# Accessing Diverse Phosphorylated 2-Aryl Pyridines: A Strategic Protocol from Pd-PEPPSI to Palladium Acetate Catalysis

Mandapalli Sreeshitha and Peddiahgari Vasu Govardhana Reddy*

*Department of Chemistry, Yogi Vemana University, Kadapa-516005, Andhra Pradesh, India*

*Corresponding author email: pvgr@yogivemanauniversity.ac.in*

**Supporting information**

**Table of Contents**

## 1. Experimental section

### 1.1 Synthesis of Pd-PEPPSI Complexes

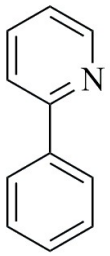
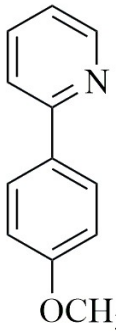
#### 1.1.1 Preparation of Benzimidazolium salts

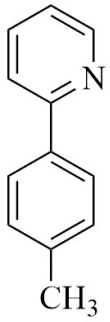
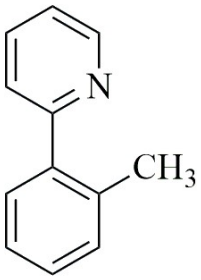
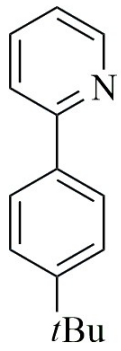
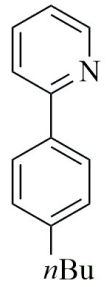
Benzimidazolium salts of corresponding Pd-PEPPSI Complexes were synthesized by following the our previous literature reports.[1]

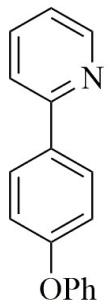
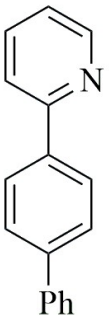
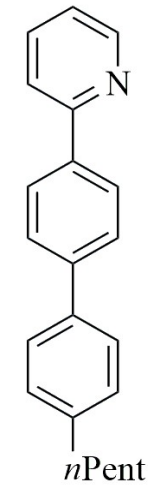
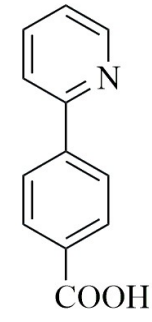
#### 1.1.2 General Procedure for the synthesis of Pd-PEPPSI Complexes (C1-C6)

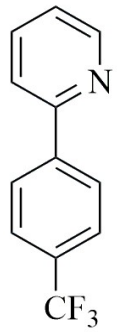
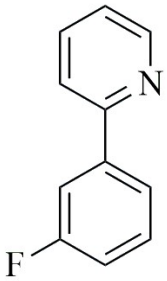
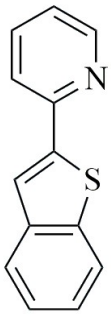
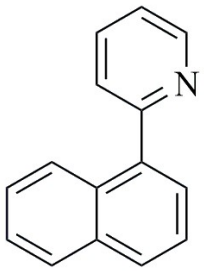
Pd-PEPPSI complexes were prepared under air by heating corresponding benzimidazolium salt (1 mmol, 1 equiv.), $K_2CO_3$ (5 mmol, 5 equiv.), and $PdCl_2$ (1.1 mmol, 1.1 equiv.) in 3-chloropyridine (3 mL) at 80 °C for 10–12 h. After cooling, the mixture was filtered through Celite, extracted with ethyl acetate and water, dried over $Na_2SO_4$, and concentrated. Purification by column chromatography (20% ethyl acetate in hexane) afforded complexes **C1-C6** as pale yellow solids.[1]

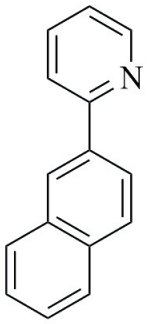
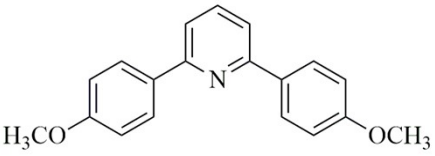
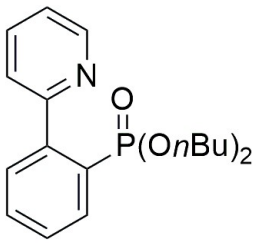
## 2. Characteristic data

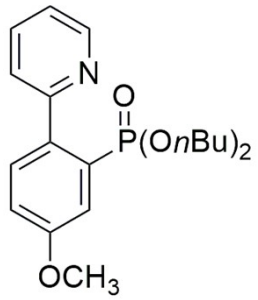
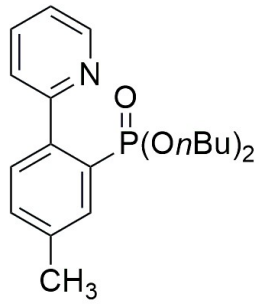
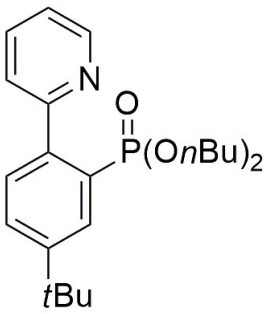
| | |
|---|---|
| **2-Phenylpyridine (3a)**[2-5]  | Colorless oil; 33 mg, yield 69%; $R_f$ = 0.85 (EtOAc); **$^1$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.66–8.64 (m, 1H, Ar-**H**), 8.00–7.98 (m, 2H, Ar-**H**), 7.64–7.58 (m, 2H, Ar-**H**), 7.46–7.32 (m, 3H, Ar-**H**), 7.24–7.12 (m, 1H, Ar-**H**); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 157.21 (Ar-**C**), 149.34 (Ar-**C**), 139.21 (Ar-**C**), 136.23 (Ar-**C**), 128.67 (Ar-**C**), 128.23 (Ar-**C**), 126.51 (Ar-**C**), 121.72 (Ar-**C**), 120.32 (Ar-**C**); **HRMS** ($ESI^+$) m/z calcd for $C_{11}H_9N$ $[M+H]^+$ 156.0735, found: 156.0732. The spectral data of this compound are in complete agreement with those reported in the literature.[3] |
| **2-(4-Methoxyphenyl)pyridine (3b)**[2,4,5]  | Colorless solid; m.p. 55-58 °C; 53 mg, yield 92%; $R_f$ = 0.85 (EtOAc); **$^1$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.56 (d, *J* = 4.6 Hz, 1H, Ar-**H**), 7.96 (d, *J* = 8.6 Hz, 2H, Ar-**H**), 7.72–7.70 (m, 2H, Ar-**H**), 7.19–7.16 (m, 1H, Ar-**H**), 7.12 (d, *J* = 7.6 Hz, 2H, Ar-**H**), 3.85 (s, 3H, Ar-O**CH$_3$**); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 159.21 (Ar-**C**), 156.21 (Ar-**C**), 148.32 (Ar-**C**), 136,52 (Ar-**C**), 132.75 (Ar-**C**), 129.21 (Ar-**C**), 122.23 (Ar-**C**), 119.43 (Ar-**C**), 113.08 (Ar-**C**), 52.87 (Ar-O**C**$H_3$); **HRMS** ($ESI^+$) m/z calcd for $C_{12}H_{11}NO$ $[M+H]^+$ 186.0841, found: 186.0843. The spectral data of this compound are in complete agreement with those reported in the literature.[2,4,5] |

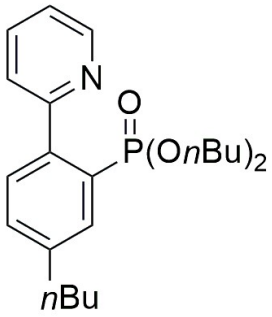
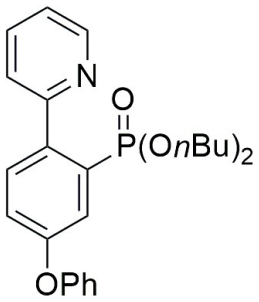
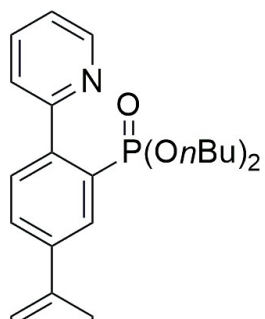
| | |
|---|---|
| **2-(*p*-Tolyl)pyridine (3c)[2-5]**<br>  | Colorless oil; 47 mg, yield 89%; $R_f$ = 0.85 (EtOAc); **$^1$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.63 (d, *J* = 4.6 Hz, 1H, Ar-**H**), 7.88 (d, *J* = 8.1 Hz, 2H, Ar-**H**), 7.65–7.63 (m, 2H, Ar-**H**), 7.14 (d, *J* = 8.2 Hz, 2H, Ar-**H**), 7.12-7.10 (m, 1H, Ar-**H**), 2.36 (s, 3H, Ar-C**H$_3$**); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 156.21 (Ar-**C**), 148.51 (Ar-**C**), 136.81 (Ar-**C**), 135.62 (Ar-**C**), 134.51 (Ar-**C**), 128.41 (Ar-**C**), 124.71 (Ar-**C**), 120.72 (Ar-**C**), 121.16 (Ar-**C**), 21.26 (Ar-**C**$H_3$); **HRMS** ($ESI^+$) m/z calcd for $C_{12}H_{11}N$ $[M+H]^+$ 170.0891, found: 170.0893. The spectral data of this compound are in complete agreement with those reported in the literature.[3] |
| **2-(*o*-Tolyl)pyridine (3d)[3,4,6]**<br>  | Colorless oil; 46 mg, yield 87%; $R_f$ = 0.85 (EtOAc); **$^1$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.66-8.64 (m, 1H, Ar-**H**), 7.74 (dt, 1H, *J* =7.6 & 1.8 Hz, Ar-**H**), 7.36 (td, 1H, *J* = 7.8 & 1.2 Hz, Ar-**H**), 7.40 (m, 1H, Ar-**H**), 7.26 (m, 3H, Ar-**H**), 7.21-7,24 (m, 1H, Ar-**H**), 2.36 (s, 3H, Ar-C**H$_3$**); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 156.21 (Ar-**C**), 148.31 (Ar-**C**), 138.62 (Ar-**C**), 135.23 (Ar-**C**), 135.21 (Ar-**C**), 128.23 (Ar-**C**), 125.52 (Ar-**C**), 121.52 (Ar-**C**), 121.01 (Ar-**C**), 21.61 (Ar-**C**$H_3$); **HRMS** ($ESI^+$) m/z calcd for $C_{12}H_{11}N$ $[M+H]^+$ 170.0891, found: 170.0893. The spectral data of this compound are in complete agreement with those reported in the literature.[3,4] |
| **2-(4-(*tert*-Butyl)phenyl)pyridine (3e)[7]**<br>  | Colorless oil; 60 mg, yield 91%; $R_f$ = 0.85 (EtOAc); **$^1$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.65 (d, *J* = 4.6 Hz, 1H, Ar-**H**), 8.10 (d, *J* = 7.6 Hz, 2H, Ar-**H**), 7.56 (d, *J* = 3.5 Hz, 2H, Ar-**H**), 7.45 (d, *J* = 8.2 Hz, 2H, Ar-**H**), 7.21 (dd, J = 8.3 & 5.1 Hz, 1H, Ar-**H**), 1.42 (s, 9H, -C(C**H$_3$**)$_3$); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 156.21 (Ar-**C**), 152.51 (Ar-**C**), 149.01 (Ar-**C**), 136.30 (Ar-**C**), 136.08 (Ar-**C**), 126.25 (Ar-**C**), 125.12 (Ar-**C**), 121.85 (Ar-**C**), 121.21 (Ar-**C**), 33.34 (-**C**$(CH_3)_3$), 32.36 (-C(**C**$H_3$)$_3$); **HRMS** ($ESI^+$) m/z calcd for $C_{15}H_{17}N$ $[M+H]^+$ 212.1361, found: 212.1364. The spectral data of this compound are in complete agreement with those reported in the literature.[7] |
| **2-(4-Butylphenyl)pyridine (3f)**<br>  | Colorless oil; 60 mg, yield 90%; $R_f$ = 0.85 (EtOAc); **$^1$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.67-8.66 (m, 1H, Ar-**H**), 7.90-7.88 (m, 2H, Ar-**H**), 7.74-7.68 (m, 2H, Ar-**H**), 7.290 (d, *J* = 6.4 Hz, 2H, Ar-**H**), 7.21-7.18 (m, 1H, Ar-**H**), 2.67 (t, *J* = 6.0 Hz, 2H, Ar-C**H$_2$**-), 1.66-1.60 (m, 2H, -C**H$_2$**-), 1.39-1.35 (m, 2H, -C**H$_2$**-$CH_3$), 0.95 (t, *J* = 5.6 Hz, 3H, -$CH_2$-C**H$_3$**); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 157.57 (Ar-**C**), 149.50 (Ar-**C**), 144.06 (Ar-**C**), 136.83 (Ar-**C**), 129.35 (Ar-**C**), 128.89 (Ar-**C**), 126.86 (Ar-**C**), 121.85 (Ar-**C**), 120.47 (Ar-**C**), 115.18 (Ar-**C**), 35.43 (Ar-**C**$H_2$-), 33.55 (-**C**$H_2$-), 22.38 (-**C**$H_2$-$CH_3$), 13.99 (-$CH_2$-**C**$H_3$); **HRMS** ($ESI^+$) m/z calcd for $C_{15}H_{17}N$ |

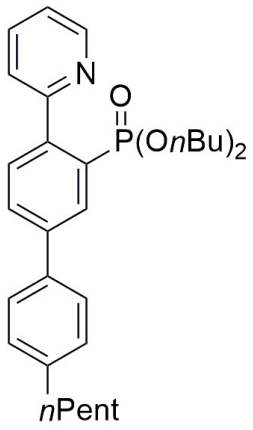
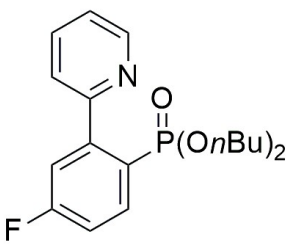
| | |
|---|---|
| | $[M+H]^+$ 212.1361, found: 212.1364. |
| **2-(4-Phenoxyphenyl)pyridine (3g)**  | Colorless solid; m. p. 46-48 °C; 72 mg, yield 92%; $R_f$ = 0.85 (EtOAc); **$^1$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.60-8.58 (m, 1H, Ar-**H**), 7.91-7.87 (m, 2H, Ar-**H**), 7.68-7.59 (m, 2H, Ar-**H**), 7.30-7.25 (m, 2H, Ar-**H**), 7.14-7.11 (m, 1H, Ar-**H**), 7.07-6.97 (m, 5H, Ar-**H**); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 158.33 (Ar-**C**), 156.87 (Ar-**C**), 149.58 (Ar-**C**), 136.86 (Ar-**C**), 134.35 (Ar-**C**), 129.85 (Ar-**C**), 128.47 (Ar-**C**), 123.60 (Ar-**C**), 121.83 (Ar-**C**), 120.21 (Ar-**C**), 119.23 (Ar-**C**), 118.84 (Ar-**C**); **HRMS** ($ESI^+$) m/z calcd for $C_{17}H_{13}NO$ $[M+H]^+$ 248.0997, found: 248.0995. |
| **2-([1,1'-Biphenyl]-4-yl)pyridine (3h)[7]**  | Colorless solid; m.p. 48-50 °C; 62 mg, yield 85%; $R_f$ = 0.85 (EtOAc); **$^1$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.73 (d, *J* = 4.7 Hz, 1H, Ar-**H**), 8.21 (d, *J* = 8.4 Hz, 2H, Ar-**H**), 7.86 – 7.80 (m, 2H, Ar-**H**), 7.76 (d, *J* = 8.3 Hz, 2H, Ar-**H**), 7.75 – 7.66 (m, 2H, Ar-**H**), 7.45 (t, *J* = 7.6 Hz, 2H, Ar-**H**), 7.39 (t, *J* = 7.3 Hz, 1H, Ar-**H**), 7.31-7.25 (m, 1H, Ar-**H**); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 156.21 (Ar-**C**), 148.34 (Ar-**C**), 141.76 (Ar-**C**), 140.87 (Ar-**C**), 139.38 (Ar-**C**), 135.96 (Ar-**C**), 126.14 (Ar-**C**), 127.58 (Ar-**C**), 127.44 (Ar-**C**), 127.35 (Ar-**C**), 127.10 (Ar-**C**), 122.65 (Ar-**C**), 120.87 (Ar-**C**); **HRMS** ($ESI^+$) m/z calcd for $C_{17}H_{13}N$ $[M+H]^+$ 232.1048, found: 232.1045. The spectral data of this compound are in complete agreement with those reported in the literature.[7] |
| **2-(4'-pentyl-[1,1'-biphenyl]-4-yl)pyridine (3i)**  | Colorless solid; m.p. 85-87 °C; 83 mg, yield 88%; $R_f$ = 0.85 (EtOAc); **$^1$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.71 (d, *J* = 3.6 Hz, 1H, Ar-**H**), 8.07 (d, *J* = 6.8 Hz, 2H, Ar-**H**), 7.78 – 7.73 (m, 2H, Ar-**H**), 7.71 (d, *J* = 6.4 Hz, 2H, Ar-**H**), 7.58 (d, *J* = 6.4 Hz, 2H, Ar-**H**), 7.28 (d, *J* = 6.4 Hz, 2H, Ar-**H**), 7.24-7.21 (m, 1H, Ar-**H**), 2.67 (t, *J* = 6.4 Hz, 2H, Ar-C**H$_2$**-), 1.69 (quin, = 6.0 Hz, 2H, Ar-$CH_2$-C**H$_2$**-$CH_2$-), 1.38-1.34 (m, 4H, -C**H$_2$**-C**H$_2$**-), 0.92 (t, *J* = 5.6 Hz, 3H, -$CH_2$-C**H$_3$**) ; **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 157.15 (Ar-**C**), 149.74 (Ar-**C**), 142.48 (Ar-**C**), 141.70 (Ar-**C**), 137.98 (Ar-**C**), 137.89 (Ar-**C**), 136.76 (Ar-**C**), 128.93 (Ar-**C**), 127.27 (Ar-**C**), 126.94 (Ar-**C**), 122.06 (Ar-**C**), 120.43 (Ar-**C**), 35.64 (Ar-**C**$H_2$-), 31.59 (Ar-$CH_2$-**C**$H_2$-$CH_2$-), 31.22 (Ar-$CH_2$-$CH_2$-**C**$H_2$-), 22.60 (-**C**$H_2$-$CH_3$), 14.08 (-$CH_2$-**C**$H_3$) ; **HRMS** ($ESI^+$) m/z calcd for $C_{22}H_{23}N$ $[M+H]^+$ 302.1830, found: 302.1834. |
| **4-(Pyridin-2-yl)benzoic acid (3j)**  | Colorless solid; m.p. 191-193 °C; 42 mg, yield 67 %; $R_f$ = 0.85 (EtOAc); **$^1$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 7.85-7.79 (m,1H, Ar-**H**), 7.70-7.66 (m, 1H, Ar-**H**), 7.44 – 7.32 (m, 3H, Ar-**H**), 7.24-7.21 (m, 2H, Ar-**H**), 6.79 (d, *J* = 3.2 Hz, 1H, Ar-**H**); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 142.96 (Ar-**C**), 135.00 (Ar-**C**), 134.03 (d, *J* = 7.3 |

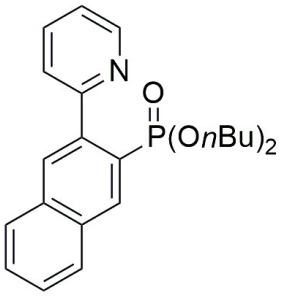
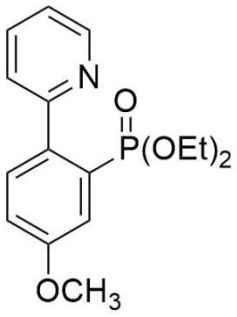
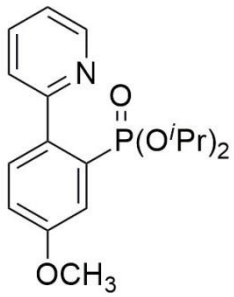
| | |
|---|---|
| | Hz, Ar-**C**), 133.44 (d, *J* = 14.6 Hz, Ar-**C**), 132.57 (d, *J* = 10.2 Hz, Ar-**C**), 132.09 (d, *J* = 9.1 Hz, Ar-**C**), 131.16 (d, *J* = 22.0 Hz, Ar-**C**), 129.56 (Ar-**C**), 128.50 (Ar-**C**), 127.42 (Ar-**C**), 125.88 (Ar-**C**); **HRMS** ($ESI^+$) m/z calcd for $C_{12}H_9NO_2$ $[M+H]^+$ 200.0633, found: 200.0637. |
| **2-(4-(Trifluoromethyl) phenyl)pyridine (3k)[7]**  | Colorless solid; m.p. 76-78 °C; 45 mg, yield 65%; $R_f$ = 0.85 (EtOAc); **$^1$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.72 (d, *J* = 4.6 Hz, 1H, Ar-**H**), 8.12 (d, *J* = 8.0 Hz, 2H, Ar-**H**), 7.84-7.65 (m, 4H, Ar-**H**), 7.35 (t, *J* = 6.5 Hz, 1H, Ar-**H**); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 156.32 (Ar-**C**), 149.65 (Ar-**C**), 142.65 (Ar-**C**), 135.23 (Ar-**C**), 131,54 (Ar-**C**), 126.43 (Ar-**C**), 125.21 (Ar-**C**), 124.23 (q, *J* = 272.0 Hz, Ar-**C**$F_3$), 122.84 (Ar-**C**), 121.21 (Ar-**C**); **HRMS** ($ESI^+$) m/z calcd for $C_{12}H_8F_3N$ $[M+H]^+$ 224.0609, found: 224.0612. The spectral data of this compound are in complete agreement with those reported in the literature.[7] |
| **2-(3-Fluorophenyl)pyridine (3m)[10,11]**  | Colorless oil; 43 mg, yield 80%; $R_f$ = 0.85 (EtOAc); **$^1$H NMR** (400 MHz, DMSO-*d6*): δ (ppm) 7.16-8.08 (m, 7H, Ar-**H**), 8.66-8.79 (m, 1H, Ar-**H**); **$^{13}$C NMR** (100 MHz, DMSO-*d6*): δ (ppm) 156.21 (Ar-**C**), 148.67 (Ar-**C**),137.23 (Ar-**C**), 136.43 (Ar-**C**) 129.54 (Ar-**C**), 128.64 (Ar-**C**), 128.23 (Ar-**C**), 128.35 (Ar-**C**), 126.40 (Ar-**C**), 122.51 (Ar-**C**), 120.10 (Ar-**C**); **HRMS** ($ESI^+$) m/z calcd for $C_{11}H_8FN$ $[M+H]^+$ 174.0641, found: 174.0645. The spectral data of this compound are in complete agreement with those reported in the literature.[10] |
| **2-(Benzo[b]thiophen-2-yl)pyridine (3o)[8,9]**  | Colorless solid; m.p. 124126 °C; 43 mg, yield 80%; $R_f$ = 0.85 (EtOAc); **$^1$H NMR** (400 MHz, DMSO-*d6*): δ (ppm) 8.62 (d, *J* = 4.3 Hz, 1H, Ar-**H**), 8.15 (s, 1H, Ar-**H**), 8.16 (d, *J* = 8.2 Hz, 1H, Ar-**H**), 7.99 (dt, *J* = 7.9 & 2.4 Hz, 1H, Ar-**H**), 7.89-7.86 (m, 2H, Ar-**H**), 7.36-7.32 (m, 3H, Ar-**H**); **$^{13}$C NMR** (100 MHz, DMSO-*d6*): δ (ppm) 151.62 (Ar-**C**), 148.53 (Ar-**C**), 144.64 (Ar-**C**), 141.32 (Ar-**C**), 138.93 (Ar-**C**), 137.34 (Ar-**C**), 125.21 (Ar-**C**), 124.42 (Ar-**C**), 124.23 (Ar-**C**), 123.65 (Ar-**C**), 122.62 (Ar-**C**), 121.45 (Ar-**C**), and 119.74 (Ar-**C**); **HRMS** ($ESI^+$) m/z calcd for $C_{13}H_9NS$ $[M+H]^+$ 212.0456, found: 212.0460. The spectral data of this compound are in complete agreement with those reported in the literature.[9] |
| **2-(Naphthalen-1-yl)pyridine (3p)[3]**  | Yellow oil; 53 mg, yield 83%; $R_f$ = 0.85 (EtOAc); **$^1$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.78 (dd, *J* = 4.8 & 1.7 Hz, 1H, Ar-**H**), 8.15 (dd, *J* = 7.2 & 2.6 Hz, 1H, Ar-**H**), 7.86 (d, *J* = 8.4 Hz, 2H, Ar-**H**), 7.81 (dt, *J* = 7.7 & 1.7 Hz, 1H, Ar-**H**), 7.57-7.53 (m, 5H, Ar-**H**), 7.33-7.31 (m, 1H, Ar-**H**); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 158.79 (Ar-**C**), 149.31 (Ar-**C**), 139.46 (Ar-**C**), 135.15 (Ar-**C**), 133.81 (Ar-**C**), 130.22 (Ar-**C**), 128.31 (Ar-**C**), |

| | |
|---|---|
| | 128.08 (Ar-**C**), 127.12 (Ar-**C**), 126.82 (Ar-**C**), 126.01 (Ar-**C**), 125.71 (Ar-**C**), 125.21 (Ar-**C**), 124.26 (Ar-**C**), 122.01 (Ar-**C**); **HRMS** ($ESI^+$) m/z calcd for $C_{15}H_{11}N$ $[M+H]^+$ 206.0891, found: 206.0895. The spectral data of this compound are in complete agreement with those reported in the literature.[3] |
| **2-(naphthalen-2-yl)pyridine (3q)[3]**  | Yellow solid; m.p. 77-78 °C; 54 mg, yield 85%; $R_f$ = 0.85 (EtOAc); **$^1$H NMR** (400 MHz, $CDCl_3$): 8.76 (d, *J* = 4.2 Hz, 1H, Ar-**H**), 8.50 (s, 1H, Ar-**H**), 8.15 (dd, *J* = 8.6 & 1.5 Hz, 1H, Ar-**H**), 7.92 (m, 4H, Ar-**H**), 7.84 (td, *J* = 7.5 & 1.8 Hz, 1H, Ar-**H**), 7.54 (m, 2H, Ar-**H**), 7.24 (dd, *J* = 7.5 & 4.2 Hz, 1H, Ar-**H**); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 156.21 (Ar-**C**), 148.52 (Ar-**C**), 136.98 (Ar-**C**), 133.21 (Ar-**C**), 133.31 (Ar-**C**), 128.91 (Ar-**C**), 128.51 (Ar-**C**), 127.81 (Ar-**C**), 126.51 (Ar-**C**), 126.31 (Ar-**C**), 123.21 (Ar-**C**), 122.11 (Ar-**C**), 120.12 (Ar-**C**). **HRMS** ($ESI^+$) m/z calcd for $C_{15}H_{11}N$ $[M+H]^+$ 206.0891, found: 206.0895. The spectral data of this compound are in complete agreement with those reported in the literature.[3] |
| **2,6-bis(4-methoxyphenyl) pyridine (6)**  | Colorless solid; m.p. 143-145 °C; 82 mg, yield 90%; $R_f$ = 0.85 (EtOAc); **$^1$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.11 (d, *J* = 7.2 Hz, 4H, Ar-**H**), 7.75 (t, *J* = 6.4 Hz, 1H, Ar-**H**), 7.57 (d, *J* = 6.0 Hz, 2H, Ar-**H**), 7.25 (s, 1H, Ar-**H**), 7.02 (d, *J* = 7.2 Hz, 3H, Ar-**H**), 3.87 (s, 6H, Ar-O**C$H_3$**); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 160.51 (Ar-**C**), 156.34 (Ar-**C**), 137.31 (Ar-**C**), 132.32 (Ar-**C**), 128.24 (Ar-**C**), 117.19 (Ar-**C**), 114.03 (Ar-**C**), 55.39 (Ar-O**C**$H_3$); **HRMS** ($ESI^+$) m/z calcd for $C_{19}H_{17}NO_2$ $[M+H]^+$ 292.1259, found: 292.1256. |
| **Dibutyl (2-(pyridin-2-yl)phenyl)phosphonate (5a)[12]**  | Colorless oil; 13 mg, yield 10%; $R_f$ = 0.85 (EtOAc); **$^1$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.64 (d, *J* = 4.8 Hz, 1H, Ar-**H**), 7.98 (dd, *J* = 14.4 Hz, 1H, Ar-**H**), 7.71-7.64 (m, 2H, Ar-**H**), 7.64-7.61 (m, 1H, Ar-**H**), 7.58-7.55 (m, 1H, Ar-**H**), 7.49-7.46 (m, 1H, Ar-**H**), 7.26-7.23 (m, 1H, Ar-**H**), 3.96-3.87 (m, 2H, -O**C$H_2$**-), 3.88-3.79 (m, 2H, -O-**C$H_2$**-), 1.52-1.44 (m, 4H, -O-$CH_2$-**C$H_2$**-$CH_2$-), 1.32-1.23 (m, 4H, -**C$H_2$**-$CH_3$), 0.83 (t, *J* = 7.6 Hz, 6H, -$CH_2$-**C$H_3$**); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 158.6 (d, *J* = 4.0 Hz, Ar-**C**), 148.80 (Ar-**C**), 143.5 (Ar-**C**), 135.43 (Ar-**C**), 132.63 (d, *J* = 9.6 Hz, Ar-**C**), 128.41 (d, *J* = 2.9 Hz, Ar-**C**), 130.6 (Ar-**C**), 127.89 (Ar-**C**), 125.02 (Ar-**C**), 118.73 (d, *J* = 8.2 Hz, Ar-**C**), 118.03 (d, *J* = 2.6 Hz, Ar-**C**), 65.60 (d, *J* = 4.8 Hz, O-**C**$H_2$-), 32.30 (d, *J* = 5.4 Hz, O-$CH_2$-**C**$H_2$-), 18.62 (-**C$H_2$**-$CH_3$), 13.30 (-$CH_2$-**C$H_3$**); **$^{31}$P NMR** (162 MHz, $CDCl_3$): δ (ppm) 24.02; **HRMS** ($ESI^+$) m/z calcd for $C_{19}H_{26}NO_3P$ $[M+H]^+$ 348.1650, found: 348.1654. The spectral data of this compound are in complete agreement with those reported in the literature.[12] |
| **Dibutyl (5-methoxy-2-(pyridin-2-yl)phenyl)phosphonate (5b)** | Colorless oil; 96 mg, yield 79%; $R_f$ = 0.15 (EtOAc); **$^1$H** |

| | |
|---|---|
|  | **NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.65 (d, *J* = 4.8 Hz, 1H, Ar-**H**), 7.72-7.64 (m, 2H, Ar-**H**), 7.58 (dd, *J* = 2.4 & 13.2 Hz, 1H, Ar-**H**), 7.49-7.46 (m, 1H, Ar-**H**), 7.26-7.23 (m, 1H, Ar-**H**), 7.14 (dd, *J* = 2.4 & 6.0 Hz, 1H, Ar-**H**), 3.95-3.89 (m, 2H, -OC**H₂**-), 3.89 (s, 3H, Ar-O**CH₃**), 3.88-3.81 (m, 2H, -O-C**H₂**-), 1.51-1.43 (m, 4H, -O-$CH_2$-C**H₂**-$CH_2$-), 1.31-1.22 (m, 4H, -C**H₂**-$CH_3$), 0.88 (t, *J* = 7.6 Hz, 6H, -$CH_2$-C**H₃**); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 159.05 (d, *J* = 14.1 Hz, Ar-**C**), 158.68 (d, *J* = 3.4 Hz, Ar-**C**), 148.80 (Ar-**C**), 137.15 (d, *J* = 7.3 Hz, Ar-**C**), 135.43 (Ar-**C**), 132.63 (d, *J* = 12.7 Hz, Ar-**C**), 128.41 (Ar-**C**), 126.94 (Ar-**C**), 124.89 (Ar-**C**), 122.02 (Ar-**C**), 118.73 (d, *J* = 8.2 Hz, Ar-**C**), 118.03 (d, *J* = 2.4 Hz, Ar-**C**), 65.80 (d, *J* = 4.8 Hz, O-**C**$H_2$-), 55.58 (Ar-O**C**$H_3$), 32.30 (d, *J* = 5.4 Hz, O-$CH_2$-**C**$H_2$-), 18.68 (-C**H₂**-$CH_3$), 13.60 (-$CH_2$-C**H₃**); **$^{31}$P NMR** (162 MHz, $CDCl_3$): δ (ppm) 23.48; **HRMS** ($ESI^+$) m/z calcd for $C_{20}H_{28}NO_4P$ $[M+H]^+$ 378.1756, found: 378.1760. |
| **Dibutyl (5-methyl-2-(pyridin-2-yl)phenyl)phosphonate (5c)**<br>  | Colorless oil; 102 mg, yield 80%; $R_f$ = 0.15 (EtOAc); **$^{1}$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.66-8.64 (m, 1H, Ar-**H**), 7.87 (d, *J* = 12.0 Hz, 1H, Ar-**H**), 7.72-7.68 (m, 1H, Ar-**H**), 7.65-7.63 (m, 1H, Ar-**H**), 7.43-7.42 (m, 2H, Ar-**H**), 7.28-7.25 (m, 1H, Ar-**H**), 3.94-3.80 (m, 4H, -O-C**H₂**-), 2.44 (s, 3H, Ar-C**H₃**), 1.49-1.43 (m, 4H, -O-$CH_2$-C**H₂**-), 1.30-1.22 (m, 4H, -C**H₂**-$CH_3$), 0.87 (t, *J* = 5.6 Hz, 6H, -$CH_2$-C**H₃**); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 158.99 (d, *J* = 4.3 Hz, Ar-**C**), 148.82 (Ar-**C**), 141.89 (d, *J* = 9.4 Hz, Ar-**C**), 137.92 (d, *J* = 14.3 Hz, Ar-**C**), 135.44 (Ar-**C**), 134.49 (d, *J* = 9.2 Hz, Ar-**C**), 132.90 (Ar-**C**), 131.10 (d, *J* = 14.4 Hz, Ar-**C**), 127.07 (Ar-**C**), 127.84 (Ar-**C**), 122.17 (Ar-**C**), 65.71 (d, *J* = 6.0 Hz, -O-**C**$H_2$-), 32.33 (d, *J* = 6.6 Hz, -O-$CH_2$-**C**$H_2$-), 21.15 (Ar-**C**$H_3$), 18.70 (-**C**$H_2$-$CH_3$), 13.62 (-$CH_2$-**C**$H_3$); **$^{31}$P NMR** (162 MHz, $CDCl_3$): δ (ppm) 24.22; **HRMS** ($ESI^+$) m/z calcd for $C_{20}H_{28}NO_3P$ $[M+H]^+$ 362.1807, found: 362.1804. |
| **dibutyl (5-(*tert*-butyl)-2-(pyridin-2-yl)phenyl)phosphonate (5d)**<br>  | Colorless oil; 96 mg, yield 84%; $R_f$ = 0.15 (EtOAc); **$^{1}$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.64-8.62 (m, 1H, Ar-**H**), 8.04 (dd, *J* = 2.4 & 13.2 Hz, 1H, Ar-**H**), 7.71-7.60 (m, 3H, Ar-**H**), 7.47-7.43 (m, 1H, Ar-**H**), 7.27-7.25 (m, 1H, Ar-**H**), 3.92-3.79 (m, 4H, -O-C**H₂**-), 1.48-1.38 (m, 4H, -O-$CH_2$-C**H₂**-), 1.35 (s, 9H, -C(C**H₃**)$_3$), 1.30-1.20 (m, 4H, -C**H₂**-$CH_3$), 0.86 (t, *J* = 7.2 Hz, 6H, -$CH_2$-C**H₃**); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 159.13 (d, *J* = 4.6 Hz, Ar-**C**), 151.05 (d, *J* = 13.3 Hz, Ar-**C**), 148.89 (Ar-**C**), 141.97 (d, *J* = 9.9 Hz, Ar-**C**), 135.50 (Ar-**C**), 131.00 (Ar-**C**), 129.43 (d, *J* = 3.3 Hz, Ar-**C**), 126.96 (Ar-**C**), 125.11 (Ar-**C**), 124.82 (Ar-**C**), 122.20 (Ar-**C**), 65.75 (d, *J* = 6.5 Hz, O-**C**$H_2$-), 34.87 (-**C**$(CH_3)_3$), 32.39 (d, *J* = 6.8 Hz, -O-$CH_2$-**C**$H_2$-), 31.25 (C(**C**$H_3$)$_3$), 18.77 (-**C**$H_2$-$CH_3$), 13.67 (-$CH_2$-**C**$H_3$); **$^{31}$P NMR** (162 MHz, $CDCl_3$): δ (ppm) |

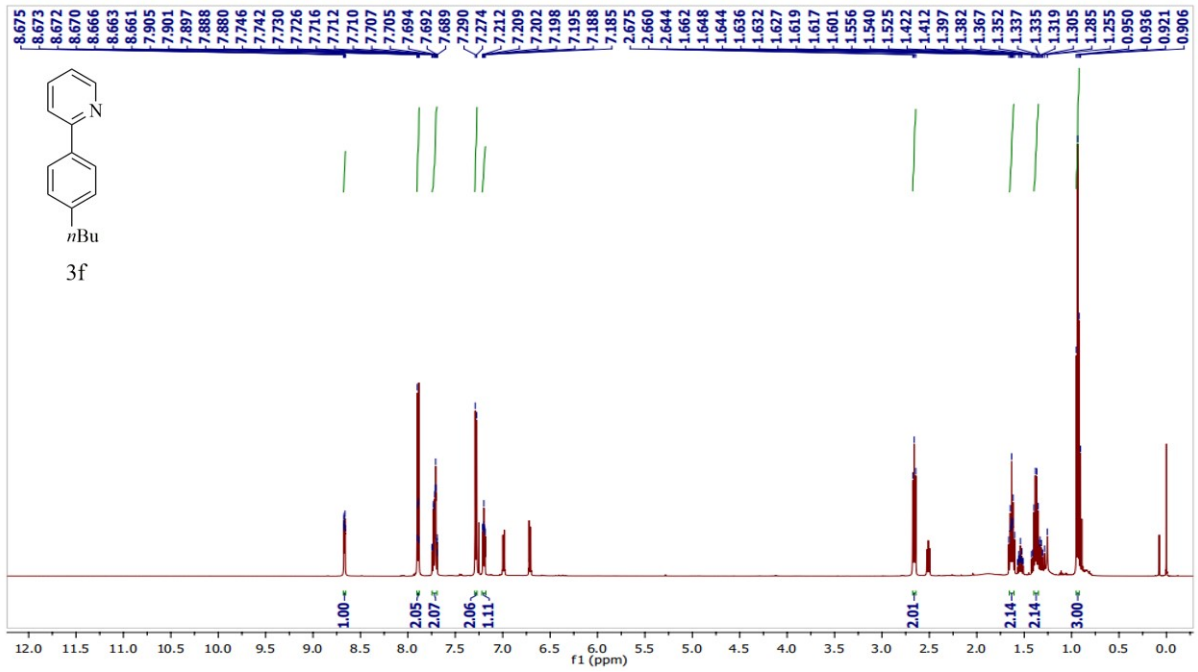
| | |
|---|---|
| | 24.37; **HRMS** (ESI$^+$) m/z calcd for $C_{23}H_{34}NO_3P$ $[M+H]^+$ 404.2276, found: 404.2274. |
| **Dibutyl (5-butyl-2-(pyridin-2-yl)phenyl)phosphonate (5e)**  | Colorless oil; 93 mg, yield 82%; $R_f$ = 0.15 (EtOAc); **$^1$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.66-8.64 (m, 1H, Ar-**H**), 7.86 (d, *J* = 14.4 Hz, 1H, Ar-**H**), 7.72-7.64 (m, 2H, Ar-**H**), 7.46-7.41 (m, 2H, Ar-**H**), 7.28-7.25 (m, 1H, Ar-**H**), 3.94-3.80 (m, 4H, -O-C**H$_2$**-), 2.71 (t, *J* = 7.6 Hz, 2H, Ar-C**H$_2$**-), 1.68- 1.60 (m, 2H, Ar-CH$_2$-C**H$_2$**-), 1.50-1.42 (m, 4H, O-CH$_2$-C**H$_2$**-), 1.40-1.33 (m, 2H, Ar-CH$_2$-CH$_2$-C**H$_2$**-CH$_3$), 1.30-1.21 (m, 4H, -O-CH$_2$-CH$_2$-C**H$_2$**-CH$_3$), 0.95 (t, *J* = 7.2 Hz, 3H, Ar-CH$_2$-CH$_2$-CH$_2$-C**H$_3$**), 0.87 (t, *J* = 7.6 Hz, 6H, -CH$_2$-C**H$_3$**); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 159.04 (Ar-**C**), 148.79 (Ar-**C**), 142.89 (d, *J* = 13.8 Hz, Ar-**C**), 142.05 (d, *J* = 9.3 Hz, Ar-**C**), 135.47 (Ar-**C**), 133.90 (d, *J* = 9.3 Hz, Ar-**C**), 132.32 (Ar-**C**), 131.10 (d, *J* = 14.3 Hz, Ar-**C**), 127.06 (Ar-**C**), 124.81 (Ar-**C**), 122.17 (Ar-**C**), 116.16 (Ar-**C**), 65.72 (d, *J* = 6.0 Hz, O-**C**H$_2$-), 35.26 (Ar-**C**H$_2$-), 33.41 (Ar-CH$_2$-**C**H$_2$-), 32.34 (d, *J* = 6.6 Hz, -O-CH$_2$-**C**H$_2$-), 22.29 (Ar-CH$_2$-CH$_2$-**C**H$_2$-), 18.71 (-O-CH$_2$-CH$_2$-**C**H$_2$-CH$_3$), 13.93 (Ar-CH$_2$- CH$_2$-CH$_2$-**C**H$_3$), 13.62 (O-CH$_2$-CH$_2$-CH$_2$-**C**H$_3$); **$^{31}$P NMR** (162 MHz, $CDCl_3$): δ (ppm) 24.22; **HRMS** (ESI$^+$) m/z calcd for $C_{23}H_{34}NO_3P$ $[M+H]^+$ 404.2276, found: 404.2350. |
| **Dibutyl (5-phenoxy-2-(pyridin-2-yl)phenyl)phosphonate (5f)**  | Colorless oil; 67 mg, yield 63%; $R_f$ = 0.15 (EtOAc); **$^1$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.67-8.65 (m, 1H, Ar-**H**), 7.73-7.71 (m, 2H, Ar-**H**), 7.64 (dd, *J* = 2.8 & 12.8 Hz, 1H, Ar-**H**), 7.53-7.49 (m, 1H, Ar-**H**), 7.39-7.35 (m, 2H, Ar-**H**), 7.29-7.27 (m, 1H, Ar-**H**), 7.23-7.20 (m, 1H, Ar-**H**), 7.17-7.13 (m, 1H, Ar-**H**), 7.07-7.05 (m, 2H, Ar-**H**), 3.92-3.79 (m, 4H, -O-C**H$_2$**-), 1.47-1.40 (m, 4H, O-CH$_2$-C**H$_2$**-), 1.28-1.18 (m, 4H, -C**H$_2$**-CH$_3$), 0.86 (t, *J* = 7.6 Hz, 6H, -CH$_2$-C**H$_3$**); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 158.36 (d, *J* = 4.1 Hz, Ar-**C**), 157.20 (d, *J* = 18.2 Hz, Ar-**C**), 156.40 (Ar-**C**), 148.87 (Ar-**C**), 139.37 (d, *J* = 9.6 Hz, Ar-**C**), 135.62 (Ar-**C**), 132.92 (d, *J* = 15.8 Hz, Ar-**C**), 129.95 (Ar-**C**), 127.55 (Ar-**C**), 124.85 (Ar-**C**), 123.99 (Ar-**C**), 123.33 (d, *J* = 9.9 Hz, Ar-**C**), 122.27 (Ar-**C**),121.94 (d, *J* = 2.4 Hz, Ar-**C**), 119.38 (Ar-**C**), 65.93 (d, *J* = 6.2 Hz, -O-**C**H$_2$-), 32.26 (d, J = 6.6 Hz, -O-CH$_2$-C**H$_2$**-), 18.65 (-C**H$_2$**-CH$_3$), 13.58 (-CH$_2$-C**H$_3$**); **$^{31}$P NMR** (162 MHz, $CDCl_3$): δ (ppm) 22.68; **HRMS** (ESI$^+$) m/z calcd for $C_{25}H_{30}NO_4P$ $[M+H]^+$ 440.1912, found: 440.1999. |
| **Dibutyl (4-(pyridin-2-yl)-[1,1'-biphenyl]-3-yl)phosphonate (5g)**  | Colorless oil; 56 mg, yield 51%; $R_f$ = 0.15 (EtOAc); **$^1$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.69-8.67 (m, 1H, Ar-**H**), 8.27 (dd, *J* = 2.0 & 12.8 Hz, 1H, Ar-**H**), 7.84-7.81 (m, 1H, Ar-**H**), 7.74-7.72 (m, 2H, Ar-**H**), 7.66-7.59 (m, 3H, Ar-**H**), 7.48-7.44 (m, 2H, Ar-**H**), 7.40-7.36 (m, 1H, Ar-**H**), 7.31-7.27 (m, 1H, Ar-**H**), 3.97-3.83 (m, 4H, -O- |

| | |
|---|---|
| | C**H$_2$**-), 1.51-1.43 (m, 4H, -O-CH$_2$-C**H$_2$**-), 1.32-1.28 (m, 4H, -C**H$_2$**-CH$_3$), 0.86 (t, *J* = 7.2 Hz, 6H, -CH$_2$-C**H$_3$**); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 149.00 (Ar-**C**), 135.65 (Ar-**C**), 132.66 (d, *J* = 10.2 Hz, Ar-**C**), 131.79 (d, *J* = 14.2 Hz, Ar-**C**), 130.75 (d, J = 3.3 Hz, Ar-**C**), 129.01 (Ar-**C**), 127.99 (Ar-**C**), 127.30 (Ar-**C**), 124.91 (Ar-**C**), 124.06 (Ar-**C**), 123.52 (Ar-**C**), 122.46 (Ar-**C**), 115.98 (Ar-**C**), 114.13 (Ar-**C**), 65.95 (d, J = 6.5 Hz, O-**C**H$_2$-), 32.41 (d, *J* = 6.8 Hz, -O-CH$_2$-**C**H$_2$-), 18.77 (-**C**H$_2$-CH$_3$), 13.66 (-CH$_2$-**C**H$_3$); **$^{31}$P NMR** (162 MHz, $CDCl_3$): δ (ppm) 23.56; **HRMS** ($ESI^+$) m/z calcd for $C_{25}H_{30}NO_3P$ $[M+H]^+$ 424.1963, found: 424.1967. |
| **Dibutyl (4'-pentyl-4-(pyridin-2-yl)-[1,1'-biphenyl]-3-yl)phosphonate (5h)**<br>  <br> | Colorless oil; 52 mg, yield 53%; $R_f$ = 0.15 (EtOAc); **$^{1}$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.69 (d, *J* = 4.8 Hz, 1H, Ar-**H**), 8.27 (dd, *J* = 2.0 & 13.2 Hz, 1H, Ar-**H**), 7.84-7.81 (m, 1H, Ar-**H**), 7.75-7.73 (m, 2H, Ar-**H**), 7.62-7.56 (m, 3H, Ar-**H**), 7.32-7.27 (m, 3H, Ar-**H**), 3.98-3.84 (m, 4H, -O-C**H$_2$**-), 2.68 (t, *J* = 7.6 Hz, 2H, Ar-C**H$_2$**-), 1.70-1.62 (m, 2H, Ar-CH$_2$-C**H$_2$**-), 1.52-1.44 (m, 4H, -O-CH$_2$-C**H$_2$**-), 1.43-1.40 (m, 2H, Ar-CH$_2$-CH$_2$-C**H$_2$**-), 1.38-1.34 (m, 2H, Ar-CH$_2$-CH$_2$-CH$_2$-C**H$_2$**-CH$_3$), 1.33-1.28 (m, 4H, O-CH$_2$-CH$_2$-CH$_2$-), 0.93-0.89 (m, 3H, Ar-CH$_2$-CH$_2$-CH$_2$-CH$_2$-C**H$_3$**), 0.88 (t, *J* = 7.2 Hz, 6H, O-CH$_2$-CH$_2$-CH$_2$-CH$_2$-C**H$_3$**); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 158.63 (Ar-**C**), 148.82 (Ar-**C**), 142.92 (Ar-**C**), 140.88 (d. *J* = 13.3 Hz, Ar-**C**), 136.91 (Ar-**C**), 135.65 (Ar-**C**), 132.35 (d, *J* = 9.7 Hz, Ar-C), 131.67 (d, *J* = 14.5 Hz, Ar-C), 130.48 (Ar-C), 129.01 (Ar-**C**), 127.03 (Ar-C), 124.89 (Ar-**C**), 122.38 (Ar-**C**), 120.85 (d, *J* = 4.5 Hz, Ar-**C**), 116.15 (Ar-**C**), 65.89 (d, *J* = 6.0 Hz, O-**C**H$_2$-), 35.60 (Ar-**C**H$_2$-), 32.33 (d, *J* = 6.8 Hz, -O-CH$_2$-**C**H$_2$-), 31.93 (Ar-CH$_2$-**C**H$_2$-), 31.16 (Ar-CH$_2$-CH$_2$-**C**H$_2$-), 22.69 (d, *J* = 13.4 Hz, Ar-CH$_2$-CH$_2$-CH$_2$-**C**H$_2$-CH$_3$), 18.70 (-O-CH$_2$-CH$_2$-**C**H$_2$-CH$_3$), 14.12 (d, *J* = 7.9 Hz, Ar-CH$_2$-CH$_2$-CH$_2$-CH$_2$-**C**H$_3$), 13.60 (-O-CH$_2$-CH$_2$-CH$_2$-**C**H$_3$); **$^{31}$P NMR** (162 MHz, $CDCl_3$): δ (ppm) 23.64; **HRMS** ($ESI^+$) m/z calcd for $C_{30}H_{40}NO_3P$ $[M+H]^+$ 494.2746, found: 494.2801. |
| **Dibutyl (4-fluoro-2-(pyridin-2-yl)phenyl)phosphonate (5i)**<br>  <br> | Colorless oil; 99 mg, yield 78%; $R_f$ = 0.15 (EtOAc); **$^{1}$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.68-8.66 (m, 1H, Ar-**H**), 8.07-8.00 (m, 1H, Ar-**H**), 7.76-7.72 (m, 1H, Ar-**H**), 7.69-7.67 (m, 1H, Ar-**H**), 7.33-7.30 (m, 1H, Ar-**H**), 7.28-7.24 (m, 1H, Ar-**H**), 7.21-7.16 (m, 1H, Ar-**H**), 3.94-3.80 (m, 4H, -O-C**H$_2$**-), 1.50-1.44 (m, 4H, -O-CH$_2$-C**H$_2$**-), 1.29-1.21 (m, 4H, -C**H$_2$**-CH$_3$), 0.88 (t, *J* = 7.6 Hz, 6H, -CH$_2$-C**H$_3$**); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 157.56 (Ar-**C**), 148.97 (Ar-**C**), 147.66 (Ar-**C**), 136.67 (t, *J* = 9.5 Hz, Ar-**C**), 135.73 (Ar-**C**), 124.62 (Ar-**C**), 123.72 (d, *J* = 2.5 Hz, Ar-**C**), 122.80 (Ar-**C**), 118.58 (Ar-**C**), 116.12 (Ar-**C**), 115.21 (Ar-**C**), 65.88 (d, *J* = 6.1 Hz, O- |

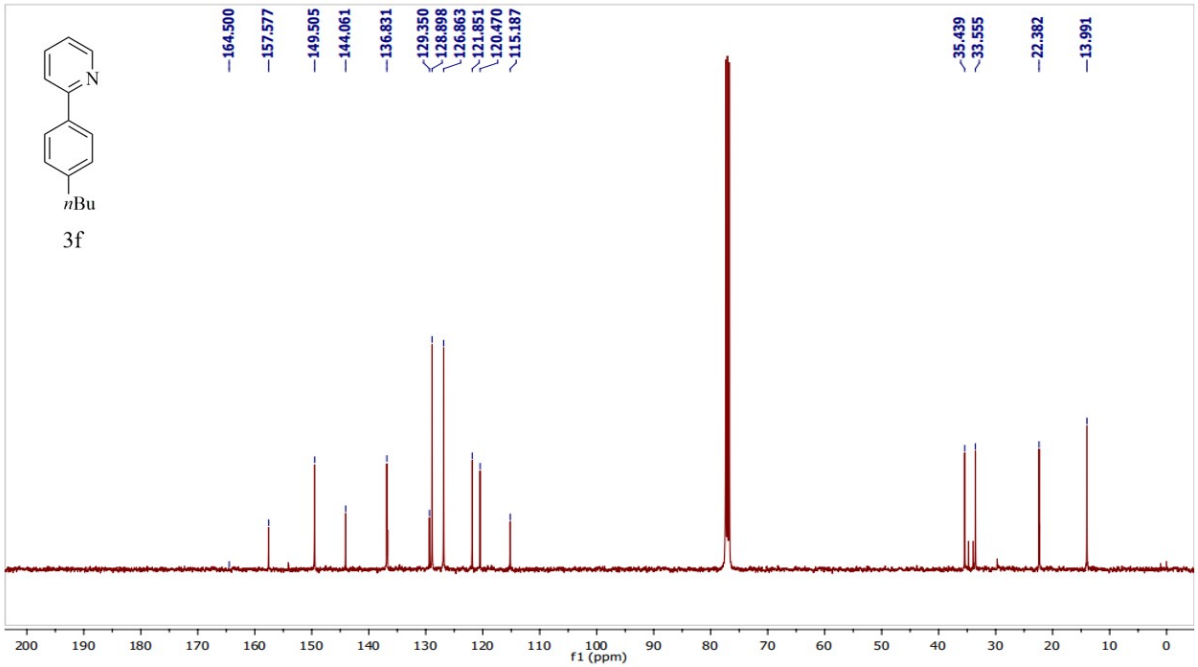
| | |
|---|---|
| | **C**$H_2$-), 32.30 (d, *J* = 6.6 Hz, -O-$CH_2$-**C**$H_2$-), 18.67 (-**C**$H_2$-$CH_3$), 13.58 (-$CH_2$-**C**$H_3$); **$^{31}$P NMR** (162 MHz, $CDCl_3$): δ (ppm) 22.64; **HRMS** ($ESI^+$) m/z calcd for $C_{19}H_{25}FNO_3P$ $[M+H]^+$ 366.1556, found: 366.1550. |
| **Dibutyl (3-(pyridin-2-yl)naphthalen-2-yl)phosphonate (5j)**<br>  <br> | Colorless oil; 83 mg, yield 72%; $R_f$ = 0.15 (EtOAc); **$^1$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.71-8.69 (m, 1H, Ar-**H**), 8.66 (d, *J* = 16.4 Hz, 1H, Ar-**H**), 7.99-7.97 (m, 2H, Ar-**H**), 7.90 (d, *J* = 7.6 Hz, 1H, Ar-**H**), 7.78-7.72 (m, 2H, Ar-**H**), 7.64-7.56 (m, 2H, Ar-**H**), 7.34-7.30 (m, 1H, Ar-**H**), 4.00-3.85 (m, 4H, -O-C**H$_2$**-), 1.54-1.47 (m, 4H, -O-$CH_2$-C**H$_2$**-), 1.33-1.27 (m, 4H, -C**H$_2$**-$CH_3$), 0.88 (t, *J* = 7.6 Hz, 6H, -$CH_2$-C**H$_3$**); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 148.74 (Ar-**C**), 136.54 (d, *J* = 9.1 Hz, Ar-C), 135.57 (Ar-**C**), 134.58 (Ar-**C**), 131.79 (d, *J* = 15.7 Hz, Ar-**C**), 130.59 (d, *J* = 12.9 Hz, Ar-**C**), 128.74 (Ar-**C**), 128.02 (Ar-**C**), 127.20 (Ar-**C**), 124.97 (Ar-**C**), 122.31 (Ar-**C**), 65.87 (d, *J* = 5.7 Hz, -O-**C**$H_2$-), 32.35 (d, *J* = 6.7 Hz, -O-$CH_2$-**C**$H_2$-), 18.71 (-**C**$H_2$-$CH_3$), 13.54 (-$CH_2$-**C**$H_3$); **$^{31}$P NMR** (162 MHz, $CDCl_3$): δ (ppm) 23.96; **HRMS** ($ESI^+$) m/z calcd for $C_{23}H_{28}NO_3P$ $[M+H]^+$ 398.1807, found: 398.1811. |
| **Diethyl (5-methoxy-2-(pyridin-2-yl)phenyl)phosphonate (5bb)**<br>  <br> | Colorless oil; 60 mg, yield 58%; $R_f$ = 0.15 (EtOAc); **$^1$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.66-8.64 (m, 1H, Ar-**H**), 7.73 (dt, *J* = 1.6 & 6.0 Hz, 1H, Ar-**H**), 7.65-7.63 (m, 1H, Ar-**H**), 7.58 (dd, *J* = 2.8 & 12.8 Hz, 1H, Ar-**H**), 7.49-7.45 (m, 1H, Ar-**H**), 7.28-7.26 (m, 1H, Ar-**H**), 7.15-7.12 (m, 1H, Ar-**H**), 4.03- 3.90 (m, 4H, -O-C**H$_2$**-), 3.89 (s, 3H, Ar-OC**H$_3$**), 1.17 (t, *J* = 6.8 Hz, 6H, -$CH_2$-C**H$_3$**); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 159.17 (Ar-**C**), 148.83 (Ar-**C**), 137.25 (d, *J* = 9.3 Hz, Ar-**C**), 135.57 (Ar-**C**), 132.65 (d, *J* = 16.1 Hz, Ar-**C**), 128.62 (Ar-**C**), 126.78 (Ar-**C**), 124.96 (Ar-**C**), 122.17 (Ar-**C**), 118.85 (d, *J* = 11.0 Hz, Ar-**C**), 118.11 (d, *J* = 3.6 Hz, Ar-**C**), 62.14 (d, *J* = 6.3 Hz, -O-**C**$H_2$- **C**$H_3$ ), 55.66 (Ar-O**C**$H_3$), 16.16 (d, *J* = 7.0 Hz, -O-$CH_2$-**C**$H_3$); **$^{31}$P NMR** (162 MHz, $CDCl_3$): δ (ppm) 18.30; **HRMS** ($ESI^+$) m/z calcd for $C_{16}H_{20}NO_4P$ $[M+H]^+$ 322.1130, found: 322.1134. |
| **Diisopropyl (5-methoxy-2-(pyridin-2-yl)phenyl)phosphonate (5bc)**[13]<br>  <br> | Colorless oil; 70 mg, yield 62%; $R_f$ = 0.15 (EtOAc); **$^1$H NMR** (400 MHz, $CDCl_3$): δ (ppm) 8.66-8.64 (m, 1H, Ar-**H**), 7.71-7.69 (m, 2H, Ar-**H**), 7.62 (dd, *J* = 3.6 Hz & 18.0 Hz, 1H, Ar-**H**), 7.50-7.45 (m, 1H, Ar-**H**), 7.28-7.23 (m, 1H, Ar-**H**), 7.14-7.10 (m, 1H, Ar-**H**), 4.67- 4.56 (m, 2H, -O-C**H**$(CH_3)_2$), 3.89 (s, 3H, Ar-OC**H$_3$**), 1.22 (d, *J* = 8.4 Hz, 6H, -O-CH(C**H$_3$**)$_2$), 1.16 (d, *J* = 8.4 Hz, 6H, -O-C**H**$(CH_3)_2$); **$^{13}$C NMR** (100 MHz, $CDCl_3$): δ (ppm) 159.11 (Ar-**C**), 148.42 (Ar-**C**), 135.59 (Ar-**C**), 132.80 (d, *J* = 21.2 Hz, Ar-**C**), 125.41 (Ar-**C**), 122.04, 118.75 (d, *J* = 14.1 Hz, Ar-**C**), 117.75 (d, *J* = 3.6 Hz, Ar-**C**), 71.10 (d, *J* = 8.1 Hz, -O-**C**-(**C**$H_3)_2$ ), 55.59 (Ar-O**C**$H_3$), 29.71 (-O-CH-(**C**$H_3)_3$), 22.97 (dd, *J* = 5.1 & 16.6 Hz, -O-CH- |

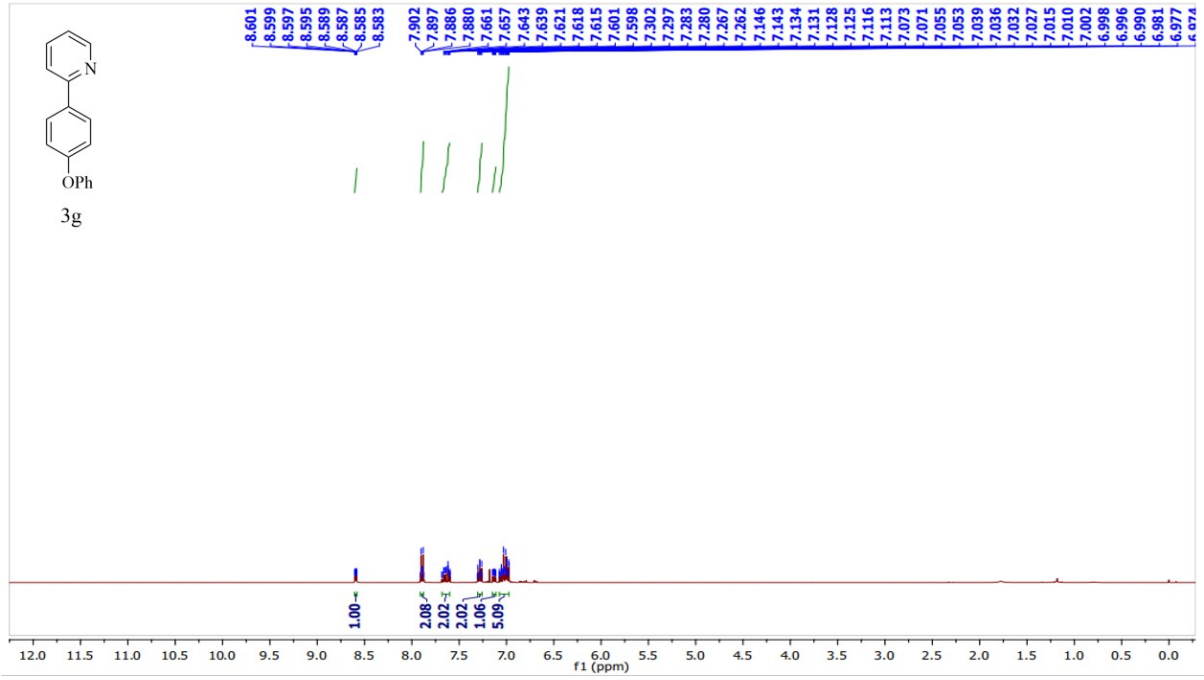
| | |
|---|---|
| | ($\mathbf{C}H_3)_3$); **$^{31}$P NMR** (162 MHz, $CDCl_3$): δ (ppm) 16.27; **HRMS** ($ESI^+$) m/z calcd for $C_{18}H_{24}NO_4P$ $[M+H]^+$ 349.1443, found: 349.1447. The spectral data of this compound are in complete agreement with those reported in the literature.[13] |

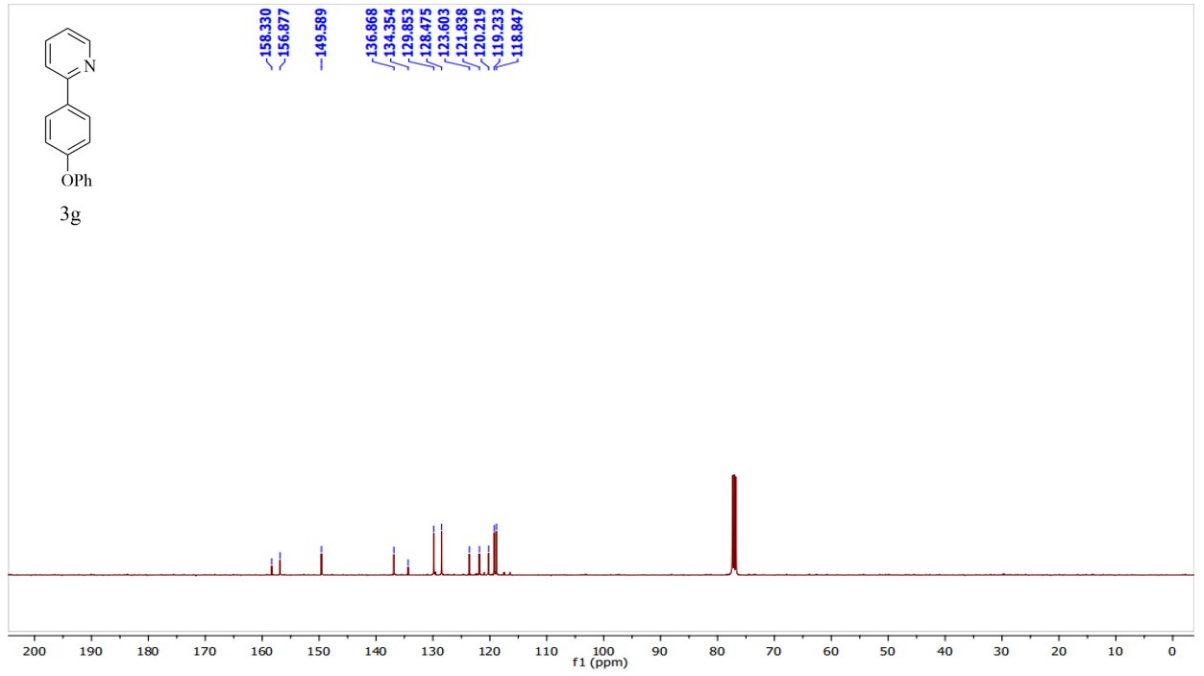
## 3. $^{1}H$, $^{13}C$ and $^{31}P$ NMR copies

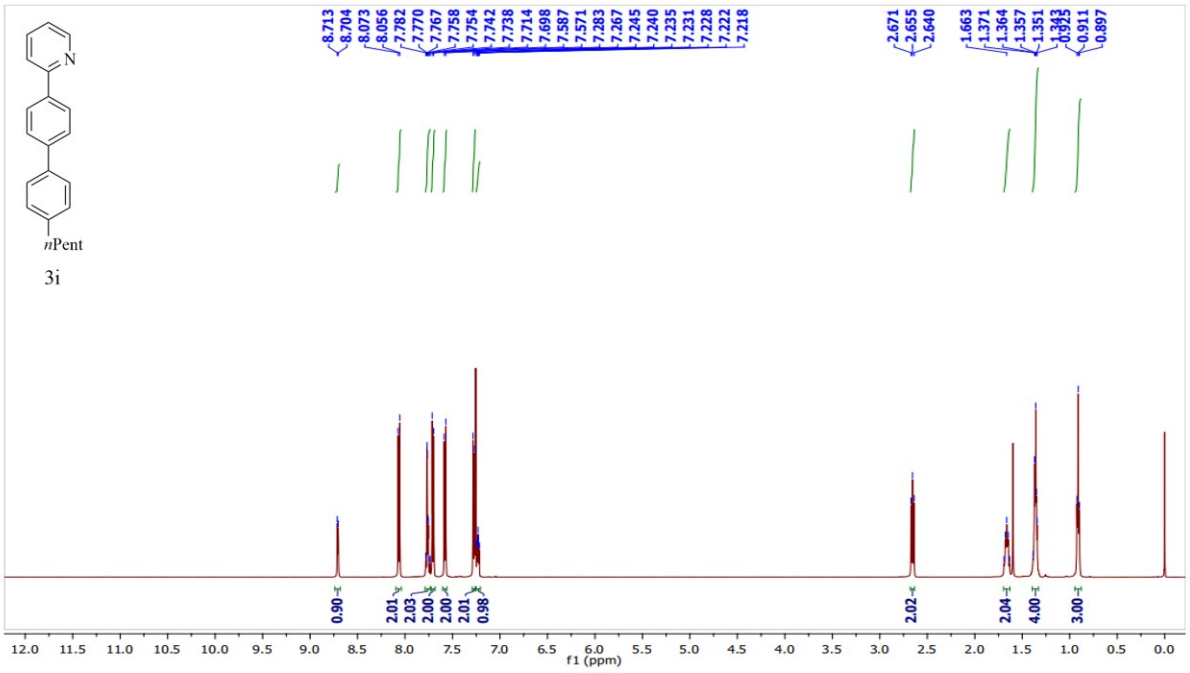



**2.**



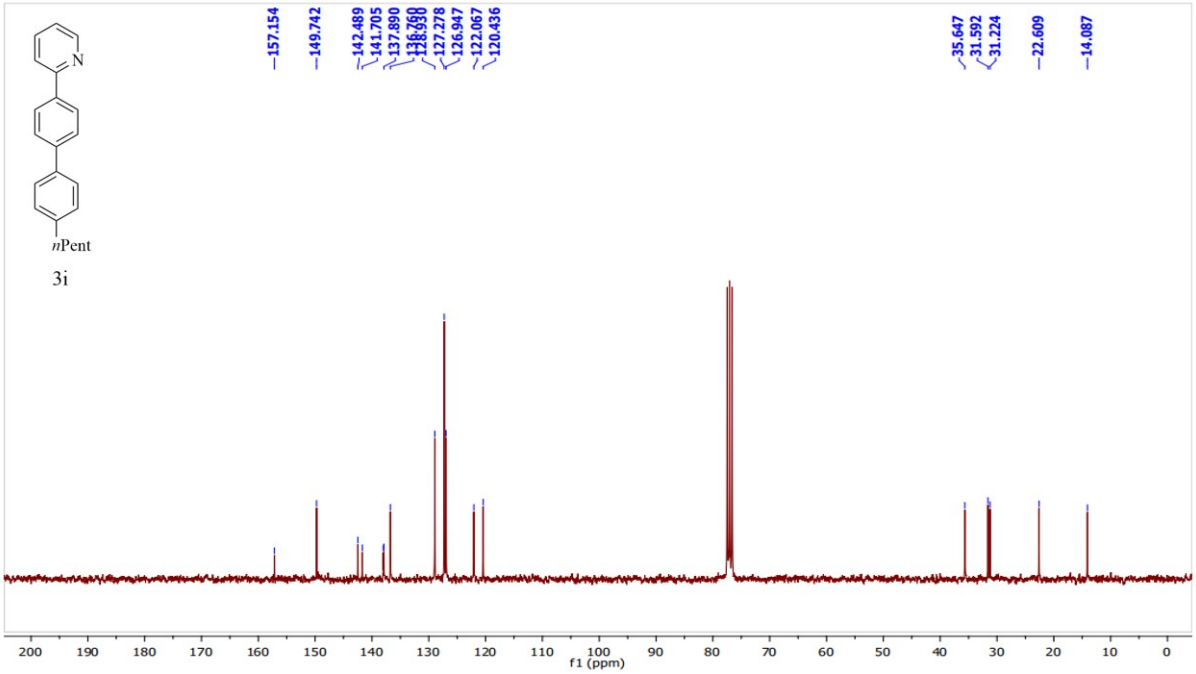

8.601
8.599
8.597
8.595
8.589
8.587
8.585
8.583
7.902
7.897
7.886
7.880
7.661
7.657
7.643
7.639
7.621
7.618
7.615
7.601
7.598
7.302
7.297
7.283
7.280
7.267
7.262
7.146
7.143
7.134
7.131
7.128
7.125
7.116
7.113
7.073
7.071
7.055
7.053
7.039
7.036
7.032
7.027
7.015
7.010
7.002
6.998
6.996
6.990
6.981
6.977
N
OPh
3g
1.00
2.08
2.02
2.02
1.06
5.09
12.0 11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)


158.330
156.877
149.589
136.868
134.354
129.853
128.475
123.603
121.838
120.219
119.233
118.847
N
OPh
3g
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)



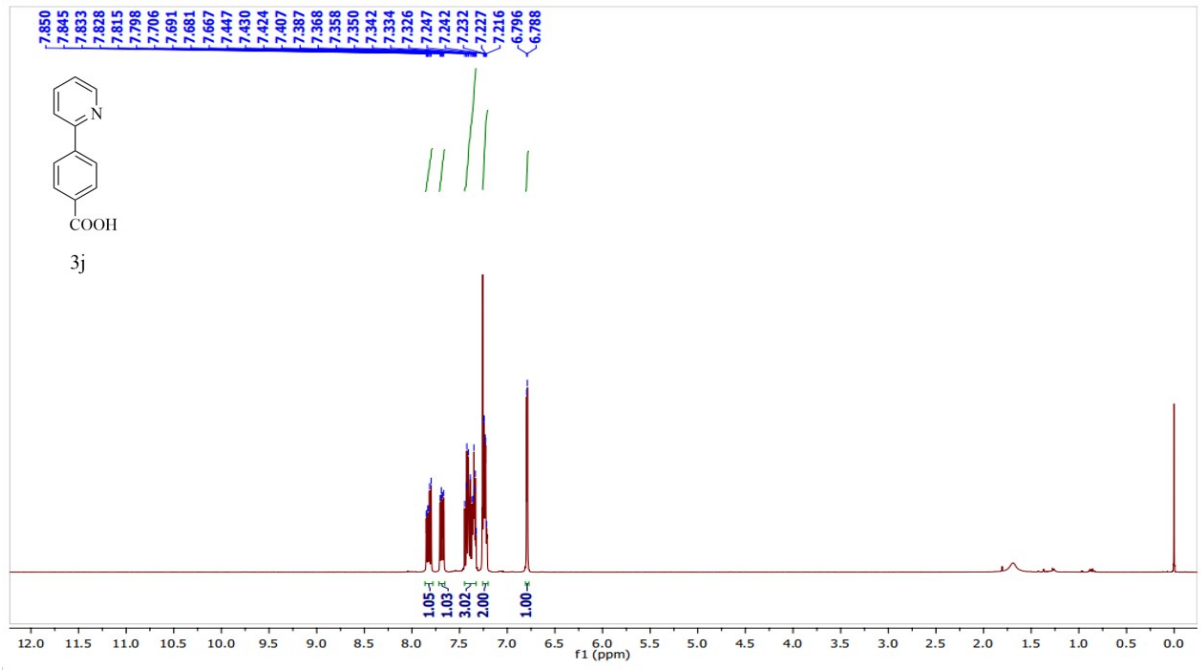

*n*Pent

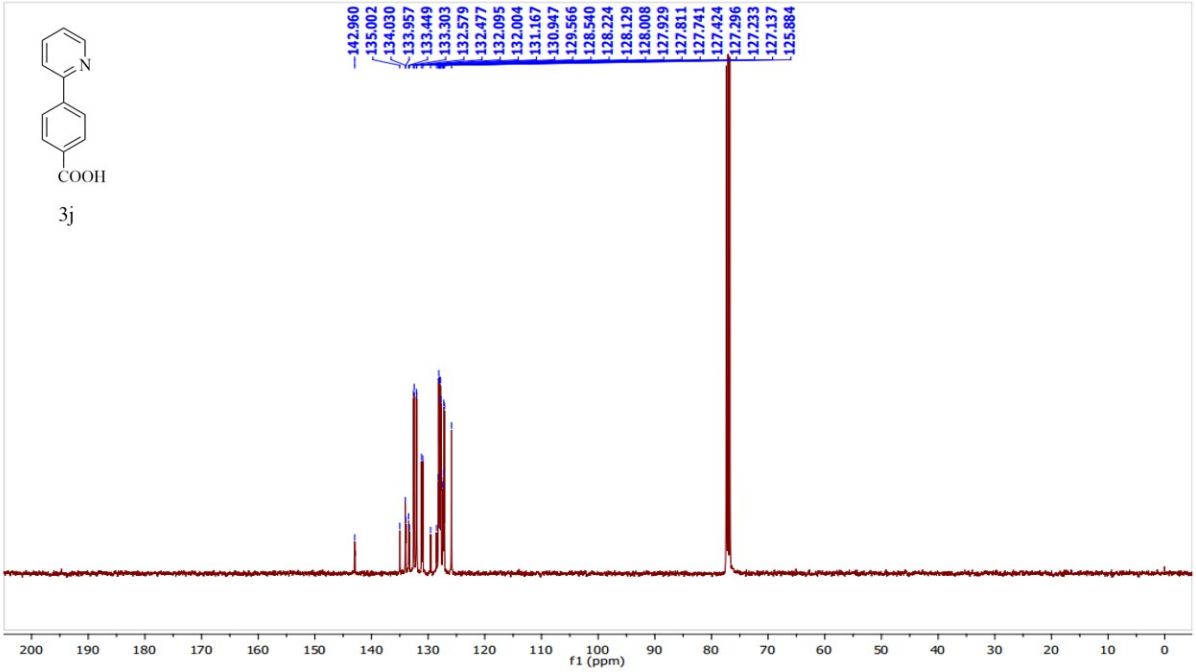
3i

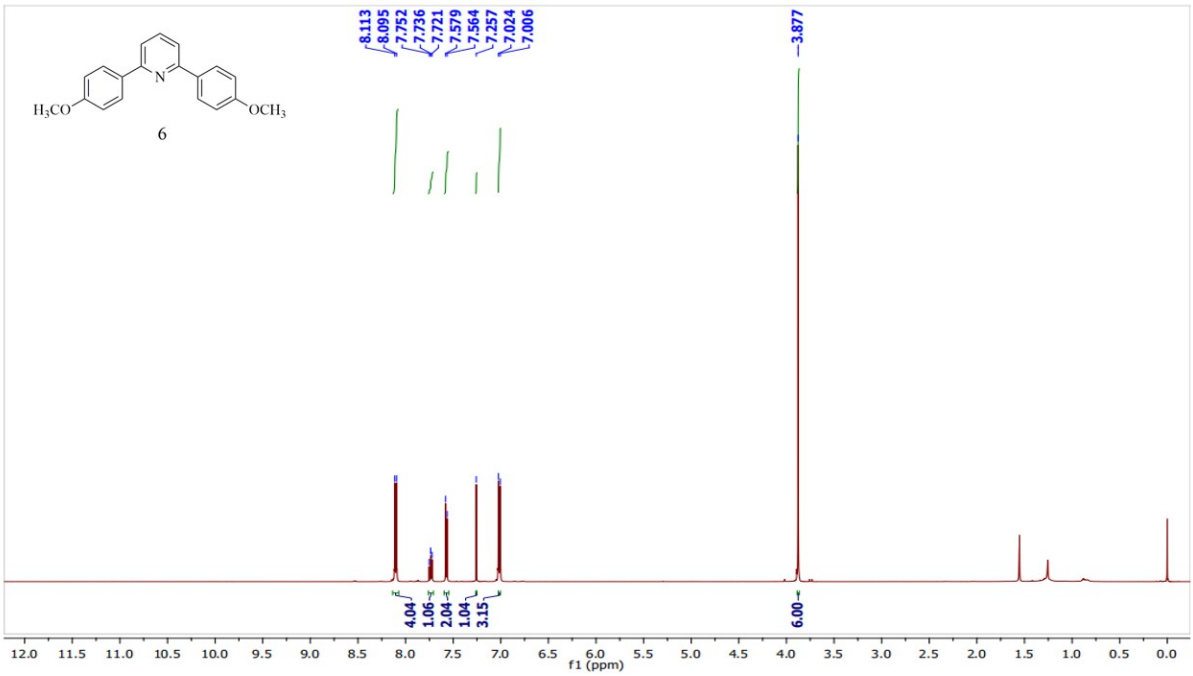



*n*Pent

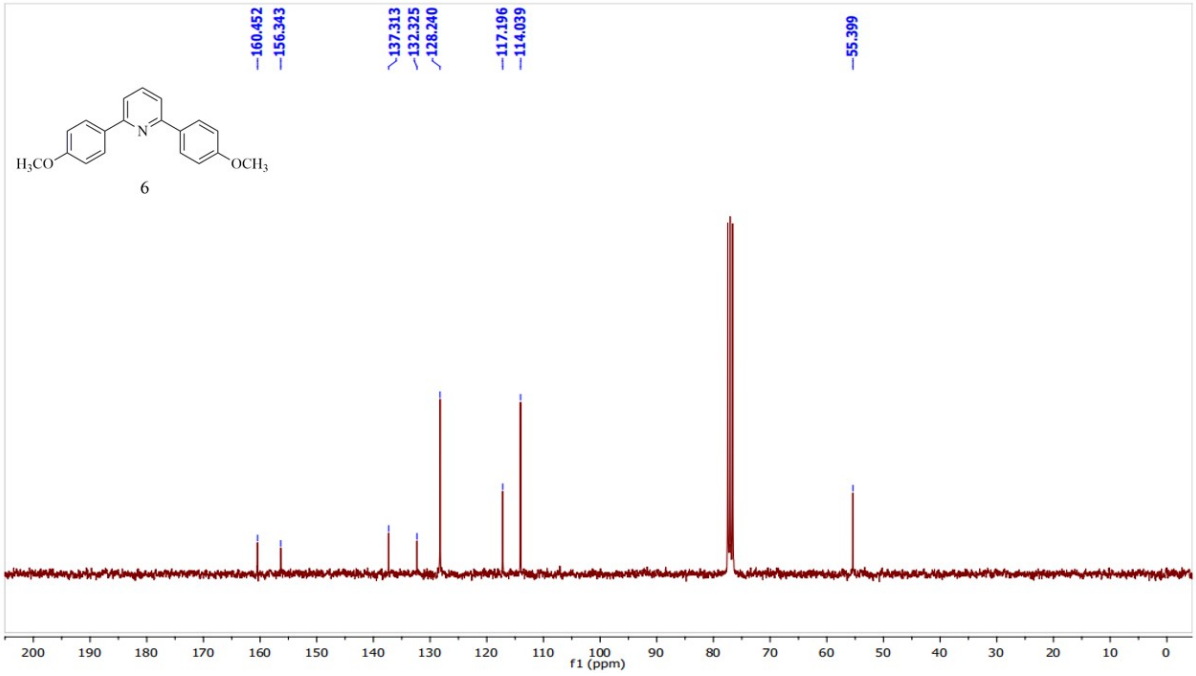
3i


7.850
7.845
7.833
7.828
7.815
7.798
7.706
7.691
7.681
7.667
7.447
7.430
7.424
7.407
7.387
7.368
7.358
7.350
7.342
7.334
7.326
7.247
7.242
7.232
7.227
7.216
6.796
6.788
N
COOH
3j
1.05
1.03
3.02
2.00
1.00
f1 (ppm)

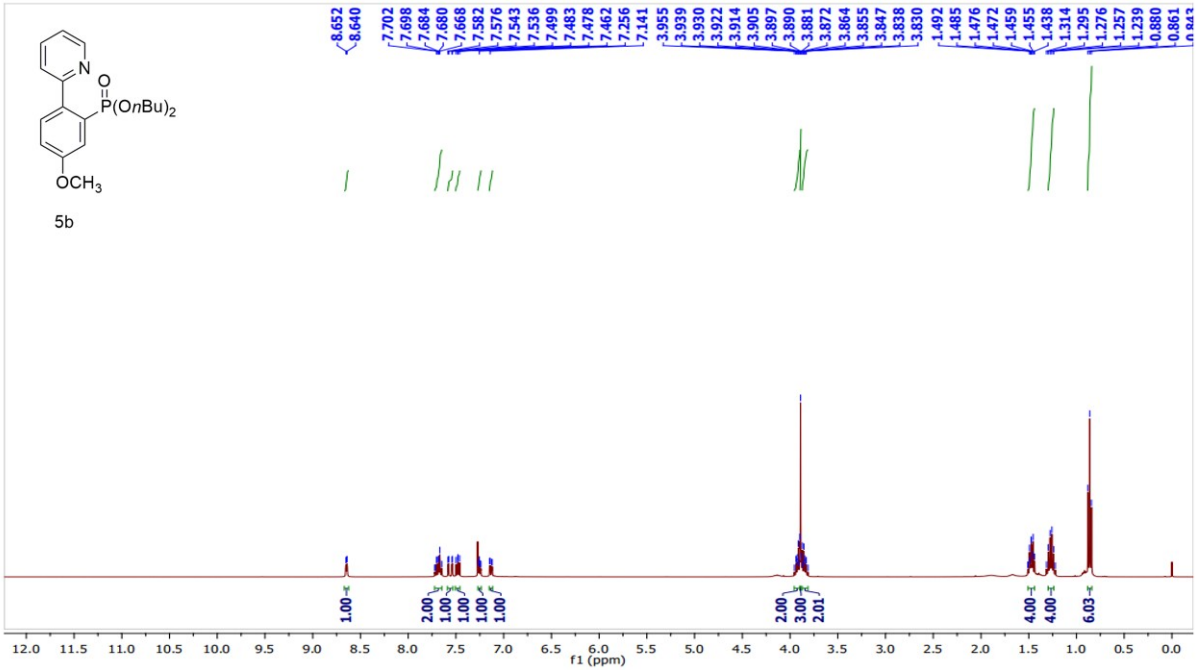

142.960
135.002
134.030
133.957
133.449
133.303
132.579
132.477
132.095
132.004
131.167
130.947
129.566
128.540
128.224
128.129
128.008
127.929
127.811
127.741
127.424
127.296
127.233
127.137
125.884
N
COOH
3j
f1 (ppm)

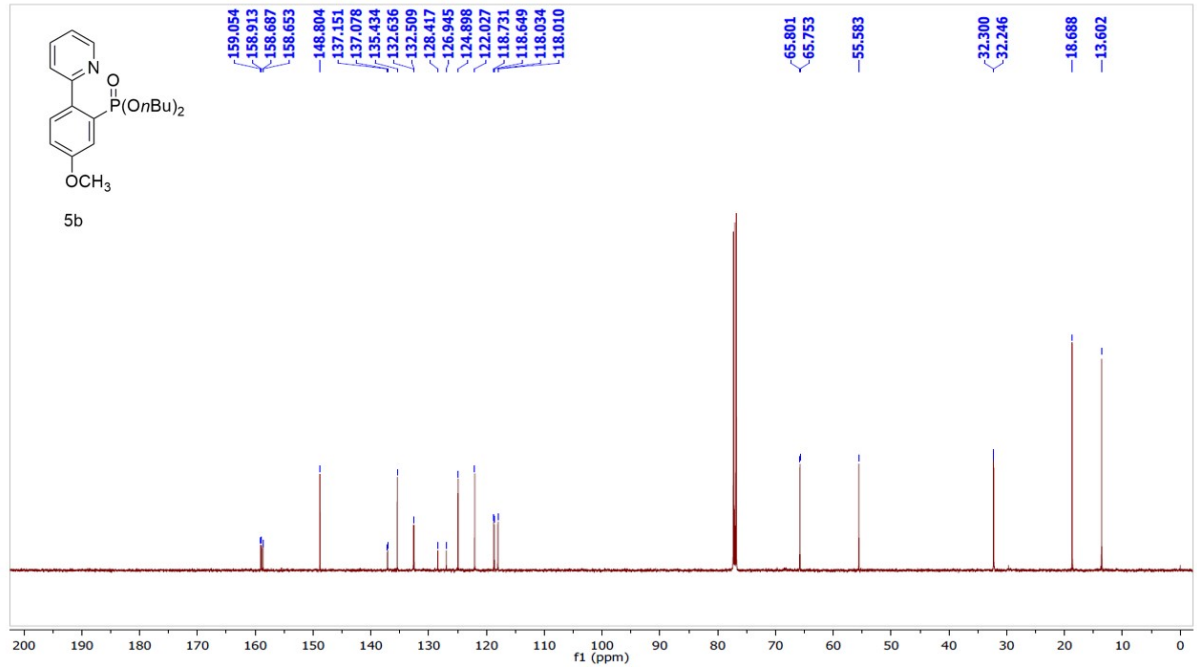

8.113
8.095
7.752
7.736
7.721
7.579
7.564
7.257
7.024
7.006
3.877
4.04
1.06
2.04
1.04
3.15
6.00
f1 (ppm)

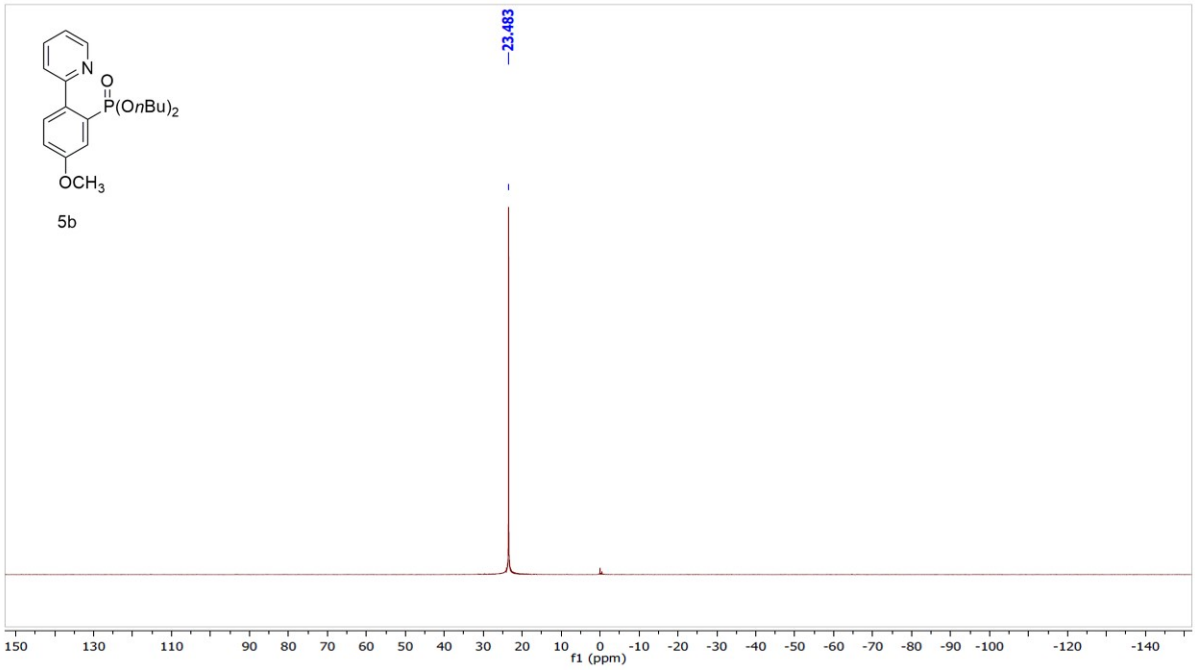
6

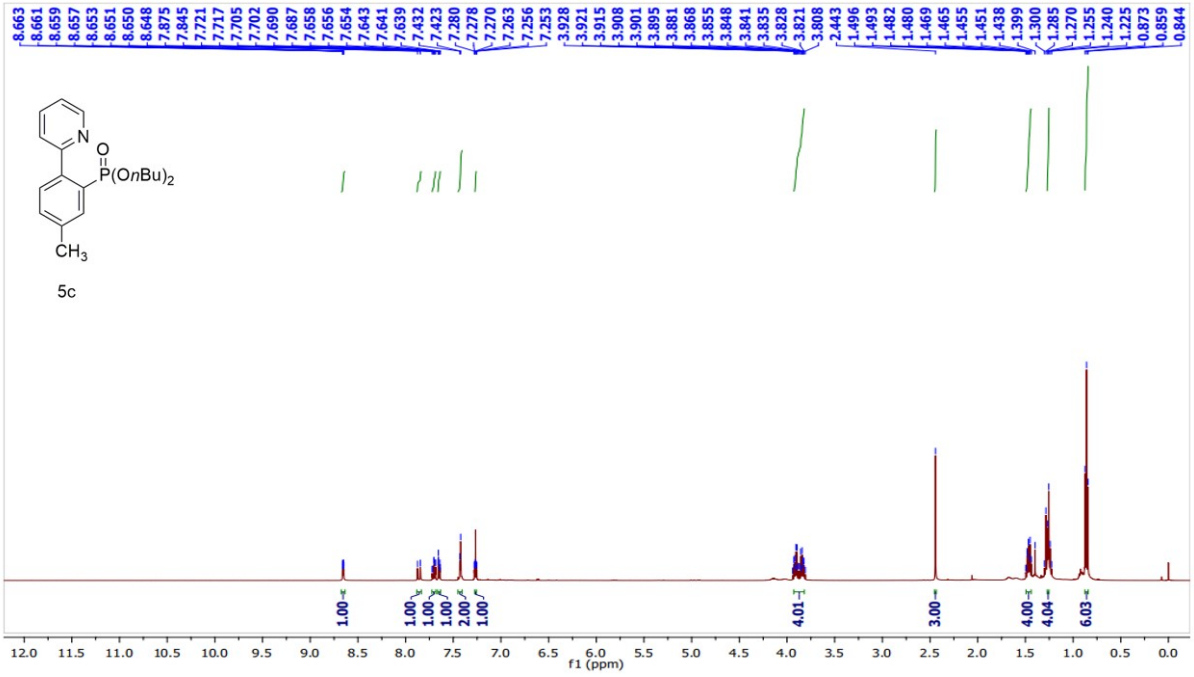

160.452
156.343
137.313
132.325
128.240
117.196
114.039
55.399
f1 (ppm)

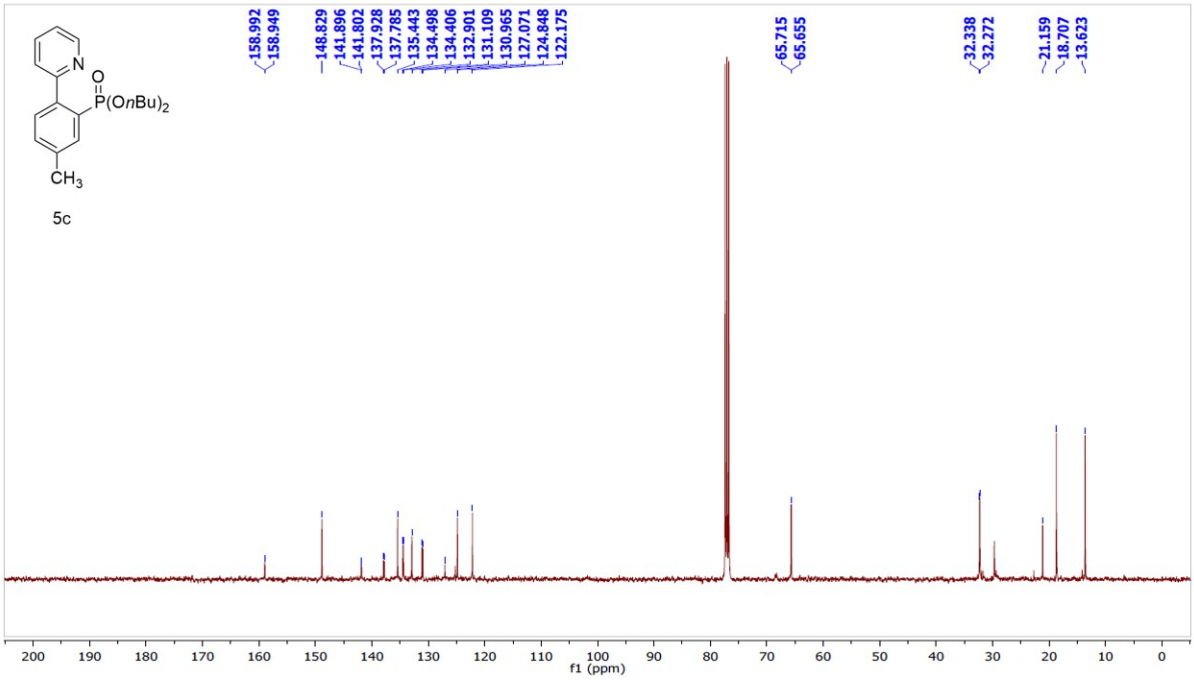
6

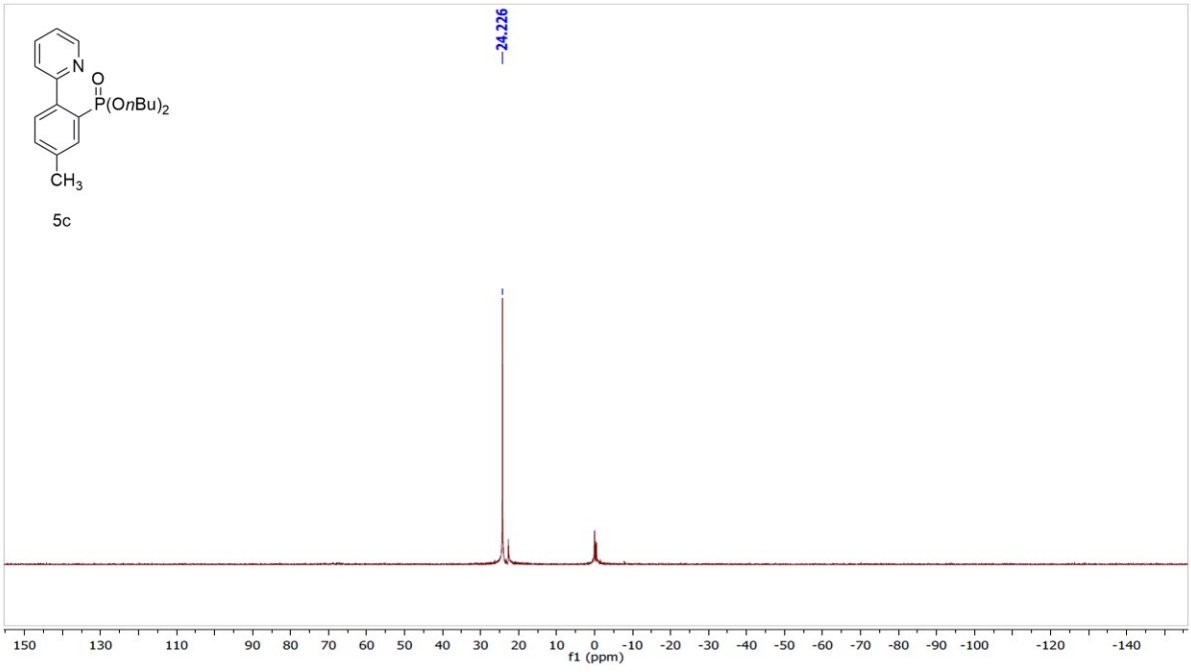

5b
8.652
8.640
7.702
7.698
7.684
7.680
7.668
7.582
7.576
7.543
7.536
7.499
7.483
7.478
7.462
7.256
7.141
3.955
3.939
3.930
3.922
3.914
3.905
3.897
3.890
3.881
3.872
3.864
3.855
3.847
3.838
3.830
1.492
1.485
1.476
1.472
1.459
1.455
1.438
1.314
1.295
1.276
1.257
1.239
0.880
0.861
1.00
2.00
1.00
1.00
1.00
1.00
2.00
3.00
2.01
4.00
4.00
6.03
f1 (ppm)

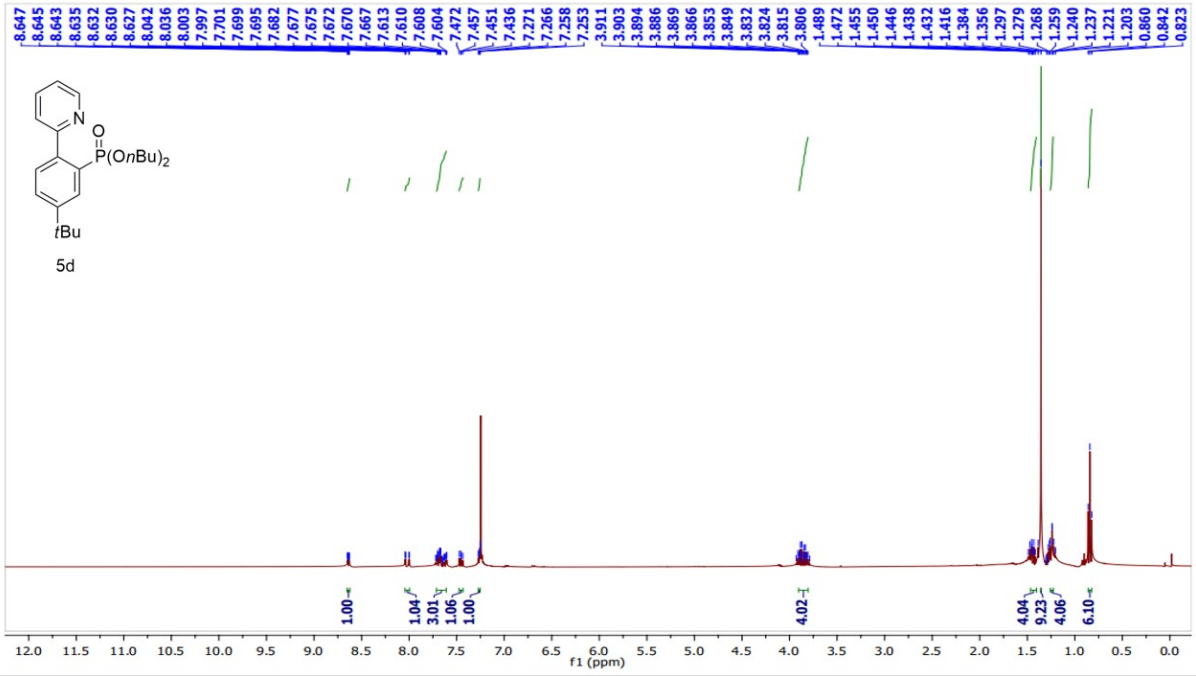

5b
159.054
158.913
158.687
158.653
148.804
137.151
137.078
135.434
132.636
132.509
128.417
126.945
124.898
122.027
118.731
118.649
118.034
118.010
65.801
65.753
55.583
32.300
32.246
18.688
13.602
f1 (ppm)

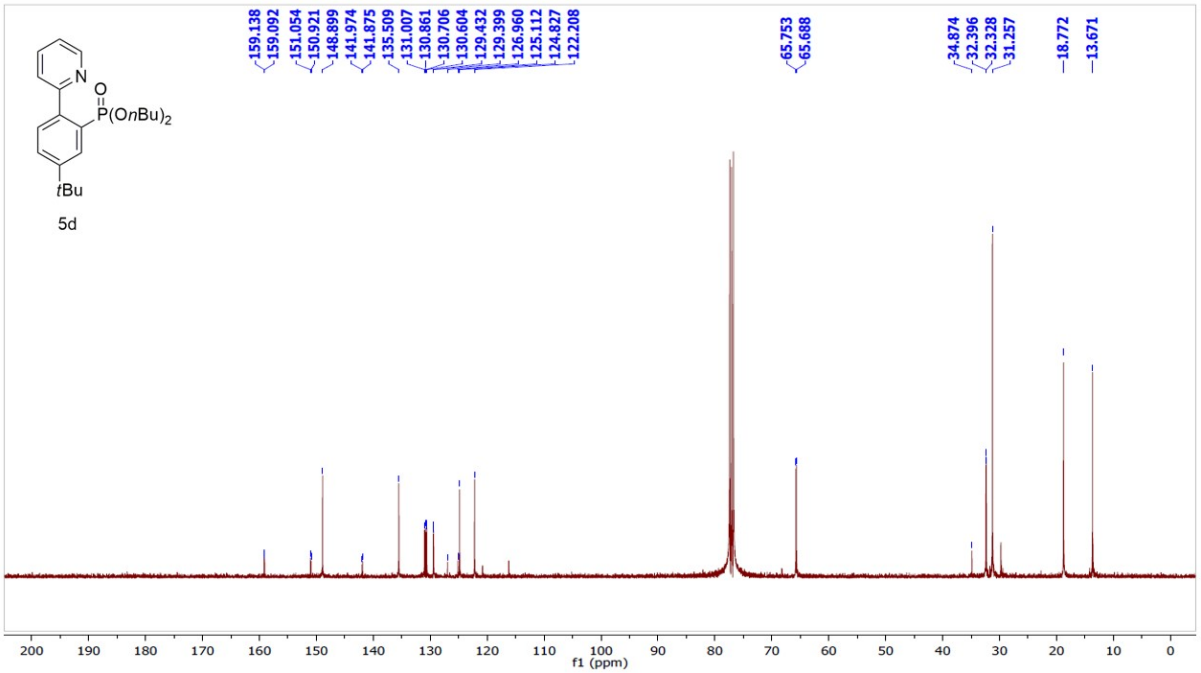

23.483
N
O
P(OnBu)2
OCH3
5b
150 130 110 90 80 70 60 50 40 30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -120 -140
f1 (ppm)

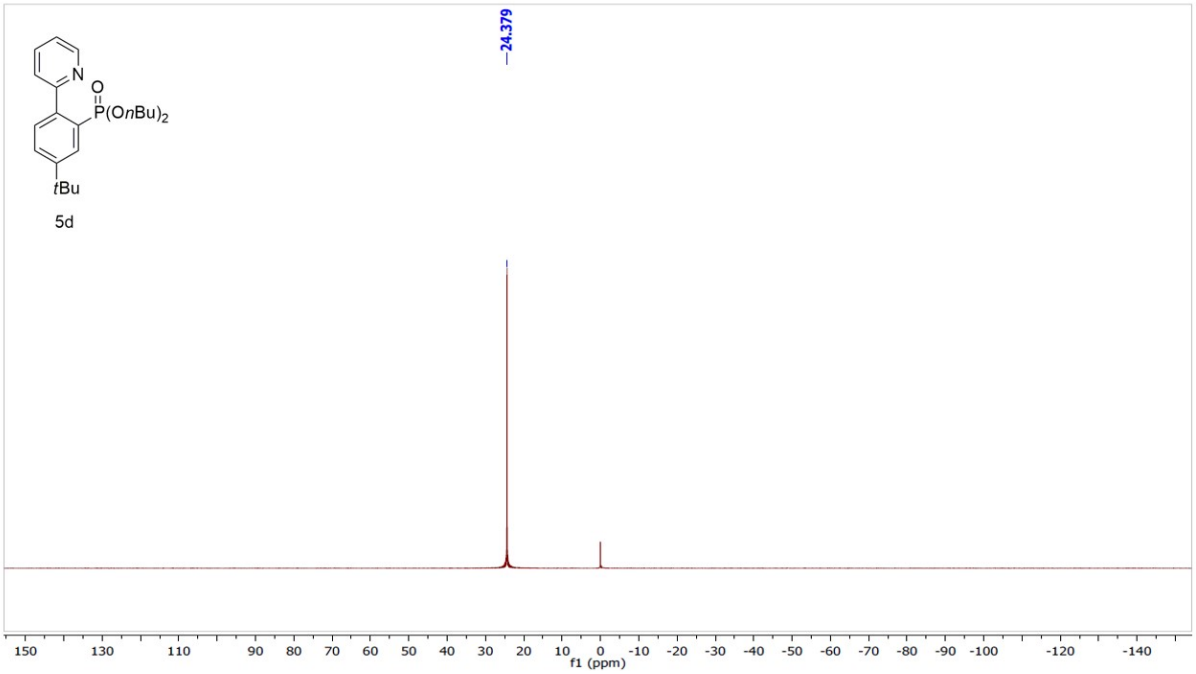

8.663 8.661 8.659 8.657 8.653 8.651 8.650 8.648 7.875 7.845 7.721 7.717 7.705 7.702 7.690 7.687 7.658 7.656 7.654 7.643 7.641 7.639 7.432 7.423 7.280 7.278 7.270 7.263 7.256 7.253 3.928 3.921 3.915 3.908 3.901 3.895 3.881 3.868 3.855 3.848 3.841 3.835 3.828 3.821 3.808 2.443 1.496 1.493 1.482 1.480 1.469 1.465 1.455 1.451 1.438 1.399 1.300 1.285 1.270 1.255 1.240 1.225 0.873 0.859 0.844
N
O
P(OnBu)2
CH3
5c
1.00 1.00 1.00 1.00 2.00 1.00 4.01 3.00 4.00 4.04 6.03
12.0 11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

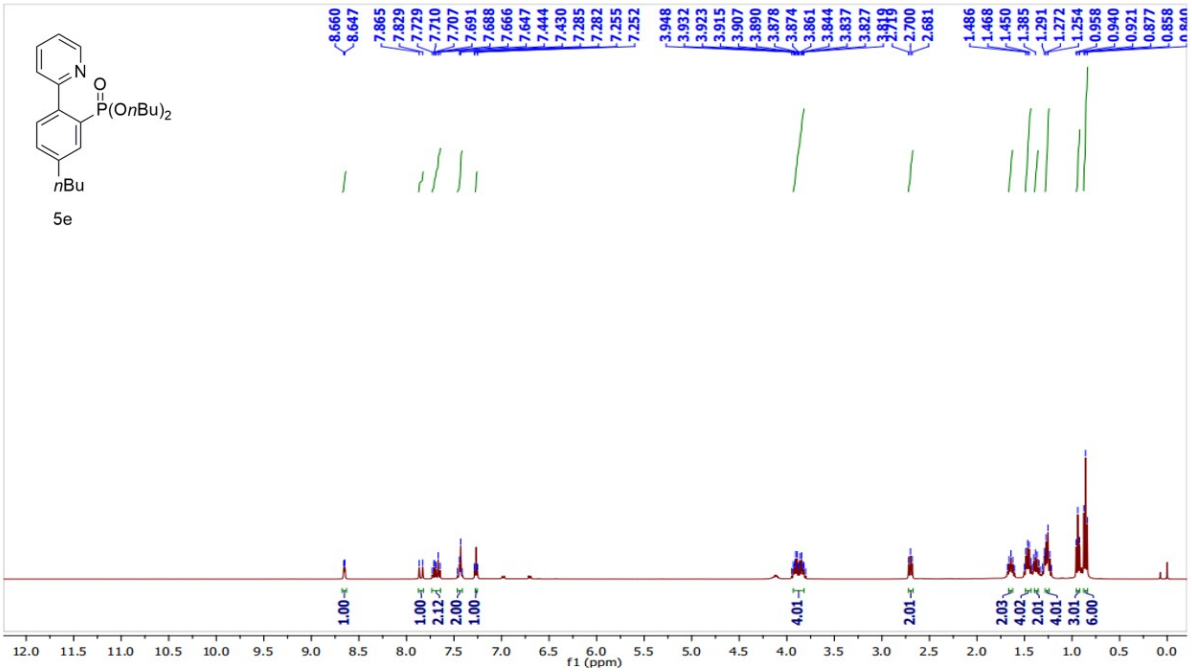

158.992
158.949
148.829
141.896
141.802
137.928
137.785
135.443
134.498
134.406
132.901
131.109
130.965
127.071
124.848
122.175
65.715
65.655
32.338
32.272
21.159
18.707
13.623
P(OnBu)2
CH3
5c
f1 (ppm)

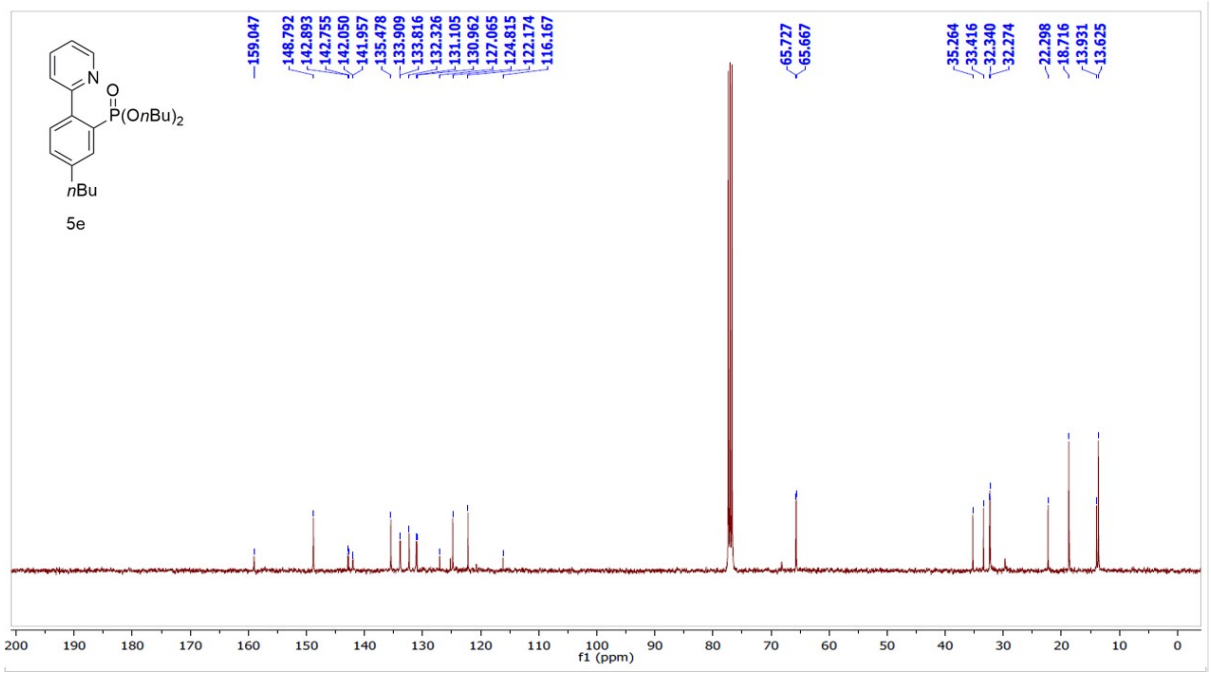

24.226
P(OnBu)2
CH3
5c
f1 (ppm)

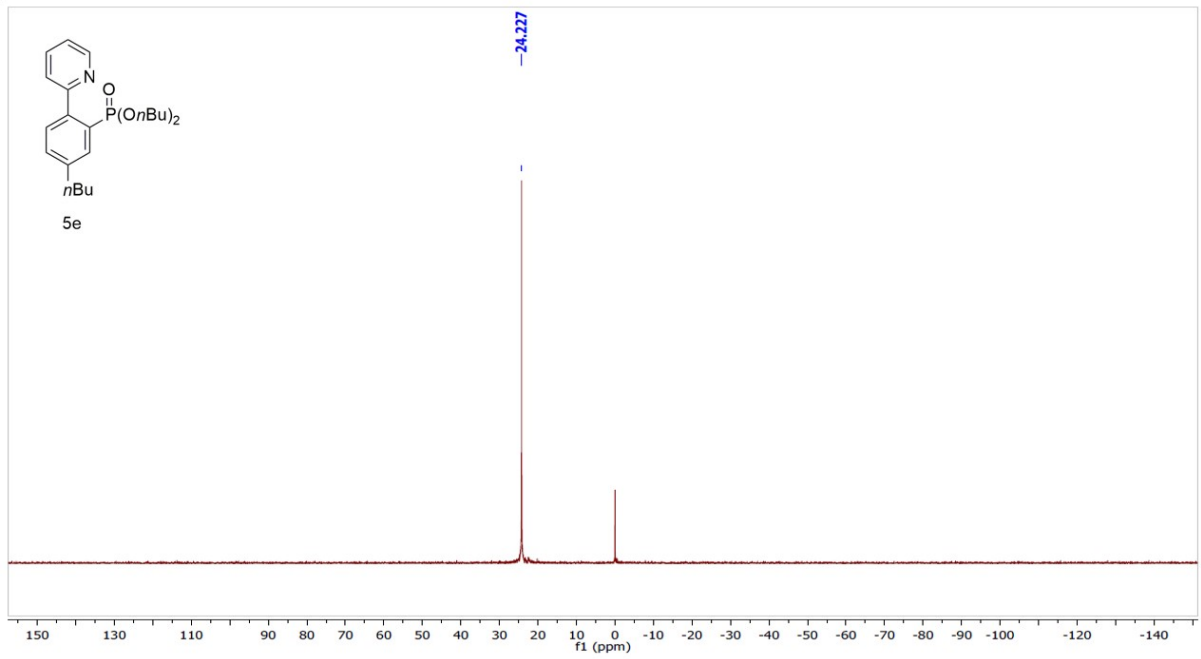

8.647 8.645 8.643 8.635 8.632 8.630 8.627 8.042 8.036 8.003 7.997 7.701 7.699 7.695 7.682 7.677 7.675 7.672 7.670 7.667 7.613 7.610 7.608 7.604 7.472 7.457 7.451 7.436 7.271 7.266 7.258 7.253 3.911 3.903 3.894 3.886 3.869 3.866 3.853 3.849 3.832 3.824 3.815 3.806 1.489 1.472 1.455 1.450 1.446 1.438 1.432 1.416 1.384 1.356 1.297 1.279 1.268 1.259 1.240 1.237 1.221 1.203 0.860 0.842 0.823
N
O
P(OnBu)2
tBu
5d
1.00 1.04 3.01 1.06 1.00 4.02 4.04 9.23 4.06 6.10
12.0 11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

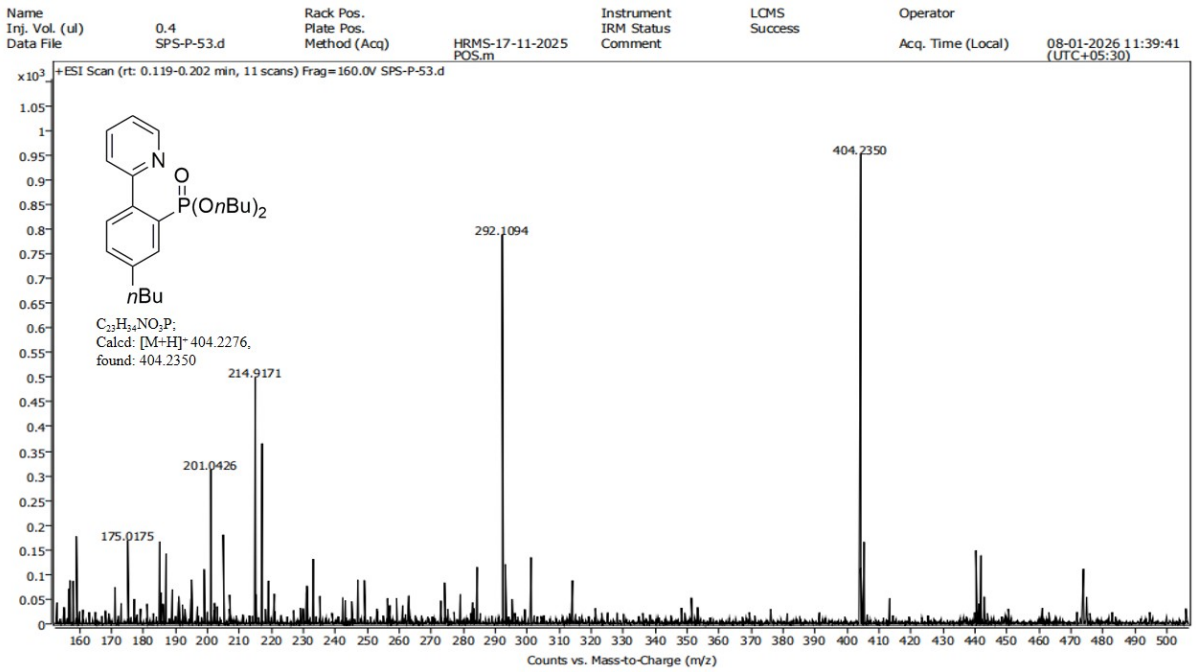

159.138 159.092 151.054 150.921 148.899 141.974 141.875 135.509 131.007 130.861 130.706 130.604 129.432 129.399 126.960 125.112 124.827 122.208 65.753 65.688 34.874 32.396 32.328 31.257 18.772 13.671
N
O
P(OnBu)2
tBu
5d
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

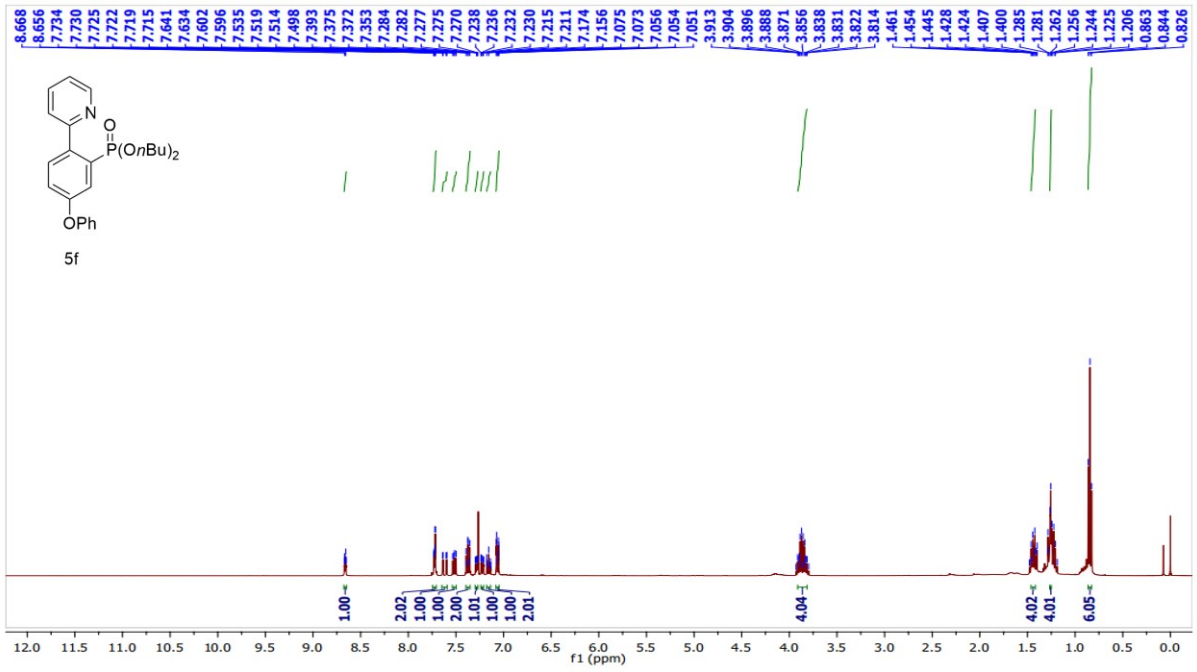

24.379
P(OnBu)2
tBu
5d
f1 (ppm)

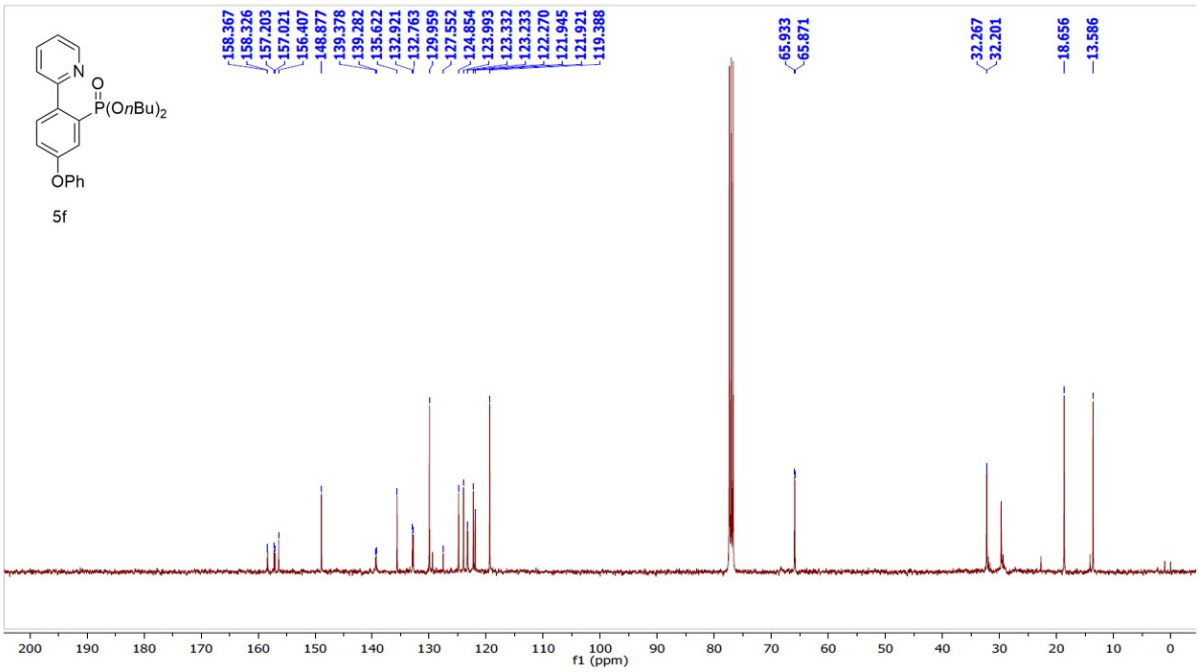

P(OnBu)2
nBu
5e
f1 (ppm)

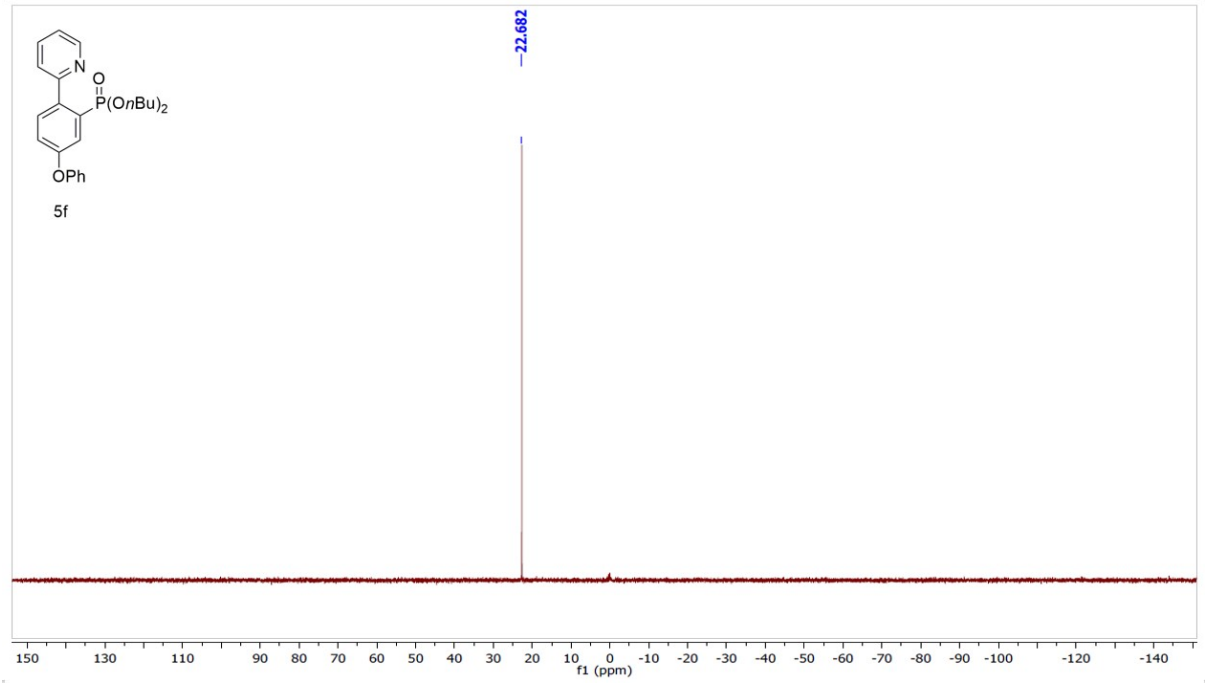

159.047
148.792
142.893
142.755
142.050
141.957
135.478
133.909
133.816
132.326
131.105
130.962
127.065
124.815
122.174
116.167
65.727
65.667
35.264
33.416
32.340
32.274
22.298
18.716
13.931
13.625
P(OnBu)2
nBu
5e
f1 (ppm)

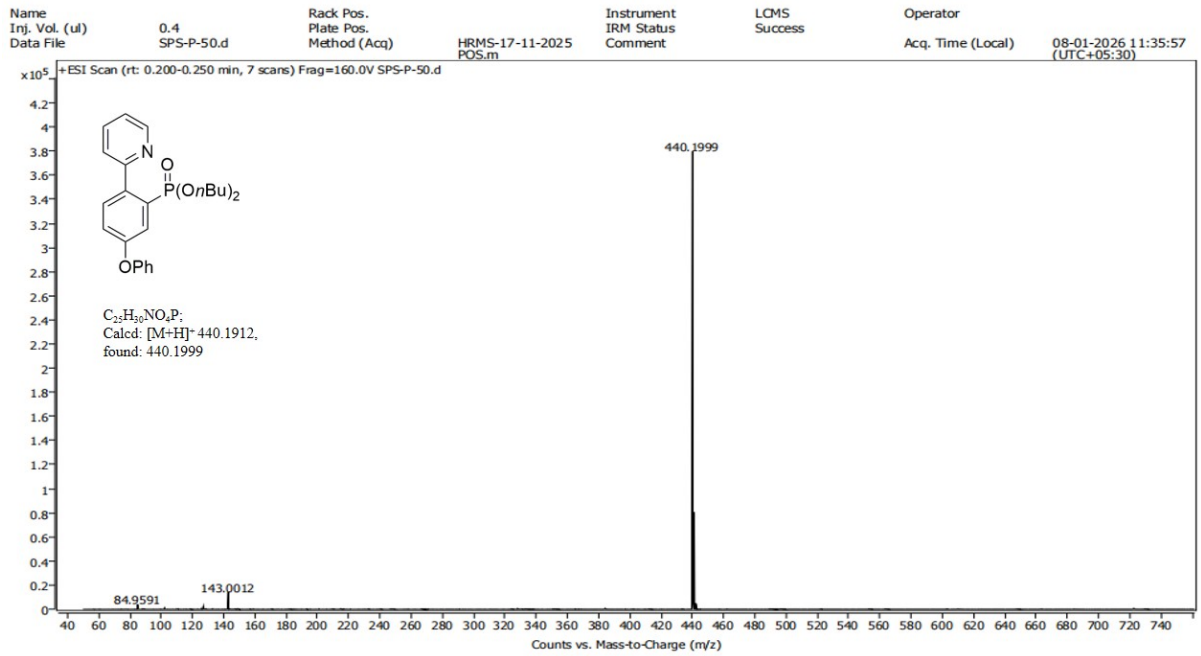

24.227
P(OnBu)2
nBu
5e
f1 (ppm)

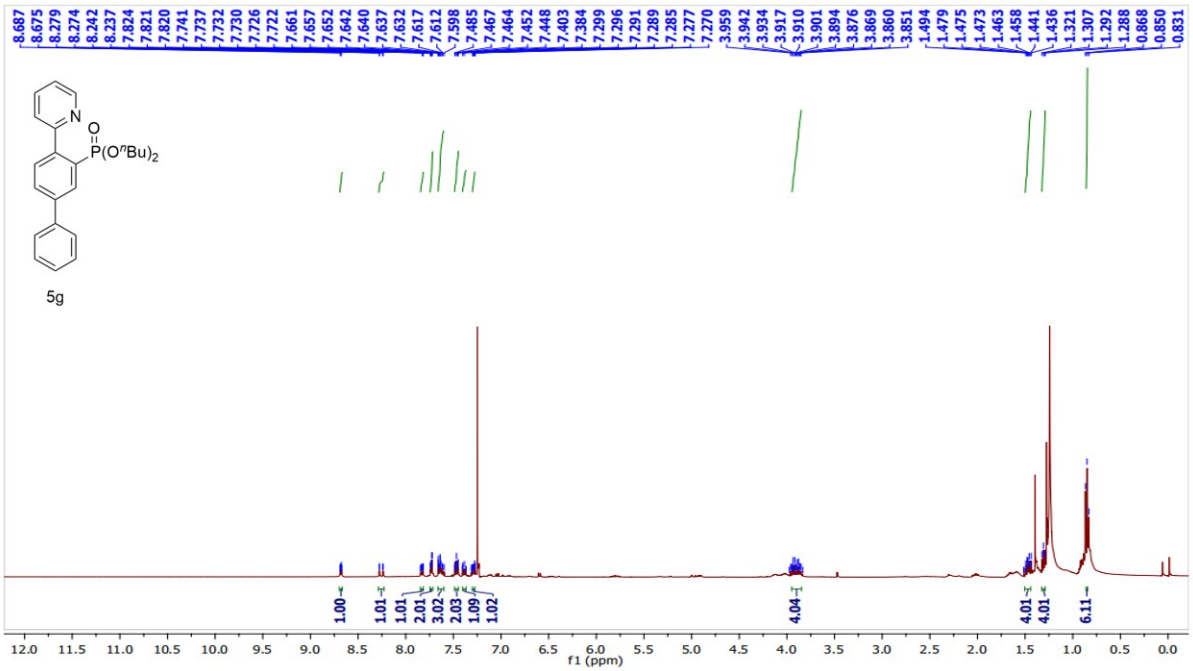

Name
Inj. Vol. (ul) 0.4
Data File SPS-P-53.d
Rack Pos.
Plate Pos.
Method (Acq) HRMS-17-11-2025 POS.m
Instrument
IRM Status
Comment
LCMS
Success
Operator
Acq. Time (Local) 08-01-2026 11:39:41 (UTC+05:30)
+ESI Scan (rt: 0.119-0.202 min, 11 scans) Frag=160.0V SPS-P-53.d
404.2350
292.1094
214.9171
201.0426
175.0175
C23H34NO3P;
Calcd: [M+H]+ 404.2276,
found: 404.2350
Counts vs. Mass-to-Charge (m/z)

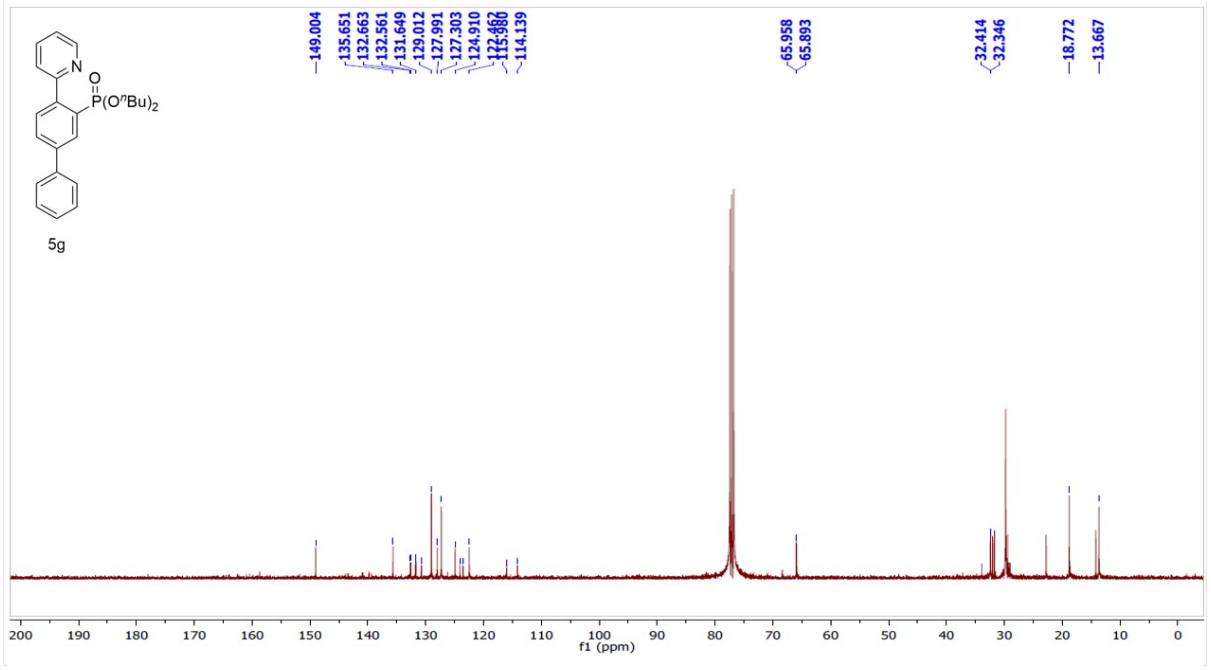

5f
f1 (ppm)

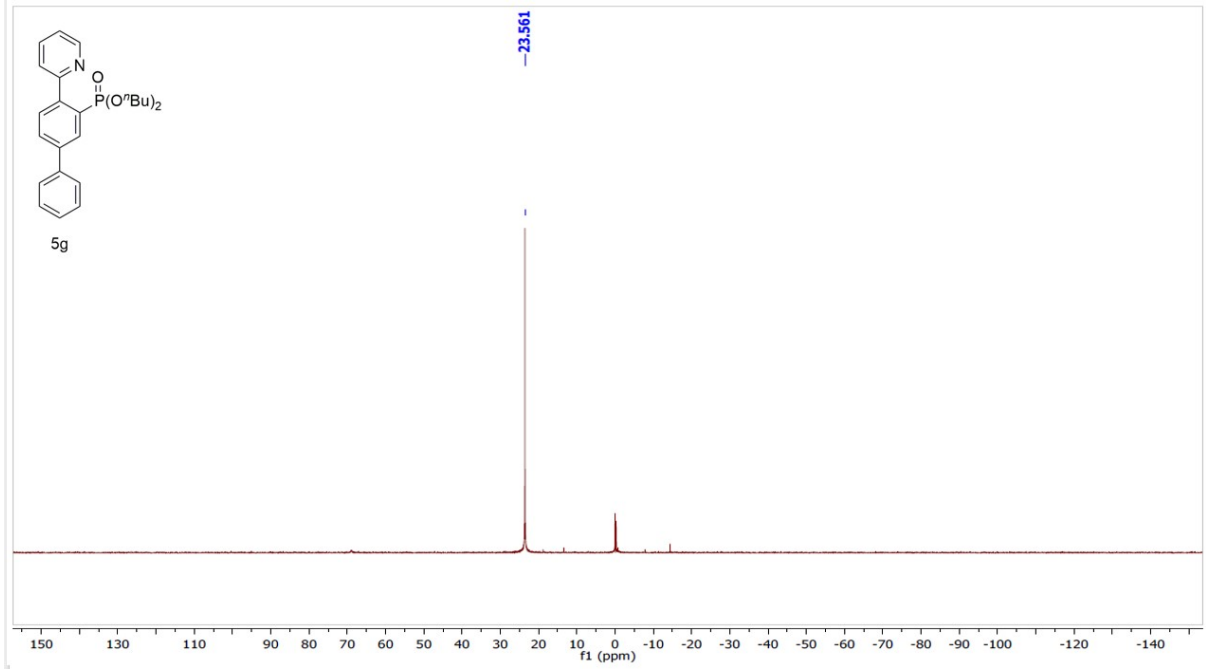

158.367
158.326
157.203
157.021
156.407
148.877
139.378
139.282
135.622
132.921
132.763
129.959
127.552
124.854
123.993
123.332
123.233
122.270
121.945
121.921
119.388
65.933
65.871
32.267
32.201
18.656
13.586
N
O
P(OnBu)2
OPh
5f
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

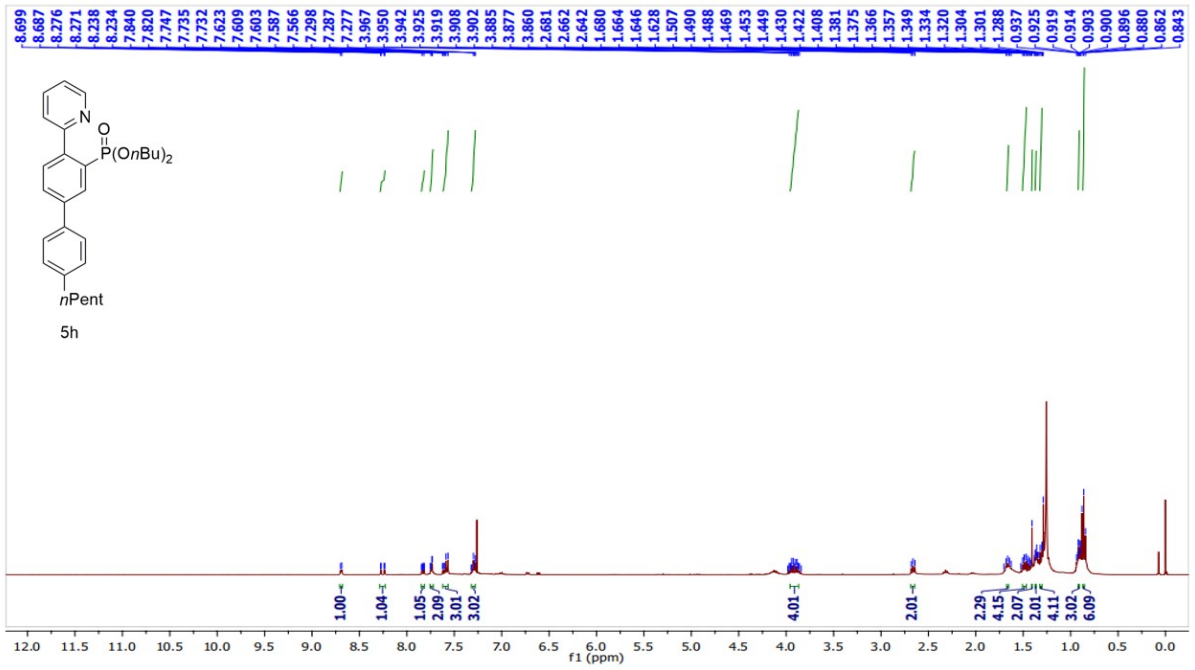

22.682
N
O
P(OnBu)2
OPh
5f
150 130 110 90 80 70 60 50 40 30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -120 -140
f1 (ppm)

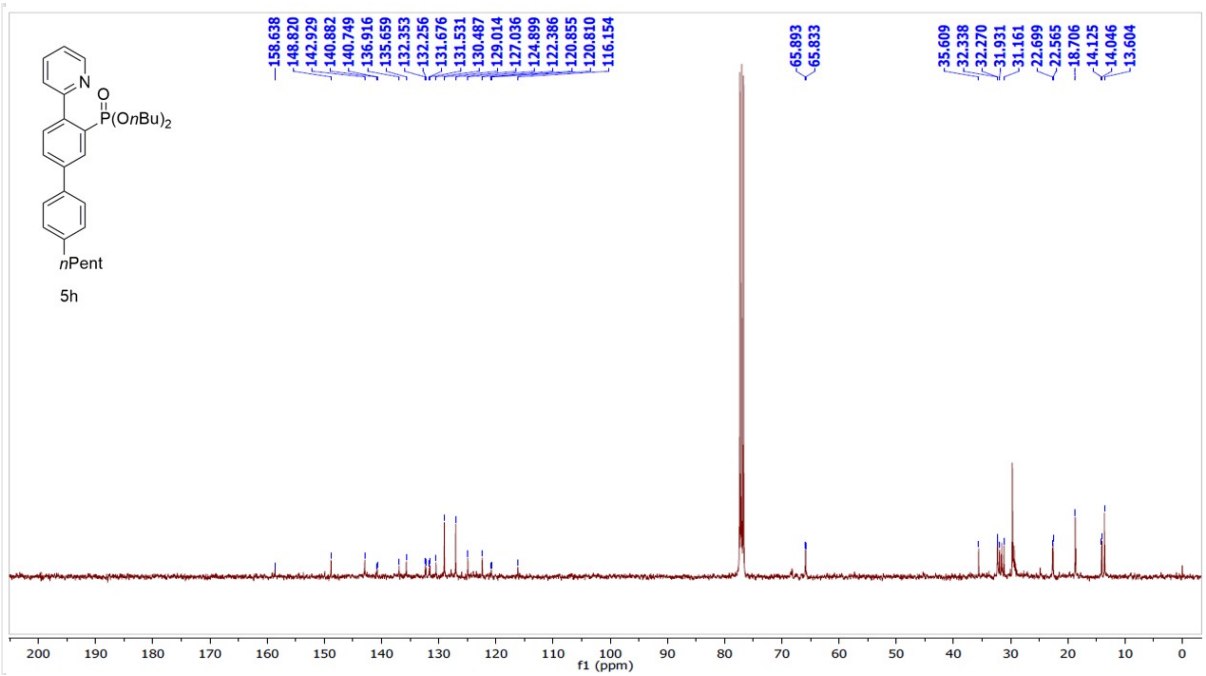

Name
Inj. Vol. (ul) 0.4
Data File SPS-P-50.d
Rack Pos.
Plate Pos.
Method (Acq) HRMS-17-11-2025 POS.m
Instrument
IRM Status
Comment
LCMS
Success
Operator
Acq. Time (Local) 08-01-2026 11:35:57 (UTC+05:30)
+ESI Scan (rt: 0.200-0.250 min, 7 scans) Frag=160.0V SPS-P-50.d
P(OnBu)2
OPh
C25H30NO4P;
Calcd: [M+H]+ 440.1912,
found: 440.1999
440.1999
143.0012
84.9591
Counts vs. Mass-to-Charge (m/z)

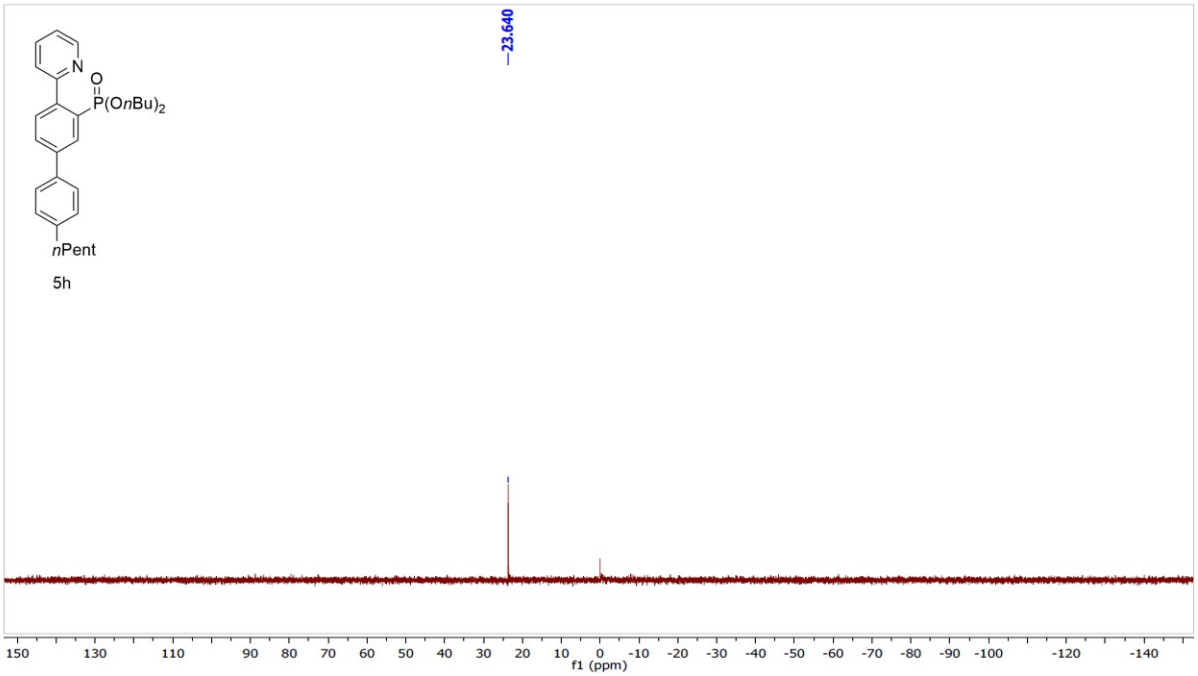

P(O$^n$Bu)$_2$
5g
f1 (ppm)

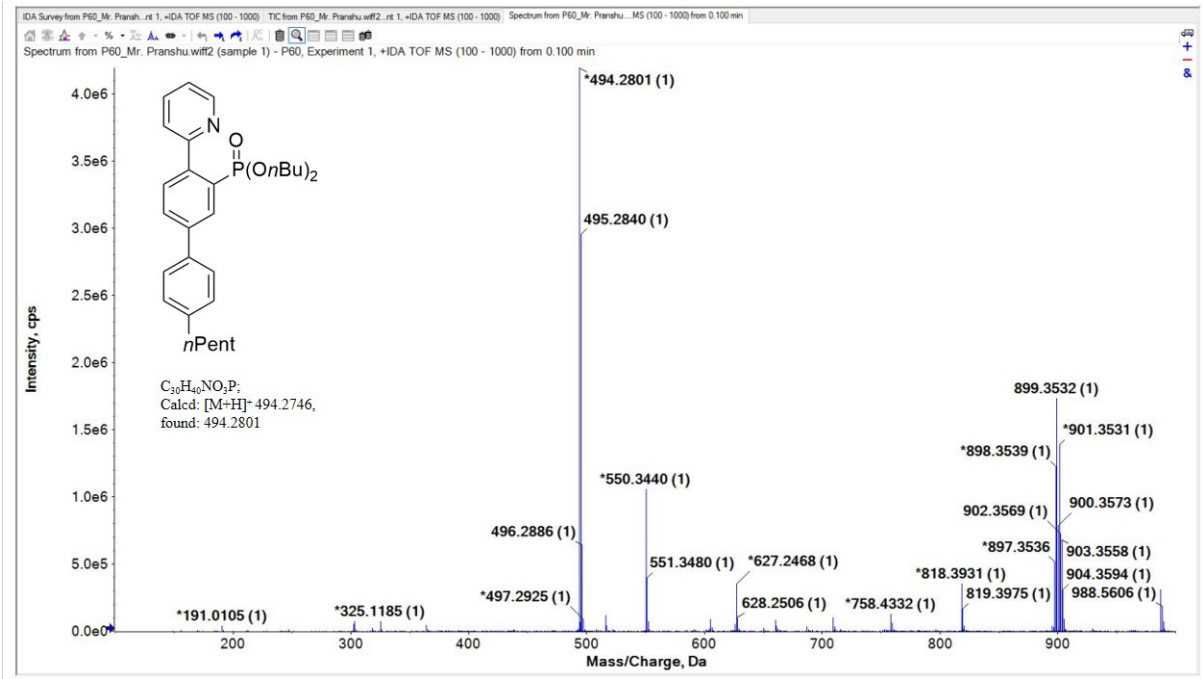

149.004
135.651
132.663
132.561
131.649
129.012
127.991
127.303
124.910
122.462
115.980
114.139
65.958
65.893
32.414
32.346
18.772
13.667
P(O$^n$Bu)$_2$
5g
f1 (ppm)

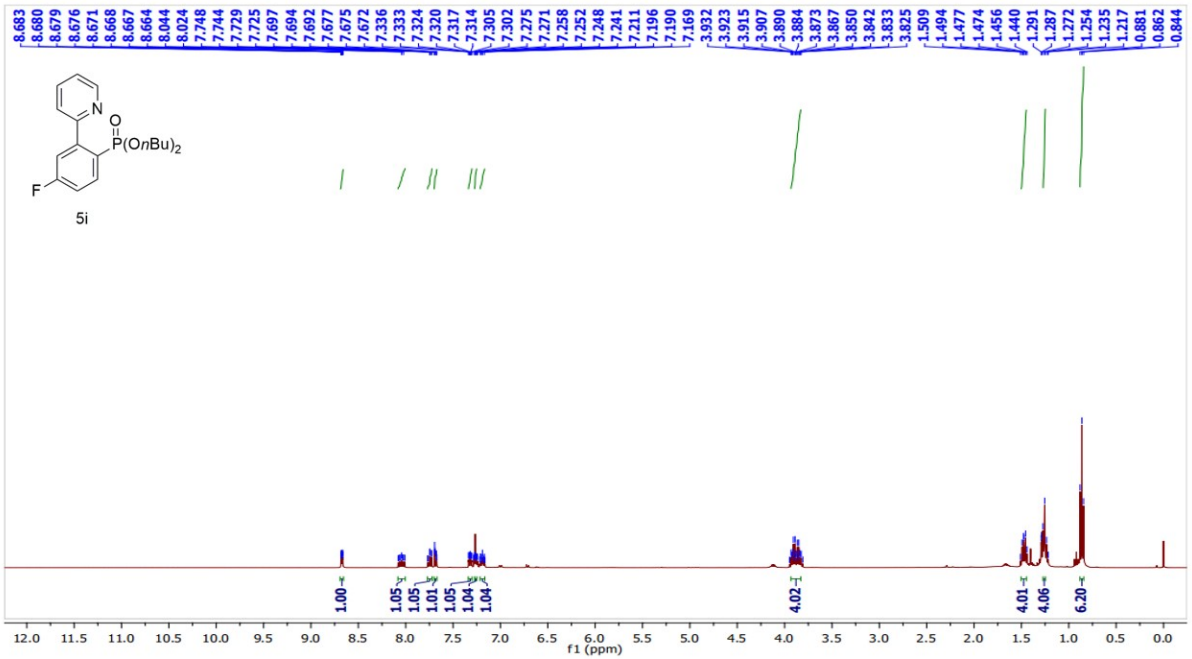

23.561
P(O$^n$Bu)$_2$
5g
f1 (ppm)

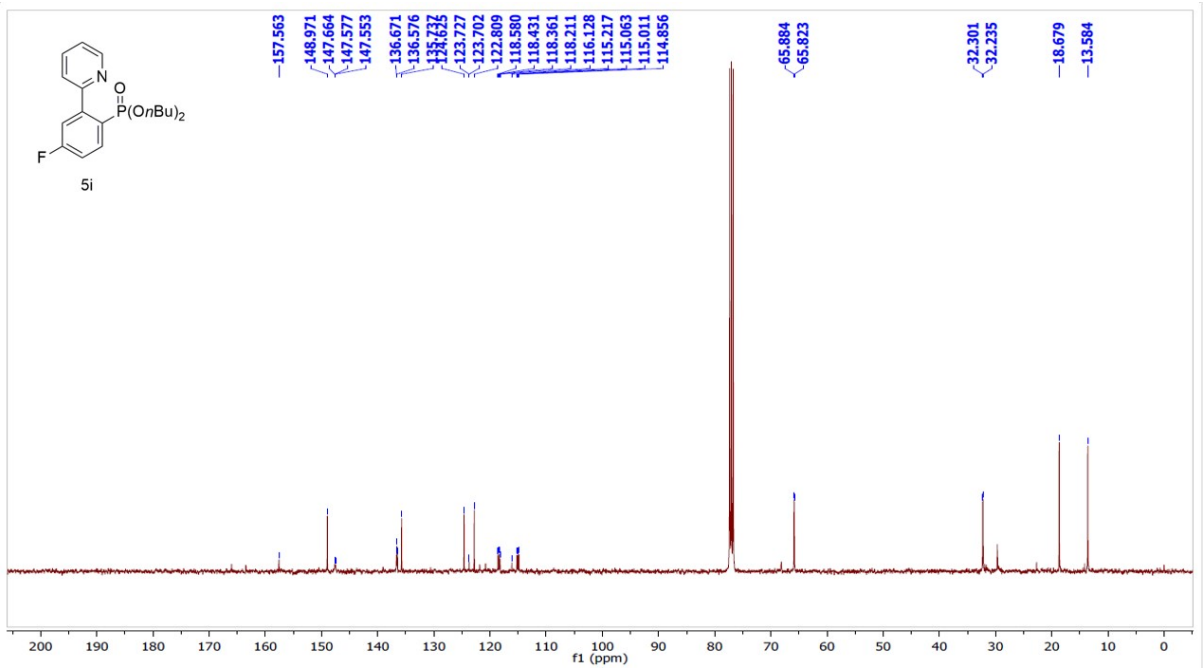

8.699
8.687
8.276
8.271
8.238
8.234
7.840
7.820
7.747
7.735
7.732
7.623
7.609
7.603
7.587
7.566
7.298
7.287
7.277
3.967
3.950
3.942
3.925
3.919
3.908
3.902
3.885
3.877
3.860
2.681
2.662
2.642
1.680
1.664
1.646
1.628
1.507
1.490
1.488
1.469
1.453
1.449
1.430
1.422
1.408
1.381
1.375
1.366
1.357
1.349
1.334
1.320
1.304
1.301
1.288
0.937
0.925
0.919
0.914
0.903
0.900
0.896
0.880
0.862
0.843
N
O
P(OnBu)2
nPent
5h
1.00
1.04
1.05
2.09
3.01
3.02
4.01
2.01
2.29
4.15
2.07
2.01
4.11
3.02
6.09
12.0 11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

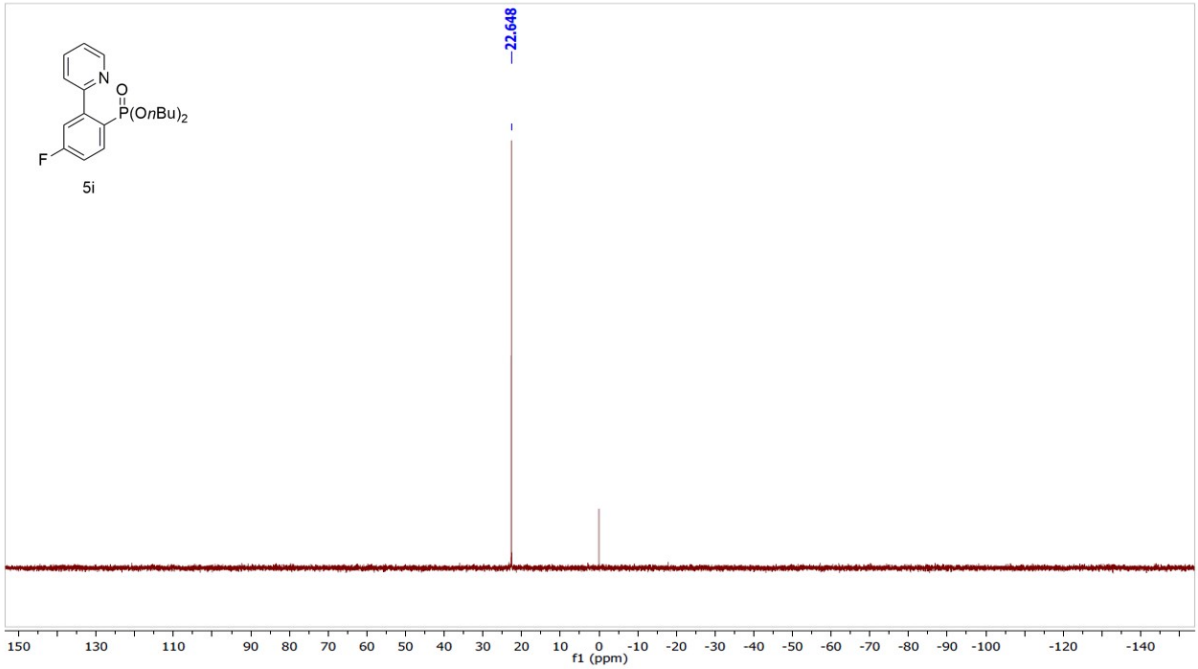

158.638
148.820
142.929
140.882
140.749
136.916
135.659
132.353
132.256
131.676
131.531
130.487
129.014
127.036
124.899
122.386
120.855
120.810
116.154
65.893
65.833
35.609
32.338
32.270
31.931
31.161
22.699
22.565
18.706
14.125
14.046
13.604
N
O
P(OnBu)2
nPent
5h
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

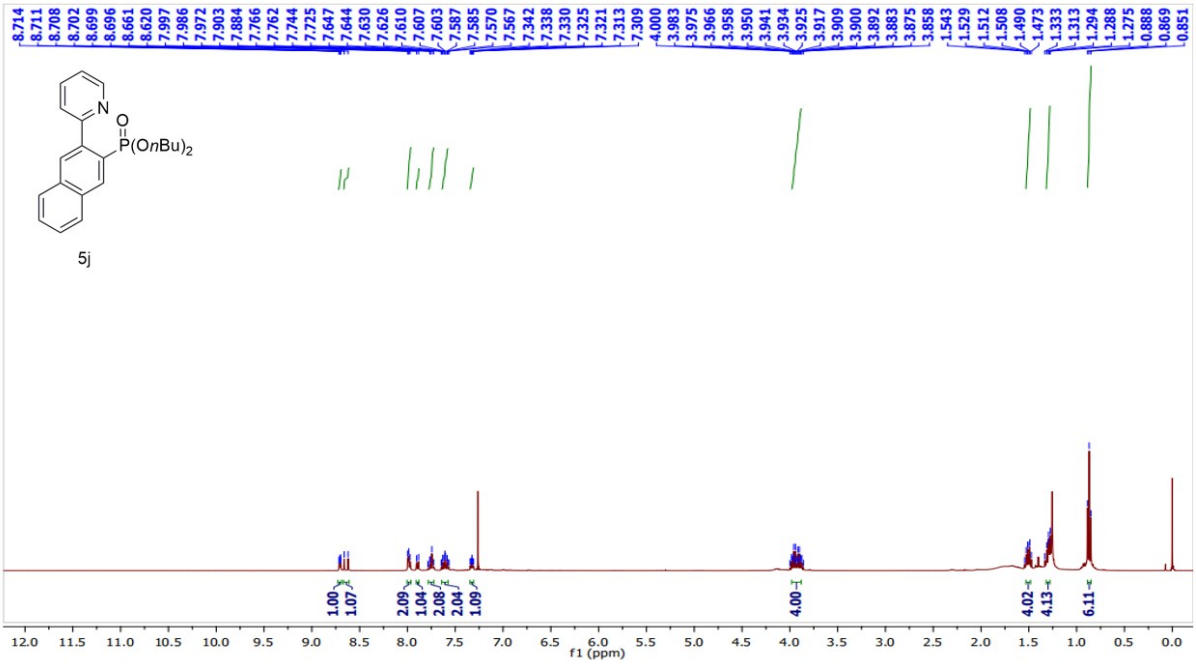

23.640
N
O
P(OnBu)2
nPent
5h
150 130 110 90 80 70 60 50 40 30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -120 -140
f1 (ppm)

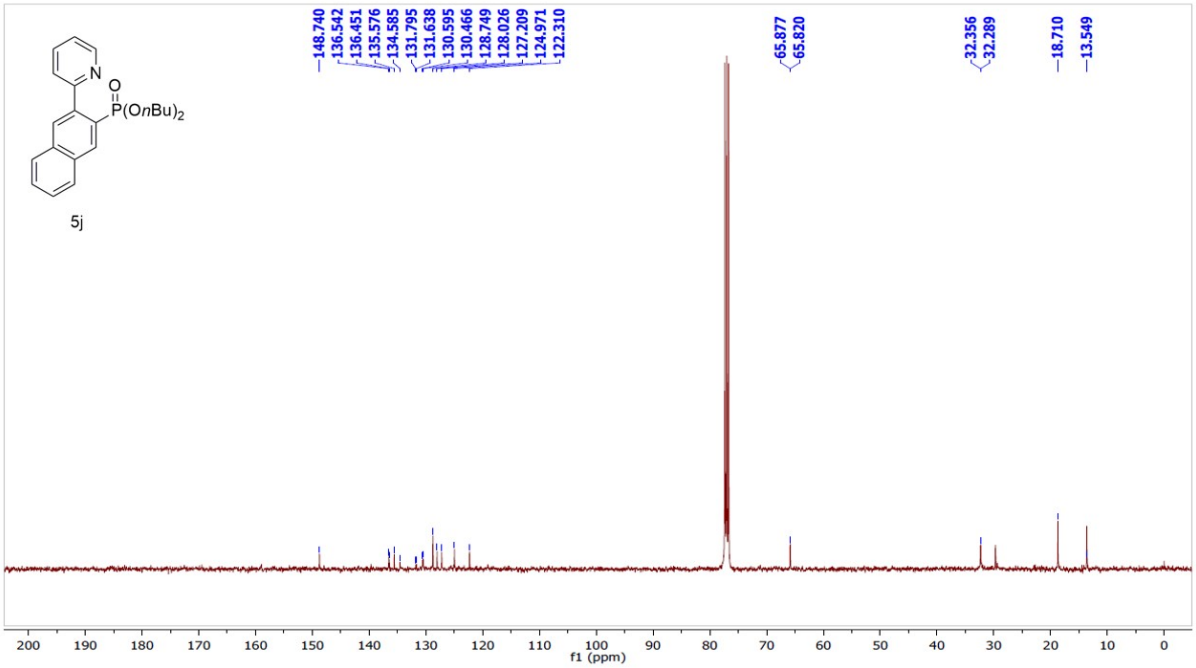

Spectrum from P60_Mr. Pranshu.wiff2 (sample 1) - P60, Experiment 1, +IDA TOF MS (100 - 1000) from 0.100 min
N
O
P(OnBu)2
nPent
C30H46NO3P;
Calcd: [M+H]+ 494.2746,
found: 494.2801
*494.2801 (1)
495.2840 (1)
*550.3440 (1)
496.2886 (1)
551.3480 (1)
*627.2468 (1)
*497.2925 (1)
628.2506 (1)
*758.4332 (1)
*818.3931 (1)
819.3975 (1)
899.3532 (1)
*901.3531 (1)
*898.3539 (1)
902.3569 (1)
900.3573 (1)
*897.3536
903.3558 (1)
904.3594 (1)
988.5606 (1)
*191.0105 (1)
*325.1185 (1)
Intensity, cps
Mass/Charge, Da

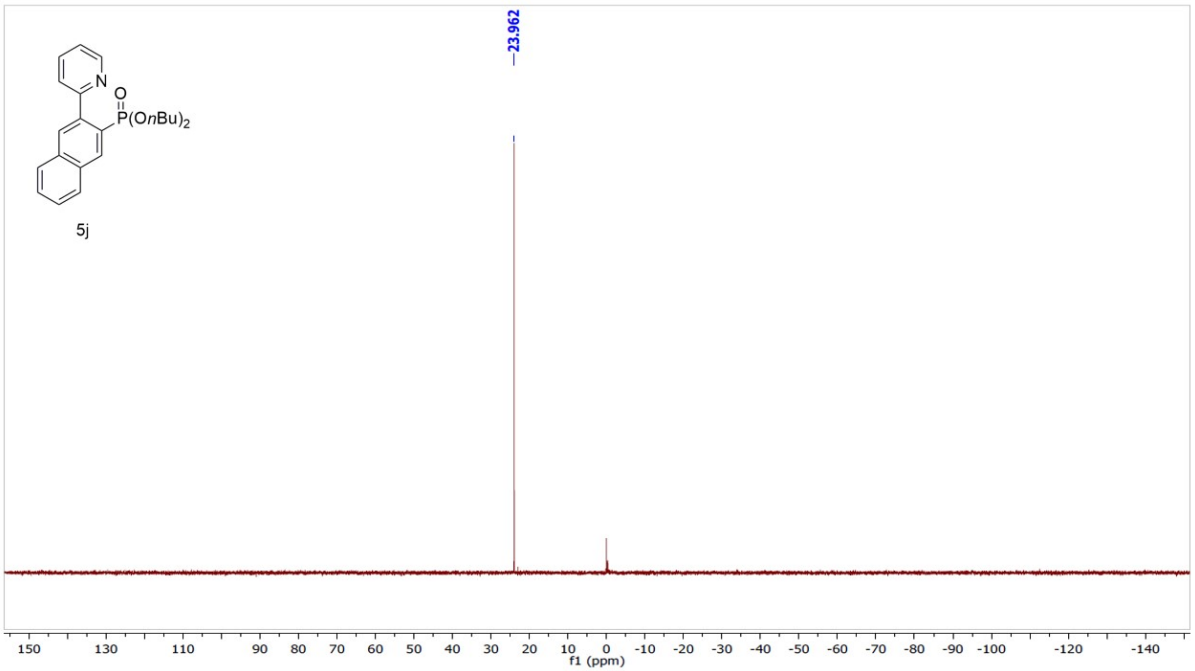

8.683 8.680 8.679 8.676 8.671 8.668 8.667 8.664 8.044 8.024 7.748 7.744 7.729 7.725 7.697 7.694 7.692 7.677 7.675 7.672 7.336 7.333 7.324 7.320 7.317 7.314 7.305 7.302 7.275 7.271 7.258 7.252 7.248 7.241 7.211 7.196 7.190 7.169 3.932 3.923 3.915 3.907 3.890 3.884 3.873 3.867 3.850 3.842 3.833 3.825 1.509 1.494 1.477 1.474 1.456 1.440 1.291 1.287 1.272 1.254 1.235 1.217 0.881 0.862 0.844
N
O
P(OnBu)2
F
5i
1.00 1.05 1.05 1.01 1.05 1.04 1.04 4.02 4.01 4.06 6.20
12.0 11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)

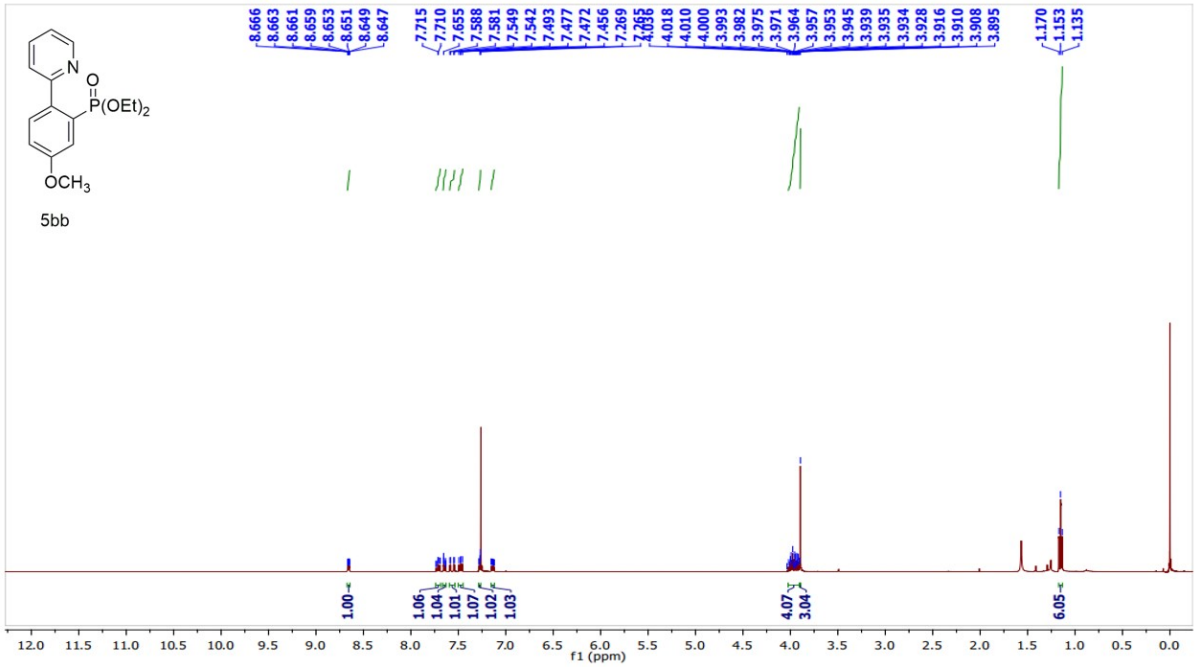

157.563 148.971 147.664 147.577 147.553 136.671 136.576 123.727 123.702 122.809 118.580 118.431 118.361 118.211 116.128 115.217 115.063 115.011 114.856 65.884 65.823 32.301 32.235 18.679 13.584
N
O
P(OnBu)2
F
5i
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

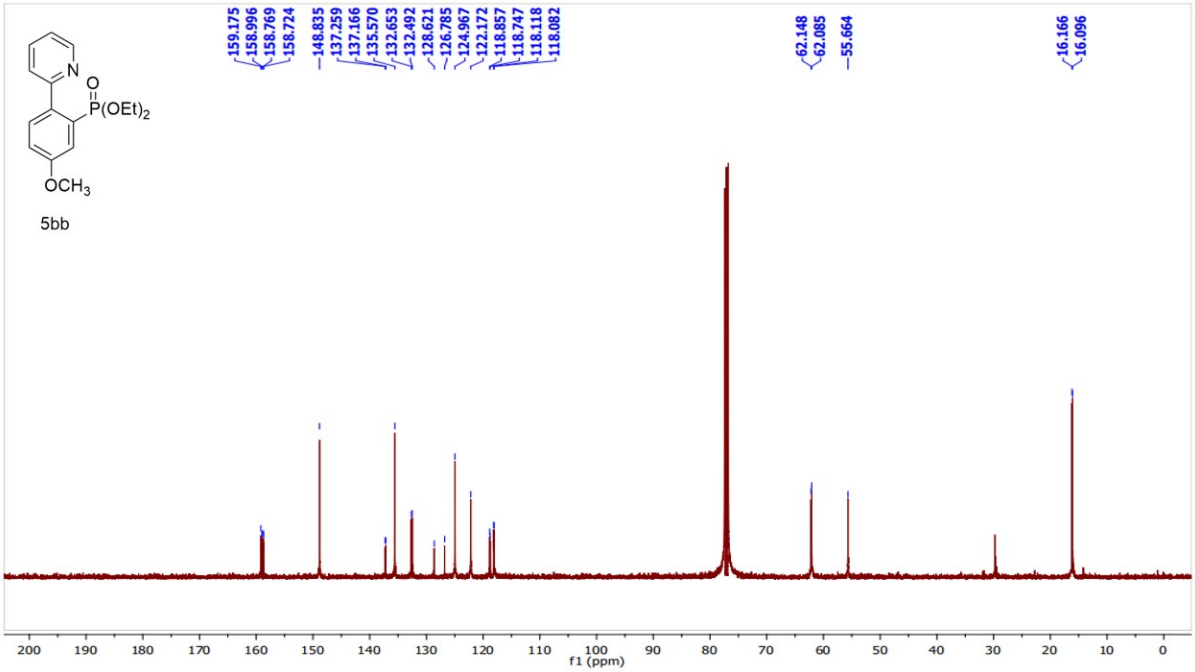

22.648
N
O
P(OnBu)2
F
5i
150
130
110
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-120
-140
f1 (ppm)

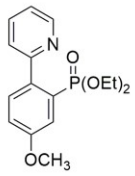

8.714
8.711
8.708
8.702
8.699
8.696
8.661
8.620
7.997
7.986
7.972
7.903
7.884
7.766
7.762
7.744
7.725
7.647
7.644
7.630
7.626
7.610
7.607
7.603
7.587
7.585
7.570
7.567
7.342
7.338
7.330
7.325
7.321
7.313
7.309
4.000
3.983
3.975
3.966
3.958
3.950
3.941
3.934
3.925
3.917
3.909
3.900
3.892
3.883
3.875
3.858
1.543
1.529
1.512
1.508
1.490
1.473
1.333
1.313
1.294
1.288
1.275
0.888
0.869
0.851
N
O
P(OnBu)2
5j
1.00
1.07
2.09
1.04
2.08
2.04
1.09
4.00
4.02
4.13
6.11
12.0
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)


148.740
136.542
136.451
135.576
134.585
131.795
131.638
130.595
130.466
128.749
128.026
127.209
124.971
122.310
65.877
65.820
32.356
32.289
18.710
13.549
P(OnBu)2
5j
f1 (ppm)


23.962
P(OnBu)2
5j
f1 (ppm)


5bb
8.666
8.663
8.661
8.659
8.653
8.651
8.649
8.647
7.715
7.710
7.655
7.588
7.581
7.549
7.542
7.493
7.477
7.472
7.456
7.269
4.036
4.018
4.010
4.000
3.993
3.982
3.975
3.971
3.964
3.957
3.953
3.945
3.939
3.935
3.934
3.928
3.916
3.910
3.908
3.895
1.170
1.153
1.135
1.00
1.06
1.04
1.01
1.07
1.02
1.03
4.07
3.04
6.05
f1 (ppm)

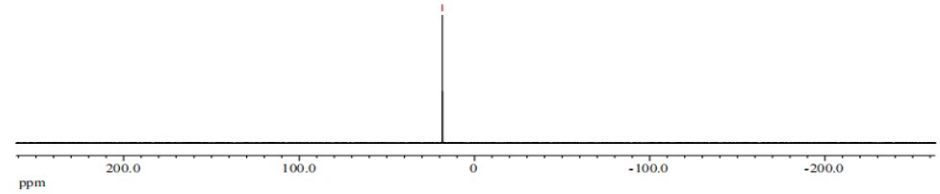

5bb
159.175
158.996
158.769
158.724
148.835
137.259
137.166
135.570
132.653
132.492
128.621
126.785
124.967
122.172
118.857
118.747
118.118
118.082
62.148
62.085
55.664
16.166
16.096
f1 (ppm)

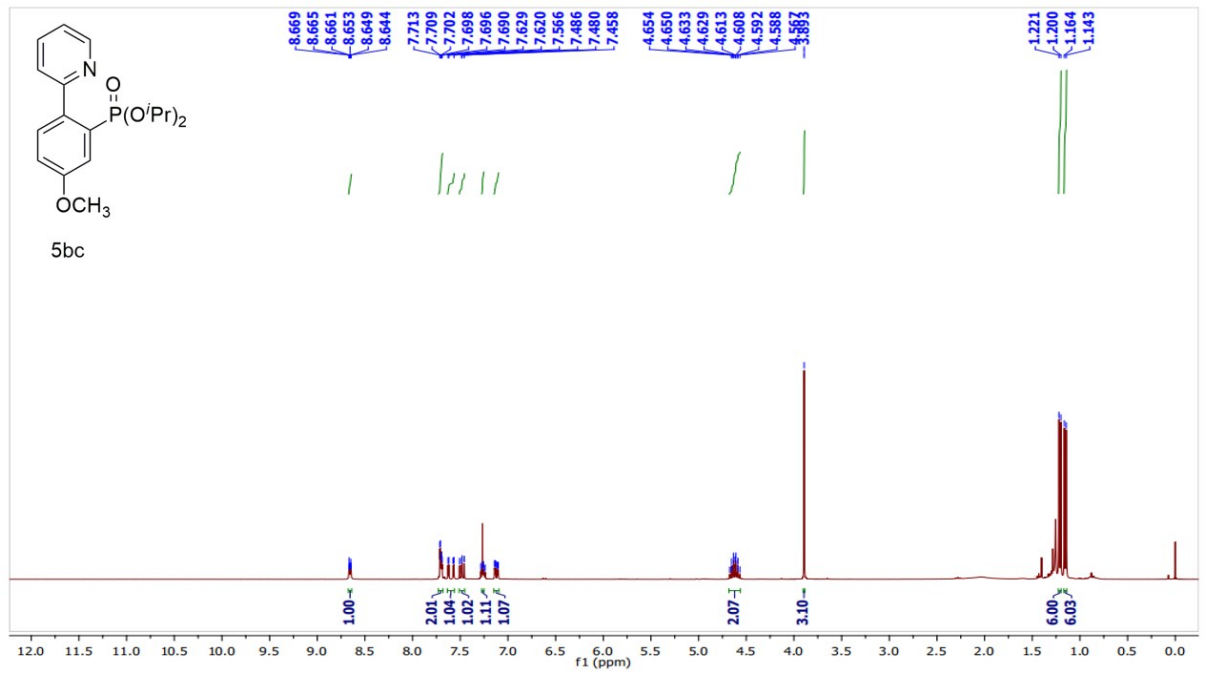


5bb

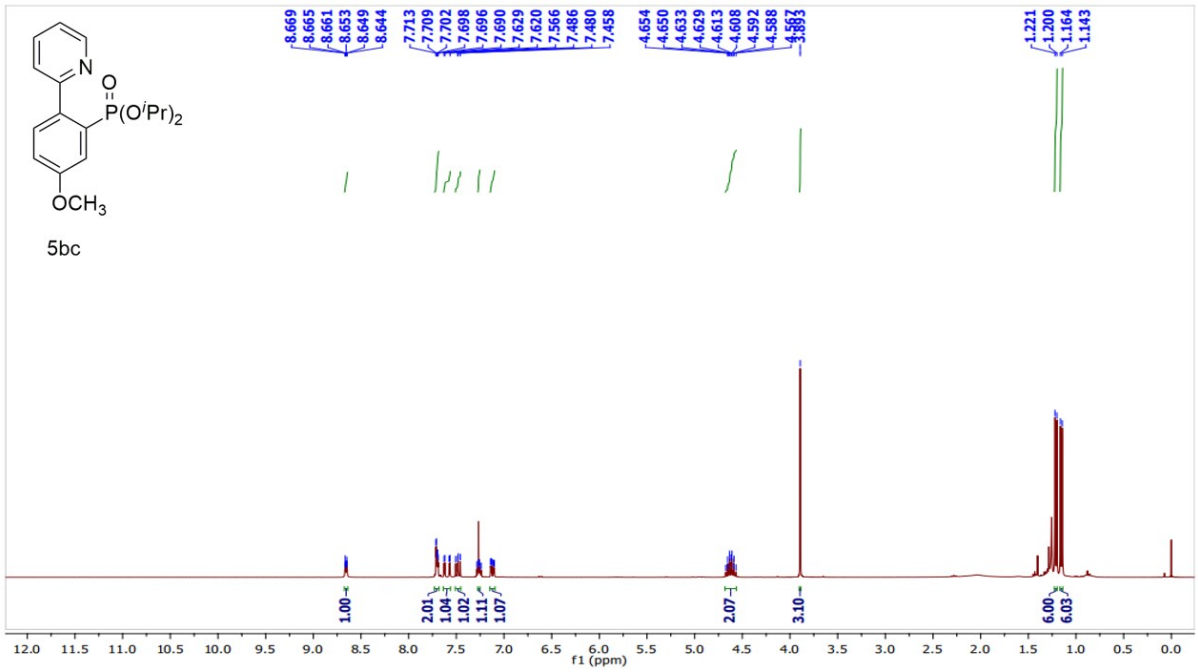


```
---- PROCESSING PARAMETERS ----
sexp( 4.33488[Hz], 0.0[s] )
trapezoid( 0[%], 0[%], 80[%], 100[%] )
zerofill( 2, TRUE )
fft( 1, TRUE, TRUE )
machinephase
ppm
auto_reference( 5[%], TRUE )
phase( -4.01367, 0, 47.38308[%] )
phase( -2.42144, 0, 47.3106[%] )

Derived from: P44_31P-1-1.jdf


Creation_Time      = 20-JAN-2025 22:04:16
Instrument         - NMR-400MHz (JEOL)
Spectrometer       = NM-70010S4L1
Instrument id      - ABNL/QC/NMR-01
Author             = 1037
Reviewed by        - BRM
Solvent            = CHLOROFORM-D
Acquisition Parameters
Experiment         = single_pulse_dec.jxp
X_Offset           = 0[ppm]
X_Sweep            = 142.04545455[kHz]
Relaxation_Delay   = 2[s]
Scans              = 512
```




5bc


5bc
8.669
8.665
8.661
8.653
8.649
8.644
7.713
7.709
7.702
7.698
7.696
7.690
7.629
7.620
7.566
7.486
7.480
7.458
4.654
4.650
4.633
4.629
4.613
4.608
4.592
4.588
3.893
1.221
1.200
1.164
1.143
1.00
2.01
1.04
1.02
1.11
1.07
2.07
3.10
6.00
6.03
f1 (ppm)

## 4. References


**[1]** a) M. V. K. Reddy, G. Anusha, P. V. G. Reddy, *New J. Chem.,* 2020, **44**, 11694-11703, DOI: https://doi.org/10.1039/D0NJ01294G. b) A. Gokanapalli, V. K. R. Motakatla, V. G. R. Peddiahgari, *Appl. Organomet. Chem.,* 2020, **34**, e5869, DOI: https://doi.org/10.1002/aoc.5869. c) A. Gokanapalli, V. K. R. Motakatla, V. G. R. Peddiahgari, *Appl. Organomet. Chem.,* 2021, **35**, e6296, DOI: https://doi.org/10.1002/aoc.6296. d) M. Sreeshitha, G. Hong, M. Indira, S. Farheen Banu, P. V. G. Reddy, *Appl. Organomet. Chem.,* 2024, **38**, e7719, DOI: https://doi.org/10.1002/aoc.7719.

[2] Y. Kitamura, S. Sako, T. Udzu, A. Tsutsui, T. Maegawa, Y. Monguchi, H. Sajiki, *Chem. Commun.*, 2007, 5069-5071, DOI: https://doi.org/10.1039/B712207A.

[3] A. Núñez, A. Sánchez, C. Burgos, J. A. Builla, *Tetrahedron*, 2004, **60**, 6217-6224, DOI: https://doi.org/10.1016/j.tet.2004.05.038.

[4] C. Liu, W. Yang, *Chem. Commun.*, 2009, 6267-6269, DOI: https://doi.org/10.1039/B912364D.

[5] C. Liu, Q. Ni, F. Bao, J. Qiu, *Green Chem.*, 2011, **13**, 1260-1266, DOI: https://doi.org/10.1039/C0GC00176G.

[6] X. Chen, C. E. Goodhue, J. Q. Yu, *J. Am. Chem. Soc.*, 2006, **128**, 12634–12635, DOI: https://doi.org/10.1021/ja0646747.

[7] X. Wang, X. Ji, C. Shao, Y. Zhang, Y. Zhang, *Org. Biomol. Chem.*, 2017, **15**, 5616-5624, DOI: https://doi.org/10.1039/C7OB01232B.

[8] G. N. Li, Y. P. Zeng, K. X. Li, H. H. Chen, H. Xie, F. L. Zhang, G. Y. Chen, Z. G. Niu, 2016, 26, 323-331. DOI: https://doi.org/10.1007/s10895-015-1718-7.

[9] S. Gu, D. Li, D. Long, X. Yu, S. Ma, W. Li, J. Liu, P. Tao, W. Y. Wong, *Inorg. Chem.*, 2025, **64**, 22513–22521, DOI: https://doi.org/10.1021/acs.inorgchem.5c04352.

[10] O. P. Shkurko, S. G. Baram, V. P. Manaev, Heterocycl. Compd., 1983, 19, 60-65. DOI: https://doi.org/10.1007/BF00512817.

[11] F. Mongin, A. S. Rebstock, F. Trécourt, G. Quéguiner, F. Marsais, *J. Org. Chem.*, 2004, **69**, 6766-6671, DOI: https://doi.org/10.1021/jo049454v.

[12] C. Li, T. Yano, N. Ishida, M. Murakami, *Angew. Chem.,* 2013, **125**, 9983-9986, DOI: https://doi.org/10.1002/ange.201305202.

[13] C. G. Feng, M. Ye, K. J. Xiao, S. Li, J. Q. Yu, *J. Am. Chem. Soc.,* 2013, **135**, 9322–9325, DOI: https://doi.org/10.1021/ja404526x.