Supplementary Information (SI) for Green Chemistry.
This journal is © The Royal Society of Chemistry 2025

Metal-free carboxamidation of P(O)H compounds with *in situ* formed isocyanates from dioxazolones: a convenient access to carbamoylphosphine oxides

Yong Zhao,[a] Longyang Chen,[a] Guohao Xu,[a] Shanshan Meng,[b] Chuan Fu[a], Pengxiang Xu,*[a] Yuxing Gao*[a] and Yufen Zhao[a,c]

[a]Department of Chemical Biology, College of Chemistry and Chemical Engineering, and the Key Laboratory for Chemical Biology of Fujian Province, Xiamen University, Xiamen, 361005, P.R. China

[b]State Key Laboratory of Vaccines for Infectious Diseases, State Key Laboratory of Molecular Vaccinology and Molecular Diagnostics, Center for Molecular Imaging and Translational Medicine, School of Public Health, Xiamen University, Xiamen, 361102, P.R. China

[c]Institute of Drug Discovery Technology, Ningbo University, Ningbo, 315211, P.R. China

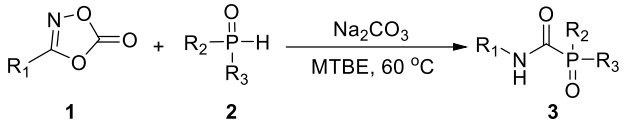
*E-mail: gaoxingchem@xmu.edu.cn; xpengxiang@xmu.edu.cn

Contents

1. General information

All reactions were carried out under dry argon (unless otherwise noted). All the heating experiments were performed in an oil bath. ^{1}H NMR, ^{13}C NMR and ^{31}P NMR spectra were recorded on a Bruker Av400 or Av500 spectrometer using tetramethylsilane (TMS) in $CDCl_3$ or DMSO-*d6* as the internal standard. Chemical shifts were reported in ppm on the scale relative to $CDCl_3$ and DMSO-*d6* (^{1}H NMR: TMS at 0.00 ppm, $CHCl_3$ at 7.26 ppm, DMSO-*d6* at 2.50 ppm; ^{13}C NMR: $CDCl_3$ at 77.2 ppm, DMSO-*d6* at 39.5 ppm) and $P(O)Ph_3$ as external standard for 31P NMR. Data are represented as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet), coupling constants in Hertz (Hz). HRMS spectra of compounds were carried out with Waters Micromass LCT Premier TOF-MS apparatus. Crystallographic data were collected on XtaLAB Synergy, Dualflex, HyPix diffractometer. Absorption corrections were applied by using the spherical harmonics program (multi-scan type). Silica gel column chromatography was performed using 300-400 mesh.

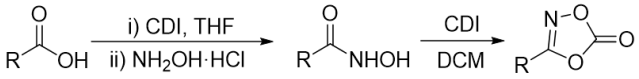
2. General procedure for the preparation of compounds 3



1 2 3

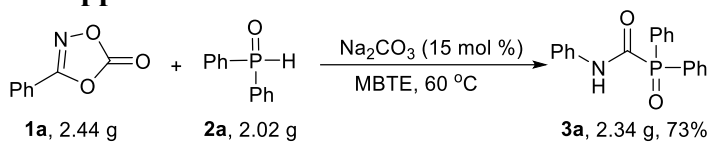
To a Schlenk tube equipped with a magnetic stir bar was added dioxazolones **1** (0.3 mmol), P(O)H compounds **2** (0.2 mmol), and Na_2CO_3 (0.03 mmol) in MTBE (0.2 mL) under argon, and the mixture was kept stirring at 60 °C in an oil bath for 9 h. Upon completion, the reaction mixture was concentrated in vacuum. The residue was purified by silica gel column chromatography using a petroleum ether/EtOAc (4 / 1) as the eluent to give the corresponding products **3**.

3. General procedure for the preparation of dioxazolones 1

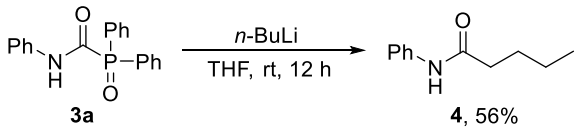


To a solution of a carboxylic acid (10 mmol, 1.0 equiv.) in freshly distilled THF (20 mL, 0.5 M) was added 1,1' carbonyldiimidazole (CDI, 2.43 g, 15 mmol, 1.5 equiv.) at room temperature. The reaction mixture was stirred for 1 h. Then, hydroxylamine hydrochloride (1.40 g, 20 mmol, 2.0 equiv.) was added. After stirring overnight, the resulting mixture was quenched with 5% aqueous $KHSO_4$ solution (20 mL), extracted with EtOAc, dried over Na_2SO_4 and concentrated under reduced pressure. The crude hydroxamic acid was used for next step without further purification. To a solution of the hydroxamic acid (10 mmol, 1.0 equiv.) in freshly distilled DCM (100 mL, 0.1 M) was added CDI (1.62 g, 10 mmol, 1.0 equiv.) in one portion. The reaction mixture was stirred at room temperature for 30 min. Then, a cold aqueous HCl solution (50 mL, 1 N) was added, and the aqueous phase was extracted with DCM (3 × 20 mL). The combined organic layers were dried over Na_2SO_4 and concentrated under reduced pressure. The desired dioxazolones **1** was purified quickly by short silica gel flash chromatography.[1]

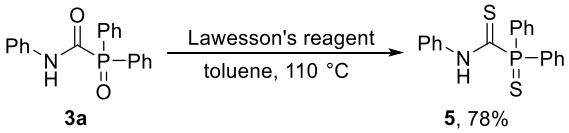
4. Procedure for the application studies



An oven - dried 50 mL Schlenk flask was charged with a stirring bar, dioxazolone **1a** (2.44 g, 15.0 mmol), diphenylphosphine oxide **2a** (2.02 g, 10 mmol), MTBE (10 ml) and Na_2CO_3 (0.16 g, 1.5 mmol) was added and the mixture was heated at 60 °C for 9 h. After cooling to room temperature, the solution was then diluted with EtOAc (50 mL) and water, extracted with EtOAc. The combined organic extracts were dried over anhydrous Na_2SO_4, filtered, and concentrated. The crude product was purified by silica gel column chromatography using a petroleum ether/EtOAc (5 / 1) as the eluent to give the corresponding products **3a** (2.34 g, 73% yield).

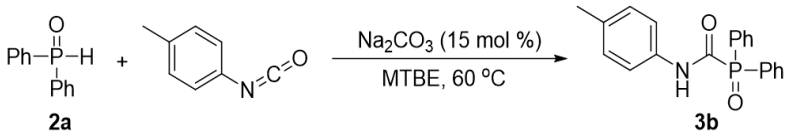


A stirred solution of compound **3a** (0.2 mmol) in anhydrous THF (2.0 mL) was added n-BuLi (320 μL, 2.5 M in hexane) at 0 °C. Then the mixture was stirred at room temperature overnight. TLC monitored the reaction to reach completion. The reaction was quenched by addition of saturated NH_4Cl solution (3.0 mL). Extracted with EtOAc (3×5.0 mL), the combined organic layers were washed with brine, dried over Na_2SO_4. The concentrated residue was purified by column chromatography to afford the desired product **4** as a white solid (19.8 mg, 56% yield).

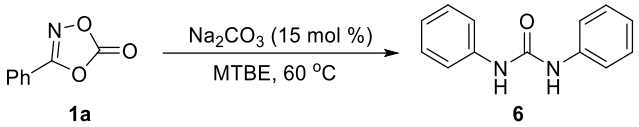


3a (0.20 mmol) and Lawesson's reagent (242.6 mg, 0.4 mmol) in toluene (2.0 mL) in an oven-dried 25 mL Schlenk tube was refluxed with vigorous stirring for 12 h under Ar atmosphere. After cooling to room temperature, the reaction mixtures were then diluted with water (5.0 mL) and extracted with EtOAc (3 × 10 mL). The combined organic layers were dried over anhydrous Na_2SO_4 and concentrated under reduced pressure. The crude residue was purified by flash chromatography on silica gel to give the pure product **5** (55.1 mg, 78% yield).[2]

5. Investigation of the reaction mechanism



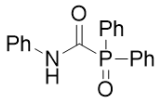
To a Schlenk tube equipped with a magnetic stir bar was added **2a** (0.2 mmol), 4-methylphenyl isocyanate (0.3 mmol), and Na_2CO_3 (0.03 mmol) in MTBE (0.2 mL) under argon, and the mixture was kept stirring at 60 °C in an oil bath for 9 h. Upon completion, the reaction mixture was concentrated in vacuum. The resulting mixture was cooled down to room temperature and purified by flash chromatography to give **3b** (51.8 mg, 73% yield).



To a Schlenk tube equipped with a magnetic stir bar was added **1a** (0.2 mmol) and Na_2CO_3 (0.02 mmol) in MTBE (0.2 mL) under argon, and the mixture was kept stirring at 60 °C in an oil bath for 9 h. Upon completion, the reaction mixture was concentrated in vacuum. The resulting mixture was cooled down to room temperature and purified by flash chromatography to give **6** (19.5 mg, 46% yield).

6. Characterization data for products 3-6

1-(diphenylphosphoryl)-N-phenylformamide 3a



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 4:1); **3a** was obtained as a white solid (55.8 mg, 87% yield).

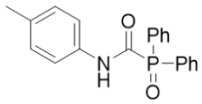
^{1}H NMR (400 MHz, $CDCl_3$): δ 10.06 (s, 1H), 8.01-7.96 (m, 4H), 7.78 (d, *J* = 7.6 Hz, 2H), 7.60-7.58 (m, 2H), 7.52-7.48 (m, 4H), 7.34 (t, *J* = 8.4 Hz, 2H), 7.23 (t, *J* = 7.5 Hz, 1H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 168.2 (d, *J* = 123.2 Hz), 137.0 (d, *J* = 9.5 Hz), 132.7 (d, *J* = 2.9 Hz), 131.8 (d, *J* = 9.6 Hz), 129.0, 128.9 (d, *J* = 100.6 Hz), 128.8 (d, *J* = 12.5 Hz), 125.5, 120.2.

^{31}P NMR (162 MHz, $CDCl_3$): δ 15.51.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{19}H_{16}NaNO_2P^+$ 344.0811; found 344.0804.

1-(diphenylphosphoryl)-N-(p-tolyl)formamide 3b



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 2:1); **3b** was obtained as a white solid (56.9 mg, 86% yield).

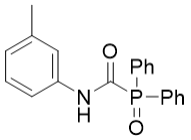
^{1}H NMR (400 MHz, $CDCl_3$): δ 9.63 (d, *J* = 14.7 Hz, 1H), 8.01-7.97 (m, 4H), 7.63-7.60 (m, 4H), 7.55-7.51 (m, 4H), 7.17 (d, *J* = 7.9 Hz, 2H), 2.35 (s, 3H),

^{13}C NMR (101 MHz, $CDCl_3$): δ 167.8 (d, *J* = 128.5 Hz), 135.4, 134.3 (d, *J* = 7.5 Hz), 132.8, 131.9 (d, *J* = 8.4 Hz), 129.6, 128.9 (d, *J* = 100.1 Hz), 128.8 (d, *J* = 11.5 Hz), 120.0, 21.1.

^{31}P NMR (162 MHz, $CDCl_3$): δ 15.63.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{20}H_{18}NaNO_2P^+$ 336.1148; found 336.1140.

1-(diphenylphosphoryl)-N-(m-tolyl)formamide 3c



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 2:1); **3c** was obtained as a white solid (59.6 mg, 90% yield).

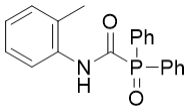
^{1}H NMR (400 MHz, $CDCl_3$): δ 9.75 (s, 1H), 8.00-7.97 (m, 4H), 7.65-7.60 (m, 3H), 7.54-7.51 (m, 5H), 7.25 (t, *J* = 7.8 Hz, 1H), 7.01 (d, *J* = 7.5 Hz, 1H), 2.35 (s, 3H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 168.1 (d, *J* = 127.0 Hz), 139.1, 136.8 (d, *J* = 9.6 Hz), 132.8 (d, *J* = 8.0 Hz), 131.8 (d, *J* = 9.9 Hz), 128.9, 128.9 (d, *J* = 12.8 Hz), 128.9 (d, *J* = 100.2 Hz), 126.4, 120.7, 117.2, 21,5.

^{31}P NMR (162 MHz, $CDCl_3$): δ 15.58.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{20}H_{18}NaNO_2P^+$ 336.1148; found 336.1140.

1-(diphenylphosphoryl)-N-(o-tolyl)formamide 3d



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 2:1); **3d** was obtained as a white solid (60.5 mg, 91% yield).

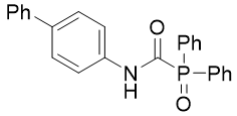
^{1}H NMR (400 MHz, $CDCl_3$): δ 9.48 (s, 1H), 8.08-8.00 (m, 5H), 7.62 (m, 2H), 7.56-7.52 (m, 4H), 7.24 (d, *J* = 6.6 Hz, 2H), 7.15-7.12 (m, 1H), 2.39 (s, 3H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 168.0 (d, *J* = 126.4 Hz), 134.6 (d, *J* = 7.2 Hz), 132.9 (d, *J* = 2.7 Hz), 131.8 (d, *J* = 9.5 Hz), 130.8, 128.7, 128.9 (d, *J* = 100.5 Hz), 128.8 (d, *J* = 12.3 Hz), 126.9, 126.0, 121.9, 17.6.

^{31}P NMR (162 MHz, $CDCl_3$): δ 15.87.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{20}H_{18}NaNO_2P^+$ 336.1148; found 336.1139.

N-([1,1'-biphenyl]-4-yl)-1-(diphenylphosphoryl)formamide 3e



Following general procedure, purification by flash column chromatography (petroleum

ether/EtOAc = 3:1); **3e** was obtained as a white solid (60.4 mg, 76% yield).

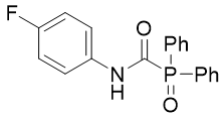
^{1}H NMR (400 MHz, DMSO): δ 11.15 (s, 1H), 7.93-7.86 (m, 6H), 7.71-7.60 (m, 10H), 7.45 (t, *J* = 7.4 Hz, 2H), 7.34 (t, *J* = 7.5 Hz, 1H).

^{13}C NMR (101 MHz, DMSO): δ 169.2 (d, *J* = 122.5 Hz), 139.9, 137.3, 137.2 (d, *J* = 9.1 Hz), 133.2 (d, *J* = 2.9 Hz), 131.9 (d, *J* = 9.4 Hz), 130.24 (d, *J* = 99.2 Hz), 129.4 (d, *J* = 11.7 Hz), 129.4, 127.8, 127.3, 126.9, 121.8.

^{31}P NMR (162 MHz, DMSO): δ 15.19.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{25}H_{20}NaNO_2P^+$ 420.1124; found 420.1115.

1-(diphenylphosphoryl)-N-(4-fluorophenyl)formamide 3f



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 2:1); **3f** was obtained as a white solid (49.5 mg, 73% yield).

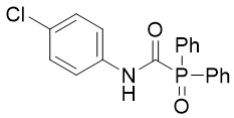
^{1}H NMR (400 MHz, DMSO): δ 11.14 (s, 1H), 7.89-7.82 (m, 6H), 7.70-7.67 (m, 2H), 7.62-7.60 (m, 4H), 7.19 (t, *J* = 8.8 Hz, 2H).

^{13}C NMR (101 MHz, DMSO): δ 173.8 (d, *J* = 123.4 Hz), 164.3 (d, *J* = 241.1 Hz), 138.9 (d, *J* = 12.3 Hz), 137.5 (d, *J* = 2.5 Hz), 136.6 (d, *J* = 9.0 Hz), 134.9 (d, *J* = 99.1 Hz), 134.2 (d, *J* = 11.8 Hz), 128.2, 120.6 (d, *J* = 22.1 Hz).

^{31}P NMR (162 MHz, DMSO): δ 14.60.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{19}H_{15}FNaNO_2P^+$ 362.0717; found 362.0706.

N-(4-chlorophenyl)-1-(diphenylphosphoryl)formamide 3g



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 1:1); **3g** was obtained as a white solid (44.9 mg, 64% yield).

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.78 (s, 1H), 7.92-7.88 (m, 4H), 7.73 (d, *J* = 7.8 Hz, 2H), 7.51 (d, *J* = 7.8 Hz, 4H), 7.40-7.36 (t, *J* = 7.5 Hz, 2H), 7.22 (t, *J* = 7.4 Hz, 2H).

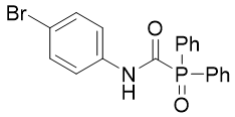
^{13}C NMR (101 MHz, $CDCl_3$): δ 167.3 (d, *J* = 127.8 Hz), 139.9 (d, *J* = 3.1 Hz), 136.6

(d, J = 9.5 Hz), 133.1 (d, J = 10.5 Hz), 129.3 (d, J = 12.5 Hz), 129.2, 127.0 (d, J = 101.9 Hz), 125.9, 120.2.

^{31}P NMR (162 MHz, $CDCl_3$): δ 14.66.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{19}H_{15}ClNaNO_2P^+$ 378.0421; found 378.0411.

N-(4-bromophenyl)-1-(diphenylphosphoryl)formamide 3h



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 2:1); **3h** was obtained as a white solid (50.2 mg, 63% yield).

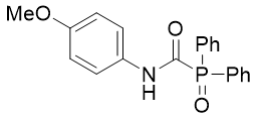
^{1}H NMR (400 MHz, $CDCl_3$): δ 9.95 (s, 1H), 7.99-7.94 (m, 4H), 7.68-7.61 (m, 4H), 7.55-7.51 (m, 4H), 7.47 (d, J = 8.9 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 168.3 (d, J = 122.8 Hz), 136.0 (d, J = 9.5 Hz), 133.0 (d, J = 2.7 Hz), 132.1, 131.8 (d, J = 10.0 Hz), 128.9 (d, J = 12.5 Hz), 128.6 (d, J = 101.3 Hz), 121.7, 118.3.

^{31}P NMR (162 MHz, $CDCl_3$): δ 15.93.

HRMS (ESI) m/z: $[M+H^+]$ Calcd for $C_{19}H_{16}BrNO_2P^+$ 400.0097; found 400.0087.

1-(diphenylphosphoryl)-N-(4-methoxyphenyl)formamide 3i



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 1:1); **3i** was obtained as a white solid (57.5 mg, 82% yield).

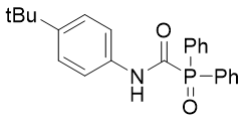
^{1}H NMR (400 MHz, $CDCl_3$): δ 9.66 (s, 1H), 8.00-7.95 (m, 4H), 7.67 (d, J = 8.6 Hz, 2H), 7.63-7.59 (m, 2H), 7.53-7.51 (m, 4H), 6.86 (d, J = 8.9 Hz, 2H), 3.81 (s, 3H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 167.3 (d, J = 123.3 Hz), 157.1, 133.8 (d, J = 2.4 Hz), 131.8 (d, J = 9.8 Hz), 129.9 (d, J = 100.6 Hz), 128.8 (d, J = 12.8 Hz), 121.6, 114.2, 55.5.

^{31}P NMR (162 MHz, $CDCl_3$): δ 15.82.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{20}H_{18}NaNO_3P^+$ 352.1097; found 352.1088.

N-(4-(tert-butyl)phenyl)-1-(diphenylphosphoryl)formamide 3j



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 2:1); **3j** was obtained as a white solid, mp 200-202 ºC. (57.3 mg, 76% yield).

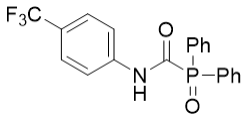
^{1}H NMR (400 MHz, $CDCl_3$): δ 9.55 (s, 1H), 8.01-7.97 (m, 4H), 7.67-7.60 (m, 4H), 7.55-7.53 (m, 4H), 7.39 (d, *J* = 7.9 Hz, 2H), 1.33 (s, 9H)

^{13}C NMR (101 MHz, $CDCl_3$): δ 167.8 (d, *J* = 123.2 Hz), 148.7, 134.2 (d, *J* = 8.6 Hz), 132.8 (d, *J* = 2.4 Hz), 131.8 (d, *J* = 9.7 Hz), 128.9 (d, *J* = 99.5 Hz), 128.7 (d, *J* = 12.3 Hz) , 126.0, 119.6, 34.5, 31.3.

^{31}P NMR (162 MHz, $CDCl_3$): δ 15.74.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{23}H_{24}NaNO_2P^+$ 400.1437; found 400.1428.

1-(diphenylphosphoryl)-N-(4-(trifluoromethyl)phenyl)formamide 3k



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 2:1); **3k** was obtained as a white solid (40.4 mg, 52% yield).

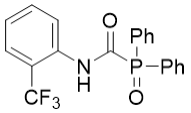
^{1}H NMR (400 MHz, $CDCl_3$): δ 10.18 (s, 1H), 7.99-7.90 (m, 6H), 7.66-7.60 (m, 4H), 7.55-7.52 (t, *J* = 7.3 Hz, 4H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 168.8 (d, *J* = 123.4 Hz), 139.8 (d, *J* = 10.4 Hz), 133.1 (d, *J* = 2.4 Hz), 131.8 (d, *J* = 10.2 Hz), 128.9 (d, *J* = 12.5 Hz), 128.4 (d, *J* = 101.3 Hz), 127.3 (q, *J* = 34.2 Hz), 126.3 (q, *J* = 3.6 Hz), 124.1 (q, *J* = 271.3 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ 16.02.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{20}H_{15}F_3NaNO_2P^+$ 412.0685; found 412.0677.

1-(diphenylphosphoryl)-N-(2-(trifluoromethyl)phenyl)formamide 3l



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 2:1); **3l** was obtained as a white solid, mp 108-110 ºC. (36.4 mg, 47% yield).

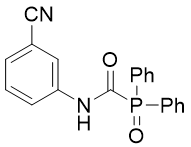
^{1}H NMR (400 MHz, $CDCl_3$): δ 9.85 (s, 1H), 8.28 (d, *J* = 7.9 Hz, 1H), 8.03-7.98 (m, 4H), 7.74 (d, *J* = 7.8 Hz, 1H), 7.65-7.60 (m, 2H), 7.58-7,53 (m, 5H), 7.34-7.29 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 169.2 (d, *J* = 122.4 Hz), 133.8 (d, *J* = 9.9 Hz), 133.0 (d, *J* = 2.8 Hz), 132.8, 131.9 (d, *J* = 9.8 Hz), 128.9 (d, *J* = 12.4 Hz), 128.5 (d, *J* = 100.4 Hz), 126.4 (q, *J* = 5.2 Hz), 125.8, 124.0, 124.9 (q, *J* = 273.3 Hz), 121.3 (q, *J* = 30.3 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ 16.25.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{20}H_{15}F_3NaNO_2P^+$ 412.0685; found 412.0675.

N-(3-cyanophenyl)-1-(diphenylphosphoryl)formamide 3m



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 1:1); **3m** was obtained as a white solid, mp 197-199 ºC. (28.3 mg, 41% yield).

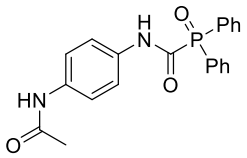
^{1}H NMR (400 MHz, $CDCl_3$): δ 10.68 (s, 1H), 8.32 (s, 1H), 8.04-7.94 (m, 5H), 7.66-7.63 (m, 2H), 7.55-7.53 (m, 4H), 7.47-7.42 (m, 2H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 169.1 (d, *J* = 125.1 Hz), 138.3 (d, *J* = 9.7 Hz), 133.1, 131.8 (d, *J* = 9.8 Hz), 129.8, 129.0 (d, *J* = 12.0 Hz), 128.6, 128.6 (d, *J* = 99.8 Hz), 124.6, 124.0, 118.3, 113.0.

^{31}P NMR (162 MHz, $CDCl_3$): δ 16.29.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{20}H_{15}NaN_2O_2P^+$ 369.0763; found 369.0754.

***N*-(4-((diphenylphosphoryl)formamido)phenyl)acetamide 3n**



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 1:3); **3n** was obtained as a white solid, mp 296-298 °C. (28.3 mg, 38% yield).

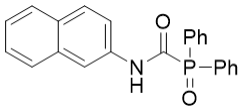
^{1}H NMR (500 MHz, $CDCl_3$): δ 9.79 (s, 1H), 8.16 (s, 1H), 7.94-7.90 (m, 4H), 7.63-7.57 (m, 4H), 7.50-7.48 (m, 6H), 2.08 (s, 3H),

^{13}C NMR (101 MHz, $CDCl_3$): δ 168.8, 167.7 (d, *J* = 123.5 Hz), 135.8, 132.9 (d, *J* = 1.9 Hz), 132.8 (d, *J* = 9.4 Hz), 131.8 (d, *J* = 9.6 Hz), 128.8 (d, *J* = 12.4 Hz), 128.6 (d, *J* = 101.1 Hz), 120.7, 120.4, 24.3.

^{31}P NMR (162 MHz, $CDCl_3$): δ 16.14.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{21}H_{19}N_2NaO_3P^+$ 401.1026; found 401.1022.

1-(diphenylphosphoryl)-N-(naphthalen-2-yl)formamide 3o



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 1:1); **3o** was obtained as a white solid (49.7 mg, 62% yield).

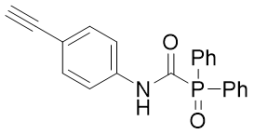
^{1}H NMR (400 MHz, $CDCl_3$): δ 9.98 (s, 1H), 8.50 (s, 1H), 8.04 (t, *J* = 9.7 Hz, 4H), 7.85-7.81 (m, 3H), 7.70 (d, *J* = 8.8 Hz, 1H), 7.65-7.62 (m, 2H), 7.57-7.44 (m, 6H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 168.3 (d, *J* = 122.4 Hz), 134.3 (d, *J* = 9.3 Hz), 133.6, 132.9, 131.9 (d, *J* = 9.5 Hz), 131.2, 129.0 128.9 (d, *J* = 100.4 Hz), 128.9 (d, *J* = 12.2 Hz), 127.9, 127.7, 126.7, 125.6, 119.6, 117.4.

^{31}P NMR (162 MHz, $CDCl_3$): δ 15.72.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{23}H_{18}NaNO_2P^+$ 394.0967; found 394.0959.

1-(diphenylphosphoryl)-N-(4-ethynylphenyl)formamide 3p



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 1:1); **3p** was obtained as a white solid, mp 184-186 ºC (51.7 mg, 75% yield).

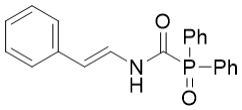
^{1}H NMR (400 MHz, $CDCl_3$): δ 10.32 (s, 1H), 7.98-7.93 (m, 4H), 7.79 (d, *J* = 8.6 Hz, 2H), 7.62-7.59 (m, 2H), 7.53-7.43 (m, 6H), 3.09 (s, 1H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 168.4 (d, *J* = 122.6 Hz), 137.5 (d, *J* = 9.8 Hz), 132.1, 131.8 (d, *J* = 10.0 Hz), 128.9 (d, *J* = 12.0 Hz), 128.7 (d, *J* = 101.0 Hz), 120.0, 119.0. 83.2, 77.4.

^{31}P NMR (162 MHz, $CDCl_3$): δ 15.83.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{21}H_{16}NaNO_2P^+$ 368.0811; found 368.0802.

(E)-1-(diphenylphosphoryl)-N-styrylformamide 3q



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 4:1); **3q** was obtained as a white solid (49.3 mg, 71% yield).

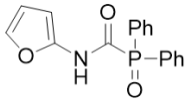
^{1}H NMR (400 MHz, $CDCl_3$): δ 10.33 (d, *J* = 10.0 Hz, 1H), 8.00-7.95 (m, 4H), 7.64-7.53 (m, 7H), 7.33-7.23 (m, 4H), 7.25-7.21 (m, 1H), 6.63 (d, *J* = 15.0 Hz, 1H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 167.3 (d, *J* = 124.7 Hz), 135.7, 133.1 (d, *J* = 2.1 Hz), 131.9 (d, *J* = 10.1 Hz), 129.0 128.9 (d, *J* = 102.3 Hz), 128.9 (d, *J* = 6.0 Hz), 127.5, 126.2, 120.9 (d, *J* = 6.7 Hz), 117.6.

^{31}P NMR (162 MHz, $CDCl_3$): δ 16.12.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{21}H_{18}NaNO_2P^+$ 370.0967; found 370.0960.

1-(diphenylphosphoryl)-N-(furan-2-yl)formamide 3r



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 4:1); **3r** was obtained as a white solid, mp 129-131 ºC (43.6 mg, 70% yield).

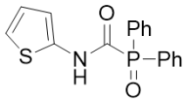
^{1}H NMR (400 MHz, $CDCl_3$): δ 10.60 (s, 1H), 8.00-7.96 (m, 4H), 7.63-7.60 (m, 2H), 7.55-7.51 (m, 4H), 7.11 (dd, *J* = 1.8, 0.9 Hz, 1H), 6.52 (d, *J* = 2.9 Hz, 1H), 6.41-6.40 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 166.1 (d, *J* = 125.3 Hz), 144.3 (d, *J* = 12.6 Hz), 136.1, 133.0, 131.8 (d, *J* = 9.5 Hz), 128.9 (d, *J* = 12.7 Hz), 128.6 (d, *J* = 102.1 Hz), 111.5, 96.5.

^{31}P NMR (162 MHz, $CDCl_3$): δ 15.98.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{17}H_{14}NaNO_3P^+$ 334.0604; found 334.0596.

1-(diphenylphosphoryl)-N-(thiophen-2-yl)formamide 3s



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 4:1); **3s** was obtained as a white solid, mp 197-199 ºC (39.9 mg, 61% yield).

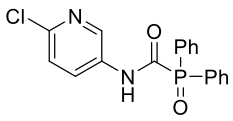
^{1}H NMR (400 MHz, $CDCl_3$): δ 11.65 (s, 1H), 8.00-7.95 (m, 4H), 7.63-7.59 (m, 2H), 7.53-7.49 (m, 4H), 7.11 (m, 1H), 6.96 (d, *J* = 5.3 Hz, 1H), 6.91-6.88 (m, 1H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 165.4 (d, *J* = 124.5 Hz), 137.8 (d, *J* = 9.3 Hz), 132.9 (d, *J* = 2.5 Hz), 131.8 (d, *J* = 10.1 Hz), 129.0 (d, *J* = 12.6 Hz), 128.7 (d, *J* = 102.5 Hz) 124.3, 118.8, 114.5.

^{31}P NMR (162 MHz, $CDCl_3$): δ 16.17.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{17}H_{14}NNaO_2SP^+$ 350.0375; found 350.0368.

***N*-(6-chloropyridin-3-yl)-1-(diphenylphosphoryl)formamide 3t**



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 2:1); **3t** was obtained as a white solid, mp 199-201 ºC (35.7 mg, 50%

yield).

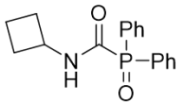
^{1}H NMR (400 MHz, $CDCl_3$): δ 10.87 (s, 1H), 8.85 (s, 1H), 8.29 (d, *J* = 8.2 Hz, 1H), 7.92-7.88 (m, 4H), 7.63-7.60 (m, 2H), 7.51-7.49 (m, 4H), 7.28-7.27 (m, 1H), .

^{13}C NMR (101 MHz, $CDCl_3$): δ 169.1 (d, *J* = 126.0 Hz), 147.0, 141.6, 138.4, 133.2 (d, *J* = 2.3 Hz), 131.8 (d, *J* = 9.7 Hz), 130.3, 129.0 (d, *J* = 12.4 Hz), 128.2 (d, *J* = 102.0 Hz), 124.2.

^{31}P NMR (162 MHz, $CDCl_3$): δ 16.51.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{20}H_{18}NaNO_2P^+$ 336.1148; found 336.1140.

N-cyclobutyl-1-(diphenylphosphoryl)formamide 3u



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 4:1); **3u** was obtained as a white solid, mp 148-150 ºC (38.3 mg, 64% yield).

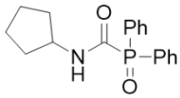
^{1}H NMR (400 MHz, $CDCl_3$): δ 8.27 (s, 1H), 7.95-7.90 (m, 4H), 7.58-7.48 (m, 6H), 4.55-4.50 (m, 1H), 2.34-2.32 (m, 2H), 2.21-2.20 (m, 2H), 1.77-1.68 (m, 2H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 168.5 (d, *J* = 119.5 Hz), 132.6 (d, *J* = 2.1 Hz), 131.7 (d, *J* = 9.6 Hz), 129.5 (d, *J* = 99.9 Hz), 128.7 (d, *J* = 12.1 Hz), 44.8 (d, *J* = 4.5 Hz), 30.8, 12.6.

^{31}P NMR (162 MHz, $CDCl_3$): δ 14.47.

HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{17}H_{19}NO_2P^+$ 300.1148; found 300.1138.

N-cyclopentyl-1-(diphenylphosphoryl)formamide 3v



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 4:1); **3v** was obtained as a white solid, mp 144-146 ºC (44.5 mg, 71% yield).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.95-7.90 (m, 4H), 7.73 (s, 1H), 7.60-7.56 (m, 2H),

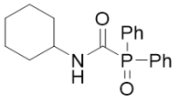
7.52-7.48 (m, 4H), 4.39-4.30 (m, 1H), 2.05-2.00 (m, 2H), 1.77-1.70 (m, 2H), 1.66-1.49 (m, 4H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 169.5 (d, *J* = 121.6 Hz), 132.6 (d, *J* = 2.8 Hz), 131.7 (d, *J* = 9.6 Hz), 129.4 (d, *J* = 99.5 Hz), 128.7 (d, *J* = 12.0 Hz), 51.5 (d, *J* = 5.0 Hz), 33.0, 24.0.

^{31}P NMR (162 MHz, $CDCl_3$): δ 14.81.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{18}H_{20}NaNO_2P^+$ 336.1124; found 336.1132.

N-cyclohexyl-1-(diphenylphosphoryl)formamide 3w



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 4:1); **3w** was obtained as a white solid (47.8 mg, 73% yield).

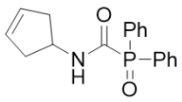
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.95-7.91 (m, 4H), 7.75-7.73 (m, 2H), 7.53-7.48 (m, 4H), 3.96-3.89 (m, 1H), 2.00-1.94 (m, 2H), 1.79-1.71 (m, 2H), 1.66-1.59 (m, 1H), 1.42-1.11 (m, 5H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 168.6 (d, *J* = 120.6 Hz), 132.6 (d, *J* = 2.4 Hz), 131.7 (d, *J* = 9.6 Hz), 129.4 (d, *J* = 99.8 Hz), 128.7 (d, *J* = 12.3 Hz), 49.1 (d, *J* = 4.9 Hz), 32.8, 25.3, 24.8.

^{31}P NMR (162 MHz, $CDCl_3$): δ 14.94.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{19}H_{23}NaNO_2P^+$ 328.1461; found 328.1453.

N-(cyclopent-3-en-1-yl)-1-(diphenylphosphoryl)formamide 3x



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 4:1); **3x** was obtained as a white solid, mp 142-144 ºC (41.1 mg, 66% yield).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.96-7.91 (m, 4H), 7.60-7.57 (m, 2H), 7.52-7.49 (m, 4H), 5.72-5.66 (m, 2H), 4.71-4.70 (m, 1H), 2.83-2.77 (m, 2H), 2.32 (d, *J* = 17.3 Hz,

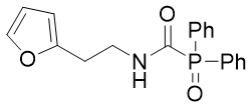
2H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 169.1 (d, *J* = 121.0 Hz), 132.6 (d, *J* = 2.1 Hz), 131.7 (d, *J* = 9.7 Hz), 129.3 (d, *J* = 100.1 Hz), 128.7 (d, *J* = 12.1 Hz), 48.9 (d, *J* = 5.0 Hz), 40.1.

^{31}P NMR (162 MHz, $CDCl_3$): δ 14.79.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{18}H_{18}NaNO_2P^+$ 334.0967; found 334.0960.

1-(diphenylphosphoryl)-N-(2-(furan-2-yl)ethyl)formamide 3y



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 2:1); **3y** was obtained as a white solid (42.7 mg, 63% yield).

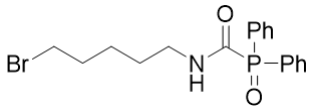
^{1}H NMR (400 MHz, $CDCl_3$): δ 8.02 (s, 1H), 7.91-7.89 (m, 4H), 7.62-7.58 (m, 2H), 7.52-7.49 (m, 4H), 7.31 (d, *J* = 1.0 Hz, 1H), 6.27 (t, *J* = 2.2 Hz, 1H), 6.06 (d, *J* = 3,0 Hz, 1H), 3.71 (t, *J* = 5.7 Hz, 2H), 2.94 (t, *J* = 6.4 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 170.0 (d, *J* = 115.5 Hz), 152.1, 141.8, 132.7 ,131.8 (d, *J* = 2.3 Hz), 129.4 (d, *J* = 99.9 Hz), 128.7 (d, *J* = 9.2 Hz), 110.3, 106.7, 38.2, 28.0.

^{31}P NMR (162 MHz, $CDCl_3$): δ 15.41.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{19}H_{18}NaNO_3P^+$ 362.0917; found 362.0907.

N-(5-bromopentyl)-1-(diphenylphosphoryl)formamide 3z



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 1:1); **3z** was obtained as a white solid, mp 98-100 ºC (49.5 mg, 63% yield).

^{1}H NMR (400 MHz, $CDCl_3$): δ 8.00-7.83 (m, 4H), 7.60 (t, *J* = 7.5 Hz, 2H), 7.52 (t, *J* = 7.12 Hz, 4H), 3.44-3.37 (m, 4H), 1.92-1.85 (m, 2H), 2.65-1.60 (m, 2H), 1.54-1.46 (m, 2H).

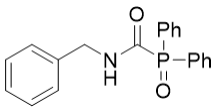
^{13}C NMR (101 MHz, $CDCl_3$): δ 169.1 (d, *J* = 121.0 Hz), 132.6, 131.7 (d, *J* = 9.7 Hz),

129.3 (d, *J* = 100.1 Hz), 128.7 (d, *J* = 10.5 Hz), 49.4 (d, *J* = 2.8 Hz), 34.2, 34.1, 28.5, 28.4.

^{31}P NMR (162 MHz, $CDCl_3$): δ 15.34.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{18}H_{21}BrNaNO_2P^+$ 416.0385; found 416.0377.

N-benzyl-1-(diphenylphosphoryl)formamide 3aa



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 2:1); **3aa** was obtained as a white solid (44.0 mg, 62% yield).

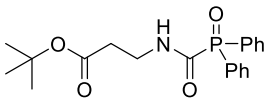
^{1}H NMR (400 MHz, $CDCl_3$): δ 8.57 (s, 1H), 7.95-7.90 (m, 4H), 7.60 (t, *J* = 7.3 Hz, 2H), 7.51-7.48 (m, 4H), 7.34-7.29 (m, 5H), 4.60 (d, *J* = 4.8 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 169.6 (d, *J* = 122.0 Hz), 137.0, 132.7 (d, *J* = 2.4 Hz), 131.7 (d, *J* = 9.4 Hz), 129.2 (d, *J* = 100.6 Hz), 128.8 128.7 (d, *J* = 11.1 Hz), 128.1, 127.7, 43.7 (d, *J* = 5.1 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ 15.30.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{20}H_{18}NaNO_2P^+$ 358.0967; found 358.0960.

Tert-butyl 3-((diphenylphosphoryl)formamido)propanoate 3ab



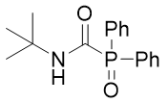
Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 2:1); **3ab** was obtained as a white solid, mp 297-299 ºC (33.6 mg, 45% yield).

^{1}H NMR (400 MHz, $CDCl_3$): δ 8.21 (s, 1H), 7.94-7.89 (m, 4H), 7.57-7.55 (m, 2H), 7.50-7.46 (m, 4H), 3.64 (q, *J* = 6.16 Hz, 2H), 2.52 (d, *J* = 6.5 Hz, 2H), 1.42 (s, 9H),

^{13}C NMR (101 MHz, $CDCl_3$): δ 170.5, 169.8 (d, *J* = 121.2 Hz), 132.6 (d, J = 2.7 Hz), 131.7 (d, *J* = 9.6 Hz), 129.2 (d, *J* = 100.2 Hz), 128.7 (d, *J* = 12.3 Hz), 81.4, 35.4 (d, J = 5.2 Hz), 35.0, 28.0.

^{31}P NMR (162 MHz, $CDCl_3$): δ 16.11.

N-tert-butyl-1-(diphenylphosphoryl)formamide 3ac



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 3:1); **3ac** was obtained as a white solid (28.9 mg, 48% yield).

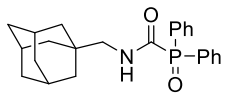
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.93-7.88 (m, 4H), 7.59-7.55 (m, 2H), 7.51-7.45 (m, 4H), 1.4 (s, 9H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 168.3 (d, *J* = 120.1 Hz), 132.5 (d, *J* = 2.9 Hz), 131.6 (d, *J* = 10.3 Hz), 129.5 (d, *J* = 99.1 Hz), 128.7 (d, *J* = 12.0 Hz), 53.4 (d, *J* = 6.9 Hz), 28.6.

^{31}P NMR (162 MHz, $CDCl_3$): δ 15.32.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{17}H_{20}NaNO_2P^+$ 324.1124; found 324.1116.

N-(((3r,5r,7r)-adamantan-1-yl)methyl)-1-(diphenylphosphoryl)formamide 3ad



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 4:1); **3ad** was obtained as white solid, mp 168-170 ºC (34.6 mg, 44% yield).

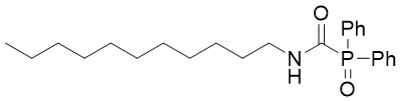
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.94-7.90 (m, 4H), 7.77 (s, 1H), 7.58-7.56 (m, 2H), 7.50-7.47 (m, 4H), 3.08 (d, *J* = 8.3 Hz, 2H), 1.96 (s, 3H), 1.70-1.58 (m, 6H), 1.50 (s, 6H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 169.7 (d, *J* = 124.2 Hz), 132.6 (d, *J* = 2.7 Hz), 131.7 (d, *J* = 9.7 Hz), 129.6 (d, *J* = 99.9 Hz), 128.6 (d, *J* = 12.1 Hz), 51.0 (d, *J* = 5.1 Hz), 40.2, 36.7, 34.0, 28.1.

^{31}P NMR (162 MHz, $CDCl_3$): δ 15.83.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{24}H_{28}NaNO_2P^+$ 416.1750; found 416.1740..

1-(diphenylphosphoryl)-N-undecylformamide 3ae



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 2:1); **3ae** was obtained as a white solid (45.5 mg, 57% yield).

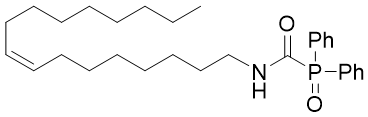
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.96-7.91 (m, 4H), 7.60-7.56 (m, 2H), 7.51-7.48 (m, 4H), 3.40 (q, *J* = 6.7 Hz, 2H), 1.62-1.55 (m, 2H), 1.31-1.26 (m, 16H), 0.90 (t, *J* = 7.2 Hz, 3H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 169.5 (d, *J* = 123.9 Hz), 132.6, 131.7 (d, *J* = 9.4 Hz), 129.4 (d, *J* = 100.0 Hz), 128.7 (d, *J* = 12.3 Hz), 39.7 (d, *J* = 4.6 Hz), 31.9, 29.6, 29.5, 29.5, 29.3, 29.3, 29.2, 26.8, 22.7, 14.1.

^{31}P NMR (162 MHz, $CDCl_3$): δ 15.11.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{24}H_{34}NaNO_2P^+$ 422.2219; found 422.2208.

(Z)-1-(diphenylphosphoryl)-N-(heptadec-8-en-1-yl)formamide 3af



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 4:1); **3af** was obtained as a white solid (43.3 mg, 45% yield).

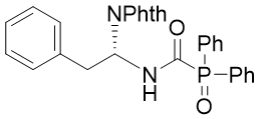
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.97-7.92 (m, 4H), 7.73 (s, 1H), 7.62-7.58 (m, 2H), 7.54-7.50 (m, 4H), 5.42-5.32 (m, 2H), 3.41 (q, *J* = 6.8 Hz, 2H), 2.04-2.00 (m, 4H), 1.62-1.56 (m, 2H), 1.35-1.26 (m, 20H), 0.91 (t, *J* = 6.2 Hz, 3H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 169.5 (d, *J* = 123.9 Hz), 132.6, 131.7 (d, *J* = 9.4 Hz), 129.4 (d, *J* = 100.0 Hz), 128.7 (d, *J* = 12.3 Hz), 39.7, 31.9, 29.8, 29.7, 29.6, 29.5, 29.3, 29.3, 29.1, 29.0, 27.2, 27.1, 26.8, 22.7, 14.1.

^{31}P NMR (162 MHz, $CDCl_3$): δ 15.04.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{30}H_{44}NaNO_2P^+$ 504.3002; found 504.2992.

(S)-N-(1-(1,3-dioxoisoindolin-2-yl)-2-phenylethyl)-1-(diphenylphosphoryl)forma mide 3ag



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 1:1); **3ag** was obtained as a white solid, mp 183-185 ºC (55.3 mg, 56% yield).

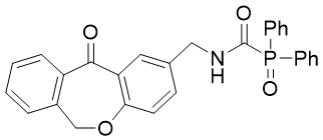
^{1}H NMR (400 MHz, $CDCl_3$): δ 8.56 (d, *J* = 9.2 Hz, 1H), 7.90-7.86 (m, 2H), 7.81-7.78 (m, 2H), 7.71-7.66 (m, 4H), 7.59-7.50 (m, 2H), 7.47-7.39 (m, 4H), 7.30-7.26 (m, 2H), 7.23-7.13 (m, 3H), 6.57 (q, *J* = 8.4 Hz, 1H), 3.46 (d, *J* = 8.1 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 169.5 (d, *J* = 120.0 Hz), 167.1, 134.9, 134.3, 132.7 (dd, *J* = 1.7, 2.7 Hz), 132.0 (d, *J* = 9.6 Hz), 131.6 (d, *J* = 10.0 Hz), 131.4, 129.3, 129.1 (d, *J* = 100.5 Hz), 128.8, 128.7 (d, *J* = 5.8 Hz), 128.2 (d, *J* = 102.6 Hz), 127.3, 123.7, 56.5 (d, *J* = 5.8 Hz), 39.1.

^{31}P NMR (162 MHz, $CDCl_3$): δ 15.56.

HRMS (ESI) m/z: [M+Na^+] Calcd for $C_{29}H_{23}NaN_2O_4P^+$ 517.1288; found 517.1280.

1-(diphenylphosphoryl)-N-((11-oxo-6,11-dihydrodibenzo[b,e]oxepin-2-yl)methyl)formamide 3ah



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 2:1); **3ah** was obtained as a white solid, mp 210-212 ºC (29.8 mg, 32% yield).

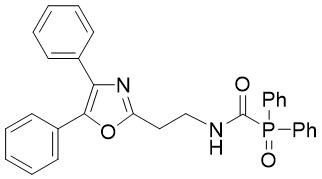
^{1}H NMR (400 MHz, DMSO): δ 9.92 (s, 1H), 8.07 (d, *J* = 2.2 Hz, 1H), 7.84-7.80 (m, 5H), 7.71-7.67 (m, 3H), 7.62-7.57 (m, 6H), 7.52-7.48 (m, 1H), 7.08 (d, *J* = 8.5 Hz, 1H), 5.3 (s, 2H), 4.43 (d, *J* = 6.2 Hz, 2H).

^{13}C NMR (101 MHz, DMSO): δ 190.6, 169.7 (d, *J* = 121.0 Hz), 160.5, 140.5, 136.4, 135.6, 133.6, 133.1 (d, *J* = 2.3 Hz), 132.70, 131.7 (d, *J* = 9.7 Hz), 130.6, 130.5 (d, *J* = 99.0 Hz), 129.7, 129.3 (d, *J* = 11.8 Hz), 129.3, 128.8, 125.0, 121.3, 73.2, 42.2 (d, *J* = 6.5 Hz).

^{31}P NMR (162 MHz, DMSO): δ 13.76.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{28}H_{22}NNaO_4P^+$ 490.1179; found 490.1171.

N-(2-(4,5-diphenyloxazol-2-yl)ethyl)-1-(diphenylphosphoryl)formamide 3ai



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 3:1); **3ai** was obtained as a white solid (42.3 mg, 43% yield).

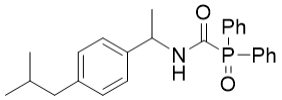
^{1}H NMR (400 MHz, $CDCl_3$): δ 8.55 (s, 1H), 7.96-7.91 (m, 4H), 7.67 (d, *J* = 7.9 Hz, 2H), 7.60-7.54 (m, 4H), 7.48-7.45 (m,4H), 7.41-7.36 (m, 6H), 3.96 (q, *J* = 6.37 Hz, 2H), 3.18 (t, *J* = 6.4 Hz, 2H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 169.9 (d, *J* = 120.1 Hz), 160.5, 145.8, 135.2, 132.7 (d, *J* = 2.7 Hz), 132.3, 131.8 (d, *J* = 9.7 Hz), 129.0 (d, *J* = 102.2 Hz), 128.8, 128.7 (d, *J* = 10.4 Hz), 128.7, 128.6, 128.1, 128.0, 127.4, 126.6. 36.7 (d, *J* = 5.4 Hz), 28.1.

^{31}P NMR (162 MHz, $CDCl_3$): δ 15.64.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{30}H_{25}N_2NaO_3P^+$ 515.1495; found 515.1486.

1-(diphenylphosphoryl)-N-(1-(4-isobutylphenyl)ethyl)formamide 3aj



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 3:1); **3aj** was obtained as a white solid, mp 141-143 ºC (41.3 mg, 51% yield).

^{1}H NMR (400 MHz, $CDCl_3$): δ 8.40 (d, *J* = 9.0 Hz, 1H), 9.00-7.95 (m, 2H), 7.86-7.80 (m, 2H), 7.60-7.50 (m, 4H), 7.44-7.41 (m, 2H), 7.27 (d, *J* = 7.6 Hz, 2H), 7.10 (d, *J* = 7.7 Hz, 2H), 5.29-5.22 (m, 1H), 2.47 (d, *J* = 7.1 Hz, 2H), 1.89-1.83 (m, 1H), 1.59 (d, *J* = 6.9 Hz, 3H), 0.92 (d, *J* = 6.9 Hz, 6H).

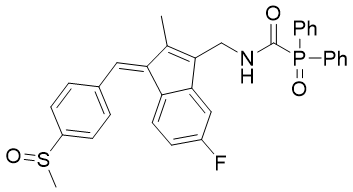
^{13}C NMR (101 MHz, $CDCl_3$): δ 168.7 (d, *J* = 120.6 Hz), 141.1, 139.3, 135.6 (dd, *J* =

2.0, 7.2 Hz), 131.8 (d, *J* = 9.5 Hz), 131.7 (d, *J* = 9.7 Hz), 129.6 (d, *J* = 99.8 Hz), 129.4, 129.3 (d, *J* = 100.4 Hz), 128.7 (d, *J* = 12.0 Hz), 126.1, 49.3 (d, *J* = 5.0 Hz), 45.1, 30.2, 22.4 (d, *J* = 2.6 Hz), 21.6.

^{31}P NMR (162 MHz, $CDCl_3$): δ 15.06.

HRMS (ESI) m/z: [M+Na^+] Calcd for $C_{25}H_{28}NaNO_2P^+$ 444.1489; found 444.1481.

(Z)-1-(diphenylphosphoryl)-N-((5-fluoro-2-methyl-1-(4-(methylsulfinyl)benzylidene)-1H-inden-3-yl)methyl)formamide 3ak



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 1:2); **3ak** was obtained as a yellow solid, mp 239-241 ºC (47.3 mg, 43% yield).

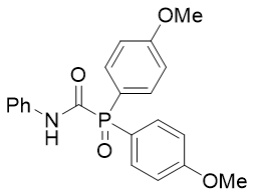
^{1}H NMR (400 MHz, $CDCl_3$): δ 8.40 (s, 1H), 7.87-7.83 (m, 4H), 7.72 (d, *J* = 8.2 Hz, 2H), 7.62-7.55 (m, 4H), 7.47-7.43 (m, 4H), 7.15-7.12 (m, 2H), 6.92 (dd, *J* = 2.3, 8.9 Hz, 1H), 6.55 (td, *J* = 2.3 , 8.7 Hz, 1H), 4.56 (d, *J* = 5.7 Hz, 2H), 2.82 (s, 3H), 2.19 (s, 3H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 169.8 (d, *J* = 120.2 Hz), 163.3 (d, *J* = 246.9 Hz), 145.7 (d, *J* = 8.8 Hz), 145.6, 141.7, 139.5, 139.0, 134.1 (d, *J* = 1.8 Hz), 132.7 (d, *J* = 2.5 Hz), 131.7 (d, *J* = 9.7 Hz), 130.5 (d, *J* = 9.6 Hz), 130.2, 129.5 (d, *J* = 2.6 Hz), 129.0, 128.9 (d, *J* = 100.7 Hz), 128.7 (d, *J* = 12.3 Hz), 123.9, 123.7, 111.0 (d, *J* = 22.5 Hz), 106.4 (d, *J* = 24.8 Hz), 43.9, 34.0 (d, *J* = 5.4 Hz), 10.4.

^{31}P NMR (162 MHz, $CDCl_3$): δ 14.84.

HRMS (ESI) m/z: [M+Na^+] Calcd for $C_{32}H_{27}FNNaO_3PS^+$ 578.1326; found 578.1317.

1-(bis(4-methoxyphenyl)phosphoryl)-N-phenylformamide 3al



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 6:1); **3al** was obtained as a white solid, mp 158-161 ºC (62.5 mg, 82% yield).

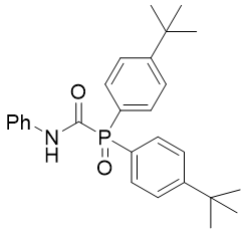
^{1}H NMR (400 MHz, $CDCl_3$): δ 9.43 (s, 1H), 7.88 (t, *J* = 9.6 Hz, 4H), 7.72 (d, *J* = 7.6 Hz, 2H), 7.37 (t, *J* = 7.7 Hz, 2H), 7.20 (t, *J* = 7.6 Hz, 1H), 7.03 (d, *J* = 6.3 Hz, 4H), 3.8 (s, 6H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 168.7 (d, *J* = 124.0 Hz), 163.3 (d, *J* = 2.9 Hz), 136.8 (d, *J* = 9.4 Hz), 133.8 (d, *J* = 12.0 Hz), 129.2, 125.5, 119.9 (d, *J* = 107.3 Hz), 119.8, 114.4 (d, *J* = 13.4 Hz), 55.4.

^{31}P NMR (162 MHz, $CDCl_3$): δ 16.96.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{21}H_{20}NaNO_4P^+$ 420.0762; found 420.0752.

1-(bis(4-(tert-butyl)phenyl)phosphoryl)-N-phenylformamide 3am



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 4:1); **3am** was obtained as a white solid, mp 230-232 ºC (53.7 mg, 62% yield).

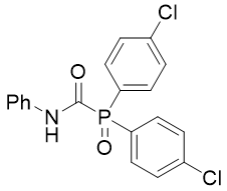
^{1}H NMR (400 MHz, $CDCl_3$): δ 9.55 (s, 1H), 7.95-7.90 (m, 4H), 7.72 (d, *J* = 8.5 Hz, 2H), 7.55 (dd, *J* = 6.7, 10.7 Hz, 4H), 7.37 (t, *J* = 7.9 Hz, 2H), 7.19 (t, *J* = 6.6 Hz, 1H), 1.36 (s, 18H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 168.6 (d, *J* = 123.0 Hz), 156.4 (d, *J* = 2.5 Hz), 136.9 (d, *J* = 9.4 Hz), 131.8 (d, *J* = 9.5 Hz), 129.1, 125.8 (d, *J* = 12.4 Hz), 125.5 (d, *J* = 104.4 Hz), 125.5, 119.9, 35.1, 31.1.

^{31}P NMR (162 MHz, $CDCl_3$): δ 16.17.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{27}H_{32}NaNO_2P^+$ 472.1802; found 472.1794.

1-(bis(4-chlorophenyl)phosphoryl)-N-phenylformamide 3an



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 2:1); **3an** was obtained as a white solid (57.5 mg, 74% yield).

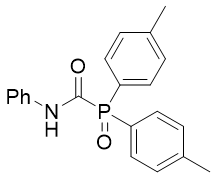
^{1}H NMR (400 MHz, $CDCl_3$): δ 9.78 (s, 1H), 7.92-7.88 (m, 4H), 7.73 (d, *J* = 7.8 Hz, 2H), 7.51 (d, *J* = 7.6 Hz, 4H), 7.37 (t, *J* = 7.6 Hz, 2H), 7.22 (t, *J* = 7.5 Hz, 1H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 167.3 (d, *J* = 124.9 Hz), 139.9 (d, *J* = 3.0 Hz), 136.6 (d, *J* = 9.7 Hz), 133.1 (d, *J* = 10.6 Hz), 129.4, 127.1 (d, *J* = 101.6 Hz), 125.9, 120.1.

^{31}P NMR (162 MHz, $CDCl_3$): δ 13.82.

HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{19}H_{14}Cl_2NaNO_2P^+$ 390.0212; found 390.0204.

1-(di-p-tolylphosphoryl)-N-phenylformamide 3ao



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 3:1); **3ao** was obtained as a white solid (53.7 mg, 77% yield).

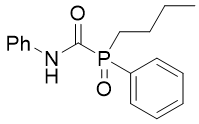
^{1}H NMR (400 MHz, $CDCl_3$): δ 9.45 (s, 1H), 7.88-7.82 (m, 4H), 7.70 (d, *J* = 7.8 Hz, 2H), 7.38-7.33 (m, 6H), 7.19 (t, *J* = 7.4 Hz, 1H). 2.43 (s, 6H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 168.7 (d, *J* = 124.0 Hz), 163.3 (d, *J* = 2.9 Hz), 136.8 (d, *J* = 9.4 Hz), 133.8 (d, *J* = 12.0 Hz), 129.2, 125.5, 119.9 (d, *J* = 107.3 Hz), 119.8, 114.4 (d, *J* = 13.4 Hz), 55.4.

^{31}P NMR (162 MHz, $CDCl_3$): δ 16.96.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{21}H_{20}NaNO_2P^+$ 340.2247; found 340.2250.

1-(butyl(phenyl)phosphoryl)-N-phenylformamide 3ap



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 2:1); **3ap** was obtained as a white solid (24.6 mg, 41% yield).

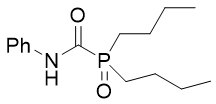
^{1}H NMR (400 MHz, $CDCl_3$): δ 9.55 (s, 1H), 8.00-7.95 (m, 2H), 7.70 (d, *J* = 8.0 Hz, 2H), 7.61-7.57 (m, 1H), 7.53-7.50 (m, 2H), 7.35 (t, *J* = 7.9 Hz, 2H), 7.18 (t, *J* = 7.9 Hz, 1H), 2.45-2.21 (m, 2H), 1.69-1.61 (m, 2H), 1.51-1.44 (m, 2H), 0.92 (t, *J* = 6.8 Hz, 3H)

^{13}C NMR (101 MHz, $CDCl_3$): δ 169.2 (d, *J* = 116.3 Hz), 136.8 (d, *J* = 8.7 Hz), 132.7 (d, *J* = 2.7 Hz), 131.0 (d, *J* = 7.9 Hz), 129.1, 125.5, 123.4 (d, *J* = 106.8 Hz), 120.0, 27.3 (d, *J* = 70.0 Hz), 23.8 (d, *J* = 12.5 Hz), 23.3 (d, *J* = 4.0 Hz), 13.6.

^{31}P NMR (162 MHz, $CDCl_3$): δ 26.25.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{17}H_{20}NaNO_2P^+$ 324.1124; found 324.1124.

1-(dibutylphosphoryl)-N-phenylformamide 3aq



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 2:1); **3aq** was obtained as a white solid (25.8 mg, 46% yield).

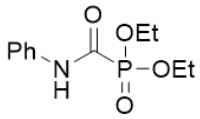
^{1}H NMR (400 MHz, $CDCl_3$): δ 9.23 (s, 1H), 7.70 (d, *J* = 8.3 Hz, 2H), 7.40 (t, *J* = 7.5 Hz, 2H), 7.22 (t, *J* = 7.5 Hz, 1H), 2.06-1.95 (m, 4H), 1.76-1.78 (m, 2H), 1.63-1.55 (m, 2H), 1.50-1.41 (m, 4H), 0.95 (t, *J* = 7.3 Hz, 6H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 169.5 (d, *J* = 109.3 Hz), 136.8 (d, *J* = 8.7 Hz), 129.2, 125.6, 119.8, 26.5 (d, *J* = 62.7 Hz), 23.9 (d, *J* = 14.6 Hz), 23.5 (d, *J* = 4.4 Hz), 13.5.

^{31}P NMR (162 MHz, $CDCl_3$): δ 41.66.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{15}H_{24}NaNO_2P^+$ 304.1437; found 304.1430.

Diethyl (phenylcarbamoyl)phosphonate 3ar



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 2:1); **3ar** was obtained as a colorless oil (41.1 mg, 80% yield).

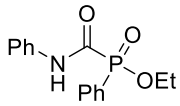
^{1}H NMR (400 MHz, $CDCl_3$): δ 9.11 (s, 1H), 7.70 (d, *J* = 8.0 Hz, 2H), 7.40-7.35 (m, 2H), 7.21 (t, *J* = 7.5 Hz, 1H), 4.37-4.26 (m, 4H), 1.43 (t, *J* = 7.0 Hz, 6H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 164.1 (d, *J* = 226.4 Hz), 136.6 (d, *J* = 13.3 Hz), 129.2, 125.6, 120.2, 64.8 (d, *J* = 6.3 Hz), 16.3 (d, *J* = 5.8 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ -1.72.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{11}H_{16}NNaO_4P^+$ 280.0709; found 280.0711.

Ethyl phenyl(phenylcarbamoyl)phosphinate 3as



Following general procedure, purification by flash column chromatography (petroleum ether/EtOAc = 2:1); **3as** was obtained as a yellow oil (45.1 mg, 78% yield).

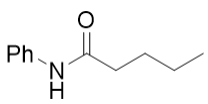
^{1}H NMR (400 MHz, $CDCl_3$): δ 9.45 (s, 1H), 8.06-8.02 (m, 2H), 7.71 (d, *J* = 8.0 Hz, 2H), 7.67-7.63 (m, 1H), 7.56-7.51 (m, 2H), 7.37-7.35 (m, 2H), 7.20-7.16 (m, 1H), 4.44-4.23 (m, 2H), 1.47 (t, *J* = 7.0 Hz, 3H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 166.4 (d, *J* = 160.0 Hz), 136.8 (d, *J* = 10.7 Hz), 133.6 (d, *J* = 2.4 Hz), 132.6 (d, *J* = 10.3 Hz), 129.1, 128.7 (d, *J* = 13.5 Hz), 126.7 (d, *J* = 137.7 Hz), 125.6, 120.0, 63.2 (d, *J* = 6.6 Hz), 16.4 (d, *J* = 6.4 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ 20.32.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{15}H_{16}NNaO_3P^+$ 312.0760; found 312.0758.

N-phenylpentanamide 4



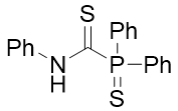
Following **P1**, purification by flash column chromatography (petroleum ether/EtOAc = 30:1); **4** was obtained as a colorless oil (28.6 mg, 56% yield).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.96 (s, 1H), 7.55 (d, *J* = 7.8 Hz, 2H), 7.30 (t, *J* = 7.5 Hz, 2H), 7.10 (t, *J* = 7.3 Hz, 1H), 2.36 (t, *J* = 7.1 Hz, 2H), 1.71 (dt, *J* = 15.1, 7.4 Hz, 2H), 1.43-1.35 (m, 2H), 0.94 (t, *J* = 9.4 Hz, 3H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 172.1, 138.1, 128.9, 124.2, 120.1, 37.4, 27.8, 22.4, 13.8.

HRMS (ESI) m/z: $[M+H]^+$ Calcd for $C_{11}H_{15}ON^+$ 163.1117; Found 163.1116.

1-(diphenylphosphorothioyl)-N-phenylmethanethioamide 5



Following **P1**, purification by flash column chromatography (petroleum ether/EtOAc = 20:1); **5** was obtained as a yellow solid. (28.6 mg, 78% yield).

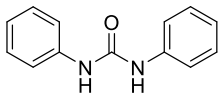
^{1}H NMR (400 MHz, $CDCl_3$): δ 12.0 (d, *J* = 8.9 Hz, 1H), 8.14 (d, *J* = 8.0 Hz, 2H), 8.10-8.05 (m, 4H), 7.63-7.58 (m, 2H), 7.54-7.46 (m, 6H), 7.35 (t, *J* = 7.4 Hz, 1H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 189.0 (d, *J* = 67.1 Hz), 138.5 (d, *J* = 13.2 Hz), 133.1 (d, *J* = 10.3 Hz), 132.3 (d, *J* = 3.3 Hz), 131.0 (d, *J* = 90.0 Hz), 129.1, 128.4 (d, *J* = 13.3 Hz), 127.6, 121.2.

^{31}P NMR (162 MHz, $CDCl_3$): δ 45.75.

HRMS (ESI) m/z: $[M+Na]^+$ Calcd for $C_{19}H_{16}NNaPS_2^+$ 376.0354; found 376.0346.

diphenylurea 6



Purification by flash column chromatography (petroleum ether/EtOAc = 1:1); **6** was obtained as a white solid (28.6 mg, 46% yield).

^{1}H NMR (400 MHz, $CDCl_3$): δ 8.62 (s, 2H), 7.41 (d, *J* = 7.6 Hz, 2H), 7.23 (t, *J* = 7.1 Hz, 4H), 6.92 (t, *J* = 7.4 Hz, 4H).

^{13}C NMR (101 MHz, $CDCl_3$): δ 157.8, 144.9, 134.0, 127.0, 123.4.

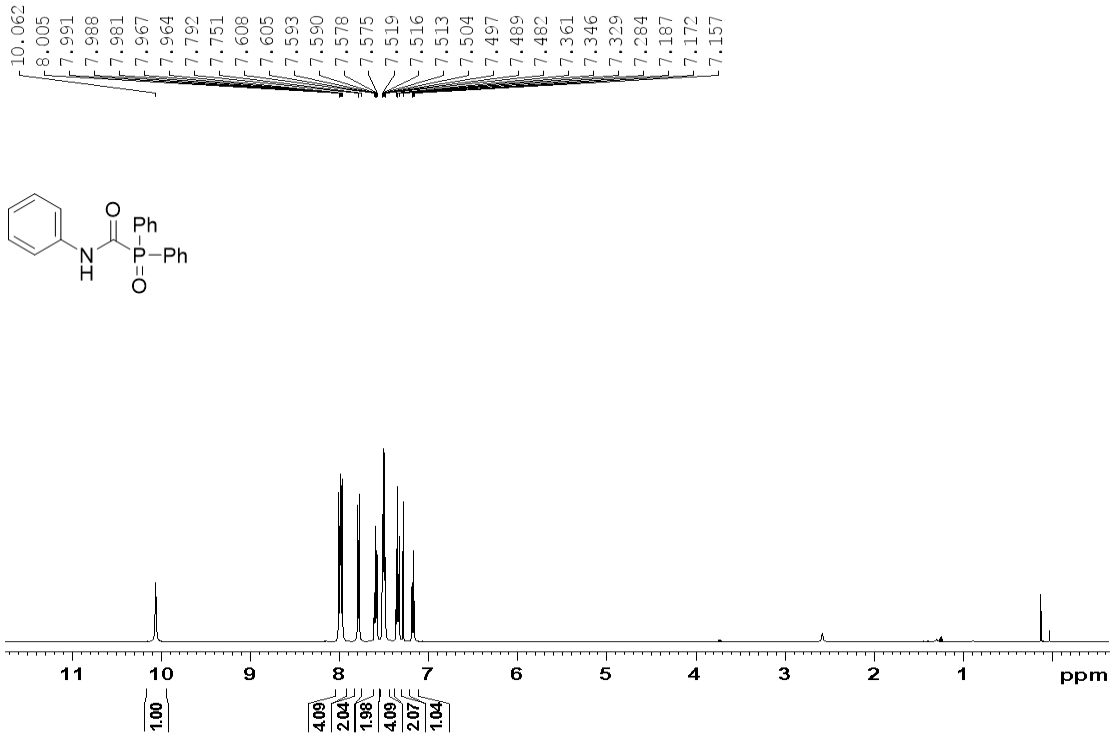
HRMS (ESI) m/z: $[M+K]^+$ Calcd for $C_{13}H_{12}N_2KO^+$ 251.0581; found 251.0573.

7. References

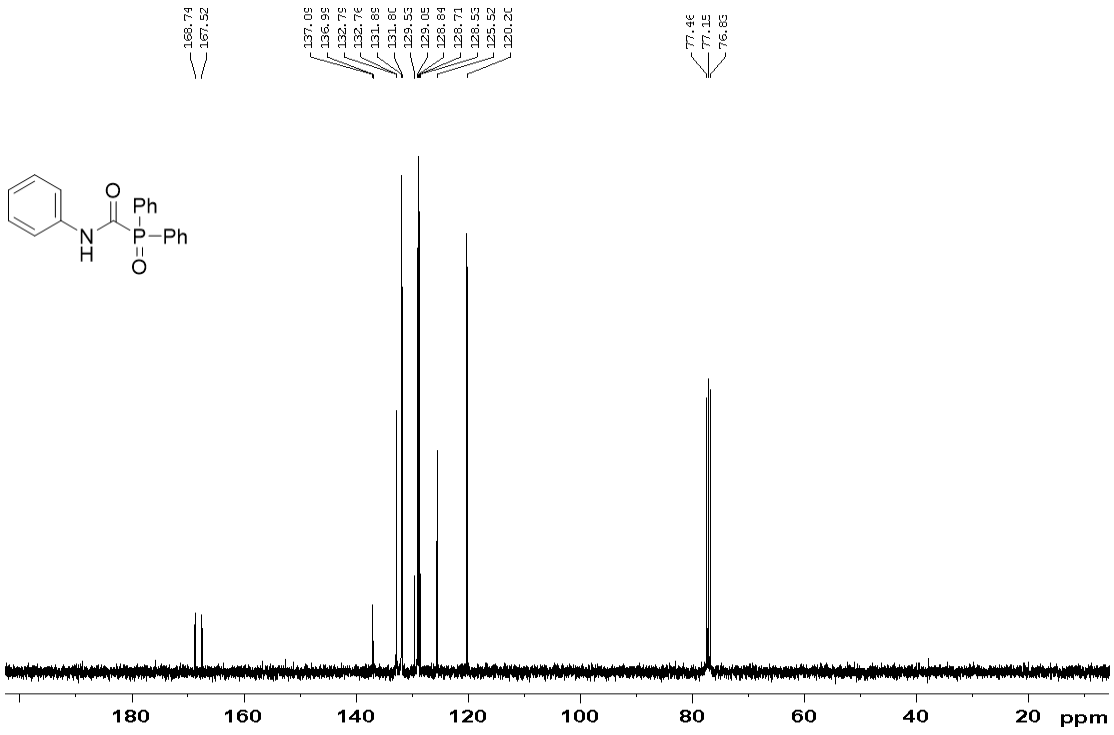
1 (a) J. Park, A. U. Krishnapriya, Y. Park, M. Kim, T. W. Reidl, R. Kuniyil and J. Son, *Adv. Synth. Catal.*, 2023, **365**, 4495-4501; (b) J.-J. Tang, N. Yan, Y. Zhang, Y. Wang, M. Bao and X. Yu, *Green Chem.*, 2023, **25**, 7529-7533.

2 G. Lu, X. Huangfu, Z. a. Wu, G. Tang and Y. Zhao, *Adv. Synth. Catal.*, 2019, **361**, 4961-4965.

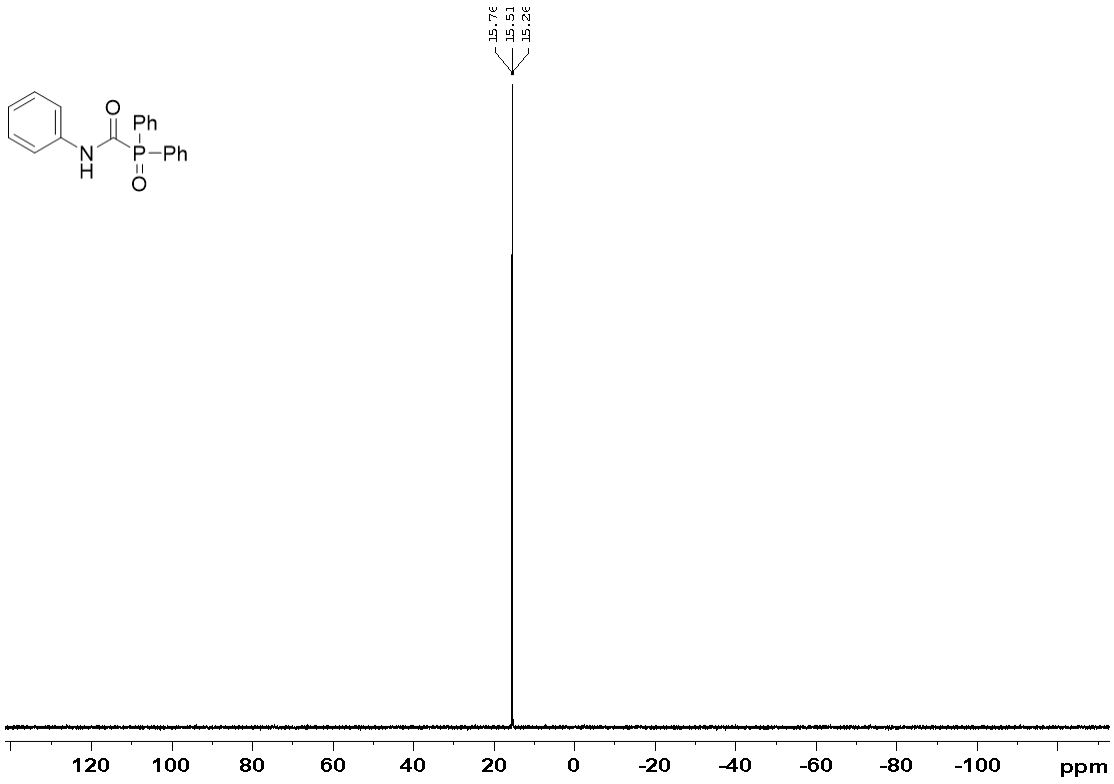
8. ^{1}H, ^{13}C, ^{31}P NMR spectra of compounds 3 and 4-6



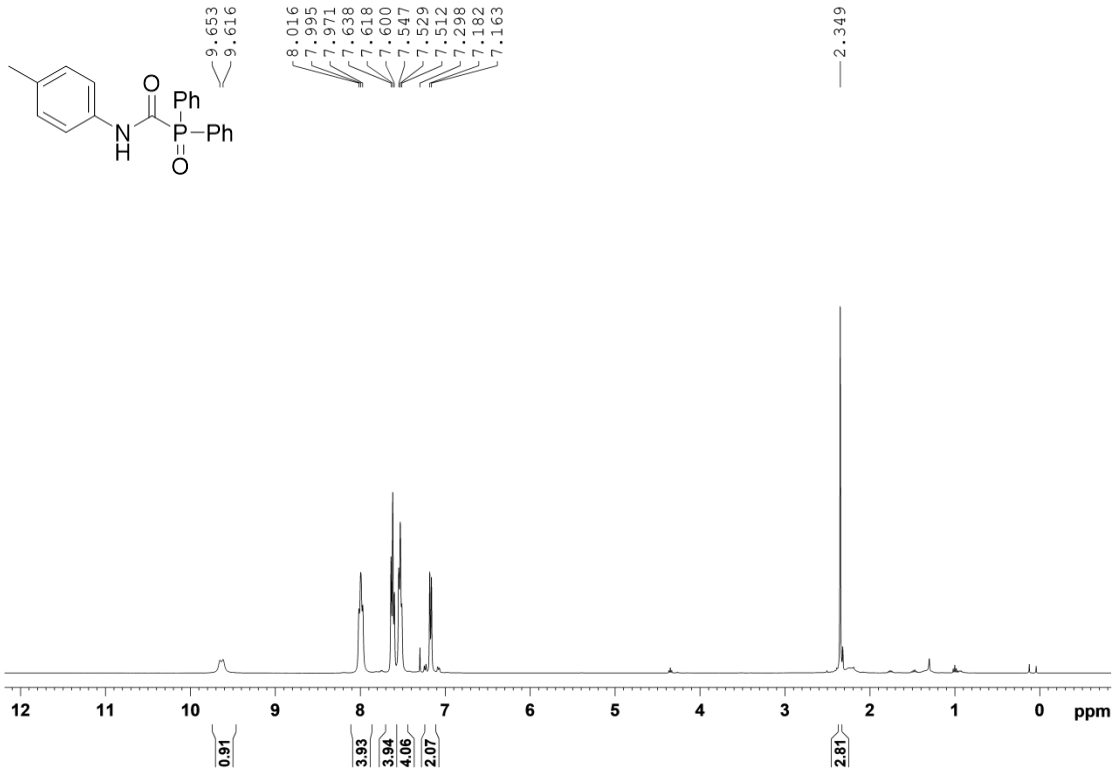
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of **3a**



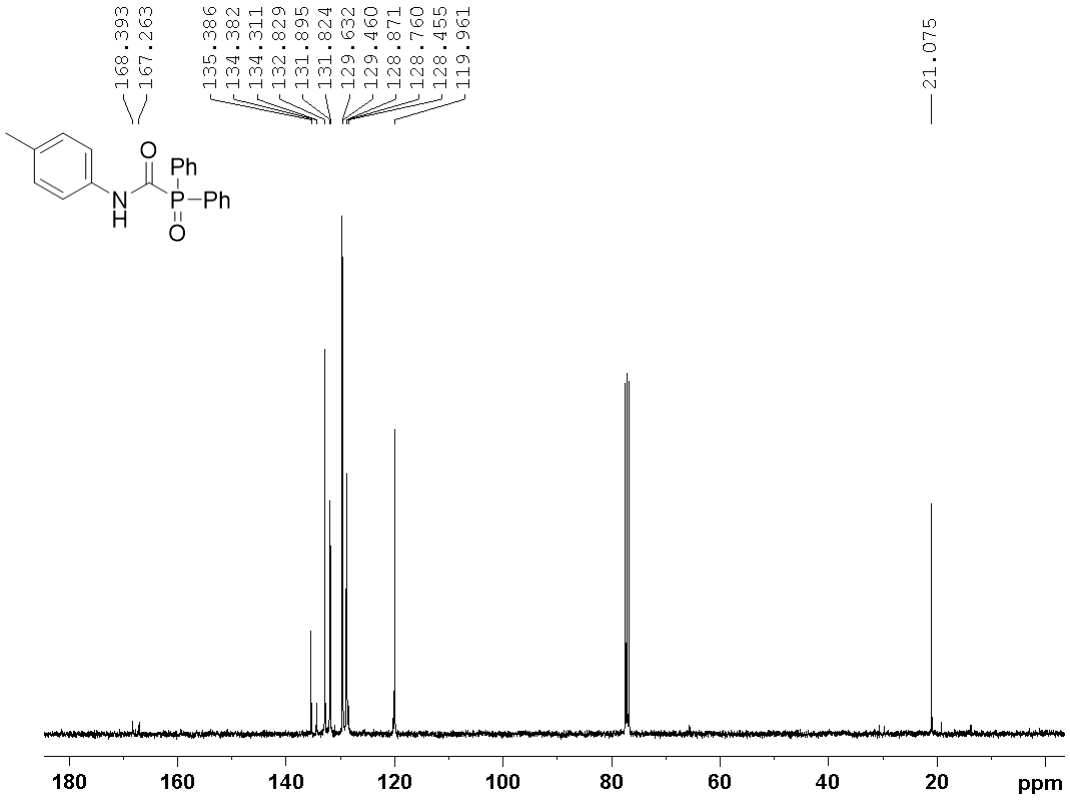
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3a**



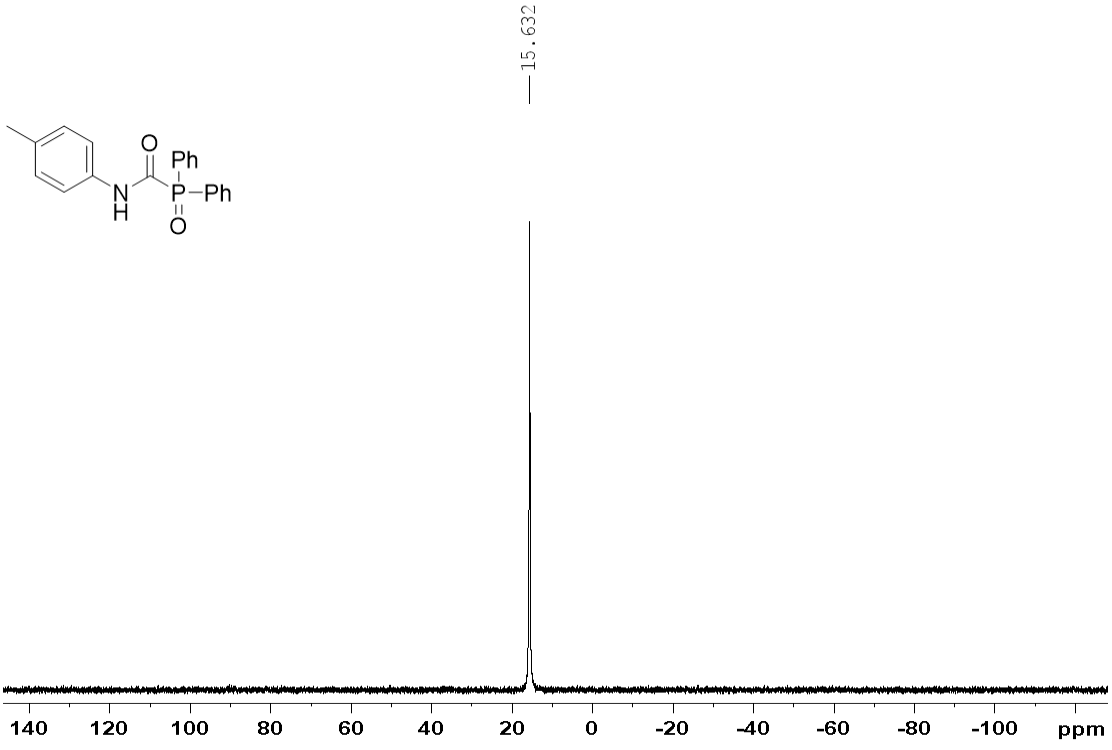
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3a**



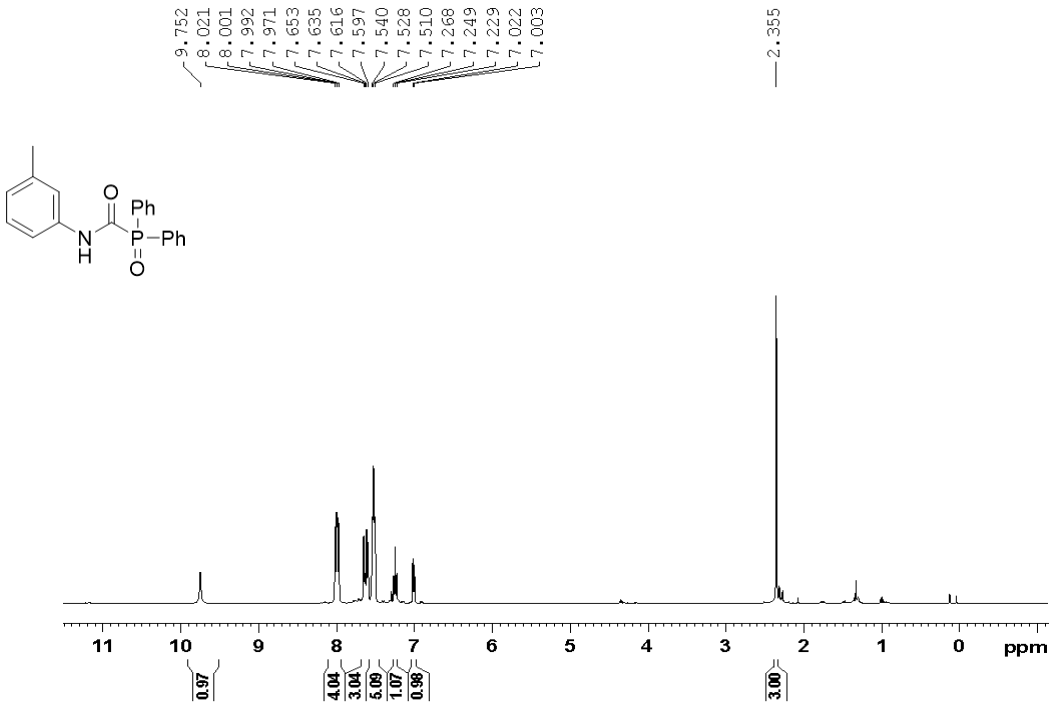
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3b**



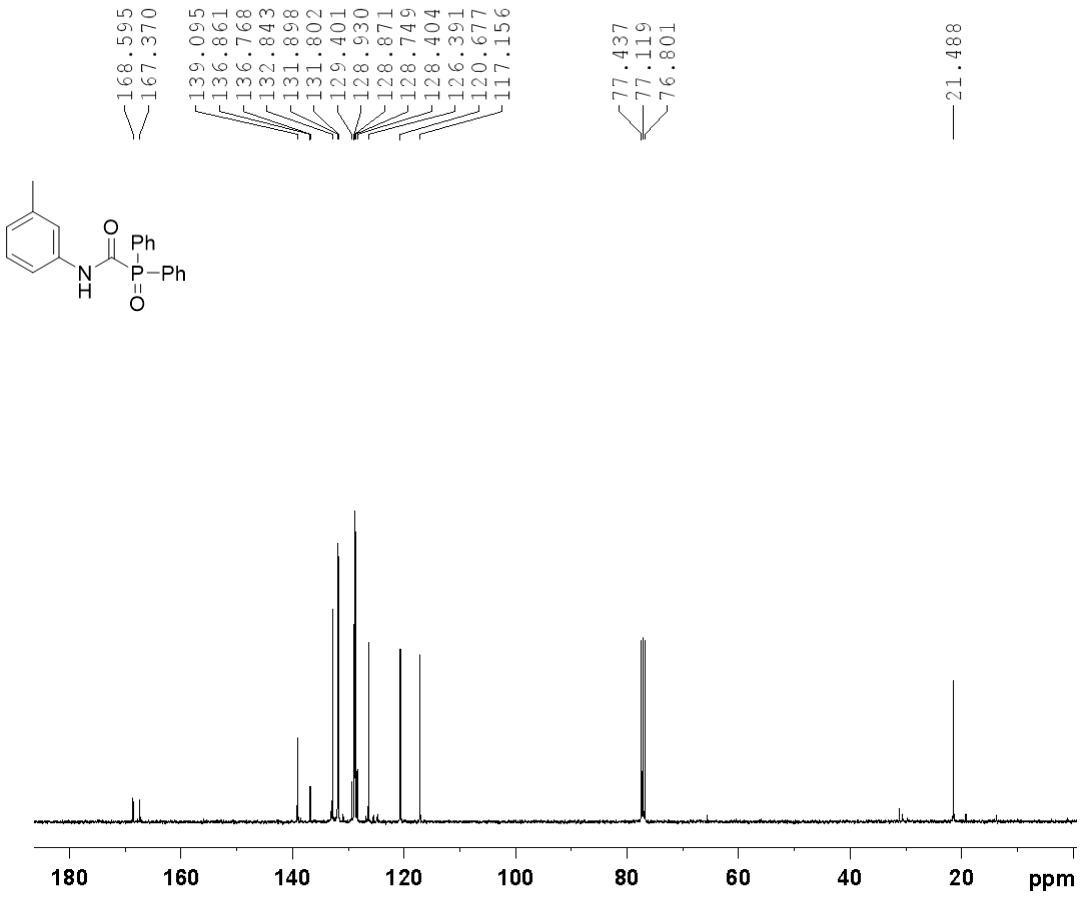
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3b**



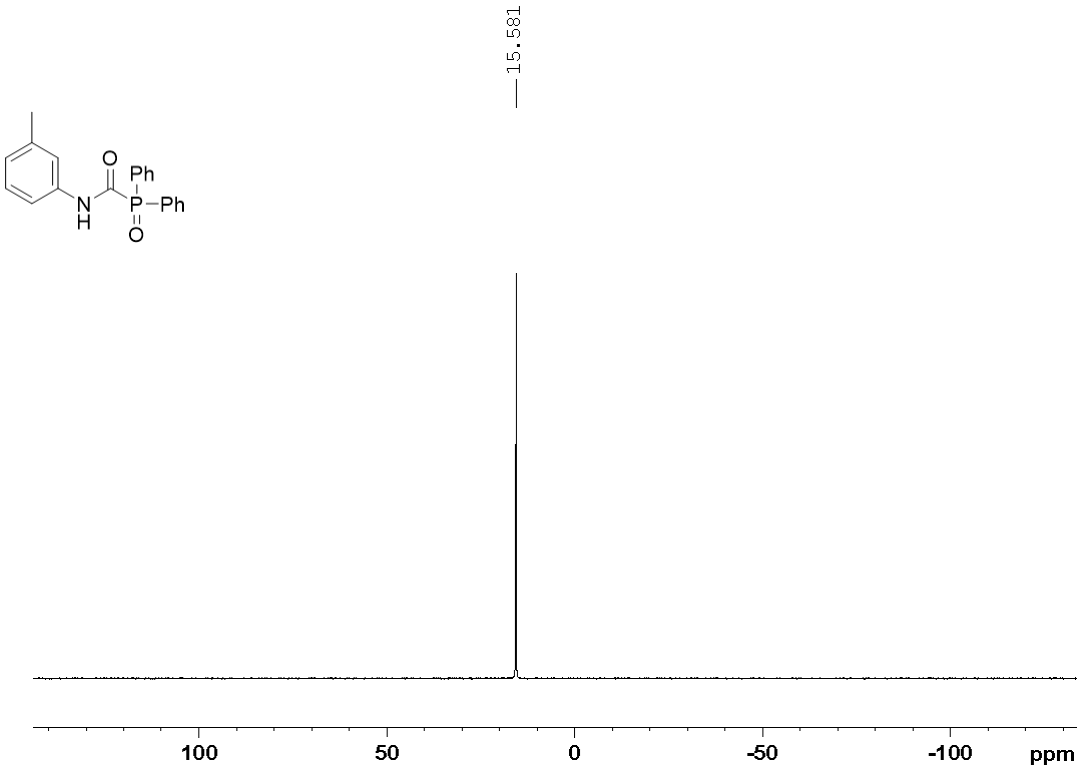
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3b**



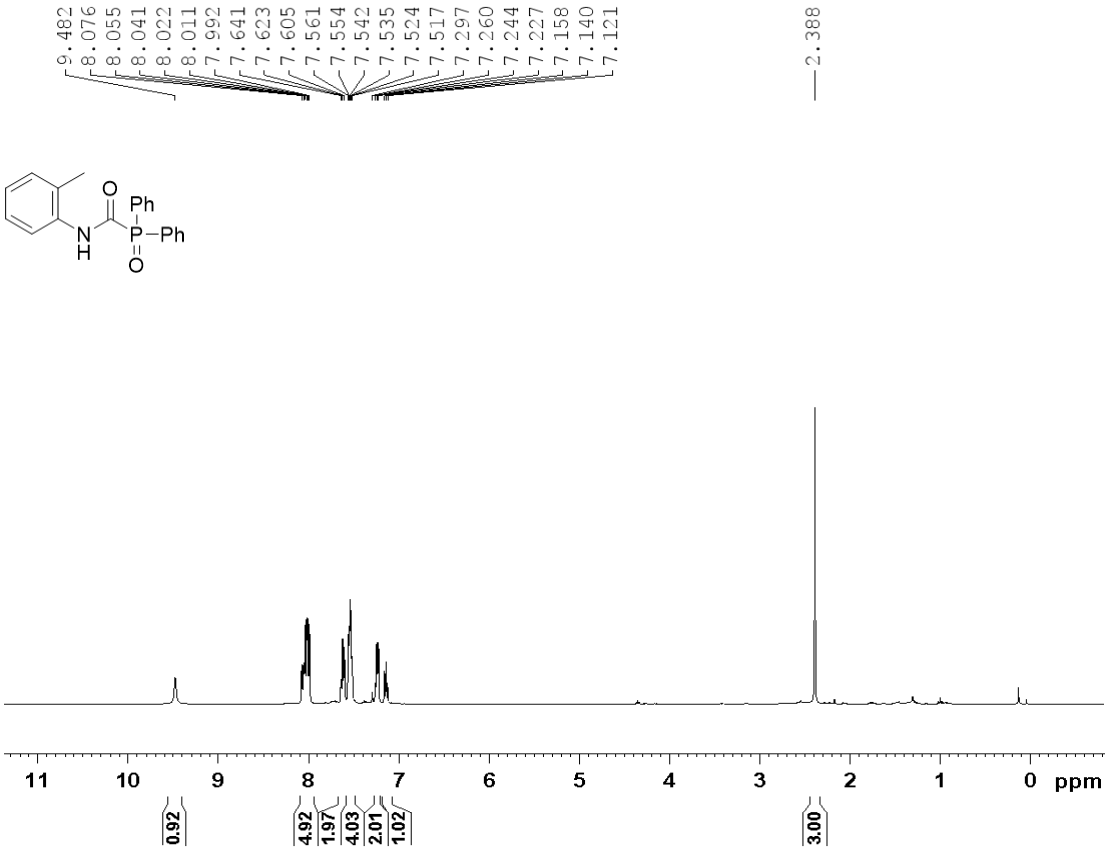
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3c**



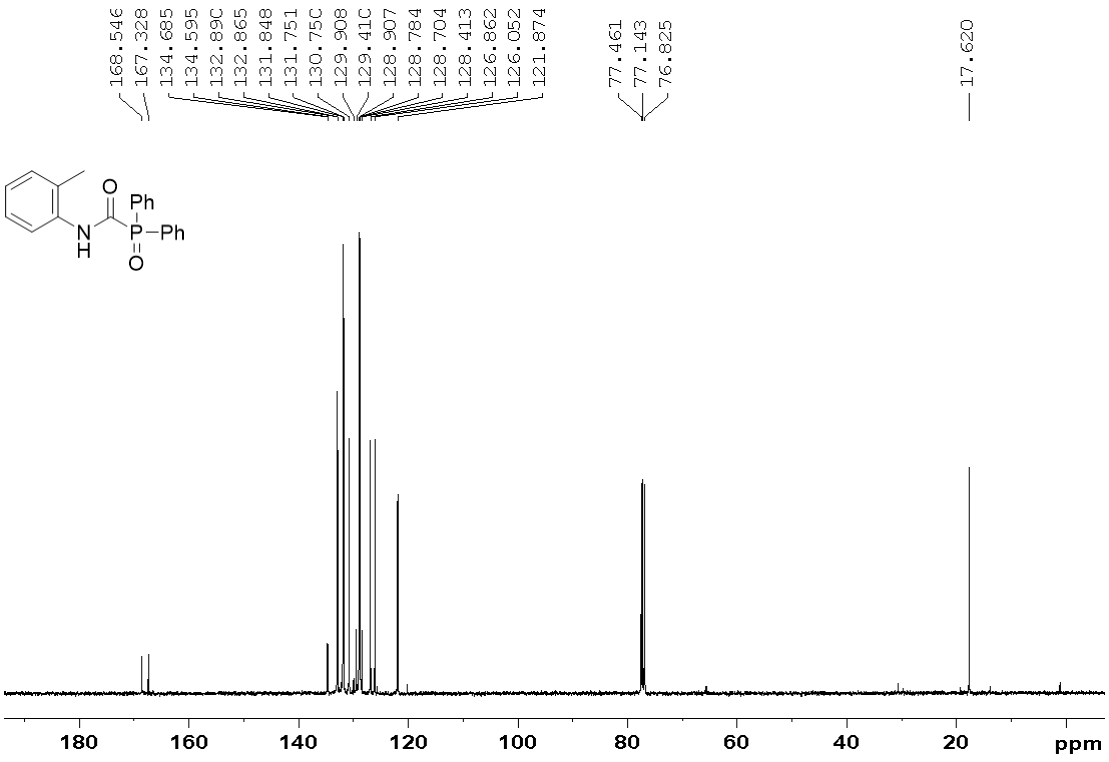
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3c**



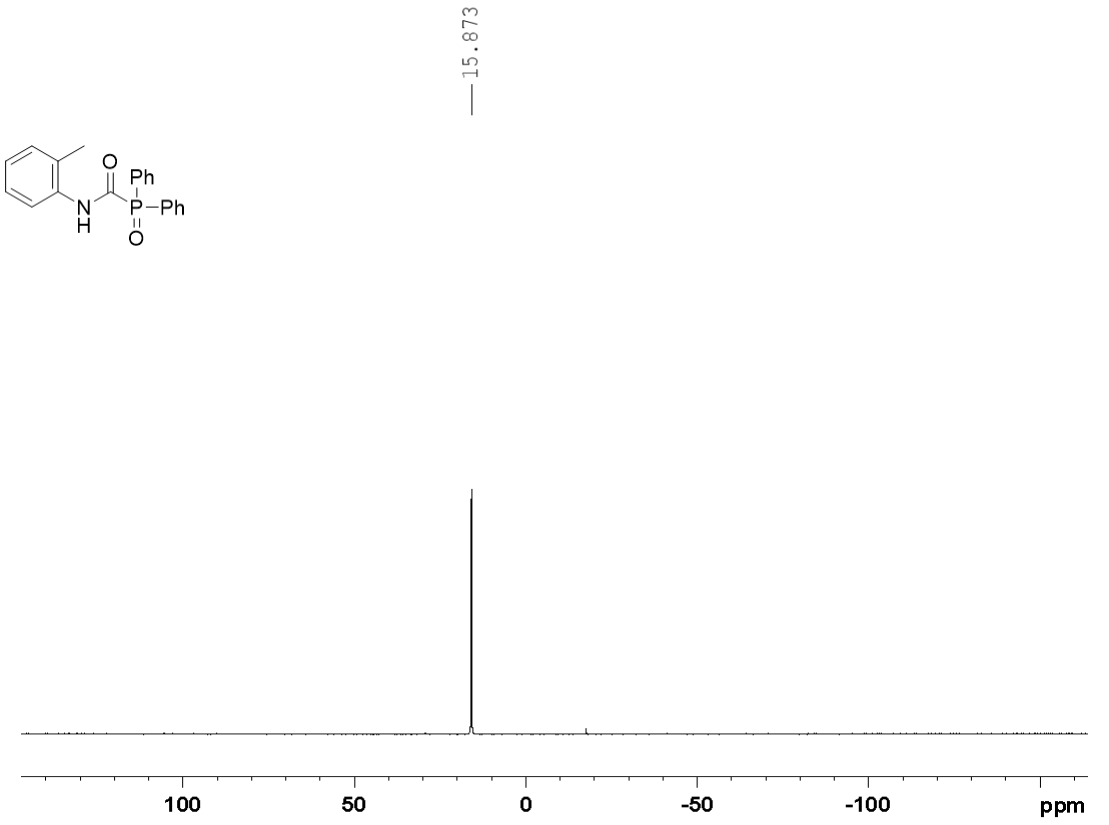
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3c**



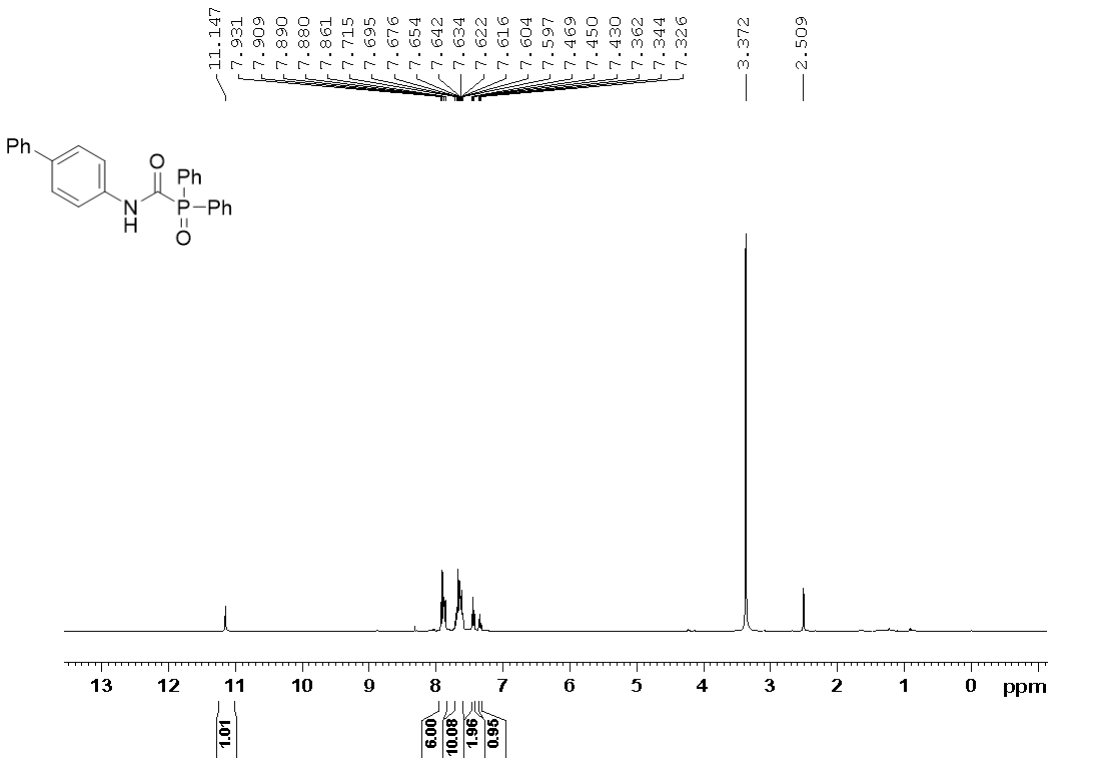
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3d**



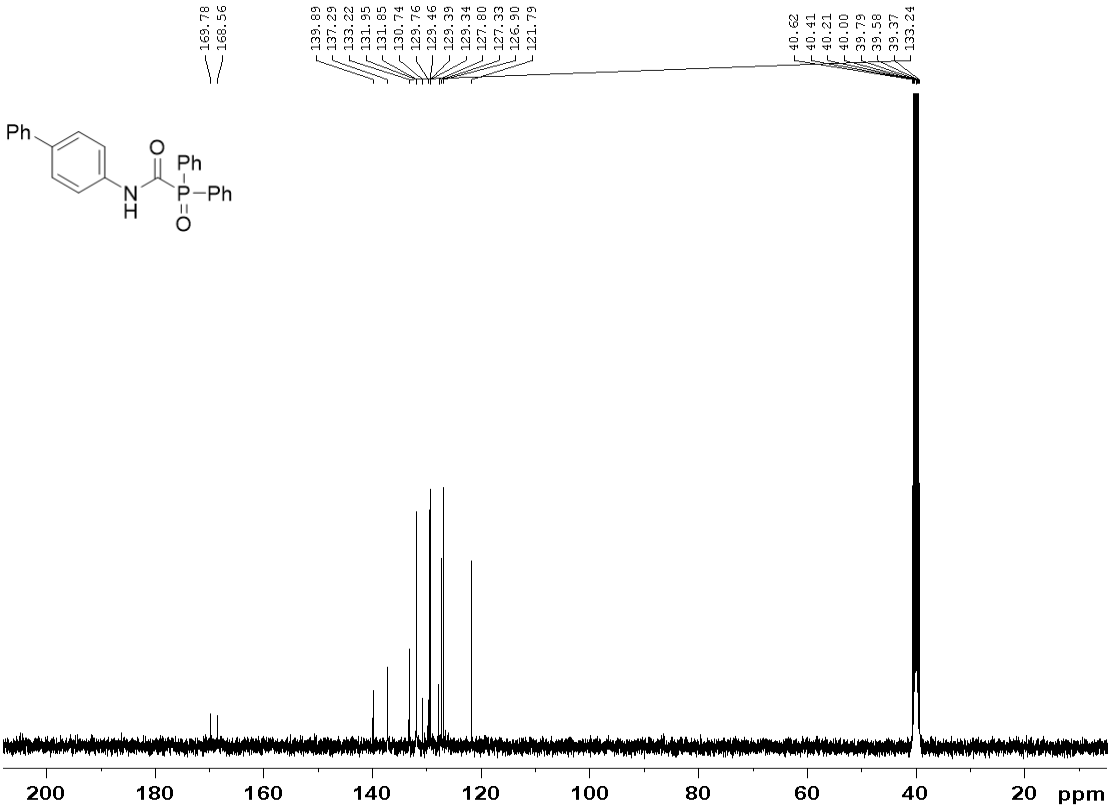
^{13}C NMR (126 MHz, $CDCl_3$) spectrum of compound **3d**



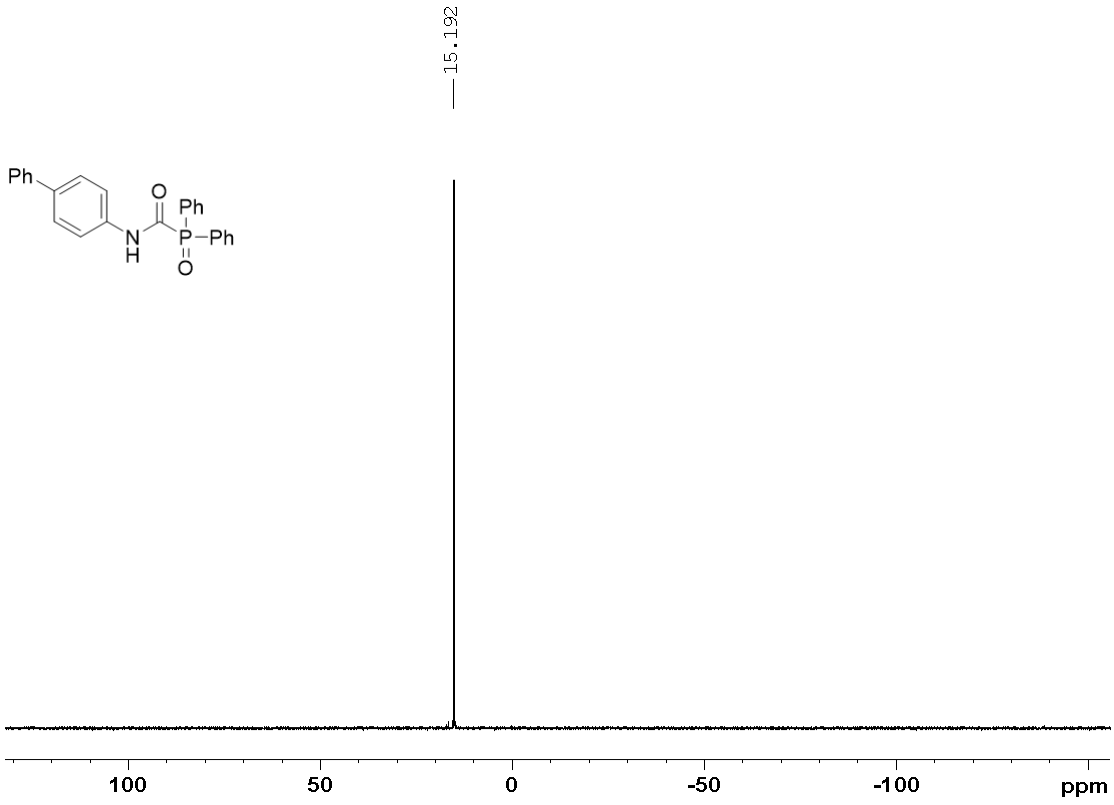
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3d**



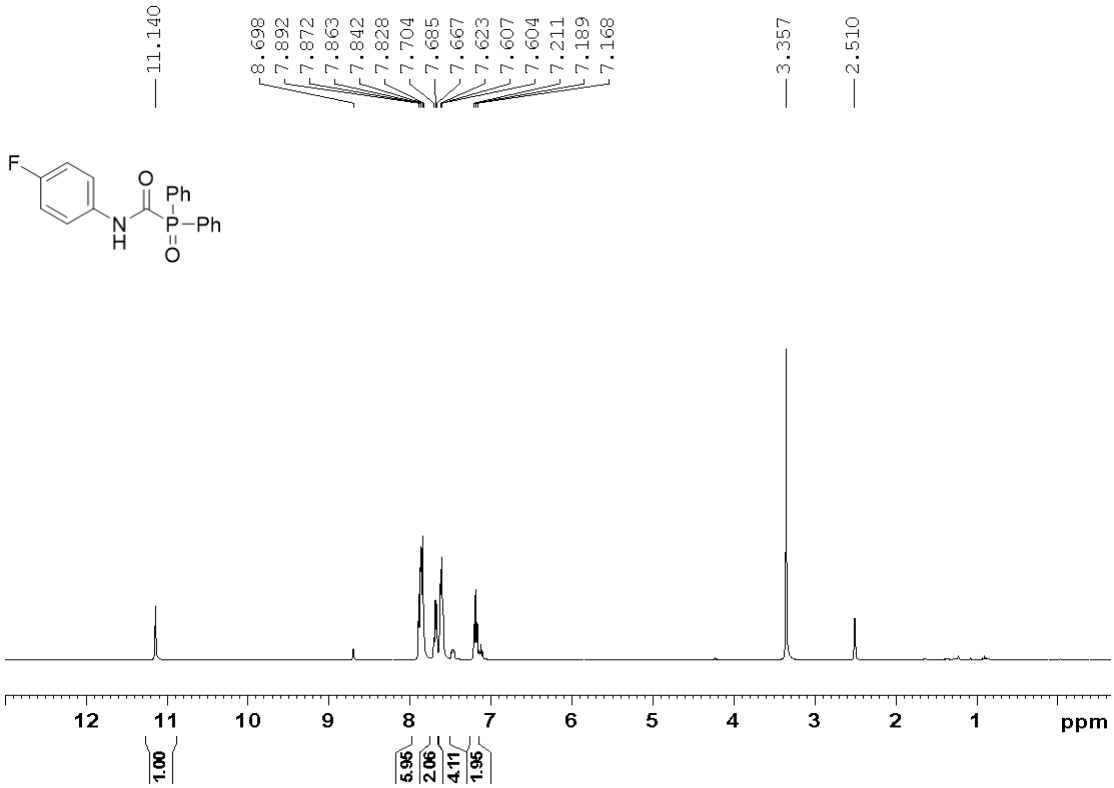
^{1}H NMR (400 MHz, DMSO) spectrum of compound **3e**



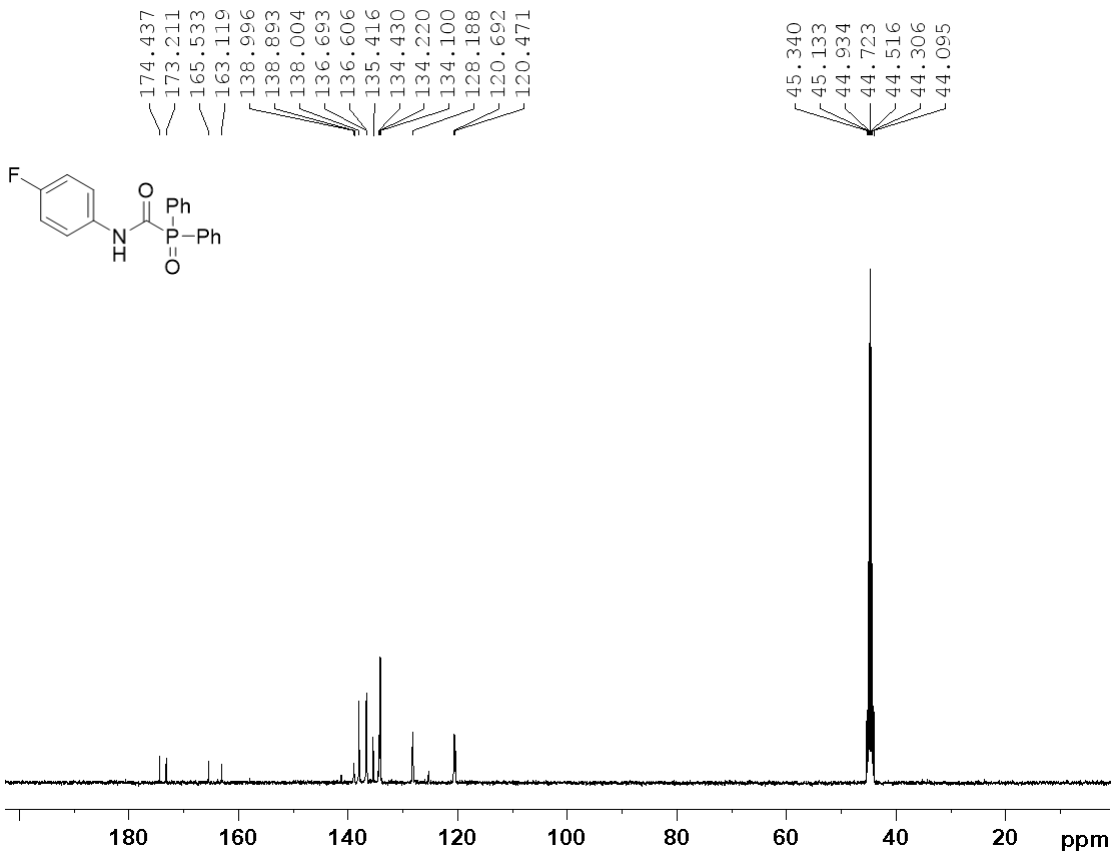
^{13}C NMR (101 MHz, DMSO) spectrum of compound **3e**



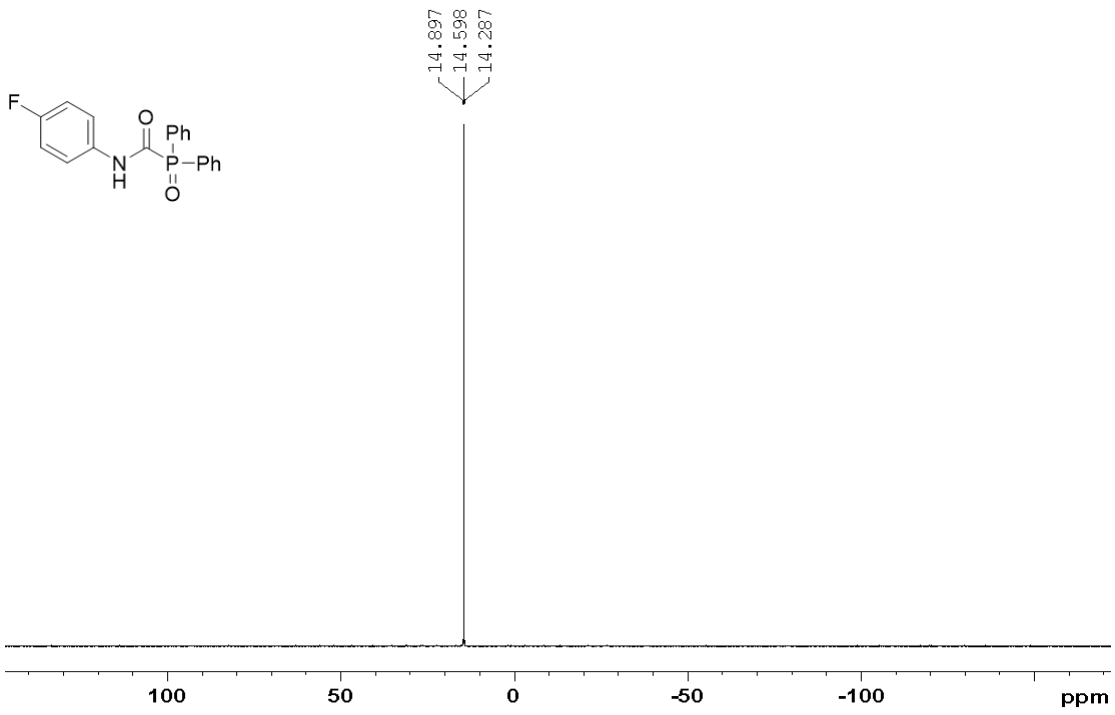
^{31}P NMR (162 MHz, DMSO) spectrum of compound **3e**



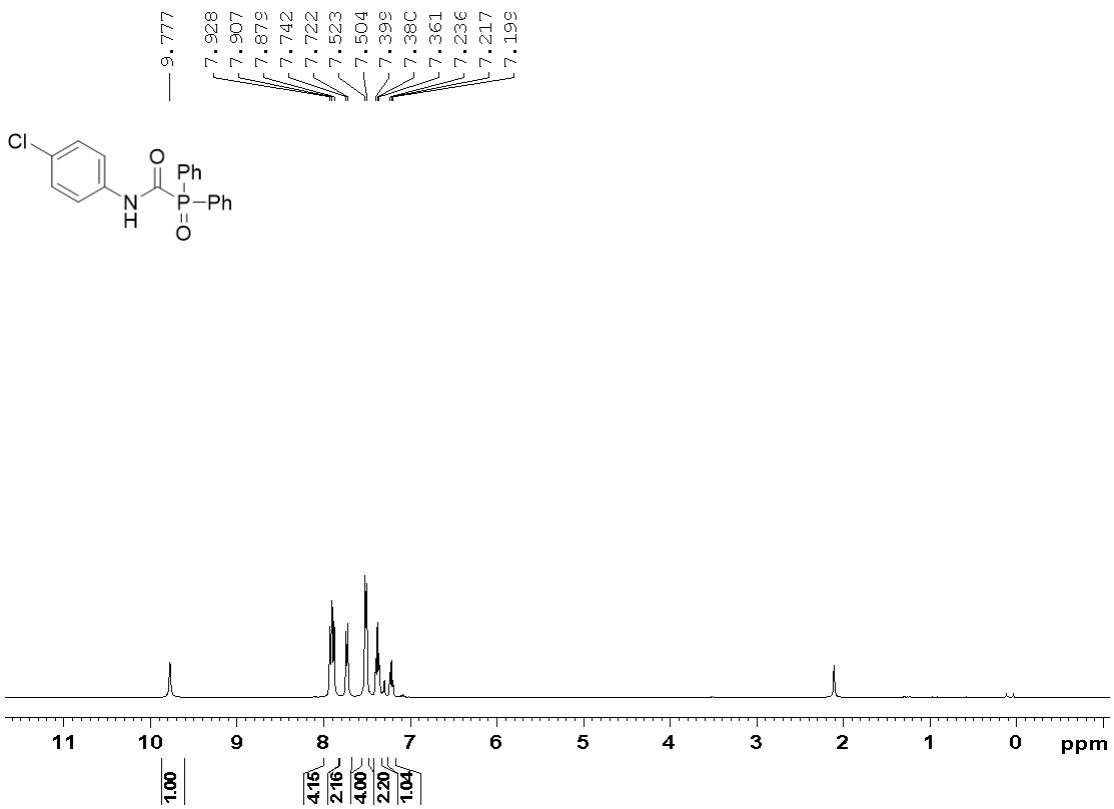
^{1}H NMR (400 MHz, DMSO) spectrum of compound **3f**



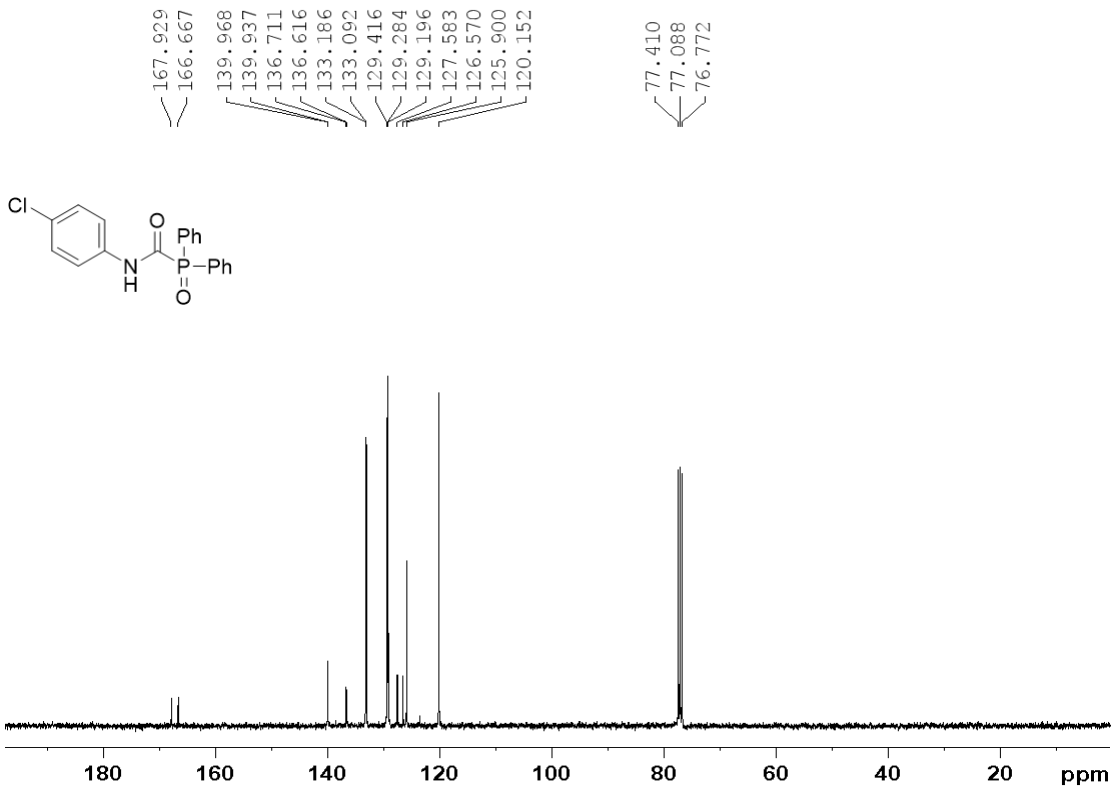
^{13}C NMR (101 MHz, DMSO) spectrum of compound **3f**



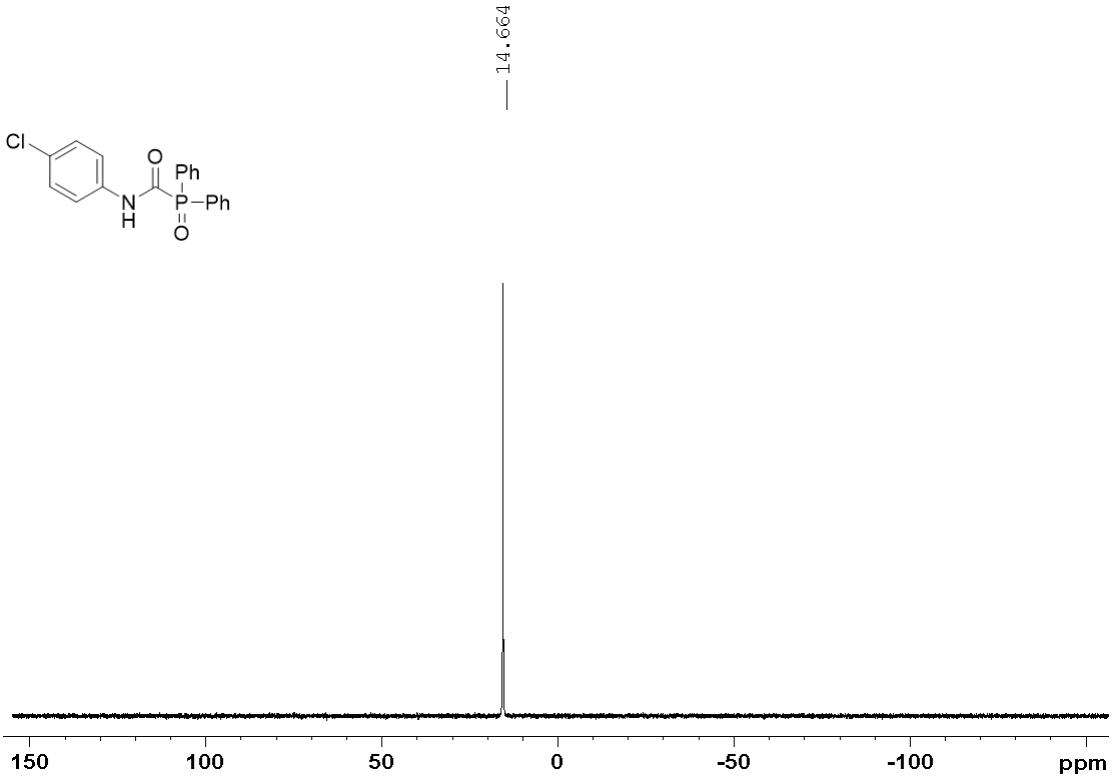
^{31}P NMR (162MHz, DMSO) spectrum of compound **3f**



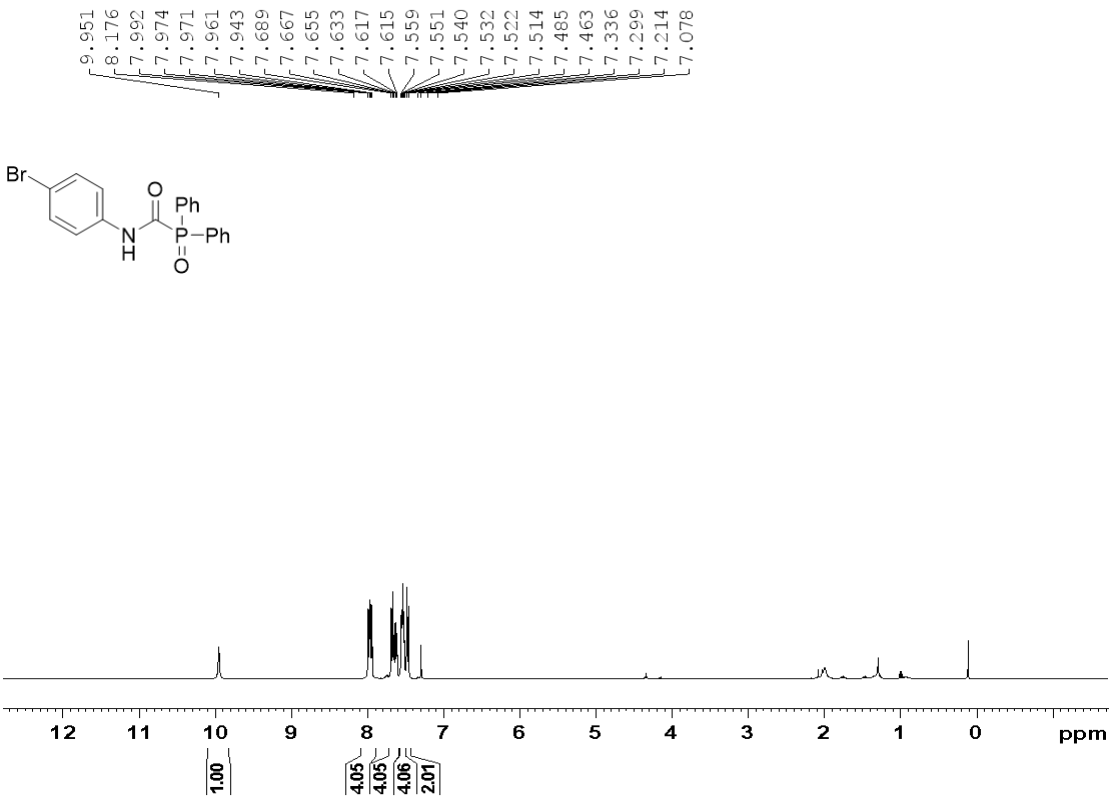
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3g**



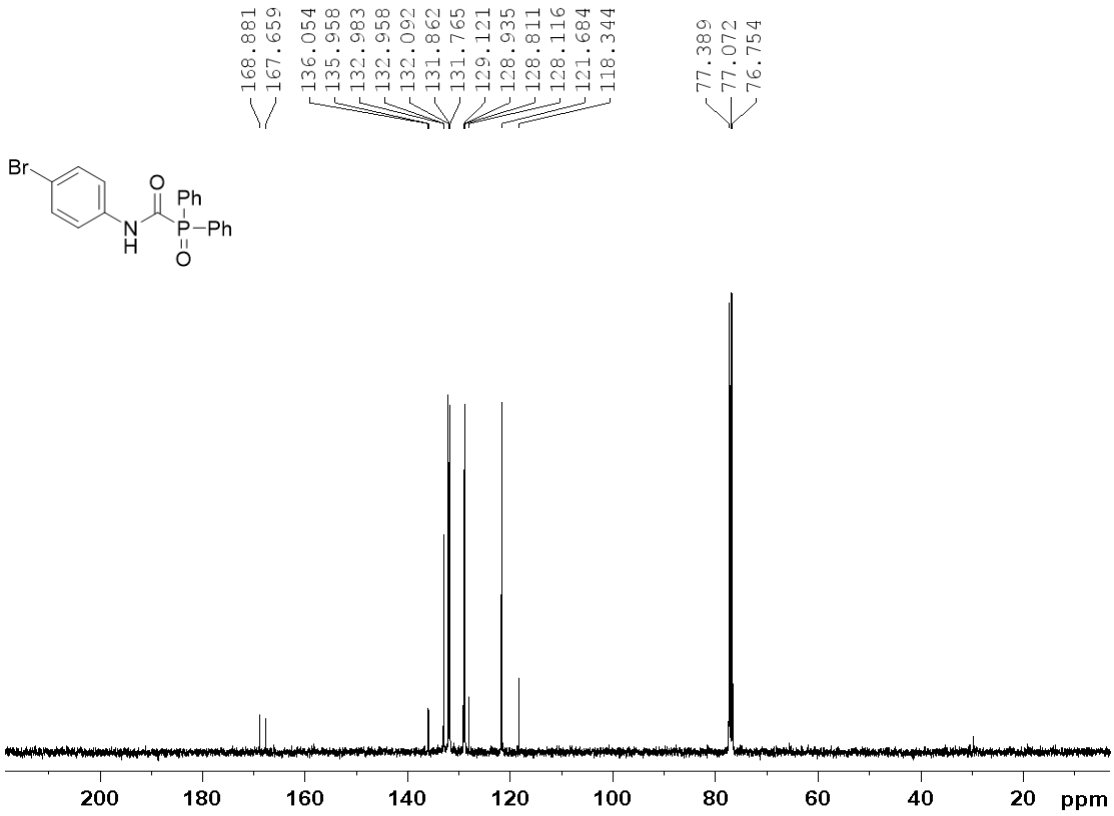
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3g**



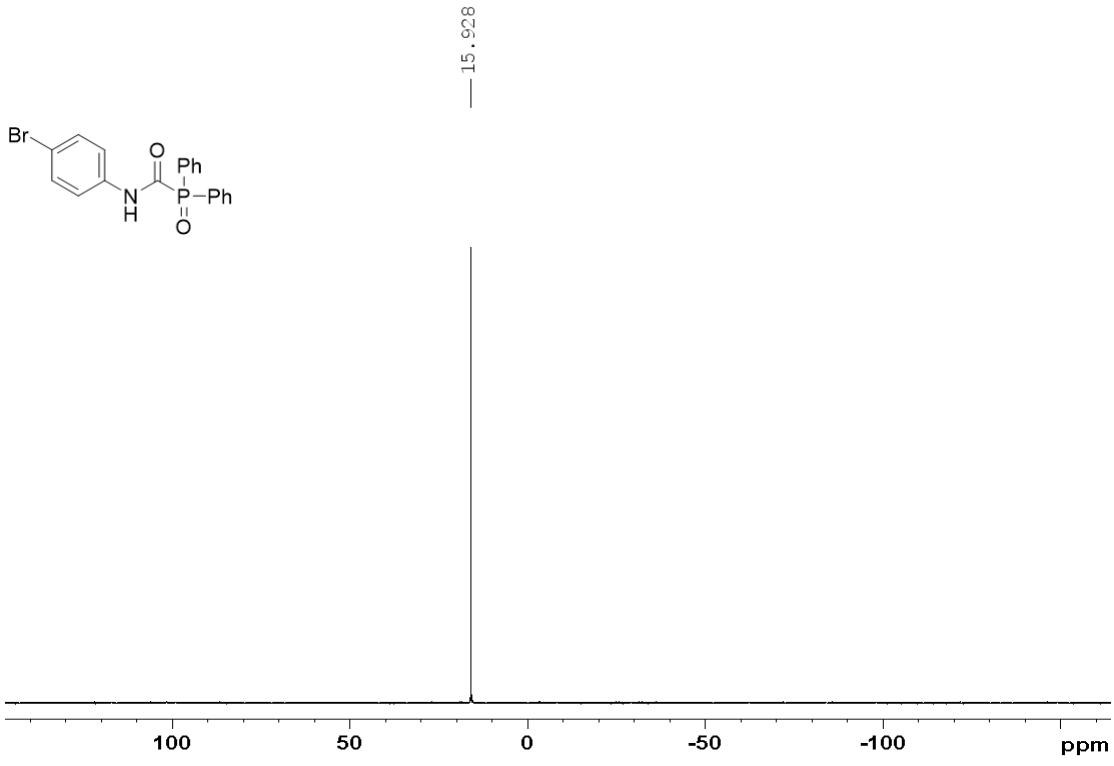
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3g**



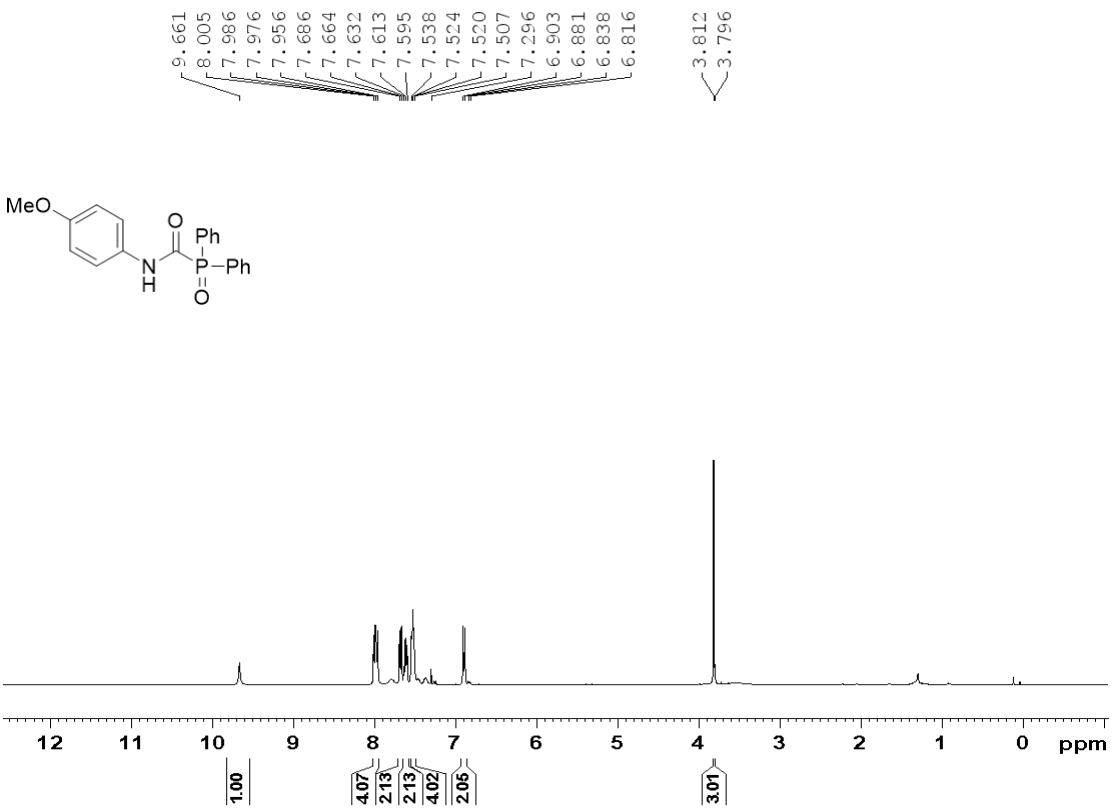
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3h**



^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3h**

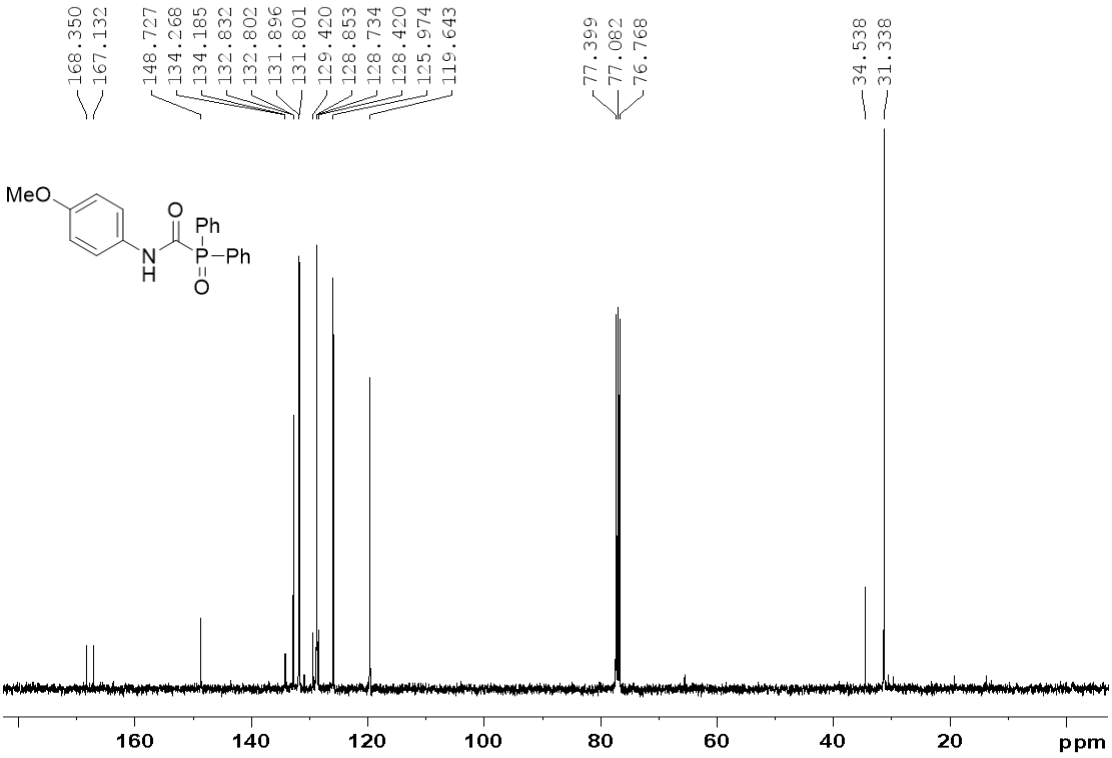


^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3h**

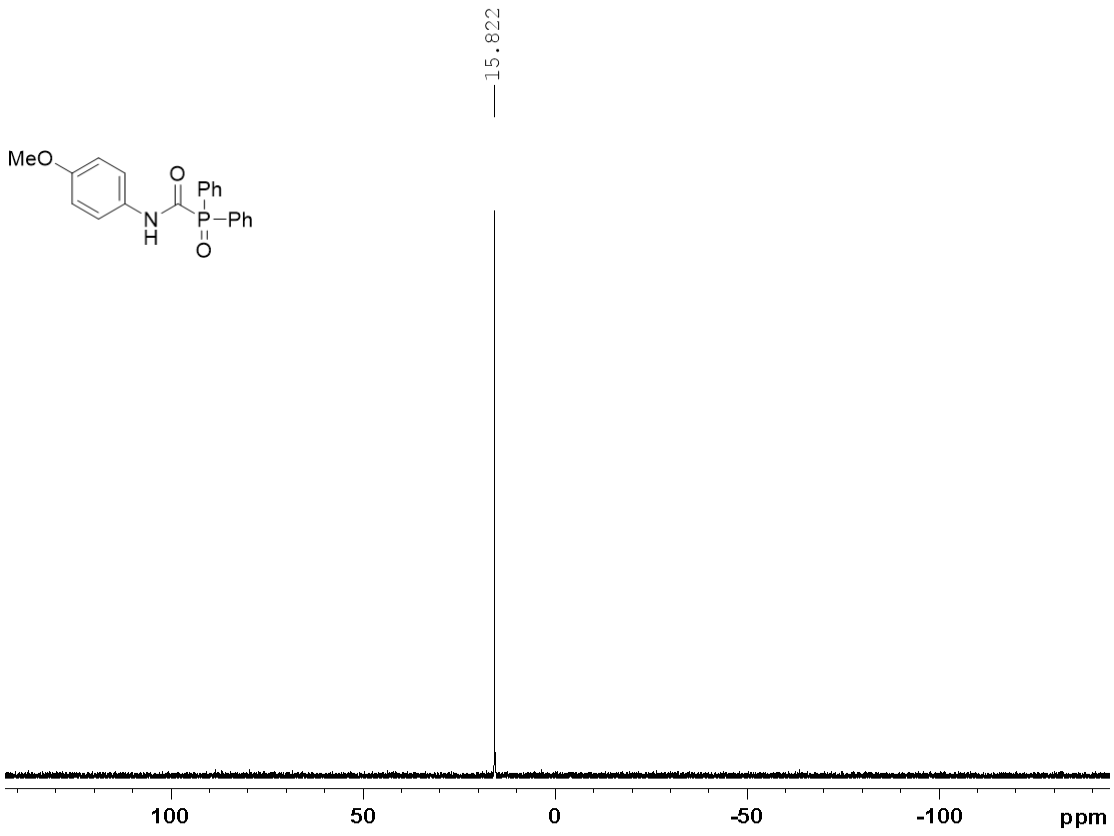


^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3i**

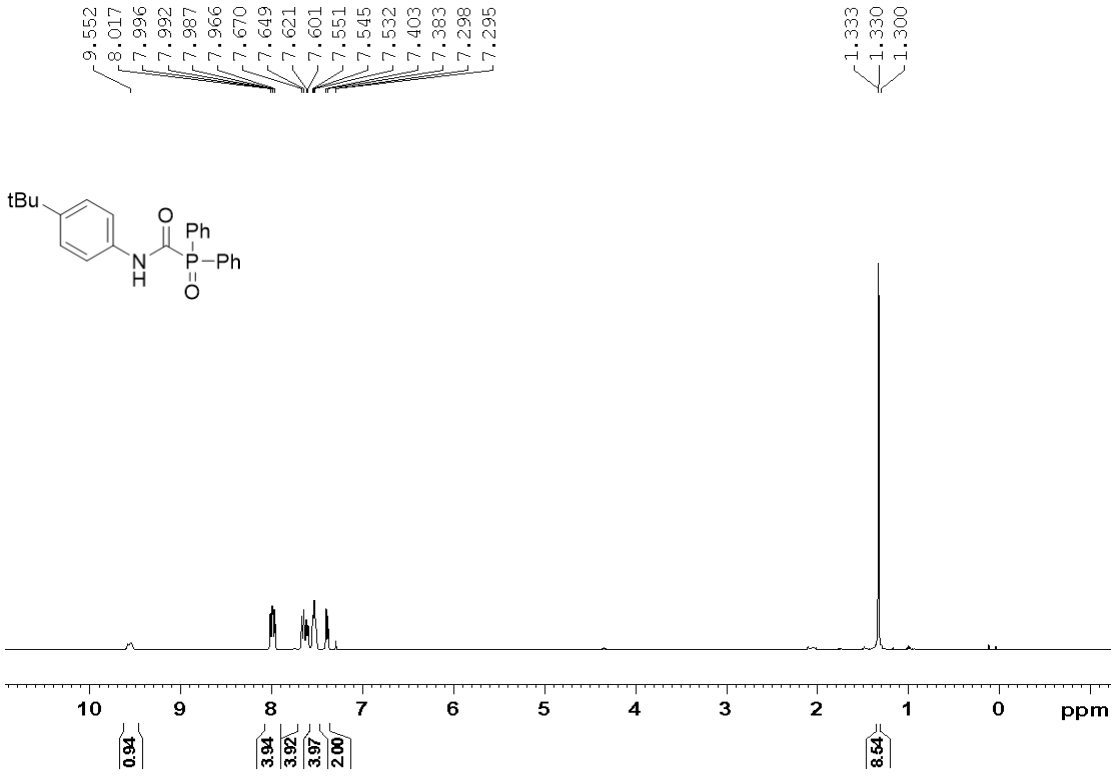
;



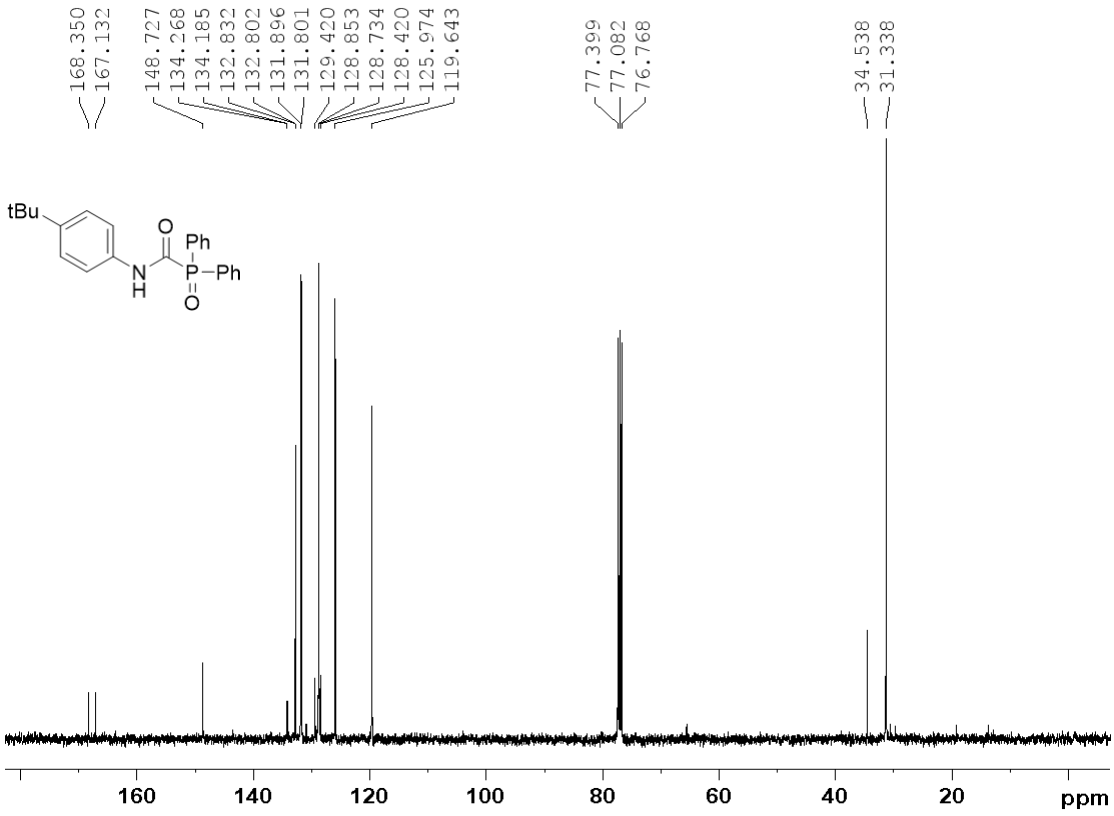
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3i**



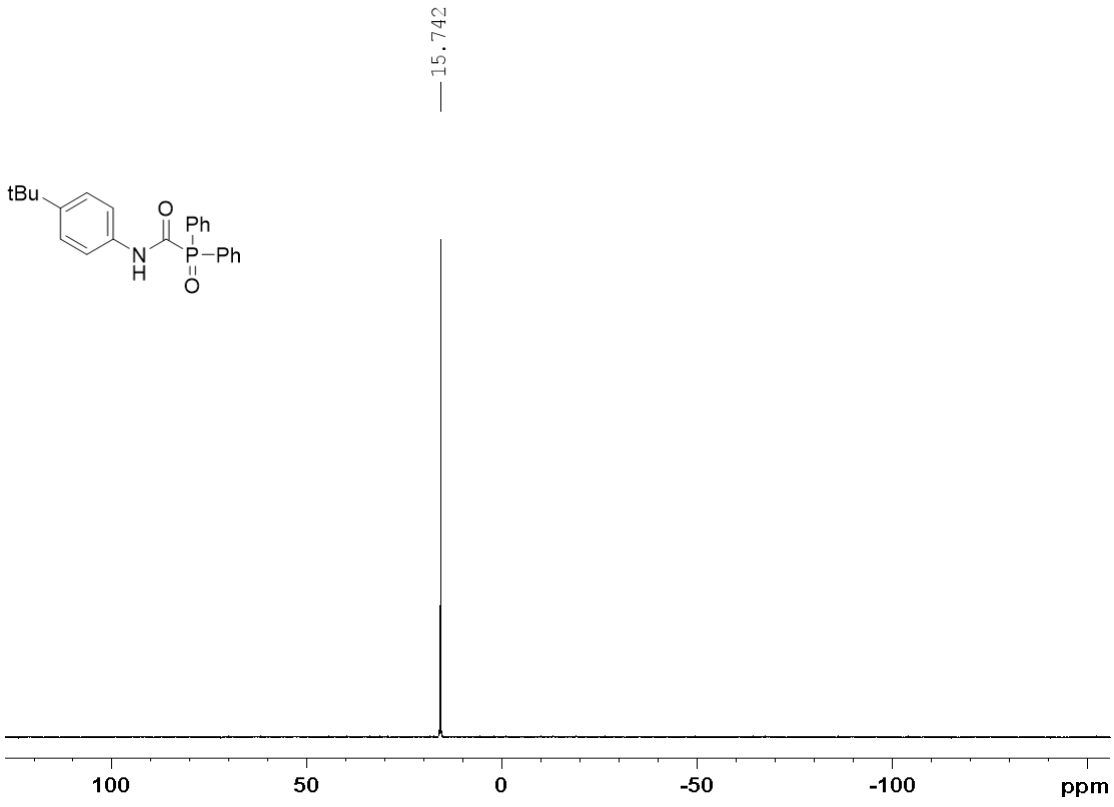
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3i**



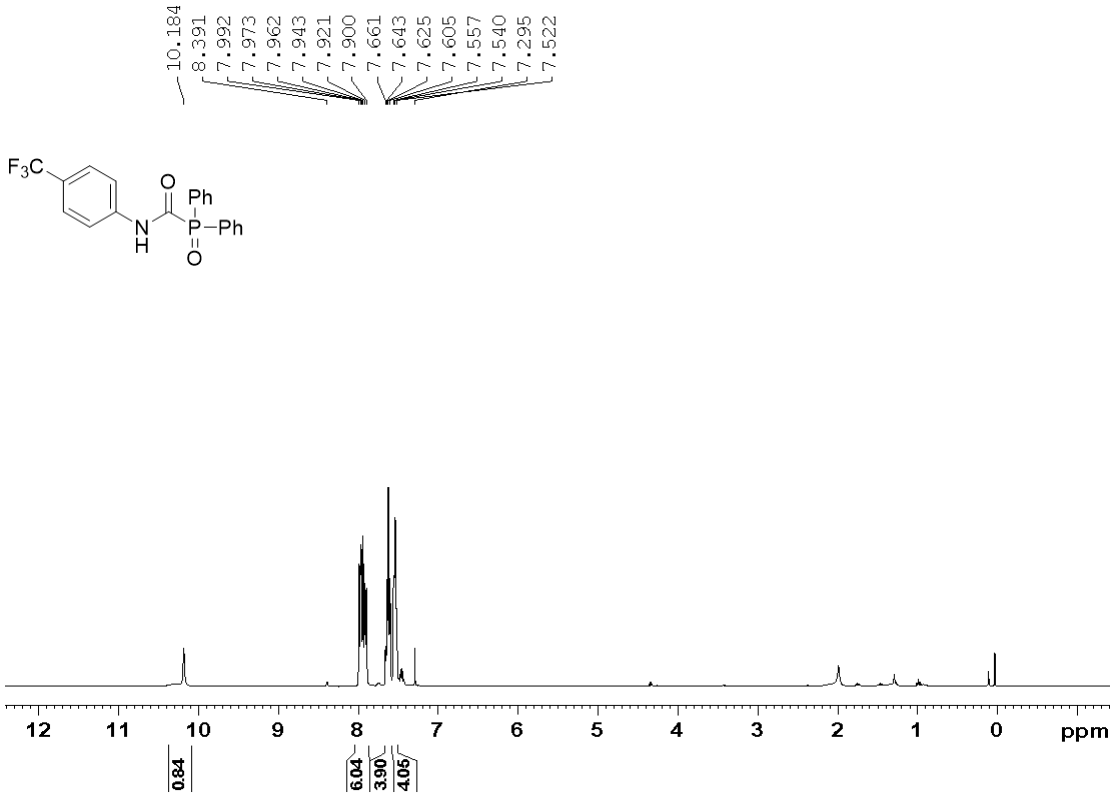
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3j**



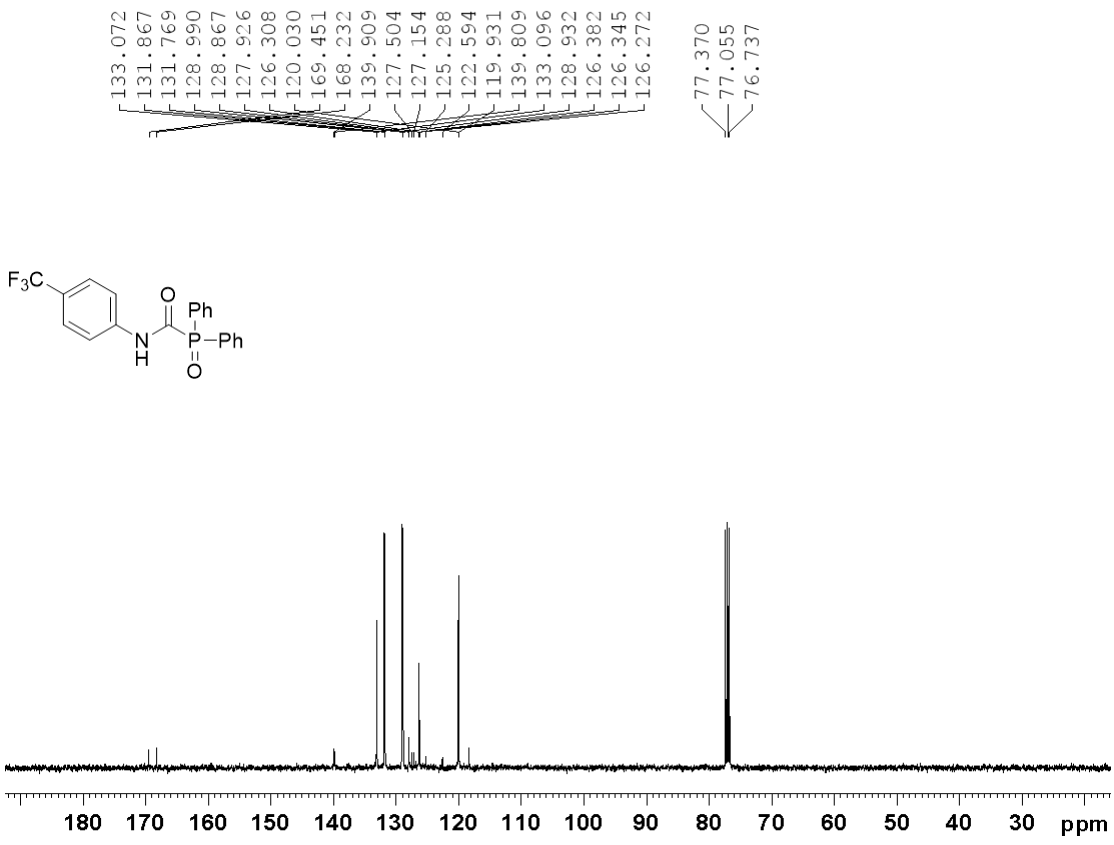
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3j**



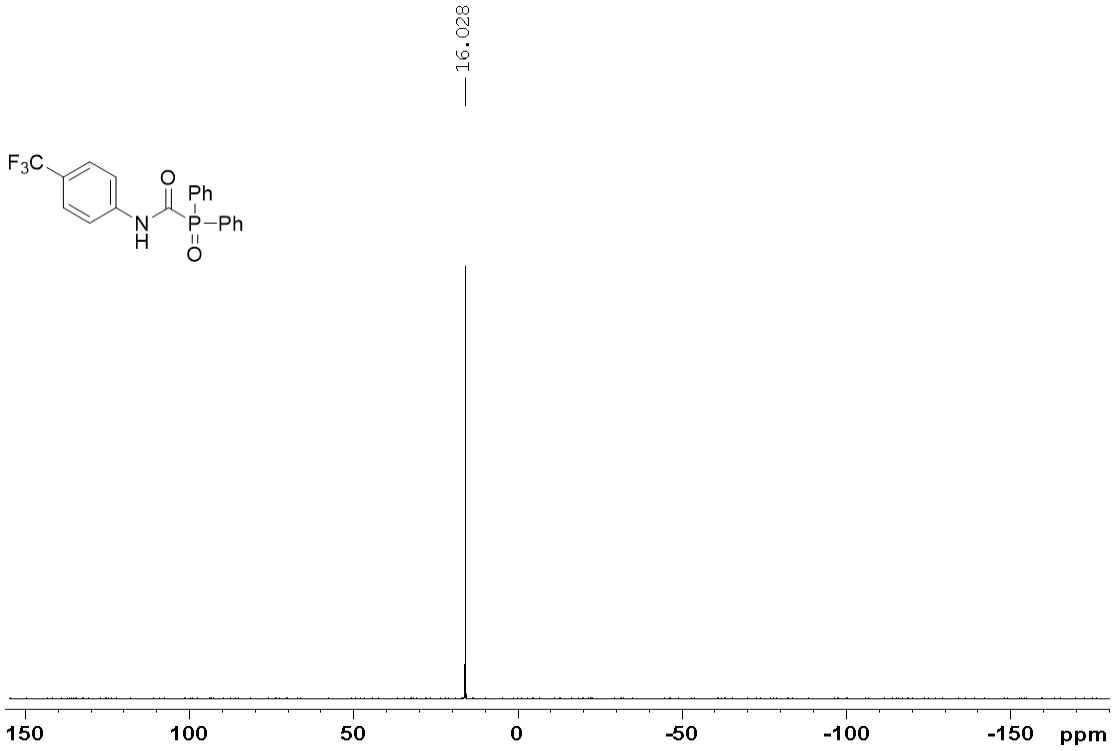
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3j**



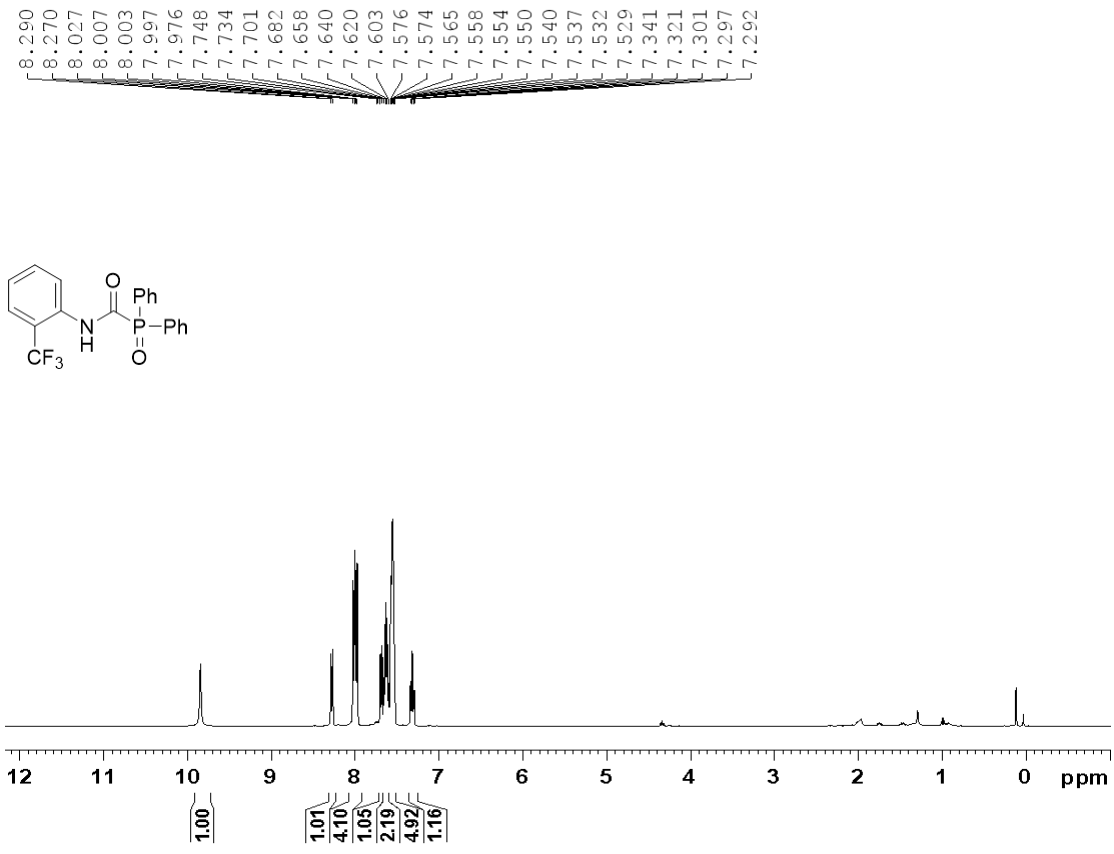
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3k**



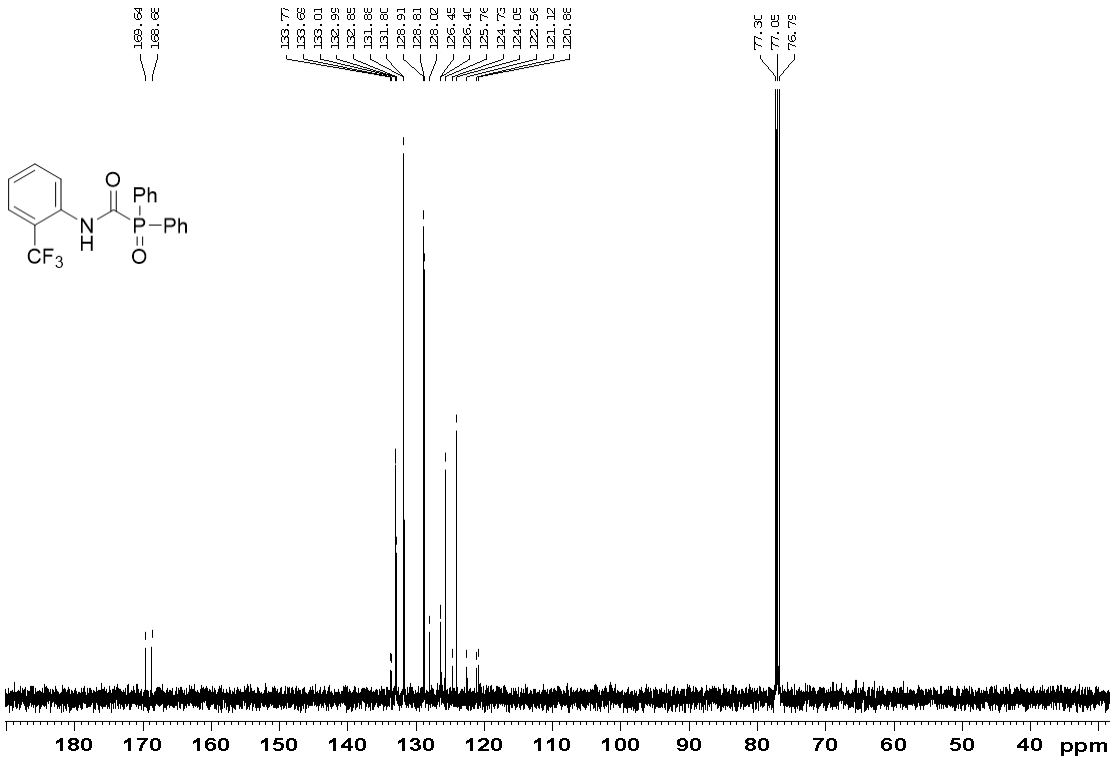
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3k**



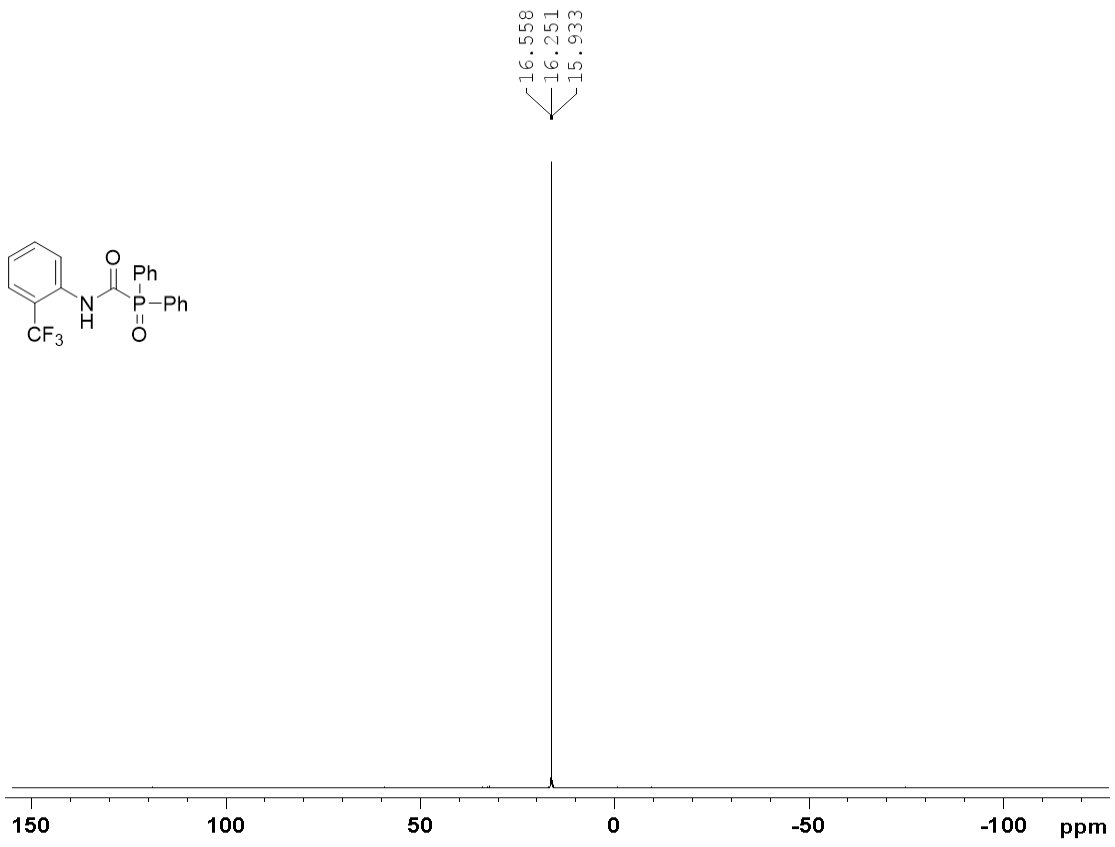
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3k**



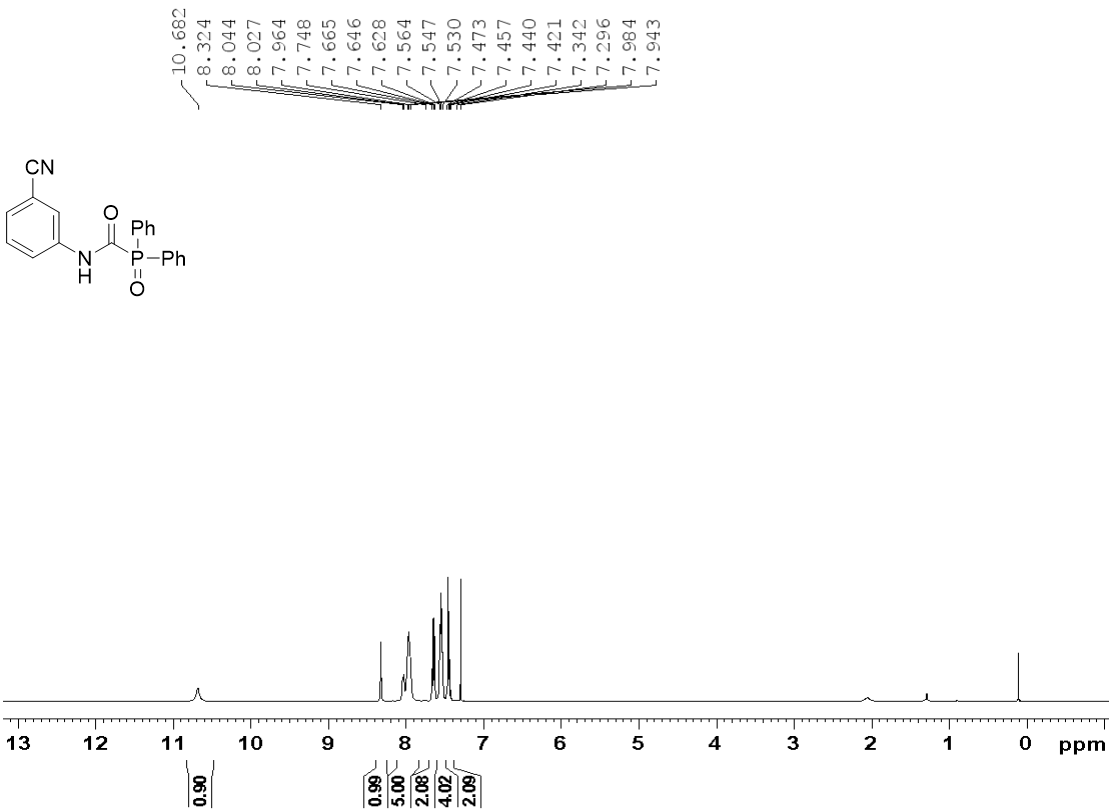
^{1}H NMR (500 MHz, $CDCl_3$) spectrum of compound **3l**



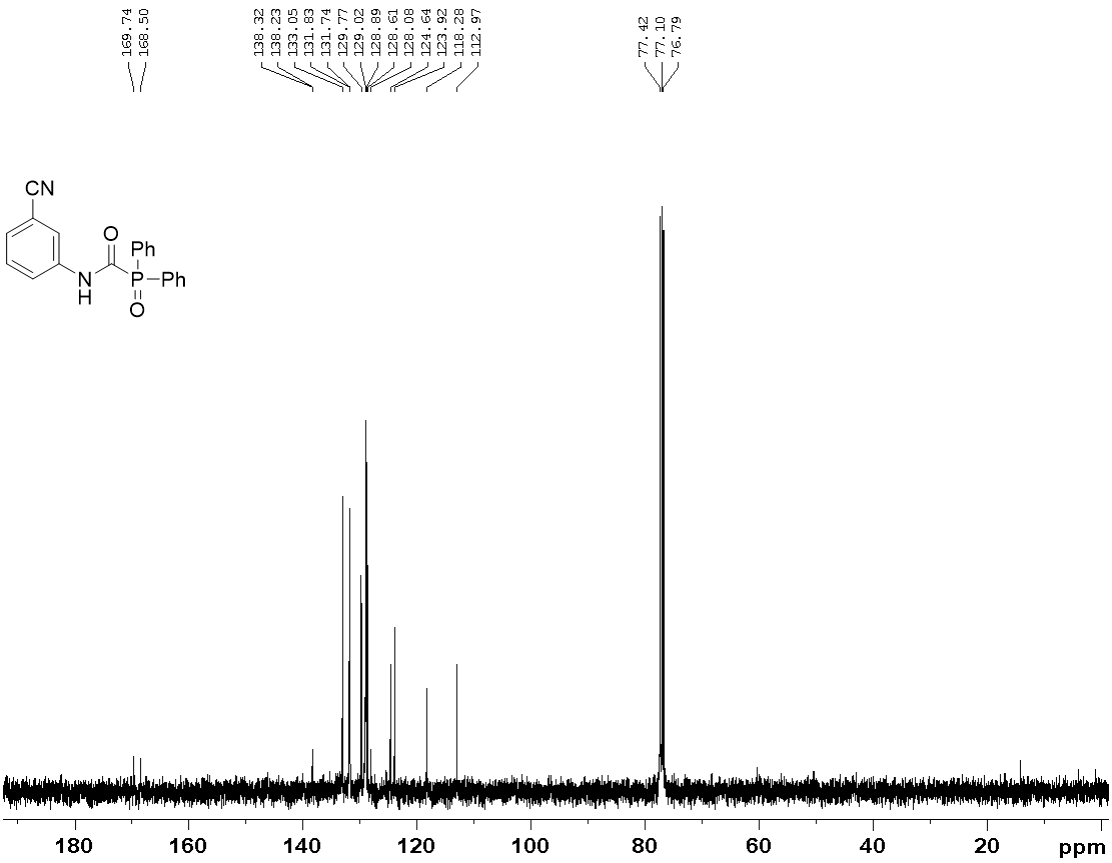
^{13}C NMR (125 MHz, $CDCl_3$) spectrum of compound **3l**



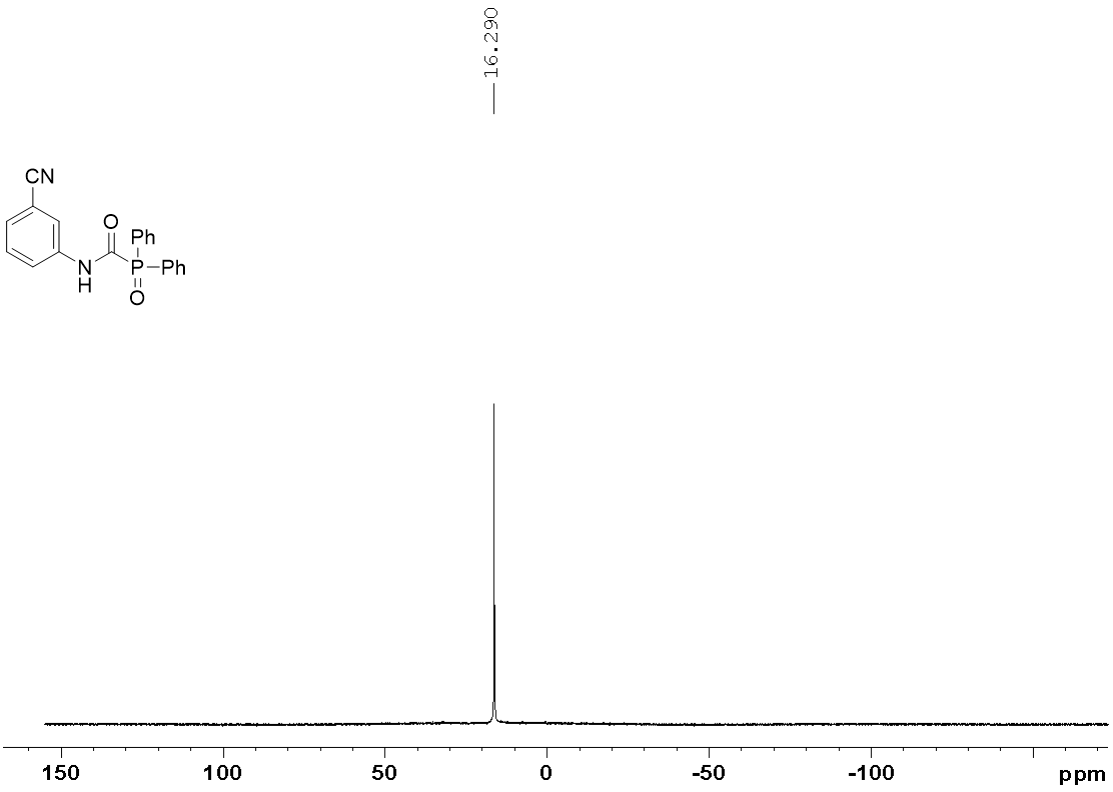
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3l**



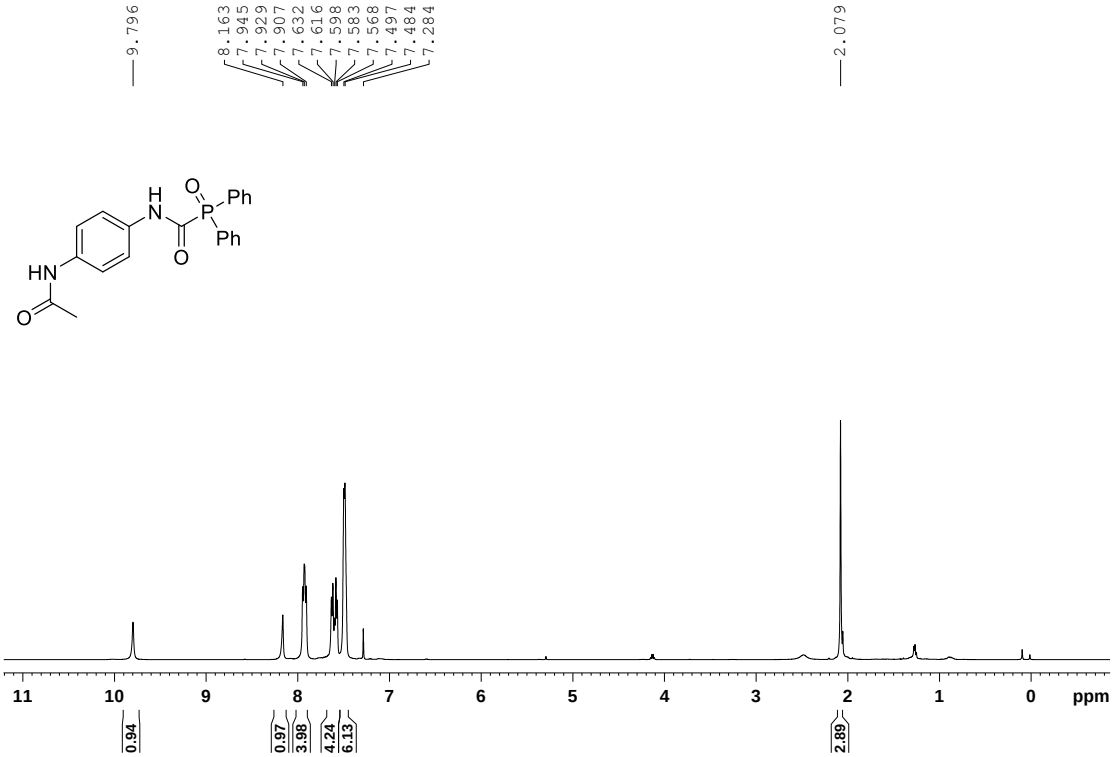
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3m**



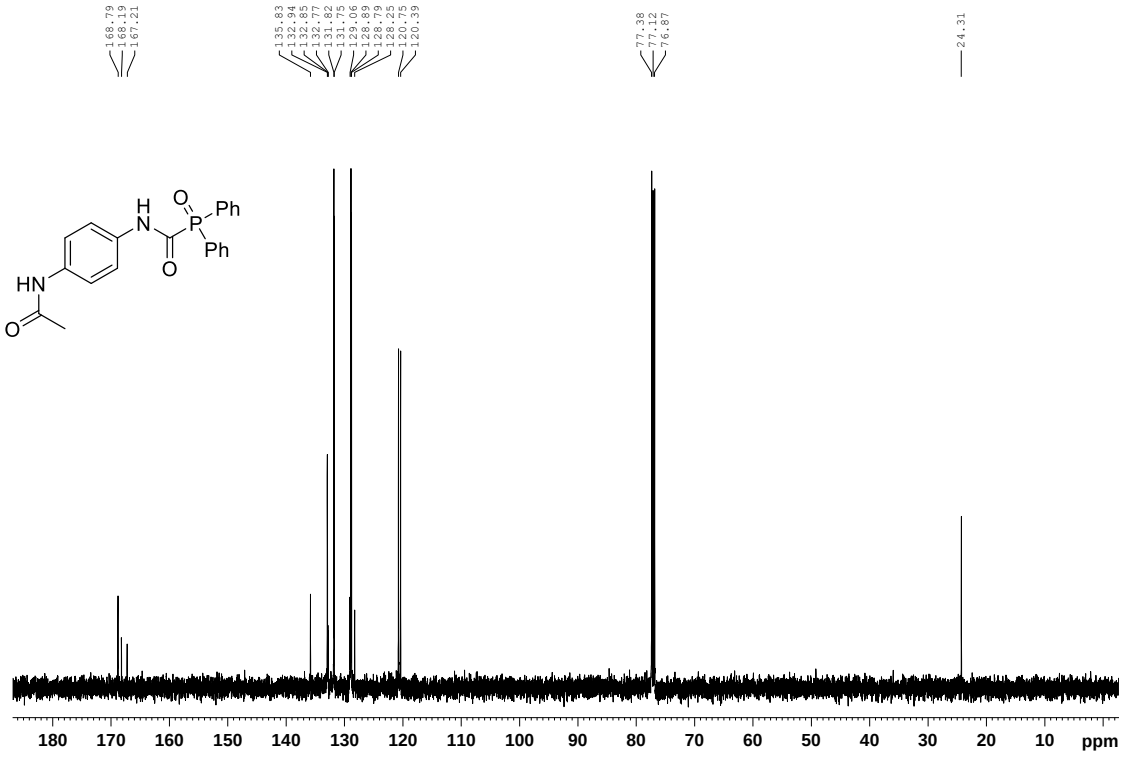
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3m**



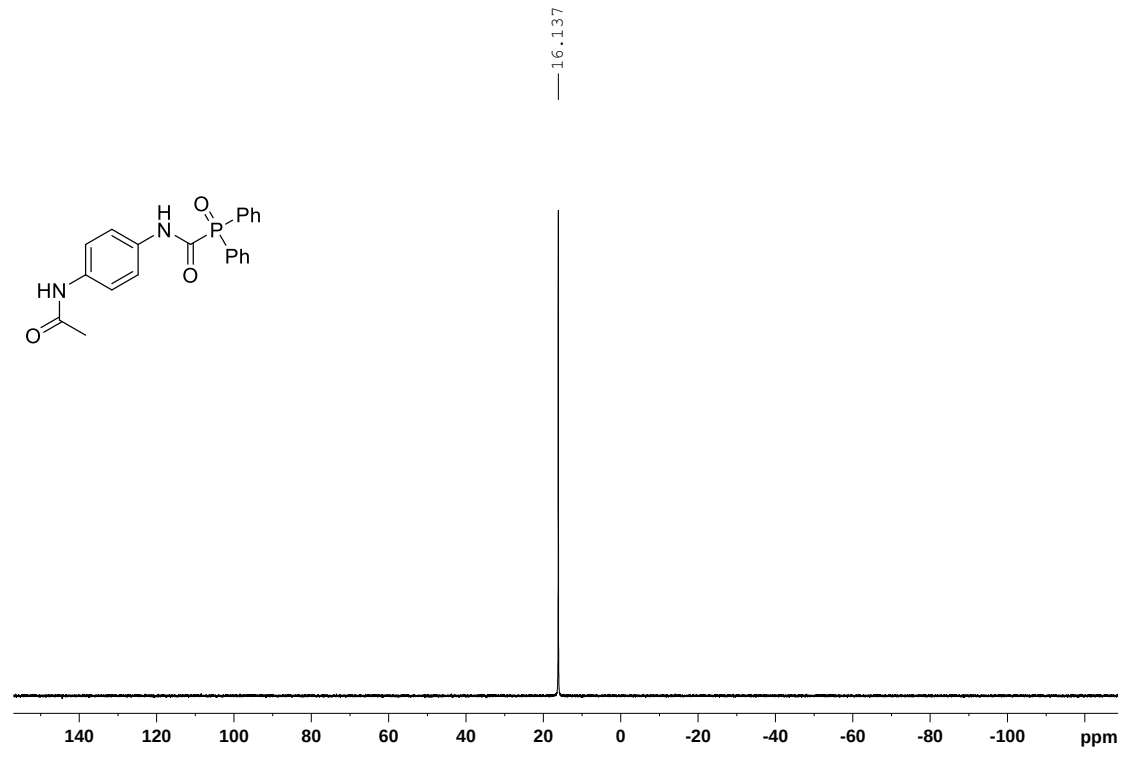
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3m**



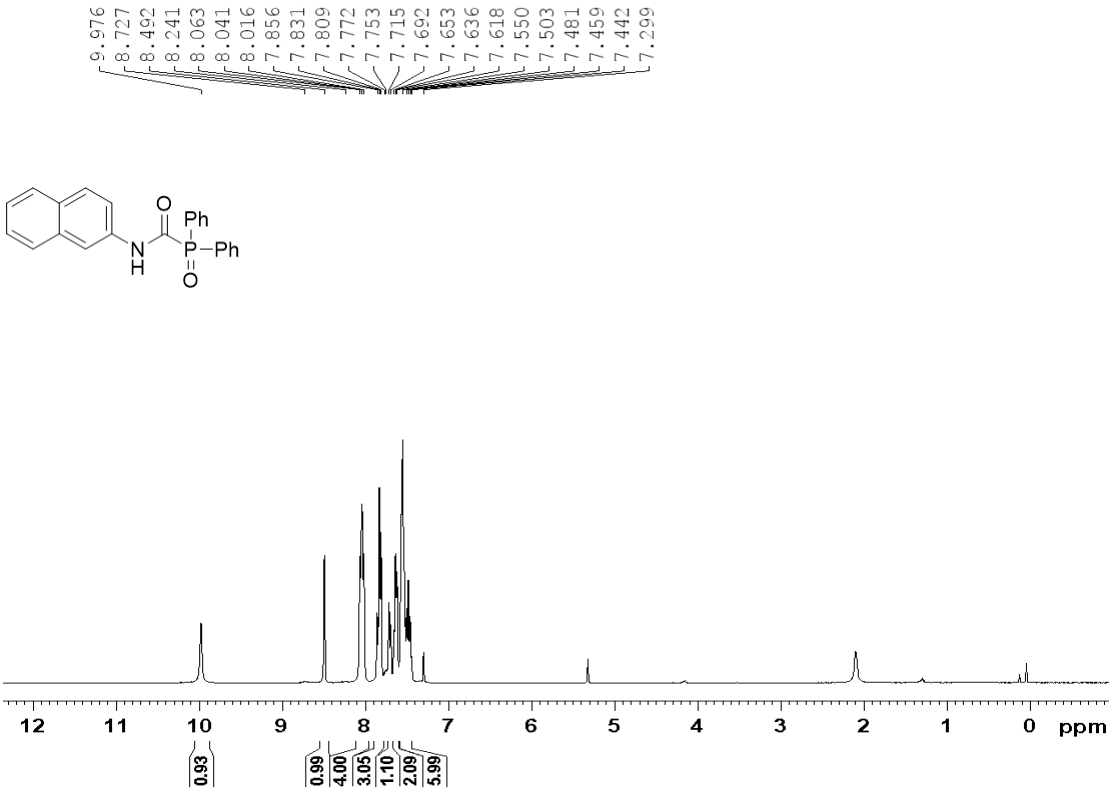
^{1}H NMR (500 MHz, $CDCl_3$) spectrum of compound **3n**



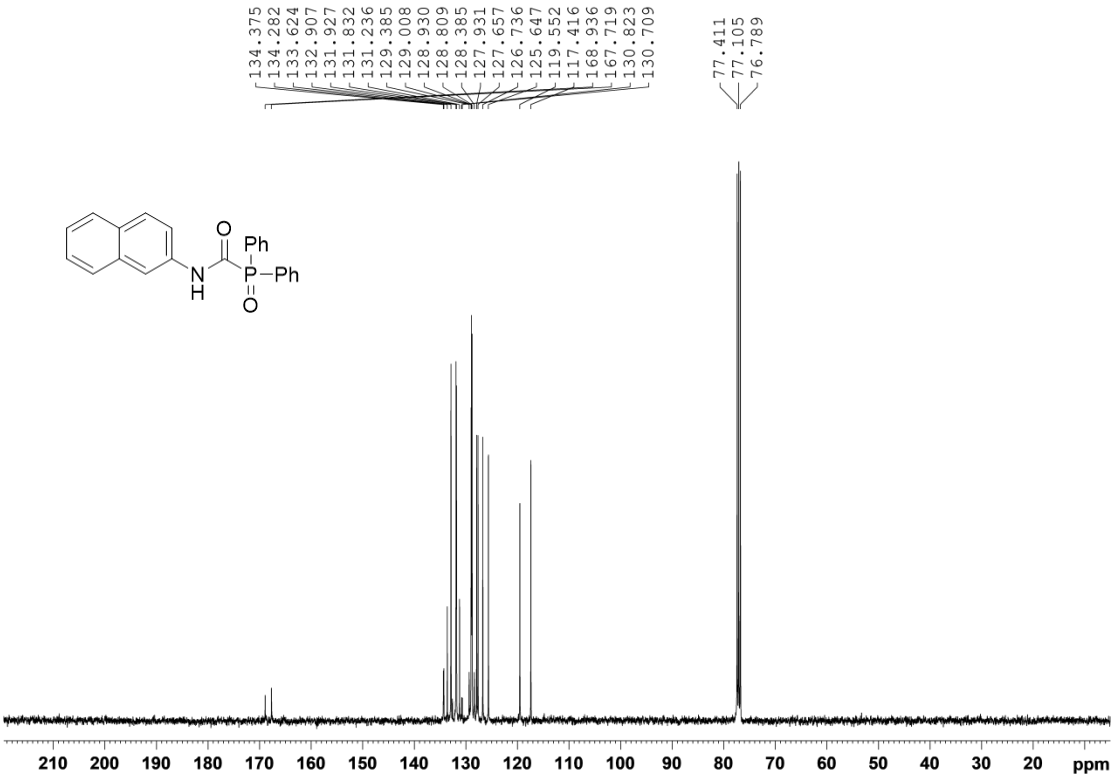
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3n**



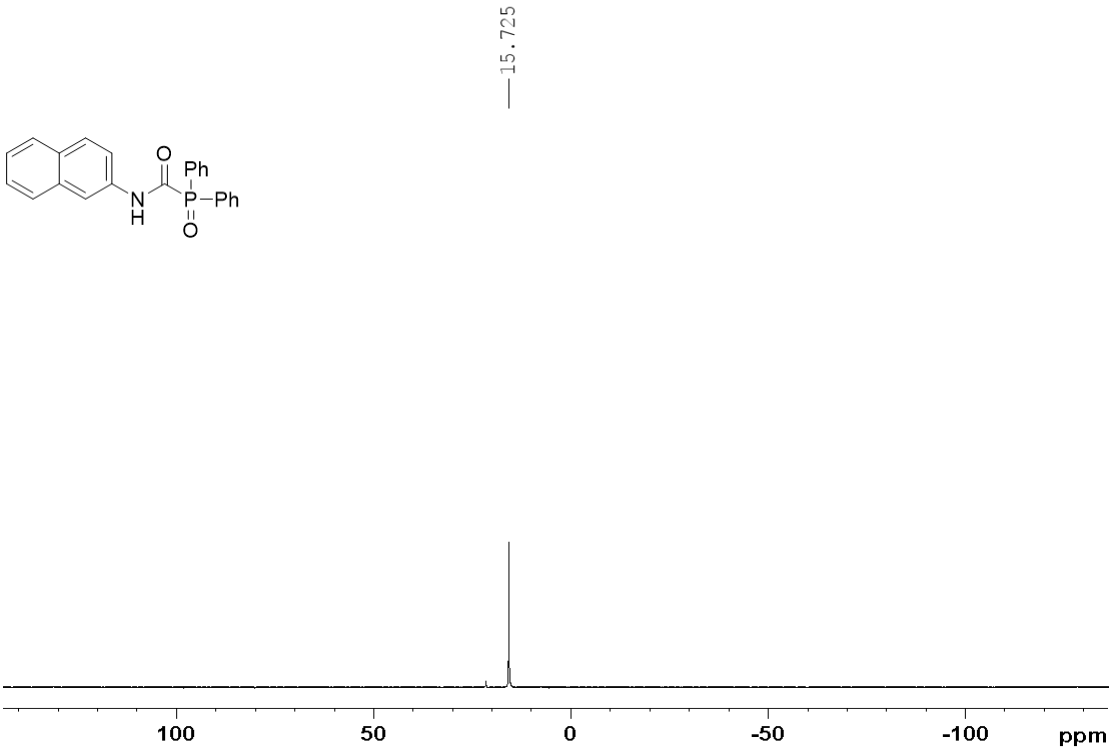
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3n**



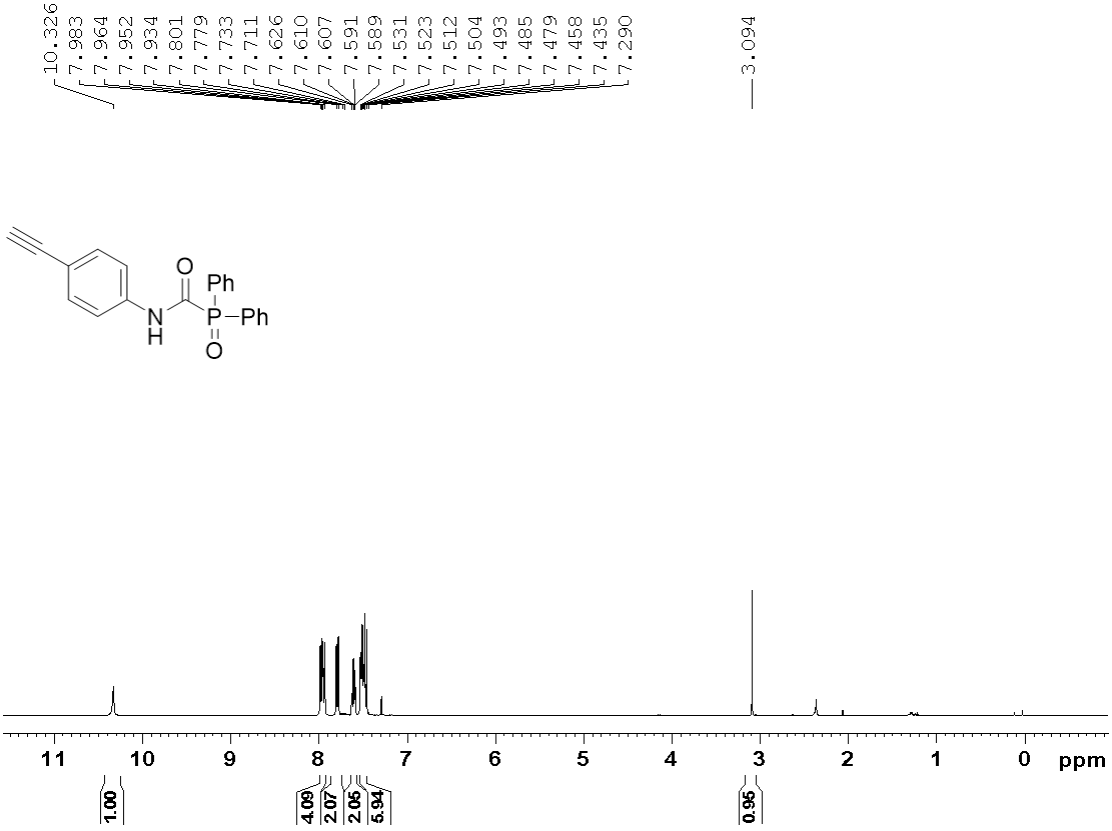
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3o**



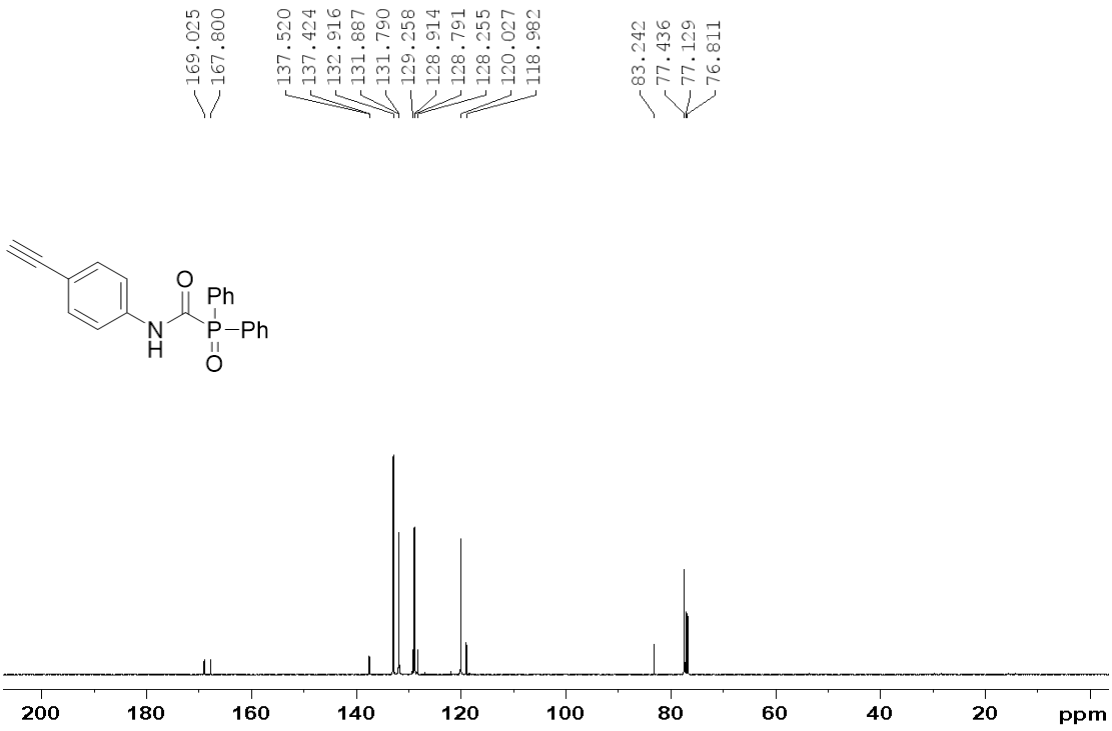
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3o**



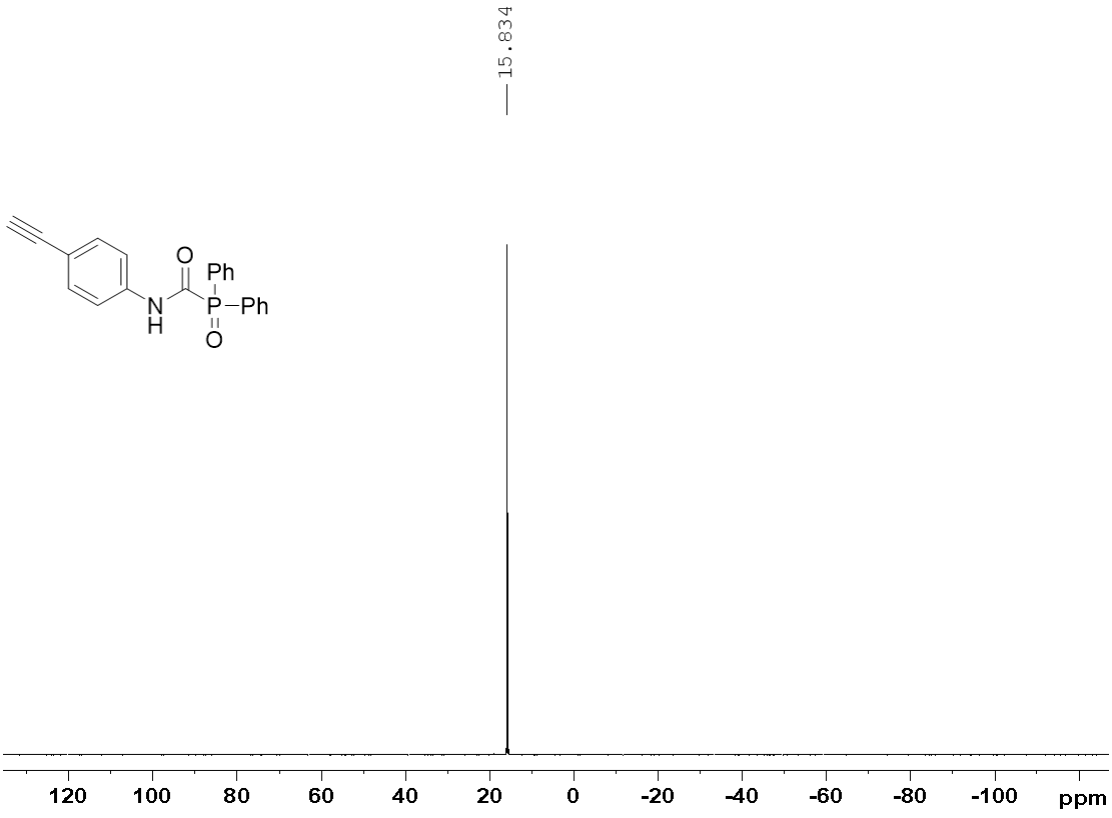
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3o**



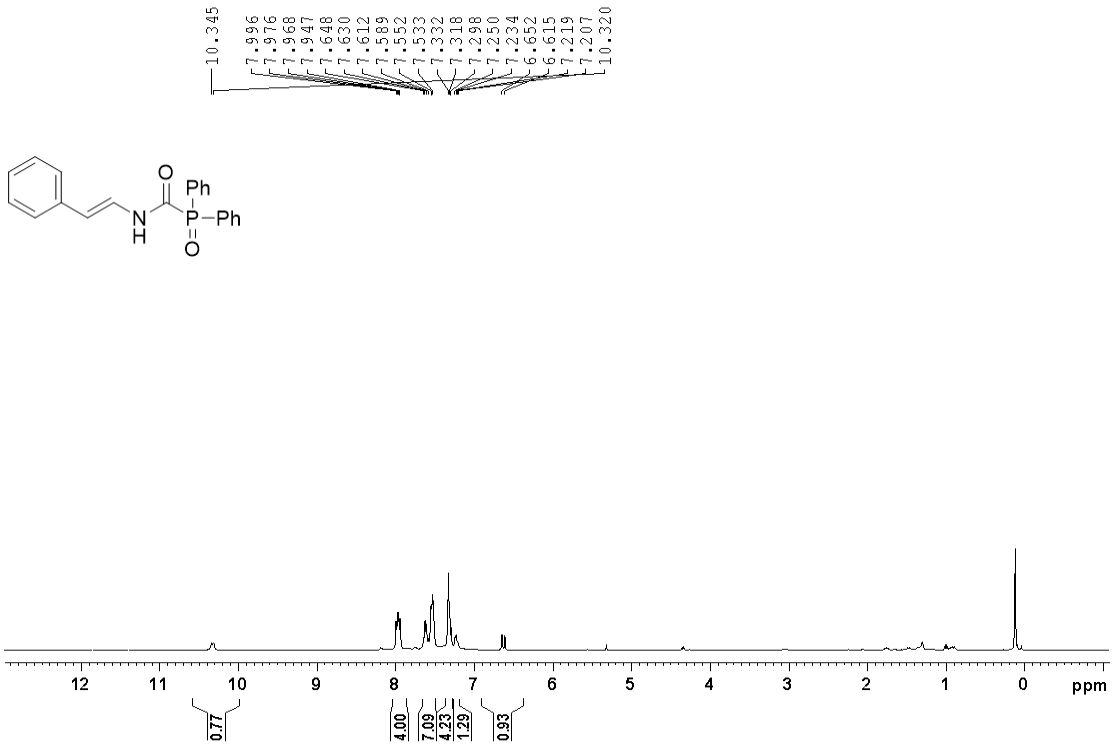
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3p**



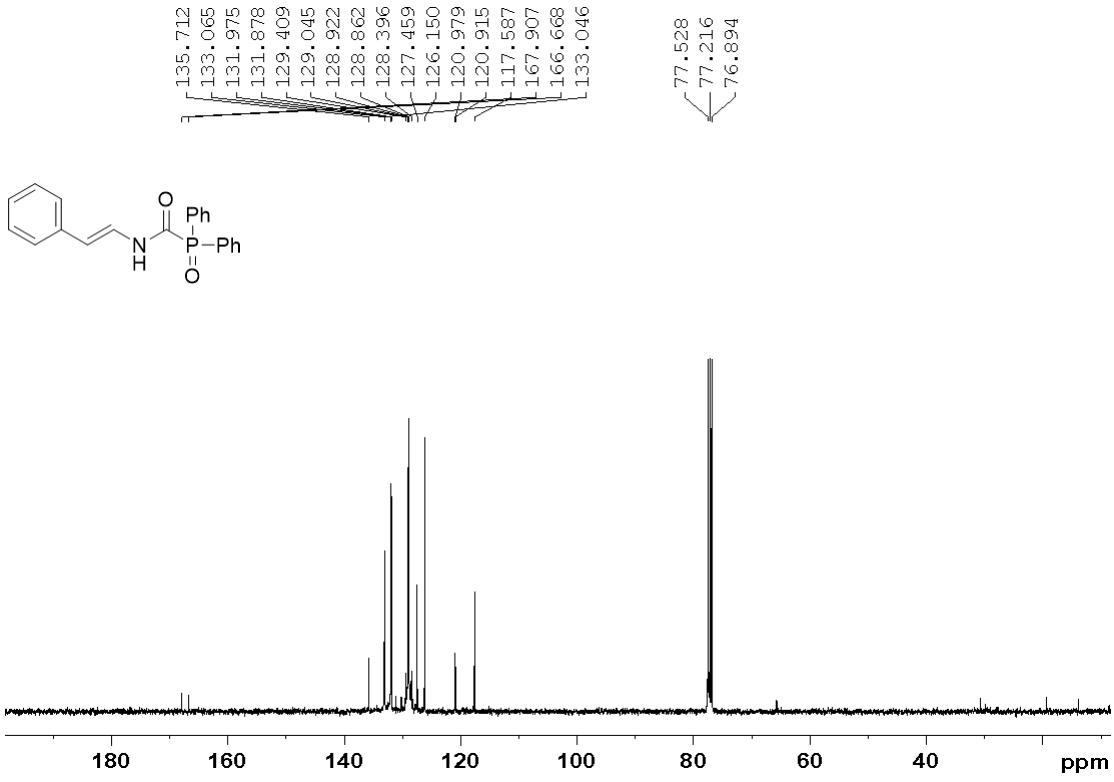
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3p**



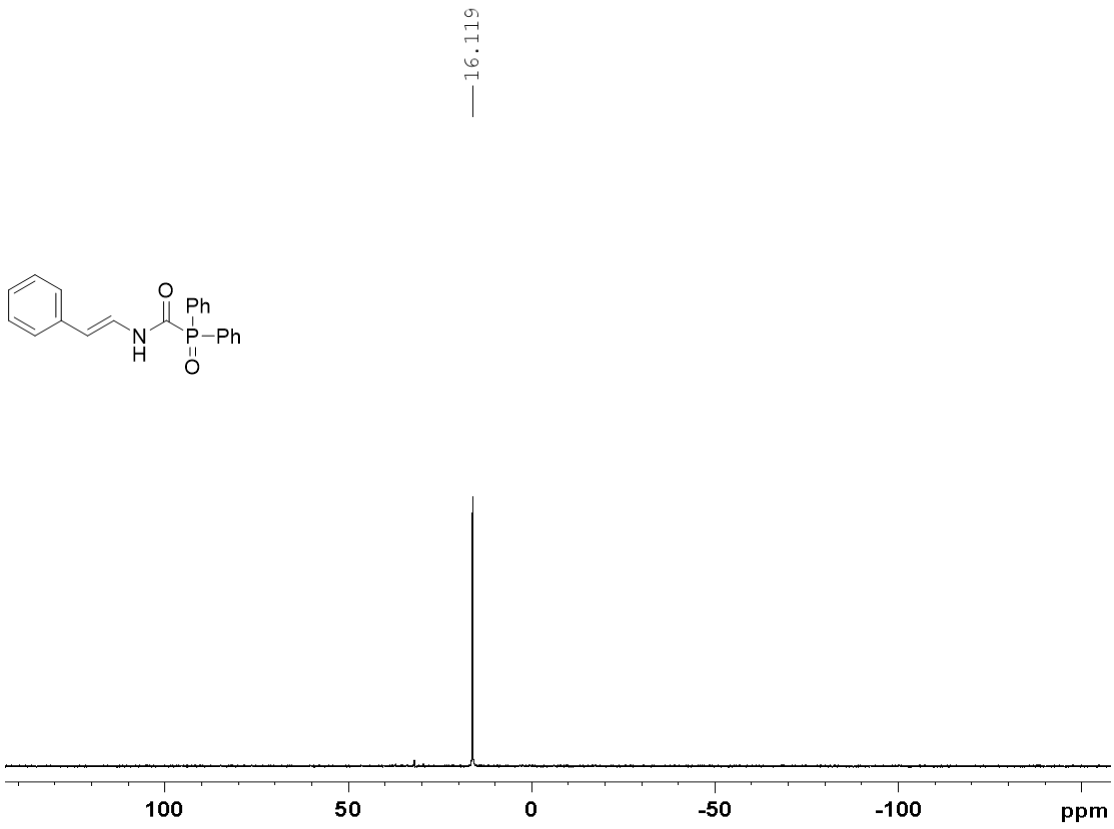
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3p**



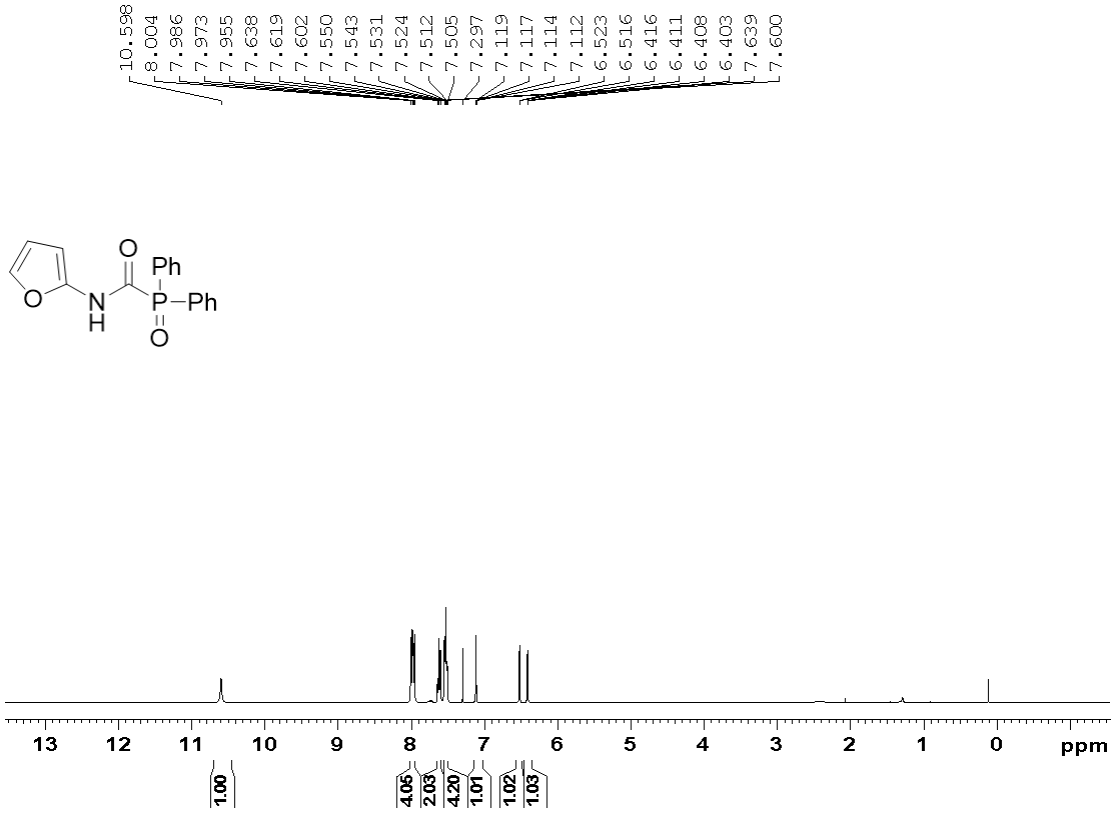
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3q**



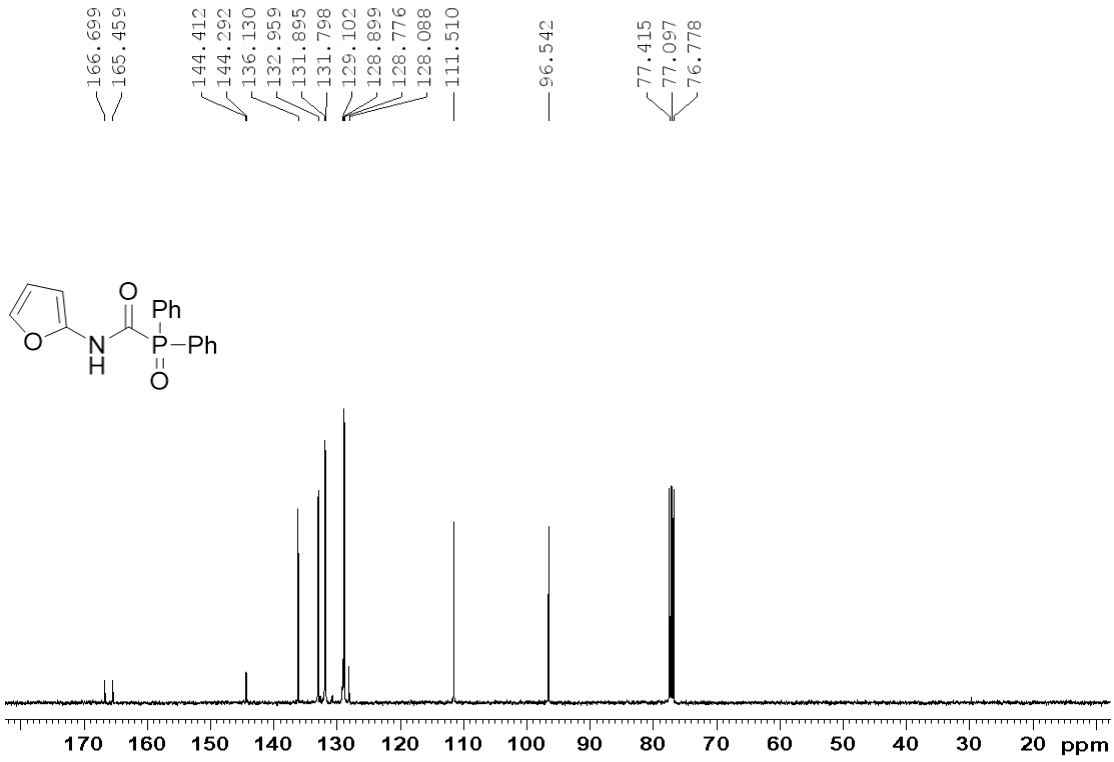
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3q**



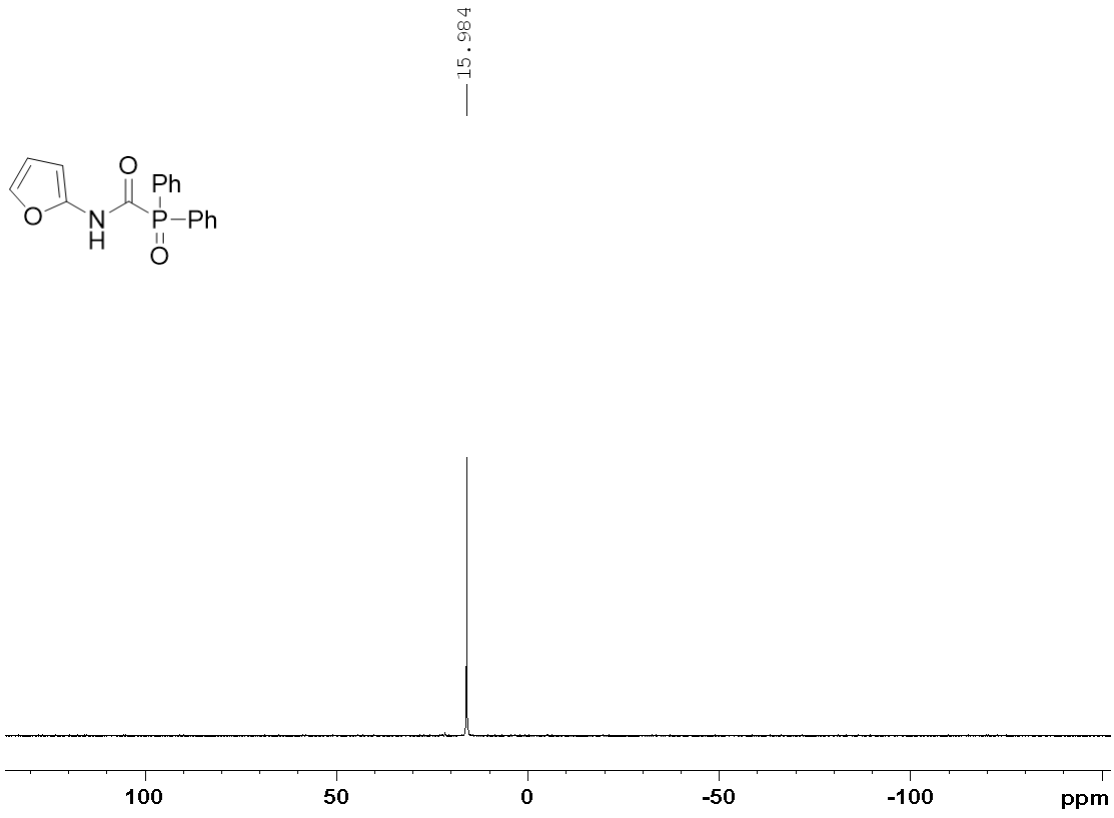
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3q**



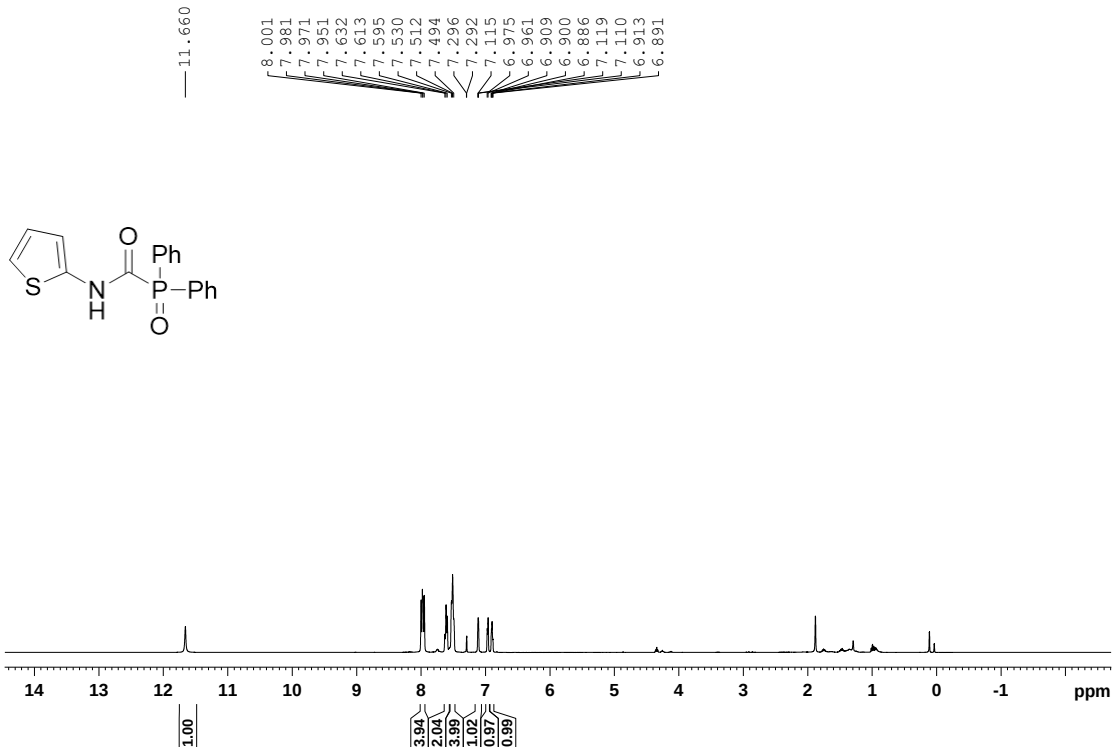
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3r**



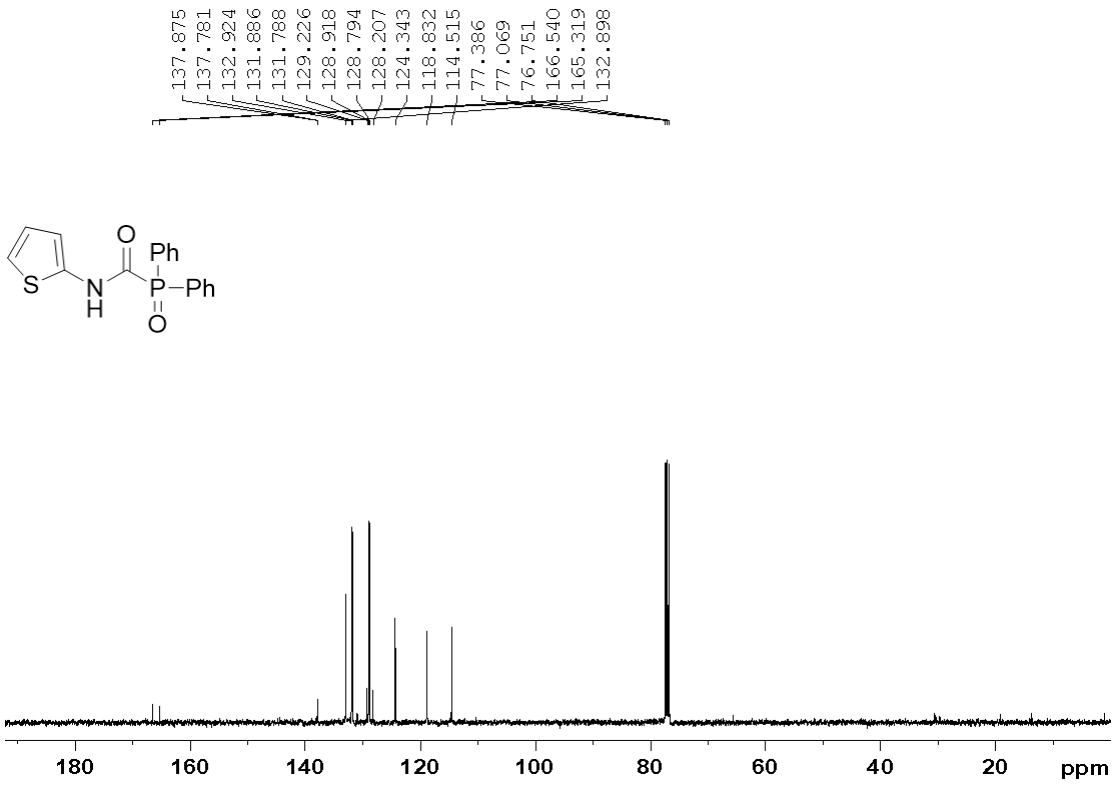
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3r**



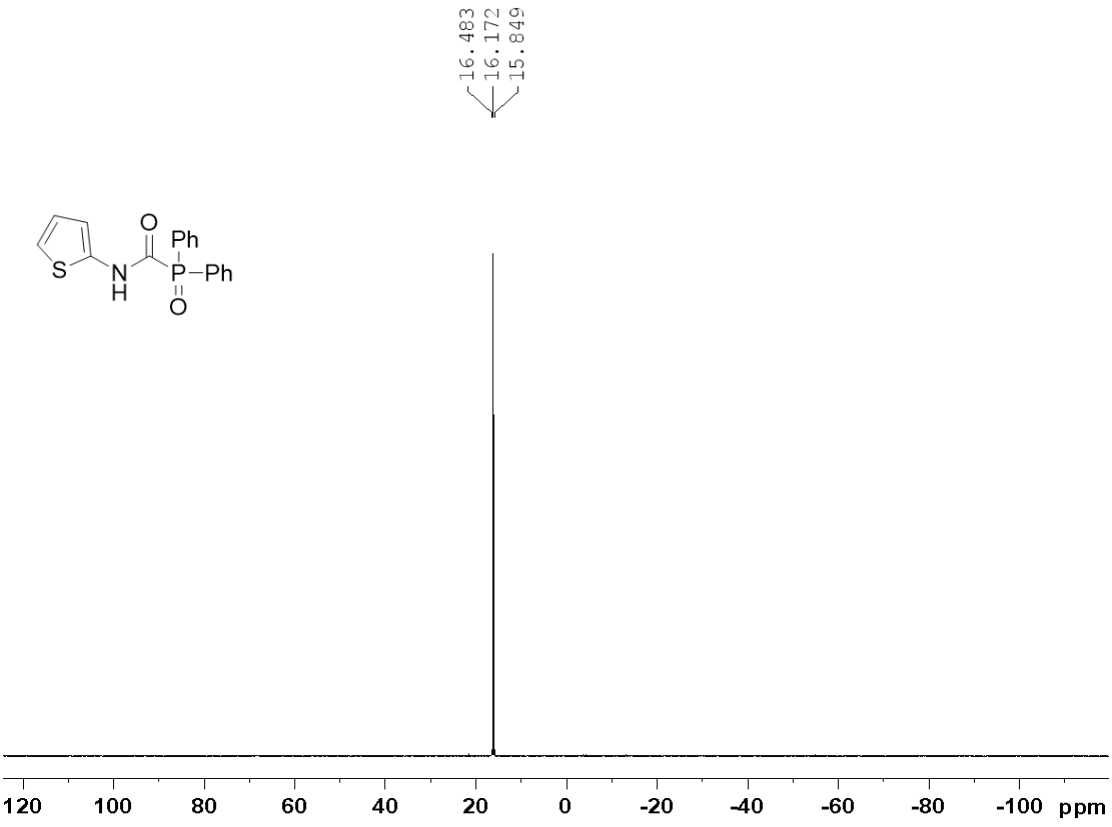
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3r**



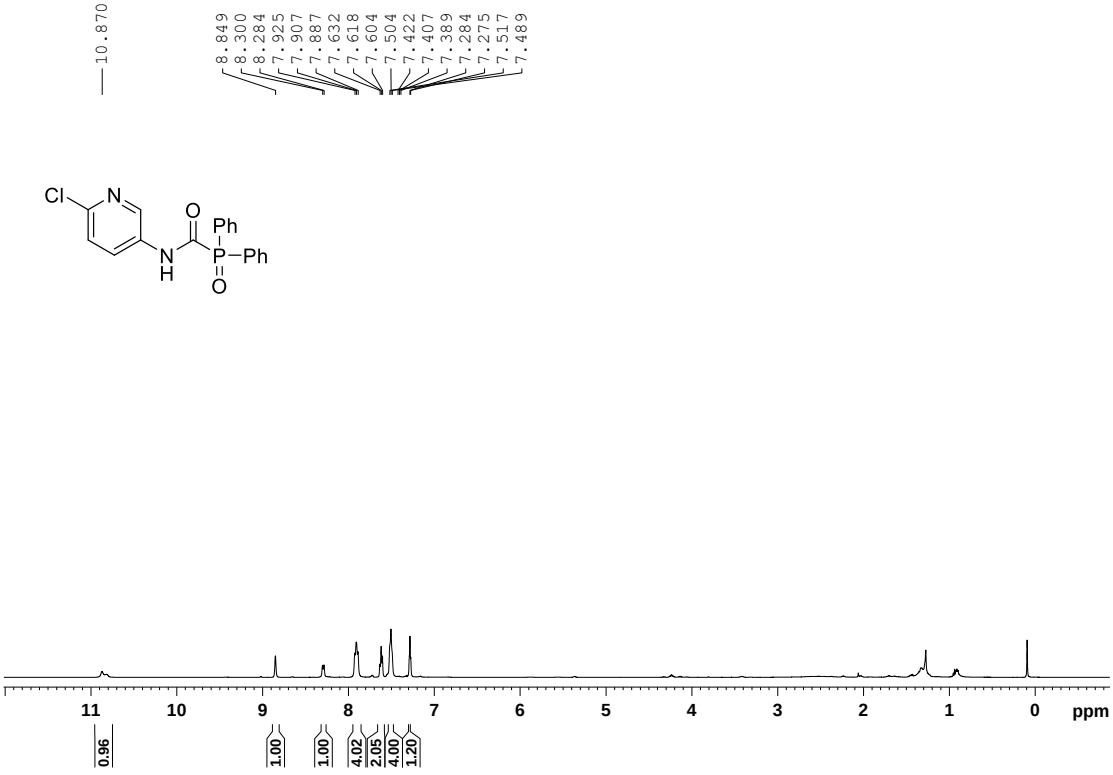
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3s**



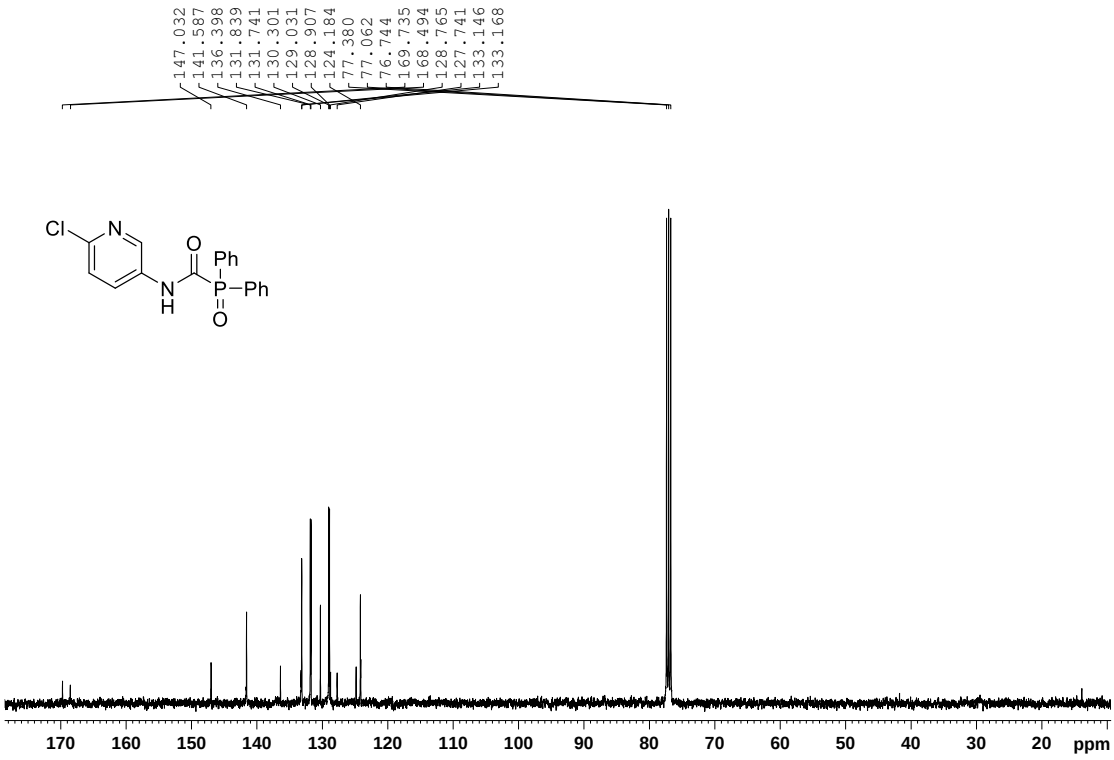
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3s**



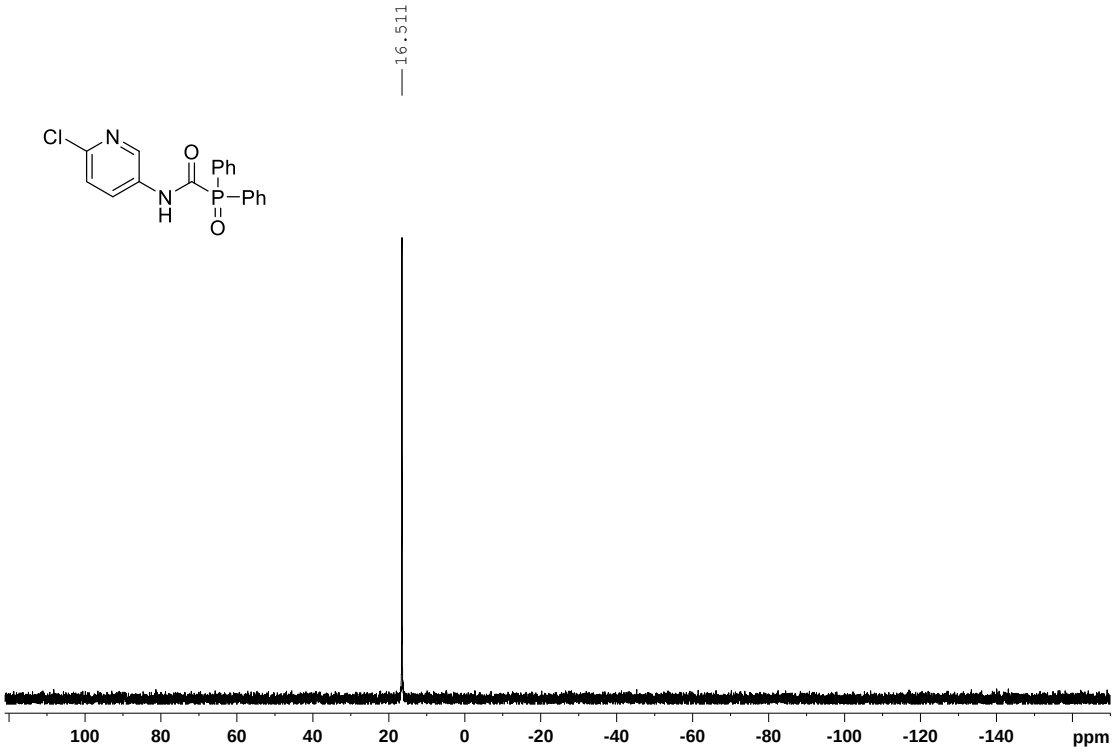
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3s**



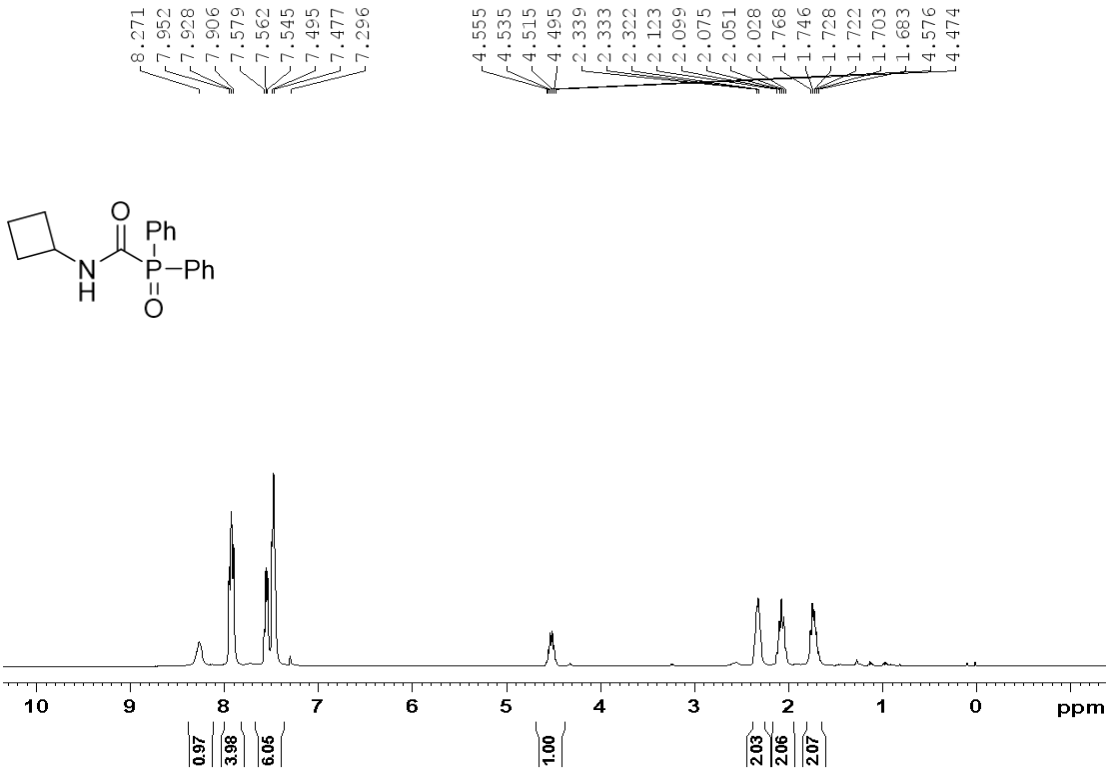
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3t**



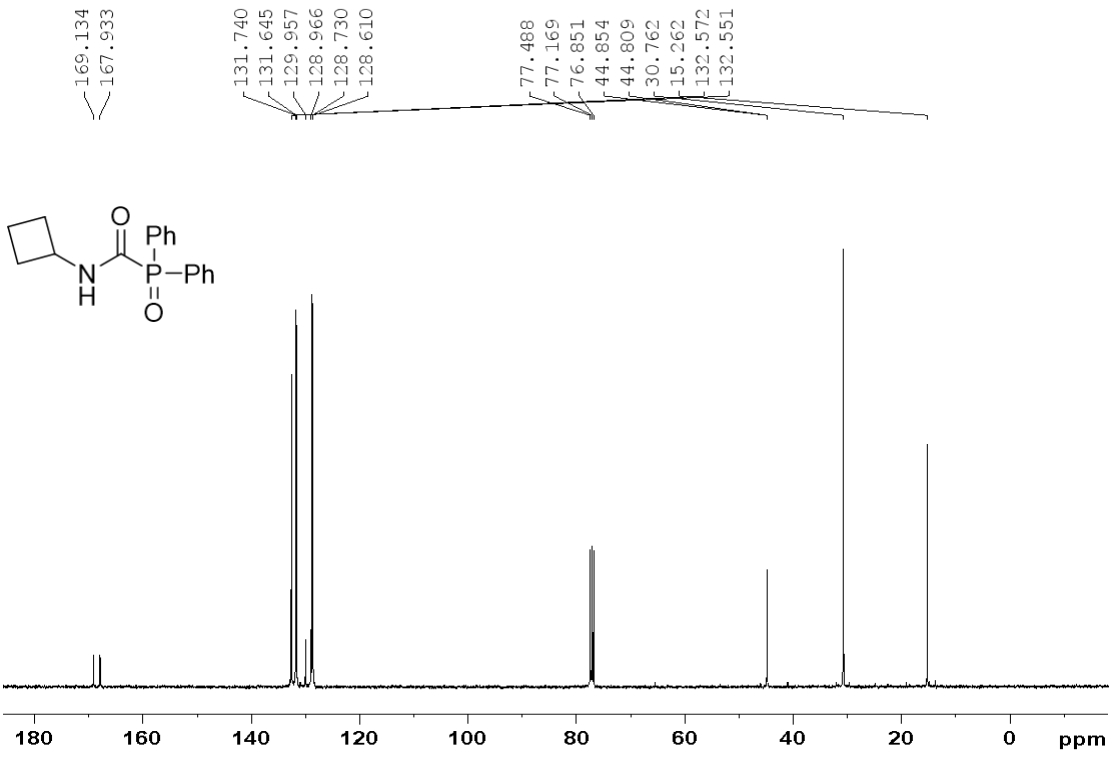
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3t**



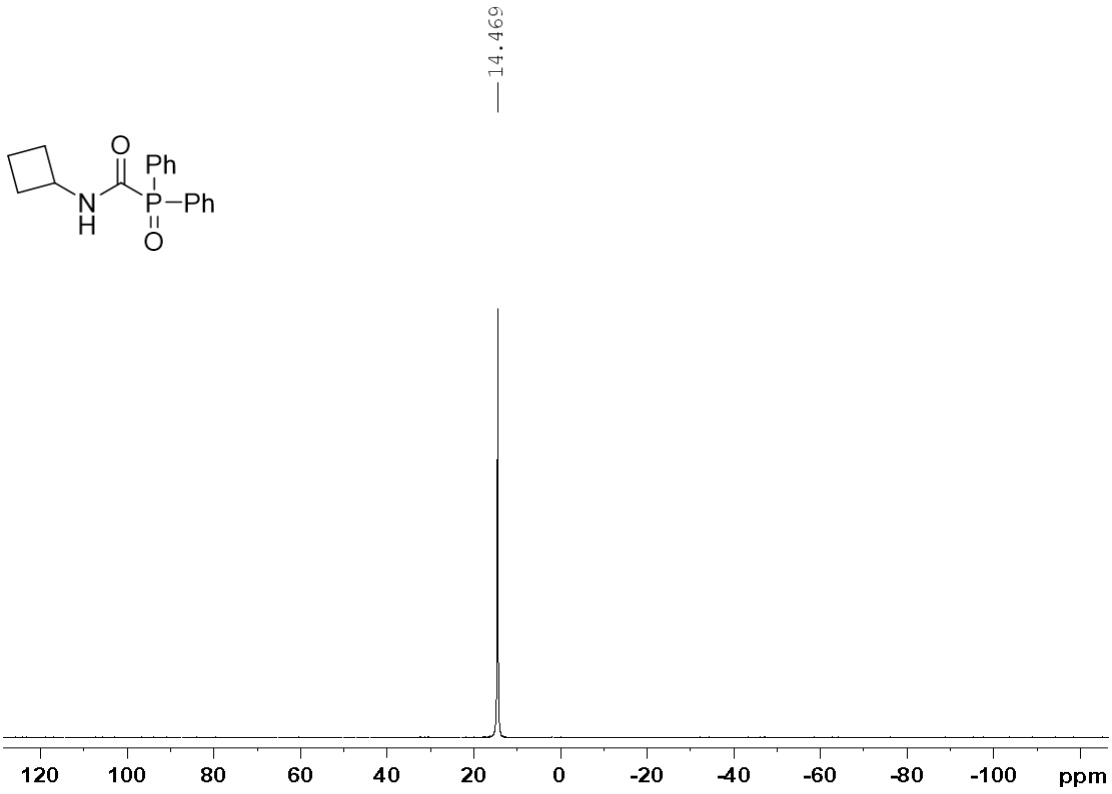
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3t**



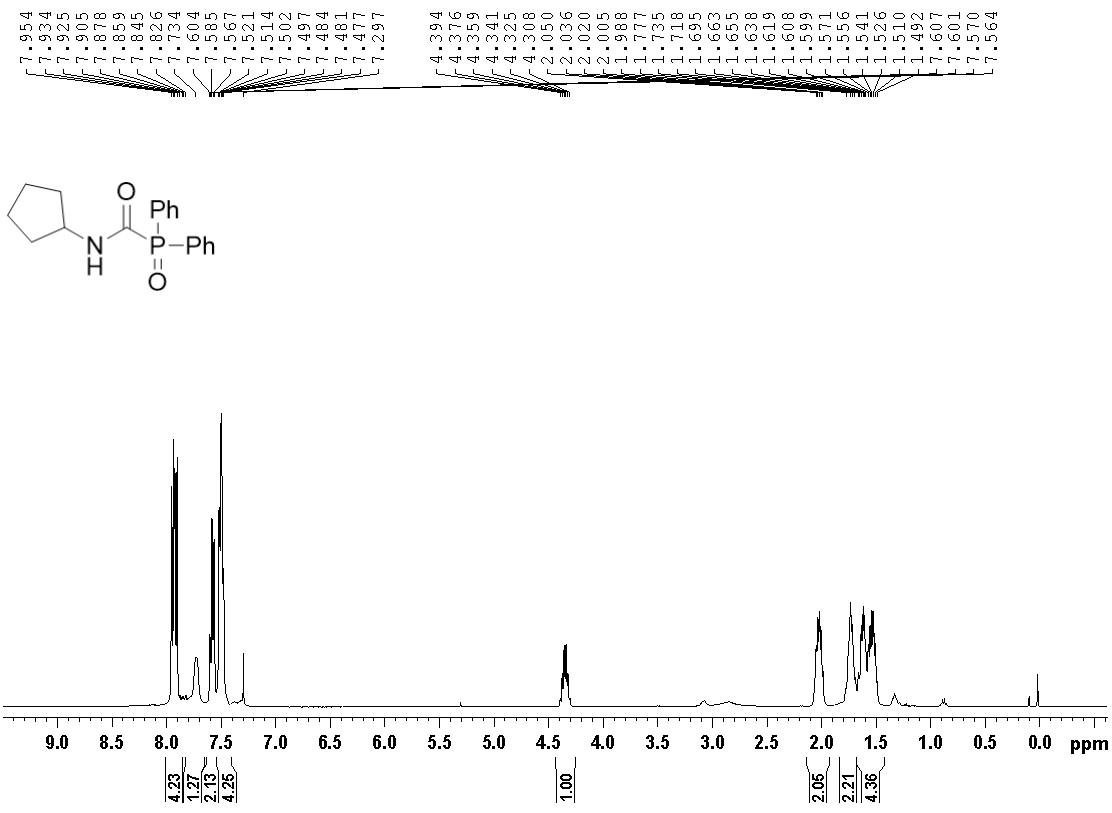
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3u**



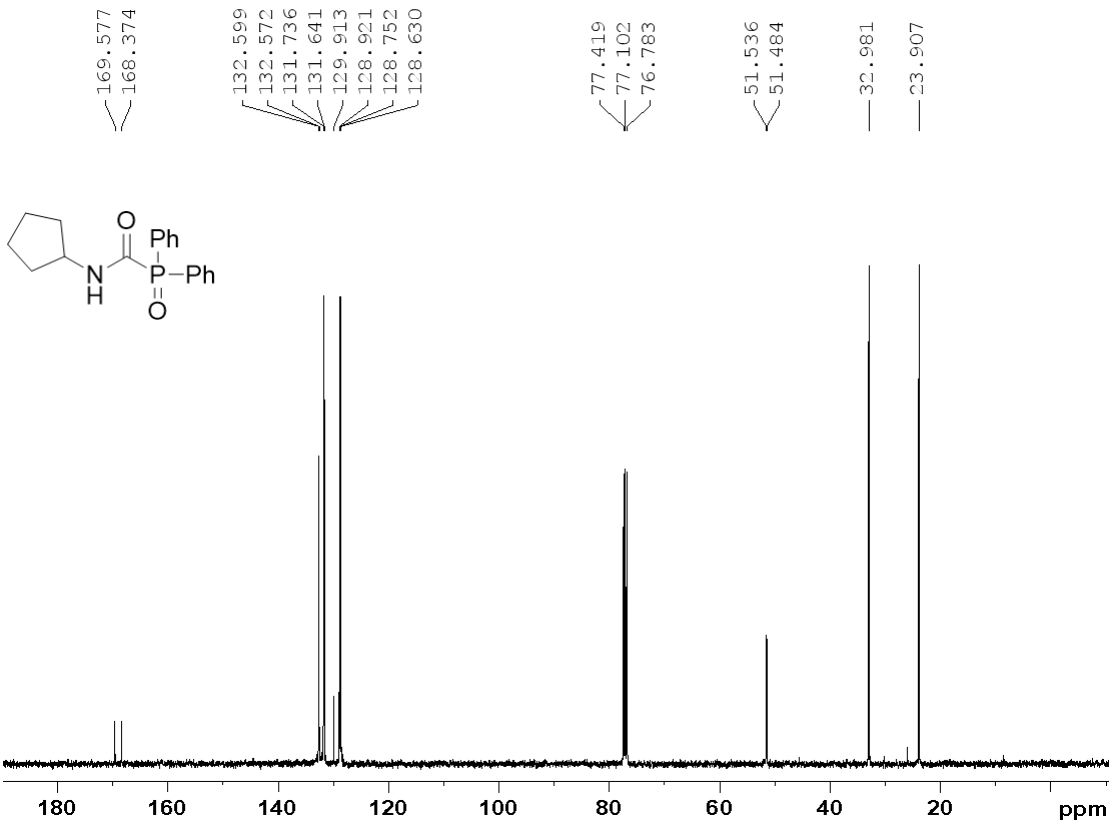
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3u**



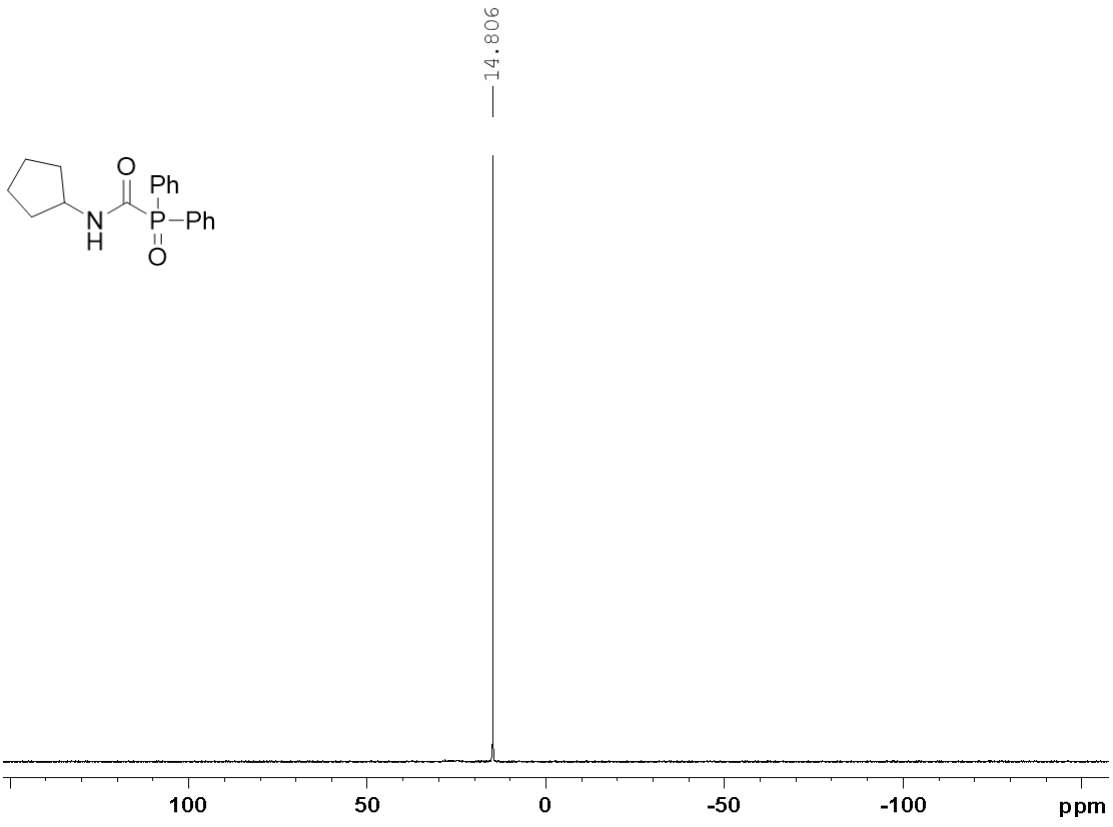
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3u**



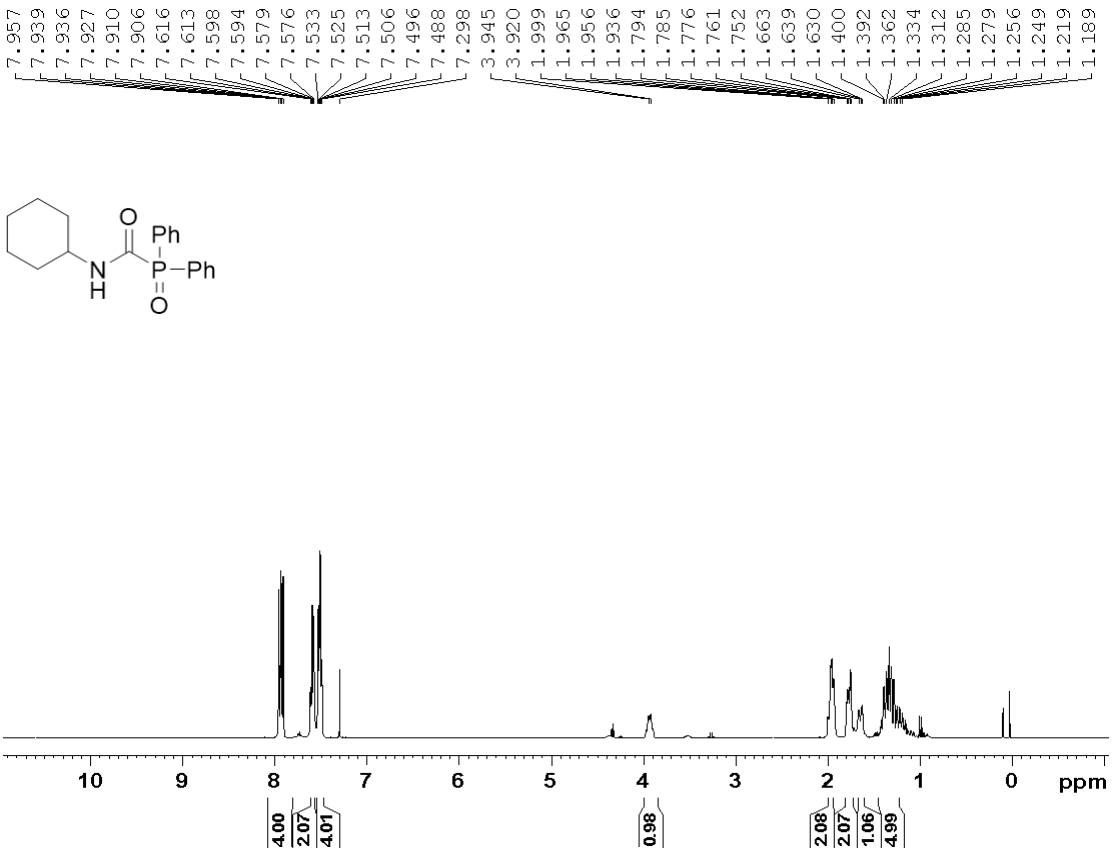
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3v**



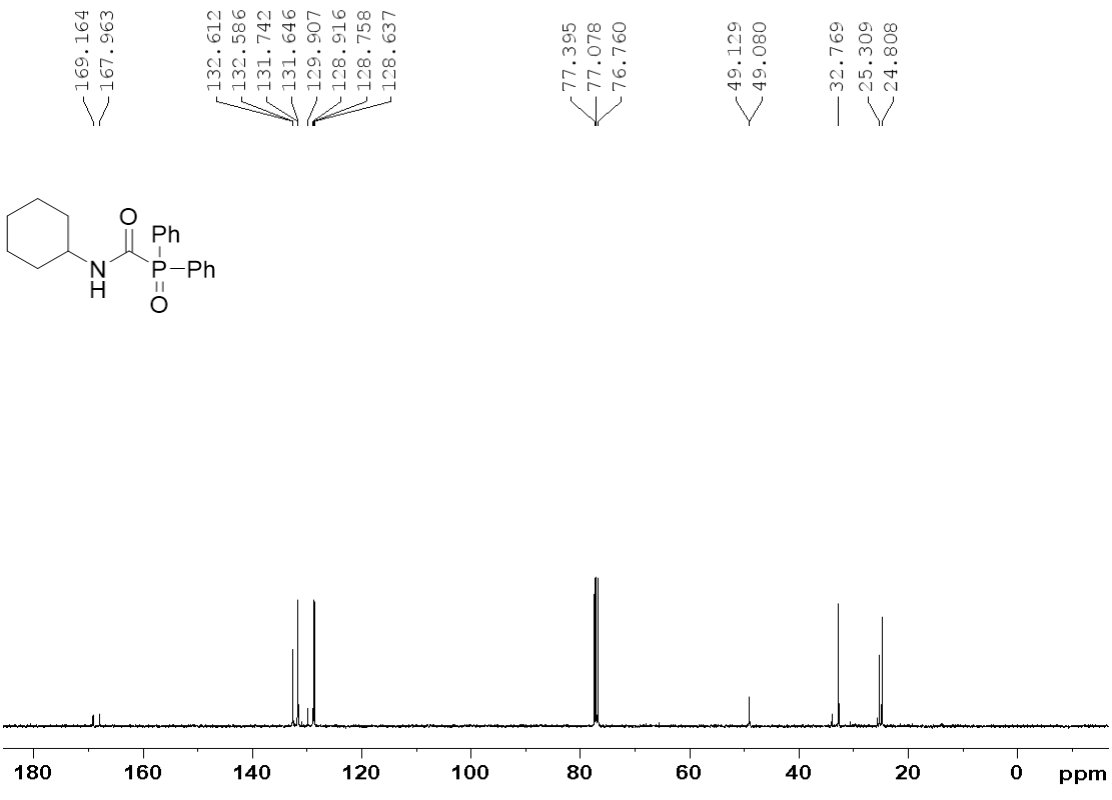
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3v**



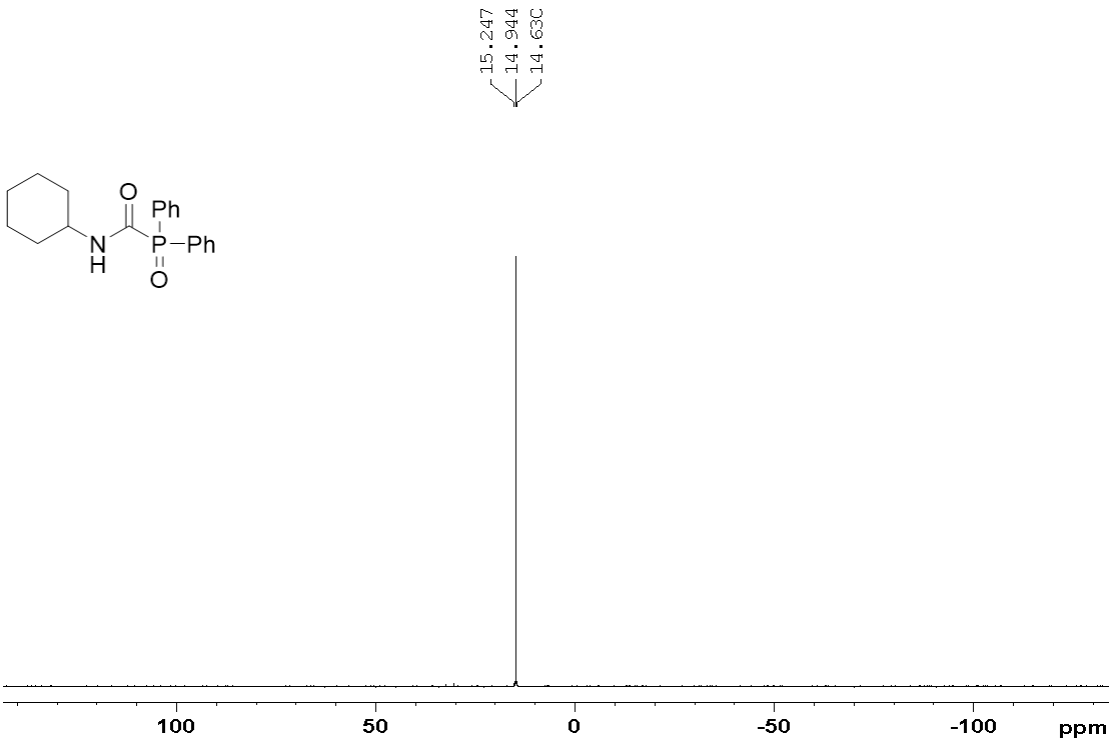
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3v**



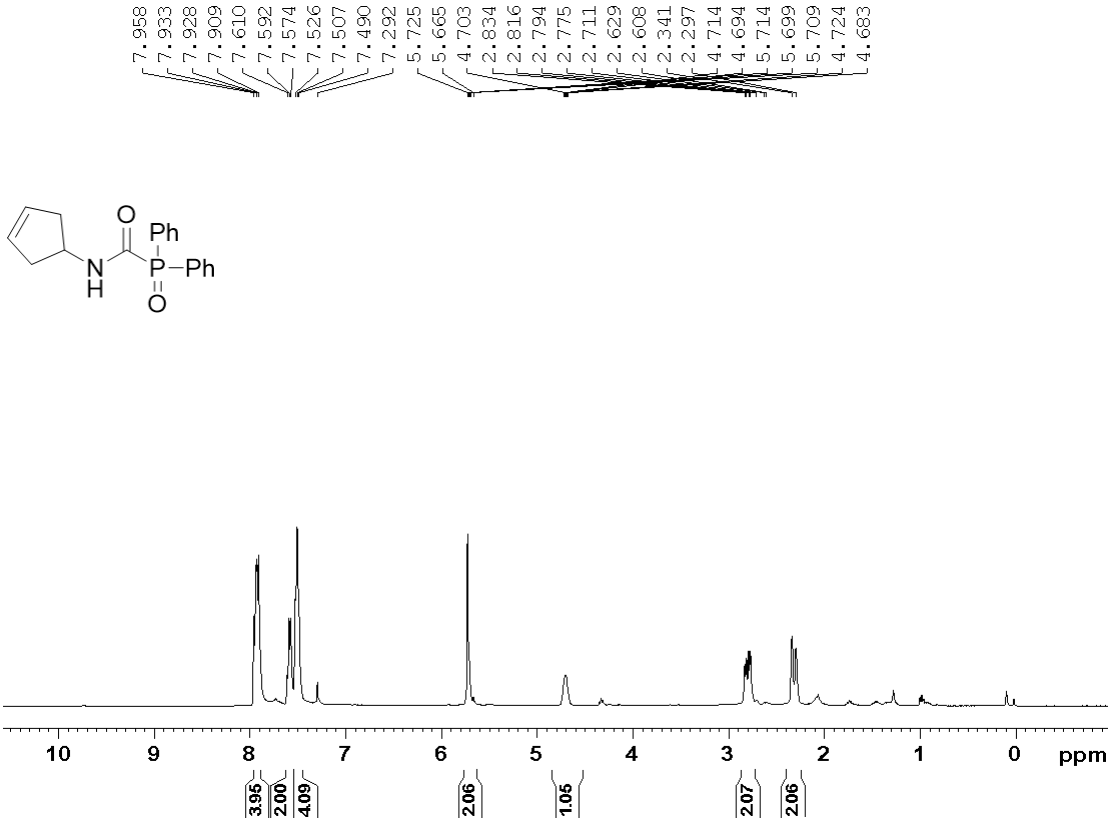
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3w**



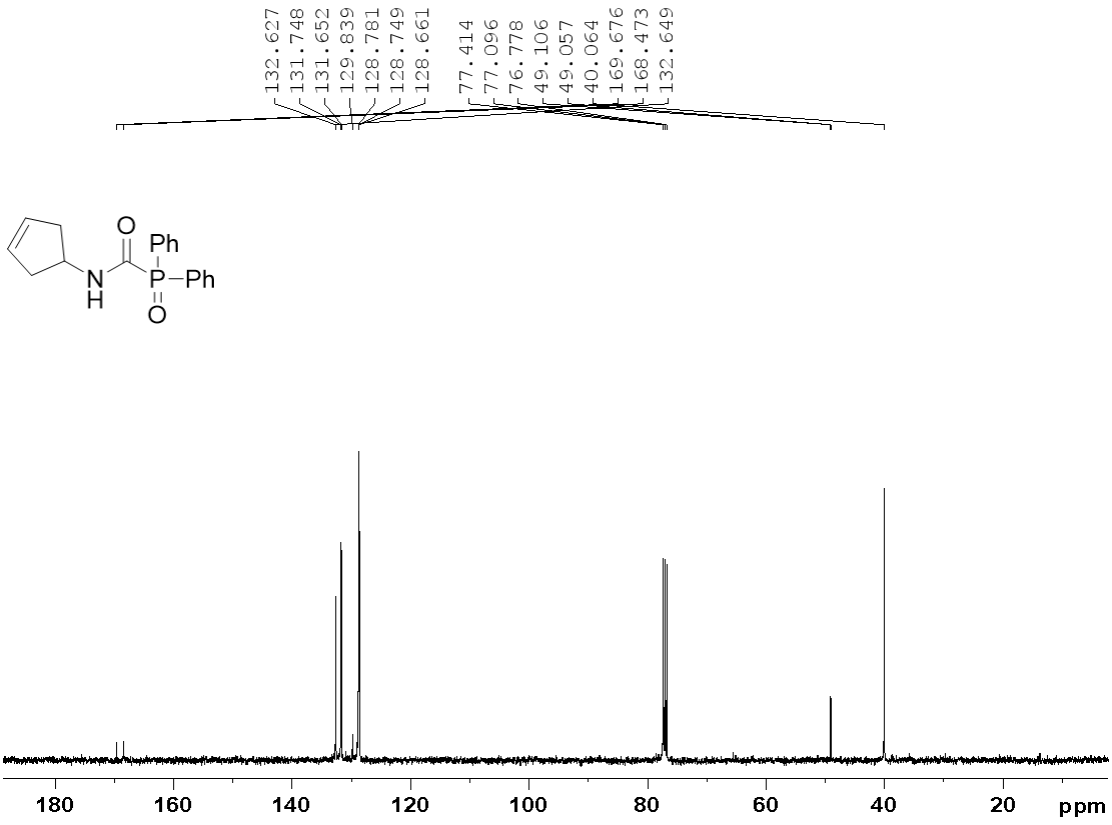
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3w**



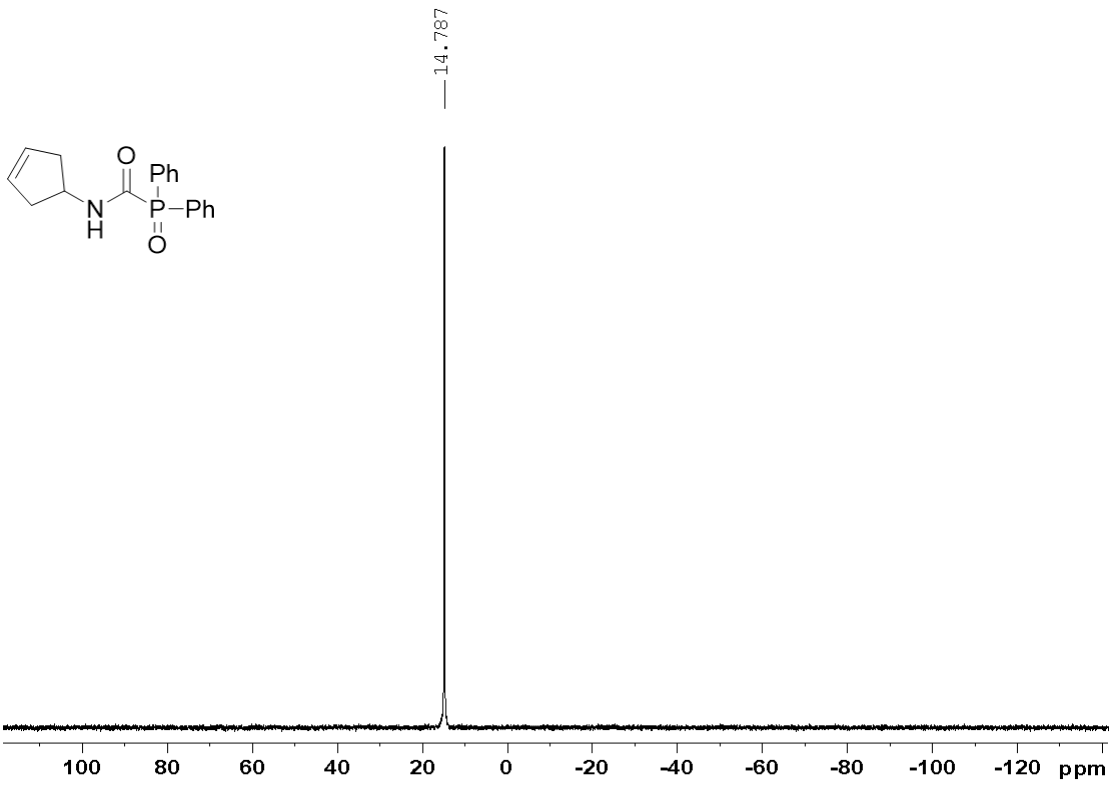
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3w**



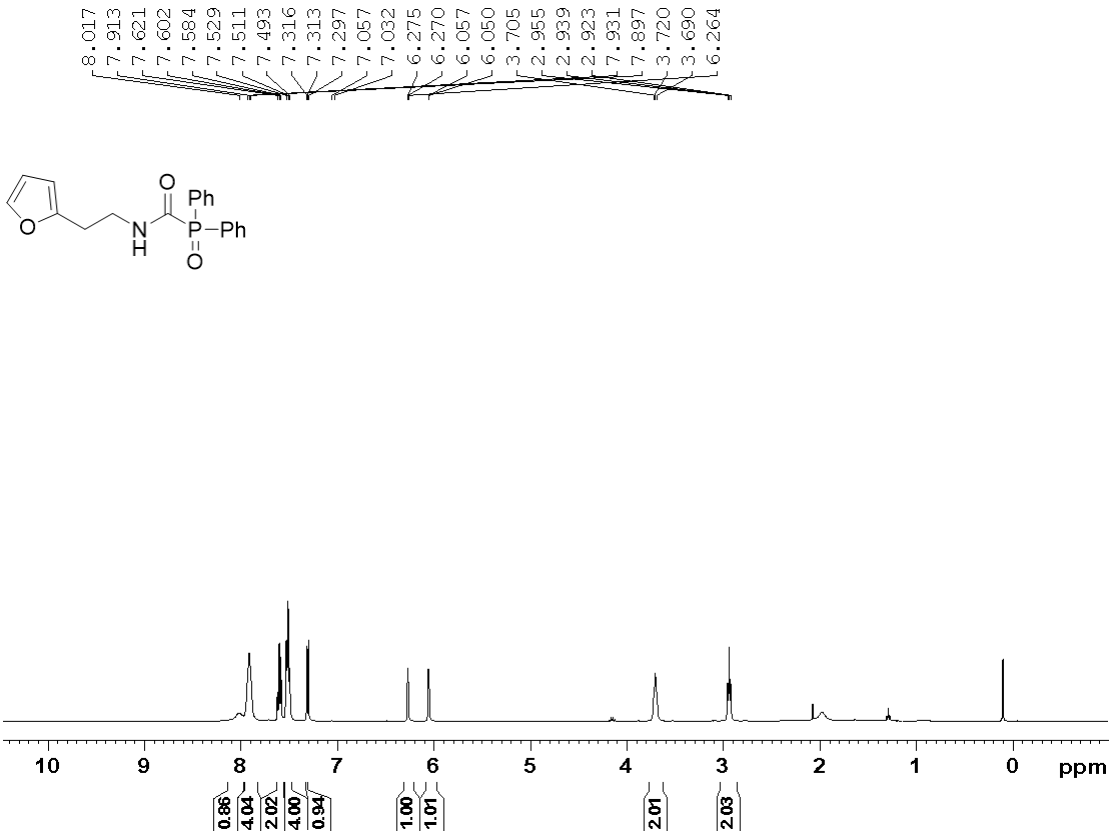
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3x**



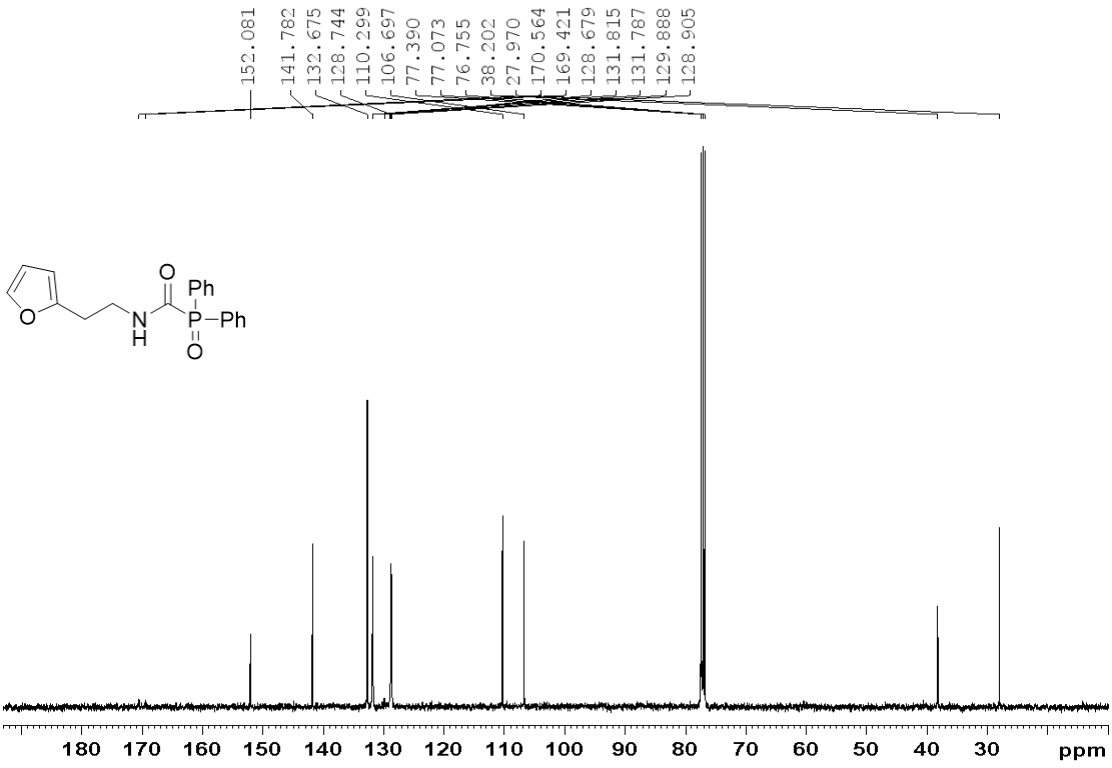
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3x**



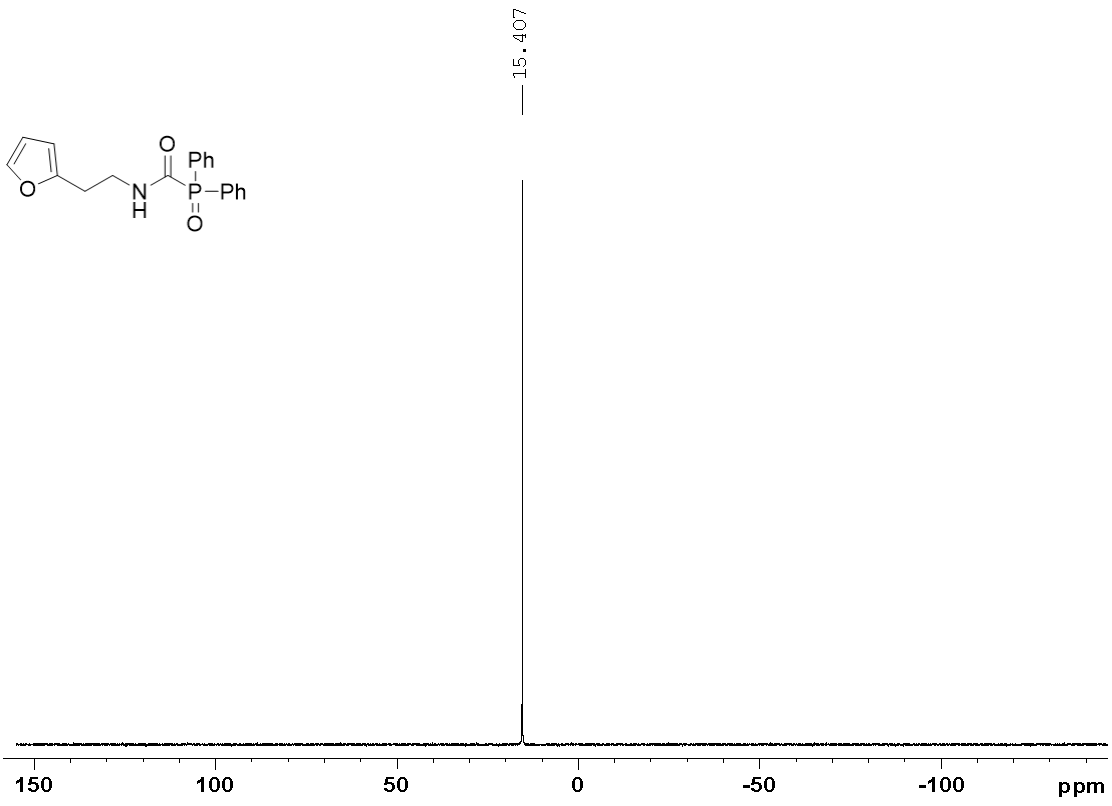
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3x**



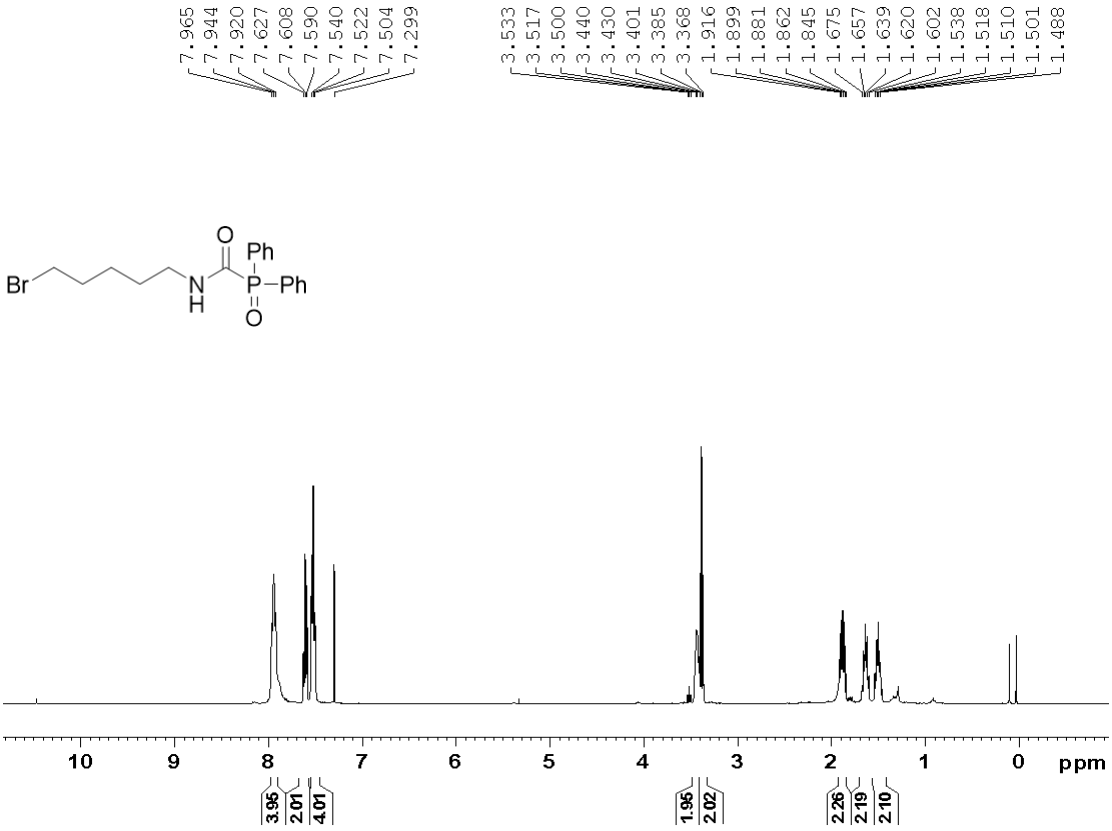
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3y**



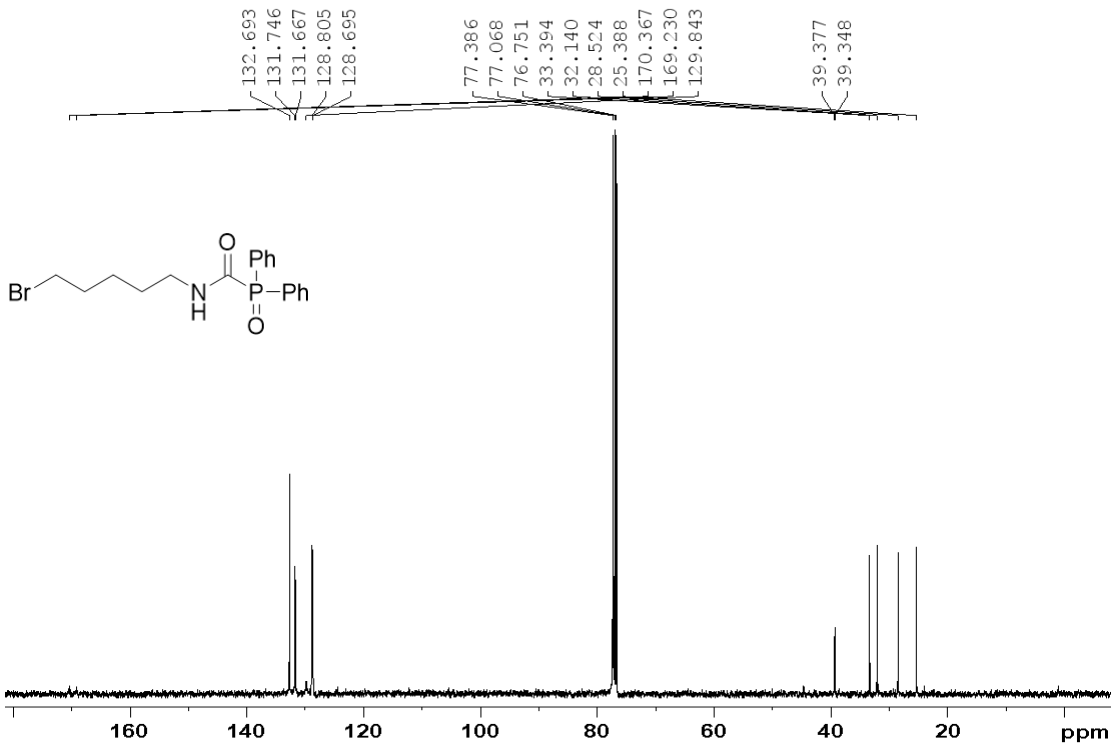
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3y**



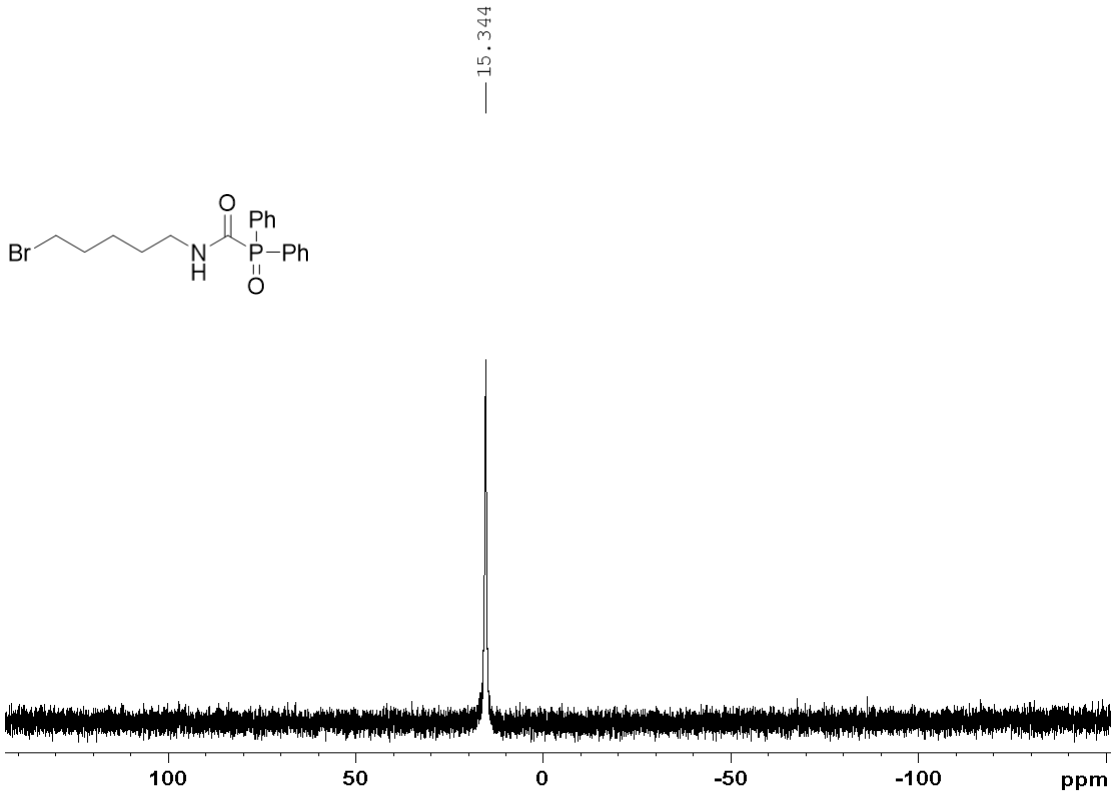
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3y**



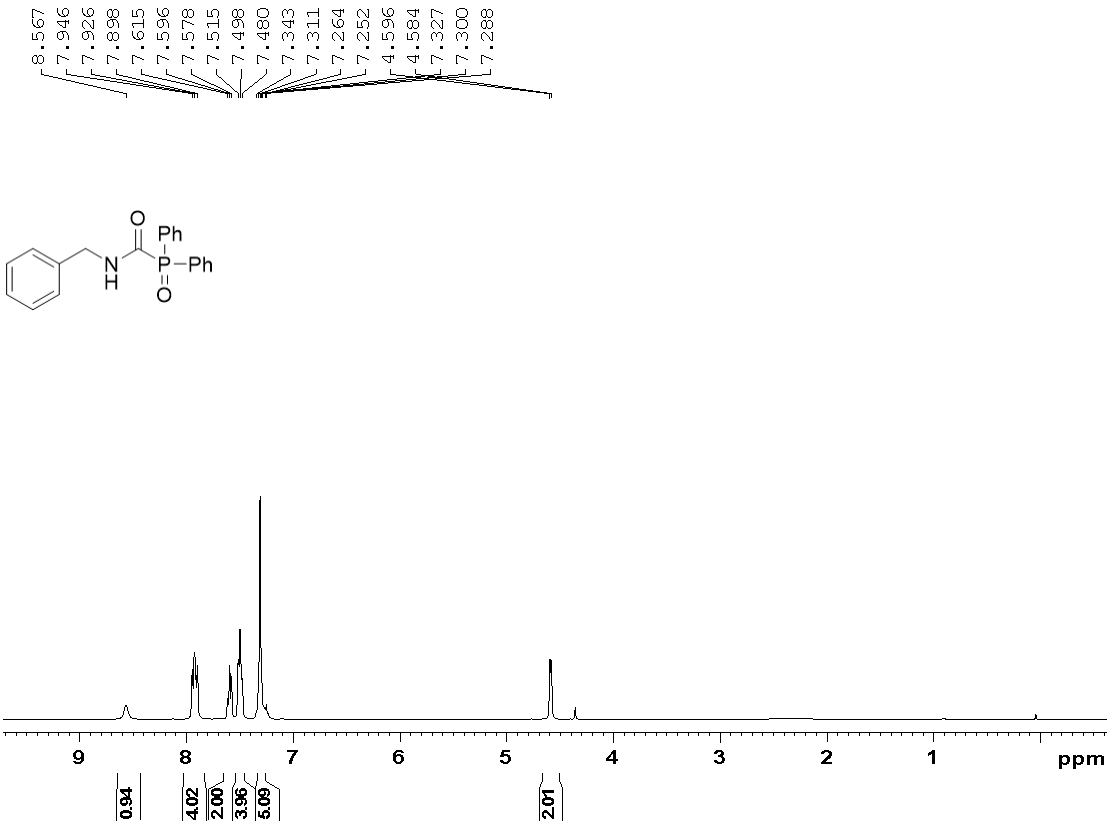
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3z**



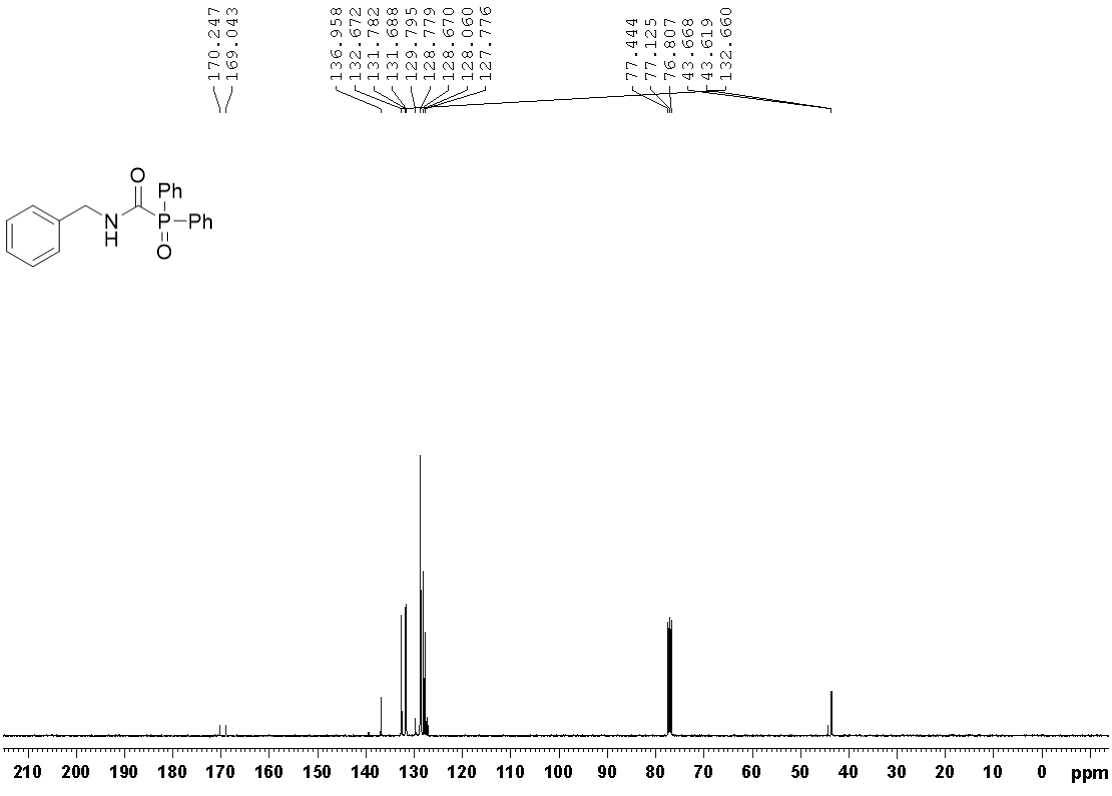
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3z**



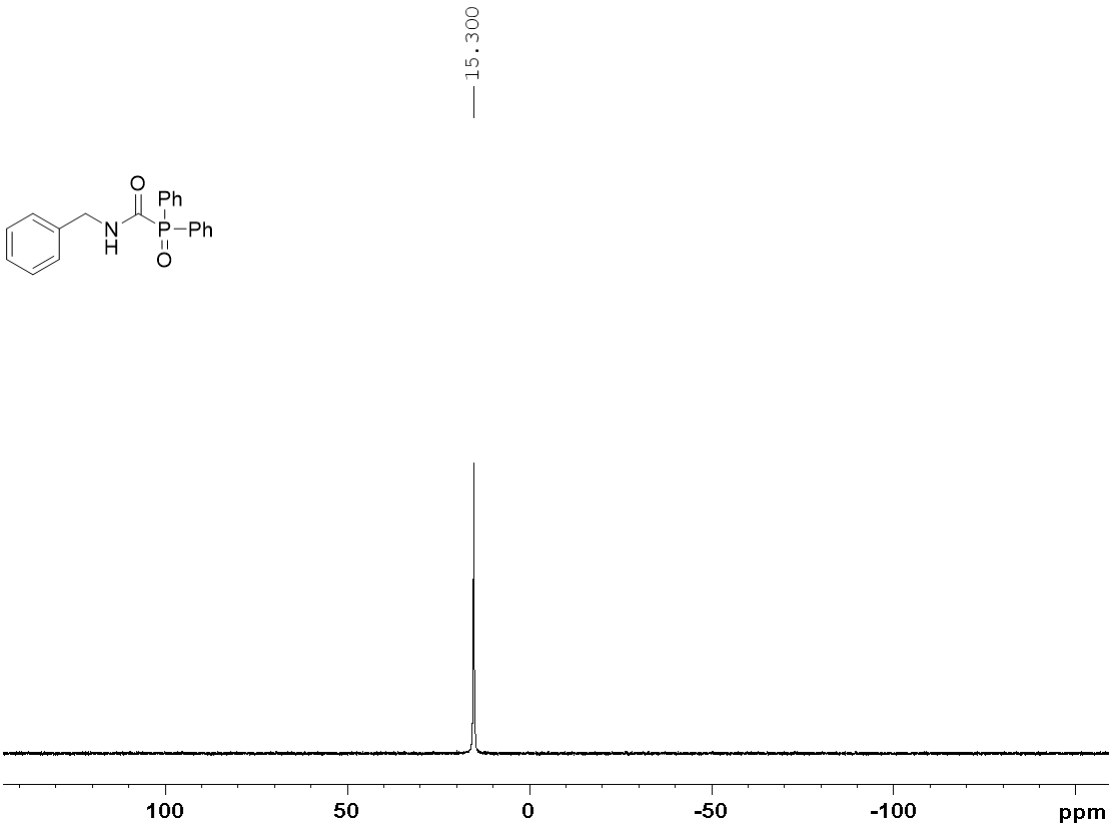
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3z**



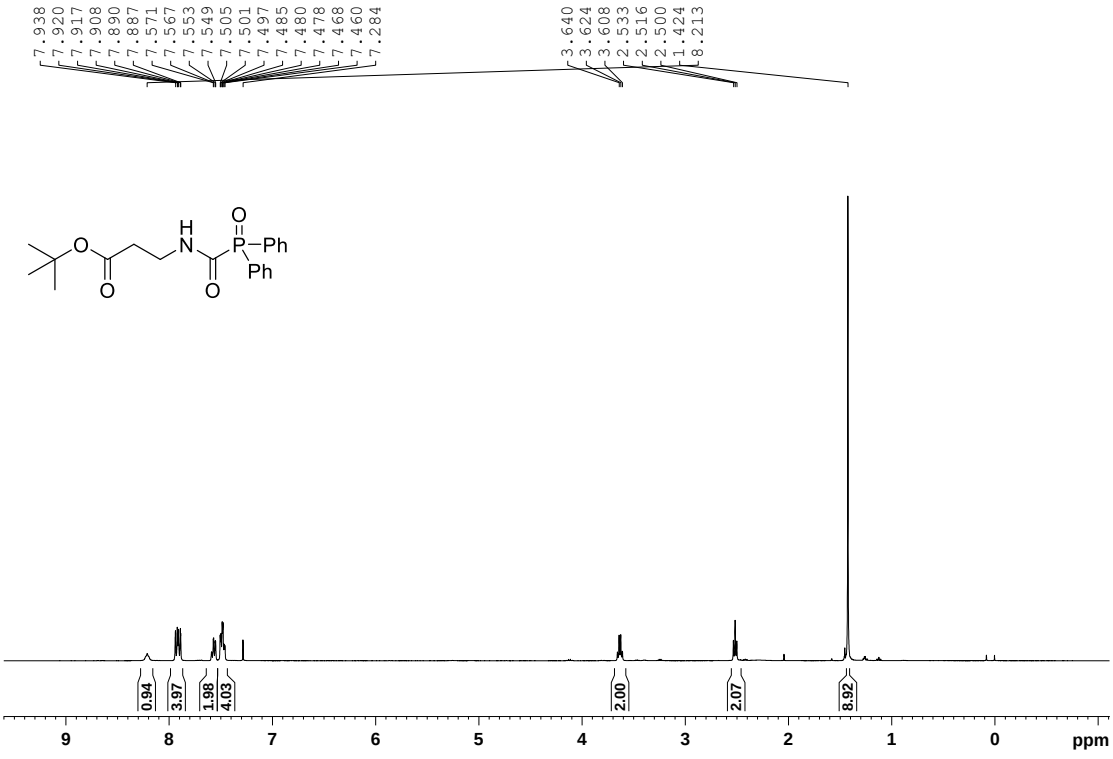
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3aa**



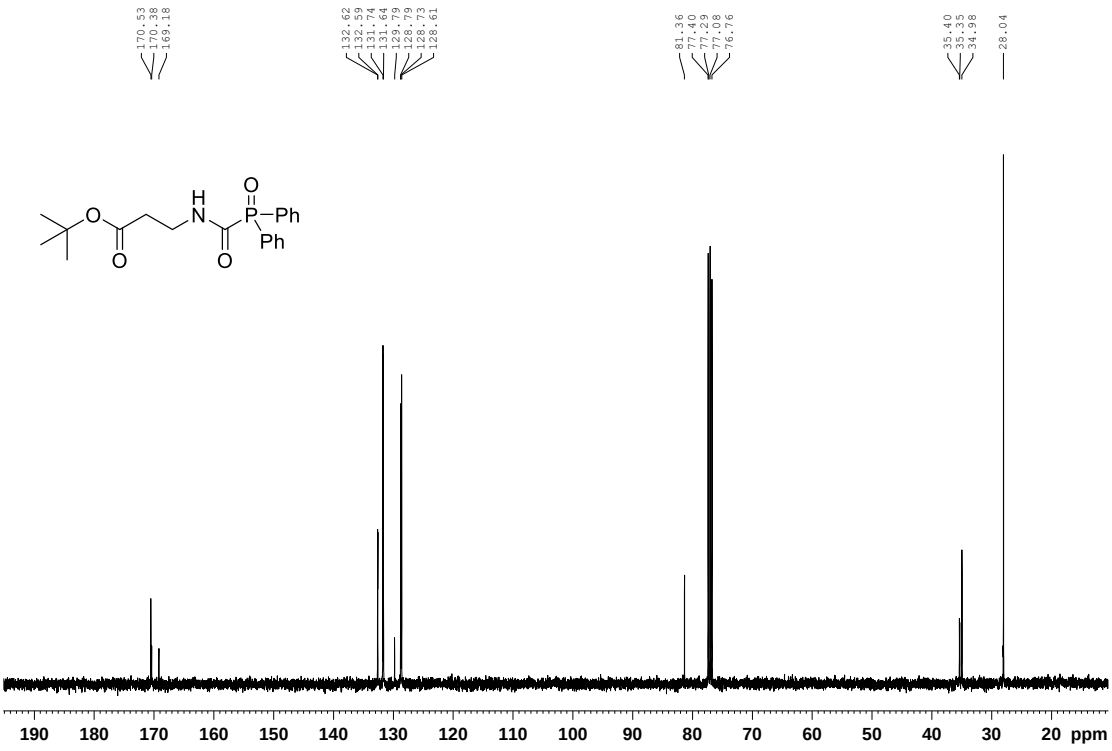
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3aa**



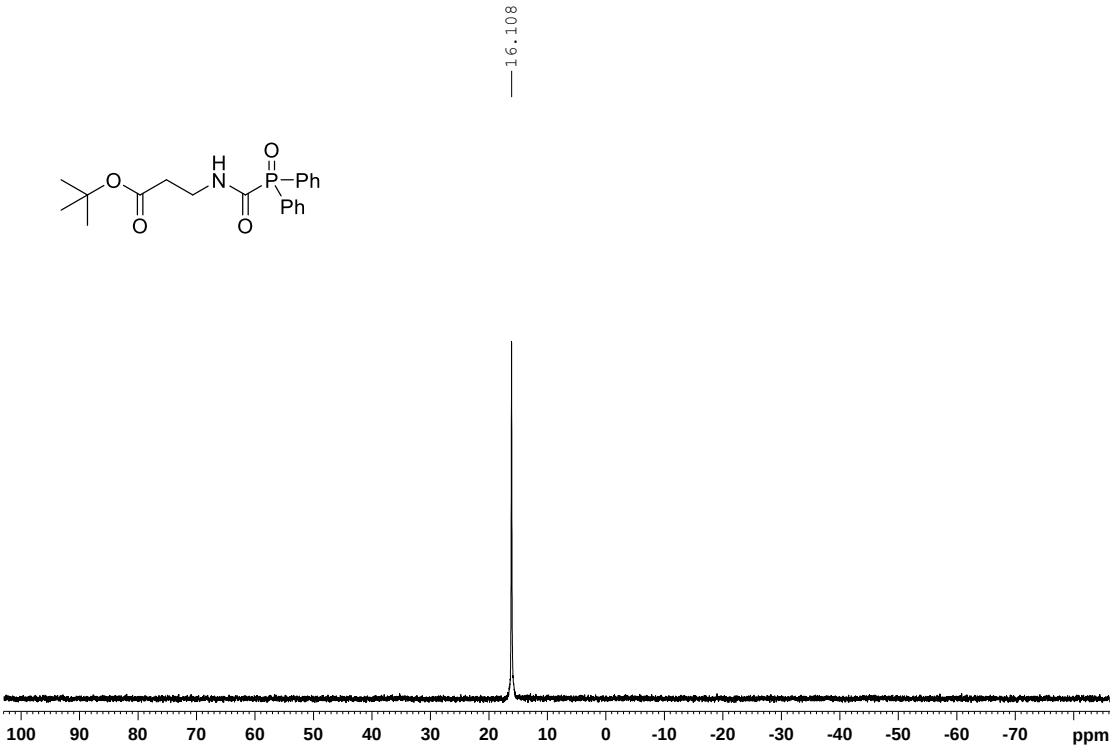
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3aa**



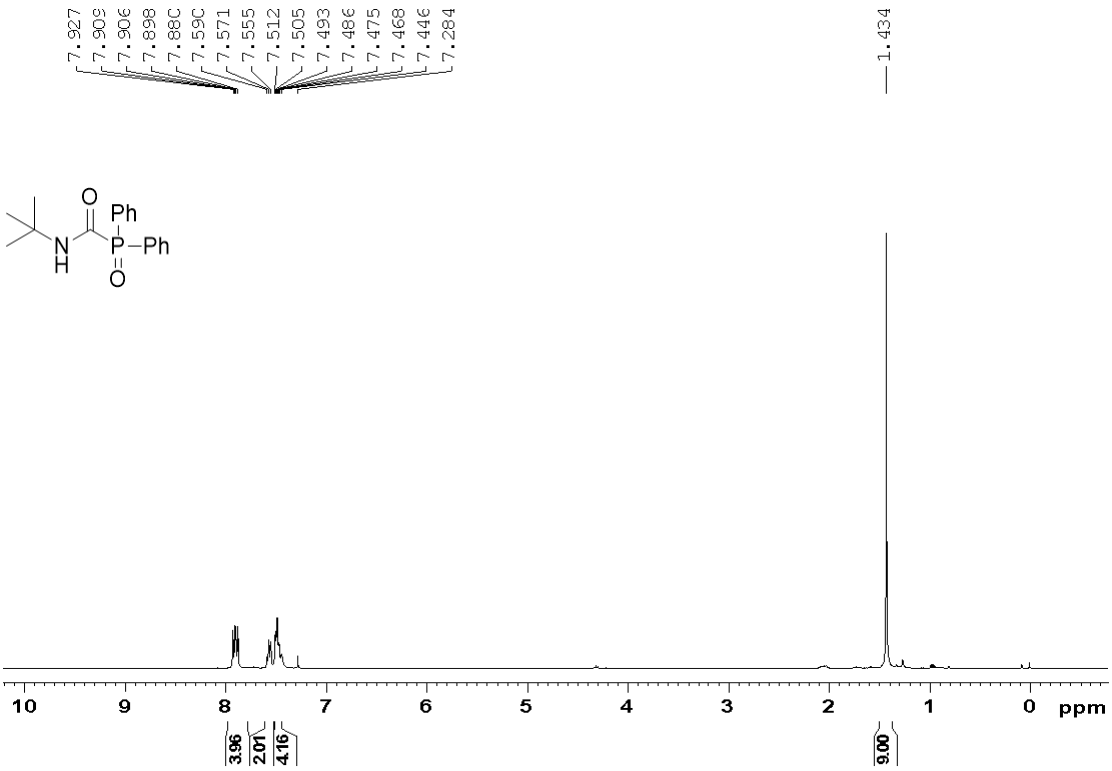
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3ab**



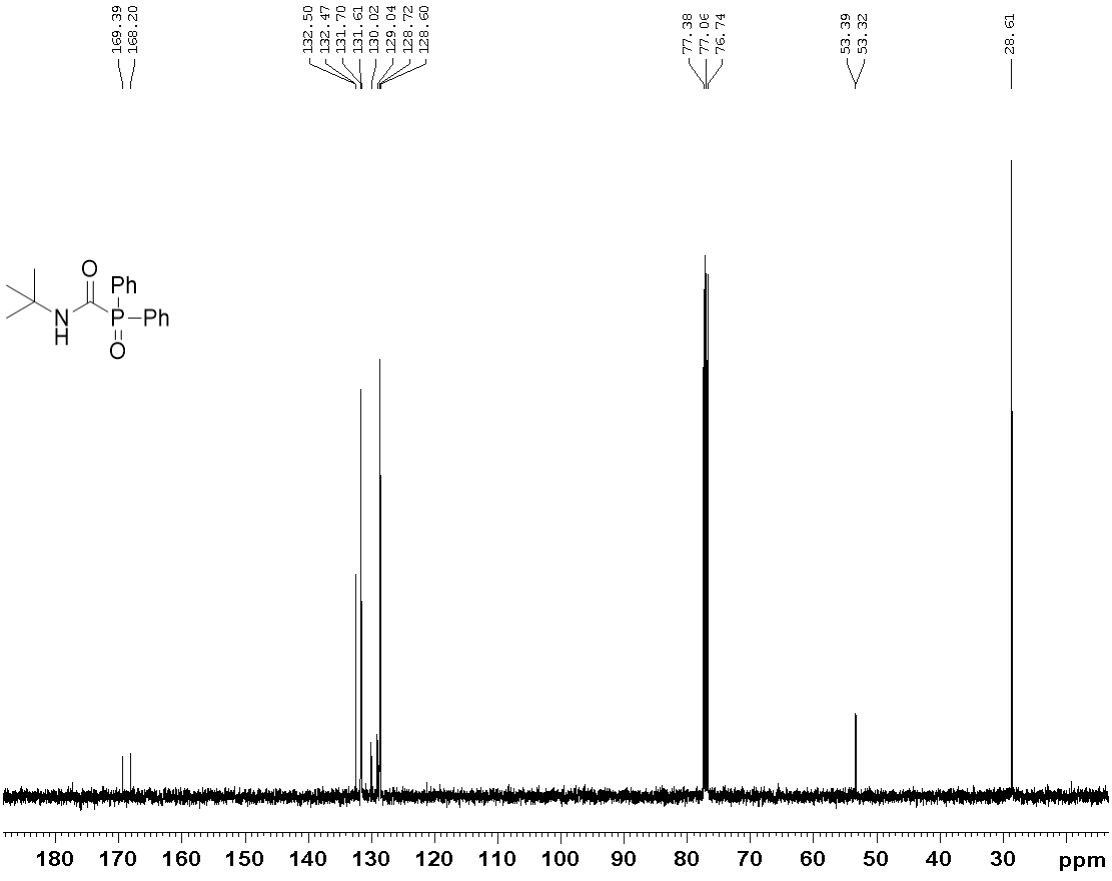
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3ab**



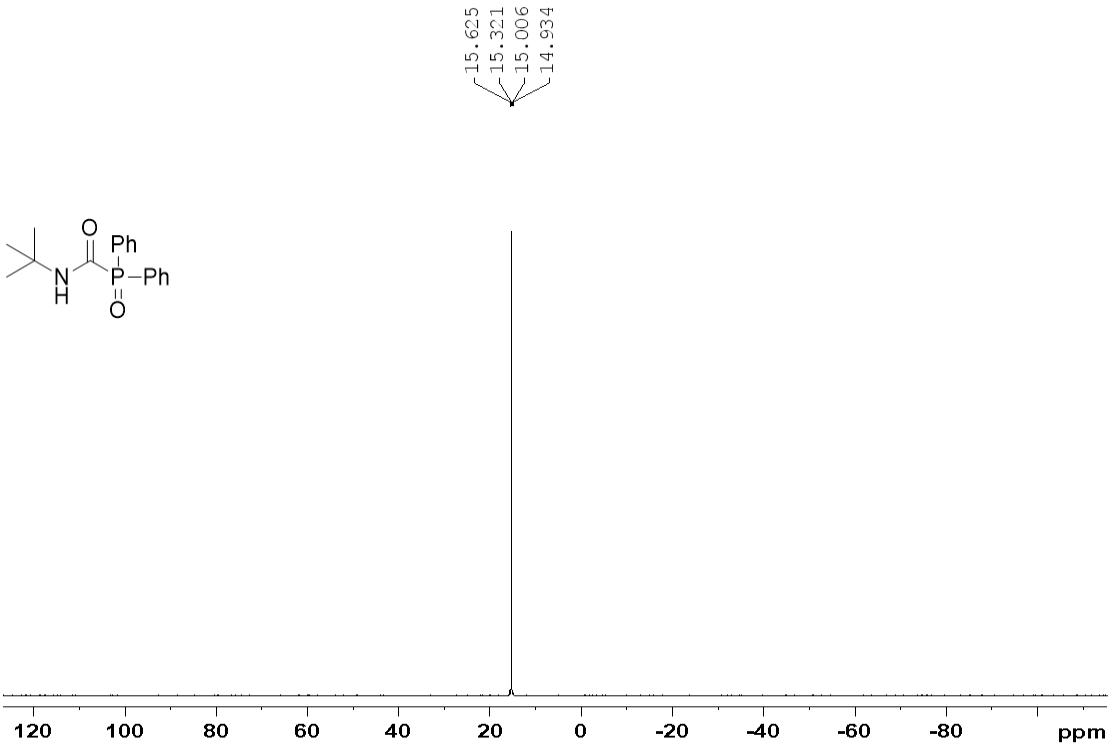
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3ab**



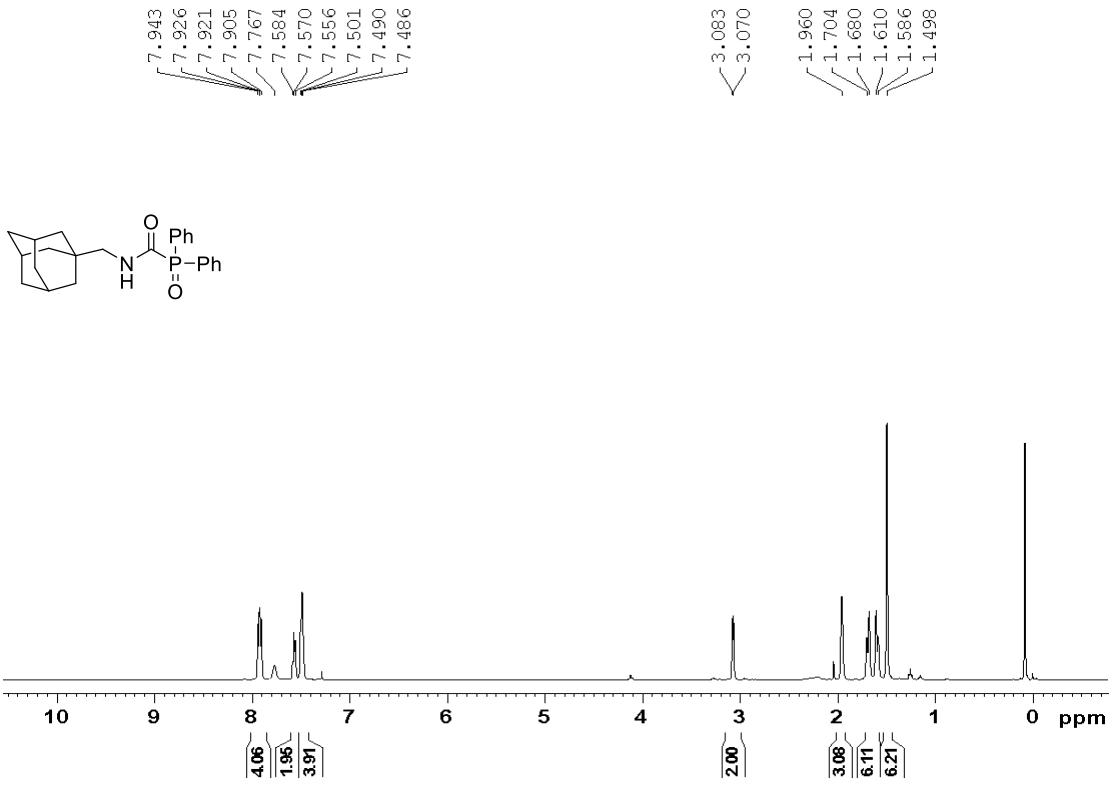
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3ac**



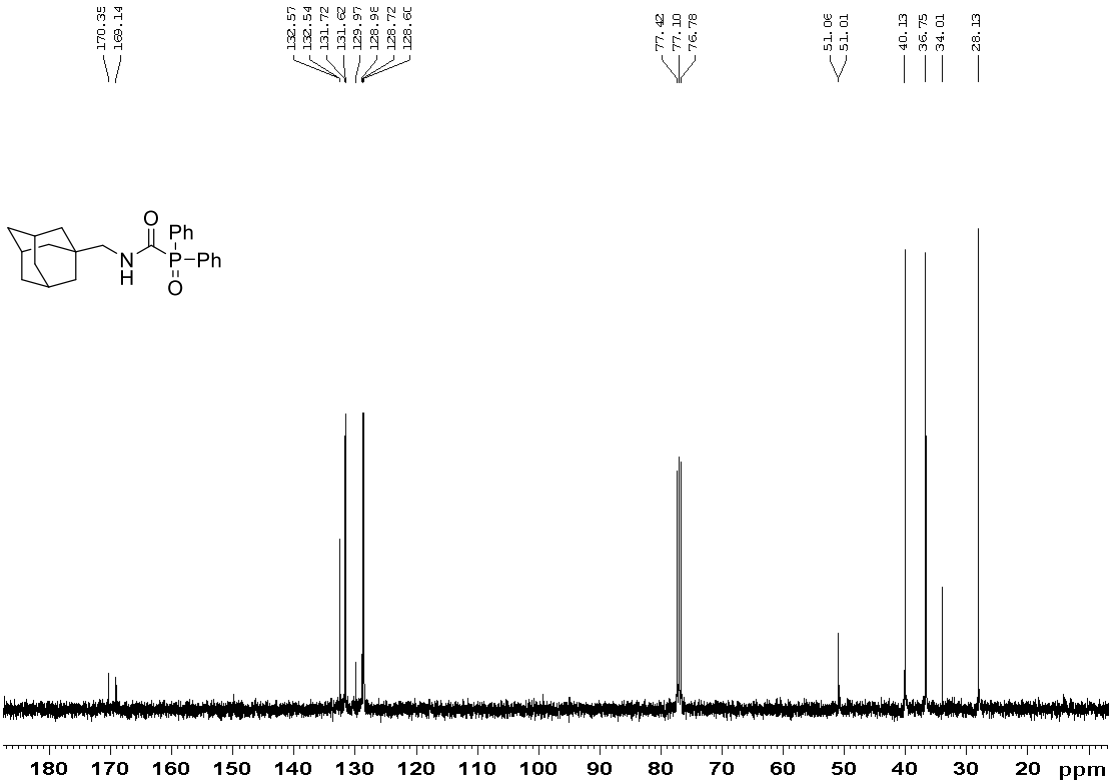
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3ac**



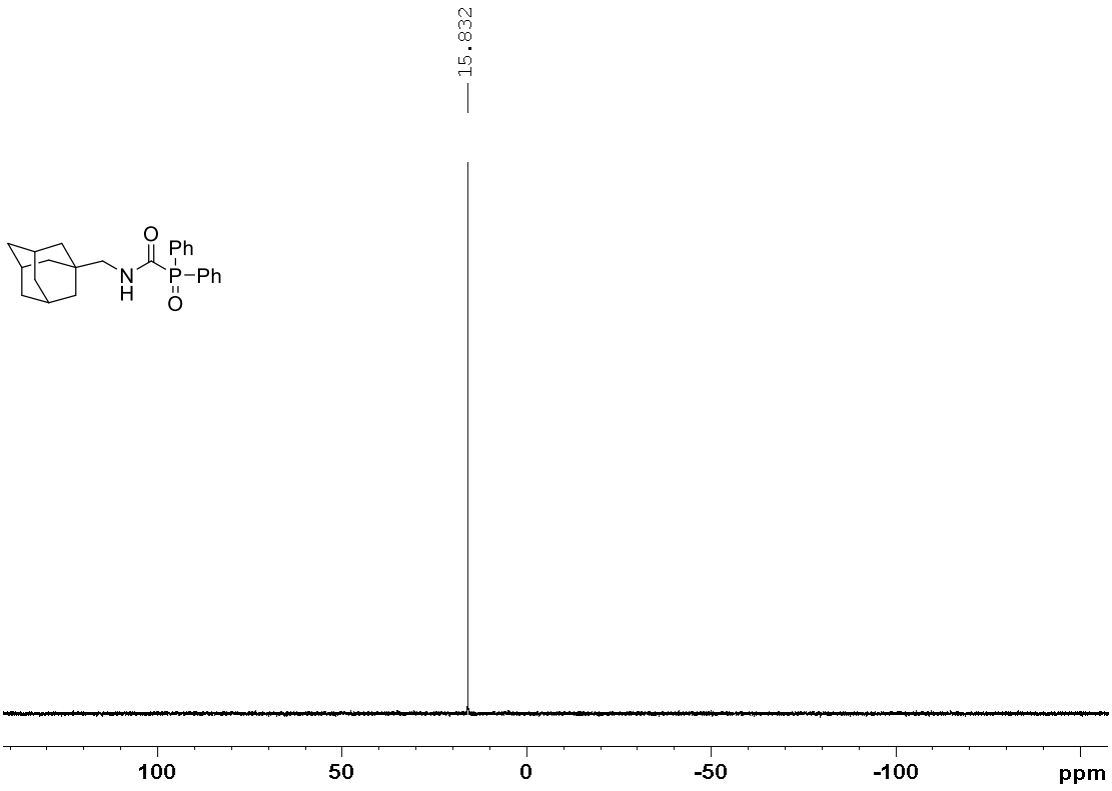
^{13}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3ac**



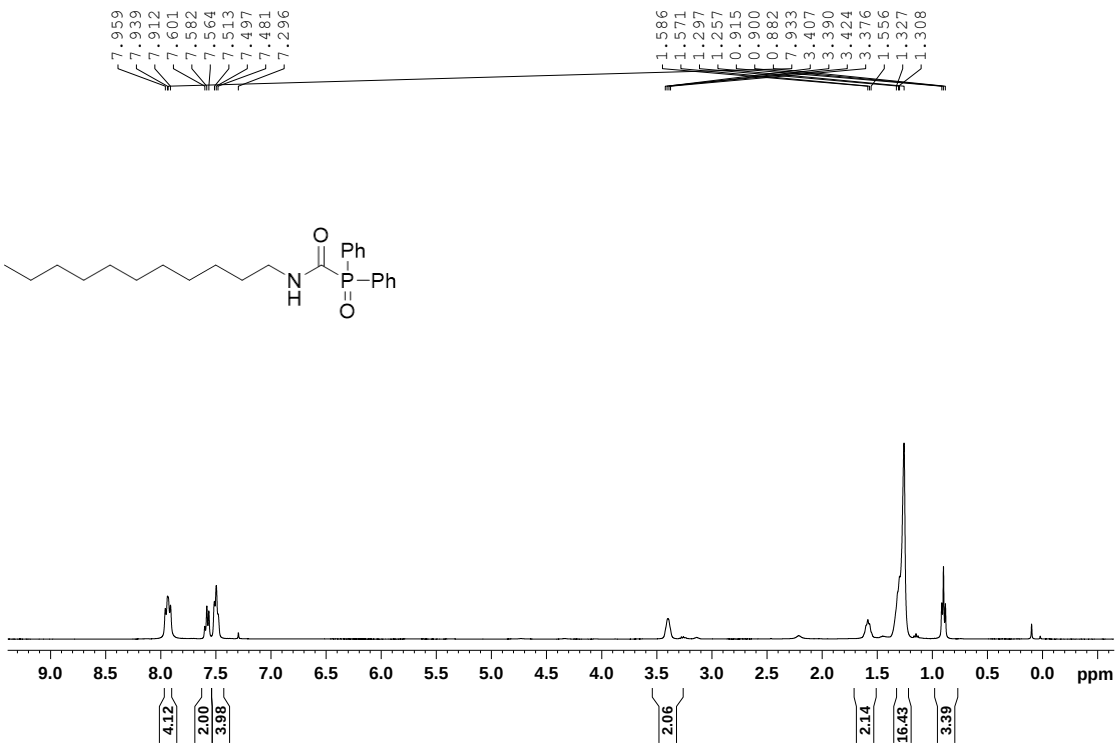
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3ad**



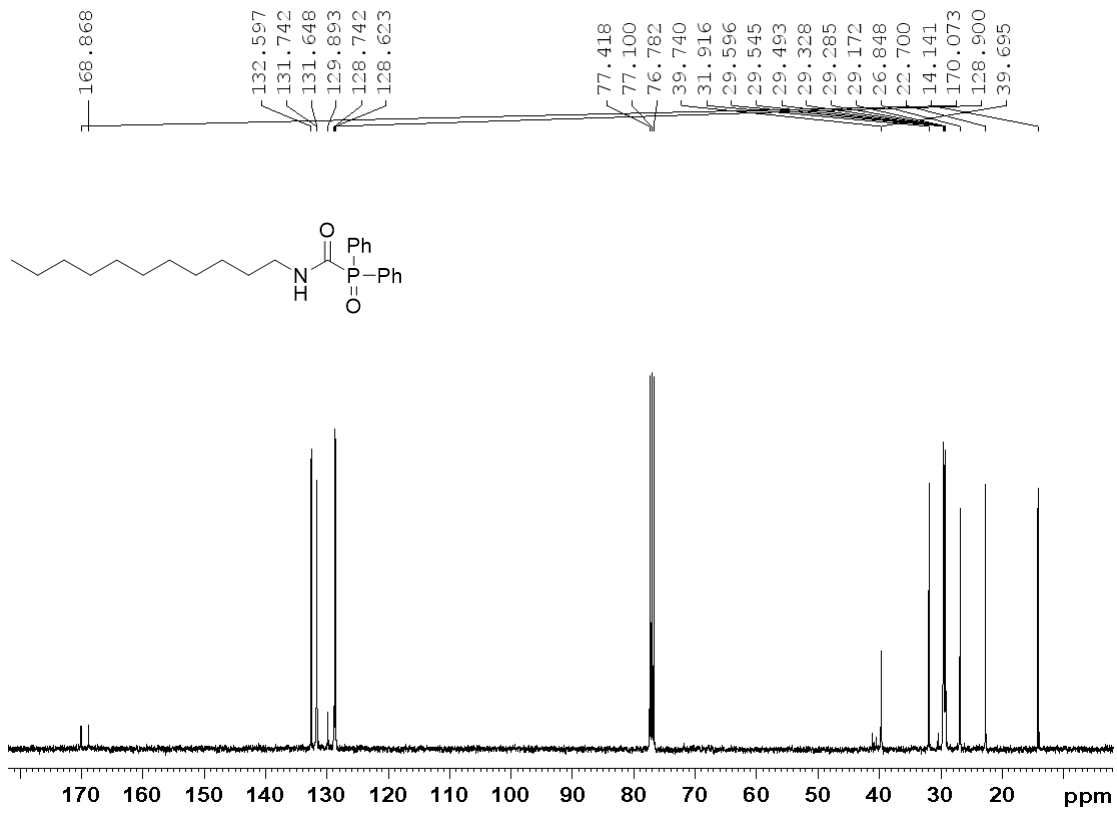
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3ad**



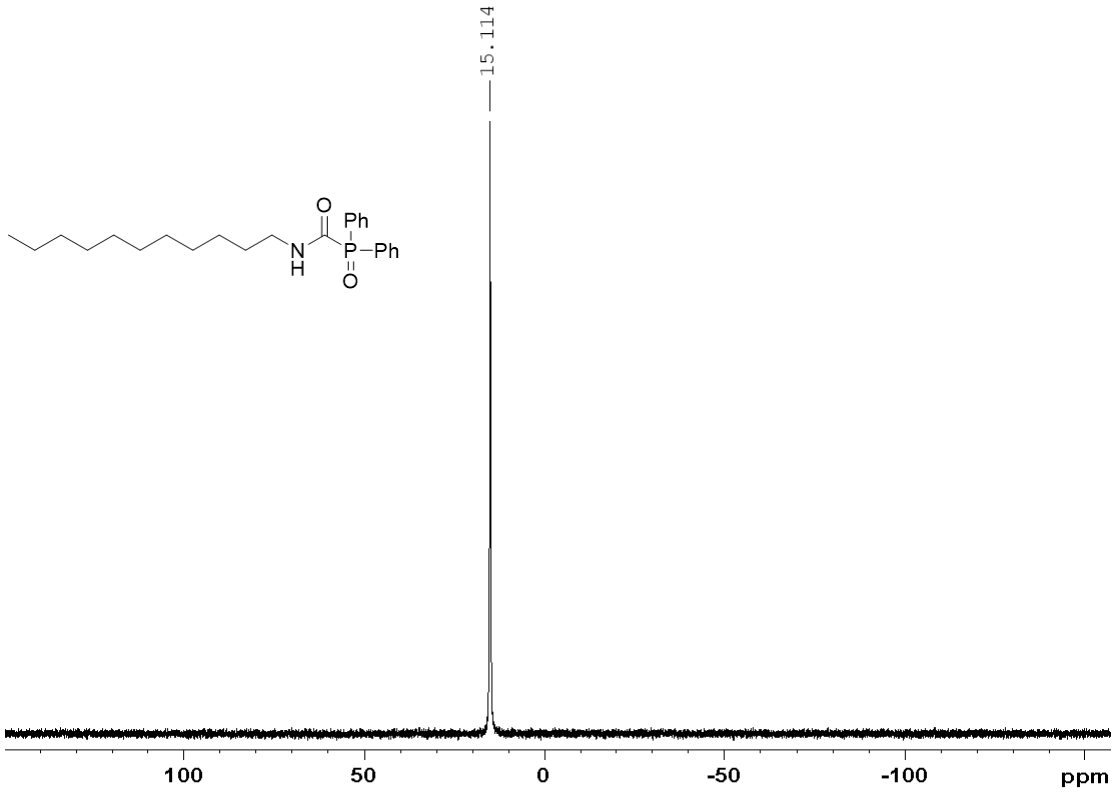
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3ad**



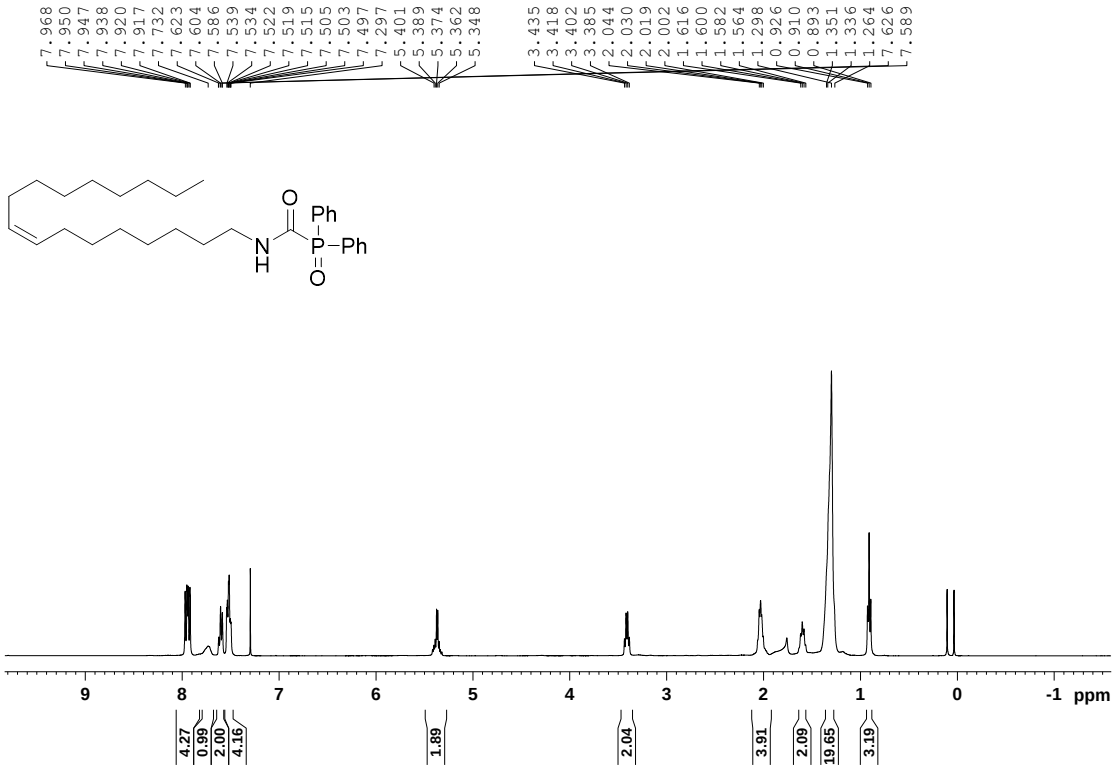
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3ae**



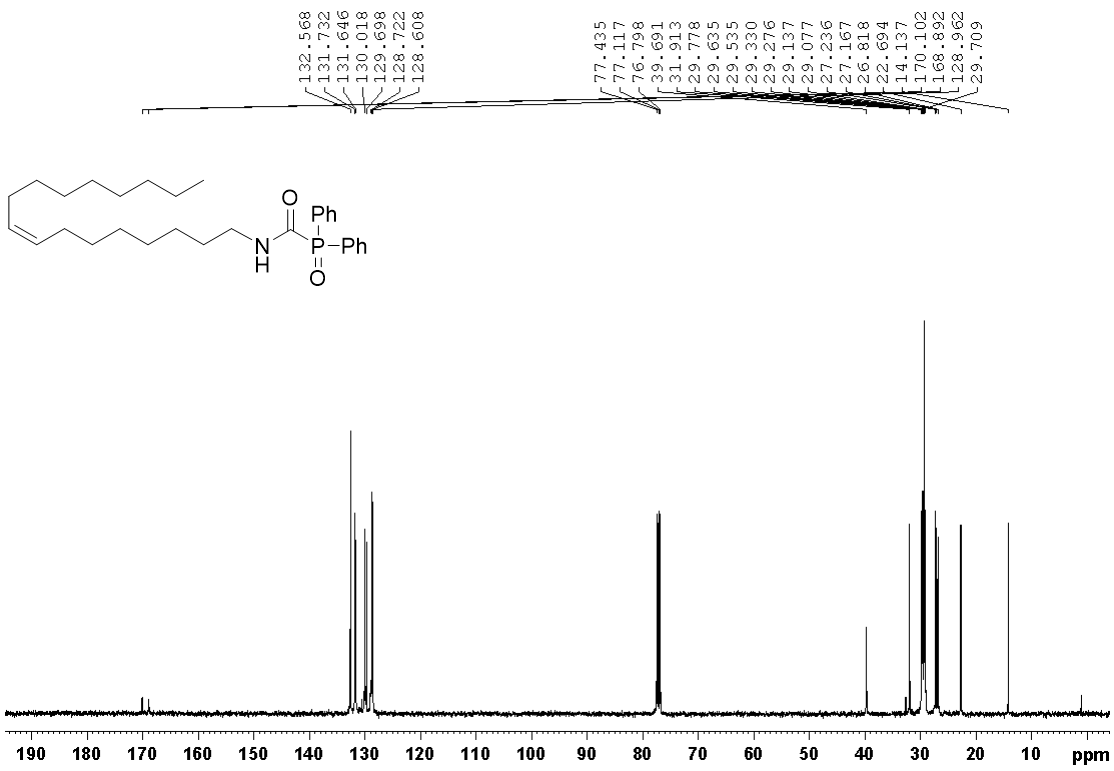
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3ae**



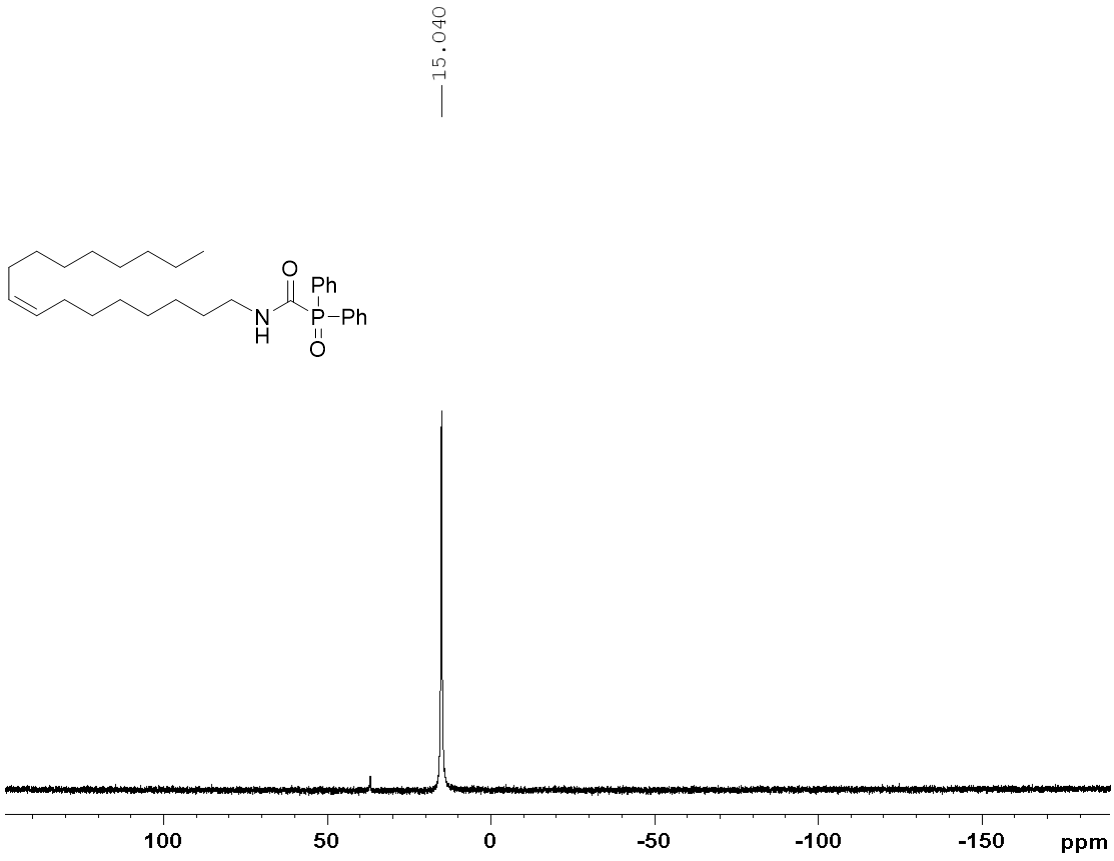
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3ae**



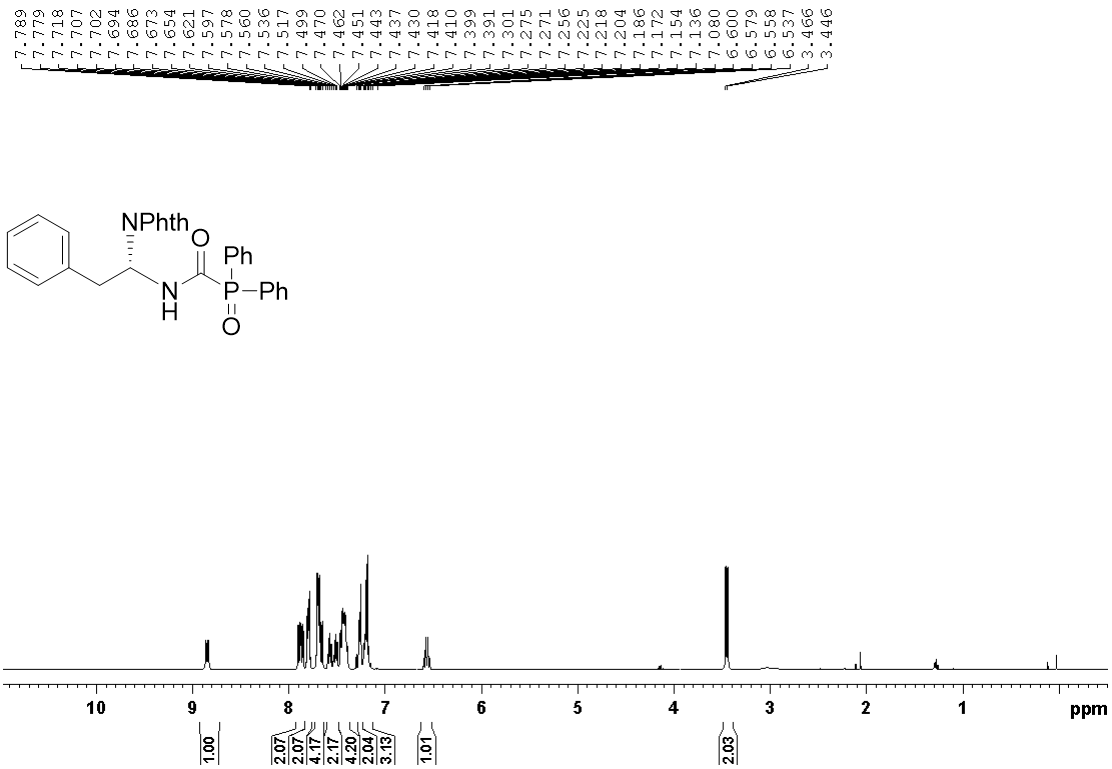
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3af**



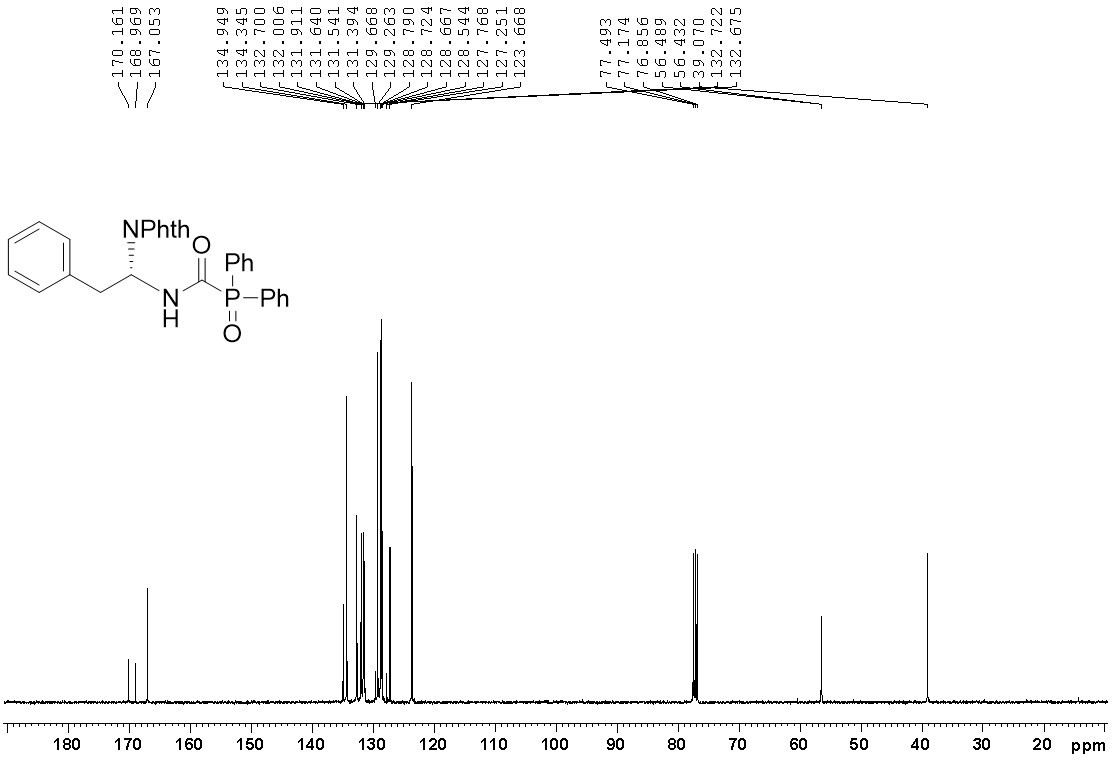
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3af**



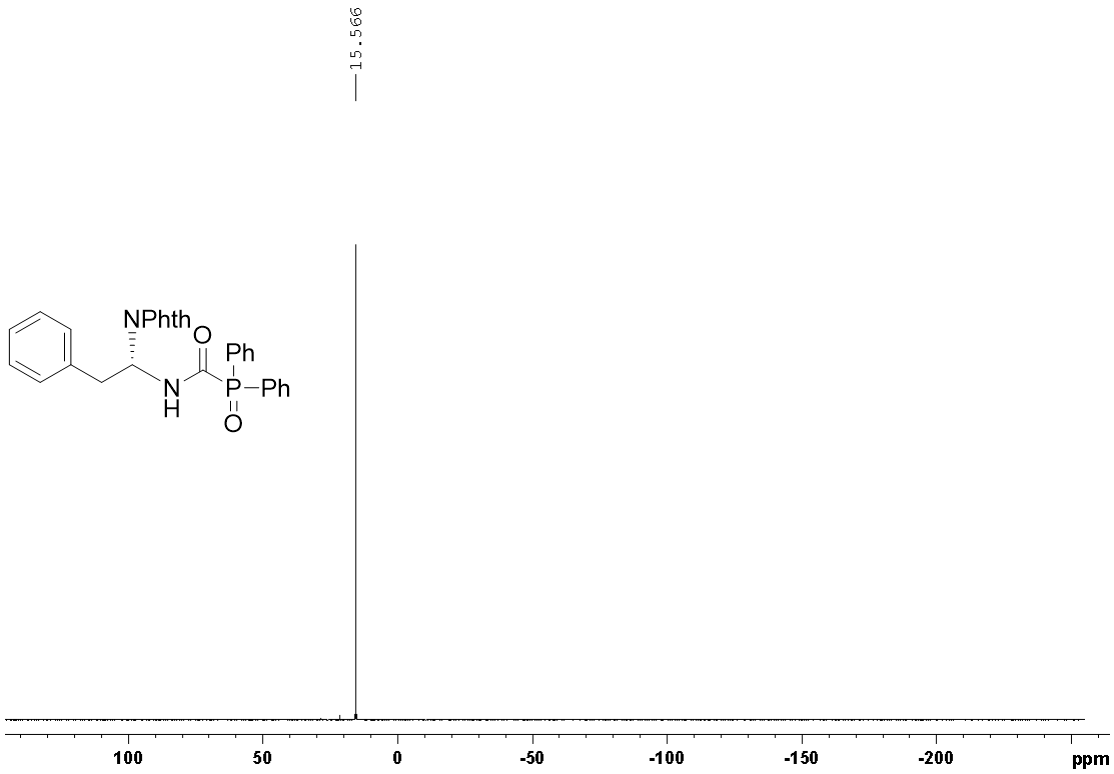
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3af**



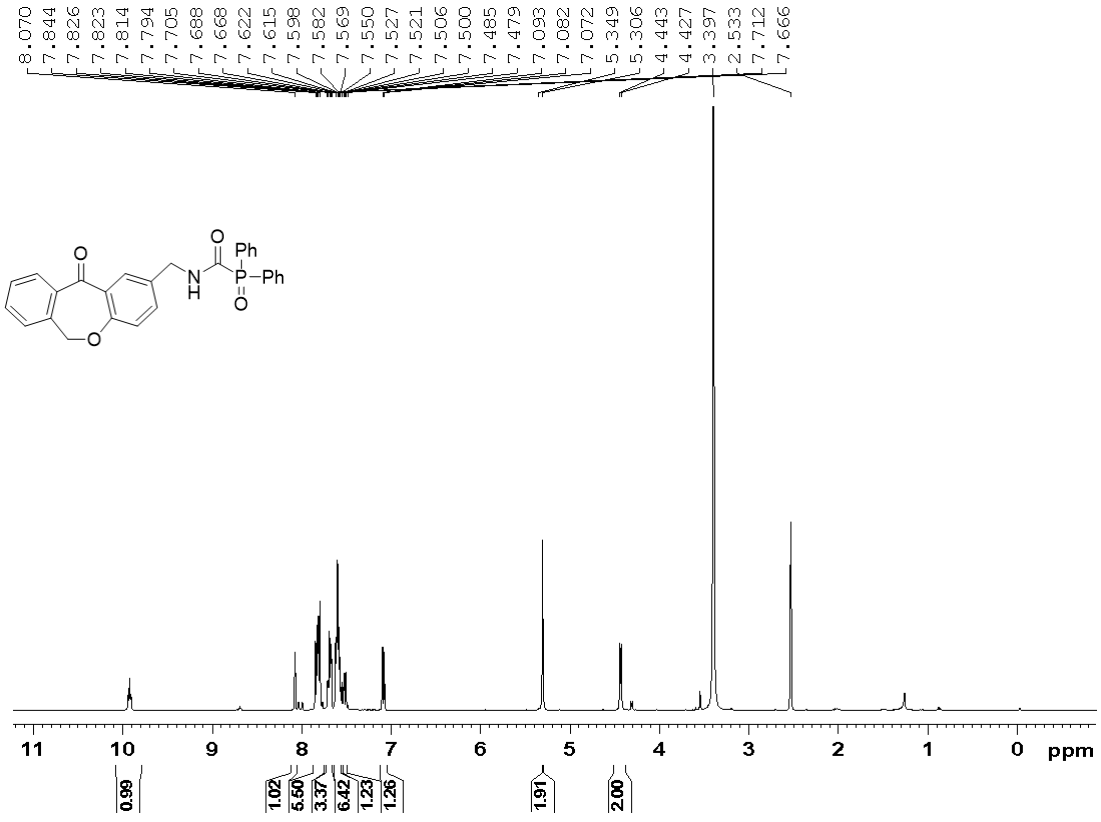
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3ag**



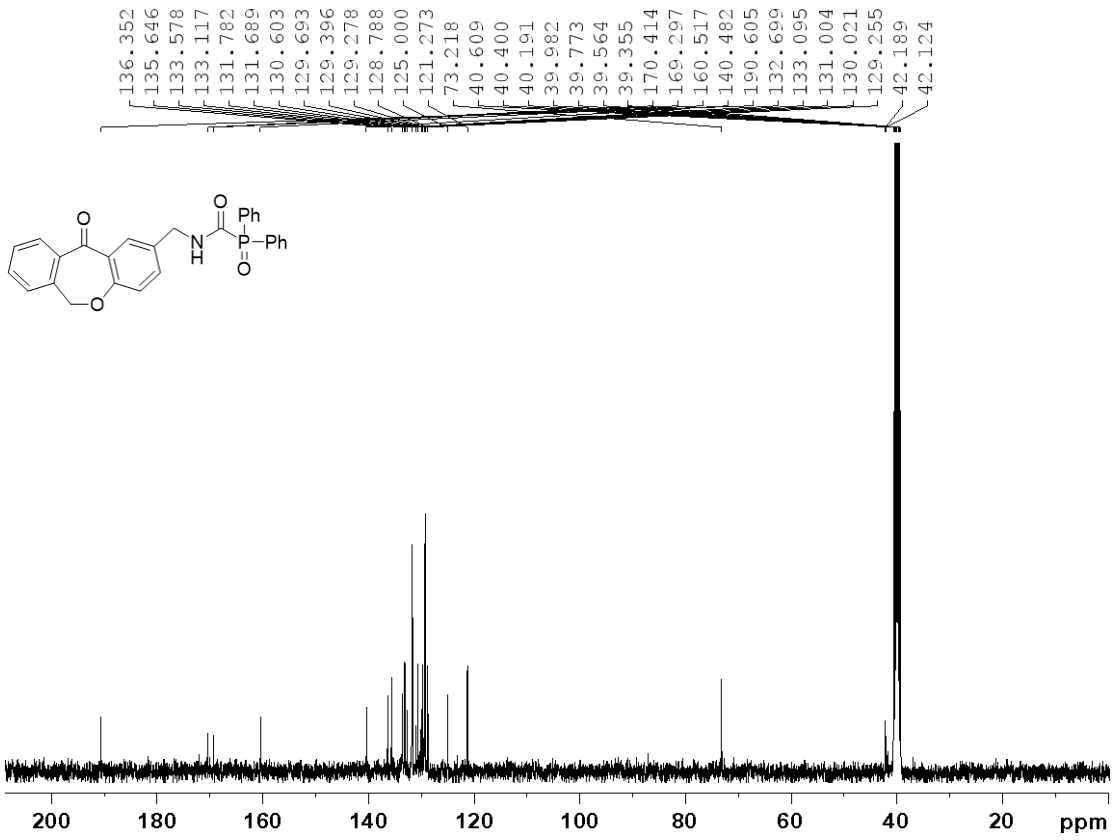
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3ag**



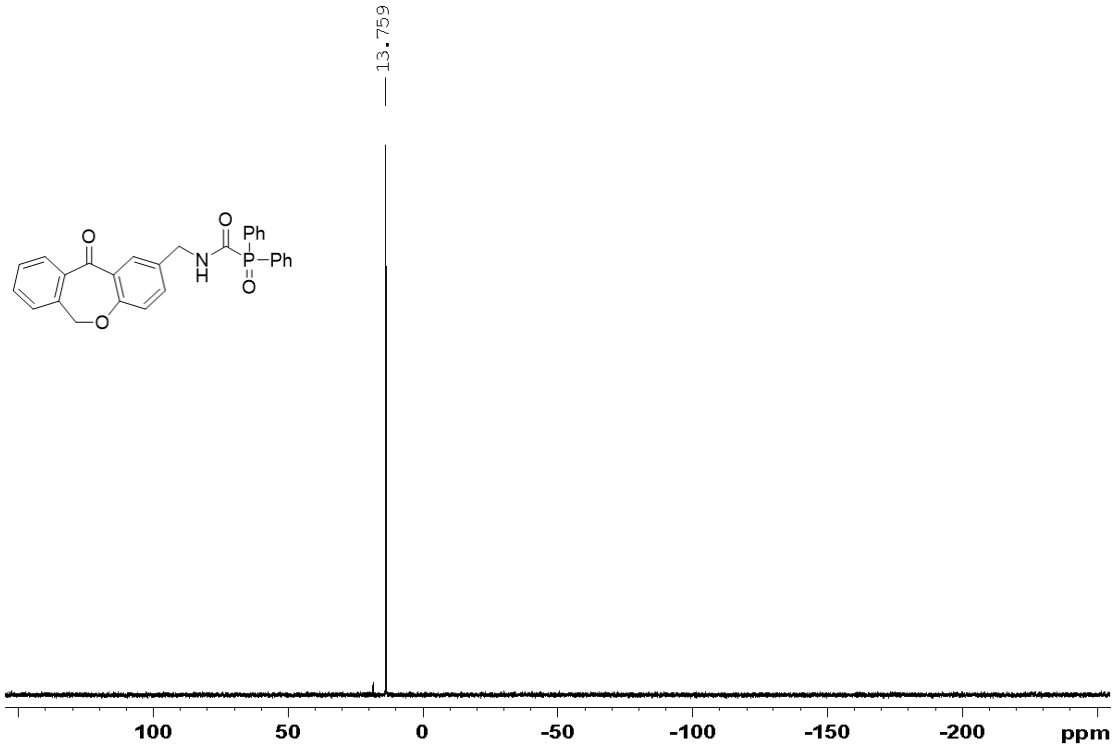
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3ag**



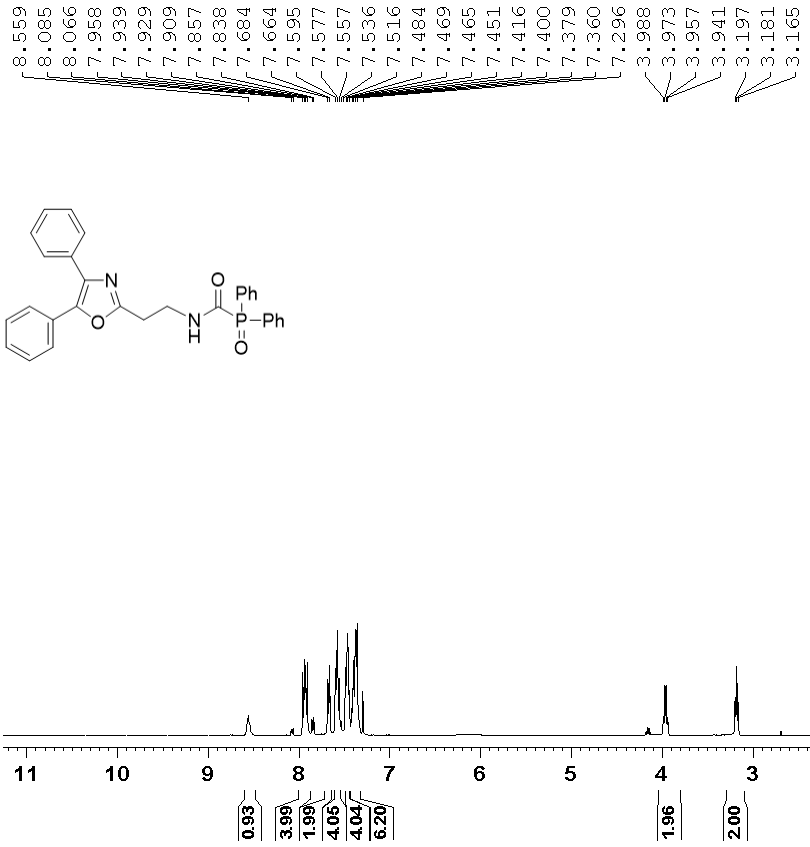
^{1}H NMR (400 MHz, DMSO) spectrum of compound **3ah**



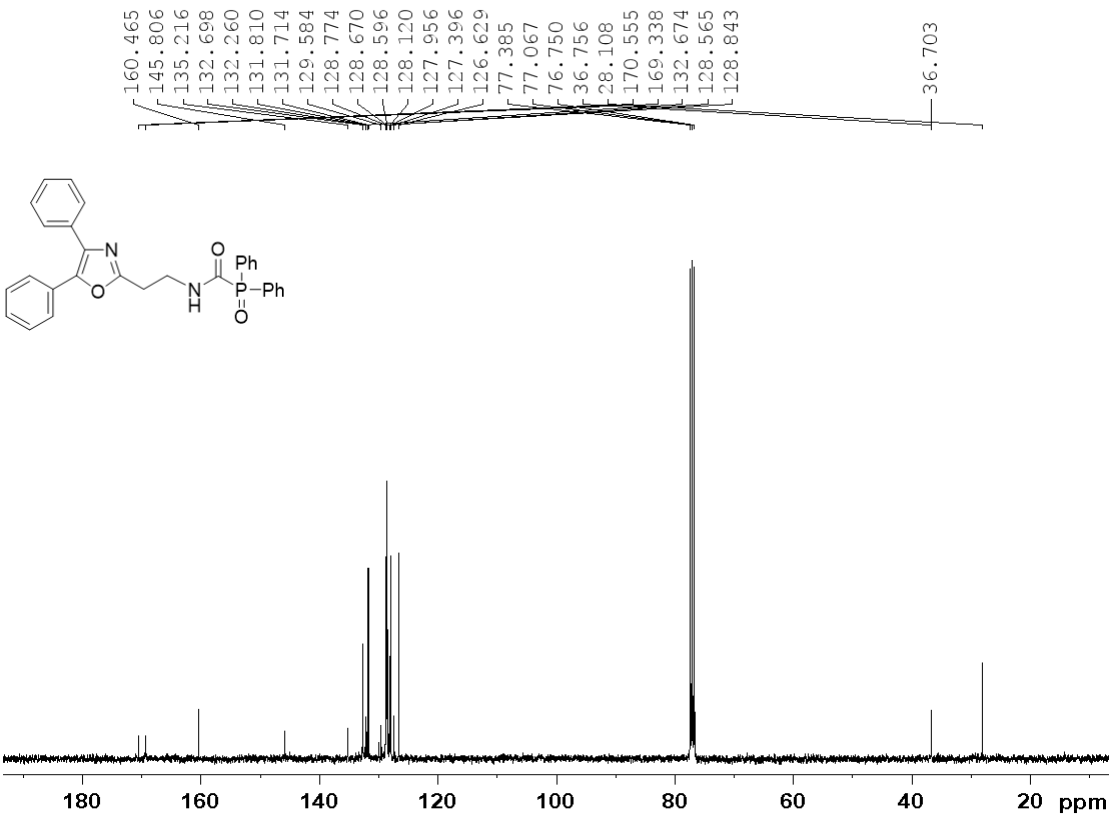
^{13}C NMR (101 MHz, DMSO) spectrum of compound **3ah**



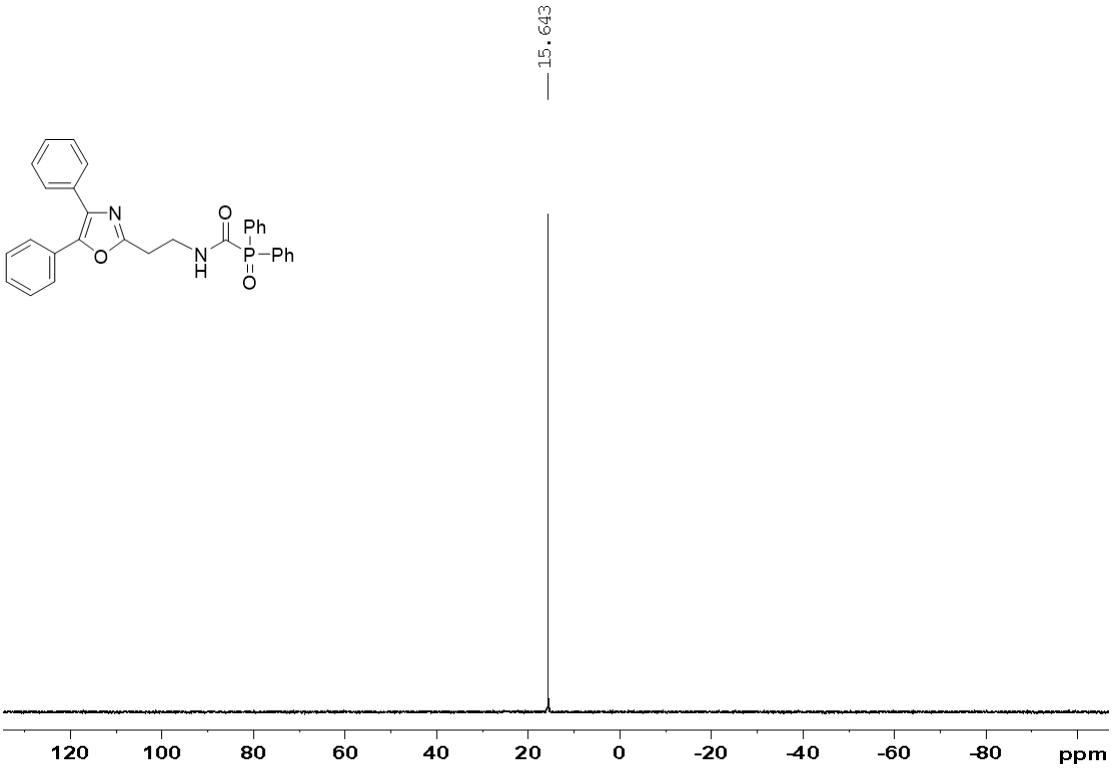
^{31}P NMR (162 MHz, DMSO) spectrum of compound **3ah**



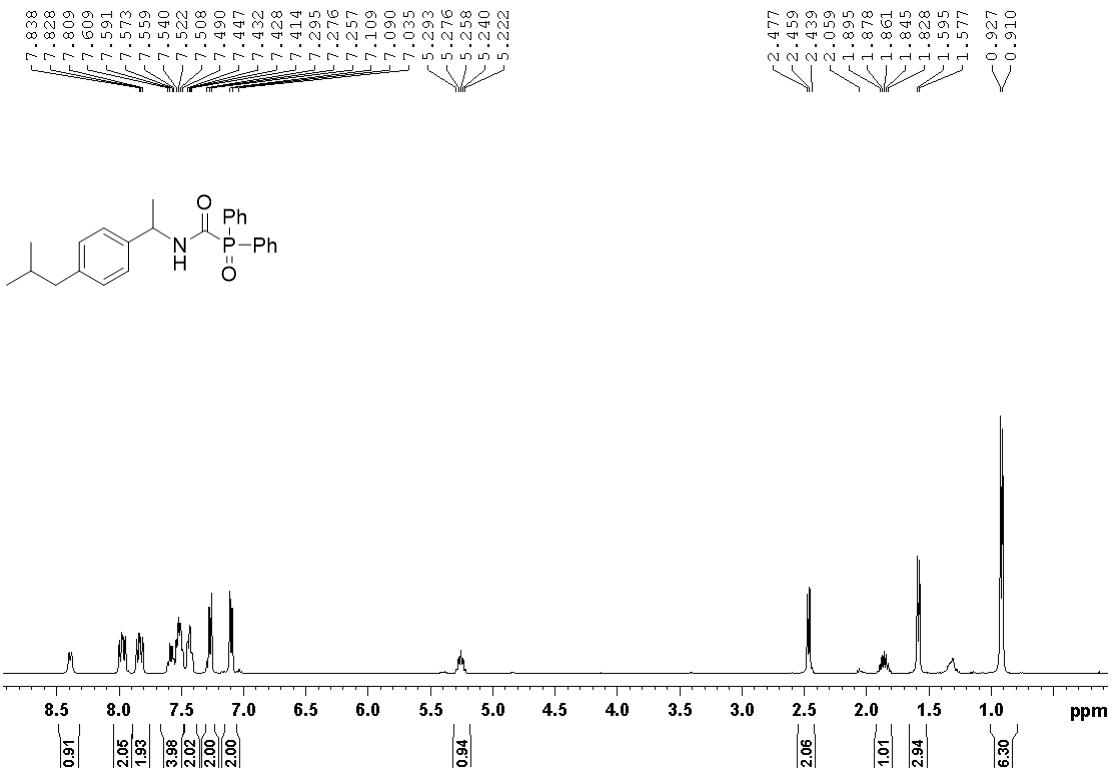
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3ai**



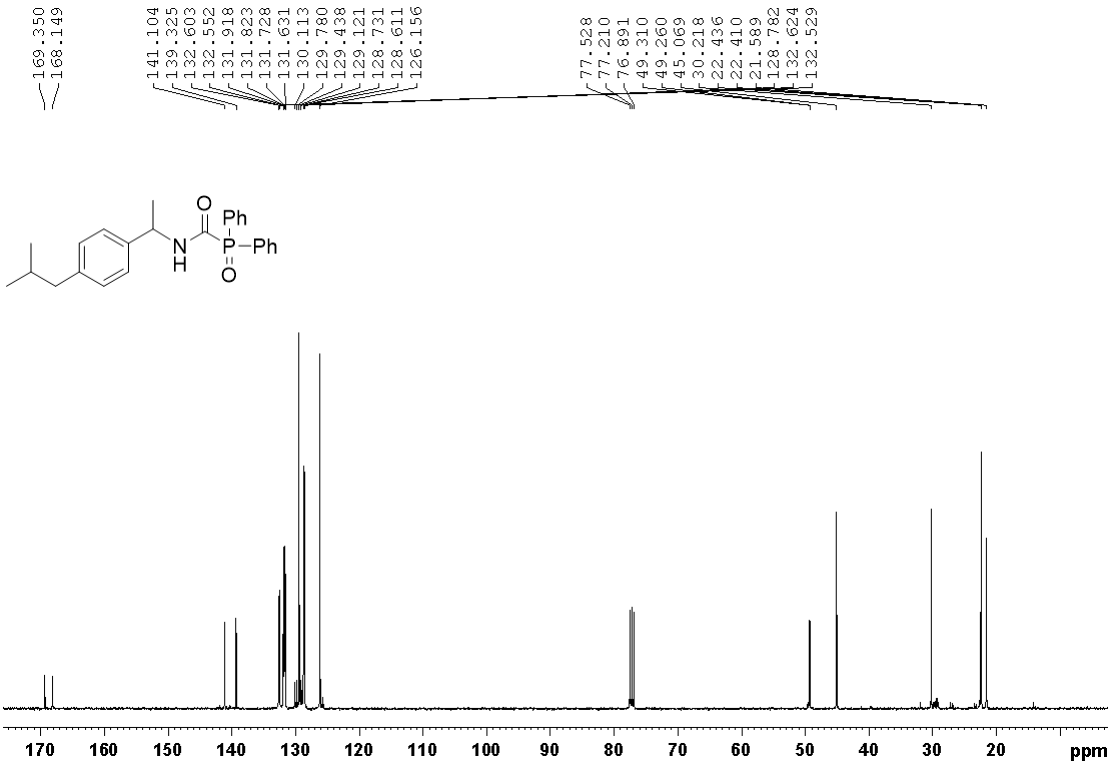
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3ai**



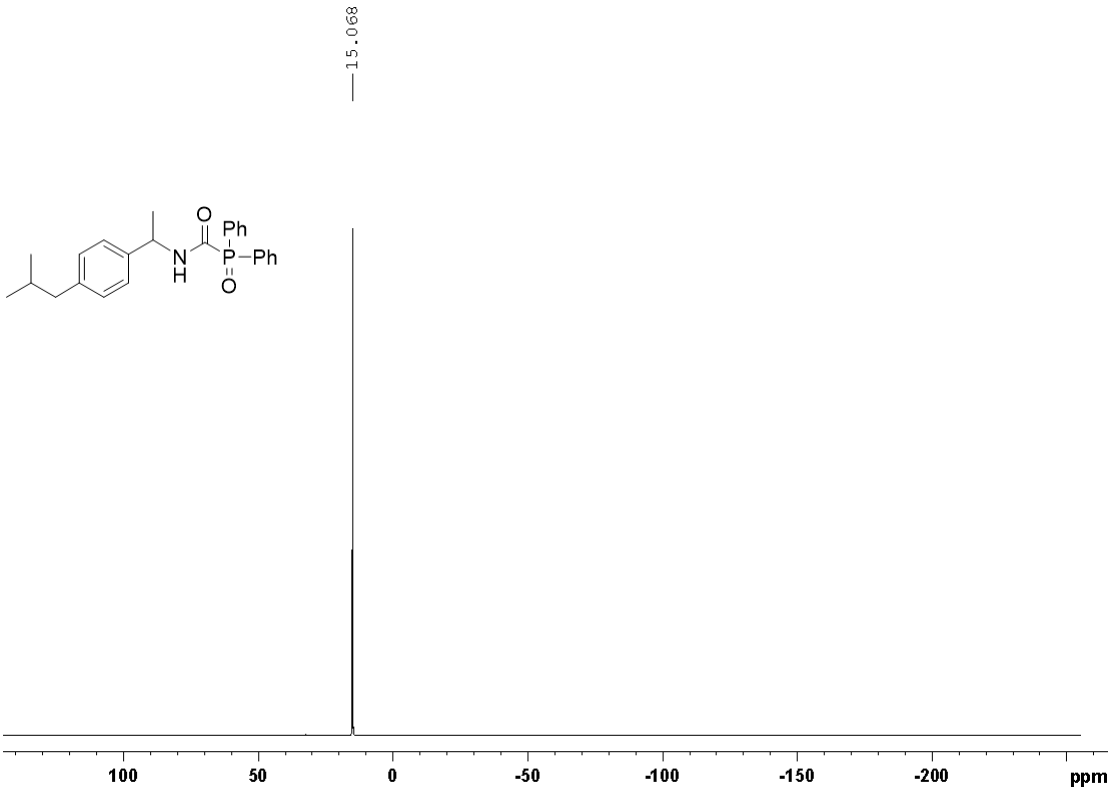
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3ai**



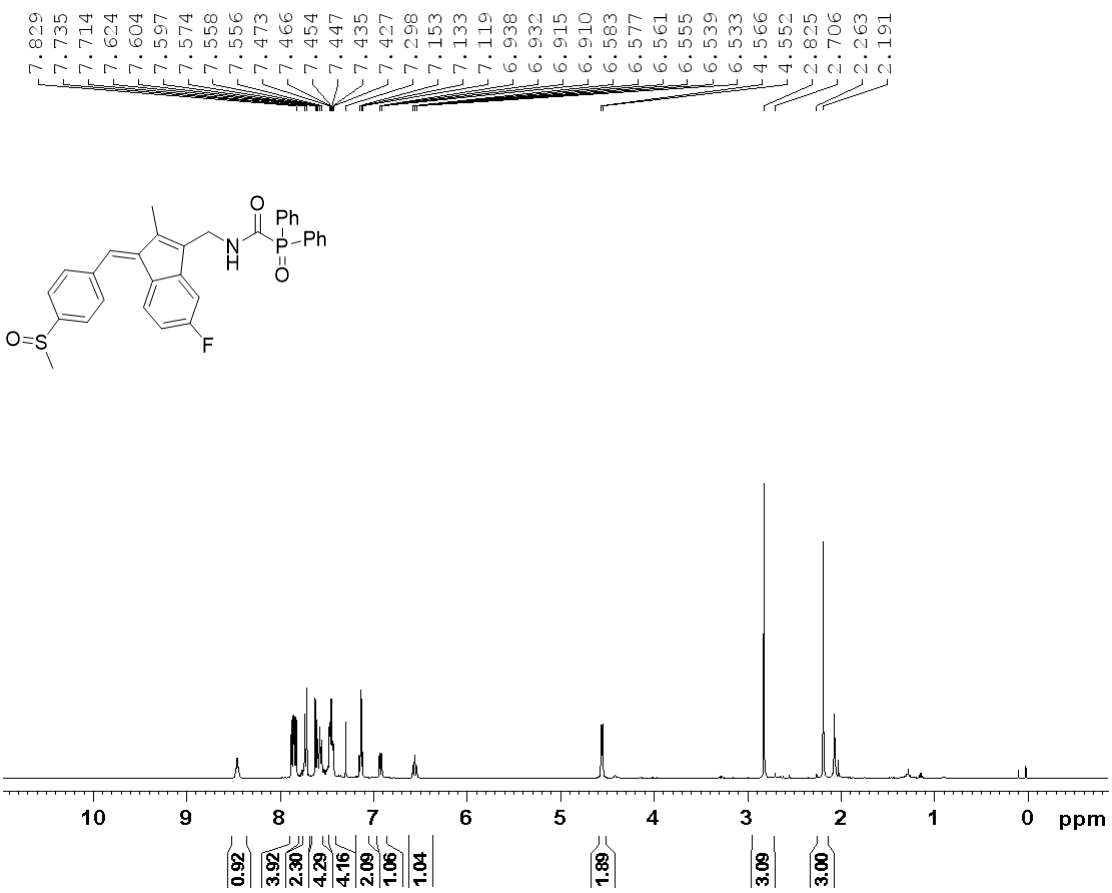
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3aj**



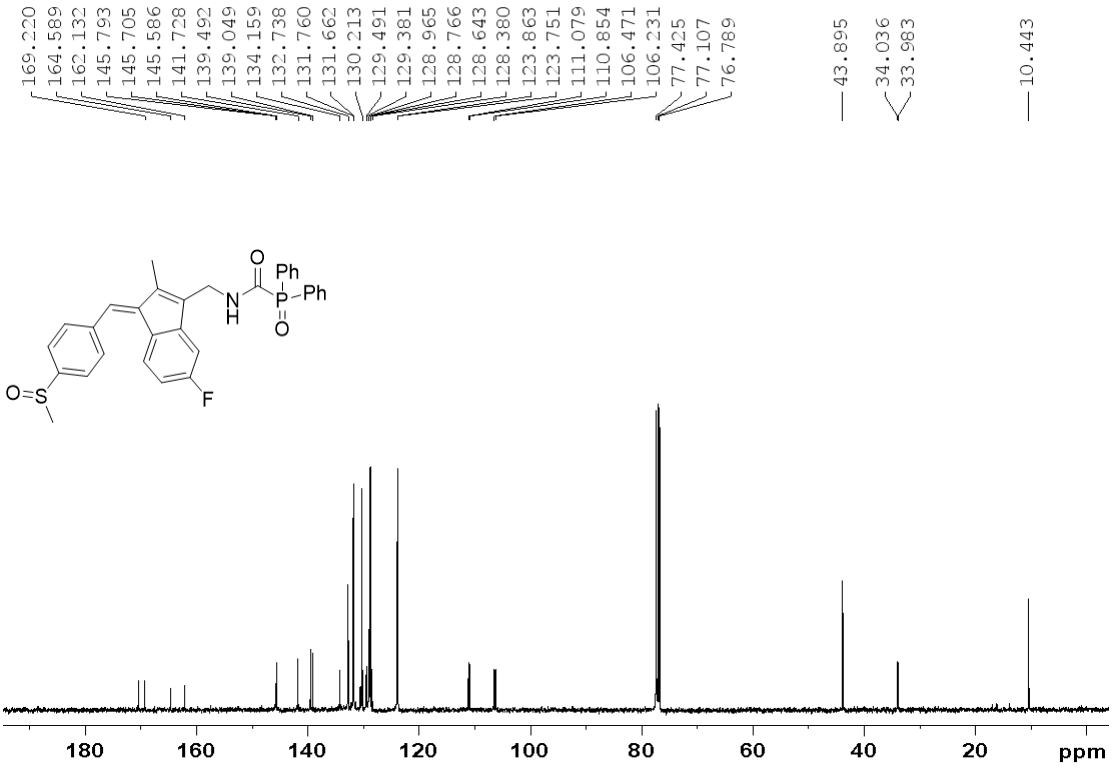
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3aj**



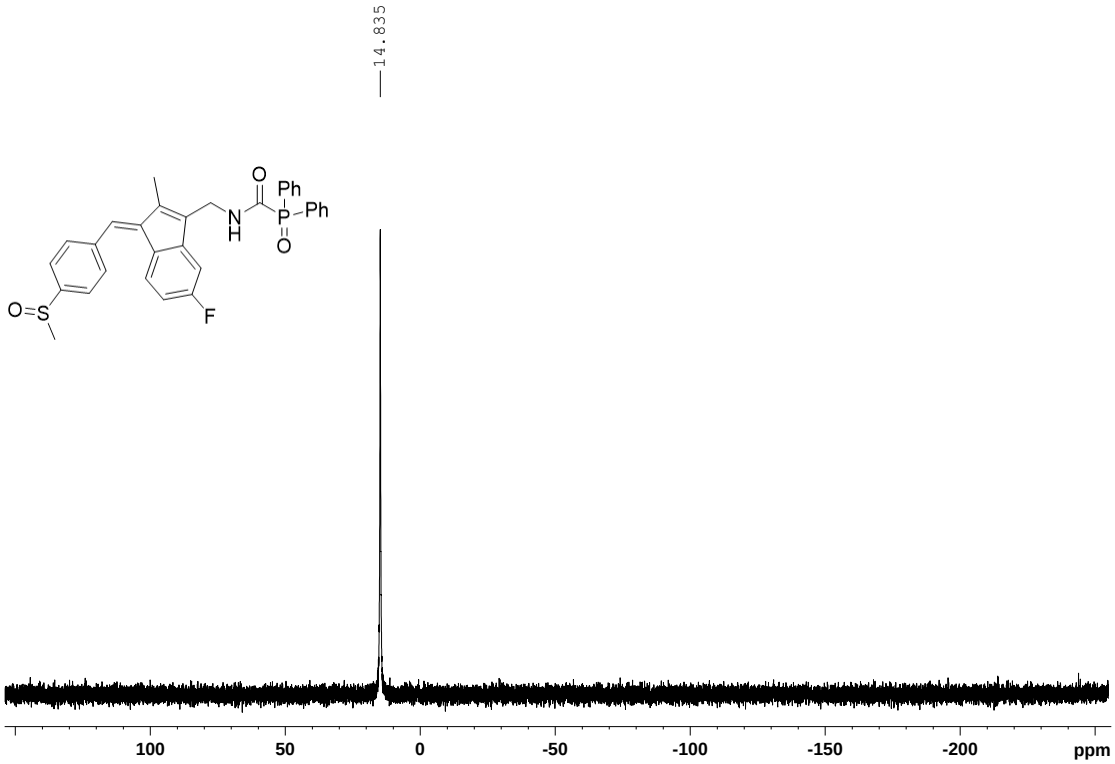
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3aj**



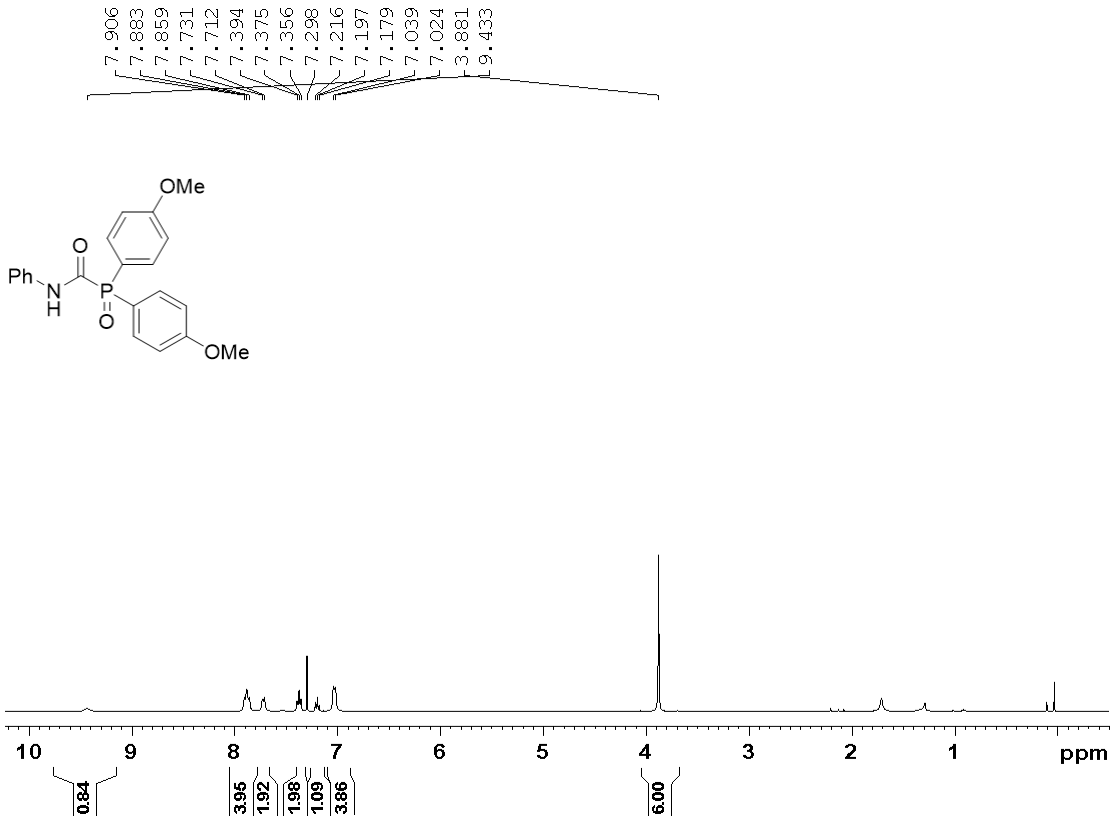
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3ak**



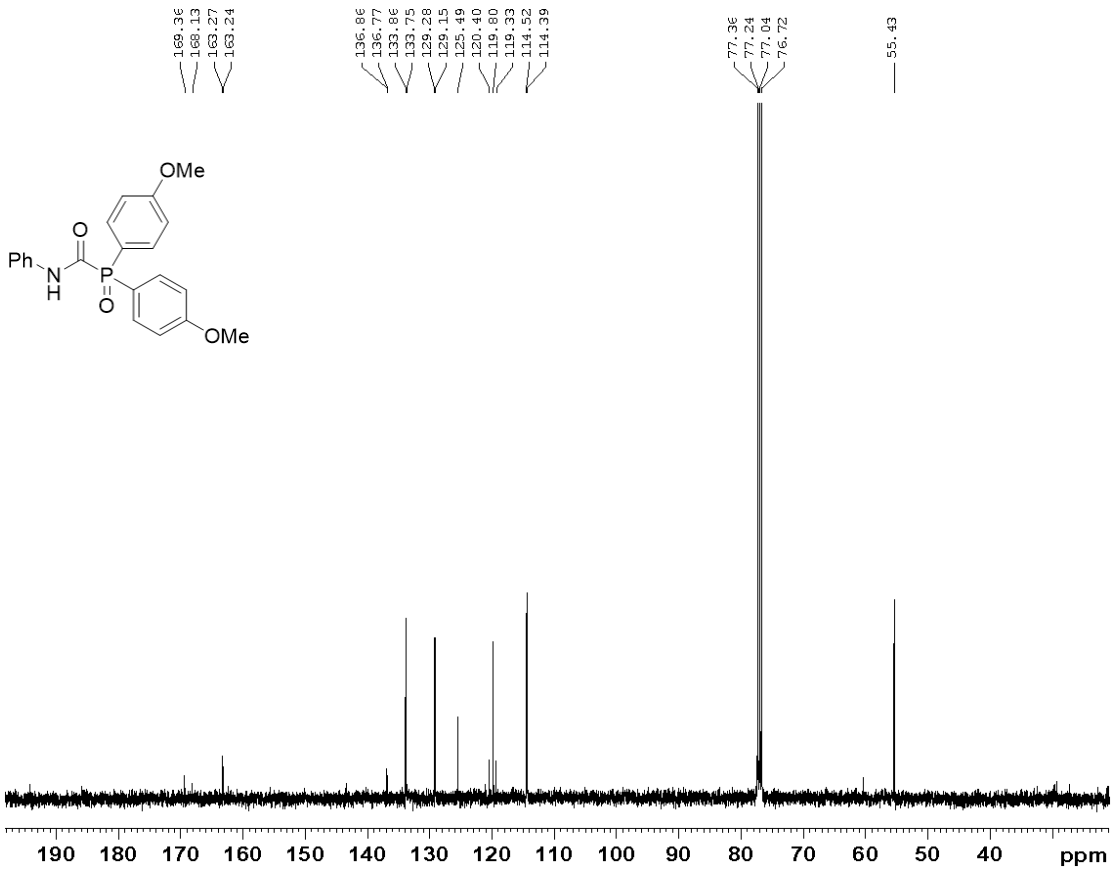
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3ak**



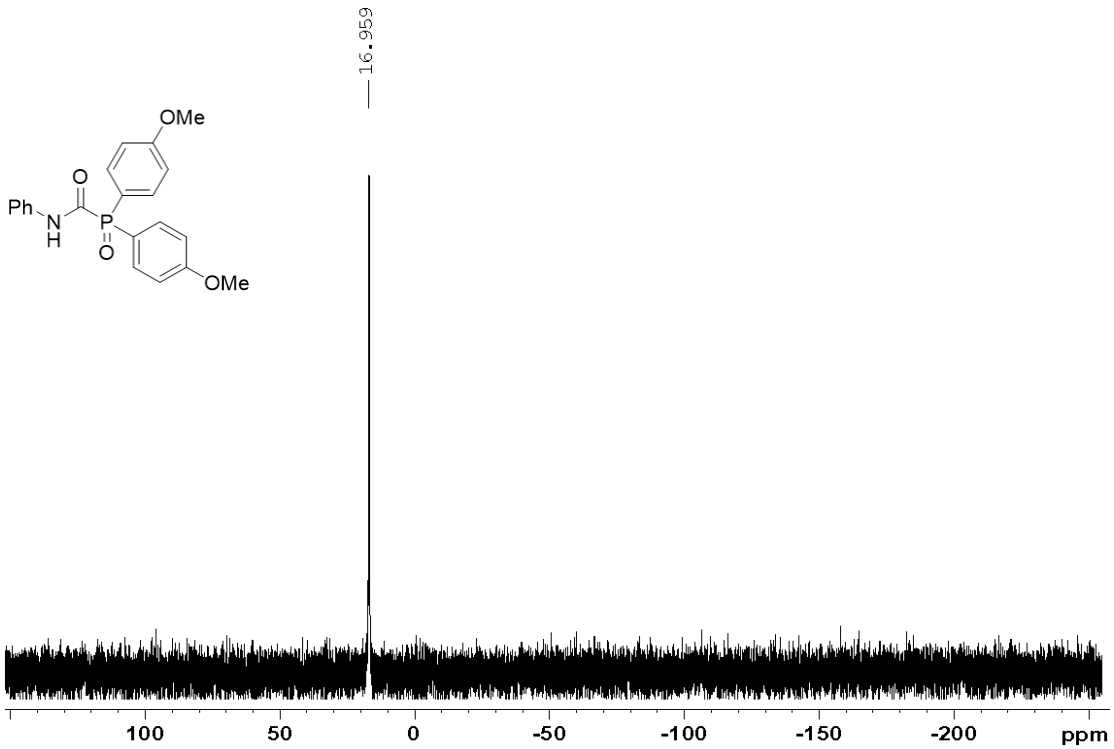
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3ak**



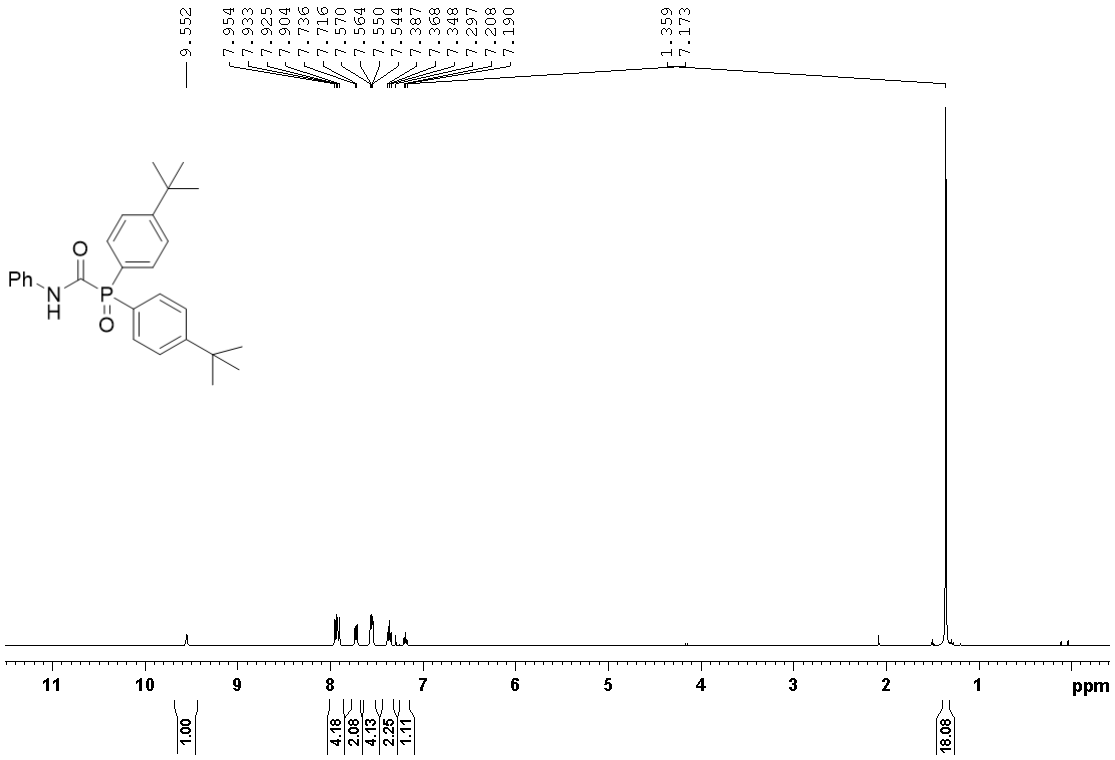
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3al**



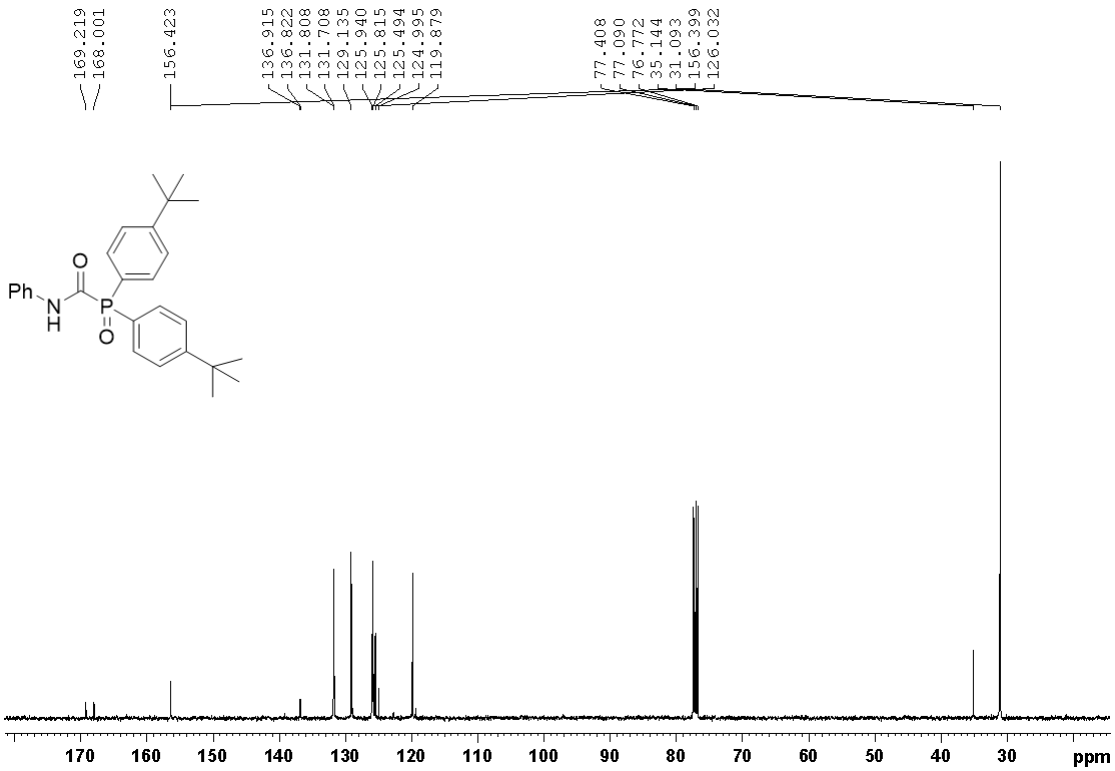
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3al**



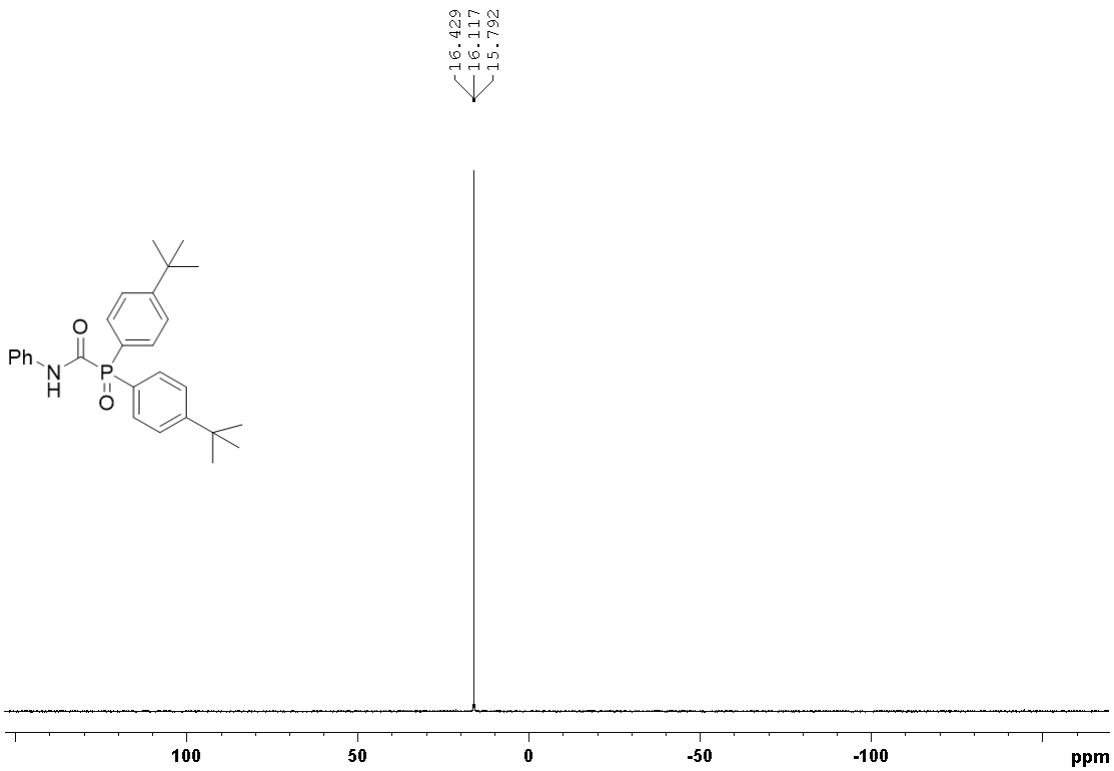
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3al**



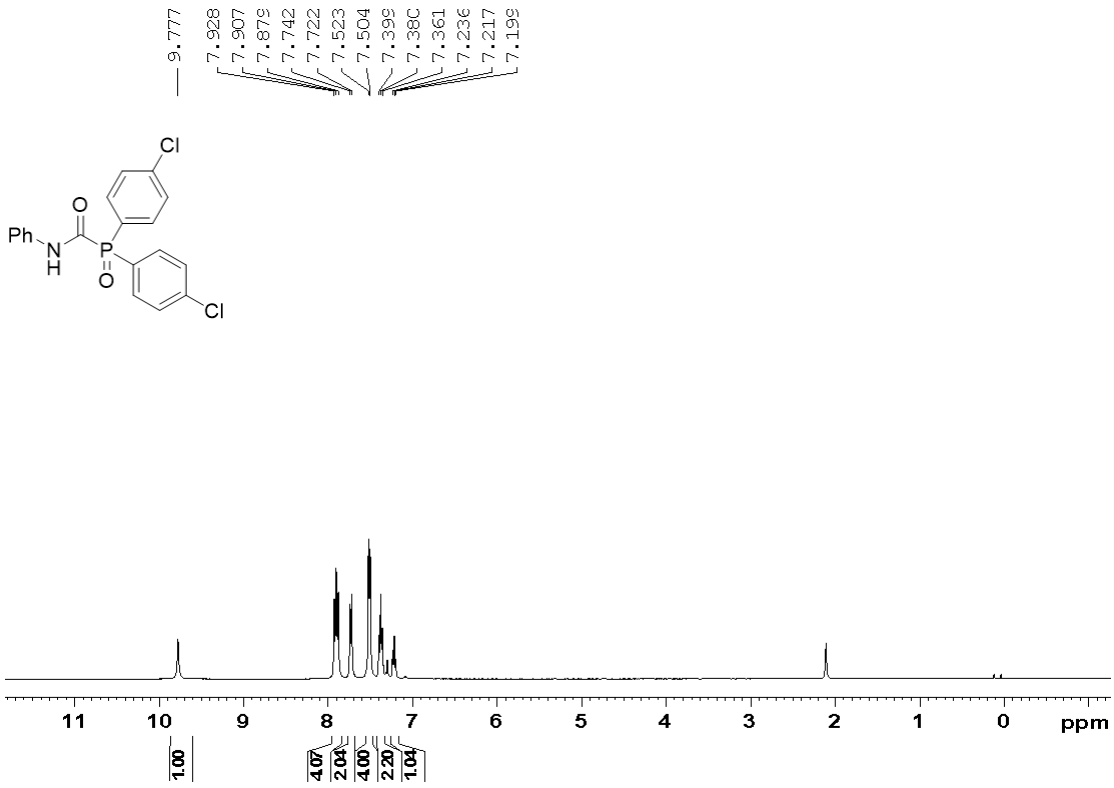
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3am**



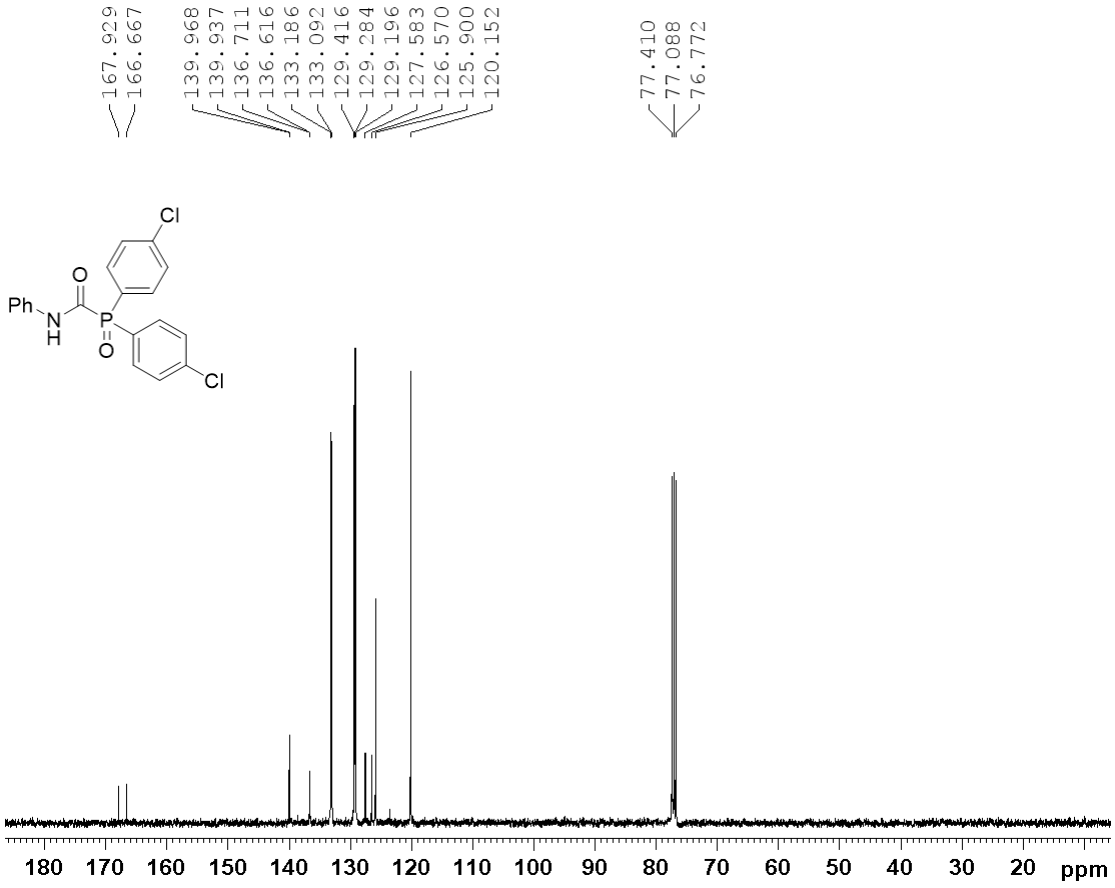
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3am**



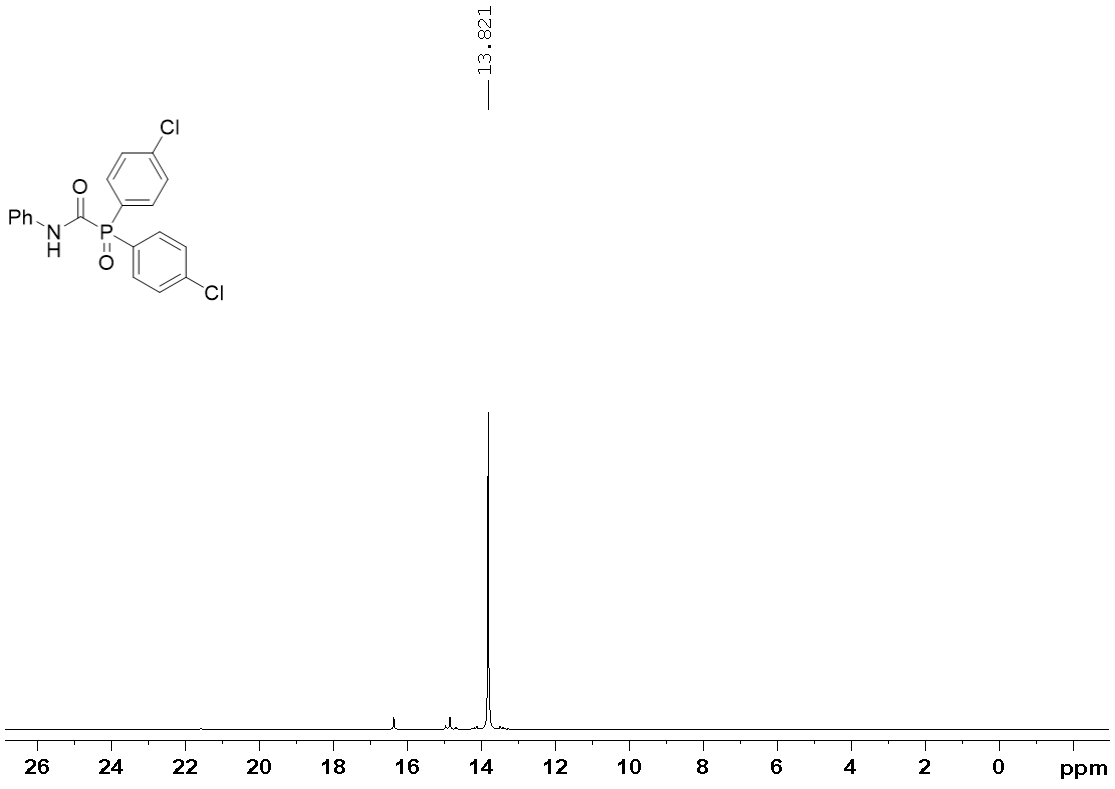
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3am**



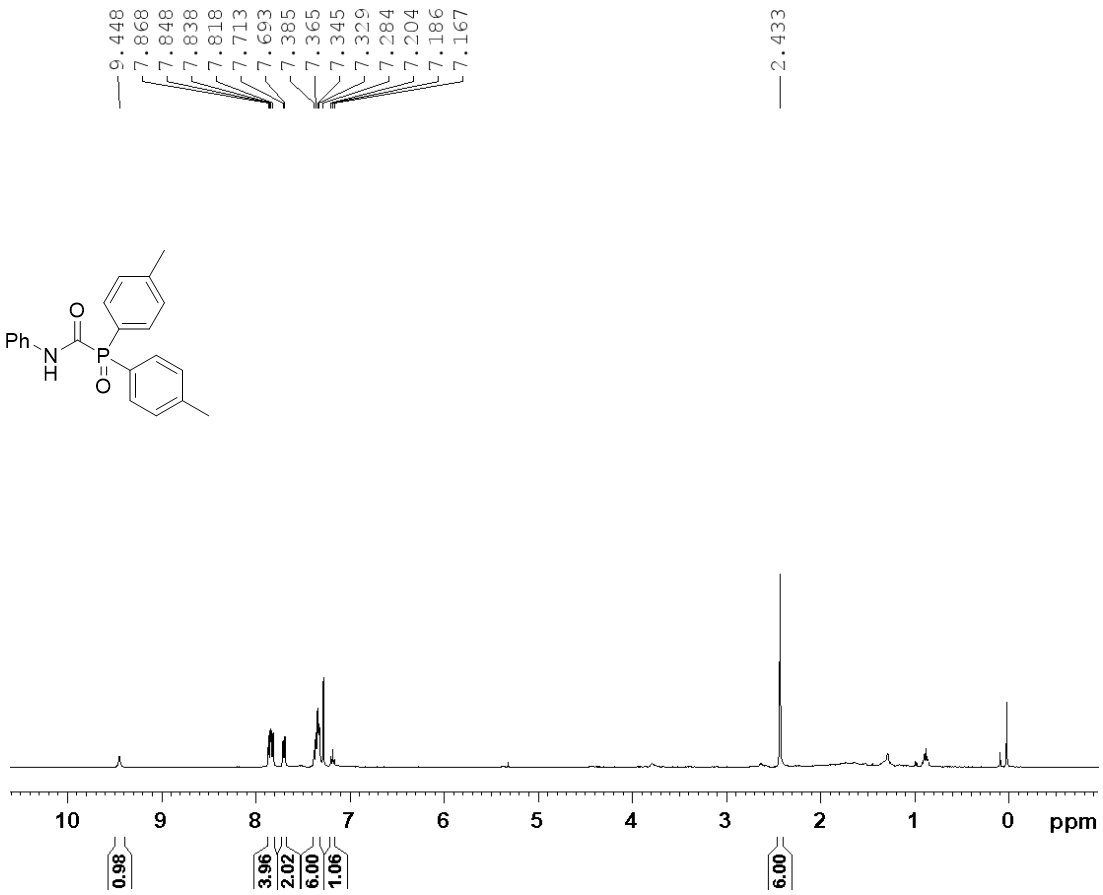
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3an**



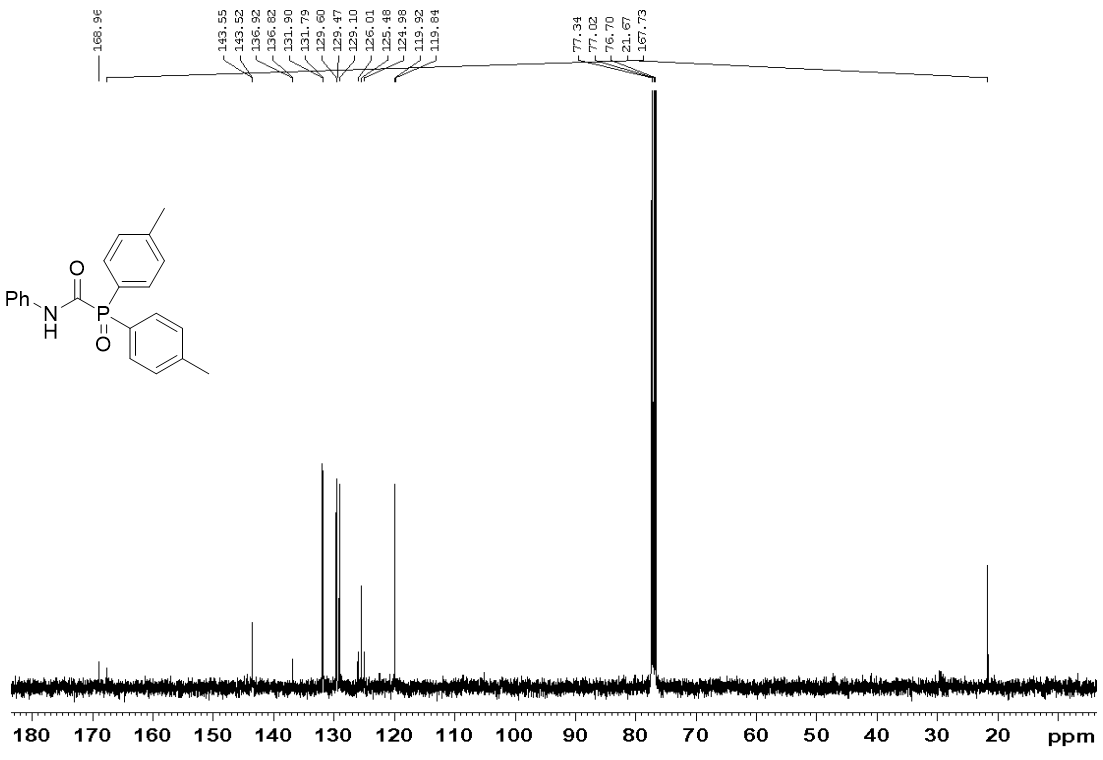
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3an**



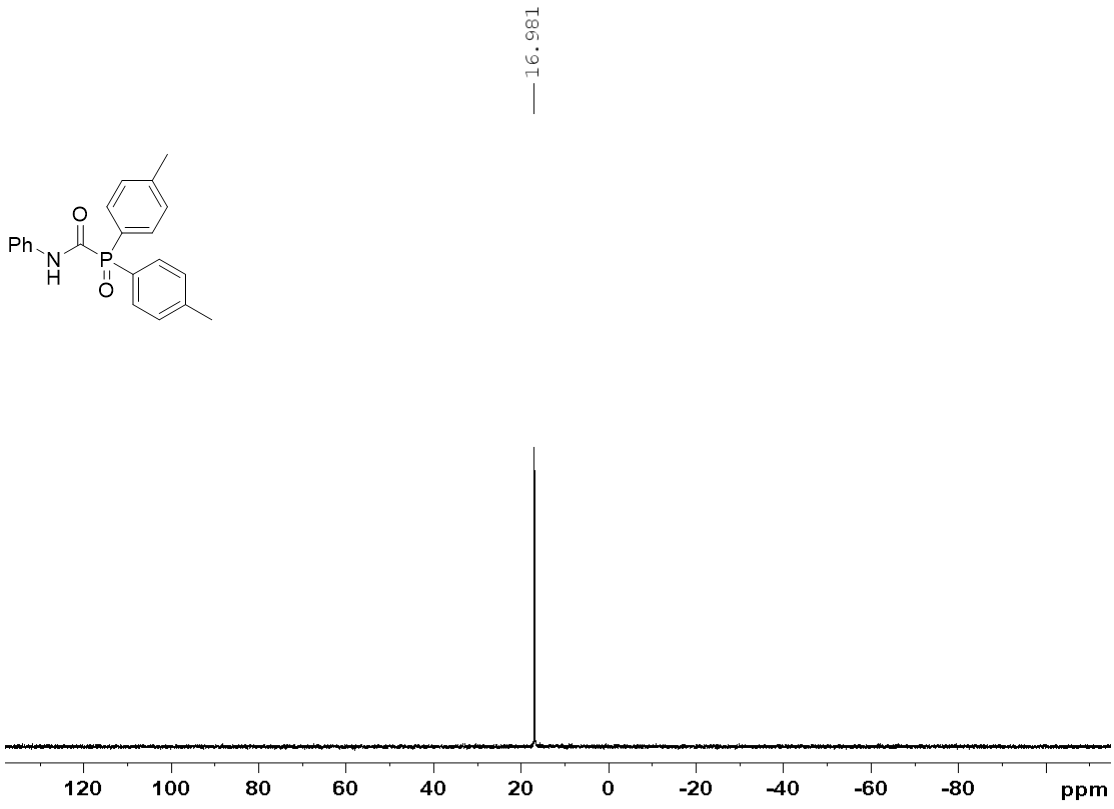
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3an**



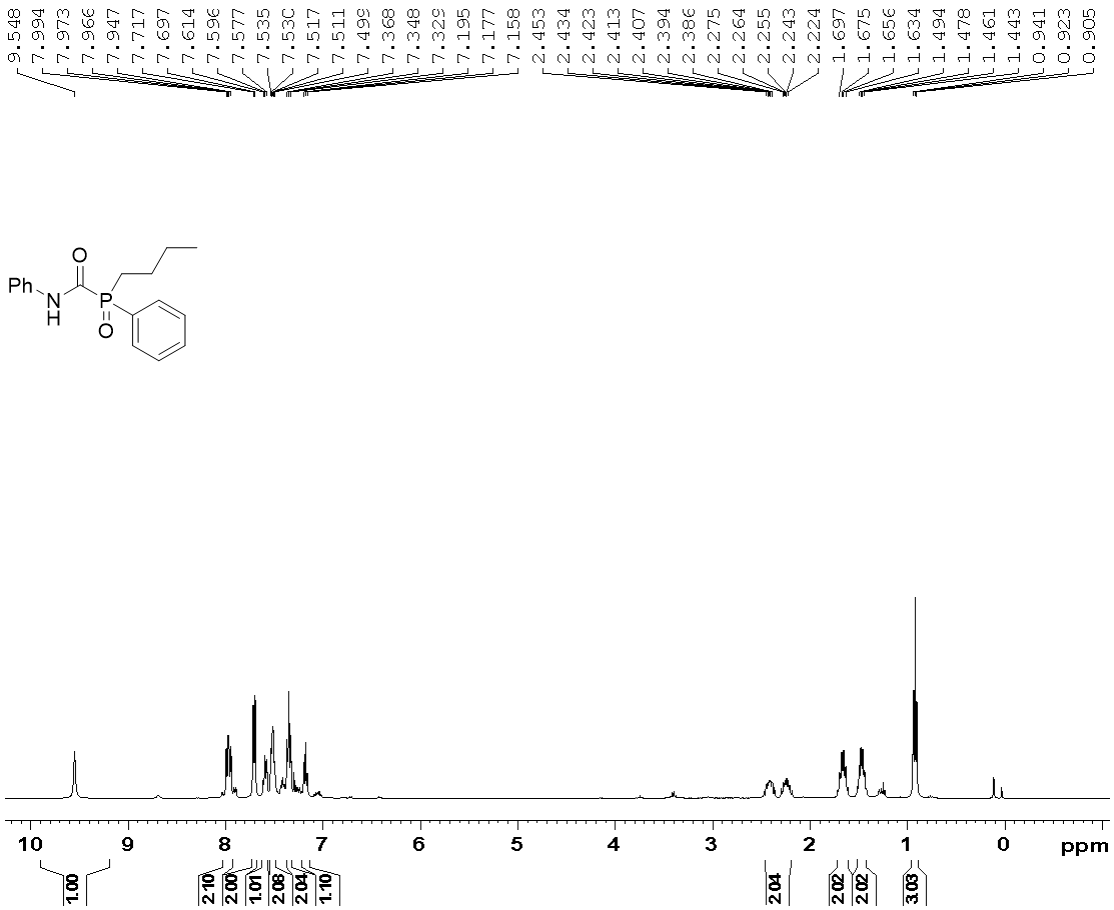
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3ao**



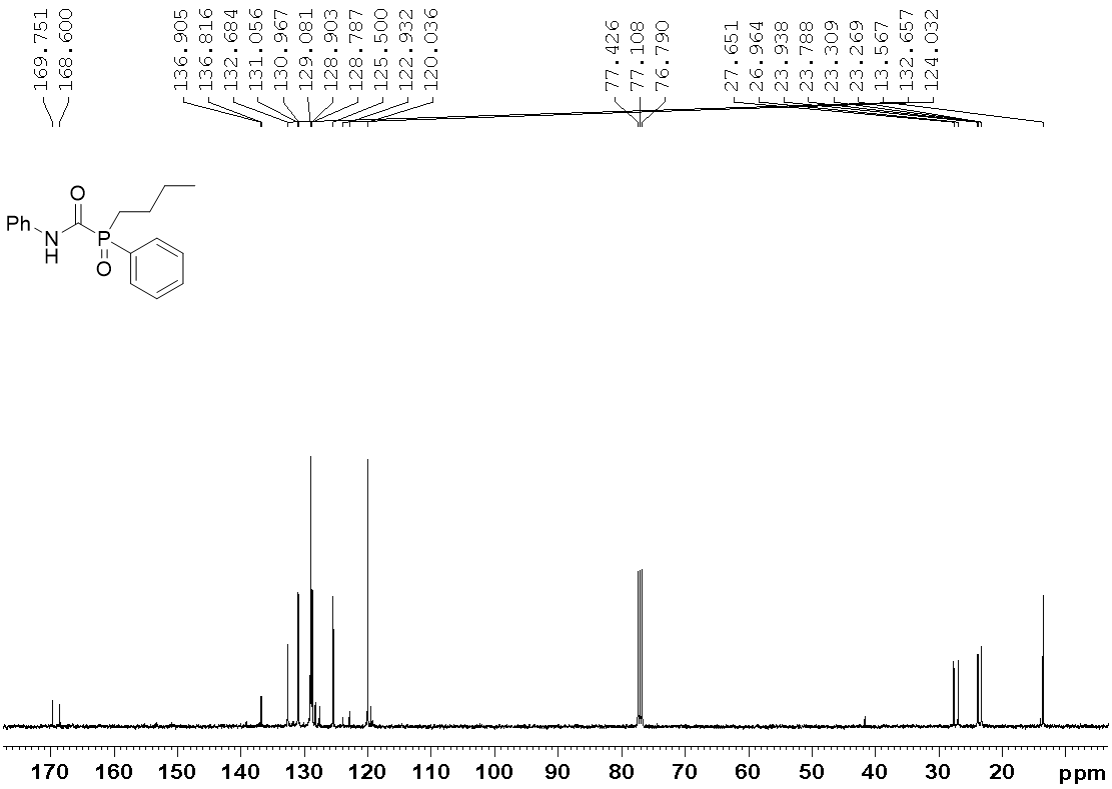
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3ao**



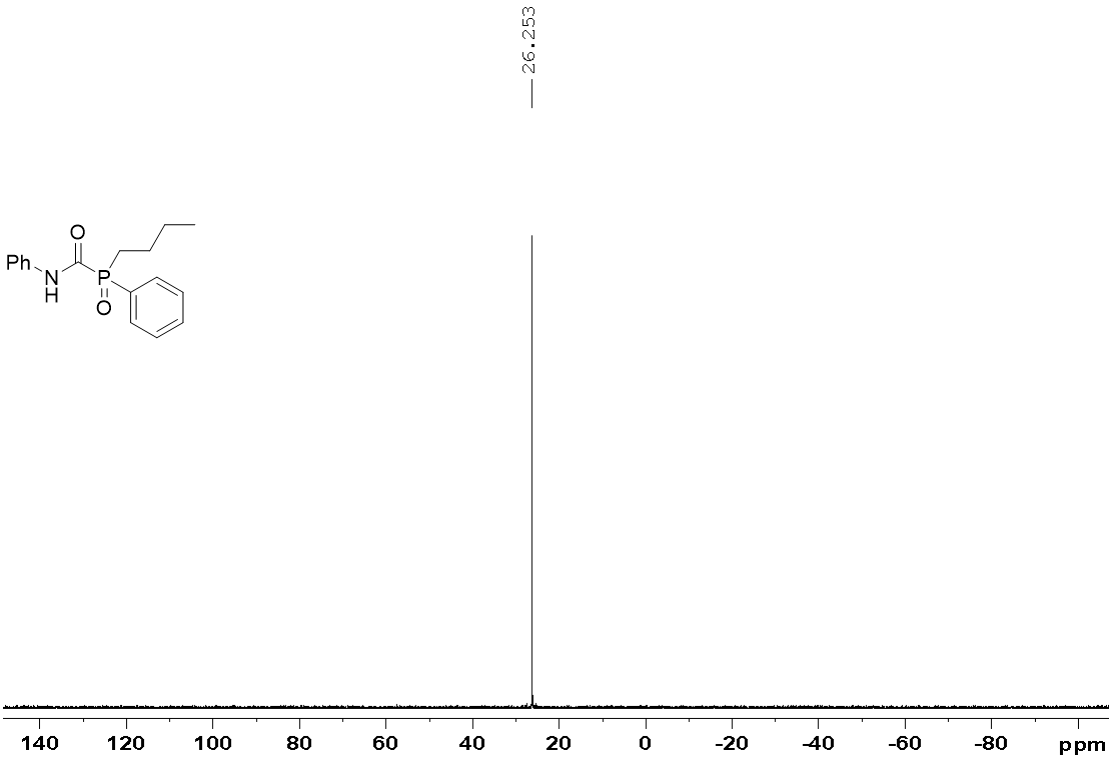
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3ao**



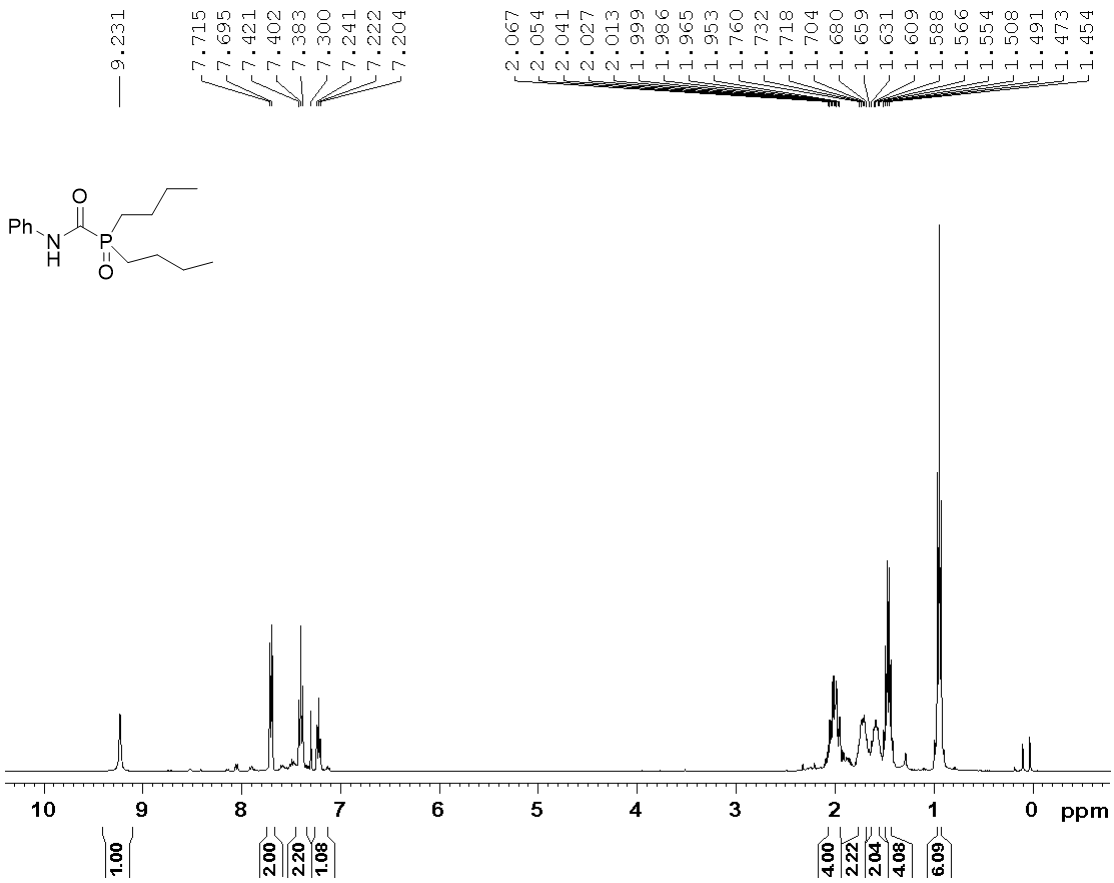
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3ap**



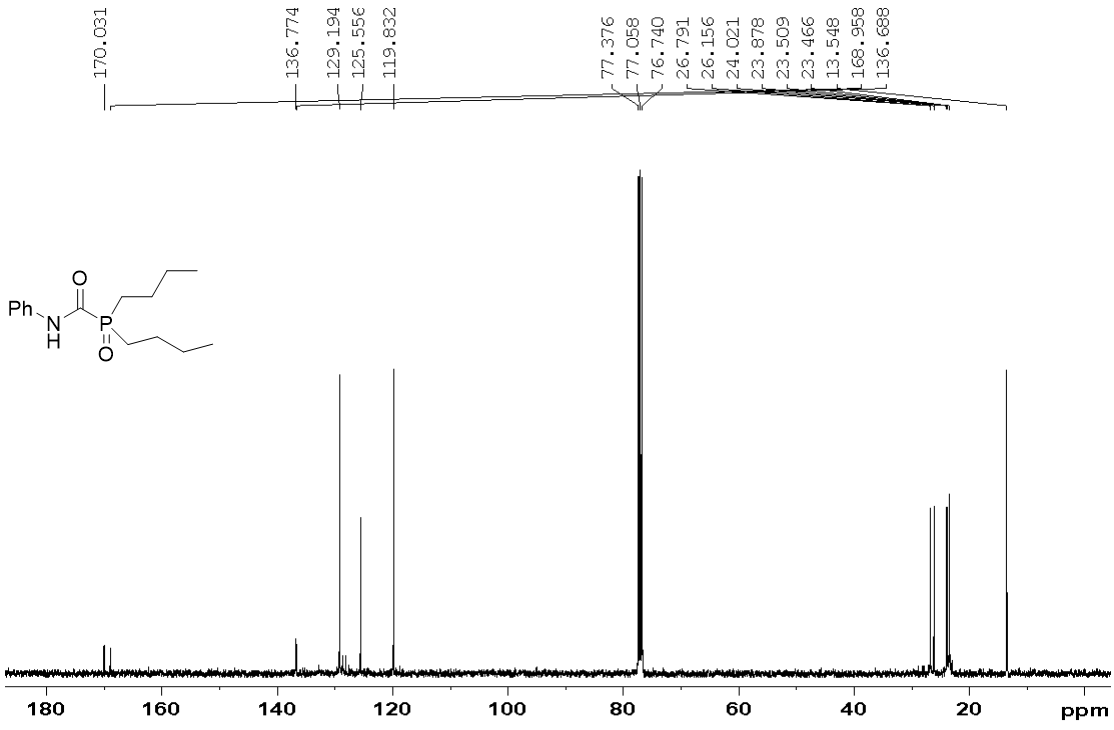
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3ap**



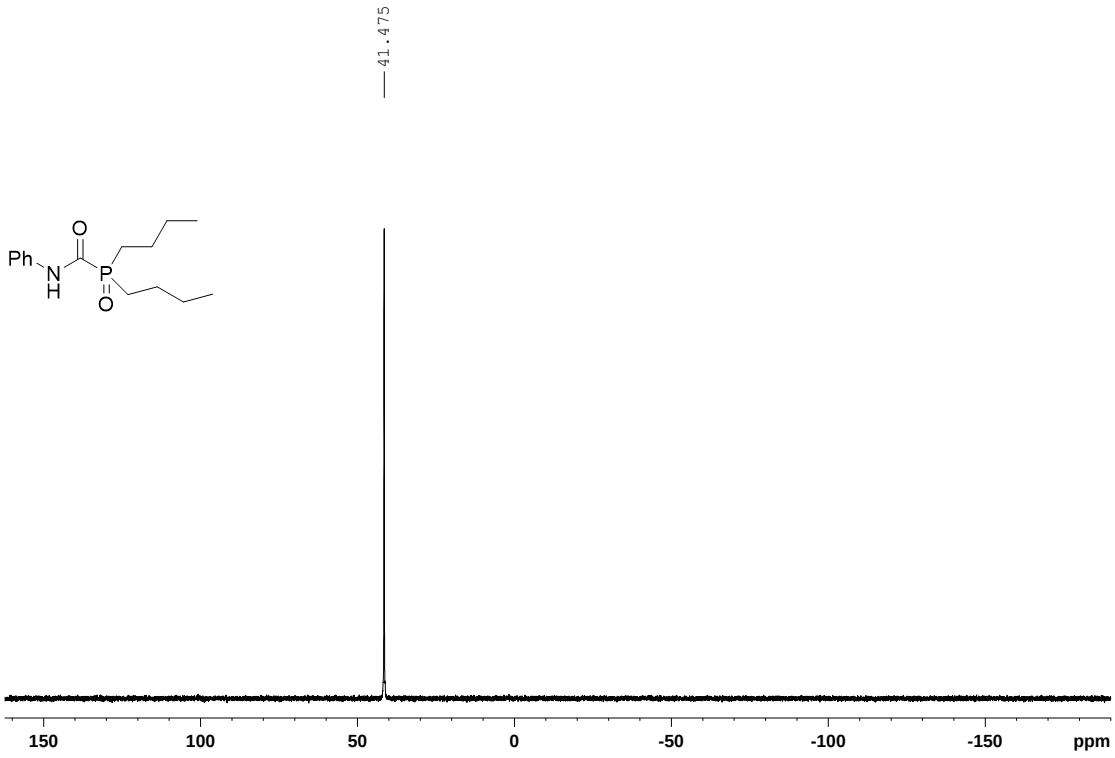
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3ap**



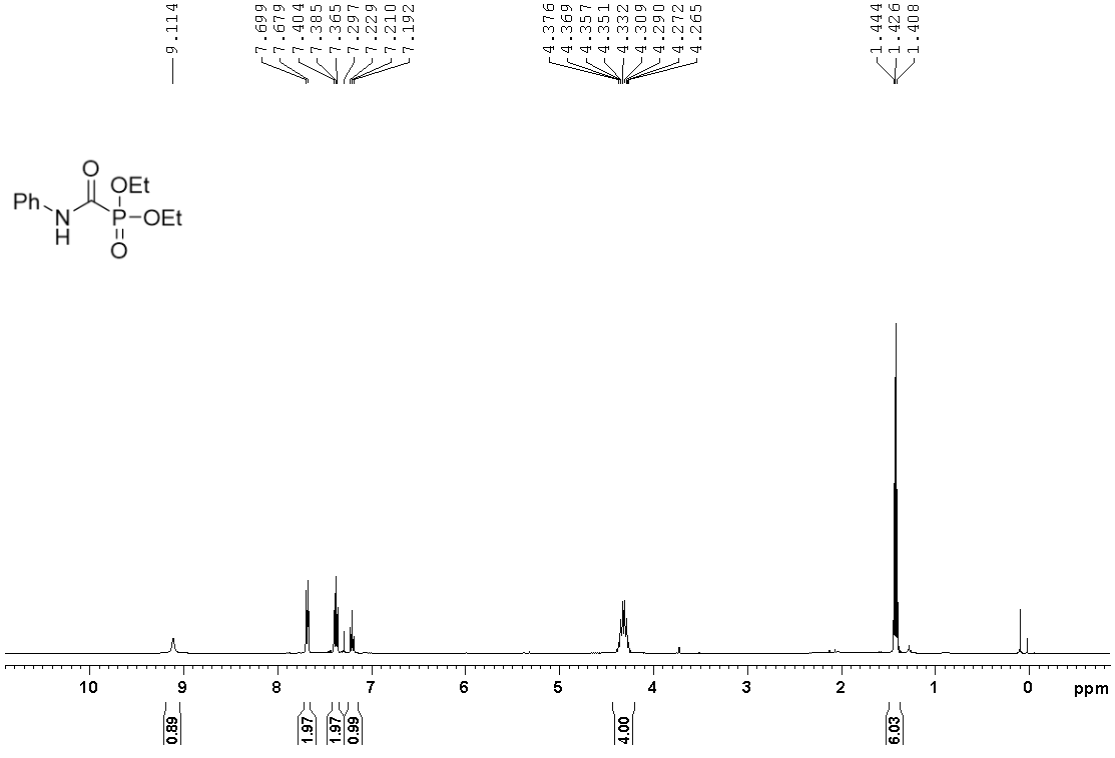
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3aq**



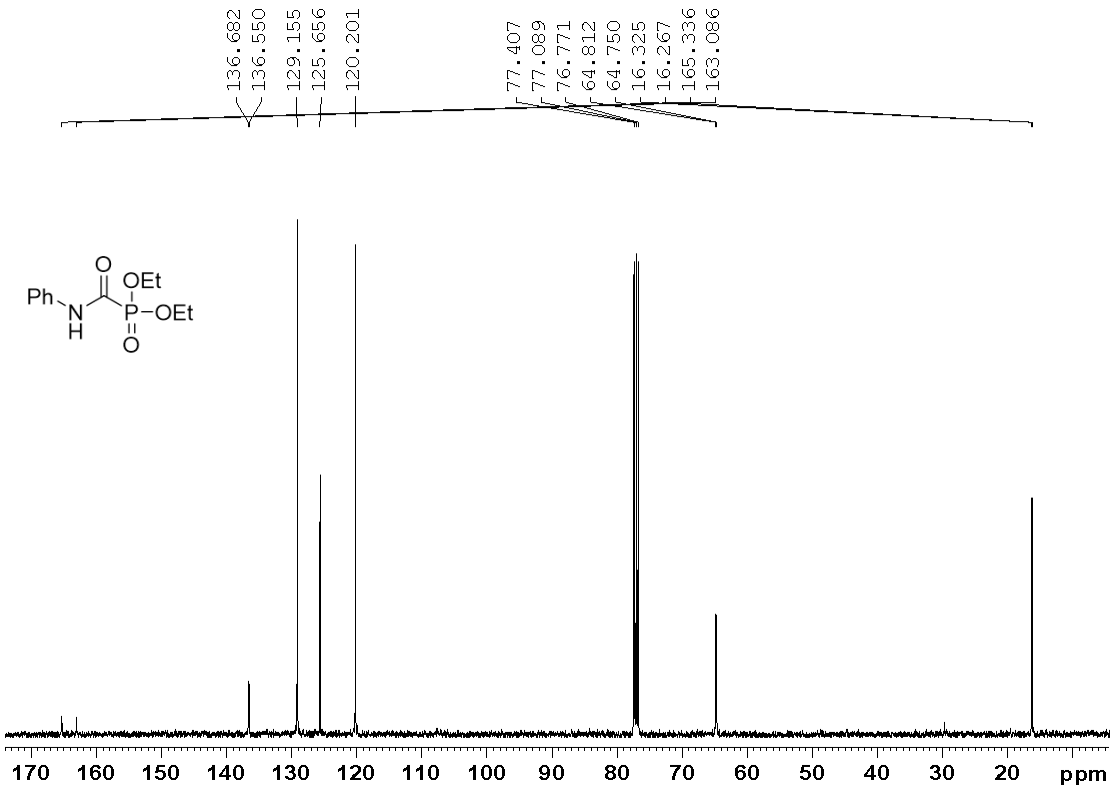
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3aq**



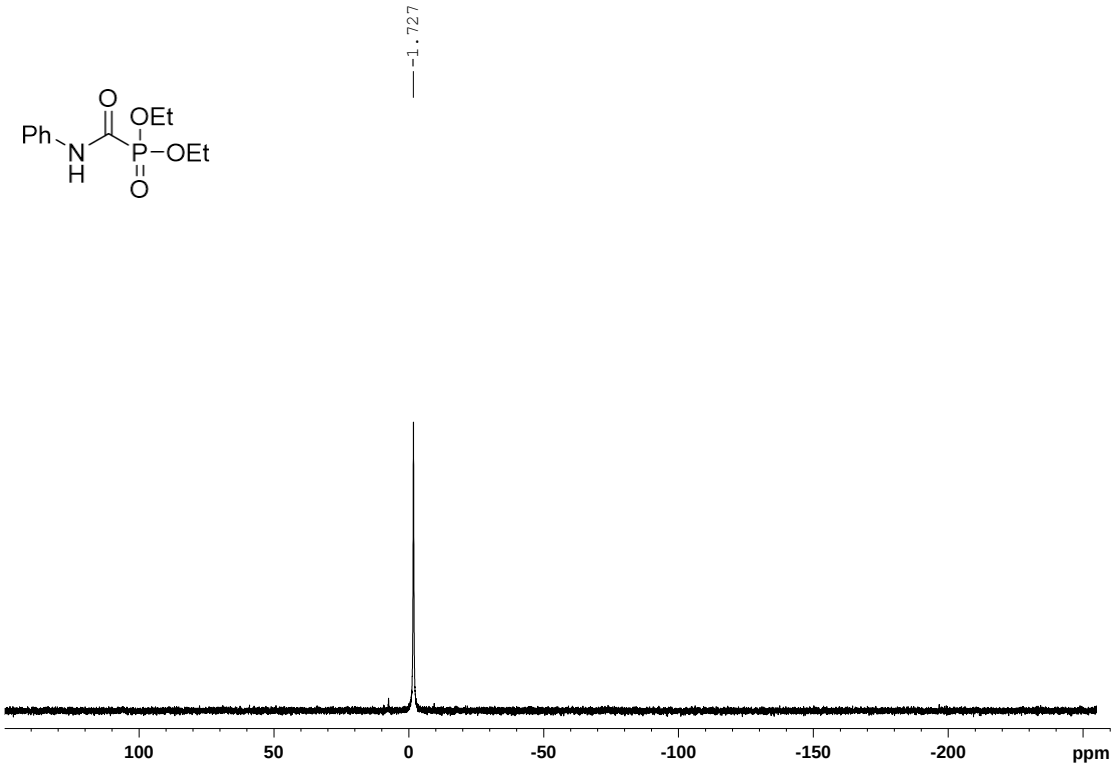
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3aq**



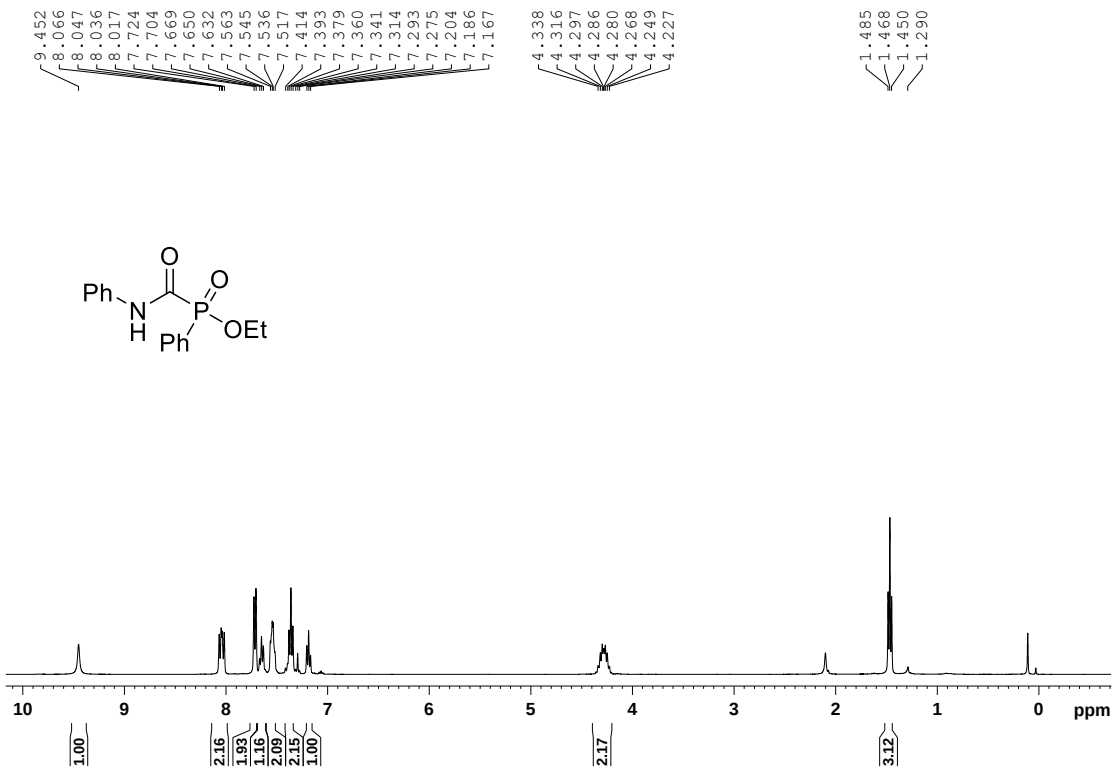
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3ar**



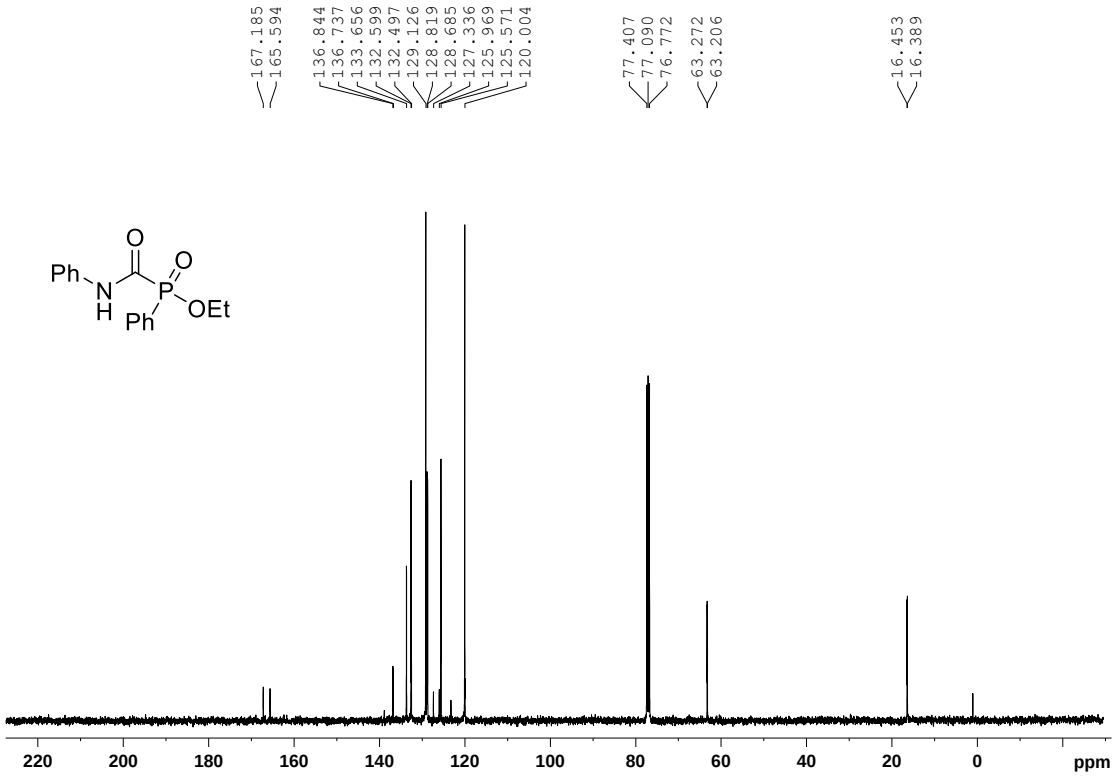
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3ar**



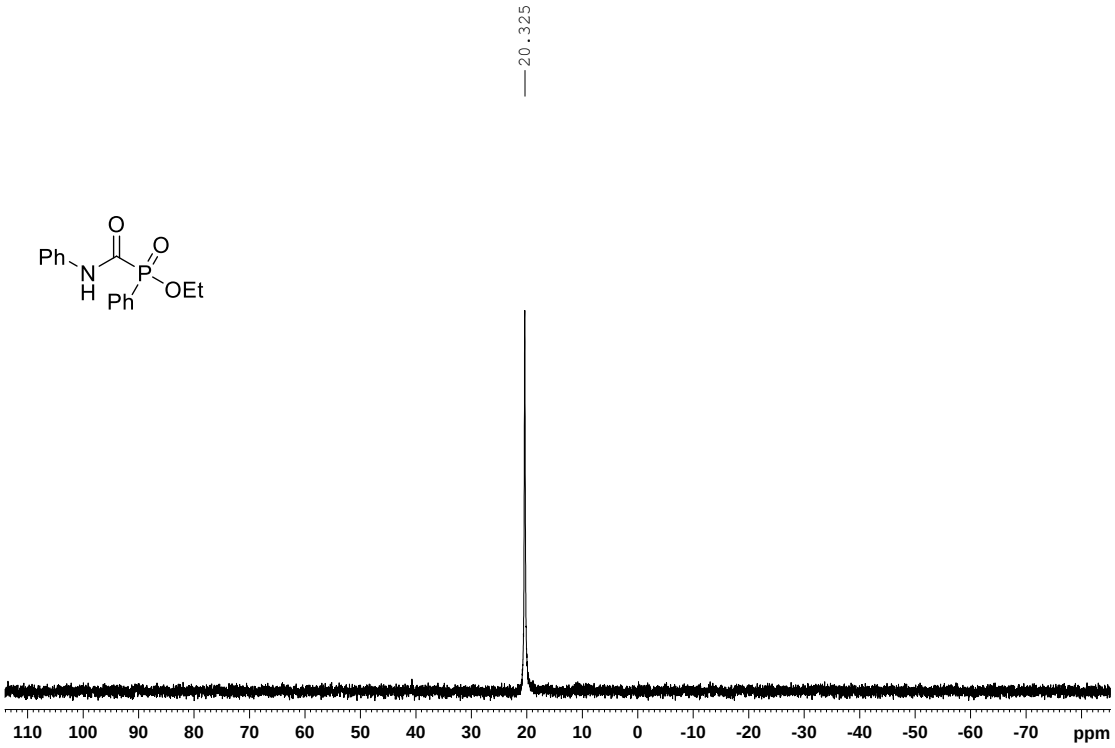
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3ar**



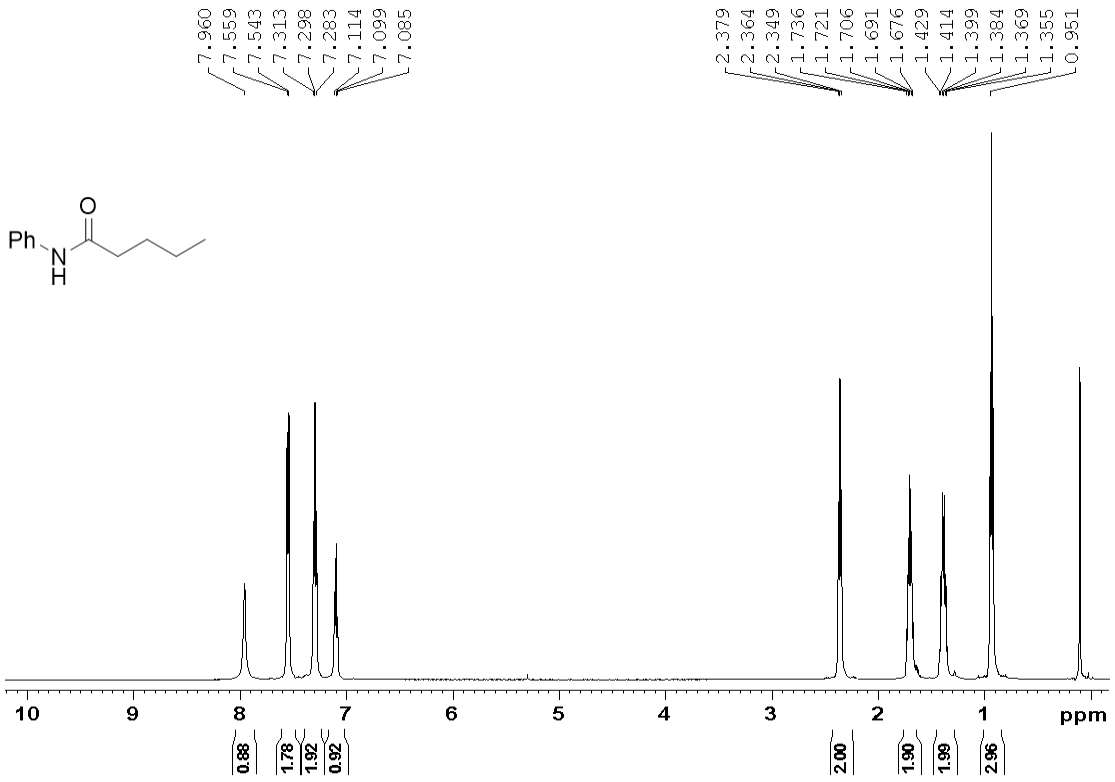
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **3as**



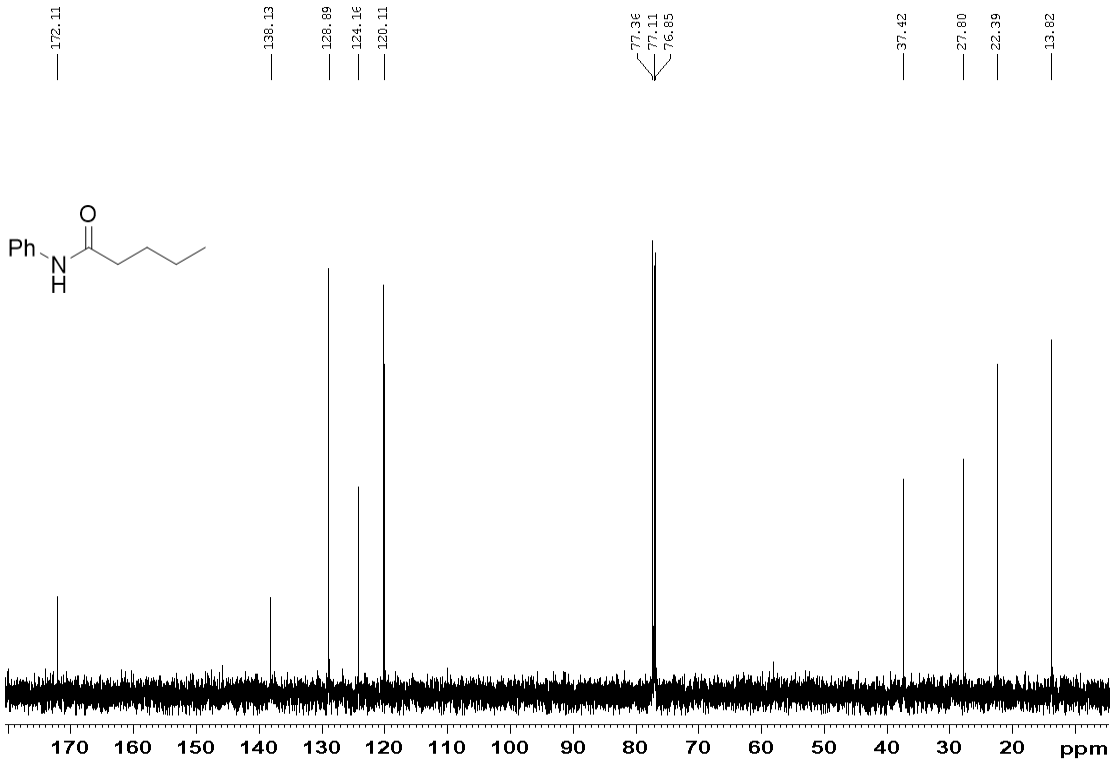
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **3as**



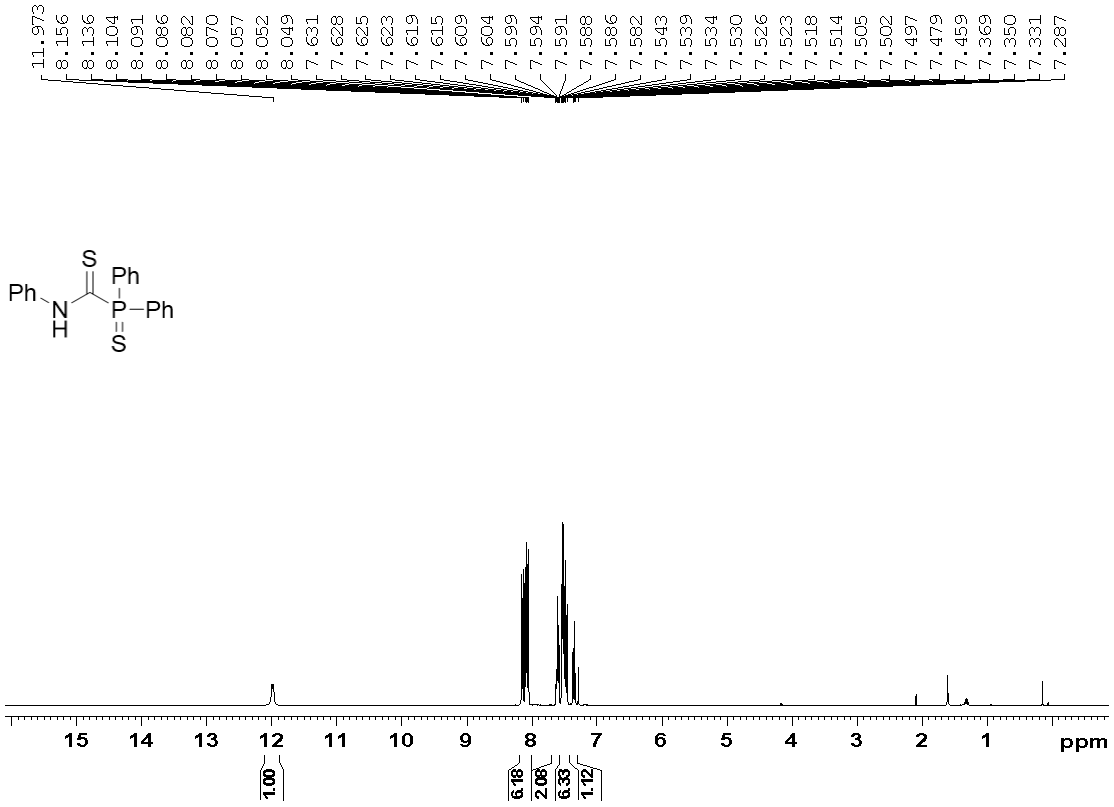
^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **3as**



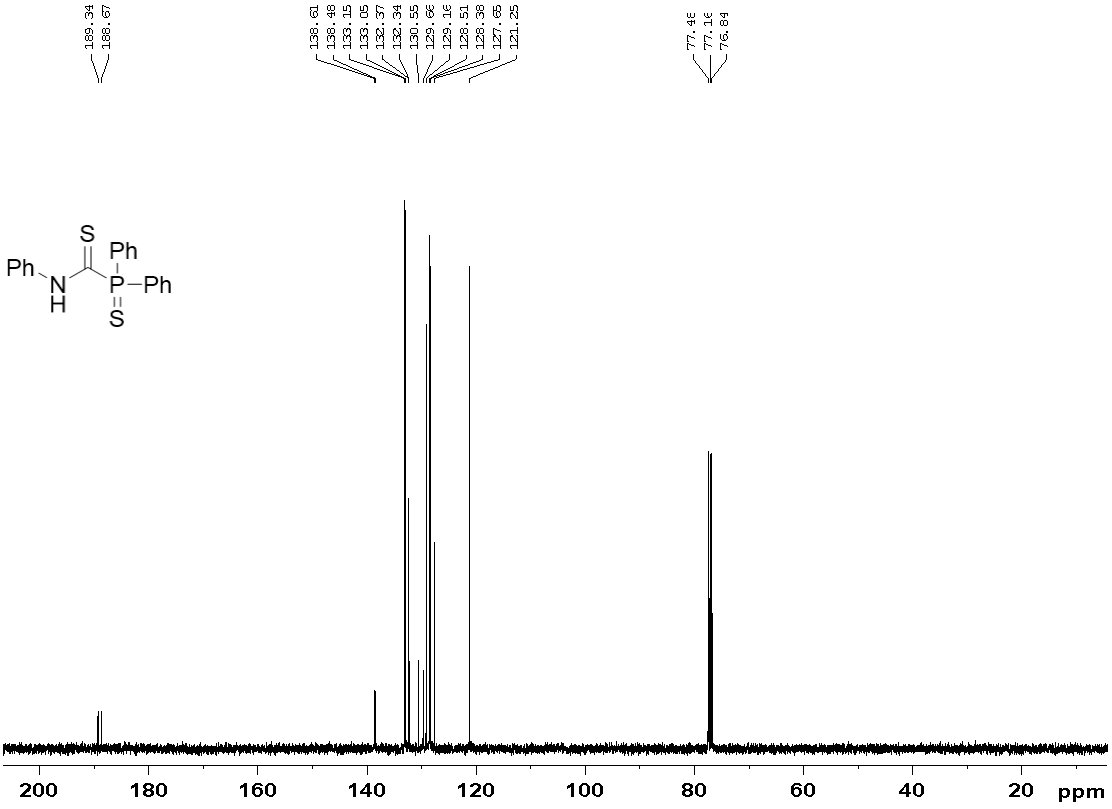
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **4**



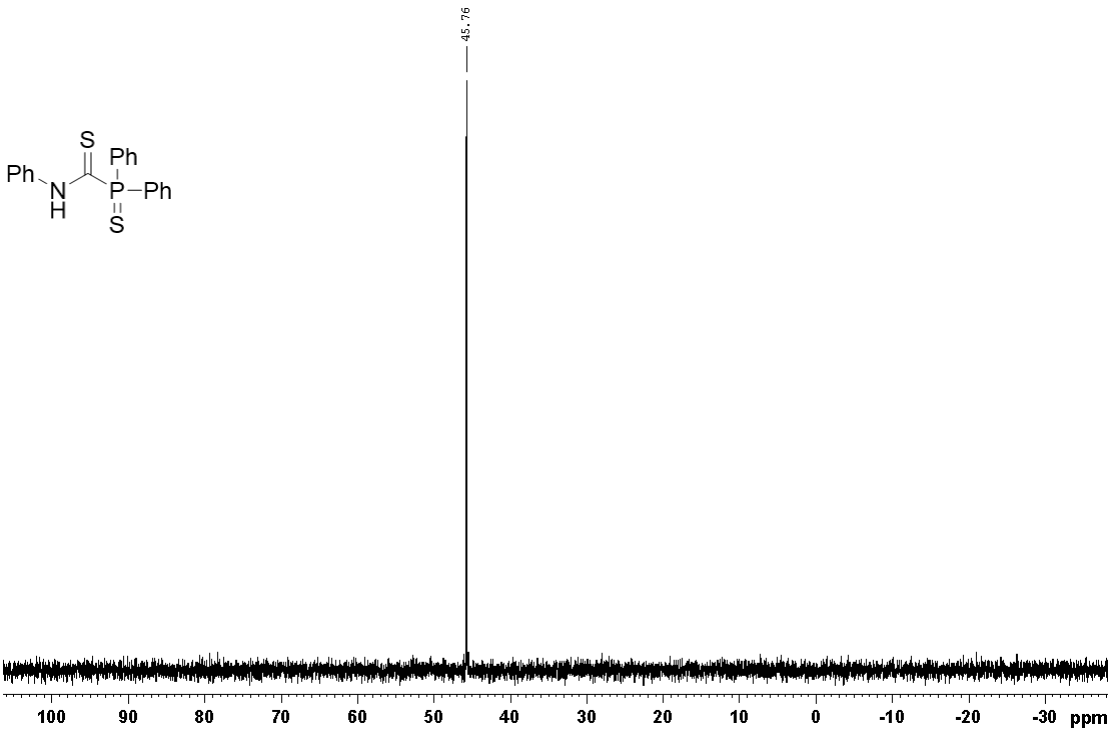
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **4**



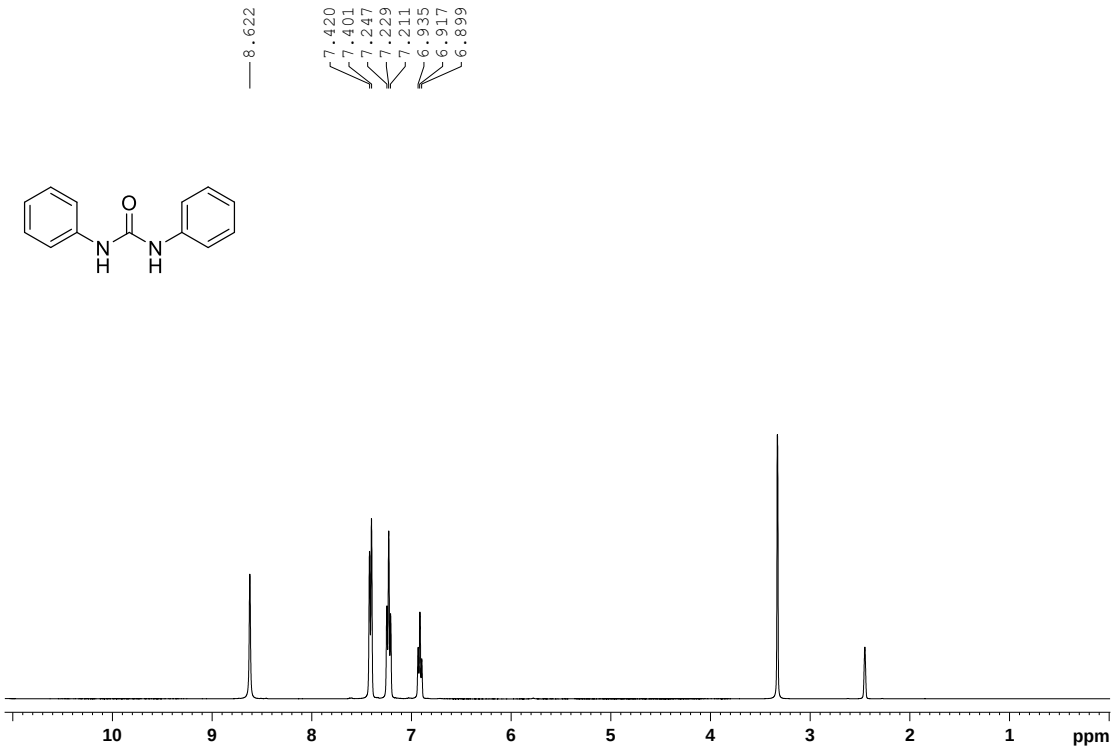
^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **5**



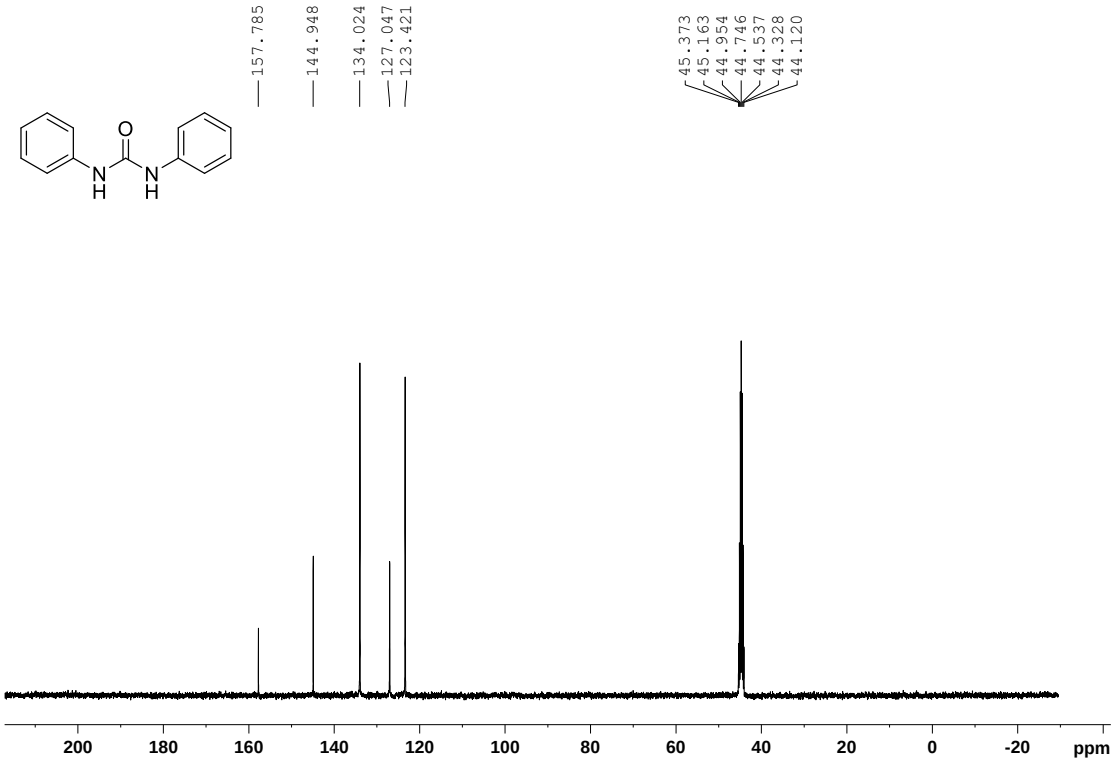
^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **5**



^{31}P NMR (162 MHz, $CDCl_3$) spectrum of compound **5**



^{1}H NMR (400 MHz, $CDCl_3$) spectrum of compound **6**



^{13}C NMR (101 MHz, $CDCl_3$) spectrum of compound **6**