# Supporting Information

## Excited-State Cobaloxime Catalysis Enabled Scalable Oxidant-Free Dehydrogenative C-H Phosphinoylation of Undirected Heterocycles

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**Table of contents**

## General Information

Thin layer chromatography (TLC) employed glass 0.25 mm silica gel plates. Flash chromatography columns were packed with 200-300 mesh silica gel in petroleum (boiling point is between 60-90 $^{o}$C). Gradient flash chromatography was conducted eluting with a continuous gradient from petroleum to the indicated solvent, and they are listed as volume/volume ratios. NMR spectra were recorded on a Varian Mercury spectrometer on a Bruker spectrometer at 400 MHz ($^{1}$H NMR), 101 MHz ($^{13}$C NMR), 162 MHz ($^{31}$P NMR), 376 MHZ ($^{19}$F NMR). Tetramethylsilane was used as an internal standard. All $^{1}$H NMR spectra were reported in delta (δ) units, parts per million (ppm) downfield from the internal standard. Coupling constants are reported in Hertz (Hz). High resolution mass spectra (HRMS) were measured with a Agilent 6220 TOF mass spectrometer (ESI-Q-TOF), accurate masses are reported for the molecular ion ($[M+H]^{+}$). Blue LEDs (3 W, λ = 450 ± 10 nm, 300mA) were used as the irradiation light.

## General Experimental Procedures

**1. General procedure for excited-state cobaloxime catalysis enables scalable oxidant-free dehydrogenative C-H phosphonylation of undirected bioactive molecules:** in an oven-dried schlenk tube (25 mL) equipped with a stir bar, diphenylphosphine oxide (0.2 mmol) and $Co(dmgH)_2pyCl$ (10 mol%) were added. After a process for removing oxygen rigorously and fill the schlenk tube with $N_2$, anhydrous $CH_2Cl_2$ (1.0 mL), benzofuran (0.4 mmol) and pyridine (0.2 mmol) was injected in the tube through a syringe. Then, the reaction mixture was irradiated with 3 W blue LEDs lights (3 W, $\lambda = 450 \pm 10$ nm) and stirred at room temperature for 24 h. After completion of the reaction, as indicated by TLC, the solvent was removed with a rotary evaporator. And the mixture was purified by column chromatography on silica gel using petroleum ether and ethyl acetate (PE/EA = 5/1 -1/2) as eluent to afford pure product.

**2. Procedure for gram scale synthesis**: in an oven-dried flask (100 mL) equipped with a stir bar, diphenylphosphine oxide (3 - 5 mmol), heterocycles or arene (6 – 10 mmol, if liquid, injected it through a syringe after protection of $N_2$) and $Co(dmgH)_2pyCl$ (10 mol%) were added. After a process for removing oxygen rigorously and fill the flask with $N_2$, anhydrous $CH_2Cl_2$ (15 – 25 mL) and pyridine (3 – 5 mmol) was injected in the tube through a syringe. Then, the reaction mixture was irradiated with 3W blue LEDs lights and stirred at room temperature for 24 - 48 h. After completion of the reaction, as indicated by TLC, the solvent was removed with a rotary evaporator. And the mixture was purified by column chromatography on silica gel using petroleum ether

and ethyl acetate (PE/EA = 5/1 -1/1) as eluent to afford pure product.

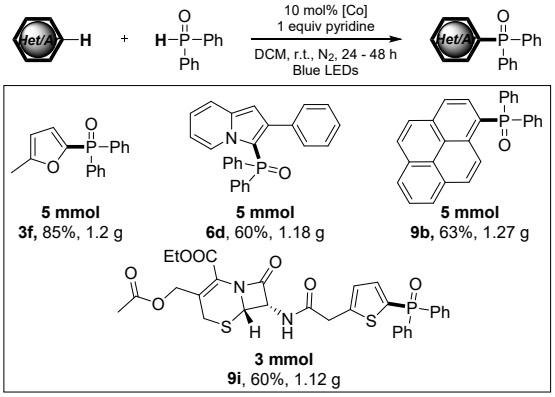



**Figure S1.** gram scale synthesis of **3f**, **6d**, **9b** and **9i**

**3. Procedure for cyclic voltammetry (CV):** cyclic voltammetry was performed in a three-electrode cell connected to a schlenk line under air at room temperature. The working electrode was a glassy-carbon disk electrode (diameter, 1 mm), the counter electrode a platinum wire. The reference was an Ag/AgCl electrode submerged in saturated aqueous KCl solution, and separated from reaction by a salt bridge. 5 mL of $CH_2Cl_2$ and $^{n}BuN_4BF_4$ was poured into the electrochemical cell in all experiments. The scan rate is 100 $mVs^{-1}$, ranging from 0 V to 4.0 V.

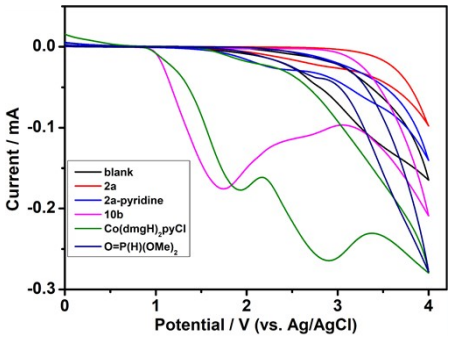



**Figure S2.** Cyclic voltammetry of **2a, 2a-pyridine, 10b, O=P(H)(OMe)$_2$, Co(dmgH)$_2$pyCl** in DCM with $^{n}Bu_4NBF_4$ under $N_2$ atmosphere. A glassy carbon working electrode (diameter (d) = 2 mm), Ag/AgCl reference electrode and a platinum wire counter electrode were used. The scan rate was 100 mV/s.

**3. Detection of hydrogen gas by GC-TCD analysis**: in an oven-dried Schlenk tube (25 mL) equipped with a stir bar, diphenylphosphine oxide (0.2 mmol) and $Co(dmgH)_2pyCl$ (10 mol%) were added. After a process for removing oxygen rigorously and fill the Schlenk tube with $N_2$, anhydrous $CH_2Cl_2$ (1.0 mL), benzofuran (0.4 mmol) and pyridine (0.2 mmol) was injected in the tube through a syringe. Then, the reaction mixture was irradiated with 3 W blue LEDs lights and stirred at room temperature for 24 h. After completion of the reaction, the extracted 1000 μL gas from the reaction system was analyzed by GC-TCD. According to the spectra (Figure S3), the only peak stands for the generation of hydrogen gas (nitrogen cannot be detected due to the instrument parameter setting).

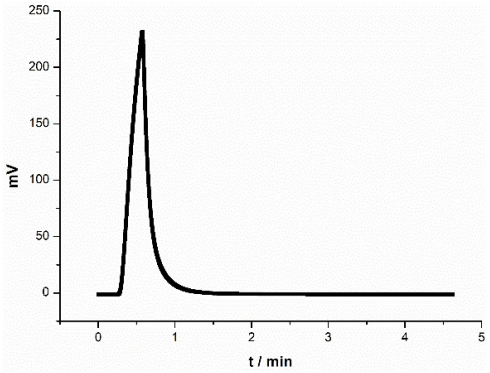



**Figure S3.** Detection of hydrogen gas by GC-TCD analysis

**4. Investigate the reactivity of phosphite reagents, indoles and thiazoles**

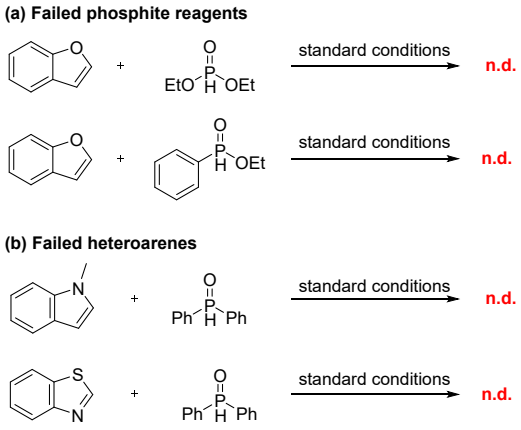



**Figure S4.** Failed phosphite reagents and heteroarenes

## 5. Crystal Data and Refinement Results

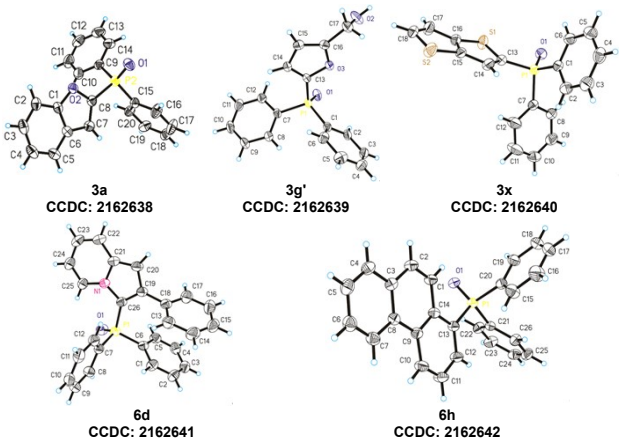



**Figure S5.** Crystal structure of **3a**, **3g'**, **3x**, **6d** and **6h**

**Table 1. Crystal Data and Refinement Results for complexes 3a, 3g', 3x, 6d and 6g**

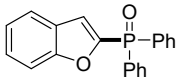
| Compound | **3a** | **3g'** | **3x** |
|---|---|---|---|
| Empirical formula | $C_{20}H_{15}O_2P$ | $C_{17}H_{15}O_3P$ | $C_{18}H_{13}OPS_2$ |
| Formula weight | 318.29 | 298.26 | 340.37 |
| Temperature / K | 296(2) | 293(2) | 293(2) |
| Crystal system | Triclinic | Monoclinic | Orthorhombic |
| Space group | *P - 1* | *P 21/n* | *P 21 21 21* |
| *a* /Å | 9.4992(2) | 10.9372(5) | 8.5680(6) |
| *b* /Å | 10.3406(3) | 9.5238(3) | 9.8972(5) |
| *c* /Å | 18.4801(5) | 14.1492(6) | 19.3273(12) |
| *β* /° | 95.138(2) | 94.251(4) | 90.00 |
| *V* (Å$^3$) | 1632.71(7) | 1469.78(10) | 2957.4(6) |
| Z | 4 | 4 | 4 |
| Dc (g cm$^{-3}$) | 1.295 | 1.348 | 1.379 |
| F(000) | 664 | 624 | 704 |
| *θ* range /° | 2.12 – 26.00 | 2.27 – 25.00 | 2.11 – 24.99 |
| Reflns. Collected | 19106 | 6798 | 4801 |
| Independent reflns. | 6417 | 2589 | 2715 |
| Goodness-of-fit | 1.074 | 1.077 | 1.049 |
| $R_1$[a] ($I > 2\sigma$ ($I$)) | 0.0410 | 0.0374 | 0.0367 |

| | | | |
|---|---|---|---|
| $wR_2$[b] ($I > 2\sigma(I)$) | 0.1219 | 0.0999 | 0.0900 |

| Compound | **6d (the crystal cell with water molecular)** | **6h** |
|---|---|---|
| Empirical formula | $C_{26}H_{20}NOP{\cdot}H_2O$ | $C_{26}H_{19}OP$ |
| Formula weight | 411.42 | 378.38 |
| Temperature / K | 293(2) | 293(2) |
| Crystal system | Monoclinic | Monoclinic |
| Space group | *P 21/n* | P 21/c |
| *a* /Å | 9.9038(3) | 12.6908(4) |
| *b* /Å | 14.8253(5) | 9.4451(3) |
| *c* /Å | 14.9817(5) | 16.5679(6) |
| $\beta$ /° | 103.847(3) | 100.759(4) |
| *V* (Å$^3$) | 2135.79 | 1951.02(11) |
| Z | 4 | 4 |
| Dc (g cm$^{-3}$) | 1.279 | 1.288 |
| F(000) | 864 | 792 |
| $\theta$ range /° | 1.96 – 24.99 | 2.49 – 25.00 |
| Reflns. Collected | 13743 | 9222 |
| Independent reflns. | 3761 | 3419 |
| Goodness-of-fit | 1.023 | 1.095 |
| $R_1$[a] ($I > 2\sigma(I)$) | 0.0415 | 0.0472 |
| $wR_2$[b] ($I > 2\sigma(I)$) | 0.1244 | 0.1343 |

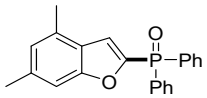
[a] $R_1 = \Sigma||F_o| - |F_c||/\Sigma|F_o|$. [b] $wR_2 = |\Sigma w(|F_o|^2 - |F_c|^2)|/\Sigma|w(F_o)^2|^{1/2}$, where $w = 1/[\sigma^2(F_o^2) + (aP)^2 + bP]$. $P = (F_o^2 + 2F_c^2)/3$.

## Detailed descriptions for products



**Benzofuran-2-yldiphenylphosphine oxide (3a)[1]**

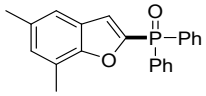
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (54 mg, 85%). $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.82 (dd, $J$ = 12.9, 7.0 Hz, 4H), 7.65 (d, $J$ = 7.8 Hz, 1H), 7.58 (td, $J$ = 7.3, 1.6 Hz, 2H), 7.54 – 7.46 (m, 5H), 7.42 (d, $J$ = 2.5 Hz, 1H), 7.39 (t, $J$ = 7.7 Hz, 1H), 7.27 (d, $J$ = 6.0 Hz, 1H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 157.91 (d, $J_{C\text{-}P}$ = 8.1 Hz), 150.33 (d, $J_{C\text{-}P}$ = 130.4 Hz), 132.50 (d, $J_{C\text{-}P}$ = 2.9 Hz), 131.74 (d, $J_{C\text{-}P}$ = 10.6 Hz), 131.00 (d, $J_{C\text{-}P}$ = 111.1 Hz), 128.63 (d, $J_{C\text{-}P}$ = 12.8 Hz), 126.74, 126.57 (d, $J_{C\text{-}P}$ = 9.1 Hz), 123.56, 122.38, 119.50 (d, $J_{C\text{-}P}$ = 17.5 Hz), 112.14. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 17.53. IR (KBr): 1110 $cm^{-1}$ (P=O).



**(4,6-Dimethylbenzofuran-2-yl)diphenylphosphine oxide (3b)**

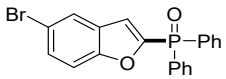
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (42.9 mg, 62%), melting point: 160 – 162 °C. $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.81 (dd, $J$ = 12.9, 7.6 Hz, 4H), 7.57 (t, $J$ = 7.5 Hz, 2H), 7.53 – 7.43 (m, 5H), 7.15 (s, 1H), 6.91 (s, 1H), 2.47 (s, 3H), 2.42 (s, 3H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 158.50 (d, $J_{C\text{-}P}$ = 8.0 Hz), 148.75 (d, $J_{C\text{-}P}$ = 132.8 Hz), 137.45, 132.44 (d, $J_{C\text{-}P}$ = 2.9 Hz), 132.04, 131.78 (d, $J_{C\text{-}P}$ = 10.6 Hz), 131.34 (d, $J_{C\text{-}P}$ = 111.1), 128.63 (d, $J_{C\text{-}P}$ = 12.8 Hz), 125.48, 124.28 (d, $J_{C\text{-}P}$ = 9.0 Hz), 118.43 (d, $J_{C\text{-}P}$ = 17.5 Hz), 109.59, 21.79, 18.52. $^{31}$P NMR

(162 MHz, $CDCl_3$) δ 17.74. HRMS (ESI) calcd for $C_{22}H_{19}O_2P$ $[M+H]^+$: 347.1195; found: 347.1201. IR (KBr): 1102 $cm^{-1}$ (P=O).



**(5,7-Dimethylbenzofuran-2-yl)diphenylphosphine oxide (3c)**

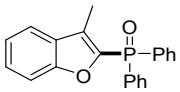
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (45 mg, 65%), melting point: 130 – 132 °C. $^1H$ NMR (400 MHz, $CDCl_3$) δ 7.80 (dd, $J$ = 12.8, 7.6 Hz, 4H), 7.57 (t, $J$ = 7.4 Hz, 2H), 7.49 (td, $J$ = 7.9, 2.7 Hz, 4H), 7.28 (t, $J$ = 1.7 Hz, 1H), 7.24 (s, 1H), 7.01 (s, 1H), 2.44 (s, 3H), 2.39 (s, 3H). $^{13}C$ NMR (101 MHz, $CDCl_3$) δ 155.83 (d, $J_{C-P}$ = 7.9 Hz), 149.77 (d, $J_{C-P}$ = 131.7 Hz), 133.25, 132.44 (d, $J_{C-P}$ = 2.9 Hz), 131.3 (d, $J_{C-P}$ = 111.1 Hz), 131.80 (d, $J_{C-P}$ = 10.6 Hz), 129.14, 128.61 (d, $J_{C-P}$ = 12.8 Hz), 126.22 (d, $J_{C-P}$ = 9.1 Hz), 121.85, 119.75 (d, $J_{C-P}$ = 18.1 Hz), 119.29, 21.22, 15.05. $^{31}P$ NMR (162 MHz, $CDCl_3$) δ 17.78. HRMS (ESI) calcd for $C_{22}H_{19}O_2P$ $[M+H]^+$: 347.1195; found: 347.1199. IR (KBr): 1102 $cm^{-1}$ (P=O).



**(5-Bromobenzofuran-2-yl)diphenylphosphine oxide (3d)**

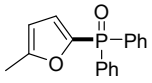
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a colorless oil (43.6 mg, 55%). $^1H$ NMR (400 MHz, $CDCl_3$) δ 7.86 – 7.74 (m, 5H), 7.61 – 7.56 (m, 2H), 7.54 – 7.43 (m, 5H), 7.42 – 7.31 (m, 2H). $^{13}C$ NMR (101 MHz, $CDCl_3$) δ 156.56 (d, $J_{C-P}$ = 8.1 Hz), 151.99 (d, $J_{C-P}$ = 127.8 Hz), 132.65 (d, $J_{C-P}$ = 2.9 Hz), 131.68 (d, $J_{C-P}$ = 10.6 Hz), 130.55 (d, $J_{C-P}$ = 111.4 Hz), 129.66, 128.69 (d, $J_{C-P}$ = 12.8

Hz), 128.49 (d, $J_{C\text{-}P}$ = 9.1 Hz), 124.87, 118.54 (d, $J_{C\text{-}P}$ = 17.4 Hz), 116.60 (d, $J_{C\text{-}P}$ = 1.4 Hz), 113.56. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 17.19. HRMS (ESI) calcd for $C_{20}H_{14}BrO_2P$ $[M+H]^+$: 396.9988; found: 396.9991. IR (KBr): 1114 $cm^{-1}$ (P=O).



**(3-Methylbenzofuran-2-yl)diphenylphosphine oxide (3e)**

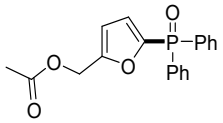
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (46.5 mg, 70%), melting point: 178 – 180 °C. $^1$H NMR (400 MHz, $CDCl_3$) δ 7.88 – 7.72 (m, 4H), 7.61 (d, $J$ = 7.7 Hz, 1H), 7.58 – 7.51 (m, 2H), 7.50 – 7.32 (m, 6H), 7.31 – 7.25 (m, 1H), 2.57 (d, $J$ = 2.0 Hz, 3H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 156.50 (d, $J_{C\text{-}P}$ = 8.5 Hz), 143.26 (d, $J_{C\text{-}P}$ = 133.3 Hz), 132.72, 132.23 (d, $J_{C\text{-}P}$ = 2.8 Hz), 131.67 (d, $J_{C\text{-}P}$ = 10.4 Hz), 130.19 (d, $J_{C\text{-}P}$ = 17.0 Hz), 129.08 (d, $J_{C\text{-}P}$ = 9.1 Hz), 128.53 (d, $J_{C\text{-}P}$ = 12.7 Hz), 126.68, 122.97, 120.58, 111.86, 8.66. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 19.51. HRMS (ESI) calcd for $C_{21}H_{17}O_2P$ $[M+H]^+$: 333.1039; found: 333.1038. IR (KBr): 1120 $cm^{-1}$ (P=O).



**(5-Methylfuran-2-yl)diphenylphosphine oxide (3f)**

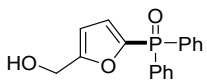
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (50.8 mg, 90%), melting point: 104 – 106 °C. $^1$H NMR (400 MHz, $CDCl_3$) δ 7.74 (dd, $J$ = 12.5, 7.4 Hz, 4H), 7.54 (t, $J$ = 7.2 Hz, 2H), 7.46 (dt, $J$ = 7.0, 3.7 Hz, 4H), 6.84 (s, 1H), 6.10 (s, 1H), 2.33 (s, 3H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 159.32 (d, $J_{C\text{-}P}$

= 7.1 Hz), 145.85 (d, $J_{C-P}$ = 139.5 Hz), 132.10 (d, $J_{C-P}$ = 2.6 Hz), 131.69 (d, $J_{C-P}$ = 111.2 Hz), 131.62 (d, $J_{C-P}$ = 10.4 Hz), 128.41 (d, $J_{C-P}$ = 12.5 Hz), 124.71 (d, $J_{C-P}$ = 18.9 Hz), 107.16 (d, $J_{C-P}$ = 8.0 Hz), 13.85. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 16.27. HRMS (ESI) calcd for $C_{17}H_{15}O_2P$ $[M+H]^+$: 283.0882; found: 283.0878. IR (KBr): 1118 $cm^{-1}$ (P=O).



**(5-(Diphenylphosphoryl)furan-2-yl)methyl acetate (3g)**

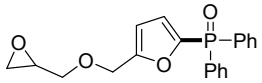
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a colorless oil (44.2 mg, 65%). $^1$H NMR (400 MHz, $CDCl_3$) δ 7.80 – 7.68 (m, 4H), 7.57 (td, *J* = 7.3, 1.5 Hz, 2H), 7.48 (td, *J* = 7.4, 3.1 Hz, 4H), 6.94 (dd, *J* = 3.4, 1.9 Hz, 1H), 6.50 (dd, *J* = 3.5, 1.5 Hz, 1H), 5.07 (s, 2H), 2.05 (s, 3H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 170.33, 155.92 (d, $J_{C-P}$ = 7.1 Hz), 148.73 (d, $J_{C-P}$ = 134.2 Hz), 132.36 (d, $J_{C-P}$ = 2.9 Hz), 131.67 (d, $J_{C-P}$ = 10.5 Hz), 131.33 (d, $J_{C-P}$ = 111.5 Hz), 128.56 (d, $J_{C-P}$ = 12.7 Hz), 123.98 (d, $J_{C-P}$ = 18.3 Hz), 111.07 (d, $J_{C-P}$ = 8.0 Hz), 57.79, 20.72. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 15.92. HRMS (ESI) calcd for $C_{19}H_{17}O_4P$ $[M+H]^+$: 341.0937; found: 341.0935. IR (KBr): 2923 (C-H), 1120 $cm^{-1}$ (P=O).



**(5-(Hydroxymethyl)furan-2-yl)diphenylphosphine oxide (3g')**

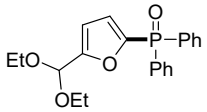
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (11.9 mg, 20%), melting point: 188 – 191 °C. $^1$H NMR (400 MHz, $CDCl_3$) δ 7.73 (ddt, *J* = 12.8, 6.9, 1.3 Hz, 4H), 7.59 – 7.54 (m, 2H), 7.48 (ddd, *J* = 10.2, 5.1, 2.2

Hz, 4H), 6.87 (dd, $J$ = 3.3, 1.8 Hz, 1H), 6.43 – 6.35 (m, 1H), 4.64 (s, 2H), 1.74 (s, 1H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 161.10 (d, $J_{C\text{-}P}$ = 6.6 Hz), 147.68 (d, $J_{C\text{-}P}$ = 135.7 Hz), 132.41 (d, $J_{C\text{-}P}$ = 2.9 Hz), 131.76 (d, $J_{C\text{-}P}$ = 10.5 Hz), 131.39 (d, $J_{C\text{-}P}$ = 111.5 Hz), 128.65 (d, $J_{C\text{-}P}$ = 12.8 Hz), 124.29 (d, $J_{C\text{-}P}$ = 18.8 Hz), 108.39 (d, $J_{C\text{-}P}$ = 8.2 Hz), 57.62. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 16.36. HRMS (ESI) calcd for $C_{17}H_{15}O_3P$ $[M+H]^+$: 299.0832; found: 299.0835. IR (KBr): 2921 (OH), 1121 $cm^{-1}$ (P=O).



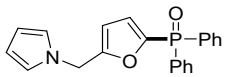

**(5-((Oxiran-2-ylmethoxy)methyl)furan-2-yl)diphenylphosphine oxide (3h)**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a colorless oil (46 mg, 65%). Colorless oil, 46 mg, 65% yield, PE/EA = 5/1 as eluent. $^1$H NMR (400 MHz, $CDCl_3$) δ 7.80 – 7.68 (m, 4H), 7.60 – 7.45 (m, 6H), 6.95 (dd, $J$ = 3.2, 1.9 Hz, 1H), 6.54 – 6.39 (m, 1H), 4.67 – 4.46 (m, 2H), 3.76 (dd, $J$ = 11.5, 2.8 Hz, 1H), 3.38 (dd, $J$ = 11.5, 5.9 Hz, 1H), 3.11 (ddt, $J$ = 5.8, 4.1, 2.8 Hz, 1H), 2.94 – 2.62 (m, 1H), 2.55 (dd, $J$ = 5.0, 2.7 Hz, 1H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 158.14 (d, $J_{C\text{-}P}$ = 6.9 Hz), 148.14 (d, $J_{C\text{-}P}$ = 135.3 Hz), 132.29 (d, $J_{C\text{-}P}$ = 2.9 Hz), 131.63 (d, $J_{C\text{-}P}$ = 10.5 Hz), 131.39 (d, $J_{C\text{-}P}$ = 111.4 Hz), 128.52 (d, $J_{C\text{-}P}$ = 12.8 Hz), 123.99 (d, $J_{C\text{-}P}$ = 18.4 Hz), 110.07 (d, $J_{C\text{-}P}$ = 8.1 Hz), 70.87, 65.02, 50.54, 44.05. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 16.15. HRMS (ESI) calcd for $C_{20}H_{19}O_4P$ $[M+H]^+$: 355.1094; found: 355.1086. IR (KBr): 1119 $cm^{-1}$ (P=O).



**(5-(Diethoxymethyl)furan-2-yl)diphenylphosphine oxide (3i)**

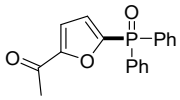
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a colorless oil (40.7 mg, 55%). $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.79 – 7.70 (m, 4H), 7.58 – 7.52 (m, 2H), 7.50 – 7.44 (m, 4H), 7.02 (dd, $J$ = 3.4, 1.9 Hz, 1H), 6.59 – 6.50 (m, 1H), 5.54 (s, 1H), 3.61 – 3.52 (m, 4H), 1.18 (t, $J$ = 7.1 Hz, 6H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 158.52 (d, $J_{C\text{-}P}$ = 6.6 Hz), 147.70 (d, $J_{C\text{-}P}$ = 135.7 Hz), 132.30 (d, $J_{C\text{-}P}$ = 2.9 Hz), 131.67 (d, $J_{C\text{-}P}$ = 10.5 Hz), 131.55 (d, $J_{C\text{-}P}$ = 111.3 Hz), 128.52 (d, $J_{C\text{-}P}$ = 12.8 Hz), 123.80 (d, $J_{C\text{-}P}$ = 18.3 Hz), 109.17 (d, $J_{C\text{-}P}$ = 8.1 Hz), 96.02, 61.44, 15.10. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 16.15. HRMS (ESI) calcd for $C_{21}H_{23}O_4P$ $[M+H]^+$: 371.1407; found: 371.1402. IR (KBr): 3053 (C-H), 1119 $cm^{-1}$ (P=O).




**(5-((1H-Pyrrol-1-yl)methyl)furan-2-yl)diphenylphosphine oxide (3j)**

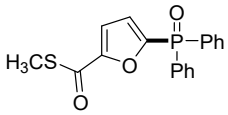
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a brown oil (34.7 mg, 50%). $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.70 (ddd, $J$ = 12.8, 8.2, 1.2 Hz, 4H), 7.60 – 7.51 (m, 2H), 7.49 – 7.42 (m, 4H), 6.88 (dd, $J$ = 3.3, 1.9 Hz, 1H), 6.65 (t, $J$ = 2.1 Hz, 2H), 6.31 – 6.23 (m, 1H), 6.15 (t, $J$ = 2.1 Hz, 2H), 5.05 (s, 2H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 157.64 (d, $J_{C\text{-}P}$ = 6.7 Hz), 148.17 (d, $J_{C\text{-}P}$ = 134.9 Hz), 132.34 (d, $J_{C\text{-}P}$ = 2.9 Hz), 131.62 (d, $J_{C\text{-}P}$ = 10.5 Hz), 131.31 (d, $J_{C\text{-}P}$ = 111.5 Hz), 128.55 (d, $J_{C\text{-}P}$ = 12.8 Hz), 124.07 (d, $J_{C\text{-}P}$ = 18.3 Hz), 120.85, 108.89, 108.72 (d, $J_{C\text{-}P}$ = 8.0 Hz), 46.21. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 16.14. HRMS (ESI) calcd for $C_{21}H_{18}NO_2P$ $[M+H]^+$:

348.1148; found: 348.1141. IR (KBr): 1118 $cm^{-1}$ (P=O).



**1-(5-(Diphenylphosphoryl)furan-2-yl)ethan-1-one (3k)[1]**

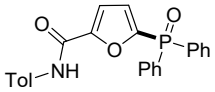
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 3/1) and obtained as a white solid (46.5 mg, 75%). $^{1}H$ NMR (400 MHz, $CDCl_3$) δ 7.76 (dd, $J$ = 13.0, 7.6 Hz, 4H), 7.60 (t, $J$ = 7.5 Hz, 2H), 7.51 (td, $J$ = 7.7, 2.8 Hz, 4H), 7.22 (d, $J$ = 3.4 Hz, 1H), 7.12 (d, $J$ = 3.5 Hz, 1H), 2.47 (s, 3H). $^{13}C$ NMR (101 MHz, $CDCl_3$) δ 187.21, 157.10 (d, $J_{C-P}$ = 5.9 Hz), 152.08 (d, $J_{C-P}$ = 126.8 Hz), 132.78 (d, $J_{C-P}$ = 2.9 Hz), 131.65 (d, $J_{C-P}$ = 10.6 Hz), 130.51 (d, $J_{C-P}$ = 111.8 Hz), 128.80 (d, $J_{C-P}$ = 12.8 Hz), 124.03 (d, $J_{C-P}$ = 17.6 Hz), 116.20 (d, $J_{C-P}$ = 7.9 Hz), 26.45. $^{31}P$ NMR (162 MHz, $CDCl_3$) δ 16.43. IR (KBr): 2919 (C-H), 1119 $cm^{-1}$ (P=O).



**S-Methyl 5-(diphenylphosphoryl)furan-2-carbothioate (3l)**

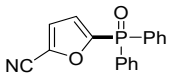
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (47.9 mg, 70%), melting point: 138 – 141 °C. $^{1}H$ NMR (400 MHz, $CDCl_3$) δ 7.86 – 7.74 (m, 4H), 7.63 – 7.56 (m, 2H), 7.51 (td, $J$ = 7.6, 3.2 Hz, 4H), 7.27 – 7.14 (m, 2H), 2.42 (s, 3H). $^{13}C$ NMR (101 MHz, $CDCl_3$) δ 181.15, 155.05 (d, $J_{C-P}$ = 6.3 Hz), 151.94 (d, $J_{C-P}$ = 126.7 Hz), 132.65 (d, $J_{C-P}$ = 2.9 Hz), 131.56 (d, $J_{C-P}$ = 10.6 Hz), 130.61 (d, $J_{C-P}$ = 111.6 Hz), 128.70 (d, $J_{C-P}$ = 12.9 Hz), 123.73 (d, $J_{C-P}$ = 17.0 Hz), 114.56 (d,

$J_{C\text{-}P}$ = 7.8 Hz), 10.91. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 16.01. HRMS (ESI) calcd for $C_{18}H_{15}O_3PS$ $[M+H]^+$: 343.0552; found: 343.0558. IR (KBr): 3090 (C-H), 1122 $cm^{-1}$ (P=O).




**5-(Diphenylphosphoryl)-N-(p-tolyl)furan-2-carboxamide (3m)**

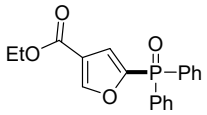
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 1/1) and obtained as a white solid (48.1 mg, 60%), melting point: 185 – 187 °C. $^1$H NMR (400 MHz, $CDCl_3$) δ 8.27 (s, 1H), 7.74 (dd, $J$ = 12.8, 7.5 Hz, 4H), 7.62 (t, $J$ = 7.4 Hz, 2H), 7.58 – 7.46 (m, 6H), 7.26 (dd, $J$ = 3.6, 1.4 Hz, 1H), 7.13 (d, $J$ = 8.4 Hz, 2H), 6.79 (dd, $J$ = 3.6, 1.4 Hz, 1H), 2.31 (s, 3H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 155.19, 153.22 (d, $J_{C\text{-}P}$ = 5.9 Hz), 150.25 (d, $J_{C\text{-}P}$ = 127.5 Hz), 134.56, 134.40, 132.91 (d, $J_{C\text{-}P}$ = 2.7 Hz), 131.76 (d, $J_{C\text{-}P}$ = 10.6 Hz), 130.29 (d, $J_{C\text{-}P}$ = 112.4 Hz), 129.57, 128.89 (d, $J_{C\text{-}P}$ = 12.8 Hz), 124.65 (d, $J_{C\text{-}P}$ = 18.2 Hz), 120.19, 114.92 (d, $J_{C\text{-}P}$ = 7.8 Hz), 20.92. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 16.94. HRMS (ESI) calcd for $C_{24}H_{20}NO_3P$ $[M+H]^+$: 402.1254; found: 402.1256. IR (KBr): 3114 (C-H), 1119 $cm^{-1}$ (P=O).




**5-(Diphenylphosphoryl)furan-2-carbonitrile (3n)**

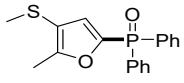
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a colorless oil (32.2 mg, 55%). $^1$H NMR (400 MHz, $CDCl_3$) δ 7.74 (ddd, $J$ = 13.0, 5.2, 3.2 Hz, 4H), 7.66 – 7.59 (m, 2H), 7.53 (td, $J$ = 7.5, 3.3 Hz, 4H), 7.20 (d, $J$ = 1.3 Hz,

2H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 154.57 (d, $J_{C-P}$ = 123.7 Hz), 133.00 (d, $J_{C-P}$ = 2.9 Hz), 131.56 (d, $J_{C-P}$ = 10.7 Hz), 130.90 (d, $J_{C-P}$ = 8.6 Hz), 129.86 (d, $J_{C-P}$ = 112.4 Hz), 128.87 (d, $J_{C-P}$ = 13.0 Hz), 122.88 (d, $J_{C-P}$ = 16.2 Hz), 122.00 (d, $J_{C-P}$ = 7.4 Hz), 110.50. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 16.09. HRMS (ESI) calcd for $C_{17}H_{12}NO_2P$ $[M+H]^+$: 294.0678; found: 294.0675. IR (KBr): 2234 (C-N), 1119 $cm^{-1}$ (P=O).




**Ethyl 5-(diphenylphosphoryl)furan-3-carboxylate (3o)**

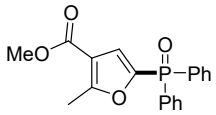
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (54.4 mg, 80%), melting point: 108 – 110 °C. $^1$H NMR (400 MHz, $CDCl_3$) δ 7.79 – 7.70 (m, 4H), 7.58 – 7.52 (m, 3H), 7.47 (td, $J$ = 7.4, 3.2 Hz, 4H), 6.92 (t, $J$ = 1.5 Hz, 1H), 4.02 (q, $J$ = 7.2 Hz, 2H), 0.98 (t, $J$ = 7.1 Hz, 3H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 161.44, 151.60 (d, $J_{C-P}$ = 124.6 Hz), 146.90 (d, $J_{C-P}$ = 7.7 Hz), 131.90 (d, $J_{C-P}$ = 2.9 Hz), 131.25 (d, $J_{C-P}$ = 10.3 Hz), 131.18 (d, $J_{C-P}$ = 114.3 Hz), 128.41 (d, $J_{C-P}$ = 14.3 Hz), 128.15 (d, $J_{C-P}$ = 13.0 Hz), 112.47 (d, $J_{C-P}$ = 5.9 Hz), 60.83, 13.36. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 17.22. HRMS (ESI) calcd for $C_{19}H_{17}O_4P$ $[M+H]^+$: 341.0937; found: 341.0931. IR (KBr): 3057 (C-H), 1116 $cm^{-1}$ (P=O).




**(5-Methyl-4-(methylthio)furan-2-yl)diphenylphosphine oxide (3p)**

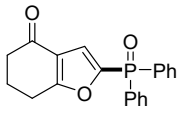
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a colorless oil (49.2 mg, 75%). $^1$H NMR (400 MHz, $CDCl_3$) δ 7.74 (ddd, $J$ = 12.7, 8.2,

1.2 Hz, 4H), 7.57 (td, $J$ = 6.5, 5.9, 1.4 Hz, 2H), 7.51 – 7.45 (m, 4H), 6.92 (d, $J$ = 1.9 Hz, 1H), 2.37 (s, 3H), 2.25 (s, 3H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 159.83 (d, $J_{C\text{-}P}$ = 5.8 Hz), 146.04 (d, $J_{C\text{-}P}$ = 136.3 Hz), 132.33 (d, $J_{C\text{-}P}$ = 2.9 Hz), 131.68 (d, $J_{C\text{-}P}$ = 10.5 Hz), 131.30 (d, $J_{C\text{-}P}$ = 111.4 Hz), 128.56 (d, $J_{C\text{-}P}$ = 12.7 Hz), 127.41 (d, $J_{C\text{-}P}$ = 17.4 Hz), 114.51 (d, $J_{C\text{-}P}$ = 8.6 Hz), 19.13, 12.40. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 15.85. HRMS (ESI) calcd for $C_{18}H_{17}O_2PS$ $[M+H]^+$: 329.0760; found: 329.0761. IR (KBr): 2920 (C-H), 1105 $cm^{-1}$ (P=O).



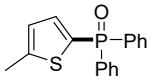

**Methyl 5-(diphenylphosphoryl)-2-methylfuran-3-carboxylate (3q)**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a colorless oil (44.2 mg, 65%). $^1$H NMR (400 MHz, $CDCl_3$) δ 7.74 (dd, $J$ = 12.7, 8.1 Hz, 4H), 7.59 (dd, $J$ = 10.5, 4.3 Hz, 2H), 7.56 – 7.42 (m, 4H), 7.09 (d, $J$ = 1.8 Hz, 1H), 3.81 (s, 3H), 2.63 (s, 3H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 165.37 (d, $J_{C\text{-}P}$ = 6.3 Hz), 163.48, 146.45 (d, $J_{C\text{-}P}$ = 134.3 Hz), 132.53 (d, $J_{C\text{-}P}$ = 2.9 Hz), 131.71 (d, $J_{C\text{-}P}$ = 10.5 Hz), 130.81 (d, $J_{C\text{-}P}$ = 112.1 Hz), 128.67 (d, $J_{C\text{-}P}$ = 12.8 Hz), 124.00 (d, $J_{C\text{-}P}$ = 18.1 Hz), 114.62 (d, $J_{C\text{-}P}$ = 8.1 Hz), 51.63, 14.29. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 15.85. HRMS (ESI) calcd for $C_{19}H_{17}O_4P$ $[M+H]^+$: 341.0937; found: 341.0938. IR (KBr): 2925 (C-H), 1118 $cm^{-1}$ (P=O).



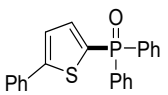

**2-(Diphenylphosphoryl)-6,7-dihydrobenzofuran-4(5H)-one (3r)**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 3/1) and obtained as a white solid (47 mg, 70%), melting point: 113 – 115 °C. $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.86 – 7.66 (m, 4H), 7.65 – 7.56 (m, 2H), 7.51 (td, $J$ = 7.5, 3.0 Hz, 4H), 7.01 (d, $J$ = 2.0 Hz, 1H), 2.94 (t, $J$ = 6.2 Hz, 2H), 2.60 – 2.48 (m, 2H), 2.26 – 2.13 (m, 2H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 193.82, 172.38 (d, $J_{C-P}$ = 7.1 Hz), 149.07 (d, $J_{C-P}$ = 131.0 Hz), 132.68 (d, $J_{C-P}$ = 2.9 Hz), 131.71 (d, $J_{C-P}$ = 10.6 Hz), 130.26 (d, $J_{C-P}$ = 112.4 Hz), 128.73 (d, $J_{C-P}$ = 12.8 Hz), 121.59 (d, $J_{C-P}$ = 8.3 Hz), 119.59 (d, $J_{C-P}$ = 18.1 Hz), 37.59, 23.77, 22.24. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 16.35. HRMS (ESI) calcd for $C_{20}H_{17}O_3P$ $[M+H]^+$: 337.0988; found: 337.0992. IR (KBr): 3061 (C-H), 1114 $cm^{-1}$ (P=O).



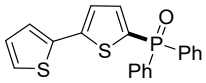

**(5-Methylthiophen-2-yl)diphenylphosphine oxide (3s)[1]**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (37 mg, 62%). $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.73 (dd, $J$ = 12.6, 7.5 Hz, 4H), 7.55 (t, $J$ = 7.5 Hz, 2H), 7.47 (td, $J$ = 7.7, 2.7 Hz, 4H), 7.27 (s, 1H), 6.85 (s, 1H), 2.53 (s, 3H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 149.64 (d, $J_{C-P}$ = 4.7 Hz), 137.52 (d, $J_{C-P}$ = 9.3 Hz), 133.04 (d, $J_{C-P}$ = 109.8 Hz), 132.11 (d, $J_{C-P}$ = 2.9 Hz), 131.82 (d, $J_{C-P}$ = 10.3 Hz), 130.91 (d, $J_{C-P}$ = 114.6 Hz), 128.48 (d, $J_{C-P}$ = 12.6 Hz), 126.88 (d, $J_{C-P}$ = 12.9 Hz), 15.47. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 21.65. IR (KBr): 2960 (C-H), 1015 $cm^{-1}$ (P=O).



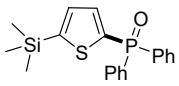

**Diphenyl(5-phenylthiophen-2-yl)phosphine oxide (3t)[1]**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (46.8 mg, 65%). $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.78 (ddt, $J$ = 12.6, 6.9, 1.4 Hz, 4H), 7.58 (dddd, $J$ = 10.6, 8.8, 3.4, 1.6 Hz, 4H), 7.49 (ddd, $J$ = 8.5, 6.6, 3.0 Hz, 4H), 7.45 – 7.29 (m, 5H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 153.33 (d, $J_{C\text{-}P}$ = 4.9 Hz), 137.92 (d, $J_{C\text{-}P}$ = 9.1 Hz), 133.35, 133.20 (d, $J_{C\text{-}P}$ = 1.4 Hz), 132.54 (d, $J_{C\text{-}P}$ = 113.1 Hz), 132.27 (d, $J_{C\text{-}P}$ = 2.8 Hz), 131.86 (d, $J_{C\text{-}P}$ = 10.4 Hz), 129.09, 128.71, 128.58 (d, $J_{C\text{-}P}$ = 12.6 Hz), 126.27, 124.15 (d, $J_{C\text{-}P}$ = 12.8 Hz). $^{31}$P NMR (162 MHz, $CDCl_3$) δ 21.67. IR (KBr): 1014 $cm^{-1}$ (P=O).



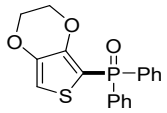

**[2,2'-Bithiophen]-5-yldiphenylphosphine oxide (3u)**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (47.6 mg, 65%), melting point: 110 – 112 °C. $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.87 – 7.69 (m, 4H), 7.62 – 7.45 (m, 6H), 7.35 (dd, $J$ = 7.6, 3.7 Hz, 1H), 7.24 (dt, $J$ = 20.1, 3.6 Hz, 3H), 7.00 (dd, $J$ = 5.0, 3.7 Hz, 1H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 146.06 (d, $J_{C\text{-}P}$ = 5.3 Hz), 137.64 (d, $J_{C\text{-}P}$ = 9.0 Hz), 135.74 (d, $J_{C\text{-}P}$ = 1.7 Hz), 132.56 (d, $J_{C\text{-}P}$ = 110.1 Hz), 132.26 (d, $J_{C\text{-}P}$ = 2.9 Hz), 131.88 (d, $J_{C\text{-}P}$ = 111.7 Hz), 131.75 (d, $J_{C\text{-}P}$ = 10.5 Hz), 128.54 (d, $J_{C\text{-}P}$ = 12.6 Hz), 128.05, 125.96, 125.20, 124.46 (d, $J_{C\text{-}P}$ = 12.9 Hz). $^{31}$P NMR (162 MHz, $CDCl_3$) δ 21.56. HRMS (ESI) calcd for $C_{20}H_{15}OPS_2$ $[M+H]^+$: 367.0375; found: 367.0373. IR (KBr): 1097 $cm^{-1}$ (P=O).



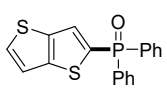
**Diphenyl(5-(trimethylsilyl)thiophen-2-yl)phosphine oxide (3v)[1]**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 3/1) and obtained as a white solid (46.3 mg, 65%). $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.75 (ddt, $J$ = 12.5, 6.9, 1.4 Hz, 4H), 7.60 – 7.53 (m, 2H), 7.53 – 7.44 (m, 5H), 7.29 (dd, $J$ = 3.5, 1.6 Hz, 1H), 0.32 (s, 9H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 150.74, 138.90, 137.83 (d, $J_{C\text{-}P}$ = 11.0 Hz), 134.72 (d, $J_{C\text{-}P}$ = 15.3 Hz), 133.10 (d, $J_{C\text{-}P}$ = 109.6 Hz), 132.14 (d, $J_{C\text{-}P}$ = 2.9 Hz), 131.80 (d, $J_{C\text{-}P}$ = 10.4 Hz), 128.51 (d, $J_{C\text{-}P}$ = 12.6 Hz), -0.13. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 21.64. IR (KBr): 2954 (C-H), 1016 cm$^{-1}$ (P=O).



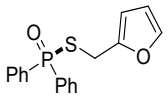

**(2,3-Dihydrothieno[3,4-b][1,4]dioxin-5-yl)diphenylphosphine oxide (3w)[1]**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (51.3 mg, 75%). $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.81 – 7.71 (m, 4H), 7.57 – 7.51 (m, 2H), 7.49 – 7.41 (m, 4H), 6.72 (d, $J$ = 5.0 Hz, 1H), 4.16 (s, 4H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 147.12 (d, $J_{C\text{-}P}$ = 4.6 Hz), 142.36 (d, $J_{C\text{-}P}$ = 11.2 Hz), 132.41 (d, $J_{C\text{-}P}$ = 111.6 Hz), 132.01 (d, $J_{C\text{-}P}$ = 2.9 Hz), 131.65 (d, $J_{C\text{-}P}$ = 10.7 Hz), 128.28 (d, $J_{C\text{-}P}$ = 12.7 Hz), 108.51 (d, $J_{C\text{-}P}$ = 4.0 Hz), 105.90 (d, $J_{C\text{-}P}$ = 114.4 Hz), 64.78, 64.06. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 20.53. IR (KBr): 2921 (C-H), 1024 cm$^{-1}$ (P=O).



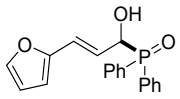

**Diphenyl(thieno[3,2-b]thiophen-2-yl)phosphine oxide (3x)**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (49 mg, 72%), melting point: 183 – 186 °C. $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.82 – 7.74 (m, 4H), 7.63 – 7.43 (m, 8H), 7.26 (d, $J$ = 5.5 Hz, 1H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 146.00 (d, $J_{C-P}$ = 6.0 Hz), 139.99 (d, $J_{C-P}$ = 15.6 Hz), 135.75 (d, $J_{C-P}$ = 108.2 Hz), 133.02, 132.35 (d, $J_{C-P}$ = 2.9 Hz), 131.89 (d, $J_{C-P}$ = 10.3 Hz), 131.15, 128.76 (d, $J_{C-P}$ = 10.0 Hz), 128.58 (d, $J_{C-P}$ = 12.6 Hz), 119.44 (d, $J_{C-P}$ = 1.7 Hz). $^{31}$P NMR (162 MHz, $CDCl_3$) δ 22.27. HRMS (ESI) calcd for $C_{18}H_{13}OPS_2$ $[M+H]^+$: 341.0218; found: 341.0225. IR (KBr): 1012 $cm^{-1}$ (P=O).



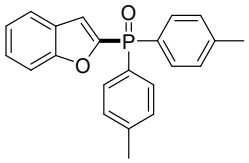

**Furan-2-ylmethyl diphenylphosphinothioate (3y)**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a colorless oil (47.1 mg, 75%). $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.89 – 7.79 (m, 4H), 7.54 – 7.48 (m, 2H), 7.44 (td, $J$ = 7.4, 3.6 Hz, 4H), 7.28 – 7.12 (m, 1H), 6.12 (dd, $J$ = 3.2, 2.0 Hz, 1H), 5.99 (d, $J$ = 3.2 Hz, 1H), 4.09 (d, $J$ = 10.0 Hz, 2H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 149.41 (d, $J_{C-P}$ = 4.8 Hz), 142.28, 132.70 (d, $J_{C-P}$ = 107.4 Hz), 132.26 (d, $J_{C-P}$ = 3.0 Hz), 131.39 (d, $J_{C-P}$ = 10.6 Hz), 128.55 (d, $J_{C-P}$ = 13.1 Hz), 110.45, 108.64, 25.33 (d, $J_{C-P}$ = 2.2 Hz). $^{31}$P NMR (162 MHz, $CDCl_3$) δ 42.98. HRMS (ESI) calcd for $C_{17}H_{15}O_2PS$ $[M+H]^+$: 315.0609; found: 315.0603. IR (KBr): 1113 $cm^{-1}$ (P=O).



**(3-(furan-2-yl)-1-hydroxyallyl)diphenylphosphine oxide (3z)**

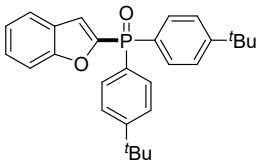
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 2/1) and obtained as a pale yellow solid (35.6 mg, 55%), melting point: 157 – 159 °C. $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.89 – 7.77 (m, 4H), 7.49 (t, *J* = 7.4 Hz, 2H), 7.44 – 7.36 (m, 4H), 7.25 (s, 1H), 6.44 (ddd, *J* = 15.7, 4.4, 1.7 Hz, 1H), 6.33 – 6.26 (m, 1H), 6.21 (dt, *J* = 15.8, 5.2 Hz, 1H), 6.08 (d, *J* = 3.3 Hz, 1H), 5.57 (s, 1H), 5.15 (dd, *J* = 9.4, 5.9 Hz, 1H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 152.27 (d, $J_{C-P}$ = 3.6 Hz), 142.12, 132.06 (d, $J_{C-P}$ = 20.7 Hz), 132.06 (d, $J_{C-P}$ = 3.0 Hz), 130.47 (d, $J_{C-P}$ = 39.8 Hz), 129.53 (d, $J_{C-P}$ = 39.8 Hz), 128.42 (d, $J_{C-P}$ = 11.4 Hz), 122.54 (d, $J_{C-P}$ = 1.8 Hz), 121.07 (d, $J_{C-P}$ = 11.1 Hz), 111.26, 108.56 (d, $J_{C-P}$ = 2.5 Hz), 72.48 (d, $J_{C-P}$ = 83.6 Hz). $^{31}$P NMR (162 MHz, $CDCl_3$) δ 31.06. HRMS (ESI) calcd for $C_{19}H_{17}O_3P$ $[M+H]^+$: 325.0988; found: 325.0979. IR (KBr): 3112 (OH), 1150 $cm^{-1}$ (P=O).




**Benzofuran-2-yldi-p-tolylphosphine oxide (4a)**

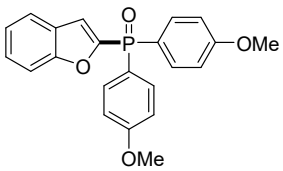
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (34.6 mg, 50%), melting point: 128 – 130 °C. $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.73 – 7.61 (m, 5H), 7.51 (d, *J* = 8.4 Hz, 1H), 7.41 – 7.35 (m, 2H), 7.34 – 7.26 (m, 5H), 2.41 (s, 6H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 157.93 (d, $J_{C-P}$ = 8.1 Hz), 150.90 (d, $J_{C-P}$ = 130.3 Hz), 143.11 (d, $J_{C-P}$ = 2.9 Hz), 131.85 (d, $J_{C-P}$ = 11.0 Hz), 129.40 (d, $J_{C-P}$

= 13.3 Hz), 127.88 (d, $J_{C\text{-}P}$ = 113.6 Hz), 126.73 (d, $J_{C\text{-}P}$ = 8.9 Hz), 126.62, 123.51, 122.38, 119.21 (d, $J_{C\text{-}P}$ = 17.5 Hz), 112.19, 21.74 (d, $J_{C\text{-}P}$ = 1.4 Hz). $^{31}$P NMR (162 MHz, $CDCl_3$) δ 17.90. HRMS (ESI) calcd for $C_{22}H_{19}O_2P$ $[M+H]^+$: 347.1195; found: 347.1194. IR (KBr): 2918 (C-H), 1101 $cm^{-1}$ (P=O).




**Benzofuran-2-ylbis(4-(tert-butyl)phenyl)phosphine oxide (4b)**

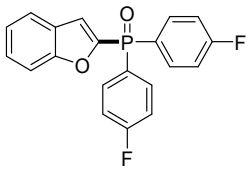
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (60.2 mg, 70%), melting point: 200 – 202 °C. $^1$H NMR (400 MHz, $CDCl_3$) δ 7.74 (dd, $J$ = 12.4, 8.0 Hz, 4H), 7.65 (d, $J$ = 7.8 Hz, 1H), 7.56 – 7.47 (m, 5H), 7.44 – 7.34 (m, 2H), 7.29 (d, $J$ = 7.6 Hz, 1H), 1.33 (s, 18H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 157.95 (d, $J_{C\text{-}P}$ = 8.0 Hz), 155.99 (d, $J_{C\text{-}P}$ = 2.9 Hz), 151.09 (d, $J_{C\text{-}P}$ = 129.6 Hz), 131.71 (d, $J_{C\text{-}P}$ = 10.9 Hz), 127.96 (d, $J_{C\text{-}P}$ = 113.5 Hz), 126.79 (d, $J_{C\text{-}P}$ = 9.0 Hz), 126.59, 125.69 (d, $J_{C\text{-}P}$ = 13.0 Hz), 123.50, 122.39, 119.14 (d, $J_{C\text{-}P}$ = 17.5 Hz), 112.21, 35.14, 31.15. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 17.46. HRMS (ESI) calcd for $C_{28}H_{31}O_2P$ $[M+H]^+$: 431.2134; found: 431.2135. IR (KBr): 2960 (C-H), 1091 $cm^{-1}$ (P=O).




**Benzofuran-2-ylbis(4-methoxyphenyl)phosphine oxide (4c)**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as

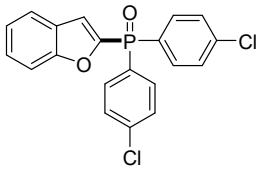
a white solid (55.2 mg, 73%), melting point: 138 – 140 °C. $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.71 (dd, *J* = 12.3, 8.3 Hz, 4H), 7.64 (d, *J* = 7.8 Hz, 1H), 7.51 (d, *J* = 8.3 Hz, 1H), 7.42 – 7.33 (m, 2H), 7.26 (d, *J* = 7.1 Hz, 1H), 6.99 (d, *J* = 8.1 Hz, 4H), 3.85 (s, 6H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 162.88 (d, $J_{C\text{-}P}$ = 2.9 Hz), 157.87 (d, $J_{C\text{-}P}$ = 8.0 Hz), 151.22 (d, $J_{C\text{-}P}$ = 130.7 Hz), 133.74 (d, $J_{C\text{-}P}$ = 12.0 Hz), 126.73 (d, $J_{C\text{-}P}$ = 9.0 Hz), 126.56, 123.48, 122.40 (d, $J_{C\text{-}P}$ = 118.0 Hz), 122.34, 118.95 (d, $J_{C\text{-}P}$ = 17.7 Hz), 114.22 (d, $J_{C\text{-}P}$ = 13.8 Hz), 112.14, 55.39. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 17.65. HRMS (ESI) calcd for $C_{22}H_{19}O_4P$ $[M+H]^+$: 379.1094; found: 379.1089. IR (KBr): 3058 (C-H), 1115 $cm^{-1}$ (P=O).




**Benzofuran-2-ylbis(4-fluorophenyl)phosphine oxide (4d)**

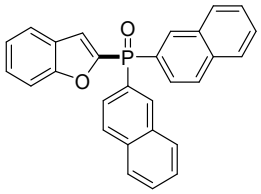
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (38.9 mg, 55%), melting point: 116 – 117 °C. $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.81 (ddd, *J* = 13.0, 8.4, 5.6 Hz, 4H), 7.68 (d, *J* = 7.8 Hz, 1H), 7.53 (d, *J* = 8.4 Hz, 1H), 7.47 (s, 1H), 7.42 (t, *J* = 7.8 Hz, 1H), 7.31 (t, *J* = 7.5 Hz, 1H), 7.20 (t, *J* = 7.7 Hz, 4H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 165.54 (dd, $J_{C\text{-}F/C\text{-}P}$ = 254.7, 3.3 Hz), 158.02 (d, $J_{C\text{-}P}$ = 8.3 Hz), 149.74 (d, $J_{C\text{-}P}$ = 133.1 Hz), 134.37 (dd, $J_{C\text{-}F/C\text{-}P}$ = 12.2, 9.0 Hz), 127.09, 126.94 (dd, $J_{C\text{-}F/C\text{-}P}$ = 114.7, 3.4 Hz), 126.55 (d, $J_{C\text{-}P}$ = 9.1 Hz), 123.83, 122.59, 119.87 (d, $J_{C\text{-}P}$ = 17.8 Hz), 116.29 (dd, $J_{C\text{-}F/C\text{-}P}$ = 21.5, 14.1 Hz), 112.21. $^{19}$F NMR (376 MHz,

$CDCl_3$) δ -105.24. $^{31}P$ NMR (162 MHz, $CDCl_3$) δ 15.88. HRMS (ESI) calcd for $C_{20}H_{13}F_2O_2P$ $[M+H]^+$: 355.0694; found: 355.0691. IR (KBr): 1118 $cm^{-1}$ (P=O).




**Benzofuran-2-ylbis(4-chlorophenyl)phosphine oxide (4e)**

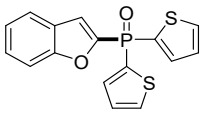
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (47.1 mg, 61%), melting point: 118 – 120 °C. $^1H$ NMR (400 MHz, $CDCl_3$) δ 7.74 (dd, $J$ = 12.4, 8.2 Hz, 4H), 7.67 (d, $J$ = 7.8 Hz, 1H), 7.56 – 7.46 (m, 6H), 7.41 (t, $J$ = 7.7 Hz, 1H), 7.30 (t, $J$ = 7.5 Hz, 1H). $^{13}C$ NMR (101 MHz, $CDCl_3$) δ 157.98 (d, $J_{C-P}$ = 8.1 Hz), 149.25 (d, $J_{C-P}$ = 133.7 Hz), 139.45 (d, $J_{C-P}$ = 3.6 Hz), 133.09 (d, $J_{C-P}$ = 11.5 Hz), 129.26 (d, $J_{C-P}$ = 113.0 Hz), 129.17 (d, $J_{C-P}$ = 13.5 Hz), 127.13, 126.44 (d, $J_{C-P}$ = 9.3 Hz), 123.83, 122.56, 120.06 (d, $J_{C-P}$ = 17.9 Hz), 112.16. $^{31}P$ NMR (162 MHz, $CDCl_3$) δ 15.83. HRMS (ESI) calcd for $C_{20}H_{13}Cl_2O_2P$ $[M+H]^+$: 387.0103; found: 387.0106. IR (KBr): 1086 $cm^{-1}$ (P=O).




**Benzofuran-2-yldi(naphthalen-2-yl)phosphine oxide (4f)**

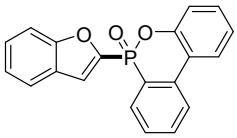
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (46 mg, 55%), melting point: 160 – 162 °C. $^1H$ NMR (400 MHz, $CDCl_3$)

δ 8.47 (d, $J$ = 14.6 Hz, 2H), 7.96 – 7.86 (m, 6H), 7.84 – 7.78 (m, 2H), 7.66 (d, $J$ = 7.8 Hz, 1H), 7.63 – 7.50 (m, 6H), 7.39 (t, $J$ = 7.8 Hz, 1H), 7.29 (t, $J$ = 7.5 Hz, 1H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 158.05 (d, $J_{C\text{-}P}$ = 8.0 Hz), 150.42 (d, $J_{C\text{-}P}$ = 131.1 Hz), 135.06 (d, $J_{C\text{-}P}$ = 2.5 Hz), 134.05 (d, $J_{C\text{-}P}$ = 9.9 Hz), 132.49 (d, $J_{C\text{-}P}$ = 14.0 Hz), 129.10, 128.59 (d, $J_{C\text{-}P}$ = 12.7 Hz), 128.56, 127.90, 127.55, 127.09, 126.85, 126.70 (d, $J_{C\text{-}P}$ = 9.1 Hz), 126.39 (d, $J_{C\text{-}P}$ = 11.5 Hz), 123.64, 122.48, 119.79 (d, $J_{C\text{-}P}$ = 17.7 Hz), 112.24. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 17.82. HRMS (ESI) calcd for $C_{28}H_{19}O_2P$ $[M+H]^+$: 419.1195; found: 419.1187. IR (KBr): 1087 $cm^{-1}$ (P=O).



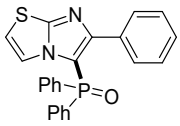

**Benzofuran-2-yldi(thiophen-2-yl)phosphine oxide (4g)**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (36.3 mg, 55%), melting point: 130 – 133 °C. $^1$H NMR (400 MHz, $CDCl_3$) δ 7.81 (t, $J$ = 4.8 Hz, 2H), 7.72 (dd, $J$ = 8.2, 3.6 Hz, 2H), 7.68 (d, $J$ = 7.9 Hz, 1H), 7.55 (d, $J$ = 8.4 Hz, 1H), 7.50 (s, 1H), 7.42 (t, $J$ = 7.8 Hz, 1H), 7.30 (t, $J$ = 7.5 Hz, 1H), 7.27 – 7.20 (m, 2H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 157.87 (d, $J_{C\text{-}P}$ = 9.2 Hz), 150.36 (d, $J_{C\text{-}P}$ = 148.2 Hz), 137.18 (d, $J_{C\text{-}P}$ = 11.5 Hz), 134.74 (d, $J_{C\text{-}P}$ = 5.9 Hz), 132.31 (d, $J_{C\text{-}P}$ = 129.8 Hz), 128.47 (d, $J_{C\text{-}P}$ = 15.4 Hz), 127.12, 126.59 (d, $J_{C\text{-}P}$ = 9.8 Hz), 123.73, 122.65, 118.99 (d, $J_{C\text{-}P}$ = 20.0 Hz), 112.26. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 1.97. HRMS (ESI) calcd for $C_{16}H_{11}O_2PS_2$ $[M+H]^+$: 331.0011; found: 331.0005. IR (KBr): 1094 $cm^{-1}$ (P=O).



**6-(benzofuran-2-yl)dibenzo[c,e][1,2]oxaphosphinine 6-oxide (4h)**

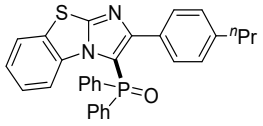
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (39.8 mg, 60%), melting point: 140 – 142 °C. $^{1}$H NMR (400 MHz, $CDCl_3$) δ 8.07 (dd, *J* = 8.2, 5.5 Hz, 1H), 8.02 (dd, *J* = 8.2, 1.6 Hz, 1H), 7.83 (dd, *J* = 14.8, 7.6 Hz, 1H), 7.74 (t, *J* = 7.8 Hz, 1H), 7.68 (d, *J* = 7.8 Hz, 1H), 7.65 (d, *J* = 2.6 Hz, 1H), 7.49 (td, *J* = 7.5, 3.1 Hz, 1H), 7.46 – 7.36 (m, 3H), 7.34 – 7.25 (m, 3H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 157.87 (d, $J_{C-P}$ = 10.5 Hz), 149.15 (d, $J_{C-P}$ = 8.2 Hz), 148.07, 146.23, 136.10 (d, $J_{C-P}$ = 6.6 Hz), 133.84 (d, $J_{C-P}$ = 2.5 Hz), 131.20 (d, $J_{C-P}$ = 11.8 Hz), 130.76, 128.60 (d, $J_{C-P}$ = 14.6 Hz), 127.38, 126.39 (d, $J_{C-P}$ = 10.9 Hz), 124.97 (d, $J_{C-P}$ = 16.1 Hz), 123.74 (d, $J_{C-P}$ = 10.5 Hz), 123.74 (d, $J_{C-P}$ = 1.0 Hz), 123.25 (d, $J_{C-P}$ = 137.8 Hz), 122.73, 121.63 (d, $J_{C-P}$ = 11.7 Hz), 120.60 (d, $J_{C-P}$ = 6.7 Hz), 120.13 (d, $J_{C-P}$ = 22.5 Hz), 112.31. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 11.32. HRMS (ESI) calcd for $C_{20}H_{13}O_3P$ $[M+H]^+$: 333.0675; found: 333.0682. IR (KBr): 1115 $cm^{-1}$ (P=O).



**Diphenyl(6-phenylimidazo[2,1-b]thiazol-5-yl)phosphine oxide (6a)**

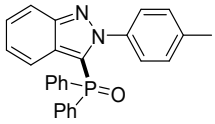
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1 – 3/1) and obtained as a white solid (60 mg, 75%), melting point: 210 – 213 °C. $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.63 (dd, *J* = 12.7, 7.4 Hz, 4H), 7.48 – 7.39 (m, 2H), 7.39 – 7.28 (m,

5H), 7.26 (d, $J$ = 7.3 Hz, 2H), 7.07 (t, $J$ = 7.3 Hz, 1H), 6.98 (t, $J$ = 7.4 Hz, 2H), 6.78 (d, $J$ = 4.5 Hz, 1H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 157.02 (d, $J_{C\text{-}P}$ = 13.4 Hz), 153.96 (d, $J_{C\text{-}P}$ = 10.8 Hz), 133.44, 132.24 (d, $J_{C\text{-}P}$ = 2.9 Hz), 131.76 (d, $J_{C\text{-}P}$ = 10.3 Hz), 131.46 (d, $J_{C\text{-}P}$ = 112.1 Hz), 129.26, 128.59 (d, $J_{C\text{-}P}$ = 12.8 Hz), 127.91, 127.48, 120.71, 113.24 (d, $J_{C\text{-}P}$ = 123.5 Hz), 112.92. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 17.35. HRMS (ESI) calcd for $C_{23}H_{17}N_2OPS$ $[M+H]^+$: 401.0872; found: 401.0871. IR (KBr): 1095 $cm^{-1}$ (P=O).



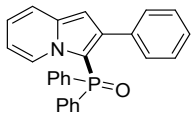

**Diphenyl(2-(4-propylphenyl)benzo[d]imidazo[2,1-b]thiazol-3-yl)phosphine oxide (6b)**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1 – 3/1) and obtained as a white solid (65.9 mg, 67%), melting point: 222 – 224 °C. $^1$H NMR (400 MHz, $CDCl_3$) δ 8.52 – 8.39 (m, 1H), 7.59 – 7.49 (m, 4H), 7.31 (t, $J$ = 7.4 Hz, 3H), 7.26 – 7.15 (m, 6H), 6.99 (d, $J$ = 8.0 Hz, 2H), 6.71 (d, $J$ = 7.9 Hz, 2H), 2.41 (t, $J$ = 7.6 Hz, 2H), 1.59 – 1.47 (m, 2H), 0.91 (t, $J$ = 7.3 Hz, 3H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 158.35 (d, $J_{C\text{-}P}$ = 14.2 Hz), 152.92 (d, $J_{C\text{-}P}$ = 10.7 Hz), 142.13, 132.84 (d, $J_{C\text{-}P}$ = 95.8 Hz), 131.95, 131.92, 131.82, 131.06 (d, $J_{C\text{-}P}$ = 37.2 Hz), 129.60, 129.38, 128.36 (d, $J_{C\text{-}P}$ = 13.0 Hz), 127.44, 126.28, 124.89, 123.54, 117.43, 115.27 (d, $J_{C\text{-}P}$ = 121.0 Hz), 37.68, 24.32, 13.79. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 18.24. HRMS (ESI) calcd for $C_{30}H_{25}N_2OPS$ $[M+H]^+$: 493.1498; found: 493.1504. IR (KBr): 2927 (C-H), 1193 $cm^{-1}$ (P=O).



**Diphenyl(2-(p-tolyl)-2H-indazol-3-yl)phosphine oxide (6c)**

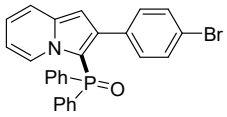
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (53 mg, 65%), melting point: 174 – 176 °C. $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.85 (d, *J* = 8.7 Hz, 1H), 7.66 (dd, *J* = 12.7, 7.7 Hz, 4H), 7.51 (t, *J* = 7.5 Hz, 2H), 7.44 – 7.33 (m, 6H), 7.30 – 7.24 (m, 1H), 7.01 (d, *J* = 7.9 Hz, 2H), 6.92 (t, *J* = 7.7 Hz, 1H), 6.33 (d, *J* = 8.7 Hz, 1H), 2.28 (s, 3H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 148.73 (d, $J_{C-P}$ = 12.4 Hz), 139.25, 138.23, 132.19 (d, $J_{C-P}$ = 2.9 Hz), 132.00 (d, $J_{C-P}$ = 112.1 Hz), 131.82 (d, $J_{C-P}$ = 10.0 Hz), 128.98, 128.59 (d, $J_{C-P}$ = 12.7 Hz), 127.72 (d, $J_{C-P}$ = 14.7 Hz), 127.62 (d, $J_{C-P}$ = 114.1 Hz), 126.60, 126.36, 124.09, 120.41, 118.47, 21.17. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 12.89. HRMS (ESI) calcd for $C_{26}H_{21}N_2OP$ $[M+H]^+$: 409.1464; found: 409.1462. IR (KBr): 3063 (C-H), 1118 $cm^{-1}$ (P=O).



**Diphenyl(2-phenylindolizin-3-yl)phosphine oxide (6d)**

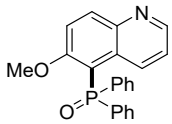
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 3/1) and obtained as a white solid (53.4 mg, 68%), melting point: 131 – 133 °C. $^{1}$H NMR (400 MHz, $CDCl_3$) δ 8.76 (d, *J* = 7.1 Hz, 1H), 7.51 – 7.41 (m, 5H), 7.38 – 7.29 (m, 2H), 7.24 – 7.13 (m, 4H), 6.99 – 6.89 (m, 4H), 6.86 (ddd, *J* = 8.5, 6.9, 1.6 Hz, 2H), 6.57 – 6.46 (m, 2H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 140.70 (d, $J_{C-P}$ = 14.1 Hz), 137.22 (d, $J_{C-P}$ = 7.2 Hz), 135.43,

132.97, 131.84 (d, $J_{C\text{-}P}$ = 10.5 Hz), 131.67 (d, $J_{C\text{-}P}$ = 2.9 Hz), 129.65, 128.31 (d, $J_{C\text{-}P}$ = 12.7 Hz), 127.83 (d, $J_{C\text{-}P}$ = 2.0 Hz), 127.13, 126.37, 121.47, 118.54, 111.63, 108.99 (d, $J_{C\text{-}P}$ = 129.7 Hz), 103.61 (d, $J_{C\text{-}P}$ = 9.3 Hz). $^{31}$P NMR (162 MHz, $CDCl_3$) δ 19.94. HRMS (ESI) calcd for $C_{26}H_{20}NOP$ $[M+H]^+$: 394.1355; found: 394.1356. IR (KBr): 1118 $cm^{-1}$ (P=O).



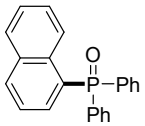

**(2-(4-Bromophenyl)indolizin-3-yl)diphenylphosphine oxide (6e)**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (70.7 mg, 75%), melting point: 194 – 196 °C. $^1$H NMR (400 MHz, $CDCl_3$) δ 8.73 (d, $J$ = 7.1 Hz, 1H), 7.50 – 7.35 (m, 7H), 7.29 – 7.18 (m, 4H), 7.03 – 6.89 (m, 3H), 6.83 – 6.72 (m, 2H), 6.54 (td, $J$ = 7.0, 1.4 Hz, 1H), 6.47 (d, $J$ = 3.3 Hz, 1H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 139.19 (d, $J_{C\text{-}P}$ = 13.8 Hz), 137.25 (d, $J_{C\text{-}P}$ = 7.1 Hz), 134.40, 132.81, 131.84 (d, $J_{C\text{-}P}$ = 10.4 Hz), 131.69 (d, $J_{C\text{-}P}$ = 3.2 Hz), 131.12, 130.12, 128.44 (d, $J_{C\text{-}P}$ = 12.6 Hz), 127.77 (d, $J_{C\text{-}P}$ = 1.9 Hz), 121.69, 120.81, 118.58, 111.88, 109.45 (d, $J_{C\text{-}P}$ = 129.0 Hz), 103.25 (d, $J_{C\text{-}P}$ = 9.1 Hz). $^{31}$P NMR (162 MHz, $CDCl_3$) δ 19.54. HRMS (ESI) calcd for $C_{26}H_{19}BrNOP$ $[M+H]^+$: 472.0460; found: 472.0463. IR (KBr): 1112 $cm^{-1}$ (P=O).




**(6-Methoxyquinolin-5-yl)diphenylphosphine oxide (6f)**

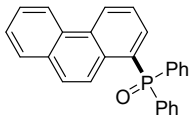
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (41.6 mg, 58%), melting point: 126 – 128 °C. $^{1}$H NMR (400 MHz, $CDCl_3$) δ 8.75 (t, *J* = 4.1 Hz, 1H), 8.05 (dd, *J* = 9.2, 1.6 Hz, 1H), 7.81 (d, *J* = 2.8 Hz, 1H), 7.78 – 7.66 (m, 4H), 7.64 – 7.57 (m, 2H), 7.51 (tdd, *J* = 8.3, 2.9, 1.3 Hz, 4H), 7.36 (dd, *J* = 9.3, 2.8 Hz, 1H), 7.12 (dd, *J* = 15.0, 4.3 Hz, 1H), 3.67 (s, 3H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 158.37, 146.34 (d, $J_{C-P}$ = 11.8 Hz), 144.89 (d, $J_{C-P}$ = 6.9 Hz), 136.60 (d, $J_{C-P}$ = 95.9 Hz), 132.46 (d, $J_{C-P}$ = 2.9 Hz), 131.96 (d, $J_{C-P}$ = 10.0 Hz), 131.61 (d, $J_{C-P}$ = 2.0 Hz), 131.33 (d, $J_{C-P}$ = 105.1 Hz), 129.08 (d, $J_{C-P}$ = 6.2 Hz), 128.87 (d, $J_{C-P}$ = 12.4 Hz), 126.18 (d, $J_{C-P}$ = 9.5 Hz), 123.07, 105.07 (d, $J_{C-P}$ = 5.8 Hz), 55.52. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 30.16. HRMS (ESI) calcd for $C_{22}H_{18}NO_2P$ $[M+H]^+$: 360.1148; found: 360.1157. IR (KBr): 2923 (C-H), 1114 $cm^{-1}$ (P=O).




**Naphthalen-1-yldiphenylphosphine oxide (6g)[1]**

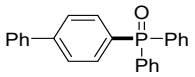
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (49.2 mg, 75%). $^{1}$H NMR (400 MHz, $CDCl_3$) δ 8.59 (d, *J* = 8.5 Hz, 1H), 8.00 (d, *J* = 8.2 Hz, 1H), 7.88 (d, *J* = 8.1 Hz, 1H), 7.69 (dd, *J* = 12.1, 7.6 Hz, 4H), 7.54 (t, *J* = 7.5 Hz, 2H), 7.51 – 7.40 (m, 6H), 7.37 (dt, *J* = 7.8, 3.9 Hz, 1H), 7.33 – 7.25 (m, 1H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 133.88 (d, $J_{C-P}$ = 9.0 Hz), 133.76 (d, $J_{C-P}$ = 12.1 Hz), 133.7 (d, $J_{C-P}$ = 8.1 Hz), 133.28 (d, $J_{C-P}$ = 2.4 Hz), 132.25, 132.05 (d, $J_{C-P}$ = 9.8 Hz), 131.89 (d, $J_{C-P}$ = 2.8 Hz), 128.87 (d, $J_{C-P}$ = 103.0 Hz), 128.76 (d, $J_{C-P}$ = 1.3 Hz),

128.58 (d, $J_{C\text{-}P}$ = 12.2 Hz), 127.58 (d, $J_{C\text{-}P}$ = 5.8 Hz), 127.34, 126.49, 124.13 (d, $J_{C\text{-}P}$ = 14.4 Hz). $^{31}$P NMR (162 MHz, $CDCl_3$) δ 32.43. IR (KBr): 1096 $cm^{-1}$ (P=O).




**Phenanthren-9-yldiphenylphosphine oxide (6h) (main product)**

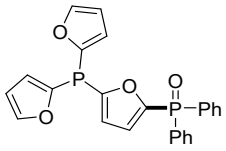
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (52.9 mg, 70%), melting point: 195 – 198 °C. $^1$H NMR (400 MHz, $CDCl_3$) δ 8.94 (d, $J$ = 8.4 Hz, 1H), 8.71 (d, $J$ = 8.3 Hz, 1H), 8.58 (d, $J$ = 9.2 Hz, 1H), 7.87 (d, $J$ = 7.8 Hz, 1H), 7.82 – 7.66 (m, 7H), 7.64 (d, $J$ = 7.4 Hz, 1H), 7.57 (t, $J$ = 7.4 Hz, 3H), 7.48 (dt, $J$ = 7.9, 4.0 Hz, 4H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 133.61 (d, $J_{C\text{-}P}$ = 12.0 Hz), 133.42, 132.38, 132.15 (d, $J_{C\text{-}P}$ = 9.8 Hz), 131.98 (d, $J_{C\text{-}P}$ = 2.8 Hz), 131.66, 131.19 (d, $J_{C\text{-}P}$ = 9.4 Hz), 130.19 (d, $J_{C\text{-}P}$ = 1.2 Hz), 129.41 (d, $J_{C\text{-}P}$ = 102.0 Hz), 128.69, 128.66 (d, $J_{C\text{-}P}$ = 12.1 Hz), 128.44, 127.44 (d, $J_{C\text{-}P}$ = 2.8 Hz), 127.23, 126.94, 125.45 (d, $J_{C\text{-}P}$ = 6.7 Hz), 124.99 (d, $J_{C\text{-}P}$ = 14.2 Hz), 122.76. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 32.98. HRMS (ESI) calcd for $C_{26}H_{19}OP$ $[M+H]^+$: 379.1246; found: 379.1254. IR (KBr): 1116 $cm^{-1}$ (P=O).




**[1,1'-Biphenyl]-4-yldiphenylphosphine oxide (6i) (single product)[2]**

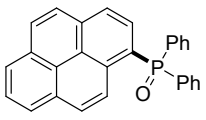
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a pale yellow solid (24.8 mg, 35%). $^1$H NMR (400 MHz, $CDCl_3$) δ 7.78 – 7.65 (m, 8H), 7.58 (dd, $J$ = 20.5, 7.5 Hz, 4H), 7.53 – 7.42 (m, 6H), 7.39 (t, $J$ = 7.3 Hz, 1H). $^{13}$C NMR

(101 MHz, $CDCl_3$) δ 144.72 (d, $J_{C-P}$ = 2.8 Hz), 139.89, 132.61 (d, $J_{C-P}$ = 10.2 Hz), 132.55 (d, $J_{C-P}$ = 104.5 Hz), 132.11 (d, $J_{C-P}$ = 10.0 Hz), 132.00 (d, $J_{C-P}$ = 2.7 Hz), 131.07 (d, $J_{C-P}$ = 105.3 Hz), 128.98, 128.56 (d, $J_{C-P}$ = 12.2 Hz), 128.19, 127.27 (d, $J_{C-P}$ = 2.1 Hz), 127.14. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 29.13. IR (KBr): 1116 $cm^{-1}$ (P=O).



**(5-(Di(furan-2-yl)phosphanyl)furan-2-yl)diphenylphosphine oxide (9a)**

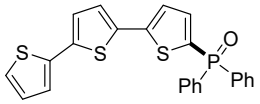
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (64.8 mg, 75%), melting point: 151 – 153 °C. $^1$H NMR (400 MHz, $CDCl_3$) δ 7.78 – 7.68 (m, 4H), 7.61 (s, 2H), 7.57 – 7.50 (m, 2H), 7.43 (td, $J$ = 7.5, 3.0 Hz, 4H), 7.12 – 7.06 (m, 1H), 6.87 – 6.63 (m, 3H), 6.39 (dt, $J$ = 3.1, 1.5 Hz, 2H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 156.55 (dd, $J_{C-P}$ = 6.9, 5.4 Hz), 152.56 (dd, $J_{C-P}$ = 132.2, 2.2 Hz), 147.69 (d, $J_{C-P}$ = 2.8 Hz), 147.62 (d, $J_{C-P}$ = 4.1 Hz), 132.20 (d, $J_{C-P}$ = 2.7 Hz), 131.65 (d, $J_{C-P}$ = 111.0 Hz), 131.58 (d, $J_{C-P}$ = 10.5 Hz), 128.45 (d, $J_{C-P}$ = 12.8 Hz), 123.52 (dd, $J_{C-P}$ = 18.3, 4.8 Hz), 122.02 (d, $J_{C-P}$ = 26.1 Hz), 120.32 (dd, $J_{C-P}$ = 20.7, 8.4 Hz), 110.90 (d, $J_{C-P}$ = 6.7 Hz). $^{31}$P NMR (162 MHz, $CDCl_3$) δ 15.84, -76.40. HRMS (ESI) calcd for $C_{24}H_{18}O_4P_2$ $[M+H]^+$: 433.0753; found: 433.0752. IR (KBr): 1118 $cm^{-1}$ (P=O).



**Diphenyl(pyren-1-yl)phosphine oxide (9b) (main product)**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as

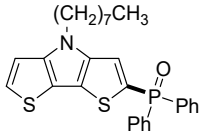
a white solid (56.3 mg, 70%), melting point: 246 – 248 °C. $^{1}$H NMR (400 MHz, $CDCl_3$) δ 8.94 (d, $J$ = 9.4 Hz, 1H), 8.20 (t, $J$ = 7.1 Hz, 2H), 8.15 (d, $J$ = 9.0 Hz, 1H), 8.10 – 8.00 (m, 4H), 7.79 – 7.66 (m, 5H), 7.57 – 7.51 (m, 2H), 7.45 (td, $J$ = 7.4, 2.8 Hz, 4H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 134.22 (d, $J_{C-P}$ = 2.5 Hz), 134.14 (d, $J_{C-P}$ = 8.0 Hz), 133.85, 132.81, 132.21 (d, $J_{C-P}$ = 9.8 Hz), 131.90 (d, $J_{C-P}$ = 2.8 Hz), 131.18 (d, $J_{C-P}$ = 12.2 Hz), 131.00, 130.40, 129.86, 128.91, 128.62 (d, $J_{C-P}$ = 12.2 Hz), 127.11, 126.48, 126.31 (d, $J_{C-P}$ = 6.6 Hz), 126.19, 125.62, 125.09 (d, $J_{C-P}$ = 10.4 Hz), 124.38 (d, $J_{C-P}$ = 42.8 Hz), 123.55 (d, $J_{C-P}$ = 13.7 Hz). $^{31}$P NMR (162 MHz, $CDCl_3$) δ 32.83. HRMS (ESI) calcd for $C_{28}H_{19}OP$ $[M+H]^+$: 403.1246; found: 403.1240. IR (KBr): 1103 $cm^{-1}$ (P=O).




**[2,2':5',2''-Terthiophen]-5-yldiphenylphosphine oxide (9c)**

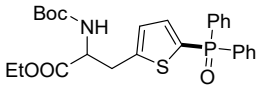
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a yellow solid (53.8 mg, 60%), melting point: 161 – 163 °C. $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.83 – 7.73 (m, 4H), 7.61 – 7.55 (m, 2H), 7.50 (td, $J$ = 7.4, 3.0 Hz, 4H), 7.35 (dd, $J$ = 7.5, 3.7 Hz, 1H), 7.26 – 7.22 (m, 1H), 7.21 (dd, $J$ = 3.8, 1.9 Hz, 1H), 7.18 (dd, $J$ = 3.6, 1.1 Hz, 1H), 7.12 (d, $J$ = 3.8 Hz, 1H), 7.07 (d, $J$ = 3.8 Hz, 1H), 7.02 (dd, $J$ = 5.1, 3.6 Hz, 1H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 145.74 (d, $J_{C-P}$ = 5.3 Hz), 137.93, 137.75 (d, $J_{C-P}$ = 8.9 Hz), 136.64, 134.40 (d, $J_{C-P}$ = 1.7 Hz), 133.17, 132.34 (d, $J_{C-P}$ = 2.8 Hz), 132.08, 132.02 (d, $J_{C-P}$ = 111.2 Hz), 131.83 (d, $J_{C-P}$ = 10.4 Hz), 128.62 (d, $J_{C-P}$ = 12.6 Hz), 128.01, 125.88, 125.04, 124.35 (d, $J_{C-P}$ = 12.8 Hz), 124.32 (d, $J_{C-P}$ = 29.9

Hz). $^{31}$P NMR (162 MHz, $CDCl_3$) δ 21.46. HRMS (ESI) calcd for $C_{24}H_{17}OPS_3$ $[M+H]^+$: 449.0252; found: 449.0251. IR (KBr): 1113 $cm^{-1}$ (P=O).



**(4-Octyl-4H-dithieno[3,2-b:2',3'-d]pyrrol-2-yl)diphenylphosphine oxide (9d)**

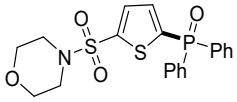
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a brown solid (66.8 mg, 68%), melting point: 113 – 115 °C. $^1$H NMR (400 MHz, $CDCl_3$) δ 7.87 – 7.71 (m, 4H), 7.61 – 7.52 (m, 3H), 7.47 (td, *J* = 7.6, 3.0 Hz, 4H), 7.22 (d, *J* = 5.3 Hz, 1H), 6.99 (d, *J* = 5.4 Hz, 1H), 4.15 (t, *J* = 7.1 Hz, 2H), 1.82 (t, *J* = 7.2 Hz, 2H), 1.31 – 1.14 (m, 10H), 0.85 (t, *J* = 6.8 Hz, 3H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 146.77, 145.12 (d, $J_{C-P}$ = 16.8 Hz), 133.04 (d, $J_{C-P}$ = 109.9 Hz), 132.11 (d, $J_{C-P}$ = 2.8 Hz), 131.85 (d, $J_{C-P}$ = 10.4 Hz), 128.47 (d, $J_{C-P}$ = 113.1 Hz), 128.40 (d, $J_{C-P}$ = 12.5 Hz), 125.79, 122.19 (d, $J_{C-P}$ = 6.5 Hz), 120.18 (d, $J_{C-P}$ = 9.8 Hz), 114.17 (d, $J_{C-P}$ = 2.3 Hz), 110.92, 47.47, 31.67, 30.25, 29.09, 29.06, 26.93, 22.54, 14.05. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 23.05. HRMS (ESI) calcd for $C_{28}H_{30}NOPS_2$ $[M+H]^+$: 492.1579; found: 492.1577. IR (KBr): 2915 (C-H), 1104 $cm^{-1}$ (P=O).



**Ethyl 2-((tert-butoxycarbonyl)amino)-3-(5-(diphenylphosphoryl)thiophen-2-yl)propanoate (9e)**

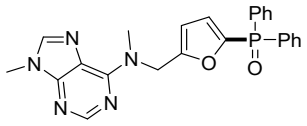
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 3/1) and obtained as

a colorless oil (69.9 mg, 70%). $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.75 – 7.67 (m, 4H), 7.60 – 7.52 (m, 2H), 7.47 (td, *J* = 7.5, 3.0 Hz, 4H), 7.32 – 7.23 (m, 1H), 6.90 (s, 1H), 5.20 (d, *J* = 7.8 Hz, 1H), 4.56 (q, *J* = 5.2 Hz, 1H), 4.15 (q, *J* = 7.1 Hz, 2H), 3.56 – 3.11 (m, 2H), 1.41 (s, 9H), 1.22 (t, *J* = 7.1 Hz, 3H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 170.73, 154.97, 147.42 (d, $J_{C-P}$ = 3.2 Hz), 137.09 (d, $J_{C-P}$ = 9.4 Hz), 132.91 (d, $J_{C-P}$ = 113.1 Hz), 132.76 (d, $J_{C-P}$ = 110.1 Hz), 132.20 (d, $J_{C-P}$ = 2.7 Hz), 131.77 (d, $J_{C-P}$ = 10.5 Hz), 128.50 (d, $J_{C-P}$ = 12.6 Hz), 128.05 (d, $J_{C-P}$ = 13.0 Hz), 80.17, 61.83, 54.11, 32.65, 28.29, 14.14. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 21.63. HRMS (ESI) calcd for $C_{26}H_{30}NO_5PS$ $[M+H]^+$: 500.1655; found: 500.1659. IR (KBr): 2977 (C-H), 1157 $cm^{-1}$ (P=O).



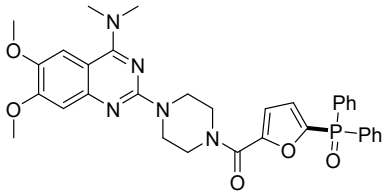

**(5-(Morpholinosulfonyl)thiophen-2-yl)diphenylphosphine oxide (9f)**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 1/1) and obtained as a pale yellow solid (47.6 mg, 55%), melting point: 110 – 113 °C. $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.79 – 7.69 (m, 4H), 7.66 – 7.59 (m, 2H), 7.59 – 7.49 (m, 5H), 7.47 (dd, *J* = 6.9, 3.8 Hz, 1H), 3.84 – 3.71 (m, 4H), 3.13 – 2.98 (m, 4H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 143.05 (d, $J_{C-P}$ = 4.5 Hz), 142.34 (d, $J_{C-P}$ = 100.7 Hz), 136.10 (d, $J_{C-P}$ = 9.0 Hz), 132.89 (d, $J_{C-P}$ = 2.9 Hz), 132.32 (d, $J_{C-P}$ = 85.3 Hz), 131.72 (d, $J_{C-P}$ = 10.5 Hz), 130.80, 128.89 (d, $J_{C-P}$ = 12.8 Hz), 65.92, 45.93. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 20.91. HRMS (ESI) calcd for $C_{20}H_{20}NO_4PS_2$ $[M+H]^+$: 434.0644; found: 434.0652. IR (KBr): 1112 $cm^{-1}$ (P=O).



**(5-((Methyl(9-methyl-9H-purin-6-yl)amino)methyl)furan-2-yl)diphenylphosphine oxide (9g)**

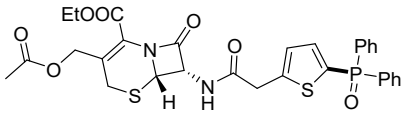
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 1/2) and obtained as a white solid (48.7 mg, 55%), melting point: 126 – 128 °C. $^{1}$H NMR (400 MHz, $CDCl_3$) δ 8.39 (s, 1H), 7.72 (s, 1H), 7.68 (dd, *J* = 12.7, 7.4 Hz, 4H), 7.57 – 7.49 (m, 2H), 7.43 (td, *J* = 7.5, 3.0 Hz, 4H), 6.91 (dd, *J* = 3.4, 1.9 Hz, 1H), 6.53 – 6.00 (m, 1H), 5.35 (s, 2H), 3.81 (s, 3H), 3.44 (s, 3H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 158.60 (d, $J_{C-P}$ = 6.2 Hz), 154.37, 152.31, 147.32 (d, $J_{C-P}$ = 136.4 Hz), 139.15, 132.22 (d, $J_{C-P}$ = 2.9 Hz), 131.59 (d, $J_{C-P}$ = 10.4 Hz), 131.49 (d, $J_{C-P}$ = 111.4 Hz), 128.47 (d, $J_{C-P}$ = 12.7 Hz), 124.22 (d, $J_{C-P}$ = 18.5 Hz), 119.99, 108.89 (d, $J_{C-P}$ = 8.2 Hz), 29.78, 29.69, 19.16. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 15.96. HRMS (ESI) calcd for $C_{24}H_{22}N_5O_2P$ $[M+H]^+$: 444.1584; found: 444.1590. IR (KBr): 2922 (C-H), 1118 $cm^{-1}$ (P=O).



**(4-(4-(Dimethylamino)-6,7-dimethoxyquinazolin-2-yl)piperazin-1-yl)(5-(diphenylphosphoryl)furan-2-yl)methanone (9h)**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 1/2) and obtained as a white solid (73.3 mg, 60%), melting point: 163 – 168 °C. $^{1}$H NMR (400 MHz, $CDCl_3$)

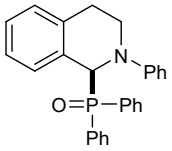
δ 7.77 (dd, $J$ = 12.9, 7.0 Hz, 4H), 7.61 (t, $J$ = 6.9 Hz, 2H), 7.56 – 7.48 (m, 4H), 7.16 (s, 1H), 7.15 – 7.12 (m, 1H), 7.10 (dd, $J$ = 3.6, 1.7 Hz, 1H), 6.96 (s, 1H), 3.98 (s, 3H), 3.92 (s, 3H), 3.92 – 3.65 (m, 8H), 3.24 (s, 6H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 164.34, 158.41, 157.73, 154.19, 153.30 (d, $J_{C-P}$ = 6.3 Hz), 151.24, 149.66 (d, $J_{C-P}$ = 129.8 Hz), 144.64, 132.69 (d, $J_{C-P}$ = 2.9 Hz), 131.69 (d, $J_{C-P}$ = 10.6 Hz), 130.76 (d, $J_{C-P}$ = 111.8 Hz), 128.76 (d, $J_{C-P}$ = 12.9 Hz), 123.69 (d, $J_{C-P}$ = 17.4 Hz), 116.64 (d, $J_{C-P}$ = 7.6 Hz), 105.76, 105.27, 105.19, 56.07, 55.99, 46.59, 44.48, 41.59. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 16.45. HRMS (ESI) calcd for $C_{33}H_{34}N_5O_5P$ $[M+H]^+$: 612.2370; found: 612.2369. IR (KBr): 2923 (C-H), 1161 $cm^{-1}$ (P=O).




**Ethyl (6S, 7S)-3-(acetoxymethyl)-7-(2-(5-(diphenylphosphoryl)thiophen-2-yl)acetamido)-8-oxo-5-thia-1-azabicyclo[4.2.0]oct-2-ene-2-carboxylate (9i)**

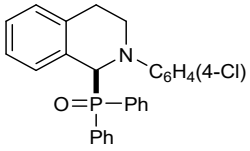
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 1/1) and obtained as a white solid (81.1 mg, 65%), melting point: 122 – 124 °C. $^1$H NMR (400 MHz, $CDCl_3$) δ 8.12 (d, $J$ = 8.3 Hz, 1H), 7.71 (dd, $J$ = 12.7, 7.6 Hz, 4H), 7.55 (t, $J$ = 7.3 Hz, 2H), 7.46 (dt, $J$ = 7.6, 3.8 Hz, 4H), 7.25 (dd, $J$ = 7.7, 3.6 Hz, 1H), 7.01 (s, 1H), 6.29 (s, 1H), 5.60 (dd, $J$ = 8.3, 4.0 Hz, 1H), 5.24 (d, $J$ = 4.0 Hz, 1H), 4.97 (s, 1H), 4.68 (d, $J$ = 12.7 Hz, 1H), 4.52 (d, $J$ = 12.8 Hz, 1H), 4.22 (q, $J$ = 6.8 Hz, 2H), 3.89 (q, $J$ = 16.2 Hz, 2H), 2.04 (s, 3H), 1.30 (t, $J$ = 7.2 Hz, 3H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 170.40, 169.41, 167.11, 163.94, 145.32 (d, $J_{C-P}$ = 5.0 Hz), 137.25 (d, $J_{C-P}$ = 9.2 Hz), 133.44, 132.59 (d, $J_{C-P}$ = 54.1 Hz), 132.23, 131.71 (d, $J_{C-P}$ = 10.4 Hz), 128.50 (d, $J_{C-P}$ = 12.7 Hz), 128.30 (d, $J_{C-}$

$_P$ = 13.0 Hz), 122.14, 118.79, 65.56, 62.38, 60.60, 53.38, 50.02, 36.77, 20.80, 14.00. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 21.70. HRMS (ESI) calcd for $C_{30}H_{29}N_2O_7PS_2$ $[M+H]^+$: 625.1227; found: 625.1230. IR (KBr): 2920 (C-H), 1104 $cm^{-1}$ (P=O).



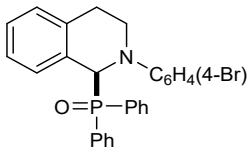

**Diphenyl(2-phenyl-1,2,3,4-tetrahydroisoquinolin-1-yl)phosphine oxide (11a)[3]**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (62.2 mg, 76%). $^1$H NMR (400 MHz, $CDCl_3$) δ 7.80 (ddt, *J* = 10.3, 6.9, 1.4 Hz, 2H), 7.70 (ddt, *J* = 10.6, 7.0, 1.4 Hz, 2H), 7.56 – 7.50 (m, 1H), 7.44 (qd, *J* = 7.5, 2.2 Hz, 3H), 7.33 (td, *J* = 7.7, 3.2 Hz, 2H), 7.14 (ddd, *J* = 8.8, 7.2, 2.3 Hz, 3H), 7.06 (d, *J* = 7.5 Hz, 1H), 6.93 (t, *J* = 7.5 Hz, 1H), 6.78 (dd, *J* = 16.7, 7.9 Hz, 3H), 6.64 (d, *J* = 7.8, 1.5 Hz, 1H), 5.56 (d, *J* = 10.6 Hz, 1H), 4.03 (ddd, *J* = 13.4, 10.1, 4.7 Hz, 1H), 3.64 – 3.51 (m, 1H), 2.88 – 2.77(m, 1H), 2.72 – 2.59 (m, 1H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 149.93 (d, $J_{C-P}$ = 7.9 Hz), 136.84 (d, $J_{C-P}$ = 4.3 Hz), 132.22 (d, $J_{C-P}$ = 8.5 Hz), 131.21 (d, $J_{C-P}$ = 85.6 Hz), 132.16 (d, $J_{C-P}$ = 99.3 Hz), 131.91 (d, $J_{C-P}$ = 2.8 Hz), 131.69, 131.60, 129.86, 129.21 (d, $J_{C-P}$ = 2.2 Hz), 129.09, 128.41 (d, $J_{C-P}$ = 11.2 Hz), 128.25 (d, $J_{C-P}$ = 11.3 Hz), 127.73 (d, $J_{C-P}$ = 3.2 Hz), 127.38 (d, $J_{C-P}$ = 2.9 Hz), 125.49 (d, $J_{C-P}$ = 2.6 Hz), 119.50, 116.70, 61.89 (d, $J_{C-P}$ = 79.8 Hz), 45.10, 25.56. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 30.74. IR (KBr): 2921 (C-H), 1064 $cm^{-1}$ (P=O).



**(2-(4-chlorophenyl)-1,2,3,4-tetrahydroisoquinolin-1-yl)diphenylphosphine oxide (11b)[3]**

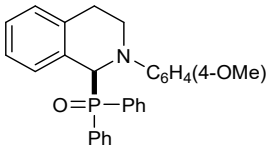
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (48,7 mg, 55%). $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.83 – 7.72 (m, 2H), 7.73 – 7.62 (m, 2H), 7.55 (t, *J* = 7.3 Hz, 1H), 7.46 (dt, *J* = 7.3, 3.7 Hz, 3H), 7.35 (td, *J* = 7.6, 2.9 Hz, 2H), 7.16 (t, *J* = 7.4 Hz, 1H), 7.11 – 7.01 (m, 3H), 6.94 (t, *J* = 7.4 Hz, 1H), 6.74 – 6.67 (m, 2H), 6.61 (d, *J* = 7.8 Hz, 1H), 5.47 (d, *J* = 10.0 Hz, 1H), 4.04 (ddd, *J* = 14.1, 9.7, 4.9 Hz, 1H), 3.50 (dt, *J* = 13.1, 4.9 Hz, 1H), 2.91 – 2.56 (m, 2H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 148.57 (d, $J_{C-P}$ = 7.2 Hz), 136.70 (d, $J_{C-P}$ = 4.2 Hz), 132.24 (d, $J_{C-P}$ = 8.5 Hz), 132.07 (d, $J_{C-P}$ = 2.8 Hz), 132.00 (d, $J_{C-P}$ = 95.0 Hz), 131.82 (d, $J_{C-P}$ = 2.8 Hz), 131.62 (d, $J_{C-P}$ = 8.8 Hz), 130.92 (d, $J_{C-P}$ = 90.9 Hz), 129.65, 129.23 (d, $J_{C-P}$ = 2.2 Hz), 128.98, 128.43 (d, $J_{C-P}$ = 23.9 Hz), 128.43 (d, $J_{C-P}$ = 1.3 Hz), 127.75 (d, $J_{C-P}$ = 3.3 Hz), 127.61 (d, $J_{C-P}$ = 2.9 Hz), 125.67 (d, $J_{C-P}$ = 2.5 Hz), 124.26, 117.73, 62.15 (d, $J_{C-P}$ = 78.9 Hz), 45.25, 25.77. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 30.53. IR (KBr): 2919 (C-H), 1086 $cm^{-1}$ (P=O).




**(2-(4-Bromophenyl)-1,2,3,4-tetrahydroisoquinolin-1-yl)diphenylphosphine oxide (11c)[3]**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as

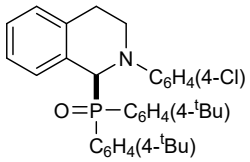
a white solid (58.4 mg, 60%). $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.76 (t, *J* = 9.1 Hz, 2H), 7.73 – 7.63 (m, 2H), 7.55 (t, *J* = 7.5 Hz, 1H), 7.46 (t, *J* = 7.5 Hz, 3H), 7.35 (t, *J* = 6.7 Hz, 2H), 7.20 (d, *J* = 8.4 Hz, 2H), 7.15 (d, *J* = 7.5 Hz, 1H), 7.08 (d, *J* = 7.6 Hz, 1H), 6.94 (t, *J* = 7.6 Hz, 1H), 6.66 (d, *J* = 8.5 Hz, 2H), 6.61 (d, *J* = 7.9 Hz, 1H), 5.48 (d, *J* = 9.9 Hz, 1H), 4.03 (ddd, *J* = 13.8, 9.5, 4.9 Hz, 1H), 3.59 – 3.38 (m, 1H), 2.81 (dt, *J* = 15.4, 7.3 Hz, 1H), 2.75 – 2.65 (m, 1H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 148.97 (d, $J_{C-P}$ = 7.1 Hz), 136.67 (d, $J_{C-P}$ = 4.1 Hz), 132.24 (d, $J_{C-P}$ = 8.4 Hz), 132.09 (d, $J_{C-P}$ = 2.7 Hz), 131.89 (d, $J_{C-P}$ = 111.1), 131.88, 131.85 (d, $J_{C-P}$ = 2.7 Hz), 131.61 (d, $J_{C-P}$ = 8.8 Hz), 130.96 (d, $J_{C-P}$ = 107.1), 129.65, 129.22 (d, $J_{C-P}$ = 2.2 Hz), 128.51 (d, $J_{C-P}$ = 12.1), 128.39 (d, $J_{C-P}$ = 12.1), 127.75 (d, $J_{C-P}$ = 3.3 Hz), 127.64 (d, $J_{C-P}$ = 2.9 Hz), 125.68 (d, $J_{C-P}$ = 2.5 Hz), 118.04, 111.51, 62.13 (d, $J_{C-P}$ = 78.7 Hz), 45.10, 25.83. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 30.71. IR (KBr): 2915 (C-H), 1090 $cm^{-1}$ (P=O).




**(2-(4-methoxyphenyl)-1,2,3,4-tetrahydroisoquinolin-1-yl)diphenylphosphine oxide (11d)[3]**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (61.5 mg, 70%). $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.77 (t, *J* = 9.1 Hz, 2H), 7.71 (t, *J* = 9.2 Hz, 2H), 7.52 (t, *J* = 7.4 Hz, 1H), 7.44 (p, *J* = 6.8, 5.8 Hz, 3H), 7.35 (dt, *J* = 8.2, 4.1 Hz, 2H), 7.14 (t, *J* = 7.5 Hz, 1H), 7.07 (d, *J* = 7.6 Hz, 1H), 6.93 (t, *J* = 7.5 Hz, 1H), 6.76 (d, *J* = 8.8 Hz, 2H), 6.71 (d, *J* = 8.8 Hz, 2H), 6.61 (d, *J* = 7.8 Hz, 1H),

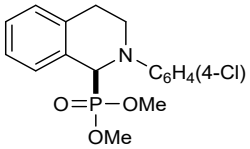
5.36 (d, $J$ = 11.8 Hz, 1H), 3.98 (ddd, $J$ = 14.5, 11.0, 4.4 Hz, 1H), 3.71 (s, 3H), 3.47 – 3.31 (m, 1H), 2.75 (dq, $J$ = 16.0, 5.5, 4.9 Hz, 1H), 2.55 (dd, $J$ = 16.4, 3.8 Hz, 1H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 154.02, 144.60 (d, $J_{C\text{-}P}$ = 11.1 Hz), 137.01 (d, $J_{C\text{-}P}$ = 4.0 Hz), 132.45 (d, $J_{C\text{-}P}$ = 96.0 Hz), 132.15 (d, $J_{C\text{-}P}$ = 8.0 Hz), 131.85 (d, $J_{C\text{-}P}$ = 90.9 Hz), 131.80, 131.74 (d, $J_{C\text{-}P}$ = 7.1 Hz), 131.53 (d, $J_{C\text{-}P}$ = 3.0 Hz), 129.69, 129.36 (d, $J_{C\text{-}P}$ = 2.0 Hz), 128.38 (d, $J_{C\text{-}P}$ = 11.1 Hz), 128.21 (d, $J_{C\text{-}P}$ = 11.1 Hz), 127.77 (d, $J_{C\text{-}P}$ = 3.0 Hz), 127.21 (d, $J_{C\text{-}P}$ = 3.0 Hz), 125.44 (d, $J_{C\text{-}P}$ = 3.0 Hz), 120.35, 114.41, 62.09 (d, $J_{C\text{-}P}$ = 81.8 Hz), 55.49, 46.79, 24.76. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 31.06. IR (KBr): 3048 (C-H), 1109 $cm^{-1}$ (P=O).




**Bis(4-(tert-butyl)phenyl)(2-(4-chlorophenyl)-1,2,3,4-tetrahydroisoquinolin-1-yl)phosphine oxide (11e)**

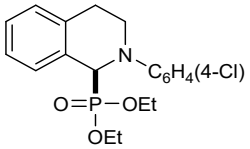
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (75.5 mg, 68%) , melting point: 233 – 235 °C. $^1$H NMR (400 MHz, $CDCl_3$) δ 7.69 – 7.64 (m, 2H), 7.61 – 7.56 (m, 2H), 7.46 (d, $J$ = 7.9 Hz, 2H), 7.36 – 7.30 (m, 2H), 7.15 (t, $J$ = 7.3 Hz, 1H), 7.08 (d, $J$ = 7.5 Hz, 1H), 7.03 (d, $J$ = 8.7 Hz, 2H), 6.92 (t, $J$ = 7.4 Hz, 1H), 6.66 (d, $J$ = 8.7 Hz, 2H), 6.61 (d, $J$ = 7.6 Hz, 1H), 5.45 (d, $J$ = 9.2 Hz, 1H), 4.05 (ddd, $J$ = 13.7, 8.7, 5.5 Hz, 1H), 3.50 (dt, $J$ = 12.2, 5.3 Hz, 1H), 2.90 – 2.68 (m, 2H), 1.34 (s, 9H), 1.27 (s, 9H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 155.58 (d, $J_{C\text{-}P}$ = 2.9 Hz), 155.25 (d, $J_{C\text{-}P}$ = 2.7 Hz), 148.46 (d, $J_{C\text{-}P}$ = 6.2 Hz), 136.70 (d, $J_{C\text{-}P}$ = 4.0 Hz),

132.09 (d, $J_{C\text{-}P}$ = 8.8 Hz), 131.53 (d, $J_{C\text{-}P}$ = 9.1 Hz), 130.06, 129.08 (d, $J_{C\text{-}P}$ = 2.2 Hz), 128.83, 127.85 (d, $J_{C\text{-}P}$ = 3.4 Hz), 127.48 (d, $J_{C\text{-}P}$ = 2.9 Hz), 125.53 (d, $J_{C\text{-}P}$ = 3.0 Hz), 125.50, 125.38, 125.26, 123.75, 117.33, 62.16 (d, $J_{C\text{-}P}$ = 77.6 Hz), 44.95, 35.06, 34.95, 31.18, 31.11, 26.08. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 31.00. HRMS (ESI) calcd for $C_{35}H_{39}ClNOP$ $[M+H]^+$: 556.2531; found: 556.2536. IR (KBr): 3048 (C-H), 1089 $cm^{-1}$ (P=O).



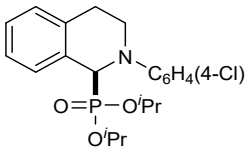

**Dimethyl (2-(4-chlorophenyl)-1,2,3,4-tetrahydroisoquinolin-1-yl)phosphonate (11f)[4]**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 20/1) and obtained as a white solid (52 mg, 75%). $^1$H NMR (400 MHz, $CDCl_3$) δ 7.34 (d, *J* = 7.2 Hz, 1H), 7.27 – 7.11 (m, *J* = 6.5 Hz, 5H), 6.89 (d, *J* = 9.0 Hz, 2H), 5.12 (d, *J* = 19.2 Hz, 1H), 3.97 (ddd, *J* = 12.7, 8.2, 4.7 Hz, 1H), 3.63 (dd, *J* = 10.5, 8.0 Hz, 6H), 3.54 (dt, *J* = 11.9, 5.7 Hz, 1H), 3.19 – 3.07 (m, 1H), 3.04 – 2.91 (m, 1H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 147.73 (d, $J_{C\text{-}P}$ = 5.3 Hz), 136.25 (d, $J_{C\text{-}P}$ = 5.5 Hz), 130.12, 129.01, 128.77 (d, $J_{C\text{-}P}$ = 2.7 Hz), 127.94 (d, $J_{C\text{-}P}$ = 4.8 Hz), 127.74 (d, $J_{C\text{-}P}$ = 3.5 Hz), 126.20 (d, $J_{C\text{-}P}$ = 2.9 Hz), 123.34, 115.68, 58.72 (d, $J_{C\text{-}P}$ = 159.9 Hz), 53.87 (d, $J_{C\text{-}P}$ = 7.2 Hz), 53.04 (d, $J_{C\text{-}P}$ = 7.7 Hz), 43.77, 26.81. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 24.06. IR (KBr): 1061 $cm^{-1}$ (P=O).



**Diethyl (2-(4-chlorophenyl)-1,2,3,4-tetrahydroisoquinolin-1-yl)phosphonate (11g)[4]**

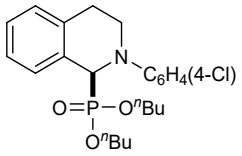
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 20/1) and obtained as a white solid (46.2 mg, 61%). $^1$H NMR (400 MHz, $CDCl_3$) δ 7.38 – 7.32 (m, 1H), 7.25 – 7.13 (m, 5H), 6.95 – 6.84 (m, 2H), 5.10 (d, $J$ = 19.2 Hz, 1H), 4.11 – 3.84 (m, 5H), 3.58 – 3.50 (m, 1H), 3.19 – 3.09 (m, 1H), 3.03 – 2.90 (m, 1H), 1.24 (t, $J$ = 7.1 Hz, 3H), 1.14 (t, $J$ = 7.1 Hz, 3H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 147.92 (d, $J_{C\text{-}P}$ = 5.1 Hz), 136.31 (d, $J_{C\text{-}P}$ = 5.5 Hz), 130.41, 128.90, 128.69 (d, $J_{C\text{-}P}$ = 2.8 Hz), 128.13 (d, $J_{C\text{-}P}$ = 4.8 Hz), 127.65 (d, $J_{C\text{-}P}$ = 3.5 Hz), 126.02 (d, $J_{C\text{-}P}$ = 2.9 Hz), 123.14, 115.73, 63.30 (d, $J_{C\text{-}P}$ = 7.4 Hz), 62.47 (d, $J_{C\text{-}P}$ = 7.7 Hz), 58.84 (d, $J_{C\text{-}P}$ = 159.7 Hz), 43.74, 26.92, 16.48 (d, $J_{C\text{-}P}$ = 5.4 Hz), 16.39 (d, $J_{C\text{-}P}$ = 5.8 Hz). $^{31}$P NMR (162 MHz, $CDCl_3$) δ 21.86. IR (KBr): 2979 (C-H), 1020 cm$^{-1}$ (P=O).




**Diisopropyl (2-(4-chlorophenyl)-1,2,3,4-tetrahydroisoquinolin-1-yl)phosphonate (11h)[5]**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 20/1) and obtained as a white solid (44.8 mg, 55%). $^1$H NMR (400 MHz, $CDCl_3$) δ 7.38 (d, $J$ = 6.7 Hz, 1H), 7.24 – 7.05 (m, 5H), 6.87 (d, $J$ = 8.7 Hz, 2H), 5.06 (d, $J$ = 20.3 Hz, 1H), 4.72 – 4.46 (m, 2H), 4.09 – 3.93 (m, 1H), 3.56 (dt, $J$ = 12.0, 5.5 Hz, 1H), 3.16 – 3.04 (m, 1H),

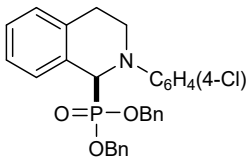
3.01 – 2.88 (m, 1H), 1.28 (t, $J$ = 5.6 Hz, 6H), 1.15 (d, $J$ = 6.2 Hz, 3H), 0.94 (d, $J$ = 6.2 Hz, 3H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 148.05 (d, $J_{C\text{-}P}$ = 5.8 Hz), 136.24 (d, $J_{C\text{-}P}$ = 5.4 Hz), 130.61, 128.74, 128.63 (d, $J_{C\text{-}P}$ = 2.7 Hz), 128.39 (d, $J_{C\text{-}P}$ = 4.7 Hz), 127.45 (d, $J_{C\text{-}P}$ = 3.6 Hz), 125.75 (d, $J_{C\text{-}P}$ = 2.8 Hz), 122.84, 115.92, 72.24 (d, $J_{C\text{-}P}$ = 7.7 Hz), 70.98 (d, $J_{C\text{-}P}$ = 8.1 Hz), 58.81 (d, $J_{C\text{-}P}$ = 161.4 Hz), 43.66, 26.71, 24.55 (d, $J_{C\text{-}P}$ = 3.1 Hz), 24.14 (d, $J_{C\text{-}P}$ = 3.2 Hz), 23.72 (d, $J_{C\text{-}P}$ = 5.7 Hz), 23.34 (d, $J_{C\text{-}P}$ = 5.4 Hz). $^{31}$P NMR (162 MHz, $CDCl_3$) δ 20.56. IR (KBr): 2976 (C-H), 1104 cm$^{-1}$ (P=O).




**Dibutyl (2-(4-chlorophenyl)-1,2,3,4-tetrahydroisoquinolin-1-yl)phosphonate (11i)**

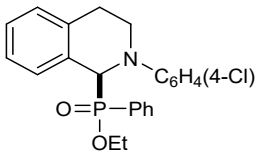
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 20/1) and obtained as a white solid (39.2 mg, 45%) , melting point: 155 – 157 °C. $^1$H NMR (400 MHz, $CDCl_3$) δ 7.35 (d, $J$ = 6.8 Hz, 1H), 7.19 (t, $J$ = 8.5 Hz, 5H), 6.88 (d, $J$ = 8.7 Hz, 2H), 5.12 (d, $J$ = 19.1 Hz, 1H), 4.05 – 3.91 (m, 3H), 3.90 – 3.81 (m, 1H), 3.81 – 3.72 (m, 1H), 3.54 (dt, $J$ = 11.9, 5.7 Hz, 1H), 3.18 – 3.08 (m, 1H), 2.96 (dt, $J$ = 14.9, 6.6 Hz, 1H), 1.59 – 1.50 (m, 2H), 1.49 – 1.40 (m, 2H), 1.40 – 1.07 (m, 5H), 0.88 (t, $J$ = 7.4 Hz, 3H), 0.82 (t, $J$ = 7.4 Hz, 3H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 147.81 (d, $J_{C\text{-}P}$ = 4.9 Hz), 136.19 (d, $J_{C\text{-}P}$ = 5.4 Hz), 130.43, 128.82, 128.62 (d, $J_{C\text{-}P}$ = 2.8 Hz), 128.06 (d, $J_{C\text{-}P}$ = 4.8 Hz), 127.56 (d, $J_{C\text{-}P}$ = 3.5 Hz), 125.95 (d, $J_{C\text{-}P}$ = 2.9 Hz), 123.00, 115.63, 66.82 (d, $J_{C\text{-}P}$ = 7.6 Hz), 66.02 (d, $J_{C\text{-}P}$ = 7.8 Hz), 58.70 (d, $J_{C\text{-}P}$ = 158.8 Hz), 43.60, 32.54 (d, $J_{C\text{-}P}$ = 6.2 Hz), 32.47 (d, $J_{C\text{-}P}$ = 6.0 Hz), 26.92, 18.65, 18.60, 13.56, 13.52. $^{31}$P NMR (162

MHz, $CDCl_3$) δ 22.03. HRMS (ESI) calcd for $C_{23}H_{31}ClNO_3P$ $[M+H]^+$: 436.1803; found: 436.1807. IR (KBr): 2958 (C-H), 1058 $cm^{-1}$ (P=O).



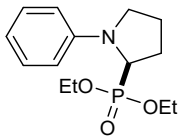

**Dibenzyl (2-(4-chlorophenyl)-1,2,3,4-tetrahydroisoquinolin-1-yl)phosphonate (11j)[6]**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 20/1) and obtained as a white solid (50.3 mg, 50%). $^1H$ NMR (400 MHz, $CDCl_3$) δ 7.41 – 7.04 (m, 16H), 6.89 – 6.79 (m, 2H), 5.18 (d, $J$ = 18.8 Hz, 1H), 5.00 – 4.82 (m, 3H), 4.75 (dd, $J$ = 11.6, 7.9 Hz, 1H), 3.99 – 3.89 (m, 1H), 3.51 (dt, $J$ = 12.0, 5.8 Hz, 1H), 3.17 – 3.06 (m, 1H), 3.01 – 2.89 (m, 1H). $^{13}C$ NMR (101 MHz, $CDCl_3$) δ 147.73 (d, $J_{C-P}$ = 4.8 Hz), 136.35 (d, $J_{C-P}$ = 5.5 Hz), 136.11, 136.11 (d, $J_{C-P}$ = 11.3 Hz), 130.10, 128.93, 128.78 (d, $J_{C-P}$ = 2.8 Hz), 128.51, 128.43, 128.39, 128.32, 128.19 (d, $J_{C-P}$ = 4.8 Hz), 128.08, 128.06, 127.78 (d, $J_{C-P}$ = 3.6 Hz), 126.14 (d, $J_{C-P}$ = 2.9 Hz), 123.28, 115.83, 68.67 (d, $J_{C-P}$ = 7.3 Hz), 67.87 (d, $J_{C-P}$ = 7.9 Hz), 59.01 (d, $J_{C-P}$ = 158.1 Hz), 43.73, 26.98. $^{31}P$ NMR (162 MHz, $CDCl_3$) δ 22.71. IR (KBr): 1046 $cm^{-1}$ (P=O).




**Ethyl (2-(4-chlorophenyl)-1,2,3,4-tetrahydroisoquinolin-1-yl)(phenyl)phosphinate (11k)**

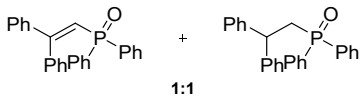
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 20/1) and obtained as a white solid (32.9 mg, 40%), melting point: 136 –138 °C. $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.77 – 7.65 (m, 2H), 7.52 – 7.45 (m, 1H), 7.44 – 7.31 (m, 3H), 7.25 – 7.15 (m, 2H), 7.12 (q, *J* = 5.8 Hz, 1H), 7.08 – 6.87 (m, 2H), 6.75 – 6.45 (m, 2H), 5.11 (d, *J* = 14.9 Hz, 1H), 4.17 – 3.90 (m, 3H), 3.49 (dt, *J* = 12.9, 5.1 Hz, 1H), 2.92 – 2.82 (m, 1H), 2.82 – 2.70 (m, 1H), 1.31 (t, *J* = 7.1 Hz, 3H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 148.07 (d, $J_{C-P}$ = 6.8 Hz), 136.29 (d, $J_{C-P}$ = 4.7 Hz), 132.37, 132.28 (d, $J_{C-P}$ = 9.5 Hz), 130.19 (d, $J_{C-P}$ = 121.3 Hz), 129.89, 128.98 (d, $J_{C-P}$ = 2.3 Hz), 128.70, 128.51 (d, $J_{C-P}$ = 3.9 Hz), 128.39 (d, $J_{C-P}$ = 12.2 Hz), 127.51 (d, $J_{C-P}$ = 3.1 Hz), 125.86 (d, $J_{C-P}$ = 2.6 Hz), 123.41, 116.50, 61.41 (d, $J_{C-P}$ = 7.3 Hz), 61.11 (d, $J_{C-P}$ = 113.7 Hz), 43.89, 26.06, 16.54 (d, $J_{C-P}$ = 6.0 Hz). $^{31}$P NMR (162 MHz, $CDCl_3$) δ 37.51. HRMS (ESI) calcd for $C_{23}H_{23}ClNO_2P$ $[M+H]^+$: 412.1228; found: 412.1228. IR (KBr): 2920 (C-H), 1024 $cm^{-1}$ (P=O).




**Diethyl (1-phenylpyrrolidin-2-yl)phosphonate (11l)**[7]

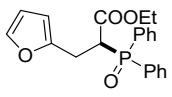
According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 20/1) and obtained as a pale yellow oil (32.9 mg, 40%). $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.29 – 7.15 (m, 2H), 6.81 (d, *J* = 8.2 Hz, 2H), 6.74 (t, *J* = 7.3 Hz, 1H), 4.17 – 4.01 (m, 4H), 3.97 – 3.86 (m, 1H), 3.59 (t, *J* = 8.4 Hz, 1H), 3.24 – 3.11 (m, 1H), 2.44 – 2.31 (m, 2H), 2.14 – 1.99

(m, 2H), 1.31 (t, $J$ = 7.1 Hz, 3H), 1.18 (t, $J$ = 7.1 Hz, 3H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 147.73, 128.77, 116.95, 113.08, 62.44 (d, $J_{C\text{-}P}$ = 7.0 Hz), 61.86 (d, $J_{C\text{-}P}$ = 7.6 Hz), 56.38 (d, $J_{C\text{-}P}$ = 169.1 Hz), 49.65 (d, $J_{C\text{-}P}$ = 2.3 Hz), 27.76, 24.21, 16.46 (d, $J_{C\text{-}P}$ = 4.7 Hz), 16.41 (d, $J_{C\text{-}P}$ = 4.8 Hz). $^{31}$P NMR (162 MHz, $CDCl_3$) δ 25.63. IR (KBr): 2977 (C-H), 1020 $cm^{-1}$ (P=O).




**(2,2-diphenylvinyl)diphenylphosphine oxide (13) and (2,2-diphenylethyl)diphenylphosphine oxide (13')[8]**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 5/1) and obtained as a white solid (68.4 mg, 90%). $^1$H NMR (400 MHz, $CDCl_3$) δ 7.73 – 7.64 (m, 4H), 7.61 – 7.52 (m, 4H), 7.32 (dtd, $J$ = 20.2, 11.9, 10.1, 6.9 Hz, 19H), 7.26 – 7.19 (m, 4H), 7.19 (d, $J$ = 7.3 Hz, 5H), 7.14 – 6.99 (m, 9H), 6.79 (d, $J$ = 18.2 Hz, 1H), 4.71 (dt, $J$ = 11.7, 7.1 Hz, 1H), 3.10 (dd, $J$ = 11.0, 7.2 Hz, 2H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 161.87, 143.77 (d, $J_{C\text{-}P}$ = 7.6 Hz), 141.76 (d, $J_{C\text{-}P}$ = 16.1 Hz), 137.90 (d, $J_{C\text{-}P}$ = 6.7 Hz), 134.26 (d, $J_{C\text{-}P}$ = 105.9 Hz), 133.15 (d, $J_{C\text{-}P}$ = 98.8 Hz), 131.20 (d, $J_{C\text{-}P}$ = 2.8 Hz), 130.97 (d, $J_{C\text{-}P}$ = 2.8 Hz), 130.74 (d, $J_{C\text{-}P}$ = 9.5 Hz), 130.52 (d, $J_{C\text{-}P}$ = 9.3 Hz), 130.20, 128.98 (d, $J_{C\text{-}P}$ = 90.1 Hz), 128.29, 128.23 (d, $J_{C\text{-}P}$ = 10.0 Hz), 128.16 (d, $J_{C\text{-}P}$ = 12.0 Hz), 127.72, 126.89 (d, $J_{C\text{-}P}$ = 117.3 Hz), 120.44 (d, $J_{C\text{-}P}$ = 103.5 Hz), 44.37 (d, $J_{C\text{-}P}$ = 2.6 Hz), 36.41 (d, $J_{C\text{-}P}$ = 70.5 Hz). $^{31}$P NMR (162 MHz, $CDCl_3$) δ 29.49, 18.70.



**Ethyl 2-(diphenylphosphoryl)-3-(furan-2-yl)propanoate (15)**

According to the general procedure, the product was purified by chromatography on silica gel eluting with petroleum ether and ethylacetate (PE/EA = 10/1) and obtained as a white solid (44.9 mg, 61%), melting point: 117 – 119 $^{o}$C. $^{1}$H NMR (400 MHz, $CDCl_3$) δ 7.93 – 7.83 (m, 4H), 7.58 – 7.46 (m, 6H), 7.25 (dd, *J* = 1.9, 0.8 Hz, 1H), 6.20 (dd, *J* = 3.2, 1.9 Hz, 1H), 6.00 (dd, *J* = 3.2, 0.9 Hz, 1H), 3.93 – 3.77 (m, 3H), 3.42 (ddd, *J* = 15.7, 11.6, 6.0 Hz, 1H), 3.13 (ddd, *J* = 15.5, 8.9, 3.1 Hz, 1H), 0.87 (t, *J* = 7.1 Hz, 3H). $^{13}$C NMR (101 MHz, $CDCl_3$) δ 168.69 (d, $J_{C-P}$ = 2.9 Hz), 151.93 (d, $J_{C-P}$ = 14.9 Hz), 141.61, 132.26, 132.23, 131.59 (d, $J_{C-P}$ = 9.4 Hz), 131.20 (d, $J_{C-P}$ = 9.4 Hz), 131.13 (d, $J_{C-P}$ = 67.0 Hz), 130.12 (d, $J_{C-P}$ = 67.2 Hz), 128.74 (d, $J_{C-P}$ = 12.0 Hz), 128.44 (d, $J_{C-P}$ = 12.2 Hz), 110.27, 106.65, 61.35, 47.90 (d, $J_{C-P}$ = 57.6 Hz), 25.18 (d, $J_{C-P}$ = 1.5 Hz), 13.59. $^{31}$P NMR (162 MHz, $CDCl_3$) δ 28.87. HRMS (ESI) calcd for $C_{21}H_{21}O_4P$ $[M+H]^+$: 369.1250; found: 369.1258. IR (KBr): 2918 (C-H), 1187 $cm^{-1}$ (P=O).

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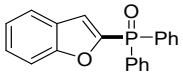
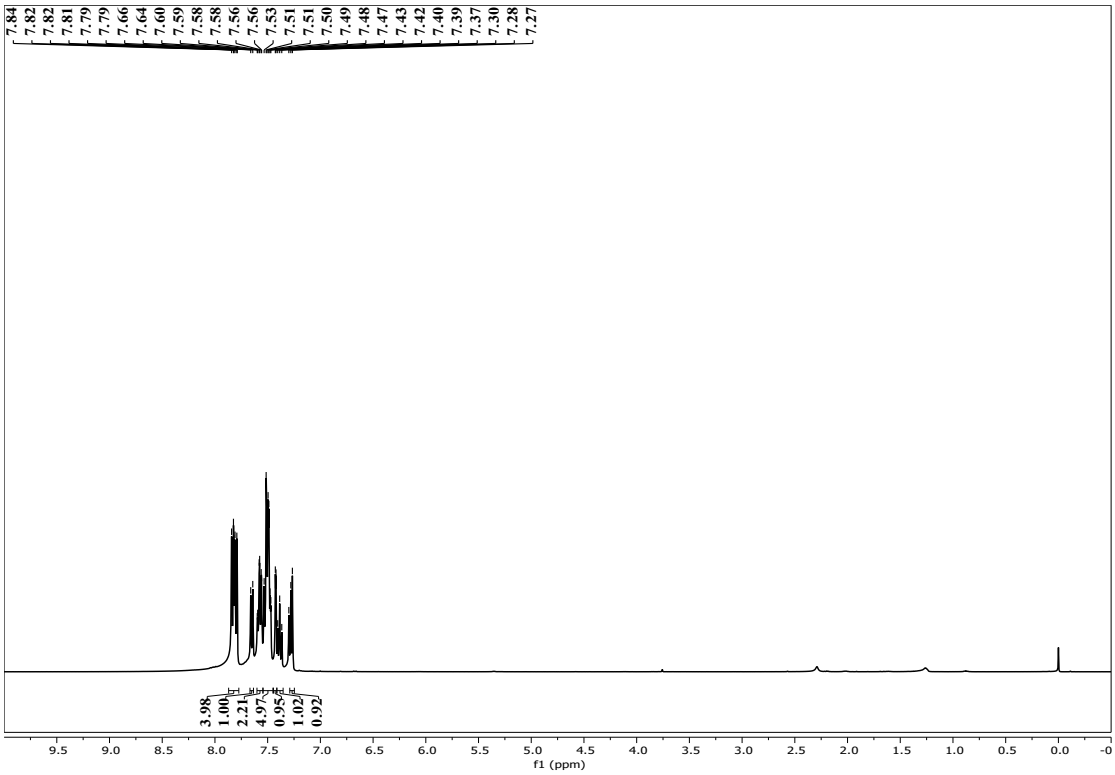
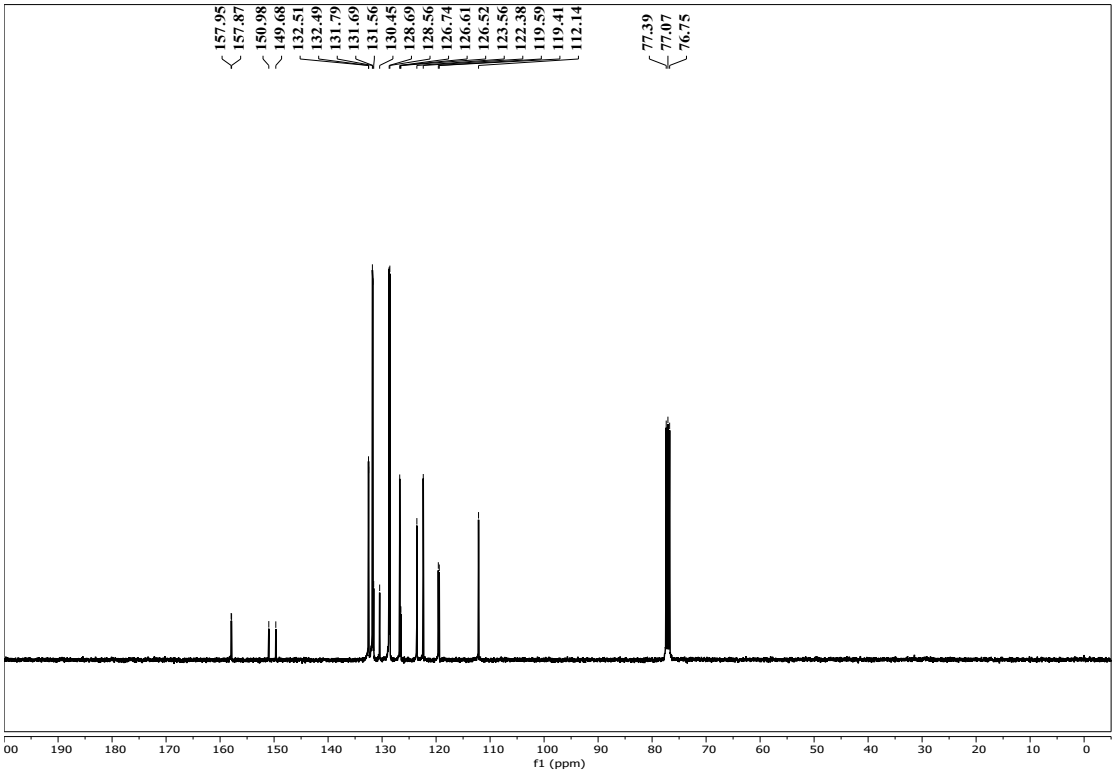
# NMR spectra of products



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




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



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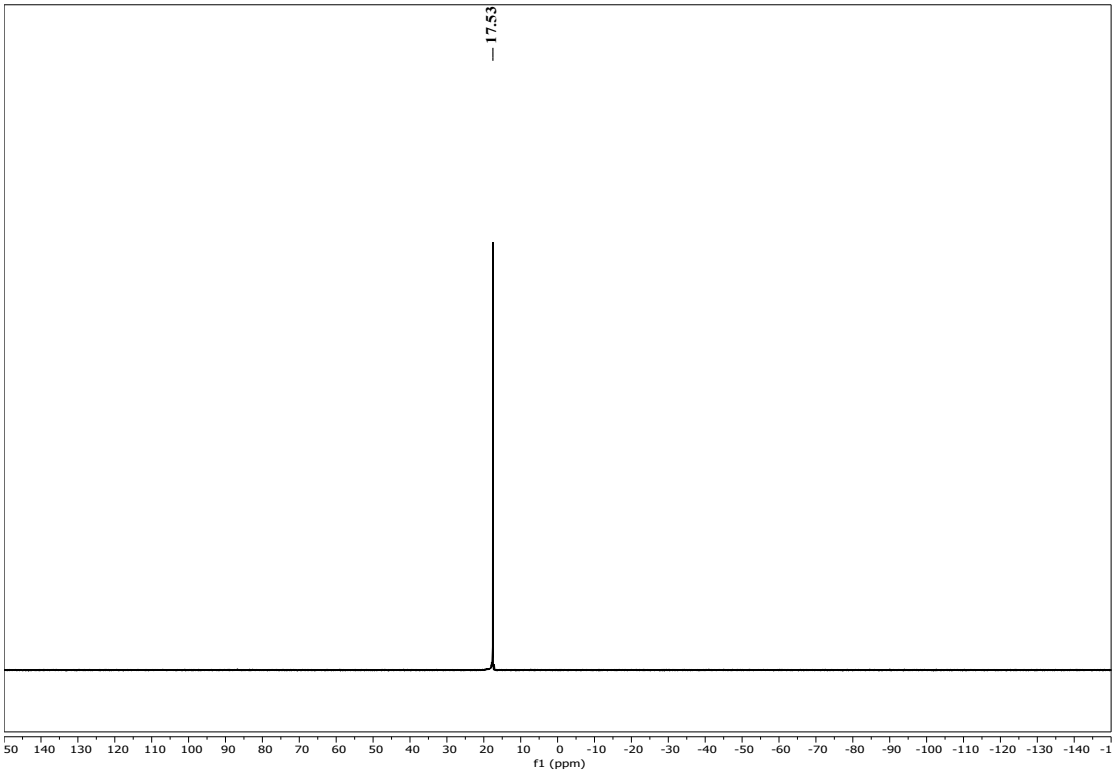

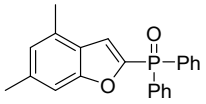

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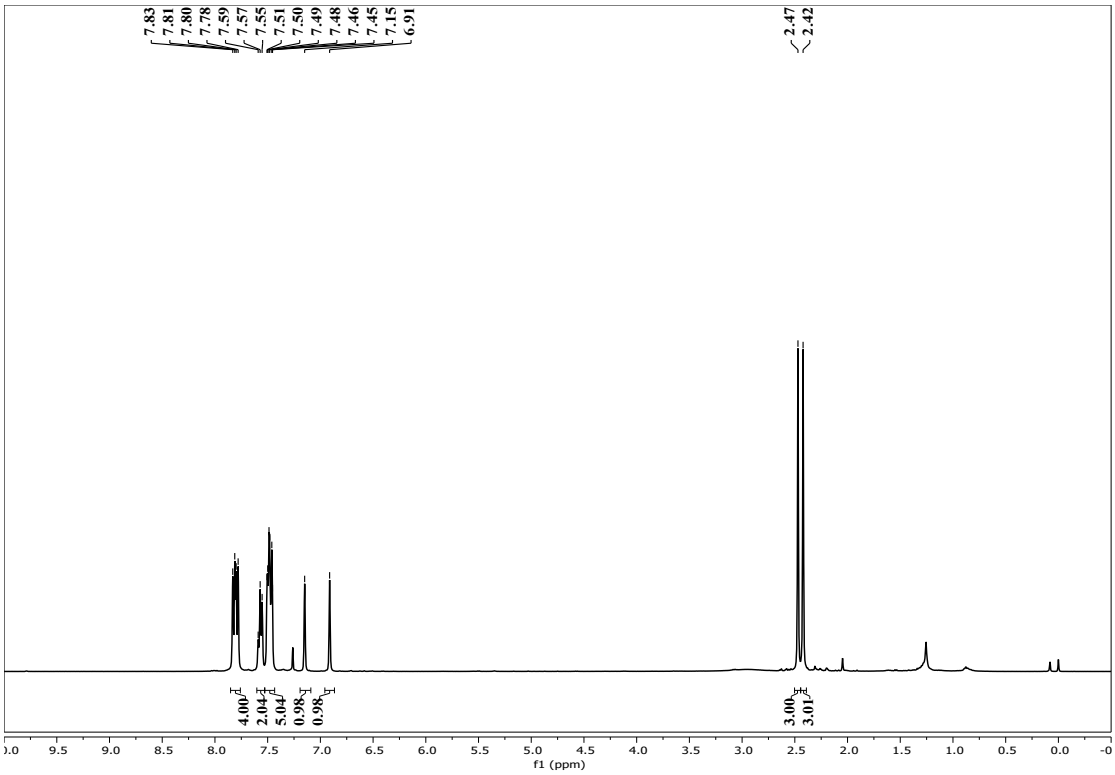


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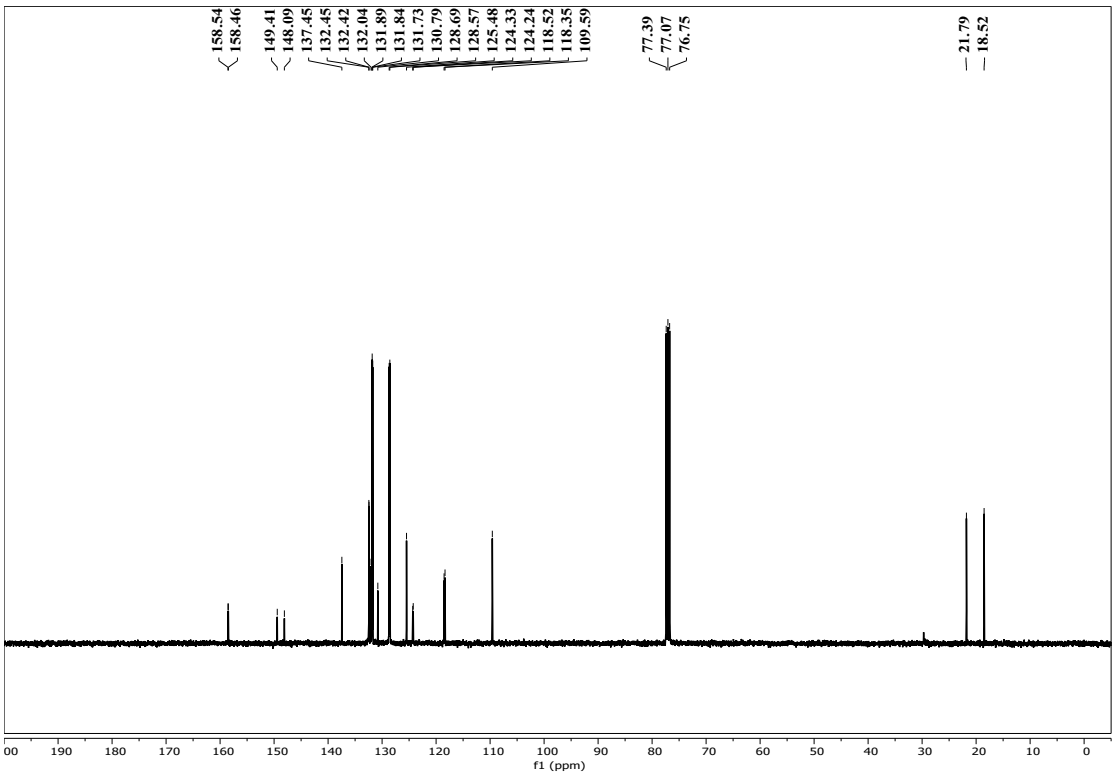

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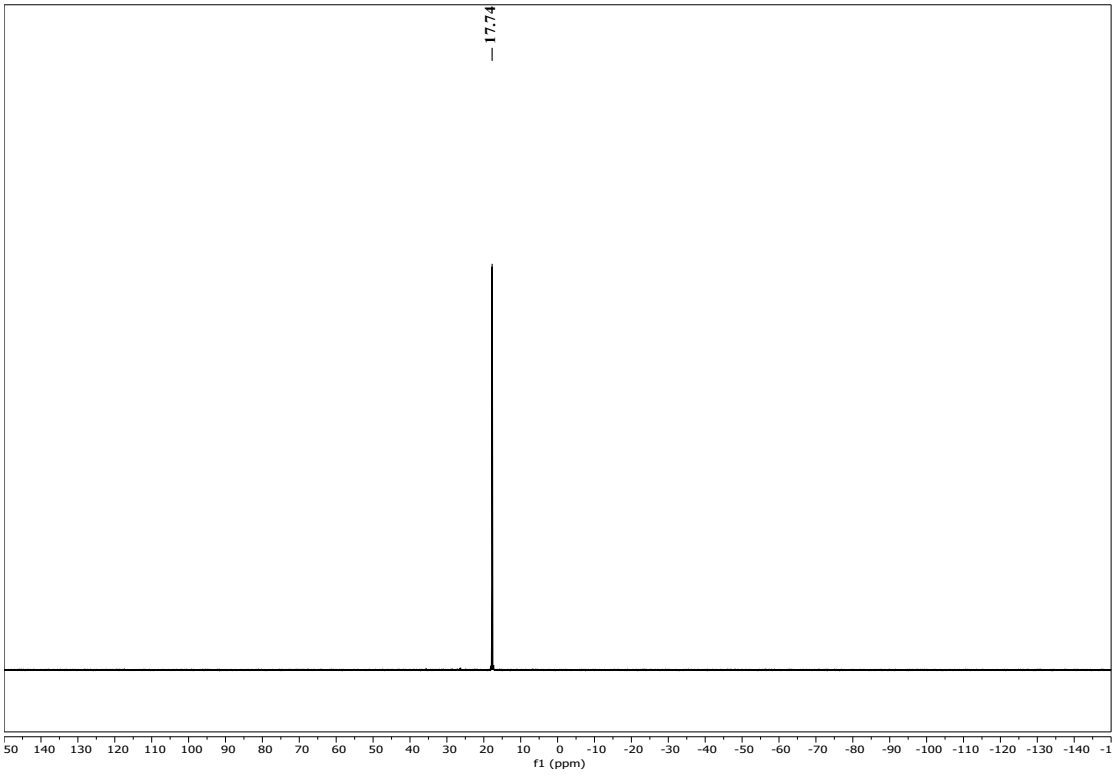

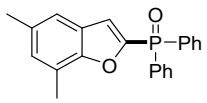

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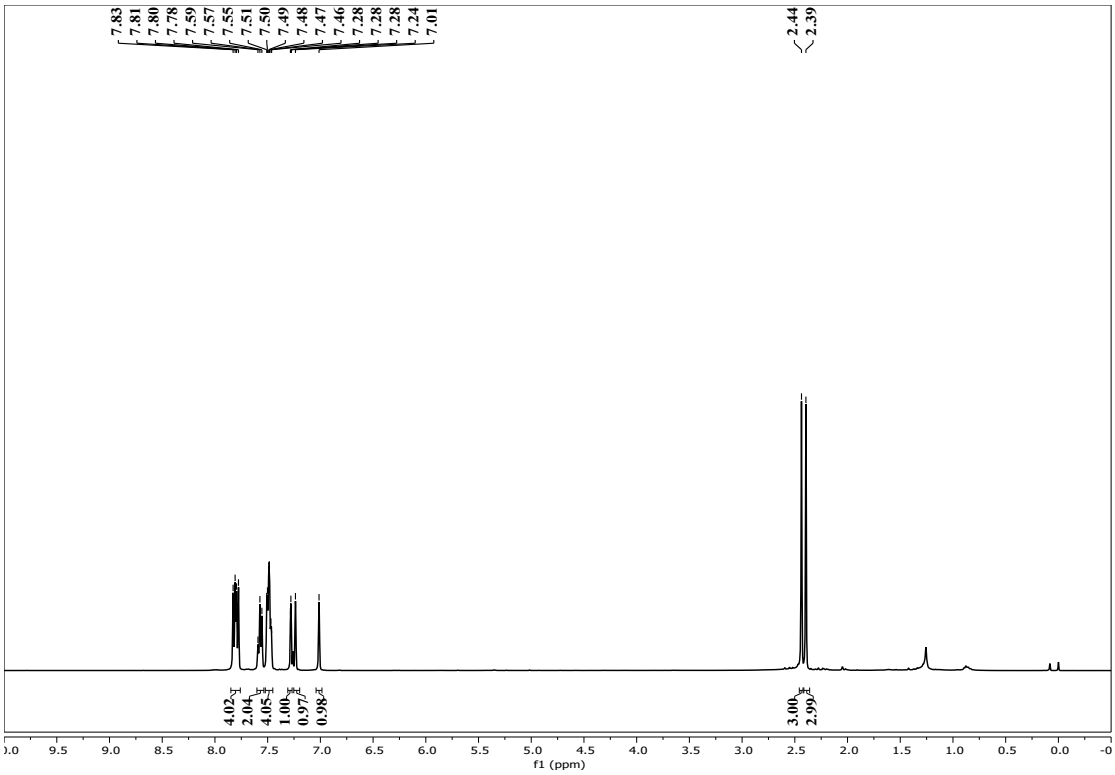


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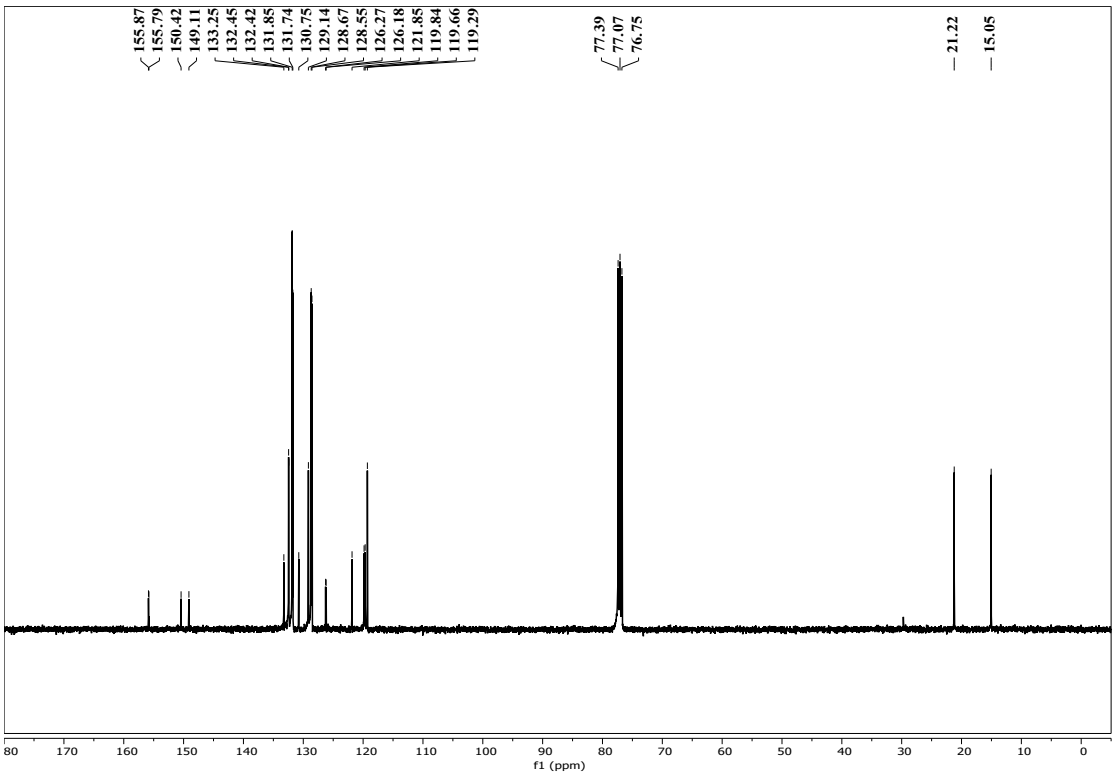

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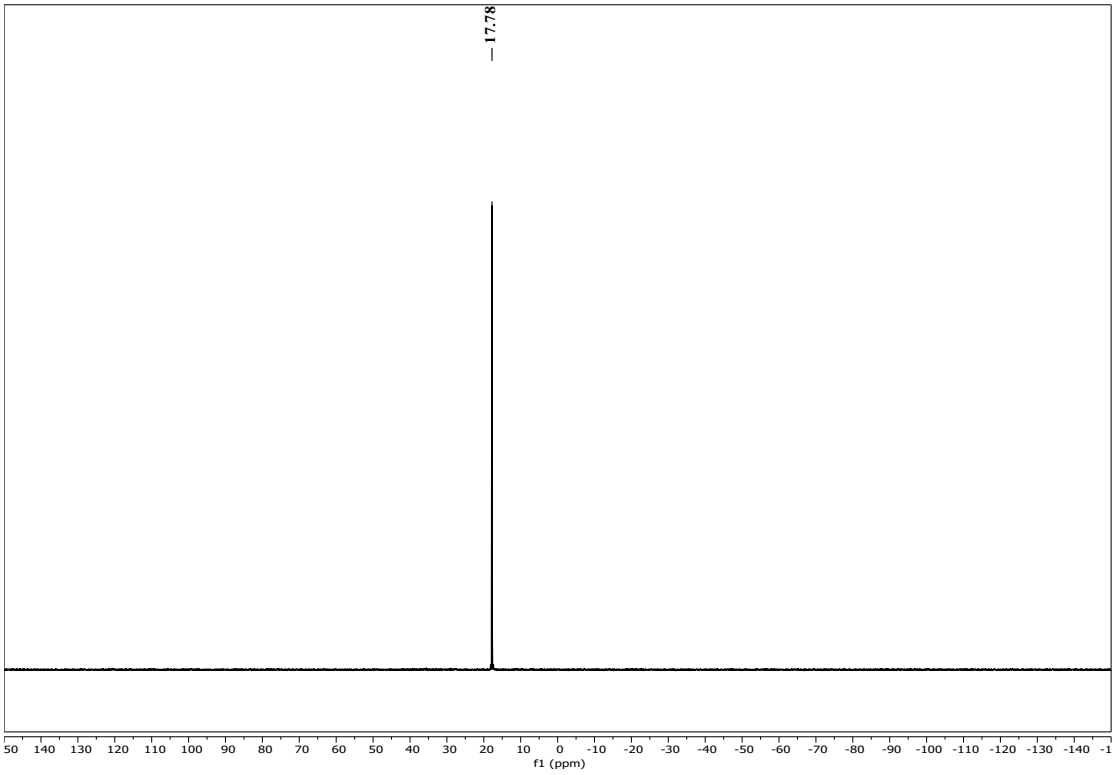

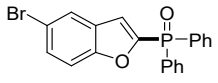

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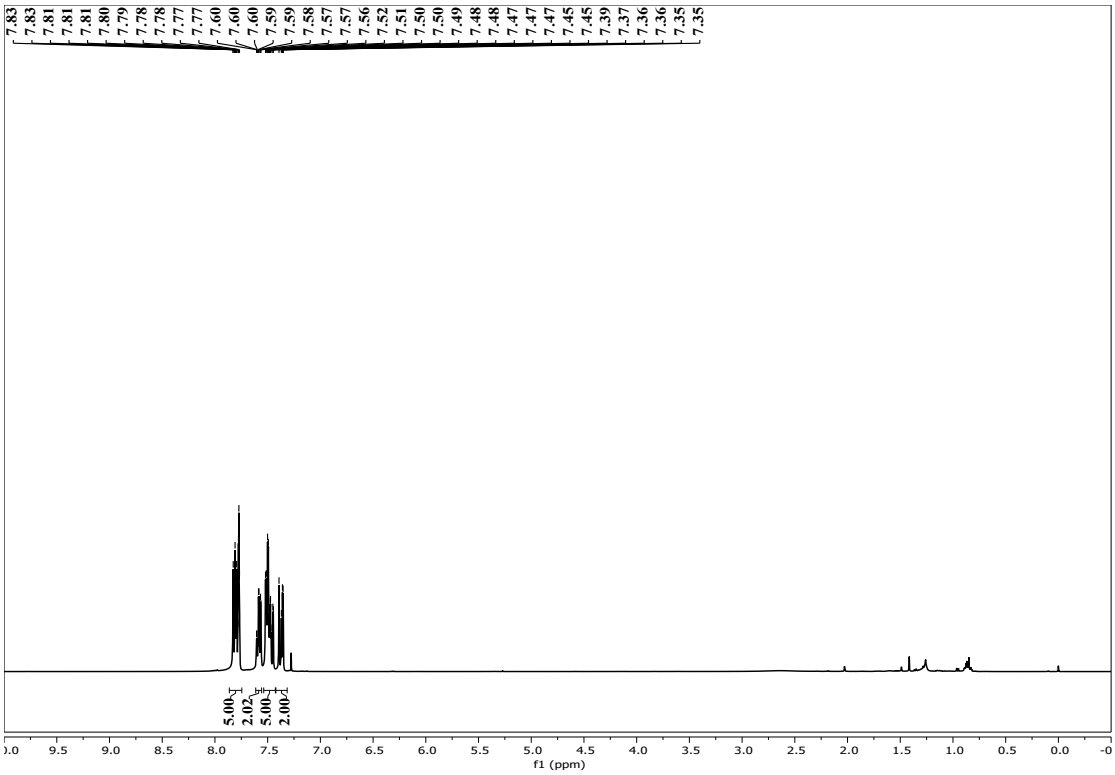


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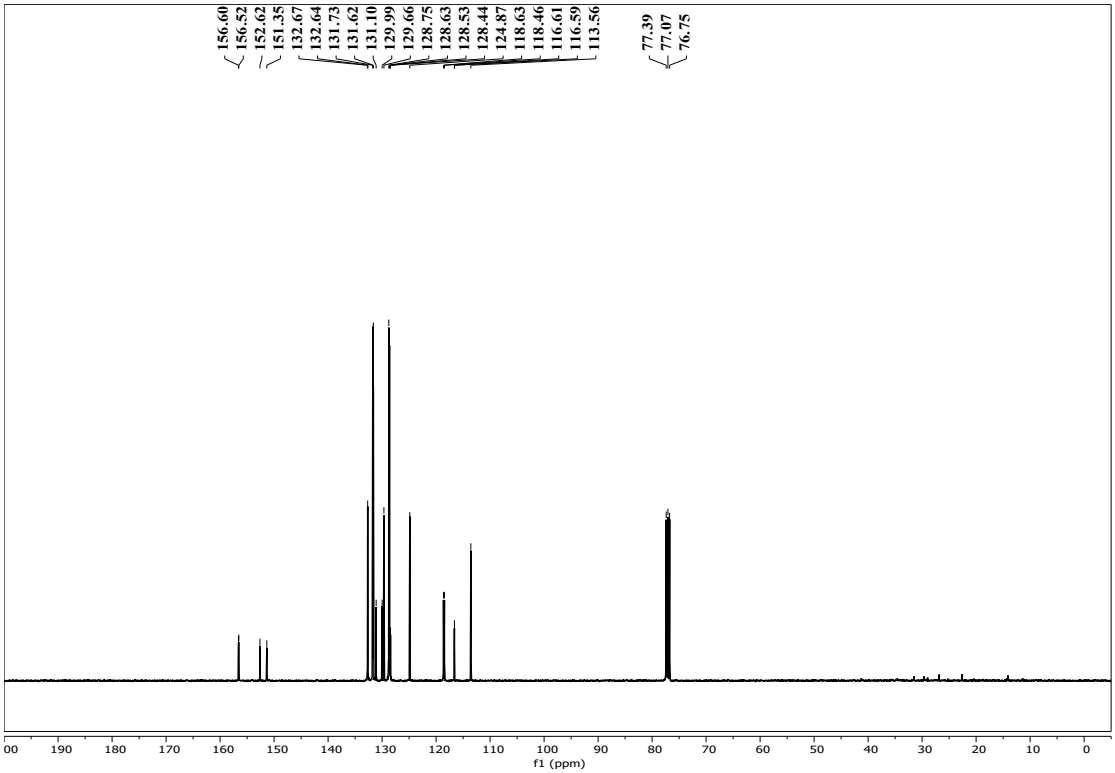

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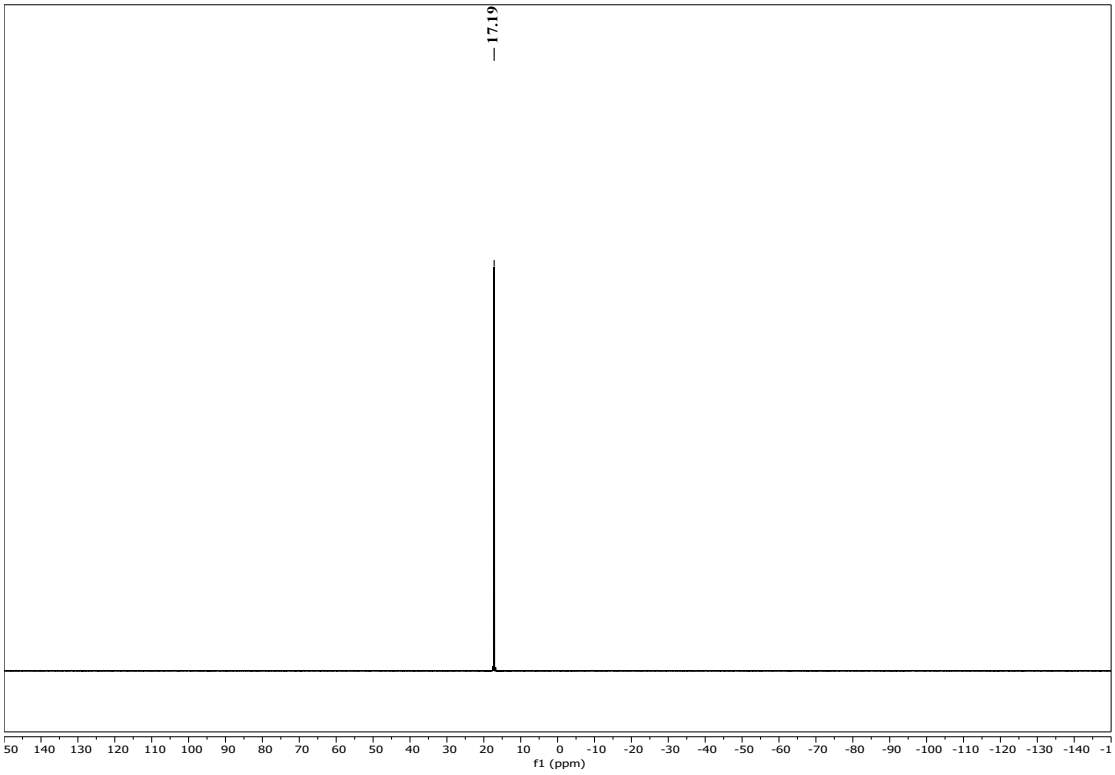

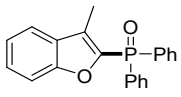

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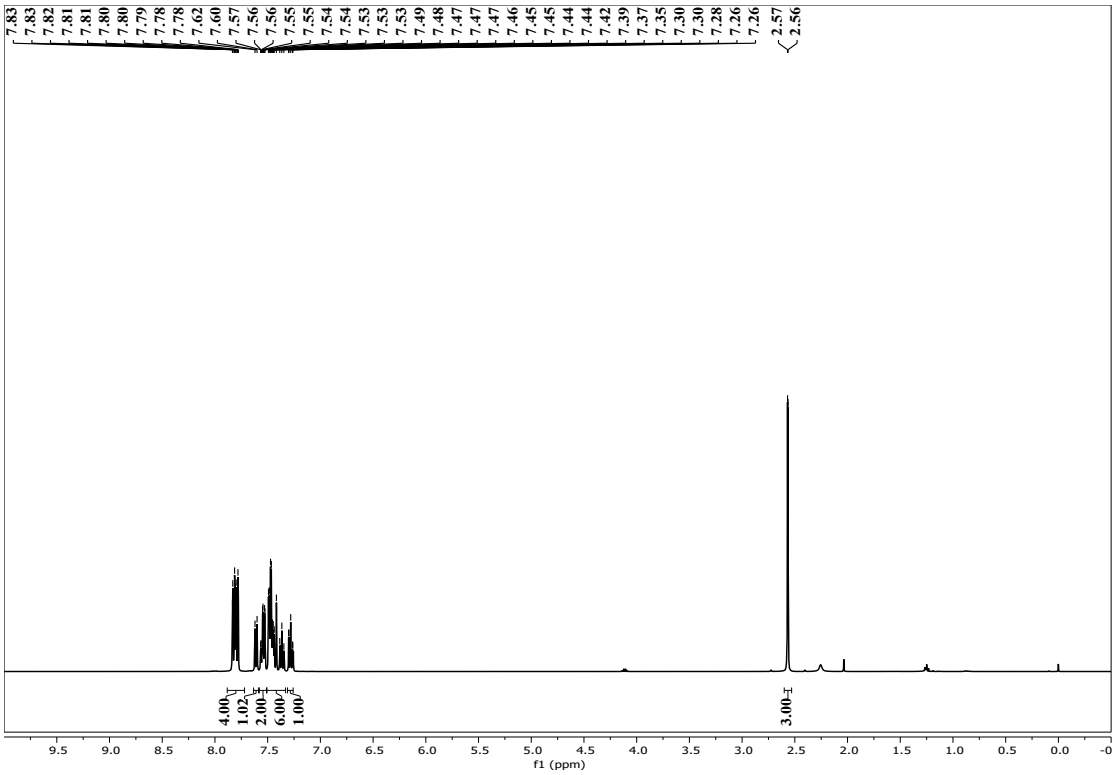


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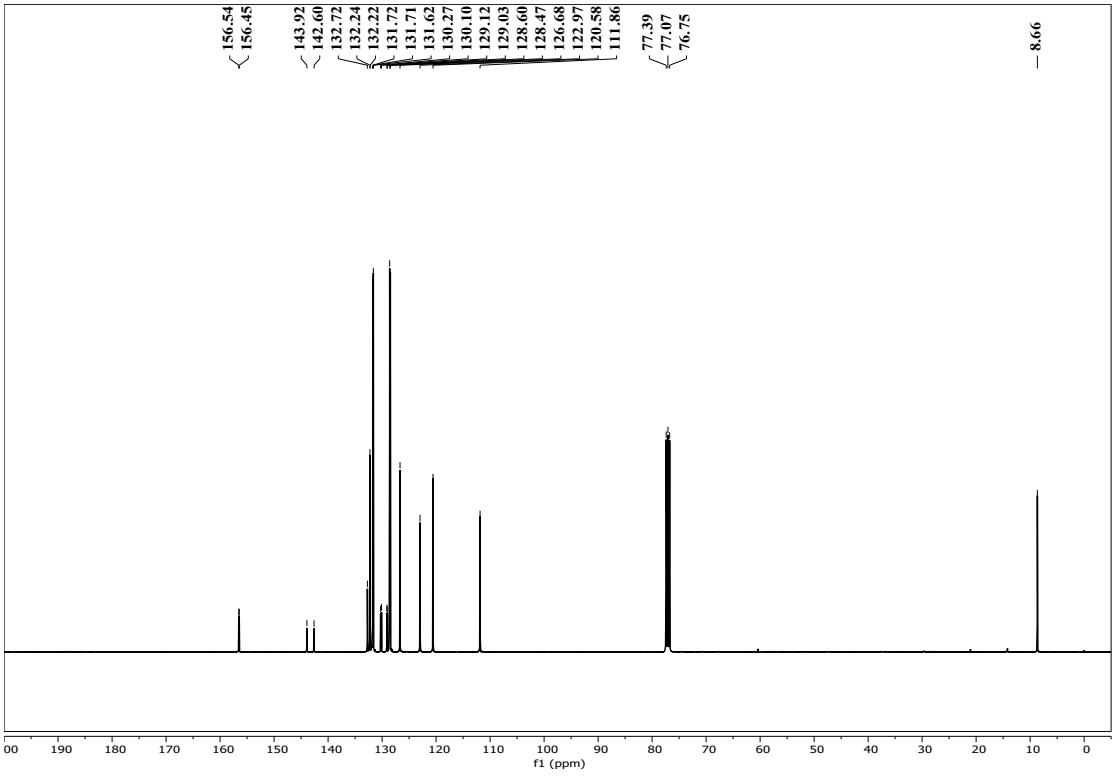

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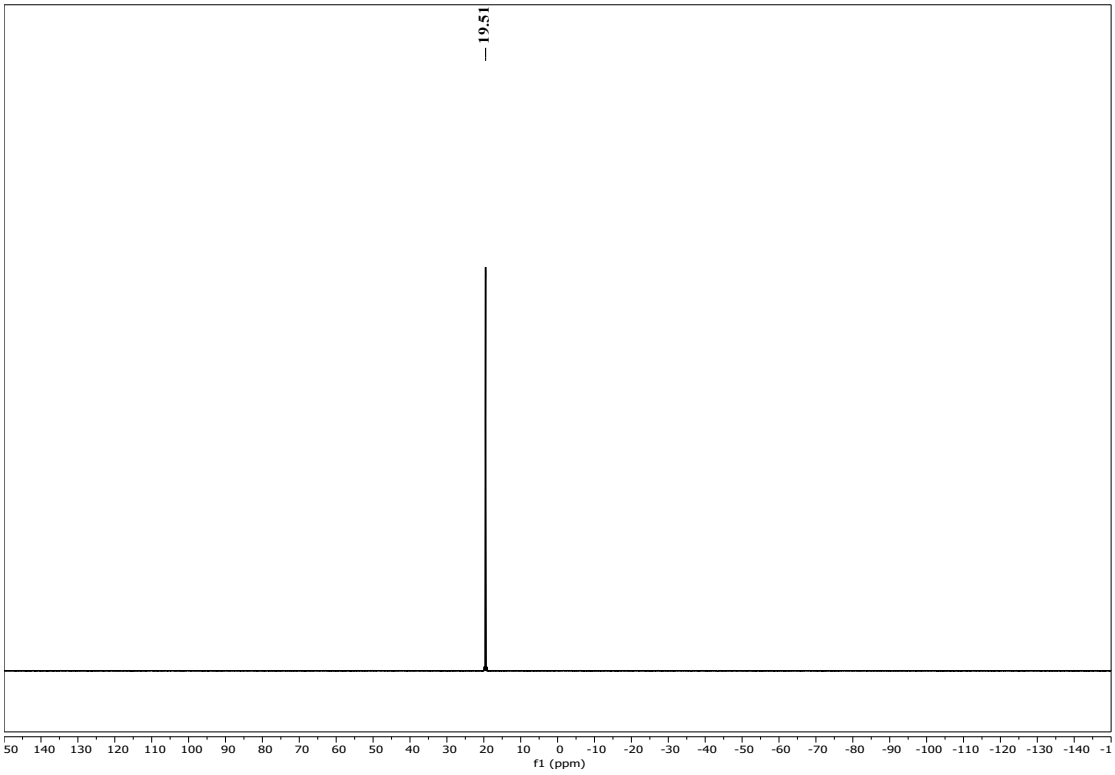

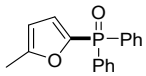

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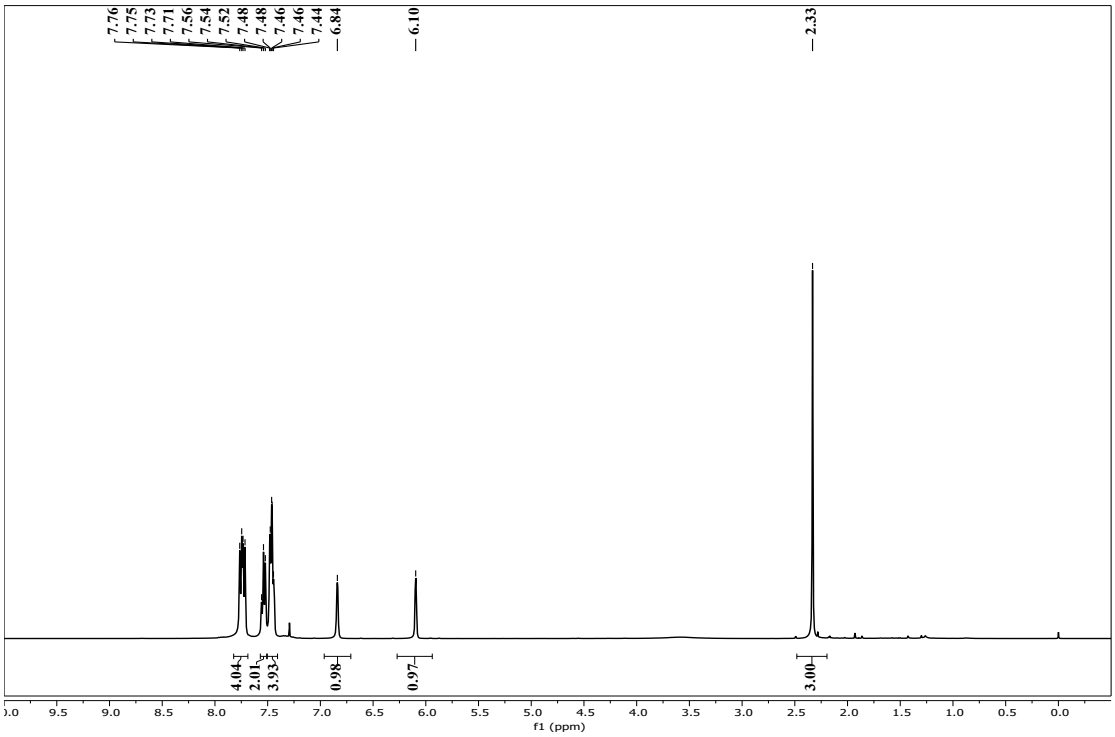


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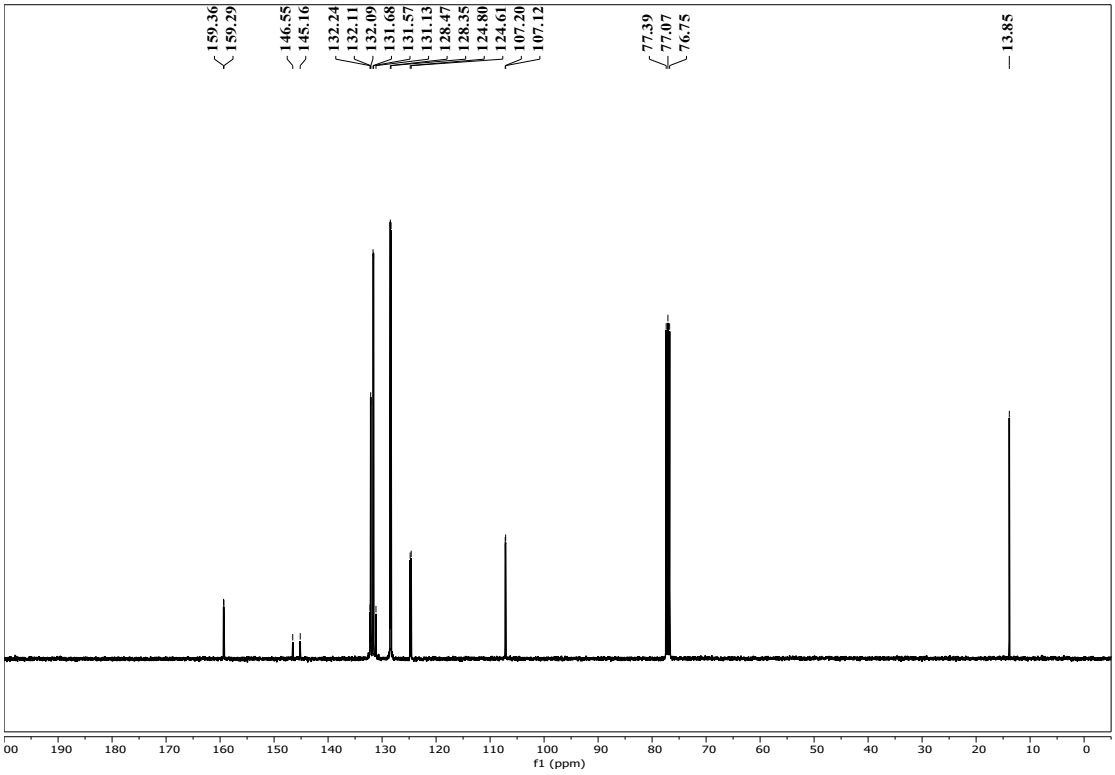

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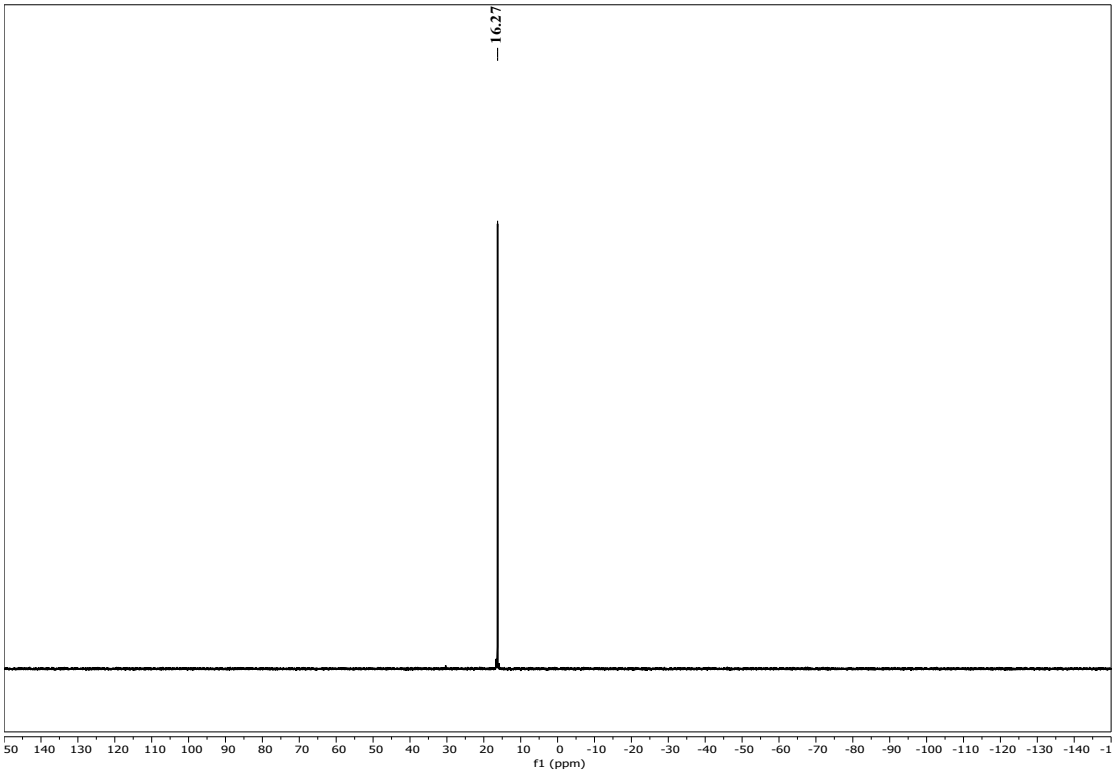

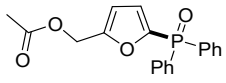

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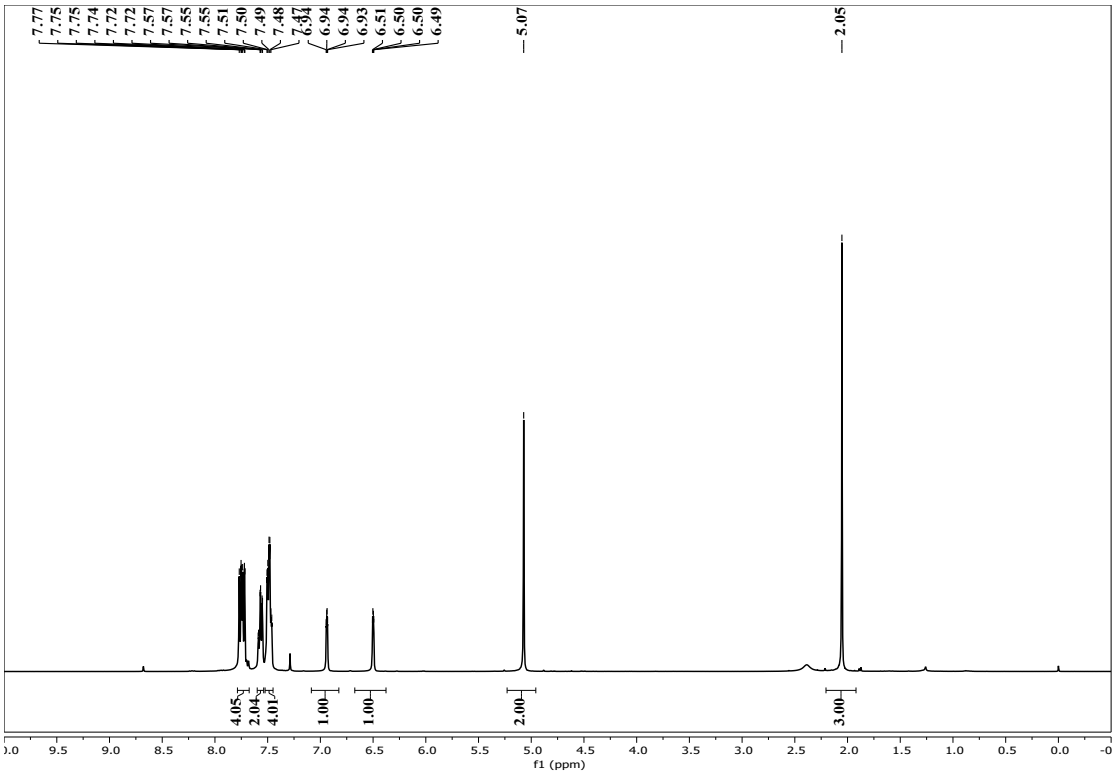


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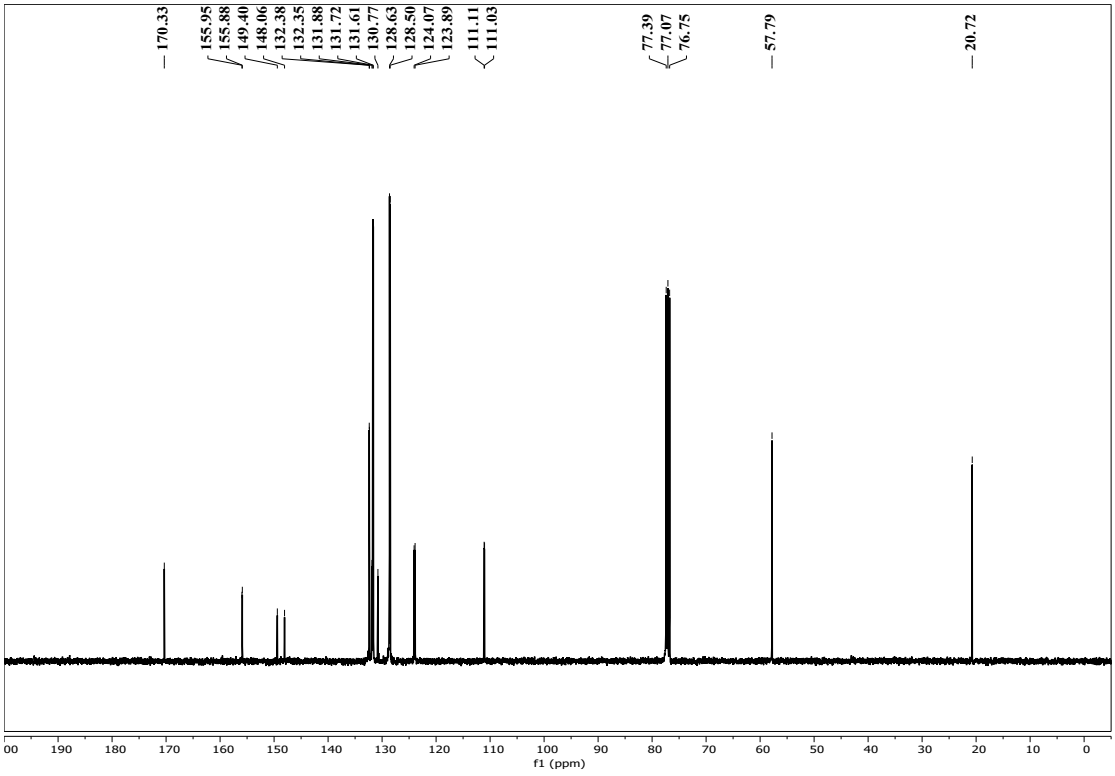

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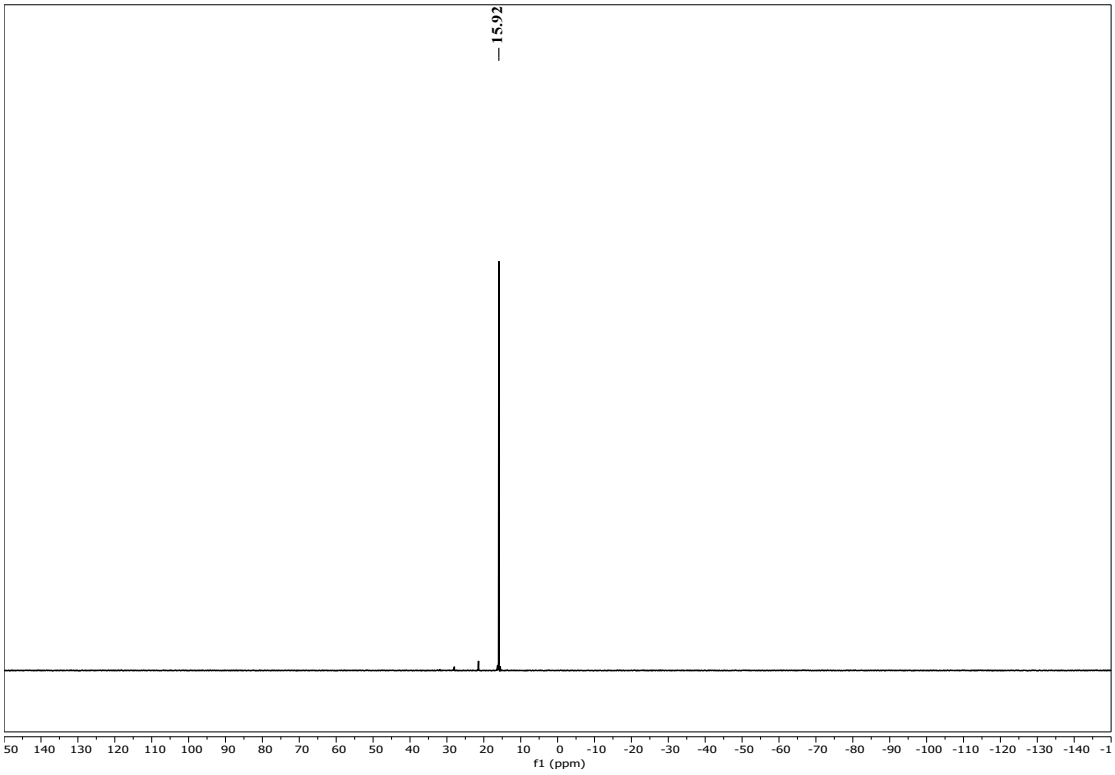

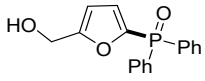

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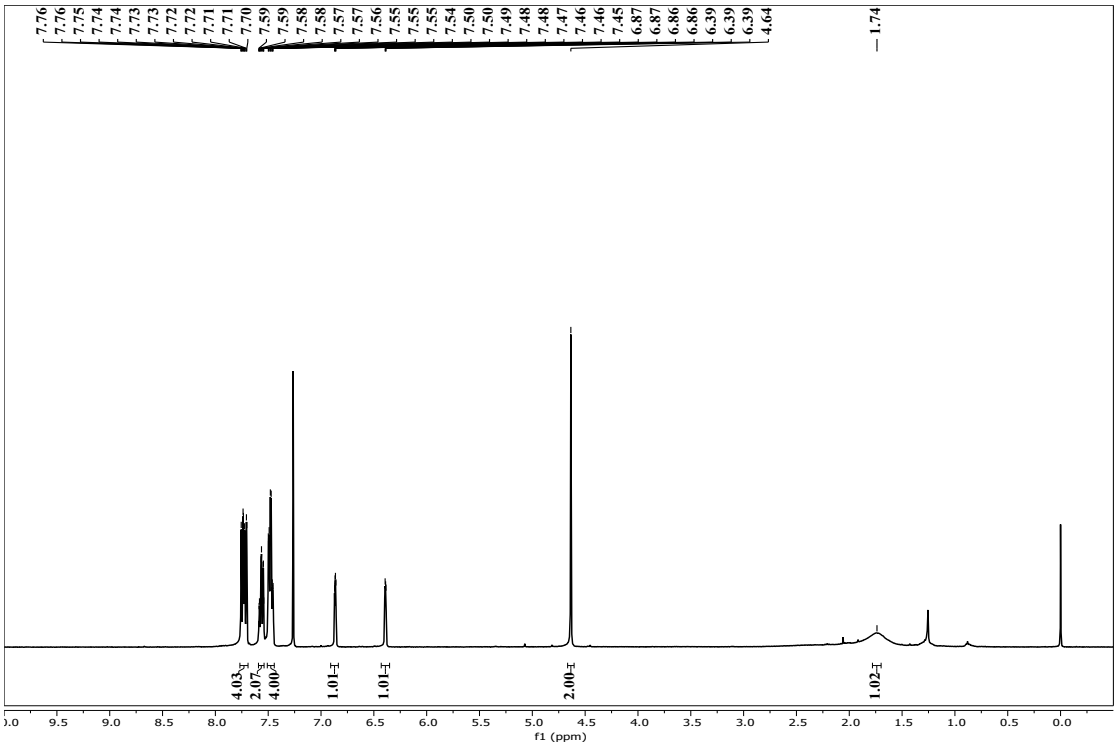


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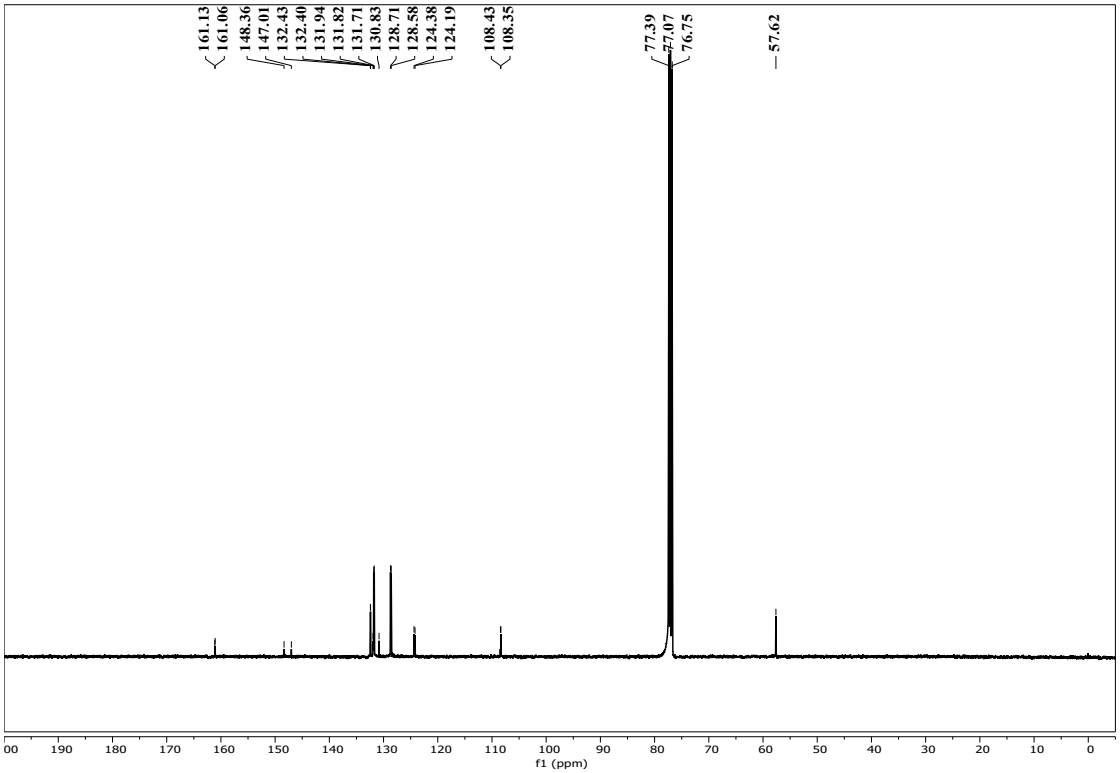

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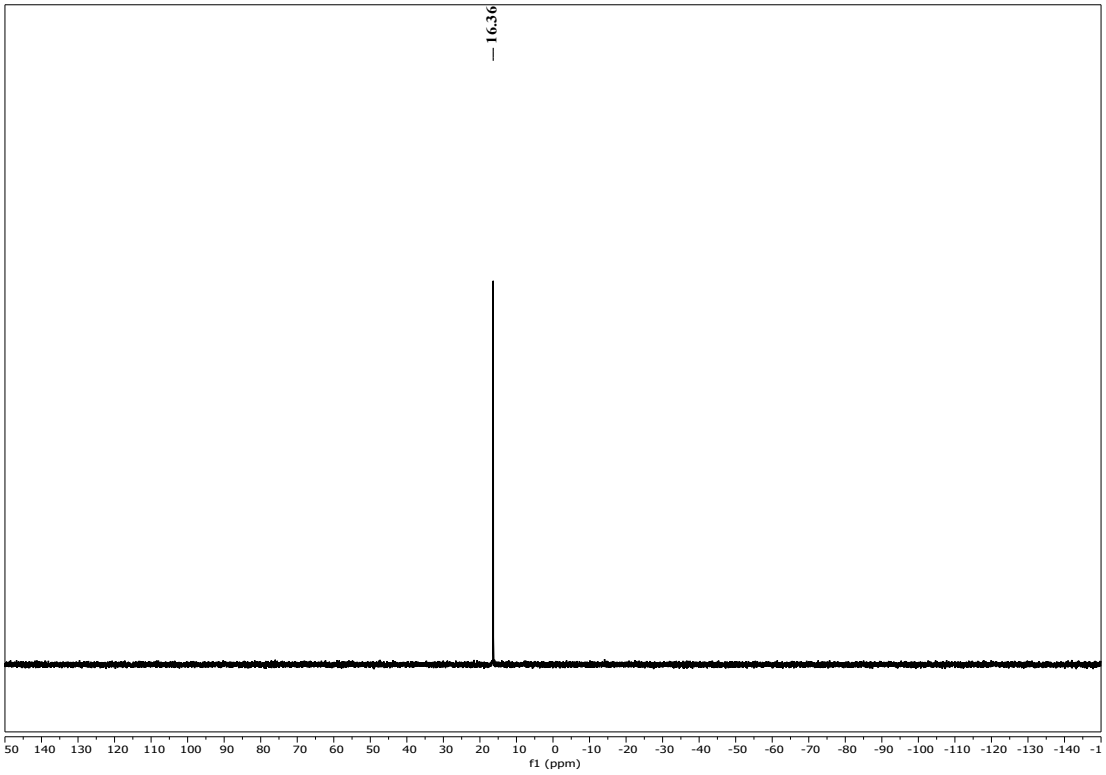

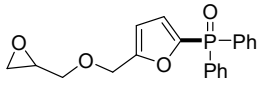

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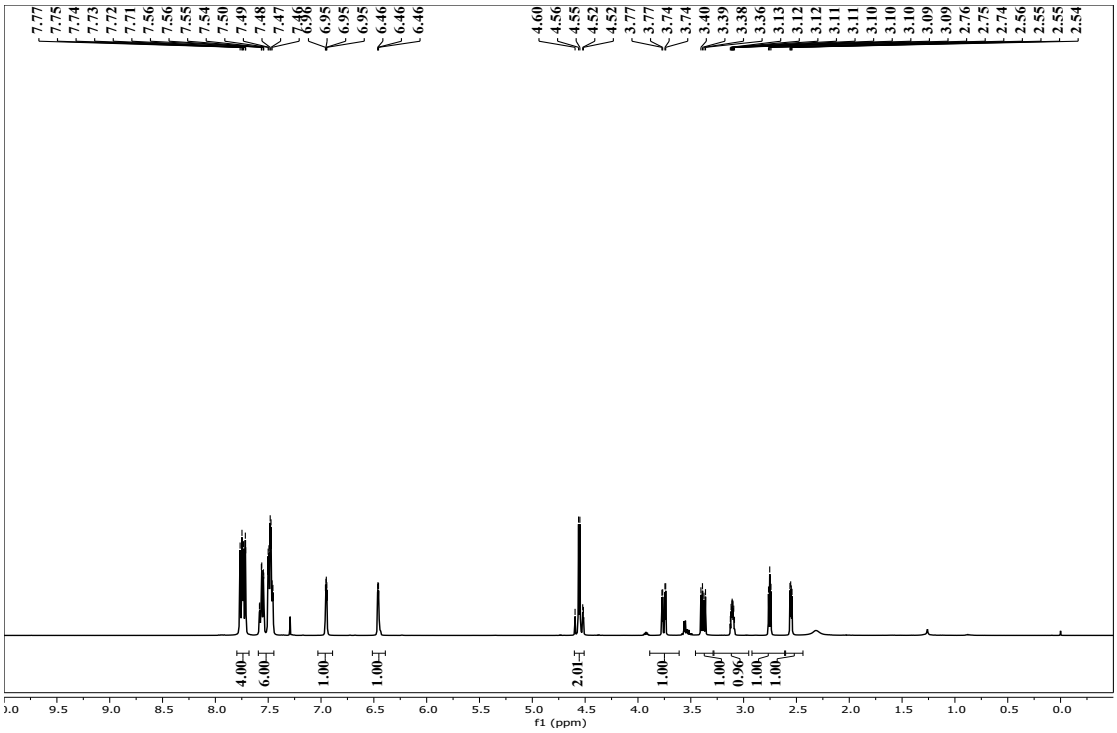


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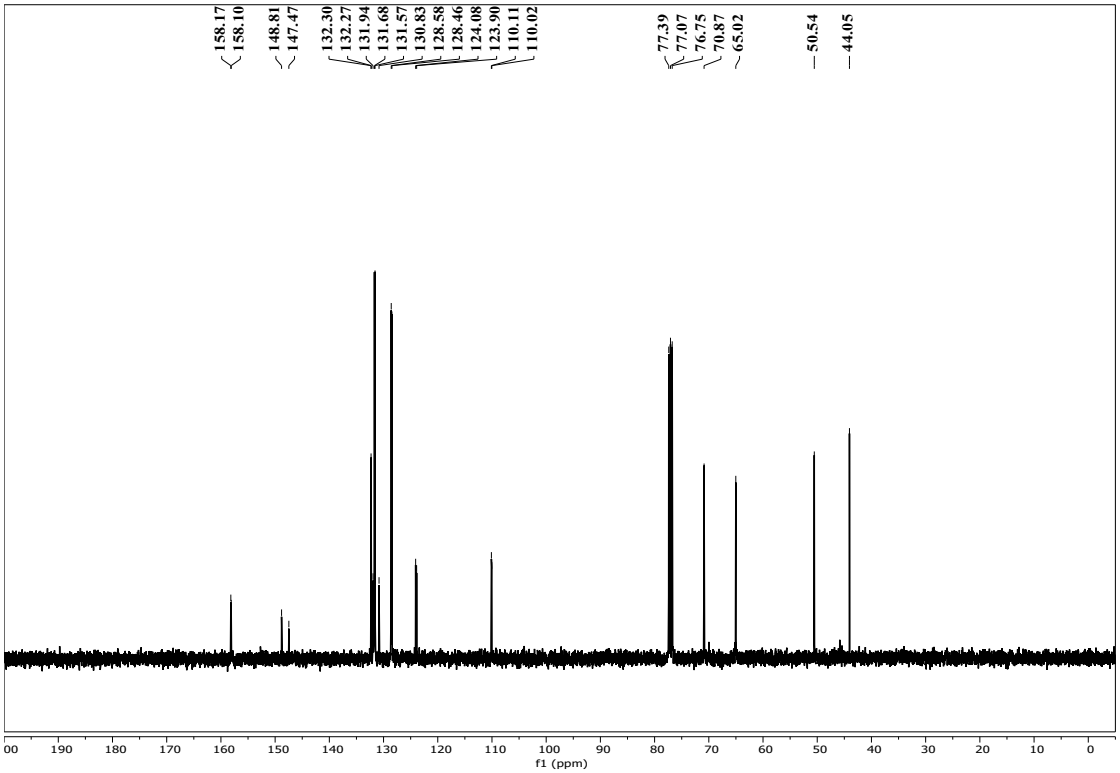

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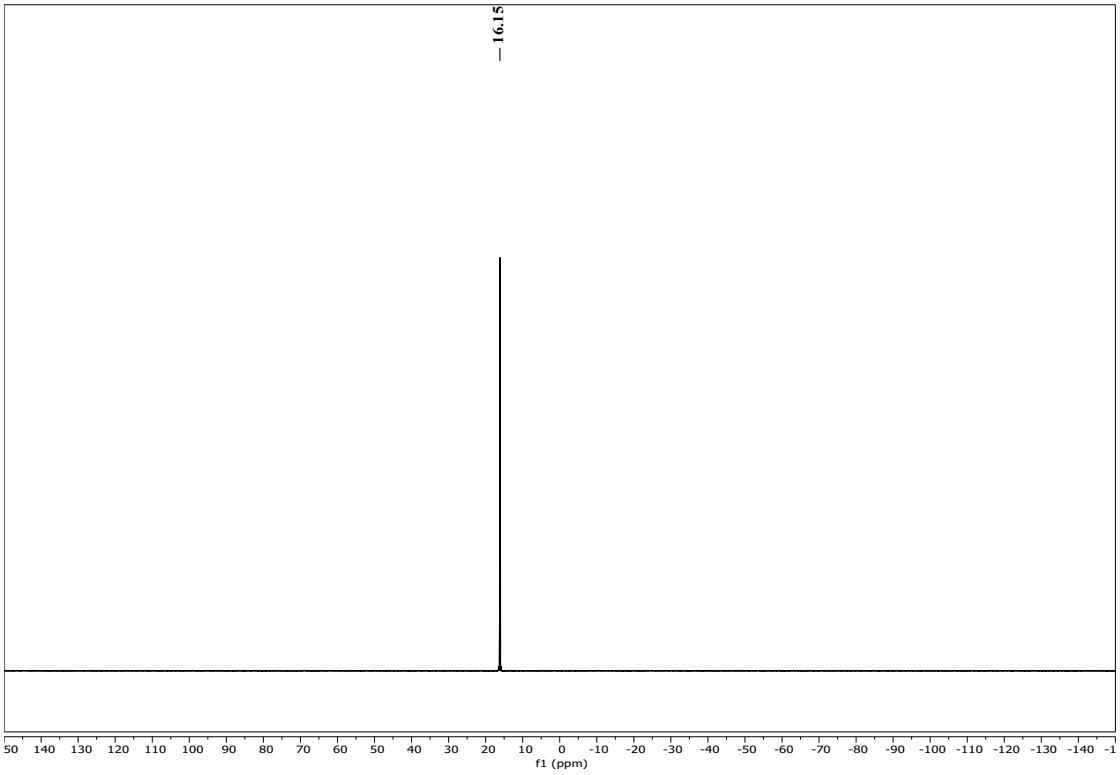

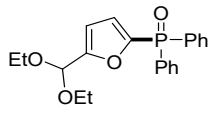


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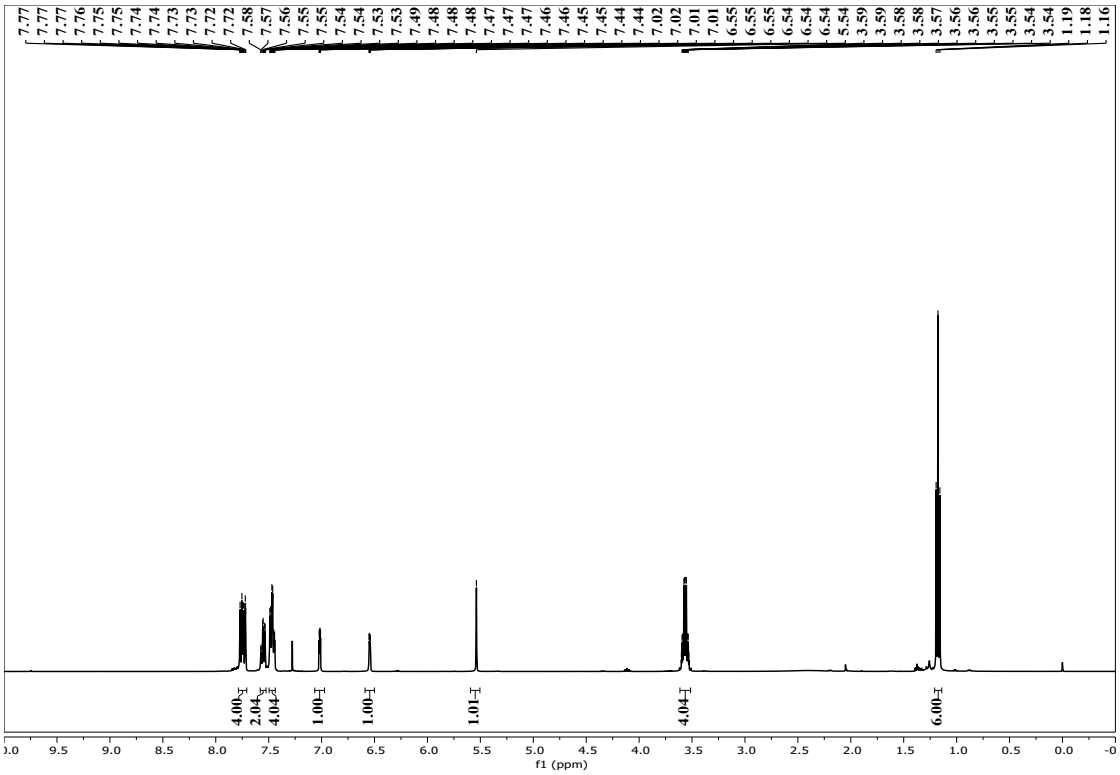


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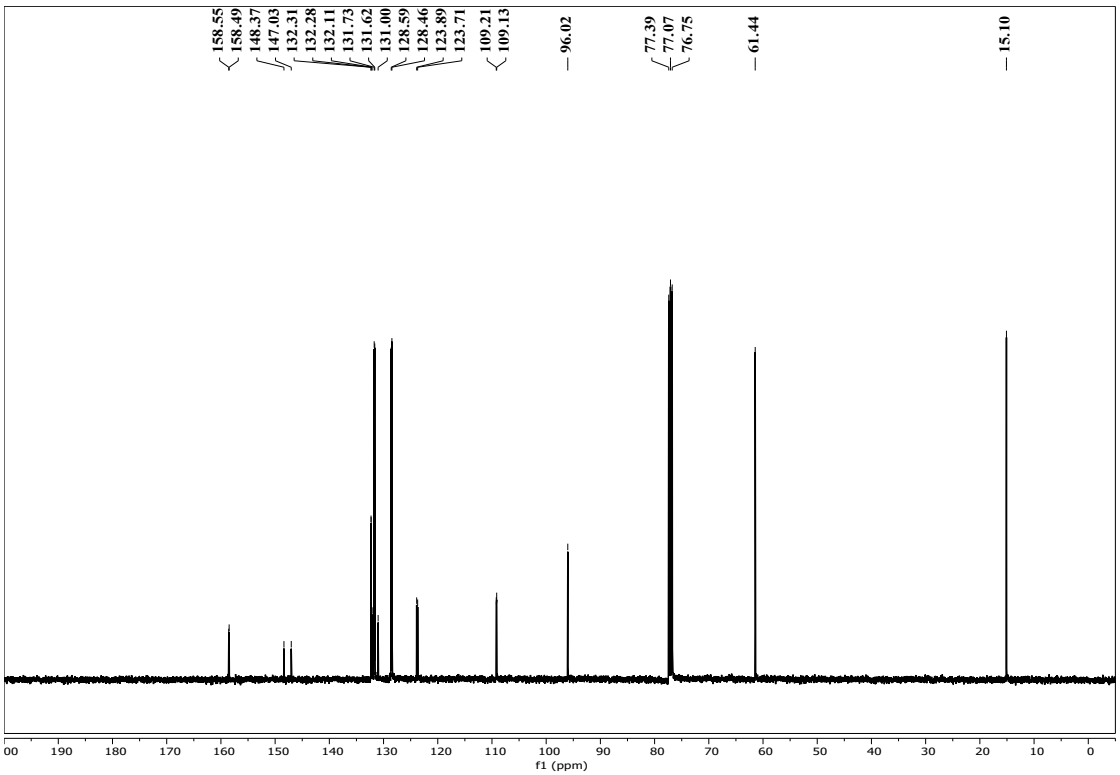

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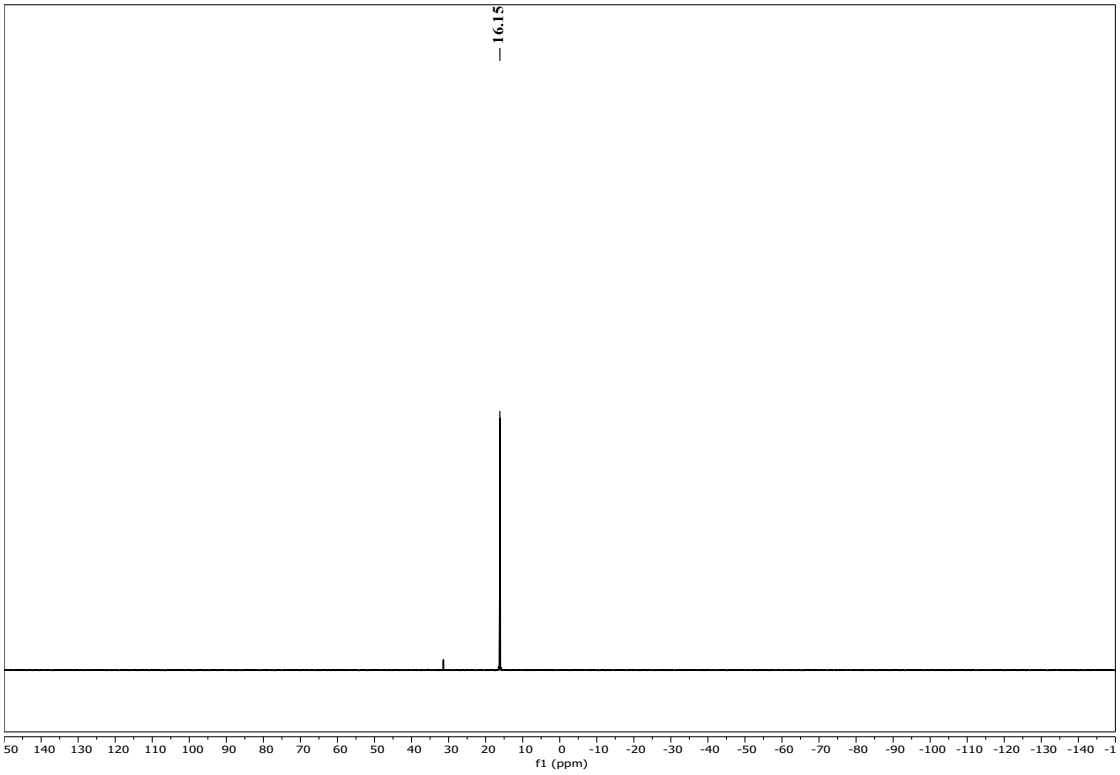

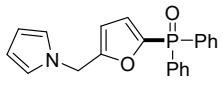

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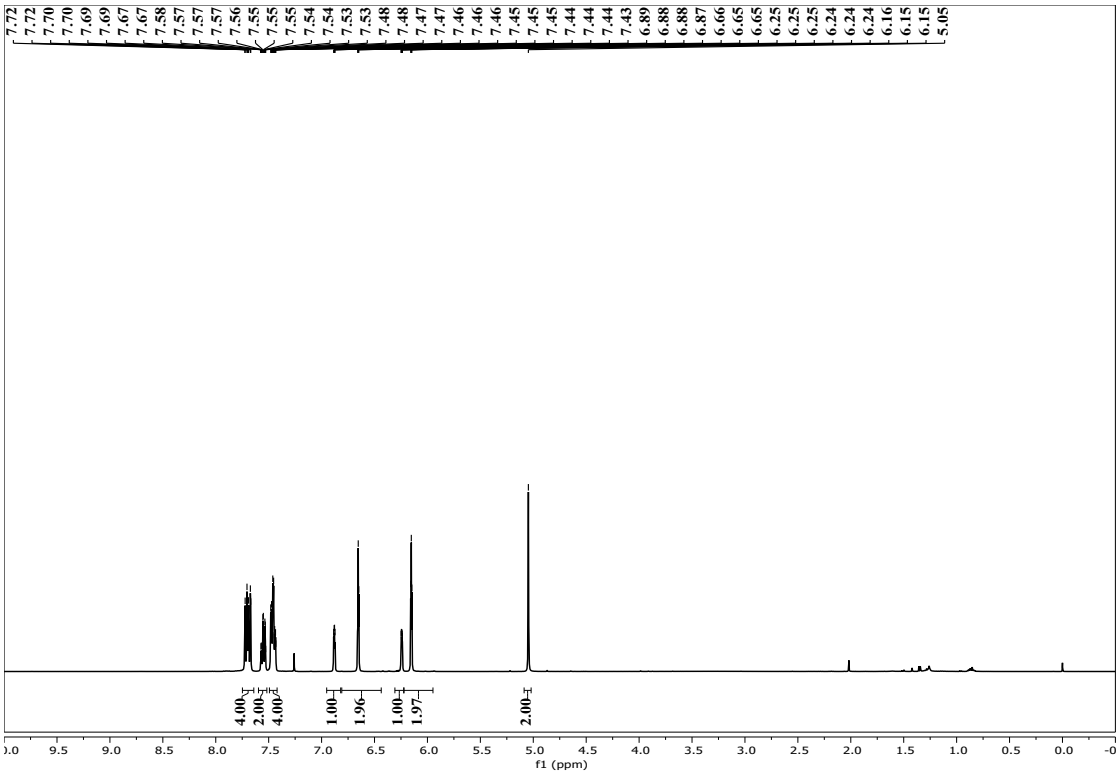
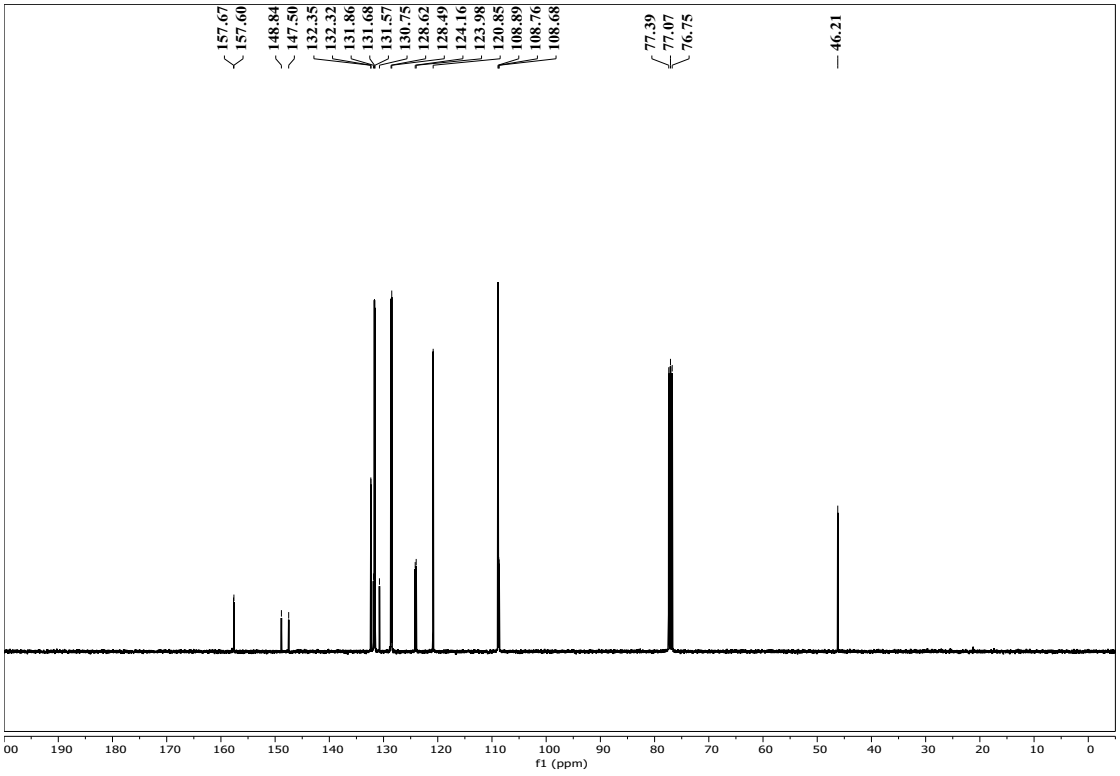
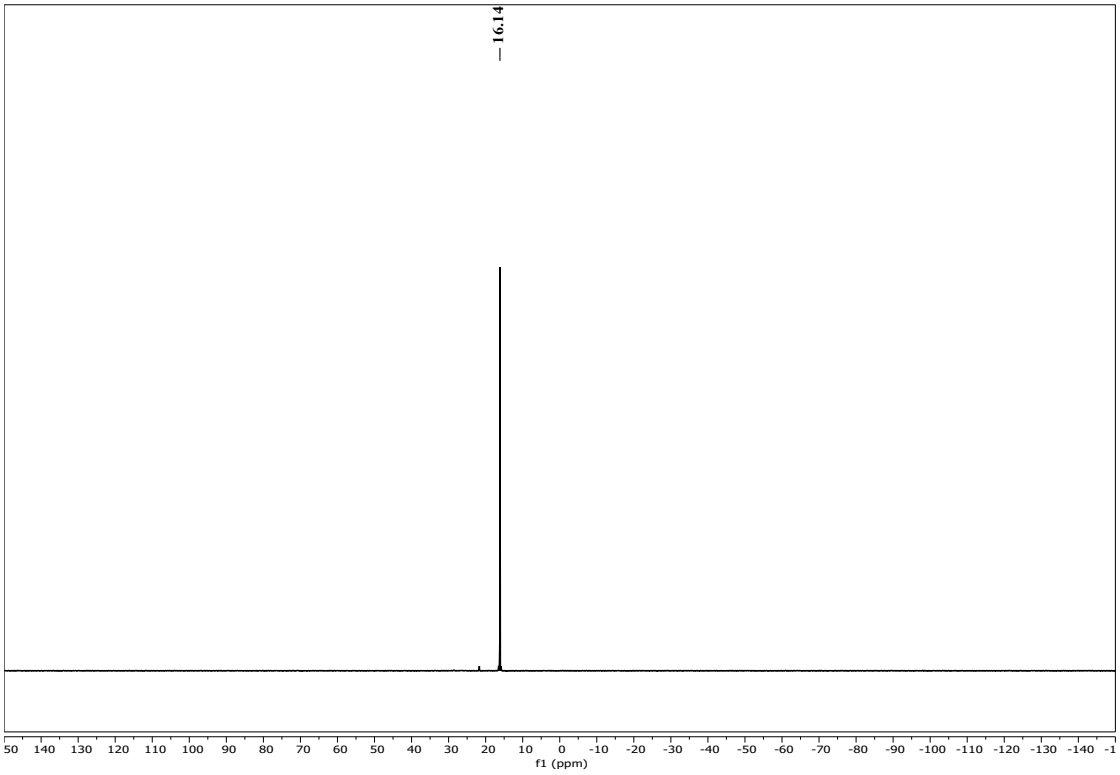
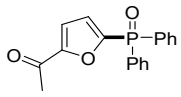



**3j**, $^{13}$C NMR (101 MHz), $CDCl_3$

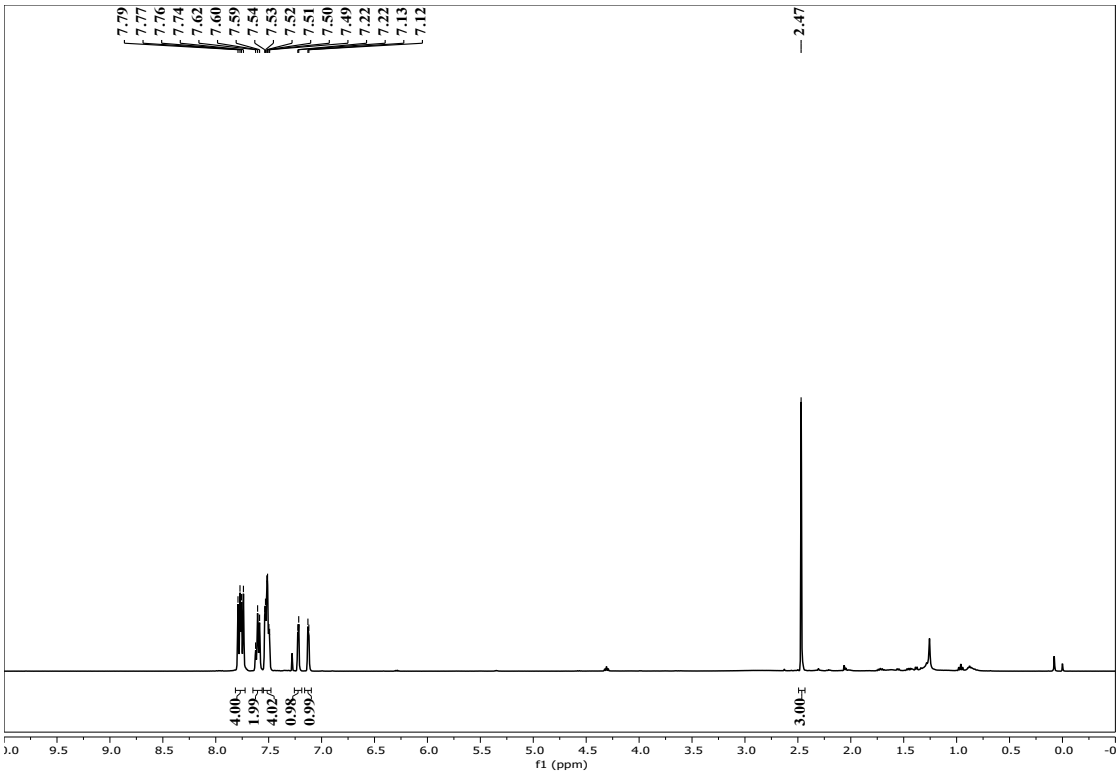


**3j**, $^{31}P$ NMR (162 MHz), $CDCl_3$

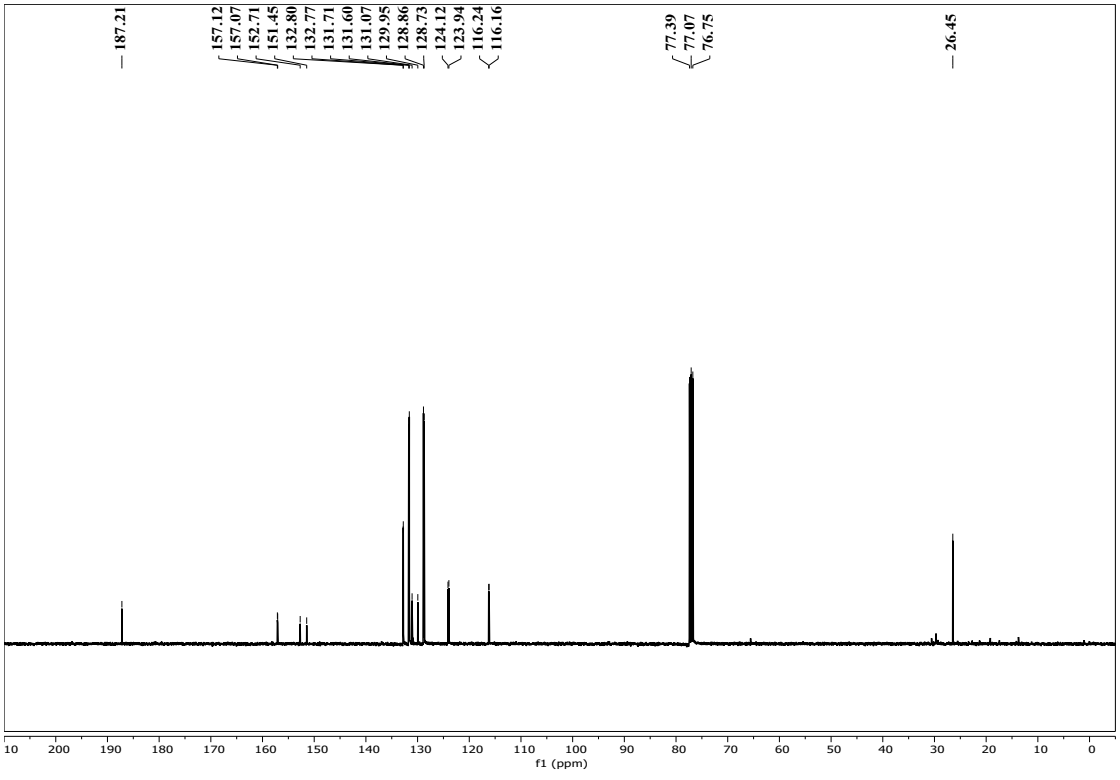




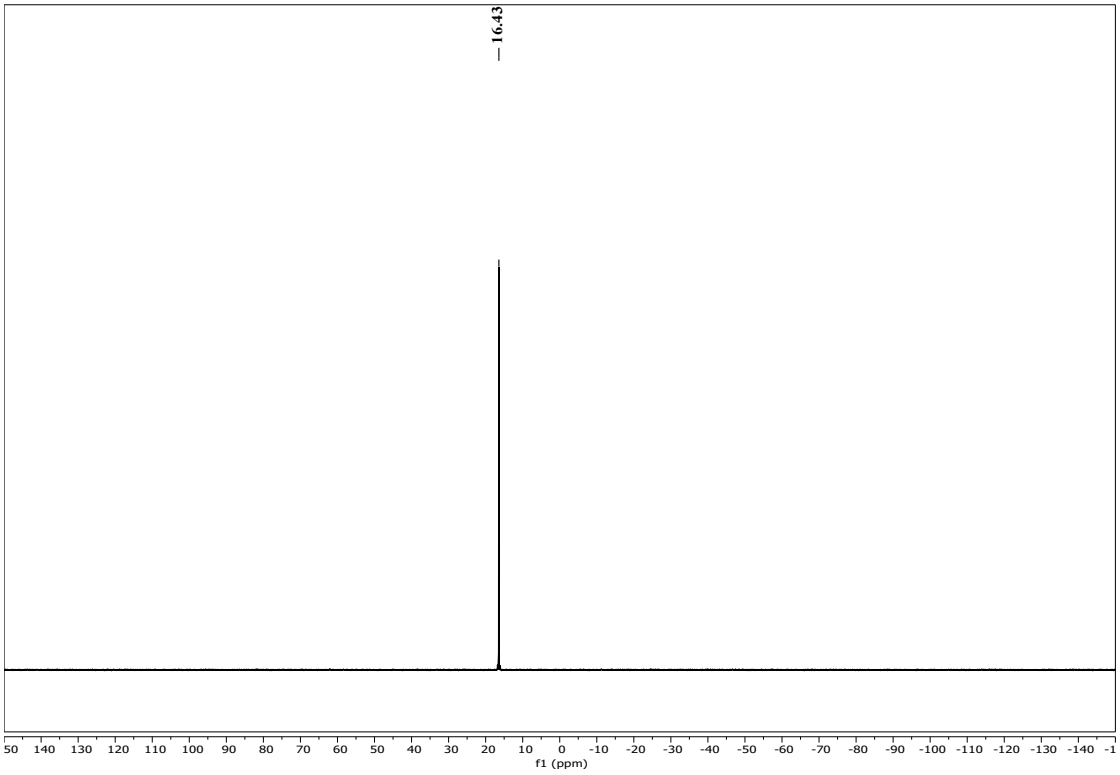
**3k,** $^{1}$H NMR (400 MHz), $CDCl_3$

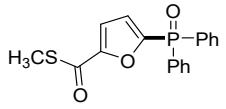



**3k**, $^{13}$C NMR (101 MHz), $CDCl_3$

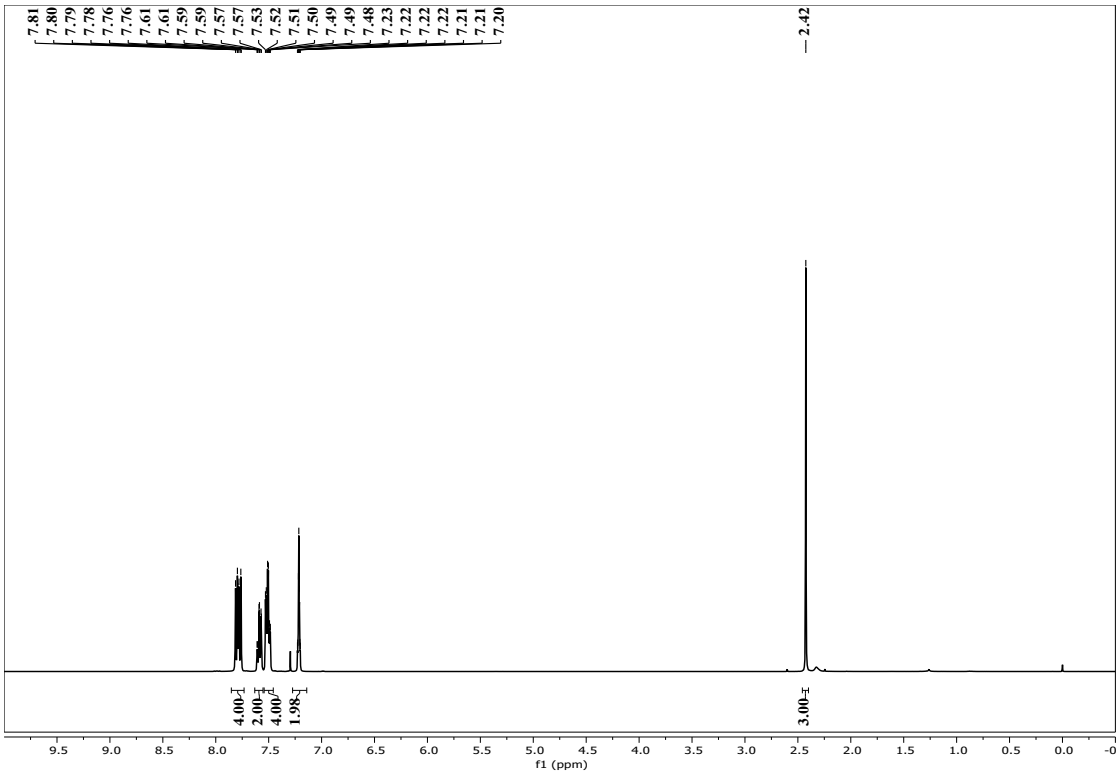


**3k**, $^{31}P$ NMR (162 MHz), $CDCl_3$

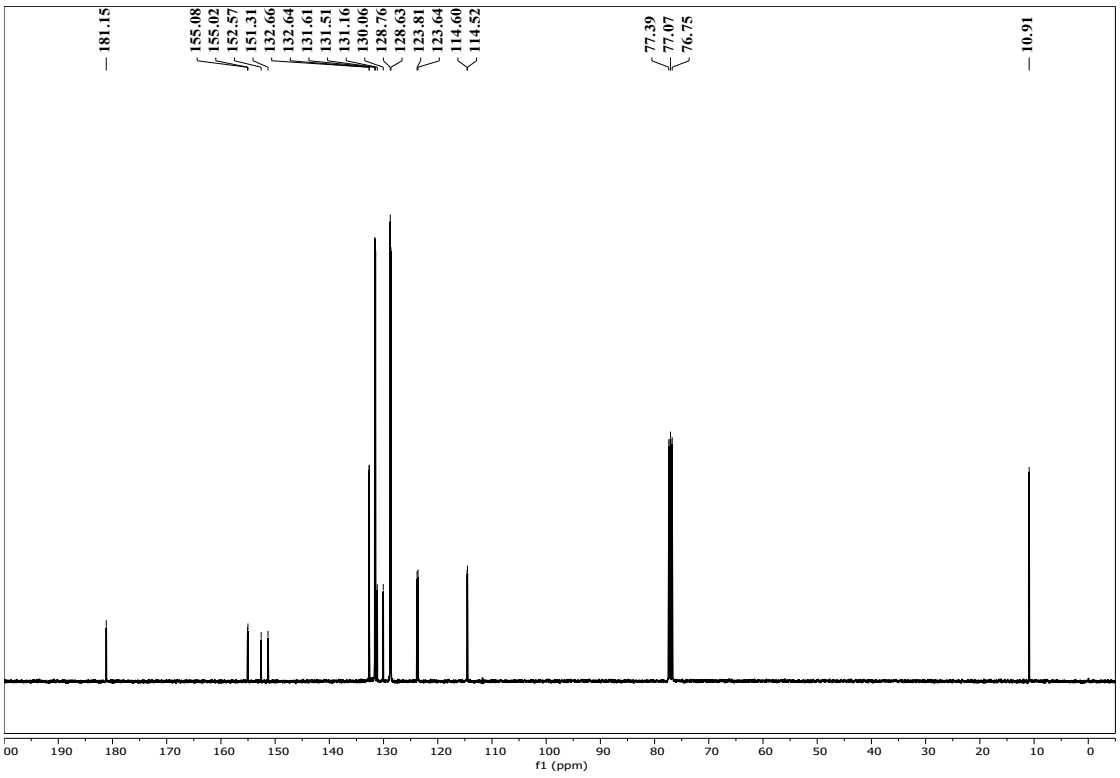




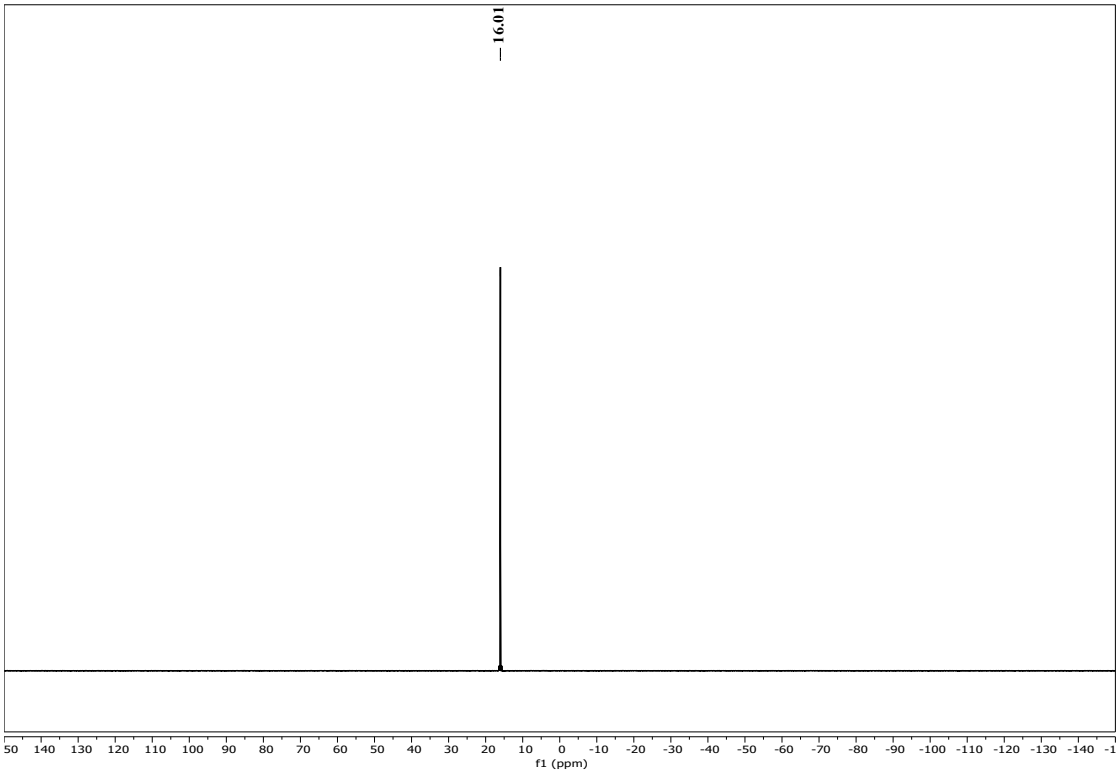

**3l,** $^{1}$H NMR (400 MHz), $CDCl_3$

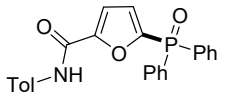



**3l**, $^{13}$C NMR (101 MHz), $CDCl_3$

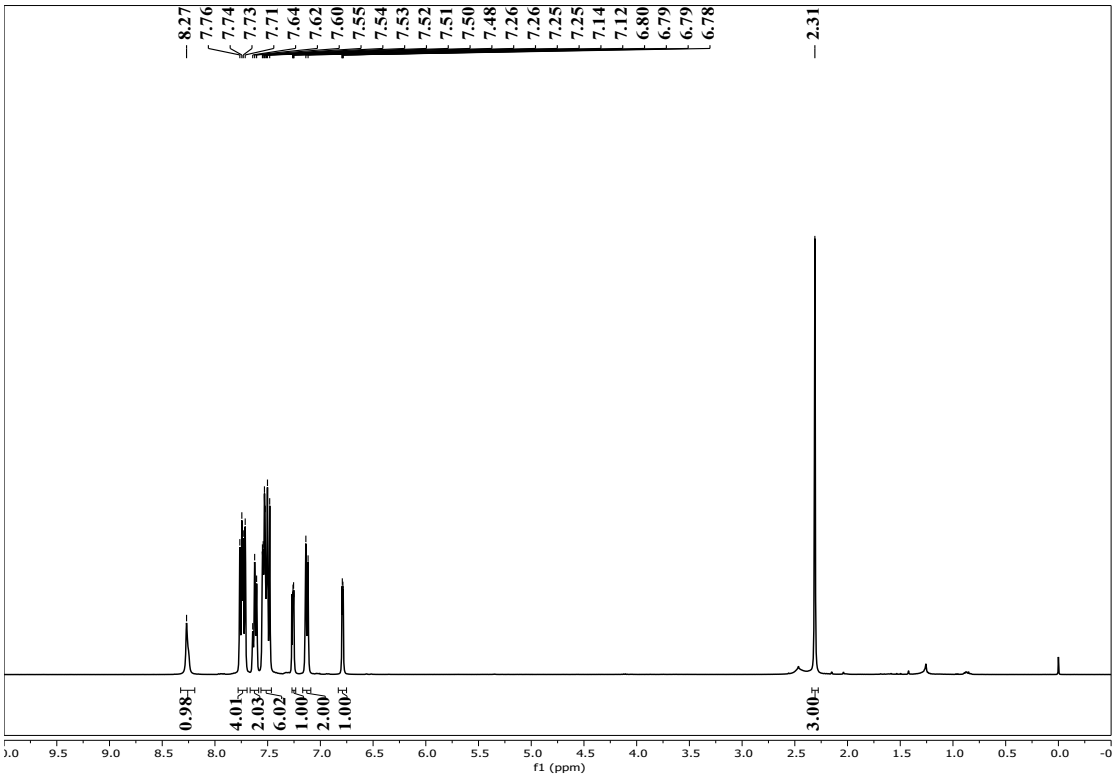


**3l**, $^{31}P$ NMR (162 MHz), $CDCl_3$

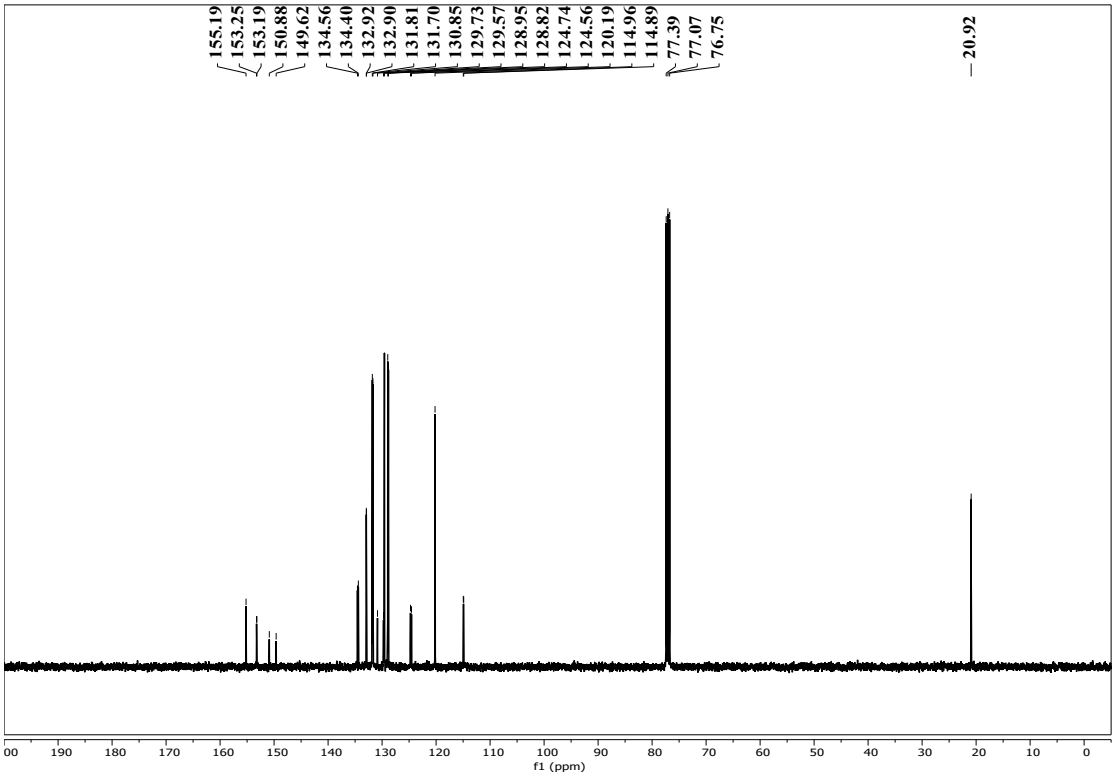




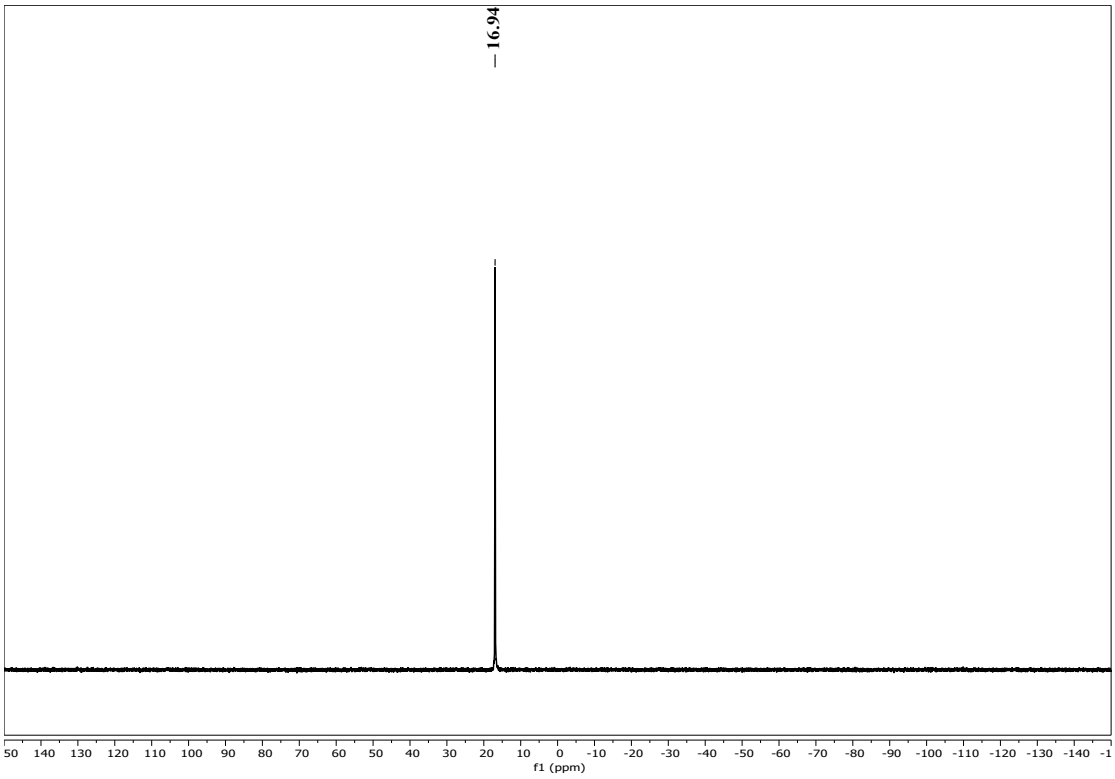

**3m,** $^{1}$H NMR (400 MHz), $CDCl_3$

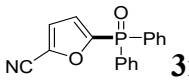



**3m**, $^{13}$C NMR (101 MHz), $CDCl_3$

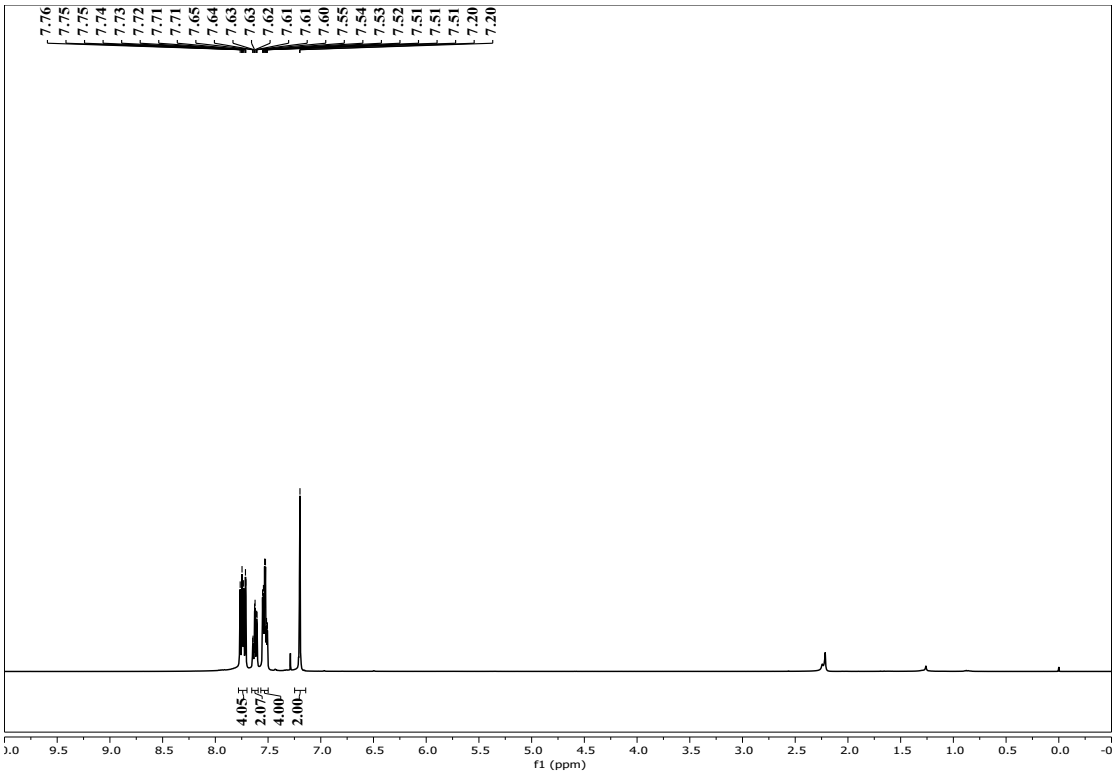


**3m**, $^{31}P$ NMR (162 MHz), $CDCl_3$

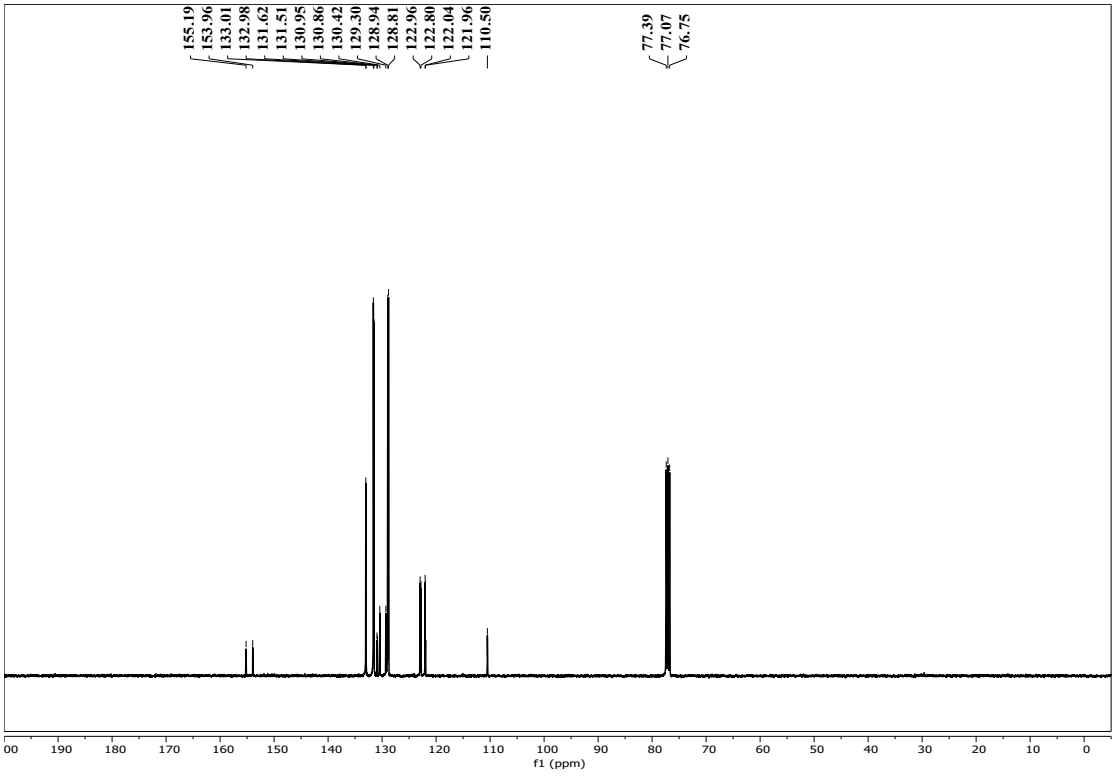




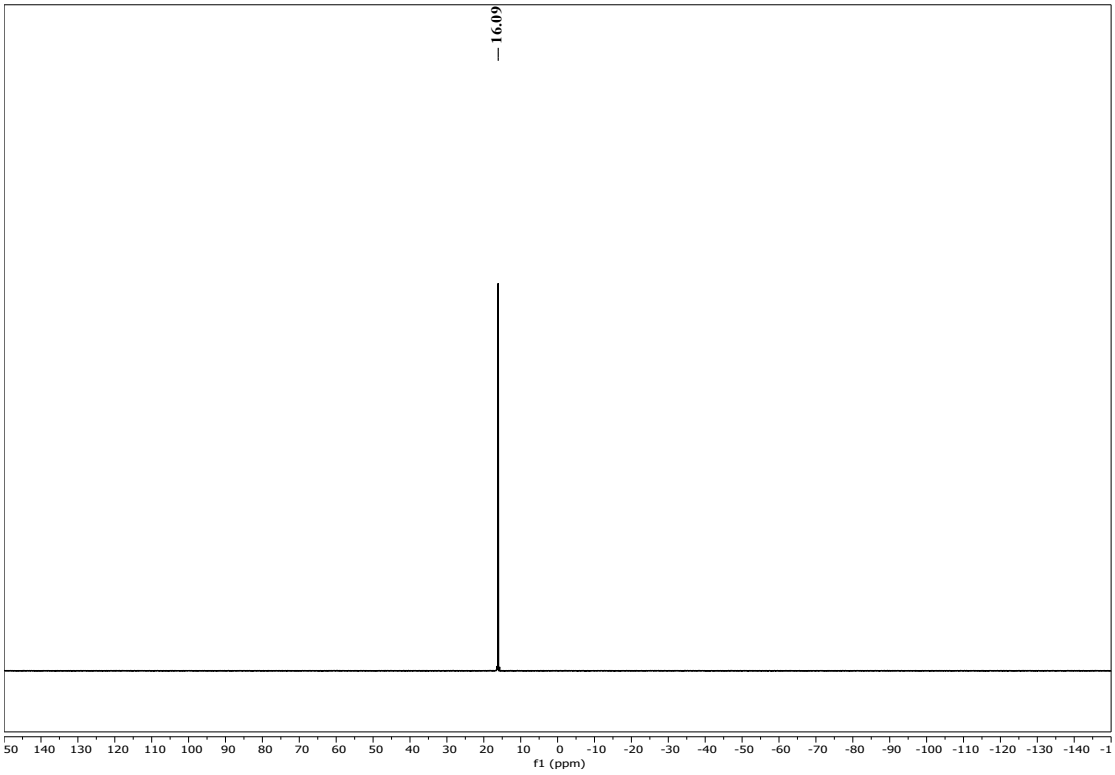
**3n,** $^{1}$H NMR (400 MHz), $CDCl_3$

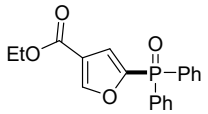



**3n**, $^{13}$C NMR (101 MHz), $CDCl_3$

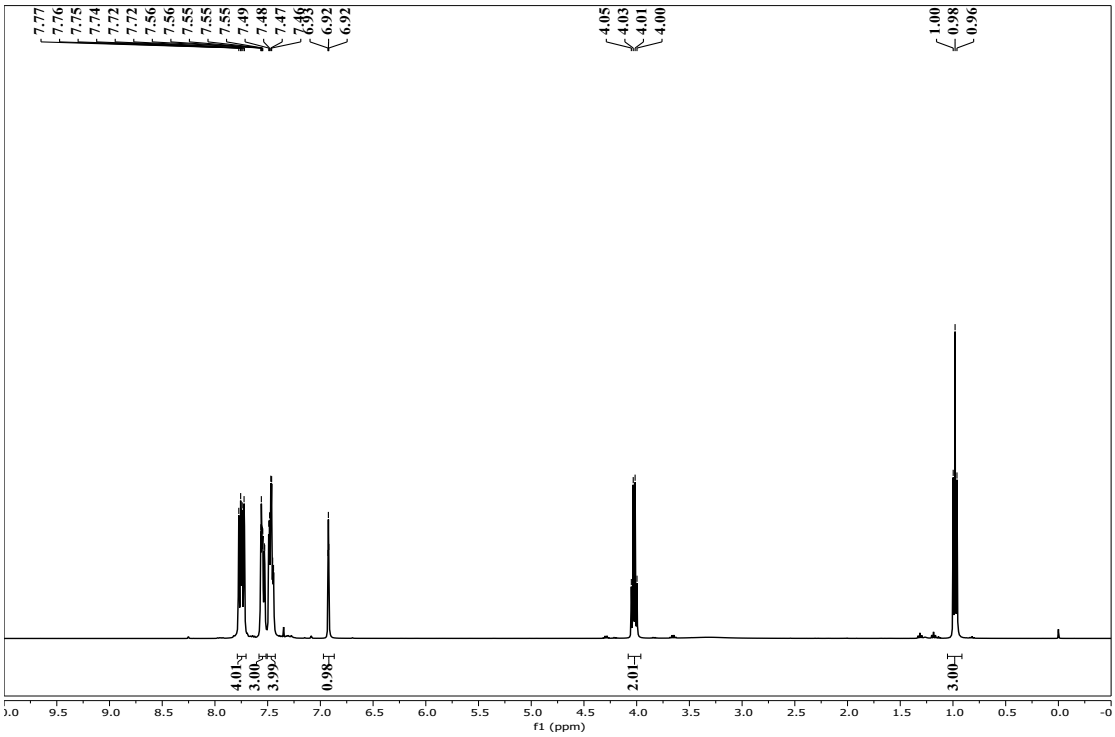


**3n**, $^{31}P$ NMR (162 MHz), $CDCl_3$

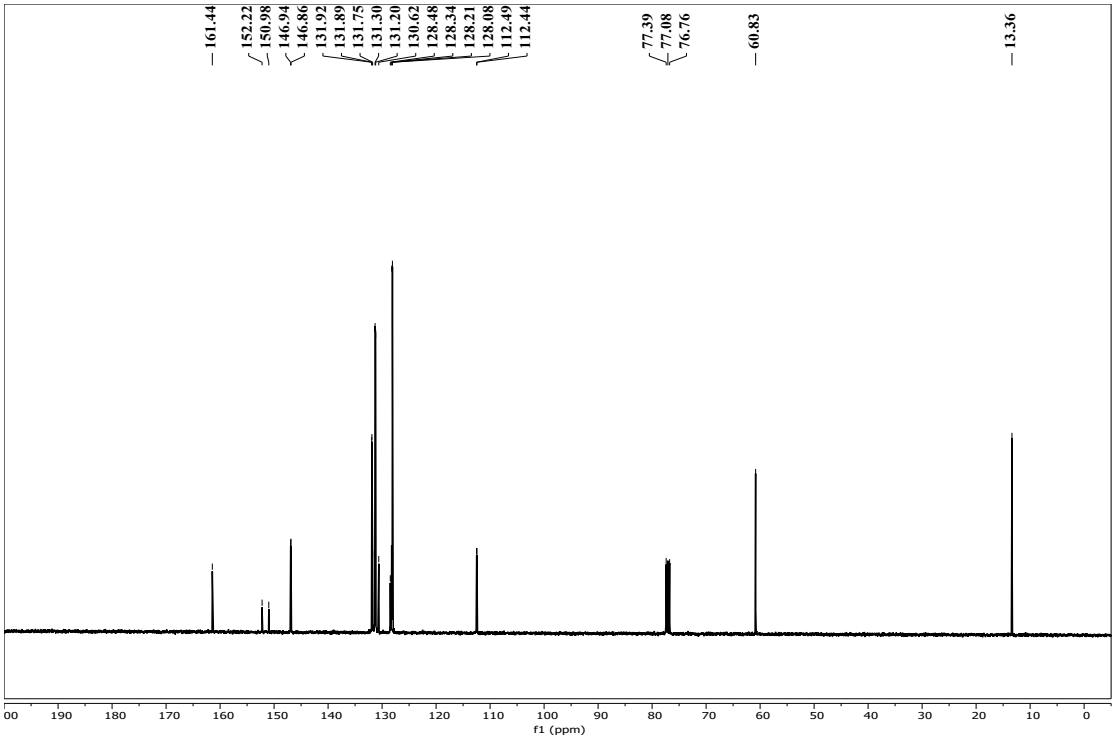




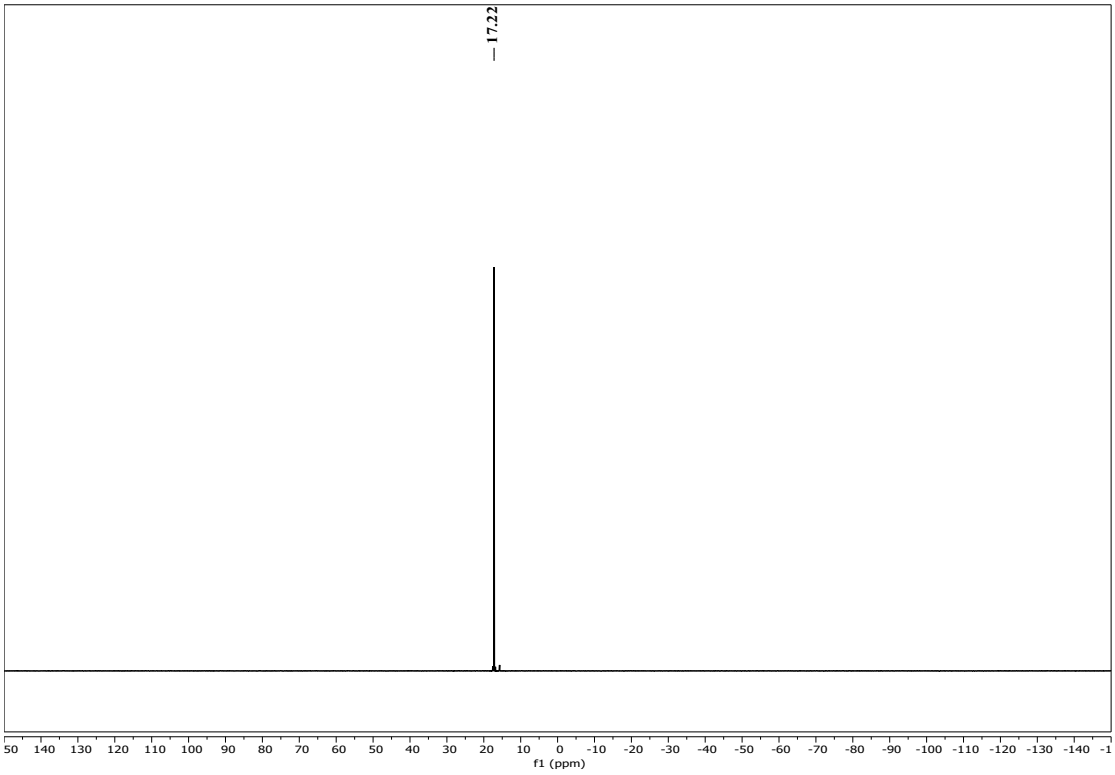
**3o,** $^{1}$H NMR (400 MHz), $CDCl_3$

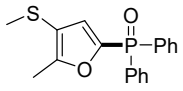



**3o**, $^{13}$C NMR (101 MHz), $CDCl_3$

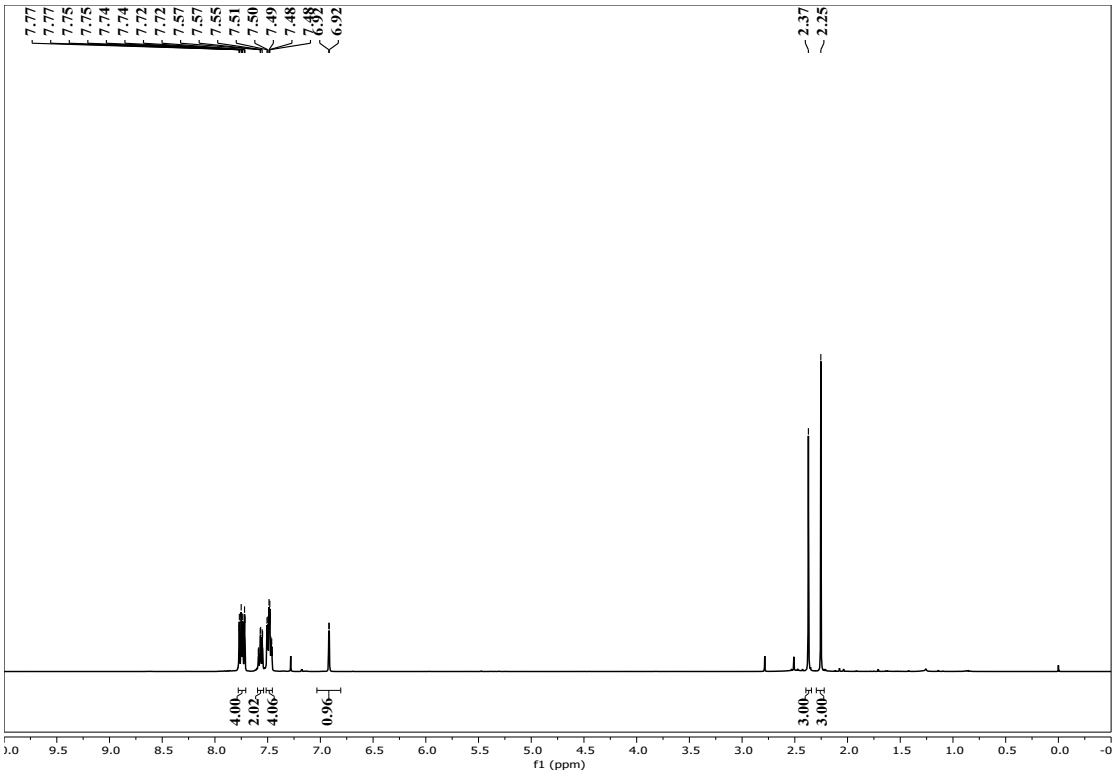


**3o**, $^{31}P$ NMR (162 MHz), $CDCl_3$

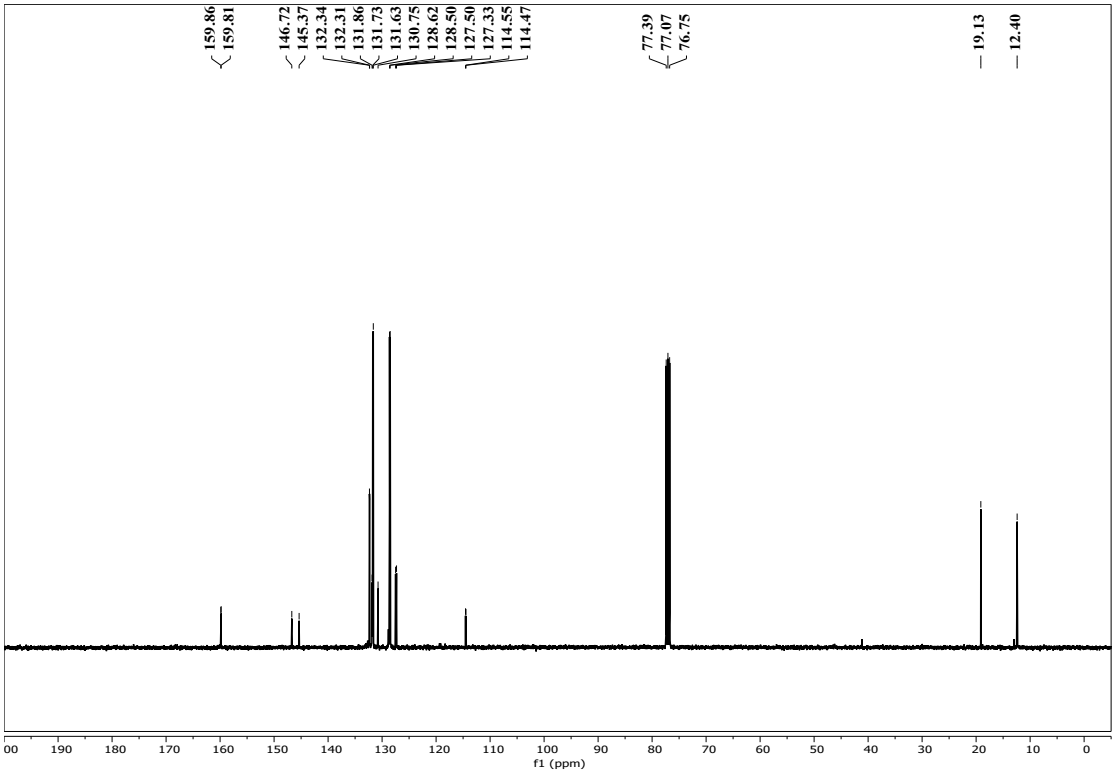




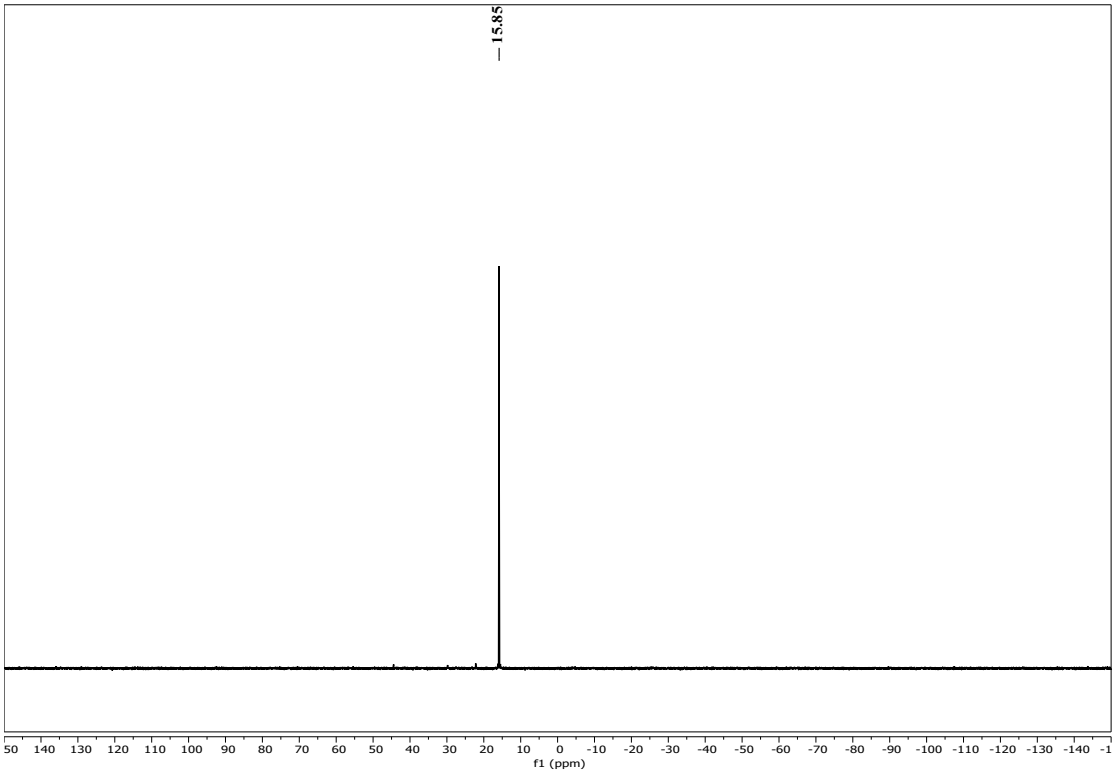
**3p,** $^{1}$H NMR (400 MHz), $CDCl_3$

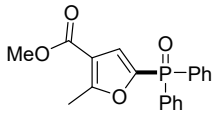



**3p**, $^{13}$C NMR (101 MHz), $CDCl_3$

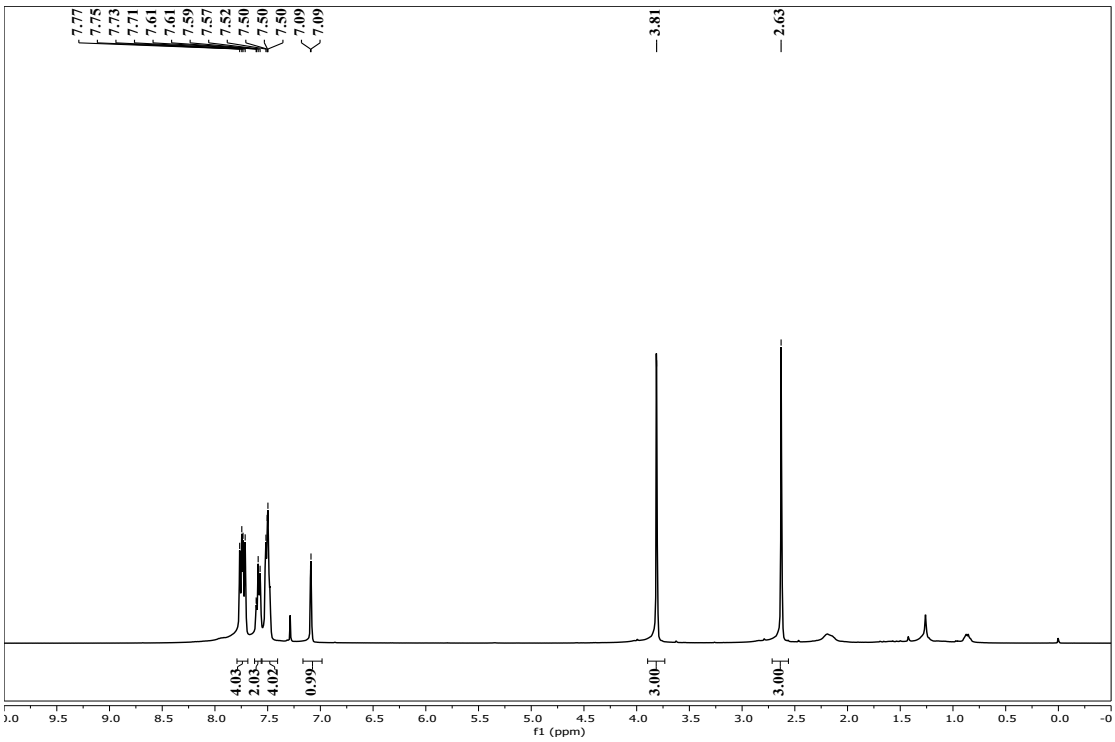


**3p**, $^{31}P$ NMR (162 MHz), $CDCl_3$

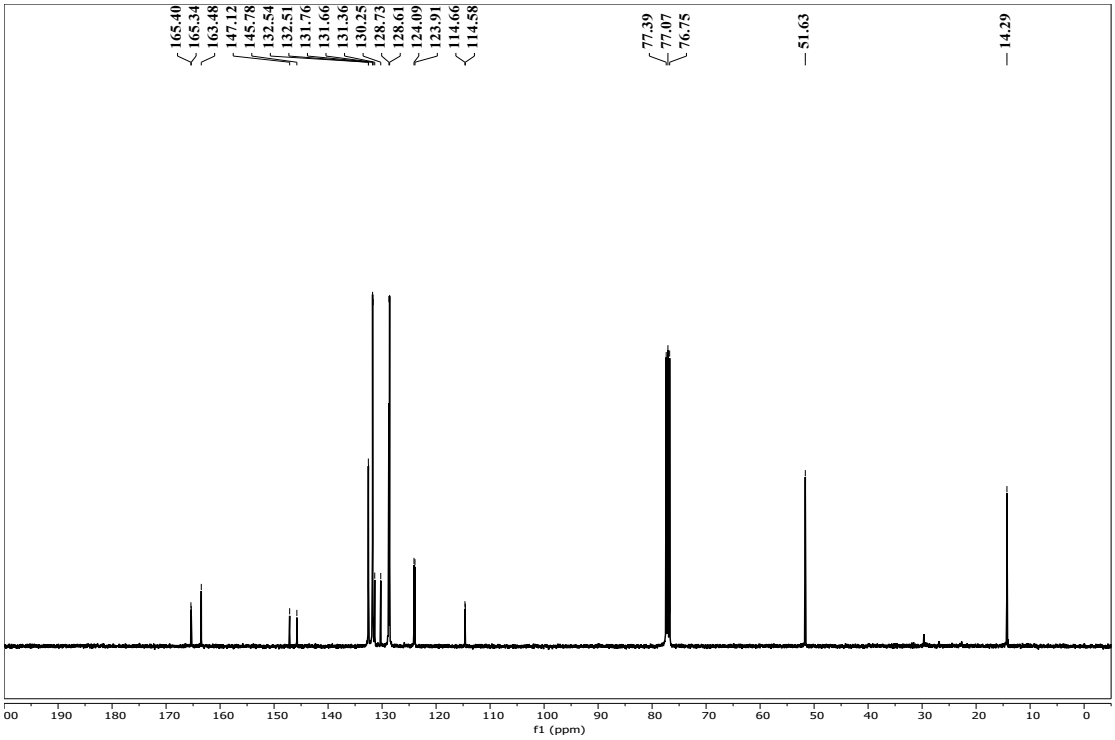




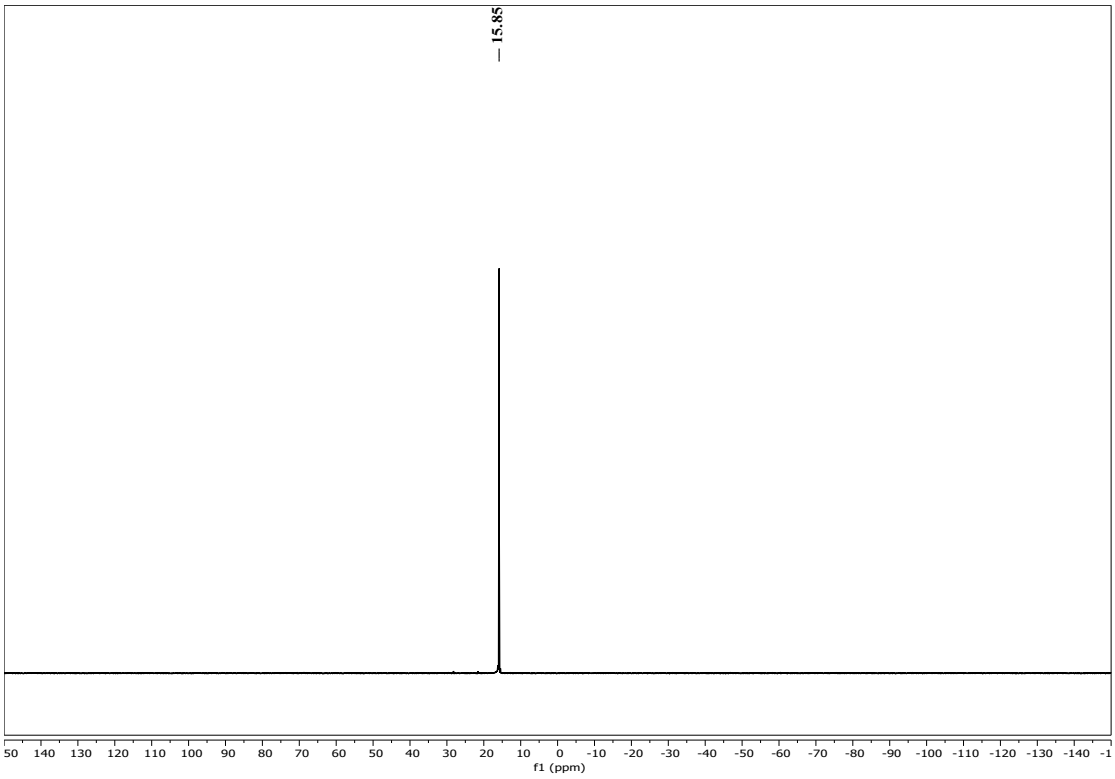
**3q,** $^{1}$H NMR (400 MHz), $CDCl_3$

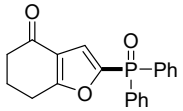



**3q**, $^{13}$C NMR (101 MHz), $CDCl_3$

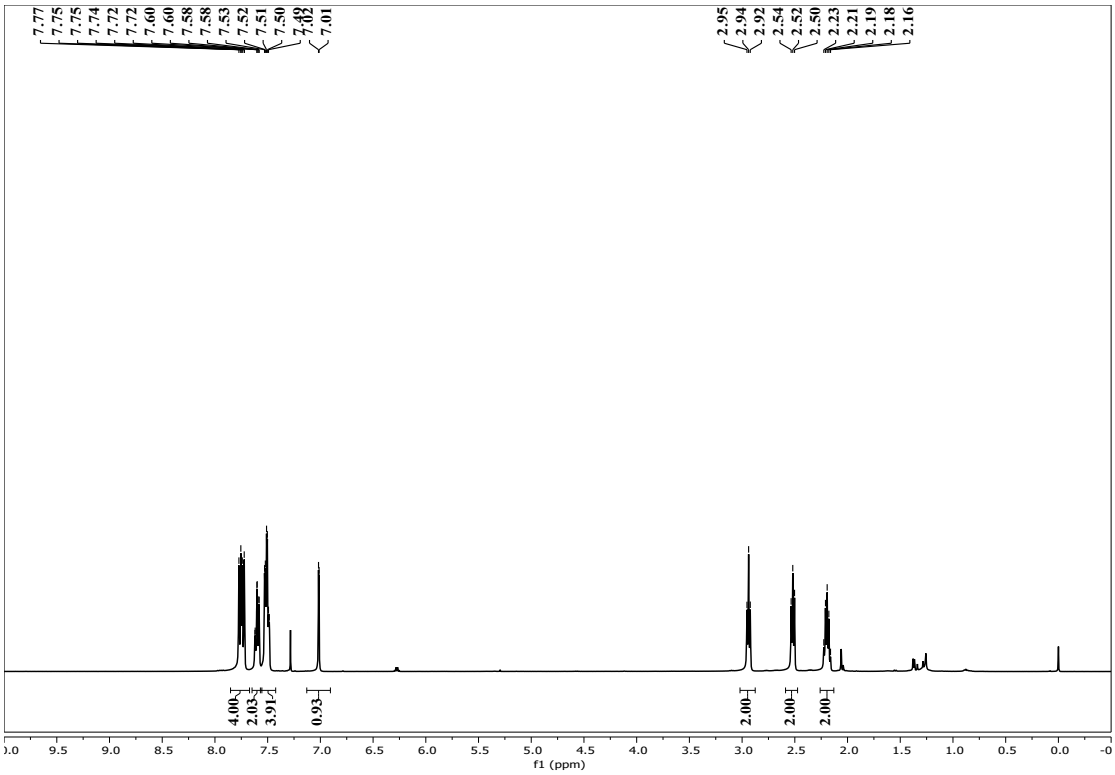


**3q**, $^{31}P$ NMR (162 MHz), $CDCl_3$

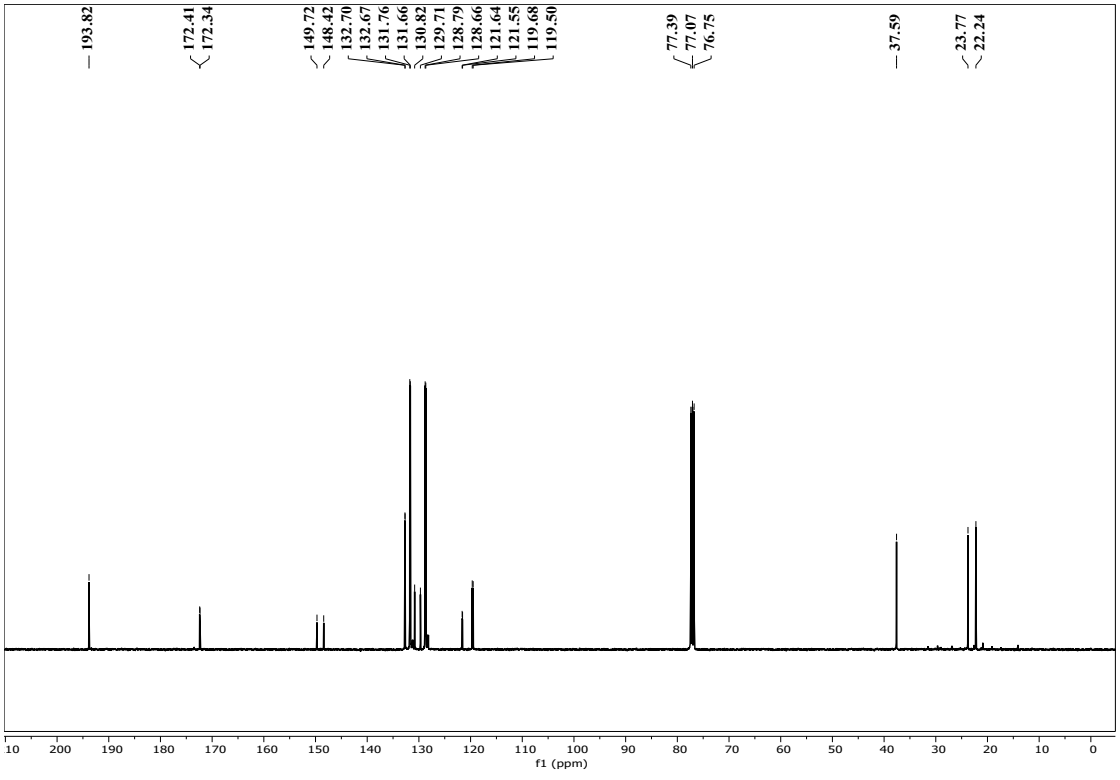




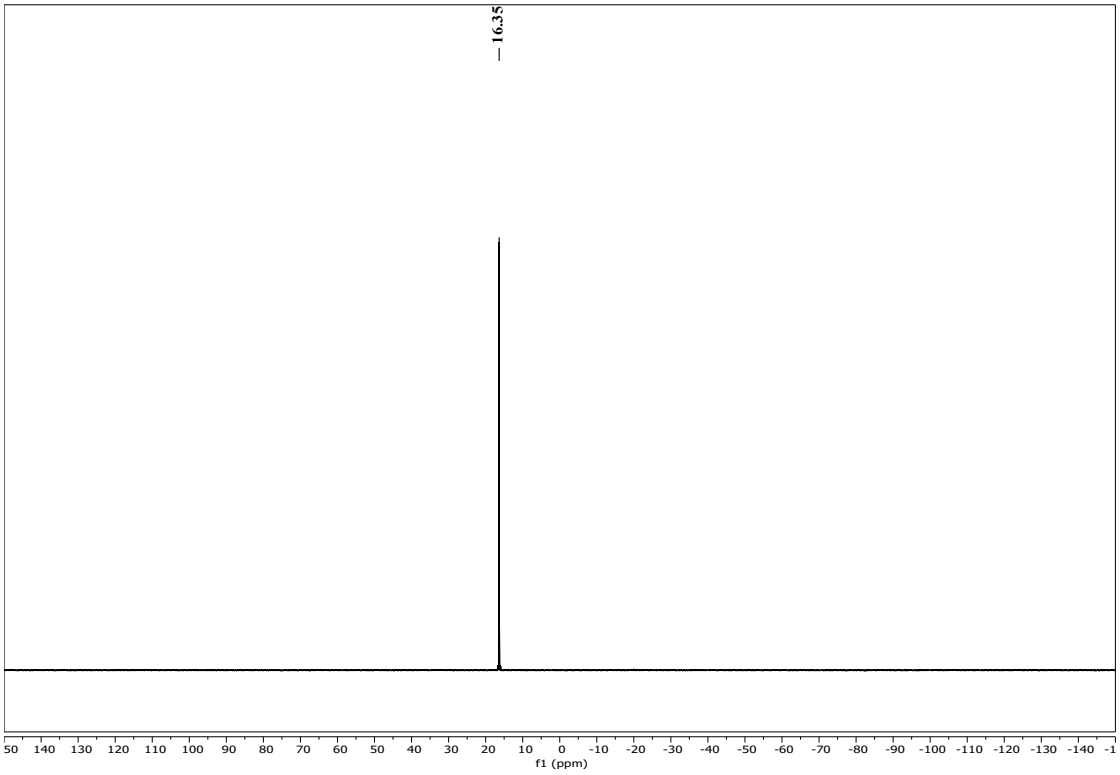
**3r,** $^{1}$H NMR (400 MHz), $CDCl_3$

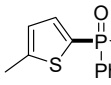



**3r**, $^{13}$C NMR (101 MHz), $CDCl_3$

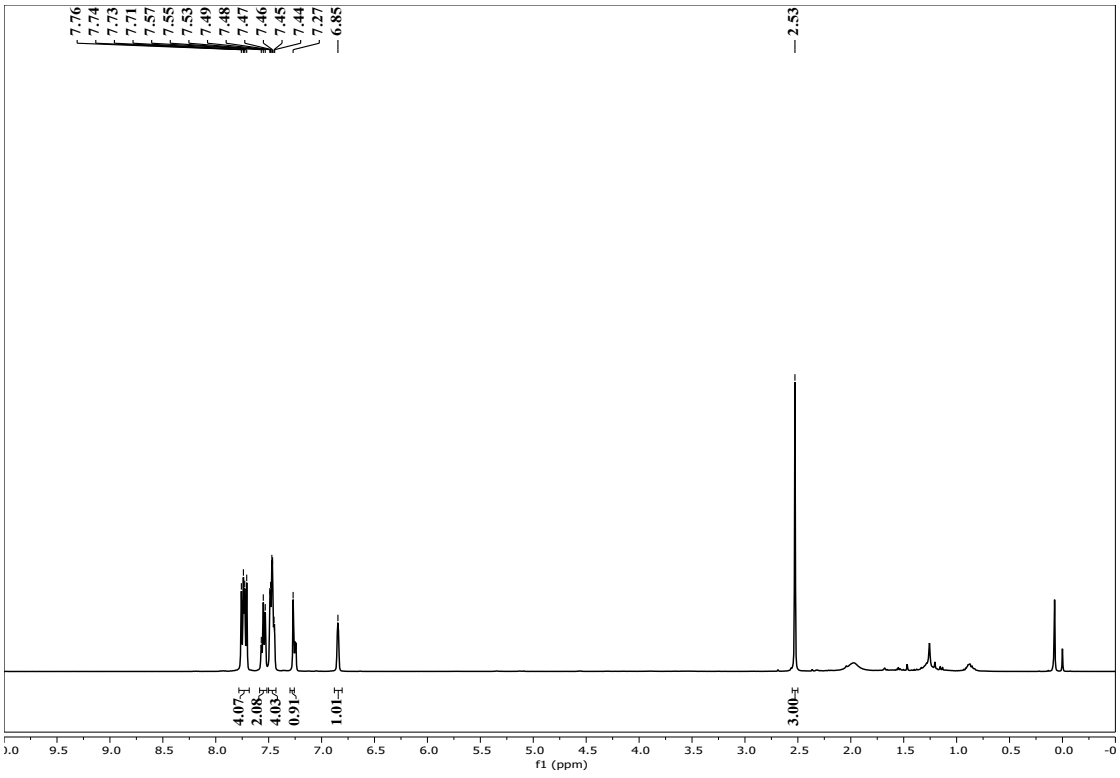


**3r**, $^{31}P$ NMR (162 MHz), $CDCl_3$

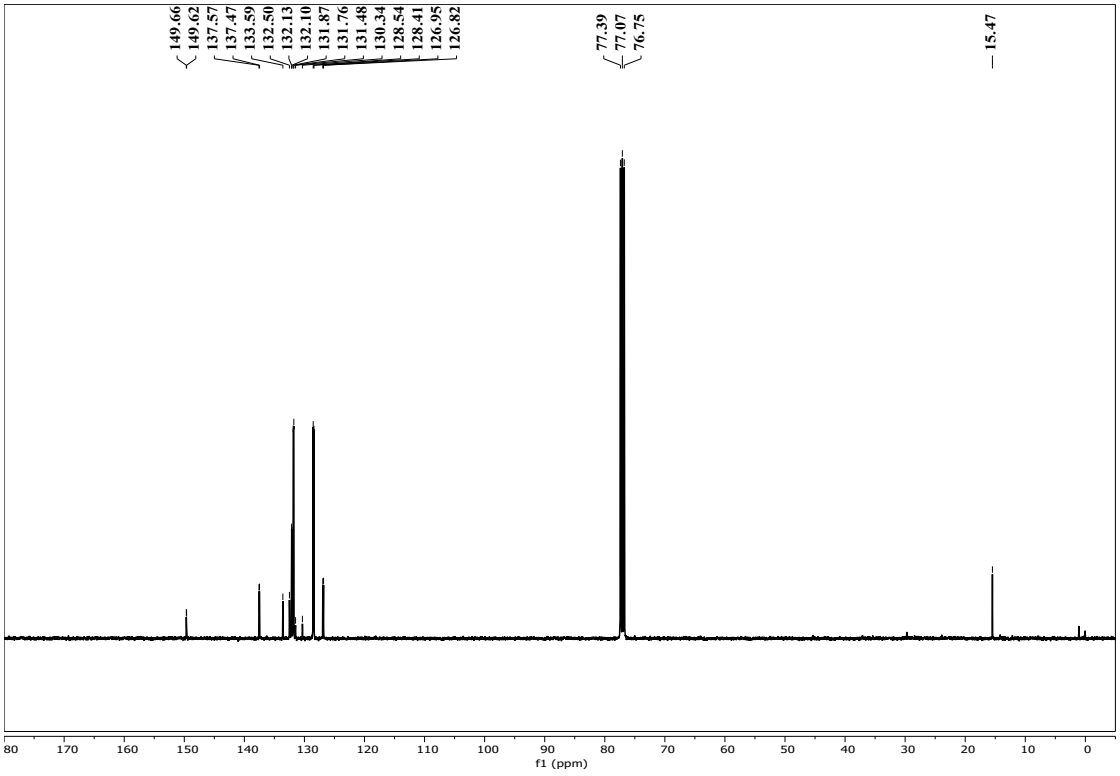




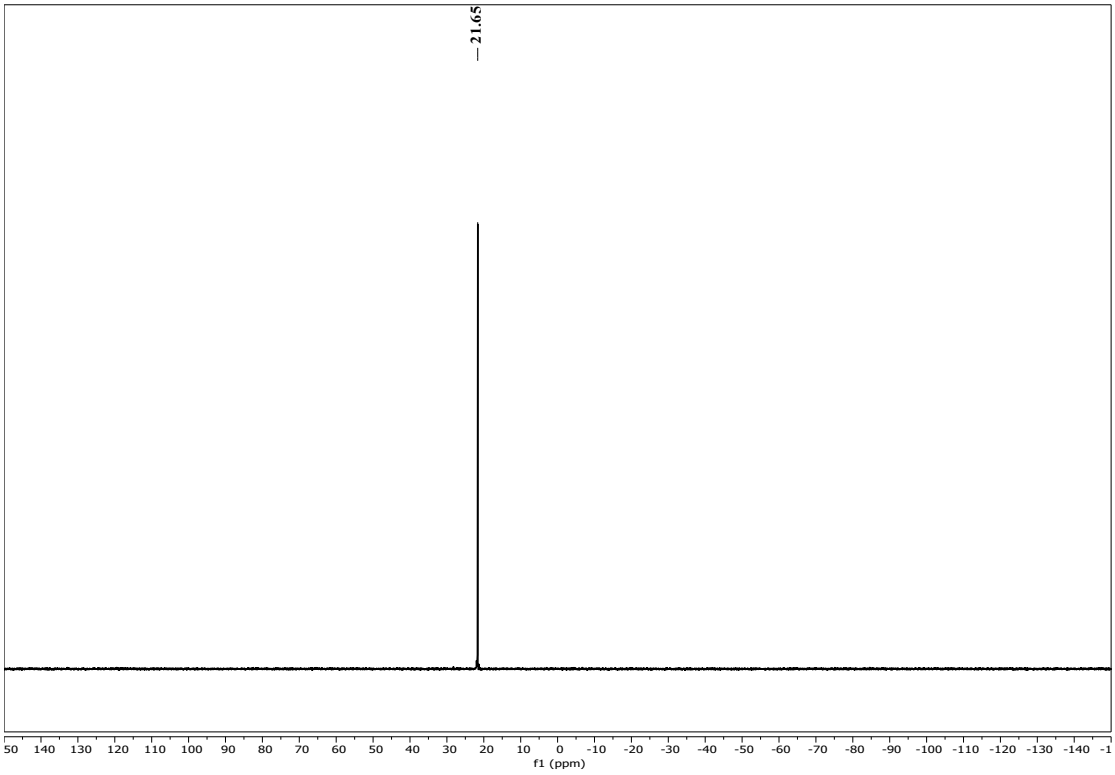
**3s,** $^{1}$H NMR (400 MHz), $CDCl_3$

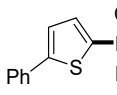



**3s**, $^{13}$C NMR (101 MHz), $CDCl_3$

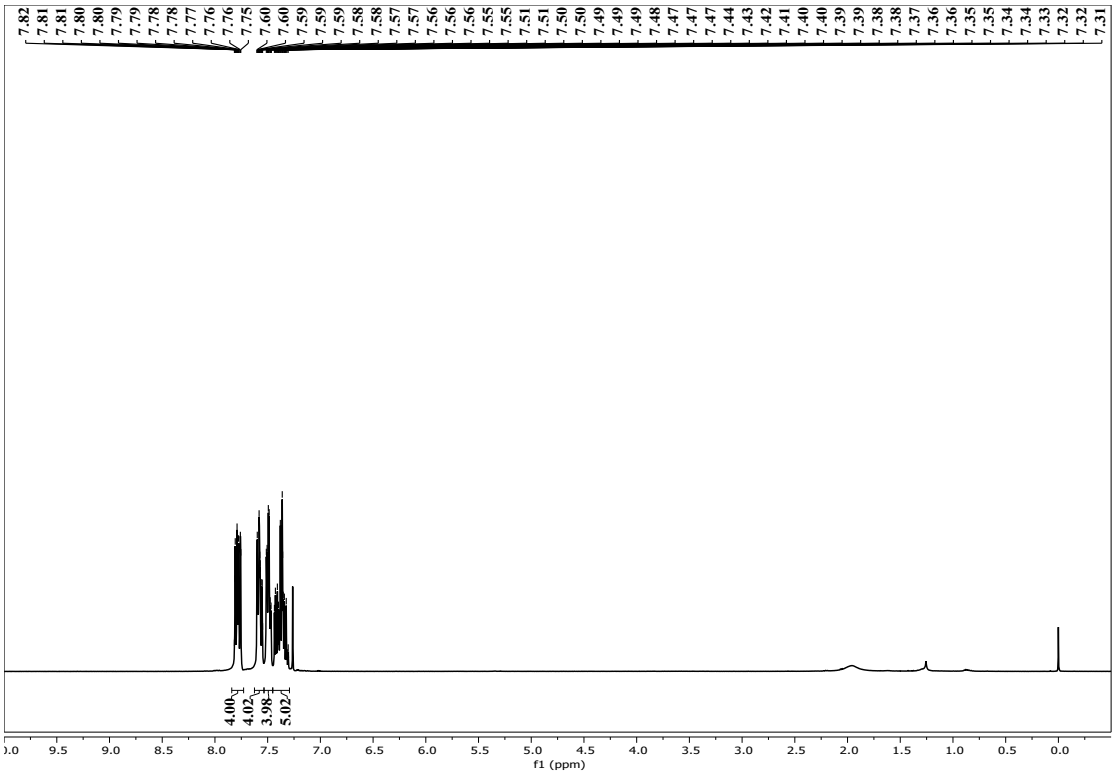


**3s**, $^{31}P$ NMR (162 MHz), $CDCl_3$

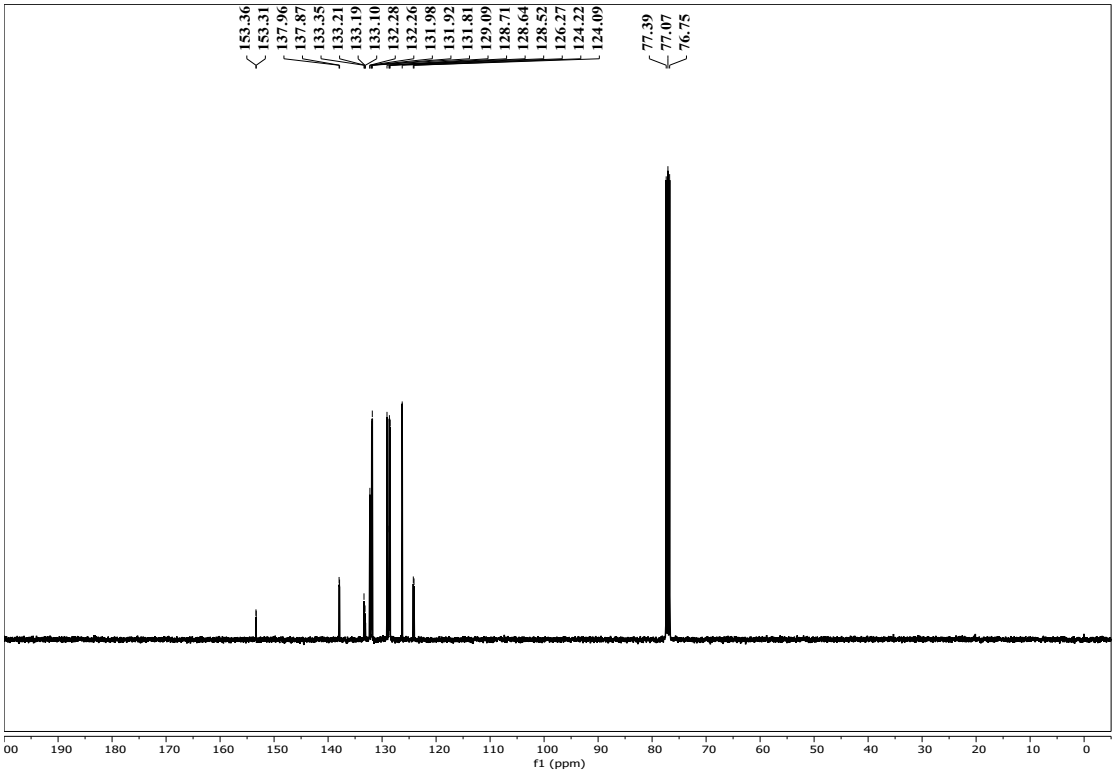




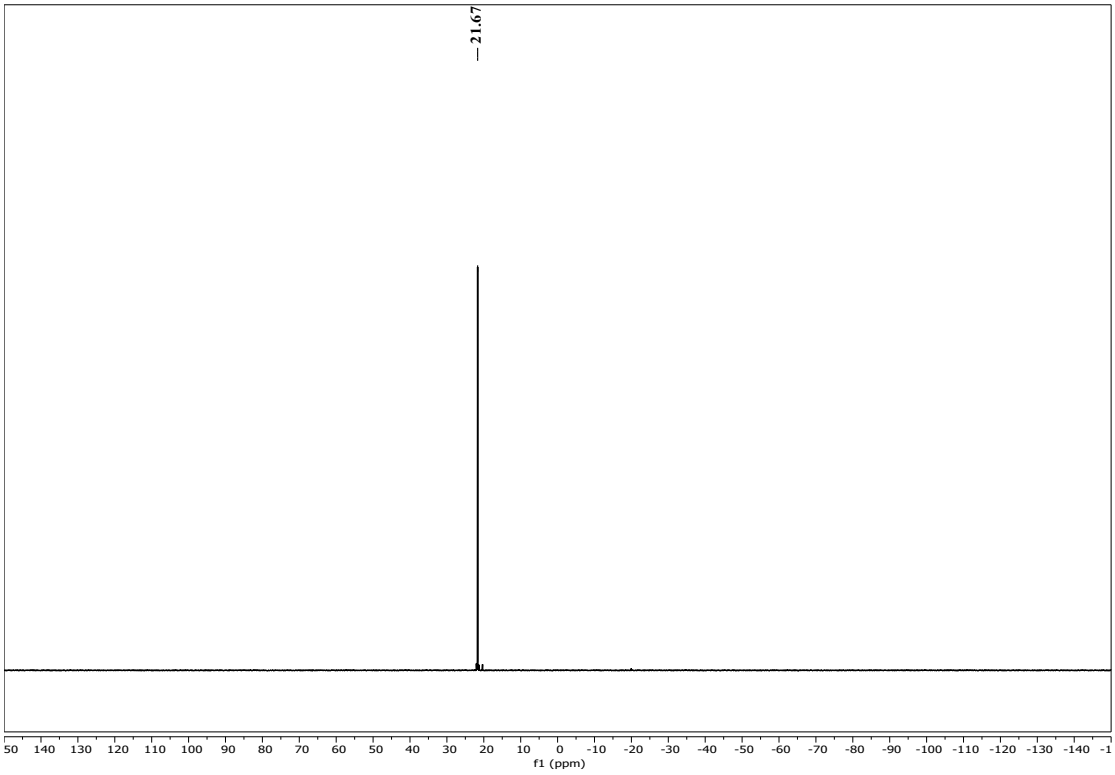
**3t,** $^{1}$H NMR (400 MHz), $CDCl_3$

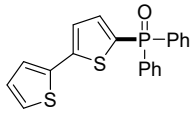



**3t**, $^{13}$C NMR (101 MHz), $CDCl_3$

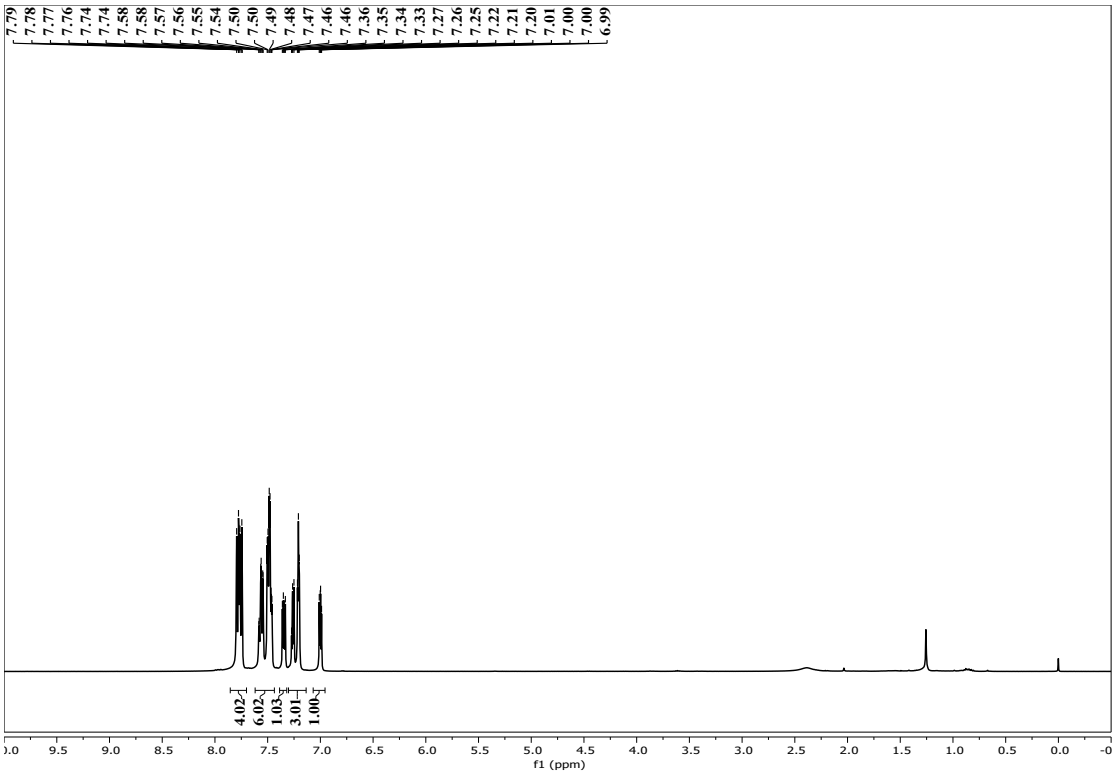


**3t**, $^{31}P$ NMR (162 MHz), $CDCl_3$

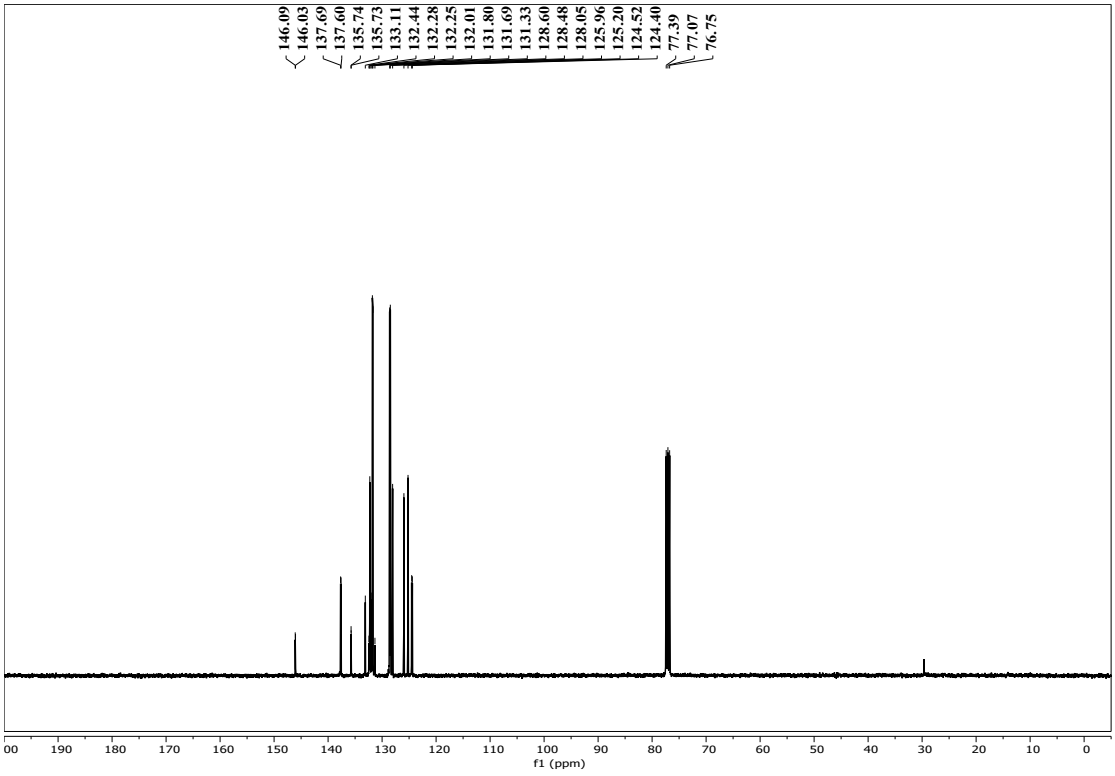




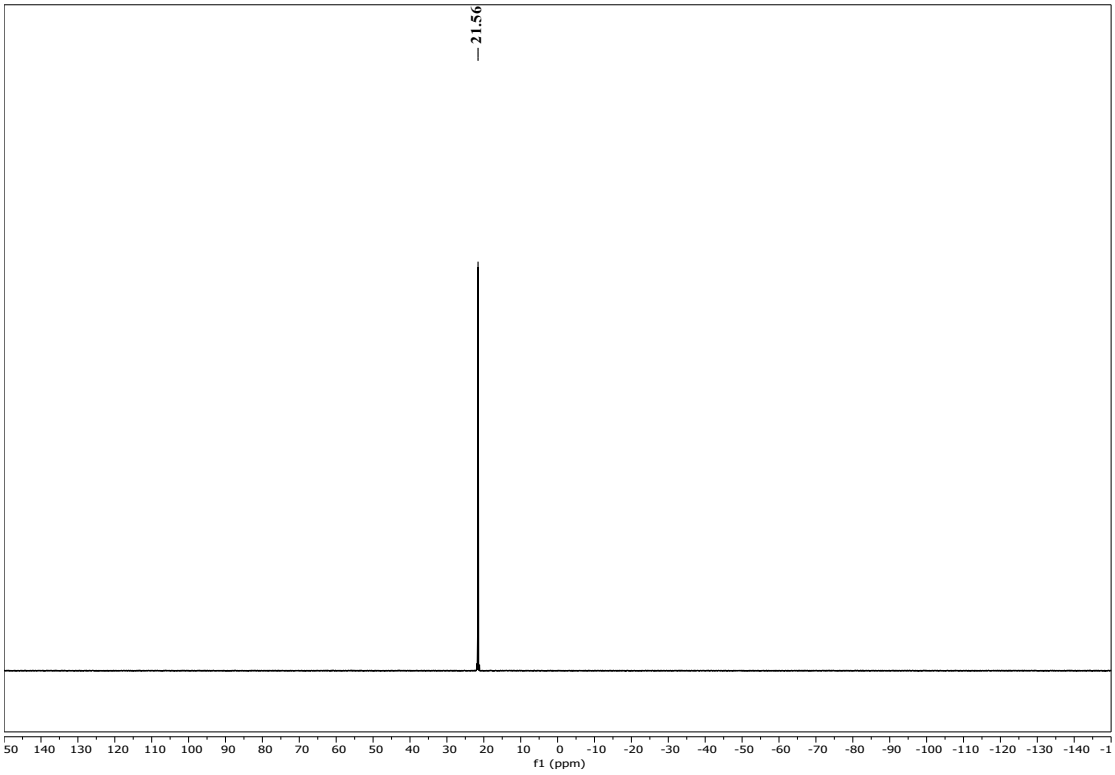
**3u,** $^{1}$H NMR (400 MHz), $CDCl_3$

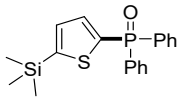



**3u**, $^{13}$C NMR (101 MHz), $CDCl_3$

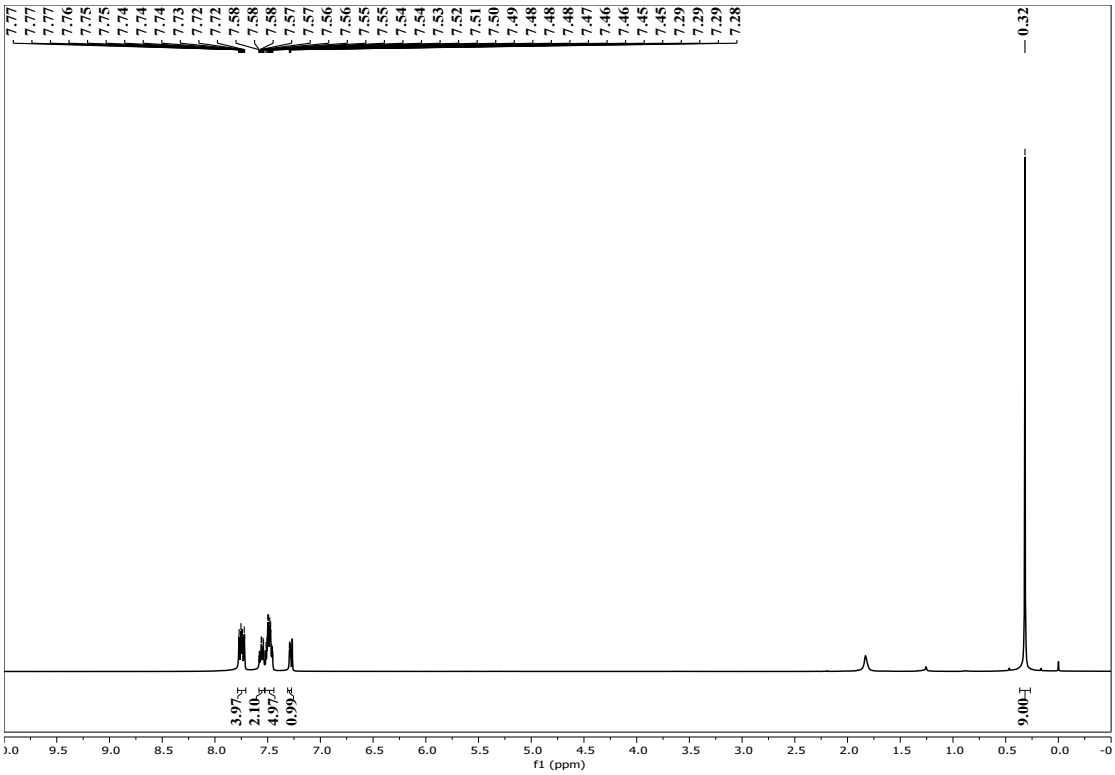


**3u**, $^{31}P$ NMR (162 MHz), $CDCl_3$

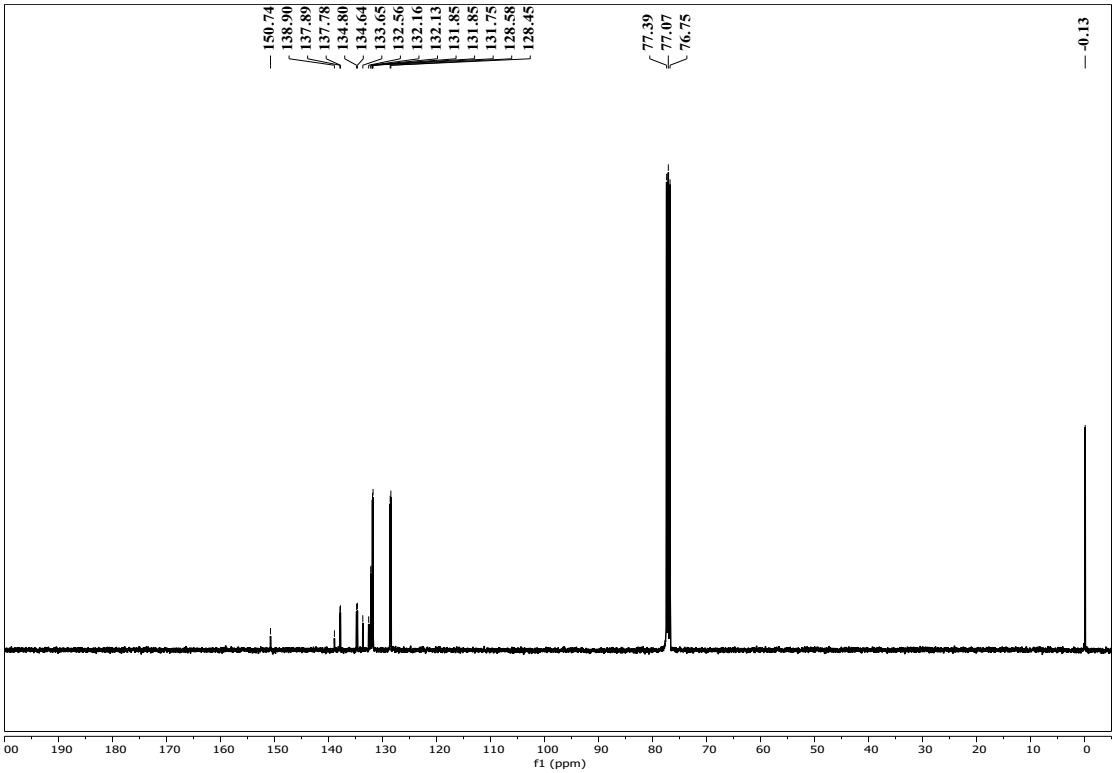




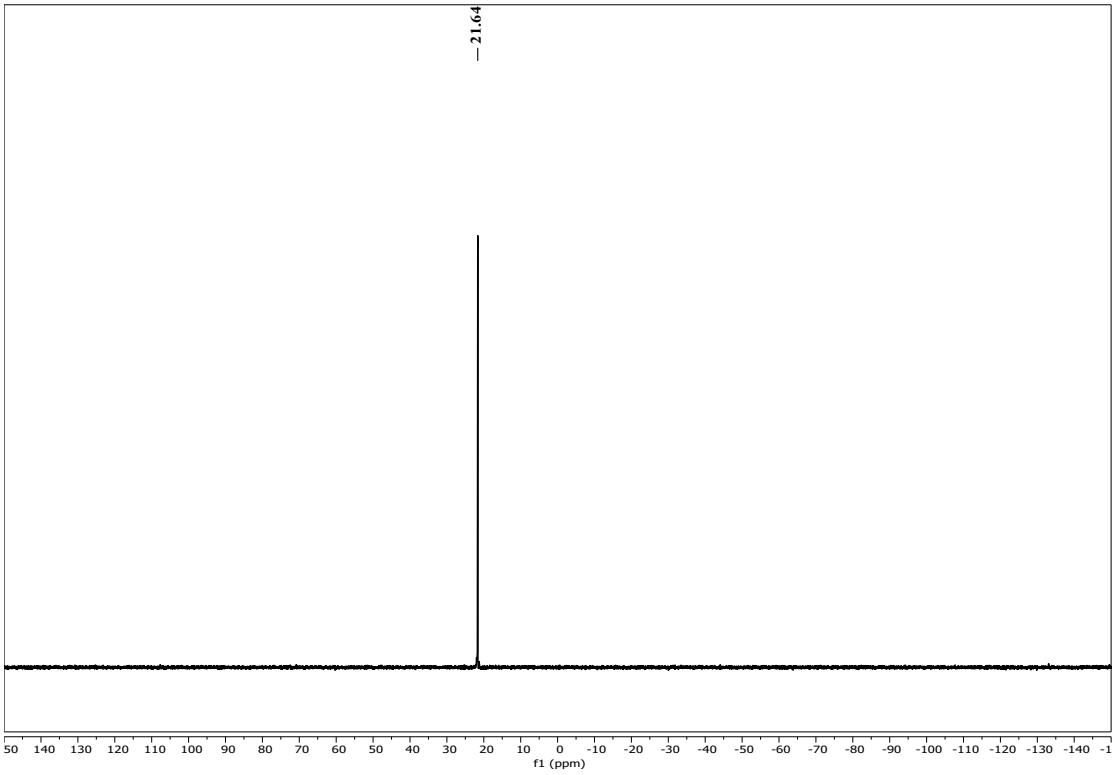
**3v,** $^{1}$H NMR (400 MHz), $CDCl_3$

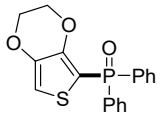



**3v**, $^{13}$C NMR (101 MHz), $CDCl_3$

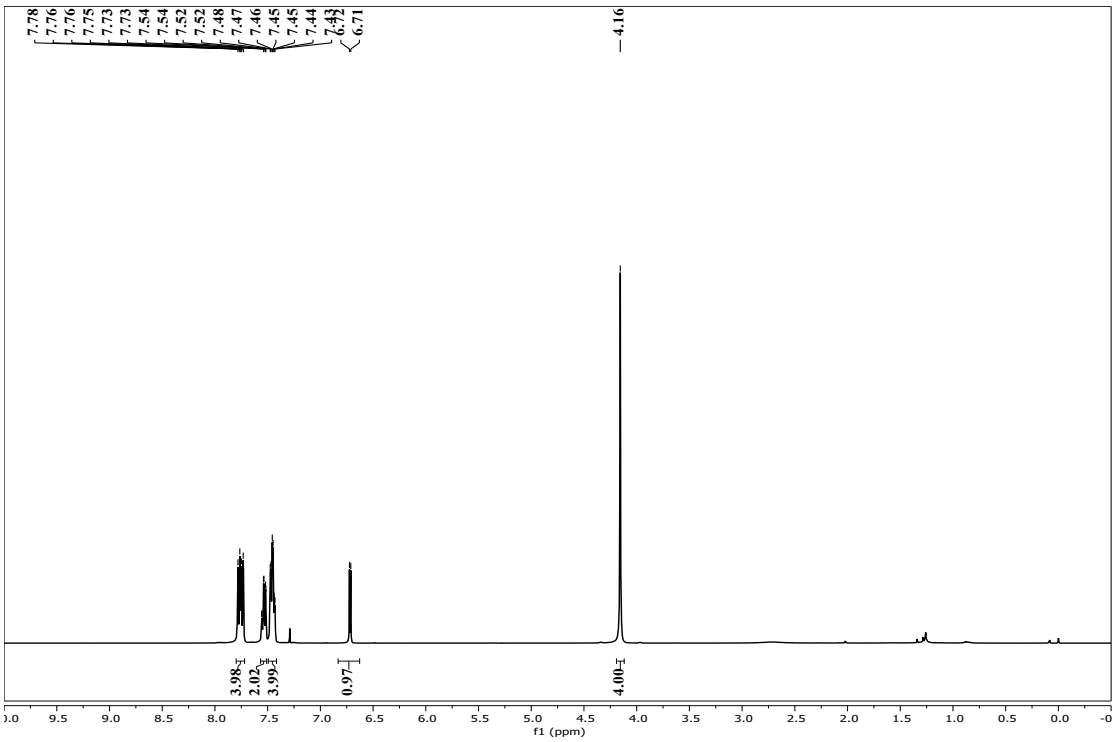


**3v**, $^{31}P$ NMR (162 MHz), $CDCl_3$

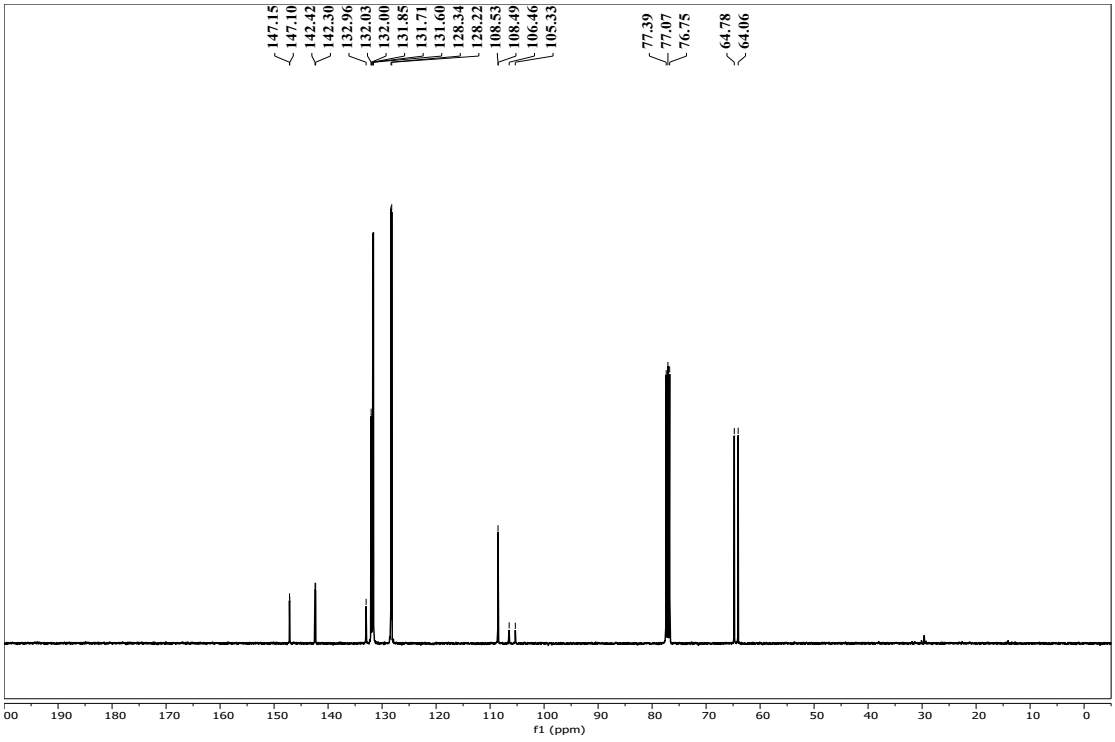




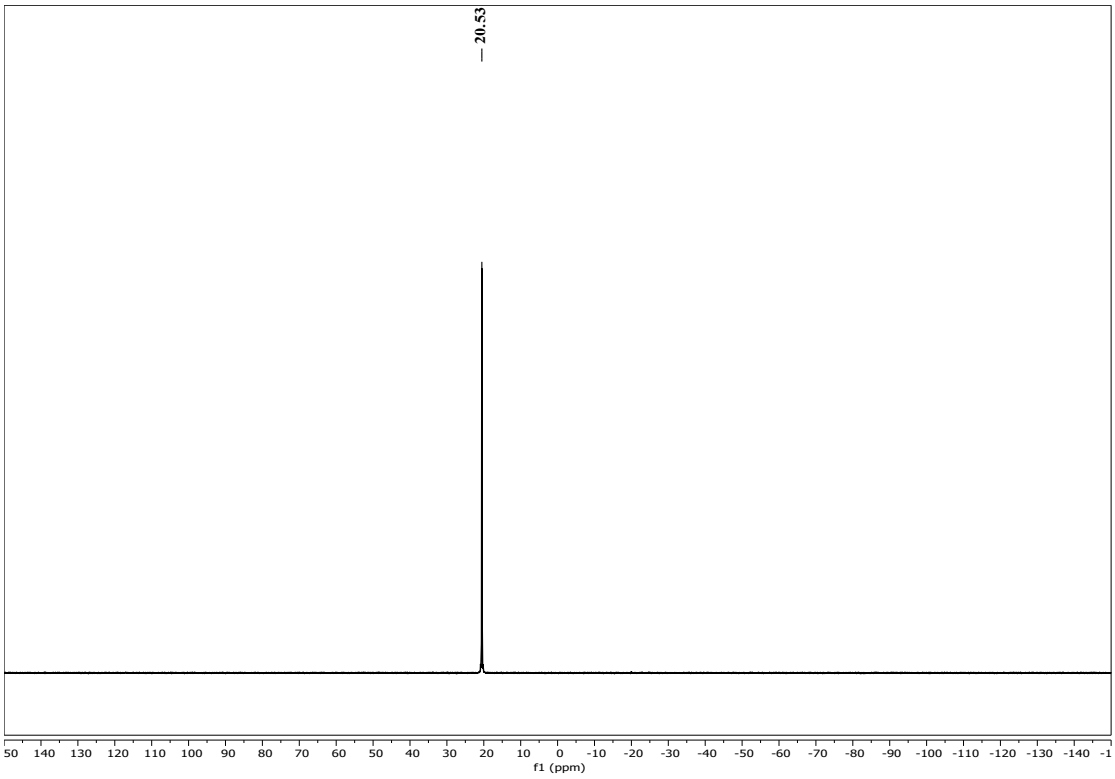
**3w,** $^{1}$H NMR (400 MHz), $CDCl_3$

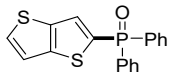



**3w**, $^{13}$C NMR (101 MHz), $CDCl_3$

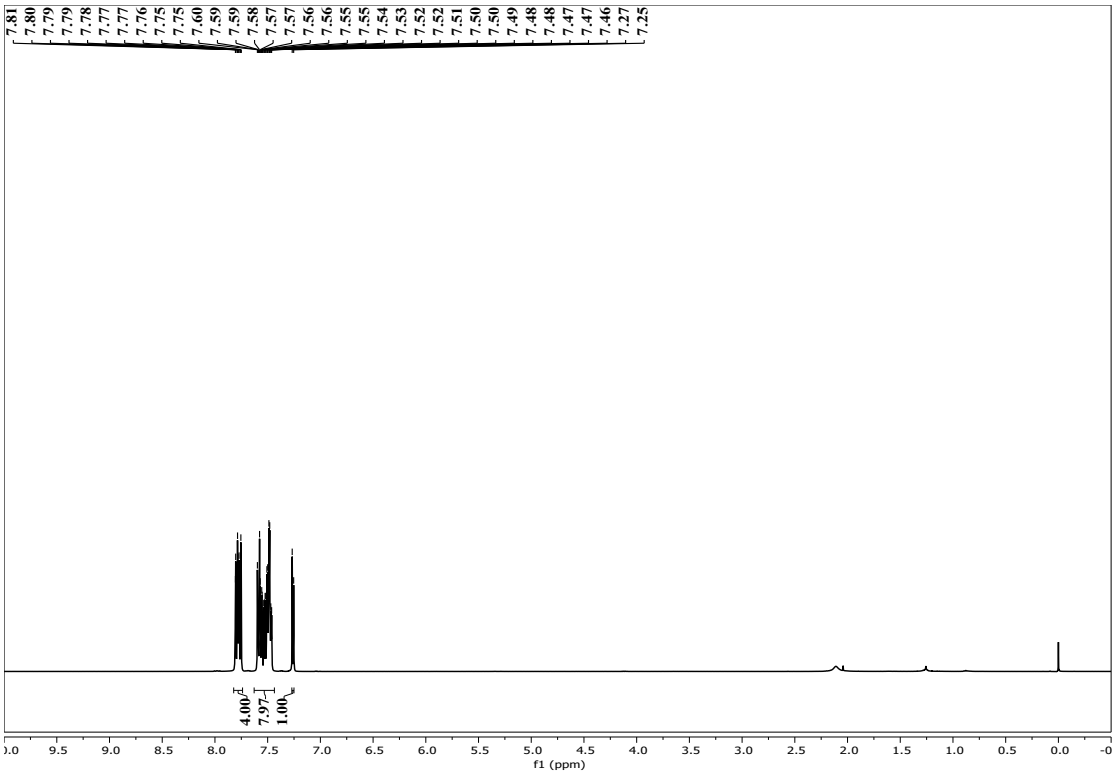


**3w**, $^{31}P$ NMR (162 MHz), $CDCl_3$

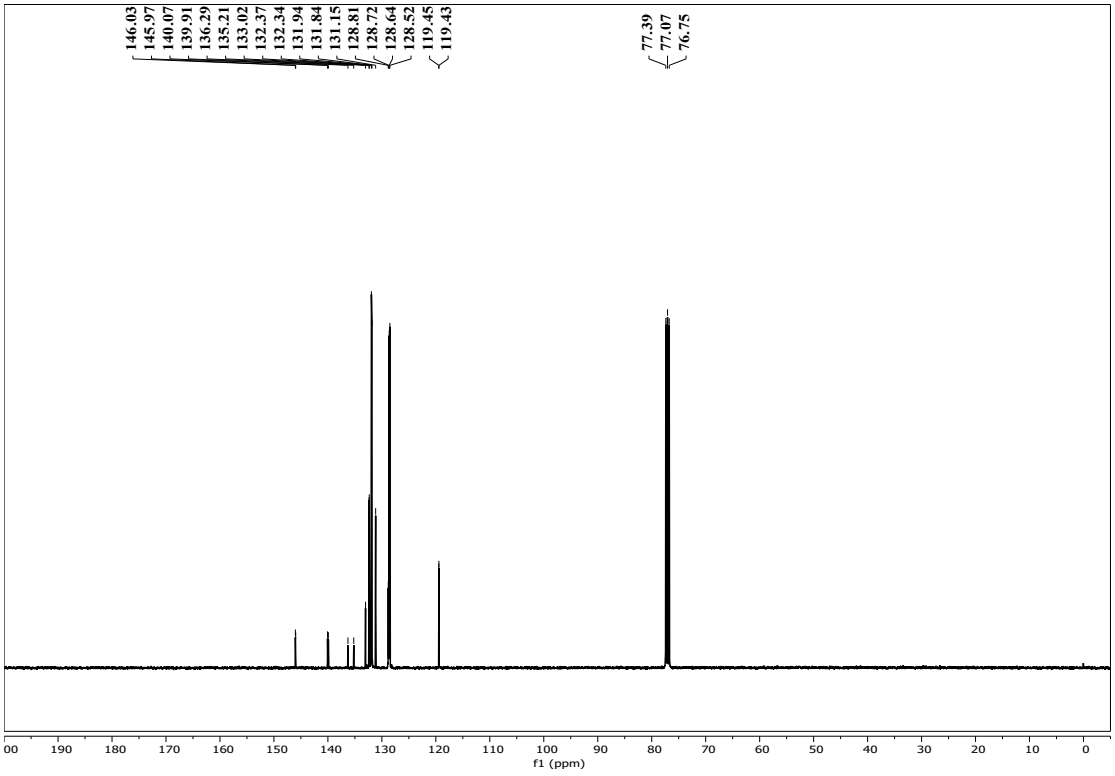




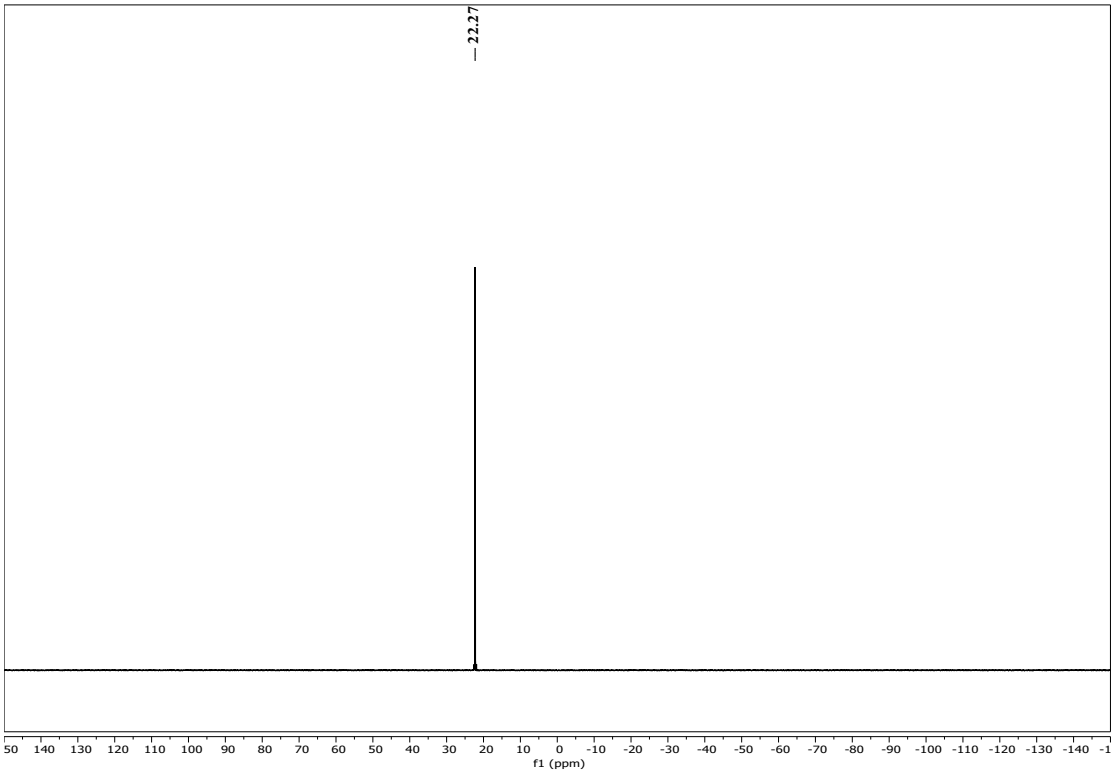
**3x,** $^{1}$H NMR (400 MHz), $CDCl_3$

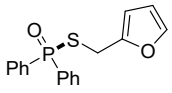



**3x**, $^{13}$C NMR (101 MHz), $CDCl_3$

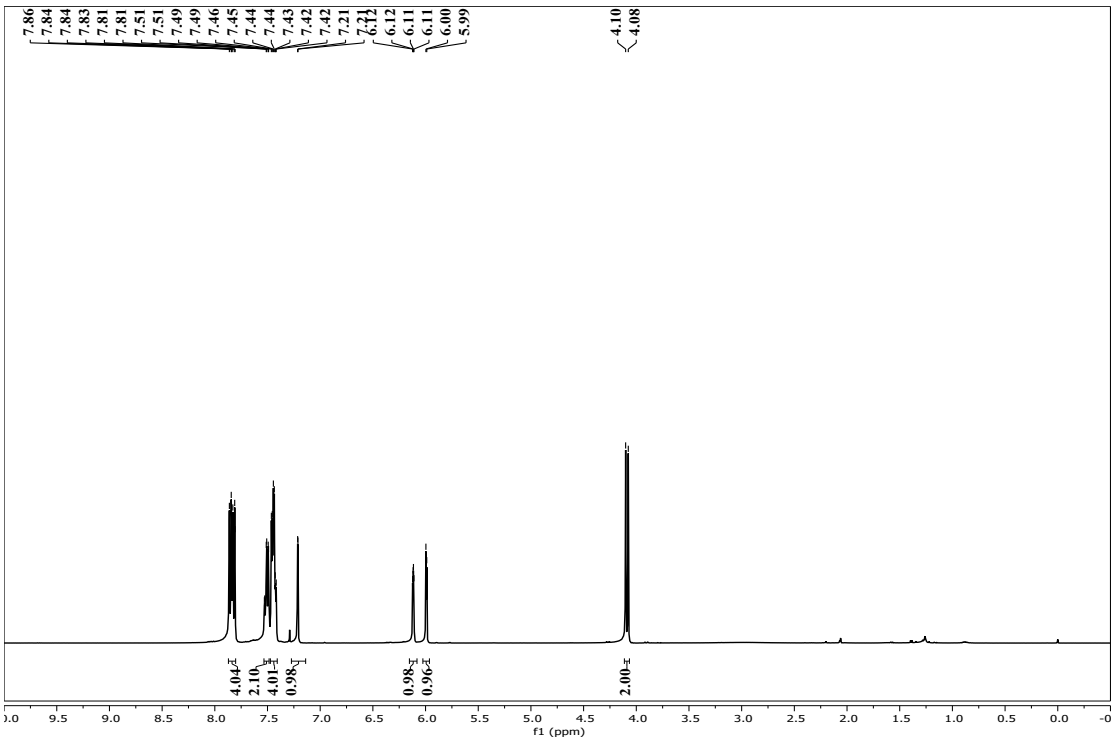


**3x**, $^{31}P$ NMR (162 MHz), $CDCl_3$

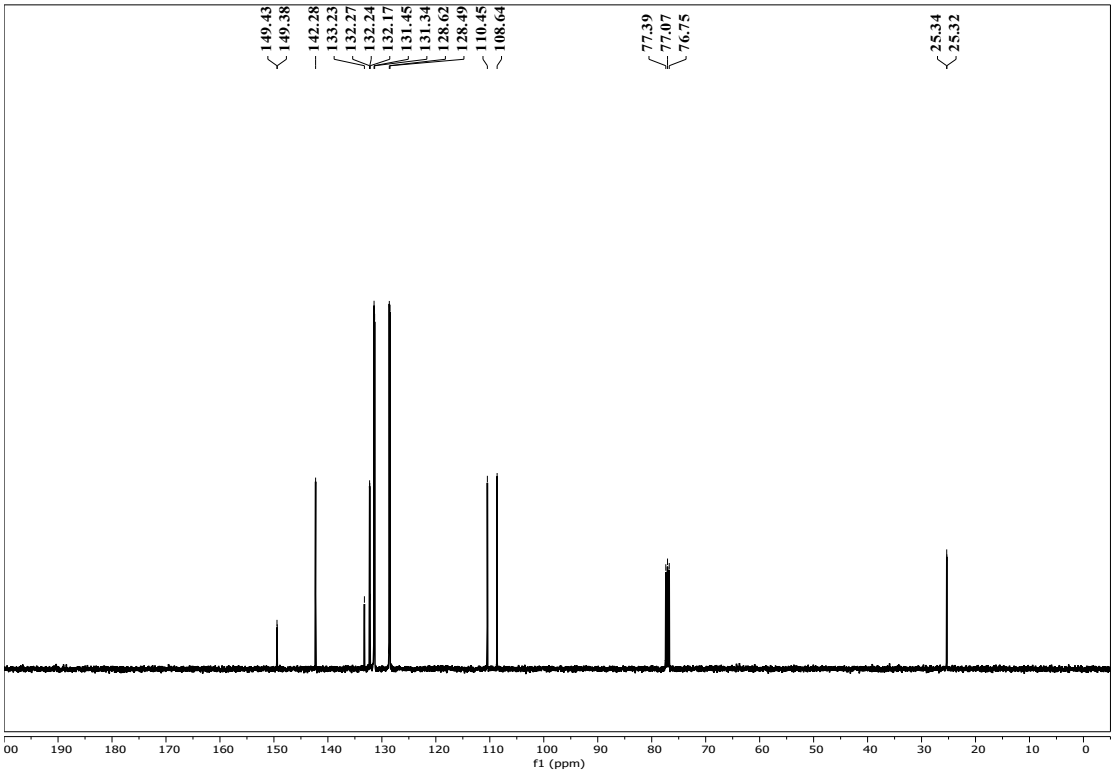




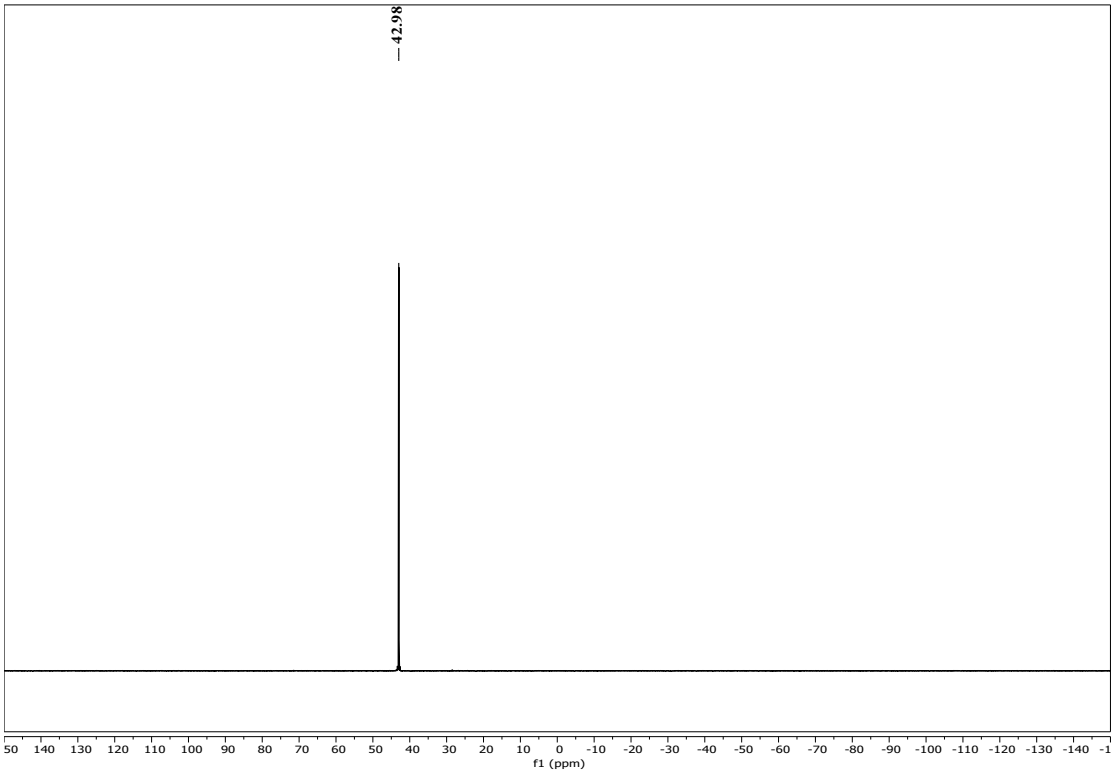
**3y,** $^{1}$H NMR (400 MHz), $CDCl_3$

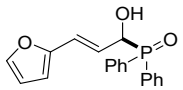



**3y**, $^{13}$C NMR (101 MHz), $CDCl_3$

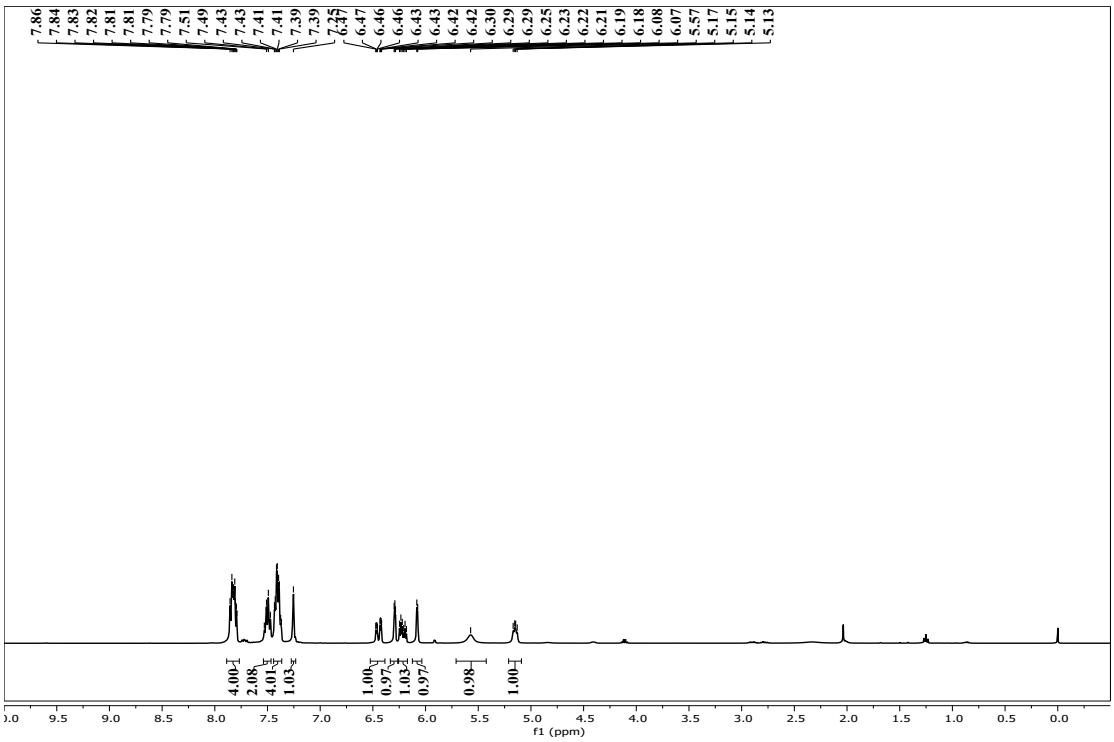


**3y**, $^{31}P$ NMR (162 MHz), $CDCl_3$

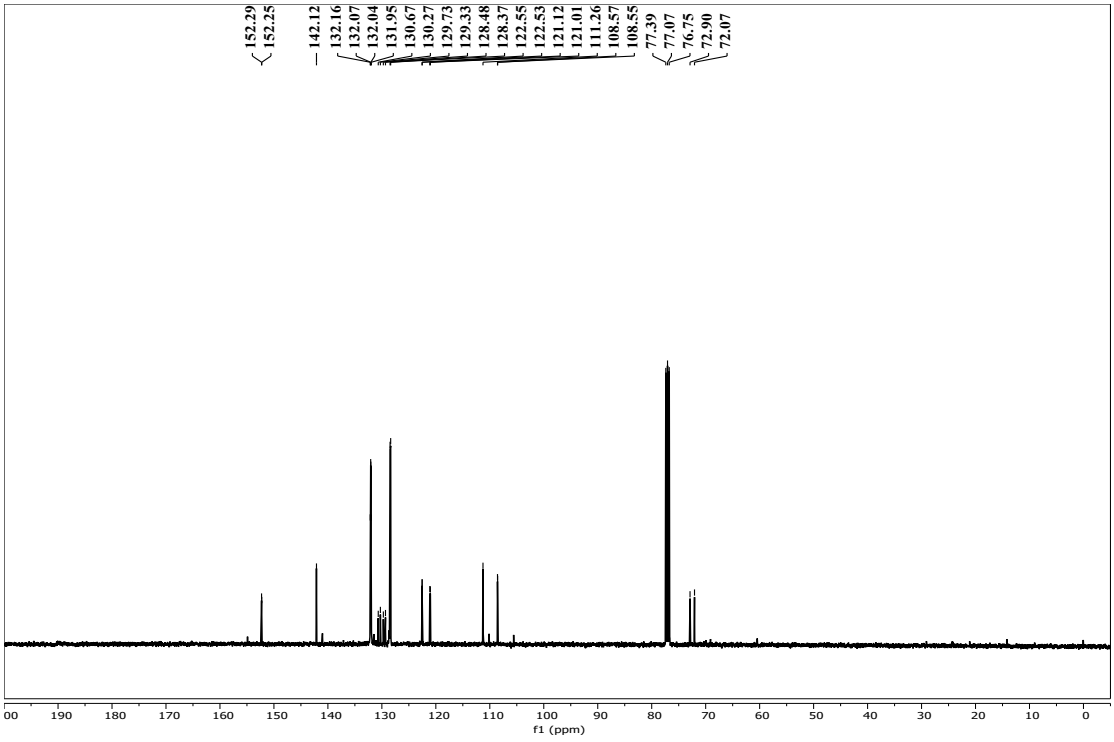




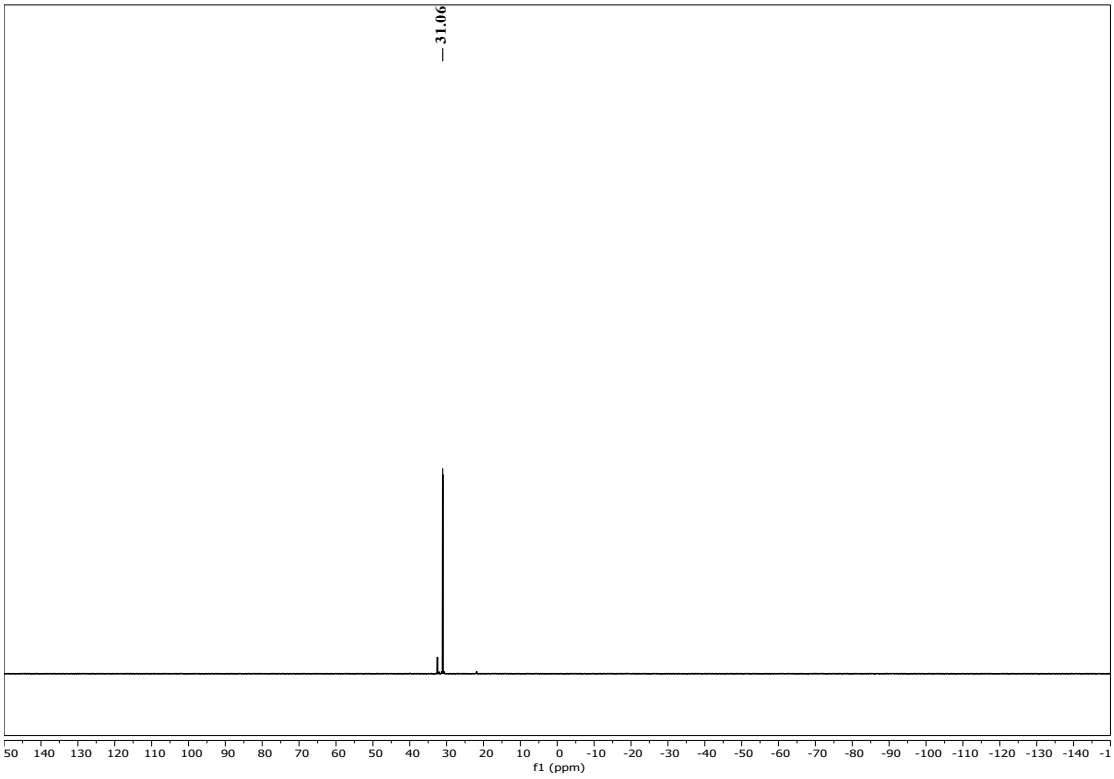
**3z,** $^{1}$H NMR (400 MHz), $CDCl_3$

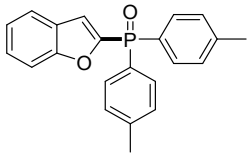



**3z**, $^{13}$C NMR (101 MHz), $CDCl_3$

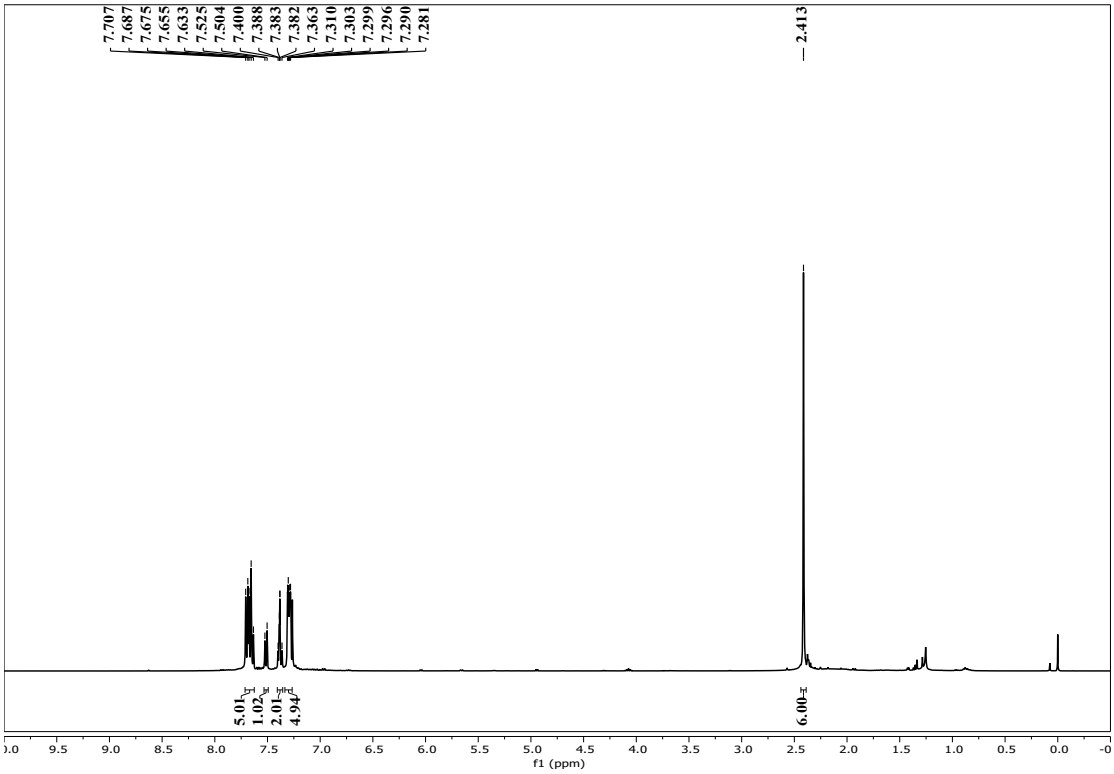


**3z**, $^{31}P$ NMR (162 MHz), $CDCl_3$

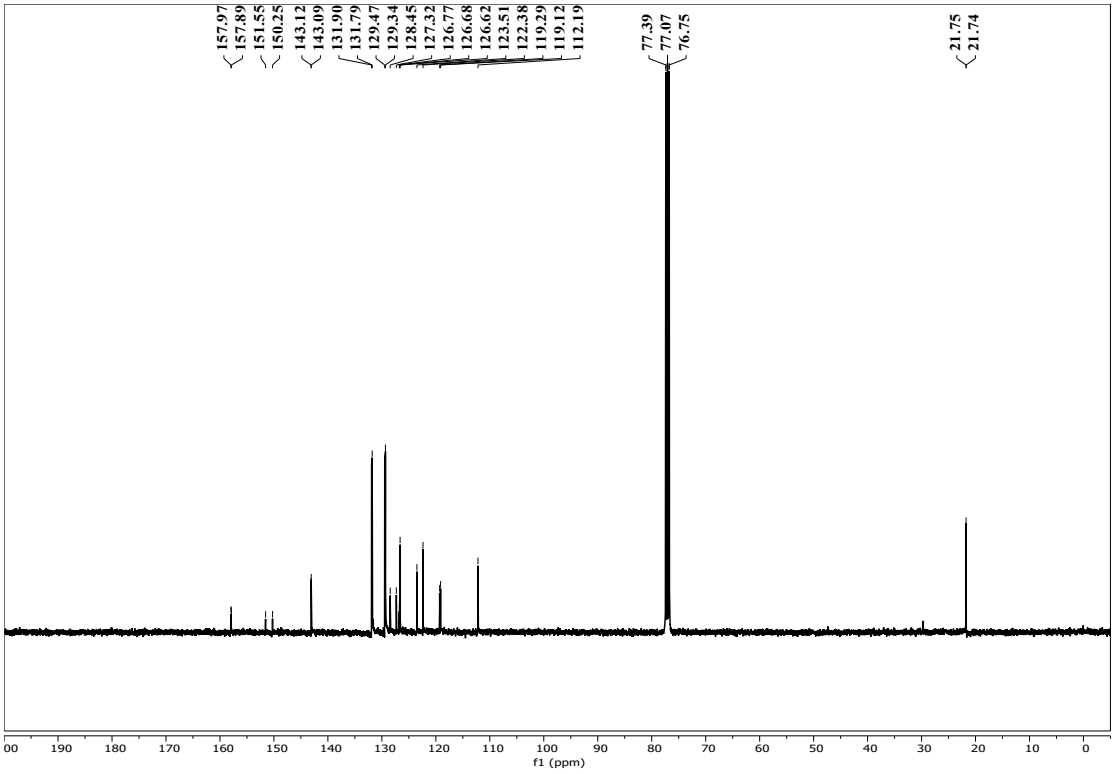




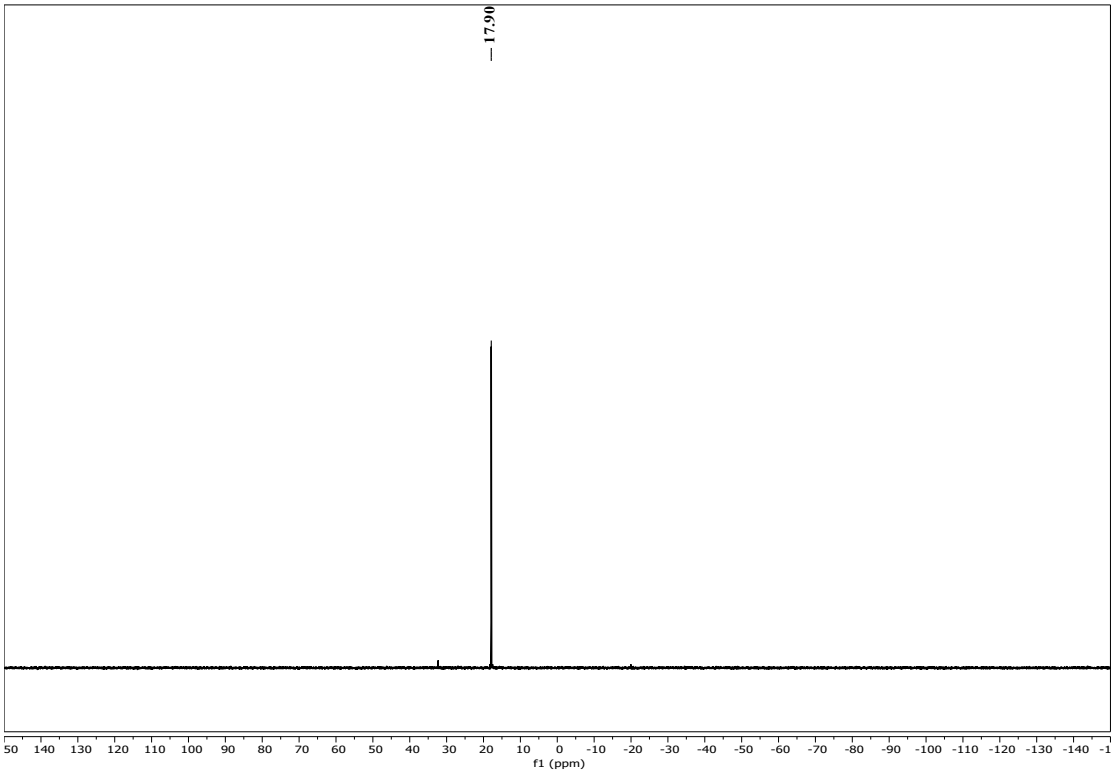
**4a,** $^{1}$H NMR (400 MHz), $CDCl_3$

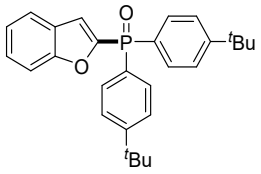



**4a**, $^{13}$C NMR (101 MHz), $CDCl_3$

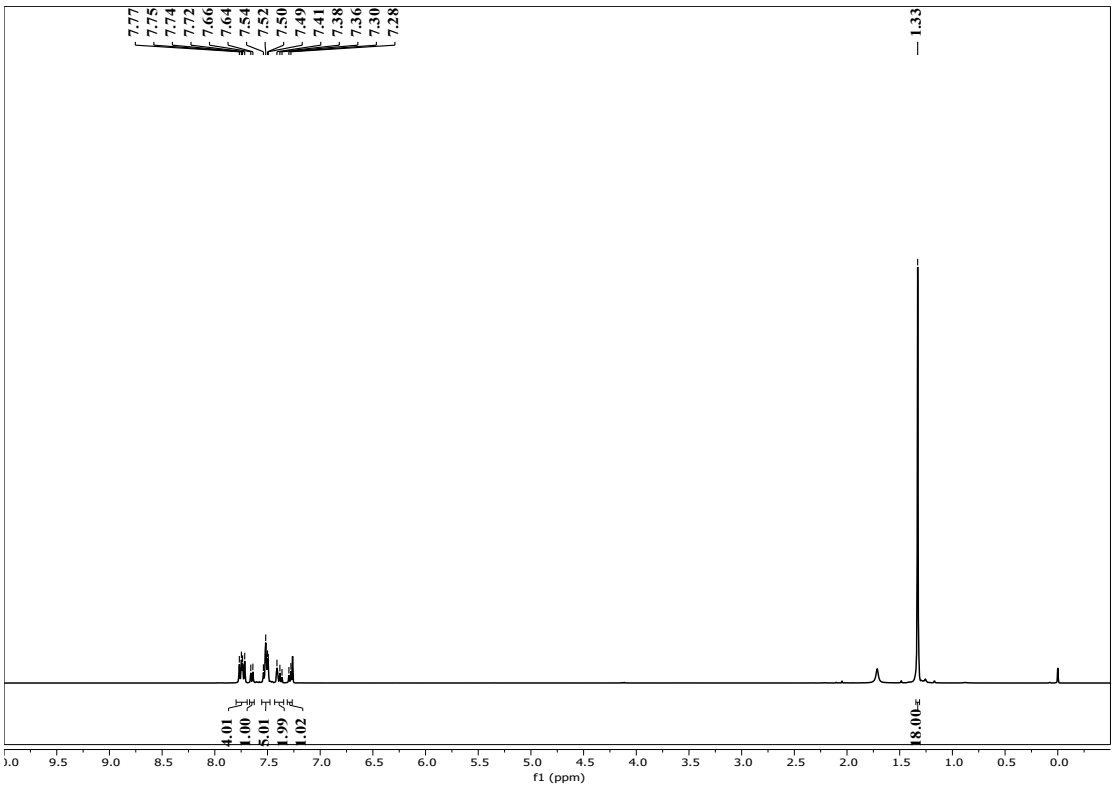


**4a**, $^{31}P$ NMR (162 MHz), $CDCl_3$

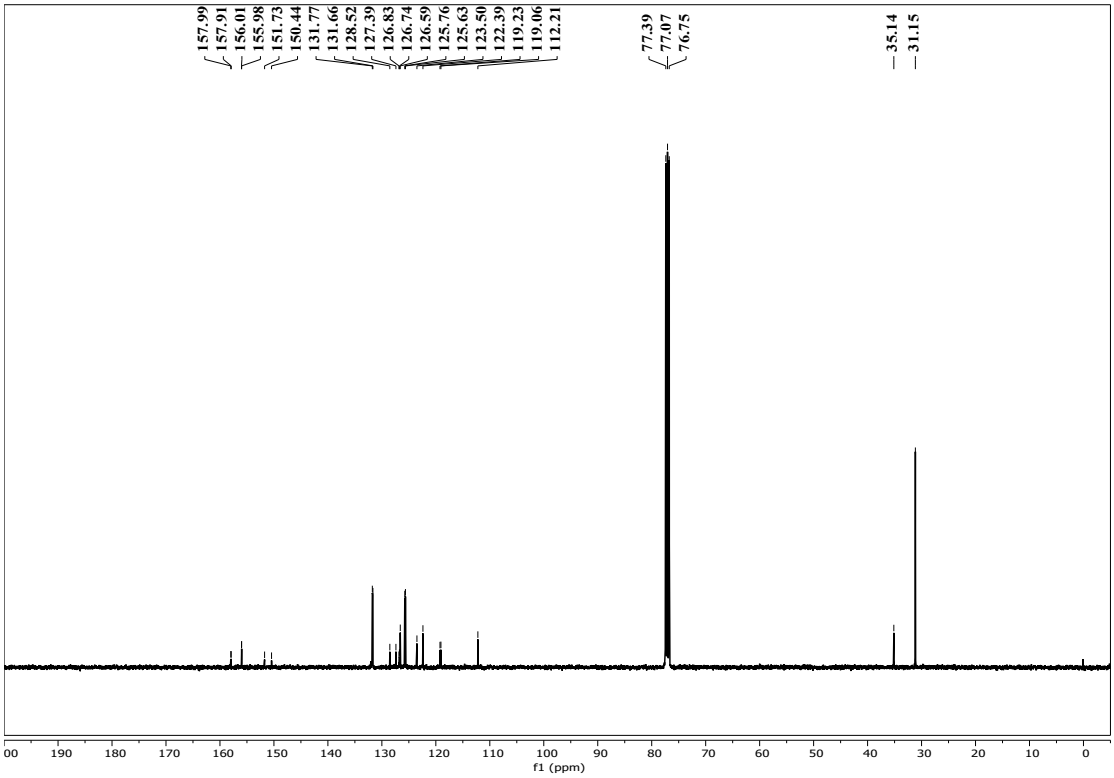




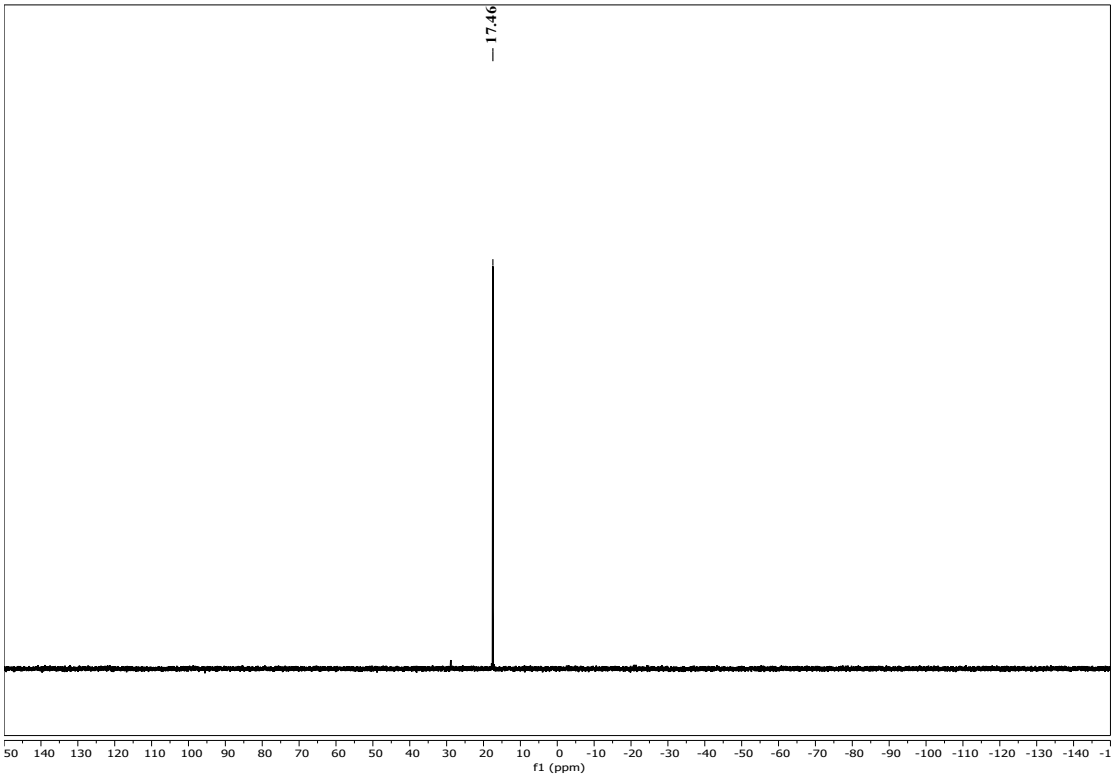
**4b,** $^{1}$H NMR (400 MHz), $CDCl_3$

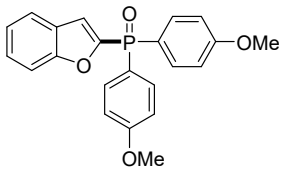



**4b**, $^{13}$C NMR (101 MHz), $CDCl_3$

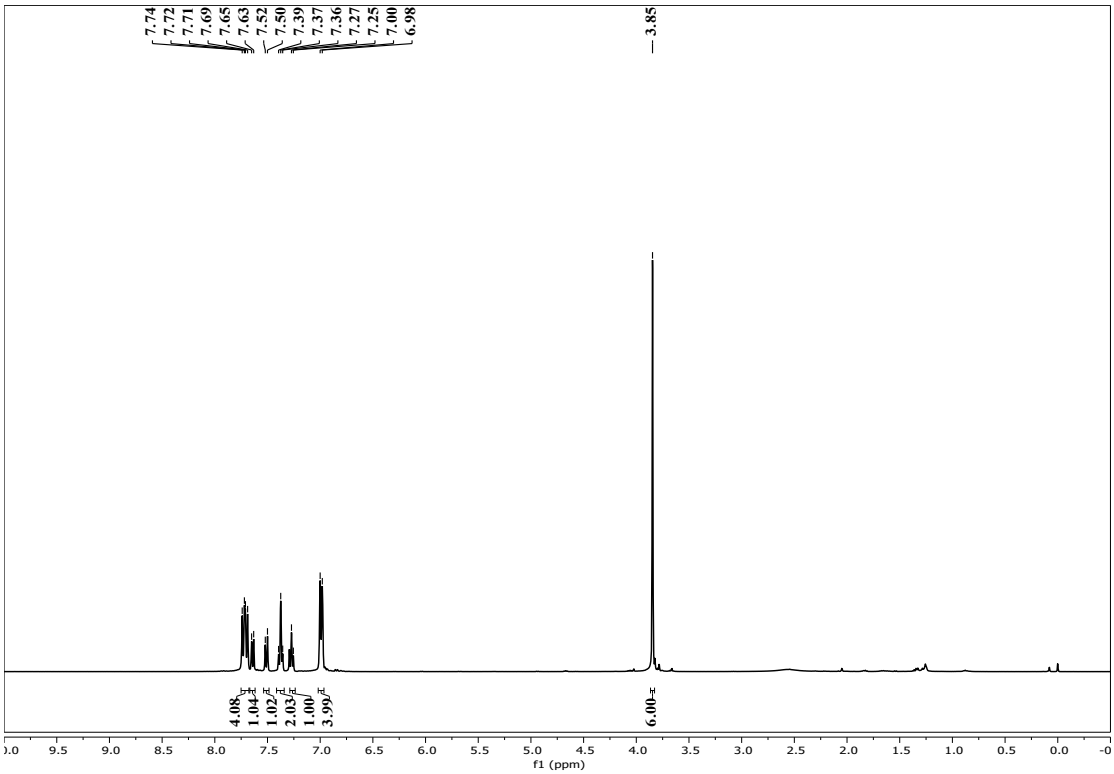


**4b**, $^{31}P$ NMR (162 MHz), $CDCl_3$

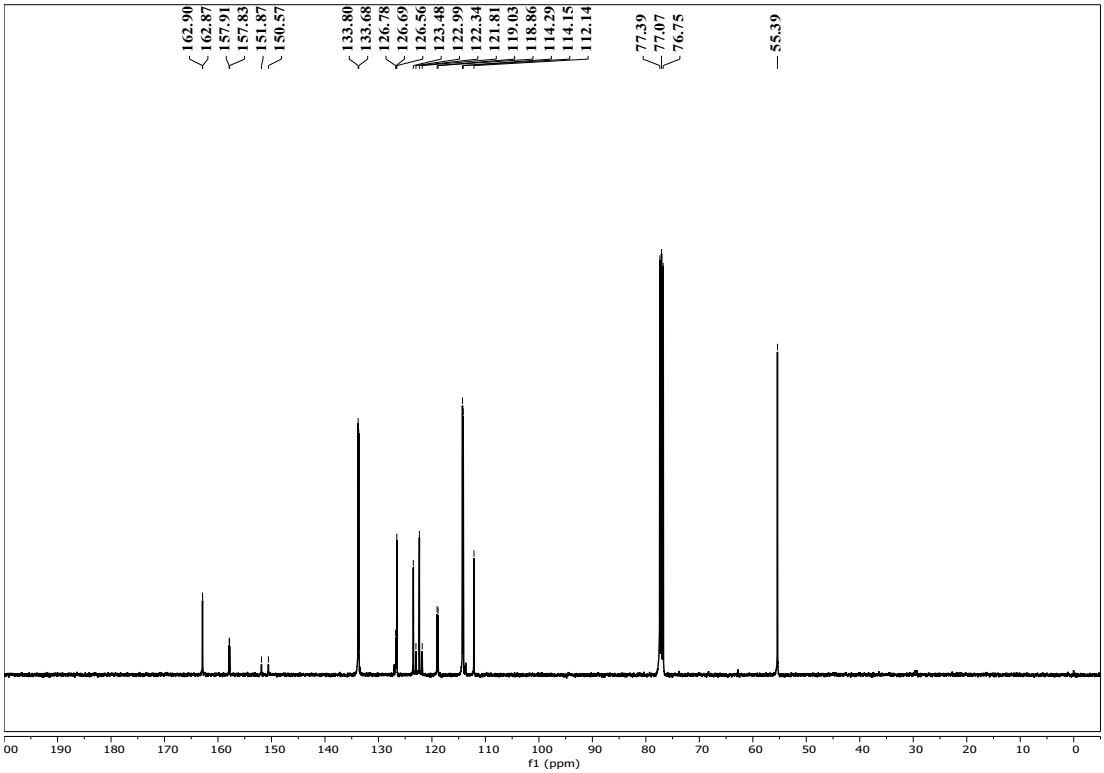




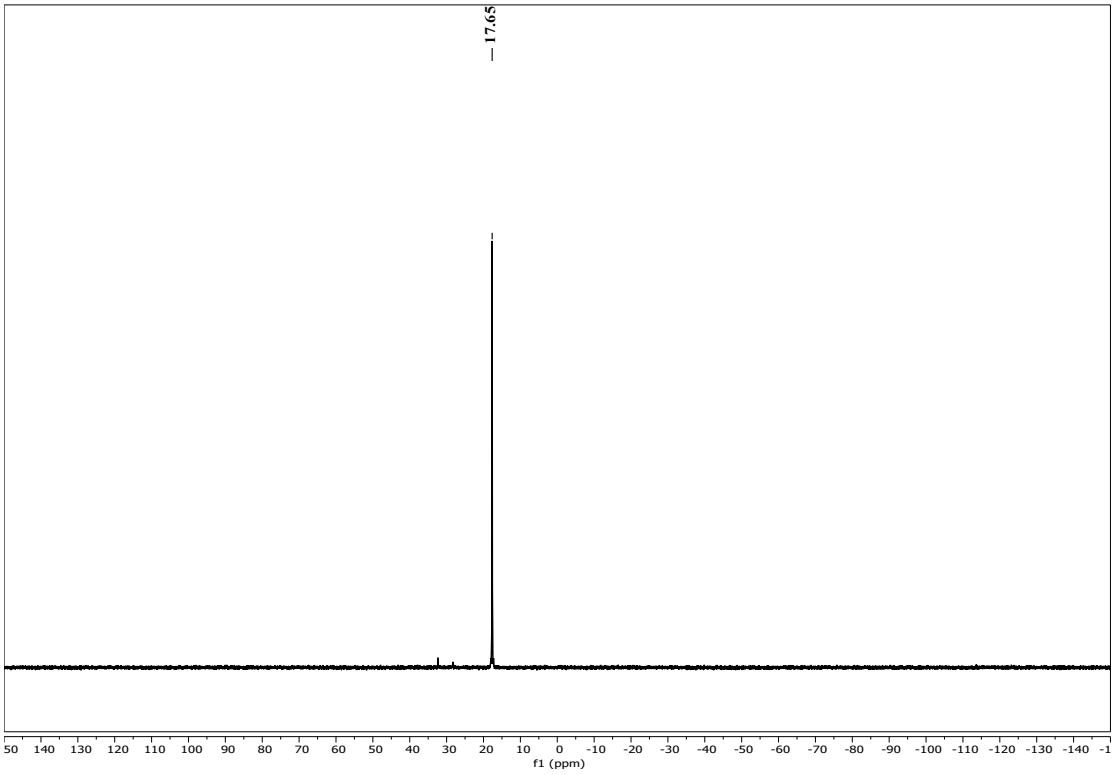

**4c,** $^{1}$H NMR (400 MHz), $CDCl_3$

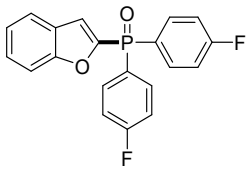



**4c**, $^{13}$C NMR (101 MHz), $CDCl_3$

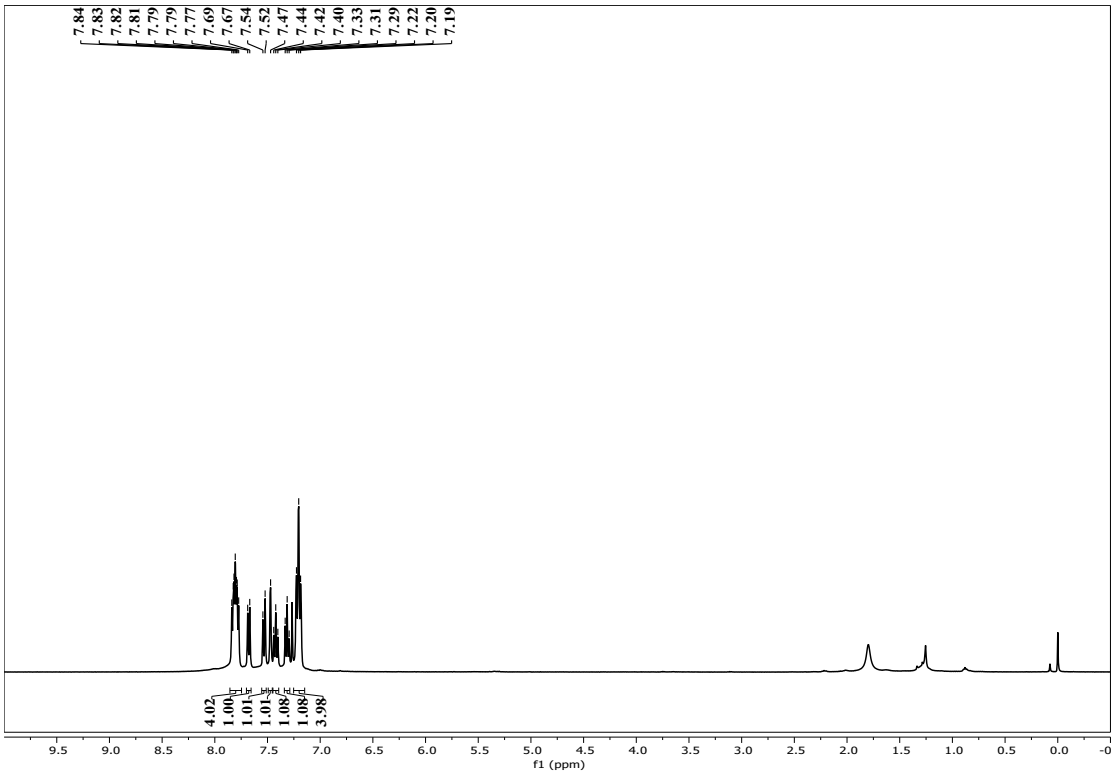


**4c**, $^{31}P$ NMR (162 MHz), $CDCl_3$

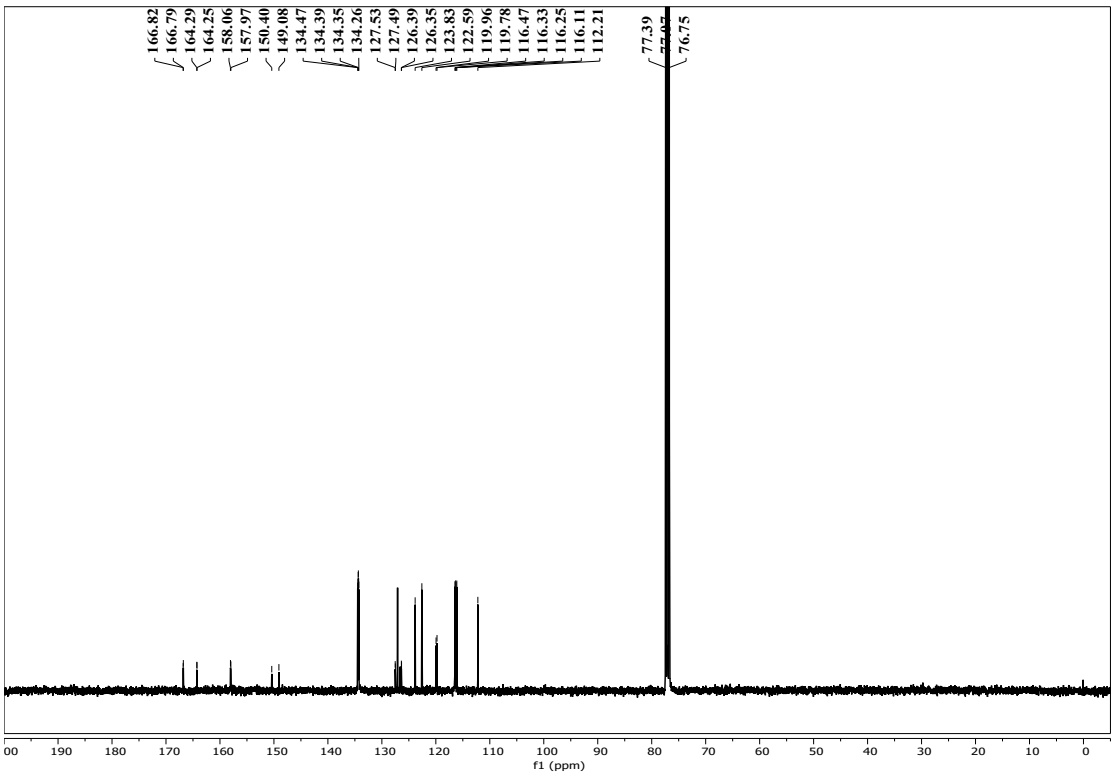




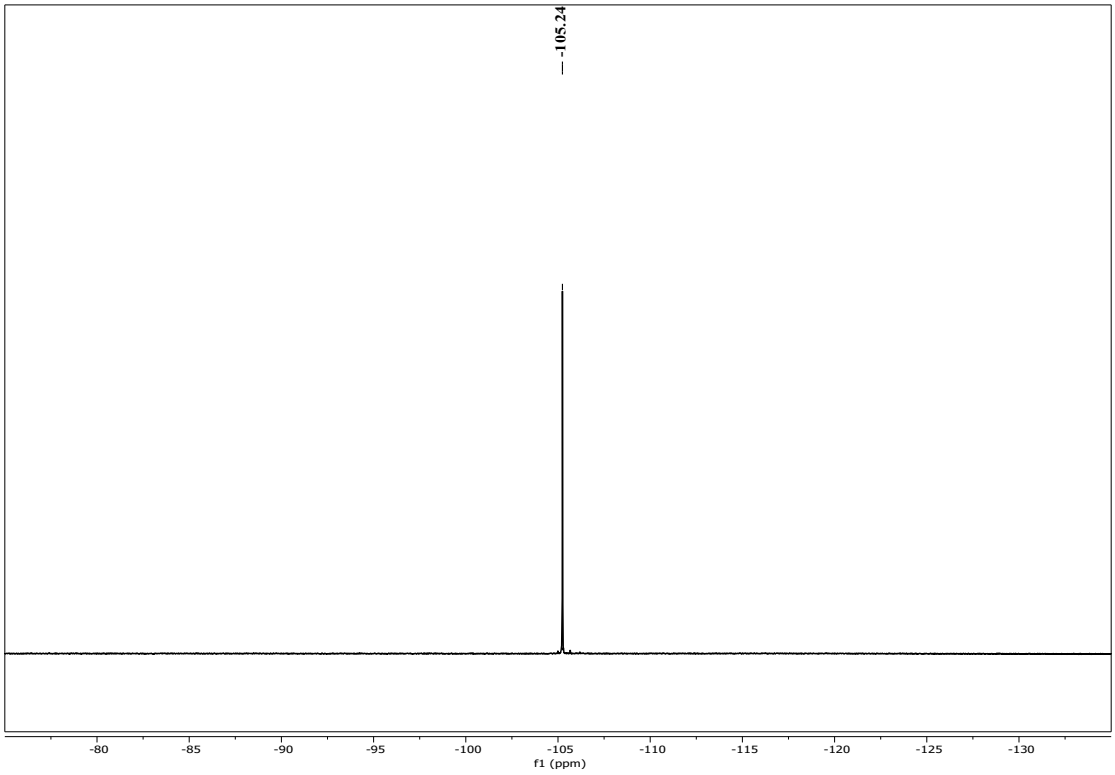

**4d,** $^{1}$H NMR (400 MHz), $CDCl_3$




**4d**, $^{13}$C NMR (101 MHz), $CDCl_3$

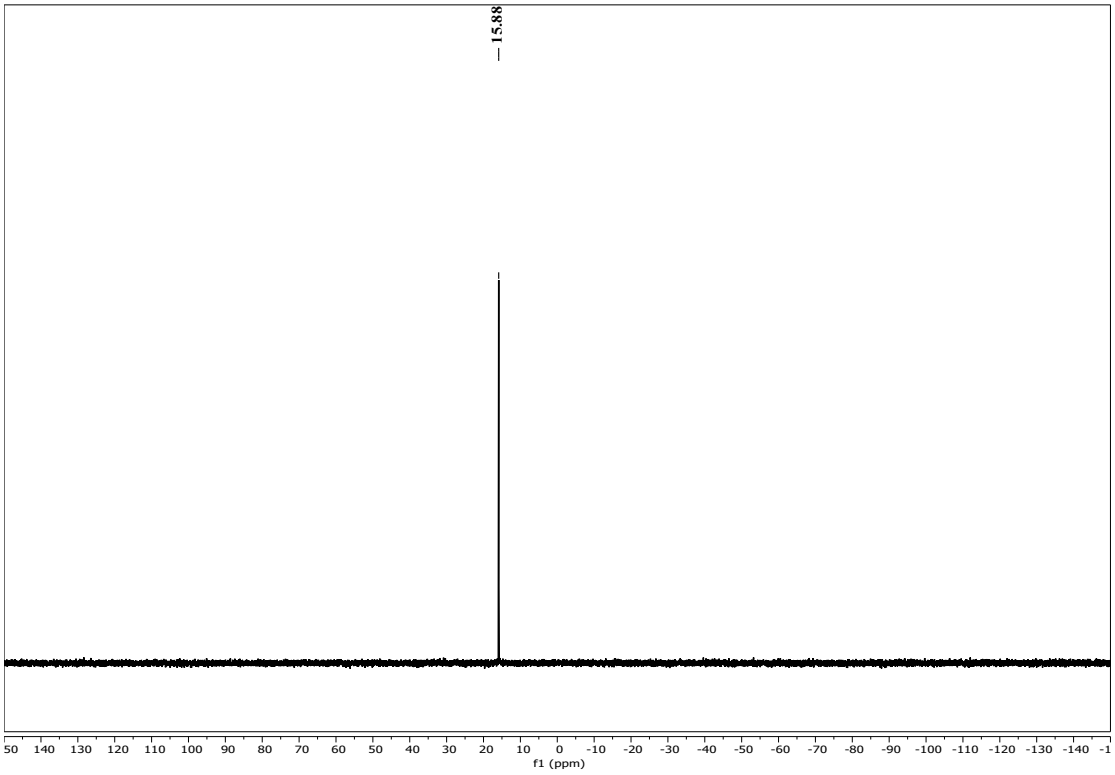


**4d**, $^{19}F$ NMR (376 MHz), $CDCl_3$

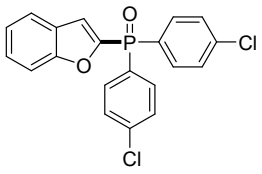



$^{19}F$ NMR spectra

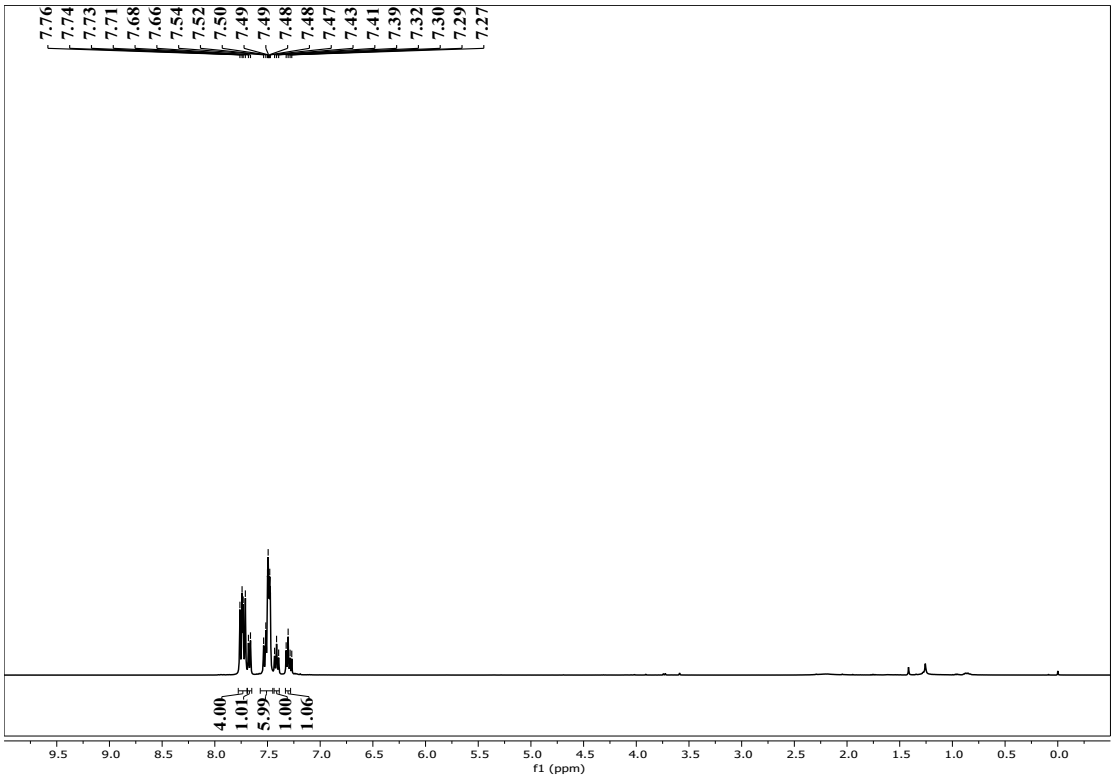
**4d**, $^{31}P$ NMR (162 MHz), $CDCl_3$



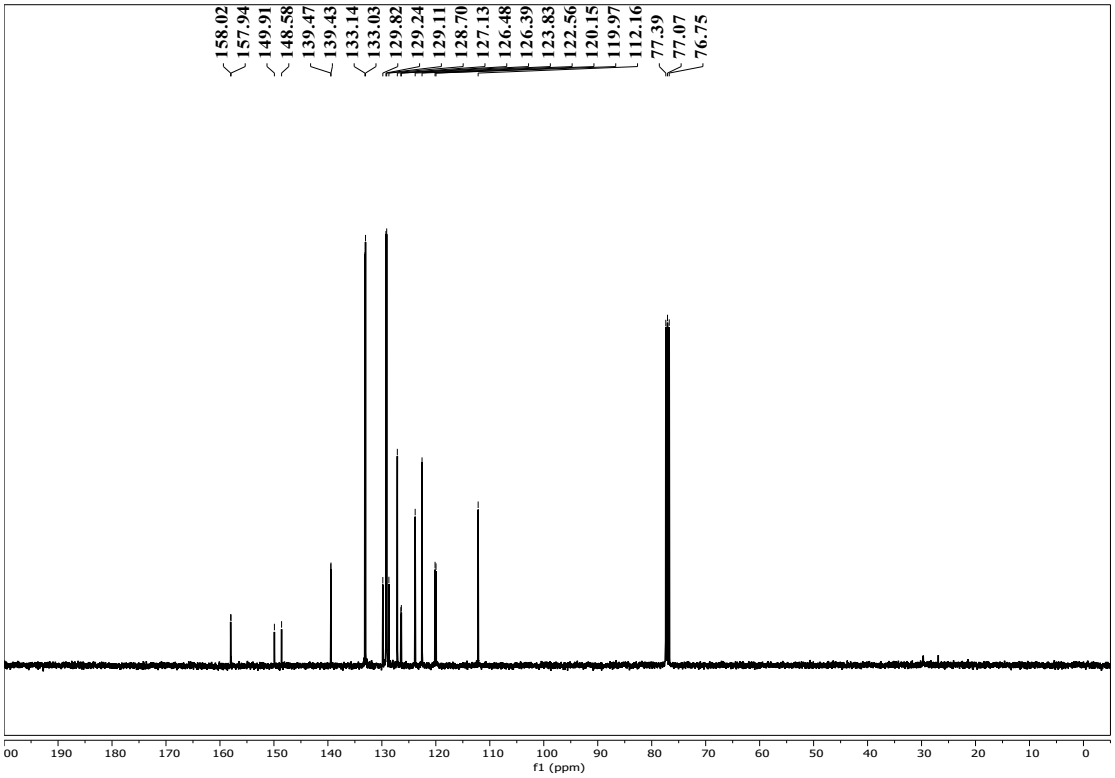

$^{31}P$ NMR spectra



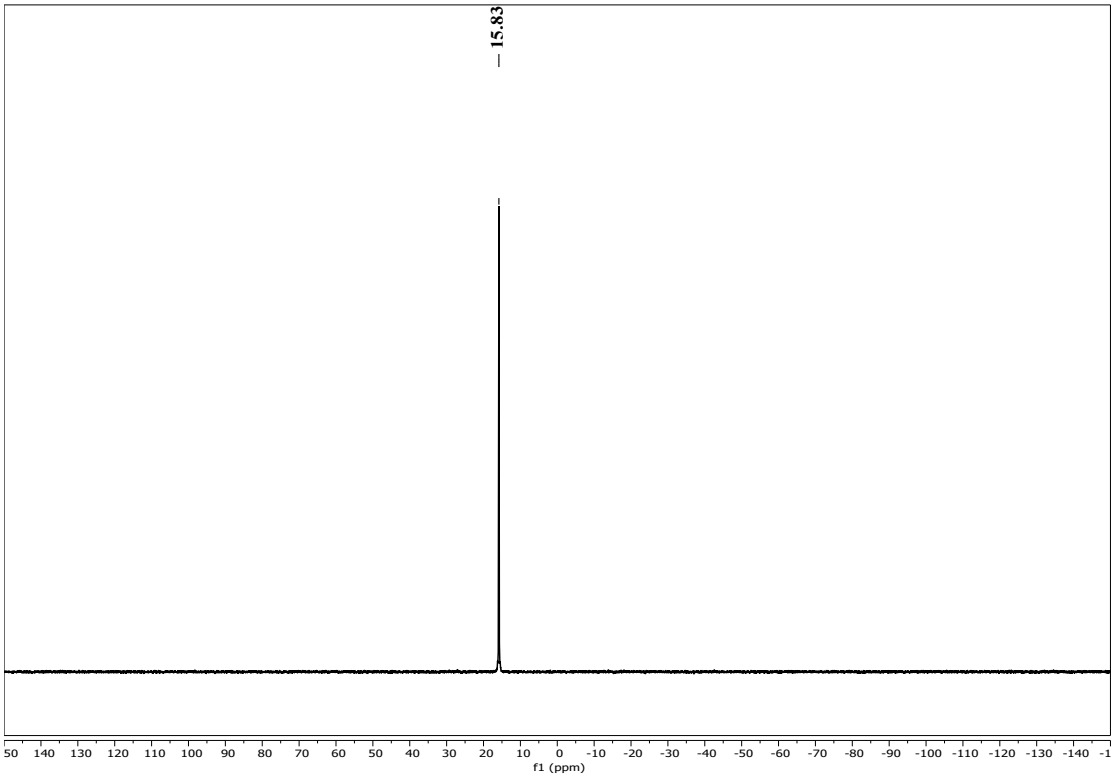

**4e,** $^{1}$H NMR (400 MHz), $CDCl_3$

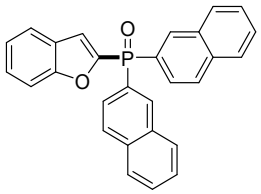



**4e**, $^{13}$C NMR (101 MHz), $CDCl_3$

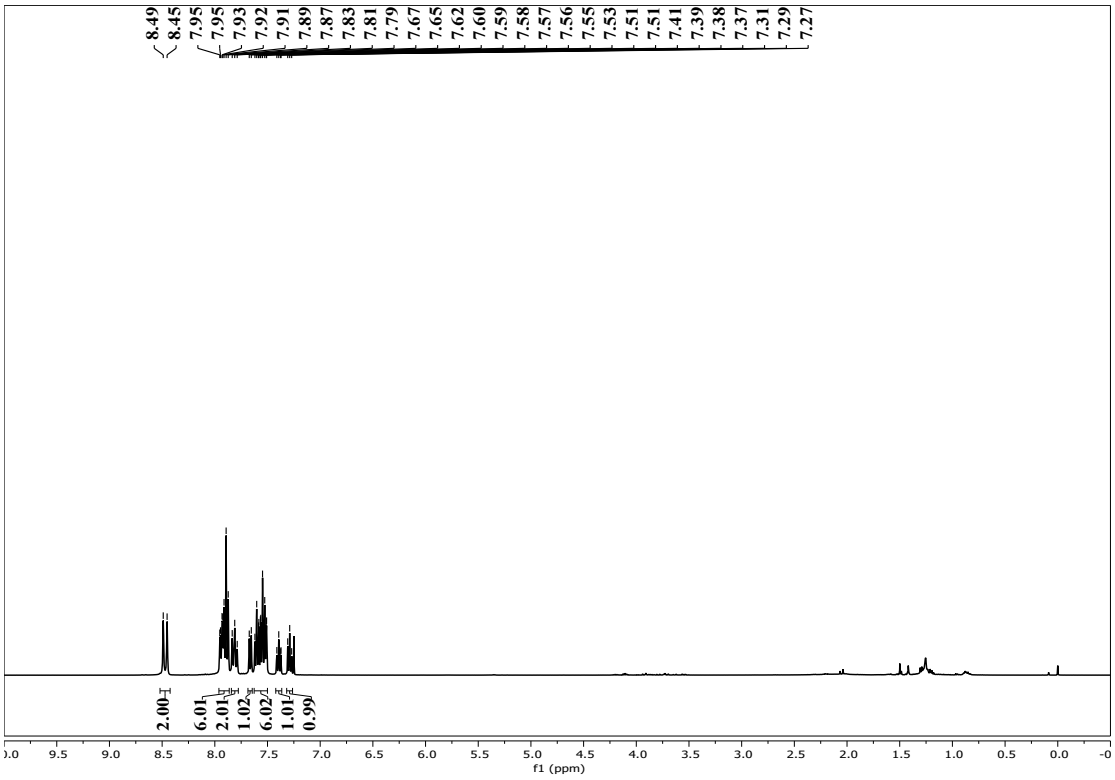


**4e**, $^{31}P$ NMR (162 MHz), $CDCl_3$

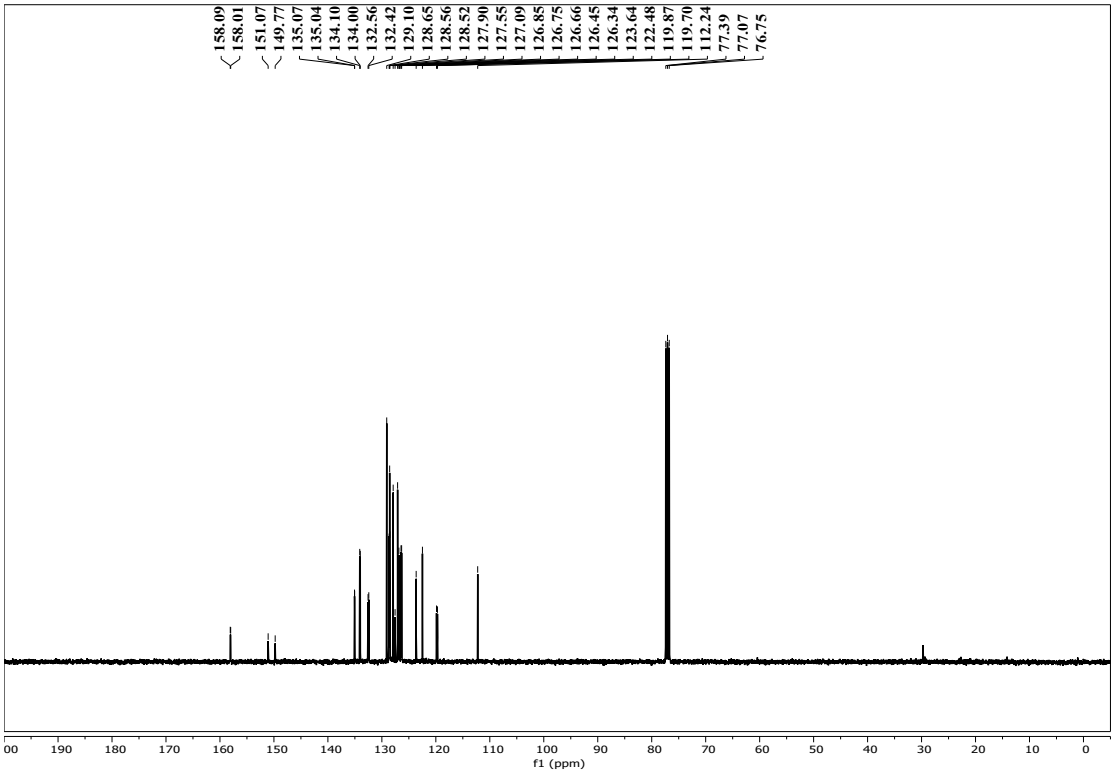




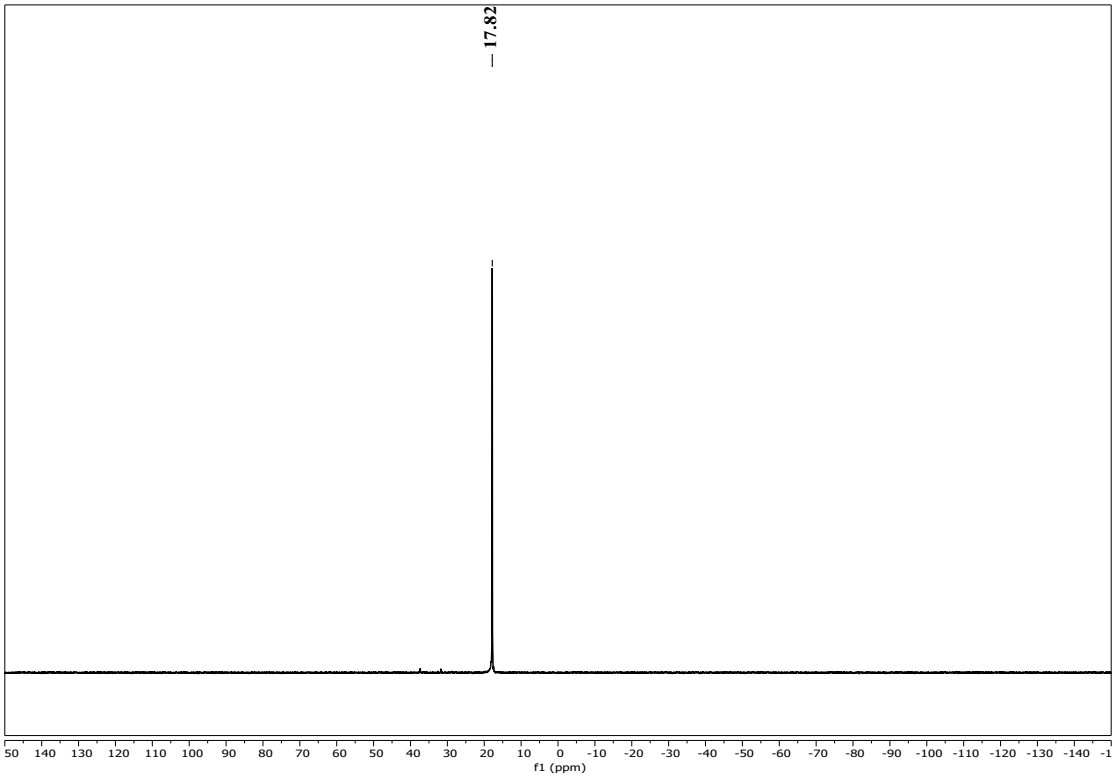
**4f,** $^{1}$H NMR (400 MHz), $CDCl_3$

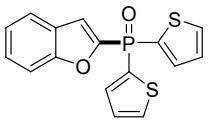



**4f**, $^{13}$C NMR (101 MHz), $CDCl_3$

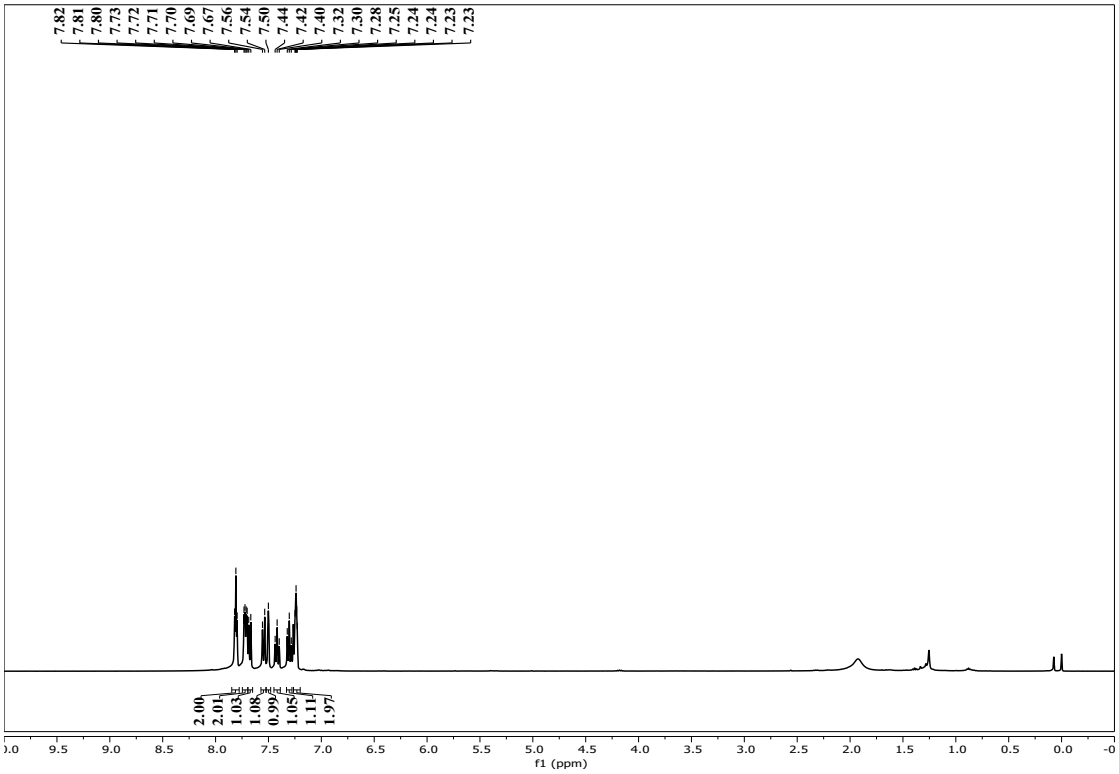


**4f**, $^{31}P$ NMR (162 MHz), $CDCl_3$

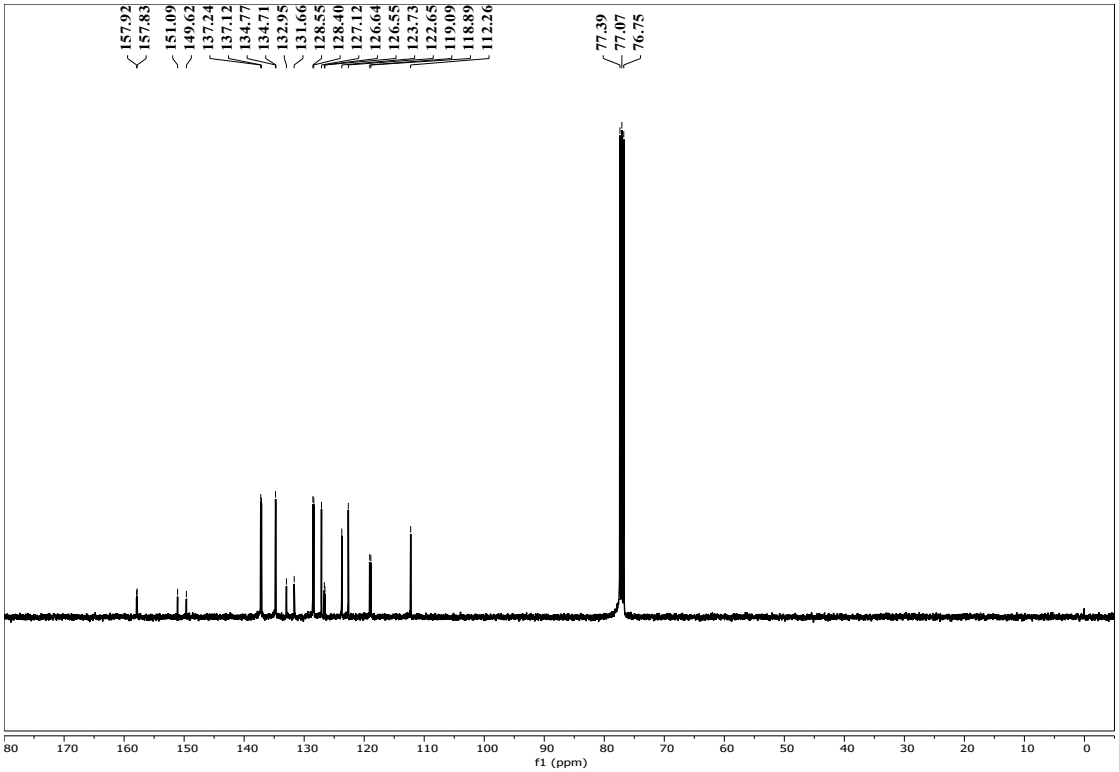




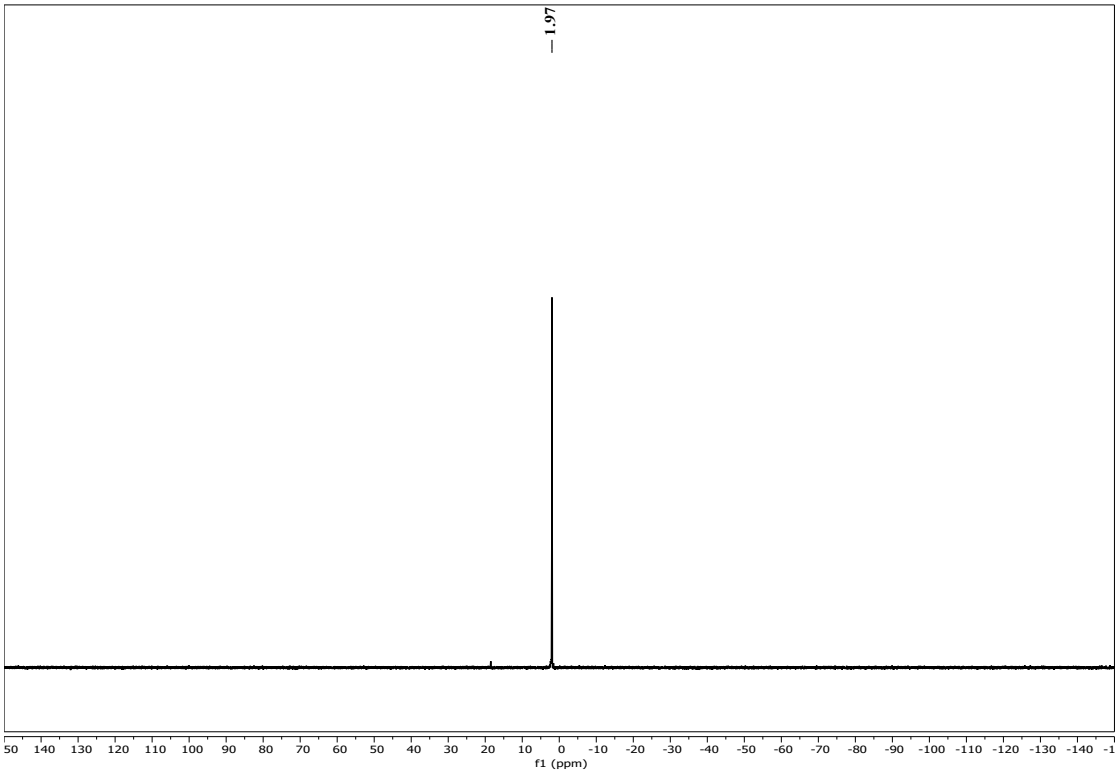
**4g,** $^{1}$H NMR (400 MHz), $CDCl_3$

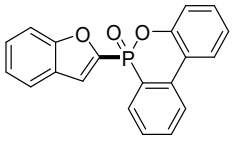



**4g**, $^{13}$C NMR (101 MHz), $CDCl_3$

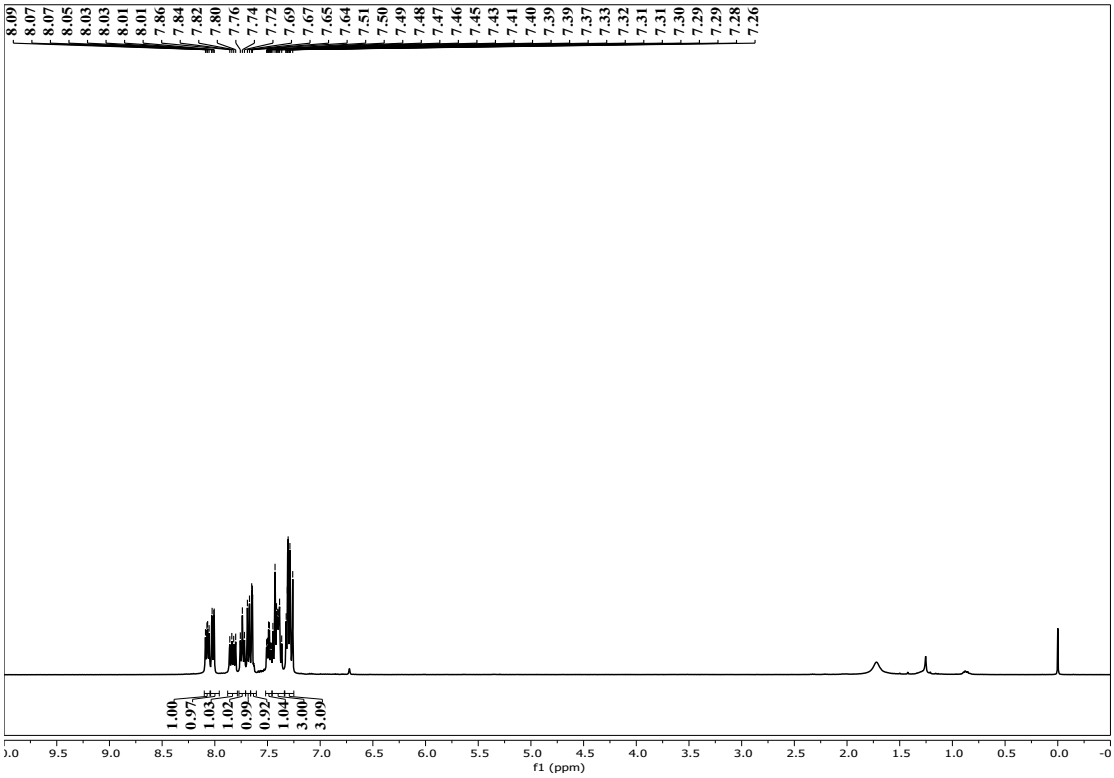


**4g**, $^{31}P$ NMR (162 MHz), $CDCl_3$

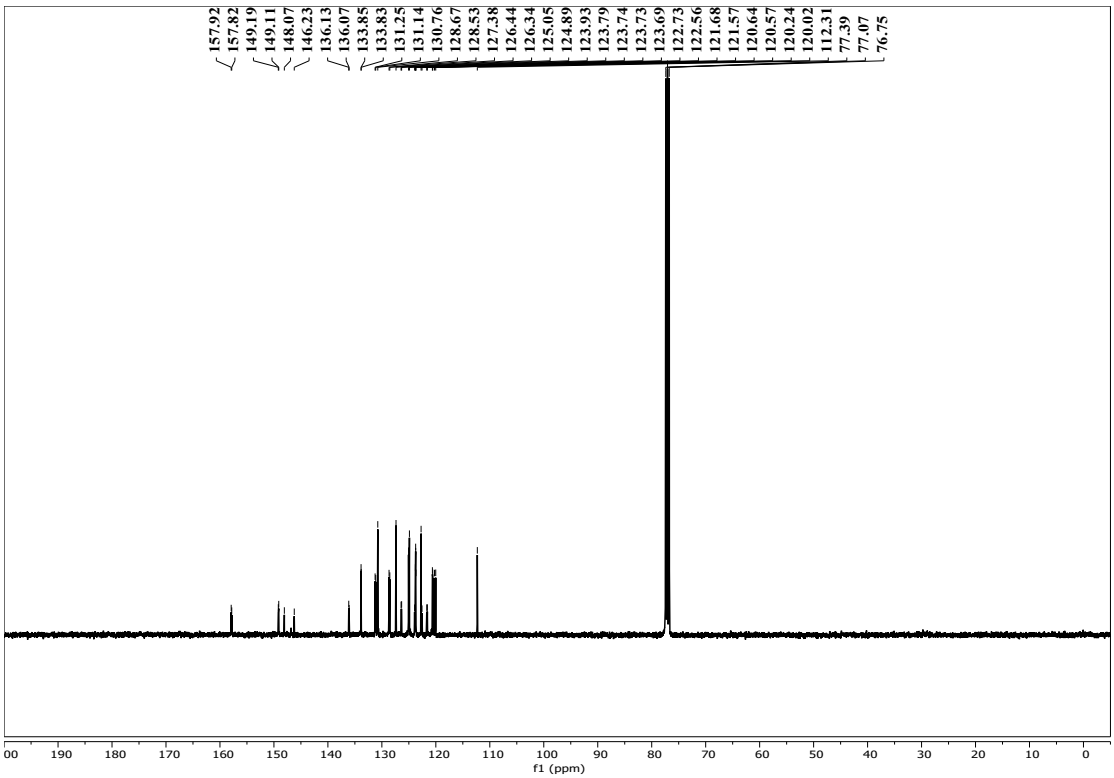




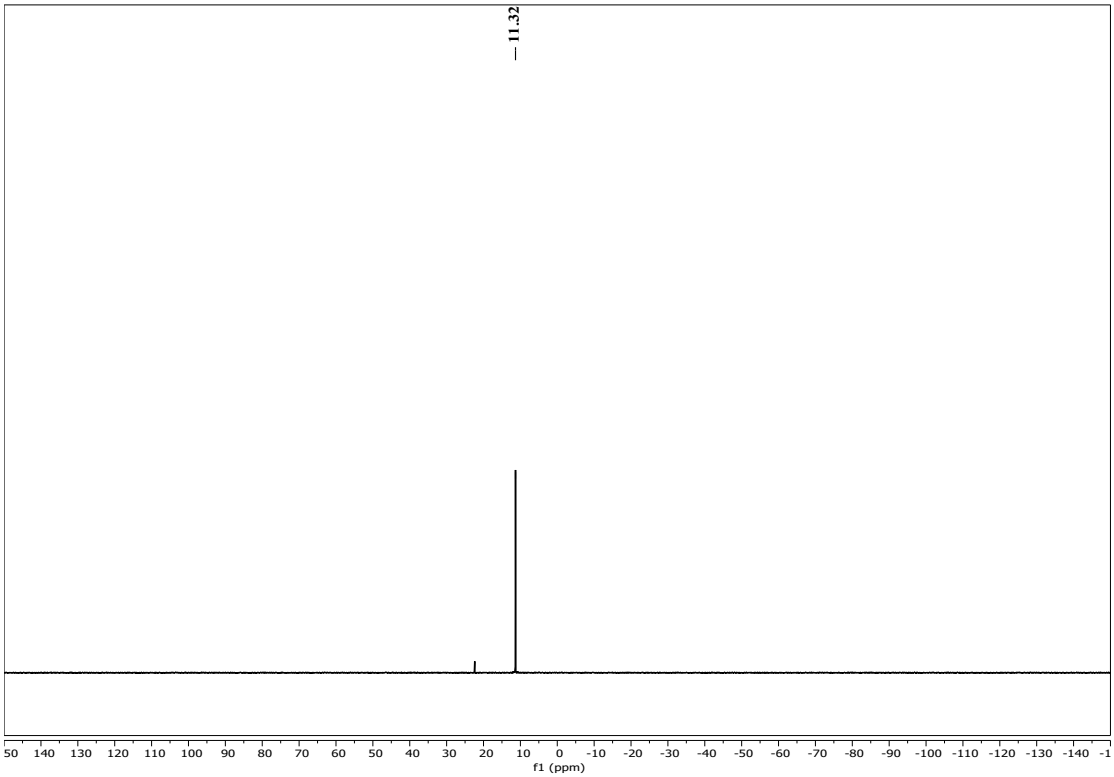
**4h,** $^{1}$H NMR (400 MHz), $CDCl_3$

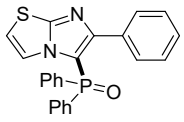



**4h**, $^{13}$C NMR (101 MHz), $CDCl_3$

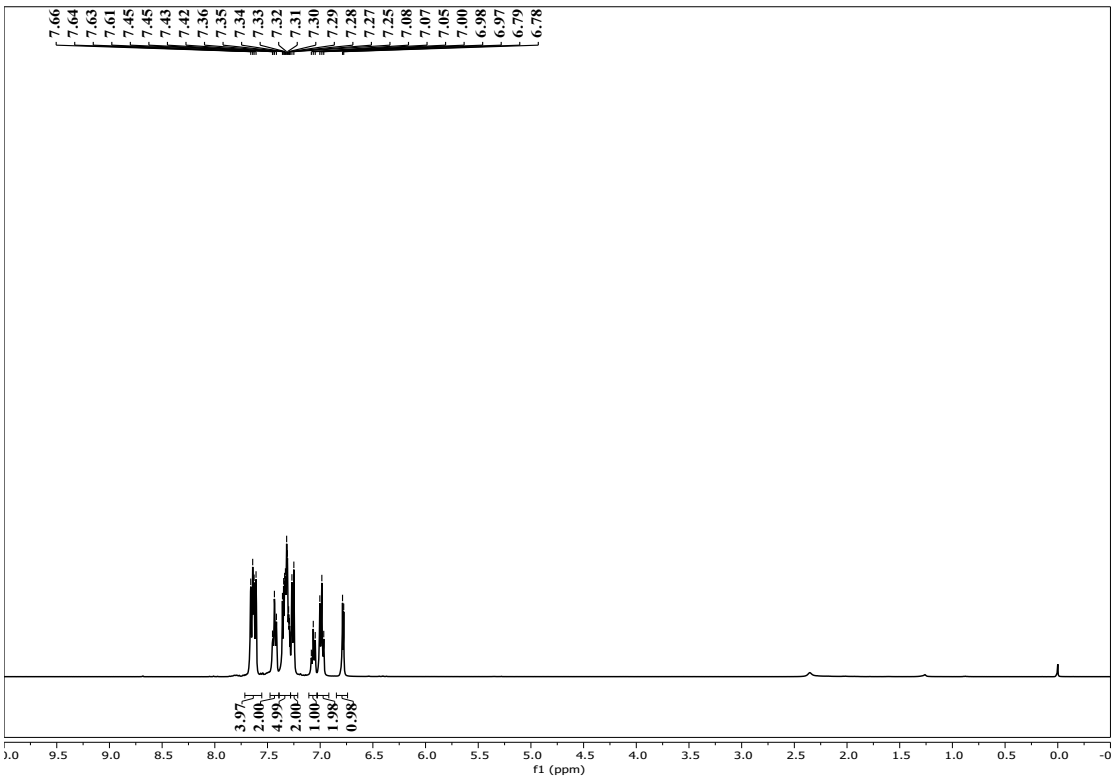


**4h**, $^{31}P$ NMR (162 MHz), $CDCl_3$

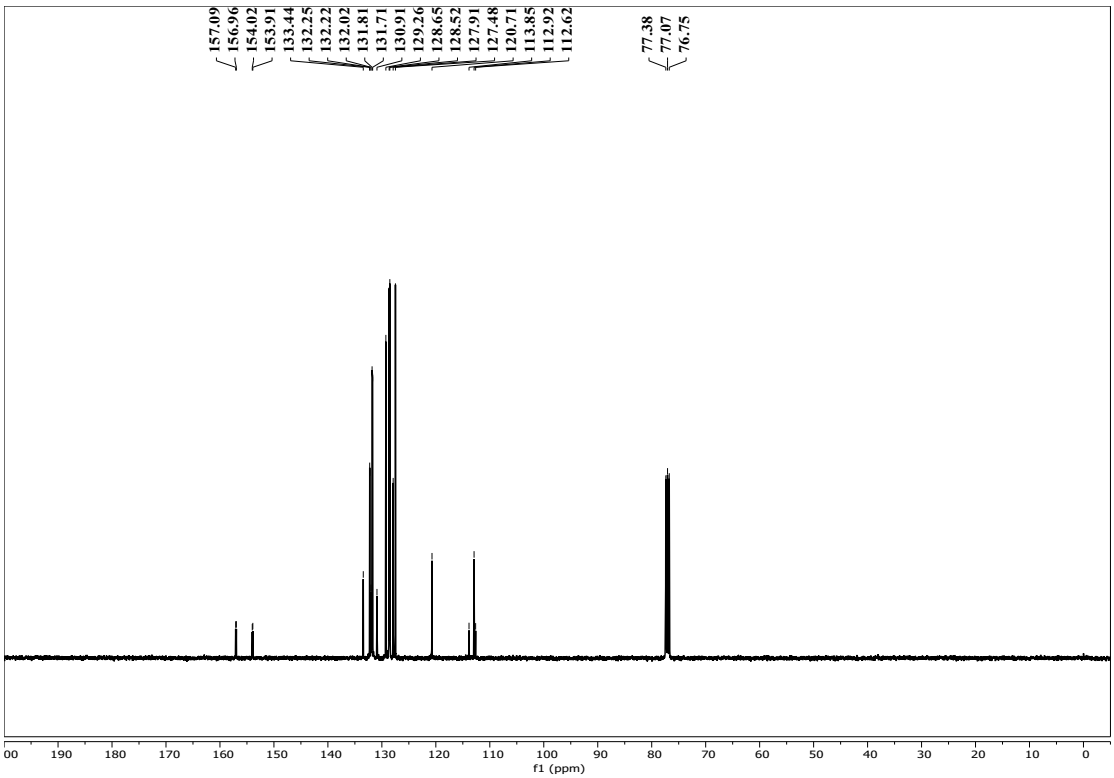




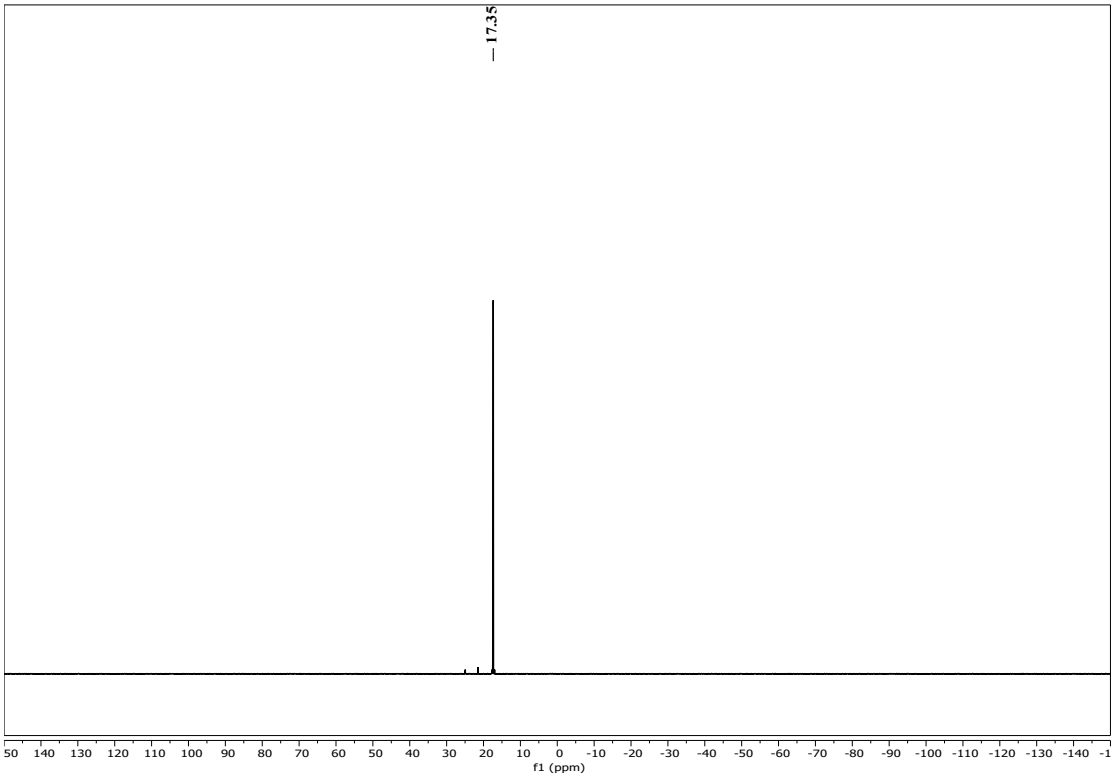
**6a,** $^{1}$H NMR (400 MHz), $CDCl_3$

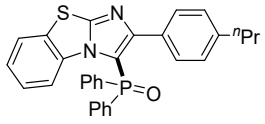



**6a**, $^{13}$C NMR (101 MHz), $CDCl_3$

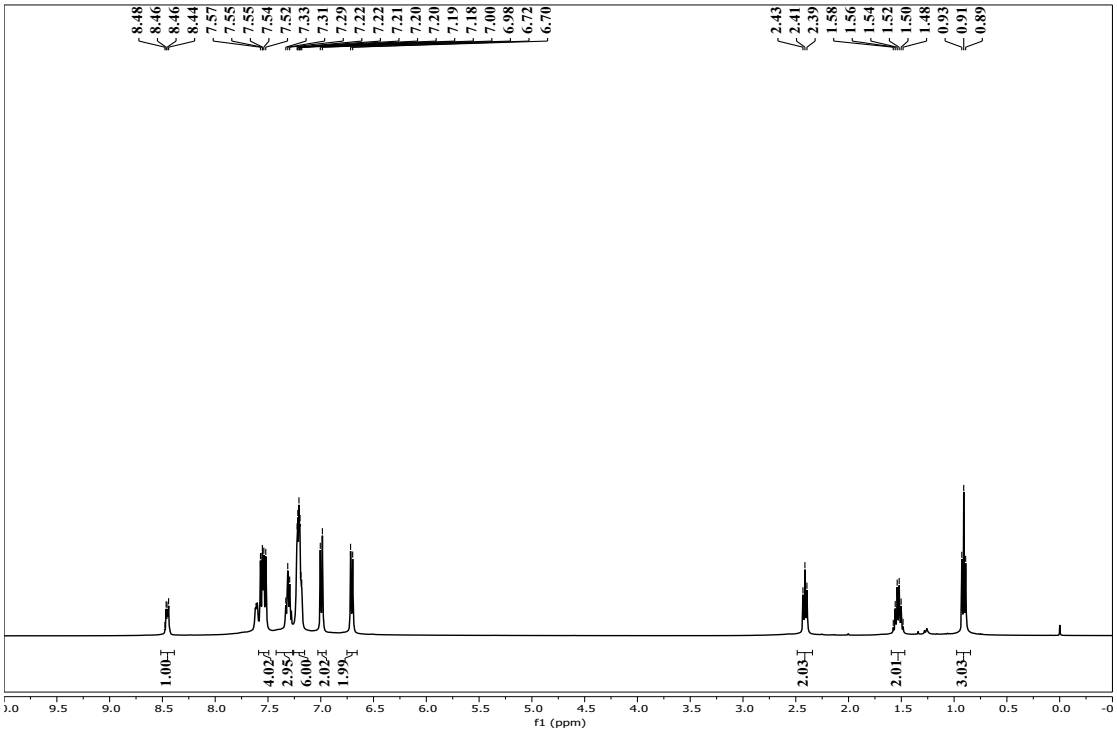


**6a**, $^{31}P$ NMR (162 MHz), $CDCl_3$

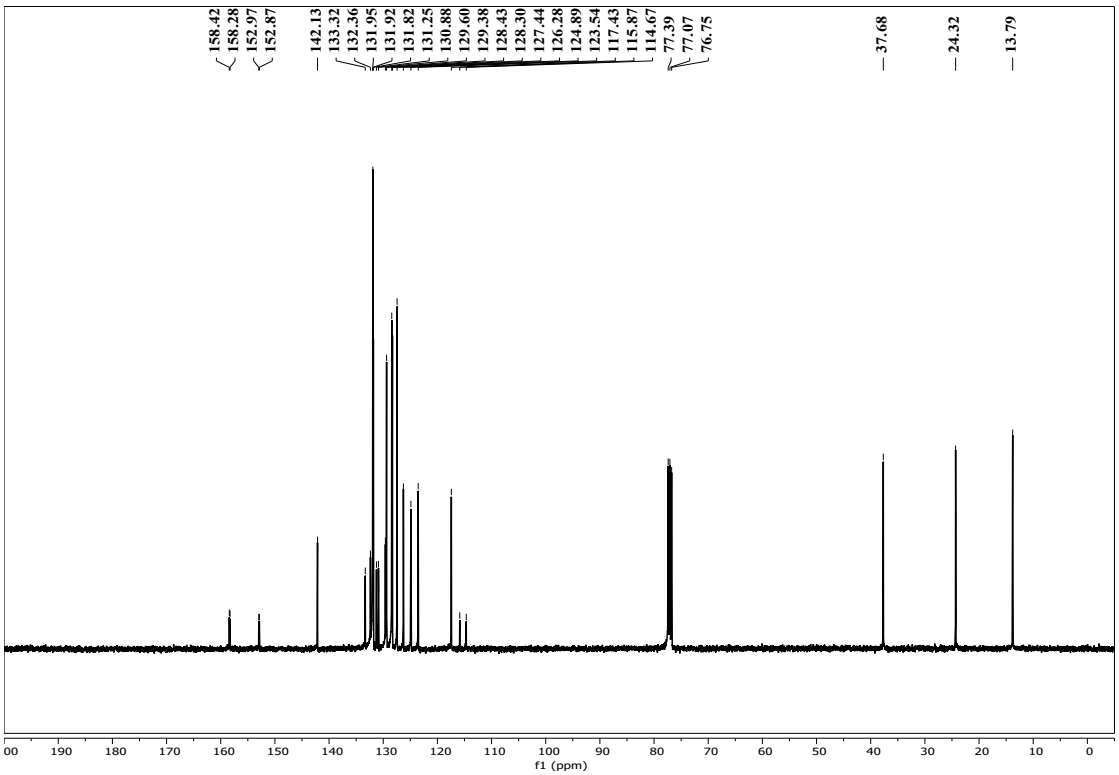




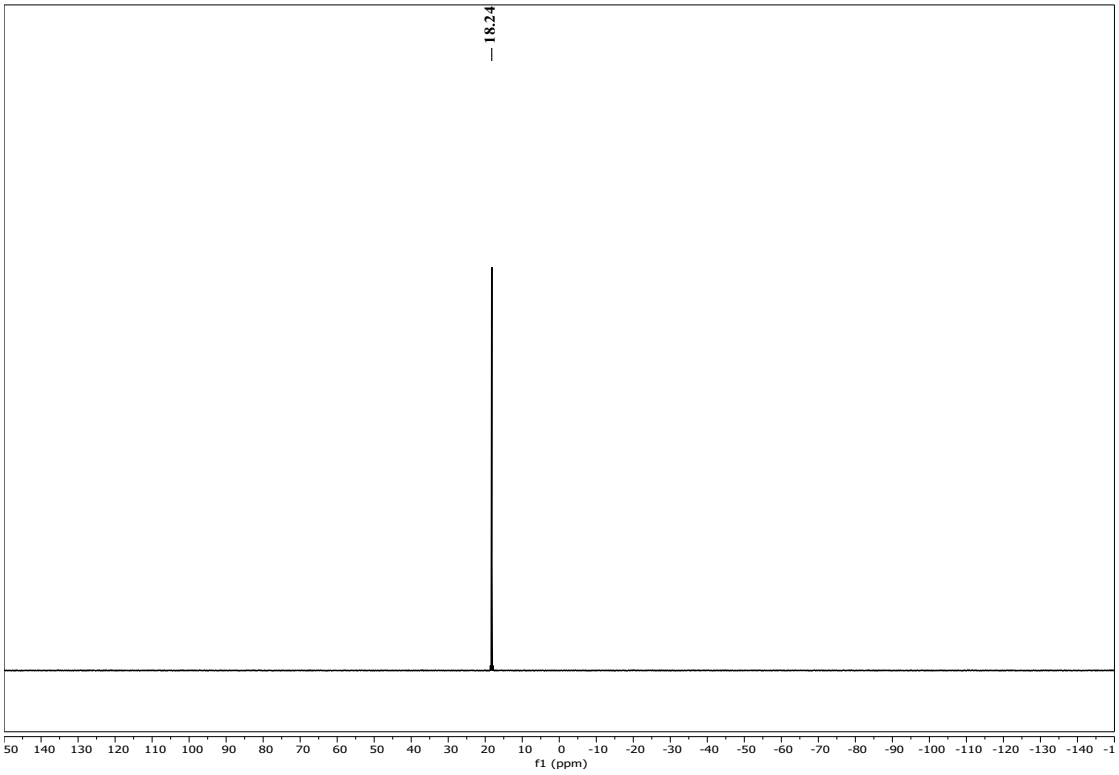
**6b,** $^{1}$H NMR (400 MHz), $CDCl_3$

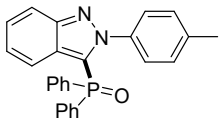



**6b**, $^{13}$C NMR (101 MHz), $CDCl_3$

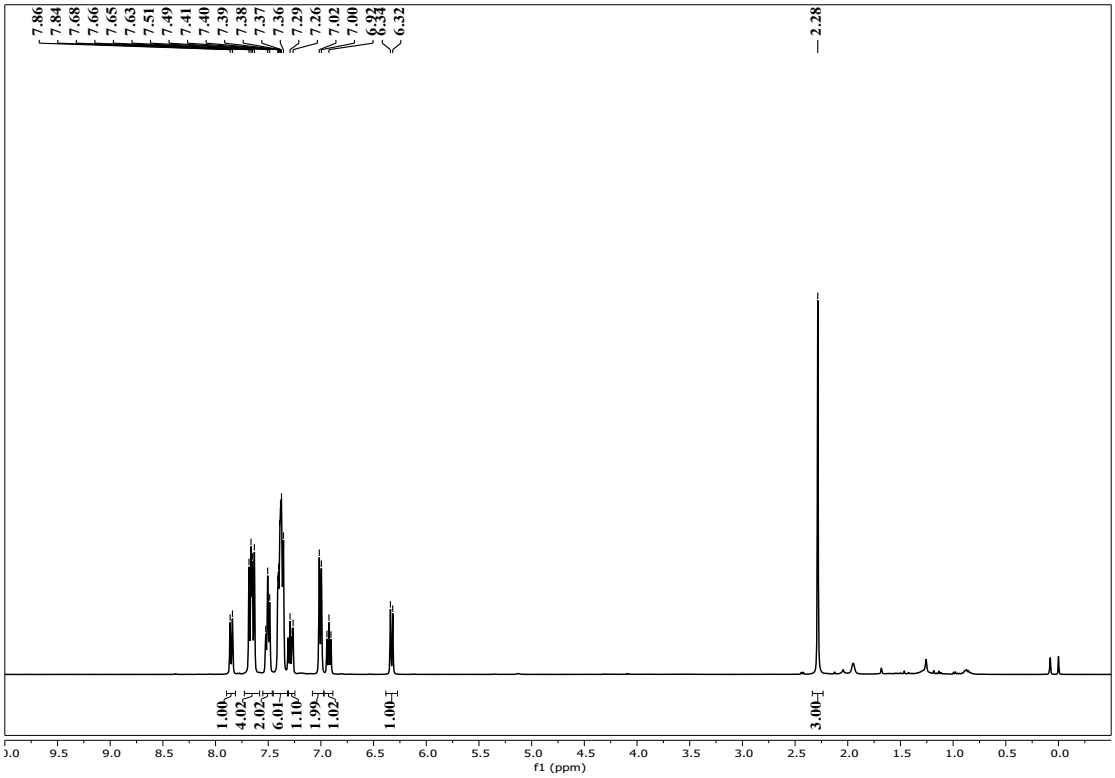


**6b**, $^{31}P$ NMR (162 MHz), $CDCl_3$

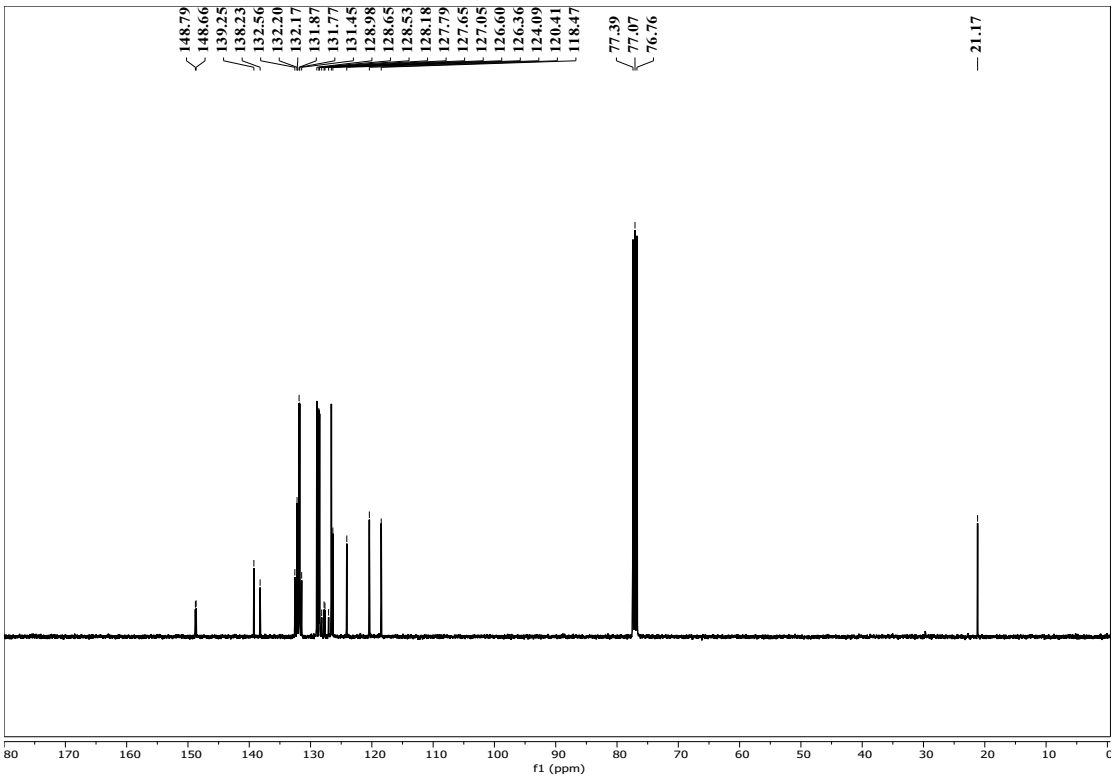




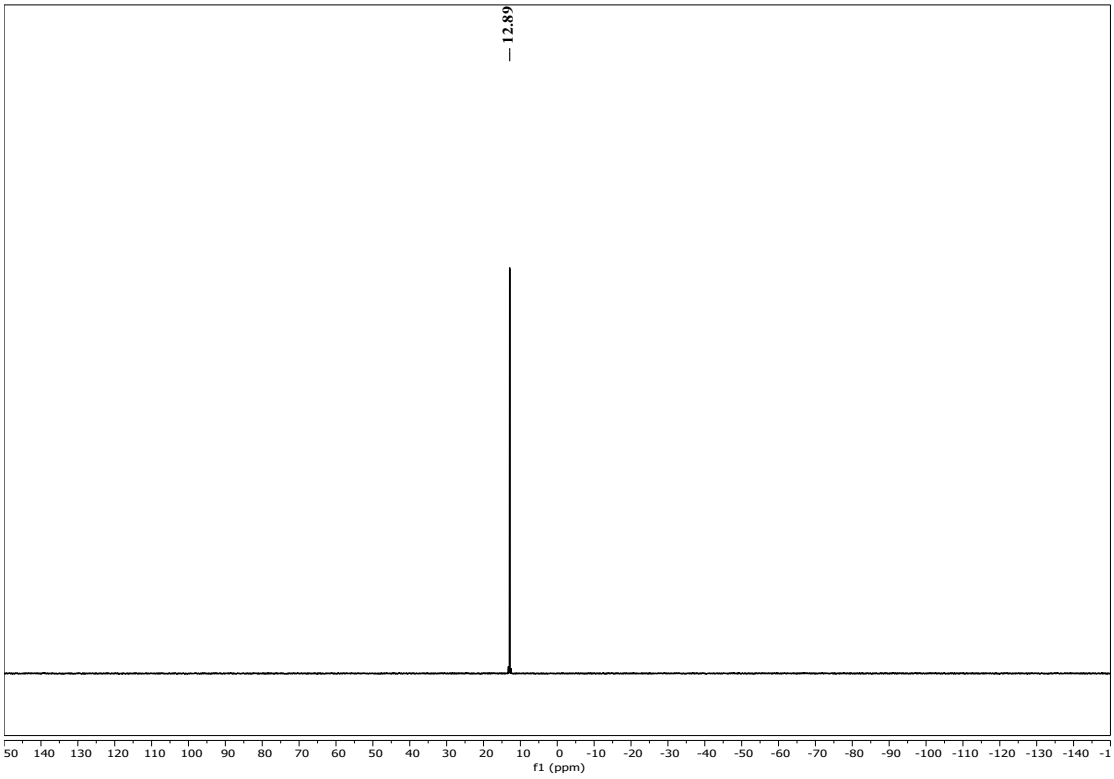
**6c,** $^{1}$H NMR (400 MHz), $CDCl_3$

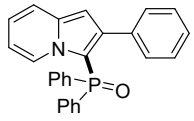



**6c**, $^{13}$C NMR (101 MHz), $CDCl_3$

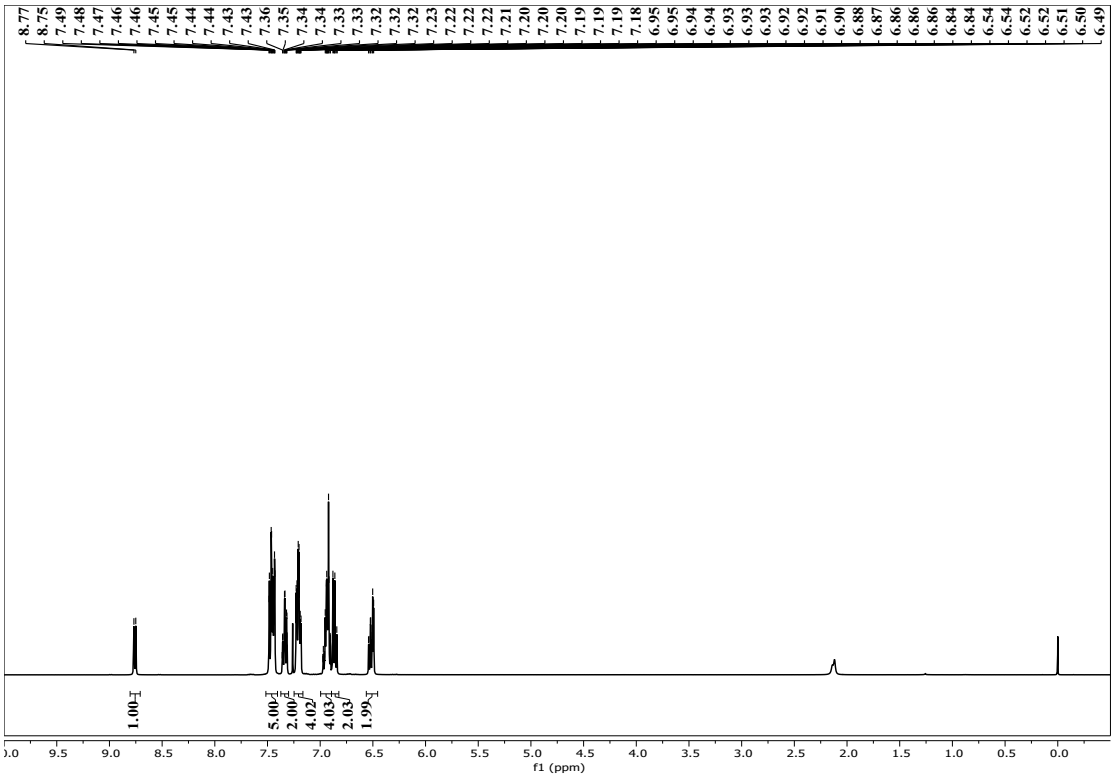


**6c**, $^{31}P$ NMR (162 MHz), $CDCl_3$

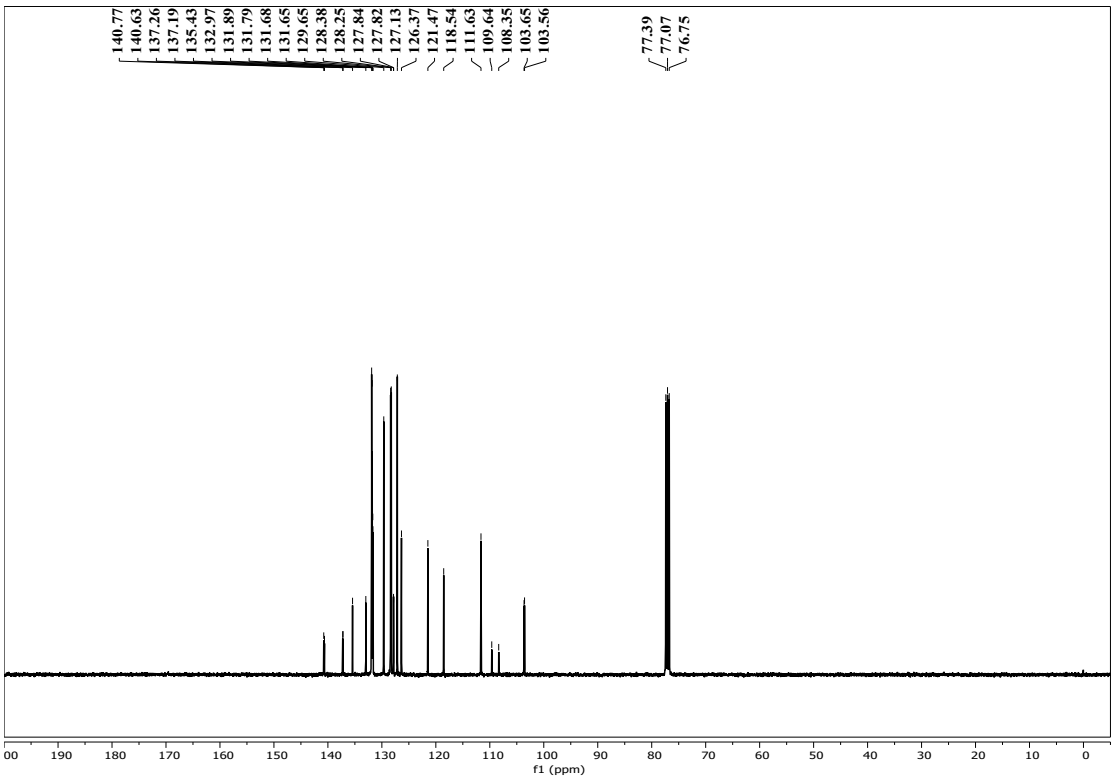




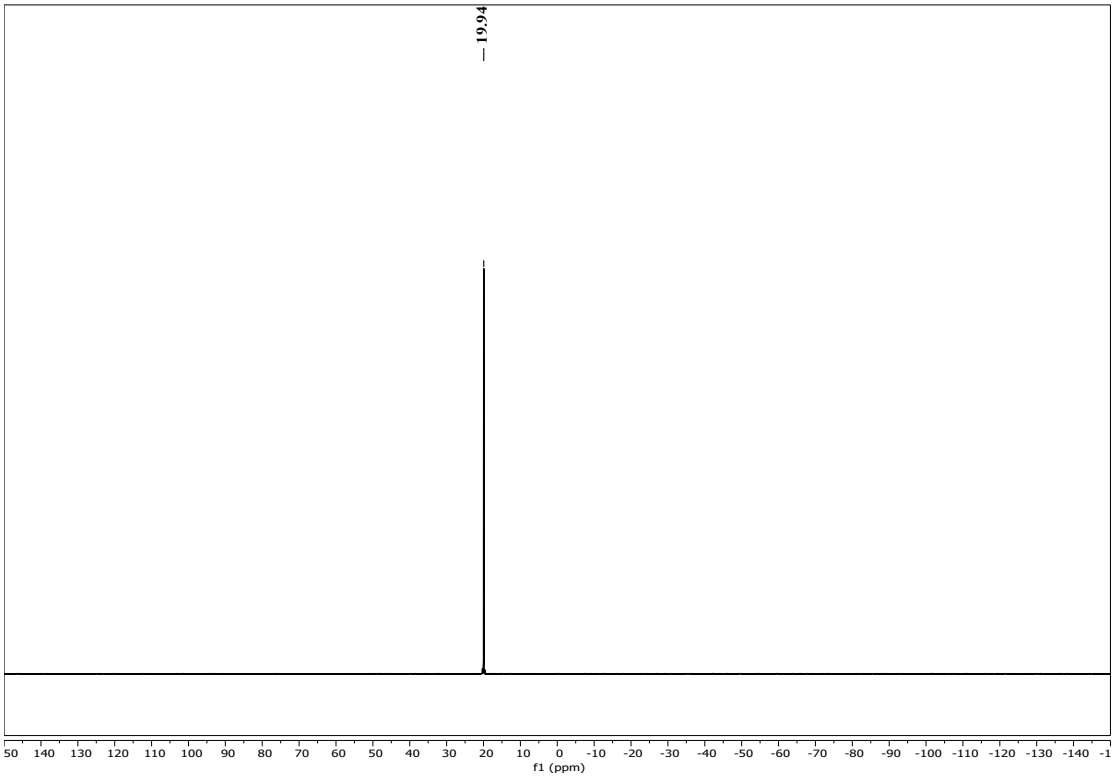
**6d,** $^{1}$H NMR (400 MHz), $CDCl_3$

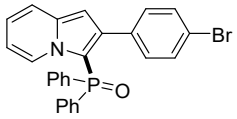



**6d**, $^{13}$C NMR (101 MHz), $CDCl_3$

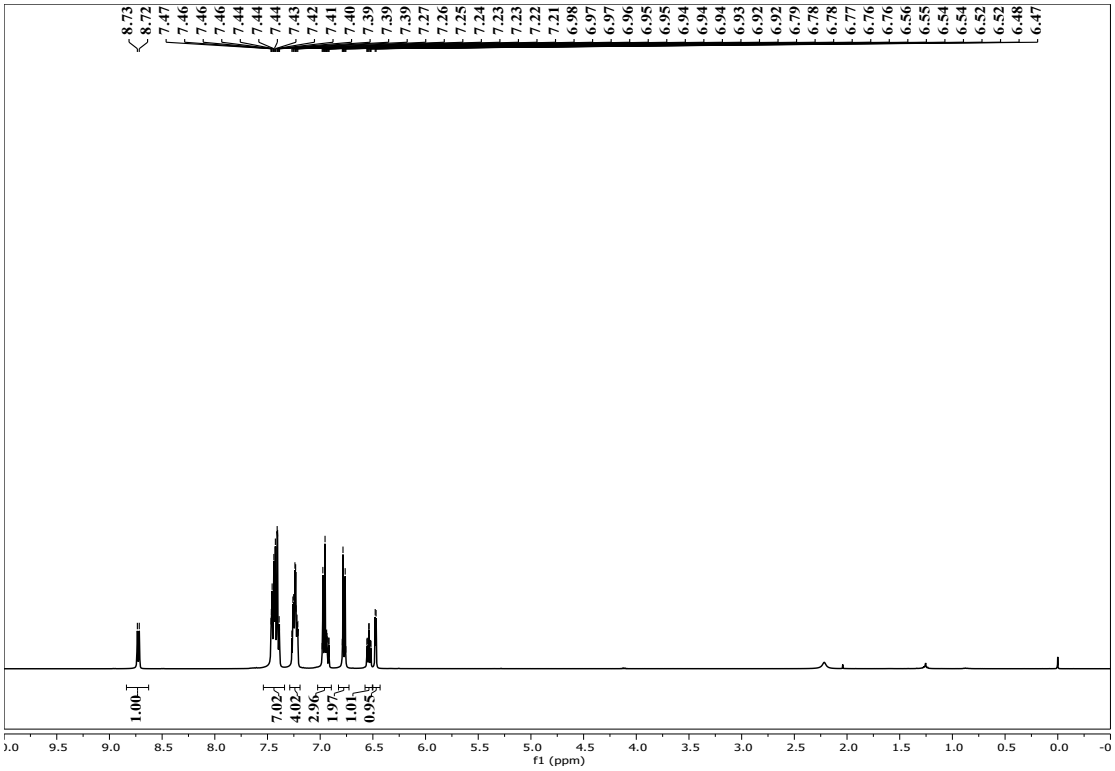


**6d**, $^{31}P$ NMR (162 MHz), $CDCl_3$

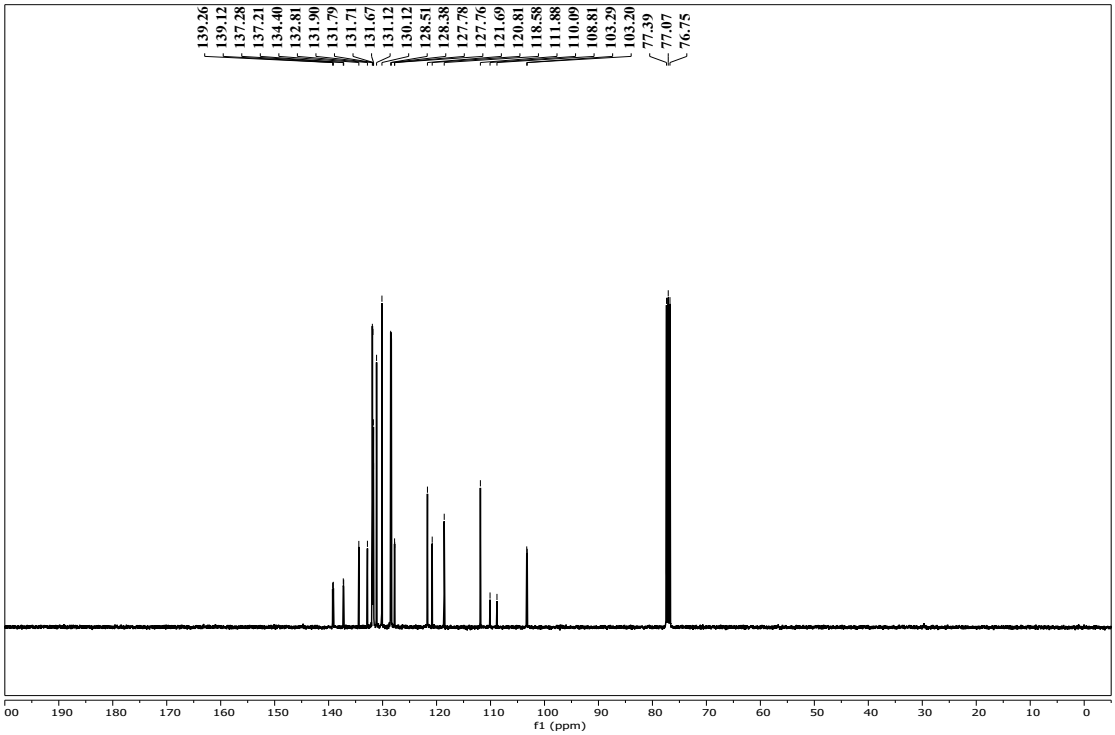




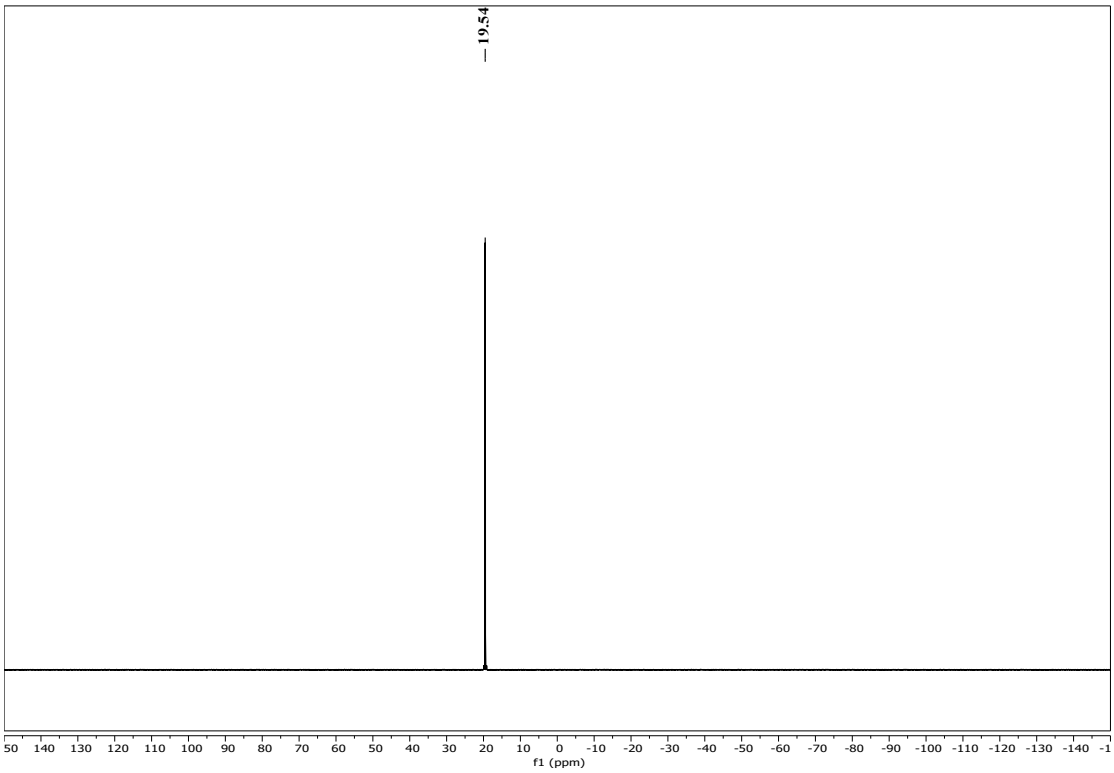

**6e,** $^{1}$H NMR (400 MHz), $CDCl_3$

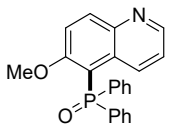



**6e**, $^{13}$C NMR (101 MHz), $CDCl_3$

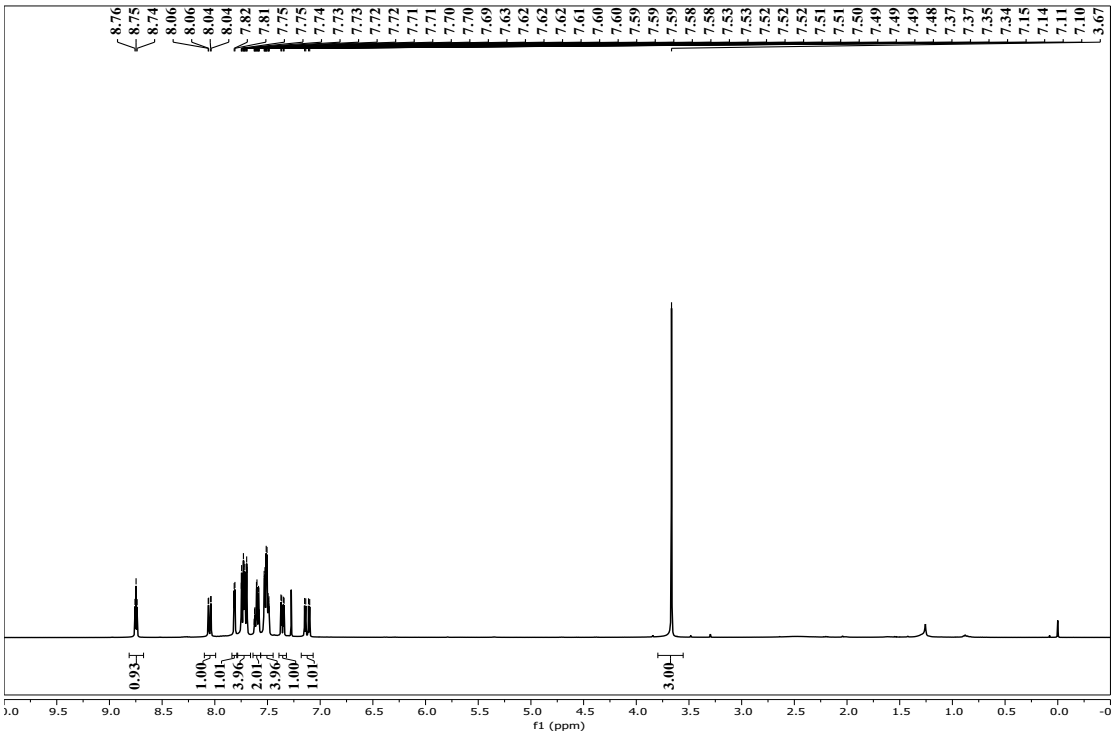


**6e**, $^{31}P$ NMR (162 MHz), $CDCl_3$

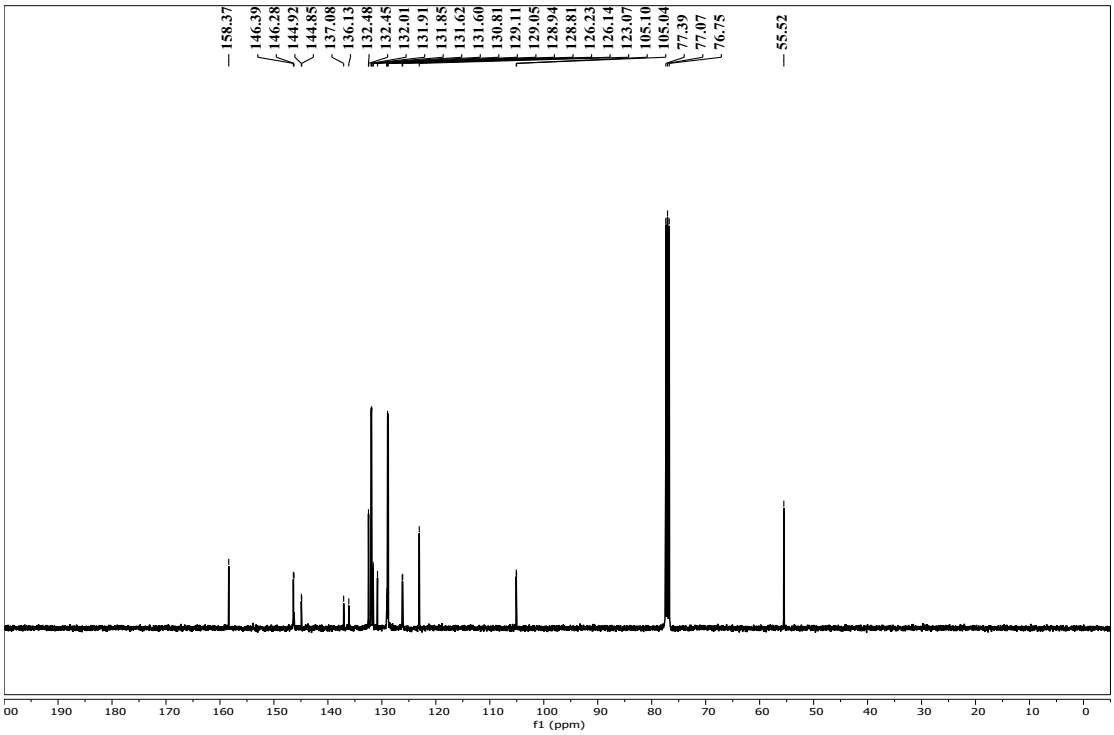




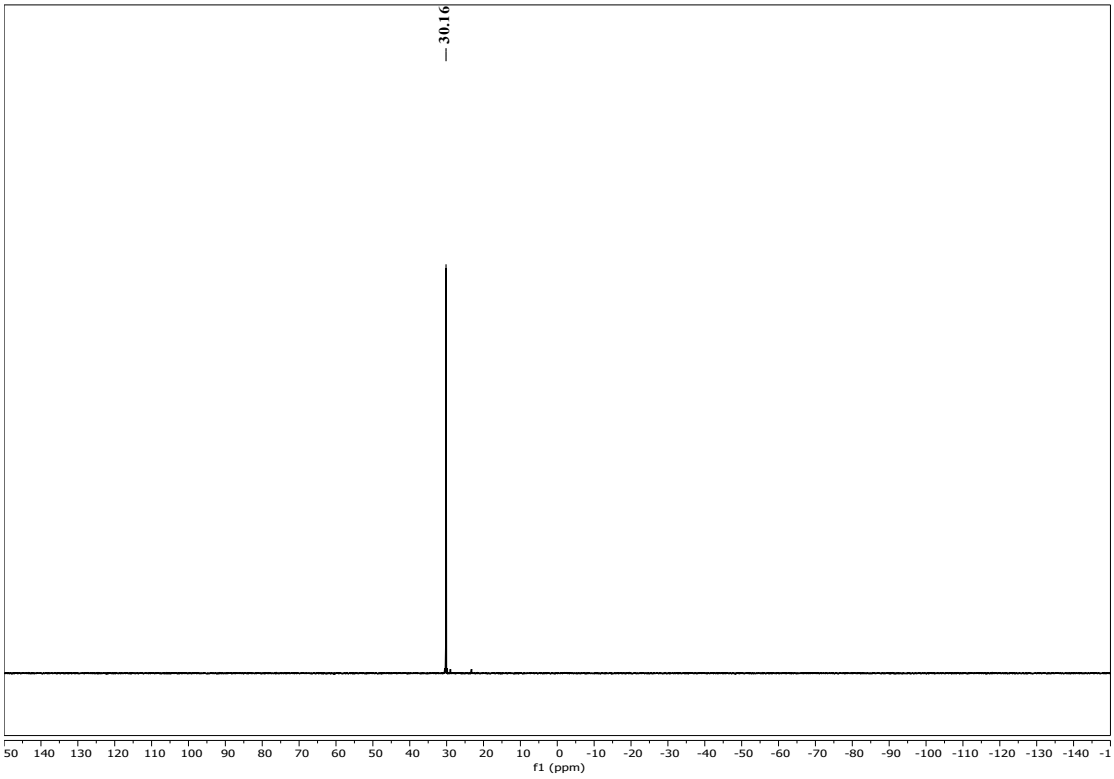

**6f,** $^{1}$H NMR (400 MHz), $CDCl_3$

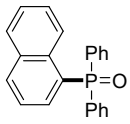



**6f**, $^{13}$C NMR (101 MHz), $CDCl_3$

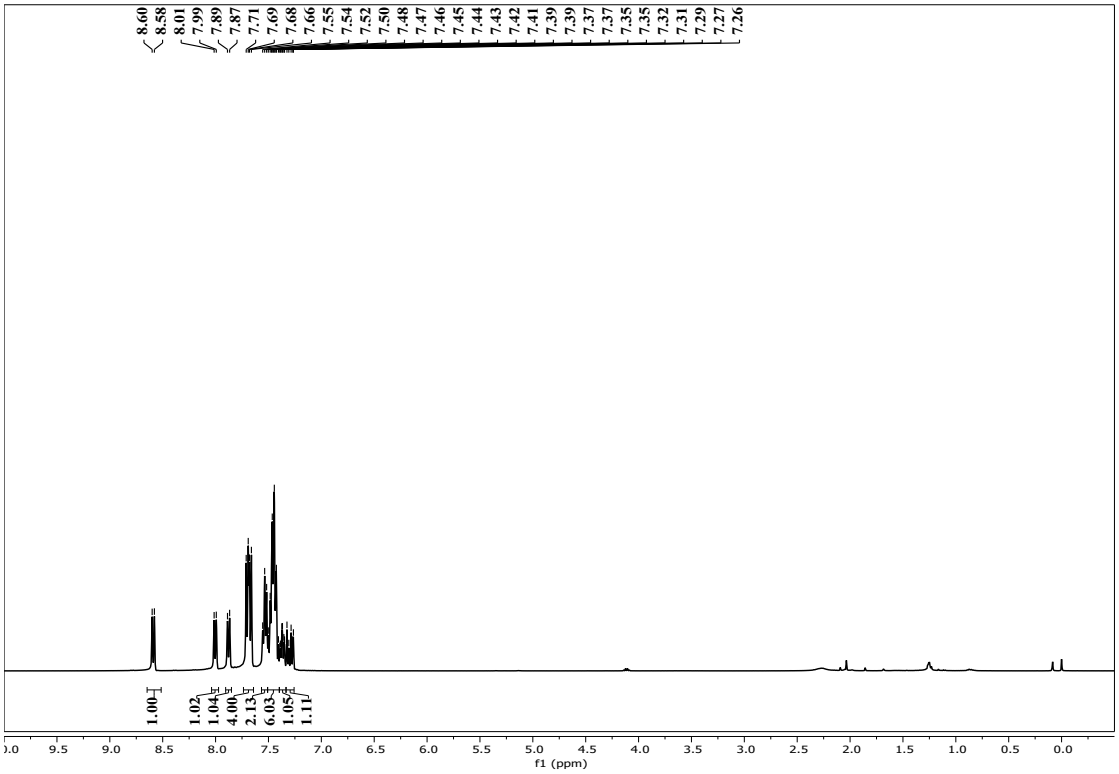


**6f**, $^{31}P$ NMR (162 MHz), $CDCl_3$

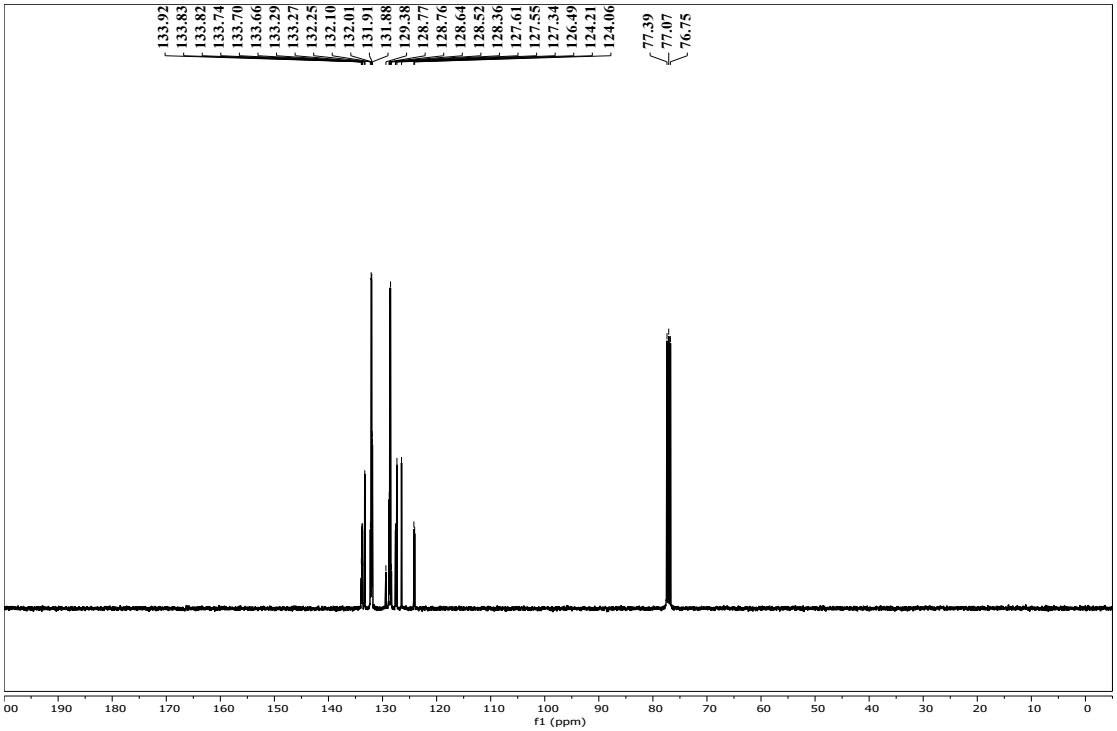




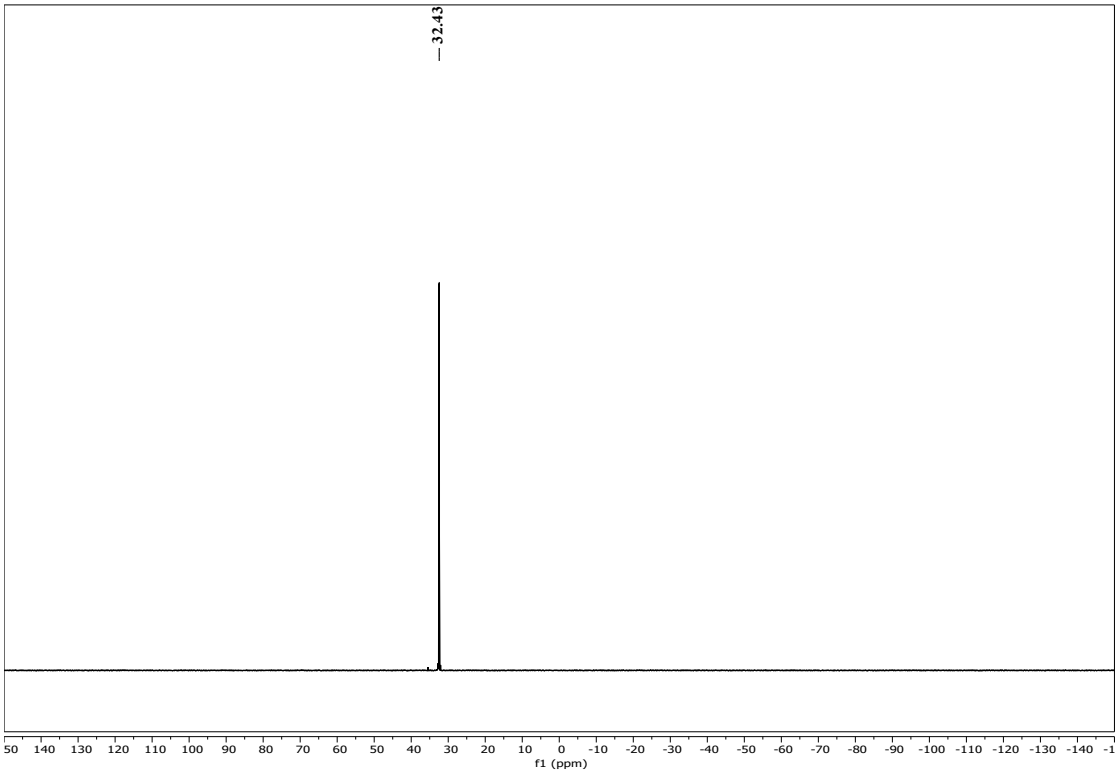

**6g,** $^{1}$H NMR (400 MHz), $CDCl_3$

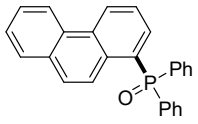



**6g**, $^{13}$C NMR (101 MHz), $CDCl_3$

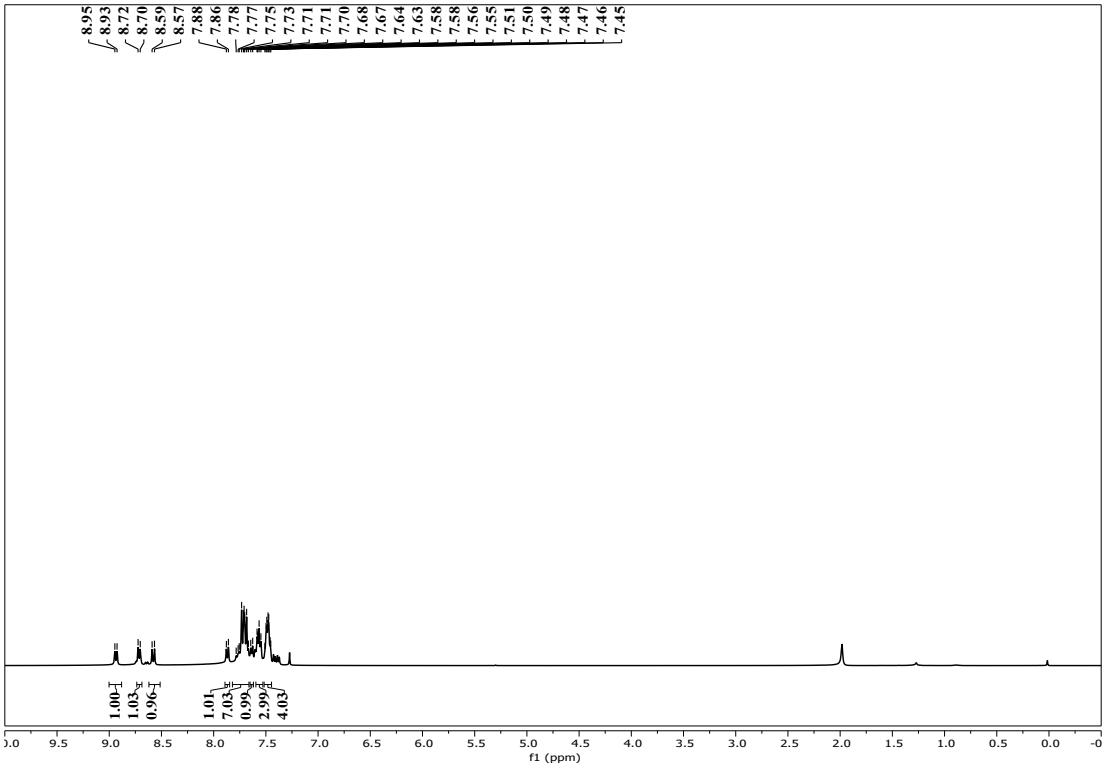


**6g**, $^{31}P$ NMR (162 MHz), $CDCl_3$

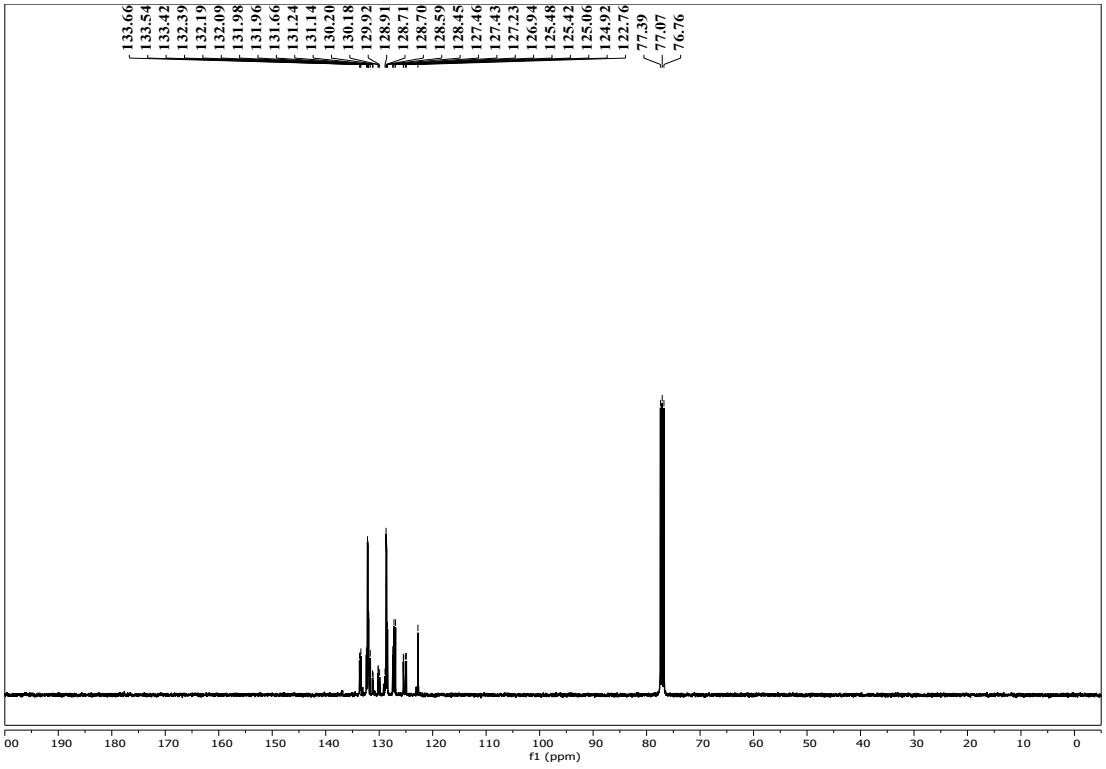




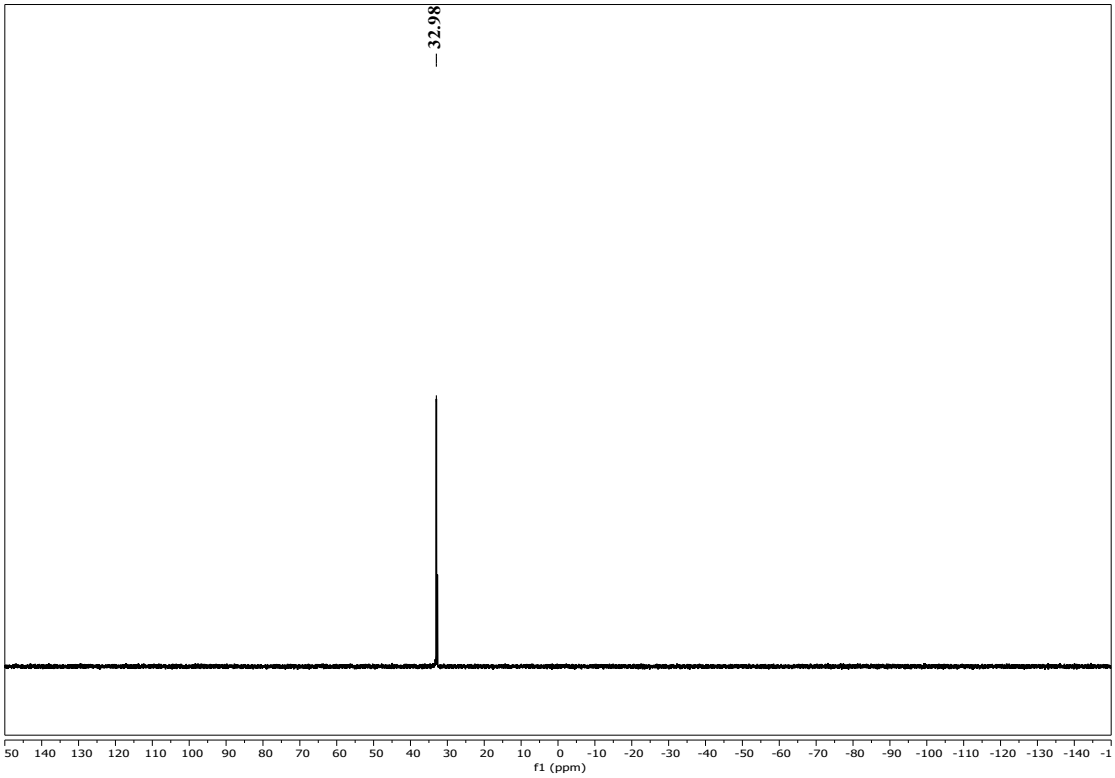
**(main product) 6h,** $^{1}$H NMR (400 MHz), $CDCl_3$

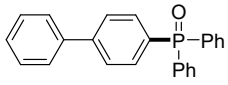



**6h**, $^{13}$C NMR (101 MHz), $CDCl_3$

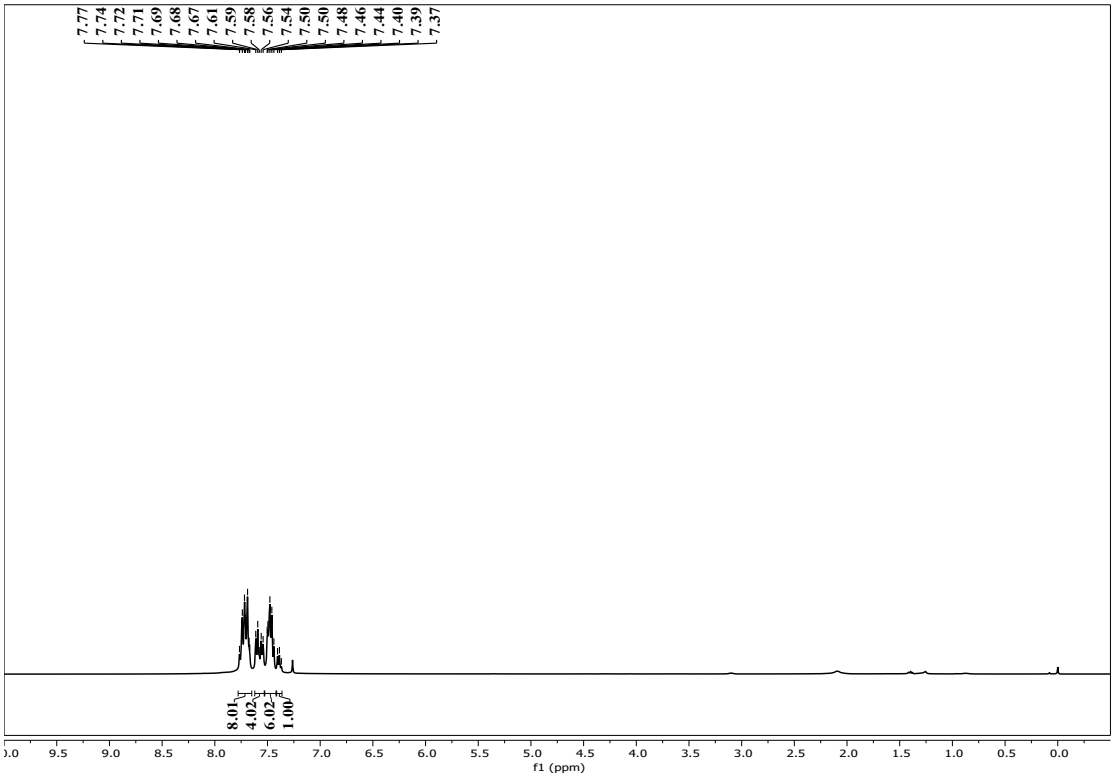


**6h**, $^{31}P$ NMR (162 MHz), $CDCl_3$

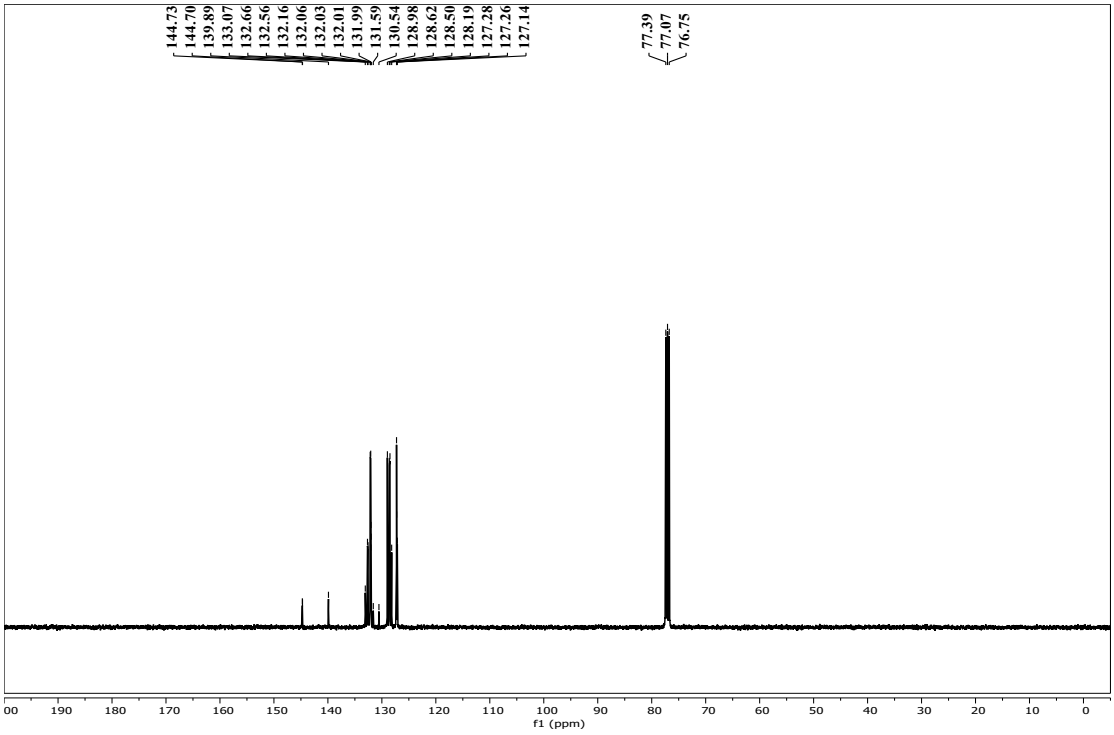




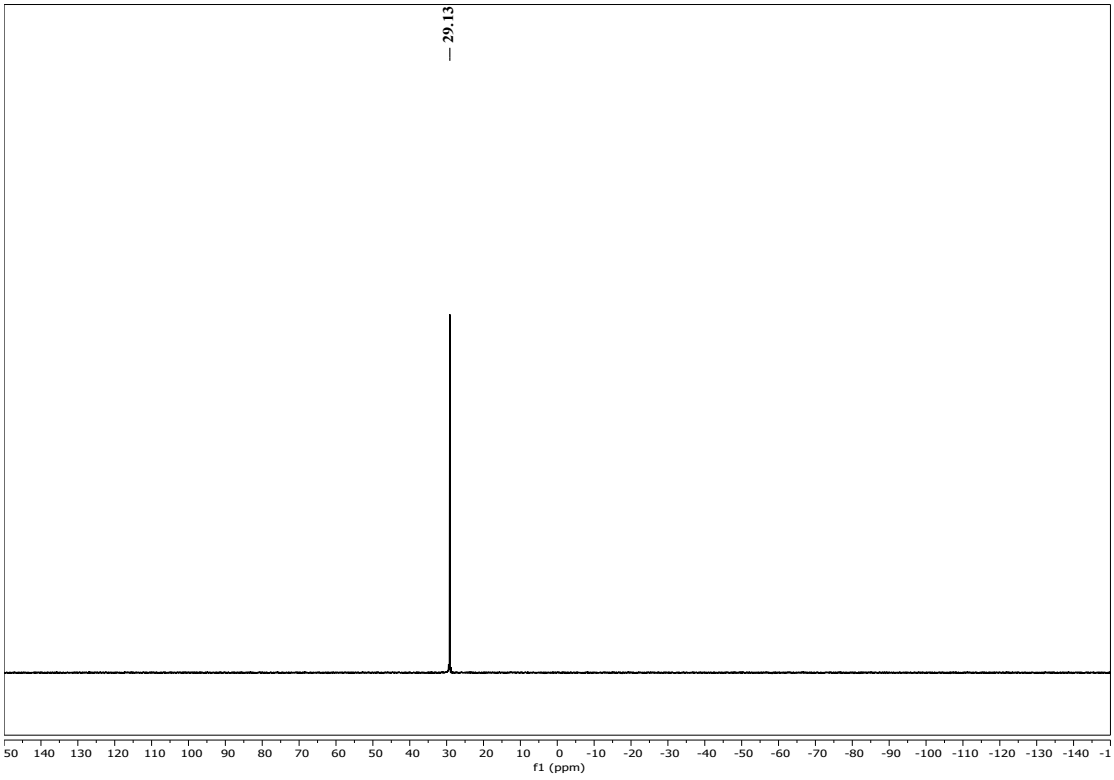
**6i,** $^{1}$H NMR (400 MHz), $CDCl_3$

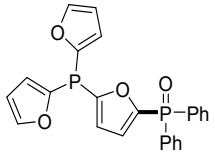



**6i**, $^{13}$C NMR (101 MHz), $CDCl_3$

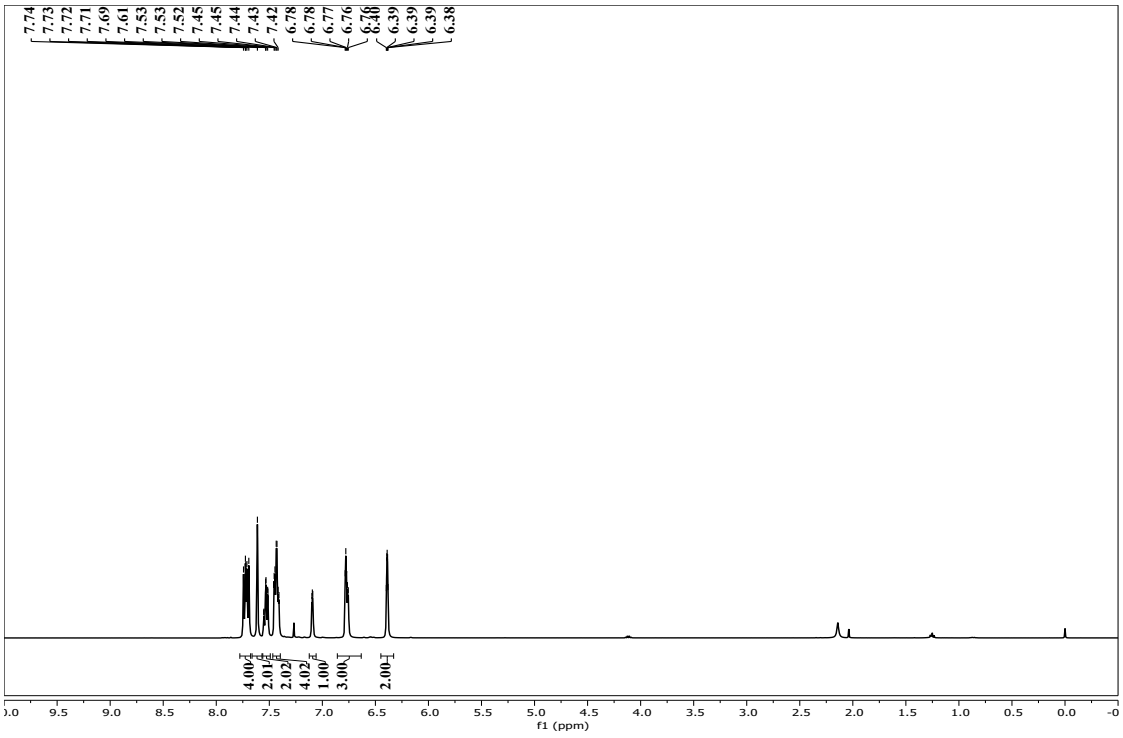


**6i**, $^{31}P$ NMR (162 MHz), $CDCl_3$

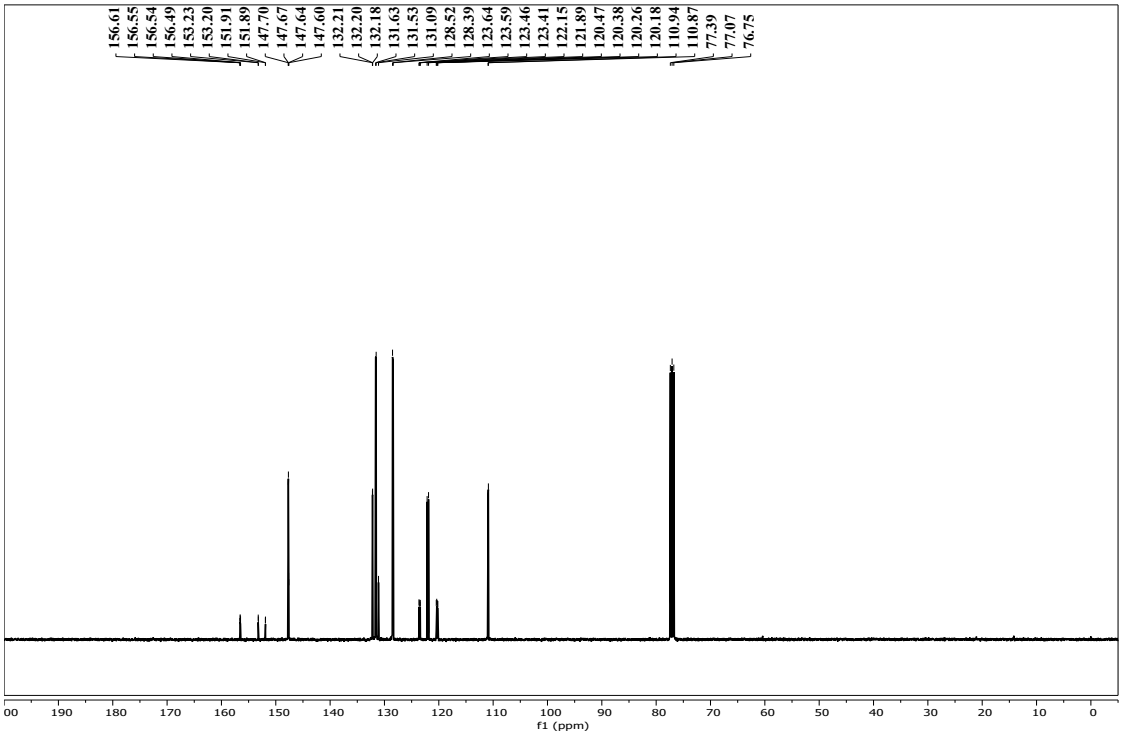




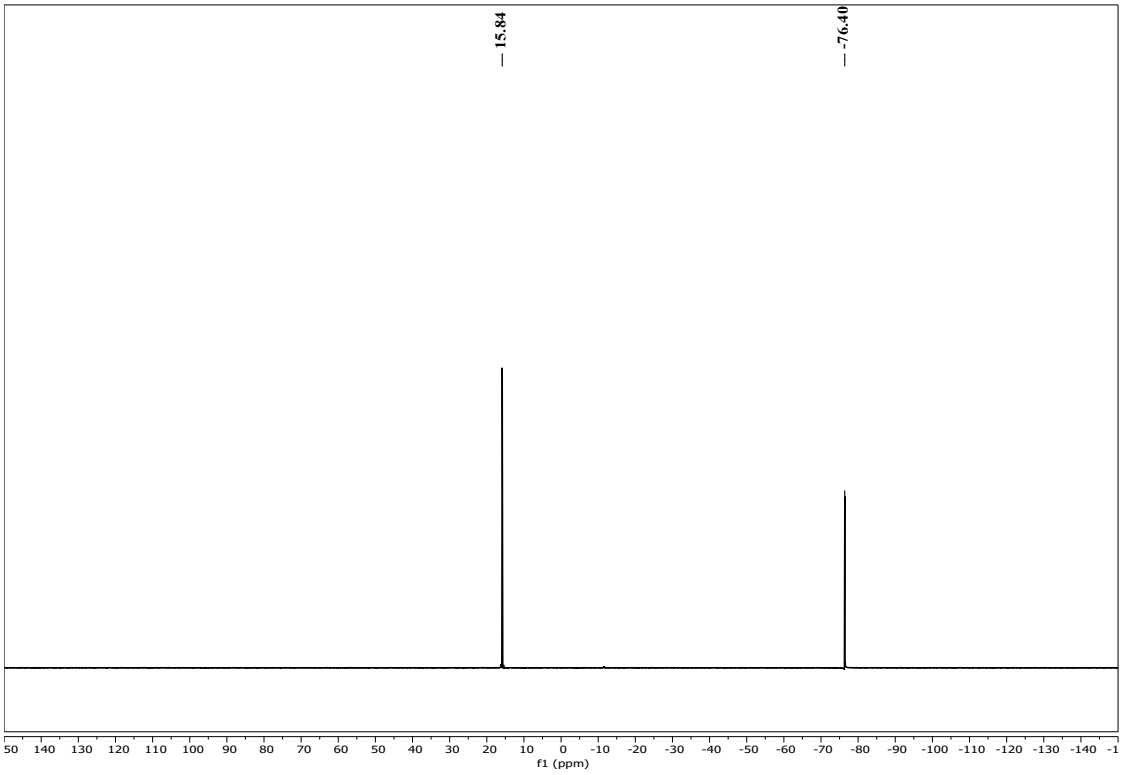
**9a,** $^{1}$H NMR (400 MHz), $CDCl_3$

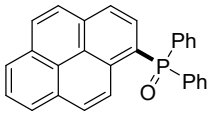



**9a**, $^{13}$C NMR (101 MHz), $CDCl_3$

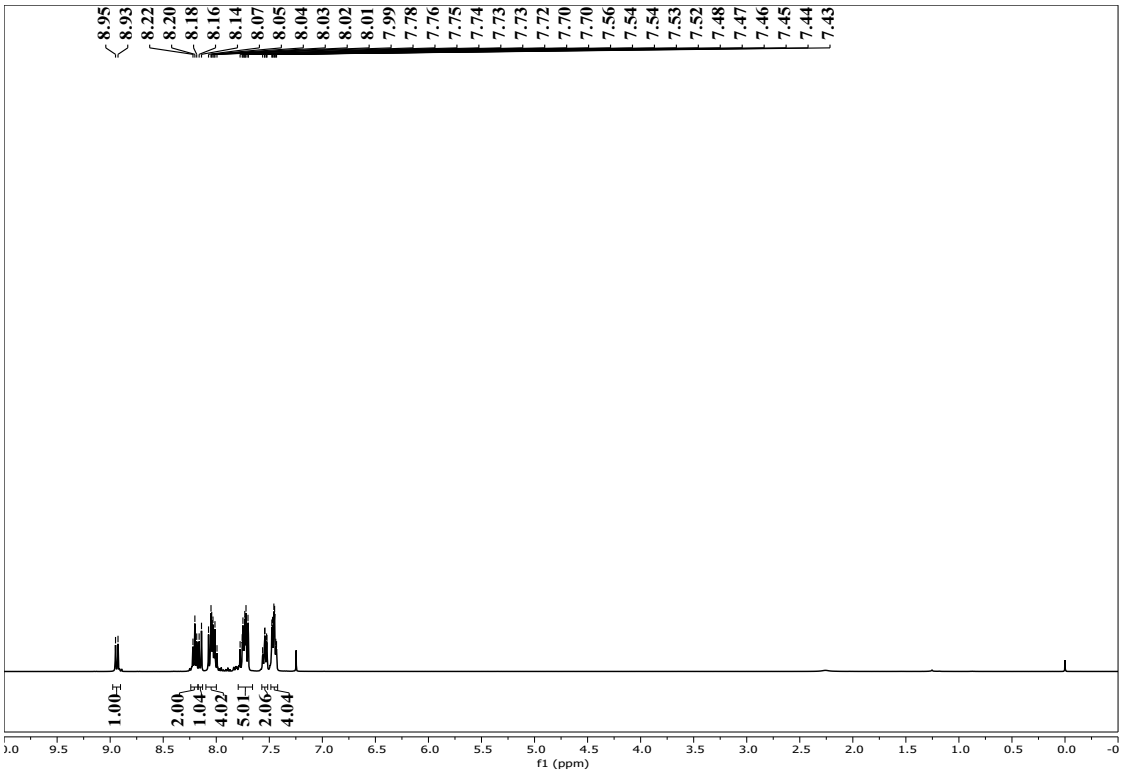


**9a**, $^{31}P$ NMR (162 MHz), $CDCl_3$

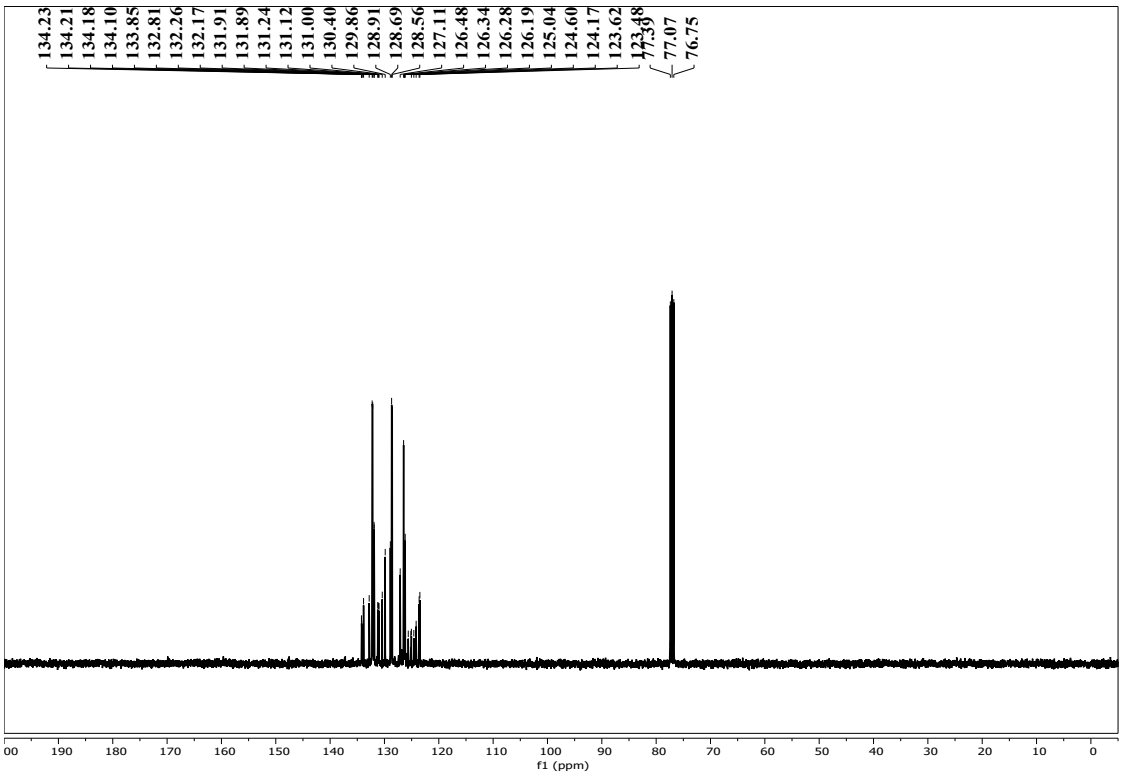




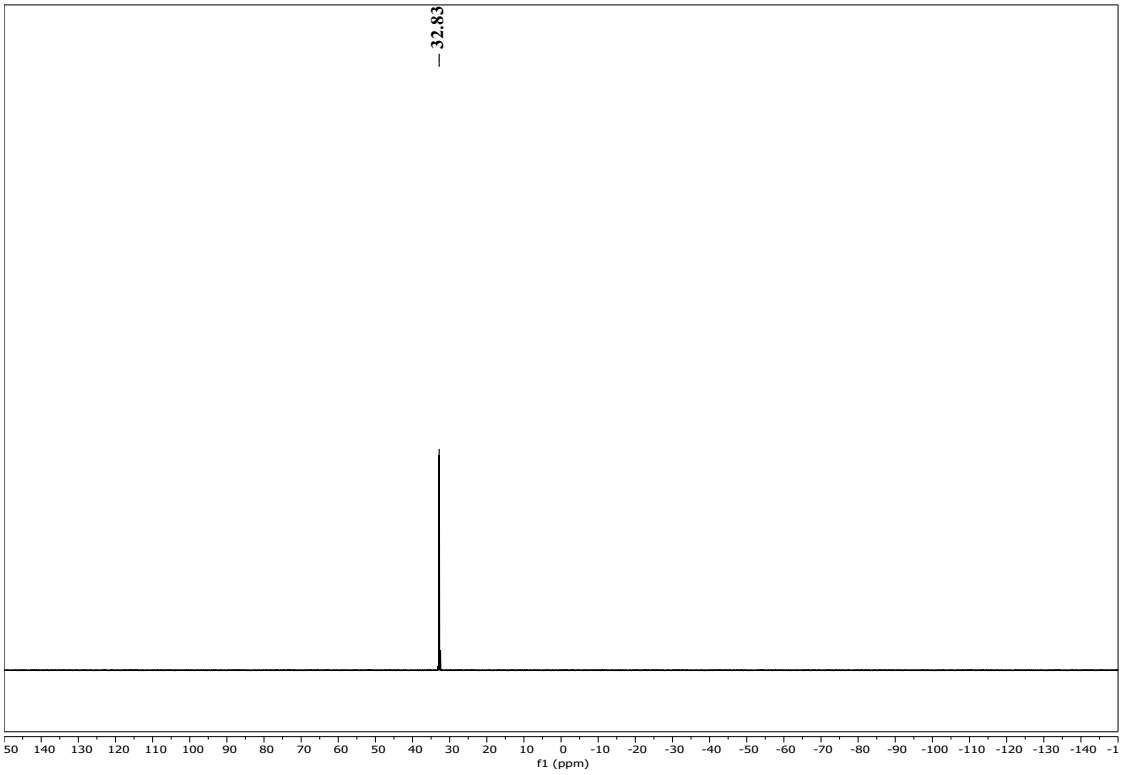

**9b,** $^{1}$H NMR (400 MHz), $CDCl_3$ **(main product)**

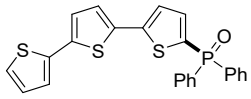



**9b**, $^{13}$C NMR (101 MHz), $CDCl_3$

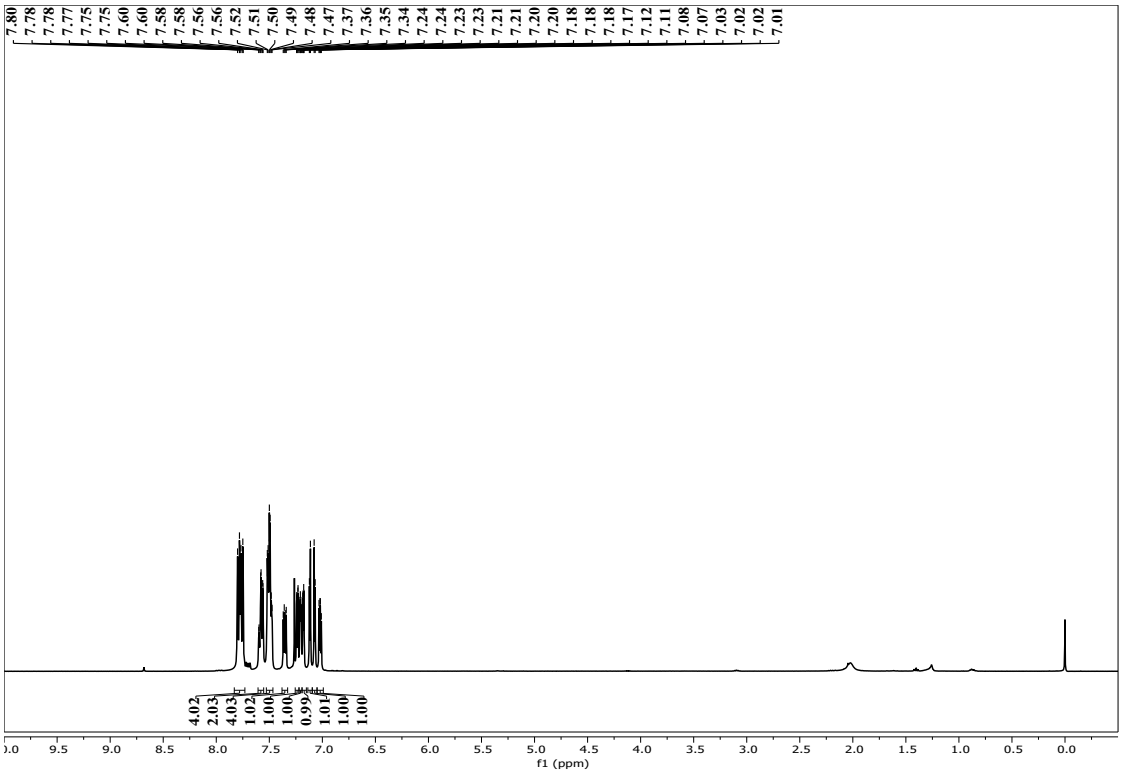


**9b**, $^{31}P$ NMR (162 MHz), $CDCl_3$

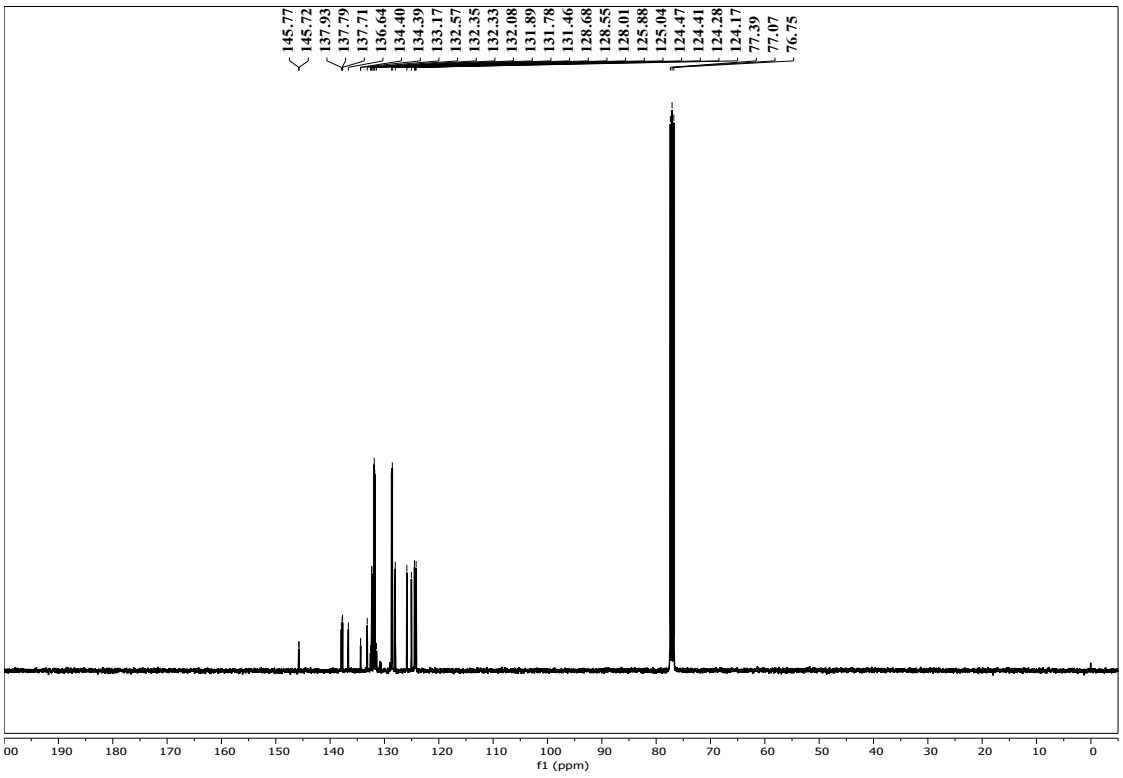




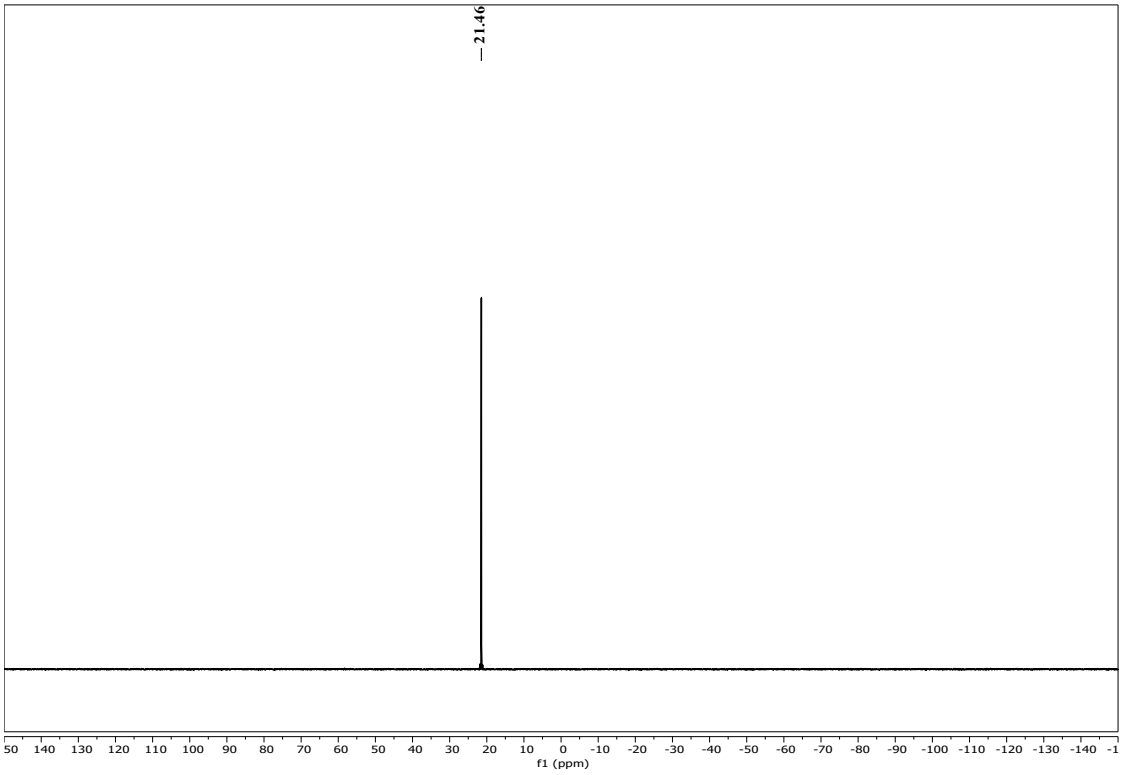
**9c,** $^{1}$H NMR (400 MHz), $CDCl_3$

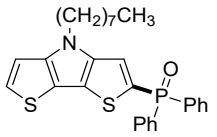



**9c**, $^{13}$C NMR (101 MHz), $CDCl_3$

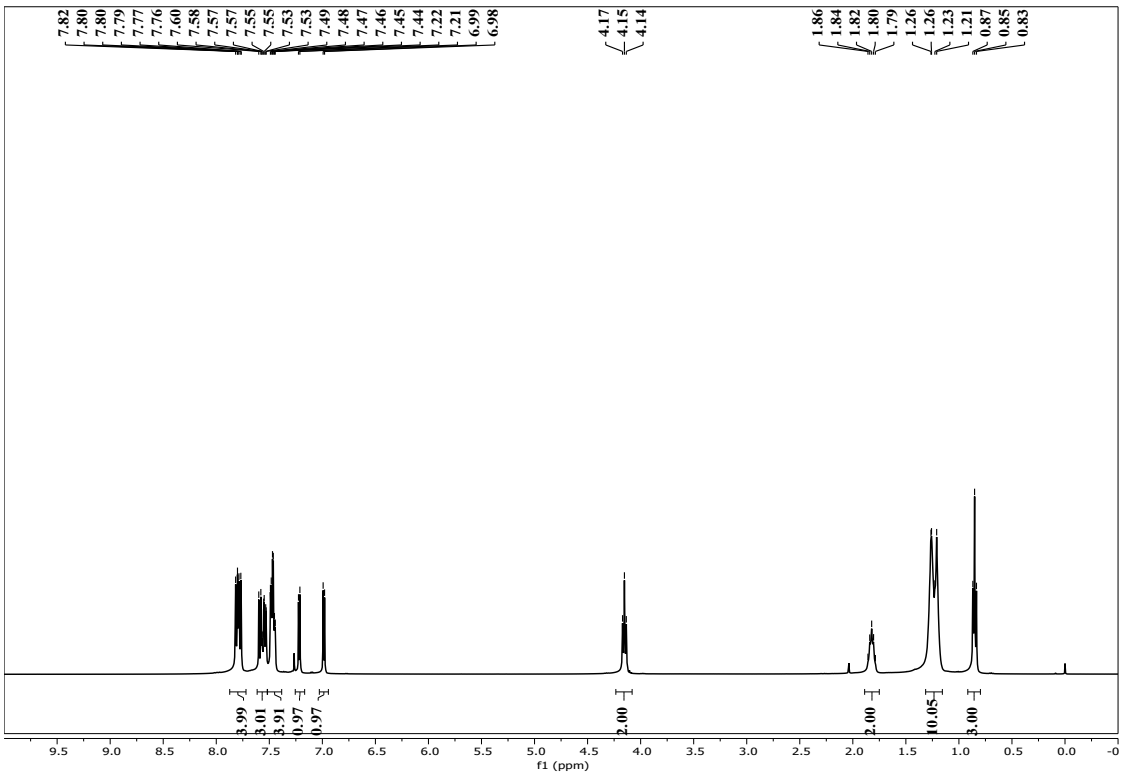


**9c**, $^{31}P$ NMR (162 MHz), $CDCl_3$

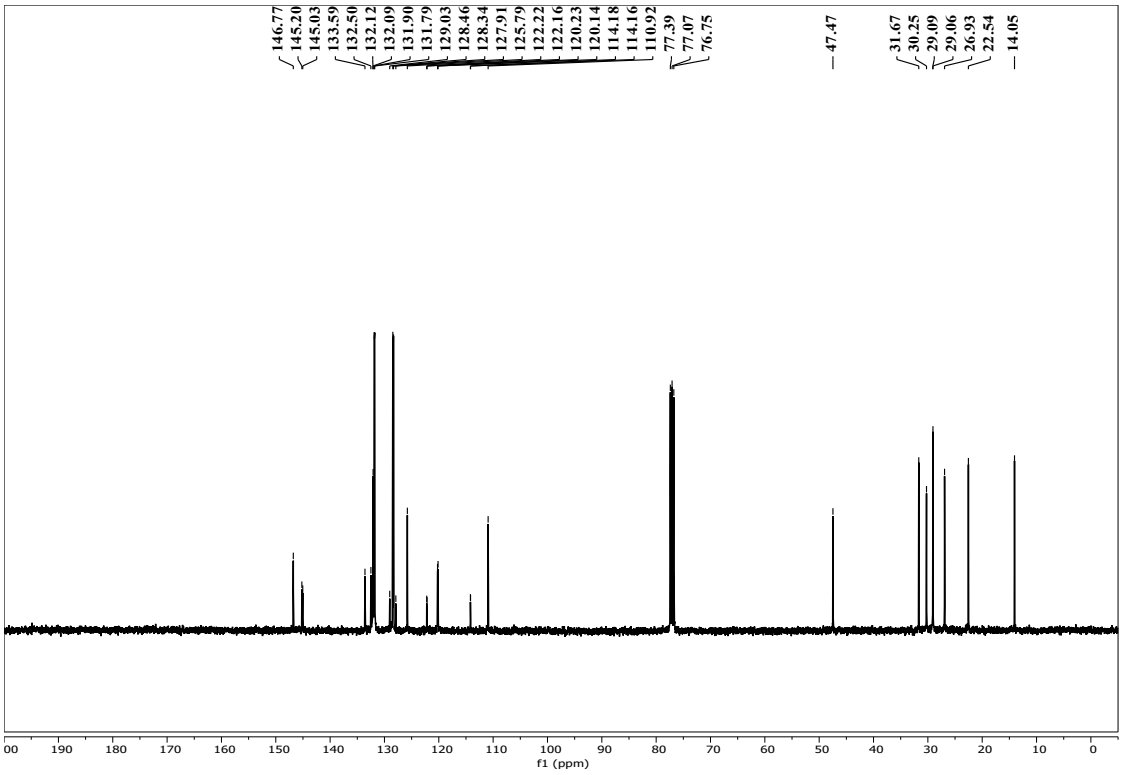




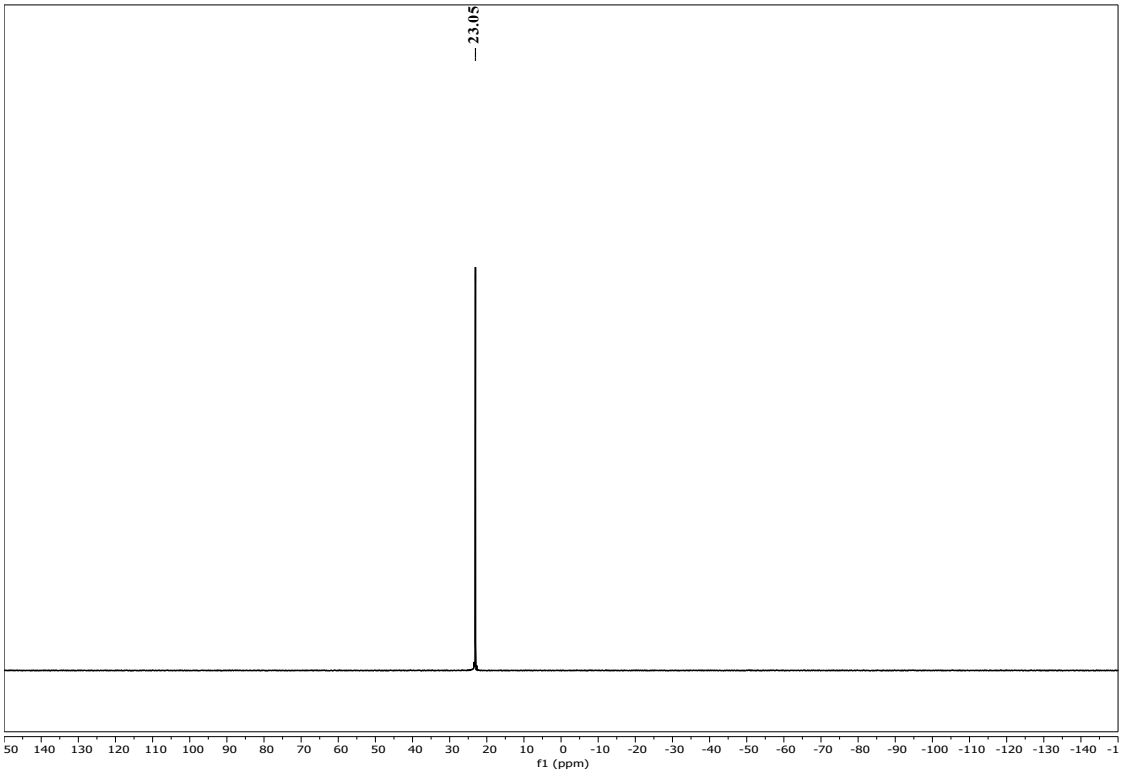

**9d,** $^{1}$H NMR (400 MHz), $CDCl_3$

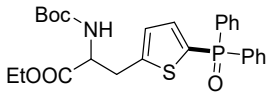



**9d**, $^{13}$C NMR (101 MHz), $CDCl_3$

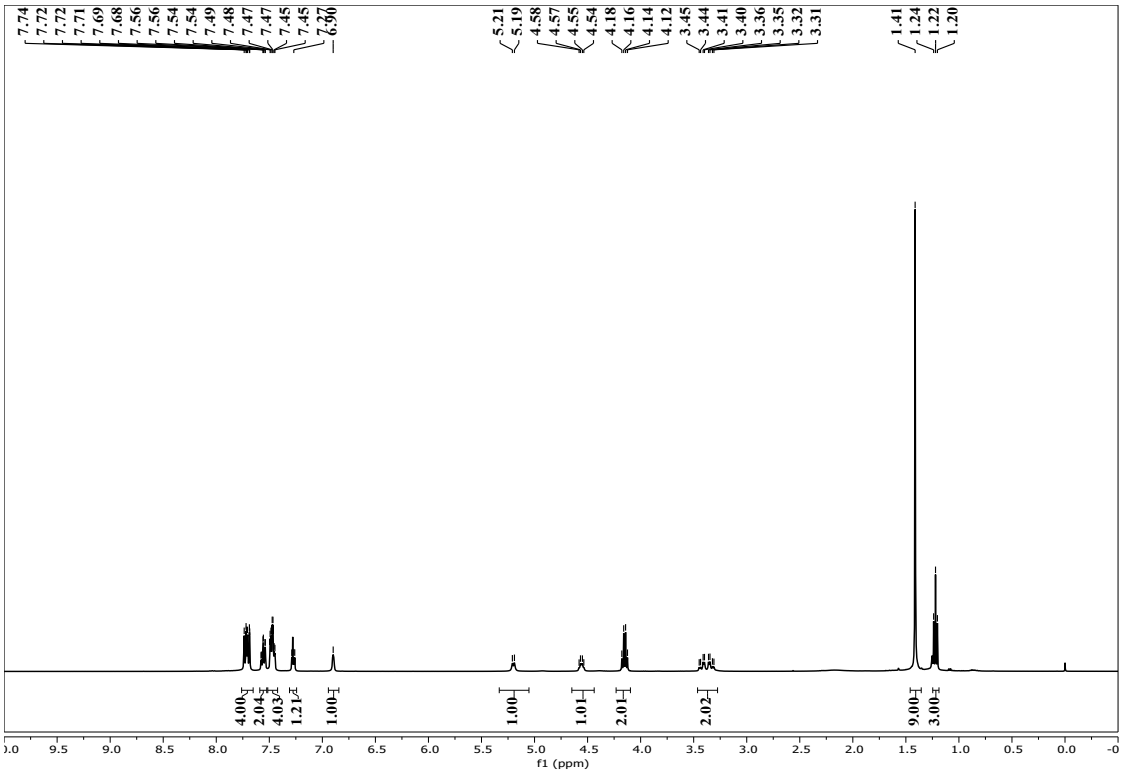


**9d**, $^{31}P$ NMR (162 MHz), $CDCl_3$

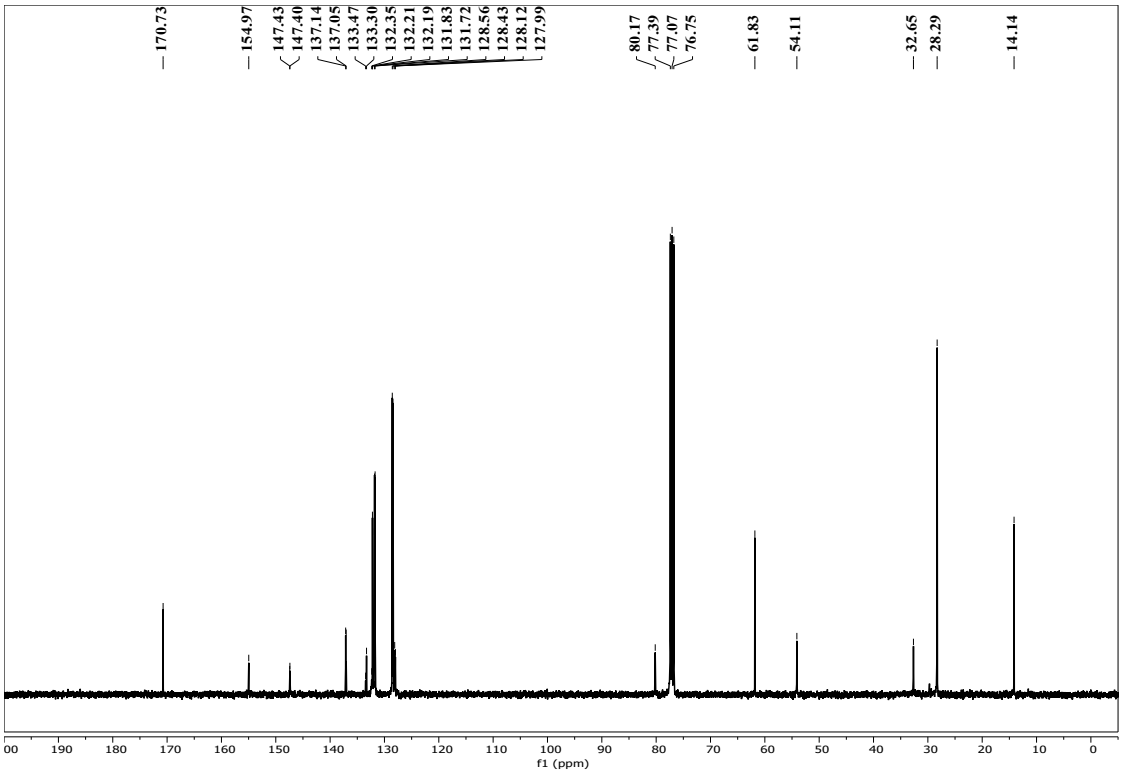




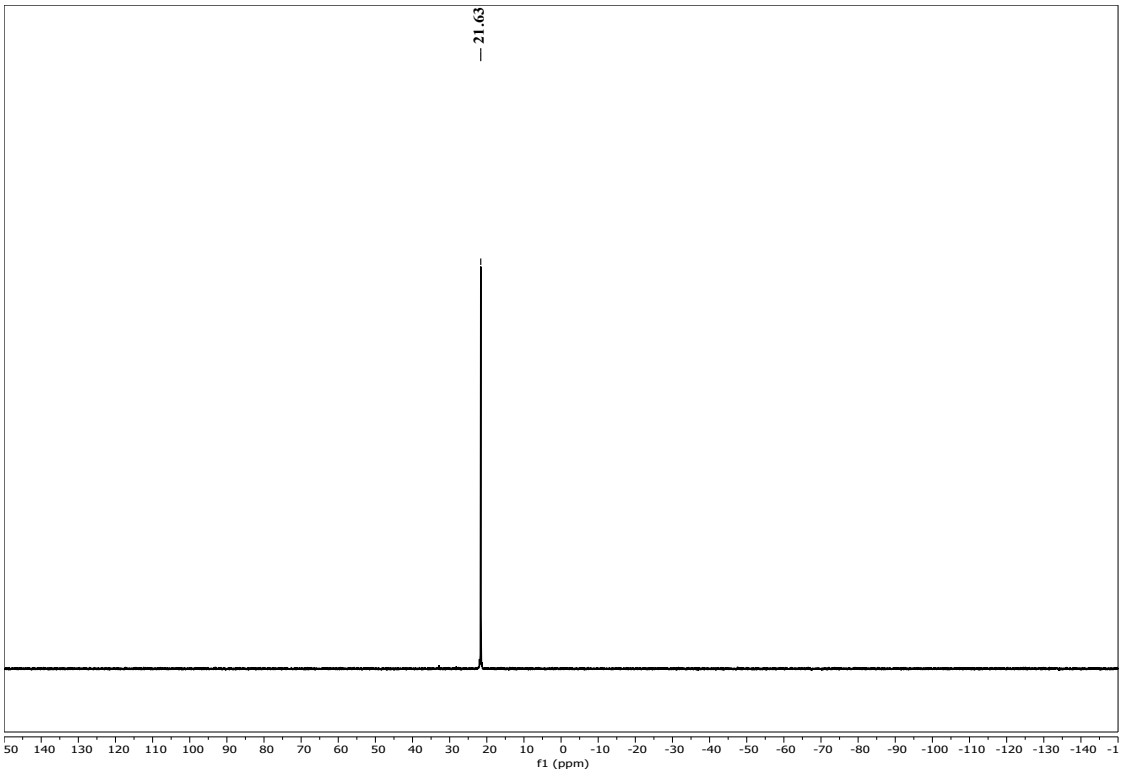

**9e,** $^{1}$H NMR (400 MHz), $CDCl_3$

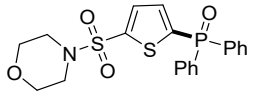



**9e**, $^{13}$C NMR (101 MHz), $CDCl_3$

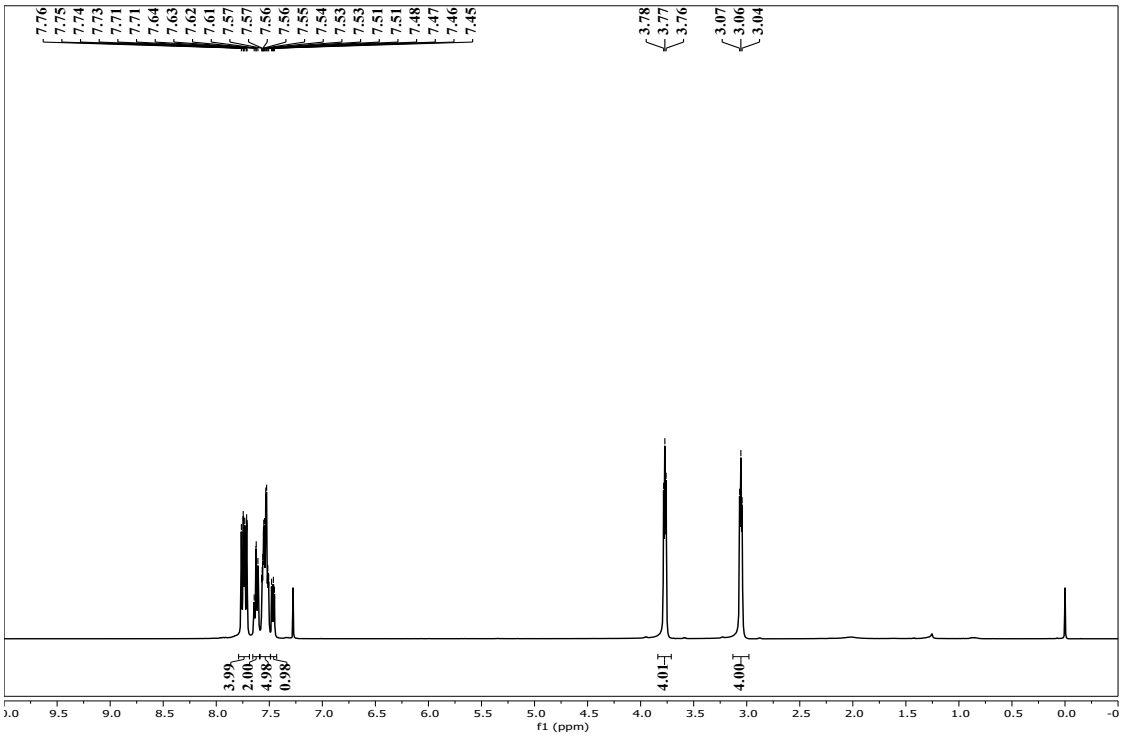


**9e**, $^{31}P$ NMR (162 MHz), $CDCl_3$

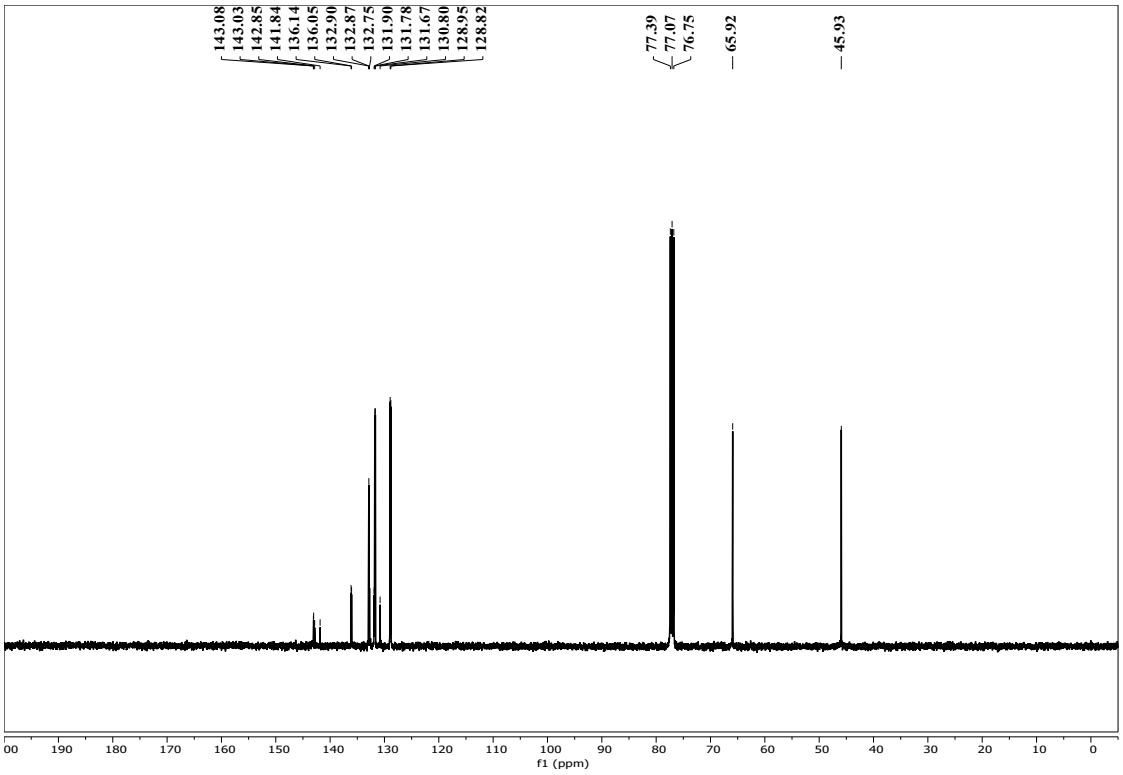




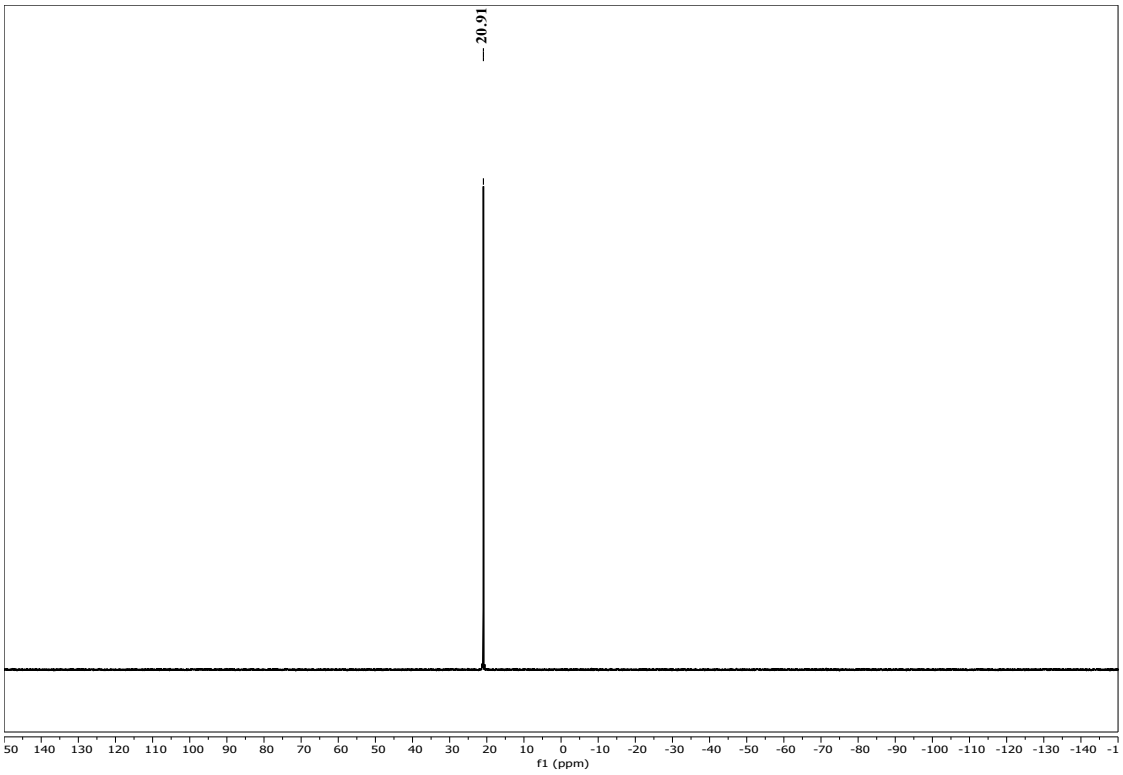
**9f,** $^{1}$H NMR (400 MHz), $CDCl_3$

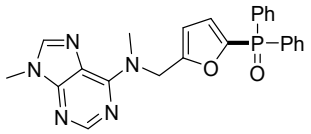



**9f**, $^{13}$C NMR (101 MHz), $CDCl_3$

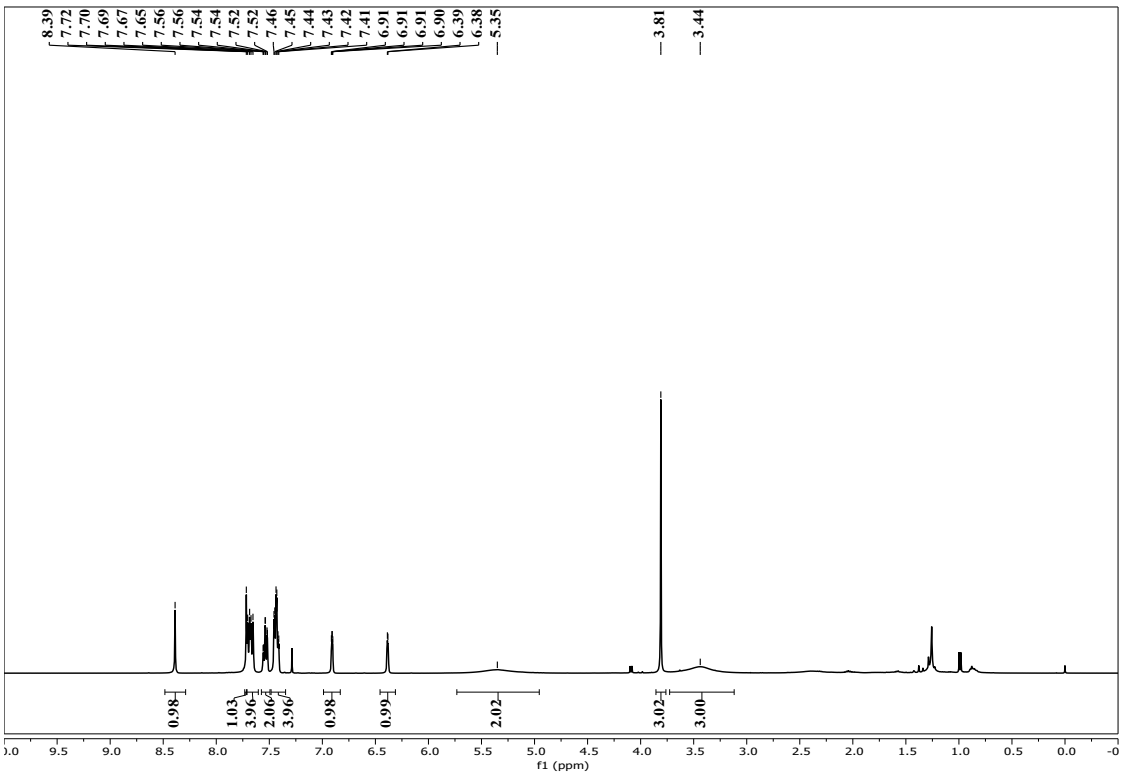


**9f**, $^{31}P$ NMR (162 MHz), $CDCl_3$

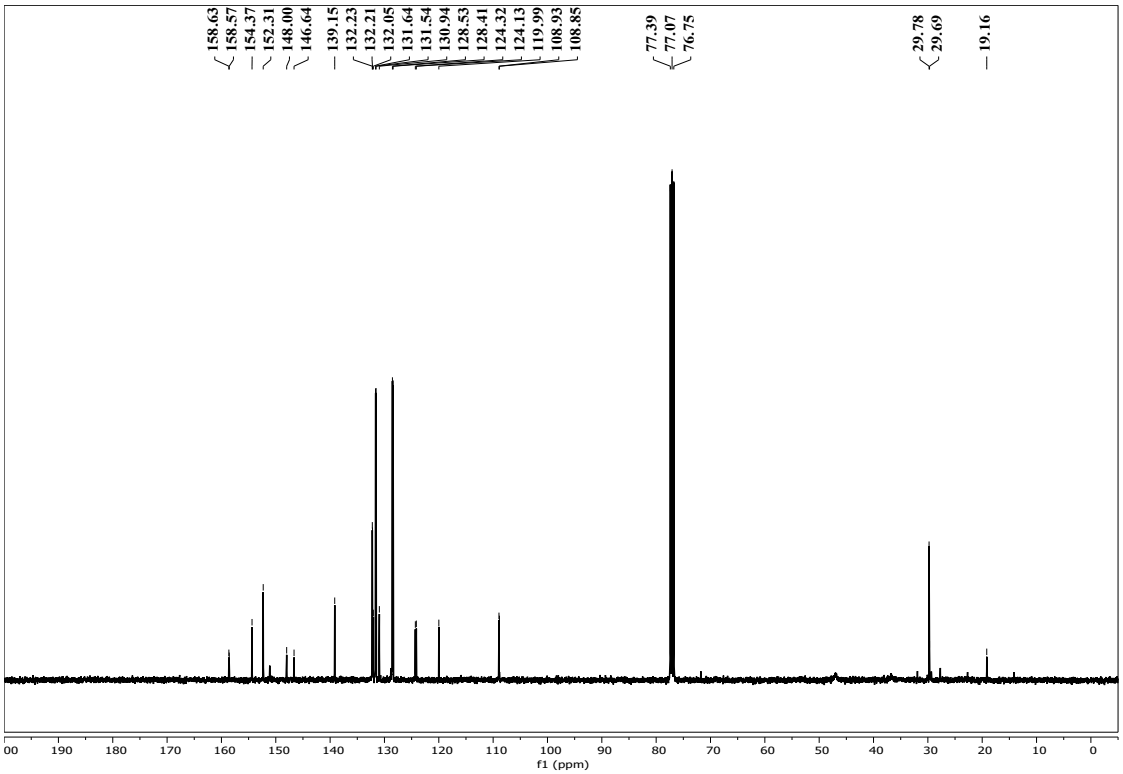




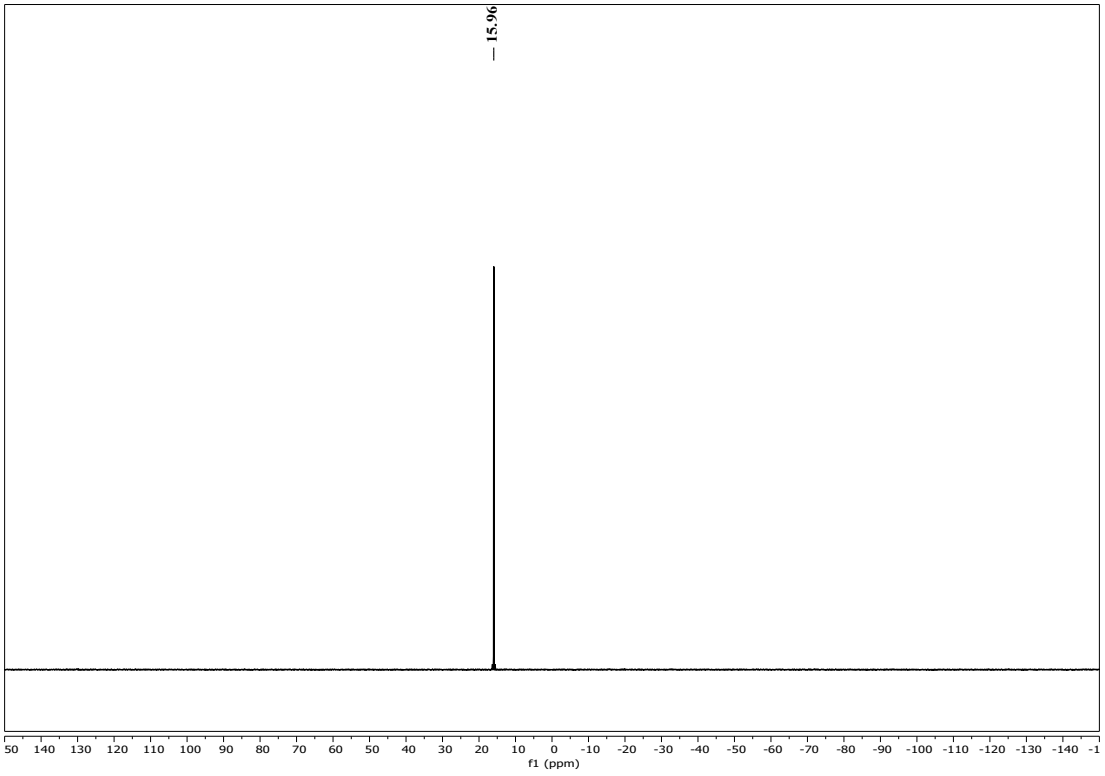
**9g,** $^{1}$H NMR (400 MHz), $CDCl_3$

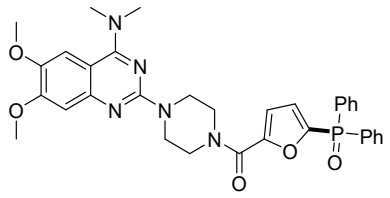



**9g**, $^{13}$C NMR (101 MHz), $CDCl_3$

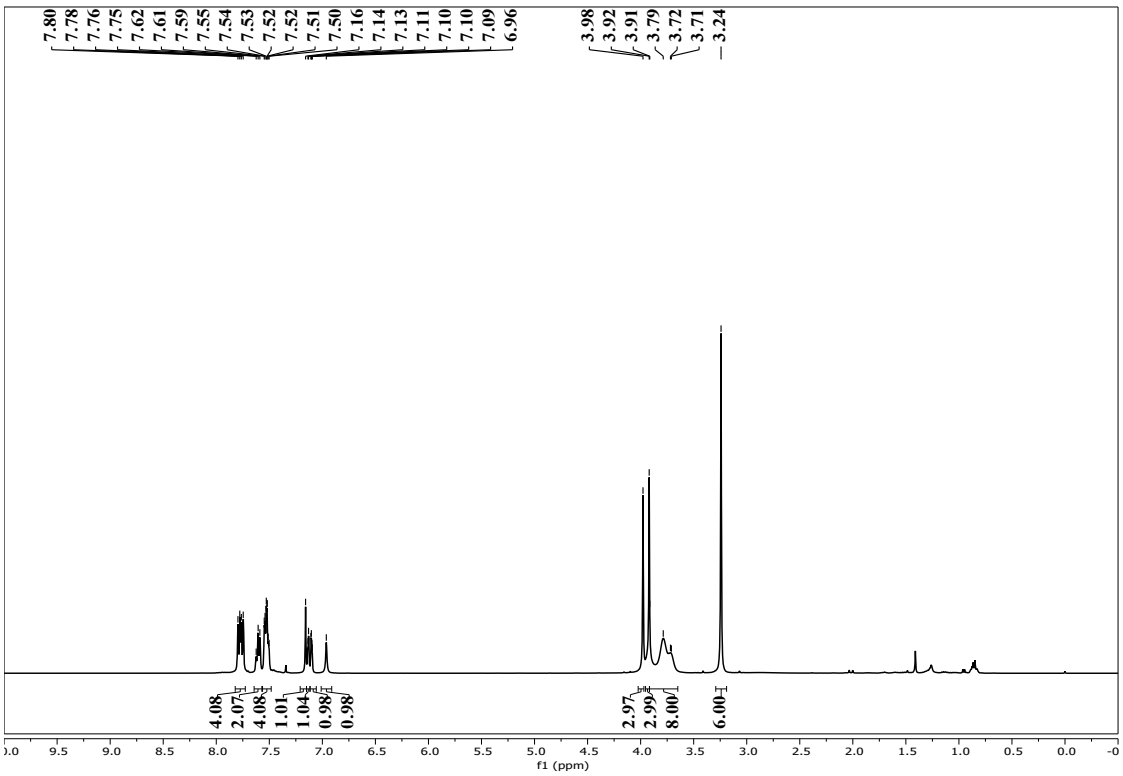


**9g**, $^{31}P$ NMR (162 MHz), $CDCl_3$

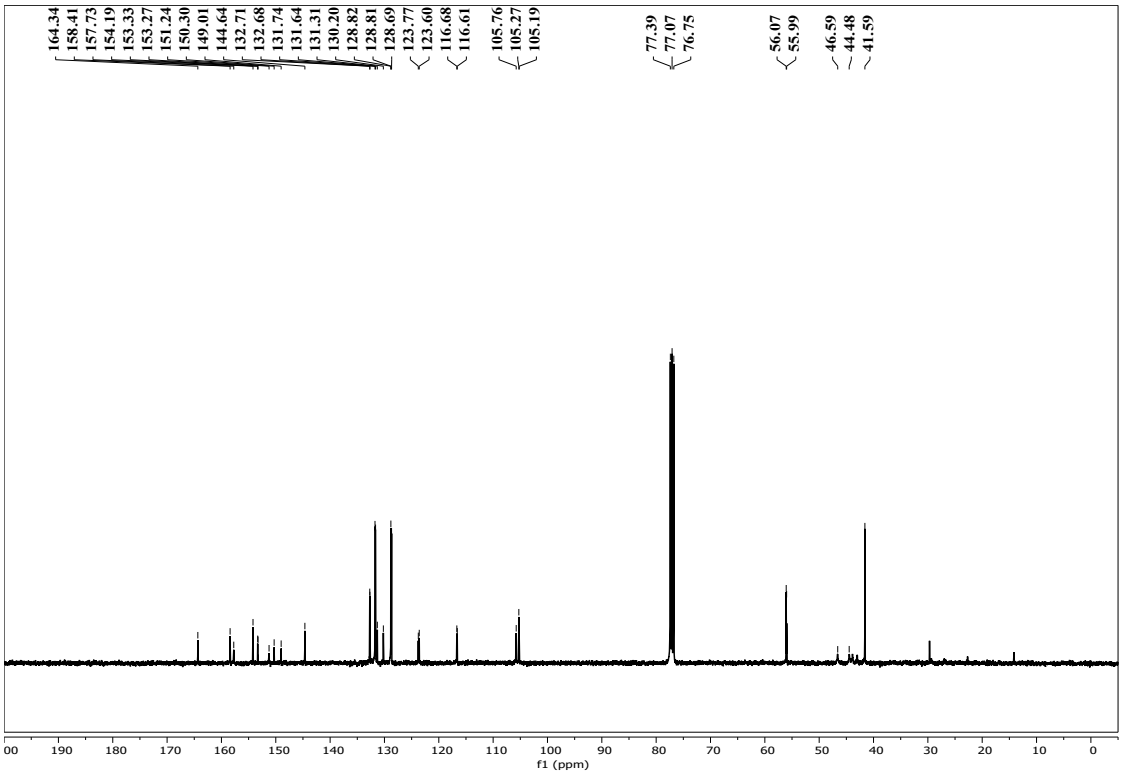




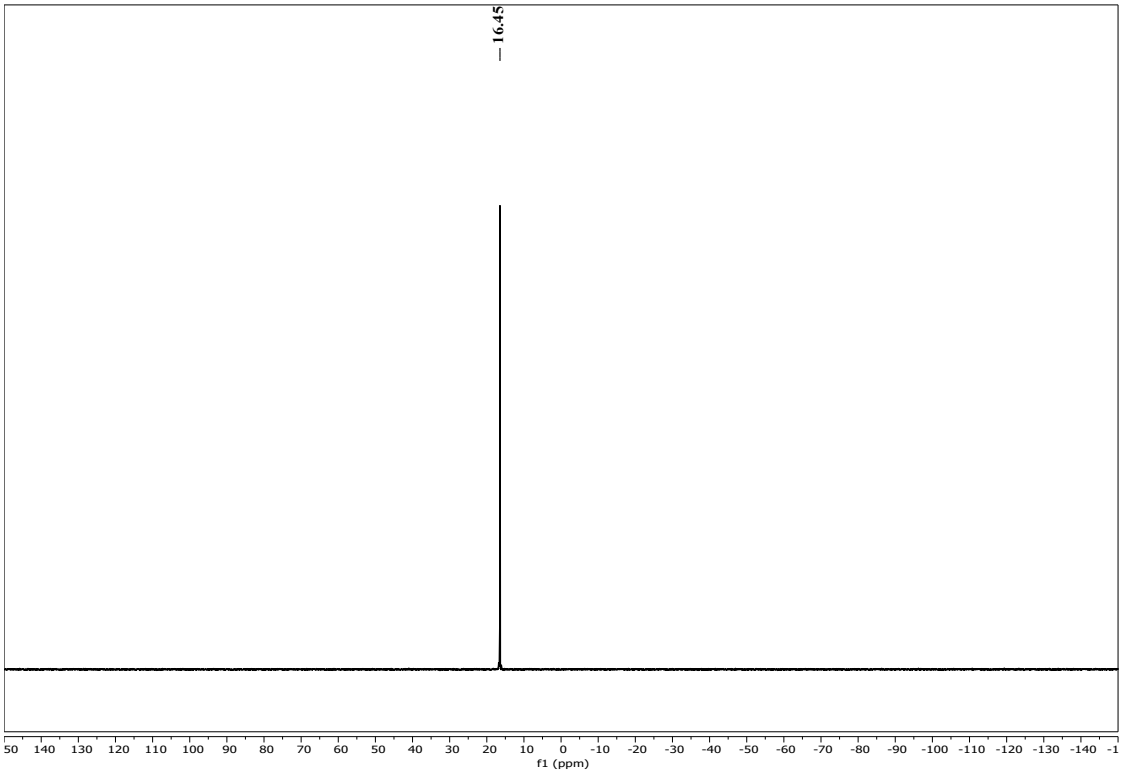
**9h,** $^{1}$H NMR (400 MHz), $CDCl_3$

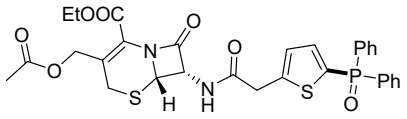



**9h**, $^{13}$C NMR (101 MHz), $CDCl_3$

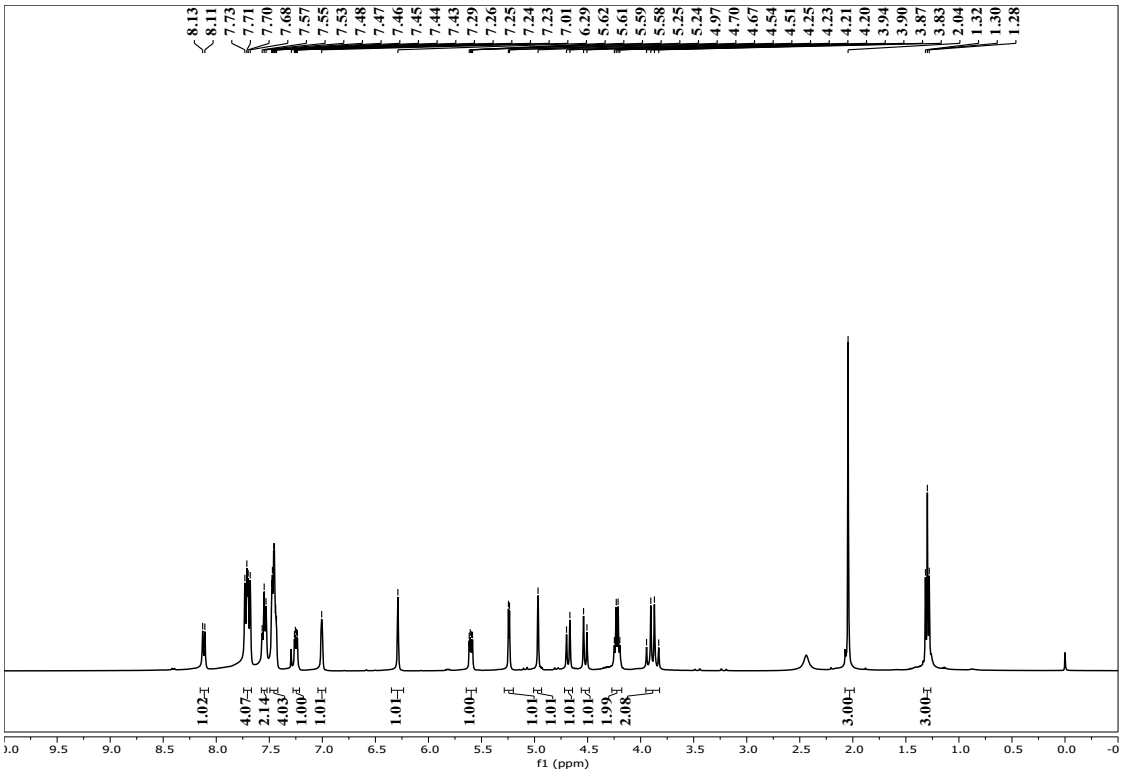


**9h**, $^{31}P$ NMR (162 MHz), $CDCl_3$

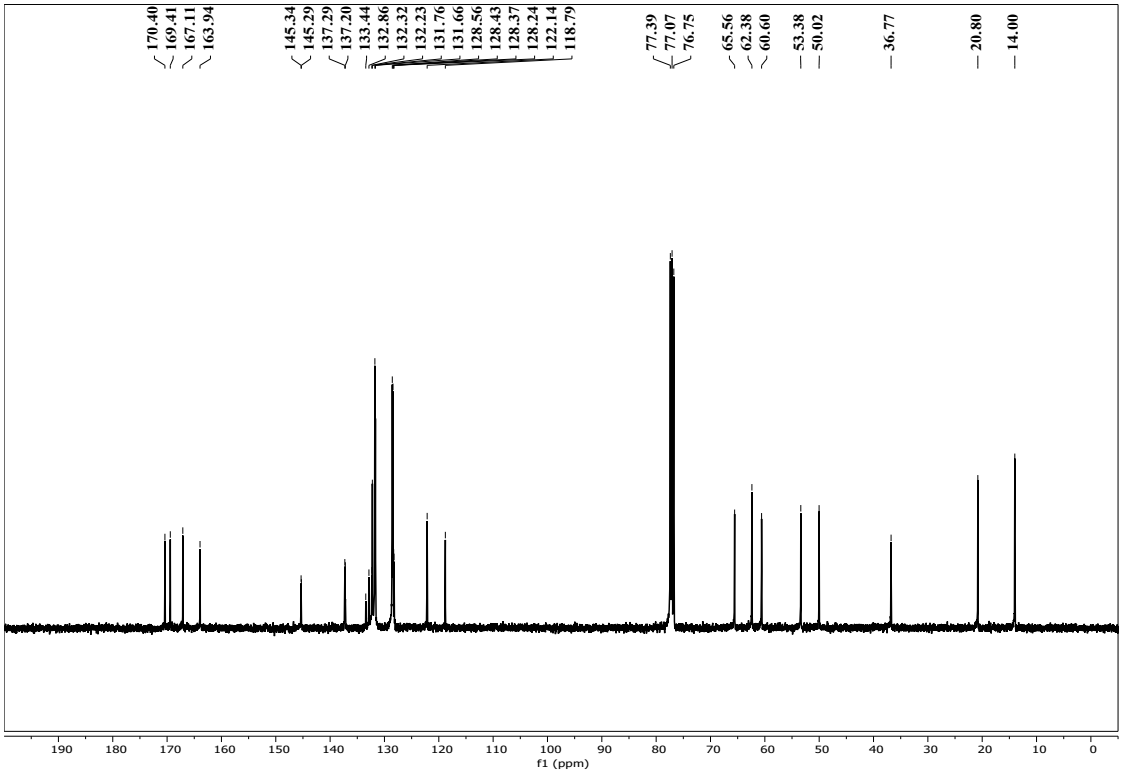




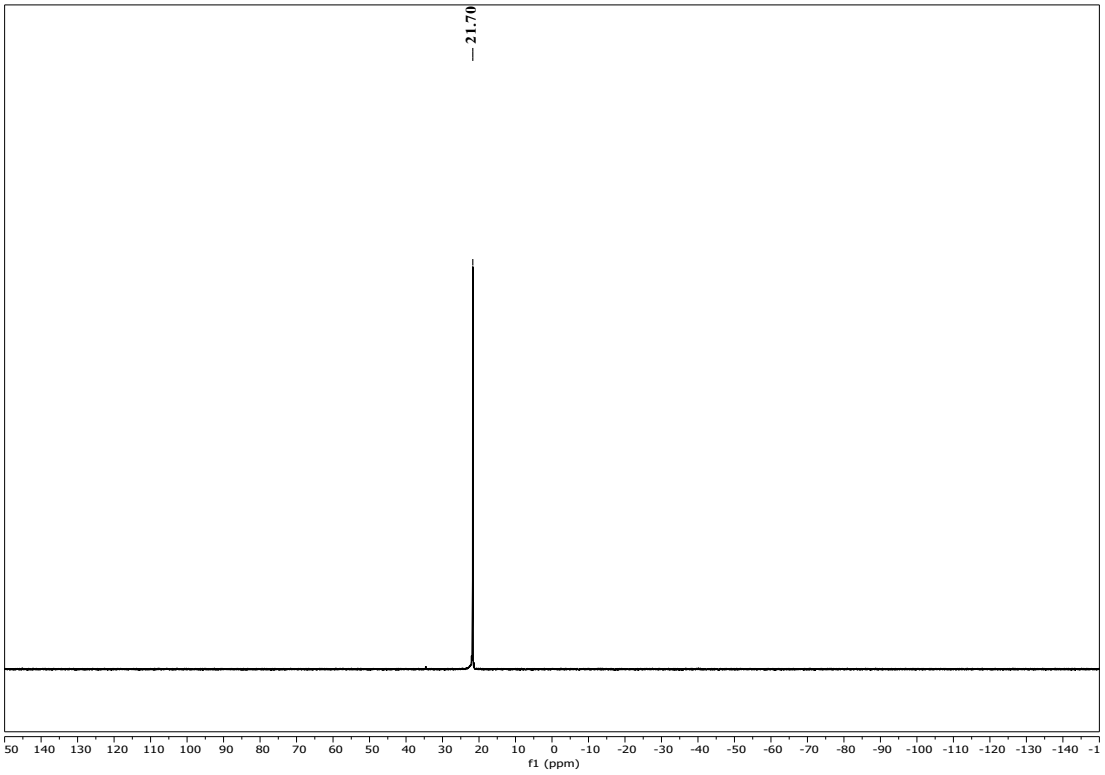

**9i,** $^{1}$H NMR (400 MHz), $CDCl_3$

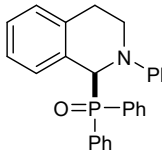



**9i**, $^{13}$C NMR (101 MHz), $CDCl_3$

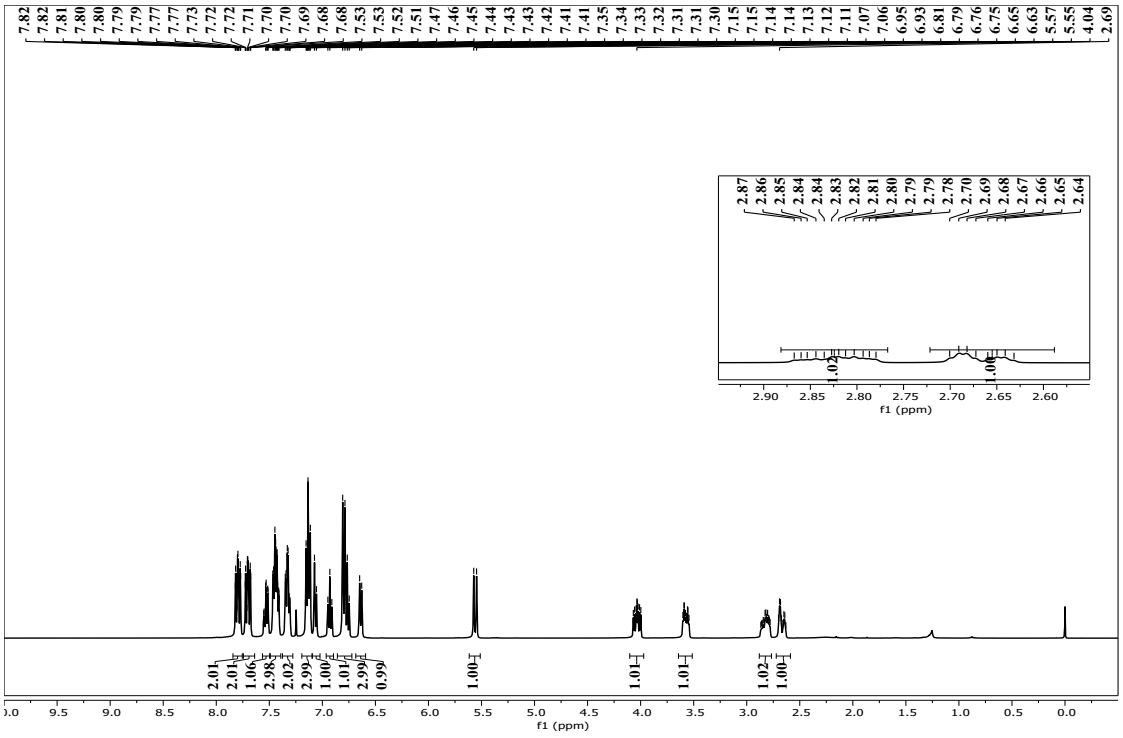


**9i**, $^{31}P$ NMR (162 MHz), $CDCl_3$

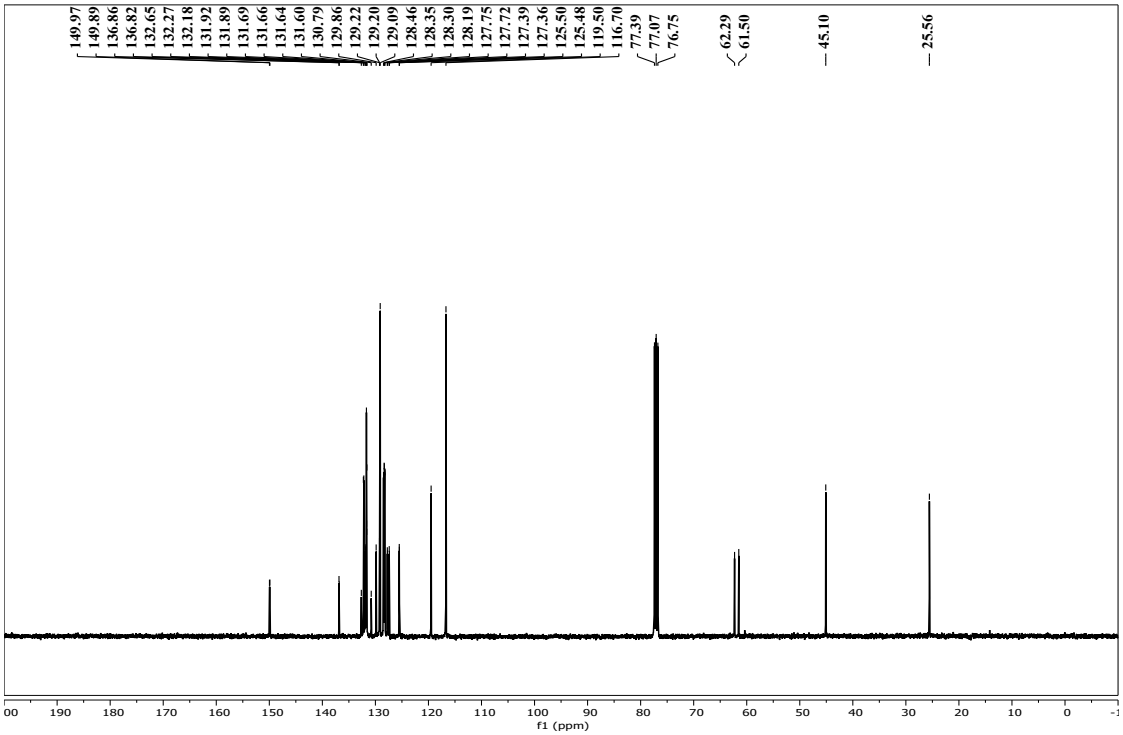




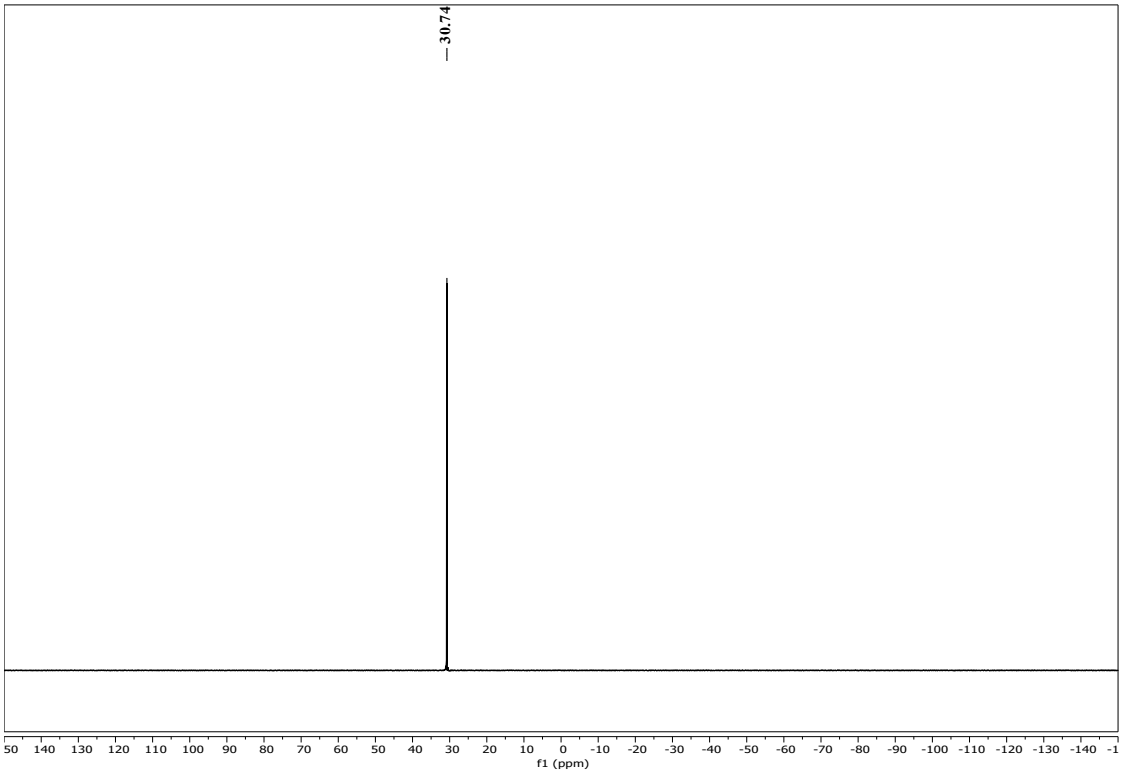

**11a,** $^{1}$H NMR (400 MHz), $CDCl_3$

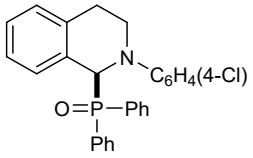



**11a**, $^{13}$C NMR (101 MHz), $CDCl_3$

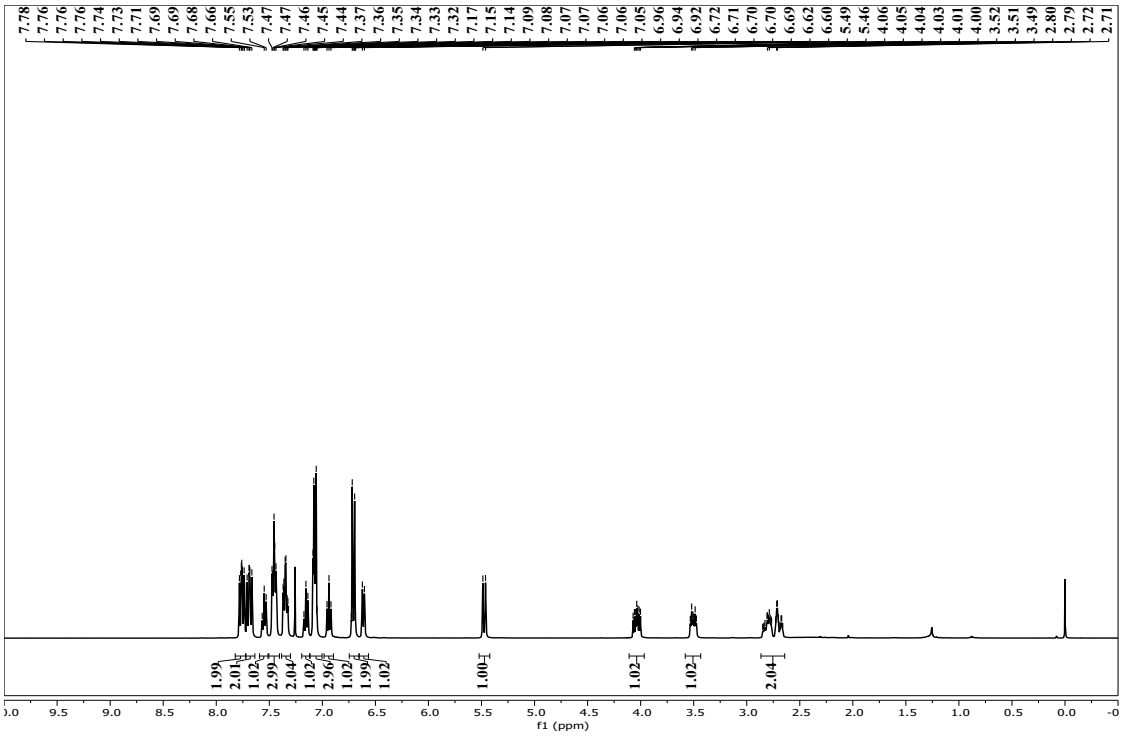


**11a**, $^{31}P$ NMR (162 MHz), $CDCl_3$

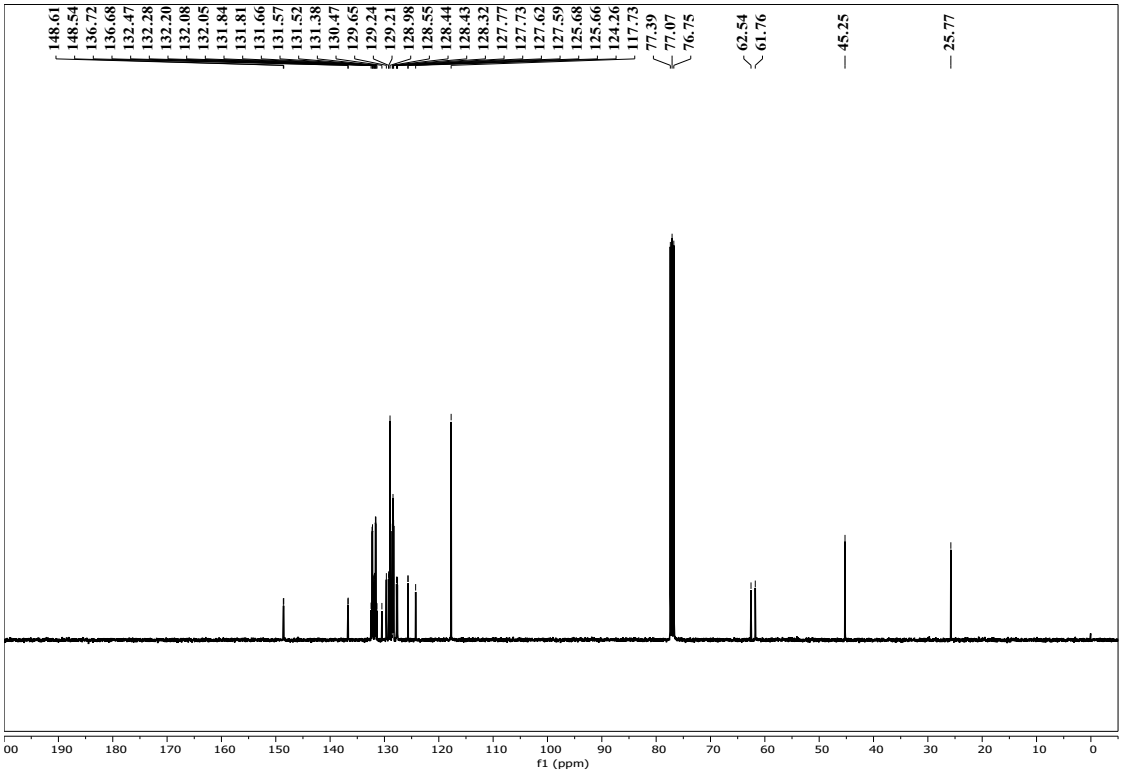




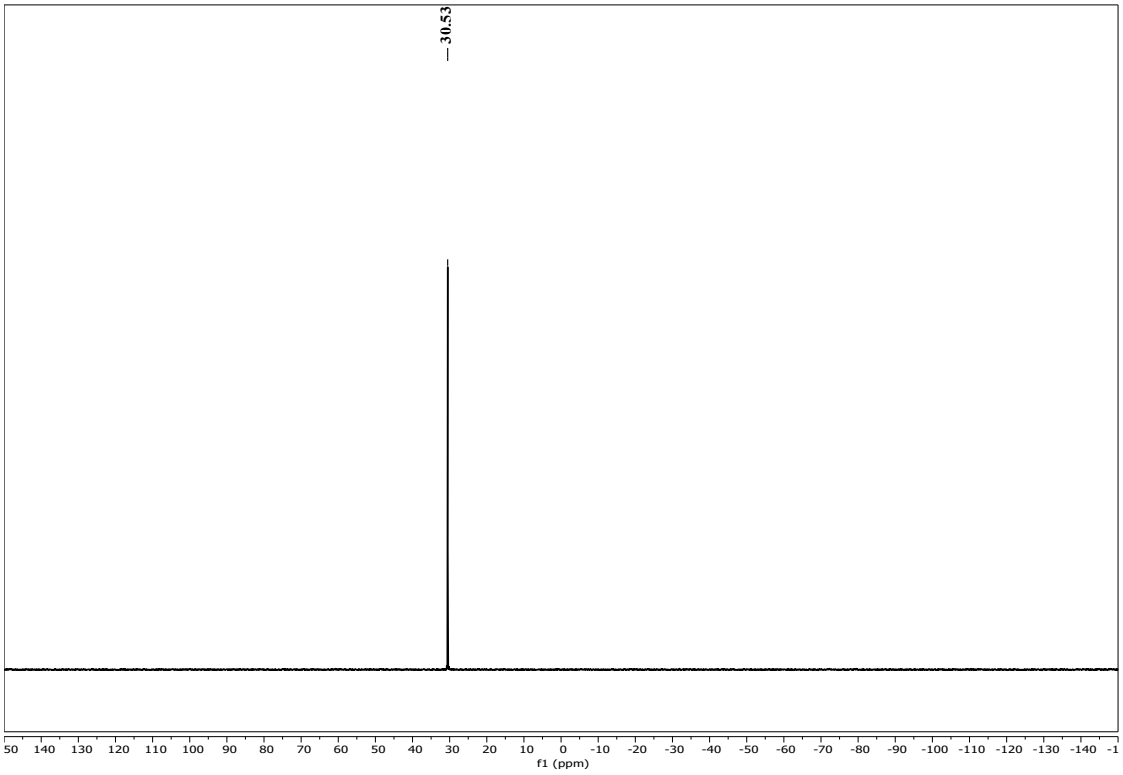

**11b,** $^{1}$H NMR (400 MHz), $CDCl_3$

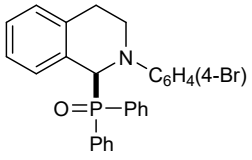



**11b**, $^{13}$C NMR (101 MHz), $CDCl_3$

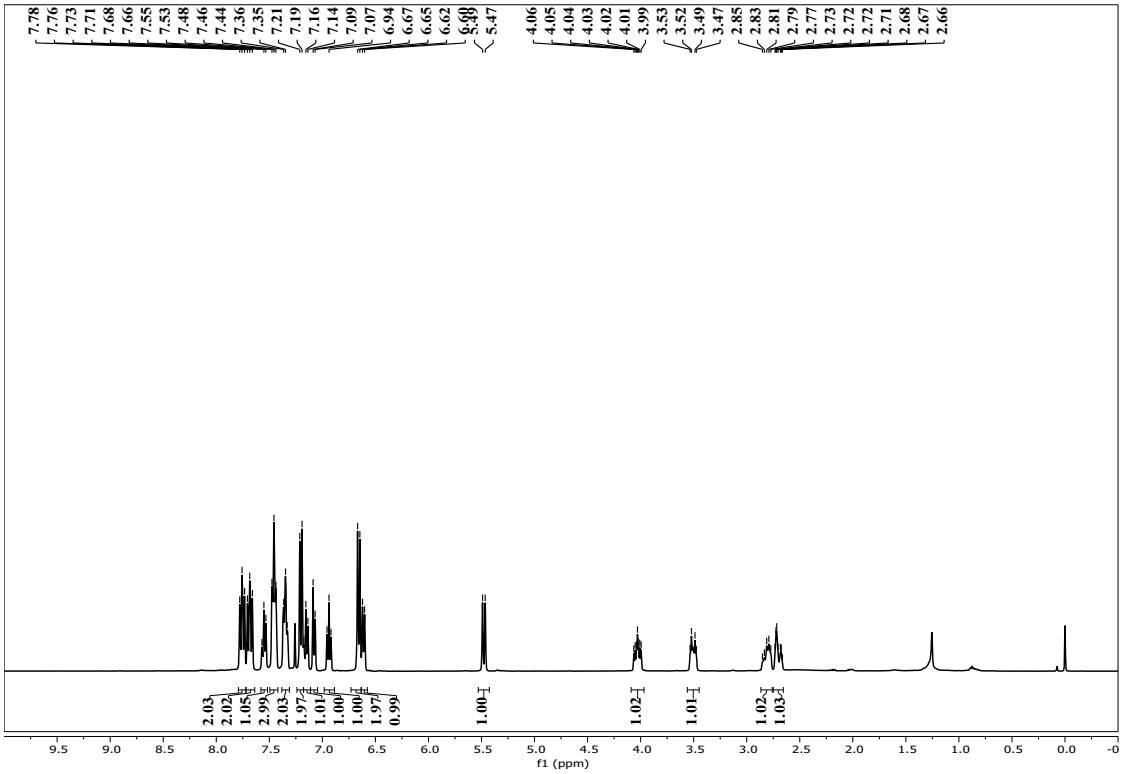


**11b**, $^{31}P$ NMR (162 MHz), $CDCl_3$

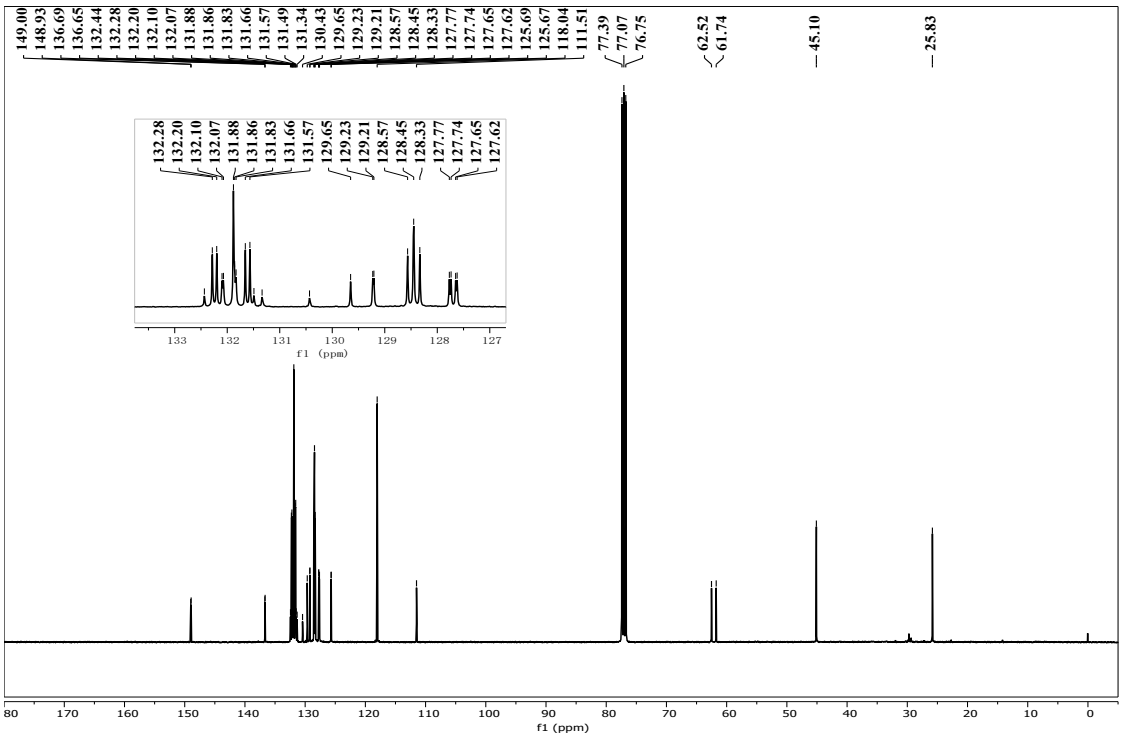




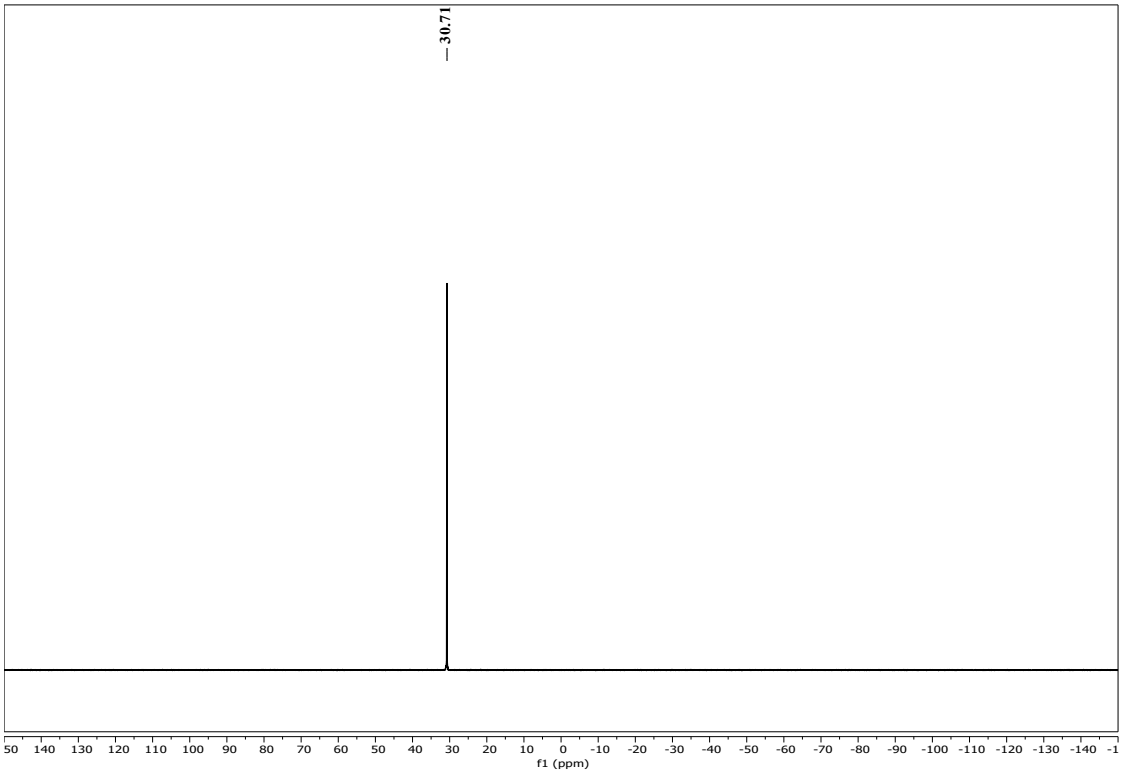

**11c,** $^{1}$H NMR (400 MHz), $CDCl_3$

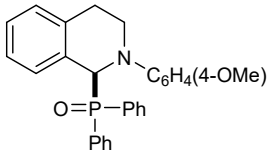



**11c**, $^{13}$C NMR (101 MHz), $CDCl_3$

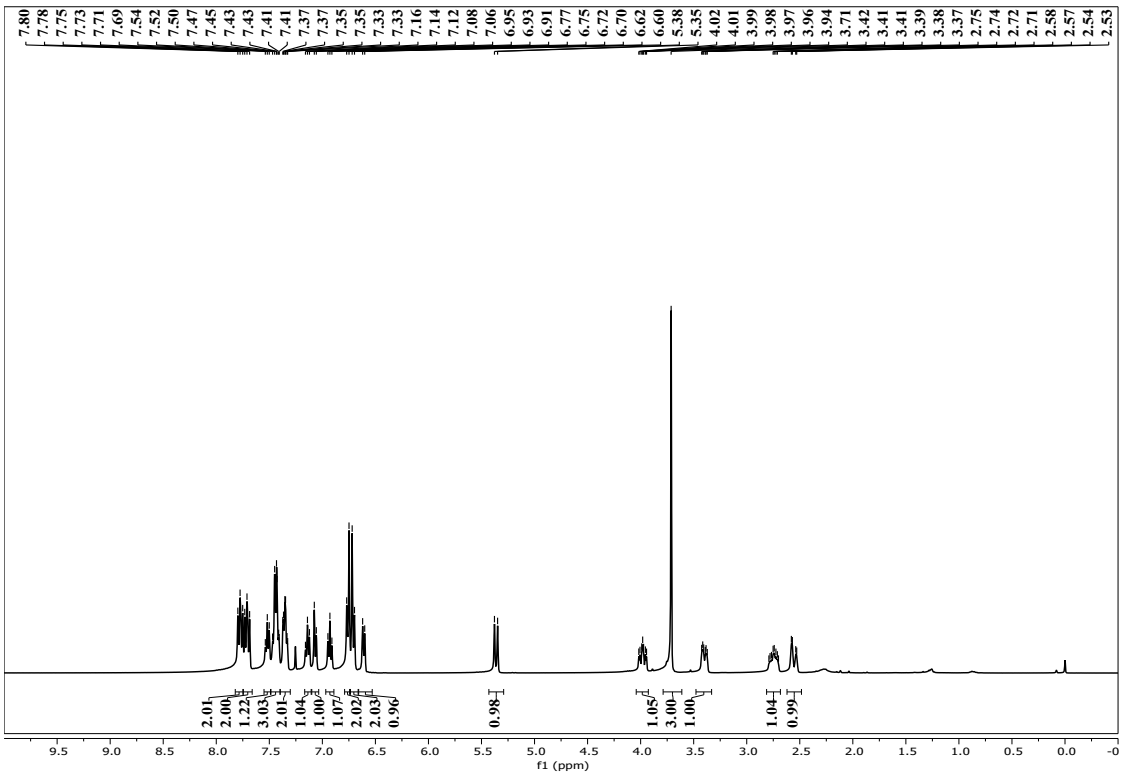


**11c**, $^{31}P$ NMR (162 MHz), $CDCl_3$

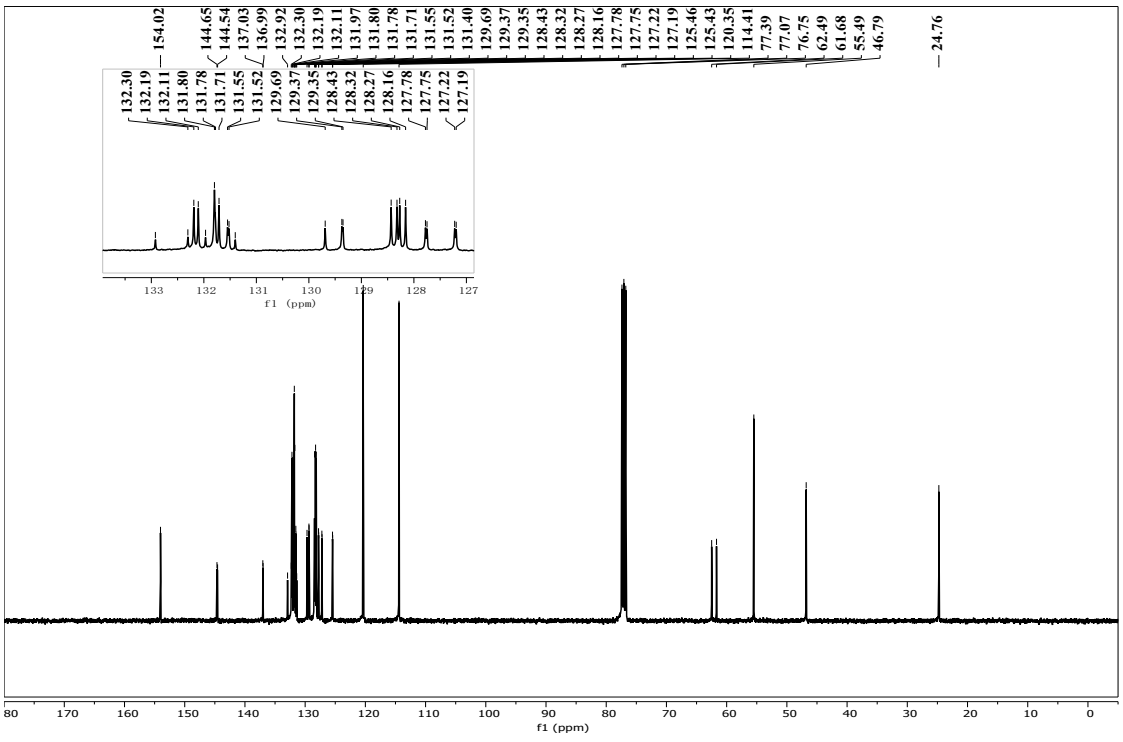




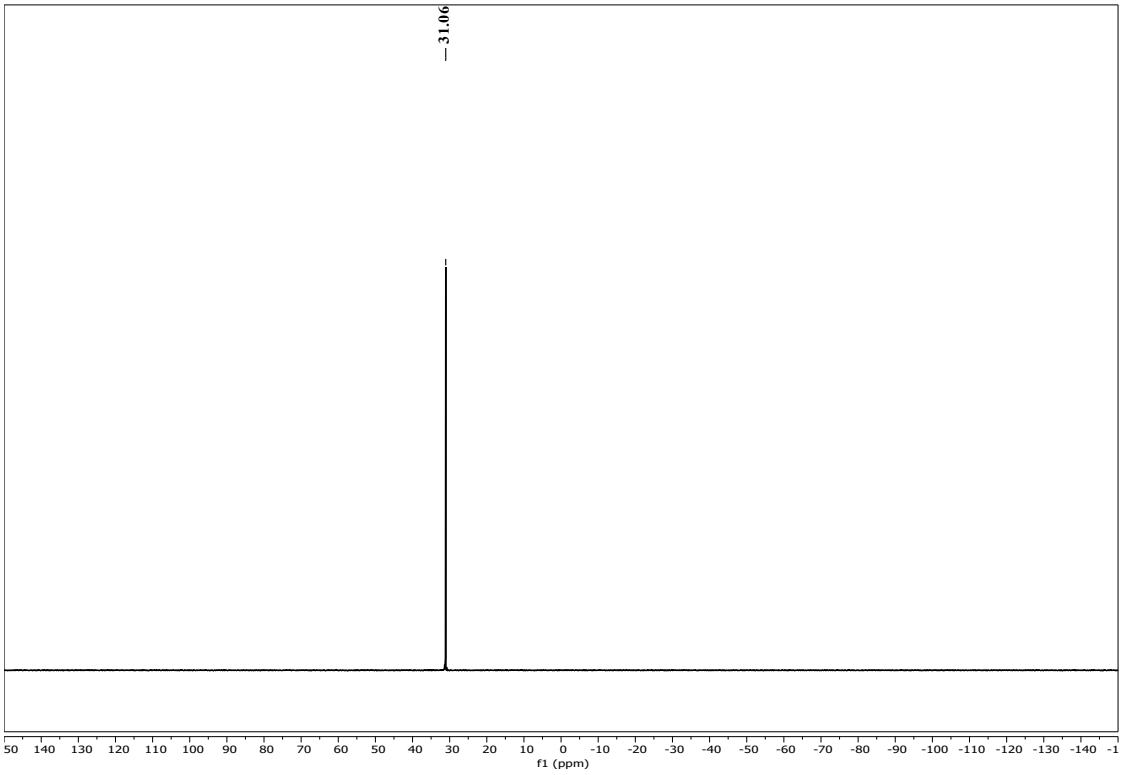

**11d,** $^{1}$H NMR (400 MHz), $CDCl_3$

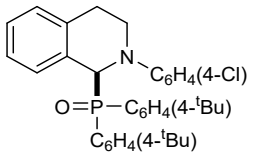



**11d**, $^{13}$C NMR (101 MHz), $CDCl_3$

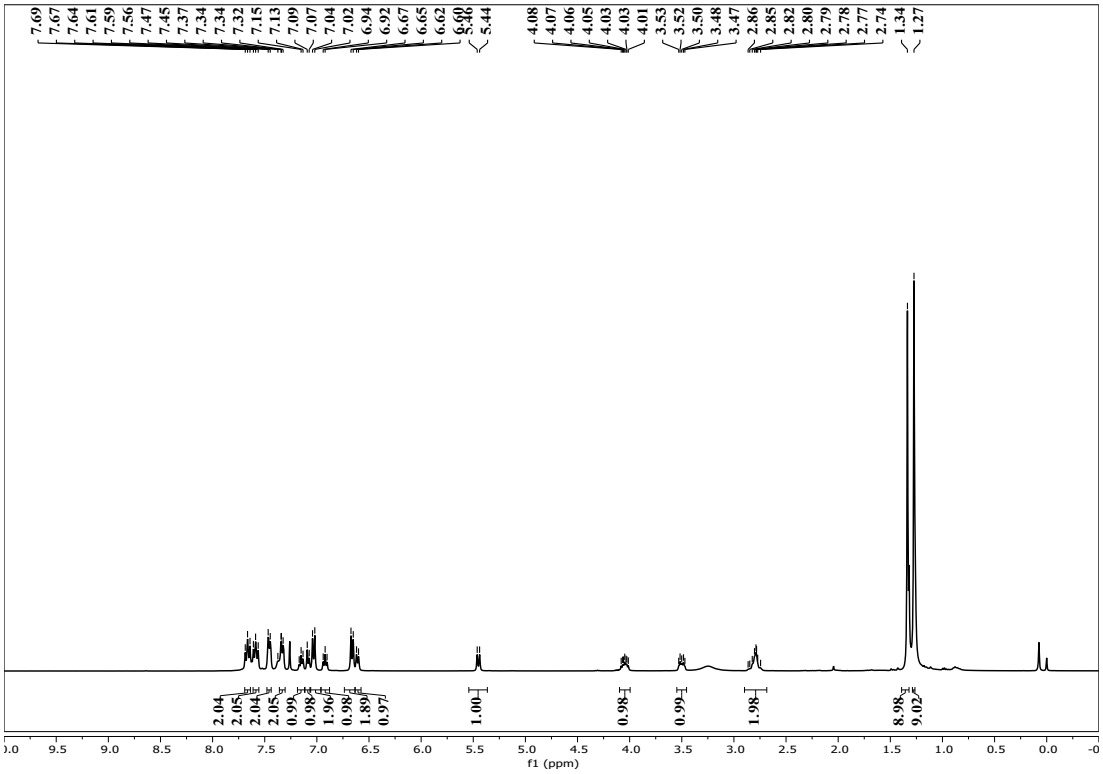


**11d**, $^{31}P$ NMR (162 MHz), $CDCl_3$

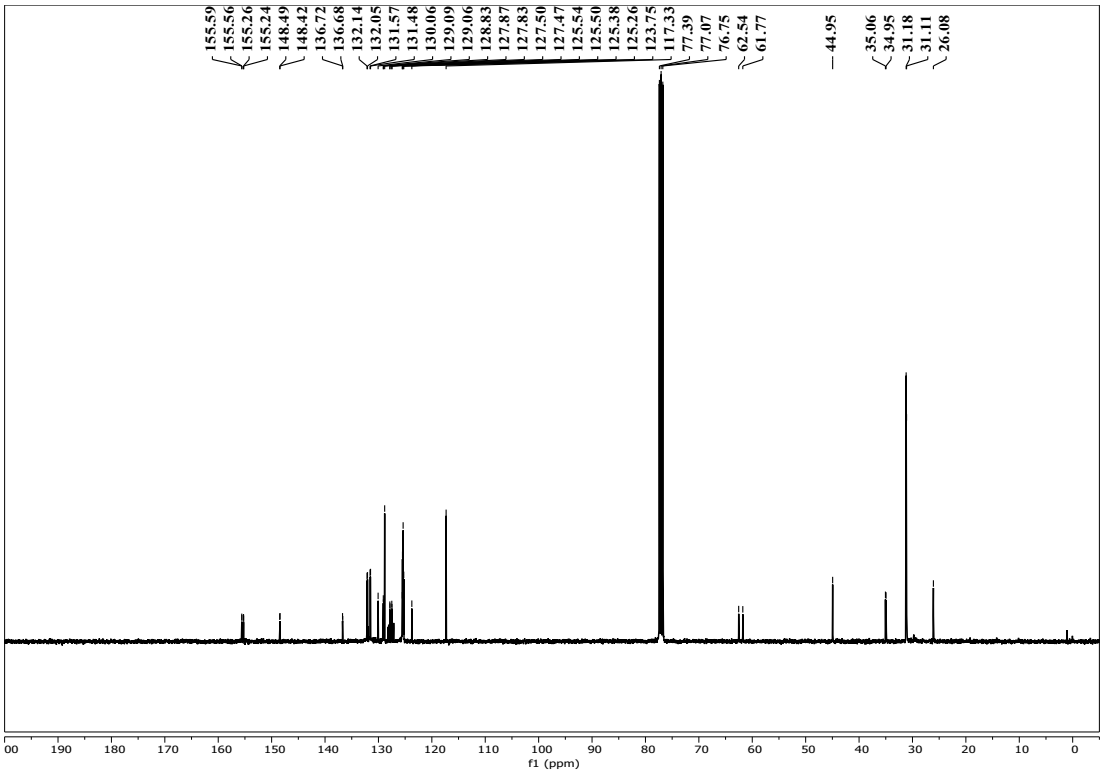




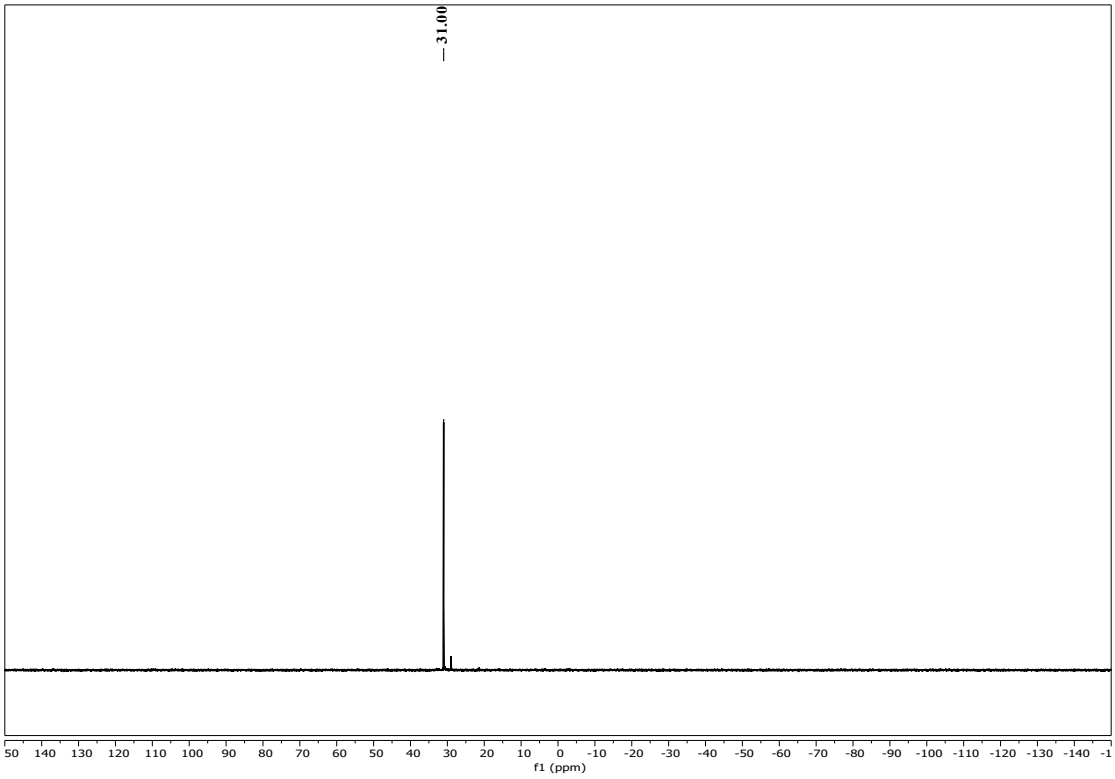

**11e,** $^{1}$H NMR (400 MHz), $CDCl_3$

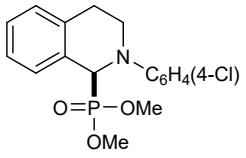



**11e**, $^{13}$C NMR (101 MHz), $CDCl_3$

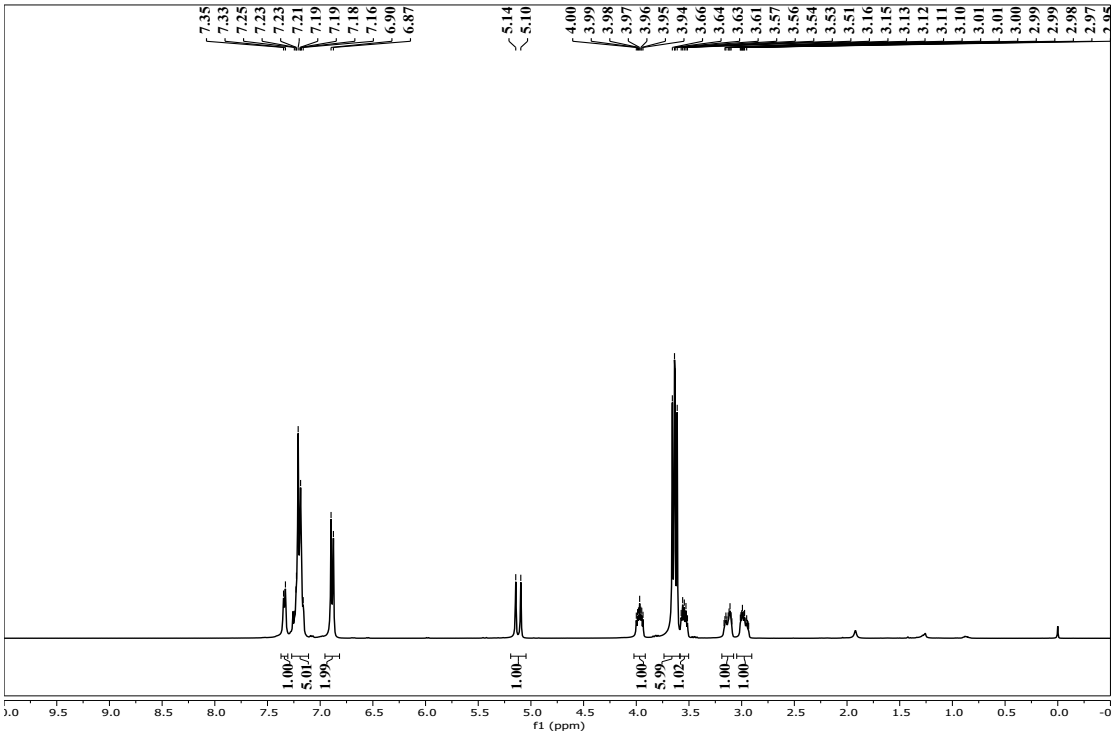


**11e**, $^{31}P$ NMR (162 MHz), $CDCl_3$

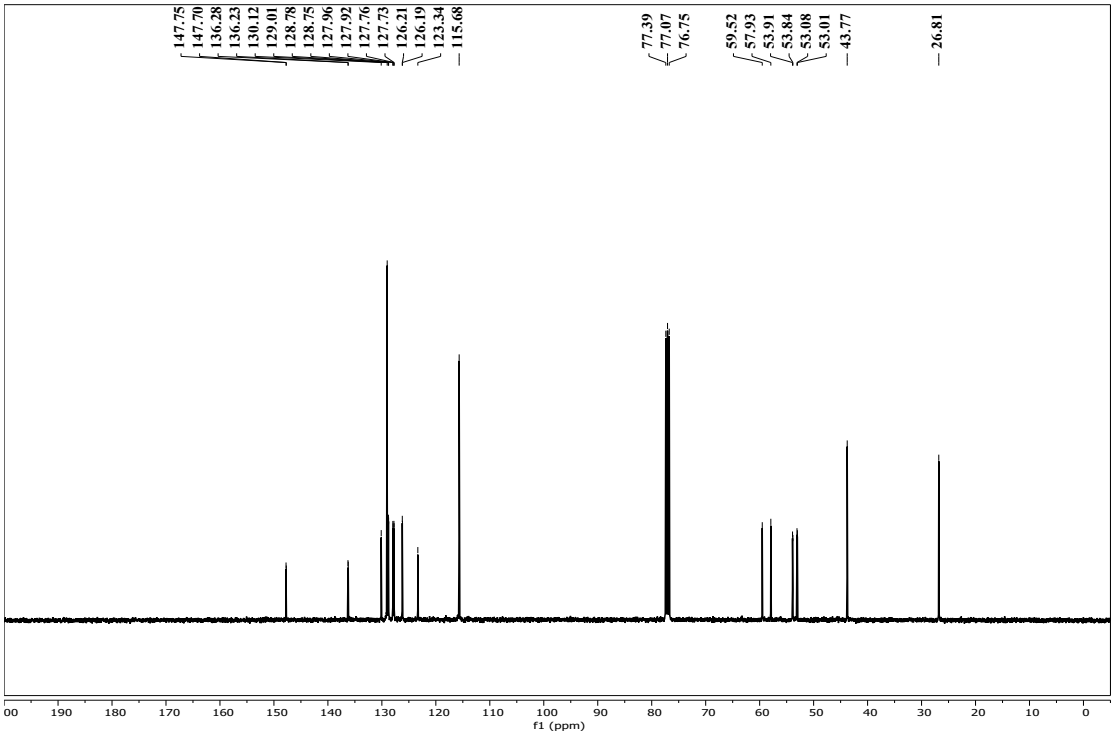




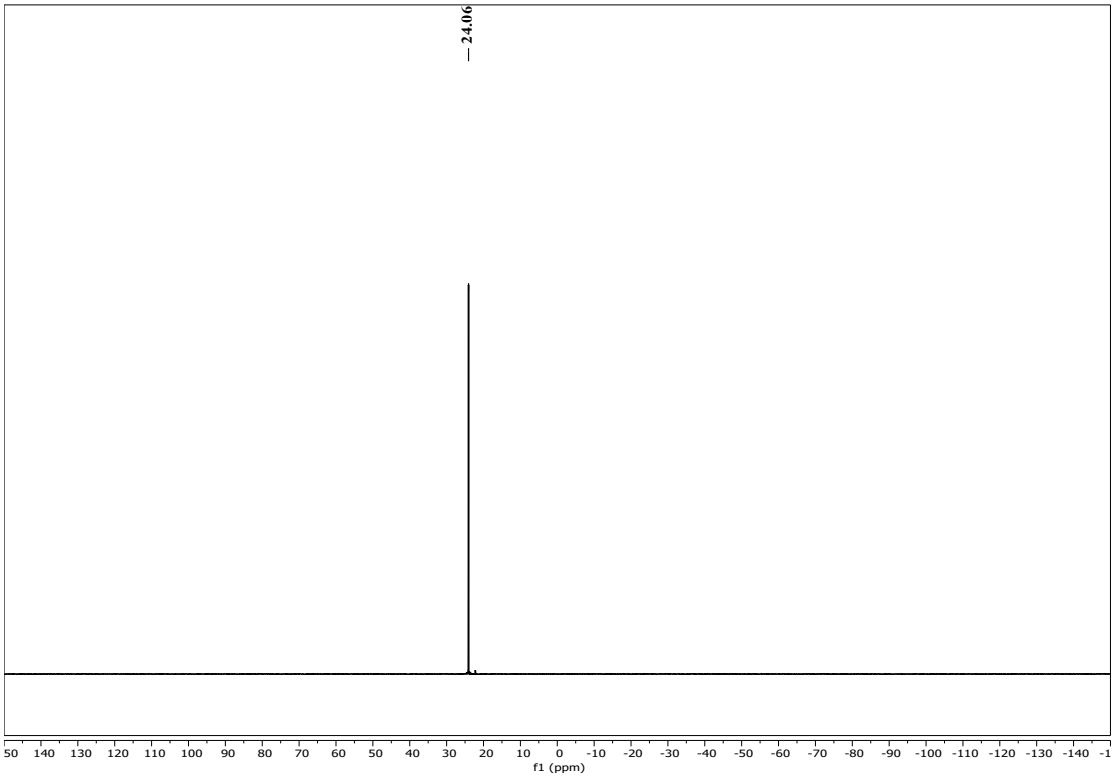

**11f,** $^{1}$H NMR (400 MHz), $CDCl_3$

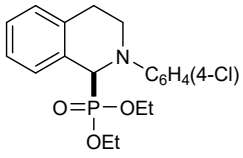



**11f**, $^{13}$C NMR (101 MHz), $CDCl_3$

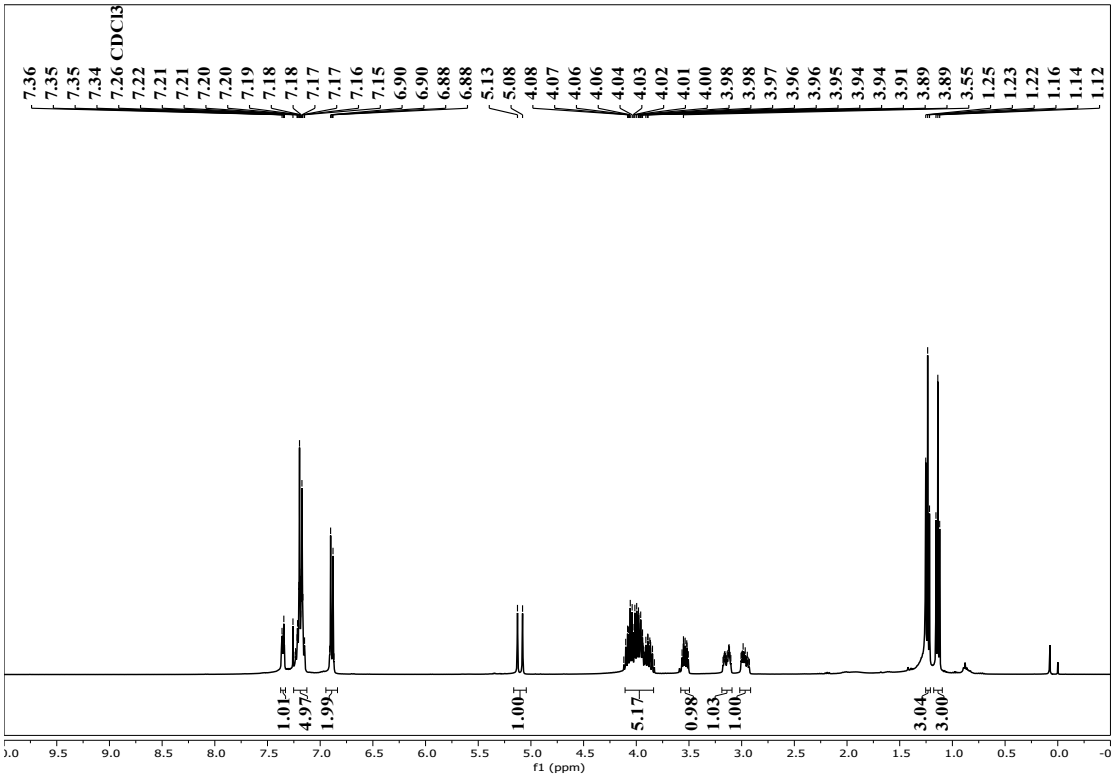


**11f**, $^{31}P$ NMR (162 MHz), $CDCl_3$

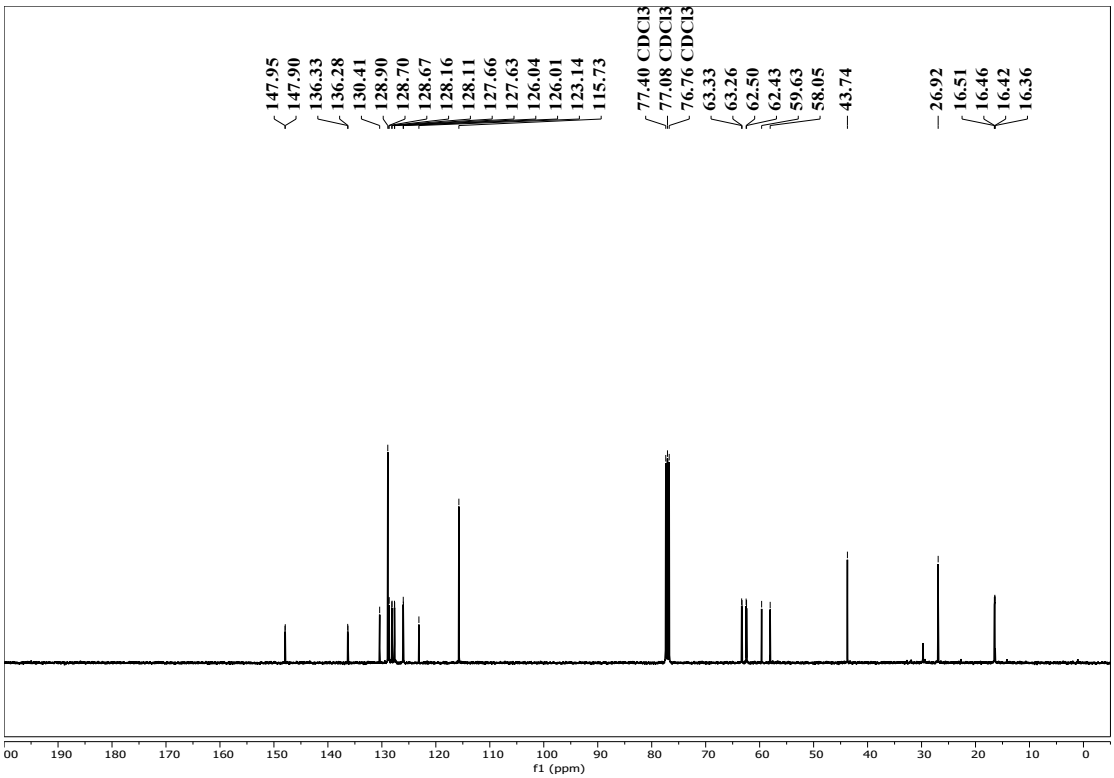




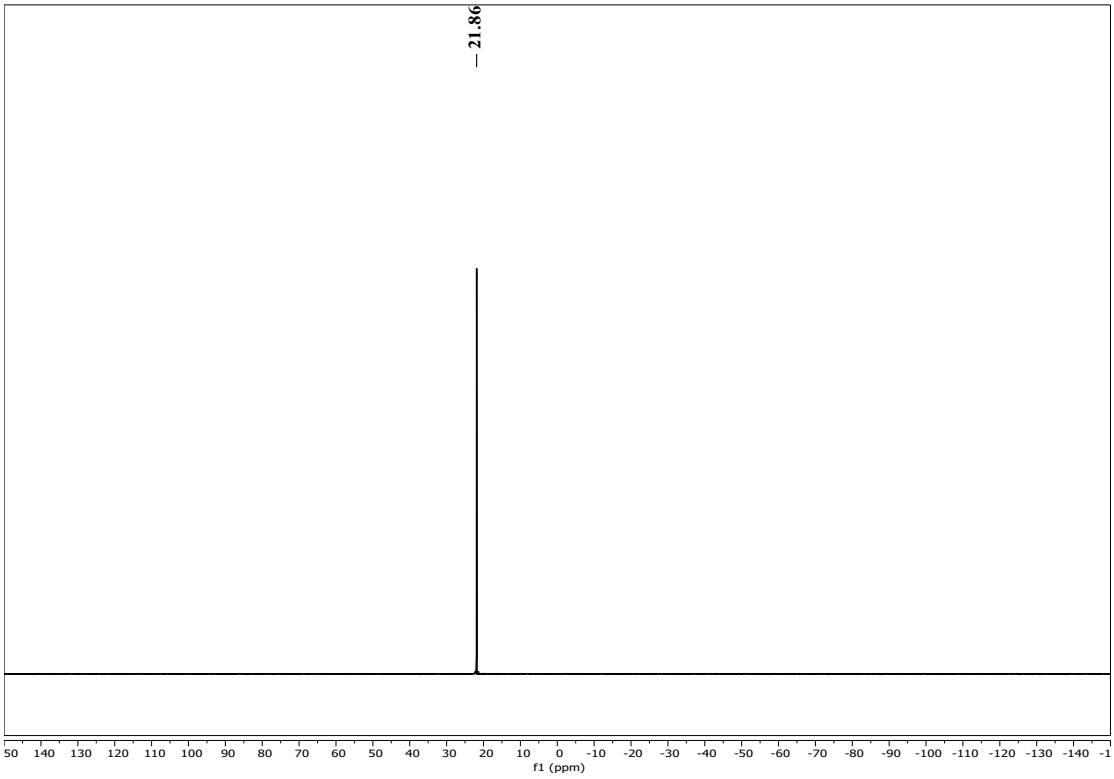

**11g,** $^{1}$H NMR (400 MHz), $CDCl_3$

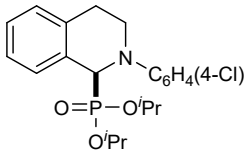



**11g**, $^{13}$C NMR (101 MHz), $CDCl_3$

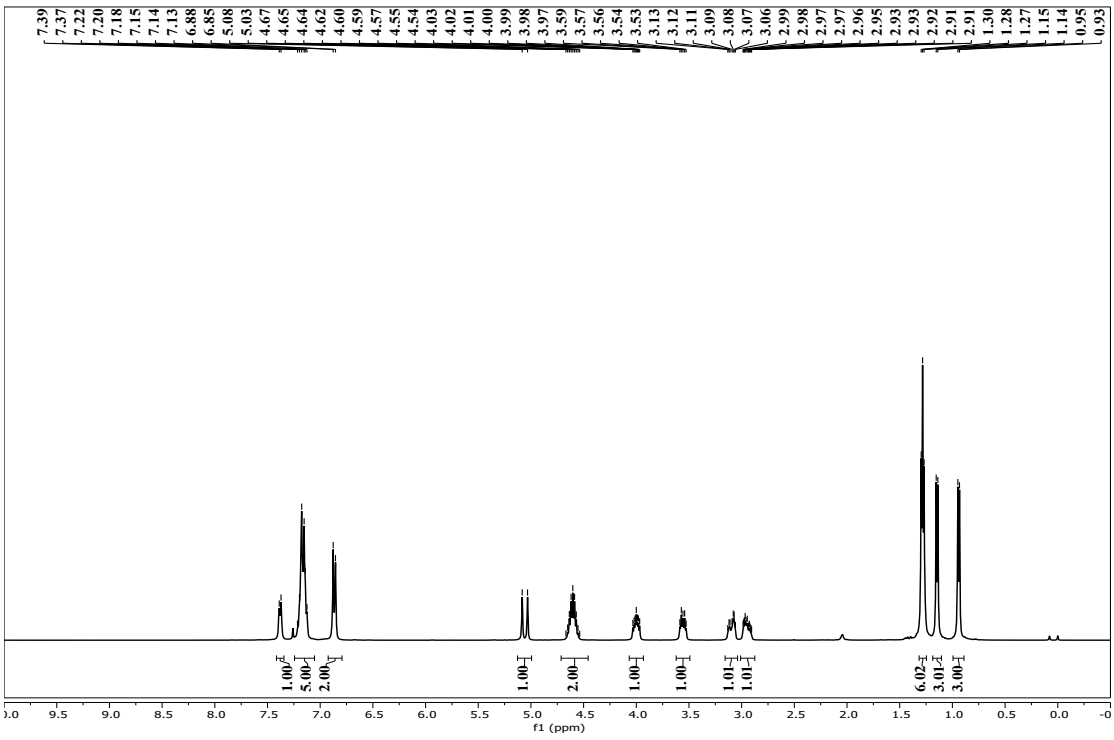


**11g**, $^{31}P$ NMR (162 MHz), $CDCl_3$

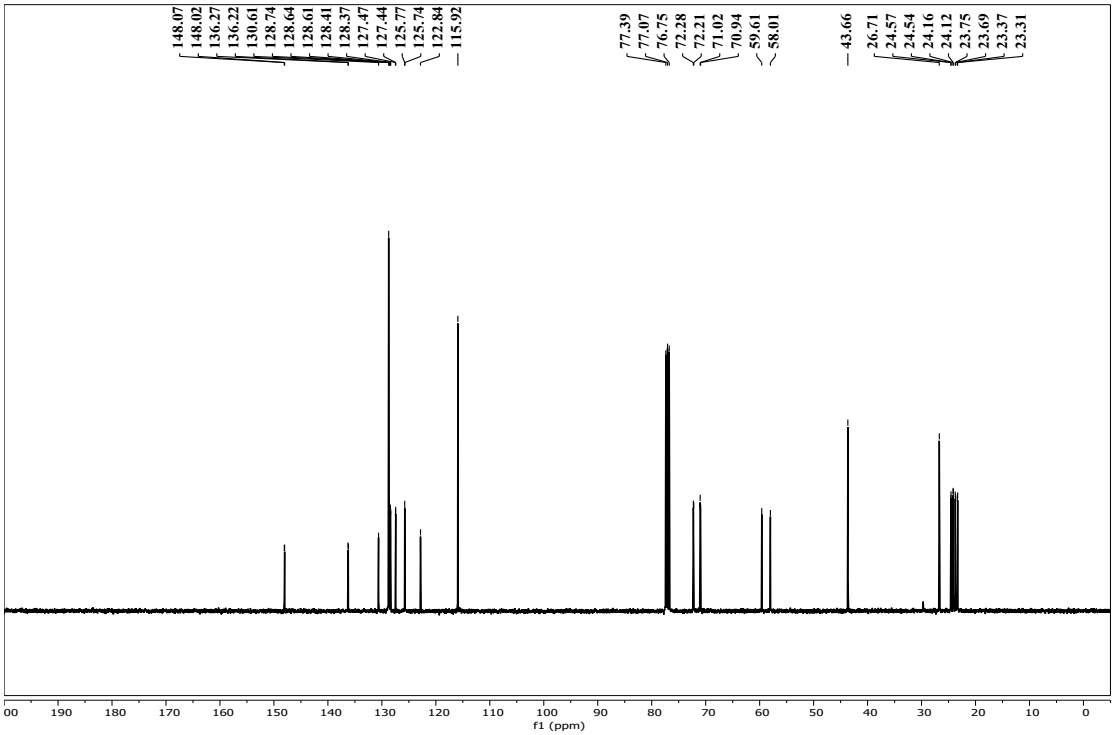




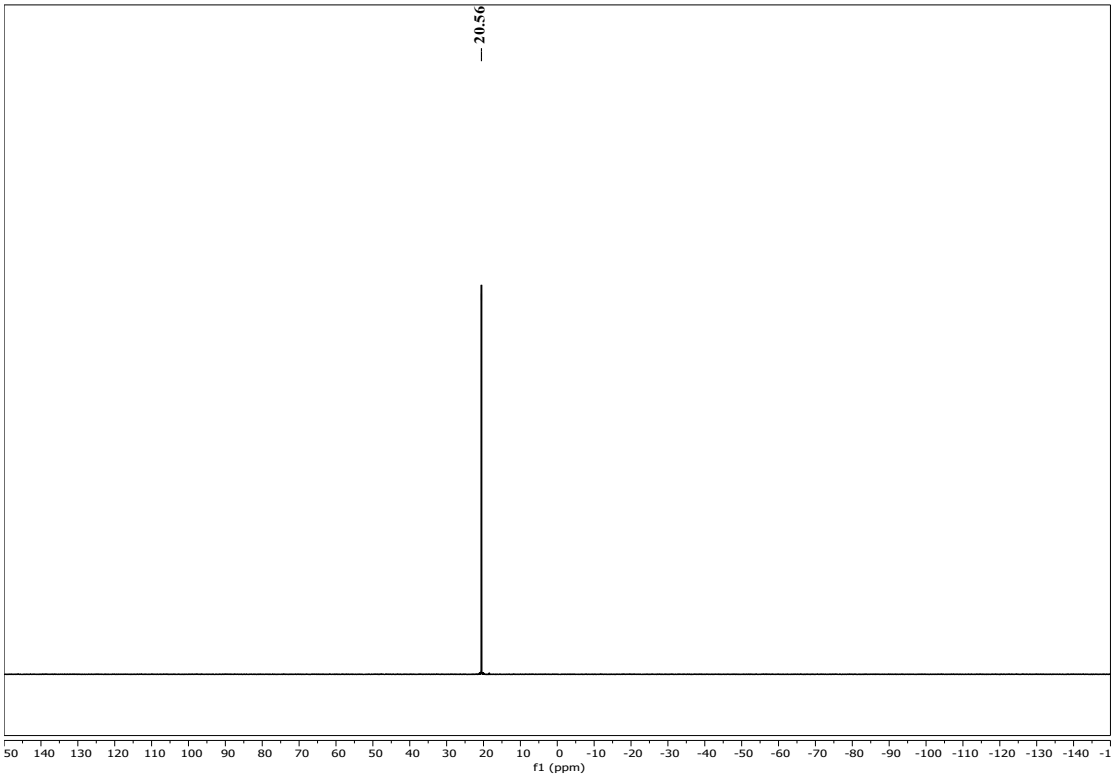

**11h,** $^{1}$H NMR (400 MHz), $CDCl_3$

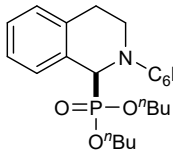



**11h**, $^{13}$C NMR (101 MHz), $CDCl_3$

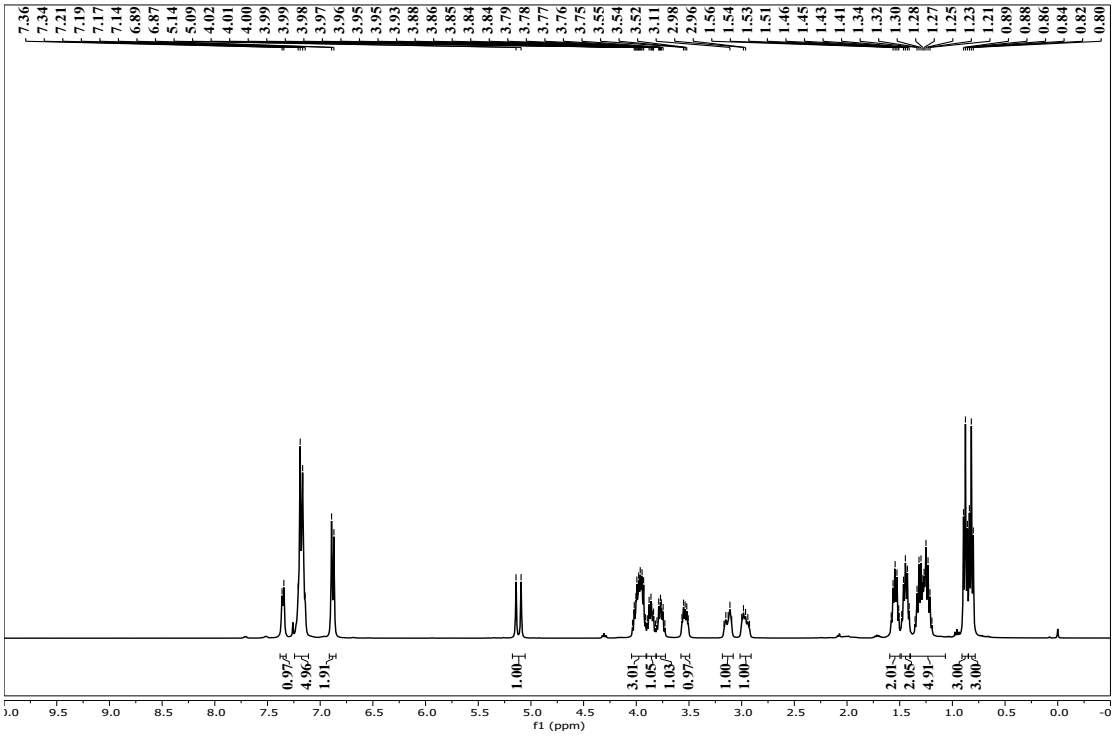


**11h**, $^{31}P$ NMR (162 MHz), $CDCl_3$

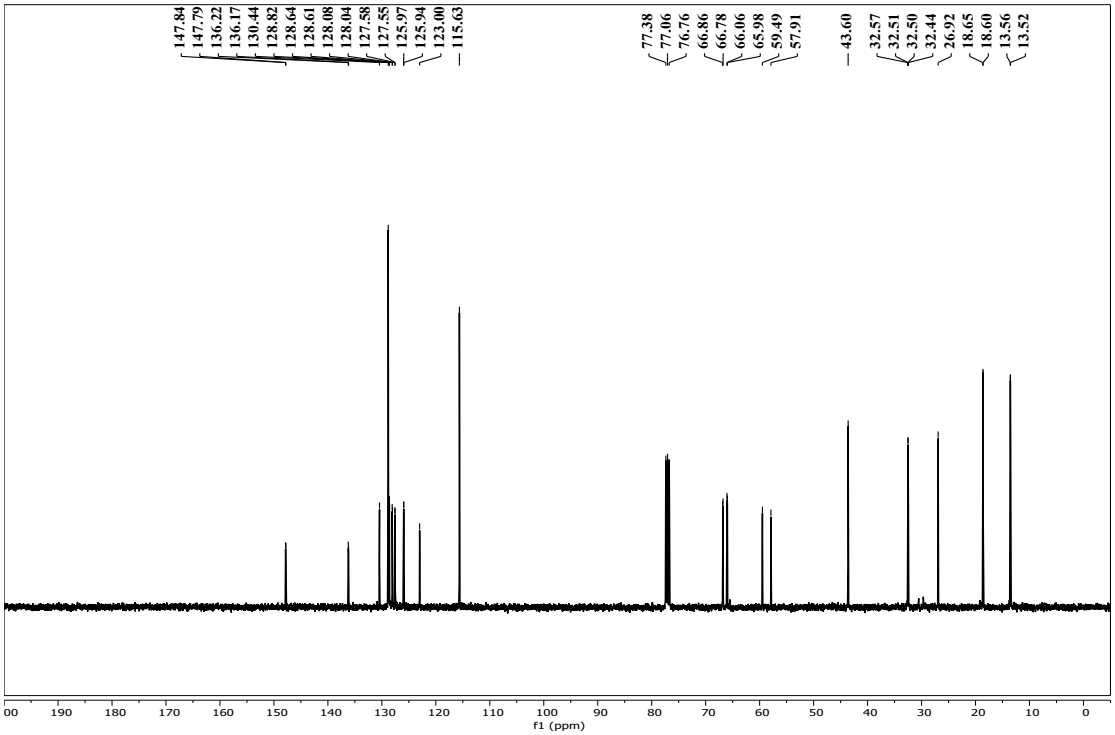




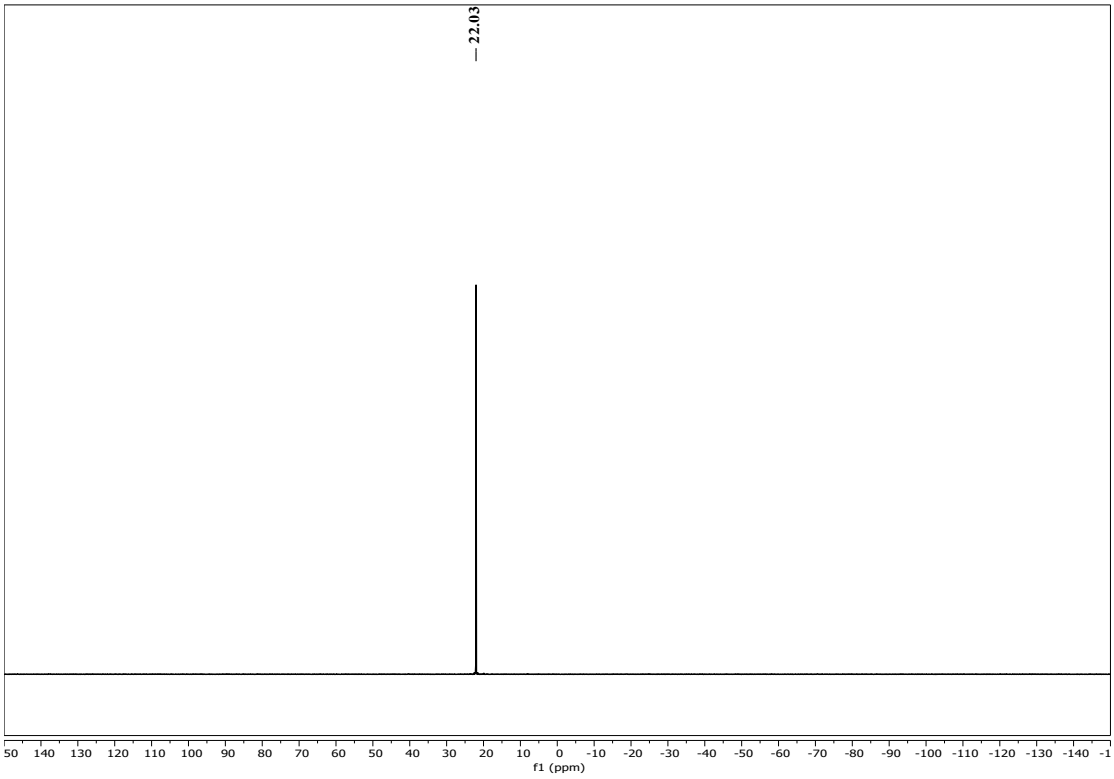

**11i,** $^1$H NMR (400 MHz), $CDCl_3$

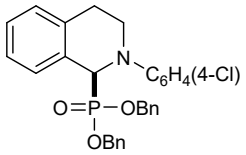



**11i**, $^{13}$C NMR (101 MHz), $CDCl_3$

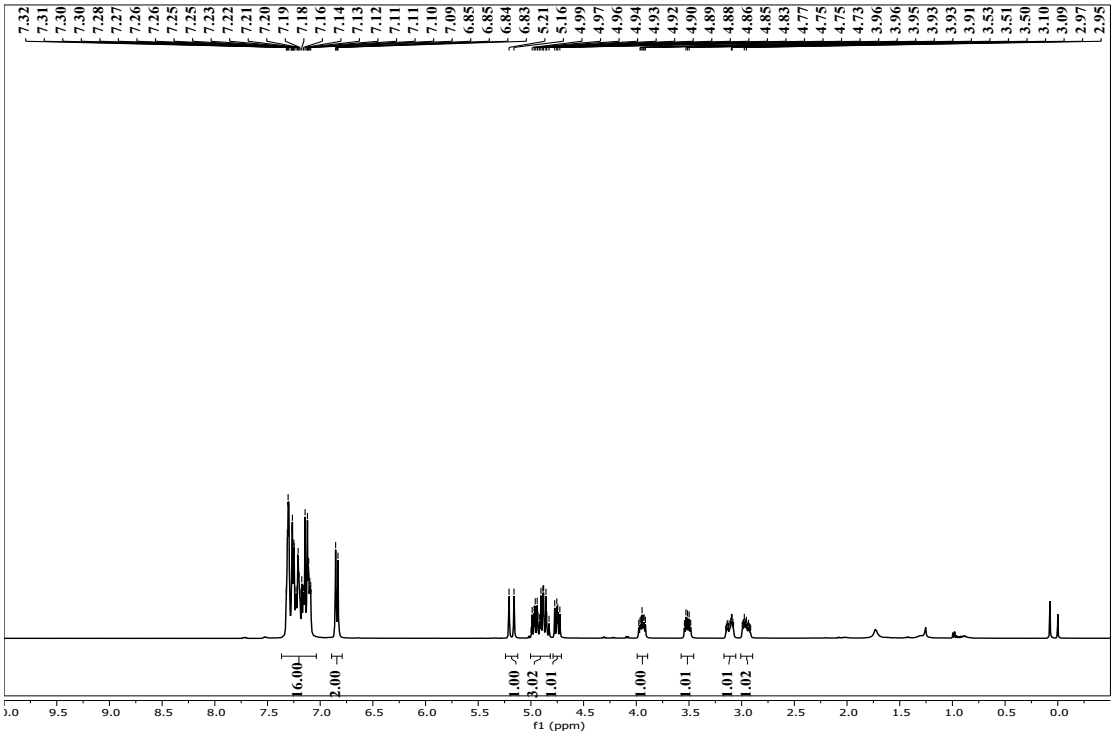


**11i**, $^{31}P$ NMR (162 MHz), $CDCl_3$

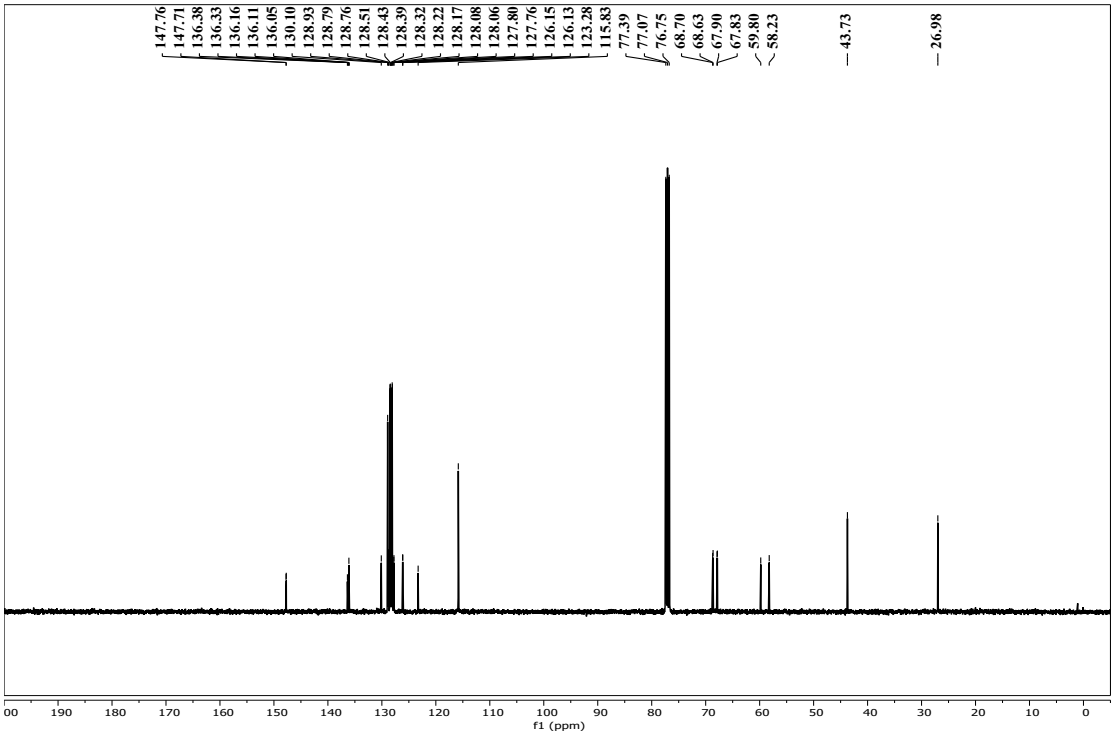




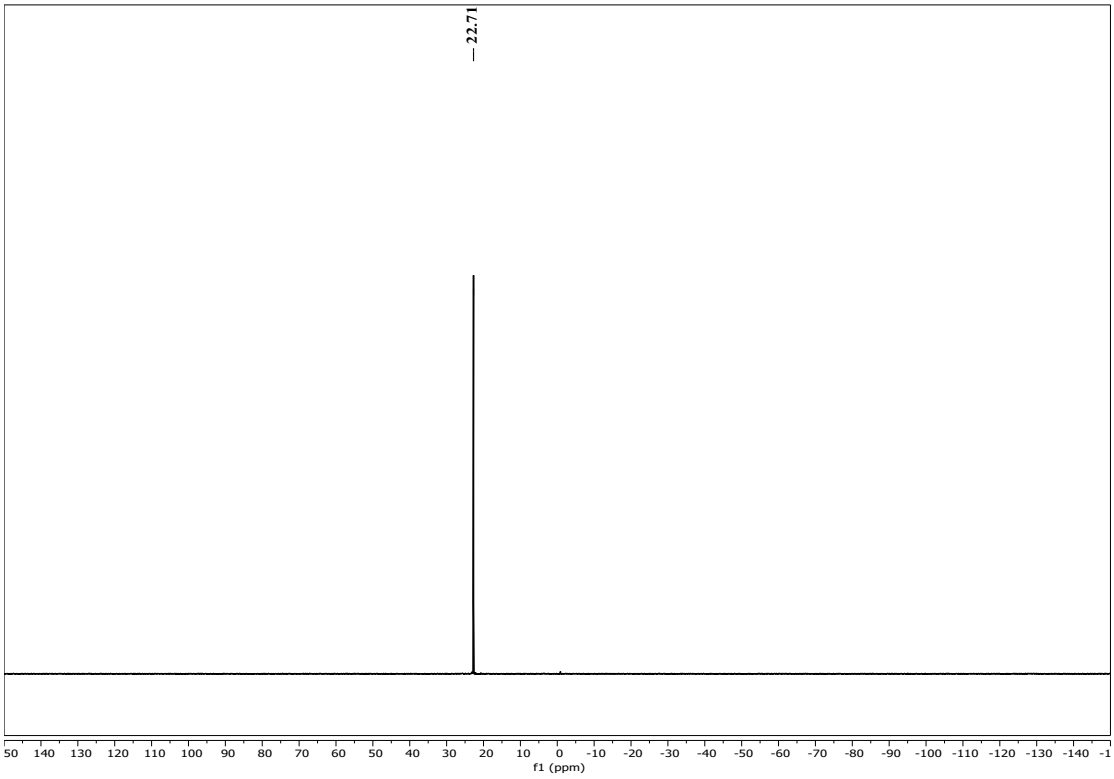

**11j,** $^{1}$H NMR (400 MHz), $CDCl_3$

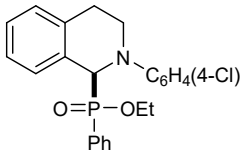



**11j**, $^{13}$C NMR (101 MHz), $CDCl_3$

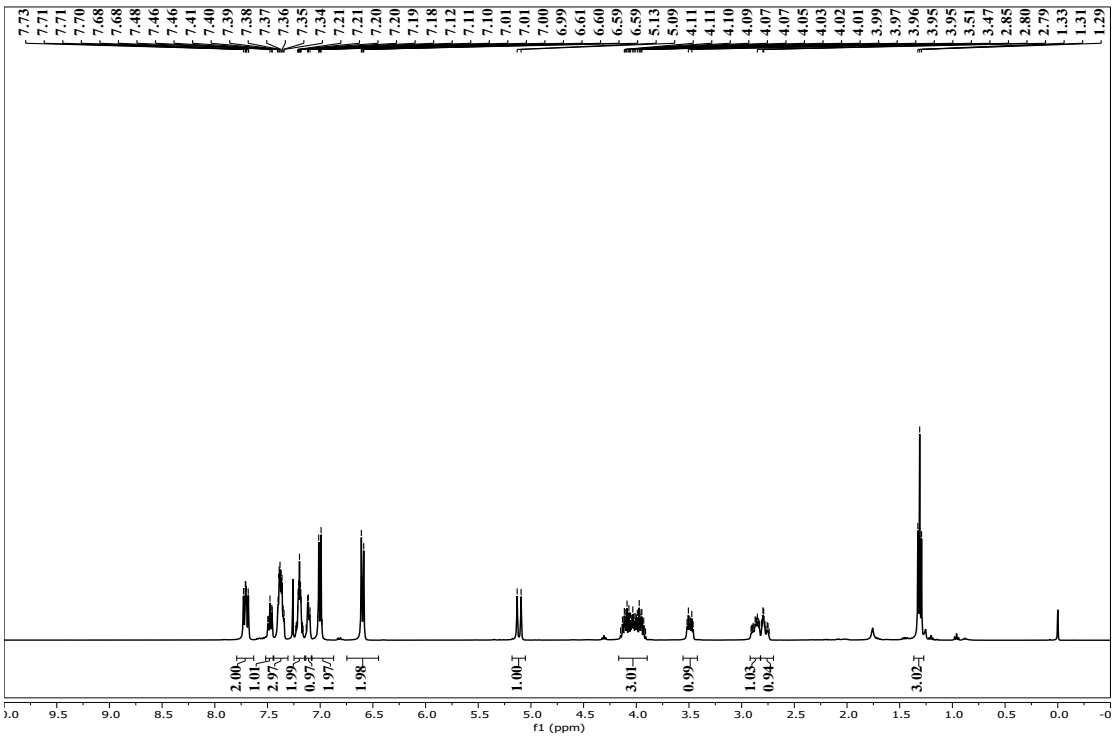


**11j**, $^{31}P$ NMR (162 MHz), $CDCl_3$

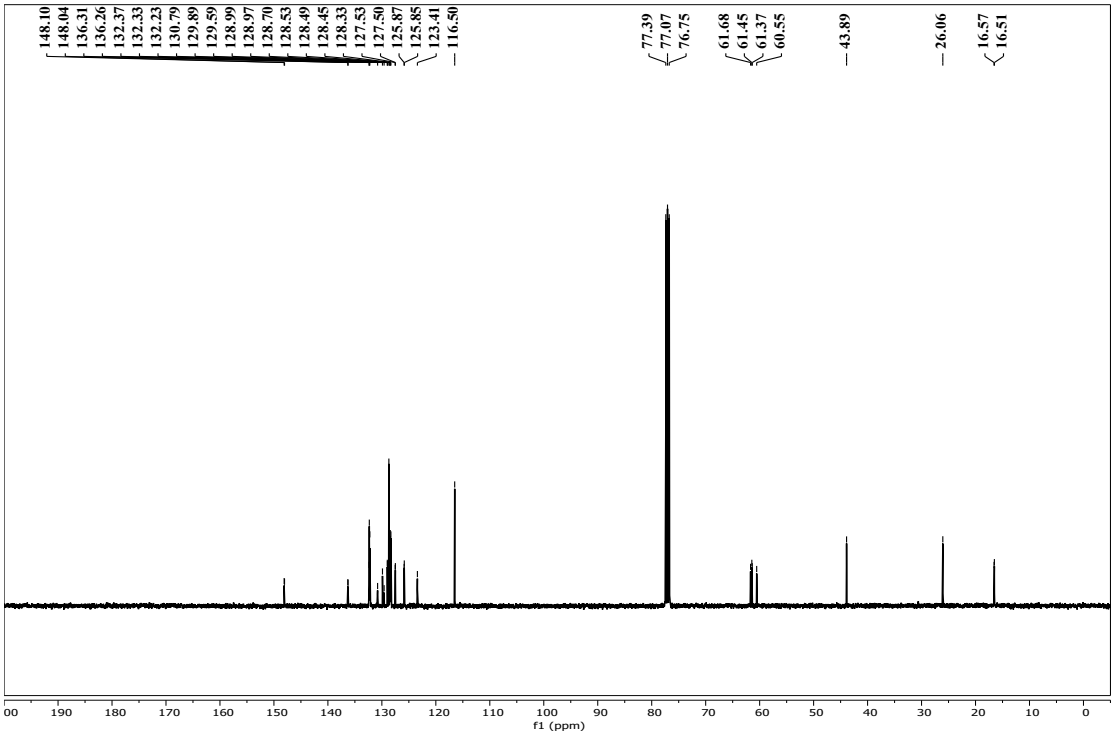




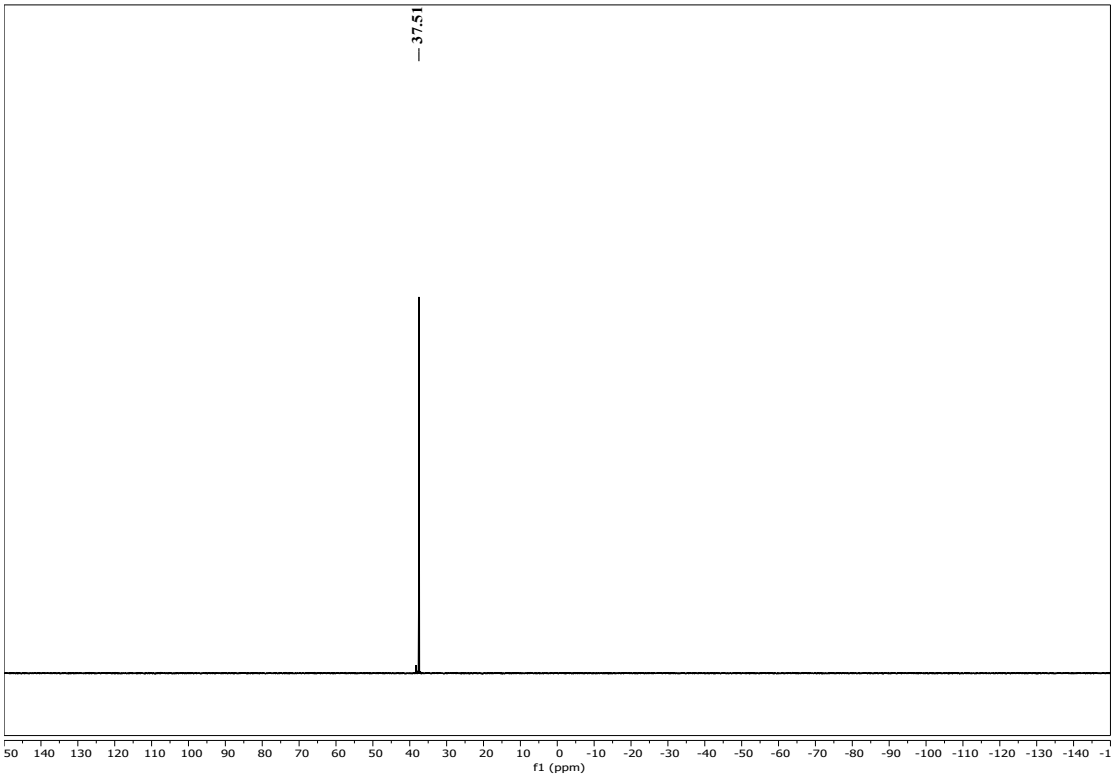

**11k,** $^{1}$H NMR (400 MHz), $CDCl_3$

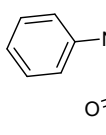



**11k**, $^{13}$C NMR (101 MHz), $CDCl_3$

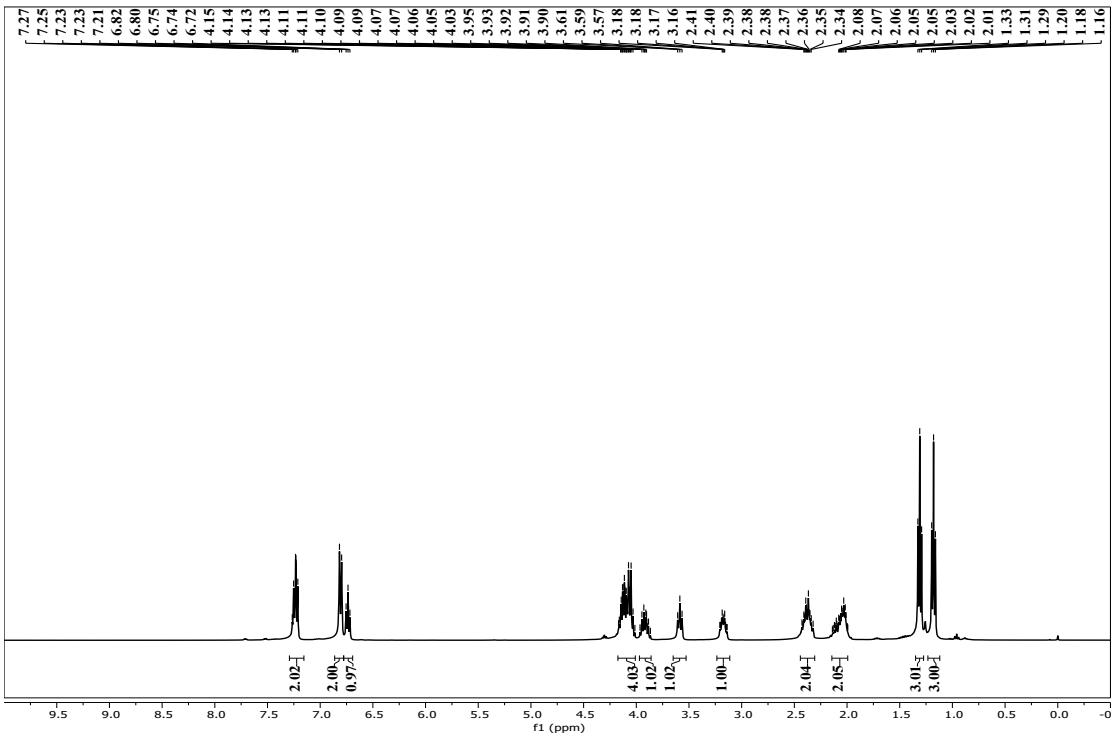


**11k**, $^{31}P$ NMR (162 MHz), $CDCl_3$

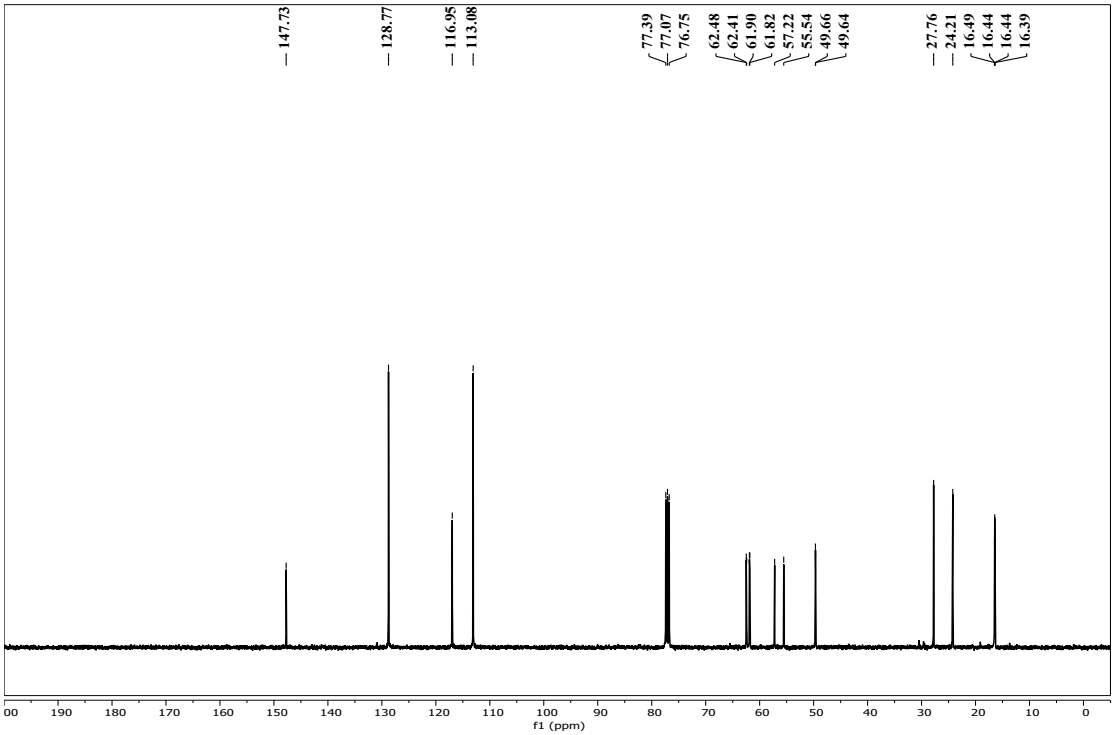




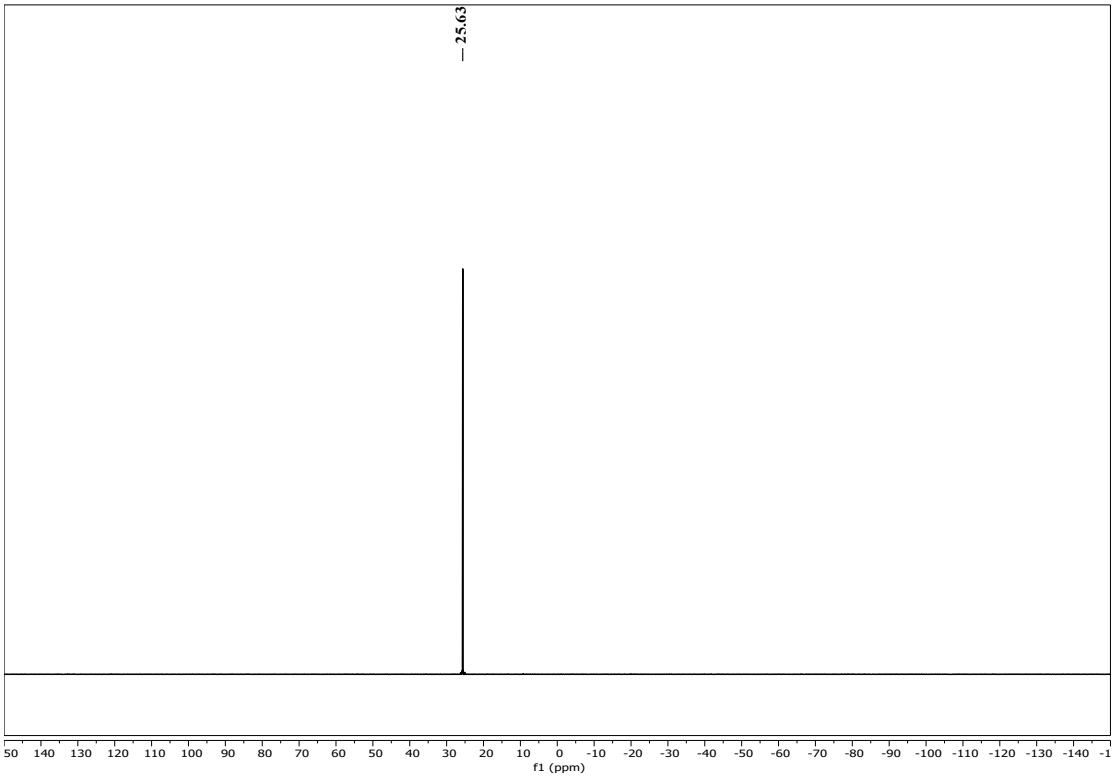
**11l,** $^{1}$H NMR (400 MHz), $CDCl_3$

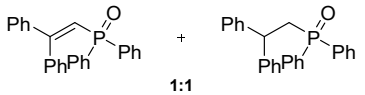



**11l**, $^{13}$C NMR (101 MHz), $CDCl_3$

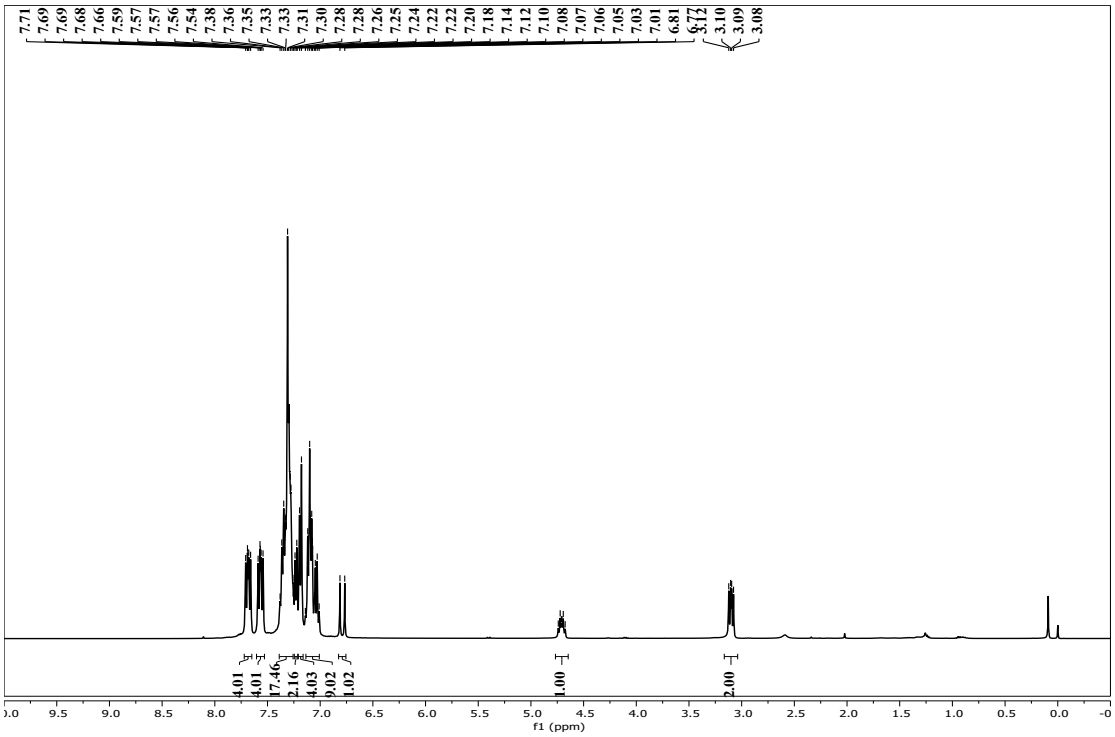


**11l**, $^{31}P$ NMR (162 MHz), $CDCl_3$

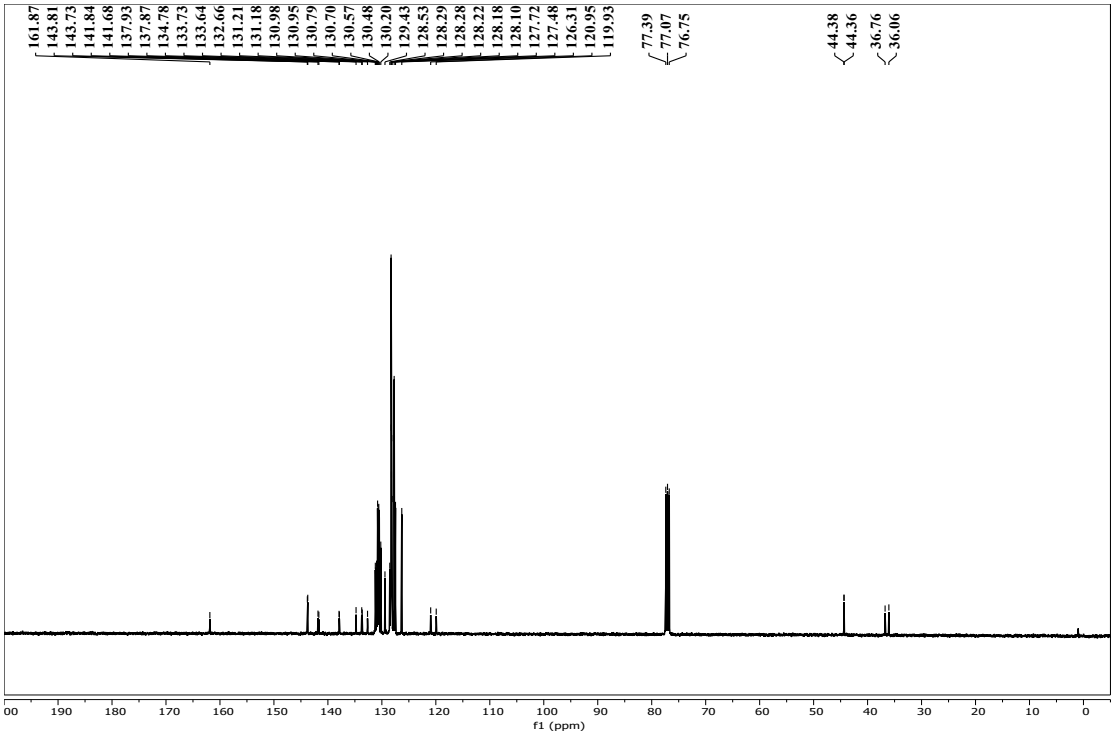




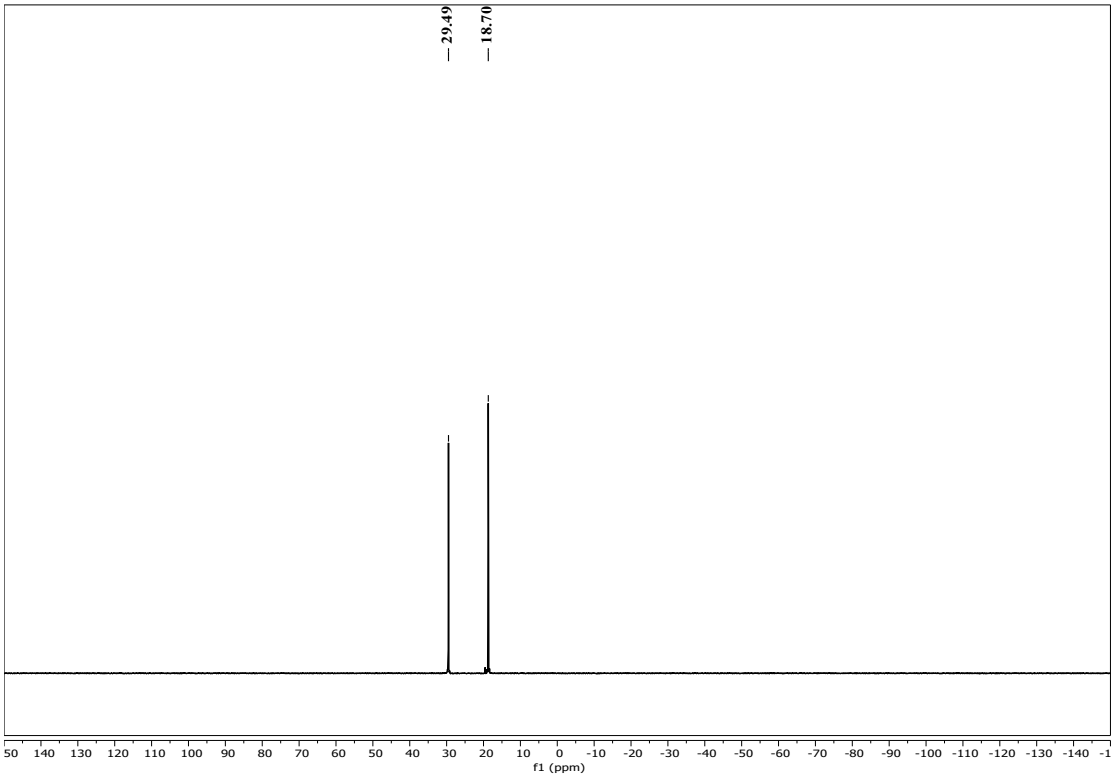

**(13 + 13'),** $^{1}$H NMR (400 MHz), $CDCl_3$

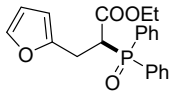



**(13 + 13')**, $^{13}$C NMR (101 MHz), $CDCl_3$

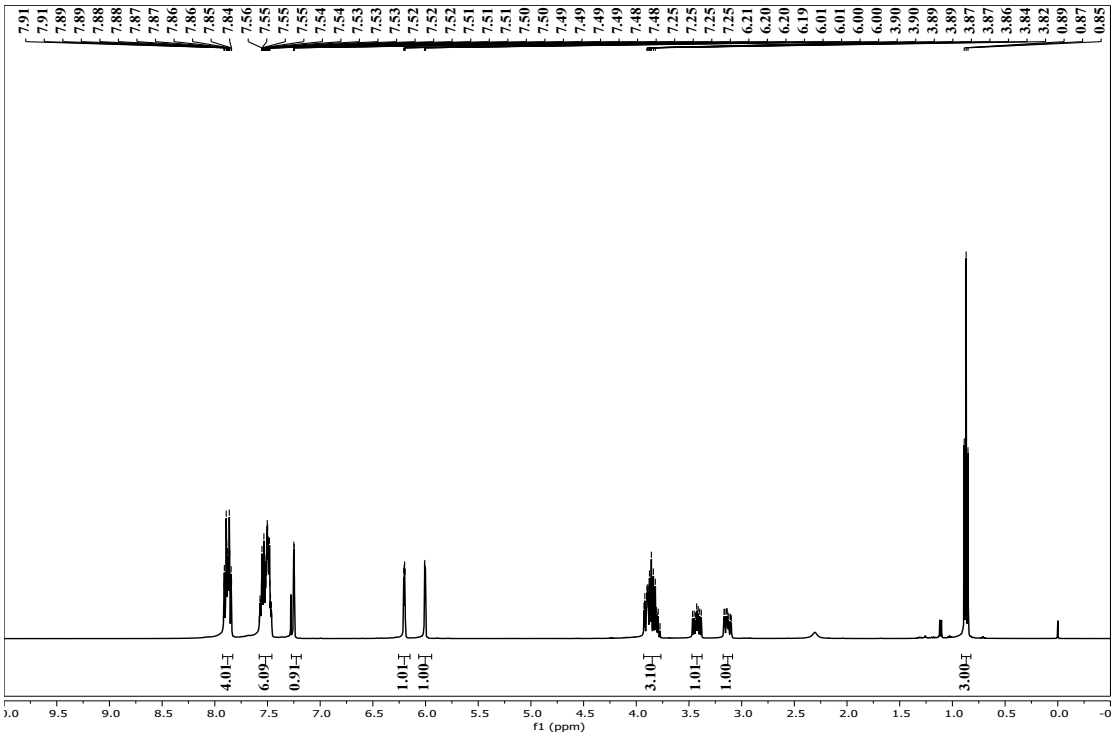


**(13 + 13'),** $^{31}P$ NMR (162 MHz), $CDCl_3$

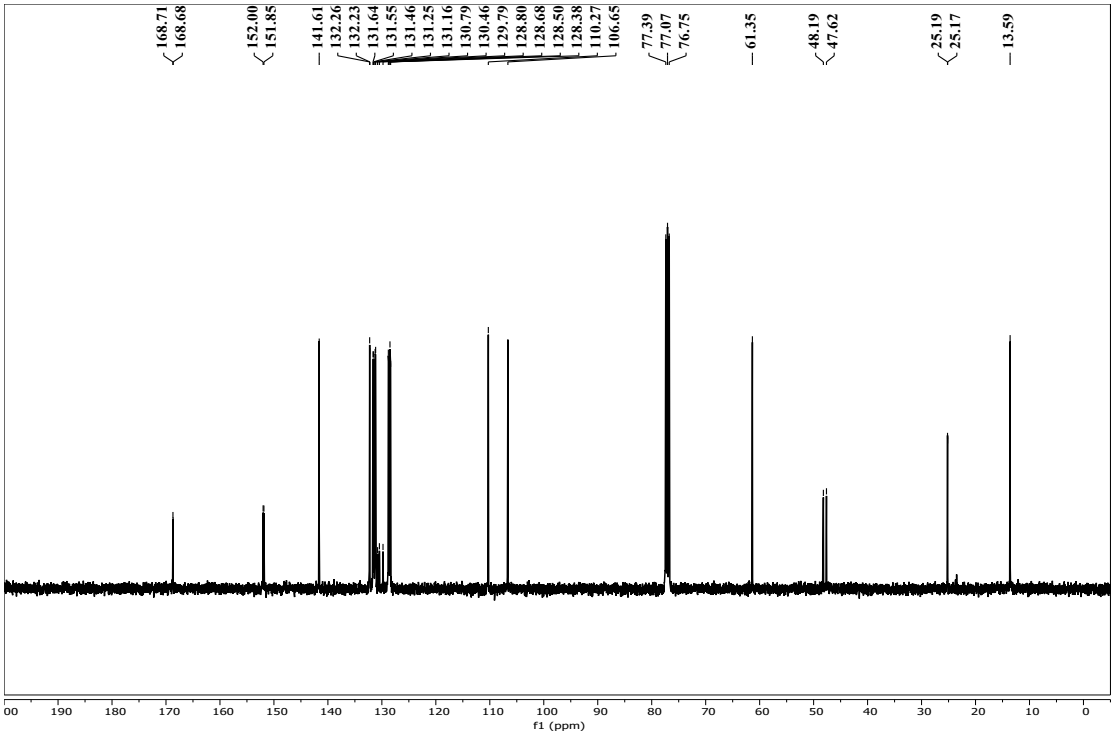





**15,** $^{1}$H NMR (400 MHz), $CDCl_3$




**15**, $^{13}$C NMR (101 MHz), $CDCl_3$



**15**, $^{31}P$ NMR (162 MHz), $CDCl_3$