23 (d, *J* = 2.0 Hz, 2H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 173.6, 165.9, 128.7 (d, *J* = 9.0 Hz), 116.7 (d, *J* = 22.0 Hz), 112.9, 70.9. ^{19}F NMR (376 MHz, $CDCl_3$) δ 106.6. HRMS (ESI) ($[M+H]^+$) Calcd. for $C_{10}H_8O_2F$: 179.0508, Found: 179.0507.



3-methyl-4-phenylfuran-2(5H)-one (2d): According to general procedure C, a solution of **1d** (0.2 mmol, 31.8 mg), I_2 (0.04 mmol, 6.4 mg), DMSO (1.0 mmol, 71 uL) in $MeNO_2$ (1.0 mL) were stirred at 100 ºC under N_2 for 24 h to afforded **2d** (29.8 mg, 85%) as white solid after purification on silica gel (PE:EA=10:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.54-7.46 (m, 5H), 5.08 (q, *J* = 2.0 Hz, 2H), 2.15 (t, *J* = 2.0 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.5, 154.9, 131.5, 130.2, 129.2, 127.3, 123.0, 70.5, 10.4. HRMS (ESI) ($[M+H]^+$) Calcd. for $C_{11}H_{11}O_2$: 175.0759, Found: 175.0760.

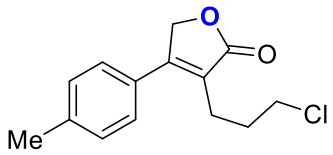


3-Ethyl-4-phenylfuran-2(5H)-one (2e). The reaction of 2-ethyl-3-phenylcyclobut-2-en-1-one **1e** (34.0 mg, 0.2 mmol), I_2 (10.1 mg, 0.04 mmol) and DMSO (78.0 mg, 1.0 mmol) in $MeNO_2$ (1 mL), under N_2 for 24 hours, afforded 23.9 mg (82%) of **2e** as yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.58–7.47 (m, 3H), 7.44 (dd, *J* = 7.6, 2.0 Hz, 2H), 5.05 (s, 2H), 2.58 (q, *J* = 7.6 Hz, 2H), 1.24 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 175.0, 154.9, 131.4, 130.2, 129.2, 128.9, 127.2, 70.6, 17.9, 12.5. HRMS (ESI) ($[M+H]^+$) Calcd. for $C_{12}H_{13}O_2$: 189.0916, Found: 189.0917.

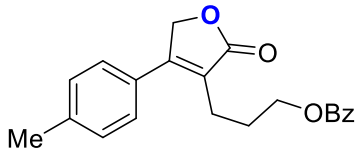


3-butyl-4-(p-tolyl)furan-2(5H)-one (2f): According to general procedure C, a solution of **1f** (0.2 mmol, 43.0 mg), I_2 (0.04 mmol, 6.4 mg), DMSO (1.0 mmol, 71 uL) in $MeNO_2$ (2.0 mL) were stirred at 100 ºC under N_2 for 24 h to afforded **2f** (39.6 mg, 86%) as light yellow oil after purification on silica gel (PE:EA=10:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.34 (d, *J* = 8.2 Hz, 2H), 7.30 (d, *J* = 8.2 Hz, 2H), 5.02 (s, 2H), 2.59 – 2.51 (m, 2H), 2.43 (s, 3H), 1.67 – 1.54 (m, 2H), 1.46-1.36 (m, 2H), 0.94 (t, *J* = 7.3 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.3, 154.9, 140.5, 129.9, 128.6, 127.0,

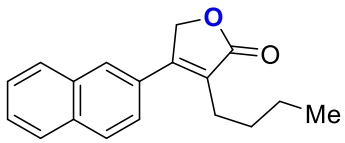
126.9, 70.6, 29.9, 24.3, 22.8, 21.4, 13.8. HRMS (ESI) ([M+H]$^+$) Calcd. for $C_{15}H_{19}O_2$: 231.1385; found: 231.1387.



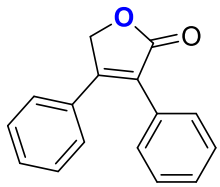
3-(3-chloropropyl)-4-(p-tolyl)furan-2(5H)-one (2g): According to general procedure , a solution of **1g** (0.2 mmol, 47.1 mg), I_2 (0.04 mmol, 6.4 mg), DMSO (1.0 mmol, 71 uL) in $MeNO_2$ (2.0 mL) were stirred at 100 ºC under N_2 for 24 h to afforded **2g** (38.5 mg, 77%) as light yellow oil after purification on silica gel (PE:EA=10:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.37 (d, *J* = 8.3 Hz, 2H), 7.32 (d, *J* = 8.1 Hz, 2H), 5.06 (d, *J* = 1.2 Hz, 2H), 3.62 (t, *J* = 6.3 Hz, 2H), 2.90 – 2.59 (m, 2H), 2.43 (s, 3H), 2.19 – 2.04 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.1, 156.3, 140.9, 129.9, 128.1, 127.1, 125.1, 70.8, 44.8, 30.4, 22.1, 21.5. HRMS (ESI) ([M+H]$^+$) Calcd. for $C_{14}H_{16}ClO_2$: 251.0839; found: 251.0842.



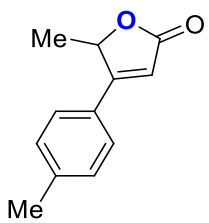
3-(2-oxo-4-(p-tolyl)-2,5-dihydrofuran-3-yl)propyl benzoate (2h): According to general procedure C, a solution of **1h** (0.2 mmol, 64.1 mg), I_2 (0.04 mmol, 6.4 mg), DMSO (1.0 mmol, 71 uL) in $MeNO_2$ (2.0 mL) were stirred at 100 ºC under N_2 for 24 h to afforded **2h** (53.1 mg, 79%) as light yellow oil after purification on silica gel (PE:EA=10:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.06 – 7.96 (m, 2H), 7.65 – 7.56 (m, 1H), 7.45 (t, *J* = 7.8 Hz, 2H), 7.31 (d, *J* = 8.2 Hz, 2H), 7.18 (d, *J* = 8.0 Hz, 2H), 5.03 (s, 2H), 4.36 (t, *J* = 6.1 Hz, 2H), 2.83 – 2.69 (m, 2H), 2.36 (s, 3H), 2.20 – 2.07 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.1, 166.5, 156.5, 140.8, 132.9, 130.2, 129.9, 129.6, 128.3, 128.2, 127.0, 125.5, 70.8, 64.2, 26.7, 21.4, 21.2. HRMS (ESI) ([M+H]$^+$) Calcd. for $C_{21}H_{21}O_4$: 337.1440; found: 337.1440.



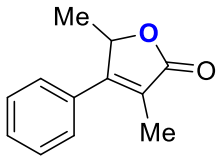
3-butyl-4-(naphthalen-2-yl)furan-2(5H)-one (2i): According to general procedure , a solution of **1i** (0.2 mmol, 50.2 mg), I_2 (0.04 mmol, 6.4 mg), DMSO (1.0 mmol, 71 uL) in $MeNO_2$ (2.0 mL) were stirred at 100 ºC under N_2 for 24 h to afforded **2i** (45.2 mg, 85%) as light yellow oil after purification on silica gel (PE:EA=10:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.04 – 7.80 (m, 4H), 7.68 – 7.48 (m, 3H), 5.16 (d, *J* = 1.2 Hz, 2H), 2.81-2.49 (m, 2H), 1.70-1.62 (m, 2H), 1.49-1.40 (m, 2H), 0.96 (t, *J* = 7.3 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.2, 155.0, 133.7, 133.1, 129.0, 128.9, 128.5, 128.1, 127.8, 127.6, 127.1, 127.0, 124.1, 70.7, 30.1, 24.4, 22.8, 13.8. HRMS (ESI) ($[M+H]^+$) Calcd. for $C_{18}H_{19}O_2$: 267.1385; found: 267.1385.



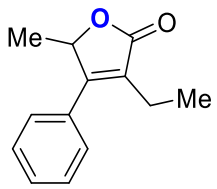
3,4-Diphenylfuran-2(5H)-one (2j). The reaction of 2,3-diphenylcyclobut-2-en-1-one **1j** (33.0 mg, 0.15 mmol), I_2 (7.5 mg, 0.03 mmol) and DMSO (59.5 mg, 0.75 mmol) in $MeNO_2$ (1 mL), under N_2 for 24 hours, afforded 28.0 mg (79%) of **2j** as yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.57 – 7.31 (m, 10H), 5.21 (s, 2H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 173.5, 156.1, 130.9, 130.6, 130.2, 129.3, 129.0, 128.8, 128.7, 127.5, 126.2, 70.6. HRMS (ESI) ($[M+H]^+$) Calcd. for $C_{16}H_{13}O_2$: 237.0916, Found: 237.0917.



5-Methyl-4-(p-tolyl)furan-2(5H)-one (2k). The reaction of 4-methyl-3-phenylcyclobut-2-en-1-one **1k** (34.4 mg, 0.2 mmol), I_2 (10.1 mg, 0.04 mmol) and DMSO (78.0 mg, 1.0 mmol) in $MeNO_2$ (1 mL), under N_2 for 24 hours, afforded 27.1 mg (58%) of **2k** as white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.42 (d, *J* = 8.0 Hz, 2H), 7.28 (s, 2H), 6.35 (s, 1H), 5.23 (d, *J* = 1.6 Hz, 1H), 2.44 (s, 3H), 1.55 (d, *J* = 6.7 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 172.9, 169.0, 142.0, 129.9, 127.2, 112.7, 78.6, 21.5, 20.0. HRMS (ESI) ($[M+H]^+$) Calcd. for $C_{12}H_{13}O_2$: 189.0916, Found: 189.0919.

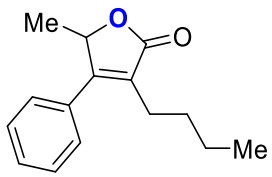


3,5-dimethyl-4-phenylfuran-2(5H)-one (2l): According to general procedure , a solution of **1l** (0.2 mmol, 34.4 mg), I_2 (0.04 mmol, 6.4 mg), DMSO (1.0 mmol, 71 uL) in $MeNO_2$ (2.0 mL) were stirred at 100 ºC under N_2 for 24 h to afforded **2l** (19.3 mg, 51%) as white solid after purification on silica gel (PE:EA=10:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.56-7.43 (m, 3H), 7.41-7.34 (m, 2H), 5.46-5.40 (m, 1H), 2.07 (d, *J* = 1.8 Hz, 3H), 1.39 (d, *J* = 6.7 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 174.4, 160.6, 131.5, 129.8, 129.0, 127.8, 123.2, 78.2, 19.2, 10.0. HRMS (ESI) ($[M+H]^+$) Calcd. for $C_{12}H_{13}O_2$: 189.0916, Found: 189.0919.

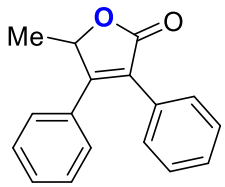


3-Ethyl-5-methyl-4-phenylfuran-2(5H)-one (2m). The reaction of 2-ethyl-4-methyl-3-phenylcyclobut-2-en-1-one **1m** (37.2 mg, 0.2 mmol), I_2 (10.1 mg, 0.04 mmol) and DMSO (78.0 mg, 1.0 mmol) in $MeNO_2$ (1 mL), under N_2 for 24 hours, afforded 28.6 mg (61%) of **2m** as yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.53 – 7.45 (m, 3H), 7.33 (dd, *J* = 8.0, 1.6 Hz, 2H), 5.39 (qd, *J* = 6.8, 1.6 Hz, 1H), 2.62 – 2.32 (m, 2H),

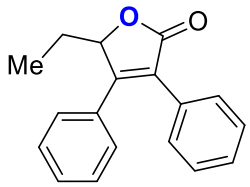
1.37 (d, *J* = 6.8 Hz, 3H), 1.20 (t, *J* = 7.6 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 173.8, 160.6, 131.6, 129.7, 129.1, 129.0, 127.6, 78.2, 19.1, 17.7, 12.8. HRMS (ESI) ($[M+H]^+$) Calcd. for $C_{13}H_{15}O_2$: 203.1072, Found: 203.1074.



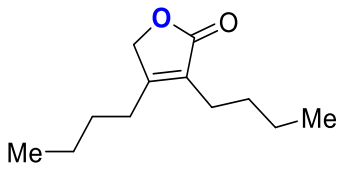
3-Butyl-5-methyl-4-phenylfuran-2(5H)-one (2n). The reaction of 2-butyl-4-methyl-3-phenylcyclobut-2-en-1-one **1n** (42.8 mg, 0.2 mmol), I_2 (10.1 mg, 0.04 mmol) and DMSO (78.0 mg, 1.0 mmol) in $MeNO_2$ (1 mL), under N_2 for 24 hours, afforded 13.6 mg (40%) of **2n** as yellow oil. (13.6 mg, 40%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.49 (q, *J* = 8.0, 7.6 Hz, 3H), 7.41 – 7.31 (m, 2H), 5.38 (q, *J* = 6.8 Hz, 1H), 2.59 – 2.28 (m, 2H), 1.58 (tdd, *J* = 23.2, 9.2, 6.0 Hz, 2H), 1.37 (d, *J* = 6.8 Hz, 5H), 0.91 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 174.0, 160.9, 131.7, 129.7, 129.1, 128.1, 127.9, 127.6, 78.2, 77.2, 30.2, 24.0, 22.7, 19.2, 13.8. HRMS (ESI) ($[M+H]^+$) Calcd. for $C_{15}H_{19}O_2$: 231.1385, Found: 231.1388.



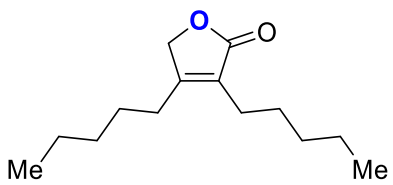
5-methyl-3,4-diphenylfuran-2(5H)-one (2o). The reaction of 4-methyl-2,3-diphenylcyclobut-2-en-1-one **1o** (47.2 mg, 0.2 mmol), I_2 (10.1 mg, 0.04 mmol) and DMSO (78.0 mg, 1.0 mmol) in $MeNO_2$ (1 mL), under N_2 for 24 hours, afforded 30.2 mg (60%) of **2o** as yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.52 – 7.22 (m, 10H), 5.55 (q, *J* = 6.8 Hz, 1H), 1.46 (d, *J* = 6.8 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 173.5, 156.1, 130.9, 130.6, 130.2, 129.3, 129.0, 128.8, 128.7, 127.5, 126.2, 70.6. HRMS (ESI) ($[M+H]^+$) Calcd. for $C_{17}H_{15}O_2$: 251.1073, Found: 251.1073.



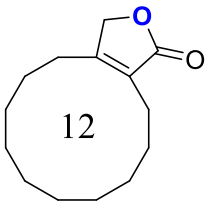
5-ethyl-3,4-diphenylfuran-2(5H)-one (2p). The reaction of 4-methyl-3-phenylcyclobut-2-en-1-one **1p** (49.6 mg, 0.2 mmol), I_2 (10.1 mg, 0.04 mmol) and DMSO (78.0 mg, 1.0 mmol) in $MeNO_2$ (1 mL), under N_2 for 24 hours, afforded 23.3 mg (44%) of **2p** as white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.47 – 7.31 (m, 8H), 7.28 – 7.22 (m, 2H), 5.48 (dd, *J* = 6.8, 3.6 Hz, 1H), 2.06-1.96 (m, 1H), 1.58 (m, 1H), 0.96 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 172.6, 160.1, 131.4, 130.0, 129.9, 129.3, 129.0, 128.6, 128.5, 128.1, 127.0, 82.4, 25.7, 8.2. HRMS (ESI) ($[M+H]^+$) Calcd. for $C_{11}H_{11}O_2$: 265.1229, Found: 265.1231.



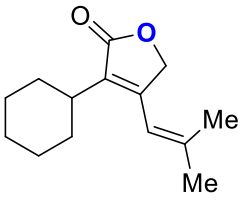
3,4-Dibutylfuran-2(5H)-one (2q). The reaction of 2,3-dibutylcyclobut-2-en-1-one **1q** (36.5 mg, 0.2 mmol), I_2 (10.1 mg, 0.04 mmol) and DMSO (78.0 mg, 1.0 mmol) in $MeNO_2$ (1 mL), under N_2 for 24 hours, afforded 36.1 mg (92%) of **2q** as yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.65 (s, 2H), 2.41 (t, *J* = 7.6 Hz, 2H), 2.25 (t, *J* = 7.6 Hz, 2H), 1.54 – 1.46 (m, 4H), 1.38-1.26 (m, 4H), 0.93 – 0.87 (m, 6H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 175.3, 160.6, 127.1, 71.2, 30.3, 30.0, 26.8, 23.3, 22.7, 22.6, 13.8, 13.7. HRMS (ESI) ($[M+H]^+$) Calcd. for $C_{12}H_{21}O_2$: 197.1542, Found: 197.1540.



3,4-Dipentylfuran-2(5H)-one (2r). The reaction of 2,3-dipentylcyclobut-2-en-1-one **1r** (41.6 mg, 0.2 mmol), I_2 (10.1 mg, 0.04 mmol) and DMSO (78.0 mg, 1.0 mmol) in $MeNO_2$ (1 mL), under N_2 for 24 hours, afforded 68.0 mg (61%) of **2r** as yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.66 (s, 2H), 2.41 (t, *J* = 8.0 Hz, 2H), 2.25 (t, *J* = 7.9 Hz, 2H), 1.50 (q, *J* = 7.4 Hz, 4H), 1.42 – 1.22 (m, 8H), 0.90 (q, *J* = 7.6 Hz, 6H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 175.4, 160.8, 127.1, 71.3, 31.7, 31.6, 27.8, 27.6, 27.1, 23.5, 22.4, 22.3, 14.0, 13.9. HRMS (ESI) ($[M+H]^+$) Calcd. for $C_{15}H_{27}O_2$: 225.1855, Found: 225.1854.

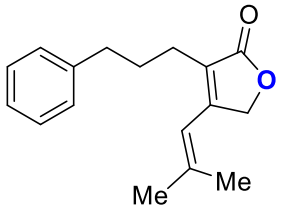


Dodecahydrocyclododeca[c]furan-1(3H)-one (2s): According to general procedure C, a solution of **1s** (0.2 mmol, 41.4 mg), I_2 (0.04 mmol, 6.4 mg), DMSO (1.0 mmol, 71 uL) in $MeNO_2$ (2.0 mL) were stirred at 100 ºC under N_2 for 24 h to afforded **2s** (41.9 mg, 94%) as light yellow oil after purification on silica gel (PE:EA=10:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.66 (s, 2H), 2.47 (t, *J* = 7.3 Hz, 2H), 2.32 (t, *J* = 6.7 Hz, 2H), 1.74-1.68 (m, 2H), 1.66-1.60 (m, 2H), 1.49 – 1.29 (m, 10H), 1.27 – 1.16 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.1, 161.2, 126.7, 71.2, 25.5, 24.97, 24.93, 24.5, 23.9, 23.6, 22.5, 21.7, 20.7. HRMS (ESI) ($[M+H]^+$) Calcd. for $C_{14}H_{23}O_2$: 223.1698; found: 223.1696.

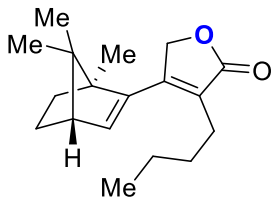


3-cyclohexyl-4-(2-methylprop-1-en-1-yl)furan-2(5H)-one (2t): According to general procedure C, a solution of **1t** (0.2 mmol, 41.1 mg), I_2 (0.04 mmol, 6.4 mg), DMSO (1.0 mmol, 71 uL) in $MeNO_2$ (2.0 mL) were stirred at 100 ºC under N_2 for 24

h to afforded **2t** (37.1 mg, 84%) as light yellow oil after purification on silica gel (PE:EA=10:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.18 (s, 1H), 4.90 (s, 2H), 2.53-2.45 (m, 1H), 1.97 (s, 3H), 1.93 – 1.61 (m, 8H), 1.55-1.51 (m, 2H), 1.32-1.26 (m, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 174.0, 153.6, 143.8, 129.9, 116.2, 70.6, 35.4, 29.6, 28.1, 26.5, 25.7, 20.6. HRMS (ESI) ($[M+H]^+$) Calcd. for $C_{14}H_{21}O_2$: 221.1542; found: 221.1543.



4-(2-methylprop-1-en-1-yl)-3-(3-phenylpropyl)furan-2(5H)-one (2u): According to general procedure , a solution of **1u** (0.2 mmol, 48.2 mg), I_2 (0.04 mmol, 6.4 mg), DMSO (1.0 mmol, 71 uL) in $MeNO_2$ (2.0 mL) were stirred at 100 ºC under N_2 for 24 h to afforded **2u** (27.2 mg, 53%) as light yellow oil after purification on silica gel (PE:EA=10:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.36 – 7.26 (m, 2H), 7.24 – 7.17 (m, 3H), 6.17 – 5.98 (m, 1H), 4.97 (s, 2H), 2.67 (t, *J* = 7.7 Hz, 2H), 2.36 (t, *J* = 7.7 Hz, 2H), 1.96 (d, *J* = 1.4 Hz, 3H), 1.92 – 1.82 (m, 2H), 1.85 (d, *J* = 1.2 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 175.0, 154.5, 144.6, 141.8, 128.4, 128.3, 125.9, 125.8, 116.5, 71.1, 35.5, 29.5, 28.2, 23.3, 20.8. HRMS (ESI) ($[M+H]^+$) Calcd. for $C_{17}H_{21}O_2$: 257.1542; found: 257.1540.



3-butyl-4-((1S,4S)-1,7,7-trimethylbicyclo[2.2.1]hept-2-en-2-yl)furan-2(5H)-one (2v): According to general procedure , a solution of **1v** (0.2 mmol, 51.8 mg), I_2 (0.04 mmol, 6.4 mg), DMSO (1.0 mmol, 71 uL) in $MeNO_2$ (2.0 mL) were stirred at 100 ºC under N_2 for 24 h to afforded **2v** (22.5 mg, 41%) as light yellow oil after purification

on silica gel (PE:EA=10:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.22 (d, *J* = 3.4 Hz, 1H), 5.09 – 4.20 (m, 2H), 2.50 (t, *J* = 3.6 Hz, 1H), 2.40-2.28 (m, 2H), 2.02-1.94 (m, 1H), 1.76 – 1.66 (m, 1H), 1.59 – 1.44 (m, 2H), 1.42-1.32 (m, 2H), 1.15 – 1.02 (m, 5H), 0.93 (t, *J* = 7.2 Hz, 3H), 0.86 (d, *J* = 18.0 Hz, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 174.7, 155.0, 141.4, 138.2, 127.7, 70.7, 57.1, 55.6, 52.1, 31.5, 30.5, 24.8, 24.5, 22.8, 19.5, 19.4, 13.9, 12.6. HRMS (ESI) ($[M+H]^+$) Calcd. for $C_{18}H_{27}O_2$: 275.2011; found: 275.2011.

4. References

(1) Qin, Q.; Luo, X.; Wei, J.; Zhu, Y.; Wen, X.; Song, S.; Jiao, N. Acetonitrile Activation: An Effective Two-Carbon Unit for Cyclization. *Angew. Chem. Int. Ed.* **2019**, 58, 4376–4380.

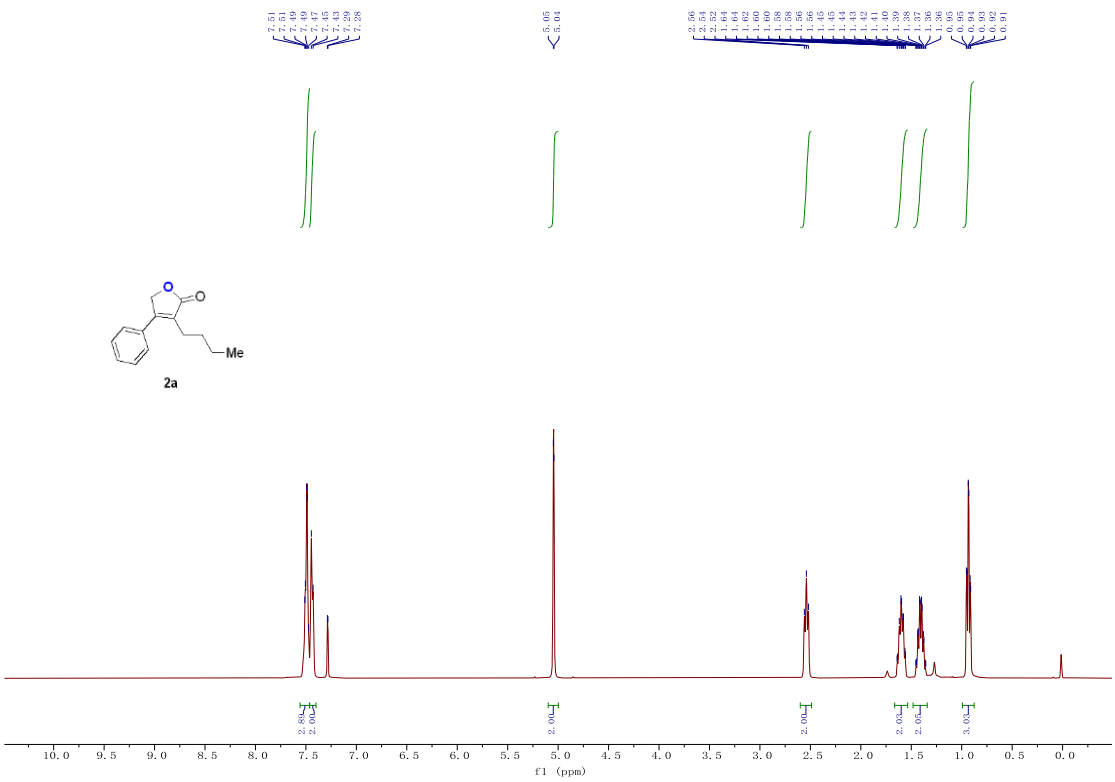
(2) Ficini, J.; Claeys, M.; Depezay, J. C. Synthese de cyclobutenones. *Tetrahedron Lett.* **1973**, 14, 3357–3359.

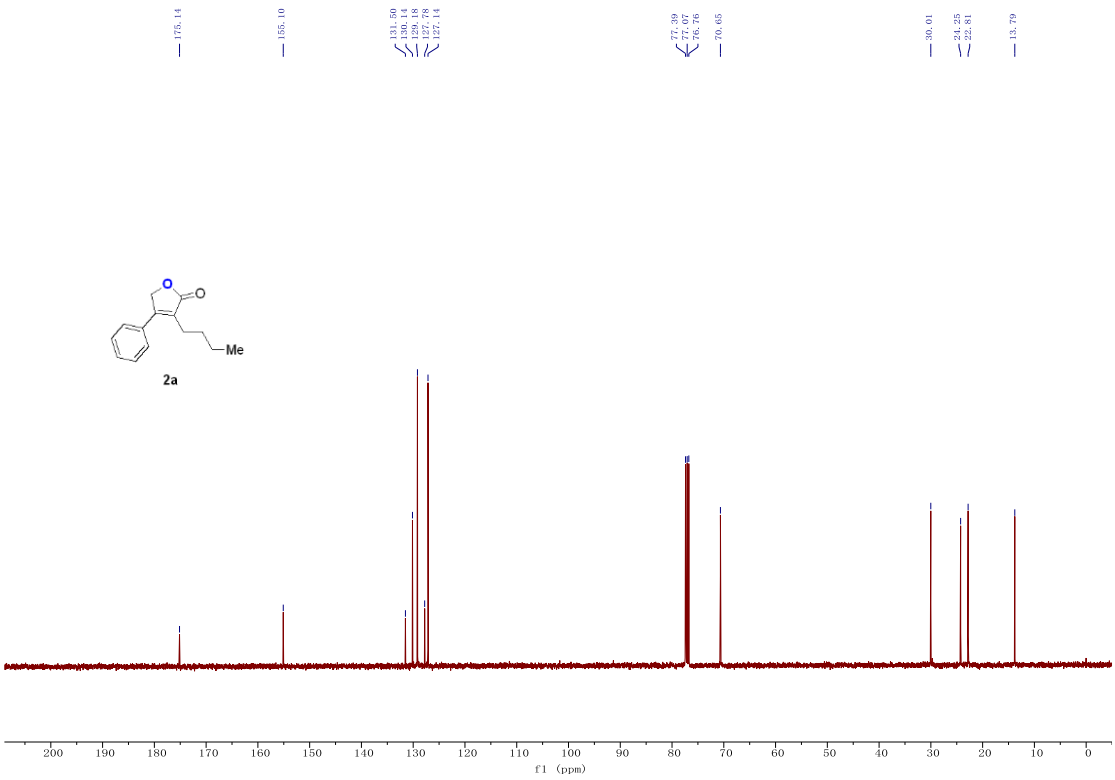
(3) Chen, P. H.; Sieber, J.; Senanayake, C. H.; Dong, G. Rh-catalyzed Reagent-Free Ring Expansion of Cyclobutenones and Benzocyclobutenones. *Chem. Sci.* **2015**, 6, 5440–5445.

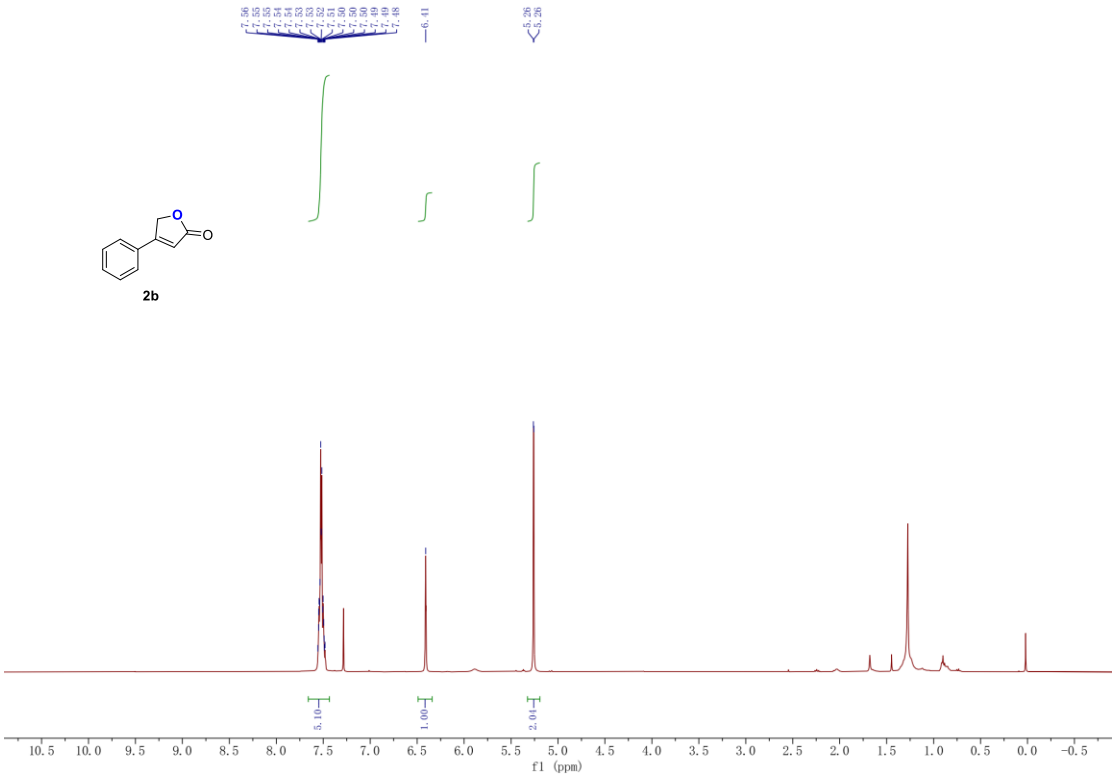
(4) Corpas, J.; Ponce, A.; Adrio, J.; Carretero, J. C. CuI-Catalyzed Asymmetric [3 + 2] Cycloaddition of Azomethine Ylides with Cyclobutenones. *Org. Lett.* **2018**, 20, 3179–3182.

(5) Clement, H. A.; Boghi, M.; McDonald, R. M.; Bernier, L.; Coe, J. W.; Farrell, W.; Helal, C. J.; Reese, M. R.; Sach, N. W.; Lee, J. C.; Hall, D. G. High-Throughput Ligand Screening Enables the Enantioselective Conjugate Borylation of Cyclobutenones to Access Synthetically Versatile Tertiary Cyclobutylboronates. *Angew. Chem. Int. Ed.* **2019**, 58, 18405–8409.

5. NMR Spectral Data



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7.48
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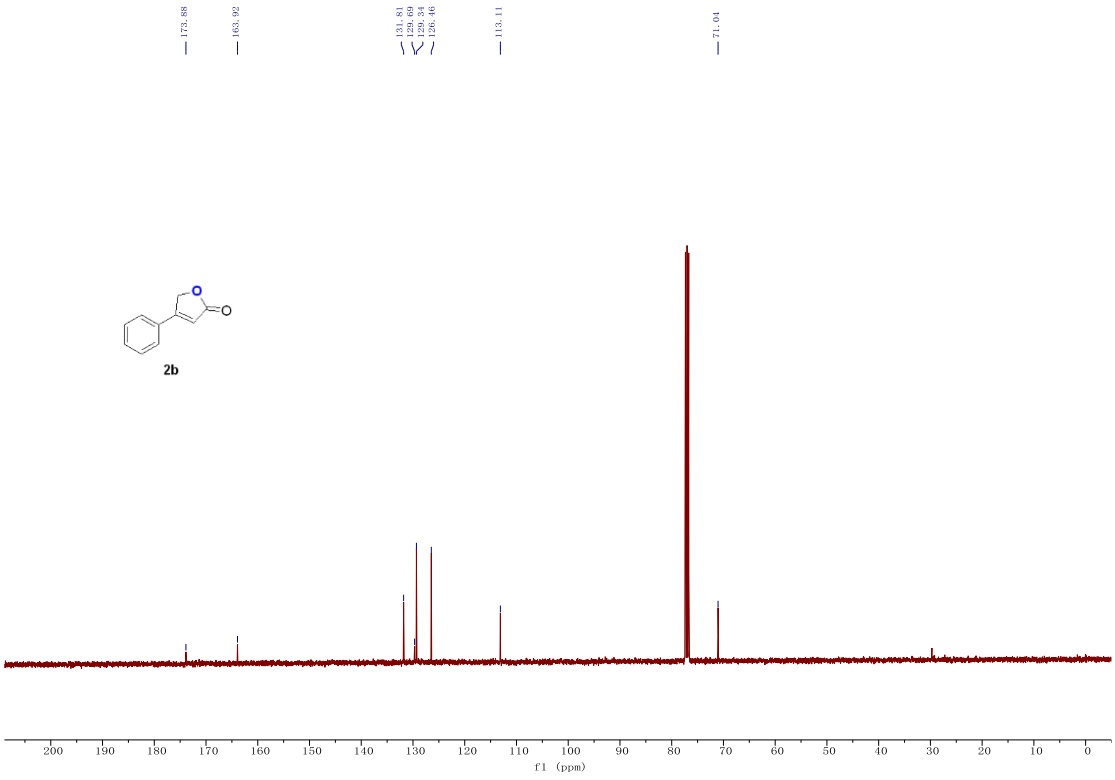
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O
2b
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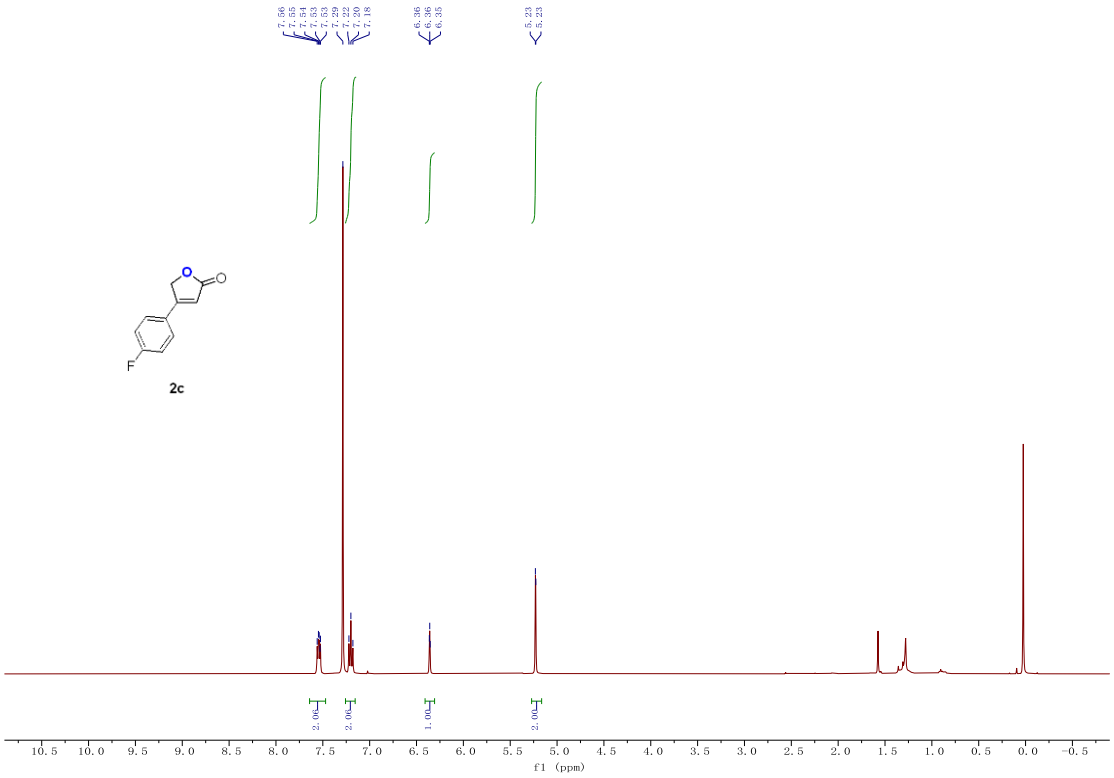
f1 (ppm)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7.54
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7.22
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6.36
6.35
5.23
5.23
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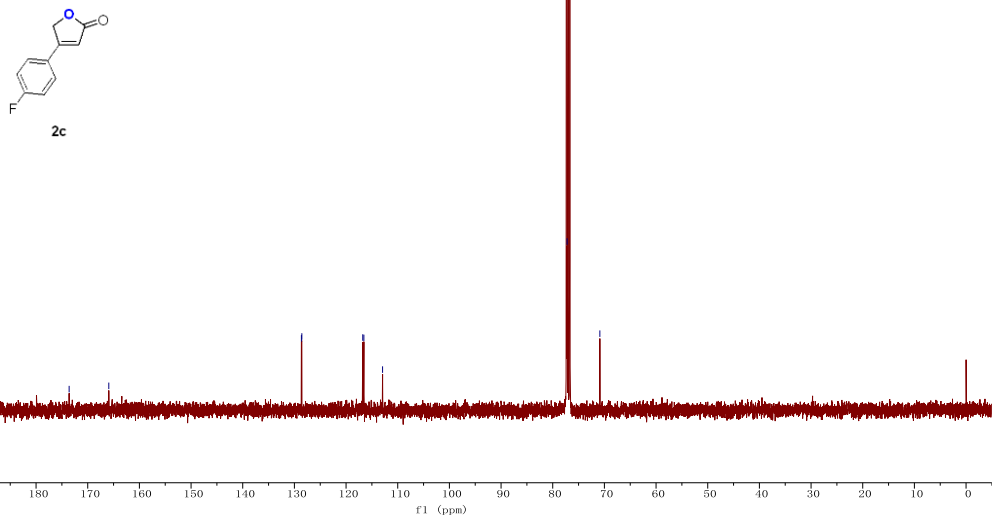
2.04
1.00
2.00
f1 (ppm)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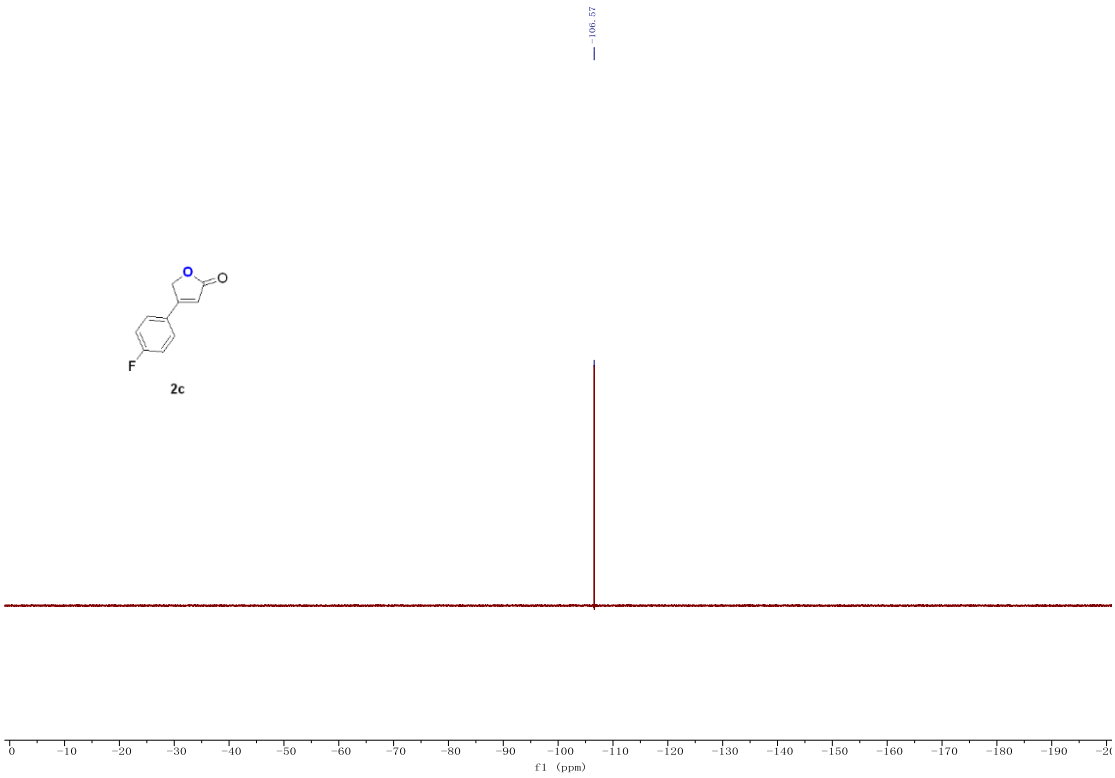
116.55
112.93
77.33
77.22
77.00
76.70
70.88
f1 (ppm)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O
O
F
2c
0
-10
-20
-30
-40
-50
-60
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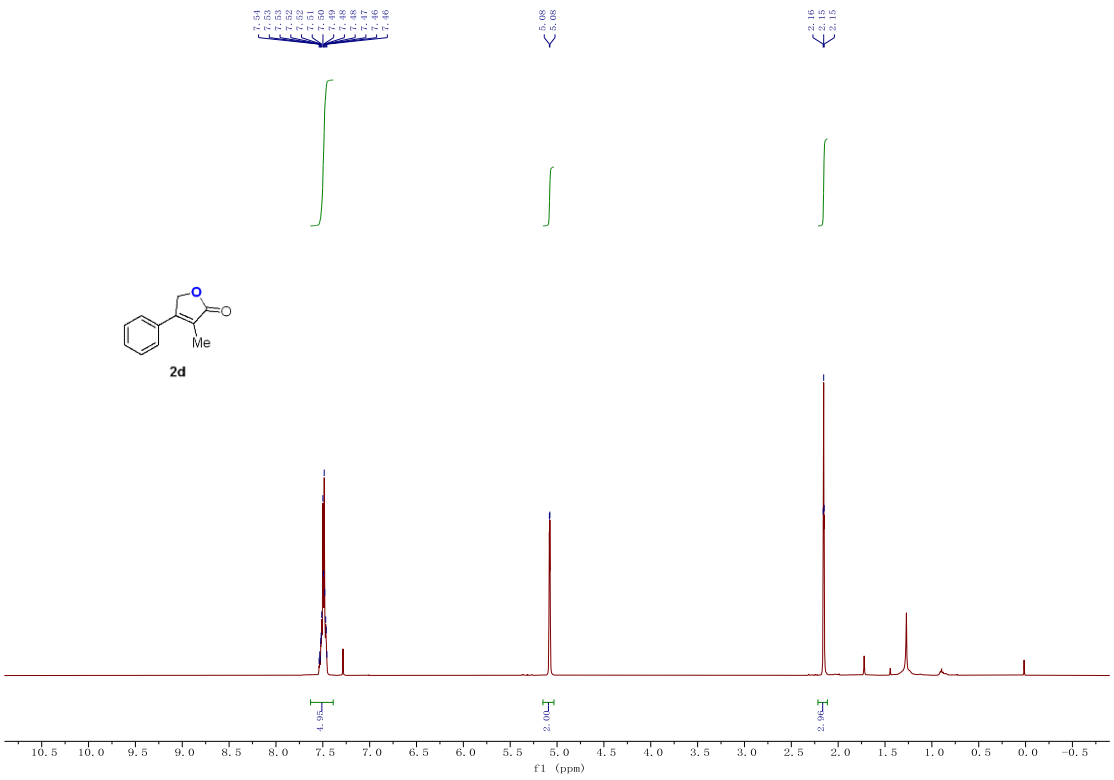
-100
-110
-120
-130
-140
-150
-160
-170
-180
-190
f1 (ppm)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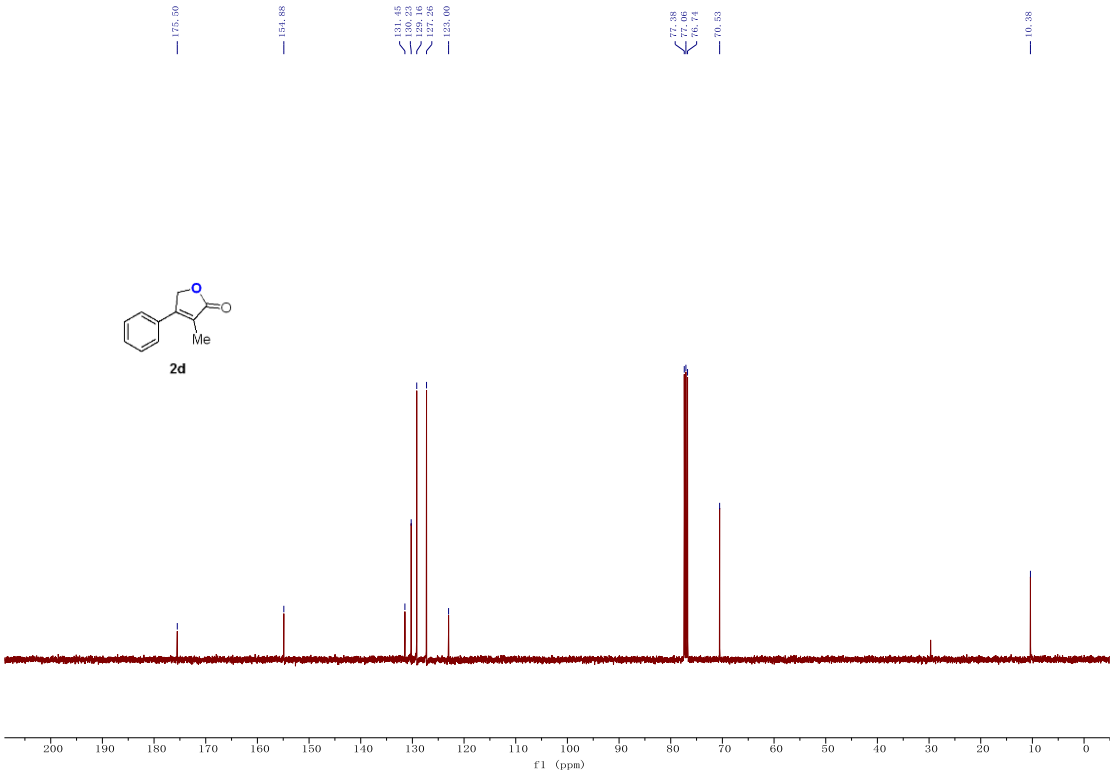
7.47
7.46
7.46
5.08
5.08
2.16
2.15
2.15
O
O
Me
2d
4.96
2.00
2.96
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)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129.16
127.26
123.00
77.38
77.06
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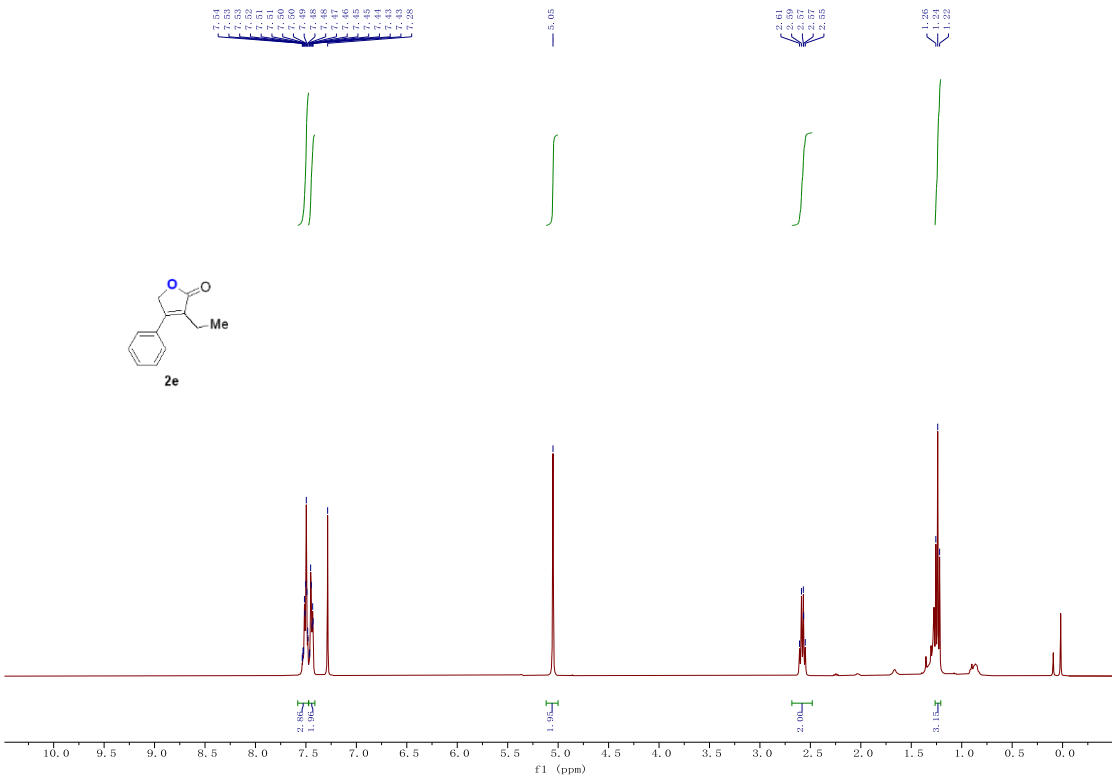
70.53
10.38
O
O
Me
2d
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)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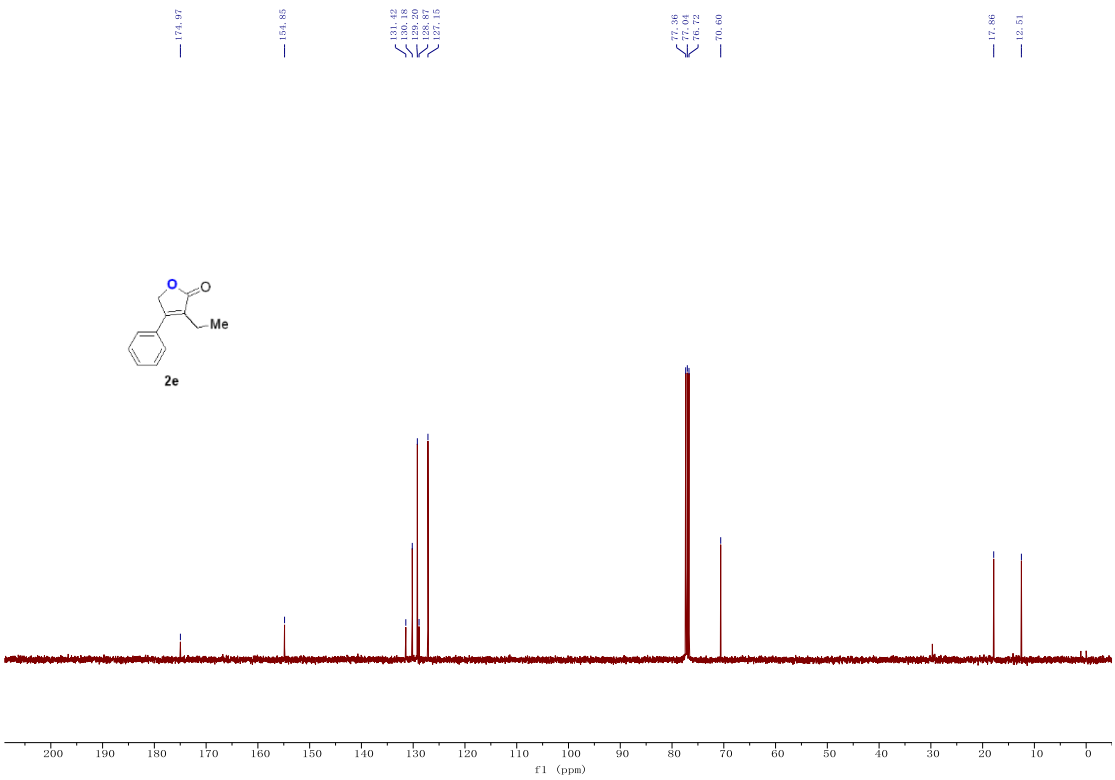
7.45
7.45
7.44
7.44
7.43
7.43
7.28
5.05
2.61
2.59
2.57
2.57
2.55
1.26
1.24
1.22
Me
2e
2.86
1.96
1.96
2.00
3.15
f1 (ppm)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130.18
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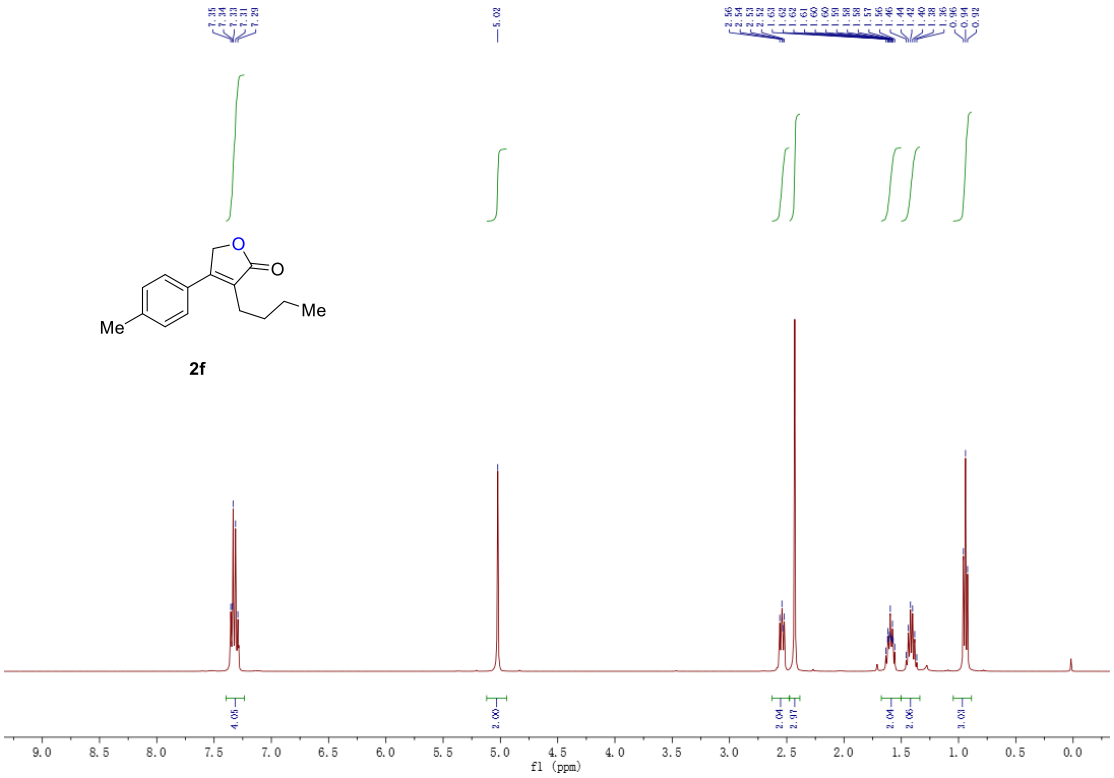
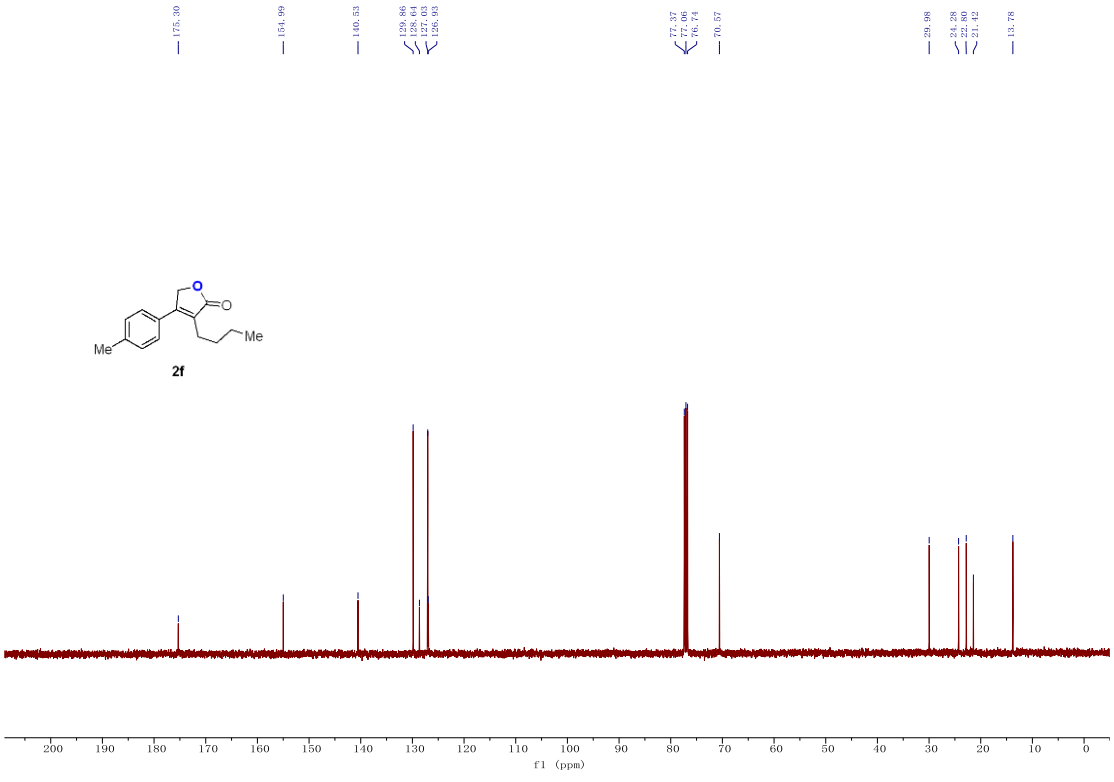
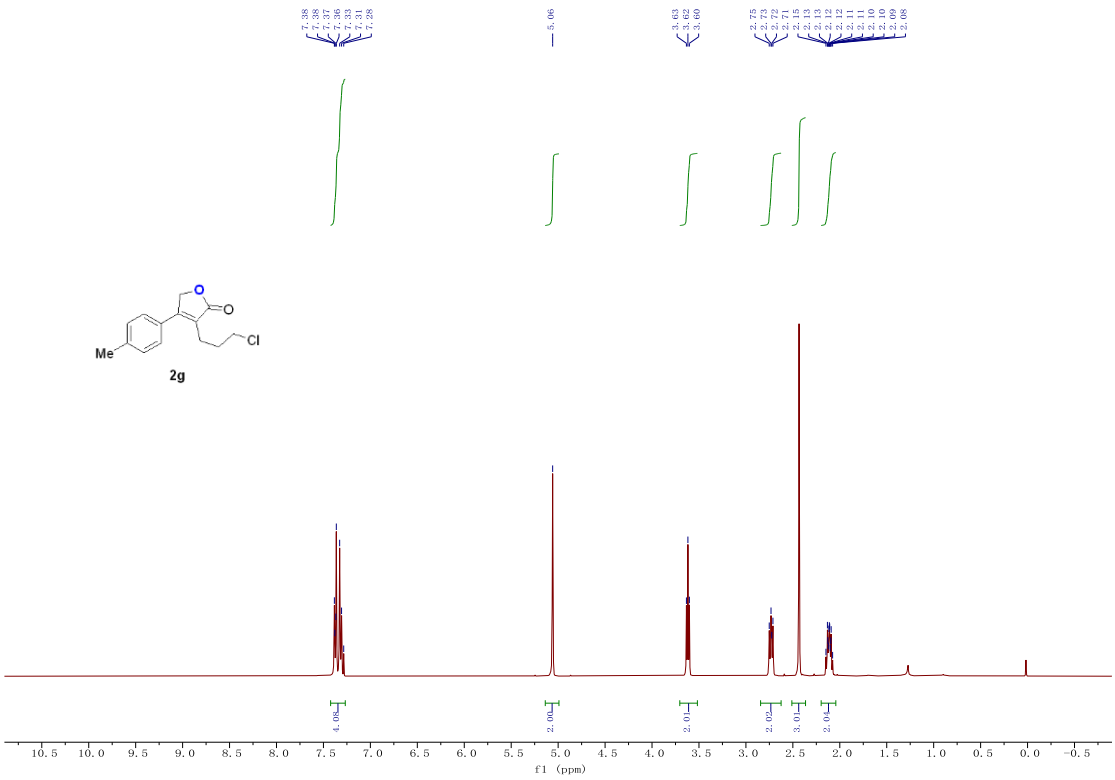
77.04
76.72
70.60
17.86
12.51
Me
2e
f1 (ppm)


Me
O
O
Me
2f
f1 (ppm)


Me
O
O
Me
2f
f1 (ppm)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7.31
7.28
5.06
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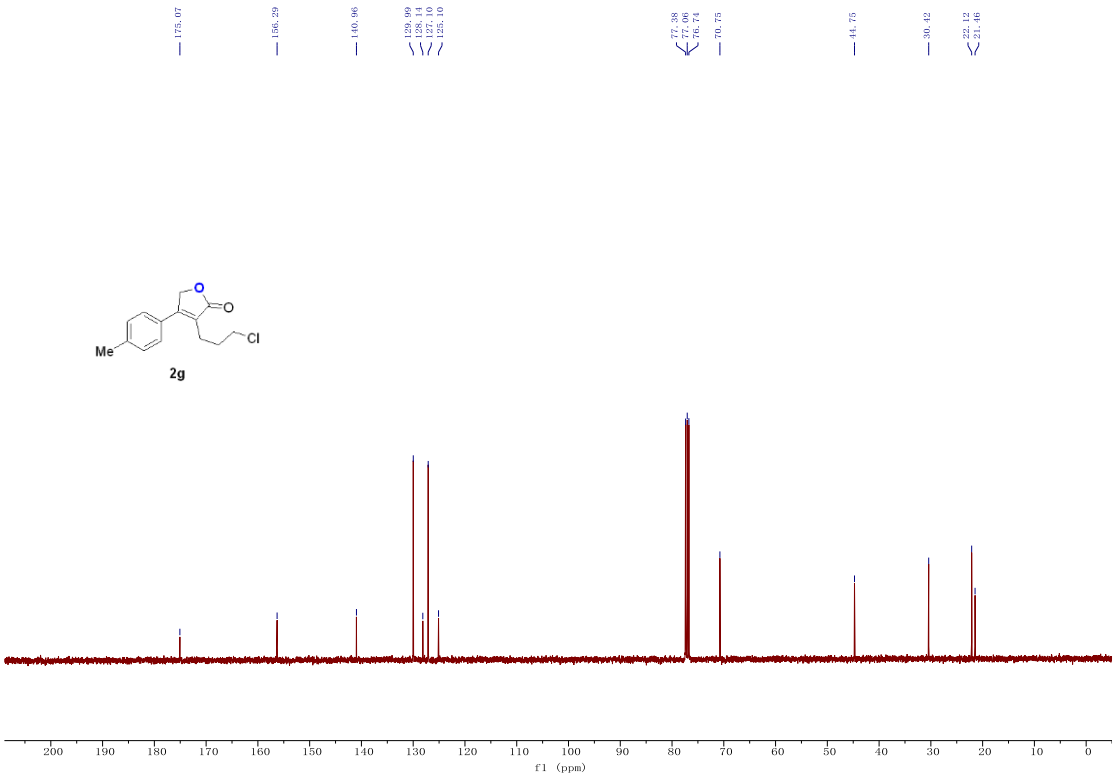
3.62
3.60
2.75
2.73
2.72
2.71
2.15
2.13
2.13
2.12
2.12
2.11
2.10
2.10
2.09
2.08
Me
Cl
2g
4.08
2.00
2.01
2.02
3.01
2.04
f1 (ppm)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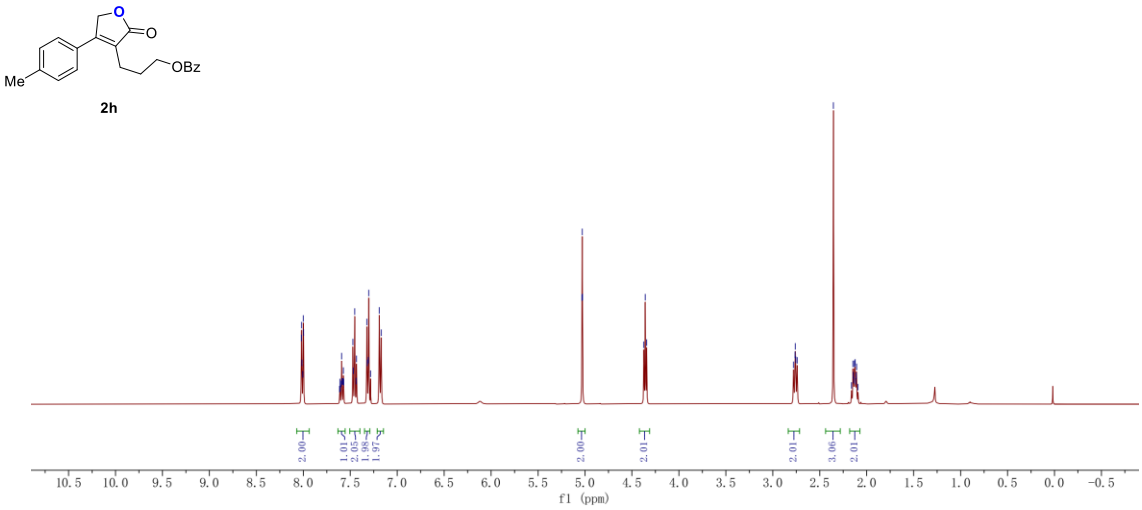
140.96
129.99
128.14
127.10
125.10
77.38
77.06
76.74
70.75
44.75
30.42
22.12
21.46
Me
Cl
2g
f1 (ppm)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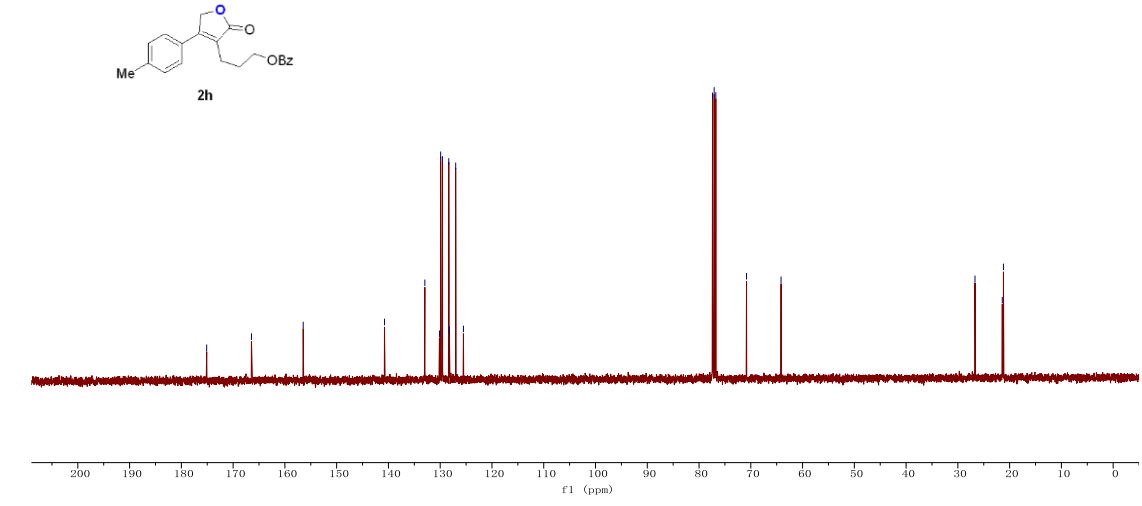
O
OBz
2h
f1 (ppm)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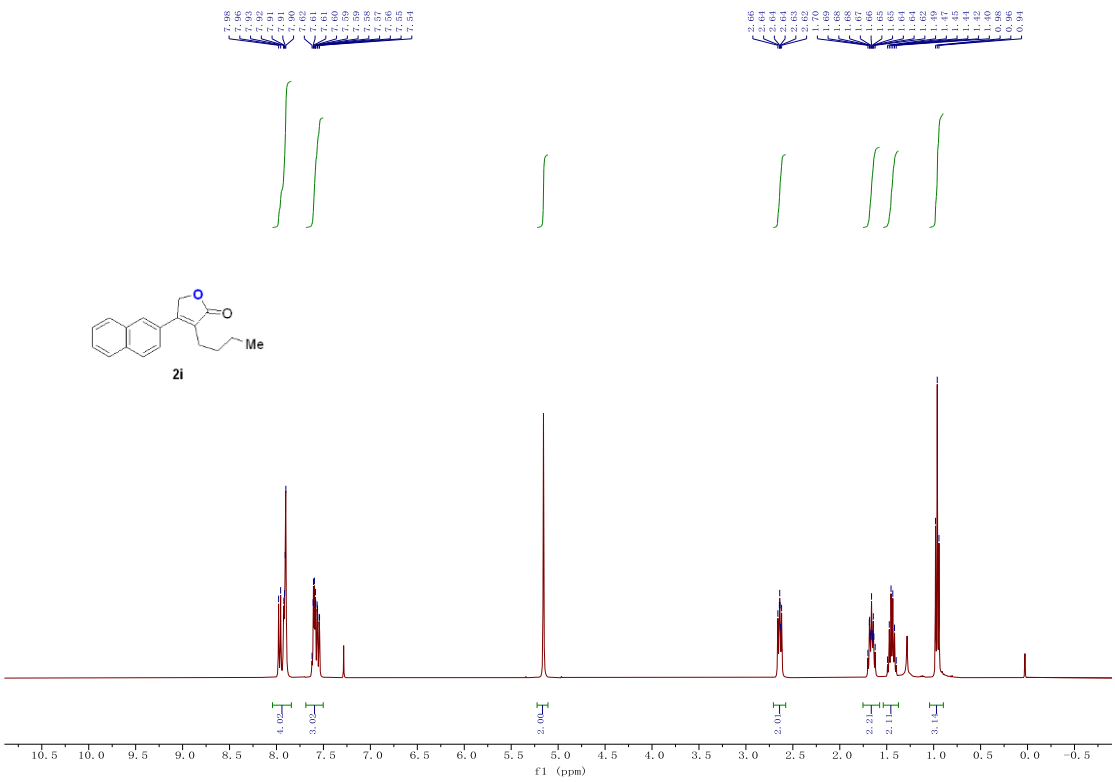
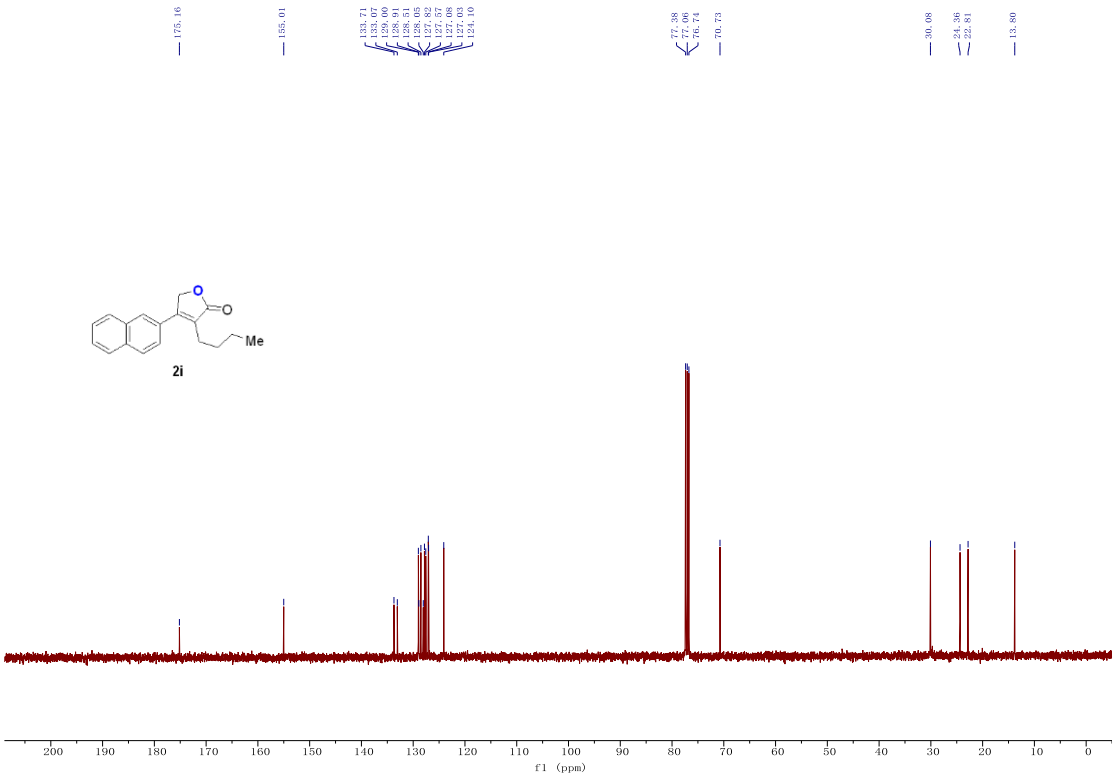
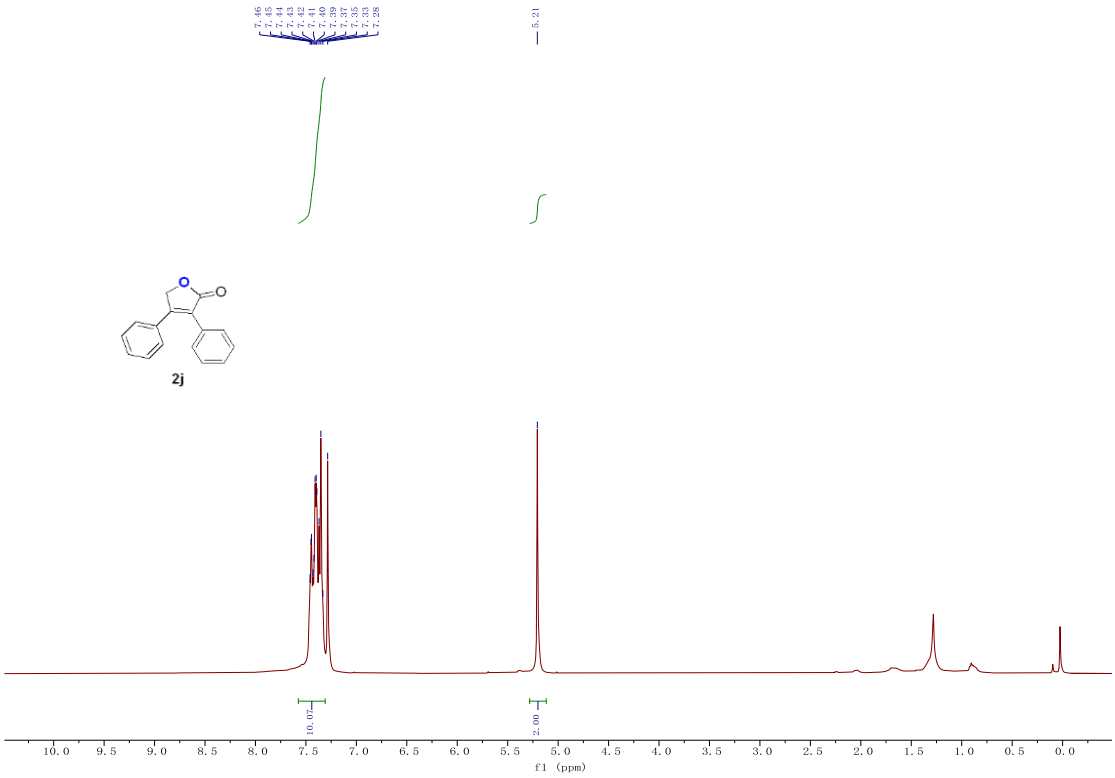
O
O
OBz
2h
f1 (ppm)


Me
2i
f1 (ppm)


Me
2i
f1 (ppm)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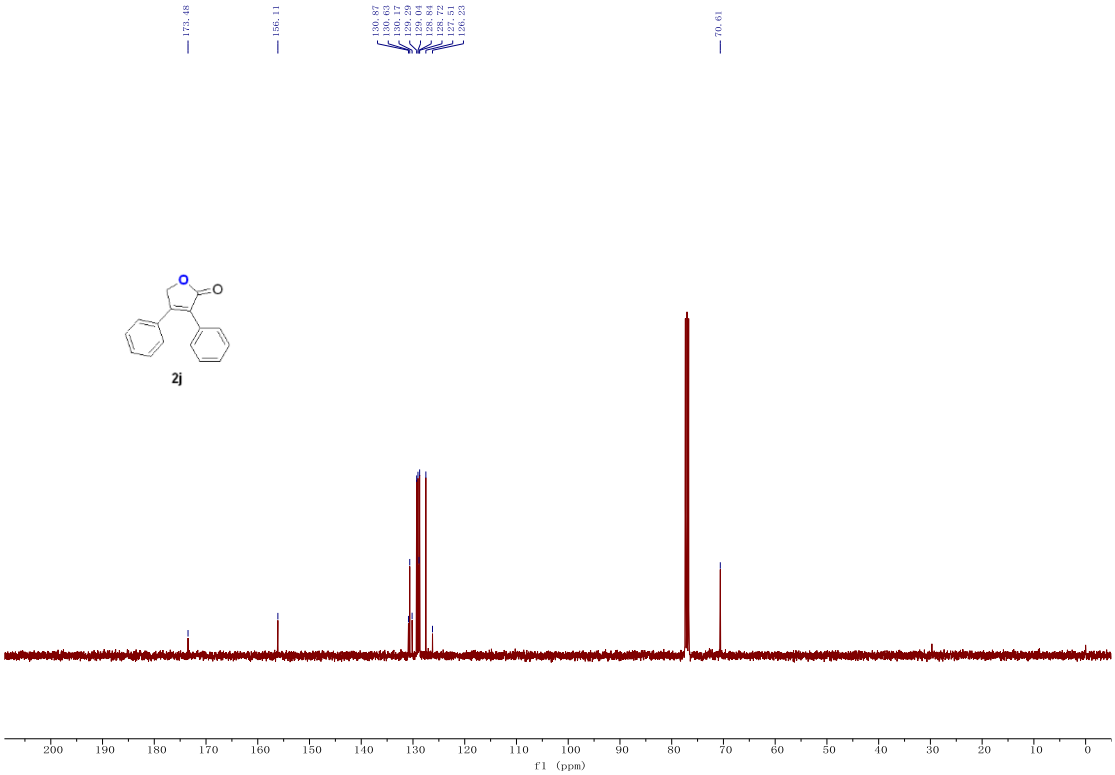
7.33
7.28
5.21
2j
10.07
2.00
f1 (ppm)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128.72
127.51
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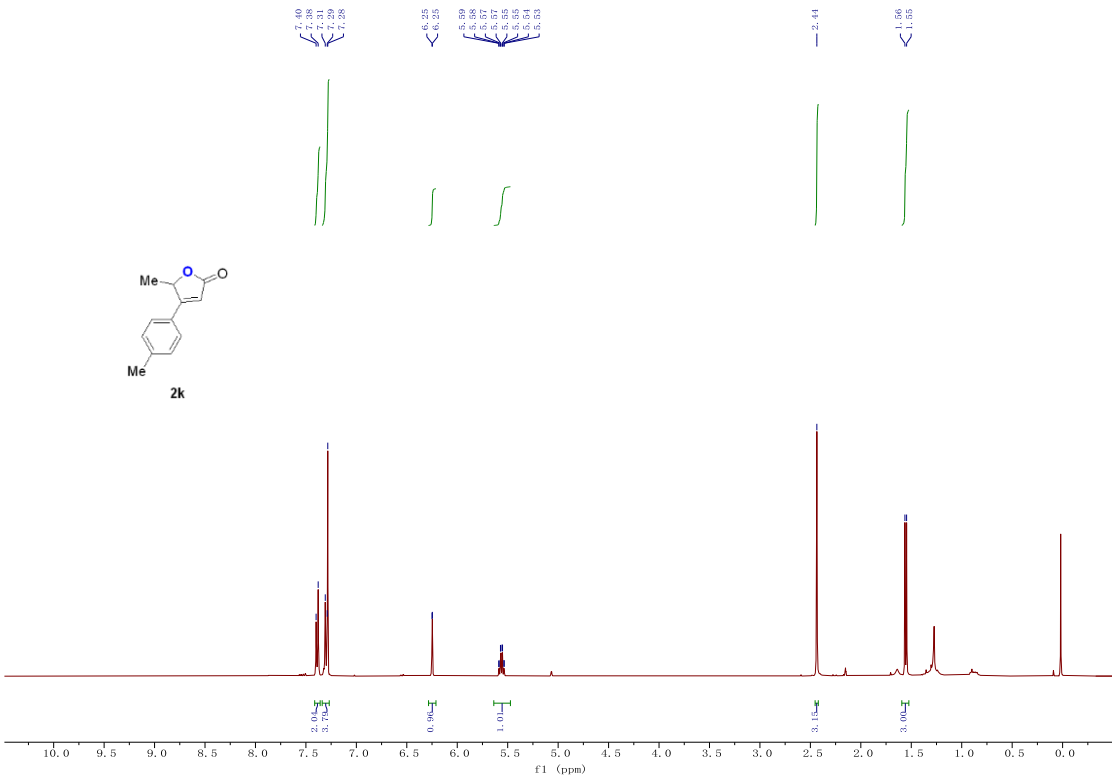
2j
f1 (ppm)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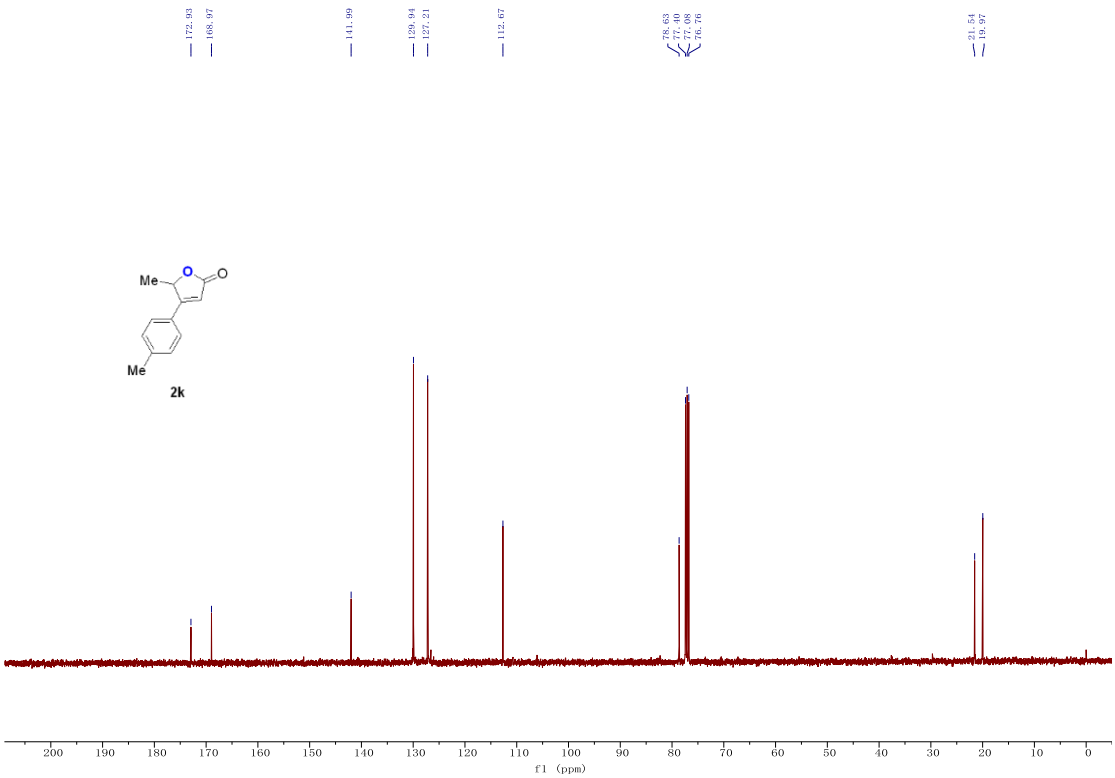
5.55
5.54
5.53
2.44
1.56
1.55
Me
Me
O
O
2k
2.04
3.76
0.96
1.01
3.15
3.00
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)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129.94
127.21
112.67
78.63
77.40
77.08
76.76
21.54
19.97
Me
Me
O
O
2k
200
190
180
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150
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110
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90
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70
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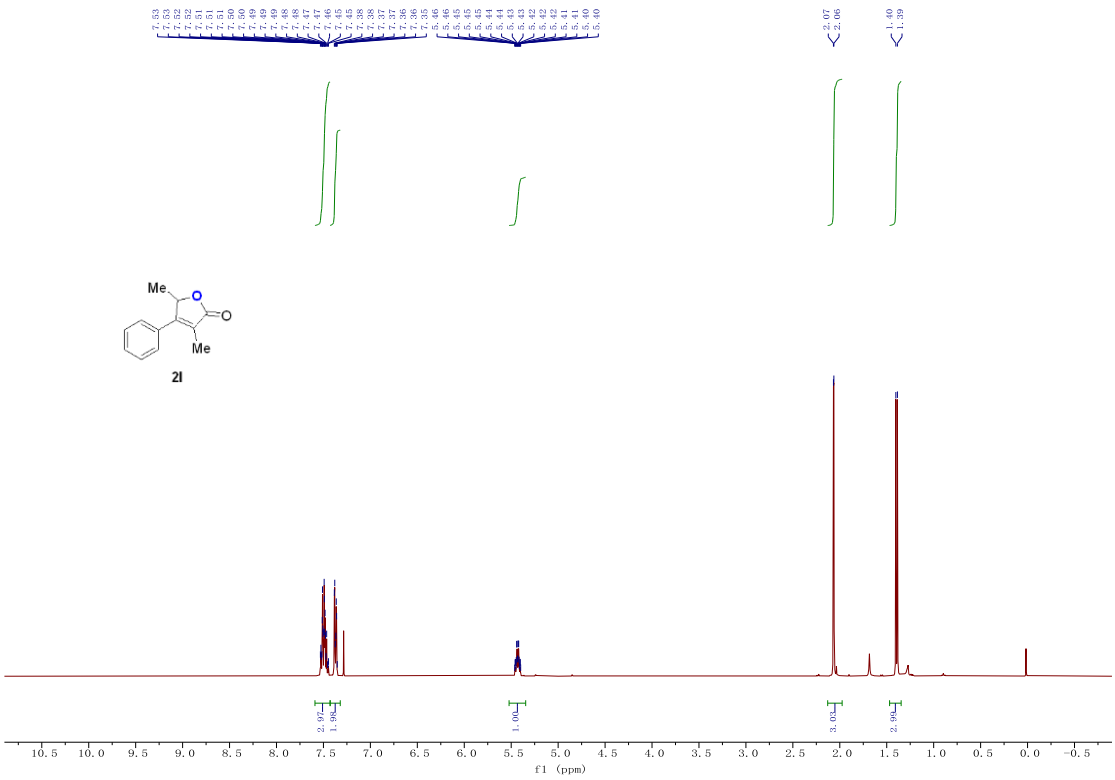
50
40
30
20
10
0
f1 (ppm)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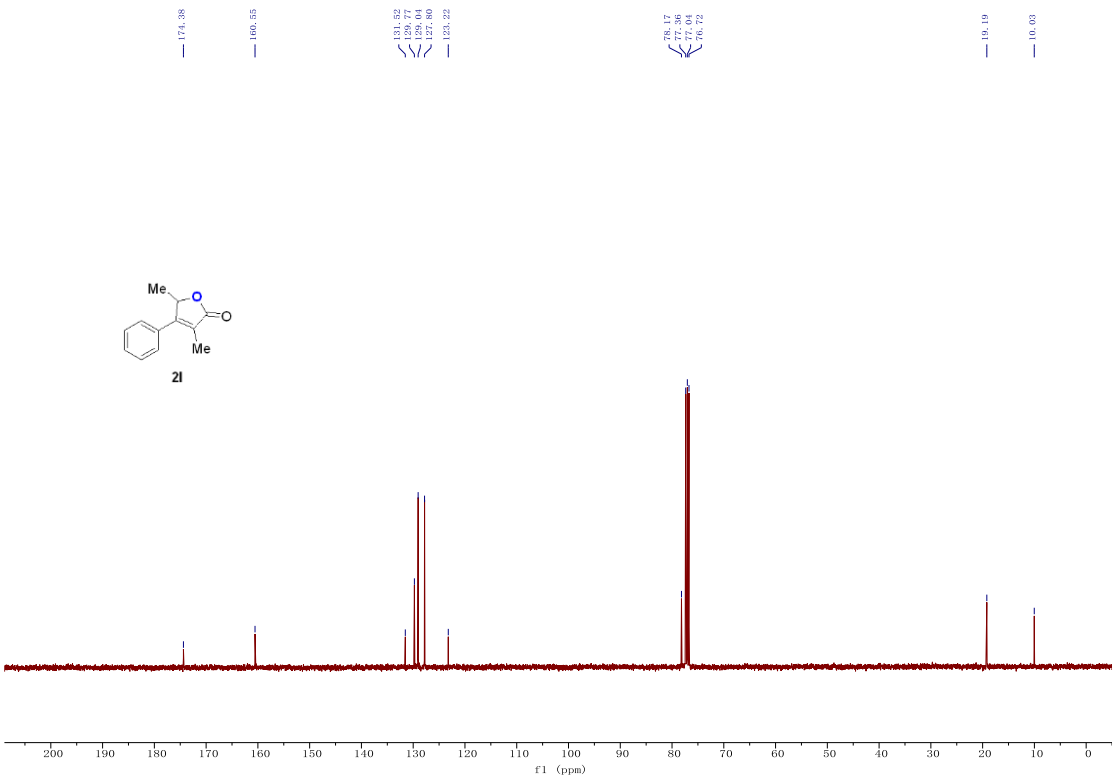
O
O
Me
2l
f1 (ppm)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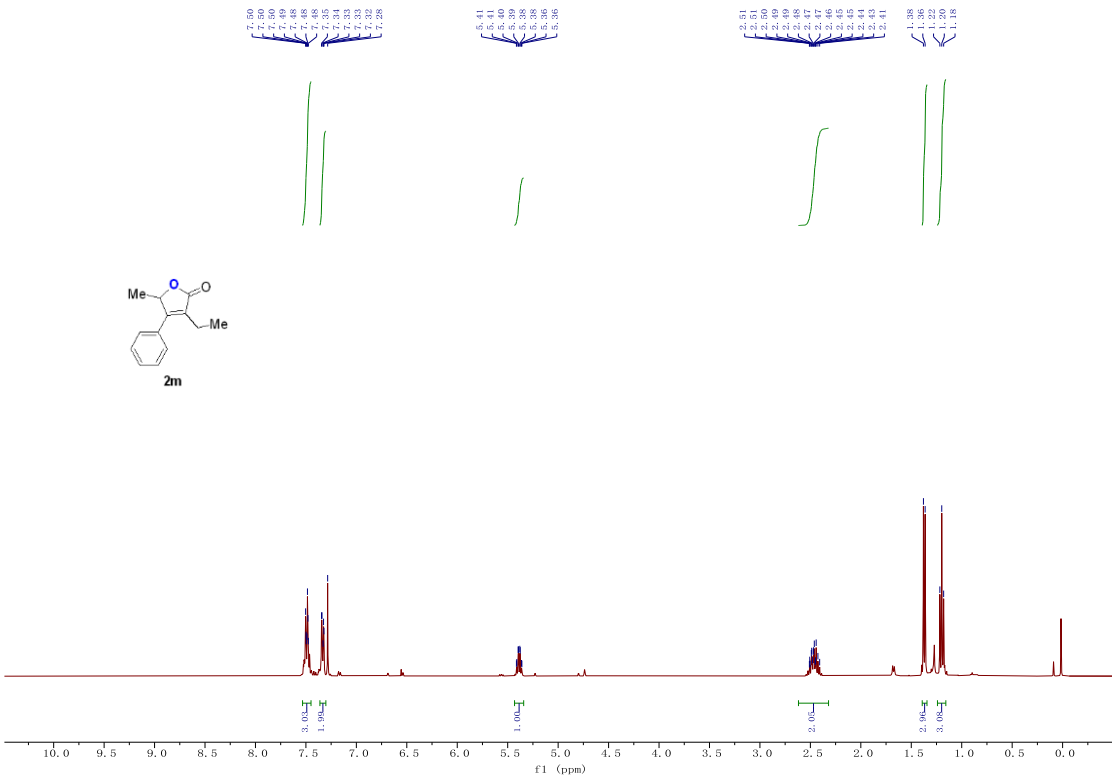
O
O
Me
2l
f1 (ppm)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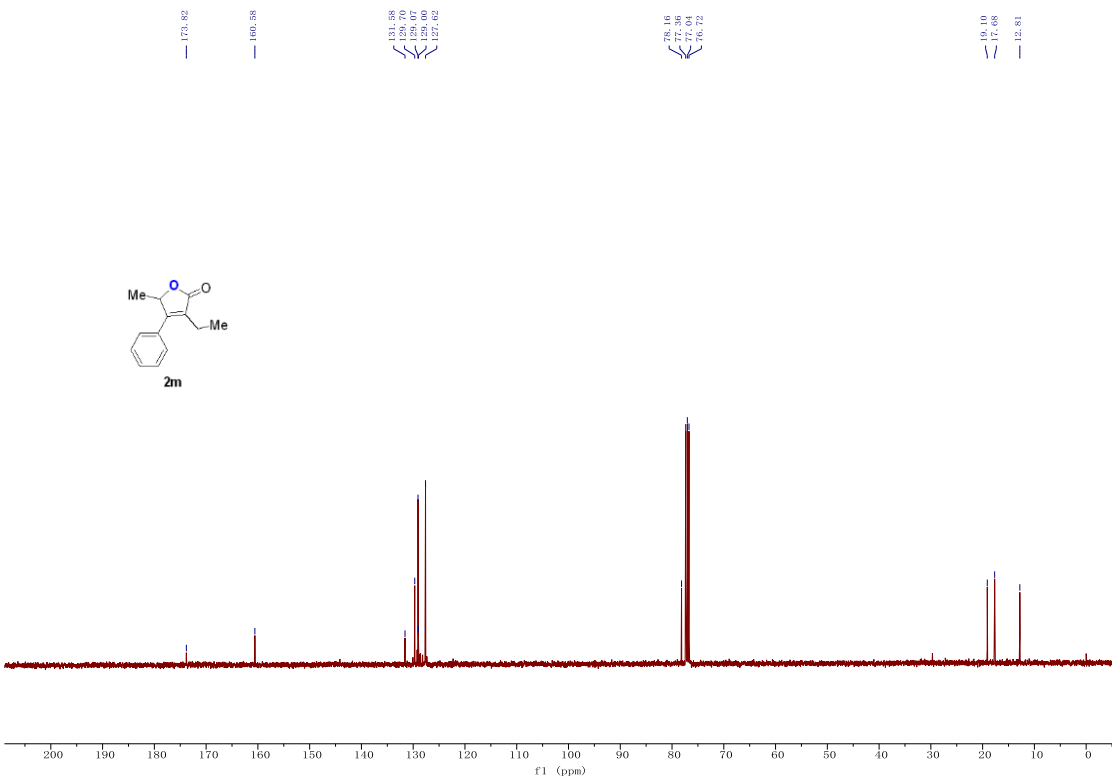
O
Me
2m
f1 (ppm)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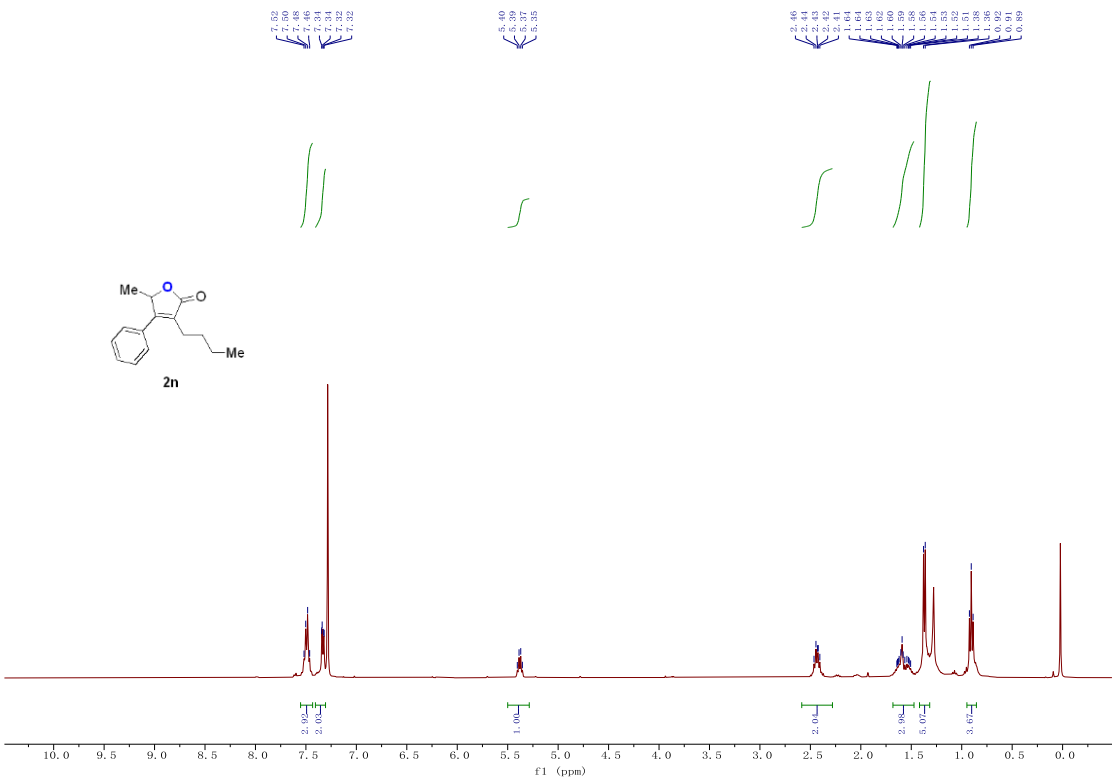
O
Me
2m
f1 (ppm)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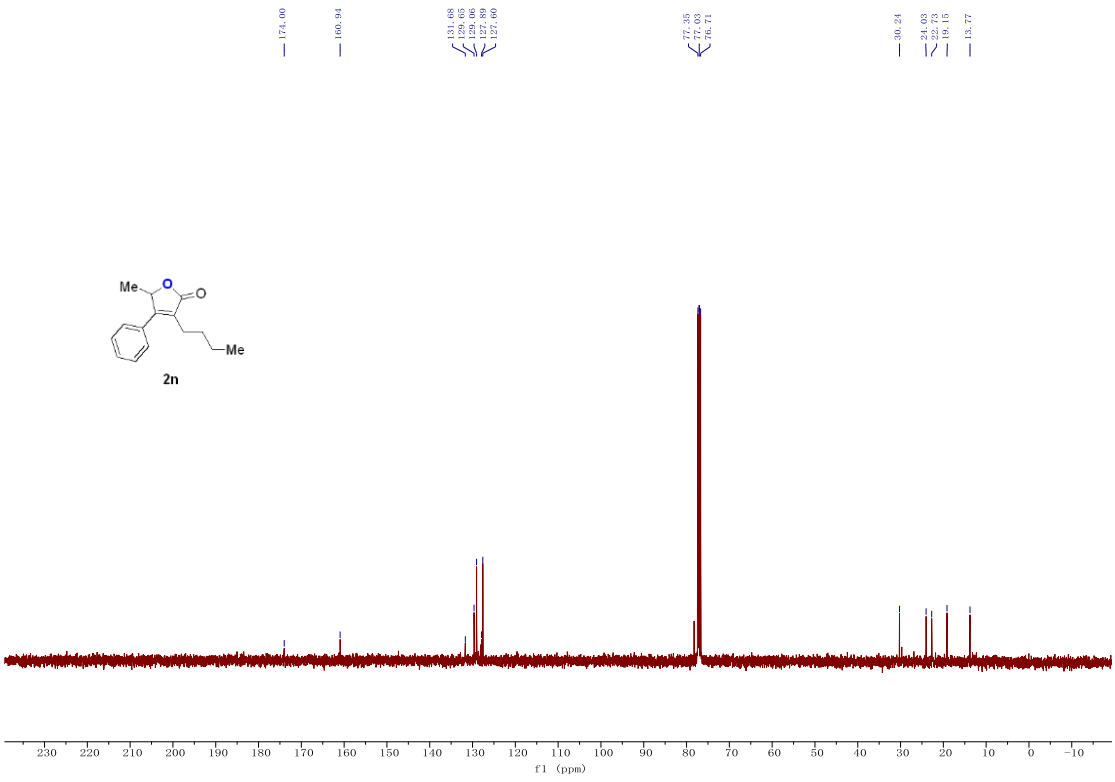
O
Me
2n
f1 (ppm)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O
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2n
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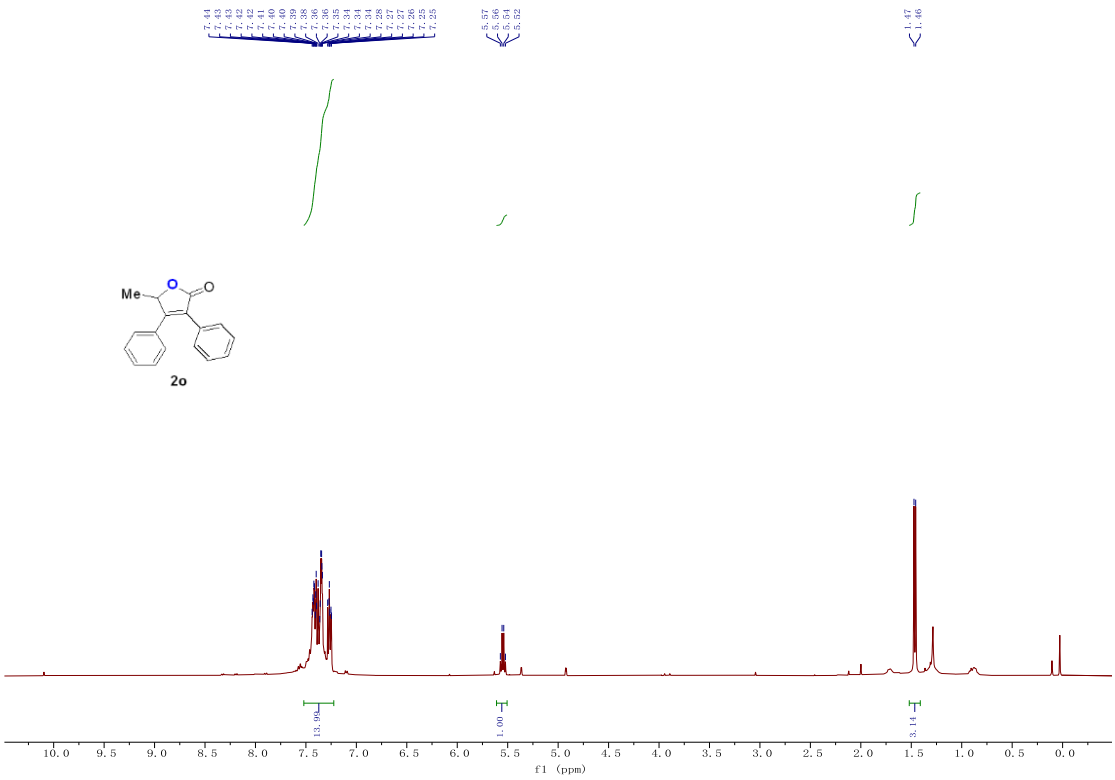
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O
2o
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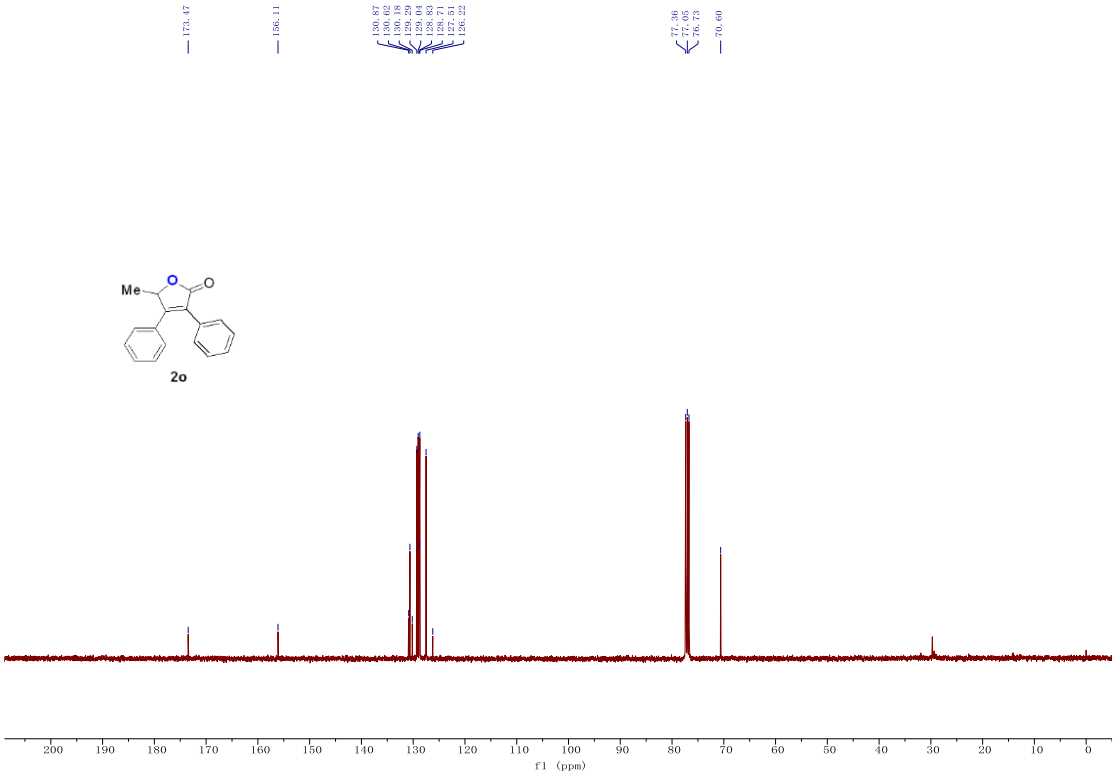
3.14
f1 (ppm)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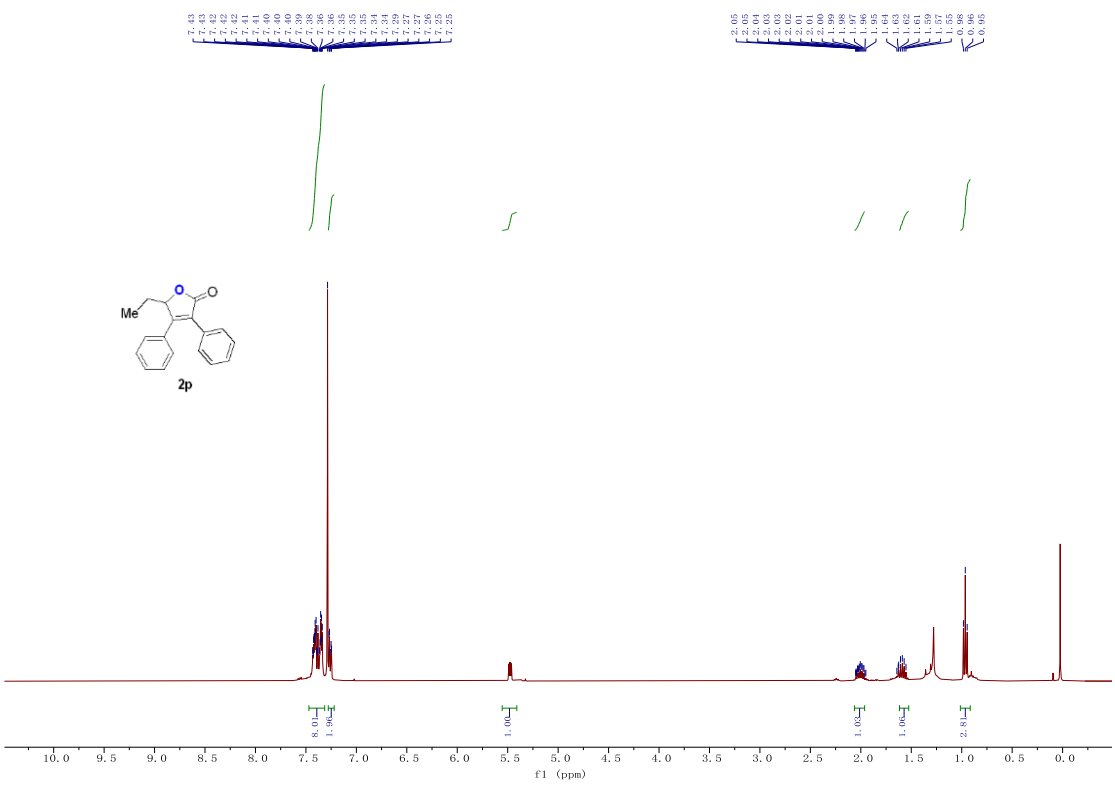
O
2o
f1 (ppm)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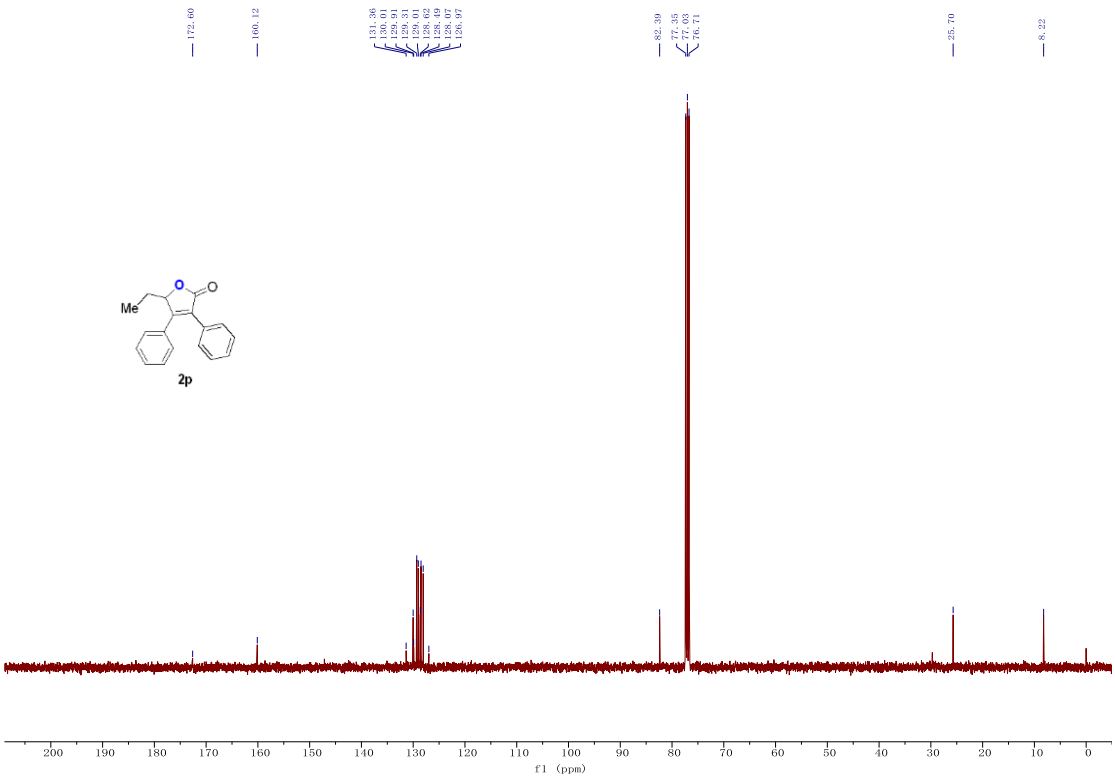
2p
f1 (ppm)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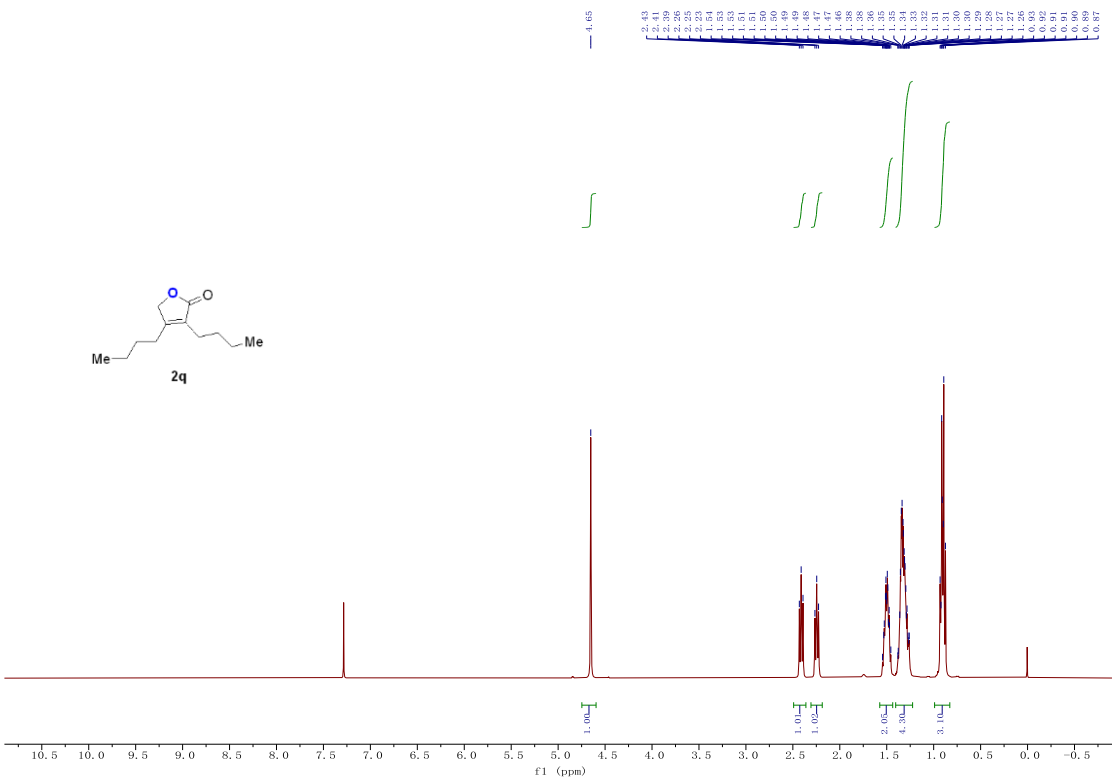
2p
f1 (ppm)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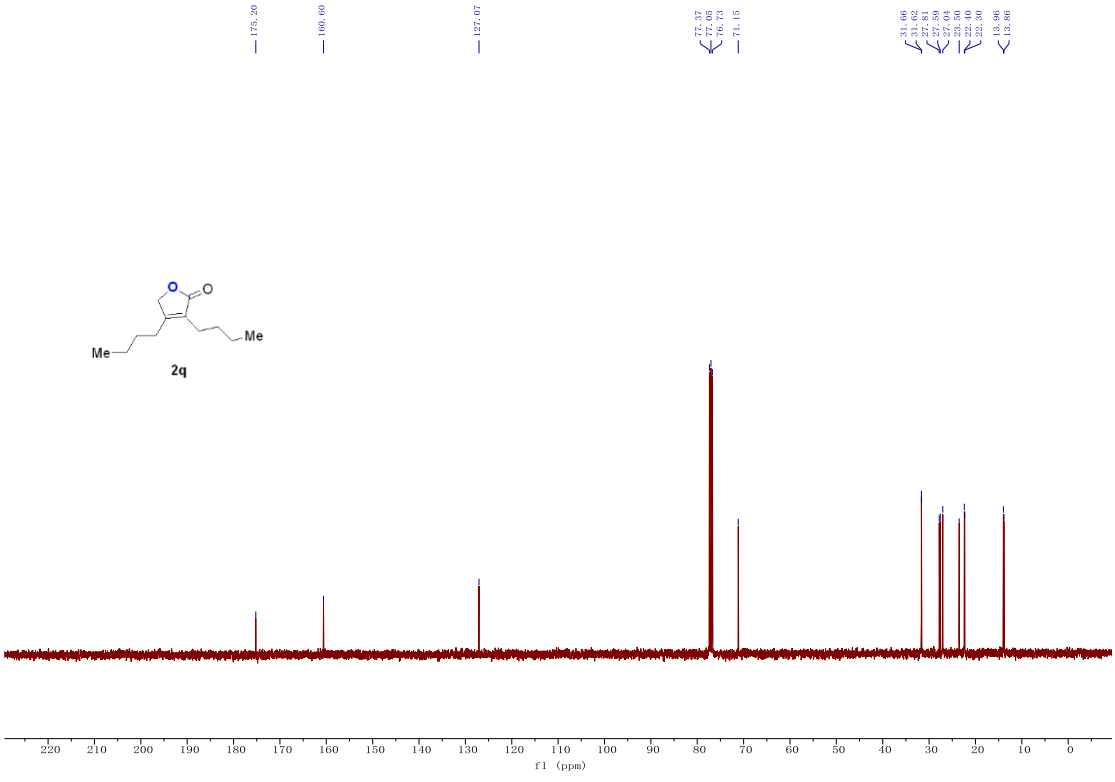
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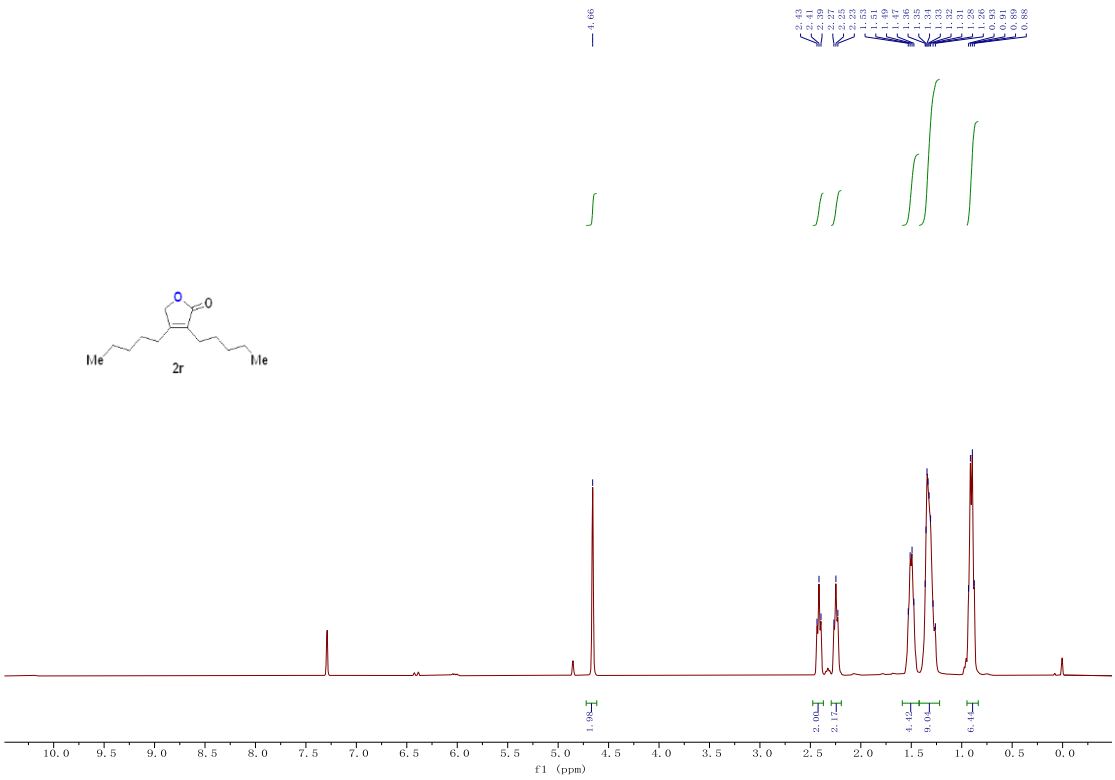
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1.33
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1.31
1.28
1.26
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Me
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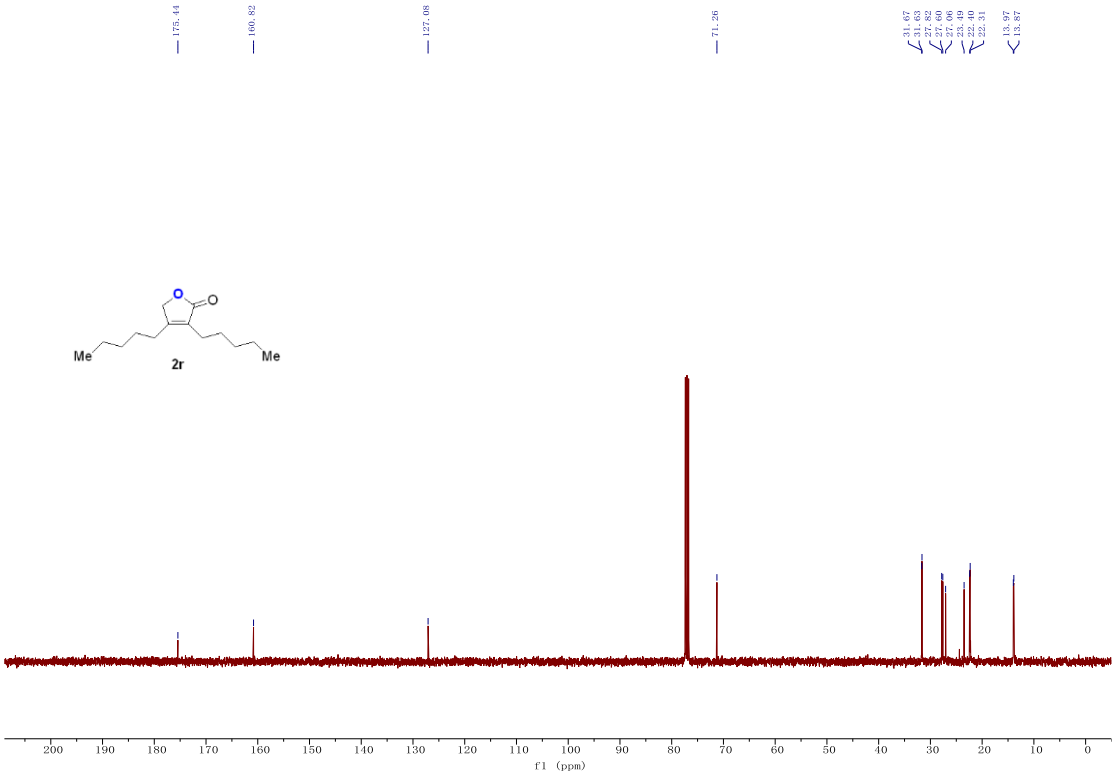
6.44
f1 (ppm)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22.31
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O
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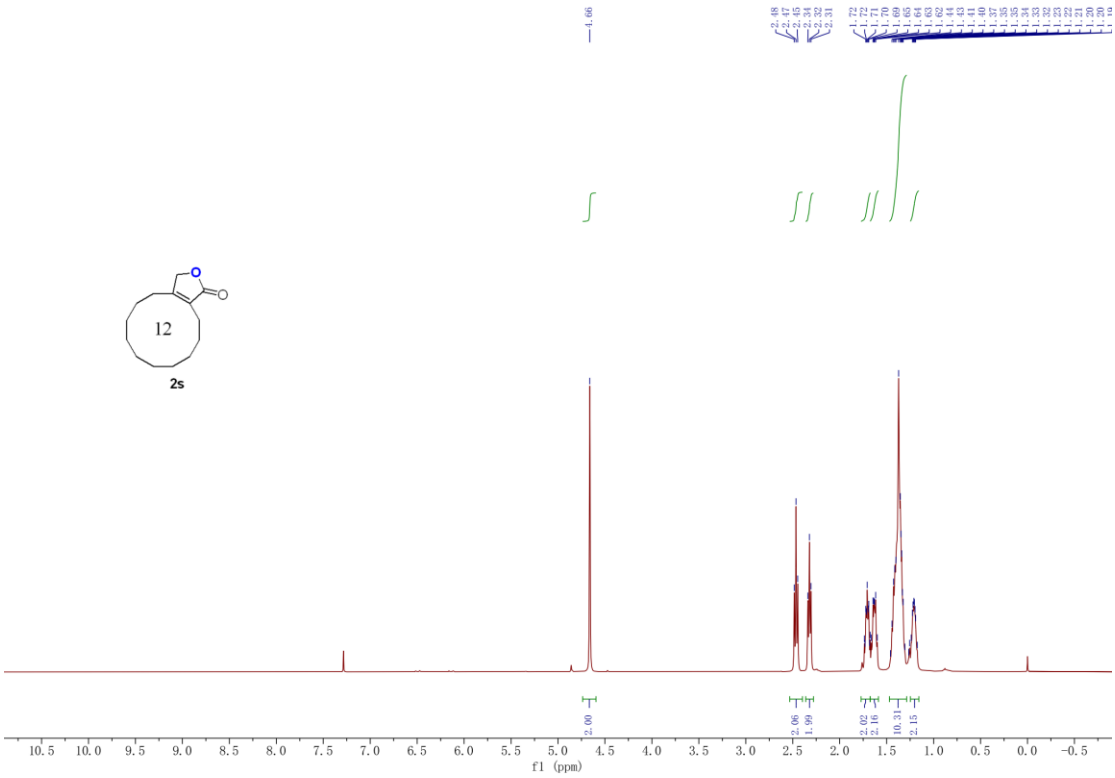
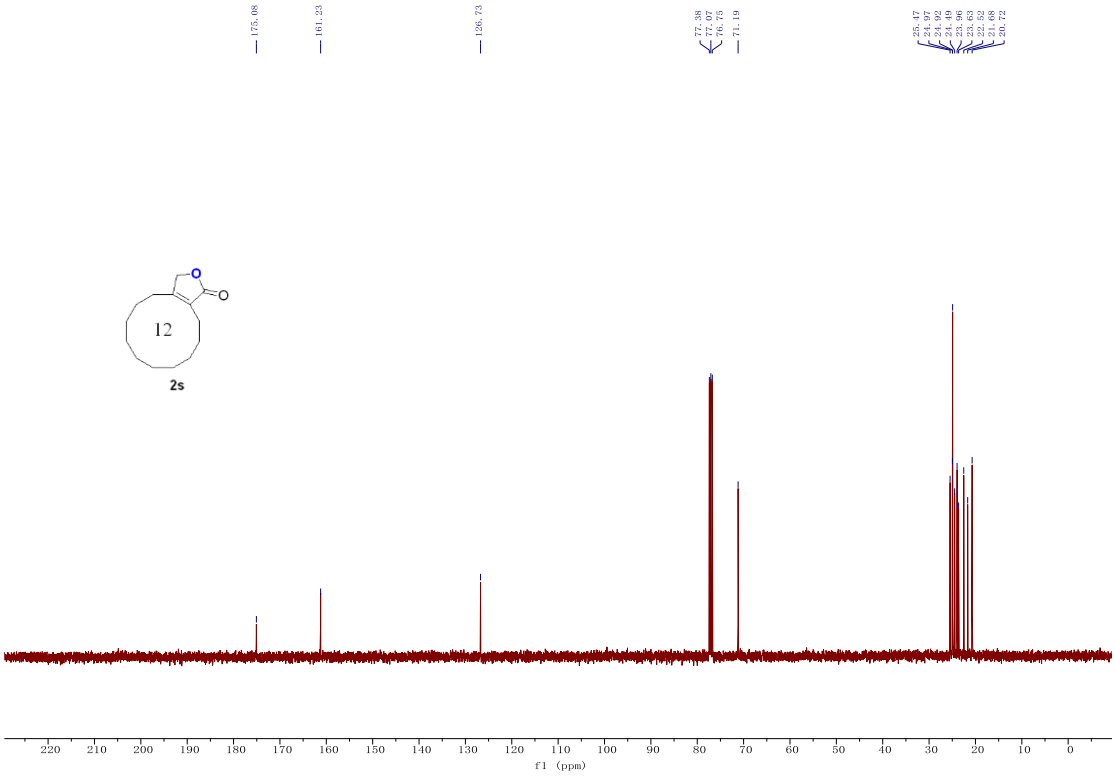
Me
Me
2r
f1 (ppm)


12
2s
f1 (ppm)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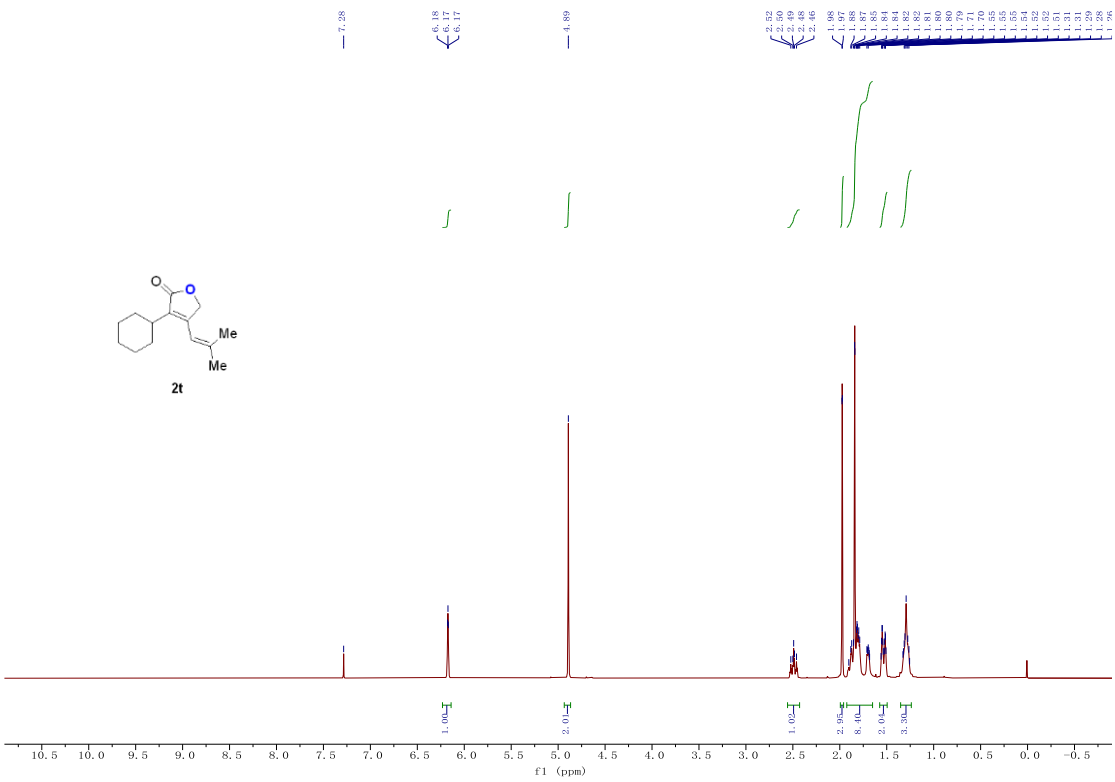
2s
f1 (ppm)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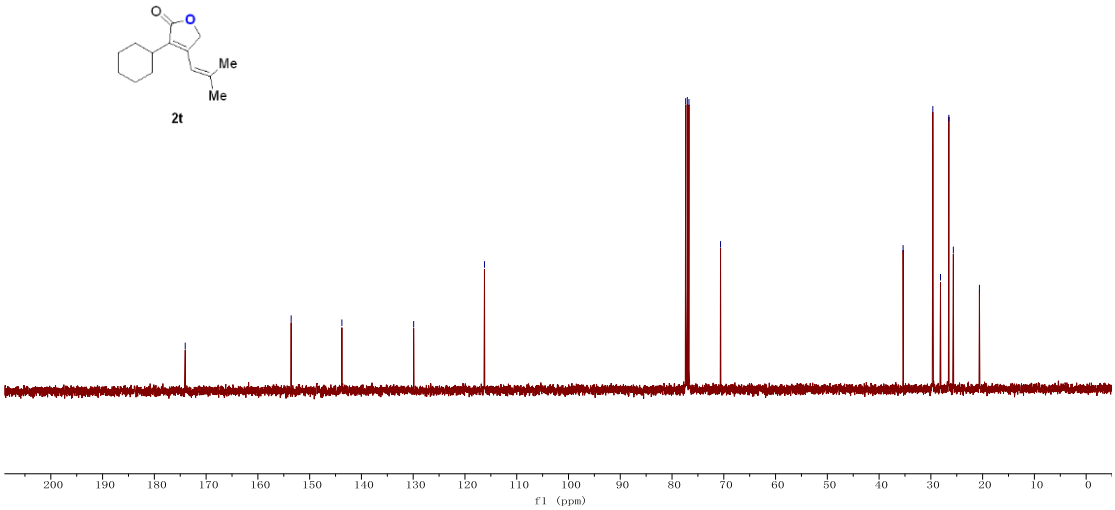
Me
2t
f1 (ppm)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Me
2t
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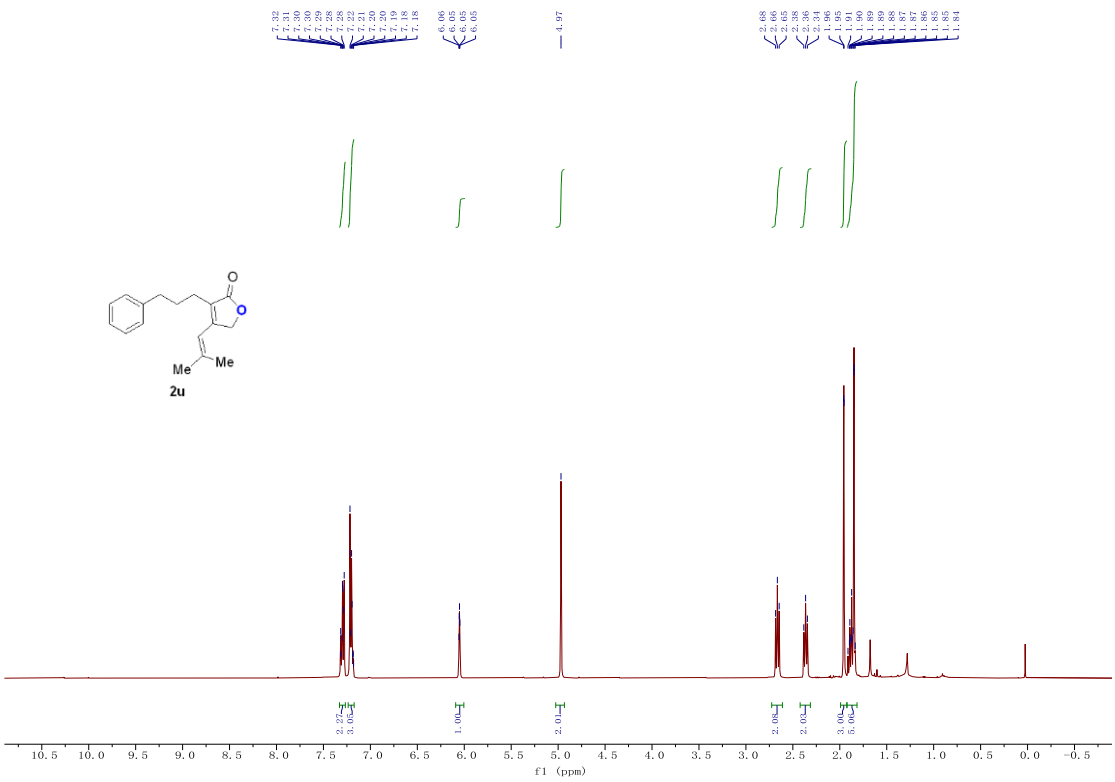
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1.90
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1.86
1.85
1.85
1.84
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O
Me
Me
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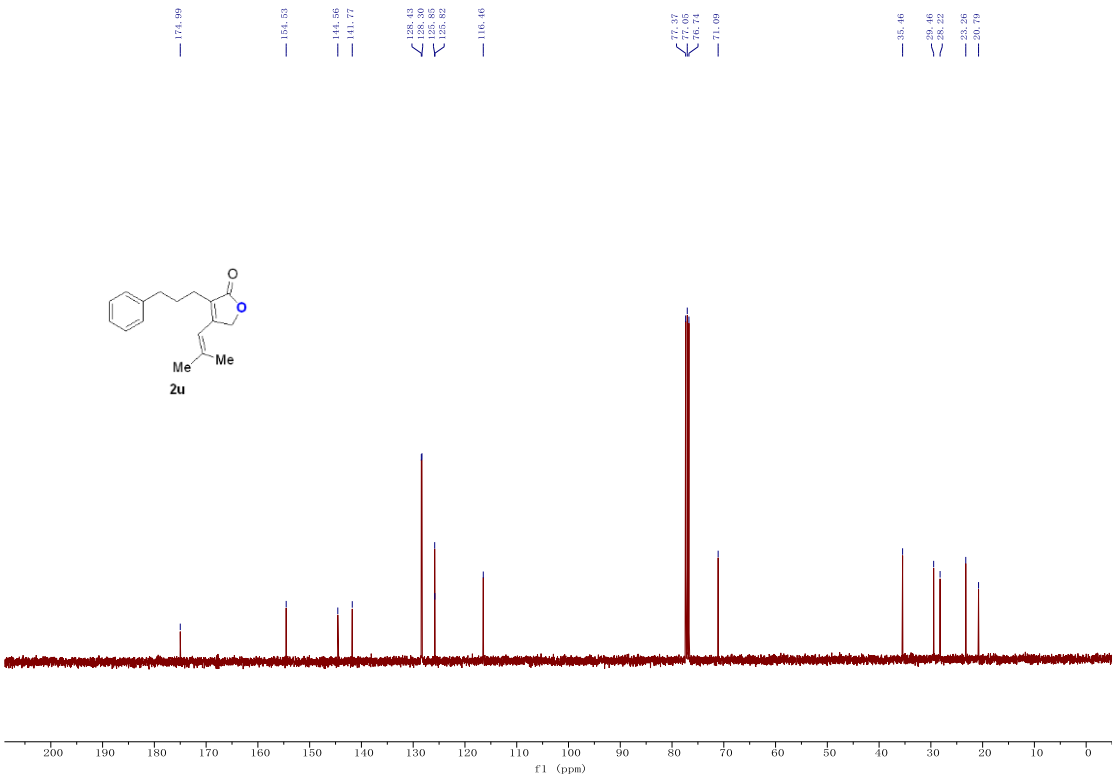
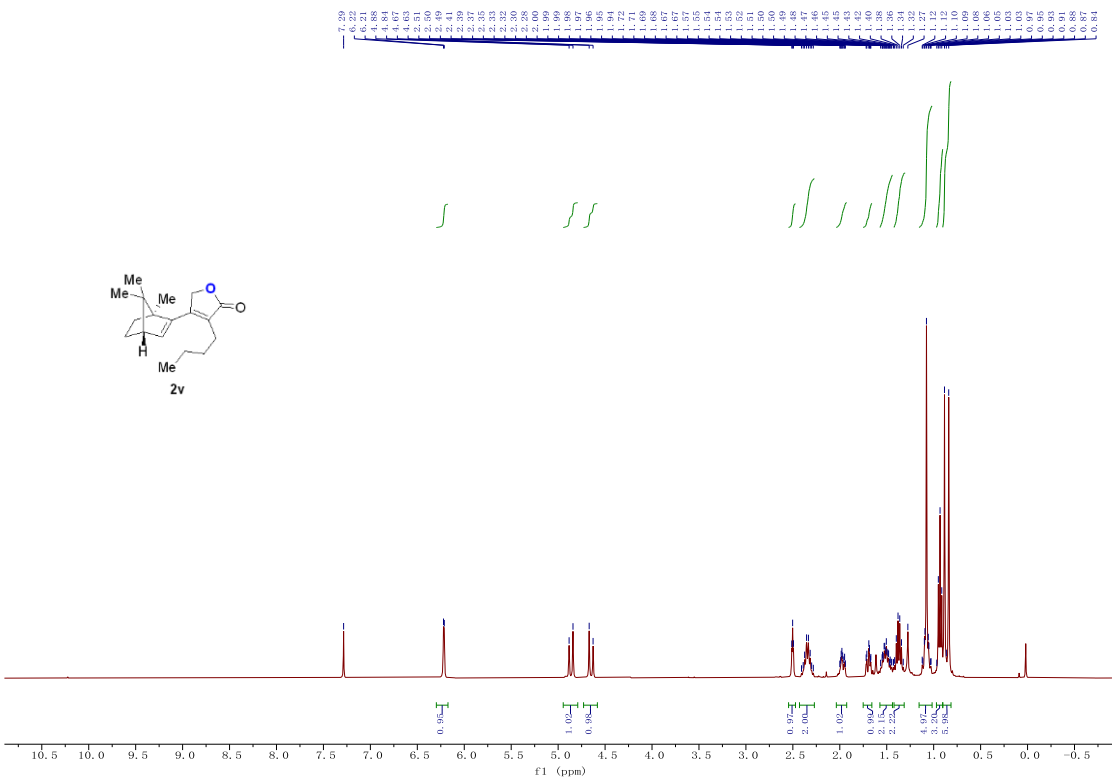
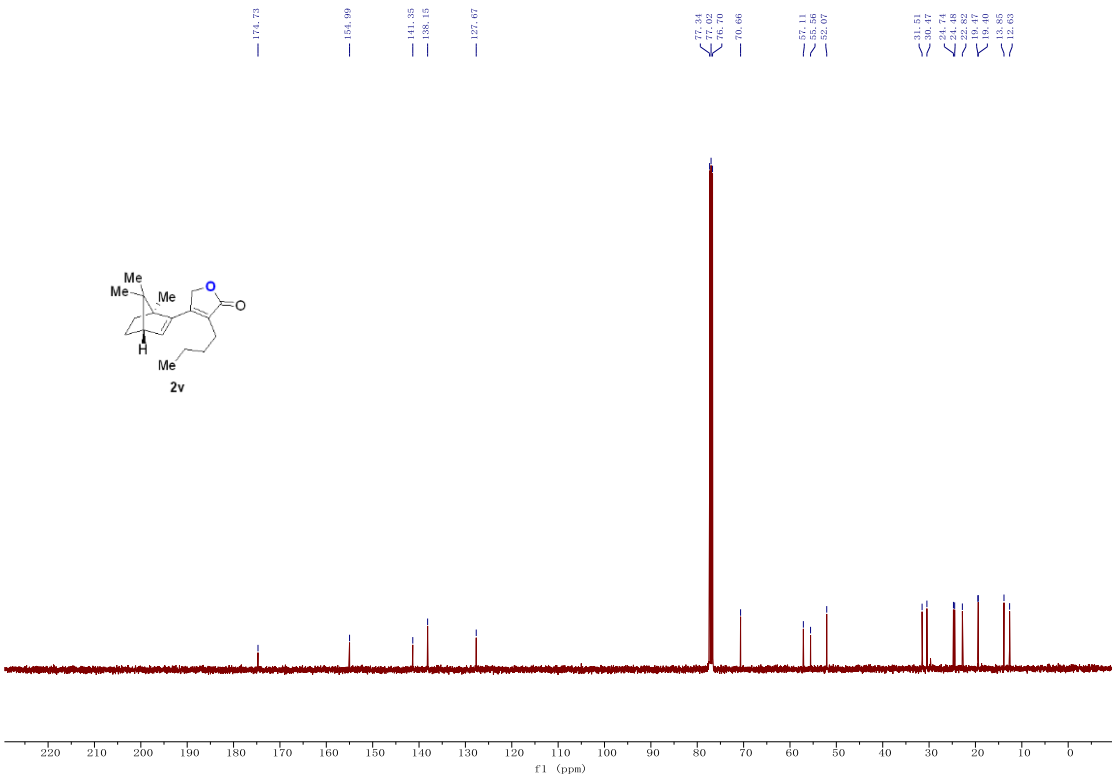
1.00
2.01
2.04
2.03
3.00
5.04
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)


174.99
154.53
144.56
141.77
128.43
128.30
125.85
125.82
116.46
77.37
77.05
76.74
71.09
35.46
29.46
28.22
23.26
20.79
O
O
Me
Me
2u
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)


Me
Me
Me
O
O
H
Me
2v
f1 (ppm)


Me
Me
Me
O
O
H
Me
2v
f1 (ppm)