Construction of Quaternary Alkyl Motifs through Palladium-Catalyzed Oxidative Coupling of 1,3-Dicarbonyl Compounds with Alkenes Followed by C-C Bond Cleavage

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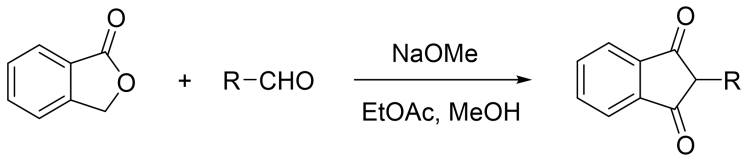
General Methods and Materials

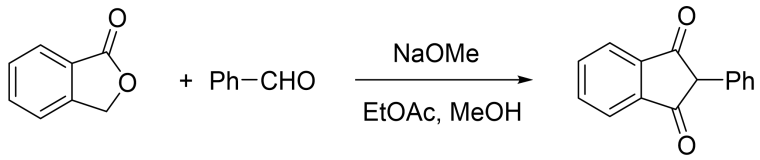
$Pd(OAc)_2$, $Cu(OAc)_2$, $Cu(OAc)_2 \cdot H_2O$, CuBr, $CuBr.SMe_2$, $CuCl_2$, CuCl, CuI, $Cu(acac)_2$, $Cu(OTf)_2$, CuOTf, $Cu(TFA)_2$, K_2CO_3, K_3PO_4, Cs_2CO_3, Na_2CO_3, NaOMe, NaO^tBu and LiO^tBu were purchased from Energy Chemical and used without further purification. Other chemicals were purchased from commercial suppliers, further dried and purified if necessary. The water used was re-distillated and ion-free. ^1H and ^{13}C NMR spectra were achieved on a Bruker AVANCE 400 MHz spectrometer (^1H 400 MHz; ^{13}C 100 MHz) in $CDCl_3$. Abbreviations for data quoted are *s*-singlet; *brs*-broad singlet; *d*-doublet; *t*-triplet; *dd*-doublet of doublets; m-multiplet. High-resolution mass spectra were measured on a Waters Micromass GCT facility. Thin-layer chromatographies were done on pre-coated silica gel 60F254 plates (Merck). Silica gel 60H (200-300 mesh) manufactured by Qingdao Haiyang Chemical Group Co. (China) was used for general chromatography.

General Procedure for Preparation of Compounds 2-Aryl-1,3-indandiones 1.[1]



EtOAc (1.8 mL) was added to a suspension of the aldehyde (7.5 mmol, 1.0 equiv.) and the phthalide (7.5 mmol, 1.0 equiv.) in anhydrous MeOH (10 mL), followed by the addition of NaOMe (25% wt in MeOH, 4.0 mL) at room temperature. The mixture was heated under reflux for 3 h and then cooled to room temperature. After concentration *in vacuo*, water (5.0 mL) was added to the residue and the solution was acidified with conc. HCl to pH 1.0. The 2-substituted indanedione was collected by filtration and dried *in vacuo* to give a yellow powder, which was used for the next step without further purification.

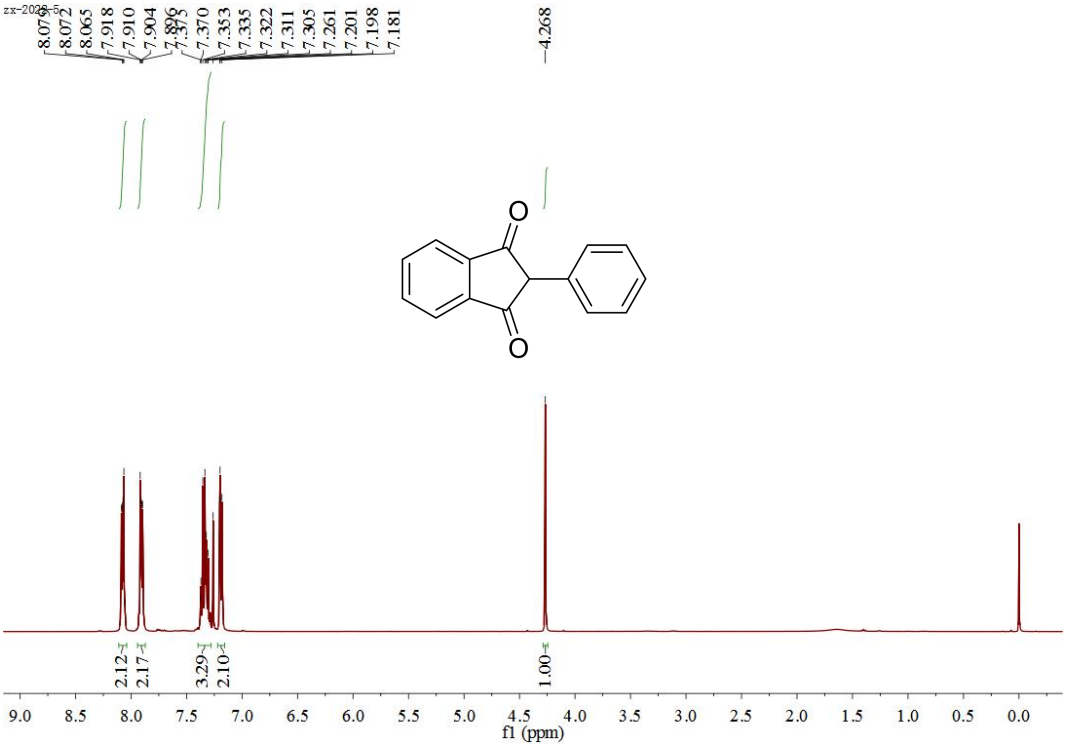
The Procedure for the Preparation of 2-Phenyl-1,3-indandione 1a

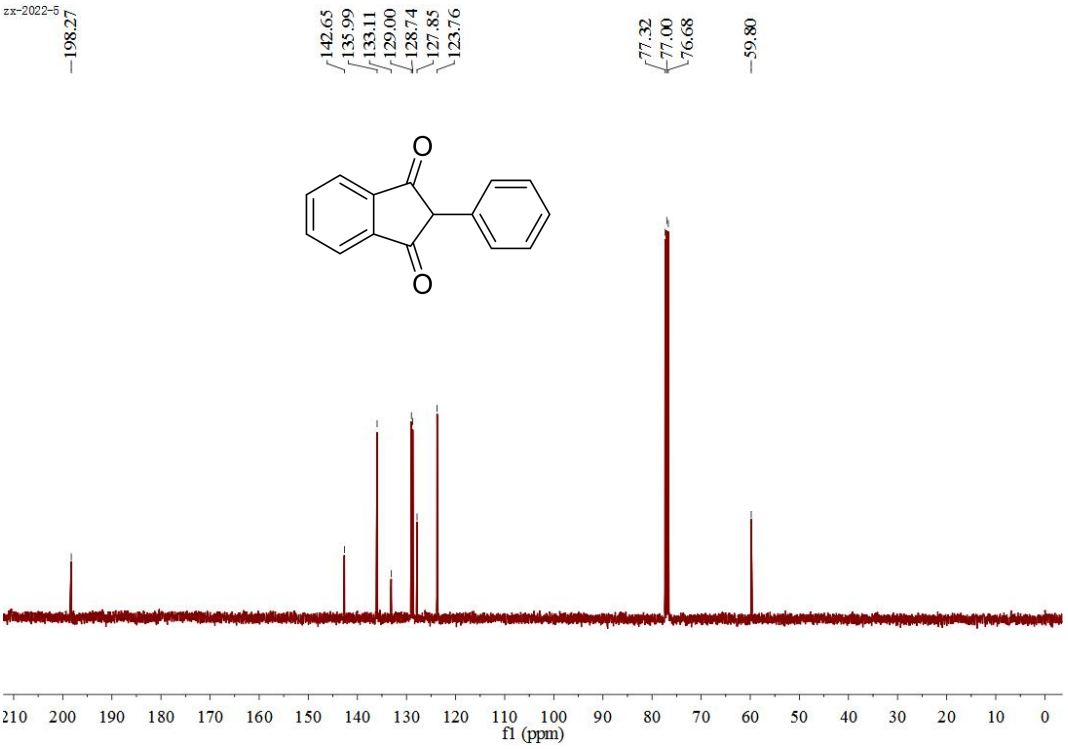


EtOAc (1.8 mL) was added to a suspension of the benzaldehyde (7.5 mmol, 795.0 mg, 1.0 equiv.) and the phthalide (7.5 mmol, 1005.0 mg, 1.0 equiv.) in anhydrous MeOH (10 mL), followed by the addition of NaOMe (25% wt in MeOH, 4.0 mL) at room temperature. The mixture was heated under reflux for 3 h and then cooled to room temperature. After concentration *in vacuo*, water (5.0 mL) was added to the residue and the solution was acidified with conc. HCl to pH 1.0. The 2-substituted indanedione was collected by filtration and dried *in vacuo* to give a yellow powder, which was used for the next step without further purification.

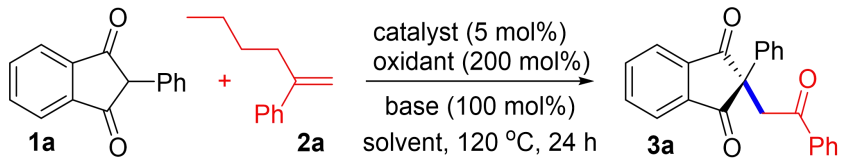
2-Phenyl-1H-indene-1,3(2H)-dione (**1a**)[1]: Obtained as a yellow solid (1581.8 mg, 95% yield); **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.09 - 8.06 (q, 2H), 7.92 - 7.90 (q, 2H), 7.38 - 7.31 (m, 3H), 7.20 - 7.18 (m, 2H), 4.27 (s, 1H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ 198.3, 142.7, 136.0, 133.1, 129.0, 128.7, 127.9, 123.8, 59.8.

^{1}H NMR and ^{13}C NMR of 1a



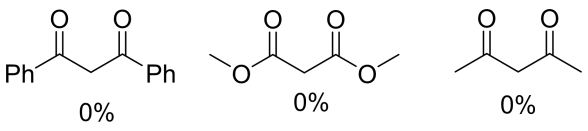


Screening of Reaction Conditions

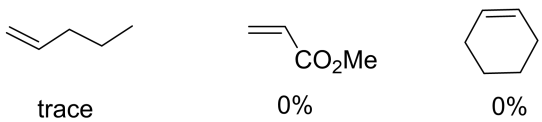


entry	catalyst	oxidant	base	solvent	yield (%)[b]
1	$Pd(OAc)_2$	BQ	NaO^{t}Bu	toluene	trace
2	$Pd(OAc)_2$	H_2O_2	NaO^{t}Bu	toluene	0
3	$Pd(OAc)_2$	TBHP	NaO^{t}Bu	toluene	0
4	$Pd(OAc)_2$	O_2	NaO^{t}Bu	toluene	trace
5	$Pd(OAc)_2$	Ag_2CO_3	NaO^{t}Bu	toluene	trace
6	$Pd(OAc)_2$	AgOTf	NaO^{t}Bu	toluene	17
7	$Pd(OAc)_2$	AgNTf	NaO^{t}Bu	toluene	21
8	$PdCl_2$	$Cu(OAc)_2$	NaO^{t}Bu	toluene	41
9	Pd_2dba_3	$Cu(OAc)_2$	NaO^{t}Bu	toluene	trace
10	$Pd(PPh_3)_4$	$Cu(OAc)_2$	NaO^{t}Bu	toluene	0
11	$Pd(acac)_2$	$Cu(OAc)_2$	NaO^{t}Bu	toluene	28
12	$Pd(TFA)_2$	$Cu(OAc)_2$	NaO^{t}Bu	toluene	56

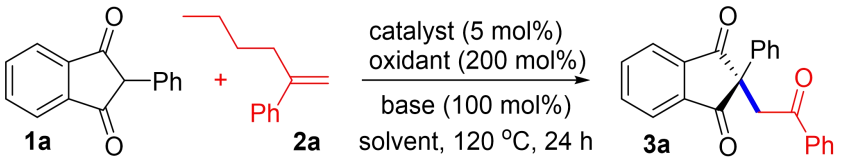
Failed 1,3-dicarbonyl compounds



Failed olefins

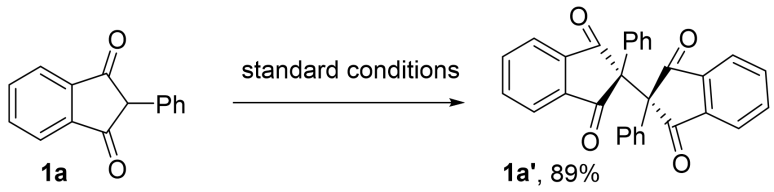


General Procedure for Palladium-Catalyzed Oxidative Coupling of 1,3-Dicarbonyl Compounds with Alkenes



To a dry thick walled pressure resistant tube (25 mL) was charged with 2-phenyl-1,3-indandione **1a** (0.2 mmol), *α*-*n*-butylstyrene **2a** (0.3 mmol, 1.5 equiv), $Pd(OAc)_2$ (2.3 mg, 5.0 mol%), $Cu(OAc)_2$ (0.4 mmol, 72.4 mg, 2.0 equiv), toluene (2 mL), then the NaO^{t}Bu (0.2 mmol) was added. The tube was closed with a PTFE thread sealing cap. The mixture was stirred at 120 °C in oil bath for 24 hours under an atmosphere of air. After the reaction finished, the resulted mixtures were diluted with 20 mL of dichloromethane and washed with 20 mL of H_2O. The aqueous layer was extracted twice with dichloromethane (10 mL) and the combined organic phase was dried over Na_2SO_4. After evaporation of the solvents, the residue was purified by silica gel chromatography (hexane/AcOEt = 20 : 1) to yield product.

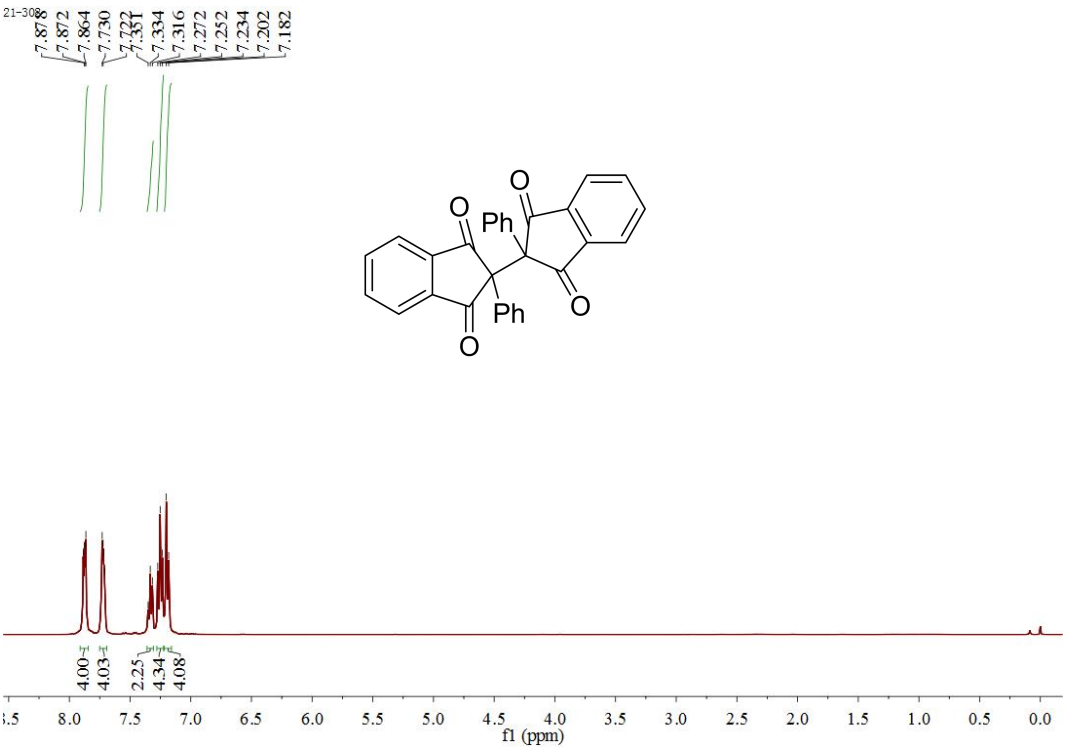
Control Experiments



(a)

A reaction flask (25 mL) was charged with 2-phenyl-1,3-indandione **1a** (0.2 mmol, 1.0 equiv), $Pd(OAc)_2$ (2.3 mg, 5.0 mol%), $Cu(OAc)_2$ (0.4 mmol, 72.4 mg, 2.0 equiv), toluene (2 mL), then the NaO^tBu (0.2 mmol) was added. The mixture was stirred at 120 °C for 8 hours under an atmosphere of air. After the reaction finished, the resulted mixtures were diluted with 20 mL of dichloromethane and washed with 20 mL of H_2O. The aqueous layer was extracted twice with dichloromethane (10 mL) and the combined organic phase was dried over Na_2SO_4. After evaporation of the solvents, the residue was purified by silica gel chromatography (hexane/AcOEt = 3 : 1) to yield product **1a'** 78.7 mg.

2,2'-Diphenyl-1H,1'H-[2,2'-biindene]-1,1',3,3'(2H,2'H)-tetraone (**1a'**): Obtained as a pale yellow solid (84.0 mg, 76% yield), eluting with 20% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 7.86 - 7.89 (m, 4H), 7.71 - 7.73 (m, 4H), 7.32 - 7.35 (t, J = 6.8 Hz, 2H), 7.23 - 7.27 (t, J = 8.0 Hz, 4H), 7.18 - 7.20 (d, J = 8.0 Hz, 4H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 197.4, 140.90, 135.6, 130.4, 129.8, 128.7, 127.5, 123.7, 64.3; **HRMS** (ESI-TOF) m/z calcd for $C_{30}H_{19}O_4$ $[M + H]^+$ 443.1278, found 443.1275.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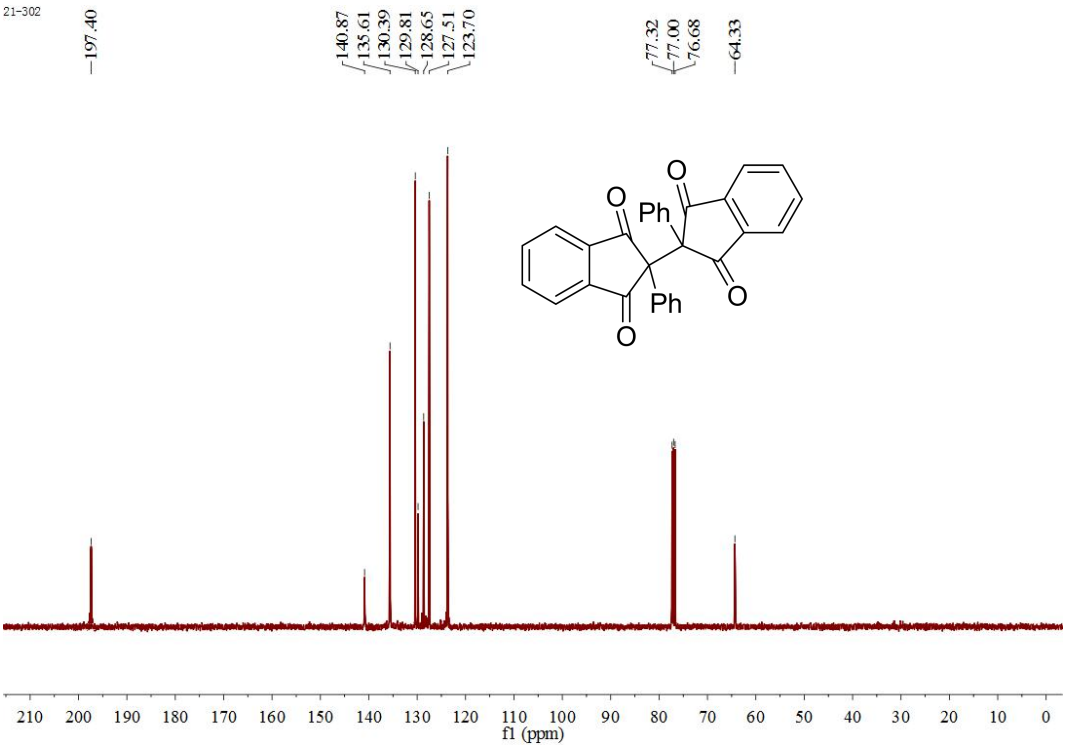
7.864
7.730
7.722
7.351
7.334
7.316
7.272
7.252
7.234
7.202
7.182
O
O
Ph
O
Ph
O
4.00
4.03
2.25
4.34
4.08
f1 (ppm)


21-302
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135.61
130.39
129.81
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127.51
123.70
77.32
77.00
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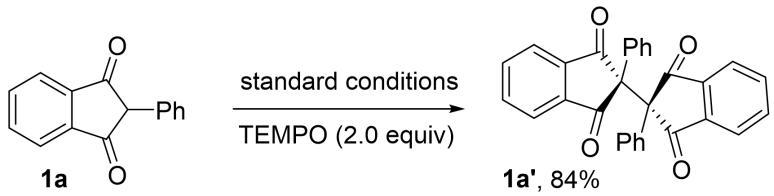
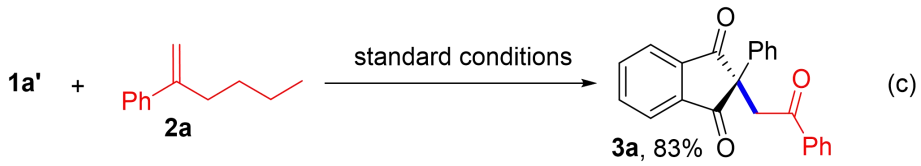
O
O
Ph
O
Ph
O
f1 (ppm)



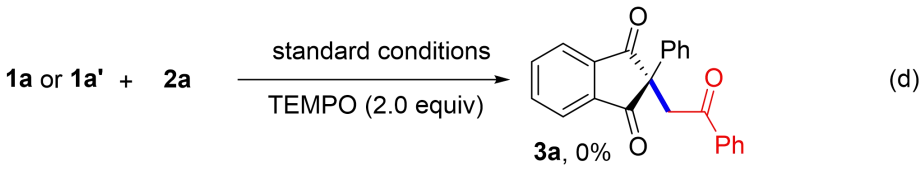
(b)

A reaction flask (25 mL) was charged with 2-phenyl-1,3-indandione **1a** (0.2 mmol, 1.0 equiv), $Pd(OAc)_2$ (2.3 mg, 5.0 mol%), $Cu(OAc)_2$ (0.4 mmol, 72.4 mg, 2.0 equiv), TEMPO (0.4 mmol, 2.0 equiv), toluene (2 mL), then the NaO^tBu (0.2 mmol) was added. The mixture was stirred at 120 °C for 8 hours under an atmosphere of air. After the reaction finished, the resulted mixtures were diluted with 20 mL of dichloromethane and washed with 20 mL of H_2O. The aqueous layer was extracted twice with dichloromethane (10 mL) and the combined organic phase was dried over Na_2SO_4. After evaporation of the solvents, the residue was purified by silica gel chromatography (hexane/AcOEt = 3 : 1) to yield product.



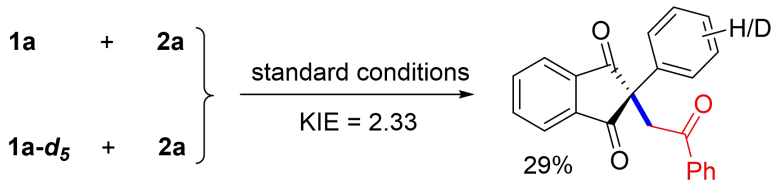
(c)

A reaction flask (25 mL) was charged with **1a'** (0.2 mmol, 1.0 equiv), *α*-*n*-butylstyrene **2a** (0.3 mmol, 1.5 equiv), $Pd(OAc)_2$ (2.3 mg, 5.0 mol%), $Cu(OAc)_2$ (0.4 mmol, 72.4 mg, 2.0 equiv), toluene (2 mL), then the NaO^tBu (0.2 mmol) was added. The tube was closed with a PTFE thread sealing cap. The mixture was stirred at 120 °C in oil bath for 24 hours under an atmosphere of air. After the reaction finished, the resulted mixtures were diluted with 20 mL of dichloromethane and washed with 20 mL of H_2O. The aqueous layer was extracted twice with dichloromethane (10 mL) and the combined organic phase was dried over Na_2SO_4. After evaporation of the solvents, the residue was purified by silica gel chromatography (hexane/AcOEt = 20 : 1) to yield product **3a**.



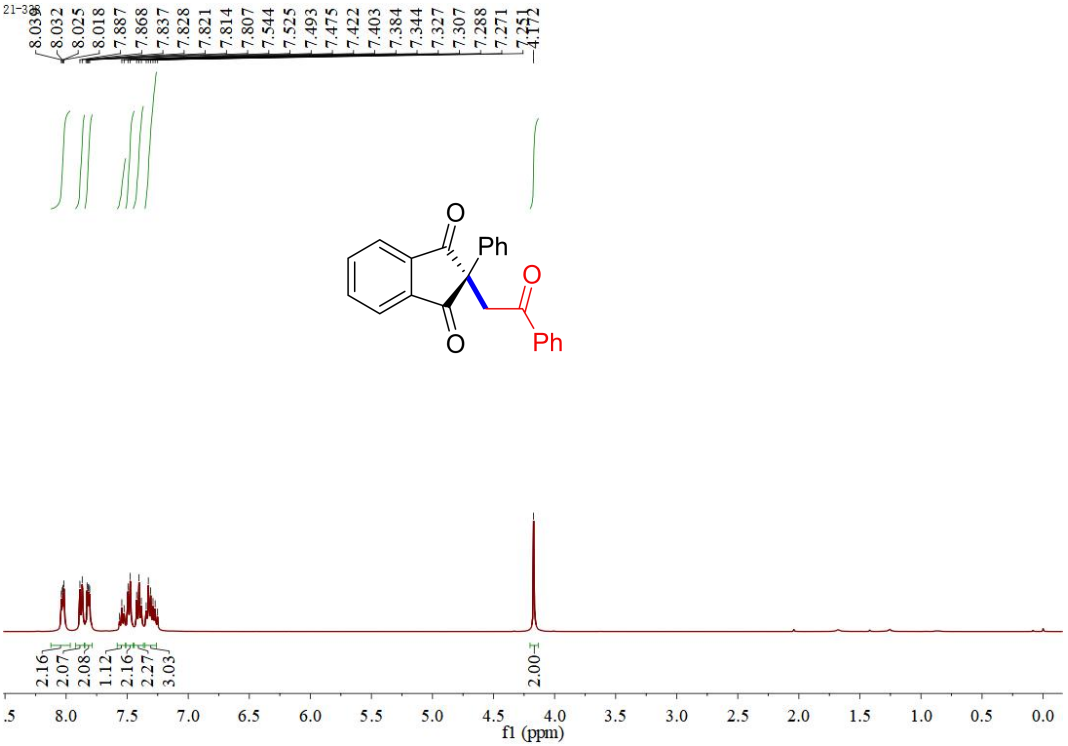
(d)

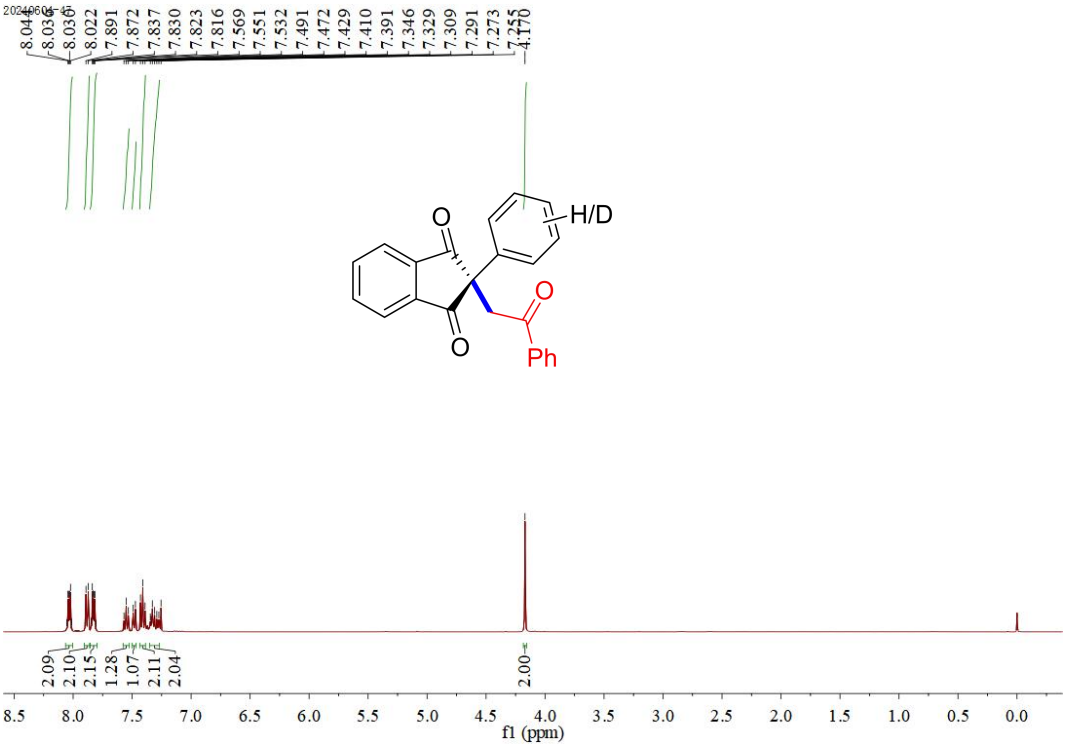
A reaction flask (25 mL) was charged with **1a'** (0.2 mmol, 1.0 equiv), or 2-phenyl-1,3-indandione **1a** (0.2 mmol, 1.0 equiv), *α*-*n*-butylstyrene **2a** (0.3 mmol, 1.5 equiv), $Pd(OAc)_2$ (2.3 mg, 5.0 mol%), $Cu(OAc)_2$ (0.4 mmol, 72.4 mg, 2.0 equiv), TEMPO (0.4 mmol, 2.0 equiv), toluene (2 mL), then the NaO^tBu (0.2 mmol) was added. The mixture was stirred at 120 °C for 8 hours under an atmosphere of air. After the reaction finished, no desired product of **3a** was detected.



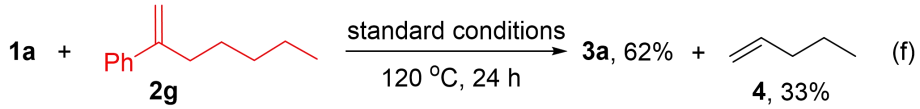
(e)

A reaction flask (25 mL) was charged with 2-phenyl-1,3-indandione **1a** (0.1 mmol, 22.2 mg, 1.0 equiv), 2-phenyl-d_5-1,3-indandione **1a**-d_5 (0.1 mmol, 22.7 mg, 1.0 equiv), α-*n*-butylstyrene **2a** (0.3 mmol, 1.5 equiv), $Pd(OAc)_2$ (2.3 mg, 5.0 mol%), $Cu(OAc)_2$ (0.4 mmol, 72.4 mg, 2.0 equiv), toluene (2 mL), then the NaO^tBu (0.2 mmol) was added. The mixture was stirred at 120 °C in the oil bath for 20 minutes under an atmosphere of air. After the reaction finished, take one tenth of the resulted mixtures for treatment, the resulted mixtures were diluted with 20 mL of dichloromethane and washed with 20 mL of H_2O. The aqueous layer was extracted twice with dichloromethane (10 mL) and the combined organic phase was dried over Na_2SO_4. After evaporation of the solvents, the residue was purified by silica gel chromatography (hexane/AcOEt = 20 : 1) to yield product.



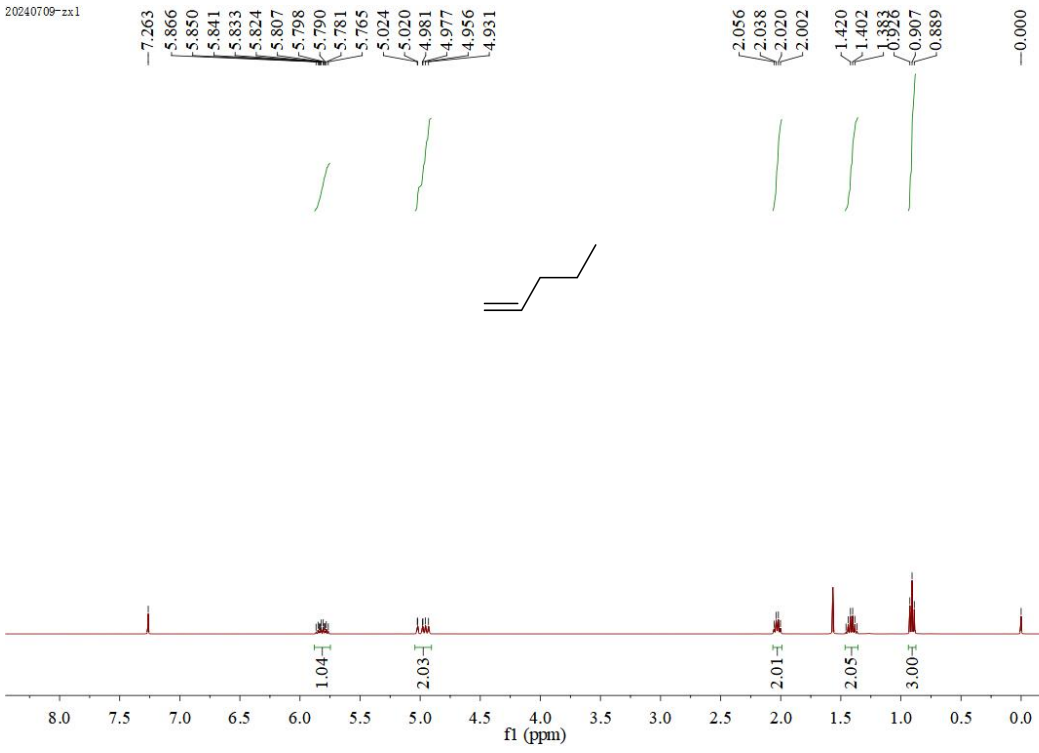


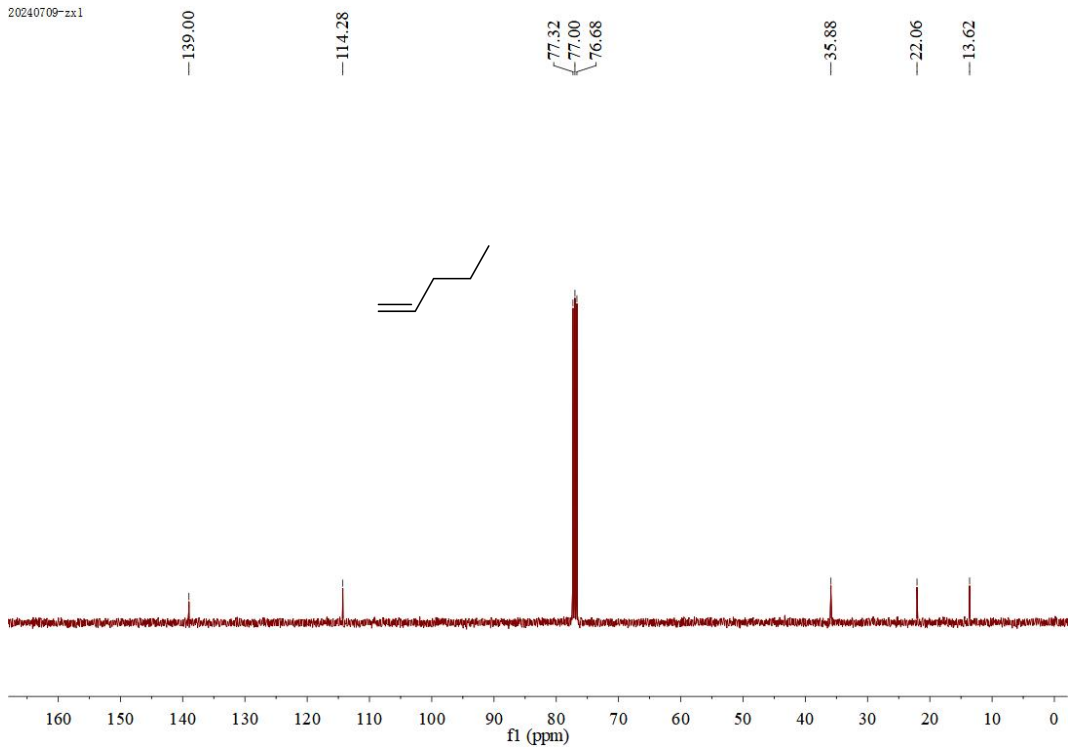
KIE = 1.07 + 2.11 + 2.04/2.16 + 2.27 + 3.03 - 1.07 - 2.11 - 2.04 = 5.22/2.24 = 2.33



To a dry thick walled pressure resistant tube (25 mL) was charged with 2-phenyl-1,3-indandione **1a** (0.2 mmol), *α*-*n*-butylstyrene **2a** (0.3 mmol, 1.5 equiv), $Pd(OAc)_2$ (2.3 mg, 5.0 mol%), $Cu(OAc)_2$ (0.4 mmol, 72.4 mg, 2.0 equiv), toluene (2 mL), then the NaO^{t}Bu (0.2 mmol) was added. The tube was closed with a PTFE thread sealing cap. The mixture was stirred at 120 °C in oil bath for 24 hours under an atmosphere of air. After the reaction finished, the resulted mixtures were diluted with 20 mL of dichloromethane and washed with 20 mL of H_2O. The aqueous layer was extracted twice with dichloromethane (10 mL) and the combined organic phase was dried over Na_2SO_4. After evaporation of the solvents, the residue was purified by silica gel chromatography (hexane/AcOEt = 100 : 1 ~ 20 : 1) to yield product.

pent-1-ene: Obtained as a pale liquid (36.5 mg, 33% yield), eluting with 5% EtOAc in PE (elution gradient); ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.77 - 5.87 (m, 1H), 4.93 - 5.02 (m, 2H), 2.00 - 2.06 (m, 2H), 1.57 (s, 1H), 1.37 - 1.46 (m, 2H), 0.89 - 0.93 (t, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 139.0, 114.3, 35.9, 22.1, 13.6.

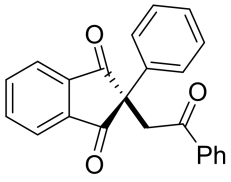




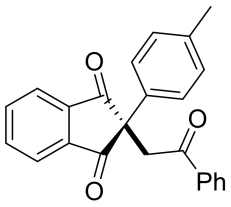
References:

[1] (a) Inoue, K.; Urushibara, K.; Kanai, M.; Yura, K.; Fujii, S.; Ishigami, Y. M.; Hashimoto, M.; Mori, S.; Kawachi, E.; Matsumura, M.; Hirano, T.; Kagechika, H.; Tanatani, A. *Eur. J. Med. Chem*. **2015**, *102*, 310 - 319. (b) Cai, L.; Zhang, K.; Chen, S.; Lepage, R. J.; Houk, K. N.; Krenske, E. H.; Kwon, O. *J. Am. Chem. Soc*. **2019**, *141*, 9537 - 9542. (c) Zhang, X.; Wang, D.; Chang, M.; Wang, W.; Shen, Z.; Xu, X. *Chem Comm*. **2023**, *59*, 12326 - 12329. (d) Shi, Y.; Wang, D.; Sun, R.; Chen, X.; Xu, X.; Xie, H.; Zhang, X. *Adv. Synth. Catal*. **2023**, *365*, 741-746.

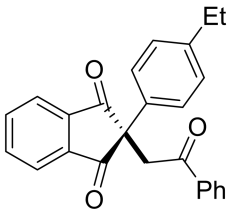
Characterization data for the products



2-(2-Oxo-2-phenylethyl)-2-phenyl-1H-indene-1,3(2*H*)-dione (**3a**). Obtained as a yellow liquid (57.1 mg, 84% yield), eluting with 10% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 8.02 - 8.04 (q, 2H), 7.88 (d, J = 7.6 Hz, 2H), 7.81 - 7.84 (q, 2H), 7.53 - 7.56 (t, 1H), 7.48 (d, J = 7.2 Hz, 2H), 7.38 - 7.42 (t, 2H), 7.25 - 7.35 (m, 3H), 4.17 (s, 2H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 200.0, 196.7, 141.7, 135.3, 135.2, 135.0, 133.7, 129.1, 128.6, 128.3, 128.1, 126.9, 123.5, 59.6, 47.3. **HRMS** (ESI-TOF) m/z calcd for $C_{23}H_{17}O_3$ $[M + H]^+$ 341.1172, found 341.1172.

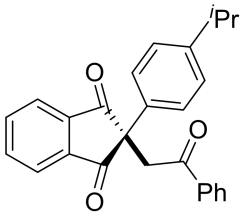


2-(2-Oxo-2-phenylethyl)-2-(*p*-tolyl)-1H-indene-1,3(2H)-dione **(3b)**. Obtained as a yellow liquid (61.6 mg, 87% yield), eluting with 10% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 8.02 - 8.04 (q, 2H), 7.81 - 7.83 (q, 2H), 7.77 (d, J = 8.0 Hz, 2H), 7.48 (d, J = 7.2 Hz, 2H), 7.26 - 7.34 (m, 3H), 7.20 (d, J = 8.0 Hz, 2H), 4.15 (s, 2H), 2.38 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 200.1, 196.3, 144.7, 141.8, 135.4, 135.2, 132.7, 129.3, 129.1, 128.4, 128.0, 127.0, 123.5, 59.7, 47.3, 21.7. **HRMS** (ESI-TOF) m/z calcd for $C_{24}H_{19}O_3$ $[M + H]^+$ 355.1329, found 355.1332.

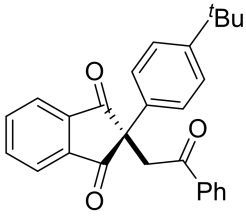


2-(4-Ethylphenyl)-2-(2-oxo-2-phenylethyl)-1H-indene-1,3(2H)-dion e **(3c)**. Obtained as a yellow liquid (63.3 mg, 86% yield), eluting with 10% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 8.01 - 8.03 (q, 2H), 7.87 (d,

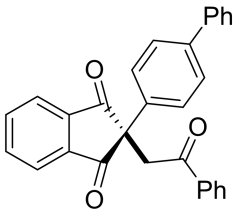
J = 8.0 Hz, 2H), 7.80 - 7.82 (m, 2H), 7.52 - 7.56 (t, 1H), 7.38 - 7.42 (t, 4H), 7.16 (d, *J* = 8.0 Hz, 2H), 4.15 (s, 2H), 2.56 - 2.61 (q, 2H), 1.16 - 1.20 (t, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 200.2, 196.7, 144.2, 141.7, 135.2, 135.0, 133.7, 132.4, 128.7, 128.6, 128.3, 126.8, 123.5, 59.4, 47.3, 28.3, 15.3; **HRMS** (ESI-TOF) m/z calcd for $C_{25}H_{21}O_3$ $[M + H]^+$ 369.1485, found 369.1482.



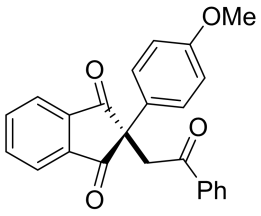
2-(4-Isopropylphenyl)-2-(2-oxo-2-phenylethyl)-1H-indene-1,3(2H)-dione **(3d)**. Obtained as a yellow solid (67.2 mg, 88% yield), eluting with 10% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 8.01 - 8.04 (q, 2H), 7.88 (d, *J* = 7.6 Hz, 2H), 7.80 - 7.83 (m, 2H), 7.53 - 7.56 (t, 1H), 7.38 - 7.42 (m, 4H), 7.18 (d, *J* = 8.0 Hz, 2H), 4.15 (s, 2H), 2.81 - 2.88 (m, 1H), 1.20 (s, 3H), 1.19 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ 200.2, 196.8, 148.8, 141.8, 135.2, 133.7, 132.6, 128.6, 128.3, 127.2, 126.9, 123.5, 59.4, 47.3, 33.6, 23.8; **HRMS** (ESI-TOF) m/z calcd for $C_{26}H_{23}O_3$ $[M + H]^+$ 383.1642, found 383.1644.



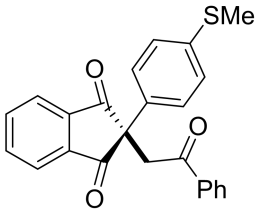
2-(4-(Tert-butyl)phenyl)-2-(2-oxo-2-phenylethyl)-1H-indene-1,3(2H)-dione **(3e)**. Obtained as a yellow solid (71.3 mg, 90% yield), eluting with 10% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 8.01 - 8.03 (q, 2H), 7.87 (d, *J* = 7.2 Hz, 2H), 7.79 - 7.81 (m, 2H), 7.51 - 7.55 (t, 1H), 7.37 - 7.41 (m, 4H), 7.33 (d, *J* = 8.4 Hz, 2H), 4.15 (s, 2H), 1.26 (s, 9H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 200.1, 196.7, 151.0, 141.8, 135.2, 133.7, 132.2, 128.6, 128.3, 126.6, 126.1, 123.5, 59.4, 47.2, 34.4, 31.1; **HRMS** (ESI-TOF) m/z calcd for $C_{27}H_{25}O_3$ $[M + H]^+$ 397.1798, found 397.1795.



2-([1,1'-Biphenyl]-4-yl)-2-(2-oxo-2-phenylethyl)-1H-indene-1,3(2H)-dione **(3f)**. Obtained as a yellow solid (76.5 mg, 92% yield), eluting with 10% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 8.03 - 8.05 (q, 2H), 7.88 (d, J = 7.6 Hz, 2H), 7.80 - 7.82 (q, 2H), 7.51 - 7.55 (m, 7H), 7.38 - 7.42 (t, 4H), 7.33 (d, J = 7.2 Hz, 1H), 4.20 (s, 2H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 200.0, 196.6, 141.7, 141.0, 140.0, 135.3, 135.0, 134.2, 133.7, 128.8, 128.6, 128.3, 127.8, 127.6, 127.3, 127.0, 123.5, 59.4, 47.3; **HRMS** (ESI-TOF) m/z calcd for $C_{29}H_{21}O_3$ $[M + H]^+$ 417.1485, found 417.1482.

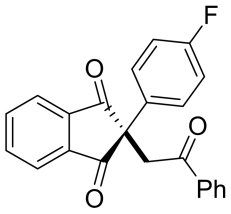


2-(4-methoxyphenyl)-2-(2-oxo-2-phenylethyl)-1H-indene-1,3(2H)-dione (**3g**): Obtained as a yellow solid (57.7 mg, 78% yield), eluting with 10% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 7.82 - 7.85 (q, 2H), 7.66 - 7.70 (q, 2H), 7.43 - 7.45 (m, 2H), 7.00 - 7.11 (m, 5H), 6.85 - 6.88 (m, 2H), 3.77 (s, 2H), 3.57 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 201.4, 159.1, 142.1, 135.6, 130.4, 129.0, 128.1, 128.0, 126.7, 123.2, 114.2, 63.2, 55.2, 42.0; **HRMS** (ESI-TOF) m/z calcd for $C_{24}H_{19}O_4$ $[M + H]^+$ 371.1278, found 371.1276.

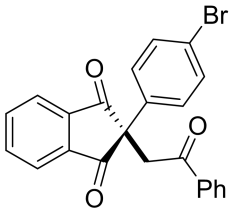


2-(4-(Methylthio)phenyl)-2-(2-oxo-2-phenylethyl)-1H-indene-1,3(2H)-dione **(3h)**. Obtained as a yellow liquid (61.0 mg, 79% yield), eluting with 10% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 7.93 - 7.95 (q, 2H), 7.79 (d, J = 7.2 Hz, 2H), 7.73 - 7.75 (m, 2H), 7.45 - 7.48 (t, 1H), 7.30 - 7.34 (m,

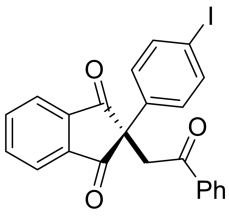
4H), 7.11 (d, J = 8.0 Hz, 2H), 4.05 (s, 2H), 2.34 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 199.9, 196.6, 141.7, 139.0, 135.3, 135.0, 133.7, 131.8, 128.6, 128.3, 127.3, 126.9, 123.5, 59.2, 47.2, 15.5; **HRMS** (ESI-TOF) m/z calcd for $C_{24}H_{19}O_3S$ $[M + H]^+$ 387.1049, found 387.1046.



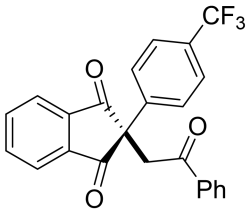
2-(4-Fluorophenyl)-2-(2-oxo-2-phenylethyl)-1H-indene-1,3(2H)-dione **(3i)**. Obtained as a yellow liquid (51.6 mg, 72% yield), eluting with 10% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 8.01 - 8.04 (m, 2H), 7.81 - 7.88 (m, 4H), 7.52 - 7.56 (t, 1H), 7.45 - 7.49 (m, 2H), 7.38 - 7.42 (m, 2H), 6.99 - 7.03 (m, 2H), 4.14 (s, 2H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 200.0, 196.5, 162.4 (d, J = 246.7 Hz), 141.5, 135.4, 134.8, 133.8, 130.8 (d, J = 3.2 Hz), 128.7 (d, J = 8.2 Hz), 128.6, 128.3, 123.5, 116.0 (d, J = 21.3 Hz), 58.8, 47.4; **^{19}F NMR** (400 MHz, $CDCl_3$) δ -116.1; **HRMS** (ESI-TOF) m/z calcd for $C_{23}H_{16}FO_3$ $[M + H]^+$ 359.1078, found 359.1075.



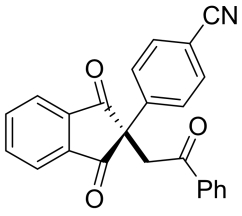
2-(4-Bromophenyl)-2-(2-oxo-2-phenylethyl)-1H-indene-1,3(2H)-dione **(3j)**. Obtained as a yellow solid (61.9 mg, 74% yield), eluting with 10% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 8.03 - 8.05 (q, 2H), 7.84 - 7.88 (m, 4H), 7.66 (s, 1H), 7.54 - 7.58 (t, 1H), 7.41 - 7.43 (m, 4H), 7.17 - 7.21 (t, 1H), 4.13 (s, 2H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 200.0, 196.7, 141.7, 135.3, 135.0, 133.8, 133.2, 132.6, 132.4, 129.0, 128.6, 128.3, 128.1, 127.5, 126.6, 126.5, 126.3, 124.2, 123.6, 59.8, 47.3. **HRMS** (ESI-TOF) m/z calcd for $C_{23}H_{16}O_3Br$ $[M + H]^+$ 419.0277, found 419.0279.



2-(4-Iodophenyl)-2-(2-oxo-2-phenylethyl)-1H-indene-1,3(2H)-dion e (**3k**): Obtained as a yellow liquid (72.7 mg, 78% yield), eluting with 10% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 8.01 - 8.03 (m, 2H), 7.81 - 7.87 (m, 4H), 7.64 (d, J = 8.0 Hz, 2H), 7.52 - 7.56 (t, 1H), 7.38 - 7.42 (t, 2H), 7.23 (d, J = 8.0 Hz, 2H), 4.12 (s, 2H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 199.6, 196.4, 141.6, 138.2, 135.4, 135.0, 134.9, 133.8, 128.8, 128.6, 128.3, 123.5, 94.2, 59.1, 47.2; **HRMS** (ESI-TOF) m/z calcd for $C_{23}H_{16}IO_3$ $[M + H]^+$ 467.0139, found 467.0141.

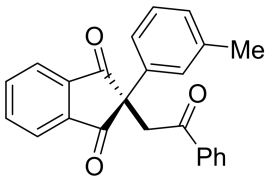


2-(2-Oxo-2-phenylethyl)-2-(4-(trifluoromethyl)phenyl)-1H-indene -1,3(2H)-dione (**3l**): Obtained as a yellow solid (53.0 mg, 65% yield), eluting with 10% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 8.03 - 8.05 (q, 2H), 7.99 (d, J = 8.4 Hz, 2H), 7.83 - 7.85 (m, 2H), 7.69 (d, J = 8.0 Hz, 2H), 7.48 (d, J = 7.6 Hz, 2H), 7.26 - 7.36 (m, 3H), 4.16 (s, 2H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 199.8, 195.9, 141.6, 137.6, 135.5, 134.9 (J, t = 15.6 Hz), 129.3, 128.6, 128.2, 126.9, 125.7 (q, t = 3.6 Hz), 123.5 (q, t = 271.3 Hz), 123.4, 59.6, 47.2. **^{19}F NMR** (400 MHz, $CDCl_3$) δ -57.8; **HRMS** (ESI-TOF) m/z calcd for $C_{24}H_{16}F_3O_3$ $[M + H]^+$ 409.1046, found 409.1047.

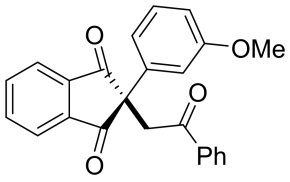


4-(1,3-Dioxo-2-(2-oxo-2-phenylethyl)-2,3-dihydro-1H-inden-2-yl) benzonitrile (**3m**): Obtained as a yellow solid (46.7 mg, 64% yield), eluting with 10% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 8.03 - 8.07 (m,

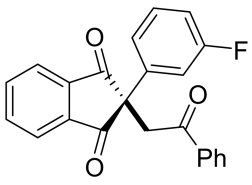
2H), 7.86 - 7.90 (m, 4H), 7.56 - 7.66 (m, 5H), 7.41 - 7.45 (t, 2H), 4.14 (s, 2H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 199.2, 196.0, 141.6, 140.5, 135.7, 134.7, 134.0, 132.8, 128.7, 128.3, 127.9, 123.7, 118.2, 112.2, 59.3, 47.4; **HRMS** (ESI-TOF) m/z calcd for $C_{24}H_{16}NO_3$ $[M + H]^+$ 366.1125, found 366.1123.



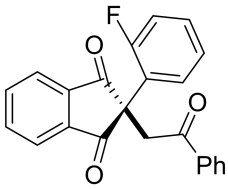
2-(2-Oxo-2-phenylethyl)-2-(*m*-tolyl)-1H-indene-1,3(2H)-dione **(3n)**. Obtained as a yellow solid (63.0 mg, 89% yield), eluting with 10% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 8.02 - 8.04 (q, 2H), 7.88 (d, J = 7.6 Hz, 2H), 7.81 - 7.83 (q, 2H), 7.53 - 7.56 (t, 1H), 7.39 - 7.42 (t, 2H), 7.25 - 7.29 (m, 2H), 7.19 - 7.22 (t, 1H), 7.08 (d, J = 7.6 Hz, 1H), 4.15 (s, 2H), 2.31 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 200.1, 196.7, 141.8, 139.0, 135.2, 135.1, 133.7, 129.0, 128.8, 128.6, 128.3, 127.5, 124.0, 123.5, 59.7, 47.3, 21.5; **HRMS** (ESI-TOF) m/z calcd for $C_{24}H_{19}O_3$ $[M + H]^+$ 355.1329, found 355.1325.



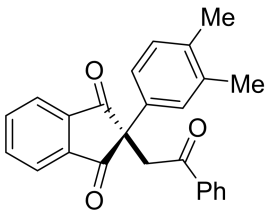
2-(3-Methoxyphenyl)-2-(2-oxo-2-phenylethyl)-1H-indene-1,3(2H)-dione **(3o)**. Obtained as a yellow solid (61.4 mg, 83% yield), eluting with 10% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 7.93 - 7.96 (q, 2H), 7.80 (d, J = 7.2 Hz, 2H), 7.73 - 7.75 (q, 2H), 7.45 - 7.49 (m, 1H), 7.31 - 7.35 (t, 2H), 7.13 - 7.18 (t, 1H), 6.95 - 6.97 (m, 2H), 6.72 - 6.74 (m, 1H), 4.08 (s, 2H), 3.69 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 199.9, 196.7, 160.1, 141.8, 136.7, 135.3, 135.1, 133.7, 130.1, 128.6, 128.3, 123.5, 119.1, 113.4, 112.9, 59.6, 55.3, 47.3; **HRMS** (ESI-TOF) m/z calcd for $C_{24}H_{19}O_4$ $[M + H]^+$ 371.1278, found 371.1276.



2-(3-Fluorophenyl)-2-(2-oxo-2-phenylethyl)-1H-indene-1,3(2H)-dione **(3p)**. Obtained as a yellow solid (47.3 mg, 66% yield), eluting with 10% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 8.02 - 8.05 (m, 2H), 7.83 - 7.88 (m, 4H), 7.54 - 7.57 (t, 1H), 7.39 - 7.43 (t, 2H), 7.22 - 7.32 (m, 3H), 6.95 - 7.00 (m, 1H), 4.15 (s, 2H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 199.5, 196.4, 163.0 (d, J = 246.0 Hz), 141.7, 137.6 (d, J = 7.3 Hz), 135.5, 135.0, 133.8, 130.6 (d, J = 8.2 Hz), 128.6, 128.3, 123.6, 122.6 (d, J = 3.0 Hz), 115.1 (d, J = 20.8 Hz), 114.4 (d, J = 23.2 Hz), 59.2, 47.3; **^{19}F NMR** (400 MHz, $CDCl_3$) δ -117.7; **HRMS** (ESI-TOF) m/z calcd for $C_{23}H_{16}FO_3$ $[M + H]^+$ 359.1078, found 359.1075.

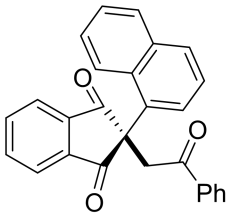


2-(2-Fluorophenyl)-2-(2-oxo-2-phenylethyl)-1H-indene-1,3(2H)-dione **(3q)**. Obtained as a yellow solid (43.7 mg, 61% yield), eluting with 10% EtOAc in PE (elution gradient); mp 217-219 °C; **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 8.03 - 8.07 (m, 2H), 7.89 - 7.91 (m, 2H), 7.83 - 7.87 (m, 2H), 7.54 - 7.58 (t, 1H), 7.40 - 7.44 (t, 2H), 7.34 - 7.39 (m, 1H), 7.23 - 7.29 (m, 1H), 7.09 - 7.13 (m, 1H), 6.98 - 7.03 (m, 1H), 4.38 (s, 2H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 199.2, 196.6, 160.7 (d, J = 249.0 Hz), 142.0 (d, J = 1.7 Hz), 135.2, 135.1, 133.8, 130.0 (d, J = 8.8 Hz), 129.5 (d, J = 4.0 Hz), 128.6, 128.3, 124.8 (d, J = 3.2 Hz), 123.4, 123.0 (d, J = 12.4 Hz), 117.0 (d, J = 23.2 Hz), 57.8 (d, J = 3.9 Hz), 44.1 (d, J = 3.7 Hz); **^{19}F NMR** (400 MHz, $CDCl_3$) δ -105.5; **HRMS** (ESI-TOF) m/z calcd for $C_{23}H_{16}FO_3$ $[M + H]^+$ 359.1078, found 359.1077.

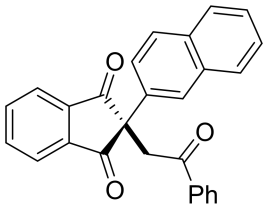


2-(3,4-Dimethylphenyl)-2-(2-oxo-2-phenylethyl)-1H-indene-1,3(

2H)-dione **(3r)**. Obtained as a yellow solid (66.2 mg, 90% yield), eluting with 10% EtOAc in PE (elution gradient); mp 221-223 °C; **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 7.99 - 8.02 (q, 2H), 7.87 (d, J = 7.2 Hz, 2H), 7.78 - 7.80 (q, 2H), 7.51 - 7.55 (t, 1H), 7.37 - 7.41 (t, 2H), 7.24 (d, J = 2.0 Hz, 1H), 7.18 - 7.20 (m, 1H), 7.08 (d, J = 8.0 Hz, 1H), 4.14 (s, 2H), 2.22 (s, 3H), 2.19 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 200.1, 196.8, 141.7, 137.6, 136.7, 135.2, 135.1, 133.7, 132.6, 130.3, 128.6, 128.3, 127.9, 124.3, 123.5, 59.4, 47.3, 19.9, 19.2; **HRMS** (ESI-TOF) m/z calcd for $C_{25}H_{21}O_3$ $[M + H]^+$ 369.1485, found 369.1482.

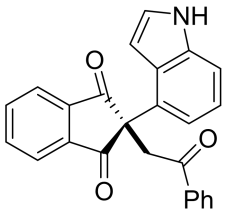


2-(Naphthalen-1-yl)-2-(2-oxo-2-phenylethyl)-1H-indene-1,3(2H)-dione **(3s)**. Obtained as a yellow liquid (60.1 mg,77% yield), eluting with 10% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 8.05 - 8.07 (q, 2H), 7.77 - 7.79 (m, 8H), 7.69 (d, J = 8.4 Hz, 1H), 7.53 - 7.57 (t, 1H), 7.39 - 7.47 (m, 4H), 4.26 (s, 2H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 200.0, 196.7, 141.7, 135.3, 135.0, 133.8, 133.2, 132.6, 132.4, 129.0, 128.6, 128.3, 128.1, 127.5, 126.6, 126.5, 126.3, 124.2, 123.6, 59.8, 47.3; **HRMS** (ESI-TOF) m/z calcd for $C_{27}H_{19}O_3$ $[M + H]^+$ 391.1329, found 391.1325.

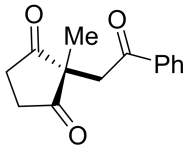


2-(Naphthalen-2-yl)-2-(2-oxo-2-phenylethyl)-1H-indene-1,3(2H)-dione **(3t)**. Obtained as a yellow solid (71.0 mg, 91% yield), eluting with 10% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 8.03 - 8.06 (q, 2H), 7.86 - 7.89 (m, 3H), 7.76 - 7.84 (m, 5H), 7.68 - 7.70 (q, 1H), 7.52 - 7.55 (t, 1H), 7.44 - 7.46 (m, 2H), 7.38 - 7.42 (t, 2H), 4.26 (s, 2H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 200.0, 196.6, 141.6, 135.3, 134.9, 133.8, 133.2, 132.6, 132.4, 129.0, 128.6, 128.3, 128.1,

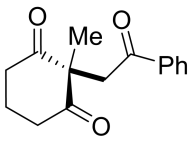
127.4, 126.6, 126.5, 126.3, 124.2, 123.6, 59.8, 47.3. **HRMS** (ESI-TOF) m/z calcd for $C_{27}H_{19}O_3$ $[M + H]^+$ 391.1329, found 391.1326.



2-(1H-indol-4-yl)-2-(2-oxo-2-phenylethyl)-1H-indene-1,3(2H)-dione (**3u**): Obtained as a yellow solid (66.7 mg, 88% yield), eluting with 10% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 8.46 (s, 1H), 7.99 - 8.01 (q, 2H), 7.89 (d, J = 7.2 Hz, 2H), 7.76 - 7.79 (q, 2H), 7.52 - 7.55 (t, 1H), 7.37 - 7.41 (t, 2H), 7.27 (d, J = 8.0 Hz, 1H), 7.22 - 7.25 (m, 2H), 7.01 - 7.05 (t, 1H), 6.92 (d, J = 7.2 Hz, 1H), 4.50 (s, 2H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 199.9, 197.3, 141.7, 137.0, 135.3, 135.1, 133.6, 128.6, 128.3, 126.9, 125.7, 124.7, 123.5, 122.1, 119.4, 111.7, 103.3, 62.1, 44.1; **HRMS** (ESI-TOF) m/z calcd for $C_{25}H_{18}NO_3$ $[M + H]^+$ 380.1281, found 380.1283.

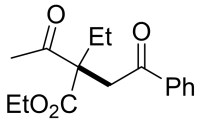


2-Methyl-2-(2-oxo-2-phenylethyl)cyclopentane-1,3-dione (**3v**): Obtained as a yellow solid (30.8 mg, 67% yield), eluting with 10% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 7.80 (d, J = 7.6 Hz, 2H), 7.48 - 7.52 (t, 1H), 7.34 - 7.38 (t, 2H), 3.65 (s, 2H), 2.93 - 3.03 (m, 2H), 2.79 - 2.90 (m, 2H), 1.10 (s, 2H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 216.5, 197.4, 134.7, 133.9, 128.6, 128.3, 52.4, 47.6, 34.7, 19.5; **HRMS** (ESI-TOF) m/z calcd for $C_{14}H_{15}O_3$ $[M + H]^+$ 231.1016, found 231.1018.

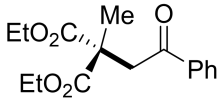


2-Methyl-2-(2-oxo-2-phenylethyl)cyclohexane-1,3-dione (**3w**): Obtained as a yellow solid (34.6 mg, 71% yield), eluting with 10% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 7.92 (d, J = 8.0 Hz, 2H), 7.54

- 7.57 (t, 1H), 7.42 - 7.46 (t, 2H), 3.81 (s, 2H), 2.70 - 2.84 (m, 4H), 2.31 - 2.42 (m, 1H), 2.11 - 2.18 (m, 1H), 1.35 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 210.7, 197.8, 135.6, 133.5, 128.5, 128.2, 60.0, 46.0, 37.7, 23.2, 17.5; **HRMS** (ESI-TOF) m/z calcd for $C_{15}H_{17}O_3$ $[M + H]^+$ 245.1172, found 245.1171.



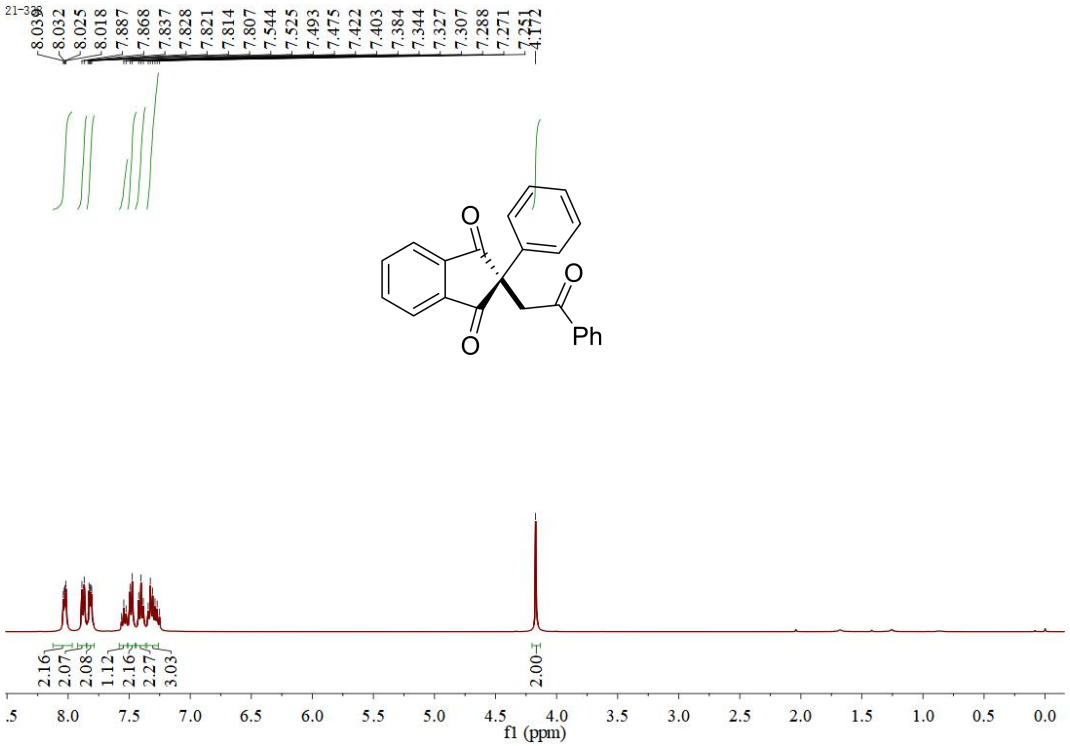
Ethyl-2-acetyl-2-ethyl-4-oxo-4-phenylbutanoate (**3x**): Obtained as a yellow solid (18.8 mg, 34% yield), eluting with 10% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 7.98 (d, J = 8.0 Hz, 2H), 7.56 - 7.59 (t, 1H), 7.45 - 7.48 (t, 2H), 4.18 - 4.23 (q, 2H), 3.61 - 3.74 (m, 2H), 2.38 (s, 3H), 2.04 - 2.22 (m, 2H), 1.21 - 1.25 (t, 3H), 0.82 - 0.86 (t, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 210.7, 197.8, 135.6, 133.5, 128.5, 128.2, 60.0, 46.0, 37.7, 23.2, 17.5; 13C NMR (101 MHz, CDCl3) δ 205.8, 197.4, 171.9, 136.5, 133.3, 128.6, 128.0, 61.6, 61.4, 41.1, 27.3, 26.8, 14.0, 9.0; **HRMS** (ESI-TOF) m/z calcd for $C_{16}H_{21}O_4$ $[M + H]^+$ 277.1434, found 277.1433.

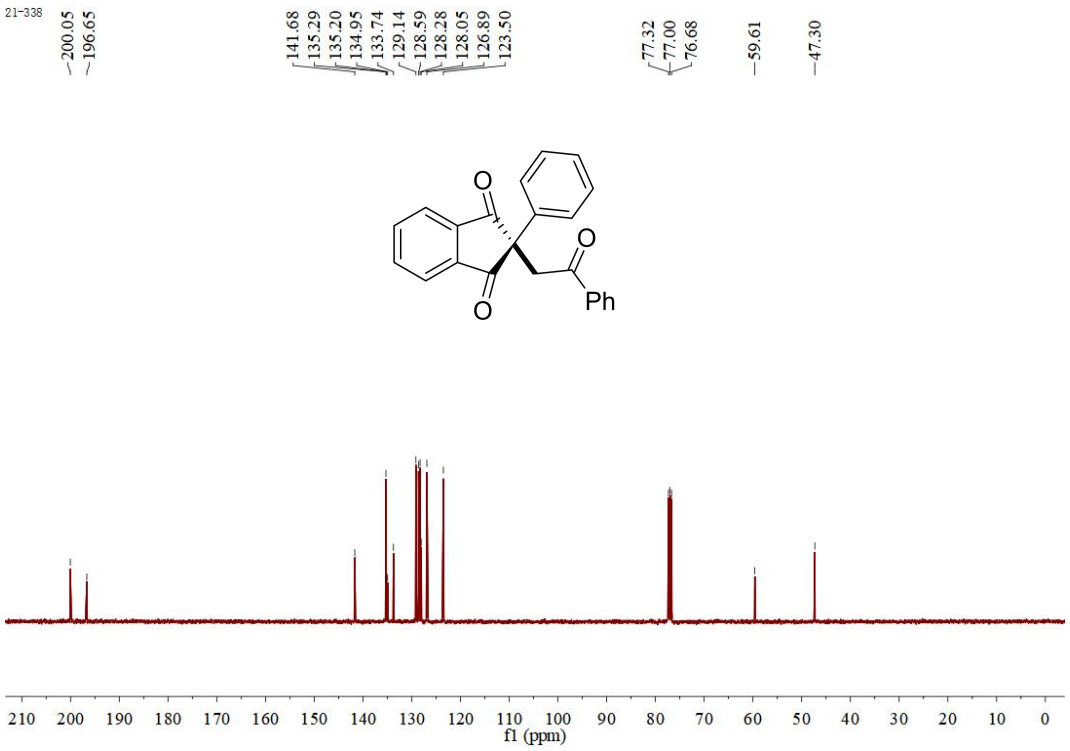


Diethyl 2-methyl-2-(2-oxo-2-phenylethyl)malonate (**3y**): Obtained as a yellow solid (38.5 mg, 66% yield), eluting with 10% EtOAc in PE (elution gradient); **^{1}H NMR** (400 MHz, $CDCl_3$) δ ppm: 7.96 - 7.98 (t, 2H), 7.56 - 7.59 (t, 1H), 7.45 - 7.49 (t, 2H), 4.19 - 4.25 (q, 4H), 3.68 (s, 2H), 1.61 (s, 3H), 1.23 - 1.29 (t, 6H); **^{13}C NMR** (100 MHz, $CDCl_3$) δ ppm: 196.4, 171.5, 136.6, 133.3, 128.6, 127.9, 61.5, 51.4, 44.2, 20.5, 13.9; **HRMS** (ESI-TOF) m/z calcd for $C_{16}H_{21}O_5$ $[M + H]^+$ 293.1384, found 293.1385.

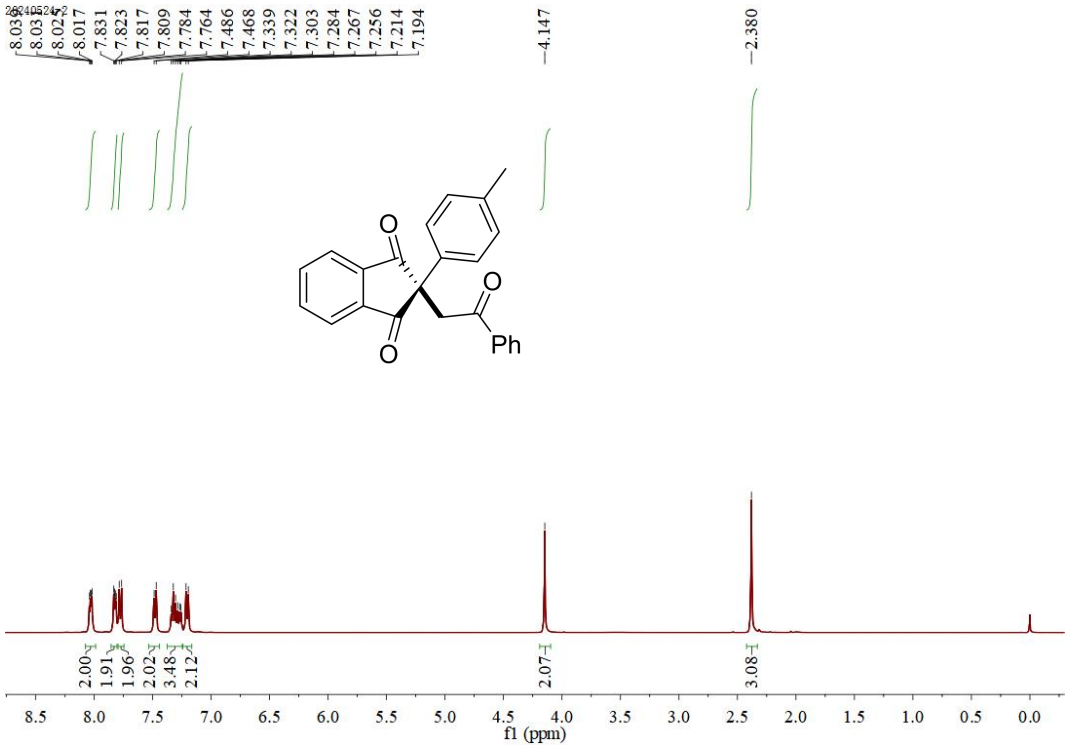
Copies of ^{1}H and ^{13}C NMR spectra of products

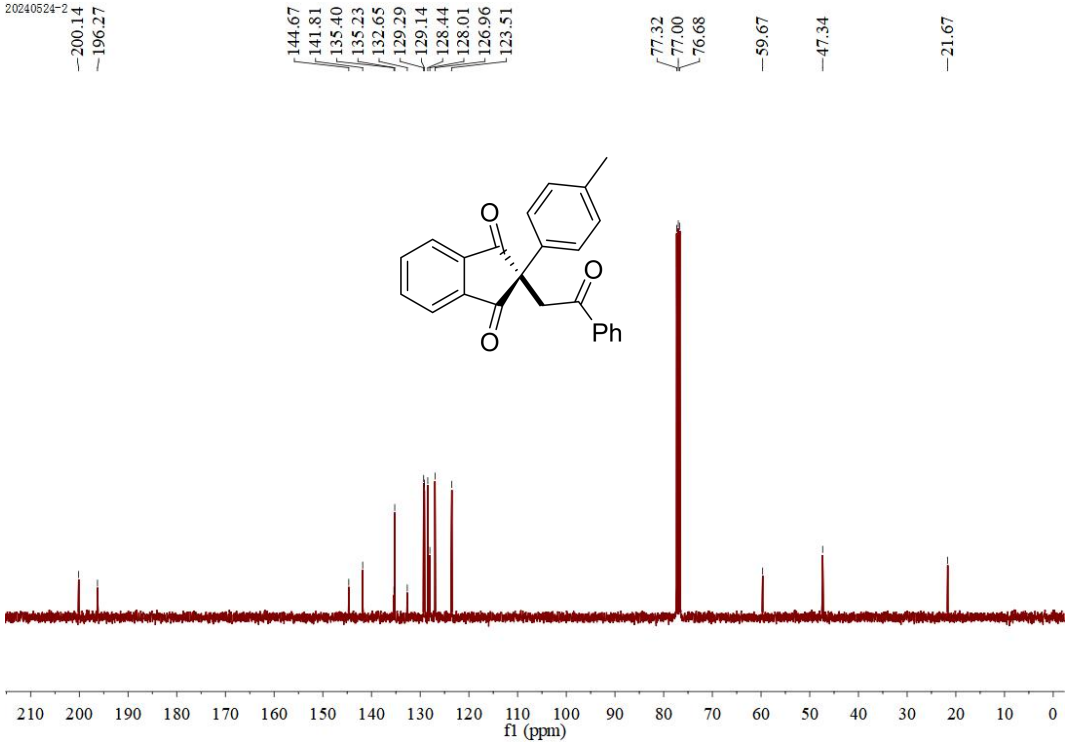
^{1}H NMR and ^{13}C NMR of 3a



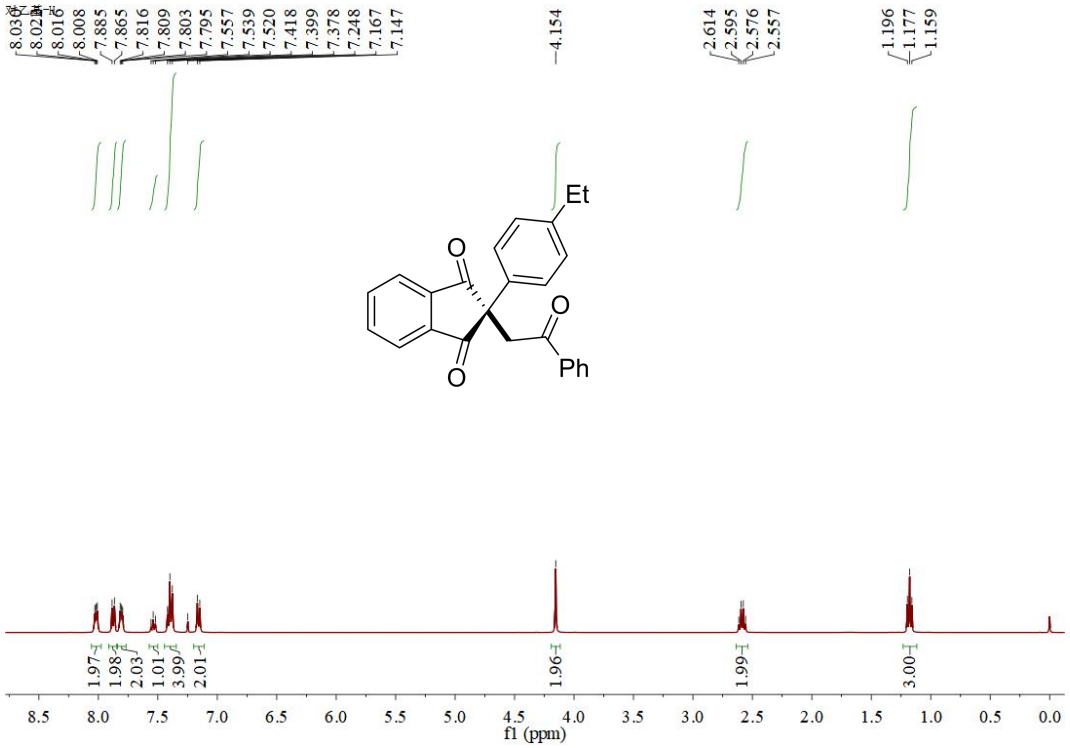


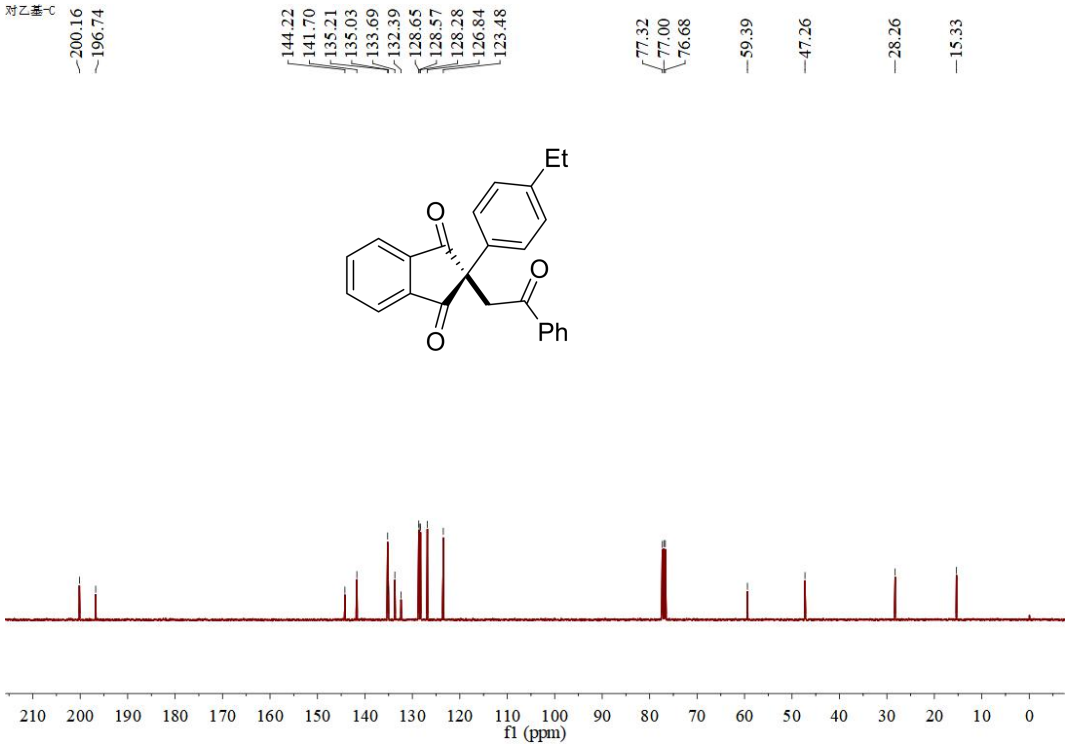
^{1}H NMR and ^{13}C NMR of 3b



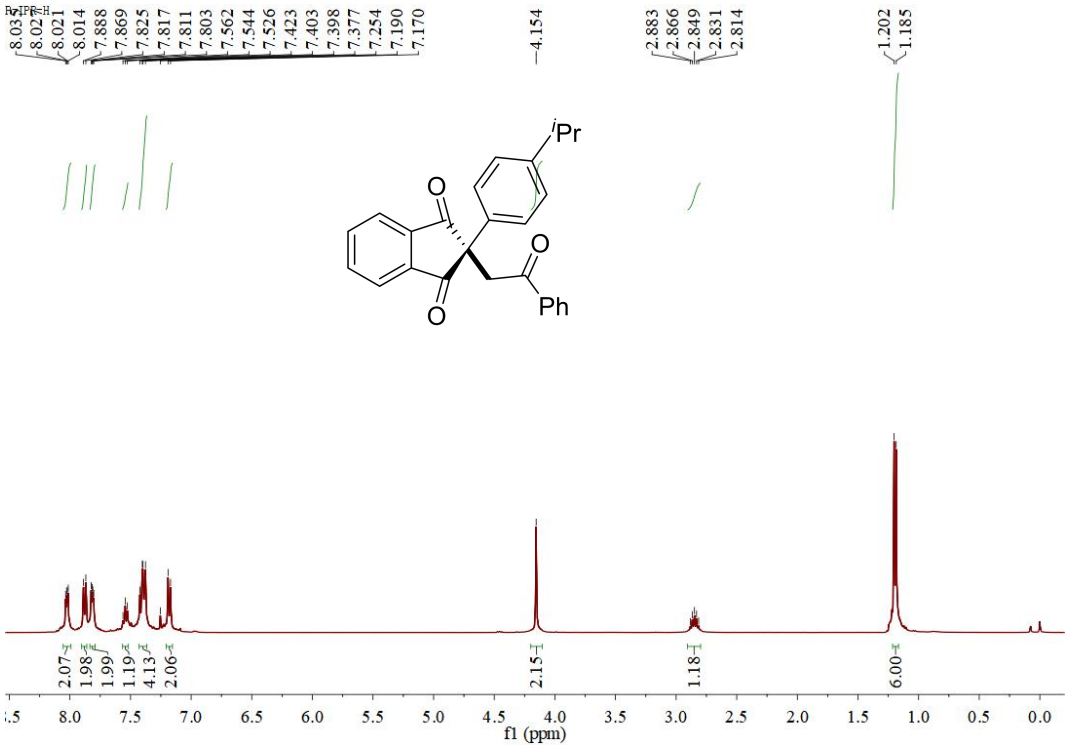


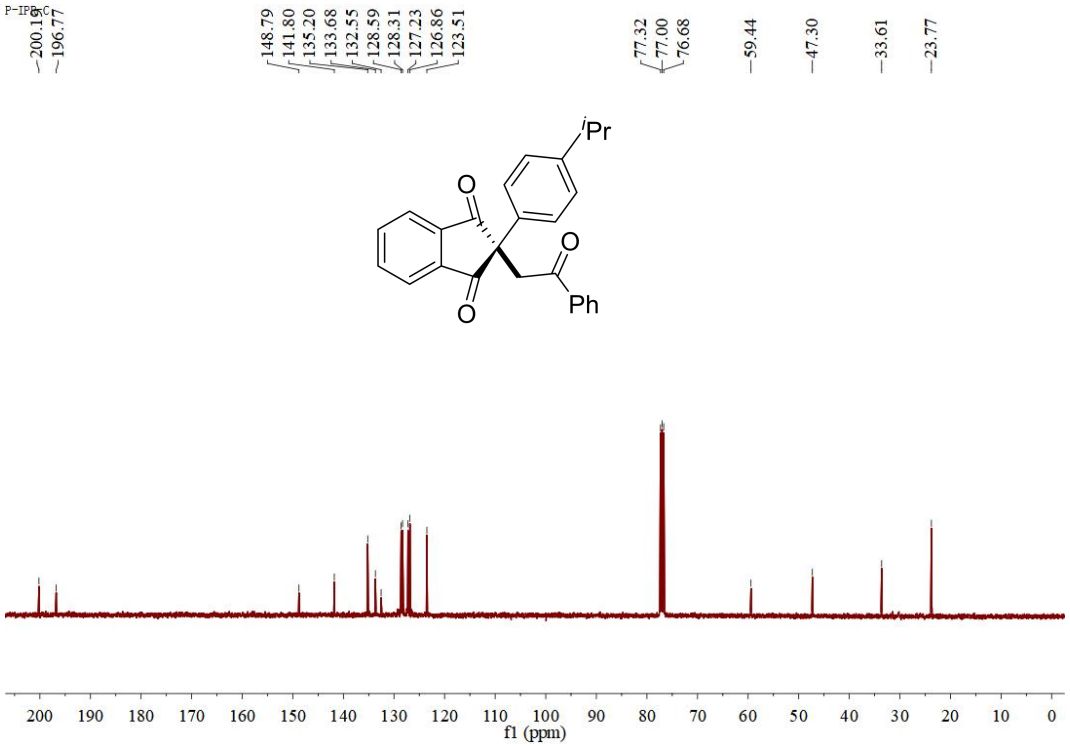
^{1}H NMR and ^{13}C NMR of 3c



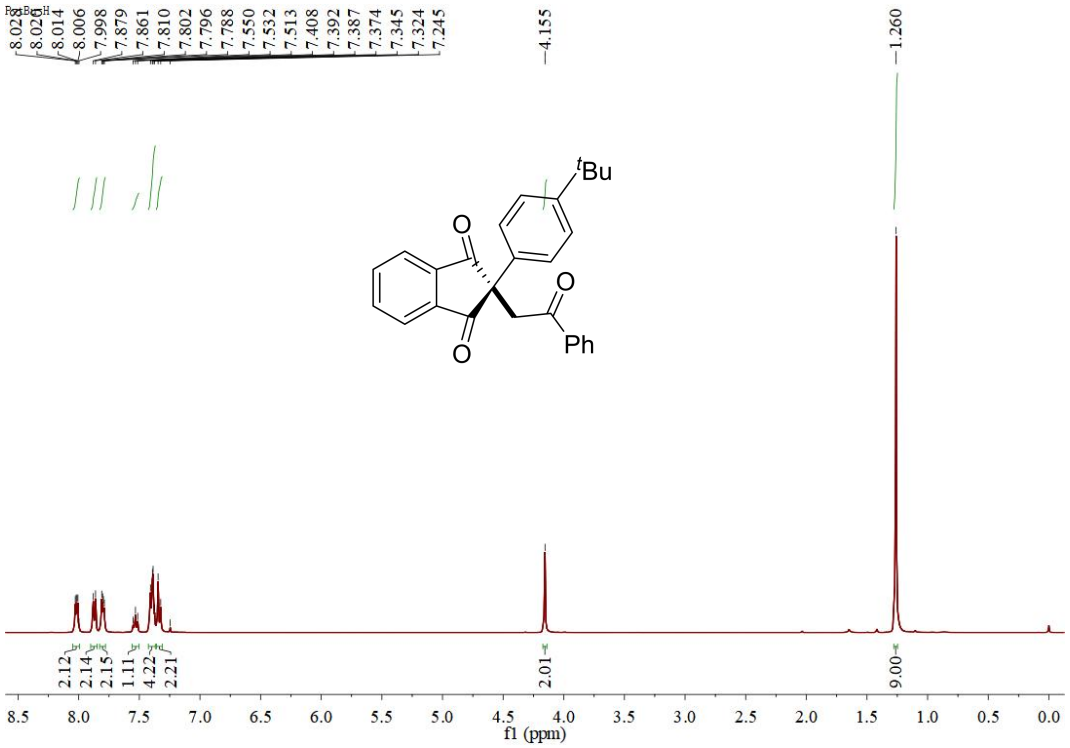


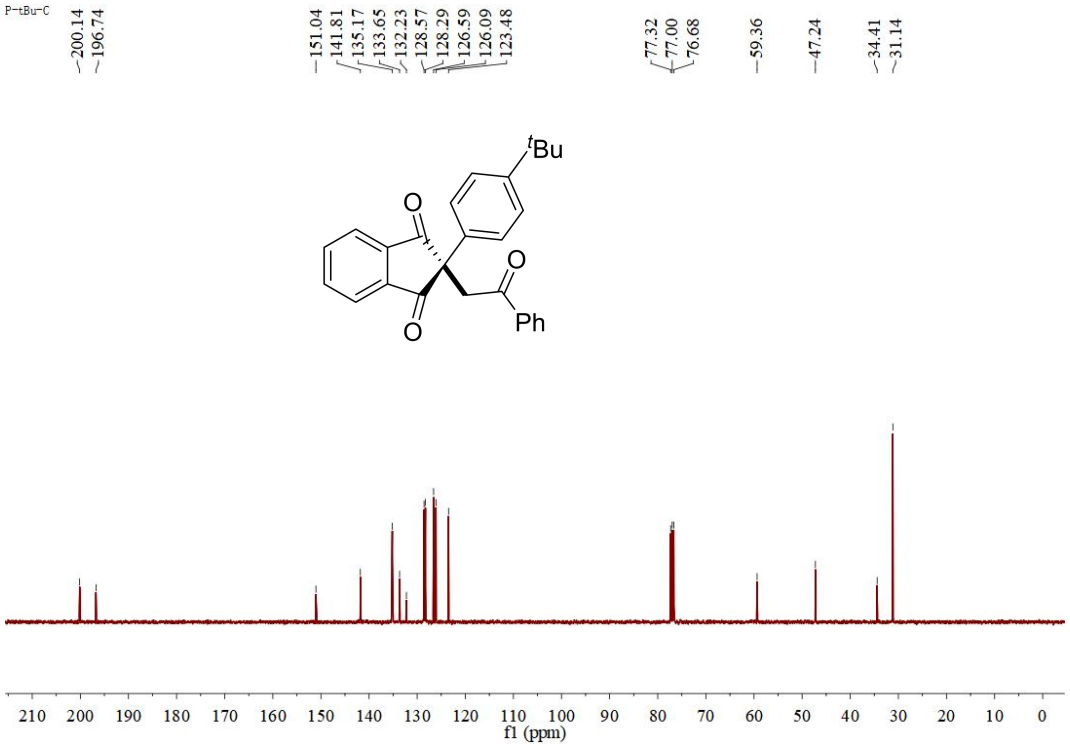
^{1}H NMR and ^{13}C NMR of 3d



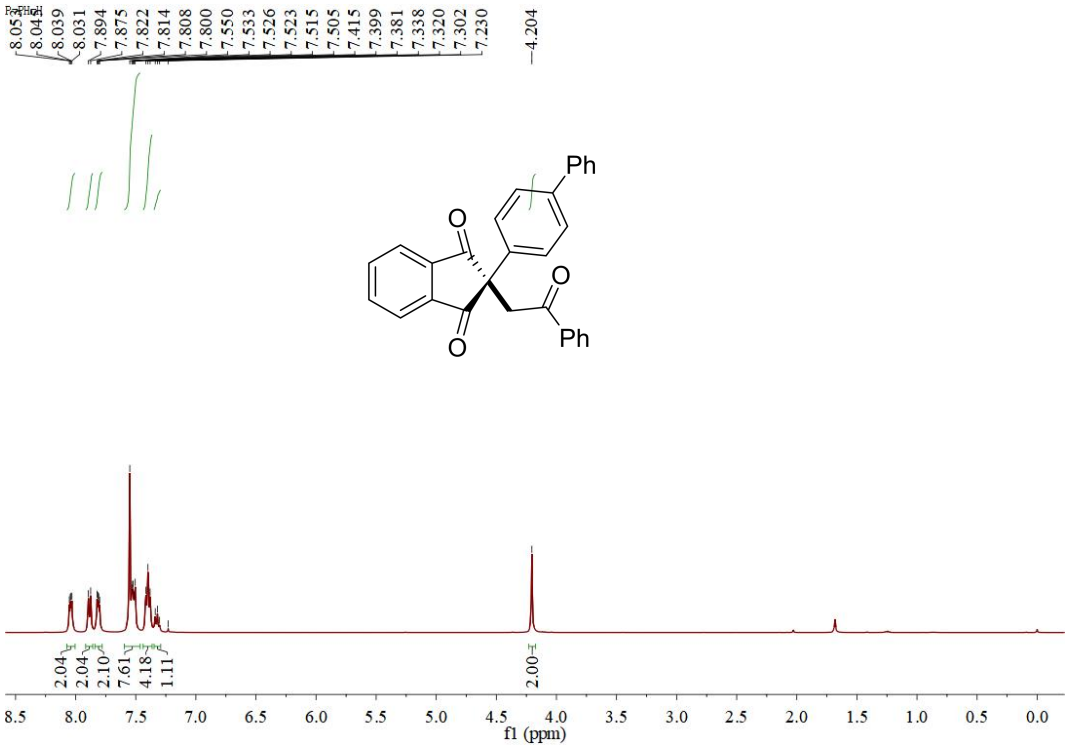


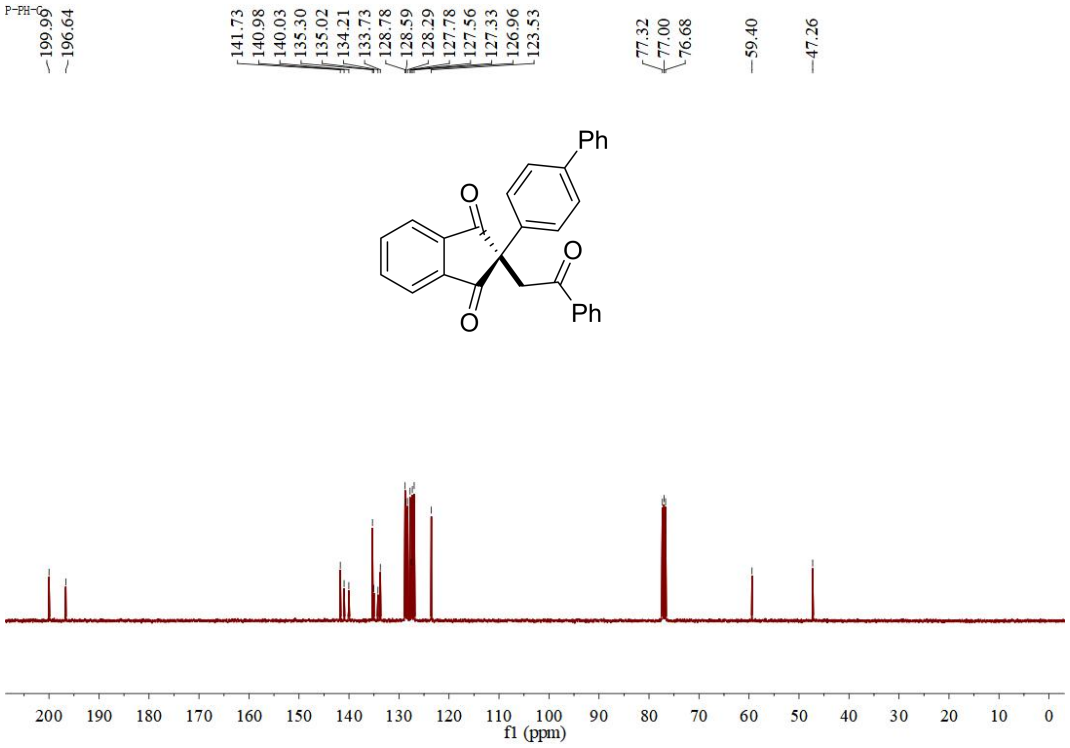
^{1}H NMR and ^{13}C NMR of 3e



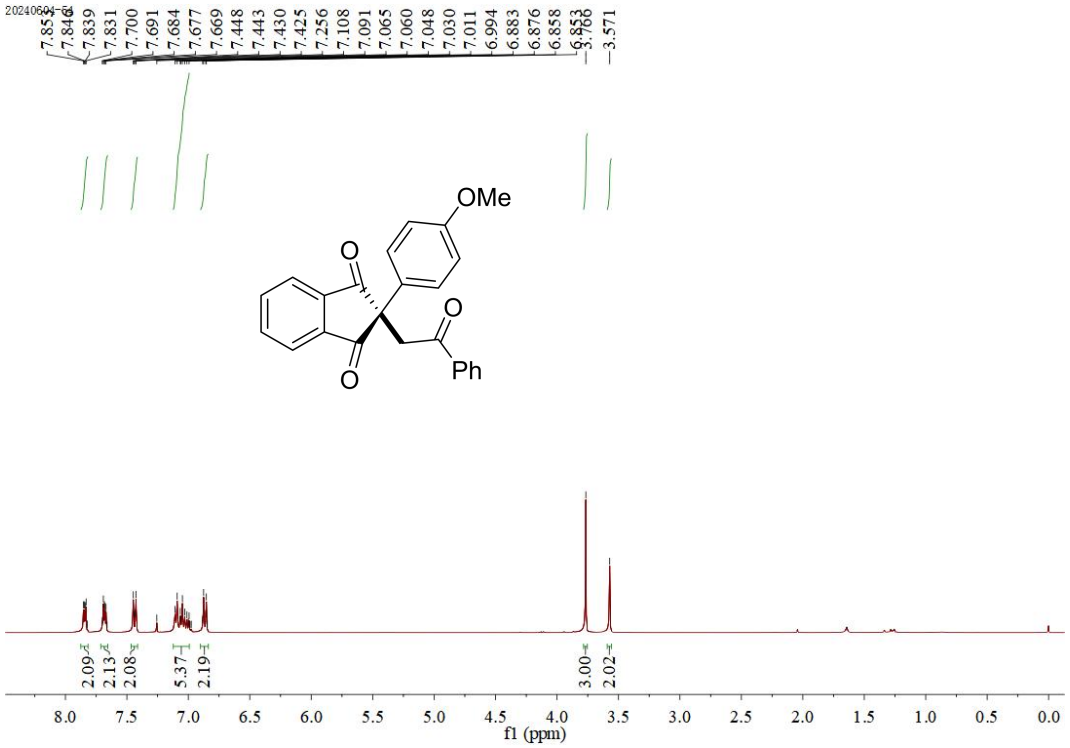


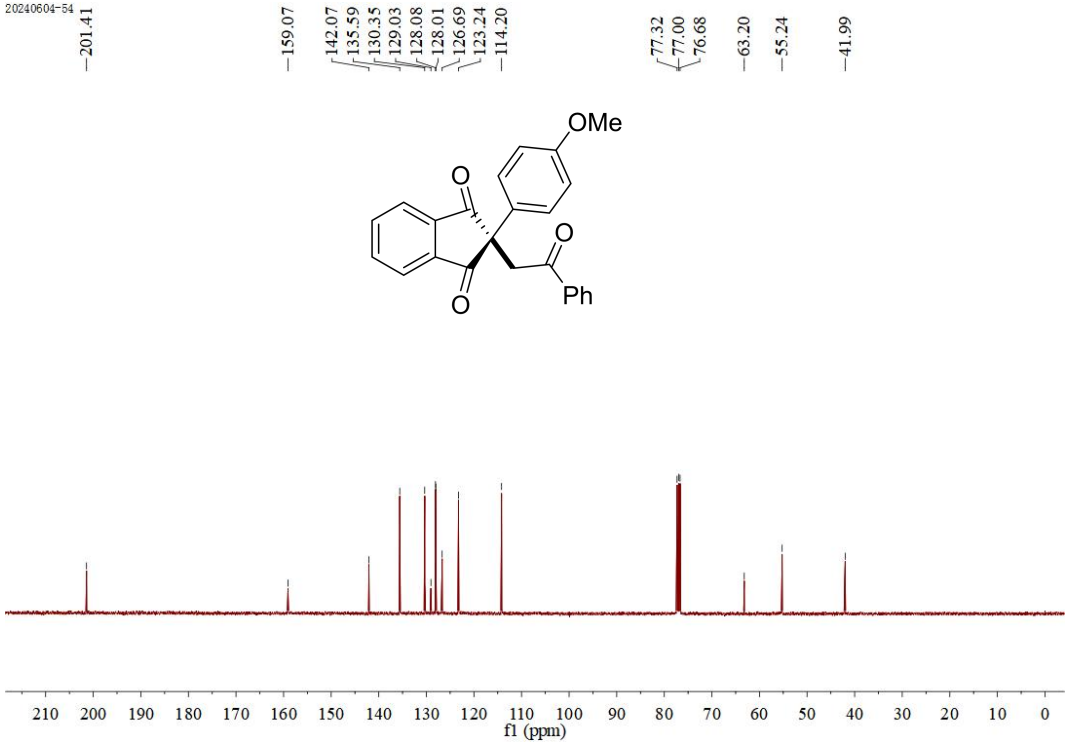
^{1}H NMR and ^{13}C NMR of 3f



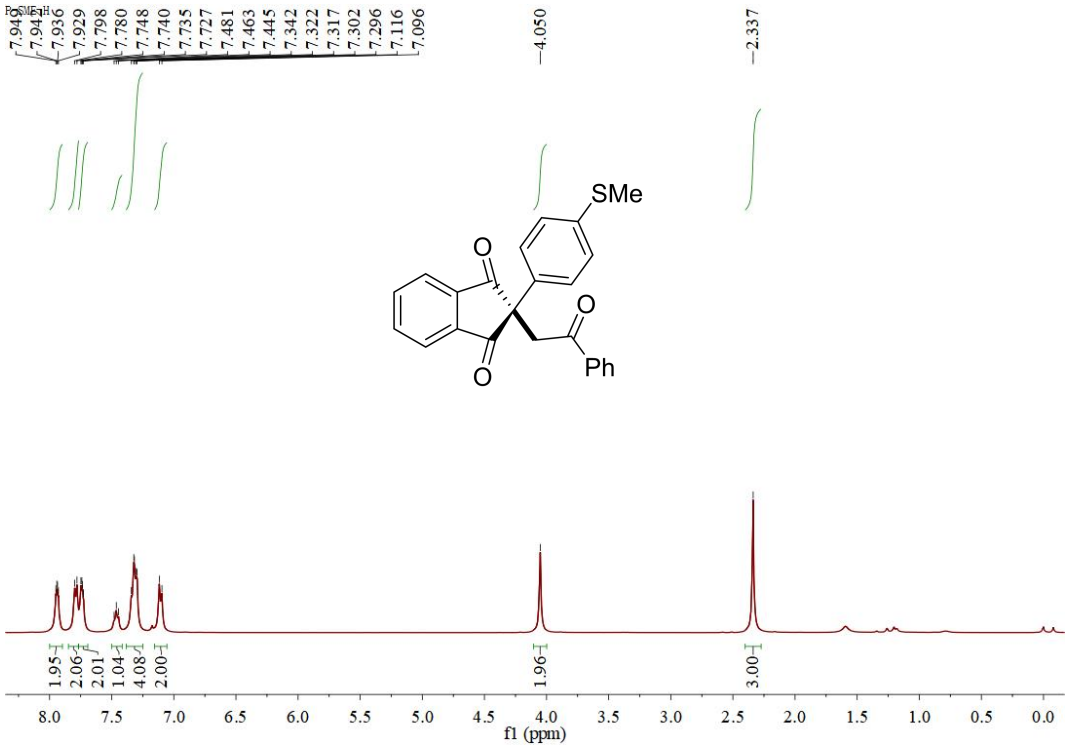


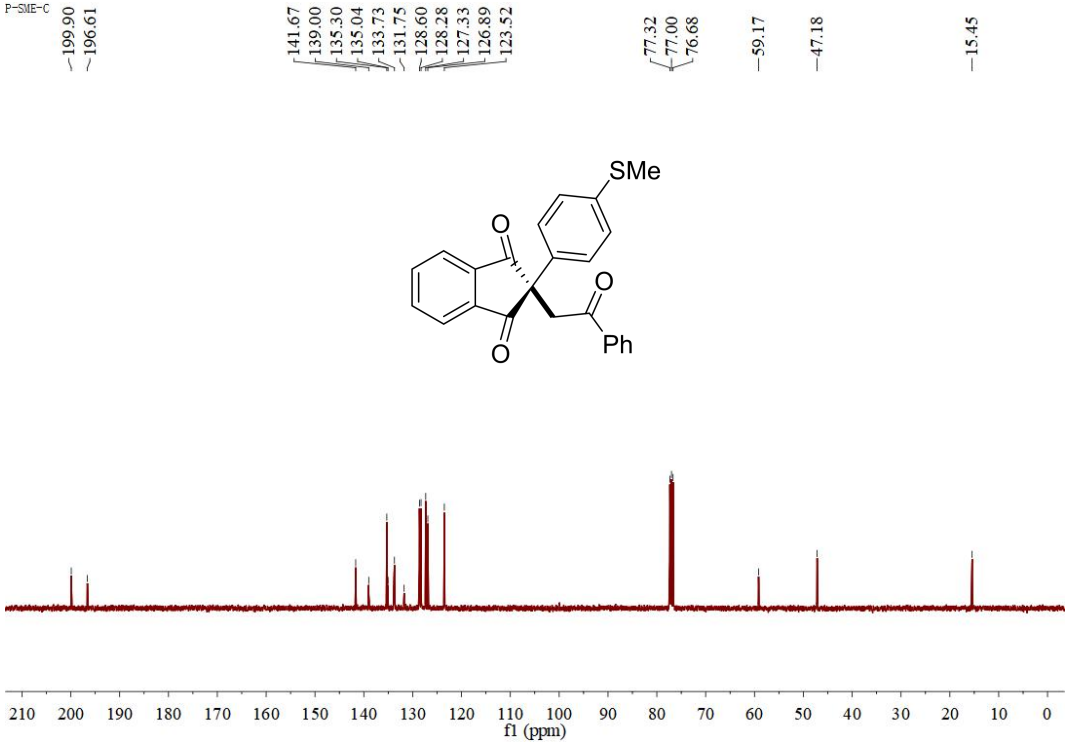
^{1}H NMR and ^{13}C NMR of 3g



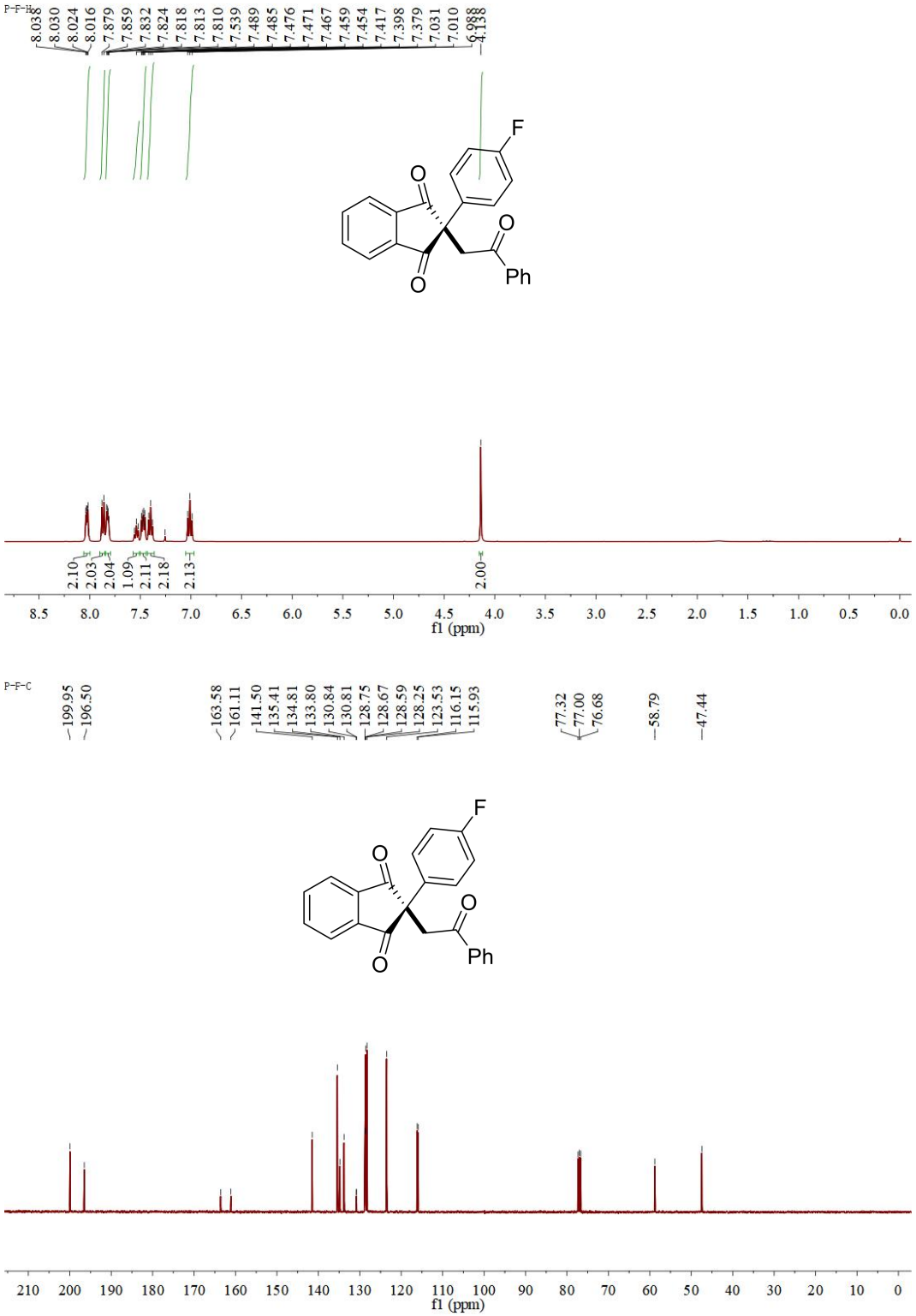


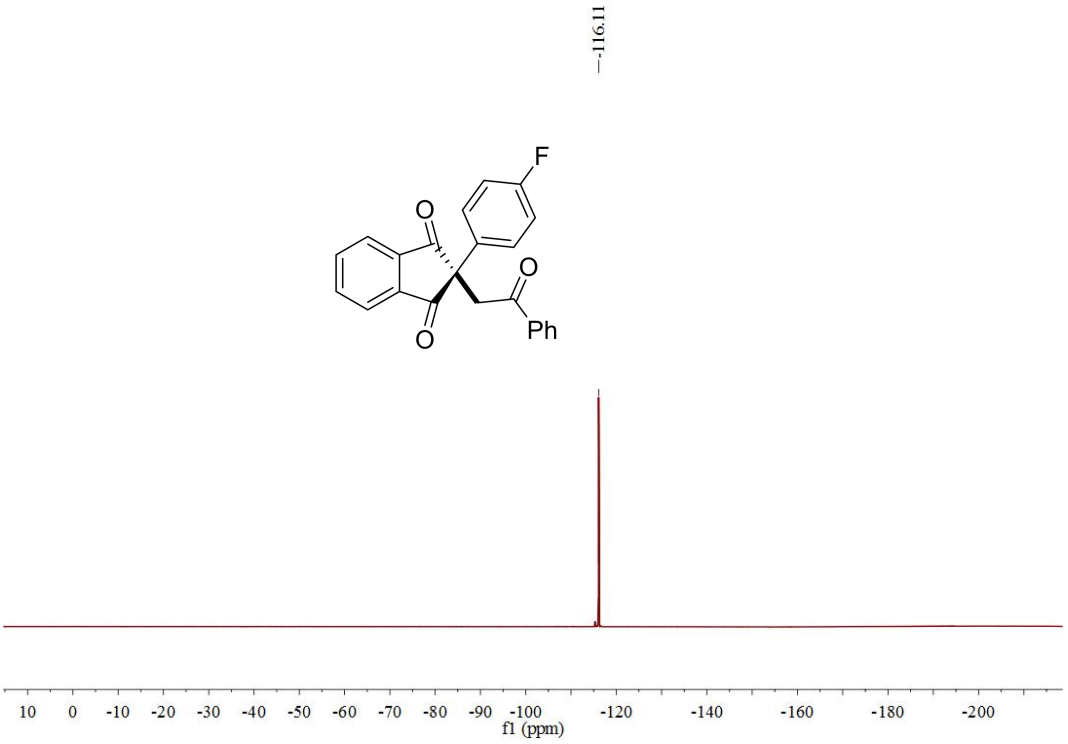
^{1}H NMR and ^{13}C NMR of 3h





^{1}H NMR, ^{13}C NMR and ^{19}F NMR of 3i

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-40
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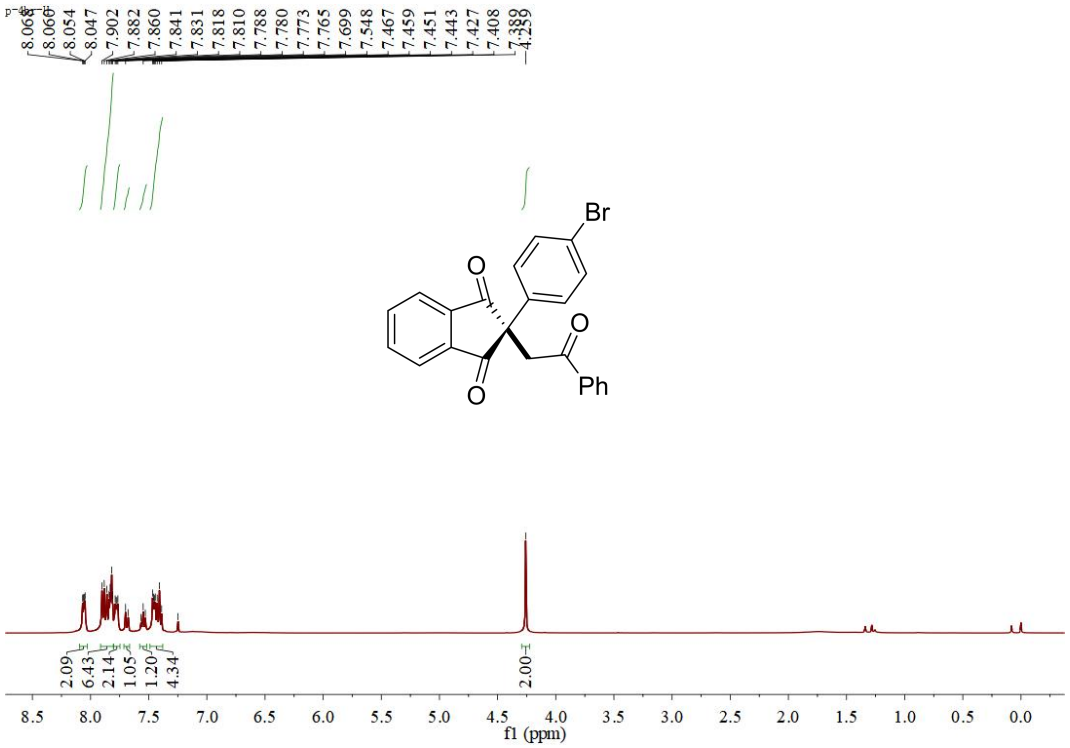
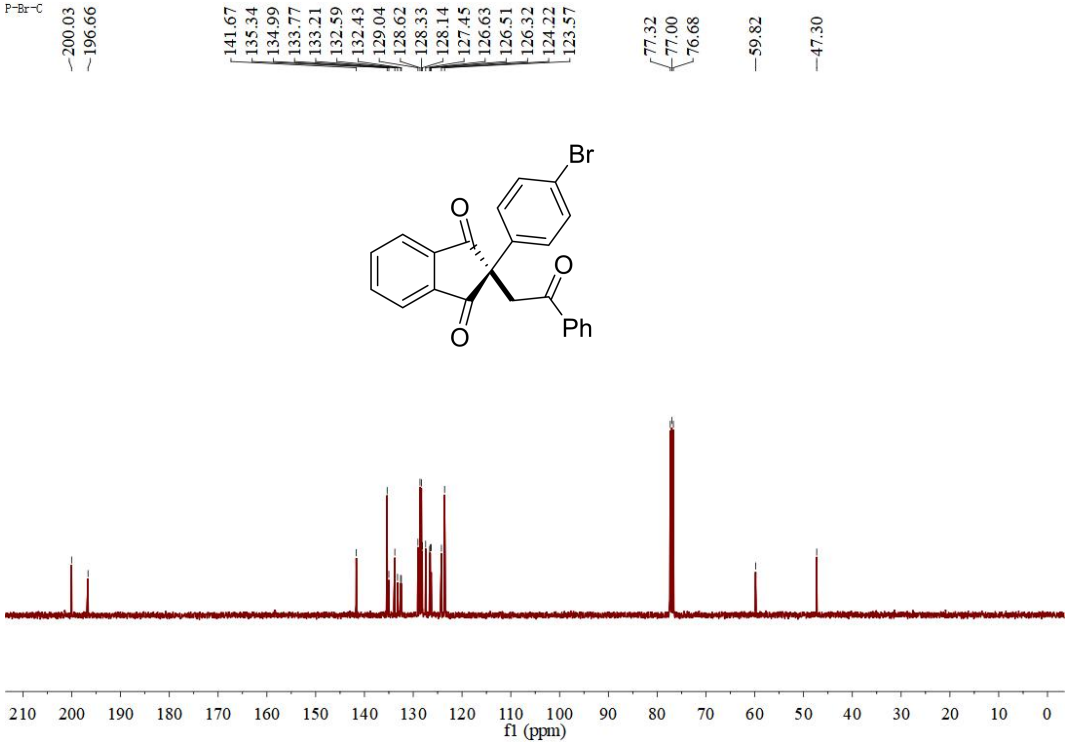
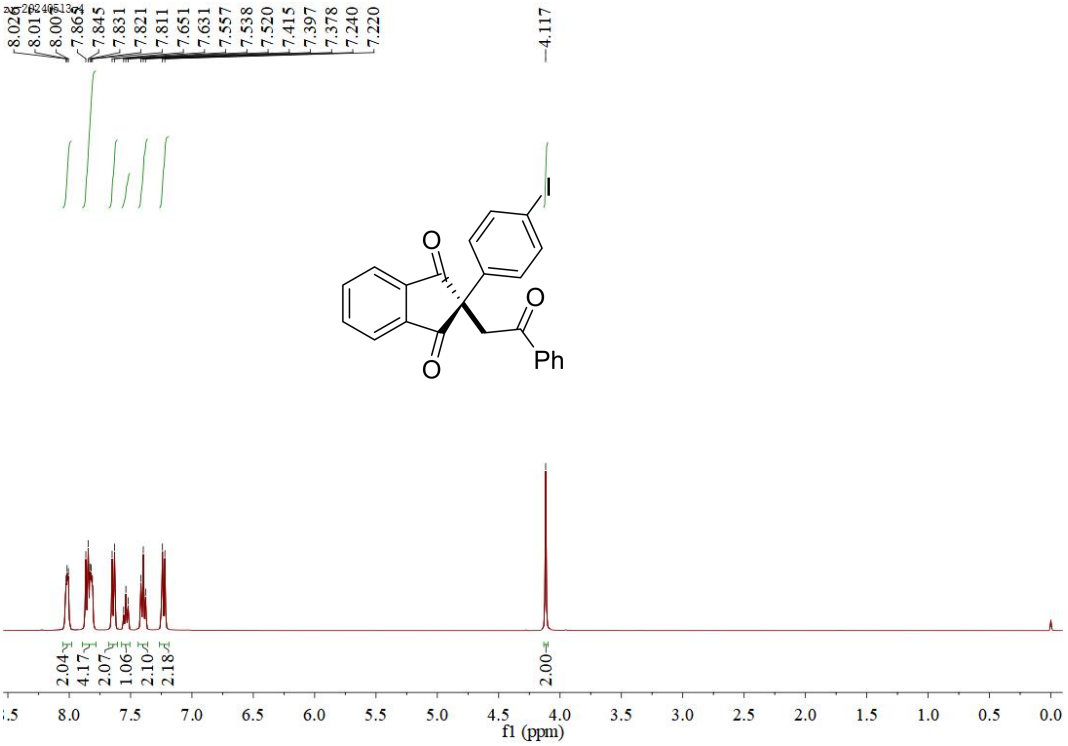
f1 (ppm)

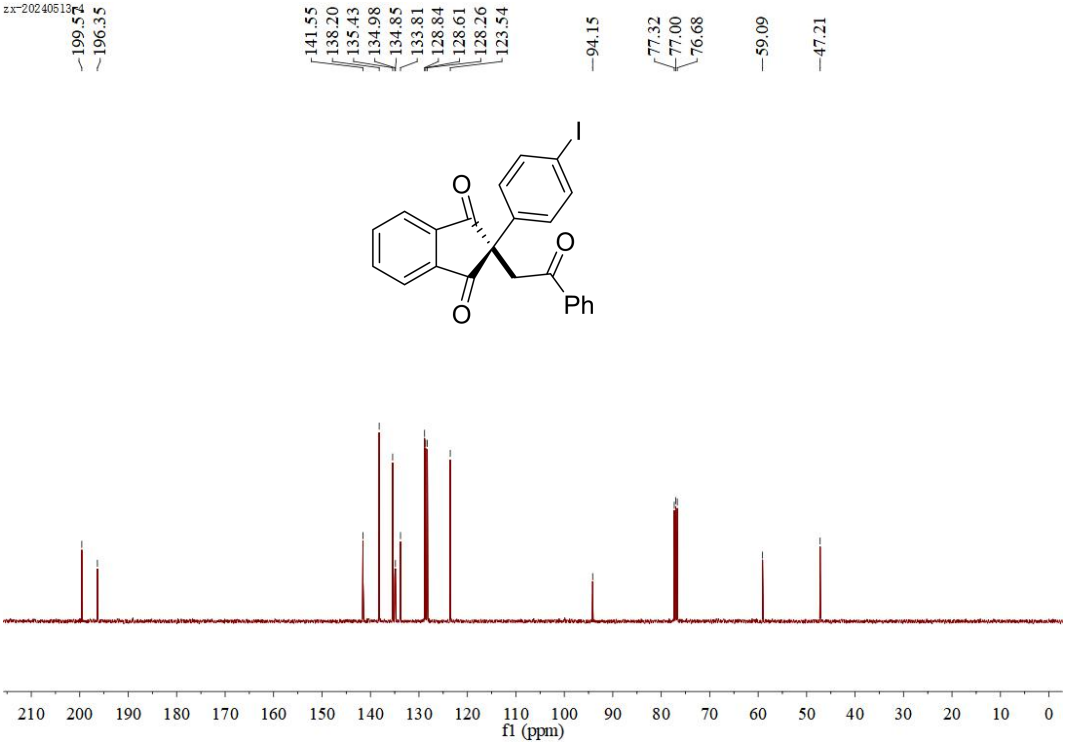
^{1}H NMR and ^{13}C NMR of 3j



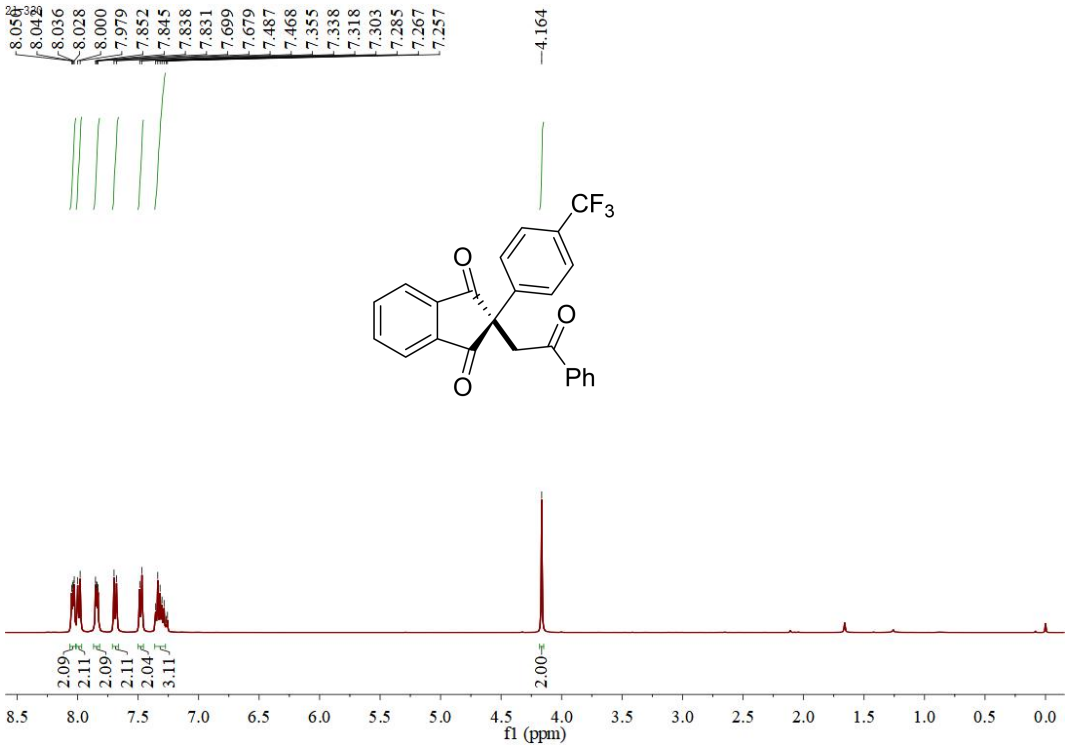


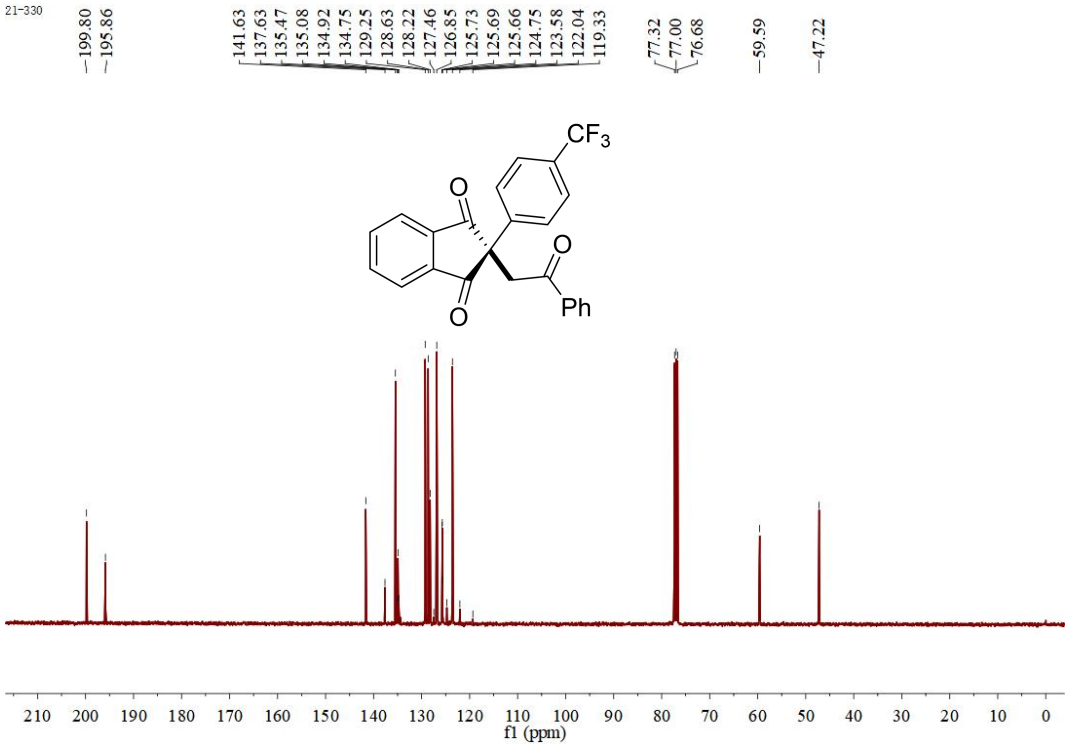
^{1}H NMR and ^{13}C NMR of 3k

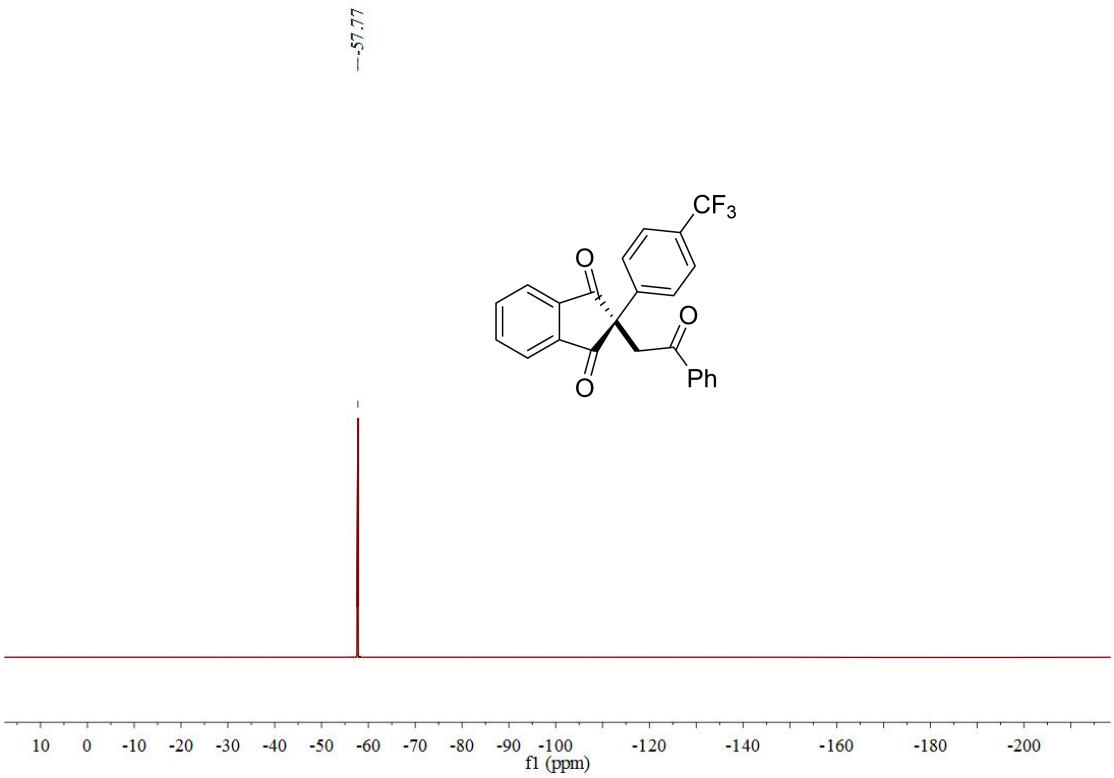




^{1}H NMR, ^{13}C NMR and ^{19}F NMR of 3l



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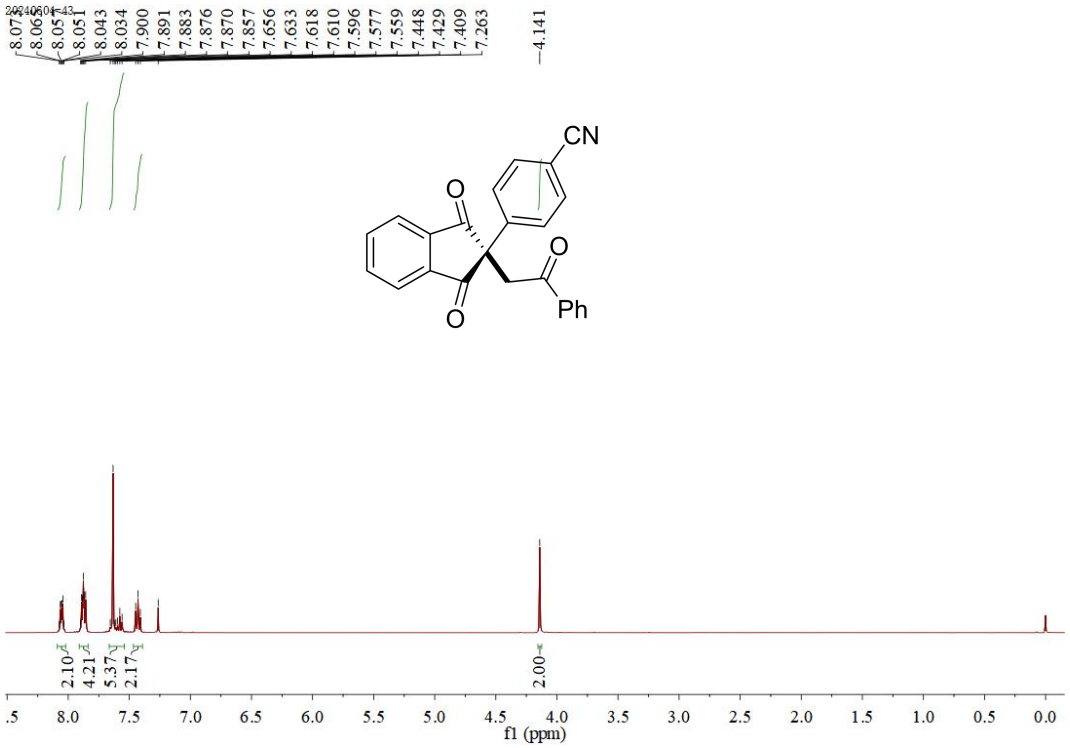
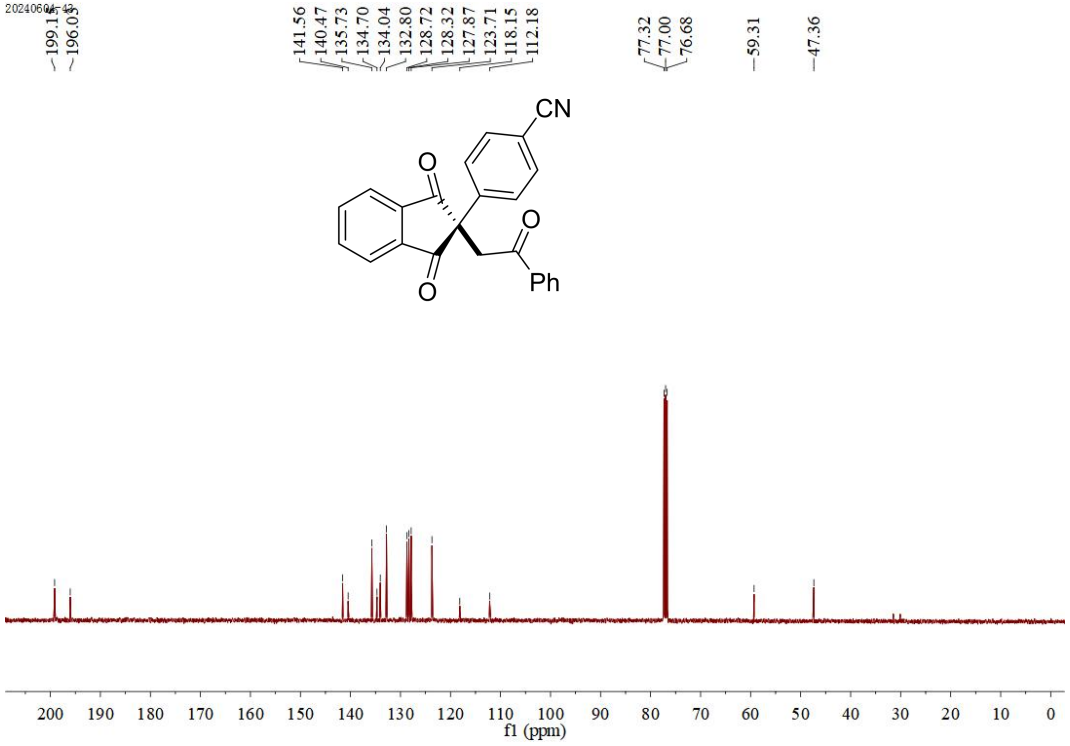
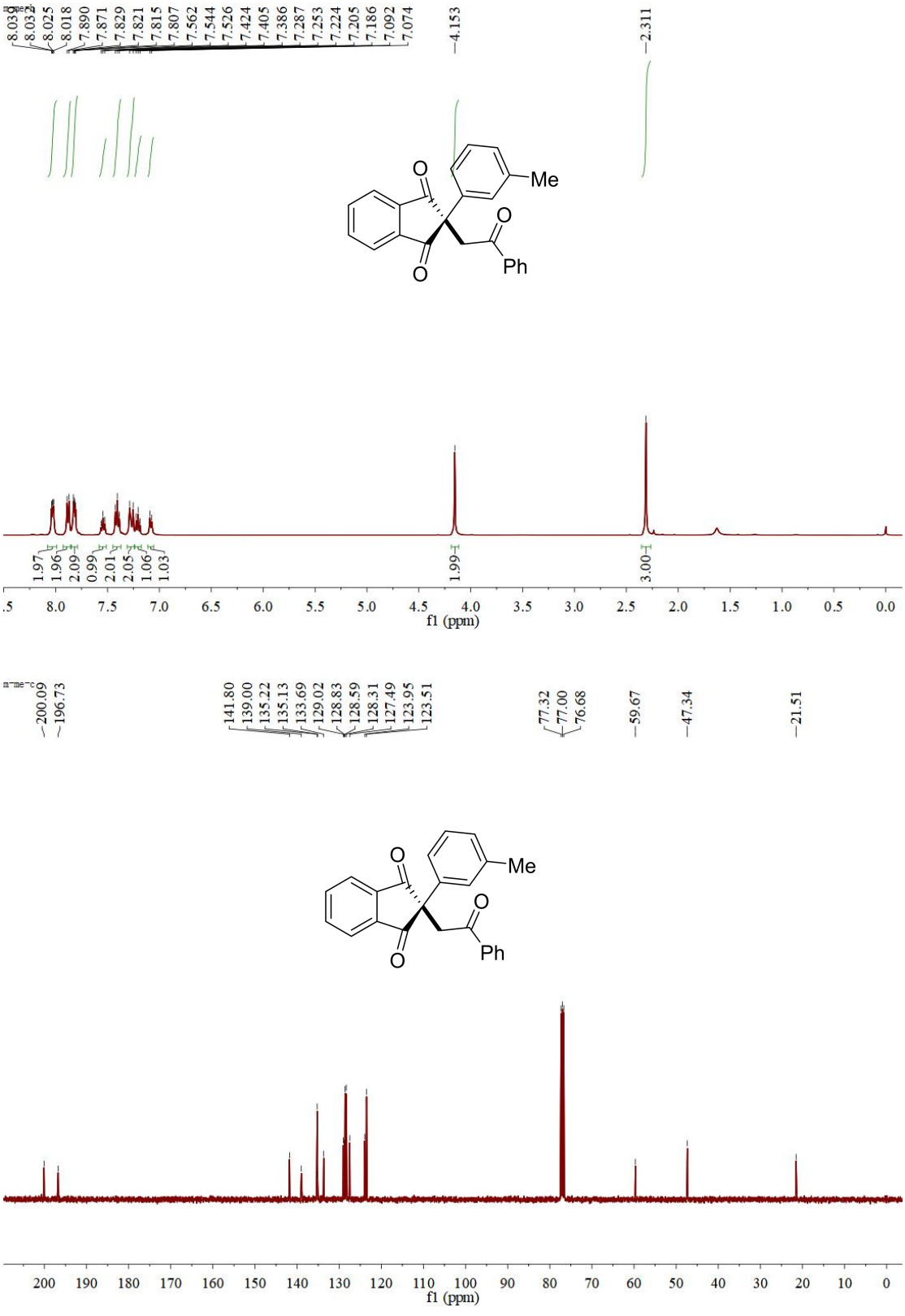
O
O
O
Ph
10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -120 -140 -160 -180 -200
f1 (ppm)

^{1}H NMR and ^{13}C NMR of 3m

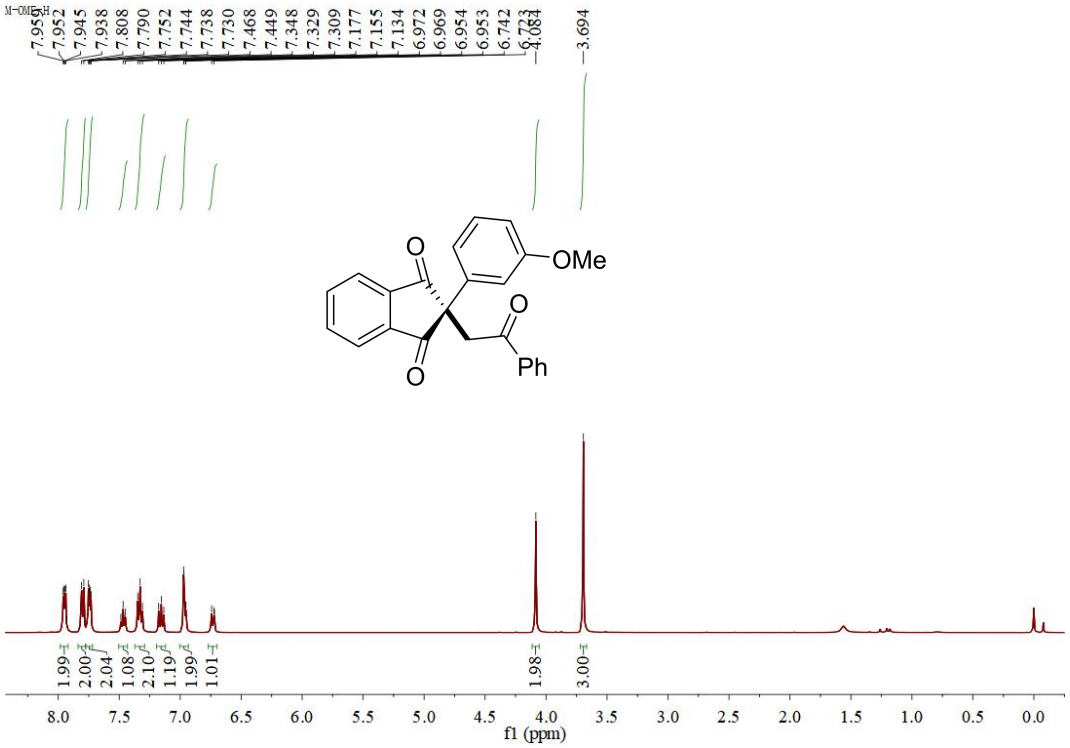


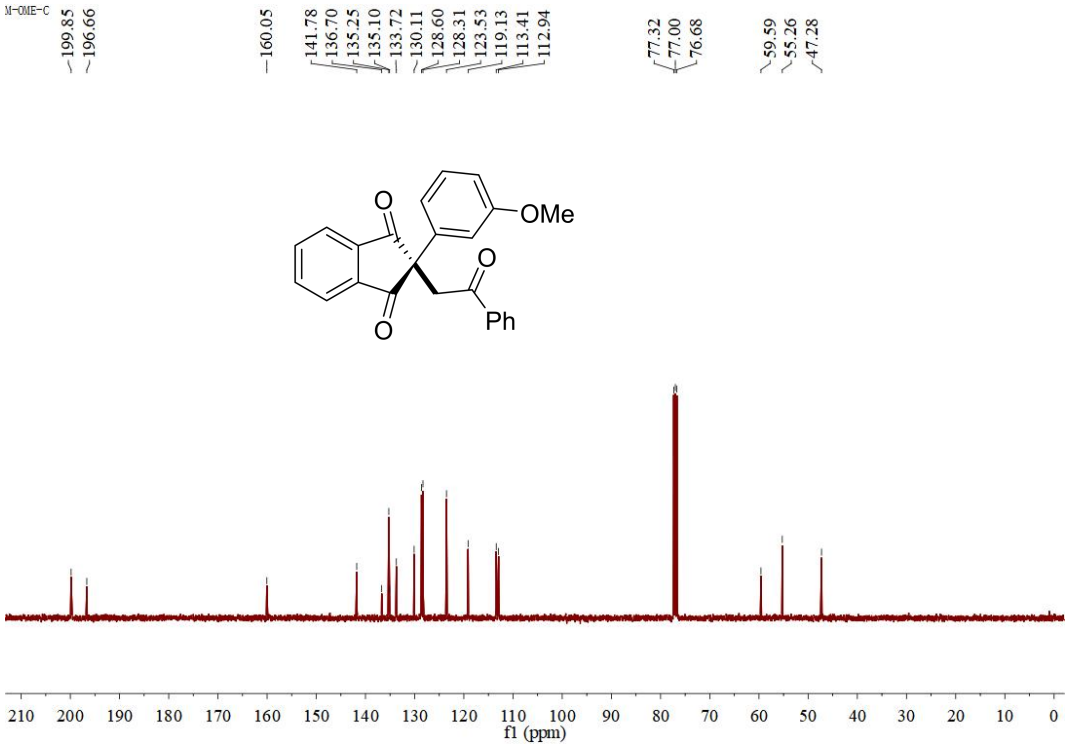


^{1}H NMR and ^{13}C NMR of 3n

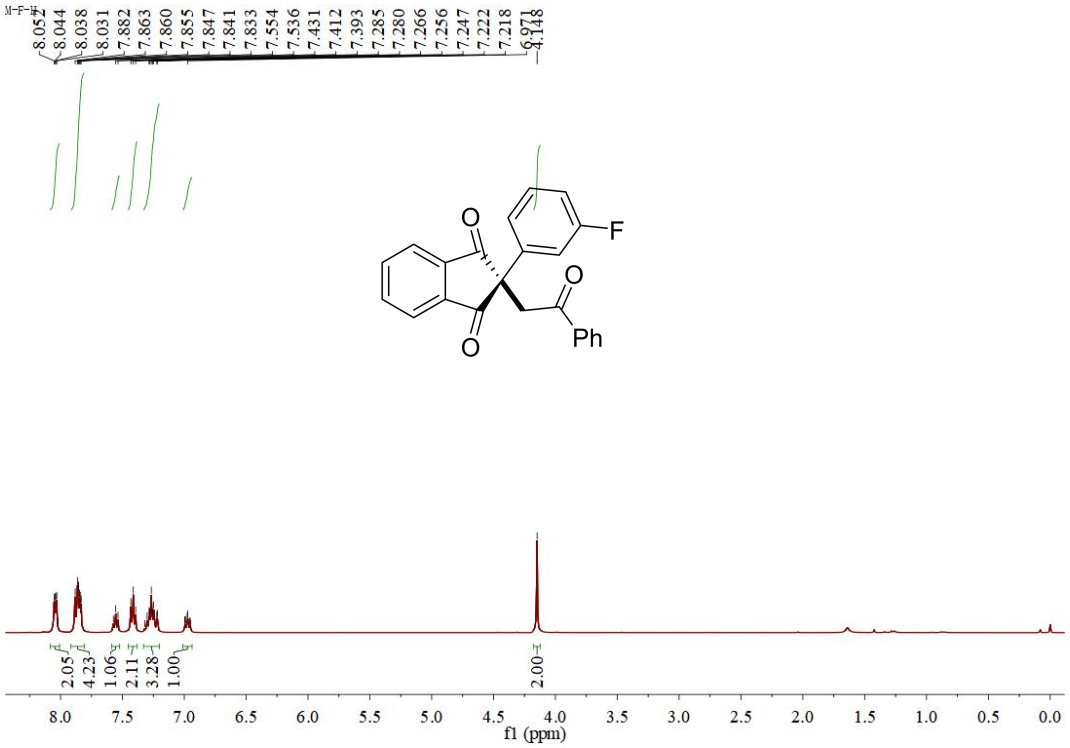


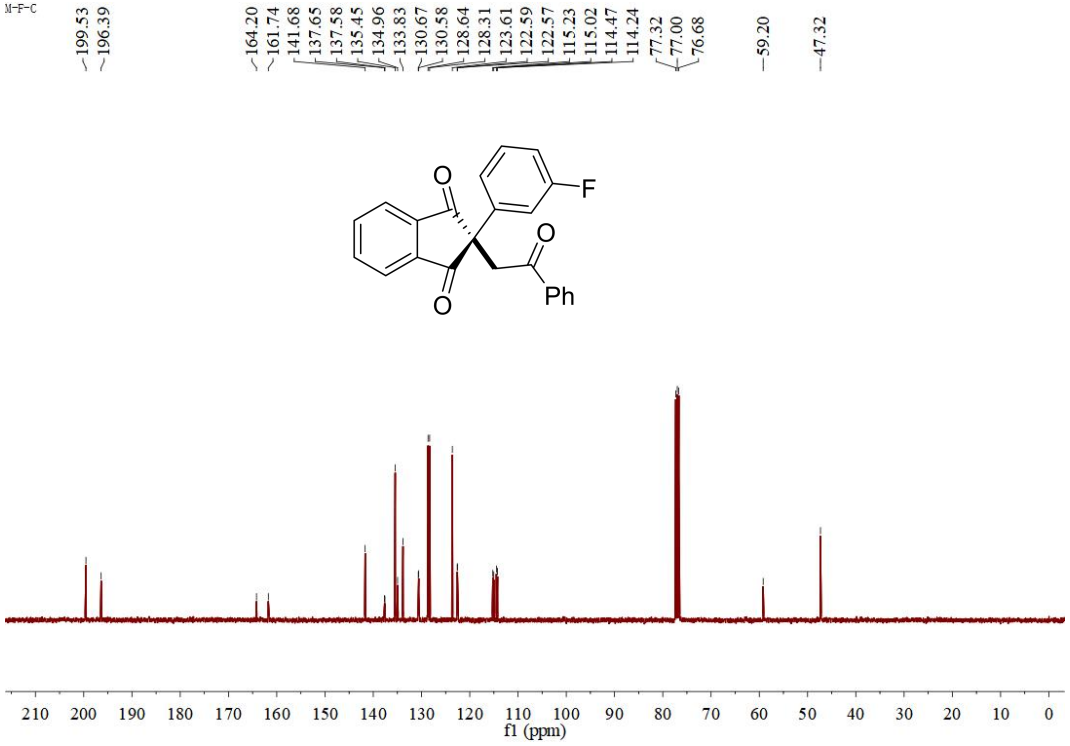
^{1}H NMR and ^{13}C NMR of 3o

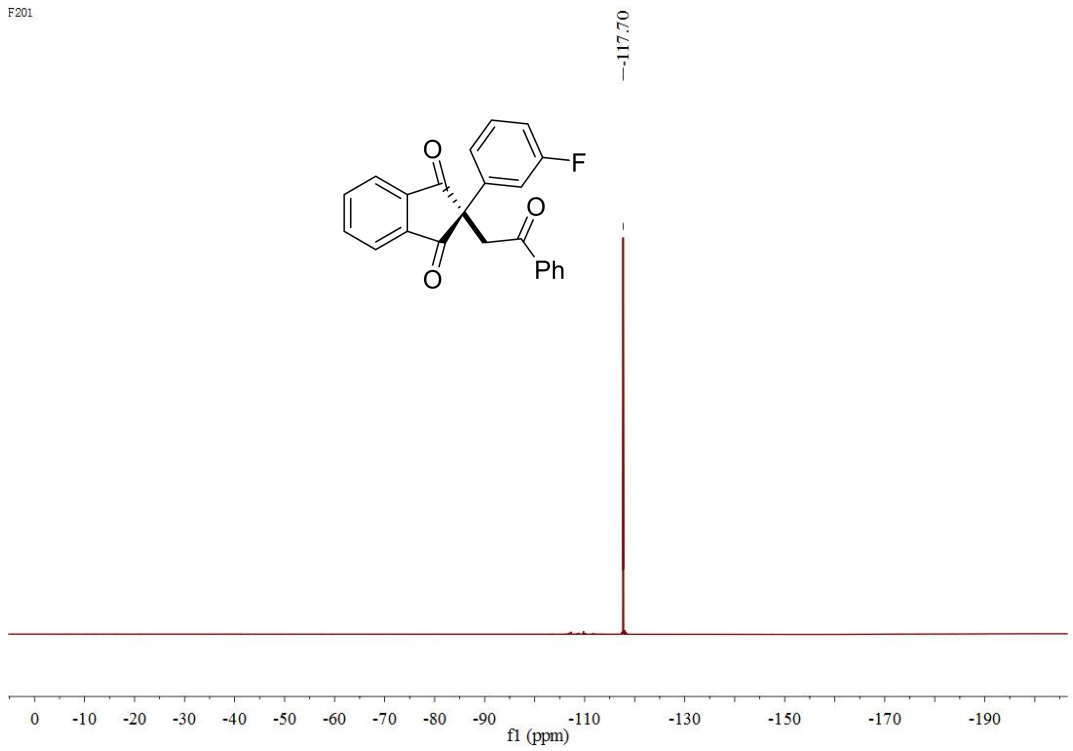




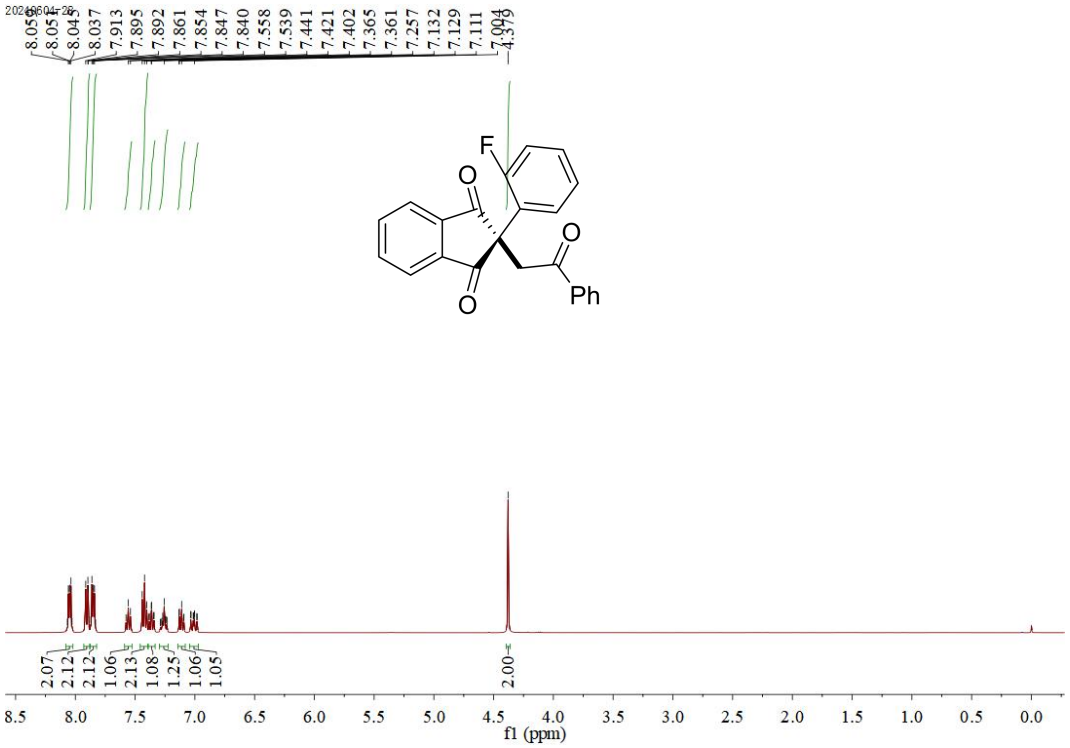
^{1}H NMR, ^{13}C NMR and ^{19}F NMR of 3p

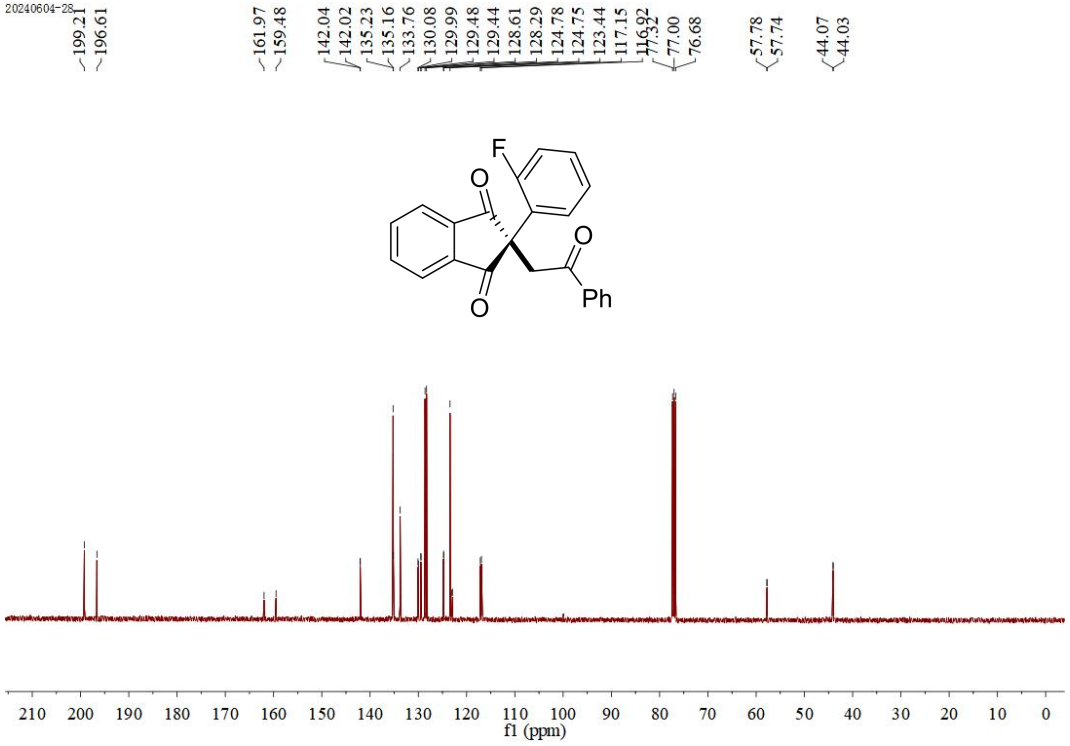


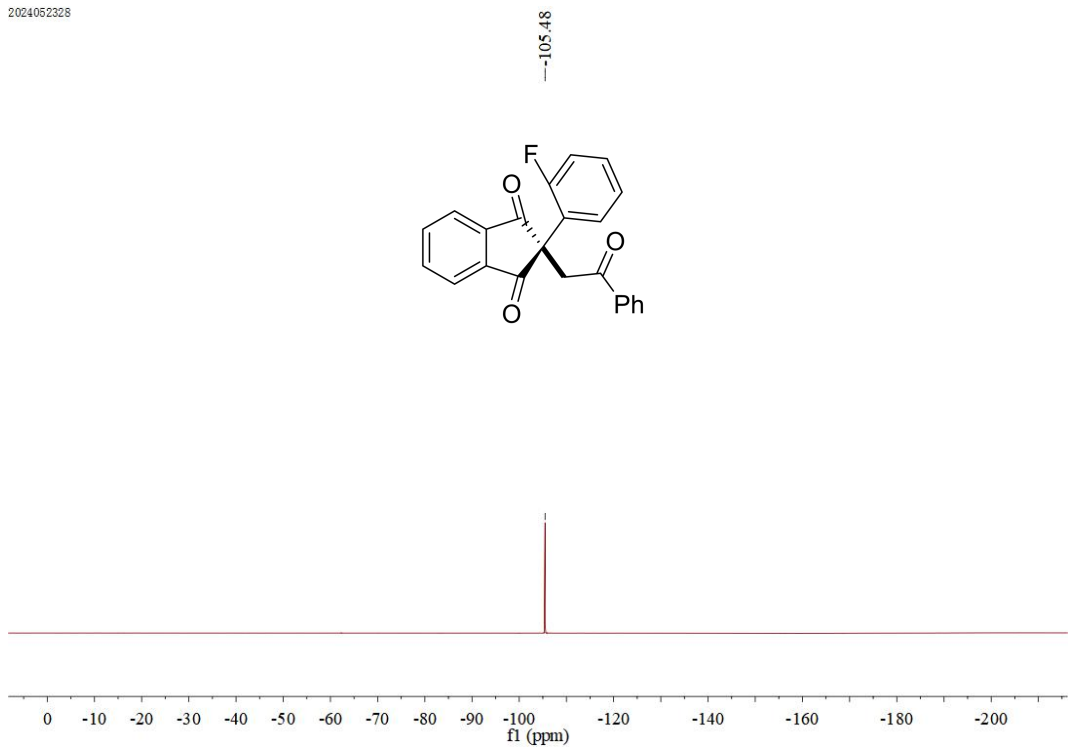



F201
-117.70
O
F
O
O
Ph
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-110
-130
-150
-170
-190
f1 (ppm)

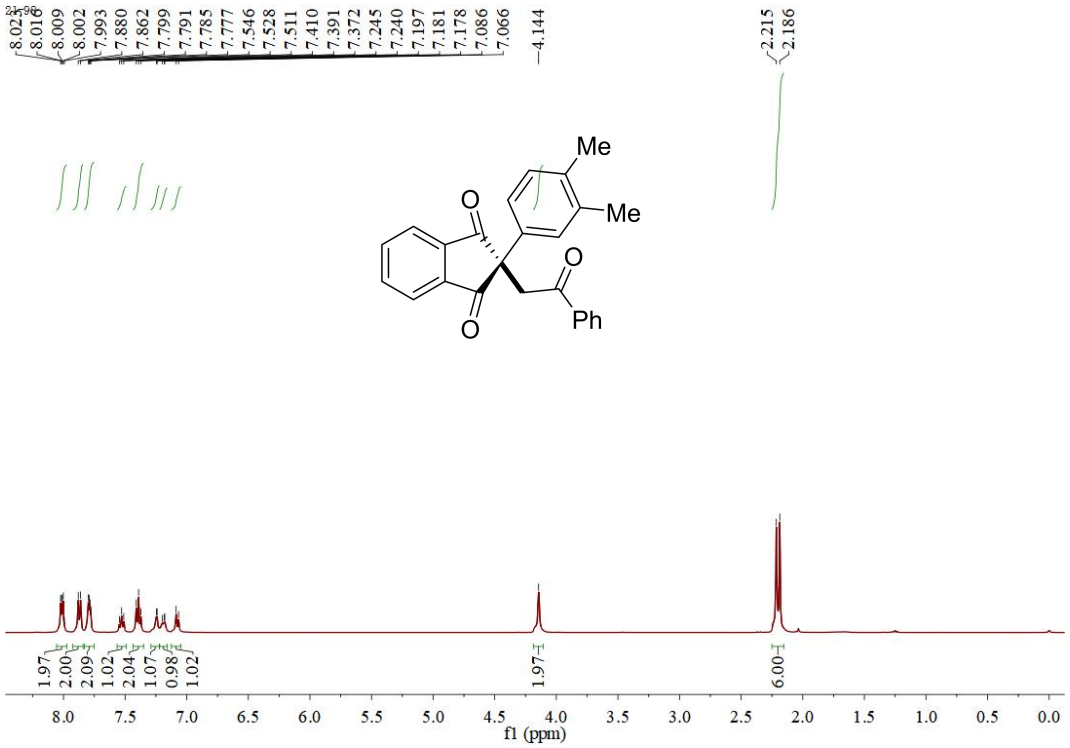
^{1}H NMR, ^{13}C NMR and ^{19}F NMR of 3q

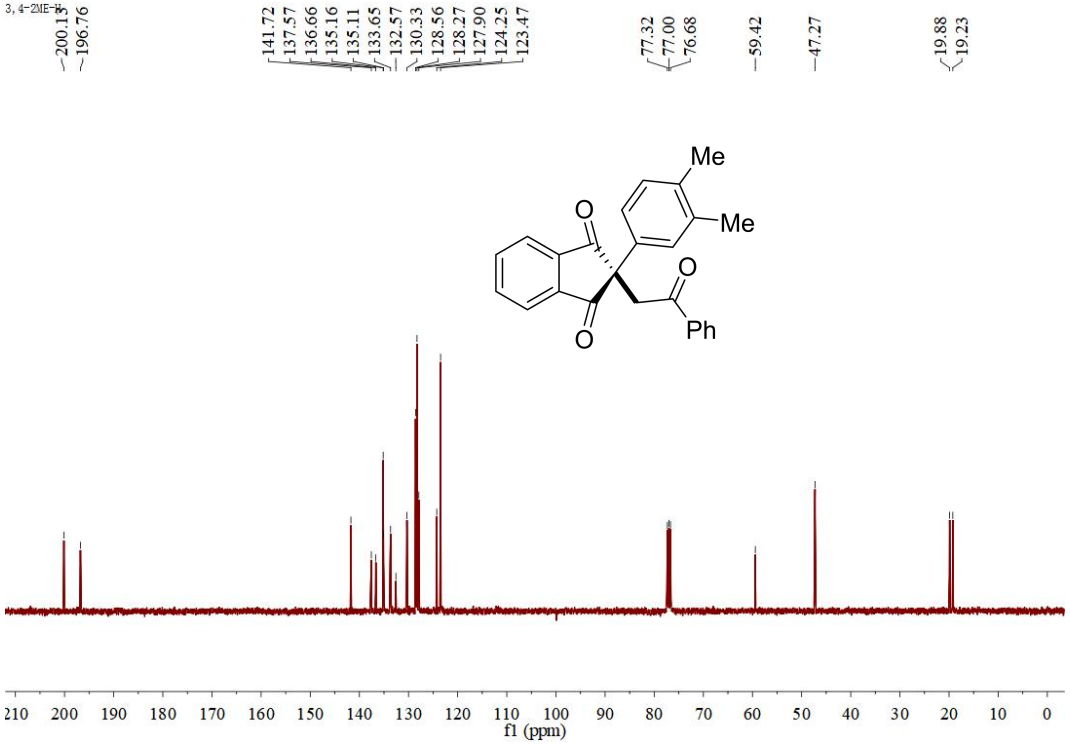




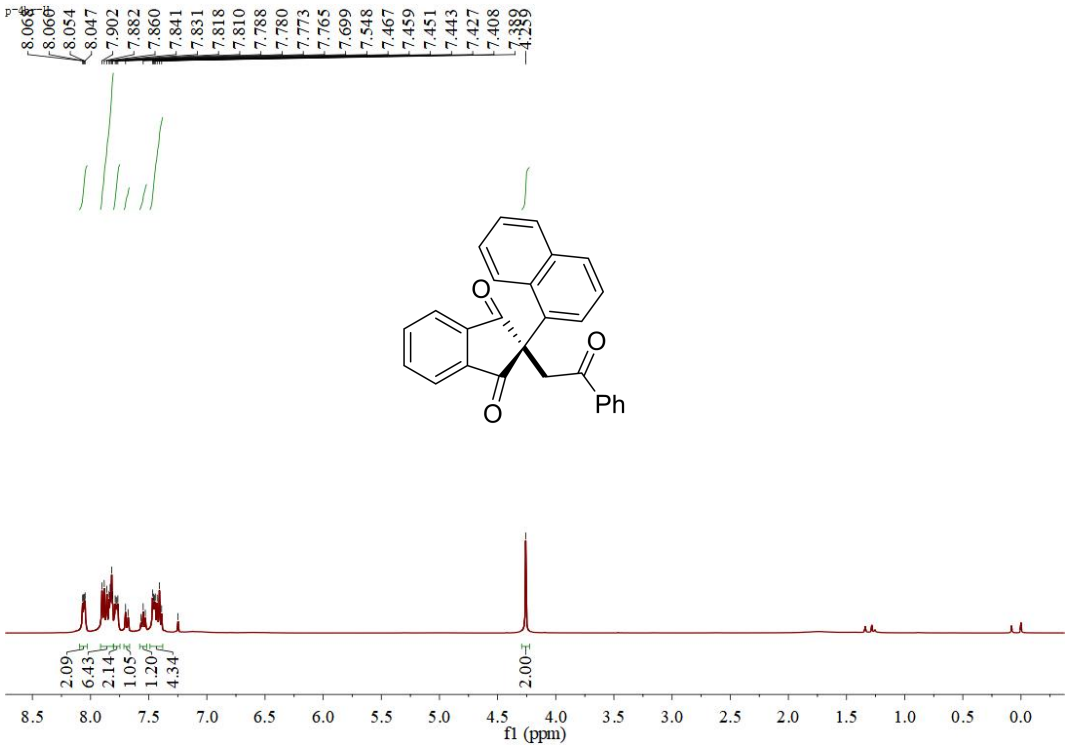

2024052328
-105.48
F
O
O
O
Ph
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-120
-140
-160
-180
-200
f1 (ppm)

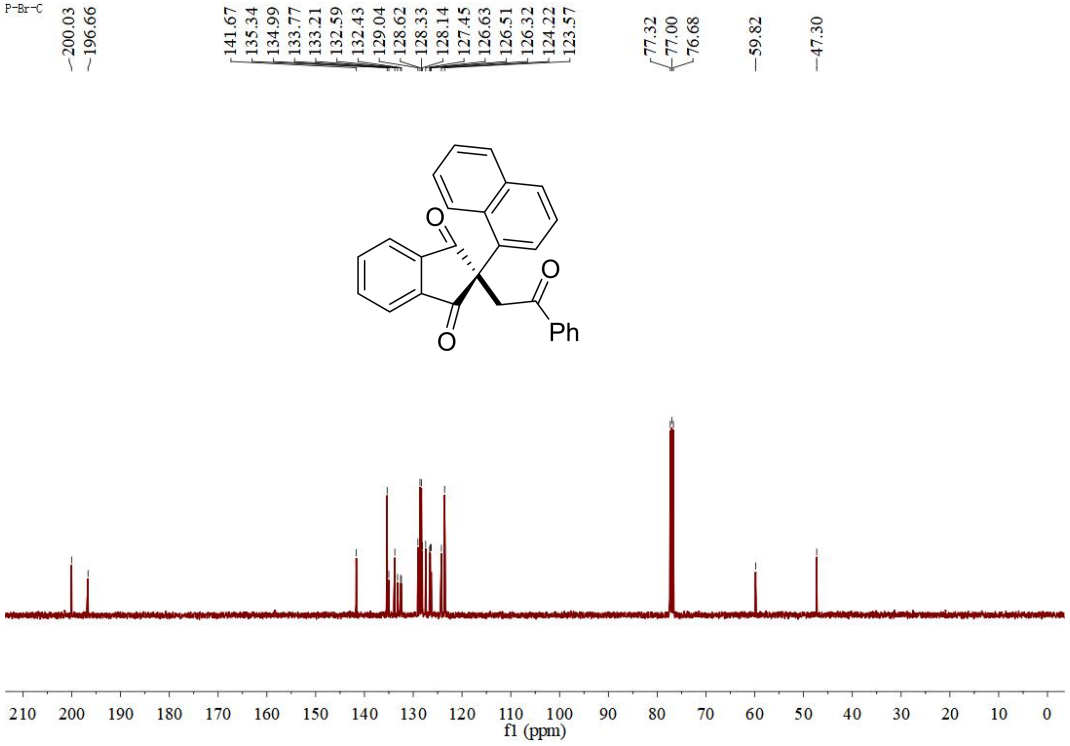
^{1}H NMR and ^{13}C NMR of 3r



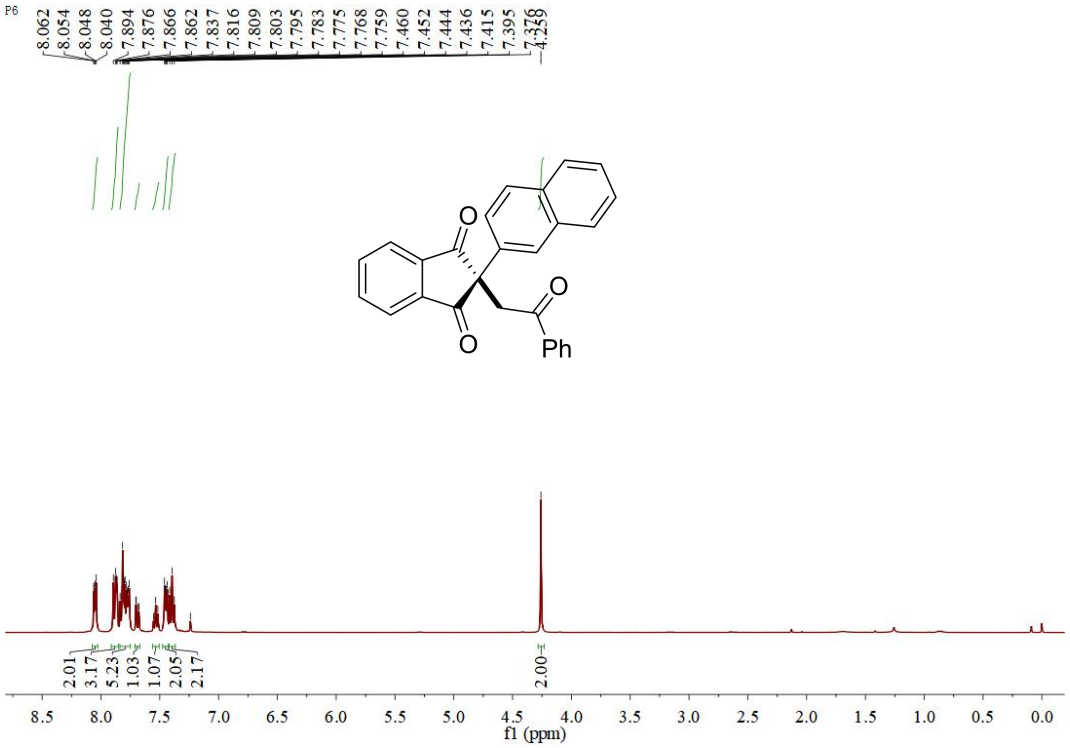


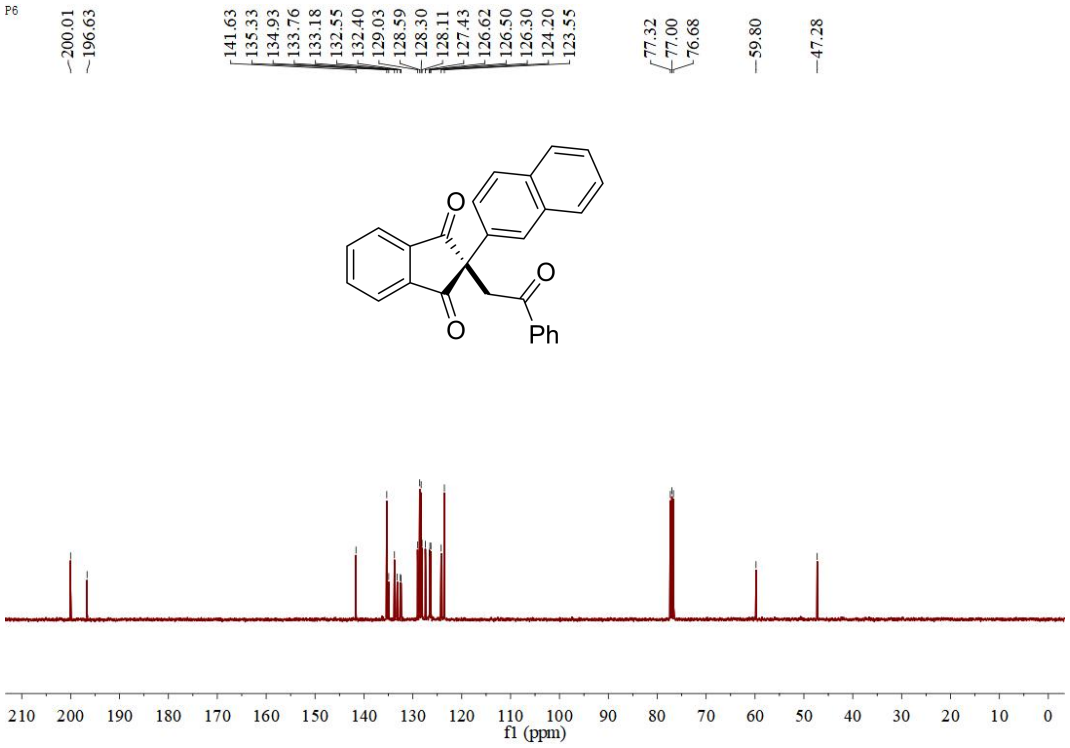
^{1}H NMR and ^{13}C NMR of 3s



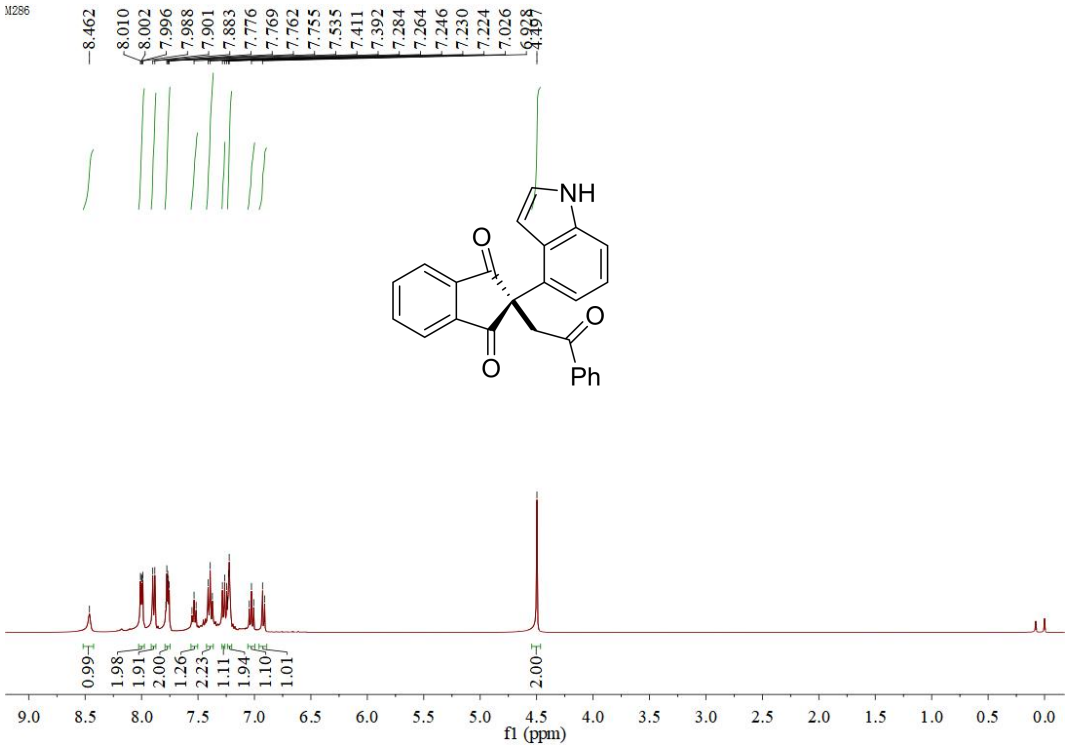


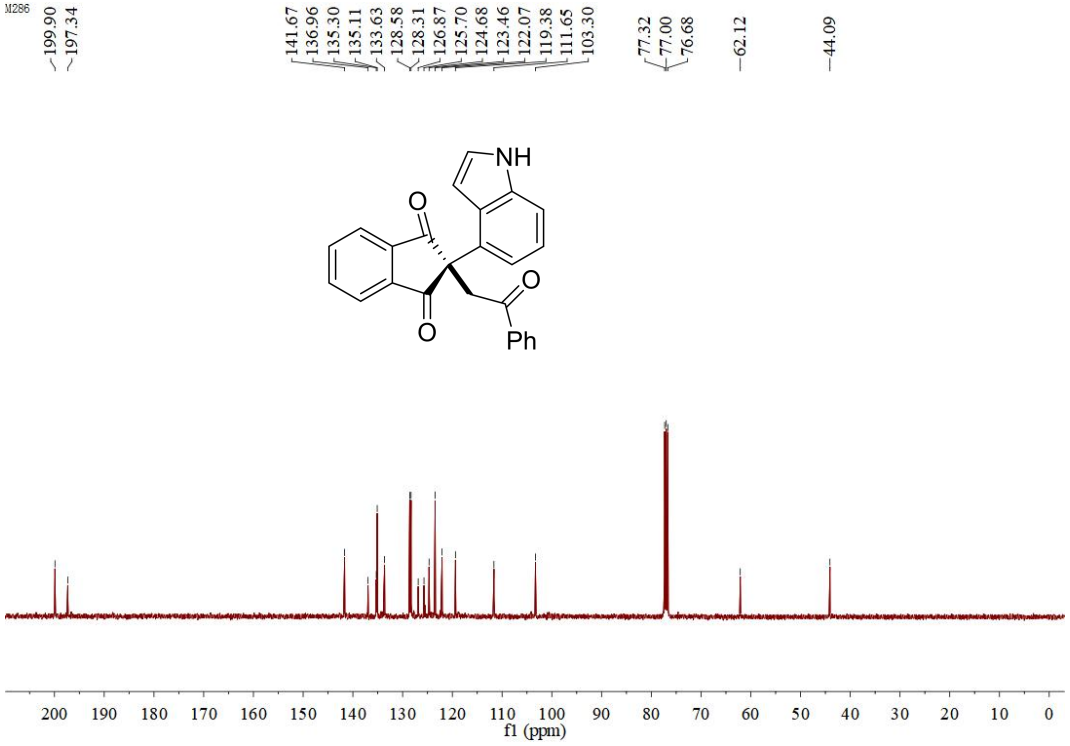
^{1}H NMR and ^{13}C NMR of 3t



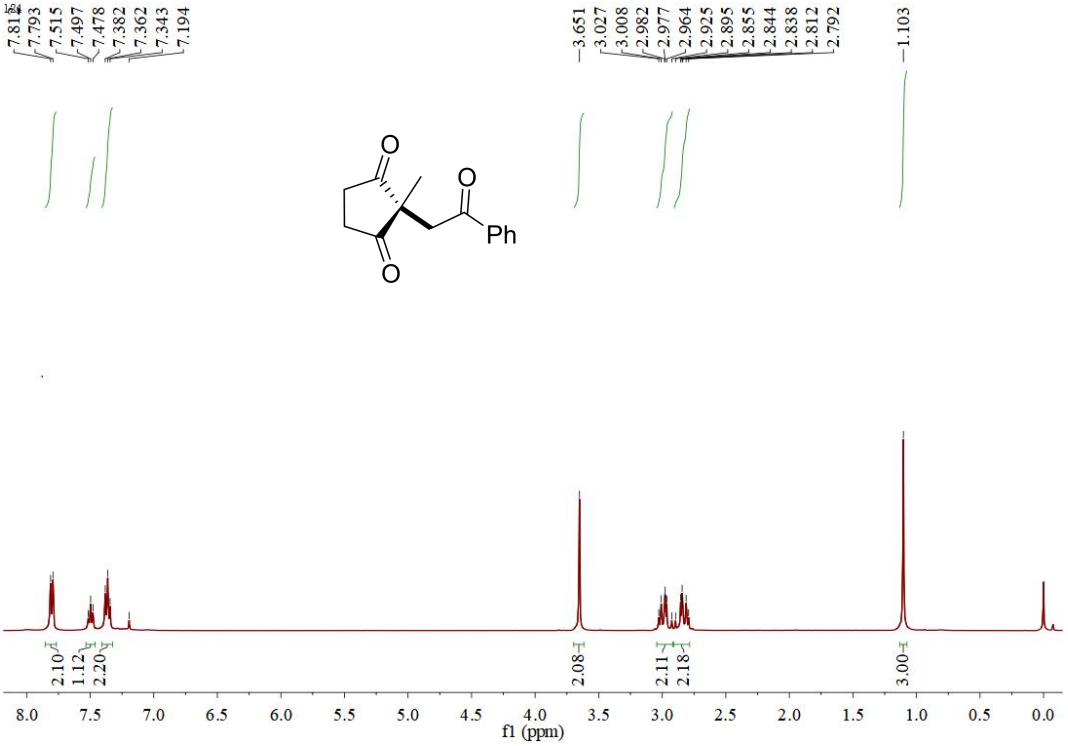


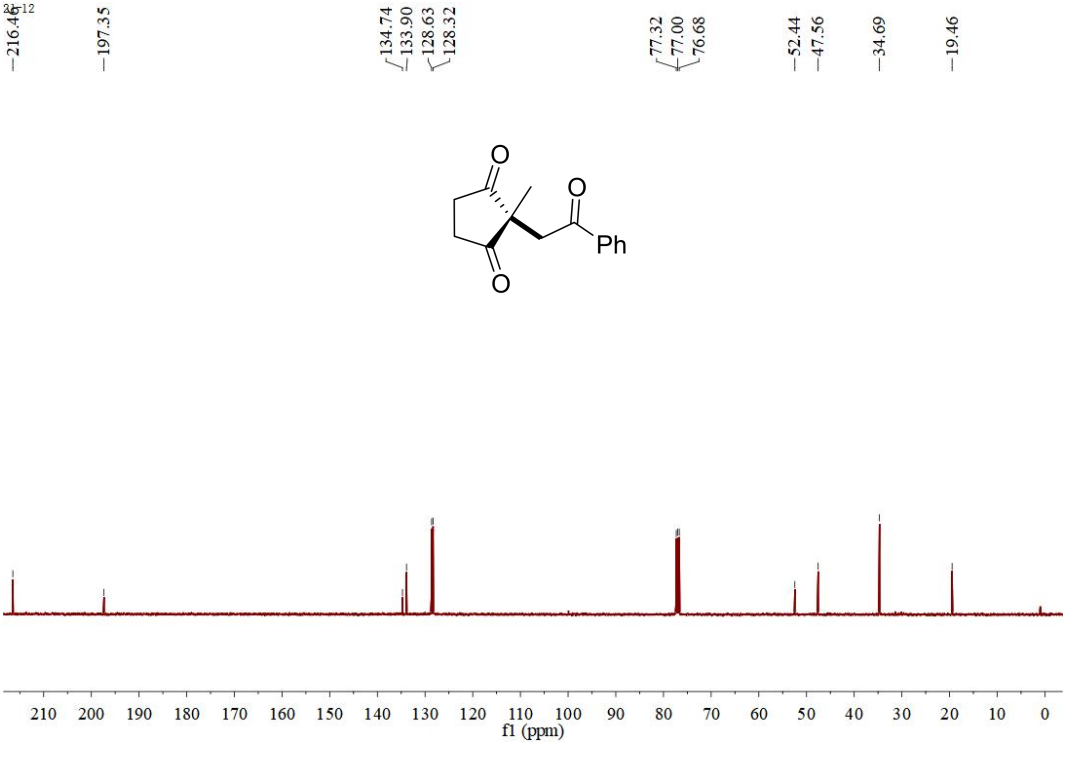
^{1}H NMR and ^{13}C NMR of 3u



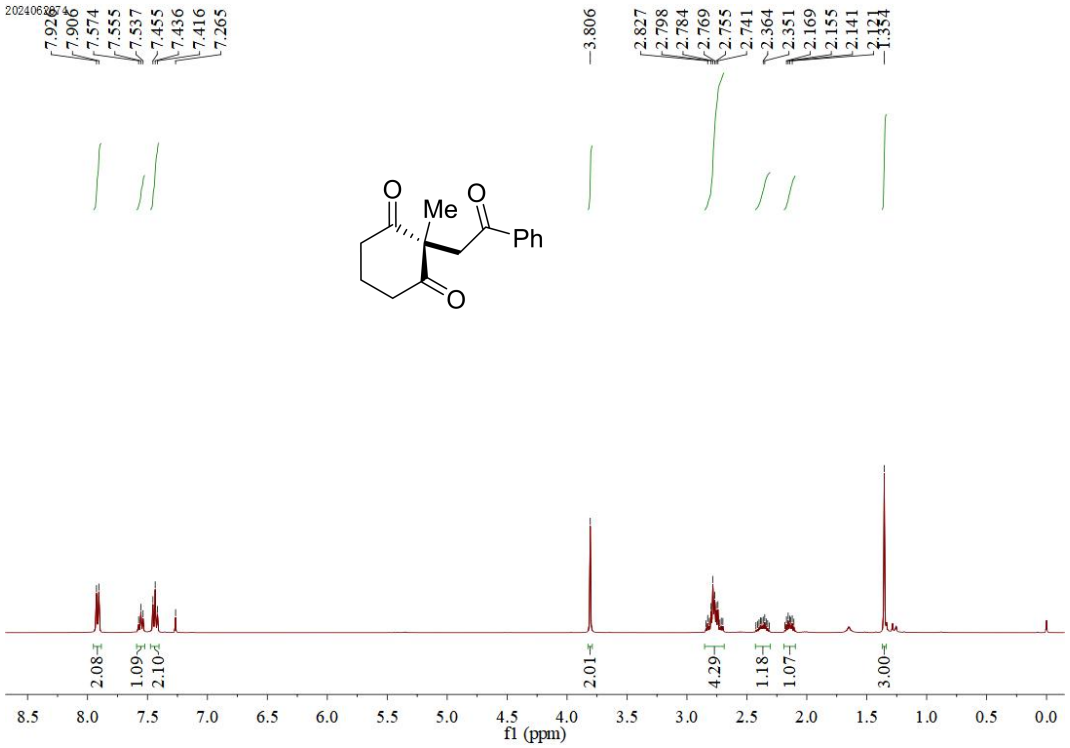


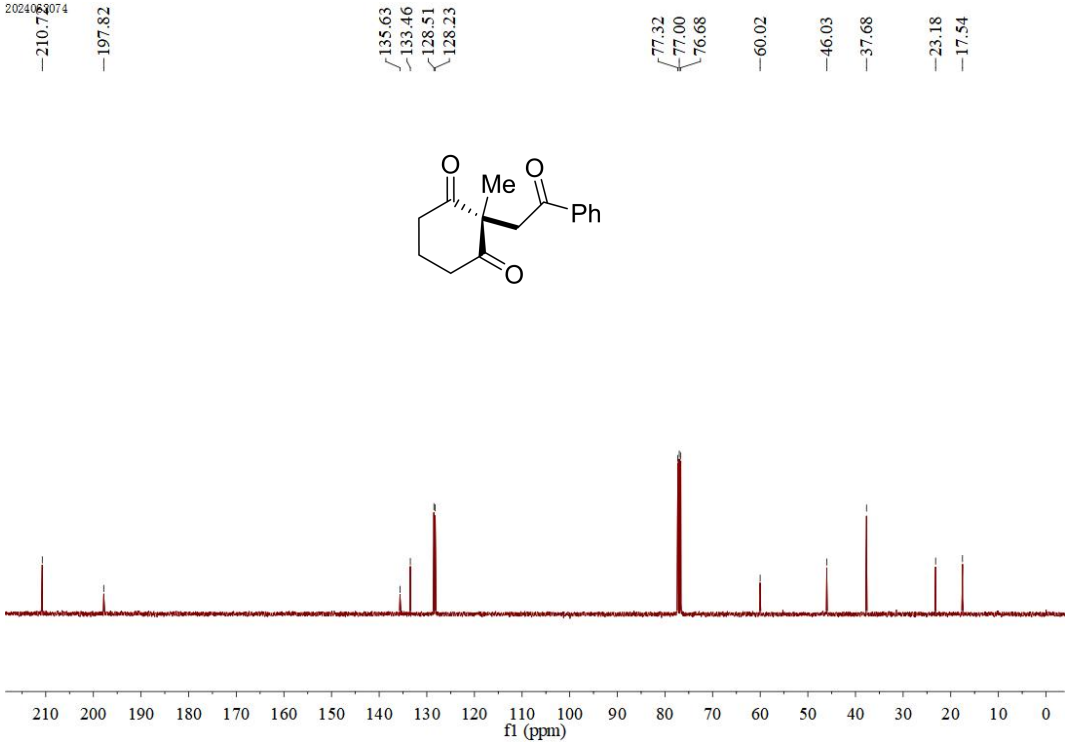
^{1}H NMR and ^{13}C NMR of 4v



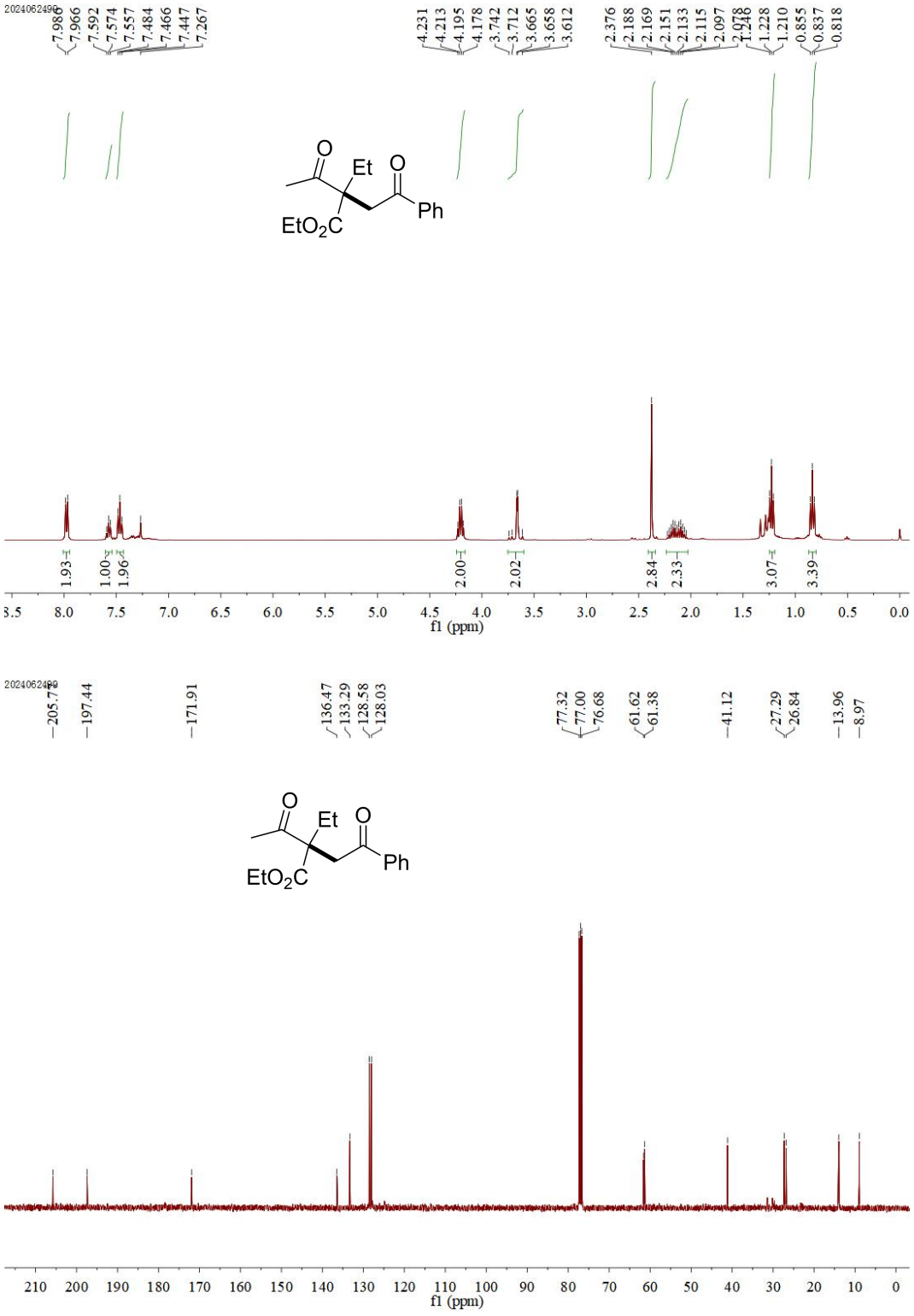


^{1}H NMR and ^{13}C NMR of 3w





^{1}H NMR and ^{13}C NMR of 3x



^{1}H NMR and ^{13}C NMR of 3y