Supporting Information

Mn-Catalyzed Electrooxidative Radical Phosphorylation of 2-isocyanobiaryls

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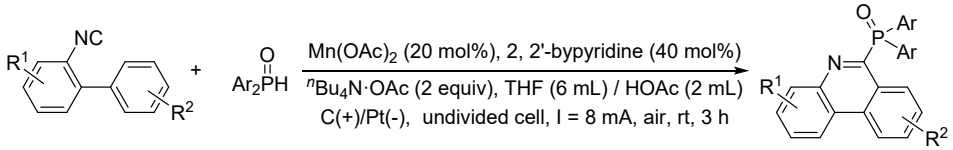
1. General Information

Unless otherwise noted, materials obtained from commercial suppliers were used without further purification. For chromatography, 200-300 mesh silica gel (Qingdao, China) was employed. ^{1}H NMR and ^{13}C NMR were recorded on a Bruker 400 MHz and 500 MHz spectrometer. The chemical shifts (δ) and coupling constants (J) were expressed in ppm and Hz respectively. ^{1}H NMR spectra were referenced to the solvent residual peak (TMS, δ 0 ppm) and ^{13}C NMR spectra were referenced to the solvent residual peak ($CDCl_3$, δ 77.0 ppm). The following abbreviations are used to illuminate the diversities: δ, chemical shift; J, coupling constant; s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet. HRMS was obtained on Waters Xevo G2-XS QTof with ESI source. 2-isocyanobiaryls[1] and diarylphosphine oxides[2] were prepared according to the literature procedures. Compounds **3aa-3ca**, **3ea-3ha**, **3oa**, **3qa-3sa**, **3va**, **3ad-3af**, **3ah** are known.

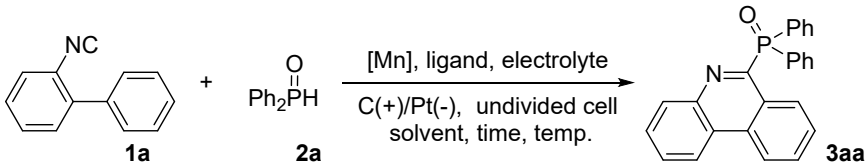
2. General Procedure for Mn-Catalyzed Electrooxidative Radical Phosphorylation of 2-isocyanobiaryls



To an overdried undivided cell equipped with a stir bar, 2-isocyanobiaryl (0.4 mmol), diaryl phosphine oxide (0.8 mmol), $Mn(OAc)_2$ (0.08 mmol), 2, 2'-bypyridine (0.16 mmol), $^{n}Bu_4N$•OAc (0.8 mmol), THF (6 mL) and HOAc (2 mL) were added. The flask was equipped with a graphite rod (ϕ 7 mm, about 15 mm immersion depth in solution) as the anode and a platinum plate (15 mm × 15 mm × 0.3 mm) as the cathode. After that, the reaction mixture was stirred and electrolyzed at a constant current of 8 mA under room temperature for 3 h (2.25 F/mol). After the reaction was finished, the reaction mixture was concentrated and purified by flash column chromatography on silica gel with petroleum and ethyl acetate as eluent to give the desired product.

Fig. S1: General electrolysis setup

3. Optimization of Reaction Conditions

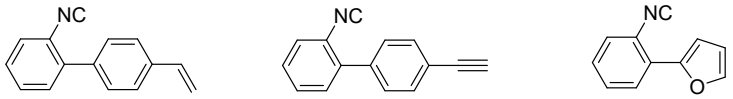


1a **2a** **3aa**

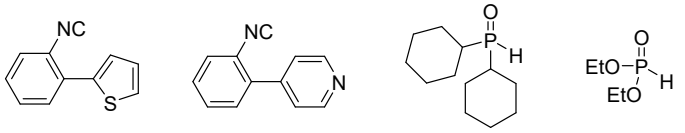
entry	**2a**	catalyst	ligand	electrolyte	solvent	yield (%)
1	1.2 equiv.	$Mn(OAc)_2$	1,10-phen	$Me_4N{\cdot}OAc$ (1 equiv)	THF (4 mL) / HOAc (4 mL)	38
2	1.2 equiv.	$Mn(OAc)_2$	1,10-phen	$Me_4N{\cdot}OAc$ (1 equiv)	CH_3CN (4 mL) / HOAc (4 mL)	20
3	1.2 equiv.	$Mn(OAc)_2$	1,10-phen	$Me_4N{\cdot}OAc$ (1 equiv)	DMF (4 mL) / HOAc (4 mL)	35
4	1.2 equiv.	$Mn(OAc)_2$	1,10-phen	$^nBu_4N{\cdot}OAc$ (1 equiv)	THF (4 mL) / HOAc (4 mL)	41
5	1.2 equiv.	$Mn(OAc)_2$	1,10-phen	$^nBu_4N{\cdot}PF_6$ (1 equiv)	THF (4 mL) / HOAc (4 mL)	trace
6	1.2 equiv.	$Mn(OAc)_2$	1,10-phen	$^nBu_4N{\cdot}OAc$ (1 equiv)	THF (4 mL) / HOAc (4 mL)	trace
7	1.2 equiv.	$Mn(OAc)_2$	1,10-phen	$^nBu_4N{\cdot}OAc$ (1 equiv)	THF (4 mL) / HFIP (4 mL)	24
8	1.2 equiv.	$Mn(OAc)_2$	1,10-phen	$^nBu_4N{\cdot}OAc$ (1 equiv)	THF (4 mL) / TFA (4 mL)	33
9	2 equiv.	$Mn(OAc)_2$	1,10-phen	$^nBu_4N{\cdot}OAc$ (1 equiv)	THF (4 mL) / HOAc (4 mL)	44
10	1.2 equiv.	$Mn(OAc)_2$	1,10-phen	$^nBu_4N{\cdot}OAc$ (1 equiv)	THF (4 mL) / HOAc (4 mL)	44
11	2 equiv.	$Mn(OAc)_2$	1,10-phen	$^nBu_4N{\cdot}OAc$ (1 equiv)	THF (4 mL) / HOAc (4 mL)	48
12	2 equiv.	$Mn(OTf)_2$	1,10-phen	$^nBu_4N{\cdot}OAc$ (1 equiv)	THF (4 mL) / HOAc (4 mL)	40
13	2 equiv.	$MnCl_2$	1,10-phen	$^nBu_4N{\cdot}OAc$ (1 equiv)	THF (4 mL) / HOAc (4 mL)	38
14	2 equiv.	$Mn(acac)_3$	1,10-phen	$^nBu_4N{\cdot}OAc$ (1 equiv)	THF (4 mL) / HOAc (4 mL)	45
15	2 equiv.	$Mn(OAc)_2$	—	$^nBu_4N{\cdot}OAc$ (1 equiv)	THF (4 mL) / HOAc (4 mL)	30
16	2 equiv.	—	—	$^nBu_4N{\cdot}OAc$ (1 equiv)	THF (4 mL) / HOAc (4 mL)	0
17	2 equiv.	$Mn(OAc)_2$	2, 2'-bipyridine	$^nBu_4N{\cdot}OAc$ (1 equiv)	THF (4 mL) / HOAc (4 mL)	58
18	2 equiv.	$Mn(OAc)_2$	4,4'-DTBDPy	$^nBu_4N{\cdot}OAc$ (1 equiv)	THF (4 mL) / HOAc (4 mL)	44
19	2 equiv.	$Mn(OAc)_2$	Bipicoline	$^nBu_4N{\cdot}OAc$ (1 equiv)	THF (4 mL) / HOAc (4 mL)	33
20 [b]	2 equiv.	$Mn(OAc)_2$	2, 2'-bipyridine	$^nBu_4N{\cdot}OAc$ (1 equiv)	THF (4 mL) / HOAc (4 mL)	54
21	2 equiv.	$Mn(OAc)_2$	2, 2'-bipyridine	$^nBu_4N{\cdot}OAc$ (1 equiv)	THF (6 mL) / HOAc (2 mL)	68
22 [c]	2 equiv.	$Mn(OAc)_2$	2, 2'-bipyridine	$^nBu_4N{\cdot}OAc$ (1 equiv)	THF (6 mL) / HOAc (2 mL)	59
23 [d]	2 equiv.	$Mn(OAc)_2$	2, 2'-bipyridine	$^nBu_4N{\cdot}OAc$ (1 equiv)	THF (6 mL) / HOAc (2 mL)	54

[a] Reaction conditions: **1a** (0.4 mmol), **2a**, [Mn] (20 mol%), ligand (40 mol%), electrolyte, solvent/HOAc, undivided cell, constant current = 8 mA, 3 h, graphite rod(+)/Pt plate(-), rt, air. [b] constant current = 5 mA, 5 h. [c] 60 °C, [d] [Mn] (10 mol%), 2, 2'-bipyridine (20 mol%).

4. Unsuccessful substrates

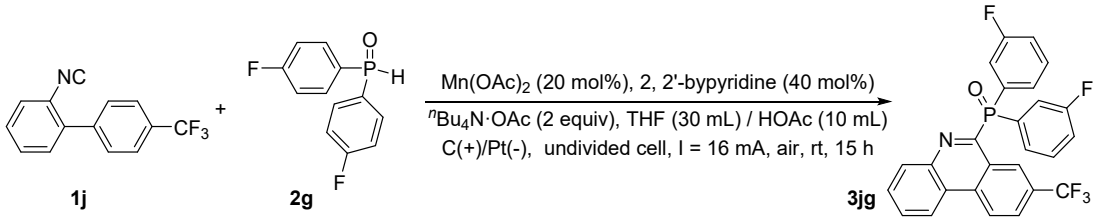


no reaction complex reaction mixture no reaction



no reaction no reaction no reaction no reaction

5. Procedure for Scale-up Experiment



To an overdried 100 mL beaker equipped with a stir bar, **1j** (2 mmol), **2g** (4 mmol), $Mn(OAc)_2$ (0.4 mmol), 2, 2'-bypyridine (0.8 mmol), $^{n}Bu_4N$•OAc (4 mmol), THF (30 mL) and HOAc (10 mL) were added. A graphite felt, which is about 60 mm wide and 20 mm high and thread it with copper wire, was connected with two electrode holders as anode, the length of the graphite felt in the solution is about 10mm. A platinum plate (15 mm × 15 mm × 0.3 mm) was equipped as cathode. After the electrodes are fixed, the reaction mixture was stirred and electrolyzed at a constant current of 16 mA under room temperature for 15 h. After the reaction was finished, the reaction mixture was concentrated and purified by flash column chromatography on silica gel with petroleum and ethyl acetate as eluent to give the desired product **3jg** as white solid.

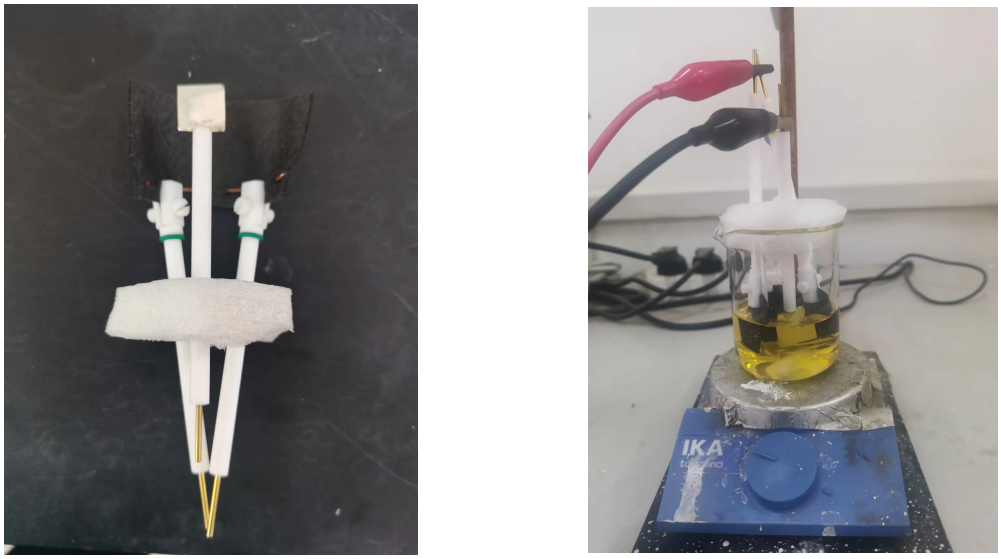
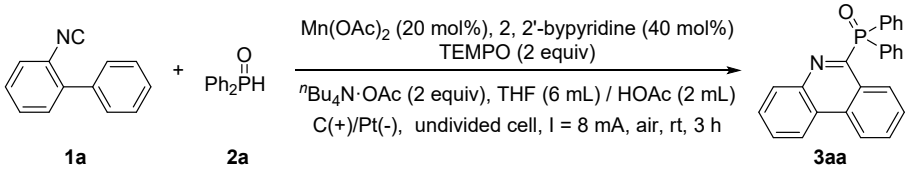


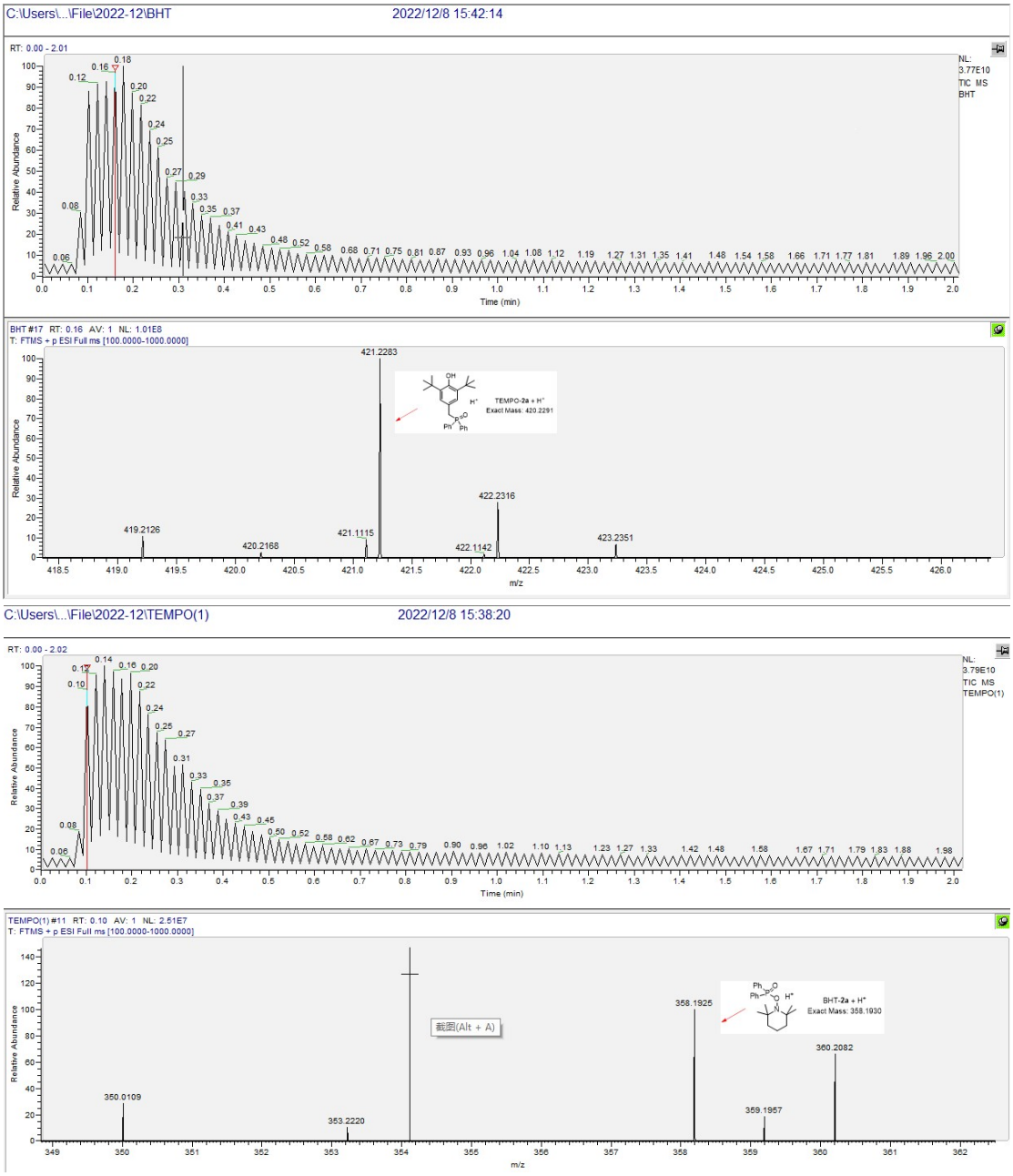
Fig. S2: Scale-up electrolysis setup

6. Procedure for Experimental Probe Reaction



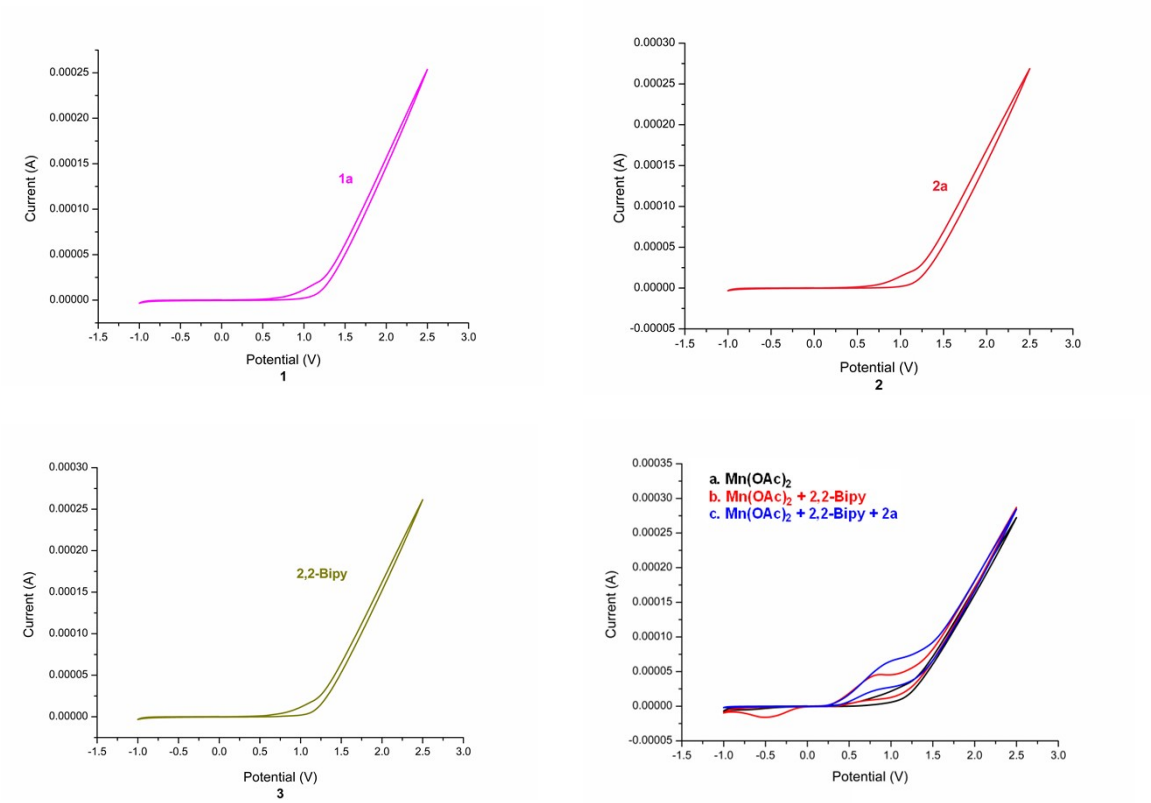
To an overdried undivided cell equipped with a stir bar, **1a** (0.4 mmol), **2a** (0.8 mmol), TEMPO (0.8 mmol) or BHT (0.8 mmol), $Mn(OAc)_2$ (0.08 mmol), 2, 2'-bypyridine (0.16 mmol), $^{n}Bu_4N$•OAc (0.8 mmol), THF (6 mL) and HOAc (2 mL) were added. The flask was equipped with a graphite rod (ϕ 7 mm, about 15 mm immersion depth in solution) as the anode and a platinum plate (15 mm × 15 mm ×

0.3 mm) as the cathode. After that, the reaction mixture was stirred and electrolyzed at a constant current of 8 mA under room temperature for 3 h. After the reaction was finished, TLC was used to detect the mount of **3aa**. The TEMPO-**2a** adduct and BHT-**2a** adduct were detected by high-resolution mass spectrometry (see below).



7. Cyclic Voltammetric Experiments

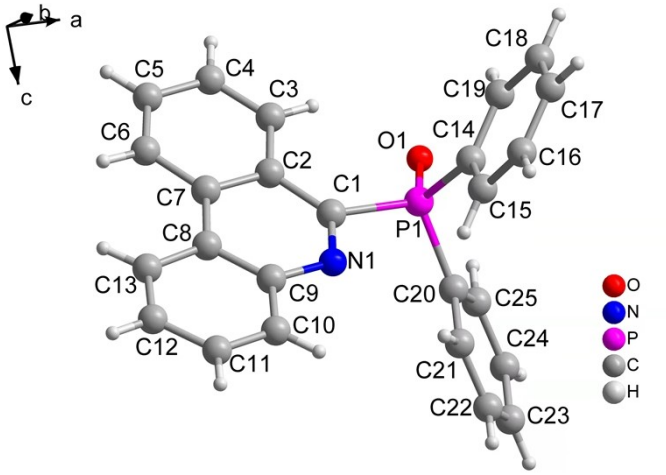
Cyclic voltammetry (CV) experiments were conducted in a 20 mL glass vial fitted with a glassy carbon working electrode (3 mm in diameter), a $Ag/AgNO_3$ (0.1 M in CH_3CN) reference electrode, and a platinum wire counter electrode. 15 mL THF and 5 mL HOAc containing 0.1 M $^nBu_4N$•OAc and substrate were poured into the electrochemical cell in all cyclic voltammetry experiments. The scan rate was 0.1 V/s, ranging from -1 V to 3 V.



Conditions: (1) 15 mL THF, 5 mL HOAc, 2 mmol $^{n}Bu_4N$•OAc, 0.4 mmol **1a**; (2) 15 mL THF, 5 mL HOAc, 2 mmol $^{n}Bu_4N$•OAc, 0.4 mmol **2a**; (3) 15 mL THF, 5 mL HOAc, 2 mmol $^{n}Bu_4N$•OAc, 0.4 mmol 2,2-Bipy; (4) (a) 15 mL THF, 5 mL HOAc, 2 mmol $^{n}Bu_4N$•OAc, 0.2 mmol $Mn(OAc)_2$; (b) 15 mL THF, 5 mL HOAc, 2 mmol $^{n}Bu_4N$•OAc, 0.2 mmol $Mn(OAc)_2$, 0.4 mmol 2,2-Bipy; (c) 15 mL THF, 5 mL HOAc, 2 mmol $^{n}Bu_4N$•OAc, 0.2 mmol $Mn(OAc)_2$, 0.4 mmol 2,2-Bipy, 0.4 mmol **2a**.

Fig. S3: Cyclic voltammetry studies

8. Crystal Data of 3aa



Bond precision: C-C = 0.0033 A Wavelength=0.71073

Cell: a=13.278(5) b=8.402(3) c=17.431(7)
alpha=90 beta=90.161(6) gamma=90
Temperature: 296 K

	Calculated	Reported
Volume	1944.6(13)	1944.8(13)
Space group	P 21/c	P2(1)/c
Hall group	-P 2ybc	?
Moiety formula	C25 H18 N O P	?
Sum formula	C25 H18 N O P	C25 H18 N O P
Mr	379.37	379.37
Dx,g cm-3	1.296	1.296
Z	4	4
Mu (mm-1)	0.157	0.156
F000	792.0	792.0
F000'	792.70	
h,k,lmax	15,9,20	15,9,20
Nref	3413	3410
Tmin,Tmax	0.945,0.959	0.946,0.959
Tmin'	0.945	

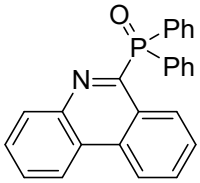
Correction method= # Reported T Limits: Tmin=0.946 Tmax=0.959
AbsCorr = MULTI-SCAN

Data completeness= 0.999 Theta(max)= 25.000

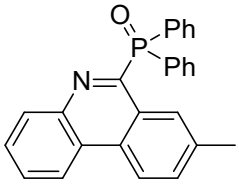
R(reflections)= 0.0444(2799) wR2(reflections)= 0.1182(3410)

S = 1.073 Npar= 253

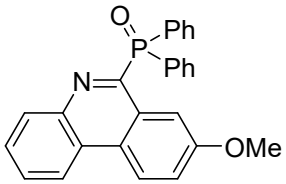
9. Characterization Data



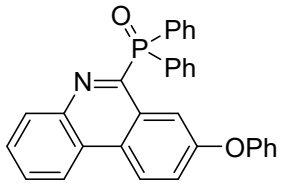
phenanthridin-6-yldiphenylphosphine oxide **(3aa)**[1a]**:** white solid，m.p. 200.5-201.6 ℃. ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.52 (d, *J* = 8.2 Hz, 1H), 8.68-8.49 (m, 2H), 8.09-8.02 (m, 1H), 8.00-7.88 (m, 4H), 7.86-7.78 (m, 1H), 7.68 (ddd, *J* = 8.6, 7.2, 2.4 Hz, 3H), 7.51 (ddd, *J* = 7.2, 2.8, 1.4 Hz, 2H), 7.48-7.40 (m, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 156.83 (d, *J* = 128.4 Hz), 142.73 (d, *J* = 23.4 Hz), 133.41 (s), 132.59 (d, *J* = 6.9 Hz), 132.39 (s), 132.30 (s), 131.76 (d, *J* = 2.5 Hz), 131.16 (s), 131.08 (s), 128.80 (d, *J* = 12.6 Hz), 128.56 (s), 128.23 (d, *J* = 12.2 Hz), 127.93 (s), 127.73 (s), 124.34 (d, *J* = 2.2 Hz), 122.17 (d, *J* = 1.1 Hz), 122.13 (d, *J* = 0.9 Hz). ^{31}P NMR (162 MHz, $CDCl_3$) δ 28.32 (s).



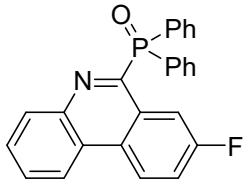
(8-methylphenanthridin-6-yl)diphenylphosphine oxide **(3ba)**[1a]**:** white solid, m.p. 210.4-211.0 ℃. ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.32 (s, 1H), 8.54 (dd, *J* = 7.0, 2.0 Hz, 2H), 8.10-8.01 (m, 1H), 7.99- 7.88 (m, 4H), 7.69 (qd, *J* = 7.0, 3.4 Hz, 3H), 7.57-7.48 (m, 2H), 7.45 (td, *J* = 7.4, 2.9 Hz, 4H), 2.56 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 156.23 (d, *J* = 128.8 Hz), 142.43 (d, *J* = 23.4 Hz), 138.11 (s), 133.61 (s), 132.95 (s), 132.57 (s), 132.36 (d, *J* = 9.2 Hz), 131.67 (d, *J* = 2.7 Hz), 131.06 (d, *J* = 1.2 Hz), 130.50 (d, *J* = 6.9 Hz), 128.75 (s), 128.24 (s), 128.11 (s), 127.71 (s), 124.45 (d, *J* = 2.5 Hz), 122.02 (d, *J* = 1.5 Hz), 121.95 (d, *J* = 0.6 Hz), 21.99 (s). ^{31}P NMR (162 MHz, $CDCl_3$) δ 28.23 (s).



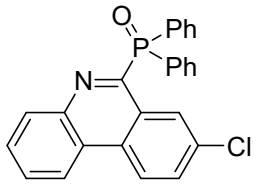
(8-methoxyphenanthridin-6-yl)diphenylphosphine oxide **(3ca)**[1a]**:** white solid, m.p. 104.6-105.7 ℃. ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.02 (d, *J* = 2.6 Hz, 1H), 8.57-8.44 (m, 2H), 8.05 (d, *J* = 7.7 Hz, 1H), 8.01-7.92 (m, 4H), 7.73-7.60 (m, 2H), 7.52 (dd, *J* = 7.3, 6.5 Hz, 2H), 7.45 (td, *J* = 7.3, 2.8 Hz, 5H), 3.94 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 158.81 (s), 155.42 (d, *J* = 129.4 Hz), 142.07 (d, *J* = 23.2 Hz), 133.53 (s), 132.49 (s), 132.33 (d, *J* = 9.2 Hz), 131.71 (d, *J* = 2.7 Hz), 131.09 (s), 129.45 (d, *J* = 23.1 Hz), 128.86 (s), 128.21 (d, *J* = 12.1 Hz), 127.68 (s), 127.07 (d, *J* = 6.8 Hz), 124.55 (d, *J* = 2.4 Hz), 123.67 (d, *J* = 1.6 Hz), 122.66 (s), 121.66 (d, *J* = 0.6 Hz), 107.48 (s), 55.67 (s). ^{31}P NMR (162 MHz, $CDCl_3$) δ 27.67 (s).



(8-***phenoxyphenanthridin-6-yl)diphenylphosphine oxide*** **(3da):** white solid, m.p. 212.4-212.8 ℃. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.93 (d, *J* = 2.4 Hz, 1H), 8.60 (d, *J* = 9.1 Hz, 1H), 8.51 (d, *J* = 8.0 Hz, 1H), 8.14-8.00 (m, 1H), 7.97-7.82 (m, 4H), 7.68 (td, *J* = 14.7, 7.0 Hz, 2H), 7.61-7.48 (m, 4H), 7.47- 7.33 (m, 6H), 7.19 (t, *J* = 7.4 Hz, 1H), 7.02 (d, *J* = 7.7 Hz, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 156.77 (s), 156.23 (d, *J* = 128.9 Hz), 156.09 (s), 142.33 (d, *J* = 23.0 Hz), 133.03 (s), 132.27 (d, *J* = 9.2 Hz), 131.99 (s), 131.70 (d, *J* = 2.7 Hz), 131.27 (s), 130.04 (s), 129.05 (s), 128.76 (d, *J* = 22.9 Hz), 128.36 (d, *J* = 6.7 Hz), 128.20 (d, *J* = 12.2 Hz), 128.16 (s), 124.31 (d, *J* = 2.5 Hz), 124.16 (s), 123.34 (s), 121.82 (s), 119.67 (s), 115.08 (s). ^{31}P NMR (162 MHz, $CDCl_3$) δ 27.90 (s). HRMS (ESI-TOF, $[M+H]^+$): calcd for $C_{31}H_{23}NO_2P$, 472.1461, found 472.1456.

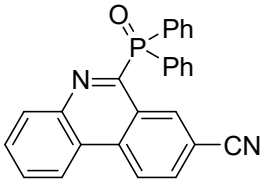


(8-fluorophenanthridin-6-yl)diphenylphosphine oxide **(3ea)**[1a]**:** white solid, m.p. 229.7-230.3 ℃. ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.33 (dd, *J* = 10.2, 2.6 Hz, 1H), 8.62 (dd, *J* = 8.2, 5.5 Hz, 1H), 8.55-8.46 (m, 1H), 8.13-8.03 (m, 1H), 8.01-7.90 (m, 4H), 7.77-7.65 (m, 2H), 7.61-7.39 (m, 7H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 161.26 (d, *J* = 249.1 Hz), 155.93 (dd, *J* = 128.4, 4.4 Hz), 142.42 (dd, *J* = 22.8, 1.0 Hz), 133.13 (s), 132.33 (d, *J* = 9.2 Hz), 132.09 (s), 131.88 (d, *J* = 2.8 Hz), 131.21 (s), 129.27 (s), 129.04 (dd, *J* = 23.1, 9.4 Hz), 128.64 (s), 128.28 (d, *J* = 12.2 Hz), 124.64 (dd, *J* = 8.7, 1.4 Hz), 123.95 (d, *J* = 1.4 Hz), 121.92 (s), 120.54 (d, *J* = 24.4 Hz), 113.19 (d, *J* = 23.2 Hz). ^{19}F NMR (376 MHz, $CDCl_3$) δ -109.58 (s). ^{31}P NMR (162 MHz, $CDCl_3$) δ 27.54 (s).

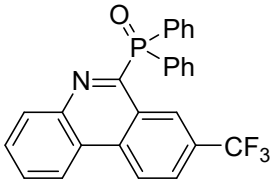


(8-chlorophenanthridin-6-yl)diphenylphosphine oxide **(3fa)**[1a]**:** white solid, m.p. 234.5-235.2 ℃. ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.66 (d, *J* = 2.1 Hz, 1H), 8.54 (ddd, *J* = 9.6, 7.4, 1.8 Hz, 2H), 8.07 (dd, *J* = 6.5, 3.0 Hz, 1H), 8.01-7.90 (m, 4H), 7.78 (dd, *J* = 8.9, 2.1 Hz, 1H), 7.73 (dd, *J* = 5.5, 4.1 Hz, 2H), 7.58-7.50 (m, 2H), 7.49-7.40 (m, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 155.79 (d, *J* = 128.1 Hz), 142.63 (d, *J* = 22.8 Hz), 133.99 (s), 133.18 (s), 132.34 (d, *J* = 9.2 Hz), 132.14 (s), 131.87 (d, *J* = 2.8 Hz), 131.83 (s), 131.19 (d, *J* = 1.1 Hz), 130.98 (d, *J* = 6.7 Hz), 129.17 (d, *J* = 22.0 Hz), 128.75 (d, *J* = 23.0 Hz), 128.28 (d, *J* = 12.2 Hz), 127.67 (s), 123.80 (d, *J* = 1.5 Hz),

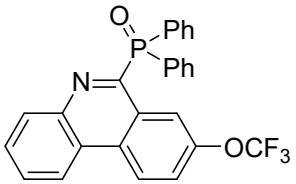
123.76 (d, J = 2.6 Hz), 122.02 (d, J = 0.8 Hz). ^{31}P NMR (162 MHz, $CDCl_3$) δ 27.41 (s).



6-(diphenylphosphoryl)phenanthridine-8-carbonitrile **(3ga)**[1a]**:** white solid, m.p. 261.5-262.0 ℃. ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.08 (s, 1H), 8.71 (d, J = 8.6 Hz, 1H), 8.62-8.52 (m, 1H), 8.17-8.10 (m, 1H), 8.04-7.91 (m, 5H), 7.87-7.78 (m, 2H), 7.59-7.51 (m, 2H), 7.51-7.44 (m, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 156.58 (d, J = 126.6 Hz), 143.50 (d, J = 22.3 Hz), 135.00 (d, J = 6.6 Hz), 133.98 (s), 132.71 (s), 132.37 (s), 132.30 (d, J = 9.3 Hz), 132.11 (d, J = 2.8 Hz), 131.66 (s), 131.39 (d, J = 0.9 Hz), 130.14 (d, J = 82.3 Hz), 128.41 (d, J = 12.3 Hz), 127.24 (d, J = 23.0 Hz), 123.45 (d, J = 1.1 Hz), 123.02 (d, J = 2.3 Hz), 122.65 (d, J = 0.6 Hz), 118.41 (s), 111.45 (s). ^{31}P NMR (162 MHz, $CDCl_3$) δ 27.39 (s).

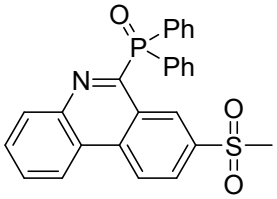


diphenyl(8-(trifluoromethyl)phenanthridin-6-yl)phosphine oxide **(3ha)**[1a]**:** white solid, m.p. 179.3-180.3 ℃**.** ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.03 (s, 1H), 8.77 (d, J = 8.6 Hz, 1H), 8.62 (dd, J = 9.2, 3.6 Hz, 1H), 8.14 (dd, J = 5.4, 2.6 Hz, 1H), 8.00 (ddd, J = 12.4, 11.7, 5.1 Hz, 5H), 7.81 (dd, J = 6.3, 2.4 Hz, 2H), 7.59-7.51 (m, 2H), 7.47 (td, J = 7.4, 3.0 Hz, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 157.06 (d, J = 127.3 Hz), 143.31 (d, J = 22.6 Hz), 134.71 (d, J = 6.7 Hz), 133.03 (s), 132.33 (d, J = 9.2 Hz), 131.98 (s), 131.94 (d, J = 2.8 Hz), 131.29 (s), 129.69 (d, J = 52.5 Hz), 129.54 (q, J = 33.2 Hz), 128.32 (d, J = 12.3 Hz), 127.24 (d, J = 23.0 Hz), 126.98 (q, J = 3.6 Hz), 126.26 (q, J = 4.1 Hz), 125.21 (d, J = 6.1 Hz), 123.39 (d, J = 2.3 Hz), 123.24 (d, J = 1.4 Hz), 122.51 (s). ^{19}F NMR (376 MHz, $CDCl_3$) δ -62.21 (s). ^{31}P NMR (162 MHz, $CDCl_3$) δ 26.95 (s).

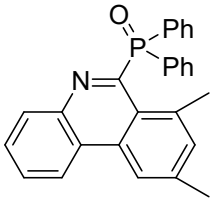


(9-***diphenyl(8-(trifluoromethoxy)phenanthridin-6-yl)phosphine oxide*** **(3ia):** white solid, m.p. 169.7-170.4 ℃. ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.53 (s, 1H), 8.72-8.62 (m, 1H), 8.58-8.47 (m, 1H), 8.14-8.07 (m, 1H), 8.02-7.91 (m, 4H), 7.72 (ddd, J = 17.2, 10.0, 6.2 Hz, 3H), 7.60-7.41 (m, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 156.33 (d, J = 128.2 Hz), 147.88 (s), 142.75 (d, J = 22.6 Hz), 132.99 (s), 132.32 (d, J = 9.2 Hz), 131.94 (s), 131.91 (d, J = 2.7 Hz), 131.25 (s), 131.02 (d, J = 6.6 Hz), 129.28 (d, J = 20.3 Hz), 128.59 (s), 128.30 (d, J = 12.2 Hz), 124.39 (s), 123.61 (s), 122.09 (s),

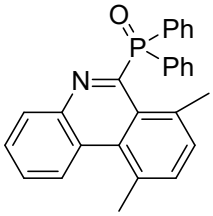
120.51 (d, J = 258.5 Hz), 119.61 (s). ^{19}F NMR (376 MHz, $CDCl_3$) δ -57.62 (s). ^{31}P NMR (162 MHz, $CDCl_3$) δ 27.16 (d, J = 1.3 Hz). HRMS (ESI-TOF, $[M+H]^+$): calcd for $C_{26}H_{18}F_3NO_2P$, 464.1022, found 464.1011.



(10-***(methylsulfonyl)phenanthridin-6-yl)diphenylphosphine oxide*** **(3ja):** white solid, m.p. 238.7-239.2 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.25 (d, J = 1.4 Hz, 1H), 8.79 (d, J = 8.8 Hz, 1H), 8.60 (d, J = 7.9 Hz, 1H), 8.33 (d, J = 8.7 Hz, 1H), 8.13 (d, J = 7.6 Hz, 1H), 8.05-7.92 (m, 4H), 7.87-7.75 (m, 2H), 7.49 (ddd, J = 11.5, 10.6, 5.7 Hz, 6H), 3.18 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 157.26 (d, J = 126.9 Hz), 143.57 (d, J = 22.3 Hz), 139.52 (s), 135.77 (d, J = 6.5 Hz), 132.30 (d, J = 9.3 Hz), 132.17 (d, J = 105.4 Hz), 132.10 (d, J = 2.6 Hz), 131.35 (s), 130.57 (s), 129.73 (s), 128.93 (s), 128.41 (d, J = 12.3 Hz), 127.80 (s), 127.14 (d, J = 22.9 Hz), 123.87 (s), 123.09 (d, J = 2.2 Hz), 122.79 (s), 44.17 (s). ^{31}P NMR (162 MHz, $CDCl_3$) δ 26.99 (s). HRMS (ESI-TOF, $[M+H]^+$): calcd for $C_{26}H_{21}NO_3PS$, 458.0974, found 458.0978.

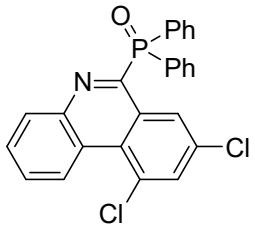


(11-***(7,9-dimethylphenanthridin-6-yl)diphenylphosphine oxide*** **(3ka):** white solid, m.p. 269.2-270.4 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.55 (d, J = 8.2 Hz, 1H), 8.34 (s, 1H), 7.84-7.76 (m, 4H), 7.73 (dd, J = 7.9, 1.3 Hz, 1H), 7.63 (dt, J = 14.9, 7.0 Hz, 2H), 7.50 (td, J = 7.2, 1.3 Hz, 2H), 7.43 (ddd, J = 7.1, 5.3, 2.3 Hz, 4H), 7.32 (s, 1H), 2.95 (s, 3H), 2.56 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 156.56 (d, J = 129.5 Hz), 141.21 (s), 140.77 (s), 137.55 (s), 135.39 (s), 134.45 (d, J = 6.6 Hz), 134.33 (s), 133.42 (s), 132.01 (d, J = 9.0 Hz), 131.17 (d, J = 2.7 Hz), 130.51 (d, J = 1.3 Hz), 128.54 (d, J = 30.5 Hz), 128.03 (d, J = 12.3 Hz), 125.59 (d, J = 23.7 Hz), 124.25 (d, J = 2.6 Hz), 122.24 (s), 120.02 (d, J = 1.9 Hz), 24.93 (s), 21.93 (s). ^{31}P NMR (162 MHz, $CDCl_3$) δ 36.25 (s). HRMS (ESI-TOF, $[M+H]^+$): calcd for $C_{27}H_{23}NOP$, 408.1512, found 408.1518.

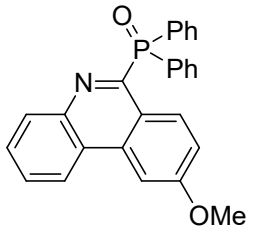


(12-***(7,10-dimethylphenanthridin-6-yl)diphenylphosphine oxide*** **(3la):** white solid, m.p. 199.9-200.4 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.66 (dd, J = 5.7, 3.8 Hz, 1H), 7.86 (dd, J = 11.0, 7.8 Hz, 5H), 7.61 (dd, J = 6.0, 3.4 Hz, 2H), 7.49 (ddd, J = 17.1, 12.3, 6.3 Hz, 7H), 7.37 (d, J = 7.4 Hz, 1H), 3.03 (s, 3H), 2.91 (s, 3H). ^{13}C NMR (101

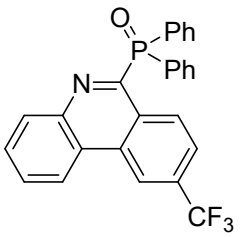
MHz, $CDCl_3$) δ 157.23 (d, *J* = 129.0 Hz), 142.18 (d, *J* = 24.5 Hz), 135.49 (d, *J* = 35.0 Hz), 134.44 (s), 134.25 (s), 133.81 (d, *J* = 6.4 Hz), 132.26 (d, *J* = 1.8 Hz), 132.05 (d, *J* = 8.9 Hz), 131.23 (d, *J* = 2.7 Hz), 130.41 (s), 130.10 (d, *J* = 1.0 Hz), 128.05 (d, *J* = 12.2 Hz), 127.84 (s), 127.82 (d, *J* = 22.8 Hz), 127.61 (s), 126.35 (s), 125.18 (d, *J* = 2.7 Hz), 26.08 (s), 24.60 (s). ^{31}P NMR (162 MHz, $CDCl_3$) δ 33.87 (s). HRMS (ESI-TOF, $[M+H]^+$): calcd for $C_{27}H_{23}NOP$, 408.1512, found 408.1517.



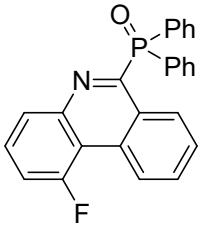
(13-***(8,10-dichlorophenanthridin-6-yl)diphenylphosphine oxide*** **(3ma):** white solid, m.p. 205.1-205.9 ℃. ^1H NMR (400 MHz, $CDCl_3$) δ 9.77 (d, *J* = 2.1 Hz, 1H), 9.73 (ddd, *J* = 6.6, 4.0, 1.7 Hz, 1H), 8.08 (dd, *J* = 10.2, 8.2 Hz, 1H), 7.92 (ddd, *J* = 13.1, 6.7, 5.3 Hz, 5H), 7.80-7.70 (m, 2H), 7.57-7.51 (m, 2H), 7.47 (td, *J* = 7.7, 3.0 Hz, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 155.68 (d, *J* = 127.7 Hz), 143.59 (d, *J* = 22.7 Hz), 134.77 (s), 132.98 (d, *J* = 15.9 Hz), 132.32 (d, *J* = 9.3 Hz), 132.09 (d, *J* = 3.2 Hz), 132.00 (d, *J* = 2.8 Hz), 131.85 (s), 131.41 (s), 130.58 (d, *J* = 23.8 Hz), 129.38 (s), 128.86 (s), 128.33 (d, *J* = 12.3 Hz), 128.14 (d, *J* = 6.6 Hz), 127.17 (s), 126.14 (s), 122.91 (d, *J* = 2.5 Hz). ^{31}P NMR (162 MHz, $CDCl_3$) δ 28.34 (s). HRMS (ESI-TOF, $[M+H]^+$): calcd for $C_{25}H_{17}C_{l2}NOP$, 448.0419, found 448.0415.



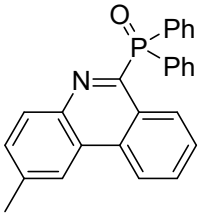
(14-(9-methoxyphenanthridin-6-yl)diphenylphosphine oxide **(3na):** white solid, m.p. 162.1-163.0 ℃. ^1H NMR (500 MHz, $CDCl_3$) δ 9.47 (d, *J* = 9.2 Hz, 1H), 8.46 (dd, *J* = 6.9, 2.7 Hz, 1H), 8.07-7.98 (m, 1H), 7.98-7.87 (m, 5H), 7.65 (dq, *J* = 6.2, 3.8, 2.5 Hz, 2H), 7.53-7.45 (m, 2H), 7.43 (td, *J* = 7.6, 2.9 Hz, 4H), 7.27 (dd, *J* = 9.2, 2.5 Hz, 1H), 3.97 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 161.47, 156.00 (d, *J* = 128.8 Hz), 143.05 (d, *J* = 23.7 Hz), 135.06 (d, *J* = 7.3 Hz), 133.49, 132.66, 132.35 (d, *J* = 9.1 Hz), 131.67 (d, *J* = 2.8 Hz), 131.09, 130.49, 128.80, 128.17 (d, *J* = 12.0 Hz), 124.09 (d, *J* = 2.6 Hz), 123.18 (d, *J* = 23.6 Hz), 122.15, 117.90, 102.99, 55.54.^{31}P NMR (202 MHz, $CDCl_3$) δ 28.03. HRMS (ESI-TOF, $[M+H]^+$): calcd for $C_{26}H_{21}NO_2P$, 410.1304, found 410.1312.



diphenyl(9-(trifluoromethyl)phenanthridin-6-yl)phosphine oxide **(3oa)**[1b]**:** white solid, m.p. 166.3-167.2 ℃. ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.75 (d, *J* = 8.6 Hz, 1H), 8.91 (s, 1H), 8.69-8.47 (m, 1H), 8.16-8.06 (m, 1H), 8.00-7.93 (m, 4H), 7.89 (dd, *J* = 8.7, 1.8 Hz, 1H), 7.82-7.71 (m, 2H), 7.54 (ddd, *J* = 7.4, 5.2, 1.5 Hz, 2H), 7.47 (td, *J* = 7.6, 3.2 Hz, 4H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 156.79 (d, *J* = 127.6 Hz), 143.02 (d, *J* = 22.7 Hz), 132.92, 132.46, 132.41, 132.31 (d, *J* = 9.3 Hz), 132.20, 132.09, 131.95 (d, *J* = 2.7 Hz), 131.37, 129.82, 129.61 (d, *J* = 10.6 Hz), 129.12 (d, *J* = 23.1 Hz), 128.33 (d, *J* = 12.0 Hz), 123.87 (q, *J* = 273.1 Hz),123.78 (dd, *J* = 4.7, 2.8 Hz), 122.11, 119.69 (d, *J* = 4.5 Hz). ^{19}F NMR (471 MHz, $CDCl_3$) δ -62.65. ^{31}P NMR (202 MHz, $CDCl_3$) δ 27.87.

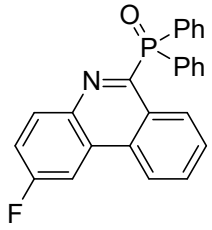


(15-(1-fluorophenanthridin-6-yl)diphenylphosphine oxide **(3pa):** white solid, m.p. 196.5-197.6 ℃. ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.56 (d, *J* = 8.2 Hz, 1H), 9.06 (d, *J* = 8.4 Hz, 1H), 8.00 -7.84 (m, 6H), 7.73 (t, *J* = 7.7 Hz, 1H), 7.63 (dtq, *J* = 7.9, 5.5, 2.8, 2.2 Hz, 1H), 7.53 (t, *J* = 7.5 Hz, 2H), 7.46 (td, *J* = 7.6, 3.0 Hz, 5H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 161.17, 158.94 (d, *J* = 49.4 Hz), 157.74, 144.59, 144.41 (d, *J* = 2.7 Hz), 133.11, 132.30 (d, *J* = 9.2 Hz), 131.81 (d, *J* = 2.8 Hz), 131.64 (d, *J* = 2.1 Hz), 130.81-130.50 (m), 128.50, 128.24 (d, *J* = 12.1 Hz), 128.10, 127.44-127.13 (m), 127.01, 115.13 (d, *J* = 24.1 Hz), 114.23 (d, *J* = 9.1 Hz). ^{19}F NMR (471 MHz, $CDCl_3$) δ -110.07. ^{31}P NMR (202 MHz, $CDCl_3$) δ 28.52 (d, *J* = 8.7 Hz). HRMS (ESI-TOF, $[M+H]^+$): calcd for $C_{25}H_{18}FNOP$, 398.1105, found 398.1112.

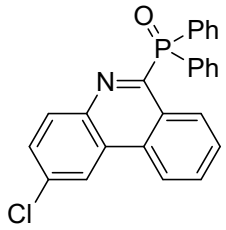


(2-methylphenanthridin-6-yl)diphenylphosphine oxide **(3qa)**[1a]**:** white solid, m.p. 214.0-214.5 ℃. ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.45 (d, *J* = 8.3 Hz, 1H), 8.65 (d, *J* = 8.3 Hz, 1H), 8.38 (s, 1H), 7.97 – 7.88 (m, 5H), 7.83 (t, *J* = 7.7 Hz, 1H), 7.67 (t, *J* = 7.3 Hz, 1H), 7.57-7.48 (m, 3H), 7.44 (ddd, *J* = 7.1, 5.4, 2.3 Hz, 4H), 2.64 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 154.53 (d, *J* = 328.7 Hz), 141.18 (d, *J* = 23.3 Hz), 139.12 (s), 133.49 (s), 132.45 (s), 132.37 (s), 132.28 (s), 131.67 (d, *J* = 2.8 Hz), 130.93 (d, *J*

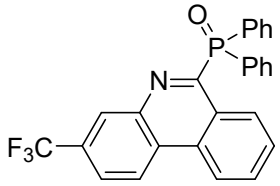
= 1.0 Hz), 130.80 (s), 130.48 (s), 128.47 (s), 128.18 (d, *J* = 12.2 Hz), 127.78 (s), 124.23 (d, *J* = 2.4 Hz), 122.11 (d, *J* = 1.6 Hz), 121.67 (d, *J* = 1.0 Hz), 22.24 (s). ^{31}P NMR (162 MHz, $CDCl_3$) δ 28.50 (s).



(2-fluorophenanthridin-6-yl)diphenylphosphine oxide **(3ra)**[1a]**:** white solid, m.p. 235.9-236.6 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.50 (d, *J* = 8.3 Hz, 1H), 8.49 (d, *J* = 7.9 Hz, 1H), 8.16 (dd, *J* = 10.0, 2.7 Hz, 1H), 8.03 (dd, *J* = 8.9, 5.8 Hz, 1H), 7.98-7.88 (m, 4H), 7.87-7.79 (m, 1H), 7.70 (dd, *J* = 8.2, 7.2 Hz, 1H), 7.56-7.38 (m, 7H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 162.43 (d, *J* = 250.0 Hz), 156.12 (d, *J* = 128.5 Hz), 139.64 (d, *J* = 23.5 Hz), 133.58 (d, *J* = 9.5 Hz), 133.27 (s), 132.29 (d, *J* = 9.3 Hz), 132.22 (s), 132.04 (dd, *J* = 6.8, 4.4 Hz), 131.81 (d, *J* = 2.7 Hz), 131.12 (s), 128.63 (d, *J* = 8.9 Hz), 128.26 (d, *J* = 12.2 Hz), 127.74 (d, *J* = 23.1 Hz), 125.98 (dd, *J* = 9.5, 2.3 Hz), 122.33 (s), 117.85 (d, *J* = 24.5 Hz), 107.11 (d, *J* = 24.2 Hz).^{19}F NMR (376 MHz, $CDCl_3$) δ -109.33 (d, *J* = 2.3 Hz). ^{31}P NMR (162 MHz, $CDCl_3$) δ 28.46 (s).

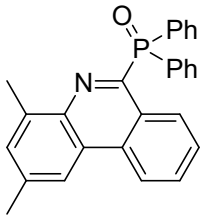


(2-***chlorophenanthridin-6-yl)diphenylphosphine oxide*** **(3sa)**[1a]**:** white solid, m.p. 266.1-266.7 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.50 (d, *J* = 8.2 Hz, 1H), 8.58-8.46 (m, 2H), 8.01-7.88 (m, 5H), 7.84 (t, *J* = 7.6 Hz, 1H), 7.70 (t, *J* = 7.5 Hz, 1H), 7.63 (dd, *J* = 8.7, 2.1 Hz, 1H), 7.56-7.49 (m, 2H), 7.45 (td, *J* = 7.3, 2.8 Hz, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 157.27 (d, *J* = 127.6 Hz), 141.08 (d, *J* = 23.4 Hz), 134.92 (s), 133.17 (s), 132.60 (s), 132.30 (d, *J* = 9.3 Hz), 132.12 (s), 131.85 (d, *J* = 2.6 Hz), 131.56 (d, *J* = 6.7 Hz), 131.37 (s), 129.34 (s), 128.65 (d, *J* = 10.5 Hz), 128.28 (d, *J* = 12.2 Hz), 127.93 (d, *J* = 22.9 Hz), 125.43 (d, *J* = 2.2 Hz), 122.18 (s), 121.81 (s). ^{31}P NMR (162 MHz, $CDCl_3$) δ 28.41 (s).

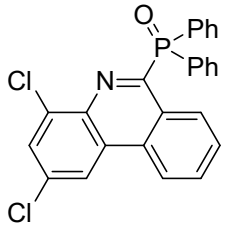


(16-diphenyl(3-(trifluoromethyl)phenanthridin-6-yl)phosphine oxide **(3ta):** white solid, m.p. 160.1-160.7 °C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.59 (d, *J* = 8.3 Hz, 1H), 8.77-8.54 (m, 2H), 8.31 (s, 1H), 8.03-7.83 (m, 6H), 7.76 (dt, *J* = 8.1, 4.4 Hz, 1H), 7.55 (t, *J* = 7.4 Hz, 2H), 7.48 (td, *J* = 7.6, 2.9 Hz, 4H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 159.02 (d, *J* = 125.9 Hz), 141.91 (d, *J* = 23.3 Hz), 132.86, 132.28 (d, *J* = 9.3 Hz),

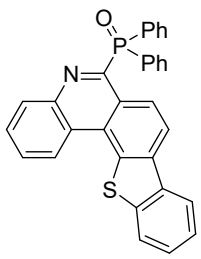
132.03, 131.97 (d, J = 2.9 Hz), 131.82 (d, J = 6.8 Hz), 131.69, 130.61 (q, J = 32.9 Hz), 129.01 (d, J = 17.8 Hz), 128.52, 128.47, 128.35 (d, J = 12.2 Hz), 126.63 (d, J = 2.2 Hz), 124.52 (q, J = 3.3 Hz), 123.91 (q, J = 272.5 Hz), 123.32, 122.51 (d, J = 1.6 Hz). ^{19}F NMR (471 MHz, $CDCl_3$) δ -62.20.^{31}P NMR (202 MHz, $CDCl_3$) δ 28.35 (d, J = 9.9 Hz). HRMS (ESI-TOF, $[M+H]^+$): calcd for $C_{26}H_{18}F_3NOP$, 448.1073, found 448.1076.



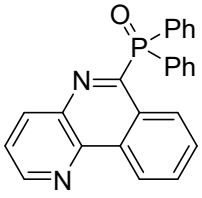
(2,4-dimethylphenanthridin-6-yl)diphenylphosphine oxide **(3ua):** white solid, m.p. 202.4-202.6 ℃. ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.39 (dd, J = 8.6, 3.7 Hz, 1H), 8.63 (t, J = 7.6 Hz, 1H), 8.22 (d, J = 5.4 Hz, 1H), 7.94-7.84 (m, 4H), 7.84-7.74 (m, 1H), 7.70-7.60 (m, 1H), 7.58-7.48 (m, 2H), 7.48-7.36 (m, 5H), 2.57 (t, J = 3.5 Hz, 3H), 2.45 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 154.00 (d, J = 131.4 Hz), 140.02 (d, J = 22.6 Hz), 138.79 (d, J = 7.2 Hz), 133.60, 132.77, 132.63 (d, J = 6.9 Hz), 132.32 (d, J = 9.3 Hz), 131.58 (d, J = 2.8 Hz), 131.32, 130.61, 128.34, 128.11 (d, J = 12.0 Hz), 127.64 (d, J = 24.0 Hz), 127.58, 124.25 (d, J = 2.5 Hz), 122.37 (d, J = 1.8 Hz), 119.43, 22.17, 18.00. ^{31}P NMR (202 MHz, $CDCl_3$) δ 29.68 (d, J = 8.1 Hz). HRMS (ESI-TOF, $[M+H]^+$): calcd for $C_{27}H_{23}NOP$, 408.1512, found 408.1507.



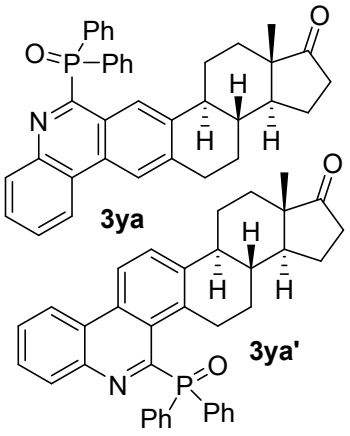
(2,4-dichlorophenanthridin-6-yl)diphenylphosphine oxide **(3va)**[1b]**:** white solid, m.p. 275.0-275.4 ℃. ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.67 (d, J = 8.2 Hz, 1H), 8.41 (d, J = 8.3 Hz, 1H), 8.36 (d, J = 1.9 Hz, 1H), 8.18-8.05 (m, 4H), 7.82 (t, J = 7.6 Hz, 1H), 7.74 (dd, J = 13.7, 4.7 Hz, 2H), 7.58-7.39 (m, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 158.08 (d, J = 126.2 Hz), 137.67 (d, J = 22.7 Hz), 136.81 (s), 134.30 (s), 133.04 (s), 132.49 (d, J = 9.1 Hz), 131.99 (s), 131.88 (d, J = 2.6 Hz), 131.80 (s), 131.27 (d, J = 6.6 Hz), 129.31 (d, J = 25.7 Hz), 128.82 (s), 128.29 (d, J = 12.2 Hz), 128.17 (d, J = 22.7 Hz), 126.53 (d, J = 2.4 Hz), 122.34 (s), 120.67 (s). ^{31}P NMR (162 MHz, $CDCl_3$) δ 25.46 (s).



benzo[4,5]thieno[3,2-k]phenanthridin-6-yldiphenylphosphine oxide **(3wa):** white solid, m.p. >325 ℃. ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.72 (d, *J* = 8.7 Hz, 1H), 9.12 (d, *J* = 8.3 Hz, 1H), 8.45 (d, *J* = 8.7 Hz, 1H), 8.28 (d, *J* = 6.9 Hz, 1H), 8.14 (d, *J* = 7.9 Hz, 1H), 7.98 (dd, *J* = 10.8, 8.0 Hz, 5H), 7.88 (t, *J* = 7.6 Hz, 1H), 7.78 (t, *J* = 7.4 Hz, 1H), 7.60-7.40 (m, 8H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 156.85 (d, *J* = 128.5 Hz), 143.63 (d, *J* = 23.6 Hz), 140.22 (s), 137.83 (s), 134.33 (s), 133.84 (d, *J* = 2.6 Hz), 133.46 (s), 132.42 (s), 132.40 (d, *J* = 9.2 Hz), 131.79 (d, *J* = 2.6 Hz), 131.61 (s), 129.35 (d, *J* = 7.1 Hz), 129.06 (s), 128.59 (s), 128.25 (d, *J* = 12.2 Hz), 127.76 (s), 127.76 (d, *J* = 23.8 Hz), 125.46 (s), 125.14 (s), 125.03 (s), 123.91 (d, *J* = 2.1 Hz), 122.36 (d, *J* = 12.7 Hz), 121.51 (s). ^{31}P NMR (162 MHz, $CDCl_3$) δ 29.39 (s). HRMS (ESI-TOF, $[M+H]^+$): calcd for $C_{27}H_{23}NOP$, 486.1076, found 486.1072.

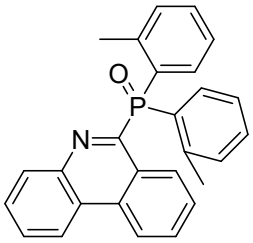


benzo[c][1,5]naphthyridin-6-yldiphenylphosphine oxide **(3xa):** white solid, m.p. 191.3-191.5 ℃. ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.48 (d, *J* = 8.3 Hz, 1H), 9.26 (d, *J* = 8.2 Hz, 1H), 9.03 (d, *J* = 4.4 Hz, 1H), 8.41-8.27 (m, 1H), 8.03-7.87 (m, 5H), 7.86-7.76 (m, 1H), 7.64 (td, *J* = 8.2, 4.3 Hz, 1H), 7.59-7.40 (m, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 159.03 (d, *J* = 5.8 Hz), 157.75 (s), 151.20 (s), 141.04 (s), 138.18 (s), 137.54 (d, *J* = 23.3 Hz), 133.52 (d, *J* = 7.4 Hz), 133.01 (s), 132.30 (d, *J* = 9.3 Hz), 132.12-131.82 (m), 131.61 (s), 129.95 (d, *J* = 23.3 Hz), 129.56 (s), 128.30 (d, *J* = 12.3 Hz), 127.96 (s), 123.83 (d, *J* = 27.9 Hz). ^{31}P NMR (162 MHz, $CDCl_3$) δ 28.48 (s). HRMS (ESI-TOF, $[M+H]^+$): calcd for $C_{24}H_{18}N_2OP$, 381.1151, found 381.1156.

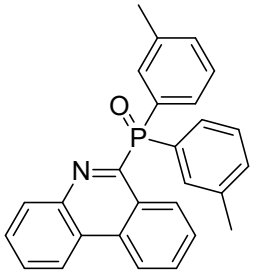


Derived from estone **(3ya + 3ya'):** white solid, m.p. 171.9-178.6. ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.55-8.35 (m, 2H), 8.29-7.92 (m, 4H), 7.81-7.31 (m, 10H), 4.67 -2.87 (m, 2H), 2.68-1.32 (m, 13H), 0.85 (d, *J* = 19.4 Hz, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 220.59, 157.07, 156.05, 142.70, 142.51, 141.02, 140.93, 140.86, 140.74, 140.65, 136.61, 136.39, 135.48, 134.53, 133.78, 133.73, 133.59, 132.95, 132.76, 132.40, 132.36, 132.32, 132.29, 132.25, 132.09, 132.04, 131.83, 131.76, 131.66, 131.64, 131.59, 131.56, 130.98, 130.87, 130.85, 130.63, 130.58, 130.04, 128.87, 128.85, 128.52, 128.49, 128.39, 128.35, 128.29, 128.21, 128.12, 127.71, 127.61, 127.40,

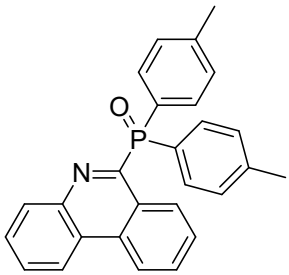
127.22, 126.63, 126.45, 124.86, 123.99, 123.97, 123.94, 122.04, 121.98, 121.52, 119.86, 50.60, 48.12, 47.93, 45.32, 44.61, 37.78, 37.49, 35.87, 35.84, 31.82, 31.45, 30.30, 30.00, 29.71, 26.32, 26.17, 25.70, 25.51, 21.58, 21.49, 13.99, 13.81.^{31}P NMR (202 MHz, $CDCl_3$) δ 34.31 (d, *J* = 6.6 Hz), 26.61 (d, *J* = 8.2 Hz). HRMS (ESI-TOF, $[M+H]^+$): calcd for $C_{37}H_{35}NO_2P$, 556.2400, found 556.1394.



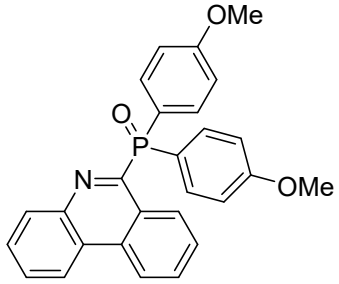
phenanthridin-6-yldi-o-tolylphosphine oxide **(3ab):** white solid, m.p. 244.2-244.9 ℃. ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.23 (d, *J* = 8.3 Hz, 1H), 8.69 (d, *J* = 8.3 Hz, 1H), 8.62 (d, *J* = 8.0 Hz, 1H), 7.93 (d, *J* = 7.9 Hz, 1H), 7.85 (t, *J* = 7.7 Hz, 1H), 7.78-7.61 (m, 3H), 7.47-7.35 (m, 4H), 7.31 (dd, *J* = 7.3, 4.2 Hz, 2H), 7.16 (t, *J* = 7.2 Hz, 2H), 2.46 (s, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 157.32 (d, *J* = 128.3 Hz), 143.39 (d, *J* = 7.9 Hz), 142.90 (d, *J* = 23.4 Hz), 133.09 (d, *J* = 12.1 Hz), 132.69 (d, *J* = 6.6 Hz), 131.85 (d, *J* = 2.5 Hz), 131.62 (d, *J* = 10.7 Hz), 131.35 (s), 130.98 (s), 130.33 (s), 128.87 (s), 128.84 (s), 128.68 (s), 127.84 (s), 127.54 (d, *J* = 22.9 Hz), 125.37 (d, *J* = 12.8 Hz), 124.43 (d, *J* = 2.4 Hz), 122.26 (d, *J* = 1.2 Hz), 122.07 (s), 22.06 (d, *J* = 3.6 Hz). ^{31}P NMR (162 MHz, $CDCl_3$) δ 38.27 (s). HRMS (ESI-TOF, $[M+H]^+$): calcd for $C_{27}H_{23}NOP$, 408.1512, found 408.1508.



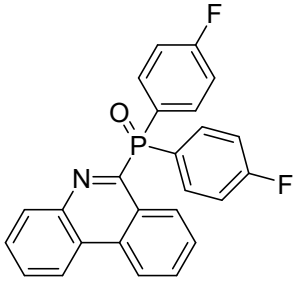
phenanthridin-6-yldi-m-tolylphosphine oxide **(3ac):** white solid, m.p. 246.0-246.9 ℃. ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.51 (d, *J* = 8.2 Hz, 1H), 8.70-8.55 (m, 2H), 8.13-8.05 (m, 1H), 7.89- 7.79 (m, 3H), 7.70 (tdd, *J* = 10.1, 5.8, 4.3 Hz, 5H), 7.40-7.29 (m, 4H), 2.37 (s, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 157.05 (d, *J* = 127.6 Hz), 142.76 (d, *J* = 23.1 Hz), 138.04 (d, *J* = 12.1 Hz), 133.28 (s), 132.67 (s), 132.61 (s), 132.56 (d, *J* = 3.1 Hz), 132.52 (s), 132.24 (s), 131.21 (d, *J* = 1.3 Hz), 131.00 (s), 129.53 (d, *J* = 9.4 Hz), 128.71 (d, *J* = 10.1 Hz), 128.01 (d, *J* = 12.9 Hz), 127.98 (s), 127.88 (s), 127.75 (s), 124.35 (d, *J* = 2.4 Hz), 122.12 (s), 21.53 (s). ^{31}P NMR (162 MHz, $CDCl_3$) δ 28.66 (s). HRMS (ESI-TOF, $[M+H]^+$): calcd for $C_{27}H_{23}NOP$, 408.1512, found 408.1519.



phenanthridin-6-yldi-p-tolylphosphine oxide **(3ad)**[1a]**:** white solid, m.p. 202.4-203.3 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.50 (d, *J* = 8.3 Hz, 1H), 8.76-8.51 (m, 2H), 8.11-8.04 (m, 1H), 7.87-7.77 (m, 5H), 7.75-7.65 (m, 3H), 7.24 (s, 4H), 2.38 (s, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 157.27 (d, *J* = 127.8 Hz), 142.77 (d, *J* = 23.3 Hz), 142.08 (d, *J* = 2.8 Hz), 132.56 (d, *J* = 6.7 Hz), 132.32 (d, *J* = 9.6 Hz), 131.21 (d, *J* = 1.1 Hz), 130.98 (s), 130.27 (s), 129.20 (s), 128.97 (d, *J* = 12.6 Hz), 128.70 (d, *J* = 3.9 Hz), 128.64 (s), 127.93 (s), 127.87 (s), 127.70 (s), 124.33 (d, *J* = 2.5 Hz), 122.10 (s), 21.67 (s). ^{31}P NMR (162 MHz, $CDCl_3$) δ 28.96 (s).

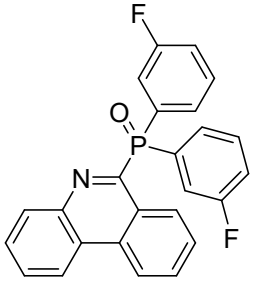


bis(4-methoxyphenyl)(phenanthridin-6-yl)phosphine oxide **(3ae)**[1a]: colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.49 (d, *J* = 8.3 Hz, 1H), 8.68-8.50 (m, 2H), 8.15-7.99 (m, 1H), 7.84 (dd, *J* = 11.0, 8.7 Hz, 5H), 7.73-7.61 (m, 3H), 6.95 (dd, *J* = 8.7, 1.9 Hz, 4H), 3.80 (s, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 162.31 (d, *J* = 2.9 Hz), 157.47 (d, *J* = 129.0 Hz), 142.76 (d, *J* = 23.2 Hz), 134.14 (d, *J* = 10.6 Hz), 132.57 (d, *J* = 6.8 Hz), 131.07 (d, *J* = 17.6 Hz), 130.40 (s), 128.72 (s), 128.67 (d, *J* = 2.0 Hz), 127.85 (s), 127.33 (d, *J* = 59.4 Hz), 124.81 (s), 124.31 (d, *J* = 2.4 Hz), 123.70 (s), 122.10 (s), 113.79 (d, *J* = 13.2 Hz), 113.66 (d, *J* = 4.6 Hz), 55.30 (s). ^{31}P NMR (162 MHz, $CDCl_3$) δ 28.85 (s).

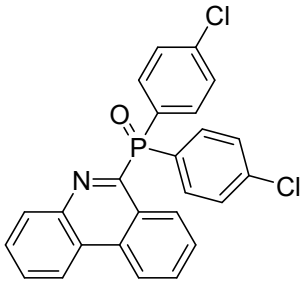


bis(4-fluorophenyl)(phenanthridin-6-yl)phosphine oxide **(3af)**[1a]**:** white solid, m.p. 144.2-145.1 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.47 (d, *J* = 8.3 Hz, 1H), 8.75-8.56 (m, 2H), 8.12-8.03 (m, 1H), 7.99-7.84 (m, 5H), 7.79-7.65 (m, 3H), 7.15 (t, *J* = 7.8 Hz, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 165.09 (dd, *J* = 253.1, 3.3 Hz), 156.33 (d, *J* = 130.9 Hz), 142.65 (d, *J* = 23.6 Hz), 134.78 (d, *J* = 1.7 Hz), 134.78 (d, *J* = 19.4 Hz), 132.66 (d, *J* = 7.1 Hz), 131.28 (s), 131.06 (d, *J* = 1.0 Hz), 129.16 (d, *J* = 3.4 Hz),

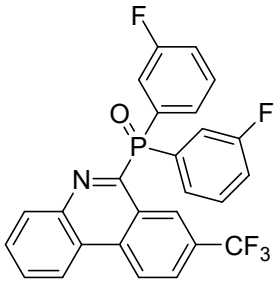
129.08 (s), 128.90 (s), 128.36 (s), 128.06 (s), 127.71 (d, J = 23.5 Hz), 124.39 (d, J = 2.4 Hz), 122.55-121.65 (m), 115.69 (dd, J = 21.4, 13.4 Hz). ^{19}F NMR (376 MHz, $CDCl_3$) δ -106.92 (s). ^{31}P NMR (162 MHz, $CDCl_3$) δ 26.69 (s). HRMS (ESI-TOF, $[M+H]^+$): calcd for $C_{25}H_{17}F_2NOP$, 416.1010, found 416.1012.



bis(3-fluorophenyl)(phenanthridin-6-yl)phosphine oxide **(3ag):** white solid, m.p. 159.8-160.9 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.48 (d, J = 8.3 Hz, 1H), 8.68 (d, J = 8.3 Hz, 1H), 8.62 (dd, J = 8.8, 3.2 Hz, 1H), 8.15-8.06 (m, 1H), 7.93-7.84 (m, 1H), 7.80-7.62 (m, 7H), 7.50-7.40 (m, 2H), 7.23 (td, J = 8.4, 1.9 Hz, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 163.61 (d, J = 17.2 Hz), 161.13 (d, J = 17.2 Hz), 155.67 (d, J = 131.5 Hz), 142.65 (d, J = 23.7 Hz), 135.64 (d, J = 6.2 Hz), 134.60 (d, J = 6.0 Hz), 132.71 (d, J = 7.1 Hz), 131.35 (s), 131.11 (s), 130.25 (dd, J = 14.2, 7.4 Hz), 129.08 (d, J = 22.9 Hz), 128.17 (d, J = 10.9 Hz), 128.00 (dd, J = 8.7, 3.2 Hz), 127.76 (d, J = 23.9 Hz), 124.44 (d, J = 2.4 Hz), 122.25 (dd, J = 8.0, 1.2 Hz), 119.27 (d, J = 1.8 Hz), 119.25 (d, J = 22.7 Hz), 119.06 (d, J = 3.0 Hz). ^{19}F NMR (376 MHz, $CDCl_3$) δ -111.39 (d, J = 6.0 Hz). ^{31}P NMR (162 MHz, $CDCl_3$) δ 24.92 (s). HRMS (ESI-TOF, $[M+H]^+$): calcd for $C_{25}H_{17}F_2NOP$, 416.1010, found 416.1014.



bis(4-chlorophenyl)(phenanthridin-6-yl)phosphine oxide **(3ah)**[1a]**:** white solid, m.p. 229.3-230.1 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.45 (d, J = 8.3 Hz, 1H), 8.67 (d, J = 8.3 Hz, 1H), 8.61 (dd, J = 6.1, 3.4 Hz, 1H), 8.07 (dd, J = 5.8, 3.7 Hz, 1H), 7.87 (dd, J = 11.3, 8.4 Hz, 5H), 7.79-7.67 (m, 3H), 7.44 (dd, J = 8.5, 2.3 Hz, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 155.93 (d, J = 130.8 Hz), 142.65 (d, J = 23.6 Hz), 138.60 (d, J = 3.4 Hz), 133.68 (d, J = 10.0 Hz), 132.68 (d, J = 7.1 Hz), 131.62 (s), 131.34 (s), 131.07 (d, J = 1.1 Hz), 130.56 (s), 129.05 (d, J = 21.5 Hz), 128.70 (d, J = 12.8 Hz), 128.18 (d, J = 15.7 Hz), 127.81 (s), 127.58 (s), 124.42 (d, J = 2.5 Hz), 122.30 (d, J = 1.4 Hz), 122.22 (s). ^{31}P NMR (162 MHz, $CDCl_3$) δ 26.48 (s).



bis(3-fluorophenyl)(8-(trifluoromethyl)phenanthridin-6-yl)phosphine oxide **(3jg):** white solid, m.p. 173.8-174.3 ℃. ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.02 (s, 1H), 8.76 (d, *J* = 8.7 Hz, 1H), 8.66-8.57 (m, 1H), 8.22-8.14 (m, 1H), 8.05 (dd, *J* = 8.7, 1.5 Hz, 1H), 7.82 (qd, *J* = 6.7, 4.8 Hz, 4H), 7.76-7.67 (m, 2H), 7.52-7.41 (m, 2H), 7.23 (dd, *J* = 8.4, 2.5 Hz, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 162.39 (dd, *J* = 249.8, 17.3 Hz), 155.83 (d, *J* = 130.2 Hz), 143.19 (d, *J* = 23.0 Hz), 135.31 (d, *J* = 5.8 Hz), 134.78 (d, *J* = 7.7 Hz), 134.27 (d, *J* = 5.8 Hz), 131.18 (d, *J* = 1.1 Hz), 130.41 (dd, *J* = 14.3, 7.4 Hz), 130.02 (d, *J* = 40.7 Hz), 129.98-129.16 (m), 128.02 (dd, *J* = 8.6, 3.2 Hz), 127.22 (q, *J* = 3.2 Hz), 127.17 (d, *J* = 23.6 Hz), 125.90 (q, *J* = 4.3 Hz), 123.78 (dd, *J* = 545.5, 272.8 Hz), 123.44 (d, *J* = 2.5 Hz), 122.98 (dd, *J* = 82.1, 1.0 Hz), 119.51 (d, *J* = 2.6 Hz), 119.30 (dd, *J* = 6.3, 3.7 Hz), 119.07 (d, *J* = 10.0 Hz). ^{19}F NMR (376 MHz, $CDCl_3$) δ -62.22 (s), -111.09 (d, *J* = 6.4 Hz). ^{31}P NMR (162 MHz, $CDCl_3$) δ 23.45 (s). HRMS (ESI-TOF, $[M+H]^+$): calcd for $C_{26}H_{16}F_5NOP$, 484.0884, found 484.0889.

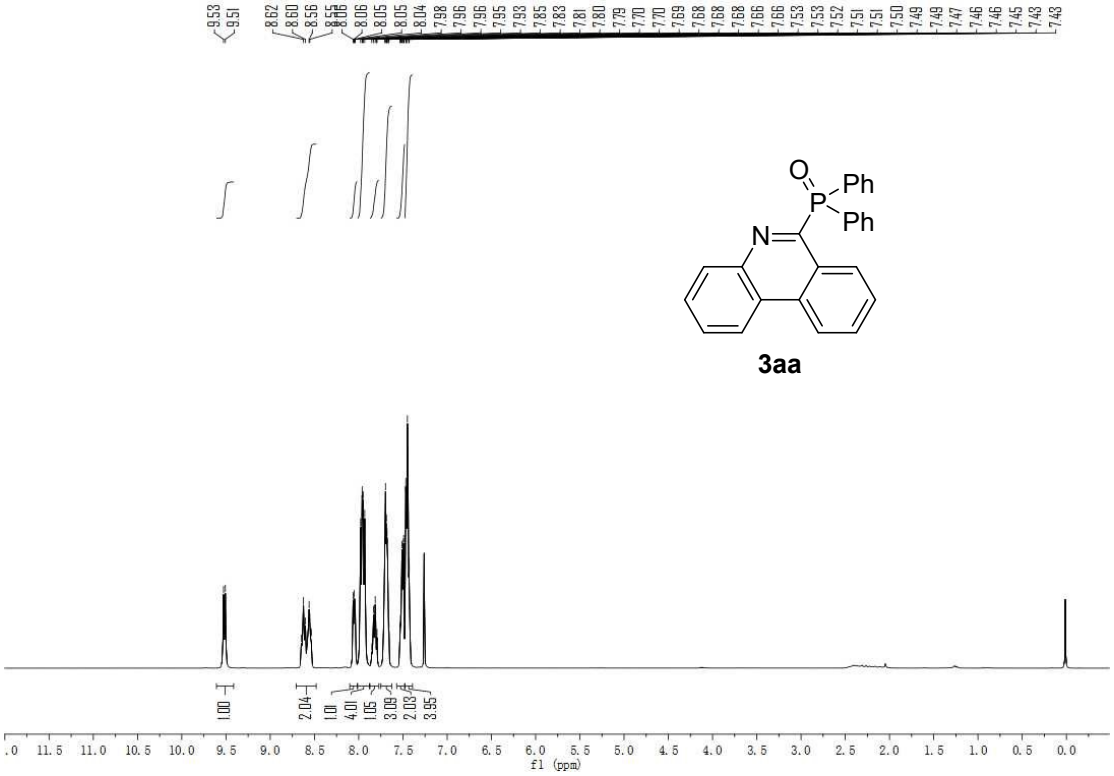
10. References

[1] (a) Y. Liu, X.-L. Chen, X.-Y. L, S.-S. Zhu, S.-J. Li, Y. Song, L.-B. Qu and B. Yu, *J. Am. Chem. Soc.,* **2021**, *143*, 964-972; (b) W.-S. Guo, Q. Dou, J. Hou, L.-R. Wen and M. Li, *J. Org. Chem.,* **2017**, *82*, 7015-7022.

[2] C. C. Chen and J. Waser, *Chem. Commun.,* **2014**, *50*, 12923-12926.

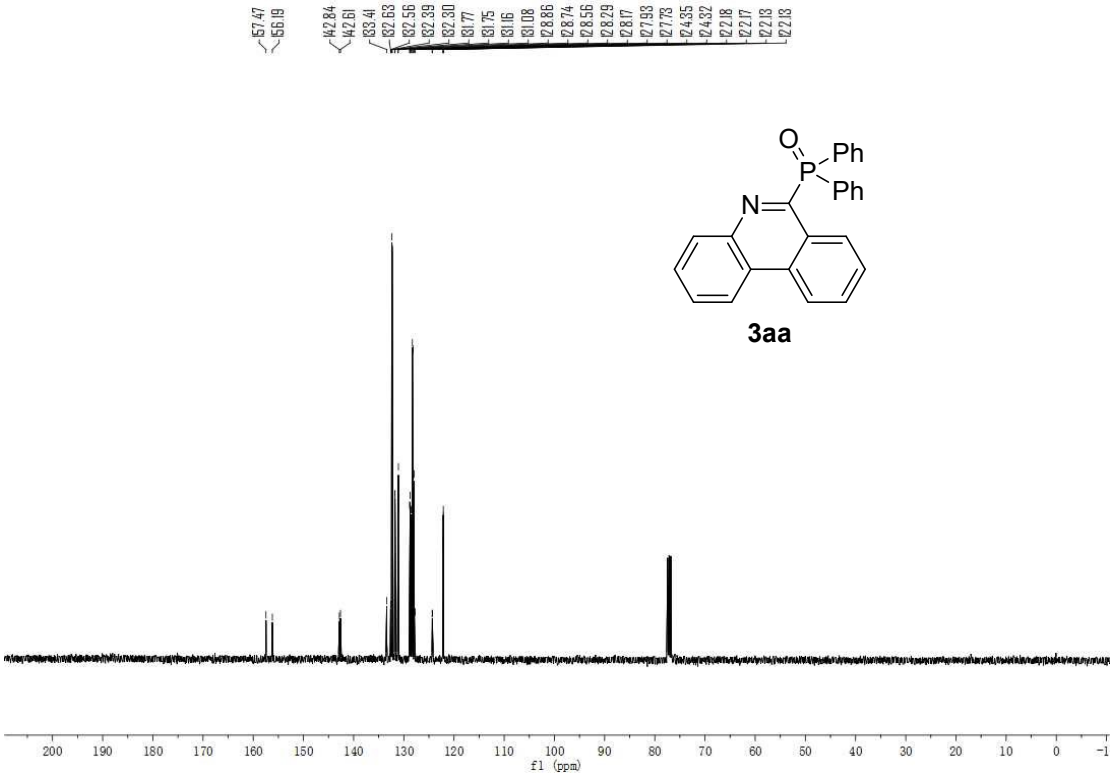
11. NMR Spectra

^{1}H NMR spectrum of 3aa



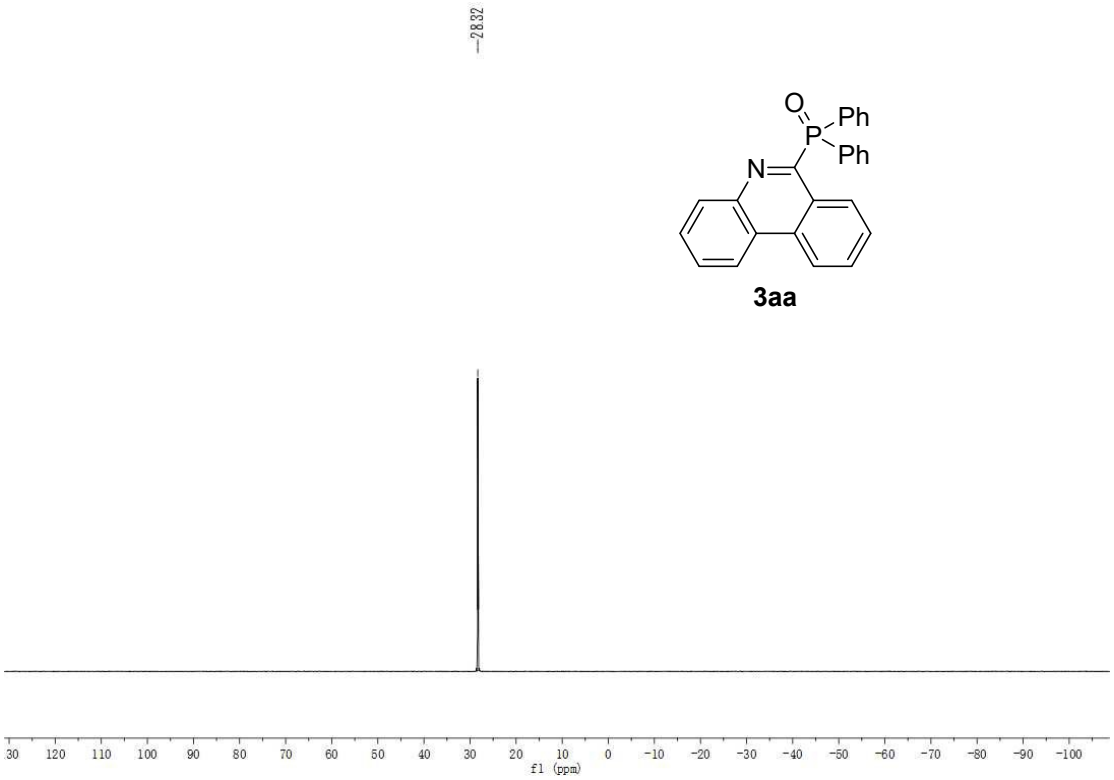
3aa

^{13}C NMR spectrum of 3aa

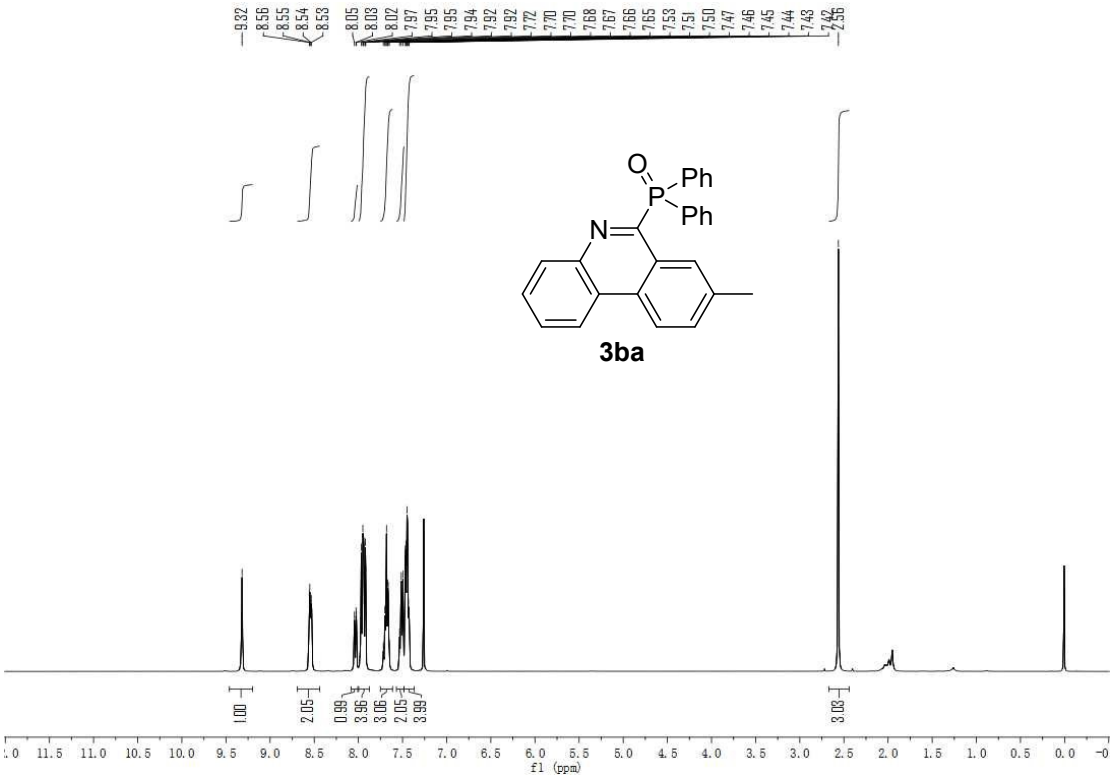


3aa

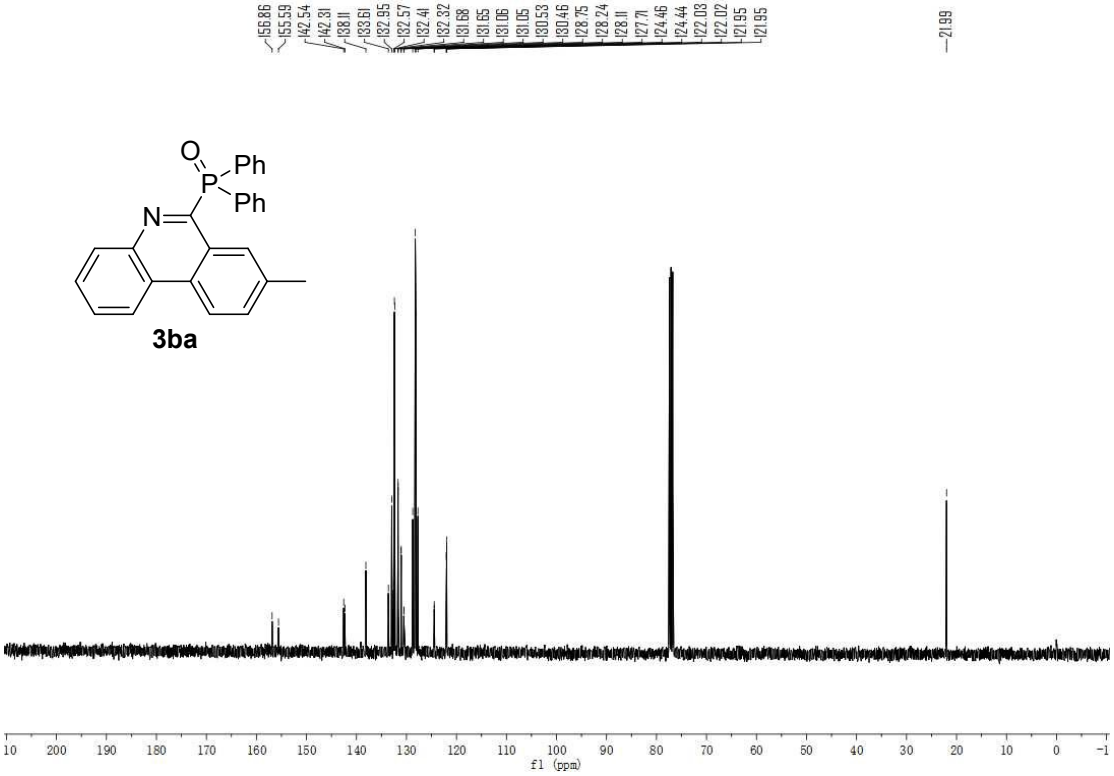
^{31}P NMR spectrum of 3aa



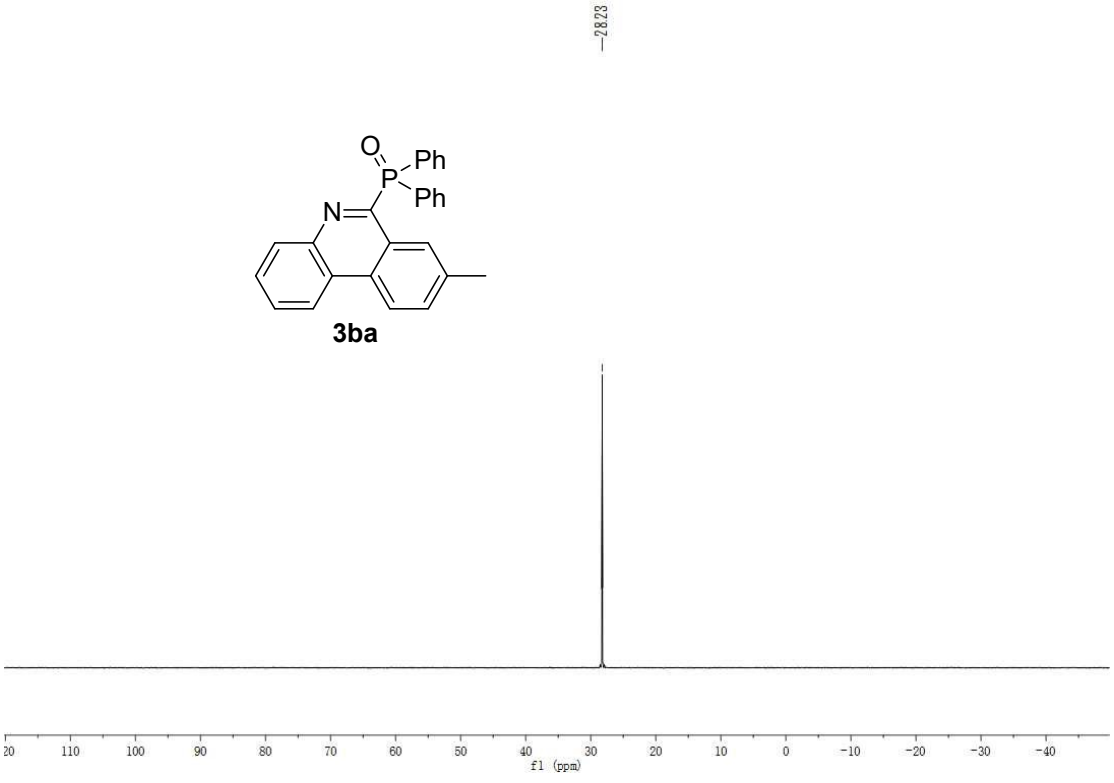
^{1}H NMR spectrum of 3ba



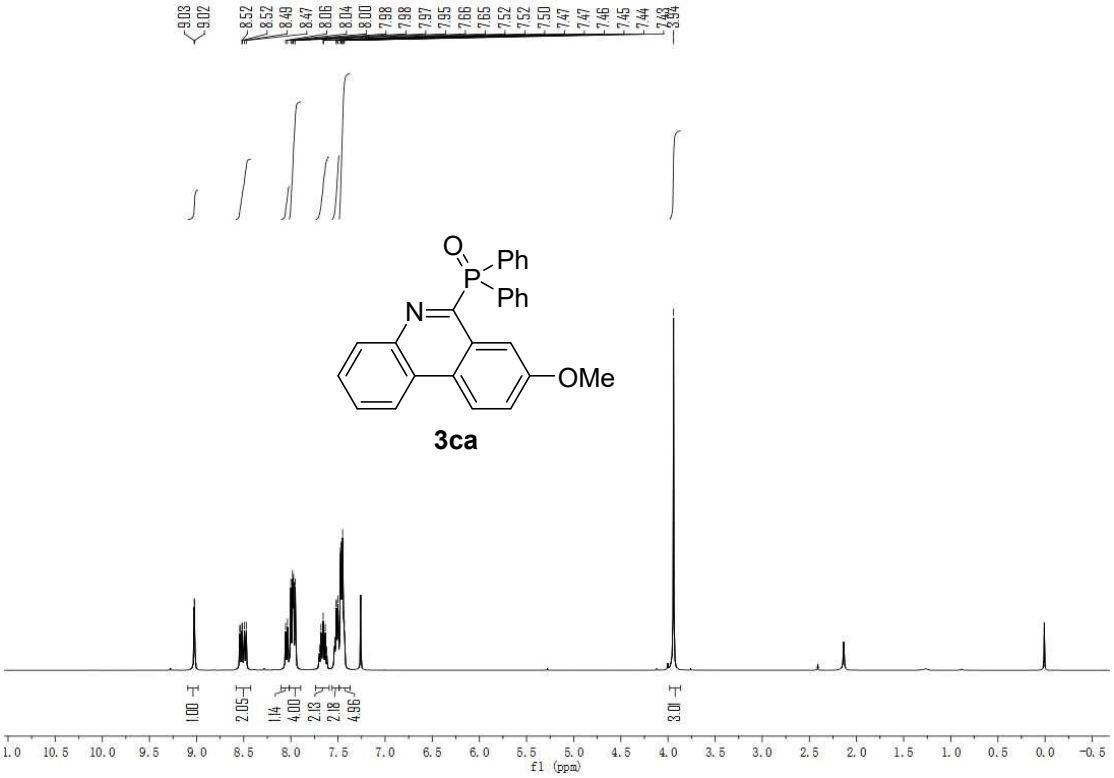
^{13}C NMR spectrum of 3ba



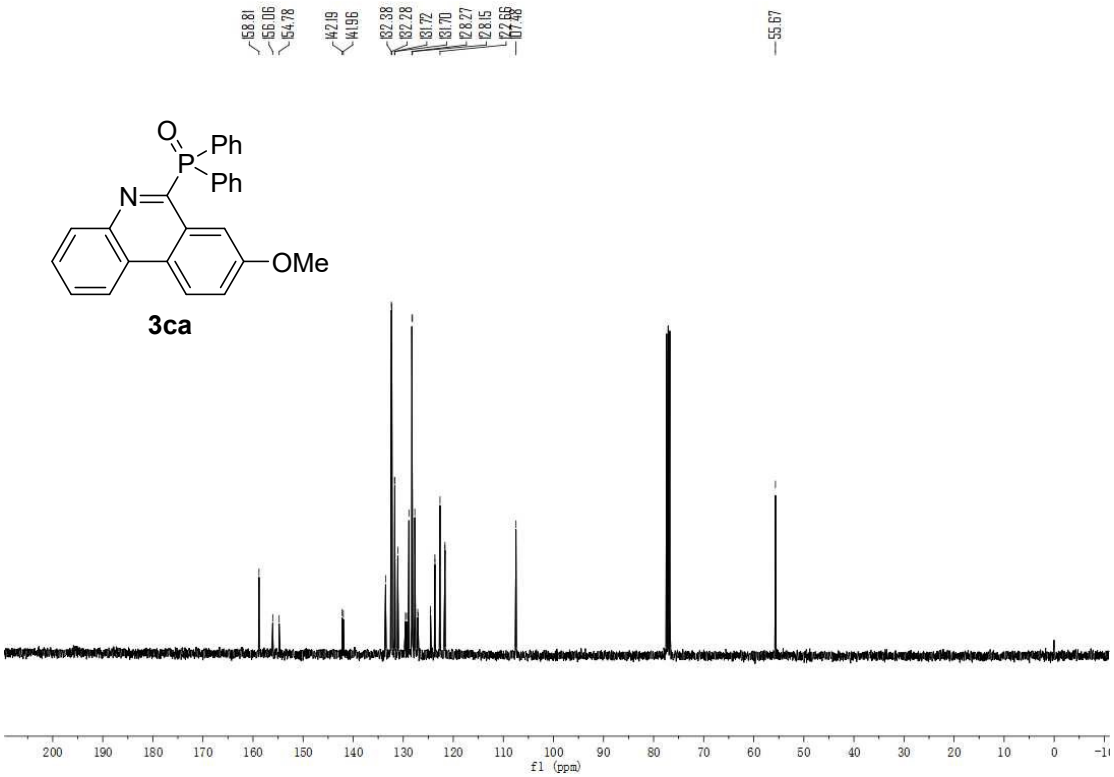
^{31}P NMR spectrum of 3ba



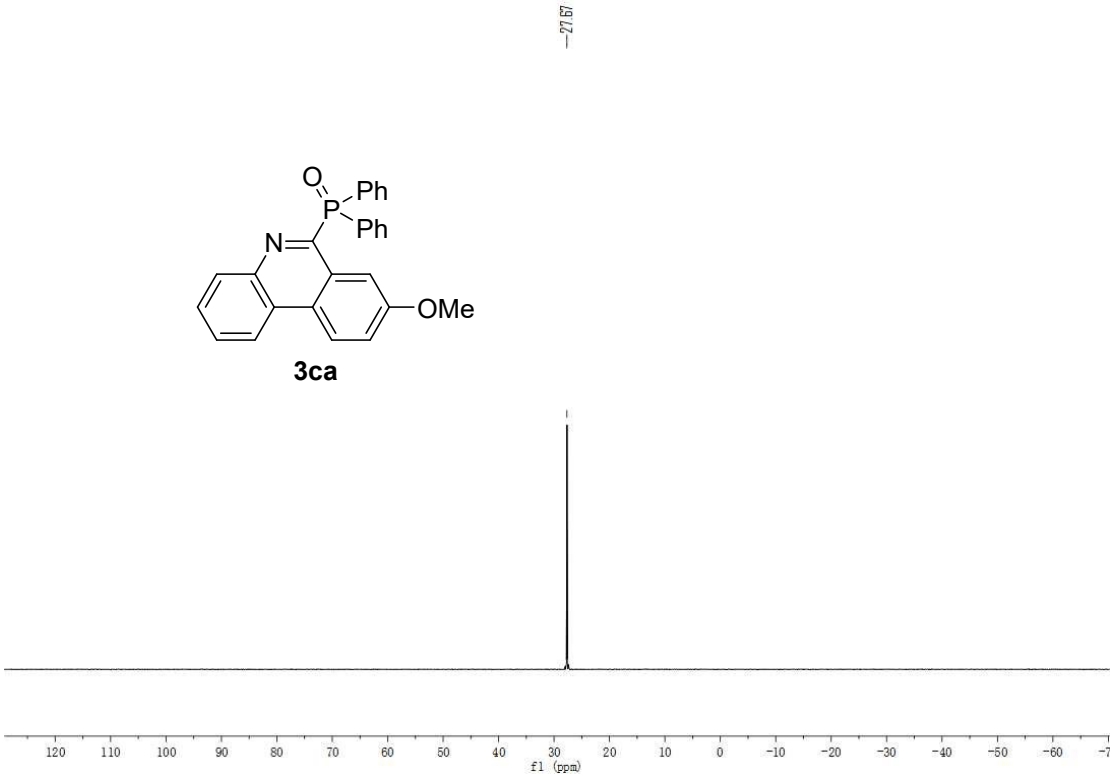
^{1}H NMR spectrum of 3ca



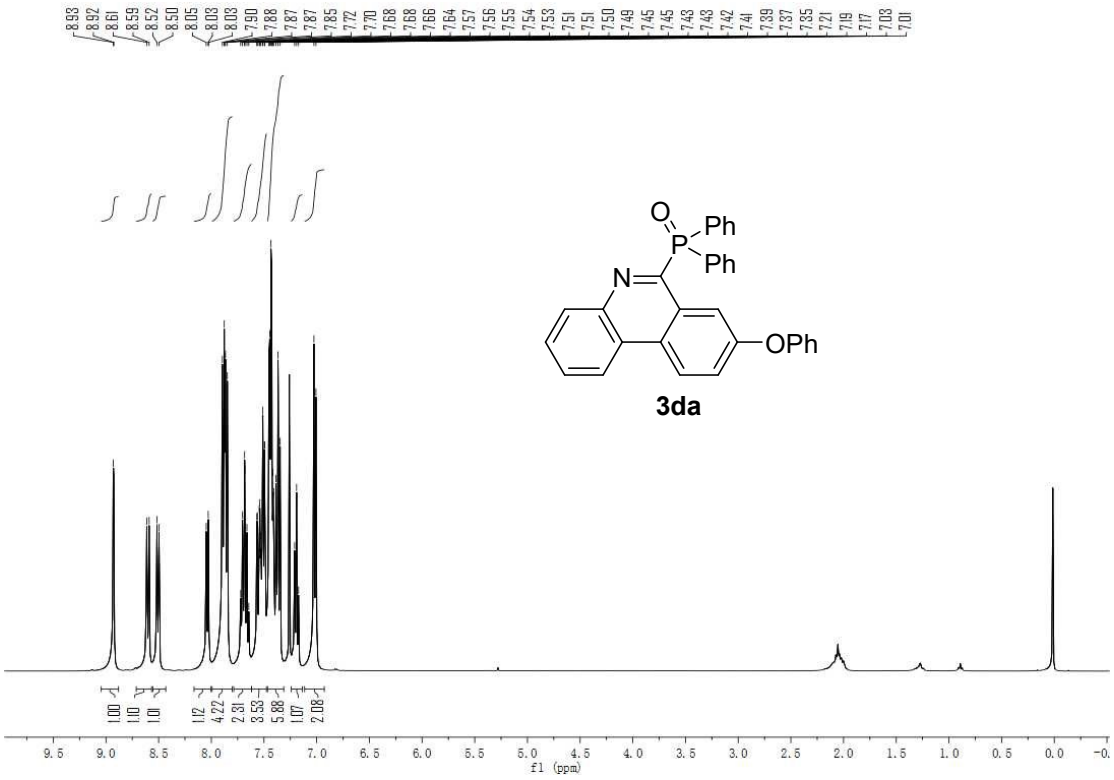
^{13}C NMR spectrum of 3ca



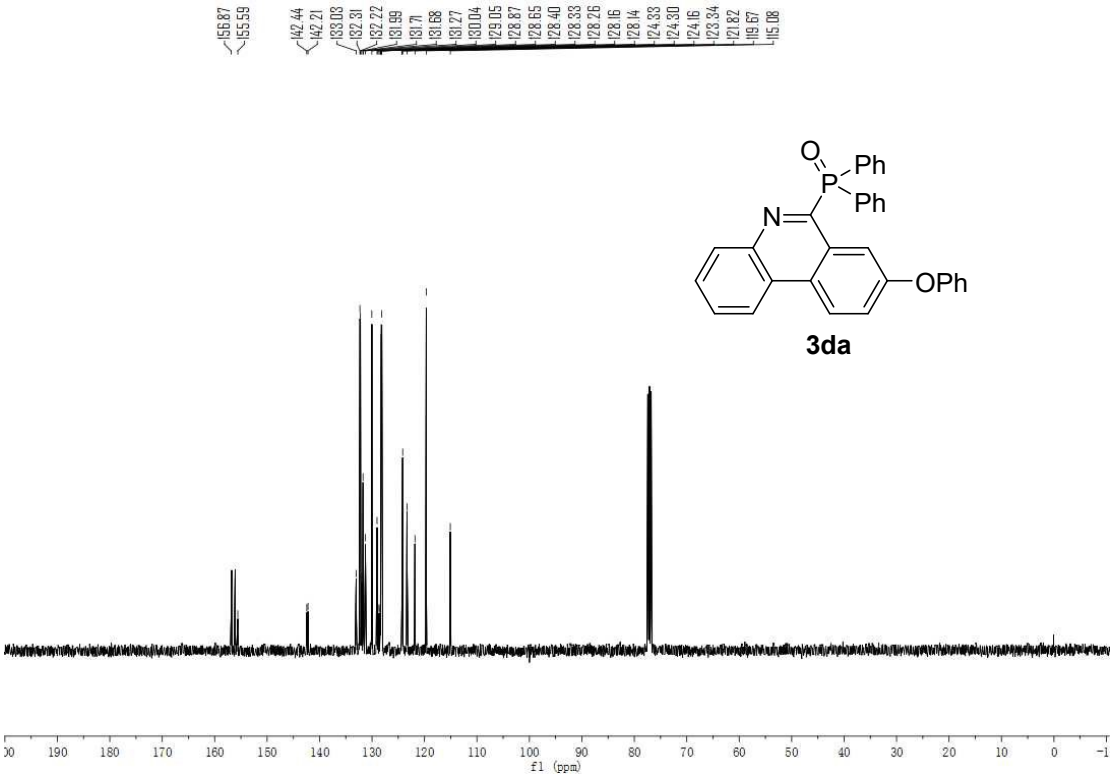
^{31}P NMR spectrum of 3ca



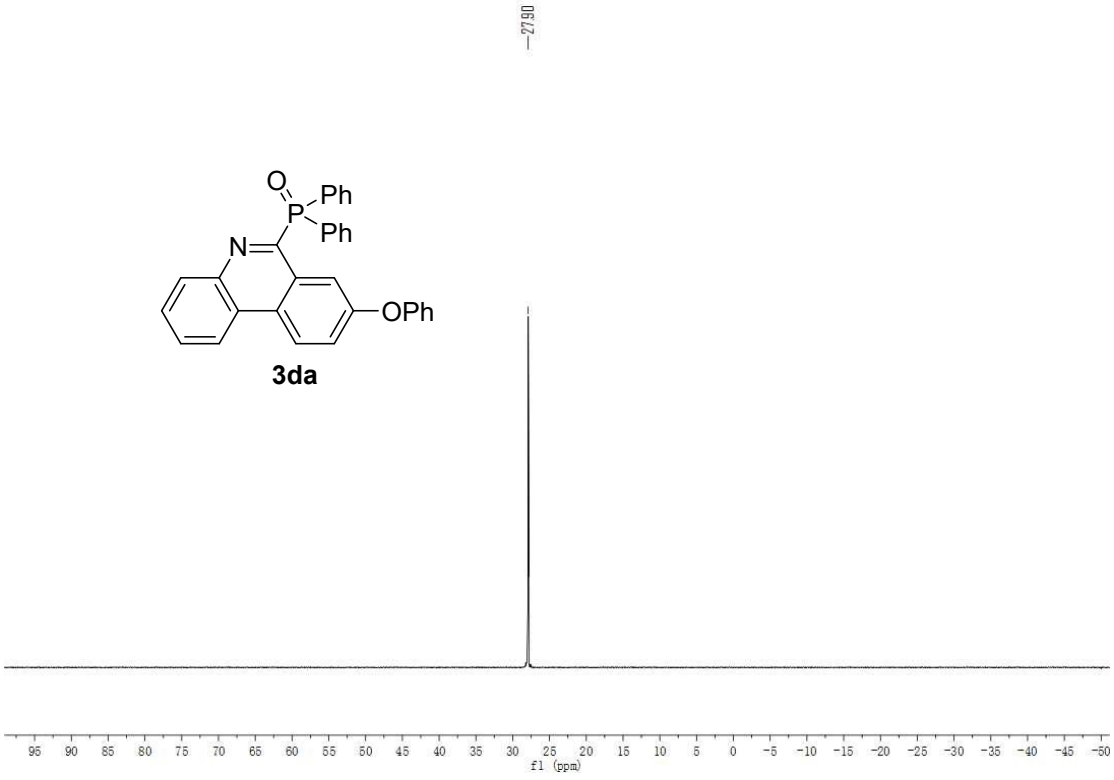
^{1}H NMR spectrum of 3da



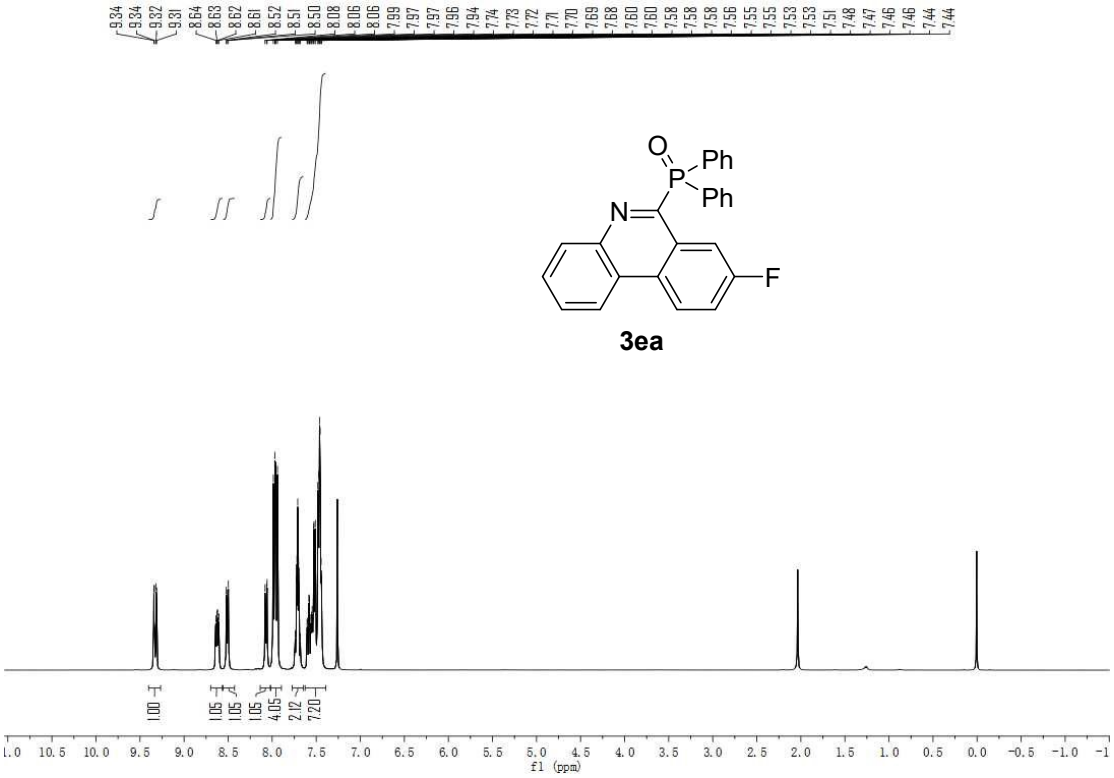
^{13}C NMR spectrum of 3da



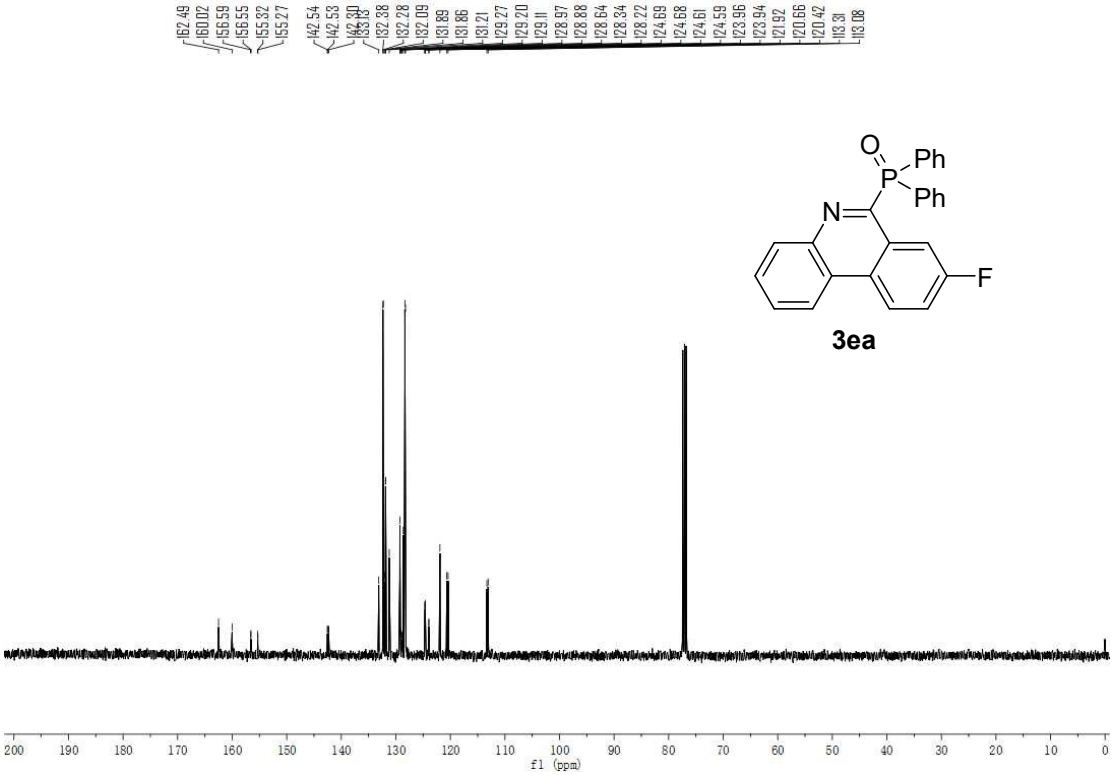
^{31}P NMR spectrum of 3da



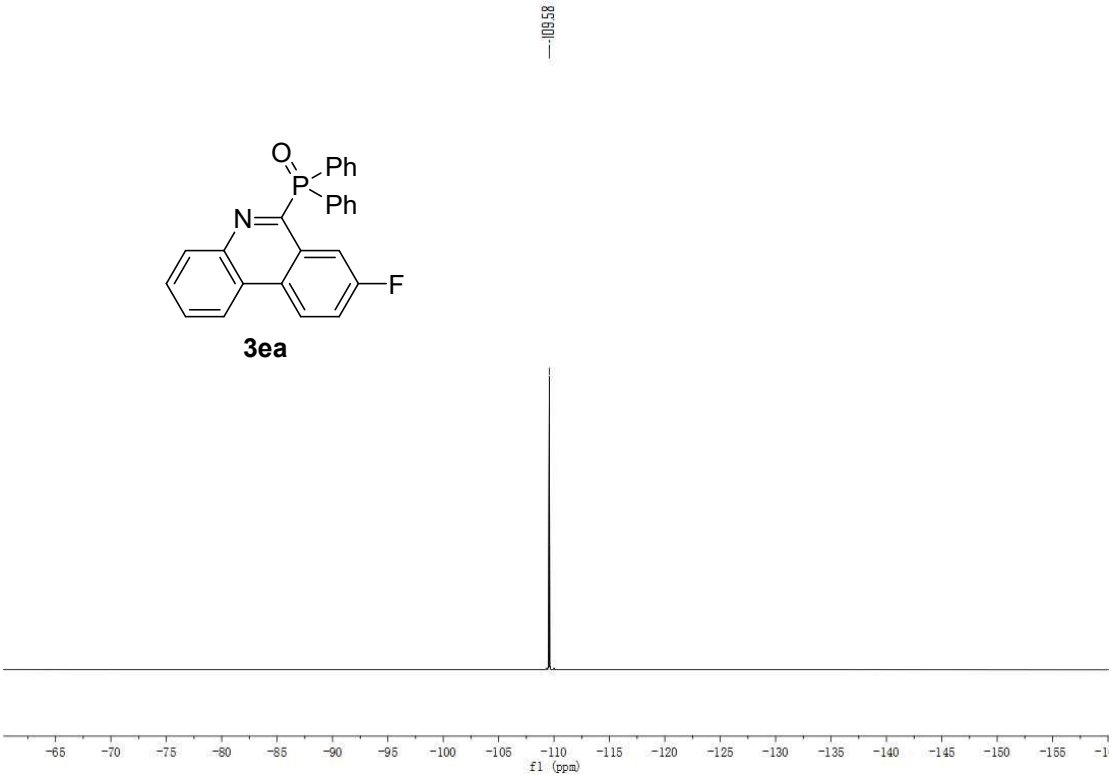
^{1}H NMR spectrum of 3ea



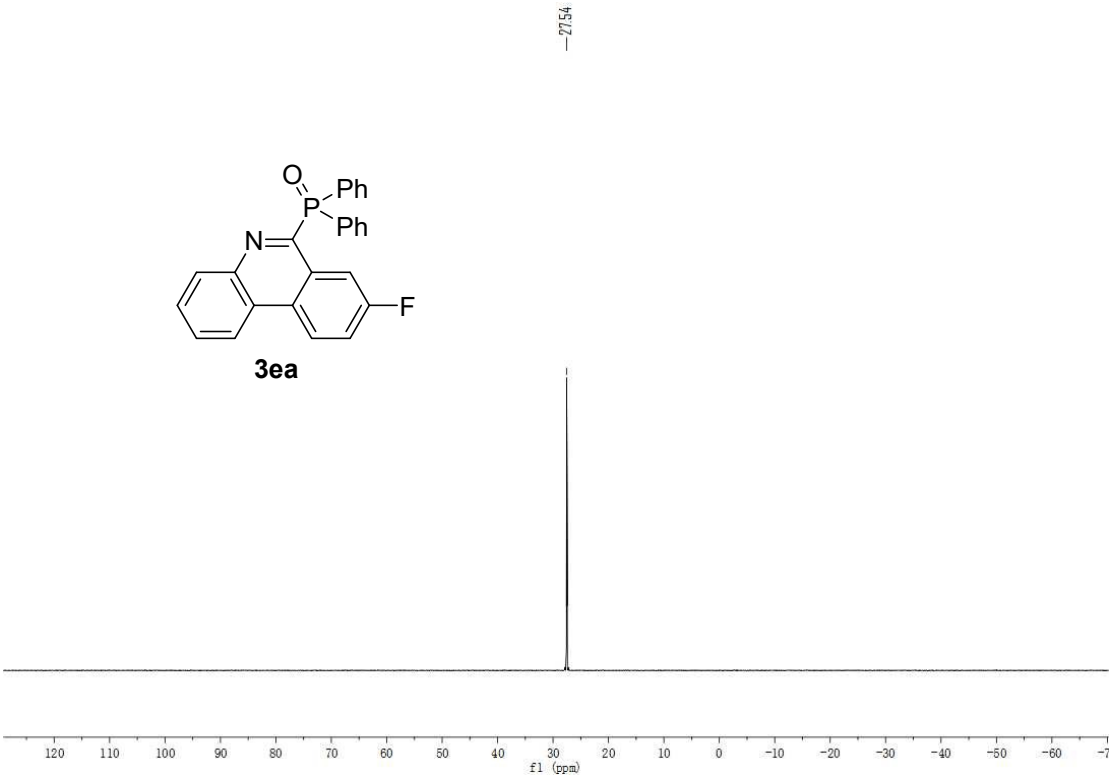
^{13}C NMR spectrum of 3ea



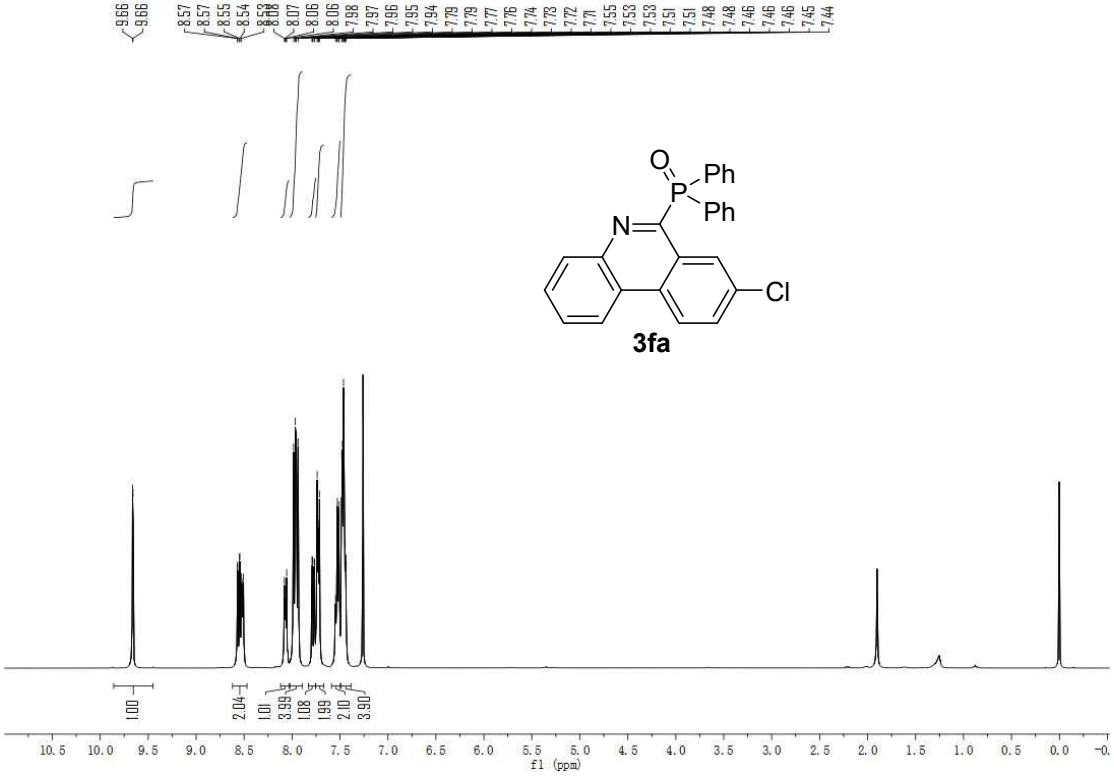
^{19}F NMR spectrum of 3ea



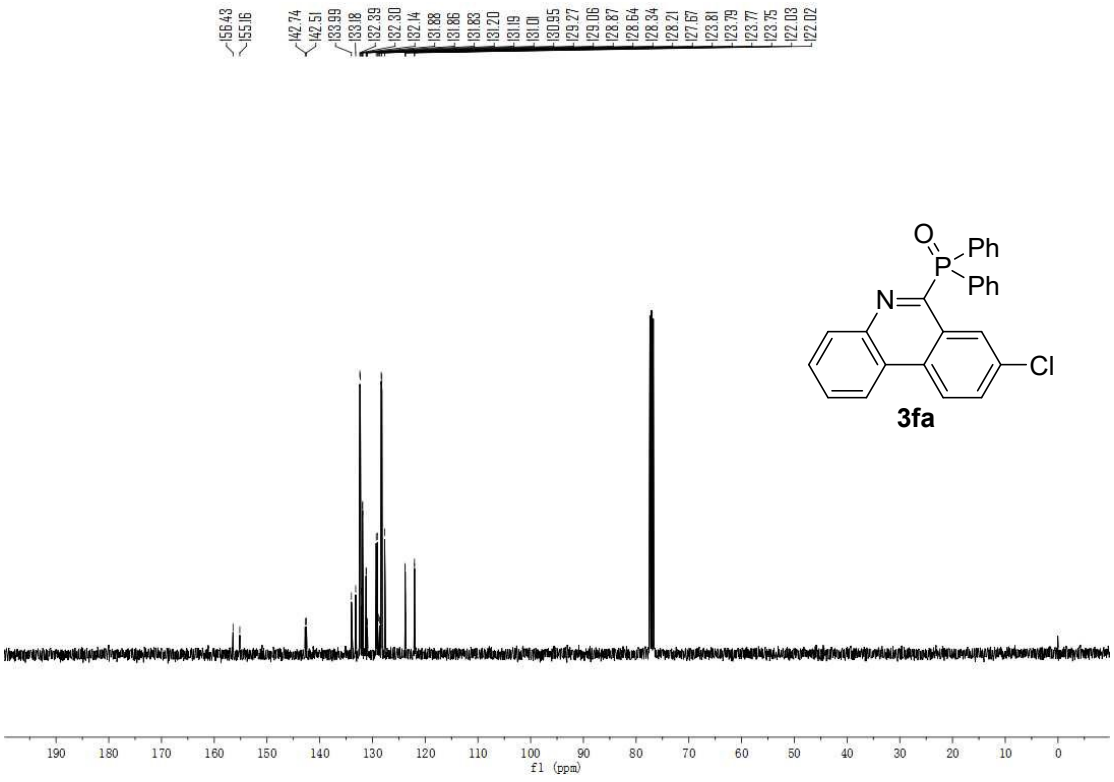
^{31}P NMR spectrum of 3ea



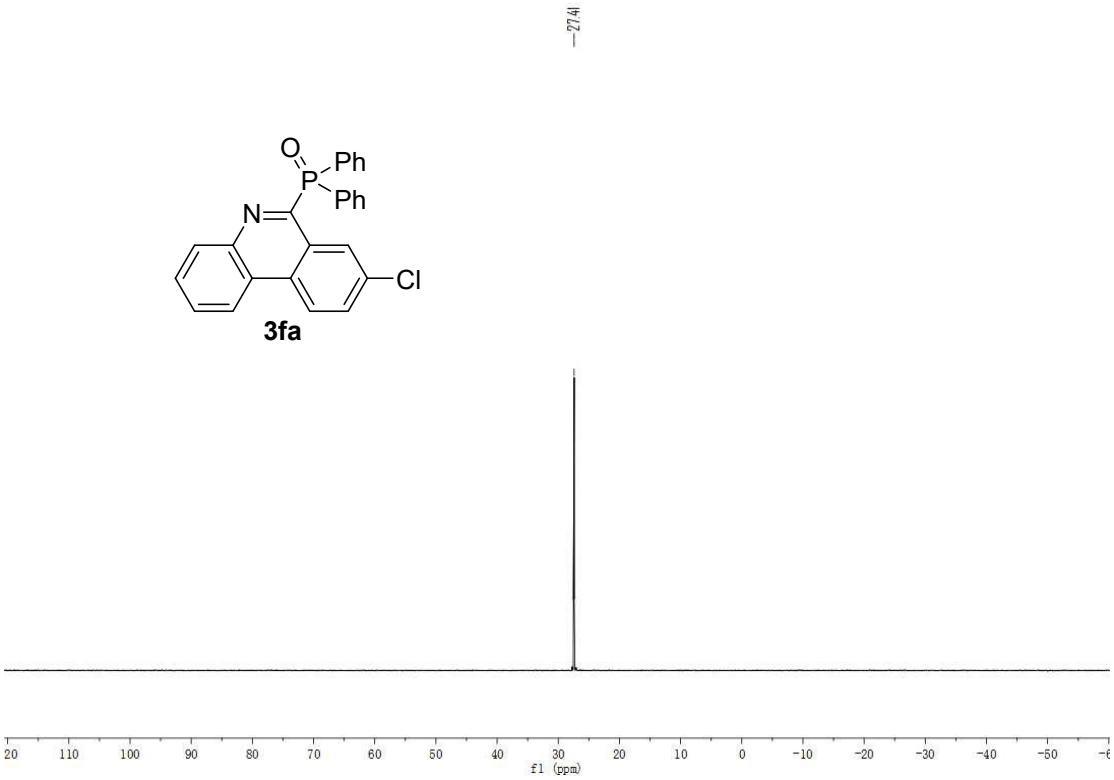
^{1}H NMR spectrum of 3fa



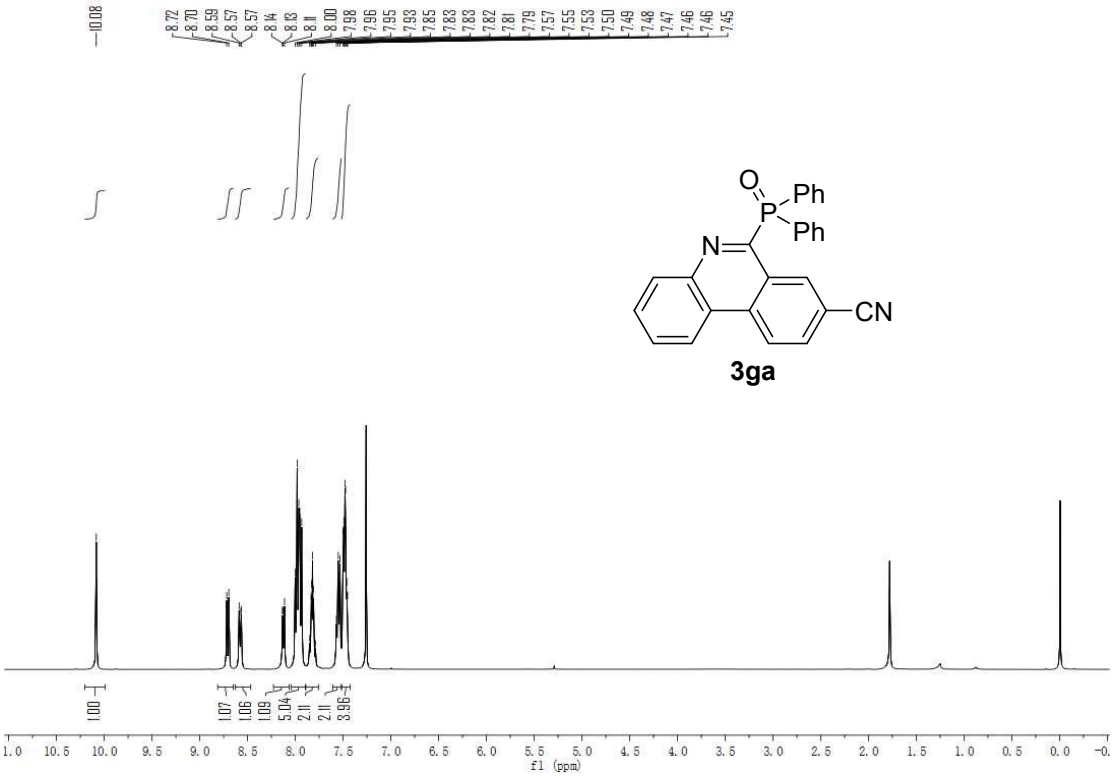
^{13}C NMR spectrum of 3fa



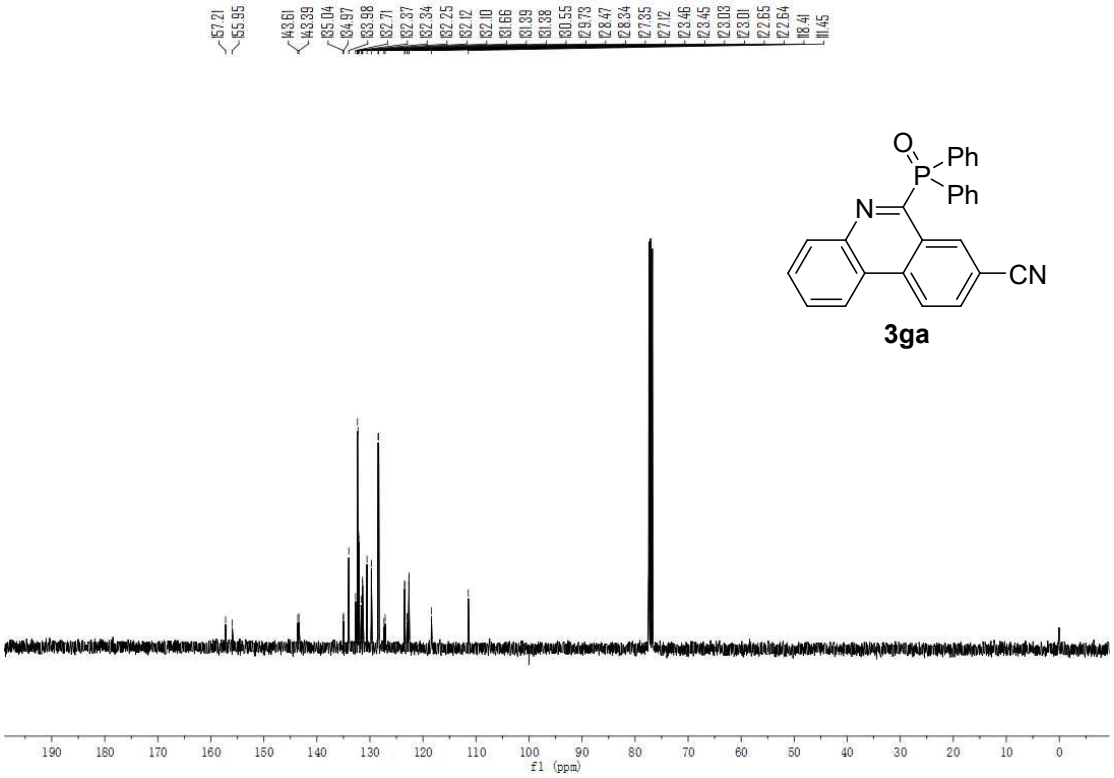
^{31}P NMR spectrum of 3fa



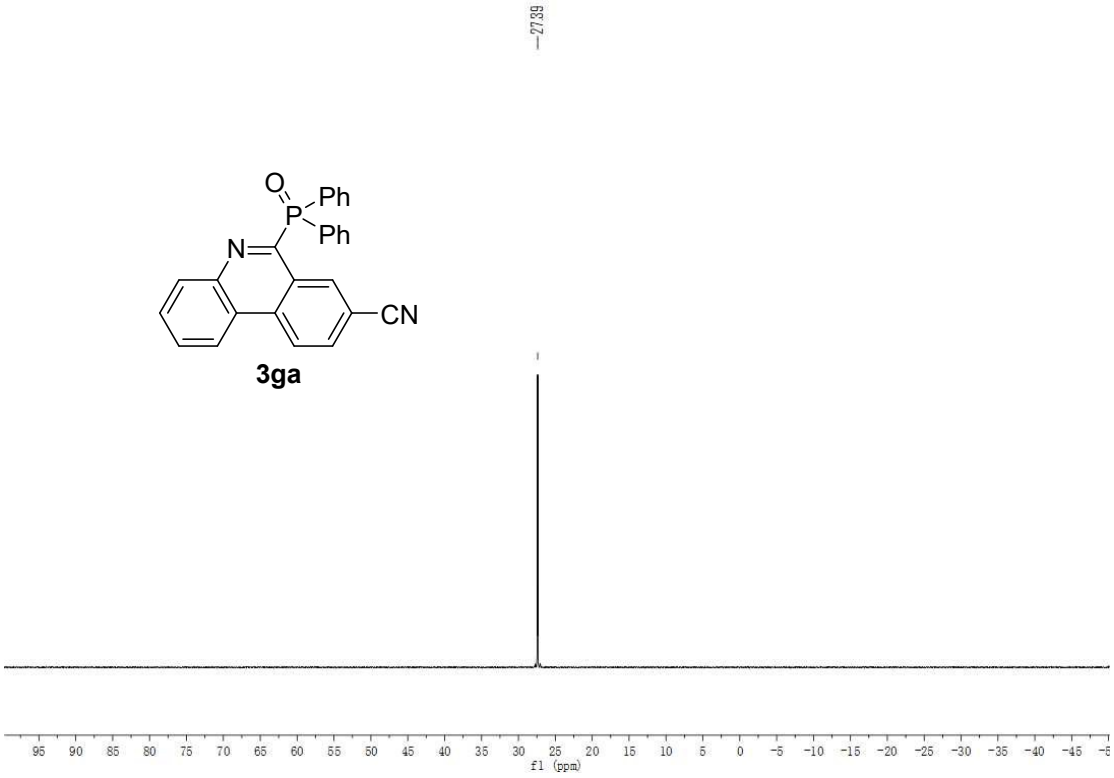
^{1}H NMR spectrum of 3ga



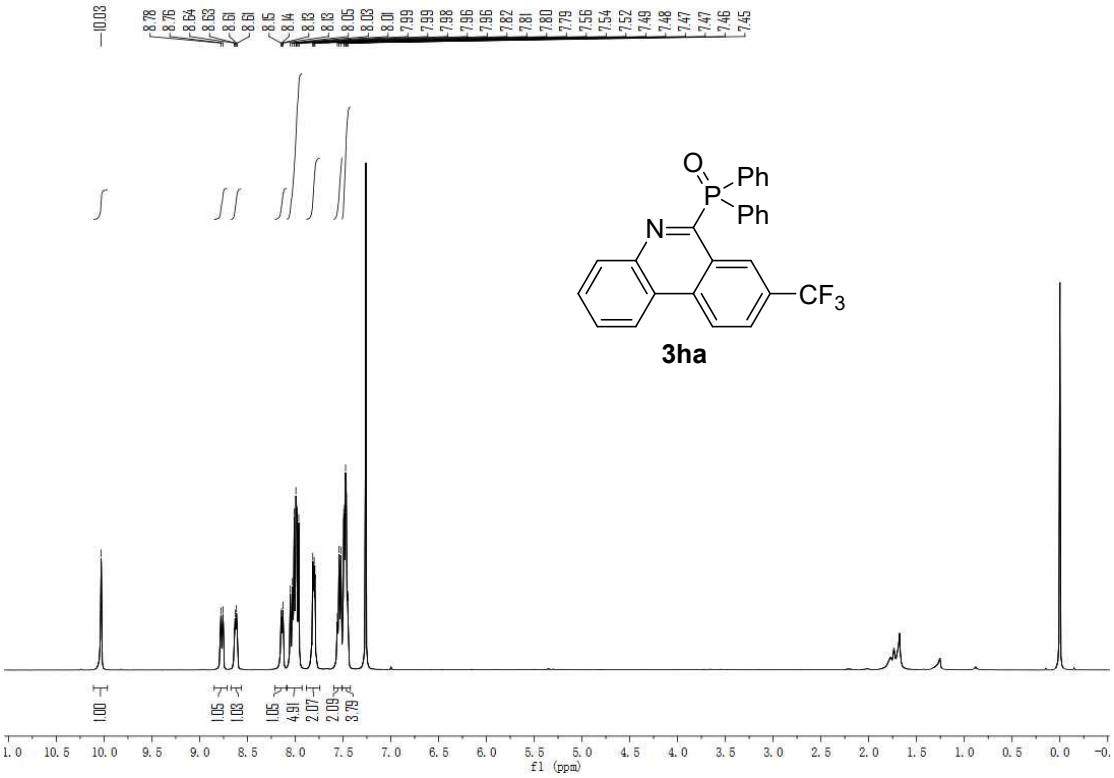
^{13}C NMR spectrum of 3ga



^{31}P NMR spectrum of 3ga

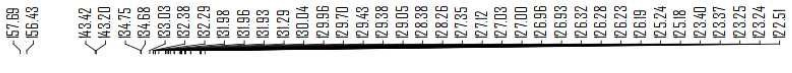


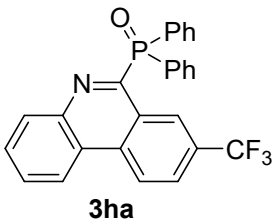
^{1}H NMR spectrum of 3ha



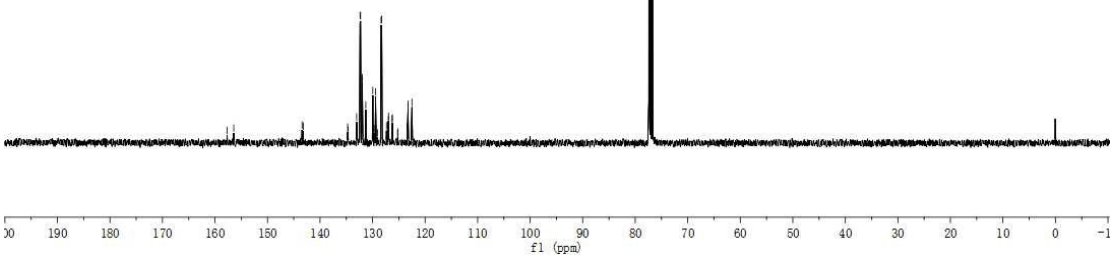
3ha

^{13}C NMR spectrum of 3ha

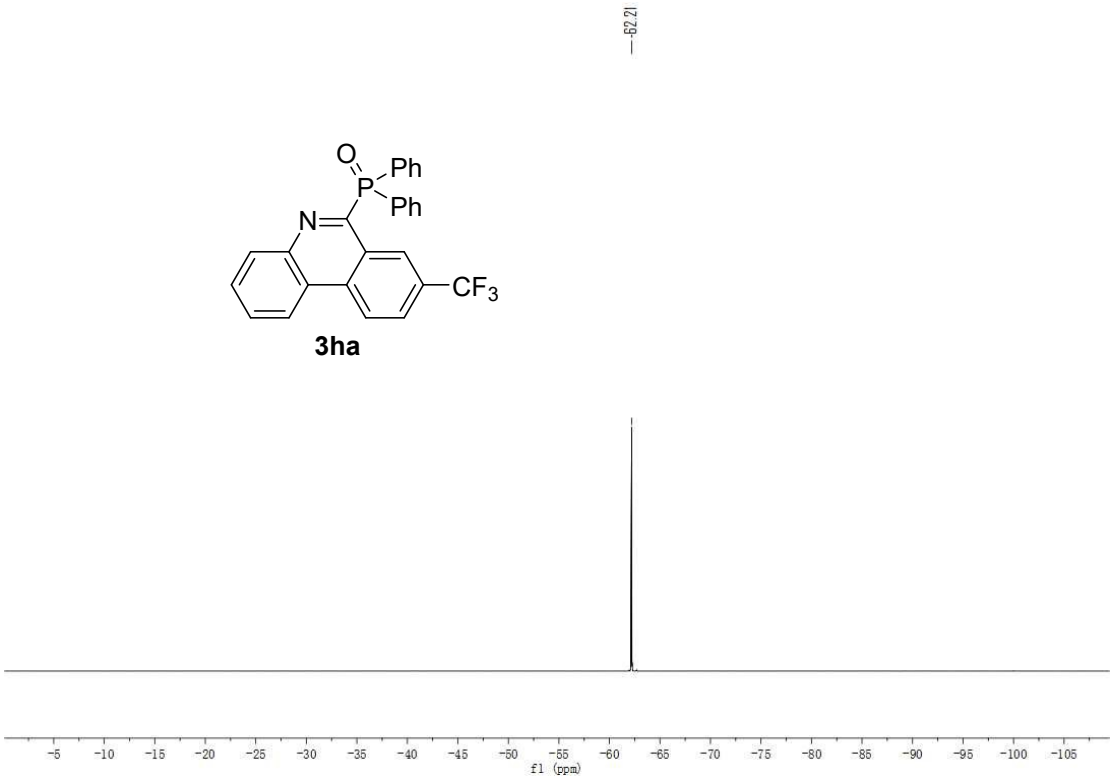




3ha

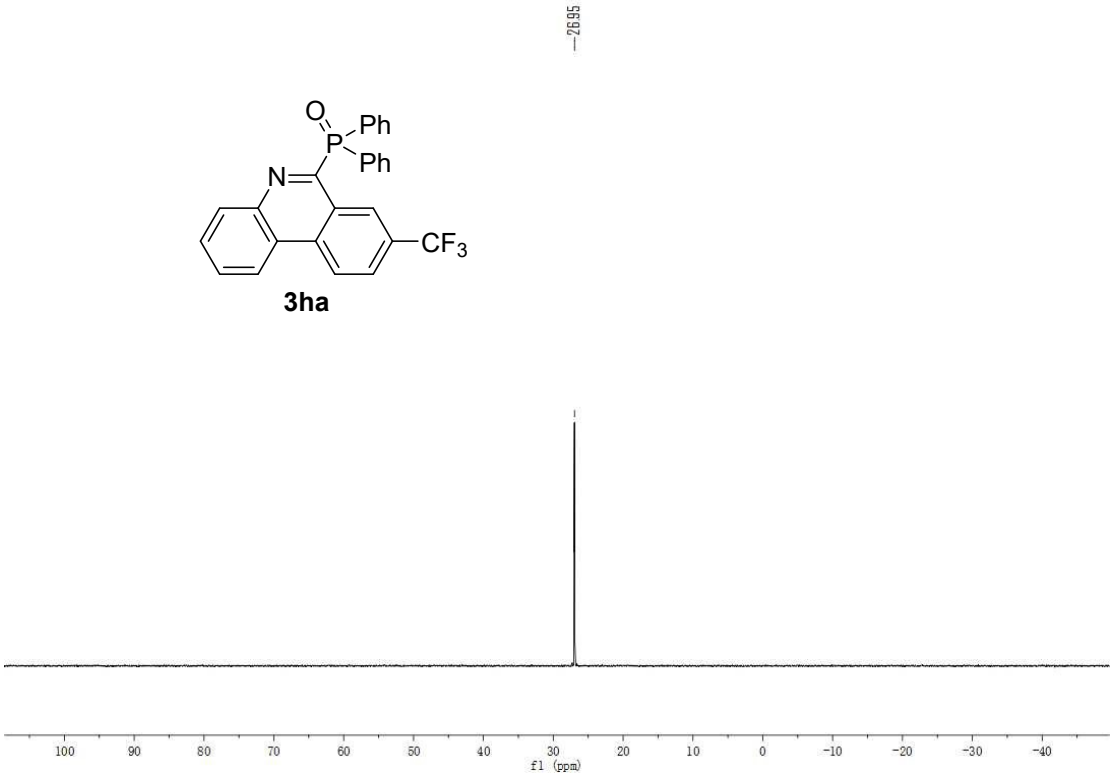


^{19}F NMR spectrum of 3ha



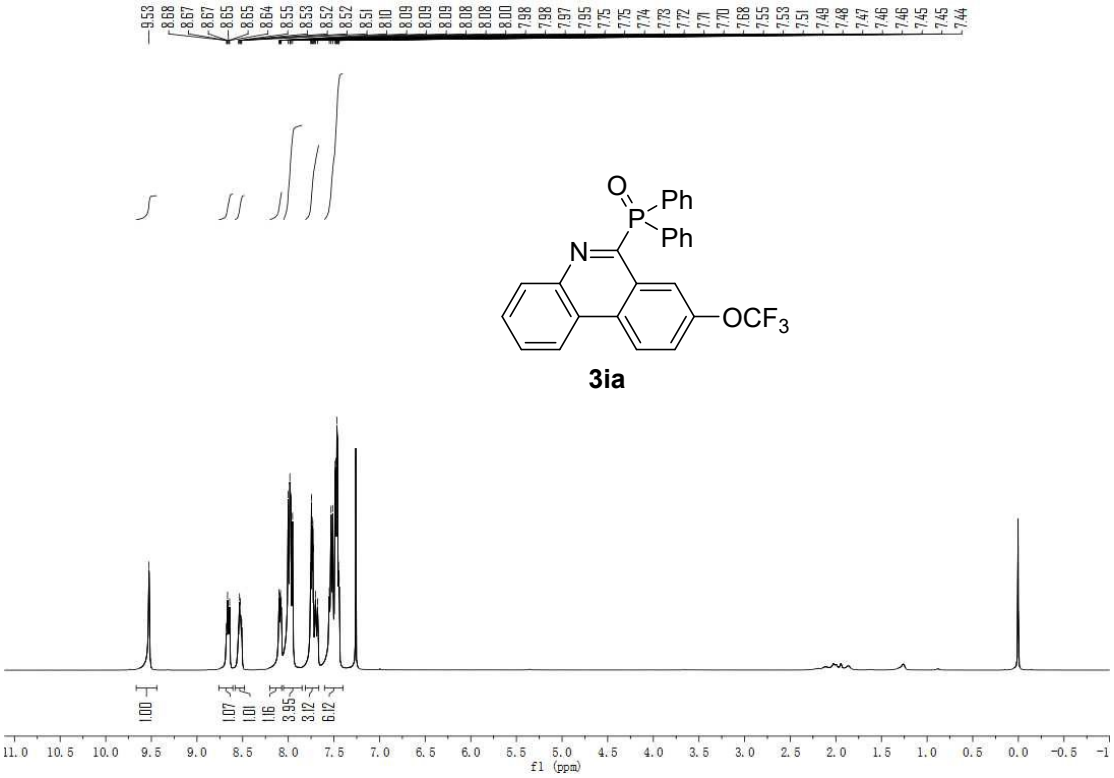
3ha

^{31}P NMR spectrum of 3ha



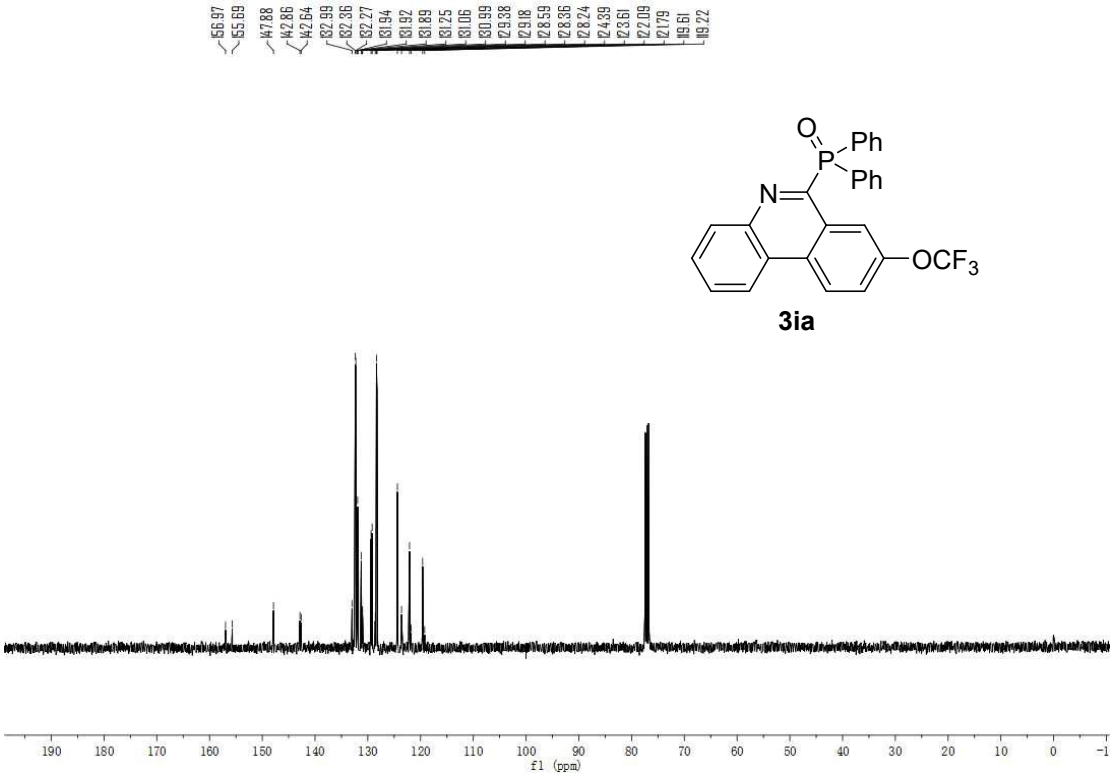
3ha

^{1}H NMR spectrum of 3ia



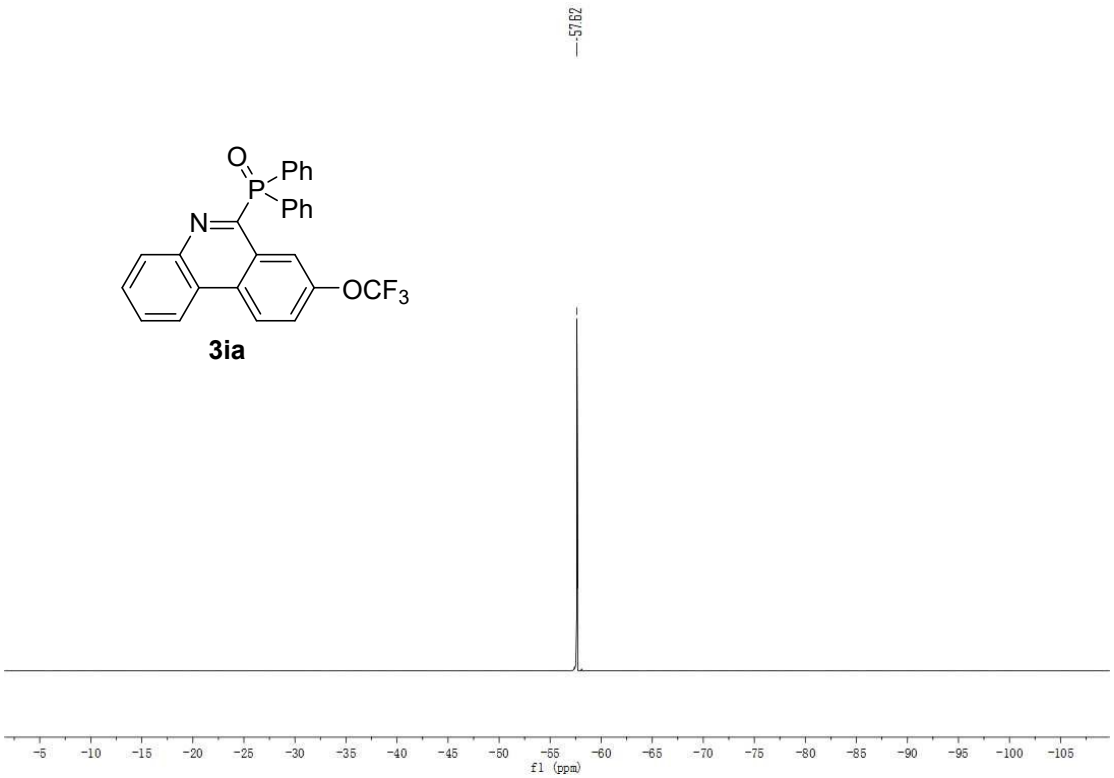
3ia

^{13}C NMR spectrum of 3ia

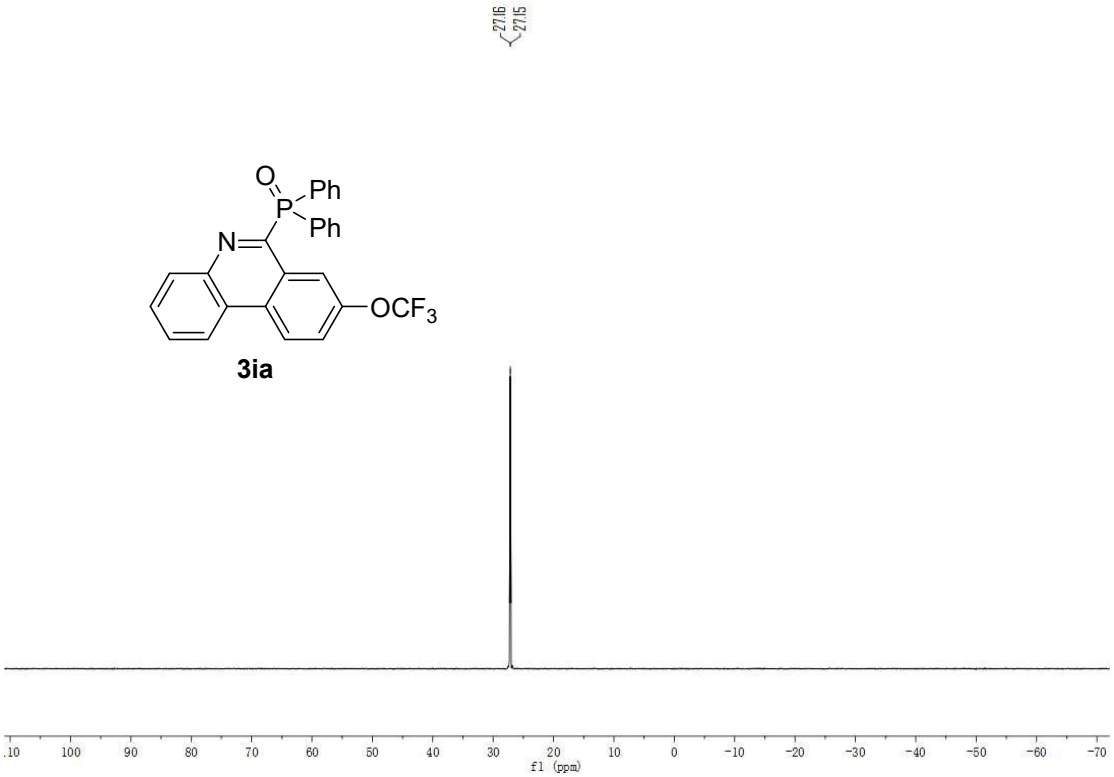


3ia

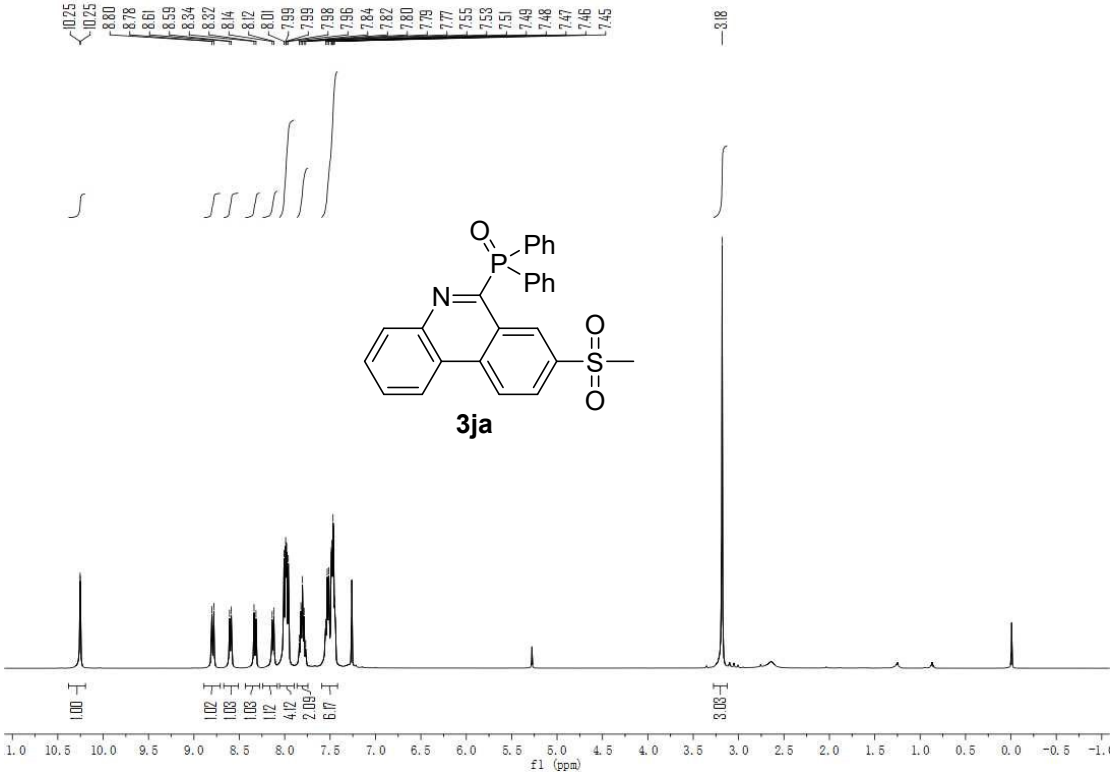
^{19}F NMR spectrum of 3ia



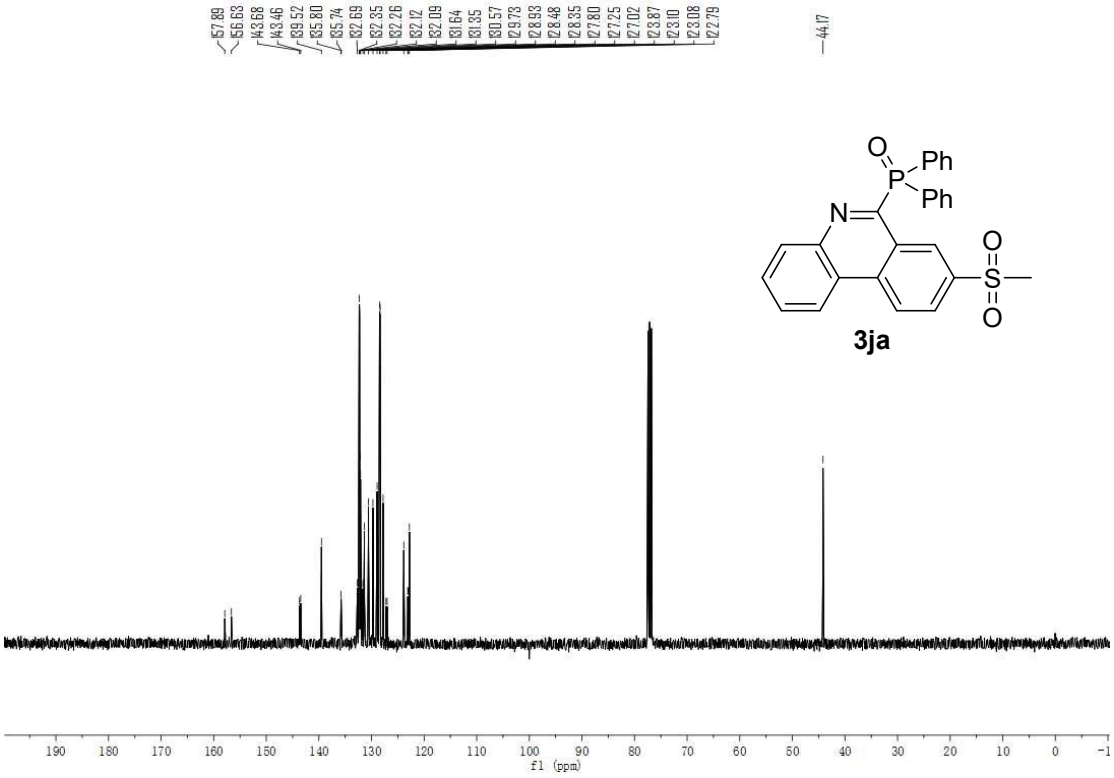
^{31}P NMR spectrum of 3ia



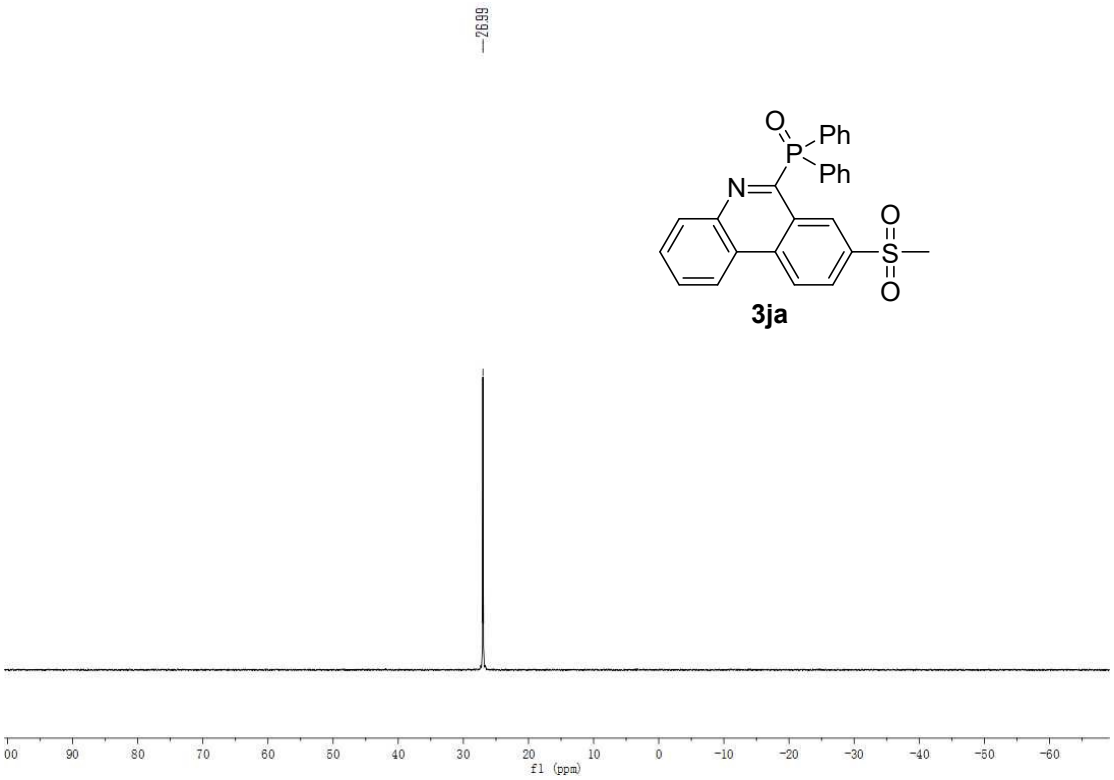
^{1}H NMR spectrum of 3ja



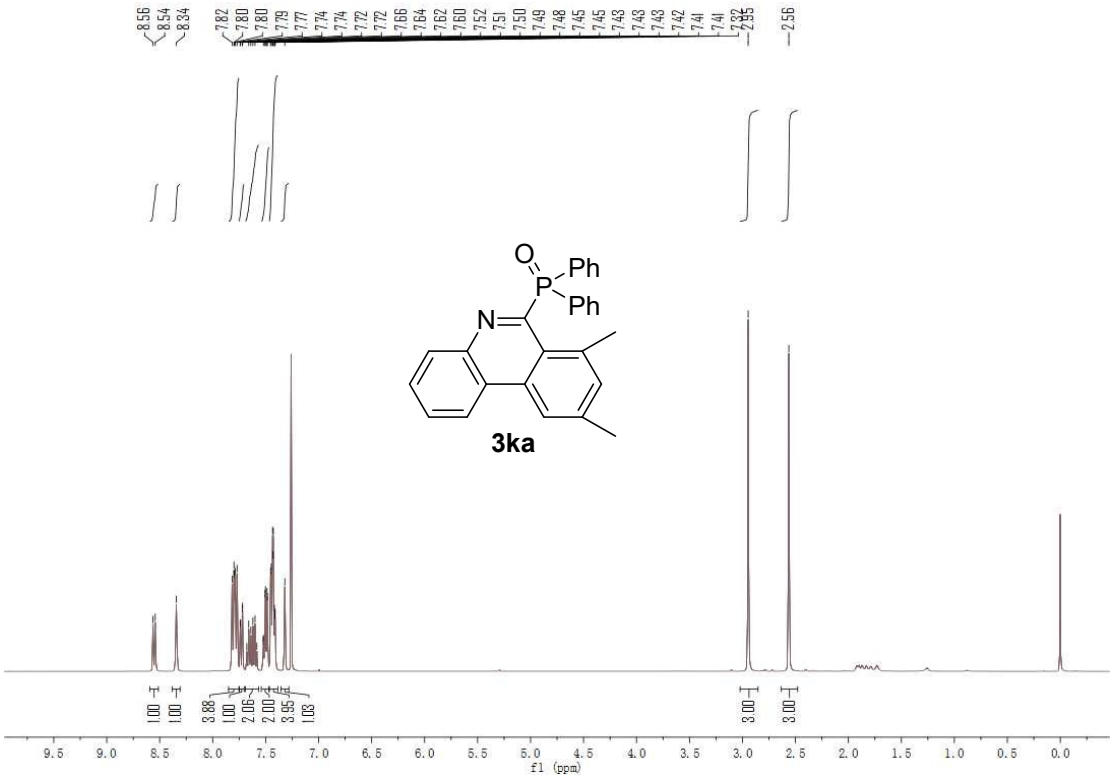
^{13}C NMR spectrum of 3ja



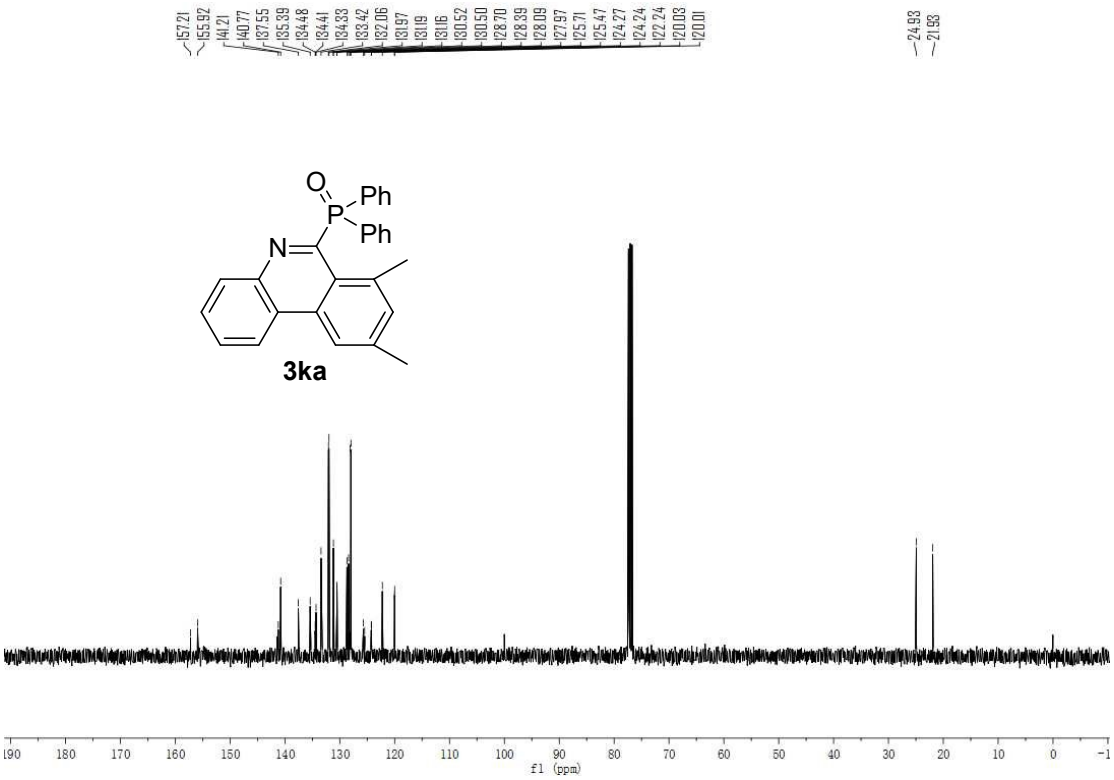
^{31}P NMR spectrum of 3ja



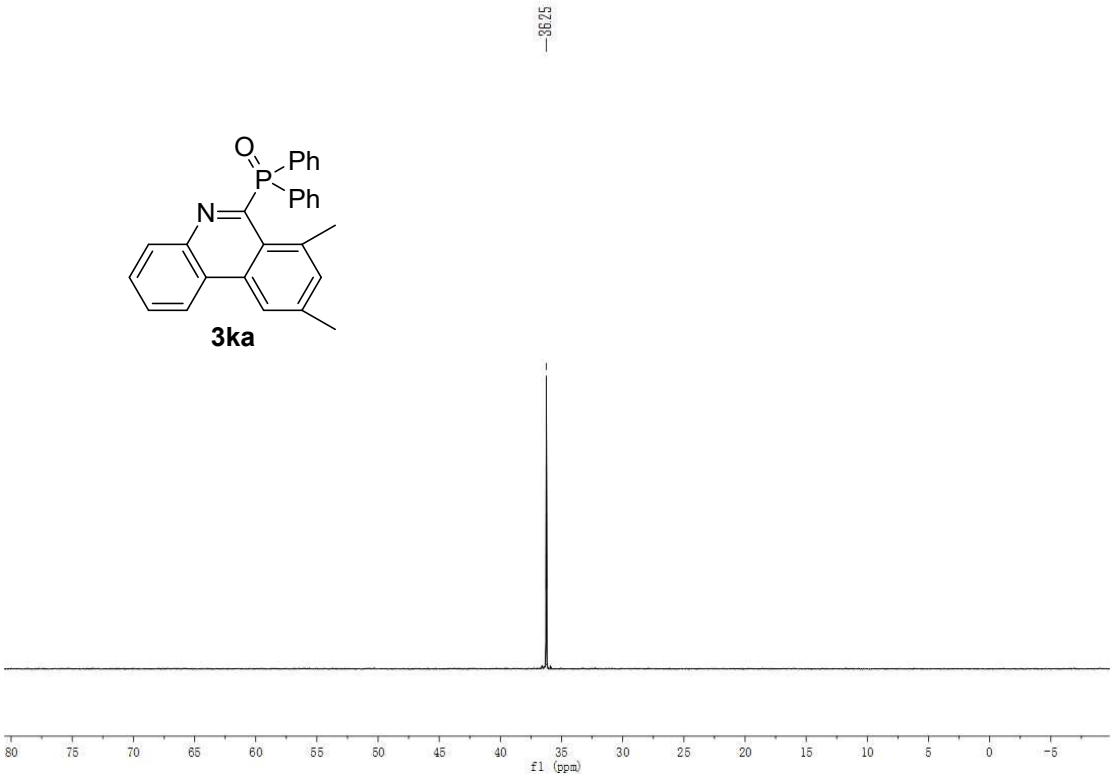
^{1}H NMR spectrum of 3ka



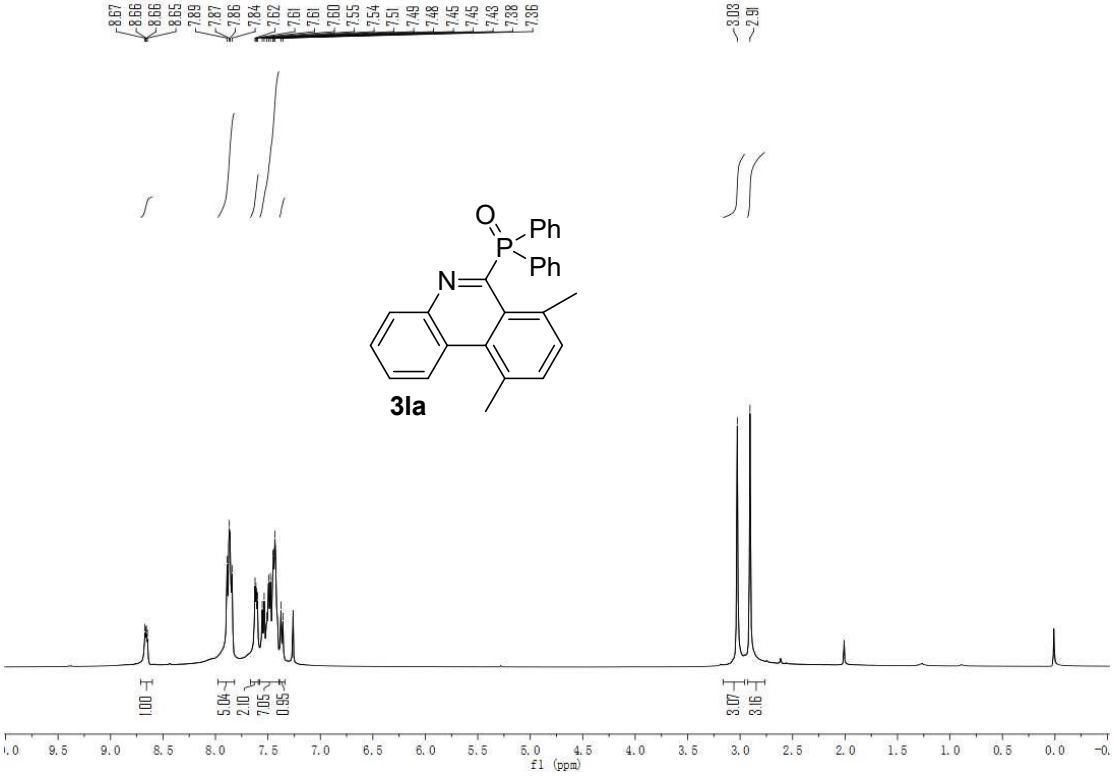
^{13}C NMR spectrum of 3ka



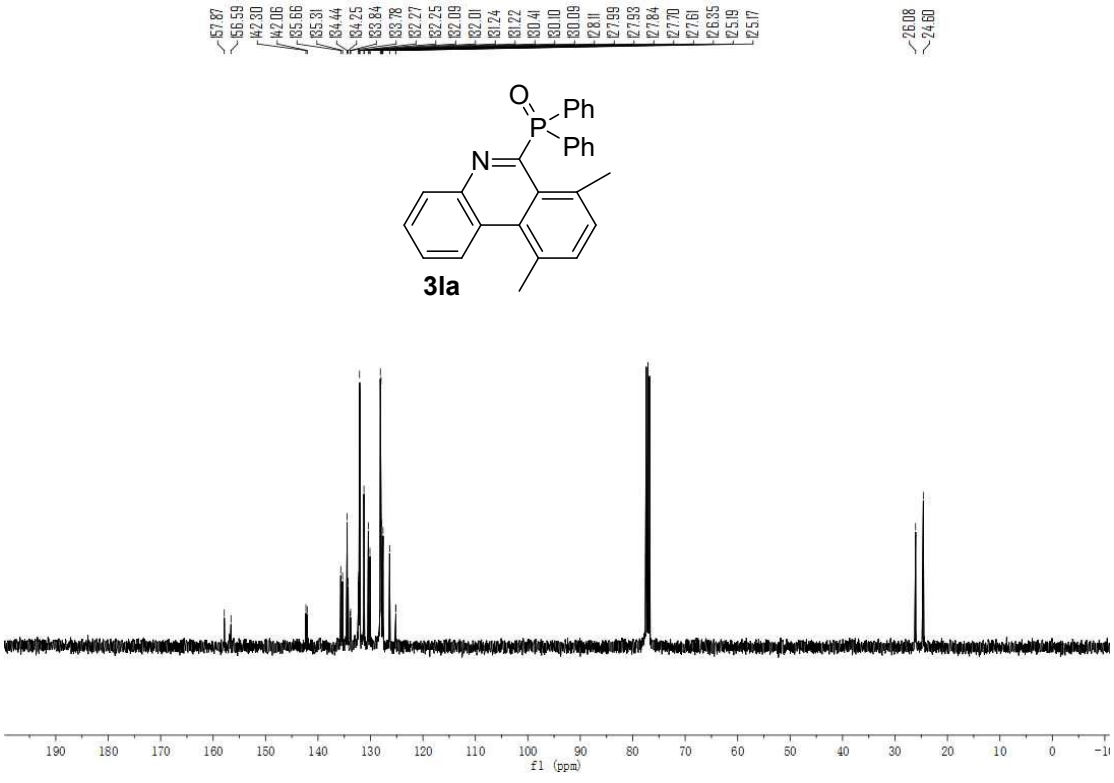
^{31}P NMR spectrum of 3ka



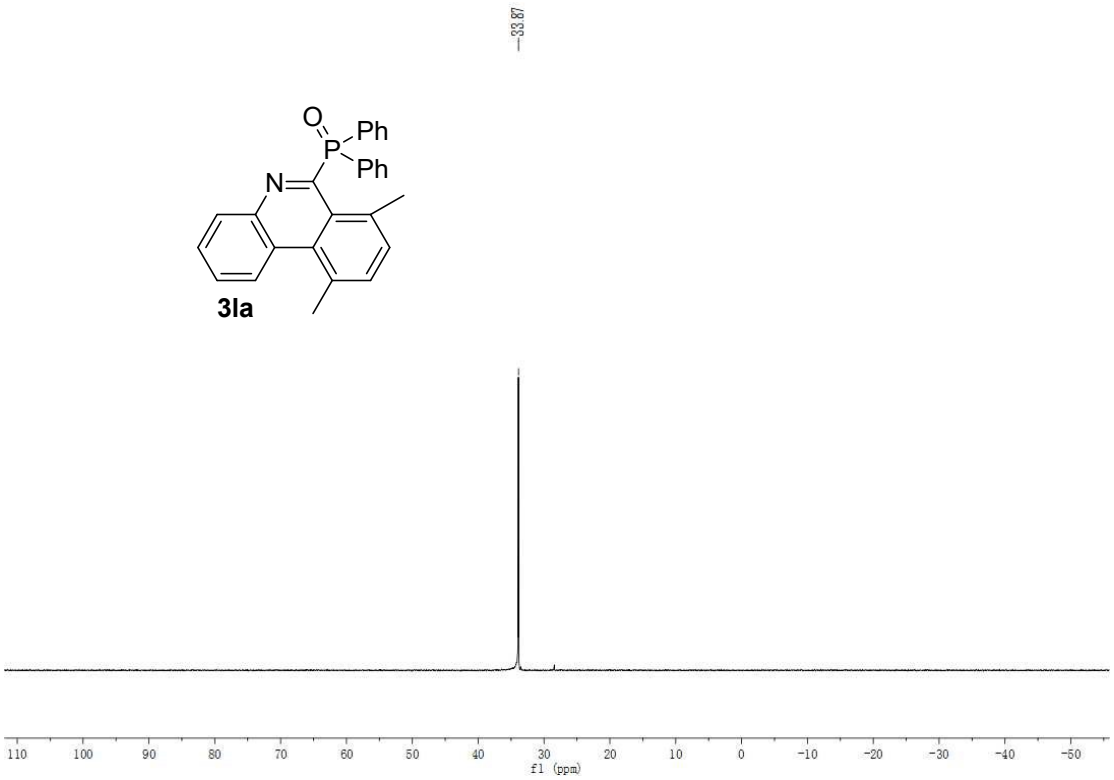
^{1}H NMR spectrum of 3la



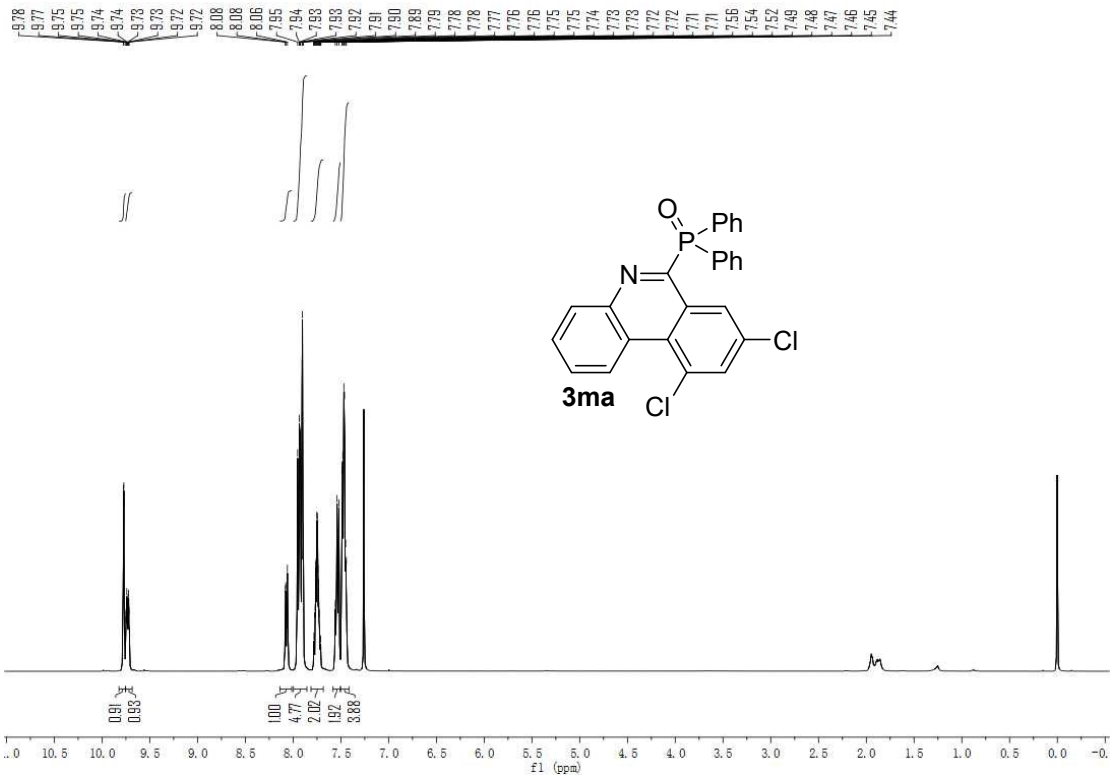
^{13}C NMR spectrum of 3la



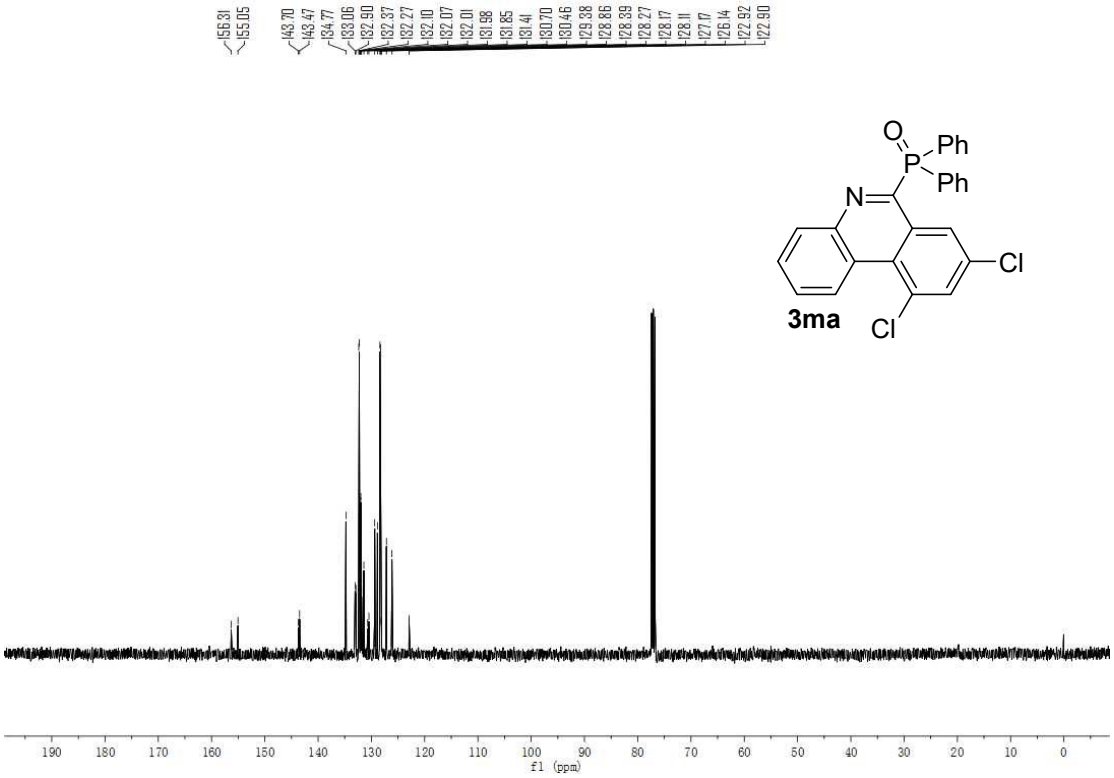
^{31}P NMR spectrum of 3la



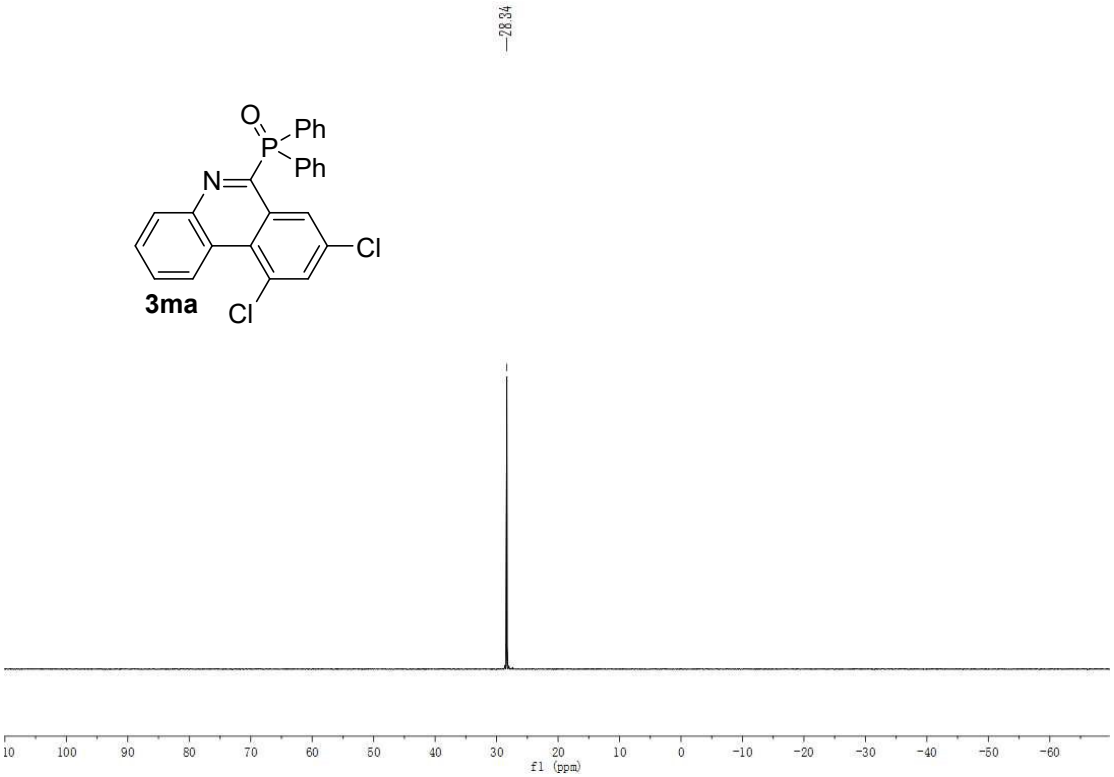
^{1}H NMR spectrum of 3ma



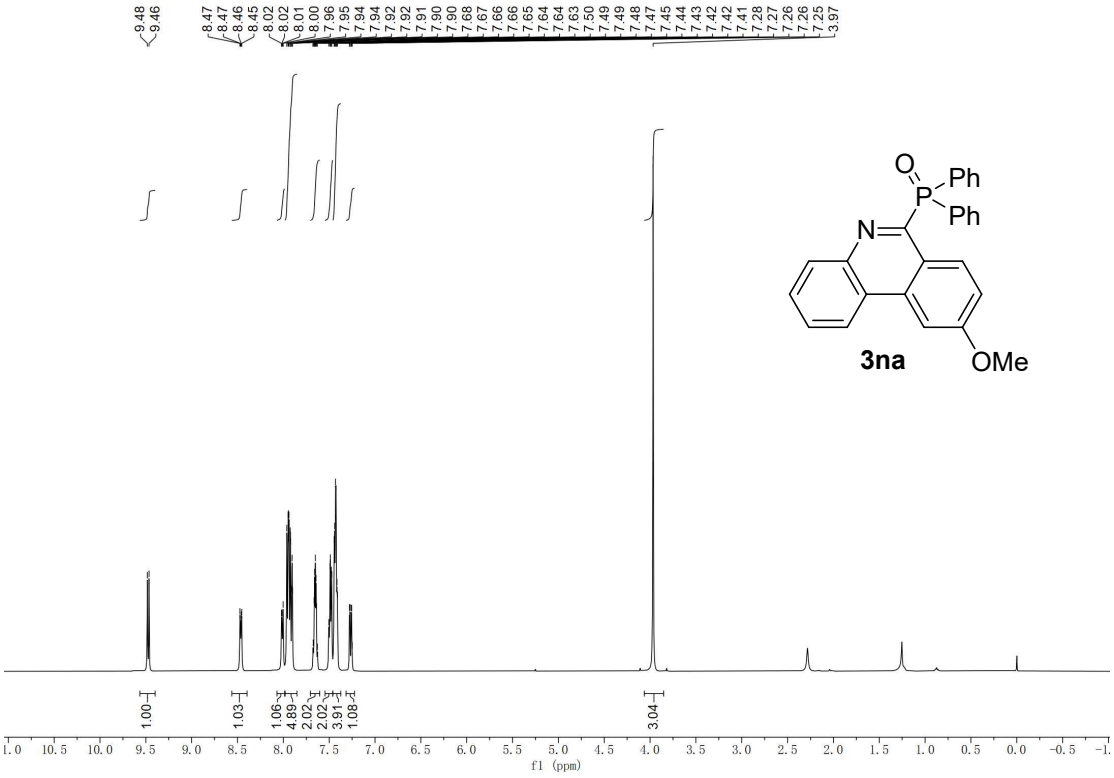
^{13}C NMR spectrum of 3ma



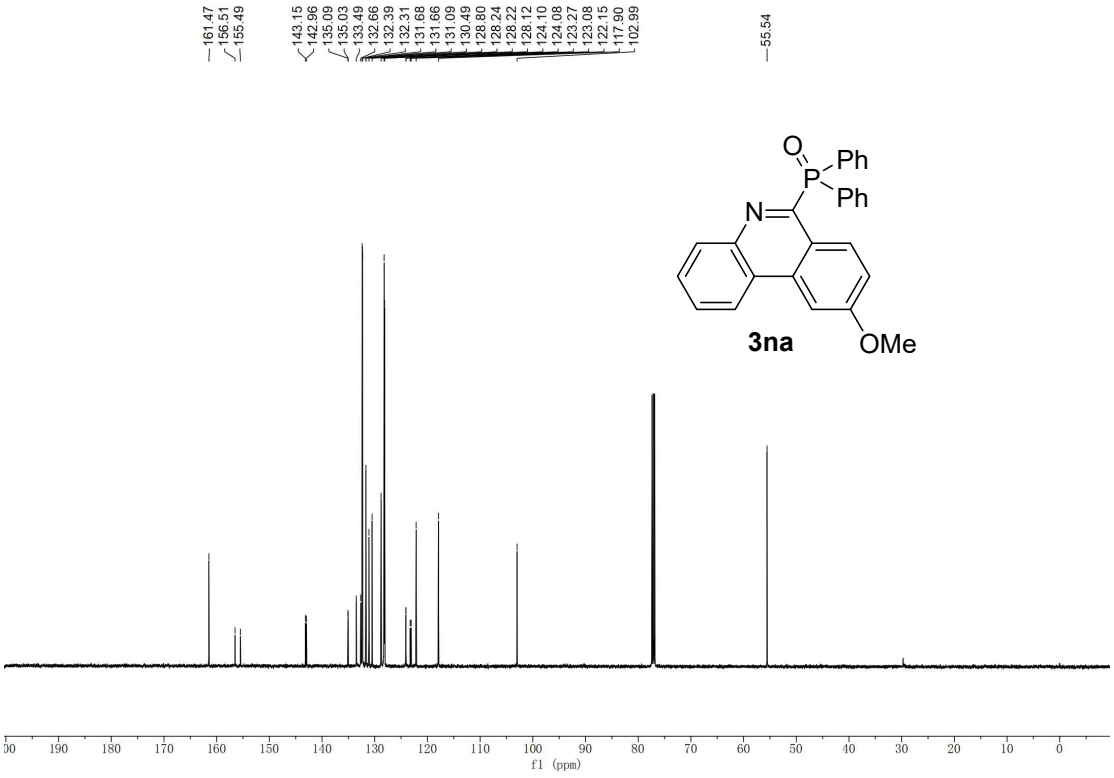
^{31}P NMR spectrum of 3ma



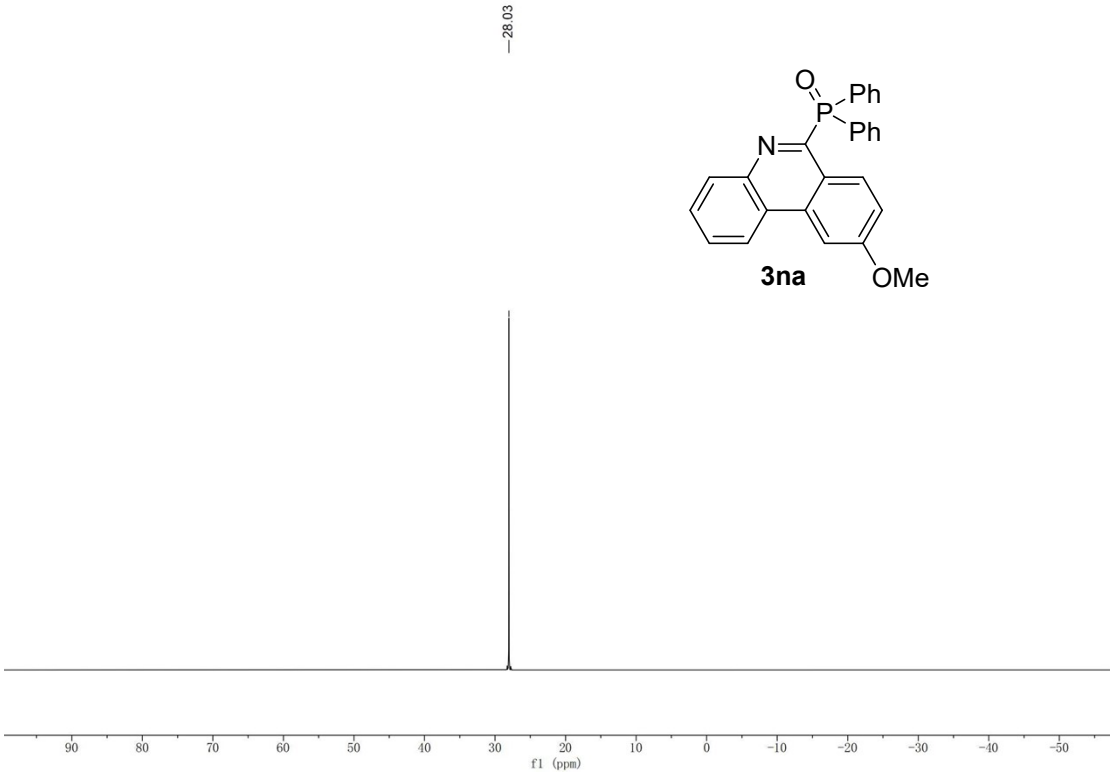
^{1}H NMR spectrum of 3na



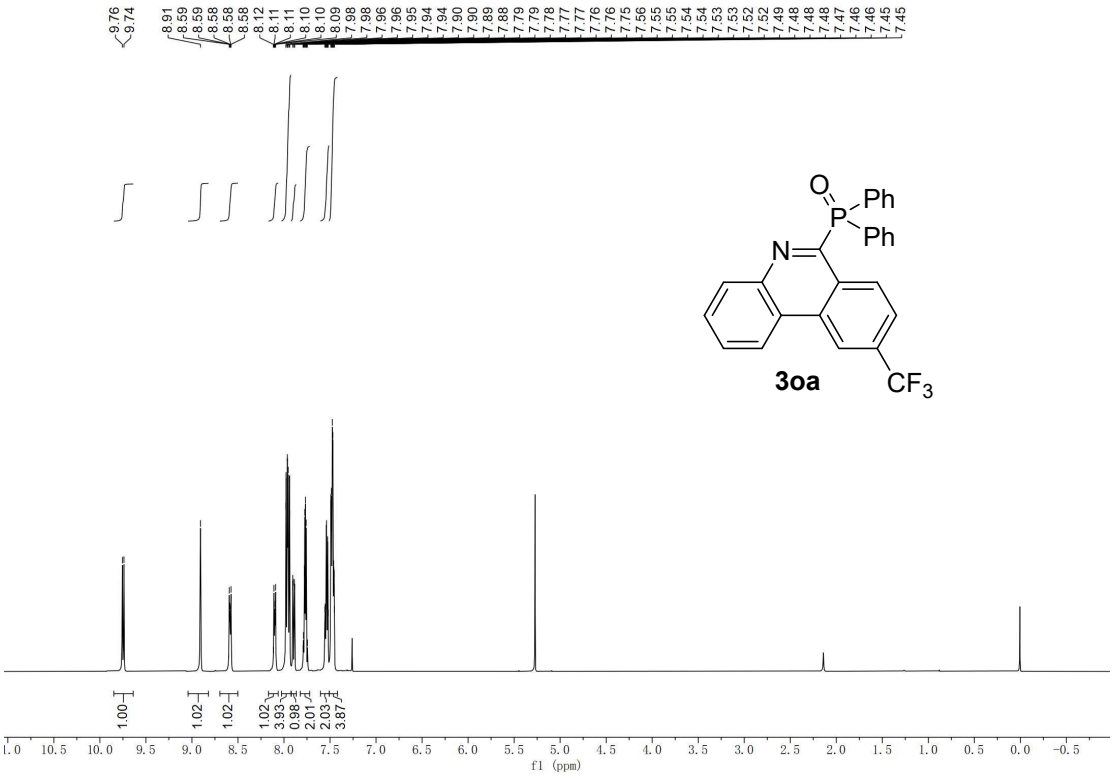
^{13}C NMR spectrum of 3na



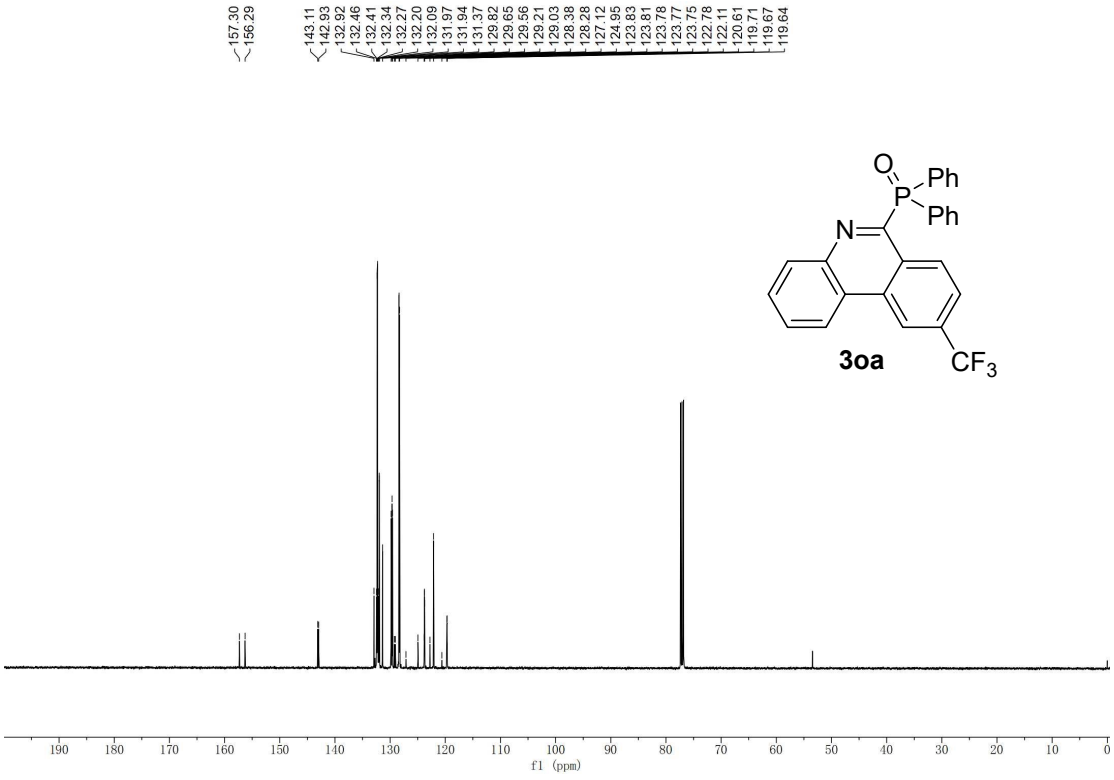
^{31}P NMR spectrum of 3na



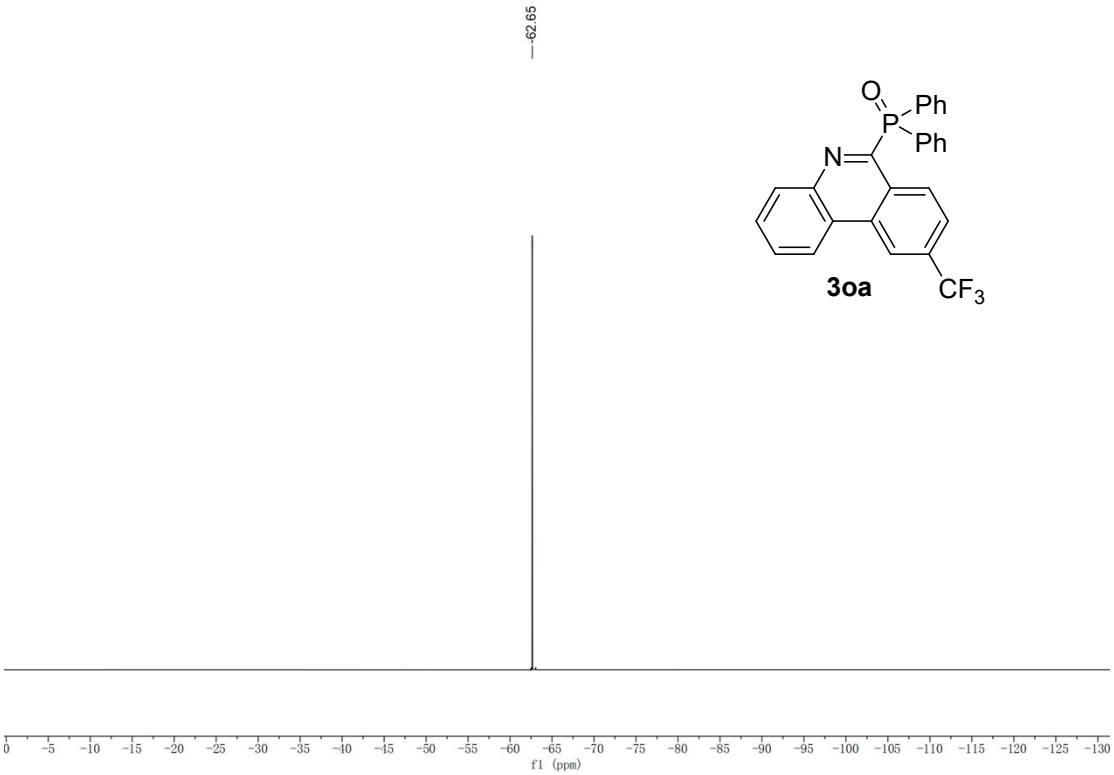
^{1}H NMR spectrum of 3oa



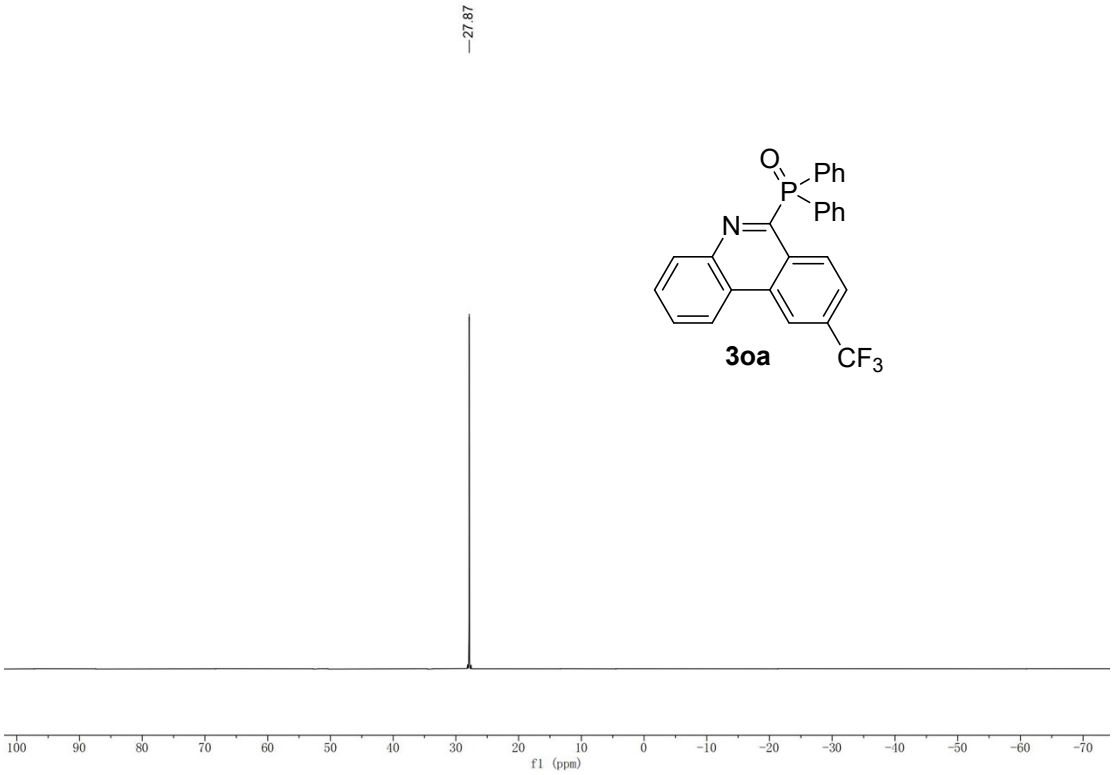
^{13}C NMR spectrum of 3oa



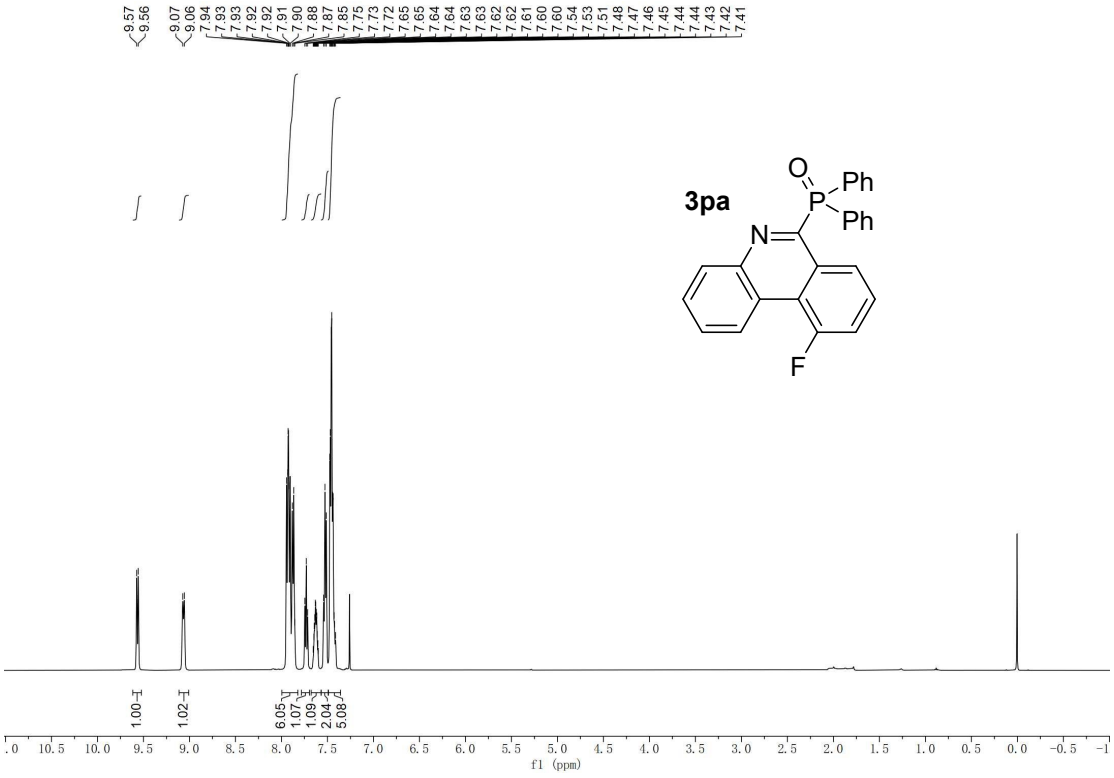
^{19}F NMR spectrum of 3oa



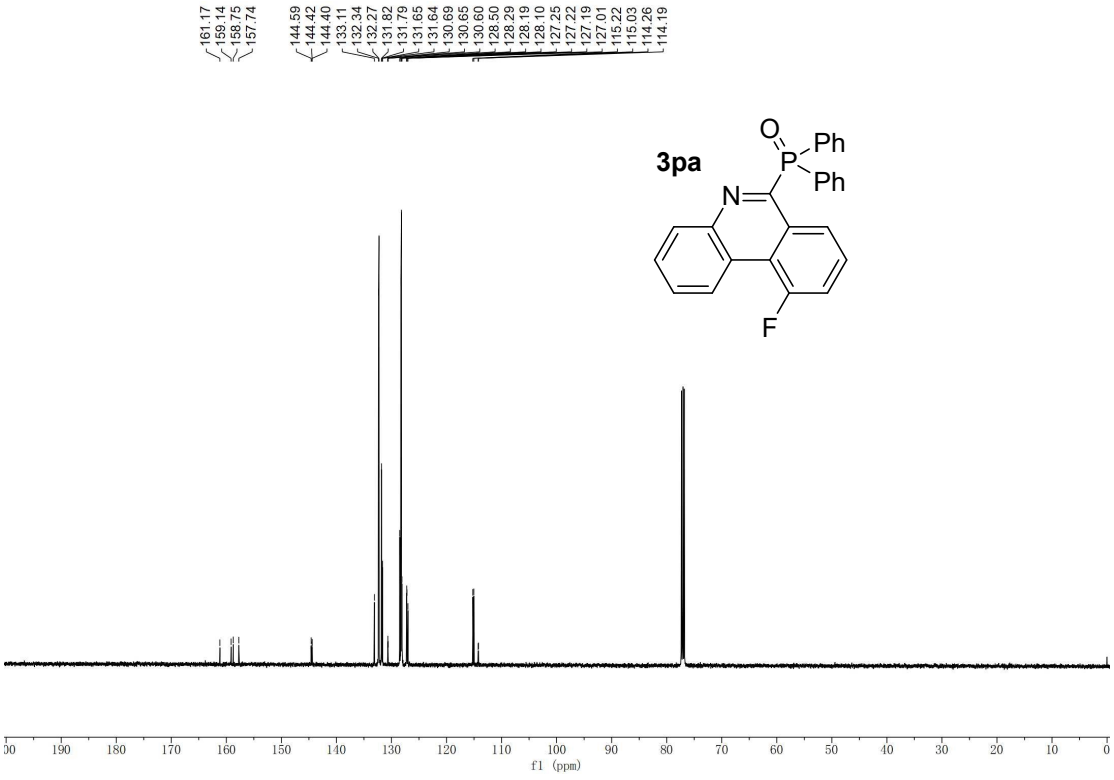
^{31}P NMR spectrum of 3oa



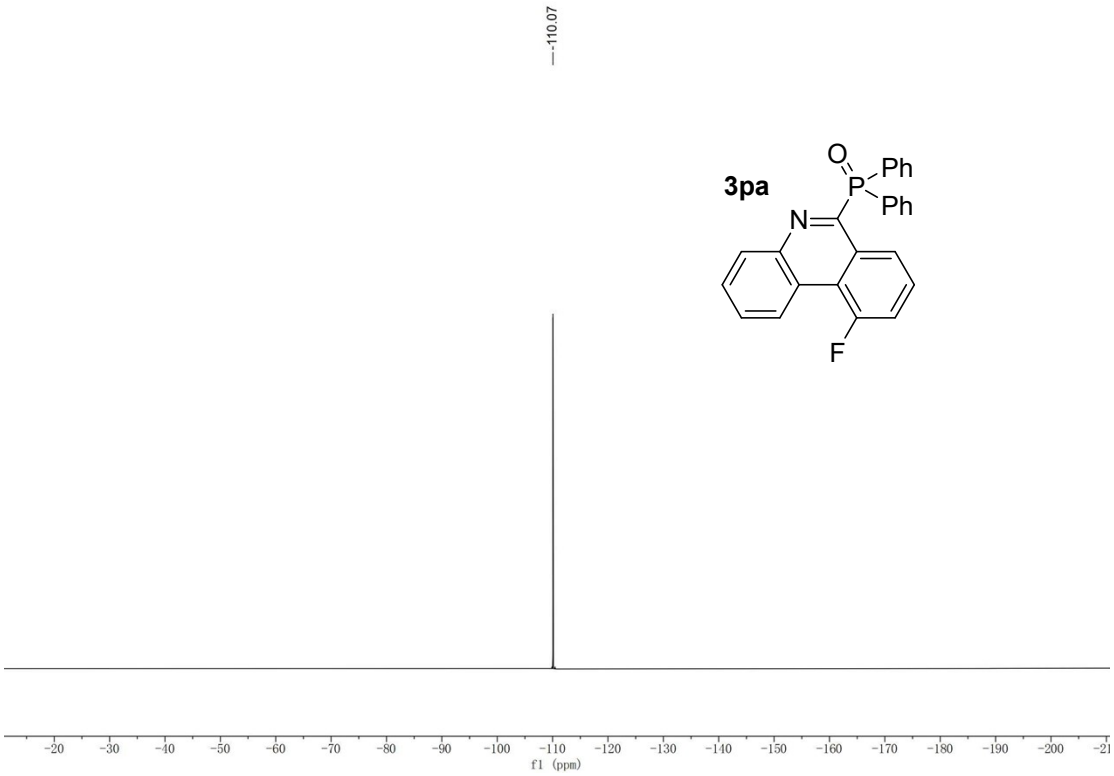
^{1}H NMR spectrum of 3pa



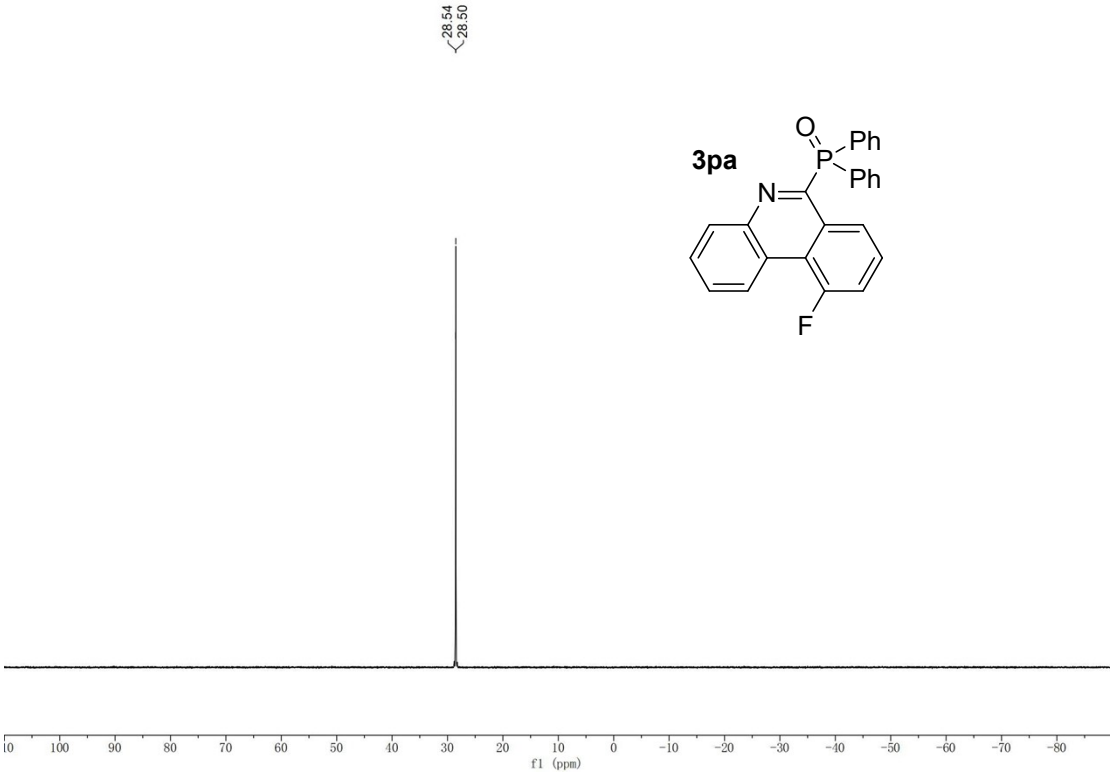
^{13}C NMR spectrum of 3pa



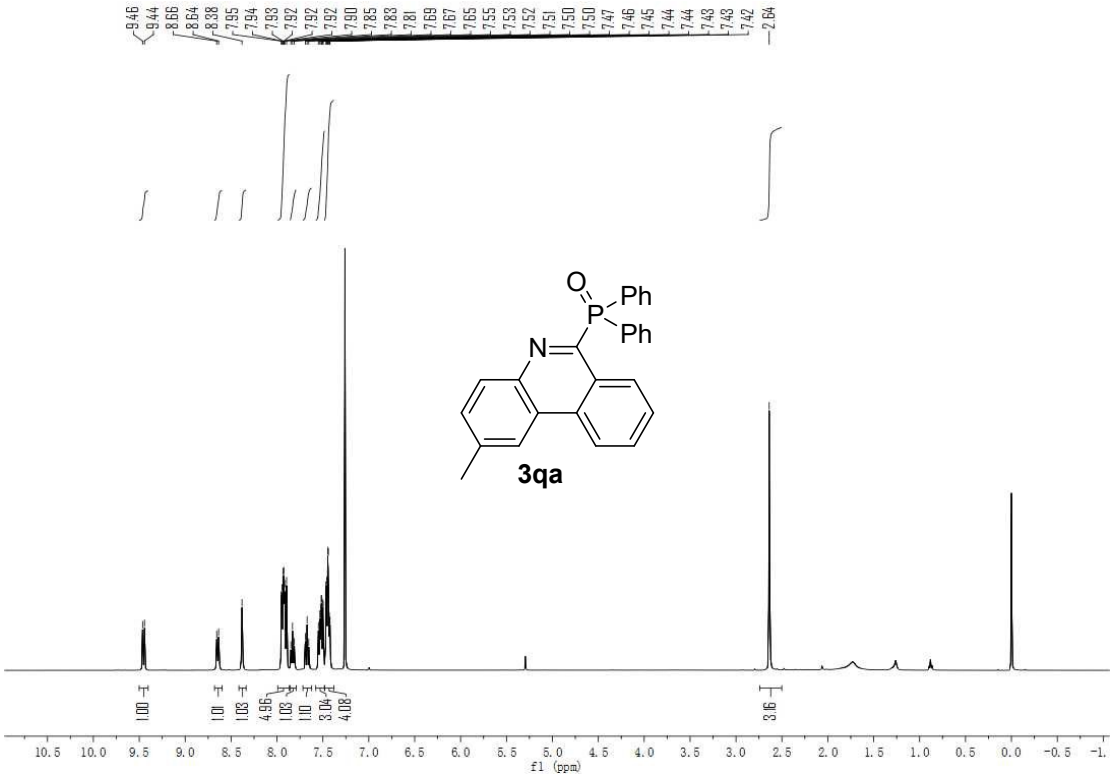
^{19}F NMR spectrum of 3pa



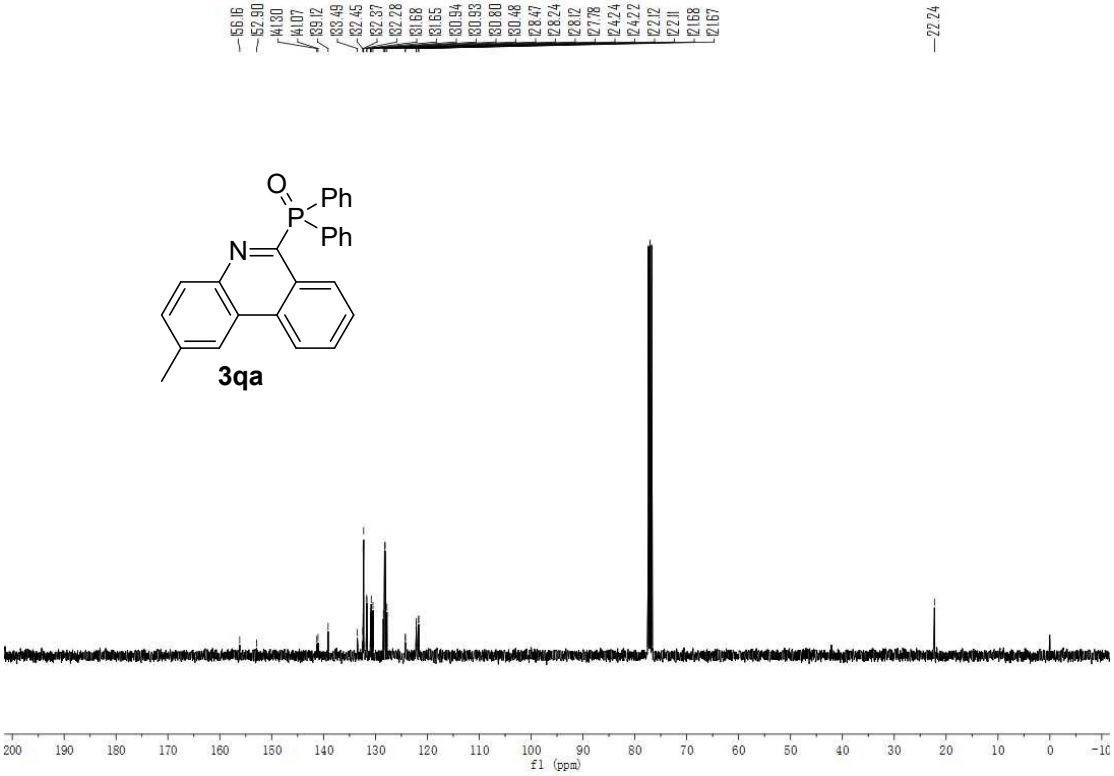
^{13}P NMR spectrum of 3pa



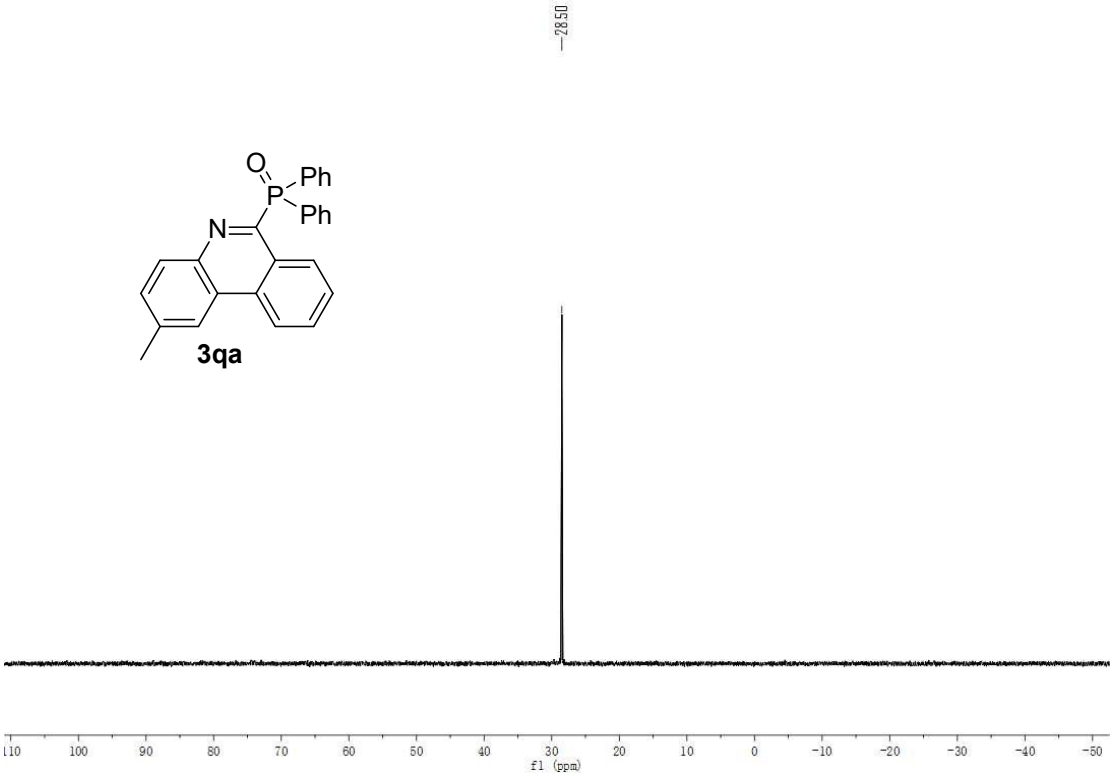
^{1}H NMR spectrum of 3qa



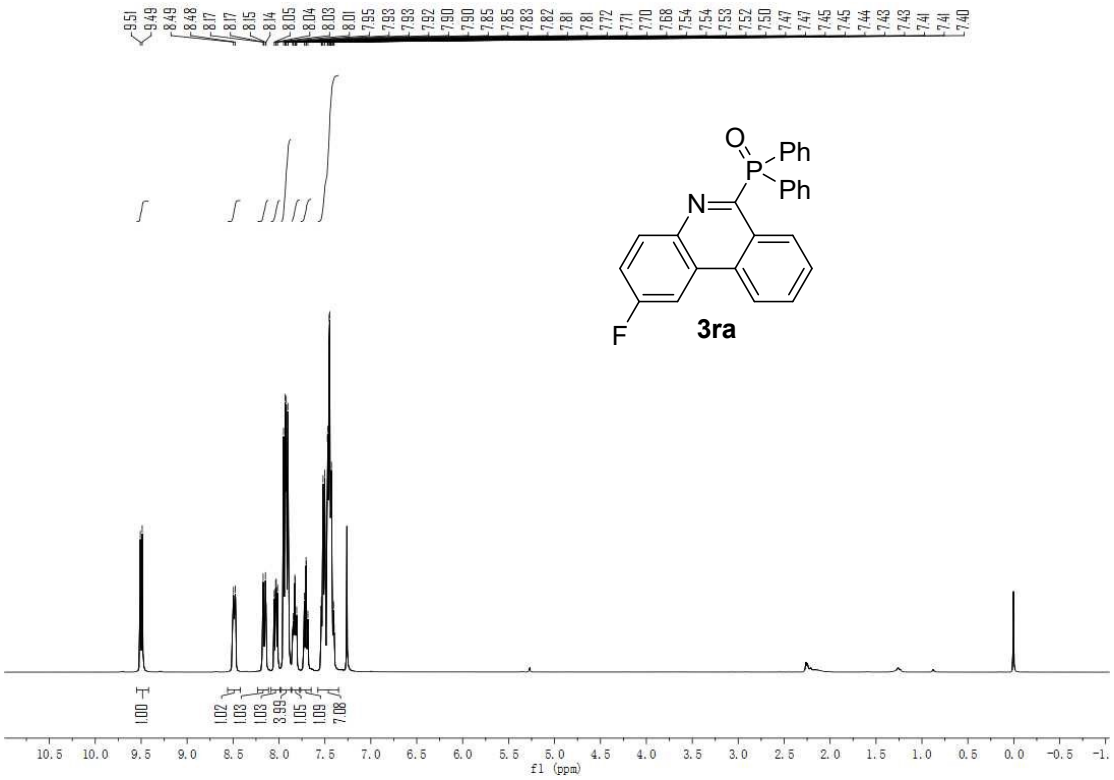
^{13}C NMR spectrum of 3qa



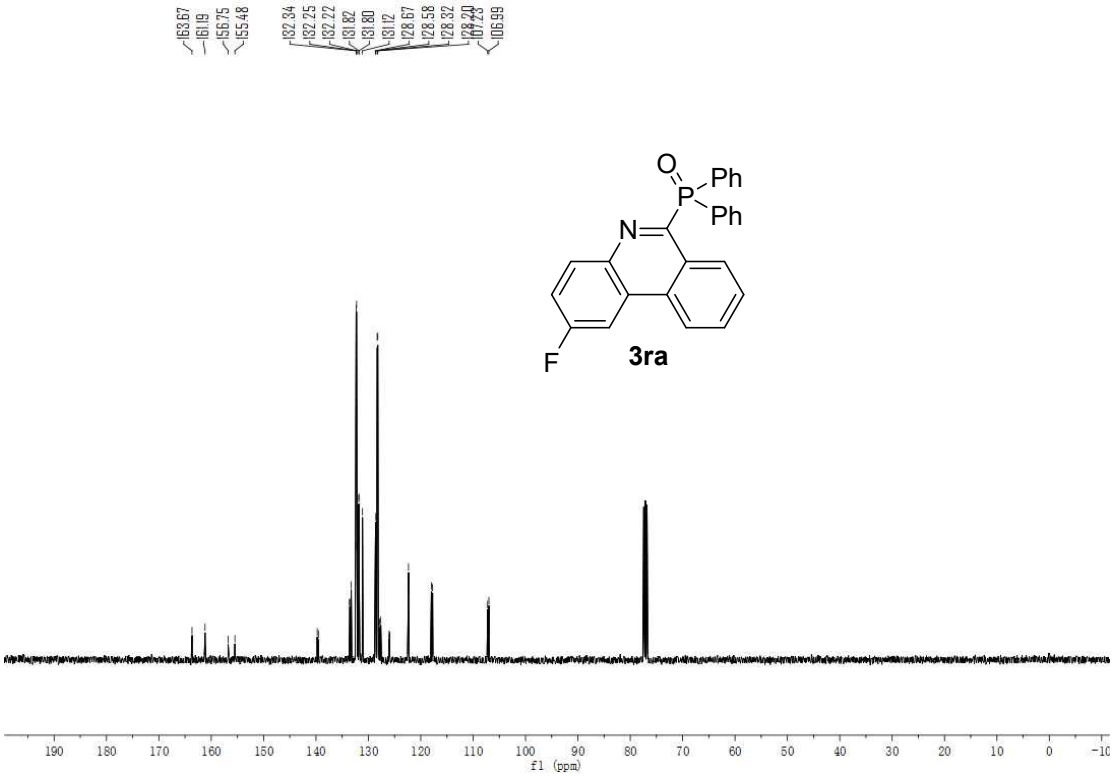
^{31}P NMR spectrum of 3qa



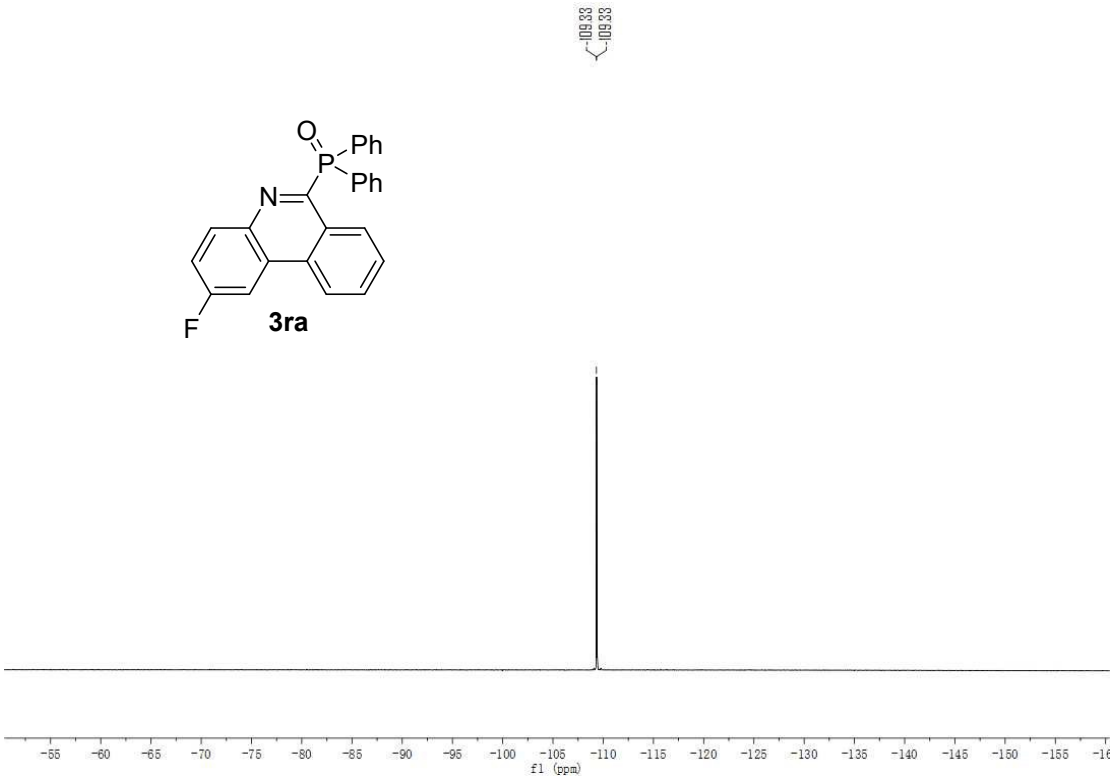
^{1}H NMR spectrum of 3ra



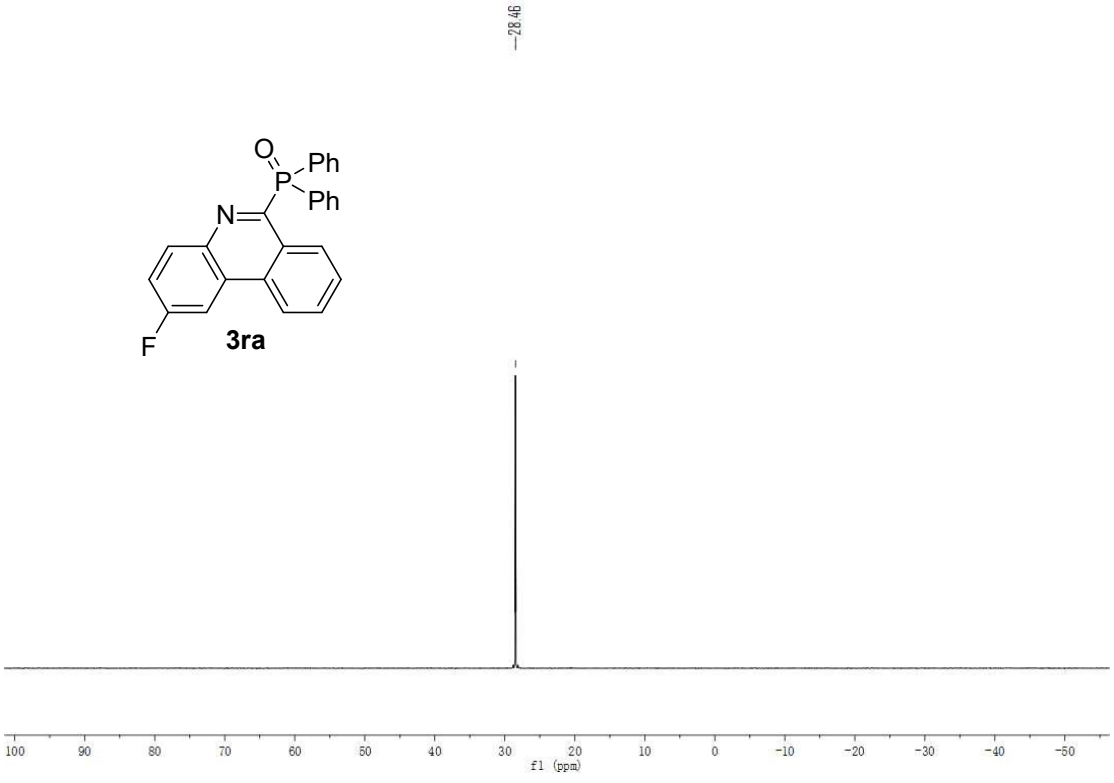
^{13}C NMR spectrum of 3ra



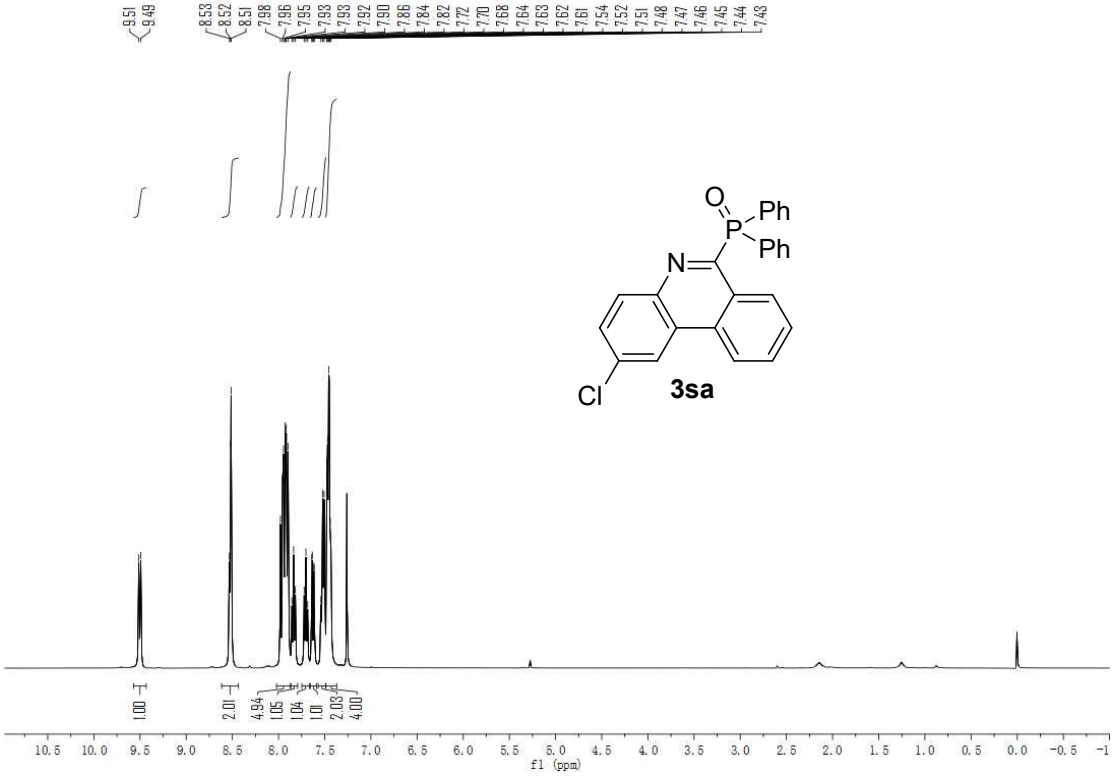
^{19}F NMR spectrum of 3ra



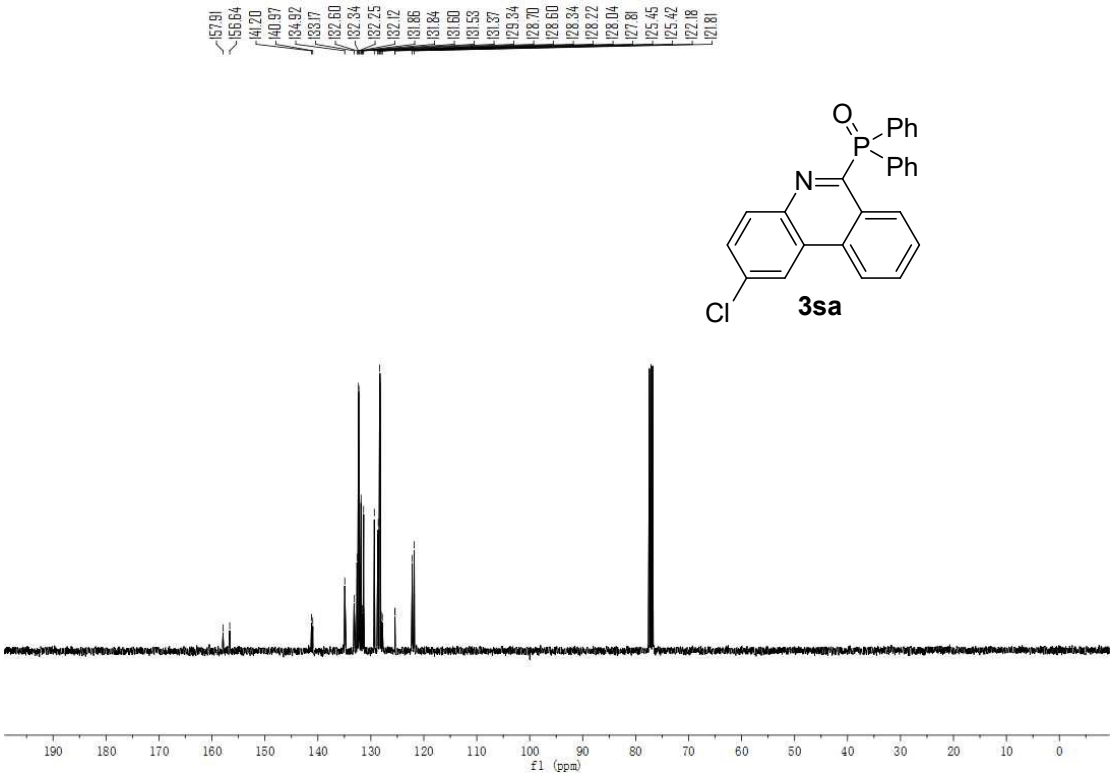
^{31}P NMR spectrum of 3ra



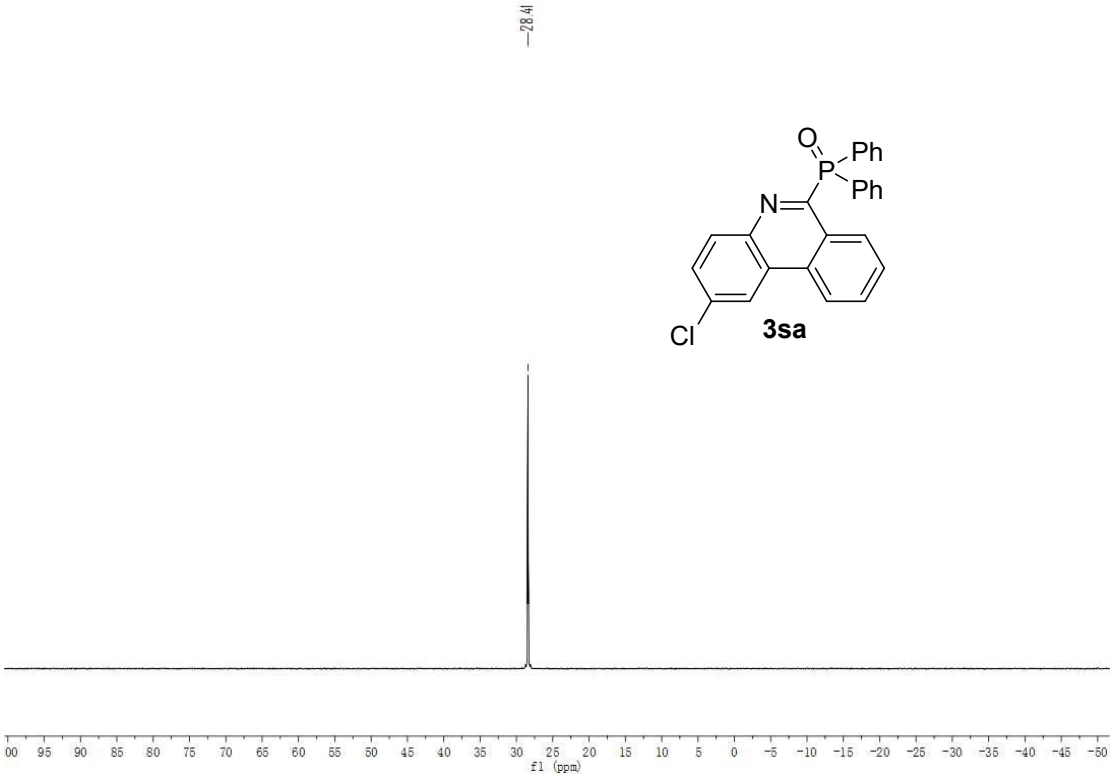
^{1}H NMR spectrum of 3sa



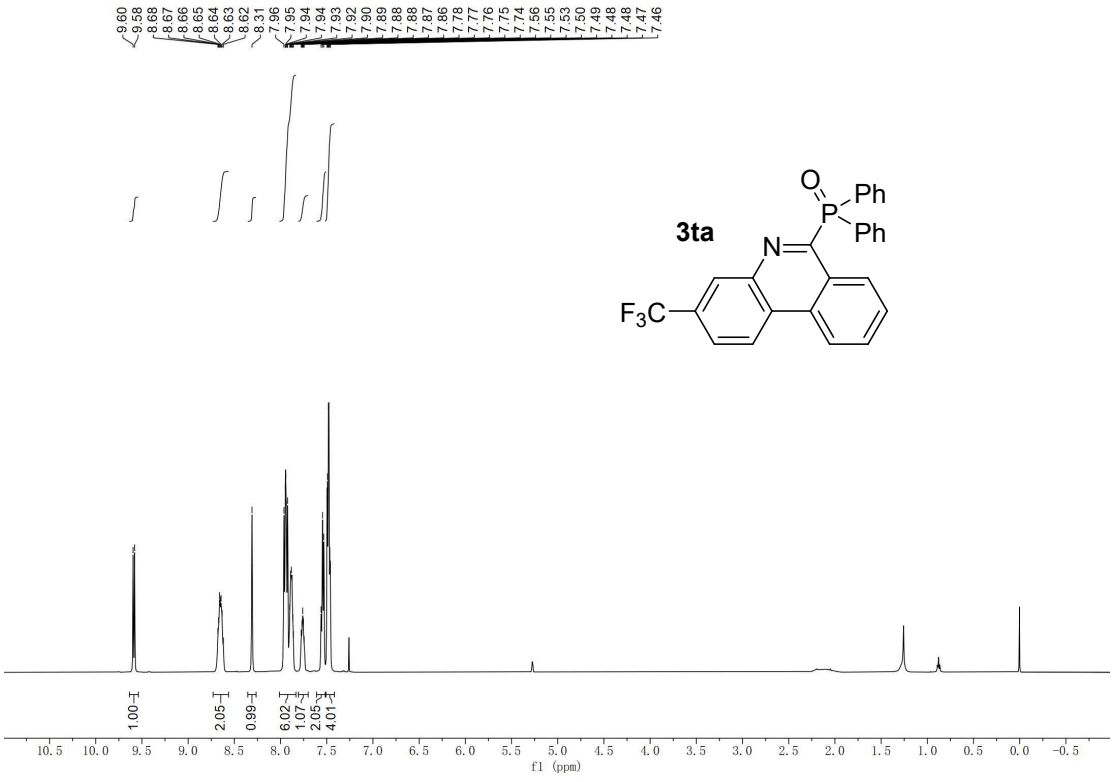
^{13}C NMR spectrum of 3sa



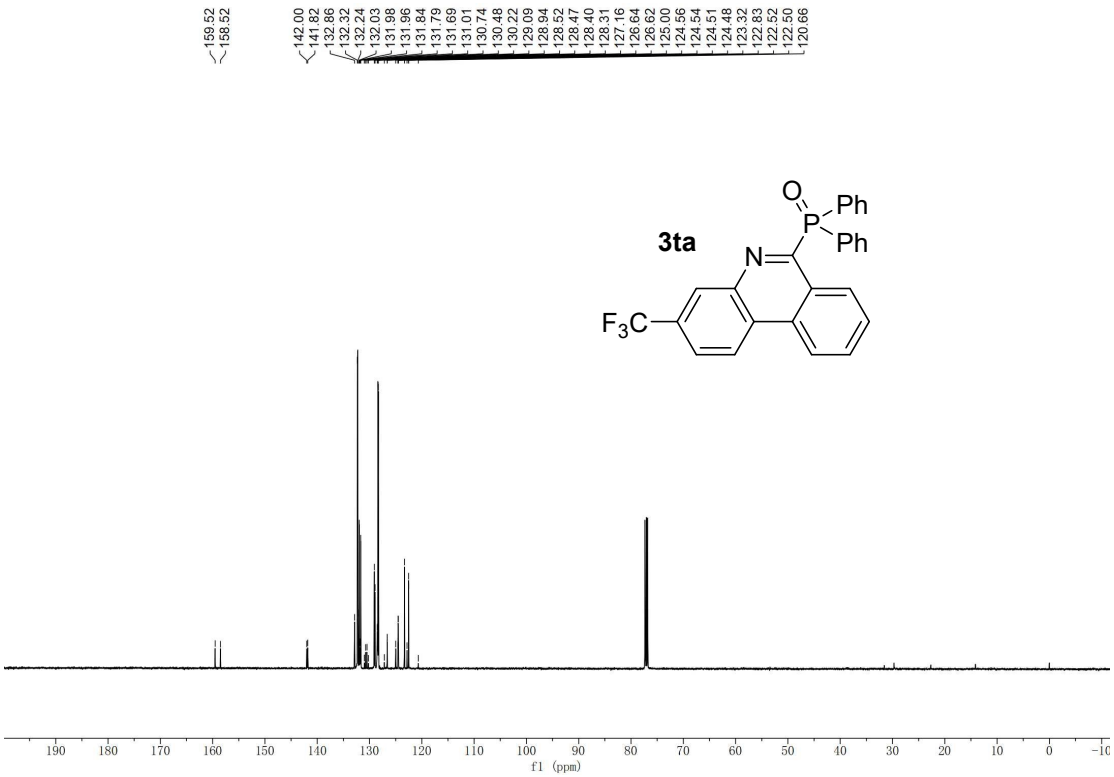
^{31}P NMR spectrum of 3sa



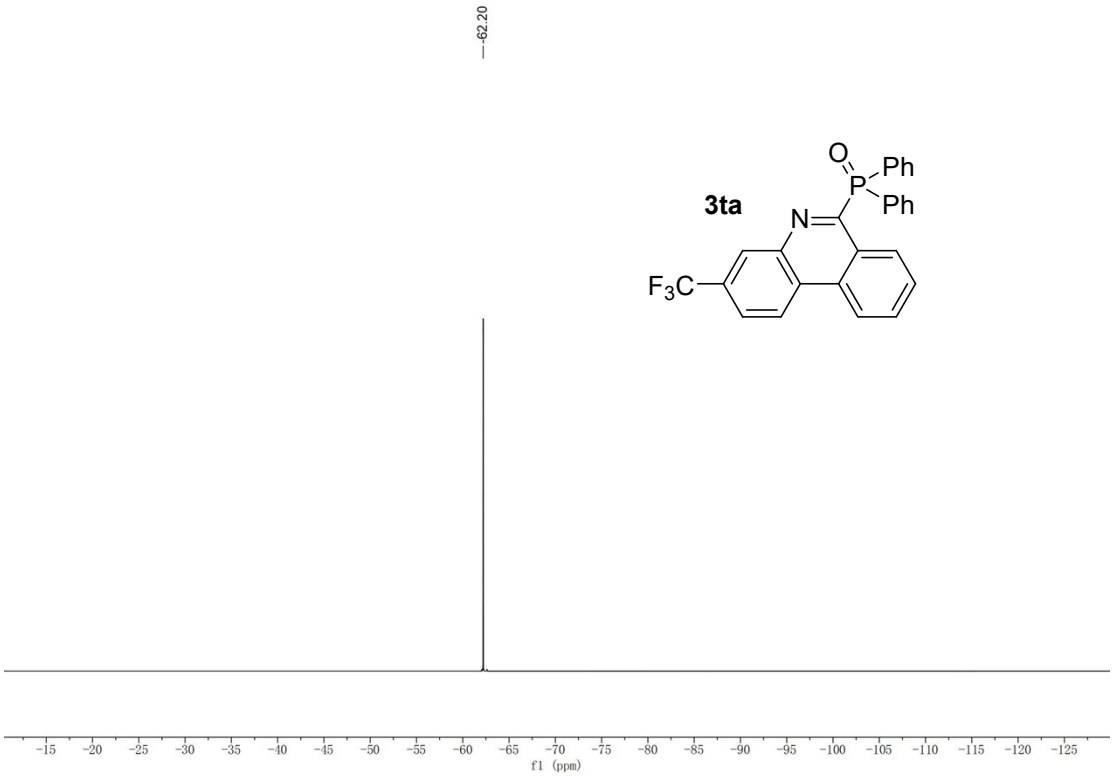
^{1}H NMR spectrum of 3ta



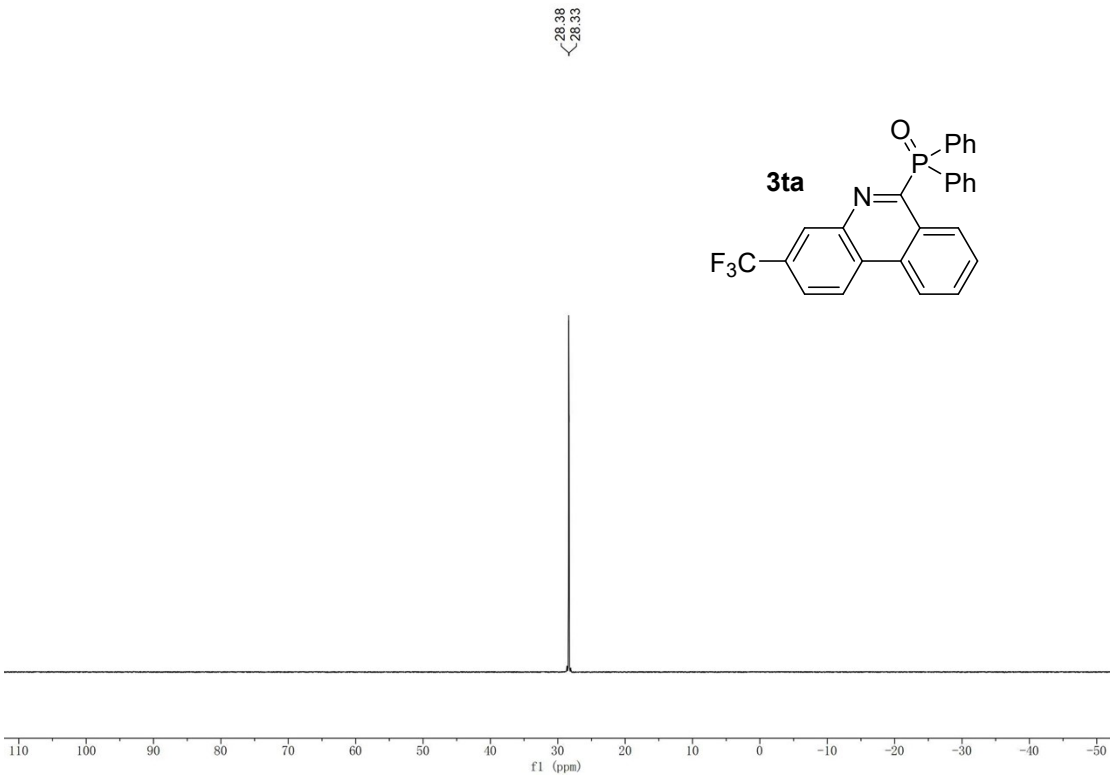
^{13}C NMR spectrum of 3ta



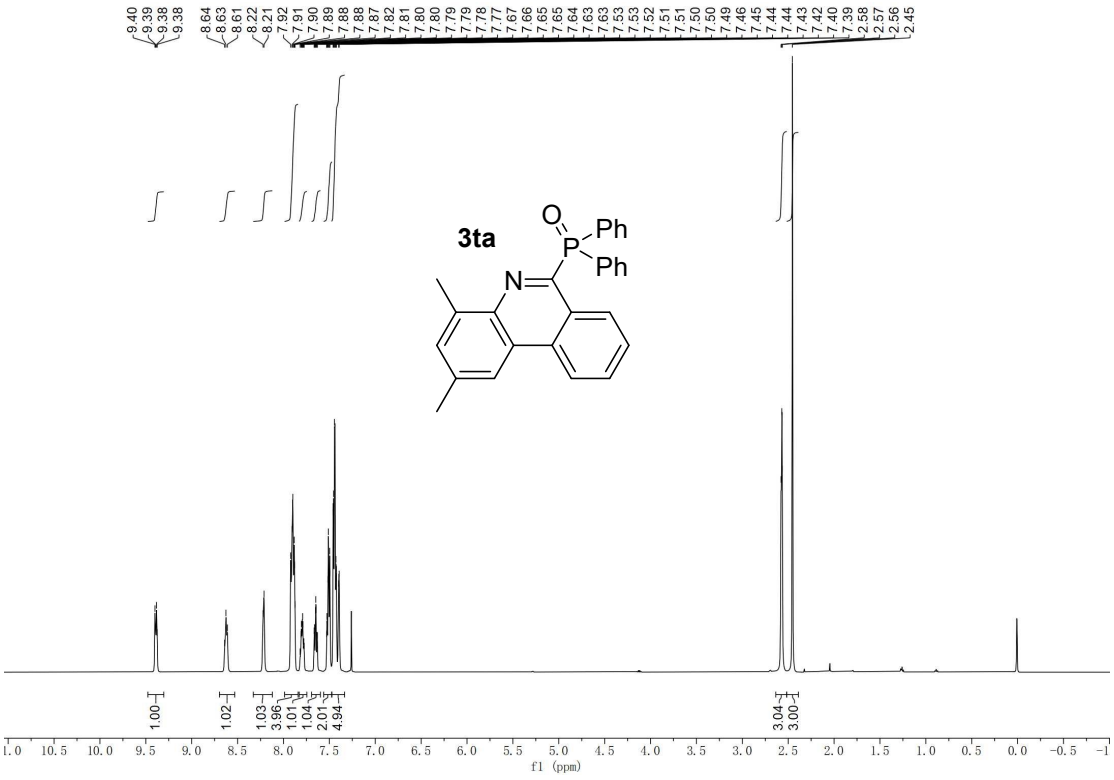
^{19}F NMR spectrum of 3ta



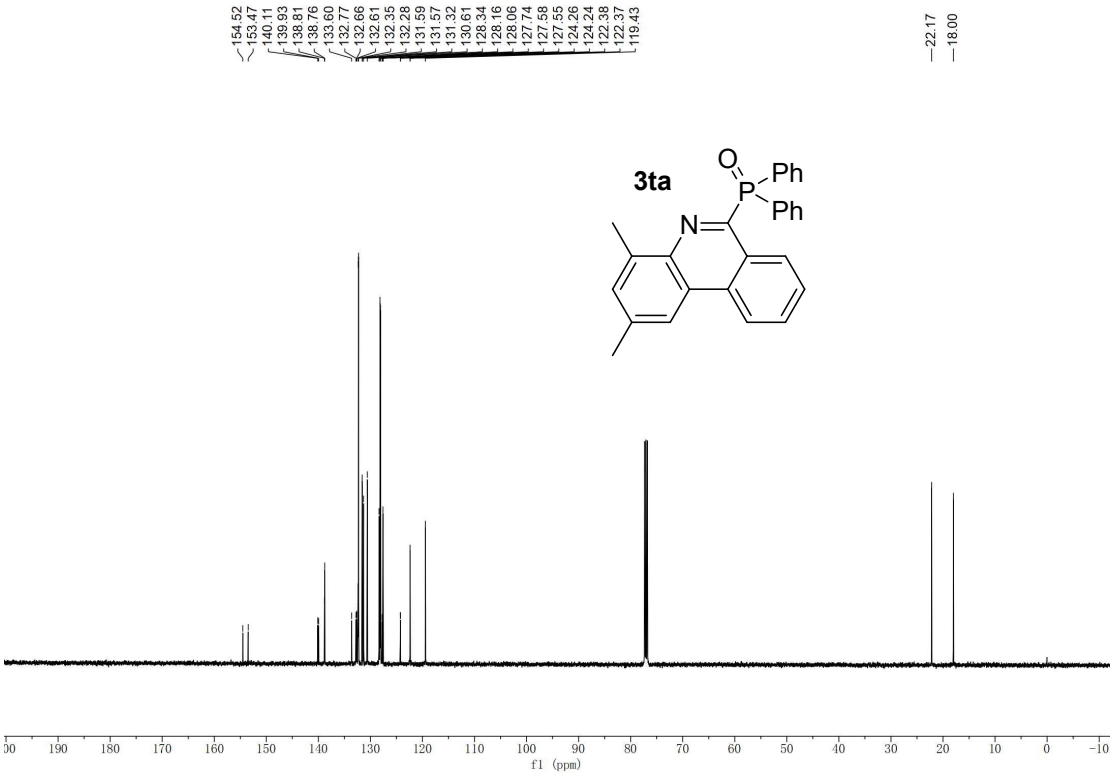
^{31}P NMR spectrum of 3ta



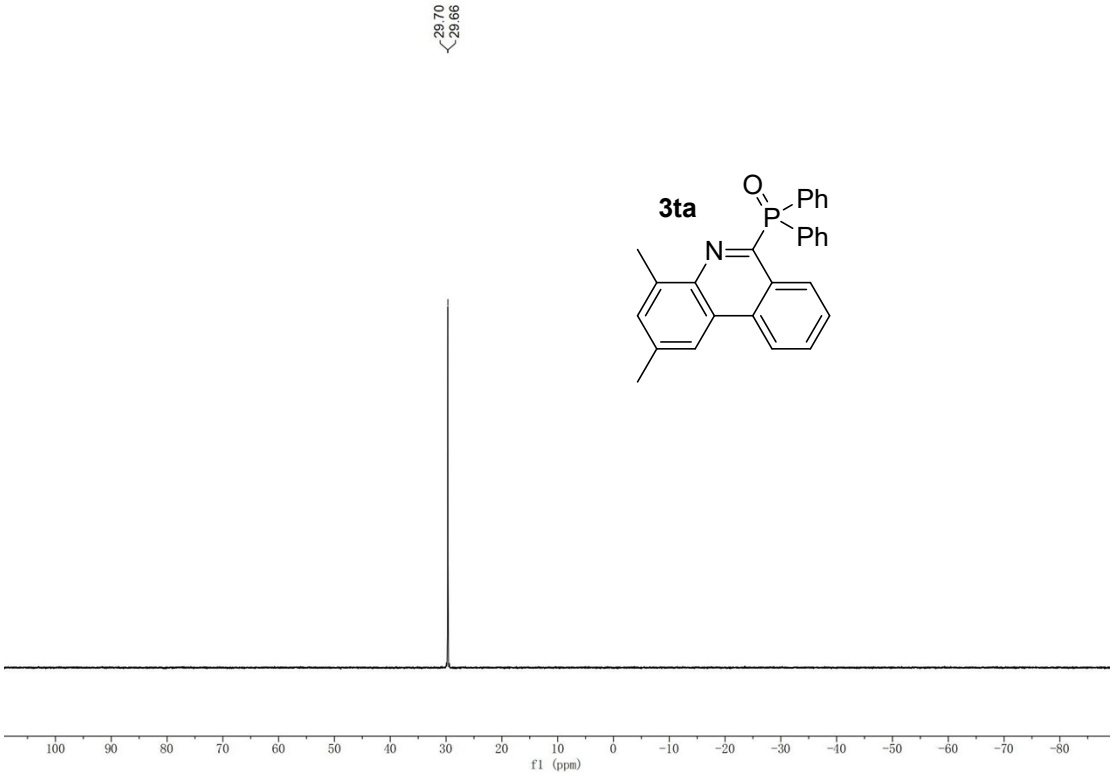
^{1}H NMR spectrum of 3ua



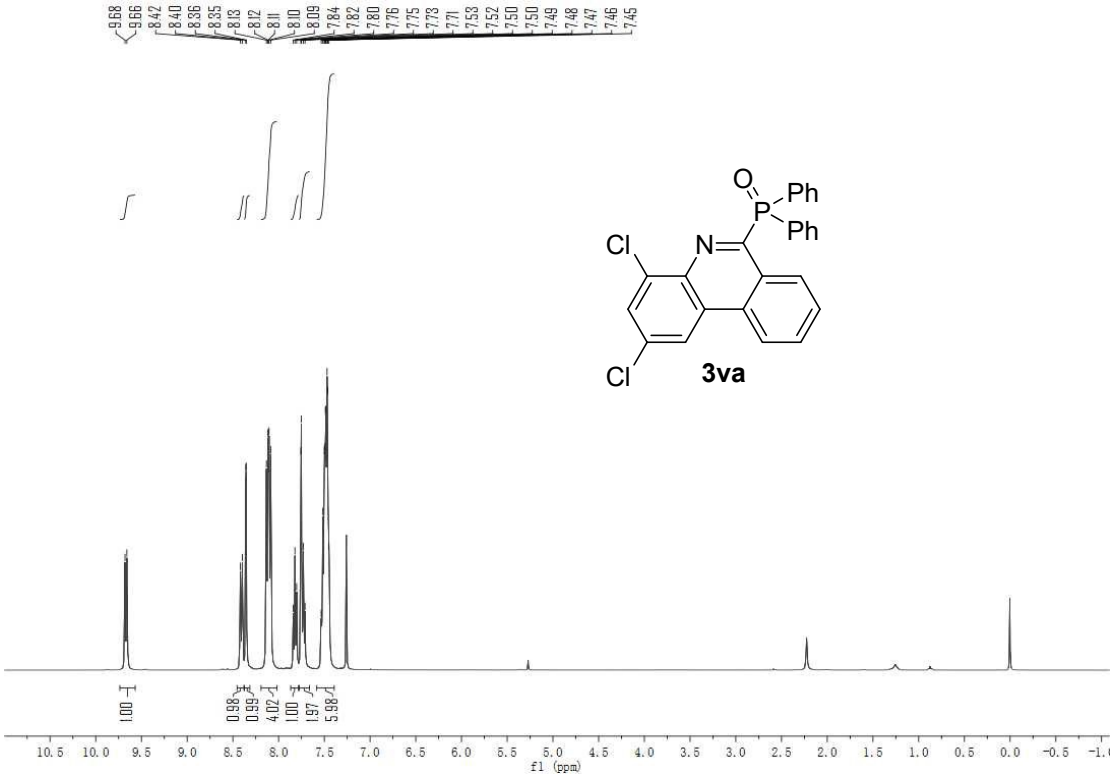
^{13}C NMR spectrum of 3ua



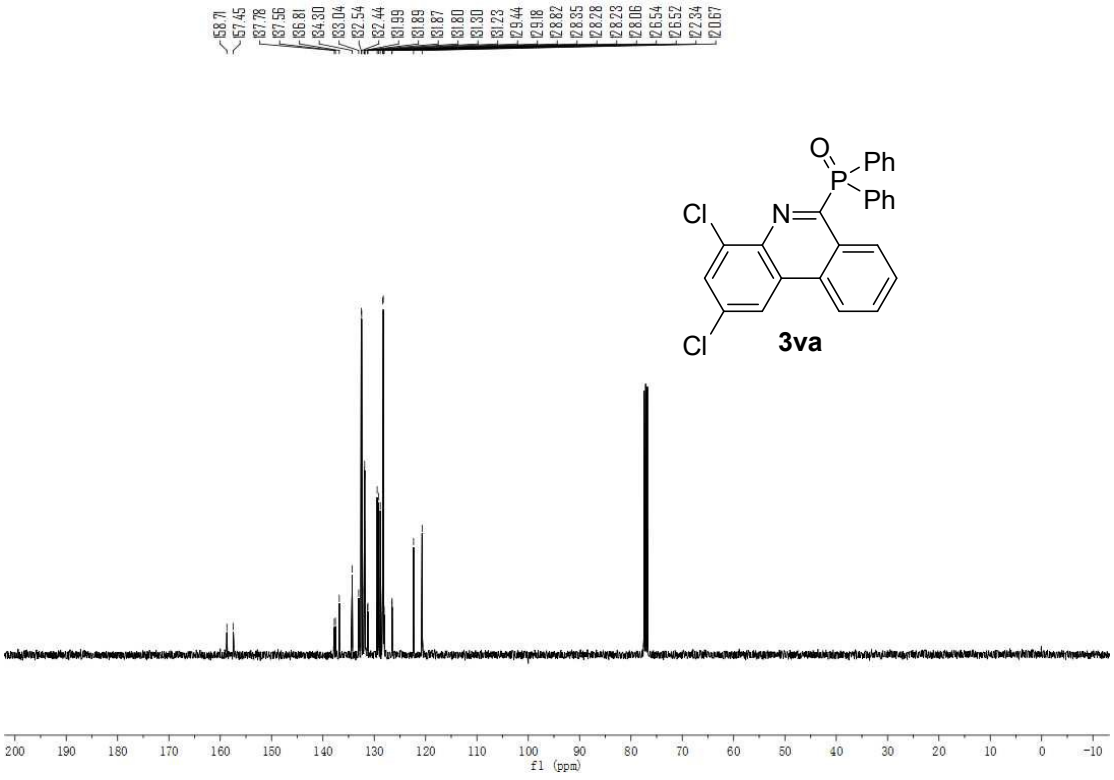
^{31}P NMR spectrum of 3ua



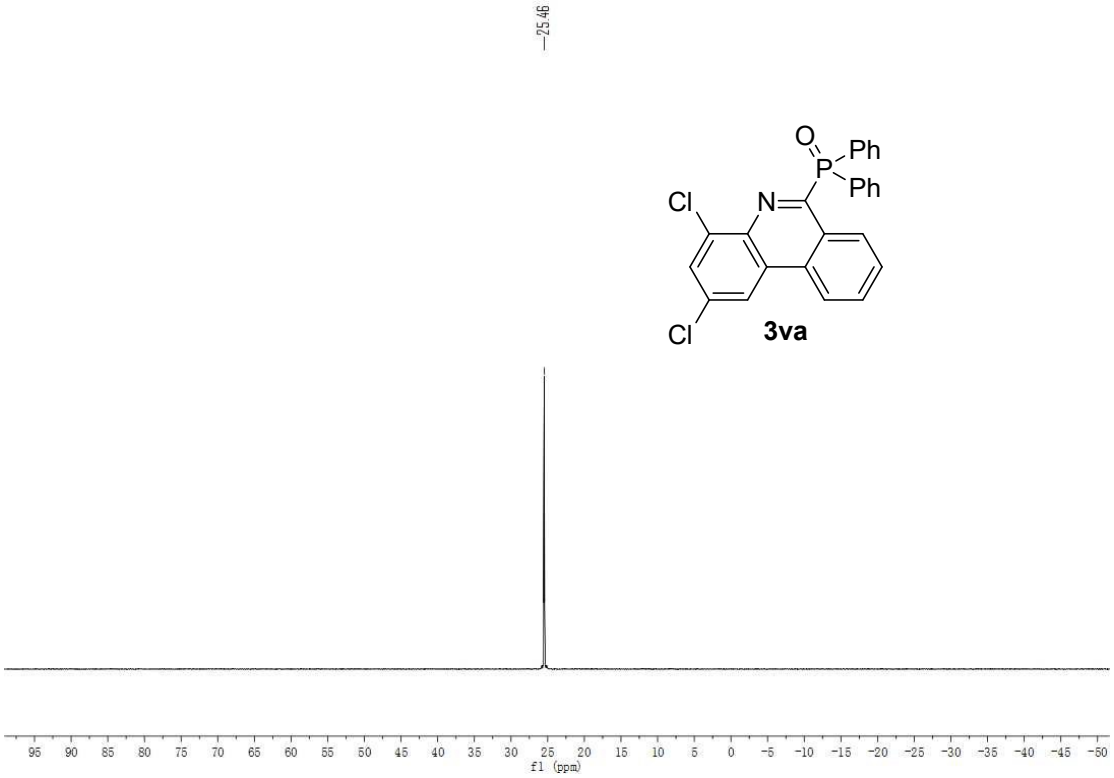
^{1}H NMR spectrum of 3va



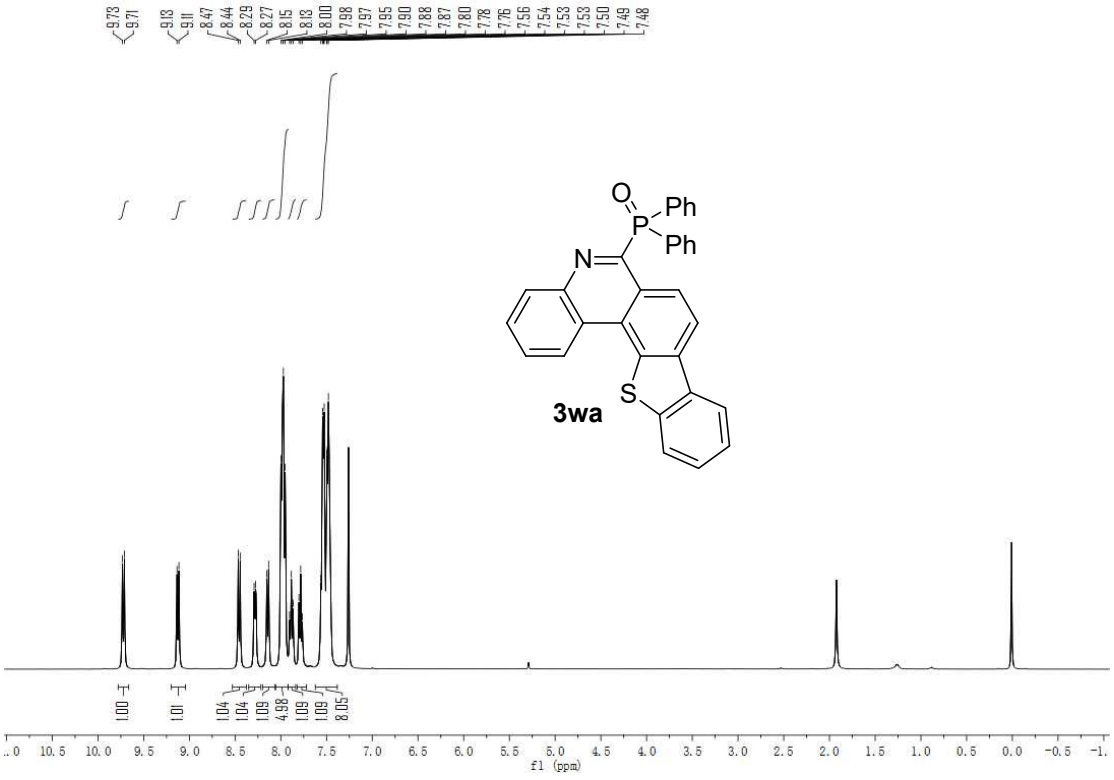
^{13}C NMR spectrum of 3va



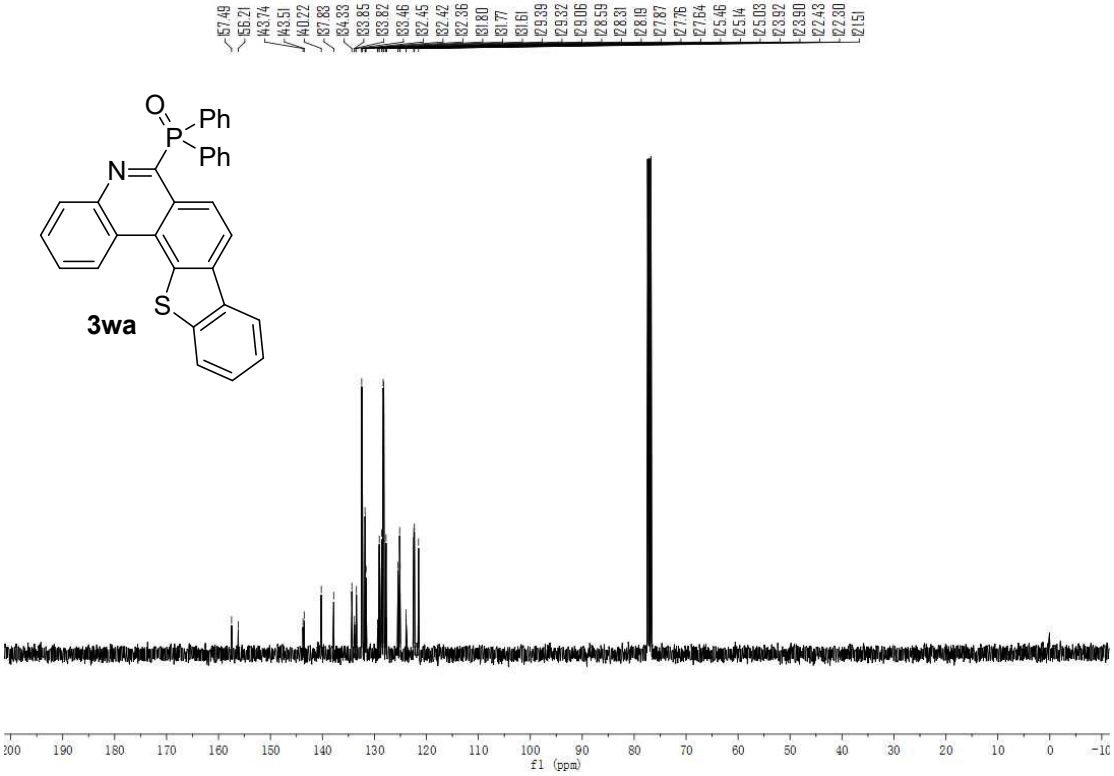
^{31}P NMR spectrum of 3va



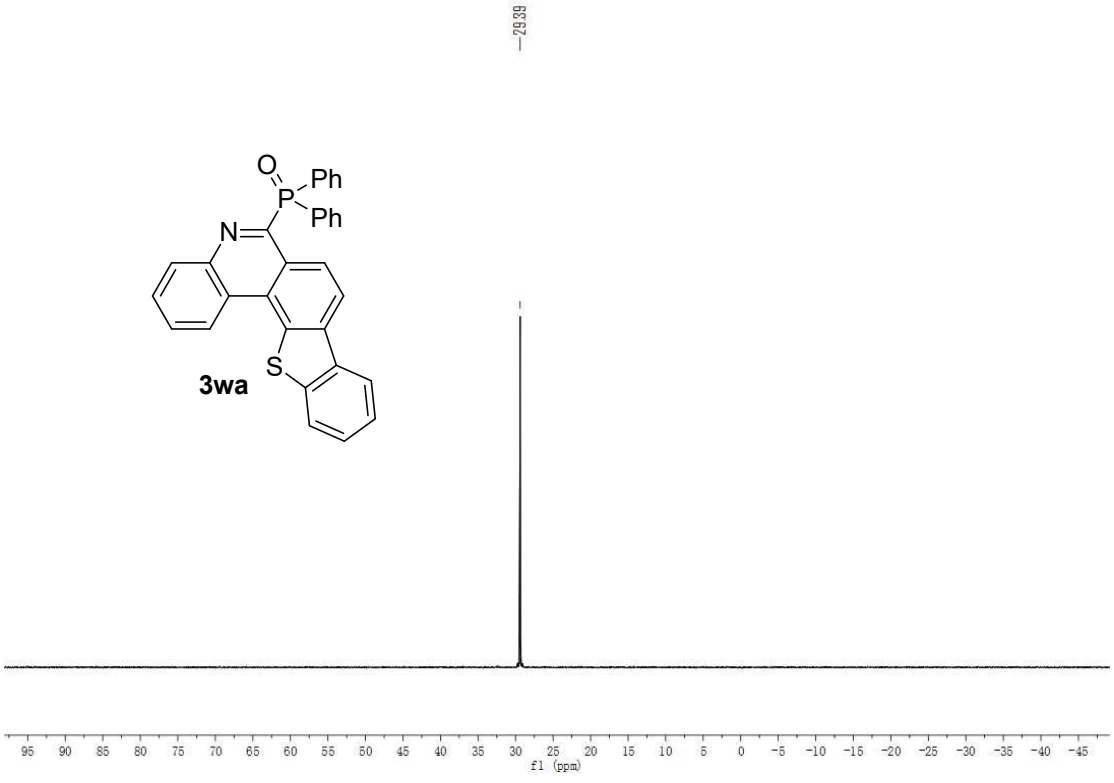
^{1}H NMR spectrum of 3wa



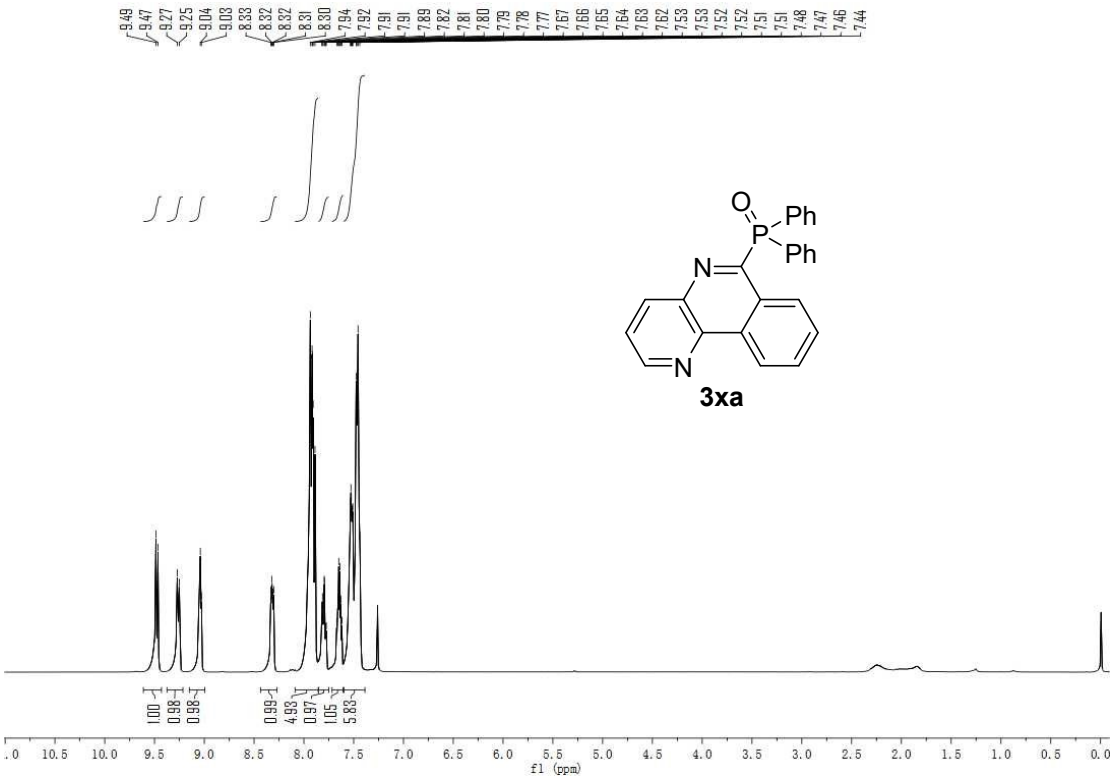
^{13}C NMR spectrum of 3wa



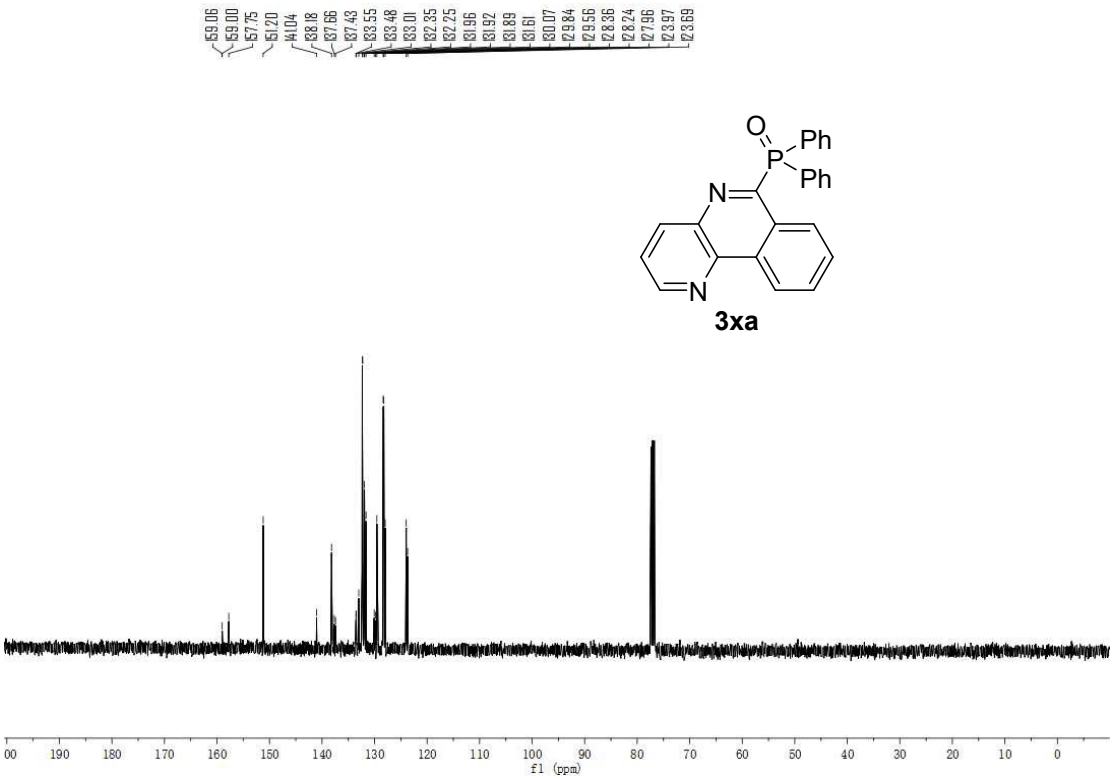
^{31}P NMR spectrum of 3wa



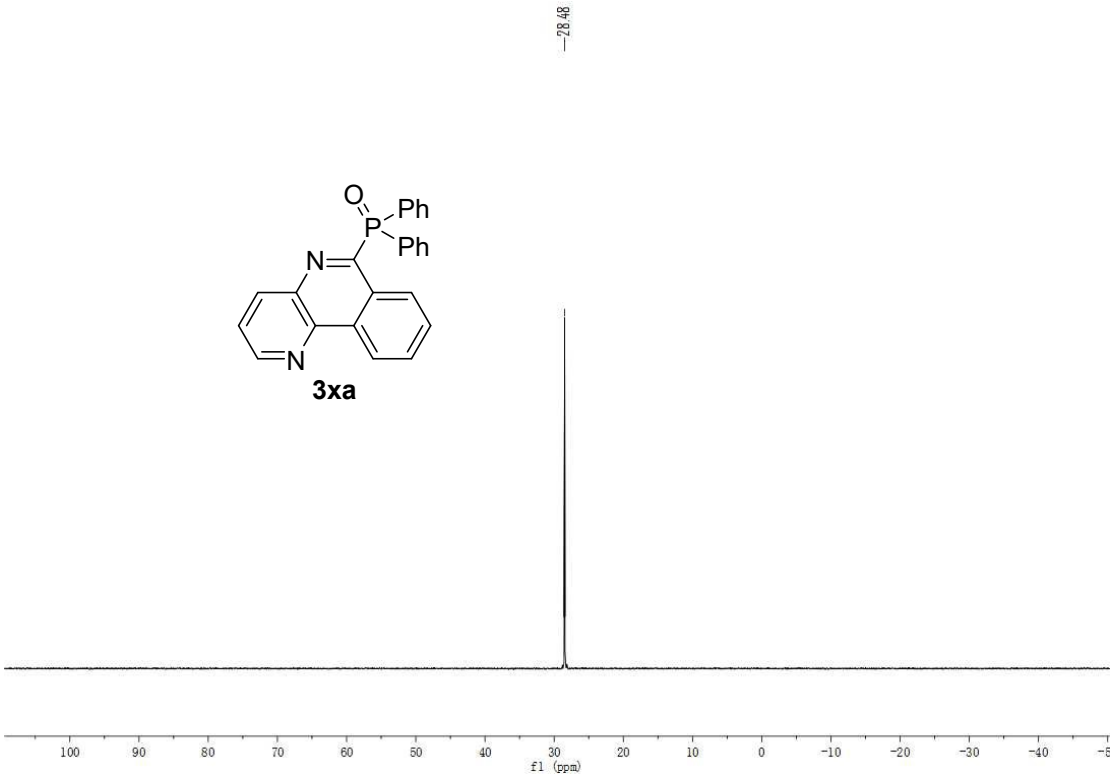
^{1}H NMR spectrum of 3ya



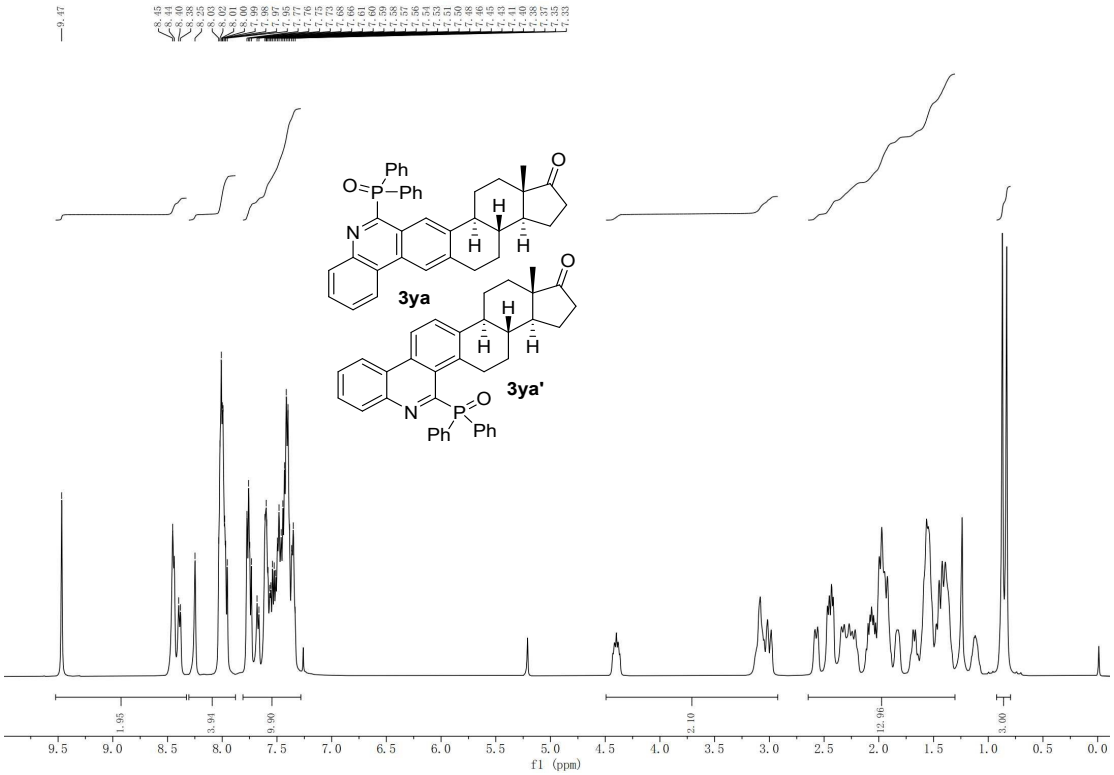
^{13}C NMR spectrum of 3xa



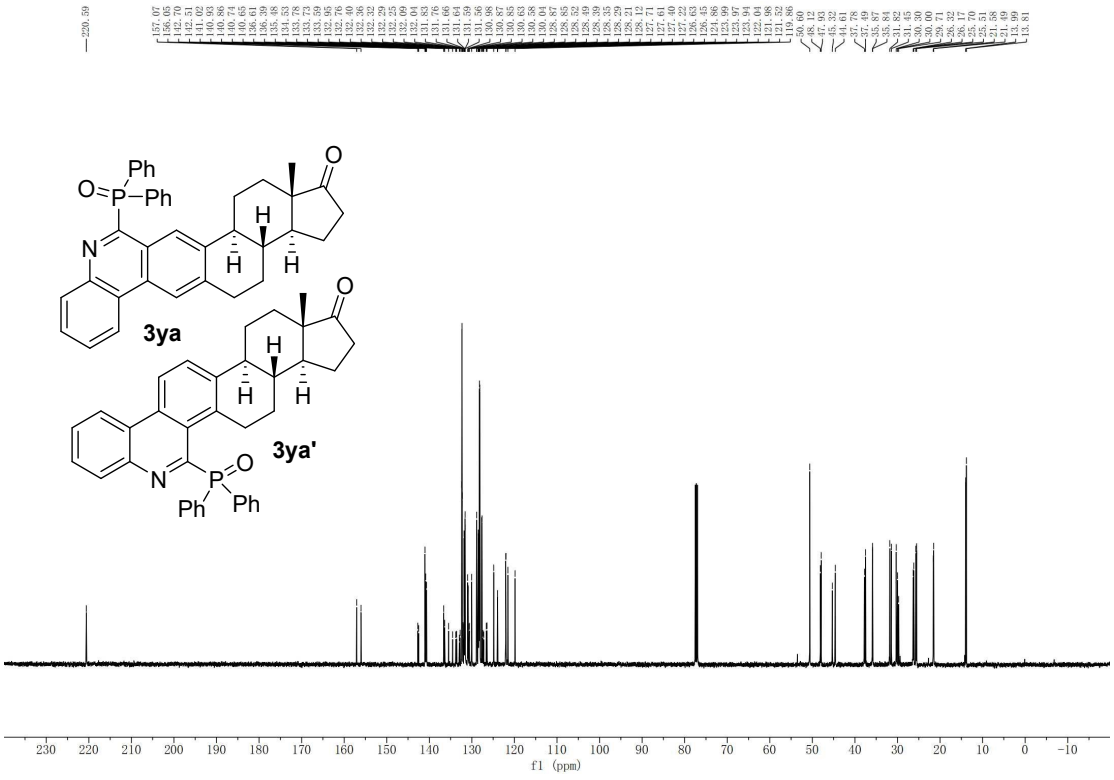
^{31}P NMR spectrum of 3xa



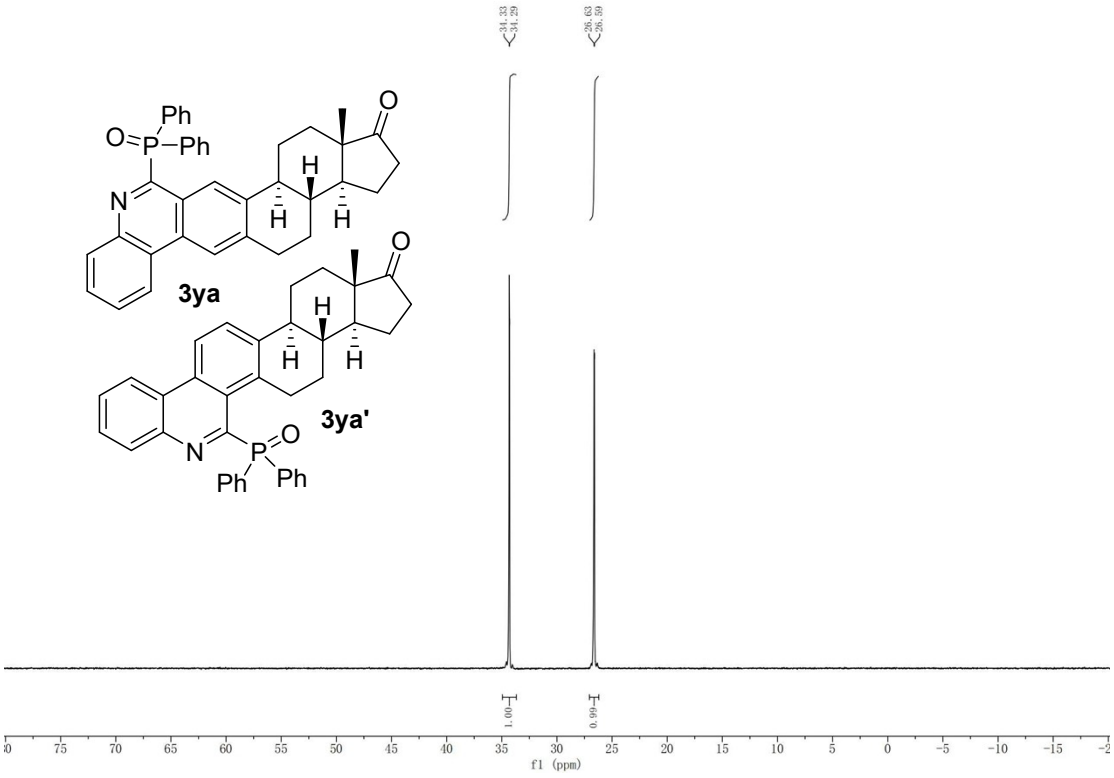
^{1}H NMR spectrum of 3ya and 3ya'



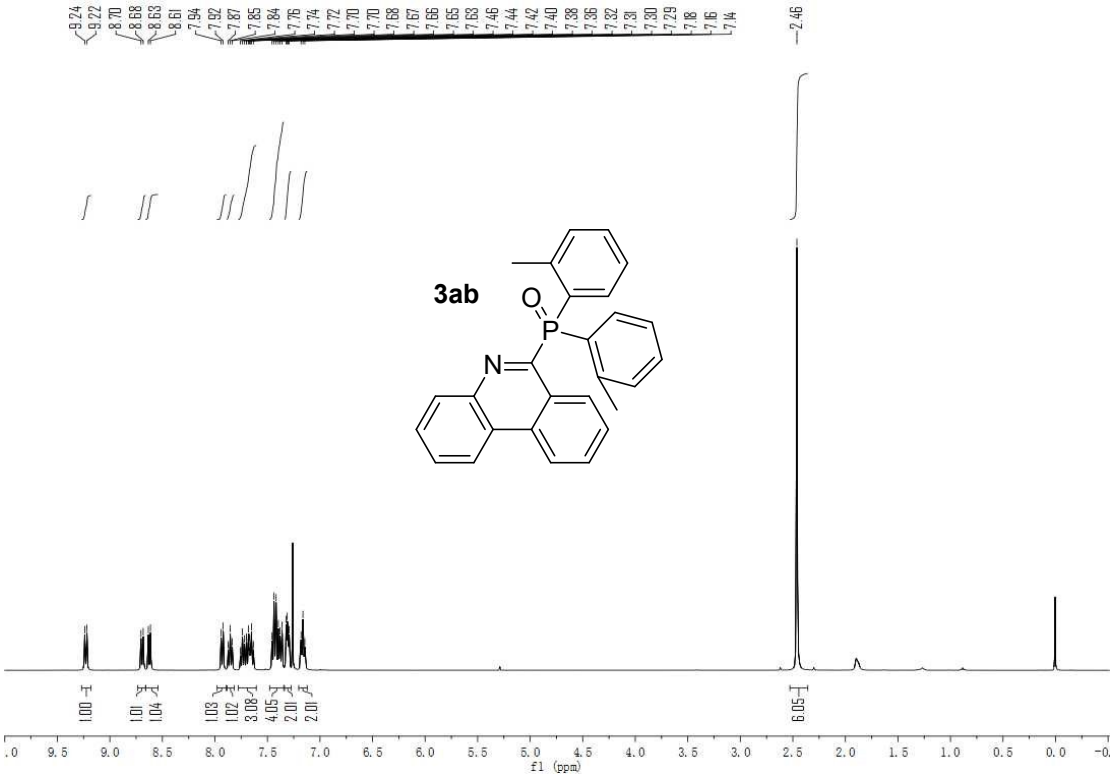
^{13}C NMR spectrum of 3ya and 3ya'



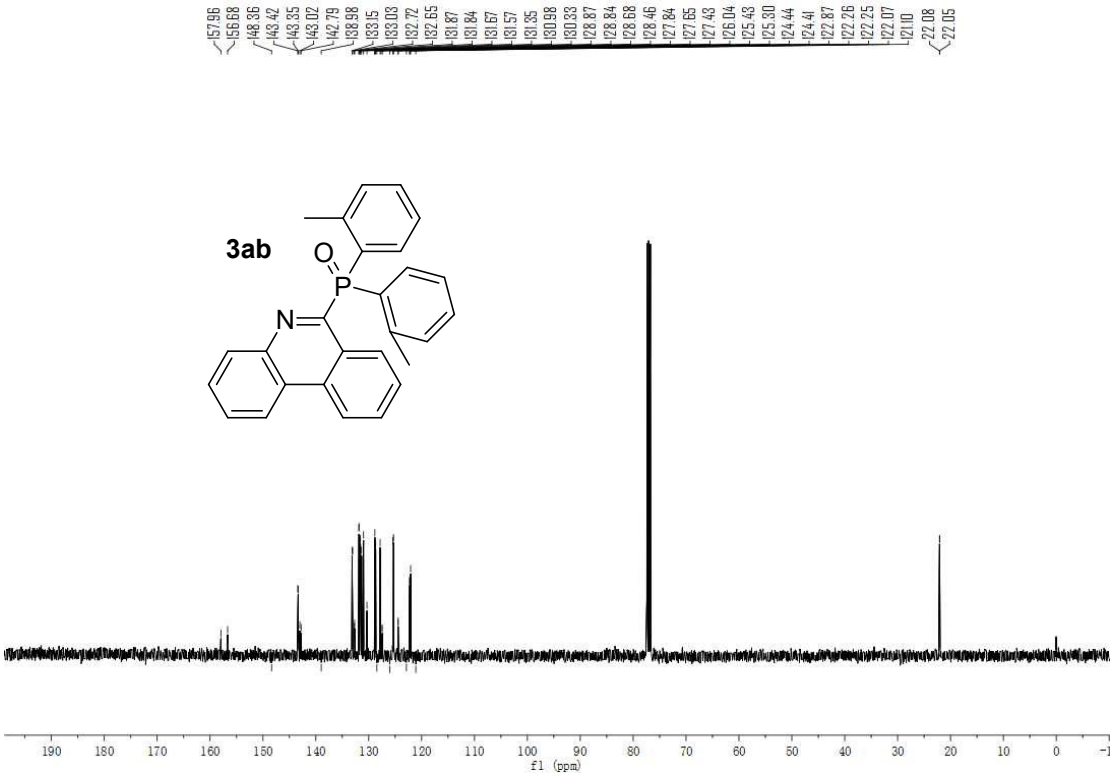
^{31}P NMR spectrum of 3ya and 3ya'



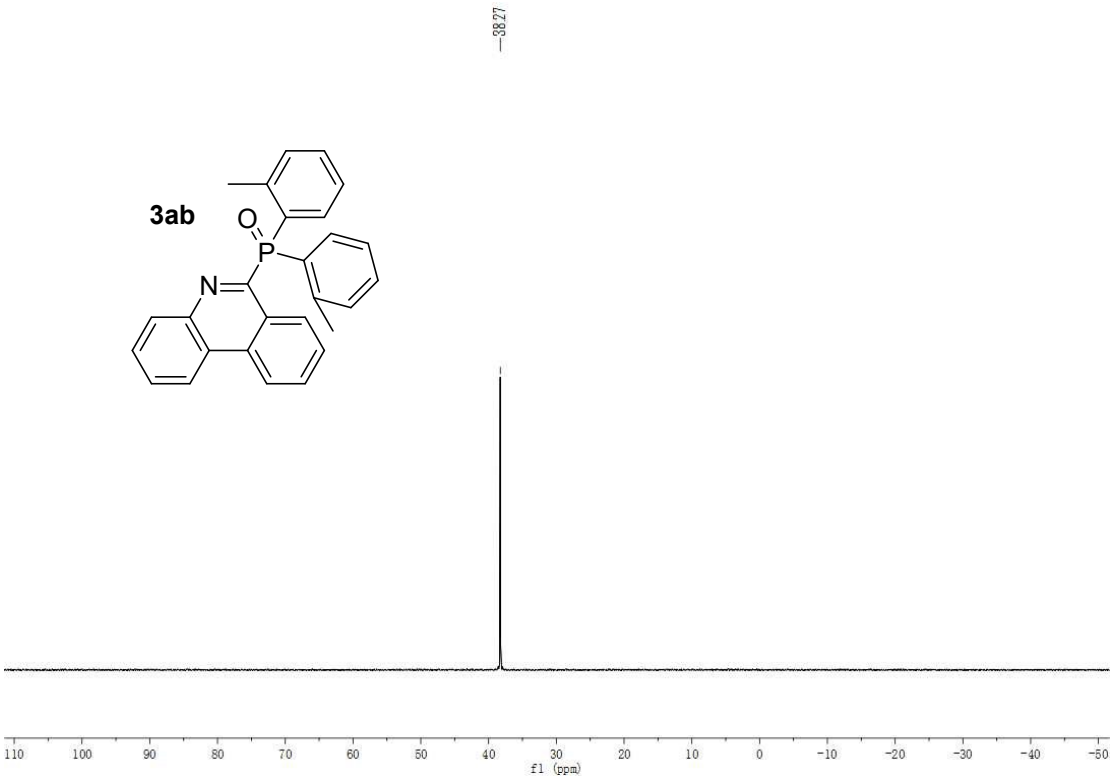
^{1}H NMR spectrum of 3ab



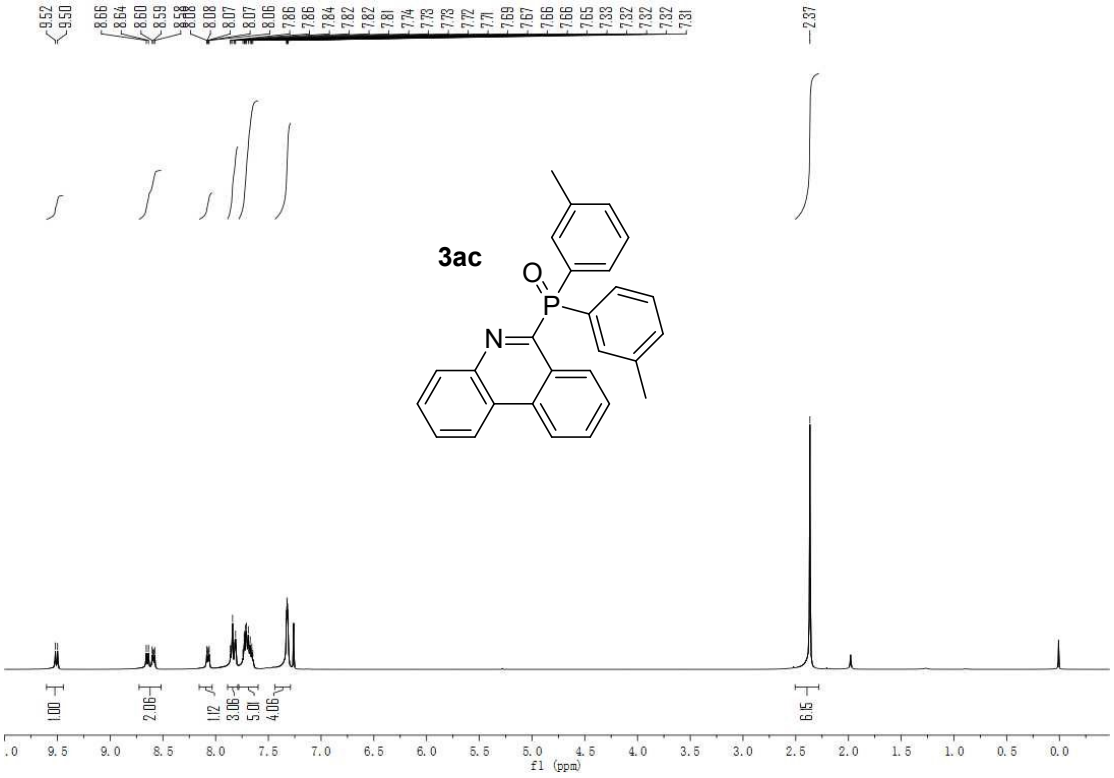
^{13}C NMR spectrum of 3ab



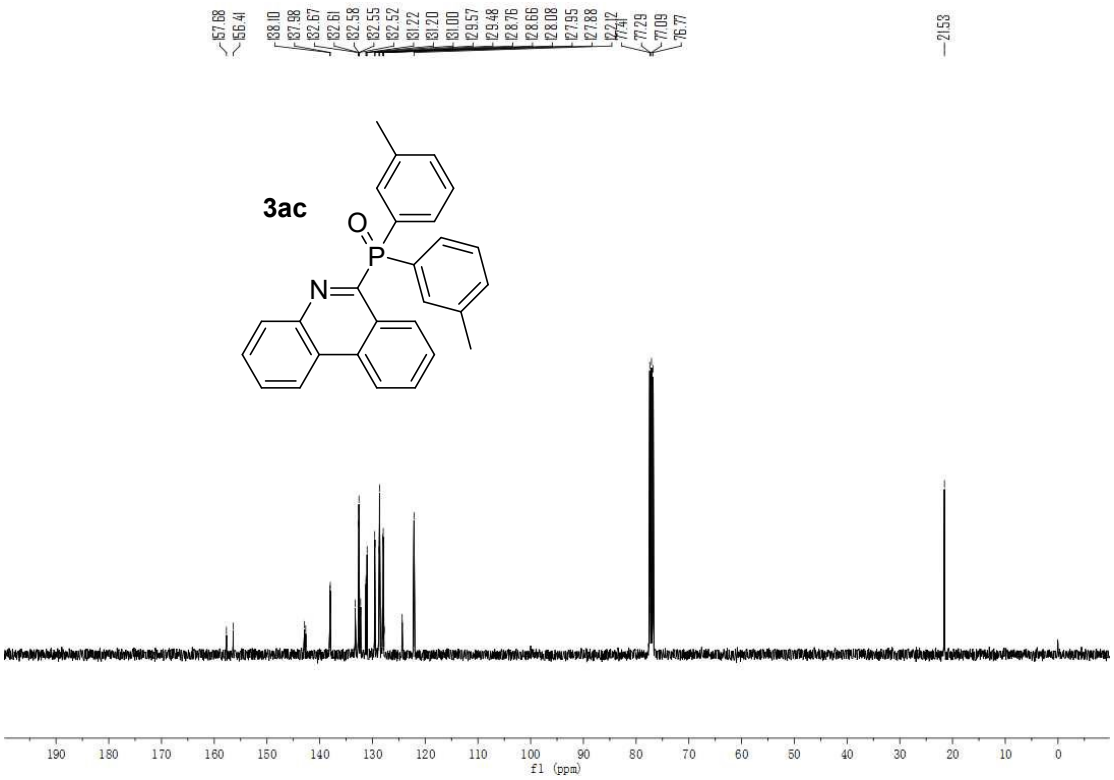
^{31}P NMR spectrum of 3ab



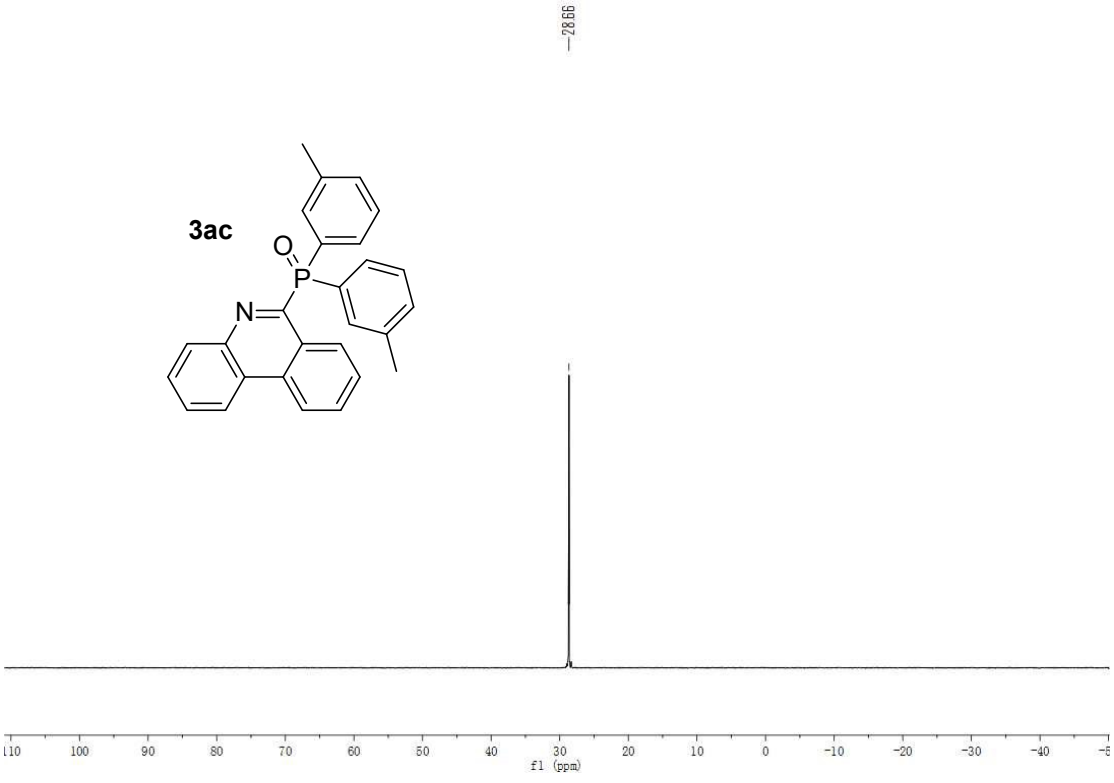
^{1}H NMR spectrum of 3ac



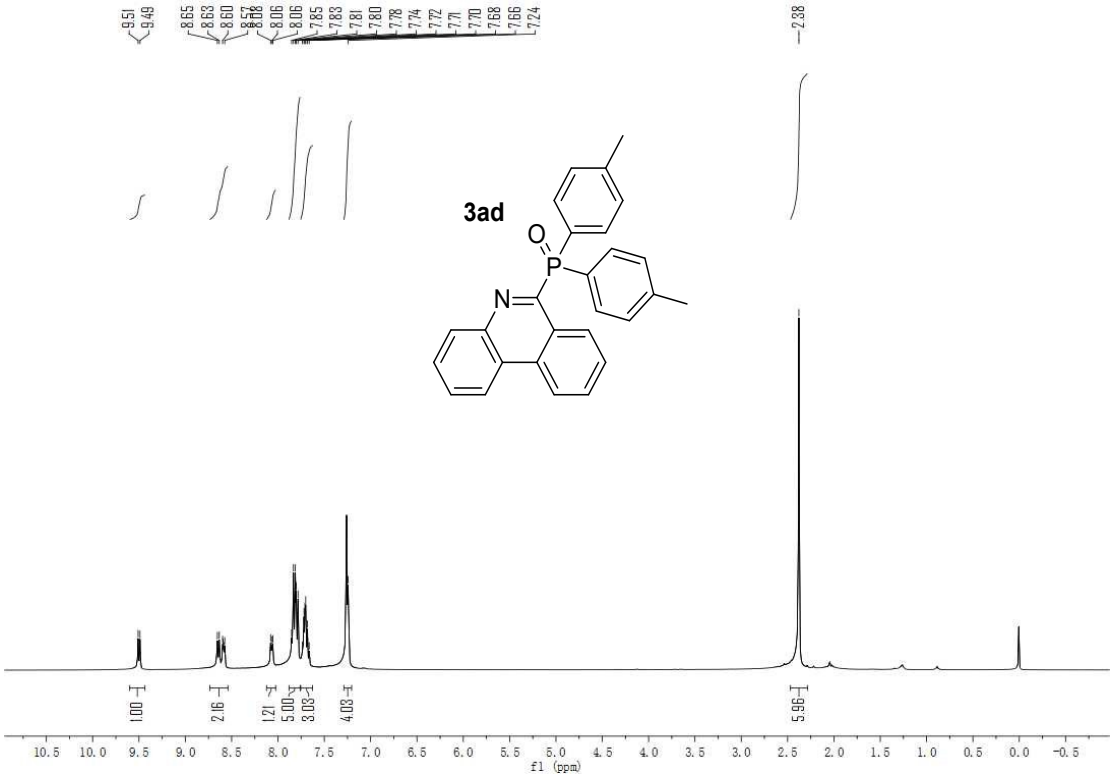
^{13}C NMR spectrum of 3ac



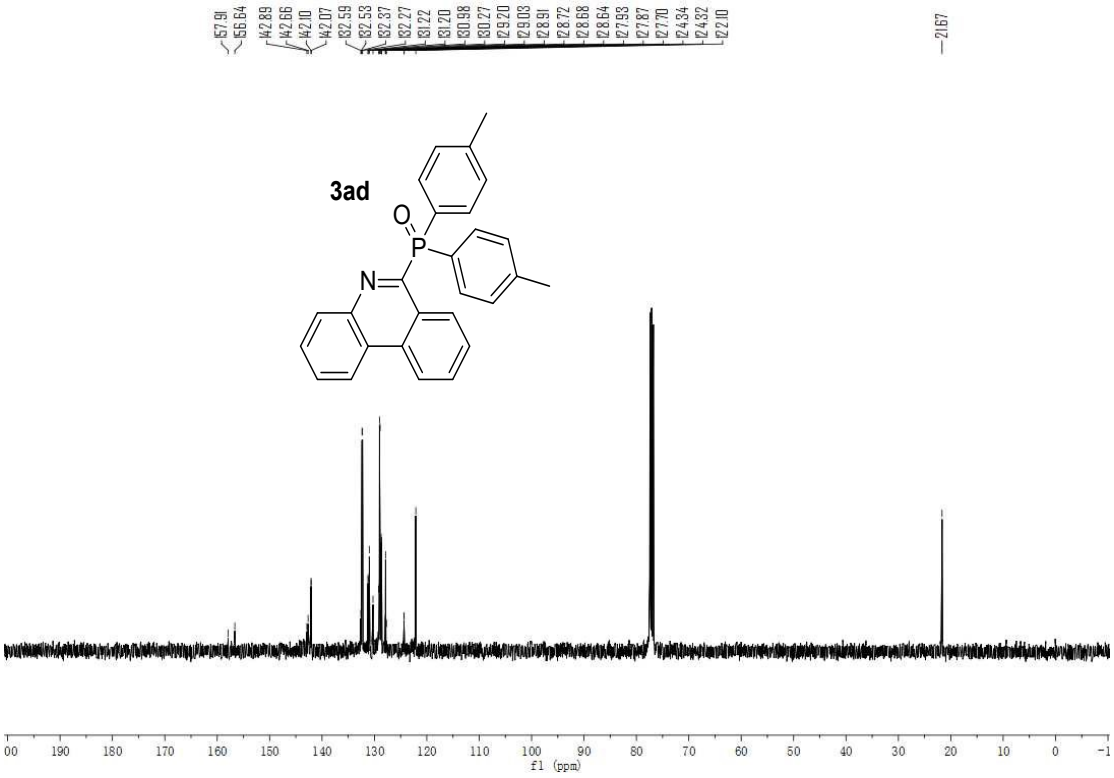
^{31}P NMR spectrum of 3ac



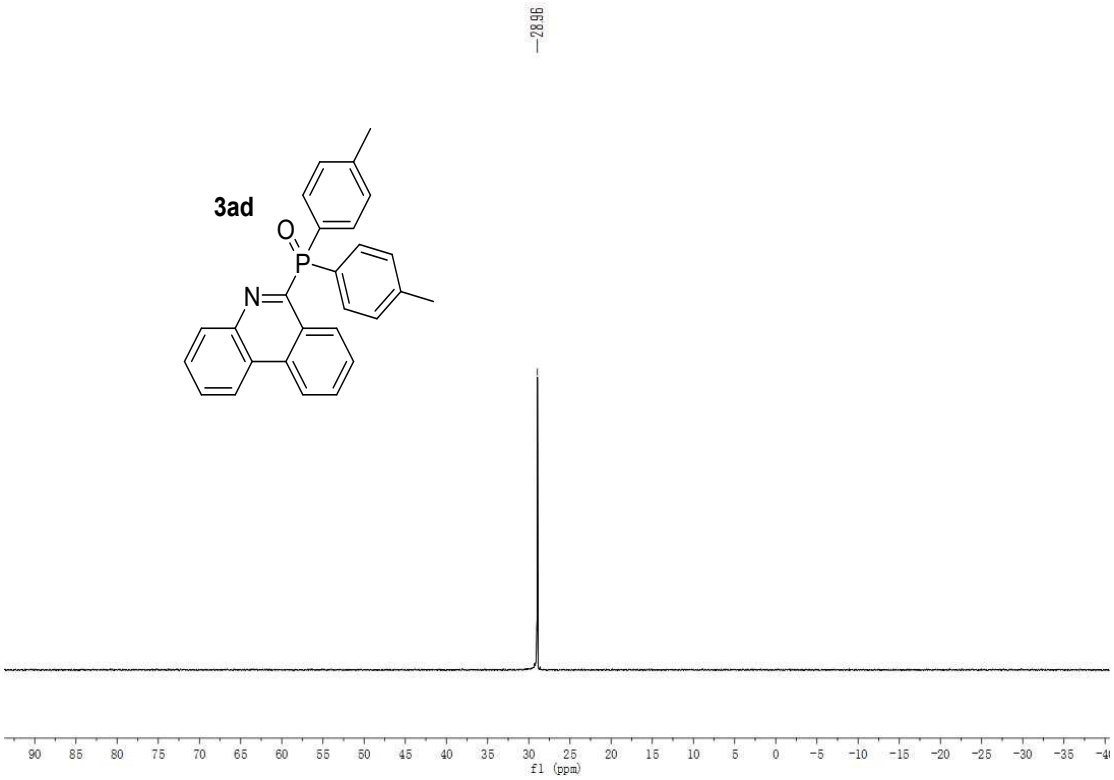
^{1}H NMR spectrum of 3ad



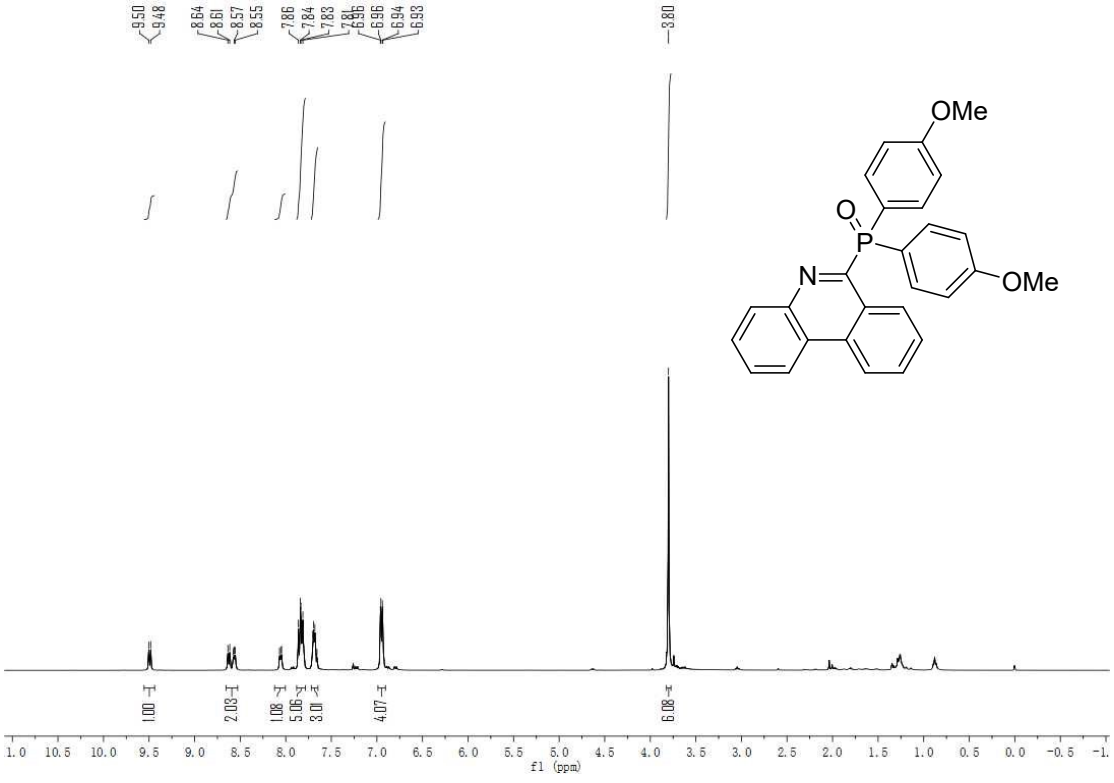
^{13}C NMR spectrum of 3ad



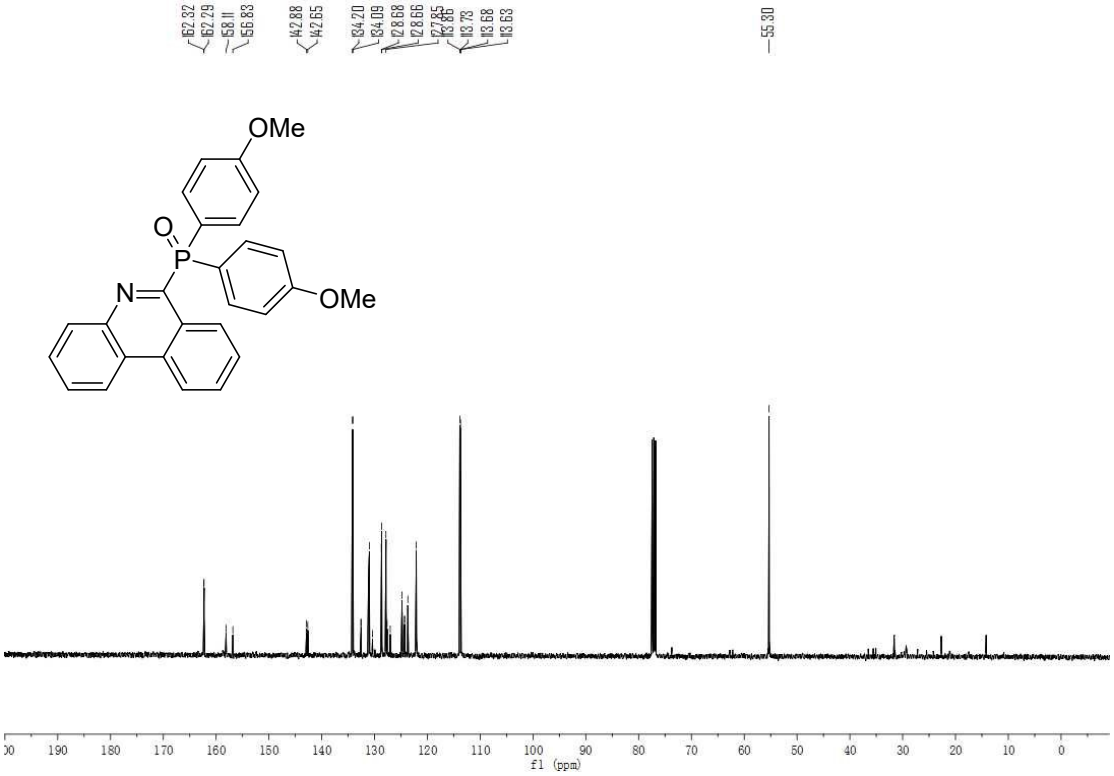
^{31}P NMR spectrum of 3ad



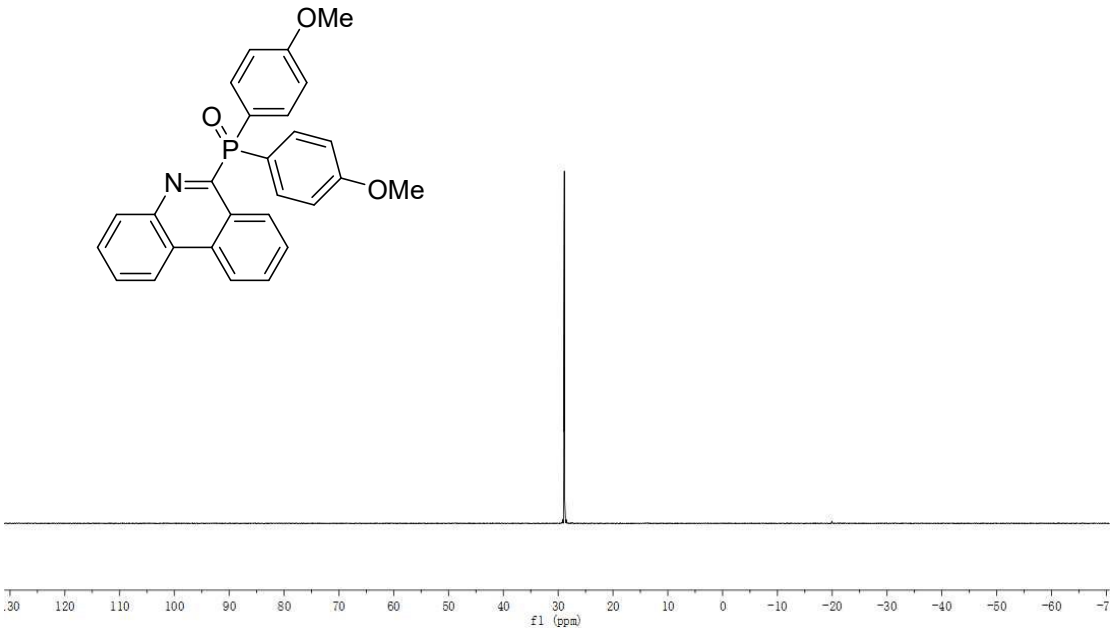
^{1}H NMR spectrum of 3ae



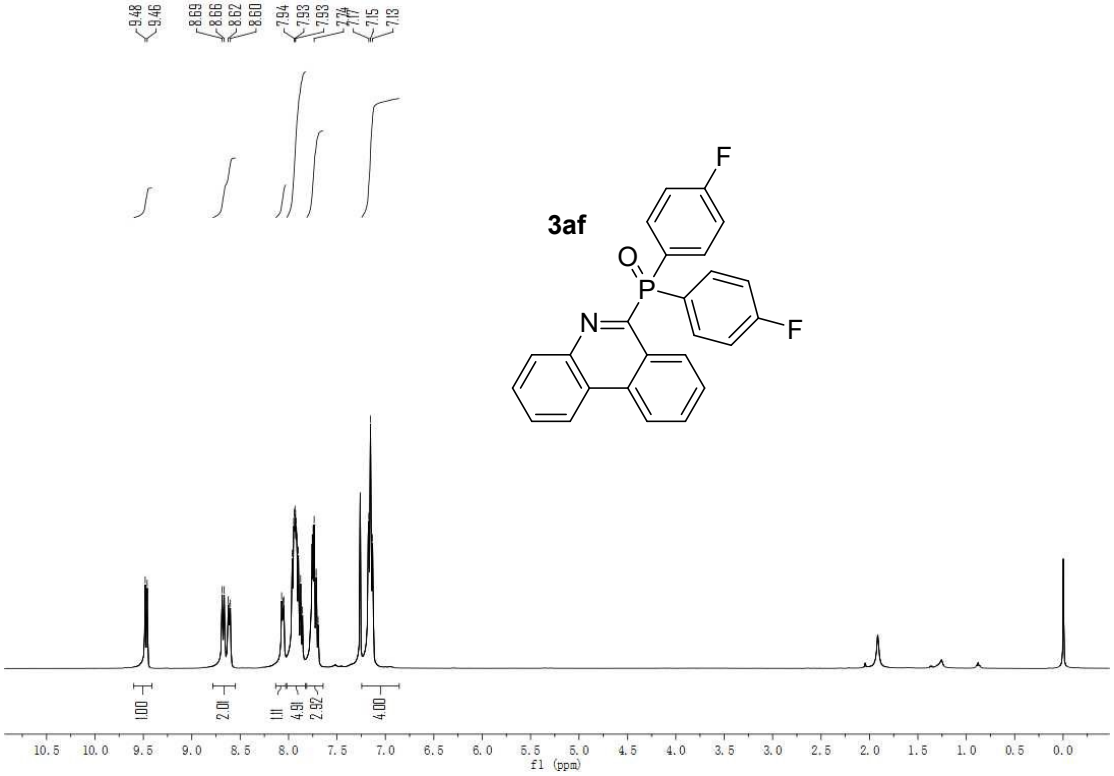
^{13}C NMR spectrum of 3ae



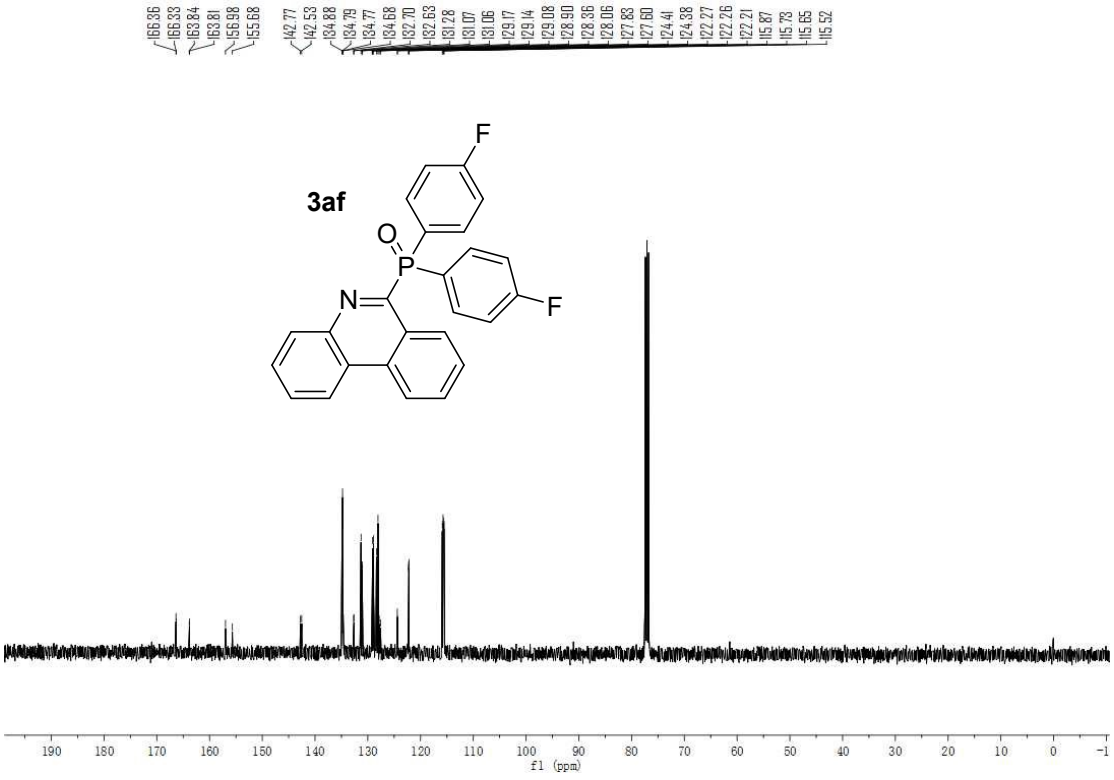
^{13}P NMR spectrum of 3ae



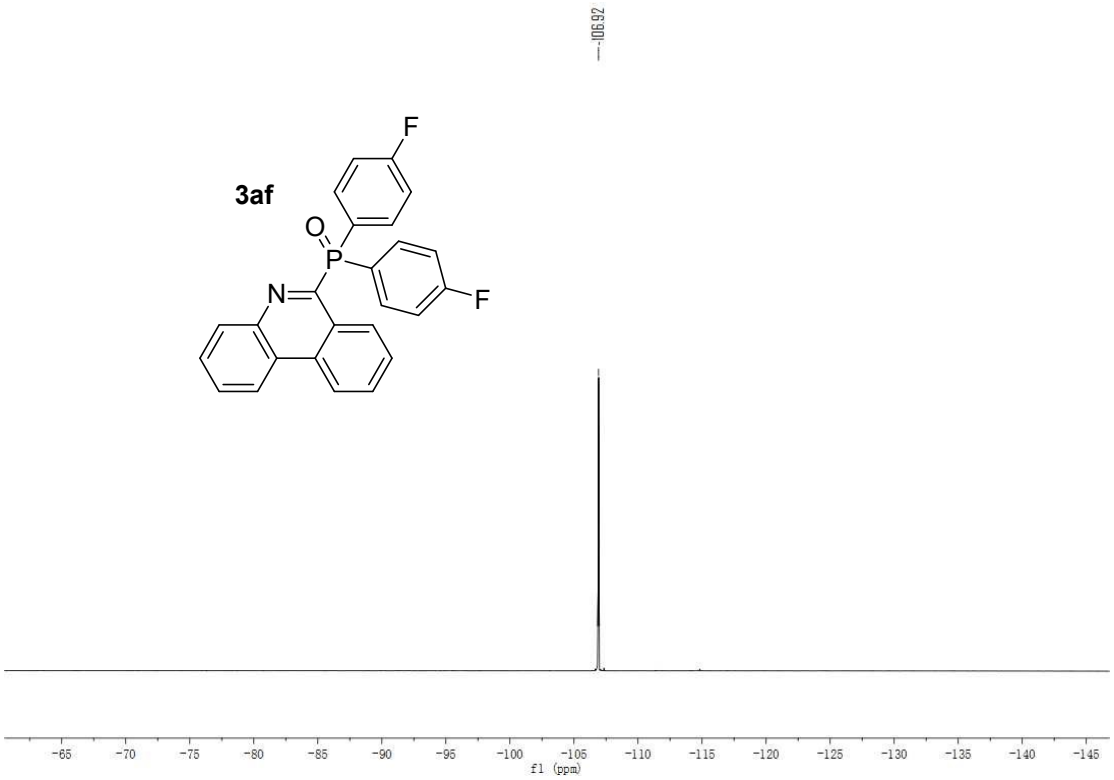
^{1}H NMR spectrum of 3af



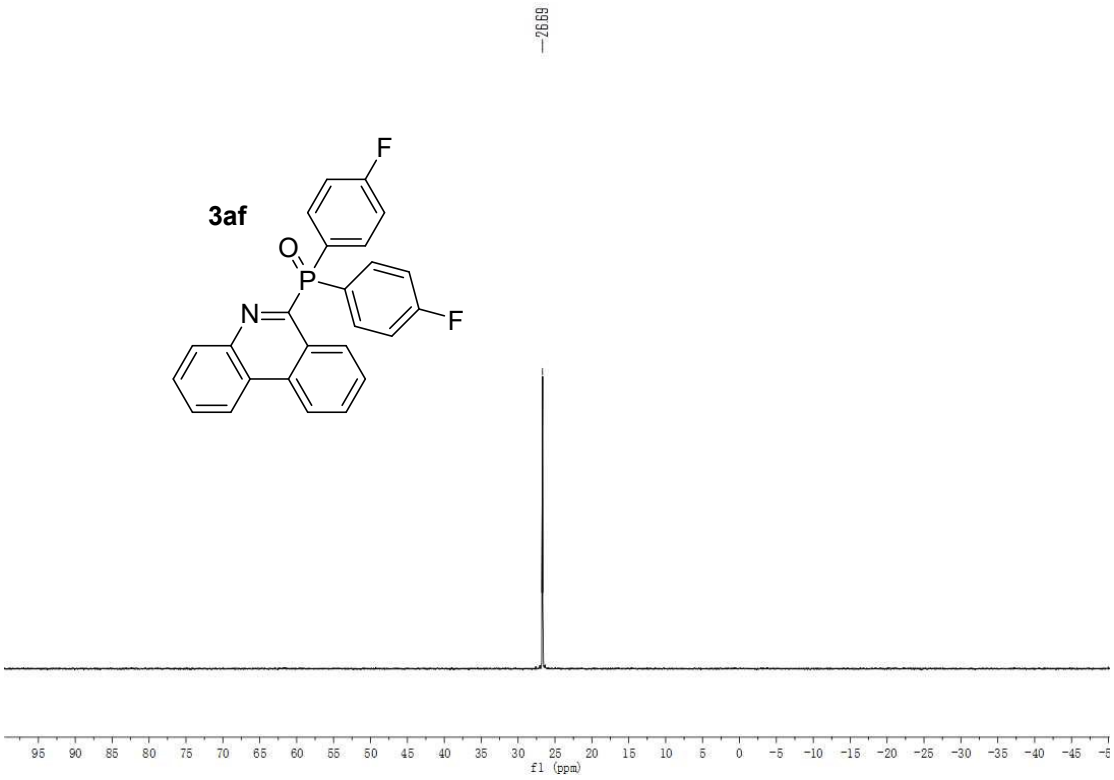
^{13}C NMR spectrum of 3af



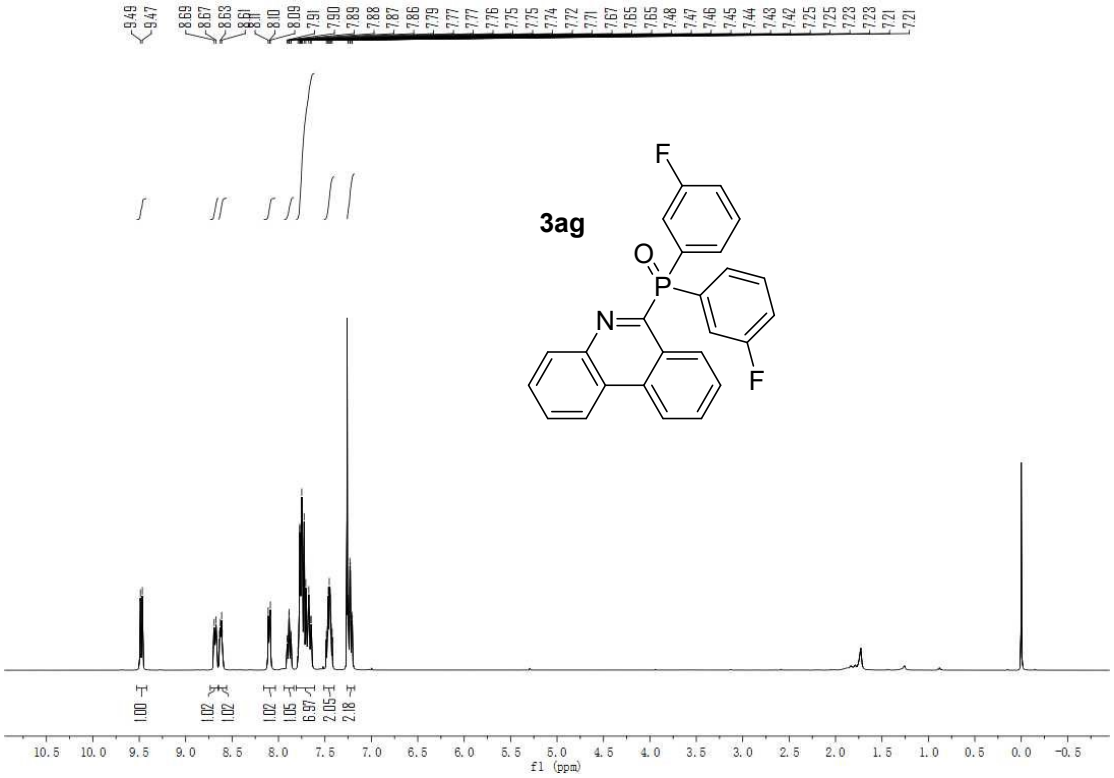
^{19}F NMR spectrum of 3af



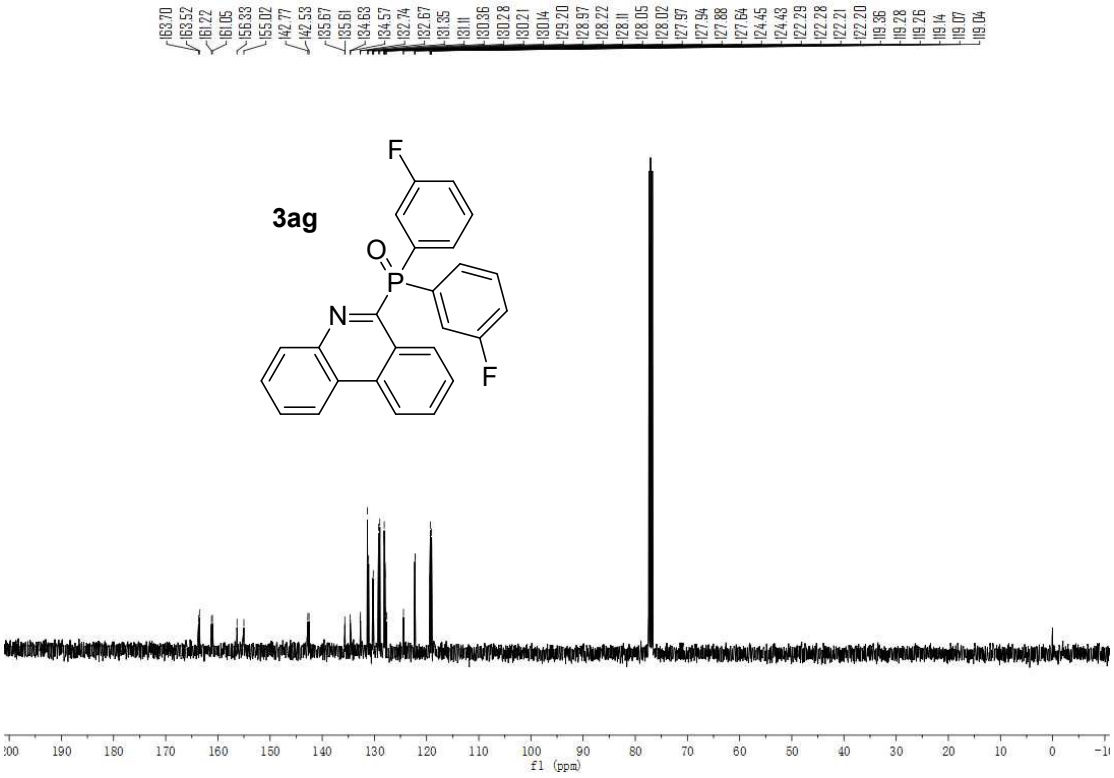
^{31}P NMR spectrum of 3af



^{1}H NMR spectrum of 3ag

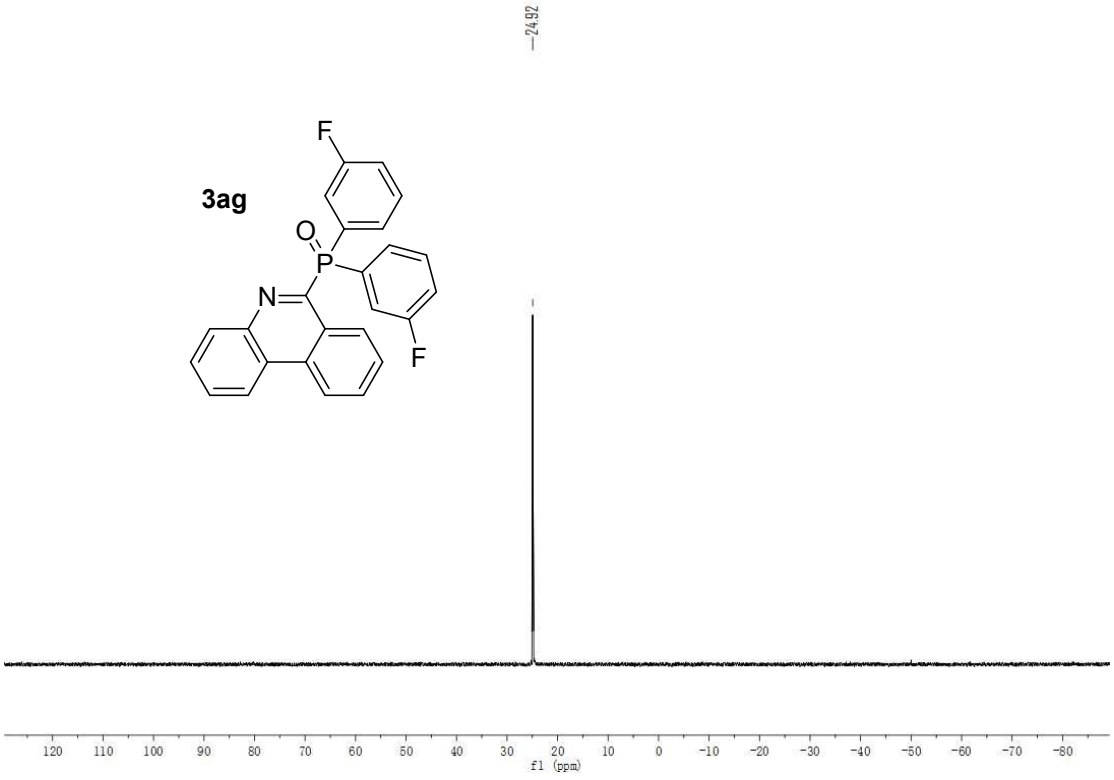


^{13}C NMR spectrum of 3ag

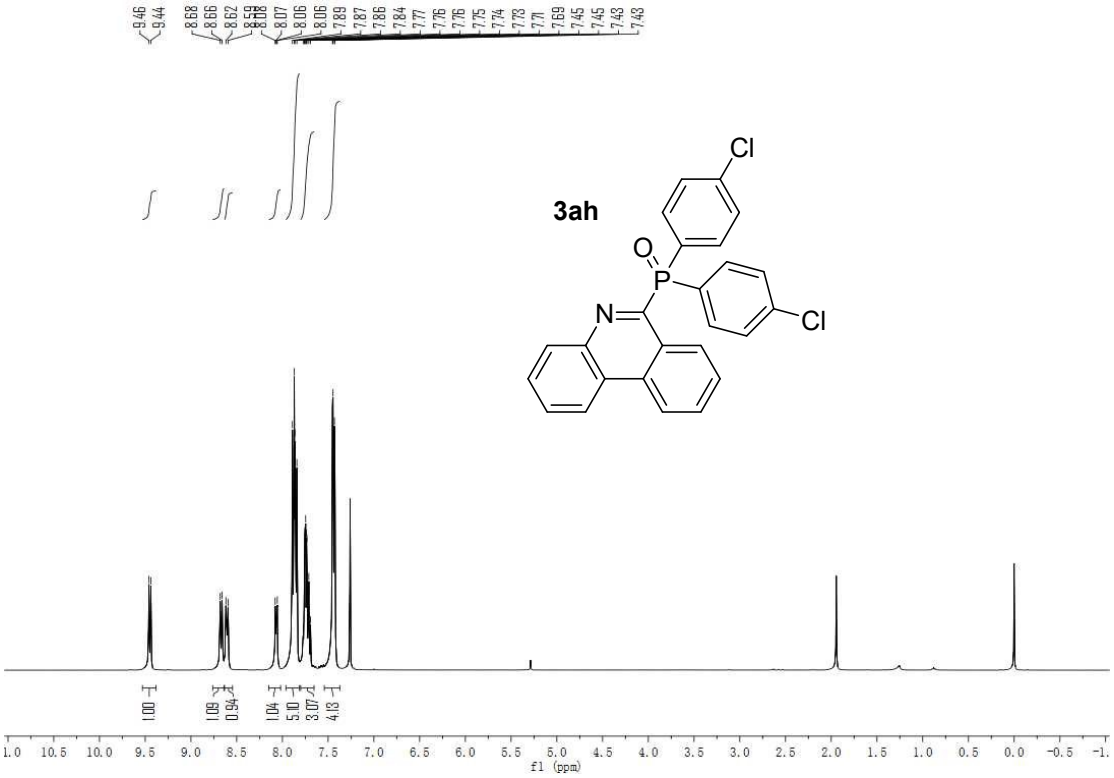


^{19}F NMR spectrum of 3ag

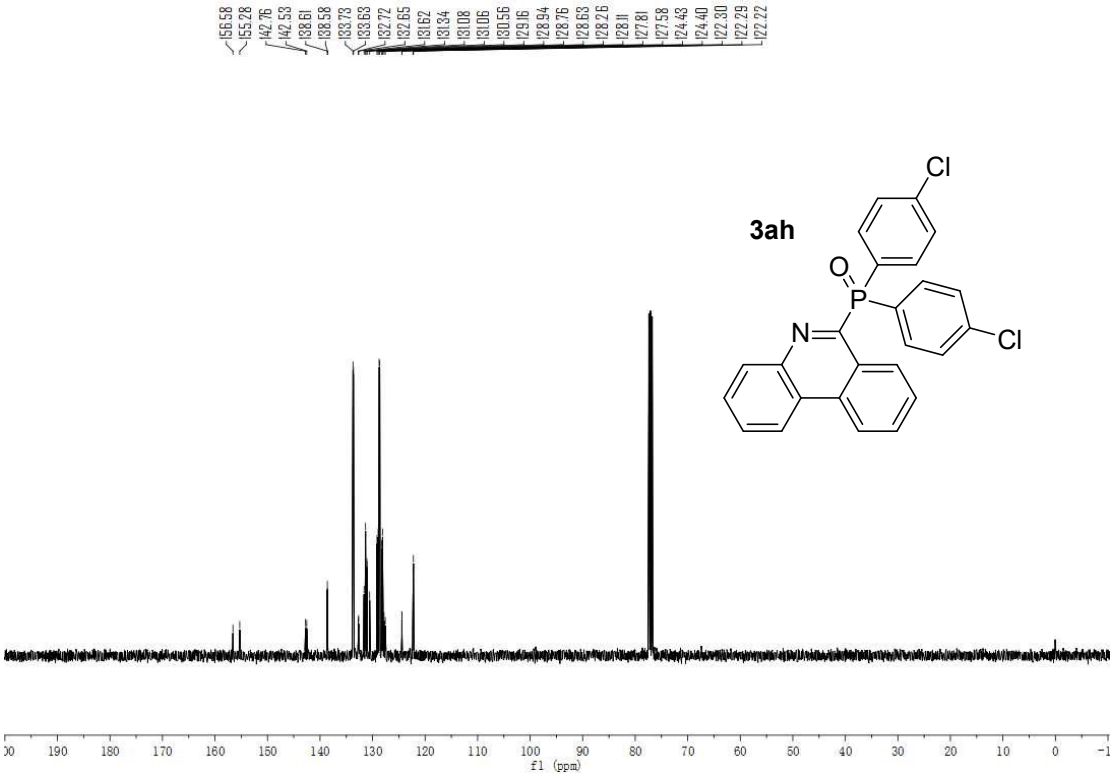
^{31}P NMR spectrum of 3ag



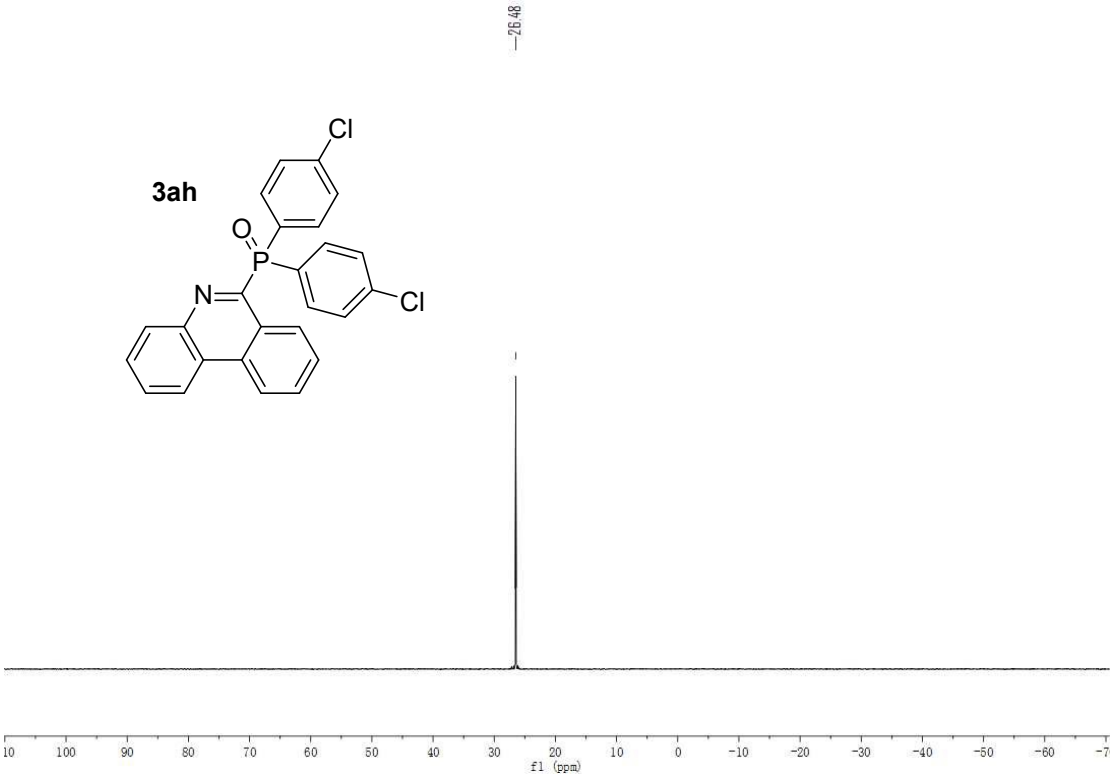
^{1}H NMR spectrum of 3ah



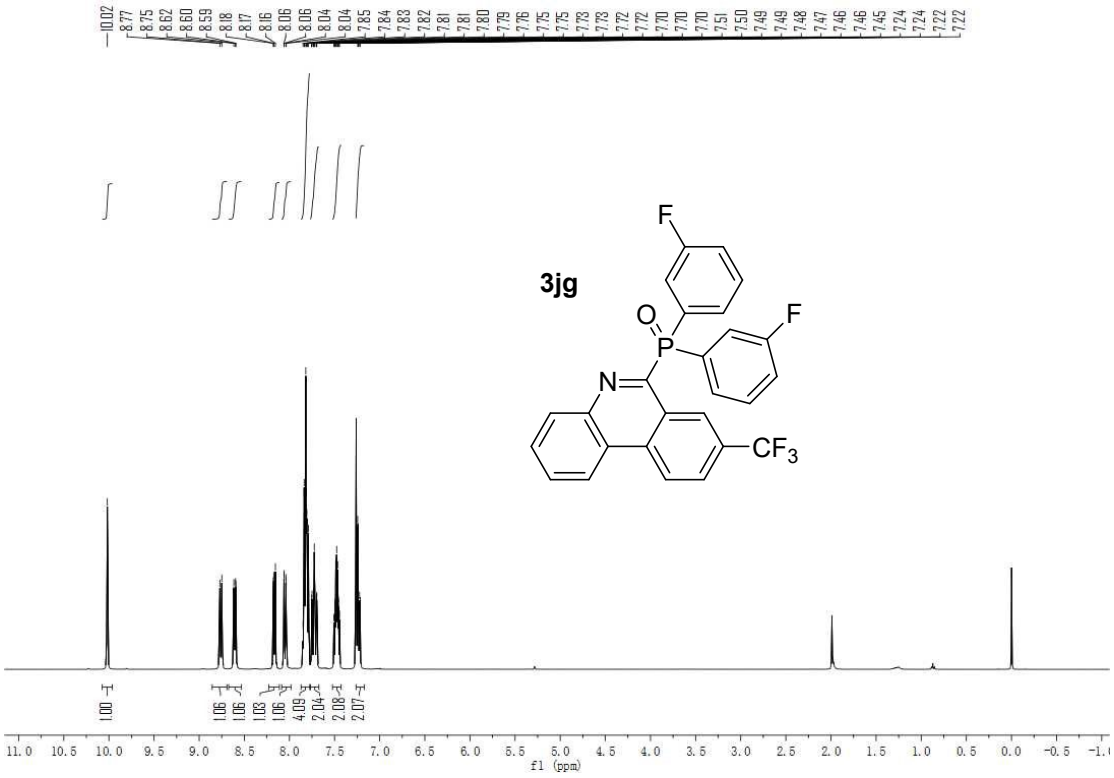
^{13}C NMR spectrum of 3ah



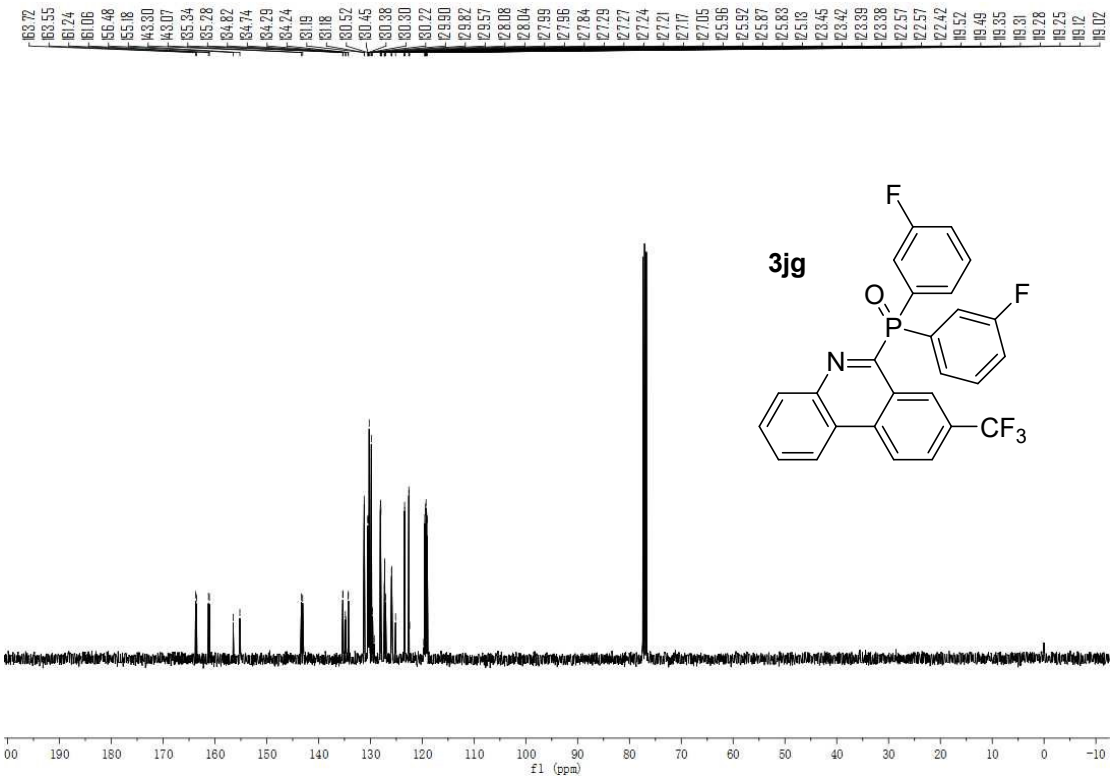
^{31}P NMR spectrum of 3ah



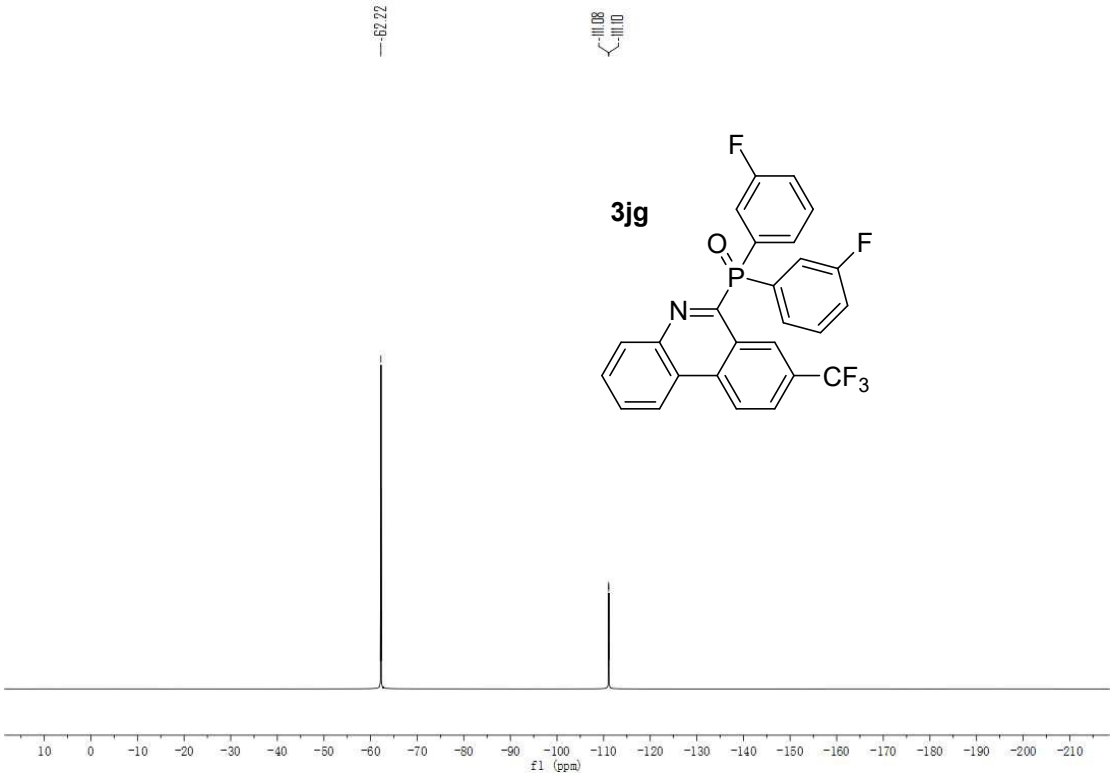
^{1}H NMR spectrum of 3jg



^{13}C NMR spectrum of 3jg



^{19}F NMR spectrum of 3jg



^{31}P NMR spectrum of 3jg