# Supplementary Information

# Palladium-Catalyzed Synthesis of Aryl Phosphonates Using Sodium Hypophosphite

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## Table of Contents

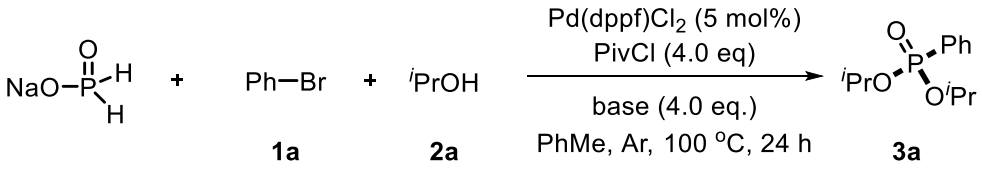
# I. General information and experimental section

## General Information

$^{1}H$ NMR, $^{13}C\{^{1}H\}$ NMR, $^{31}P$ NMR and $^{19}F$ NMR spectra were recorded at room temperature using a Avance-400 instruments ($^{1}H$ NMR at 400 MHz, $^{13}C\{^{1}H\}$ NMR at 101 MHz, $^{31}P$ NMR at 162 MHz and $^{19}F\{^{1}H\}$ NMR at 376 MHz), NMR spectra of all products were reported in ppm with reference to solvent signals [$^{1}H$ NMR: $CD(H)Cl_3$ (7.26 ppm), $^{13}C$ NMR: $CD(H)Cl_3$ (77.00 ppm)]. Signal patterns are indicated as s, singlet; d, doublet; dd, doublets of doublet; t, triplet, and m, multiplet. The mass spectrometry was performed in the positive electrospray ionization (ESI+) mode. Reactions were monitored by thin-layer chromatography Column chromatography (petroleum ether/ethyl acetate) was performed on silica gel (200-300 mesh). Analytical grade solvents and commercially available reagents were purchased from commercial sources and used directly without further purification unless otherwise stated.

# II. Optimization of the reaction conditions

**Table S1. Effect of bases on the reaction.[a,b]**

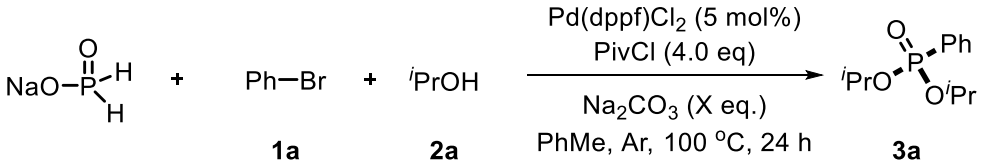



**1a** **2a** **3a**

| entry | base | Yield (%)[b] |
|---|---|---|
| 1 | $Na_2CO_3$ | 93 |
| 2 | $NaHCO_3$ | 45 |
| 3 | NaOAc | n.r. |
| 4 | $Cs_2CO_3$ | 24 |
| 5 | DABCO | 38 |
| 6 | DBU | 51 |
| 7 | $Et_3N$ | 46 |

[a]Reaction conditions: bromobenzene (0.2 mmol), $NaH_2PO_2$ (0.4 mmol), base (0.8 mmol), $^{i}$PrOH (1.6 mmol), PivCl (0.8 mmol), $Pd(dppf)Cl_2$ (5 mol%), PhMe (2.0 mL), under Ar, 100 °C, 24 h. [b]Isolated yield.

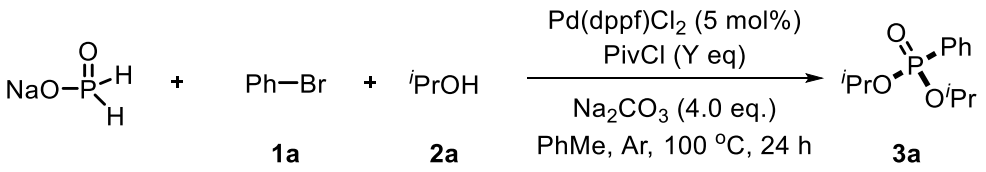
**Table S2. Effect of $Na_2CO_3$ equivalents on the reaction.[a,b]**




| entry | $Na_2CO_3$ (X eq.) | Yield (%)[b] |
|---|---|---|
| 1 | 1.0 | n.r. |
| 2 | 2.0 | trace |
| 3 | 3.0 | 44 |
| 4 | 4.0 | 93 |
| 5 | 5.0 | 90 |
| 6 | 6.0 | 77 |

[a]Reaction conditions: bromobenzene (0.2 mmol), $NaH_2PO_2$ (0.4 mmol), $Na_2CO_3$ (X eq.), $^i$PrOH (1.6 mmol), PivCl (0.8 mmol), $Pd(dppf)Cl_2$ (5 mol%), PhMe (2.0 mL), under Ar, 100 °C, 24 h. [b]Isolated yield.

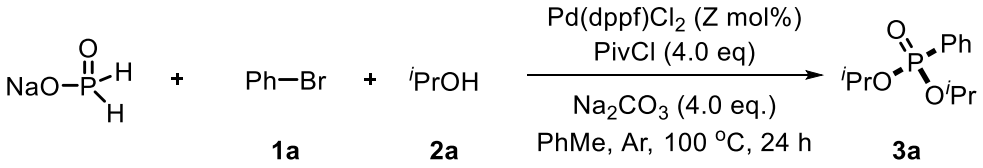
**Table S3. Effect of additive PivCl equivalents on the reaction.[a,b]**




| entry | PivCl (Y eq.) | Yield (%)[b] |
|---|---|---|
| 1 | 1.0 | n.r. |
| 2 | 2.0 | trace |
| 3 | 3.0 | 45 |
| 4 | 4.0 | 93 |
| 5 | 5.0 | 93 |
| 6 | 6.0 | 89 |

[a]Reaction conditions: bromobenzene (0.2 mmol), $NaH_2PO_2$ (0.4 mmol), $Na_2CO_3$ (0.8 mmol), $^i$PrOH (1.6 mmol), PivCl (Y eq.), $Pd(dppf)Cl_2$ (5 mol%), PhMe (2.0 mL), under Ar, 100 °C, 24 h. [b]Isolated yield.

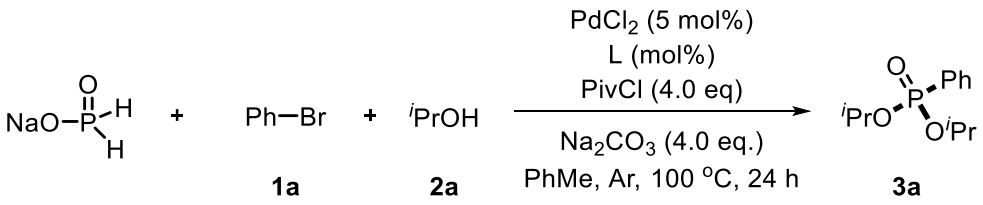
**Table S4. Effect of catalyst $Pd(dppf)Cl_2$ equivalents on the reaction.[a,b]**




| entry | $Pd(dppf)Cl_2$ (Z mol%) | Yield (%)[b] |
|---|---|---|
| 1 | 1 | 74 |
| 2 | 2.5 | 87 |
| 3 | 3 | 89 |
| 4 | 5 | 93 |
| 5 | 10 | 90 |

[a]Reaction conditions: bromobenzene (0.2 mmol), $NaH_2PO_2$ (0.4 mmol), $Na_2CO_3$ (0.8 mmol), $^i$PrOH (1.6 mmol), PivCl (0.8 mmol), $Pd(dppf)Cl_2$ (Z mol%), PhMe (2.0 mL), under Ar, 100 °C, 24 h. [b]Isolated yield.

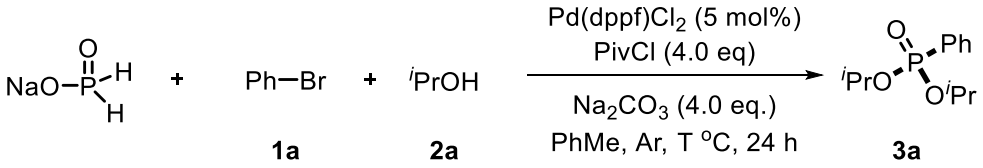
**Table S5. Effect of ligand on the reaction.[a,b]**




| entry | L (mol%) | Yield (%)[b] |
|---|---|---|
| 1 | $PPh_3$ (10 mol%) | 12 |
| 2 | Dppf (5 mol%) | 93 |
| 3 | Dppp (5 mol%) | trace |
| 4 | BINAP (5 mol%) | 66 |
| 5 | DPEphos (5 mol%) | 34 |
| 6 | Xantphos (5 mol%) | n.r. |

[a]Reaction conditions: bromobenzene (0.2 mmol), $NaH_2PO_2$ (0.4 mmol), $Na_2CO_3$ (0.8 mmol), $^i$PrOH (1.6 mmol), PivCl (Y eq.), $PdCl_2$ (5 mol%), L (5-10 mol%), PhMe (2.0 mL), under Ar, 100 °C, 24 h. [b]Isolated yield.

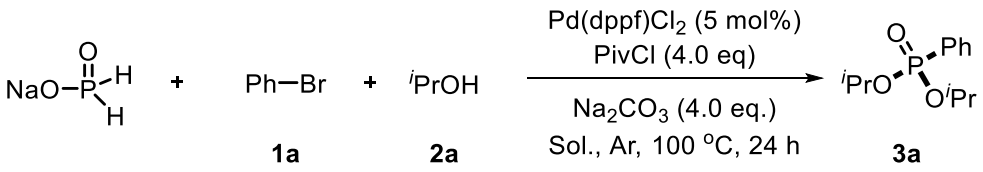
**Table S6. Effect of temperature on the reaction.[a,b]**




| entry | T (° C) | Yield (%)[b] |
|---|---|---|
| 1 | rt | n.r. |
| 2 | 40 | trace |
| 3 | 60 | 48 |
| 4 | 80 | 69 |
| 5 | 100 | 93 |
| 6 | 120 | 90 |

[a]Reaction conditions: bromobenzene (0.2 mmol), $NaH_2PO_2$ (0.4 mmol), $Na_2CO_3$ (0.8 mmol), $^i$PrOH (1.6 mmol), PivCl (0.8 mmol), $Pd(dppf)Cl_2$ (5 mol%), PhMe (2.0 mL), under Ar, 24 h. [b]Isolated yield.

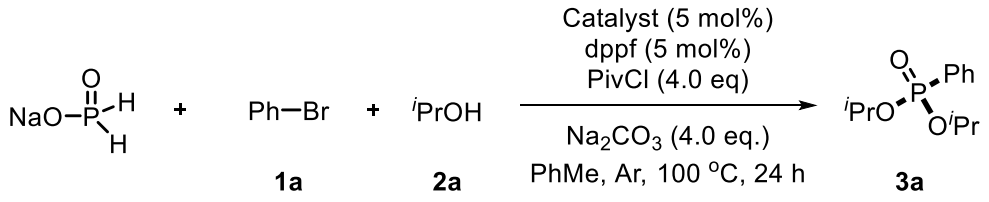
**Table S7. Effect of solvents on the reaction.[a,b]**




| entry | Sol. | Yield (%)[b] |
|---|---|---|
| 1 | PhMe | 93 |
| 2 | 1,4-dioxane | 60 |
| 3 | THF | 48 |
| 4 | EtOAc | 38 |
| 5 | DCE | n.r |
| 6 | MeCN | 31 |

[a]Reaction conditions: bromobenzene (0.2 mmol), $NaH_2PO_2$ (0.4 mmol), $Na_2CO_3$ (0.8 mmol), $^i$PrOH (1.6 mmol), PivCl (0.8 mmol), $Pd(dppf)Cl_2$ (5 mol%), solvent (2.0 mL), under Ar, 100 °C, 24 h. [b]Isolated yield.

**Table S8. Effect of catalysts on the reaction.[a,b]**

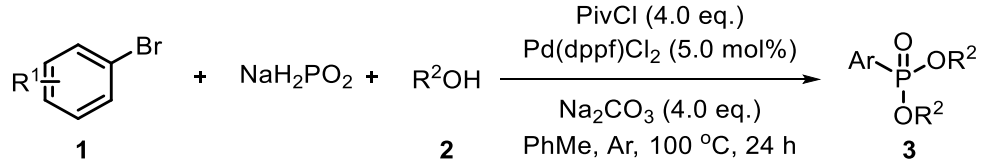



1a 2a 3a

| entry | Catalyst (5 mol%) | Yield (%)[b] |
|---|---|---|
| 1 | $PdCl_2$ | 93 |
| 2 | $Pd(OAc)_2$ | 81 |
| 3 | $Pd(acac)_2$ | 69 |
| 4 | $Pd_2(dba)_3$ | trace |
| 5 | $NiCl_2$ | n.r. |
| 6 | $CoCl_2$ | n.r. |

[a]Reaction conditions: bromobenzene (0.2 mmol), $NaH_2PO_2$ (0.4 mmol), $Na_2CO_3$ (0.8 mmol), $^i$PrOH (1.6 mmol), PivCl (0.8 mmol), catalyst (5 mol%), dppf (5 mol%), PhMe (2.0 mL), under Ar, 100 °C, 24 h. [b]Isolated yield.

## III. Experimental procedure for the synthesis of product

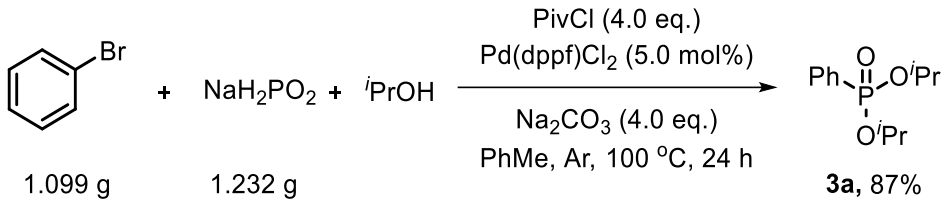



1 2 3

Under an inert gas atmosphere, sodium hypophosphite solid (0.4 mmol, 2.0 equiv), sodium carbonate (0.8 mmol, 4.0 equiv), and $Pd(dppf)Cl_2$ (0.01 mmol, 5.0 mol%) were weighed into a dried reaction tube containing 2 mL of anhydrous toluene. Subsequently, the aryl halide (0.2 mmol, 1.0 equiv), the alcohol compound (1.6 mmol, 8.0 equiv), and the activator pivaloyl chloride (PivCl, 0.8 mmol, 4.0 equiv) were added to the reaction mixture via a microsyringe. The mixture was heated in an oil bath at 100 °C for 24 hours until thin-layer chromatography (TLC) analysis confirmed complete consumption of the aryl halide starting material. After completion, the reaction was removed from heating and allowed to cool gradually to ambient temperature. Silica gel was directly added to the reaction mixture, followed by concentration under reduced

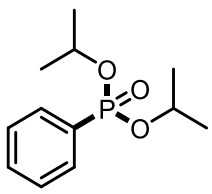
pressure to remove the solvent. The resulting crude product was purified by silica gel column chromatography (dry loading) to afford the diaryl phosphonate compound.

## IV. Larger-scale reaction



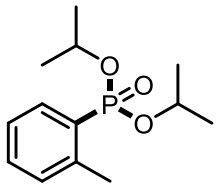

Under an inert gas atmosphere, sodium hypophosphite solid (14 mmol, 2.0 equiv), sodium carbonate (28 mmol, 4.0 equiv), and Pd(dppf)$Cl_2$ catalyst (5.0 mol%) were weighed into a dried round-bottom flask containing 50 mL of anhydrous toluene. Subsequently, bromobenzene (1.099 g, 7.0 mmol, 1.0 equiv), isopropanol (56 mmol, 8.0 equiv), and the activator pivaloyl chloride (PivCl, 28 mmol, 4.0 equiv) were added to the reaction mixture using a microsyringe. The mixture was heated in an oil bath at 100 °C for 24 hours until thin-layer chromatography (TLC) analysis indicated complete consumption of the bromobenzene starting material. After completion, the reaction was removed from heating and allowed to cool gradually to ambient temperature. Silica gel was directly added to the mixture, followed by concentration under reduced pressure to remove the solvent. The resulting crude product was purified by silica gel column chromatography (dry loading) to afford the phosphonate compound **3a**.

## V. Characterization data for products

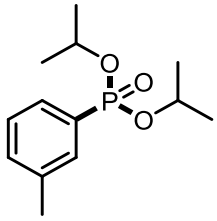



**diisopropyl phenylphosphonate (3a):** Compound **3a** was isolated in 93% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^1$H NMR** (400 MHz, $CDCl_3$) δ 7.87 – 7.76 (m, 2H), 7.57 – 7.49 (m, 1H), 7.49 – 7.40 (m, 2H), 4.79 – 4.56 (m, 2H), 1.37 (d, *J* = 6.2 Hz, 6H), 1.23 (d, *J* = 6.2 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 132.03 (d, *J*

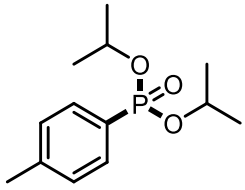
= 3.1 Hz), 131.69 (d, *J* = 9.8 Hz), 129.91 (d, *J* = 188.6 Hz), 128.28 (d, *J* = 15.0 Hz), 70.69 (d, *J* = 5.5 Hz), 24.04 (d, *J* = 4.0 Hz), 23.80 (d, *J* = 4.8 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 16.61 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{12}H_{20}O_3P^+$ 243.1145, found 243.1145.



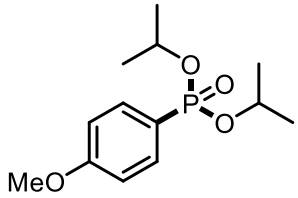
**diisopropyl o-tolylphosphonate (3b):** Compound **3b** was isolated in 61% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^1$H NMR** (400 MHz, $CDCl_3$) δ 7.94 (dd, *J* = 14.7, 7.6 Hz, 1H), 7.40 (t, *J* = 7.5 Hz, 1H), 7.31 – 7.12 (m, 2H), 4.81 – 4.50 (m, 2H), 2.57 (d, *J* = 1.2 Hz, 3H), 1.37 (d, *J* = 6.2 Hz, 7H), 1.23 (d, *J* = 6.2 Hz, 9H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 141.63 (d, *J* = 9.9 Hz), 133.85 (d, *J* = 10.5 Hz), 132.15 (d, *J* = 3.0 Hz), 131.09 (d, *J* = 14.8 Hz), 128.34 (d, *J* = 184.8 Hz), 125.26 (d, *J* = 15.0 Hz), 70.59 (d, *J* = 5.7 Hz), 24.10 (d, *J* = 4.1 Hz), 23.78 (d, *J* = 4.7 Hz), 21.28 (d, *J* = 3.5 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 17.19 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{13}H_{22}O_3P^+$ 257.1301, found 257.1301.



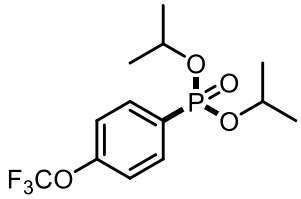
**diisopropyl m-tolylphosphonate (3c):** Compound **3c** was isolated in 84% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^1$H NMR** (400 MHz, $CDCl_3$) δ 7.72 – 7.54 (m, 2H), 7.33 (t, *J* = 3.9 Hz, 2H), 4.68 (dq, *J* = 12.5, 6.2 Hz, 2H), 2.39 (s, 3H), 1.37 (d, *J* = 6.2 Hz, 6H), 1.23 (d, *J* = 6.2 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 138.05 (d, *J* = 15.0 Hz), 132.84 (d, *J* = 3.2 Hz), 132.29 (d, *J* = 10.0 Hz), 130.64 (s), 128.75 (d, *J* = 9.6 Hz), 128.22 (d, *J* = 15.7 Hz), 70.61 (d, *J* = 5.5 Hz), 24.07 (d, *J* = 3.9 Hz), 23.84 (d, *J* = 4.9 Hz), 21.32 (s). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 17.15 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{13}H_{22}O_3P^+$ 257.1301, found 257.1303.



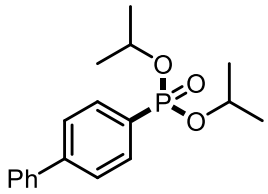
**diisopropyl p-tolylphosphonate (3d):** Compound **3d** was isolated in 90% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 7.69 (dd, *J* = 12.9, 7.6 Hz, 2H), 7.25 (t, *J* = 6.7 Hz, 2H), 4.65 (dq, *J* = 12.3, 6.0 Hz, 2H), 2.38 (s, 3H), 1.35 (d, *J* = 5.4 Hz, 6H), 1.20 (d, *J* = 5.6 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 142.50 (d, *J* = 3.1 Hz), 131.78 (d, *J* = 10.2 Hz), 129.02 (d, *J* = 15.4 Hz), 126.67 (d, *J* = 190.8 Hz), 70.50 (d, *J* = 5.4 Hz), 24.06 (d, *J* = 3.9 Hz), 23.82 (d, *J* = 4.8 Hz), 21.60 (s). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 17.33 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{13}H_{22}O_3P^+$ 257.1301, found 257.1306. **HRMS (ESI):** $[M+H]^+$ calcd for $C_{13}H_{22}O_3P^+$ 257.1301, found 257.1306.



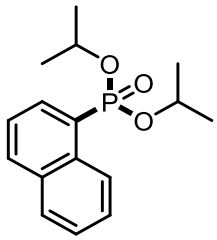

**diisopropyl (4-methoxyphenyl)phosphonate (3e):** Compound **3e** was isolated in 96% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 7.75 (dd, *J* = 12.7, 8.6 Hz, 2H), 6.95 (dd, *J* = 8.6, 3.1 Hz, 2H), 4.78 – 4.49 (m, 2H), 3.85 (s, 3H), 1.36 (d, *J* = 6.2 Hz, 6H), 1.21 (d, *J* = 6.2 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 162.58 (d, *J* = 3.4 Hz), 133.70 (d, *J* = 11.3 Hz), 121.26 (d, *J* = 195.3 Hz), 113.81 (d, *J* = 16.0 Hz), 70.41 (d, *J* = 5.4 Hz), 55.27 (s), 24.07 (d, *J* = 3.9 Hz), 23.83 (d, *J* = 4.9 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 17.47 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{13}H_{22}O_4P^+$ 273.1250, found 273.1250.



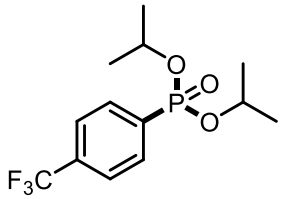

**diisopropyl (4-(trifluoromethoxy)phenyl)phosphonate (3f):** Compound **3f** was isolated in 91% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 7.81 (dd, *J* = 12.7, 8.5 Hz, 2H), 7.23 (d, *J* = 5.3 Hz, 2H), 4.66 (dq, *J* = 12.6, 6.3 Hz, 2H), 1.33 (d, *J* = 6.1 Hz, 6H), 1.19 (d, *J* = 6.3 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) 151.98 (s), 133.71 (d, *J* = 10.9 Hz), 129.73 (s), 127.82 (s), 120.29 (d, *J* = 15.8 Hz), 120.28 (q, *J* = 259.57 Hz), 71.09 (d, *J* = 5.6 Hz), 23.92 (dd, *J* = 20.2, 4.4 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 14.81 (s). **$^{19}$F NMR** (376 MHz, $CDCl_3$) δ -57.68 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{13}H_{19}F_3O_4P^+$ 319.1458, found 319.1457.



**diisopropyl [1,1'-biphenyl]-4-ylphosphonate (3g):** Compound **3g** was isolated in 92% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NM** (400 MHz, $CDCl_3$) δ 7.68 (dd, *J* = 12.9, 8.1 Hz, 2H), 7.46 (dd, *J* = 7.7, 3.5 Hz, 2H), 7.39 (d, *J* = 7.5 Hz, 2H), 7.24 (t, *J* = 7.4 Hz, 2H), 7.17 (d, *J* = 7.2 Hz, 1H), 4.51 (dd, *J* = 13.4, 6.4 Hz, 2H), 1.18 (d, *J* = 6.1 Hz, 6H), 1.03 (t, *J* = 9.5 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 144.81 (d, *J* = 3.2 Hz), 140.04 (s), 132.25 (d, *J* = 10.2 Hz), 128.91 (s), 128.56 (d, *J* = 191.9 Hz), 128.08 (s), 127.25 (s), 127.00 (d, *J* = 15.3 Hz), 70.75 (d, *J* = 5.5 Hz), 24.11 (d, *J* = 3.9 Hz), 23.90 (d, *J* = 4.8 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 16.76 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{18}H_{24}O_3P^+$ 319.1458, found 319.1455.

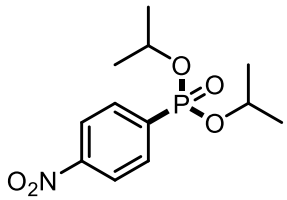


**diisopropyl naphthalen-1-ylphosphonate (3h):** Compound **3h** was isolated in 49% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 8.52 (d, *J* = 8.5 Hz, 1H), 8.28 (ddd, *J* = 16.4, 7.0, 1.3 Hz, 1H), 8.02 (d, *J* = 8.2 Hz, 1H), 7.88 (d, *J* = 8.1 Hz, 1H), 7.64 – 7.48 (m, 3H), 4.73 (ddt, *J* = 12.4, 8.0, 6.2 Hz, 2H), 1.41 (d, *J* = 6.2 Hz, 6H), 1.15 (d, *J* = 6.2 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 134.53 (d, *J* = 9.3 Hz), 133.62 (d, *J* = 12.6 Hz), 133.36 (d, *J* = 3.4 Hz), 132.70 (d, *J* = 10.6 Hz), 128.69 (d, *J* = 1.8 Hz), 127.08 (d, *J* = 2.8 Hz), 126.22 (s), 125.21 (s), 124.51 (d, *J* = 16.6 Hz), 70.96 (d, *J* = 5.3 Hz), 24.18 (d, *J* = 3.8 Hz), 23.78 (d, *J* = 4.9 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 16.73 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{16}H_{22}O_3P^+$ 293.1301, found 293.1303.

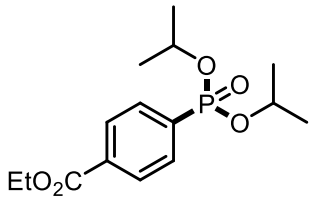


**diisopropyl (4-(trifluoromethyl)phenyl)phosphonate (3i):** Compound **3i** was isolated in 92% yield; flash column chromatography eluent: PE /EA (2:1, v/v); flash

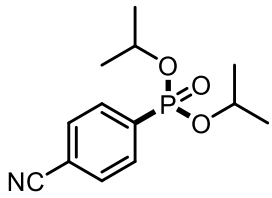
column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 7.87 (dd, *J* = 12.9, 8.1 Hz, 2H), 7.64 (dd, *J* = 7.9, 3.0 Hz, 2H), 4.66 (dq, *J* = 12.5, 6.2 Hz, 2H), 1.31 (d, *J* = 6.2 Hz, 6H), 1.16 (d, *J* = 6.3 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 135.34 (s), 133.71 (dd, *J* = 39.3, 6.7 Hz), 132.12 (d, *J* = 10.1 Hz), 125.23 (d, *J* = 3.8 Hz), 125.08 (d, *J* = 3.7 Hz), 71.33 (d, *J* = 5.7 Hz), 24.02 (d, *J* = 4.1 Hz), 23.81 (d, *J* = 4.8 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 14.04 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{13}H_{19}F_3O_3P^+$ 311.1018, found 311.1013.



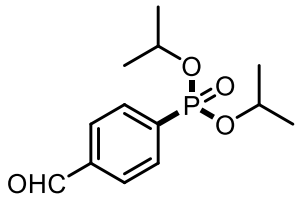
**diisopropyl (4-nitrophenyl)phosphonate (3j):** Compound **3j** was isolated in 88% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 8.22 (dd, *J* = 8.7, 3.2 Hz, 2H), 7.93 (dd, *J* = 12.6, 8.7 Hz, 2H), 4.69 (qd, *J* = 12.4, 6.2 Hz, 2H), 1.33 (d, *J* = 6.2 Hz, 6H), 1.18 (d, *J* = 6.2 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 150.09 (s), 137.42 (d, *J* = 187.8 Hz), 132.85 (d, *J* = 10.5 Hz), 123.25 (d, *J* = 15.3 Hz), 71.75 (d, *J* = 5.8 Hz), 24.05 (d, *J* = 4.1 Hz), 23.86 (d, *J* = 4.8 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 12.67 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{12}H_{19}NO_5P^+$ 288.0995, found 288.0995.



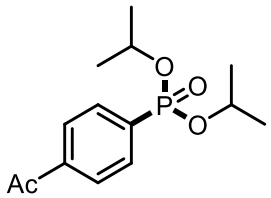
**ethyl 4-(diisopropoxyphosphoryl)benzoate (3k):** Compound **3k** was isolated in 87% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 8.14 – 7.96 (m, 2H), 7.82 (dd, *J* = 12.9, 8.0 Hz, 2H), 4.64 (dq, *J* = 12.5, 6.3 Hz, 2H), 4.33 (q, *J* = 7.1 Hz, 2H), 1.32 (dd, *J* = 14.1, 6.6 Hz, 9H), 1.15 (d, *J* = 6.2 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 165.81 (s), 134.70 (d, *J* = 187.1 Hz), 133.59 (d, *J* = 3.2 Hz), 131.68 (d, *J* = 10.0 Hz), 129.24 (d, *J* = 15.0 Hz), 71.16 (d, *J* = 5.6 Hz), 61.37 (s), 24.03 (d, *J* = 4.0 Hz), 23.79 (d, *J* = 4.8 Hz), 14.25 (s). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 14.83 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{15}H_{24}O_5P^+$ 315.1356, found 315.1356.



**diisopropyl (4-cyanophenyl)phosphonate (3l):** Compound **3l** was isolated in 88% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 7.93 (dd, *J* = 13.0, 8.1 Hz, 2H), 7.75 (dd, *J* = 8.1, 3.5 Hz, 2H), 4.74 (dq, *J* = 12.5, 6.2 Hz, 2H), 1.39 (d, *J* = 6.2 Hz, 6H), 1.24 (d, *J* = 6.2 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 135.50 (d, *J* = 188.4 Hz), 132.17 (d, *J* = 9.8 Hz), 131.88 (d, *J* = 14.9 Hz), 117.94 (s), 115.68 (d, *J* = 3.6 Hz), 71.59 (d, *J* = 5.8 Hz), 24.02 (d, *J* = 4.1 Hz), 23.83 (d, *J* = 4.8 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 13.08 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{13}H_{19}NO_3P^+$ 268.1097, found 268.1097.

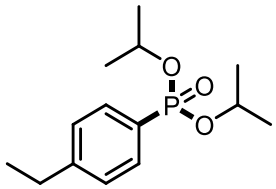


**diisopropyl (4-formylphenyl)phosphonate (3m):** Compound **3m** was isolated in 94% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 10.02 (s, 1H), 8.08 – 7.71 (m, 4H), 4.67 (qd, *J* = 12.4, 6.2 Hz, 2H), 1.32 (d, *J* = 6.2 Hz, 6H), 1.17 (d, *J* = 6.2 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 191.72 (s), 138.54 (d, *J* = 3.0 Hz), 136.52 (d, *J* = 186.5 Hz), 132.30 (d, *J* = 9.9 Hz), 129.27 (d, *J* = 15.1 Hz), 71.38 (d, *J* = 5.7 Hz), 24.06 (d, *J* = 4.1 Hz), 23.84 (d, *J* = 4.8 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 14.11 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{13}H_{20}O_4P^+$ 271.1094, found 271.1094.

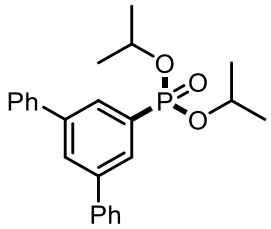


**diisopropyl (4-acetylphenyl)phosphonate (3n):** Compound **3n** was isolated in 89% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 7.94 (dd, *J* = 8.0, 3.8 Hz, 2H), 7.85 (dd, *J* = 12.8, 8.0 Hz, 2H), 4.65 (dq, *J* = 12.6, 6.3 Hz, 2H), 2.57 (s, 3H), 1.31 (d, *J* = 6.2 Hz, 6H), 1.16 (d, *J* = 6.2 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 197.60 (s), 139.59 (d, *J* = 3.2 Hz), 134.99 (d, *J* = 187.2 Hz), 131.99 (d, *J* = 10.0 Hz), 127.94 (d, *J* = 15.0 Hz), 71.24 (d, *J* = 5.7 Hz), 26.80 (s), 24.05

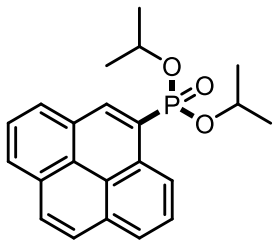
(d, $J$ = 4.0 Hz), 23.83 (d, $J$ = 4.8 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 14.60 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{14}H_{22}O_4P^+$ 285.1250, found 285.1256.



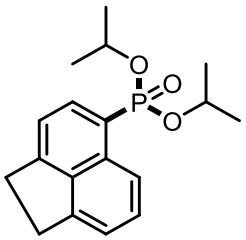
**diisopropyl (4-ethylphenyl)phosphonate (3o):** Compound **3o** was isolated in 87% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^1$H NMR** (400 MHz, $CDCl_3$) δ 7.65 (dd, $J$ = 13.1, 7.9 Hz, 2H), 7.20 (dd, $J$ = 7.8, 3.7 Hz, 2H), 4.60 (dq, $J$ = 12.6, 6.3 Hz, 2H), 2.61 (q, $J$ = 7.6 Hz, 2H), 1.29 (d, $J$ = 6.2 Hz, 6H), 1.18 (d, $J$ = 7.6 Hz, 3H), 1.15 (d, $J$ = 6.1 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 148.68 (d, $J$ = 3.1 Hz), 131.86 (d, $J$ = 10.3 Hz), 127.86 (d, $J$ = 15.3 Hz), 125.90 (s), 70.52 (d, $J$ = 5.5 Hz), 28.92 (s), 24.08 (d, $J$ = 3.9 Hz), 23.84 (d, $J$ = 4.9 Hz), 15.14 (s). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 17.36 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{14}H_{24}O_3P^+$ 271.1458, found 271.1461.



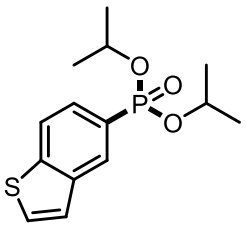
**diisopropyl [1,1':3',1''-terphenyl]-5'-ylphosphonate (3p):** Compound **3p** was isolated in 89% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^1$H NMR** (400 MHz, $CDCl_3$) δ 7.97 (d, $J$ = 1.7 Hz, 1H), 7.93 (d, $J$ = 1.7 Hz, 1H), 7.88 (d, $J$ = 0.9 Hz, 1H), 7.63 – 7.55 (m, 4H), 7.40 (t, $J$ = 7.5 Hz, 4H), 7.31 (t, $J$ = 7.3 Hz, 2H), 4.89 – 4.46 (m, 2H), 1.34 (d, $J$ = 6.2 Hz, 6H), 1.21 (d, $J$ = 6.2 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 141.99 (d, $J$ = 15.5 Hz), 140.16 (d, $J$ = 1.2 Hz), 131.20 (d, $J$ = 187.9 Hz), 129.68 (d, $J$ = 3.2 Hz), 129.24 (d, $J$ = 10.3 Hz), 128.97 (s), 127.94 (s), 127.33 (s), 71.01 (d, $J$ = 5.6 Hz), 24.09 (dd, $J$ = 16.1, 4.4 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 16.54 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{24}H_{28}O_3P^+$ 395.1771, found 395.1776.



**diisopropyl pyren-4-ylphosphonate (3q):** Compound **3q** was isolated in 31% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 8.78 (d, *J* = 9.3 Hz, 1H), 8.64 (dd, *J* = 14.4, 7.9 Hz, 1H), 8.16 (ddd, *J* = 20.4, 16.2, 8.5 Hz, 5H), 8.01 (dd, *J* = 15.4, 8.0 Hz, 2H), 4.81 – 4.62 (m, 2H), 1.38 (d, *J* = 6.1 Hz, 6H), 1.07 (d, *J* = 6.2 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 134.46 (s), 132.70 (d, *J* = 10.7 Hz), 132.03 (d, *J* = 9.5 Hz), 131.03 (s), 130.43 (s), 129.63 (s), 128.72 (s), 127.27 (s), 126.30 (d, *J* = 10.6 Hz), 126.17 (s), 124.77 (d, *J* = 14.1 Hz), 124.25 (s), 123.97 (d, *J* = 15.6 Hz), 121.68 (s), 71.11 (d, *J* = 5.1 Hz), 24.24 (d, *J* = 3.7 Hz), 23.82 (d, *J* = 4.9 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 17.40 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{22}H_{24}O_3P^+$ 367.1458, found 367.1451.

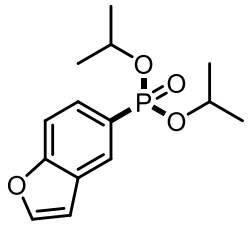


**diisopropyl (1,2-dihydroacenaphthylen-5-yl)phosphonate (3r):** Compound **3r** was isolated in 66% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 8.19 (dd, *J* = 16.0, 7.1 Hz, 1H), 8.11 (d, *J* = 8.4 Hz, 1H), 7.54 (dd, *J* = 8.3, 7.0 Hz, 1H), 7.33 (dd, *J* = 11.5, 4.5 Hz, 2H), 4.68 (ddt, *J* = 12.4, 8.0, 6.2 Hz, 2H), 3.41 (s, 4H), 1.40 (d, *J* = 6.2 Hz, 6H), 1.12 (d, *J* = 6.2 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 152.22 (d, *J* = 3.4 Hz), 146.37 (d, *J* = 2.1 Hz), 139.22 (d, *J* = 13.8 Hz), 136.40 (d, *J* = 11.4 Hz), 131.18 (d, *J* = 10.7 Hz), 129.00 (s), 122.42 (d, *J* = 3.0 Hz), 121.91 (s), 120.04 (d, *J* = 5.3 Hz), 118.41 (d, *J* = 16.8 Hz), 70.59 (d, *J* = 5.2 Hz), 30.35 (d, *J* = 15.6 Hz), 24.22 (d, *J* = 3.8 Hz), 23.82 (d, *J* = 5.0 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 17.49 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{18}H_{24}O_3P^+$ 319.1458, found 319.1457.

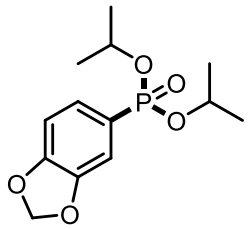


**diisopropyl benzo[b]thiophen-5-ylphosphonate (3s):** Compound **3s** was isolated in 74% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 8.34 (d, *J* = 14.5 Hz, 1H), 7.94 (dd, *J* = 8.3, 3.4 Hz, 1H), 7.71 (ddd, *J*

= 11.9, 8.3, 1.0 Hz, 1H), 7.51 (d, *J* = 5.4 Hz, 1H), 7.40 (d, *J* = 5.5 Hz, 1H), 4.81 – 4.30 (m, 2H), 1.38 (d, *J* = 6.2 Hz, 7H), 1.21 (t, *J* = 4.5 Hz, 7H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 143.34 (d, *J* = 3.2 Hz), 139.09 (d, *J* = 17.1 Hz), 128.09 (d, *J* = 10.9 Hz), 127.57 (s), 126.26 (d, *J* = 11.0 Hz), 125.60 (d, *J* = 190.9 Hz), 124.17 (d, *J* = 1.3 Hz), 122.59 (d, *J* = 15.9 Hz), 70.73 (d, *J* = 5.4 Hz), 24.11 (d, *J* = 3.9 Hz), 23.88 (d, *J* = 4.9 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 17.56 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{14}H_{20}O_3PS^+$ 299.0856, found 299.0856.

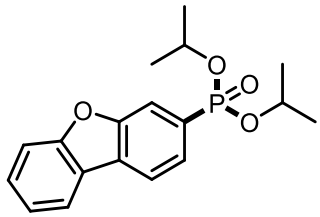


**diisopropyl benzofuran-5-ylphosphonate (3t):** Compound **3t** was isolated in 80% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 8.15 (dd, *J* = 13.8, 0.7 Hz, 1H), 7.74 (ddd, *J* = 12.4, 8.5, 1.4 Hz, 1H), 7.69 (d, *J* = 2.2 Hz, 1H), 7.57 (dd, *J* = 8.5, 3.0 Hz, 1H), 6.95 – 6.74 (m, 1H), 4.85 – 4.56 (m, 2H), 1.39 (d, *J* = 6.2 Hz, 6H), 1.22 (d, *J* = 6.2 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 156.88 (d, *J* = 3.3 Hz), 146.04 (s), 127.67 (d, *J* = 11.8 Hz), 127.41 (d, *J* = 18.6 Hz), 126.17 (d, *J* = 11.5 Hz), 124.20 (d, *J* = 190.7 Hz), 111.60 (d, *J* = 16.5 Hz), 106.85 (d, *J* = 1.4 Hz), 70.63 (d, *J* = 5.4 Hz), 24.10 (d, *J* = 3.9 Hz), 23.87 (d, *J* = 4.9 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 17.72 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{14}H_{20}O_4P^+$ 283.1094, found 283.1093.

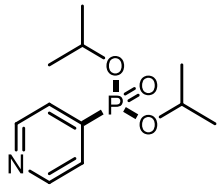


**diisopropyl benzo[d][1,3]dioxol-5-ylphosphonate (3u):** Compound **3u** was isolated in 86% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 7.38 (ddd, *J* = 14.0, 7.9, 1.4 Hz, 1H), 7.20 (dd, *J* = 12.9, 1.3 Hz, 1H), 6.86 (dd, *J* = 7.9, 3.6 Hz, 1H), 6.01 (s, 2H), 4.80 – 4.48 (m, 2H), 1.36 (d, *J* = 6.2 Hz, 6H), 1.22 (d, *J* = 6.2 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 150.88 (d, *J* = 3.4 Hz), 147.67 (d, *J* = 22.5 Hz), 127.31 (d, *J* = 11.1 Hz), 123.01 (d, *J* = 194.0 Hz), 111.25 (d, *J* = 12.1 Hz), 108.41 (d, *J* = 18.6 Hz), 101.50 (s), 70.64 (d, *J* = 5.5 Hz), 24.06 (d, *J* = 4.0

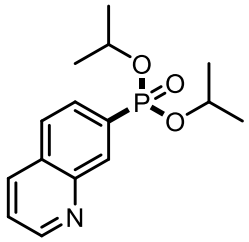
Hz), 23.83 (d, $J$ = 4.9 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 16.72 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{13}H_{20}O_5P^+$ 287.1043, found 287.1043.



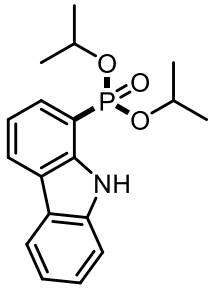
**diisopropyl dibenzo[b,d]furan-3-ylphosphonate (3v):** Compound **3v** was isolated in 86% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^1$H NMR** (400 MHz, $CDCl_3$) δ 8.10 – 8.01 (m, 2H), 7.98 (d, $J$ = 7.7 Hz, 1H), 7.82 (dd, $J$ = 12.6, 7.9 Hz, 1H), 7.60 (d, $J$ = 8.3 Hz, 1H), 7.56 – 7.46 (m, 1H), 7.37 (td, $J$ = 7.8, 1.0 Hz, 1H), 4.92 – 4.55 (m, 2H), 1.41 (d, $J$ = 6.2 Hz, 6H), 1.25 (d, $J$ = 6.2 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 156.99 (s), 155.42 (d, $J$ = 22.2 Hz), 129.50 (s), 128.45 (s), 128.17 – 126.88 (m), 125.96 (d, $J$ = 10.3 Hz), 123.33 (s), 123.12 (s), 121.26 (s), 120.69 (d, $J$ = 17.5 Hz), 115.32 (d, $J$ = 11.2 Hz), 111.97 (s), 70.98 (d, $J$ = 5.5 Hz), 24.11 (d, $J$ = 4.0 Hz), 23.86 (d, $J$ = 4.8 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 16.48 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{18}H_{22}O_4P^+$ 333.1250, found 333.1253.



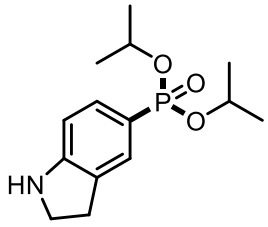
**diisopropyl pyridin-4-ylphosphonate (3w):** Compound **3w** was isolated in 94% yield; flash column chromatography eluent: PE /EA (1:1, v/v); **$^1$H NMR** (400 MHz, $CDCl_3$) δ 8.74 (t, $J$ = 4.6 Hz, 2H), 7.65 (dd, $J$ = 13.4, 5.4 Hz, 2H), 4.73 (dq, $J$ = 12.5, 6.2 Hz, 2H), 1.38 (d, $J$ = 6.2 Hz, 6H), 1.24 (d, $J$ = 6.2 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 149.95 (d, $J$ = 12.3 Hz), 139.02 (d, $J$ = 186.5 Hz), 125.22 (d, $J$ = 8.1 Hz), 71.65 (d, $J$ = 5.8 Hz), 24.03 (d, $J$ = 4.1 Hz), 23.82 (d, $J$ = 4.8 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 12.36 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{11}H_{19}NO_3P^+$ 244.1097, found 244.1105.



**diisopropyl quinolin-7-ylphosphonate (3x):** Compound **3x** was isolated in 48% yield; flash column chromatography eluent: PE /EA (1:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 8.89 (dd, *J* = 5.7, 3.8 Hz, 1H), 8.66 – 8.39 (m, 1H), 8.19 – 8.01 (m, 1H), 7.81 (dd, *J* = 9.2, 5.6 Hz, 2H), 7.38 (dt, *J* = 7.7, 4.6 Hz, 1H), 4.94 – 4.45 (m, 2H), 1.30 (dd, *J* = 8.6, 3.8 Hz, 6H), 1.16 (dd, *J* = 8.6, 3.8 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 151.32 (s), 147.24 (d, *J* = 19.1 Hz), 135.85 (s), 134.40 (d, *J* = 9.3 Hz), 131.32 (d, *J* = 188.1 Hz), 129.93 (d, *J* = 2.7 Hz), 128.14 (d, *J* = 15.2 Hz), 127.53 (d, *J* = 9.9 Hz), 122.74 (s), 71.08 (d, *J* = 5.7 Hz), 24.02 (d, *J* = 4.0 Hz), 23.83 (d, *J* = 4.8 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 15.07 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{15}H_{21}NO_3P^+$ 294.1254, found 294.1255.

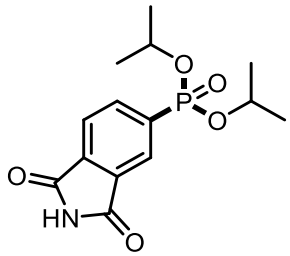



**diisopropyl (9H-carbazol-1-yl)phosphonate (3y):** Compound **3y** was isolated in 63% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 10.05 (s, 1H), 8.24 (d, *J* = 7.7 Hz, 1H), 8.09 (d, *J* = 7.8 Hz, 1H), 7.67 (dd, *J* = 14.2, 7.4 Hz, 1H), 7.47 (ddd, *J* = 11.9, 9.2, 4.6 Hz, 2H), 7.35 – 7.14 (m, 2H), 4.86 – 4.53 (m, 2H), 1.41 (d, *J* = 6.2 Hz, 6H), 1.19 (d, *J* = 6.2 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 141.92 (d, *J* = 7.7 Hz), 139.68 (s), 128.93 (d, *J* = 6.8 Hz), 126.58 (s), 124.51 (d, *J* = 3.1 Hz), 123.79 (d, *J* = 11.5 Hz), 122.42 (s), 120.40 (s), 119.65 (s), 118.67 (d, *J* = 13.7 Hz), 71.14 (d, *J* = 4.9 Hz), 24.15 (d, *J* = 3.8 Hz), 23.76 (d, *J* = 5.1 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 17.53 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{17}H_{16}N_2O_2P^+$ 311.0944, found 311.0944.

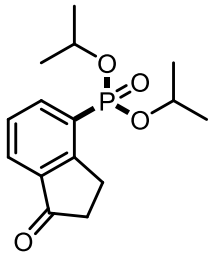



**diisopropyl indolin-5-ylphosphonate (3z):** Compound **3z** was isolated in 51% yield; flash column chromatography eluent: PE /EA (1:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 8.28 (dd, *J* = 8.1, 3.3 Hz, 1H), 7.65 (d, *J* = 12.7 Hz, 2H), 4.64 (tt, *J* = 7.3, 3.6 Hz, 2H), 4.28 (t, *J* = 8.2 Hz, 2H), 3.18 (t, *J* = 8.2 Hz, 2H), 1.38 (d, *J* = 1.0 Hz, 14H), 1.21 (d, *J* = 6.2 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 177.14 (s), 148.13 (d, *J* = 3.4 Hz), 131.86

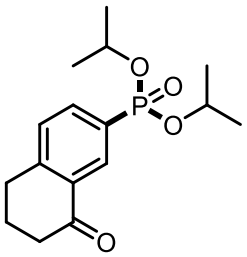
(d, $J$ = 10.8 Hz), 130.96 (d, $J$ = 16.4 Hz), 127.79 (d, $J$ = 11.1 Hz), 124.16 (d, $J$ = 191.9 Hz), 117.84 (d, $J$ = 15.6 Hz), 70.52 (d, $J$ = 5.4 Hz), 49.68 (s), 40.38 (s), 27.60 (s), 24.06 (d, $J$ = 3.9 Hz), 23.84 (d, $J$ = 4.8 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 17.36 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{18}H_{23}NO_3P^+$ 332.1410, found 332.1410.



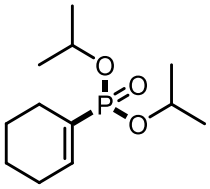
**diisopropyl (1,3-dioxoisoindolin-5-yl)phosphonate (3A):** Compound **3A** was isolated in 90% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 9.07 (s, 1H), 8.20 (t, $J$ = 10.6 Hz, 2H), 7.88 (d, $J$ = 5.1 Hz, 1H), 4.73 (d, $J$ = 5.7 Hz, 2H), 1.34 (d, $J$ = 5.2 Hz, 6H), 1.19 (d, $J$ = 5.1 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 167.62 (s), 137.70 (d, $J$ = 11.3 Hz), 137.32 (d, $J$ = 189.9 Hz), 135.45 (s), 132.59 (d, $J$ = 16.1 Hz), 126.56 (d, $J$ = 10.3 Hz), 123.41 (d, $J$ = 15.4 Hz), 72.01 (d, $J$ = 5.9 Hz), 24.04 (d, $J$ = 4.1 Hz), 23.90 (d, $J$ = 4.6 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 12.68 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{14}H_{19}NO_5P^+$ 312.0995, found 312.0999.



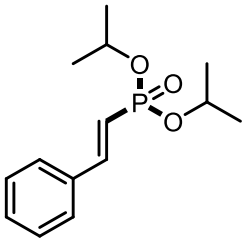
**diisopropyl (1-oxo-2,3-dihydro-1H-inden-4-yl)phosphonate (3B):** Compound **3B** was isolated in 86% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 8.05 (dd, $J$ = 13.8, 7.3 Hz, 1H), 7.84 (d, $J$ = 7.6 Hz, 1H), 7.52 – 7.37 (m, 1H), 4.71 (dq, $J$ = 12.5, 6.2 Hz, 2H), 3.40 – 3.21 (m, 2H), 2.79 – 2.50 (m, 2H), 1.33 (d, $J$ = 6.2 Hz, 6H), 1.18 (d, $J$ = 6.2 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 206.30 (s), 157.80 (d, $J$ = 9.9 Hz), 138.68 (d, $J$ = 11.0 Hz), 137.62 (d, $J$ = 12.5 Hz), 129.32 (s), 127.45 (d, $J$ = 3.4 Hz), 127.25 (d, $J$ = 13.9 Hz), 71.17 (d, $J$ = 5.9 Hz), 36.00 (s), 26.28 (d, $J$ = 2.1 Hz), 24.10 (d, $J$ = 4.1 Hz), 23.88 (d, $J$ = 4.6 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 13.93 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{15}H_{22}O_4P^+$ 297.1250, found 297.1254.



**diisopropyl (8-oxo-5,6,7,8-tetrahydronaphthalen-2-yl)phosphonate (3C):** Compound **3C** was isolated in 92% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 8.35 (dd, *J* = 13.9, 1.0 Hz, 1H), 7.84 (ddd, *J* = 12.5, 7.8, 1.5 Hz, 1H), 7.38 – 7.20 (m, 1H), 4.69 – 4.51 (m, 2H), 2.92 (t, *J* = 6.0 Hz, 2H), 2.65 – 2.53 (m, 2H), 2.13 – 2.01 (m, 2H), 1.28 (d, *J* = 6.2 Hz, 6H), 1.14 (d, *J* = 6.2 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 197.26 (s), 148.22 (d, *J* = 2.9 Hz), 136.02 (d, *J* = 10.8 Hz), 132.43 (d, *J* = 14.2 Hz), 130.76 (d, *J* = 10.6 Hz), 129.05 (d, *J* = 14.4 Hz), 128.83 (d, *J* = 192.9 Hz), 70.96 (d, *J* = 5.7 Hz), 39.03 (s), 29.79 (s), 24.03 (d, *J* = 4.0 Hz), 23.86 (d, *J* = 4.8 Hz), 22.83 (s). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 15.35 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{16}H_{24}O_4P^+$ 311.1407, found 311.1409.

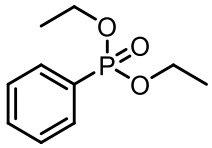


**diisopropyl cyclohex-1-en-1-ylphosphonate (3D):** Compound **3D** was isolated in 87% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 6.87 – 6.57 (m, 1H), 4.56 (tt, *J* = 13.9, 6.2 Hz, 2H), 2.09 (s, 4H), 1.56 (d, *J* = 4.7 Hz, 4H), 1.26 (d, *J* = 6.2 Hz, 6H), 1.21 (d, *J* = 6.2 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 142.46 (d, *J* = 9.3 Hz), 128.78 (d, *J* = 181.9 Hz), 69.89 (d, *J* = 5.7 Hz), 25.94 (d, *J* = 18.2 Hz), 24.29 (d, *J* = 8.9 Hz), 24.09 (d, *J* = 3.9 Hz), 23.87 (d, *J* = 4.7 Hz), 21.99 (d, *J* = 10.0 Hz), 21.43 (d, *J* = 1.4 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 18.12 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{12}H_{24}O_3P^+$ 247.1458, found 247.1458.

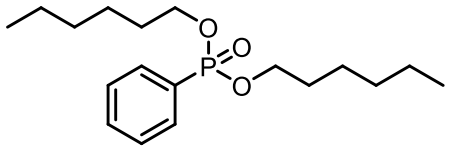


**diisopropyl (E)-styrylphosphonate (3E):** Compound **3E** was isolated in 58% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$)

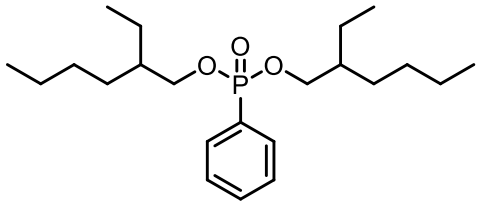
δ 7.57 – 7.43 (m, 3H), 7.42 – 7.33 (m, 3H), 6.28 (t, *J* = 17.4 Hz, 1H), 4.72 (dq, *J* = 12.5, 6.2 Hz, 2H), 1.37 (d, *J* = 6.2 Hz, 6H), 1.32 (d, *J* = 6.2 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 147.80 (d, *J* = 6.7 Hz), 135.01 (d, *J* = 23.3 Hz), 130.06 (s), 128.23 (d, *J* = 118.6 Hz), 115.57 (d, *J* = 191.9 Hz), 70.46 (d, *J* = 5.6 Hz), 24.10 (d, *J* = 4.1 Hz), 24.01 (d, *J* = 4.7 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 17.32 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{14}H_{22}O_3P^+$ 269.1301, found 269.1298.



**diethyl phenylphosphonate (4a):** Compound **4a** was isolated in 93% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 7.82 – 7.64 (m, 2H), 7.54 – 7.44 (m, 1H), 7.39 (td, *J* = 7.4, 4.3 Hz, 2H), 4.18 – 3.89 (m, 4H), 1.25 (t, *J* = 7.1 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 131.35 (d, *J* = 3.0 Hz), 130.75 (d, *J* = 9.9 Hz), 127.45 (d, *J* = 15.0 Hz), 127.39 (d, *J* = 188.9 Hz), 61.09 (d, *J* = 5.4 Hz), 15.31 (d, *J* = 6.5 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 18.81 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{10}H_{16}O_3P^+$ 215.0832, found 215.0839.

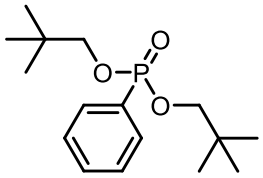


**dihexyl phenylphosphonate (4b):** Compound **4b** was isolated in 90% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 7.73 (dd, *J* = 13.2, 7.9 Hz, 2H), 7.48 (dd, *J* = 10.1, 4.5 Hz, 1H), 7.39 (dd, *J* = 6.9, 3.7 Hz, 2H), 4.15 – 3.78 (m, 4H), 1.79 – 1.47 (m, 4H), 1.22 (dt, *J* = 19.3, 11.3 Hz, 12H), 0.79 (t, *J* = 6.3 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 132.30 (d, *J* = 2.9 Hz), 131.76 (d, *J* = 9.8 Hz), 128.41 (d, *J* = 15.0 Hz), 128.351 (d, *J* = 188.9 Hz), 66.13 (d, *J* = 5.7 Hz), 31.28 (s), 30.37 (d, *J* = 6.5 Hz), 25.16 (s), 22.49 (s), 13.94 (s). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 18.78 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{18}H_{32}O_3P^+$ 327.2084, found 327.2080.

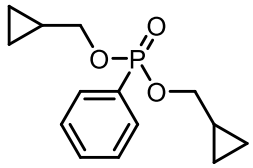


**bis(2-ethylhexyl) phenylphosphonate (4c):** Compound **4c** was isolated in 86% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, Chloroform-

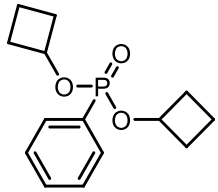
*d*) δ 7.80 (dd, *J* = 13.3, 7.4 Hz, 2H), 7.55 (t, *J* = 7.5 Hz, 1H), 7.46 (td, *J* = 7.3, 4.0 Hz, 2H), 4.05 – 3.95 (m, 2H), 3.90 (ddd, *J* = 13.2, 10.4, 5.8 Hz, 2H), 1.56 (p, *J* = 6.0 Hz, 2H), 1.41 – 1.13 (m, 16H), 0.86 (dt, *J* = 7.6, 3.8 Hz, 12H). **$^{13}$C NMR** (101 MHz, Chloroform-*d*) δ 132.24 (d, *J* = 3.0 Hz), 131.76 (d, *J* = 9.7 Hz), 128.33 (d, *J* = 188.9 Hz), 128.37 (d, *J* = 15.0 Hz), 68.00 (dd, *J* = 6.1, 1.8 Hz), 40.14 (dd, *J* = 6.9, 2.2 Hz), 29.93, 28.82 (d, *J* = 4.9 Hz), 23.31, 22.94, 14.00, 10.88 (d, *J* = 1.7 Hz). **$^{31}$P NMR** (162 MHz, Chloroform-*d*) δ 18.71. **HRMS (ESI):** $[M+H]^+$ calcd for $C_{22}H_{40}O_3P^+$ 383.2710, found 383.2706.



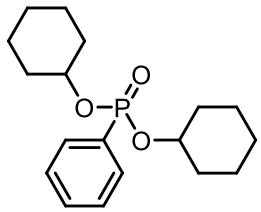
**dineopentyl phenylphosphonate (4d):** Compound **4d** was isolated in 87% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR (**400 MHz, $CDCl_3$) δ 7.88 – 7.77 (m, 2H), 7.61 – 7.51 (m, 1H), 7.51 – 7.42 (m, 2H), 4.00 – 3.41 (m, 4H), 0.94 (d, *J* = 2.0 Hz, 18H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 132.27 (d, *J* = 3.0 Hz), 131.76 (d, *J* = 9.6 Hz), 128.38 (d, *J* = 15.0 Hz), 128.10 (d, *J* = 189.9 Hz), 75.19 (d, *J* = 6.4 Hz), 32.14 (d, *J* = 7.3 Hz), 26.08 (s). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 18.43 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{16}H_{28}O_3P^+$ 299.1771, found 299.1769.



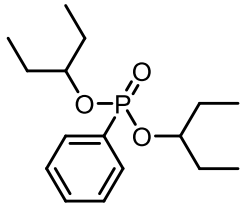
**bis(cyclopropylmethyl) phenylphosphonate (4e):** Compound **4e** was isolated in 81% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 7.85 (dd, *J* = 13.2, 7.6 Hz, 2H), 7.55 (d, *J* = 7.4 Hz, 1H), 7.52 – 7.38 (m, 2H), 4.27 – 3.40 (m, 4H), 1.22 – 1.09 (m, 2H), 0.74 – 0.38 (m, 4H), 0.28 (dt, *J* = 14.2, 10.1 Hz, 4H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 132.27 (d, *J* = 3.0 Hz), 131.85 (d, *J* = 9.9 Hz), 128.37 (d, *J* = 15.0 Hz), 128.68 (d, *J* = 188.9Hz), 70.94 (d, *J* = 5.4 Hz), 11.37 (d, *J* = 7.0 Hz), 3.43 (d, *J* = 13.9 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 18.77 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{14}H_{20}O_3P^+$ 267.1145, found 267.1144.



**dicyclobutyl phenylphosphonate (4f):** Compound **4f** was isolated in 84% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 7.79 (dd, *J* = 13.3, 7.0 Hz, 2H), 7.61 – 7.50 (m, 1H), 7.45 (dt, *J* = 11.5, 5.8 Hz, 2H), 4.74 (dt, *J* = 14.5, 7.1 Hz, 2H), 2.39 – 2.08 (m, 8H), 1.72 (dd, *J* = 19.8, 10.0 Hz, 2H), 1.58 – 1.37 (m, 2H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 132.27 (d, *J* = 3.0 Hz), 131.68 (d, *J* = 10.0 Hz), 129.04 (d, *J* = 186.9 Hz), 128.35 (d, *J* = 15.0 Hz), 69.77 (d, *J* = 7.2 Hz), 32.07 (d, *J* = 4.7 Hz), 31.82 (d, *J* = 5.1 Hz), 12.66 (s). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 15.48 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{14}H_{20}O_3P^+$ 267.1145, found 267.1143.

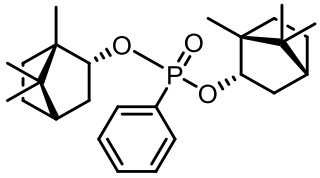


**dicyclohexyl phenylphosphonate (4g):** Compound **4g** was isolated in 89% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 7.75 (dd, *J* = 13.3, 7.1 Hz, 2H), 7.44 (t, *J* = 6.9 Hz, 1H), 7.36 (dt, *J* = 11.4, 5.8 Hz, 2H), 4.47 – 4.00 (m, 2H), 2.02 – 1.80 (m, 2H), 1.77 – 1.49 (m, 8H), 1.39 (dd, *J* = 13.2, 6.7 Hz, 4H), 1.22 (ddt, *J* = 27.3, 19.7, 6.1 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 131.93 (d, *J* = 3.0 Hz), 131.63 (d, *J* = 9.8 Hz), 130.31 (d, *J* = 189.4 Hz), 128.22 (d, *J* = 15.0 Hz), 75.53 (d, *J* = 5.9 Hz), 33.64 (dd, *J* = 24.1, 3.9 Hz), 25.17 (s), 23.61 (d, *J* = 7.6 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 16.60 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{18}H_{28}O_3P^+$ 323.1771, found 323.1771.

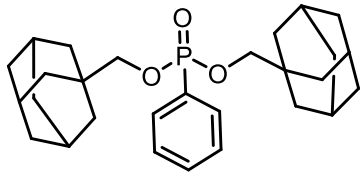


**di(pentan-3-yl) phenylphosphonate (4h):** Compound **4h** was isolated in 87% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 7.91 – 7.76 (m, 2H), 7.52 (dd, *J* = 10.9, 3.9 Hz, 1H), 7.44 (td, *J* = 7.5, 4.5 Hz, 2H), 4.36 (dp, *J* = 8.1, 5.9 Hz, 2H), 1.82 – 1.61 (m, 4H), 1.63 – 1.47 (m, 4H), 0.97 (t, *J* = 7.4 Hz, 6H), 0.77 (t, *J* = 7.4 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 131.87 (d, *J* = 3.0 Hz), 131.70 (d, *J* = 9.6 Hz), 130.37 (d, *J* = 190.9 Hz), 128.16 (d, *J* = 15.0 Hz), 80.04 (d, *J* = 6.3 Hz), 27.46 (d, *J* = 3.7 Hz), 27.16 (d, *J* = 4.4 Hz), 9.19 (d, *J* = 10.1 Hz). **$^{31}$P NMR**

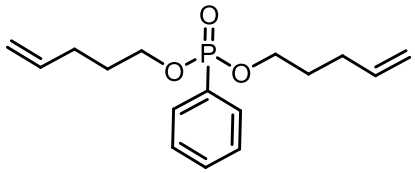
(162 MHz, $CDCl_3$) δ 18.76 (s). **HRMS (ESI):** [M+H] $^+$ calcd for $C_{18}H_{28}O_3P^+$ 299.1771, found 299.1773.



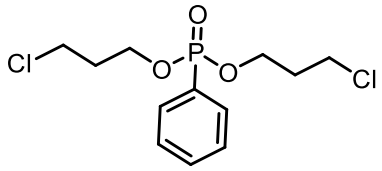
**(1R,2S,4R)-1,7,7-trimethylbicyclo[2.2.1]heptan-2-yl ((1S,2R,4R)-1,7,7-trimethylbicyclo[2.2.1]heptan-2-yl) phenylphosphonate (4i):** Compound **4i** was isolated in 63% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^1$H NMR** (400 MHz, $CDCl_3$) δ 7.82 (dd, *J* = 13.2, 7.2 Hz, 2H), 7.52 (t, *J* = 7.0 Hz, 1H), 7.45 (dd, *J* = 11.4, 7.2 Hz, 2H), 4.59 (dd, *J* = 42.1, 34.8 Hz, 2H), 2.41 – 2.26 (m, 1H), 2.17 (ddd, *J* = 17.8, 9.2, 4.6 Hz, 1H), 2.07 – 1.87 (m, 2H), 1.70 (ddd, *J* = 13.1, 8.5, 4.1 Hz, 3H), 1.61 (d, *J* = 3.7 Hz, 1H), 1.40 – 1.15 (m, 6H), 1.14 – 0.98 (m, 2H), 0.93 (s, 3H), 0.85 (d, *J* = 8.0 Hz, 12H), 0.73 (d, *J* = 8.6 Hz, 3H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 131.95 (s), 131.71 (dd, *J* = 9.5, 3.5 Hz), 128.30 (d, *J* = 2.9 Hz), 128.15 (d, *J* = 2.9 Hz), 84.51 – 79.95 (m), 50.20 – 49.04 (m), 47.55 (dd, *J* = 11.6, 4.7 Hz), 44.92 (d, *J* = 1.9 Hz), 37.36 (d, *J* = 85.4 Hz), 28.76 – 27.38 (m), 26.96 – 25.89 (m), 19.10 (dd, *J* = 59.2, 56.7 Hz), 13.34 (d, *J* = 21.1 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 18.06 (t, *J* = 83.4 Hz). **HRMS (ESI):** [M+H] $^+$ calcd for $C_{26}H_{40}O_3P^+$ 431.2710, found 431.2710.



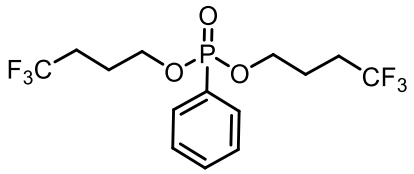
**bis(adamantan-1-ylmethyl) phenylphosphonate (4j):** Compound **4j** was isolated in 83% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^1$H NMR** (400 MHz, $CDCl_3$) δ 7.81 (dd, *J* = 13.2, 7.9 Hz, 2H), 7.55 (t, *J* = 7.4 Hz, 1H), 7.51 – 7.42 (m, 2H), 3.60 (ddd, *J* = 32.9, 9.5, 5.2 Hz, 4H), 1.98 (s, 6H), 1.71 (d, *J* = 12.1 Hz, 6H), 1.63 (d, *J* = 12.1 Hz, 6H), 1.54 (s, 12H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 132.21 (d, *J* = 3.0 Hz), 131.82 (d, *J* = 9.6 Hz), 128.37 (d, *J* = 14.9 Hz), 128.18 (d, *J* = 189.9 Hz), 75.49 (d, *J* = 6.4 Hz), 38.91 (s), 36.94 (s), 33.91 (d, *J* = 7.2 Hz), 27.99 (s). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 18.84 (s). **HRMS (ESI):** [M+H] $^+$ calcd for $C_{28}H_{40}O_3P^+$ 455.2710, found 455.2705.



**di(pent-4-en-1-yl) phenylphosphonate (4k):** Compound **4k** was isolated in 91% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NM** (400 MHz, $CDCl_3$) δ 7.81 (dd, *J* = 13.1, 7.3 Hz, 2H), 7.56 (t, *J* = 6.8 Hz, 1H), 7.47 (d, *J* = 3.9 Hz, 2H), 5.77 (ddt, *J* = 13.3, 10.1, 6.6 Hz, 1H), 5.63 – 5.29 (m, 1H), 4.99 (t, *J* = 14.0 Hz, 2H), 4.20 – 3.85 (m, 4H), 2.51 – 2.28 (m, 1H), 2.14 (dd, *J* = 14.2, 7.0 Hz, 2H), 1.85 – 1.72 (m, 2H), 1.71 – 1.54 (m, 2H), 1.29 (dd, *J* = 20.3, 6.2 Hz, 2H), 0.88 (t, *J* = 6.8 Hz, 1H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 137.26 (s), 132.42 (s), 131.77 (d, *J* = 9.8 Hz), 128.47 (dd, *J* = 15.0, 2.4 Hz), 125.28 (d, *J* = 109.9 Hz), 115.40 (s), 65.38 (d, *J* = 5.6 Hz), 29.60 (d, *J* = 2.1 Hz), 27.61 (s)**. $^{31}$P NMR** (162 MHz, $CDCl_3$) δ 18.96 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{16}H_{24}O_3P^+$ 295.1458, found 295.1454.

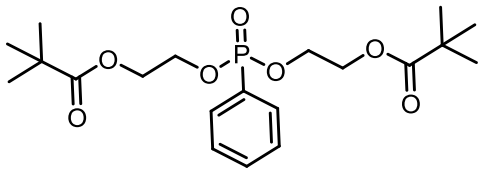


**bis(3-chloropropyl) phenylphosphonate (4l):**Compound **4l** was isolated in 88% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 7.73 (dd, *J* = 13.1, 7.4 Hz, 2H), 7.50 (d, *J* = 7.4 Hz, 1H), 7.42 (dt, *J* = 11.6, 6.0 Hz, 2H), 4.31 – 3.88 (m, 4H), 3.57 (t, *J* = 6.1 Hz, 4H), 2.05 (dd, *J* = 7.5, 3.7 Hz, 4H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 132.79 (d, *J* = 2.9 Hz), 131.75 (d, *J* = 9.9 Hz), 128.66 (d, *J* = 15.1 Hz), 127.32 (d, *J* = 188.4 Hz), 62.67 (d, *J* = 5.3 Hz), 40.73 (s), 33.15 (d, *J* = 6.7 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 19.38 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{12}H_{18}Cl_2O_3P^+$ 311.0365, found 311.0366.

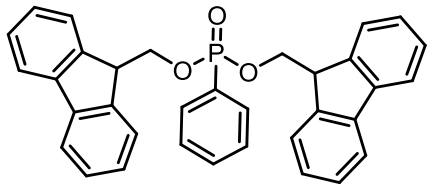


**bis(4,4,4-trifluorobutyl) phenylphosphonate (4m):** Compound **4m** was isolated in 57% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 7.88 – 7.74 (m, 2H), 7.62 (td, *J* = 7.5, 1.3 Hz, 1H), 7.51 (td, *J* = 7.5, 4.4 Hz, 2H), 4.27 – 3.96 (m, 4H), 2.35 – 2.10 (m, 4H), 2.05 – 1.85 (m, 4H). **$^{13}$C NMR** (101

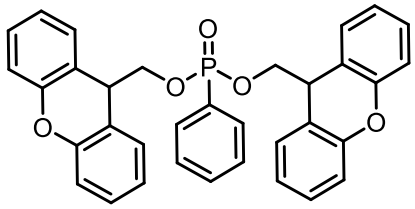
MHz, $CDCl_3$) δ 132.96 (d, *J* = 3.1 Hz), 131.73 (d, *J* = 10.0 Hz), 128.75 (d, *J* = 15.1 Hz), 64.32 (d, *J* = 5.2 Hz), 30.29 (q, *J* = 29.4 Hz), 23.27 (dd, *J* = 6.7, 3.2 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 19.66 (s). **$^{19}$F NMR** (376 MHz, $CDCl_3$) δ -66.29 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{14}H_{18}F_6O_3P^+$ 379.0892, found 379.0889.



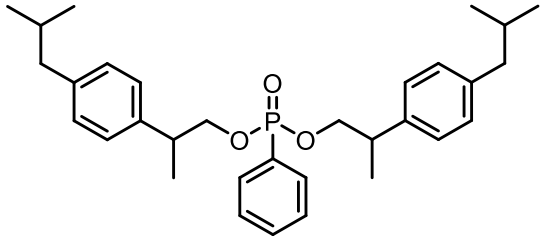
**((phenylphosphoryl)bis(oxy))bis(ethane-2,1-diyl) bis(2,2-dimethylpropanoate) (4n):** Compound **4n** was isolated in 80% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^1$H NMR** (400 MHz, $CDCl_3$) δ 7.81 (dd, *J* = 13.5, 7.2 Hz, 2H), 7.58 (dd, *J* = 10.7, 4.0 Hz, 1H), 7.48 (dd, *J* = 11.7, 7.4 Hz, 2H), 4.38 – 4.06 (m, 8H), 1.18 (s, 18H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 178.19 (s), 132.82 (d, *J* = 3.0 Hz), 131.78 (d, *J* = 10.1 Hz), 128.59 (d, *J* = 15.3 Hz), 127.23 (d, *J* = 190.4 Hz), 63.77 (d, *J* = 5.4 Hz), 62.97 (d, *J* = 7.3 Hz), 38.71 (s), 27.08 (s). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 19.60 (s). **HRMS (ESI):** $[M+Na]^+$ calcd for $C_{20}H_{32}O_7P^+$ 415.1880., found 415.1878.



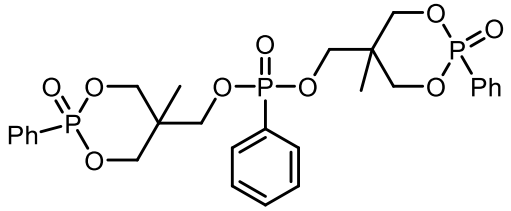
**bis((9H-fluoren-9-yl)methyl) phenylphosphonate (4o):** Compound **4o** was isolated in 85% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^1$H NMR** (400 MHz, $CDCl_3$) δ 7.57 (dd, *J* = 17.4, 8.4 Hz, 6H), 7.39 (dd, *J* = 13.1, 8.2 Hz, 5H), 7.32 – 7.17 (m, 6H), 7.12 (td, *J* = 7.0, 4.1 Hz, 4H), 4.22 (dt, *J* = 12.7, 6.5 Hz, 2H), 4.16 – 4.07 (m, 2H), 4.02 (t, *J* = 6.5 Hz, 2H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 143.34 (d, *J* = 1.5 Hz), 141.42 (d, *J* = 3.0 Hz), 132.65 (d, *J* = 2.9 Hz), 131.79 (d, *J* = 10.0 Hz), 128.62 (d, *J* = 15.2 Hz), 127.86 (d, *J* = 1.8 Hz), 127.12 (d, *J* = 2.5 Hz), 125.19 (d, *J* = 10.6 Hz), 120.03 (d, *J* = 4.3 Hz), 67.66 (d, *J* = 5.9 Hz), 48.14 (d, *J* = 7.3 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 18.94 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{34}H_{28}O_3P^+$ 515.1771, found 515.1776.



**bis((9H-xanthen-9-yl)methyl) phenylphosphonate (4p):** Compound **4p** was isolated in 78% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 7.47 – 7.37 (m, 1H), 7.35 – 7.13 (m, 10H), 7.12 – 6.92 (m, 10H), 4.11 (t, *J* = 6.1 Hz, 2H), 4.01 – 3.75 (m, 4H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 152.22 (d, *J* = 1.6 Hz), 132.44 (d, *J* = 3.1 Hz), 131.63 (d, *J* = 10.0 Hz), 129.50 (d, *J* = 10.3 Hz), 128.53 (d, *J* = 1.0 Hz), 128.41 (d, *J* = 15.2 Hz), 126.75 (d, *J* = 188.7 Hz), 123.23 (d, *J* = 4.1 Hz), 120.81 (d, *J* = 7.8 Hz), 116.51 (d, *J* = 1.4 Hz), 70.51 (d, *J* = 6.2 Hz), 39.90 (d, *J* = 7.5 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 18.67 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{34}H_{28}O_5P^+$ 547.1669, found 547.1662.

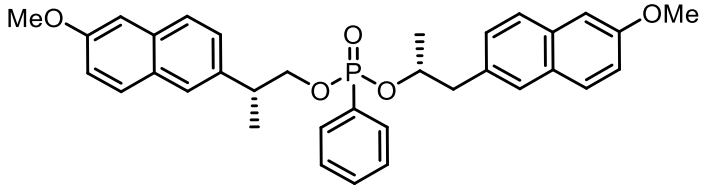


**bis(2-(4-isobutylphenyl)propyl) phenylphosphonate (4q):** Compound **4q** was isolated in 84% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 7.66 – 7.52 (m, 2H), 7.52 – 7.43 (m, 1H), 7.42 – 7.30 (m, 2H), 7.14 – 6.98 (m, 8H), 4.21 – 3.81 (m, 4H), 3.13 – 2.95 (m, 2H), 2.43 (d, *J* = 7.1 Hz, 4H), 1.83 (dp, *J* = 13.4, 6.7 Hz, 2H), 1.26 (t, *J* = 6.2 Hz, 6H), 0.89 (d, *J* = 6.6 Hz, 12H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 140.07 (s), 139.85 (d, *J* = 3.6 Hz), 132.30 (s), 131.77 (d, *J* = 9.9 Hz), 129.18 (s), 128.35 (d, *J* = 15.1 Hz), 127.17 (s), 70.84 (dt, *J* = 9.7, 6.4 Hz), 45.07 (s), 41.59 – 38.21 (m), 30.27 (s), 22.44 (s), 18.47 – 16.16 (m). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 18.51 (t, *J* = 25.0 Hz). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{32}H_{44}O_3P^+$ 507.3023, found 507.3023.

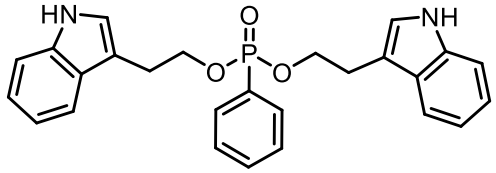


**bis((5-methyl-2-oxido-2-phenyl-1,3,2-dioxaphosphinan-5-yl)methyl) phenylphosphonate (4r):** Compound **4r** was isolated in 79% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 7.80 – 7.56 (m, 1H), 7.46 (dd, *J* = 13.8, 9.4 Hz, 1H), 7.41 – 7.24 (m, 1H), 4.31 (dt, *J* = 32.5, 14.7 Hz, 1H), 4.23 – 4.05 (m, 1H), 4.06 – 3.89 (m, 1H), 1.24 – 0.26 (m, 1H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ

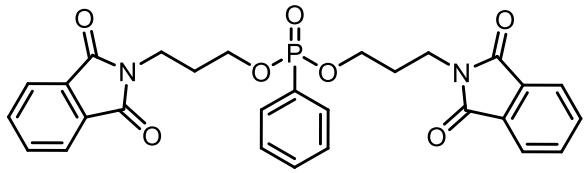
133.25 (d, *J* = 21.8 Hz), 131.77 (d, *J* = 10.3 Hz), 129.31 – 128.13 (m), 126.28 (s), 124.35 (s), 69.66 (dd, *J* = 12.3, 5.9 Hz), 66.67 (s), 36.90 (d, *J* = 5.0 Hz), 16.79 (d, *J* = 68.6 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 20.30 (s), 17.36 (s). **HRMS (ESI):** $[M+Na]^+$ calcd for $C_{28}H_{33}NaO_9P_3^+$ 629.1230., found 629.1233.



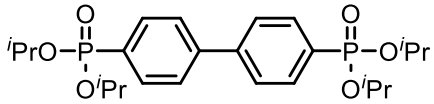

**(R)-1-(6-methoxynaphthalen-2-yl)propan-2-yl ((R)-2-(6-methoxynaphthalen-2-yl)propyl) phenylphosphonate (4s):** Compound **4s** was isolated in 86% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^1$H NMR** (400 MHz, $CDCl_3$) δ 7.59 (td, *J* = 8.6, 2.5 Hz, 4H), 7.55 – 7.43 (m, 4H), 7.39 (t, *J* = 7.2 Hz, 1H), 7.27 – 7.14 (m, 4H), 7.14 – 7.07 (m, 2H), 7.06 (s, 2H), 4.26 – 3.95 (m, 4H), 3.85 (s, 6H), 3.14 (td, *J* = 13.7, 6.9 Hz, 2H), 1.28 (dd, *J* = 16.7, 7.0 Hz, 6H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 157.47 (s), 137.84 (d, *J* = 2.8 Hz), 133.58 (s), 132.31 (d, *J* = 2.9 Hz), 131.71 (d, *J* = 9.9 Hz), 129.20 (s), 128.98 (s), 128.33 (d, *J* = 15.1 Hz), 127.79 (d, *J* = 189.9 Hz), 126.99 (d, *J* = 2.0 Hz), 126.37 (d, *J* = 2.9 Hz), 125.85 (d, *J* = 7.7 Hz), 118.88 (d, *J* = 2.9 Hz), 105.57 (s), 70.71 (d, *J* = 5.1 Hz), 55.31 (s), 40.32 (dd, *J* = 6.8, 1.9 Hz), 17.73 (d, *J* = 9.2 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 18.59 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{34}H_{36}O_5P^+$ 555.2295, found 555.2287.



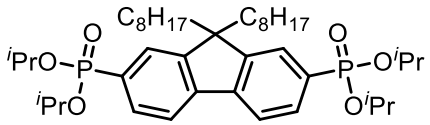

**bis(2-(1H-indol-3-yl)ethyl) phenylphosphonate (4t):** Compound **4t** was isolated in 44% yield; flash column chromatography eluent: PE /EA (1:1, v/v); **$^1$H NMR** (400 MHz, $CDCl_3$) δ 8.35 (s, 2H), 7.80 – 7.61 (m, 2H), 7.50 (dd, *J* = 12.4, 8.3 Hz, 3H), 7.35 (td, *J* = 7.6, 4.3 Hz, 2H), 7.29 (d, *J* = 8.1 Hz, 2H), 7.14 (t, *J* = 7.2 Hz, 2H), 7.05 (dd, *J* = 11.0, 3.9 Hz, 2H), 6.85 (d, *J* = 1.1 Hz, 2H), 4.38 – 4.10 (m, 4H), 3.07 (t, *J* = 7.1 Hz, 4H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 136.18 (s), 132.49 (d, *J* = 3.0 Hz), 131.76 (d, *J* = 9.9 Hz), 128.51 (d, *J* = 15.1 Hz), 127.36 (s), 122.60 (s), 121.92 (s), 119.29 (s), 118.59 (s), 111.29 (s), 111.03 (s), 66.09 (d, *J* = 5.9 Hz), 26.58 (d, *J* = 6.7 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 19.13 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{26}H_{26}N_2O_3P^+$ 445.1676, found 445.1676.



**bis(3-(1,3-dioxoisoindolin-2-yl)propyl) phenylphosphonate (4u):** Compound **4u** was isolated in 90% yield; flash column chromatography eluent: PE /EA (2:1, v/v); **$^{1}$H NMR** (400 MHz, $CDCl_3$) δ 7.87 – 7.74 (m, 6H), 7.69 (dd, *J* = 5.2, 3.1 Hz, 4H), 7.53 (t, *J* = 7.4 Hz, 1H), 7.44 (dd, *J* = 12.1, 6.9 Hz, 2H), 4.26 – 3.99 (m, 4H), 3.91 – 3.65 (m, 4H), 2.18 – 1.94 (m, 4H). **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 168.15 (s), 133.91 (s), 132.52 (d, *J* = 3.0 Hz), 132.04 (s), 131.77 (d, *J* = 10.0 Hz), 128.49 (d, *J* = 15.2 Hz), 126.56 (s), 123.20 (s), 63.56 (d, *J* = 5.6 Hz), 34.81 (s), 29.38 (d, *J* = 6.6 Hz). **$^{31}$P NMR** (162 MHz, $CDCl_3$) δ 19.24 (s). **HRMS (ESI):** $[M+H]^+$ calcd for $C_{28}H_{26}N_2O_7P^+$ 533.1472, found 533.1462.

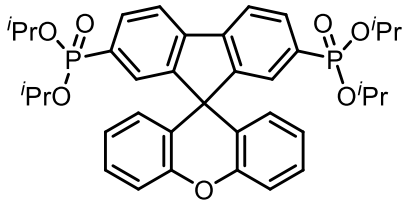


**tetraisopropyl [1,1'-biphenyl]-4,4'-diylbis(phosphonate) (5a):** ompound **5a** was isolated in 93% yield; flash column chromatography eluent: PE /EA (1:2, v/v); **$^{1}$H NMR** (400 MHz, Chloroform-*d*) δ 7.83 (dd, *J* = 13.0, 8.0 Hz, 4H), 7.61 (dd, *J* = 8.2, 3.7 Hz, 4H), 4.64 (dp, *J* = 7.8, 6.1 Hz, 4H), 1.31 (d, *J* = 6.2 Hz, 12H), 1.17 (d, *J* = 6.2 Hz, 12H). **$^{13}$C NMR** (101 MHz, Chloroform-*d*) δ 143.55 (d, *J* = 3.4 Hz), 132.30 (d, *J* = 10.1 Hz), 129.55 (d, *J* = 190.1 Hz), 127.11 (d, *J* = 15.3 Hz), 70.79 (d, *J* = 5.5 Hz), 24.05 (d, *J* = 4.0 Hz), 23.84 (d, *J* = 4.8 Hz). **$^{31}$P NMR** (162 MHz, Chloroform-*d*) δ 16.28. **HRMS (ESI):** $[M+H]^+$ calcd for $C_{24}H_{37}O_6P_2^+$ 483.2060, found 483.2058.

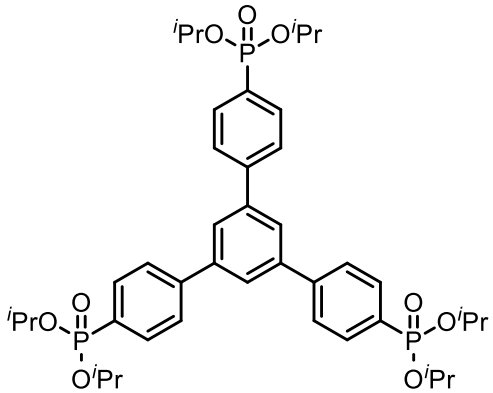


**tetraisopropyl (9,9-dioctyl-9H-fluorene-2,7-diyl)bis(phosphonate) (5b):** Compound **5b** was isolated in 61% yield; flash column chromatography eluent: PE /EA (1:2, v/v); **$^{1}$H NMR** (400 MHz, Chloroform-*d*) δ 8.17 – 7.51 (m, 6H), 5.12 – 4.29 (m, 4H), 2.78 – 1.68 (m, 4H), 1.39 (d, *J* = 6.2 Hz, 12H), 1.29 – 1.15 (m, 18H), 1.04 (dddd, *J* = 41.3, 14.7, 11.6, 5.3 Hz, 18H), 0.80 (t, *J* = 7.1 Hz, 6H), 0.62 – 0.40 (m, 4H). **$^{13}$C NMR** (101 MHz, Chloroform-*d*) δ 151.25 (d, *J* = 15.3 Hz), 143.71 (d, *J* = 2.2 Hz), 130.93 (d, *J* = 10.7 Hz), 129.31 (d, *J* = 186.6 Hz), 126.34 (d, *J* = 10.6 Hz), 120.35 (d, *J* = 16.2 Hz),

70.76 (d, $J$ = 5.4 Hz), 55.70, 40.10, 31.70, 29.85, 29.21 (d, $J$ = 16.0 Hz), 24.10 (d, $J$ = 4.2 Hz), 23.83, 23.73 (d, $J$ = 4.6 Hz), 22.52, 14.03. **$^{31}$P NMR** (162 MHz, Chloroform-*d*) δ 17.20. **HRMS (ESI):** $[M+H]^+$ calcd for $C_{41}H_{69}O_6P_2^+$ 719.4564, found 719.4563.

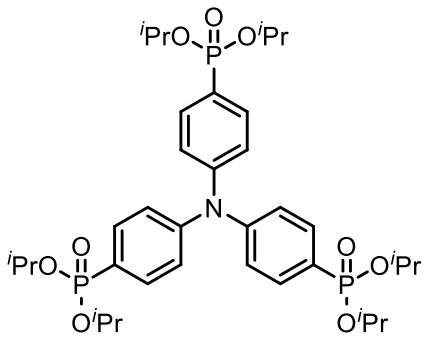


**tetraisopropyl spiro[fluorene-9,9'-xanthene]-2,7-diylbis(phosphonate) (5c):** Compound **5c** was isolated in 56% yield; flash column chromatography eluent: PE /EA (1:2, v/v); **$^{1}$H NMR** (400 MHz, Chloroform-*d*) δ 8.14 – 7.79 (m, 4H), 7.61 (d, $J$ = 13.3 Hz, 2H), 7.20 (dt, $J$ = 15.3, 8.1 Hz, 4H), 6.72 (t, $J$ = 7.4 Hz, 2H), 6.29 (dd, $J$ = 7.9, 1.7 Hz, 2H), 4.96 – 4.33 (m, 4H), 1.27 (dd, $J$ = 6.3, 1.8 Hz, 12H), 1.05 (dd, $J$ = 6.3, 1.7 Hz, 12H). **$^{13}$C NMR** (101 MHz, Chloroform-*d*) δ 155.71 (d, $J$ = 15.8 Hz), 151.24, 142.14 (d, $J$ = 3.1 Hz), 131.88 (d, $J$ = 10.6 Hz), 129.97, 129.41 (d, $J$ = 10.8 Hz), 128.55, 127.55, 123.20, 122.81, 120.59 (d, $J$ = 16.1 Hz), 117.16, 70.87 (d, $J$ = 5.4 Hz), 54.37, 23.98 (d, $J$ = 4.0 Hz), 23.53 (d, $J$ = 4.8 Hz). **$^{31}$P NMR** (162 MHz, Chloroform-*d*) δ 16.10. **HRMS (ESI):** $[M+H]^+$ calcd for $C_{37}H_{43}O_7P_2^+$ 661.2479, found 661.2473.

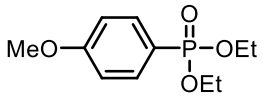


**bis(propan-2-yl) {4-[3,5-bis(4-{oxo[bis(prop-2-yloxidanyl)]-λ5-phosphanyl}-phenyl)phenyl]phenyl}phosphonate (5d):** Compound **5d** was isolated in 68% yield; flash column chromatography eluent: PE /EA (1:4, v/v); **$^{1}$H NMR** (400 MHz, Chloroform-*d*) δ 7.95 (dd, $J$ = 13.0, 7.9 Hz, 6H), 7.85 (s, 3H), 7.79 (dd, $J$ = 8.1, 3.7 Hz, 6H), 4.75 (ddtd, $J$ = 12.4, 7.4, 6.1, 1.2 Hz, 6H), 1.41 (dd, $J$ = 6.3, 1.3 Hz, 18H), 1.28 (d, $J$ = 6.3 Hz, 18H). **$^{13}$C NMR** (101 MHz, Chloroform-*d*) δ 144.17 (d, $J$ = 3.2 Hz), 141.66, 132.41 (d, $J$ = 10.2 Hz), 129.33 (d, $J$ = 190.1 Hz), 127.21 (d, $J$ = 15.2 Hz), 126.01, 70.84 (d, $J$ = 5.6 Hz), 24.10 (d, $J$ = 4.0 Hz), 23.90 (d, $J$ = 4.9 Hz). **$^{31}$P NMR** (162 MHz,

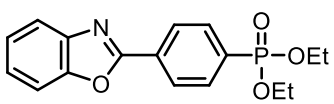
Chloroform-*d*) δ 16.33. **HRMS (ESI):** $[M+H]^+$ calcd for $C_{42}H_{58}O_9P_3^+$ 799.3288, found 799.3287.



**hexaisopropyl (nitrilotris(benzene-4,1-diyl))tris(phosphonate) (5e):** Compound **5e** was isolated in 62% yield; flash column chromatography eluent: PE /EA (1:4, v/v); **$^1$H NMR** (400 MHz, Chloroform-*d*) δ 7.71 (ddd, *J* = 11.6, 8.4, 2.5 Hz, 6H), 7.13 (dt, *J* = 8.8, 2.9 Hz, 6H), 4.73 (qt, *J* = 6.4, 2.0 Hz, 6H), 1.39 (dd, *J* = 6.5, 2.7 Hz, 18H), 1.28 (dd, *J* = 6.4, 2.6 Hz, 18H). **$^{13}$C NMR** (101 MHz, Chloroform-*d*) δ 149.58 (d, *J* = 3.4 Hz), 133.20 (d, *J* = 10.9 Hz), 125.77, 123.78 (d, *J* = 15.6 Hz), 70.74 (d, *J* = 5.8 Hz), 24.06 (d, *J* = 4.0 Hz), 23.91 (d, *J* = 4.9 Hz). **$^{31}$P NMR** (162 MHz, Chloroform-*d*) δ 16.39. **HRMS (ESI):** $[M+H]^+$ calcd for $C_{36}H_{55}NO_9P_3^+$ 738.3084, found 738.3076.



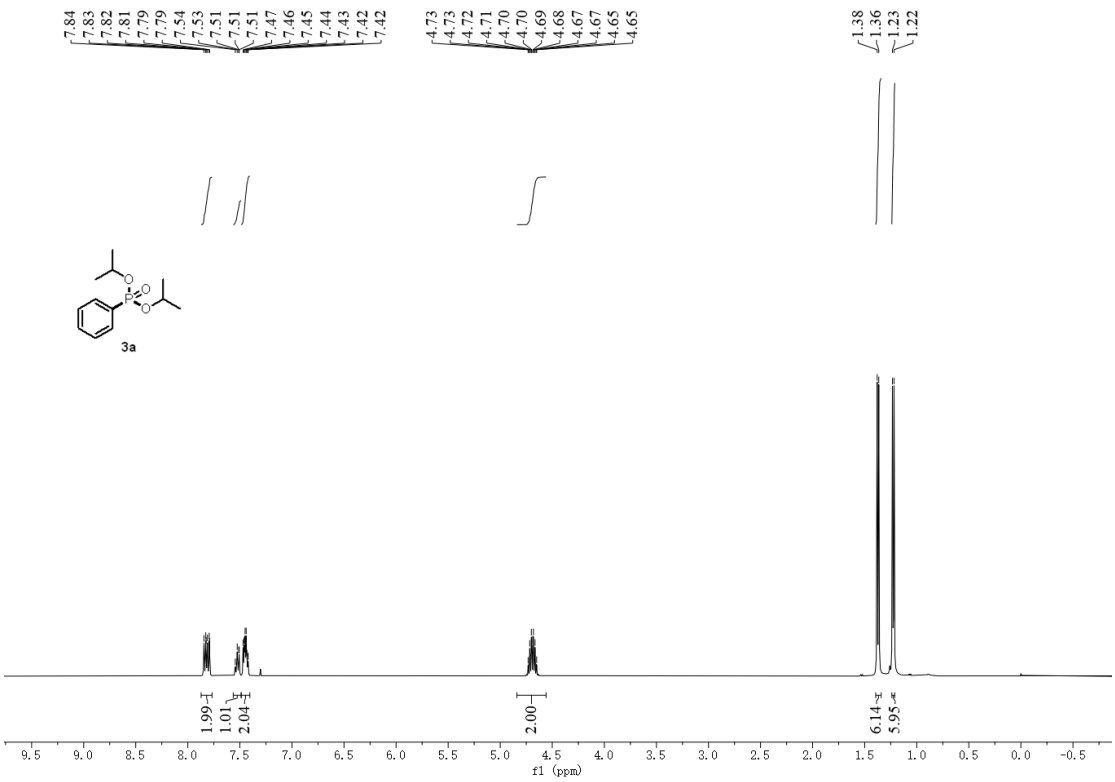
**diethyl (4-methoxyphenyl)phosphonate (6):** Compound **6** was isolated in 89% yield; flash column chromatography eluent: PE /EA (1:4, v/v); **$^1$H NMR** (400 MHz, Chloroform-*d*) δ 7.75 (dd, *J* = 12.7, 8.4 Hz, 2H), 6.97 (dd, *J* = 8.7, 3.2 Hz, 2H), 4.41 – 3.92 (m, 4H), 3.85 (s, 3H), 1.31 (t, *J* = 7.0 Hz, 6H). **$^{13}$C NMR** (101 MHz, Chloroform-*d*) δ 162.84 (d, *J* = 3.3 Hz), 133.78 (d, *J* = 11.4 Hz), 119.54 (d, *J* = 194.8 Hz), 114.00 (d, *J* = 16.0 Hz), 61.91 (d, *J* = 5.2 Hz), 55.33, 16.33 (d, *J* = 6.6 Hz). **$^{31}$P NMR** (162 MHz, Chloroform-*d*) δ 19.74. **HRMS (ESI):** [M+H]+ calcd for $C_{11}H_{18}O_4P^+$ 245.0937, found 245.0933.



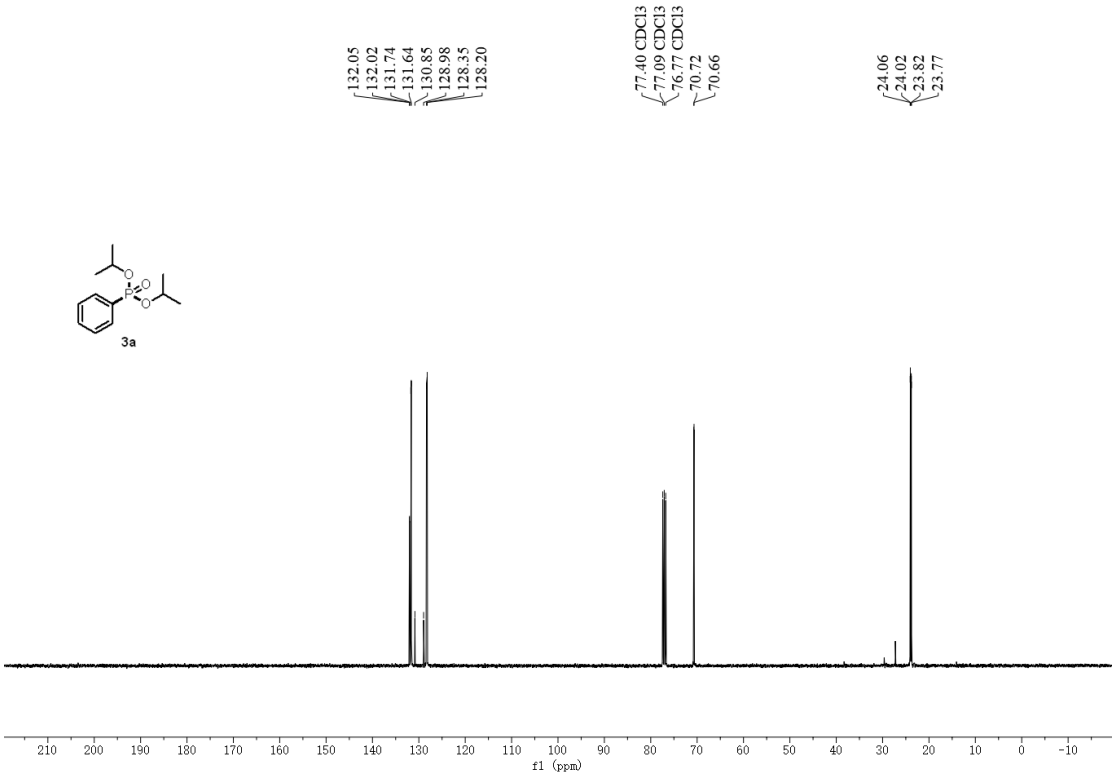
**diethyl (4-(benzo[d]oxazol-2-yl)phenyl)phosphonate (7):** Compound **7** was isolated in 76% yield; flash column chromatography eluent: PE /EA (1:2, v/v); **$^{1}$H NMR** (400 MHz, Chloroform-*d*) δ 8.18 (dd, *J* = 8.2, 3.7 Hz, 2H), 8.09 (d, *J* = 8.2 Hz, 1H), 8.00 – 7.82 (m, 3H), 7.57 – 7.46 (m, 1H), 7.45 – 7.35 (m, 1H), 4.87 – 3.60 (m, 4H), 1.35 (t, *J* = 7.1 Hz, 6H). **$^{13}$C NMR** (101 MHz, Chloroform-*d*) δ 166.43, 154.02, 137.01 (d, *J* = 3.3 Hz), 135.17, 132.43 (d, *J* = 10.2 Hz), 130.90 (d, *J* = 188.2 Hz), 127.36 (d, *J* = 15.2 Hz), 126.58, 125.71, 123.56, 121.72, 62.34 (d, *J* = 5.5 Hz), 16.35 (d, *J* = 6.3 Hz). **$^{31}$P NMR** (162 MHz, Chloroform-*d*) δ 17.46. **HRMS (ESI):** [M+H]+ calcd for $C_{17}H_{19}NO_4P^+$ 332.1046, found 332.1040.

# VI. NMR spectra of the products

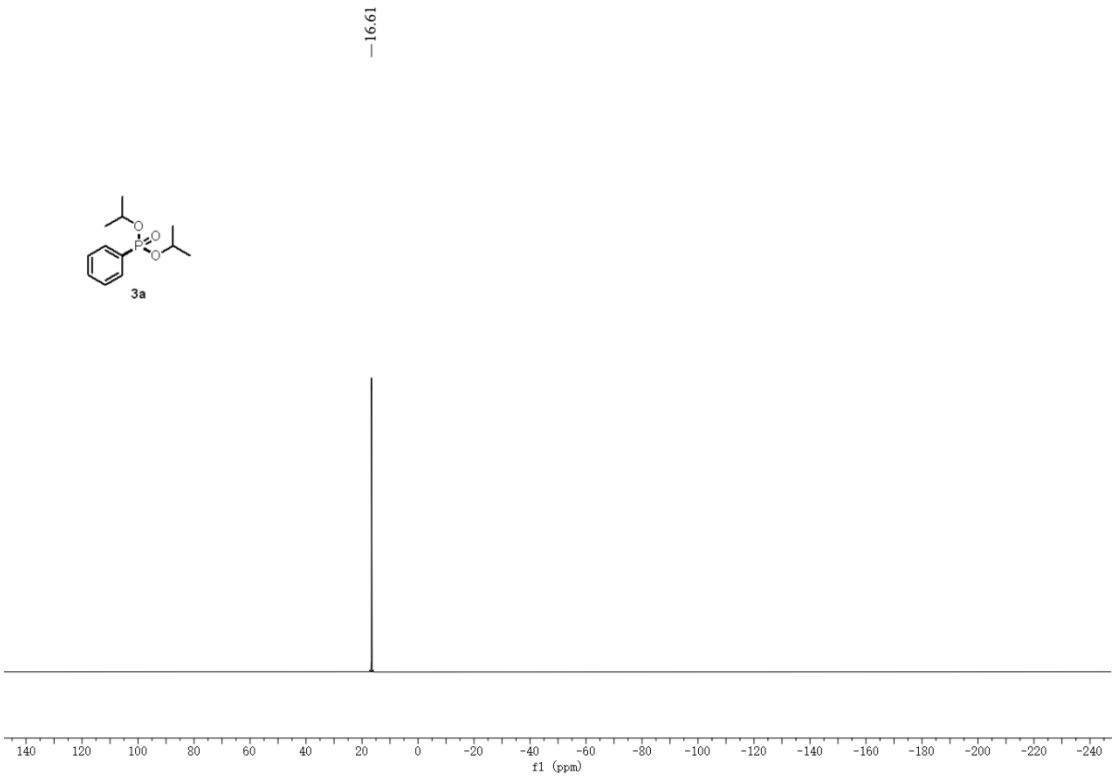
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3a



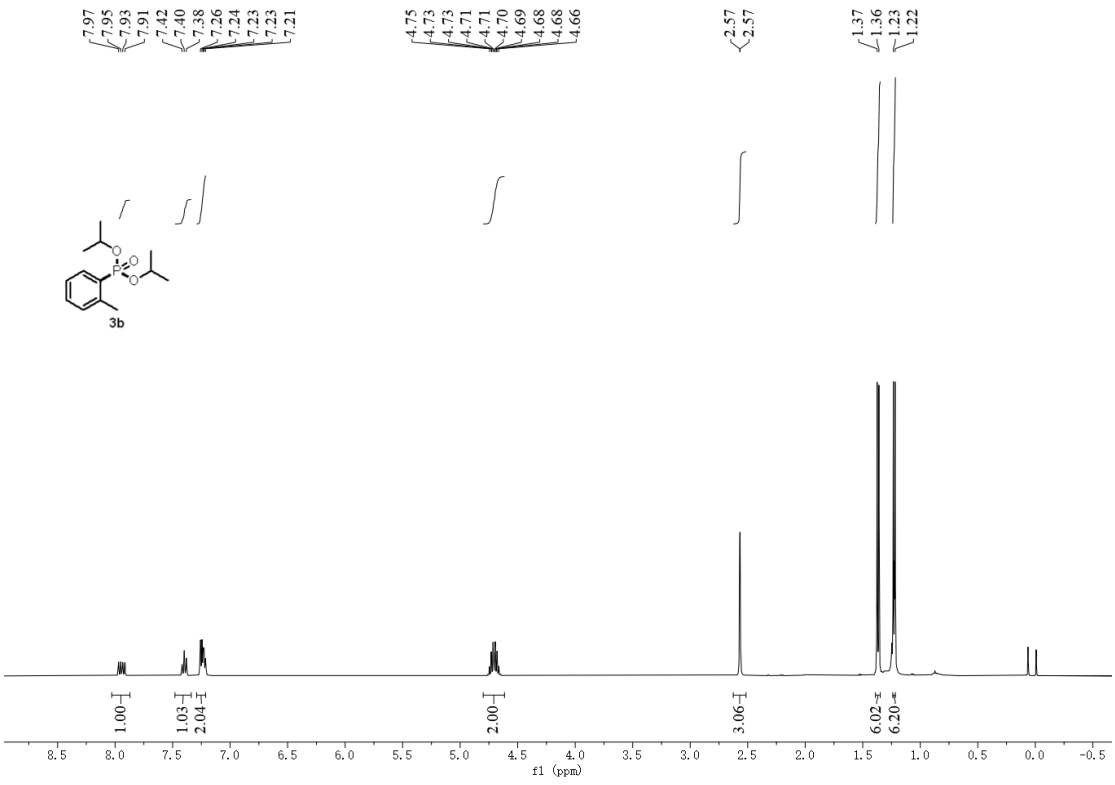

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 3a



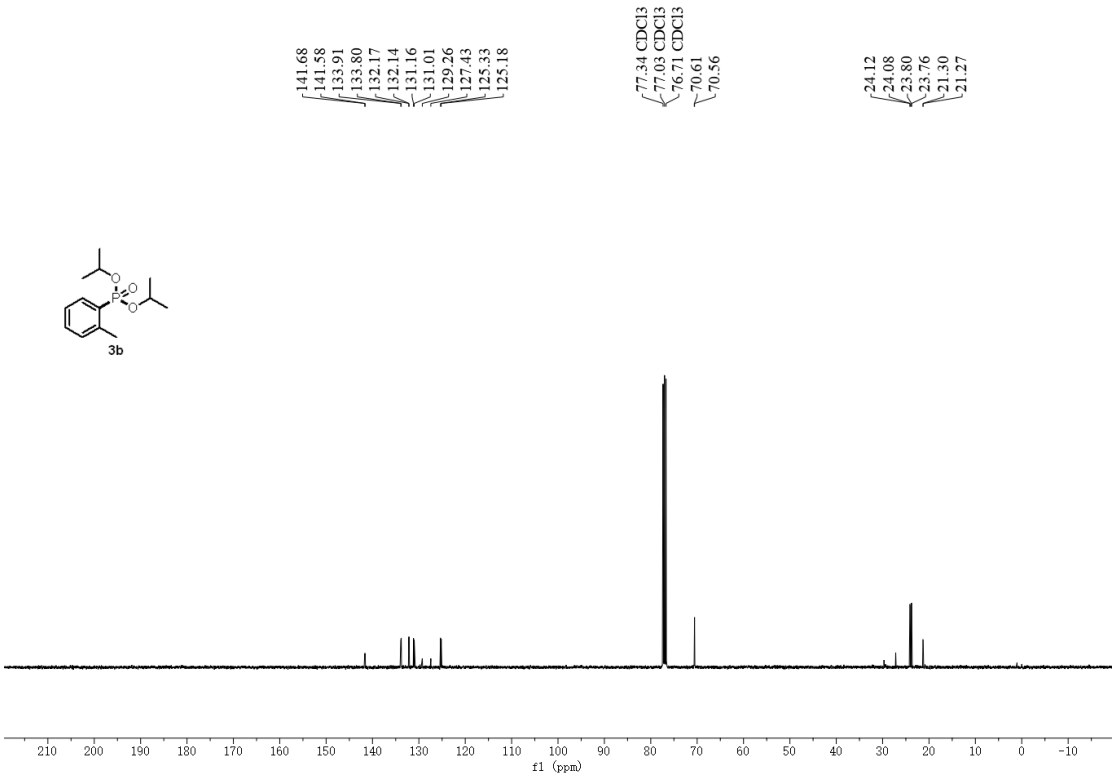
## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 3a



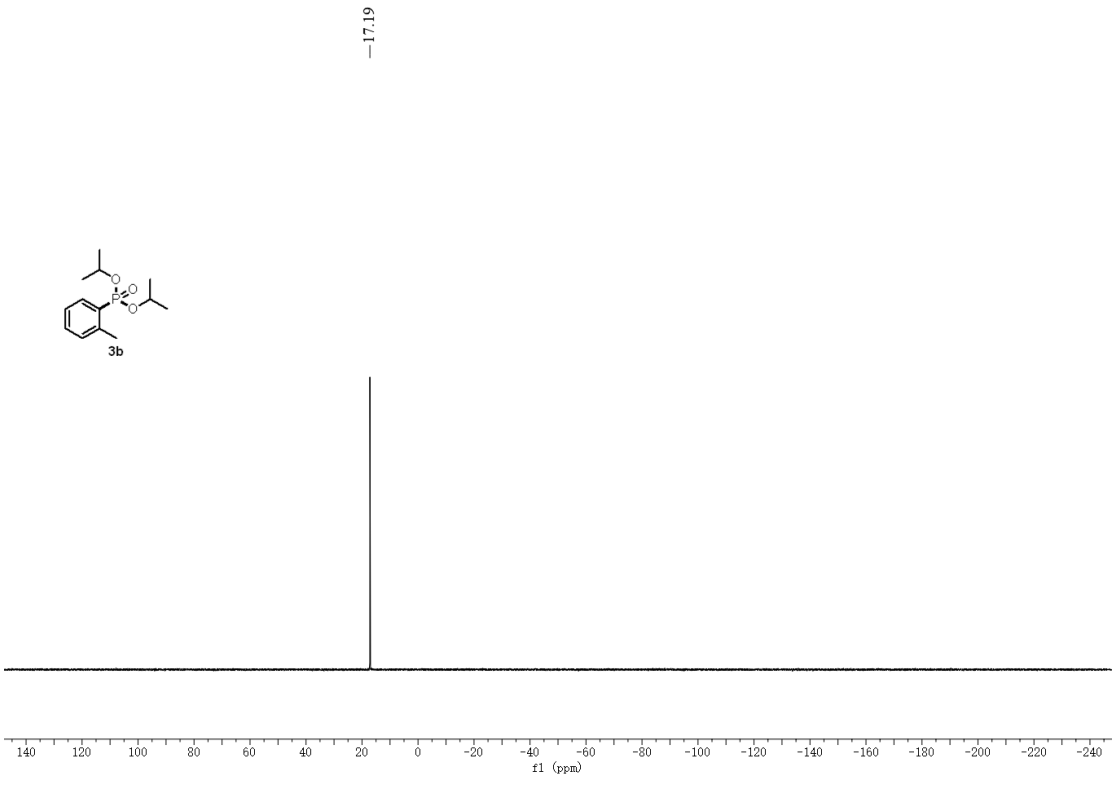

## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3b



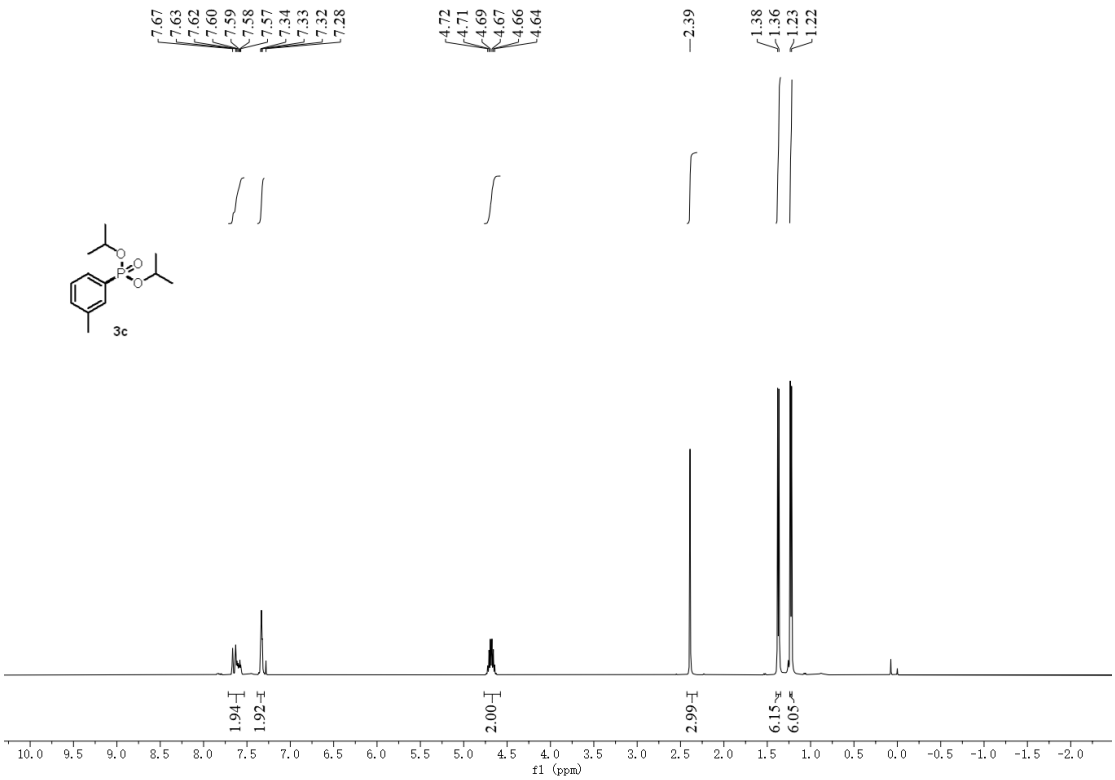
## $^{13}C$ NMR (101 MHz, $CDCl_3$) spectrum for 3b



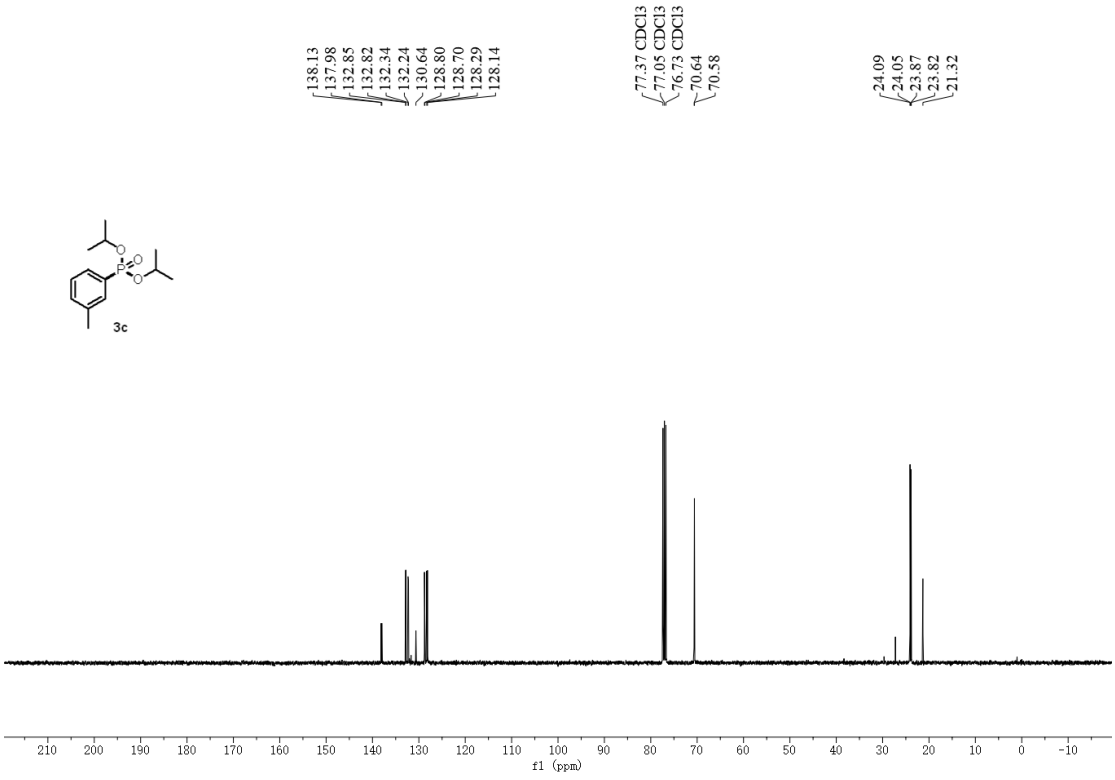

## $^{31}P$ NMR (121 MHz, $CDCl_3$) spectrum for 3b



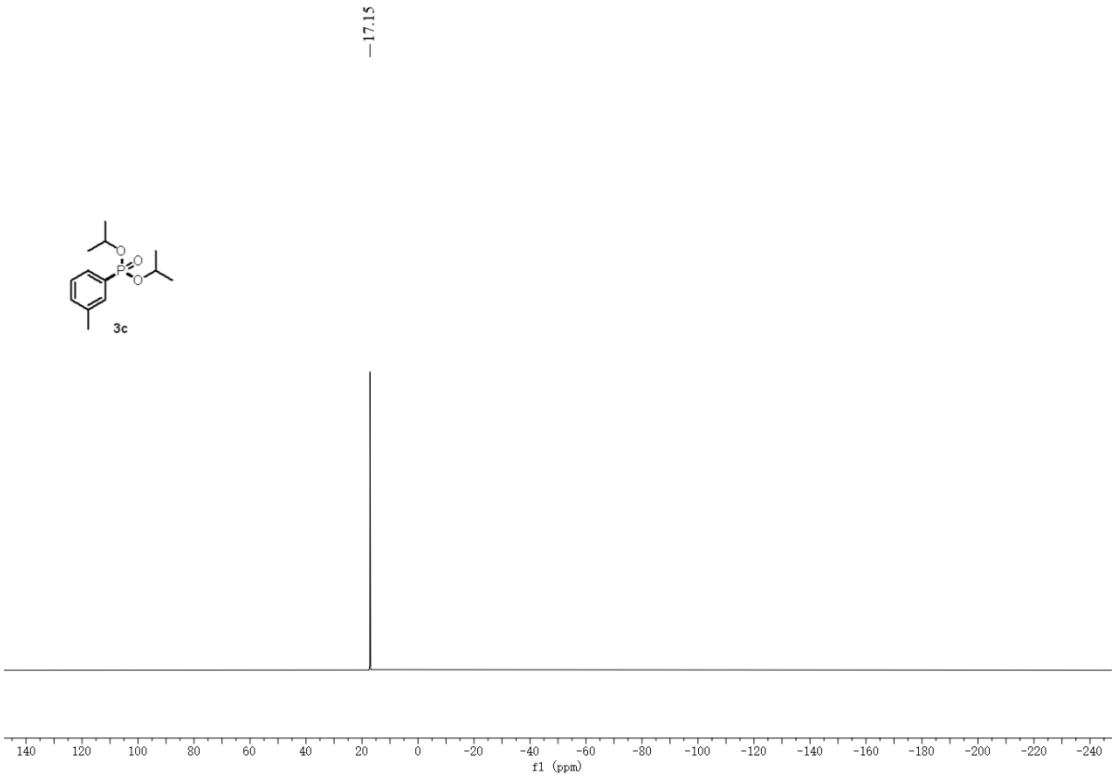
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3c



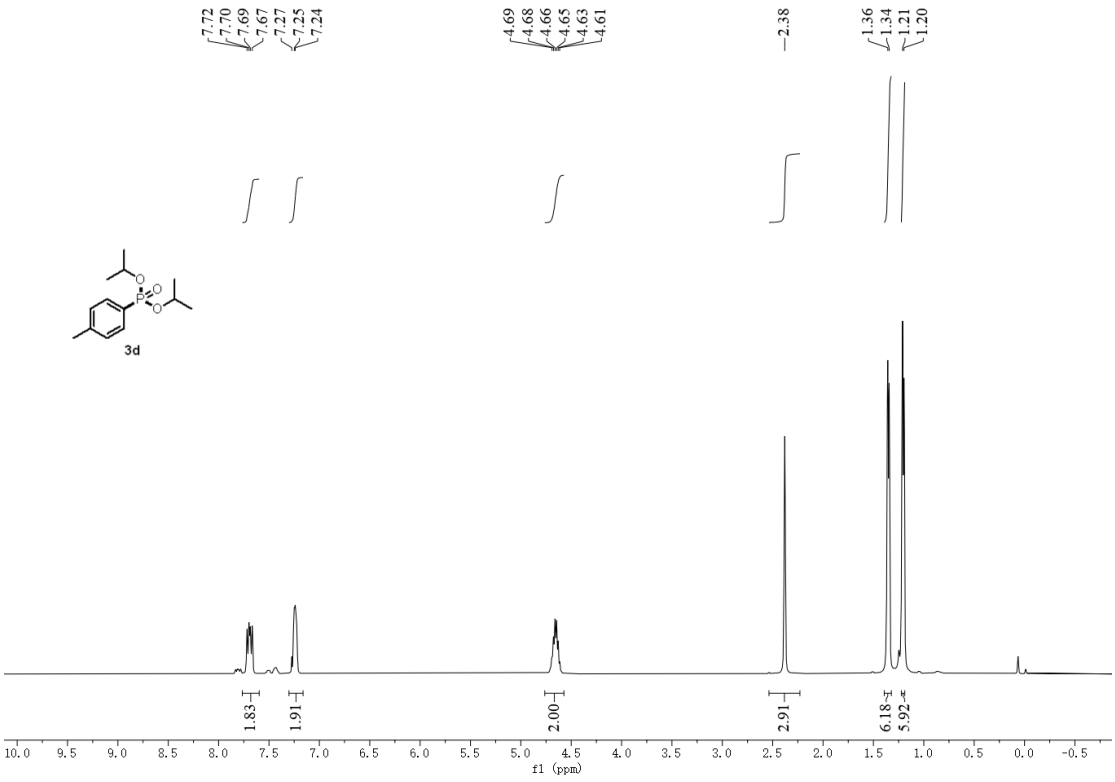

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 3s



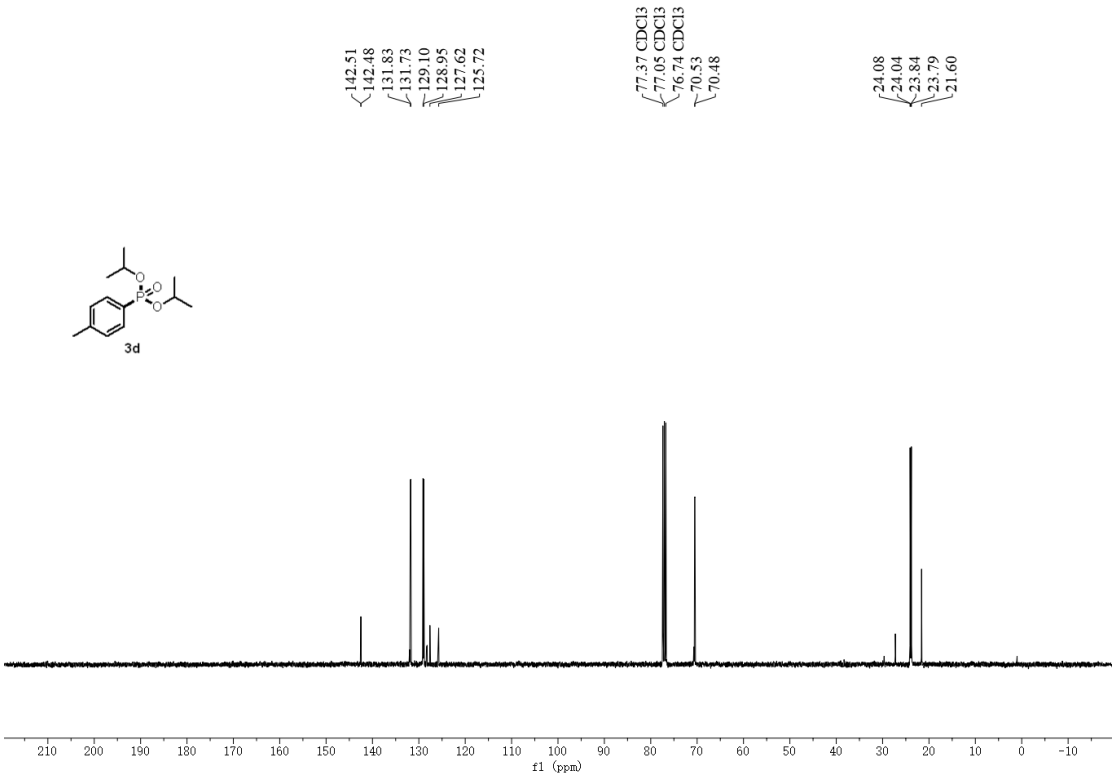
**$^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 3c**



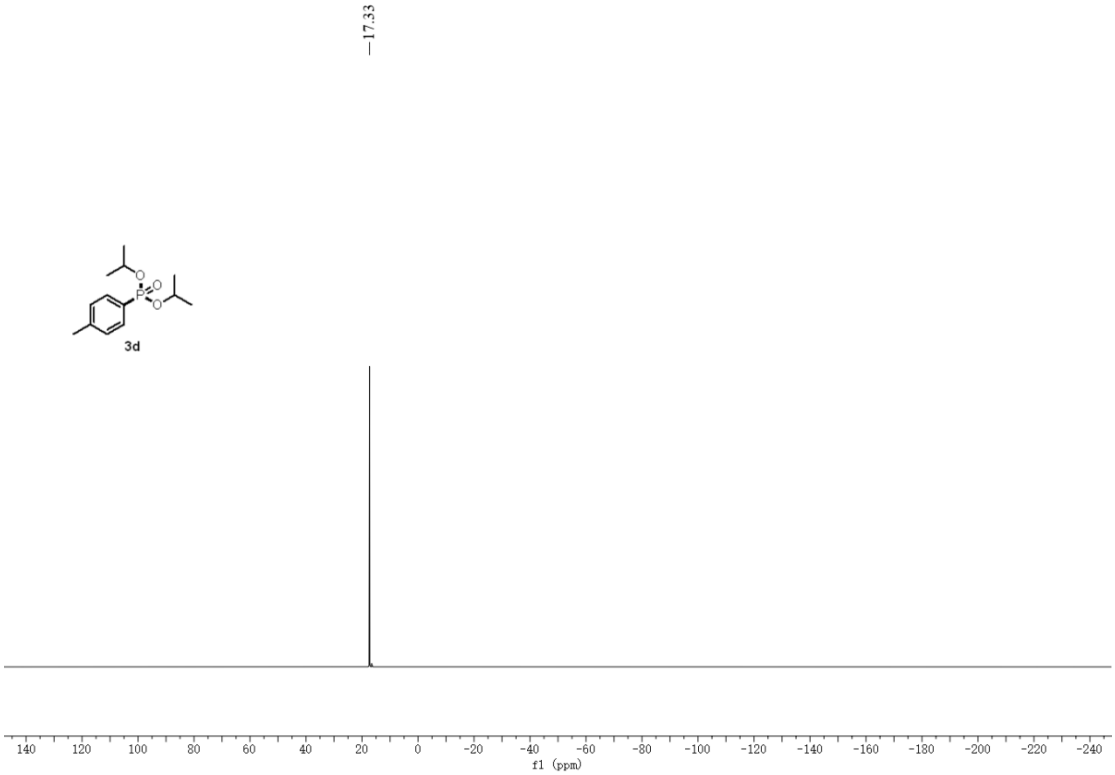

**$^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3d**



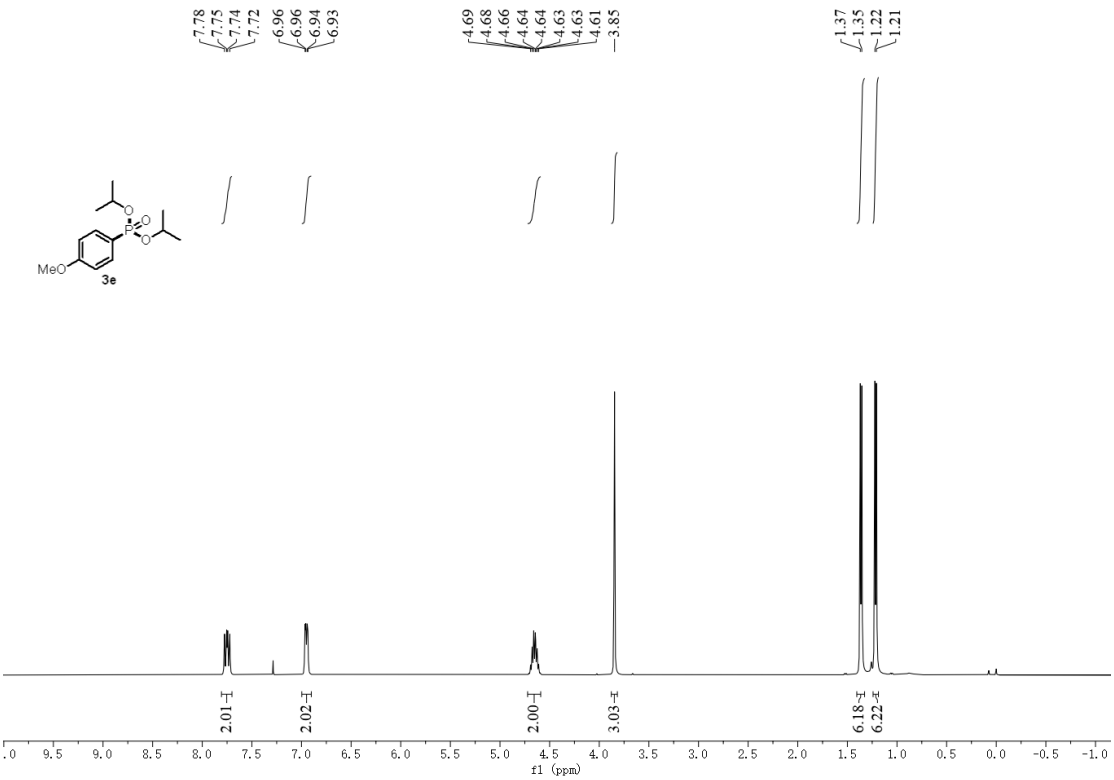
## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 3d



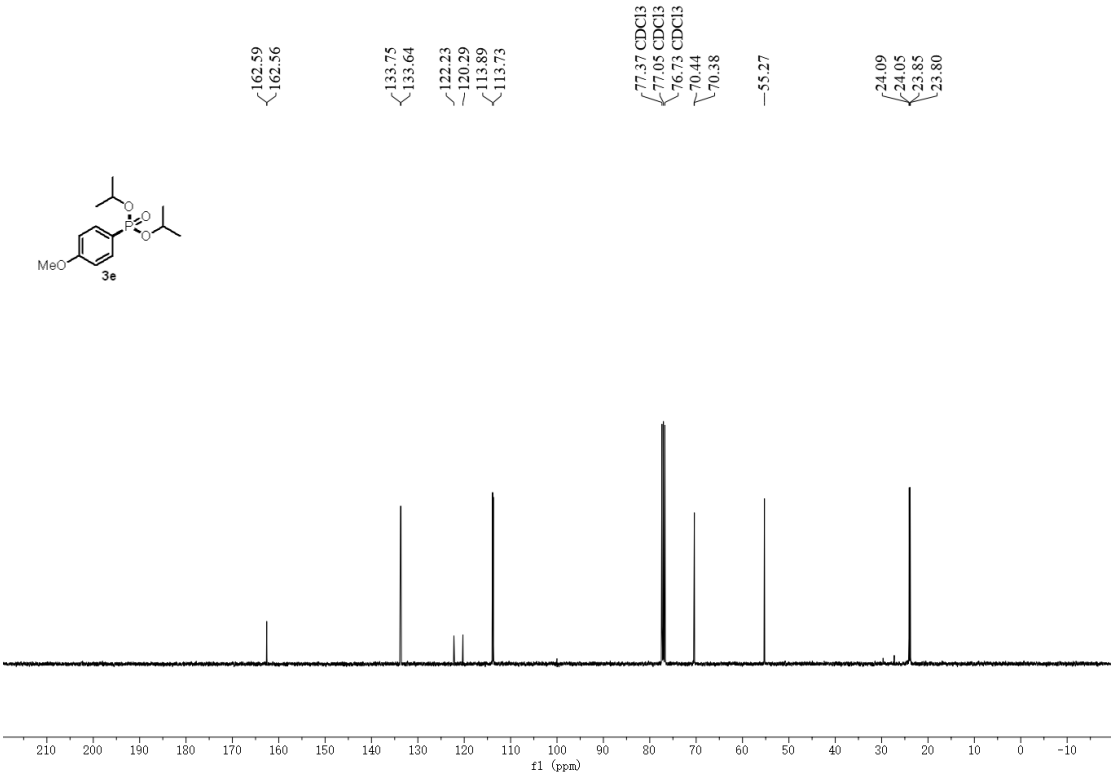

## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 3d



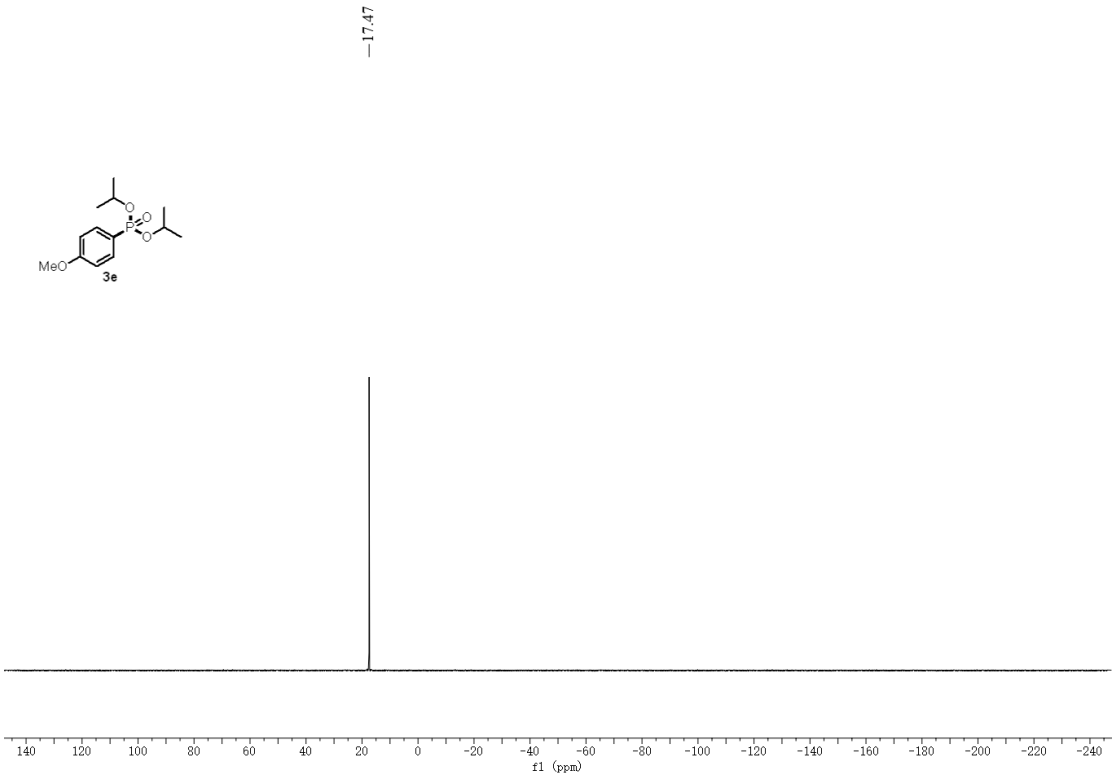
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3e



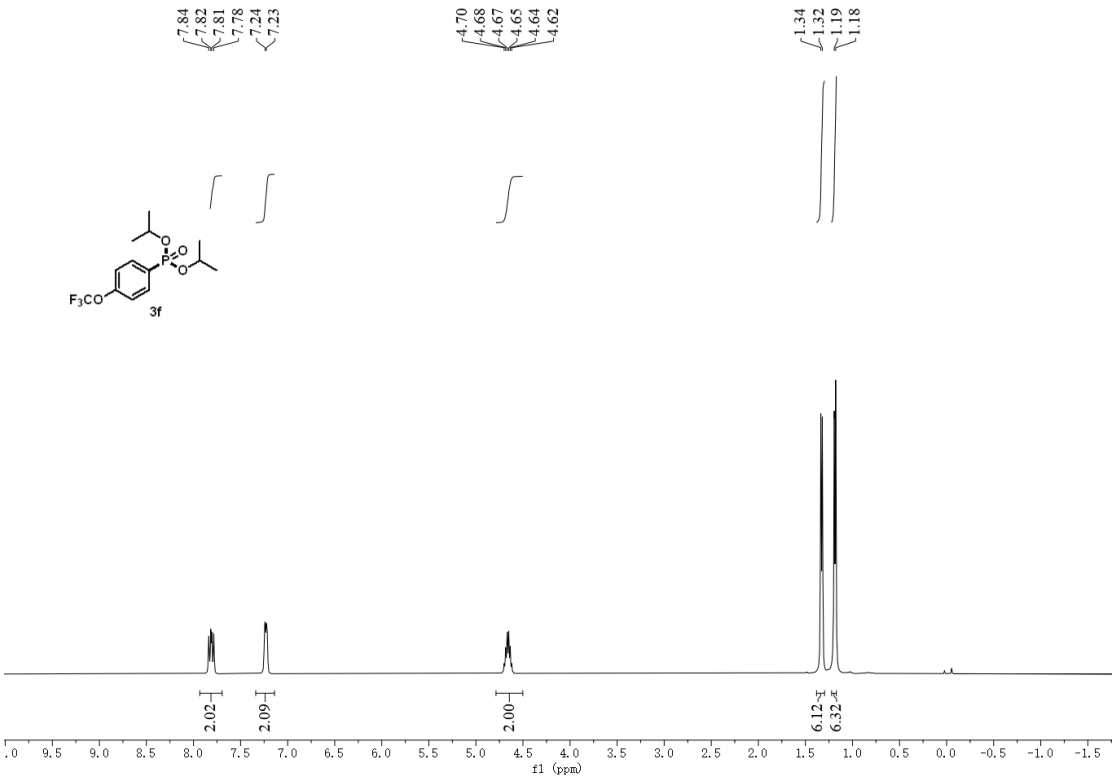

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 3e



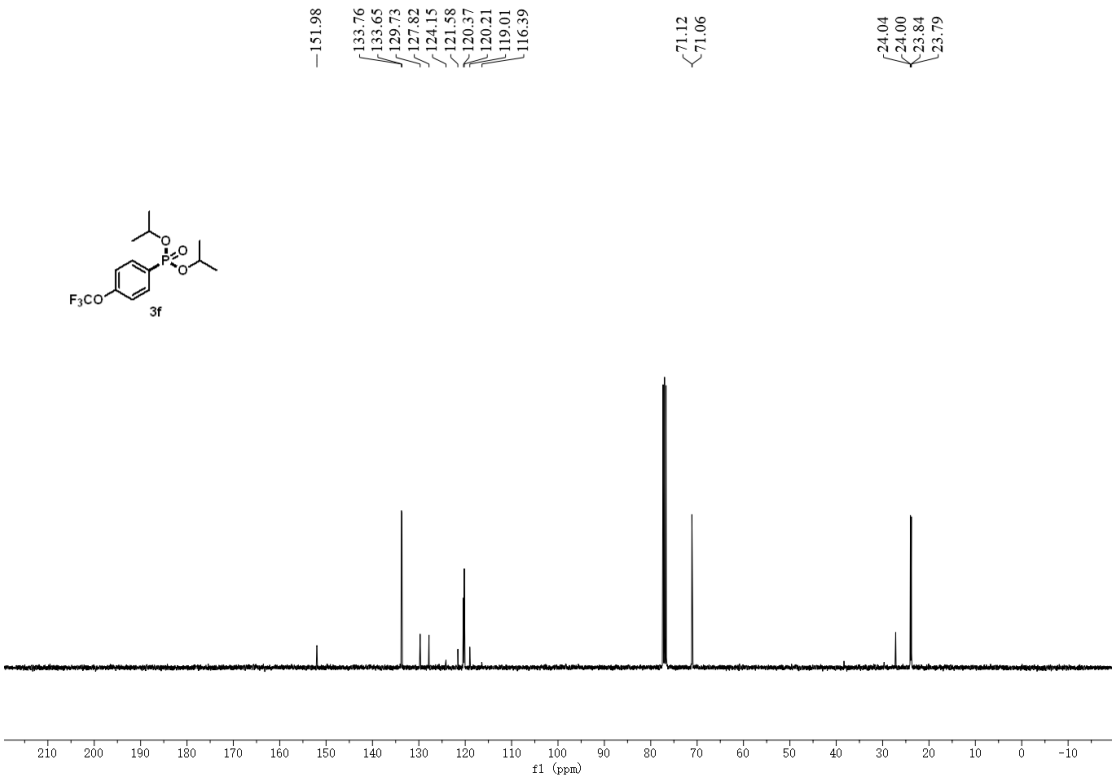
## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 3e



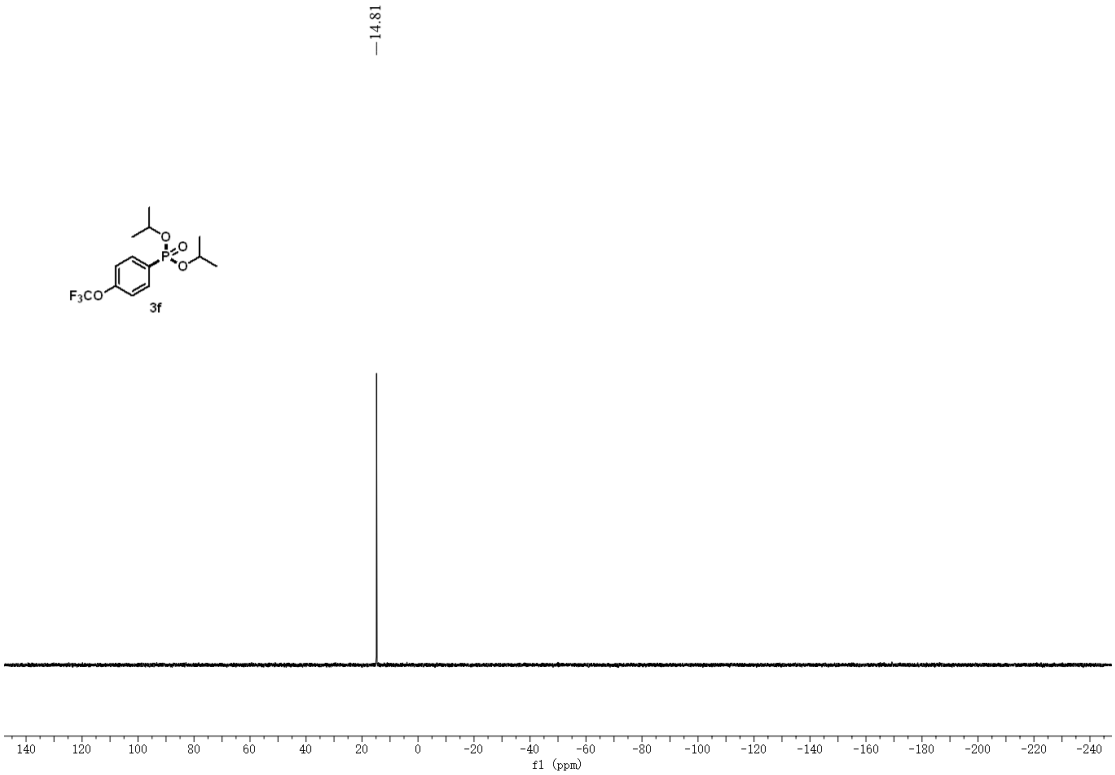

## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3f



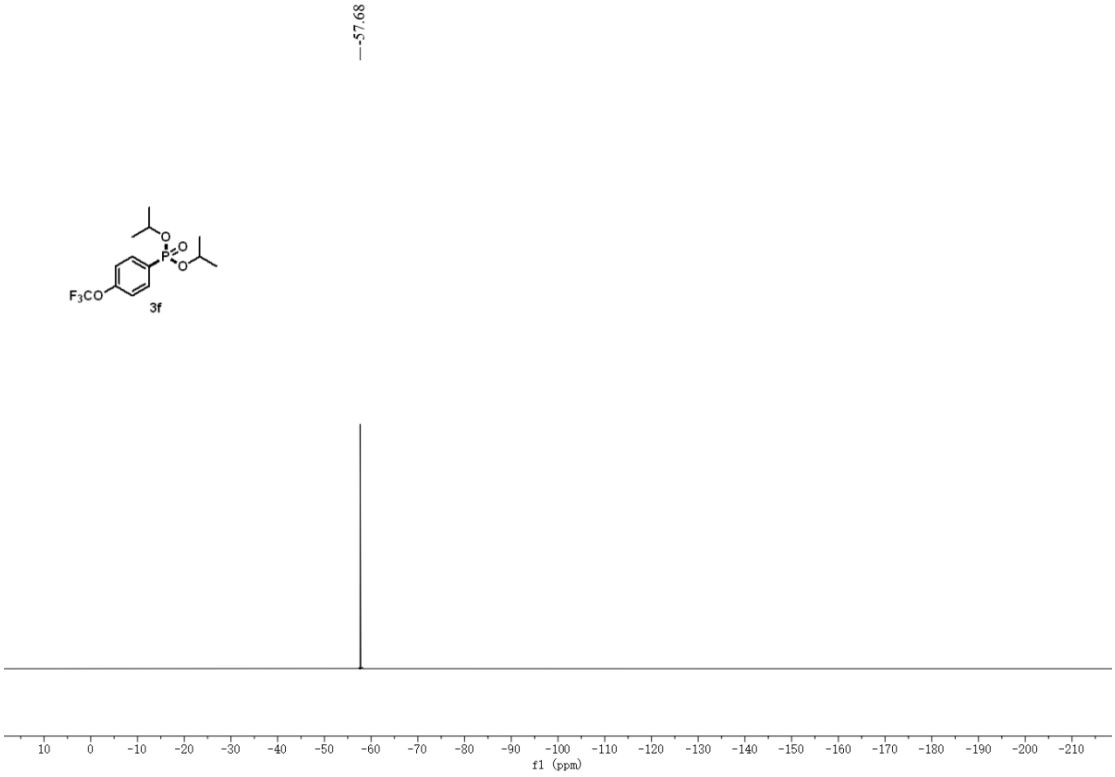
## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 3f



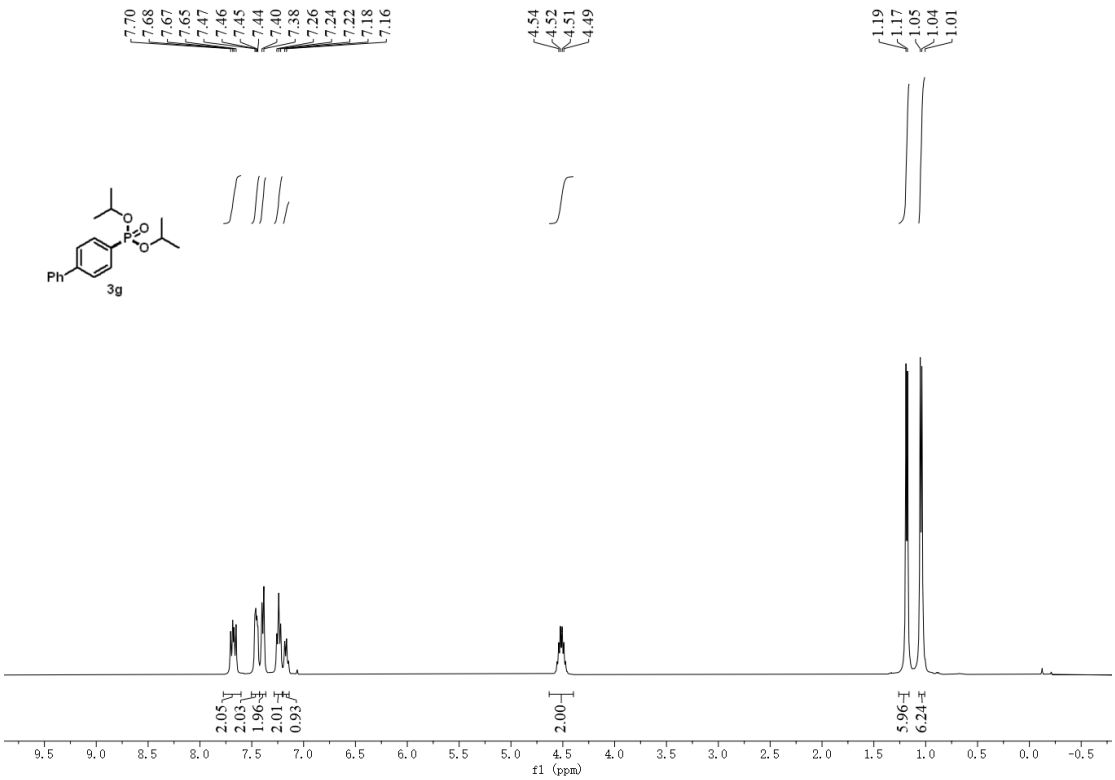

## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 3f



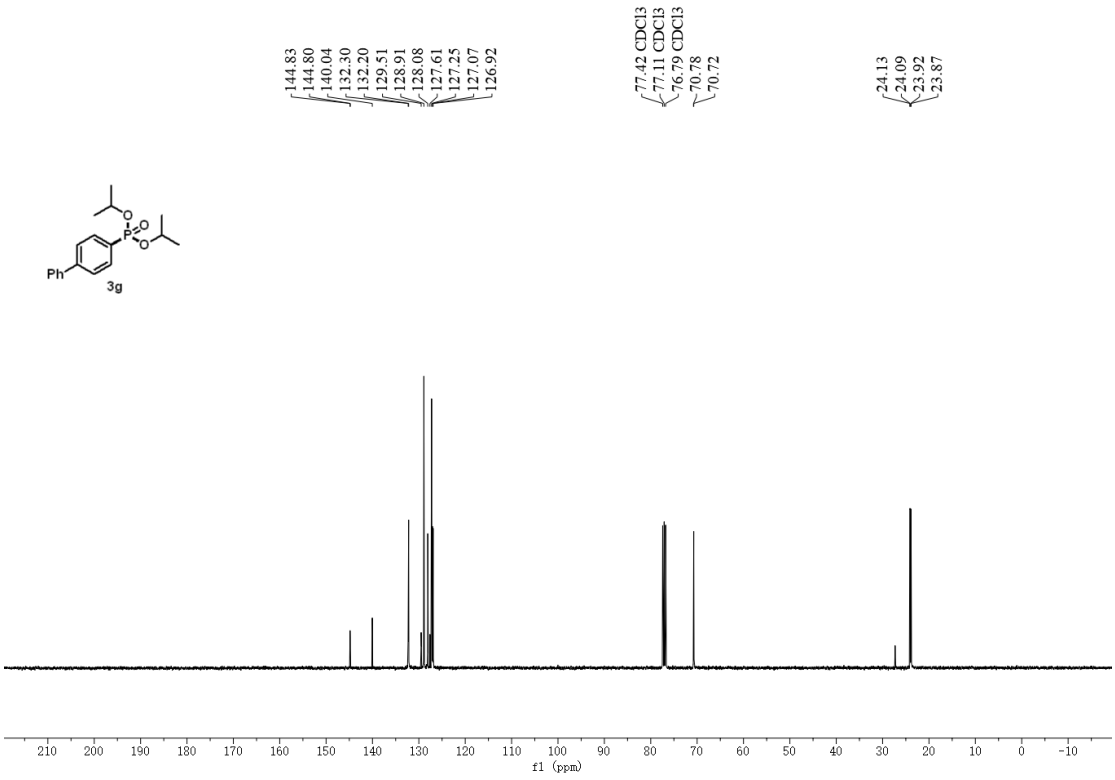
**$^{19}$F NMR (282 MHz, $CDCl_3$) spectrum for 3f**



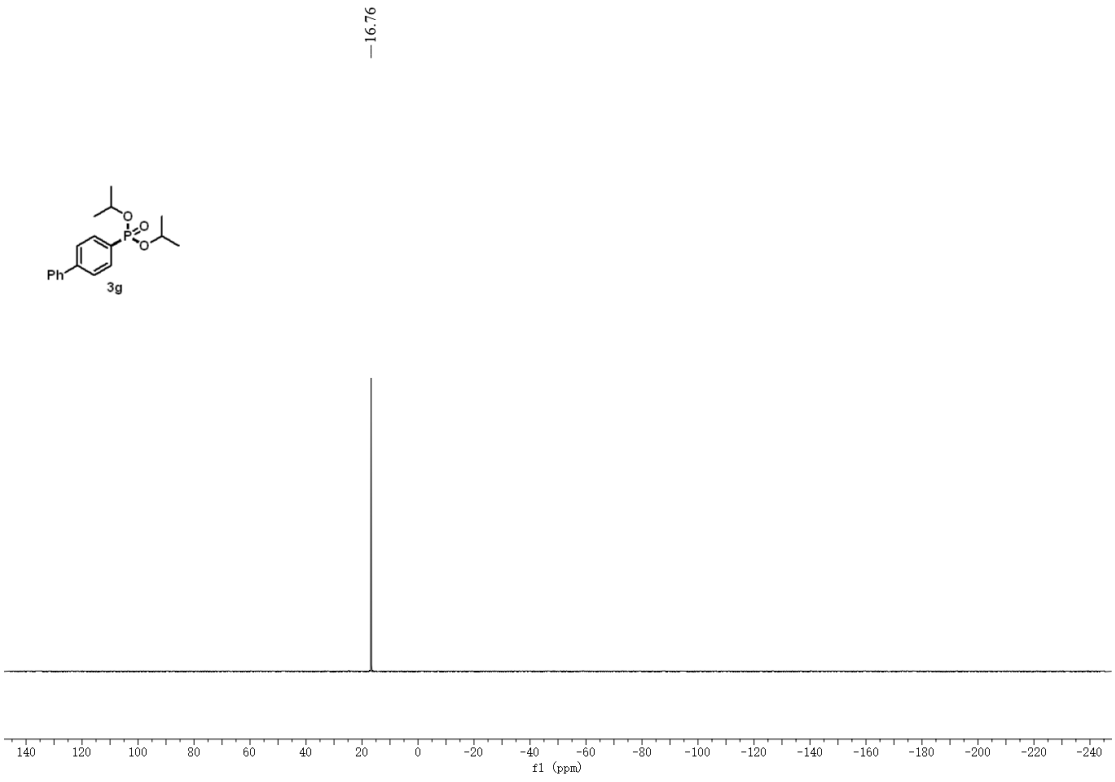

**$^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3g**



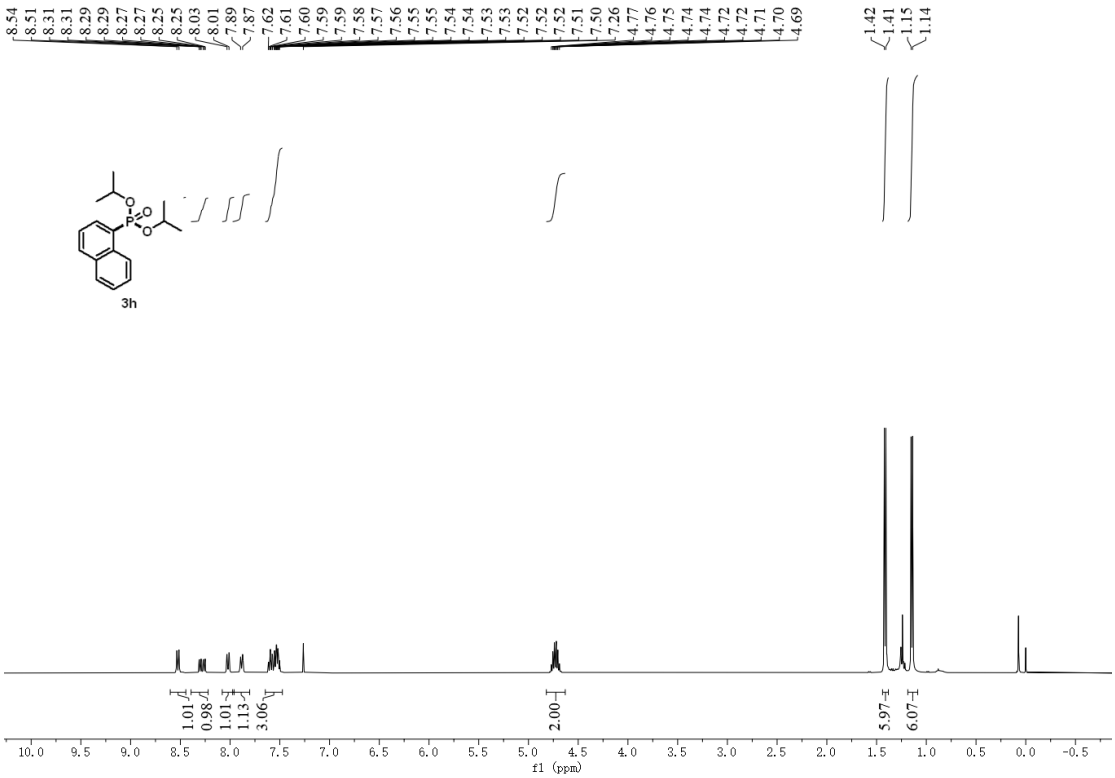
## $^{13}C$ NMR (101 MHz, $CDCl_3$) spectrum for 3g



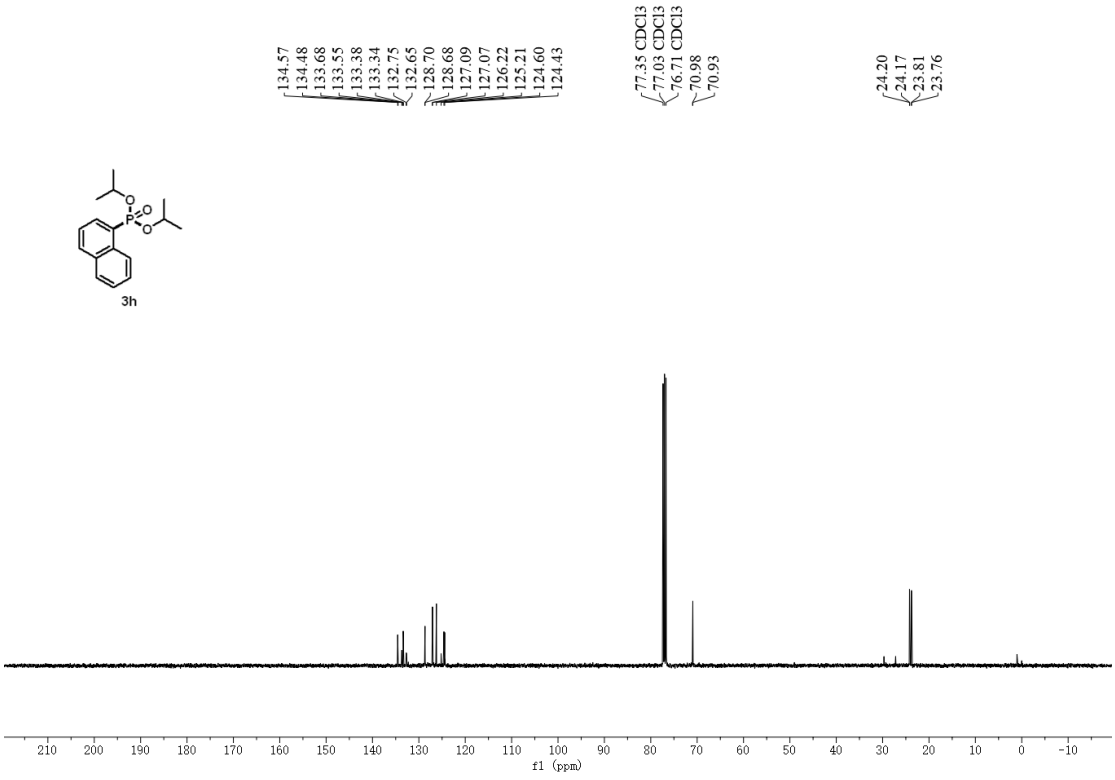

## $^{31}P$ NMR (121 MHz, $CDCl_3$) spectrum for 3g



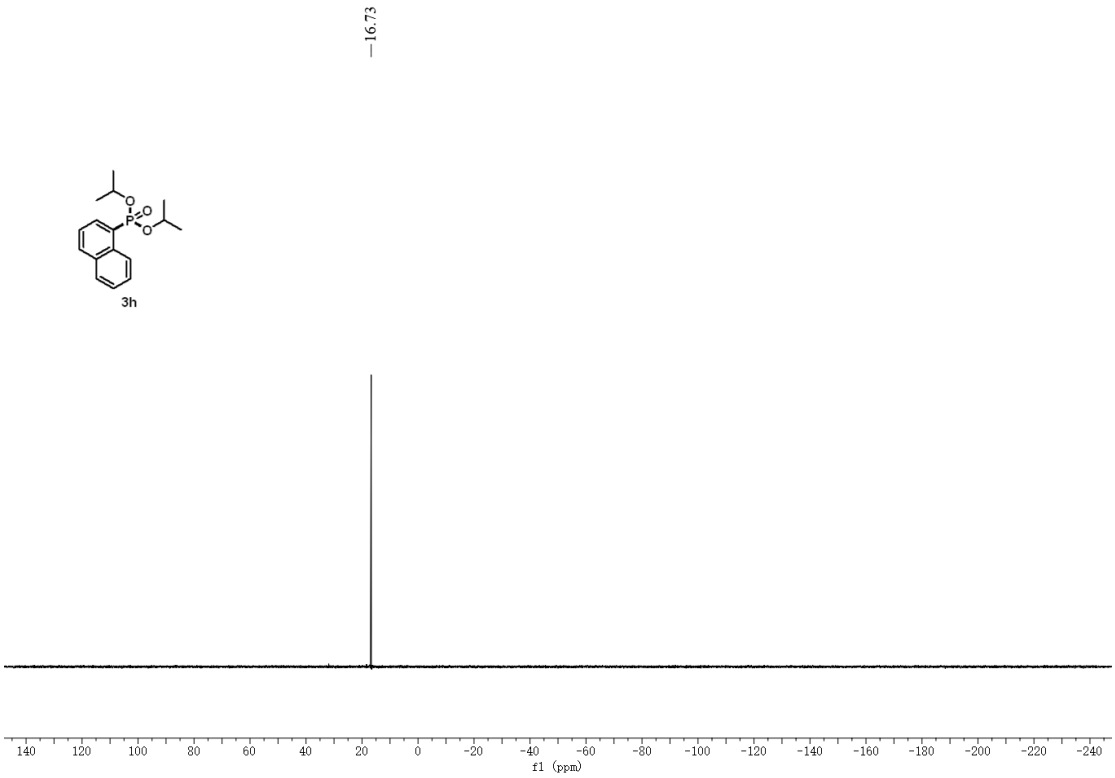
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3h



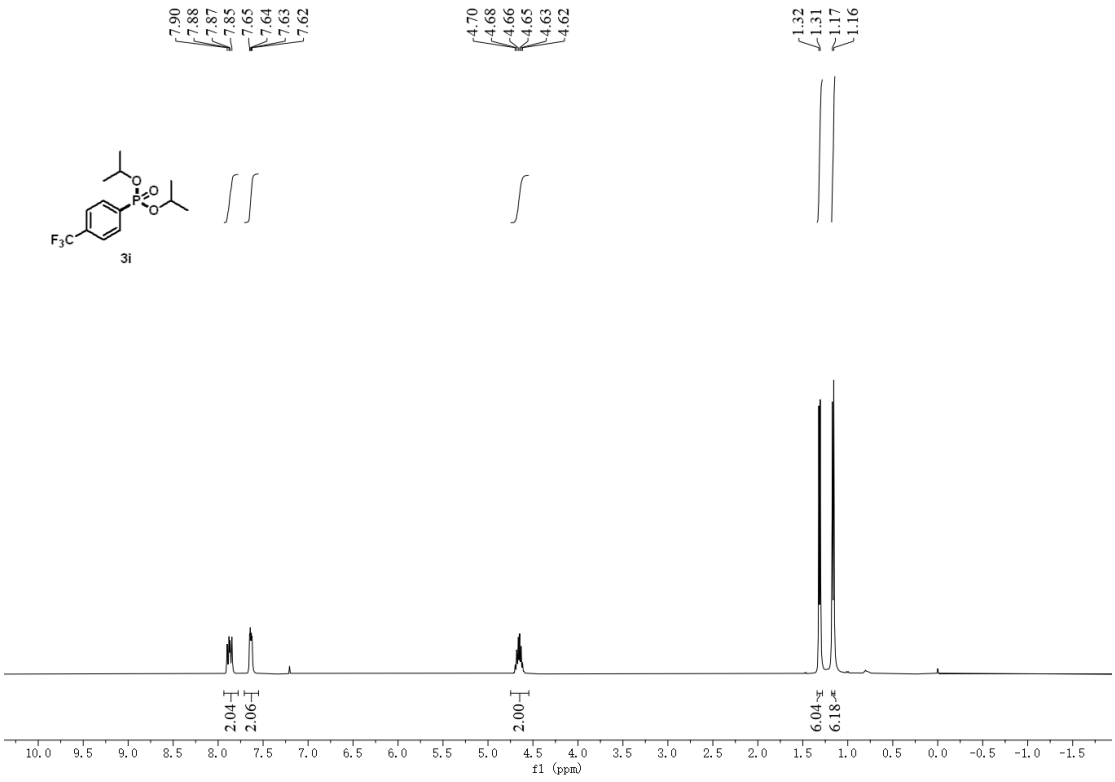

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 3h



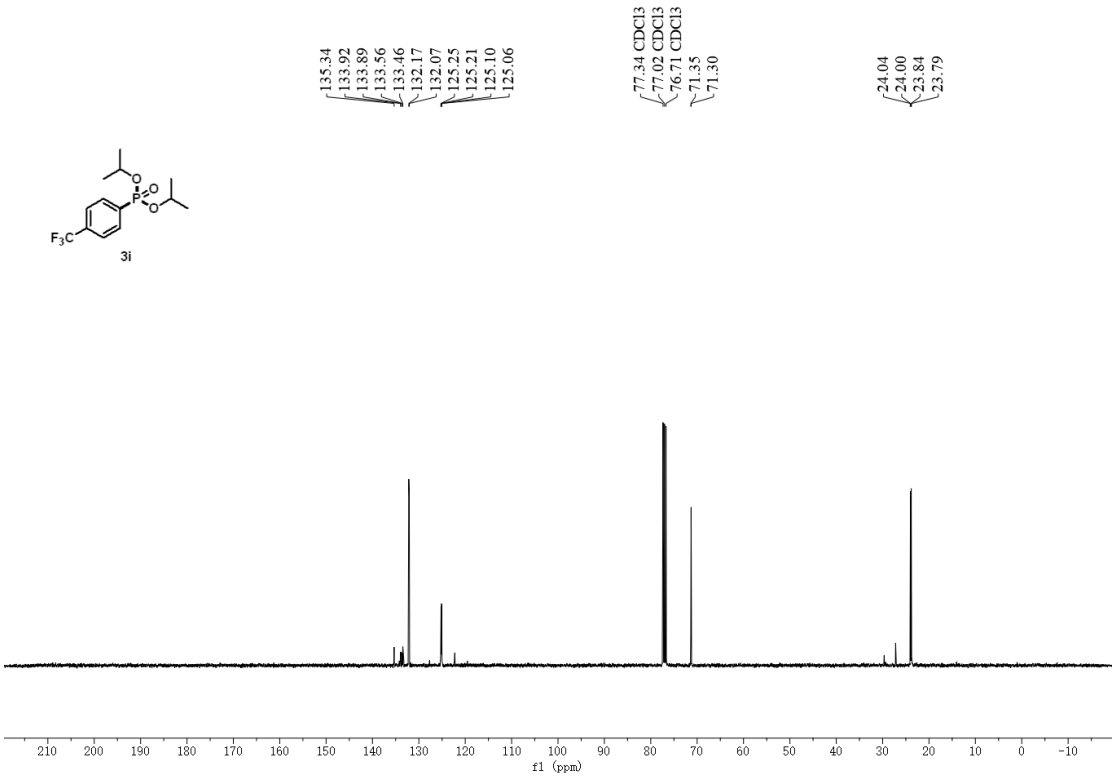
## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 3h



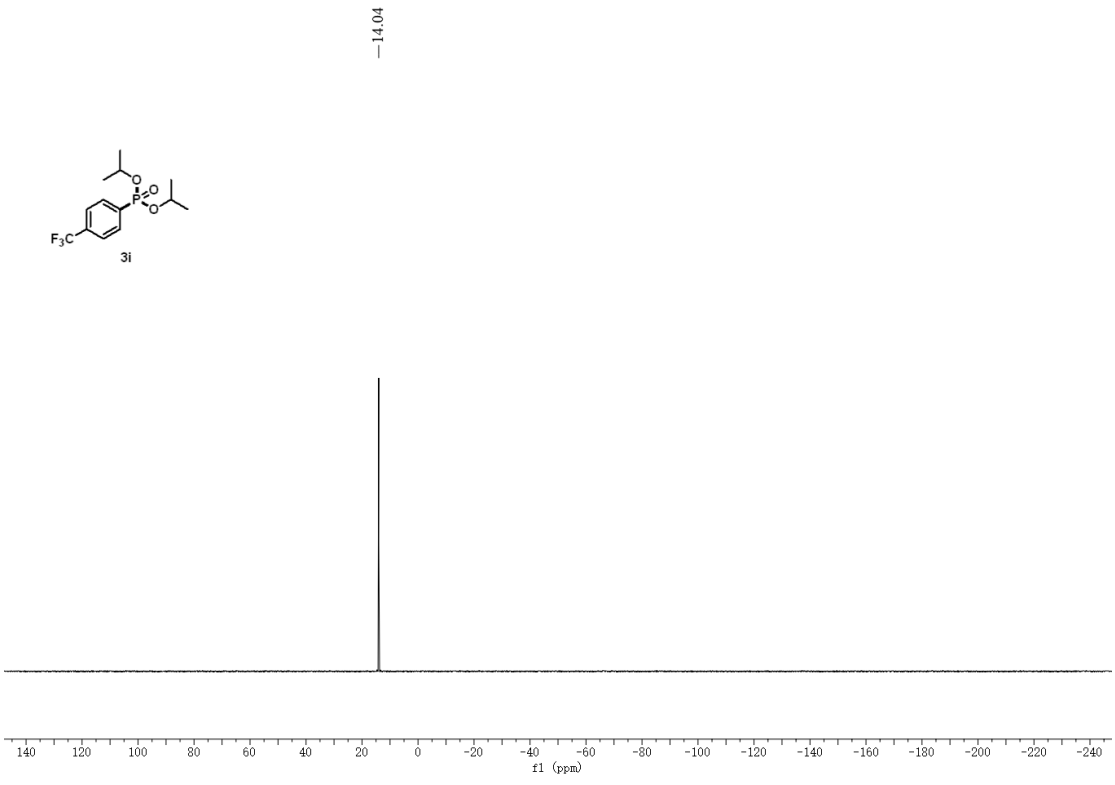

## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3i



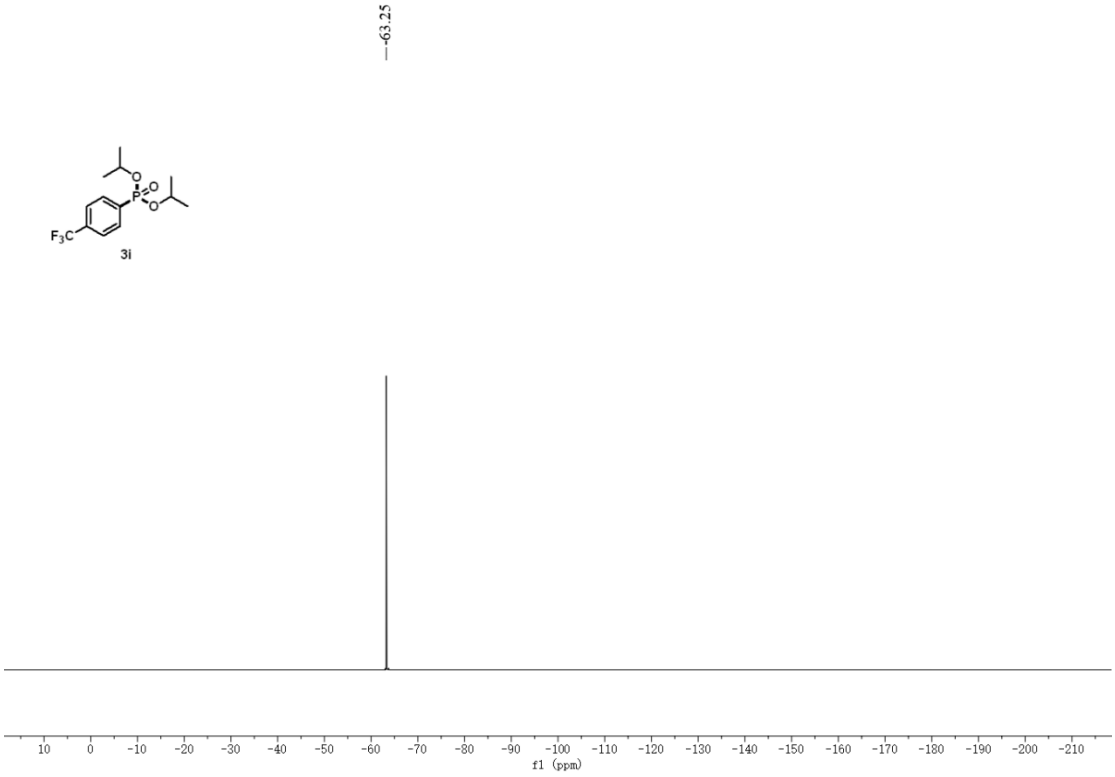
## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 3i



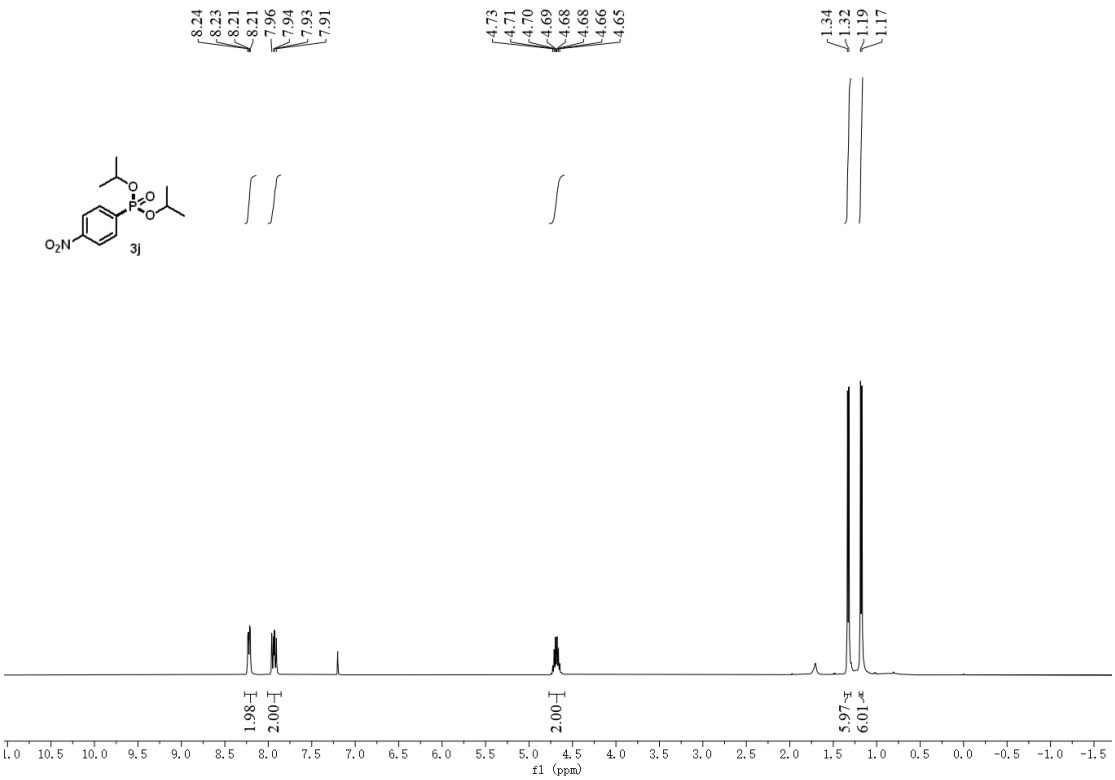

## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 3i



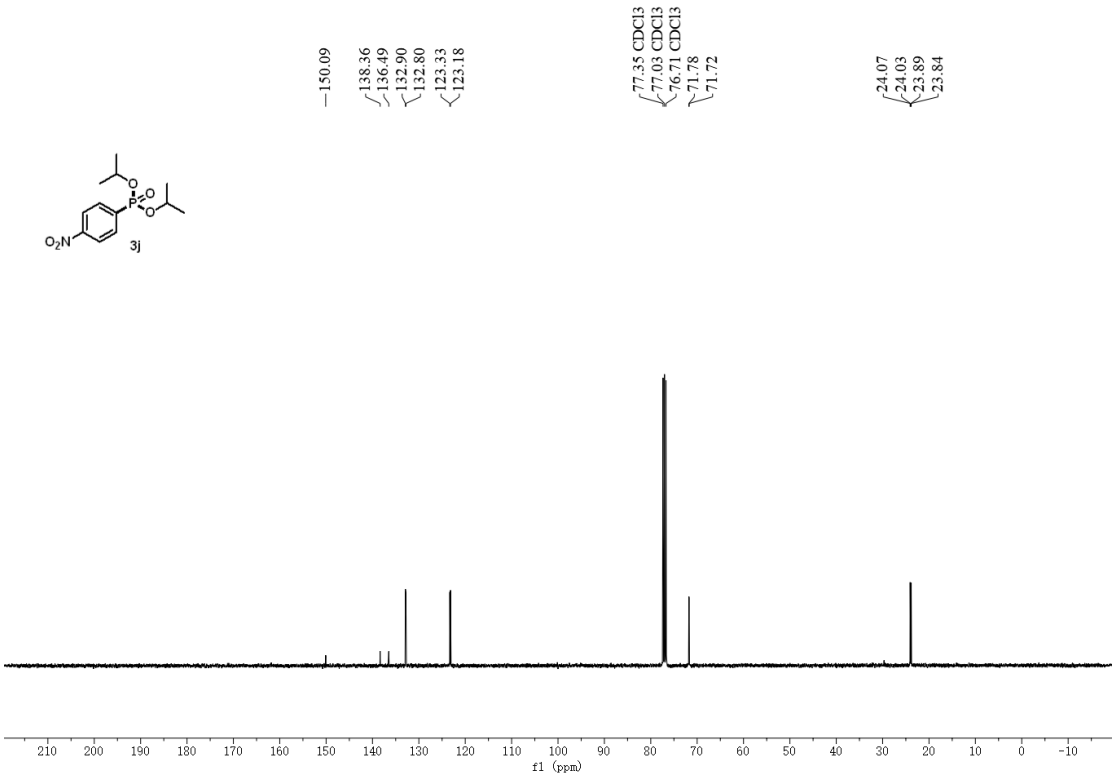
## $^{19}$F NMR (282 MHz, $CDCl_3$) spectrum for 3i



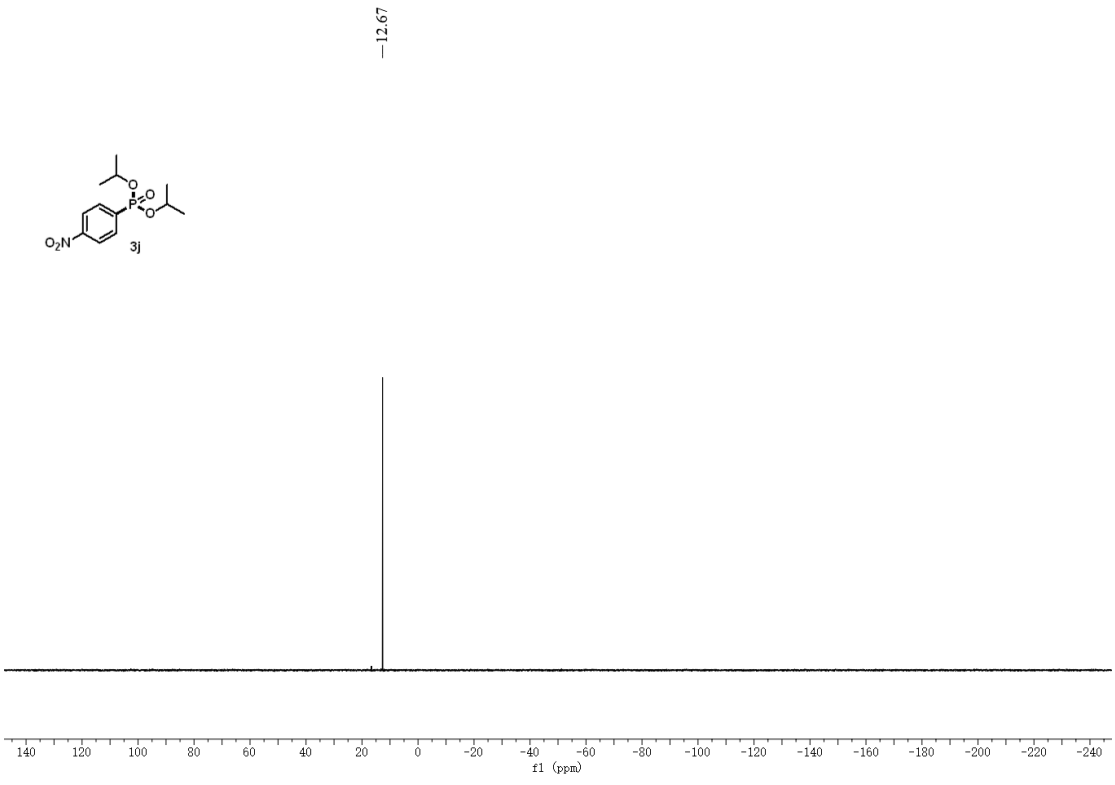

## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3j



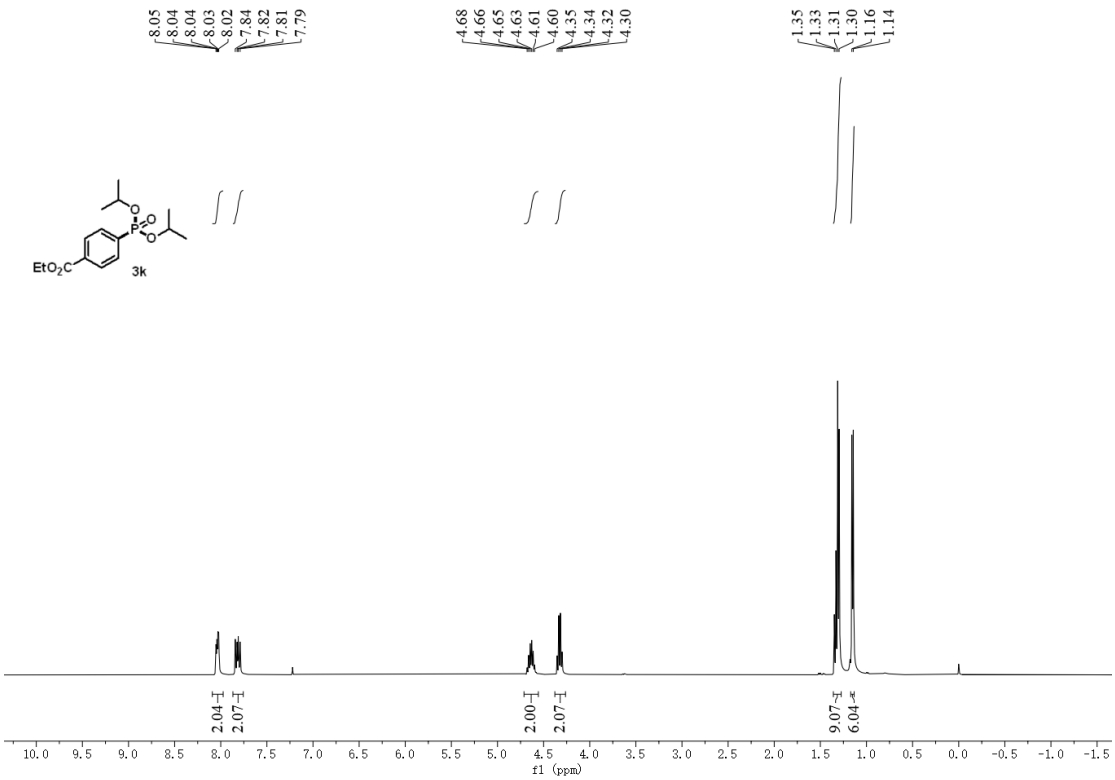
## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 3j



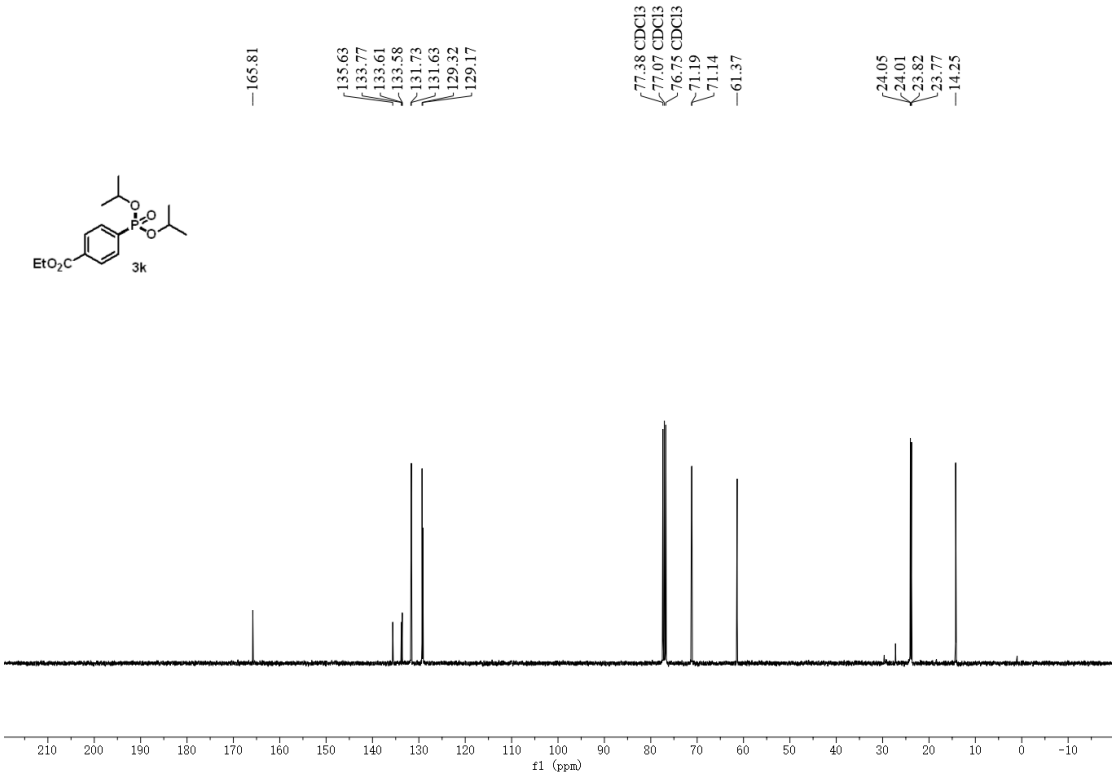

## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 3j



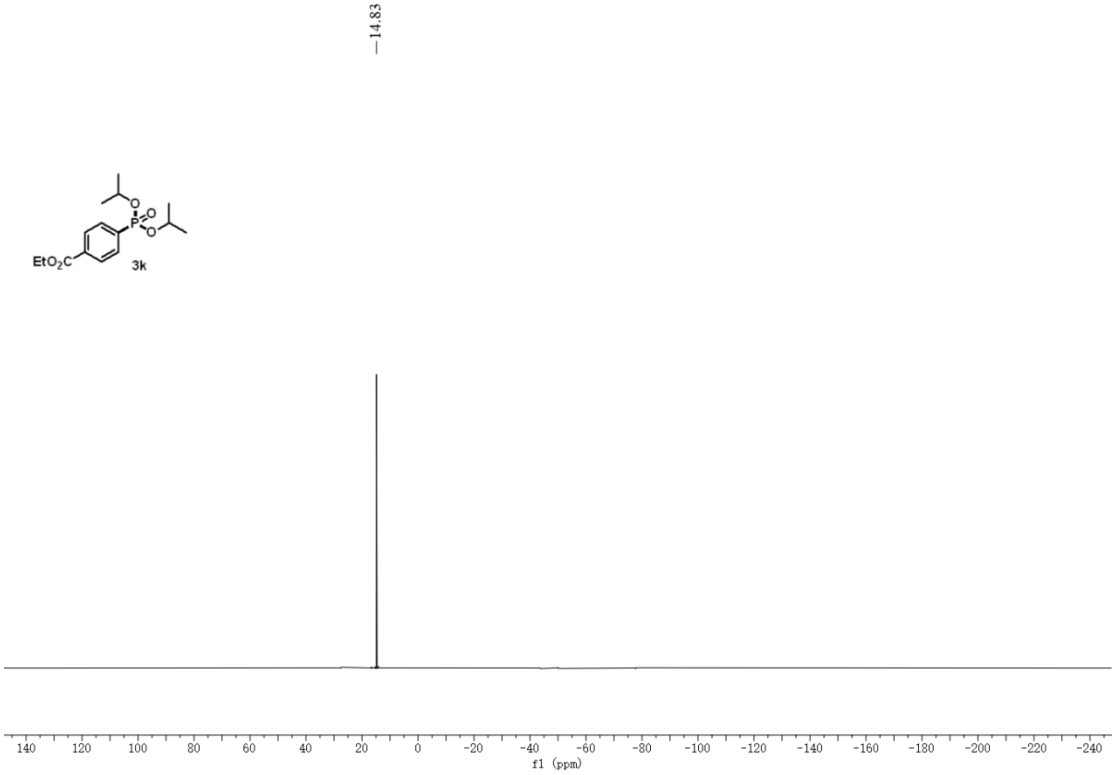
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3k



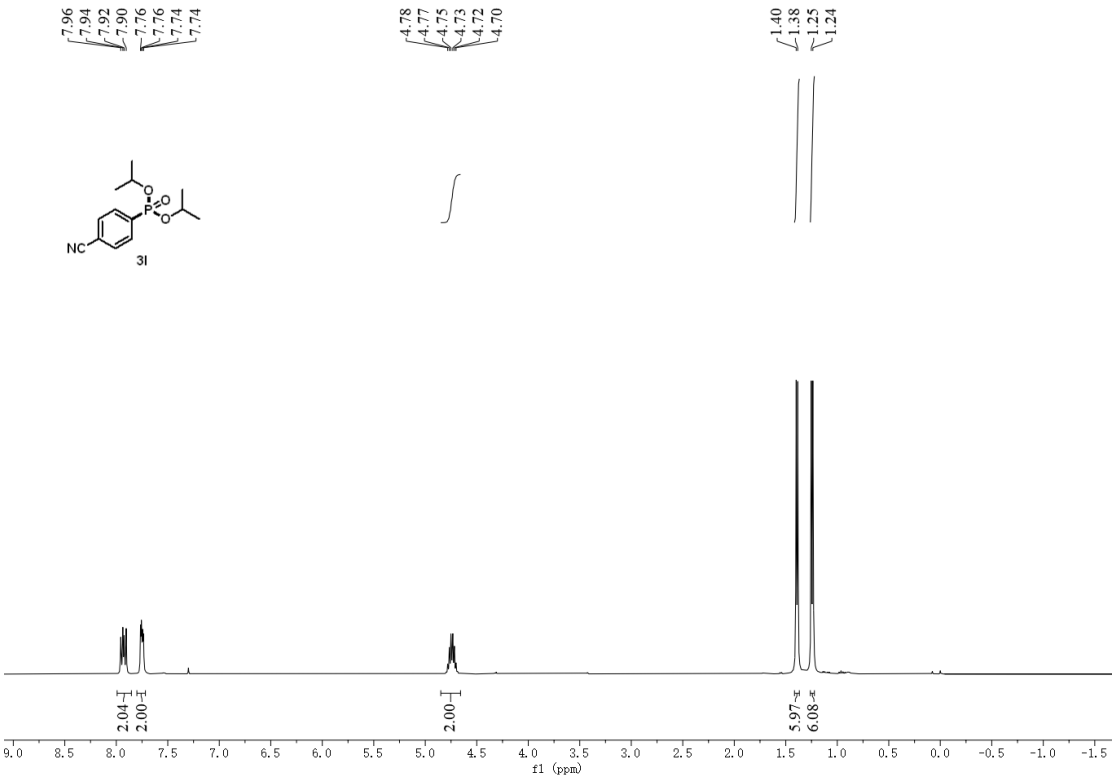

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 3k



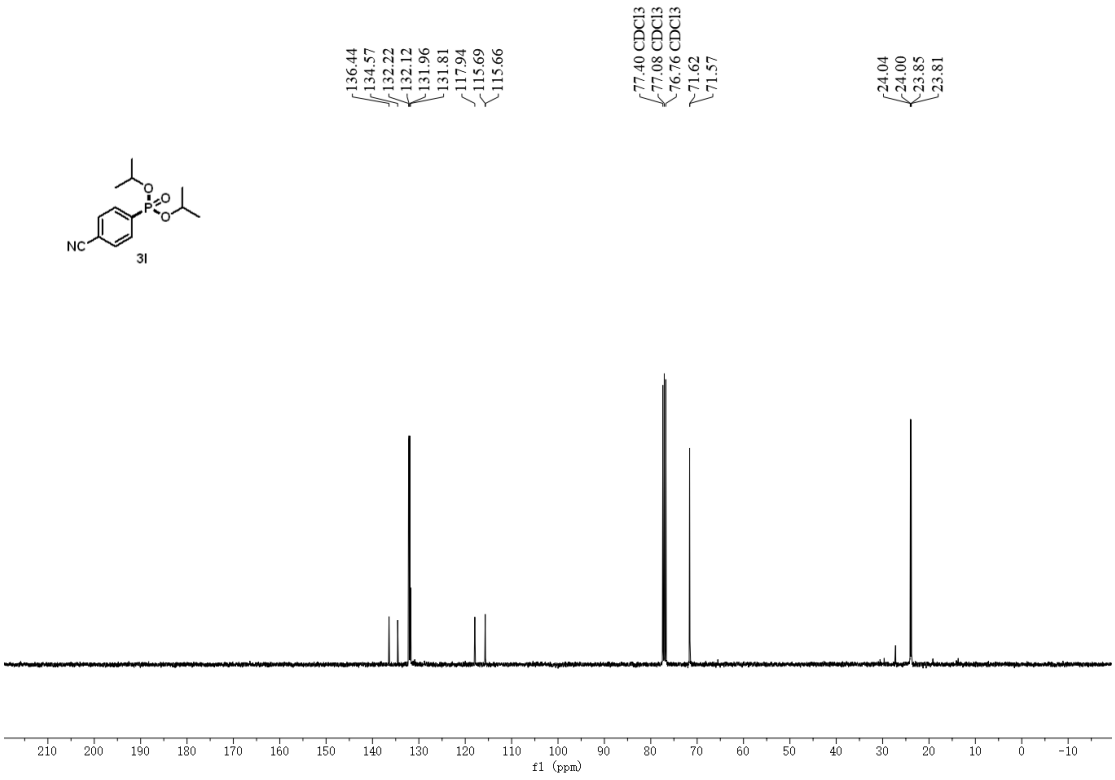
## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 3k



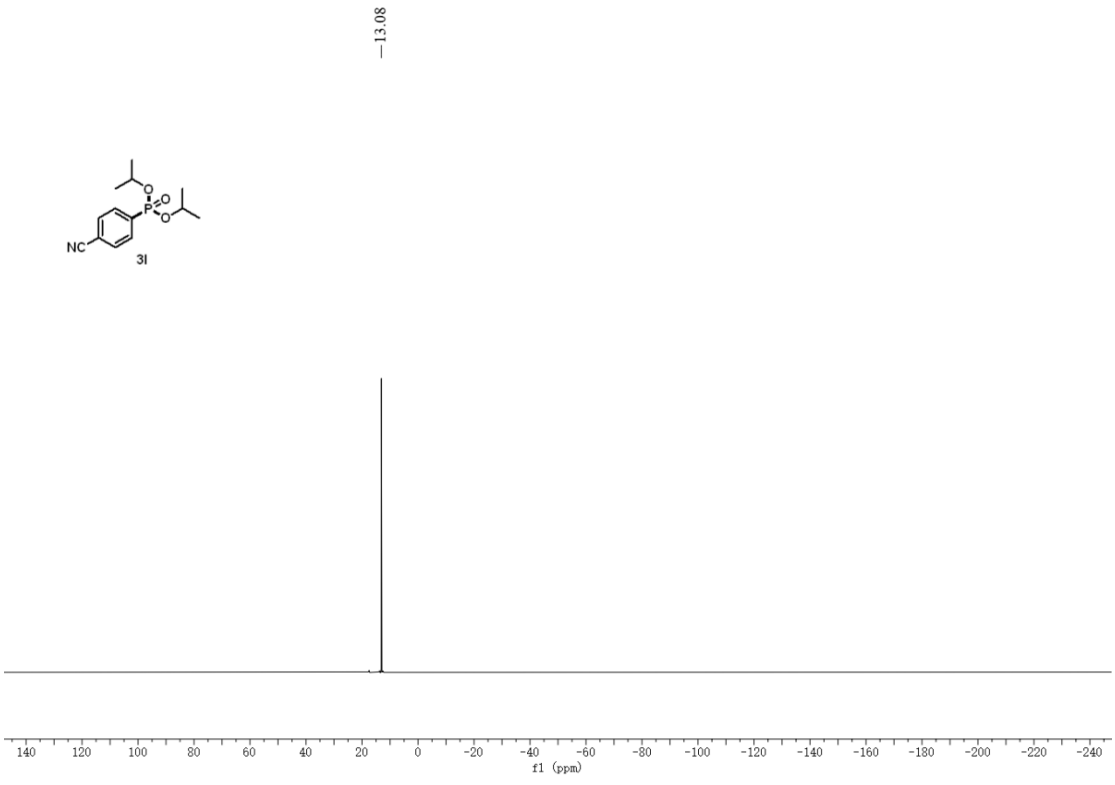

## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3l



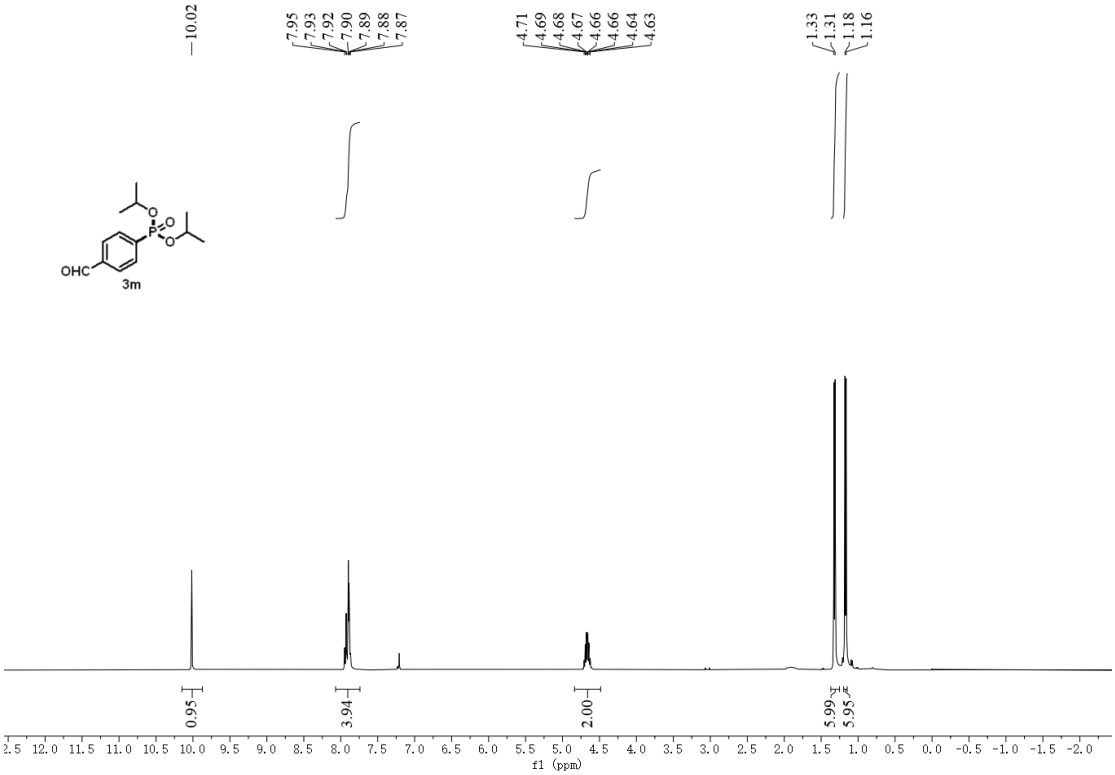
## $^{13}C$ NMR (101 MHz, $CDCl_3$) spectrum for 3l



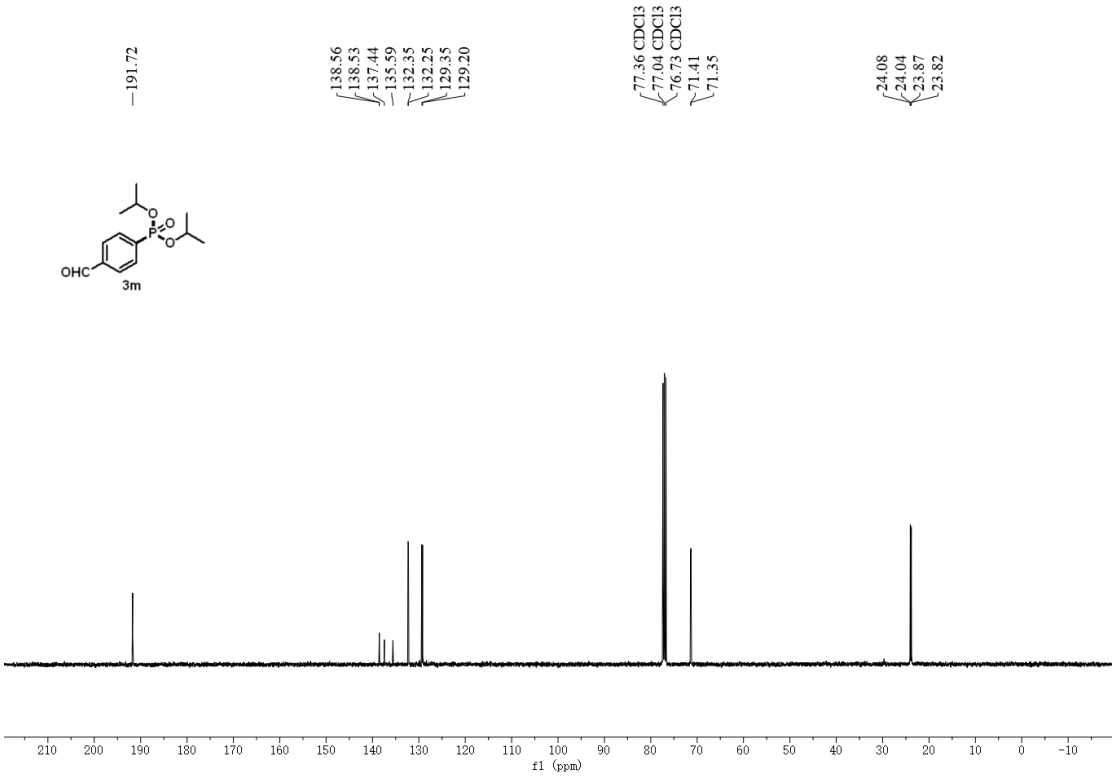

## $^{31}P$ NMR (121 MHz, $CDCl_3$) spectrum for 3l



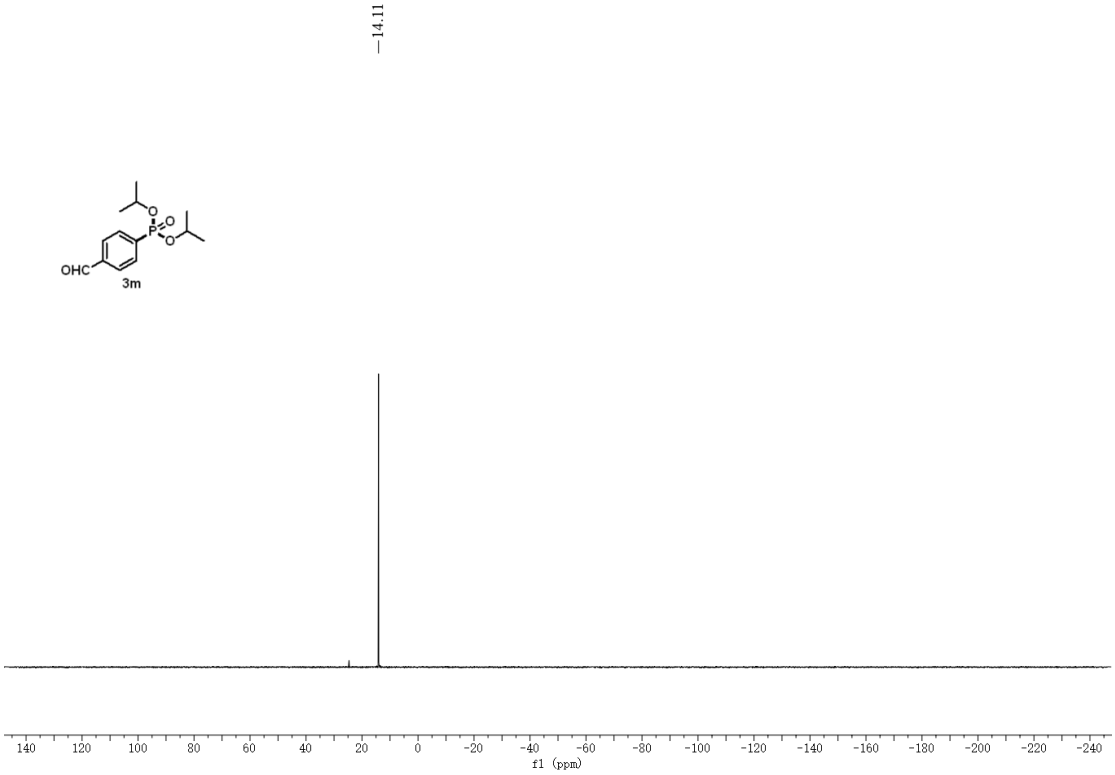
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3m



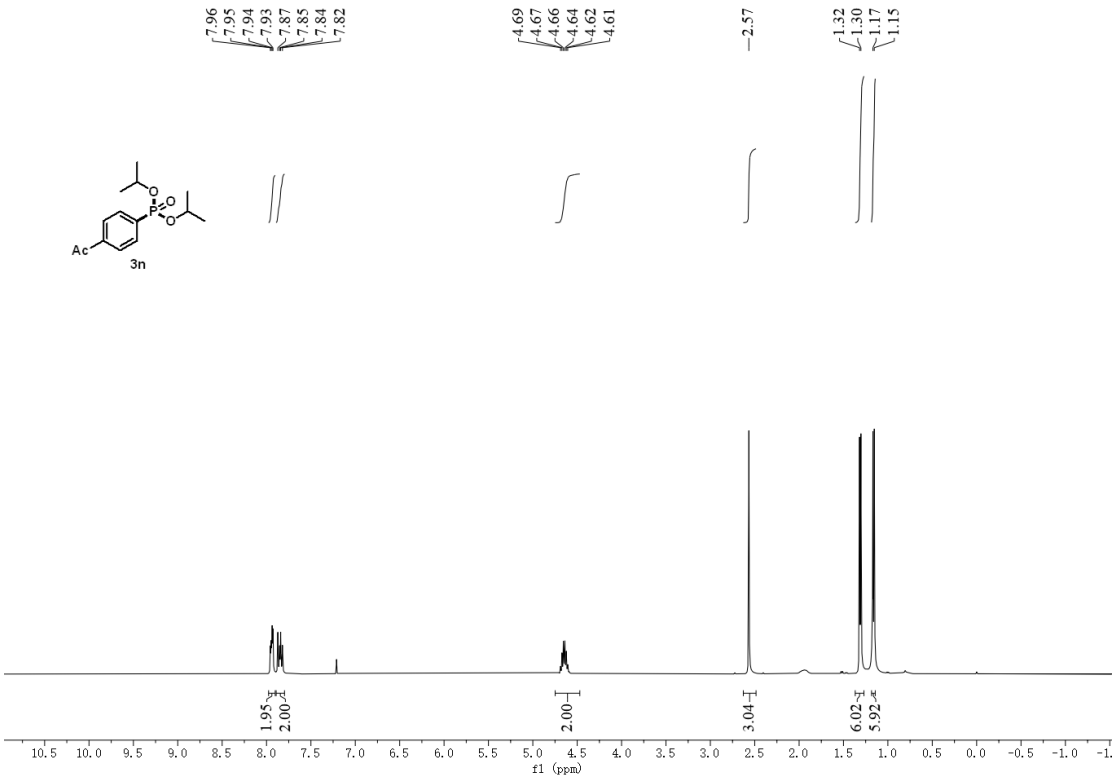

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 3m



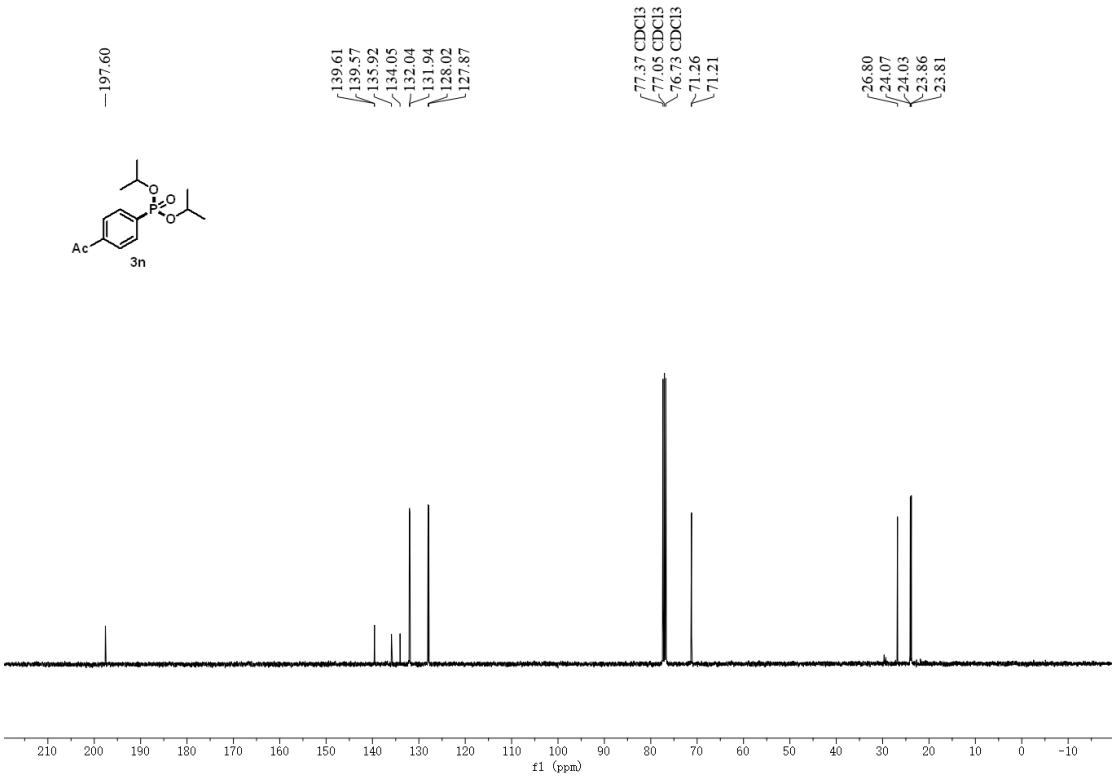
## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 3m



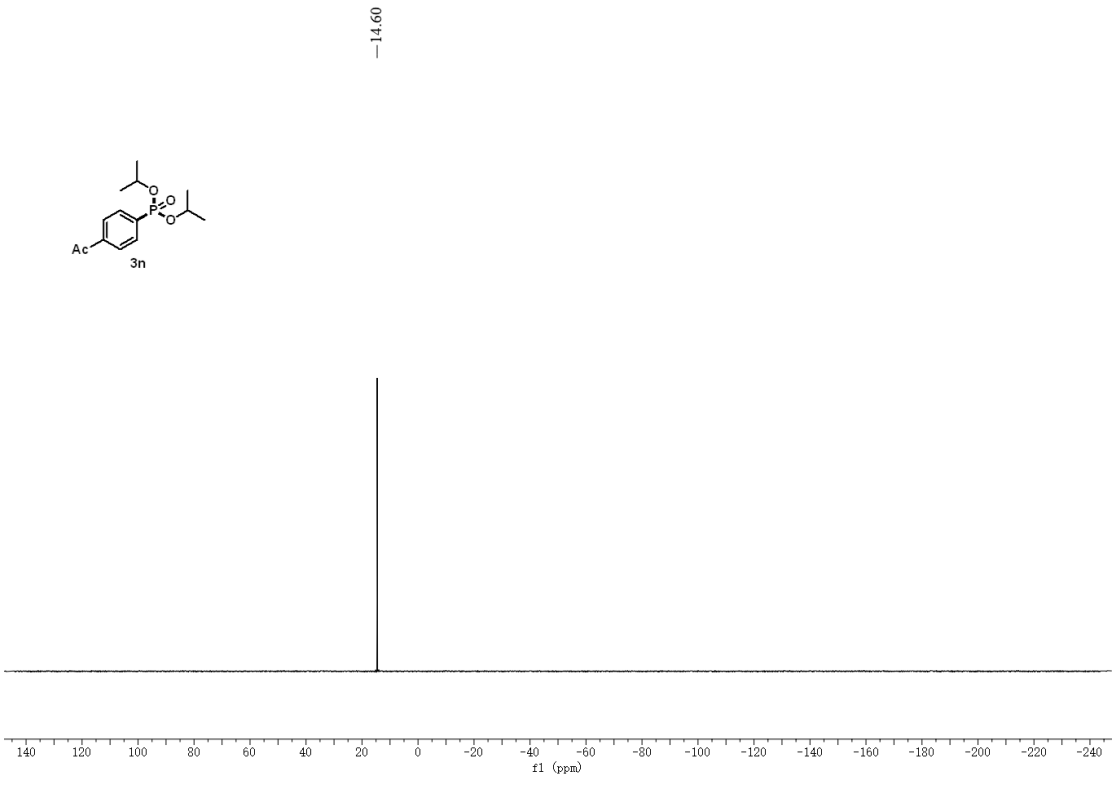

## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3n



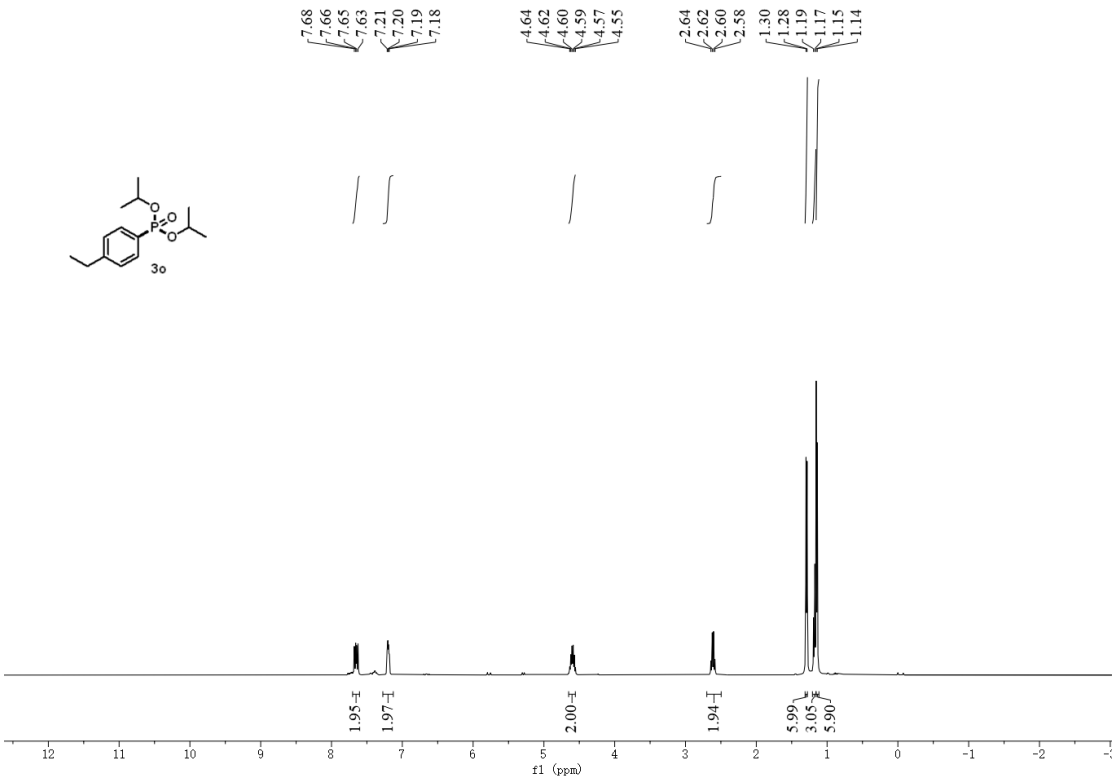
## $^{13}C$ NMR (101 MHz, $CDCl_3$) spectrum for 3n



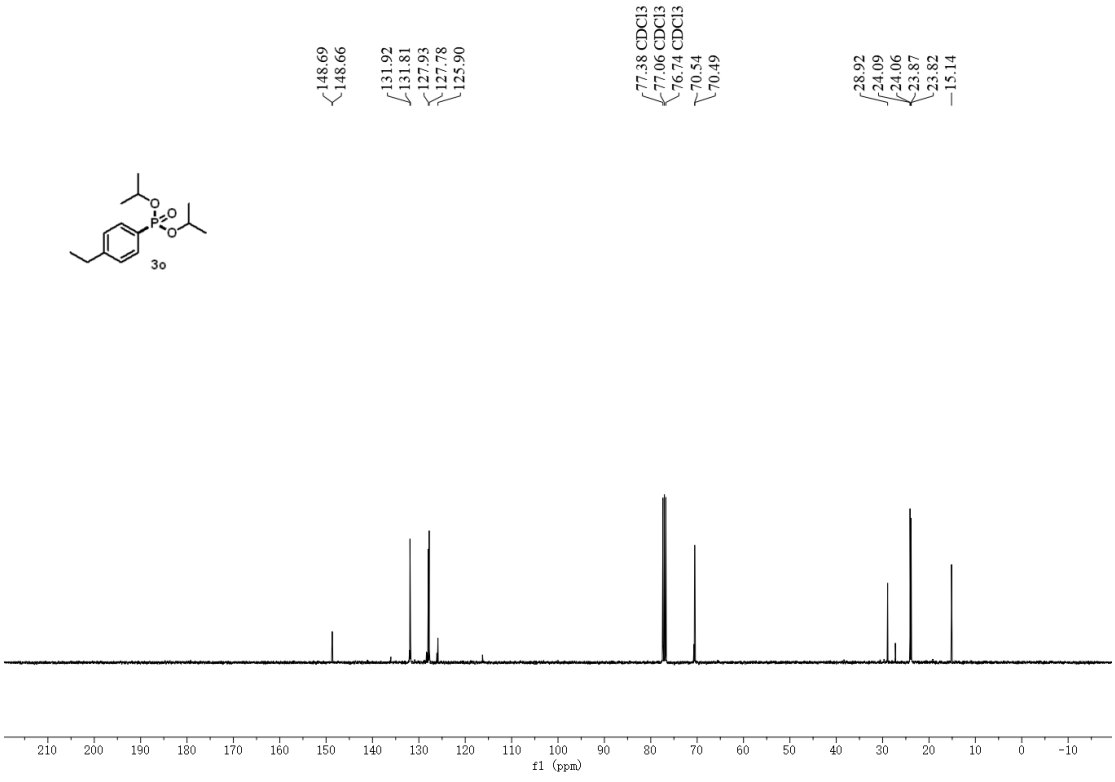

## $^{31}P$ NMR (121 MHz, $CDCl_3$) spectrum for 3n



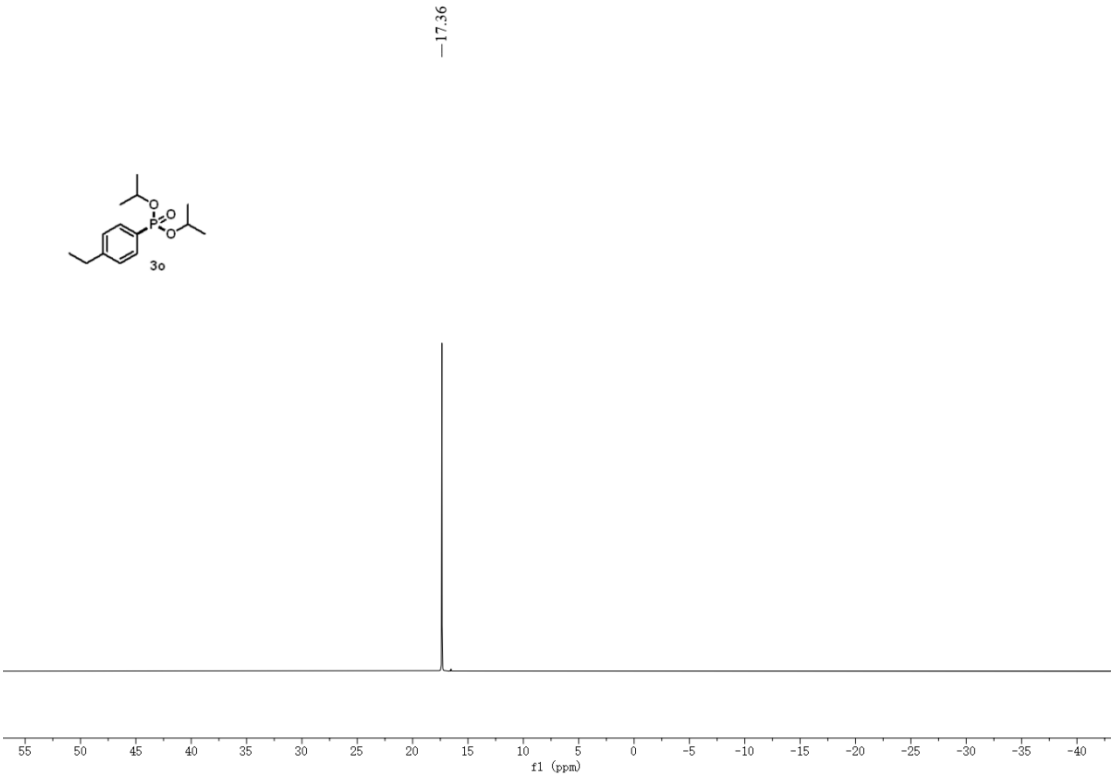
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3o



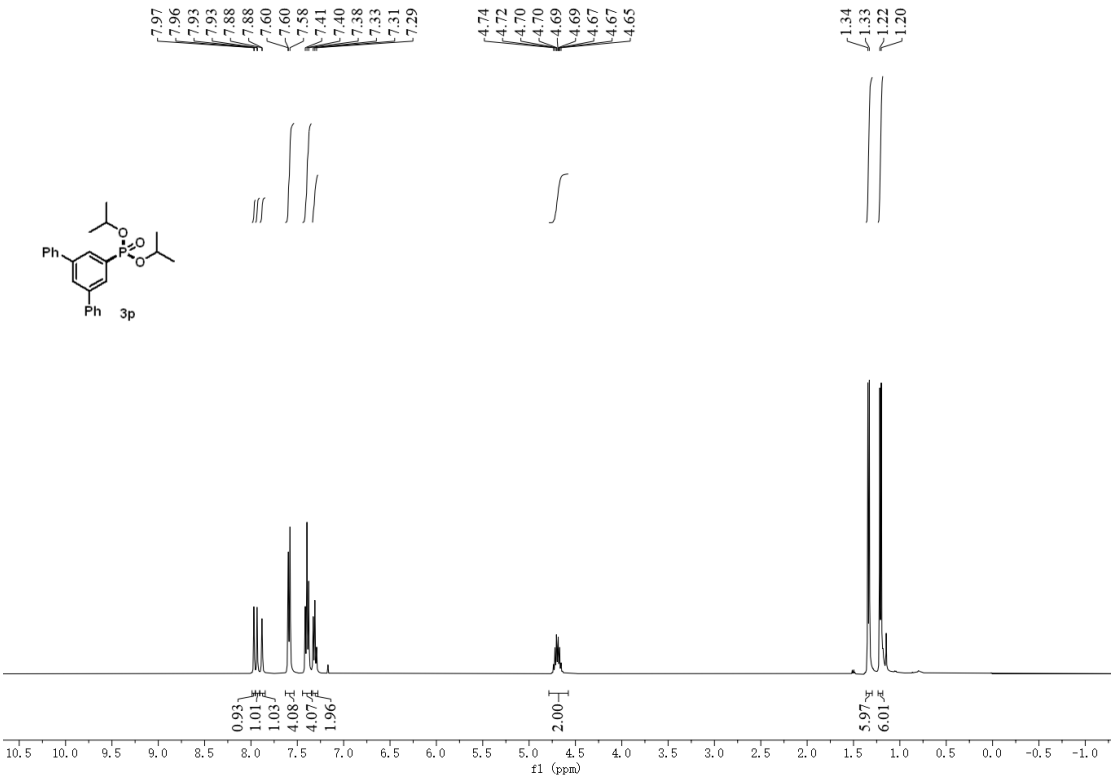

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 3o



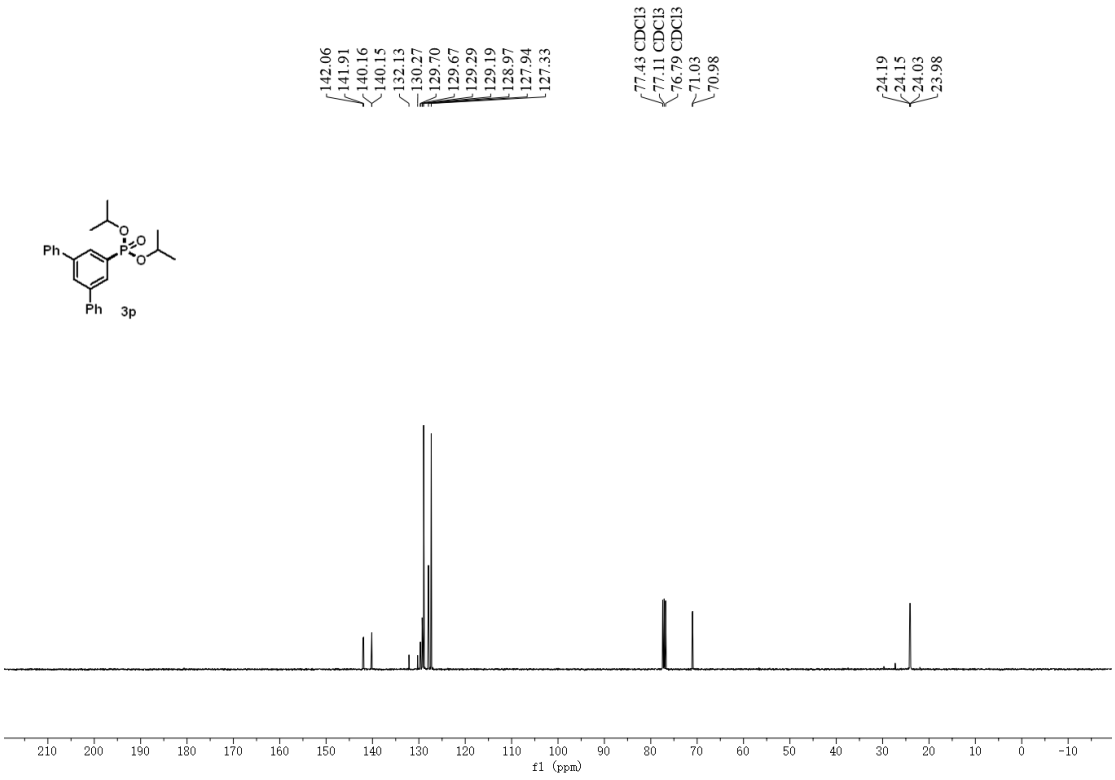
## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 3o



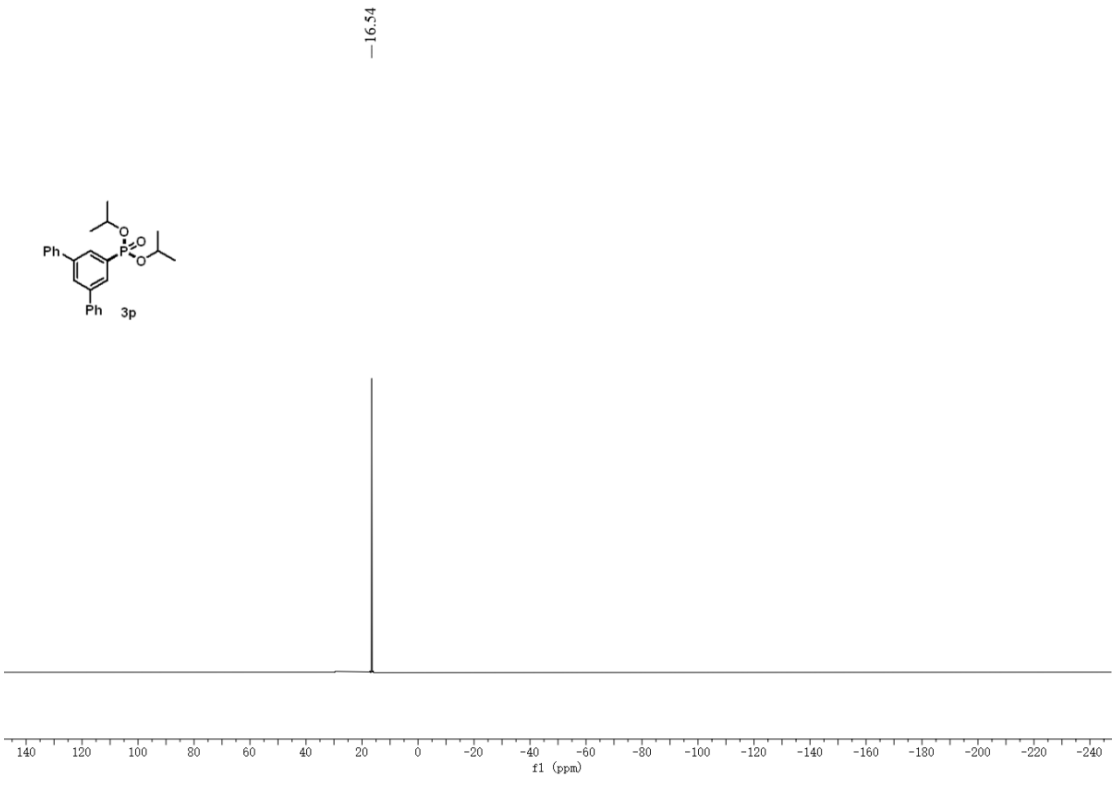

## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3p



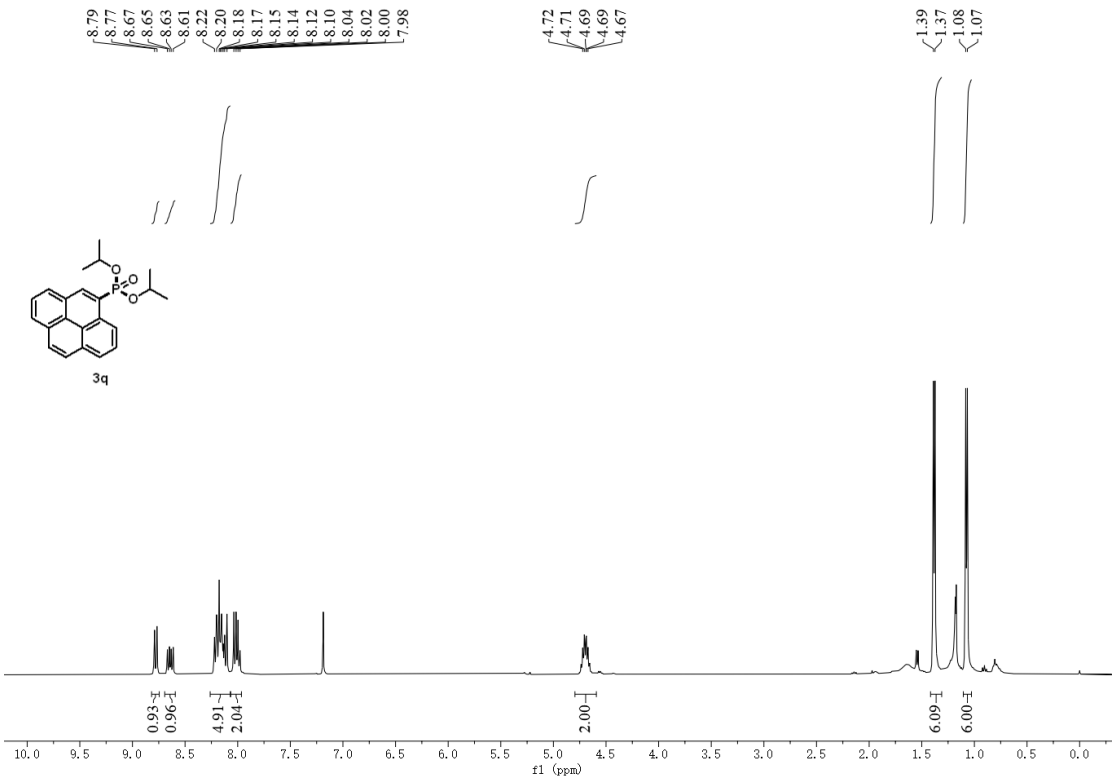
## $^{13}C$ NMR (101 MHz, $CDCl_3$) spectrum for 3p



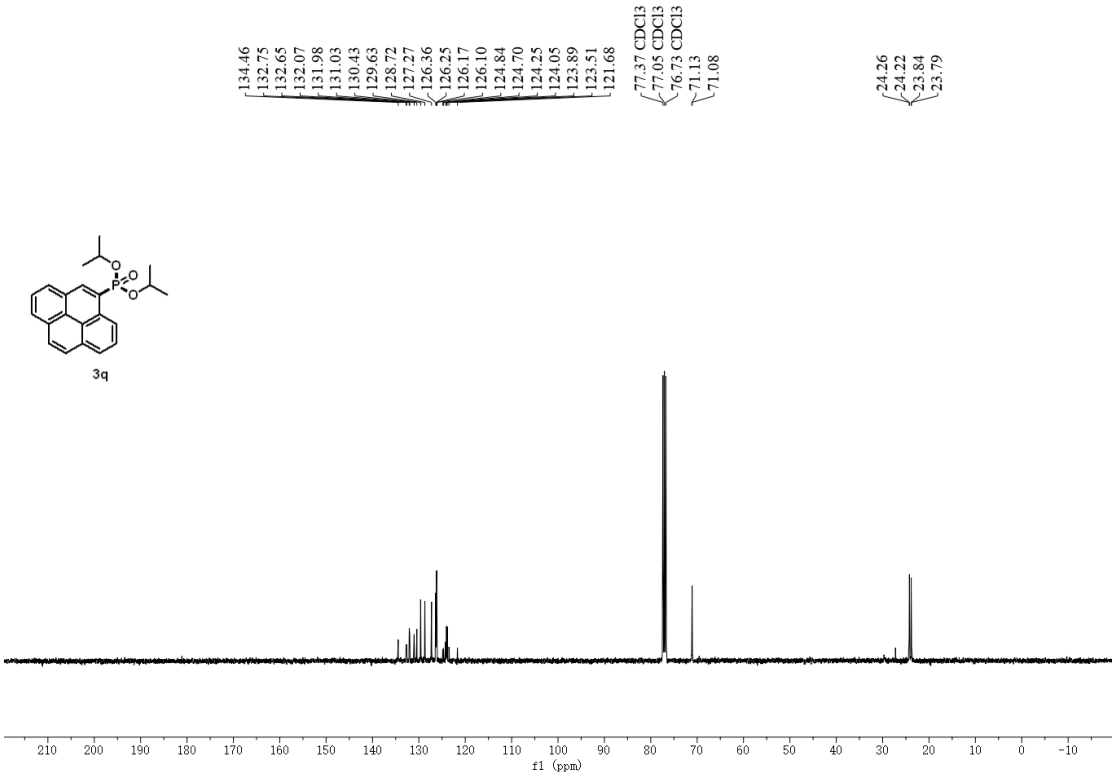

## $^{31}P$ NMR (121 MHz, $CDCl_3$) spectrum for 3p



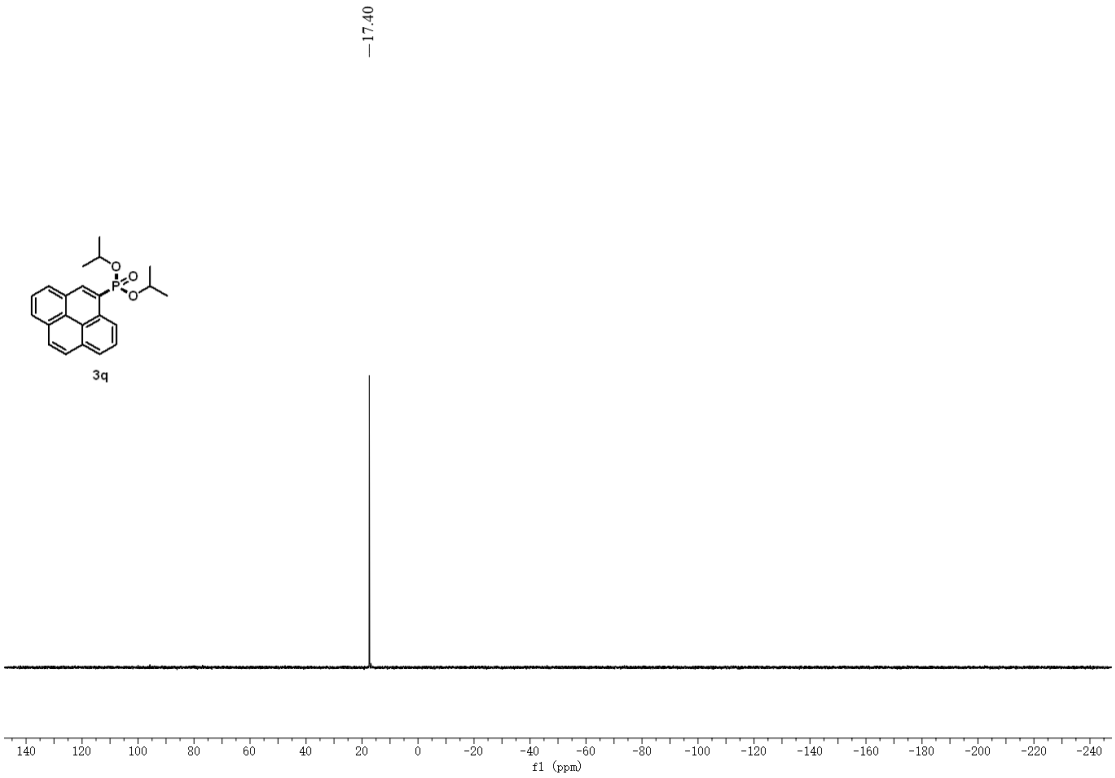
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3q



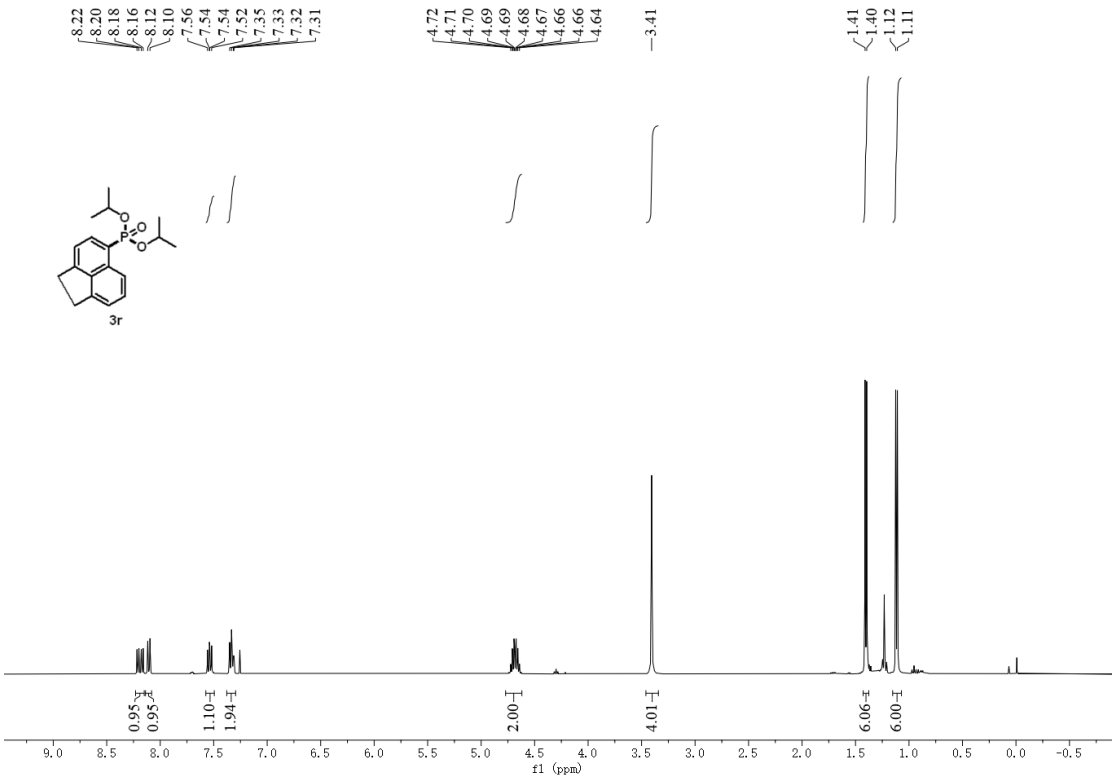

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 3q



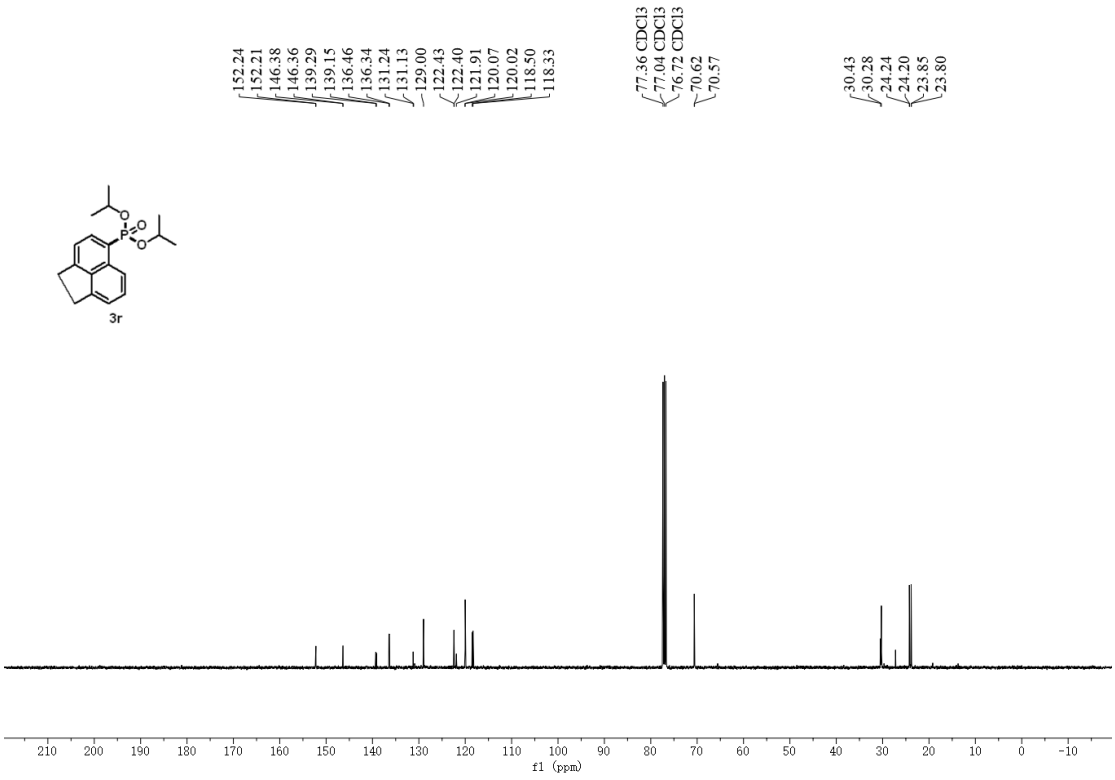
**$^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 3q**



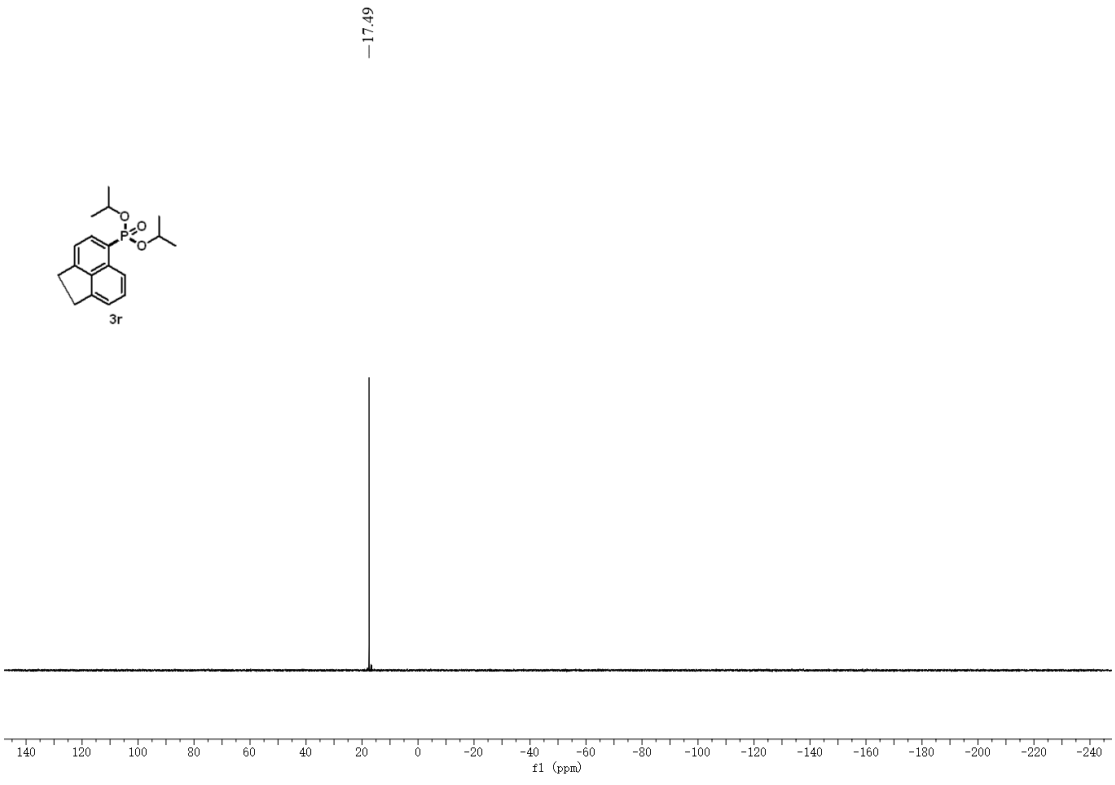

**$^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3r**



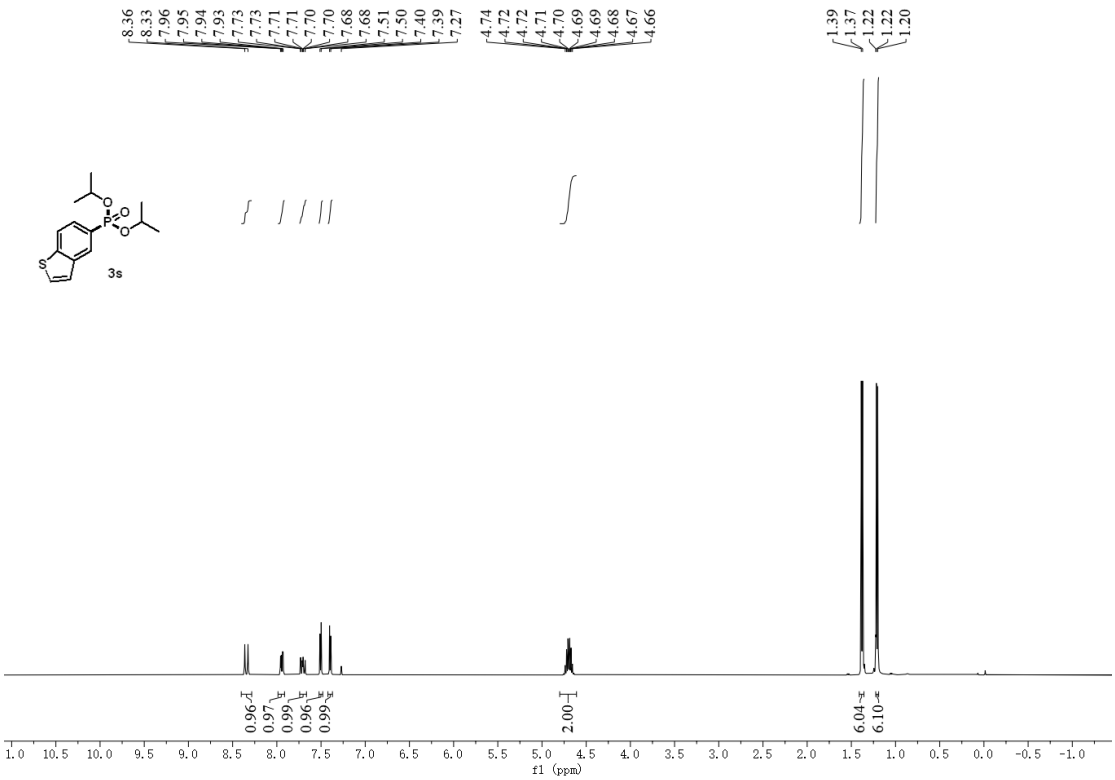
## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 3r



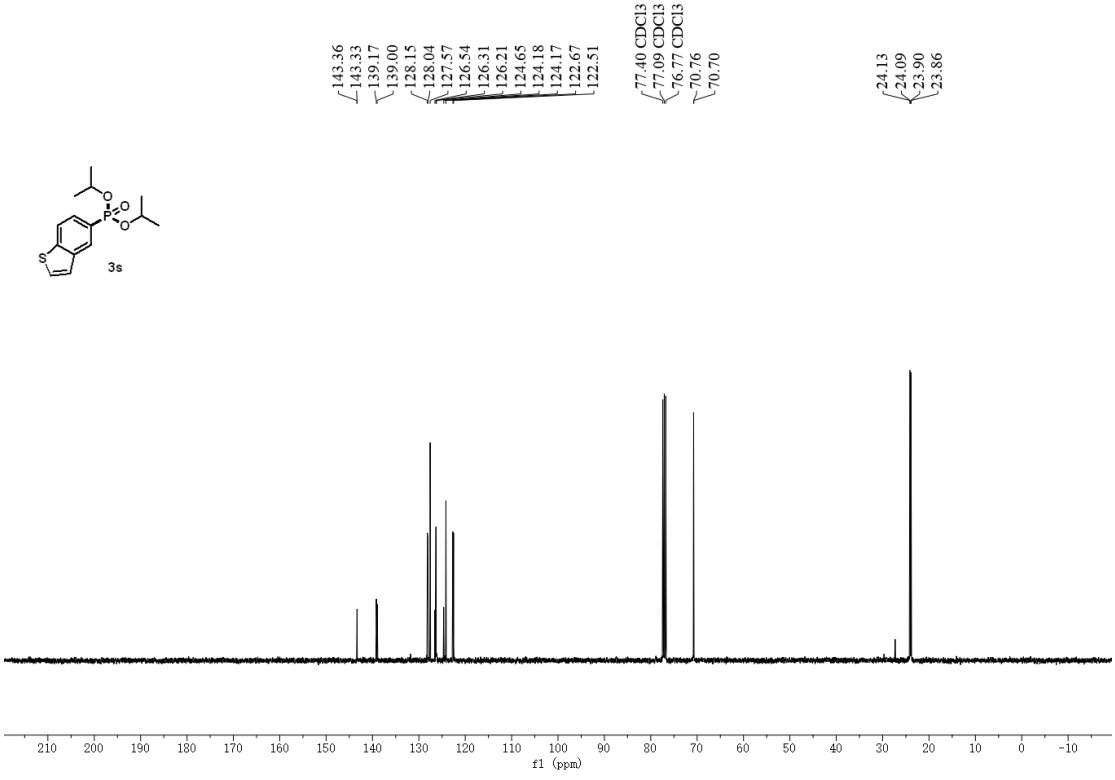

## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 3r



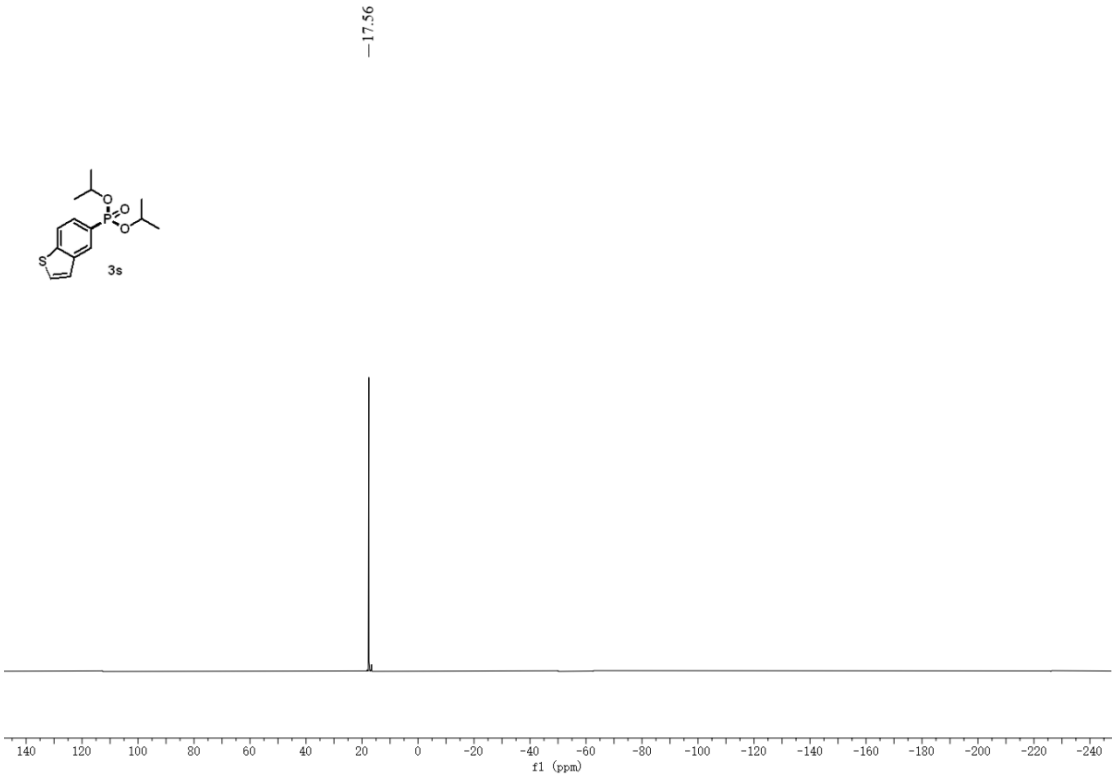
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3s



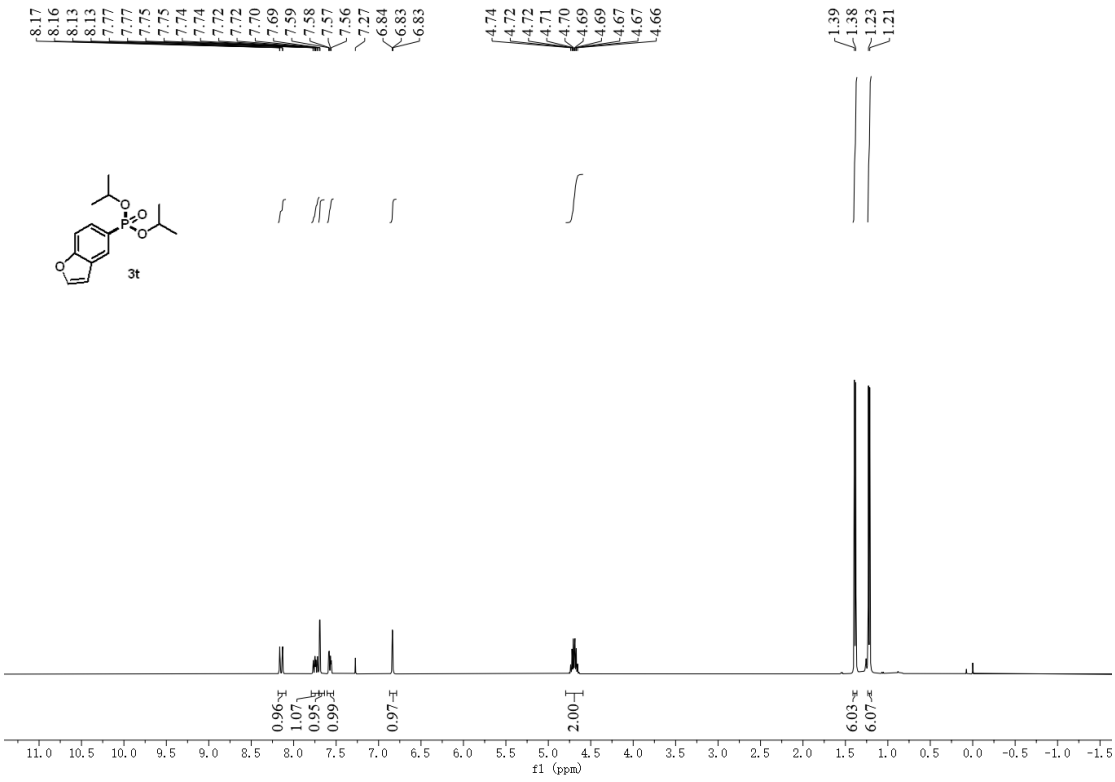

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 3s



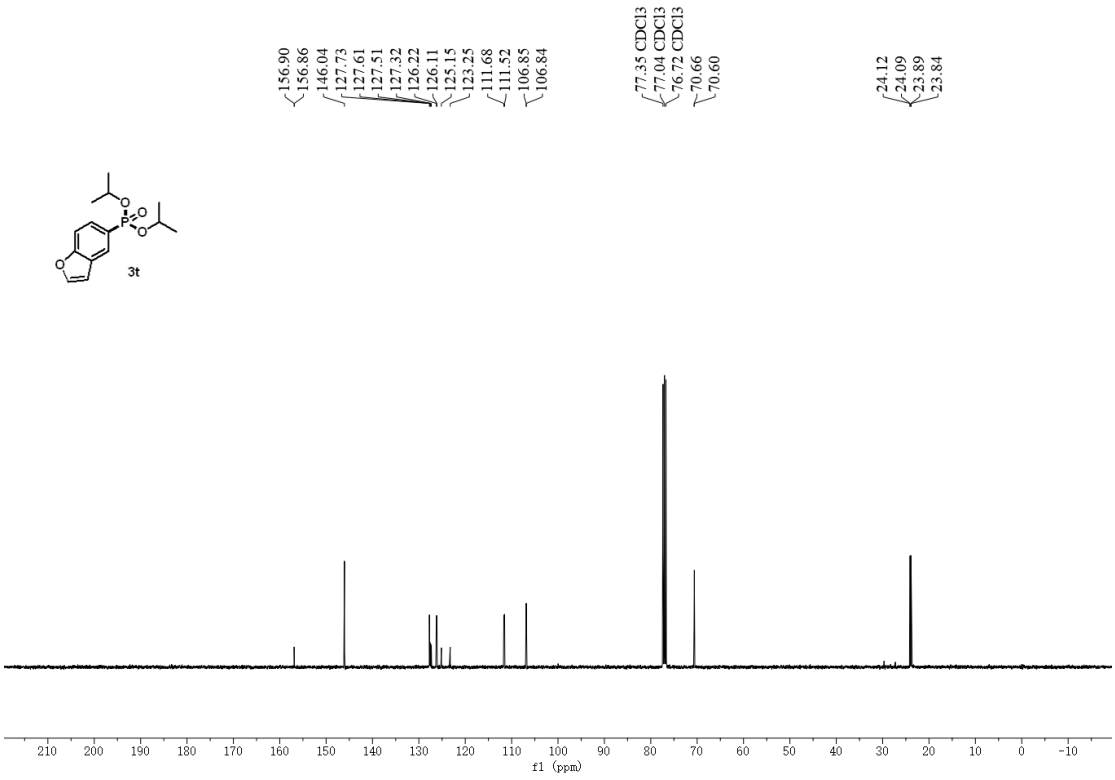
## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 3s



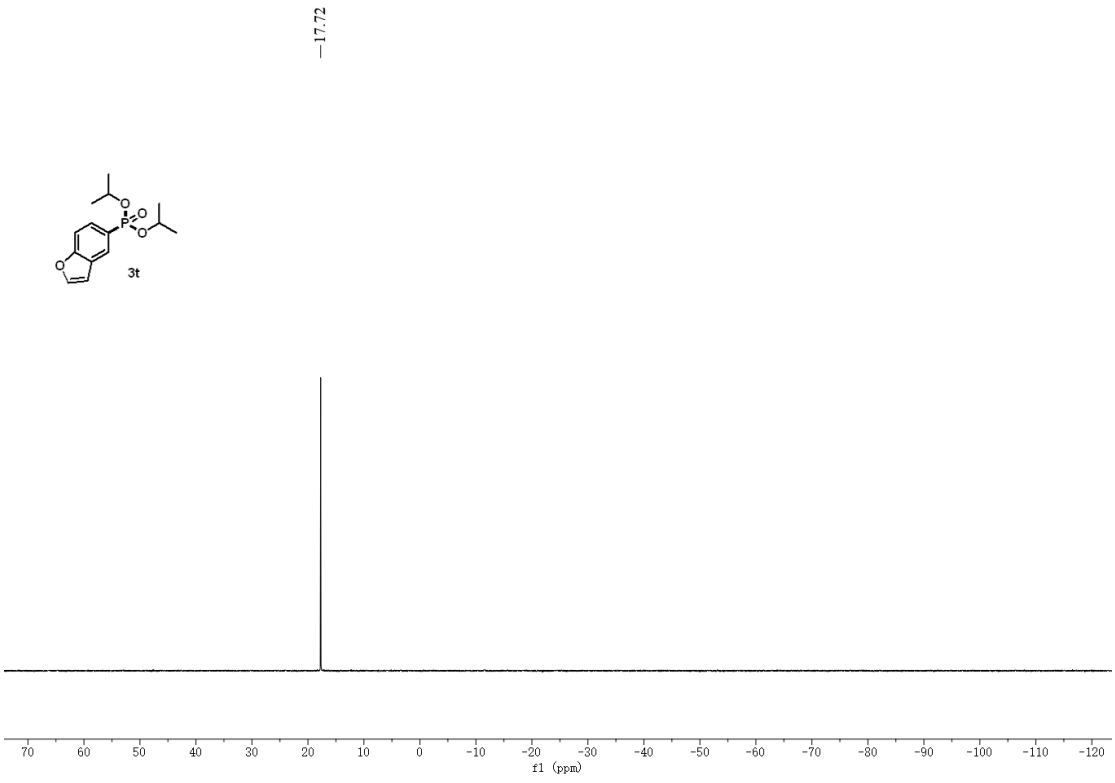

## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3t



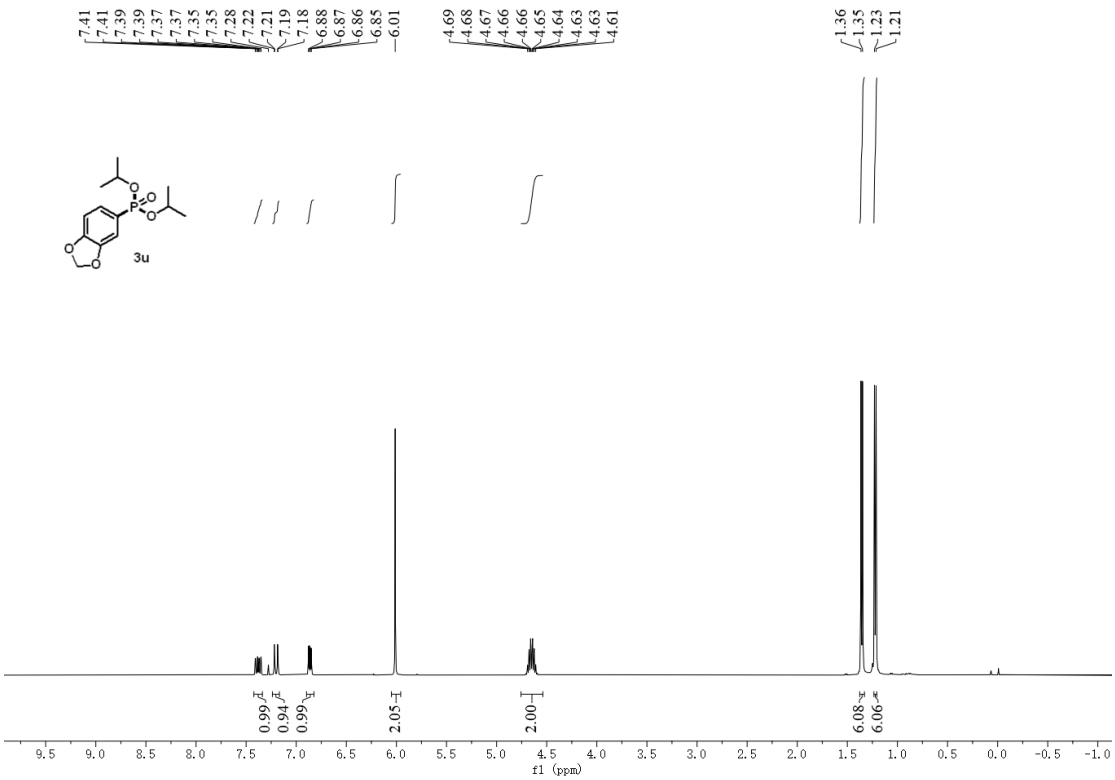
## $^{13}C$ NMR (101 MHz, $CDCl_3$) spectrum for 3t



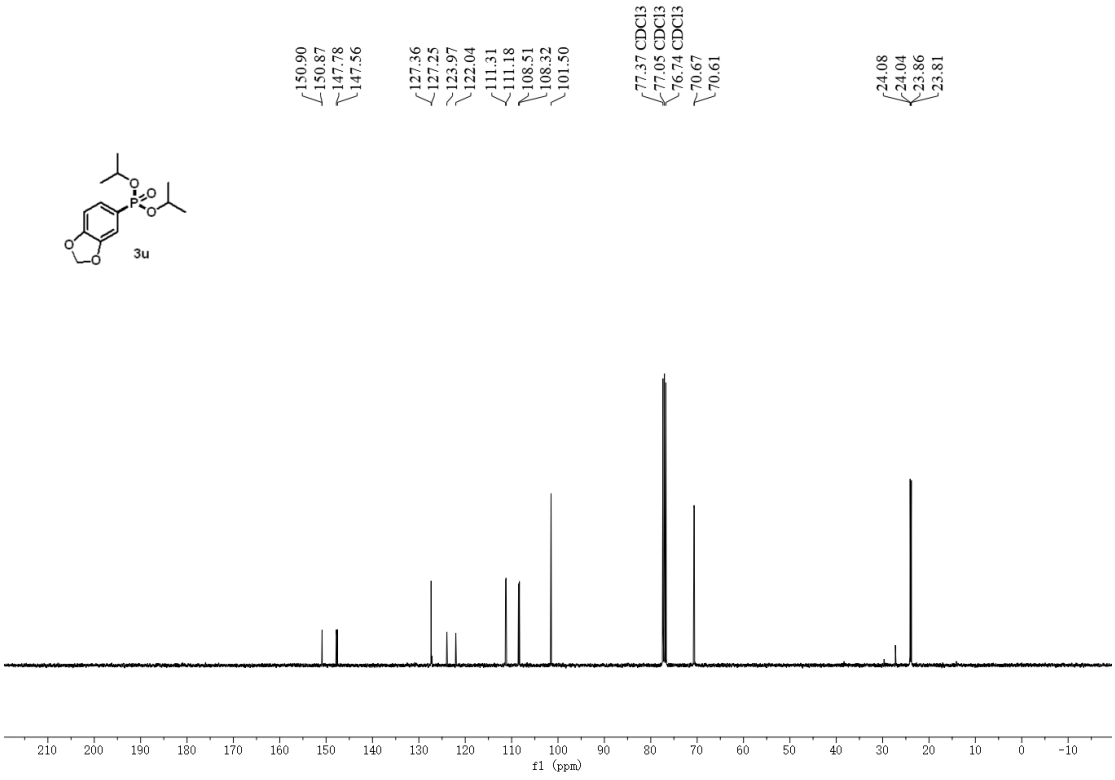

## $^{31}P$ NMR (121 MHz, $CDCl_3$) spectrum for 3t



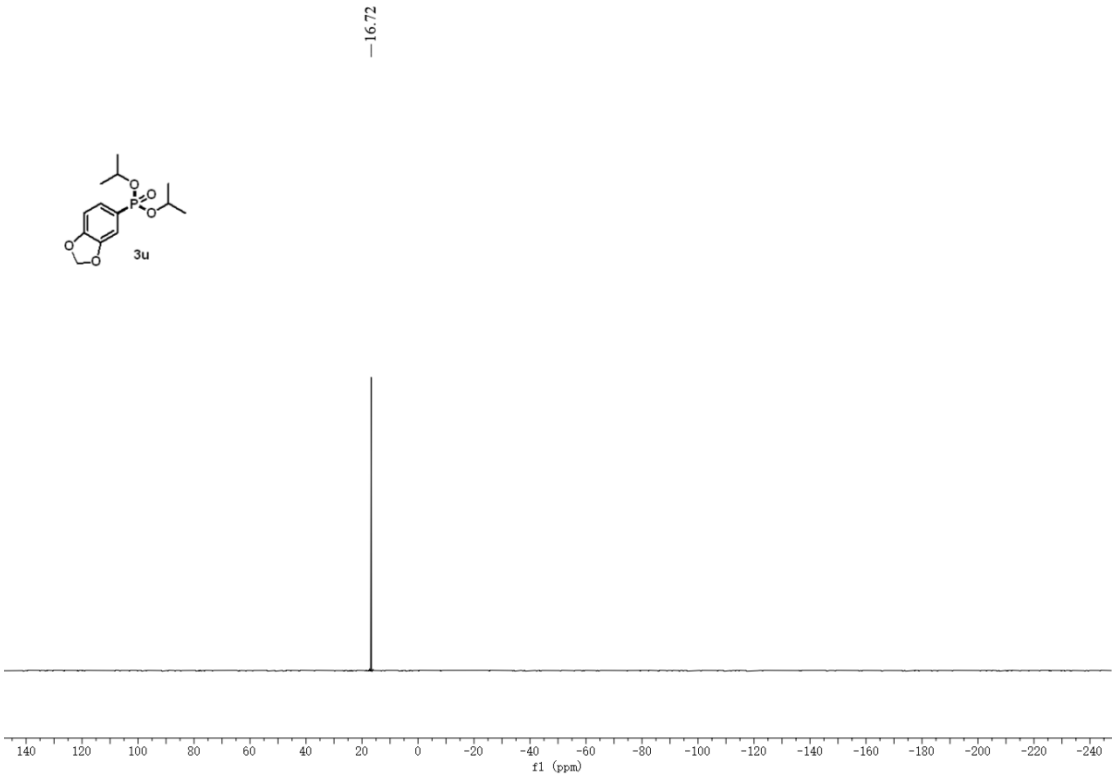
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3u



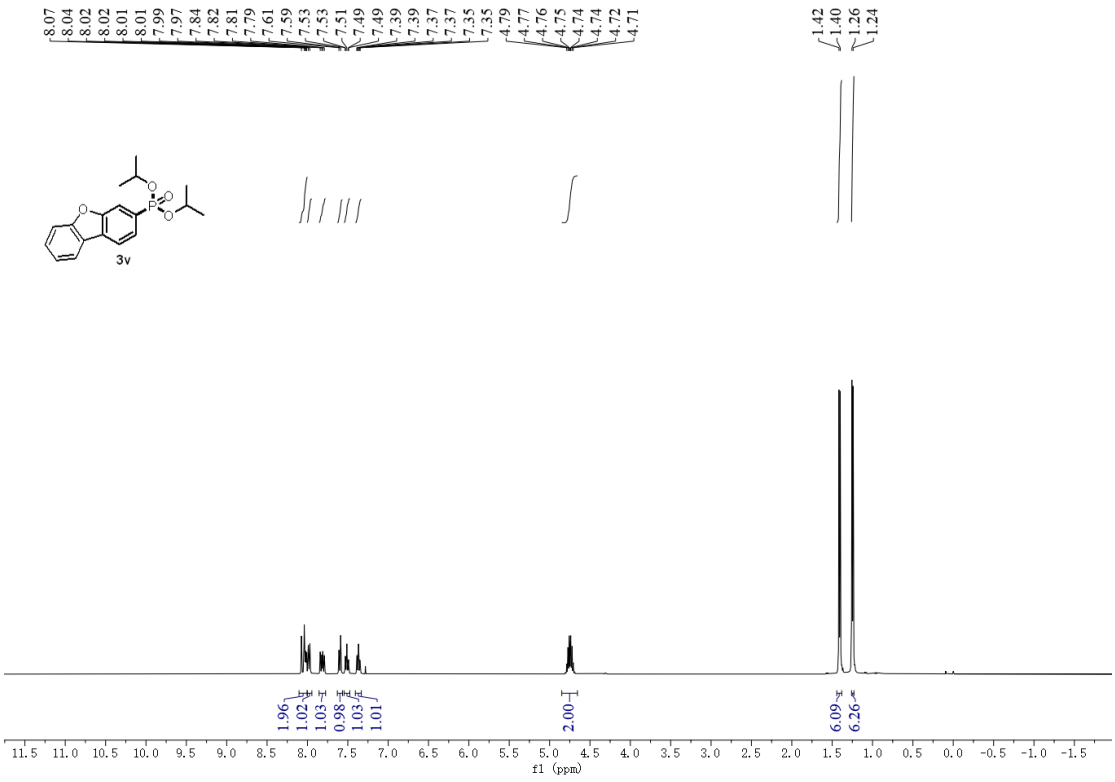

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 3u



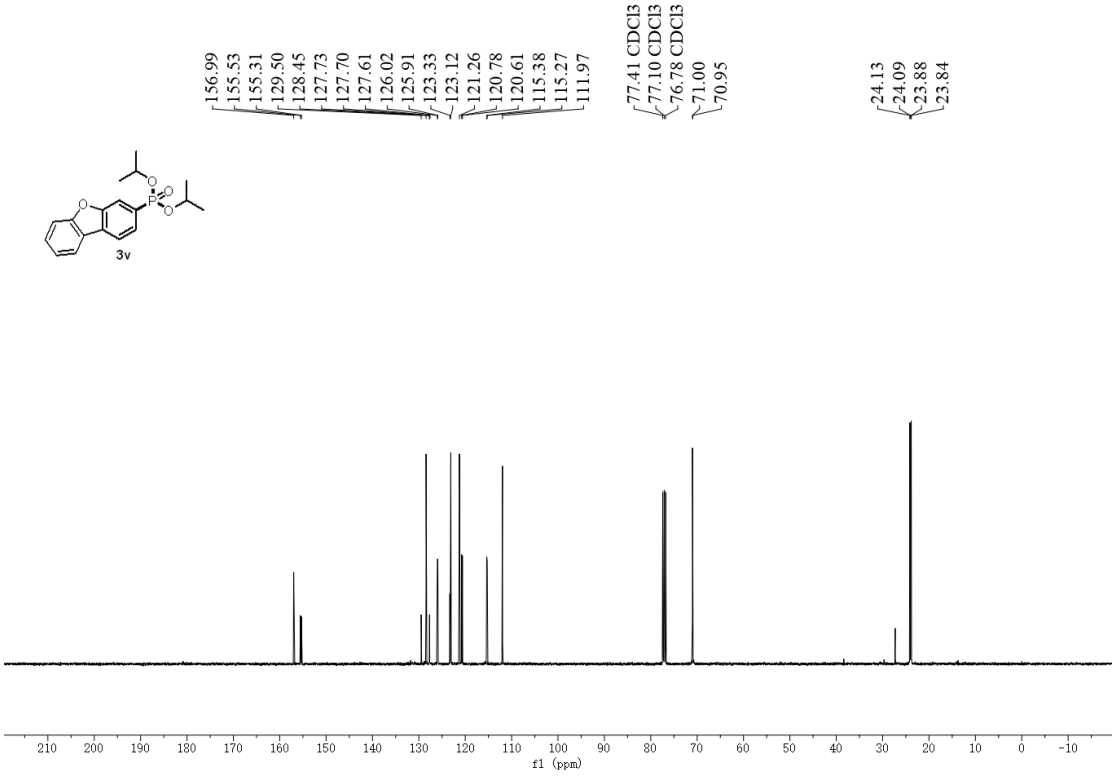
## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 3u



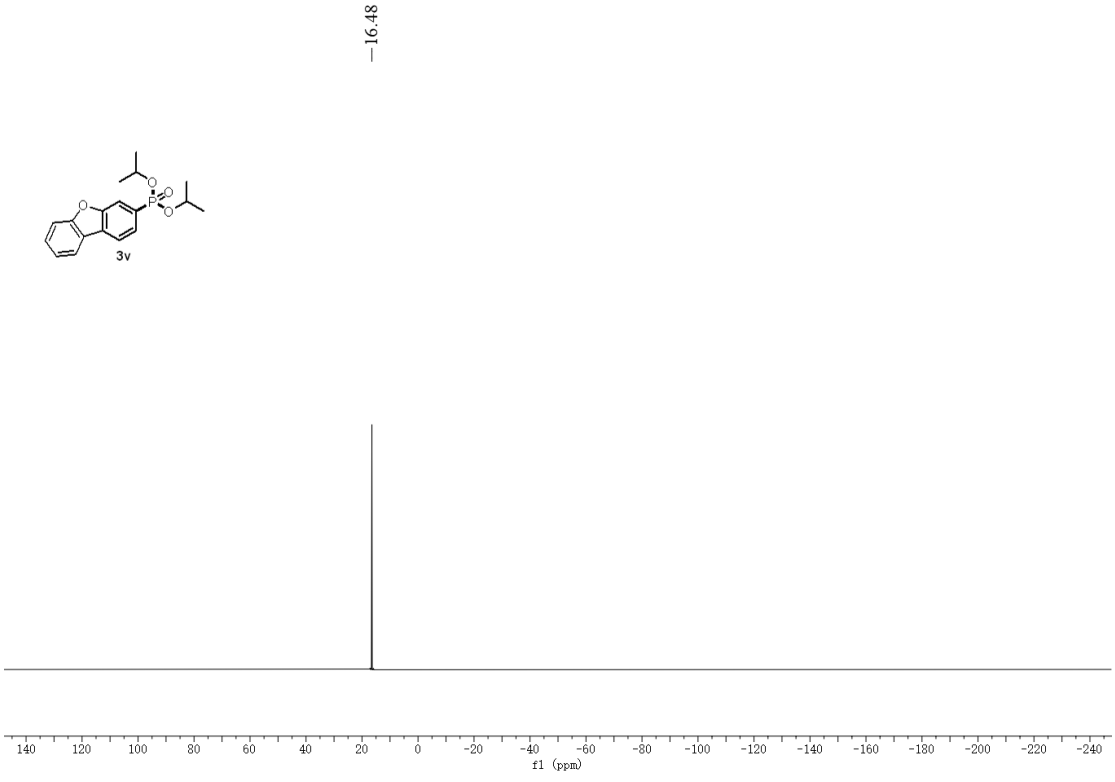

## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3v



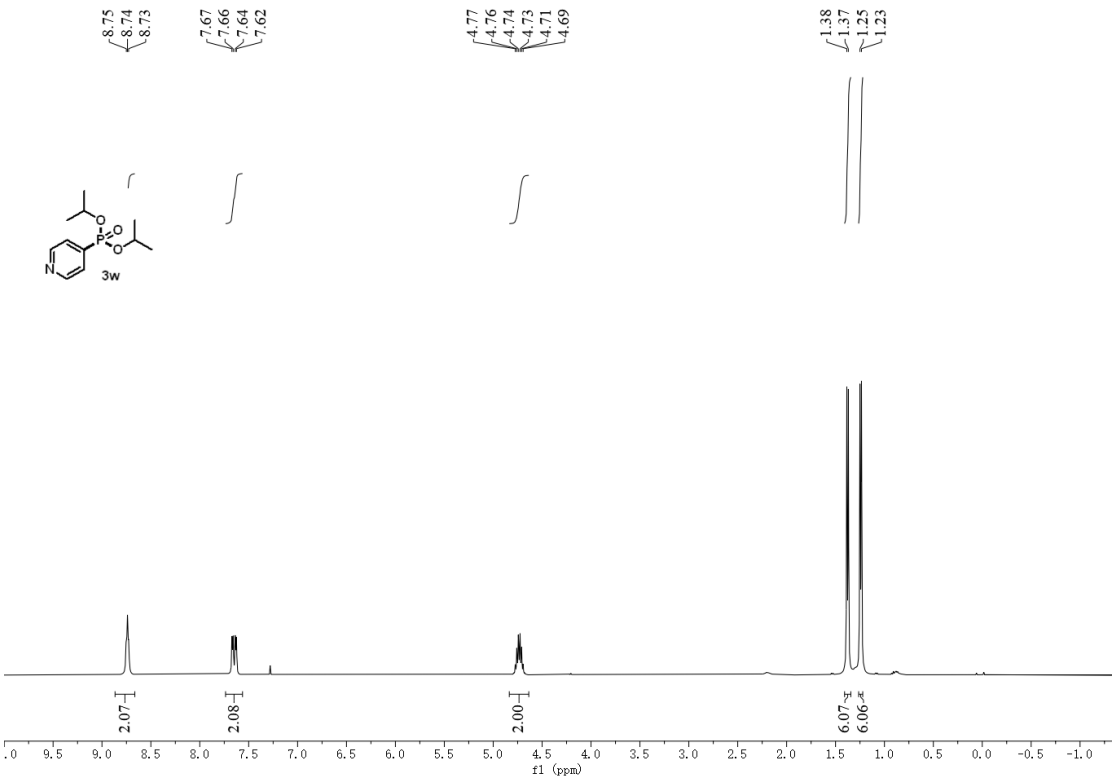
## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 3v



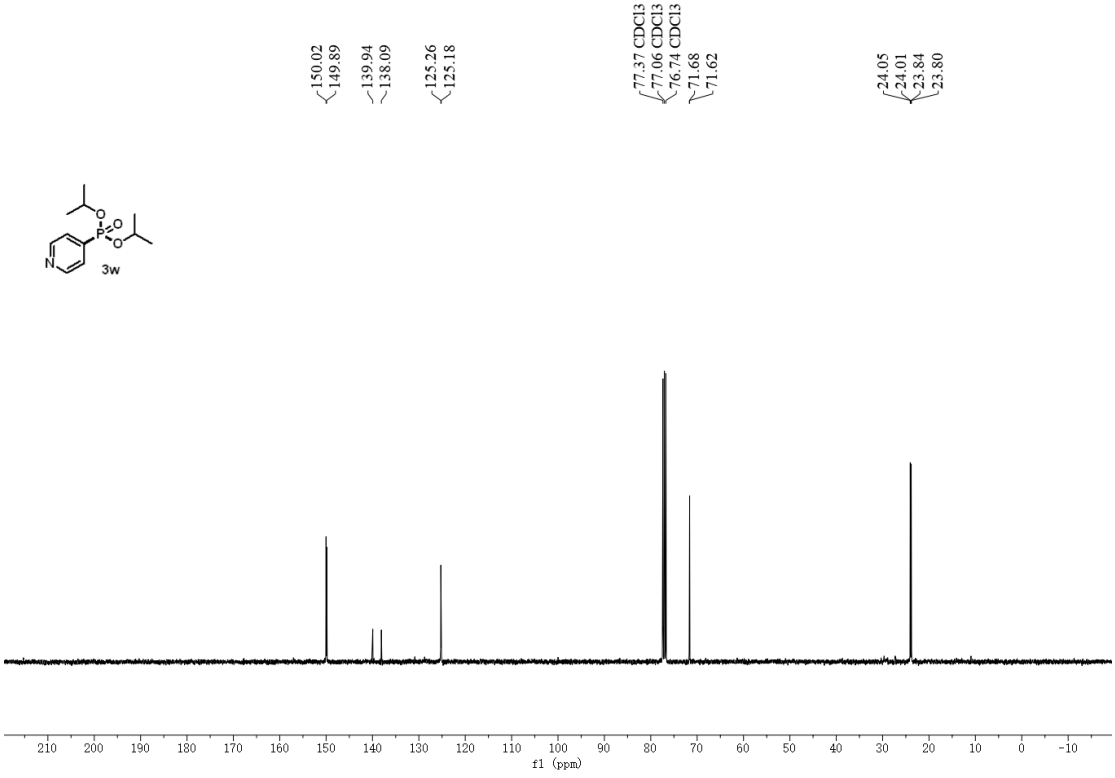

## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 3v



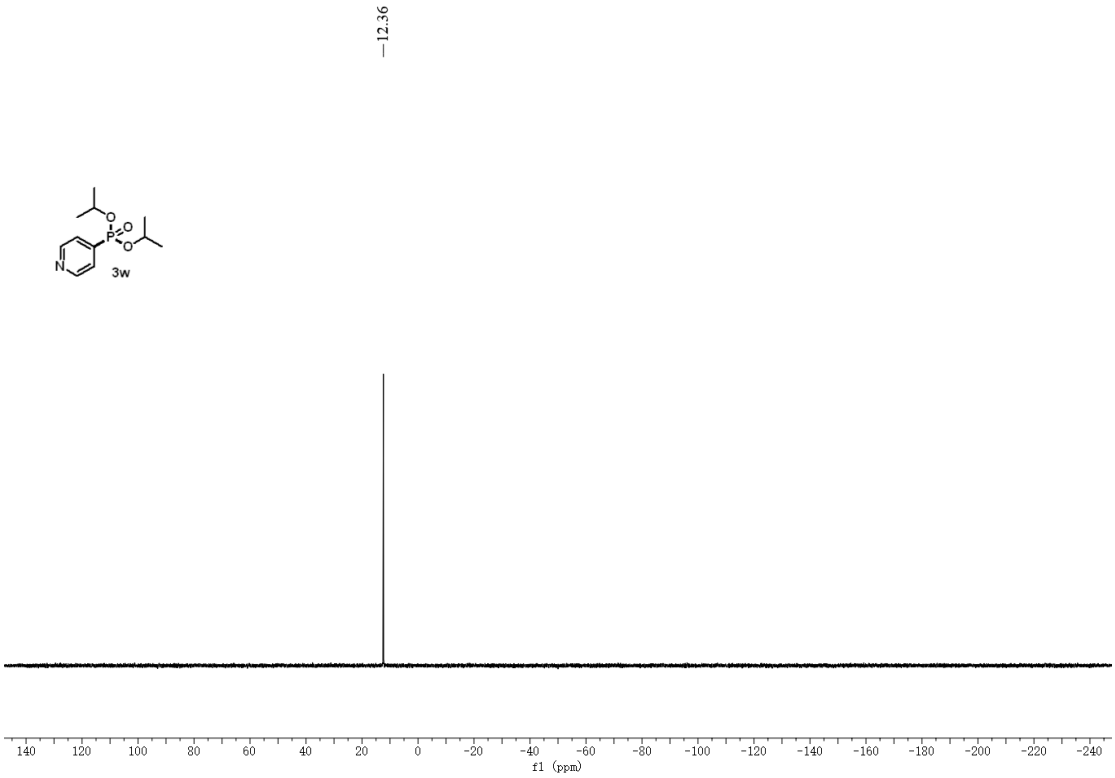
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3w



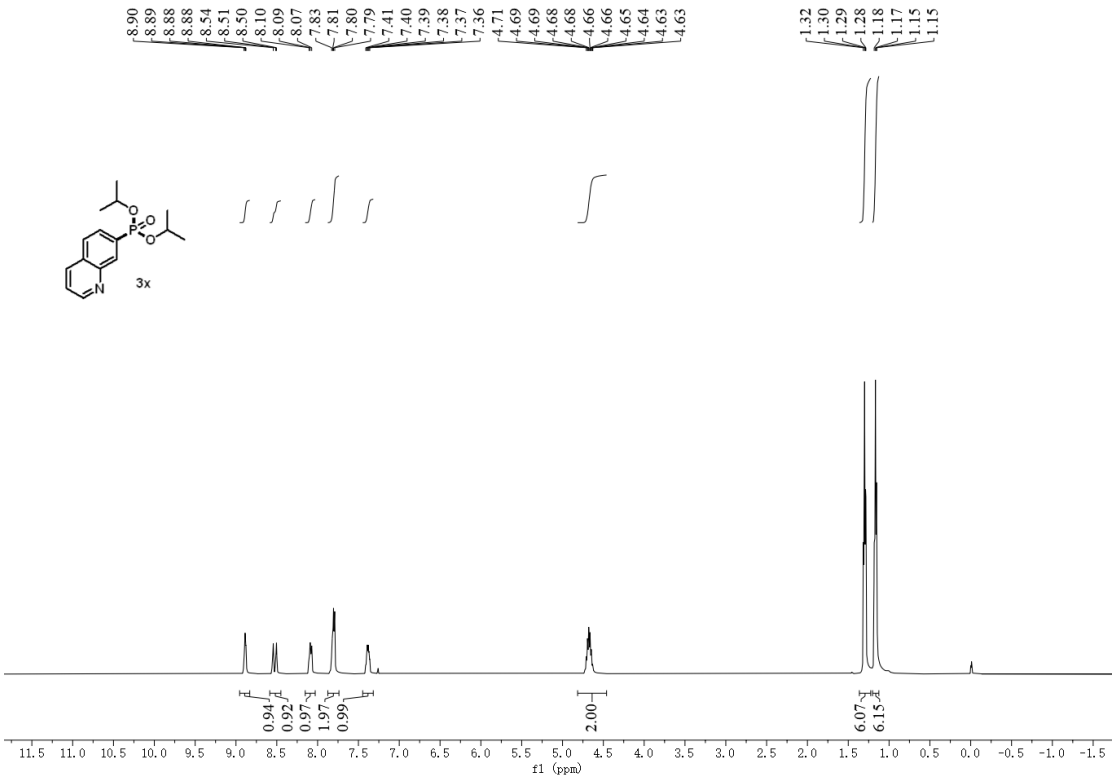

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 3w



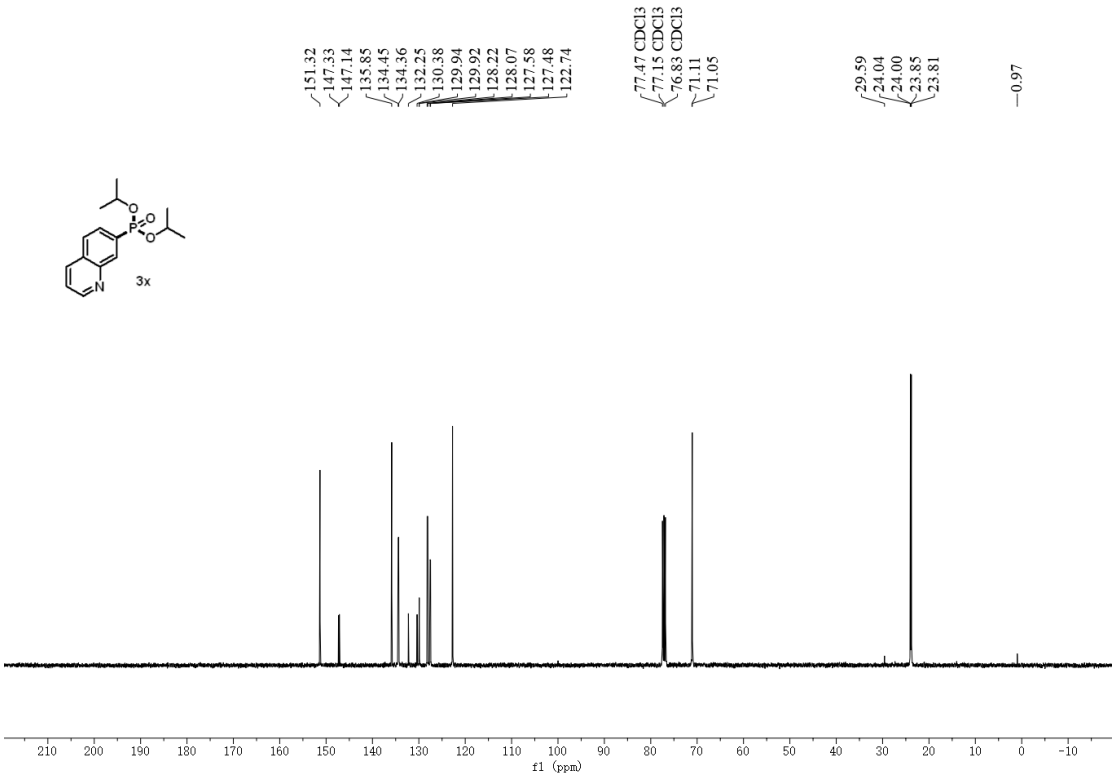
## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 3w



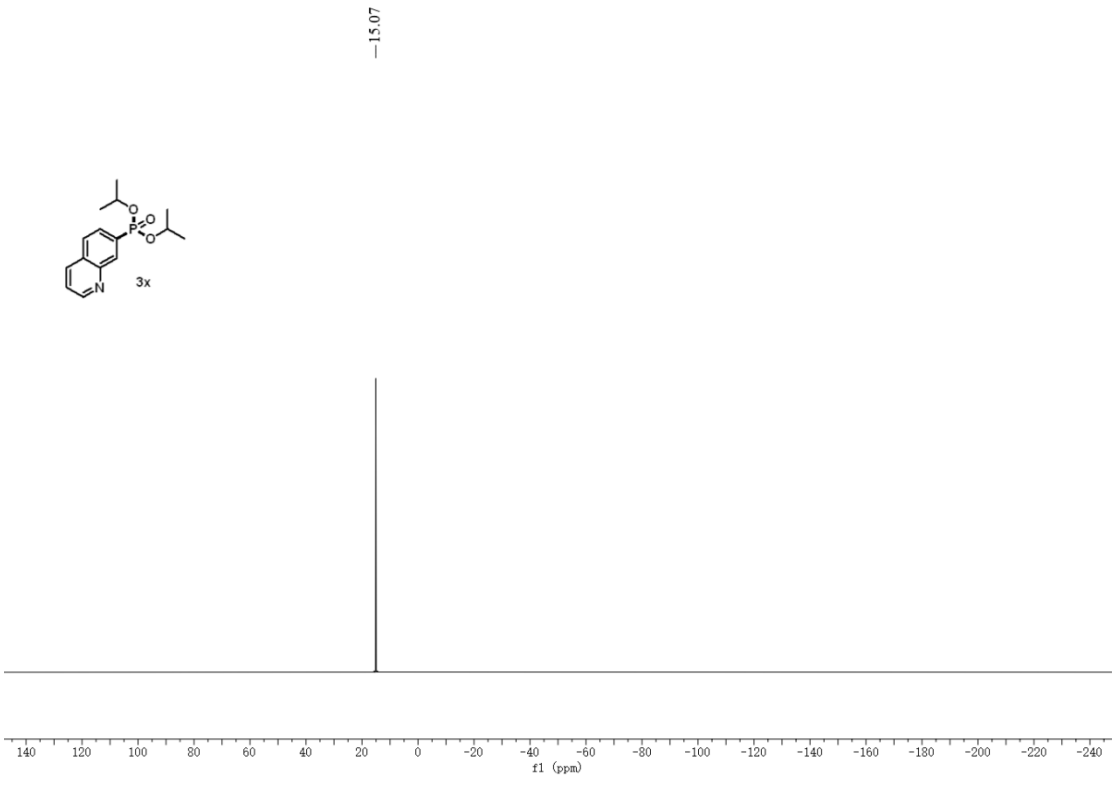

## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3x



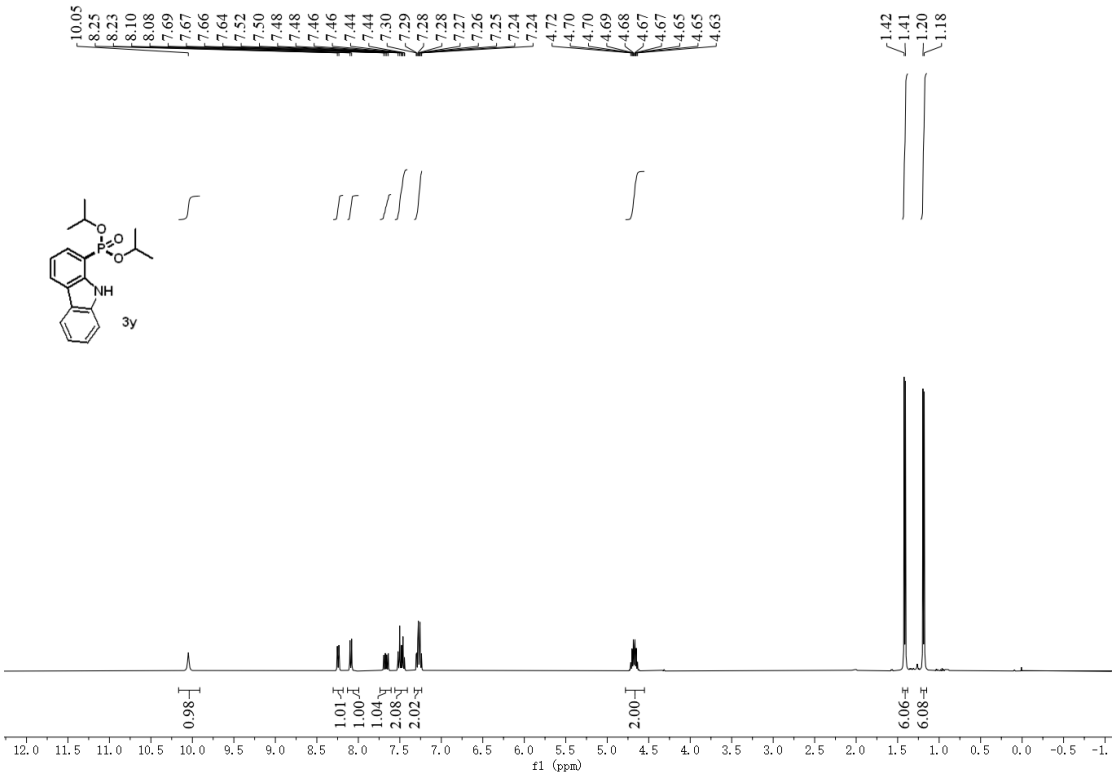
## $^{13}C$ NMR (101 MHz, $CDCl_3$) spectrum for 3x



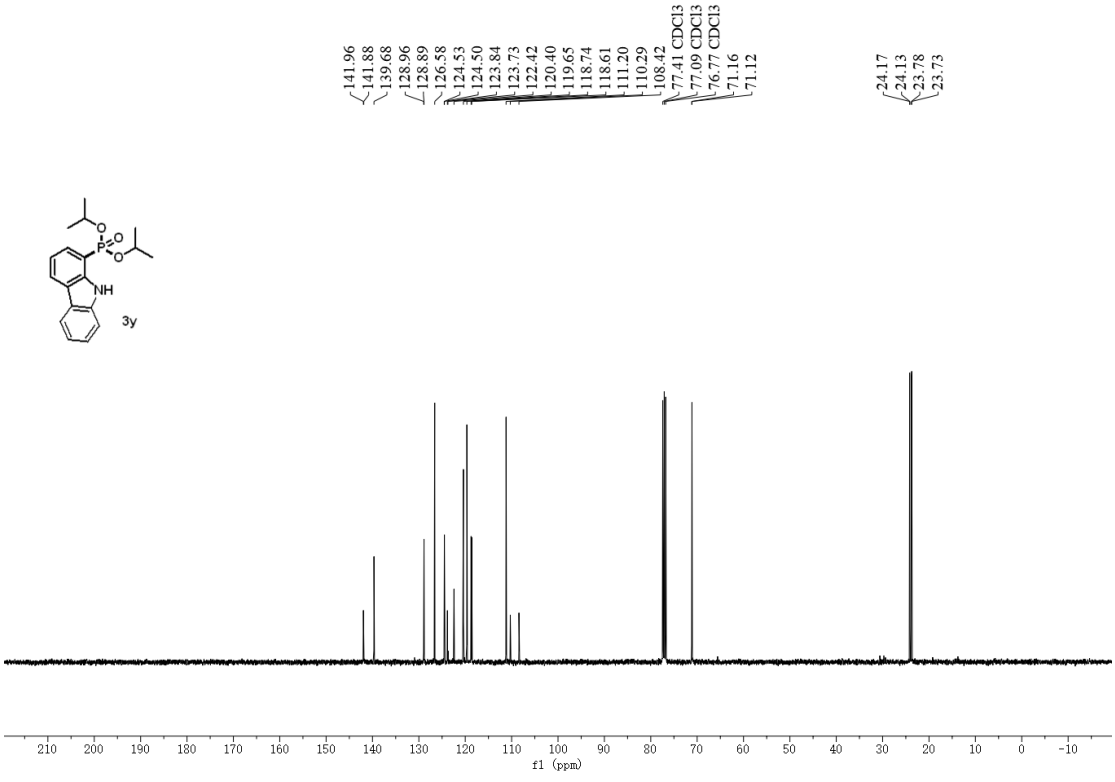

## $^{31}P$ NMR (121 MHz, $CDCl_3$) spectrum for 3x



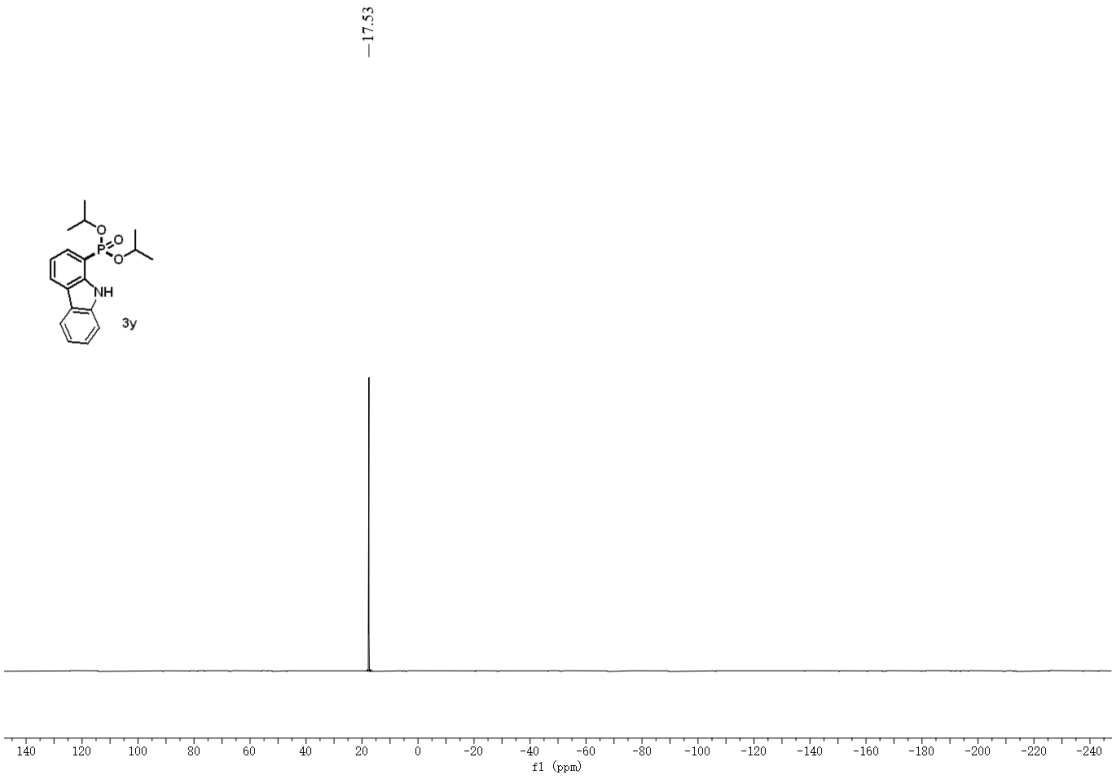
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3y



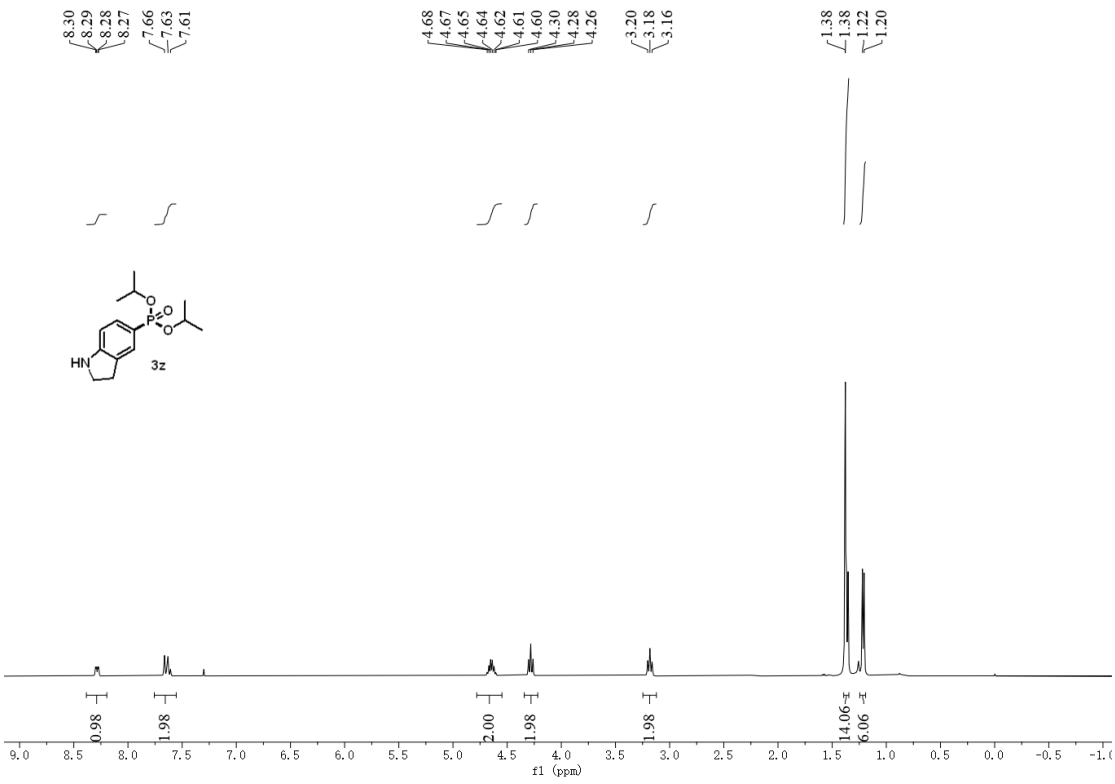

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 3y



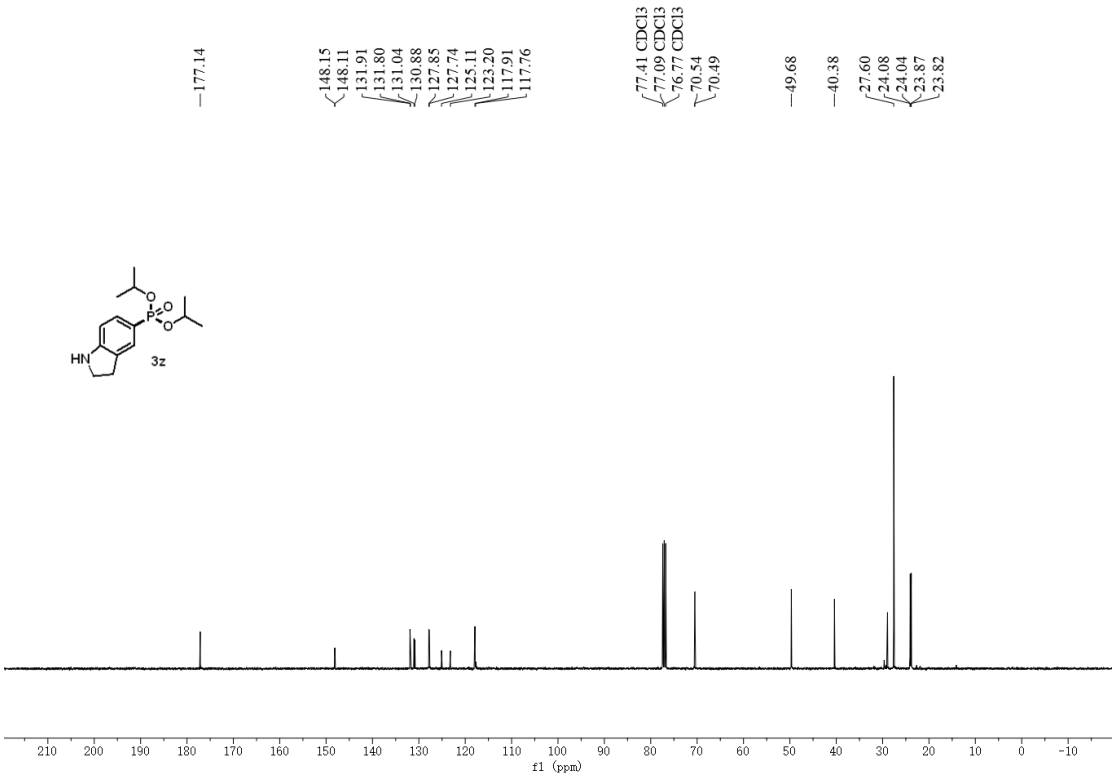
## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 3y



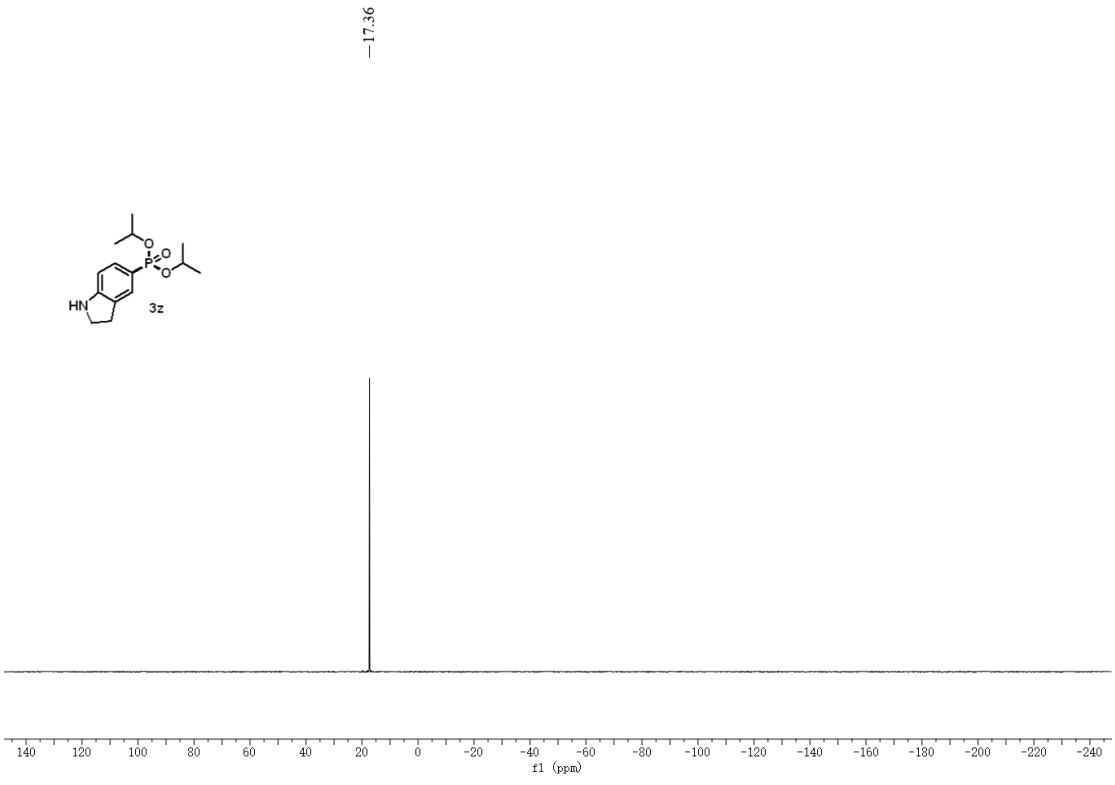

## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3z



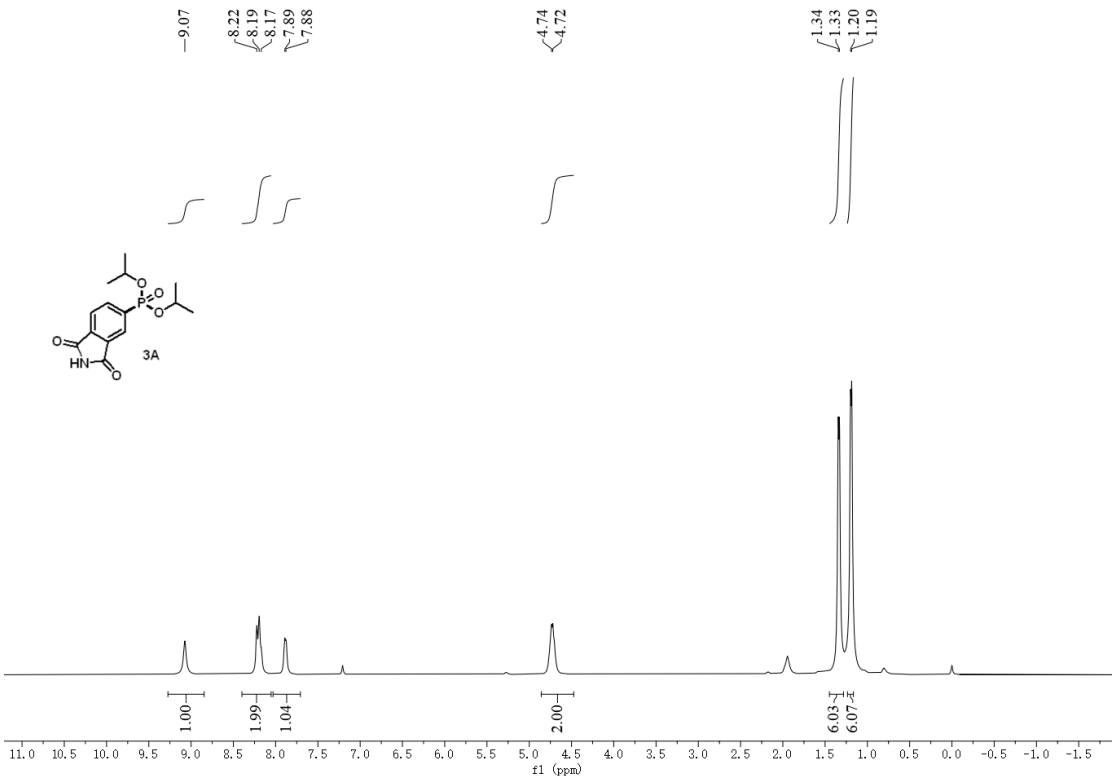
## $^{13}C$ NMR (101 MHz, $CDCl_3$) spectrum for 3z



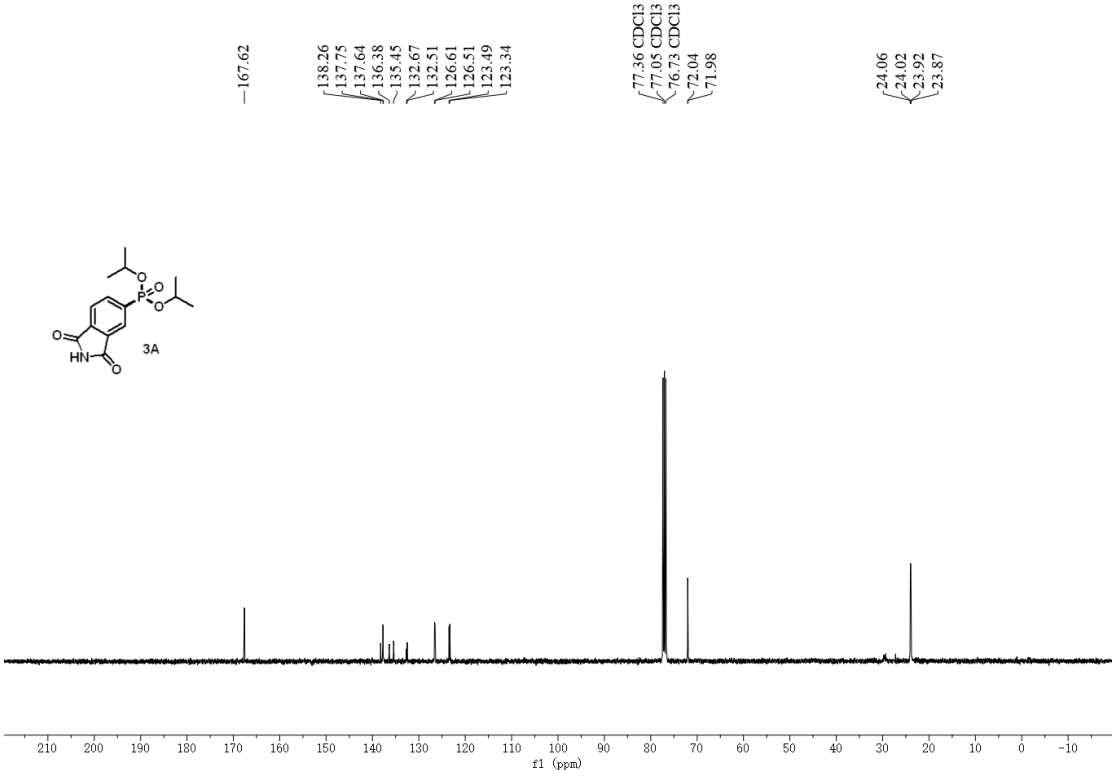

## $^{31}P$ NMR (121 MHz, $CDCl_3$) spectrum for 3z



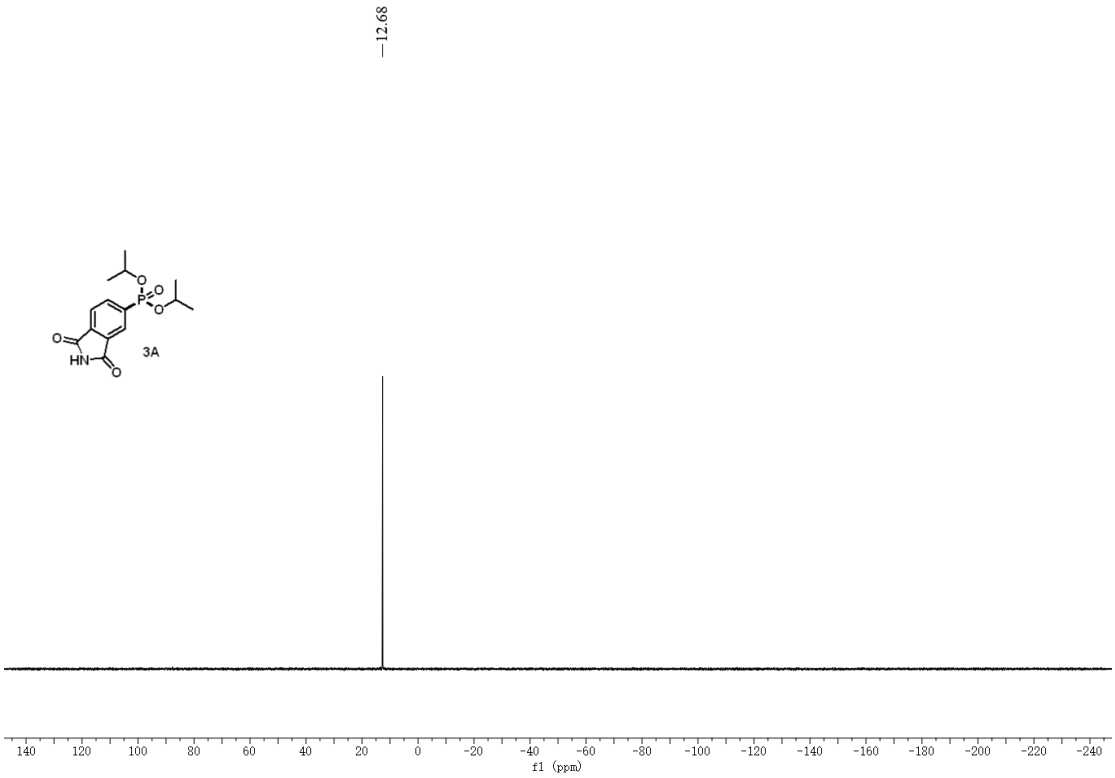
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3A



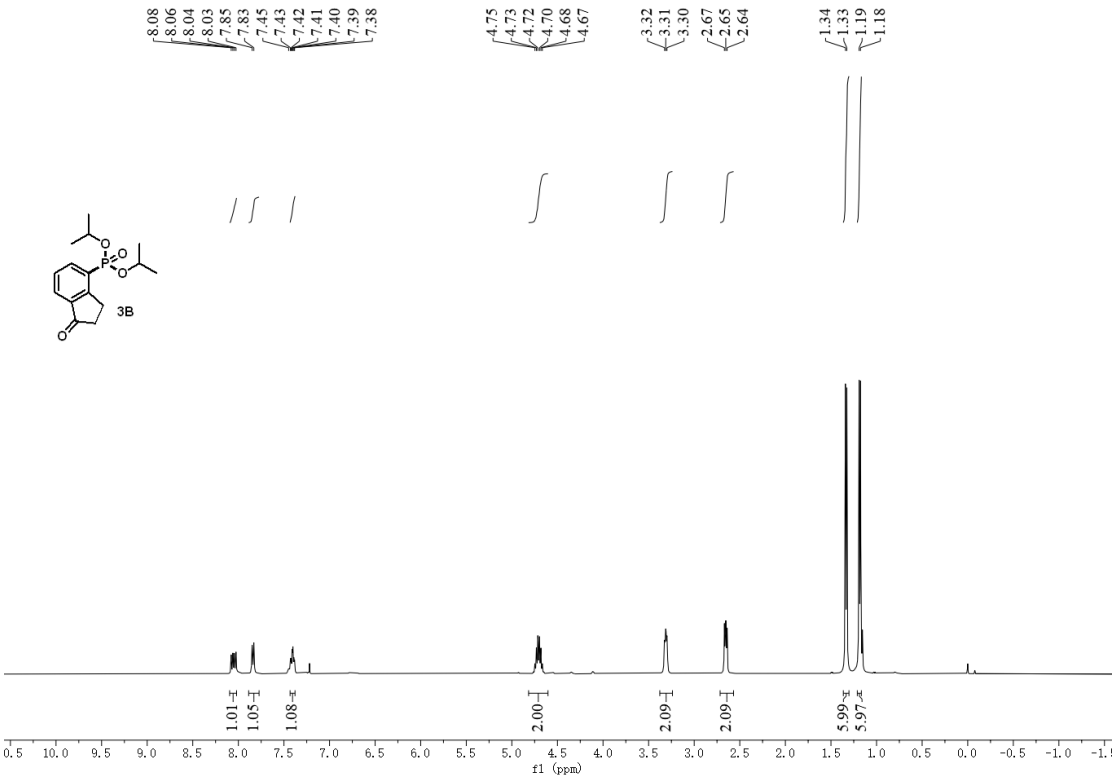

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 3A



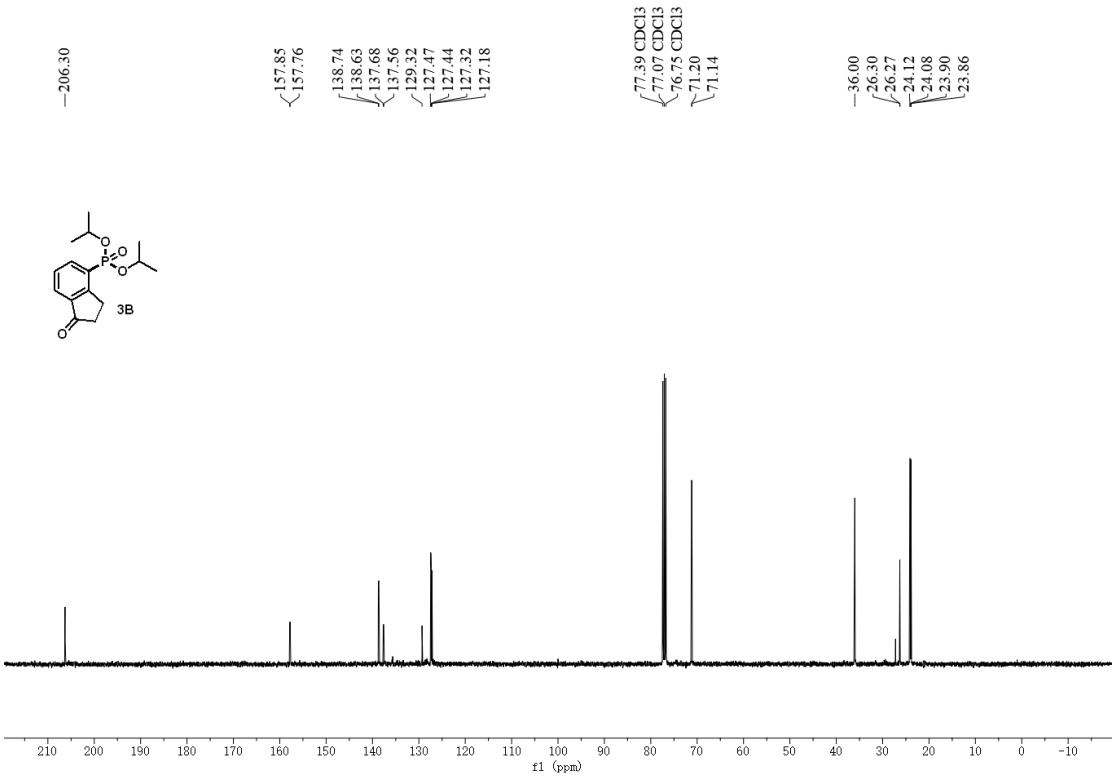
## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 3A



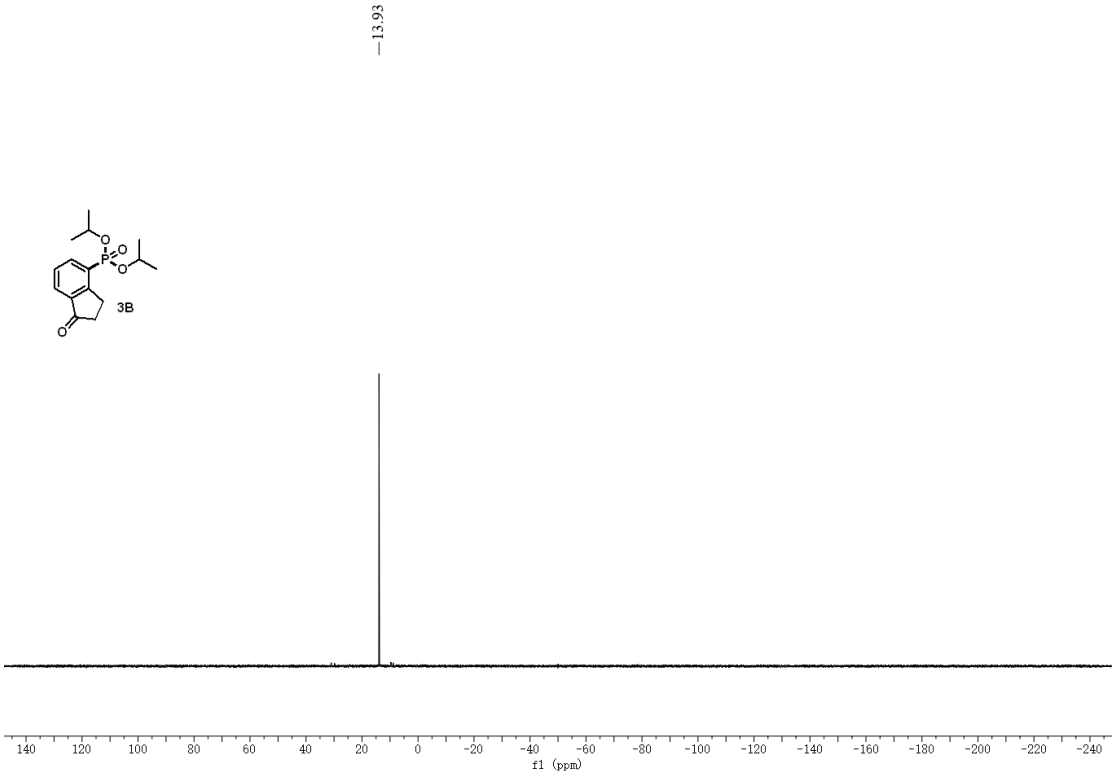

## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3B



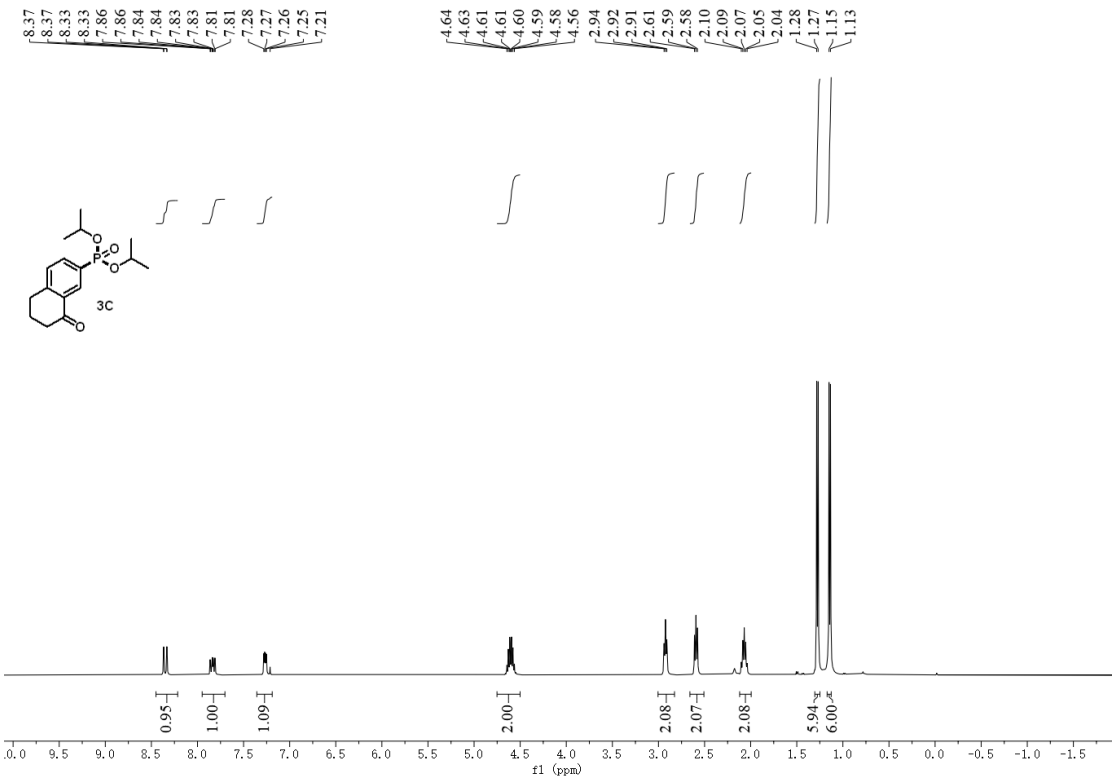
## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 3B



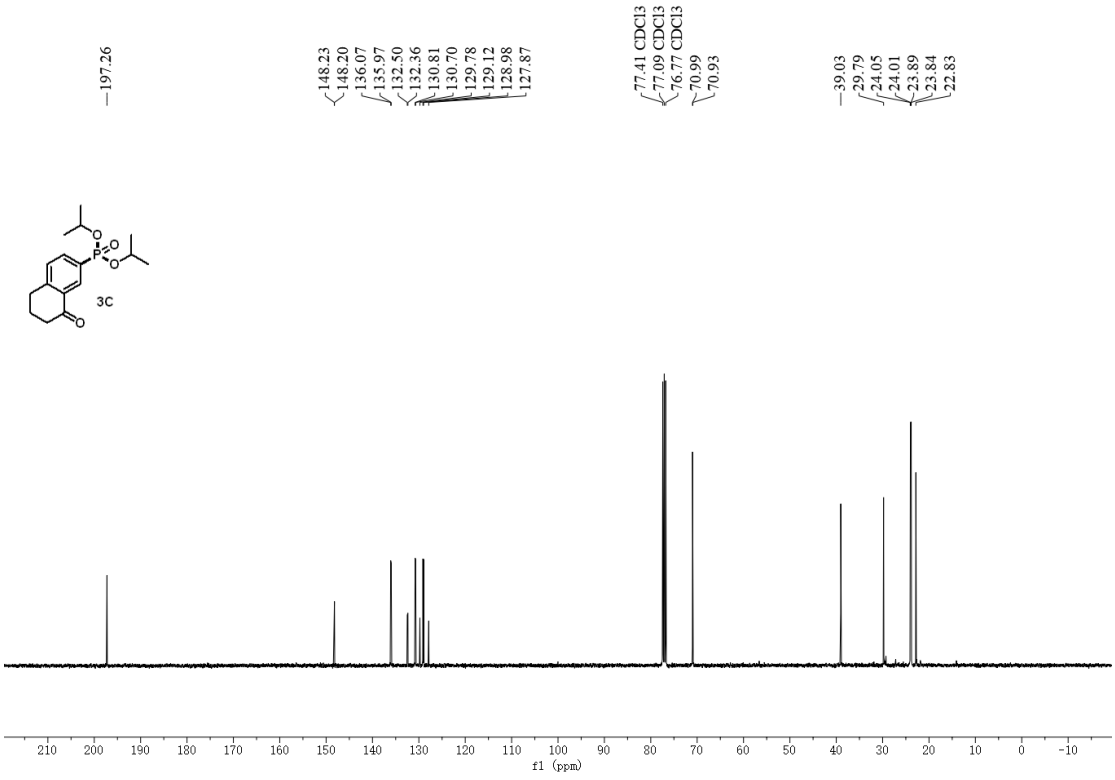

## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 3B



## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3C




## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 3C



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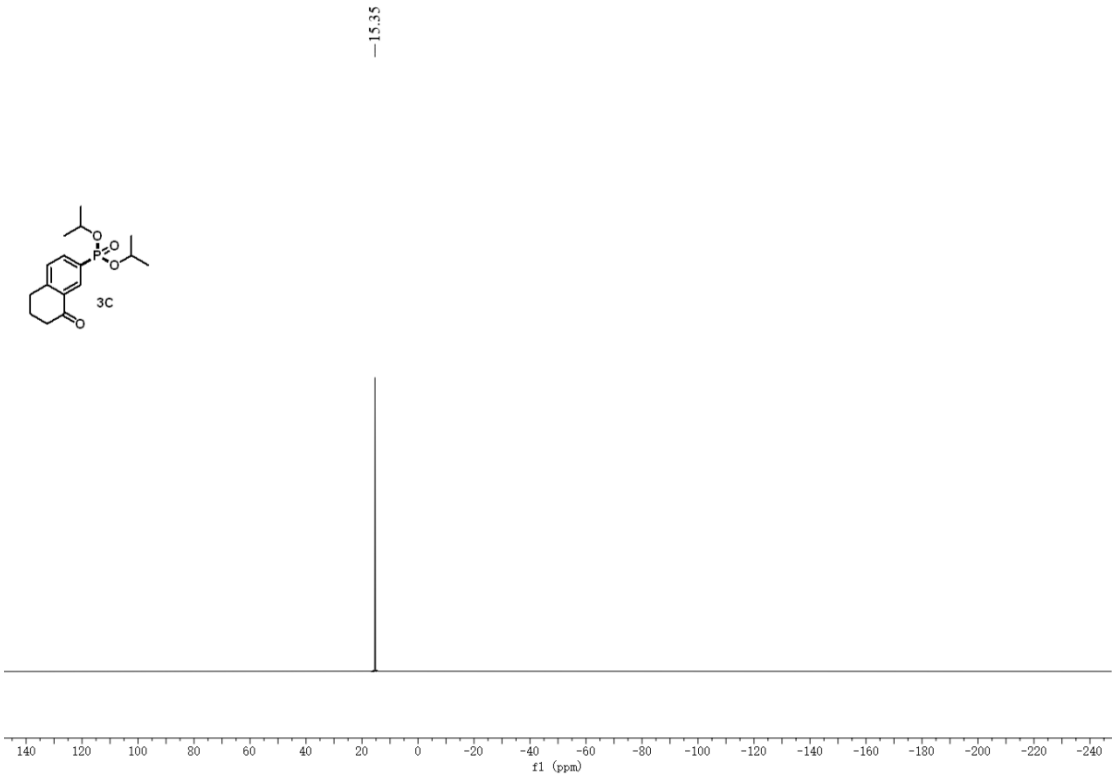
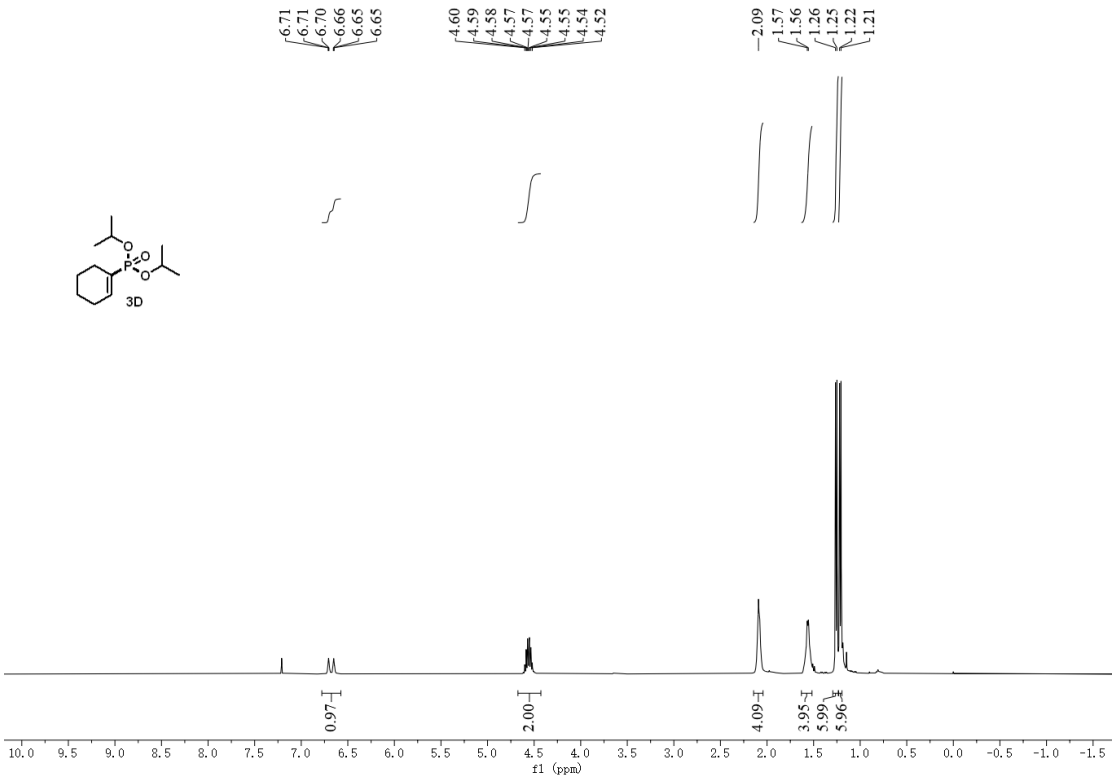
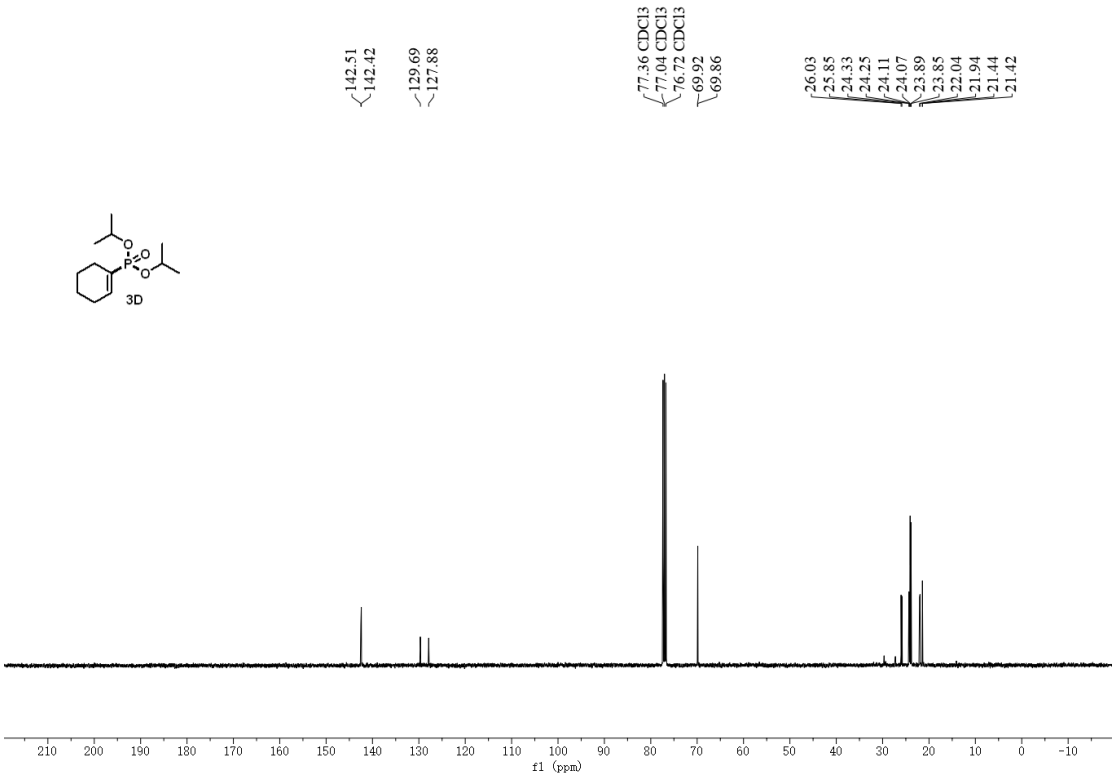


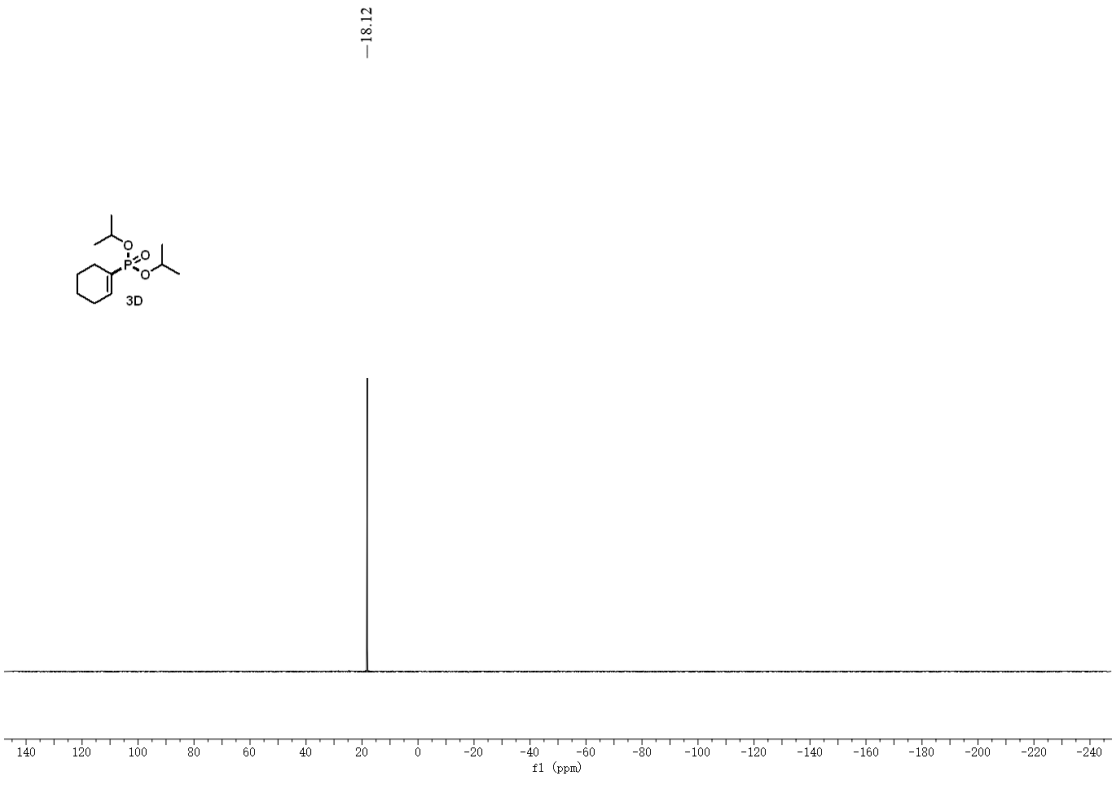

## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3D



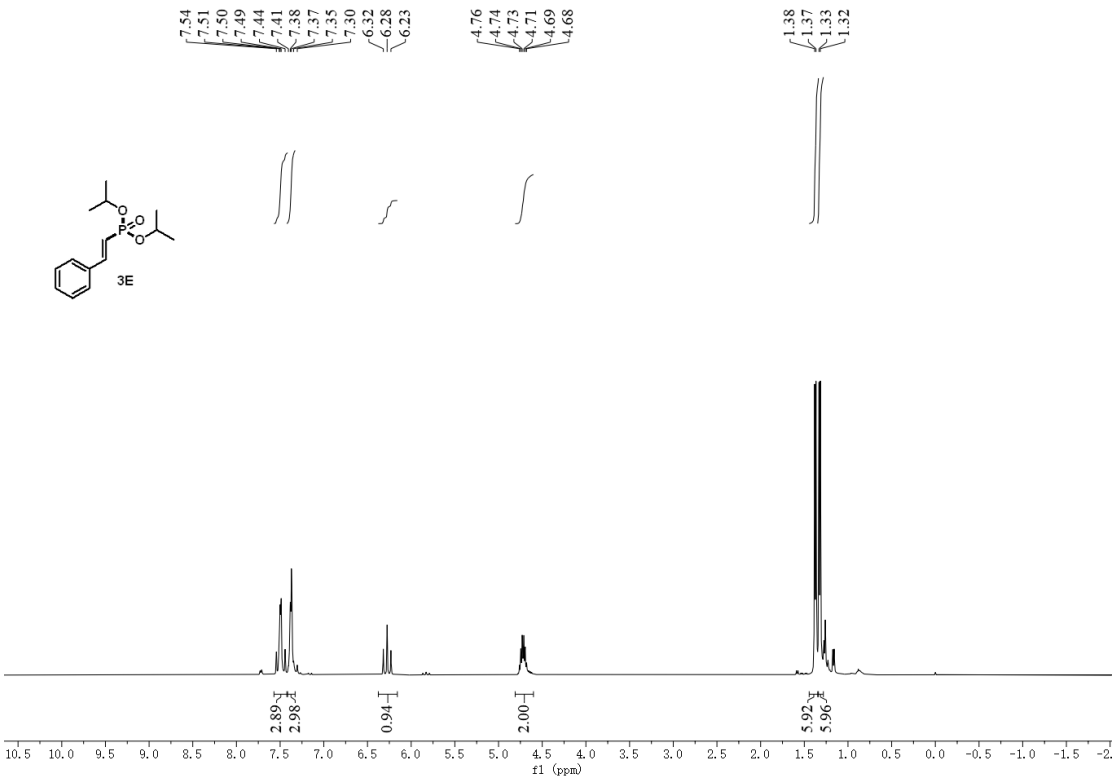
## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 3D



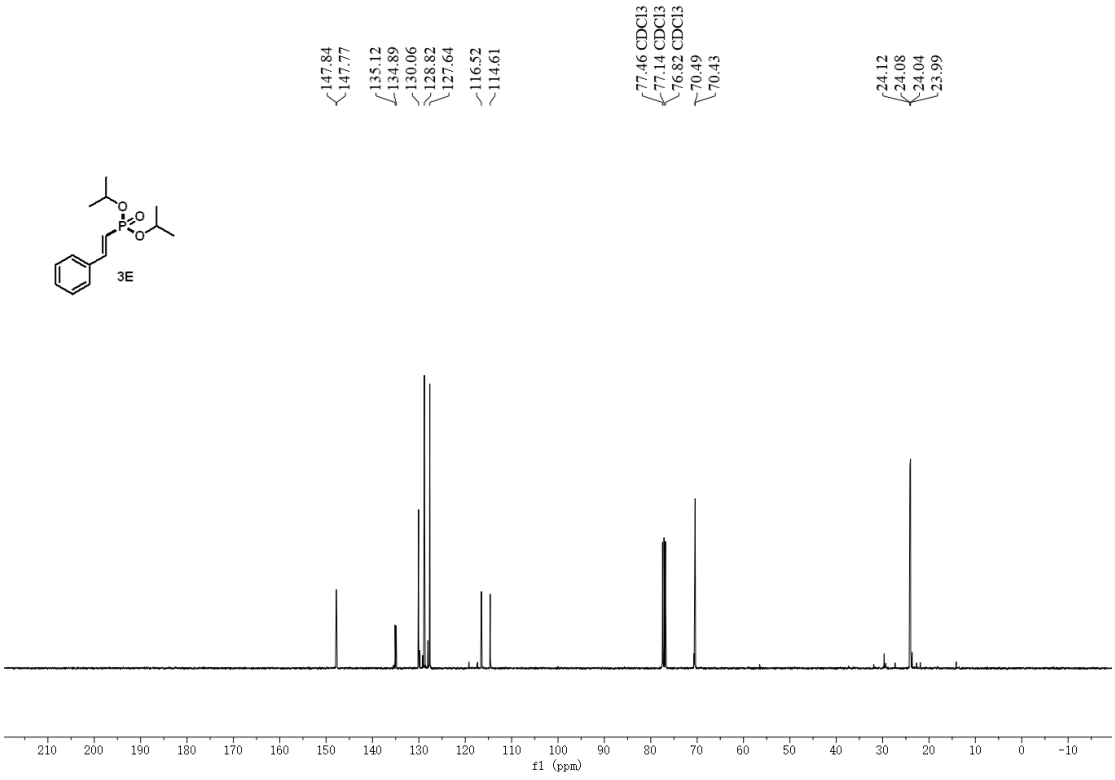

## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 3D



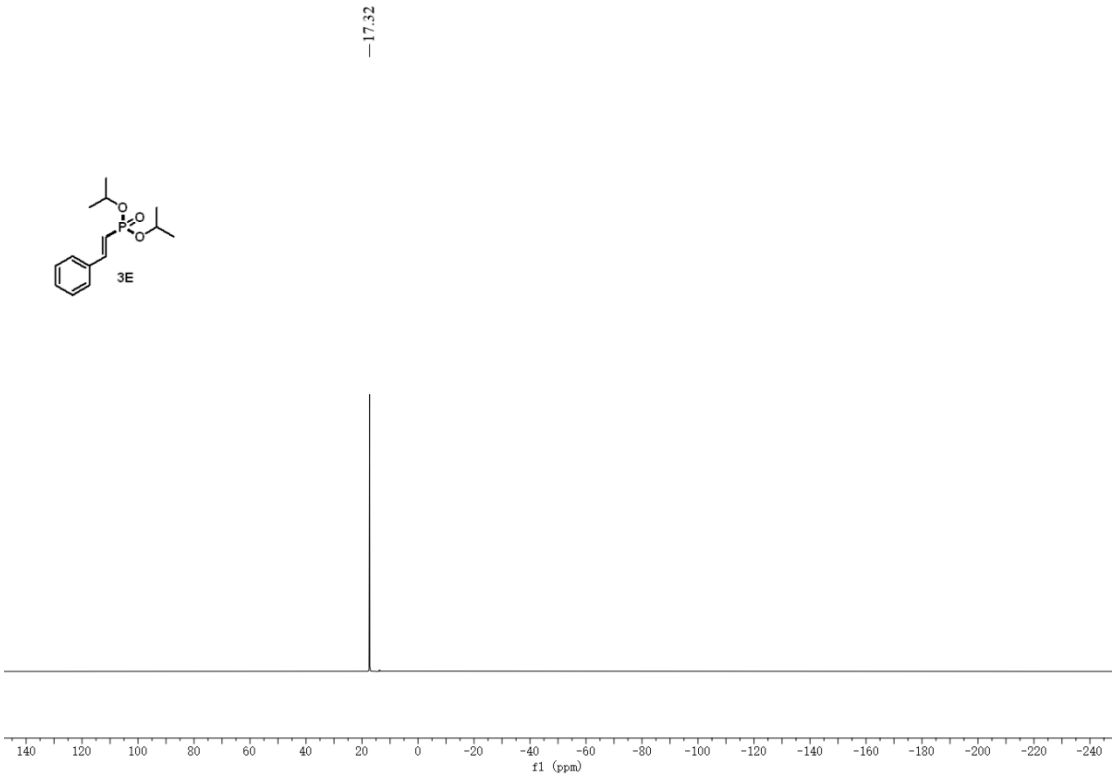
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 3E



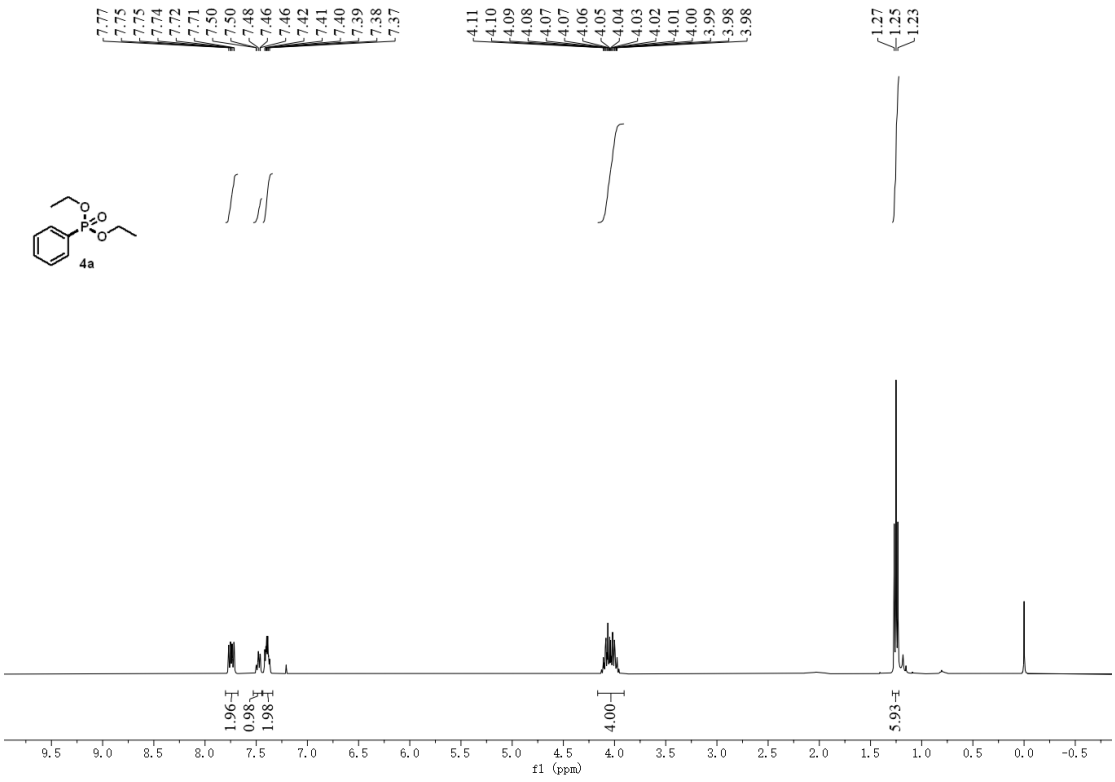

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 3E



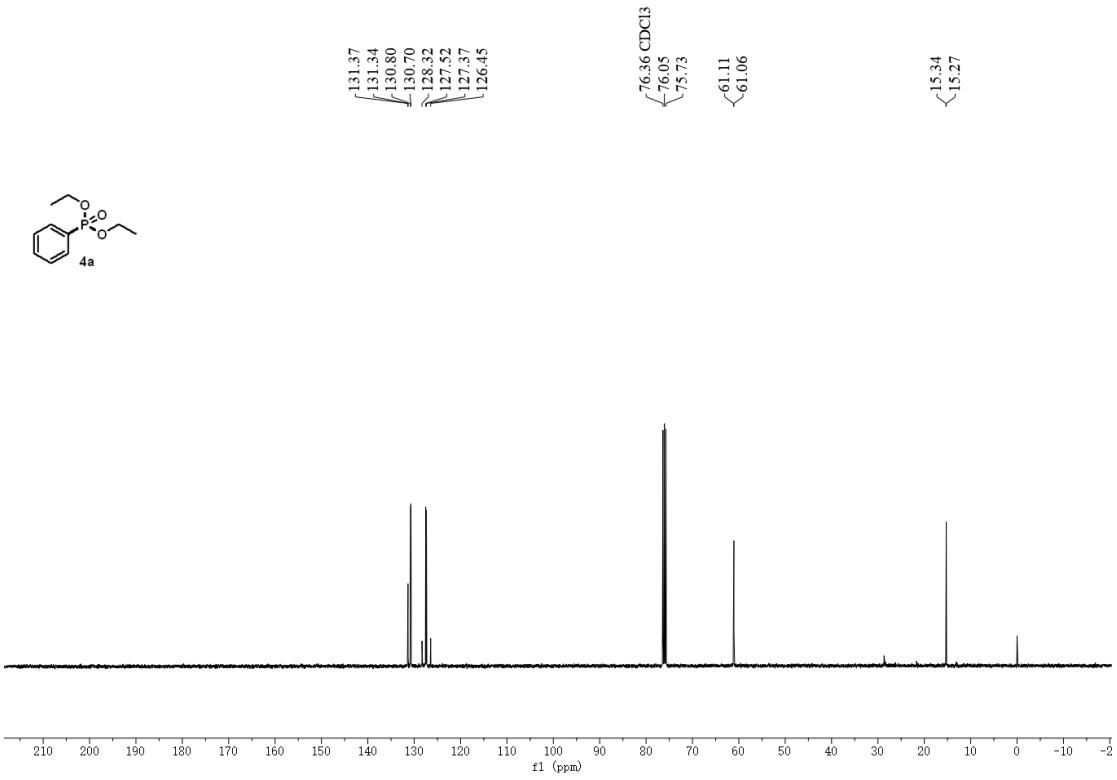
## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 3E



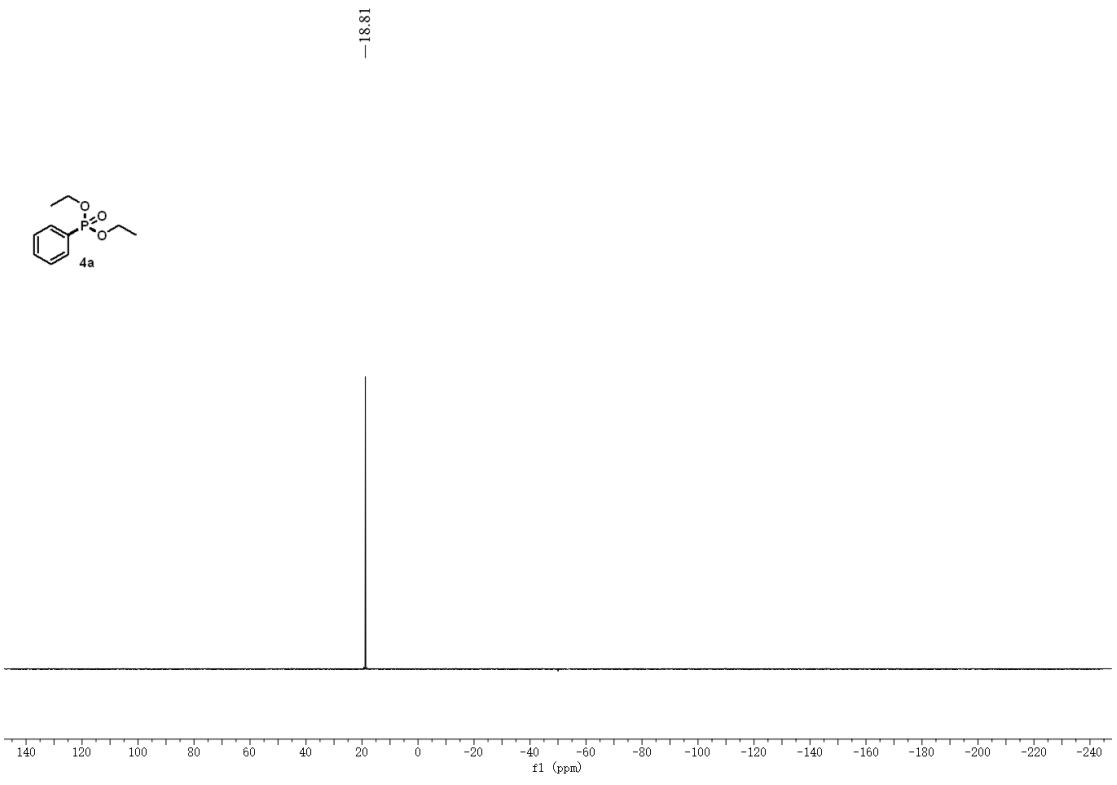

## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 4a



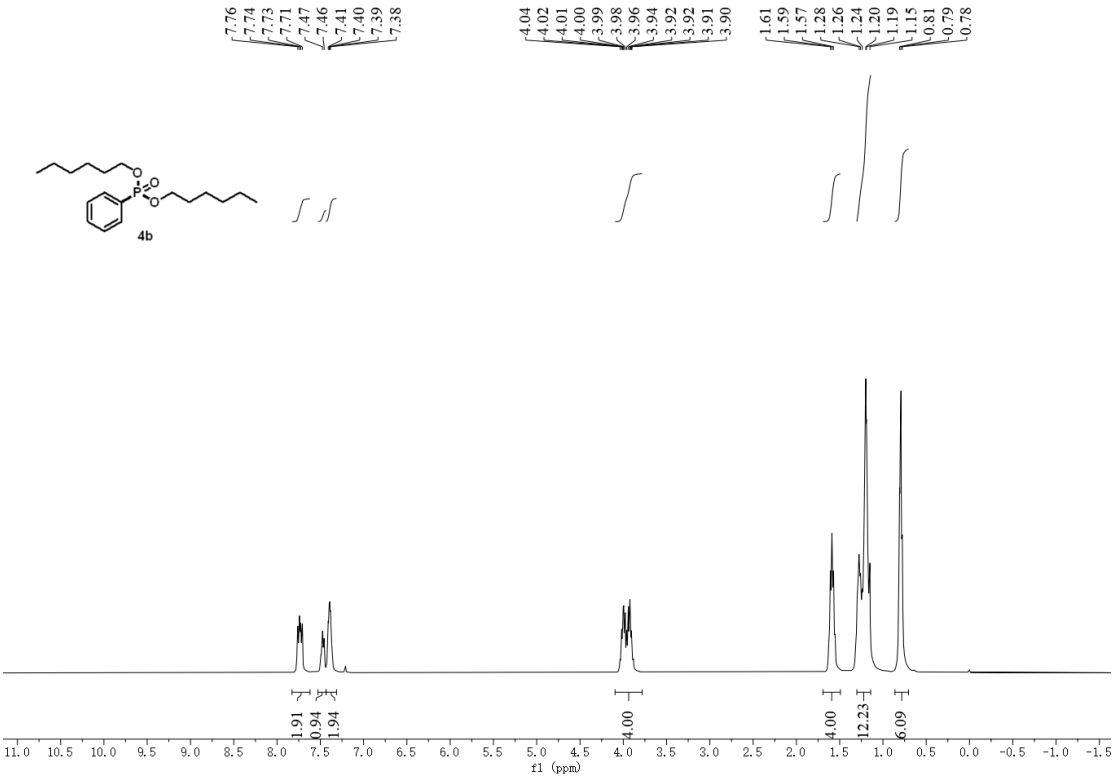
## $^{13}C$ NMR (101 MHz, $CDCl_3$) spectrum for 4a



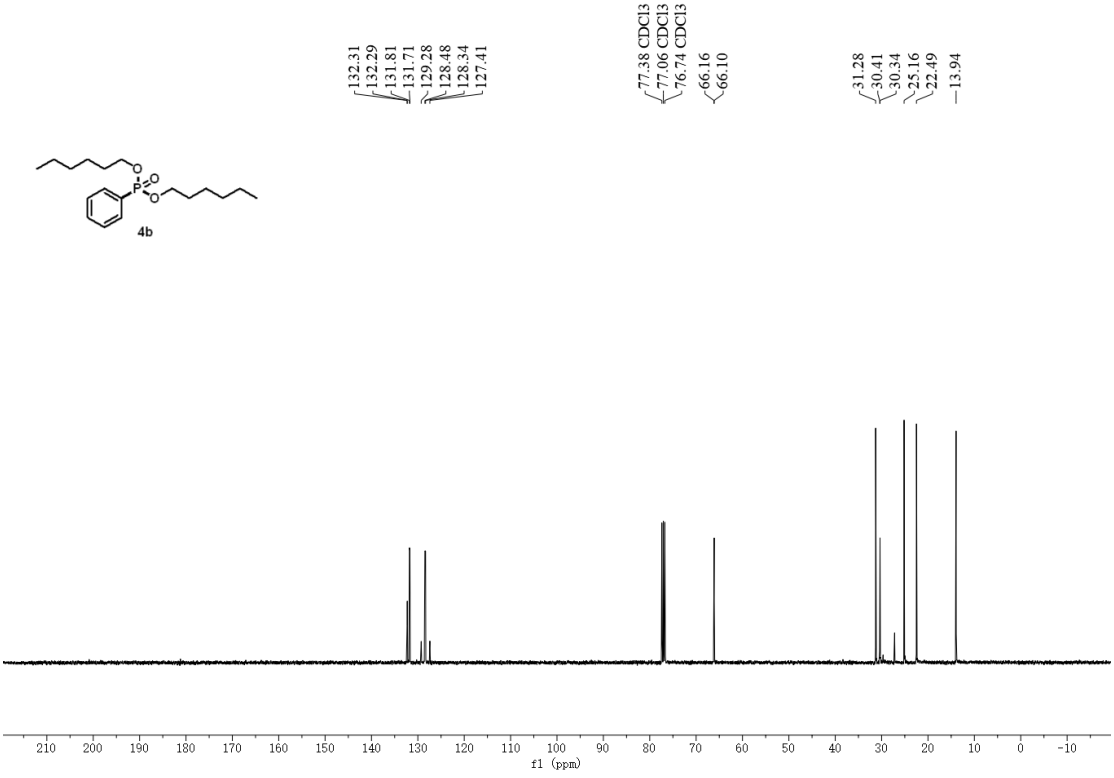

## $^{31}P$ NMR (121 MHz, $CDCl_3$) spectrum for 4a



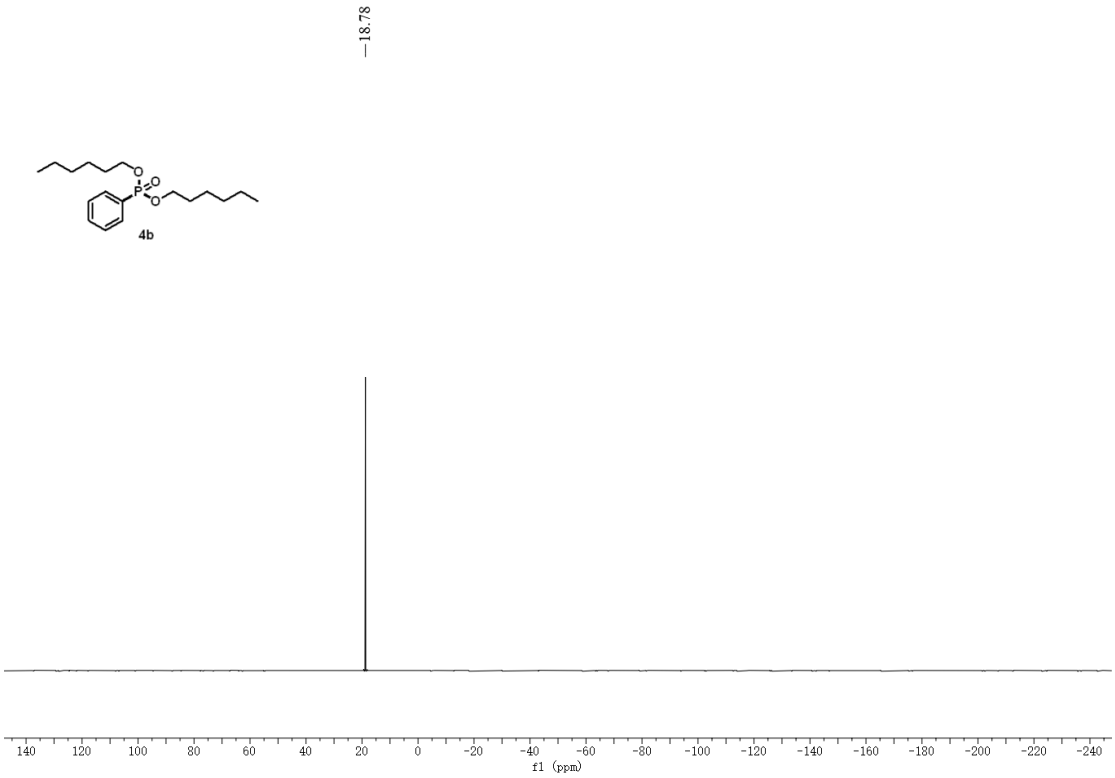
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 4b



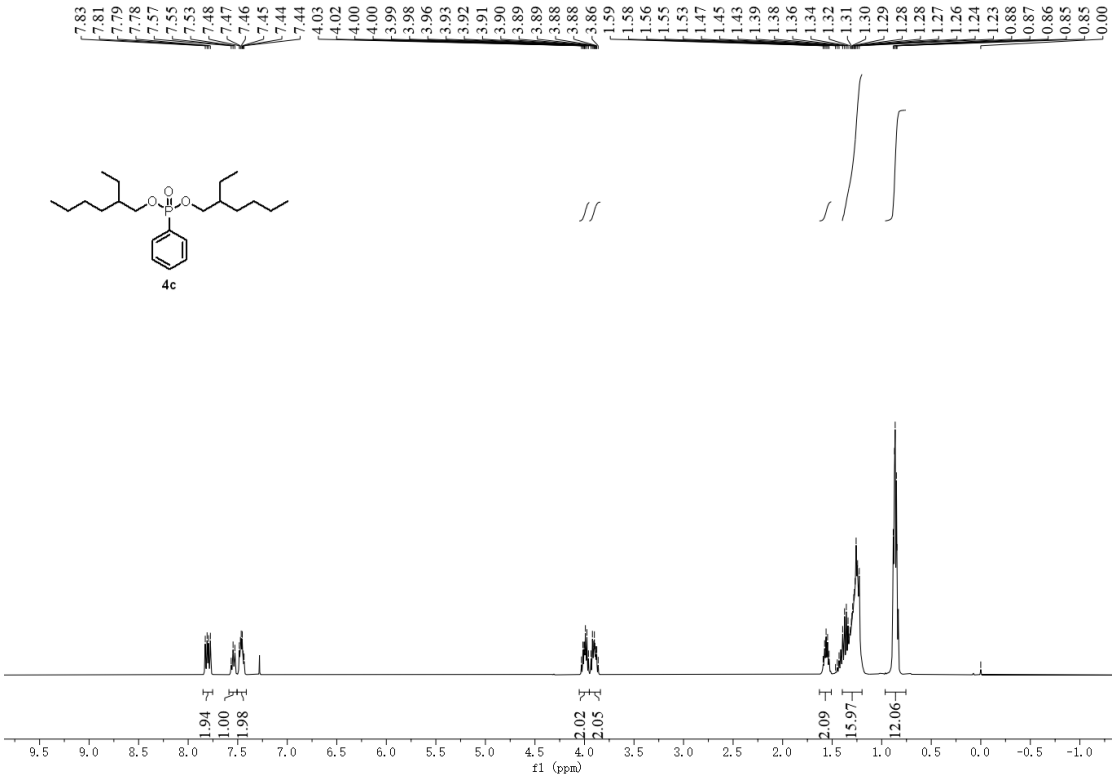

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 4b



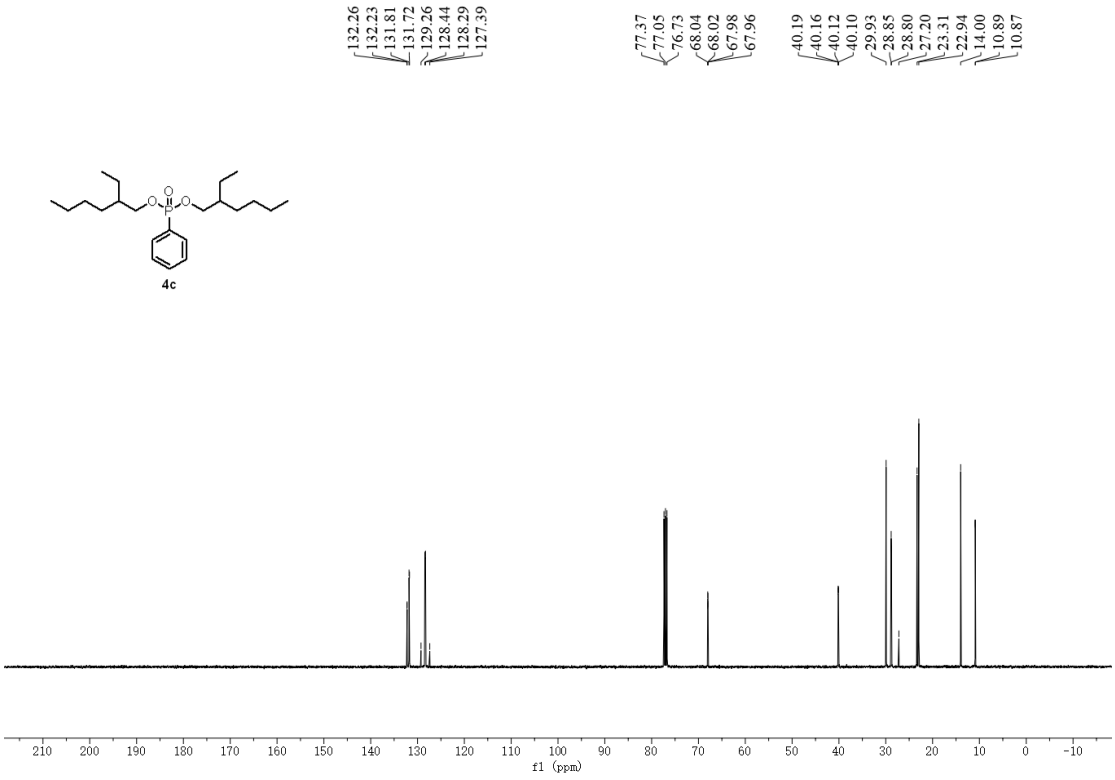
## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 4b



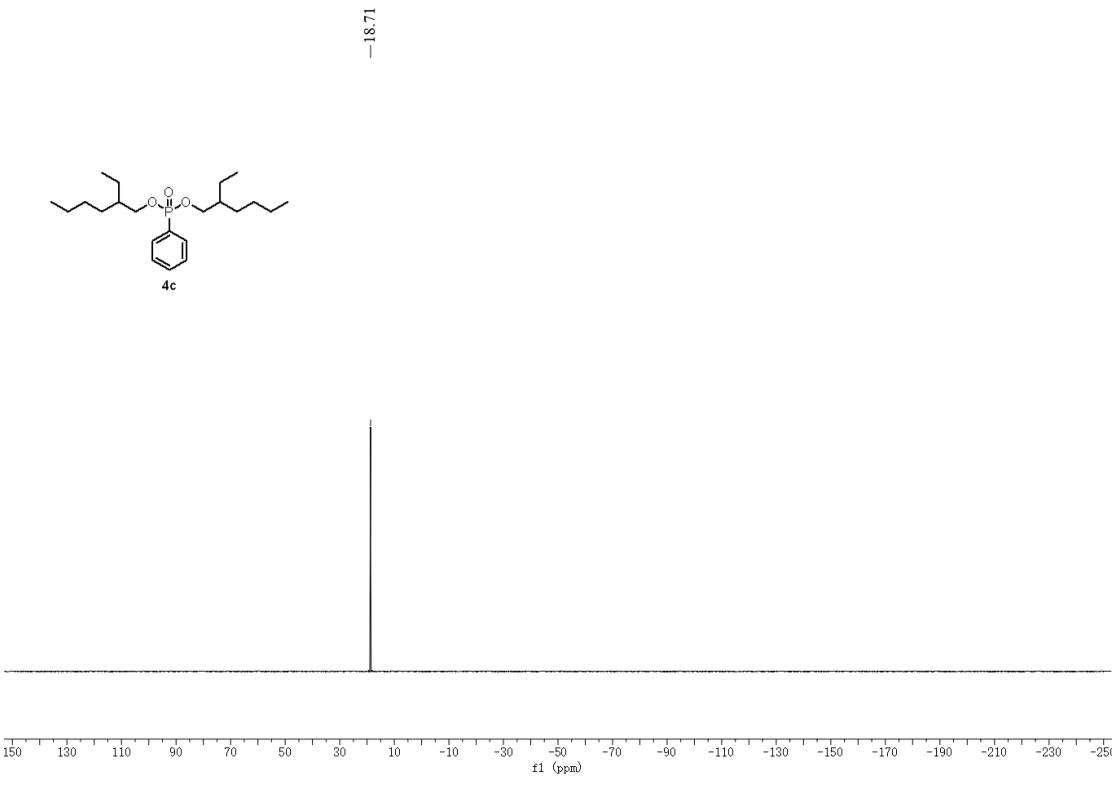

## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 4c



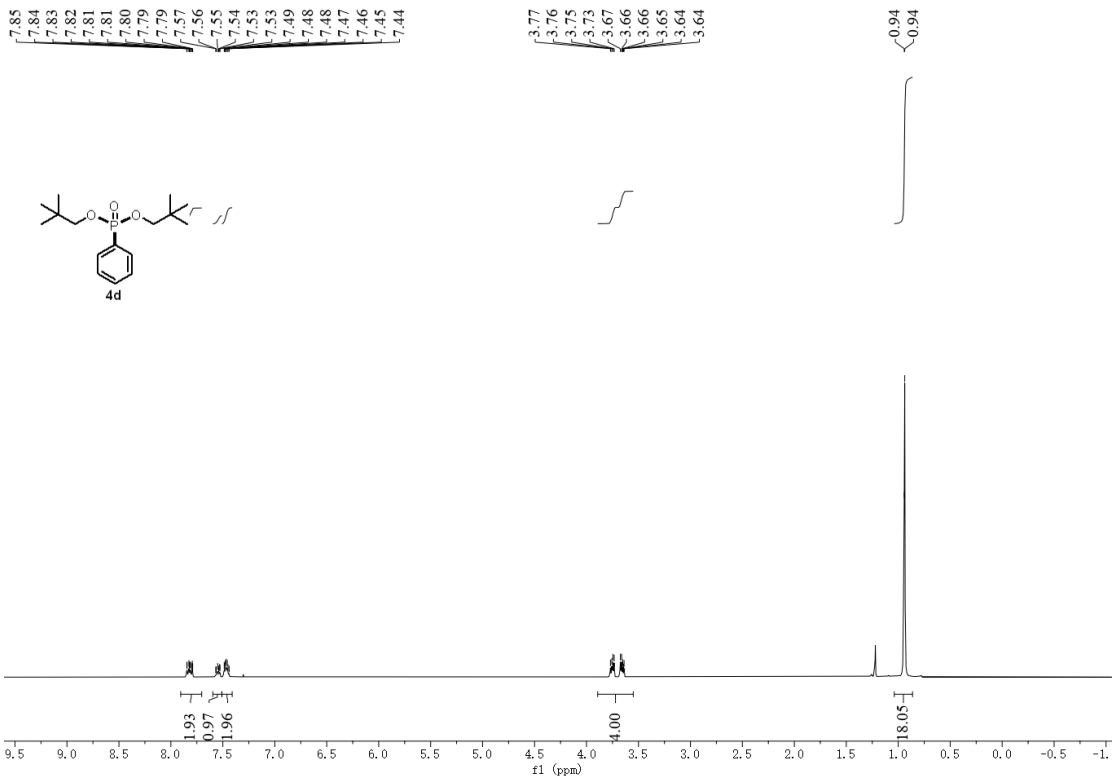
## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 4c



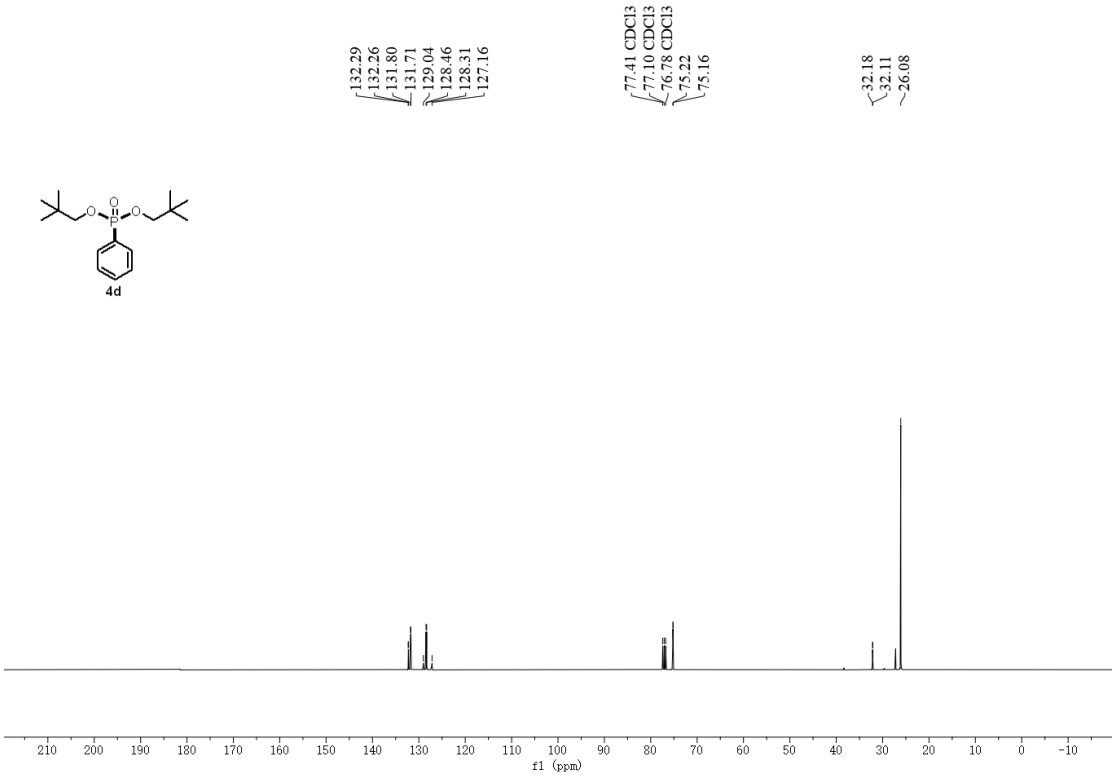

## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 4c



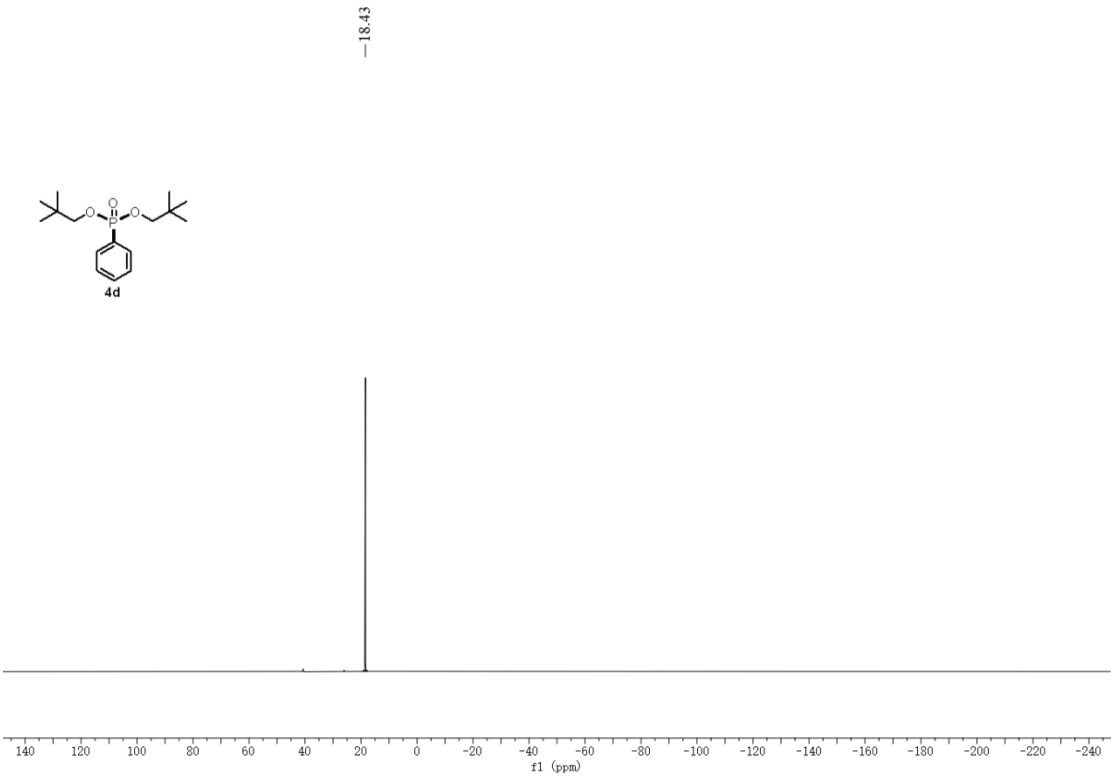
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 4d



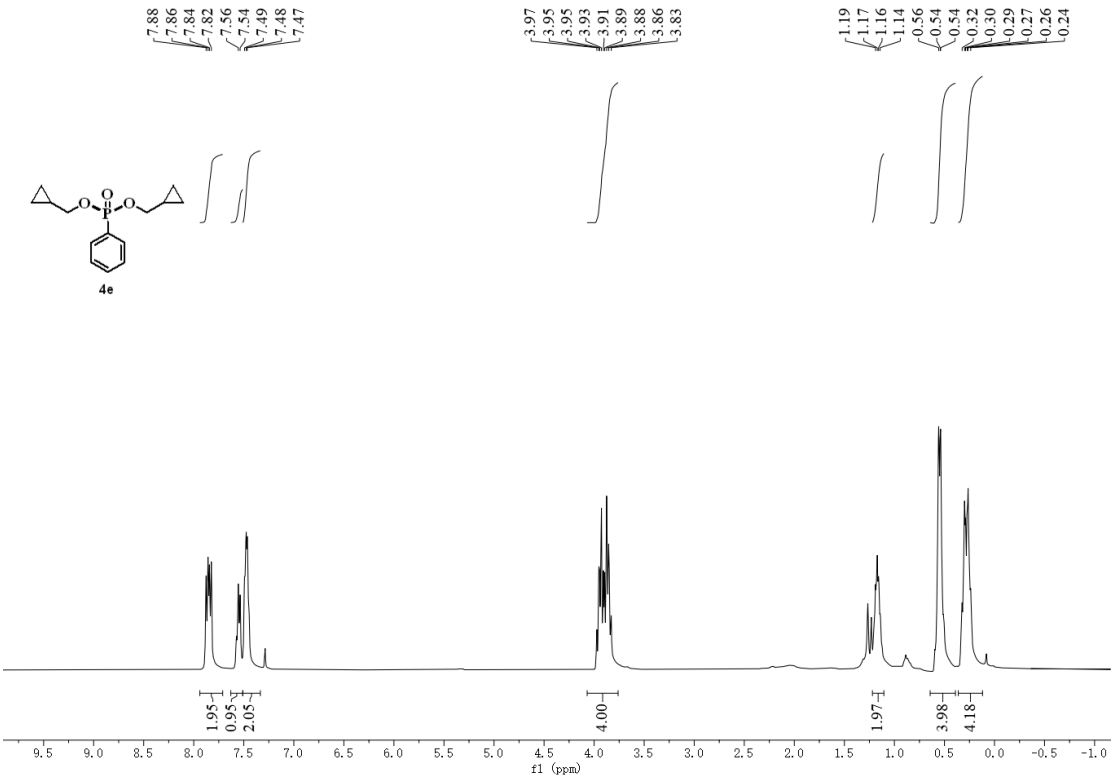

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 4d



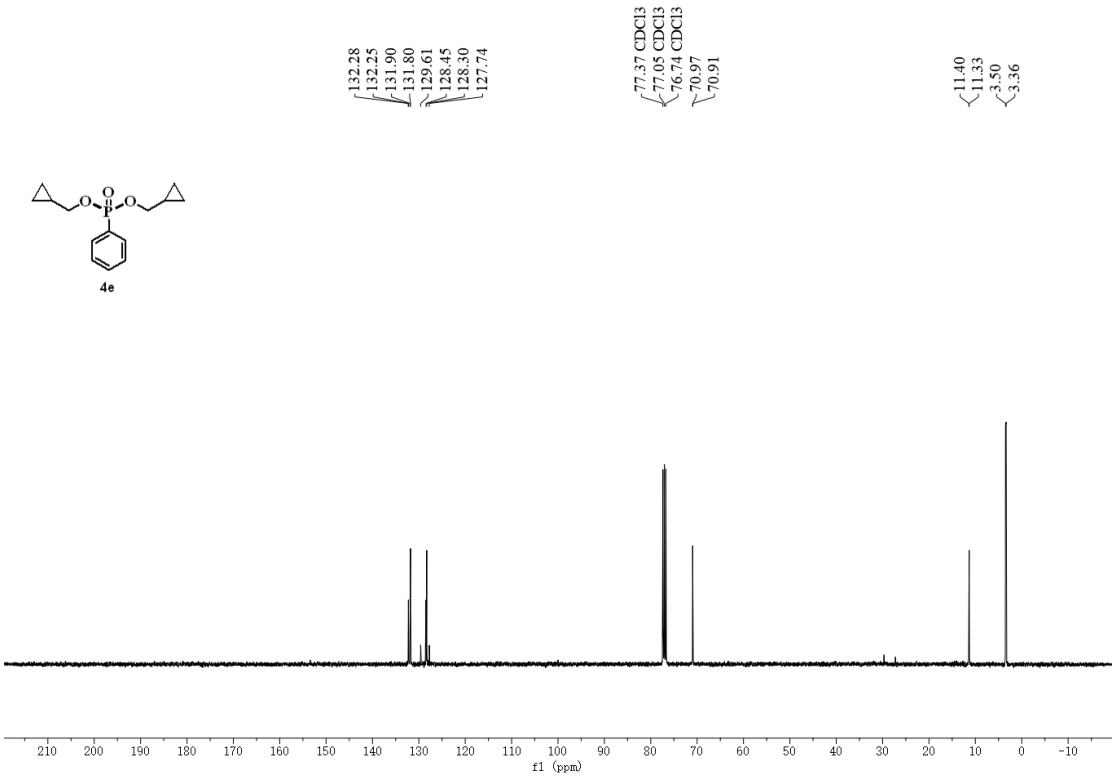
## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 4d



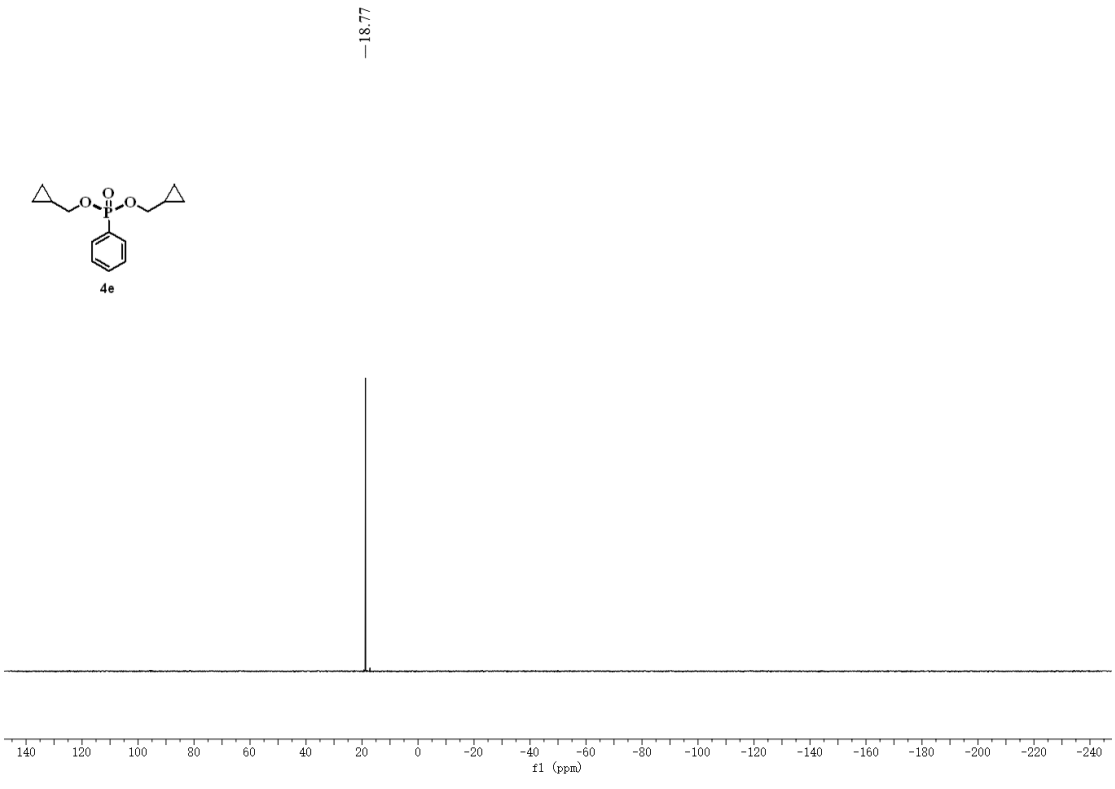

## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 4e



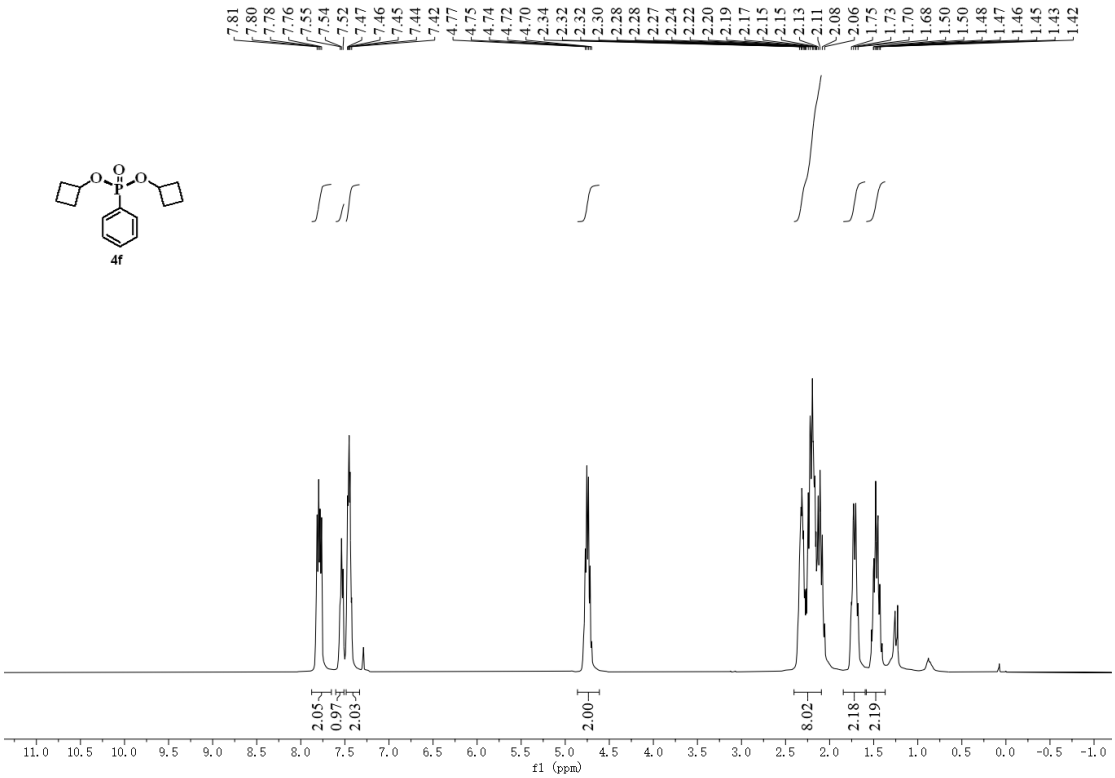
## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 4e



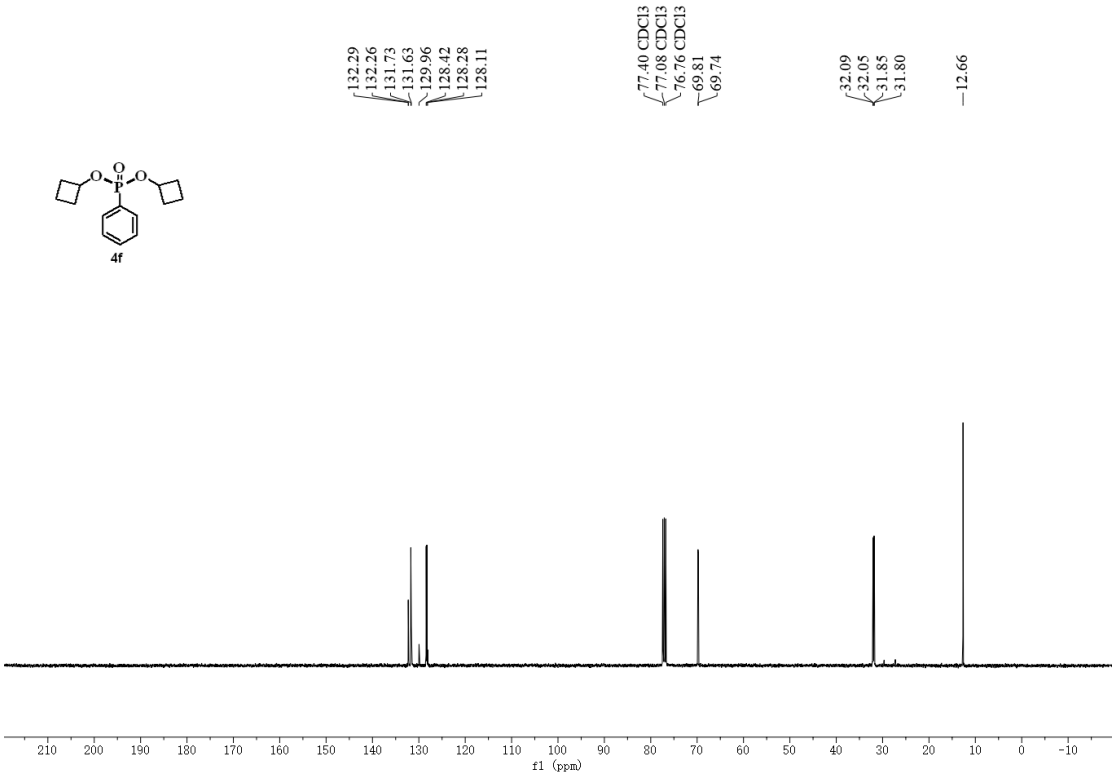

## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 4e



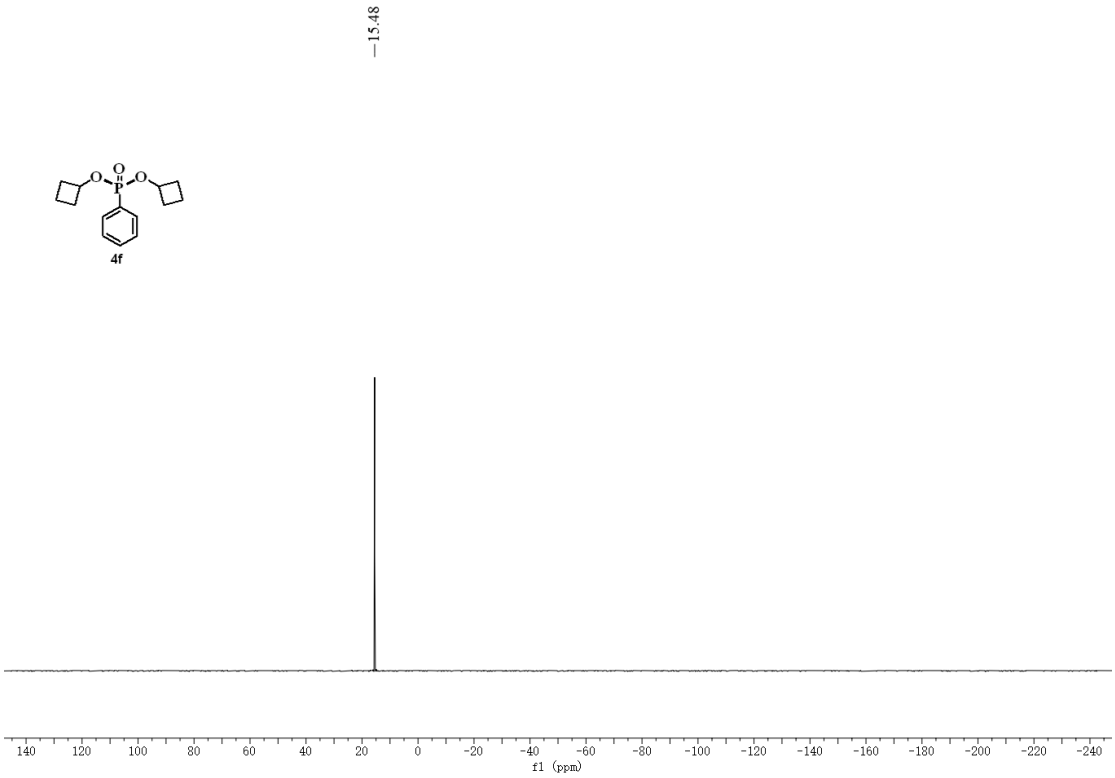
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 4f



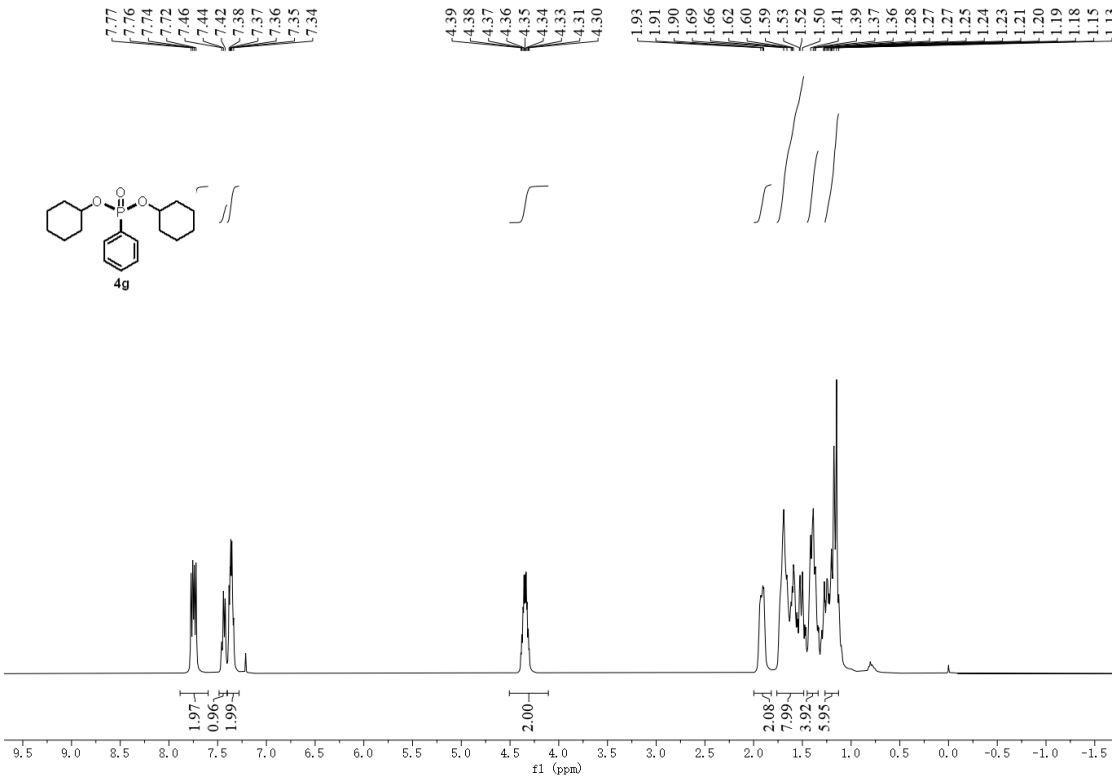

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 4f



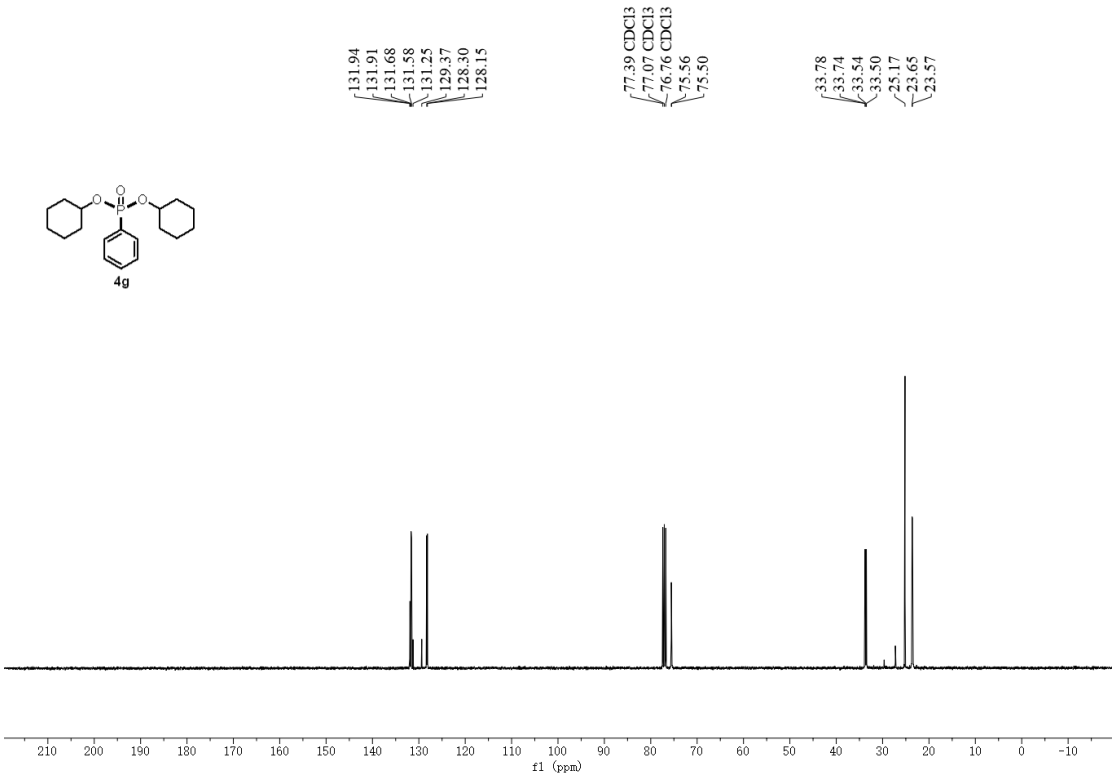
## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 4f



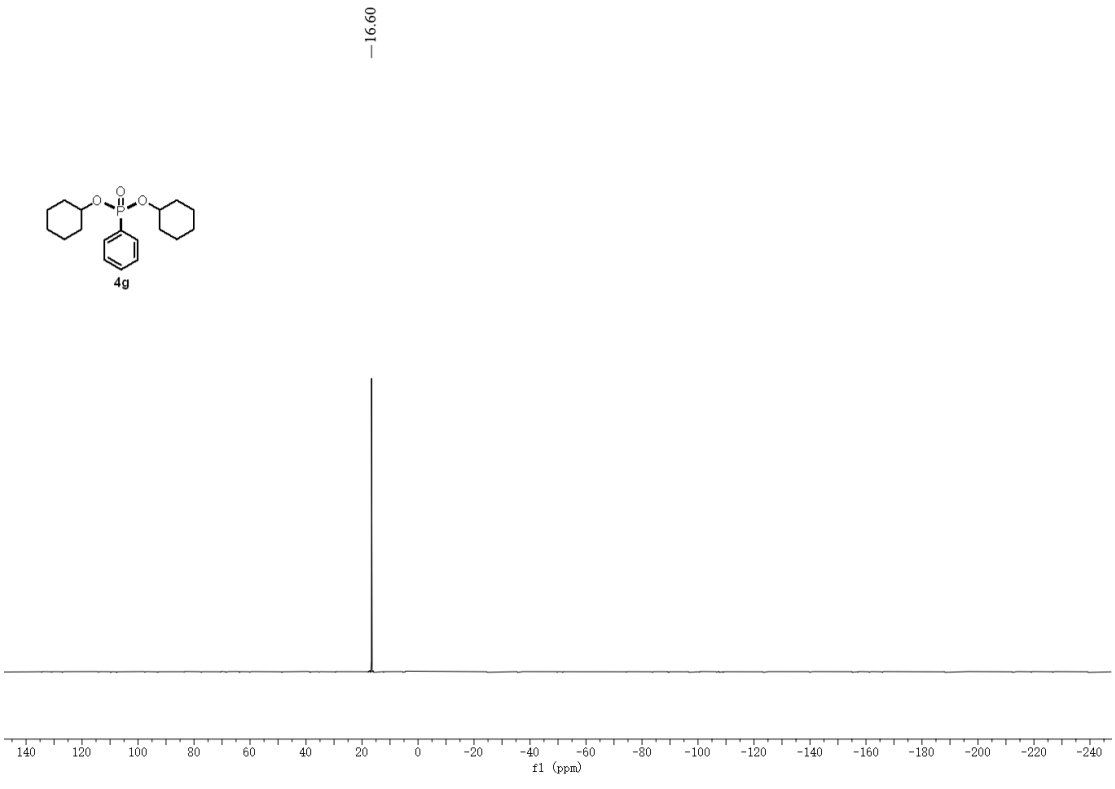

## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 4g



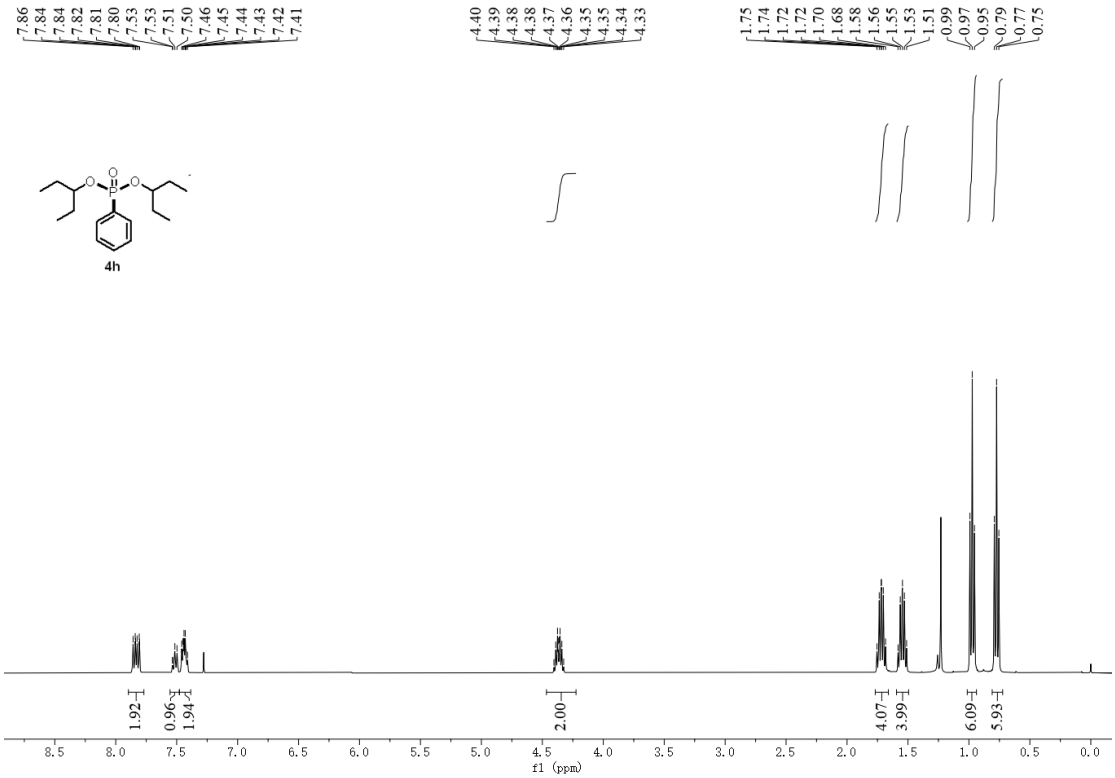
## $^{13}C$ NMR (101 MHz, $CDCl_3$) spectrum for 4g



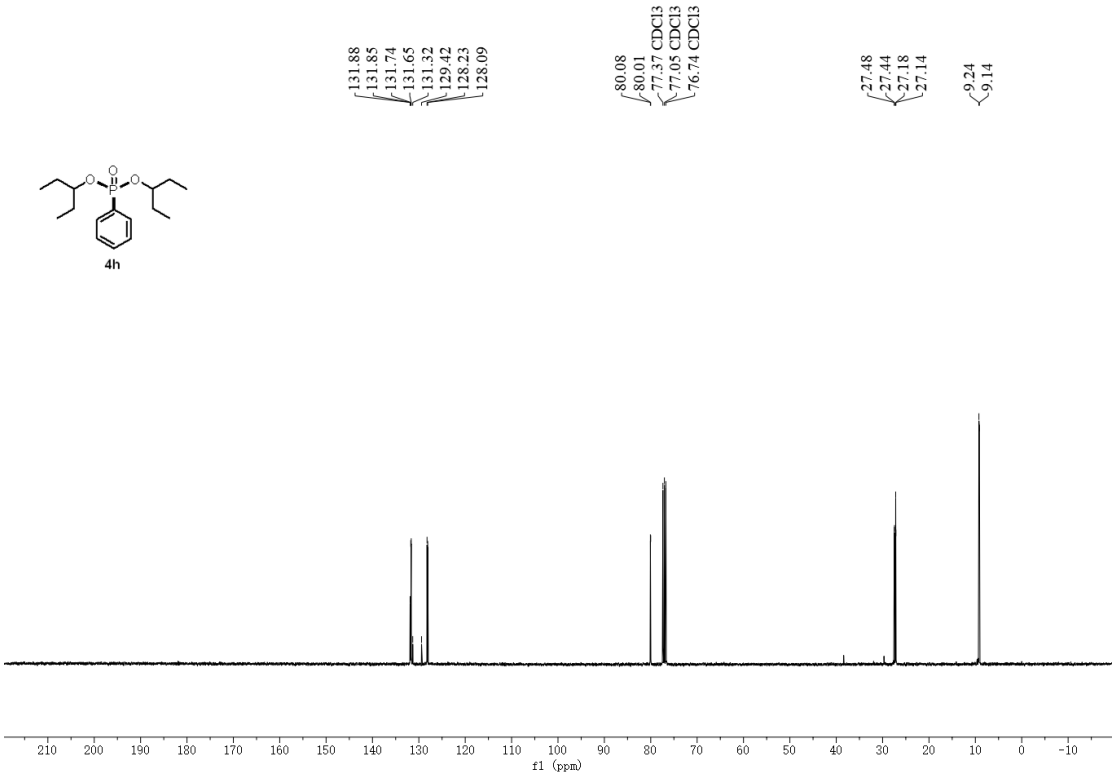

## $^{31}P$ NMR (121 MHz, $CDCl_3$) spectrum for 4g



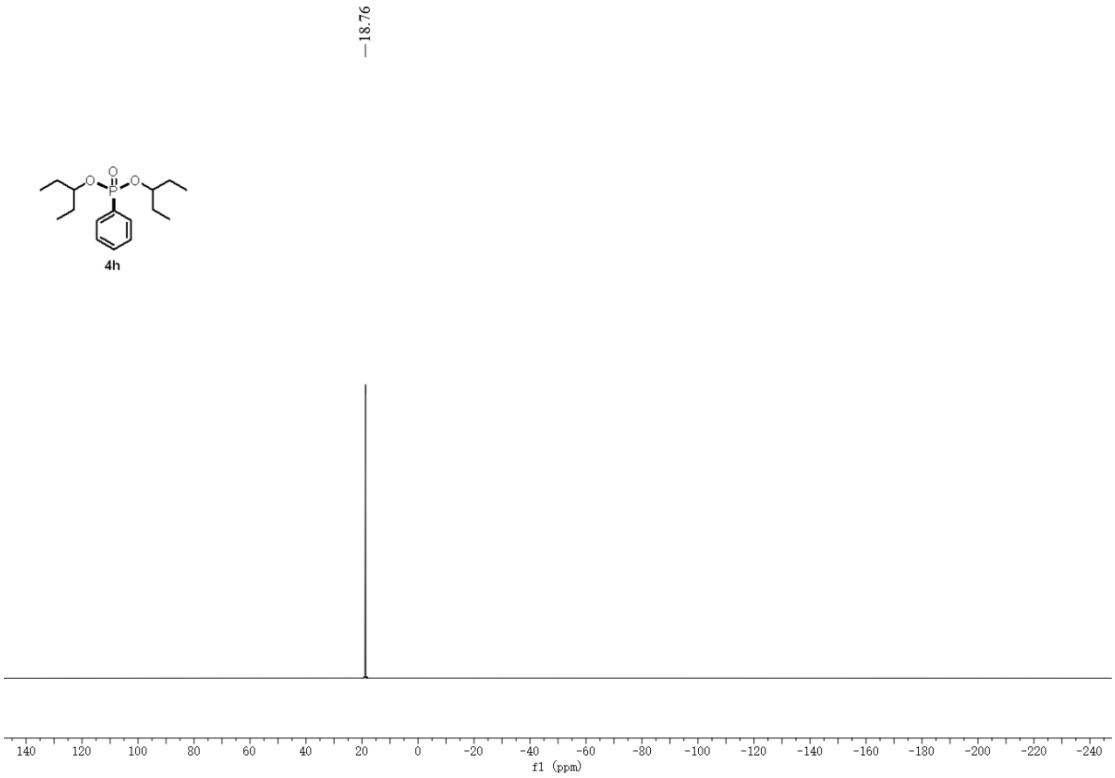
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 4h



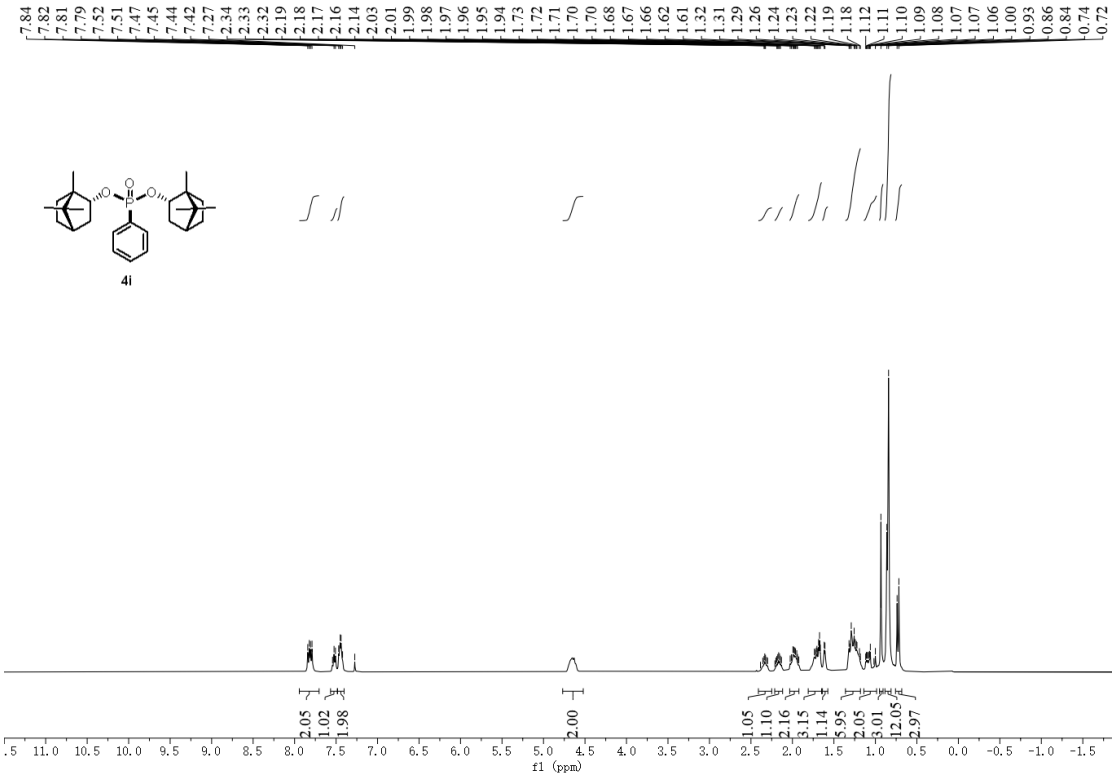

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 4h



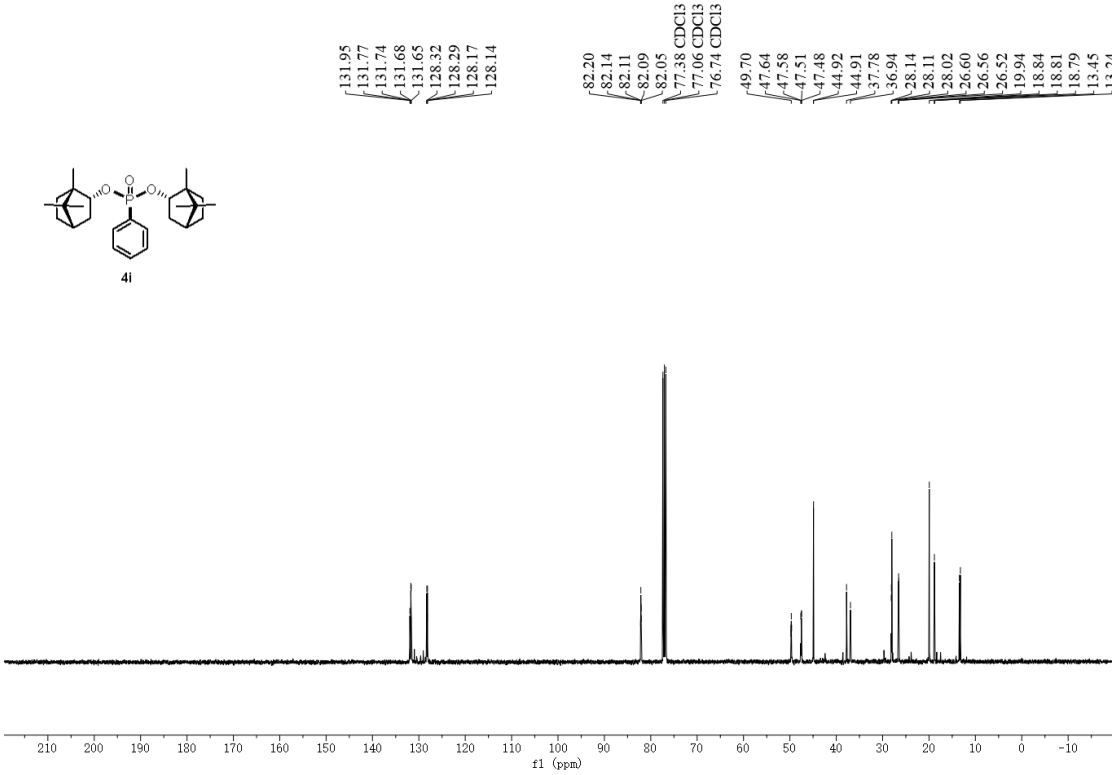
## $^{31}P$ NMR (121 MHz, $CDCl_3$) spectrum for 4h



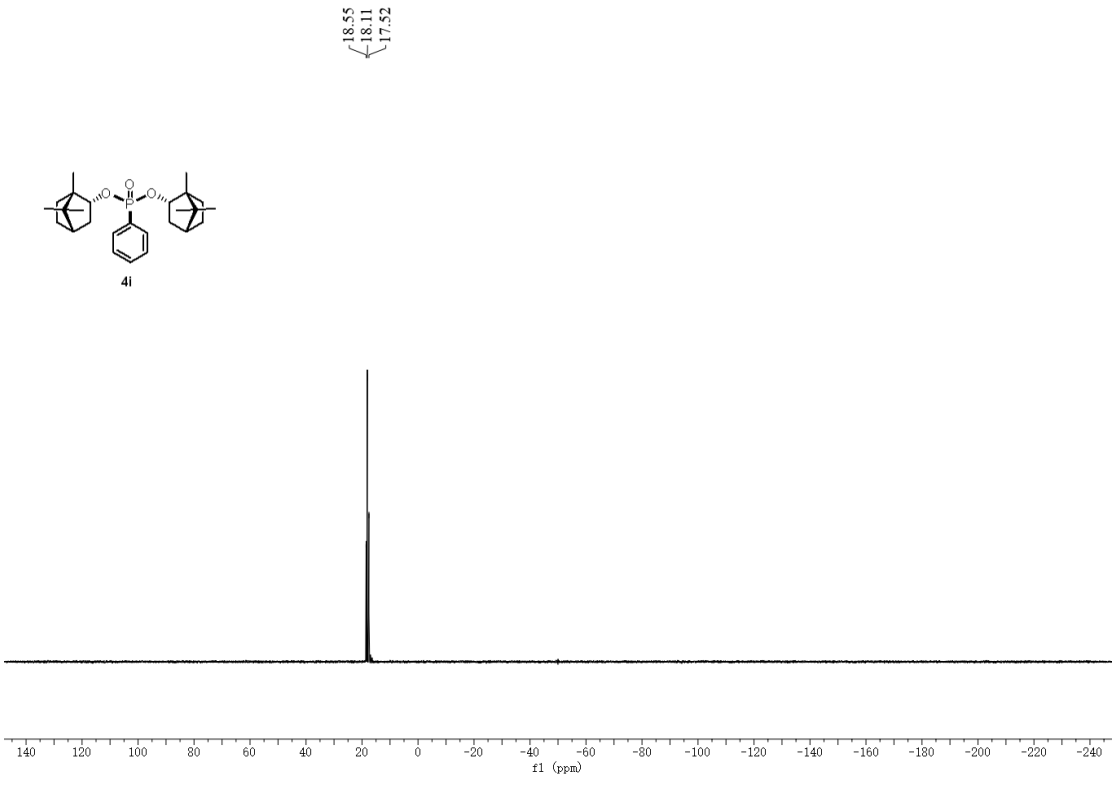

## $^{1}H$ NMR (400 MHz, $CDCl_3$) spectrum for 4i



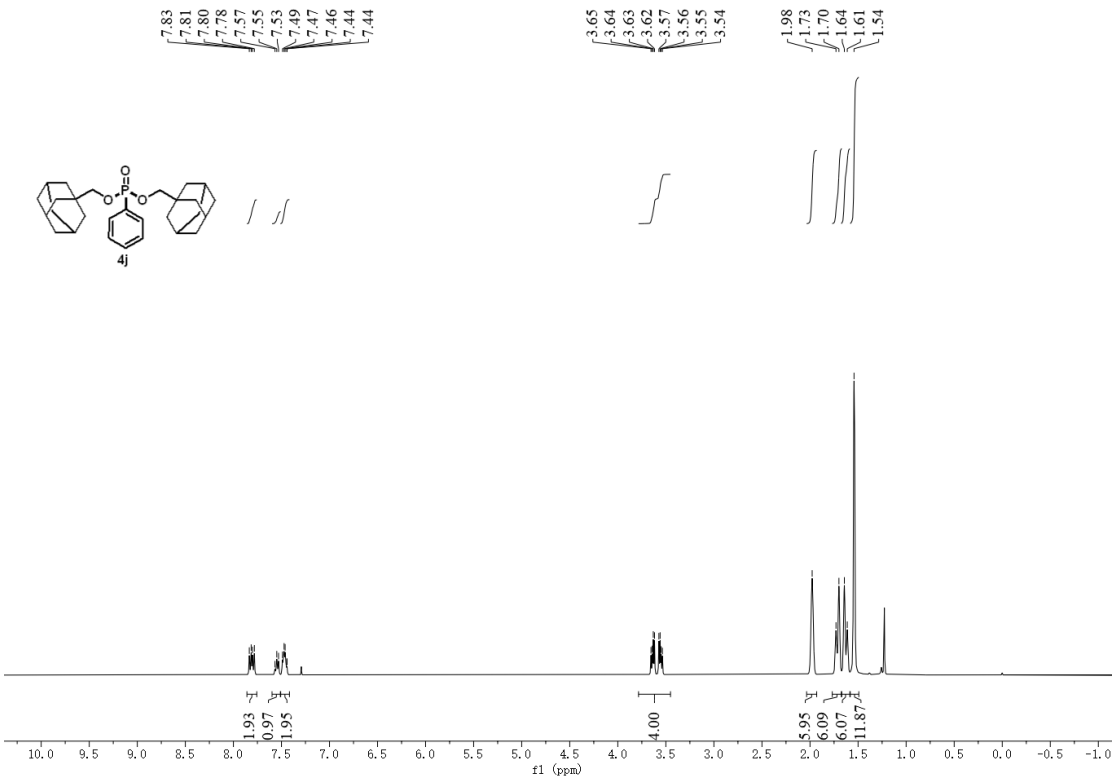
## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 4i



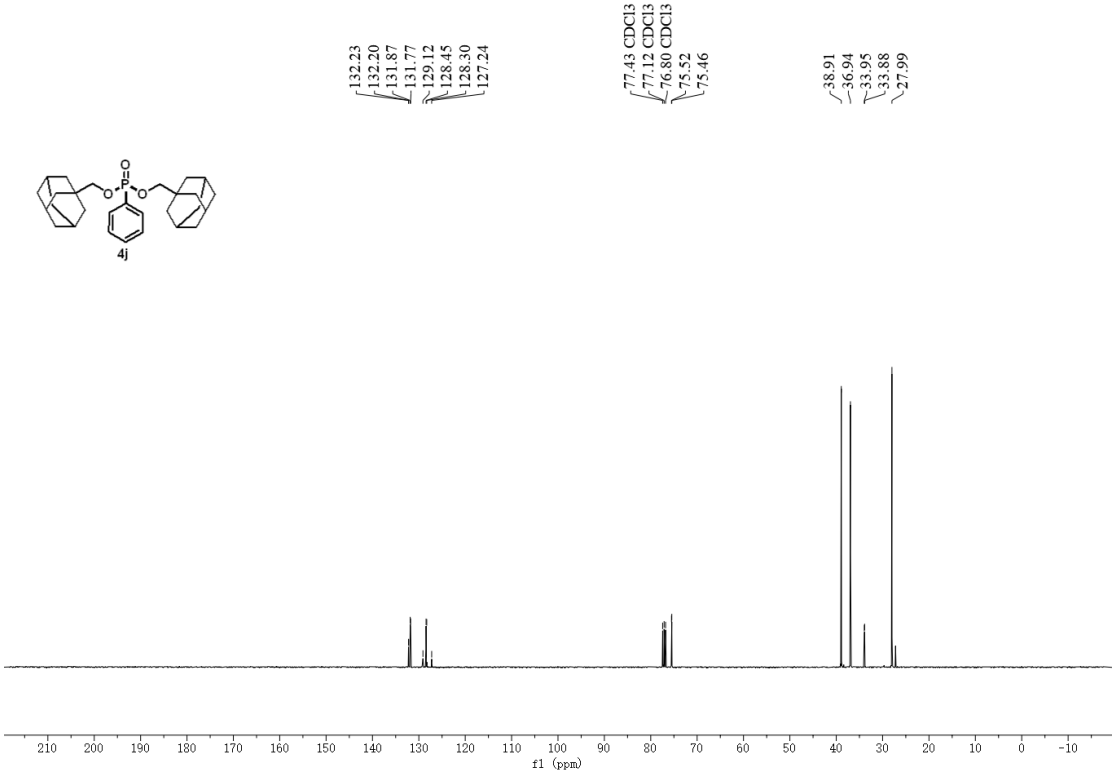

## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 4i



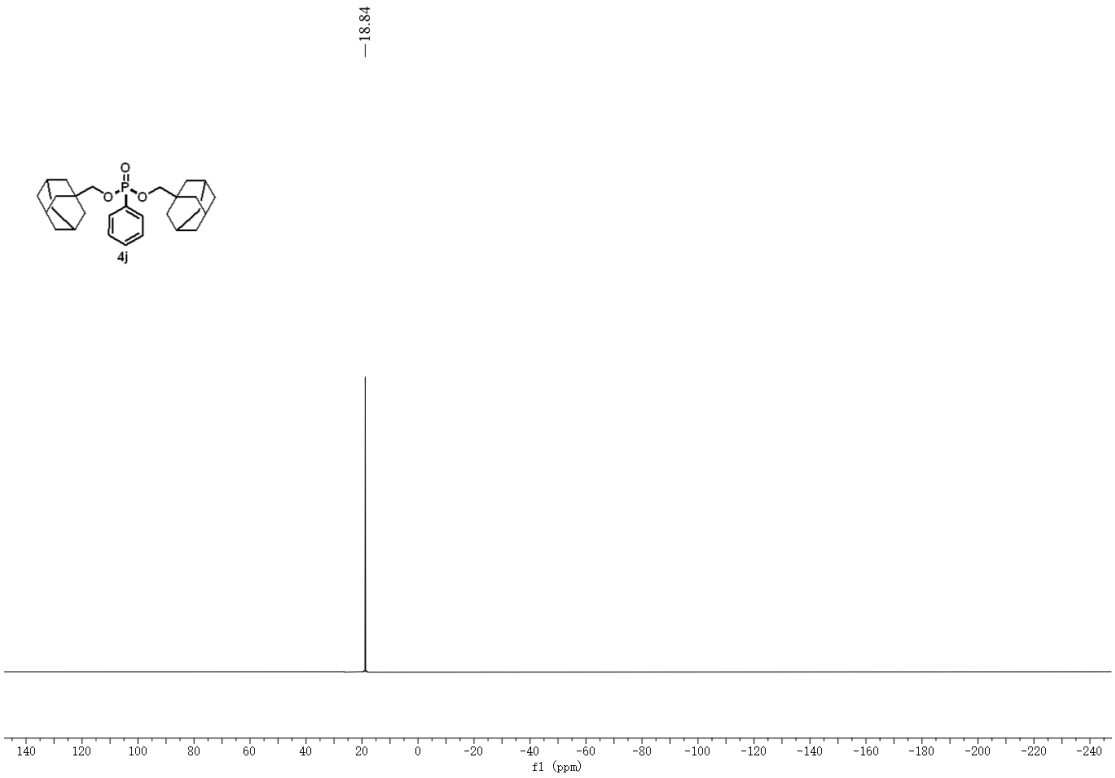
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 4j



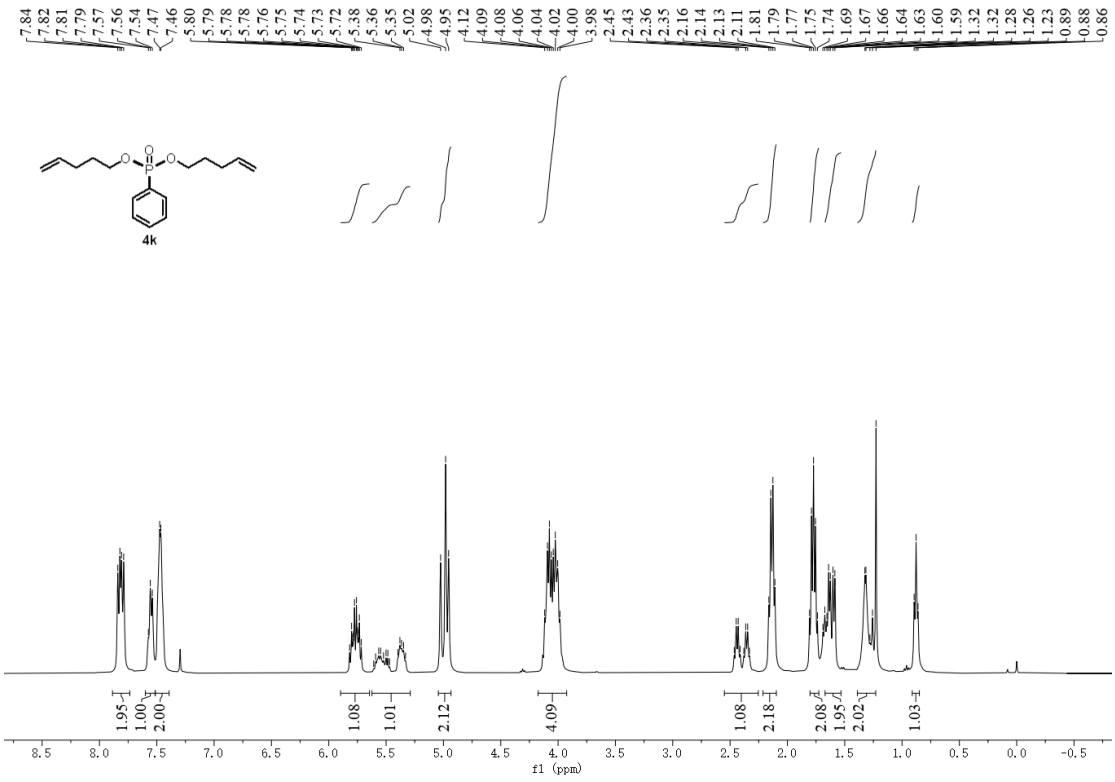

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 4j



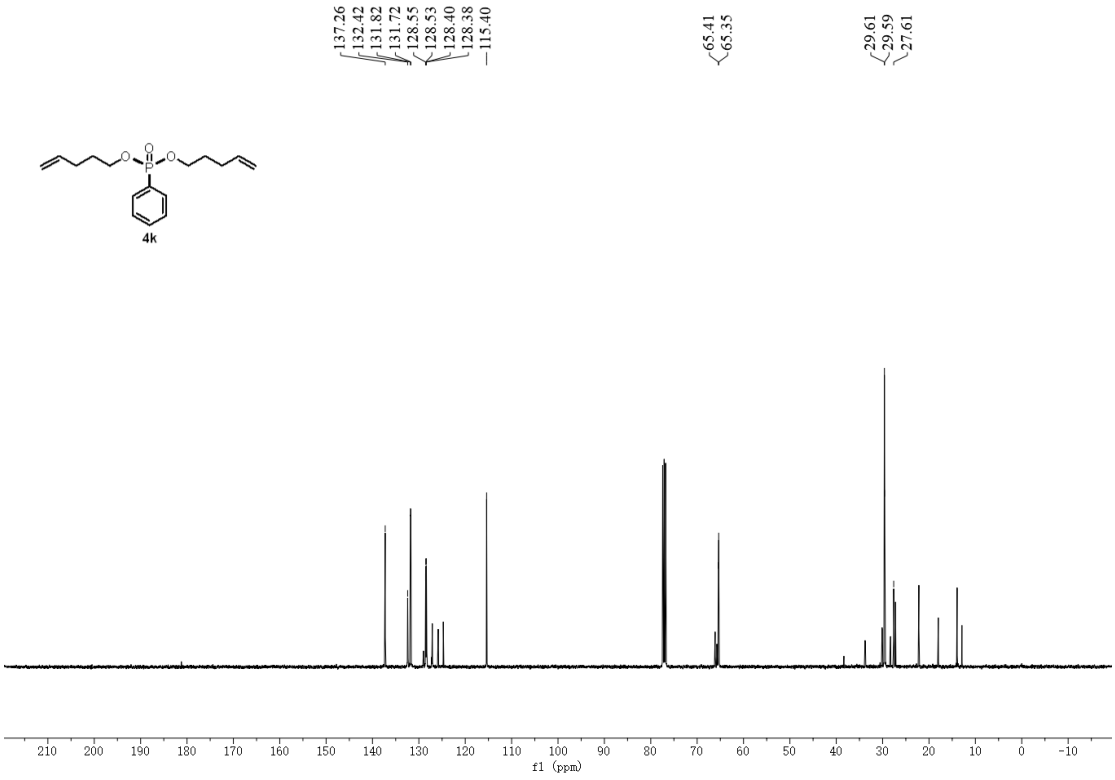
## $^{31}P$ NMR (121 MHz, $CDCl_3$) spectrum for 4j



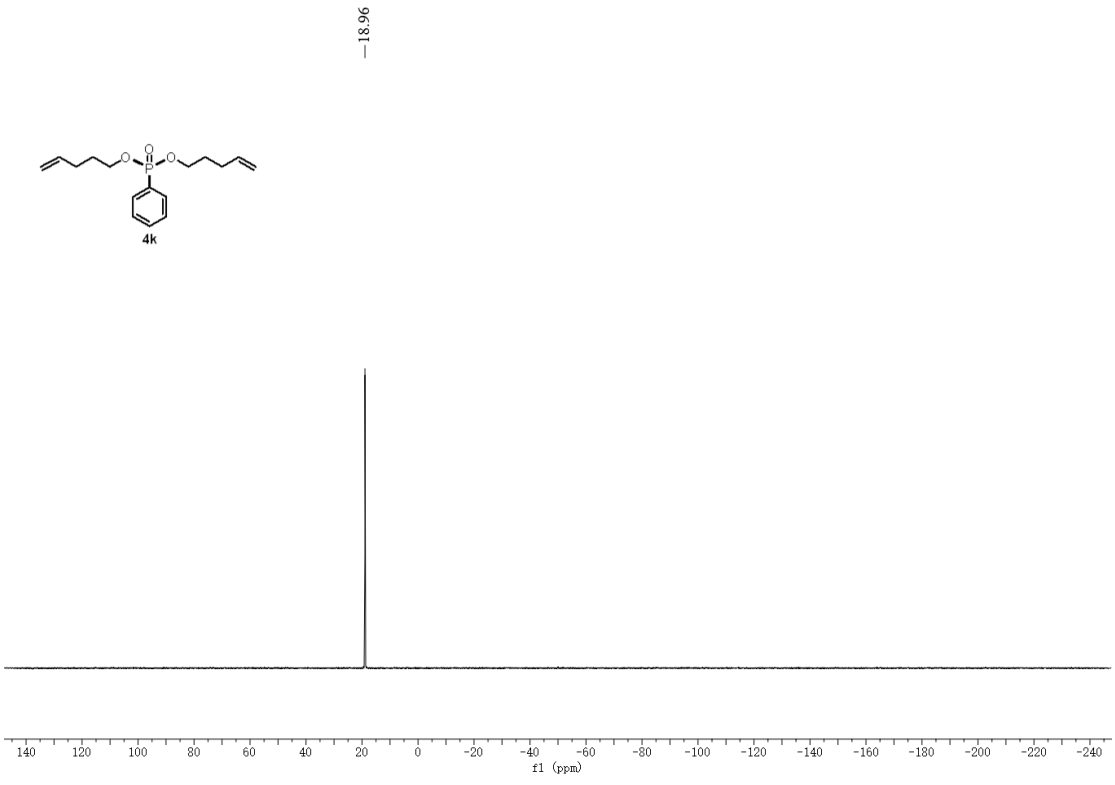

## $^{1}H$ NMR (400 MHz, $CDCl_3$) spectrum for 4k



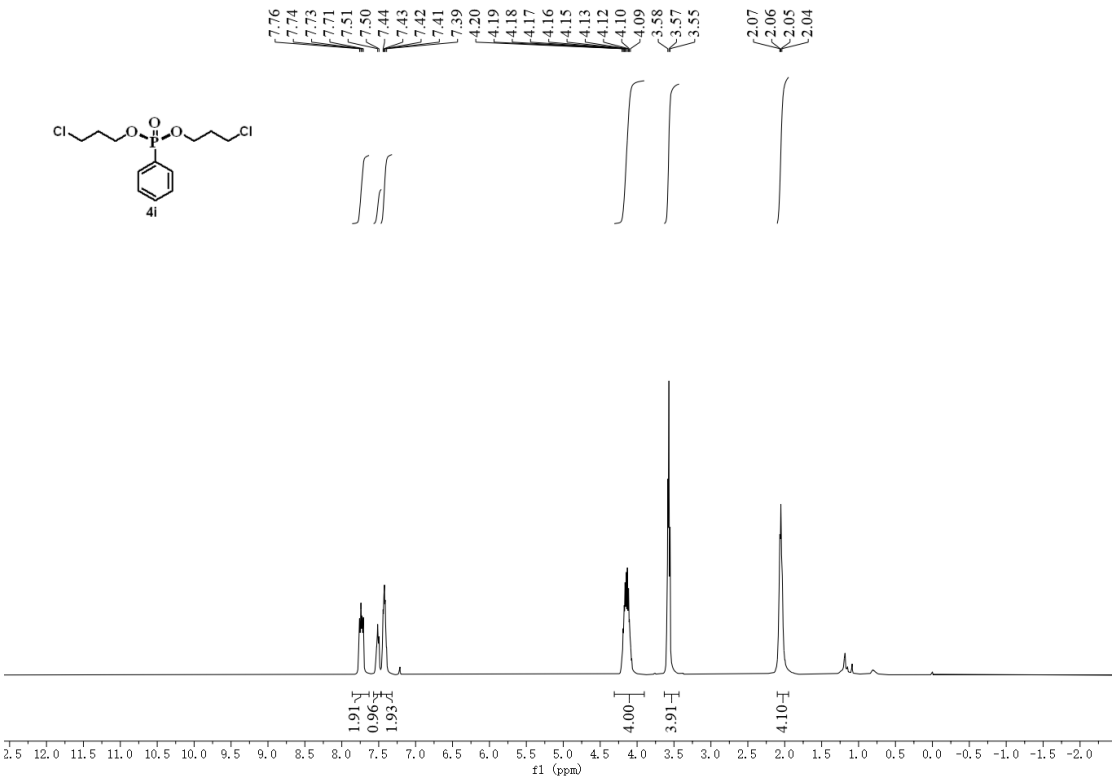
## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 4k



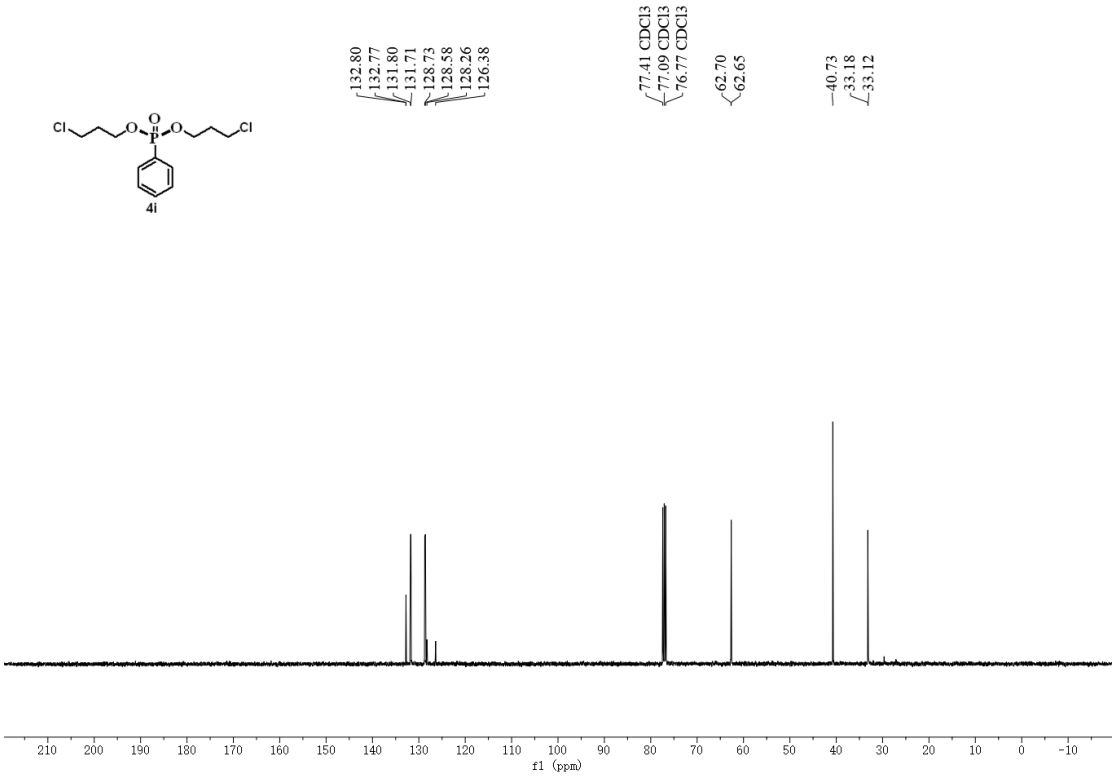

## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 4k



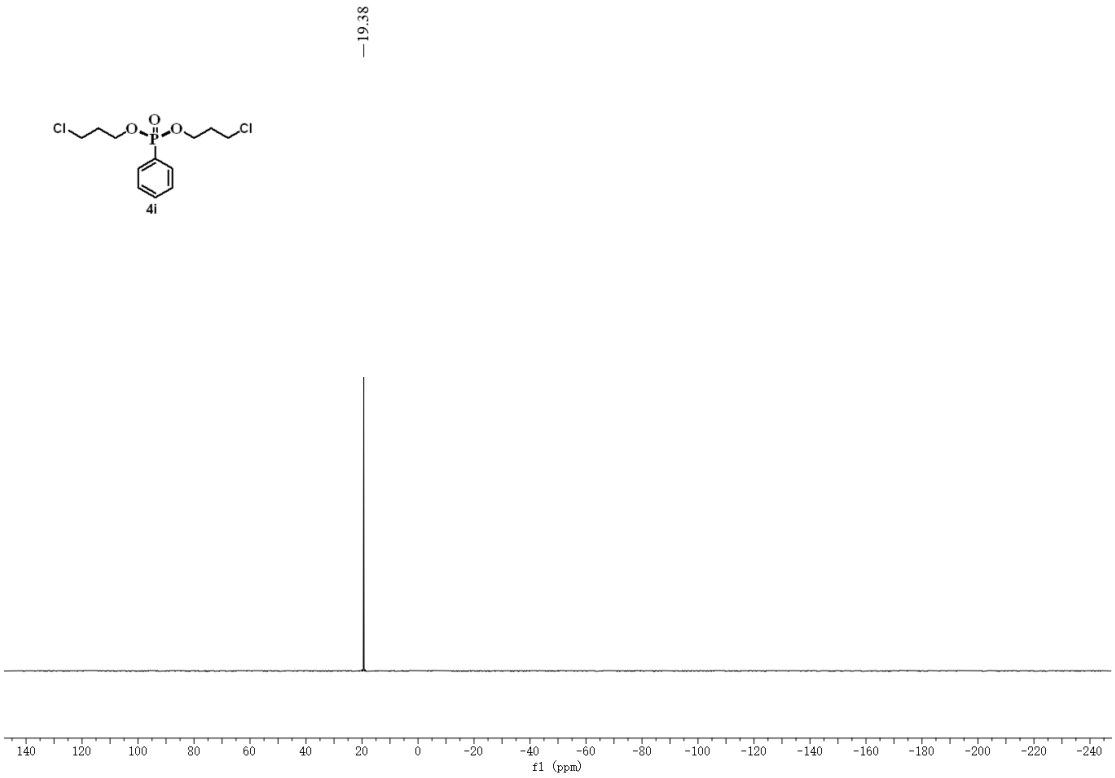
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 4l



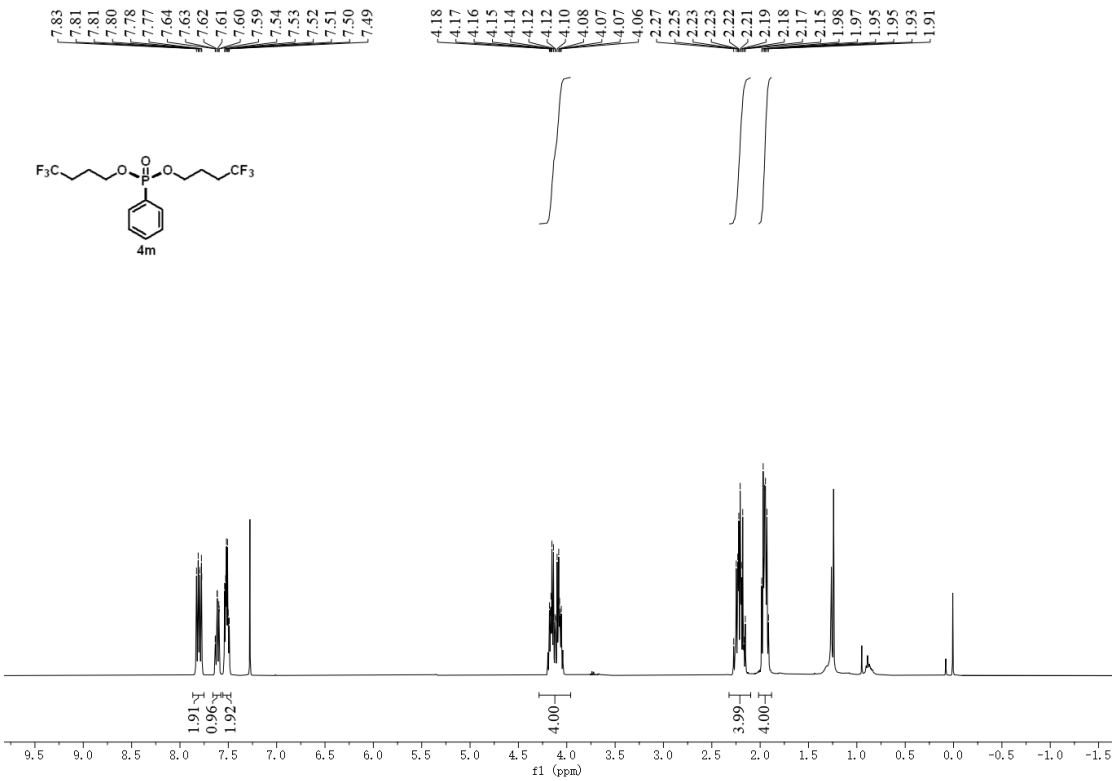

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 4l



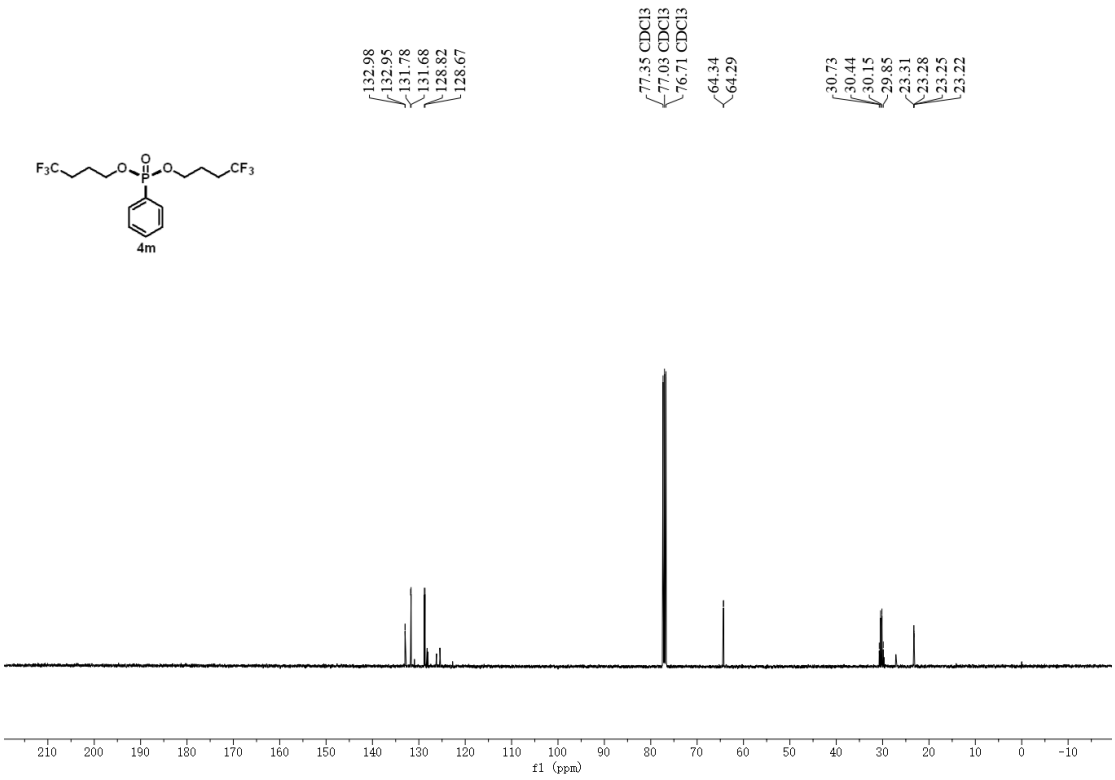
## $^{31}P$ NMR (121 MHz, $CDCl_3$) spectrum for 4l



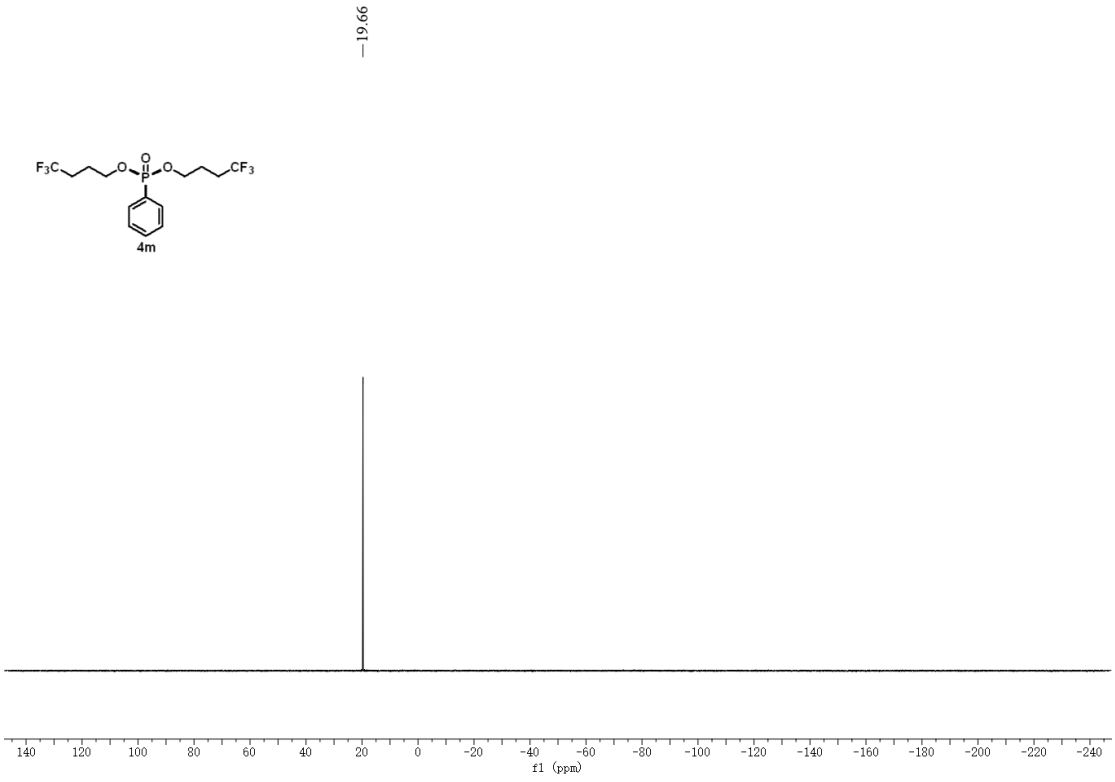

## $^{1}H$ NMR (400 MHz, $CDCl_3$) spectrum for 4m



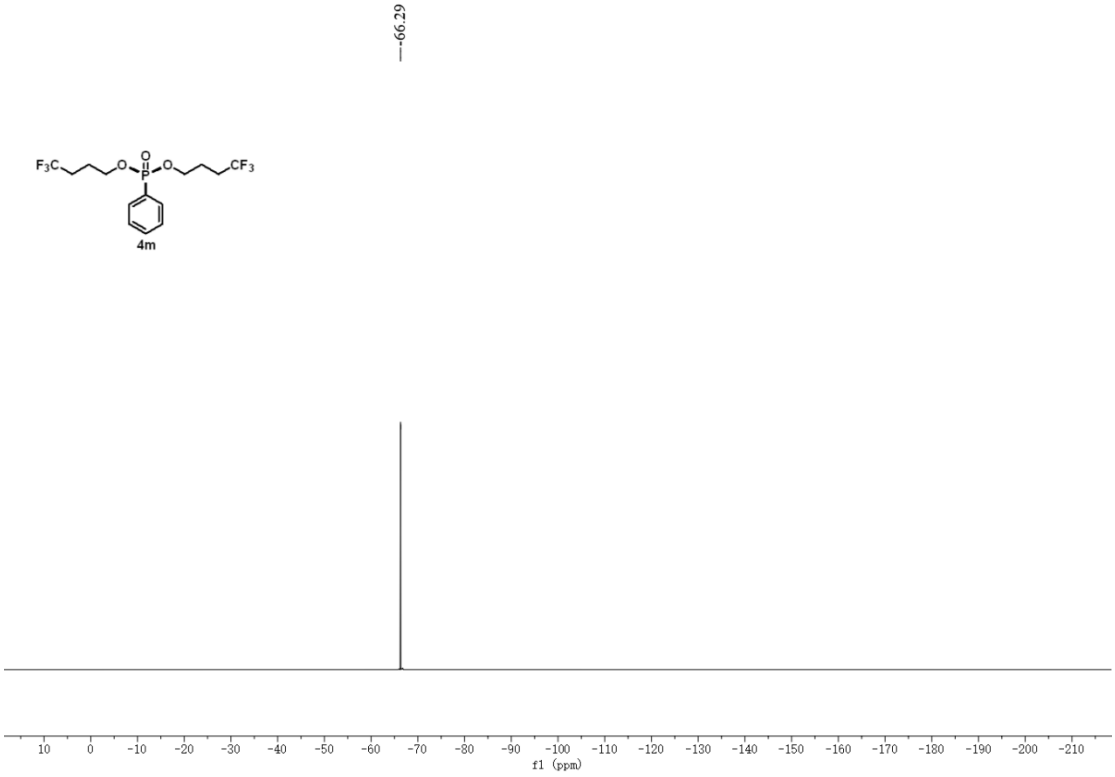
## $^{13}C$ NMR (101 MHz, $CDCl_3$) spectrum for 4m



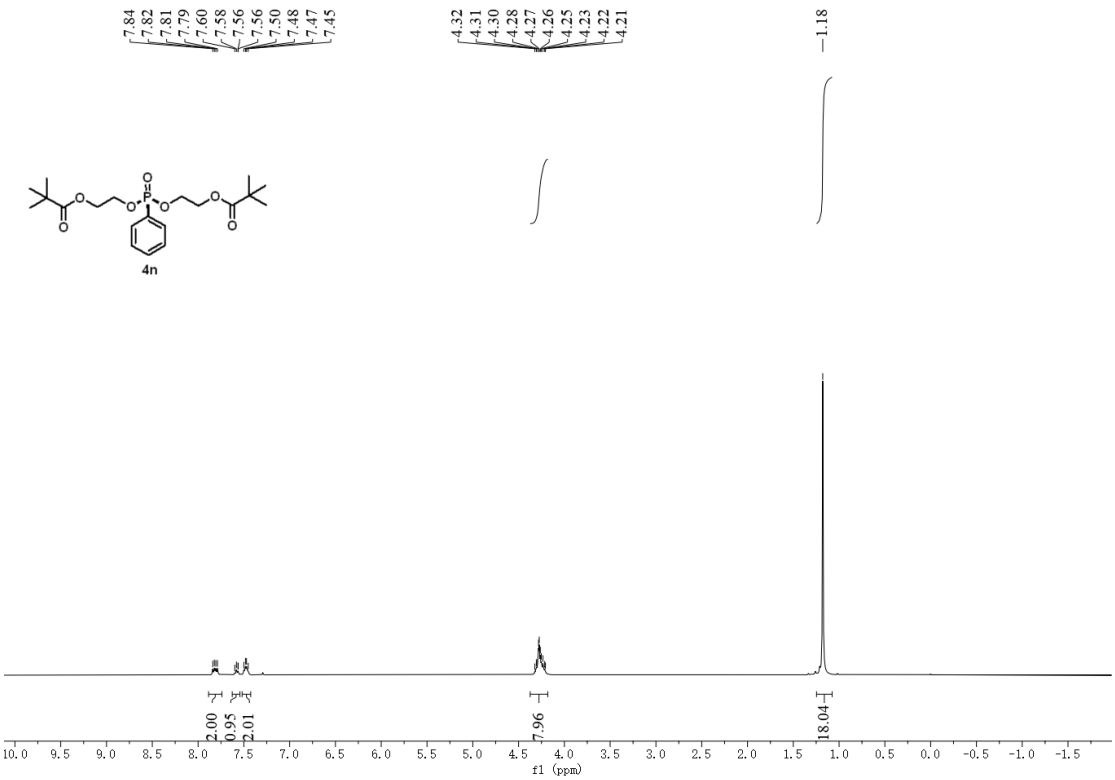

## $^{31}P$ NMR (121 MHz, $CDCl_3$) spectrum for 4m



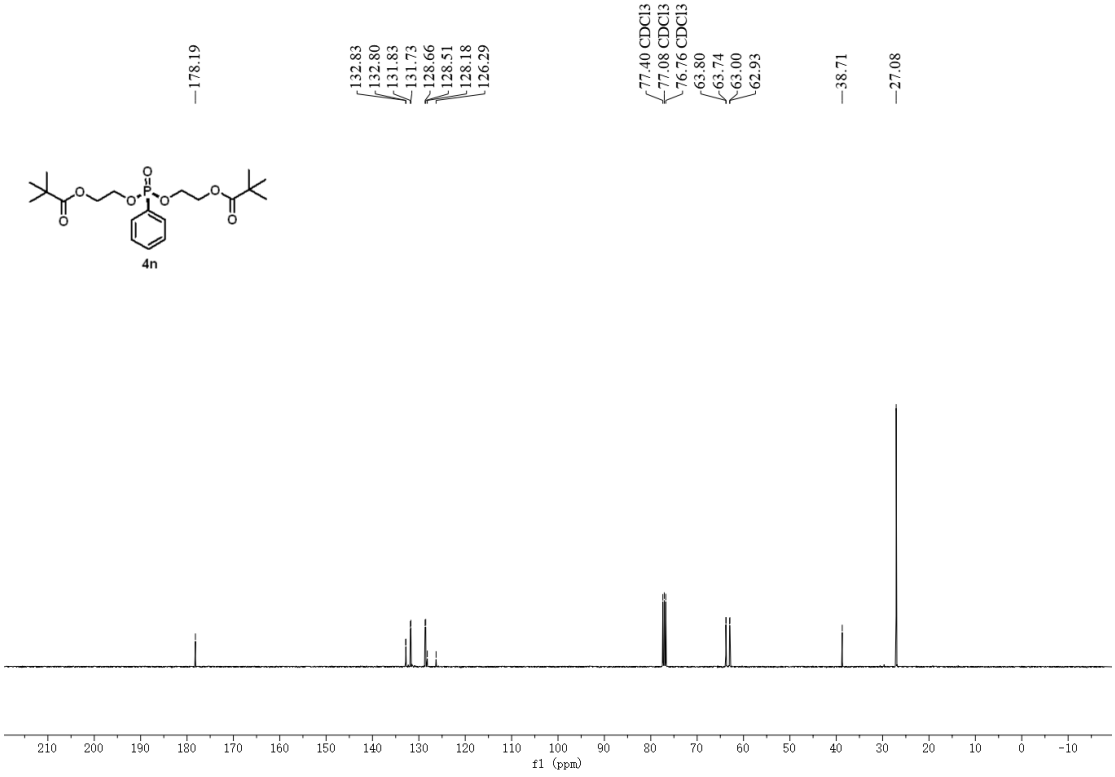
## $^{19}F$ NMR (282 MHz, $CDCl_3$) spectrum for 4m



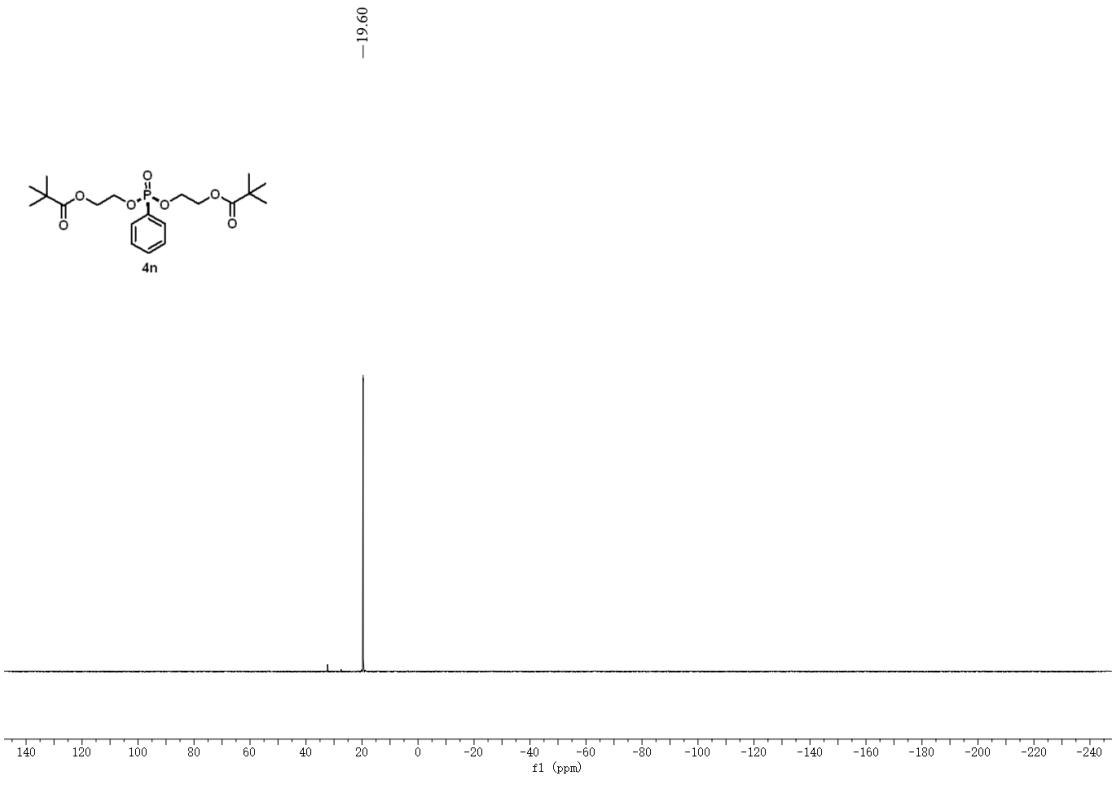

## $^{1}H$ NMR (400 MHz, $CDCl_3$) spectrum for 4n



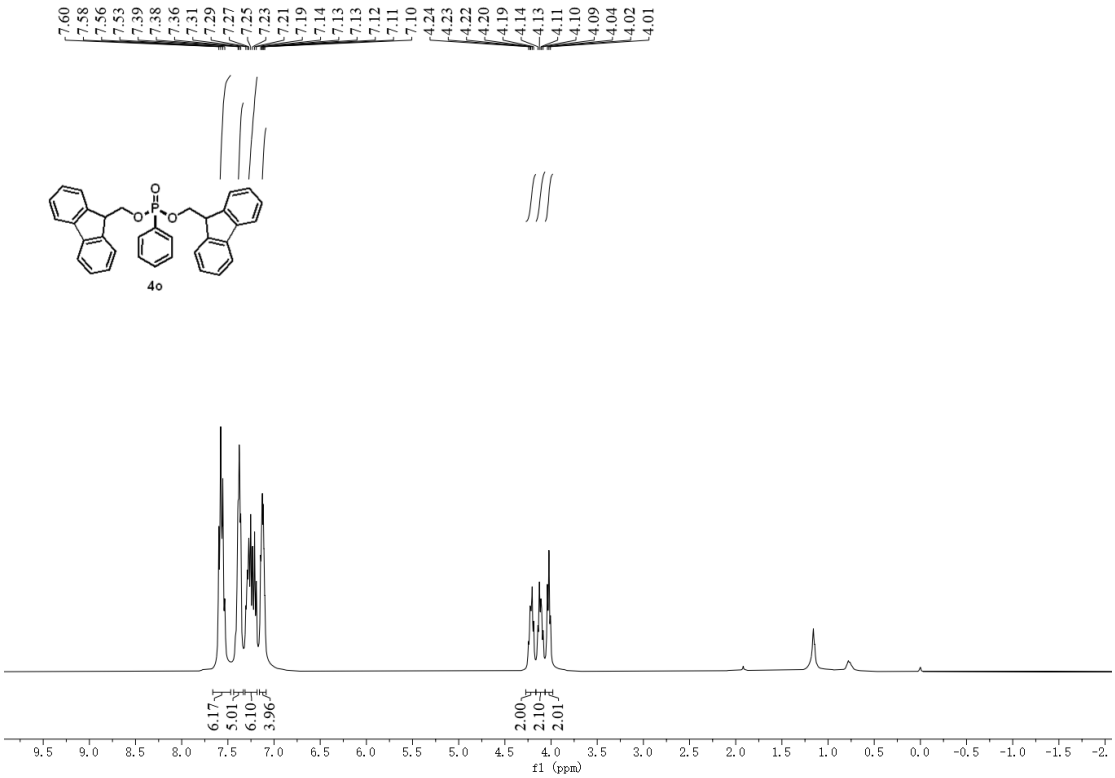
## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 4n



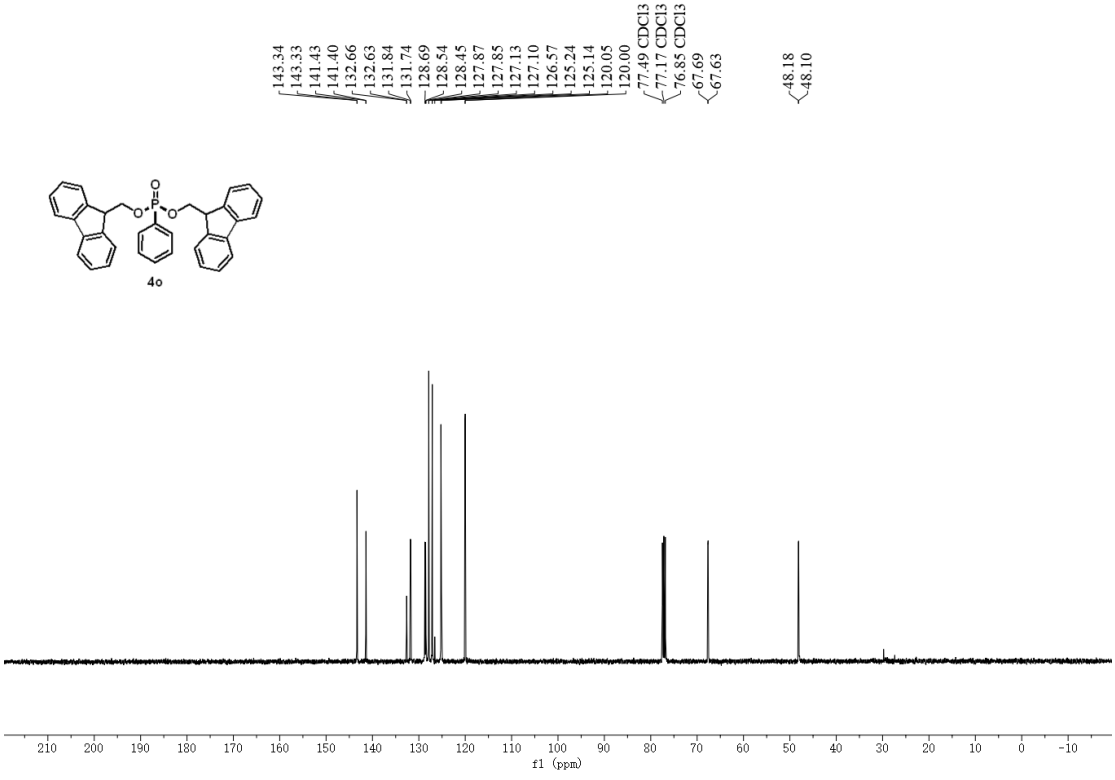

## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 4n



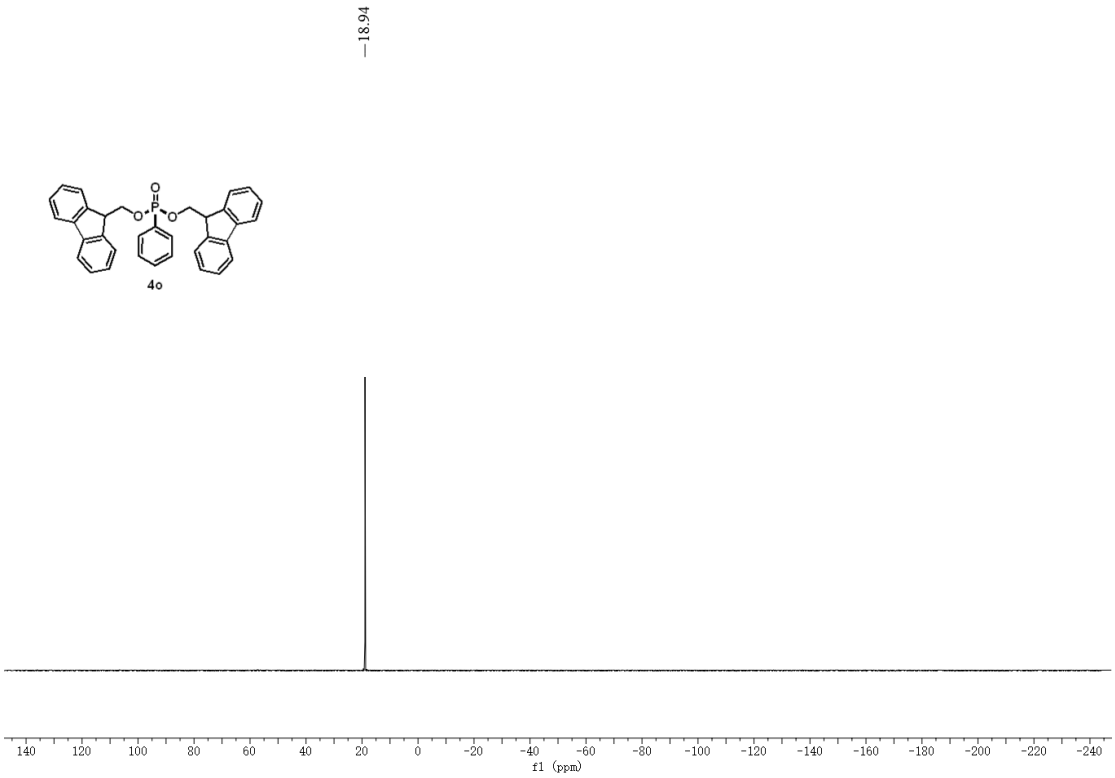
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 4o



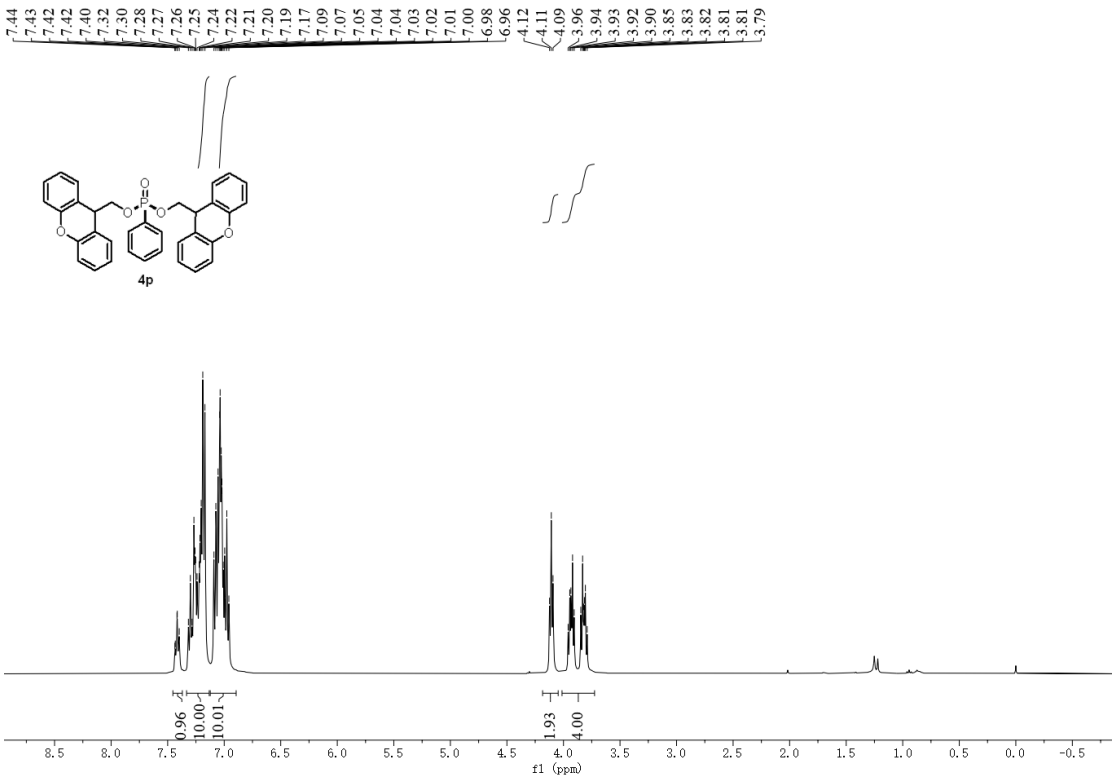

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 4o



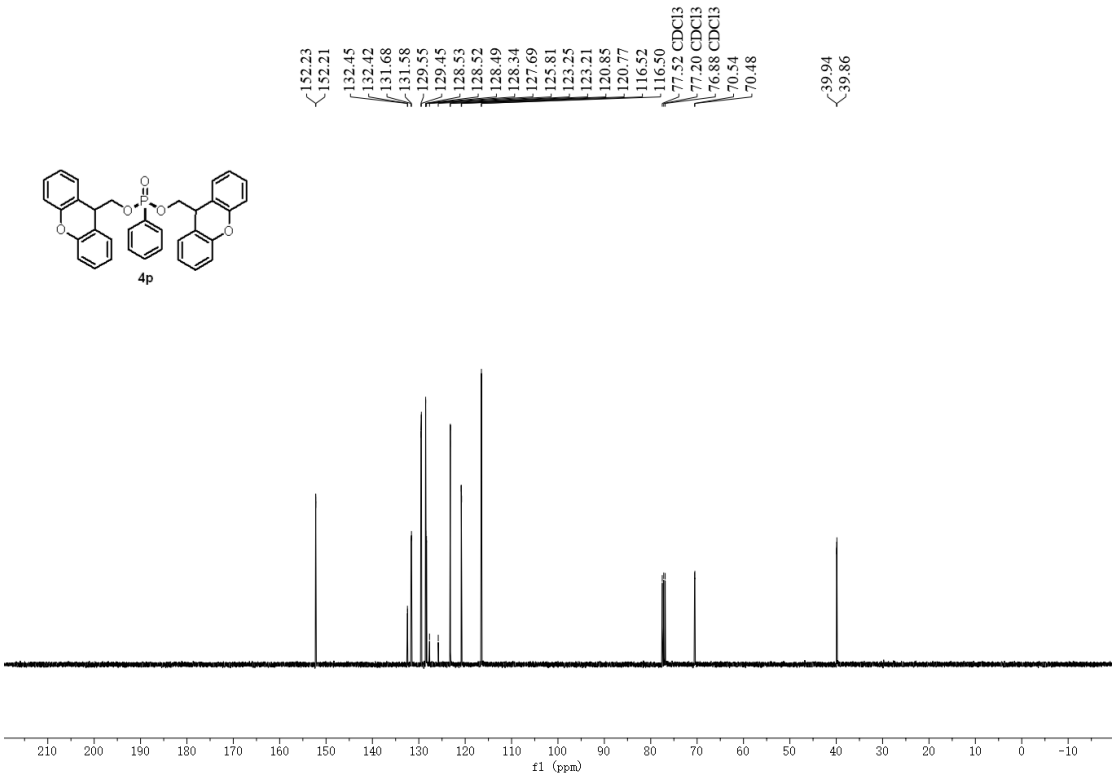
## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 4o



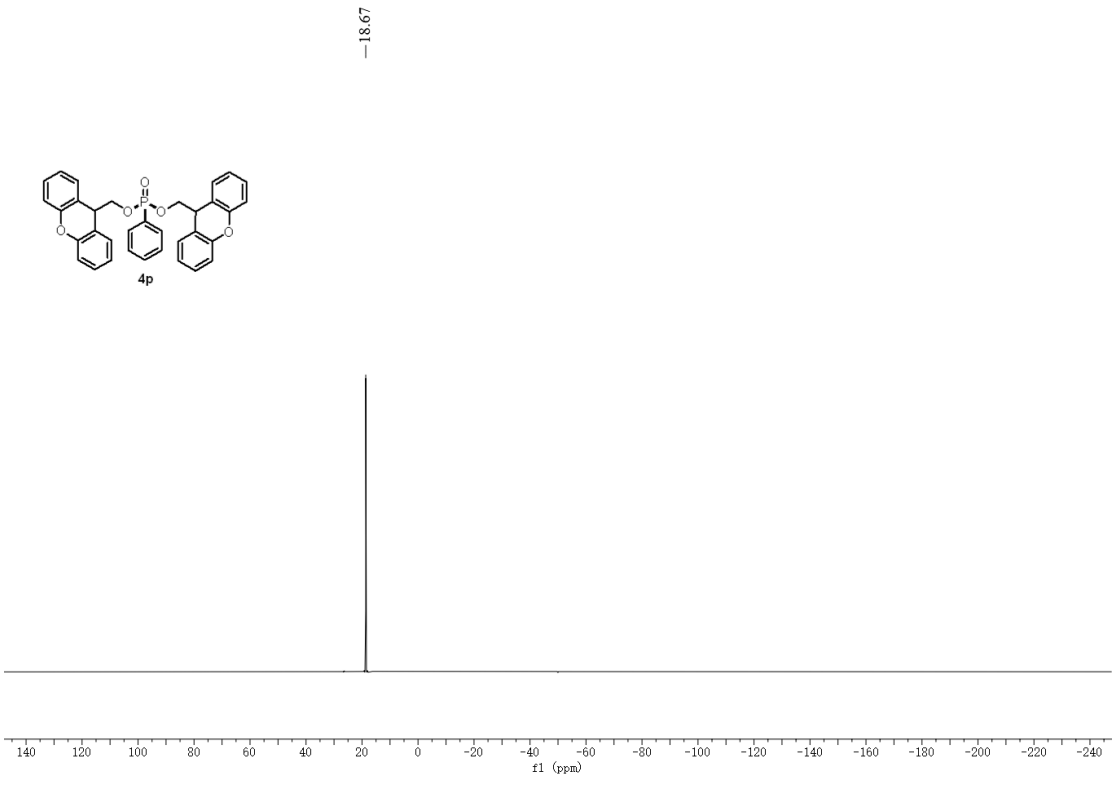

## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 4p



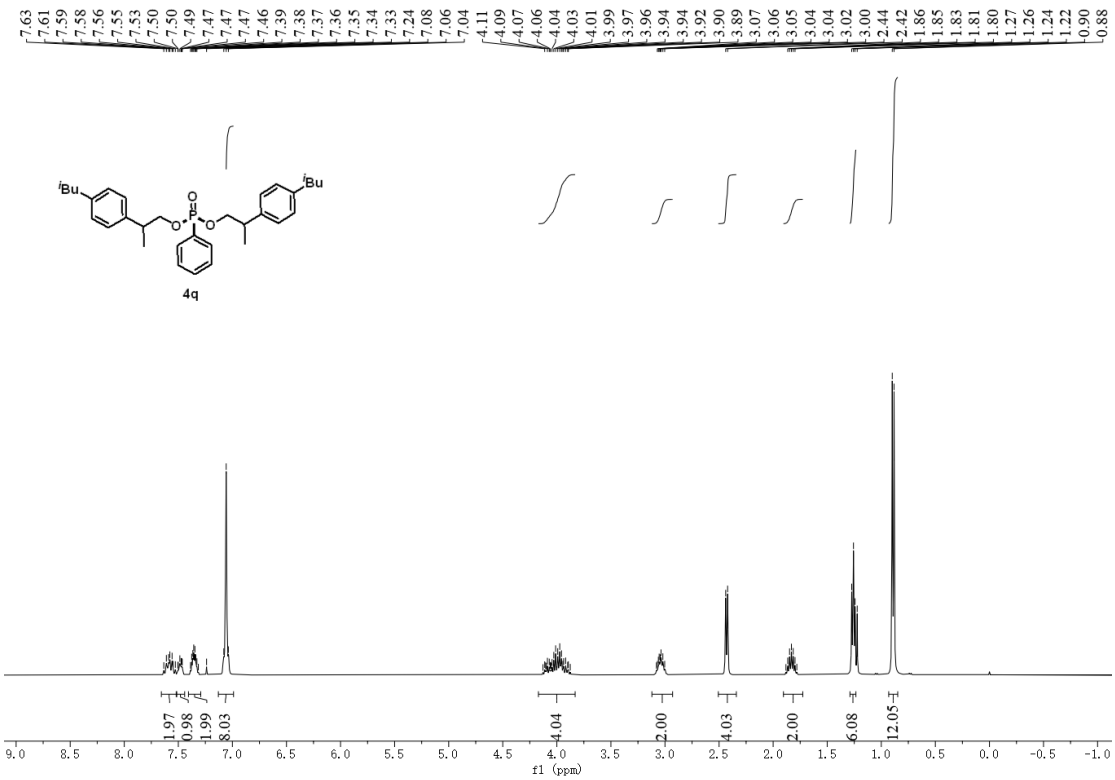
## $^{13}C$ NMR (101 MHz, $CDCl_3$) spectrum for 4p



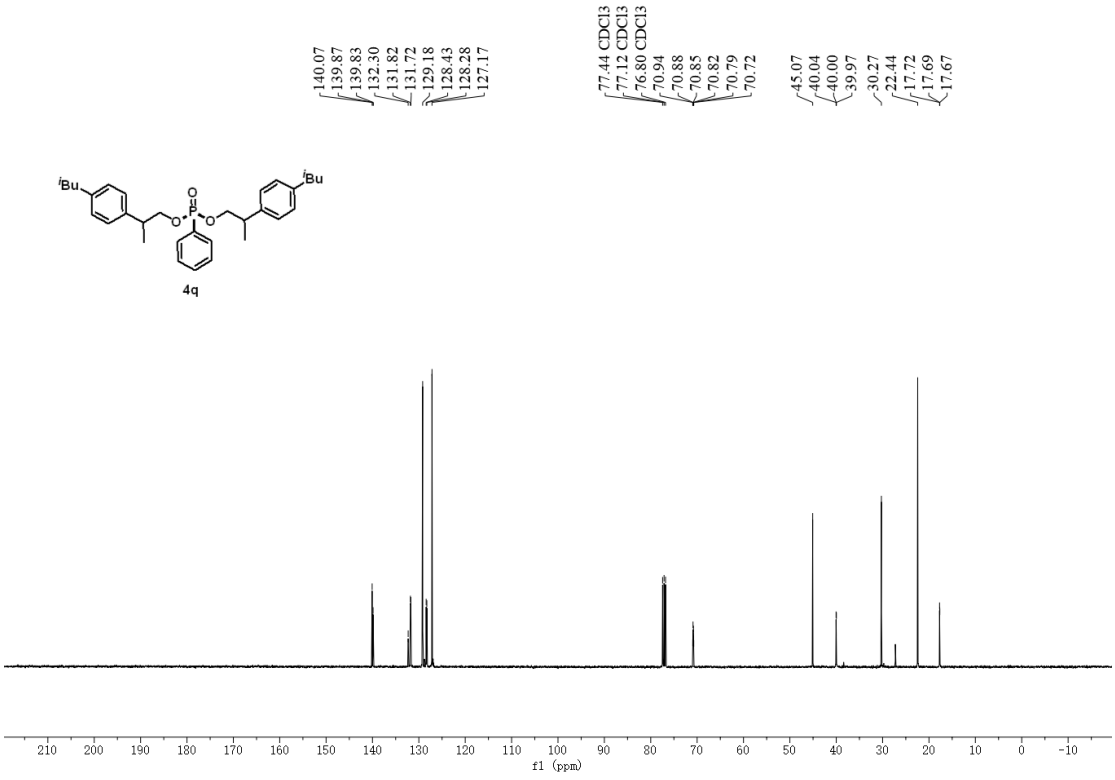

## $^{31}P$ NMR (121 MHz, $CDCl_3$) spectrum for 4p



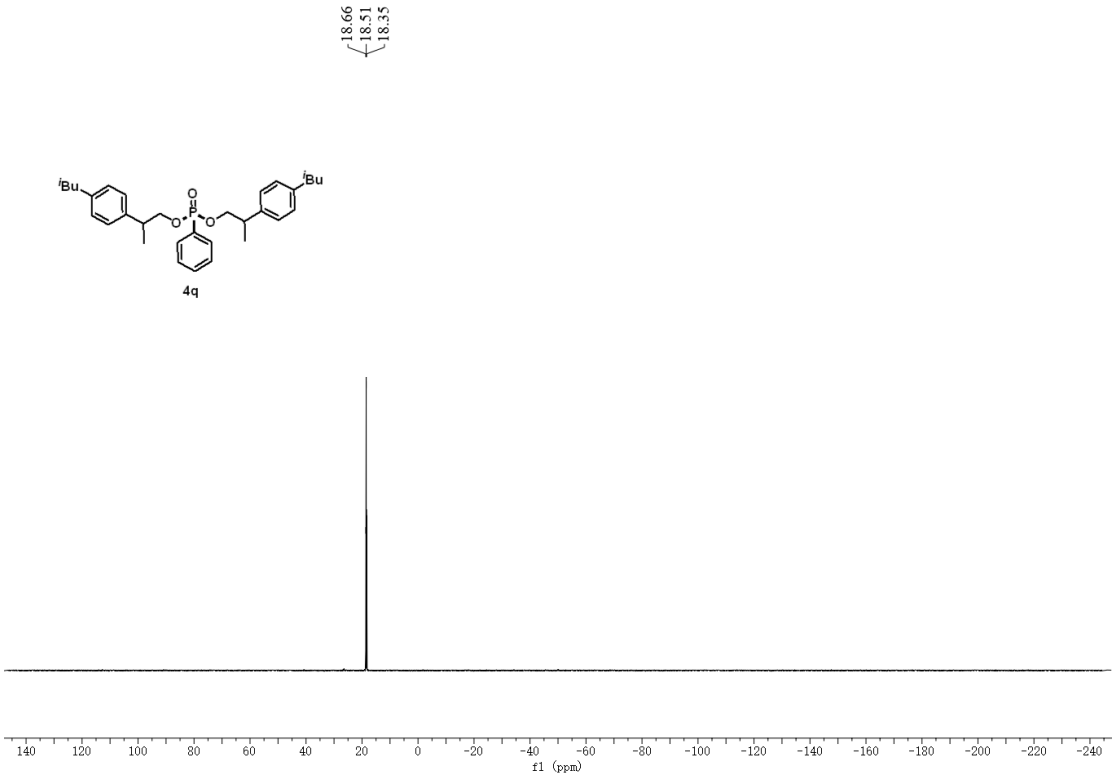
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 4q



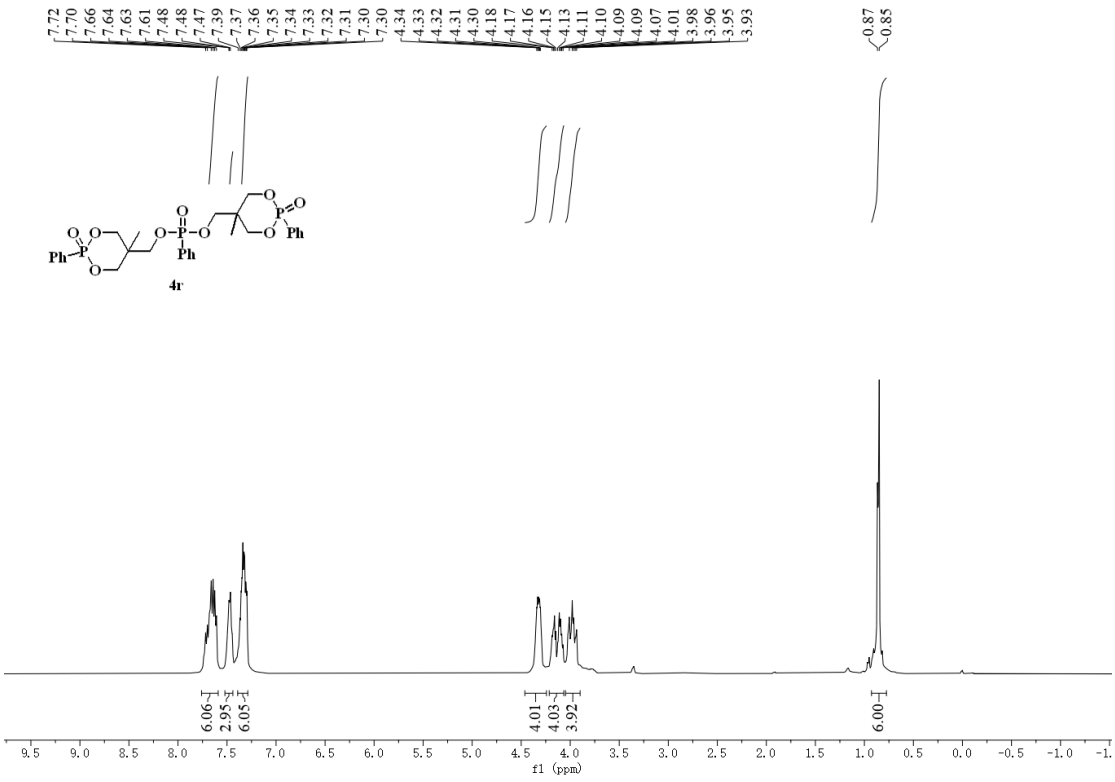

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 4q



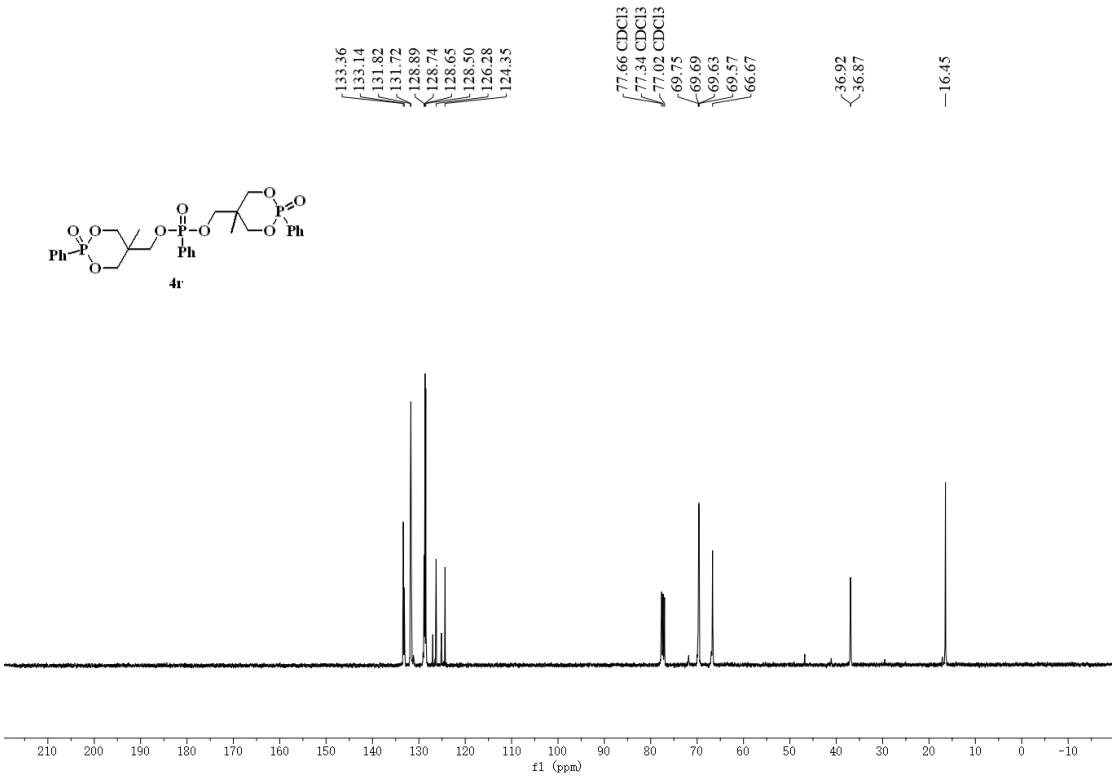
## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 4q



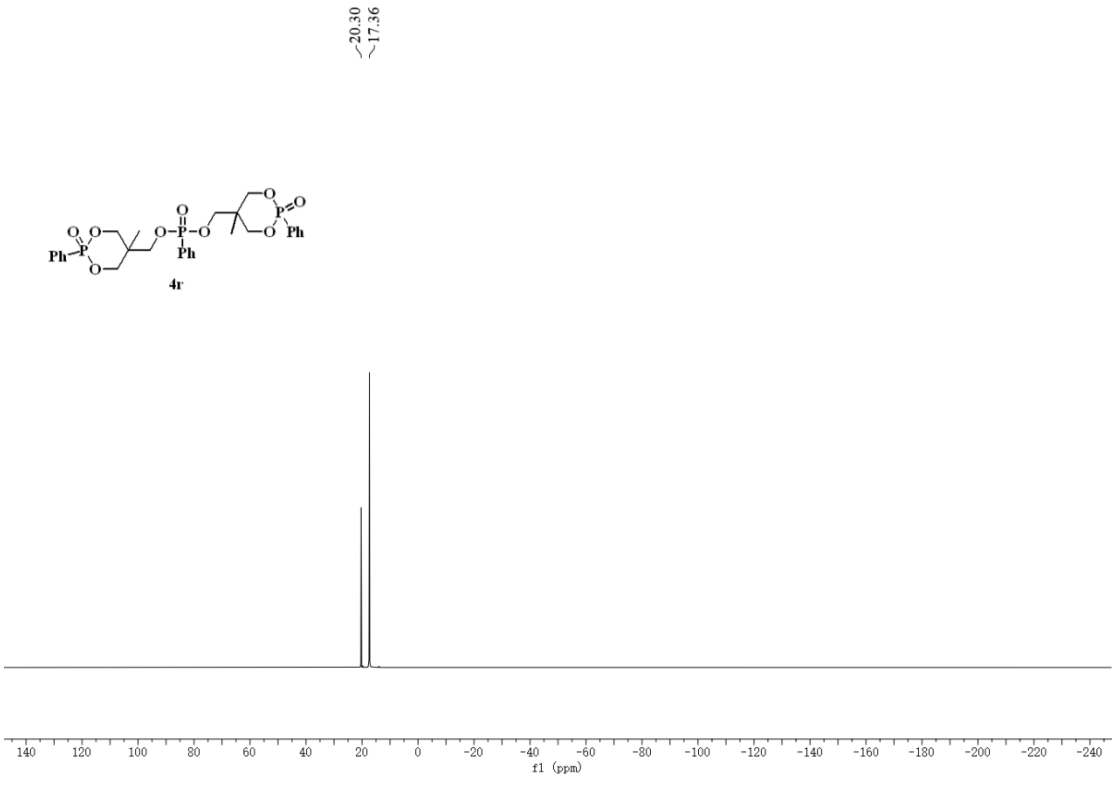

## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 4r



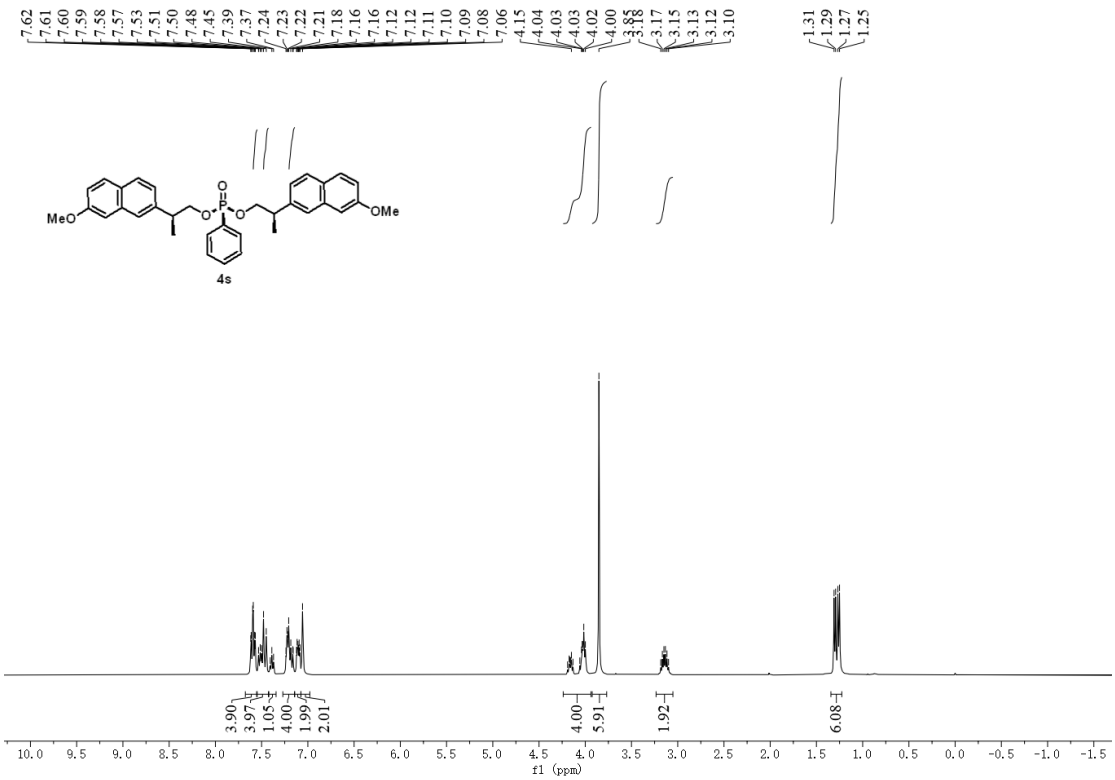
## $^{13}C$ NMR (101 MHz, $CDCl_3$) spectrum for 4r



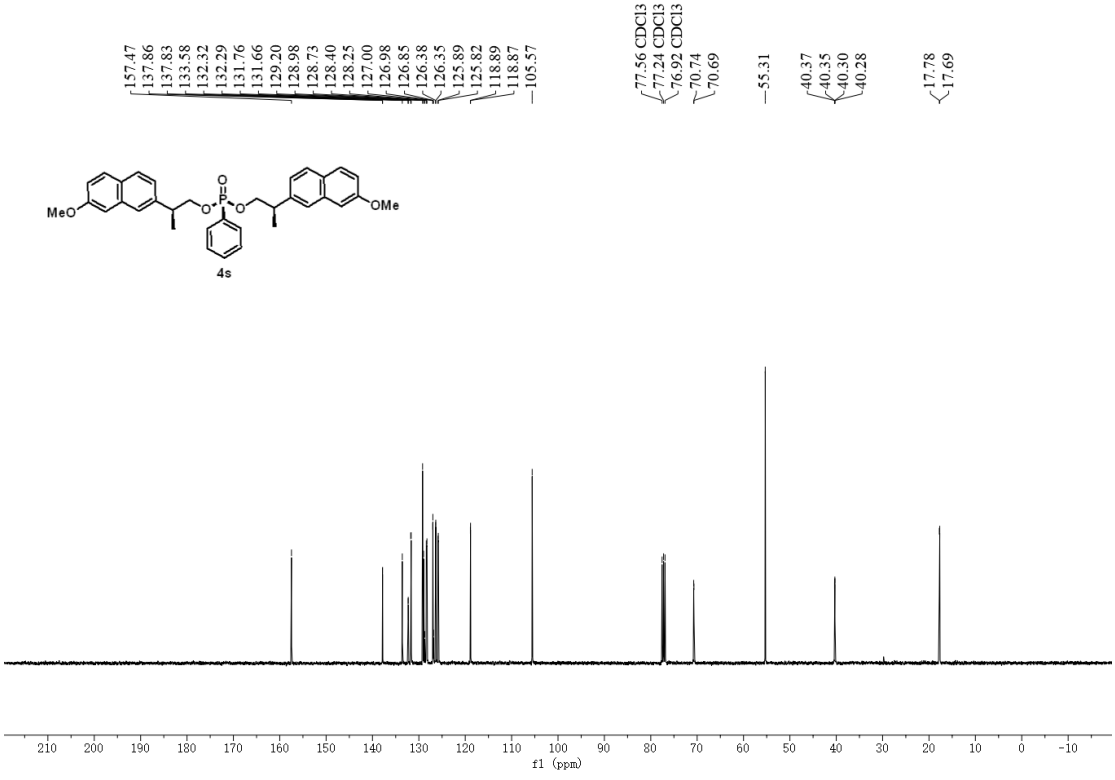

## $^{31}P$ NMR (121 MHz, $CDCl_3$) spectrum for 4r



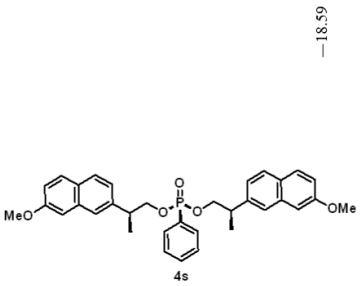
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 4s




## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 4s



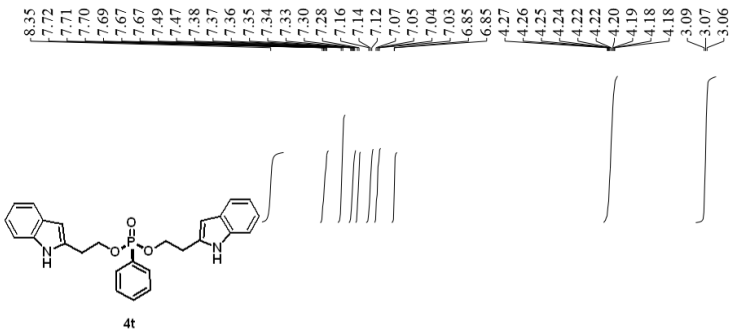
## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 4s




4s

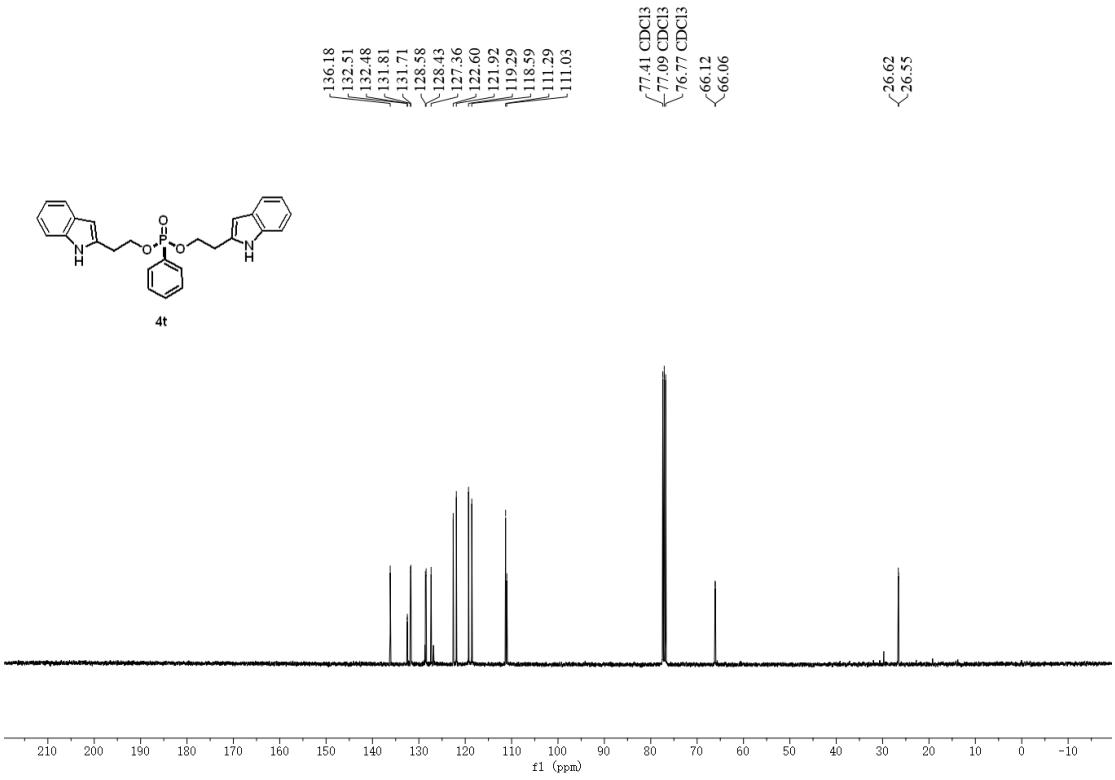



## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 4t

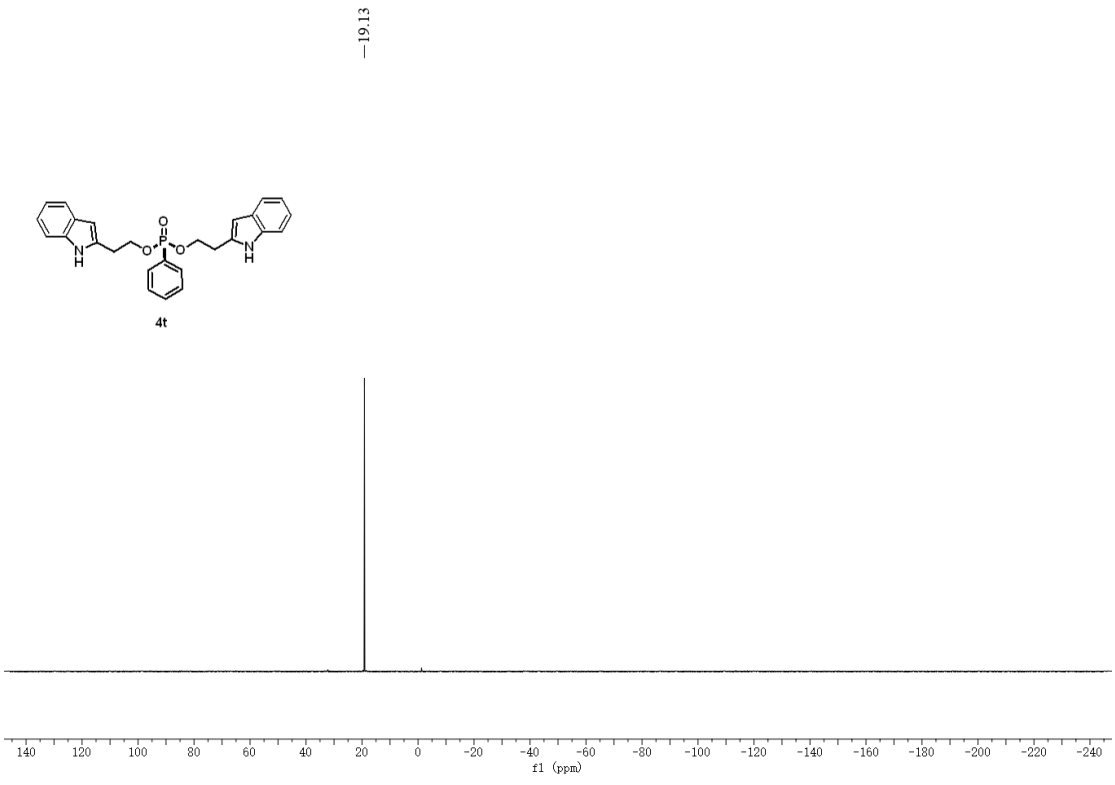



4t

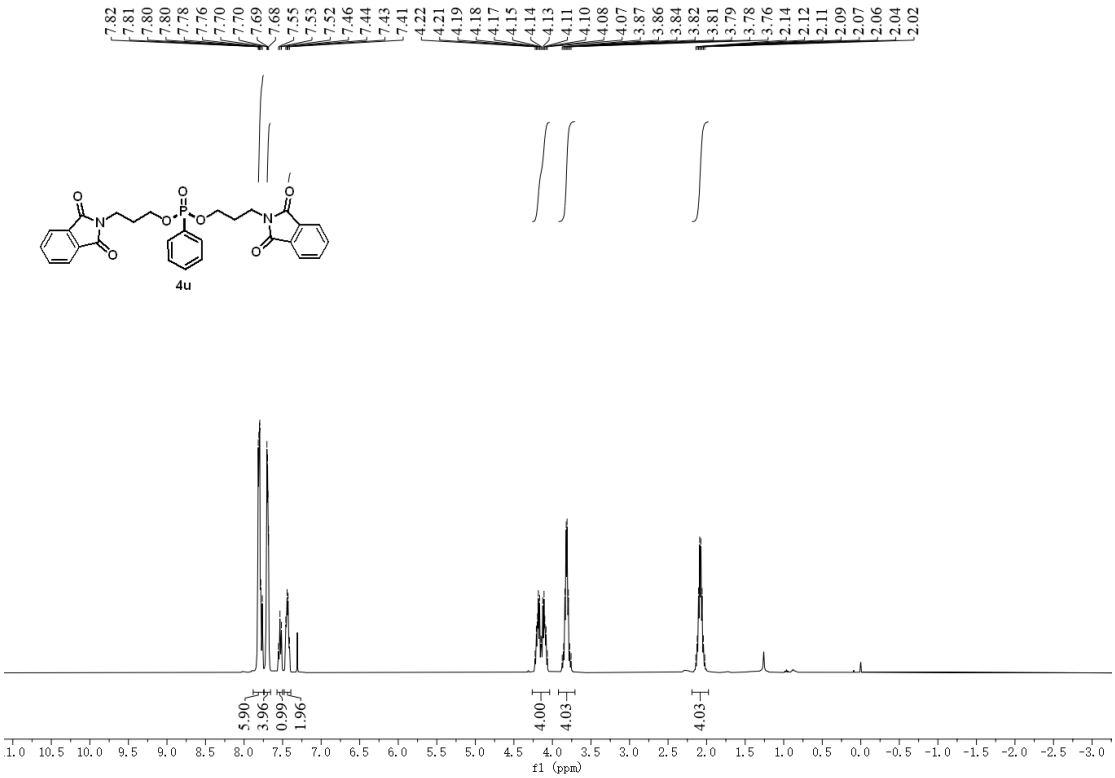
## $^{13}C$ NMR (101 MHz, $CDCl_3$) spectrum for 4t



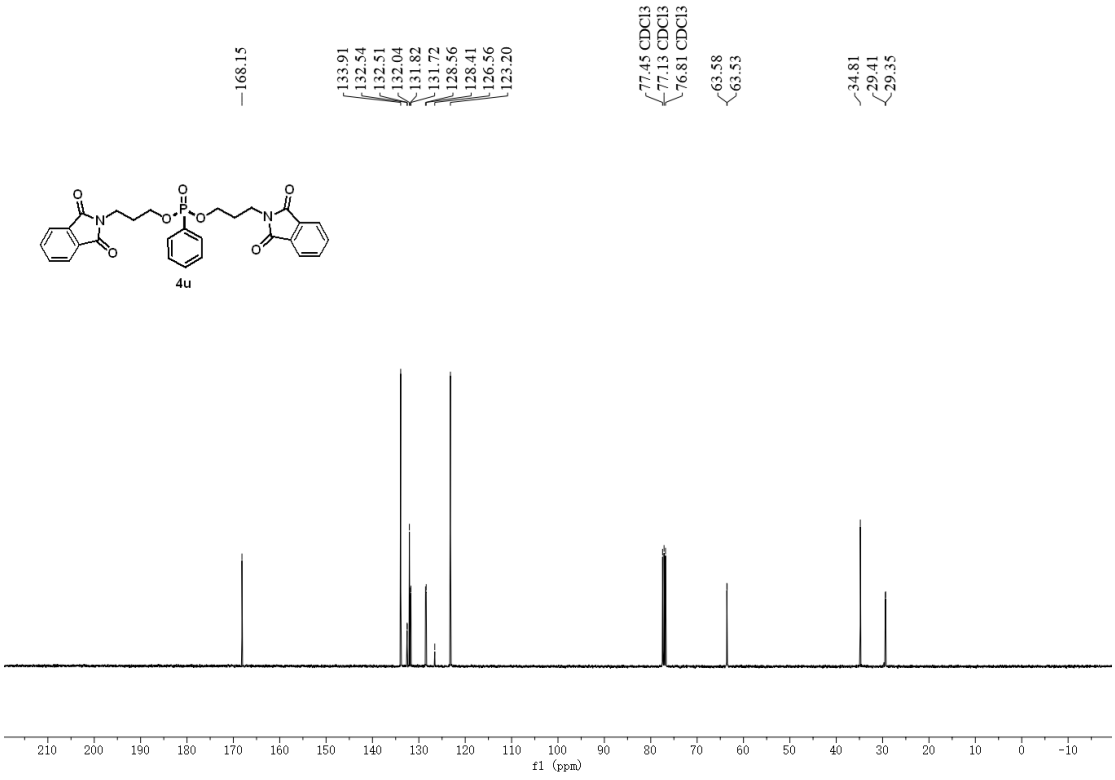

## $^{31}P$ NMR (121 MHz, $CDCl_3$) spectrum for 4t



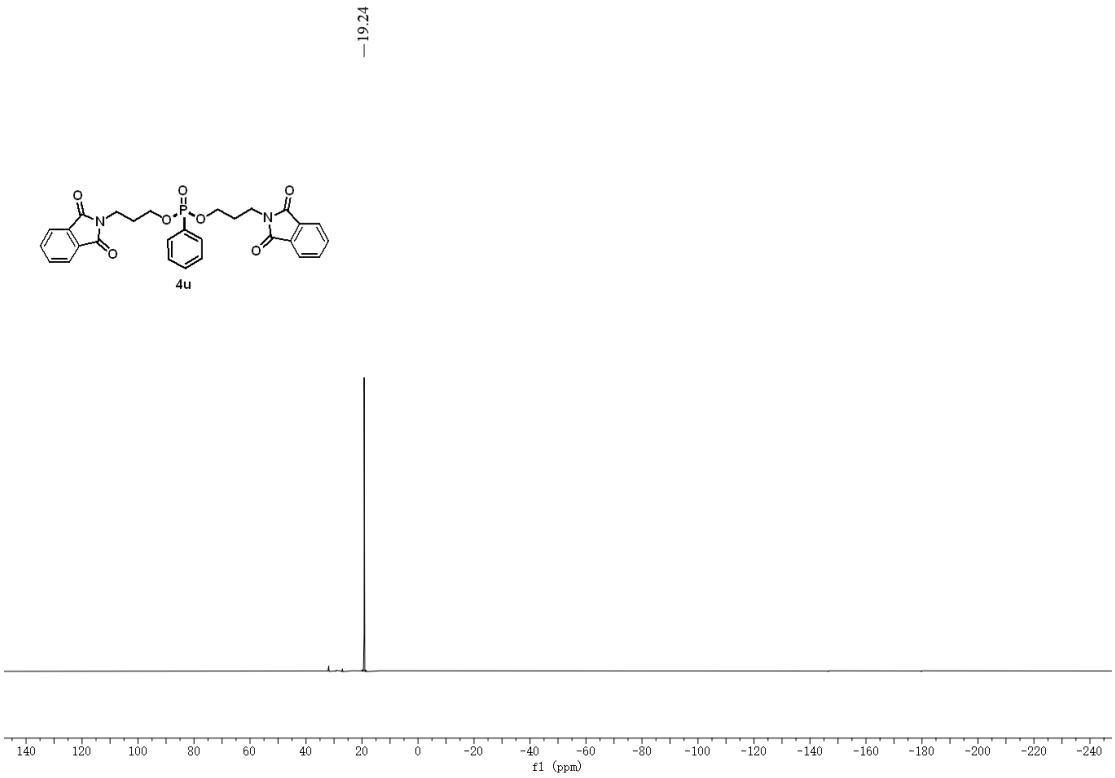
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 4u



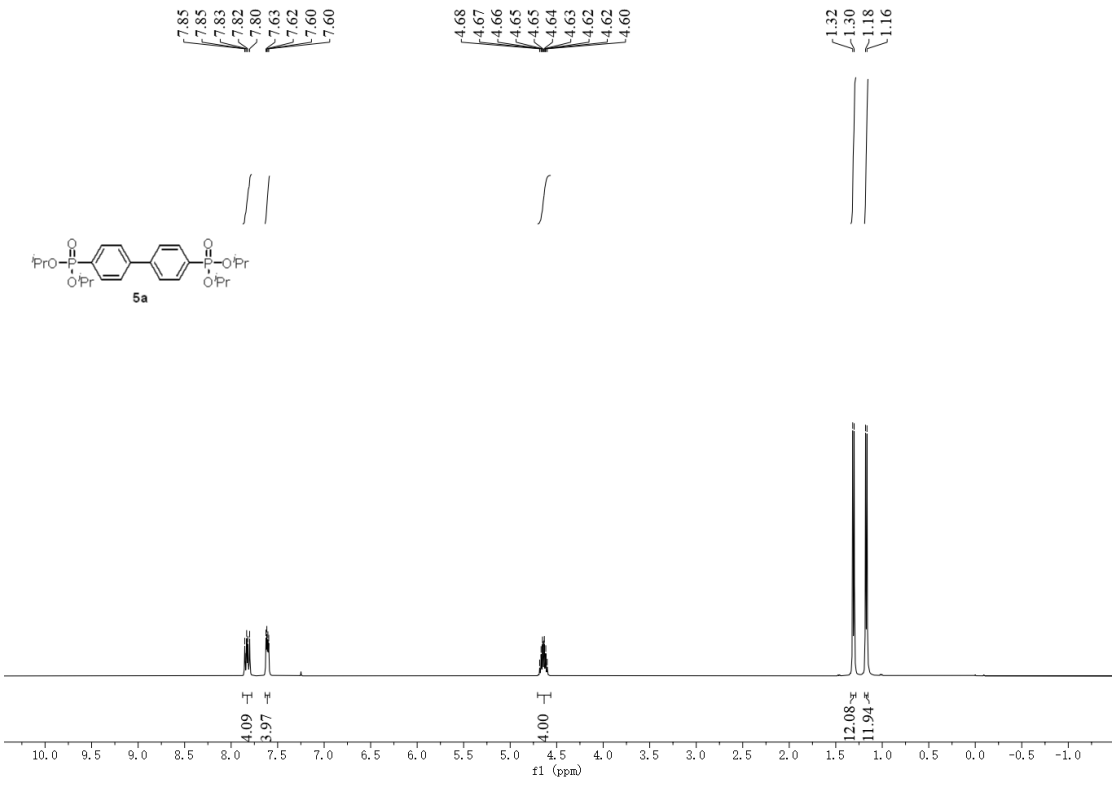

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 4u



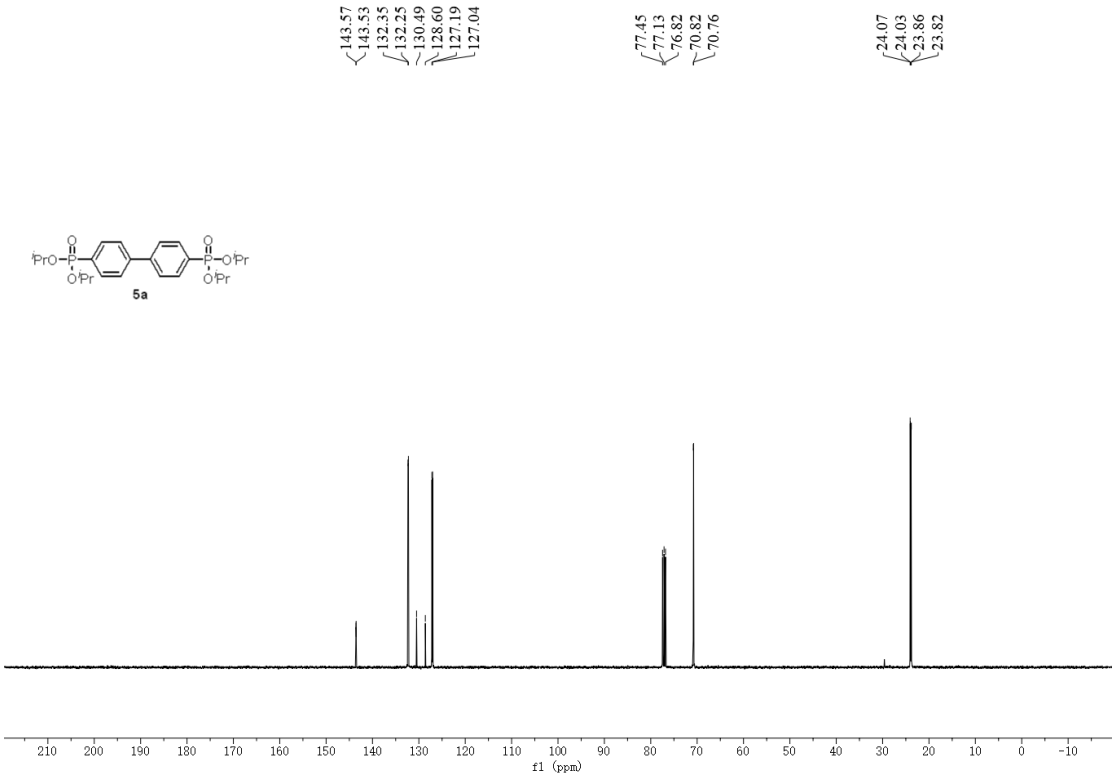
## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 4u



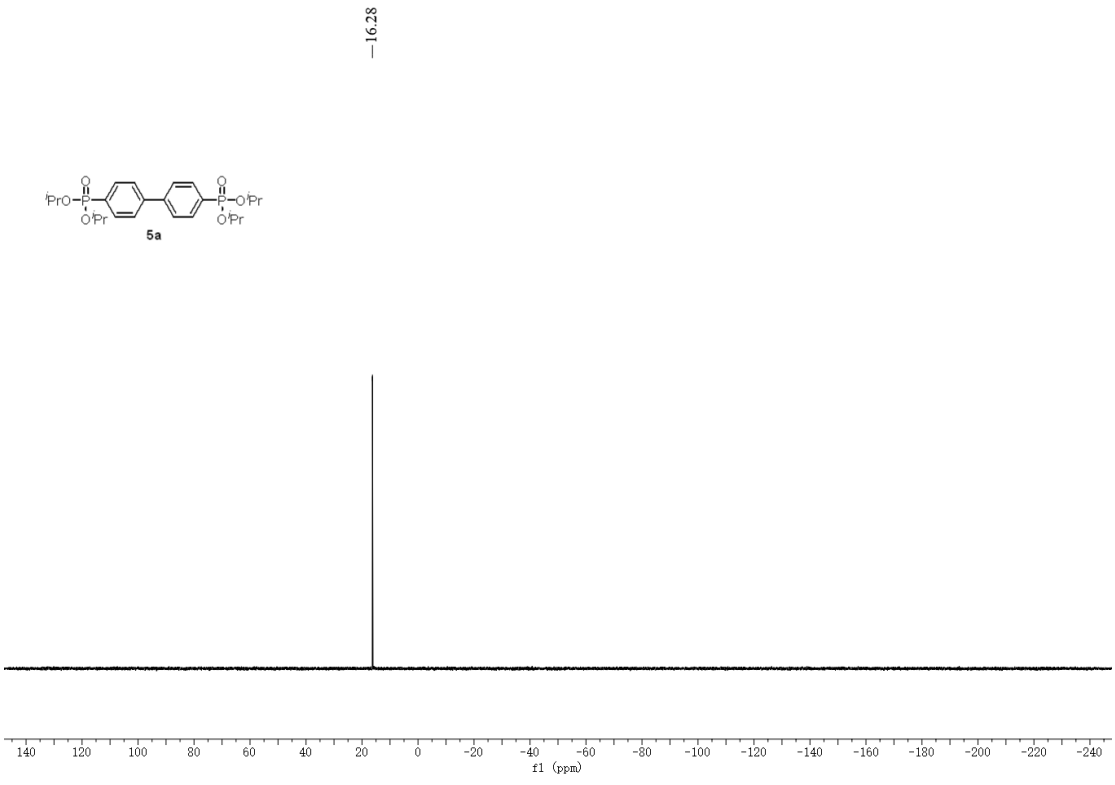

## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 5a



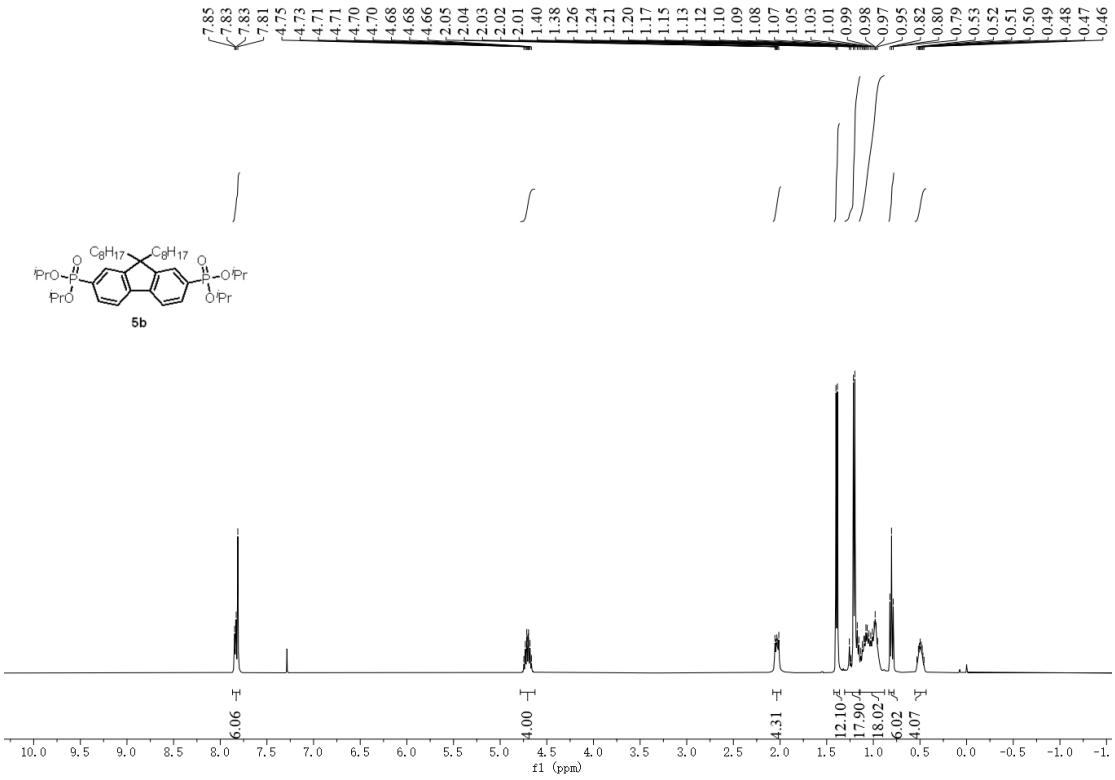
## $^{13}C$ NMR (101 MHz, $CDCl_3$) spectrum for 5a



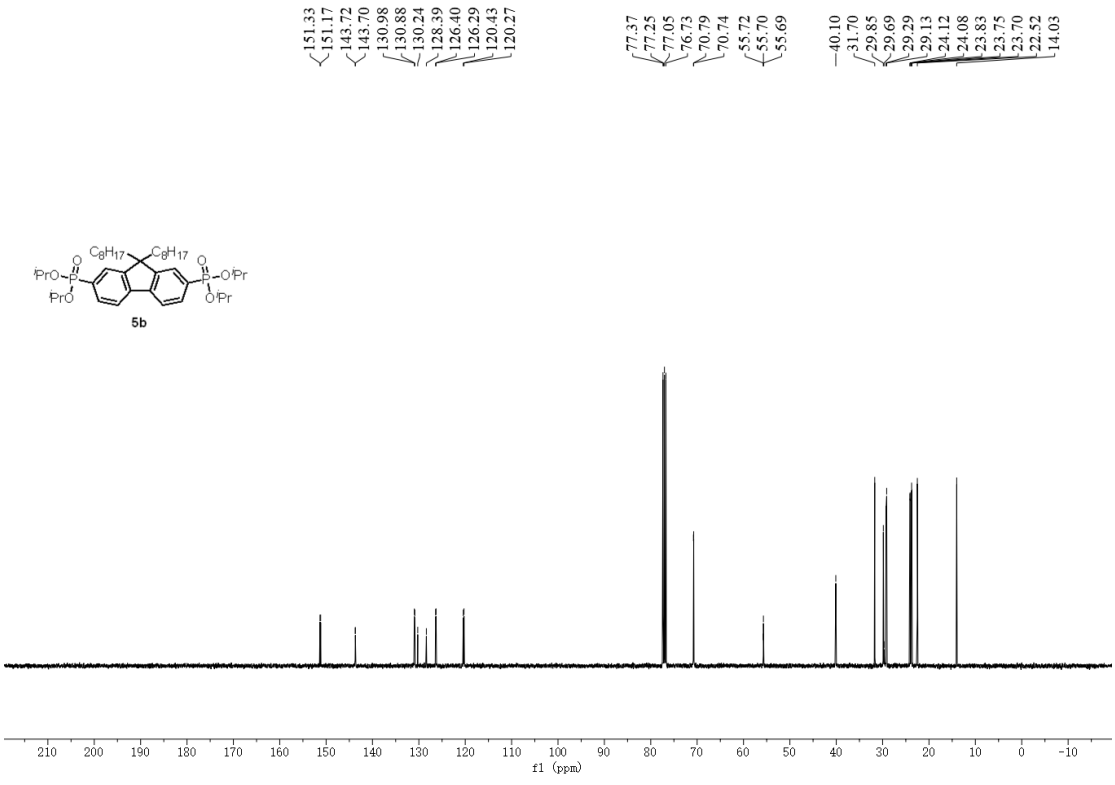

## $^{31}P$ NMR (121 MHz, $CDCl_3$) spectrum for 5a



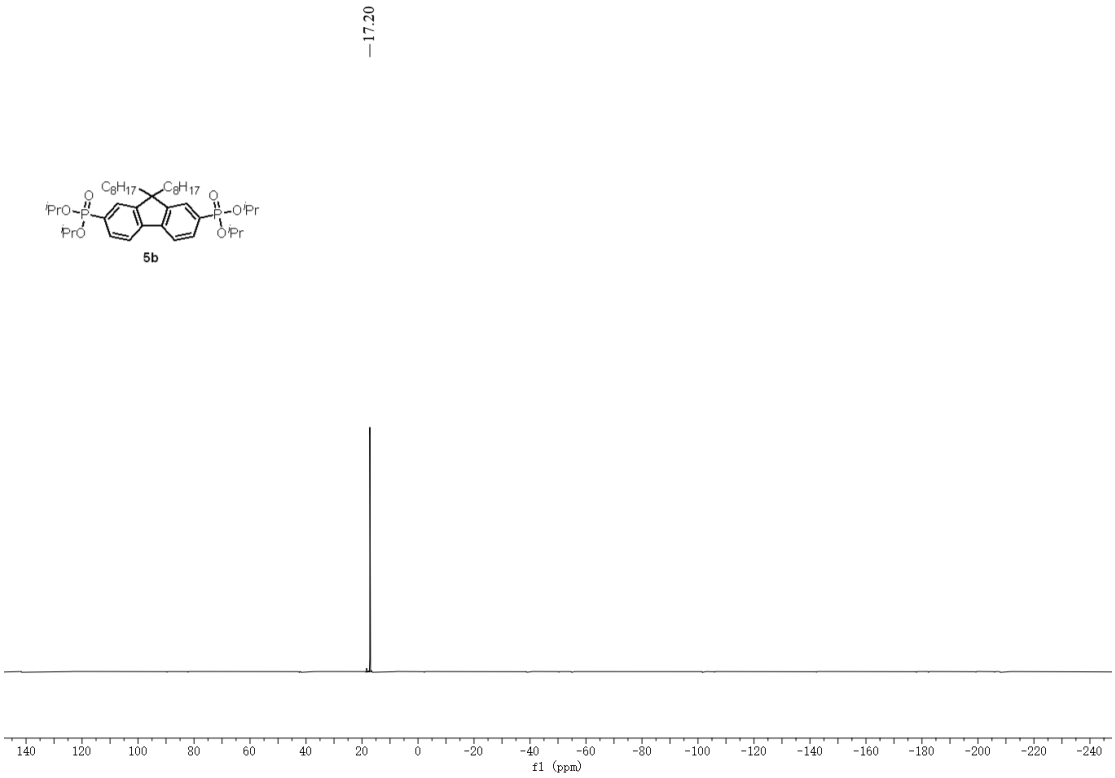
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 5b



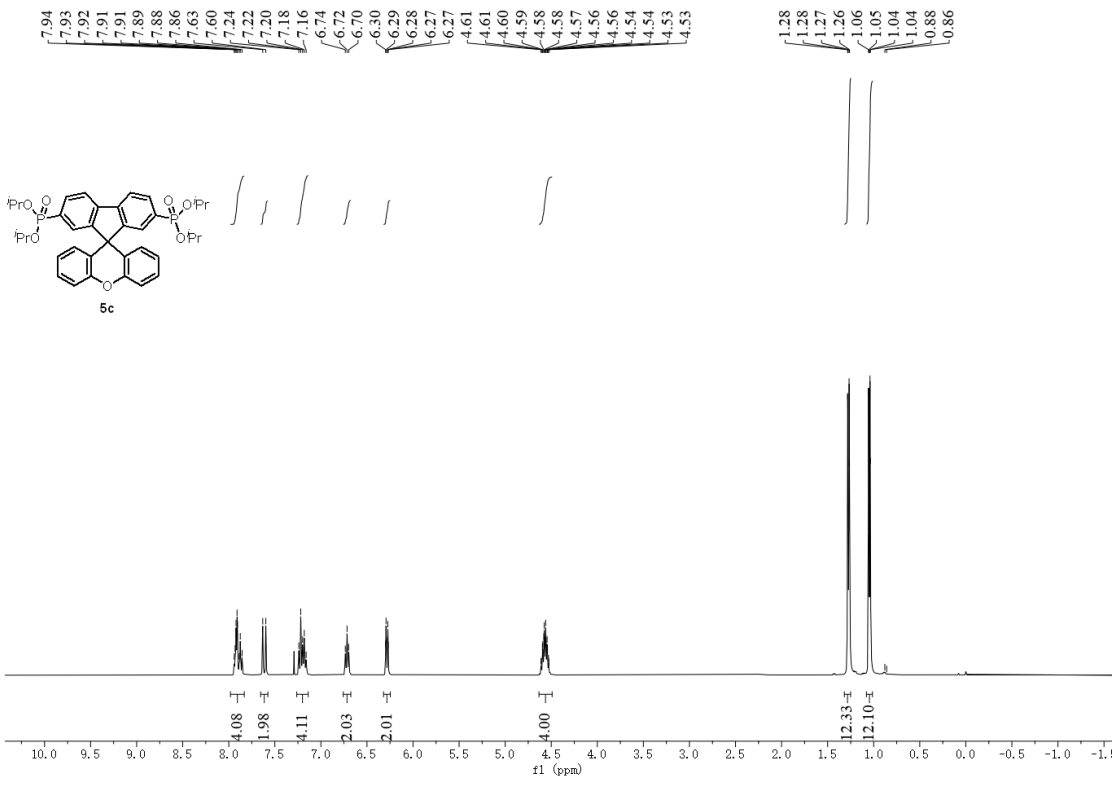

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 5b



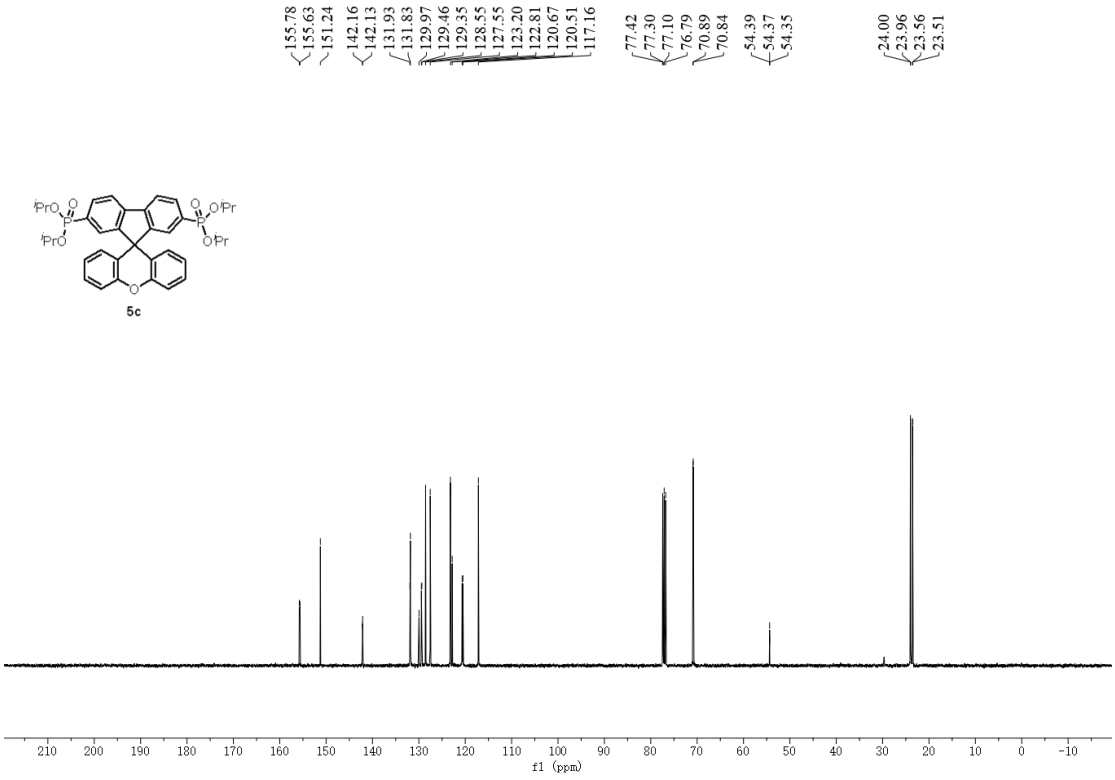
## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 5b



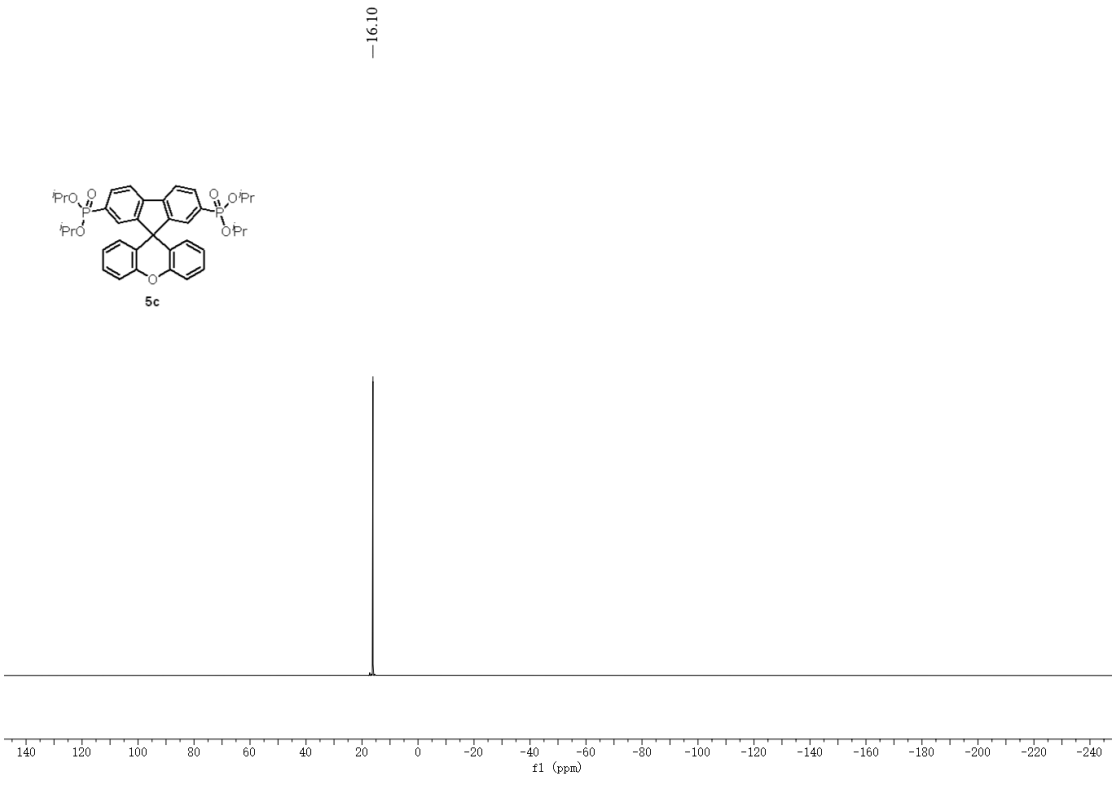

## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 5c



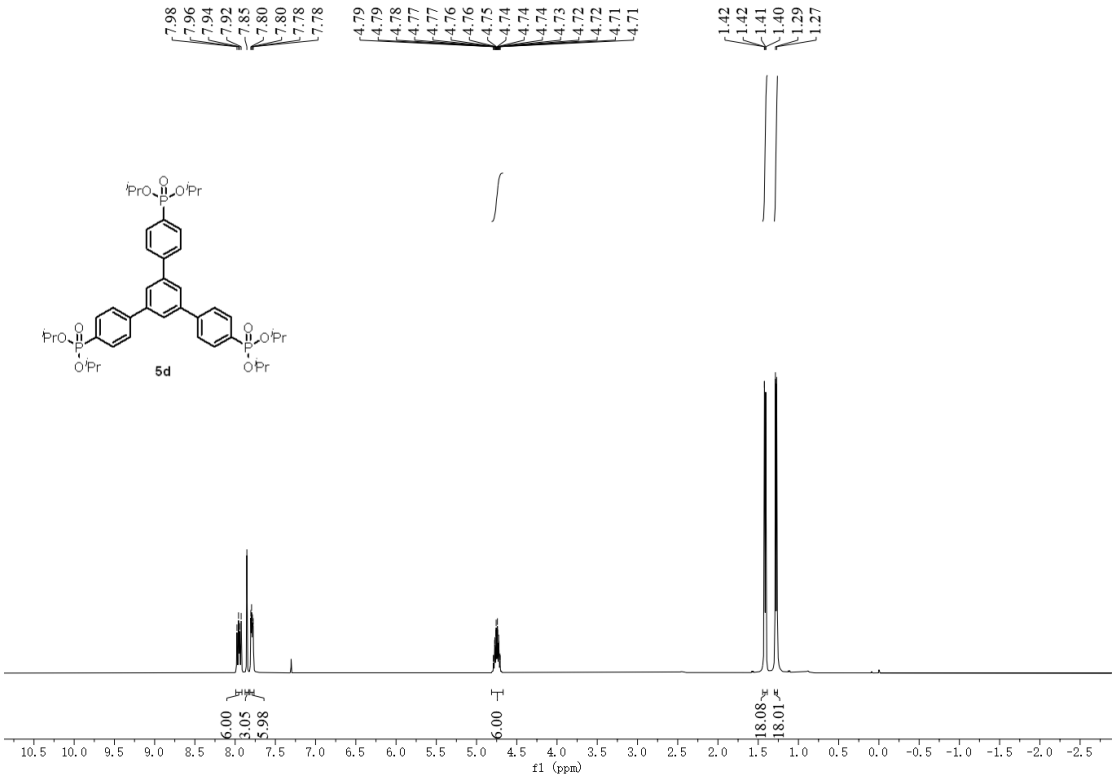
## $^{13}C$ NMR (101 MHz, $CDCl_3$) spectrum for 5c



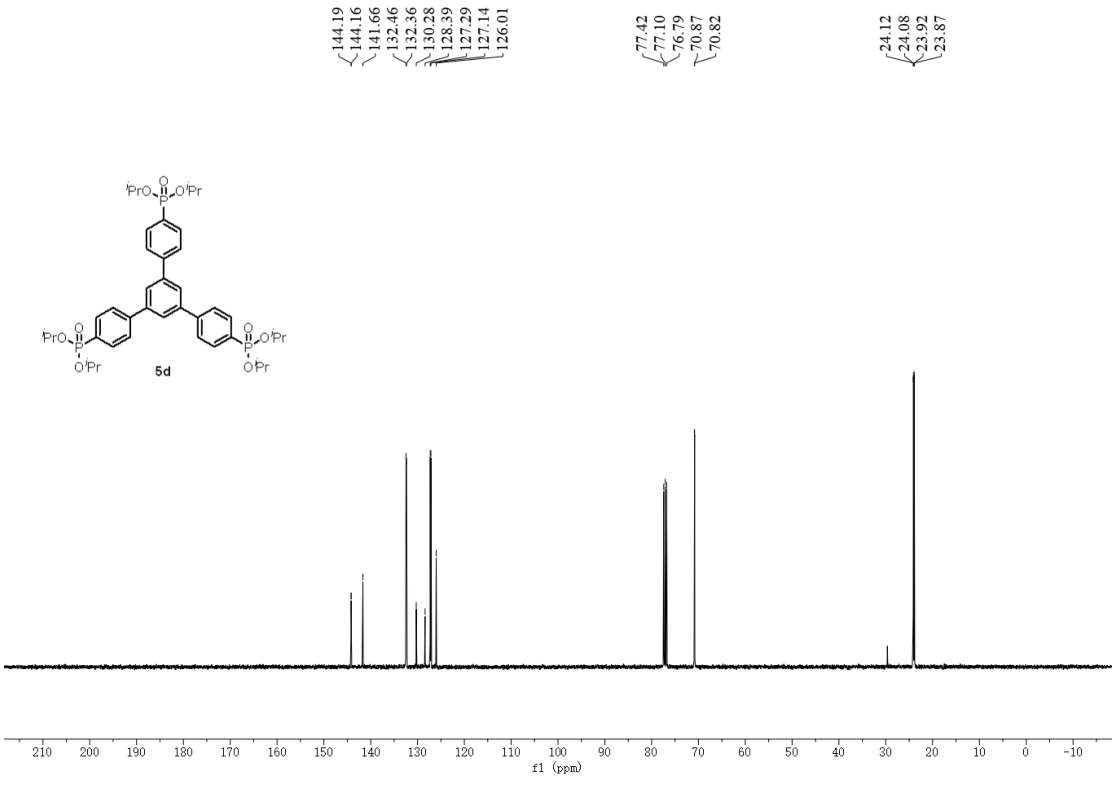

## $^{31}P$ NMR (121 MHz, $CDCl_3$) spectrum for 5c



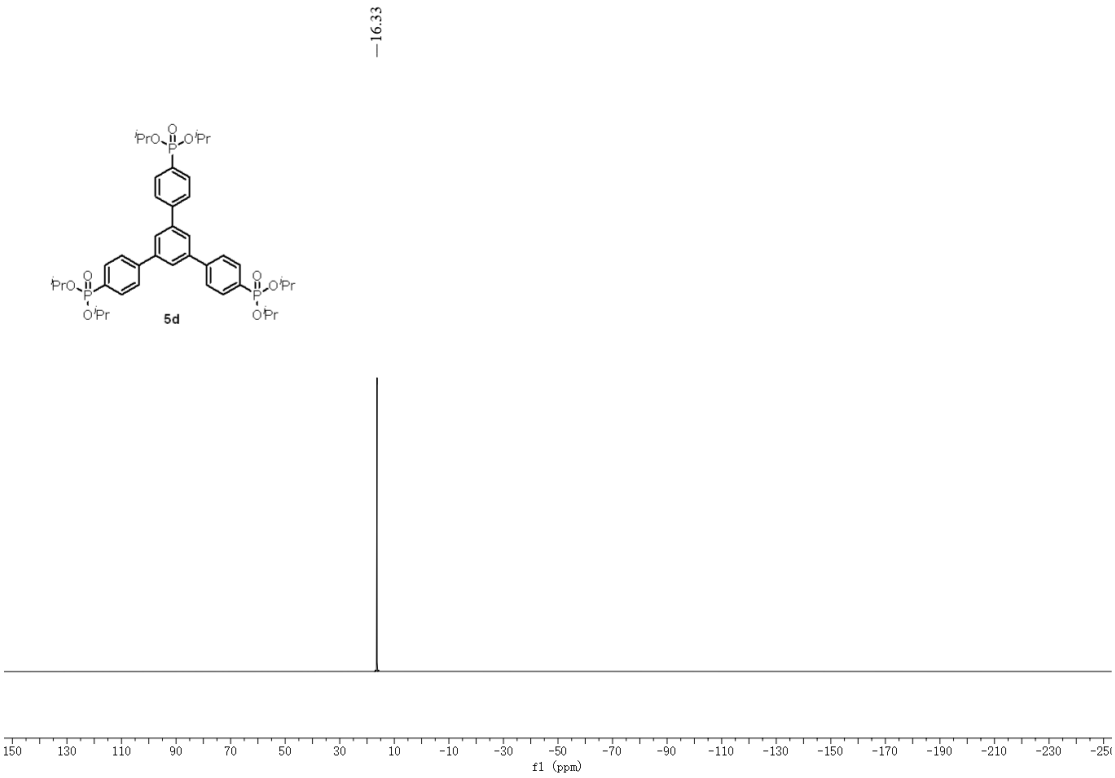
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 5d



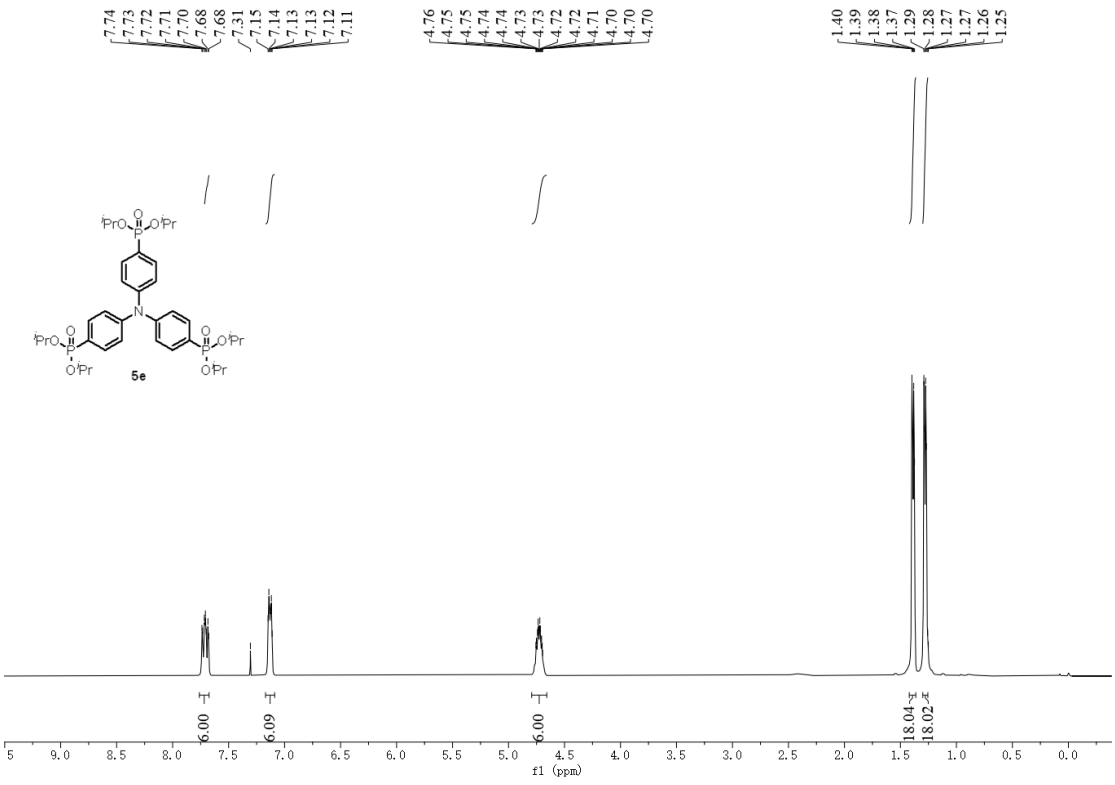

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 5d



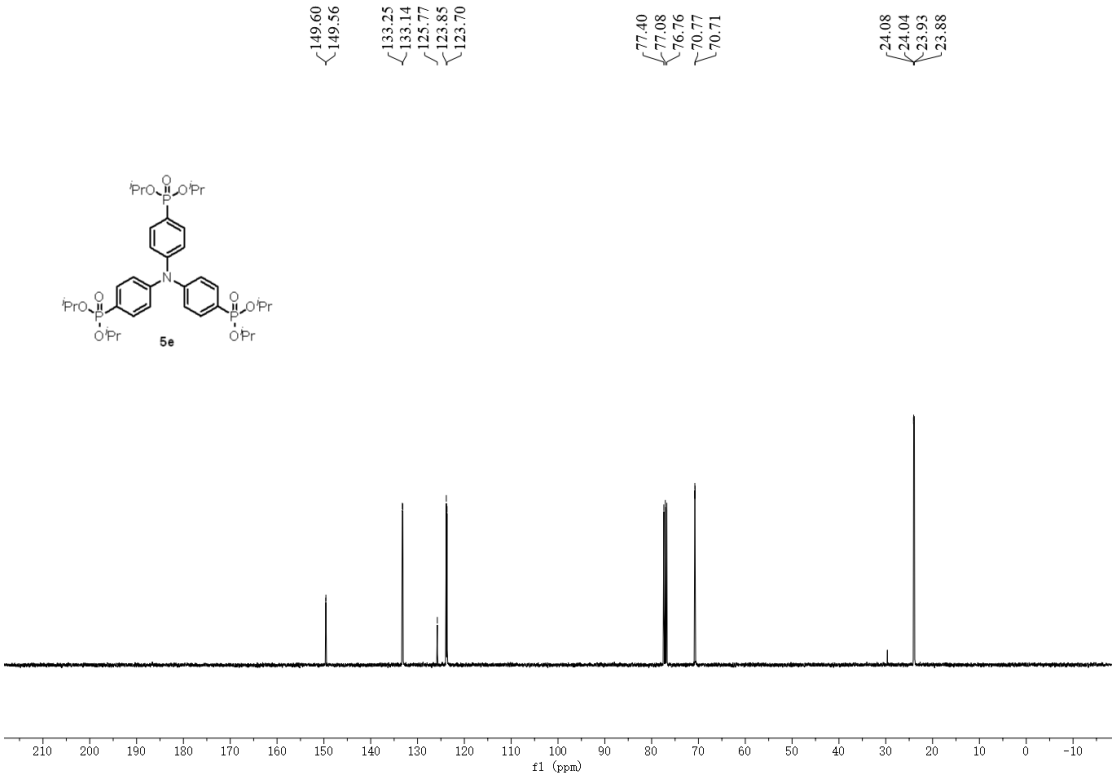
## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 5d



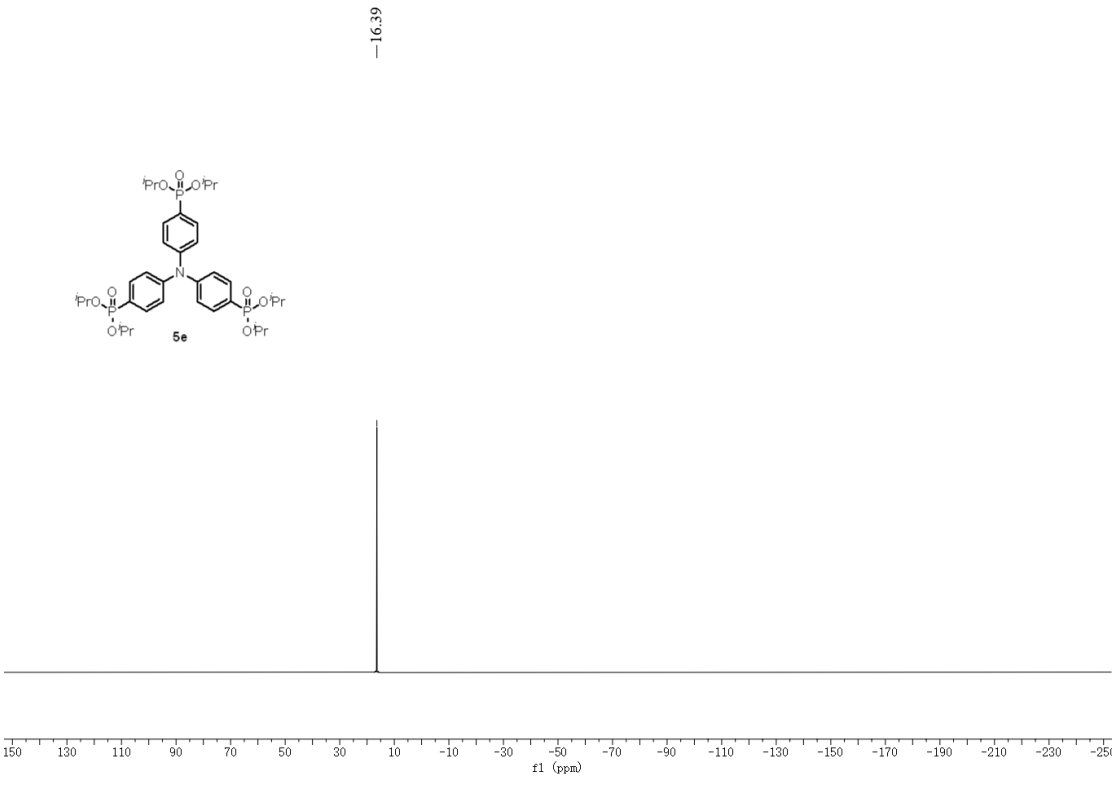

## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 5e



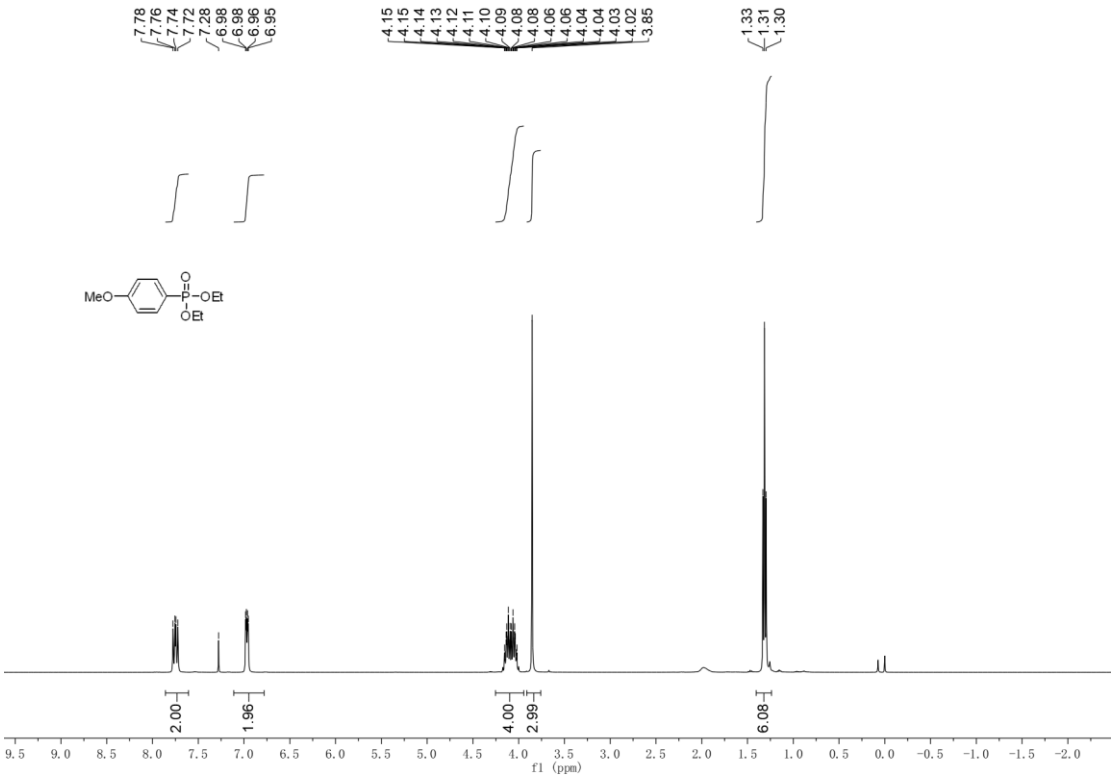
## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 5e



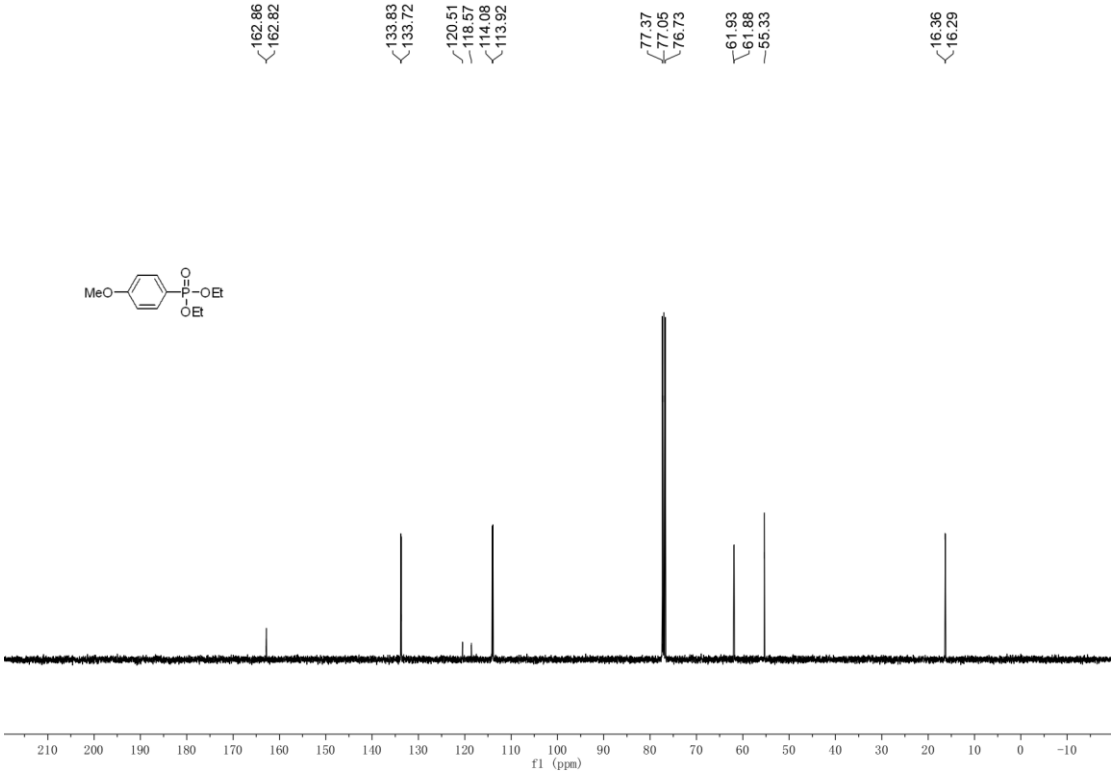

## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 5e



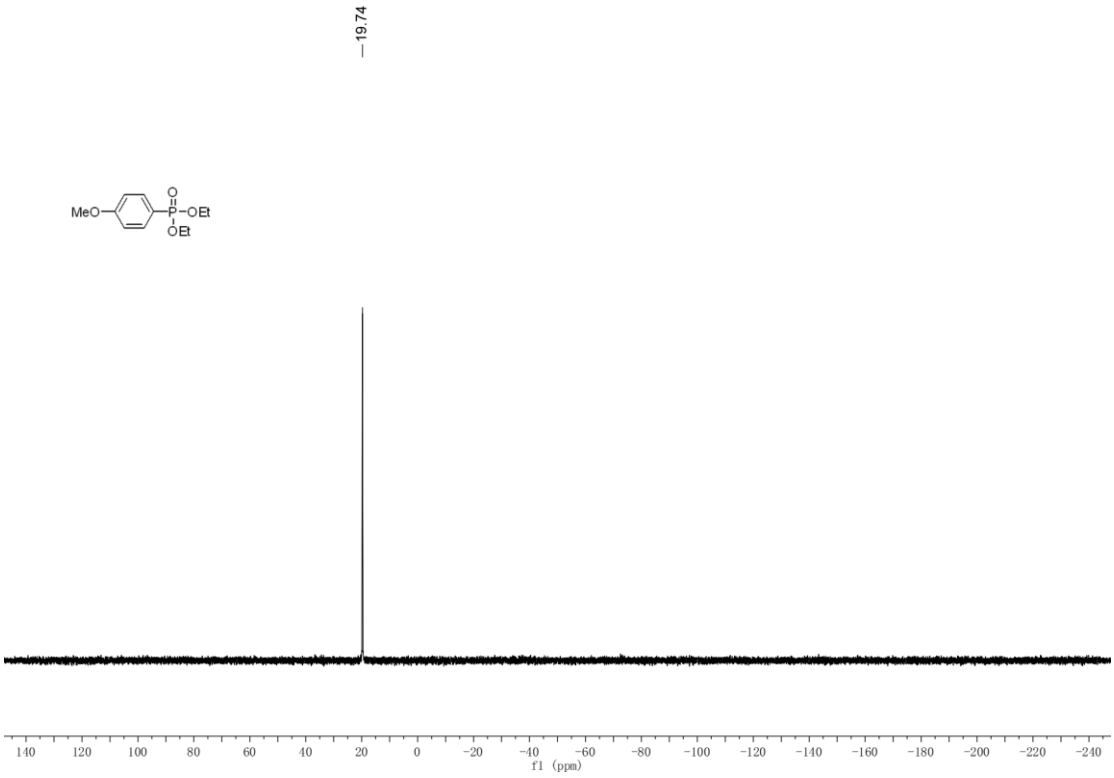
## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 6



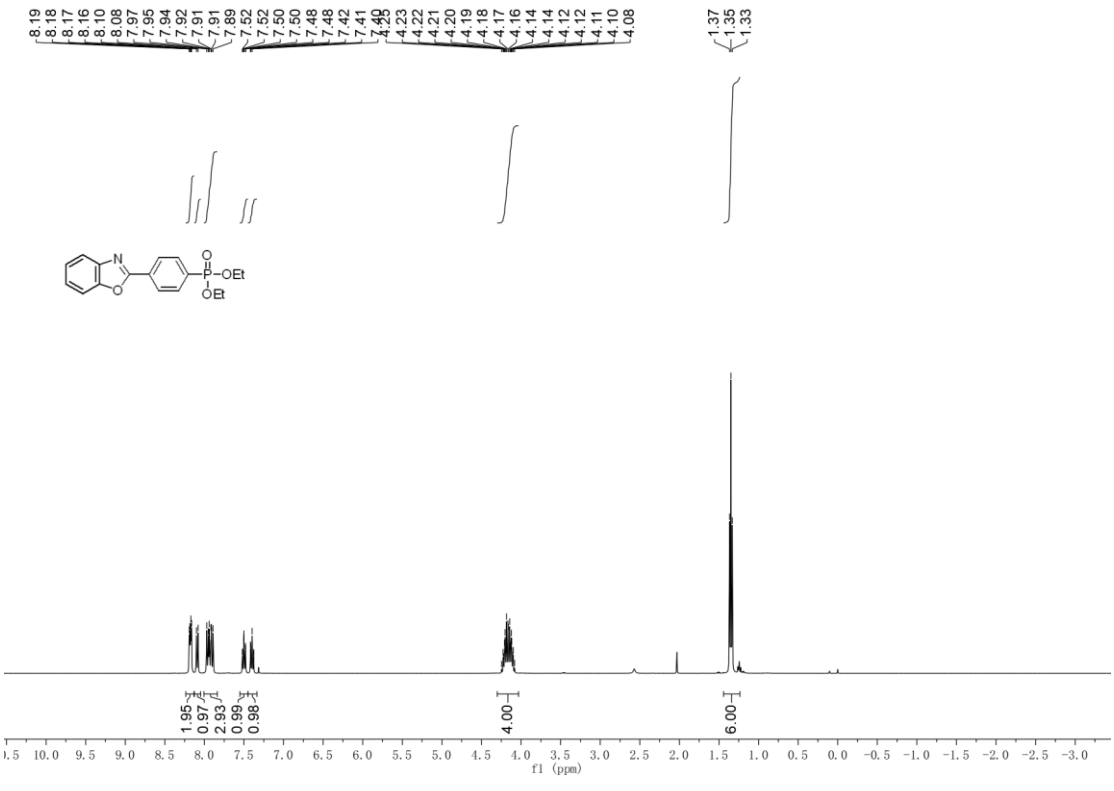

## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 6



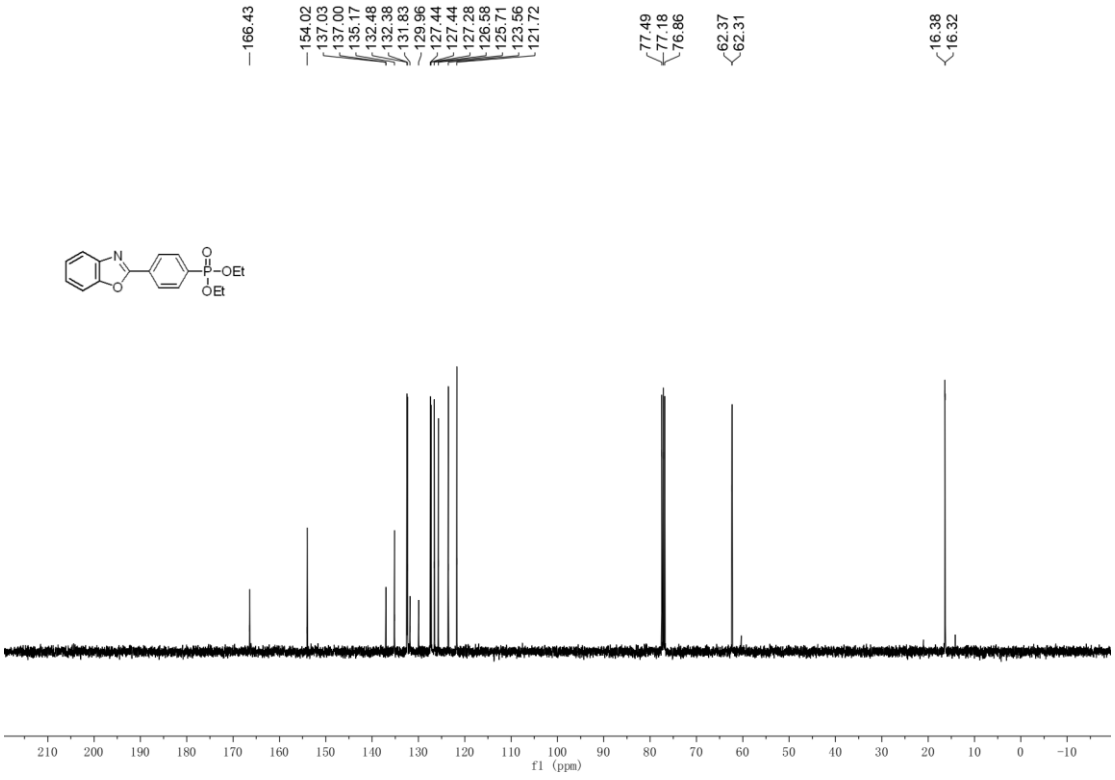
## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 6




## $^{1}$H NMR (400 MHz, $CDCl_3$) spectrum for 7



## $^{13}$C NMR (101 MHz, $CDCl_3$) spectrum for 7




## $^{31}$P NMR (121 MHz, $CDCl_3$) spectrum for 7