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Supporting Information

Chemoselective Activation of Diethyl Phosphonates: Modular Synthesis of Biologically Relevant Phosphonylated Scaffolds

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Table of Contents

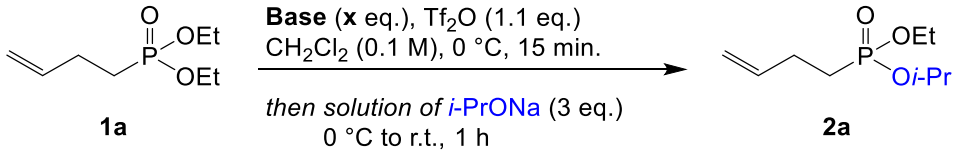
1. General Information

Unless otherwise stated, all glassware was flame-dried before use and all reactions were performed under an atmosphere of argon. All solvents were distilled from appropriate drying agents prior to use. Triflic anhydride was distilled over P_4O_{10} prior to use. All other reagents were used as received from commercial suppliers unless otherwise stated. Reaction progress was monitored by thin layer chromatography (TLC) performed on aluminium plates coated with silica gel F_{254} with 0.2 mm thickness. Chromatograms were visualized by fluorescence quenching with UV light at 254 nm or by staining using potassium permanganate. Flash column chromatography was performed using silica gel 60 (230-400 mesh, Merck and co.). Neat infra-red spectra were recorded using a Perkin-Elmer Spectrum 100 FT-IR spectrometer. Wavenumbers (ν_{max}) are reported in cm^{-1}. Mass spectra were obtained using a Finnigan MAT 8200 or (70 eV) or an Agilent 5973 (70 eV) spectrometer, using electrospray ionization (ESI). All ^{1}H NMR, ^{13}C NMR, ^{18}F NMR and ^{31}P NMR spectra were recorded using a Bruker AV-400, AV-600 and AV-700 spectrometer at 300K. Chemical shifts were given in parts per million (ppm, δ), referenced to the solvent peak of $CDCl_3$, defined at δ = 7.26 ppm (^{1}H NMR) and δ = 77.16 (^{13}C NMR). Coupling constants are quoted in Hz (*J*). ^{1}H NMR splitting patterns were designated as singlet (s), doublet (d), triplet (t), quartet (q), pentet (p). Splitting patterns that could not be interpreted or easily visualized were designated as multiplet (m) or broad (br). Selected ^{13}C NMR spectra were recorded using the attached proton test (APT) to facilitate the confirmation and assignment of the structure.

2. Optimization

2.1. Screening of bases

Table S1 - Screening of bases



1a **2a**

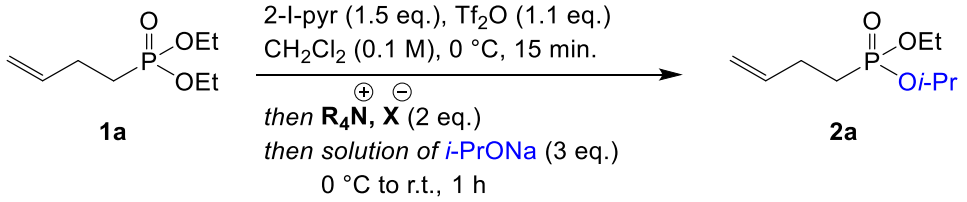
alkoxide solution: ROH (3 eq.), NaH (3 eq.)
THF (0.8 M), 0 °C, 30 min.

Base (1.5 eq.)		% desired product	%starting material	%unkown
2-I-pyr		***71***	***22***	***8***
2-F-pyr		62	30	8
Triethylamine		13	87	0
Proton Sponge®		60	34	6
DBU		12	60	27
2,6-di-*t*-Bu-4-Me-pyr		52	31	14
2,6-Lutidine		35	43	25
Pyridine		51	40	9
Pyridine (with TEAC)*		49	40	11
2-Cl-pyr		40	54	7
2-MeO-pyr		41	52	7
4-I-pyr		13	83	4
2-I-pyr	0.2 eq.	Not observed		
	1 eq.	72		
	1.5 eq.	**71**		
	2.2 eq.	75		

The percentages have been determined by ^{31}P NMR of the crude residue. DBU = 1,8-Diazabicyclo[5.4.0]undec-7-ene. *modification with TEAC (tetraethylammonium chloride) addition like in fully optimized conditions.

2.2 Screening of chloride sources

Table S2 - Screening of chloride sources



1a **2a**

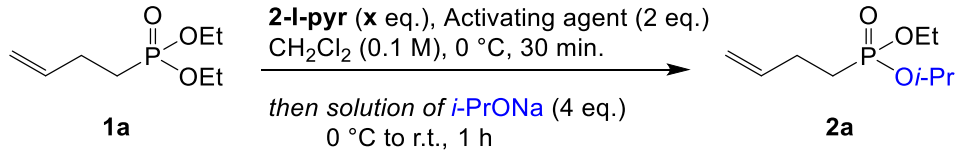
alkoxide solution: ROH (3 eq.), NaH (3 eq.)
THF (0.8 M), 0 °C, 30 min.

R_4NX	% desired product	%starting material	%unkown
None	71	22	8
TBAC (1 eq.)	32	9	58
TBAC (2 eq.)	84	16	0
TBAB (2 eq.)	36	0	64
TBAI (2 eq.)	77	16	5
TEAC (2 eq.)	***89***	***11***	***0***

The percentages have been determined by ^{31}P NMR of the crude residue. TBAC = Tetrabutylammonium chloride; TBAB = Tetrabutylammonium bromide; TBAI = Tetrabutylammonium iodide; TEAC = Tetraethylammonium chloride.

2.3 Screening of activating agent

Table S3 - Screening activating agent



1a **2a**

alkoxide solution: ROH (4 eq.), NaH (4 eq.)
THF (0.8 M), 0 °C, 30 min.

Activating agent	2-I-pyr (x eq.)	% desired product	%starting material	%unkown
Tf_2O (with TEAC)*	***1.5 eq.***	***89***	***11***	***0***
TfCl	1.5 eq.	0	100	0
TfCl	none	0	100	0

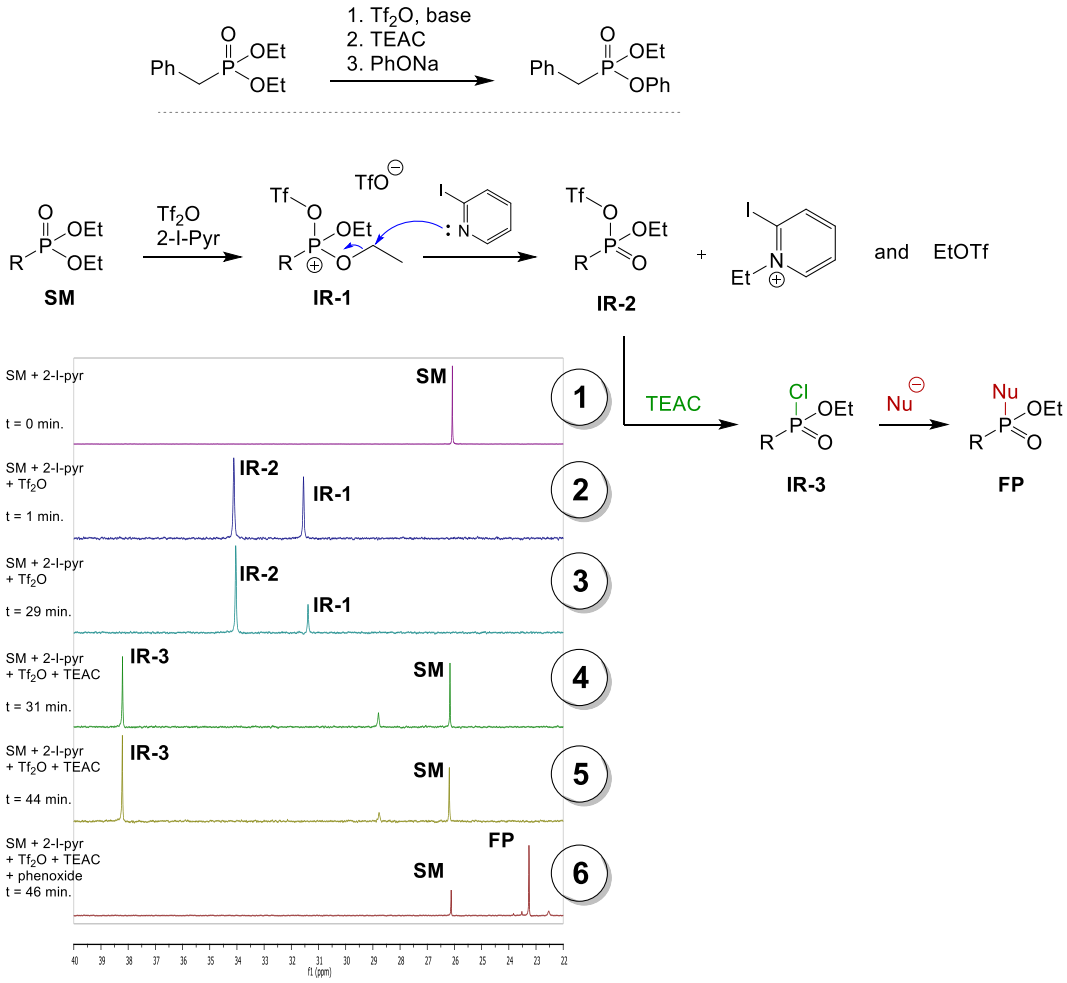
The percentages have been determined by ^{31}P NMR of the crude residue. *modification with TEAC (tetraethylammonium chloride) addition like in fully optimized conditions.

3 NMR studies and proposed mechanism

3.1. ^{31}P NMR study

We decided to follow the reaction with this starting with this benzyl diethylphosphonate because Kang *et al*. reported their NMR study on the exact same compound.[1]

The reaction was followed by ^{31}P NMR, (CD_2Cl_2, 243 MHz).



In total, 6 spectra have been measured.

Spectrum 1: starting material (SM) in solution with 2-I-pyridine.

Spectrum 2: Triflic anhydride had just been added. The activation of the phosphonate is total because the peak of SM disappeared. Two intermediates appeared: IR-1 and IR-2.

Spectrum 3: After 15 more minutes, the IR-1 disappear in favour of IR-2 suggesting the Arbuzov reaction noted above.

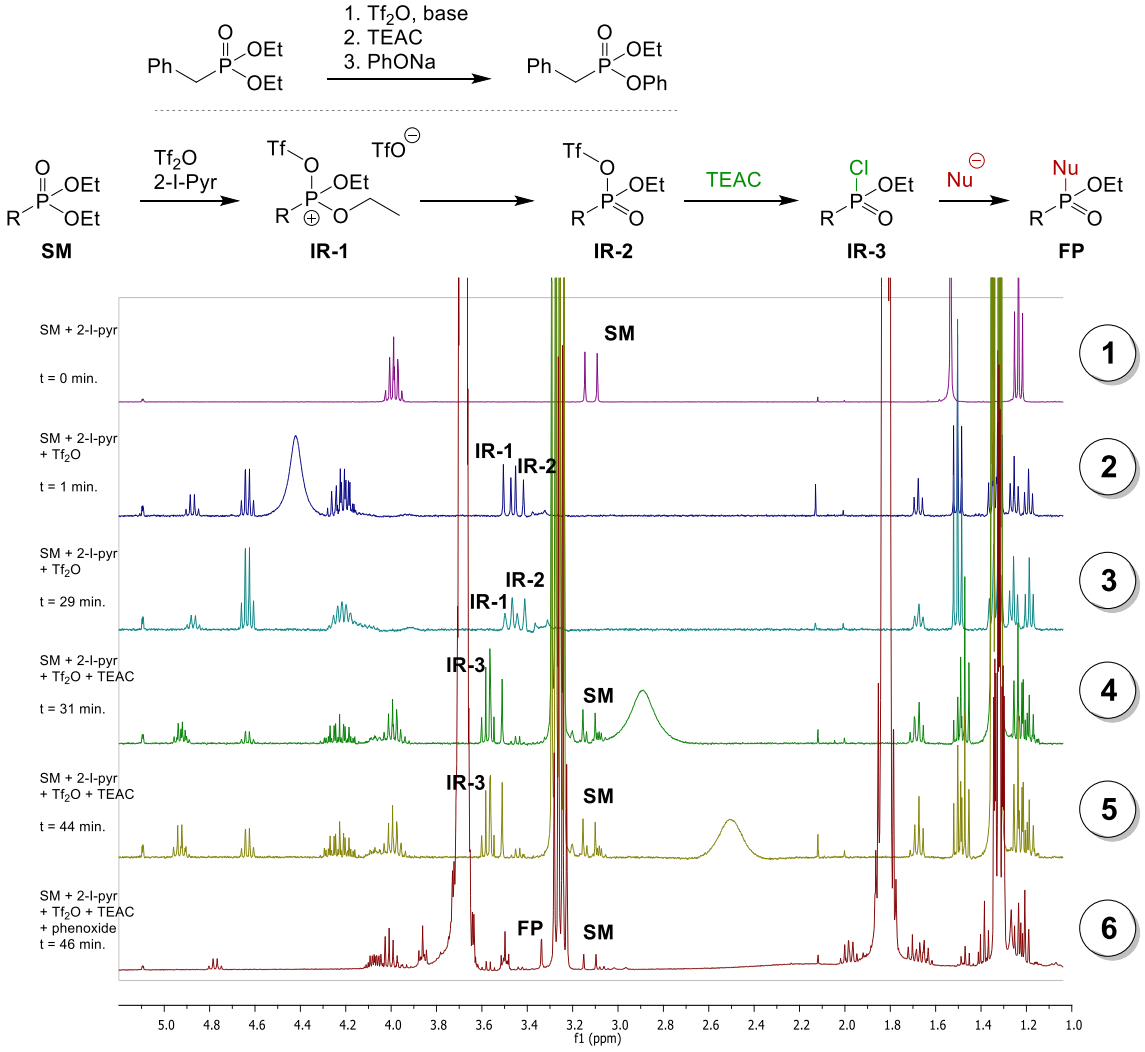
Spectrum 4: The tetraethylammonium chloride was just added. According to integration, all IR-1 become SM again, while all IR-2 because the phosphoryl chloride IR-3.

Spectrum 5: No changes after 10 minutes.

Spectrum 6: The nucleophile was just added. The peak of the final product (FP) appeared while IR-3 disappeared.

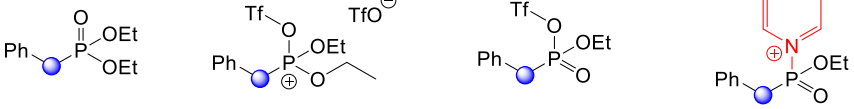
3.2. ^{1}H NMR study

The reaction was followed by ^{1}H NMR, (CD_2Cl_2, 400 MHz).



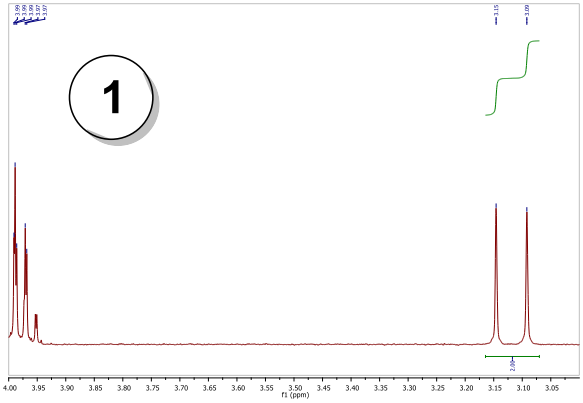
The comments are the same than previously.

On this study, we got particularly interested in the signal of the benzylic CH_2. In particular for the spectra 1, 2 and 3. Indeed, in Kang's paper,[1] the chemical shifts are the following, depending on their intermediate.

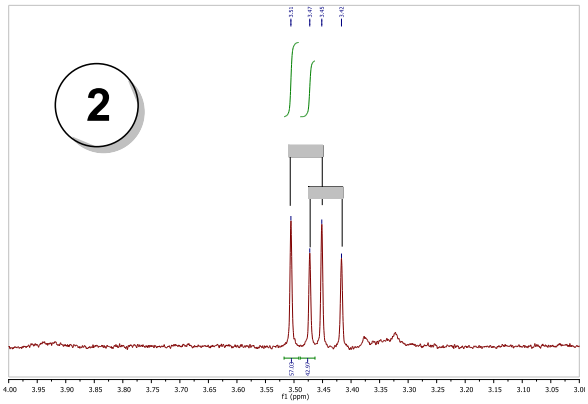


δ (ppm) according to Kang's report	3.1 (d)	3.5 (d)	3.4 (d)	4 (d)

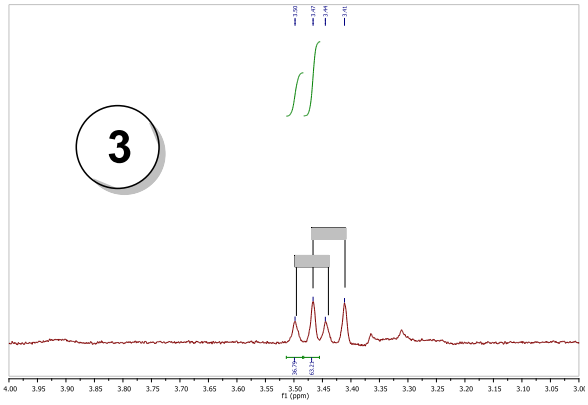
In our case, on the spectrum 1, we clearly observed the doublet of the starting material.



As soon as triflic anhydride was added, this doublet disappeared and two new doublets appeared around 3.4 and 3.5 ppm.



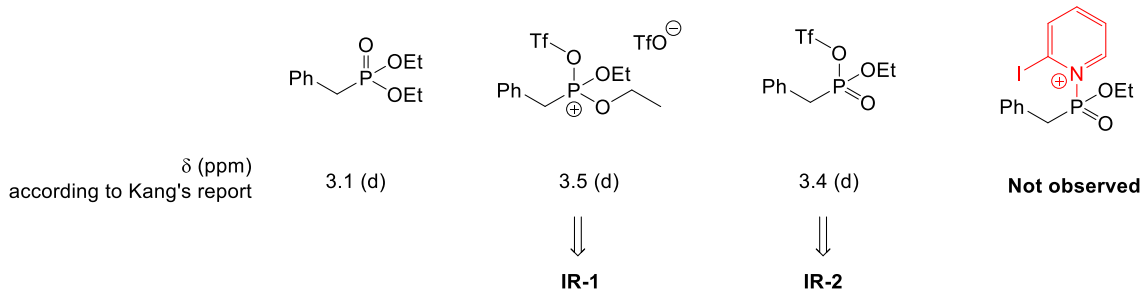
The integration here is 57% for the signal at 3.5 ppm and 43% for the signal at 3.4 ppm. On the phosphorus spectrum 2, we had the same integration: IR-2 (60%) IR-1 (40%).



After 30 minutes, the doublet at 3.5 ppm disappeared slowly (integration 36%) and the doublet at 3.4 ppm increased (integration 64%). (Same assessment for phosphorus spectrum)

At this stage, the doublet disappearing seems to be the phosphonium **IR-1** and the doublet appearing the triflyl phosphonate **IR-2**.

It has to be noted that no signal appeared around 4 ppm as Kang and co-workers observed in their work, corresponding to the pyridinium species.



This allows us to conclude that we don't form the pyridinium species under our conditions. And this supports the proposed mechanism written above.

4 Preparation of the starting materials

4.1 Preparation of phosphonates

General Procedure A:

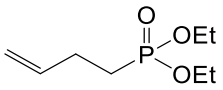
Trialkylphosphite (1 eq.) and alkyl bromide (1 eq.) were stirred for 3 hours at 240 °C and 20 bar. The resulting crude material was purified by flash column chromatography on silica gel (heptane/ethyl acetate) to afford the desired compound.

General Procedure B:

Diethyl phosphite (6.6 mmol, 1.3 eq.) was added to a suspension of sodium hydride (1.3 eq.) in THF (10 mL) at 0 °C. The mixture was stirred at reflux for 2 hours, then bromoalkane (5 mmol, 1 eq.) was added at 0 °C. The mixture was stirred overnight at room temperature and quenched with water. The aqueous layer was extracted 3 times with dichloromethane, the combined organic layers were dried over $MgSO_4$ and concentrated under reduced pressure. The resulting crude material was purified by flash column chromatography on silica gel (heptane/ethyl acetate) to afford the desired compound.

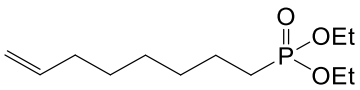
4.2 Characterizations

Diethyl but-3-en-1-ylphosphonate (1a)



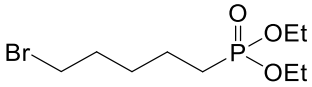
General Procedure A; (85%). All analytical data were in good accordance with data reported in the literature.[2]

Diethyl oct-7-en-1-ylphosphonate (1b)



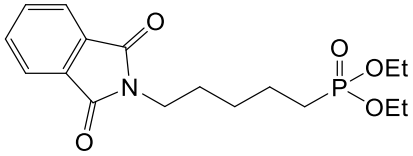
General Procedure B; (94%). All analytical data were in good accordance with data reported in the literature.[3]

Diethyl (5-bromopentyl)phosphonate (1c)



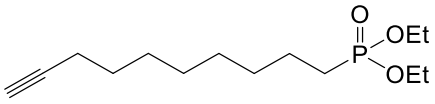
General Procedure B; (14%). All analytical data were in good accordance with data reported in the literature.[4]

Diethyl (5-(1,3-dioxoisoindolin-2-yl)pentyl)phosphonate (1d)



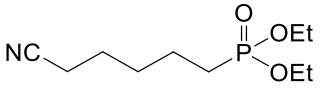
To a solution of diethyl (5-bromopentyl)phosphonate (0.35 mmol, 1 eq.) in DMF (3 mL) was added potassium phthalimide (1.5 eq.) at room temperature. The mixture was stirred at room temperature for 16 hours, then diluted with water. The aqueous layer was extracted 3 times with ethyl acetate, the combined organic layers were dried over $MgSO_4$ and concentrated under reduced pressure. The crude material was purified by flash column chromatography on silica gel (heptane/ethyl acetate) to afford the desired compound in 61% yield. **^{1}H NMR (400 MHz, $CDCl_3$)**: δ 7.85 – 7.78 (m, 2H), 7.72 – 7.67 (m, 2H), 4.12 – 3.98 (m, 4H), 3.66 (t, *J* = 7.2 Hz, 2H), 1.74 – 1.55 (m, 6H), 1.42 (dd, *J* = 15.0, 7.9 Hz, 2H), 1.28 (t, *J* = 7.1 Hz, 6H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 168.5 (2C), 134.0 (2C), 132.2 (2C), 123.3 (2C), 61.5 (d, *J* = 6.5 Hz, 2C), 37.8, 28.2, 27.9 (d, *J* = 17.0 Hz), 25.7 (d, *J* = 140.9 Hz), 22.2 (d, *J* = 5.2 Hz), 16.6 (d, *J* = 6.0 Hz, 2C); **^{31}P NMR (162 MHz, $CDCl_3$)**: δ 31.9; **IR (neat) ν_{max}:** 2932, 1770, 1706, 1439, 1396, 1368, 1229, 1021, 958, 720; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{17}H_{24}NNaO_5P$) requires *m*/*z* 376.1284, found *m*/*z* 376.1282.

Diethyl dec-9-yn-1-ylphosphonate (1e)



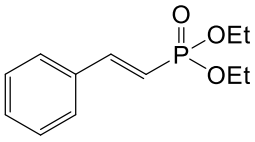
General Procedure A from the iodoalkane; (60%). **^{1}H NMR (600 MHz, $CDCl_3$):** δ 3.98-4.13 (m, 4H), 2.16-2.19 (m, 2H), 1.93 (t, *J* = 6.0 Hz, 1H), 1.68-1.72 (m, 3H), 1.49-1.61 (m, 4H), 1.28-1.41 (m, 13H); **^{13}C NMR (150 MHz, $CDCl_3$)** δ 68.1, 65.4 (d, *J* = 4 Hz), 61.4 (d, *J* = 4.0 Hz), 30.6, 30.5, 28.9, 28.8, 28.6, 28.4, 26.1, 25.2, 22.4 (d, J = 4.0 Hz), 18.4, 16.5 (d, J = 4.0 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 32.6; **IR (neat) ν_{max}:** 2981, 1230, 1052, 1024, 956, 768, 700, 626, 489; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{14}H_{27}NaO_3P$) requires *m*/*z* 297.1590, found *m*/*z* 297.1590.

Diethyl (5-cyanopentyl)phosphonate (1f)



Prepared according to general Procedure B; (62%). **^{1}H NMR (400 MHz, $CDCl_3$):** δ 4.14 – 3.99 (m, 4H), 2.33 (t, *J* = 7.0 Hz, 2H), 1.77 – 1.49 (m, 8H), 1.30 (t, *J* = 7.1 Hz, 6H); **^{13}C NMR (100 MHz, $CDCl_3$)** δ 119.5, 61.6 (d, *J* = 6.5 Hz, 2C), 29.5 (d, *J* = 16.4 Hz), 25.5 (d, *J* = 140.0 Hz), 25.1 (d, *J* = 0.9 Hz), 21.9 (d, *J* = 5.1 Hz), 17.1, 16.55 (d, *J* = 6.0 Hz, 2C); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 31.5; **IR (neat) ν_{max}:** 2934, 2245, 1641, 1446, 1392, 1218, 1163, 1097, 1020, 957, 785; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{10}H_{20}NNaO_3P$) requires *m*/*z* 256.1073, found *m*/*z* 256.1068.

Diethyl (*E*)-styrylphosphonate (1g)

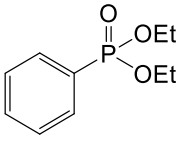


21% yield

(*E*)-β-Nitrostyrene (4 mmol, 1 eq.), diethyl phosphite (1.5 eq.) and silver nitrate (0.2 eq.) in acetonitrile (40 mL) were added in a round bottom flask. The mixture was heated at 90 °C for 2 hours. After stirring for 2 h, the reaction mixture was cooled down to room temperature and diluted with H_2O. The aqueous phase was extracted three times with EtOAc. The organic layers were combined and dried over anhydrous sodium sulfate, filtered and concentrated under reduced pressure. The resulting crude material was purified by flash column chromatography on silica gel (heptane/ethyl acetate) to afford the desired compound in 21% yield.

All analytical data were in good accordance with data reported in the literature.[5]

Diethyl phenylphosphonate (1h)



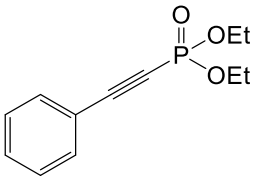
64% yield

To a solution of dichloro(phenyl)phosphine (5.0 mmol, 1 eq.) in diethyl ether (15 mL) were added ethanol (2.1 eq.) and Et_3N (2.1 eq.) at 0 °C. The reaction mixture was allowed to warm up to room temperature. After stirring for 3 hours, the reaction mixture was filtered through a pad of Celite®. The filtrate was concentrated under reduced pressure. The residue was dissolved in THF (5.0 mL) followed by addition at 0 °C of 30% H_2O_2 (1.5 eq.). After stirring for 1 hour at room temperature, the reaction mixture was

quenched with saturated $Na_2S_2O_3$ solution (10 mL). The aqueous phase was extracted with diethyl ether (3×10 mL). The washed solution was dried over anhydrous sodium sulfate, filtered and concentrated under reduced pressure. The resulting crude material was purified by flash column chromatography on silica gel (heptane/ethyl acetate) to afford the desired compound in 64% yield.

All analytical data were in good accordance with data reported in the literature.[6]

Diethyl (phenylethynyl)phosphonate (1i)

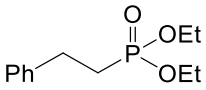


83% yield

To a solution of phenylacetylene (2 mmol, 1 eq.) in THF (7 mL) was added *n*-butyl lithium (1.2 eq., 2.5 M in hexane) at -78 °C. The mixture was stirred at -78 °C for 2 hours, then a solution of diethylchlorophosphate (1.2 eq.) in THF (7mL) was added at -78 °C. The solution was stirred for 1 hour at -78°C, warmed to room temperature and stirred for 3 hours. The mixture was evaporated under reduced pressure. The resulting crude material was purified by flash column chromatography on silica gel (heptane/ethyl acetate) to afford the desired compound in 83% yield.

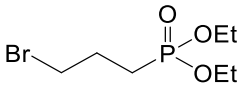
All analytical data were in good accordance with data reported in the literature.[7]

Diethyl phenethylphosphonate (1j)



General Procedure A; (70%). All analytical data were in good accordance with data reported in the literature.[8]

Diethyl (5-bromopentyl)phosphonate (1k)



General Procedure B; (50%). All analytical data were in good accordance with data reported in the literature.[9]

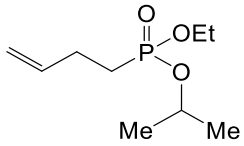
5 Product of substitution

5.1 General procedure C

To a solution of phosphonate (0.2 mmol, 1 eq.) and 2-iodopyridine (1.5 eq.) in dichloromethane (4 mL) was added triflic anhydride (2 eq.) at 0 °C. After 30 minutes stirring, the tetraethylammonium chloride salt (2,5 eq.) was added. The solution was stirred 15 minutes at 0 °C followed by the addition of the solution of the deprotonated nucleophile in THF (4 eq. of nucleophile + 4 eq. of Base in 1 mL of THF). The reaction mixture was stirred at room temperature during 16 hours and quenched with a saturated solution of ammonium chloride. After separation of the phases, the aqueous phase was extracted three times with ethyl acetate. The organic phases were combined and dried on magnesium sulfate. After filtration and evaporation, the crude was then purified by flash column chromatography on silica gel.

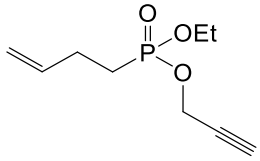
5.2. Alcohols as nucleophiles: preparation of mixed phosphonates

Ethyl isopropyl but-3-en-1-ylphosphonate (2a)



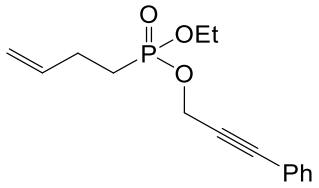
Prepared according to general procedure C; 60% yield; **^{1}H NMR (400 MHz, $CDCl_3$)**: δ 5.84 (ddt, *J* = 16.7, 10.2, 6.4 Hz, 1H), 5.11 – 4.94 (m, 2H), 4.76 – 4.63 (m, 1H), 4.16 – 3.99 (m, 2H), 2.41 – 2.26 (m, 2H), 1.86 – 1.71 (m, 2H), 1.36 – 1.27 (m, 9H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 137.5 (d, *J* = 17.8 Hz), 115.2, 70.3 (d, *J* = 6.6 Hz), 61.4 (d, *J* = 6.3 Hz), 26.8 (d, *J* = 4.2 Hz), 25.8 (d, *J* = 141.6 Hz), 24.2, 16.6 (d, *J* = 6.0 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 30.4; **IR (neat) ν_{max}:** 2980, 2929, 1642, 1442, 1386, 1283, 1240, 1216, 1045, 998, 962, 914, 816, 781; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_9H_{19}NaO_3P$) requires *m/z* 229.0970, found *m/z* 229.0964.

Ethyl prop-2-yn-1-yl but-3-en-1-ylphosphonate (2b)



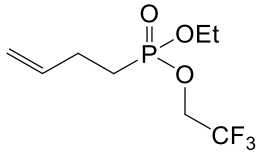
Prepared according to general procedure C (tetrabutylammonium chloride was used instead of tetraethylammonium; extraction with dichloromethane); 58% yield; **^{1}H NMR (400 MHz, $CDCl_3$)**: δ 5.84 (ddt, *J* = 16.7, 10.2, 6.4 Hz, 1H), 5.06 (ddd, *J* = 17.1, 3.2, 1.6 Hz, 1H), 5.01 (ddd, *J* = 10.2, 2.7, 1.3 Hz, 1H), 4.66 (ddd, *J* = 10.6, 2.5, 0.8 Hz, 2H), 4.22 – 4.03 (m, 2H), 2.53 (t, *J* = 2.5 Hz, 1H), 2.43 – 2.31 (m, 2H), 1.96 – 1.82 (m, 2H), 1.33 (t, *J* = 7.1 Hz, 3H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 137.0 (d, *J* = 17.8 Hz), 115.2, 75.4 (d, *J* = 3.0 Hz), 61.8 (d, *J* = 6.8 Hz), 53.0 (d, *J* = 5.6 Hz), 26.3 (d, *J* = 4.6 Hz), 25.3 (d, *J* = 140.5 Hz), 16.3 (d, *J* = 6.1 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 33.0; **IR (neat) ν_{max}:** 2982, 2930, 2122, 1642, 1445, 1394, 1371, 1331, 1241, 1217, 1051,1020, 995, 962, 916, 823, 751, 716; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_9H_{15}NaO_3P$) requires *m*/*z* 225.0657, found *m*/*z* 225.0650.

Ethyl (3-phenylprop-2-yn-1-yl) but-3-en-1-ylphosphonate (2c)



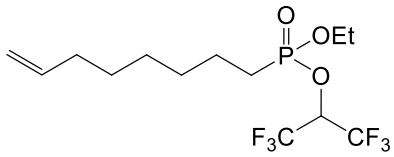
Prepared according to general procedure C; 80% yield; **^{1}H NMR (600 MHz, $CDCl_3$)**: δ 7.47 – 7.40 (m, 2H), 7.37 – 7.29 (m, 3H), 5.85 (ddt, *J* = 16.7, 10.2, 6.4 Hz, 1H), 5.08 – 4.98 (m, 2H), 4.90 (dd, *J* = 10.6, 1.7 Hz, 2H), 4.21 – 4.11 (m, 2H), 2.44 – 2.37 (m, 2H), 1.96 – 1.88 (m, 2H), 1.34 (t, *J* = 7.1 Hz, 3H); **^{13}C NMR (150 MHz, $CDCl_3$):** δ 137.2 (d, *J* = 17.9 Hz), 132.0, 129.0, 128.5, 122.1, 115.4, 87.2, 83.8 (d, *J* = 5.8 Hz), 61.9 (d, *J* = 6.8 Hz), 54.1 (d, *J* = 5.6 Hz), 26.6 (d, *J* = 4.4 Hz), 25.5 (d, *J* = 140.2 Hz), 16.5 (d, *J* = 6.2 Hz); **^{31}P NMR (243 MHz, $CDCl_3$):** δ 33.0; **IR (neat) ν_{max}:** 3079, 2981, 2928, 1641, 1599, 1491, 1443, 1242, 1216, 1048, 1016, 992, 962, 915, 823, 756, 691; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{15}H_{19}NaO_3P$) requires *m*/*z* 301.0964, found *m*/*z* 301.0961.

Ethyl (2,2,2-trifluoroethyl) but-3-en-1-ylphosphonate (2d)



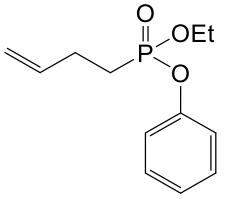
Prepared according to general procedure C; 82% yield; **^{1}H NMR (400 MHz, $CDCl_3$)**: δ 5.83 (ddt, *J* = 16.7, 10.2, 6.4 Hz, 1H), 5.07 (dd, *J* = 17.1, 1.5 Hz, 1H), 5.02 (dd, *J* = 10.2, 1.2 Hz, 1H), 4.35 (m, *J* = 8.2 Hz, 2H), 4.23 – 4.03 (m, 2H), 2.41 – 2.29 (m, 2H), 1.97 – 1.83 (m, 2H), 1.33 (t, *J* = 7.1 Hz, 3H); **^{13}C NMR (150 MHz, $CDCl_3$):** δ 136.6 (d, *J* = 17.6 Hz), 122.9 (qd, *J* = 277.6, 7.7 Hz), 115.6, 62. (d, *J* = 7.0 Hz), 61.9 (qd, *J* = 37.5, 7.4 Hz), 26.2 (d, *J* = 4.8 Hz), 25.0 (d, *J* = 141.7 Hz), 16.3 (d, *J* = 6.2 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 33.0; **^{19}F NMR (565 MHz, $CDCl_3$):** δ -75.3 (t, *J* = 8.3 Hz); **IR (neat) ν_{max}:** 2987, 2918, 1643, 1447, 1418, 1288, 1248, 1200, 1163, 1092, 1032, 963, 917, 839, 758, 652; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_8H_{14}NaO_3PF_3$) requires *m*/*z* 269.0530, found *m*/*z* 269.0527.

Ethyl (1,1,1,3,3,3-hexafluoropropan-2-yl) oct-7-en-1-ylphosphonate (2e)



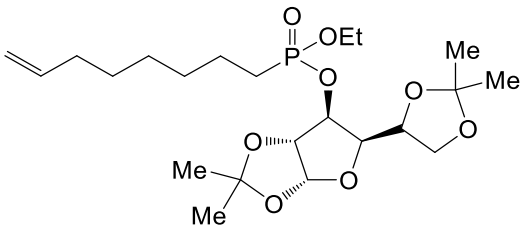
Prepared according to general procedure C; 68% yield; **^{1}H NMR (700 MHz, $CDCl_3$)**: δ 5.79 (ddt, *J* = 16.9, 10.2, 6.7 Hz, 1H), 5.27 – 5.21 (m, 1H), 5.02 – 4.91 (m, 2H), 4.25 – 4.16 (m, 1H), 4.12 – 4.04 (m, 1H), 2.04 (dd, *J* = 14.4, 7.0 Hz, 2H), 1.88 – 1.81 (m, 2H), 1.66 – 1.60 (m, 2H), 1.43 – 1.36 (m, 4H), 1.35 – 1.29 (m, 5H); **^{13}C NMR (176 MHz, $CDCl_3$):** δ 139.0, 120.8 (q, *J* = 282.9 Hz), 114.6, 70.2 (dtd, *J* = 69.3, 34.5, 5.0 Hz), 62.4 (d, *J* = 7.6 Hz), 33.8, 30.3 (d, *J* = 17.6 Hz), 28.7, 28.5, 26.2 (d, *J* = 141.1 Hz), 22.1 (d, *J* = 5.7 Hz), 16.2 (d, *J* = 6.6 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 35.0; **^{19}F NMR (659 MHz, $CDCl_3$):** δ -74.1 (t, *J* = 6.4 Hz), -74.2 (t, *J* = 6.5 Hz); **IR (neat) ν_{max}:** 2934, 2860, 1642, 1384, 1295, 1251, 1222, 1196, 1107, 1031, 995, 970, 901, 874, 687; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{13}H_{21}NaO_3PF_6$) requires *m*/*z* 393.1025, found *m*/*z* 393.1025.

Ethyl phenyl but-3-en-1-ylphosphonate (2f)



Prepared according to general procedure C; (tetrabutylammonium chloride was used instead of tetraethylammonium; extraction with dichloromethane); 76% yield; **^{1}H NMR (400 MHz, $CDCl_3$)**: δ 7.40 – 7.28 (m, 2H), 7.22 – 7.18 (m, 2H), 7.17 – 7.12 (m, 1H), 5.85 (ddt, *J* = 16.7, 10.2, 6.4 Hz, 1H), 5.07 (ddd, *J* = 17.1, 3.1, 1.5 Hz, 1H), 5.01 (dd, *J* = 10.2, 1.3 Hz, 1H), 4.26 – 4.07 (m, 2H), 2.52 – 2.36 (m, 2H), 2.04 – 1.90 (m, 2H), 1.29 (t, *J* = 7.1 Hz, 3H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 150.6 (d, *J* = 8.4 Hz), 136.8 (d, *J* = 17.8 Hz), 129.7 (2C), 124.8 (d, *J* = 0.9 Hz), 120.4 (d, *J* = 4.2 Hz,, 2C), 115.4, 62.4 (d, *J* = 6.9 Hz), 26.4 (d, *J* = 4.7 Hz), 25.1 (d, *J* = 141.2 Hz), 16.3 (d, *J* = 5.9 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 28.4; **IR (neat) ν_{max}:** 2982 ,2912 ,1642, 1592, 1489, 1445, 1394, 1254, 1204, 1163, 1097, 1035, 962, 916, 811, 752, 691; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{12}H_{17}NaO_3P$) requires *m*/*z* 263.0813, found *m*/*z* 263.0812.

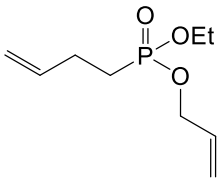
(3a*R*,5*R*,6*S*,6a*R*)-5-((*R*)-2,2-Dimethyl-1,3-dioxolan-4-yl)-2,2-dimethyltetrahydrofuro[2,3-d][1,3]dioxol-6-yl ethyl oct-7-en-1-ylphosphonate (2g)



Prepared according to general procedure C; 53% yield, d.r. 1.13:1; **^{1}H NMR (400 MHz, $CDCl_3$)**: δ 5.88 (t, *J* = 3.3 Hz, 1H), 5.79 (ddt, *J* = 16.9, 10.2, 6.7 Hz, 1H), 5.02 – 4.95 (m, 1H), 4.93 (ddd, *J* = 10.2, 2.1, 1.0 Hz, 1H), 4.83 (dd, *J* = 8.2, 2.4 Hz, 1H), 4.72 (dd, *J* = 18.3, 3.6 Hz, 1H), 4.25 – 4.05 (m, 5H), 4.00 (ddd, *J* = 8.6, 5.2, 2.8 Hz, 1H), 2.03 (q, *J* = 6.6 Hz, 2H), 1.83 – 1.69 (m, 2H), 1.65 – 1.55 (m, 2H), 1.49 (s, 3H), 1.43 – 1.28 (m, 18H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 139, 114.5, 112.5 (dia1), 112.5 (dia2), 109.5 (dia1), 109.4 (dia2), 105.2 (dia1), 105.2 (dia2), 84.4 (dia2), 84.1 (dia1), 80.8 (d, *J* = 7.2 Hz, dia1), 80.7 (d, *J* = 7.0 Hz, dia2), 78.0 (d, *J* = 5.7 Hz, dia1), 77.8 (d, *J* = 7.1 Hz, dia2), 72.4 (dia1), 72.3 (dia2), 67.6 (dia1), 67.5 (dia2), 62.3 (d, *J* = 6.5 Hz, dia2), 61.6 (d, *J* = 6.7 Hz, dia1), 33.8 (dia1), 33.8 (dia2), 30.7 (d, *J* = 18.1 Hz, dia1), 30.5 (d, *J* = 17.3 Hz, dia2), 28.8 (dia1), 28.8 (dia2), 28.7 (dia1), 28.7 (dia2), 27.0, 27.0 (dia1), 26.9 (dia2), 26.4 (dia1), 26.4 (dia2), 26.3 (d, *J* = 141.0 Hz, dia1), 25.9 (d, *J* = 138.0 Hz, dia2), 25.5 (dia2), 25.4 (dia1), 22.4 (d, *J* = 1.8 Hz, dia1), 22.4 (d, *J* =

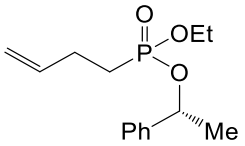
1.9 Hz, dia2), 16.6 (d, *J* = 6.3 Hz, dia2), 16.5 (d, *J* = 5.9 Hz, dia1); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 33.9, 32.6; **IR (neat) ν_{max}:** 2932, 1640, 1374, 1250, 1215, 1164, 1072, 1019, 957, 842, 636; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{22}H_{39}NaO_8P$) requires *m*/*z* 485.2275, found *m*/*z* 485.2274.

Allyl ethyl but-3-en-1-ylphosphonate (2h)



Prepared according to general procedure C; (tetrabutylammonium chloride was used instead of tetraethylammonium; extraction with dichloromethane); 60% yield; **^{1}H NMR (600 MHz, $CDCl_3$)**: δ 5.94 (ddd, *J* = 22.5, 10.7, 5.5 Hz, 1H), 5.85 (ddt, *J* = 16.7, 10.2, 6.3 Hz, 1H), 5.36 (dd, *J* = 17.1, 1.3 Hz, 1H), 5.24 (dd, *J* = 10.4, 0.9 Hz, 1H), 5.07 (dd, *J* = 17.1, 1.4 Hz, 1H), 5.01 (dd, *J* = 10.2, 1.0 Hz, 1H), 4.55 – 4.51 (m, 2H), 4.17 – 4.05 (m, 2H), 2.40 – 2.32 (m, 2H), 1.93 – 1.78 (m, 2H), 1.32 (t, *J* = 7.1 Hz,3H); **^{13}C NMR (150 MHz, $CDCl_3$):** δ 137.1 (d, *J* = 18.0 Hz), 133.1 (d, *J* = 6.1 Hz), 117.8, 115.2, 65.9 (d, *J* = 6.1 Hz), 61.6 (d, *J* = 6.6 Hz), 26.5 (d, *J* = 4.5 Hz), 25.2 (d, *J* = 140.8 Hz), 16.5 (d, *J* = 6.1 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 31.9; **IR (neat) ν_{max}:** 2982. 2928, 1644, 1445, 1245, 1217, 1100, 1048, 1020, 963, 922, 846, 824, 752; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_9H_{17}NaO_3P$) requires *m*/*z* 227.0813, found *m*/*z* 227.0808.

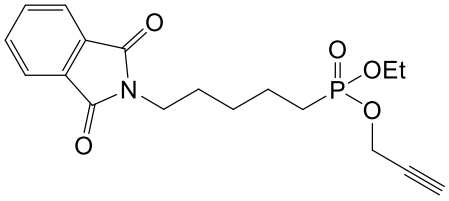
Ethyl ((*R*)-1-phenylethyl) but-3-en-1-ylphosphonate (2i)



Prepared according to general procedure C; (tetrabutylammonium chloride was used instead of tetraethylammonium; extraction with dichloromethane); 40% yield, d.r. 1.15:1; **^{1}H NMR (600 MHz, $CDCl_3$)**: δ 7.41 – 7.33 (m, 4H), 7.33 – 7.27 (m, 1H), 5.84 (ddt, *J* = 16.7, 10.2, 6.3 Hz, 1H, dia1), 5.73 – 5.65 (m, 1H, dia2), 5.60 – 5.50 (m, 1H), 5.05 (dd, *J* = 17.1, 1.5 Hz, 1H, dia1), 4.99 (dd, *J* = 10.2, 1.3 Hz, 1H, dia2), 4.93 – 4.88 (m, 2H), 4.18 – 4.10 (m, 1H, dia2), 4.10 – 4.02 (m, 1H, dia1), 3.90 – 3.83 (m, 1H, dia2), 3.71 – 3.63 (m, 1H, dia1), 2.39 – 2.31 (m, 2H, dia1), 2.20 – 2.13 (m, 2H, dia2), 1.89 – 1.76 (m, 2H), 1.63-1.59 (4H), 1.60 (d, *J* = 6.5 Hz, 3H, dia1), 1.32 (t, *J* = 7.1 Hz, 3H, dia1), 1.08 (t, J = 7.1 Hz, 3H, dia2); **^{13}C NMR (150 MHz, $CDCl_3$):** δ 142.2 (d, *J* = 3.5 Hz), 142.0 (d, *J* = 4.2 Hz), 137.3 (d, *J* = 7.8 Hz), 137.2 (d, *J* = 8.2 Hz), 128.5 (s, 2C), 128.5 (s, 2C), 128.1, 128.0, 125.9, 115.1, 114.9, 74.8 (d, *J* = 5.9 Hz), 74.3 (d, *J* = 6.7 Hz), 61.3 (d, *J* = 6.7 Hz), 61.1

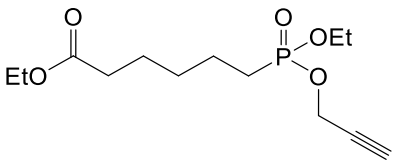
(d, *J* = 6.7 Hz), 26.5 (d, *J* = 4.5 Hz), 26.4 (d, *J* = 4.5 Hz), 25.6 (d, *J* = 142.3 Hz), 25.5 (d, *J* = 139.9 Hz), 24.7 (d, *J* = 6.0 Hz), 24.6 (d, *J* = 4.8 Hz), 16.4 (d, *J* = 6.4 Hz), 16.2 (d, *J* = 6.3 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 31.1, 30.6; **IR (neat) ν_{max}:** 2980, 2930, 1642, 1449, 1374, 1283, 1243, 1212, 1173, 1041, 1008, 995, 960, 914, 824, 755, 699; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{14}H_{21}NaO_3P$) requires *m*/*z* 291.1126, found *m*/*z* 291.1123.

Ethyl prop-2-yn-1-yl (5-(1,3-dioxoisoindolin-2-yl)pentyl)phosphonate (2j)



Prepared according to general procedure C; 45% yield; **^{1}H NMR (400 MHz, $CDCl_3$):** δ 7.85 – 7.78 (m, 2H), 7.72 – 7.65 (m, 2H), 4.63 (dd, *J* = 10.5, 2.4 Hz, 2H), 4.16 – 4.01 (m, 2H), 3.66 (t, *J* = 7.2 Hz, 2H), 2.53 (t, *J* = 2.4 Hz, 1H), 1.82 – 1.71 (m, 2H), 1.71 – 1.58 (m, 4H), 1.48 – 1.37 (m, 2H), 1.29 (t, *J* = 7.1 Hz, 3H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 168.5 (2C), 134.0 (2C), 132.2 (2C), 123.3 (2C), 75.5 (d, *J* = 2.0 Hz), 61.8 (d, *J* = 6.8 Hz), 53.1 (d, *J* = 5.7 Hz), 37.8, 28.2, 27.8 (d, *J* = 17.2 Hz), 25.9 (d, *J* = 140.3 Hz), 22.0 (d, *J* = 5.2 Hz), 16.4 (d, *J* = 6.2 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 33.4; **IR (neat) ν_{max}:** 2939, 1770, 1705, 1439, 1396, 1368, 1232, 1019, 995, 961, 718; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{18}H_{22}NNaO_5P$) requires *m*/*z* 386.1128, found *m*/*z* 386.1127.

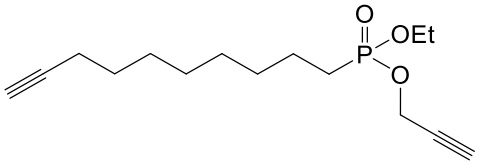
Ethyl 6-(ethoxy(prop-2-yn-1-yloxy)phosphoryl)hexanoate (2k)



Prepared according to general procedure C (tetrabutylammonium chloride was used instead of tetraethylammonium; extraction with dichloromethane); 75% yield; **^{1}H NMR (600 MHz, $CDCl_3$)**: δ 4.65 (ddd, *J* = 10.6, 2.4, 0.8 Hz, 2H, H11), 4.18 – 4.04 (m, 4H, H7,9), 2.54 (t, *J* = 2.4 Hz, 1H, H13), 2.29 (t, *J* = 7.5 Hz, 2H, H5), 1.82 – 1.74 (m, 2H, H1), 1.67 – 1.58 (m, 4H, H2,4), 1.45 – 1.36 (m, 2H, H3), 1.32 (t, *J* = 7.1 Hz, 3H, H10), 1.24 (t, *J* = 7.1 Hz, 3H, H8); **^{13}C NMR (150 MHz, $CDCl_3$):** δ 173.5, 75.4, 61.7 (d, *J* = 6.9 Hz), 60.3, 53.0 (d, *J* = 5.7 Hz), 34.0, 29.9 (d, *J* = 17.5 Hz), 25.7 (d, *J* = 140.2 Hz), 24.3, 22.0 (d, *J* = 5.2 Hz), 16.3 (d, *J* = 6.3 Hz), 14.2; **^{31}P NMR (243 MHz, $CDCl_3$):** δ 33.7; **IR (neat) ν_{max}:** 2982, 2937, 1730, 1450, 1373, 1328, 1122,

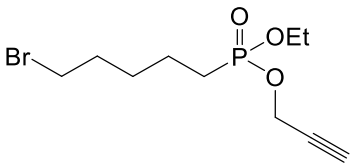
1097, 1052, 996, 962, 829, 749, 704; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{13}H_{23}NaO_5P$) requires *m*/*z* 313.1181, found *m*/*z* 313.1177.

Ethyl prop-2-yn-1-yl dec-9-yn-1-ylphosphonate (2l)



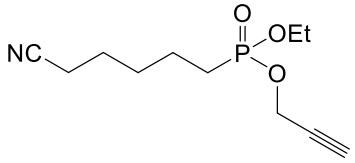
Prepared according to general procedure C; 60% yield; **^{1}H NMR (700 MHz, $CDCl_3$)**: δ 4.64-4.71 (m, 2H), 4.07-4.18 (m, 2H), 2.55 (t, *J* = 2.1 Hz, 1H), 2.17-2.20 (m, 2H), 1.95 (t, *J* = 2.1 Hz, 1H), 1.76-1.83 (m, 2H), 1.62-1.64 (m, 2H), 1.51-1.54 (m, 2H), 1.37-1.42 (m, 4H), 1.34 (t, *J* = 7.0 Hz, 3H), 1.28-1.32 (m, 4H); **^{13}C NMR (175 MHz, $CDCl_3$)**: δ 75.3, 68.1, 61.7 (d, *J* = 7 Hz), 52.9 (d, *J* = 7 Hz), 30. 5, 30.4, 28.9, 28.8, 28.6, 28.4, 26.3, 25.5, 22.2 (d, *J* = 5.3 Hz), 18.4, 16.4 (d, *J* = 2.1 Hz); **^{31}P NMR (243 MHz, $CDCl_3$):** δ 34.0; **IR (neat) ν_{max}:** 1459, 1371, 1235, 1164, 1097, 1053, 1024, 995, 963, 836, 705, 636; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{15}H_{25}NaO_3P$) requires *m*/*z* 307.1434, found *m*/*z* 307.1427.

Ethyl prop-2-yn-1-yl (5-cyanopentyl)phosphonate (2m)



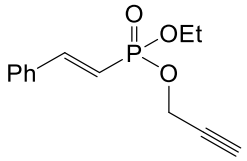
Prepared according to general procedure C; 69% yield; **^{1}H NMR (400 MHz, $CDCl_3$):** δ 4.66 (dd, *J* = 10.5, 2.4 Hz, 2H), 4.19 – 4.05 (m, 2H), 3.40 (t, *J* = 6.7 Hz, 2H), 2.54 (t, *J* = 2.4 Hz, 1H), 1.91 – 1.75 (m, 4H), 1.73 – 1.59 (m, 2H), 1.58 – 1.50 (m, 2H), 1.33 (t, *J* = 7.1 Hz, 3H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 75.5 (d, *J* = 2.1 Hz), 61.9 (d, *J* = 6.8 Hz), 53.2 (d, *J* = 5.7 Hz), 33.4, 32.3 (d, *J* = 1.1 Hz), 29.1 (d, *J* = 17.1 Hz), 25.9 (d, *J* = 140.5 Hz), 21.7 (d, *J* = 5.2 Hz), 16.5 (d, *J* = 6.2 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 33.3; **IR (neat) ν_{max}:** 2938, 1639, 1446, 1371, 1241, 1224, 1050, 1017, 994, 960, 839, 815, 704, 639; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{10}H_{18}BrNaO_3P$) requires *m*/*z* 319.0069, found *m*/*z* 319.0068.

Ethyl prop-2-yn-1-yl (5-cyanopentyl)phosphonate (2n)



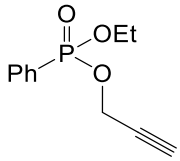
Prepared according to general procedure C; 49% yield; **^{1}H NMR (400 MHz, $CDCl_3$):** δ 4.65 (dd, *J* = 10.6, 2.5 Hz, 2H), 4.18 – 4.03 (m, 2H), 2.54 (t, *J* = 2.4 Hz, 1H), 2.34 (t, *J* = 7.0 Hz, 2H), 1.85 – 1.73 (m, 2H), 1.72 – 1.59 (m, 4H), 1.58 – 1.51 (m, 2H), 1.32 (t, *J* = 7.1 Hz, 3H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 119.5, 75.6 (d, *J* = 1.9 Hz), 61. 9 (d, *J* = 6.9 Hz), 53.2 (d, *J* = 5.8 Hz), 29.4 (d, *J* = 16.7 Hz), 25.7 (d, *J* = 143.0 Hz), 25.0 (d, *J* = 2.2 Hz), 21.7 (d, *J* = 5.2 Hz), 17.1, 16.4 (d, *J* = 6.2 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 33.0; **IR (neat) ν_{max}:** 2939, 2246, 1657, 1450, 1220, 1018, 962, 826; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{11}H_{18}NNaO_3P$) requires *m*/*z* 266.0917, found *m*/*z* 266.0913.

Ethyl prop-2-yn-1-yl (*E*)-styrylphosphonate (2o)



Prepared according to general procedure C; 56% yield; **^{1}H NMR (400 MHz, $CDCl_3$)**: δ 7.55 (d, *J* = 17.5 Hz, 1H), 7.52 – 7.46 (m, 2H), 7.41 – 7.33 (m, 3H), 6.26 (dd, *J* = 18.3, 17.6 Hz, 1H), 4.75 – 4.61 (m, 2H), 4.22 – 4.12 (m, 2H), 2.53 (t, *J* = 2.5 Hz, 1H), 1.36 (t, *J* = 7.1 Hz, 3H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 149.4 (d, *J* = 6.8 Hz), 134.8 (d, *J* = 23.6 Hz), 130.5, 129.0, 127.9, 113.4 (d, *J* = 193.1 Hz), 75.7, 62.4 (d, *J* = 5.5 Hz), 53.3 (d, *J* = 4.2 Hz), 16.4 (d, *J* = 6.5 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 20.7; **IR (neat) ν_{max}:** 3291, 3207, 3027, 2982, 1615, 1576, 1522, 1449, 1392, 1371, 1341, 1240, 1046, 1016, 992, 951, 860, 829, 802, 741, 688; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{13}H_{15}NaO_3P$) requires *m*/*z* 273.0651, found *m*/*z* 273.0647.

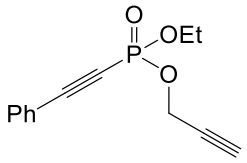
Ethyl prop-2-yn-1-yl phenylphosphonate (2p)



Prepared according to general procedure C; 77% yield; **^{1}H NMR (400 MHz, $CDCl_3$)**: δ 7.78 – 7.65 (m, 2H), 7.50 – 7.40 (m, 1H), 7.39 – 7.31 (m, 2H), 4.58 (dddd, *J* = 43.5, 15.5, 9.5, 2.5 Hz, 2H), 4.13 – 3.99 (m, 2H), 2.38 (t, *J* = 2.5 Hz, 1H), 1.30 – 1.19 (m, 3H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 132.8 (d, *J* = 3.1 Hz), 131.9 (d, *J* =

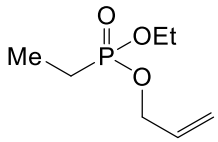
10.1 Hz), 128.6 (d, *J* = 15.3 Hz), 126.8, 75.7 (d, *J* = 2.2 Hz), 62.6 (d, *J* = 5.8 Hz), 53.5 (d, *J* = 4.4 Hz), 16.4 (d, *J* = 6.5 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 19.8; **IR (neat) ν_{max}:** 3294, 3213, 2983, 1652, 1594, 1440, 1238, 1131, 1047, 1015, 992, 949, 849, 818, 775, 748, 693; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{11}H_{13}NaO_3P$) requires *m*/*z* 247.0495, found *m*/*z* 247.0496.

Ethyl prop-2-yn-1-yl (phenylethynyl)phosphonate (2q)



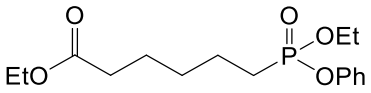
Prepared according to general procedure C; 59% yield; **^{1}H NMR (400 MHz, $CDCl_3$)**: 7.62 – 7.53 (m, 2H), 7.51 – 7.42 (m, 1H), 7.42 – 7.33 (m, 2H), 4.80 – 4.70 (m, 2H), 4.26 (dq, *J* = 8.7, 7.1 Hz, 2H), 2.58 (t, *J* = 2.5 Hz, 1H), 1.42 (td, *J* = 7.1, 0.7 Hz, 3H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 132.7 (d, *J* = 1.8 Hz), 130.9, 128.6, 119.3 (d, *J* = 5.7 Hz), 99.9 (d, *J* = 54.5 Hz), 79.2, 76.0, 63.7 (d, *J* = 5.4 Hz), 54.2 (d, *J* = 3.8 Hz), 16.1 (d, *J* = 6.9 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ -5.6; **IR (neat) ν_{max}:** 3294, 3216, 2985, 2932, 2185, 2126, 1490, 1444, 1259, 1163, 1016, 990, 860, 757, 687; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{13}H_{13}NaO_3P$) requires *m*/*z* 271.0495, found *m*/*z* 271.0492.

Allyl ethyl ethylphosphonate (2r)



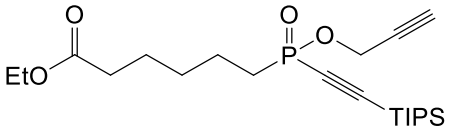
Prepared according to general procedure C on 15 mmol scale; 82% yield; **^{1}H NMR (600 MHz, $CDCl_3$):** δ 5.98 – 5.90 (m, 1H), 5.36 (ddd, *J* = 17.1, 3.1, 1.5 Hz, 1H), 5.24 (ddd, *J* = 10.4, 2.5, 1.2 Hz, 1H), 4.57 – 4.50 (m, 2H), 4.17 – 4.05 (m, 2H), 1.83 – 1.73 (m, 2H), 1.32 (t, *J* = 7.1 Hz, 3H), 1.17 (dt, *J* = 20.2, 7.7 Hz, 3H); **^{13}C NMR (150 MHz, $CDCl_3$):** δ 133.3 (d, *J* = 6.2 Hz), 117.9, 66.2 (d, *J* = 6.0 Hz), 61.9 (d, *J* = 6.3 Hz), 19.0 (d, *J* = 142.8 Hz), 16.6 (d, *J* = 6.1 Hz), 6.7 (d, *J* = 6.9 Hz); **^{31}P NMR (243 MHz, $CDCl_3$):** δ 33.9; **IR (neat) ν_{max}:** 2984, 2945, 1651, 1460, 1410, 1247, 1220, 1161, 1099, 1008, 962, 922, 851, 794, 732, 638; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_7H_{15}NaO_3P$) requires *m*/*z* 201.0651, found *m*/*z* 201.0652.

Ethyl 6-(ethoxy(phenoxy)phosphoryl)hexanoate (2s)



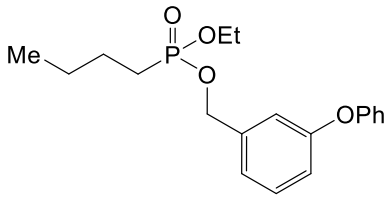
Prepared according to general procedure C on 2 mmol scale; 86% yield; **^{1}H NMR (400 MHz, $CDCl_3$):** δ 7.31 (t, *J* = 7.8 Hz, 2H), 7.21 – 7.16 (m, 2H), 7.14 (t, *J* = 7.4 Hz, 1H), 4.23 – 4.15 (m, 1H), 4.15 – 4.07 (m, 3H), 2.28 (t, *J* = 7.4 Hz, 2H), 1.94 – 1.82 (m, 2H), 1.76 – 1.59 (m, 4H), 1.48 – 1.38 (m, 2H), 1.28 (t, *J* = 7.1 Hz, 3H), 1.23 (td, *J* = 7.1, 0.8 Hz, 3H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 173.6, 150.8 (d, *J* = 8.4 Hz), 129.8 (2C), 124.9, 120.6 (d, *J* = 4.3 Hz, 2C), 62.4 (d, *J* = 7.0 Hz), 60.4, 34.1, 30.0 (d, *J* = 17.1 Hz), 25.7 (d, *J* = 141.0 Hz), 24.5, 22.2 (d, *J* = 5.3 Hz), 16.5 (d, *J* = 5.9 Hz), 14.3; **^{31}P NMR (162 MHz, $CDCl_3$):** δ 29.1; **IR (neat) ν_{max}:** 2935, 1730, 1592, 1490, 1251, 1204, 1162, 1025, 918, 762, 729, 690; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{16}H_{25}NaO_5P$) requires *m*/*z* 351.1332, found *m*/*z* 351.1325.

Ethyl 6-((prop-2-yn-1-yloxy)((triisopropylsilyl)ethynyl)phosphoryl)hexanoate (6b)



Prepared according to general procedure C; 52% yield; **^{1}H NMR (400 MHz, $CDCl_3$)**: δ 4.70 (dd, *J* = 9.8, 2.5 Hz, 2H), 4.11 (q, *J* = 7.1 Hz, 2H), 2.53 (t, *J* = 2.5 Hz, 1H), 2.28 (t, *J* = 7.5 Hz, 2H), 1.95 – 1.85 (m, 2H), 1.76 – 1.58 (m, 4H), 1.49 – 1.40 (m, 2H), 1.24 (t, *J* = 7.1 Hz, 3H), 1.14 – 1.07 (m, 21H); **^{13}C NMR (100 MHz, $CDCl_3$)**: δ 173.6, 109.1 (d, *J* = 24.1 Hz), 98.7 (d, *J* = 175.3 Hz), 75.9 (d, *J* = 2.4 Hz), 60.4, 52.9 (d, *J* = 6.3 Hz), 34.1, 30.9 (d, *J* = 116.5 Hz), 29.9 (d, *J* = 17.3 Hz), 24.6, 21.6 (d, *J* = 4.1 Hz), 18.6 (6C), 14.4, 11.0 (3C); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 23.0; **IR (neat) ν_{max}:** 3212, 2943, 2866, 2124, 1732, 1462, 1371, 1235, 1192, 1027, 993, 794, 764, 713; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{22}H_{39}NaO_4PSi$) requires *m*/*z* 447.2247, found *m*/*z* 447.2244.

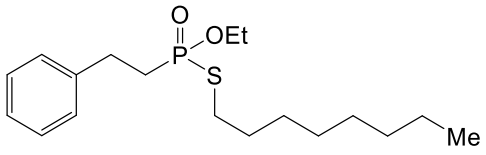
Ethyl (3-phenoxybenzyl) but-3-en-1-ylphosphonate (7)



Prepared according to general procedure C; 55% yield; **^{1}H NMR (400 MHz, $CDCl_3$)**: δ 7.38 – 7.28 (m, 3H), 7.15 – 7.07 (m, 2H), 7.04 – 6.93 (m, 4H), 5.02 (d, *J* = 8.2 Hz, 2H), 4.14 – 3.95 (m, 2H), 1.78 – 1.67 (m, 2H), 1.61 – 1.49 (m, 2H), 1.42 – 1.32 (m, 2H), 1.27 (t, *J* = 7.1 Hz, 3H), 0.88 (t, *J* = 7.3 Hz, 3H); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 33.3; All analytical data were in good accordance with data reported in the literature.[11]

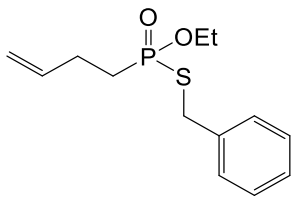
5.3. Thiols as nucleophiles: preparation of phosphonothioates

***O*-Ethyl *S*-octyl phenethylphosphonothioate (3a)**



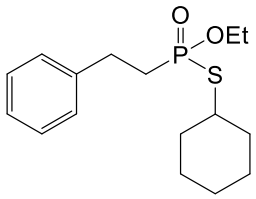
Prepared according to general procedure C; 80% yield; **^{1}H NMR (600 MHz, $CDCl_3$)**: δ 7.28-7.31 (m, 2H), 7.20-7.22 (m, 3H), 4.17-4.24 (m, 1H), 4.08-4.15 (m, 1H), 2.95-3.01 (m, 2H), 2.81-2.90 (m, 2H), 2.24-2.31 (m, 2H), 1.65-1.70 (m, 2H), 1.35-1.42 (m, 2H), 1.23-1.32 (m, 9H), 1.34 (t, *J* = 6.0 Hz, 3H), 0.87 (t, *J* = 6.0, 3H); **^{13}C NMR (150 MHz, $CDCl_3$):** δ 140.7 (d, *J* = 2.0 Hz), 128.6, 128, 126.4, 61.2 (d, *J* = 5.0 Hz), 35.7, 35.0, 31.8, 31.4 (d, *J* = 3.0 Hz), 29.2, 29.0, 28.7, 28.4 (d, *J* = 3.0 Hz), 22.6, 16.3 (d, *J* = 5.0 Hz), 14.1; **^{31}P NMR (243 MHz, $CDCl_3$):** δ 56.1; . **IR (neat) ν_{max}:** 1455, 1231, 1033, 953, 761, 743, 698; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{18}H_{31}NaO_2PS$) requires *m*/*z* 365.1675, found *m*/*z* 365.1675.

***S*-Benzyl *O*-ethyl but-3-en-1-ylphosphonothioate (3b)**



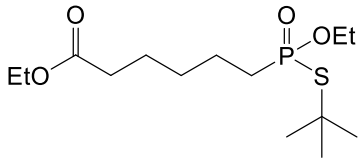
Prepared according to general procedure C; (tetrabutylammonium chloride was used instead of tetraethylammonium; extraction with dichloromethane); 63% yield; **^{1}H NMR (400 MHz, $CDCl_3$)**: δ 7.33 – 7.28 (m, 2H), 7.28 – 7.22 (m, 2H), 7.22 – 7.16 (m, 1H), 5.69 (ddt, *J* = 16.7, 10.2, 6.4 Hz, 1H), 4.96 – 4.91 (m, 1H), 4.91 – 4.87 (m, 1H), 4.09 (ddq, *J* = 14.1, 10.0, 7.1 Hz, 1H), 3.99 (dd, *J* = 12.2, 2.8 Hz, 2H), 3.97 – 3.89 (m, 1H), 2.31 – 2.18 (m, 2H), 1.87 – 1.74 (m, 2H), 1.23 (t, *J* = 7.1 Hz, 3H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 138.1 (d, *J* = 3.7 Hz), 136.8 (d, *J* = 18.8 Hz), 128.9 (2C), 128.7 (2C), 127.5, 115.3, 61.4 (d, *J* = 7.4 Hz, 34.5 (d, *J* = 2.8 Hz), 32.8 (d, *J* = 106.0 Hz), 26.2 (d, *J* = 3.9 Hz), 16.2 (d, *J* = 6.8 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 55.8; **IR (neat) ν_{max}:** 2979, 2926, 1641, 1495, 1391, 1227, 1160, 1907, 1080, 1012, 952, 914, 793, 761, 699; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{13}H_{19}NaO_2PS$) requires *m*/*z* 293.0741, found *m*/*z* 293.0740.

_S_-Cyclohexyl _O_-ethyl phenethylphosphonothioate (3c)



Prepared according to general procedure C; 55% yield; **^{1}H NMR (400 MHz, $CDCl_3$)**: δ 7.28-7.34 (m, 2H), 7.21-7.24 (m, 3H), 4.08-4.27 (m, 2H), 3.31-3.41 (m, 1H), 2.97-3.03 (m, 2H), 2.24-2.32 (m, 2H), 2.06-2.13 (m, 2H), 1.75-1.78 (m, 1H), 1.52-1.62 (m, 3H), 1.26-1.47 (m, 2H), 1.35 (t, *J* = 8.0 Hz, 3H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 140.9 (d, *J* = 19 Hz), 128.6, 128.1, 126.4, 61.2 (d, *J* = *7* Hz), 45.2 (d, *J* = 3 Hz), 36.7, 36.1 (d, *J* = 4.0 Hz), 35.8 (d, *J* = 4.0 Hz), 35.7, 28.5 (d, *J* = 4.0 Hz), 26.0, 25.3, 16.2 (d, *J* = 7.0 Hz); **^{31}P NMR (243 MHz, $CDCl_3$):** δ 55.2; **IR (neat) ν_{max}:** 1450, 1265, 1231, 1033, 998, 954, 763, 748, 699, 599; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{16}H_{25}NaO_2PS$) requires *m*/*z* 335.1205, found *m*/*z* 335.1198.

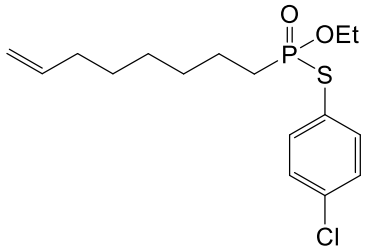
Ethyl 6-((*tert*-butylthio)(ethoxy)phosphoryl)hexanoate (3d)



Prepared according to general procedure C; 61% yield; **^{1}H NMR (600 MHz, $CDCl_3$)**: δ 4.22 – 4.04 (m, 4H), 2.30 (t, *J* = 7.5 Hz, 2H), 1.98 – 1.87 (m, 2H), 1.72 – 1.60 (m, 4H), 1.56 (s, 9H), 1.47 – 1.38 (m, 2H), 1.31 (t, *J* = 7.1 Hz, 3H), 1.25 (t, *J* = 7.1 Hz, 3H); **^{13}C NMR (150 MHz, $CDCl_3$):** δ 173.7, 61.0 (d, *J* = 7.3 Hz), 60.4, 50.5, 35.5 (d, *J* = 105.8 Hz), 34.2, 33.2 (d, *J* = 4.5 Hz), 30.0 (d, *J* = 17.6 Hz), 24.6, 22.3 (d, *J* = 5.2 Hz), 16.4 (d, *J* =

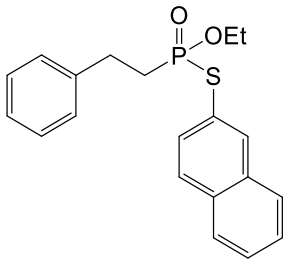
6.9 Hz), 14.4; **^{31}P NMR (243 MHz, $CDCl_3$):** δ 55.2; **IR (neat) ν_{max}:** 2934, 2868, 1734, 1460, 1367, 1232, 1195, 1162, 1029, 952; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{14}H_{29}NaO_4PS$) requires *m*/*z* 347.1416, found *m*/*z* 347.1409.

***S*-(4-Chlorophenyl) *O*-ethyl oct-7-en-1-ylphosphonothioate (3e)**



Prepared according to general procedure C; 71% yield; **^{1}H NMR (600 MHz, $CDCl_3$)**: δ 7.49-7.52 (m, 2H), 7.34-7.36 (m, 2H), 5.77-5.84 (m,. 1H), 4.94-5.03 (m, 2H), 4.26-4.35 (m, 1H), 4.13-4.22 (m, 1H), 2.03-2.07 (m, 2H), 1.86-1.91 (m, 2H), 1.63-1.71 (m, 1H), 1.34-1.45 (m, 8H), 1.27-1.31 (m, 2H); **^{13}C NMR (150 MHz, $CDCl_3$):** δ 138.9, 136.2 (d, *J* = 2.5Hz, 2C), 135.5 (d, *J* = 2.5 Hz, 1C), 129.6 (d, *J* = 1.3 Hz, 2C), 126 (d, *J* = 5.0 Hz, 1C), 114.4, 61.8 (d, *J* = 6.3 Hz, 1C), 33.6, 32.0, 31.3, 30.2 (d, *J* = 13.8 Hz, 1C), 28.5 (d, *J* = 6.3 Hz, 1C), 22.1 (d, *J* = 3.8 Hz, 1C), 16.3 (d, *J* = 5.0 Hz, 1C); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 55.1; **IR (neat) ν_{max}:** 1640, 1475, 1391, 1236, 1162, 1092, 1028, 1013, 956, 911, 821, 745; **HRMS (ESI+):** exact mass calculated for $[M+H]^+$ ($C_{16}H_{25}ClO_2PS$) requires *m*/*z* 347.0996, found *m*/*z* 347.0989.

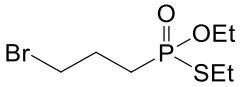
***O*-Ethyl *S*-(naphthalen-2-yl) phenethylphosphonothioate (3f)**



Prepared according to general procedure C; 61% yield; **^{1}H NMR (400 MHz, $CDCl_3$)**: δ 8.10 (s, 1H), 7.81-7.88 (m, 3H), 7.53-7.64 (m, 3H), 7.13-7.30 (m, 5H), 4.26-4.45 (m, 2H), 2.93-3.09 (m, 2H), 2.19-2.28 (m, 2H), 1.42 (t, *J* = 7.2 Hz, 3H); **^{13}C NMR (150 MHz, $CDCl_3$):** δ **^{13}C NMR (100 MHz, $CDCl_3$):** δ 140.5 (d , *J* = 9.0 Hz), 135.0 (d, *J* = 5.0 Hz), 133.7 (d, *J* = 2.0 Hz), 133.1 (d, *J* = 1 Hz), 131.4 (d, *J* = 3.0 Hz), 129.2 (d, *J* = 1.0 Hz), 128.6, 128.1, 127.8 (d, *J* = 1.0 Hz), 127.7 (d, *J* = 1Hz), 127.2 (d, *J* = 1.0 Hz), 126.9, 126.4, 124.3 (d, *J* = 6.0 Hz), 61.9 (d, *J* = 8.0 Hz), 33.8, 32.8, 28.3 (d, *J* = 4.0 Hz), 16.3, 16.2; **^{31}P NMR (162 MHz, $CDCl_3$):** δ 54.1; **IR (neat) ν_{max}:**

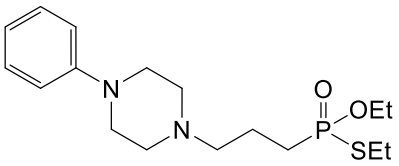
1498, 1454, 1267, 1231, 1030, 958, 941, 860, 958, 941, 699; **HRMS (ESI+):** exact mass calculated for $[M+H]^+$ ($C_{20}H_{22}O_2PS$) requires *m/z* 357.1073, found *m/z* 357.1066.

***O,S*-Diethyl (3-bromopropyl)phosphonothioate (3g)**



Prepared according to general procedure C; 75% yield; **^{1}H NMR (400 MHz, $CDCl_3$)**: δ 4.27 – 4.04 (m, 2H), 3.50 (t, *J* = 6.3 Hz, 2H), 2.96 – 2.81 (m, 2H), 2.29 – 2.18 (m, 2H), 2.17 – 2.07 (m, 2H), 1.38 (t, *J* = 6.9 Hz, 2H), 1.34 (t, J = 6.5 Hz, 2H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 61.5 (d, *J* = 7.2 Hz), 33.1 (d, *J* = 55.8 Hz), 32.7 (d, *J* = 183.4 Hz), 25.9 (d, *J* = 3.5 Hz), 25.2 (d, *J* = 3.2 Hz), 17.0 (d, *J* = 4.7 Hz), 16.4 (d, *J* = 6.9 Hz); **^{31}P NMR (243 MHz, $CDCl_3$):** δ 55.6; **IR (neat) ν_{max}:** 2955, 2923, 2852, 1659, 1633, 1467, 1264, 1213, 1160, 1030, 959, 751, 639, 590; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_7H_{16}NaO_2PSBr$) requires *m/z* 298.9669, found *m/z* 298.9661.

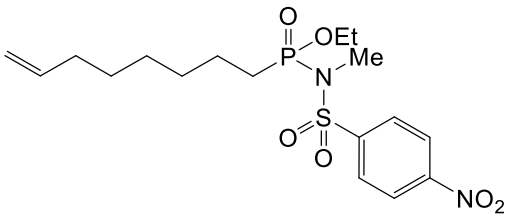
***O,S*-Diethyl (3-(4-phenylpiperazin-1-yl)propyl)phosphonothioate (9)**



Prepared according the method reported by Lewkowski *et al.*;[10] 88% yield; **^{1}H NMR (400 MHz, $CDCl_3$)**: δ 7.30 – 7.21 (m, 3H), 6.93 (dd, J = 8.8, 1.0 Hz, 2H), 6.90 – 6.81 (m, 1H), 4.29 – 4.03 (m, 2H), 3.29 – 3.12 (m, 4H), 2.96 – 2.79 (m, 2H), 2.61 (dd, J = 5.8, 4.2 Hz, 4H), 2.48 (t, J = 7.1 Hz, 2H), 2.10 – 1.99 (m, 2H), 1.96 – 1.81 (m, 2H), 1.61 (d, J = 6.7 Hz, 2H), 1.43 – 1.29 (m, 6H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 151.5, 129.3, 119.8, 116.2, 61.3 (d, *J* = 7.3 Hz), 58.4 (d, *J* = 18.4 Hz), 53.2, 49.3, 31.4 (d, *J* = 107.9 Hz), 25.1 (d, *J* = 3.1 Hz), 19.9 (d, *J* = 4.0 Hz), 17.1 (d, *J* = 5 Hz), 16.4 (d, *J* = 7 Hz); **^{31}P NMR (243 MHz, $CDCl_3$):** δ 57.4; **IR (neat) ν_{max}:** 2930, 2818, 2358, 1718, 1599, 1578, 1498, 1453, 1379, 1353, 1306, 1265, 1233, 1158, 1139, 1101, 1025, 954, 758, 693, 647, 582, 527, 462, 435, 416; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{17}H_{29}NaN_2O_2PS$) requires *m/z* 379.1585, found *m/z* 379.1565.

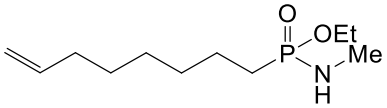
5.4. Amines and amides as nucleophiles: preparation of phosphonamidates

Ethyl *N*-methyl-*N*-((4-nitrophenyl)sulfonyl)-*P*-(oct-7-en-1-yl)phosphonamidate (4a)



Prepared according to general procedure C; 72% yield; **^{1}H NMR (600 MHz, $CDCl_3$)**: δ 8.38 (d, *J* = 8.9 Hz, 2H), 8.19 (d, *J* = 8.9 Hz, 2H), 5.80 (ddt, *J* = 16.9, 10.2, 6.7 Hz, 1H), 5.03 – 4.91 (m, 2H), 4.15 – 4.05 (m, 1H), 3.85 – 3.76 (m, 1H), 3.08 (d, *J* = 6.8 Hz, 3H), 2.19 – 2.11 (m, 2H), 2.07 – 2.01 (m, 2H), 1.69 – 1.58 (m, 2H), 1.46 – 1.37 (m, 4H), 1.35 – 1.31 (m, 2H), 1.29 (t, *J* = 7.1 Hz, 3H); **^{13}C NMR (150 MHz, $CDCl_3$):** δ 150.6, 144.8, 139.0, 129.3, 124.4, 114.6, 62.3 (d, *J* = 7.0 Hz), 33.9, 33.8, 30.4 (d, *J* = 18.4 Hz), 29.3 (d, *J* = 128.7 Hz), 28.7, 28.7, 22.0 (d, *J* = 4.7 Hz), 16.3 (d, *J* = 6.3 Hz); **^{31}P NMR (243 MHz, $CDCl_3$):** δ 33.4; **IR (neat) ν_{max}:** 3106, 3072, 2978, 2929, 2856, 1640, 1607, 1530, 1462, 1350, 1311, 1245, 1168, 1090, 1025, 964, 868, 849, 784, 686, 647; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{17}H_{27}N_2NaO_6PS$) requires *m/z* 441.1220, found *m/z* 441.1219.

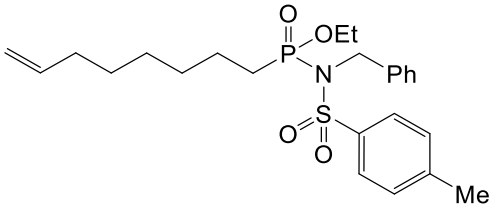
Ethyl *N*-methyl-*P*-(oct-7-en-1-yl)phosphonamidate (10)



To a solution of the nosyl protected phosphonamidate **4a** (0.03 mmol) in DMF (0.3 mL) was added dry potassium carbonate (3 eq.) and the thiophenol (2 eq.). After stirring 2 hours, the mixture was diluted with a saturated solution of ammonium chloride and ethyl acetate. After separation of the phases, the aqueous phase was extracted three times with ethyl acetate. The organic phases were combined and dried on magnesium sulfate. After filtration and evaporation, the crude was then purified by flash column chromatography on silica gel (dichloromethane/methanol); 75% yield; **^{1}H NMR (600 MHz, $CDCl_3$)**: δ 5.79 (ddt, *J* = 16.9, 10.2, 6.7 Hz, 1H), 5.03 – 4.88 (m, 2H), 4.11 – 4.01 (m, 1H), 4.01 – 3.91 (m, 1H), 2.59 (dd, *J* = 11.0, 4.6 Hz, 3H), 2.33 (br. s, 1H), 2.08 – 1.98 (m, 2H), 1.74 – 1.63 (m, 2H), 1.62 – 1.53 (m, 2H), 1.43 – 1.34 (m, 4H), 1.34 – 1.26 (m, 5H); **^{13}C NMR (150 MHz, $CDCl_3$):** δ 139.1, 114.4, 59.4 (d, *J* = 6.6 Hz), 33.8, 30.8, 30.7, 28.8, 27.4, 26.2 (d, *J* = 129.8 Hz), 22.4 (d, *J* = 4.1 Hz), 16.6 (d, *J* = 6.4 Hz); **^{31}P NMR (243 MHz, $CDCl_3$):** δ 36.8; **IR (neat) ν_{max}:** 3335, 3236, 3077, 2977, 2928, 2856, 1641, 1441, 1276, 1205, 1114, 1042, 952, 910,

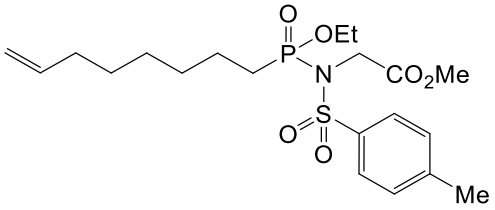
861, 804, 765, 750; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{11}H_{24}NNaO_2P$) requires *m*/*z* 256.1437, found *m*/*z* 256.1433.

Ethyl *N*-benzyl-*P*-(oct-7-en-1-yl)-*N*-tosylphosphonamidate (4b)



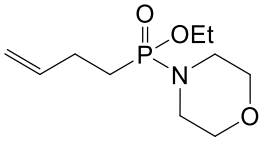
Prepared according to general procedure C; 65% yield; **^{1}H NMR (400 MHz, $CDCl_3$)**: δ 7.62 (d, *J* = 8.3 Hz, 2H), 7.45 – 7.37 (m, 2H), 7.26 – 7.21 (m, 3H), 7.18 (d, *J* = 8.1 Hz, 2H), 5.79 (ddt, *J* = 16.9, 10.2, 6.7 Hz, 1H), 5.02 – 4.91 (m, 2H), 4.72 (d, *J* = 9.3 Hz, 2H), 4.10 – 3.99 (m, 1H), 3.56 – 3.44 (m, 1H), 2.38 (s, 3H), 2.15 – 1.97 (m, 4H), 1.56 – 1.43 (m, 2H), 1.38 – 1.23 (m, 6H), 1.20 (t, *J* = 7.1 Hz, 3H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 144.1, 139.1, 137.7, 137.0, 129.4, 129.3, 128.3, 127.9, 127.8, 114.4, 61.9 (d, *J* = 7.0 Hz), 51.1, 33.8, 30.4 (d, *J* = 18.7 Hz), 30.1 (d, *J* = 128.5 Hz), 28.7, 28.6, 21.9 (d, *J* = 4.6 Hz), 21.6, 16.3 (d, *J* = 6.5 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 34.3; **IR (neat) ν_{max}:** 2968, 2855, 1599, 1496, 1456, 1348, 1245, 1164, 1091, 1023, 998, 833; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{24}H_{34}NNaO_4PS$) requires *m*/*z* 486.1838, found *m*/*z* 486.1842.

Methyl *N*-(ethoxy(oct-7-en-1-yl)phosphoryl)-*N*-tosylglycinate (4c)



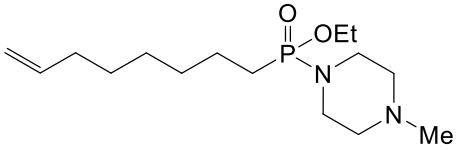
Prepared according to general procedure C; 80% yield; **^{1}H NMR (400 MHz, $CDCl_3$)**: δ 7.80 (d, *J* = 8.3 Hz, 2H), 7.32 (d, *J* = 8.0 Hz, 2H), 5.81 (ddt, *J* = 16.9, 10.2, 6.7 Hz, 1H), 5.03 – 4.90 (m, 2H), 4.40 – 4.08 (m, 3H), 3.82 – 3.72 (m, 1H), 3.62 (s, 3H), 2.44 (s, 3H), 2.33 – 2.22 (m, 2H), 2.09 – 1.99 (m, 2H), 1.73 – 1.59 (m, 2H), 1.48 – 1.31 (m, 6H), 1.28 (t, *J* = 7.1 Hz, 3H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 169.5, 144.8, 139.1, 136.5, 129.7, 128.2, 114.5, 62.3 (d, *J* = 7.5 Hz), 52.4, 47.9, 33.8, 30.5 (d, *J* = 14.1 Hz), 29.8 (d, *J* = 125.8 Hz), 28.8, 28.7, 22.0 (d, *J* = 4.8 Hz), 21.8, 16.3 (d, *J* = 6.9 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 33.7; **IR (neat) ν_{max}:** 2980, 2929, 2856, 1758, 1640, 1598, 1439, 1350, 1214, 1163, 1119, 1091, 1026, 965, 842, 816; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{20}H_{32}NNaO_6PS$) requires *m*/*z* 468.1580, found *m*/*z* 468.1586.

Ethyl but-3-en-1-yl(morpholino)phosphinate (4d)



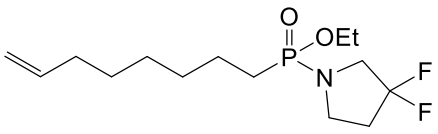
Prepared according to general procedure C; 77% yield; **^{1}H NMR (400 MHz, $CDCl_3$)**: δ 5.84 (ddt, *J* = 16.7, 10.2, 6.4 Hz, 1H), 5.11 – 4.91 (m, 2H), 4.15 – 3.99 (m, 1H), 3.99 – 3.84 (m, 1H), 3.63 (t, *J* = 4.6 Hz, 4H), 3.20 – 3.03 (m, 4H), 2.42 – 2.25 (m, 2H), 1.87 – 1.62 (m, 2H), 1.29 (t, *J* = 7.1 Hz, 3H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 137.6 (d, *J* = 17.3 Hz), 115.2, 67.5 (d, *J* = 4.7 Hz), 59.7 (d, *J* = 6.7 Hz), 44.2, 26.5 (d, *J* = 3.2 Hz), 25.2 (d, *J* = 130.2 Hz), 16.5 (d, *J* = 6.5 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 33.1; **IR (neat) ν_{max}:** 2978, 2914, 2853, 1642, 1449, 1392, 1257, 1225, 1210, 1136, 1032, 967, 914, 805, 774, 638; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{10}H_{20}NNaO_3P$) requires *m/z* 256.1073, found *m/z* 256.1064.

Ethyl (4-methylpiperazin-1-yl)(oct-7-en-1-yl)phosphinate (4e)



Prepared according to general procedure C; 76% yield; **^{1}H NMR (400 MHz, $CDCl_3$):** δ 5.78 (ddt, *J* = 16.9, 10.2, 6.7 Hz, 1H), 5.01 – 4.89 (m, 2H), 4.10 – 3.99 (m, 1H), 3.96 – 3.85 (m, 1H), 3.26 – 3.10 (m, 4H), 2.47 (bs, 4H), 2.37 (s, 3H), 2.07 – 1.98 (m, 2H), 1.74 – 1.59 (m, 2H), 1.59 – 1.46 (m, 2H), 1.39 – 1.24 (m, 9H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 139.0, 114.5, 60.0, 55.3 (d, *J* = 4.2 Hz, 2C), 46.2, 43.5 (2C), 33.8, 30.7 (d, *J* = 17.5 Hz), 28.8, 28.7, 26.0 (d, *J* = 131.0 Hz), 22.2 (d, *J* = 4.2 Hz), 16.3 (d, *J* = 6.8 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 34.5; **IR (neat) ν_{max}:** 2978, 2855, 1641, 1454, 1286, 1224, 1159, 1031, 972, 910, 729, 637; **HRMS (ESI+):** exact mass calculated for $[M+H]^+$ ($C_{15}H_{32}NO_2P$) requires *m/z* 303.2196, found *m/z* 303.2189.

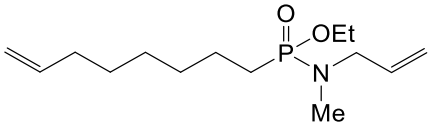
Ethyl (3,3-difluoropyrrolidin-1-yl)(oct-7-en-1-yl)phosphinate (4f)



Prepared according to general procedure C; 76% yield; **^{1}H NMR (400 MHz, $CDCl_3$):** δ 5.79 (ddt, *J* = 16.9, 10.2, 6.7 Hz, 1H), 5.01 – 4.95 (m, 1H), 4.95 – 4.90 (m, 1H), 4.13 – 4.04 (m, 1H), 3.98 – 3.87 (m, 1H), 3.52 – 3.34 (m, 4H), 2.37 – 2.23 (m, 2H), 2.06 – 1.99 (m, 2H), 1.76 – 1.63 (m, 2H), 1.63 – 1.49 (m, 2H), 1.41 – 1.27 (m, 9H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 139.0, 129.2 (td, *J* = 249.1, 10.4 Hz), 114.5, 60.1 (d, *J* = 6.9 Hz), 53.3

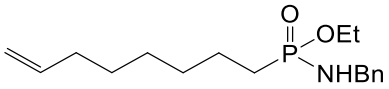
(td, *J* = 31.9, 4.6 Hz), 44.2 (d, *J* = 3.4 Hz), 35.2 (td, *J* = 24.4, 5.1 Hz), 33.8, 30.7 (d, *J* = 17.0 Hz), 28.8, 28.7, 25.7 (d, *J* = 131.1 Hz), 22.0 (d, *J* = 4.5 Hz), 16.4 (d, *J* = 6.5 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 33.1; **^{19}F NMR (565 MHz, $CDCl_3$):** δ -100.1 (dp, *J* = 230.3, 13.3 Hz), -100.6 (dp, *J* = 230.4, 13.0 Hz); **IR (neat) ν_{max}:** 2929, 1641, 1441, 1393, 1223, 1160, 1121, 1030, 957, 9817, 638; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{14}H_{26}F_2NNaO_2P$) requires *m*/*z* 332.1561, found *m*/*z* 332.1559.

Ethyl *N*-allyl-*N*-methyl-*P*-(oct-7-en-1-yl)phosphonamidate (4g)



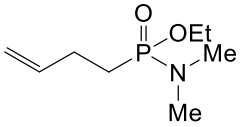
Prepared according to general procedure C; 33% yield; **^{1}H NMR (400 MHz, $CDCl_3$):** δ 5.84 – 5.67 (m, 2H), 5.23 – 5.13 (m, 2H), 5.02 – 4.94 (m, 1H), 4.94 – 4.89 (m, 1H), 4.08 – 3.97 (m, 1H), 3.90 – 3.80 (m, 1H), 3.66 – 3.52 (m, 2H), 2.58 (d, *J* = 8.9 Hz, 3H), 2.06 – 1.98 (m, 2H), 1.75 – 1.51 (m, 4H), 1.39 – 1.25 (m, 9H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 139.1, 135.0 (d, *J* = 2.9 Hz), 117.5, 114.4, 59.2 (d, *J* = 6.8 Hz), 51.2 (d, *J* = 4.2 Hz), 33.8, 32.8, 30.7 (d, *J* = 16.9 Hz), 28.8, 28.8 (d, *J* = 0.9 Hz), 26.1 (d, *J* = 130.8 Hz), 22.3 (d, *J* = 4.3 Hz), 16.4 (d, *J* = 6.6 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 36.5; **IR (neat) ν_{max}:** 2928, 2854, 1641, 1444, 1217, 1164, 1034, 948, 933, 811, 782; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{14}H_{28}NNaO_2P$) requires *m*/*z* 296.1750, found *m*/*z* 196.1738.

Ethyl *N*-benzyl-*P*-(oct-7-en-1-yl)phosphonamidate (4h)



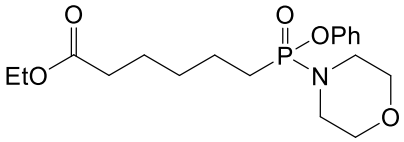
Prepared according to general procedure C; 66% yield; **^{1}H NMR (400 MHz, $CDCl_3$):** δ 7.39 – 7.28 (m, 5H), 5.79 (ddt, *J* = 16.9, 10.2, 6.7 Hz, 1H), 5.02 – 4.95 (m, 1H), 4.95 – 4.91 (m, 1H), 4.08 – 3.96 (m, 3H), 3.92 – 3.85 (m, 1H), 3.68 (bs, 1H), 2.05 – 1.96 (m, 2H), 1.67 – 1.55 (m, 2H), 1.54 – 1.41 (m, 2H), 1.35 – 1.18 (m, 9H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 139.7 (d, *J* = 4.8 Hz), 139.1, 128.7 (2C), 127.5, 127.3 (2C), 114.4, 60.1 (d, *J* = 6.5 Hz), 44.7 (d, *J* = 16.7 Hz), 33.8, 30.7 (d, *J* = 17.9 Hz), 28.8, 28.7, 26.6 (d, *J* = 131.0 Hz), 22.1 (d, *J* = 4.0 Hz), 16.3 (d, *J* = 6.7 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 36.9; **IR (neat) ν_{max}:** 2978, 1640, 1454, 1244, 1166, 1029, 960, 698, 638; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{17}H_{28}NNaO_2P$) requires *m*/*z* 332.1750, found *m*/*z* 332.1739.

Ethyl *P*-(but-3-en-1-yl)-*N*,*N*-dimethylphosphonamidate (4i)



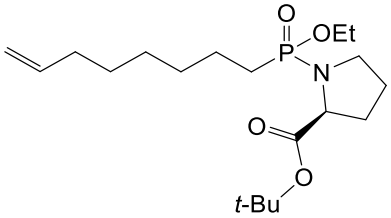
Prepared according to general procedure C (tetrabutylammonium chloride was used instead of tetraethylammonium; extraction with dichloromethane); 29% yield; **^{1}H NMR (400 MHz, $CDCl_3$):** δ 5.84 (ddt, *J* = 16.7, 10.2, 6.4 Hz, 1H), 5.05 (ddd, *J* = 17.1, 3.3, 1.6 Hz, 1H), 4.98 (ddd, *J* = 10.1, 2.7, 1.3 Hz, 1H), 4.04 (ddq, *J* = 14.3, 10.2, 7.1 Hz, 1H), 3.88 (ddq, *J* = 14.2, 10.2, 7.1 Hz, 1H), 2.68 (d, *J* = 8.9 Hz, 6H), 2.43 – 2.23 (m, 2H), 1.82 – 1.68 (m, 2H), 1.29 (t, *J* = 7.1 Hz, 3H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 137.8 (d, *J* = 16.9 Hz), 114.8, 59.2 (d, *J* = 6.8 Hz), 36.1 (2C), 26.3 (d, *J* = 3.4 Hz), 24.7 (d, *J* = 130.4 Hz), 16.3(d, *J* = 6.6 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 36.0; **IR (neat) ν_{max}:** 2981, 2905, 1642, 1447, 1300, 1230, 1211, 1040, 990, 952, 809, 765, 750; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_8H_{18}NNaO_2P$) requires *m*/*z* 214.0973, found *m*/*z* 214.0968.

Ethyl 6-(morpholino(phenoxy)phosphoryl)hexanoate (6)



Prepared according to general procedure C; 45% yield; **^{1}H NMR (400 MHz, $CDCl_3$):** δ 7.30 (t, *J* = 7.9 Hz, 2H), 7.19 (d, *J* = 7.9 Hz, 2H), 7.12 (t, *J* = 7.3 Hz, 1H), 4.11 (q, *J* = 7.1 Hz, 2H), 3.55 – 3.41 (m, 4H), 3.19 – 3.07 (m, 4H), 2.30 (t, *J* = 7.4 Hz, 2H), 1.96 – 1.77 (m, 2H), 1.77 – 1.60 (m, 4H), 1.51 – 1.41 (m, 2H), 1.23 (t, *J* = 7.1 Hz, 3H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 173.6, 151.0 (d, *J* = 9.3 Hz), 129.8 (2C), 124.6, 120.4 (d, *J* = 5.0 Hz, 2C), 67.1 (d, *J* = 4.8 Hz, 2C), 60.4, 44.1 (2C), 34.1, 30.2 (d, *J* = 16.9 Hz), 26.0 (d, *J* = 132.8 Hz), 24.6, 22.0 (d, *J* = 4.4 Hz), 14.3; **^{31}P NMR (162 MHz, $CDCl_3$):** δ 32.1; **IR (neat) ν_{max}:** 2935, 2855, 1728, 1592, 1489, 1201, 1112, 970, 894, 764, 732, 692; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{18}H_{28}NNaO_5P$) requires *m*/*z* 392.1597, found *m*/*z* 392.1592.

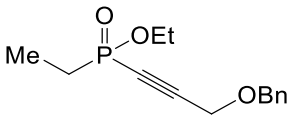
***tert*-Butyl (ethoxy(oct-7-en-1-yl)phosphoryl)-*L*-prolinate (8)**



Prepared according to general procedure C; 43% yield, d.r. 1:1.8; **^{1}H NMR (600 MHz, $CDCl_3$)**: δ 5.85 – 5.77 (m, 1H), 5.04 – 4.87 (m, 2H), 4.26 – 4.19 (m, 1H, dia2), 4.18 – 4.12 (m, 1H, dia1), 4.10 – 4.03 (m, 1H), 3.92 – 3.81 (m, 1H), 3.31 – 3.20 (m, 2H), 2.17 – 2.11 (m, 1H), 2.08 – 2.02 (m, 2H), 1.99 – 1.93 (m, 2H), 1.89 – 1.85 (m, 1H), 1.84 – 1.76 (m, 3H), 1.69 – 1.58 (m, 3H), 1.48 (s, 9H, dia1), 1.47 (s, 9H, dia2), 1.43 – 1.36 (m, 5H), 1.33 – 1.26 (m, 3H); **^{13}C NMR (150 MHz, $CDCl_3$):** δ 173.9 (dia1), 173.6 (dia2), 139.2 (dia2), 139.2 (dia1), 114.4 (dia2), 114.4 (dia1), 81.1 (dia2), 80.9 (dia1), 60.4 (d, *J* = 5.0 Hz), 59.8 (d, *J* = 6.5 Hz, dia1), 59.2 (d, *J* = 6.4 Hz, dia2), 46.8 (d, *J* = 3.7 Hz, dia2), 46.7 (d, *J* = 4.4 Hz, dia1), 33.9, 31.6 (d, *J* = 6.6 Hz, dia1), 31.4 (d, *J* = 6.3 Hz, dia2), 30.9 (d, *J* = 17.3 Hz, dia2), 30.8 (d, *J* = 16.7 Hz, dia1), 28.9, 28.8, 28.2 (dia2, 3C), 28.1 (dia1, 3C), 26.7 (d, *J* = 130.9 Hz, dia2), 26.4 (d, *J* = 131.4 Hz, dia1), 25.4 – 25.2 (m), 22.4 – 22.1 (m), 16.6 – 16.4 (m); **^{31}P NMR (243 MHz, $CDCl_3$):** δ 33.6, 33.1; **IR (neat) ν_{max}:** 2973, 2929, 2859, 1736, 1653, 1453, 1223, 1147, 1036, 952, 845, 812; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{10}H_{20}NNaO_3P$) requires *m*/*z* 396.2274, found *m*/*z* 396.2267.

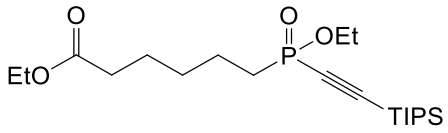
5.5. Alkynes as nucleophiles: preparation of phosphinates

Ethyl (3-(benzyloxy)prop-1-yn-1-yl)(ethyl)phosphinate (5a)



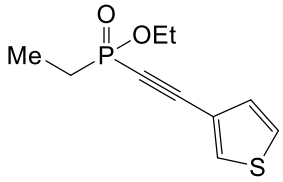
Prepared according to general procedure C; 57% yield; **^{1}H NMR (600 MHz, $CDCl_3$)**: δ 7.40 – 7.28 (m, 5H), 4.60 (s, 2H), 4.27 (d, *J* = 2.9 Hz, 2H), 4.26 – 4.18 (m, 1H), 4.17 – 4.09 (m, 1H), 1.94 – 1.80 (m, 2H), 1.37 (t, *J* = 7.1 Hz, 3H), 1.21 (dt, *J* = 21.6, 7.7 Hz, 3H); **^{13}C NMR (150 MHz, $CDCl_3$):** δ 136.8, 128.7, 128.3, 128.2, 97.6 (d, *J* = 32.1 Hz), 79.1 (d, *J* = 186.4 Hz), 72.3, 62.1 (d, *J* = 7.4 Hz), 57.2 (d, *J* = 2.3 Hz), 24.0 (d, *J* = 120.6 Hz), 16.4 (d, *J* = 6.8 Hz), 6.0 (d, *J* = 5.6 Hz); **^{31}P NMR (243 MHz, $CDCl_3$):** δ 24.4; **IR (neat) ν_{max}:** 3032, 2980, 2940, 2905, 2196, 1643, 1496, 1391, 1353, 1282, 1212, 1076, 1022, 1003, 957, 787, 751, 699; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{14}H_{19}NaO_3P$) requires *m*/*z* 289.0964, found *m*/*z* 289.0962.

Ethyl 6-(ethoxy((triisopropylsilyl)ethynyl)phosphoryl)hexanoate (5b)



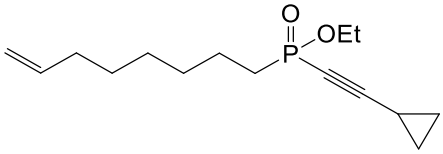
Prepared according to general procedure C; 90% yield; **^{1}H NMR (600 MHz, $CDCl_3$)**: δ 4.23 – 4.15 (m, 2H), 4.12 (q, *J* = 7.1 Hz, 2H), 2.29 (t, *J* = 7.5 Hz, 2H), 1.90 – 1.80 (m, 2H), 1.73 – 1.66 (m, 2H), 1.63 (dd, *J* = 15.3, 7.7 Hz, 2H), 1.50 – 1.42 (m, 2H), 1.36 (t, *J* = 7.1 Hz, 3H), 1.25 (t, *J* = 7.1 Hz, 3H), 1.13 – 1.06 (m, 21H); **^{13}C NMR (150 MHz, $CDCl_3$):** δ 173.7, 107.4 (d, *J* = 23.3 Hz), 99.7 (d, *J* = 172.3 Hz), 62.0 (d, *J* = 7.5 Hz), 60.4, 34.1, 30.8 (d, *J* = 118.3 Hz), 30.0 (d, *J* = 17.2 Hz), 24.6, 21.8 (d, *J* = 4.0 Hz), 18.6, 16.4 (d, *J* = 6.6 Hz), 14.4, 11.0; **^{31}P NMR (243 MHz, $CDCl_3$):** δ 21.5; **IR (neat) ν_{max}:** 2943, 2867, 2123, 1735, 1463, 1371, 1240, 1194, 1120, 1097, 1032, 998, 957, 883, 790, 708, 679, 587; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{21}H_{41}NaO_4PSi$) requires *m*/*z* 439.2404, found *m*/*z* 439.2399.

Ethyl ethyl(thiophen-3-ylethynyl)phosphinate (5c)



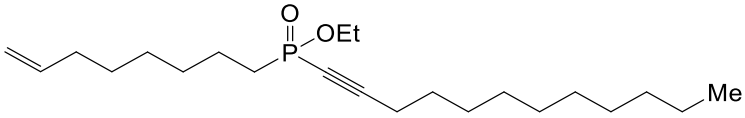
Prepared according to general procedure C; 47% yield; **^{1}H NMR (400 MHz, $CDCl_3$)**: 7.70 (dd, *J* = 3.0, 0.6 Hz, 1H), 7.32 (dd, *J* = 5.0, 3.0 Hz, 1H), 7.20 (dd, *J* = 5.0, 1.1 Hz, 1H), 4.32 – 4.12 (m, 2H), 1.92 (dq, *J* = 17.1, 7.7 Hz, 2H), 1.39 (t, *J* = 7.1 Hz, 3H), 1.25 (dt, *J* = 21.5, 7.7 Hz, 3H); **^{13}C NMR (150 MHz, $CDCl_3$):** δ 133.2 (d, *J* = 2.0 Hz), 130.1, 126.3, 119.3 (d, *J* = 4.4 Hz), 95.7 (d, *J* = 35.6 Hz), 81.0 (d, *J* = 192.4 Hz), 62.0 (d, *J* = 7.4 Hz), 24.2 (d, *J* = 121.1 Hz), 16.4 (d, *J* = 6.9 Hz), 6.1 (d, *J* = 5.6 Hz); **^{31}P NMR (243 MHz, $CDCl_3$):** δ 25.3; **IR (neat) ν_{max}:** 2978, 2924, 2856, 2169, 1656, 1458, 1395, 1360, 1259, 1208, 1160, 1030, 952, 874, 787, 772, 697, 668, 638, 604; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{10}H_{13}NaO_2PS$) requires *m*/*z* 251.0272, found *m*/*z* 251.0265.

Ethyl (cyclopropylethynyl)(oct-7-en-1-yl)phosphinate (5d)



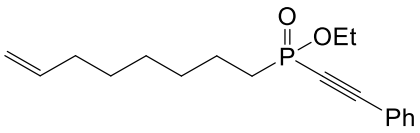
Prepared according to general procedure C; 68% yield; **^{1}H NMR (600 MHz, $CDCl_3$)**: δ 5.79 (ddt, *J* = 16.9, 10.2, 6.7 Hz, 1H), 5.05 – 4.85 (m, 2H), 4.20 – 4.11 (m, 1H), 4.12 – 3.99 (m, 1H), 2.08 – 1.99 (m, 2H), 1.83 – 1.73 (m, 2H), 1.66 – 1.57 (m, 2H), 1.43 – 1.29 (m, 10H), 0.95 – 0.90 (m, 2H), 0.89 – 0.84 (m, 2H); **^{13}C NMR (150 MHz, $CDCl_3$):** δ 139.1, 114.5 (d, *J* = 4.6 Hz), 107.0 (d, *J* = 36.9 Hz), 68.4 (d, *J* = 198.9 Hz), 61.6 (d, *J* = 7.3 Hz), 33.8, 31.0 (d, *J* = 119.2 Hz), 30.4 (d, *J* = 17.4 Hz), 28.8, 28.7, 21.9 (d, *J* = 4.3 Hz), 16.4 (d, *J* = 6.9 Hz), 9.3 (dd, *J* = 2.9, 1.1 Hz), -0.0 (d, *J* = 4.1 Hz); **^{31}P NMR (243 MHz, $CDCl_3$):** δ 23.2; **IR (neat) ν_{max}:** 2979, 2929, 2856, 2191, 1640, 1456, 1229, 1031, 957, 836; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{15}H_{25}NaO_2P$) requires *m*/*z* 291.1484, found *m*/*z* 291.1479.

Ethyl dodec-1-yn-1-yl(oct-7-en-1-yl)phosphinate (5e)



Prepared according to general procedure C; 59% yield; **^{1}H NMR (400 MHz, $CDCl_3$)**: δ 5.77 (ddt, *J* = 16.9, 10.2, 6.7 Hz, 1H), 5.03 – 4.84 (m, 2H), 4.22 – 4.00 (m, 2H), 2.36 – 2.23 (m, 2H), 2.06 – 1.98 (m, 2H), 1.83 – 1.74 (m, 2H), 1.67 – 1.50 (m, 4H), 1.42 – 1.21 (m, 23H), 0.86 (t, *J* = 6.9 Hz, 3H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 139.0, 114.4, 104.3 (d, *J* = 35.5 Hz), 73.6 (d, *J* = 197.1 Hz), 61.6 (d, *J* = 7.2 Hz), 33.8, 32.0, 31.0 (d, *J* = 111.4 Hz), 30.4, 30.3, 29.6, 29.6, 29.4, 29.1, 28.81 (d, *J* = 18.6 Hz), 28.7, 27.7, 22.8, 21.9 (d, *J* = 4.0 Hz), 19.4 (d, *J* = 2.6 Hz), 16.4 (d, *J* = 6.8 Hz), 14.2; **^{31}P NMR (162 MHz, $CDCl_3$):** δ 23.1; **IR (neat) ν_{max}:** 2924, 2854, 2195, 1640, 1463, 1240, 1035, 956, 909, 717; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{22}H_{41}NaO_2P$) requires *m*/*z* 391.2736, found *m*/*z* 391.2734.

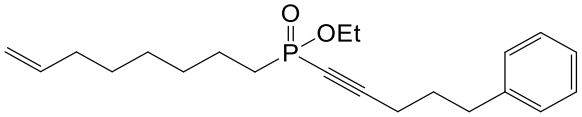
Ethyl oct-7-en-1-yl(phenylethynyl)phosphinate (5f)



Prepared according to general procedure C; 62% yield; **^{1}H NMR (600 MHz, $CDCl_3$)**: δ 7.56 – 7.51 (m, 2H), 7.47 – 7.41 (m, 1H), 7.39 – 7.34 (m, 2H), 5.78 (ddt, *J* = 16.9, 10.2, 6.7 Hz, 1H), 5.00 – 4.89 (m, 2H), 4.30 –

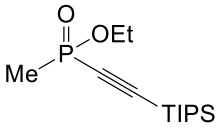
4.14 (m, 2H), 2.07 – 2.00 (m, 2H), 1.95 – 1.88 (m, 2H), 1.74 – 1.67 (m, 2H), 1.47 – 1.31 (m, 9H); **^{13}C NMR (150 MHz, $CDCl_3$):** δ 139.0, 132.7 (d, *J* = 1.8 Hz), 130.6, 128.7, 120.0 (d, *J* = 3.8 Hz), 114.5, 100.3 (d, *J* = 35.0 Hz), 81.5 (d, *J* = 191.7 Hz), 62.0 (d, *J* = 7.3 Hz), 33.8, 31.0 (d, *J* = 119.2 Hz), 30.4 (d, *J* = 17.3 Hz), 28.7, 28.7, 21.9 (d, *J* = 4.0 Hz), 16.4 (d, *J* = 6.8 Hz); **^{31}P NMR (243 MHz, $CDCl_3$):** δ 23.6; **IR (neat) ν_{max}:** 2978, 2929, 2856, 2179, 1640, 1490, 1461, 1443, 1393, 1240, 1033, 959, 848, 759; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{18}H_{25}NaO_2P$) requires *m*/*z* 327.1484, found *m*/*z* 327.1479.

Ethyl oct-7-en-1-yl(5-phenylpent-1-yn-1-yl)phosphinate (5g)



Prepared according to general procedure C; 83% yield; **^{1}H NMR (400 MHz, $CDCl_3$)**: δ 7.32 – 7.27 (m, 2H), 7.24 – 7.14 (m, 3H), 5.88 – 5.71 (m, 1H), 5.04 – 4.86 (m, 2H), 4.28 – 4.02 (m, 2H), 2.73 (t, *J* = 7.5 Hz, 2H), 2.34 (td, *J* = 7.1, 3.4 Hz, 2H), 2.03 (q, *J* = 6.9 Hz, 2H), 1.95 – 1.77 (m, 4H), 1.73 – 1.59 (m, 2H), 1.46 – 1.28 (m, 9H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 140.9, 139.1, 128.6 (d, *J* = 5.3 Hz), 126.4, 114.5, 103.5 (d, J = 35.5 Hz), 74.2 (d, *J* = 195.8 Hz), 61.7 (d, *J* = 7.4 Hz), 34.8, 33.8, 31.0 (d, *J* = 130.8 Hz), 30.5, 29.3, 28.7 (d, *J* = 4.6 Hz), 21.9 (d, *J* = 4.3 Hz), 18.8, 16.4 (d, *J* = 6.9 Hz); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 23.0; **IR (neat) ν_{max}:** 452, 3064, 3027, 2978, 2928, 2856, 2195, 1640, 1603, 1496, 1455, 1393, 1350, 1236, 1162, 1098, 1034, 957, 910, 850, 805, 748, 701, 618; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{21}H_{31}NaO_2P$) requires *m*/*z* 369.1959, found *m*/*z* 369.1950.

Ethyl methyl((triisopropylsilyl)ethynyl)phosphinate (5h)



Prepared according to general procedure C on 1 mmol scale; 40% yield; **^{1}H NMR (400 MHz, $CDCl_3$):** δ 4.25 – 4.06 (m, 2H), 1.64 (d, *J* = 16.6 Hz, 3H), 1.35 (t, *J* = 7.1 Hz, 3H), 1.14 – 1.04 (m, 21H); **^{13}C NMR (100 MHz, $CDCl_3$):** δ 106.8 (d, *J* = 25.5 Hz), 100.5 (d, *J* = 178.7 Hz), 61.9 (d, *J* = 7.0 Hz), 18.5 (6C), 17.9 (d, *J* = 121.8 Hz), 16.3 (d, *J* = 6.9 Hz), 11.0 (3C); **^{31}P NMR (162 MHz, $CDCl_3$):** δ 16.8; **IR (neat) ν_{max}:** 2945, 1867, 1464, 1305, 1239, 1037, 962, 884, 797, 776; **HRMS (ESI+):** exact mass calculated for $[M+Na]^+$ ($C_{14}H_{29}NaO_2PSi$) requires *m*/*z* 311.1572, found *m*/*z* 311.1561.

6 References

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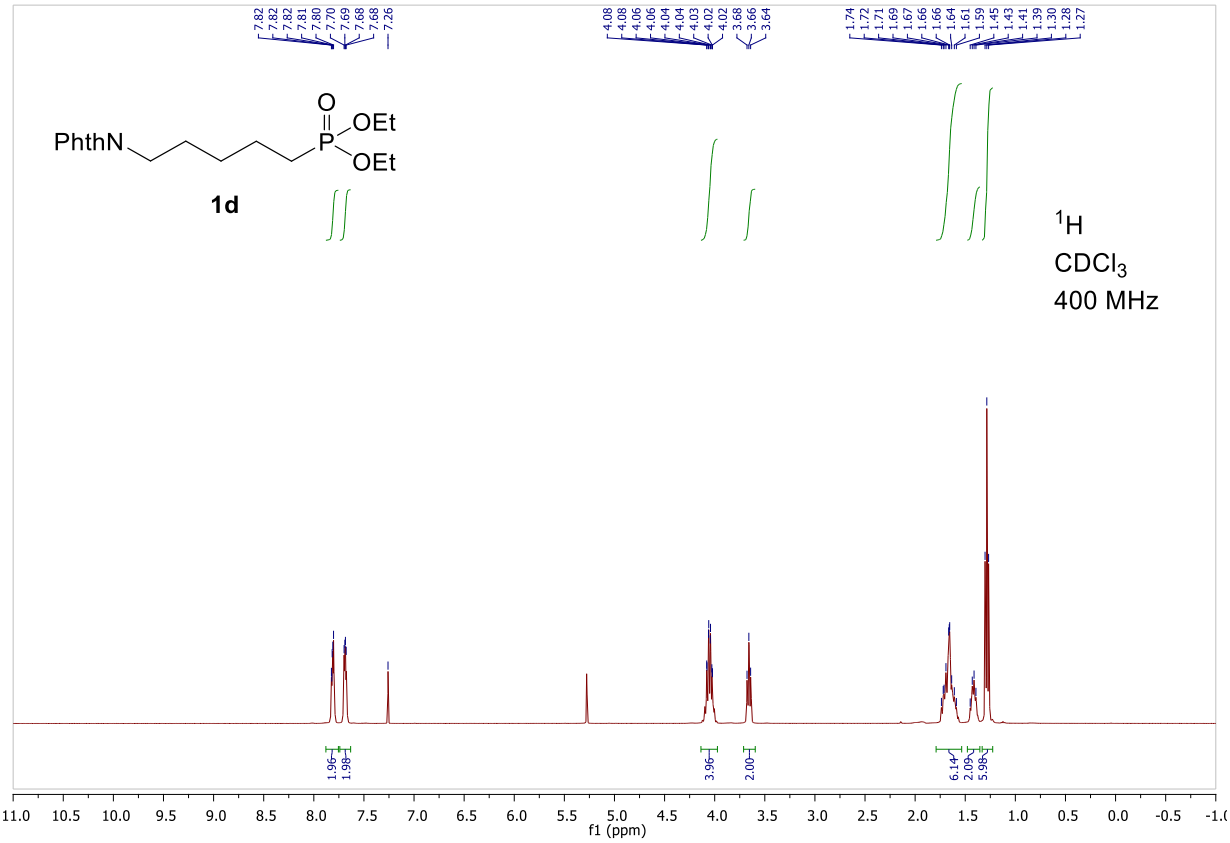
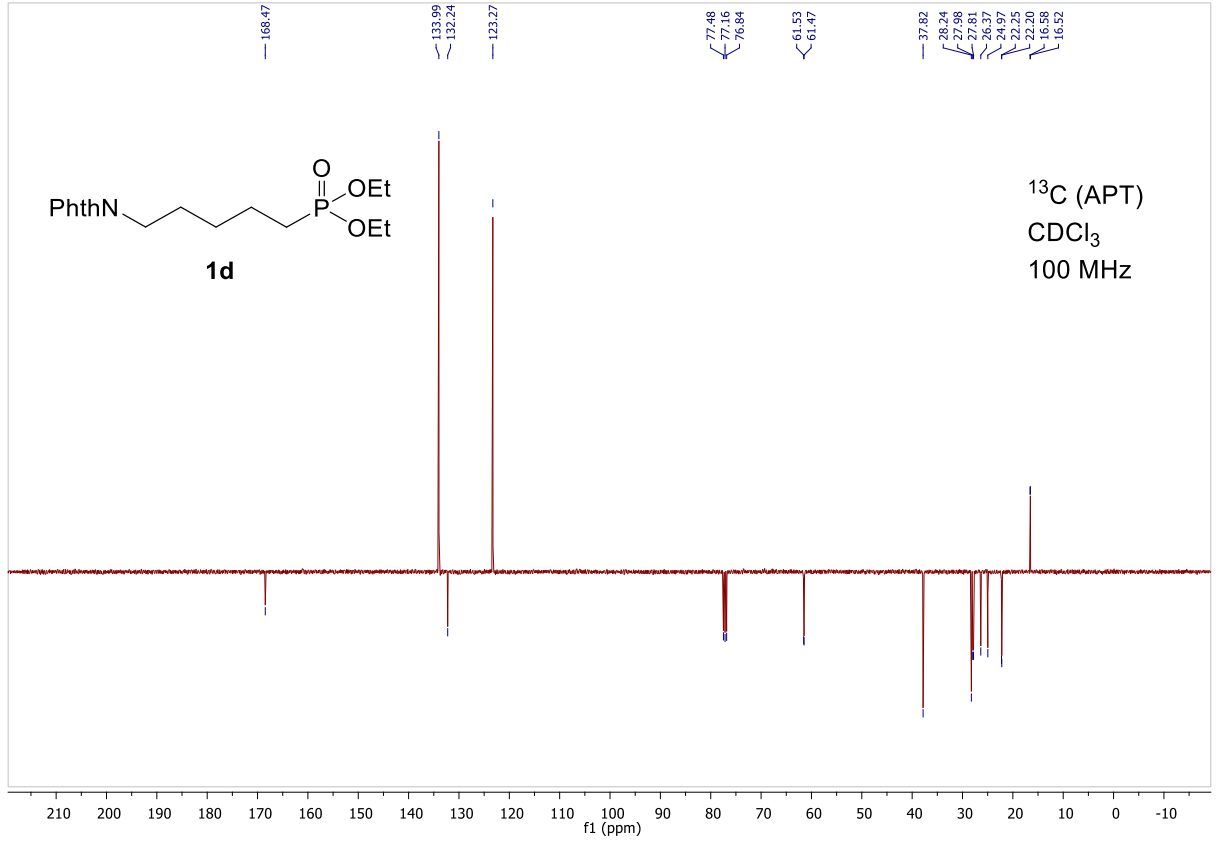
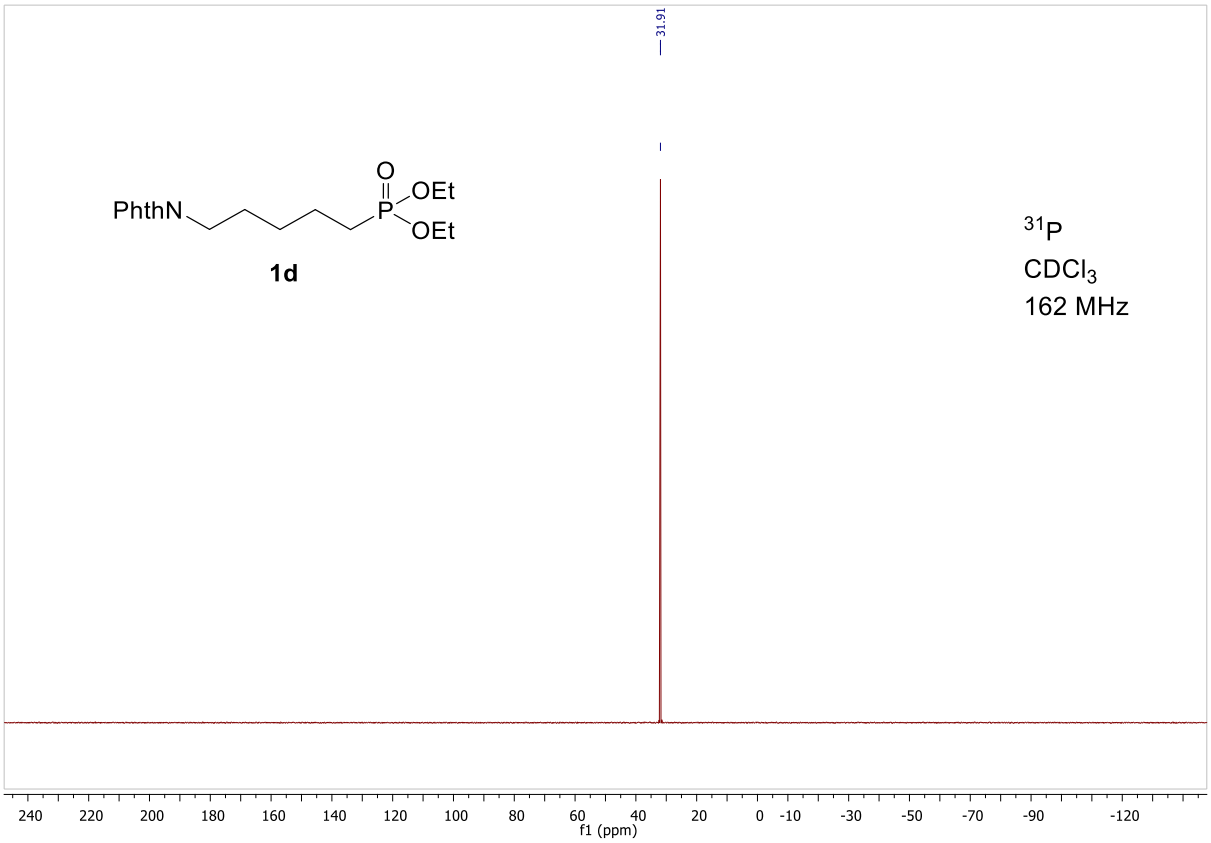
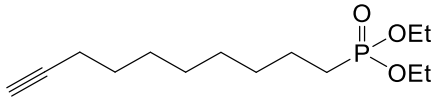
7 NMR spectra


PhthN
O
OEt
P
OEt
1d
^{1}H
$CDCl_3$
400 MHz
f1 (ppm)

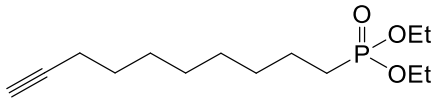

PhthN
O
OEt
P
OEt
1d
^{13}C (APT)
$CDCl_3$
100 MHz
f1 (ppm)


31.91
PhthN
O
OEt
P
OEt
1d
31P
CDCl3
162 MHz
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)



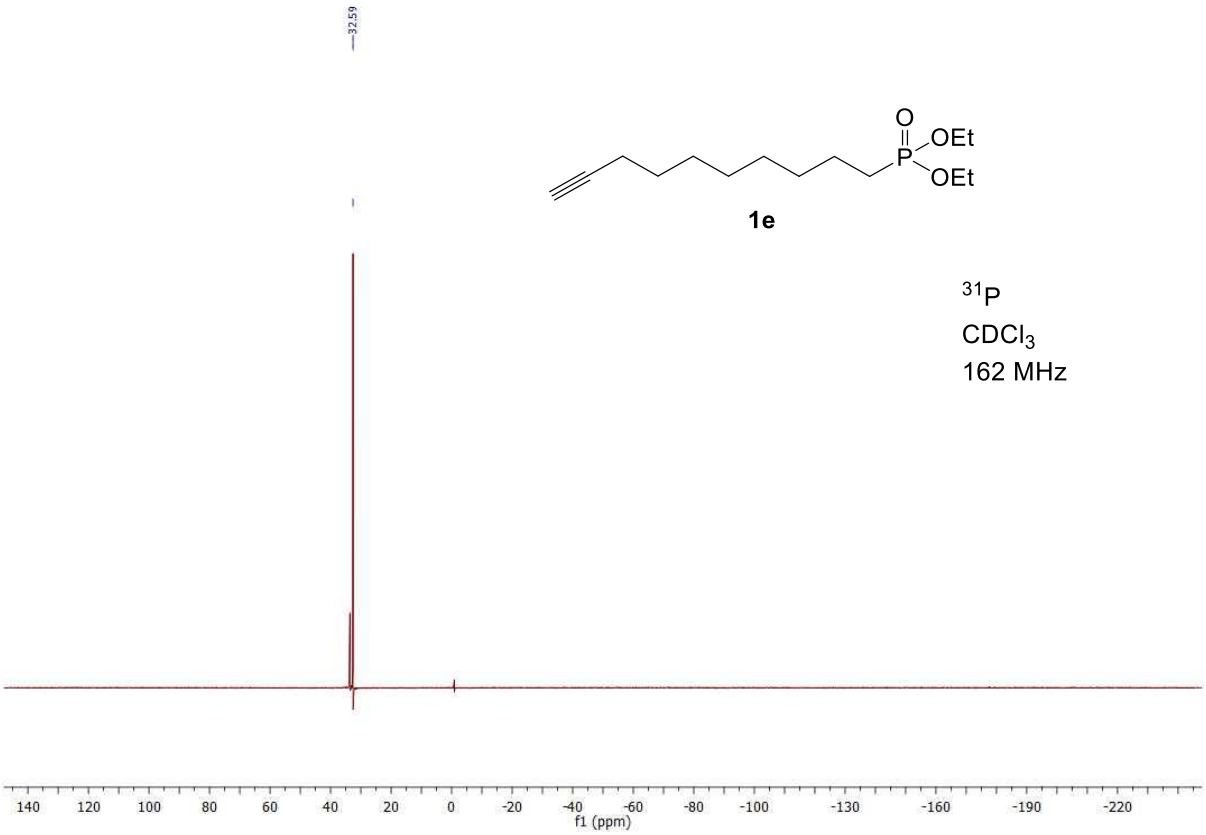
1e

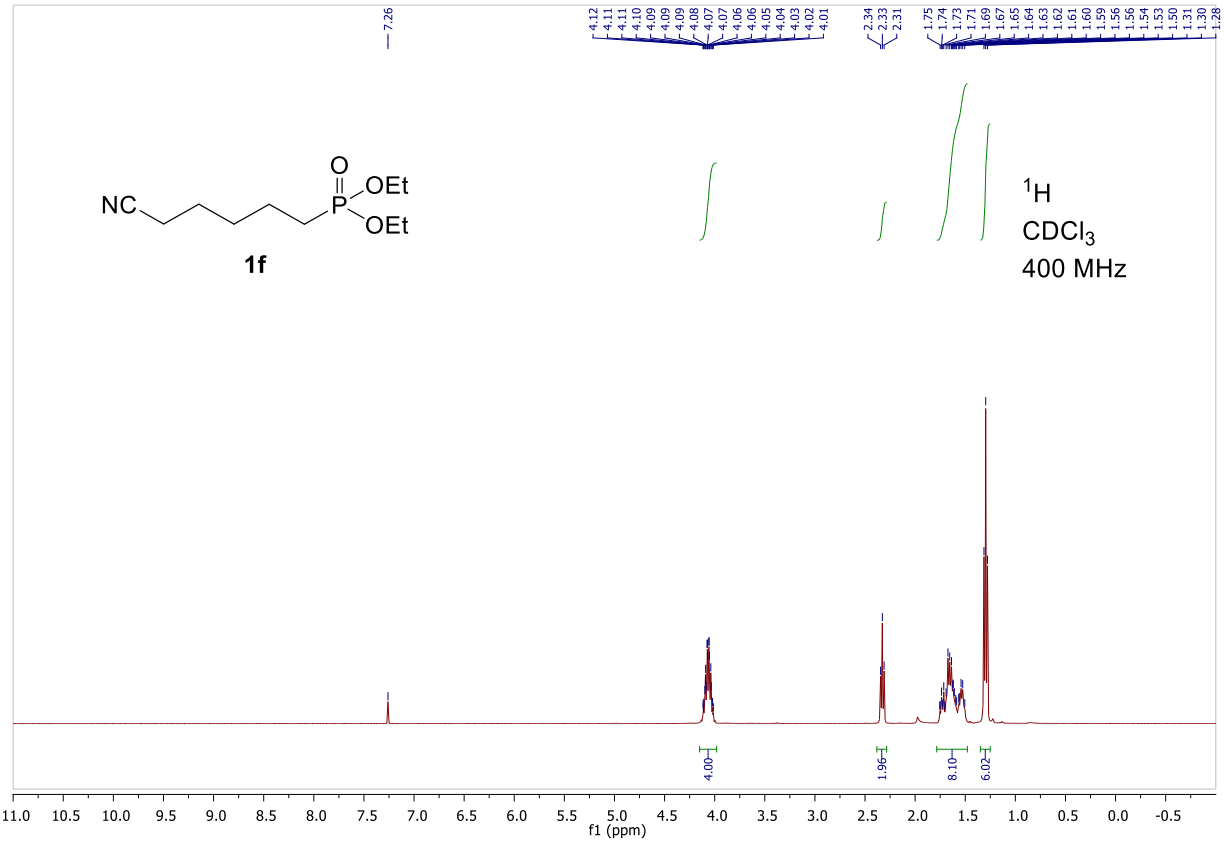
^{1}H
$CDCl_3$
600 MHz

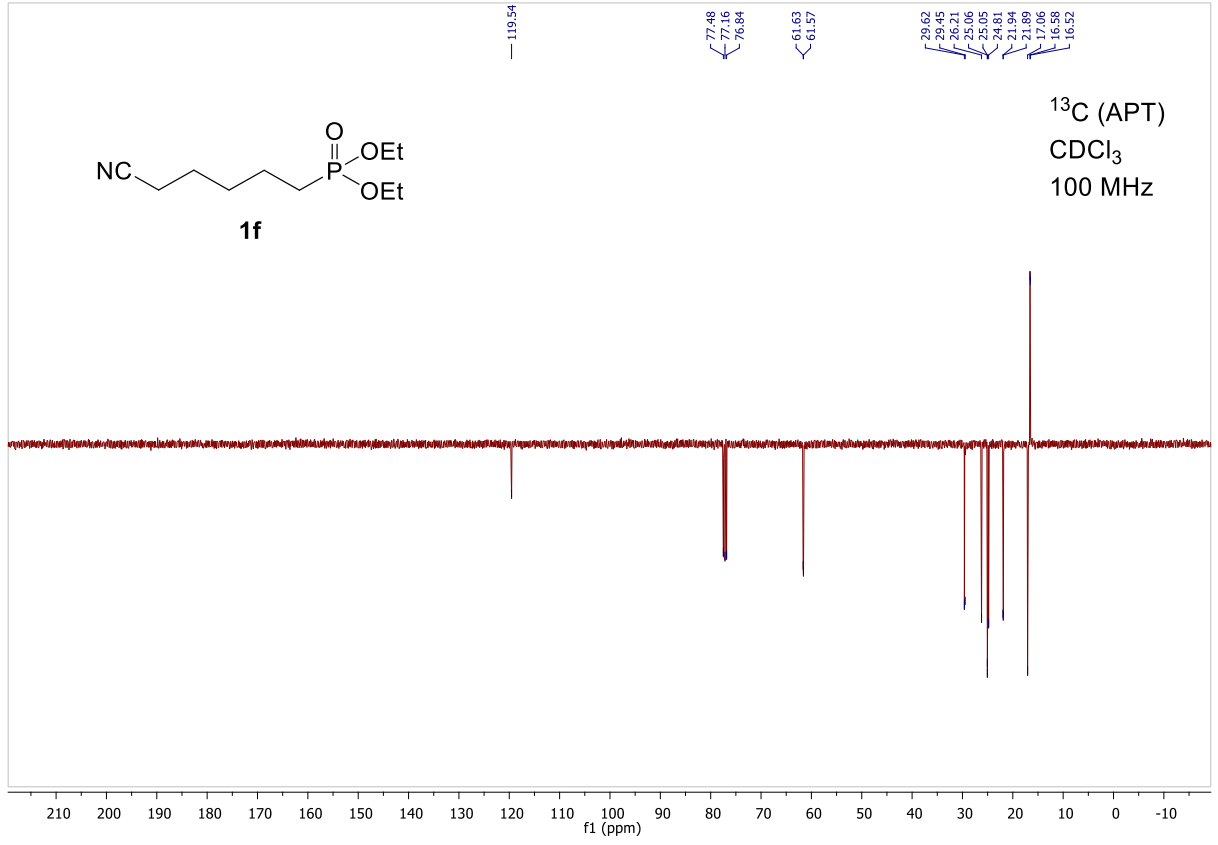


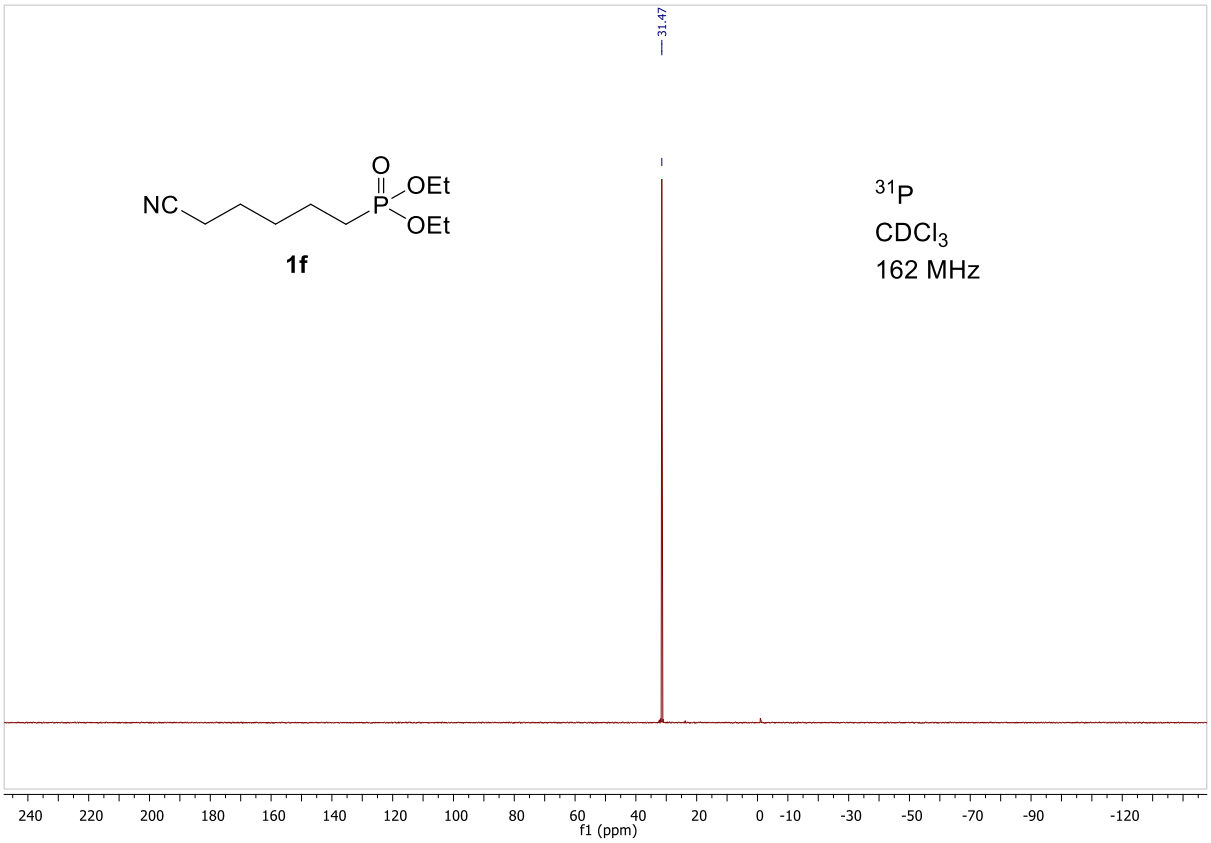
1e

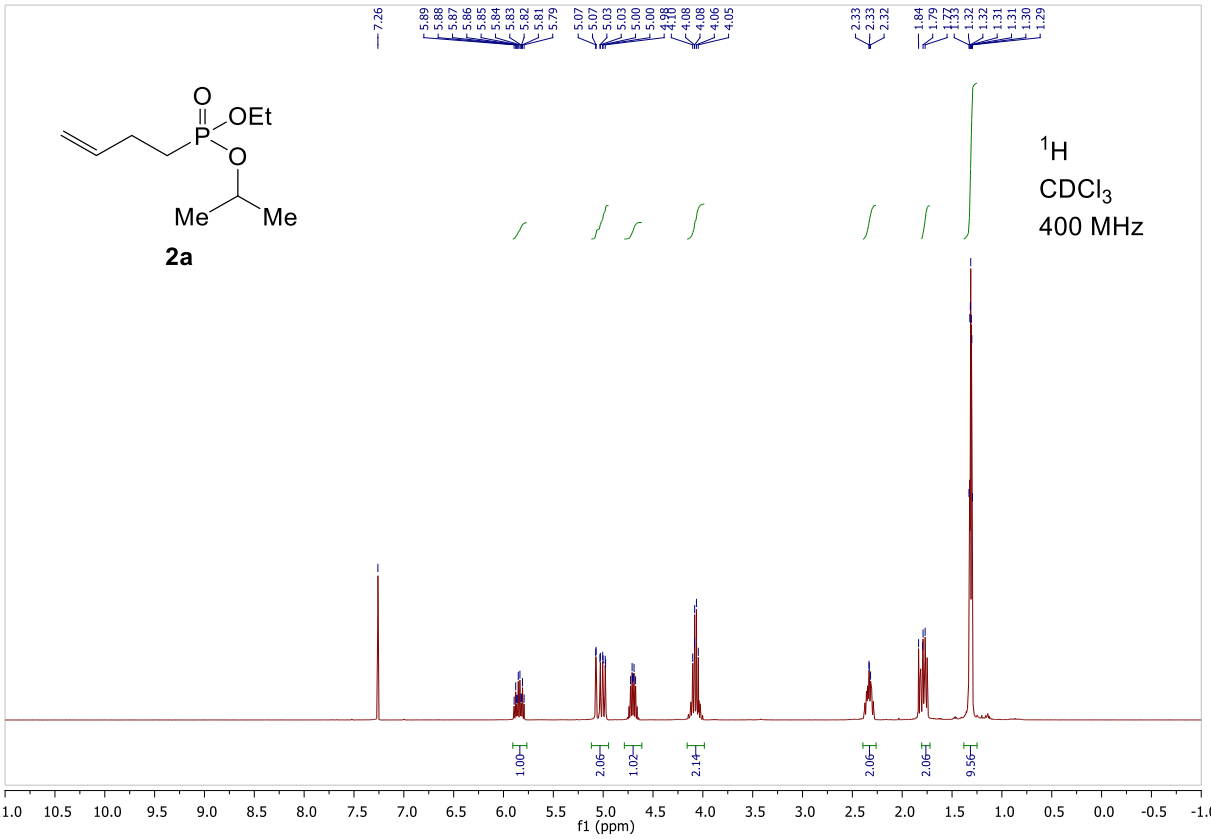
^{13}C (APT)
$CDCl_3$
150 MHz

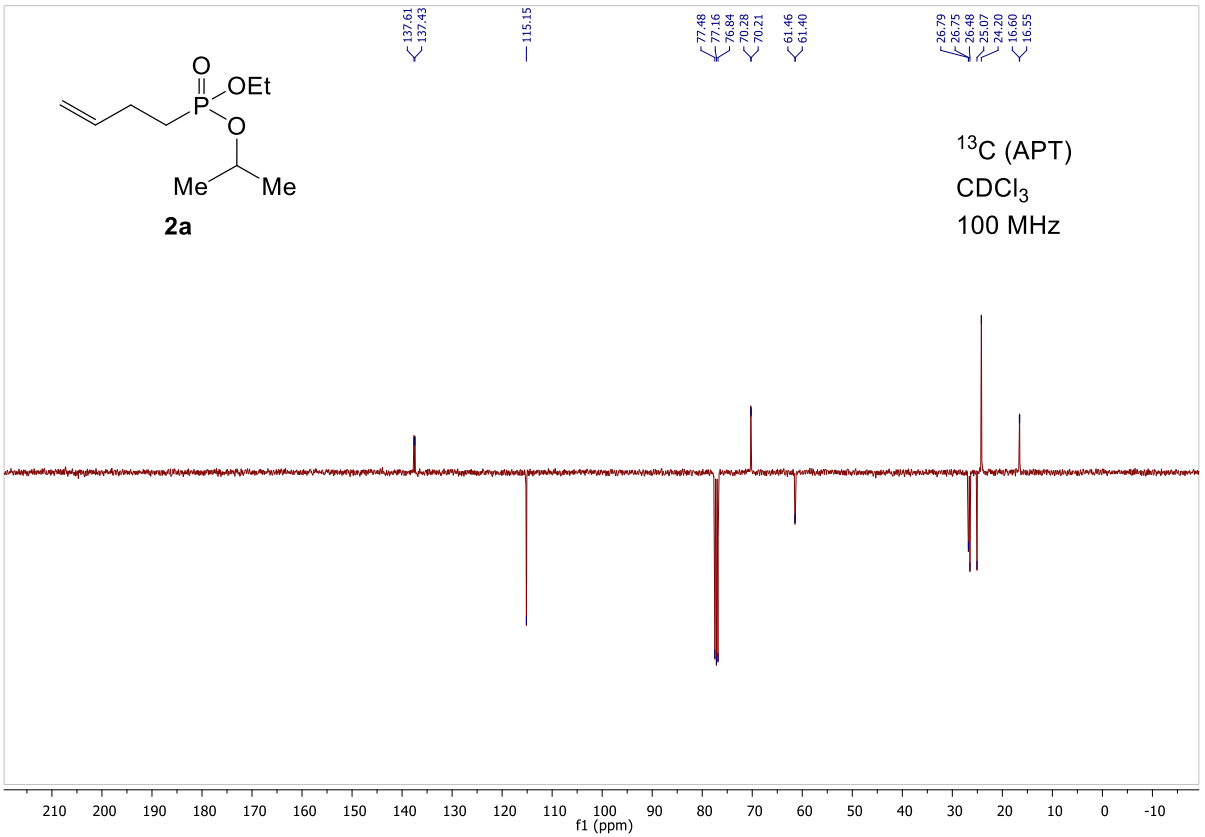

32.59
O
OEt
P
OEt
1e
31P
CDCl3
162 MHz
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-130
-160
-190
-220
f1 (ppm)

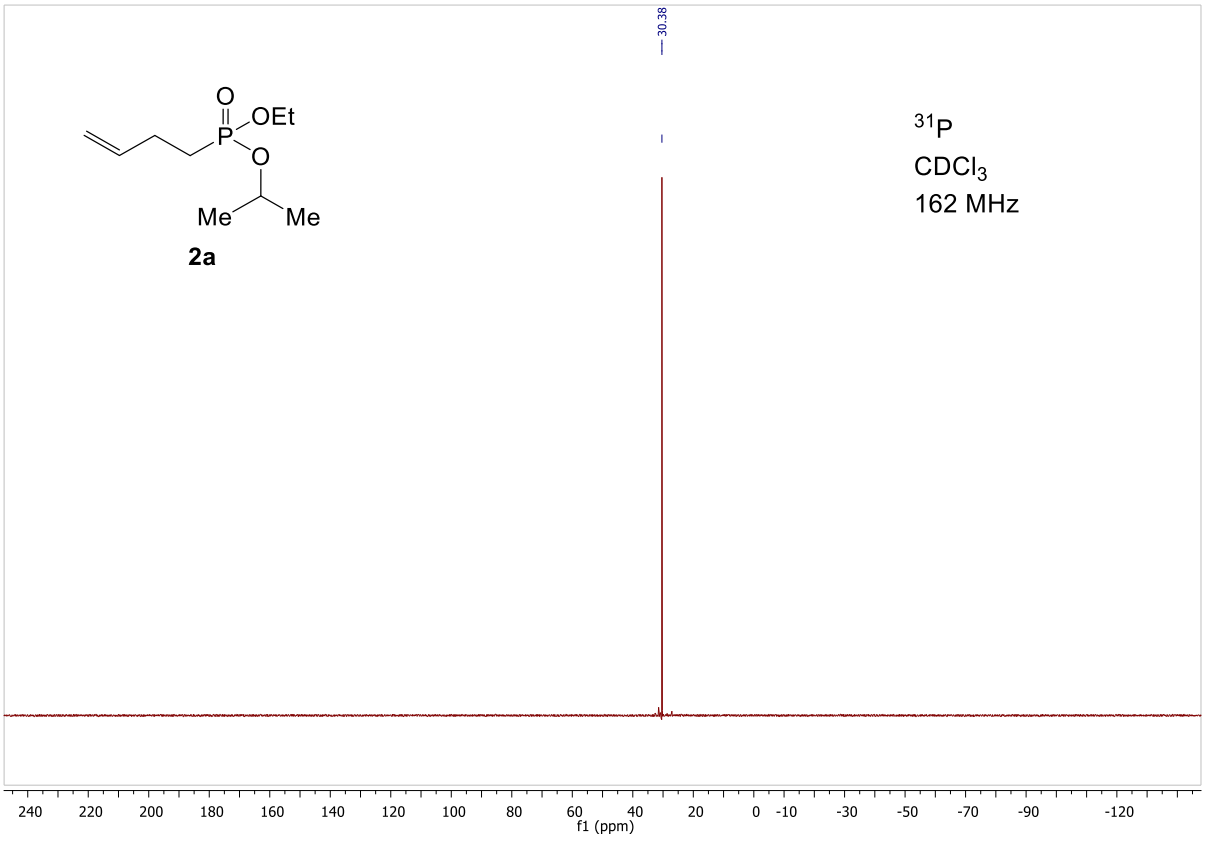

NC
O
OEt
P
OEt
1f
^{1}H
$CDCl_3$
400 MHz
f1 (ppm)

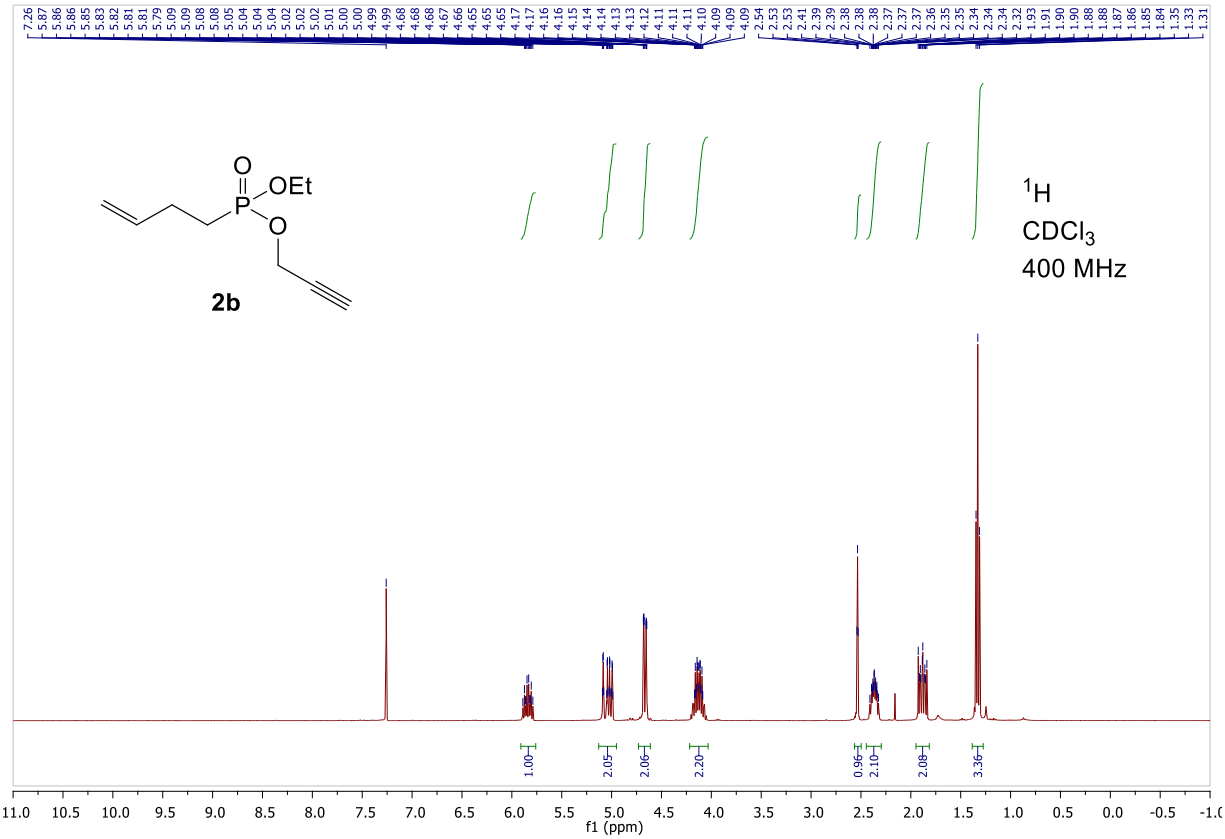

NC
O
OEt
P
OEt
1f
^{13}C (APT)
$CDCl_3$
100 MHz
f1 (ppm)

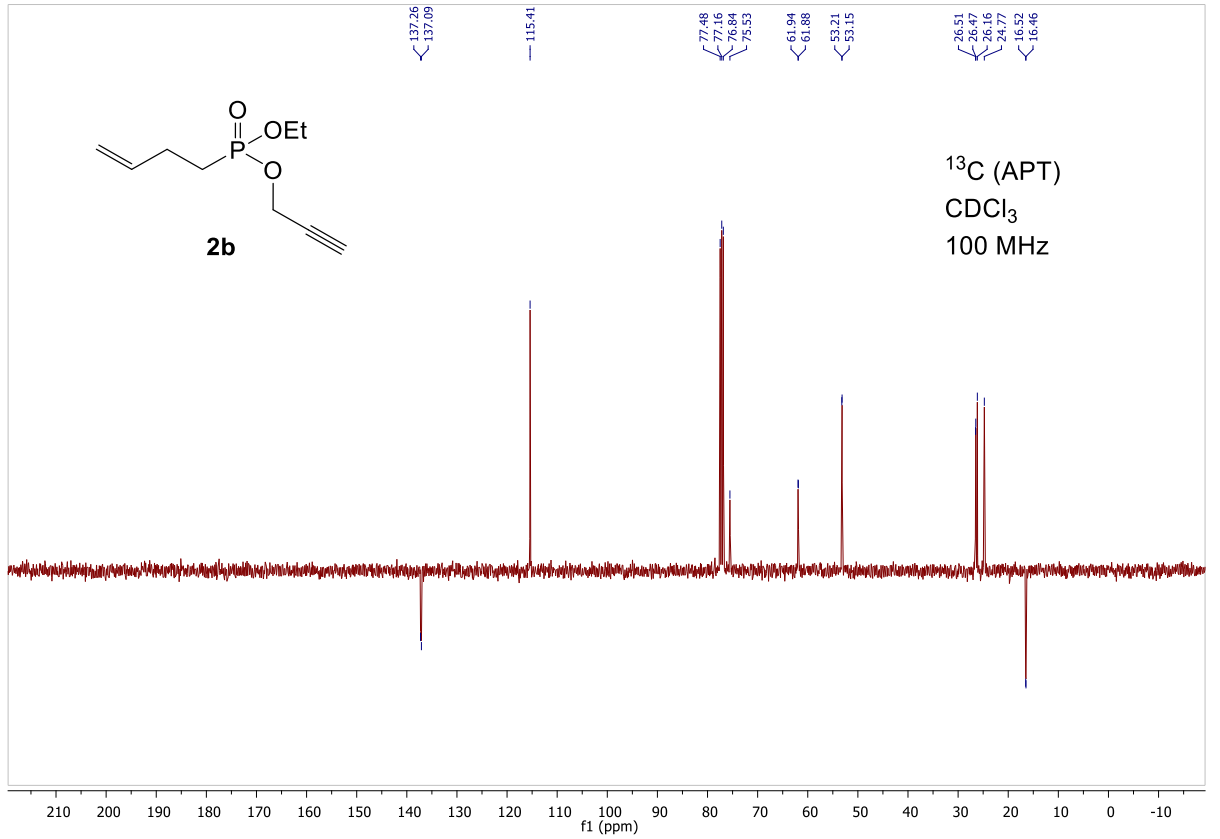

31.47
NC
O
OEt
P
OEt
1f
31P
CDCl3
162 MHz
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)

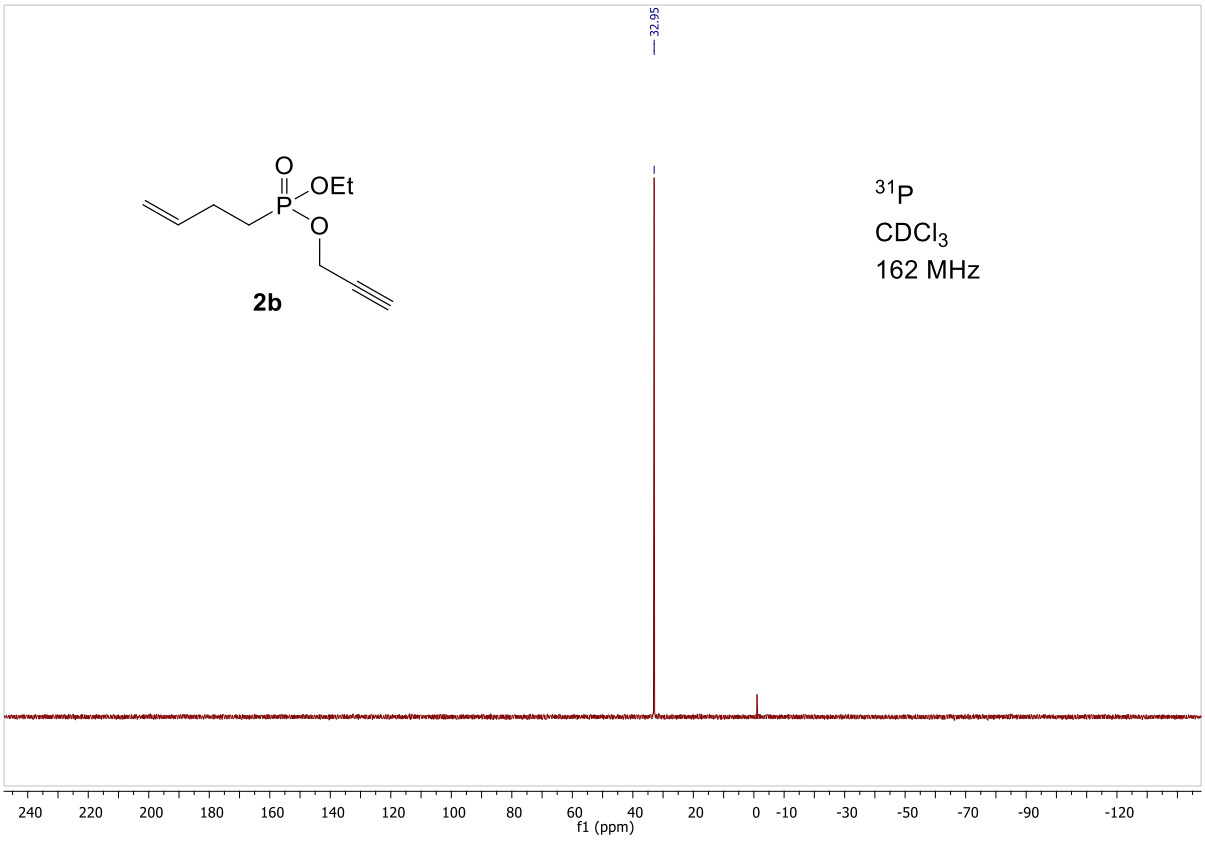

O
OEt
P
O
Me
Me
2a
^{1}H
$CDCl_3$
400 MHz
f1 (ppm)

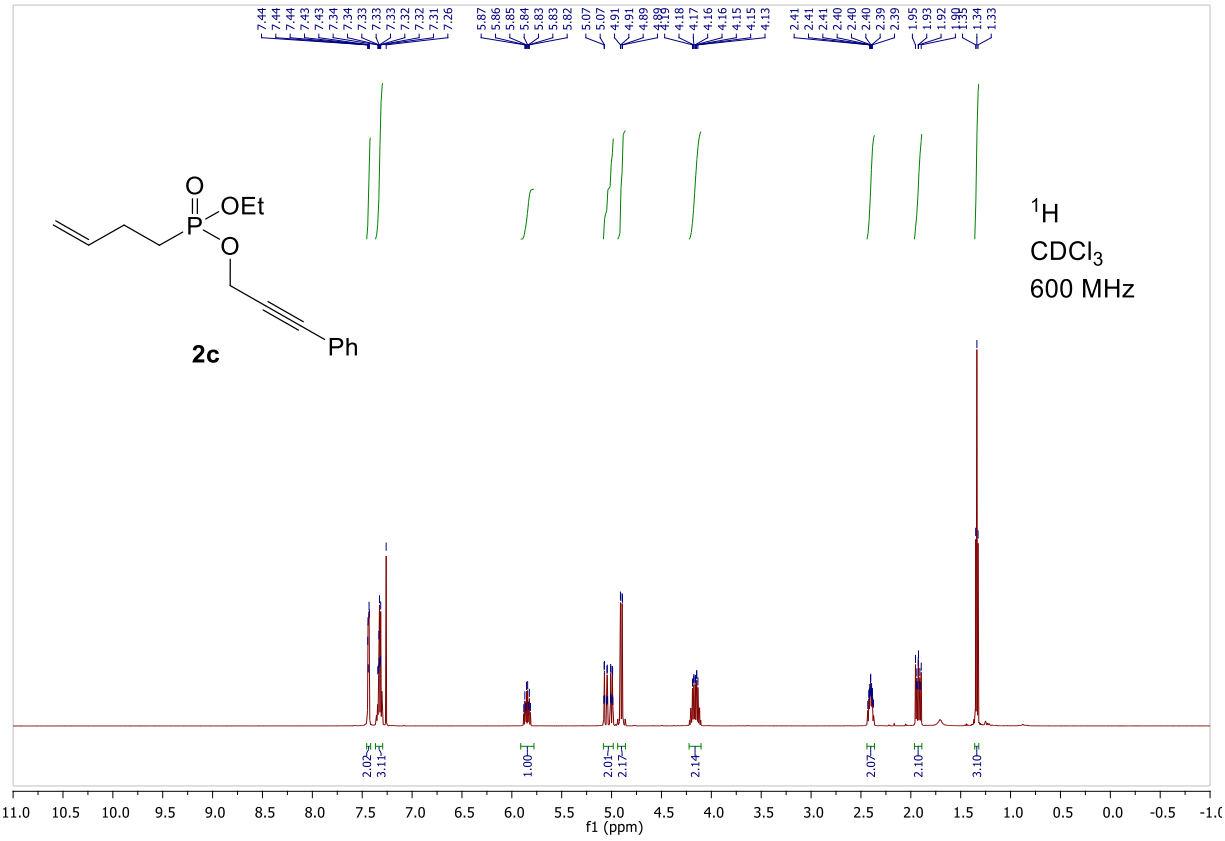

O
OEt
P
O
Me
Me
2a
^{13}C (APT)
$CDCl_3$
100 MHz
f1 (ppm)

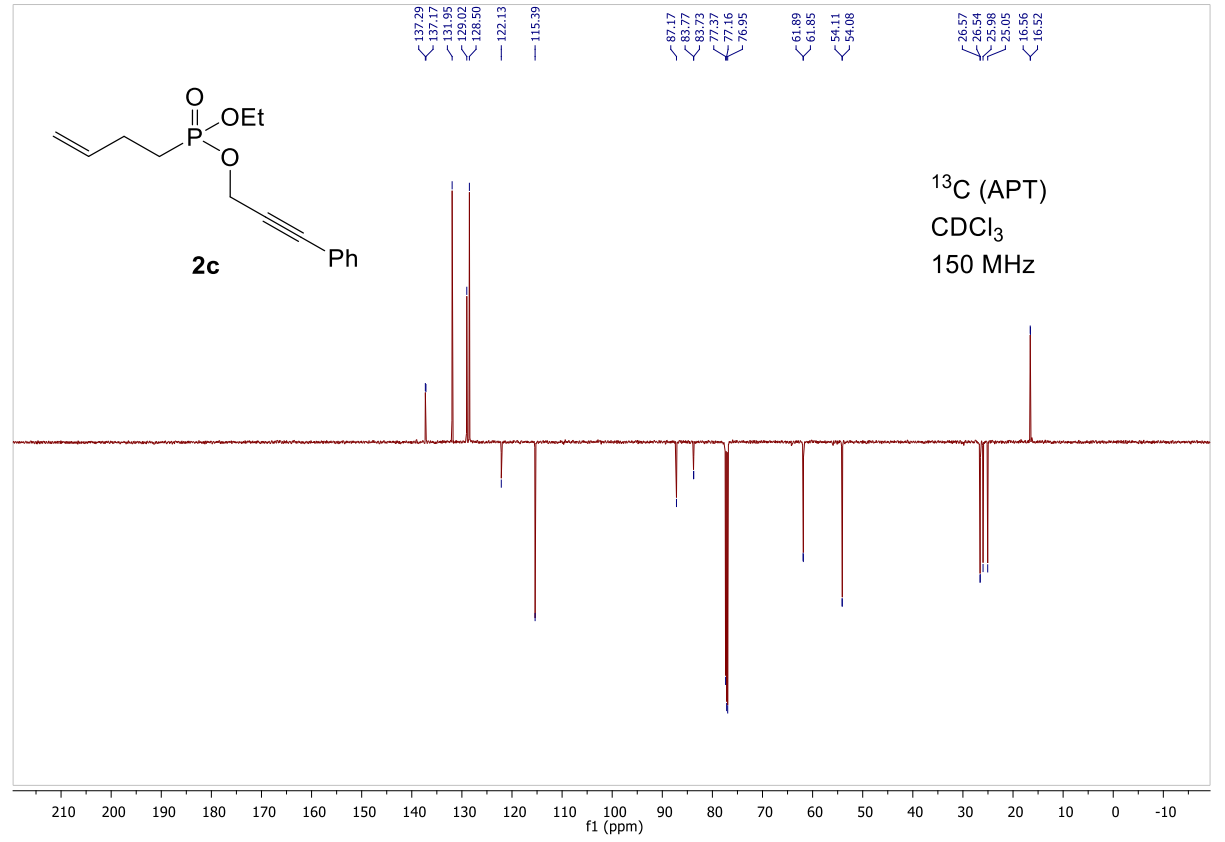

30.38
O
OEt
P
O
Me
Me
2a
31P
CDCl3
162 MHz
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)

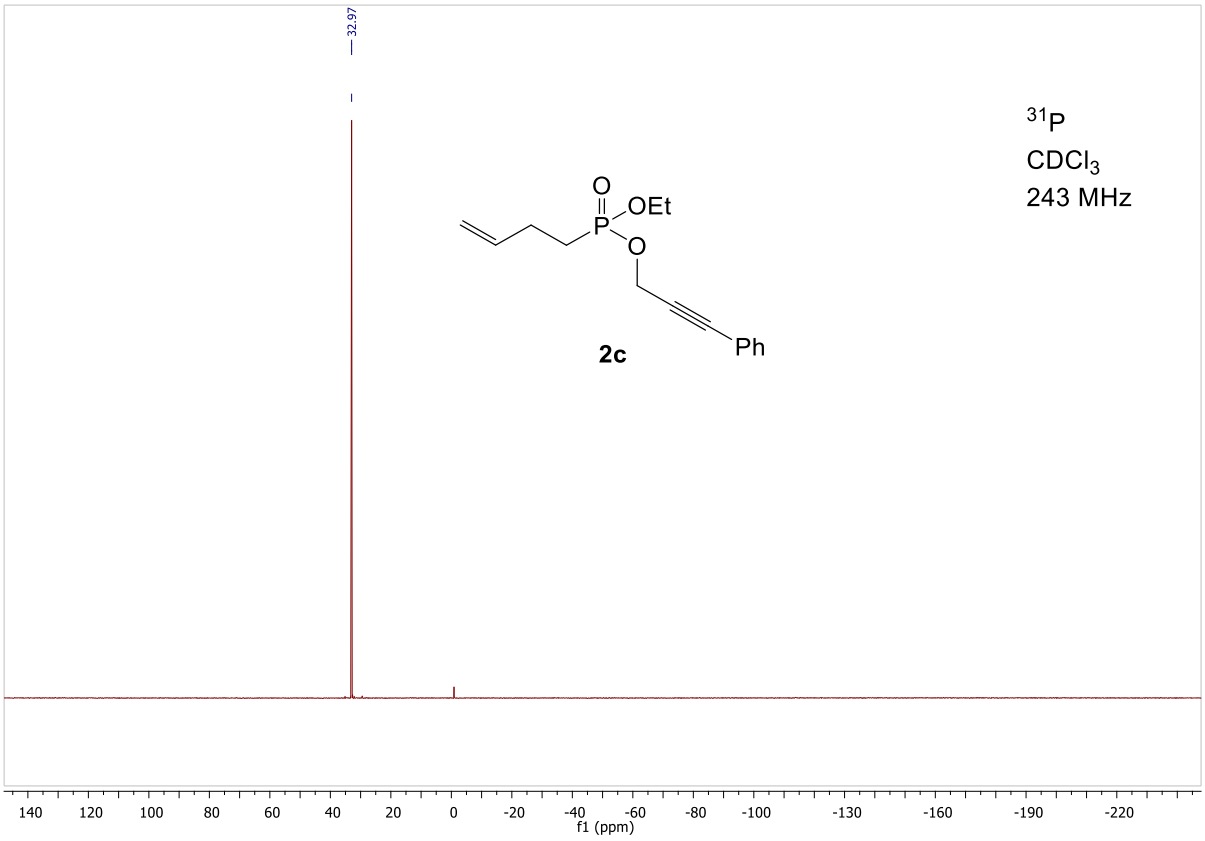

2b
^{1}H
$CDCl_3$
400 MHz
f1 (ppm)

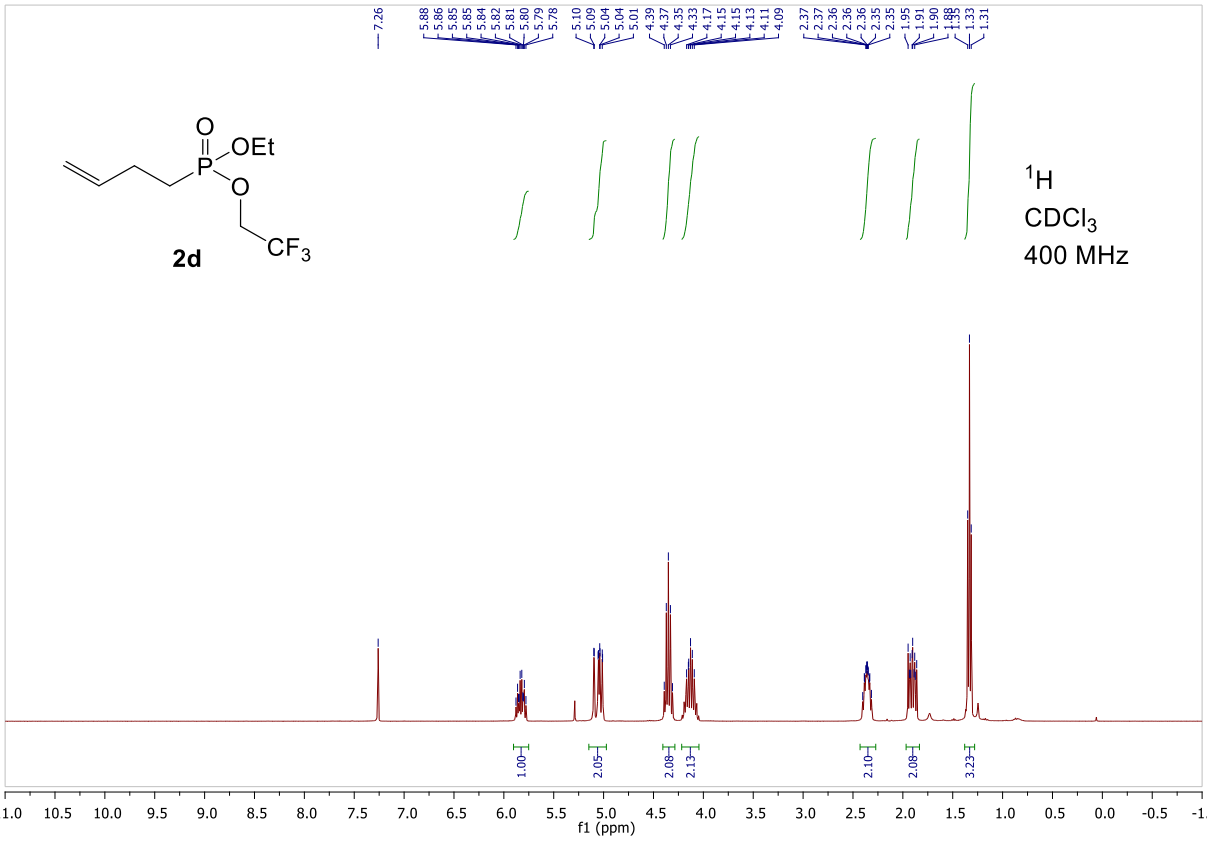

2b
^{13}C (APT)
$CDCl_3$
100 MHz
f1 (ppm)

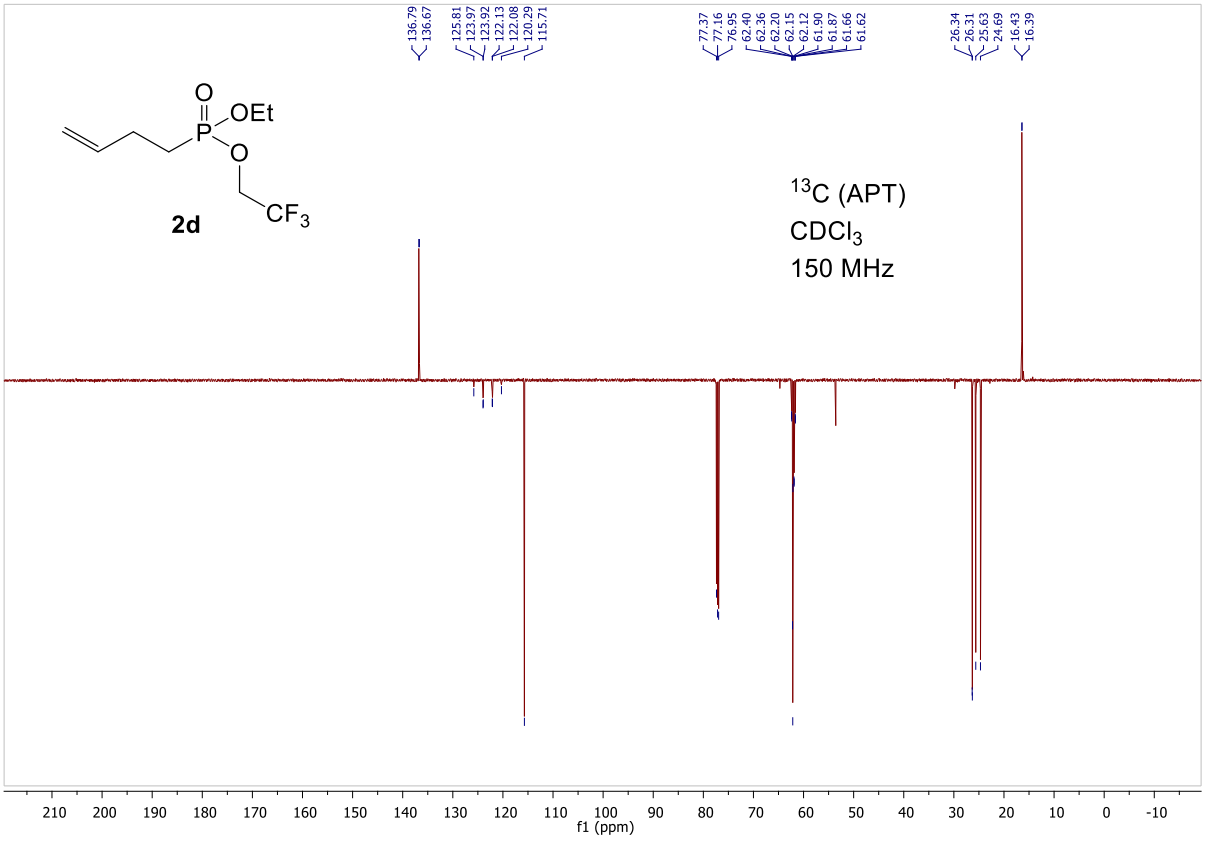

32.95
O
OEt
P
O
2b
31P
CDCl3
162 MHz
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)

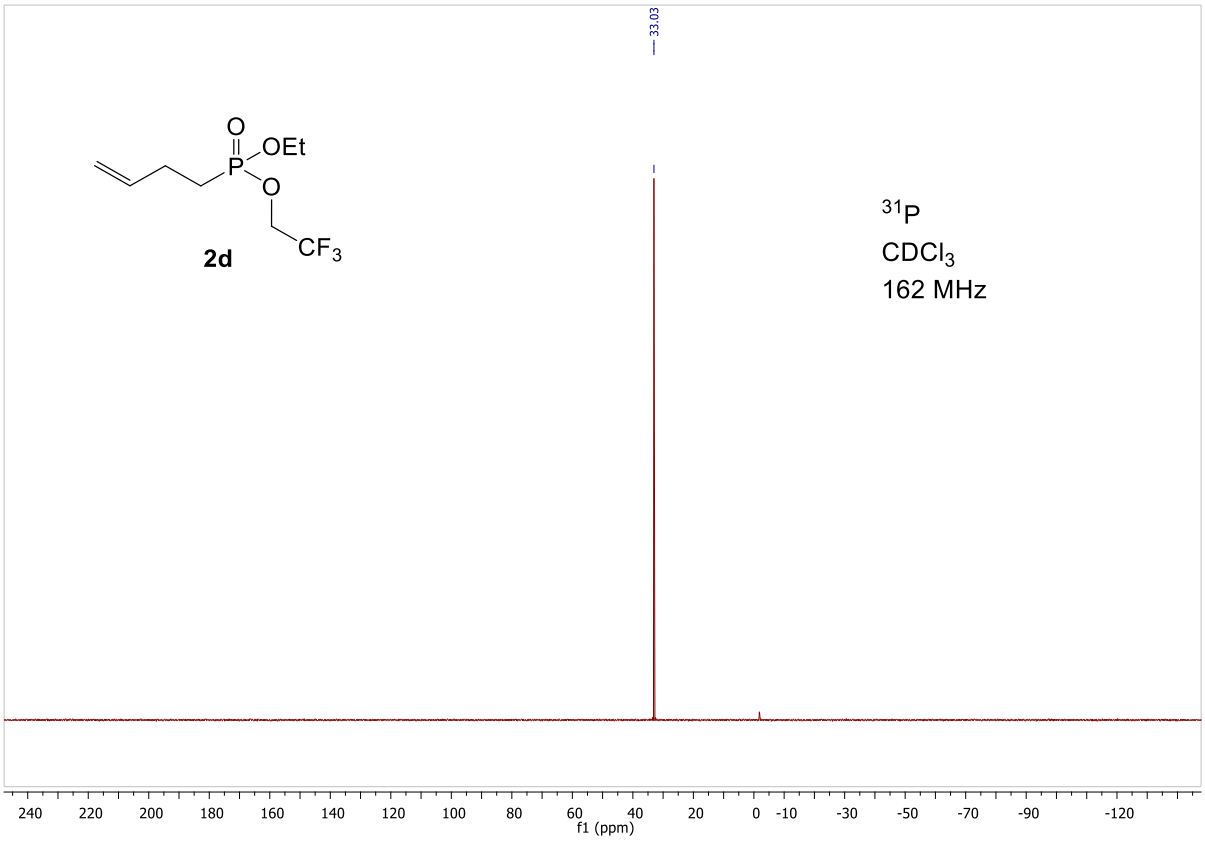

2c
^{1}H
$CDCl_3$
600 MHz
f1 (ppm)

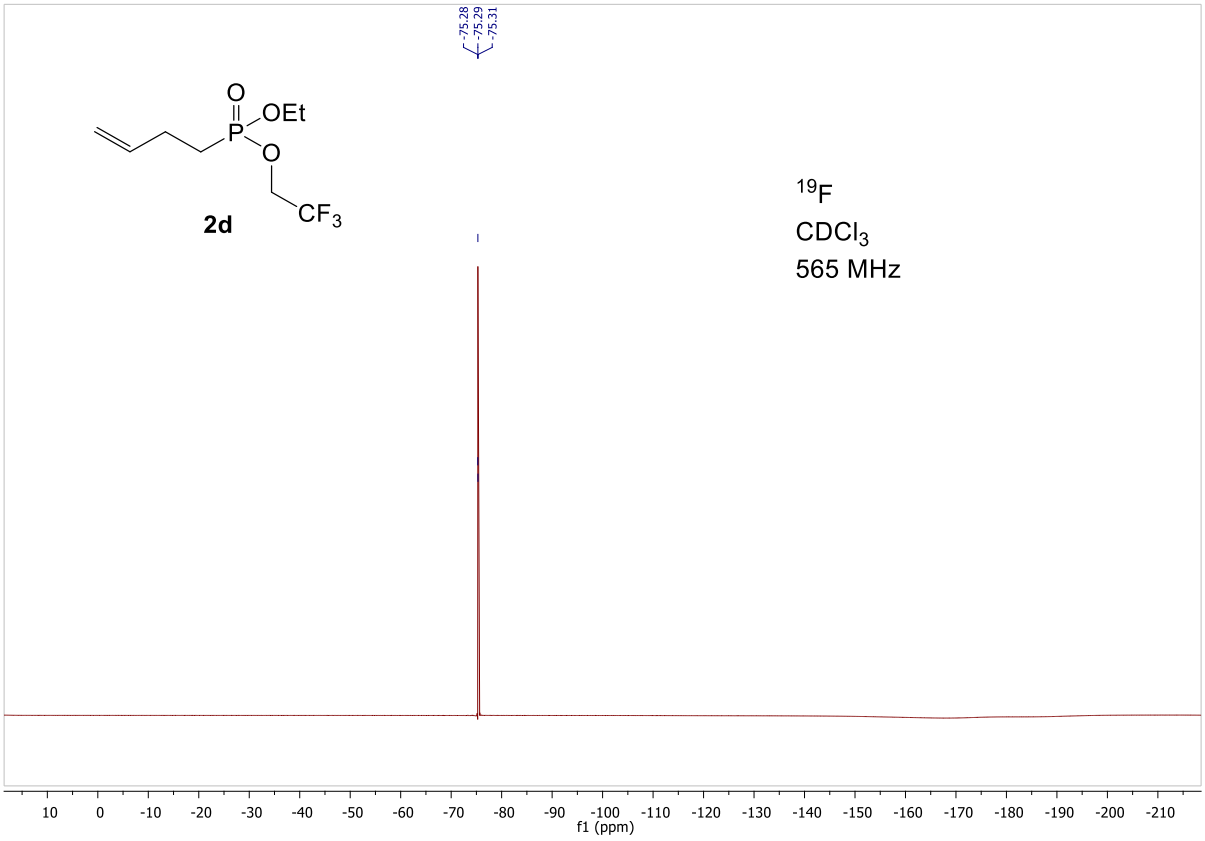

2c
^{13}C (APT)
$CDCl_3$
150 MHz
f1 (ppm)

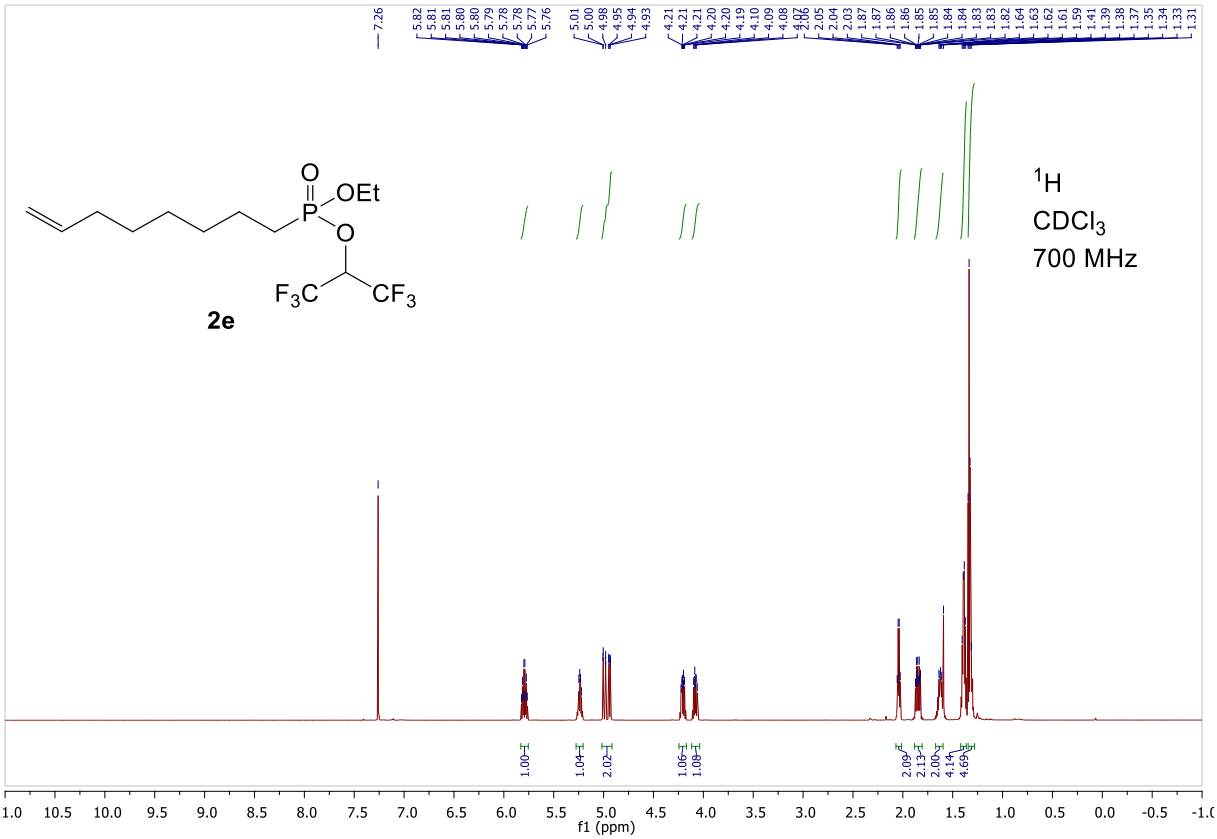

32.97
^{31}P
$CDCl_3$
243 MHz
O
OEt
P
O
Ph
2c
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-130
-160
-190
-220
f1 (ppm)

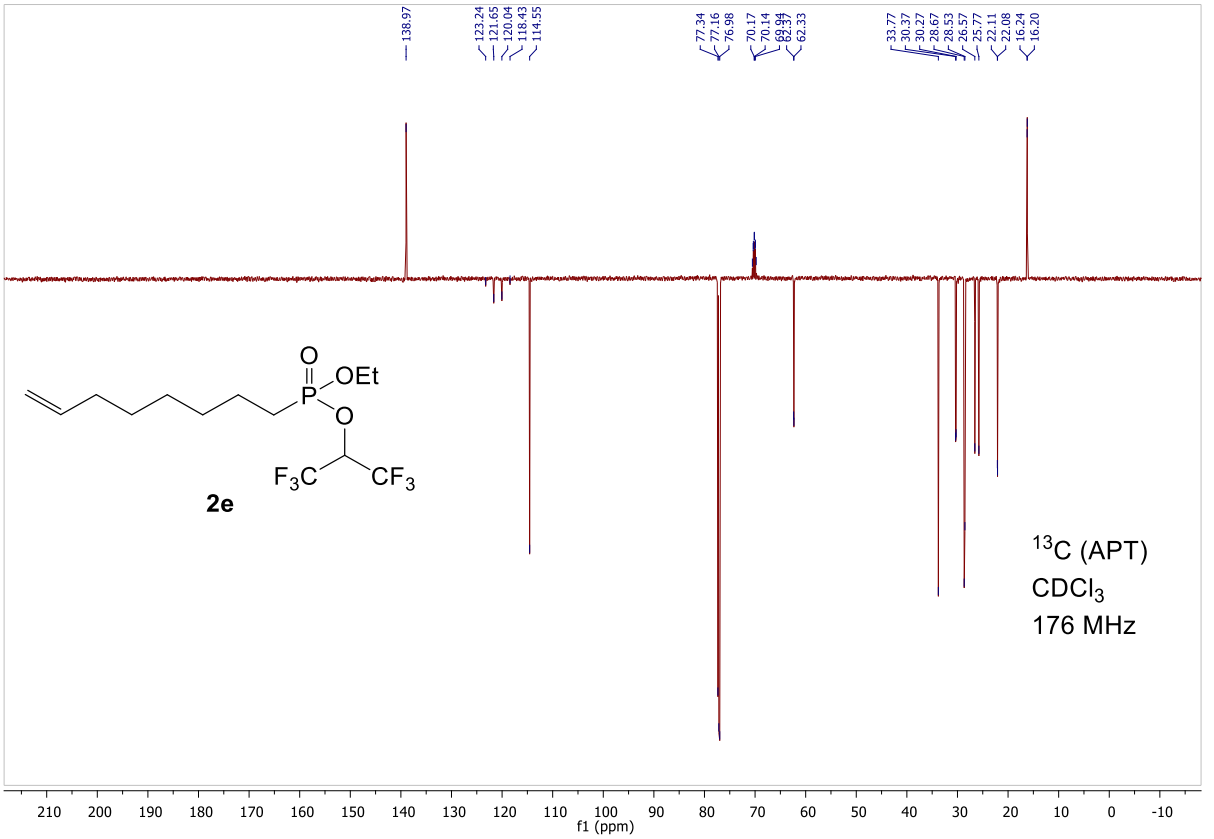

2d
^{1}H
$CDCl_3$
400 MHz
f1 (ppm)

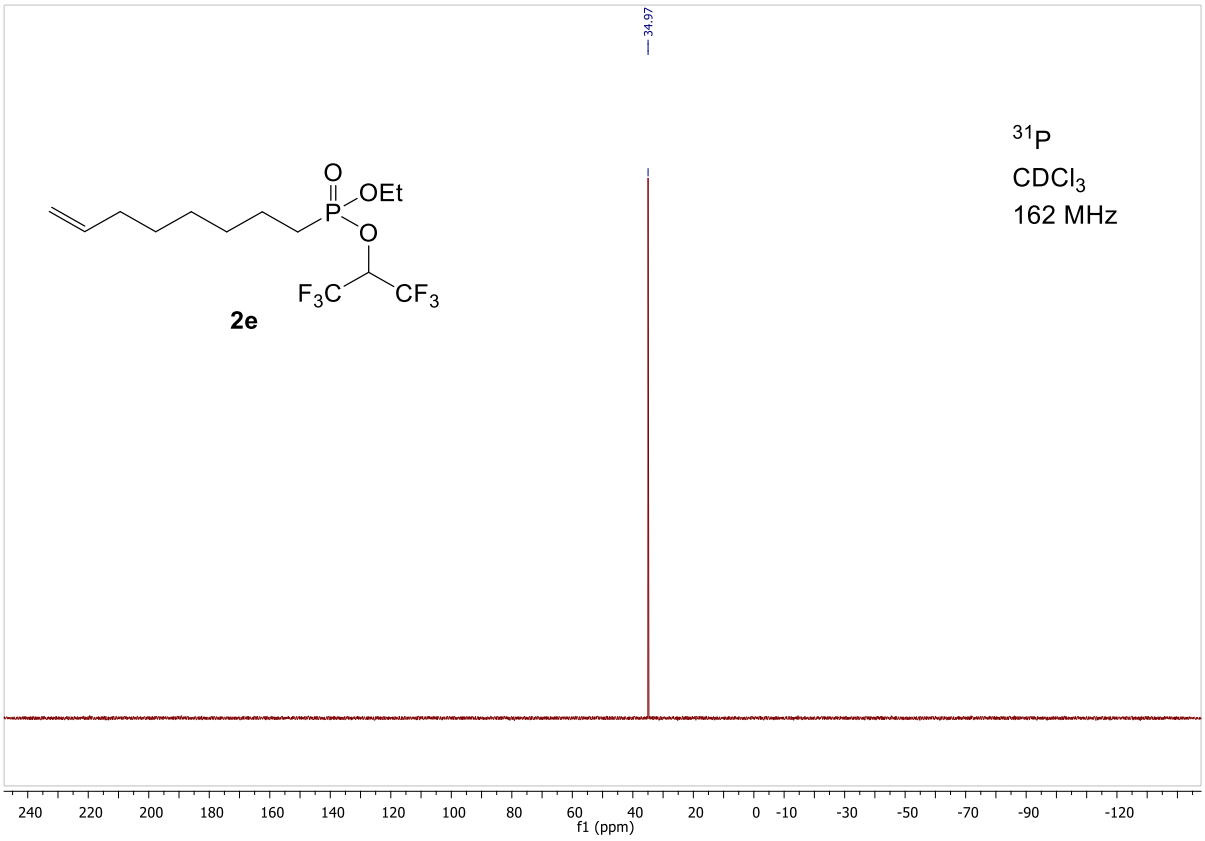

2d
^{13}C (APT)
$CDCl_3$
150 MHz
f1 (ppm)

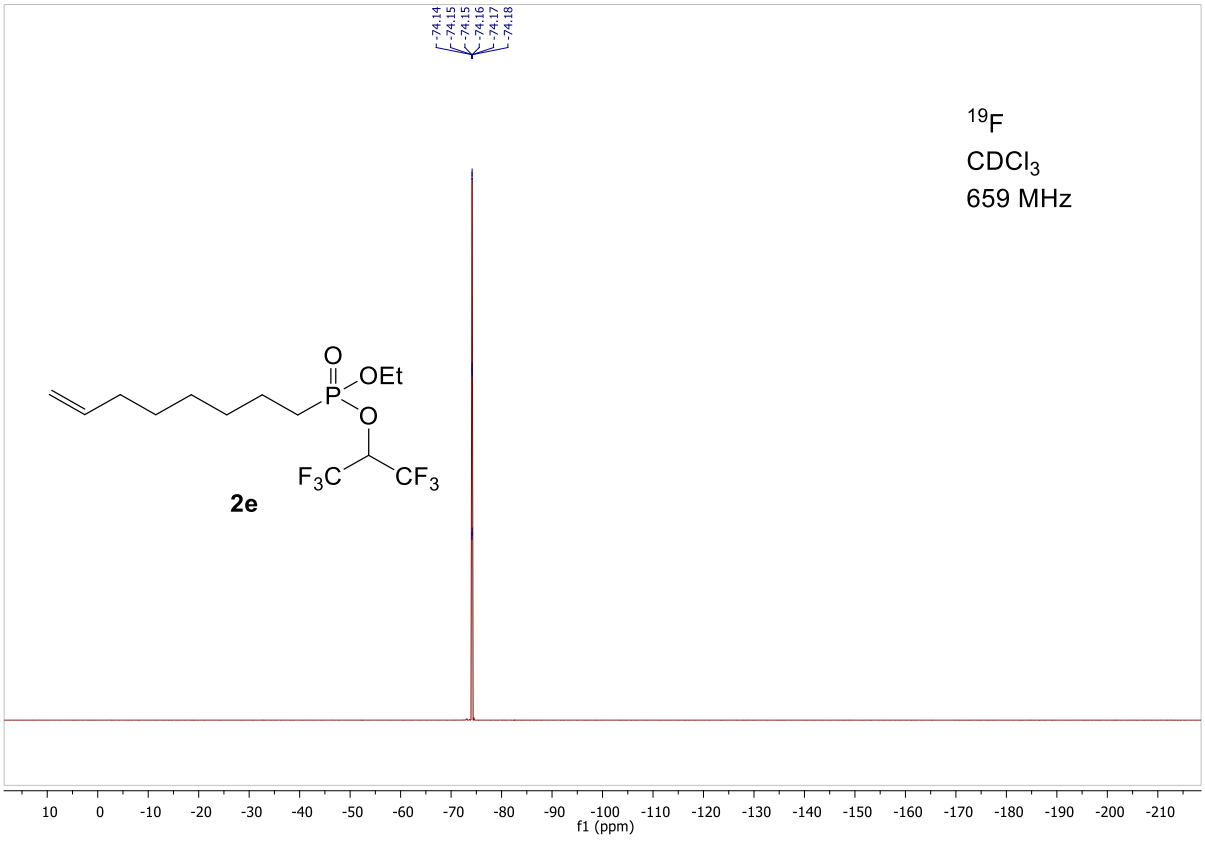

33.03
O
OEt
P
O
CF3
2d
31P
CDCl3
162 MHz
240 220 200 180 160 140 120 100 80 60 40 20 0 -10 -30 -50 -70 -90 -120
f1 (ppm)

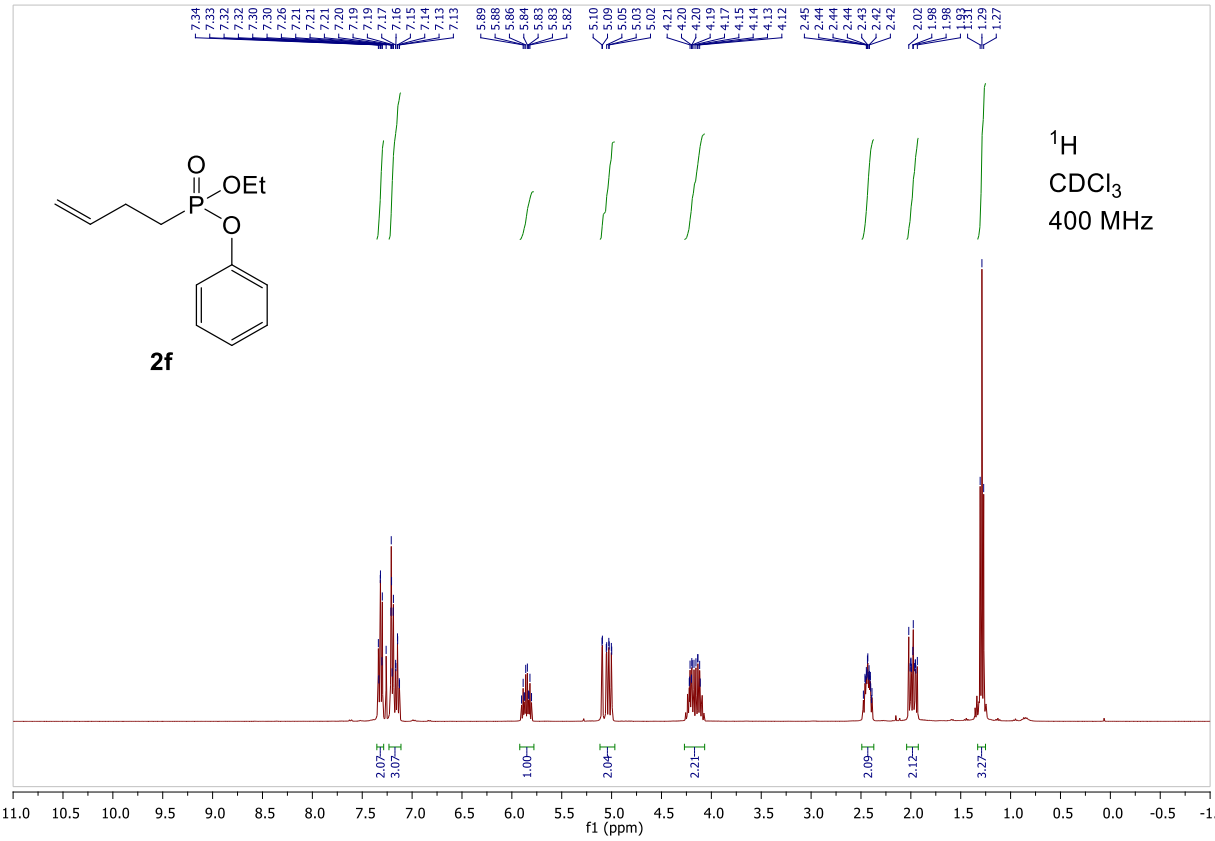

-75.28
-75.29
-75.31
O
OEt
P
O
CF3
2d
19F
CDCl3
565 MHz
10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210
f1 (ppm)


2e
^{1}H
$CDCl_3$
700 MHz
f1 (ppm)


2e
^{13}C (APT)
$CDCl_3$
176 MHz
f1 (ppm)


34.97
^{31}P
$CDCl_3$
162 MHz
O
OEt
P
O
F_3C
CF_3
2e
240 220 200 180 160 140 120 100 80 60 40 20 0 -10 -30 -50 -70 -90 -120
f1 (ppm)


-74.14
-74.15
-74.15
-74.16
-74.17
-74.18
^{19}F
$CDCl_3$
659 MHz
O
OEt
P
O
F_3C
CF_3
2e
10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180 -190 -200 -210
f1 (ppm)


7.34
7.33
7.32
7.32
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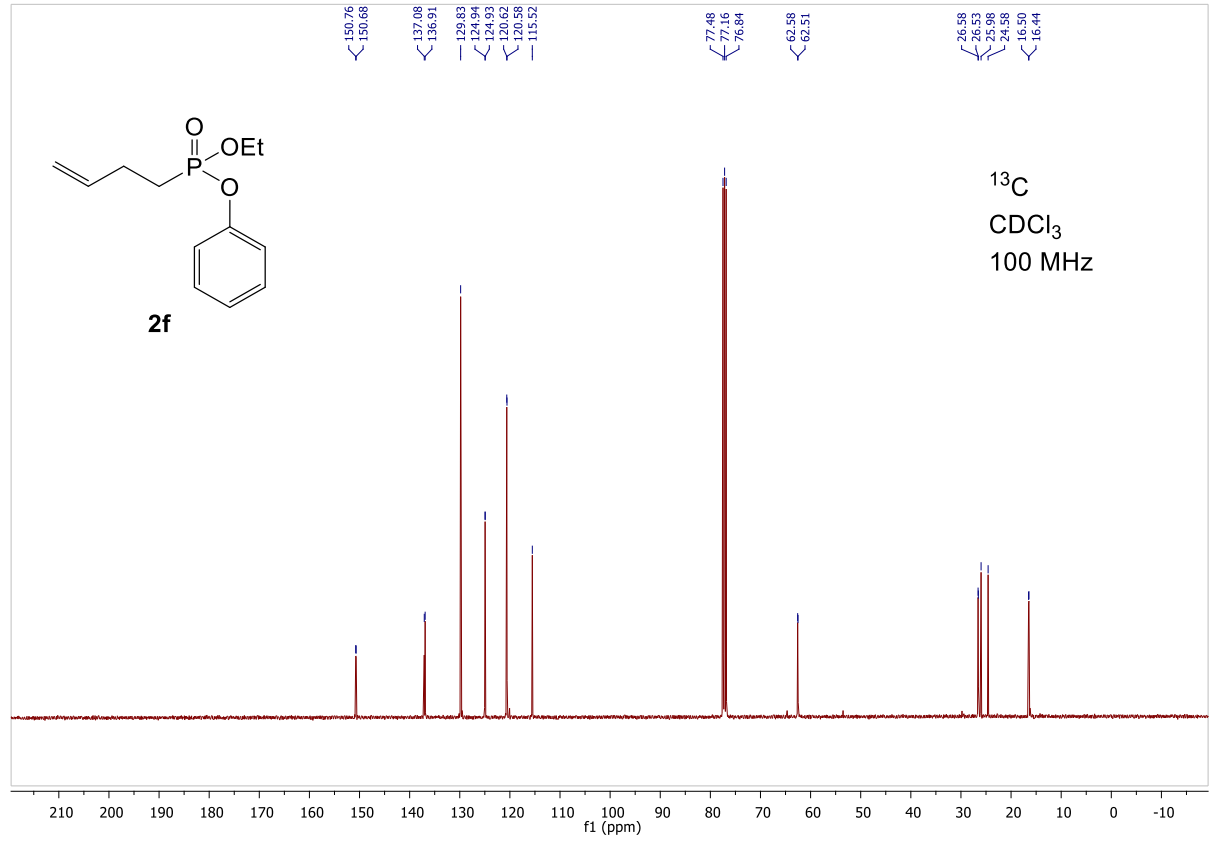
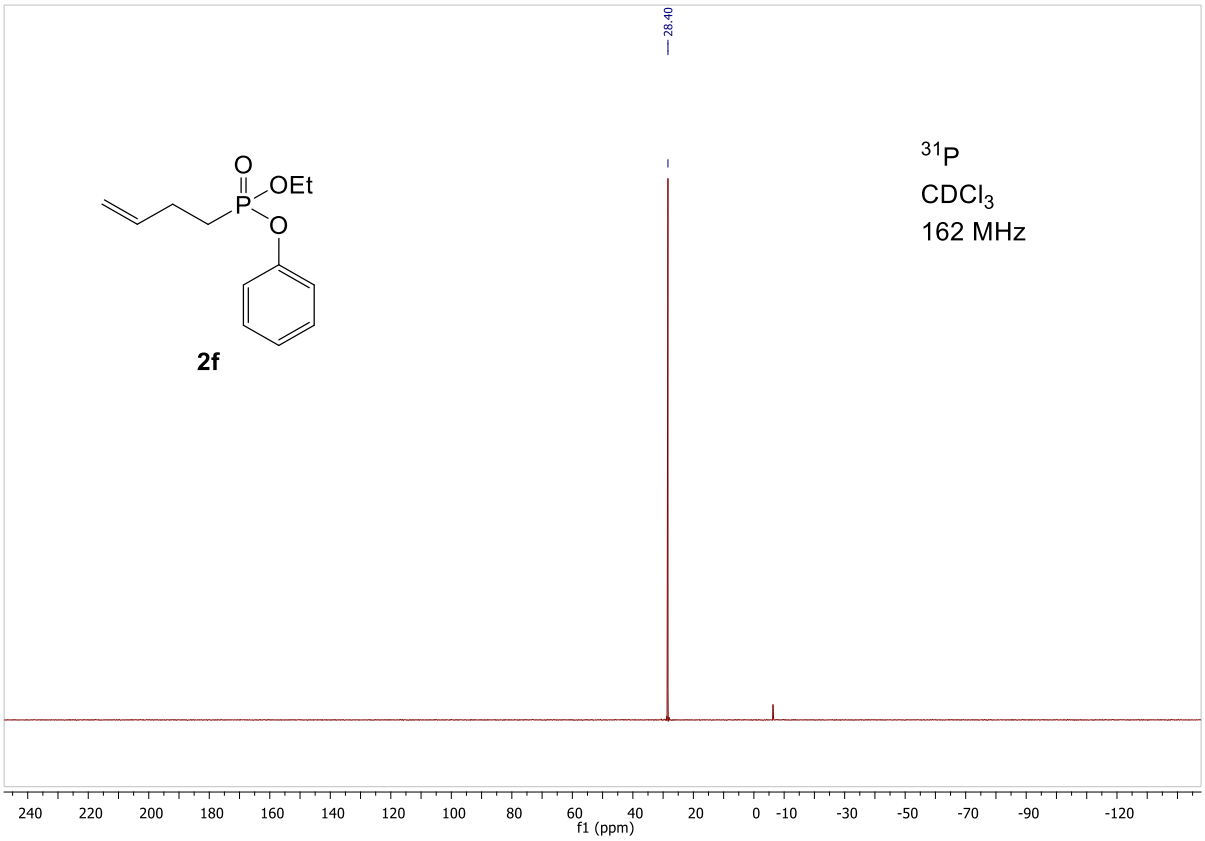
7.30
7.26
7.21
7.21
7.21
7.20
7.19
7.19
7.17
7.16
7.15
7.14
7.13
7.13
5.89
5.88
5.86
5.84
5.83
5.83
5.82
5.10
5.09
5.05
5.03
5.02
4.21
4.20
4.20
4.19
4.17
4.15
4.14
4.13
4.12
2.45
2.44
2.44
2.44
2.43
2.42
2.42
2.02
1.98
1.98
1.33
1.29
1.27
O
OEt
P
O
2f
1H
CDCl3
400 MHz
2.07
3.07
1.00
2.04
2.21
2.09
2.12
3.27
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 -0.5
f1 (ppm)


150.76
150.68
137.08
136.91
129.83
124.94
124.93
120.62
120.58
115.52
77.48
77.16
76.84
62.58
62.51
26.58
26.53
25.98
24.58
16.50
16.44
O
OEt
P
O
2f
13C
CDCl3
100 MHz
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


28.40
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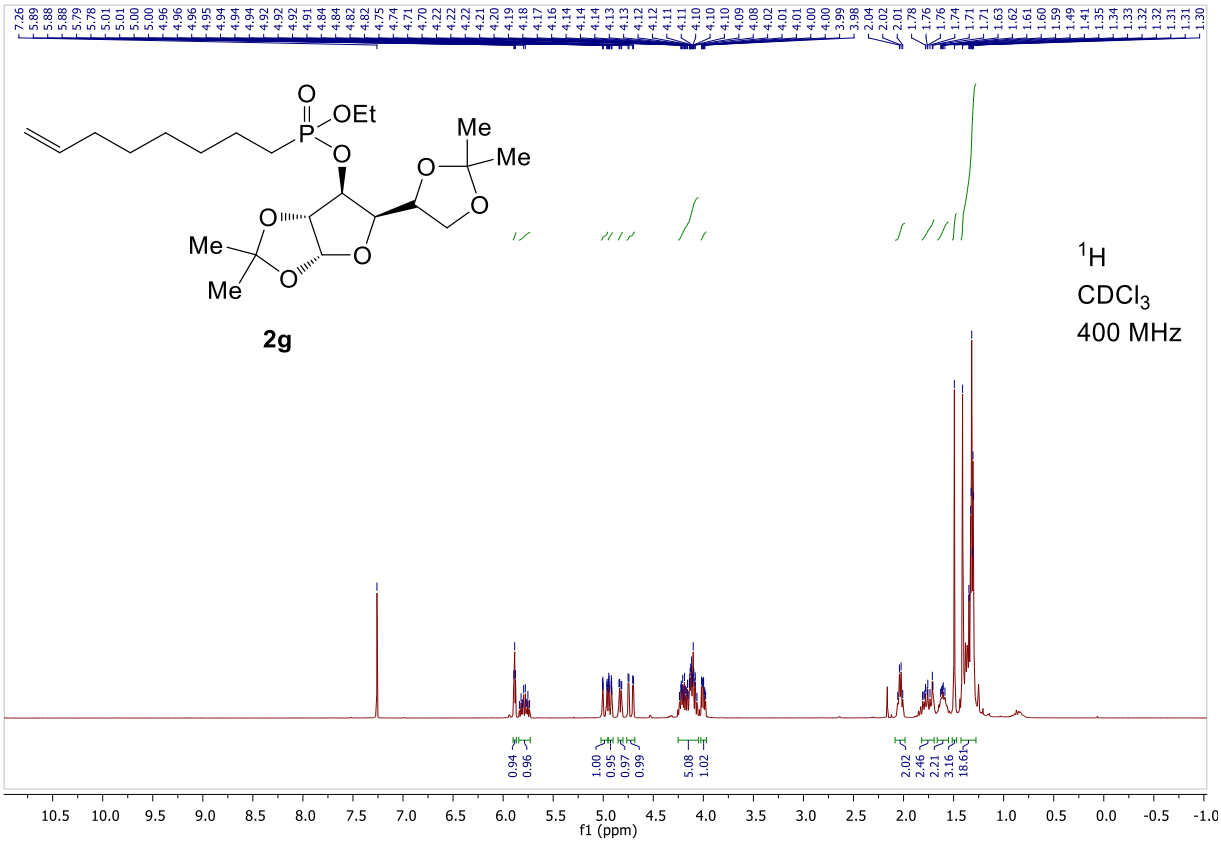
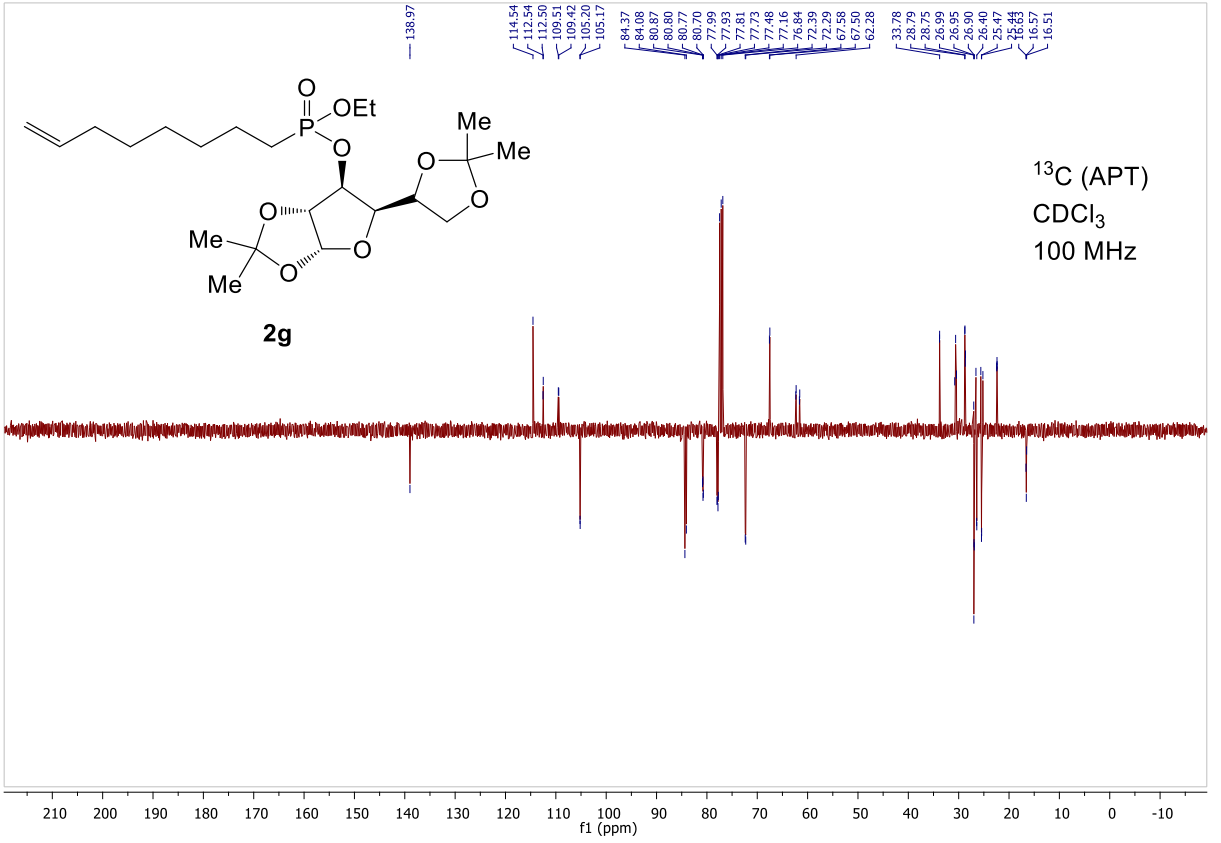
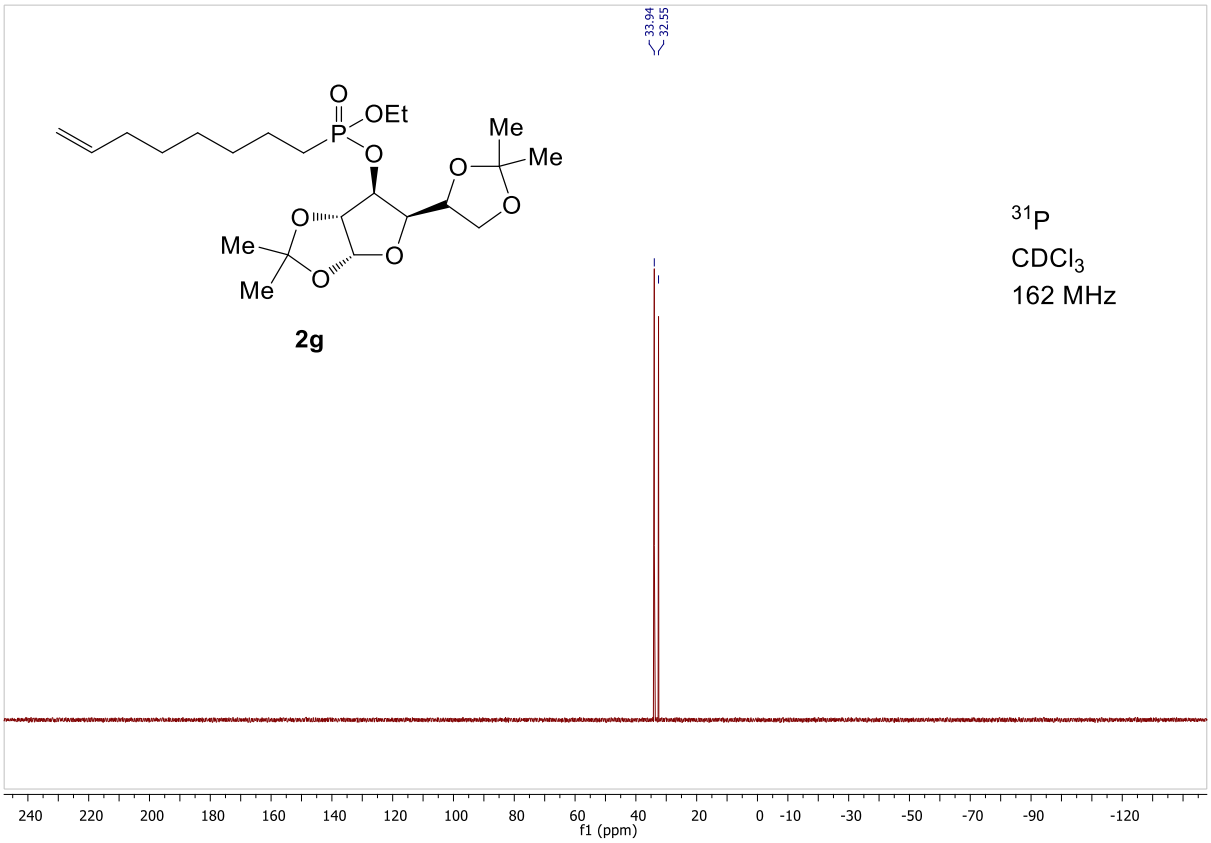
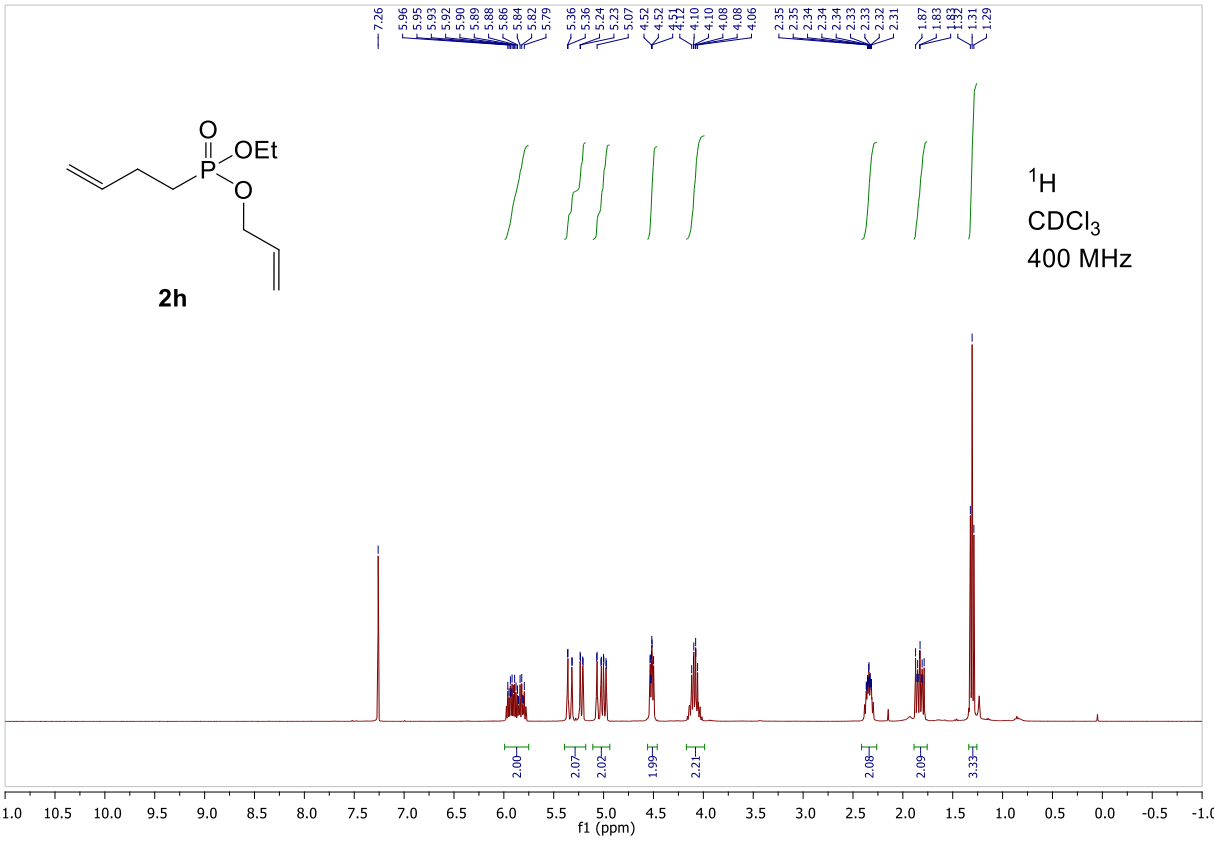
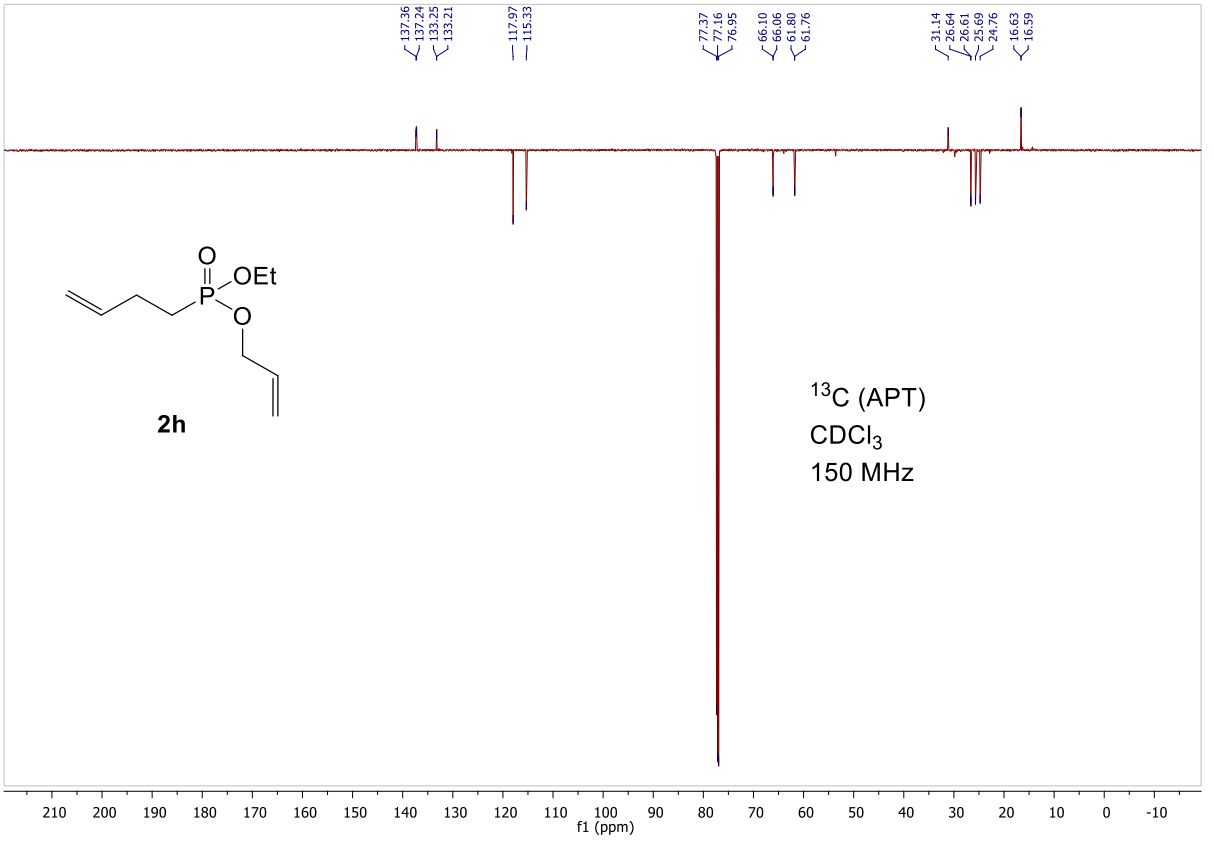
OEt
P
O
2f
31P
CDCl3
162 MHz
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)

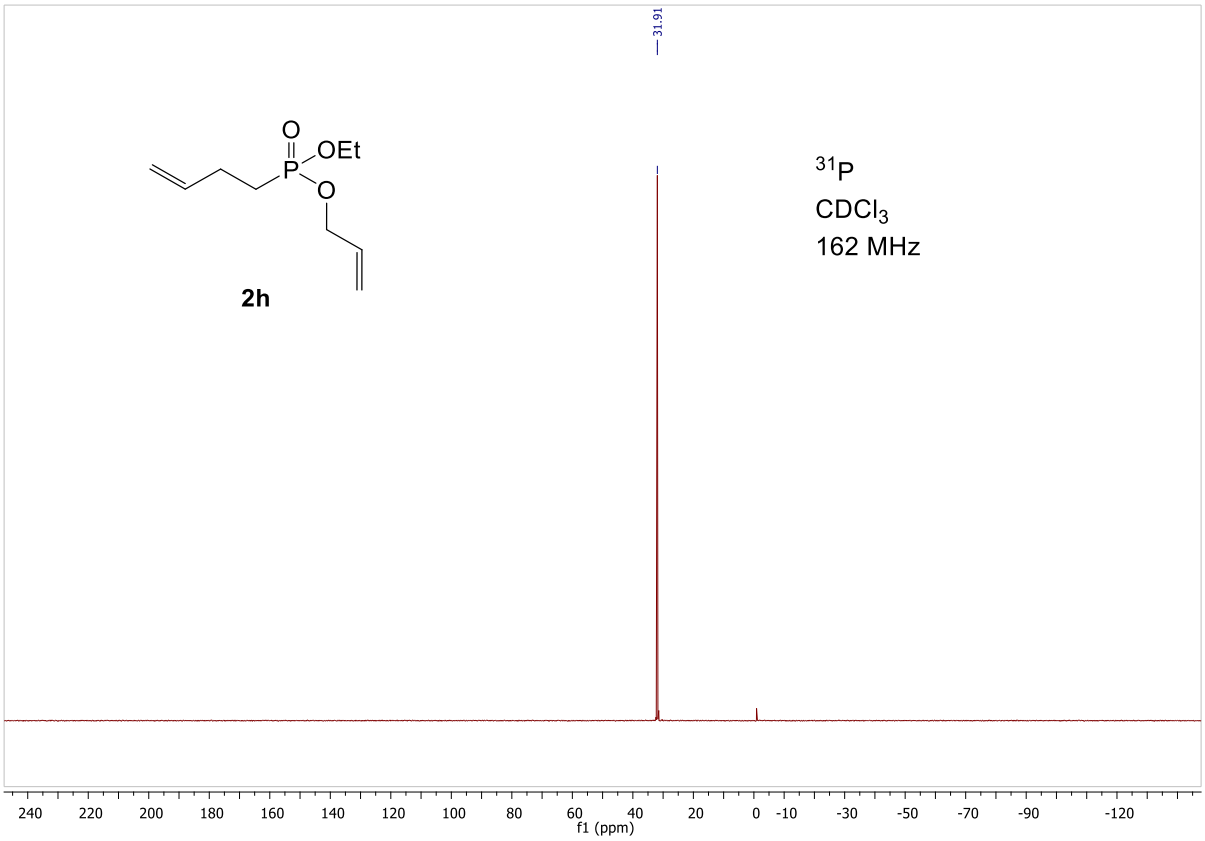

2g
^{1}H
$CDCl_3$
400 MHz
f1 (ppm)

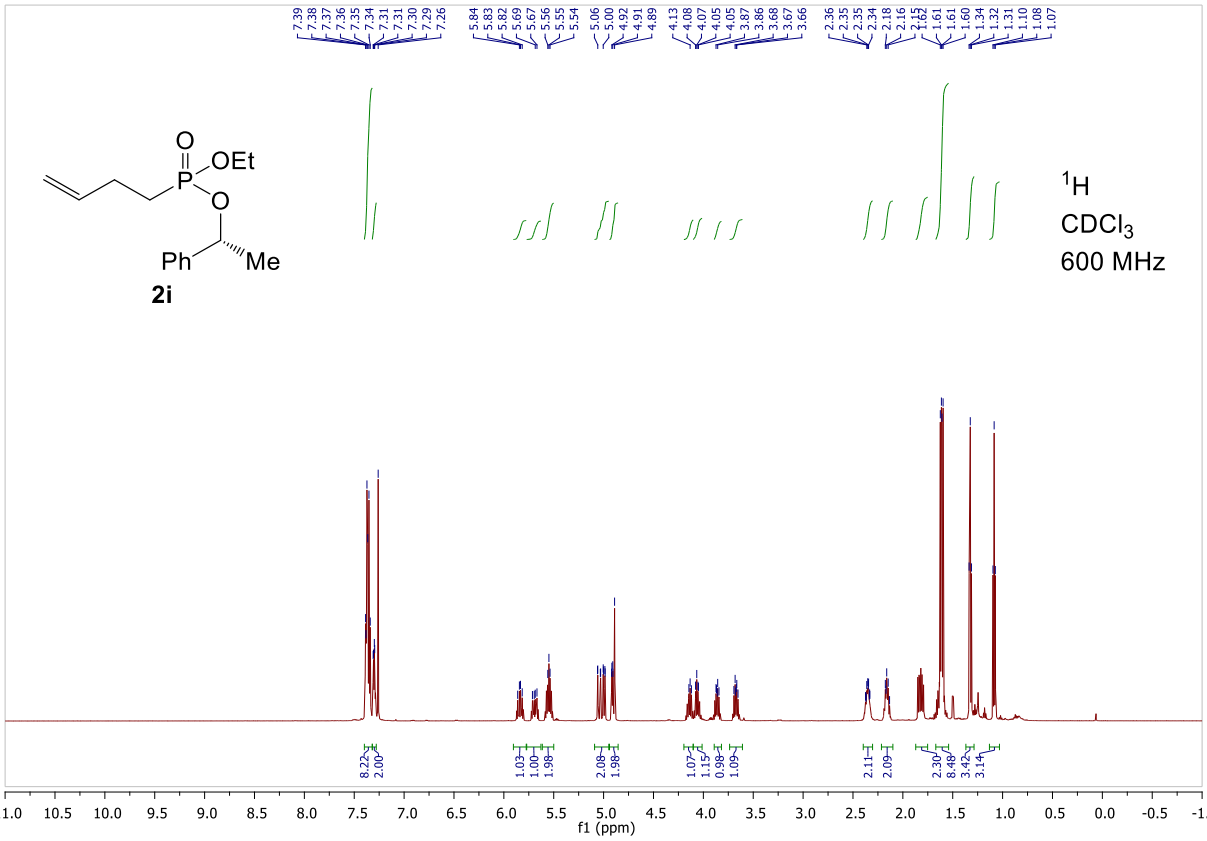

2g
^{13}C (APT)
$CDCl_3$
100 MHz
f1 (ppm)

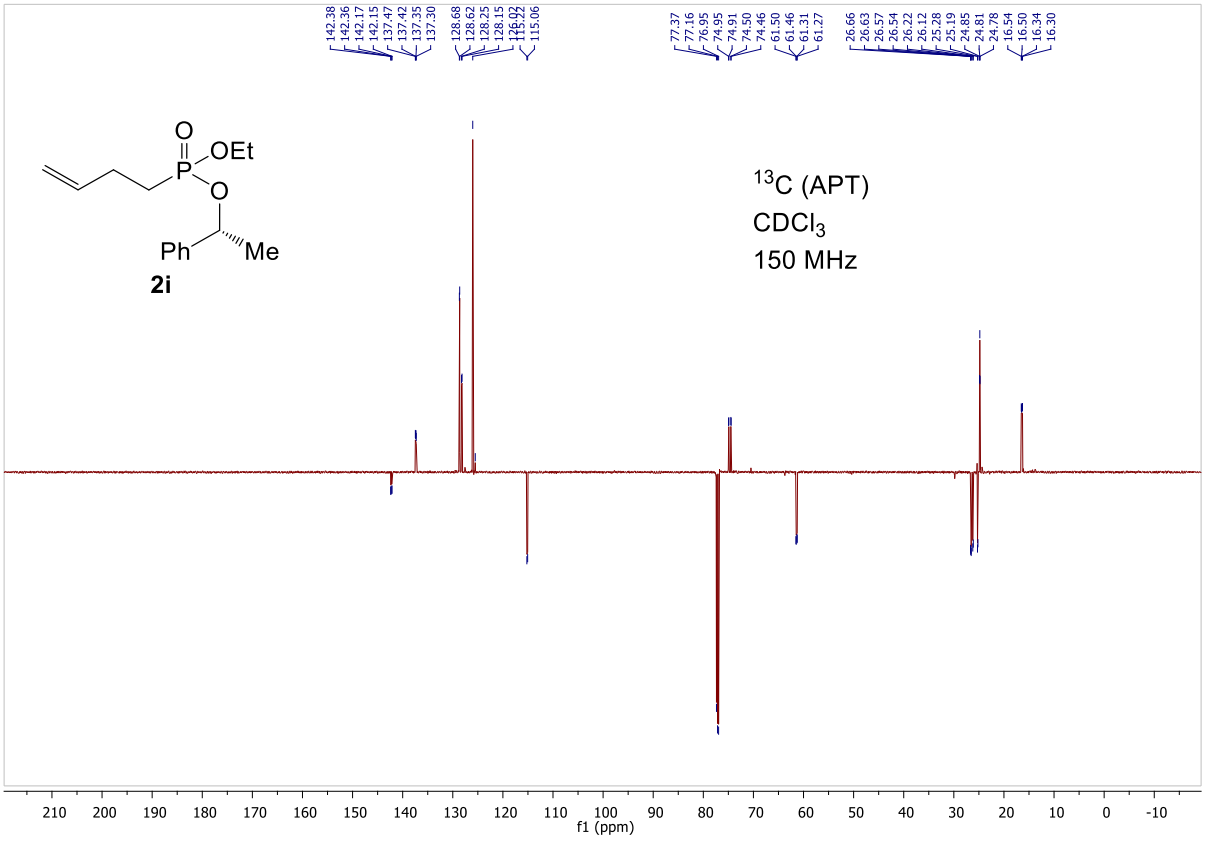

33.94
32.55
O
OEt
P
O
Me
Me
O
O
O
Me
Me
O
O
2g
31P
CDCl3
162 MHz
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)

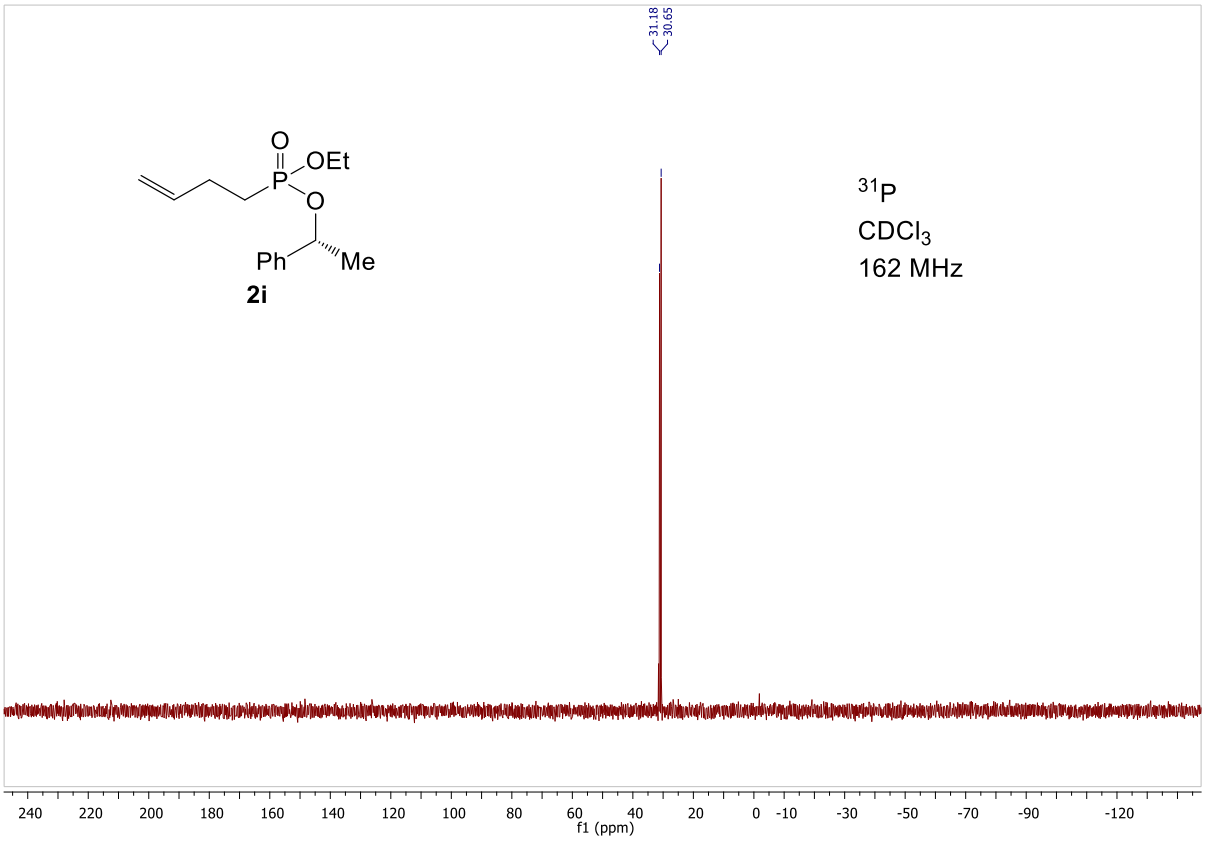

2h
^{1}H
$CDCl_3$
400 MHz
f1 (ppm)

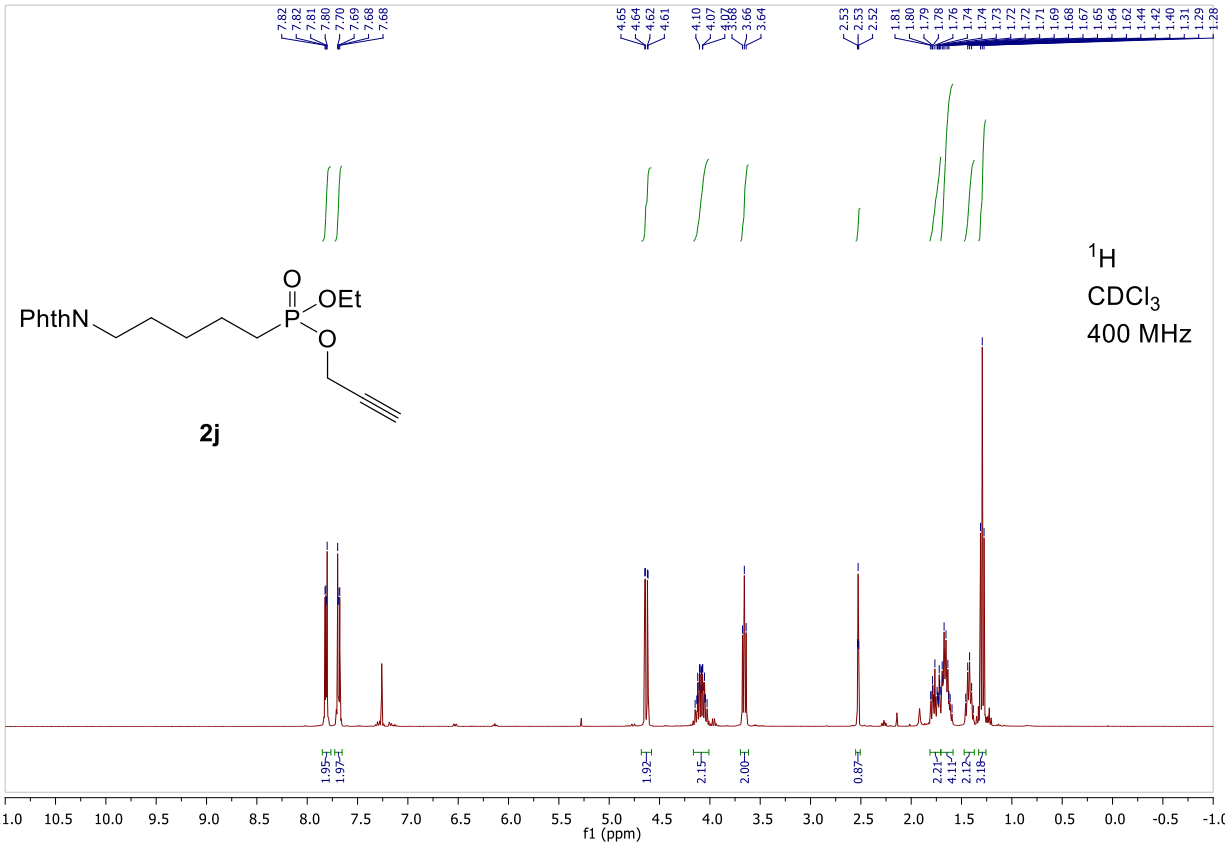

2h
^{13}C (APT)
$CDCl_3$
150 MHz
f1 (ppm)

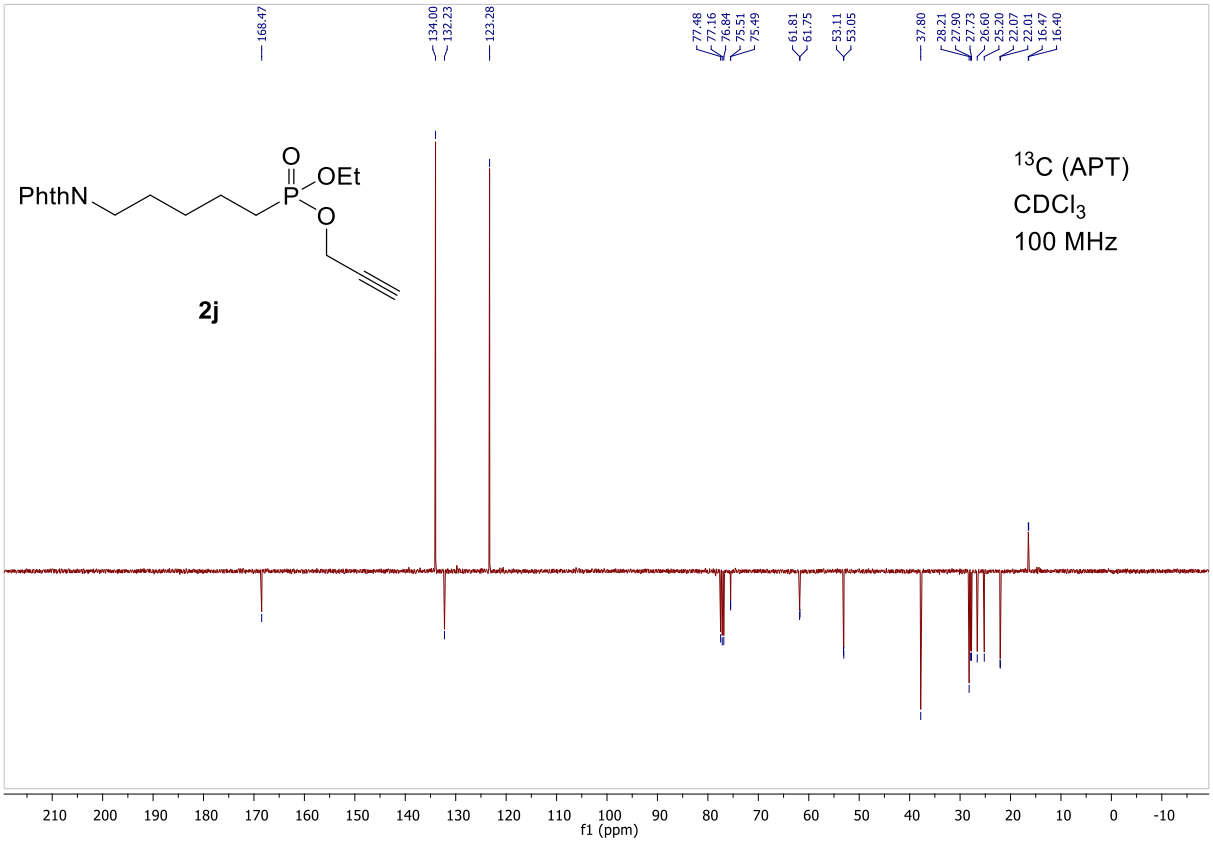

31.91
O
OEt
P
O
2h
31P
CDCl3
162 MHz
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)

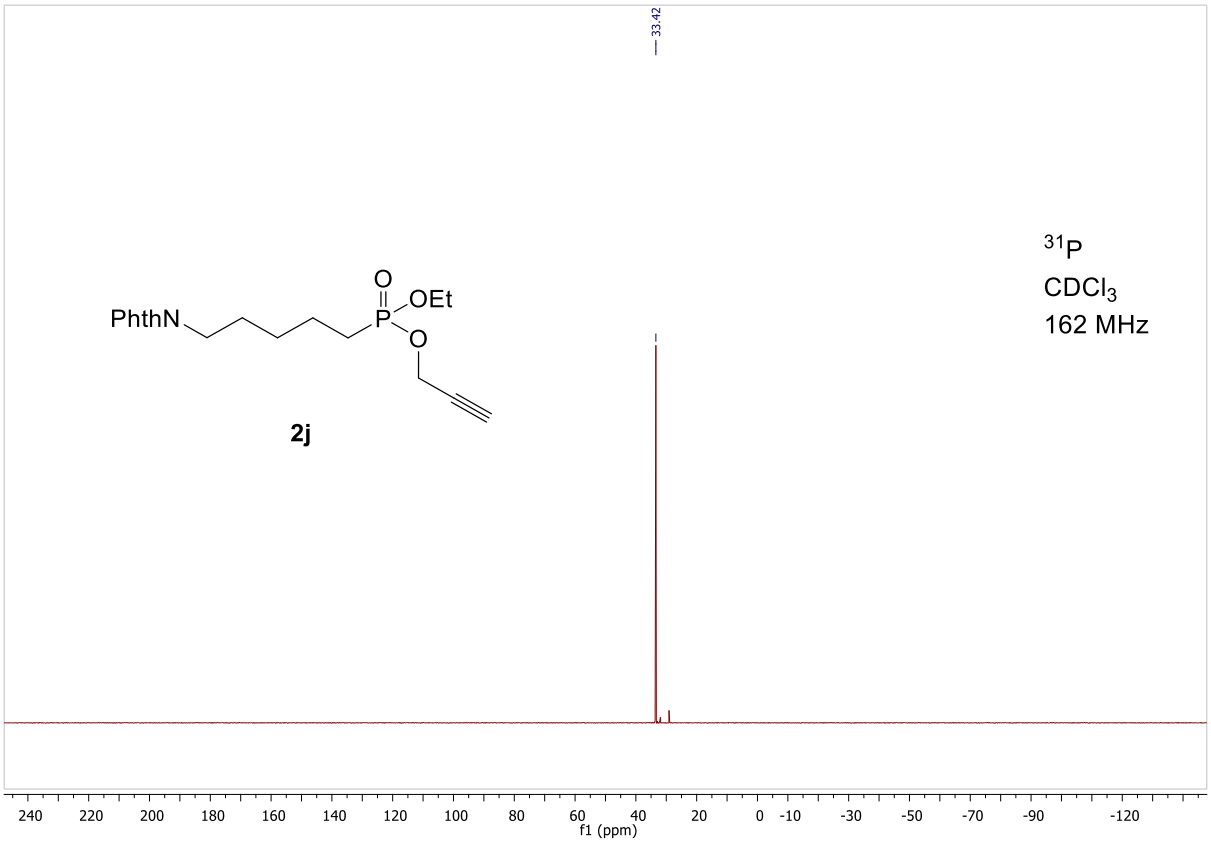

O
OEt
P
O
Ph
Me
2i
^{1}H
$CDCl_3$
600 MHz
f1 (ppm)

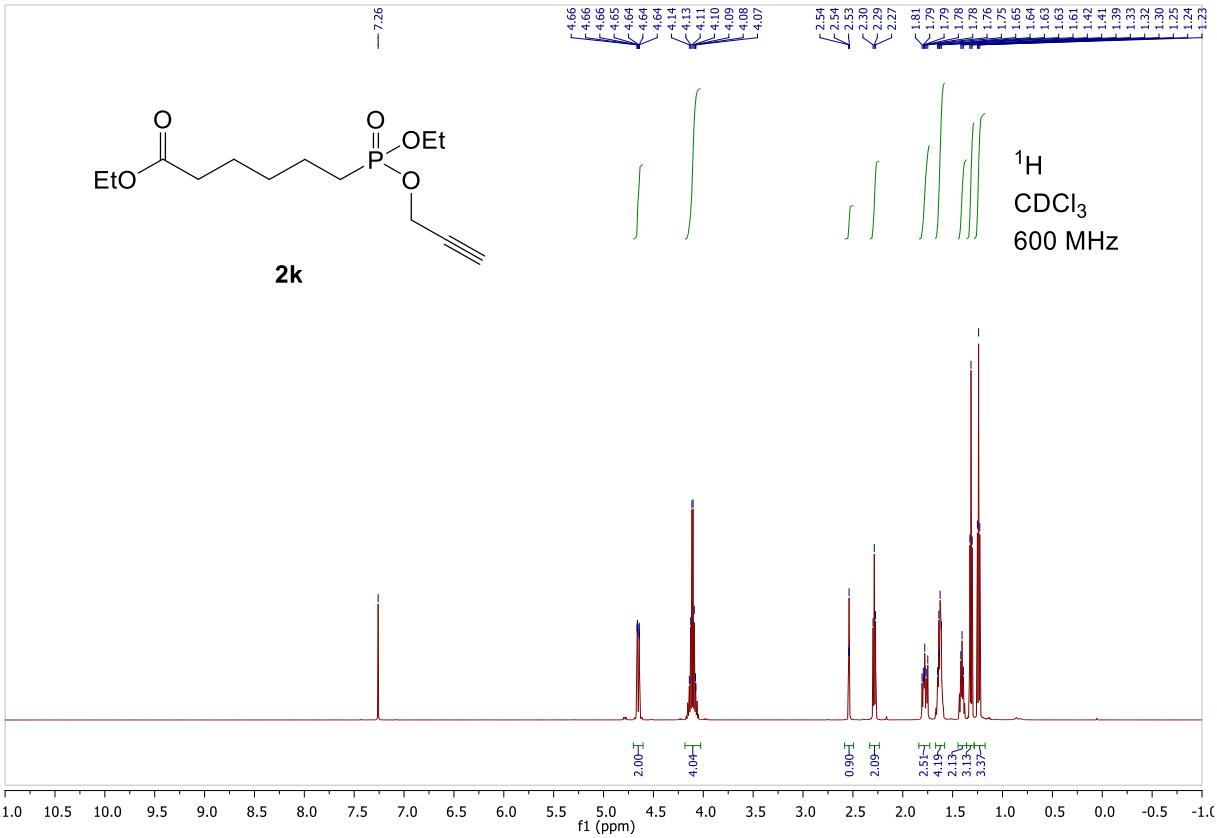

O
OEt
P
O
Ph
Me
2i
^{13}C (APT)
$CDCl_3$
150 MHz
f1 (ppm)

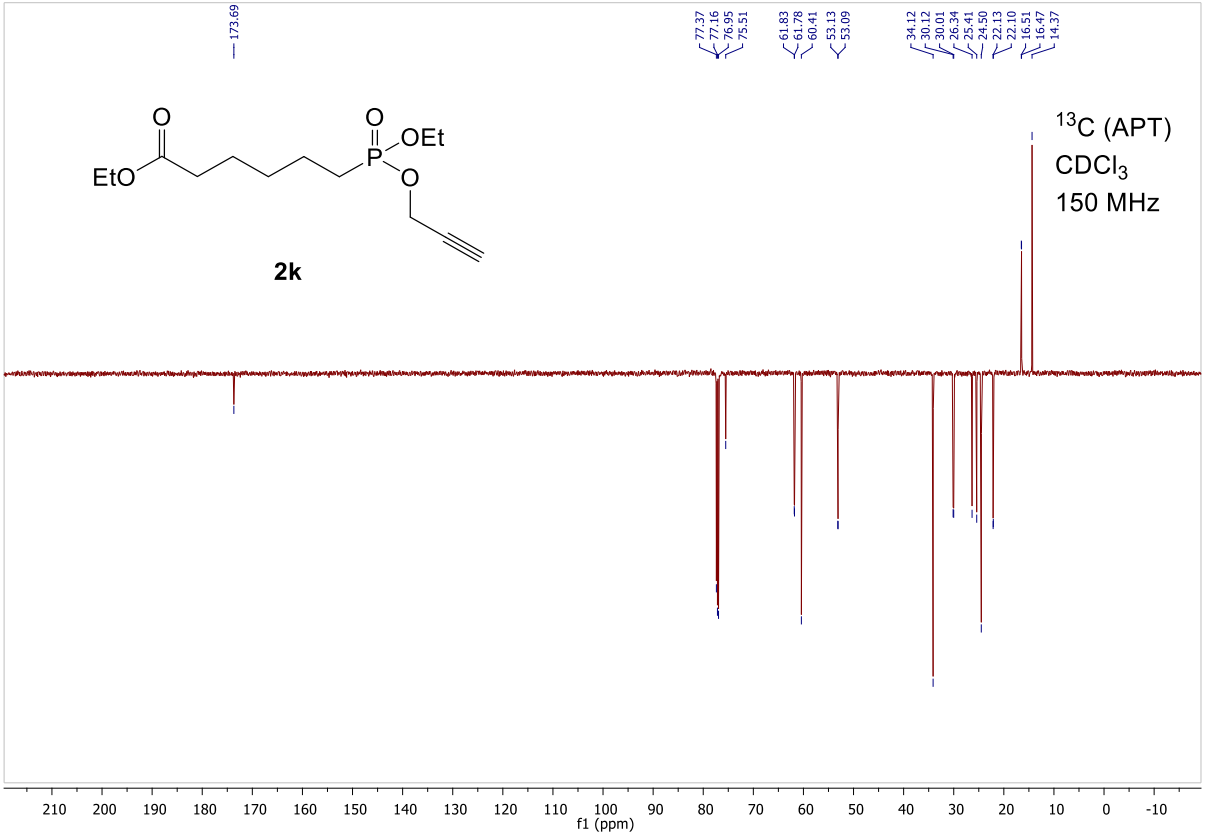

31.18
30.65
O
OEt
P
O
Ph
Me
2i
^{31}P
$CDCl_3$
162 MHz
240 220 200 180 160 140 120 100 80 60 40 20 0 -10 -30 -50 -70 -90 -120
f1 (ppm)

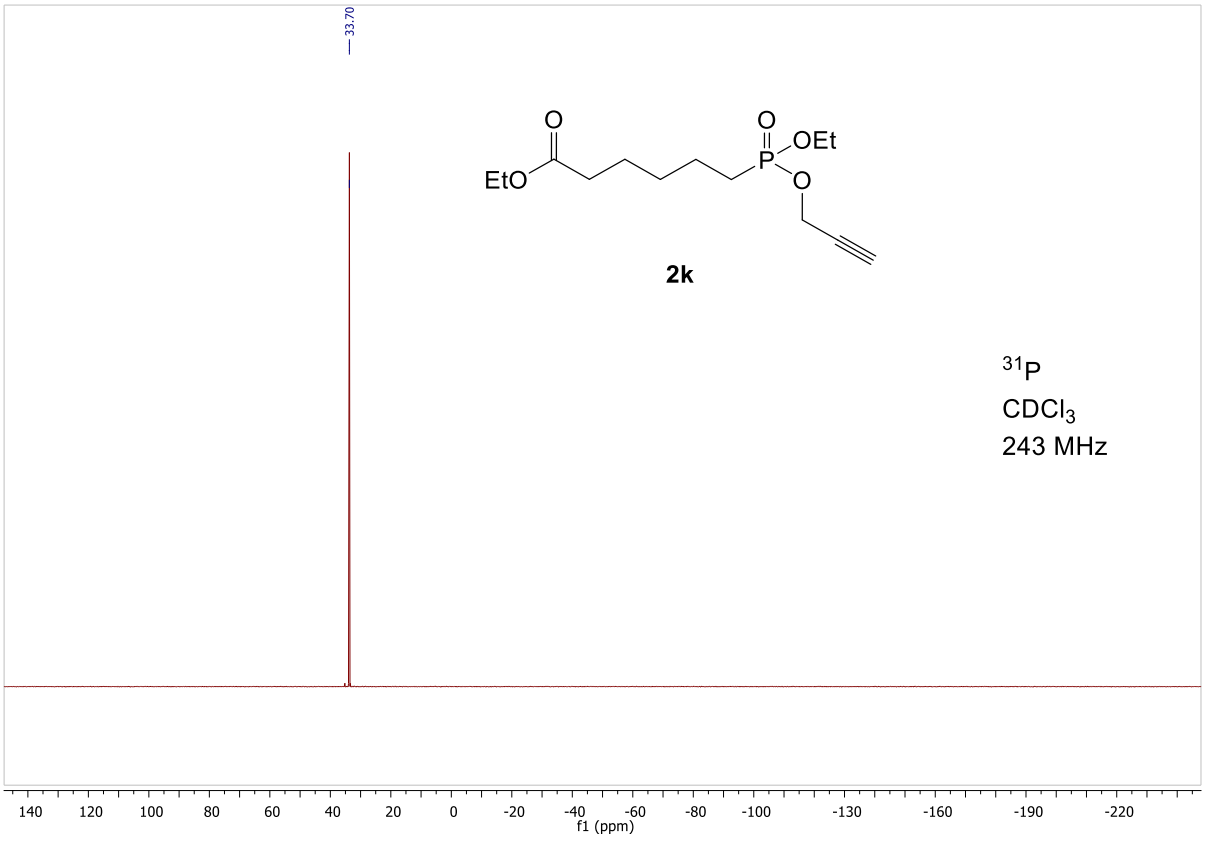

PhthN
O
OEt
P
O
2j
^{1}H
$CDCl_3$
400 MHz
f1 (ppm)

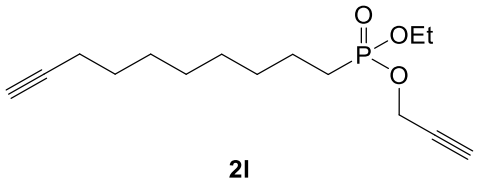

PhthN
O
OEt
P
O
2j
^{13}C (APT)
$CDCl_3$
100 MHz
f1 (ppm)


33.42
PhthN
O
OEt
P
O
2j
31P
CDCl3
162 MHz
240 220 200 180 160 140 120 100 80 60 40 20 0 -10 -30 -50 -70 -90 -120
f1 (ppm)


7.26
4.66
4.66
4.66
4.65
4.64
4.64
4.64
4.14
4.13
4.11
4.10
4.09
4.08
4.07
2.54
2.54
2.53
2.30
2.29
2.27
1.81
1.79
1.79
1.78
1.78
1.76
1.75
1.65
1.64
1.63
1.63
1.61
1.42
1.41
1.39
1.33
1.32
1.30
1.25
1.24
1.23
O
O
OEt
EtO
P
O
2k
1H
CDCl3
600 MHz
2.00
4.04
0.90
2.09
2.51
4.19
2.13
3.13
3.37
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 -0.5
f1 (ppm)

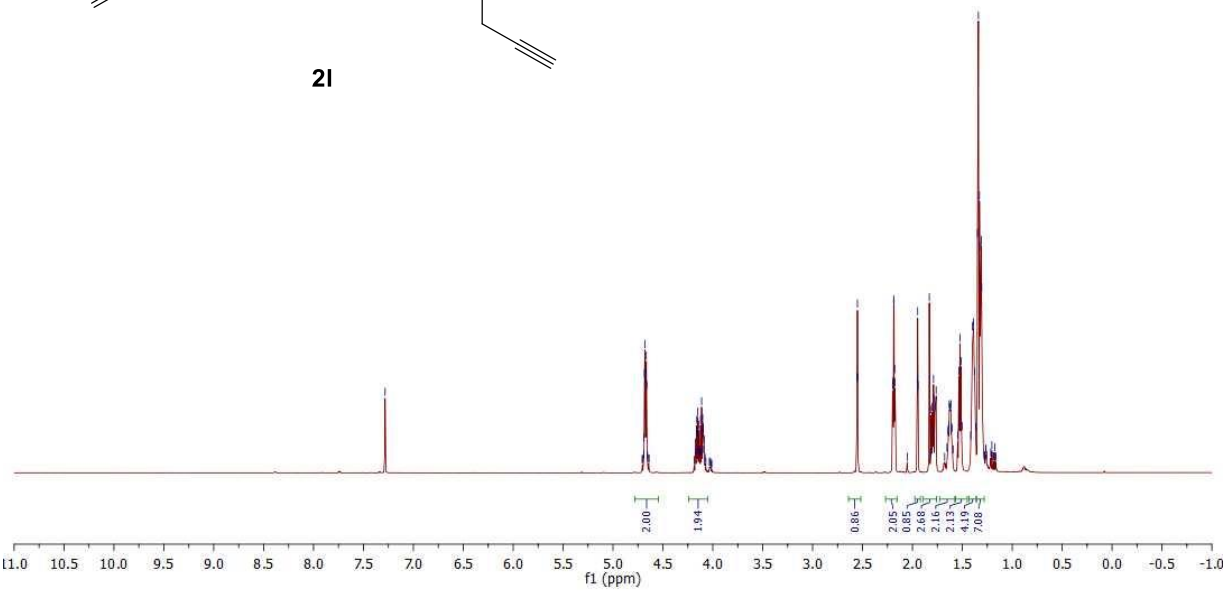

173.69
77.37
77.16
76.95
75.51
61.83
61.78
60.41
53.13
53.09
34.12
30.12
30.01
26.34
25.41
24.50
22.13
22.10
16.51
16.47
14.37
O
O
OEt
EtO
P
O
2k
13C (APT)
CDCl3
150 MHz
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

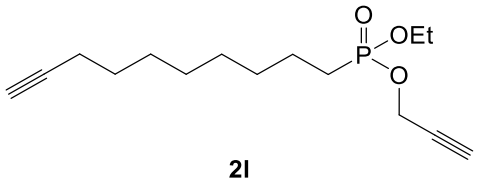

33.70
O
O
OEt
EtO
P
O
2k
^{31}P
$CDCl_3$
243 MHz
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-130
-160
-190
-220
f1 (ppm)



2l

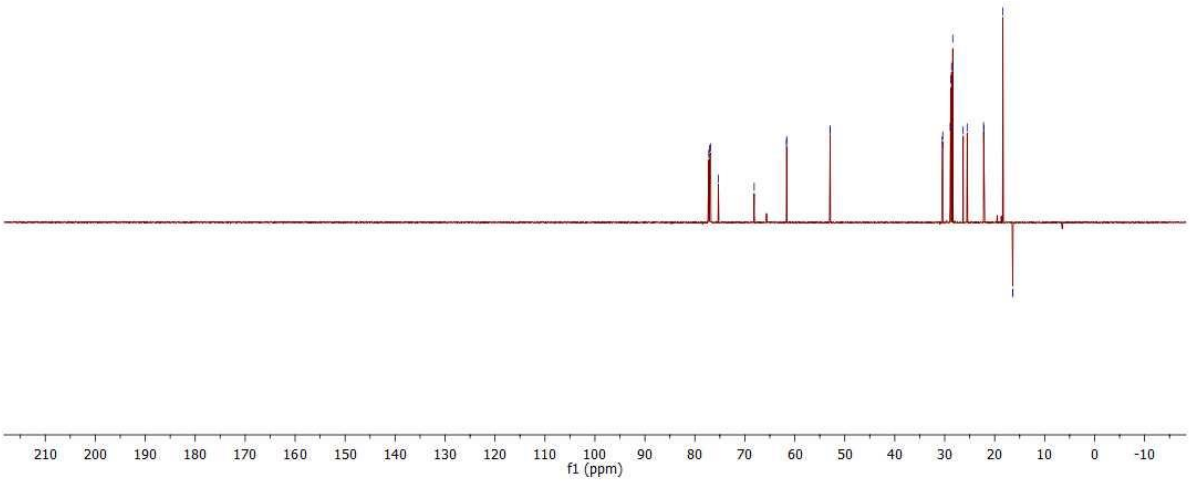
^{1}H
$CDCl_3$
700 MHz

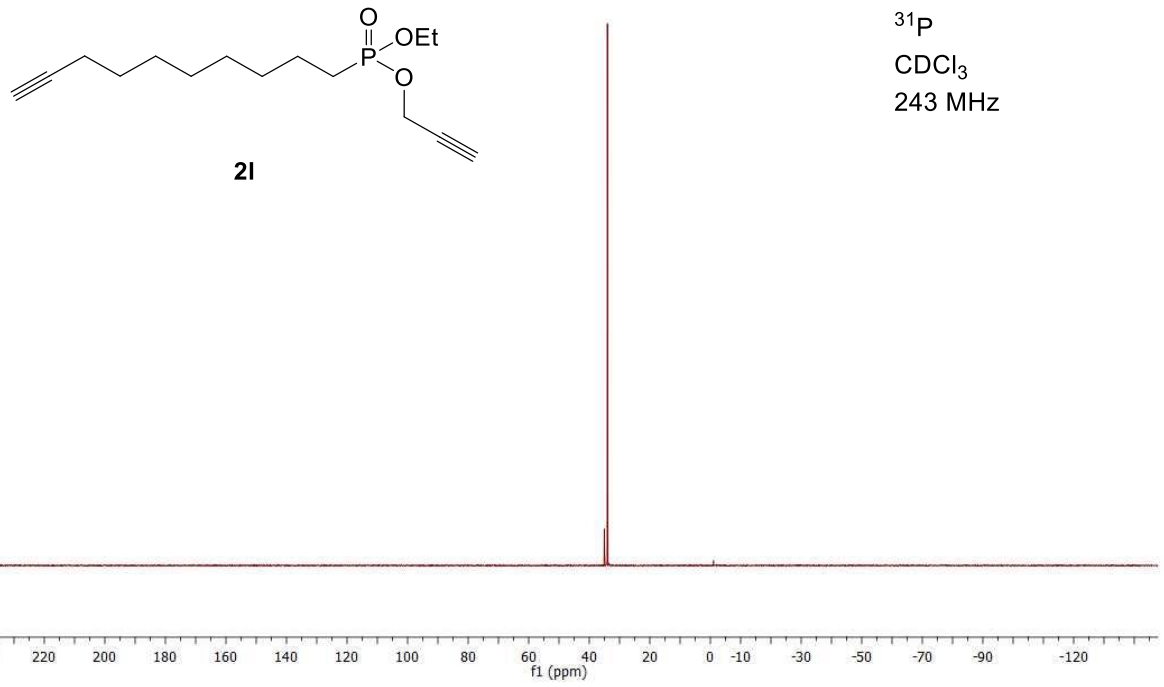




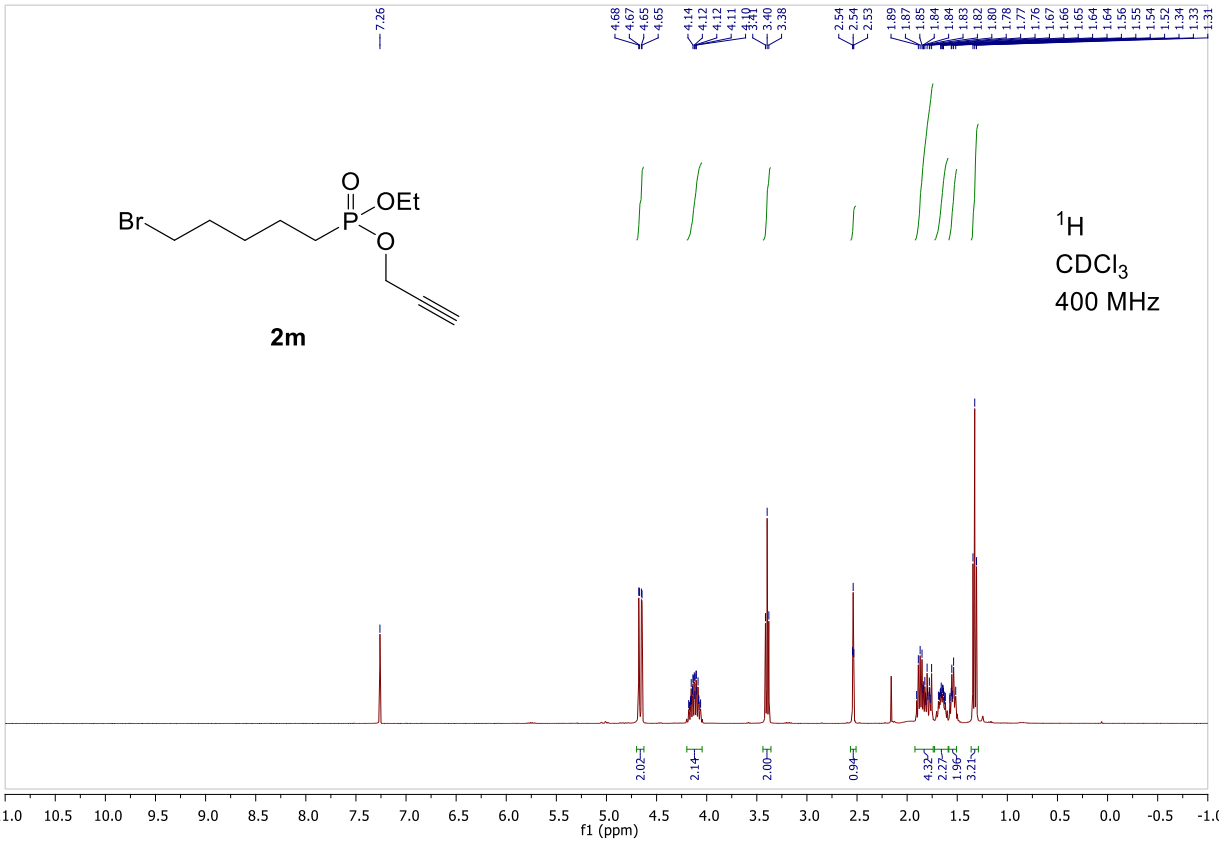
2l

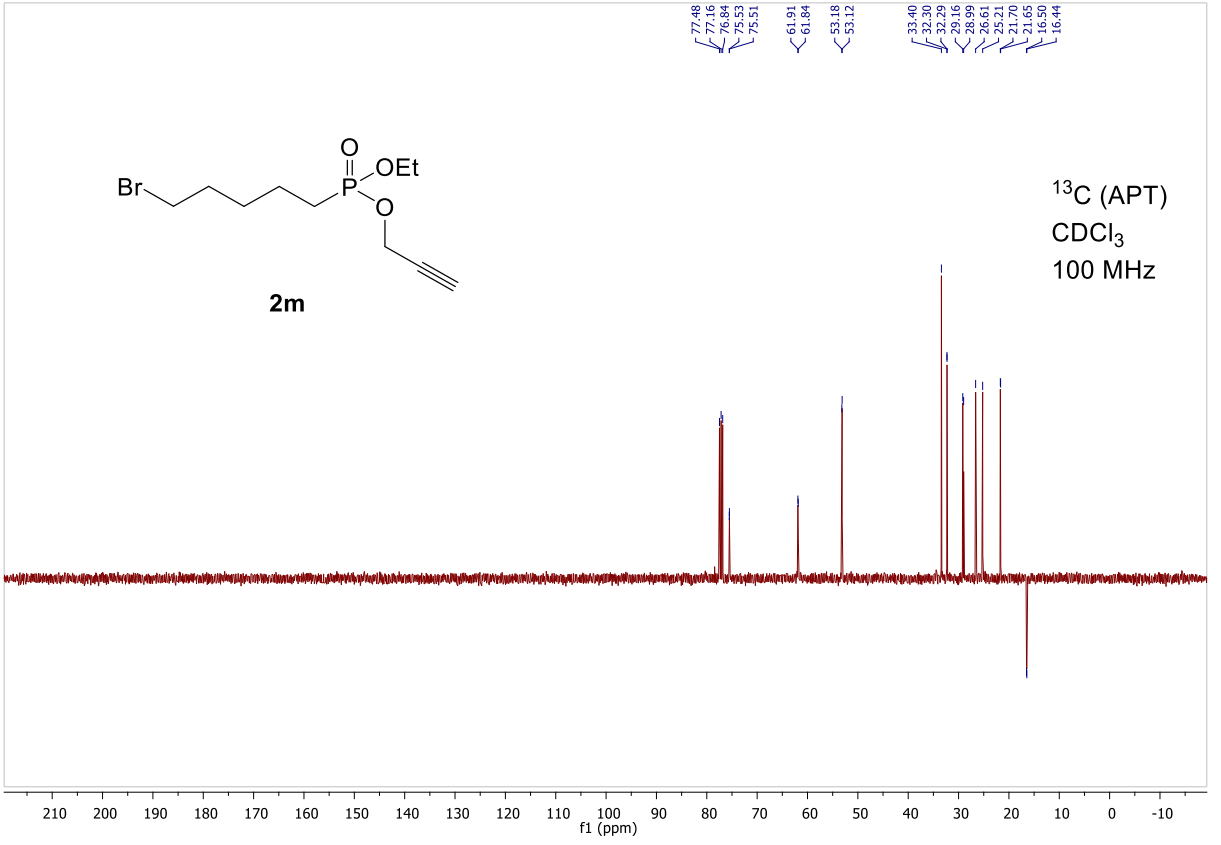
^{13}C (APT)
$CDCl_3$
175 MHz

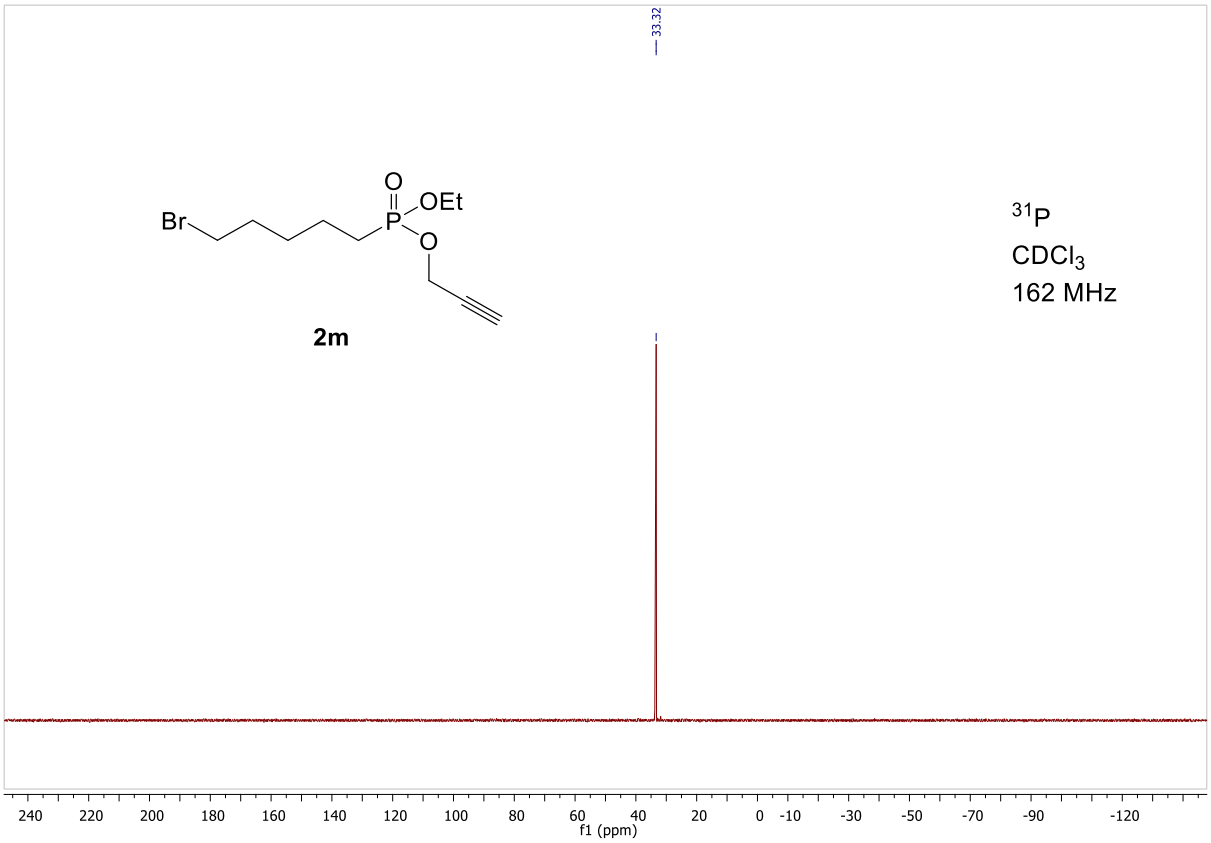


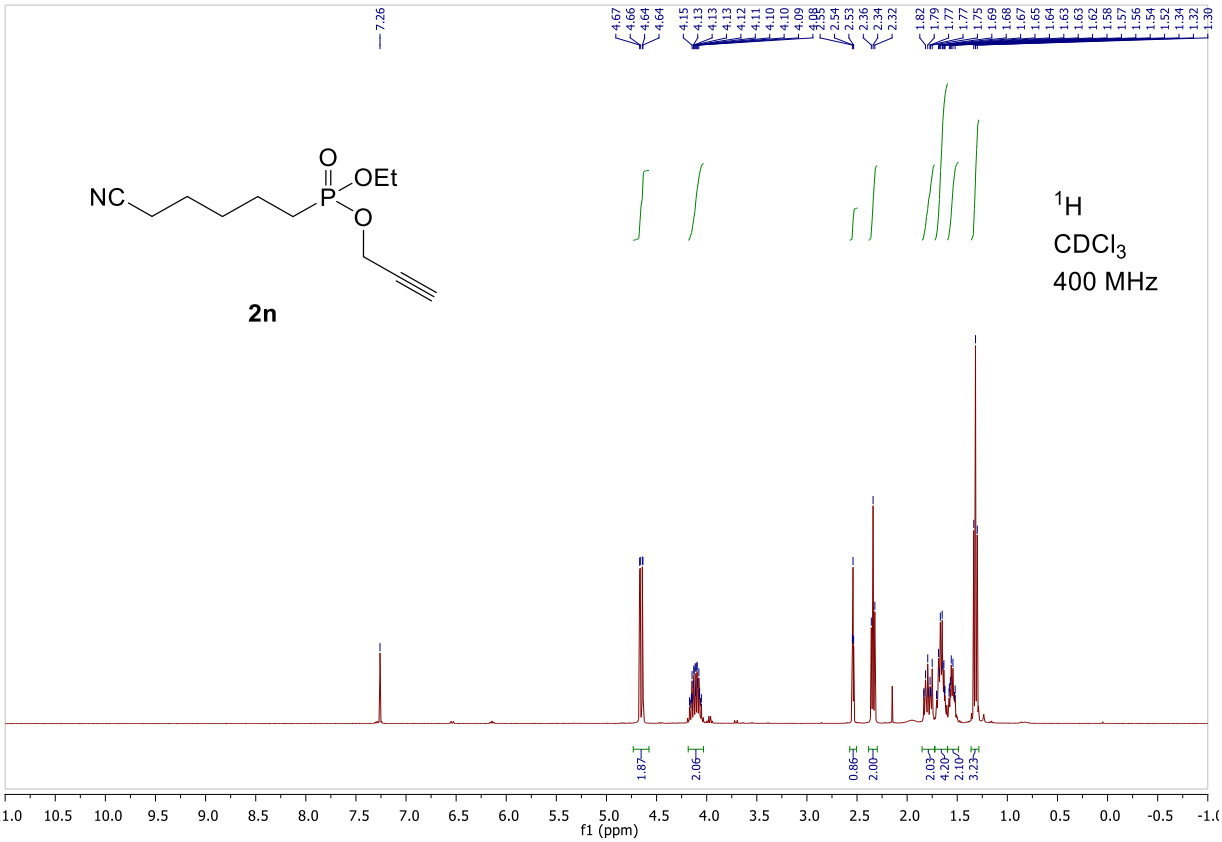

34.01
O
OEt
P
O
31P
CDCl3
243 MHz
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)

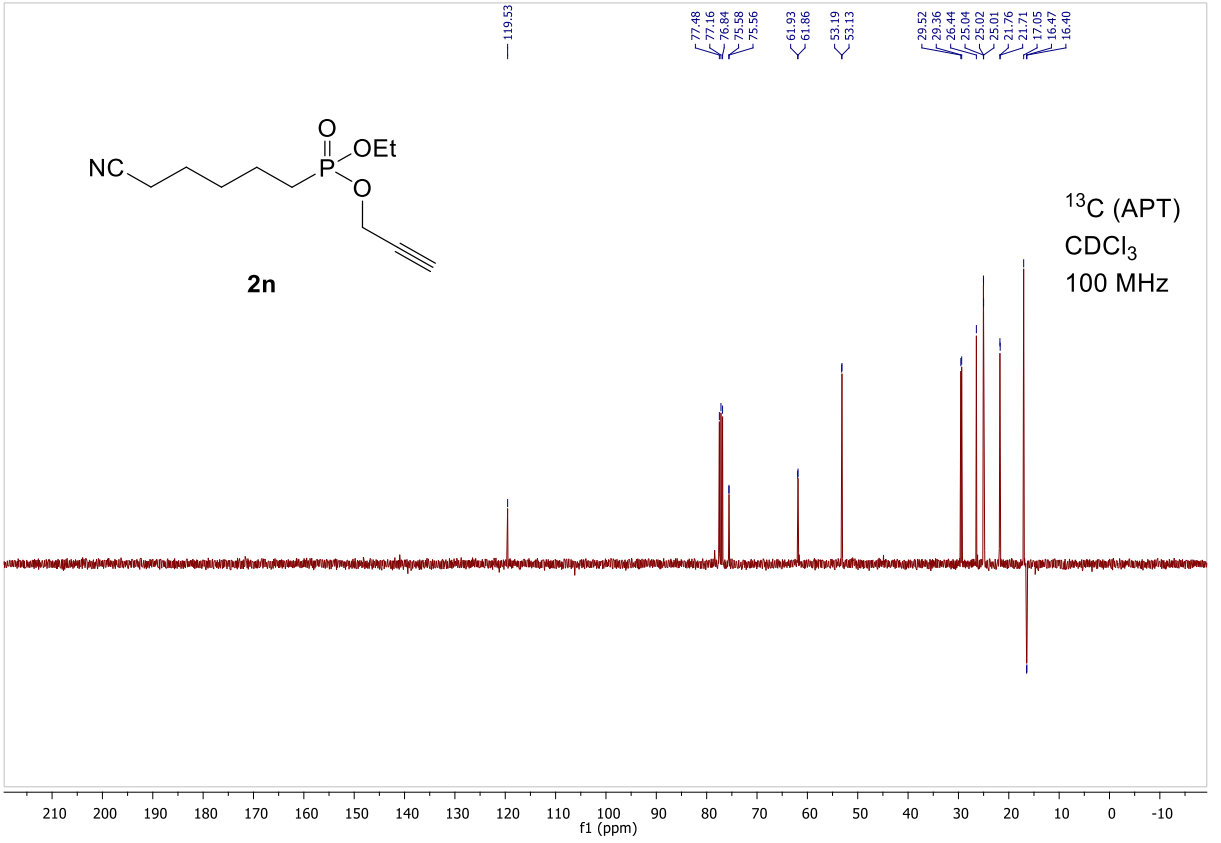
2l

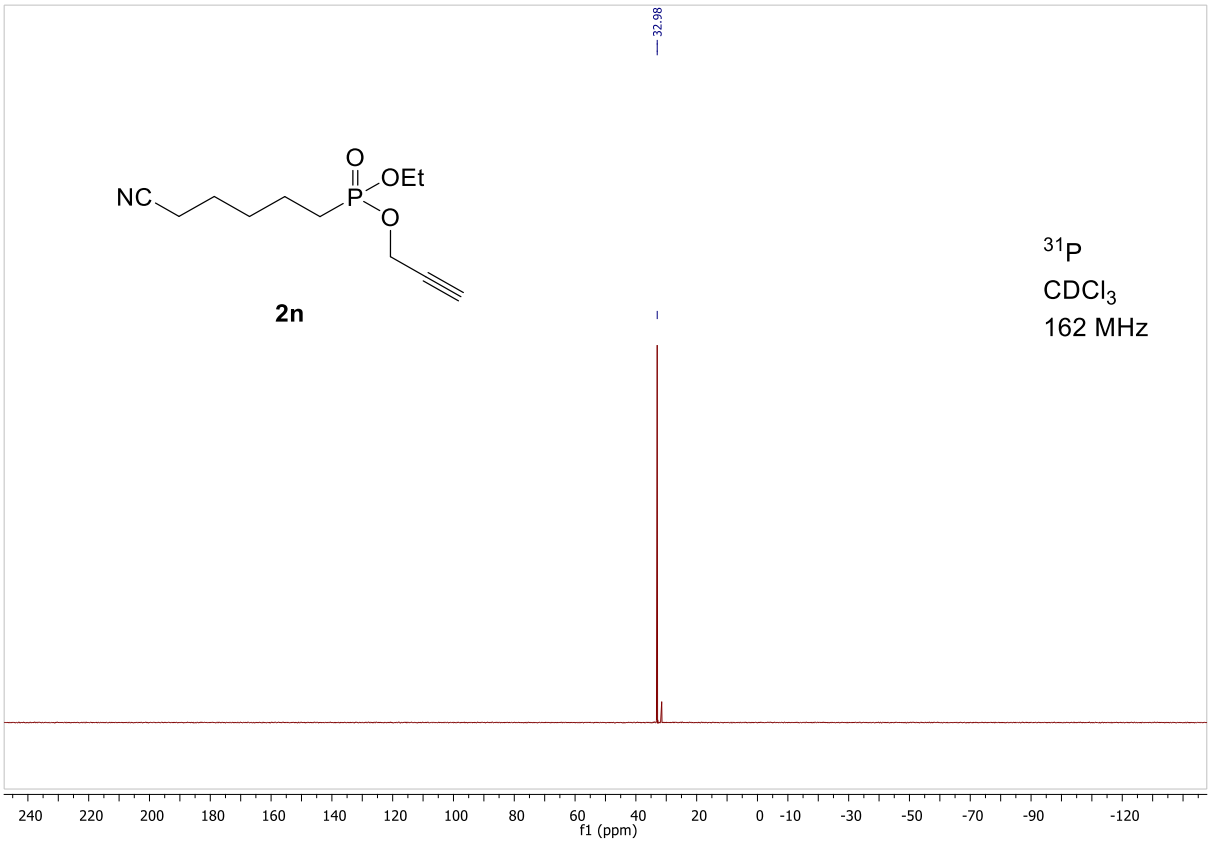

Br
O
OEt
P
O
2m
^{1}H
$CDCl_3$
400 MHz
f1 (ppm)

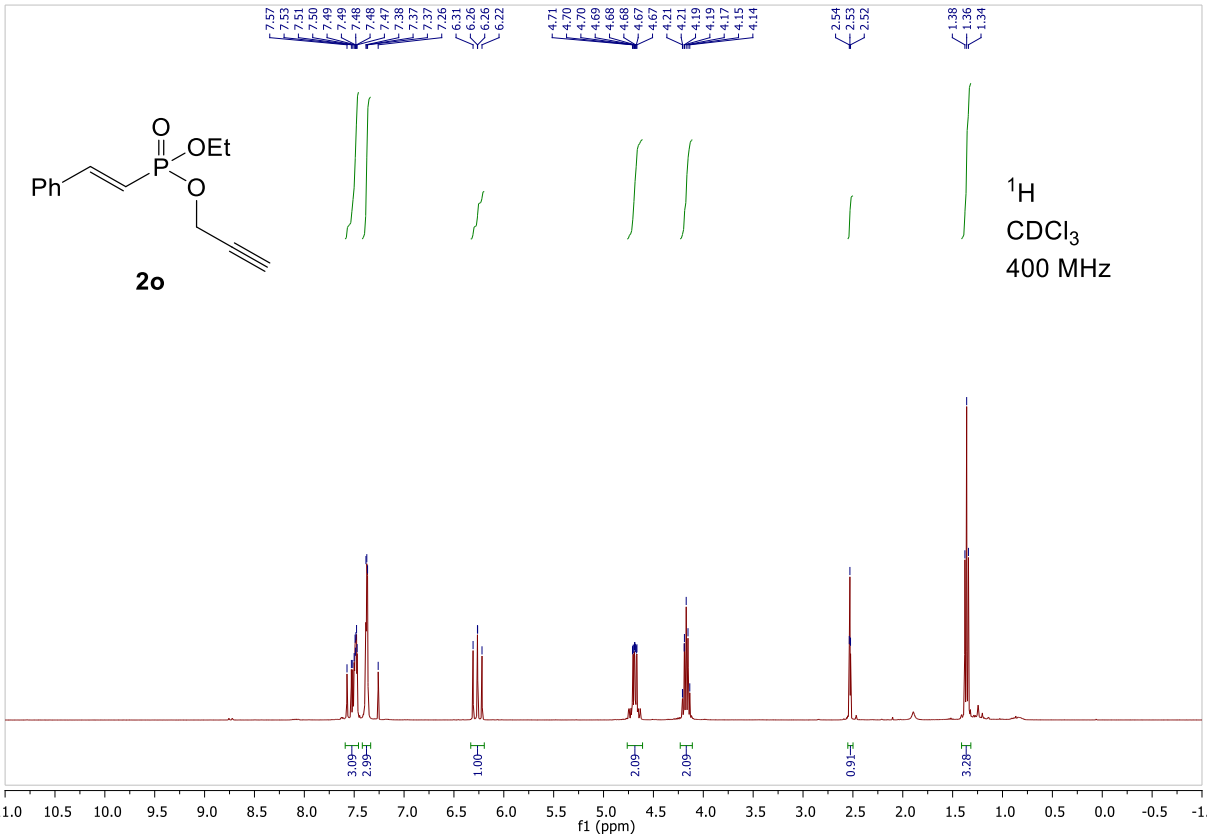

Br
O
OEt
P
O
2m
^{13}C (APT)
$CDCl_3$
100 MHz
f1 (ppm)

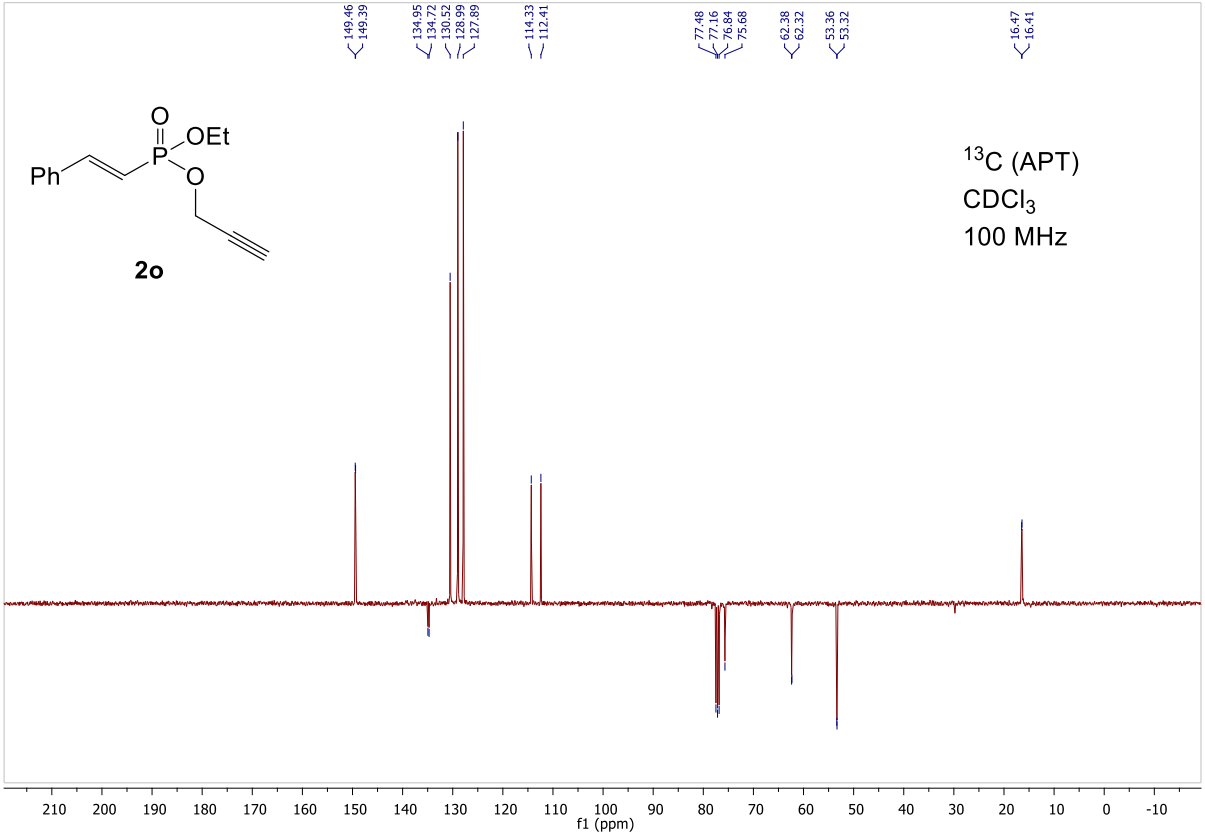

33.32
O
OEt
Br
P
O
2m
31P
CDCl3
162 MHz
240 220 200 180 160 140 120 100 80 60 40 20 0 -10 -30 -50 -70 -90 -120
f1 (ppm)

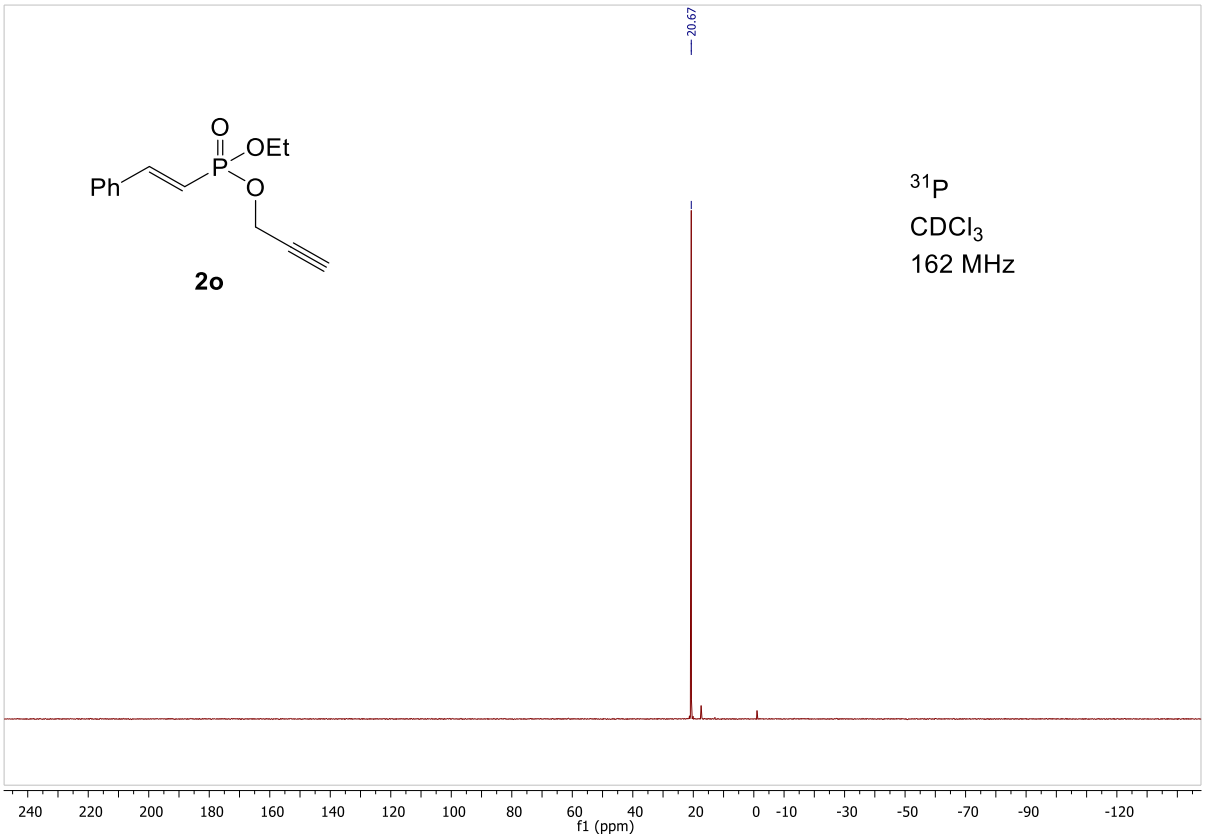

NC
O
OEt
P
O
2n
^{1}H
$CDCl_3$
400 MHz
f1 (ppm)

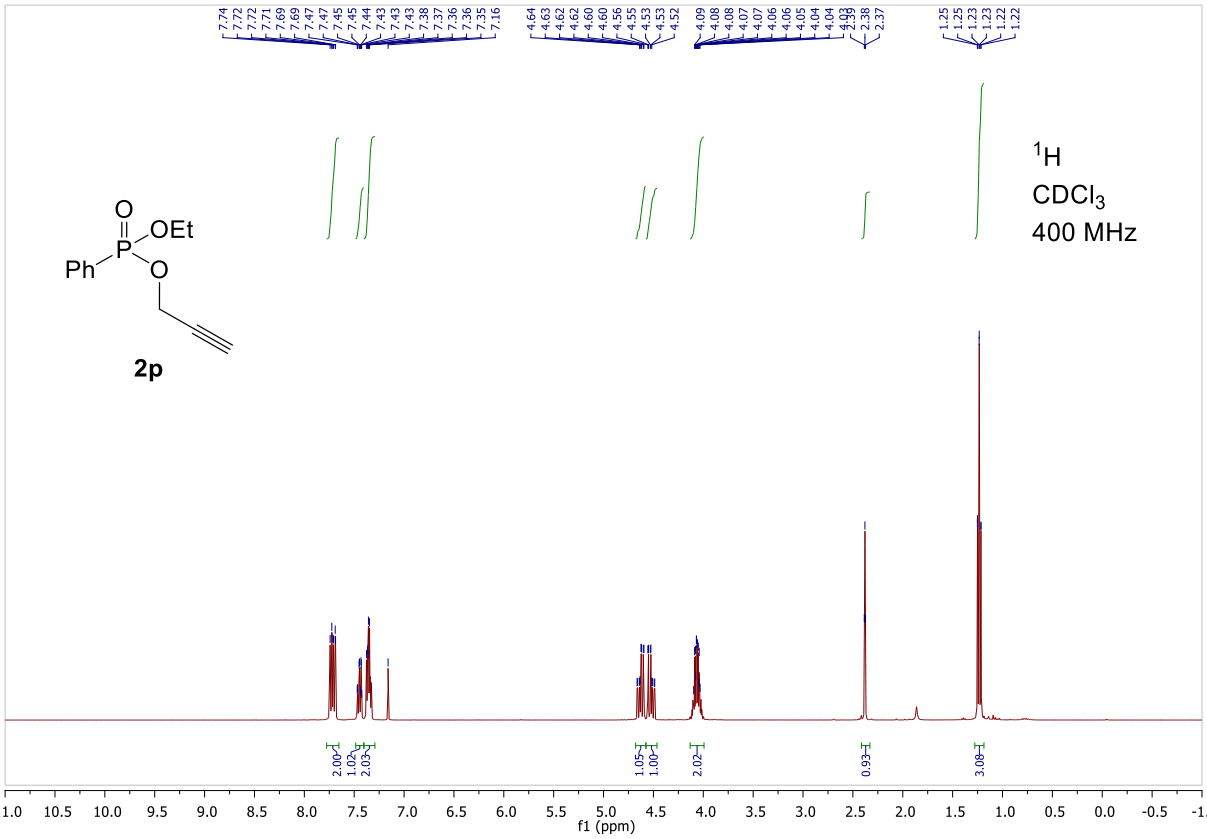

NC
O
OEt
P
O
2n
^{13}C (APT)
$CDCl_3$
100 MHz
f1 (ppm)

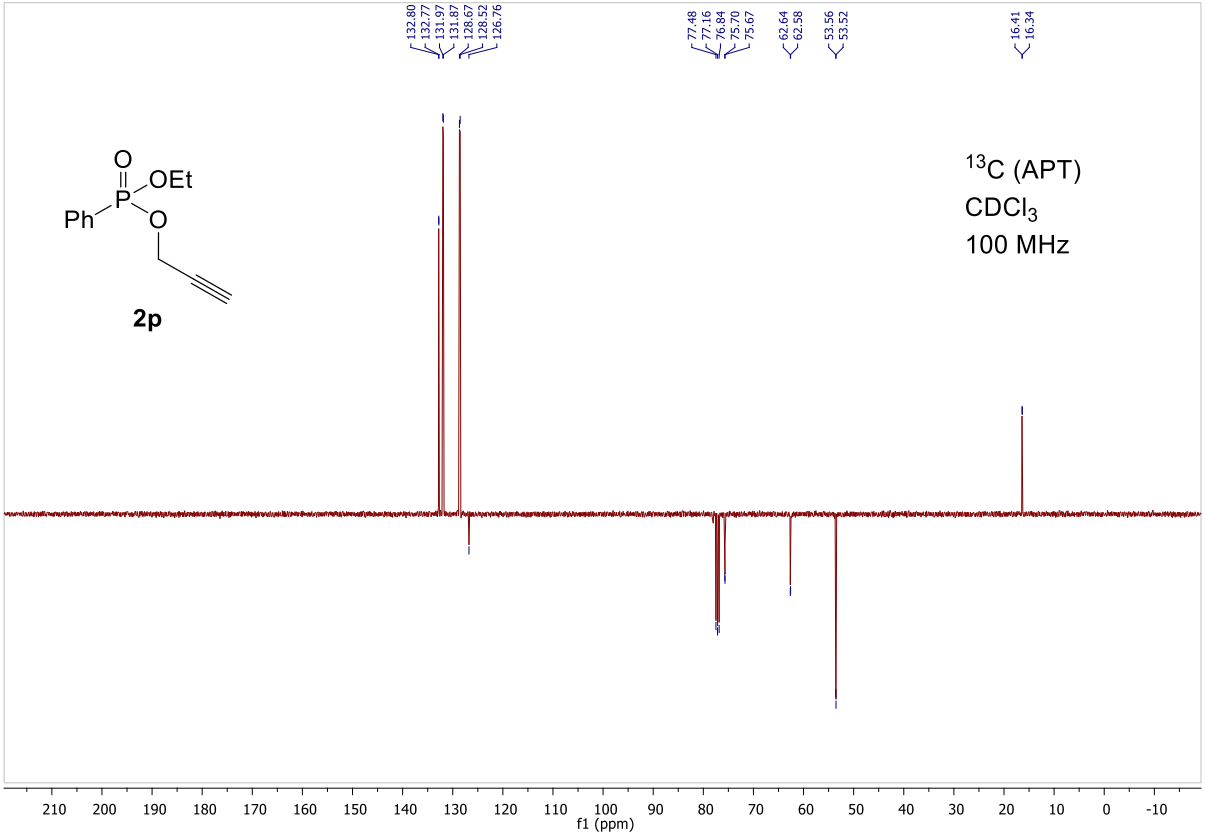

32.98
NC
O
OEt
P
O
2n
31P
CDCl3
162 MHz
240 220 200 180 160 140 120 100 80 60 40 20 0 -10 -30 -50 -70 -90 -120
f1 (ppm)

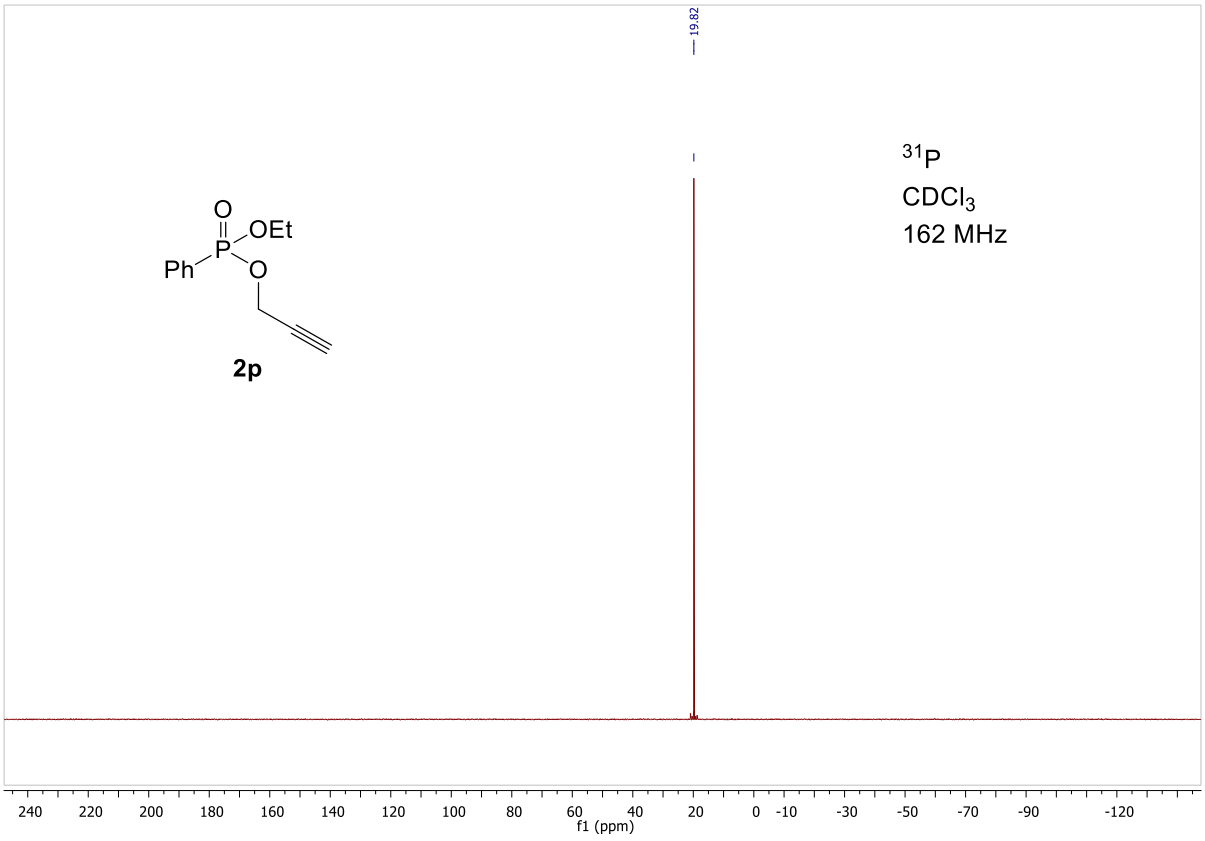

7.57
7.53
7.51
7.50
7.49
7.49
7.48
7.48
7.47
7.38
7.37
7.37
7.26
6.31
6.26
6.26
6.22
4.71
4.70
4.70
4.69
4.68
4.68
4.67
4.67
4.21
4.21
4.19
4.19
4.17
4.15
4.14
2.54
2.53
2.52
1.38
1.36
1.34
O
OEt
P
Ph
O
2o
1H
CDCl3
400 MHz
3.09
2.99
1.00
2.09
2.09
0.91
3.28
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 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 -0.5
f1 (ppm)

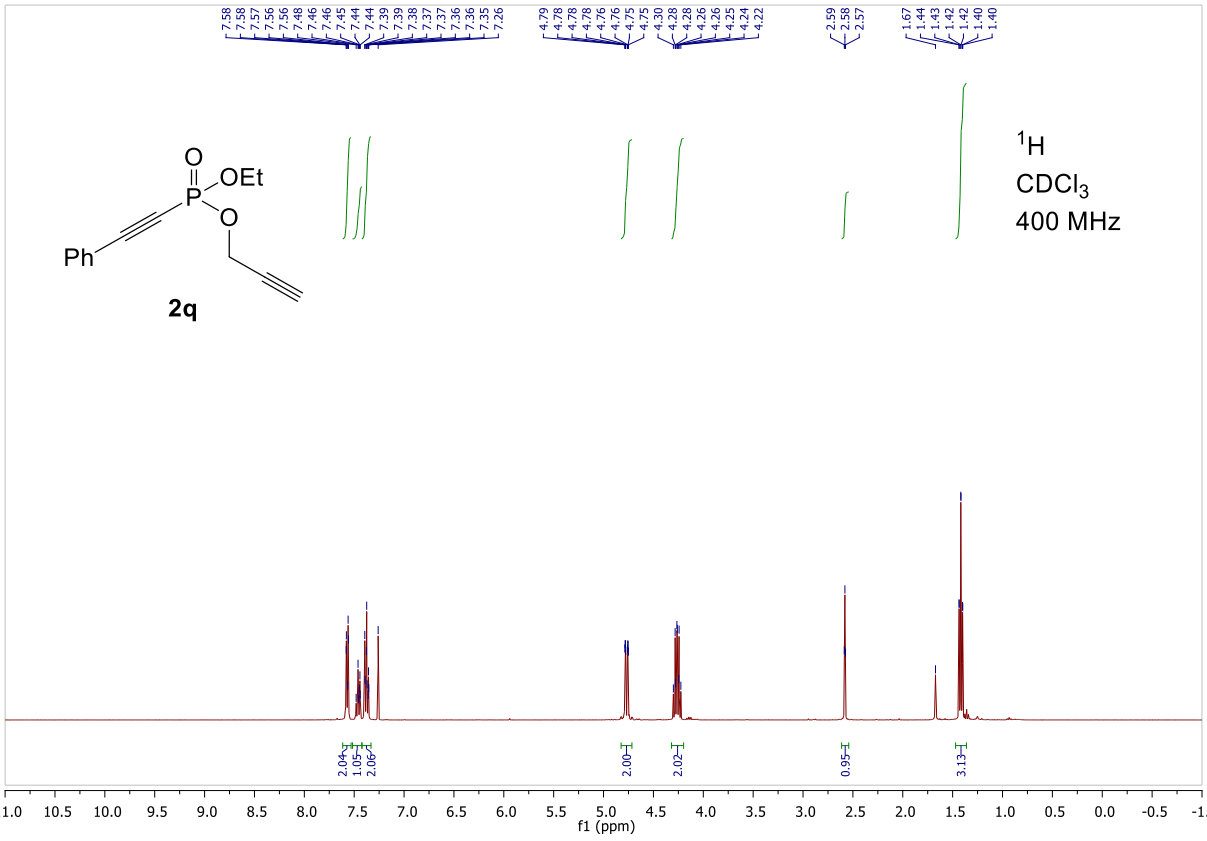

149.46
149.39
134.95
134.72
130.52
128.99
127.89
114.33
112.41
77.48
77.16
76.84
75.68
62.38
62.32
53.36
53.32
16.47
16.41
O
OEt
P
Ph
O
2o
13C (APT)
CDCl3
100 MHz
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

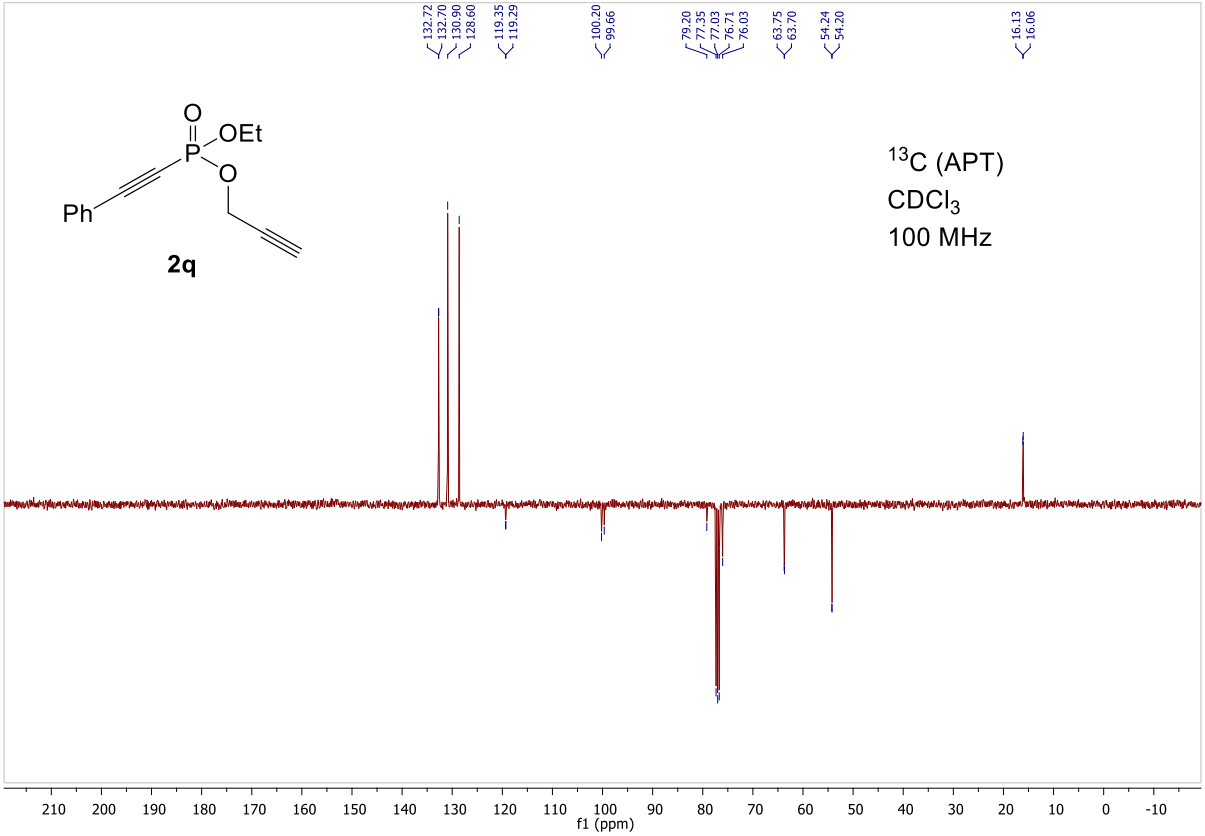

20.67
O
OEt
P
Ph
O
2o
31P
CDCl3
162 MHz
240 220 200 180 160 140 120 100 80 60 40 20 0 -10 -30 -50 -70 -90 -120
f1 (ppm)

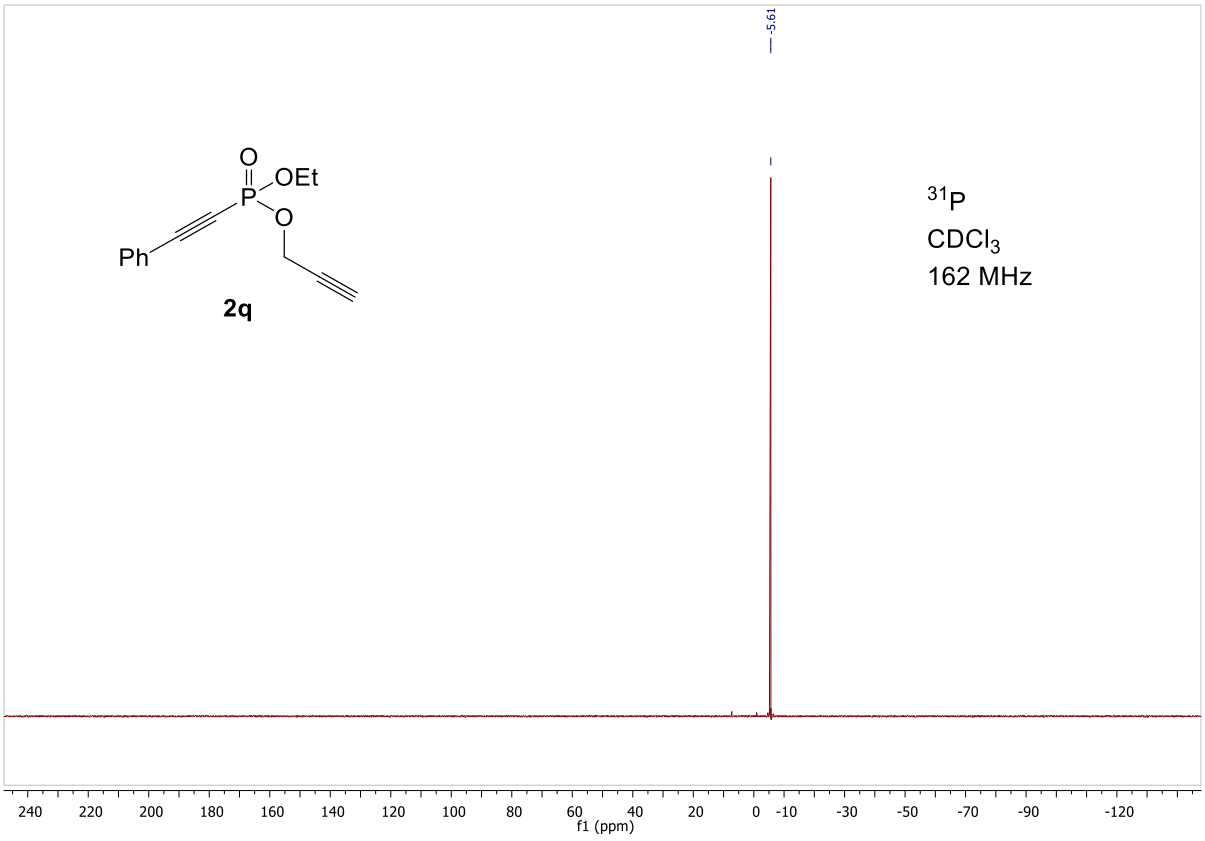

7.74 7.72 7.72 7.71 7.69 7.69 7.47 7.47 7.45 7.45 7.44 7.43 7.43 7.38 7.37 7.36 7.36 7.35 7.16
4.64 4.63 4.62 4.62 4.60 4.60 4.56 4.55 4.53 4.53 4.52
4.09 4.08 4.08 4.07 4.07 4.06 4.06 4.05 4.04 4.04 4.03 4.03
2.38 2.37
1.25 1.25 1.23 1.23 1.22 1.22
^{1}H
$CDCl_3$
400 MHz
O
OEt
Ph
P
O
2p
2.00 1.02 2.03 1.05 1.00 2.02 0.93 3.08
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 -0.5
f1 (ppm)

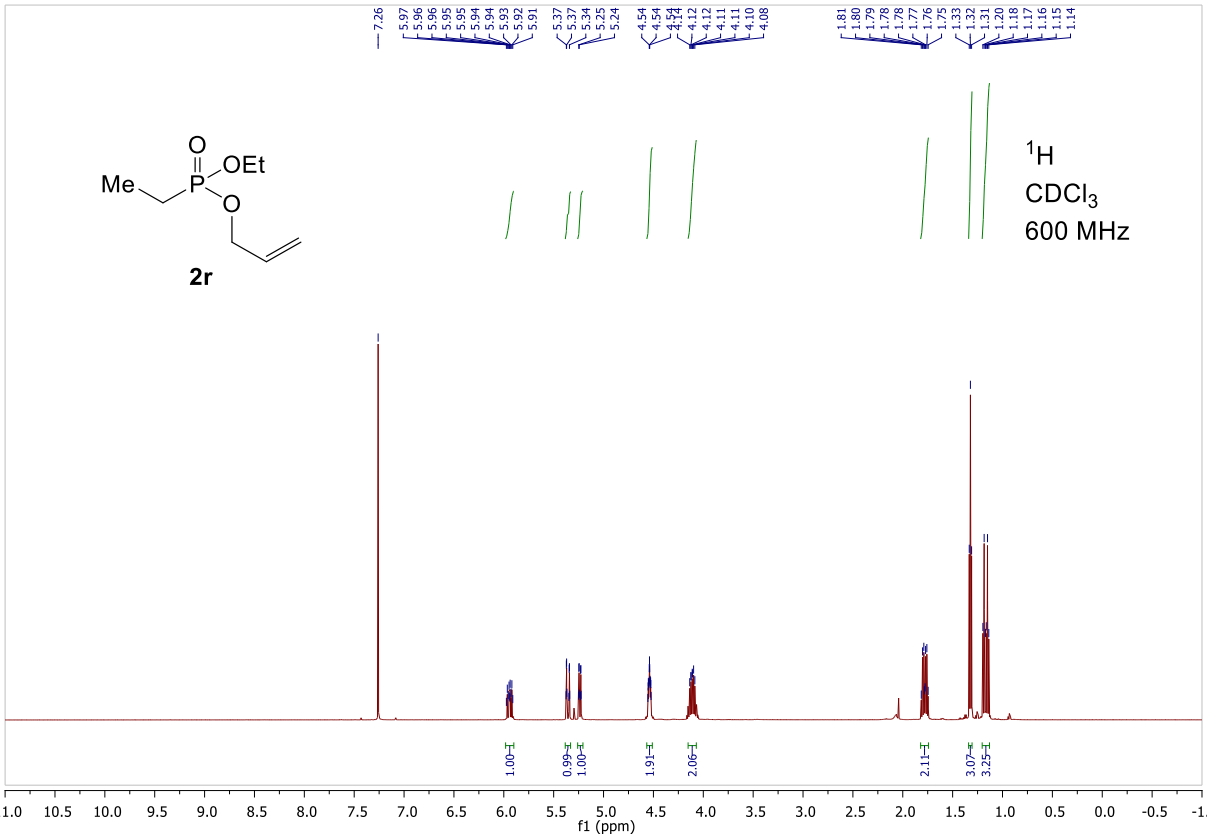

132.80 132.77 131.97 131.87 128.67 128.52 126.76
77.48 77.16 76.84 75.70 75.67
62.64 62.58
53.56 53.52
16.41 16.34
^{13}C (APT)
$CDCl_3$
100 MHz
O
OEt
Ph
P
O
2p
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

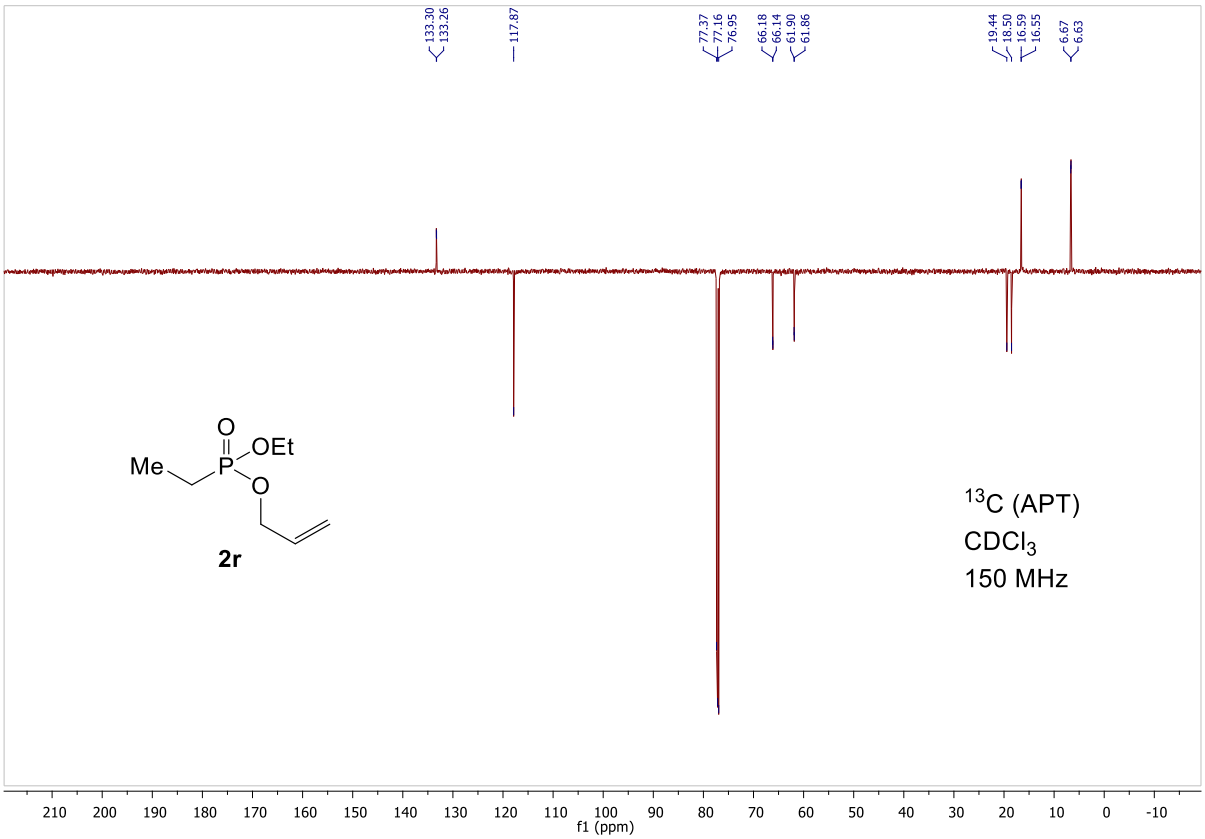

19.82
O
OEt
P
Ph
O
2p
31P
CDCl3
162 MHz
240 220 200 180 160 140 120 100 80 60 40 20 0 -10 -30 -50 -70 -90 -120
f1 (ppm)

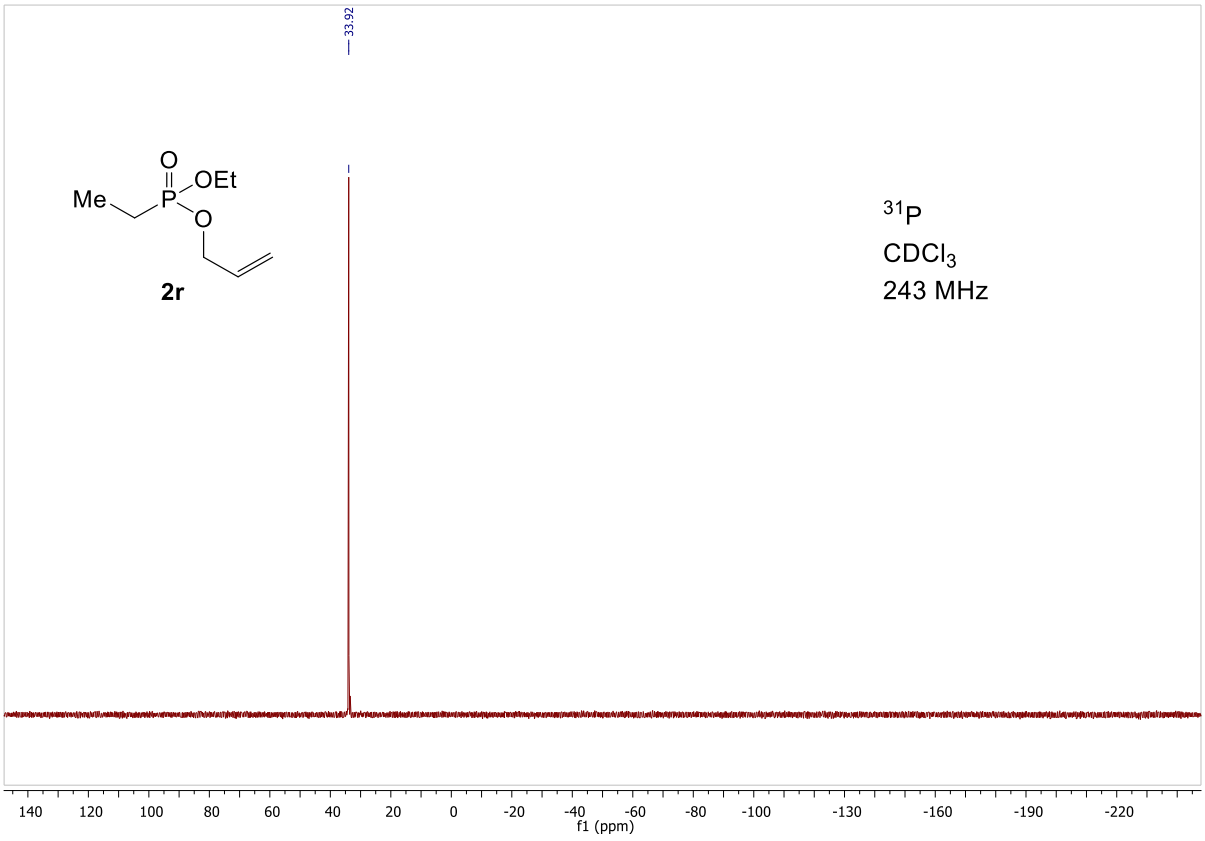

7.58 7.58 7.57 7.56 7.56 7.48 7.46 7.46 7.45 7.44 7.44 7.39 7.39 7.38 7.37 7.37 7.36 7.36 7.35 7.26
4.79 4.78 4.78 4.78 4.76 4.76 4.75 4.75 4.30 4.28 4.28 4.26 4.26 4.25 4.24 4.22
2.59 2.58 2.57
1.67 1.44 1.43 1.42 1.42 1.40 1.40
O
OEt
P
O
Ph
2q
1H
CDCl3
400 MHz
2.04 1.05 2.06 2.00 2.02 0.95 3.13
11.0 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 -0.5
f1 (ppm)

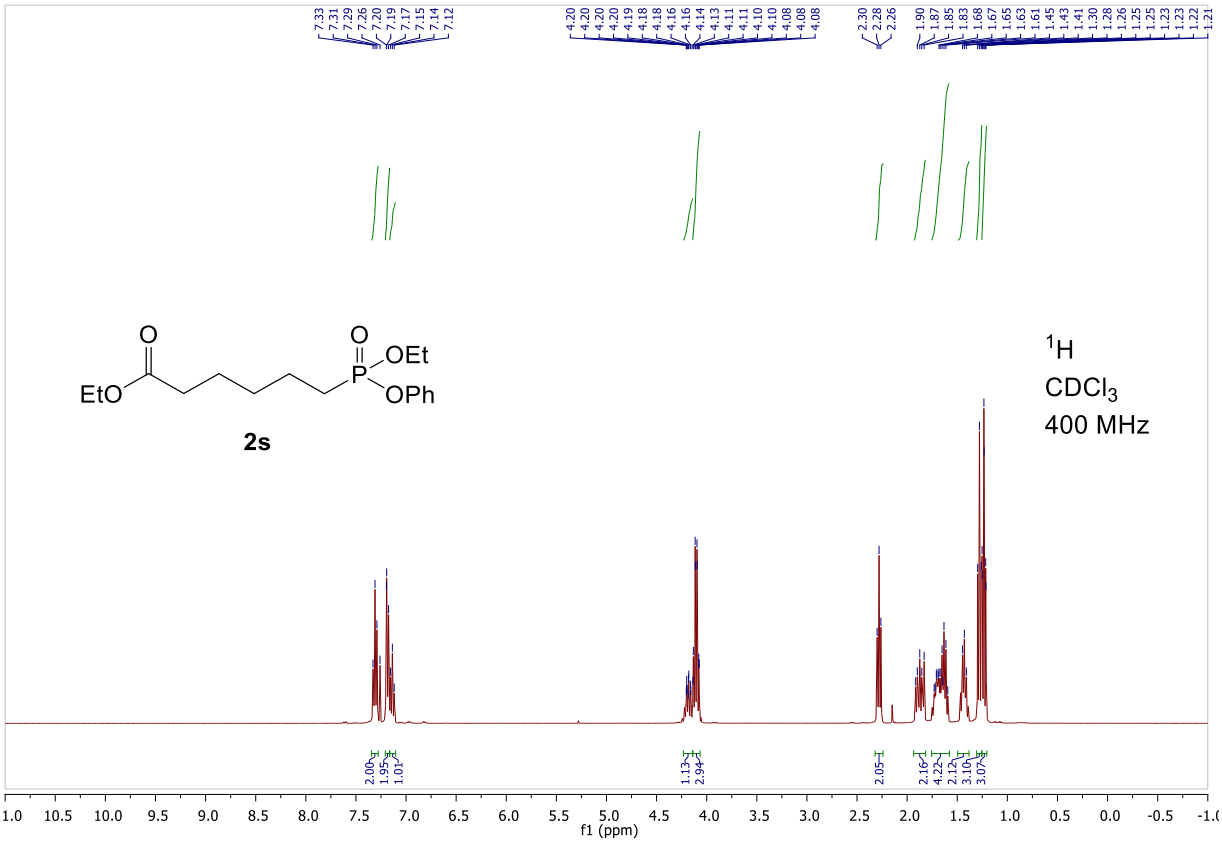

132.72 132.70 130.90 128.60 119.35 119.29 100.20 99.66 79.20 77.35 77.03 76.71 76.03 63.75 63.70 54.24 54.20 16.13 16.06
O
OEt
P
O
Ph
2q
13C (APT)
CDCl3
100 MHz
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

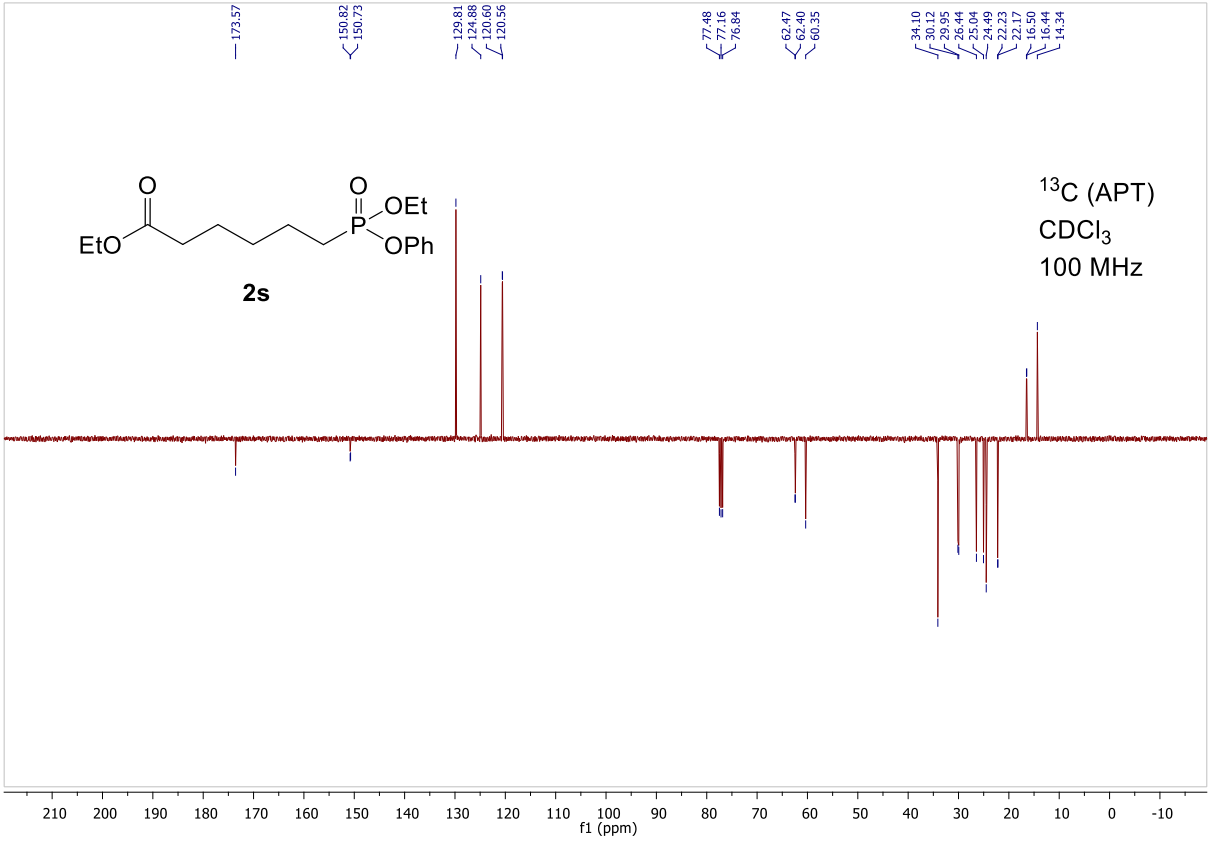

-5.61
O
OEt
P
O
Ph
2q
31P
CDCl3
162 MHz
240 220 200 180 160 140 120 100 80 60 40 20 0 -10 -30 -50 -70 -90 -120
f1 (ppm)

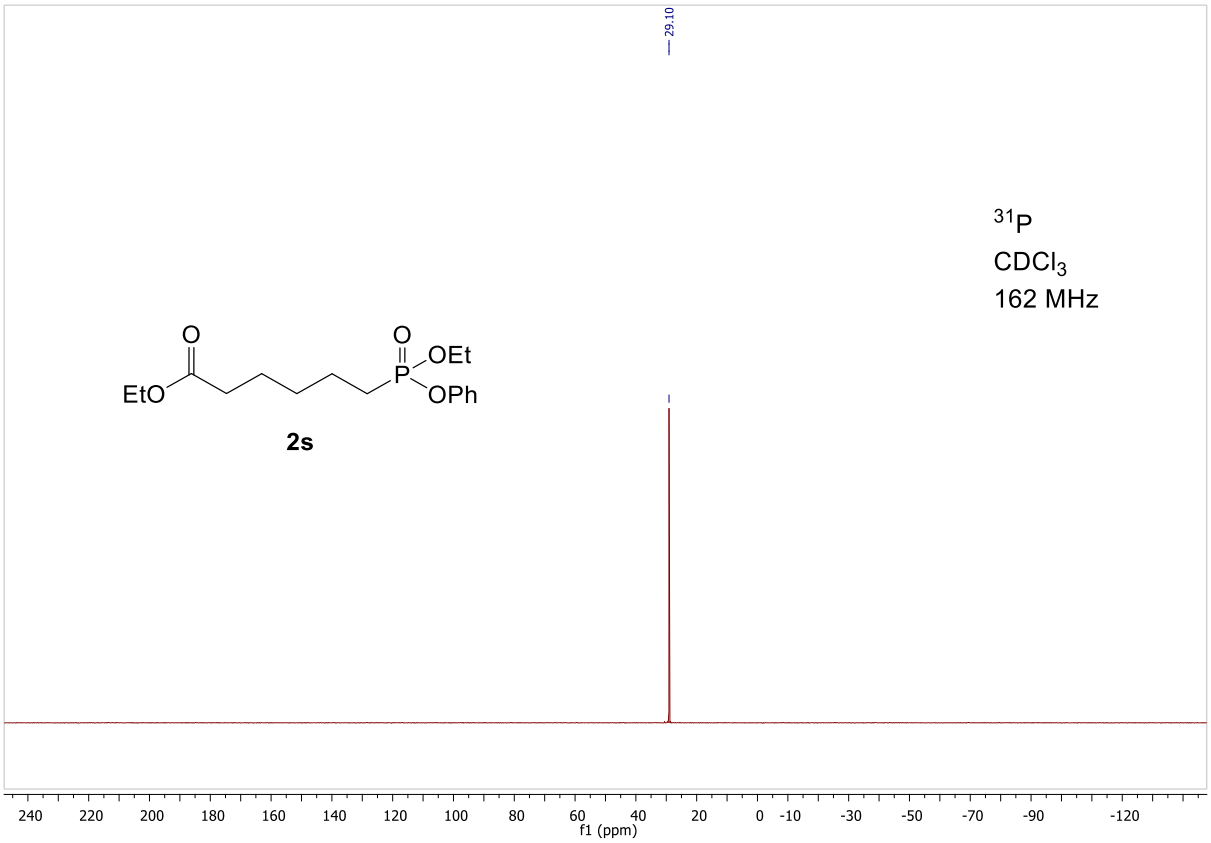

Me
O
OEt
P
O
2r
^{1}H
$CDCl_3$
600 MHz
f1 (ppm)

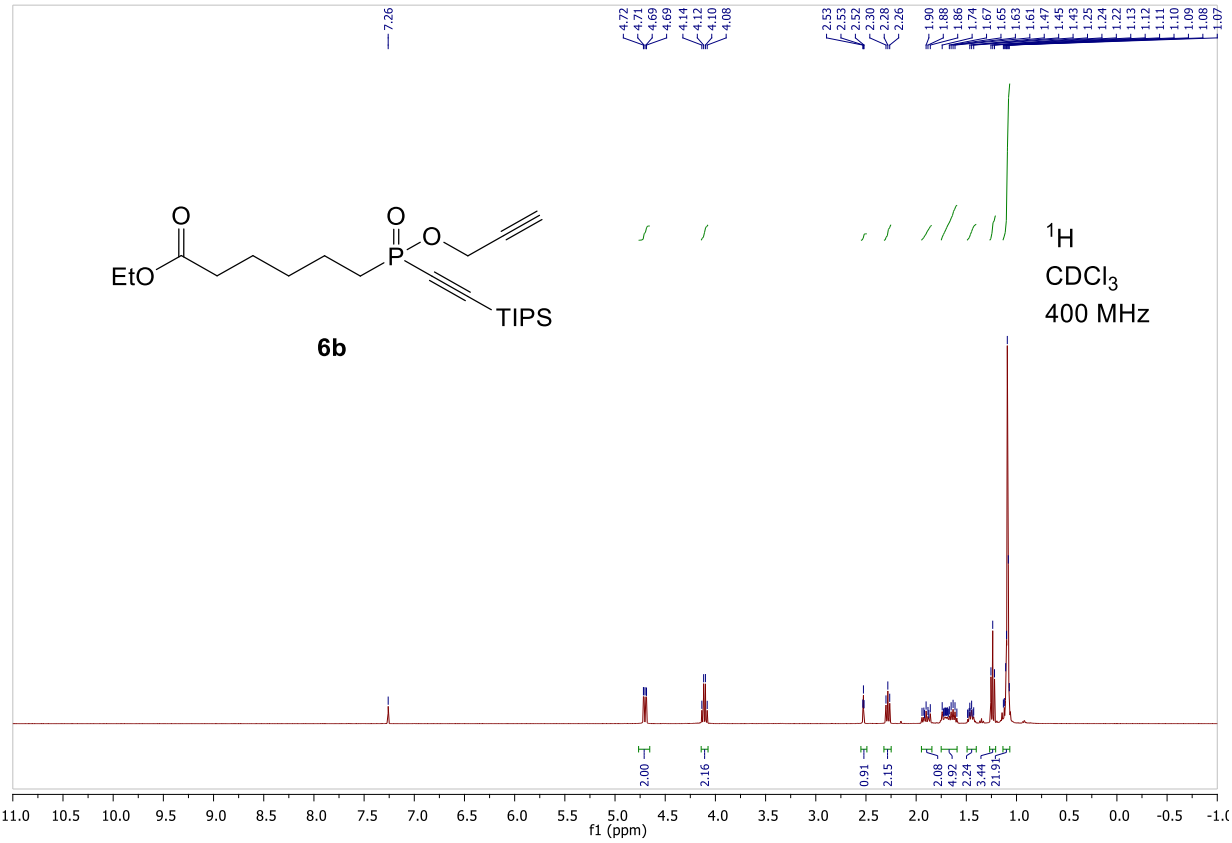

Me
O
OEt
P
O
2r
^{13}C (APT)
$CDCl_3$
150 MHz
f1 (ppm)

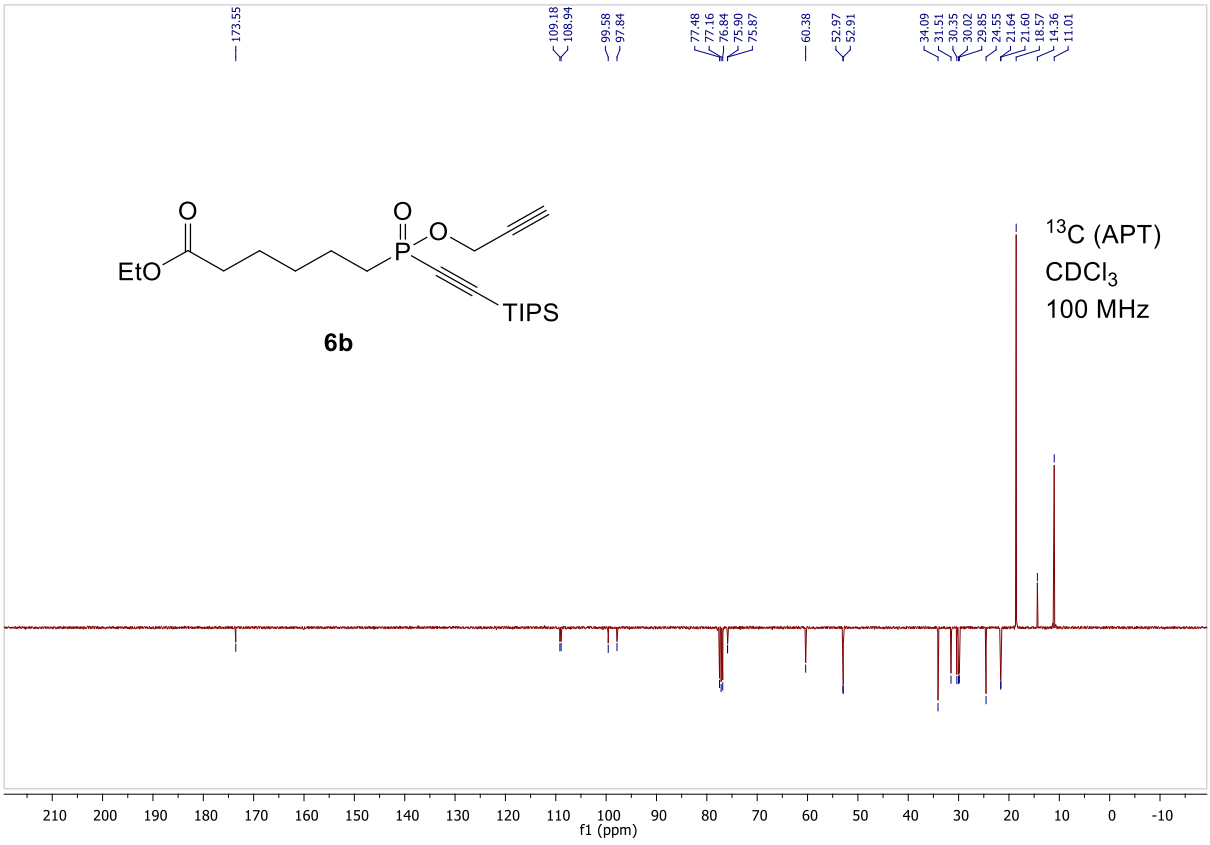

33.92
O
OEt
Me
P
O
2r
31P
CDCl3
243 MHz
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-130
-160
-190
-220
f1 (ppm)

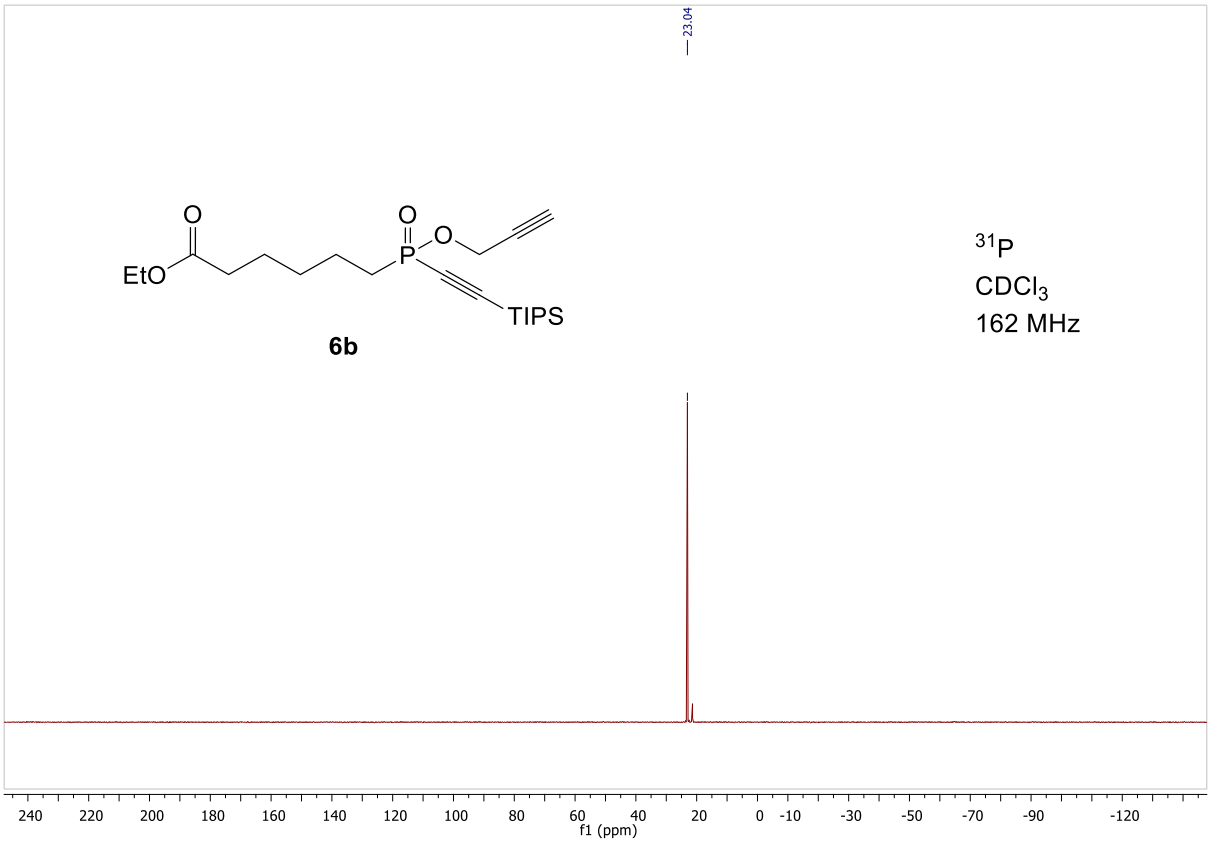

EtO
OEt
OPh
2s
^{1}H
$CDCl_3$
400 MHz
f1 (ppm)

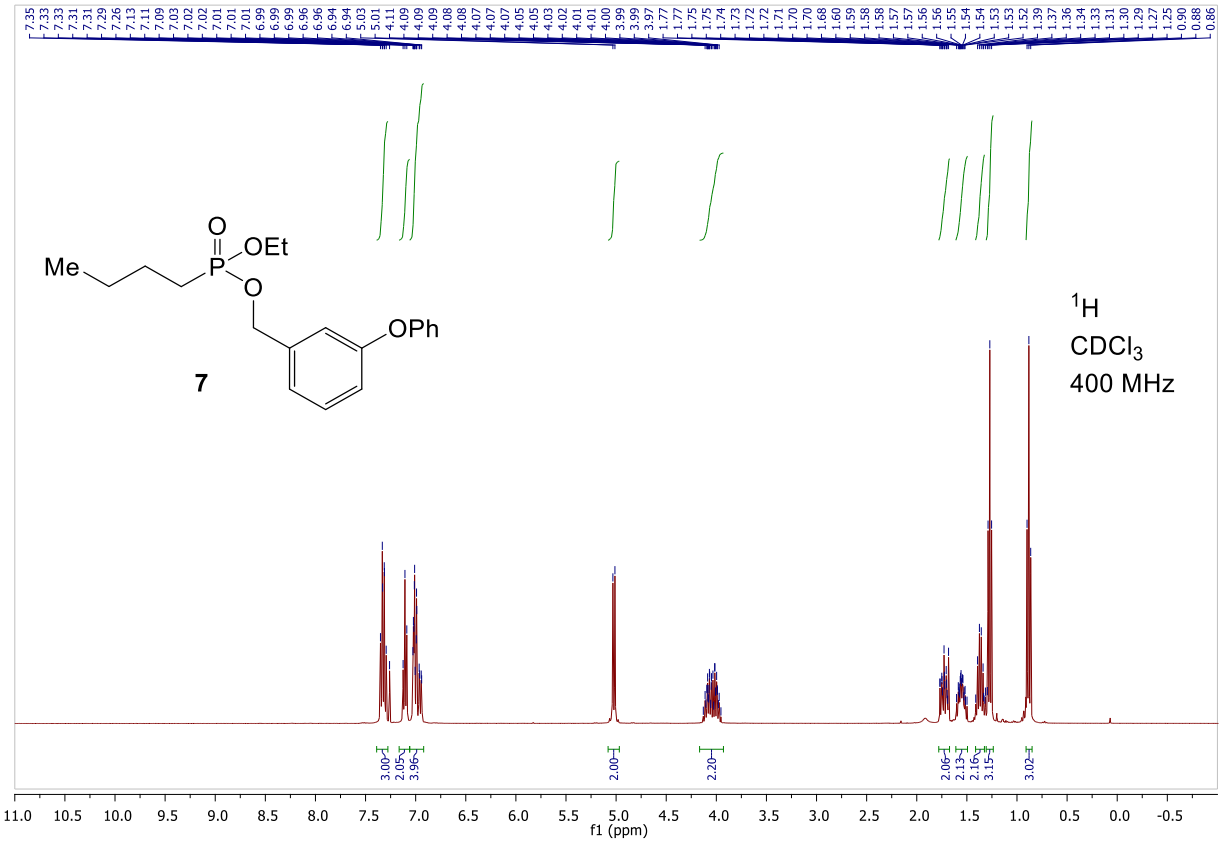

EtO
OEt
OPh
2s
^{13}C (APT)
$CDCl_3$
100 MHz
f1 (ppm)

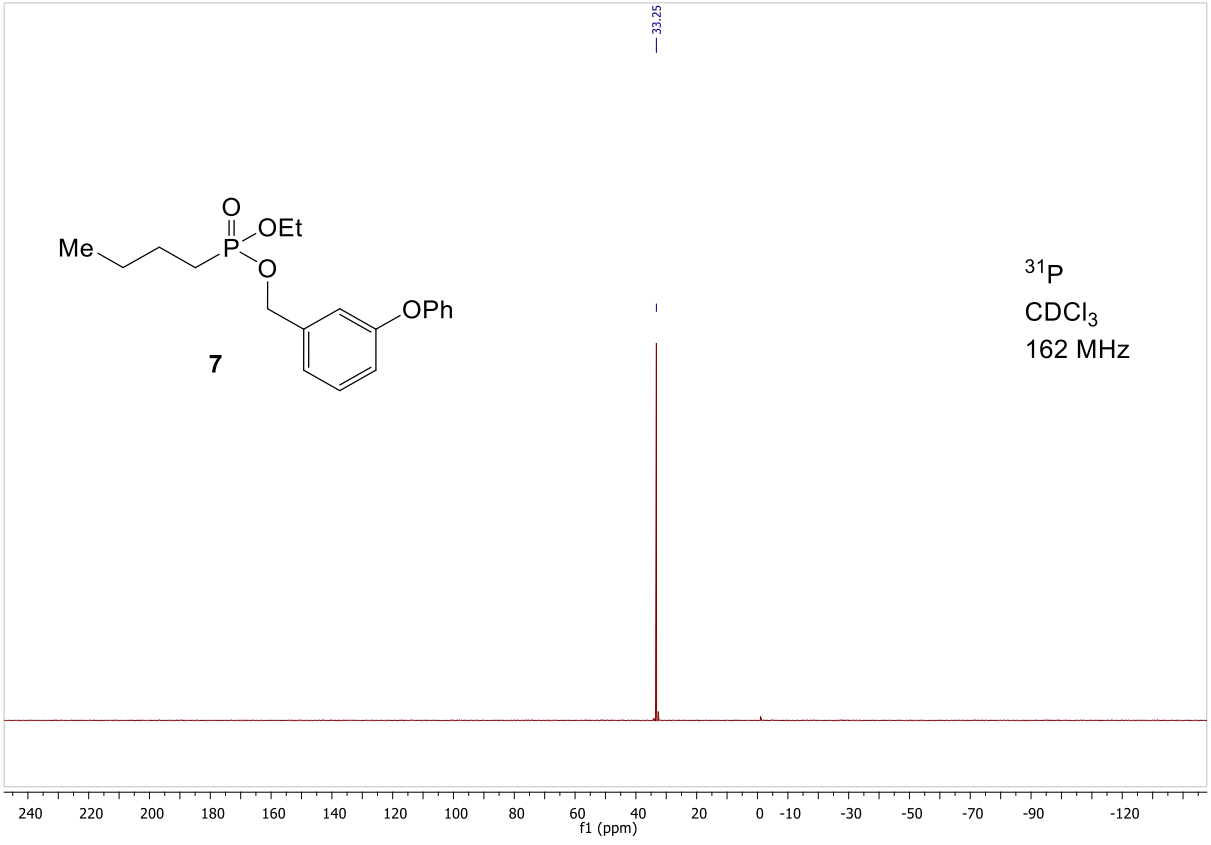

29.10
^{31}P
$CDCl_3$
162 MHz
O
O
OEt
EtO
P
OPh
2s
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)

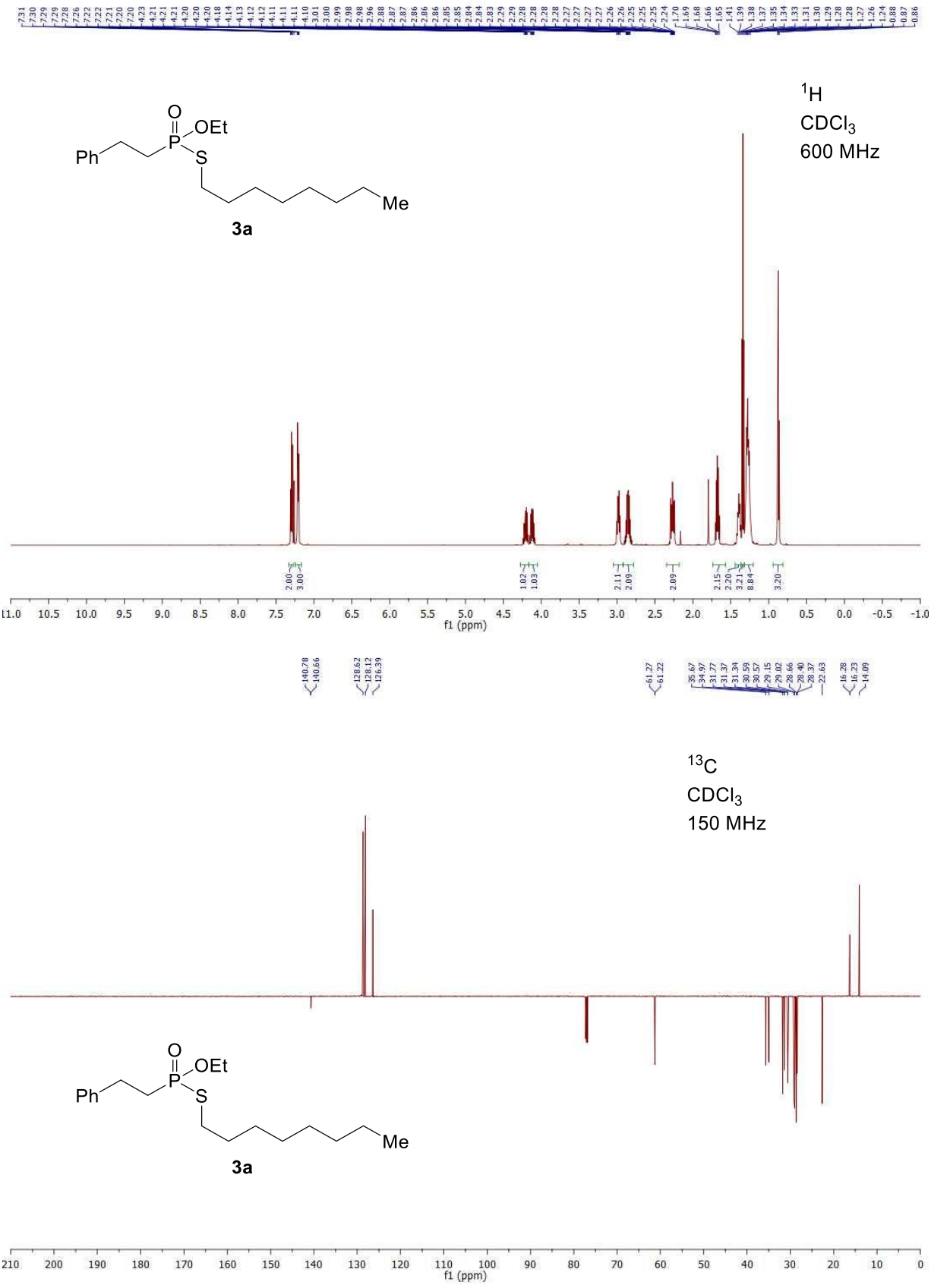

7.26
4.72
4.71
4.69
4.69
4.14
4.12
4.10
4.08
2.53
2.53
2.52
2.30
2.28
2.26
1.90
1.88
1.86
1.74
1.67
1.65
1.63
1.61
1.47
1.45
1.43
1.25
1.24
1.22
1.13
1.12
1.11
1.10
1.09
1.08
1.07
O
O
O
P
O
EtO
TIPS
6b
1H
CDCl3
400 MHz
2.00
2.16
0.91
2.15
2.08
4.92
2.24
3.44
21.91
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 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 -0.5
f1 (ppm)

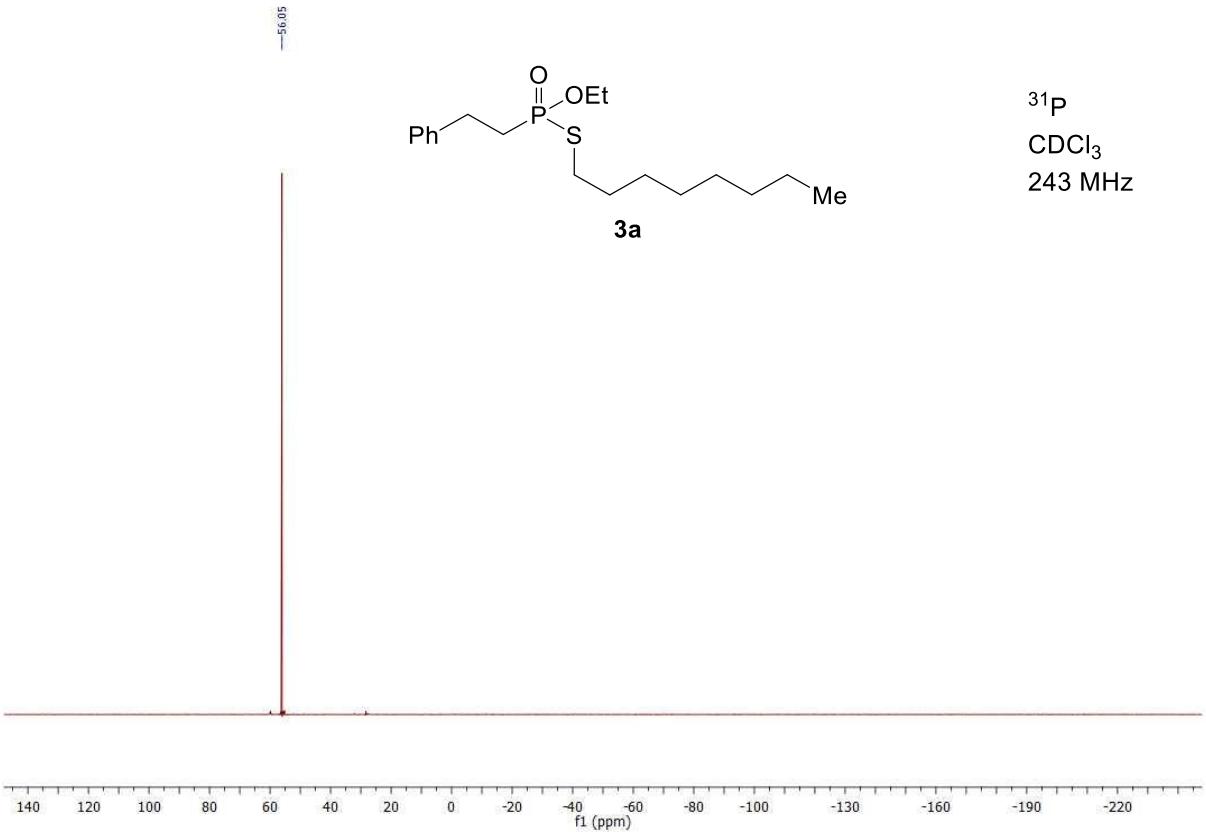

173.55
109.18
108.94
99.58
97.84
77.48
77.16
76.84
75.90
75.87
60.38
52.97
52.91
34.09
31.51
30.35
30.02
29.85
24.55
21.64
21.60
18.57
14.36
11.01
O
O
O
P
O
EtO
TIPS
6b
13C (APT)
CDCl3
100 MHz
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

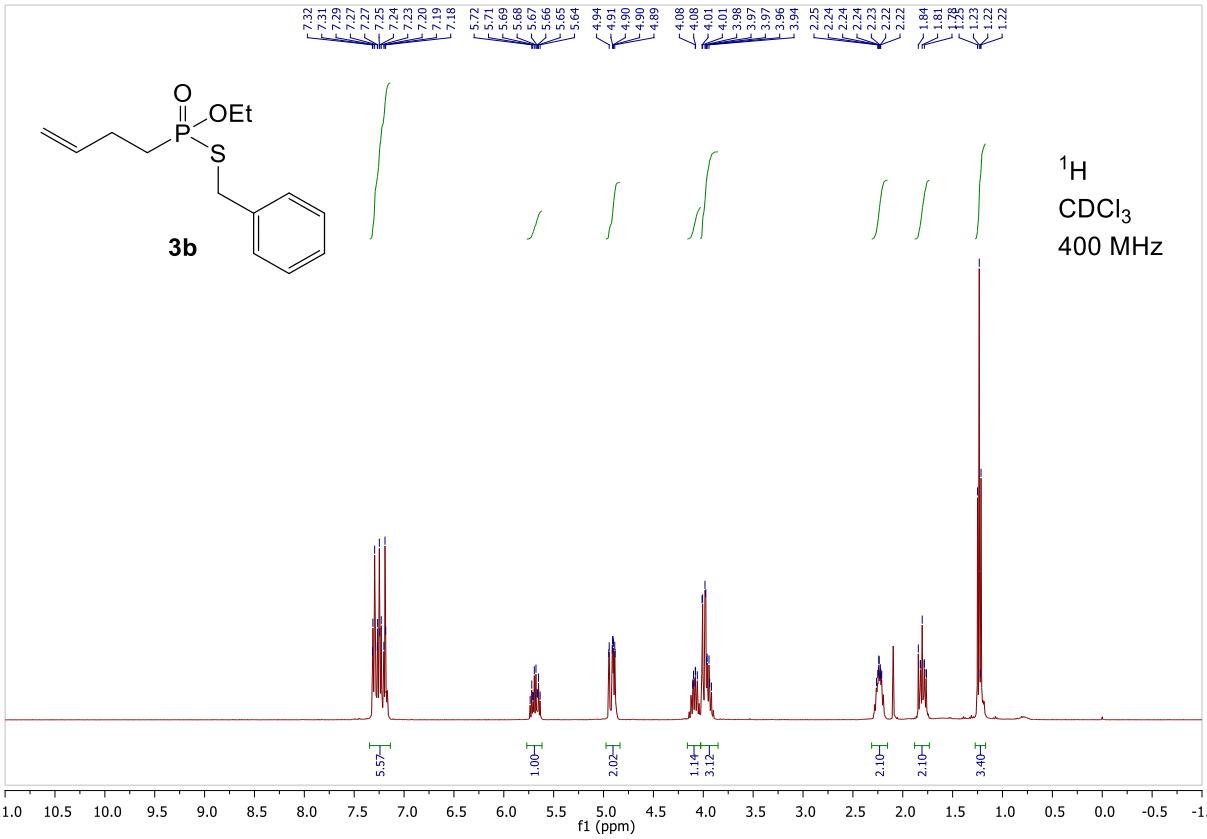

23.04
O
O
O
P
O
EtO
TIPS
6b
31P
CDCl3
162 MHz
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)

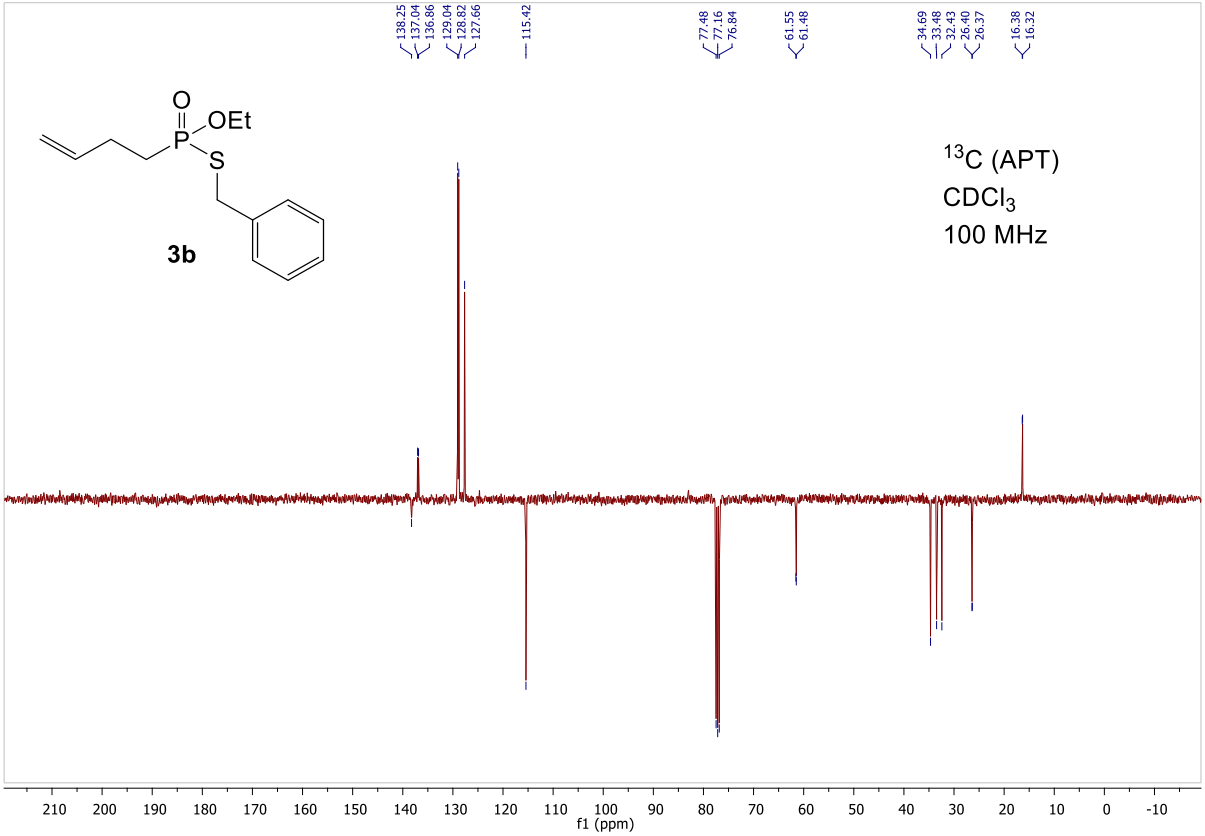

Me
O
OEt
P
O
OPh
7
^{1}H
$CDCl_3$
400 MHz
f1 (ppm)

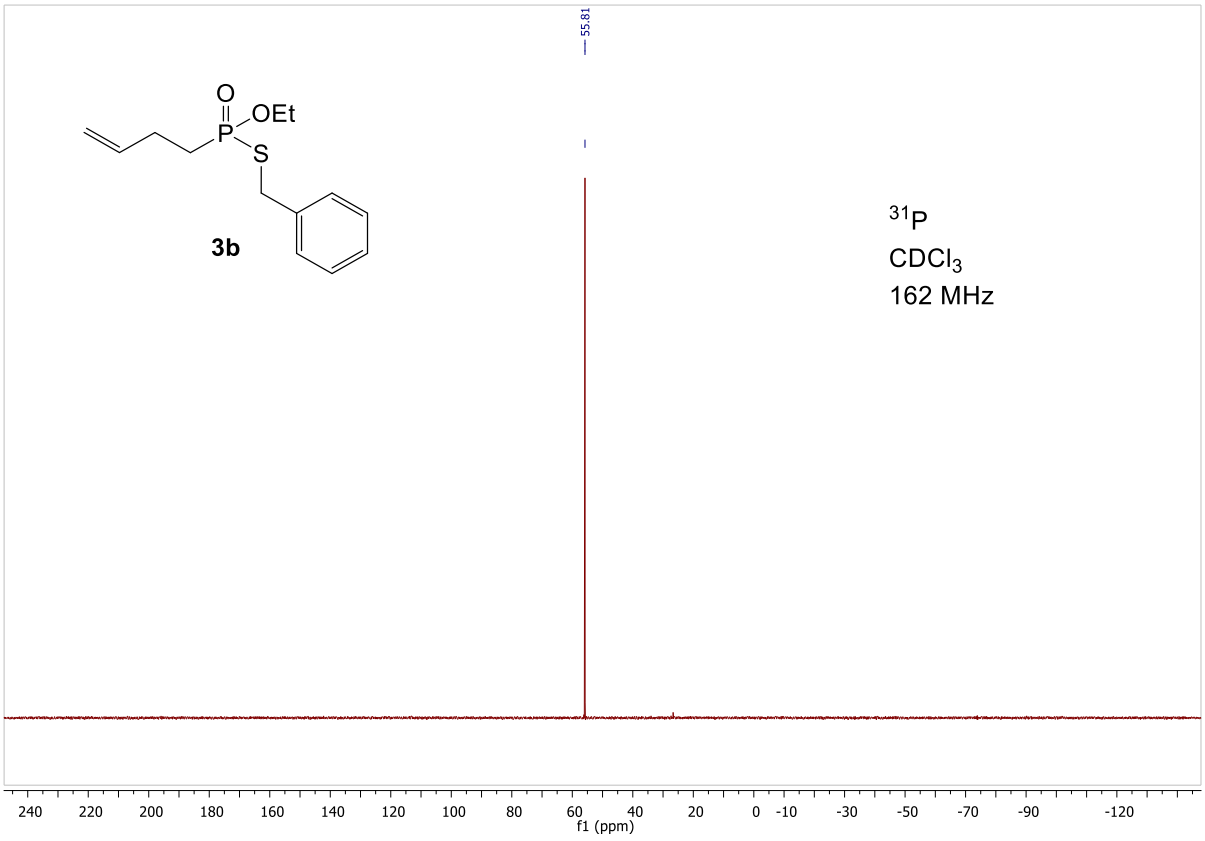

33.25
Me
O
OEt
P
O
OPh
7
^{31}P
$CDCl_3$
162 MHz
f1 (ppm)

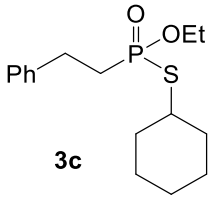

^{1}H
$CDCl_3$
600 MHz
O
OEt
P
S
Ph
Me
3a
f1 (ppm)
^{13}C
$CDCl_3$
150 MHz
O
OEt
P
S
Ph
Me
3a
f1 (ppm)


56.05
O
OEt
P
Ph
S
Me
3a
^{31}P
$CDCl_3$
243 MHz
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-130
-160
-190
-220
f1 (ppm)


3b
^{1}H
$CDCl_3$
400 MHz
f1 (ppm)

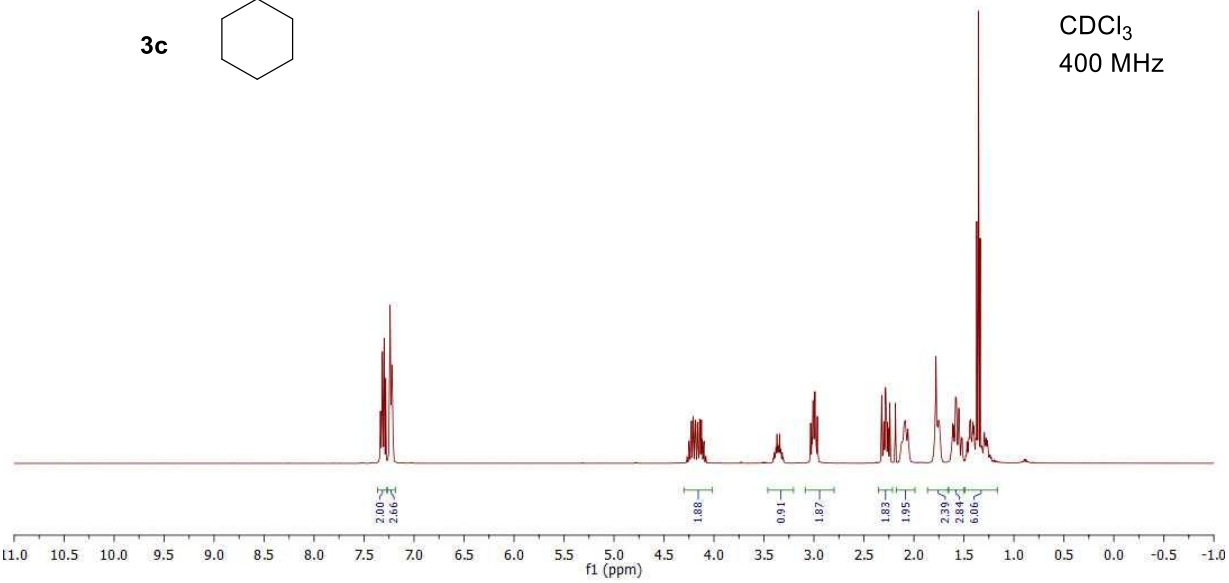

3b
^{13}C (APT)
$CDCl_3$
100 MHz
f1 (ppm)

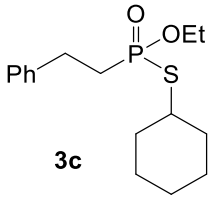

55.81
O
OEt
P
S
3b
31P
CDCl3
162 MHz
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)



3c

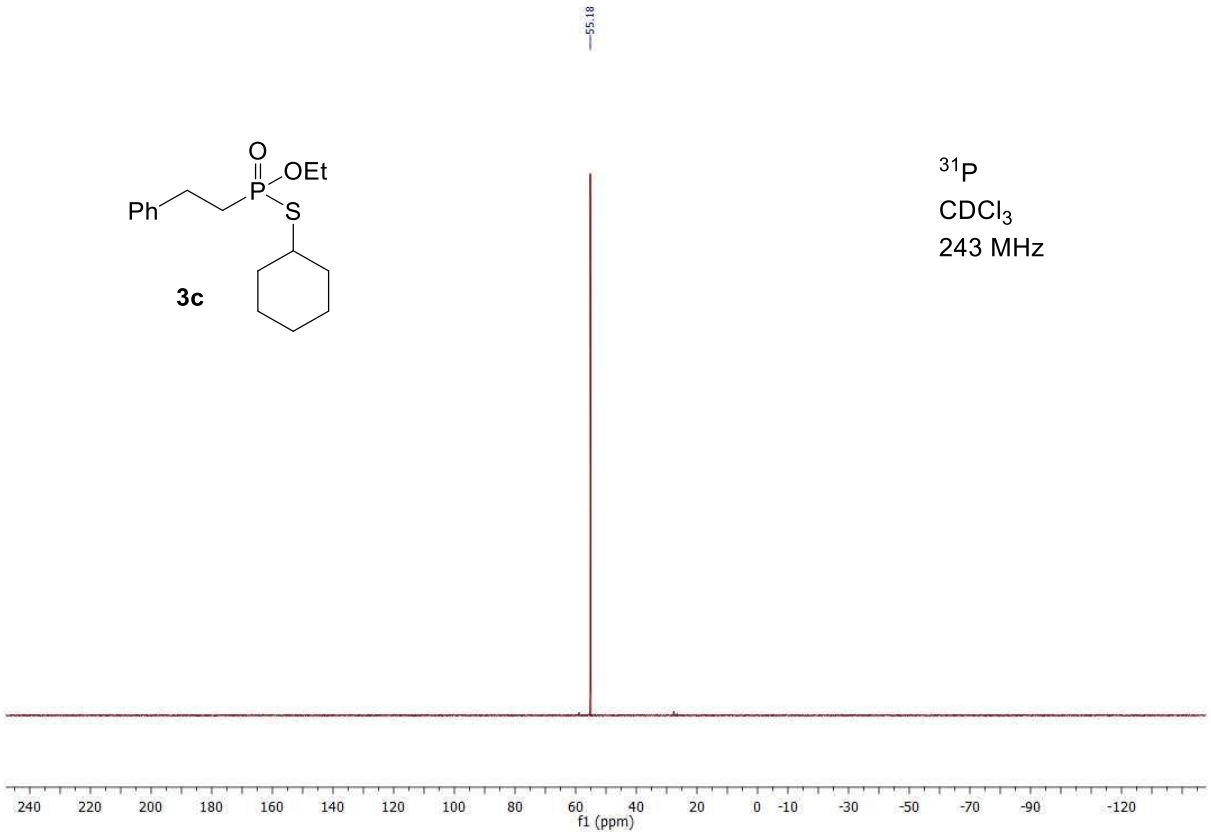
^{1}H
$CDCl_3$
400 MHz

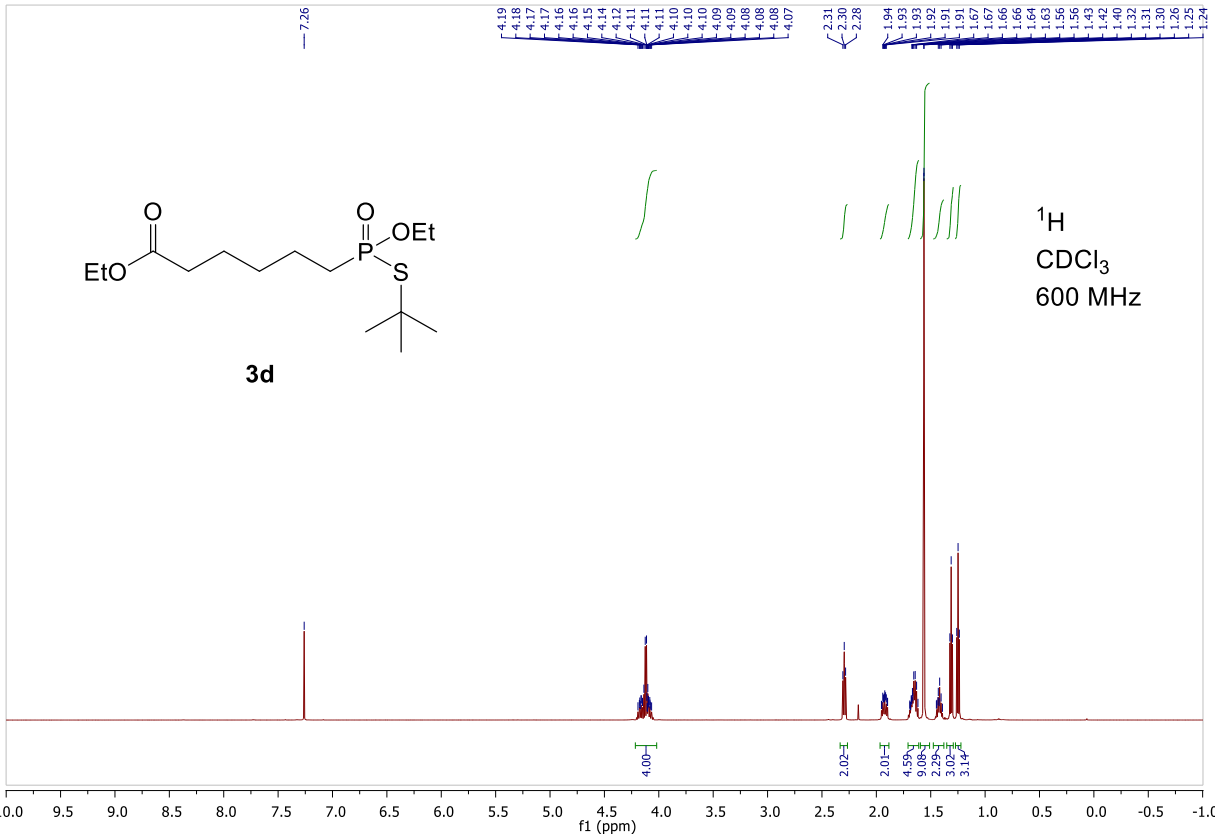


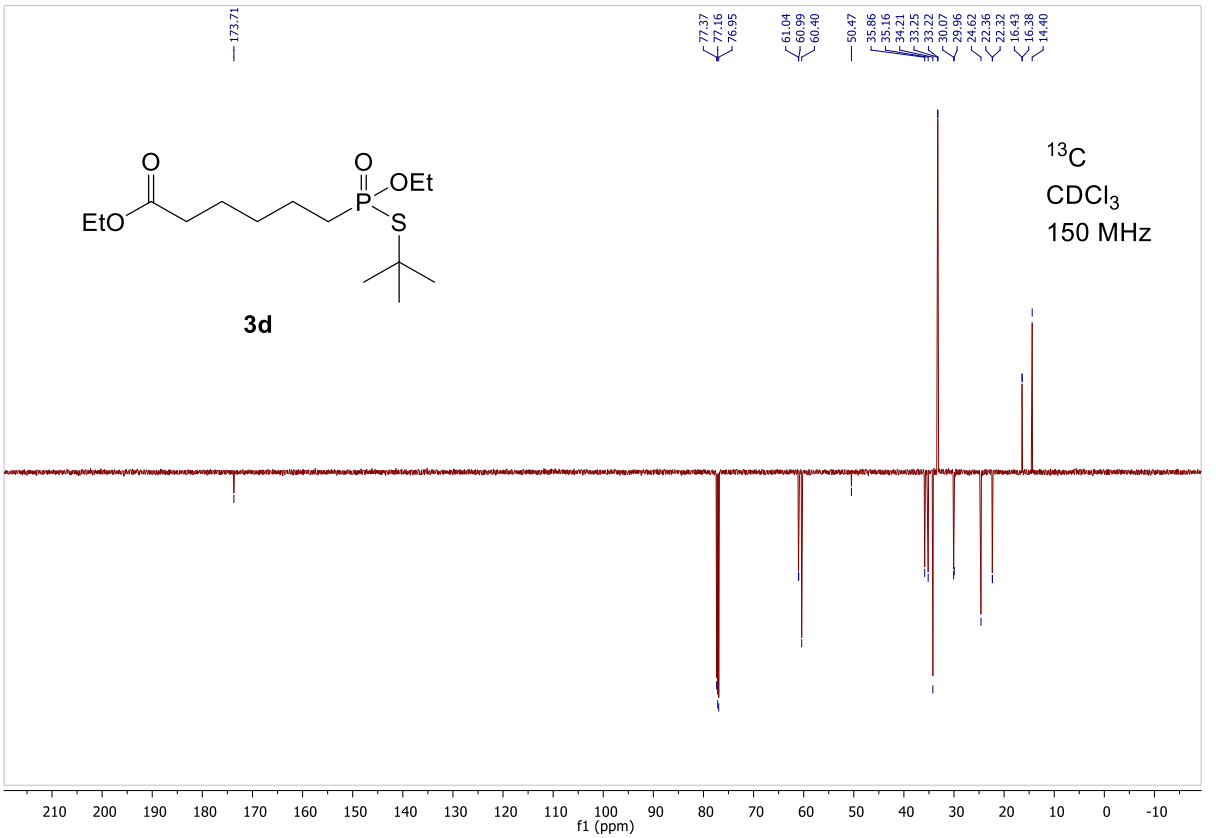


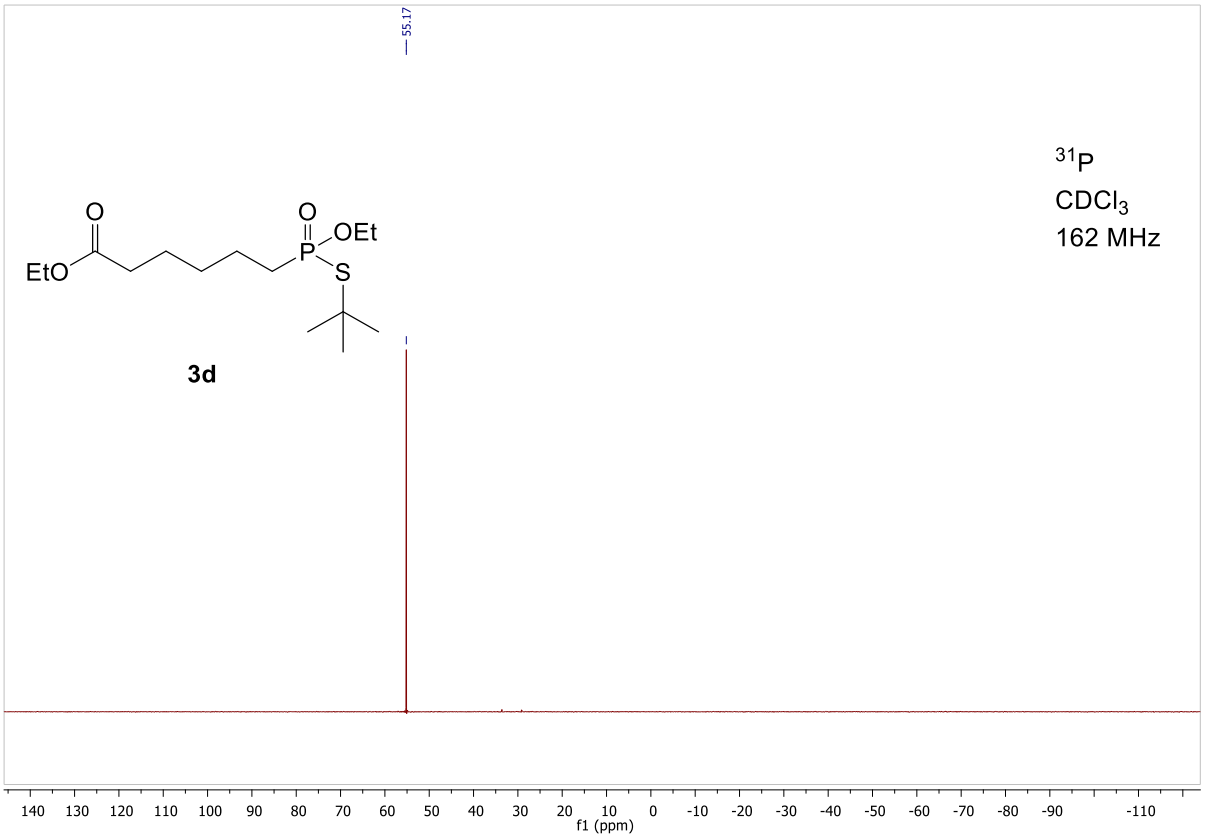
3c

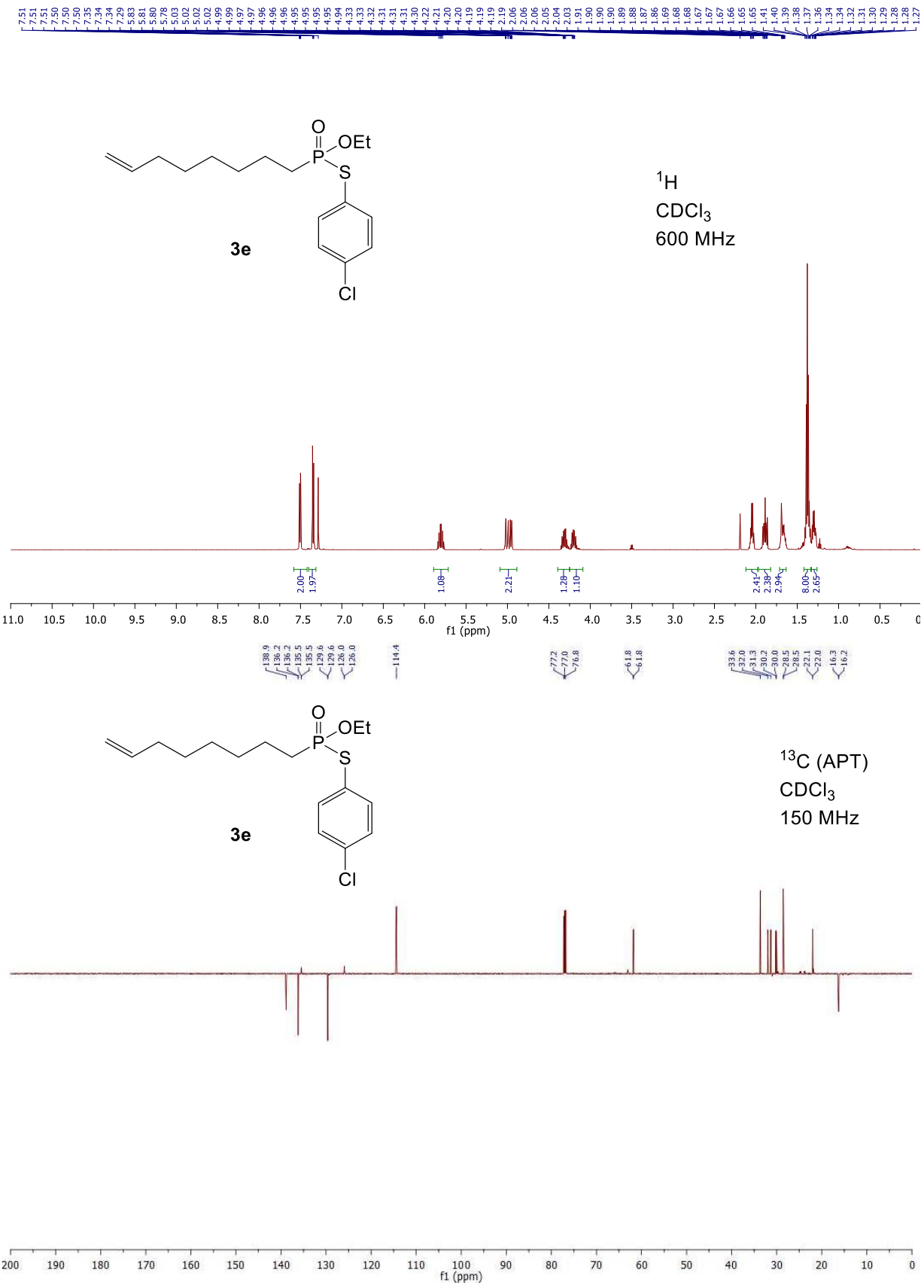
^{13}C
$CDCl_3$
100 MHz

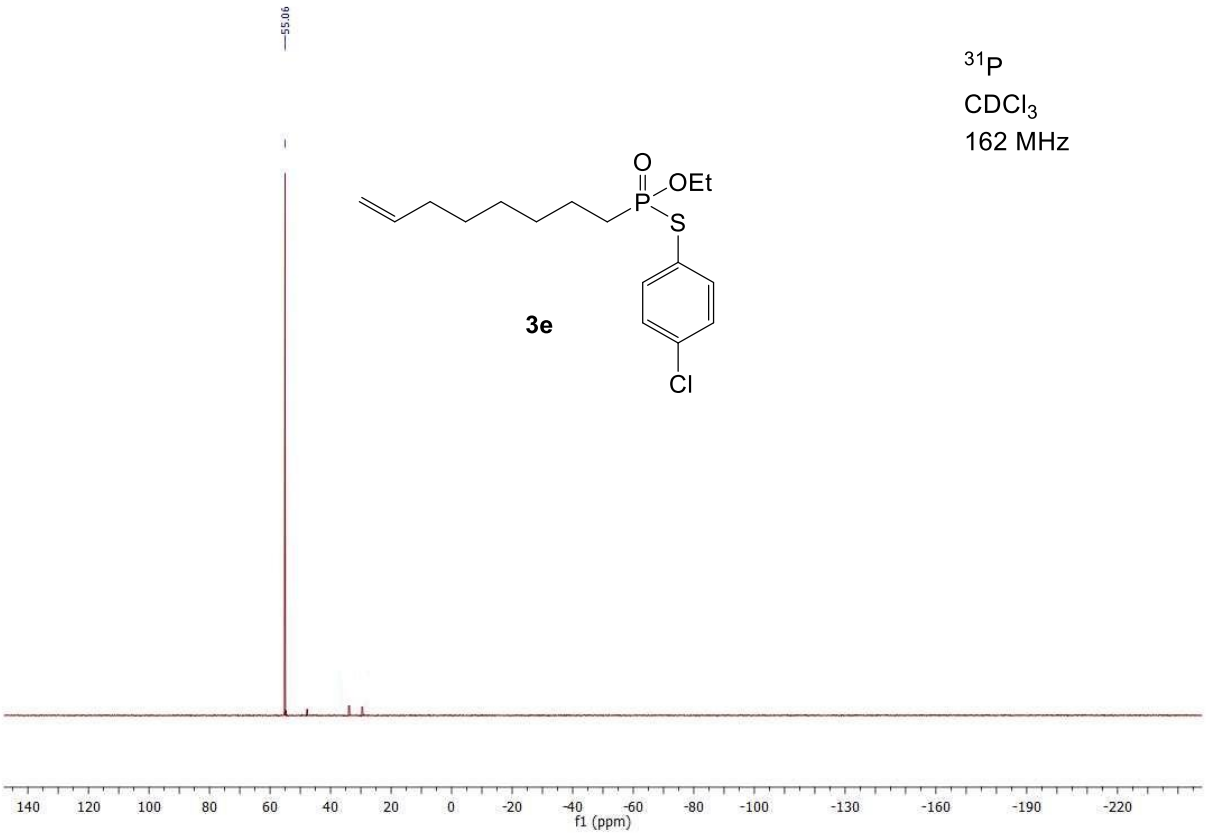

55.18
O
OEt
P
Ph
S
3c
31P
CDCl3
243 MHz
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)

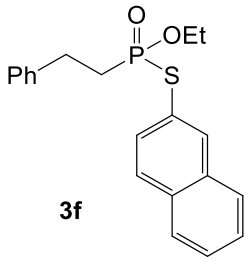

7.26
4.19
4.18
4.17
4.17
4.16
4.16
4.15
4.14
4.12
4.11
4.11
4.11
4.10
4.10
4.10
4.09
4.09
4.08
4.08
4.08
4.07
2.31
2.30
2.28
1.94
1.93
1.93
1.92
1.91
1.91
1.67
1.67
1.66
1.66
1.64
1.63
1.56
1.56
1.43
1.42
1.40
1.32
1.31
1.30
1.26
1.25
1.24
O
O
OEt
EtO
P
S
3d
^{1}H
$CDCl_3$
600 MHz
4.00
2.02
2.01
4.59
9.08
2.29
3.02
3.14
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
-0.5
f1 (ppm)


173.71
77.37
77.16
76.95
61.04
60.99
60.40
50.47
35.86
35.16
34.21
33.25
33.22
30.07
29.96
24.62
22.36
22.32
16.43
16.38
14.40
O
O
OEt
EtO
P
S
3d
^{13}C
$CDCl_3$
150 MHz
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)


55.17
O
O
OEt
EtO
P
S
3d
31P
CDCl3
162 MHz
140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -110
f1 (ppm)

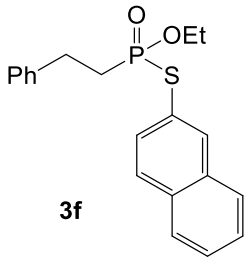

3e
^{1}H
$CDCl_3$
600 MHz
f1 (ppm)
3e
^{13}C (APT)
$CDCl_3$
150 MHz
f1 (ppm)


55.06
31P
CDCl3
162 MHz
O
OEt
P
S
Cl
3e
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-130
-160
-190
-220
f1 (ppm)



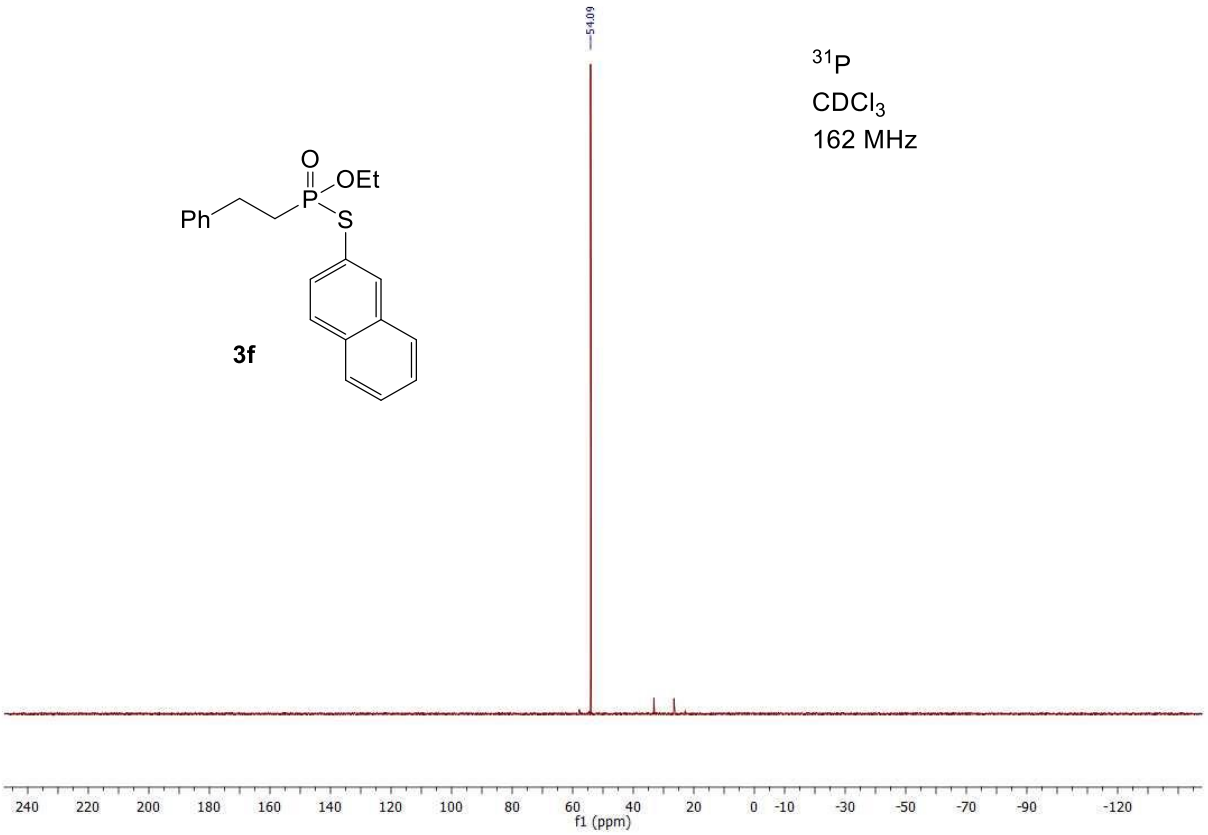
3f

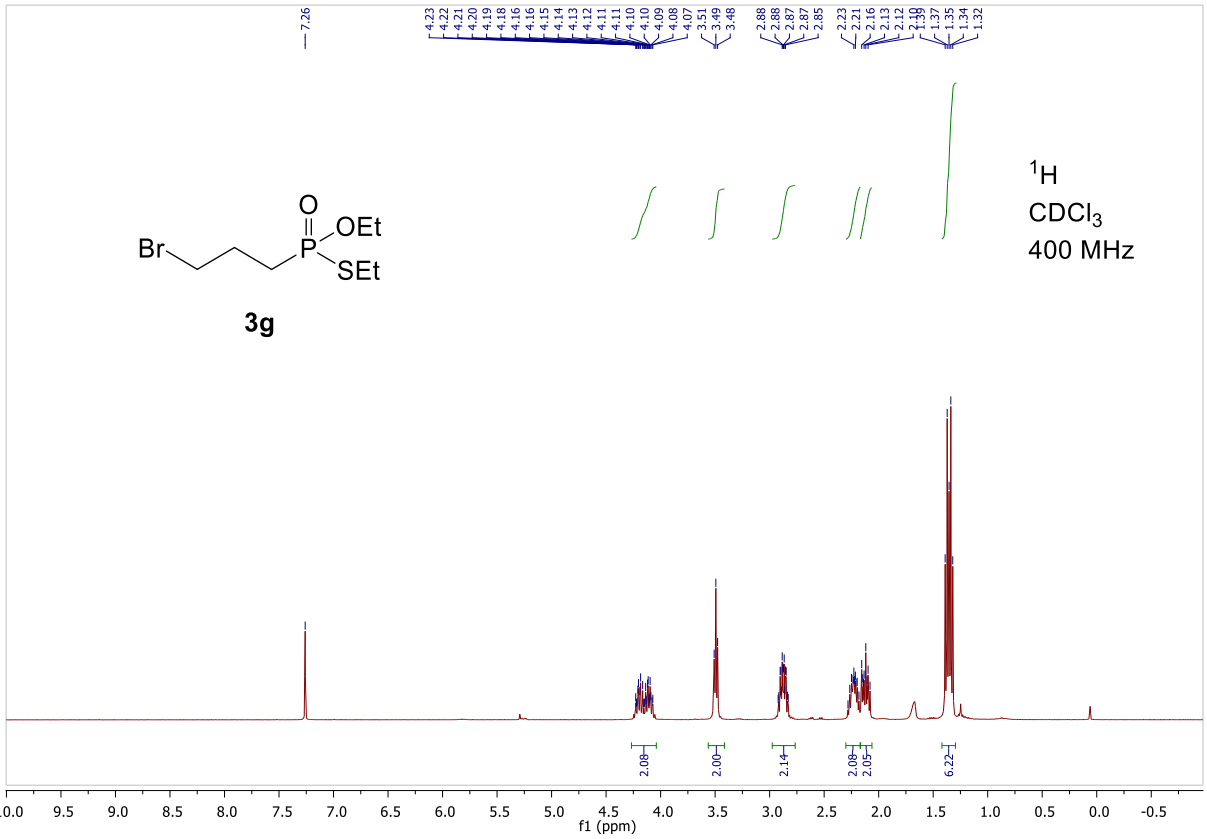
^{1}H
$CDCl_3$
400 MHz

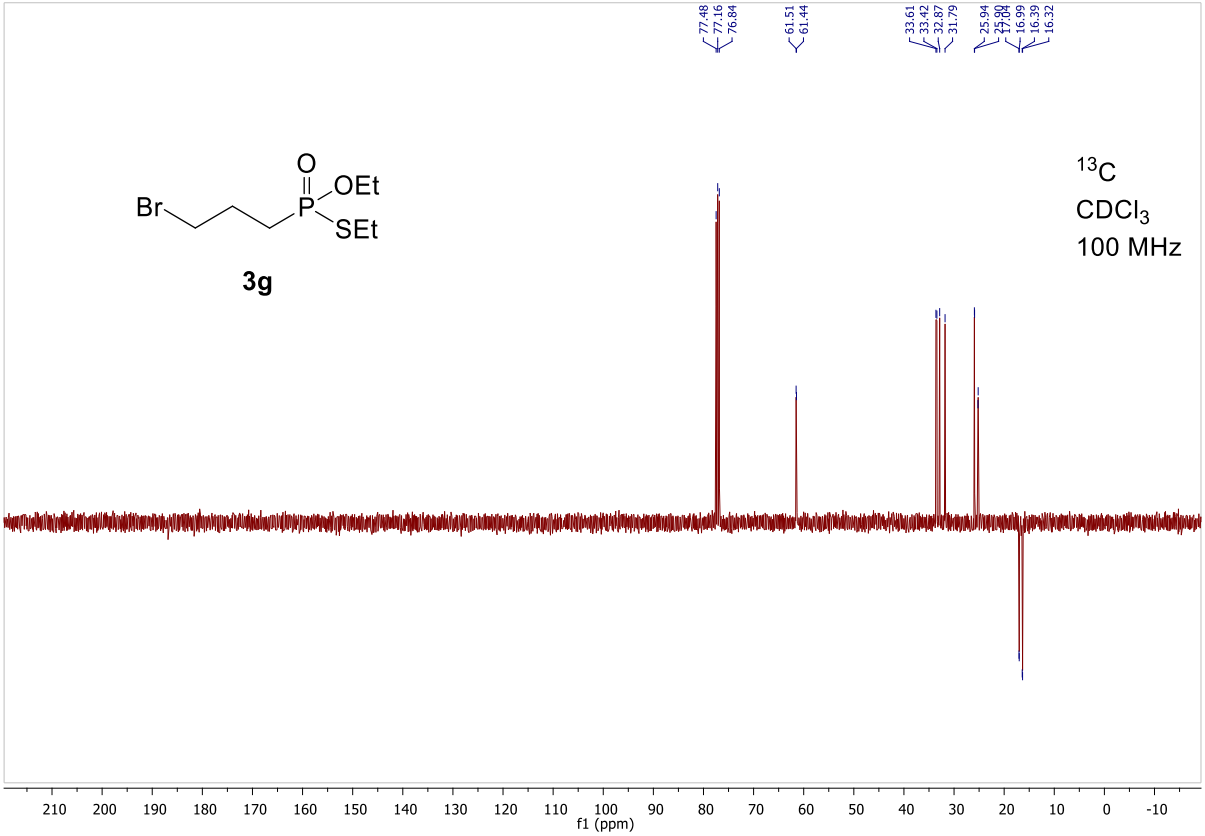


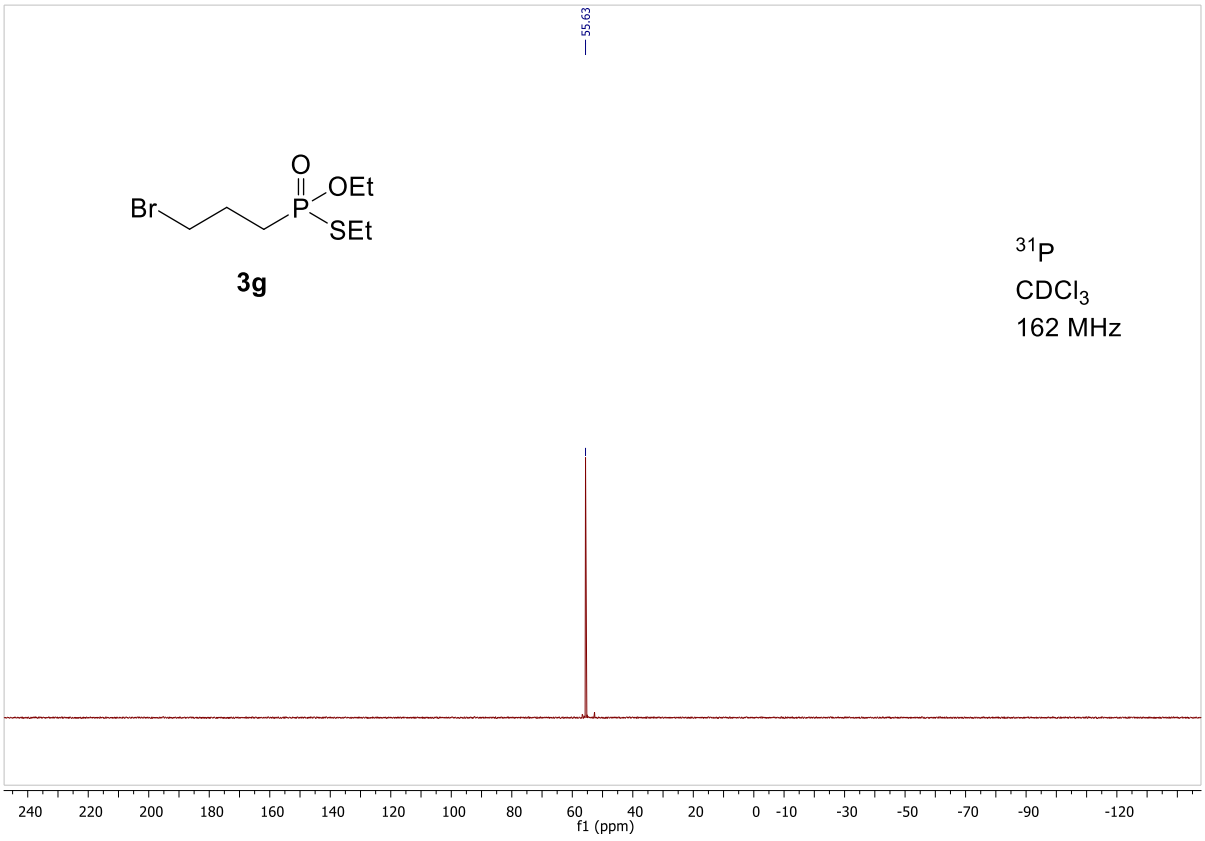
3f

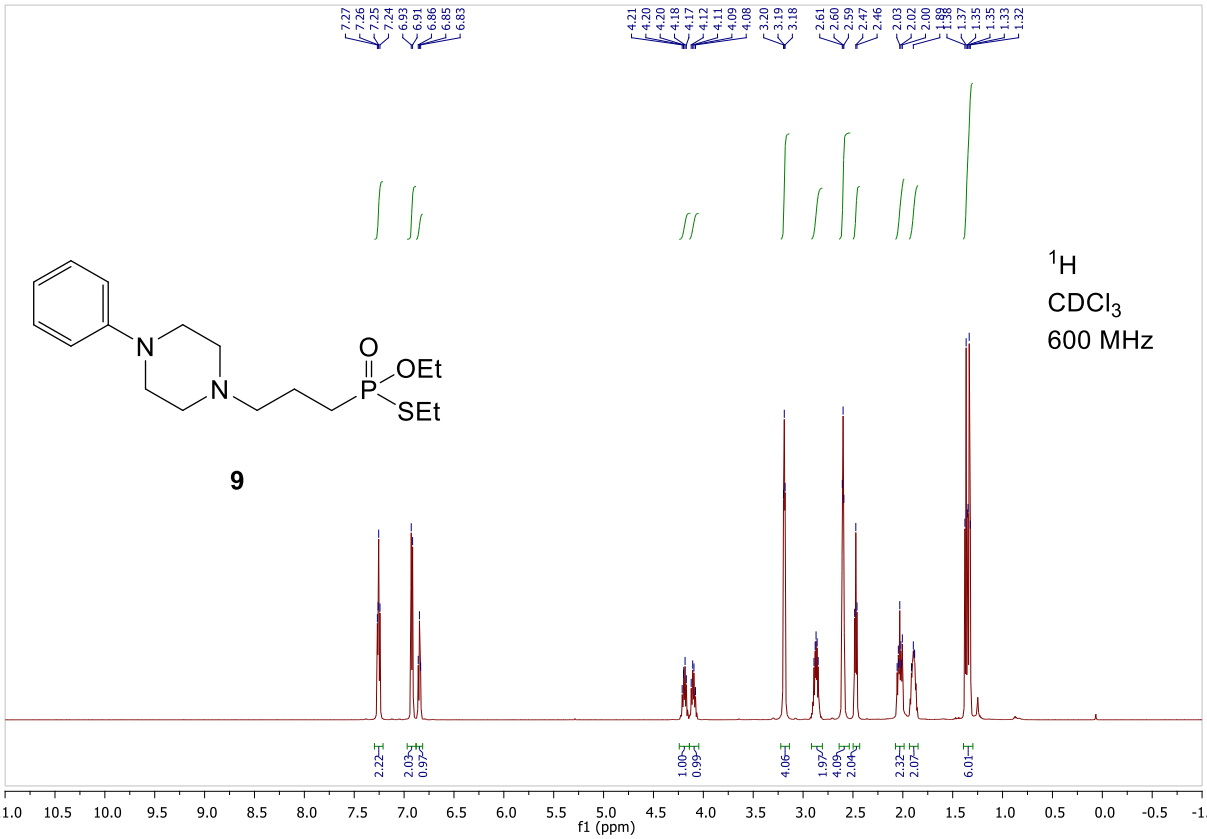
^{13}C
$CDCl_3$
100 MHz

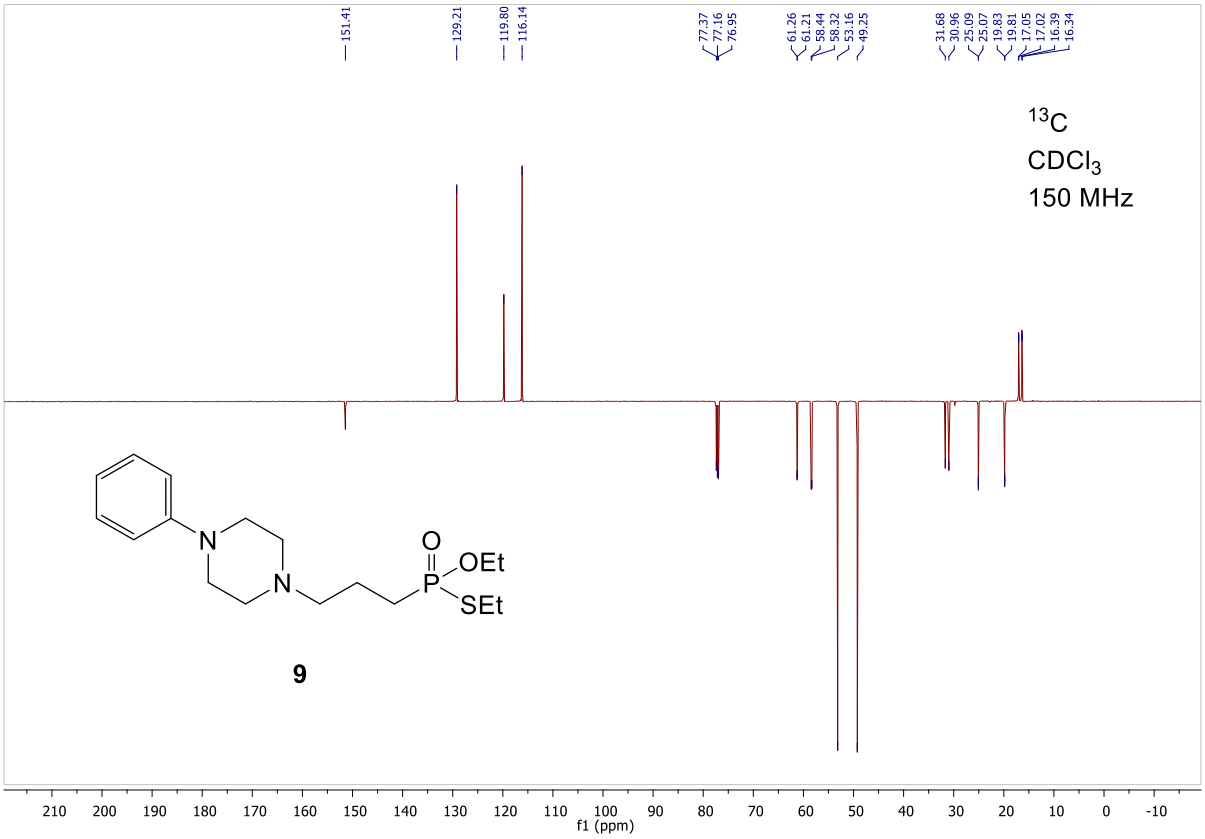

54.09
31P
CDCl3
162 MHz
O
OEt
P
S
Ph
3f
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)

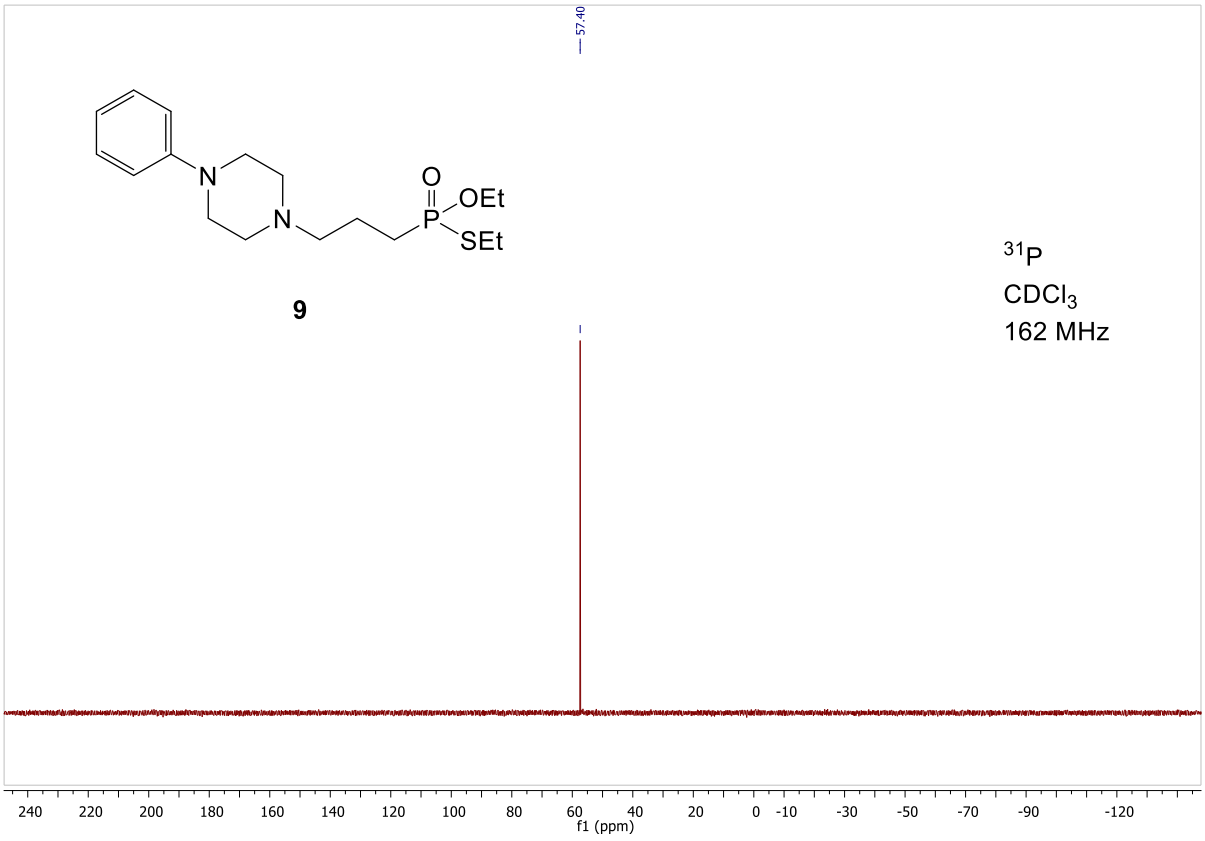

Br
O
OEt
P
SEt
3g
^{1}H
$CDCl_3$
400 MHz
f1 (ppm)

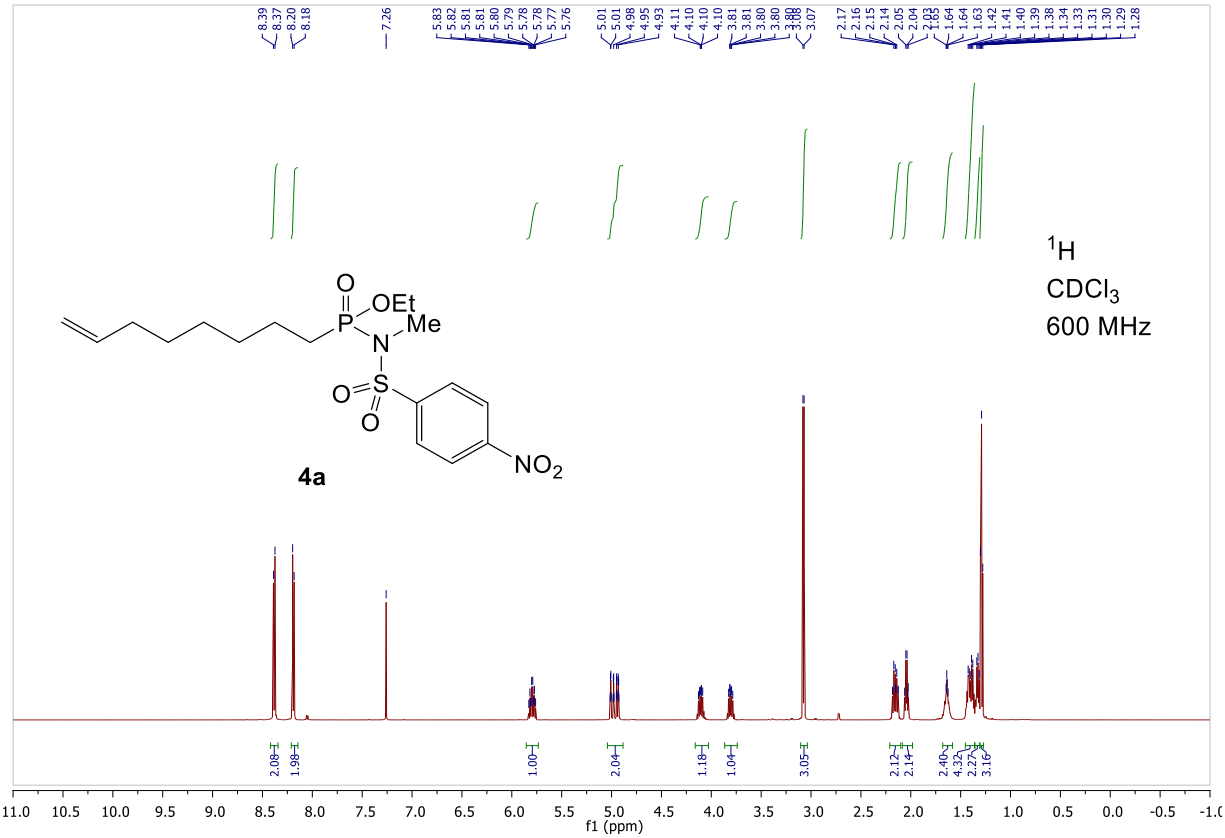

Br
O
OEt
P
SEt
3g
^{13}C
$CDCl_3$
100 MHz
f1 (ppm)

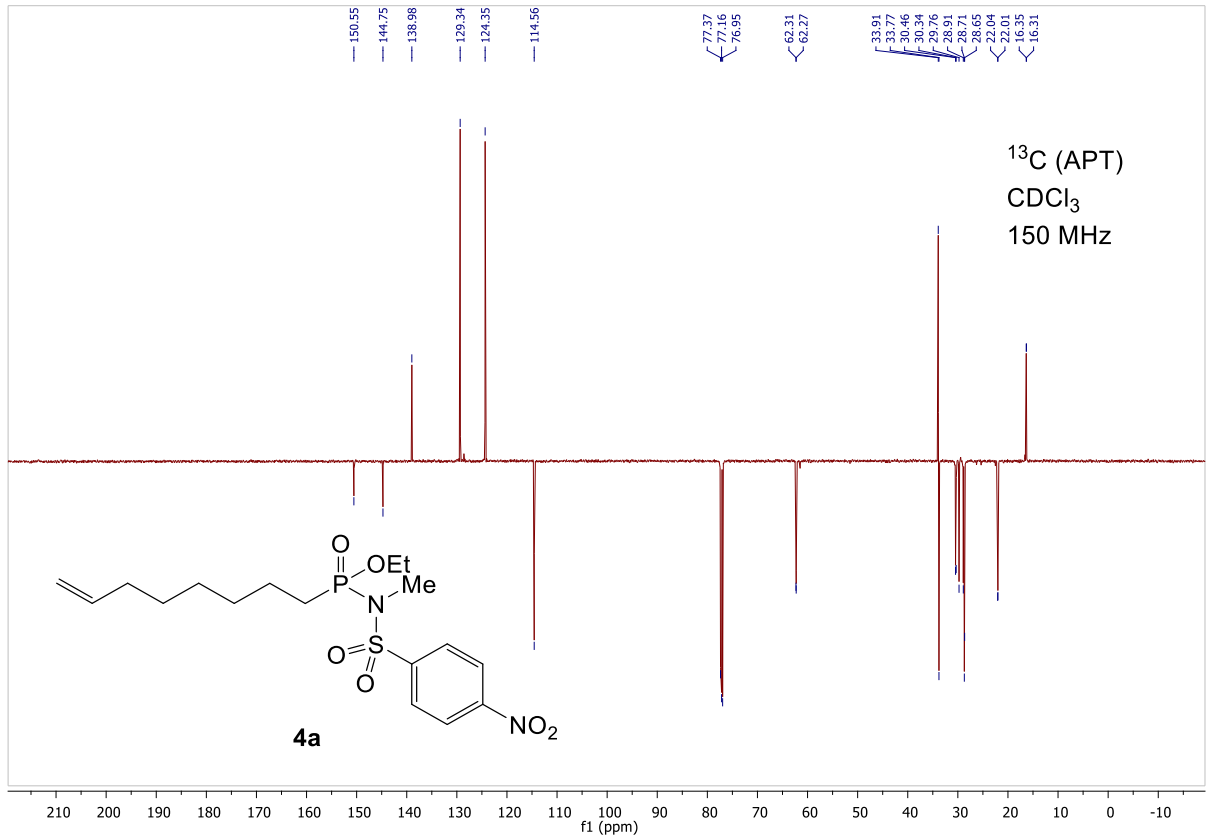

55.63
O
OEt
Br
P
SEt
3g
31P
CDCl3
162 MHz
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)

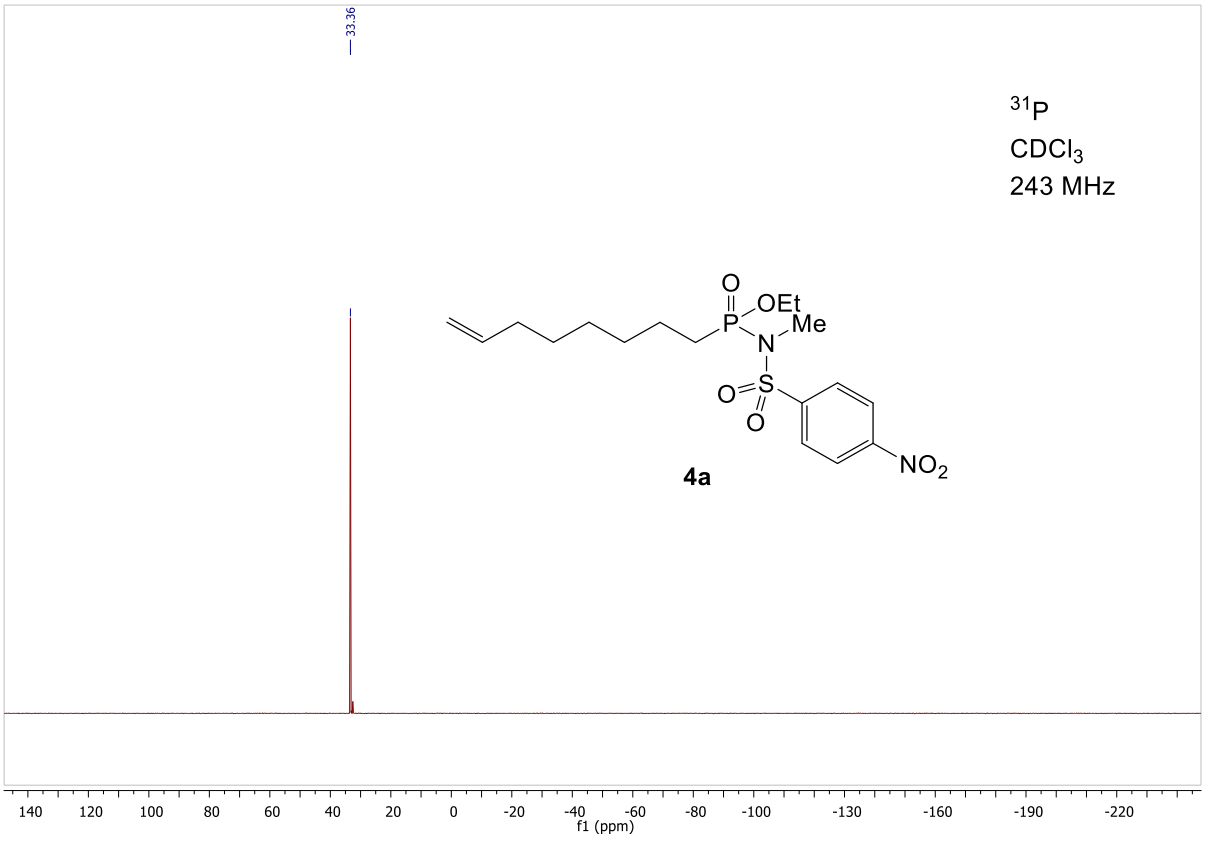

^{1}H
$CDCl_3$
600 MHz
9
f1 (ppm)

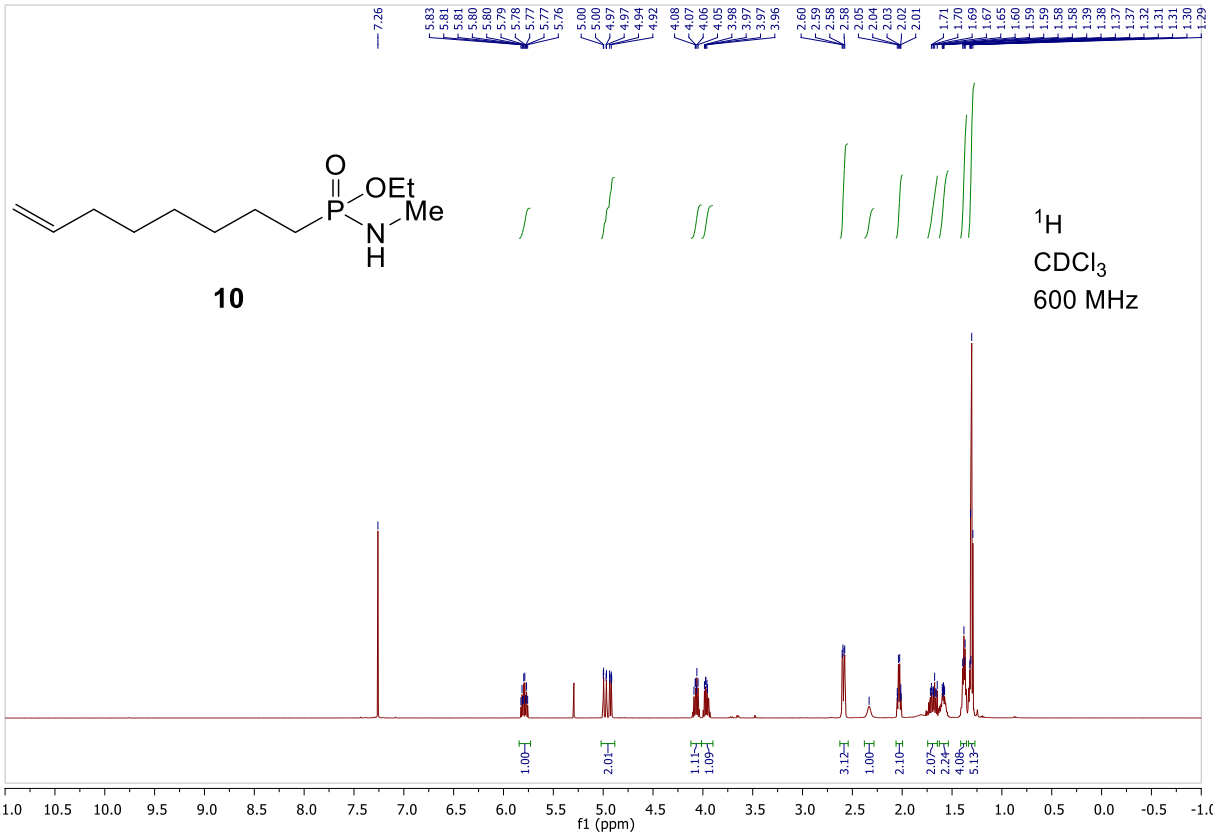

^{13}C
$CDCl_3$
150 MHz
9
f1 (ppm)

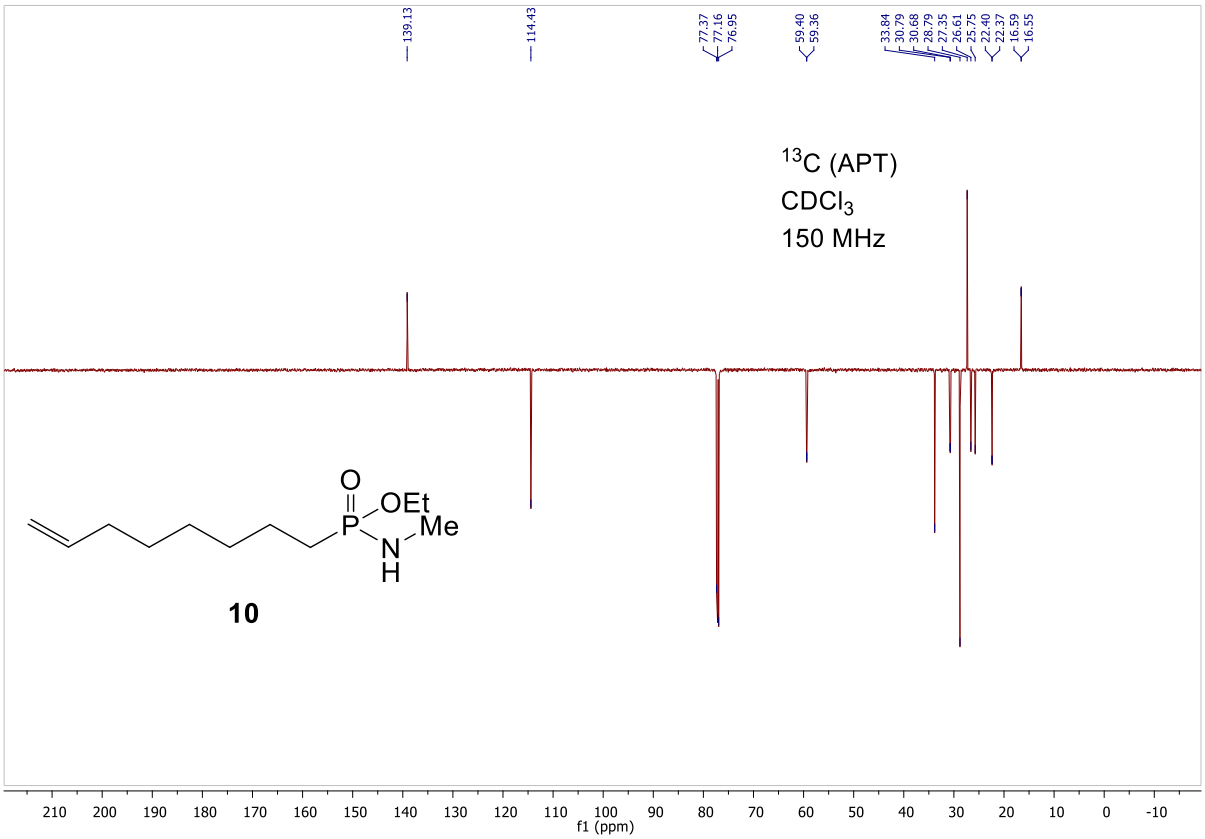

57.40
N
N
O
OEt
P
SEt
9
31P
CDCl3
162 MHz
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)

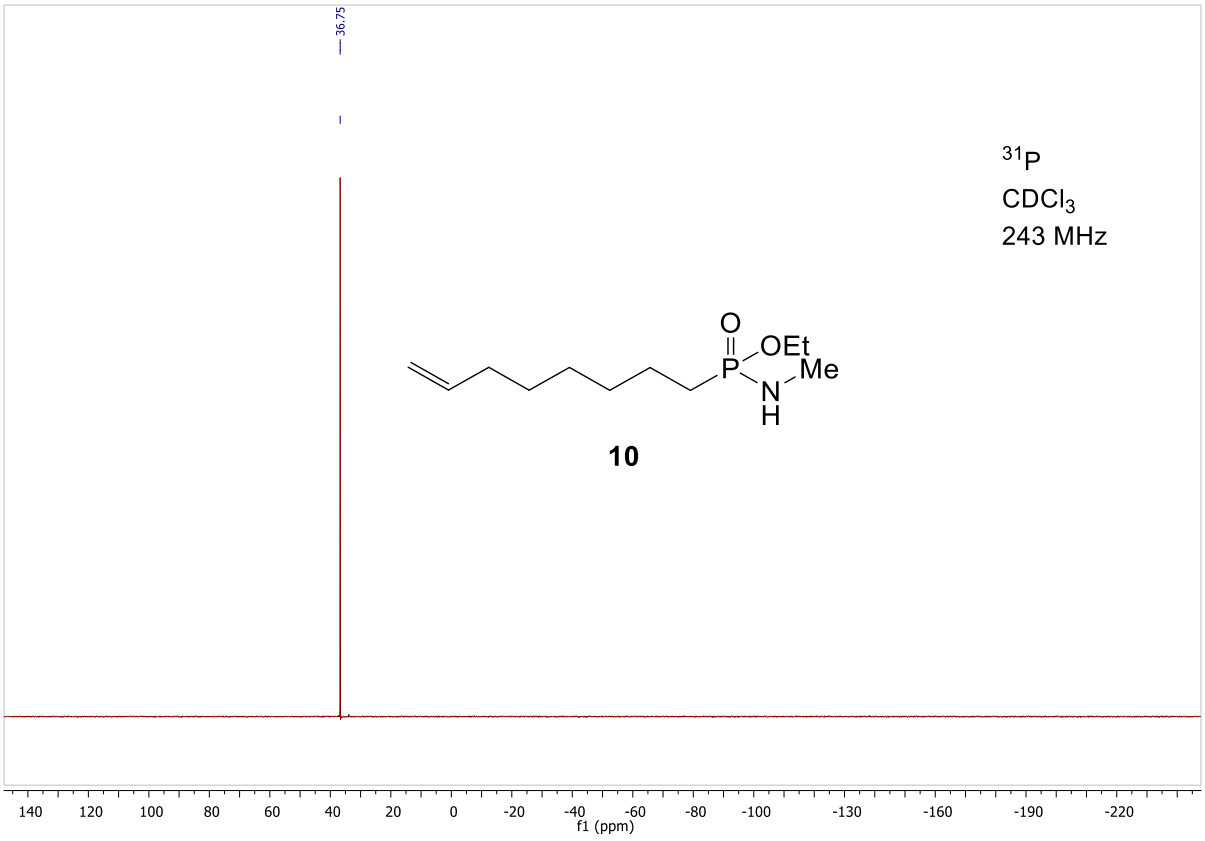

^{1}H
$CDCl_3$
600 MHz
4a
f1 (ppm)

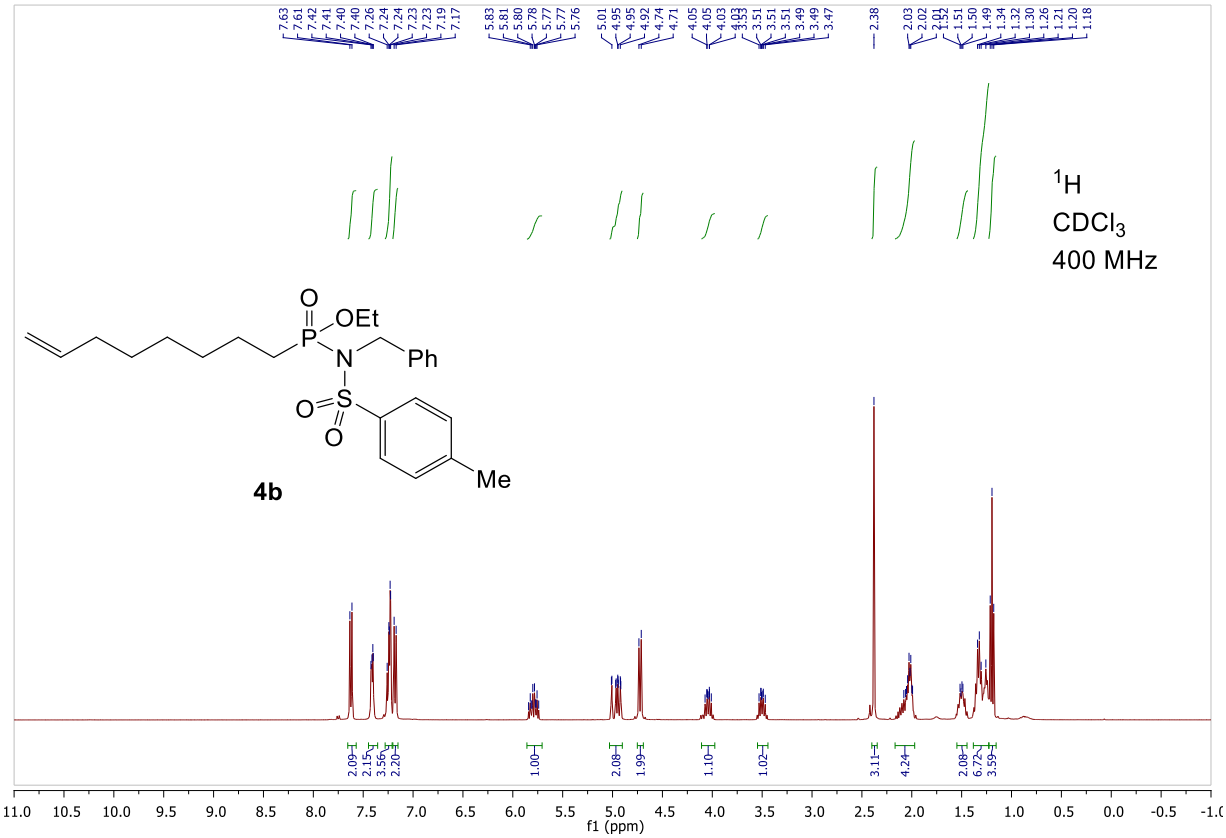

^{13}C (APT)
$CDCl_3$
150 MHz
4a
f1 (ppm)

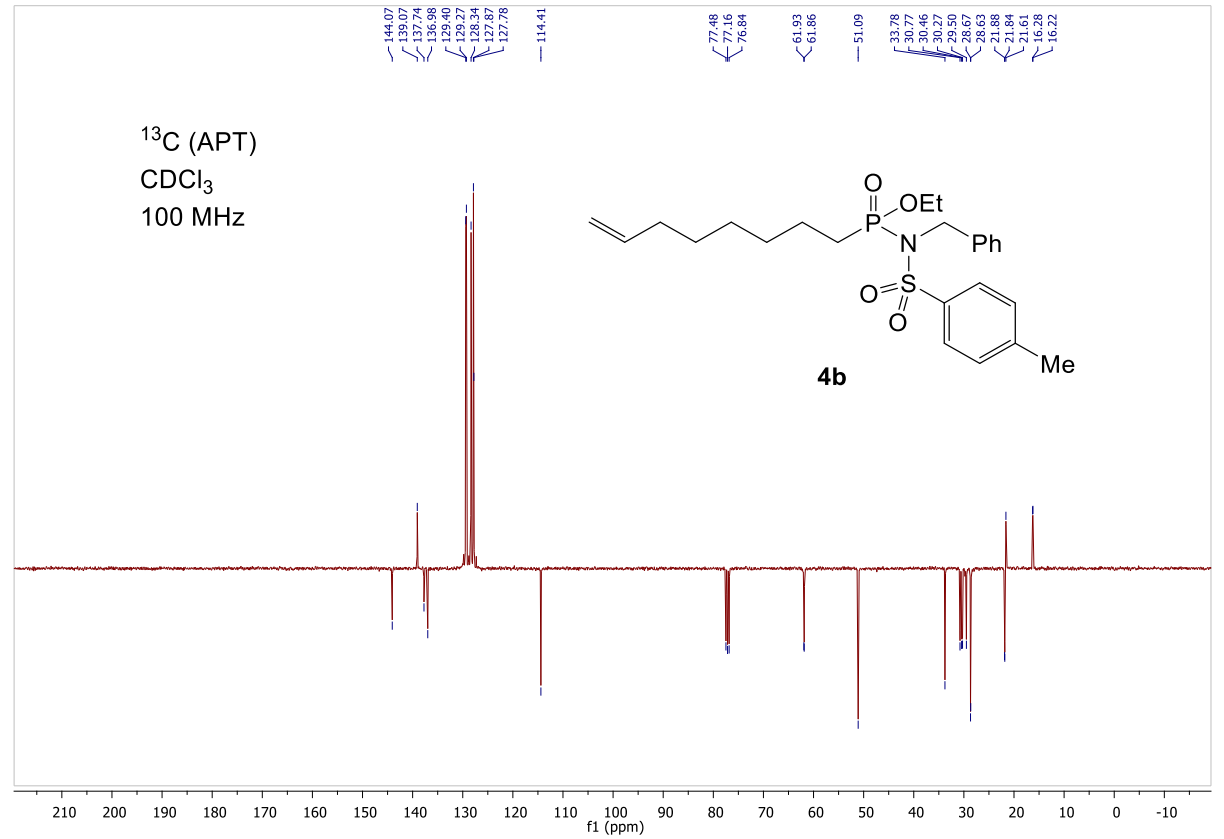

33.36
31P
CDCl3
243 MHz
O
OEt
P
Me
N
O
S
O
O
NO2
4a
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-130
-160
-190
-220
f1 (ppm)

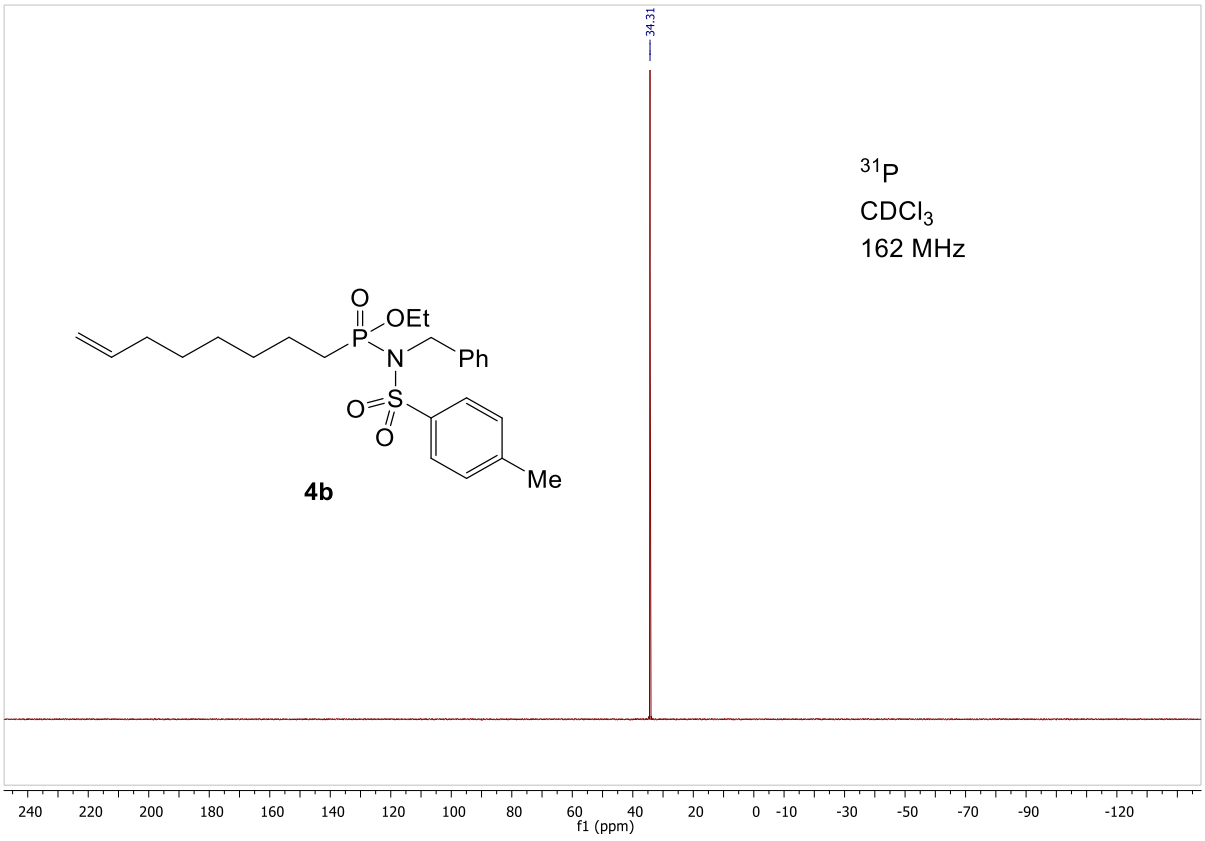

10
^{1}H
$CDCl_3$
600 MHz
f1 (ppm)

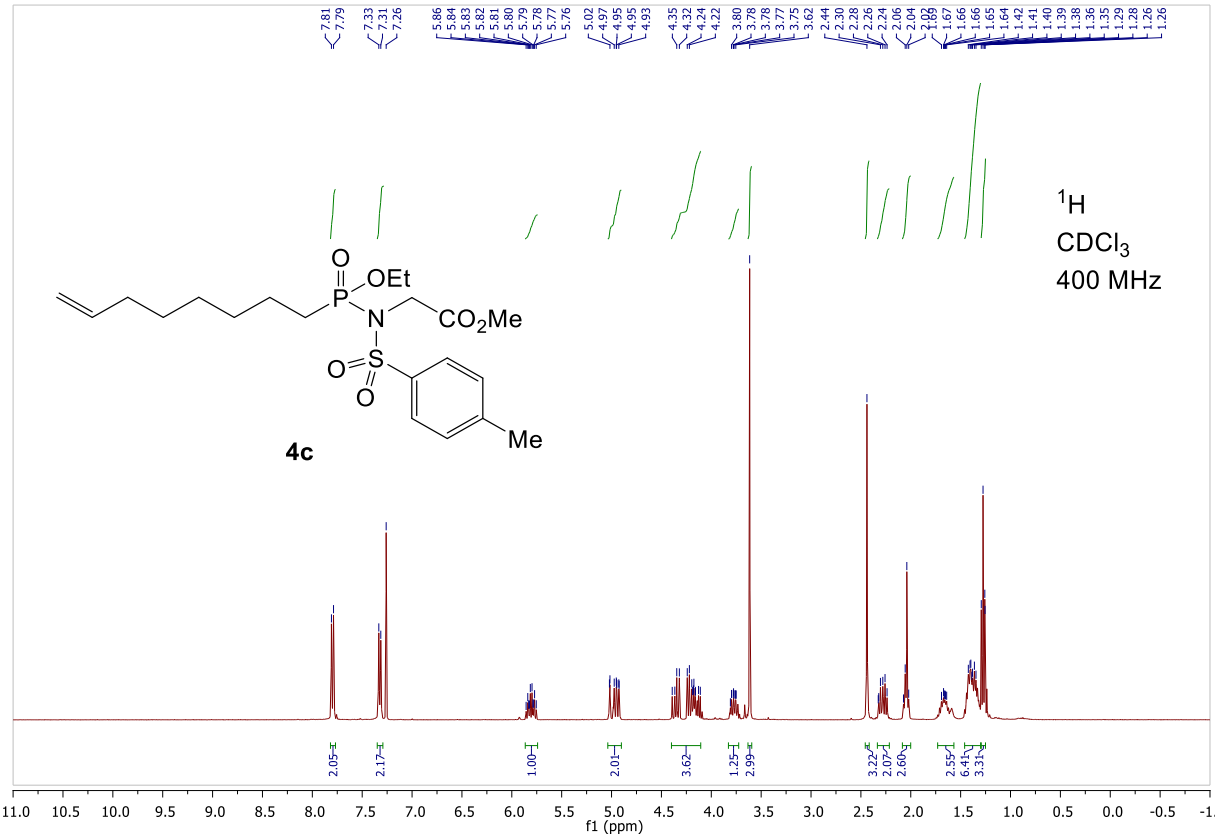

10
^{13}C (APT)
$CDCl_3$
150 MHz
f1 (ppm)

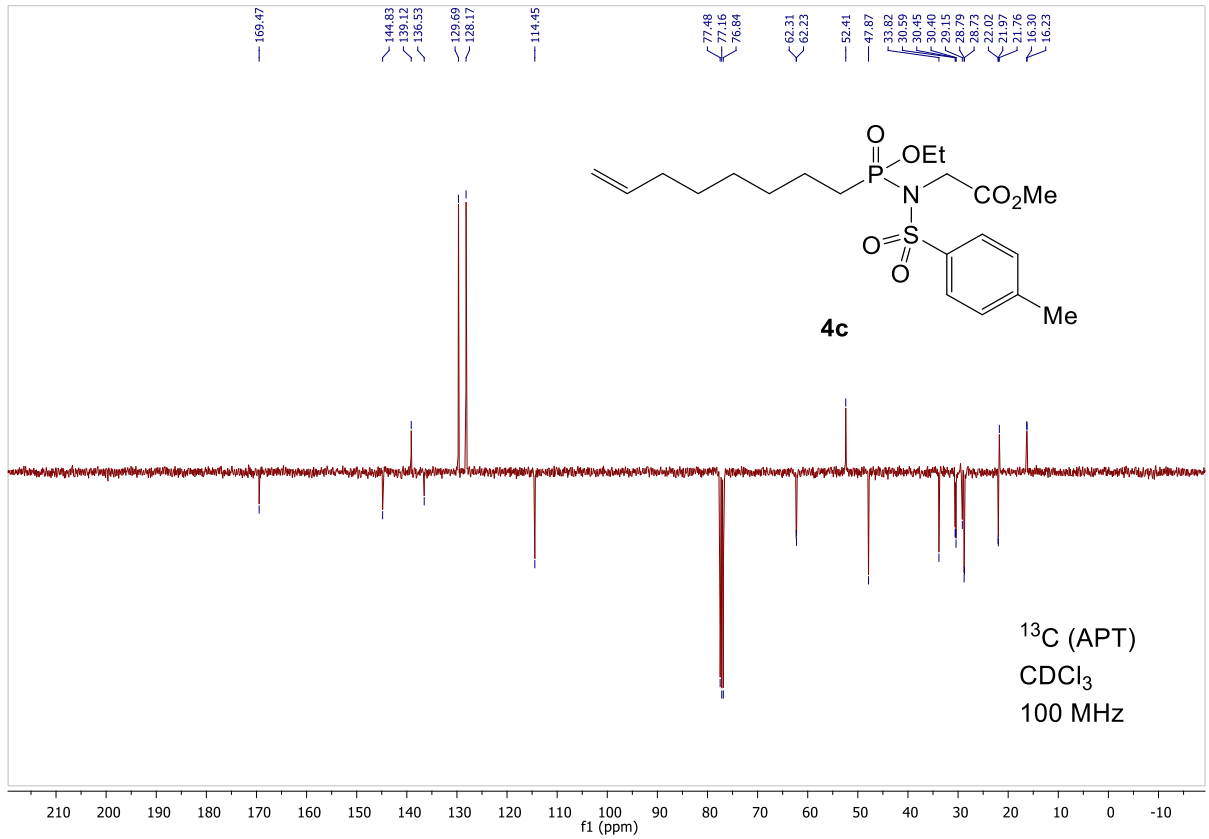

36.75
31P
CDCl3
243 MHz
O
OEt
P
Me
N
H
10
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-130
-160
-190
-220
f1 (ppm)

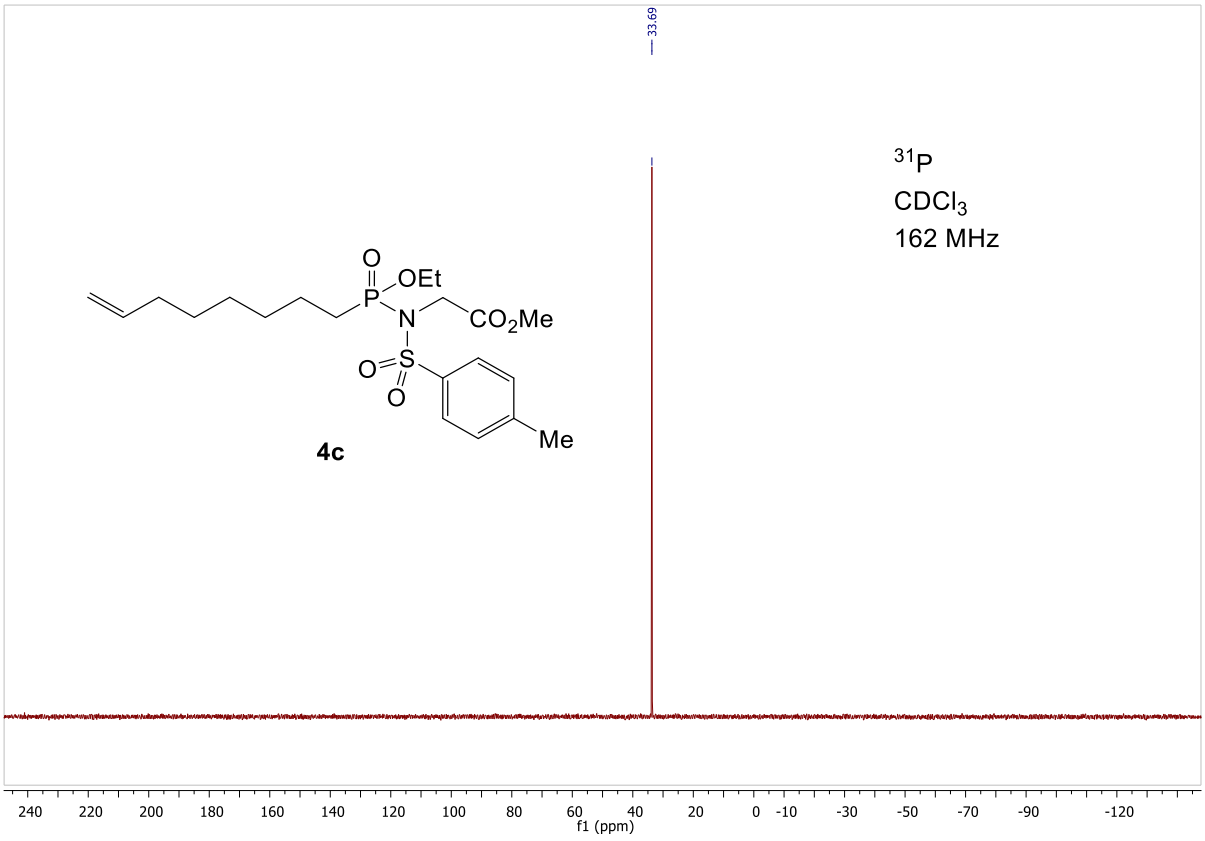

^{1}H
$CDCl_3$
400 MHz
4b
f1 (ppm)

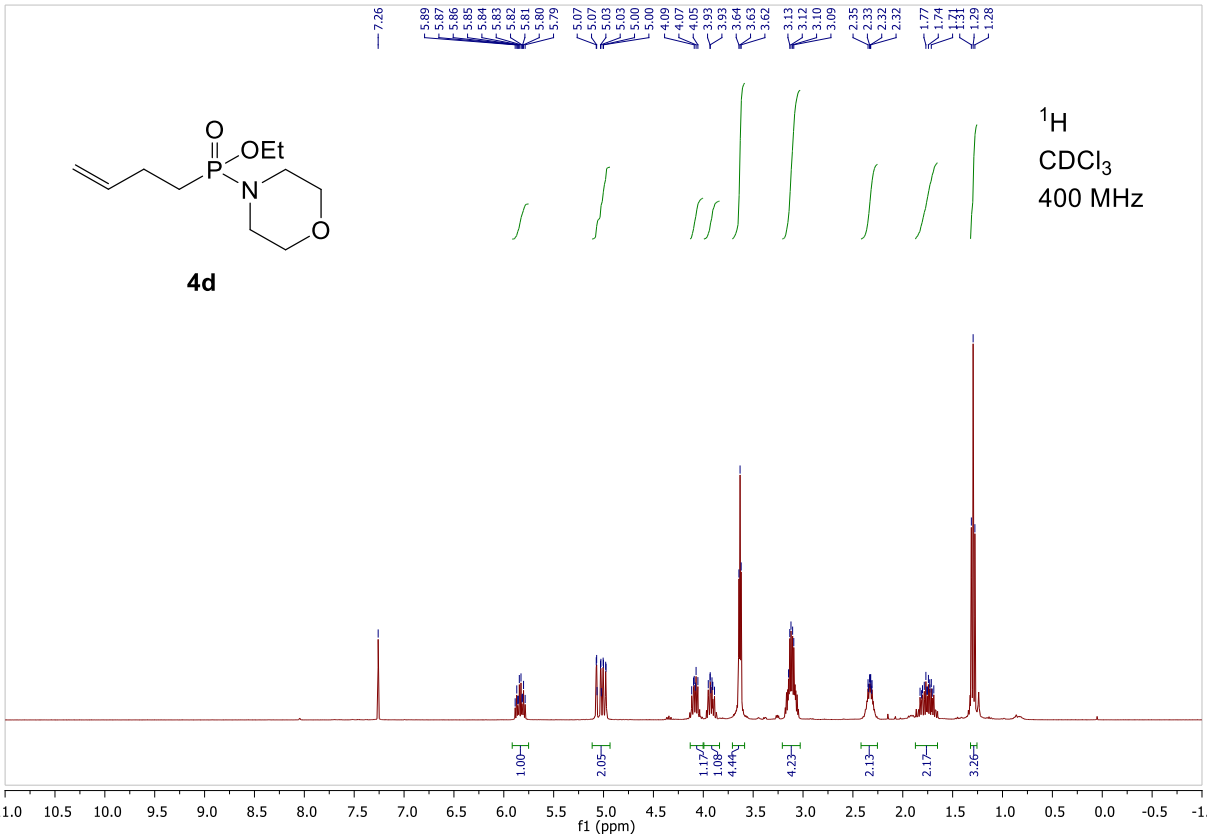

^{13}C (APT)
$CDCl_3$
100 MHz
4b
f1 (ppm)

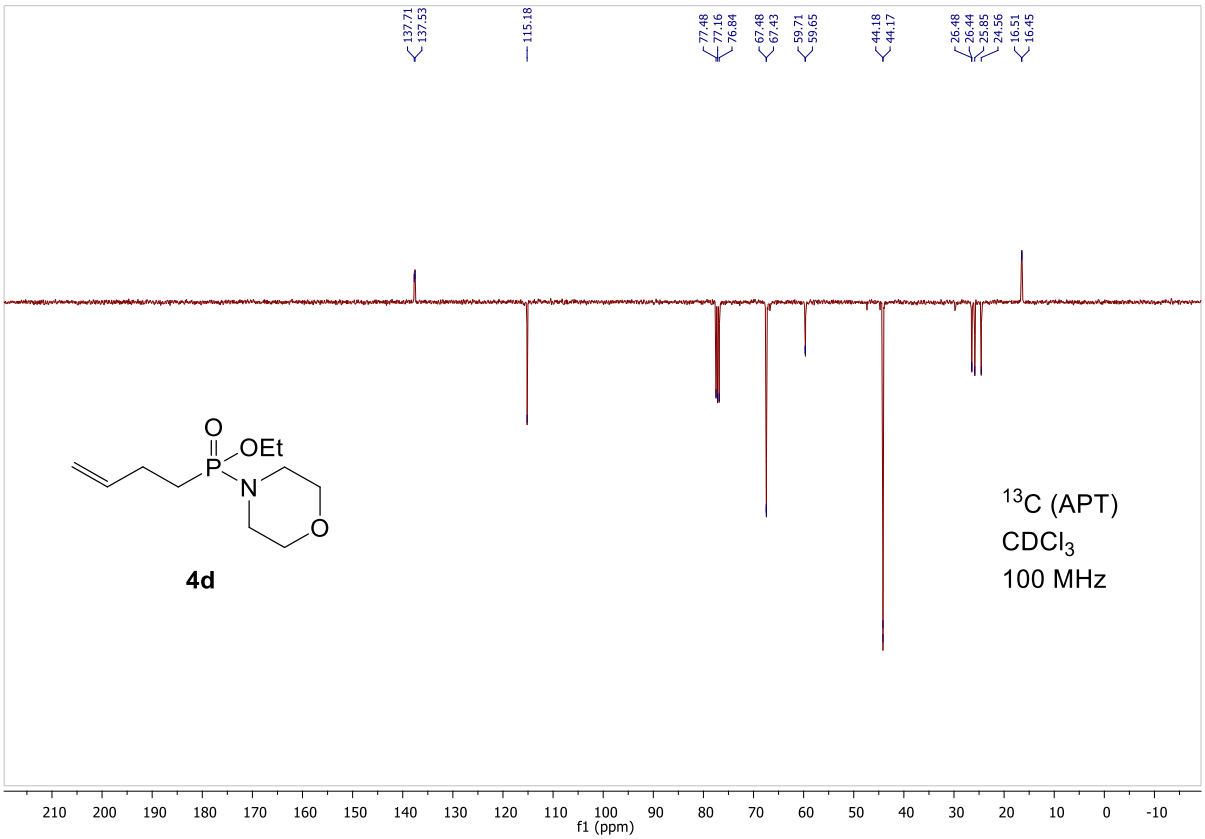

34.31
^{31}P
$CDCl_3$
162 MHz
O
OEt
P
N
Ph
O
S
O
Me
4b
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)

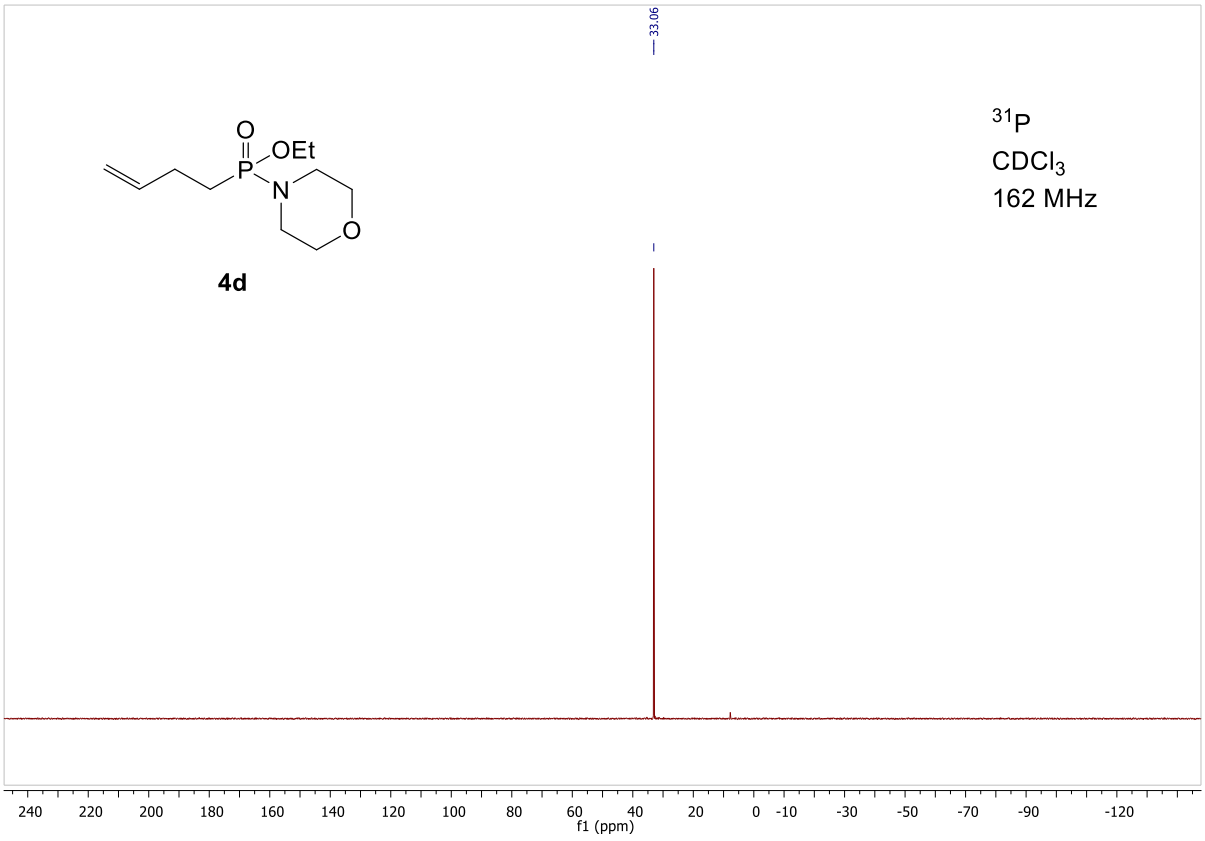

^{1}H
$CDCl_3$
400 MHz
4c
f1 (ppm)

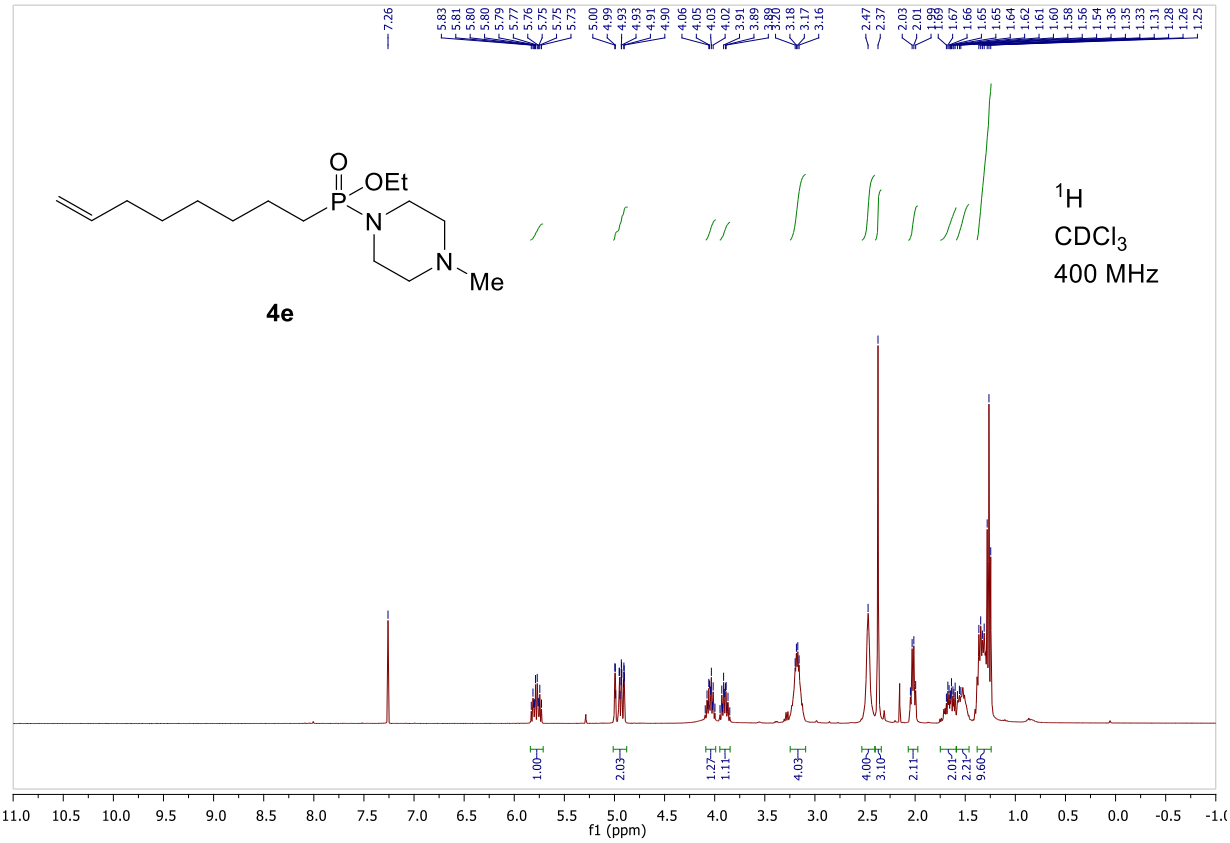

^{13}C (APT)
$CDCl_3$
100 MHz
4c
f1 (ppm)

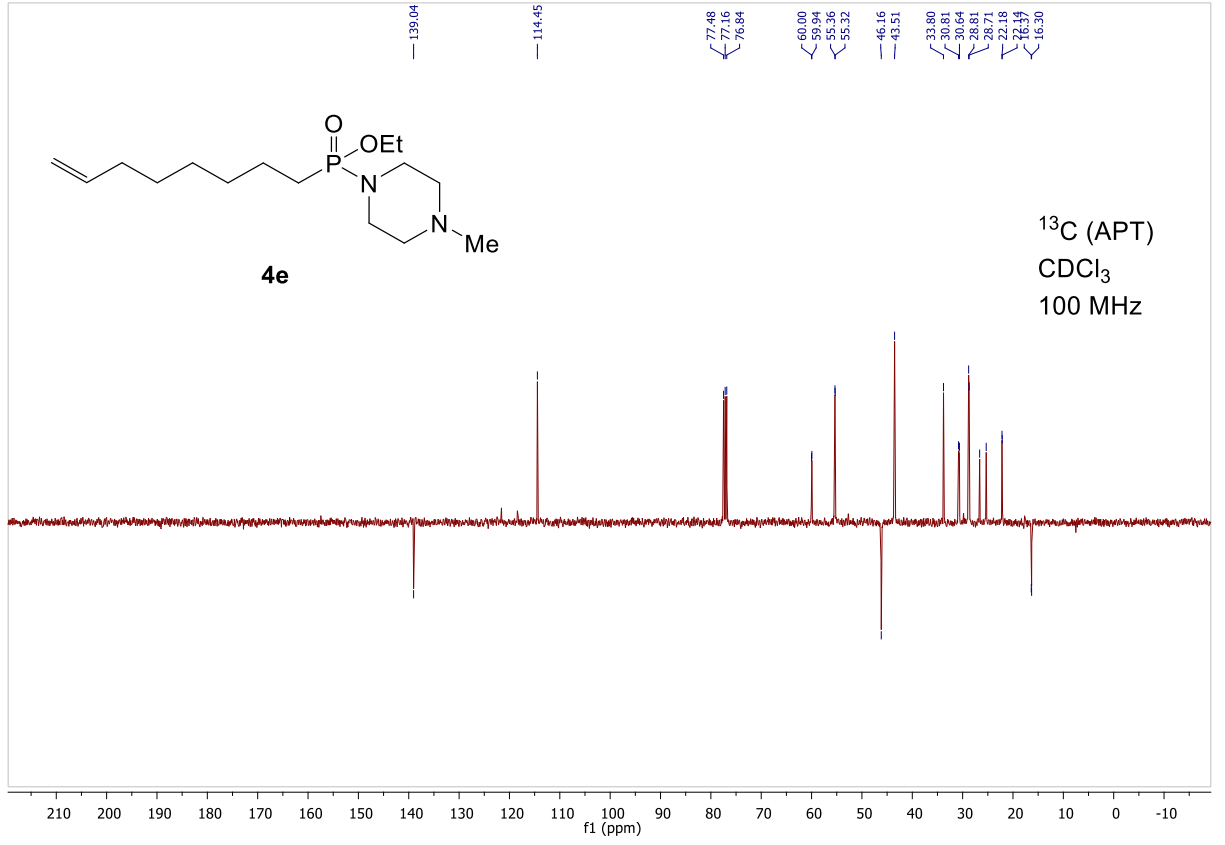

33.69
^{31}P
$CDCl_3$
162 MHz
O
OEt
P
N
CO_2Me
O
S
O
Me
4c
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)

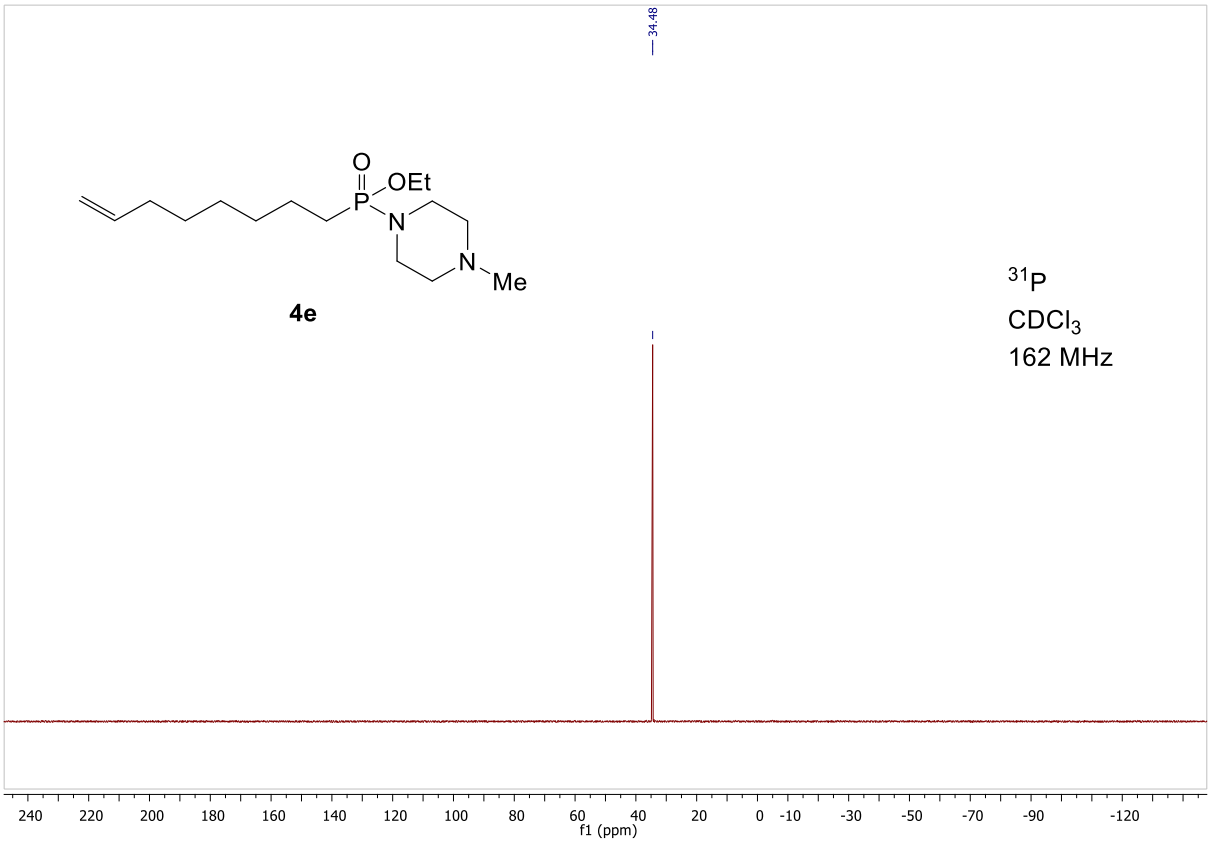

7.26
5.89
5.87
5.86
5.85
5.84
5.83
5.82
5.81
5.80
5.79
5.07
5.07
5.03
5.03
5.00
5.00
4.09
4.07
4.05
3.93
3.93
3.64
3.63
3.62
3.13
3.12
3.10
3.09
2.35
2.33
2.32
2.32
1.77
1.74
1.31
1.29
1.28
O
OEt
P
N
O
4d
1H
CDCl3
400 MHz
1.00
2.05
1.17
1.08
4.44
4.23
2.13
2.17
3.26
11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 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 -0.5
f1 (ppm)

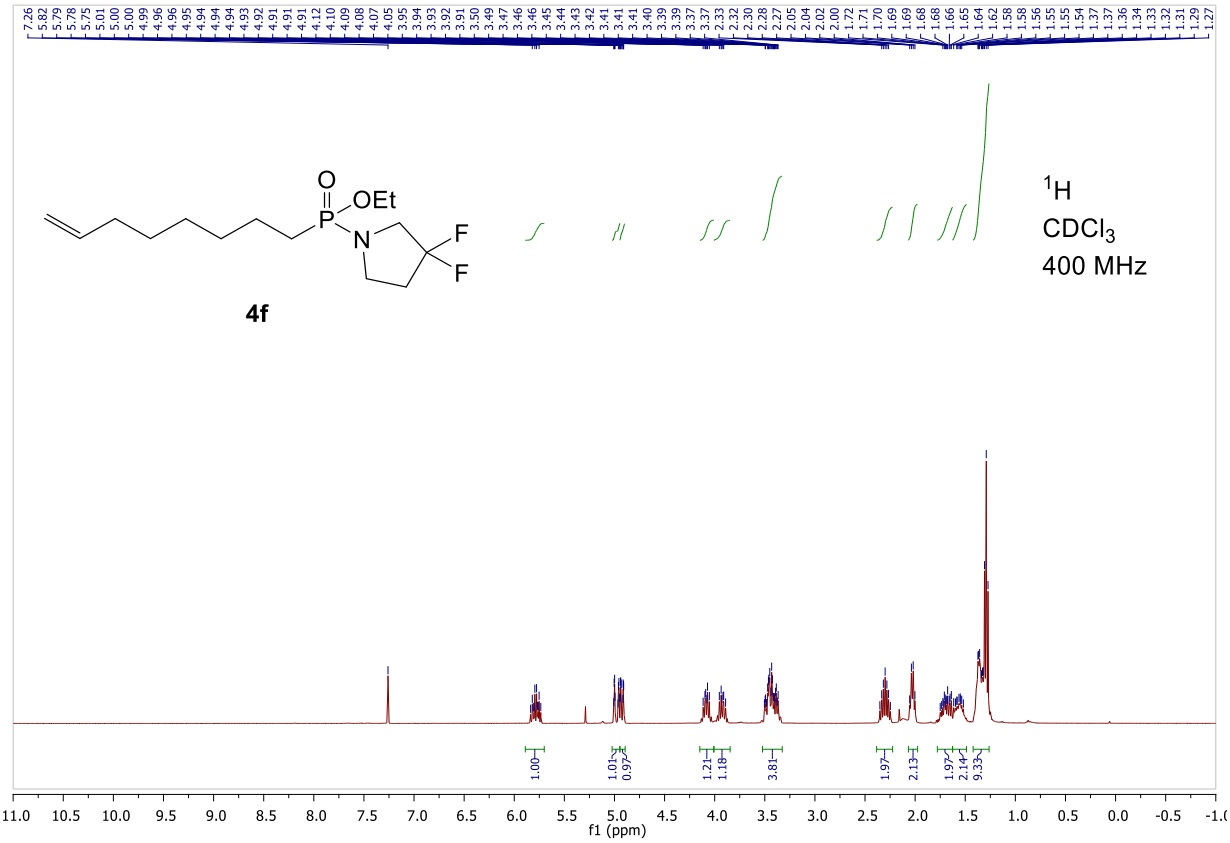

137.71
137.53
115.18
77.48
77.16
76.84
67.48
67.43
59.71
59.65
44.18
44.17
26.48
26.44
25.85
24.56
16.51
16.45
O
OEt
P
N
O
4d
13C (APT)
CDCl3
100 MHz
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)

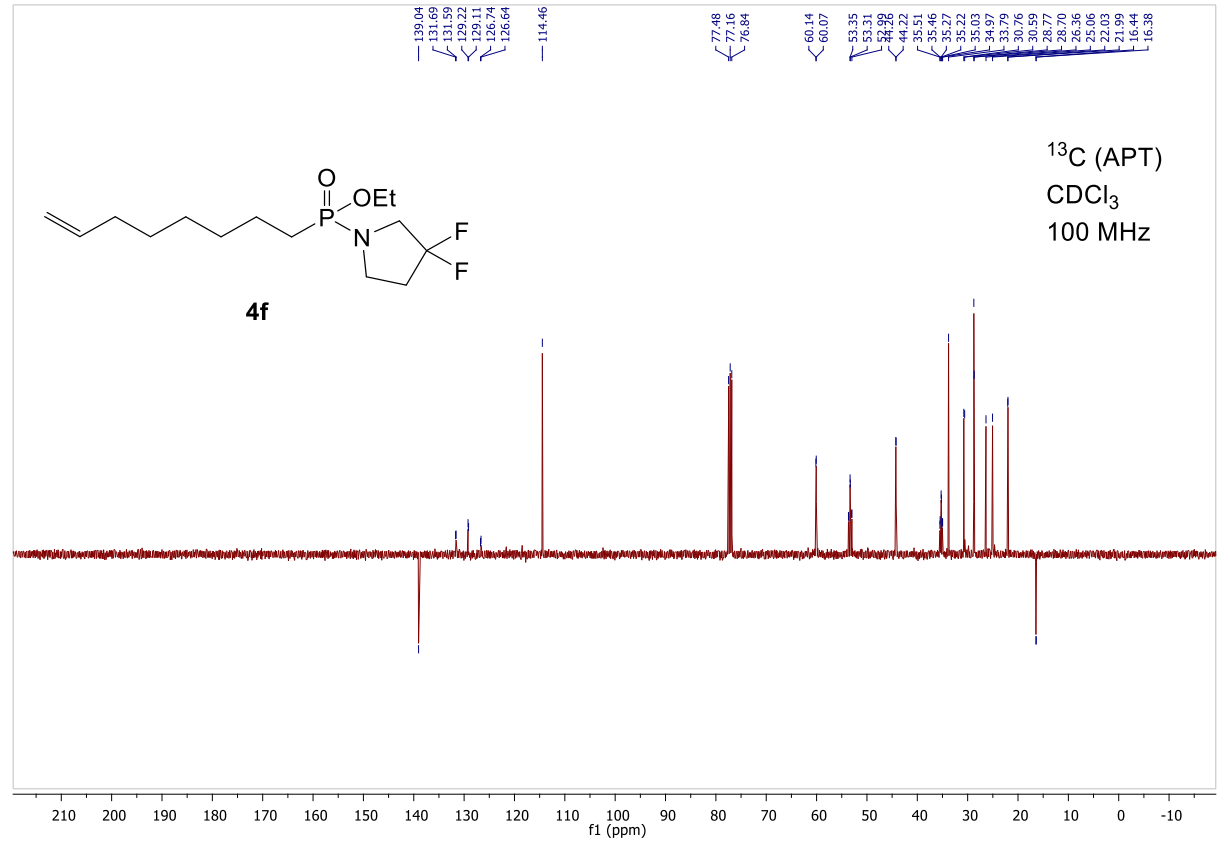

33.06
O
OEt
P
N
O
4d
31P
CDCl3
162 MHz
240 220 200 180 160 140 120 100 80 60 40 20 0 -10 -30 -50 -70 -90 -120
f1 (ppm)

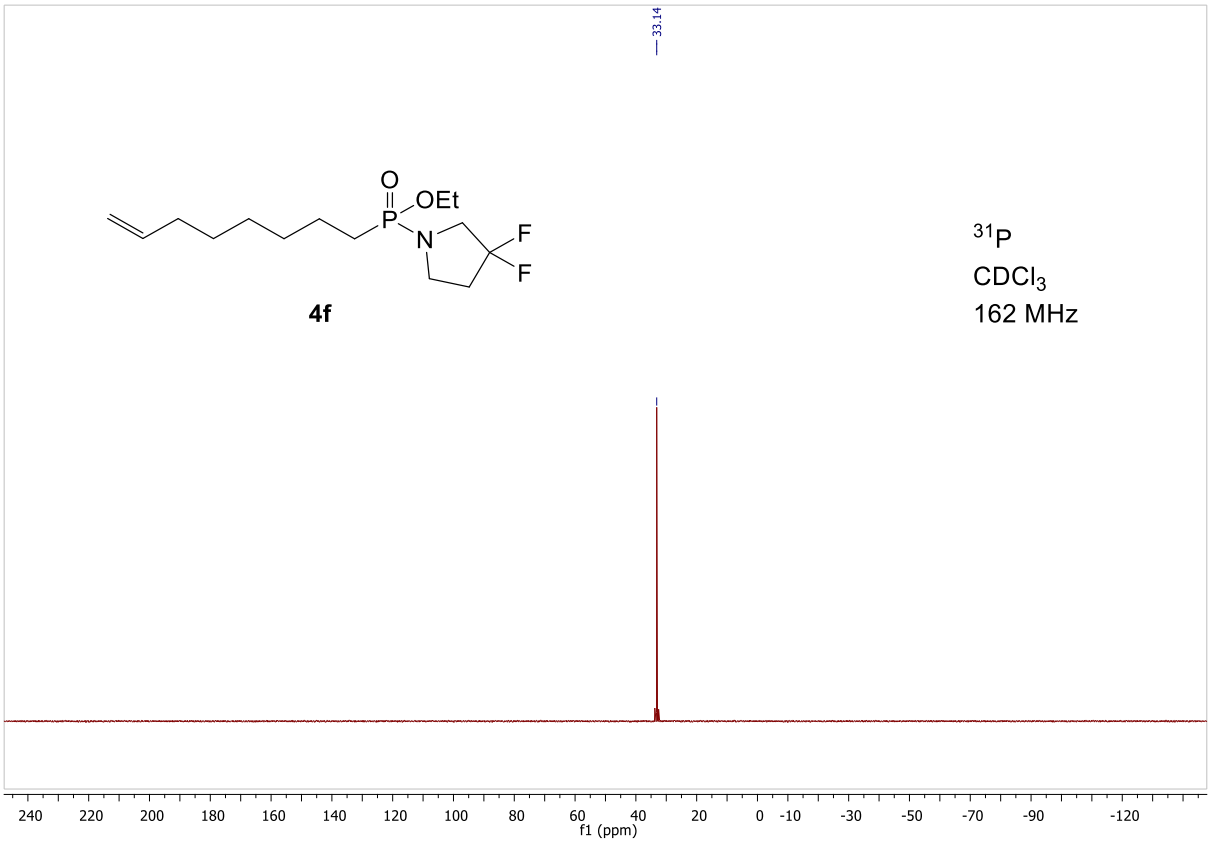

4e
^{1}H
$CDCl_3$
400 MHz
f1 (ppm)

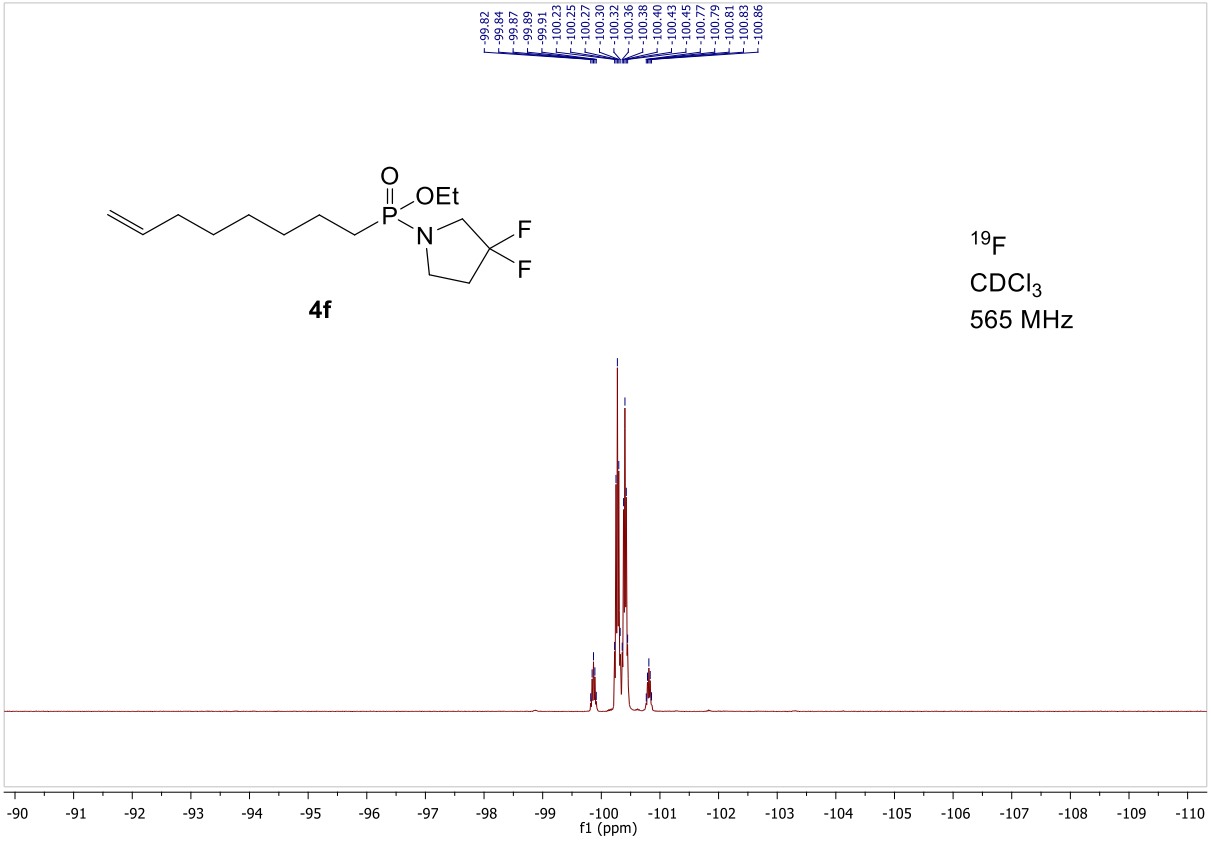

4e
^{13}C (APT)
$CDCl_3$
100 MHz
f1 (ppm)

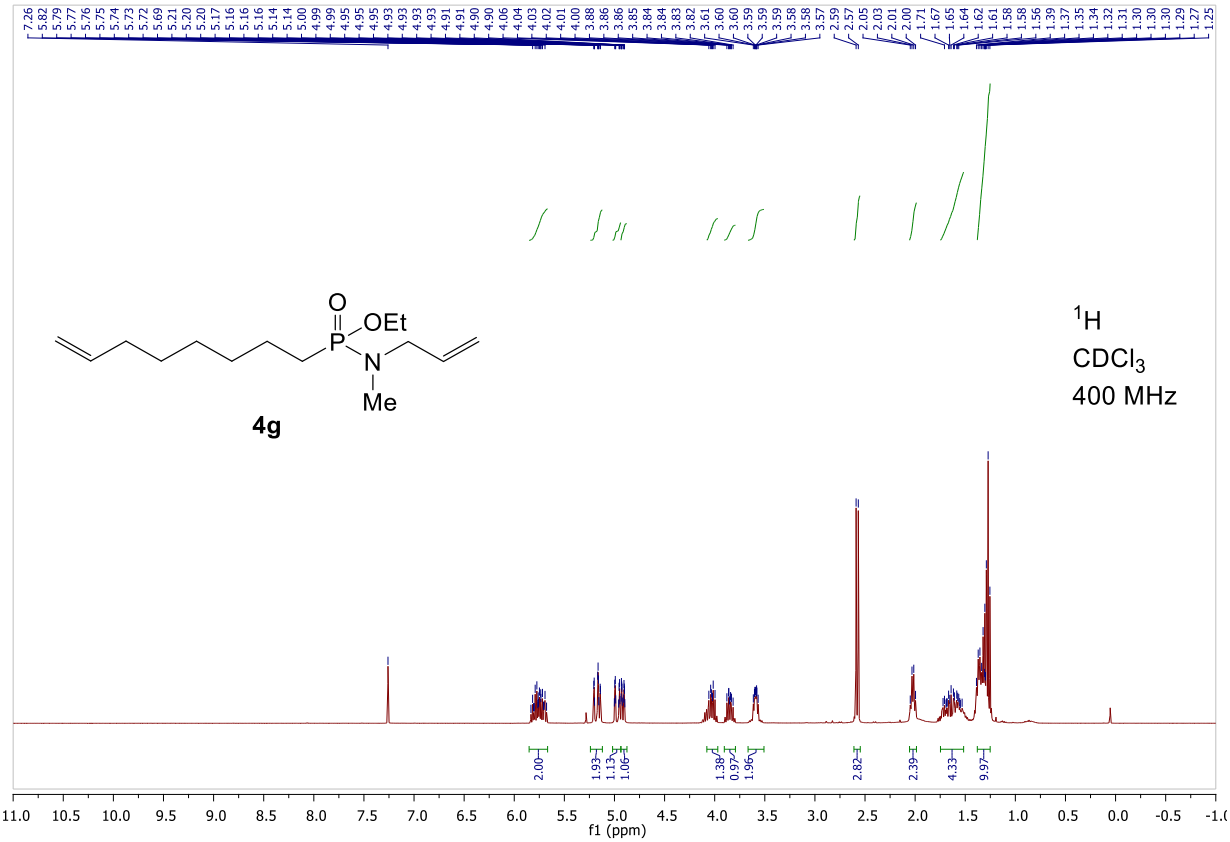

34.48
O
OEt
P
N
N
Me
4e
31P
CDCl3
162 MHz
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)

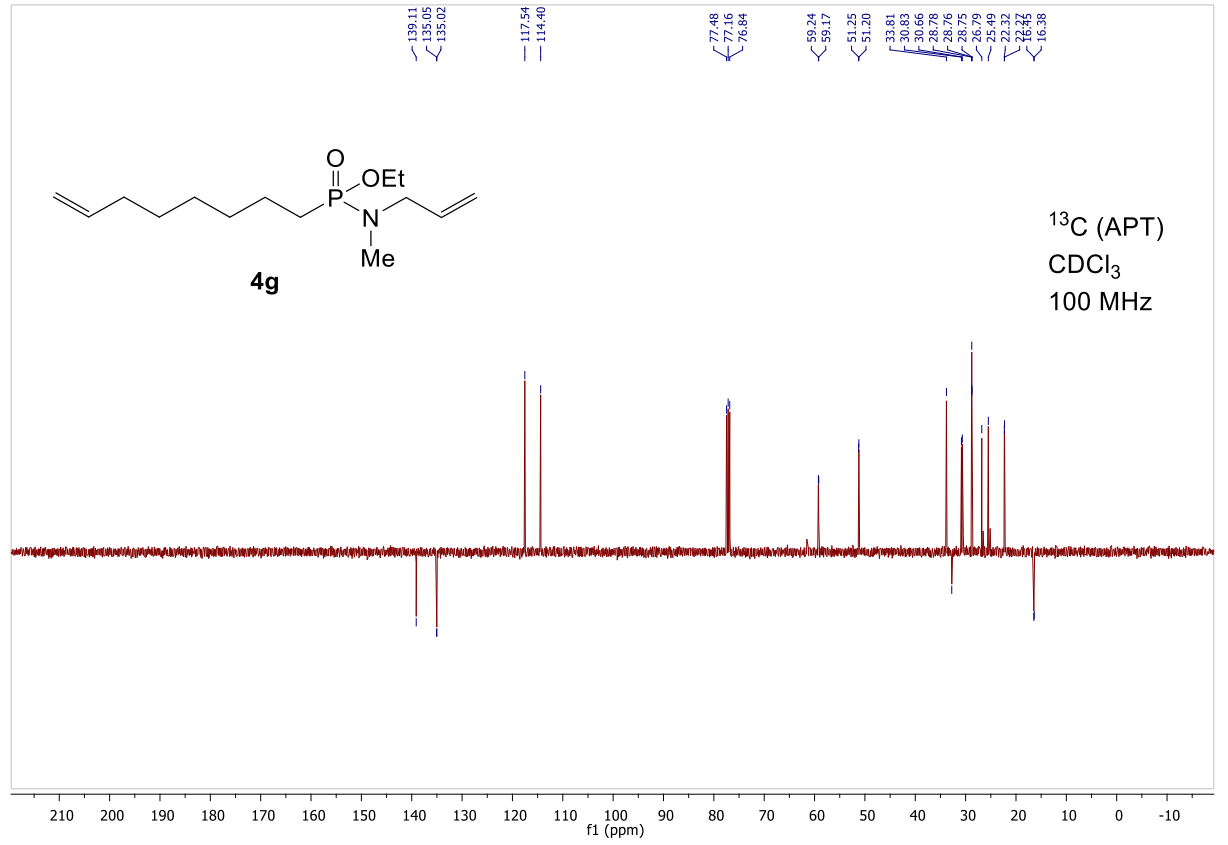

O
OEt
P
N
F
F
4f
^{1}H
$CDCl_3$
400 MHz
f1 (ppm)

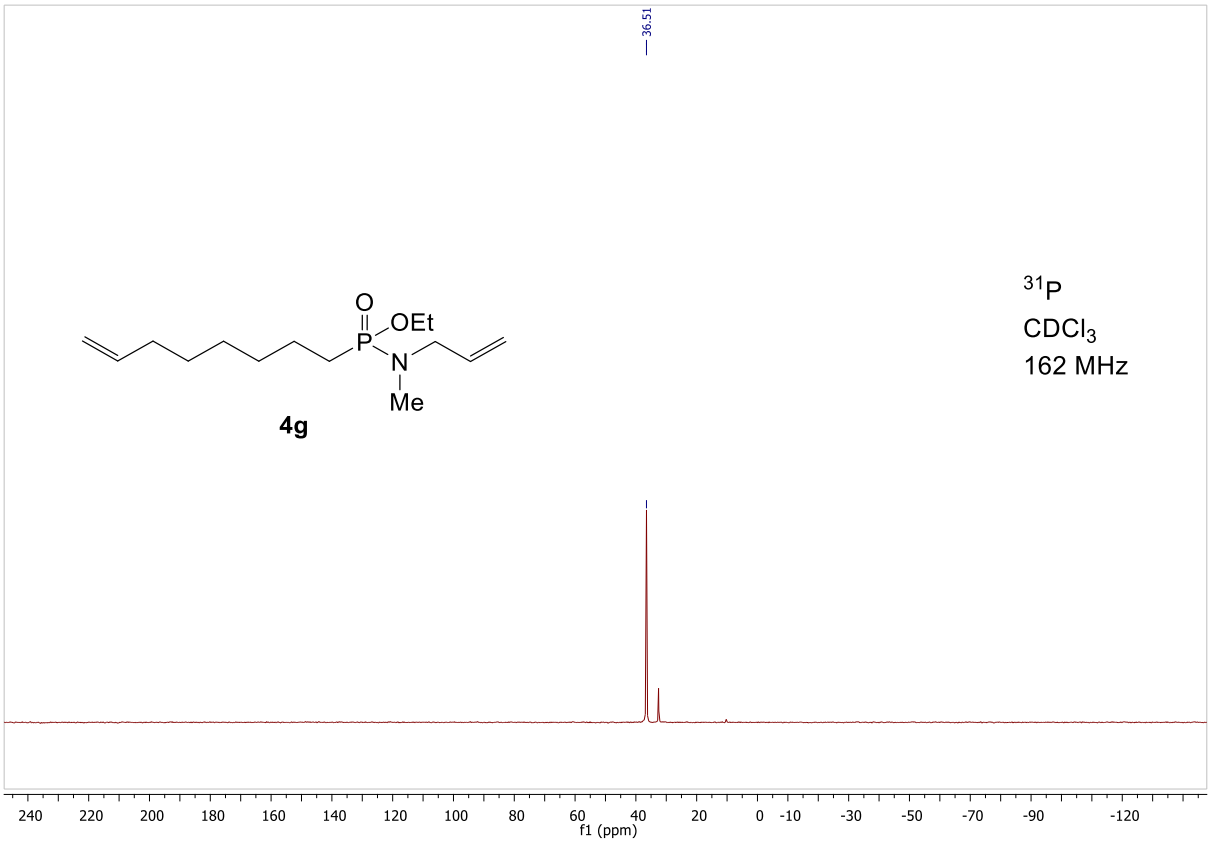

O
OEt
P
N
F
F
4f
^{13}C (APT)
$CDCl_3$
100 MHz
f1 (ppm)

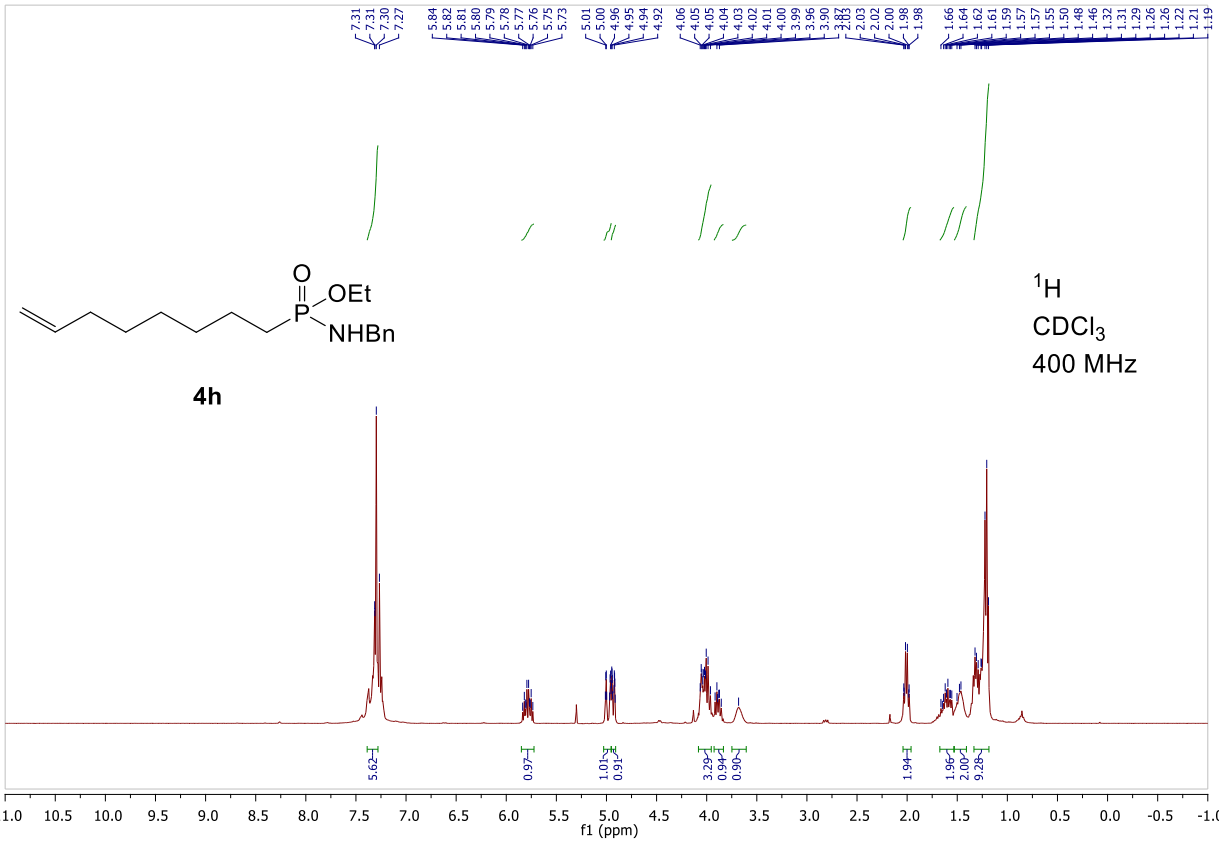

33.14
O
OEt
P
N
F
F
4f
31P
CDCl3
162 MHz
240 220 200 180 160 140 120 100 80 60 40 20 0 -10 -30 -50 -70 -90 -120
f1 (ppm)

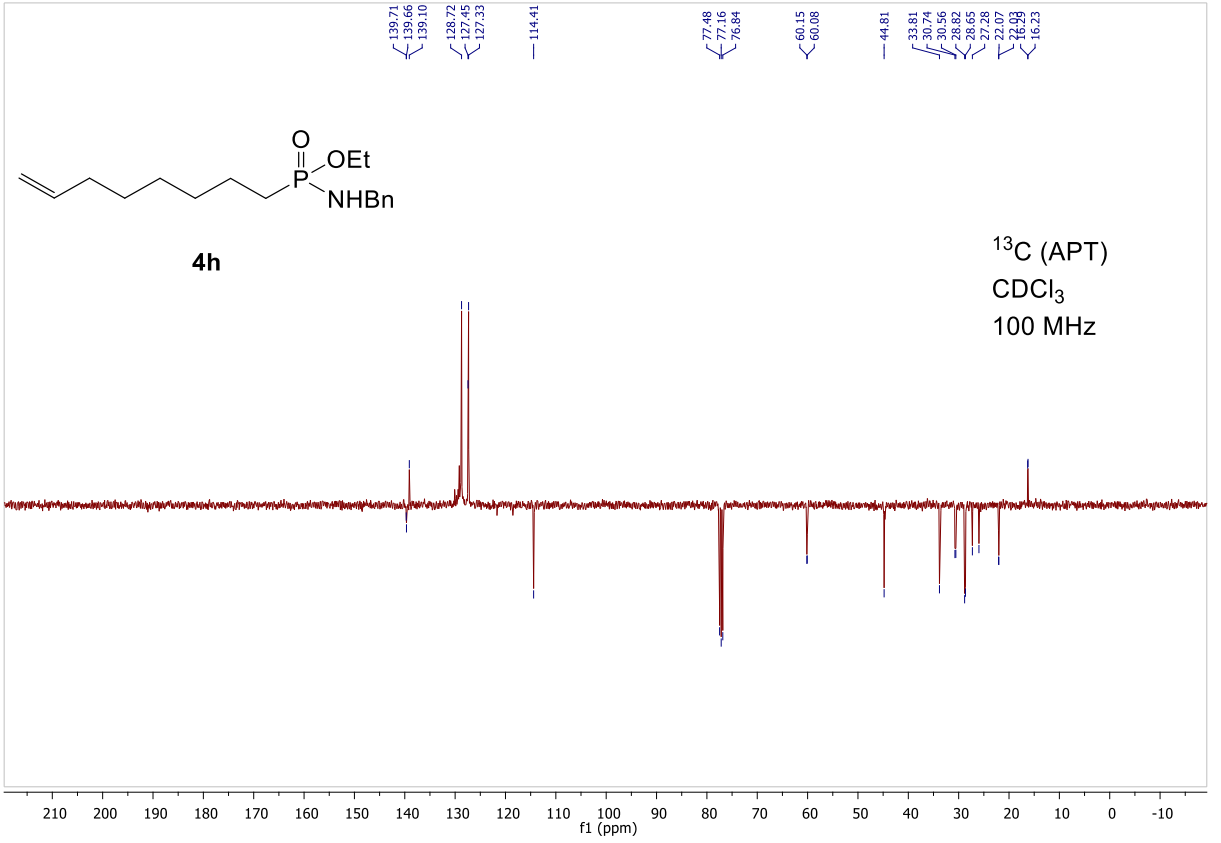

-99.82
-99.84
-99.87
-99.89
-99.91
-100.23
-100.25
-100.27
-100.30
-100.32
-100.36
-100.38
-100.40
-100.43
-100.45
-100.77
-100.79
-100.81
-100.83
-100.86
O
OEt
P
N
F
F
4f
19F
CDCl3
565 MHz
-90 -91 -92 -93 -94 -95 -96 -97 -98 -99 -100 -101 -102 -103 -104 -105 -106 -107 -108 -109 -110
f1 (ppm)

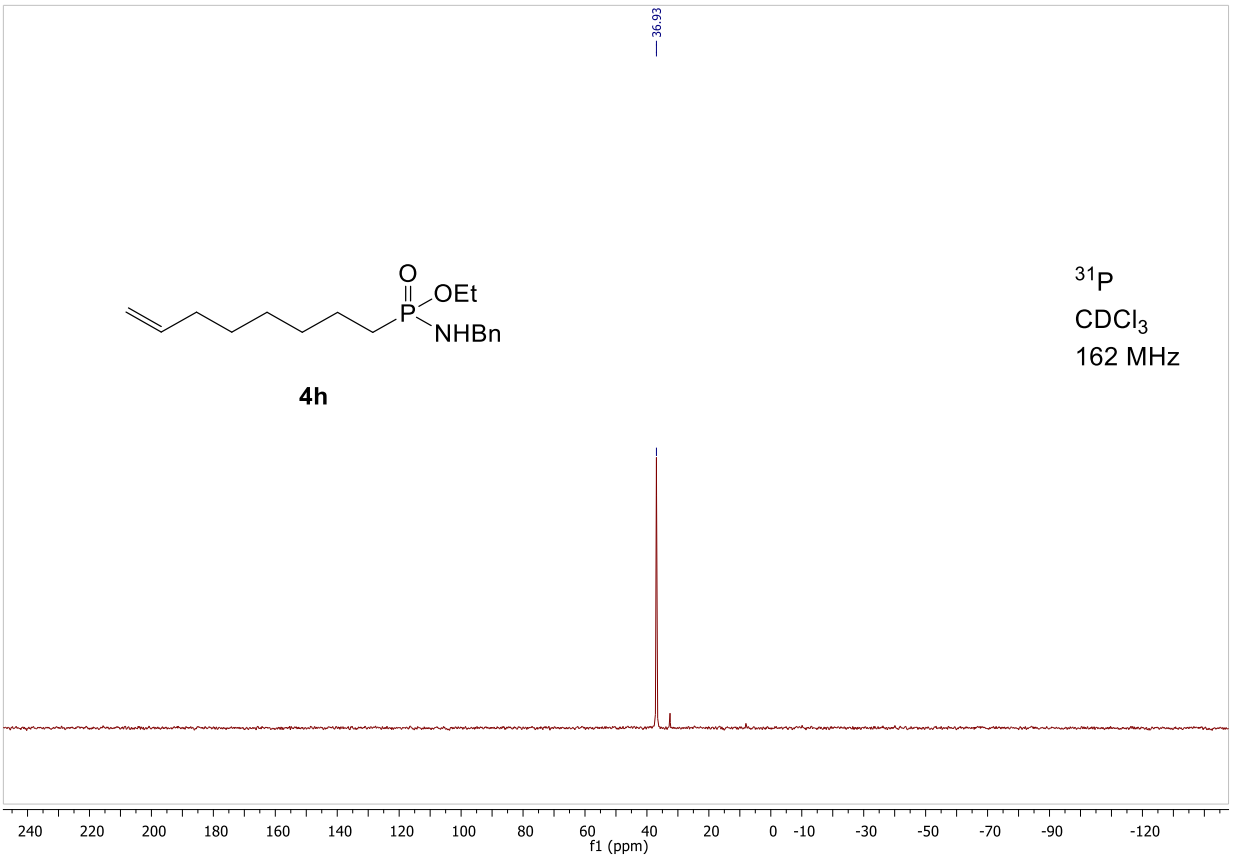

O
OEt
P
N
Me
4g
^{1}H
$CDCl_3$
400 MHz
f1 (ppm)

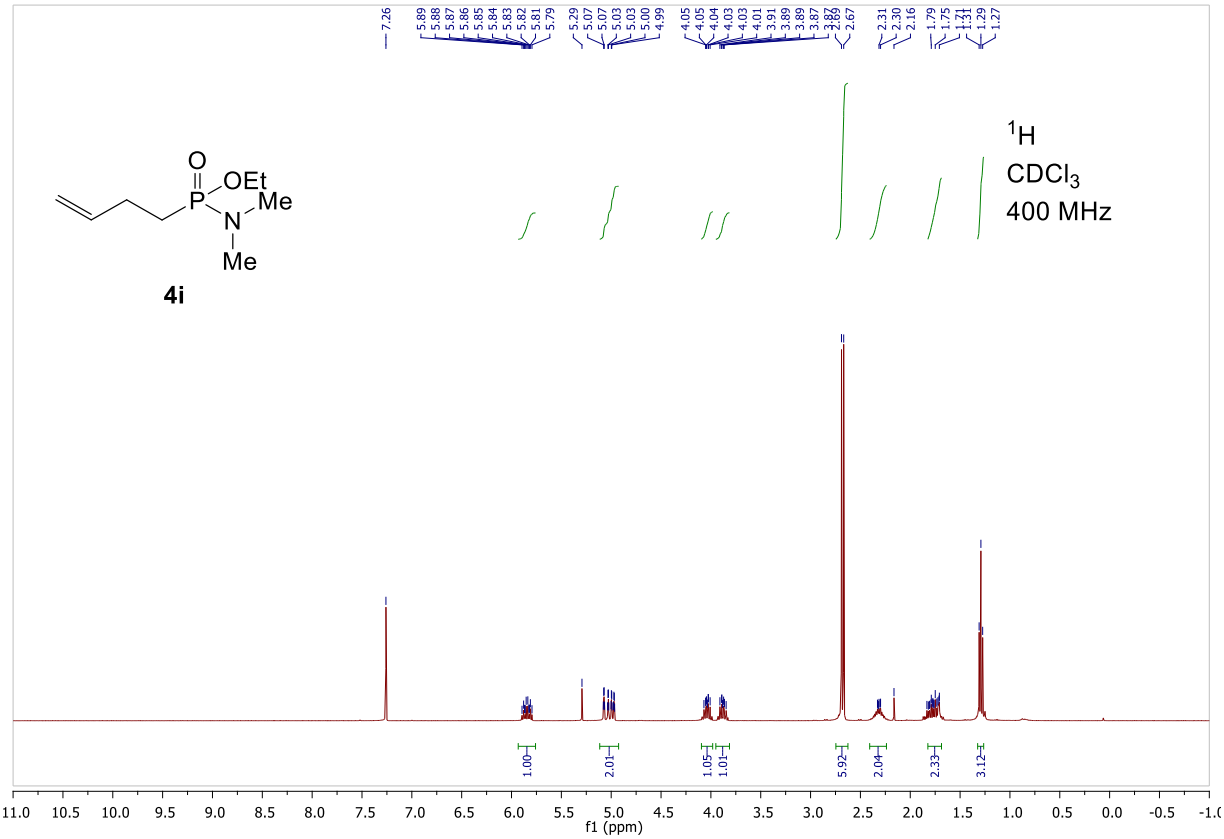

O
OEt
P
N
Me
4g
^{13}C (APT)
$CDCl_3$
100 MHz
f1 (ppm)

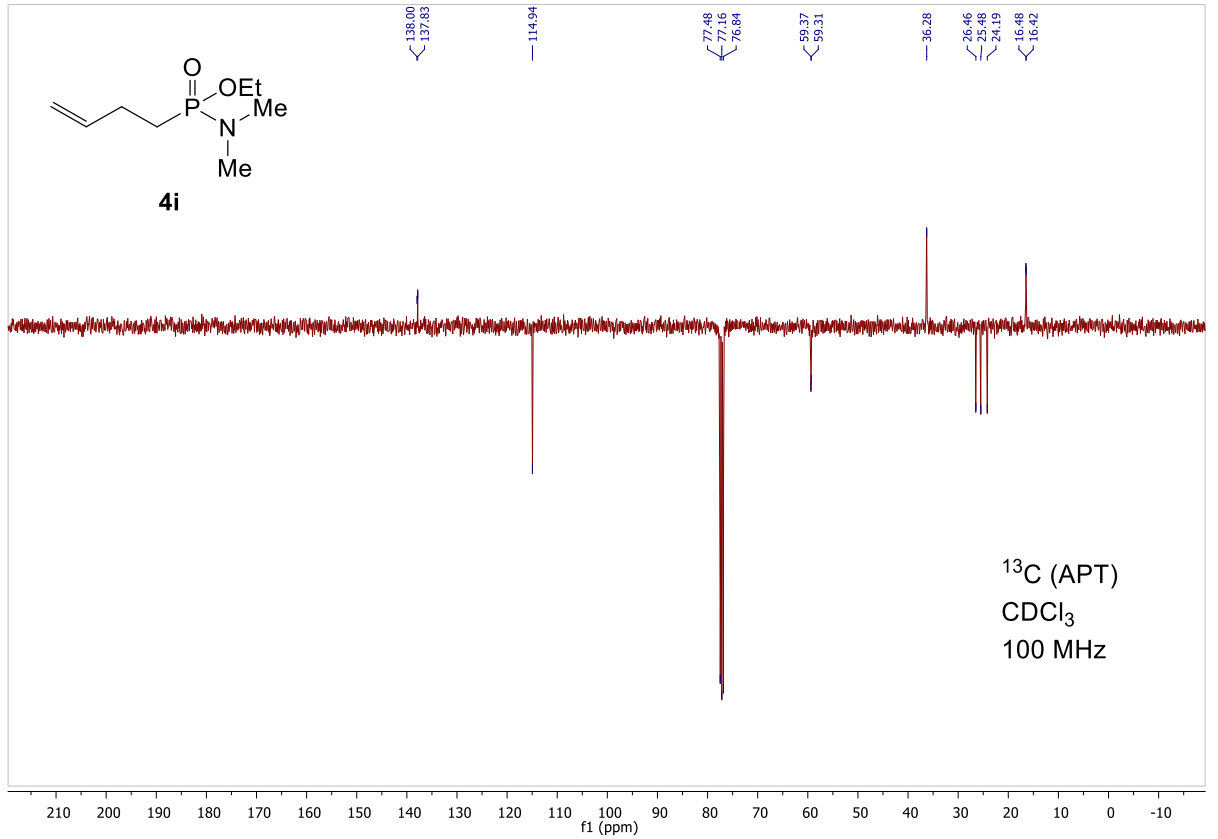

36.51
O
OEt
P
N
Me
4g
31P
CDCl3
162 MHz
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)

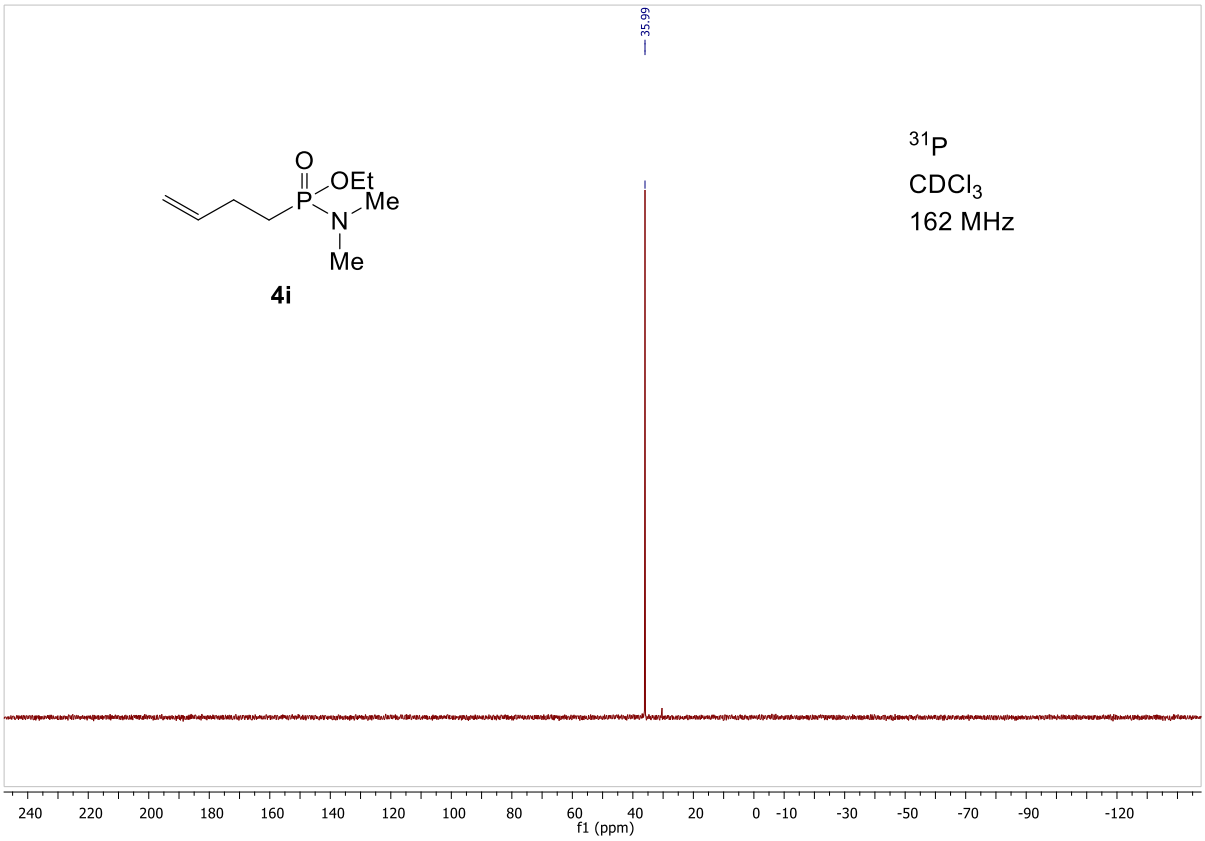

OEt
NHBn
4h
1H
CDCl3
400 MHz
f1 (ppm)

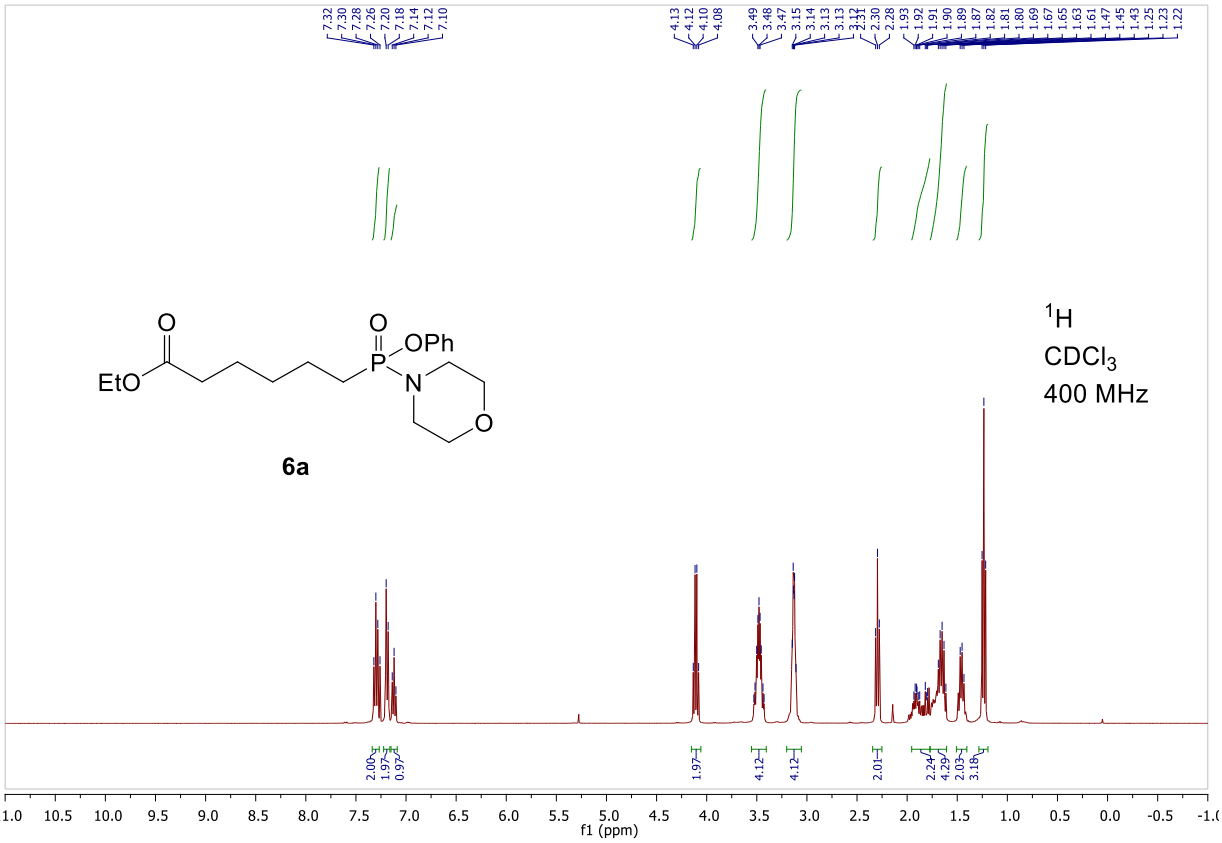

OEt
NHBn
4h
13C (APT)
CDCl3
100 MHz
f1 (ppm)

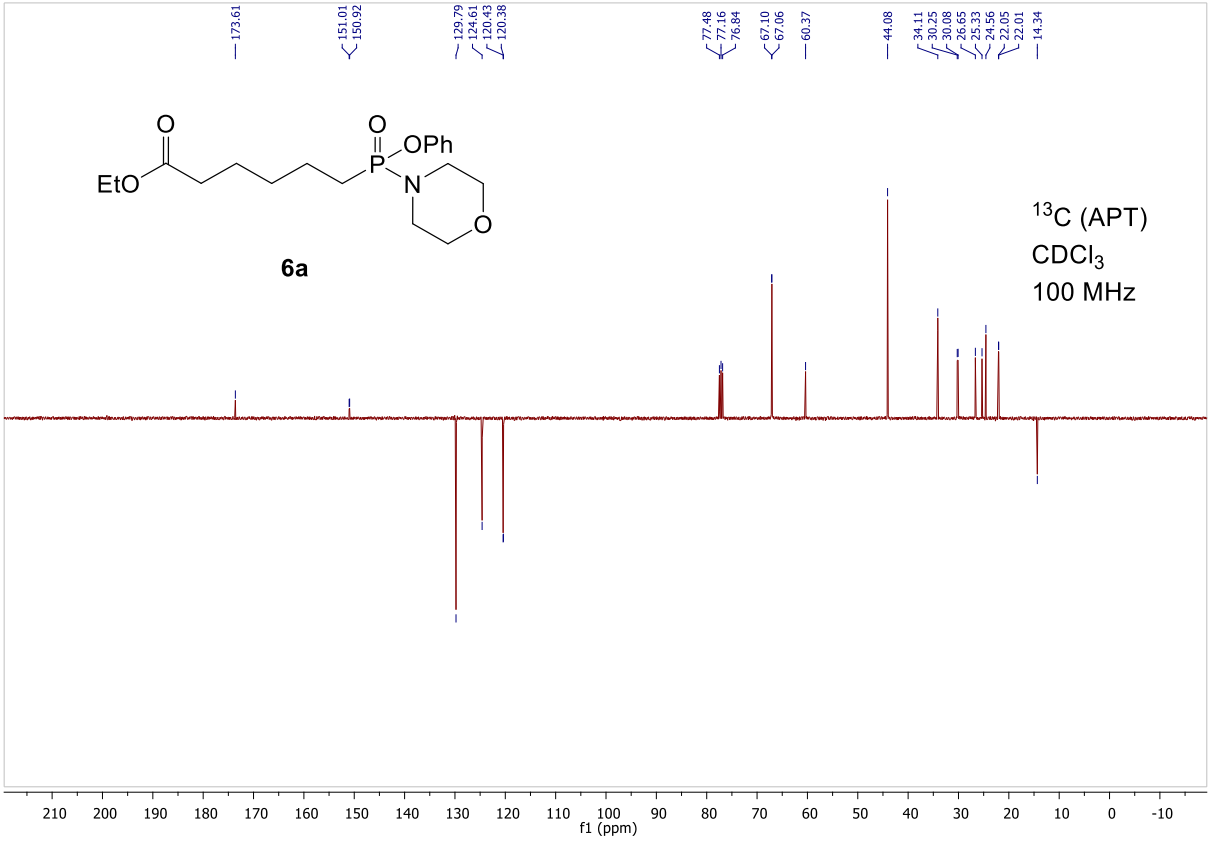

36.93
O
OEt
P
NHBn
4h
31P
CDCl3
162 MHz
240 220 200 180 160 140 120 100 80 60 40 20 0 -10 -30 -50 -70 -90 -120
f1 (ppm)

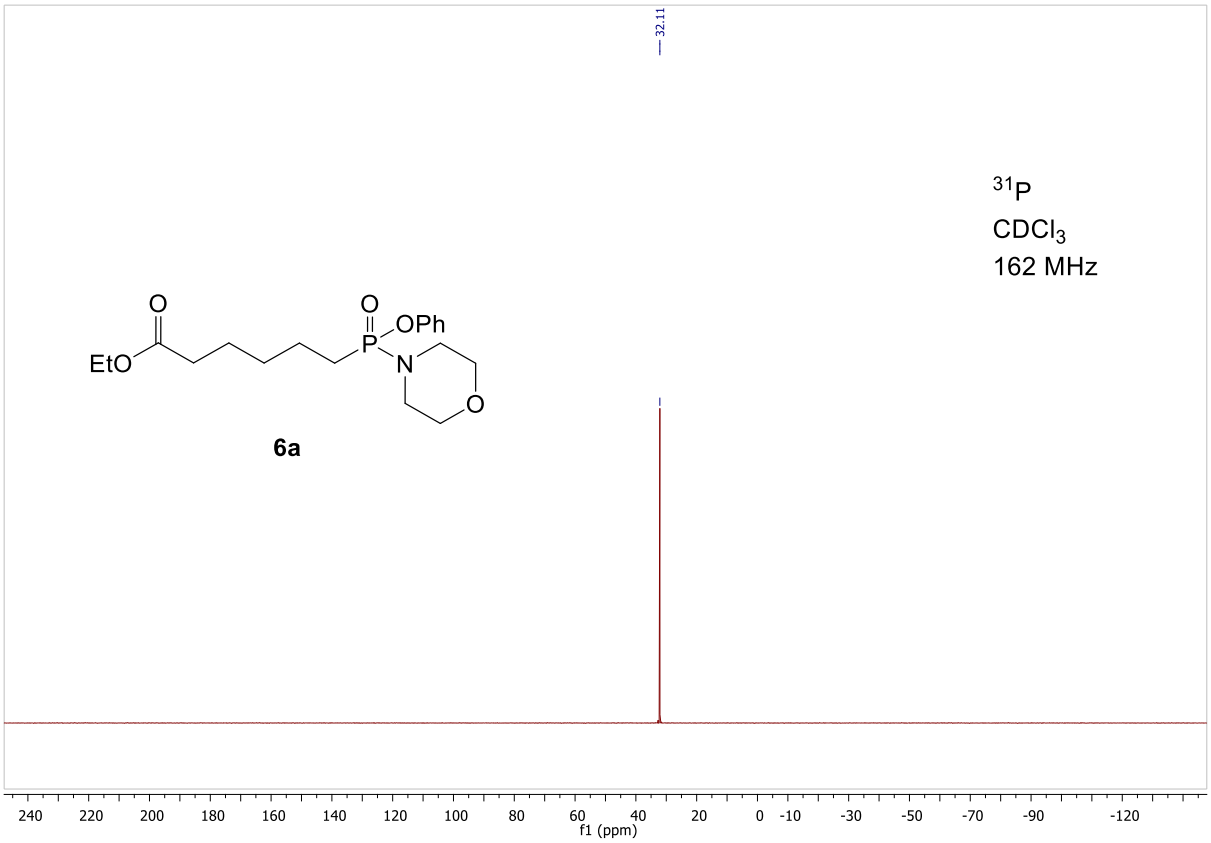

4i
^{1}H
$CDCl_3$
400 MHz
f1 (ppm)

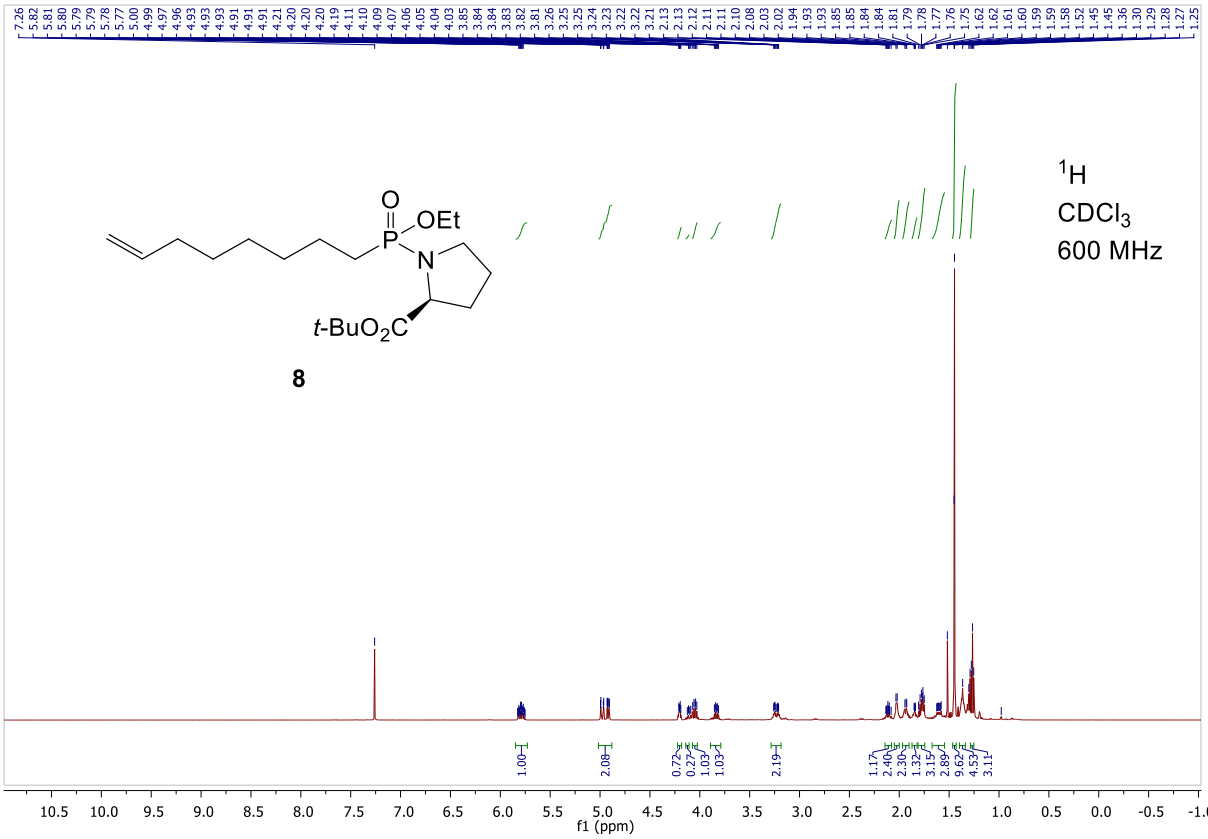

4i
^{13}C (APT)
$CDCl_3$
100 MHz
f1 (ppm)


35.99
O
OEt
P
Me
N
Me
4i
31P
CDCl3
162 MHz
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)


EtO
OPh
N
O
6a
1H
CDCl3
400 MHz
f1 (ppm)

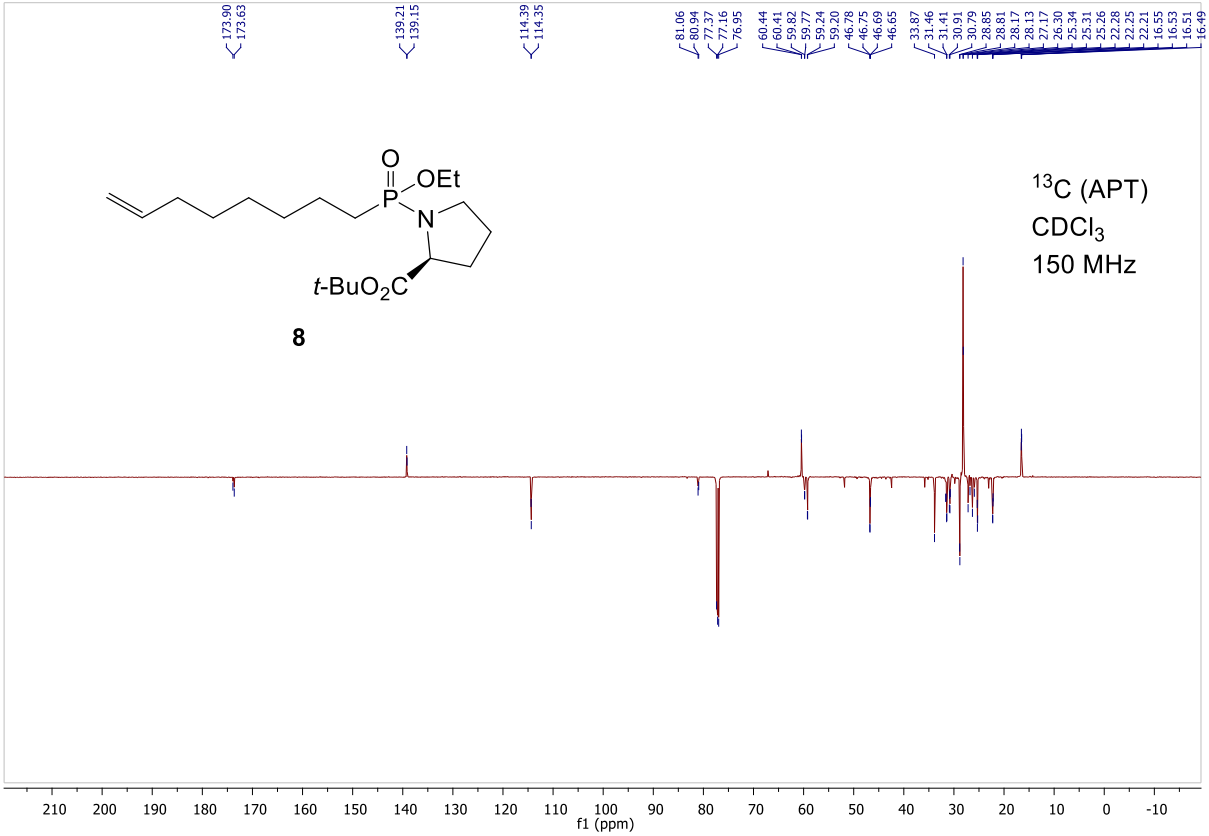

EtO
OPh
N
O
6a
13C (APT)
CDCl3
100 MHz
f1 (ppm)


32.11
31P
CDCl3
162 MHz
O
O
OPh
EtO
P
N
O
6a
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)


^{1}H
$CDCl_3$
600 MHz
f1 (ppm)

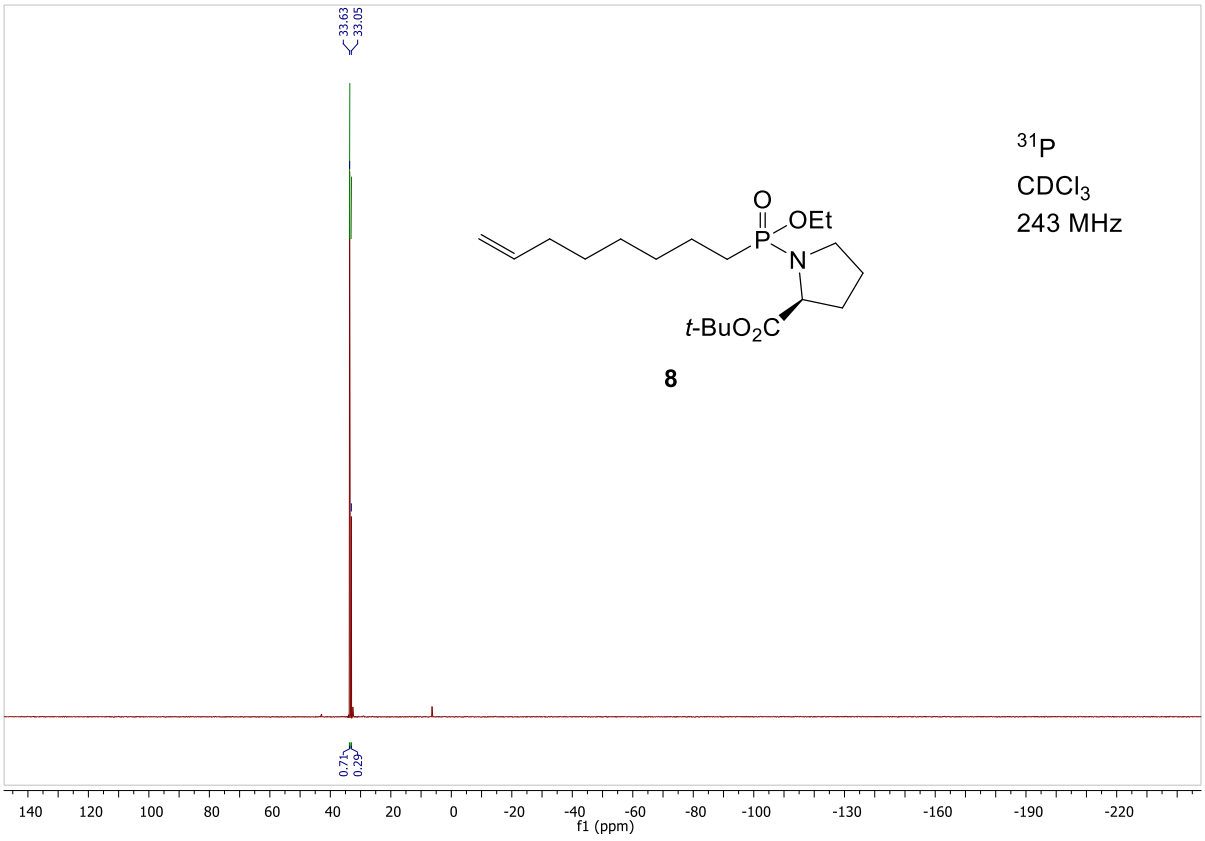
O
OEt
P
N
t-BuO2C

8

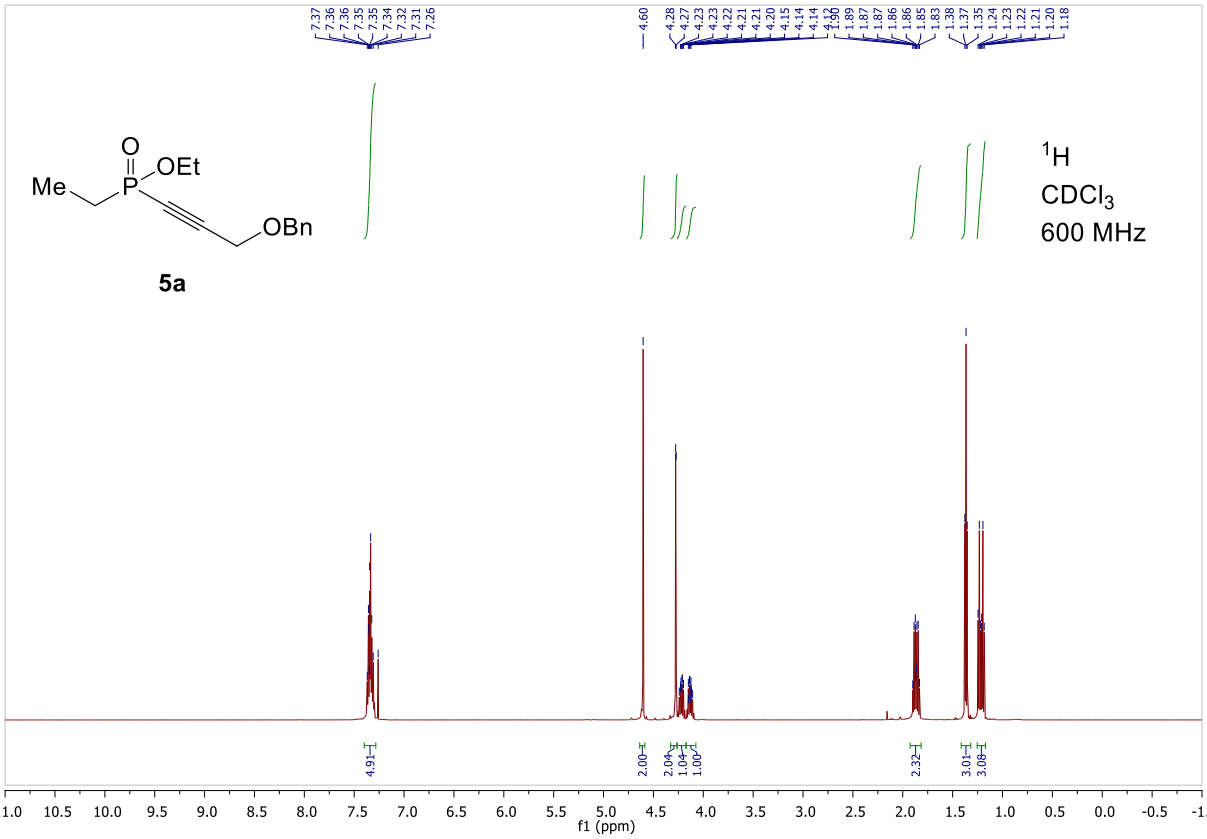

^{13}C (APT)
$CDCl_3$
150 MHz
f1 (ppm)

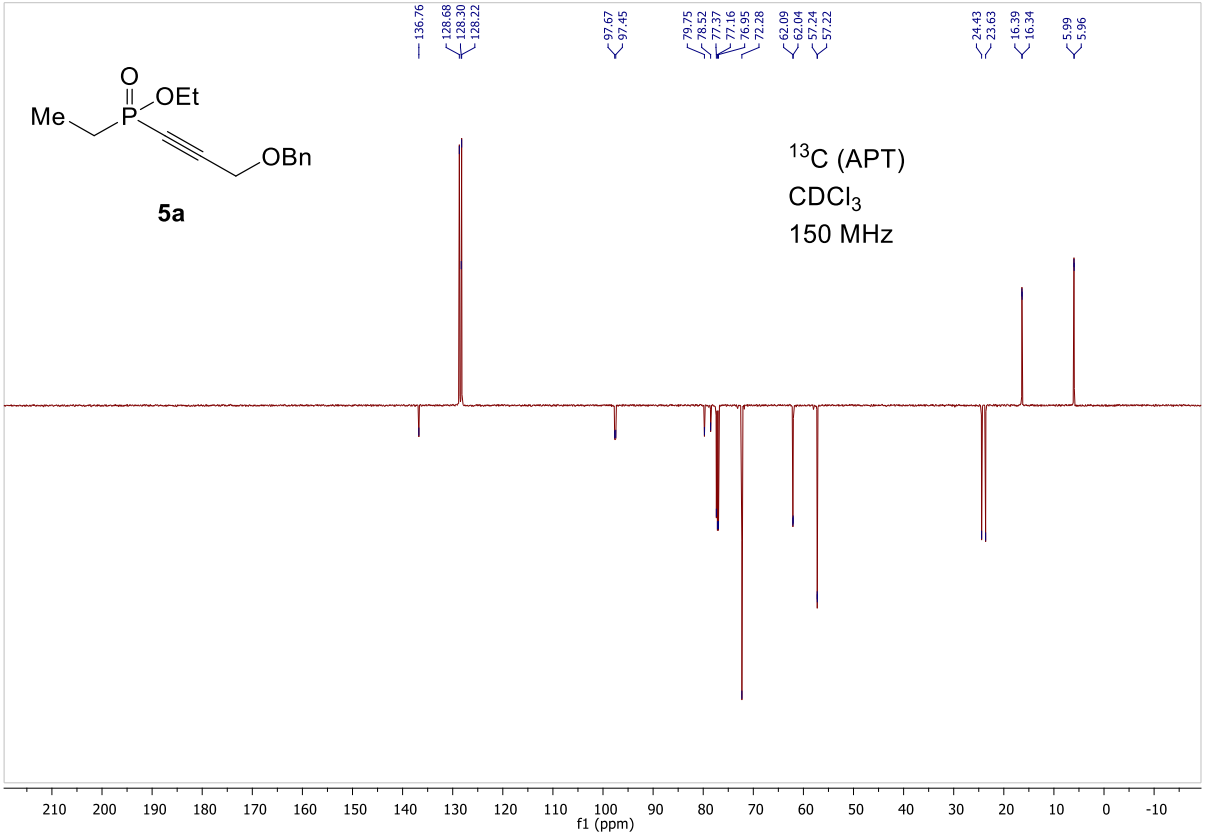
O
OEt
P
N
t-BuO2C

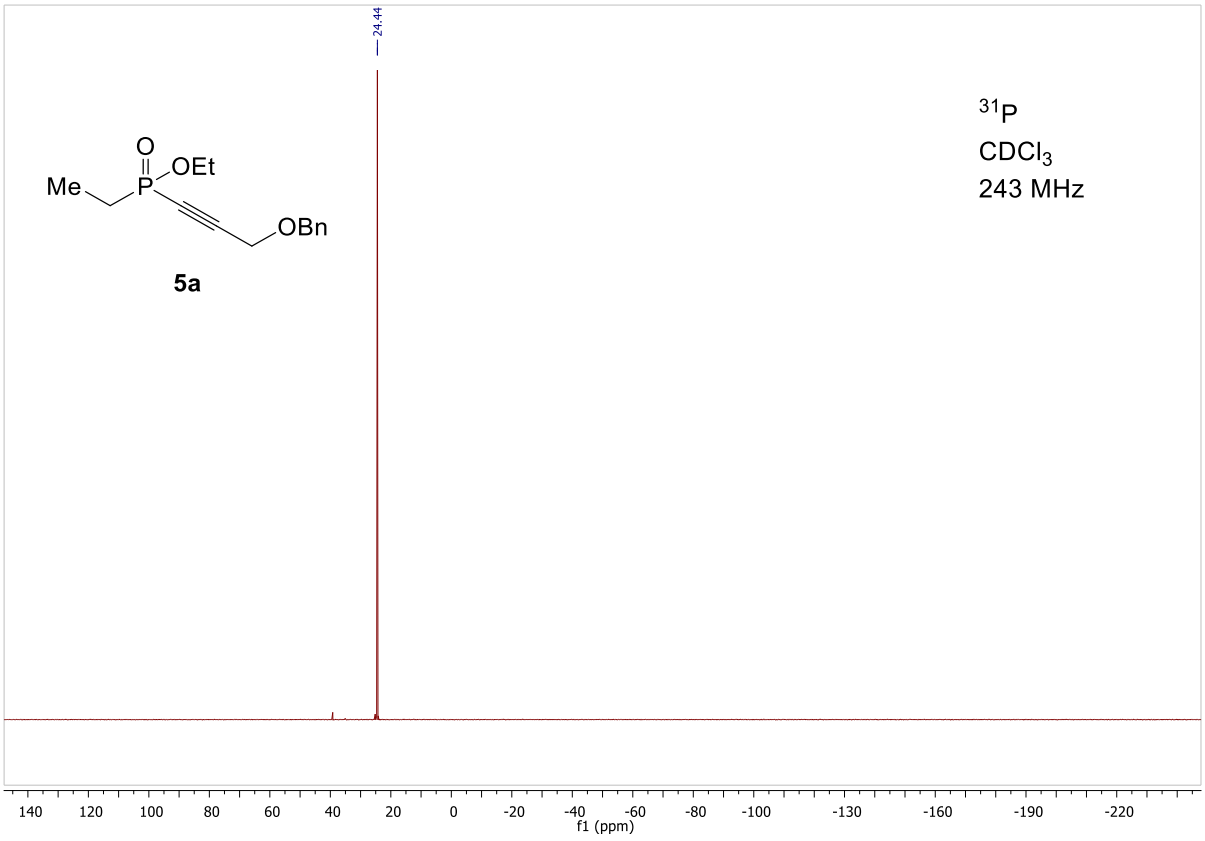
8

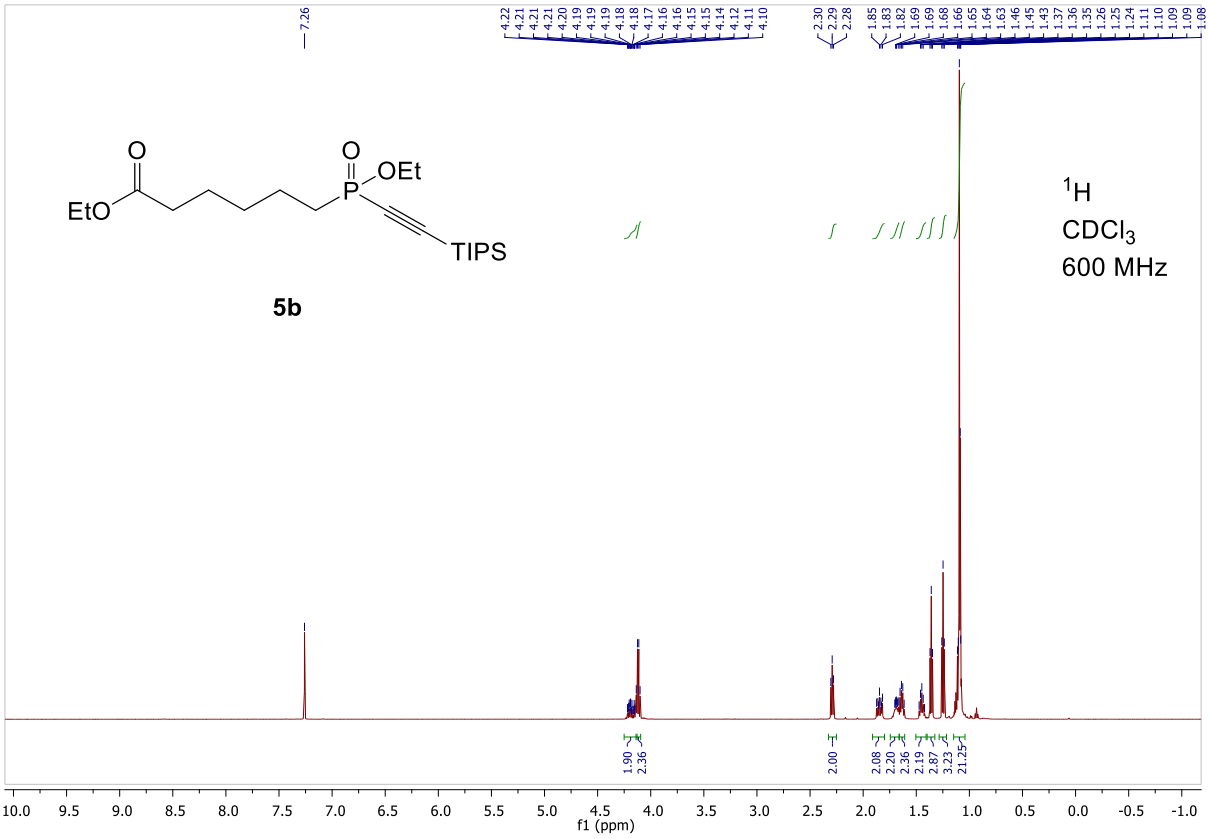

33.63
33.05
O
OEt
P
N
t-BuO2C
31P
CDCl3
243 MHz
0.71
0.29
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-130
-160
-190
-220
f1 (ppm)

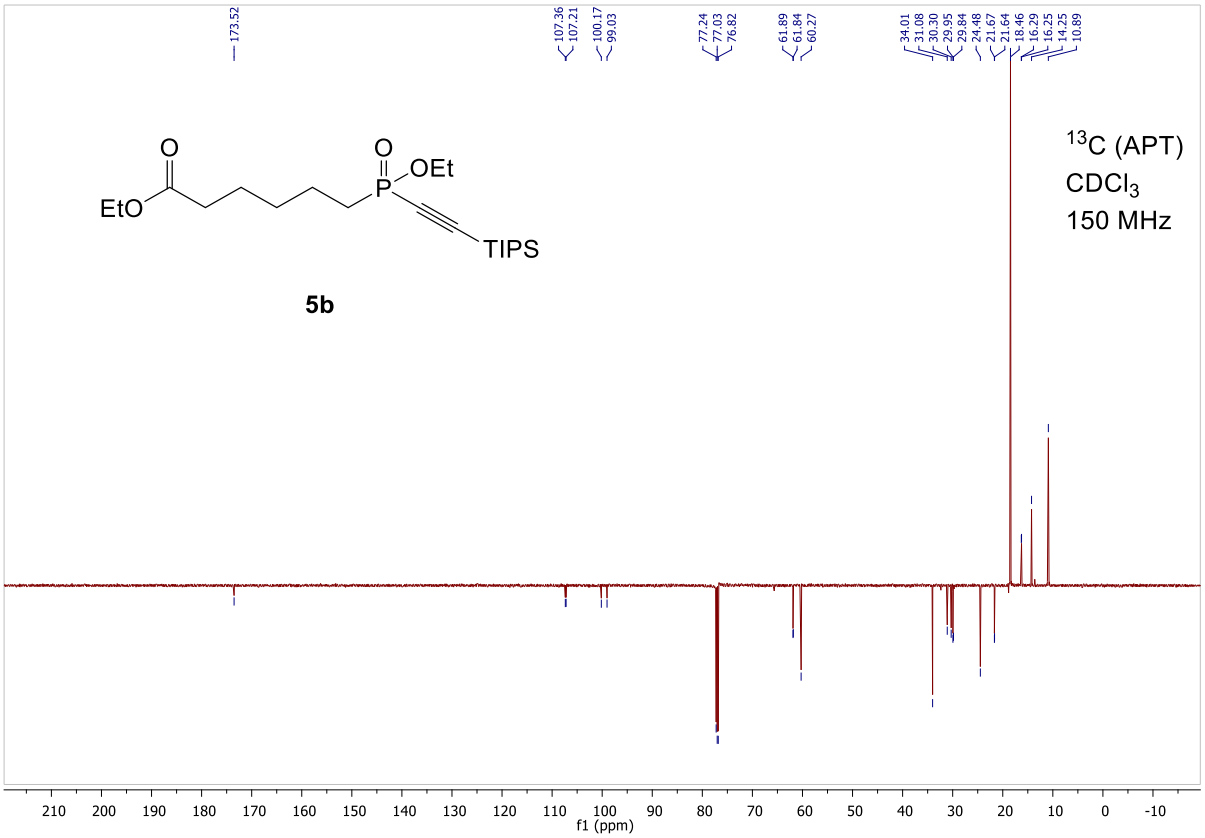
8

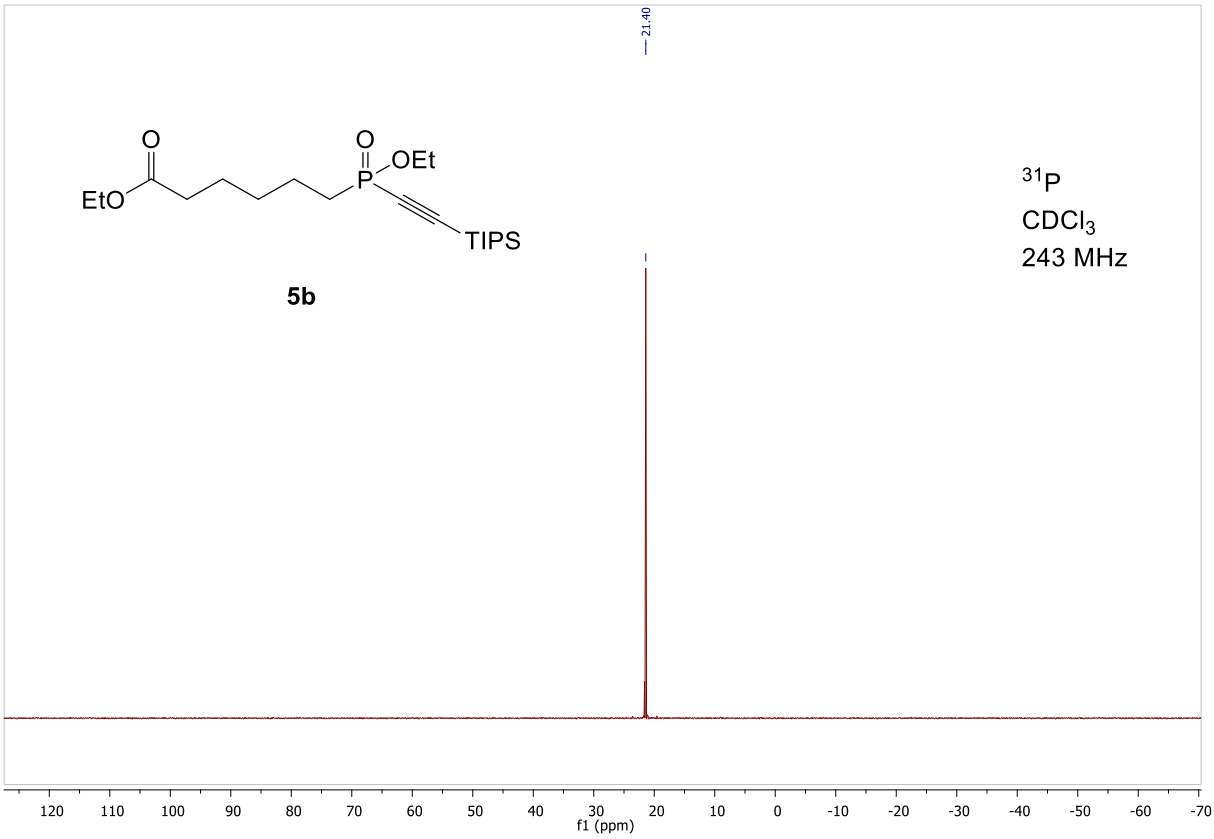

Me
O
OEt
P
OBn
5a
^{1}H
$CDCl_3$
600 MHz
f1 (ppm)

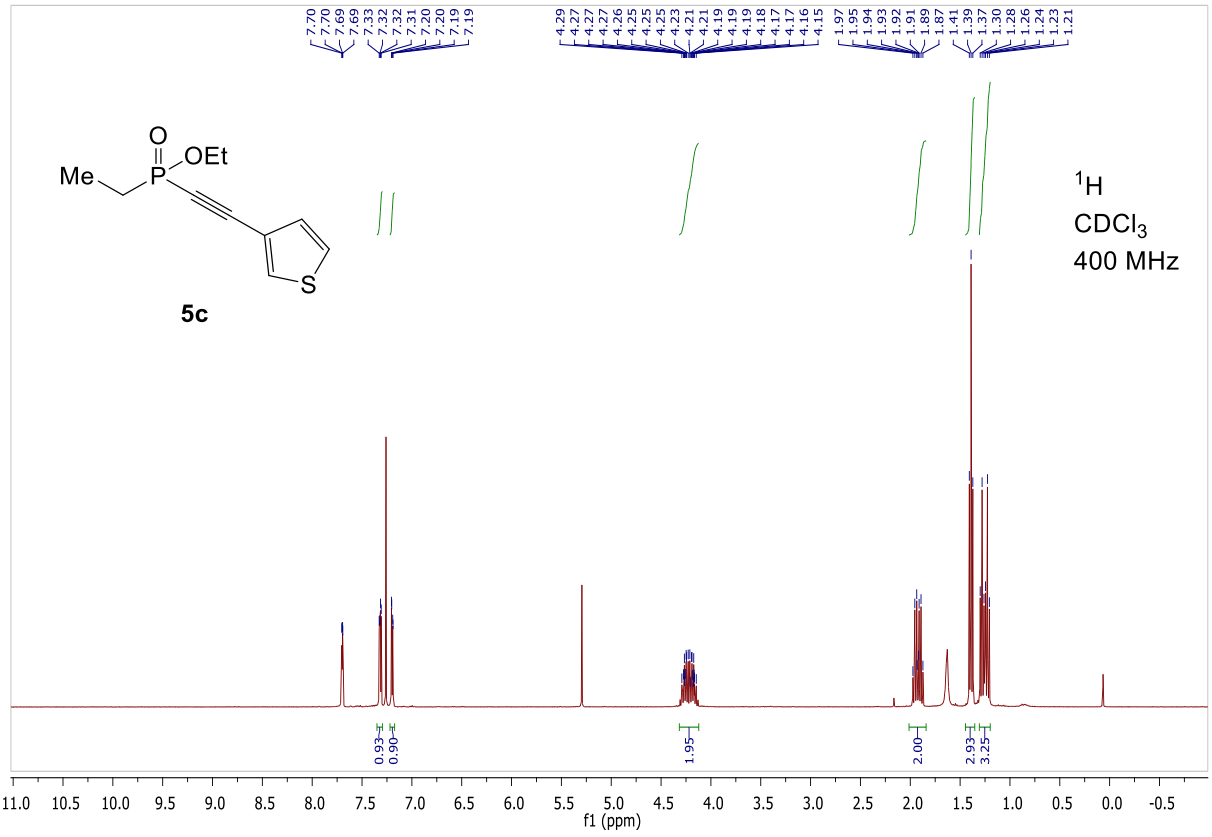

Me
O
OEt
P
OBn
5a
^{13}C (APT)
$CDCl_3$
150 MHz
f1 (ppm)

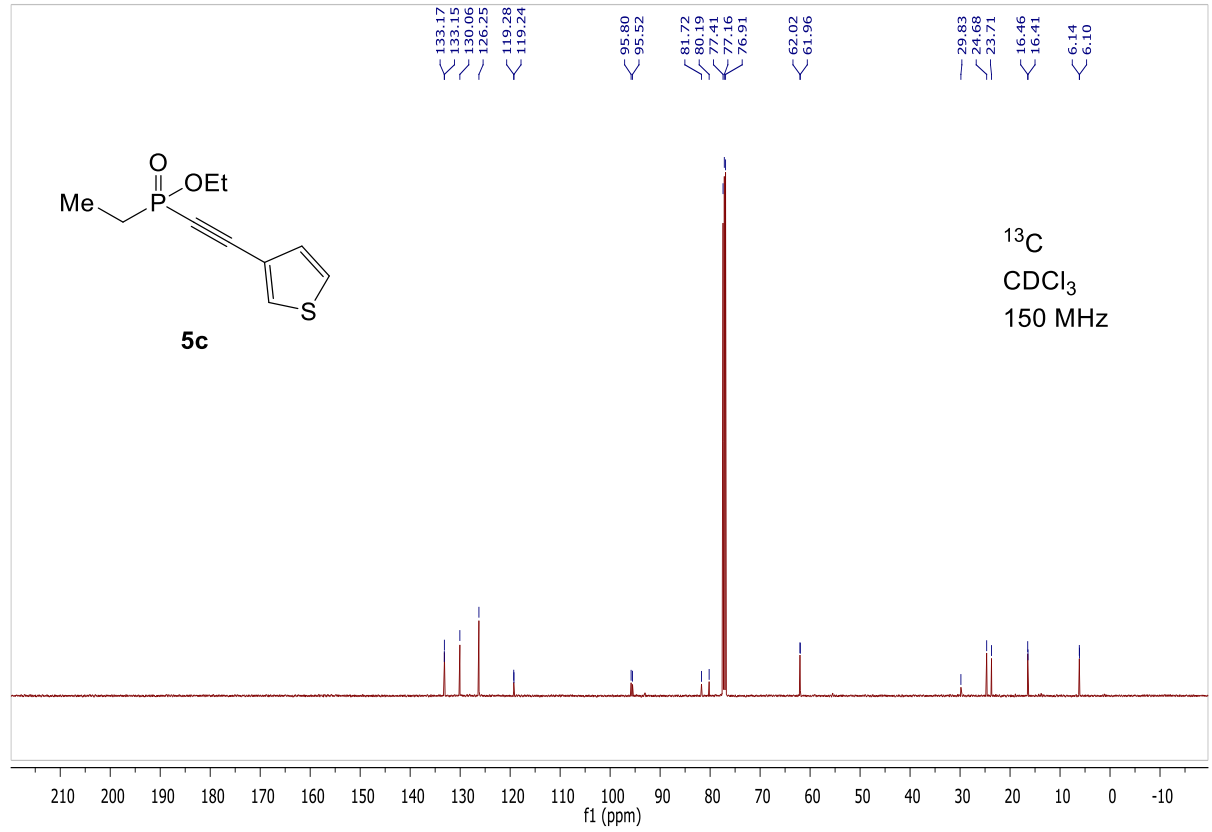

24.44
O
OEt
Me
P
OBn
5a
31P
CDCl3
243 MHz
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-130
-160
-190
-220
f1 (ppm)

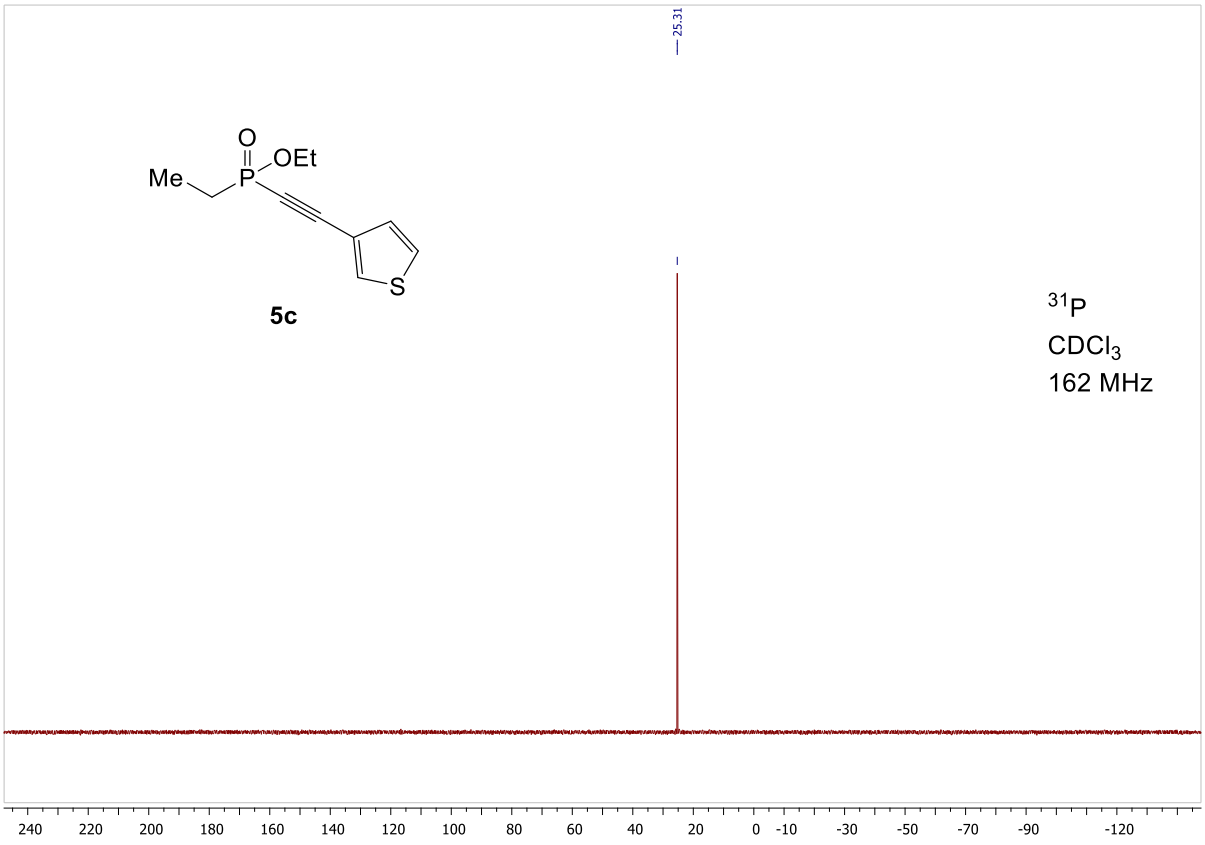

EtO
O
O
OEt
P
TIPS
5b
^{1}H
$CDCl_3$
600 MHz
f1 (ppm)

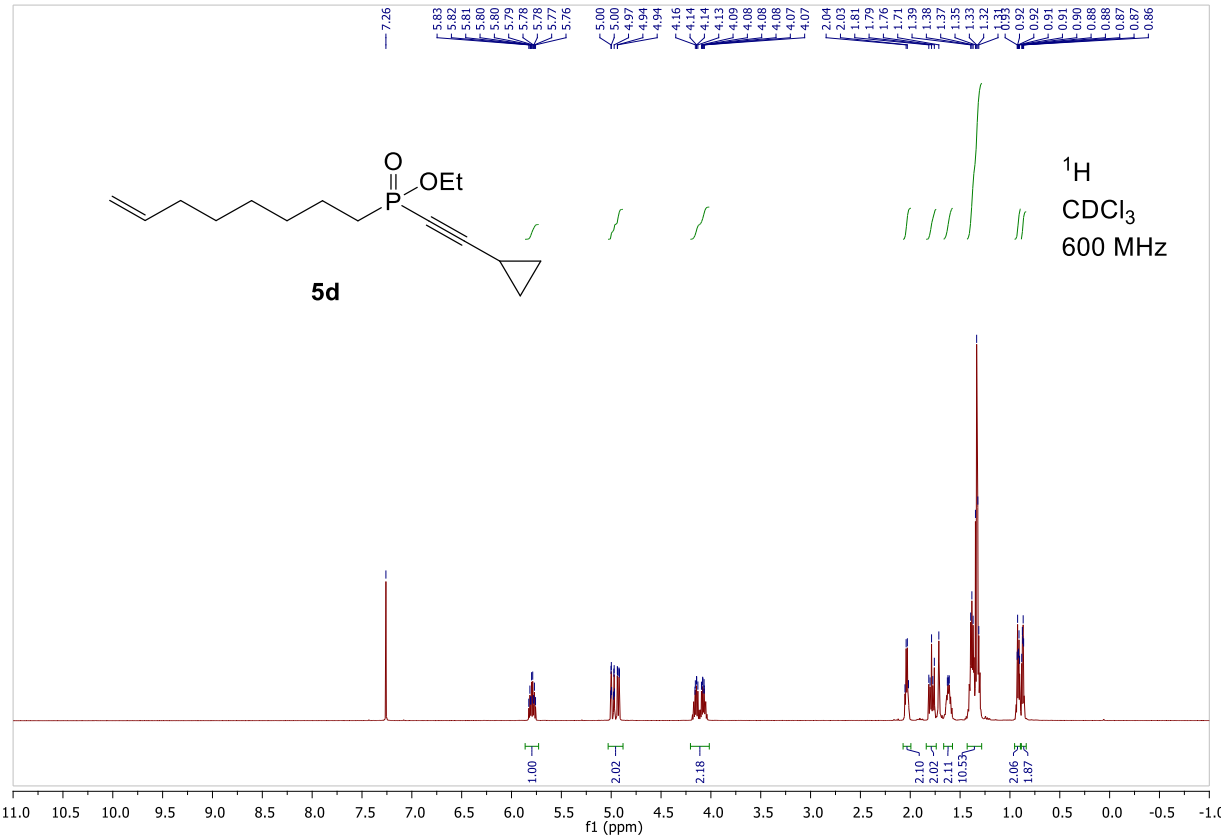

EtO
O
O
OEt
P
TIPS
5b
^{13}C (APT)
$CDCl_3$
150 MHz
f1 (ppm)

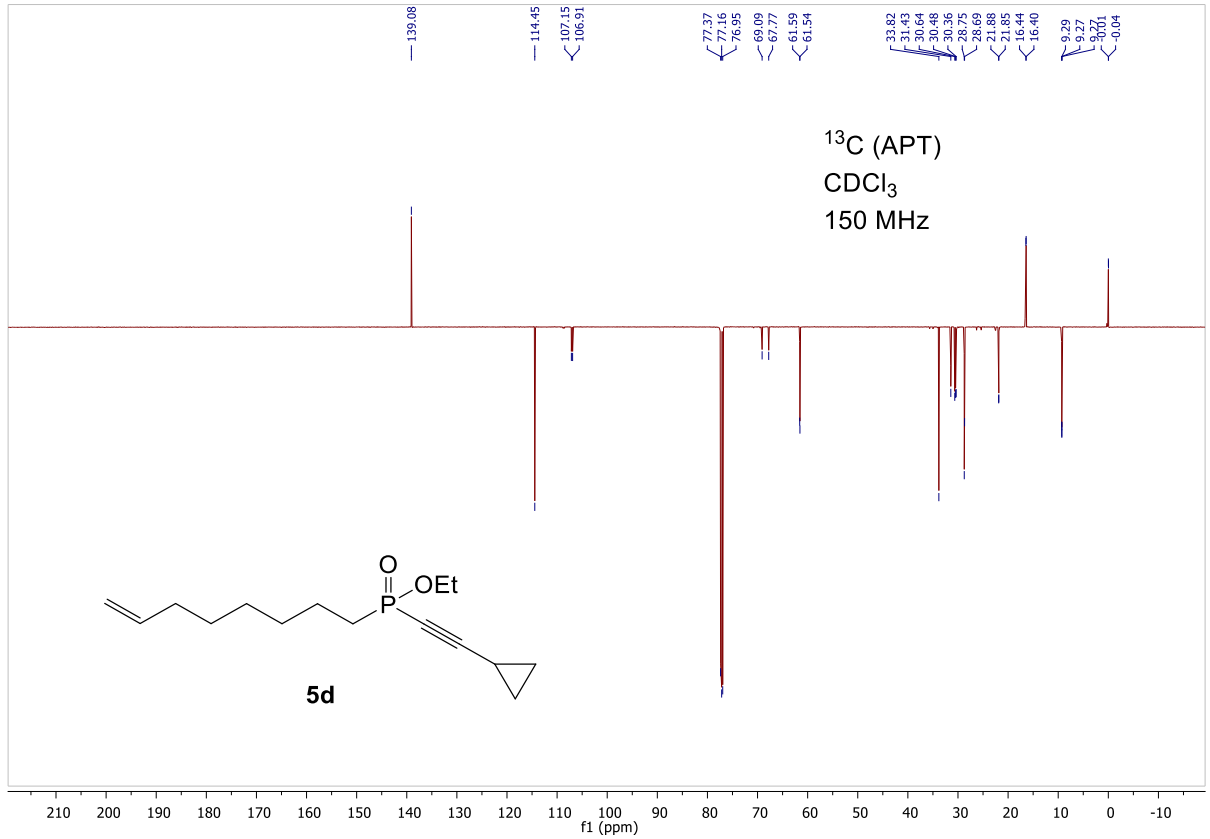

21.40
O
O
OEt
EtO
P
TIPS
5b
31P
CDCl3
243 MHz
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
f1 (ppm)

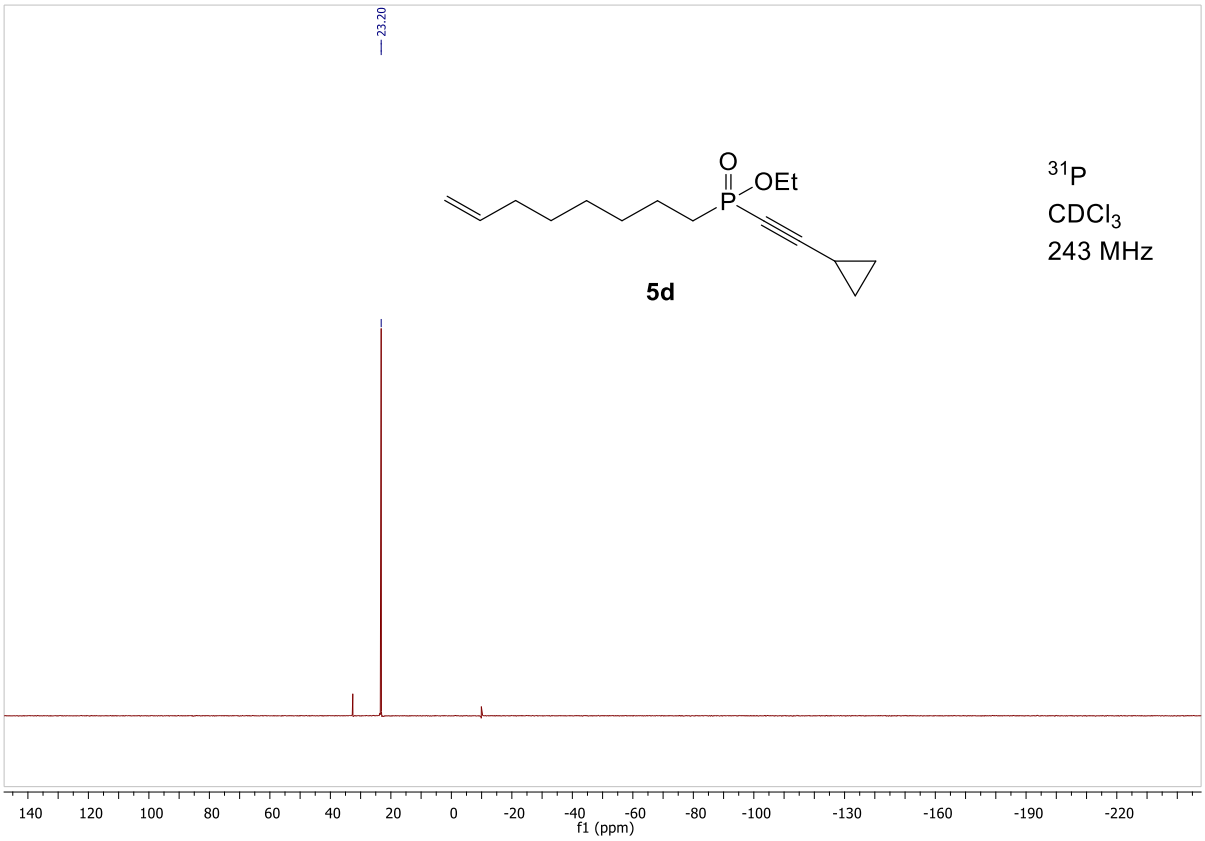

Me
O
OEt
P
S
5c
^{1}H
$CDCl_3$
400 MHz
f1 (ppm)

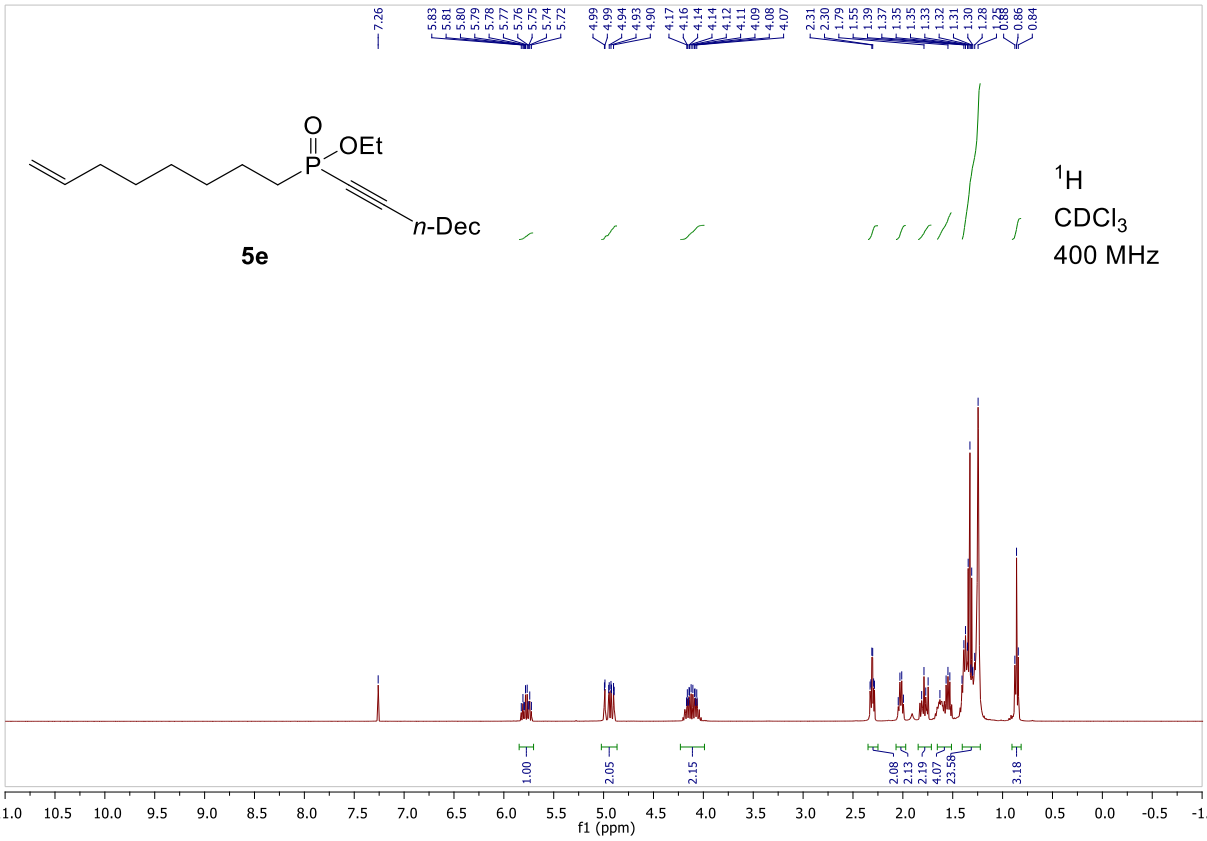

Me
O
OEt
P
S
5c
^{13}C
$CDCl_3$
150 MHz
f1 (ppm)

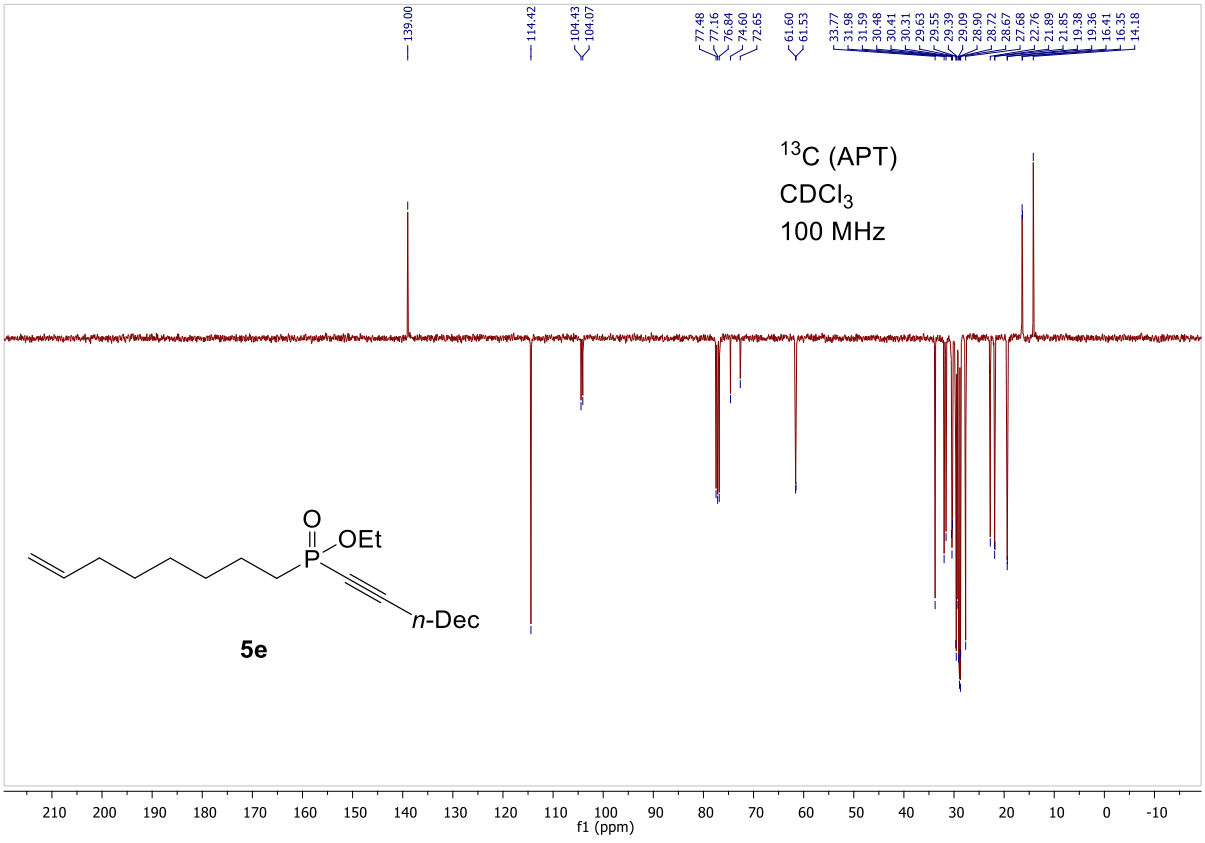

25.31
O
OEt
Me
P
S
5c
31P
CDCl3
162 MHz
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120

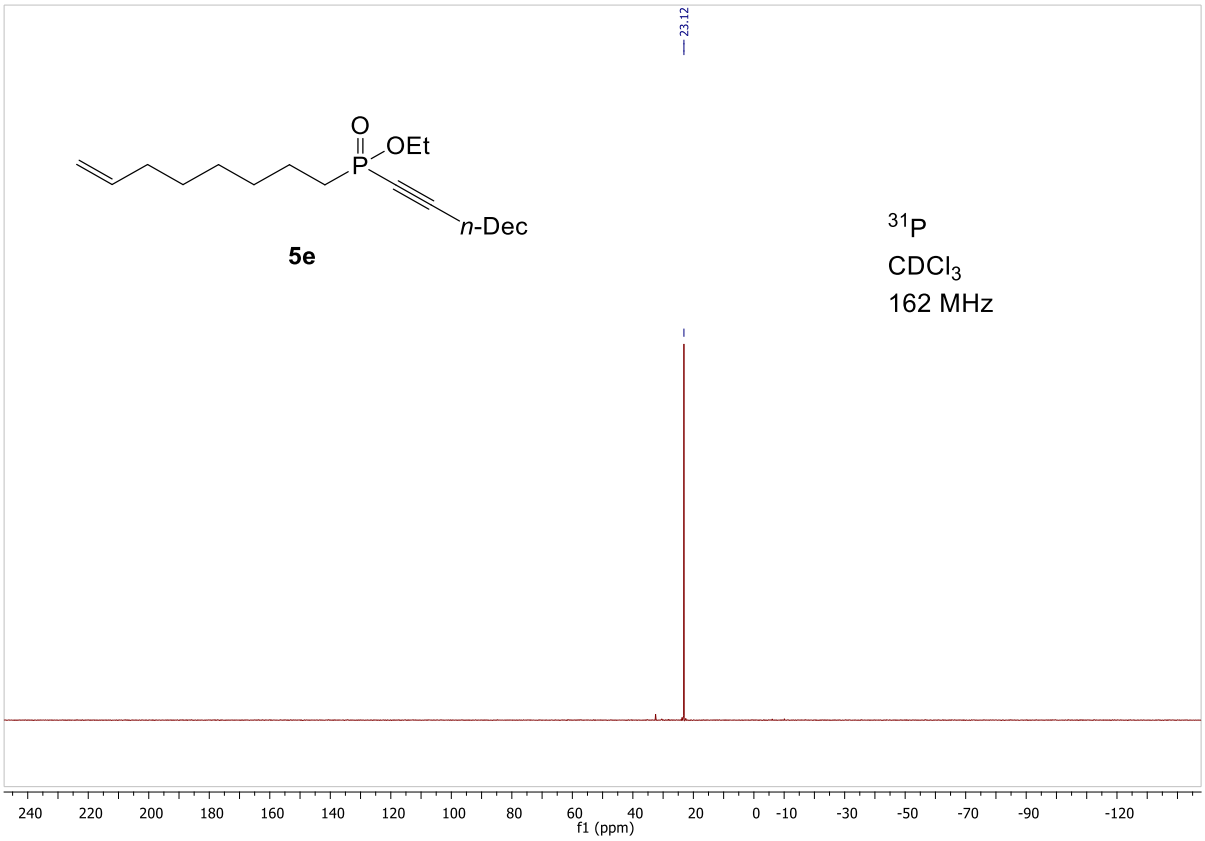

7.26
5.83
5.82
5.81
5.80
5.79
5.78
5.77
5.76
5.00
5.00
4.97
4.94
4.94
4.16
4.14
4.14
4.13
4.09
4.08
4.08
4.07
4.07
2.04
2.03
1.81
1.79
1.76
1.71
1.39
1.38
1.37
1.35
1.33
1.32
0.93
0.92
0.92
0.91
0.91
0.90
0.88
0.88
0.87
0.87
0.86
O
OEt
P
5d
1H
CDCl3
600 MHz
1.00
2.02
2.18
2.10
2.02
2.11
10.53
2.06
1.87
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 -0.5
f1 (ppm)

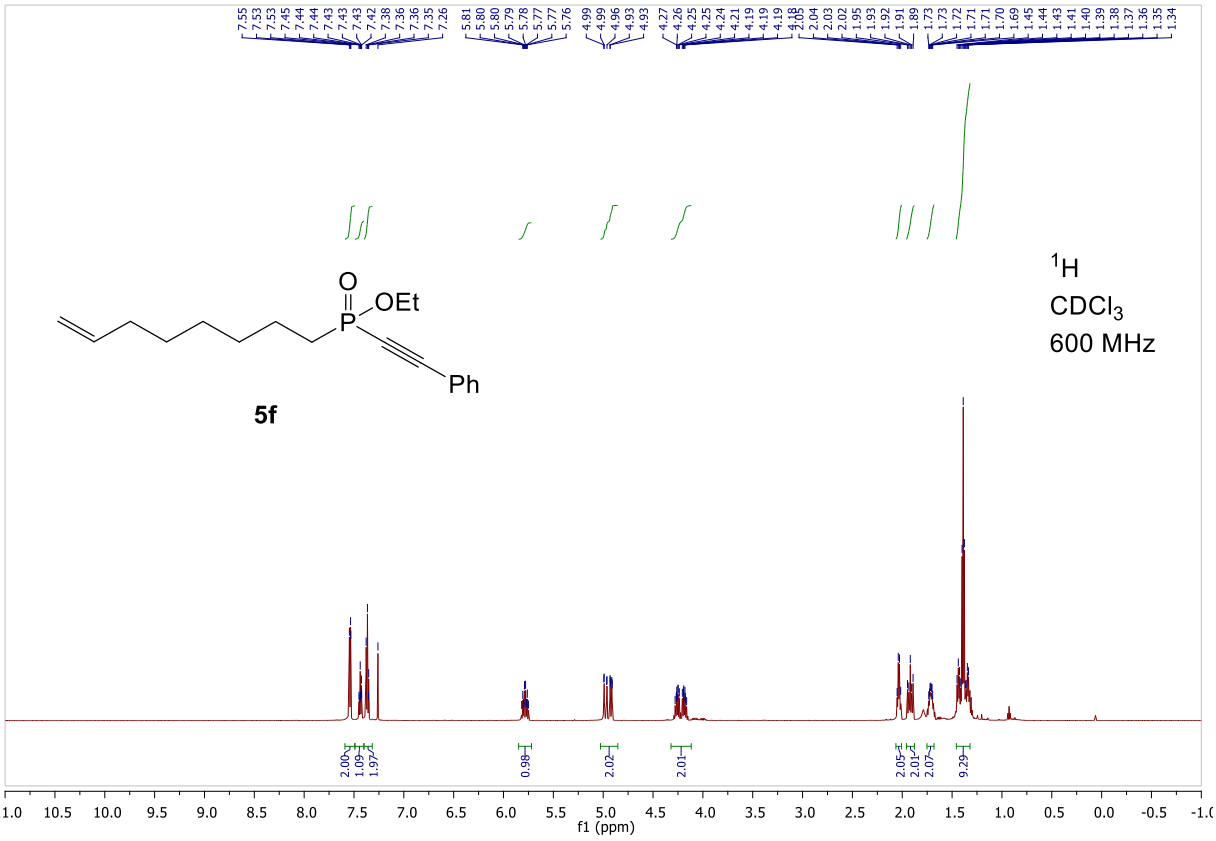

139.08
114.45
107.15
106.91
77.37
77.16
76.95
69.09
67.77
61.59
61.54
33.82
31.43
30.64
30.48
30.36
28.75
28.69
21.88
21.85
16.44
16.40
9.29
9.27
9.01
-0.04
O
OEt
P
5d
13C (APT)
CDCl3
150 MHz
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


23.20
O
OEt
P
5d
31P
CDCl3
243 MHz
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-130
-160
-190
-220
f1 (ppm)


7.26
5.83
5.81
5.80
5.79
5.78
5.77
5.76
5.75
5.74
5.72
4.99
4.99
4.94
4.93
4.90
4.17
4.16
4.14
4.14
4.12
4.11
4.09
4.08
4.07
2.31
2.30
1.79
1.55
1.39
1.37
1.35
1.35
1.33
1.32
1.31
1.30
1.28
0.86
0.84
O
OEt
P
n-Dec
5e
1H
CDCl3
400 MHz
1.00
2.05
2.15
2.08
2.13
2.19
4.07
23.58
3.18
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
-0.5
f1 (ppm)

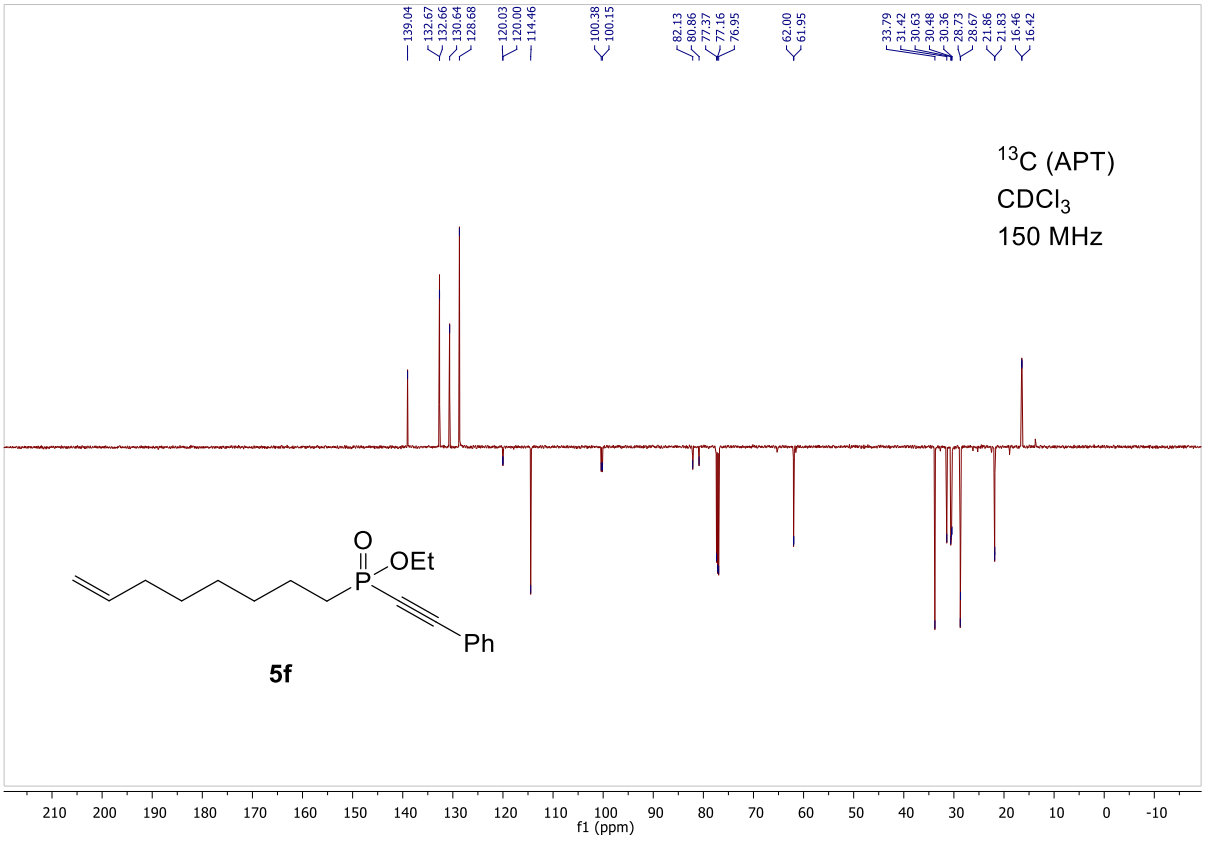

139.00
114.42
104.43
104.07
77.48
77.16
76.84
74.60
72.65
61.60
61.53
33.77
31.98
31.59
30.48
30.41
30.31
29.63
29.55
29.39
29.09
28.90
28.72
28.67
27.68
22.76
21.89
21.85
19.38
19.36
16.41
16.35
14.18
13C (APT)
CDCl3
100 MHz
O
OEt
P
n-Dec
5e
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
f1 (ppm)


23.12
O
OEt
P
n-Dec
5e
31P
CDCl3
162 MHz
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)


^{1}H
$CDCl_3$
600 MHz
f1 (ppm)

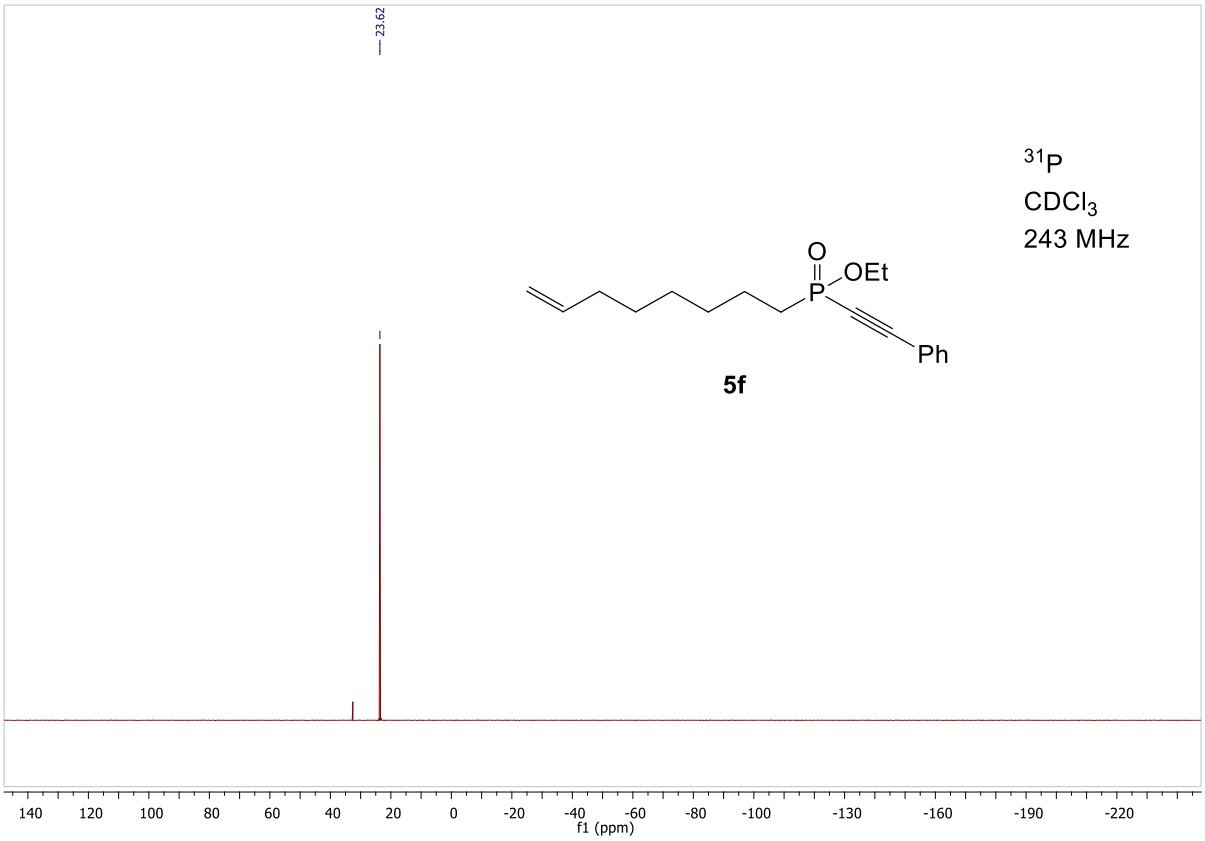
O
OEt
P
Ph

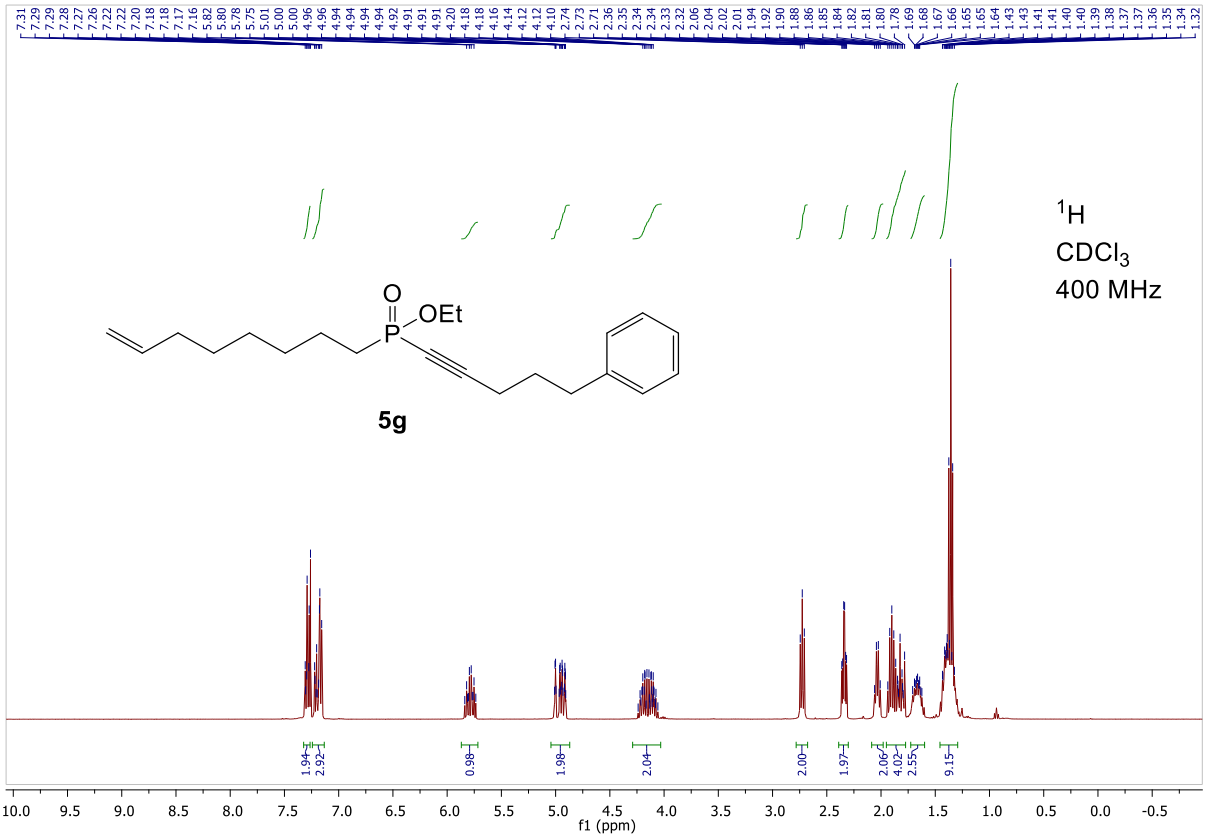
5f

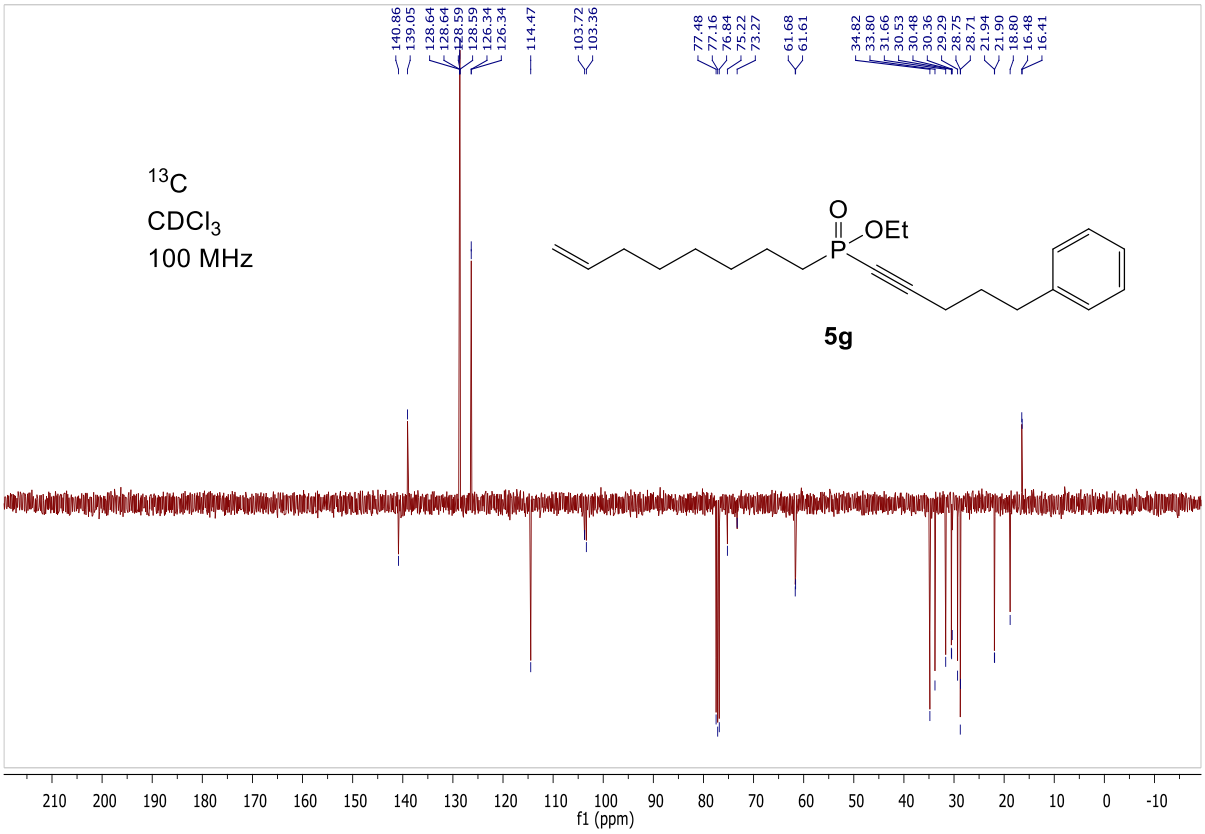

^{13}C (APT)
$CDCl_3$
150 MHz
f1 (ppm)

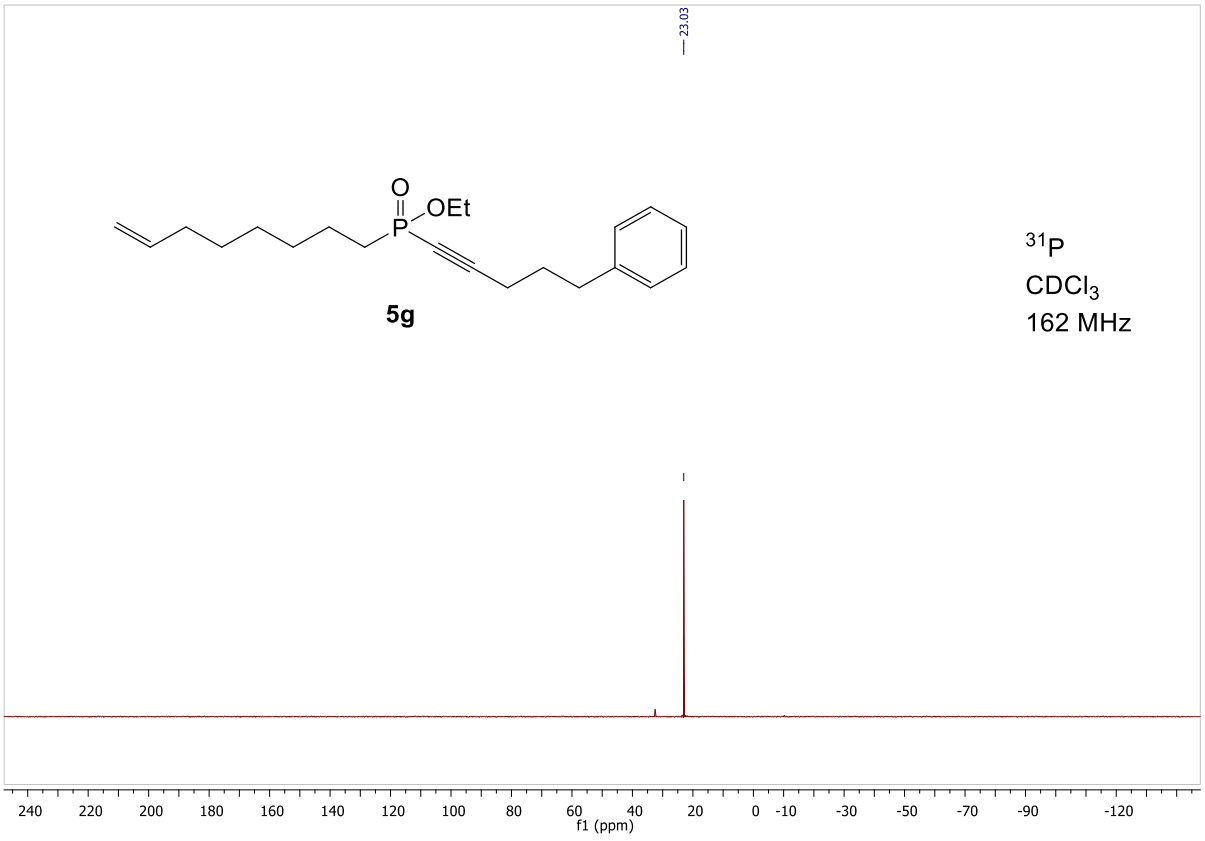
O
OEt
P
Ph

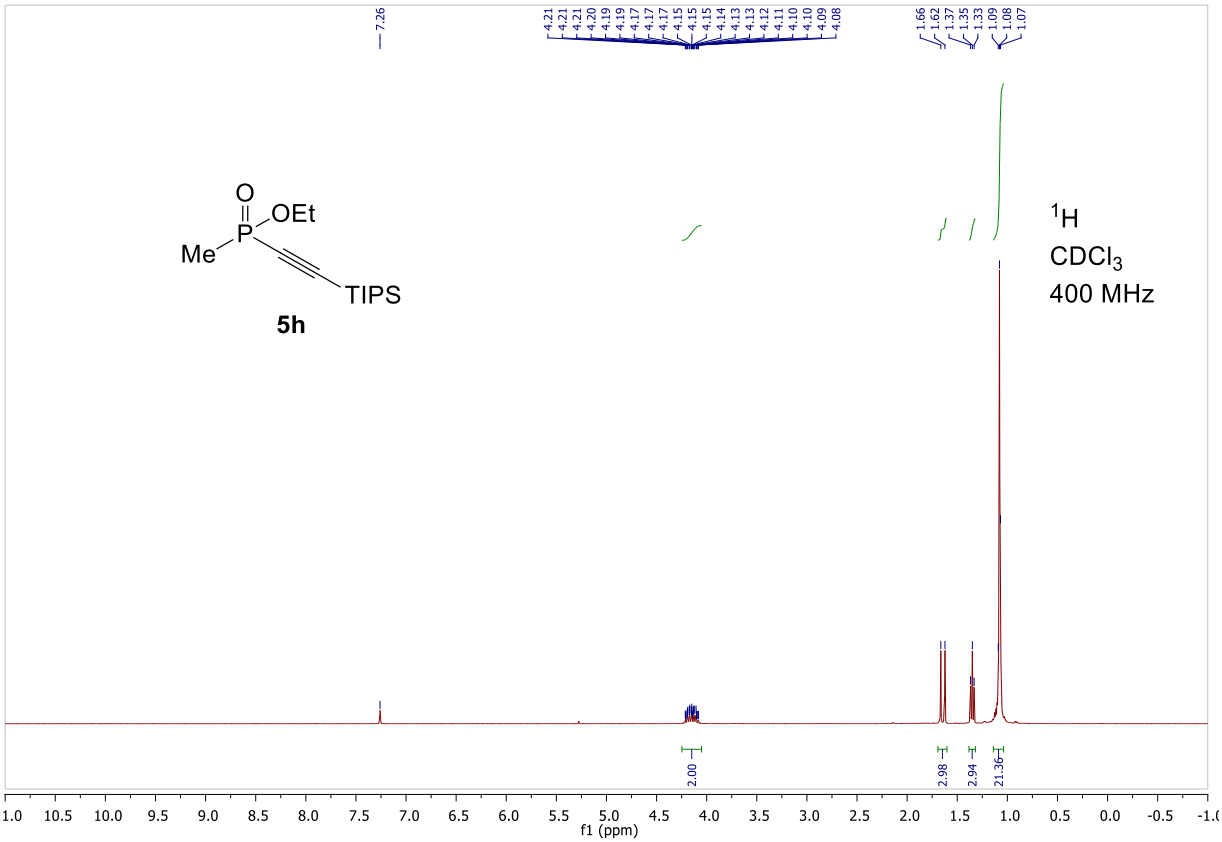
5f

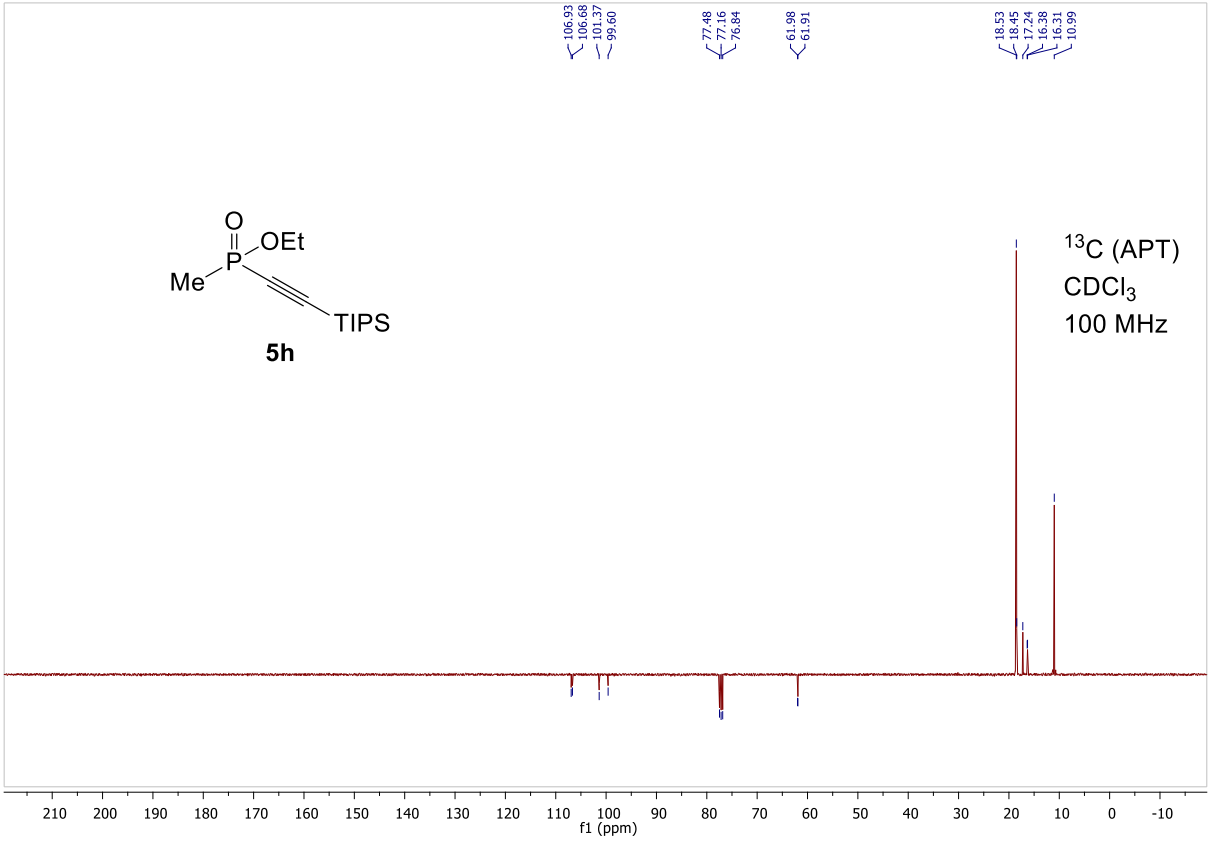

23.62
31P
CDCl3
243 MHz
O
OEt
P
Ph
5f
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-130
-160
-190
-220
f1 (ppm)

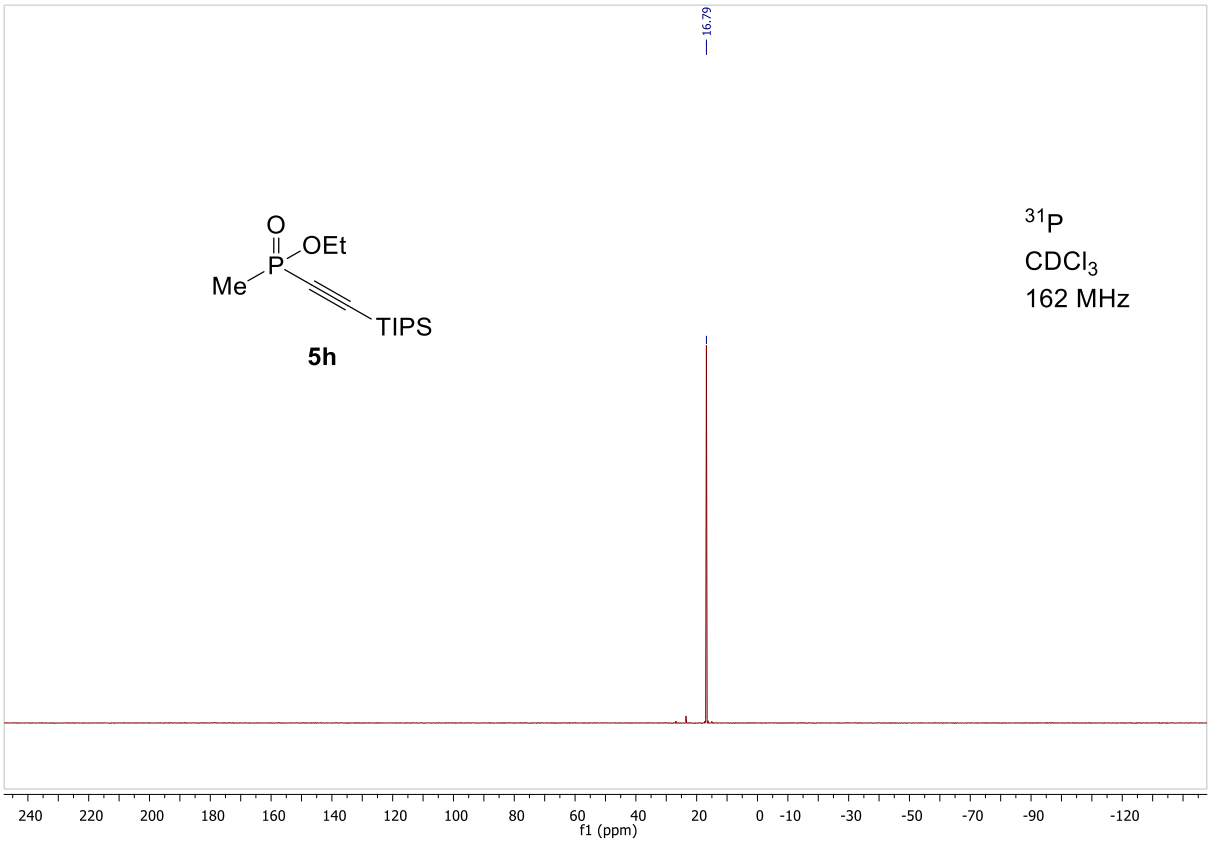

^{1}H
$CDCl_3$
400 MHz
O
OEt
P
5g
f1 (ppm)


^{13}C
$CDCl_3$
100 MHz
O
OEt
P
5g
f1 (ppm)


23.03
O
OEt
P
5g
31P
CDCl3
162 MHz
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)


7.26
4.21
4.21
4.21
4.20
4.19
4.19
4.17
4.17
4.17
4.15
4.15
4.15
4.14
4.13
4.13
4.12
4.11
4.10
4.10
4.09
4.08
1.66
1.62
1.37
1.35
1.33
1.09
1.08
1.07
O
OEt
P
Me
TIPS
5h
1H
CDCl3
400 MHz
2.00
2.98
2.94
21.36
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 -0.5
f1 (ppm)


106.93
106.68
101.37
99.60
77.48
77.16
76.84
61.98
61.91
18.53
18.45
17.24
16.38
16.31
10.99
O
OEt
P
Me
TIPS
5h
13C (APT)
CDCl3
100 MHz
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


16.79
O
OEt
P
Me
TIPS
5h
31P
CDCl3
162 MHz
240
220
200
180
160
140
120
100
80
60
40
20
0
-10
-30
-50
-70
-90
-120
f1 (ppm)