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Carbonylative Coupling of Simple Alkanes and Alkenes Enabled by Organic Photoredox Catalysis

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Contents

1. General Information

Chemicals and solvents were purchased from commercial suppliers and used as received. ^{1}H NMR, ^{13}C NMR spectra were recorded on a Bruker AVANCEIII-500 (500 MHz) spectrometer. Chemical shifts were calibrated using residual undeuterated solvent as an internal reference ($CDCl_3$: 7.26 ppm ^{1}H NMR, 77.16 ppm ^{13}C NMR). Multiplicity was indicated as follows: s (singlet), d (doublet), t (triplet), q (quartet), m (multiplet), dd (doublet of doublet), brs (broad singlet). All high resolution mass spectra (HRMS) were obtained on a AB Sciex TripieTOF 4600 spectrometer. Column chromatography was carried out over 200-300 mesh silica gel. Blue LED (40 W, λ_{max} = 440 nm) purchased from Kessil was used for blue light irradiation. Alkenes (**1b**[1], **1c**[2], **1d**[2], **1e**[2], **1f**[3], **1g**[1], **1h**[1], **1i**[4], **1j**[5], **1k**[6], **1l**[2], **1m**[1], **1n**[3], **1o**[4], **1p**[1], **1q**[7], **1r**[8]) and *N*-alkoxyazinium salts (**A**[9], **B**[10], **C**[10], **D**[10]) were all prepared following reported literature protocols.

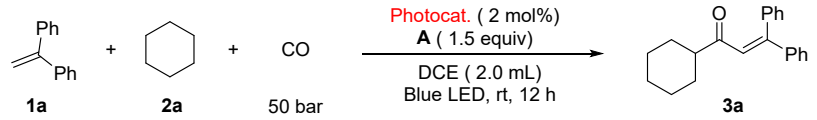
Figure S1. Devices for the photocatalytic reactions

2. General procedures

General procedure for carbonylation of alkanes: a 5 mL vial equipped with a magnetic stir bar was added 4CzIPN (3.2 mg, 0.004 mmol, 2 mol%), 4-cyano-1-isopropoxypyridin-1-ium trifluoromethanesulfonate (93.6 mg, 0.3 mmol, 1.5 equiv). Subsequently, corresponding alkene (0.2 mmol, 1.0 equiv), cyclohexane (1.5 mL) and 1,2-dichloromethane (1.5 mL) was added through injection port. The vials were placed into an autoclave with one inserted quartz-glass windows. After the autoclave was flushed three times, it was filled with 20 atm of CO and then irradiated with blue LED (40 W, λ_{max} = 440 nm) at rt for 12 h. Upon completion of the reaction, the pressure was carefully released and the solvent was removed under reduced pressure. The products were purified by flash chromatography (hexanes/EtOAc = 50/1).

3. Complementary Reaction Optimization Data

Table S1 Photocat. evaluation[a]



entry	Photocat.	Yield (%)[b]
1	4CzIPN	55
2	EosinY	13
3	$Ru(bpy)_3Cl_2$	16
4	$Ru(bpy)_3[PF_6]_2$	16
5	$Ir(ppy)_2(dtbpy)PF_6$	33
6	$Ir(ppy)_3$	28
7	$[Ir(dF(CF_3)ppy)_2)(dtbbpy)]PF_6$	37

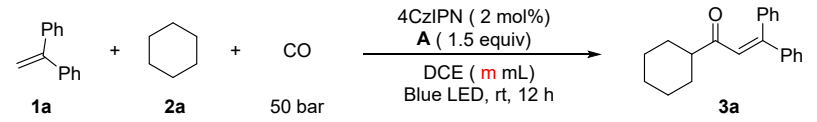
[a]Standard conditions: **1a** (0.2 mmol), **A** (1.5 equiv), Photocat. (2 mol%), **2a** (1 mL), DCE (2 mL) and CO (50 bar) at rt under LED irradiation, 12 h. [b]Isolated yields.

Table S2 Screening of solvent[a]

entry	Solvent	Yield (%)[b]
1	EA	24
2	MeCN	10
3	Acetone	30
4	DCE	55
5	DMSO	3
6	DCM	50
7	$CHCl_3$	14

[a]Standard conditions: **1a** (0.2 mmol), **A** (1.5 equiv), 4CzIPN (2 mol%), **2a** (1 mL), Solvent (2 mL) and CO (50 bar) at rt under LED irradiation, 12 h. [b]Isolated yields.

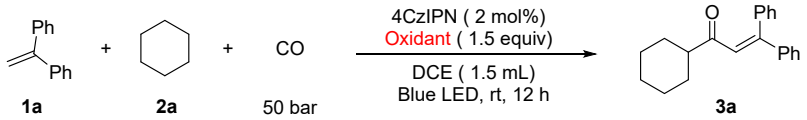
Table S3 Screening of the solvent ratio[a]

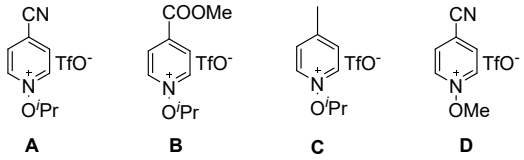


entry	**2a** (n mL)	DCE (m mL)	Yield (%)[b]
1	1	3	38
2	0.5	2.5	21
3	1	2	55
4	1.5	1.5	71
5	2	1	54

[a]Standard conditions: **1a** (0.2 mmol), **A** (1.5 equiv), 4CzIPN (2 mol%), **2a** (n mL), DCE (m mL) and CO (50 bar) at rt under LED irradiation, 12 h. [b]Isolated yields.

Table S4 Screening of the oxidant[a]

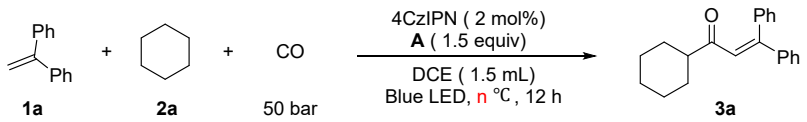




entry	Oxidant	Yield (%)[b]
1	**A**	71
2	**B**	47
3	**C**	32
4	**D**	53
5	$K_2S_2O_8$	NR
6	$(NH_4)_2S_2O_8$	NR

[a]Standard conditions: **1a** (0.2 mmol), Oxidant (1.5 equiv), 4CzIPN (2 mol%), **2a** (1.5 mL), DCE (1.5 mL) and CO (50 bar) at rt under LED irradiation, 12 h. [b]Isolated yields. NR= no reaction.

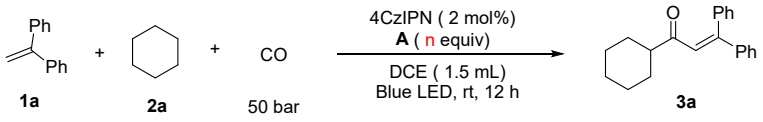
Table S5 Screening of the temperature[a]



entry	Temperature (℃)	Yield (%)[b]
1	rt	71
2	50	67
3	70	65

[a]Standard conditions: **1a** (0.2 mmol), **A** (n equiv), 4CzIPN (2 mol%), **2a** (1.5 mL), DCE (1.5 mL) and CO (50 bar) at n ℃ under LED irradiation, 12 h. [b]Isolated yields.

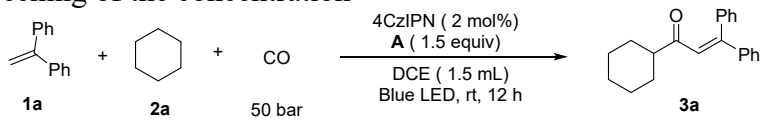
Table S6 Screening of the amount of **A**[a]



entry	**A** (n equiv)	Yield (%)[b]
1	1.0	69
2	1.5	71
3	2.0	60

[a]Standard conditions: **1a** (0.2 mmol), **A** (n equiv), 4CzIPN (2 mol%), **2a** (1.5 mL), DCE (1.5 mL) and CO (50 bar) at rt under LED irradiation, 12 h. [b]Isolated yields.

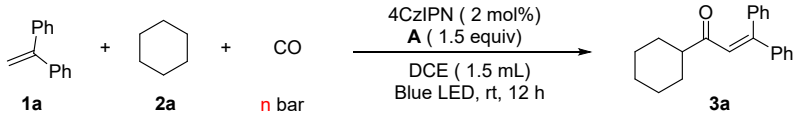
Table S7 Screening of the concentration[a]



entry	**1a** (mmol)	Yield (%)[b]
1	0.1	69
2	0.2	71
3	0.3	60

[a]Standard conditions: **1a** (n mmol), **A** (1.5 equiv), 4CzIPN (2 mol%), **2a** (1.5 mL), DCE (1.5 mL) and CO (50 bar) at rt under LED irradiation, 12 h. [b]Isolated yields.

Table S8 Screening of the CO pressure[a]



entry	CO pressure (bar)	Yield (%)[b]
1	10	55
2	20	72
3	50	71

[a]Standard conditions: **1a** (0.2 mmol), **A** (1.5 equiv), 4CzIPN (2 mol%), **2a** (1.5 mL), DCE (1.5 mL) and CO (n bar) at rt under LED irradiation, 12 h. [b]Isolated yields.

4. Mechanistic Studies

In a typical experiment, a solution of 4CzIPN in anhydrous DCE (0.125 mM) was added with an appropriate amount of quencher in a quartz cuvette. Then the emission of the sample was collected. The emission intensity at 538 nm was collected with excited wavelength of 380 nm.

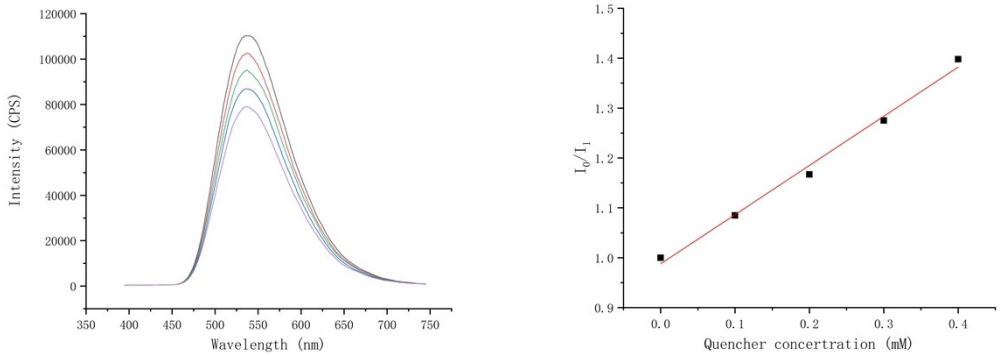


Figure S2. Luminescence quenching of 4CzIPN by **A**

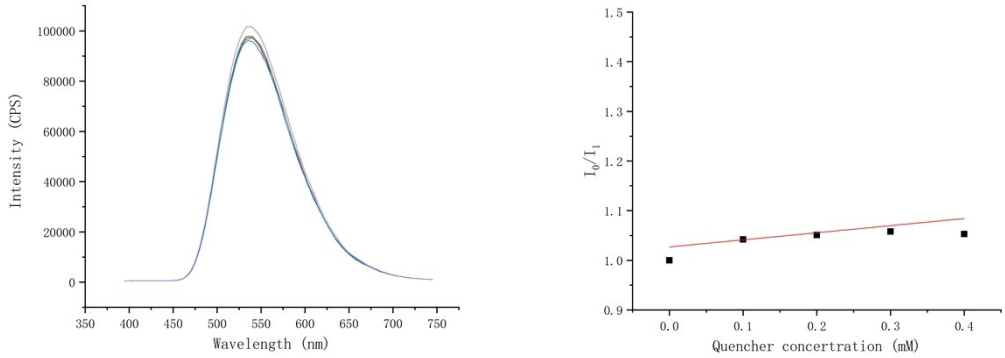
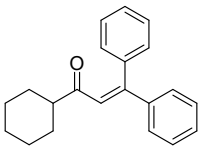
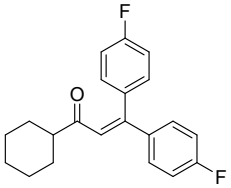


Figure S3. Luminescence quenching of 4CzIPN by **2a**

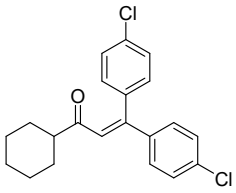
5. Analytical Data of the Products



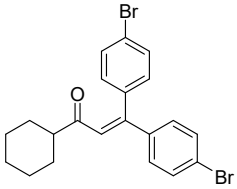
1-cyclohexyl-3,3-diphenylprop-2-en-1-one (**3a**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a yellow oil, 41.8 mg, 72% yield. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.40 – 7.27 (m, 8H), 7.22 – 7.14 (m, 2H), 6.62 (s, 1H), 2.25 (tt, *J* = 11.6, 3.5 Hz, 1H), 1.84 – 1.68 (m, 4H), 1.62 (d, *J* = 10.7 Hz, 1H), 1.35 – 1.27 (m, 2H), 1.19 – 1.08 (m, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 204.9, 153.5, 141.3, 139.2, 129.4, 129.3, 128.4, 128.4, 128.4, 128.2, 125.5, 50.9, 28.8, 25.9, 25.8. The data consistent with previously reported literature.[11]



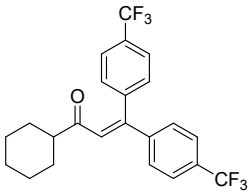
1-cyclohexyl-3,3-bis(4-fluorophenyl)prop-2-en-1-one (**3b**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a yellow oil, 45.8 mg, 70% yield. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.28 – 7.24 (m, 2H), 7.17 – 7.11 (m, 2H), 7.04 (dt, *J* = 20.5, 8.6 Hz, 4H), 6.59 (s, 1H), 2.31 (tt, *J* = 11.5, 3.4 Hz, 1H), 1.86 – 1.72 (m, 4H), 1.68 – 1.59 (m, 1H), 1.36 – 1.30 (m, 2H), 1.22 – 1.15 (m, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 204.1, 163.5 (d, *J* = 250.5 Hz), 162.8 (d, *J* = 248.3 Hz), 151.7, 137.4 (d, *J* = 3.5 Hz), 134.8 (d, *J* = 3.3 Hz), 131.3 (d, *J* = 8.3 Hz), 130.3 (d, *J* = 8.4 Hz), 125.0, 115.5 (d, *J* = 21.7 Hz), 115.3 (d, *J* = 21.5 Hz), 51.2, 28.7, 25.8, 25.8. ^{19}F NMR (470 MHz, $CDCl_3$) δ -111.47, -112.81. HRMS ESI $[M + H]^+$ Calcd for $C_{21}H_{21}F_2O$ 327.1555, found 327.1546.



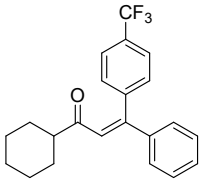
3,3-bis(4-chlorophenyl)-1-cyclohexylprop-2-en-1-one (**3c**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a yellow oil, 49.5 mg, 69% yield. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.32 (dd, *J* = 21.1, 8.5 Hz, 4H), 7.20 (d, *J* = 8.6 Hz, 2H), 7.09 (d, *J* = 8.4 Hz, 2H), 6.63 (s, 1H), 2.34 (tt, *J* = 11.4, 3.4 Hz, 1H),1.85 – 1.73 (m, 4H), 1.68 – 1.61 (m, 1H), 1.36 – 1.27 (m, 2H), 1.25 – 1.15 (m, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 203.8, 151.4, 139.4, 137.1, 135.6, 134.6, 130.7, 129.7, 128.8, 128.5, 125.4, 51.3, 28.6, 25.8, 25.7. HRMS ESI $[M + H]^+$ Calcd for $C_{21}H_{21}Cl_2O$ 359.0964, found 359.0963.



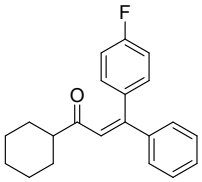
3,3-bis(4-bromophenyl)-1-cyclohexylprop-2-en-1-one (**3d**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a colorless oil, 53.6 mg, 60% yield. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.48 (dd, *J* = 20.2, 8.5 Hz, 4H), 7.13 (d, *J* = 8.5 Hz, 2H), 7.02 (d, *J* = 8.4 Hz, 2H), 6.64 (s, 1H), 2.34 (tt, *J* = 11.4, 3.4 Hz, 1H), 1.88 – 1.73 (m, 4H), 1.68 – 1.61 (m, 1H), 1.35 – 1.29 (m, 2H), 1.25 – 1.16 (m, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 203.8, 151.5, 139.8, 137.5, 131.7, 131.5, 131.0, 129.9, 125.4, 124.0, 122.8, 51.3, 28.6, 25.8, 25.7. HRMS ESI $[M + H]^+$ Calcd for $C_{21}H_{21}Br_2O$ 446.9954, found 446.9960.



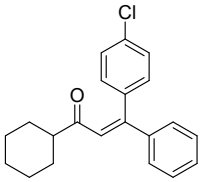
1-cyclohexyl-3,3-bis(4-(trifluoromethyl)phenyl)prop-2-en-1-one (**3e**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a yellow oil, 54.8 mg, 64% yield. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.65 (t, *J* = 9.0 Hz, 2H), 7.57 (s, 1H), 7.50 (dt, *J* = 26.5, 7.8 Hz, 2H), 7.43 – 7.34 (m, 3H), 6.74 (s, 1H), 2.36 (tt, *J* = 11.4, 3.4 Hz, 1H), 1.90 – 1.73 (m, 4H), 1.68 – 1.60 (m, 1H), 1.38 – 1.27 (m, 2H), 1.27 – 1.16 (m, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 203.46, 150.47, 141.45, 139.12, 132.71, 131.73, 131.23 (q, *J* = 32.8 Hz), 130.85 (q, *J* = 32.8 Hz), 129.22, 128.85, 127.17, 126.19 (q, *J* = 3.7 Hz), 126.03 (q, *J* = 3.8 Hz), 125.40 (q, *J* = 3.4 Hz), 123.93 (q, *J* = 272.3 Hz), 123.81 (q, *J* = 272.6 Hz), 124.62 (q, *J* = 3.8 Hz), 51.28, 28.48, 25.78, 25.67. ^{19}F NMR (470 MHz, Chloroform-*d*) δ -62.60, -62.68. HRMS ESI $[M + H]^+$ Calcd for $C_{23}H_{21}F_6O$ 427.1491, found 427.1493.



cyclohexyl-3-phenyl-3-(4-(trifluoromethyl)phenyl)prop-2-en-1-one (**3f**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a yellow oil, 47.0 mg, 66% yield. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.61 (dd, *J* = 24.7, 7.9 Hz, 2H), 7.43 – 7.32 (m, 4H), 7.31 – 7.27 (m, 2H), 7.20 – 7.13 (m, 1H), 6.76 (s, 0.64H), 6.64 (s, 0.36H), 2.38 (tt, *J* = 11.4, 3.5 Hz, 0.68H), 2.26 (tt, *J* = 11.7, 3.5 Hz, 0.42H), 1.90 – 1.73 (m, 4H), 1.68 – 1.60 (m, 1H), 1.35 – 1.23 (m, 3H), 1.22 – 1.12 (m, 2H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 204.8, 203.4, 152.6, 151.6, 144.9, 143.1, 140.5, 138.4, 131.1, 130.8, 130.2, 130.0, 129.7, 129.6, 129.4, 128.7, 128.7, 128.6, 128.4, 128.3, 127.2, 125.4 (q, *J* = 3.7 Hz), 125.3, 125.1 (q, *J* = 3.6 Hz), 125.0, 123.1, 51.4, 50.9, 28.7, 28.6, 25.9, 25.8, 25.7. ^{19}F NMR (470 MHz, $CDCl_3$) δ -62.49, -62.66. The data consistent with previously reported literature.[11]

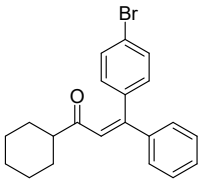


1-cyclohexyl-3-(4-fluorophenyl)-3-phenylprop-2-en-1-one (**3g**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a yellow oil, 47.9 mg, 78% yield (*E*:*Z* isomer: 55:45 based on crude product's NMR). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.41 – 7.32 (m, 3H), 7.30 – 7.26 (m, 2H), 7.20 – 7.13 (m, 2H), 7.09 – 6.98 (m, 2H), 6.64 (s, 0.17H), 6.57 (s, 0.83H), 2.32 (tt, *J* = 11.5, 3.4 Hz, 0.18H), 2.23 (tt, J = 11.6, 3.4 Hz, 0.84H), 1.84 – 1.69 (m, 4H), 1.64 – 1.59 (m, 1H), 1.34 – 1.25 (m, 2H), 1.19 – 1.07 (m, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 204.7, 204.3, 163.4 (d, *J* = 249.5 Hz), 162.8 (d, *J* = 247.6 Hz), 152.8, 152.4, 141.3, 139.0, 137.4 (d, *J* = 3.4 Hz), 135.0 (d, *J* = 3.2 Hz), 131.3 (d, *J* = 8.1 Hz), 130.3 (d, *J* = 8.5 Hz), 129.4 (d, *J* = 10.9 Hz), 128.5 (d, *J* = 9.7 Hz), 128.3, 125.3, 115.4 (d, *J* = 29.0 Hz), 115.2 (d, *J* = 29.2 Hz), 51.2, 50.8, 28.7 (d, *J* = 9.0 Hz), 25.8 (d, *J* = 9.3 Hz). ^{19}F NMR (470 MHz, $CDCl_3$) δ -111.87, -113.17. The data consistent with previously reported literature.[11]

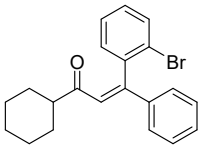


3-(4-chlorophenyl)-1-cyclohexyl-3-phenylprop-2-en-1-one (**3h**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the

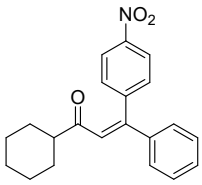
product as a yellow oil, 50.0 mg, 77% yield (*E*:*Z* isomer: 54:46 based on crude product's NMR). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.41 – 7.31 (m, 4H), 7.31 – 7.26 (m, 2H), 7.23 (d, *J* = 8.6 Hz, 1H), 7.19 – 7.08 (m, 2H), 6.63 (d, *J* = 37.1 Hz, 1H), 2.29 (dtt, *J* = 57.7, 11.5, 3.4 Hz, 1H), 1.86 – 1.70 (m, 4H), 1.67 – 1.59 (m, 1H), 1.36 – 1.26 (m, 2H), 1.19 – 1.10 (m, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 204.7, 203.9, 152.7, 152.1, 141.0, 139.8, 138.7, 137.6, 135.3, 134.3, 130.8, 129.7, 129.5, 129.4, 128.6, 128.6, 128.5, 128.4, 128.3, 125.7, 125.2, 51.3, 50.8, 28.7, 28.6, 25.9, 25.8, 25.8. The data consistent with previously reported literature.[11]



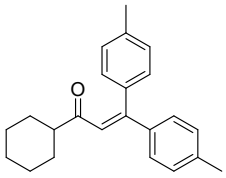
(4-bromophenyl)-1-cyclohexyl-3-phenylprop-2-en-1-one (**3i**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a yellow oil, 56.0 mg, 76% yield (*E*:*Z* isomer: 53:47 based on crude product's NMR).^{1}H NMR (500 MHz, $CDCl_3$) δ 7.48 (dd, J = 22.7, 8.5 Hz, 2H), 7.38 (dd, *J* = 5.1, 2.2 Hz, 2H), 7.34 – 7.26 (m, 1H), 7.18 – 7.03 (m, 4H), 6.67 (s, 0.27H), 6.59 (s, 0.73H), 2.35 (tt, *J* = 11.4, 3.4 Hz, 0.30H), 2.23 (tt, J = 11.6, 3.3 Hz, 0.78H), 1.87 – 1.70 (m, 4H), 1.67 – 1.60 (m, 1H), 1.37 – 1.24 (m, 3H), 1.20 – 1.10 (m, 2H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 204.8, 203.9, 152.8, 152.2, 140.9, 140.2, 138.7, 138.1, 131.6, 131.3, 131.1, 123.0, 129.6, 129.4, 128.6, 128.5, 128.4, 128.3, 125.8, 125.1, 123.7, 122.5, 51.3, 50.8, 28.7, 28.6, 25.9, 25.9, 25.8. The data consistent with previously reported literature.[11]



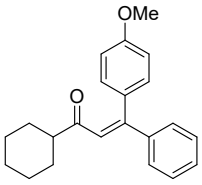
3-(2-bromophenyl)-1-cyclohexyl-3-phenylprop-2-en-1-one (**3j**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a yellow oil, 29.3 mg, 40% yield (*E*:*Z* isomer: 88:12 based on crude product's NMR). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.63 (d, *J* = 8.0 Hz, 1H), 7.35 (d, *J* = 8.5 Hz, 6H), 7.26 – 7.22 (m, 1H), 7.15 (d, *J* = 7.9 Hz, 1H), 6.88 (s, 0.95H), 6.31 (s, 0.05H), 2.39 (tt, *J* = 11.4, 3.4 Hz, 0.96H), 2.30 (tt, J = 11.6, 3.5 Hz, 0.05H), 1.93 – 1.72 (m, 4H), 1.66 – 1.60 (m, 1H), 1.38 – 1.24 (m, 3H), 1.23 – 1.14 (m, 2H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 202.8, 151.9, 140.4, 139.0, 132.8, 130.4, 129.5, 129.2, 128.6, 127.6, 127.3, 125.1, 122.4, 51.3, 51.0, 29.8, 28.7, 28.3, 25.9, 25.9, 25.8. The data consistent with previously reported literature.[11]



1-cyclohexyl-3-(4-nitrophenyl)-3-phenylprop-2-en-1-one (**3k**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a yellow oil, 20.6 mg, 31% yield (*E*:*Z* isomer: 52:48 based on crude product's NMR). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.15 (dd, *J* = 29.5, 8.3 Hz, 2H), 7.37 (dd, *J* = 23.6, 7.5 Hz, 4H), 7.29 (dd, *J* = 16.9, 8.1 Hz, 1H), 7.22 – 7.07 (m, 2H), 6.76(s,0.27H), 6.61 (s, 0.73H), 2.38 (tt, *J* = 11.1, 3.5 Hz, 0.28H), 2.20 (tt, *J* = 11.7, 3.5 Hz, 0.77H), 1.86 – 1.64 (m, 4H), 1.64 – 1.55 (m, 1H), 1.29 – 1.20 (m, 3H), 1.11 – 1.02 (m, 2H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 204.7, 202.9, 150.4, 148.0, 147.6, 146.6 139.8, 137.9, 130.0, 130.0, 129.3, 129.2, 129.0, 128.8, 128.6, 128.3, 128.2, 125.1, 123.7, 123.4, 51.6, 50.9, 28.6, 28.4, 25.8, 25.8, 25.7, 25.7. HRMS ESI $[M + H]^+$ Calcd for $C_{21}H_{22}NO_3$ 336.1594, found 336.1597.

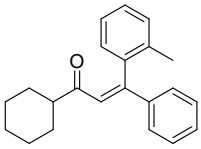


[1]-cyclohexyl-3,3-di-p-tolylprop-2-en-1-one (**3l**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a yellow oil, 26.3 mg, 41% yield. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.22 – 7.10 (m, 6H), 7.06 (d, *J* = 7.8 Hz, 2H), 6.56 (s, 1H), 2.38 (s, 3H), 2.36 (s, 3H), 2.26 (tt, *J* = 11.7, 3.4 Hz, 1H), 1.83 – 1.69 (m, 4H), 1.63 – 1.58 (m, 1H), 1.36 – 1.29 (m, 3H), 1.18 – 1.07 (m, 2H). 13C NMR (126 MHz, $CDCl_3$) δ 204.9, 154.0, 139.5, 138.8, 138.2, 136.4, 129.5, 129.1, 128.8, 128.5, 124.3, 50.9, 28.8, 25.9, 25.8, 21.4, 21.3. The data consistent with previously reported literature.[11]

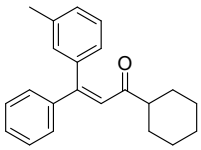


1-cyclohexyl-3-(4-methoxyphenyl)-3-phenylprop-2-en-1-one (**3m**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a yellow oil, 22.5 mg, 35% yield (*E*:*Z* isomer: 63:37 based on crude product's NMR). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.40 – 7.29 (m, 3H), 7.27 – 7.22 (m, 2H), 7.20 – 7.09 (m, 2H), 6.87 (dd, *J* = 23.4, 8.4 Hz, 2H), 6.56 (d, *J* = 25.2 Hz, 1H), 3.83 (d, *J* = 11.6 Hz, 3H), 2.36 – 2.17 (m, 1H), 1.84 – 1.69 (m, 4H), 1.64 – 1.59 (m, 1H), 1.34 – 1.24 (m, 3H), 1.15 – 1.10 (m, 2H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 204.6, 160.7, 153.5, 139.5, 133.6, 131.2, 129.9, 129.4, 128.7, 128.3, 128.2, 128.1, 125.0,

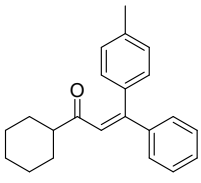
123.6, 113.8, 113.5, 55.4, 55.3, 50.9, 50.8, 29.7, 28.8, 25.9, 25.8. The data consistent with previously reported literature.[11]



cyclohexyl-3-phenyl-3-(o-tolyl)prop-2-en-1-one (**3n**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a yellow oil, 40.0 mg, 66% yield (*E*:*Z* isomer: 83:17 based on crude product's NMR). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.34 – 7.28 (m, 5H), 7.26 – 7.15 (m, 3H), 7.04 (dd, *J* = 7.4, 1.4 Hz, 1H), 6.80 (s, 0.76H), 6.25 (s, 0.24H), 2.33 – 2.20(m, 1H), 2.07 (d, *J* = 11.5 Hz, 3H), 1.88 – 1.68 (m, 4H), 1.64 – 1.60 (m, 1H), 1.42 – 1.24 (m, 3H), 1.16 – 1.10 (m, 2H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 204.0, 153.0, 139.9, 138.8, 135.7, 130.7, 130.1, 129.7, 129.3, 129.2, 128.8, 128.6, 128.6, 128.3, 128.2, 128.0, 128.0, 127.5, 125.7, 125.7, 125.2, 51.1, 50.7, 29.7, 28.8, 25.9, 25.9, 25.8, 20.4, 19.7. The data consistent with previously reported literature.[11]

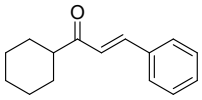


1-cyclohexyl-3-phenyl-3-(m-tolyl)prop-2-en-1-one (**3o**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a yellow oil, 45.4 mg, 75% yield (*E*:*Z* isomer: 50:50 based on crude product's NMR). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.39 – 7.29 (m, 4H), 7.25 – 7.15 (m, 3H), 7.13 – 7.05 (m, 1H), 6.98 (d, *J* = 7.2 Hz, 1H), 6.59 (d, *J* = 8.2 Hz, 1H), 2.34 (d, *J* = 6.9 Hz, 3H), 2.23 (tdd, *J* = 11.6, 6.4, 3.2 Hz, 1H), 1.82 – 1.69 (m, 4H), 1.64 – 1.58 (m, 1H), 1.36 – 1.24 (m, 3H), 1.15 – 1.08 (m, 2H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 205.2, 204.9, 153.7, 153.6, 141.4, 141.3, 139.3, 139.2, 138.0, 137.8, 130.1, 130.0, 129.4, 129.2, 129.1, 129.0, 128.4, 128.4, 128.3, 128.3, 128.1, 128.0, 126.6, 125.7, 125.6, 125.4, 50.8, 50.7, 28.8, 28.8, 25.9, 25.8, 21.4. The data consistent with previously reported literature.[11]

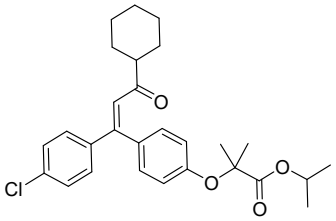


cyclohexyl-3-phenyl-3-(p-tolyl)prop-2-en-1-one (**3p**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a yellow oil, 36.2 mg, 60% yield (*E*:*Z* isomer: 58:42 based on crude product's NMR). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.43 – 7.29 (m, 4H), 7.20 – 7.16 (m, 3H), 7.14 – 7.06 (m, 2H), 6.60 (d, *J* = 14.0 Hz, 1H), 2.38 (d, *J* = 15.1 Hz, 3H), 2.27 (dtt, *J* = 23.6, 11.5,

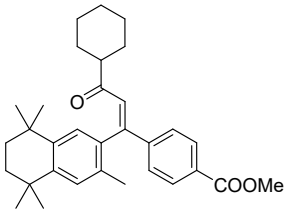
3.5 Hz, 1H), 1.84 – 1.70 (m, 4H), 1.65 – 1.59 (m, 1H), 1.36 – 1.27 (m, 2H), 1.15 – 1.10 (m, 2H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 204.8, 153.6, 141.6, 139.5, 139.4, 138.5, 138.3, 136.2, 129.5, 129.4, 129.2, 129.1, 128.8, 128.5, 128.4, 128.3, 128.3, 128.1, 125.2, 124.6, 50.9, 50.8, 28.8, 28.8, 25.9, 25.8, 21.4, 21.3. The data consistent with previously reported literature.[11]



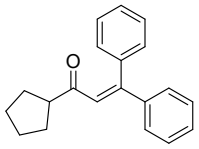
(*E*)-1-cyclohexyl-3-phenylprop-2-en-1-one (**3q**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a yellow oil, 11.0 mg, 26% yield (*E*:*Z* isomer: 92:8 based on crude product's NMR). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.64 – 7.50 (m, 3H), 7.42 – 7.34 (m, 3H), 6.82 (d, *J* = 16.0 Hz, 1H), 2.66 (tt, *J* = 11.4, 3.4 Hz, 1H), 1.95 – 1.80 (m, 4H), 1.75 – 1.67 (m, 1H), 1.48 – 1.37 (m, 2H), 1.37 – 1.24 (m, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 203.2, 142.2, 134.8, 130.3, 128.9, 128.3, 124.8, 49.5, 28.8, 25.9, 25.8. The data consistent with previously reported literature.[12]



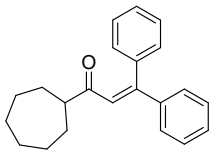
isopropyl -2-(4-(1-(4-chlorophenyl)-3-cyclohexyl-3-oxoprop-1-en-1-yl)phenoxy)-2-methylpropanoate (**3r**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a yellow oil, 46.9 mg, 50% yield (*E*:*Z* isomer: 61:39 based on crude product's NMR). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.31 (dd, *J* = 23.4, 8.2 Hz, 2H), 7.17 (dd, *J* = 19.6, 8.6 Hz, 2H), 7.06 (dd, *J* = 22.4, 8.2 Hz, 2H), 6.79 (dd, *J* = 29.4, 8.6 Hz, 2H), 6.61 (s, 0.62H), 6.45 (s, 0.38H), 5.07 (tq, J = 12.5, 6.2 Hz, 1H), 2.32 (tt, J = 11.5, 3.4 Hz, 0.58H), 2.20 (tt, J = 11.8, 3.2 Hz, 0.4H), 1.86 – 1.67 (m, 4H), 1.61 (d, *J* = 8.9 Hz, 7H), 1.36 – 1.24 (m, 3H), 1.22 (dd, *J* = 11.3, 6.2 Hz, 6H), 1.19 – 1.15 (m, 2H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 205.5, 203.7, 173.6, 173.3, 157.0, 156.2, 152.4, 151.5, 150.1, 142.9, 140.2, 137.8, 135.2, 134.2, 134.0, 131.8, 130.8, 130.7, 129.8, 129.4, 128.5, 128.3, 125.8, 123.4, 118.2, 118.1, 79.2, 79.2, 69.2, 69.1, 51.3, 50.6, 28.9, 28.7, 25.9, 25.8, 25.8, 25.8, 25.4, 25.4, 21.6. HRMS ESI $[M + H]^+$ Calcd for $C_{28}H_{34}ClO_4$ 469.2140, found 469.2140.



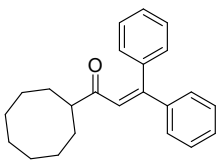
methyl -4-(3-cyclohexyl-3-oxo-1-(3,5,5,8,8-pentamethyl-5,6,7,8-tetrahydronaphthalen-2-yl)prop-1-en-1-yl)benzoate (**3s**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a yellow oil, 38.9 mg, 41% yield (*E*:*Z* isomer: 66:34 based on crude product's NMR). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.97 (t, *J* = 8.8 Hz, 2H), 7.31 (dd, *J* = 69.5, 8.2 Hz, 2H), 7.15 – 6.95 (m, 2H), 6.67 (s, 0.72H), 6.35 (s, 0.28H), 3.90 (d, *J* = 3.0 Hz, 3H), 2.34 (tt, *J* = 11.7, 3.6 Hz, 0.33H), 2.00 (dt, *J* = 11.4, 3.0 Hz, 0.71H), 1.96 (d, *J* = 6.7 Hz, 3H), 1.92 – 1.72 (m, 2H), 1.71 – 1.49 (m, 8H), 1.33 – 1.18 (m, 16H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 206.1, 204.8, 166.8, 166.7, 153.6, 151.3, 145.5, 145.5, 144.6, 144.3, 142.5, 142.5, 138.8, 134.8, 132.8, 132.7, 130.4, 129.8, 129.6, 129.2, 129.2, 128.8, 128.8, 128.4, 128.3, 128.0, 127.9, 127.4, 52.2, 52.1, 51.3, 49.4, 35.2, 35.1, 35.1, 34.1, 34.1, 33.9, 33.9, 31.9, 31.8, 29.7, 28.7, 25.8, 25.8, 25.7, 20.3, 19.5. HRMS ESI $[M + H]^+$ Calcd for $C_{33}H_{41}O_3$ 473.3050, found 473.3043.



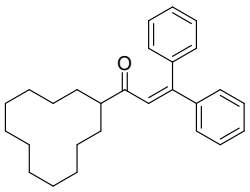
1-cyclopentyl-3,3-diphenylprop-2-en-1-one (**4a**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a yellow oil, 31.8 mg, 58% yield. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.43 – 7.28 (m, 8H), 7.23 – 7.14 (m, 2H), 6.64 (s, 1H), 2.83 (p, *J* = 7.9 Hz, 1H), 1.80 – 1.67 (m, 4H), 1.62 (td, *J* = 10.5, 9.8, 4.5 Hz, 2H), 1.54 – 1.48 (m, 2H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 204.2, 153.3, 141.4, 139.2, 129.5, 129.3, 128.4, 128.4, 128.3, 128.1, 125.9, 51.8, 29.4, 26.2. HRMS ESI $[M + H]^+$ Calcd for $C_{20}H_{21}O$ 277.1587, found 277.1583.



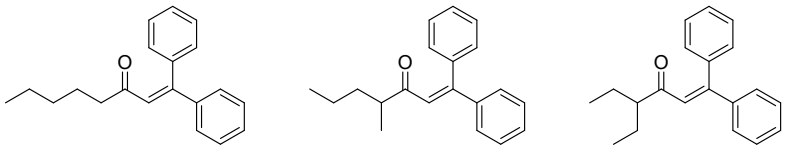
1-cycloheptyl-3,3-diphenylprop-2-en-1-one (**4b**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a yellow oil, 33.1 mg, 54% yield. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.41 – 7.28 (m, 8H), 7.18 (dd, *J* = 6.6, 3.0 Hz, 2H), 6.61 (s, 1H), 2.43 (tt, *J* = 9.8, 3.9 Hz, 1H), 1.82 (ddt, *J* = 14.2, 7.2, 3.8 Hz, 2H), 1.71 – 1.63 (m, 2H), 1.53 (dtd, *J* = 13.7, 10.0, 3.5 Hz, 2H), 1.46 (p, *J* = 2.9 Hz, 4H), 1.33 – 1.26 (m, 2H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 205.5, 153.4, 141.3, 139.2, 129.4, 129.2, 128.4, 128.4, 128.2, 125.8, 52.0, 30.2, 28.2, 26.8. HRMS ESI $[M + H]^+$ Calcd for $C_{22}H_{25}O$ 305.1900, found 305.1894.



1-cyclooctyl-3,3-diphenylprop-2-en-1-one (**4c**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a yellow oil, 26.1 mg, 41% yield. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.41 – 7.35 (m, 4H), 7.36 – 7.28 (m, 5H), 7.21 – 7.17 (m, 2H), 6.59 (s, 1H), 2.49 (tt, *J* = 9.4, 3.5 Hz, 1H), 1.76 (ddt, *J* = 14.9, 7.7, 3.6 Hz, 2H), 1.67 – 1.59 (m, 3H), 1.56 – 1.49 (m, 2H), 1.42 (dq, *J* = 8.1, 3.7 Hz, 3H), 1.37 – 1.26 (m, 4H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 206.0, 153.1, 141.3, 139.3, 129.5, 129.2, 128.4, 128.4, 128.3, 126.1, 50.1, 28.7, 26.4, 26.4, 25.6. HRMS ESI $[M + H]^+$ Calcd for $C_{23}H_{27}O$ 319.2056, found 319.2053.

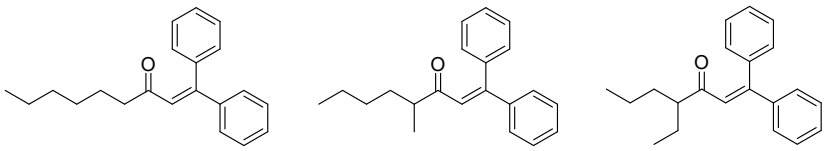


1-cyclododecyl-3,3-diphenylprop-2-en-1-one(**4d**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a yellow oil, 18.3 mg, 25% yield. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.40 – 7.27 (m, 8H), 7.20 – 7.15 (m, 2H), 6.59 (s, 1H), 2.54 (p, *J* = 6.4 Hz, 1H), 1.58 – 1.53 (m, 2H), 1.47 (dq, *J* = 13.6, 6.7 Hz, 2H), 1.32 – 1.20 (m, 14H), 1.20 – 1.16 (m, 2H), 1.10 (dt, *J* = 13.2, 6.6 Hz, 2H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 206.0, 152.6, 141.4, 139.2, 129.6, 129.2, 128.5, 128.4, 128.4, 128.3, 126.5, 47.1, 29.8, 26.4, 23.7, 23.7, 23.1, 22.8. HRMS ESI $[M + H]^+$ Calcd for $C_{27}H_{35}O$ 375.2682, found 375.2678.



4e-1 **4e-2** **4e-3**

1,1-diphenyloct-1-en-3-one (**4e-1**), 4-methyl-1,1-diphenylhept-1-en-3-one (**4e-2**), 4-ethyl-1,1-diphenylhex-1-en-3-one (**4e-3**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a yellow oil, 30.0 mg, 54% total yield (Isomer: 28:61:11 based on crude product's NMR). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.40 – 7.29 (m, 8H), 7.19 (dt, *J* = 7.4, 3.3 Hz, 2H), 6.67 – 6.57 (m, 1H), 2.52 – 2.20 (m, 1H), 1.69 – 1.61 (m, 1H), 1.54 – 1.38 (m, 1H), 1.29 – 1.21 (m, 2H), 1.11 – 0.99 (m, 2H), 0.84 (dt, *J* = 14.4, 7.2 Hz, 4H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 205.8, 204.7, 202.6, 153.6, 141.4, 141.4, 139.2, 139.2, 129.6, 129.5, 129.5, 129.3, 129.3, 128.5, 128.4, 128.4, 128.3, 128.3, 128.2, 128.1, 127.0, 125.8, 125.6, 55.2, 46.0, 43.2, 35.6, 31.4, 24.2, 20.5, 16.3, 14.1, 14.0, 11.9. HRMS ESI $[M + H]^+$ Calcd for $C_{20}H_{23}O$ 279.1743, found 279.1743.



4f-1 **4f-2** **4f-3**

1,1-diphenylnon-1-en-3-one (**4f-1**), 4-methyl-1,1-diphenyloct-1-en-3-one (**4f-2**), 4-ethyl-1,1-diphenylhept-1-en-3-one (**4f-3**): The compound was purified by flash column chromatography (petroleum ether/EtOAc =50:1) to give the product as a yellow oil, 41.5 mg, 71% total yield (Isomer: 7:47:46 based on crude product's NMR). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.39 – 7.29 (m, 8H), 7.18 (dd, *J* = 6.6, 3.0 Hz, 2H), 6.64 (s, 0.49H), 6.62 (s, 0.49H), 6.58 (s, 0.02H), 2.45 (h, *J* = 6.9 Hz, 0.48H), 2.36 (tt, *J* = 7.6, 5.7 Hz, 0.47H), 2.23 (t, *J* = 7.5 Hz, 0.03H), 1.68 – 1.54 (m, 2H), 1.49 – 1.30 (m, 1H), 1.30 – 1.18 (m, 3H), 1.02 (d, *J* = 6.9 Hz, 1H), 0.91 – 0.79 (m, 5H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 205.5, 204.8, 153.7, 153.6, 141.4, 141.4, 139.2, 139.2, 129.5, 129.3, 129.3, 128.4, 128.4, 128.4, 128.3, 128.2, 128.1, 125.7, 125.6, 53.5, 46.2, 33.5, 33.1, 29.5, 24.6, 22.8, 20.7, 16.4, 14.3, 14.0, 11.9. HRMS ESI $[M + H]^+$ Calcd for $C_{21}H_{25}O$ 293.1900, found 293.1903.

6. Reference

(1) Zhang, G.; Bai, R. X.; Li, C. H.; Feng, C. G.; Lin, G. Q. *Tetrahedron* **2019**, *72*, 1658-1662.

(2) Liu, W. Q.; Lei, T.; Zhou, S.; Yang, X. L.; Li, J.; Chen, B.;Wu, L. Z. *J. Am. Chem. Soc*. **2019**, *141*, 13941-13947.

(3) Cheng, H. C.; Lam, T. L.; Liu, Y.; Tang, Z.; Che, C. M. *Angew. Chem. Int. Ed.* **2021**, *60*, 1383-1389.

(6) Zhang, H. R.; Xiao, C.; Zhang, S. L.; Zhang, X. *Adv. Synth. Catal.* **2019**, *361*, 5305-5310.

(4) Pei, C., Yang, Z.; Koenigs, R. M. *Org. Lett.* **2020**, *22*, 18, 7300-7304.

(5) Pagire, S. K.; Kumagai, N.; Shibasaki, M. *Org. Lett.* **2020**, *22*, 7853-7858.

(7) Ritz, M. D.; Parsons, A. M.; Palermo, P. N.; Jones, W. D. *Polyhedron* **2020**, *180*, 114416.

(8) Wagner, C. E.; Jurutka, P. W.; Marshall, P. A.; Groy, T. L.; Van Der Vaart, A.; Ziller, J. W.; Furmick, J. K.; Graeber, M. E.; Matro, E.; Miguel, B. V.; Tran, I. T.; Kwon, J.; Tedeschi, J. N.; Moosavi, S.; Dansihyar, A.; Philp, J. S.; Khamees, R. O.; Jackson, J. N.; Grupe, D. K.; Badshah, S. L.; Hart, J. W. *J. Med. Chem.* **2009**, *52*, 5950-5966.

(9) Barthelemy, A. L.; Tuccio, B.; Magnier, E.; Dagousset, G. *Angew. Chem. Int. Ed.* **2019**, *57*, 13790-13794.

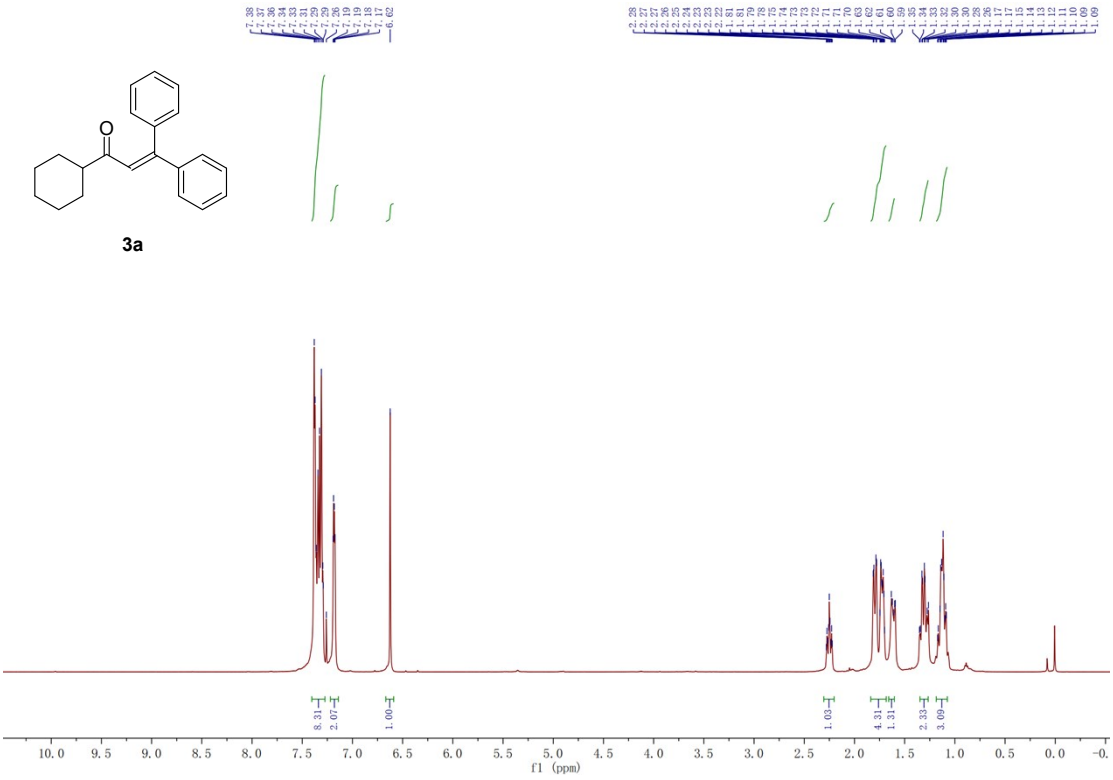
(10) Tang, W. Y.; Chen, L.; Zheng, Z.; Zhan, L. W.; Hou, J.; Li, B. D. *Org. Lett.* **2021**, *23*, 3939-3943.

(11) Zhao, F.; Li, C. L.;Wu, X. F. *Chem. Commun.* **2020**, *56*, 9182-9185.

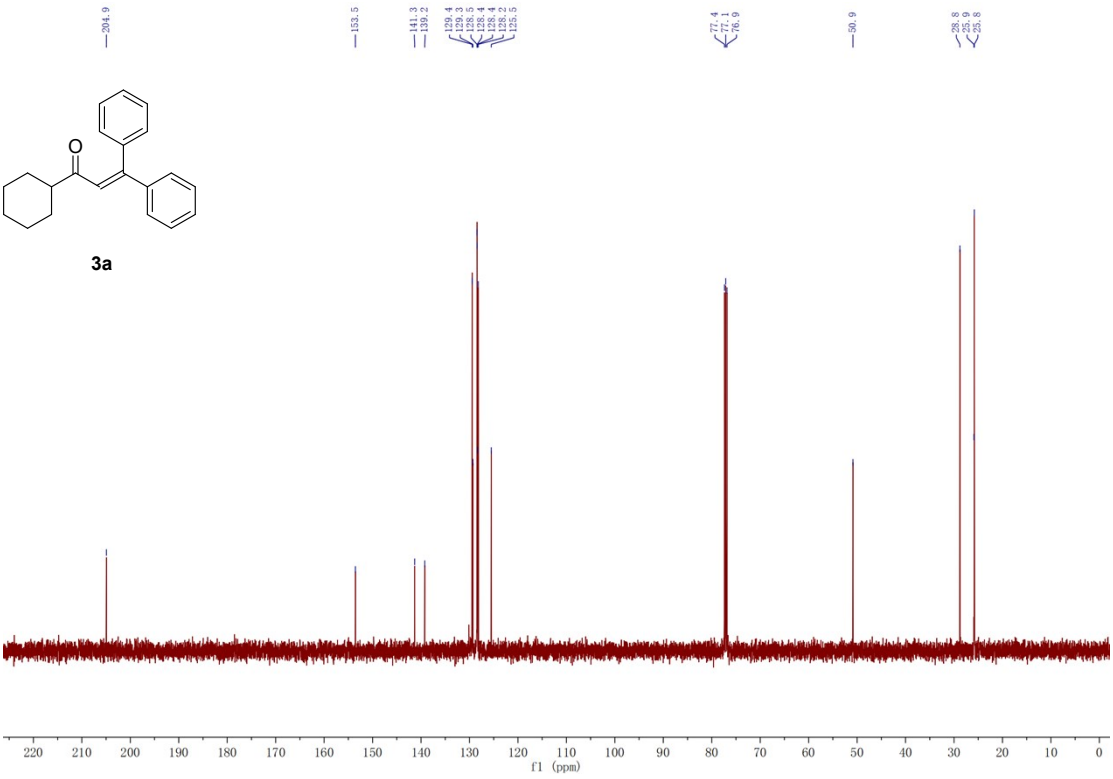
(12) Kerr, W. J.; Mudd, R. J.; Brown, *J. A. Chem. Eur. J.* **2016**, *22*, 4738-4742.

7. NMR Spectra of New Compounds and Products

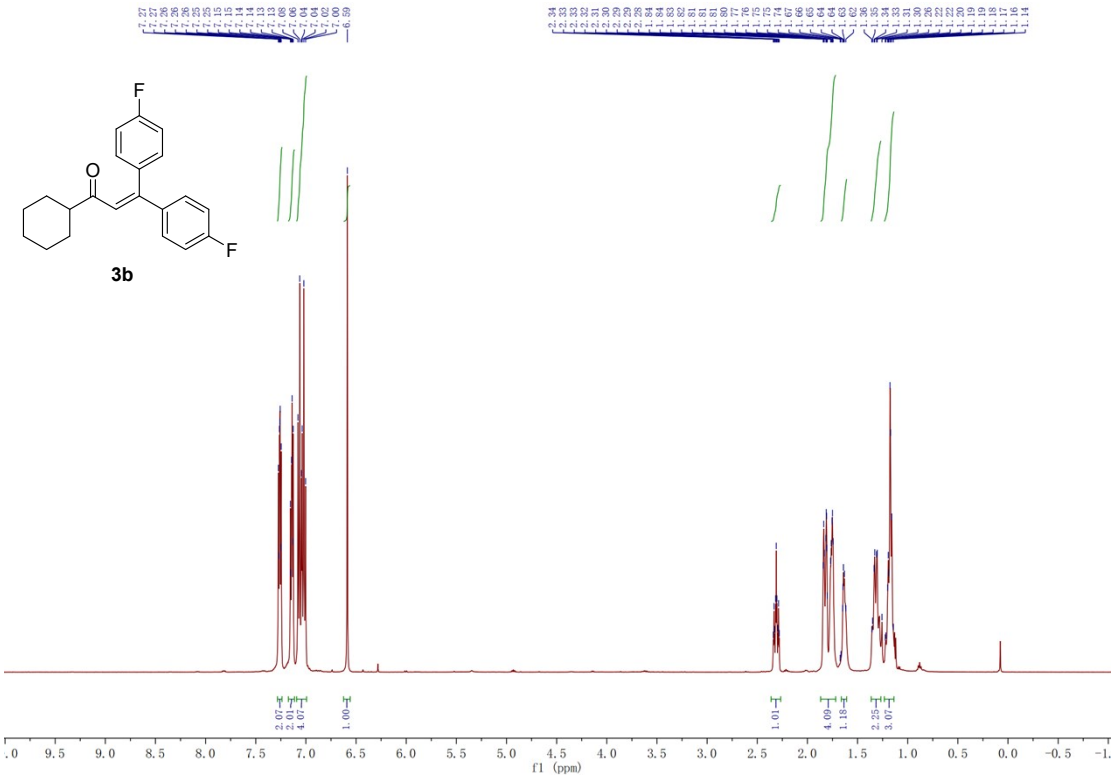
^{1}H NMR spectrum of **3a** in $CDCl_3$ at 500 MHz



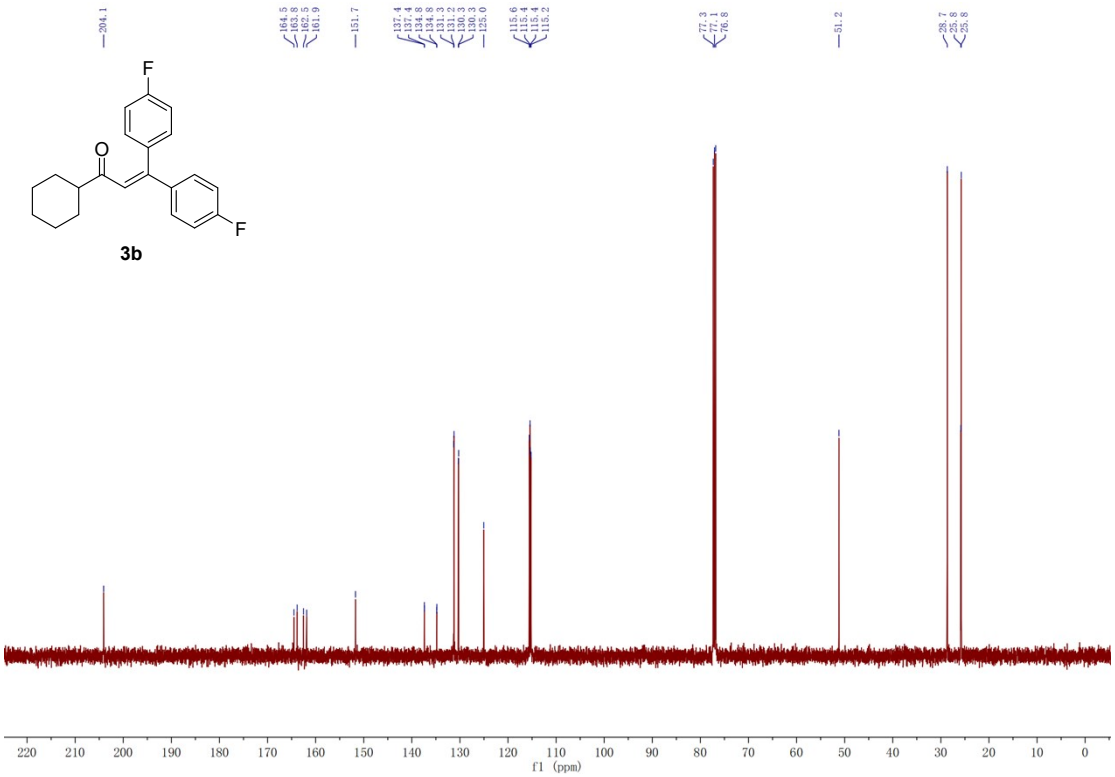
^{13}C NMR spectrum of **3a** in $CDCl_3$ at 126 MHz



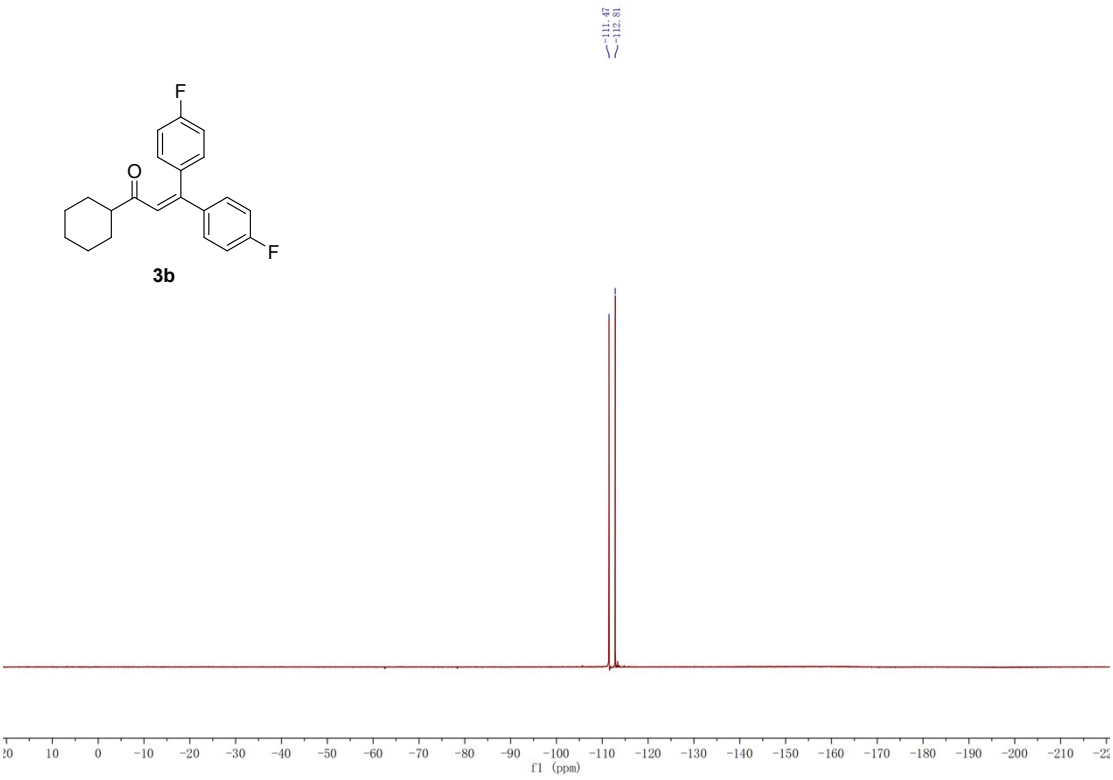
^{1}H NMR spectrum of **3b** in $CDCl_3$ at 500 MHz



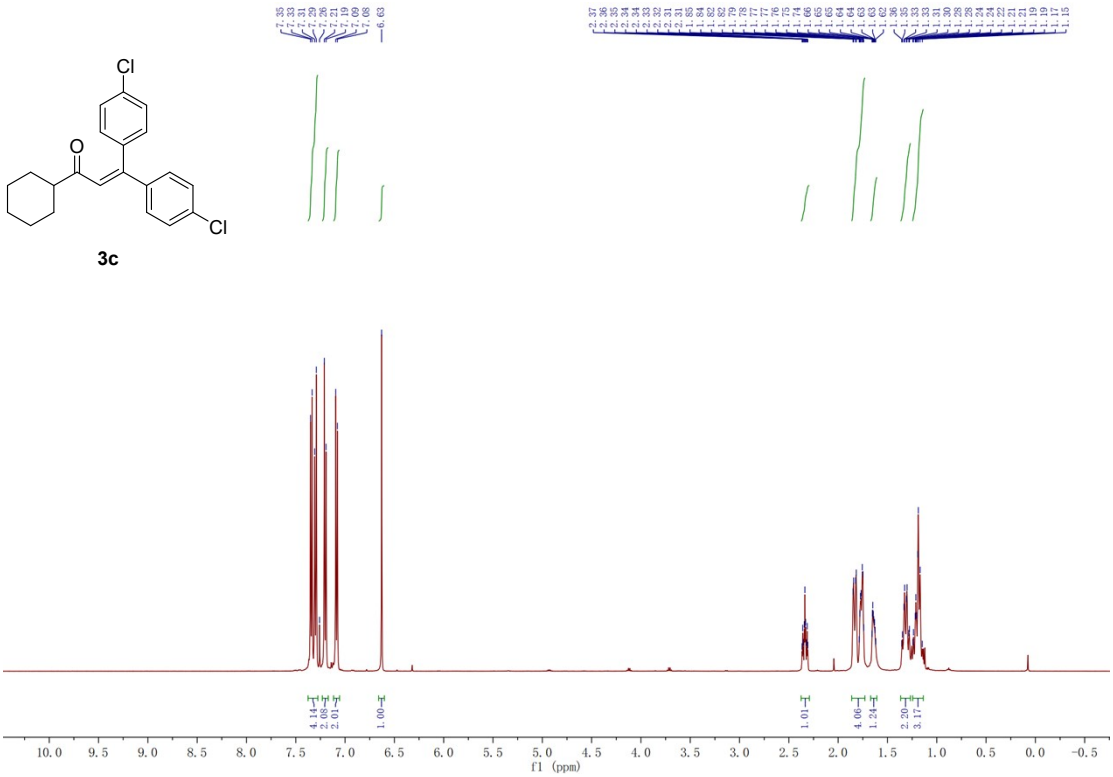
^{13}C NMR spectrum of **3b** in $CDCl_3$ at 126 MHz



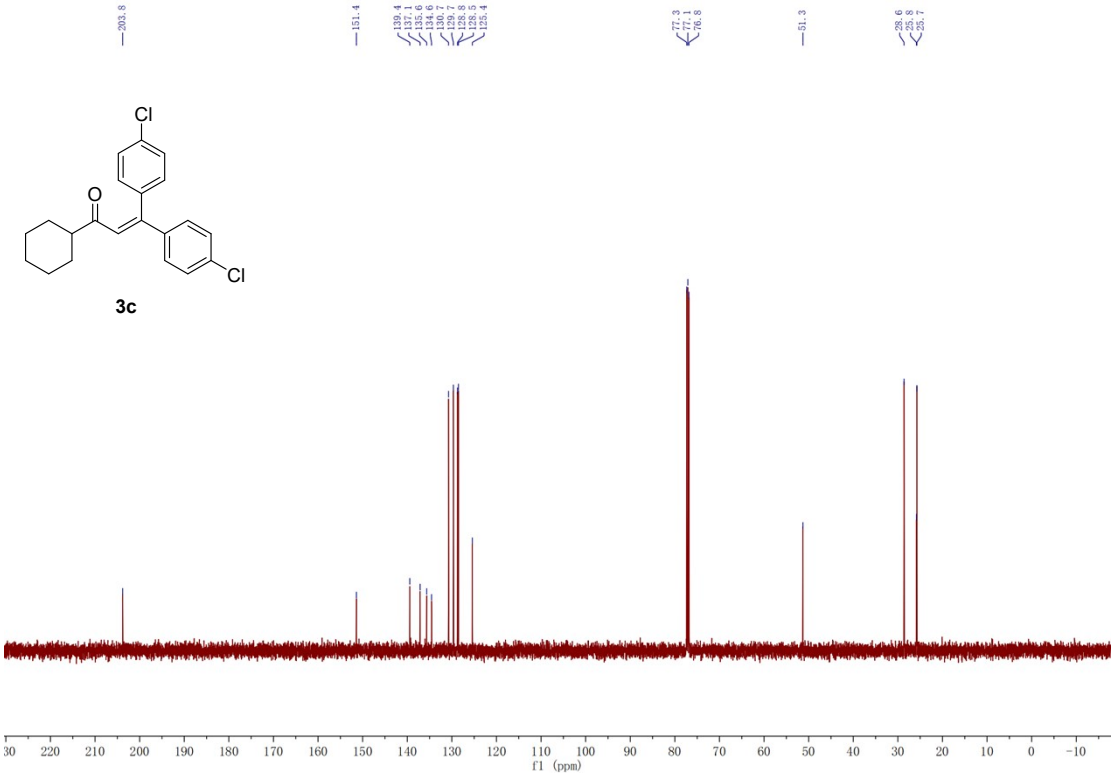
^{19}F NMR spectrum of **3b** in $CDCl_3$ at 470 MHz



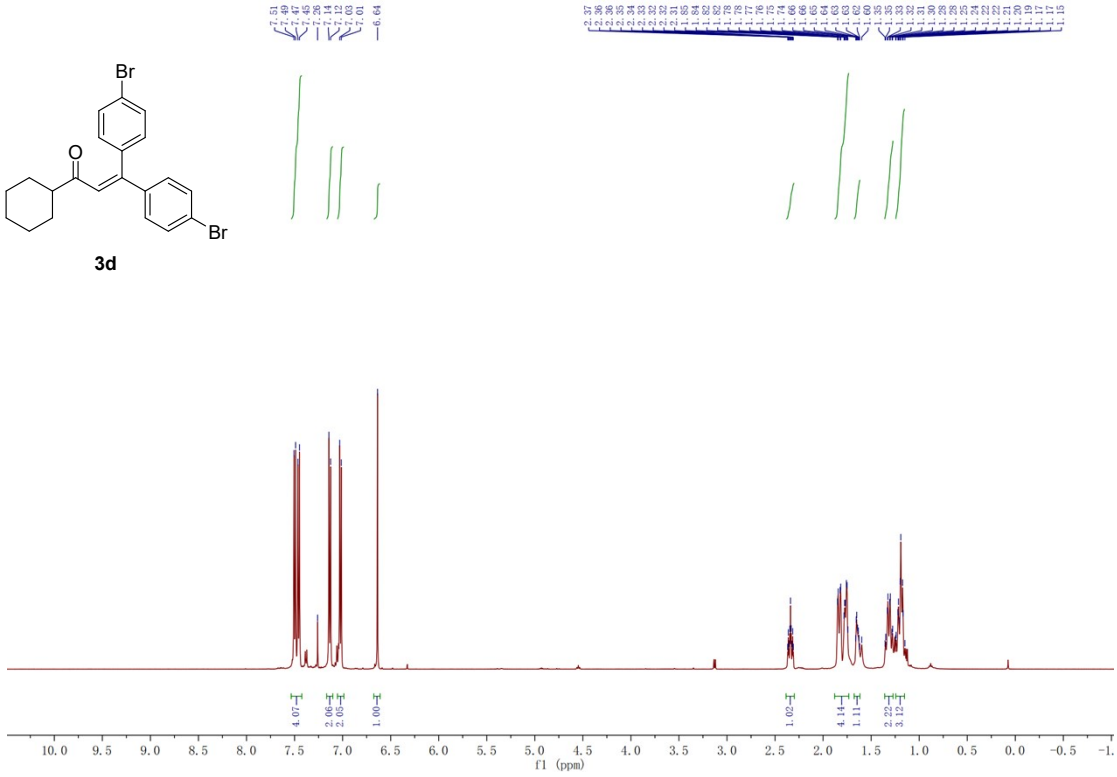
^{1}H NMR spectrum of **3c** in $CDCl_3$ at 500 MHz



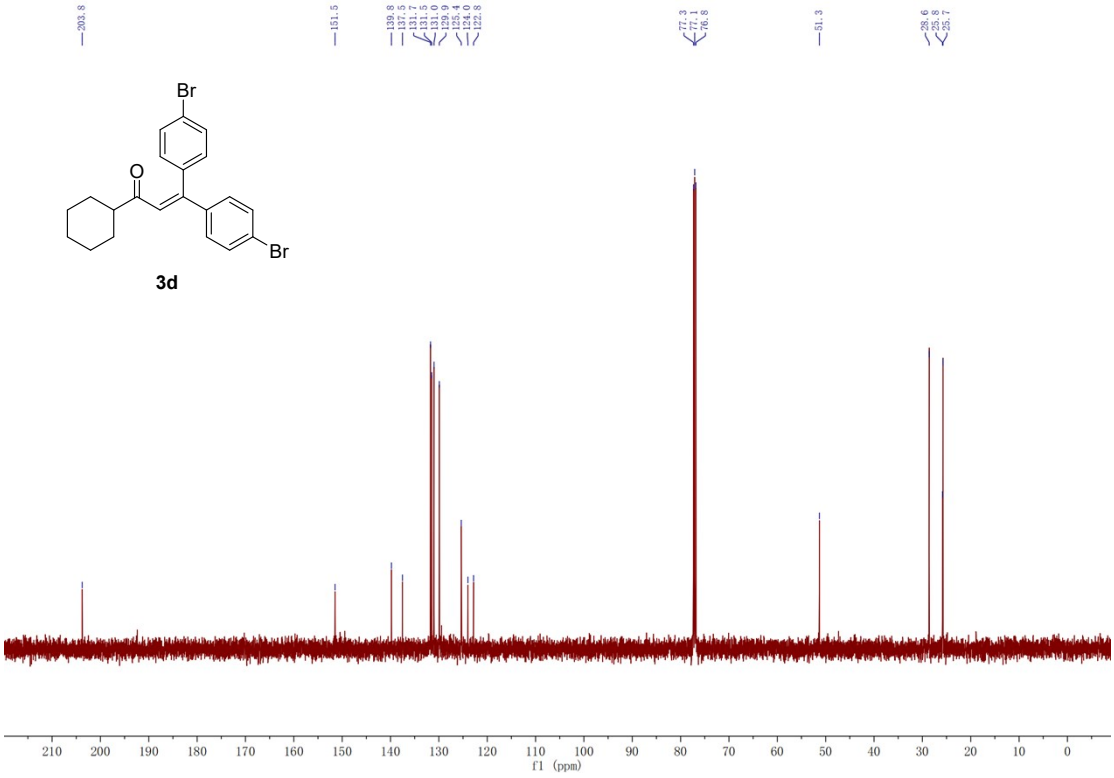
^{13}C NMR spectrum of **3c** in $CDCl_3$ at 126 MHz



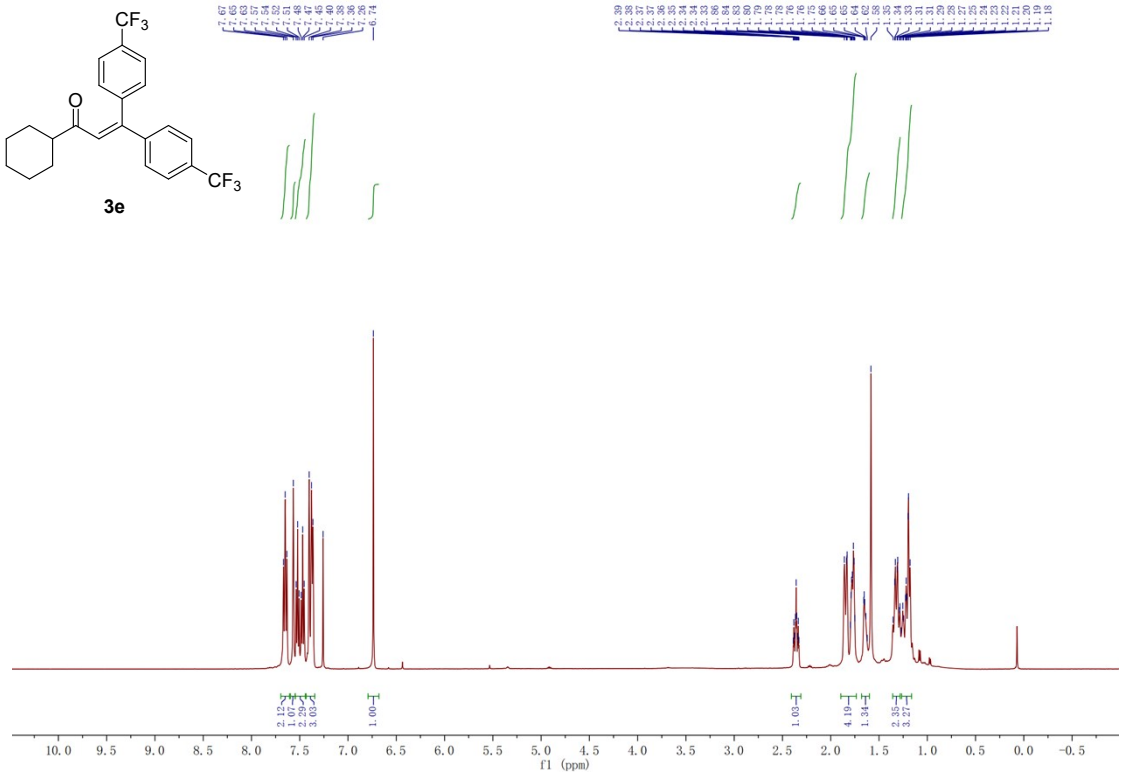
^{1}H NMR spectrum of **3d** in $CDCl_3$ at 500 MHz



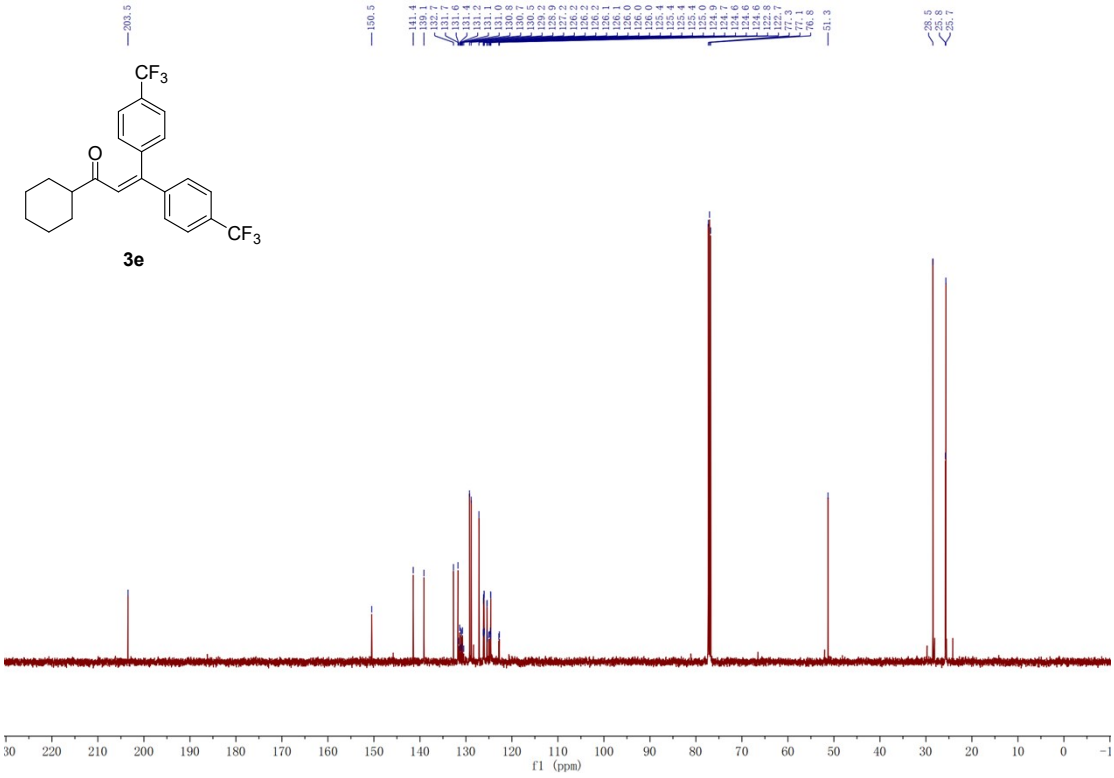
^{13}C NMR spectrum of **3d** in $CDCl_3$ at 126 MHz



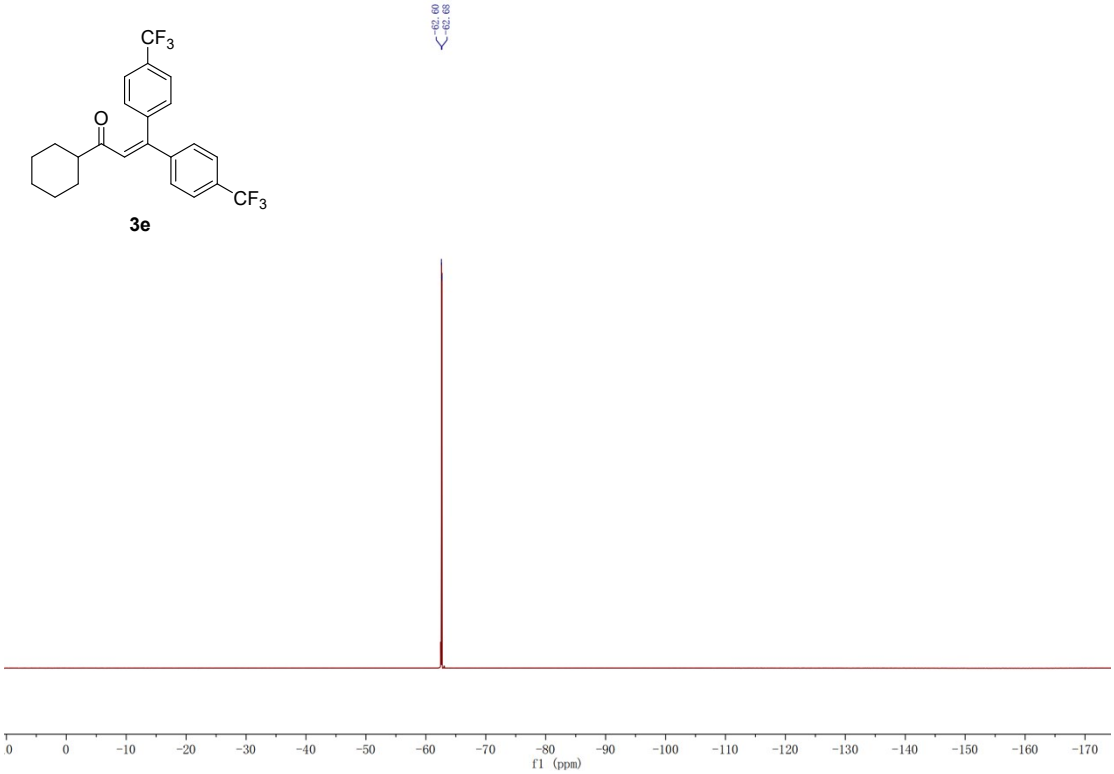
^{1}H NMR spectrum of **3e** in $CDCl_3$ at 500 MHz



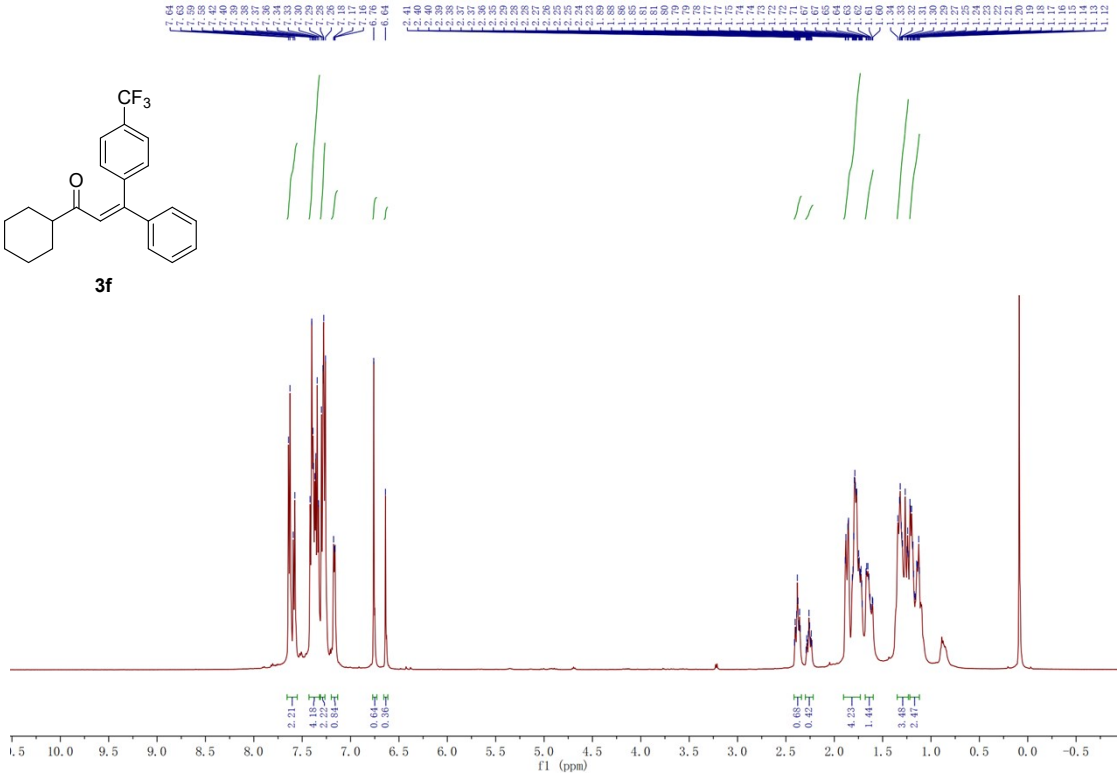
^{13}C NMR spectrum of **3e** in $CDCl_3$ at 126 MHz



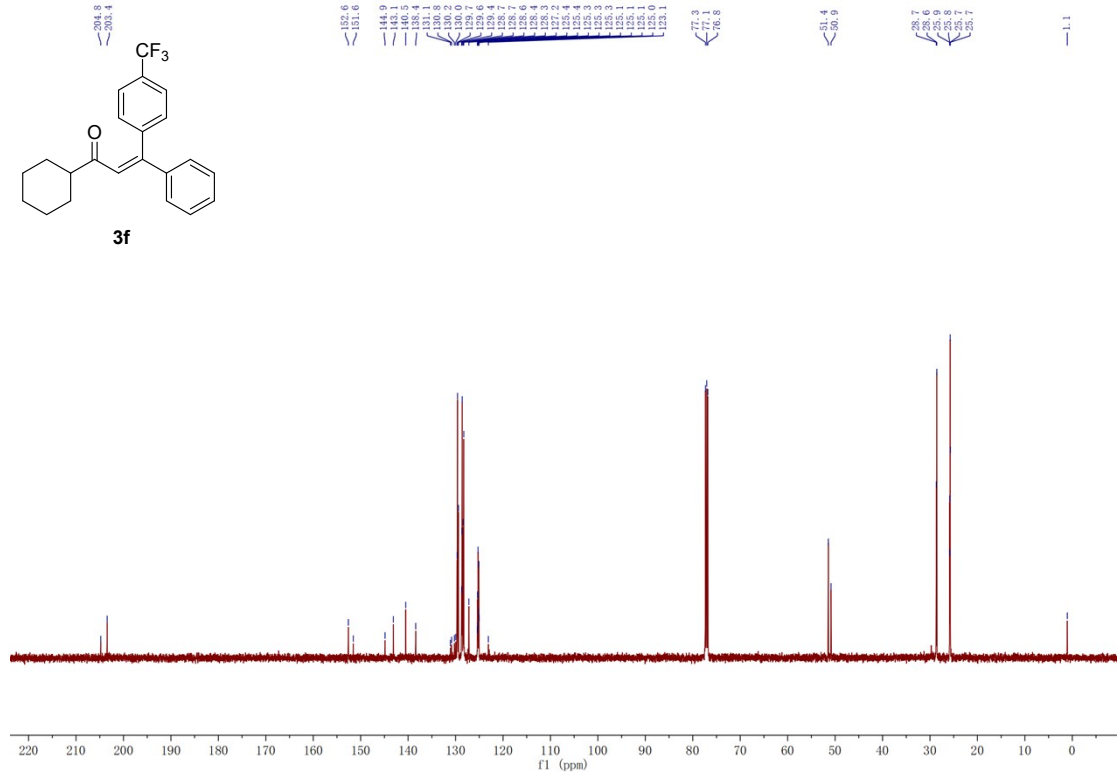
^{19}F NMR spectrum of **3e** in $CDCl_3$ at 470 MHz



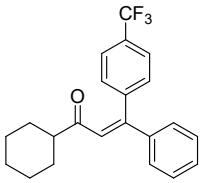
^{1}H NMR spectrum of **3f** in $CDCl_3$ at 500 MHz



^{13}C NMR spectrum of **3f** in $CDCl_3$ at 126 MHz

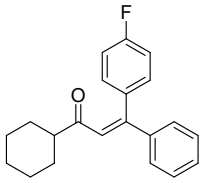


^{19}F NMR spectrum of **3f** in $CDCl_3$ at 470 MHz



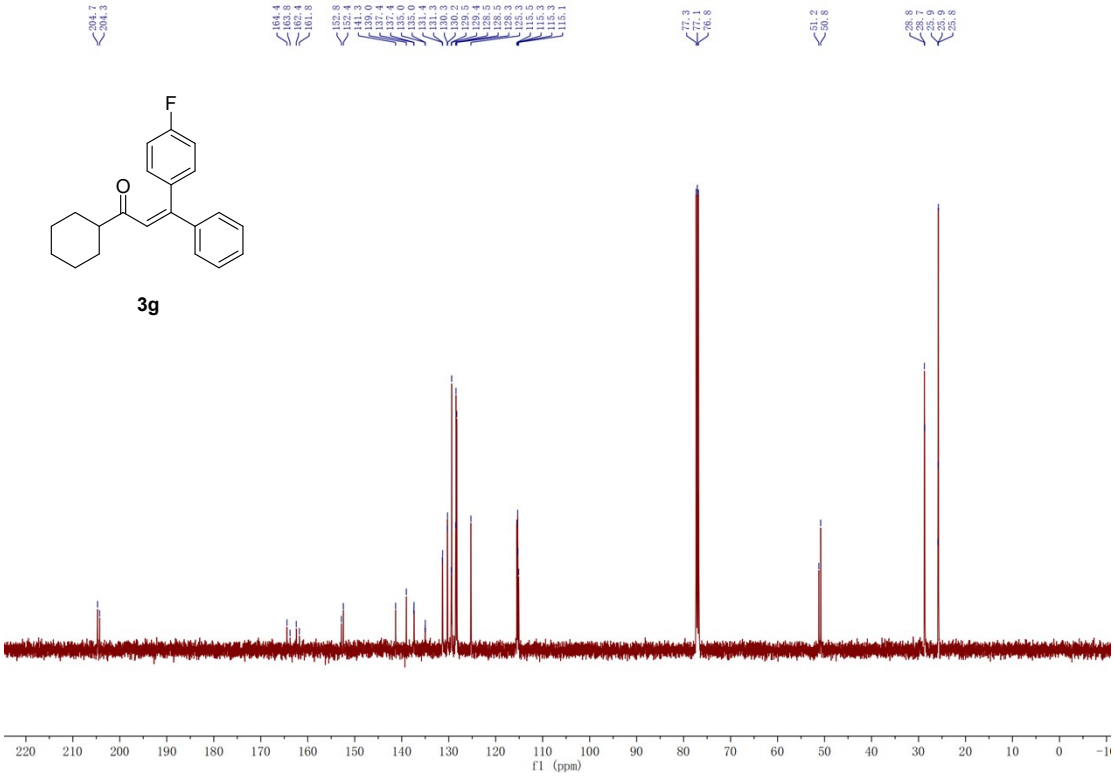
3f

^{1}H NMR spectrum of **3g** in $CDCl_3$ at 500 MHz

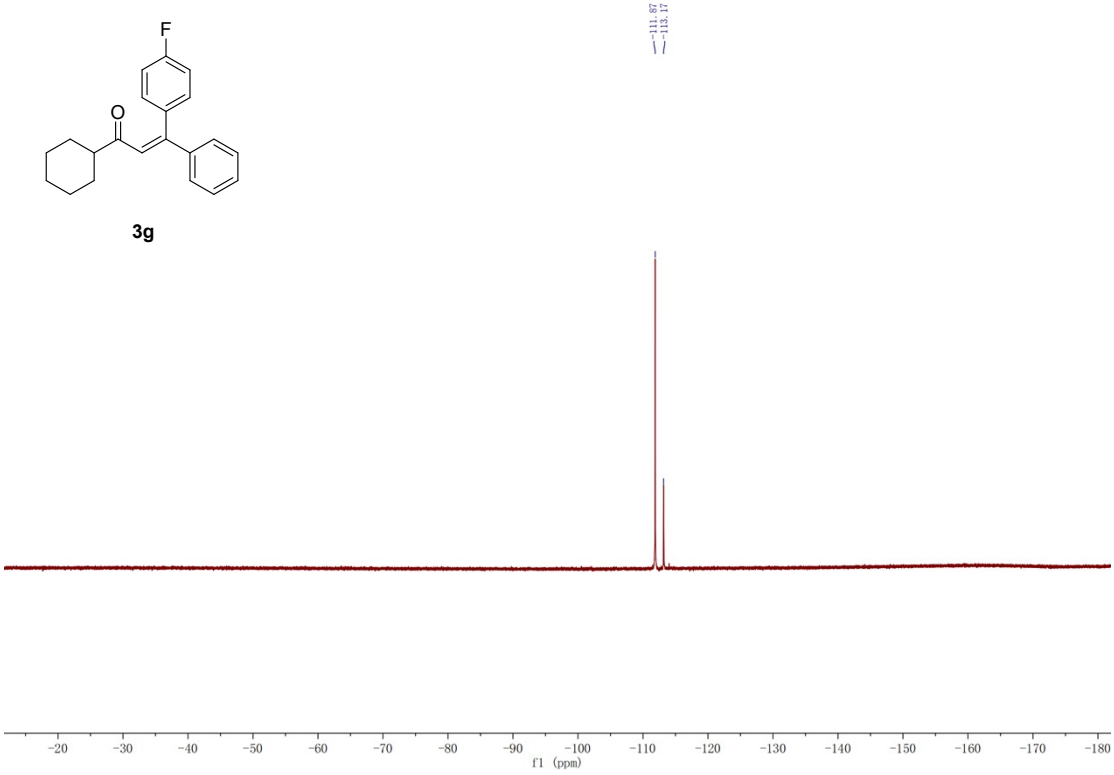


3g

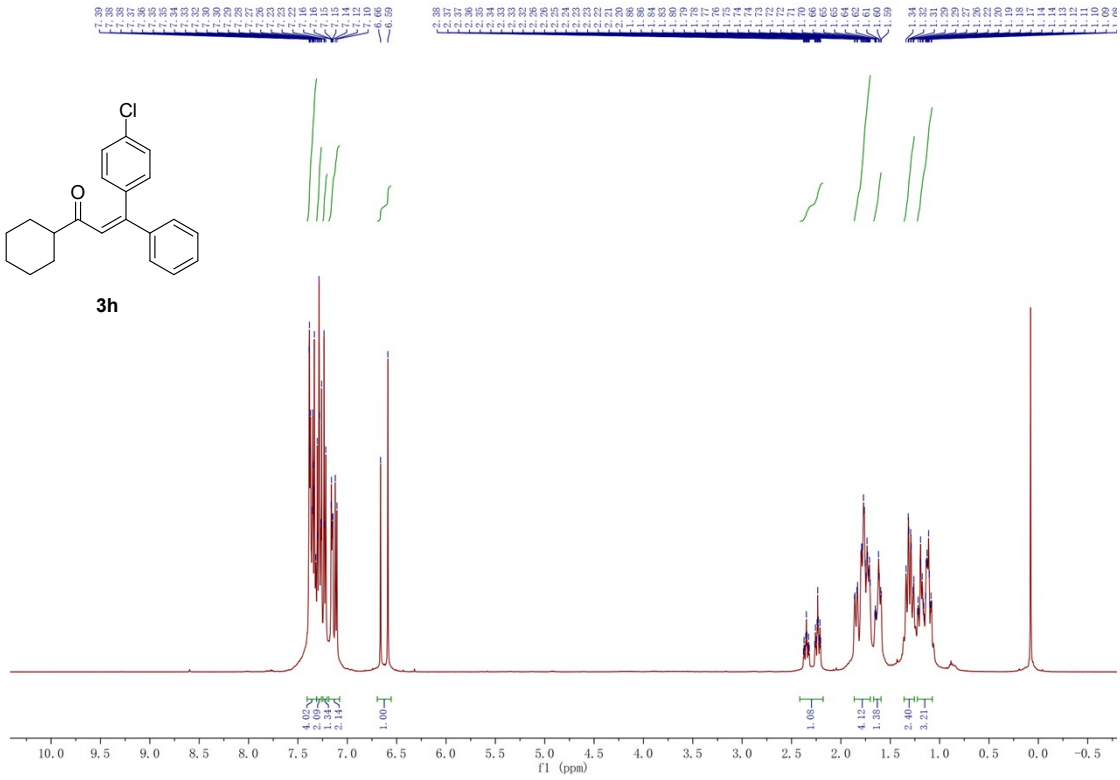
^{13}C NMR spectrum of **3g** in $CDCl_3$ at 126 MHz



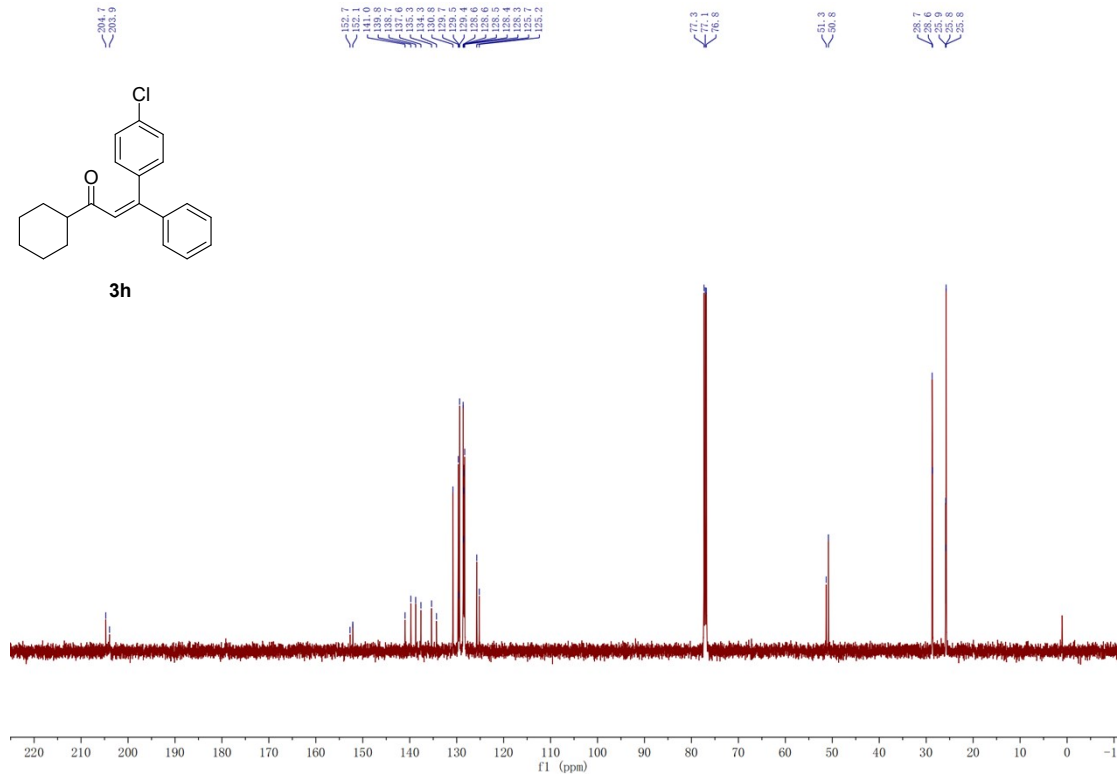
^{19}F NMR spectrum of **3g** in $CDCl_3$ at 470 MHz



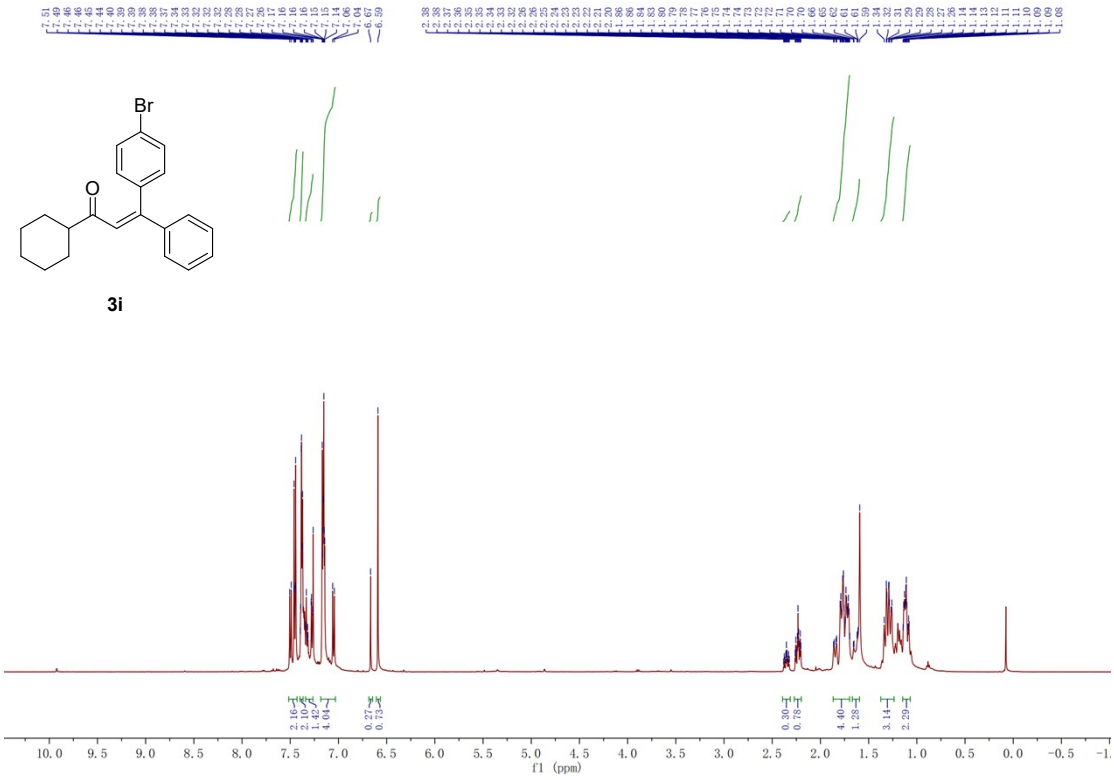
^{1}H NMR spectrum of **3h** in $CDCl_3$ at 500 MHz



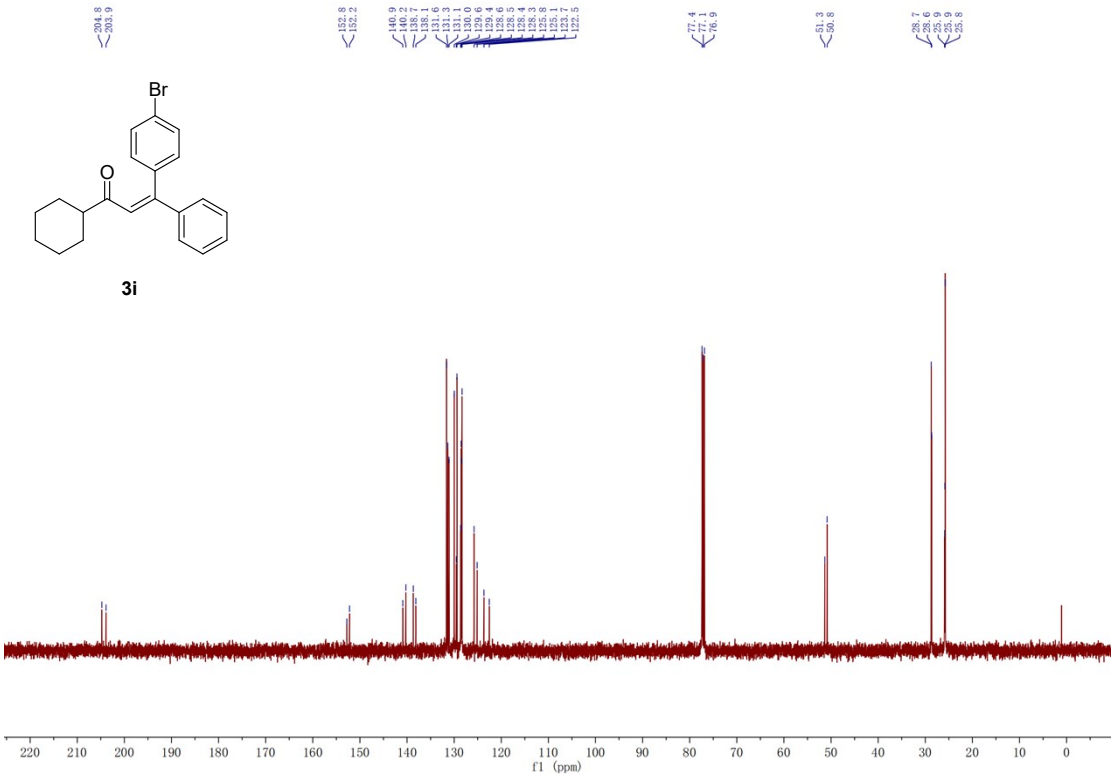
^{13}C NMR spectrum of **3h** in $CDCl_3$ at 126 MHz



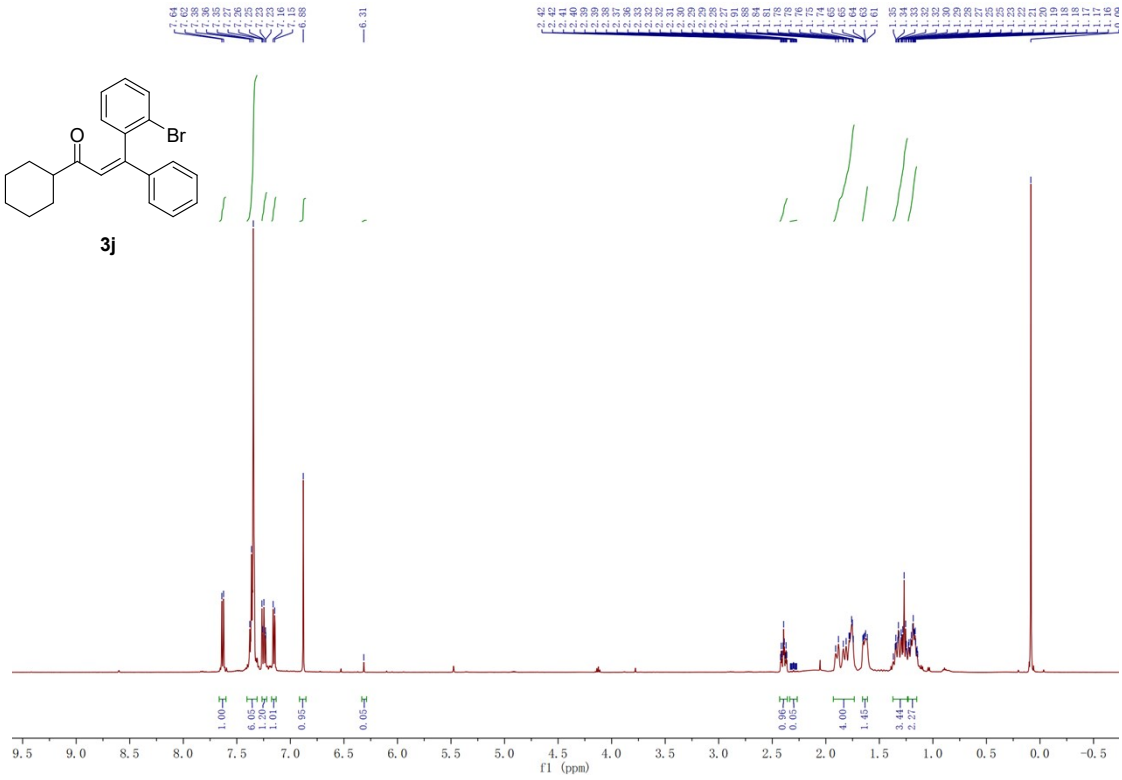
^{1}H NMR spectrum of **3i** in $CDCl_3$ at 500 MHz



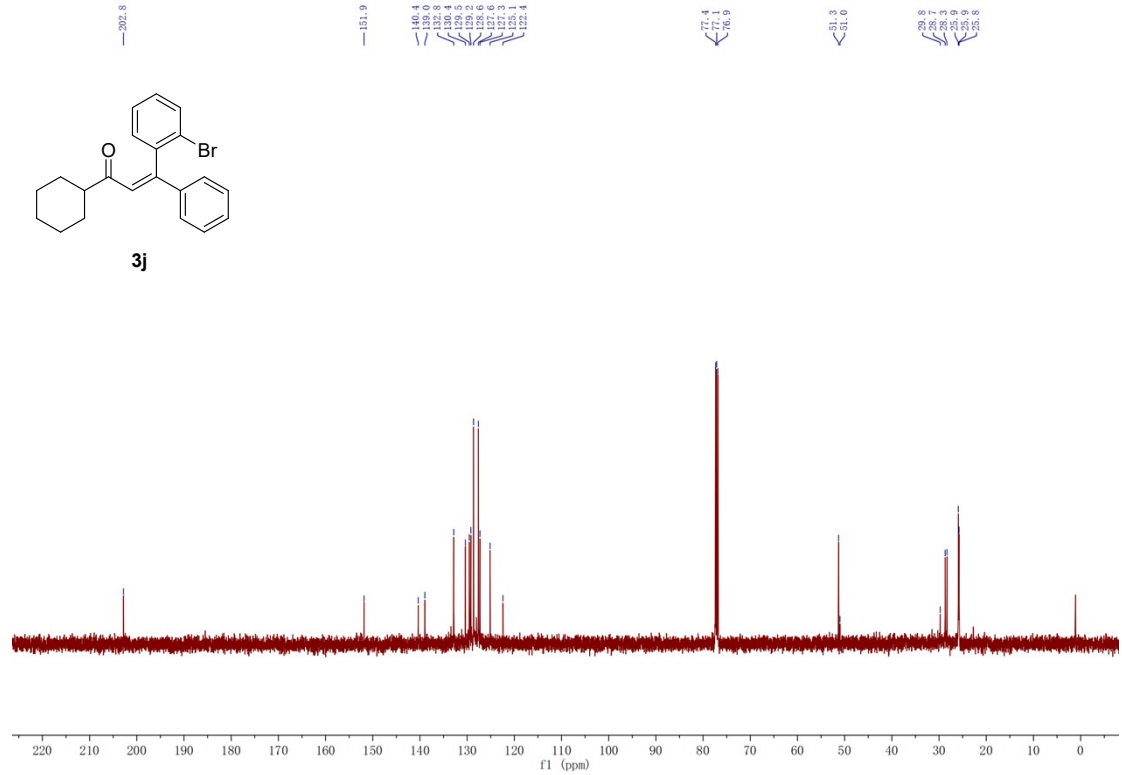
^{13}C NMR spectrum of **3i** in $CDCl_3$ at 126 MHz



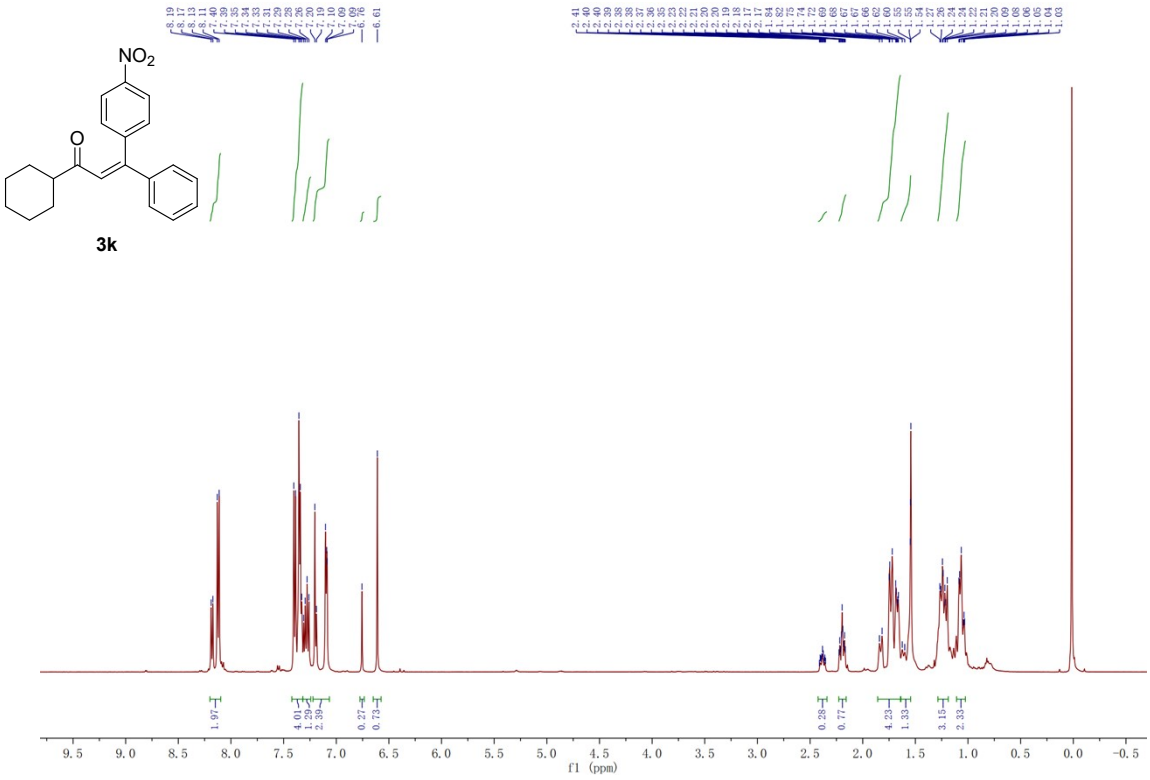
^{1}H NMR spectrum of **3j** in $CDCl_3$ at 500 MHz



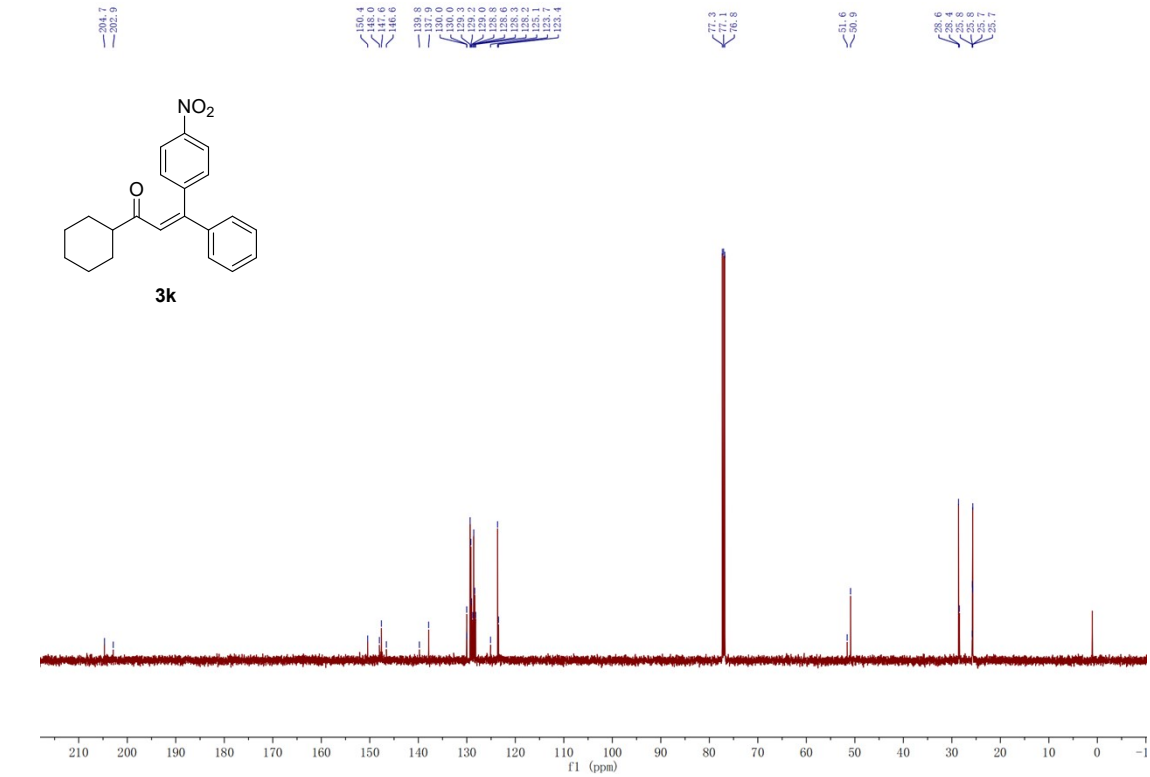
^{13}C NMR spectrum of **3j** in $CDCl_3$ at 126 MHz



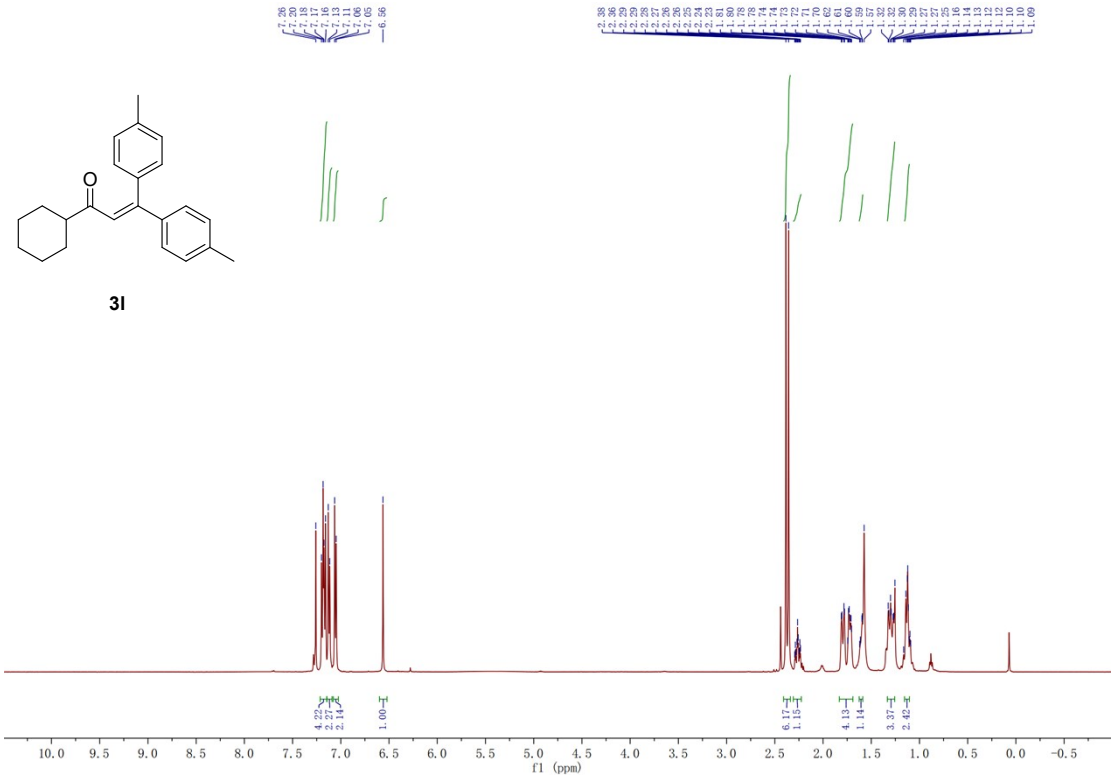
^{1}H NMR spectrum of **3k** in $CDCl_3$ at 500 MHz



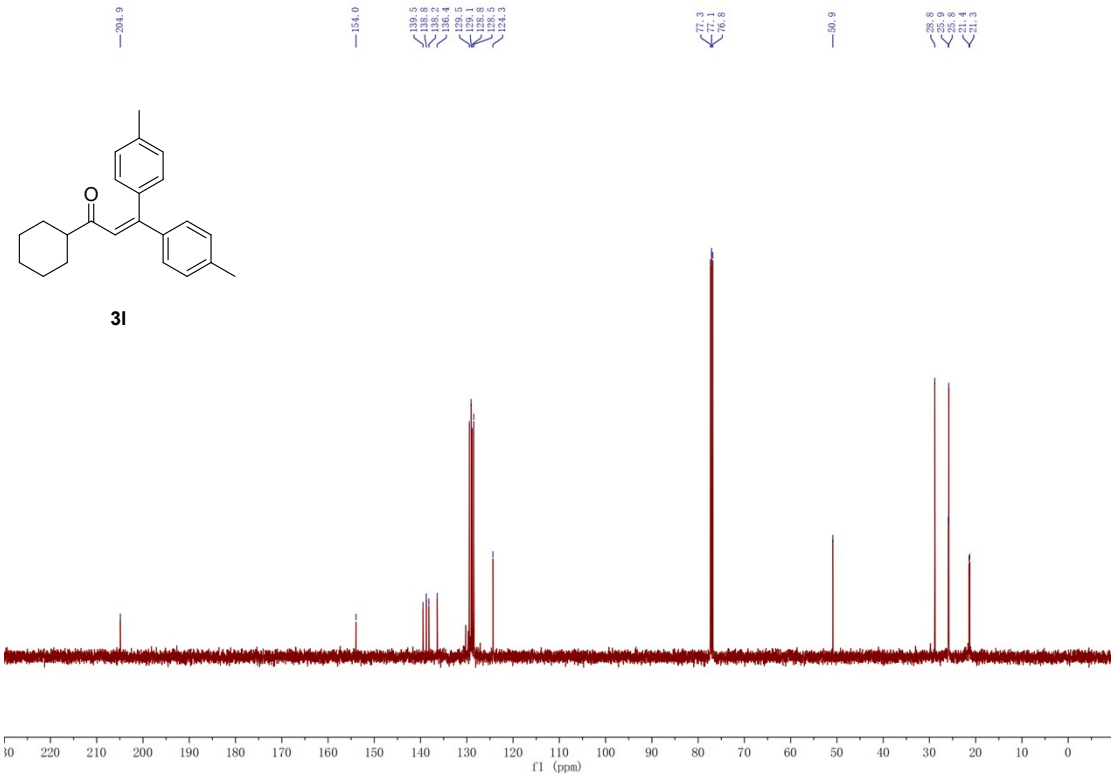
^{13}C NMR spectrum of **3k** in $CDCl_3$ at 126 MHz



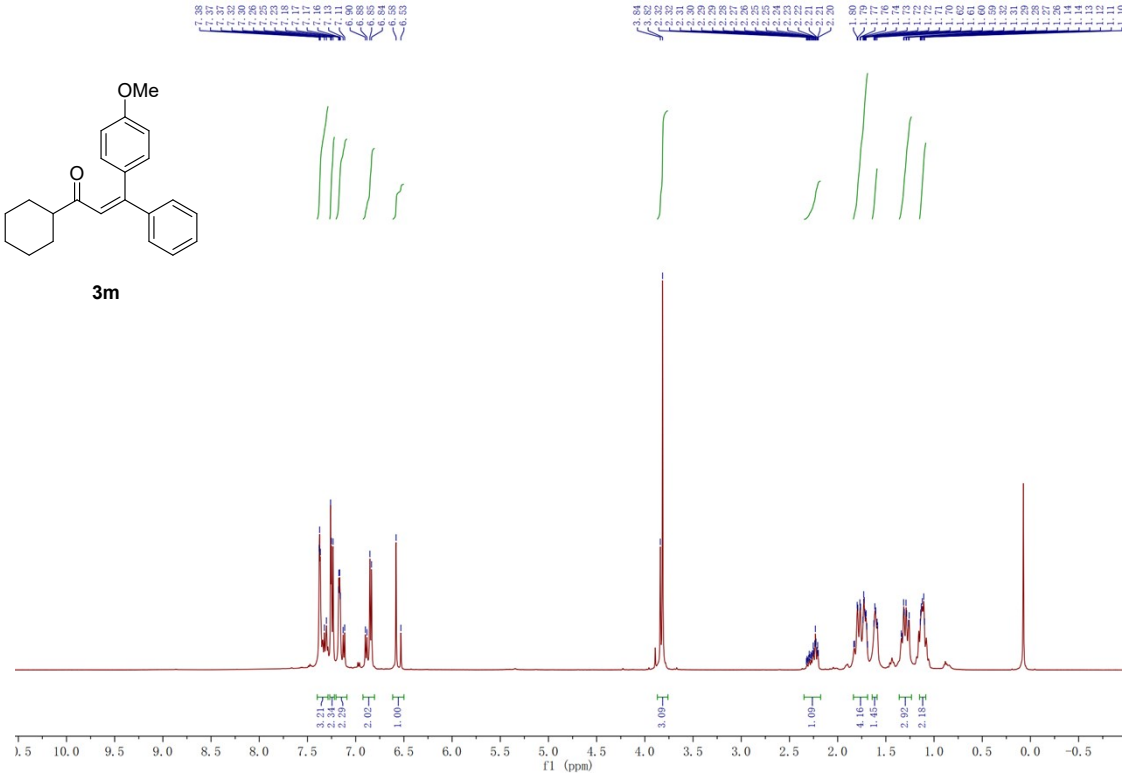
^{1}H NMR spectrum of **3l** in $CDCl_3$ at 500 MHz



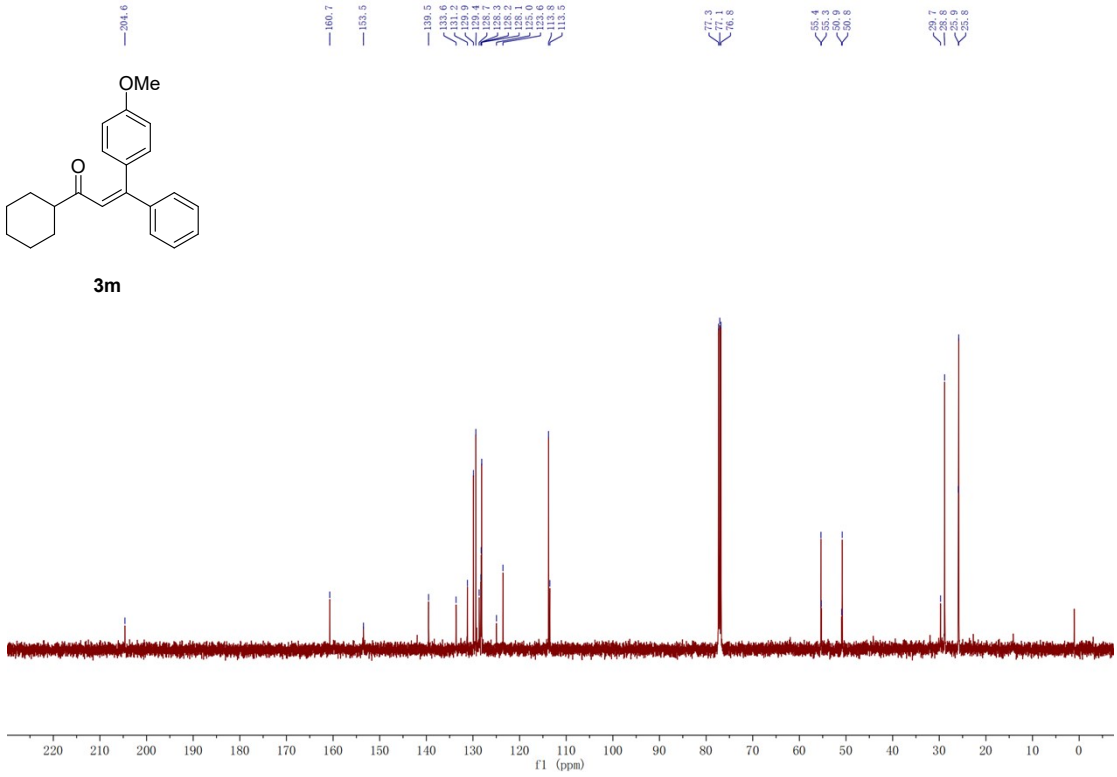
^{13}C NMR spectrum of **3l** in $CDCl_3$ at 126 MHz



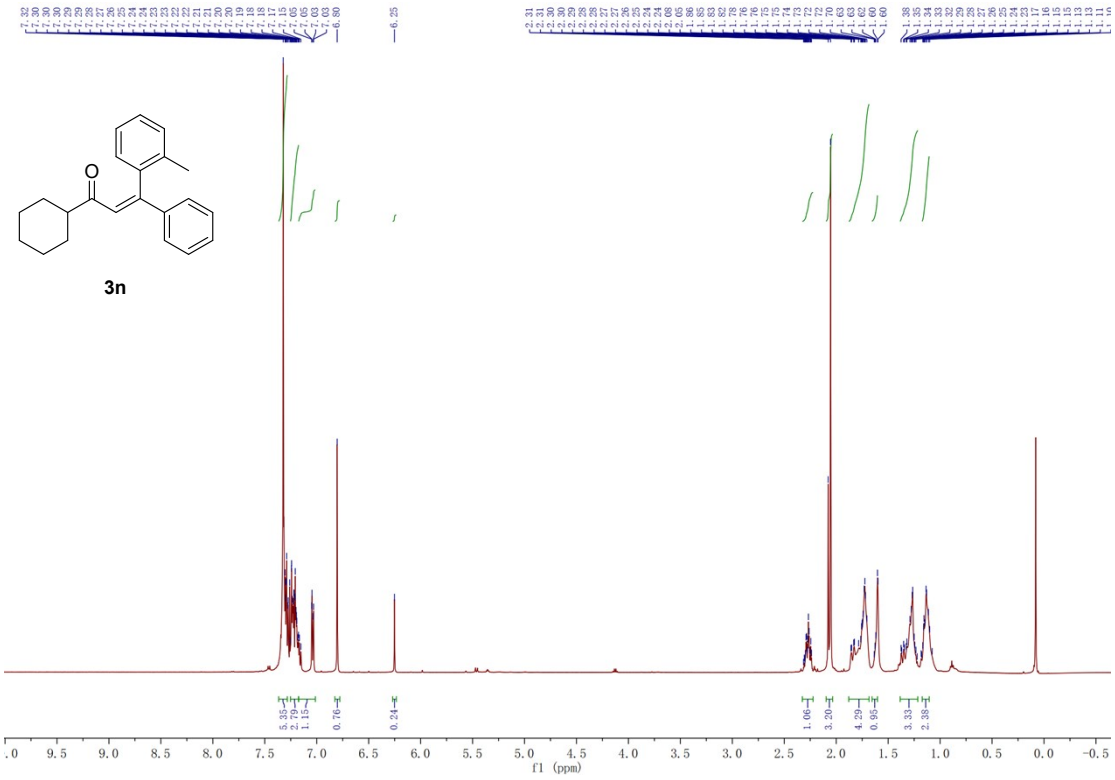
^{1}H NMR spectrum of **3m** in $CDCl_3$ at 500 MHz



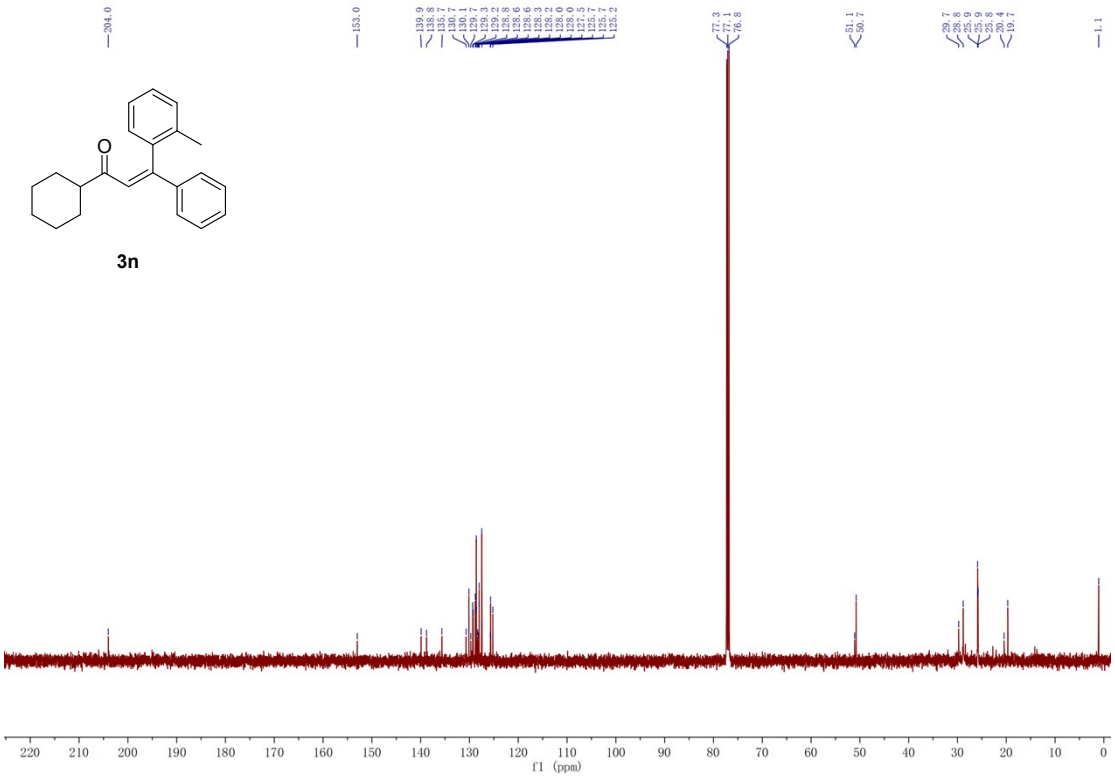
^{13}C NMR spectrum of **3m** in $CDCl_3$ at 126 MHz



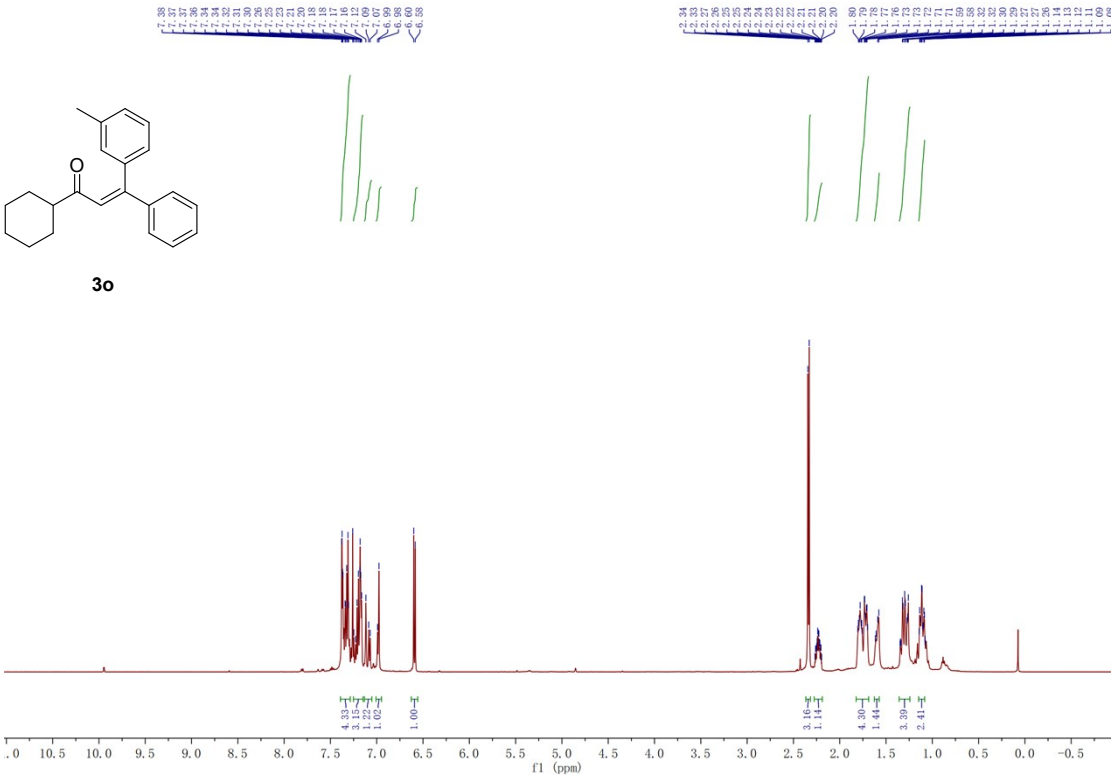
^{1}H NMR spectrum of **3n** in $CDCl_3$ at 500 MHz



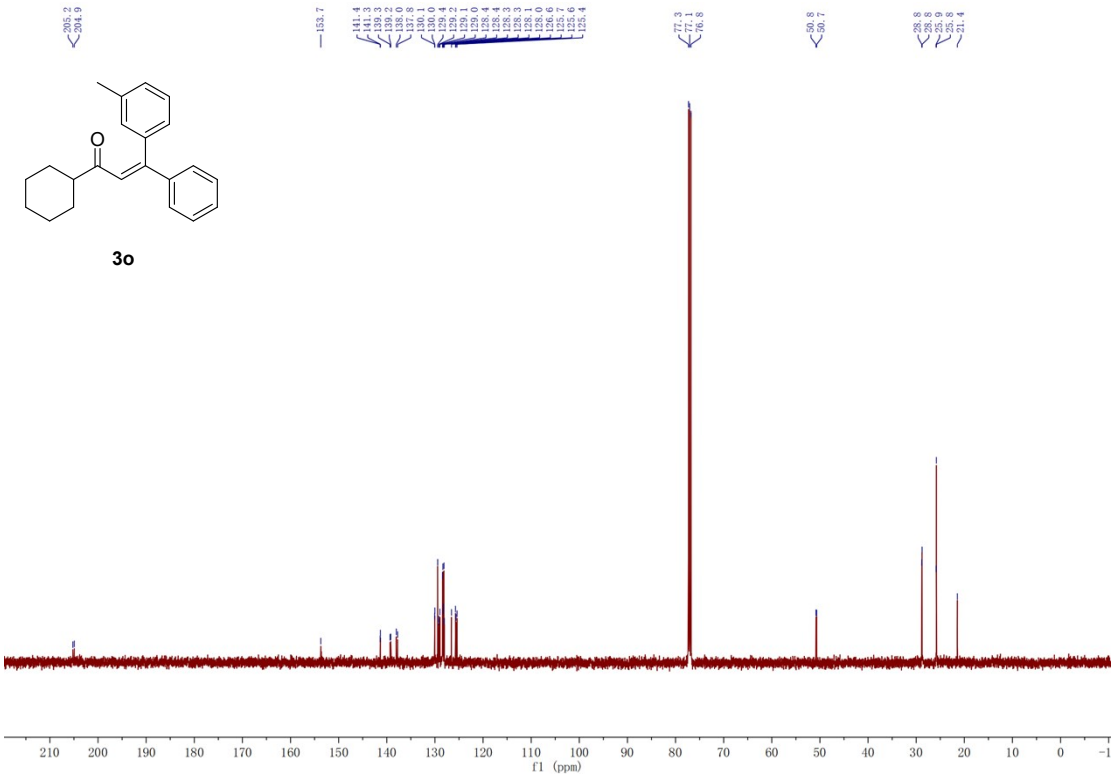
^{13}C NMR spectrum of **3n** in $CDCl_3$ at 126 MHz



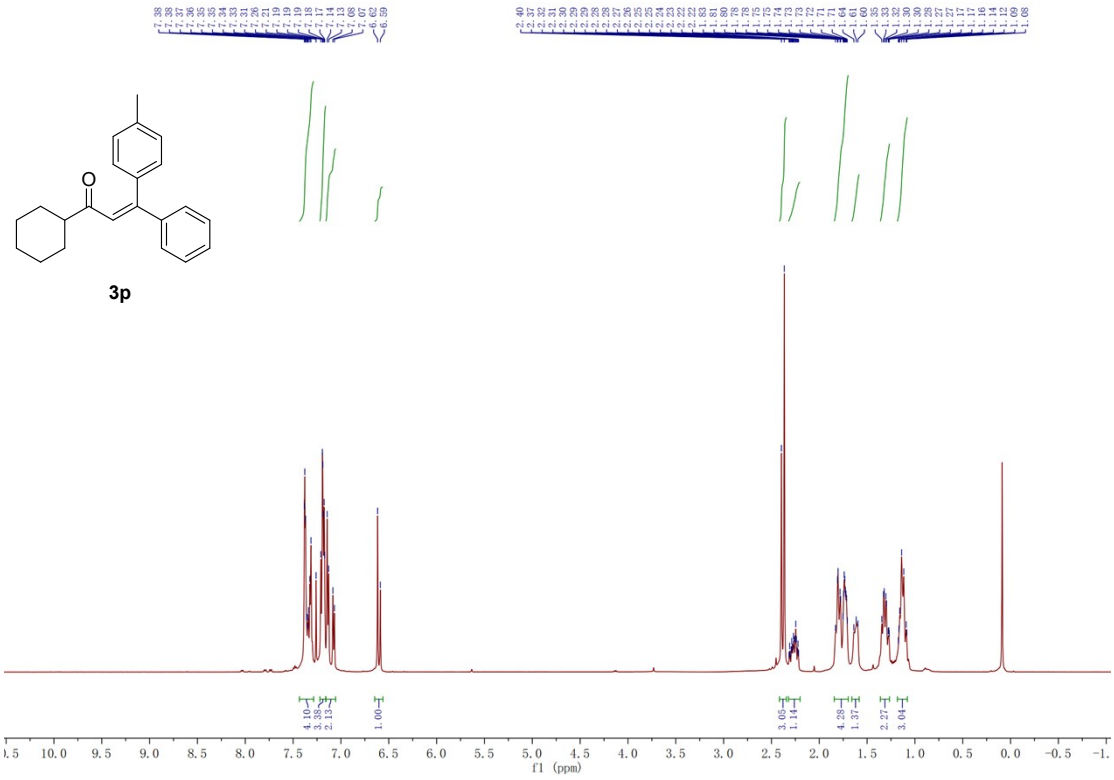
^{1}H NMR spectrum of **3o** in $CDCl_3$ at 500 MHz



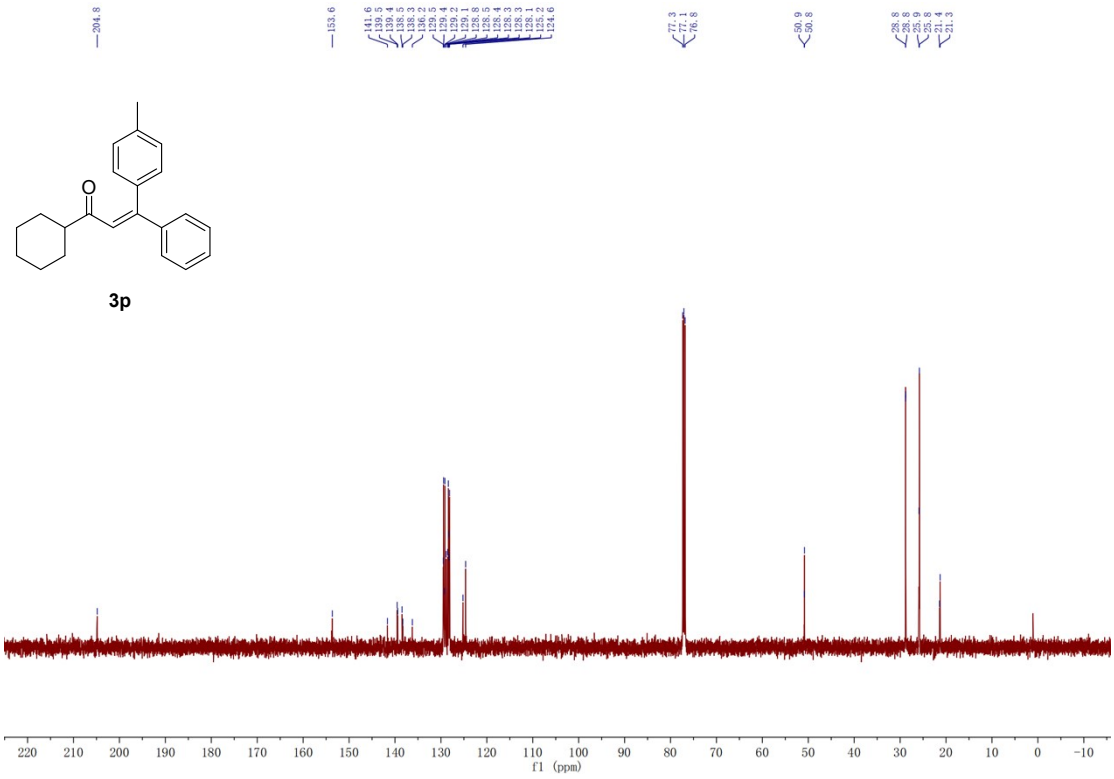
^{13}C NMR spectrum of **3o** in $CDCl_3$ at 126 MHz



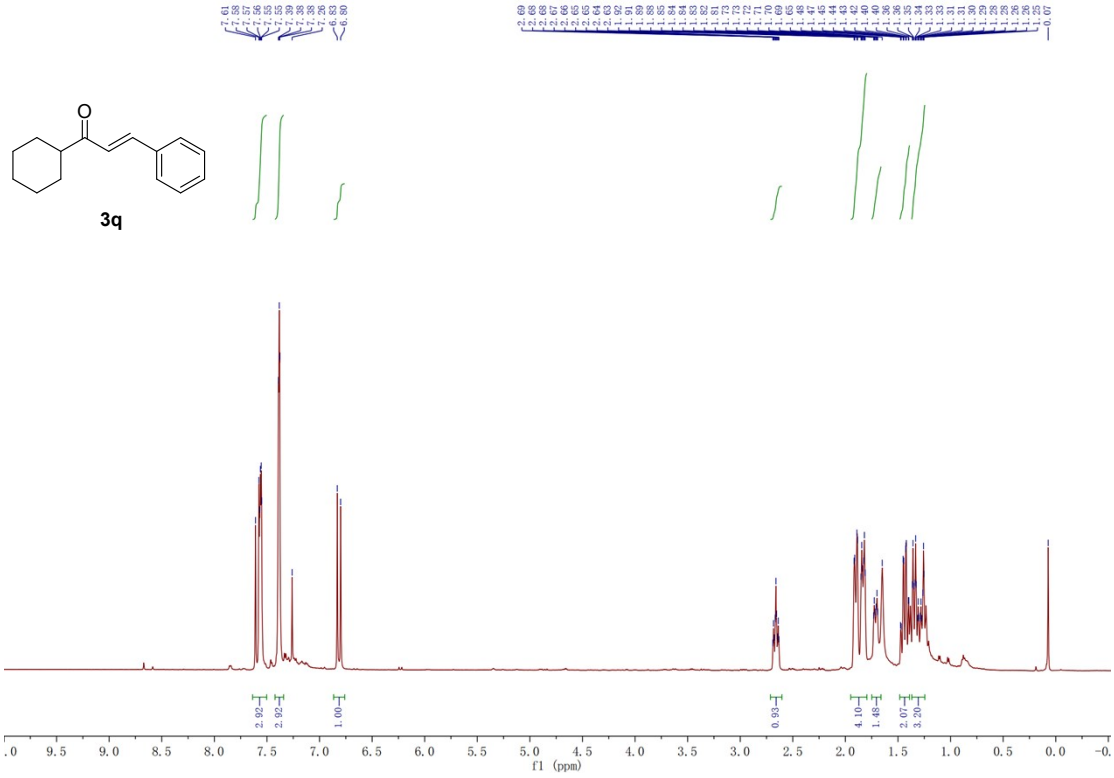
^{1}H NMR spectrum of **3p** in $CDCl_3$ at 500 MHz



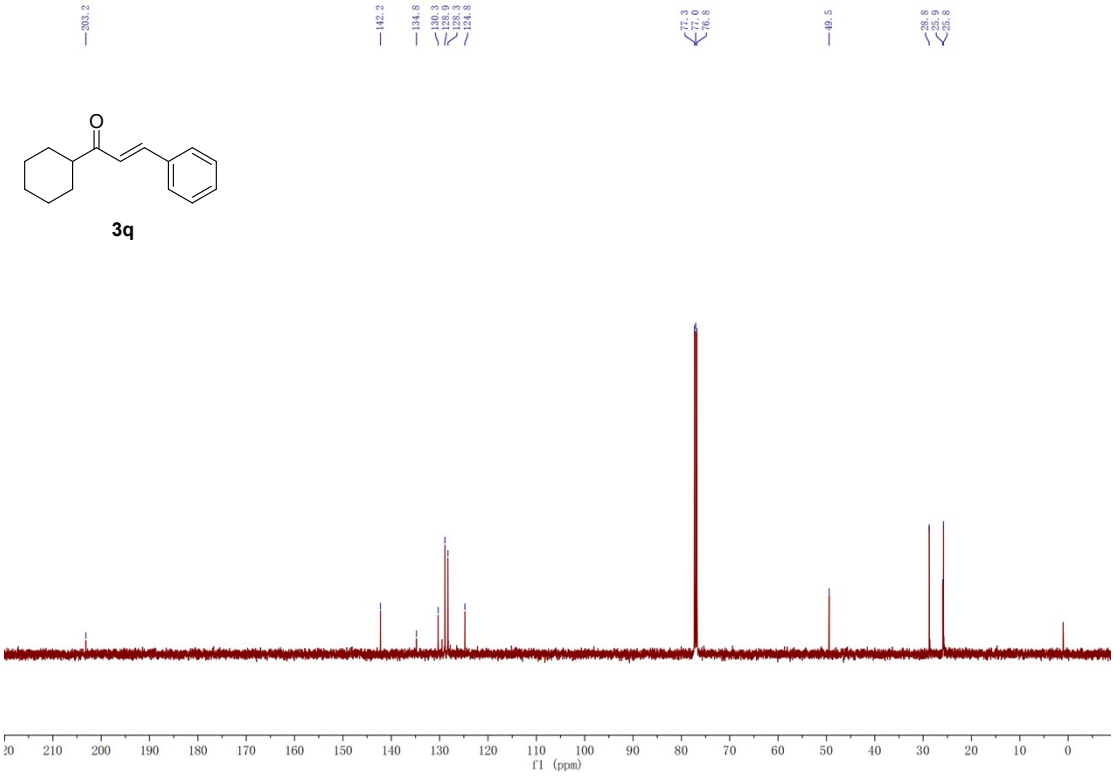
^{13}C NMR spectrum of **3p** in $CDCl_3$ at 126 MHz



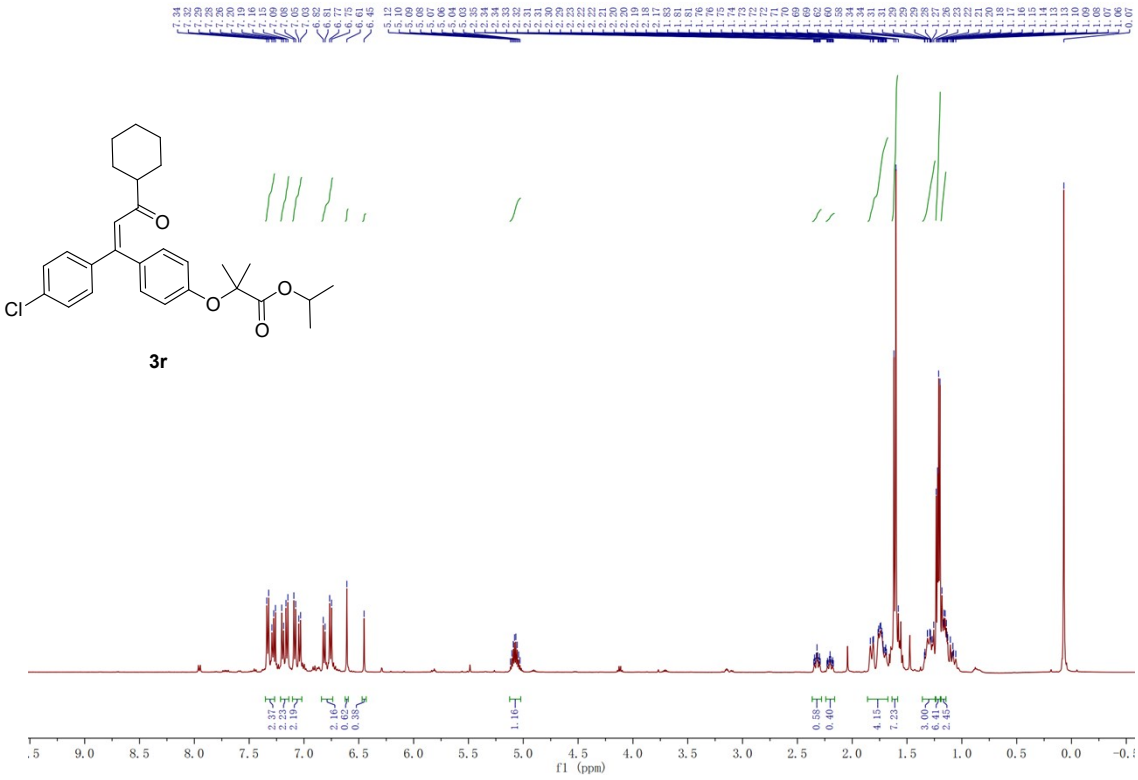
^{1}H NMR spectrum of **3q** in $CDCl_3$ at 500 MHz



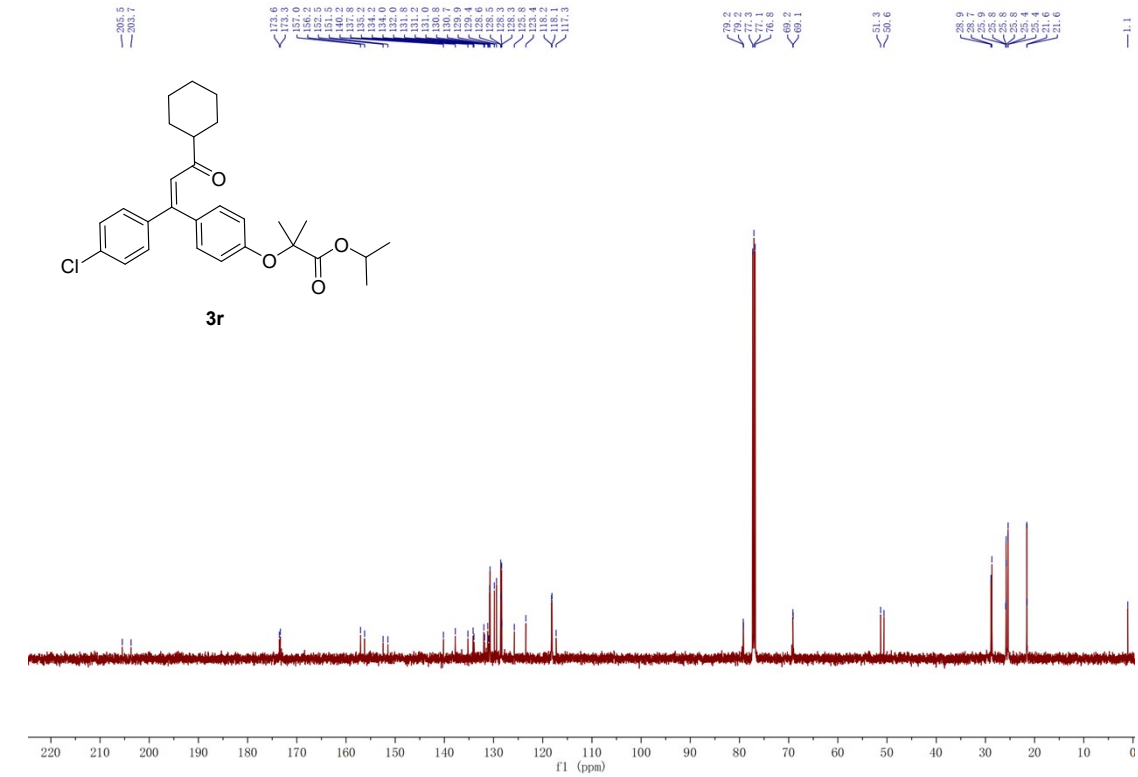
^{13}C NMR spectrum of **3q** in $CDCl_3$ at 126 MHz



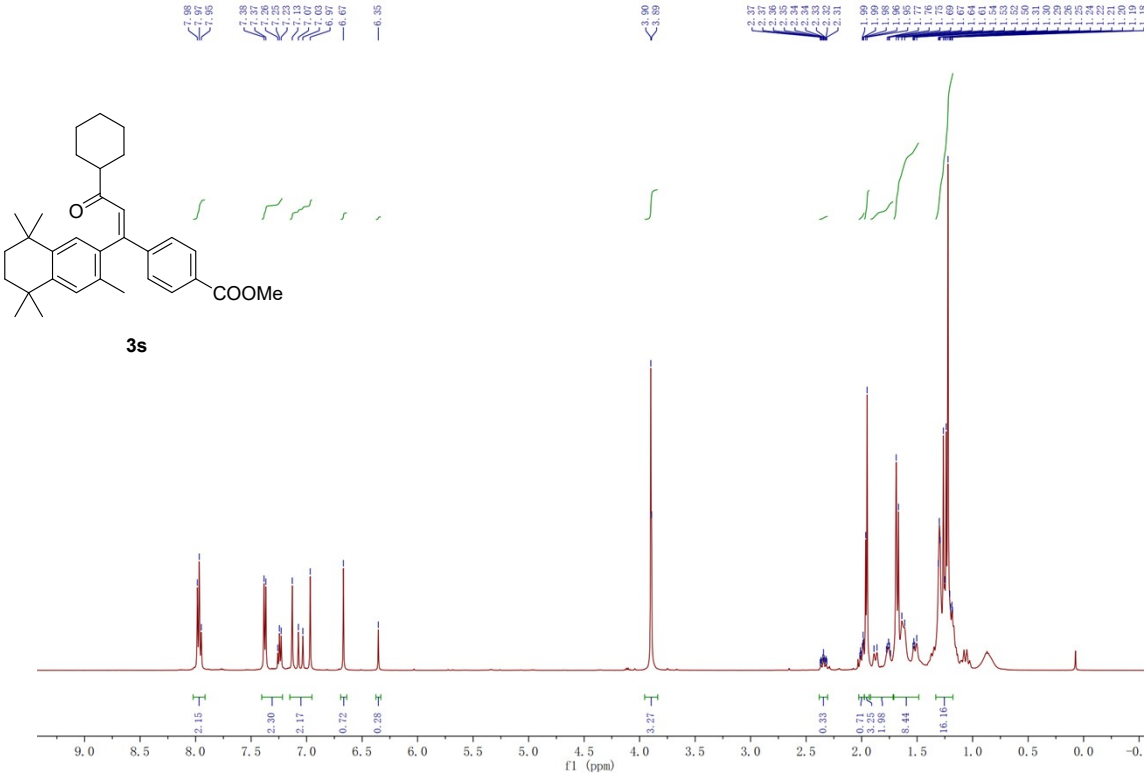
^{1}H NMR spectrum of **3r** in $CDCl_3$ at 500 MHz



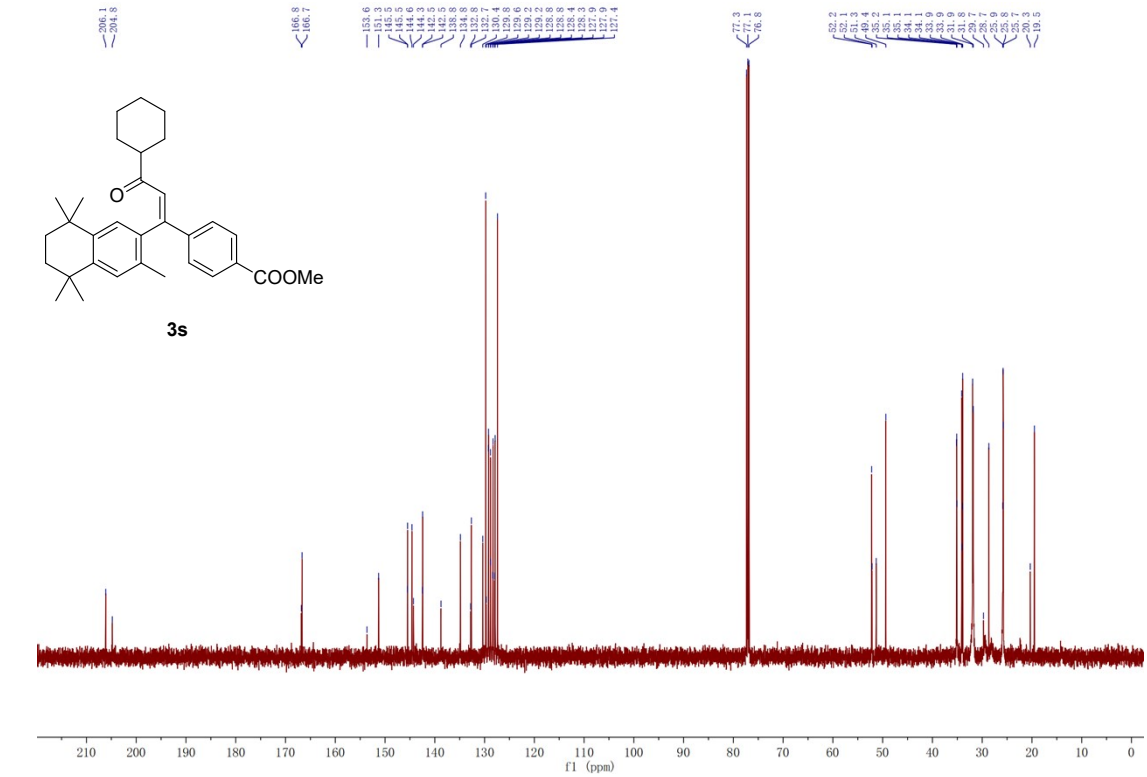
^{13}C NMR spectrum of **3r** in $CDCl_3$ at 126 MHz



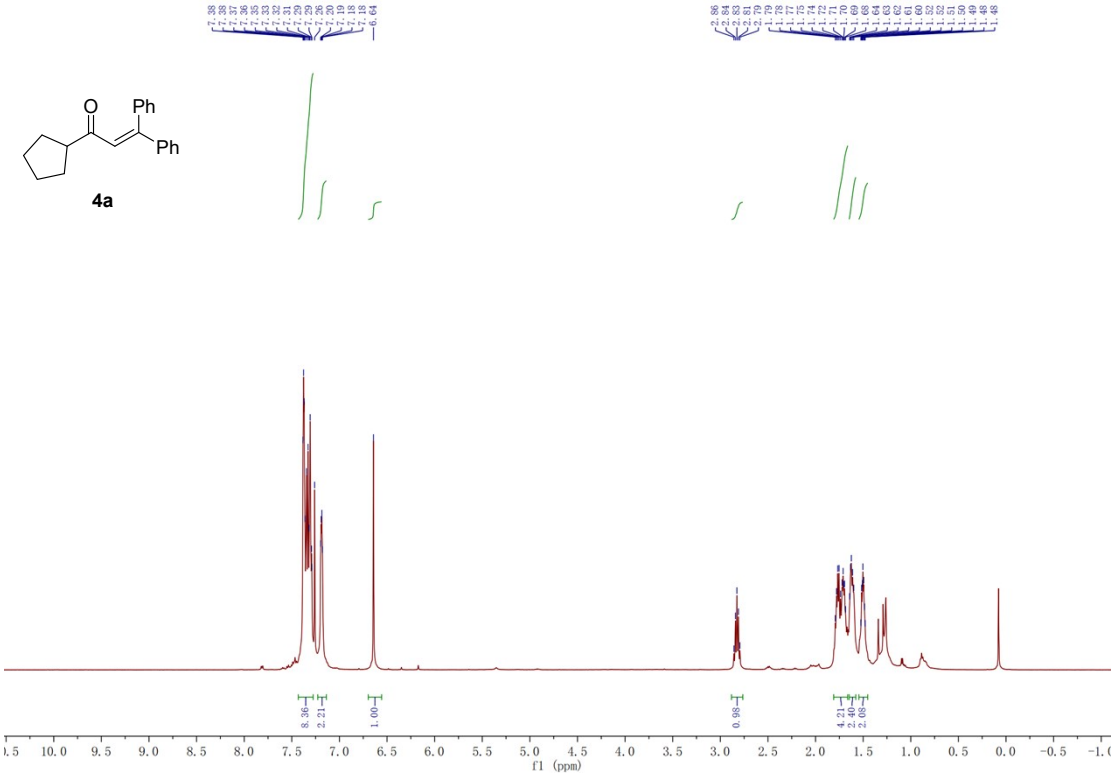
^{1}H NMR spectrum of **3s** in $CDCl_3$ at 500 MHz



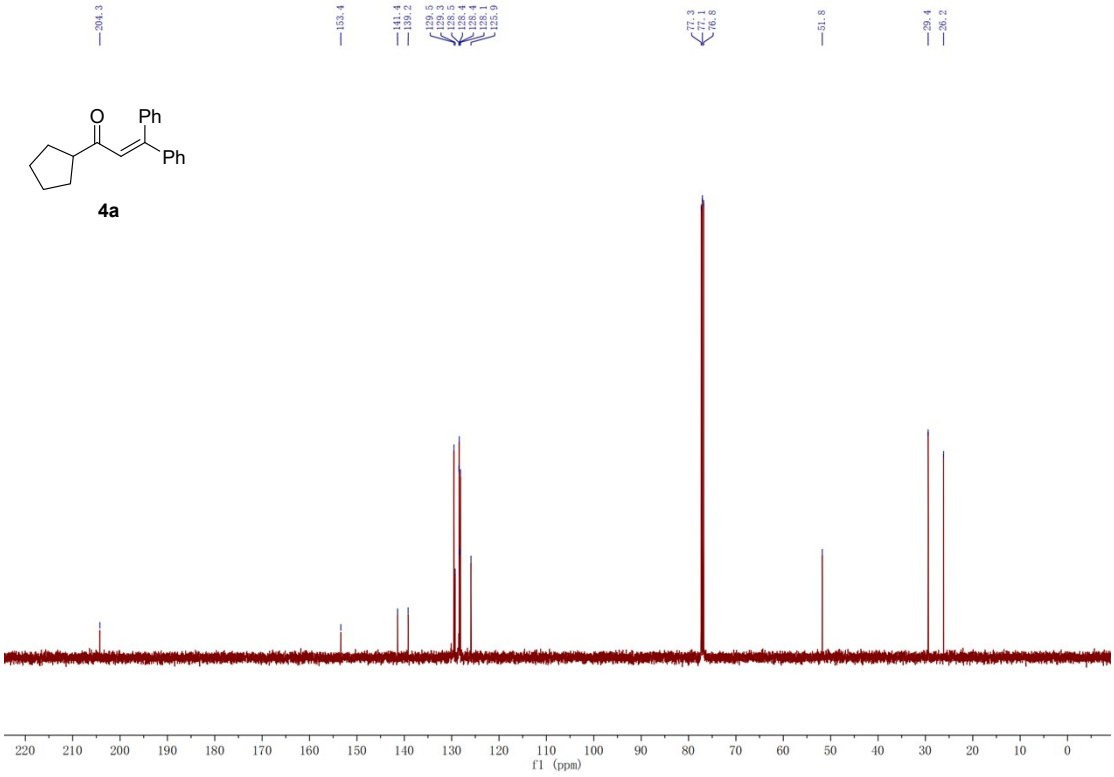
^{13}C NMR spectrum of **3s** in $CDCl_3$ at 126 MHz



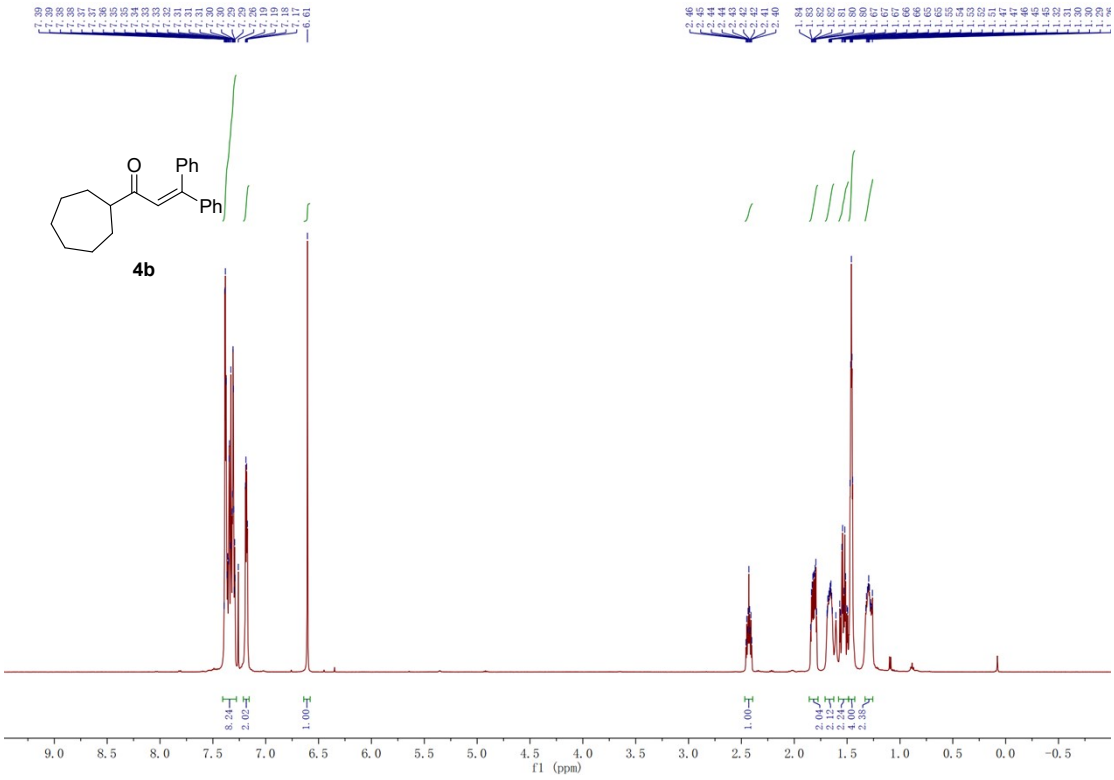
^{1}H NMR spectrum of **4a** in $CDCl_3$ at 500 MHz



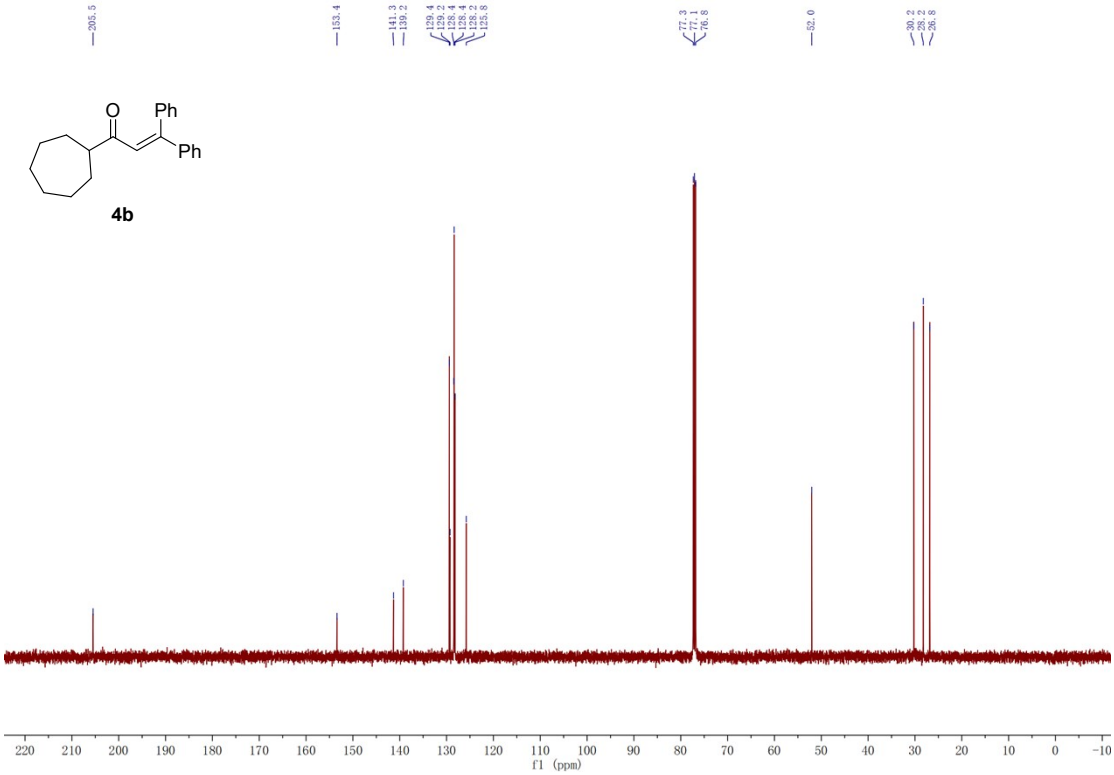
^{13}C NMR spectrum of **4a** in $CDCl_3$ at 126 MHz



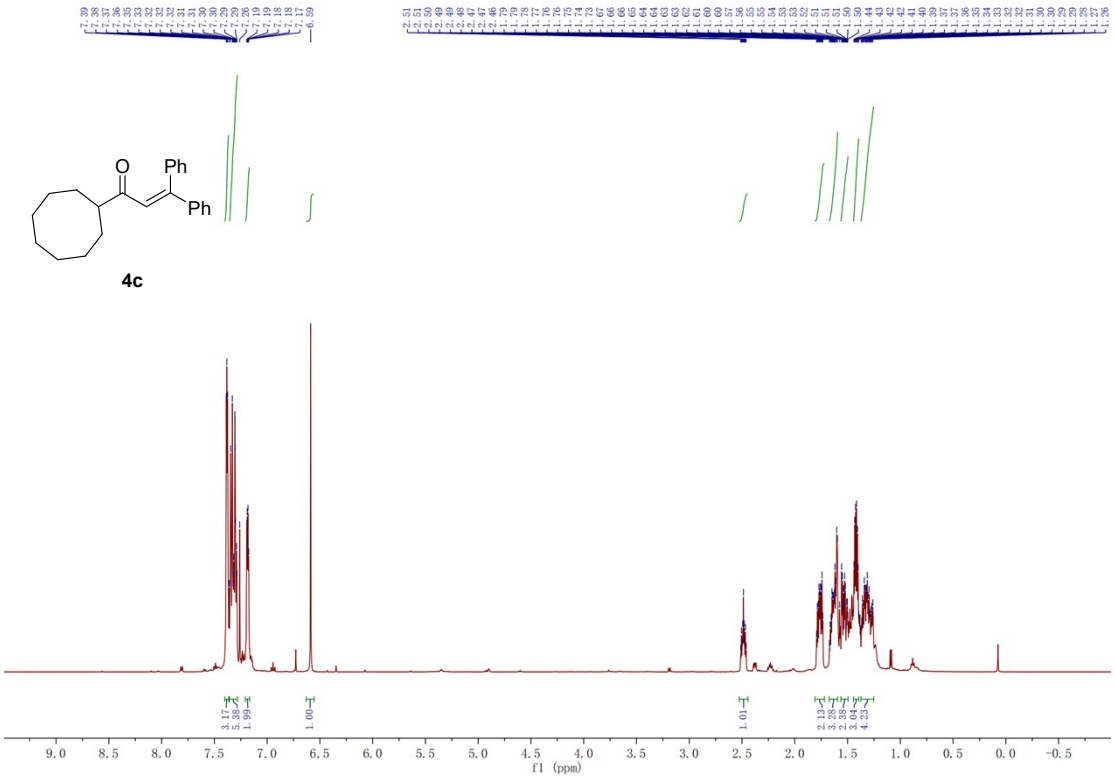
^{1}H NMR spectrum of **4b** in $CDCl_3$ at 500 MHz



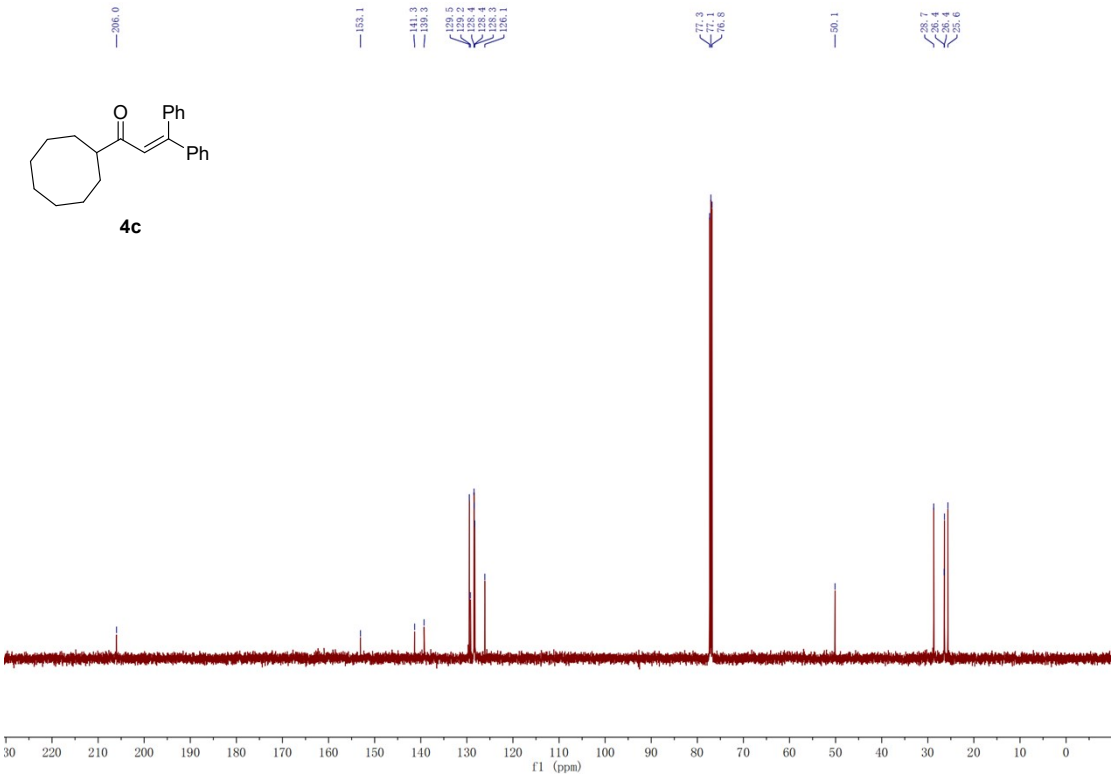
^{13}C NMR spectrum of **4b** in $CDCl_3$ at 126 MHz



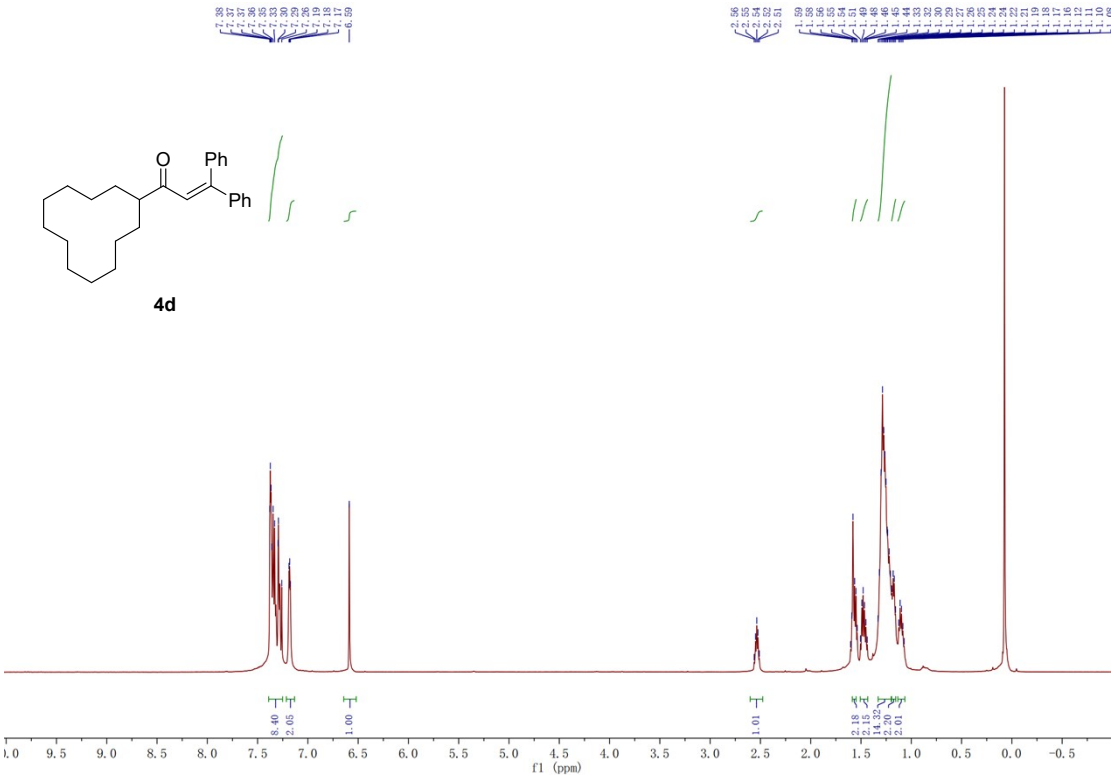
^{1}H NMR spectrum of **4c** in $CDCl_3$ at 500 MHz



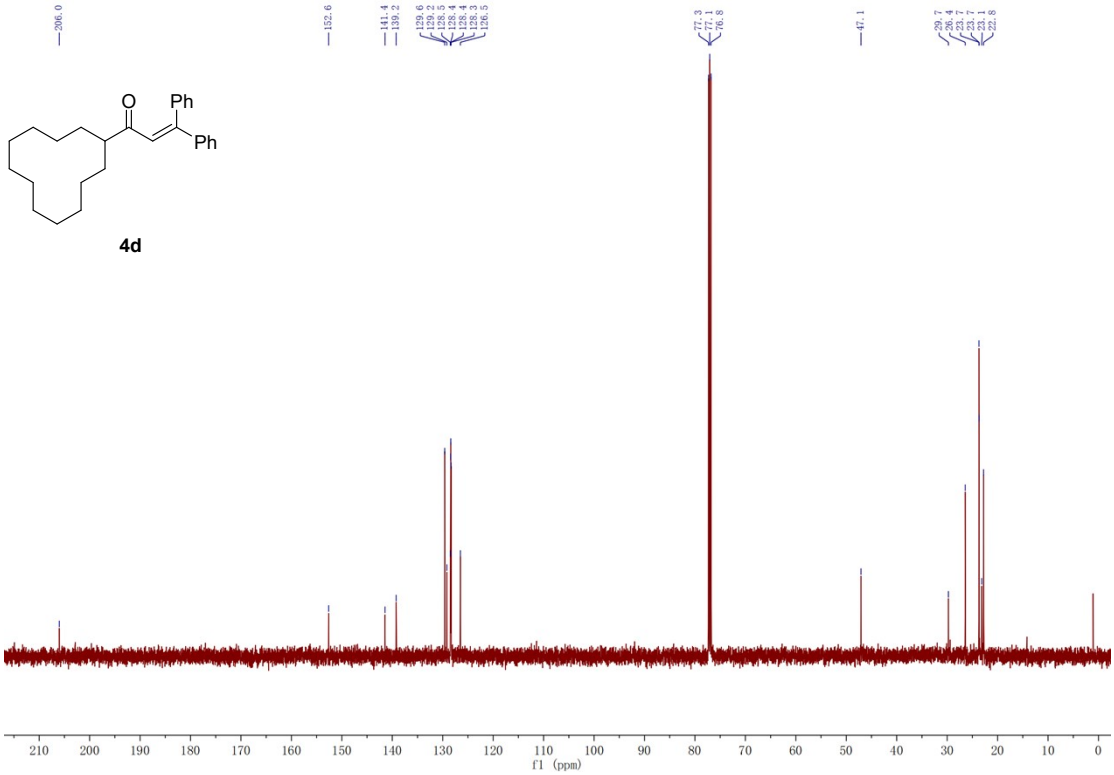
^{13}C NMR spectrum of **4c** in $CDCl_3$ at 126 MHz



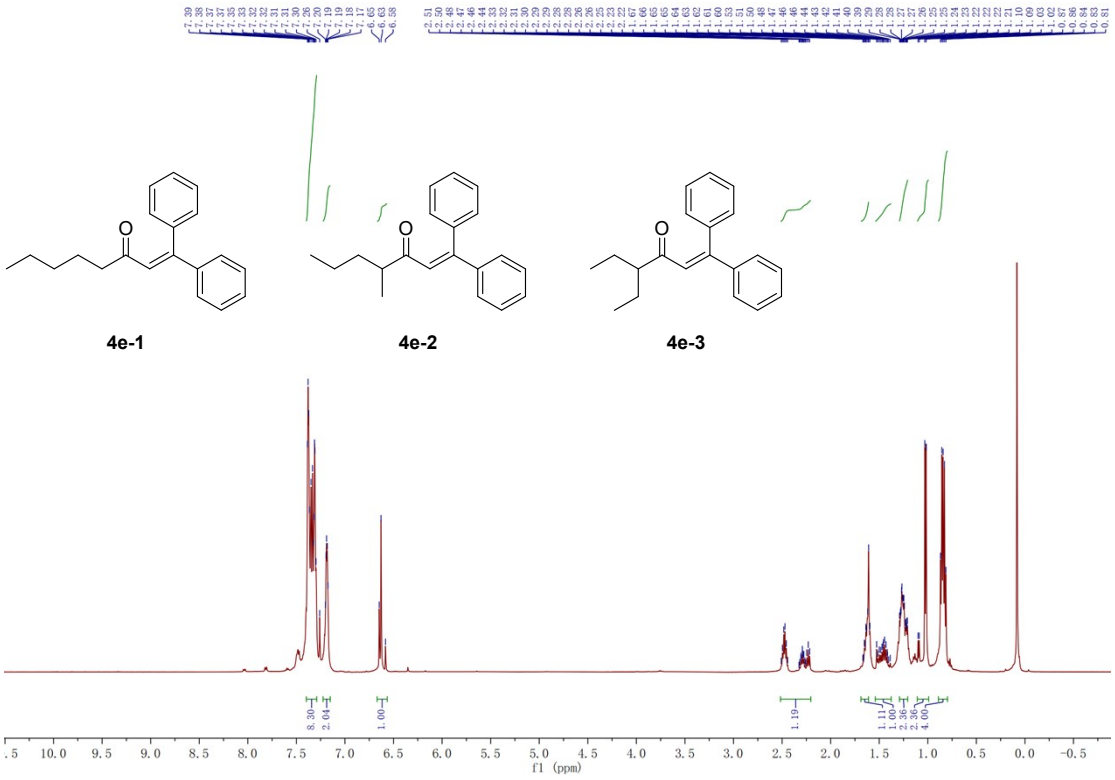
^{1}H NMR spectrum of **4d** in $CDCl_3$ at 500 MHz



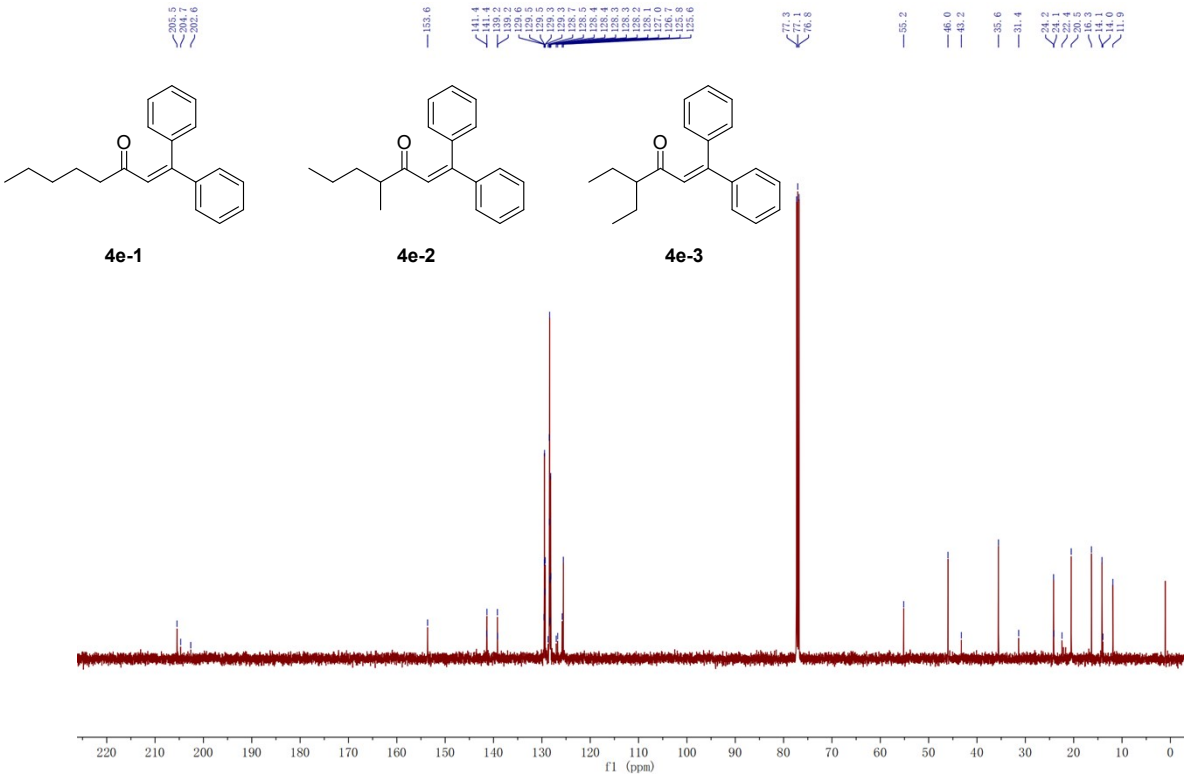
^{13}C NMR spectrum of **4d** in $CDCl_3$ at 126 MHz



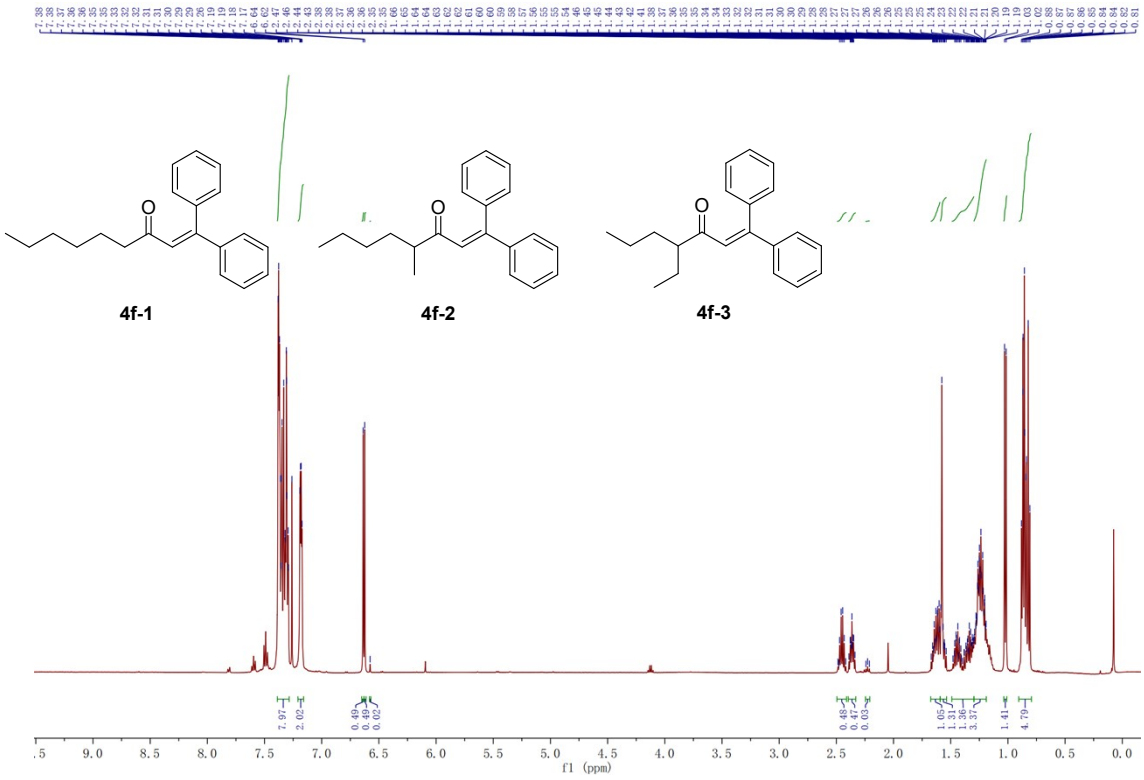
^{1}H NMR spectrum of **4e** in $CDCl_3$ at 500 MHz



^{13}C NMR spectrum of **4e** in $CDCl_3$ at 126 MHz



^{1}H NMR spectrum of **4f** in $CDCl_3$ at 500 MHz



^{13}C NMR spectrum of **4f** in $CDCl_3$ at 126 MHz