Electronic Supplementary Material (ESI) for Organic Chemistry Frontiers.

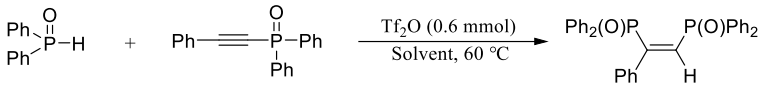
Content

1. General Information

Unless otherwise noted, materials were purchased from commercial suppliers and used without further purification. All reactions were carried out in sealed tubes filled with argon. All reactions were monitored by Thin Layer Chromatography (TLC) and visualized using UV light. Products were purified by column chromatography by 200-300 mesh silica. NMR spectra (^{1}H, ^{13}C, ^{31}P, ^{11}B, ^{19}F) were recorded on 400 or 600 MHz spectrophotometers. Chemical shifts (δ) are reported in ppm from the resonance of the residual solvent peak or tetramethylsilane (TMS) as the internal standard. ^{1}H NMR data are reported as follows: chemical shift (δ ppm), multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet), coupling constants (Hz) and integration. Data for ^{13}C, ^{31}P, ^{11}B and ^{19}F NMR are reported in terms of chemical shifts and multiplicity where appropriate. The high resolution mass spectra (HRMS) were measured on a Thermo-Fisher Scientific Q Exactive MS/MS System ESI spectrometer. X-ray diffraction data was collected on an Oxford Diffraction Xcalibur CCD (X-ray single-crystal diffractometer).

2. Optimization of Reaction Conditions

Table S1. **Screening of the solvents** [a]



s2a, 0.4 mmol **s3a**, 0.2 mmol **6a**

Entry	Solvent	Yield (%)[b]
1	DCM	56
2	CH_3CN	60
3	toluene	62
4	DMSO	N.R.
5	DMAC	N.R.
6	DCE	67
7	THF	N.D.
8	$PhCF_3$	64
9	$CHCl_3$	75

[a]Reaction conditions: **s2a** (0.4 mmol, 2.0 equiv), **s3a** (0.2 mmol, 1.0 equiv) and Tf_2O (0.6 mmol, 3.0 equiv) in Solvent (2.0 mL) at 60 °C under Ar for 3 h.[b]Isolated yelid.

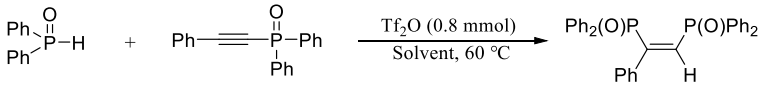
Table S2. **Screening of loading of Tf_2O** [a]

s2a, 0.4 mmol **s3a**, 0.2 mmol **6a**

Entry	Tf_2O (x equiv)	Yield (%)[b]
1	2.0	53
2	3.0	75
3	4.0	79

[a]Reaction conditions: **s2a** (0.4 mmol, 2.0 equiv), **s3a** (0.2 mmol, 1.0 equiv) and Tf_2O (x equiv) in Solvent (2.0 mL) at 60 °C under Ar for 3 h.[b]Isolated yelid.

Table S3. **Screening of the mixed solvents** [a]



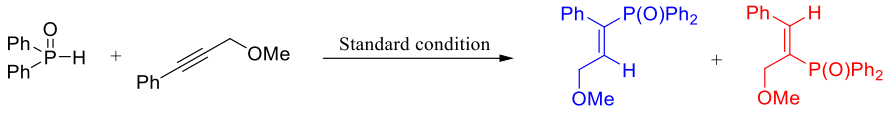
s2a, 0.4 mmol **s3a**, 0.2 mmol **6a**

Entry	Solvent	Yield (%)[b]
1	$CHCl_3$:CH_3CN (1:1)	71
2	$CHCl_3$:CH_3CN (3:1)	84
3	$CHCl_3$:CH_3CN (10:1)	89

[a]Reaction conditions: **s2a** (0.4 mmol, 2.0 equiv), **s3a** (0.2 mmol, 1.0 equiv) and Tf_2O (0.8 mmol, 4.0 equiv) in Solvent (2.0 mL) at 60 °C under Ar for 3 h.[b]Isolated yelid.

3. Mechanism experiments

3.1 Control experiments with (3-methoxyprop-1-yn-1-yl)benzene



s2a **9a** **9b**

A 10 mL oven-dried sealed tube equipped with a magnetic stir bar was charged with **s2a** (80.8 mg, 0.4 mmol, 2.0 equiv), **(3-methoxyprop-1-yn-1-yl)benzene** (29.2 mg, 0.2 mmol, 1.0 equiv). The tube was evacuated and backfilled with argon (three times) and then $CHCl_3$ (2.0 mL) and CH_3CN (0.2 mL) was added sequentially via a syringe. The resulting mixture was stirred until it became a homogeneous solution. Tf_2O (133 uL, 0.8 mmol, 4.0 equiv) was then added by a syringe. The resulting mixture was stirred for 3 h at 60 ºC. After cooled to ambient temperature, sat. $NaHCO_3$ aq (5.0 mL) was added and the resulting mixture was extracted with DCM (3 x 10.0 mL). The organic layer was washed with brine, and dried over $MgSO_4$ and volatiles were removed under reduced pressure. The residue was purified by flash column chromatography on silica gel to give the products **9a** and **9b**. The corresponding mixed products **9a** and **9b** was isolated, which indicated that the reaction proceeded through a three-membered phosphirenium cation process previously reported by Masahiro Miura group.[40]

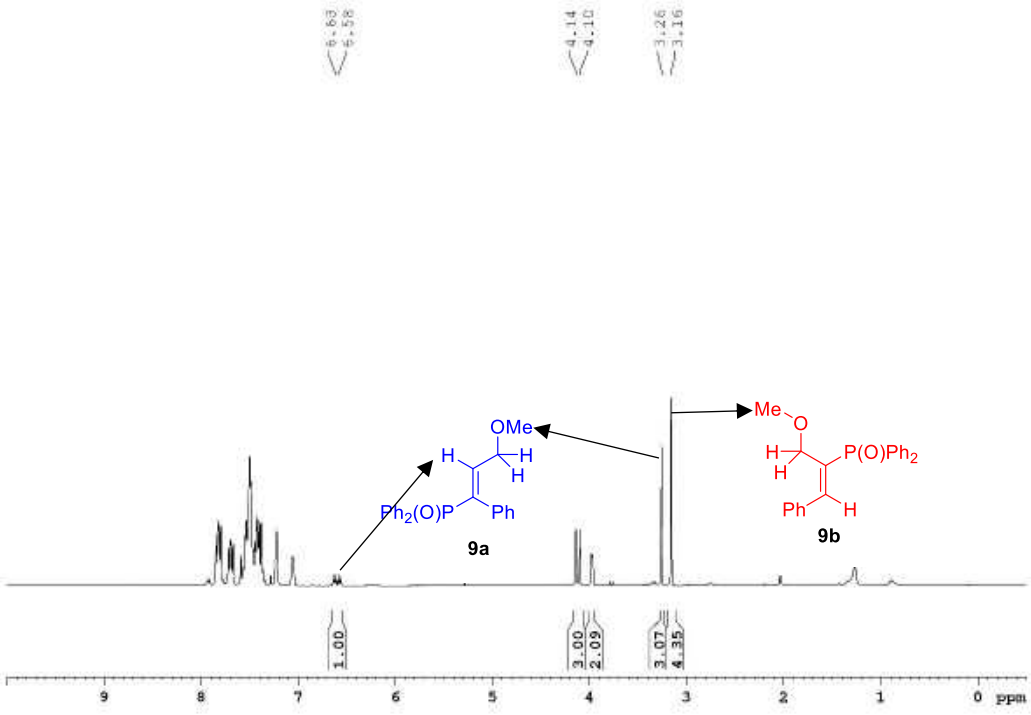
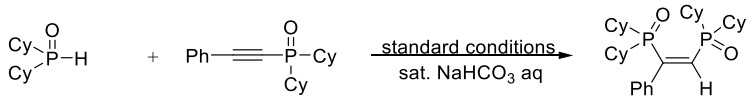


Figure S1. ^{1}H NMR Spectra of **9a** and **9b**

3.2 Control experiment using H_2O or D_2O

3.2.1 Control experiment using H_2O



s2q **s3ac** **7m**, 93%

A 10 mL oven-dried sealed tube equipped with a magnetic stir bar was charged with **s2q** (85.6 mg, 0.4 mmol, 2.0 equiv), **s3ac** (62.8 mg, 0.2 mmol, 1.0 equiv). The tube was evacuated and backfilled with argon (three times) and then $CHCl_3$ (2.0 mL) and CH_3CN (0.2 mL) was added sequentially via a syringe. The resulting mixture was stirred until it became a homogeneous solution. Tf_2O (133 uL, 0.8 mmol, 4.0 equiv) was then added by a syringe. The resulting mixture was stirred for 3 h at 60 °C. After cooled to ambient temperature, sat. $NaHCO_3$ aq (5.0 mL) was added and the resulting mixture was extracted with DCM (3 x 10.0 mL). The organic layer was washed with brine, and dried over $MgSO_4$ and volatiles were removed under reduced pressure. The residue was purified by flash column chromatography on silica gel to give the desired product.

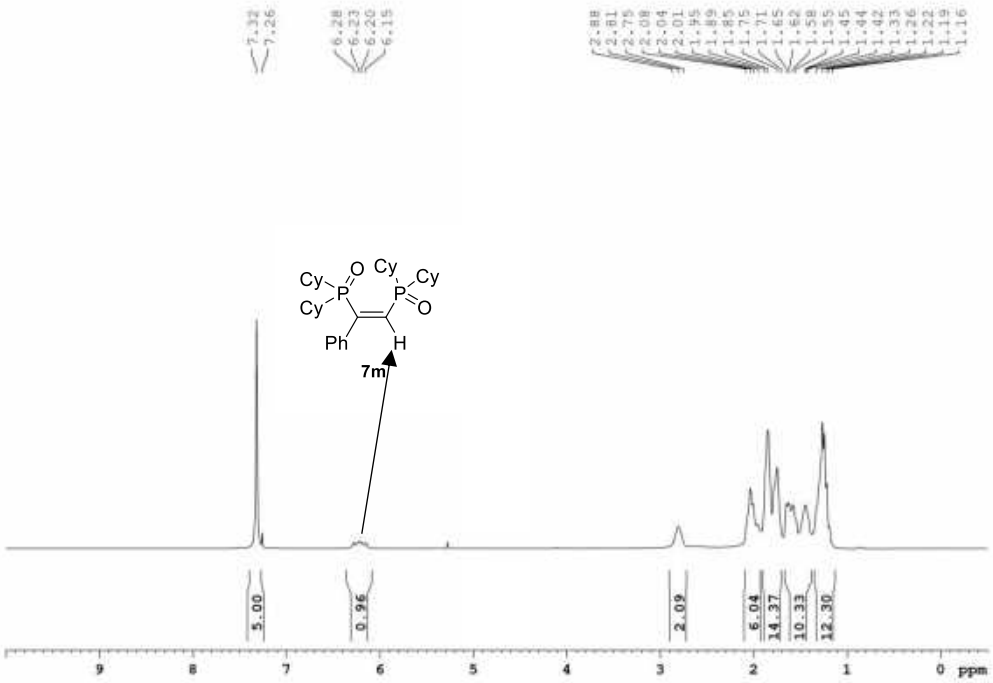
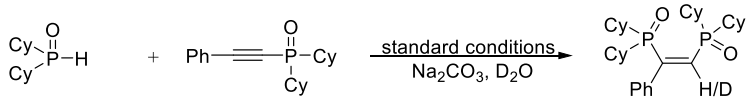


Figure S2. ^{1}H NMR Spectra of **7m** (quenched with **H_2O**)

3.2.2 Control experiment using D_2O



s2q **s3ac** **7m,** 93%, H:D = 1:0

A 10 mL oven-dried sealed tube equipped with a magnetic stir bar was charged with **s2q** (85.6 mg, 0.4 mmol, 2.0 equiv), **s3ac** (62.8 mg, 0.2 mmol, 1.0 equiv). The tube was evacuated and backfilled with argon (three times) and then $CHCl_3$ (2.0 mL) and CH_3CN (0.2 mL) was added sequentially via a syringe. The resulting mixture was stirred until it became a homogeneous solution. Tf_2O (133 uL, 0.8 mmol, 4.0 equiv) was then added by a syringe. The resulting mixture was stirred for 3 h at 60 °C. After cooled to ambient temperature, D_2O (1.0 mL) was added to the mixture and stirred for additional 30 min at room temperature. Na_2CO_3 was added and the resulting mixture was extracted with DCM (3 x 10.0 mL). The organic layer was

dried over $MgSO_4$ and volatiles were removed under reduced pressure. The residue was purified by flash column chromatography on silica gel to give the desired product. The corresponding products **7m** (0% D) was isolated, which indicated that the hydrogen didn't come from outside water.

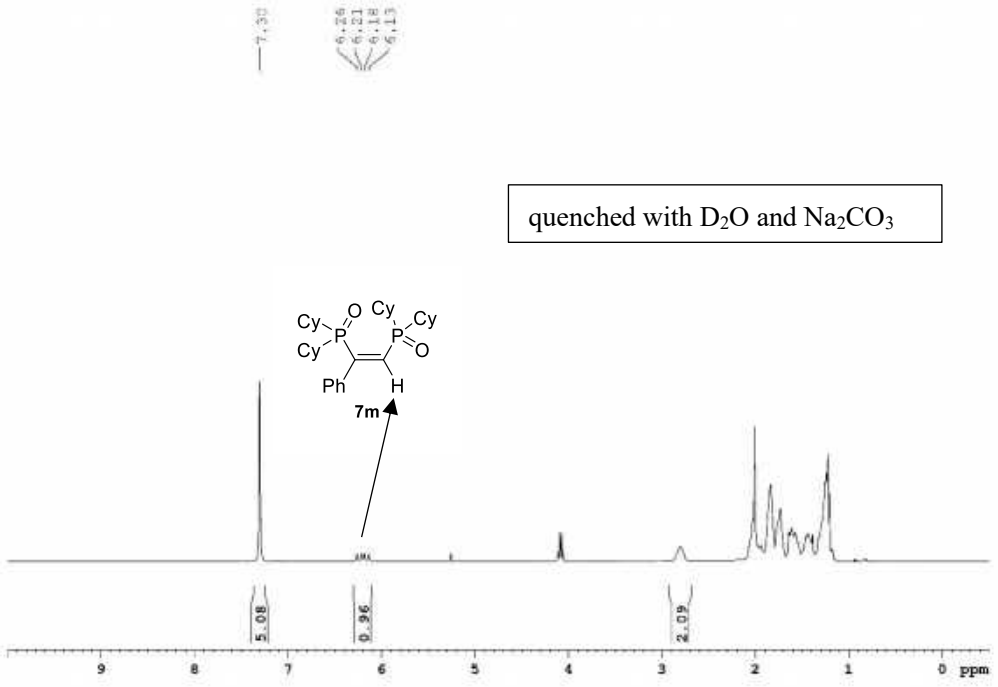
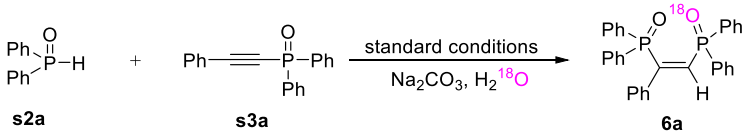


Figure S3. ^{1}H NMR Spectra of **7m** (quenched with **D_2O**)

3.2.3 Control experiment using $H_2{}^{18}O$



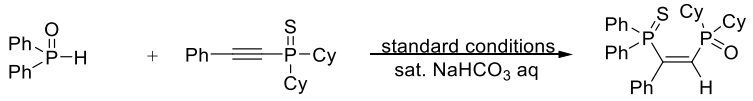
s2a **s3a** **6a**

HRMS:$[C_{32}H_{27}O^{18}OP_2]^+$ *Found:507.1523*

A 10 mL oven-dried sealed tube equipped with a magnetic stir bar was charged with **s2a** (80.8 mg, 0.4 mmol, 2.0 equiv), **s3a** (60.4 mg, 0.2 mmol, 1.0 equiv). The tube was evacuated and backfilled with argon (three times) and then $CHCl_3$ (2.0 mL) and CH_3CN (0.2 mL) was added sequentially via a syringe. The resulting mixture was stirred until it became a homogeneous solution. Tf_2O (133 uL, 0.8 mmol, 4.0 equiv) was then added by a syringe. The resulting mixture was stirred for 3 h at 60 °C. After cooled to ambient temperature, $H_2{}^{18}O$ (0.1 mL) was added to the mixture and stirred for additional 30 min at room temperature. Then sat. $NaHCO_3$ aq (5.0 mL) was added and the resulting mixture was extracted with DCM (3 x 10.0 mL). The organic layer was dried over $MgSO_4$ and volatiles were removed under reduced pressure. The residue was purified by flash column chromatography on silica gel to give the desired product. The corresponding products **6a** (HRMS: $[C_{32}H_{27}O^{18}OP_2]^+$, calcd:507.1523, Found 507.1525, labelled with single **^{18}O**) was isolated, which indicated that one of the oxygens did come from outside water.

3.3 Control experiment using $Ph_2P(O)H$ or $Ph_2P(O)D$

3.3.1 Control experiment using $Ph_2P(O)H$



s2a **s3ah** **8b**, 83%

A 10 mL oven-dried sealed tube equipped with a magnetic stir bar was charged with **s2a** (80.8 mg, 0.4 mmol, 2.0 equiv), **s3ah** (66.0 mg, 0.2 mmol, 1.0 equiv). The tube was evacuated and backfilled with argon (three times) and then $CHCl_3$ (2.0 mL) and CH_3CN (0.2 mL) was added sequentially via a syringe. The resulting mixture was stirred until it became a homogeneous solution. Tf_2O (133 uL, 0.8 mmol, 4.0 equiv) was then added by a syringe. The resulting mixture was stirred for 3 h at 60 ºC. After cooled to ambient temperature, sat. $NaHCO_3$ aq (5.0 mL) was added and the resulting mixture was extracted with DCM (3 x 10.0 mL). The organic layer was washed with brine, and dried over $MgSO_4$ and volatiles were removed under reduced pressure. The residue was purified by flash column chromatography on silica gel to give the desired product.

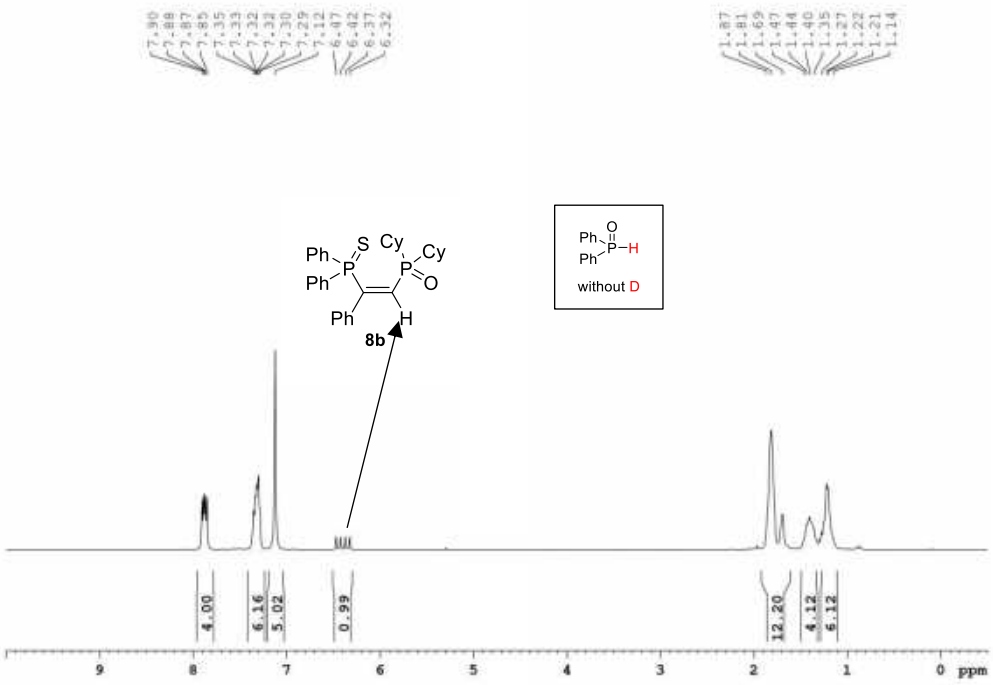
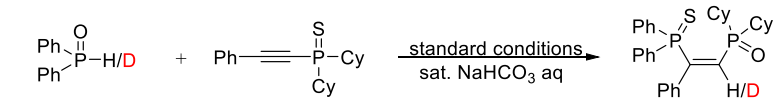


Figure S4. ^1H NMR Spectra of **8b** (using $Ph_2P(O)H$)

3.3.2 Control experiment using $Ph_2P(O)D$



s2a with 80% D **s3ah** **8b**, 65%, 88% D

A 10 mL oven-dried sealed tube equipped with a magnetic stir bar was charged with **s2a** (80.8 mg, 0.4 mmol, 2.0 equiv), **s3ah** (66.0 mg, 0.2 mmol, 1.0 equiv). The tube was evacuated and backfilled with argon (three times) and then $CHCl_3$ (2.0 mL) and CH_3CN (0.2 mL) was added sequentially via a syringe. The resulting mixture was stirred until it became a homogeneous solution. Tf_2O (133 uL, 0.8 mmol, 4.0 equiv) was then added by a syringe. The resulting mixture was stirred for 3 h at 60 °C. After cooled to ambient temperature, sat. $NaHCO_3$ aq (5.0 mL) was added and the resulting mixture was extracted with DCM (3 x 10.0 mL). The organic layer was washed with brine, and dried over $MgSO_4$ and volatiles were removed under reduced pressure. The residue was purified by flash column chromatography on silica gel to give the desired product. The corresponding products **8b** (H/D = 12/88) was isolated, which indicated that the hydrogen did come from secondary phosphine oxide (**s2a**).

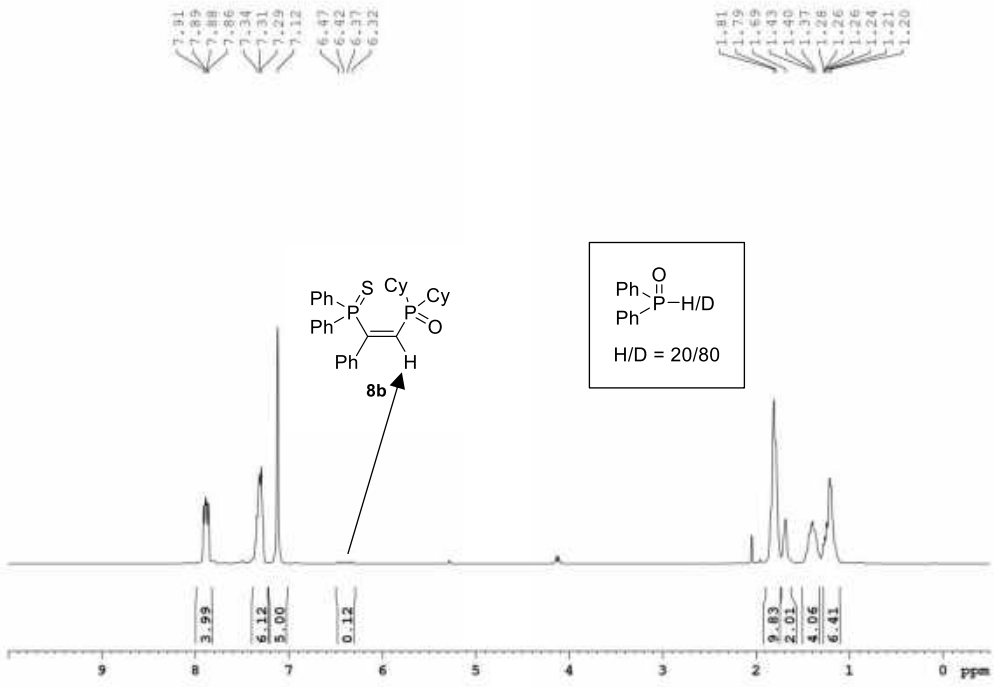
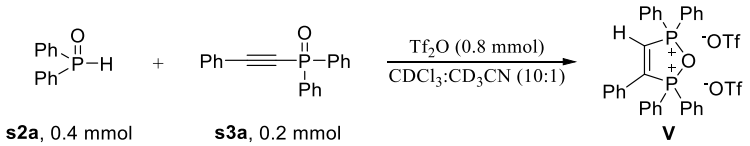


Figure S5. ^1H NMR Spectra of **8b** (using $Ph_2P(O)D$)

3.4 *In situ* ^{31}P NMR and ^{1}H NMR spectra

3.4.1 *In situ* ^{31}P NMR spectra



s2a, 0.4 mmol **s3a**, 0.2 mmol **V**

A 10 mL oven-dried sealed tube equipped with a magnetic stir bar was charged with **s2a** (80.8mg, 0.4 mmol, 2.0 equiv), **s3a** (60.4 mg, 0.2 mmol, 1.0 equiv). The tube was evacuated and backfilled with argon (three times) and then $CDCl_3$ (2.0 mL) and CD_3CN (0.2 mL) was added sequentially via a syringe. The resulting mixture was stirred until it became a homogeneous solution. Tf_2O (133 uL, 0.8 mmol, 4.0 equiv) was then added by a syringe. After 2.5 h at 60 °C, ca. 0.5 mL of this mixture was transferred to a NMR tube by a syringe. The resulting solution was monitored by ^{31}P NMR (Figure S6). It showed three singlet signals (δ 89.0, 88.0 and 43.2) when the reaction was over. The third peak (δ 43.2) is corresponding to $Ph_2P(O)Cl$ that previously reported by Masahiro Miura group.[40] We speculated that the first two peaks belong to **V** according to the published paper.[44]

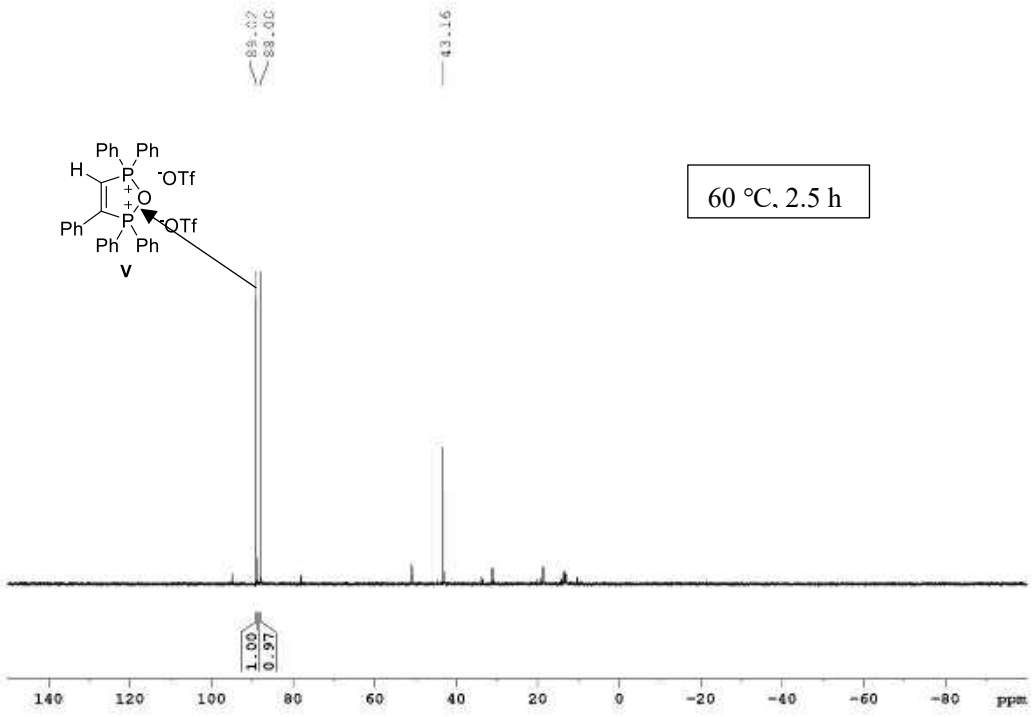
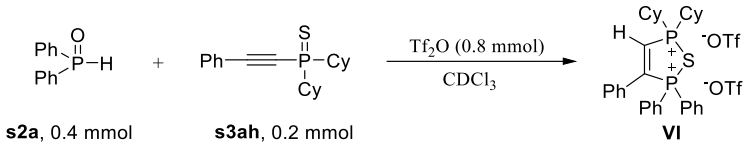


Figure S6. *In situ* ^{31}P NMR spectra

3.4.2 *In situ* ^{1}H NMR spectra



s2a, 0.4 mmol **s3ah**, 0.2 mmol **VI**

A 10 mL oven-dried sealed tube equipped with a magnetic stir bar was charged with **s2a** (80.8mg, 0.4 mmol, 2.0 equiv), **s3ah** (66.0 mg, 0.2 mmol, 1.0 equiv). The tube was evacuated and backfilled with argon (three times) and then $CDCl_3$ (2.0 mL) was added sequentially via a syringe. The resulting mixture was stirred until it became a homogeneous solution. Tf_2O (133 uL, 0.8 mmol, 4.0 equiv) was then added by a syringe. After 3.0 h at 60 °C, ca. 0.5 mL of this mixture was transferred to a NMR tube by a syringe. The resulting solution was monitored by ^{1}H NMR (Figure S7). It showed one doublet of doublets at δ 8.78. This indicated that the hydrogen atom is added to the intermediate before quenching.

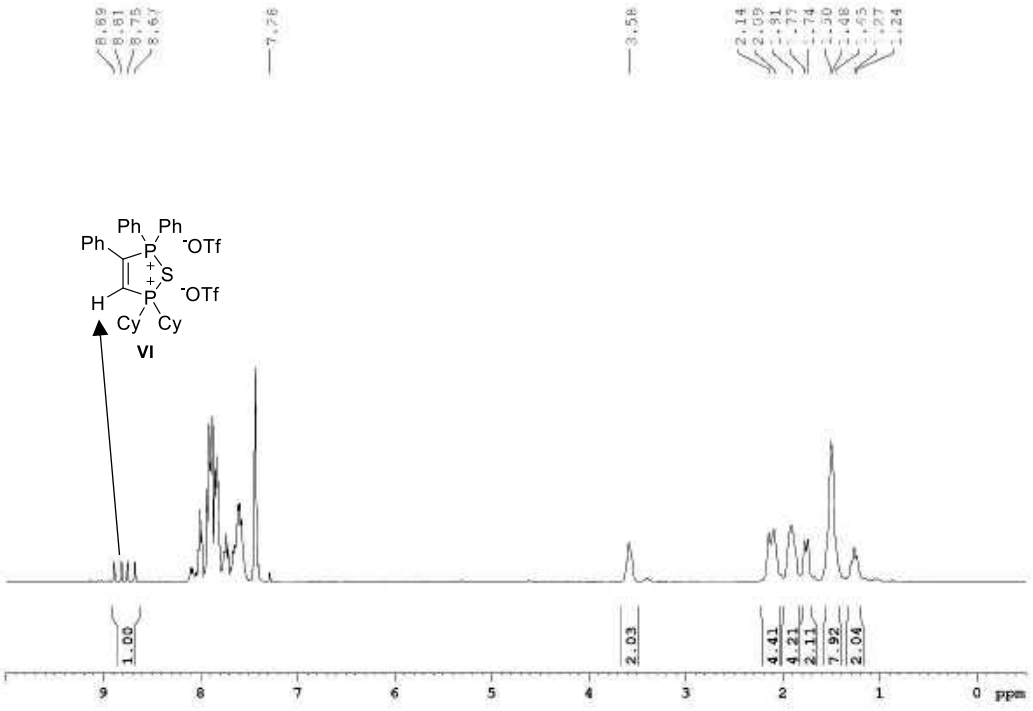
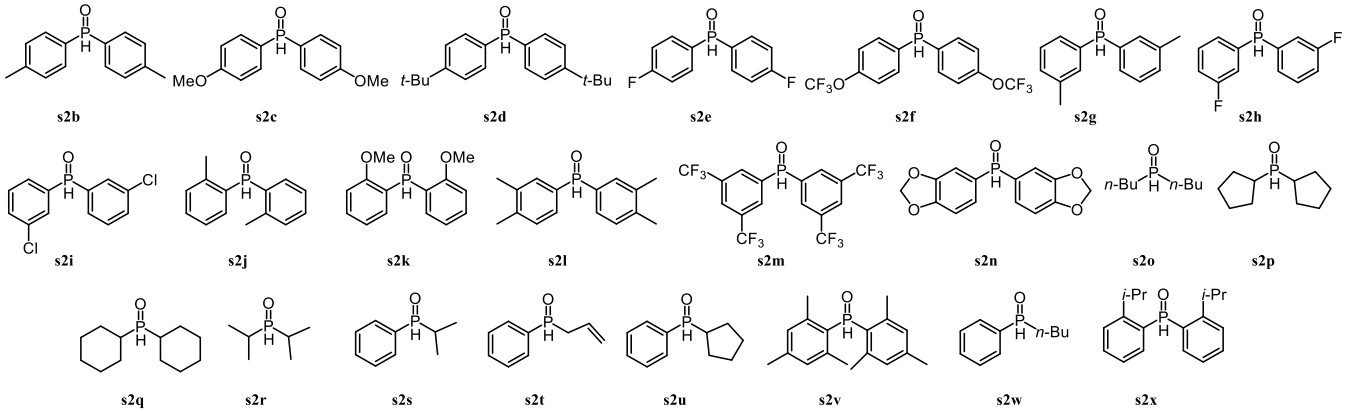


Figure S7. *In situ* ^{1}H NMR spectra

4. General procedure for the synthesis of secondary phosphine oxides

Diaryl secondary phosphine oxides (**s2b** – **s2r, s2v and s2x**) were synthesized according to the published procedure.[45] Phenyl - alkyl secondary phosphine oxides (**s2s – s2u and s2w**) were synthesized according to reference the published procedure.[46]

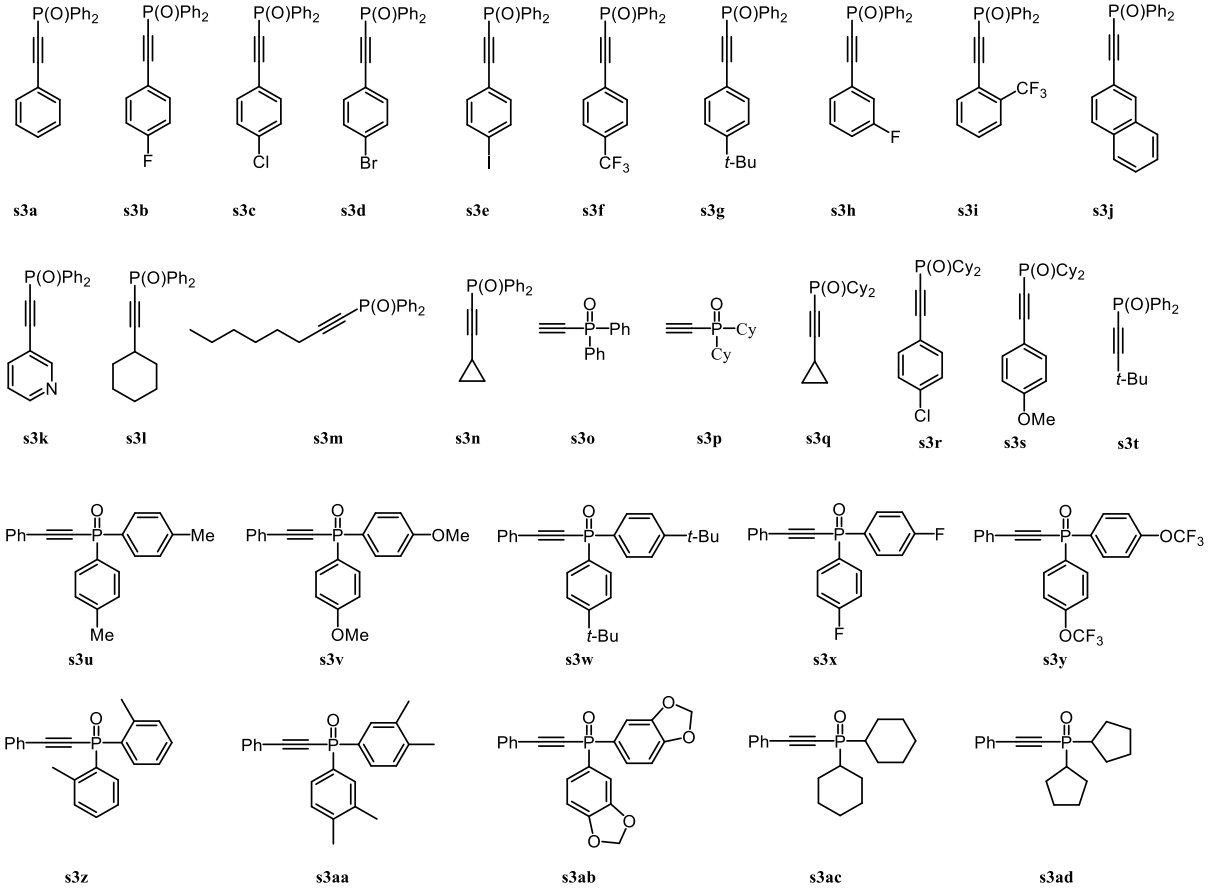
***Table S4*. Substrates of secondary phosphine oxides**



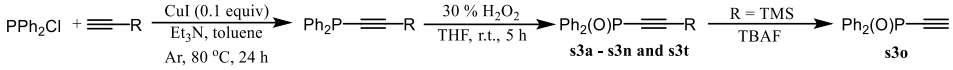
5. General procedure for the synthesis of alkynylphosphine oxides

The alkynylphosphine oxides (**s3a** – **s3o and s3t**) were synthesized according to the following procedure (**GP1**).[47] The alkynylphosphine oxides (**s3p – s3s and s3ac**) were synthesized according to the published procedure.[48] The alkynylphosphine oxides (**s3u** – **s3ab and s3ad**) were synthesized according to the following procedure (**GP2**).[49]

***Table S5*. Substrates of alkynylphosphine oxides**

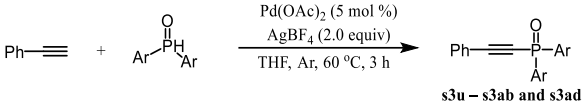


General Procedure 1 (GP1)



To a flask were added CuI (0.5 mmol, 0.1 equiv), Ph_2PCl (5.0 mmol, 1.0 equiv), alkyne (6.0 mmol, 1.2 equiv), triethylamine (10.0 mmol, 2.0 equiv) and toluene (15.0 mL), and the mixture was stirred under Ar at 80 °C for 24 h. After workup with AcOEt/water, the organic layer was washed with aqueous NH_4Cl and brine, and dried over $MgSO_4$. After filtration, the volatiles were removed under reduced pressure. The crude product was used for next step without purification. To the crude product were added THF (20.0 mL) and then 30% H_2O_2 (1.0 mL) at 0 °C, and the mixture was stirred under air at r.t. for 5 h. After workup with CH_2Cl_2/water, the organic layer was washed with brine, and dried over $MgSO_4$. After filtration, the volatiles were removed under reduced pressure. For **s3o** the crude product was used for next step without purification. To the crude product were added water (0.25 mL) and THF (30.0 mL), and then TBAF (1.0 M in THF, 0.5 mL, 0.5 mmol) at 0 °C, and the mixture was stirred under air at r.t. for 5 h. After the volatiles were removed under reduced pressure, the residue was purified by flash column chromatography on silica gel to afford corresponding alkynylphosphine oxides (65% - 80% overall yield).

General Procedure 2 (GP2)

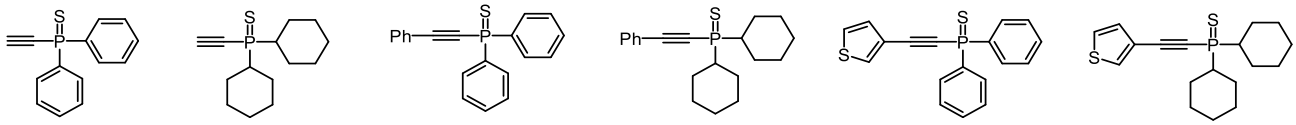


A 10 mL oven-dried sealed tube equipped with a magnetic stir bar was charged with secondary phosphine oxide (1.0 mmol, 1.0 equiv), phenylacetylene (1.0 mmol, 1.0 equiv), $Pd(OAc)_2$ (5 mol %), $AgBF_4$ (2.0 mmol, 2.0 equiv) and THF (3.0 mL). The mixture was stirred under Ar at 60 °C for 3 h. Then Et_3N (5.0 mL) was added. After the volatiles were removed under reduced pressure, the residue was purified by flash column chromatography on silica gel to afford corresponding alkynylphosphine oxides (20% - 79% yield).

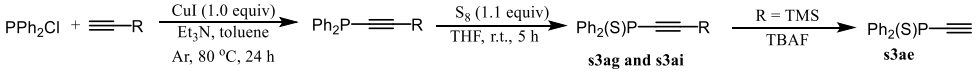
6. General procedure for the synthesis of alkynylphosphine sulfides

The alkynylphosphine sulfides (**s3ae**, **s3ag and s3ai**) were synthesized according to the following procedure (**GP3**). The alkynylphosphine sulfides (**s3af**, **s3ah and s3aj**) were synthesized according to the following procedure (**GP4**).

Table S6. **Substrates of alkynylphosphine sulfides**

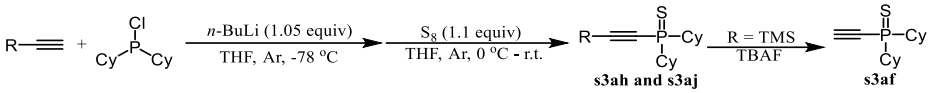


General Procedure 3 (GP3)



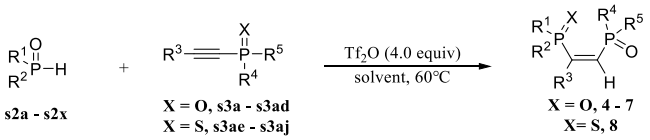
To a flask were added CuI (0.5 mmol, 0.1 equiv), Ph_2PCl (5.0 mmol, 1.0 equiv), alkyne (6.0 mmol, 1.2 equiv), triethylamine (10.0 mmol, 2.0 equiv) and toluene (15.0 mL), and the mixture was stirred under Ar at 80 °C for 24 h. After workup with AcOEt/water, the organic layer was washed with aqueous NH_4Cl and brine, and dried over $MgSO_4$. After filtration, the volatiles were removed under reduced pressure. The crude product was used for next step without purification. To the crude product were added THF (20.0 mL) and then S_8 (5.5 mmol, 1.1 equiv) at 0 °C, and the mixture was stirred under Ar at r.t. for 5 h. After workup with CH_2Cl_2/water, the organic layer was washed with brine, and dried over $MgSO_4$. After filtration, the volatiles were removed under reduced pressure. For **s3ae**, the crude product was used for next step without purification. To the crude product were added water (0.25 mL) and THF (30.0 mL), and then TBAF (1.0 M in THF, 0.5 mL, 0.5 mmol) at 0 °C, and the mixture was stirred under air at r.t. for 5 h. After the volatiles were removed under reduced pressure, the residue was purified by flash column chromatography on silica gel to afford corresponding alkynylphosphine sulfides (65% - 80% overall yield).

General Procedure 4 (GP4)



To a flask was added THF (40.0 mL) and alkyne (8.8 mmol, 1.05 equiv), cooled to -78 °C and *n*-BuLi (8.8 mmol, 1.05 equiv) was added dropwise over 20 min under Ar. The resulting mixture was stirred and allowed to warm to 0 °C over 20 min, then cooled to –78 °C and chlorodicyclohexylphosphine (8.4 mmol, 1.0 equiv) added dropwise over 10 min. The resulting mixture was allowed to warm to room temperature over 2 h then cooled to 0 °C and S_8 (9.2 mmol, 1.1 equiv) was added under Ar. The reaction mixture was allowed to warm to room temperature and stirred for additional 4 h. The reaction was quenched with water (20.0 mL), and the aqueous phase was extracted with diethyl ether (3 x 40.0 mL). The combined organic layer was washed with brine, dried over $MgSO_4$, and the solvent removed under reduced pressure. For **s3af**, the crude product was used for next step without purification. To the crude product were added water (0.5 mL) and THF (40.0 mL), and then TBAF (1.0 M in THF, 1.0 mL, 1.0 mmol) at 0 °C, and the mixture was stirred under air at r.t. for 5 h. After the volatiles were removed under reduced pressure, the residue was purified by flash column chromatography on silica gel to afford corresponding alkynylphosphine sulfides (80% - 85% overall yield).

7. Hydrophosphination of alkynylphosphine oxides/sulfides



General Procedure 5 (GP5)

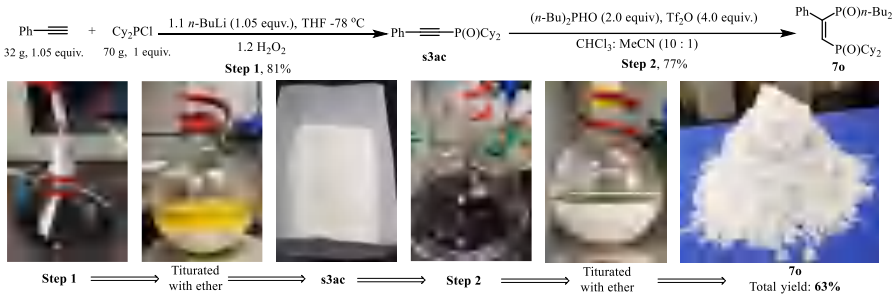
A 10 mL oven-dried sealed tube equipped with a magnetic stir bar was charged with secondary phosphine oxide (0.4 mmol, 2.0 equiv), alkynylphosphine oxide/alkynylphosphine sulfide (0.2 mmol, 1.0 equiv). The tube was evacuated and backfilled with argon (three times) and then $CHCl_3$ (2.0 mL) and CH_3CN (0.2 mL) was added sequentially via a syringe. The resulting mixture was stirred until it became a homogeneous solution. Tf_2O (0.8 mmol, 4.0 equiv) was then added by a syringe. The resulting mixture was stirred for 3 h at 60 °C. After cooled to ambient temperature, sat. $NaHCO_3$ aq (5.0 mL) was added and the resulting mixture was extracted with DCM (3 x 10.0 mL). The organic layer was washed with brine, and dried over $MgSO_4$ and volatiles were removed under reduced pressure. The residue was purified by flash column chromatography on silica gel to give the desired products.

8. Synthetic applications

8.1 Scale-up synthesis for 6n, 7m and 7at

A 50 mL oven-dried sealed tube equipped with a magnetic stir bar was charged with secondary phosphine oxide **s2q** (0.86 g, 4.0 mmol, 2.0 equiv). Alkynylphosphine oxide **s3a** (0.60 g, 2.0 mmol, 1.0 equiv), **s3ac** (0.63 g, 2.0 mmol, 1.0 equiv) or **s3p** (0.48 g, 2.0 mmol, 1.0 equiv) was added respectively. The tube was evacuated and backfilled with argon (three times) and then $CHCl_3$ (10.0 mL) and CH_3CN (1.0 mL) was added sequentially via a syringe. The resulting mixture was stirred until it became a homogeneous solution. Tf_2O (1.33 mL, 8.0 mmol, 4.0 equiv) was then added by a syringe. The resulting mixture was stirred for 3 h at 60 °C. After cooled to ambient temperature, sat. $NaHCO_3$ aq (20.0 mL) was added and the resulting mixture was extracted with DCM (3 x 30.0 mL). The organic layer was washed with brine, and dried over $MgSO_4$ and volatiles were removed under reduced pressure. The residue was purified by flash column chromatography on silica gel to give the corresponding product **6n** (0.96 g, 93% yield), **7m** (0.85 g, 80% yield) or **7at** (0.63 g, 70% yield) respectively.

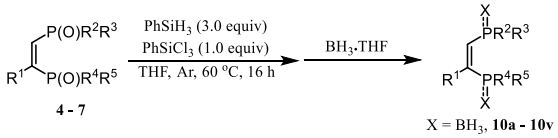
8.2 100 g Scale-up synthesis of 7o



Step 1 Synthesis of s3ac: The product of **s3ac** were synthesized according to published procedure.[48] To a flask was added THF (600 mL) and alkyne (32.2 g, 315 mmol, 1.05 equiv), cooled to -78 °C and *n*-BuLi (315 mmol, 1.05 equiv) was added dropwise under Ar. The resulting mixture was stirred and allowed to warm to 0 °C over 20 min, then cooled to –78 °C and chlorodicyclohexylphosphine (69.8 g, 300 mmol, 1.0 equiv) added dropwise. The resulting mixture was allowed to warm to room temperature over 2 h then 30% H_2O_2 (50 mL) at 0 °C, and the mixture was stirred under air at r.t. for 2 h. The reaction was quenched with water (200 mL), and the aqueous phase was extracted with ethyl acetate (3 x 200 mL). The combined organic layer was washed with sodium sulfite (50 g in 500 mL water), dried over $MgSO_4$, and the solvent removed under reduced pressure. The resulting mixture was triturated with ether, filtered and washed the filter cake with a minimum amount of ether afforded **s3ac** as white solid (56.6 g, 60% yield). The filtrate was concentrated under reduced pressure. The residue was purified by flash column chromatography on silica gel to give the desired product (76.3 g, 81% overall yield).

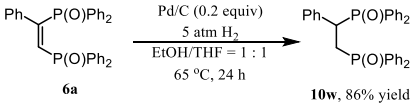
Step 2 Synthesis of 7o:To a flask equipped with a magnetic stir bar was charged with **s2o** (64.8 g, 400 mmol, 2.0 equiv), **s3ac** (62.8 g, 200 mmol, 1.0 equiv). The flask was evacuated and backfilled with argon (three times) and then $CHCl_3$ (1000 mL) and CH_3CN (100 mL) was added sequentially via a syringe. The resulting mixture was stirred until it became a homogeneous solution. Tf_2O (133 mL, 800 mmol, 4.0 equiv) was then added by a syringe. The resulting mixture was stirred for 5 h at 60 °C. After cooled to ambient temperature, sat. $NaHCO_3$ aq was added and the resulting mixture was extracted with DCM. The organic layer was washed with brine, and dried over $MgSO_4$ and volatiles were removed under reduced pressure. The resulting mixture was triturated with ether, filtered and washed the filter cake with a minimum amount of ether afforded **7o** as white solid (44.7 g, 47% yield). The filtrate was concentrated under reduced pressure. The residue was purified by flash column chromatography on silica gel to give the desired product (73.3 g, 77% overall yield).

8.3 Synthesis of 10a – 10v



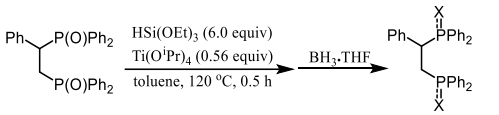
The product of **10a – 10v** were synthesized according to published procedure.[50] A 10 mL oven-dried sealed tube equipped with a magnetic stir bar was charged with **4 - 7** (0.2 mmol, 1.0 equiv). The tube was evacuated and backfilled with argon (three times) and then THF (1.0 mL), $PhSiH_3$ (0.6 mmol, 3.0 equiv) and $PhSiCl_3$ (0.2 mmol, 1.0 equiv) was added sequentially via a syringe. The resulting mixture was stirred for 16 h at 60 °C. After that, the reaction was cooled to room temperature and BH_3 (1 M in THF, 1.1 equiv or 2.2 equiv) was added via syringe under Ar atmosphere. The resulting reaction mixture was stirred at room temperature for 4 h. The reaction was quenched with water (5.0 mL) and the resulting mixture was extracted with ethyl acetate (3 x 10.0 mL). The organic layer was washed with brine, and dried over $MgSO_4$ and volatiles were removed under reduced pressure. The residue was purified by flash column chromatography on silica gel to give the desired product (20% - 70% yield).

8.4 Synthesis of 10w and 10z



6a **10w**, 86% yield

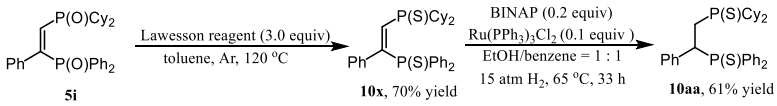
An autoclave equipped with a magnetic stir bar was charged with **6a** (0.2 mmol, 1.0 equiv), Pd/C (0.04 mmol, 0.2 equiv), EtOH (7.0 mL) and THF (7.0 mL). The autoclave was charged with 5 atm H_2, and the resulting mixture was stirred for 24 h at 65 °C. After that, the reaction was cooled to room temperature and volatiles were removed under reduced pressure. The residue was purified by flash column chromatography on silica gel to give the desired product **10w**.



10w X = BH_3 **10z**, 92% yield

The product of **10z** was synthesized according to published procedure.[51] A 10 mL oven-dried sealed tube equipped with a magnetic stir bar was charged with **10w** (0.2 mmol, 1.0 equiv). The tube was evacuated and backfilled with argon (three times) and then toluene (4.0 mL), $HSi(OEt)_3$ (1.2 mmol, 6.0 equiv) and $Ti(O^iPr)_4$ (0.112 mmol, 0.56 equiv) was added sequentially via a syringe. The resulting mixture was stirred for 0.5 h at 120 °C. After that, the reaction was cooled to room temperature and BH_3 (0.6 mL 1 M in THF, 3.0 equiv) was added via syringe under Ar atmosphere. The resulting reaction mixture was stirred at room temperature for 4 h. After removal of the volatiles under reduced pressure, the residue was purified by flash column chromatography on silica gel to give the desired product **10z**.

8.5 Synthesis of 10x and 10aa

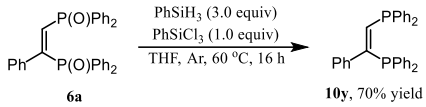


5i **10x**, 70% yield **10aa**, 61% yield

A 10 mL oven-dried sealed tube equipped with a magnetic stir bar was charged with **5i** (0.2 mmol, 1.0 equiv), Lawesson reagent (0.6 mmol, 3.0 equiv). The tube was evacuated and backfilled with argon (three times) and then toluene (1.0 mL) was added via a syringe. The resulting mixture was stirred for 4 h at 120 °C. After that, the reaction was cooled to room temperature and volatiles were removed under reduced pressure. The residue was purified by flash column chromatography on silica gel to give the desired product **10x**.

The product of **10aa** was synthesized according to published procedure.[35] An autoclave equipped with a magnetic stir bar was charged with **10x** (0.2 mmol, 1.0 equiv), BINAP (0.04 mmol, 0.2 equiv), $Ru(PPh_3)_3Cl_2$ (0.02 mmol, 0.1 equiv), EtOH (7.0 mL) and benzene (7.0 mL). The autoclave was charged with 15 atm H_2, and the resulting mixture was stirred for 33 h at 65 °C. After that, the reaction was cooled to room temperature and volatiles were removed under reduced pressure. The residue was purified by flash column chromatography on silica gel to give the desired product **10aa**.

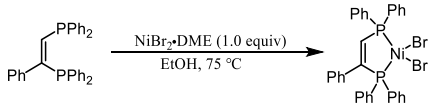
8.6 Synthesis of 10y



6a **10y**, 70% yield

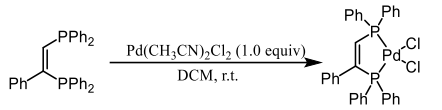
The product of **10y** was synthesized according to published procedure.[50] A 10 mL oven-dried sealed tube equipped with a magnetic stir bar was charged with **6a** (1.0 mmol, 1.0 equiv). The tube was evacuated and backfilled with argon (three times) and then THF (2.0 mL), $PhSiH_3$ (3.0 mmol, 3.0 equiv) and $PhSiCl_3$ (1.0 mmol, 1.0 equiv) was added sequentially via a syringe. The resulting mixture was stirred for 16 h at 60 °C. After cooled to room temperature, the reaction was quenched with water (10.0 mL) and the resulting mixture was extracted with ethyl acetate (3 x 15.0 mL). The organic layer was washed with brine, and dried over $MgSO_4$ and volatiles were removed under reduced pressure. The residue was purified by flash column chromatography on silica gel to give the desired product **10y**.

8.7 Synthesis of 10ab and 10ac



10y **10ab**, 60% yield

$NiBr_2$·DME (0.20 mmol, 1.0 equiv) was placed in a 25 mL reaction flask under argon. Ethanol (5.0 mL) was charged to dissolve the nickel salt at 75 °C. Diphosphine **10y** (0.22 mmol, 1.1 equiv) in ethanol (15.0 mL) was added. Immediately, red precipitate appeared. The precipitate was washed with ether and dried in vacuo. The complex weighed 82.6 mg (60%, unoptimized).

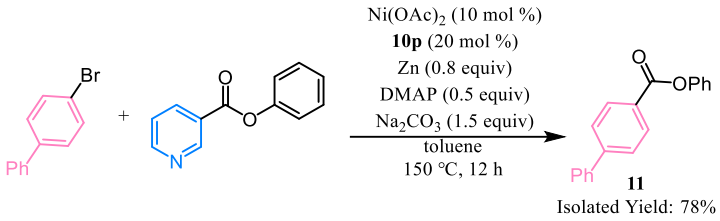


10y **10ac**, > 99% yield

$Pd(CH_3CN)_2Cl_2$ (0.20 mmol, 1.0 equiv) was placed in a 25 mL reaction flask under argon. DCM (5.0 mL) was charged to dissolve the nickel salt. Diphosphine **10y** (0.20 mmol, 1.0 equiv) in DCM (10.0 mL) was added. Immediately, orange precipitate appeared. The resulting mixture was stirred for 30 min at r.t. and volatiles were removed under reduced pressure (> 99 %, unoptimized).

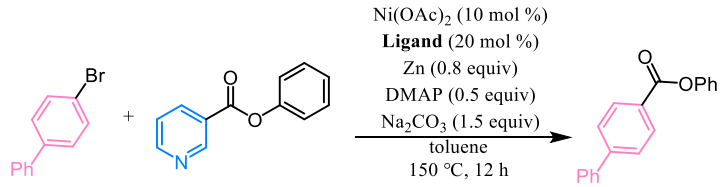
9. Catalytic potential of the biphosphine ligands library

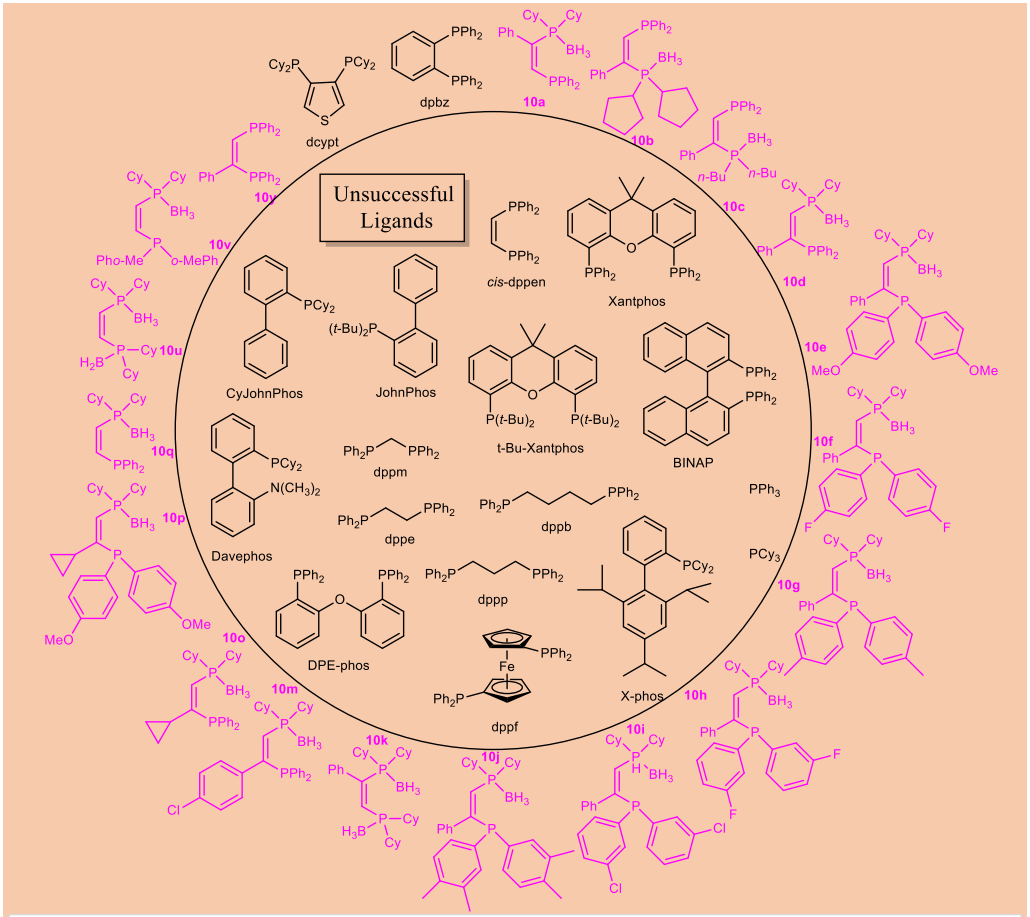
To further prove the superiority of our methods, we utilized our disphosphine ligand library (DPPEN type) and currently reported phosphine ligands in optimizing the demanding functional group metathesis reaction which had been reported by Junichiro Yamaguchi group in 2020.[52]

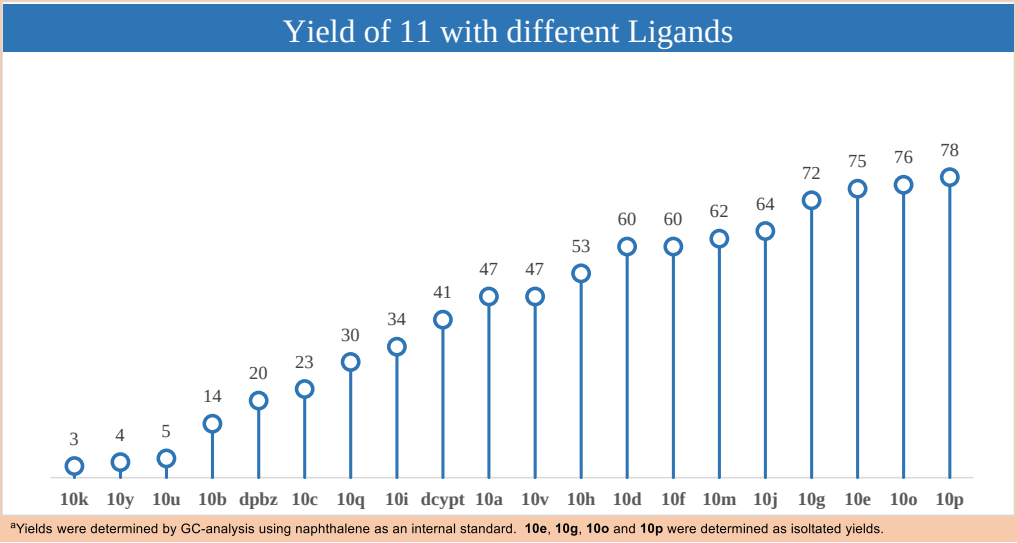


A 10 mL oven-dried sealed tube equipped with a magnetic stir bar, $Ni(OAc)_2 \cdot 4H_2O$ (5.0 mg, 0.020 mmol, 10 mol %) and Na_2CO_3 (31.8 mg, 0.30 mmol, 1.5 equiv) were dried with a heat-gun in vacuo and filled with Ar after cooling to room temperature. To this vessel were added 4-bromobiphenyl (92.8 mg, 0.40 mmol, 2.0 equiv), phenyl nicotinate (39.8 mg, 0.20 mmol, 1.0 equiv), Zn powder (10.5 mg, 0.16 mmol, 80 mol %), N,N-dimethyl-4-aminopyridine (DMAP; 12.2 mg, 0.10 mmol, 1.0 equiv) and **10p** (0.040 mmol, 20 mol %). The vessel was vacuumed and refilled Ar gas three times. To this was added toluene (0.9 mL). The resulting mixture was stirred for 12 h at 150 °C. After cooling the reaction mixture to room temperature, the mixture was purified by flash column chromatography on silica gel to give the desired product.

9.1 Screening of DPPEN type and known phosphine ligands







[a]Yields were determined by GC-analysis using naphthalene as an internal standard. **10e**, **10g**, **10o** and **10p** were determined as isoltated yields.

Figure S8. Screening of DPPEN type and known phosphine ligands

10. X-ray crystal structures

10.1 X-ray crystal structure analysis of 6m

The structure of **6m** was confirmed X-ray analysis (Figure S9). The crystal data of compound **6m** was collected at 293 (2) K with graphite monochromatic Cu Kα radiation (λ = 1.54184 Å). The crystal structures were solved and refined by full matrix least-squares methods against F^2 by using Olex2 programs. Crystallographic data for the structure has been deposited to the Cambridge Crystallographic Data Center (CCDC 2098758).

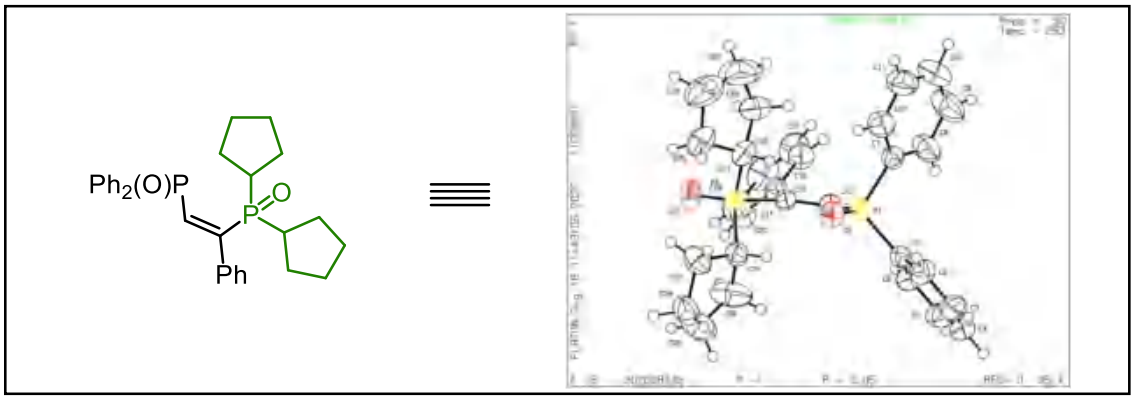


Figure 9. ORTEP drawing of **6m**

***Table S7*. Crystal data and structure refinement for 6m**

Identification code	202008135
Empirical formula	$C_{30}H_{34}O_2P_2$
Formula weight	488.51
Temperature/K	293(2)
Crystal system	triclinic
Space group	P-1
a/Å	10.1908(5)
b/Å	10.8041(7)
c/Å	13.8826(7)
α/°	93.707(5)
β/°	106.837(4)
γ/°	111.227(5)
Volume/Å^3	1338.90(14)
Z	2
ρ_{calc}g/cm^3	1.212
μ/mm^{-1}	1.656
F(000)	520.0
Crystal size/mm^3	0.15 × 0.13 × 0.09
Radiation	CuKα (λ = 1.54184)
2Θ range for data collection/°	8.944 to 134.15
Index ranges	-12 ≤ h ≤ 12, -12 ≤ k ≤ 12, -14 ≤ l ≤ 16
Reflections collected	9433
Independent reflections	4768 [R_{int} = 0.0320, R_{sigma} = 0.0482]
Data/restraints/parameters	4768/0/307
Goodness-of-fit on F^2	1.020
Final R indexes [I>=2σ (I)]	R_1 = 0.0527, wR_2 = 0.1364
Final R indexes [all data]	R_1 = 0.0697, wR_2 = 0.1517
Largest diff. peak/hole / e Å^{-3}	0.42/-0.30

10.2 X-ray crystal structure analysis of 7aw

The structure of **7aw** was confirmed X-ray analysis (Figure S10). The crystal data of compound **7aw** was collected at 293 (2) K with graphite monochromatic Cu Kα radiation (λ = 1.54184 Å). The crystal structures were solved and refined by full matrix least-squares methods against F^2 by using Olex2 programs. Crystallographic data for the structure has been deposited to the Cambridge Crystallographic Data Center (CCDC 2098742).

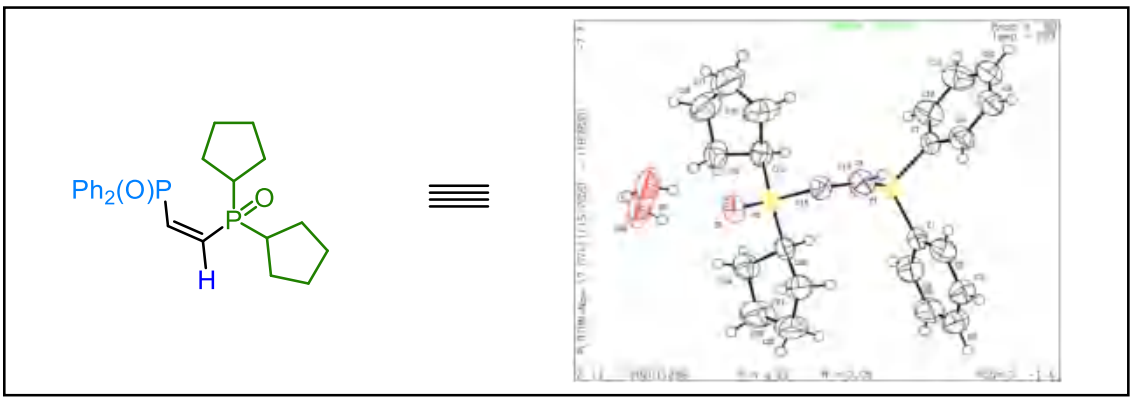


Figure S10. ORTEP drawing of **7aw**

***Table S8*. Crystal data and structure refinement for 7aw**

Identification code	202011239
Empirical formula	$C_{24}H_{32}O_3P_2$
Formula weight	430.43
Temperature/K	293(2)
Crystal system	orthorhombic
Space group	$Pna2_1$
a/Å	22.8622(10)
b/Å	16.9970(9)
c/Å	5.9571(3)
α/°	90
β/°	90
γ/°	90
Volume/Å^3	2314.87(19)
Z	4
ρ_{calc}g/cm^3	1.235
μ/mm^{-1}	1.875
F(000)	920.0
Crystal size/mm^3	0.2 × 0.14 × 0.1
Radiation	CuKα (λ = 1.54184)
2Θ range for data collection/°	7.734 to 134.15
Index ranges	-27 ≤ h ≤ 27, -14 ≤ k ≤ 20, -5 ≤ l ≤ 7
Reflections collected	8829
Independent reflections	3106 [R_{int} = 0.0837, R_{sigma} = 0.0744]
Data/restraints/parameters	3106/21/243
Goodness-of-fit on F^2	1.089
Final R indexes [I>=2σ (I)]	R_1 = 0.0514, wR_2 = 0.1335
Final R indexes [all data]	R_1 = 0.0791, wR_2 = 0.1697
Largest diff. peak/hole / e Å^{-3}	0.54/-0.41
Flack parameter	0.02(3)

10.3 X-ray crystal structure analysis of 8b

The structure of **8b** was confirmed X-ray analysis (Figure S11). The crystal data of compound **8b** was collected at 293 (2) K with graphite monochromatic Cu Kα radiation (λ = 1.54184 Å). The crystal structures were solved and refined by full matrix least-squares methods against F^2 by using Olex2 programs. Crystallographic data for the structure has been deposited to the Cambridge Crystallographic Data Center (CCDC 2098768).

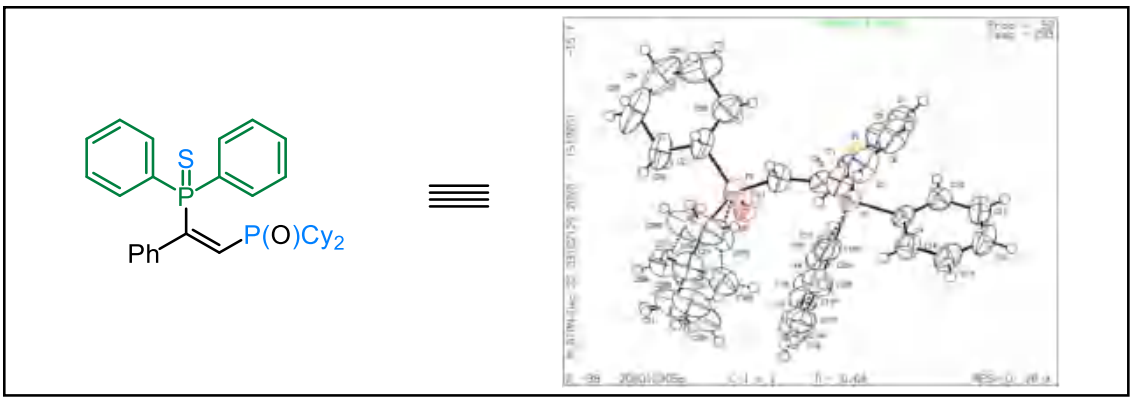


Figure S11. ORTEP drawing of **8b**

***Table S9*. Crystal data and structure refinement for 8b**

Identification code	202012305A
Empirical formula	$C_{32}H_{37}OP_2S$
Formula weight	531.61
Temperature/K	293(2)
Crystal system	monoclinic
Space group	Cc
a/Å	11.5958(3)
b/Å	14.5589(3)
c/Å	18.0307(4)
α/°	90
β/°	105.716(2)
γ/°	90
Volume/Å^3	2930.20(12)
Z	4
ρ_{calc}g/cm^3	1.205
μ/mm^{-1}	2.175
F(000)	1132.0
Crystal size/mm^3	0.16 × 0.13 × 0.1
Radiation	CuKα (λ = 1.54184)
2Θ range for data collection/°	9.986 to 141.742
Index ranges	-14 ≤ h ≤ 14, -17 ≤ k ≤ 17, -22 ≤ l ≤ 18
Reflections collected	11219
Independent reflections	4341 [R_{int} = 0.0296, R_{sigma} = 0.0332]
Data/restraints/parameters	4341/147/339
Goodness-of-fit on F^2	1.029
Final R indexes [I>=2σ (I)]	R_1 = 0.0426, wR_2 = 0.1132
Final R indexes [all data]	R_1 = 0.0454, wR_2 = 0.1165
Largest diff. peak/hole / e Å^{-3}	0.29/-0.21
Flack parameter	-0.024(14)

10.4 X-ray crystal structure analysis of 8j

The structure of **8j** was confirmed X-ray analysis (Figure S12). The crystal data of compound **8j** was collected at 273.15 K with graphite monochromatic Mo Kα radiation (λ = 0.71073 Å). The crystal structures were solved and refined by full matrix least-squares methods against F^2 by using Olex2 programs. Crystallographic data for the structure has been deposited to the Cambridge Crystallographic Data Center (CCDC 2100843).

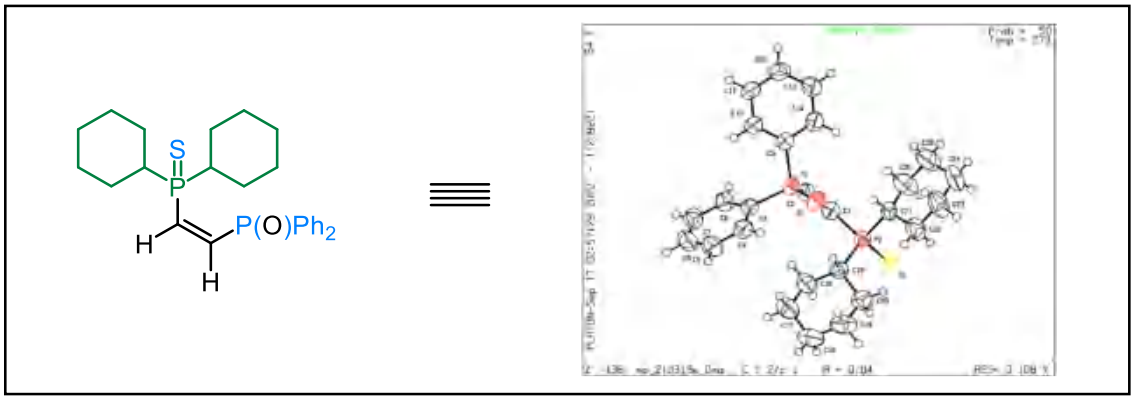


Figure S12. ORTEP drawing of **8j**

***Table S10*. Crystal data and structure refinement for 8j**

Identification code	mo_210313e_0ma
Empirical formula	$C_{26}H_{34}OP_2S$
Formula weight	456.53
Temperature/K	273.15
Crystal system	monoclinic
Space group	C2/c
a/Å	22.1014(5)
b/Å	13.3847(5)
c/Å	19.0796(6)
α/°	90
β/°	118.479(2)
γ/°	90
Volume/Å^3	4961.2(3)
Z	8
ρ_{calc}g/cm^3	1.222
μ/mm^{-1}	0.275
F(000)	1952.0
Crystal size/mm^3	0.14 × 0.1 × 0.08
Radiation	MoKα (λ = 0.71073)
2Θ range for data collection/°	6.088 to 52.744
Index ranges	-27 ≤ h ≤ 27, -15 ≤ k ≤ 16, -23 ≤ l ≤ 23
Reflections collected	60625
Independent reflections	5072 [R_{int} = 0.0728, R_{sigma} = 0.0283]
Data/restraints/parameters	5072/0/271
Goodness-of-fit on F^2	1.026
Final R indexes [I>=2σ (I)]	R_1 = 0.0434, wR_2 = 0.1078
Final R indexes [all data]	R_1 = 0.0668, wR_2 = 0.1211
Largest diff. peak/hole / e Å^{-3}	0.41/-0.24

10.5 X-ray crystal structure analysis of 10d

The structure of **10d** was confirmed X-ray analysis (Figure S13). The crystal data of compound **10d** was collected at 293 (2) K with graphite monochromatic Cu Kα radiation (λ = 1.54184 Å). The crystal structures were solved and refined by full matrix least-squares methods against F^2 by using Olex2 programs. Crystallographic data for the structure has been deposited to the Cambridge Crystallographic Data Center (CCDC 2098738).

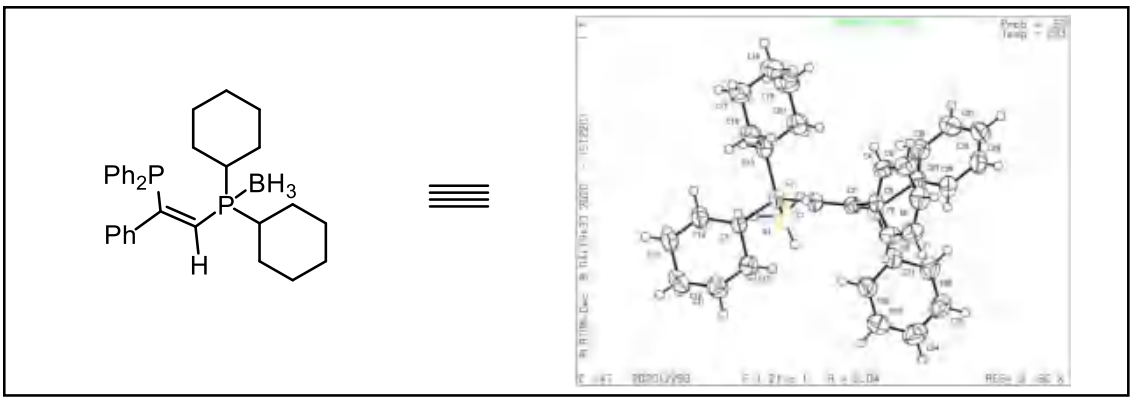


Figure S13. ORTEP drawing of **10d**

***Table S11*. Crystal data and structure refinement for 10d**

Identification code	202012293
Empirical formula	$C_{32}H_{41}BP_2$
Formula weight	498.40
Temperature/K	293(2)
Crystal system	monoclinic
Space group	$P2_1/c$
a/Å	10.7442(2)
b/Å	12.9675(3)
c/Å	20.7744(4)
α/°	90
β/°	99.080(2)
γ/°	90
Volume/Å^3	2858.13(11)
Z	4
ρ_{calc}g/cm^3	1.158
μ/mm^{-1}	1.498
F(000)	1072.0
Crystal size/mm^3	0.15 × 0.11 × 0.1
Radiation	CuKα (λ = 1.54184)
2Θ range for data collection/°	8.066 to 134.14
Index ranges	-12 ≤ h ≤ 8, -15 ≤ k ≤ 14, -24 ≤ l ≤ 24
Reflections collected	11199
Independent reflections	5089 [R_{int} = 0.0345, R_{sigma} = 0.0426]
Data/restraints/parameters	5089/0/332
Goodness-of-fit on F^2	1.023
Final R indexes [I>=2σ (I)]	R_1 = 0.0442, wR_2 = 0.1113
Final R indexes [all data]	R_1 = 0.0577, wR_2 = 0.1235
Largest diff. peak/hole / e Å^{-3}	0.32/-0.18

10.6 X-ray crystal structure analysis of 10ab

The structure of **10ab** was confirmed X-ray analysis (Figure S14). The crystal data of compound **10ab** was collected at 293 (2) K with graphite monochromatic Cu Kα radiation (λ = 1.54184 Å). The crystal structures were solved and refined by full matrix least-squares methods against F^2 by using Olex2 programs. Crystallographic data for the structure has been deposited to the Cambridge Crystallographic Data Center (CCDC 2098743).

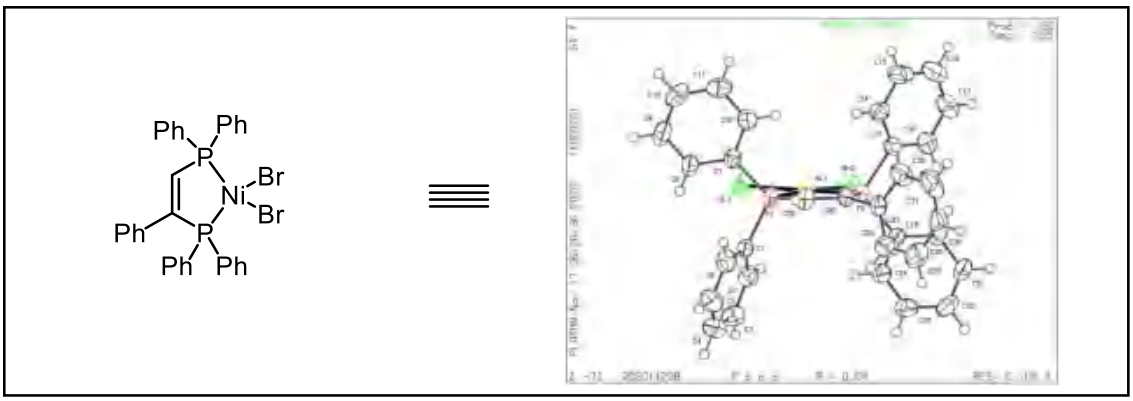


Figure S14. ORTEP drawing of **10ab**

***Table S12*. Crystal data and structure refinement for 10ab**

Identification code	202011238
Empirical formula	$C_{32}H_{26}Br_2NiP_2$
Formula weight	691.00
Temperature/K	293(2)
Crystal system	orthorhombic
Space group	Pbca
a/Å	15.3937(4)
b/Å	16.9791(5)
c/Å	22.1496(10)
α/°	90
β/°	90
γ/°	90
Volume/Å^3	5789.3(4)
Z	8
ρ_{calc}g/cm^3	1.586
μ/mm^{-1}	5.391
F(000)	2768.0
Crystal size/mm^3	0.15 × 0.1 × 0.09
Radiation	CuKα (λ = 1.54184)
2Θ range for data collection/°	7.984 to 134.026
Index ranges	-16 ≤ h ≤ 18, -20 ≤ k ≤ 12, -13 ≤ l ≤ 26
Reflections collected	14854
Independent reflections	5159 [R_{int} = 0.0368, R_{sigma} = 0.0399]
Data/restraints/parameters	5159/0/334
Goodness-of-fit on F^2	1.034
Final R indexes [I>=2σ (I)]	R_1 = 0.0355, wR_2 = 0.0857
Final R indexes [all data]	R_1 = 0.0490, wR_2 = 0.0951
Largest diff. peak/hole / e Å^{-3}	0.36/-0.40

10.7 X-ray crystal structure analysis of 10ac

The structure of **10ac** was confirmed X-ray analysis (Figure S15). The crystal data of compound **10ac** was collected at 273.15 K with graphite monochromatic Mo Kα radiation (λ = 0.71073 Å). The crystal structures were solved and refined by full matrix least-squares methods against F^2 by using Olex2 programs. Crystallographic data for the structure has been deposited to the Cambridge Crystallographic Data Center (CCDC 2098780).

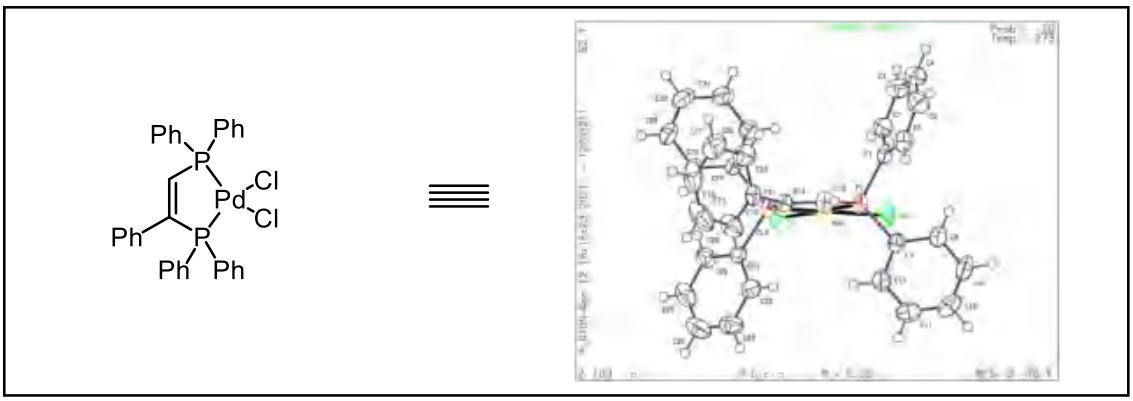
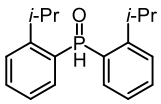


Figure S15. ORTEP drawing of **10ac**

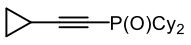
***Table S13*. Crystal data and structure refinement for 10ac**

Identification code	A
Empirical formula	$C_{32}H_{26}Cl_2P_2Pd$
Formula weight	649.77
Temperature/K	273.15
Crystal system	orthorhombic
Space group	Pbca
a/Å	15.2106(3)
b/Å	16.9416(4)
c/Å	22.0596(6)
α/°	90
β/°	90
γ/°	90
Volume/Å^3	5684.6(2)
Z	8
ρ_{calc}g/cm^3	1.518
μ/mm^{-1}	0.974
F(000)	2624.0
Crystal size/mm^3	0.12 × 0.09 × 0.08
Radiation	MoKα (λ = 0.71073)
2Θ range for data collection/°	4.044 to 54.948
Index ranges	-16 ≤ h ≤ 19, -21 ≤ k ≤ 21, -28 ≤ l ≤ 28
Reflections collected	125225
Independent reflections	6503 [R_{int} = 0.0605, R_{sigma} = 0.0221]
Data/restraints/parameters	6503/0/334
Goodness-of-fit on F^2	1.024
Final R indexes [I>=2σ (I)]	R_1 = 0.0252, wR_2 = 0.0526
Final R indexes [all data]	R_1 = 0.0432, wR_2 = 0.0583
Largest diff. peak/hole / e Å^{-3}	0.31/-0.30

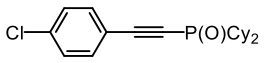
11. Characteristic data



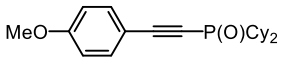
(s2x) ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.90 – 7.66 (m, 3H), 7.53 – 7.48 (m, 2H), 7.37 – 7.26 (m, 4H), 3.27 – 3.19 (m, 2H), 1.20 – 0.85 (m, 12H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 152.3 (d, *J* = 9.8 Hz), 132.8 (d, *J* = 2.6 Hz), 132.2 (d, *J* = 12.5 Hz), 129.0 (d, *J* = 101.3 Hz), 126.4 (d, *J* = 10.3 Hz), 126.2 (d, *J* = 13.1 Hz), 31.0 (d, *J* = 7.2 Hz), 23.8, 23.6; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 17.7. HRMS (ESI) calcd for $C_{18}H_{24}OP^+$ $[M+H]^+$ 287.1560, found 287.1553.



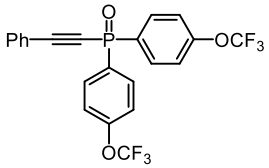
(s3q) ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.90 – 1.63 (m, 12H), 1.36 – 1.16 (m, 11H), 0.86 – 0.77 (m, 4H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 109.6 (d, *J* = 23.5 Hz), 67.7 (d, *J* = 143.9 Hz), 36.6 (d, *J* = 79.7 Hz), 26.3 (d, *J* = 9.7 Hz), 26.1 (d, *J* = 9.3 Hz), 25.8, 25.6 (d, *J* = 3.0 Hz), 24.6 (d, *J* = 3.1 Hz), 9.1, 0.0 (d, *J* = 3.3 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 34.3. HRMS (ESI) calcd for $C_{17}H_{28}OP^+$ $[M+H]^+$ 279.1873, found 279.1870.



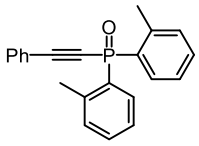
(s3r) White solid (m.p.: 143 - 145 ℃); 75% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.45 (d, *J* = 8.4 Hz, 2H), 7.32 (d, *J* = 8.5 Hz, 2H), 2.06 – 1.71 (m, 12H), 1.57 – 1.45 (m, 4H), 1.35 – 1.18 (m, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 136.5, 133.6 (d, *J* = 1.7 Hz), 128.9, 118.9 (d, *J* = 3.5 Hz), 101.8 (d, *J* = 21.0 Hz), 82.6 (d, *J* = 133.4 Hz), 36.8 (d, *J* = 79.0 Hz), 26.3 (d, *J* = 9.7 Hz), 26.2 (d, *J* = 9.3 Hz), 25.84 – 25.79 (m), 24.7 (d, *J* = 3.3 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 35.7. HRMS (ESI) calcd for $C_{20}H_{27}ClOP^+$ $[M+H]^+$ 349.1483, found 349.1477.



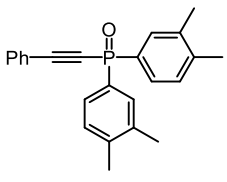
(s3s) White solid (m.p.: 86 - 88 ℃); 73% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.46 (d, *J* = 8.8 Hz, 2H), 6.85 (d, *J* = 8.8 Hz, 2H), 3.81 (s, 3H), 2.05 – 1.82 (m, 10H), 1.72 – 1.69 (m, 2H), 1.58 – 1.46 (m, 4H), 1.34 – 1.21 (m, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 161.0, 134.1 (d, *J* = 1.7 Hz), 114.2, 112.4 (d, *J* = 3.5 Hz), 103.6 (d, *J* = 22.4 Hz), 80.2 (d, *J* = 138.9 Hz), 55.4, 36.9 (d, *J* = 79.3 Hz), 26.3 (d, *J* = 9.7 Hz), 26.2 (d, *J* = 9.3 Hz), 25.88, 25.87, 25.8 (d, *J* = 3.2 Hz), 24.8 (d, *J* = 3.3 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 35.2. HRMS (ESI) calcd for $C_{21}H_{30}O_2P^+$ $[M+H]^+$ 345.1978, found 345.1981.



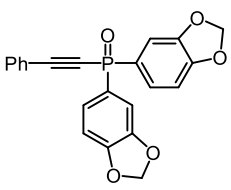
(s3y) ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.93 (dd, *J* = 13.2, 8.5 Hz, 4H), 7.57 (d, *J* = 7.7 Hz, 2H), 7.45 – 7.31 (m, 7H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 152.3 (dd, *J* = 3.2, 1.7 Hz), 133.0 (d, *J* = 12.6 Hz), 132.6 (d, *J* = 1.5 Hz), 131.3 (d, *J* = 125.2 Hz), 131.1, 128.7, 120.8 (d, *J* = 14.5 Hz), 120.3 (q, *J* = 260.0 Hz), 119.3 (d, *J* = 4.1 Hz), 106.6 (d, *J* = 31.5 Hz), 81.9 (d, *J* = 175.8 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 5.2; **^{19}F NMR** (376 MHz, $CDCl_3$) δ -57.6. HRMS (ESI) calcd for $C_{22}H_{14}F_6O_3P^+$ $[M+H]^+$ 471.0579, found 471.0585.



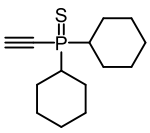
(s3z) ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.07 (dd, *J* = 15.6, 7.6 Hz, 2H), 7.59 (d, *J* = 7.3 Hz, 2H), 7.49 – 7.24 (m, 9H), 2.45 (s, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 141.6 (d, *J* = 10.6 Hz), 132.8 (d, *J* = 11.9 Hz), 132.4, 131.7 (d, *J* = 11.8 Hz), 130.61 (d, *J* = 119.5 Hz), 130.59, 128.6, 125.8 (d, *J* = 13.5 Hz), 120.2 (d, *J* = 3.9 Hz), 104.9 (d, *J* = 29.5 Hz), 83.2 (d, *J* = 167.9 Hz), 21.3 (d, *J* = 5.3 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 8.6. HRMS (ESI) calcd for $C_{22}H_{20}OP^+$ $[M+H]^+$ 331.1246, found 331.1246.



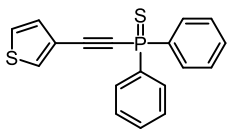
(s3aa) ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.71 – 7.59 (m, 6H), 7.44 (t, *J* = 7.6 Hz, 1H), 7.37 (t, *J* = 7.1 Hz, 2H), 7.28 – 7.24 (m, 2H), 2.31 (s, 12H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 141.5 (d, *J* = 2.9 Hz), 137.2 (d, *J* = 13.7 Hz), 132.5 (d, *J* = 1.7 Hz), 131.9 (d, *J* = 11.4 Hz), 130.5, 130.3 (d, *J* = 124.3 Hz), 129.9 (d, *J* = 14.4 Hz), 128.6 (d, *J* = 11.3 Hz), 128.5, 120.3 (d, *J* = 3.9 Hz), 104.7 (d, *J* = 29.7 Hz), 83.6 (d, *J* = 167.9 Hz), 20.1, 19.8; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 8.8. HRMS (ESI) calcd for $C_{24}H_{24}OP^+$ $[M+H]^+$ 359.1559, found 359.1559.



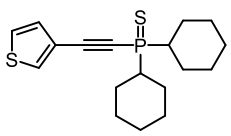
(s3ab) **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.56 (d, *J* = 7.3 Hz, 2H), 7.46 – 7.41 (m, 3H), 7.34 (t, *J* = 7.5 Hz, 2H), 7.23 (d, *J* = 13.3 Hz, 2H), 6.89 (d, *J* = 7.6 Hz, 2H), 5.99 (s, 4H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 151.2 (d, *J* = 3.0 Hz), 148.1 (d, *J* = 20.5 Hz), 132.5 (d, *J* = 1.4 Hz), 130.7, 128.6, 126.5 (d, *J* = 12.3 Hz), 126.2 (d, *J* = 128.6 Hz), 119.9 (d, *J* = 3.9 Hz), 110.4 (d, *J* = 14.7 Hz), 108.8 (d, *J* = 17.0 Hz), 105.0 (d, *J* = 30.6 Hz), 101.8, 83.0 (d, *J* = 172.0 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 8.1. HRMS (ESI) calcd for $C_{22}H_{16}O_5P^+$ $[M+H]^+$ 391.0730, found 391.0730.



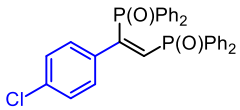
(s3af) **^{1}H NMR** (400 MHz, $CDCl_3$) δ 3.06 (d, *J* = 8.8 Hz, 1H), 2.02 – 1.86 (m, 10H), 1.73 – 1.27 (m, 10H), 1.24 – 1.18 (m, 2H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 92.6 (d, *J* = 15.5 Hz), 76.3 (d, *J* = 112.5 Hz), 38.4 (d, *J* = 58.4 Hz), 26.3 – 26.0 (m), 25.7 (d, *J* = 1.4 Hz), 24.8 (d, *J* = 1.8 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 46.1. HRMS (ESI) calcd for $C_{14}H_{24}PS^+$ $[M+H]^+$ 255.1331, found 255.1331.



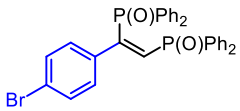
(s3ai) **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.02 – 7.95 (m, 4H), 7.74 (d, *J* = 2.8 Hz, 1H), 7.54 – 7.45 (m, 6H), 7.32 (dd, *J* = 5.0, 3.0 Hz, 1H), 7.24 (dd, *J* = 5.0, 0.8 Hz, 1H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 133.7 (d, *J* = 99.1 Hz), 133.1 (d, *J* = 2.5 Hz), 131.9 (d, *J* = 3.3 Hz), 130.9 (d, *J* = 12.2 Hz), 129.9 (d, *J* = 1.3 Hz), 128.7 (d, *J* = 13.9 Hz), 126.1, 119.5 (d, *J* = 4.4 Hz), 101.2 (d, *J* = 27.4 Hz), 81.8 (d, *J* = 153.9 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 20.3. HRMS (ESI) calcd for $C_{18}H_{14}PS_2^+$ $[M+H]^+$ 325.0269, found 325.0266.



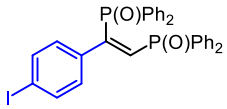
(s3aj) **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.65 (s, 1H), 7.31 – 7.29 (m, 1H), 7.17 (d, *J* = 4.7 Hz, 1H), 2.08 – 1.88 (m, 10H), 1.76 – 1.71 (m, 2H), 1.61 – 1.45 (m, 5H), 1.37 – 1.26 (m, 5H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 132.4 (d, *J* = 2.1 Hz), 130.0, 125.9, 119.8 (d, *J* = 3.8 Hz), 99.3 (d, *J* = 18.6 Hz), 79.9 (d, *J* = 121.9 Hz), 38.9 (d, *J* = 59.2 Hz), 26.5 – 26.1 (m), 25.8 (d, *J* = 0.9 Hz), 25.1 (d, *J* = 1.3 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 45.1. HRMS (ESI) calcd for $C_{18}H_{26}PS_2^+$ $[M+H]^+$ 337.1208, found 337.1208.



(4a) White solid (m.p.: 76 - 78 °C); 82% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.65 – 7.58 (m, 8H), 7.47 – 7.34 (m, 8H), 7.28 – 7.23 (m, 4H), 7.18 – 7.04 (m, 3H), 7.01 – 6.98 (m, 2H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 156.0 (d, *J* = 84.1 Hz), 141.3 (dd, *J* = 92.2, 8.2 Hz), 138.8 (dd, *J* = 16.8, 10.2 Hz), 134.8 (d, *J* = 1.0 Hz), 133.8 (d, *J* = 108.7 Hz), 132.3 (d, *J* = 10.1 Hz), 132.1 (d, *J* = 2.6 Hz), 131.7 (d, *J* = 2.6 Hz), 130.84 (d, *J* = 106.2 Hz), 130.82 (d, *J* = 9.9 Hz), 129.8 (d, *J* = 3.2 Hz), 128.5 (d, *J* = 12.5 Hz), 128.4, 128.2 (d, *J* = 12.7 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 25.6 (d, *J* = 13.3 Hz), 18.5 (d, *J* = 13.9 Hz). HRMS (ESI) calcd for $C_{32}H_{26}ClO_2P_2^+$ $[M+H]^+$ 539.1091, found 539.1091.

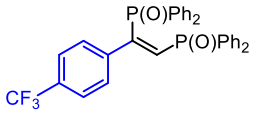


(4b) White solid (m.p.: 85 - 87 °C); 87% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.65 – 7.55 (m, 8H), 7.47 – 7.34 (m, 8H), 7.30 – 7.23 (m, 6H), 7.12 (dd, *J* = 35.6, 19.0 Hz, 1H), 6.90 (d, *J* = 7.6 Hz, 2H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 156.1 (d, *J* = 84.2 Hz), 141.4 (dd, *J* = 92.0, 8.1 Hz), 139.1 (dd, *J* = 16.8, 10.4 Hz), 133.6 (d, *J* = 108.8 Hz), 132.3 (d, *J* = 10.3 Hz), 132.2 (overlap one peak of 132.3), 131.8 (d, *J* = 2.6 Hz), 131.4, 130.8 (d, *J* = 9.7 Hz), 130.7 (d, *J* = 106.3 Hz), 130.0 (d, *J* = 3.2 Hz), 128.6 (d, *J* = 12.5 Hz), 128.2 (d, *J* = 12.6 Hz), 123.0 (d, *J* = 1.1 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 25.6 (d, *J* = 13.8 Hz), 18.7 (d, *J* = 13.9 Hz). HRMS (ESI) calcd for $C_{32}H_{26}BrO_2P_2^+$ $[M+H]^+$ 583.0586, found 583.0583.

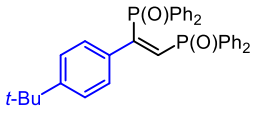


(4c) Light yellow solid (m.p.: 100 - 102 °C); 83% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.65 (dd, *J* = 12.1, 7.8 Hz, 4H), 7.57 (dd, *J* = 12.2, 7.8 Hz, 4H), 7.51 – 7.36 (m, 10H), 7.29 – 7.26 (m, 4H), 7.13 (dd, *J* = 35.6, 19.4 Hz, 1H), 6.76 (d, *J* = 8.1 Hz, 2H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 156.3 (d, *J* = 84.2 Hz), 141.5 (dd, *J* = 92.0, 8.0 Hz), 139.6 (dd, *J* = 16.6, 10.3 Hz), 137.3, 133.5 (d, *J* = 109.0 Hz), 132.3 – 132.2 (m), 131.8 (d, *J* = 2.3 Hz), 130.8 (d, *J* = 9.9 Hz), 130.6 (d, *J* = 104.6 Hz) (overlap one peak of 130.1), 130.1 (d, *J* = 3.3 Hz), 128.6 (d, *J* = 12.5 Hz), 128.3 (d, *J* = 12.6 Hz),

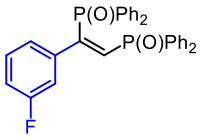
94.8; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 25.6 (d, *J* = 13.9 Hz), 18.8 (d, *J* = 13.9 Hz). HRMS (ESI) calcd for $C_{32}H_{26}IO_2P_2^+$ $[M+H]^+$ 631.0447, found 631.0447.



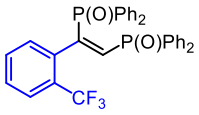
(4d) Colorless oil; 76% yield; **^{1}H NMR** (400 MHz, $CDCl_3$ δ 7.73 (dd, *J* = 12.4, 7.8 Hz, 4H), 7.64 (dd, *J* = 12.1, 7.7 Hz, 4H), 7.51 – 7.40 (m, 10H), 7.33 – 7.29 (m, 4H), 7.26 (d, *J* = 8.0 Hz, 2H), 7.15 (dd, *J* = 35.6, 18.6 Hz, 1H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 156.1 (d, *J* = 83.3 Hz), 144.3 (dd, *J* = 16.6, 9.2 Hz), 141.4 (dd, *J* = 91.8, 8.1 Hz), 133.7 (d, *J* = 108.3 Hz), 132.5 (d, *J* = 10.3 Hz), 132.1 (d, *J* = 2.8 Hz), 131.7 (d, *J* = 2.7 Hz), 130.9 (d, *J* = 106.4 Hz), 130.8 (d, *J* = 9.7 Hz), 130.4 (q, *J* = 32.8 Hz) (overlap one peak of 130.8), 128.8 (d, *J* = 2.9 Hz), 128.5 (d, *J* = 12.4 Hz), 128.1 (d, *J* = 12.9 Hz), 125.1 (q, *J* = 3.7 Hz), 123.8 (q, *J* = 273.2 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 25.7 (d, *J* = 13.8 Hz), 17.7 (d, *J* = 14.0 Hz); **^{19}F NMR** (376 MHz, $CDCl_3$) δ -62.7. HRMS (ESI) calcd for $C_{33}H_{26}F_3O_2P_2^+$ $[M+H]^+$ 573.1355, found 573.1356.



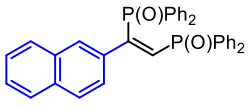
(4e) White solid (m.p.: 94 - 96 °C); 86% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.67 – 7.61 (m, 4H), 7.54 – 7.49 (m, 4H), 7.47 – 7.33 (m, 8H), 7.26 – 7.06 (m, 7H), 6.89 (d, *J* = 7.8 Hz, 2H), 1.22 (s, 9H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 157.3 (d, *J* = 84.5 Hz), 152.0, 140.6 (dd, *J* = 93.1, 8.2 Hz), 137.1 (dd, *J* = 16.5, 10.8 Hz), 133.9 (d, *J* = 108.9 Hz), 132.2 (d, *J* = 9.9 Hz), 132.1 (d, *J* = 2.6 Hz), 131.7 (d, *J* = 2.4 Hz), 130.9 (d, *J* = 106.1 Hz), 130.8 (d, *J* = 9.8 Hz), 128.6 (d, *J* = 12.4 Hz), 128.2 (d, *J* = 12.5 Hz), 128.1 (d, *J* = 3.5 Hz), 125.2, 34.6, 31.2; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 26.1 (d, *J* = 14.2 Hz), 19.0 (d, *J* = 14.4 Hz). HRMS (ESI) calcd for $C_{36}H_{35}O_2P_2^+$ $[M+H]^+$ 561.2107, found 561.2106.



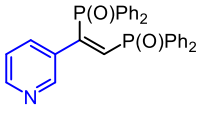
(4f) White solid (m.p.: 62 - 64 °C); 71% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.68 – 7.62 (m, 8H), 7.47 – 7.35 (m, 8H), 7.30 – 7.25 (m, 4H), 7.19 – 7.06 (m, 2H), 6.94 – 6.86 (m, 2H), 6.79 (d, *J* = 9.5 Hz, 1H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 162.1 (d, *J* = 248.6 Hz), 155.8 (d, *J* = 83.8 Hz), 142.7 – 142.4 (m), 141.5 (dd, *J* = 92.3, 8.2 Hz), 134.0 (d, *J* = 108.4 Hz), 132.4 (d, *J* = 10.2 Hz), 132.0 (d, *J* = 2.7 Hz), 131.6 (d, *J* = 2.5 Hz), 131.1 (d, *J* = 106.2 Hz), 130.9 (d, *J* = 9.7 Hz), 129.8 (d, *J* = 8.4 Hz), 128.5 (d, *J* = 12.4 Hz), 128.1 (d, *J* = 12.7 Hz), 124.3 – 124.2 (m), 115.7 – 115.2 (m); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 25.2 (d, *J* = 13.6 Hz), 18.0 (d, *J* = 13.8 Hz); **^{19}F NMR** (376 MHz, $CDCl_3$) δ -112.3. HRMS (ESI) calcd for $C_{32}H_{26}FO_2P_2^+$ $[M+H]^+$ 523.1387, found 523.1384.



(4g) Colorless oil; 74% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.71 – 7.64 (m, 8H), 7.50 – 7.38 (m, 9H), 7.36 – 7.27 (m, 6H), 7.24 (s, 1H), 7.16 (dd, *J* = 35.3, 18.2 Hz, 1H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 155.8 (d, *J* = 83.6 Hz), 142.0 (dd, *J* = 91.6, 8.0 Hz), 141.2 (dd, *J* = 16.8, 10.2 Hz), 133.7 (d, *J* = 108.5 Hz), 132.3 (d, *J* = 10.0 Hz), 132.1 (d, *J* = 2.7 Hz), 131.8, 131.7 (d, *J* = 2.7 Hz), 130.93 (d, *J* = 106.3 Hz), 130.91 (d, *J* = 9.9 Hz), 130.4 (q, *J* = 32.7 Hz) (overlap one peak of 130.91), 128.8, 128.5 (d, *J* = 12.5 Hz), 128.2 (d, *J* = 12.7 Hz), 125.2 - 125.1 (m), 123.6 (q, *J* = 273.6 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 25.2 (d, *J* = 13.9 Hz), 18.3 (d, *J* = 13.9 Hz); **^{19}F NMR** (376 MHz, $CDCl_3$) δ -62.7. HRMS (ESI) calcd for $C_{33}H_{26}F_3O_2P_2^+$ $[M+H]^+$ 573.1355, found 573.1355.

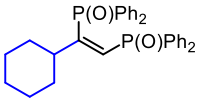


(4h) White solid (m.p.: 107 - 109 °C); 91% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.77 – 7.72 (m, 5H), 7.65 – 7.58 (m, 6H), 7.50 – 7.39 (m, 11H), 7.34 – 7.20 (m, 5H), 7.11 (d, *J* = 8.5 Hz, 1H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 157.2 (d, *J* = 84.4 Hz), 141.7 (dd, *J* = 92.7, 8.1 Hz), 137.5 (dd, *J* = 16.4, 10.5 Hz), 134.0 (d, *J* = 109.0 Hz), 132.8, 132.5, 132.3 (d, *J* = 9.9 Hz), 132.1 (d, *J* = 2.4 Hz), 131.7 (d, *J* = 2.5 Hz), 131.0 (d, *J* = 106.0 Hz), 130.9 (d, *J* = 9.9 Hz), 128.6 (d, *J* = 12.5 Hz), 128.24 (d, *J* = 12.5 Hz), 128.18 (overlap one peak of 128.24), 127.9, 127.8 (d, *J* = 4.1 Hz), 127.6, 126.9, 126.7, 125.9 (d, *J* = 2.7 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 25.3 (d, *J* = 14.0 Hz), 19.2 (d, *J* = 14.0 Hz). HRMS (ESI) calcd for $C_{36}H_{29}O_2P_2^+$ $[M+H]^+$ 555.1637, found 555.1637.

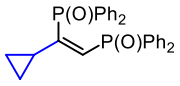


(4i) Yellow oil; 85% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.45 (d, *J* = 4.5 Hz, 1H), 8.37 (s, 1H), 7.73 – 7.68 (m, 4H), 7.63 – 7.58 (m, 4H), 7.50 (d, *J* = 7.9 Hz, 1H), 7.46 – 7.34 (m, 8H), 7.27 (td, *J* = 7.8, 3.3 Hz, 4H), 7.21 – 7.07 (m, 2H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 153.6 (d, *J* = 84.0 Hz), 149.4, 148.4 (d, *J* = 3.5 Hz), 141.8 (dd,

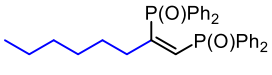
J = 91.5, 8.1 Hz), 136.8 (dd, *J* = 16.7, 9.5 Hz), 136.1 (d, *J* = 2.4 Hz), 133.6 (d, *J* = 108.2 Hz), 132.5 (d, *J* = 10.3 Hz), 132.1 (d, *J* = 2.8 Hz), 131.7 (d, *J* = 2.6 Hz), 130.78 (d, *J* = 9.9 Hz), 130.77 (d, *J* = 106.5 Hz), 128.6 (d, *J* = 12.5 Hz), 128.2 (d, *J* = 12.8 Hz), 122.6; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 26.0 (d, *J* = 13.9 Hz), 17.7 (d, *J* = 13.5 Hz). HRMS (ESI) calcd for $C_{31}H_{26}NO_2P_2^+$ $[M+H]^+$ 506.1433, found 506.1434.



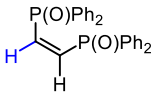
(4j) Colorless oil; 62% yield; **^{1}H NMR** (400 MHz, CDCl3) δ 7.70 (dd, *J* = 12.3, 7.4 Hz, 4H), 7.55 (dd, *J* = 12.0, 7.2 Hz, 4H), 7.44 – 7.39 (m, 4H), 7.37 – 7.27 (m, 8H), 7.01 (dd, *J* = 40.2, 17.7 Hz, 1H), 2.88 – 2.79 (m, 1H), 1.75 – 1.63 (m, 5H), 1.21 – 1.11 (m, 5H); **^{13}C NMR** (101 MHz, CDCl3) δ 162.9 (d, *J* = 82.6 Hz), 134.53 (dd, *J* = 107.8, 8.1 Hz), 134.48 (d, *J* = 107.5 Hz), 132.5 (d, *J* = 10.3 Hz), 131.8 (d, *J* = 2.8 Hz), 131.6 (d, *J* = 104.4 Hz), 131.3 (d, *J* = 2.5 Hz), 130.7 (d, *J* = 9.8 Hz), 128.3 (d, *J* = 12.3 Hz), 127.9 (d, *J* = 12.5 Hz), 43.0 (dd, *J* = 13.4, 10.2 Hz), 34.09, 34.07, 26.5, 25.8; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 28.9 (d, *J* = 19.7 Hz), 19.0 (d, *J* = 19.4 Hz). HRMS (ESI) calcd for $C_{32}H_{33}O_2P_2^+$ $[M+H]^+$ 511.1950, found 511.1951.



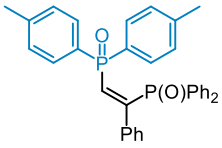
(4k) White solid (m.p.: 77 - 79 °C); 75% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.66 – 7.60 (m, 8H), 7.46 – 7.31 (m, 12H), 6.62 (dd, *J* = 37.6, 15.2 Hz, 1H), 1.78 – 1.69 (m, 1H), 0.85 – 0.80 (m, 2H), 0.67 – 0.63 (m, 2H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 158.9 (d, *J* = 86.5 Hz), 134.3 (d, *J* = 108.9 Hz), 132.2 – 130.8 (m), 128.2 (d, *J* = 12.5 Hz), 18.4 (t, *J* = 17.1 Hz), 11.2 (d, *J* = 2.7 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 28.5 (d, *J* = 16.4 Hz), 20.7 (d, *J* = 16.7 Hz). HRMS (ESI) calcd for $C_{29}H_{27}O_2P_2$ $[M+H]^+$ 469.1481, found 469.1472.



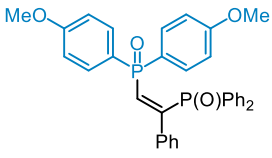
(4l) Colorless oil; 67% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.70 (dd, *J* = 12.4, 7.3 Hz, 4H), 7.57 – 7.53 (m, 4H), 7.40 – 7.37 (m, 4H), 7.33 – 7.24 (m, 8H), 6.97 (dd, *J* = 38.9, 18.1 Hz, 1H), 2.57 – 2.5 (m, 2H), 1.43 – 1.36 (m, 2H), 1.21 – 1.08 (m, 6H), 0.77 (t, *J* = 6.7 Hz, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 157.6 (d, *J* = 83.6 Hz), 136.0 (dd, *J* = 98.1, 8.6 Hz), 134.1 (d, *J* = 107.6 Hz), 132.3 (d, *J* = 10.3 Hz), 131.8 (d, *J* = 2.7 Hz), 131.4 (d, *J* = 102.1 Hz) (overlap one peak of 130.8), 131.3 (d, *J* = 2.5 Hz), 130.8 (d, *J* = 9.8 Hz), 128.3 (d, *J* = 12.3 Hz), 128.0 (d, *J* = 12.6 Hz), 37.9 (dd, *J* = 14.9, 10.4 Hz), 31.4, 29.3 (d, *J* = 3.2 Hz), 28.7, 22.5, 14.0; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 28.1 (d, *J* = 17.2 Hz), 18.7 (d, *J* = 17.7 Hz). HRMS (ESI) calcd for $C_{32}H_{35}O_2P_2^+$ $[M+H]^+$ 513.2107, found 513.2107.



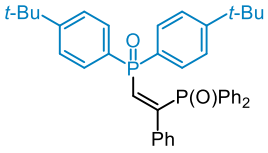
(4m) White solid (m.p.: 226 - 228 °C); 48% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.70 – 7.65 (m, 8H), 7.46 (t, *J* = 7.0 Hz, 4H), 7.38 – 7.21 (m, 10H) (overlap one peak of 7.26); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 143.1 (dd, *J* = 96.6, 4.1 Hz), 133.0 – 131.2 (m), 128.6 – 128.2 (m); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 20.7.



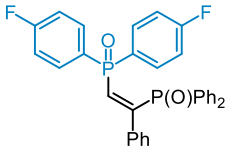
(5a) White solid (m.p.: 76 - 77 °C); 97% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.64 – 7.59 (m, 4H), 7.54 (dd, *J* = 12.0, 8.0 Hz, 4H), 7.41 – 7.36 (m, 2H), 7.27 – 7.03 (m, 14H), 2.34 (s, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 156.1 (d, *J* = 84.5 Hz), 141.8 (d, *J* = 2.8 Hz), 141.7 (dd, *J* = 92.4, 8.4 Hz), 140.6 (dd, *J* = 16.3, 10.2 Hz), 132.3 (d, *J* = 10.1 Hz), 131.8 (d, *J* = 67.5 Hz), 131.7 (d, *J* = 2.7 Hz), 131.0 (d, *J* = 10.2 Hz), 130.7 (d, *J* = 69.9 Hz), 129.1 (d, *J* = 12.9 Hz), 128.37 – 128.35 (m), 128.1, 128.0 (d, *J* = 12.7 Hz), 21.6; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 25.3 (d, *J* = 14.0 Hz), 18.9 (d, *J* = 14.0 Hz). HRMS (ESI) calcd for $C_{34}H_{31}O_2P_2^+$ $[M+H]^+$ 533.1794, found 533.1794.



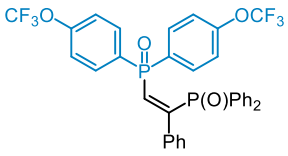
(5b) White solid (m.p.: 151 - 153 °C); 90% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.66 – 7.60 (m, 8H), 7.42 (t, *J* = 7.3 Hz, 2H), 7.31 – 7.27 (m, 4H) (overlap one peak of 7.26), 7.25 – 7.06 (m, 6H), 6.89 (d, *J* = 8.5 Hz, 4H), 3.83 (s, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 162.1 (d, *J* = 2.8 Hz), 155.3 (d, *J* = 84.9 Hz), 142.3 (dd, *J* = 92.9, 8.5 Hz), 140.8 (dd, *J* = 16.5, 10.3 Hz), 133.0 (d, *J* = 11.2 Hz), 132.3 (d, *J* = 10.0 Hz), 131.9 (d, *J* = 105.7 Hz), 131.7 (d, *J* = 2.6 Hz), 128.4 (d, *J* = 3.3 Hz), 128.2, 128.1 127.9 (d, *J* = 12.6 Hz), 125.3 (d, *J* = 114.8 Hz), 113.9 (d, *J* = 13.4 Hz), 55.3; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 25.1 (d, *J* = 14.1 Hz), 19.1 (d, *J* = 14.1 Hz). HRMS (ESI) calcd for $C_{34}H_{31}O_4P_2^+$ $[M+H]^+$ 565.1692, found 565.1692.



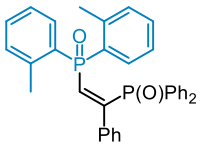
(5c) White solid (m.p.: 122 - 124 °C); 76% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.65 – 7.55 (m, 8H), 7.40 – 7.35 (m, 6H), 7.25 – 7.07 (m, 10H), 1.29 (s, 18H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 156.1 (d, *J* = 84.7 Hz), 154.8 (d, *J* = 2.5 Hz), 141.6 (dd, *J* = 92.4, 8.7 Hz), 140.6 (dd, *J* = 16.4, 10.0 Hz), 132.4 (d, *J* = 10.0 Hz), 131.8 (d, *J* = 2.5 Hz), 131.7 (d, *J* = 68.1 Hz), 130.8 (d, *J* = 10.1 Hz), 130.6 (d, *J* = 72.8 Hz), 128.4 – 128.3 (m), 128.1, 128.0 (d, *J* = 12.6 Hz), 125.4 (d, *J* = 12.7 Hz), 35.0, 31.1; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 25.6 (d, *J* = 14.1 Hz), 18.1 (d, *J* = 14.2 Hz). HRMS (ESI) calcd for $C_{40}H_{43}O_2P_2^+$ $[M+H]^+$ 617.2733, found 617.2730.



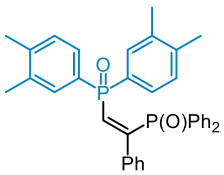
(5d) White solid (m.p.: 82 - 83 °C); 82% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.80 – 7.74 (m, 4H), 7.52 (dd, *J* = 12.1, 7.8 Hz, 4H), 7.44 (t, *J* = 7.3 Hz, 2H), 7.31 (t, *J* = 7.5 Hz, 4H) (overlap one peak of 7.26), 7.23 (t, *J* = 7.5 Hz, 1H), 7.19 – 7.06 (m, 7H), 6.97 (d, *J* = 7.5 Hz, 2H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 164.8 (dd, *J* = 253.8, 3.3 Hz), 157.0 (d, *J* = 83.8 Hz), 141.7 (dd, *J* = 94.7, 7.8 Hz), 140.0 (dd, *J* = 16.7, 10.7 Hz), 133.7 (dd, *J* = 11.4, 8.8 Hz), 132.2 (d, *J* = 9.8 Hz), 132.0 (d, *J* = 2.7 Hz), 131.1 (d, *J* = 105.4 Hz), 129.9 (dd, *J* = 112.4, 3.2 Hz), 128.6, 128.3 (d, *J* = 3.4 Hz), 128.2, 128.2 (d, *J* = 8.7 Hz), 115.6 (dd, *J* = 21.6, 13.8 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 24.6 (d, *J* = 14.1 Hz), 18.9 (d, *J* = 14.2 Hz); **^{19}F NMR** (376 MHz, $CDCl_3$) δ -107.3. HRMS (ESI) calcd for $C_{32}H_{25}F_2O_2P_2^+$ $[M+H]^+$ 541.1292, found 541.1292.



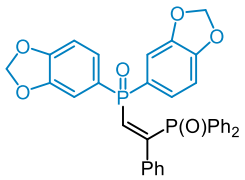
(5e) White solid (m.p.: 117 - 119 °C); 73% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.85 – 7.80 (m, 4H), 7.49 – 7.42 (m, 6H), 7.31 – 7.27 (m, 4H) (overlap one peak of 7.26), 7.23 – 7.05 (m, 8H), 6.94 (d, *J* = 7.5 Hz, 2H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 157.7 (d, *J* = 83.4 Hz), 151.61 – 151.57 (m), 141.2 (dd, *J* = 95.7, 7.6 Hz), 139.7 (dd, *J* = 16.7, 10.7 Hz), 133.3 – 132.1 (m), 130.8 (d, *J* = 105.3 Hz), 128.7, 128.3 – 128.2 (m), 120.4 (d, *J* = 13.4 Hz), 120.3 (q, *J* = 259.6 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 24.4 (d, *J* = 14.4 Hz), 18.4 (d, *J* = 14.2 Hz); **^{19}F NMR** (376 MHz, $CDCl_3$) δ -57.6. HRMS (ESI) calcd for $C_{34}H_{25}F_6O_4P_2^+$ $[M+H]^+$ 673.1127, found 673.1129.



(5f) White solid (m.p.: 72 - 73 °C); 98% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.78 (dd, *J* = 12.4, 7.4 Hz, 4H), 7.37 – 7.31 (m, 6H), 7.26 – 7.11 (m, 13H), 7.01 (dd, *J* = 36.6, 19.5 Hz, 1H), 2.42 (s, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 157.1 (d, *J* = 84.1 Hz), 141.8 (d, *J* = 8.4 Hz), 141.3 (dd, *J* = 69.4, 8.9 Hz), 140.8 (dd, *J* = 9.5, 5.6 Hz), 132.7 (d, *J* = 10.3 Hz), 132.5 (d, *J* = 12.3 Hz), 132.0 – 131.8 (m), 131.7 (d, *J* = 11.0 Hz), 130.8 (d, *J* = 26.6 Hz), 128.3, 128.23 – 128.20 (m), 127.8 (d, *J* = 12.7 Hz), 125.5 (d, *J* = 12.9 Hz), 21.9 (d, *J* = 4.1 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 26.0 (d, *J* = 14.2 Hz), 23.7 (d, *J* = 14.1 Hz). HRMS (ESI) calcd for $C_{34}H_{31}O_2P_2^+$ $[M+H]^+$ 533.1794, found 533.1795.

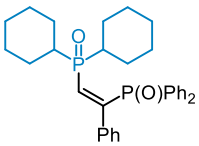


(5g) White solid (m.p.: 75 - 77 °C); 92% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.60 (dd, *J* = 12.2, 7.4 Hz, 4H), 7.41 – 7.34 (m, 6H), 7.26 – 7.02 (m, 12H) (overlap one peak of 7.26), 2.25 (s, 6H), 2.20 (s, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 156.0 (d, *J* = 84.8 Hz), 141.9 (dd, *J* = 91.9, 8.6 Hz), 140.7 (d, *J* = 2.8 Hz) (overlap one peak of 140.6), 140.6 (dd, *J* = 16.5, 10.3 Hz), 136.9 (d, *J* = 12.5 Hz), 132.3 (d, *J* = 10.1 Hz), 131.808 (d, *J* = 31.1 Hz), 131.804 (d, *J* = 9.8 Hz), 131.7 (d, *J* = 2.7 Hz), 130.7 (d, *J* = 35.3 Hz), 129.7 (d, *J* = 13.2 Hz), 128.5, 128.39 – 128.36 (m), 128.1, 128.0 (d, *J* = 12.6 Hz), 19.9, 19.8; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 25.6 (d, *J* = 14.1 Hz), 18.8 (d, *J* = 13.9 Hz). HRMS (ESI) calcd for $C_{36}H_{35}O_2P_2^+$ $[M+H]^+$ 561.2107, found 561.2106.

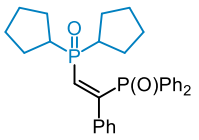


(5h) White solid (m.p.: 91 - 92 °C); 93% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.64 – 7.59 (m, 4H), 7.41 – 7.37 (m, 2H), 7.30 – 7.25 (m, 4H) (overlap one peak of 7.26), 7.22 – 6.98 (m, 10H), 6.79 (d, *J* = 2.5 Hz, 1H), 6.77 (d, *J* = 2.5 Hz, 1H), 5.95 – 5.94 (m, 4H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 156.3 (d, *J* = 84.2 Hz), 150.5 (d, *J* = 2.8 Hz), 147.7 (d, *J* = 18.7 Hz), 141.5 (dd, *J* = 94.3, 8.4 Hz), 140.6 (dd, *J* = 16.6, 10.1 Hz), 132.3 (d, *J* = 10.0 Hz), 131.8 (d, *J* = 2.6 Hz), 131.6 (d, *J* = 105.7 Hz), 128.4, 128.3 (d, *J* = 3.4 Hz), 128.1, 128.0 (d, *J* = 12.6 Hz), 127.1 (d, *J* = 113.5 Hz), 126.4 (d, *J* = 11.0 Hz), 110.7 (d, *J* = 12.7 Hz), 108.5 (d, *J* = 15.6 Hz), 101.5; **^{31}P**

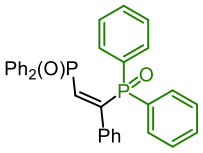
NMR (162 MHz, $CDCl_3$) δ 25.3 (d, *J* = 14.3 Hz), 19.2 (d, *J* = 14.2 Hz). HRMS (ESI) calcd for $C_{34}H_{27}O_6P_2^+$ $[M+H]^+$ 593.1277, found 593.1270.



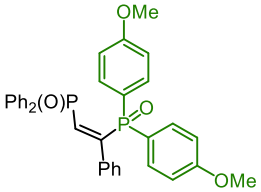
(5i) White solid (m.p.: 118 - 120 ℃); 93% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.52 – 7.43 (m, 6H), 7.35 – 7.30 (m, 4H), 7.14 (t, *J* = 7.2 Hz, 1H), 7.05 (t, *J* = 7.8 Hz, 2H), 6.73 (d, *J* = 7.4 Hz, 2H), 6.60 (dd, *J* = 37.4, 9.6 Hz, 1H), 2.48 – 2.40 (m, 2H), 1.93 – 1.91 (m, 2H), 1.83 – 1.80 (m, 2H), 1.75 – 1.72 (m, 4H), 1.63 – 1.59 (m, 2H), 1.51 – 1.40 (m, 4H), 1.21 – 1.13 (m, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 153.9 (d, *J* = 85.3 Hz), 145.5 (d, *J* = 68.8 Hz), 140.2 – 139.9 (m), 132.3 (d, *J* = 2.3 Hz), 132.0 (d, *J* = 9.8 Hz), 131.2 (d, *J* = 105.2 Hz), 128.5 – 128.4 (m), 128.1, 38.3 (d, *J* = 67.9 Hz), 26.7 (d, *J* = 3.3 Hz), 26.4 (d, *J* = 27.9 Hz), 26.4, 26.1 (d, *J* = 2.7 Hz), 25.8; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 48.7, 25.0 (d, *J* = 11.2 Hz). HRMS (ESI) calcd for $C_{32}H_{39}O_2P_2^+$ $[M+H]^+$ 517.2420, found 517.2420.



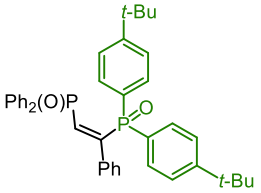
(5j) White solid (m.p.: 171 - 173 ℃); 74% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.53 – 7.48 (m, 6H), 7.38 – 7.34 (m, 4H), 7.15 (t, *J* = 7.0 Hz, 1H), 7.04 (t, *J* = 7.7 Hz, 2H), 6.92 – 6.80 (m, 1H), 6.70 (d, *J* = 7.4 Hz, 2H), 3.16 – 3.08 (m, 2H), 1.94 – 1.46 (m, 16H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 151.1 (d, *J* = 87.4 Hz), 149.3 (d, *J* = 73.8 Hz), 140.0 – 139.7 (m), 132.4 (d, *J* = 2.6 Hz), 132.0 (d, *J* = 9.6 Hz), 131.0 (d, *J* = 104.6 Hz), 128.9 (d, *J* = 3.0 Hz), 128.5 (d, *J* = 12.3 Hz), 128.3, 128.1, 38.9 (d, *J* = 70.9 Hz), 27.8 (d, *J* = 1.3 Hz), 26.7 (d, *J* = 10.4 Hz), 26.6, 26.1 (d, *J* = 10.5 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 49.1 (d, *J* = 12.0 Hz), 24.7 (d, *J* = 12.4 Hz). HRMS (ESI) calcd for $C_{30}H_{35}O_2P_2^+$ $[M+H]^+$ 489.2107, found 489.2105.



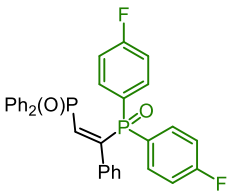
(6a) White solid (m.p.: 87 - 89 ℃); 89% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.72 – 7.61 (m, 8H), 7.48 – 7.37 (m, 8H), 7.30 – 7.26 (m, 4H) (overlap one peak of 7.26), 7.25 – 7.06 (m, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 157.1 (d, *J* = 84.2 Hz), 141.1 (dd, *J* = 92.9, 8.1 Hz), 140.4 (dd, *J* = 16.6, 10.4 Hz), 134.3 (d, *J* = 108.5 Hz), 132.4 (d, *J* = 10.1 Hz), 131.9 (d, *J* = 2.4 Hz), 131.5 (d, *J* = 2.1 Hz) , 131.3 (d, *J* = 105.6 Hz), 130.9 (d, *J* = 9.7 Hz), 128.5 – 128.3 (m), 128.2, 128.1 (d, *J* = 12.6 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 25.1 (d, *J* = 14.0 Hz), 18.4 (d, *J* = 14.0 Hz). HRMS (ESI) calcd for $C_{32}H_{27}O_2P_2^+$ $[M+H]^+$ 505.1481, found 505.1480.



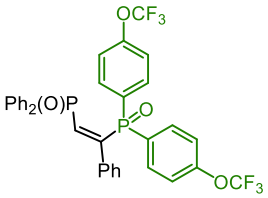
(6b) White solid (m.p.: 85 - 87 ℃); 92% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.68 – 7.63 (m, 4H), 7.59 – 7.54 (m, 4H), 7.45 – 7.41 (m, 2H), 7.38 – 7.34 (m, 4H), 7.25 – 6.99 (m, 6H), 6.75 (dd, *J* = 8.8, 2.2 Hz, 4H), 3.76 (s, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 162.4 (d, *J* = 2.8 Hz), 158.4 (d, *J* = 84.7 Hz), 140.8 (dd, *J* = 16.8, 9.9 Hz), 139.7 (dd, *J* = 94.1, 8.5 Hz), 134.8 (d, *J* = 108.3 Hz), 134.6 (d, *J* = 11.5 Hz), 131.3 (d, *J* = 2.4 Hz), 130.7 (d, *J* = 9.6 Hz), 128.4 – 128.3 (m), 128.1, 122.3 (d, *J* = 112.3 Hz), 113.6 (d, *J* = 13.6 Hz), 55.2; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 25.0 (d, *J* = 13.8 Hz), 18.0 (d, *J* = 13.7 Hz). HRMS (ESI) calcd for $C_{34}H_{31}O_4P_2^+$ $[M+H]^+$ 565.1692, found 565.1690.



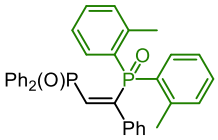
(6c) Colorless oil; 97% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.69 – 7.64 (m, 4H), 7.53 (dd, *J* = 12.0, 8.3 Hz, 4H), 7.45 – 7.41 (m, 2H), 7.38 – 7.33 (m, 4H), 7.28 – 7.25 (m, 4H) (overlap one peak of 7.26), 7.23 – 7.03 (m, 6H), 1.26 (s, 18H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 157.6 (d, *J* = 83.7 Hz), 155.1 (d, *J* = 2.7 Hz), 140.7 (dd, *J* = 16.6, 9.8 Hz) (overlap one peak of 140.4), 140.4 (dd, *J* = 93.7, 8.1 Hz), 134.4 (d, *J* = 108.4 Hz), 132.3 (d, *J* = 10.5 Hz), 131.4 (d, *J* = 2.4 Hz), 130.9 (d, *J* = 9.8 Hz), 128.4 - 128.3 (m), 128.1 (d, *J* = 108.1 Hz), 128.0, 125.0 (d, *J* = 12.8 Hz), 34.9, 31.1; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 25.4 (d, *J* = 14.5 Hz), 18.6 (d, *J* = 13.3 Hz). HRMS (ESI) calcd for $C_{40}H_{43}O_2P_2^+$ $[M+H]^+$ 617.2733, found 617.2730.



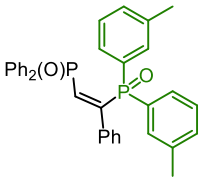
(6d) White solid (m.p.: 72 - 74 ℃); 85% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.77 – 7.70 (m, 4H), 7.61 – 7.56 (m, 4H), 7.47 – 7.43 (m, 2H), 7.40 – 7.36 (m, 4H), 7.28 – 7.05 (m, 6H) (overlap one peak of 7.26), 6.94 (td, *J* = 8.8, 2.2 Hz, 4H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 165.1 (dd, *J* = 254.6, 3.3 Hz), 157.2 (d, *J* = 85.7 Hz), 140.4 (dd, *J* = 16.5, 9.5 Hz), 140.2 (dd, *J* = 92.5, 9.3 Hz), 135.2 (dd, *J* = 11.7, 9.0 Hz), 134.0 (d, *J* = 107.9 Hz), 131.7 (d, *J* = 2.4 Hz), 130.6 (d, *J* = 9.7 Hz), 128.7, 128.6 (d, *J* = 12.4 Hz), 128.3, 127.1 (dd, *J* = 109.4, 3.0 Hz), 115.4 (dd, *J* = 21.5, 14.0 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 24.5 (d, *J* = 14.7 Hz), 17.4 (d, *J* = 14.2 Hz); **^{19}F NMR** (376 MHz, $CDCl_3$) δ -106.5 (d, *J* = 9.1 Hz). HRMS (ESI) calcd for $C_{32}H_{25}F_2O_2P_2^+$ $[M+H]^+$ 541.1292, found 541.1296.



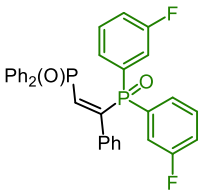
(6e) White solid (m.p.: 120 - 122 ℃); 58% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.80 (dd, *J* = 11.8, 8.6 Hz, 4H), 7.57 (dd, *J* = 12.1, 7.2 Hz, 4H), 7.48 (t, *J* = 7.5 Hz, 2H), 7.40 (td, *J* = 7.6, 3.0 Hz, 4H), 7.30 – 7.14 (m, 6H) (overlap one peak of 7.26), 7.10 (d, *J* = 7.0 Hz, 4H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 156.5 (d, *J* = 86.0 Hz), 152.0 (q, *J* = 1.5 Hz), 140.3 (dd, *J* = 91.8, 9.5 Hz), 140.2 (dd, *J* = 16.4, 9.3 Hz), 134.6 (d, *J* = 11.5 Hz), 133.6 (d, *J* = 107.7 Hz), 131.8 (d, *J* = 2.7 Hz), 130.6 (d, *J* = 9.8 Hz), 129.8 (d, *J* = 108.0 Hz), 128.8, 128.6 (d, *J* = 12.4 Hz), 128.4, 128.3 (d, *J* = 3.5 Hz), 120.3 (q, *J* = 259.7 Hz), 119.9 (d, *J* = 13.5 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 24.2 (d, *J* = 14.8 Hz), 17.3 (d, *J* = 14.6 Hz); **^{19}F NMR** (376 MHz, $CDCl_3$) δ -57.5. HRMS (ESI) calcd for $C_{34}H_{25}F_6O_4P_2^+$ $[M+H]^+$ 673.1127, found 673.1128.



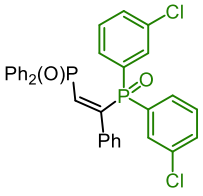
(6f) White solid (m.p.: 85 - 86 ℃); 98% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.71 (dd, *J* = 12.1, 7.6 Hz, 4H), 7.44 – 7.25 (m, 11H) (overlap one peak of 7.26), 7.19 – 7.10 (m, 7H), 6.97 (dd, *J* = 7.2, 4.2 Hz, 2H), 2.36 (s, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 155.7 (d, *J* = 82.8 Hz), 143.2 (d, *J* = 7.7 Hz), 142.2 (dd, *J* = 94.0, 7.8 Hz), 140.4 (dd, *J* = 16.6, 9.8 Hz), 133.8 (d, *J* = 13.8 Hz), 132.9 (d, *J* = 108.0 Hz), 132.0 (d, *J* = 2.6 Hz), 131.5 – 131.4 (m), 129.7 (d, *J* = 104.3 Hz), 128.5, 128.4 (d, *J* = 3.6 Hz), 128.1 - 127.9 (m), 125.0 (d, *J* = 13.6 Hz), 21.8 (d, *J* = 4.3 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 33.9 (d, *J* = 14.4 Hz), 21.2 (d, *J* = 14.6 Hz). HRMS (ESI) calcd for $C_{34}H_{31}O_2P_2^+$ $[M+H]^+$ 533.1794, found 533.1793.



(6g) Colorless oil; 90% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.71 – 7.66 (m, 4H), 7.46 – 7.35 (m, 10H), 7.25 – 7.04 (m, 10H), 2.21 (s, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 157.1 (d, *J* = 83.5 Hz), 140.8 (dd, *J* = 101.7, 8.4 Hz), 140.6 (dd, *J* = 16.7, 10.0 Hz), 137.8 (d, *J* = 12.4 Hz), 134.3 (d, *J* = 108.3 Hz), 132.8 (d, *J* = 9.7 Hz), 132.6 (d, *J* = 2.8 Hz), 131.4 (d, *J* = 2.7 Hz), 131.3 (d, *J* = 105.1 Hz), 131.0 (d, *J* = 9.9 Hz), 129.6 (d, *J* = 10.4 Hz), 128.5 - 128.3 (m), 128.1, 127.9 (d, *J* = 13.4 Hz), 21.4; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 25.3 (d, *J* = 13.8 Hz), 18.5 (d, *J* = 13.8 Hz). HRMS (ESI) calcd for $C_{34}H_{31}O_2P_2^+$ $[M+H]^+$ 533.1794, found 533.1792.

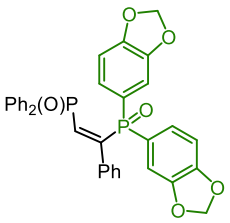


(6h) White solid (m.p.: 65 - 66 ℃); 83% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.66 – 7.61 (m, 4H), 7.49 – 7.45 (m, 4H), 7.42 – 7.34 (m, 6H), 7.30 – 7.05 (m, 10H) (overlap one peak of 7.26); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 162.1 (dd, *J* = 250.8, 17.9 Hz), 155.7 (d, *J* = 86.3 Hz), 141.4 (dd, *J* = 91.6, 9.0 Hz), 140.1 (dd, *J* = 16.4, 9.9 Hz), 134.0 (dd, *J* = 105.7, 5.8 Hz), 133.6 (d, *J* = 108.2 Hz), 131.8 (d, *J* = 2.6 Hz), 130.8 (d, *J* = 9.7 Hz), 130.0 (dd, *J* = 14.7, 7.3 Hz), 128.8, 128.6 (d, *J* = 12.4 Hz), 128.33, 128.25 (d, *J* = 3.5 Hz), 128.1 (dd, *J* = 9.6, 3.1 Hz), 119.3 – 119.0 (m); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 23.3 (dt, *J* = 13.4, 6.7 Hz), 17.9 (d, *J* = 14.9 Hz); **^{19}F NMR** (376 MHz, $CDCl_3$) δ -111.2 (d, *J* = 5.6 Hz). HRMS (ESI) calcd for $C_{32}H_{25}F_2O_2P_2^+$ $[M+H]^+$ 541.1292, found 541.1292.

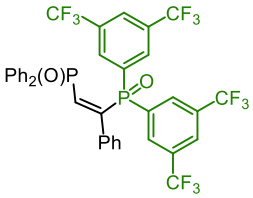


(6i) White solid (m.p.: 65 - 66 ℃); 70% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.71 – 7.58 (m, 8H), 7.50 (td, *J* = 7.3, 1.1 Hz, 2H), 7.45 – 7.37 (m, 6H), 7.31 – 7.12 (m, 8H) (overlap one peak of 7.26); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 155.4 (d, *J* = 86.1 Hz), 141.3 (dd, *J* = 91.3, 9.3 Hz), 140.1 (dd, *J* = 16.6, 9.7 Hz), 134.6 (d, *J* = 16.5 Hz), 133.9 (d, *J* = 104.6 Hz), 133.3 (d, *J* = 107.9 Hz), 132.12, 132.08 (d, *J* = 14.0 Hz), 131.9 (d, *J* = 2.7 Hz), 130.8 (d, *J* = 9.7 Hz), 130.5 (d, *J* = 9.9 Hz), 129.5 (d, *J* = 13.8 Hz), 128.8, 128.6 (d, *J* = 12.4 Hz), 128.4, 128.3

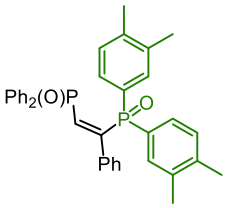
(d, J = 3.8 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 23.6 (d, J = 14.8 Hz), 17.9 (d, J = 14.9 Hz). HRMS (ESI) calcd for $C_{32}H_{25}Cl_2O_2P_2^+$ $[M+H]^+$ 573.0701, found 573.0700.



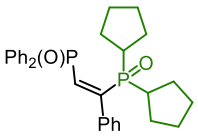
(6j) White solid (m.p.: 97 - 99 ℃); 95% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.65 (dd, J = 12.1, 7.3 Hz, 4H), 7.46 – 7.37 (m, 6H), 7.27 – 7.00 (m, 10H) (overlap one peak of 7.26), 6.69 (dd, J = 8.1, 2.4 Hz, 2H), 5.92 (d, J = 1.7 Hz, 4H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 157.8 (d, J = 85.8 Hz), 150.9 (d, J = 2.9 Hz), 147.5 (d, J = 19.1 Hz), 140.5 (dd, J = 16.5, 9.9 Hz), 140.2 (dd, J = 93.3, 8.6 Hz), 134.3 (d, J = 108.4 Hz), 131.5 (d, J = 2.5 Hz), 130.7 (d, J = 9.8 Hz), 128.6, 128.5 – 128.2 (m), 124.0 (d, J = 111.1 Hz), 112.0 (d, J = 13.0 Hz), 108.3 (d, J = 15.9 Hz), 101.5; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 25.8 (d, J = 14.2 Hz), 18.2 (d, J = 14.3 Hz). HRMS (ESI) calcd for $C_{34}H_{27}O_6P_2^+$ $[M+H]^+$ 593.1277, found 593.1278.



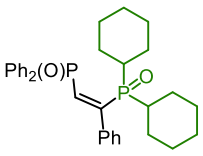
(6k) White solid (m.p.: 70 - 71 ℃); 60% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.29 (d, J = 12.2 Hz, 4H), 7.91 (s, 2H), 7.53 – 7.46 (m, 6H), 7.43 – 7.24 (m, 10H) (overlap one peak of 7.26); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 153.6 (d, J = 88.9 Hz), 142.4 (dd, J = 88.7, 9.9 Hz), 139.1 (dd, J = 16.0, 9.5 Hz), 135.3 (d, J = 107.4 Hz), 132.5, - 132.4 (m), 131.8 (d, J = 107.6 Hz), 131.7 (q, J = 34.2 Hz), 131.5 (q, J = 34.2 Hz), 130.5 (d, J = 10.0 Hz), 129.5, 128.9 (d, J = 12.5 Hz), 128.8, 128.3 (d, J = 3.8 Hz), 125.9 (q, J = 3.1 Hz), 122.7 (q, J = 274.2 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 23.8 (d, J = 15.9 Hz), 18.6 (d, J = 15.1 Hz); **^{19}F NMR** (376 MHz, $CDCl_3$) δ -62.9. HRMS (ESI) calcd for $C_{36}H_{23}F_{12}O_2P_2^+$ $[M+H]^+$ 777.0976, found 777.0977.



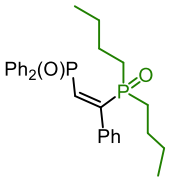
(6l) Colorless oil; 86% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.69 – 7.64 (m, 4H), 7.45 – 7.30 (m, 10H), 7.24 – 7.01 (m, 8H), 2.21 (s, 6H), 2.11 (s, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 157.8 (d, J = 83.3 Hz), 140.9 – 140.7 (m) (overlap one peak of 140.2), 140.2 (dd, J = 94.2, 8.3 Hz), 136.4 (d, J = 12.9 Hz), 134.6 (d, J = 108.4 Hz), 133.4 (d, J = 10.1 Hz), 131.2 (d, J = 2.7 Hz), 130.9 (d, J = 9.8 Hz), 130.3 (d, J = 10.5 Hz), 129.2 (d, J = 13.5 Hz), 128.5 (d, J = 3.2 Hz), 128.36 (d, J = 107.3 Hz), 128.35 128.2 (d, J = 12.4 Hz), 128.0, 19.9, 19.7; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 25.6 (d, J = 13.4 Hz), 18.5 (d, J = 13.9 Hz). HRMS (ESI) calcd for $C_{36}H_{35}O_2P_2^+$ $[M+H]^+$ 561.2107, found 561.2108.



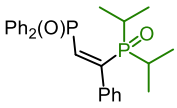
(6m) White solid (m.p.: 200 - 202 ℃); 91% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.72 (dd, J = 11.9, 7.3 Hz, 4H), 7.57 – 7.47 (m, 6H), 7.37 – 7.31 (m, 5H), 6.79 (dd, J = 31.9, 22.0 Hz, 1H), 3.34 – 3.25 (m, 2H), 1.97 – 1.91 (m, 4H), 1.79 – 1.56 (m, 10H), 1.41 – 1.32 (m, 2H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 160.6 (dd, J = 65.2, 1.8 Hz), 141.8 (dd, J = 18.0, 5.7 Hz), 133.5 (dd, J = 95.3, 10.1 Hz), 133.2 (d, J = 107.2 Hz), 132.2 (d, J = 2.7 Hz), 130.9 (d, J = 9.6 Hz), 128.9 (d, J = 12.2 Hz), 128.7 (d, J = 2.5 Hz), 128.5, 127.9, 39.5 (d, J = 68.7 Hz), 27.7 (d, J = 2.0 Hz), 26.7 (d, J = 10.5 Hz), 26.3, 25.8 (d, J = 11.4 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 46.9 (d, J = 13.0 Hz), 18.6 (d, J = 12.1 Hz). HRMS (ESI) calcd for $C_{30}H_{35}O_2P_2^+$ $[M+H]^+$ 489.2107, found 489.2105.



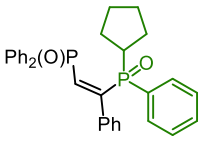
(6n) White solid (m.p.: 250 - 251 ℃); 91% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.72 (dd, J = 11.9, 7.1 Hz, 4H), 7.55 – 7.46 (m, 6H), 7.34 – 7.29 (m, 5H), 6.84 (dd, J = 31.2, 22.4 Hz, 1H), 2.97 – 2.89 (m, 2H), 2.08 – 2.05 (m, 2H), 1.76 – 1.74 (m, 4H), 1.65 – 1.43 (m, 8H), 1.33 – 1.23 (m, 2H), 1.19 – 1.09 (m, 2H), 0.98 – 0.89 (m, 2H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 158.6 (dd, J = 61.5, 1.8 Hz), 141.8 (dd, J = 18.0, 5.5 Hz), 134.0 (dd, J = 95.5, 9.1 Hz), 133.2 (d, J = 106.8 Hz), 132.2 (d, J = 2.7 Hz), 130.9 (d, J = 9.6 Hz), 129.0 (d, J = 12.3 Hz), 128.8 (d, J = 2.6 Hz), 128.5, 127.9, 39.2 (d, J = 64.3 Hz), 26.6 (d, J = 3.8 Hz), 26.4 - 26.3 (m), 26.2 (d, J = 3.7 Hz), 25.7; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 50.7 (d, J = 11.8 Hz), 18.3 (d, J = 11.9 Hz). HRMS (ESI) calcd for $C_{32}H_{39}O_2P_2^+$ $[M+H]^+$ 517.2420, found 517.2416.



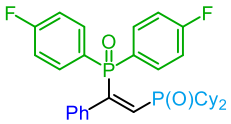
(6o) White solid (m.p.: 158 - 159 °C); 99% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.74 – 7.68 (m, 4H), 7.55 – 7.44 (m, 6H), 7.36 – 7.28 (m, 5H), 6.82 (dd, *J* = 32.7, 21.6 Hz, 1H), 2.65 – 2.55 (m, 2H), 2.31 – 2.20 (m, 2H), 1.74 – 1.61 (m, 2H), 1.47 – 1.36 (m, 2H), 1.32 – 1.11 (m, 4H) (overlap one peak of 1.26), 0.77 (t, *J* = 7.3 Hz, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 159.0 (dd, *J* = 67.1, 1.3 Hz), 141.4 (dd, *J* = 17.7, 6.3 Hz), 134.6 (dd, *J* = 94.1, 9.9 Hz), 133.1 (d, *J* = 107.2 Hz), 132.2 (d, *J* = 2.7 Hz), 130.9 (d, *J* = 9.6 Hz), 128.9 (d, *J* = 12.2 Hz), 128.6, 128.5 (d, *J* = 2.6 Hz), 128.0, 31.0 (d, *J* = 66.9 Hz), 24.1 (d, *J* = 16.1 Hz), 23.9 (d, *J* = 4.7 Hz), 13.6; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 44.2 (d, *J* = 12.3 Hz), 18.4 (d, *J* = 13.7 Hz). HRMS (ESI) calcd for $C_{28}H_{35}O_2P_2^+$ $[M+H]^+$ 461.2107, found 461.2108.



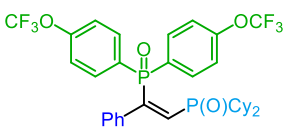
(6p) White solid (m.p.: 150 - 151 °C); 89% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.73 – 7.68 (m, 4H), 7.55 – 7.45 (m, 6H), 7.38 – 7.28 (m, 5H), 6.85 (dd, *J* = 31.5, 21.9 Hz, 1H), 3.21 – 3.12 (m, 2H), 1.29 (dd, *J* = 15.6, 7.0 Hz, 6H), 1.10 (dd, *J* = 16.8, 7.3 Hz, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 158.9 (d, *J* = 63.2 Hz), 141.7 (dd, *J* = 18.0, 5.7 Hz), 134.2 (dd, *J* = 94.9, 9.2 Hz), 132.9 (d, *J* = 107.2 Hz), 132.2 (d, *J* = 2.7 Hz), 130.9 (d, *J* = 9.7 Hz), 129.0 (d, *J* = 12.2 Hz), 128.8 (d, *J* = 2.6 Hz), 128.6, 128.0, 29.2 (d, *J* = 64.1 Hz), 17.5 (d, *J* = 3.9 Hz), 16.5 (d, *J* = 3.6 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 54.9, 19.0 (d, *J* = 11.5 Hz). HRMS (ESI) calcd for $C_{26}H_{31}O_2P_2^+$ $[M+H]^+$ 437.1794, found 437.1796.



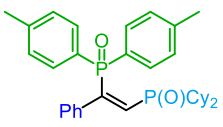
(6q) Colorless oil; 88% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.80 – 7.75 (m, 2H), 7.71 – 7.66 (m, 2H), 7.55 – 7.26 (m, 14H) (overlap one peak of 7.26), 7.16 – 7.14 (m, 2H), 6.86 (dd, *J* = 33.9, 20.1 Hz, 1H), 3.45 – 3.37 (m, 1H), 2.05 – 1.91 (m, 1H), 1.89 – 1.77 (m, 3H), 1.66 – 1.60 (m, 2H), 1.58 – 1.51 (m, 2H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 158.9 (d, *J* = 74.6 Hz), 140.8 (dd, *J* = 17.3, 8.8 Hz), 138.4 (dd, *J* = 94.0, 8.6 Hz), 134.5 (d, *J* = 107.9 Hz), 134.2 (d, *J* = 108.7 Hz), 132.7 (d, *J* = 96.5 Hz), 132.1 (d, *J* = 9.5 Hz), 131.6 (d, *J* = 2.5 Hz), 131.5 (d, *J* = 2.3 Hz), 131.4 (d, *J* = 2.4 Hz), 131.0 (d, *J* = 9.7 Hz), 130.7 (d, *J* = 9.8 Hz), 128.6 (d, *J* = 12.3 Hz), 128.5 – 128.1 (m), 128.0, 35.4 (d, *J* = 74.2 Hz), 27.0 - 26.9 (m), 26.5, 26.4; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 35.8 (d, *J* = 13.2 Hz), 18.3 (d, *J* = 13.5 Hz). HRMS (ESI) calcd for $C_{31}H_{31}O_2P_2^+$ $[M+H]^+$ 497.1794, found 497.1793.



(7a) White solid (m.p.: 196 - 198 °C); 84% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.59 – 7.53 (m, 4H), 7.18 – 7.01 (m, 7H), 6.81 – 6.77 (m, 2H), 6.60 (dd, *J* = 38.3, 9.6 Hz, 1H), 2.36 – 2.29 (m, 2H), 1.88 – 1.43 (m, 14H), 1.21 – 1.09 (m, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 165.1 (dd, *J* = 255.3, 2.9 Hz), 153.6 (d, *J* = 88.4 Hz), 145.2 (d, *J* = 70.0 Hz), 140.2 – 139.9 (m), 134.7 – 134.5 (m), 128.5,128.2, 127.6 (dd, *J* = 108.6, 3.1 Hz), 115.7 (dd, *J* = 21.5, 13.6 Hz), 38.3 (d, *J* = 67.4 Hz), 26.6 – 26.0 (m), 25.8; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 47.6, 23.2 – 23.0 (m); **^{19}F NMR** (377 MHz, $CDCl_3$) δ -105.8. HRMS (ESI) calcd for $C_{32}H_{37}F_2O_2P_2^+$ $[M+H]^+$ 553.2231, found 553.2235.

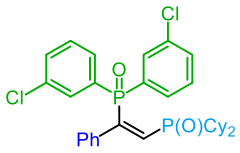


(7b) Colorless oil; 89% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.71 (dd, *J* = 11.4, 8.5 Hz, 4H), 7.25 – 7.21 (m, 5H), 7.17 (t, *J* = 7.3 Hz, 2H), 6.90 (d, *J* = 7.4 Hz, 2H), 6.63 (dd, *J* = 38.4, 12.7 Hz, 1H), 2.21 – 2.12 (m, 2H), 1.88 – 1.85 (m, 2H), 1.80 – 1.74 (m, 6H), 1.66 – 1.64 (m, 2H), 1.42 – 1.38 (m, 4H), 1.22 – 1.12 (m, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 153.2 (d, *J* = 88.6 Hz), 151.0 (q, *J* = 1.6 Hz), 143.2 (dd, *J* = 72.3, 8.9 Hz), 139.3 (dd, *J* = 13.9, 11.4 Hz), 133.2 (d, *J* = 11.0 Hz), 129.6 (d, *J* = 107.4 Hz), 127.5, 127.4 (d, *J* = 3.3 Hz), 127.3, 119.3 (q, *J* = 259.9 Hz), 119.2 (d, *J* = 13.3 Hz), 37.0 (d, *J* = 67.7 Hz), 25.5 – 25.2 (m), 24.9 (d, *J* = 3.0 Hz), 24.8; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 45.6 (d, *J* = 9.1 Hz), 22.7 (d, *J* = 12.1 Hz); **^{19}F NMR** (377 MHz, $CDCl_3$) δ -57.7. HRMS (ESI) calcd for $C_{34}H_{37}F_6O_4P_2^+$ $[M+H]^+$ 685.2066, found 685.2065.

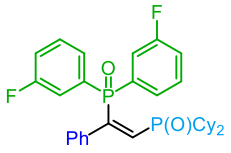


(7c) White solid (m.p.: 173 - 175 °C); 95% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.34 (dd, *J* = 11.7, 8.0 Hz, 4H), 7.14 – 7.11 (m, 5H), 7.02 (t, *J* = 7.7 Hz, 2H), 6.71 (d, *J* = 7.7 Hz, 2H), 6.60 (dd, *J* = 37.6, 4.4 Hz, 1H), 2.78 – 2.69 (m, 2H), 2.29 (s, 6H), 1.98 – 1.95 (m, 2H), 1.84 – 1.81 (m, 2H), 1.75 – 1.68 (m, 4H), 1.59 – 1.48 (m, 6H), 1.29 – 1.15 (m, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 152.5 (d, *J* = 88.3 Hz), 147.3 (d, *J* = 74.8 Hz), 142.8 (d, *J* = 2.7 Hz), 140.0 – 139.8 (m), 132.1 (d, *J* = 10.0 Hz), 129.1 (d, *J* = 12.6 Hz), 128.8 (d, *J* = 3.0 Hz), 128.3, 128.0, 127.7 (d, *J* = 106.8 Hz), 38.8

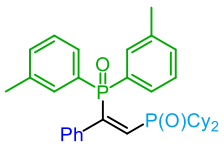
(d, *J* = 67.1 Hz), 26.9 (d, *J* = 3.6 Hz), 26.5 – 26.2 (m), 25.9, 21.6; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 51.1, 24.4 (d, *J* = 10.3 Hz). HRMS (ESI) calcd for $C_{34}H_{43}O_2P_2^+$ $[M+H]^+$ 545.2733, found 545.2730.



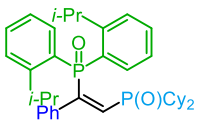
(7d) Colorless oil; 95% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.64 (d, *J* = 12.5 Hz, 2H), 7.46 – 7.41 (m, 4H), 7.31 (td, *J* = 7.7, 3.5 Hz, 2H), 7.23 (d, *J* = 7.1 Hz, 1H), 7.18 (t, *J* = 7.4 Hz, 2H), 6.91 (d, *J* = 7.4 Hz, 2H), 6.65 (dd, *J* = 38.6, 13.1 Hz, 1H), 2.22 – 2.14 (m, 2H), 1.92 – 1.89 (m, 2H), 1.82 – 1.76 (m, 6H), 1.69 – 1.66 (m, 2H), 1.48 – 1.39 (m, 4H), 1.27 – 1.17 (m, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 153.9 (d, *J* = 88.2 Hz), 144.5 (dd, *J* = 71.9, 8.7 Hz), 140.0 (dd, *J* = 13.7, 11.7 Hz), 134.8 (d, *J* = 16.4 Hz), 134.1 (d, *J* = 104.4 Hz), 132.3 (d, *J* = 2.3 Hz), 131.8 (d, *J* = 10.8 Hz), 130.0 (d, *J* = 9.3 Hz), 129.8 (d, *J* = 13.5 Hz), 128.6, 128.38 – 128.35 (m), 37.9 (d, *J* = 67.8 Hz), 26.6 – 26.3 (m), 25.9 (d, *J* = 3.0 Hz), 25.8; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 46.1, 22.9 (d, *J* = 11.9 Hz). HRMS (ESI) calcd for $C_{32}H_{37}Cl_2O_2P_2^+$ $[M+H]^+$ 585.1640, found 585.1641.



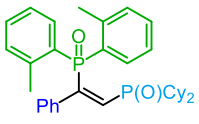
(7e) White solid (m.p.: 75 - 77 ℃); 85% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.41 – 7.34 (m, 6H), 7.27 – 7.17 (m, 5H), 6.92 (d, *J* = 7.5 Hz, 2H), 6.71 (dd, *J* = 38.6, 11.8 Hz, 1H), 2.35 – 2.27 (m, 2H), 1.98 – 1.70 (m, 10H), 1.56 – 1.45 (m, 4H), 1.31 – 1.20 (m, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 162.2 (dd, *J* = 251.3, 17.5 Hz), 153.4 (d, *J* = 86.8 Hz), 145.4 (d, *J* = 68.1 Hz), 140.1 – 139.9 (m), 134.4 (dd, *J* = 105.1, 5.6 Hz), 130.3 (dd, *J* = 14.5, 7.4 Hz), 128.6, 128.4 – 128.3 (m), 127.7 (dd, *J* = 9.1, 2.9 Hz), 119.3 (d, *J* = 21.2 Hz), 118.8 (dd, *J* = 22.8, 10.6 Hz), 38.0 (d, *J* = 67.9 Hz), 26.6 – 26.3 (m), 25.9 (d, *J* = 2.4 Hz), 25.8; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 46.2, 22.4; **^{19}F NMR** (377 MHz, $CDCl_3$) δ -110.9. HRMS (ESI) calcd for $C_{32}H_{37}F_2O_2P_2^+$ $[M+H]^+$ 553.2231, found 553.2232.



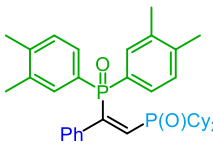
(7f) White solid (m.p.: 153 - 155 ℃); 80% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.38 (d, *J* = 12.5 Hz, 2H), 7.28 – 7.15 (m, 7H) (overlap one peak of 7.26), 7.07 (t, *J* = 6.8 Hz, 2H), 6.75 – 6.73 (m, 2H), 6.70 – 6.60 (m, 1H), 2.75 – 2.70 (m, 2H), 2.27 (s, 6H), 2.02 – 1.98 (m, 2H), 1.84 – 1.53 (m, 12H), 1.32 – 1.14 (m, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 152.4 (d, *J* = 87.2 Hz), 147.5 (d, *J* = 73.2 Hz), 140.1 – 139.8 (m), 138.3 (d, *J* = 12.2 Hz), 133.0 (d, *J* = 2.8 Hz), 132.6 (d, *J* = 9.5 Hz), 130.9 (d, *J* = 103.9 Hz), 129.2 (d, *J* = 9.8 Hz), 128.9 (d, *J* = 3.2 Hz), 128.3, 128.1, 128.0, 38.8 (d, *J* = 67.0 Hz), 26.9 (d, *J* = 3.7 Hz), 26.5 (d, *J* = 13.6 Hz), 26.4, 26.3 (d, *J* = 8.9 Hz), 25.9, 21.4; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 50.4, 24.5 (d, *J* = 11.3 Hz). HRMS (ESI) calcd for $C_{34}H_{43}O_2P_2^+$ $[M+H]^+$ 545.2733, found 545.2729.



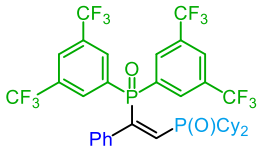
(7g) White solid (m.p.: 284 - 286 ℃); 90% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.46 – 6.89 (m, 14H) (overlap one peak of 7.26), 3.67 – 3.59 (m, 2H), 2.59 – 2.47 (m, 2H), 1.94 – 0.76 (m, 32H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 154.5, 152.5 (d, *J* = 85.6 Hz), 148.9 (dd, *J* = 73.0, 6.9 Hz), 140.0 – 139.8 (m), 133.4 (d, *J* = 14.4 Hz), 132.5, 130.2 (d, *J* = 103.3 Hz), 128.6 (d, *J* = 3.7 Hz), 128.2, 127.6, 127.1, 125.2, 38.1 (d, *J* = 66.5 Hz), 31.8 (d, *J* = 4.8 Hz), 26.6 – 22.9 (m); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 50.9 (d, *J* = 6.1 Hz), 35.1 (d, *J* = 10.6 Hz). HRMS (ESI) calcd for $C_{38}H_{51}O_2P_2^+$ $[M+H]^+$ 601.3359, found 601.3369.



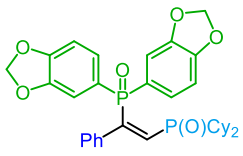
(7h) Colorless oil; 86% yield;**^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.34 – 7.26 (m, 4H), 7.16 – 6.91 (m, 10H), 2.52 – 2.44 (m, 8H), 1.95 – 1.91 (m, 2H), 1.78 – 1.72 (m, 2H), 1.69 – 1.65 (m, 2H), 1.55 – 1.45 (m, 8H), 1.15 – 1.03 (m, 4H), 0.78 – 0.62 (m, 2H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 152.1 (d, *J* = 85.8 Hz), 148.7 (d, *J* = 72.7 Hz), 143.0 (d, *J* = 7.8 Hz), 140.0 (dd, *J* = 13.5, 12.1 Hz), 133.2 (d, *J* = 13.4 Hz), 132.2 (d, *J* = 2.5 Hz), 131.8 (d, *J* = 10.7 Hz), 130.3 (d, *J* = 102.9 Hz), 128.4 (d, *J* = 3.7 Hz), 128.2, 127.8, 125.4 (d, *J* = 13.2 Hz), 38.4 (d, *J* = 66.8 Hz), 26.6 (d, *J* = 3.7 Hz), 26.4 – 26.0 (m), 25.8, 21.7 (d, *J* = 4.2 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 49.7, 34.2 (d, *J* = 10.8 Hz). HRMS (ESI) calcd for $C_{34}H_{43}O_2P_2^+$ $[M+H]^+$ 545.2733, found 545.2734.



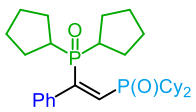
(7i) White solid (m.p.: 130 - 132 ℃); 70% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.32 (d, *J* = 12.2 Hz, 2H), 7.21 – 7.07 (m, 7H), 6.75 (d, *J* = 7.5 Hz, 2H), 6.65 (dd, *J* = 37.5, 3.5 Hz, 1H), 2.91 – 2.83 (m, 2H), 2.27 (s, 6H), 2.20 (s, 6H), 2.05 – 2.02 (m, 2H), 1.93 – 1.88 (m, 2H), 1.82 – 1.74 (m, 4H), 1.66 – 1.53 (m, 6H), 1.33 – 1.23 (m, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 151.7 (d, *J* = 87.1 Hz), 146.0 (dd, *J* = 72.4, 6.3 Hz), 140.5 (d, *J* = 2.8 Hz), 138.9 (t, *J* = 13.3 Hz), 136.0 (d, *J* = 12.5 Hz), 132.1 (d, *J* = 9.9 Hz), 128.7 (d, *J* = 9.8 Hz), 128.6 (d, *J* = 13.0 Hz), 128.0 (d, *J* = 3.1 Hz), 127.2, 126.91, 126.88 (d, *J* = 106.1 Hz), 37.9 (d, *J* = 67.0 Hz), 25.9 (d, *J* = 3.7 Hz), 25.6 – 25.3 (m), 24.9, 19.0, 18.7; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 52.3, 24.5 (d, *J* = 11.3 Hz). HRMS (ESI) calcd for $C_{36}H_{47}O_2P_2^+$ $[M+H]^+$ 573.3046, found 573.3044.



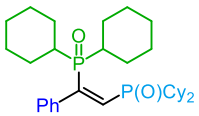
(7j) White solid (m.p.: 218 - 219 ℃); 72% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.10 (d, *J* = 11.9 Hz, 4H), 7.90 (s, 2H), 7.26 – 7.21 (m, 3H), 7.03 – 7.01 (m, 2H), 6.78 (dd, *J* = 39.4, 20.1 Hz, 1H), 1.81 – 1.68 (m, 12H), 1.30 – 1.17 (m, 10H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 154.8 (d, *J* = 91.2 Hz), 142.9 (dd, *J* = 70.4, 9.9 Hz), 140.1 (dd, *J* = 13.9, 11.2 Hz), 137.0 (d, *J* = 106.9 Hz), 132.2 – 131.0 (m), 128.8 – 128.7 (m), 127.8 (d, *J* = 3.8 Hz), 125.4 – 125.2 (m), 122.7 (q, *J* = 274.2 Hz), 36.8 (d, *J* = 68.0 Hz), 26.5 – 26.1 (m), 25.6, 25.3 (d, *J* = 2.9 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 42.6 (d, *J* = 9.0 Hz), 20.4 (d, *J* = 12.6 Hz); **^{19}F NMR** (377 MHz, $CDCl_3$) δ -63.0. HRMS (ESI) calcd for $C_{36}H_{35}F_{12}O_2P_2^+$ $[M+H]^+$ 789.1915, found 789.1900.



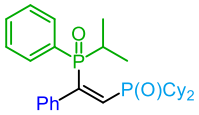
(7k) White solid (m.p.: 154 - 156 ℃); 96% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.19 – 7.16 (m, 1H), 7.11 – 7.02 (m, 4H), 6.84 (dd, *J* = 11.4, 1.2 Hz, 2H), 6.79 – 6.75 (m, 4H), 6.60 (dd, *J* = 38.0, 6.1 Hz, 1H), 5.94 (s, 4H), 2.67 – 2.55 (m, 2H), 1.97 – 1.92 (m, 2H), 1.83 – 1.72 (m, 6H), 1.62 – 1.47 (m, 6H), 1.24 – 1.11 (m, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 152.8 (d, *J* = 89.6 Hz), 151.1 (d, *J* = 2.8 Hz), 147.9 (d, *J* = 18.6 Hz), 146.7 (d, *J* = 79.6 Hz)， 140.2 – 139.9 (m), 128.7 (d, *J* = 2.8 Hz), 128.4, 128.1, 127.7 (d, *J* = 10.9 Hz), 124.0 (d, *J* = 109.9 Hz), 111.4 (d, *J* = 12.6 Hz), 108.6 (d, *J* = 15.5 Hz), 101.8, 38.6 (d, *J* = 67.2 Hz), 26.8 (d, *J* = 3.5 Hz), 26.5 – 26.3 (m), 25.8; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 50.4, 24.4. HRMS (ESI) calcd for $C_{34}H_{39}O_6P_2^+$ $[M+H]^+$ 605.2217, found 605.2209.



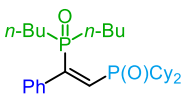
(7l) White solid (m.p.: 272 - 274 ℃); 90% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.29 (s, 5H), 6.17 – 6.00 (m, 1H), 3.14 – 3.03 (m, 2H), 1.96 – 1.75 (m, 18H), 1.72 – 1.36 (m, 15H), 1.22 – 1.18 (m, 5H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 161.6 (d, *J* = 56.2 Hz), 142.2, 133.6 (d, *J* = 73.2 Hz), 128.4, 128.2, 127.9, 39.8 (d, *J* = 69.0 Hz), 37.0 (d, *J* = 69.2 Hz), 27.8 (d, *J* = 2.1 Hz), 26.6– 26.3 (m), 25.9 – 25.8 (m), 25.3 (d, *J* = 3.0 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 46.0, 43.1. HRMS (ESI) calcd for $C_{30}H_{47}O_2P_2^+$ $[M+H]^+$ 501.3046, found 501.3038.



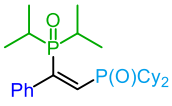
(7m) White solid (m.p.: 247 - 248 ℃); 97% yield; **^{1}H NMR** (400 MHz, CD_3OD) δ 7.41 – 7.29 (m, 5H), 6.44 (dd, *J* = 33.8, 20.2 Hz, 1H), 2.91 – 2.84 (m, 2H), 2.17 – 2.06 (m, 6H), 1.94 – 1.71 (m, 16H), 1.60 – 1.22 (m, 20H); **^{13}C NMR** (101 MHz, CD_3OD) δ 159.2 (d, *J* = 65.8 Hz), 141.8 (dd, *J* = 15.8, 6.3 Hz), 135.2 (d, *J* = 76.8 Hz), 128.3 (d, *J* = 2.4 Hz), 128.1, 127.8, 39.4 (d, *J* = 63.7 Hz), 36.9 (d, *J* = 68.6 Hz), 26.5 (d, *J* = 3.4 Hz), 26.4 (d, *J* = 3.6 Hz), 26.2 – 25.5 (m); **^{31}P NMR** (162 MHz, CD_3OD) δ 52.6 (d, *J* = 11.2 Hz), 46.4 (d, *J* = 5.4 Hz). HRMS (ESI) calcd for $C_{32}H_{51}O_2P_2^+$ $[M+H]^+$ 529.3359, found 529.3359.



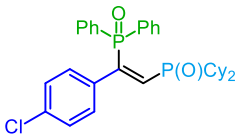
(7n) White solid (m.p.: 180 - 182 ℃); 90% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.42 – 7.31 (m, 3H), 7.24 – 7.16 (m, 5H), 6.92 (d, *J* = 6.6 Hz, 2H), 6.24 (dd, *J* = 35.9, 9.9 Hz, 1H), 2.99 – 2.90 (m, 1H), 2.42 – 2.18 (m, 2H), 1.96 – 1.89 (m, 1H), 1.80 – 1.66 (m, 4H), 1.58 – 1.43 (m, 7H), 1.35 – 1.16 (m, 7H), 1.10 – 0.87 (m, 7H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 155.2 (d, *J* = 75.9 Hz), 142.8 (d, *J* = 72.9 Hz), 140.4 – 140.2 (m), 131.9 (d, *J* = 8.5 Hz), 131.7 (d, *J* = 2.1 Hz), 130.7 (d, *J* = 94.4 Hz), 128.3, 128.1, 128.0 (d, *J* = 11.4 Hz), 38.5 (d, *J* = 67.7 Hz), 37.5 (d, *J* = 67.2 Hz), 26.6 – 25.1 (m), 15.5 (d, *J* = 2.7 Hz), 14.9 (d, *J* = 2.6 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 48.4, 37.6 (d, *J* = 10.5 Hz). HRMS (ESI) calcd for $C_{29}H_{41}O_2P_2^+$ $[M+H]^+$ 483.2577, found 483.2570.



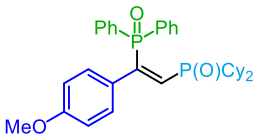
(7o) White solid (m.p.: 169 - 171 ℃); 86% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.32 – 7.23 (m, 5H), 6.16 – 6.03 (m, 1H), 2.46 – 2.37 (m, 2H), 2.27 – 2.16 (m, 2H), 1.96 – 1.93 (m, 2H), 1.88 – 1.67 (m, 12H), 1.57 – 1.45 (m, 2H), 1.40 – 1.16 (m, 14H), 0.84 (t, *J* = 7.3 Hz, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 160.2 (d, *J* = 69.3 Hz), 141.9 – 141.7 (m), 134.2 (d, *J* = 82.9 Hz), 128.4, 128.3, 128.0, 36.3 (d, *J* = 68.8 Hz), 31.0 (d, *J* = 66.8 Hz), 26.5 – 26.2 (m), 25.8, 25.1 (d, *J* = 2.2 Hz), 24.2 (d, *J* = 16.3 Hz), 23.9 (d, *J* = 4.6 Hz), 13.8; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 43.4. HRMS (ESI) calcd for $C_{28}H_{47}O_2P_2^+$ $[M+H]^+$ 477.3046, found 477.3040.



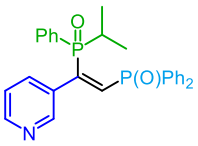
(7p) White solid (m.p.: 278 - 280 ℃); 84% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.34 – 7.30 (m, 5H), 6.21 (dd, *J* = 31.7, 19.3 Hz, 1H), 3.05 – 2.96 (m, 2H), 1.99 – 1.71 (m, 12H), 1.45 – 1.16 (m, 22H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 160.2 (d, *J* = 66.2 Hz), 142.0, 134.8 (d, *J* = 86.9 Hz), 128.6 (d, *J* = 2.5 Hz), 128.4, 128.0, 37.3 (d, *J* = 68.9 Hz), 29.3 (d, *J* = 64.1 Hz), 26.6 – 26.4 (m), 25.8, 25.5 (d, *J* = 3.2 Hz), 17.9 (d, *J* = 3.9 Hz), 16.6 (d, *J* = 3.4 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 54.2, 43.4. HRMS (ESI) calcd for $C_{26}H_{43}O_2P_2^+$ $[M+H]^+$ 449.2733, found 449.2739.



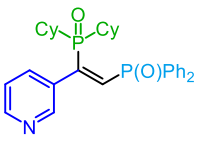
(7q) White solid (m.p.: 70 - 72 ℃); 85% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.57 – 7.49 (m, 6H), 7.40 – 7.37 (m, 4H), 7.06 (d, *J* = 8.4 Hz, 2H), 6.73 – 6.62 (m, 3H), 2.55 – 2.45 (m, 2H), 1.95 – 1.49 (m, 14H), 1.26 – 1.16 (m, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 152.3 (d, *J* = 94.5 Hz), 146.7 (d, *J* = 80.0 Hz), 138.6 – 138.4 (m), 134.6, 132.5, 132.1 (d, *J* = 9.8 Hz), 131.0 (d, *J* = 104.8 Hz), 130.0 (d, *J* = 2.9 Hz), 128.6, 128.4 (d, *J* = 13.4 Hz), 38.5 (d, *J* = 67.5 Hz), 26.7 – 26.2 (m), 25.8; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 48.7, 24.6. HRMS (ESI) calcd for $C_{32}H_{38}ClO_2P_2^+$ $[M+H]^+$ 551.2031, found 551.2029.



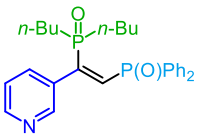
(7r) White solid (m.p.: 118 - 120 ℃); 76% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.56 – 7.46 (m, 6H), 7.38 – 7.34 (m, 4H), 6.69 – 6.58 (m, 5H), 3.68 (s, 3H), 2.64 – 2.57 (m, 2H), 1.98 – 1.95 (m, 2H), 1.80 – 1.48 (m, 12H), 1.29 – 1.09 (m, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 159.7, 152.0 (d, *J* = 87.7 Hz), 146.7 (d, *J* = 79.3 Hz), 132.2 – 131.0 (m), 130.1 (d, *J* = 3.3 Hz), 128.4 (d, *J* = 12.2 Hz), 113.5, 55.2, 38.7 (d, *J* = 67.4 Hz), 26.8 (d, *J* = 3.5 Hz), 26.5 – 26.3 (m), 25.9; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 49.6, 24.4 (d, *J* = 8.6 Hz). HRMS (ESI) calcd for $C_{33}H_{41}O_3P_2^+$ $[M+H]^+$ 547.2526, found 547.2521.



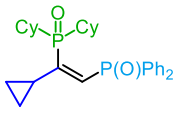
(7s) White solid (m.p.: 126 – 128 ℃); 80% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.47 – 8.32 (m, 2H), 7.87 – 7.83 (m, 2H), 7.72 – 7.65 (m, 3H), 7.49 – 7.23 (m, 12H), 6.79 (dd, *J* = 33.3, 20.1 Hz, 1H), 3.89 – 3.81 (m, 1H), 1.23 – 1.16 (m, 3H), 1.15 – 1.09 (m, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 154.5 (d, *J* = 69.9 Hz), 149.0, 147.8, 138.2 (dd, *J* = 92.3, 9.0 Hz), 137.5, 137.0, 133.3 – 131.2 (m), 131.0 (d, *J* = 9.6 Hz), 130.6 (d, *J* = 10.0 Hz), 128.9 (d, *J* = 12.3 Hz), 128.7 (d, *J* = 12.5 Hz), 128.3 (d, *J* = 11.8 Hz), 122.6, 26.3 (d, *J* = 70.4 Hz), 15.6 (d, *J* = 3.2 Hz), 15.3 (d, *J* = 3.2 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 38.8 (d, *J* = 13.0 Hz), 18.3 (d, *J* = 13.0 Hz). HRMS (ESI) calcd for $C_{28}H_{28}NO_2P_2^+$ $[M+H]^+$ 472.1590, found 472.1588.



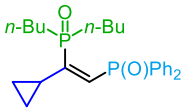
(7t) Yellow solid (m.p.: 267 - 269 ℃); 80% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.50 – 8.43 (m, 2H), 7.83 (d, *J* = 7.9 Hz, 1H), 7.73 – 7.68 (m, 4H), 7.57 – 7.46 (m, 6H), 7.25 – 7.22 (m, 1H), 6.89 (dd, *J* = 30.5, 21.9 Hz, 1H), 2.99 – 2.91 (m, 2H), 2.06 – 2.03 (m, 2H), 1.76 – 1.69 (m, 4H), 1.60 – 1.55 (m, 6H), 1.49 – 1.39 (m, 2H), 1.32 – 1.22 (m, 2H), 1.18 – 1.08 (m, 2H), 0.98 – 0.88 (m, 2H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 154.9 (dd, *J* = 61.0, 2.6 Hz), 149.2, 148.2, 137.9, 137.1, 135.4 (dd, *J* = 94.1, 8.4 Hz), 132.6 (d, *J* = 107.0 Hz), 132.4 (d, *J* = 2.5 Hz), 130.8 (d, *J* = 9.6 Hz), 129.1 (d, *J* = 12.1 Hz), 122.3, 39.2 (d, *J* = 64.2 Hz), 26.5 (d, *J* = 4.0 Hz), 26.3 (d, *J* = 3.7 Hz), 26.2 (d, *J* = 2.2 Hz), 26.1 (d, *J* = 1.9 Hz), 25.6; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 51.4 (d, *J* = 10.8 Hz), 18.3 (d, *J* = 10.1 Hz). HRMS (ESI) calcd for $C_{31}H_{38}NO_2P_2^+$ $[M+H]^+$ 518.2372, found 518.2372.



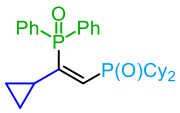
(7u) White solid (m.p.: 183 - 185 ℃); 85% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.52 (d, *J* = 4.4 Hz, 1H), 8.47 (s, 1H), 7.82 (d, *J* = 8.0 Hz, 1H), 7.73 – 7.67 (m, 4H), 7.57 – 7.53 (m, 2H), 7.51 – 7.46 (m, 4H), 7.26 (dd, *J* = 7.9, 4.9 Hz, 1H), 6.88 (dd, *J* = 32.0, 21.1 Hz, 1H), 2.69 – 2.58 (m, 2H), 2.32 – 2.21 (m, 2H), 1.72 – 1.59 (m, 2H), 1.44 – 1.33 (m, 2H), 1.32 – 1.23 (m, 2H), 1.22 – 1.13 (m, 2H), 0.76 (t, *J* = 7.3 Hz, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 155.2 (dd, *J* = 66.6, 2.5 Hz), 149.6, 148.1 (d, *J* = 2.9 Hz), 137.5 (dd, *J* = 17.9, 6.3 Hz), 136.7 (d, *J* = 1.3 Hz), 136.1 (dd, *J* = 92.9, 9.3 Hz), 132.53 (d, *J* = 107.5 Hz), 132.46 (d, *J* = 2.7 Hz), 130.9 (d, *J* = 9.6 Hz), 129.1 (d, *J* = 12.3 Hz), 122.4, 31.0 (d, *J* = 67.0 Hz), 24.0 (d, *J* = 16.1 Hz), 23.8 (d, *J* = 4.9 Hz), 13.6; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 45.1 (d, *J* = 12.1 Hz), 18.4 (d, *J* = 12.1 Hz). HRMS (ESI) calcd for $C_{27}H_{34}NO_2P_2^+$ $[M+H]^+$ 466.2059, found 466.2059.



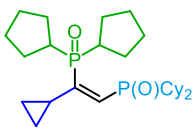
(7v) White solid (m.p.: 209 - 211 ℃); 94% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.60 (dd, *J* = 11.9, 7.0 Hz, 4H), 7.50 – 7.47 (m, 2H), 7.45 – 7.41 (m, 4H), 6.04 (dd, *J* = 33.1, 20.5 Hz, 1H), 2.76 – 2.68 (m, 2H), 2.42 – 2.35 (m, 1H), 2.03 – 2.00 (m, 2H), 1.72 – 1.70 (m, 2H), 1.62 – 1.52 (m, 8H), 1.44 – 1.34 (m, 2H), 1.27 – 0.99 (m, 6H), 0.91 – 0.81 (m, 2H), 0.60 – 0.56 (m, 2H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 161.7 (d, *J* = 64.6 Hz), 132.8 (d, *J* = 106.9 Hz), 130.9 (d, *J* = 2.6 Hz), 129.7 (d, *J* = 9.6 Hz), 127.8 (d, *J* = 12.1 Hz), 120.5 (d, *J* = 111.0 Hz), 37.4 (d, *J* = 64.3 Hz), 25.3 – 24.7 (m), 15.8 (dd, *J* = 18.4, 10.3 Hz), 11.4; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 52.7, 19.4. HRMS (ESI) calcd for $C_{29}H_{38}O_2P_2Na^+$ $[M+Na]^+$ 503.2240, found 503.2240.



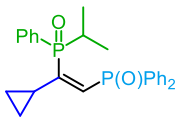
(7w) White solid (m.p.: 91 - 93 ℃); 96% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.62 – 7.57 (m, 4H), 7.51 – 7.48 (m, 2H), 7.44 – 7.41 (m, 4H), 6.10 (dd, *J* = 34.7, 20.1 Hz, 1H), 2.46 – 2.37 (m, 3H), 2.20 – 2.10 (m, 2H), 1.63 – 1.55 (m, 2H), 1.37 – 1.23 (m, 4H), 1.18 – 1.04 (m, 4H), 0.74 (t, *J* = 7.2 Hz, 6H), 0.60 – 0.59 (m, 2H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 161.7 (d, *J* = 69.5 Hz), 132.7 (d, *J* = 107.2 Hz), 131.0 (d, *J* = 2.6 Hz), 129.8 (d, *J* = 9.6 Hz), 127.8 (d, *J* = 12.2 Hz), 121.7 (d, *J* = 100.1 Hz), 29.4 (d, *J* = 66.6 Hz), 23.0 (d, *J* = 15.8 Hz), 22.7 (d, *J* = 4.8 Hz), 16.2 (dd, *J* = 18.3, 11.2 Hz), 12.6, 10.8; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 46.4 (d, *J* = 14.3 Hz), 19.5 (d, *J* = 15.1 Hz). HRMS (ESI) calcd for $C_{25}H_{35}O_2P_2^+$ $[M+H]^+$ 429.2107, found 429.2100.



(7x) White solid (m.p.: 301 - 303 ℃); 76% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.66 – 7.61 (m, 4H), 7.51 – 7.47 (m, 2H), 7.43 – 7.38 (m, 4H), 6.06 (d, *J* = 40.1 Hz, 1H), 2.59 – 2.51 (m, 2H), 1.90 – 1.87 (m, 2H), 1.67 – 1.28 (m, 13H), 1.20 – 1.02 (m, 4H), 0.95 – 0.86 (m, 2H), 0.69 – 0.57 (m, 4H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 152.4 (d, *J* = 89.3 Hz), 136.7 (d, *J* = 85.1 Hz), 132.2 (d, *J* = 2.7 Hz), 131.8 (d, *J* = 9.9 Hz), 131.7 (d, *J* = 104.0 Hz), 128.6 (d, *J* = 12.0 Hz), 38.6 (d, *J* = 67.3 Hz), 26.7 (d, *J* = 3.6 Hz), 26.4 – 26.3 (m), 26.2 (d, *J* = 2.4 Hz), 25.8, 17.6 (dd, *J* = 20.0, 14.0 Hz), 11.6 (d, *J* = 2.4 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 51.7 (d, *J* = 10.9 Hz), 28.3 (d, *J* = 13.8 Hz). HRMS (ESI) calcd for $C_{29}H_{39}O_2P_2^+$ $[M+H]^+$ 481.2420, found 481.2413.

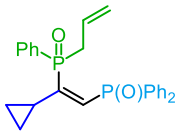


(7y) White solid (m.p.: 231 - 233 ℃); 84% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 5.34 (dd, *J* = 34.0, 16.3 Hz, 1H), 2.86 (brs, 2H), 2.20 (brs, 1H), 1.89 – 1.14 (m, 38H), 0.95 – 0.91 (m, 2H), 0.51 – 0.46 (m, 2H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 163.5, 120.6, 38.7 (d, *J* = 68.4 Hz), 37.1 (d, *J* = 69.5 Hz), 27.5 (d, *J* = 1.3 Hz), 26.5 – 25.7 (m), 25.2, 16.8 – 16.6 (m), 11.4; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 48.2 (d, *J* = 13.0 Hz), 43.3. HRMS (ESI) calcd for $C_{27}H_{47}O_2P_2^+$ $[M+H]^+$ 465.3046, found 465.3051.

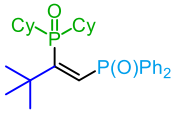


(7z) Colorless oil; 94% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.80 – 7.75 (m, 2H), 7.65 – 7.60 (m, 2H), 7.43 – 7.18 (m, 11H) (overlap one peak of 7.26), 6.20 (dd, *J* = 35.8, 17.8 Hz, 1H), 3.51 – 3.42 (m, 1H), 2.33 – 2.16 (m, 1H), 1.14 – 1.05 (m, 6H), 0.96 – 0.86 (m, 2H), 0.54 – 0.45 (m, 2H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 159.8 (d, *J* = 74.0 Hz), 133.1 (dd, *J* = 108.8, 8.4 Hz), 131.4 – 130.3 (m), 129.9 (d, *J* = 9.6 Hz), 129.5 (d, *J* = 9.9 Hz), 127.5 (d, *J* = 12.3 Hz), 127.3 (d, *J* = 12.4 Hz), 127.1 (d, *J* = 11.5 Hz), 125.8 (dd, *J* = 102.4, 9.5 Hz), 24.6 (d, *J* = 70.4 Hz), 16.1 (dd, *J* = 18.0, 13.3 Hz), 14.4

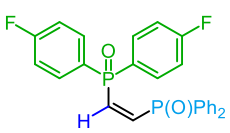
(d, J = 2.7 Hz), 14.2 (d, J = 3.2 Hz), 10.0 (d, J = 2.2 Hz), 9.5 (d, J = 2.4 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 40.1 (d, J = 15.8 Hz), 20.1 (d, J = 15.7 Hz). HRMS (ESI) calcd for $C_{26}H_{29}O_2P_2^+$ $[M+H]^+$ 435.1637, found 435.1635.



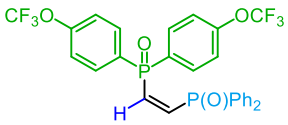
(7aa) White solid (m.p.: 125 - 127 ℃); 51% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.80 (dd, J = 11.9, 7.2 Hz, 2H), 7.66 – 7.61 (m, 2H), 7.52 – 7.48 (m, 1H), 7.45 – 7.26 (m, 10H) (overlap one peak of 7.26), 6.32 (dd, J = 37.4, 19.1 Hz, 1H), 5.88 – 5.76 (m, 1H), 5.19 – 5.12 (m, 2H), 3.73 – 3.57 (m, 2H), 2.31 – 2.23 (m, 1H), 1.03 – 0.93 (m, 2H), 0.66 – 0.61 (m, 1H), 0.54 – 0.49 (m, 1H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 160.9 (d, J = 77.9 Hz), 133.8 (d, J = 107.6 Hz), 133.3 (d, J = 108.6 Hz), 132.4 (d, J = 99.0 Hz), 131.9 (d, J = 2.7 Hz), 131.7 (d, J = 2.7 Hz), 131.6 (d, J = 2.7 Hz), 131.3 (d, J = 9.8 Hz), 131.0 (d, J = 9.8 Hz), 130.7 (d, J = 9.8 Hz), 128.8 (d, J = 12.3 Hz), 128.5 (d, J = 12.4 Hz), 128.2 (d, J = 12.2 Hz), 127.3 (d, J = 10.2 Hz), 126.6 (dd, J = 101.8, 10.3 Hz), 121.0 (d, J = 12.5 Hz), 35.3 (d, J = 66.8 Hz), 17.7 (dd, J = 17.9, 13.2 Hz), 11.2 (d, J = 2.4 Hz), 10.3 (d, J = 3.2 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 33.2 (d, J = 14.5 Hz), 20.0. HRMS (ESI) calcd for $C_{26}H_{27}O_2P_2^+$ $[M+H]^+$ 433.1481, found 433.1480.



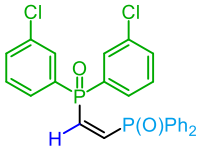
(7ab) White solid (m.p.: 173 - 175 ℃); 80% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.69 – 7.63 (m, 4H), 7.54 – 7.44 (m, 6H), 6.68 (dd, J = 35.3, 19.6 Hz, 1H), 2.84 – 2.76 (m, 2H), 2.03 – 2.00 (m, 2H), 1.75 – 1.71 (m, 2H), 1.55 – 1.07 (m, 23H), 0.90 – 0.78 (m, 2H); **^{13}C NMR** (101 MHz, Chloroform-*d*) δ 167.2 (d, J = 56.7 Hz), 133.9 (d, J = 106.6 Hz), 131.9 (d, J = 2.6 Hz), 130.7 (d, J = 9.2 Hz), 128.9 (d, J = 12.0 Hz), 126.7 (dd, J = 98.1, 10.4 Hz), 42.4 (dd, J = 14.9, 6.3 Hz), 39.6 (d, J = 63.8 Hz), 30.3 (d, J = 2.1 Hz), 27.2 (d, J = 3.7 Hz), 26.7 (d, J = 3.7 Hz), 26.4, 26.3, 25.9; **^{31}P NMR** (162 MHz, Chloroform-*d*) δ 54.0 (d, J = 16.1 Hz), 17.9 (d, J = 16.1 Hz). HRMS (ESI) calcd for $C_{30}H_{43}O_2P_2^+$ $[M+H]^+$ 497.2733, found 497.2728.



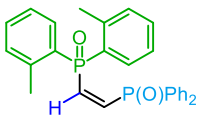
(7ac) White solid (m.p.: 192 - 194 ℃); 63% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.77 – 7.71 (m, 4H), 7.58 – 7.53 (m, 4H), 7.48 – 7.44 (m, 2H), 7.38 – 7.19 (m, 6H) (overlap one peak of 7.26), 7.02 – 6.97 (m, 4H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 164.0 (dd, J = 254.5, 3.2 Hz), 143.0 (d, J = 94.0 Hz), 141.4 (d, J = 91.8 Hz), 133.3 (dd, J = 11.7, 9.0 Hz), 131.3 (d, J = 107.0 Hz), 131.0 (d, J = 2.5 Hz), 129.9 (d, J = 10.0 Hz), 127.6 (d, J = 12.4 Hz), 126.6 (d, J = 110.8 Hz), 114.7 (dd, J = 21.5, 13.9 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 21.2 (d, J = 20.5 Hz), 19.2 (d, J = 20.8 Hz); **^{19}F NMR** (377 MHz, $CDCl_3$) δ -106.5. HRMS (ESI) calcd for $C_{26}H_{20}F_2O_2P_2Na^+$ $[M+Na]^+$ 487.0799, found 487.0805.



(7ad) White solid (m.p.: 136 - 138 ℃); 50% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.82 (dd, J = 11.9, 8.7 Hz, 4H), 7.57 – 7.46 (m, 6H), 7.44 – 7.24 (m, 6H), 7.17 (d, J = 7.9 Hz, 4H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 152.1 – 152.0 (m), 143.4 (d, J = 94.4 Hz), 143.0 (d, J = 91.0 Hz), 133.8 (d, J = 11.6 Hz), 132.2 (d, J = 2.6 Hz), 132.0 (d, J = 107.3 Hz), 130.9 (d, J = 10.0 Hz), 130.2 (d, J = 109.6 Hz), 128.7 (d, J = 12.5 Hz), 120.29 (d, J = 13.5 Hz), 120.28 (q, J = 258.9 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 21.0 (d, J = 21.0 Hz), 19.2 (d, J = 20.0 Hz). HRMS (ESI) calcd for $C_{28}H_{21}F_6O_4P_2^+$ $[M+H]^+$ 597.0814, found 597.0811.

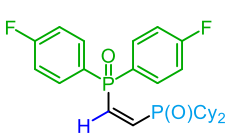


(7ae) White solid (m.p.: 148 - 150 ℃); 74% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.62 – 7.50 (m, 8H), 7.43 – 7.39 (m, 2H), 7.35 – 7.06 (m, 10H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 144.5 (d, J = 90.4 Hz), 141.9 (d, J = 94.4 Hz), 134.9 (d, J = 16.4 Hz), 134.6 (d, J = 105.7 Hz), 132.3 – 131.1 (m), 130.0 (d, J = 13.7 Hz), 129.4 (d, J = 9.8 Hz), 128.6 (d, J = 12.5 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 20.0 (d, J = 20.9 Hz), 18.9 (d, J = 20.9 Hz). HRMS (ESI) calcd for $C_{26}H_{21}Cl_2O_2P_2^+$ $[M+H]^+$ 497.0388, found 497.0391.

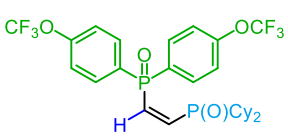


(7af) Oil; 80% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.75 – 7.70 (m, 4H), 7.43 – 7.09 (m, 16H), 2.29 (s, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 144.0 (d, J = 92.5 Hz), 143.0 (d, J = 91.1 Hz), 141.8 (d, J = 8.6 Hz), 132.7 (d, J = 12.3 Hz), 132.1 (d, J = 2.3 Hz), 131.9 (d, J = 107.4 Hz), 131.8 (d, J = 2.5 Hz), 131.7 – 131.6 (m), 130.3 (d,

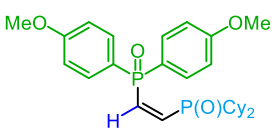
J = 104.8 Hz), 128.2 (d, J = 12.6 Hz), 125.6 (d, J = 13.0 Hz), 21.7 (d, J = 4.3 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 24.6 (d, J = 20.4 Hz), 22.0 (d, J = 20.4 Hz). HRMS (ESI) calcd for $C_{28}H_{27}O_2P_2^+$ $[M+H]^+$ 457.1481, found 457.1485.



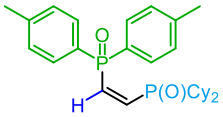
(7ag) White solid (m.p.: 213 – 215 °C); 80% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.77 – 7.71 (m, 4H), 7.17 – 6.99 (m, 5H), 6.84 – 6.67 (m, 1H), 2.23 – 2.15 (m, 2H), 1.86 – 1.83 (m, 2H), 1.74 – 1.72 (m, 2H), 1.67 – 1.58 (m, 6H), 1.41 – 1.30 (m, 3H), 1.25 – 1.00 (m, 7H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 165.1 (dd, J = 255.1, 3.2 Hz), 145.3 (d, J = 72.7 Hz), 140.6 (d, J = 96.3 Hz), 133.8 (dd, J = 11.4, 8.9 Hz), 128.5 (dd, J = 110.2, 3.0 Hz), 116.1 (dd, J = 21.5, 13.6 Hz), 37.4 (d, J = 66.8 Hz), 26.3 – 26.1 (m), 25.7, 25.5 (d, J = 3.2 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 47.5 (d, J = 16.3 Hz), 19.1 (d, J = 17.2 Hz); **^{19}F NMR** (377 MHz, $CDCl_3$) δ -106.0. HRMS (ESI) calcd for $C_{26}H_{33}F_2O_2P_2^+$ $[M+H]^+$ 477.1918, found 477.1921.



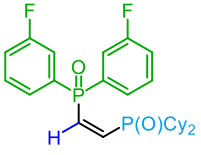
(7ah) White solid (m.p.: 156 - 158 °C); 65% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.85 (dd, J = 11.5, 8.6 Hz, 4H), 7.29 (d, J = 8.0 Hz, 4H), 7.22 – 7.08 (m, 1H), 6.88 – 6.70 (m, 1H), 2.06 – 2.01 (m, 2H), 1.82 – 1.61 (m, 10H), 1.32 – 1.02 (m, 10H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 152.0, 145.0 (d, J = 72.9 Hz), 141.5 (d, J = 96.7 Hz), 133.5 (d, J = 11.2 Hz), 131.1 (d, J = 108.9 Hz), 120.6 (d, J = 13.3 Hz), 120.3 (q, J = 259.9 Hz), 37.0 (d, J = 67.2 Hz), 26.3 – 26.1 (m), 25.7, 25.3 (d, J = 3.0 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 46.3 (d, J = 17.0 Hz), 18.8 (d, J = 17.5 Hz); **^{19}F NMR** (377 MHz, $CDCl_3$) δ -57.7. HRMS (ESI) calcd for $C_{28}H_{33}F_6O_4P_2^+$ $[M+H]^+$ 609.1753, found 609.1745.



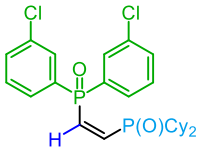
(7ai) White solid (m.p.: 121 - 123 °C); 60% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.58 (dd, J = 11.6, 8.7 Hz, 4H), 7.03 – 6.84 (m, 5H), 6.77 – 6.61 (m, 1H), 3.79 (s, 6H), 2.55 – 2.47 (m, 2H), 1.95 – 1.92 (m, 2H), 1.74 – 1.32 (m, 13H), 1.17 – 1.00 (m, 5H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 162.6 (d, J = 2.8 Hz), 145.5 (d, J = 73.5 Hz), 139.5 (d, J = 95.4 Hz), 132.9 (d, J = 11.2 Hz), 123.9 (d, J = 112.9 Hz), 114.3 (d, J = 13.3 Hz), 55.4, 38.0 (d, J = 66.2 Hz), 26.5 (d, J = 3.5 Hz), 26.3 (d, J = 5.1 Hz), 26.2 (d, J = 4.8 Hz), 25.9 (d, J = 3.5 Hz), 25.8; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 49.4 (d, J = 16.4 Hz), 19.5 (d, J = 16.7 Hz). HRMS (ESI) calcd for $C_{28}H_{39}O_4P_2^+$ $[M+H]^+$ 501.2319, found 501.2310.



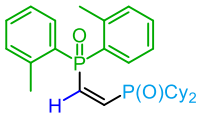
(7aj) White solid (m.p.: 107 - 109 °C); 72% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.55 (dd, J = 11.9, 8.0 Hz, 4H), 7.26 – 7.24 (m, 4H), 7.07 – 6.68 (m, 2H), 2.58 – 2.50 (m, 2H), 2.36 (s, 6H), 1.97 – 1.94 (m, 2H), 1.75 – 1.58 (m, 8H), 1.51 – 1.36 (m, 4H), 1.21 – 1.00 (m, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 146.0 (d, J = 73.2 Hz), 142.7 (d, J = 2.7 Hz), 139.1 (d, J = 94.6 Hz), 131.0 (d, J = 10.2 Hz), 129.5 (d, J = 12.7 Hz), 129.3 (d, J = 108.7 Hz), 37.9 (d, J = 66.0 Hz), 26.4 (d, J = 3.5 Hz), 26.3, 26.2, 25.9 (d, J = 3.5 Hz), 25.8, 21.6; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 50.2, 19.9 (d, J = 15.7 Hz). HRMS (ESI) calcd for $C_{28}H_{39}O_2P_2^+$ $[M+H]^+$ 469.2420, found 469.2415.



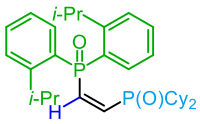
(7ak) White solid (m.p.: 152 - 154 °C); 78% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.53 – 7.41 (m, 6H), 7.21 – 7.03 (m, 3H), 6.93 – 6.75 (m, 1H), 2.21 – 2.13 (m, 2H), 1.88 – 1.58 (m, 10H), 1.42 – 1.02 (m, 10H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 162.5 (dd, J = 251.7, 17.4 Hz), 146.3 (d, J = 72.2 Hz), 139.9 (d, J = 96.7 Hz), 135.2 (d, J = 106.2 Hz), 130.8 (dd, J = 14.4, 7.4 Hz), 126.8 (dd, J = 9.3, 2.9 Hz), 119.4 (d, J = 20.6 Hz), 118.0 (dd, J = 22.7, 10.8 Hz), 37.2 (d, J = 66.9 Hz), 26.3 – 26.1 (m), 25.7, 25.4 (d, J = 3.2 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 47.6 (d, J = 16.1 Hz), 17.7 (d, J = 17.1 Hz); **^{19}F NMR** (377 MHz, $CDCl_3$) δ -110.5 (d, J = 5.1 Hz). HRMS (ESI) calcd for $C_{26}H_{32}F_2O_2P_2Na^+$ $[M+Na]^+$ 499.1738, found 499.1739.



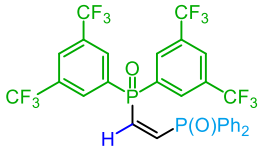
(7al) White solid (m.p.: 106 - 108 ℃); 70% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.76 (d, *J* = 12.5 Hz, 2H), 7.62 (dd, *J* = 11.4, 7.6 Hz, 2H), 7.48 – 7.46 (m, 2H), 7.42 – 7.37 (m, 2H), 7.25 – 7.07 (m, 1H), 6.94 – 6.76 (m, 1H), 2.13 – 2.04 (m, 2H), 1.86 – 1.63 (m, 10H), 1.39 – 1.29 (m, 4H), 1.20 – 1.06 (m, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 145.7 (d, *J* = 71.9 Hz), 140.9 (d, *J* = 96.3 Hz), 135.1 (d, *J* = 16.3 Hz), 134.9 (d, *J* = 106.0 Hz), 132.3, 131.0 (d, *J* = 11.0 Hz), 130.2 (d, *J* = 13.5 Hz), 129.2 (d, *J* = 9.4 Hz), 36.9 (d, *J* = 67.2 Hz), 26.4 – 26.2 (m), 25.7, 25.4 (d, *J* = 3.0 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 47.1 (d, *J* = 14.2 Hz), 18.3 (d, *J* = 17.3 Hz). HRMS (ESI) calcd for $C_{26}H_{33}Cl_2O_2P_2^+$ $[M+H]^+$ 509.1327, found 509.1330.



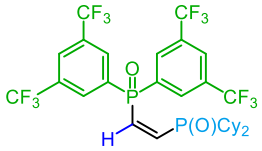
(7am) White solid (m.p.: 75 - 77 ℃); 90% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.53 (dd, *J* = 13.8, 7.6 Hz, 2H), 7.39 (t, *J* = 7.4 Hz, 2H), 7.24 – 7.19 (m, 4H), 7.06 – 6.78 (m, 2H), 2.58 – 2.51 (m, 2H), 2.31 (s, 6H), 1.97 – 1.94 (m, 2H), 1.70 – 1.68 (m, 4H), 1.57 – 1.37 (m, 8H), 1.17 – 1.05 (m, 4H), 0.95 – 0.89 (m, 2H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 148.1 (d, *J* = 72.8 Hz), 141.5 (d, *J* = 8.9 Hz), 138.9 (d, *J* = 93.9 Hz), 132.3 (d, *J* = 2.5 Hz), 132.2 (d, *J* = 11.5 Hz), 132.0 (d, *J* = 10.9 Hz), 130.7 (d, *J* = 103.4 Hz), 125.9 (d, *J* = 12.5 Hz), 38.0 (d, *J* = 66.0 Hz), 26.4 – 25.9 (m), 25.7, 21.4 (d, *J* = 4.4 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 50.5, 23.8 (d, *J* = 16.3 Hz). HRMS (ESI) calcd for $C_{28}H_{38}NaO_2P_2^+$ $[M+Na]^+$ 491.2240, found 491.2245.



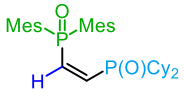
(7an) White solid (m.p.: 181 - 183 ℃); 87% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.48 – 7.38 (m, 6H), 7.20 – 7.16 (m, 2H), 7.06 – 6.80 (m, 2H), 3.54 – 3.46 (m, 2H), 2.64 – 2.55 (m, 2H), 1.98 – 1.95 (m, 2H), 1.67 – 1.42 (m, 12H), 1.22 – 1.01 (m, 16H), 0.83 – 0.74 (m, 2H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 153.3 (d, *J* = 9.2 Hz), 148.3 (d, *J* = 68.3 Hz), 139.9 (d, *J* = 92.3 Hz), 132.6, 132.1 (d, *J* = 12.4 Hz), 130.4 (d, *J* = 104.3 Hz), 127.4 (d, *J* = 10.7 Hz), 125.8 (d, *J* = 12.7 Hz), 37.8 (d, *J* = 65.8 Hz), 31.4 (d, *J* = 4.7 Hz), 26.4 – 25.7 (m), 24.2, 24.0; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 50.8, 24.6. HRMS (ESI) calcd for $C_{32}H_{47}O_2P_2^+$ $[M+H]^+$ 525.3046, found 525.3038.



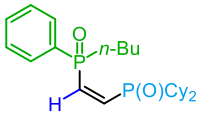
(7ao) White solid (m.p.: 166 - 168 ℃); 41% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.36 (d, *J* = 12.1 Hz, 4H), 7.97 (s, 2H), 7.53 – 7.23 (m, 12H) (overlap one peak of 7.26); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 146.0 (d, *J* = 87.0 Hz), 141.3 (d, *J* = 96.9 Hz), 135.2 (d, *J* = 107.8 Hz), 132.7 (d, *J* = 2.6 Hz), 132.5 – 131.4 (m), 130.8 (d, *J* = 10.0 Hz), 130.6 (d, *J* = 106.1 Hz), 129.0 (d, *J* = 12.4 Hz), 126.2 – 126.0 (m), 122.7 (q, *J* = 274.2 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 20.7 (d, *J* = 21.3 Hz), 20.1 (d, *J* = 21.1 Hz); **^{19}F NMR** (377 MHz, $CDCl_3$) δ -62.9. HRMS (ESI) calcd for $C_{30}H_{19}F_{12}O_2P_2^+$ $[M+H]^+$ 701.0664, found 701.0669.



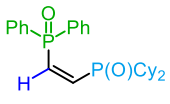
(7ap) White solid (m.p.: 192 - 194 ℃); 39% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.32 (d, *J* = 12.0 Hz, 4H), 8.01 (s, 2H), 7.40 – 7.23 (m, 1H), 7.11 – 6.90 (m, 1H), 1.76 – 1.64 (m, 12H), 1.21 – 1.14 (m, 10H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 145.1 (d, *J* = 70.8 Hz), 141.7 (d, *J* = 99.3 Hz), 135.8 (d, *J* = 108.3 Hz), 131.0 (qd, *J* = 34.1, 12.8 Hz), 130.4 – 130.2 (m), 124.9 – 124.7 (m), 121.8 (q, *J* = 273.1 Hz), 34.9 (d, *J* = 67.6 Hz), 25.3 – 25.0 (m), 24.6, 23.9 (d, *J* = 3.2 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 44.7 (d, *J* = 17.9 Hz), 17.7 (d, *J* = 18.1 Hz); **^{19}F NMR** (377 MHz, $CDCl_3$) δ -62.9. HRMS (ESI) calcd for $C_{30}H_{31}F_{12}O_2P_2^+$ $[M+H]^+$ 713.1602, found 713.1603.



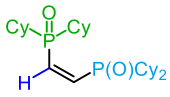
(7aq) White solid (m.p.: 177 - 179 ℃); 63% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.16 – 6.97 (m, 1H), 6.77 (d, *J* = 3.6 Hz, 4H), 6.56 (ddd, *J* = 42.6, 16.3, 7.3 Hz, 1H), 2.46 – 2.31 (m, 14H), 2.19 (s, 6H), 1.93 – 1.91 (m, 2H), 1.68 – 1.39 (m, 12H), 1.21 – 1.00 (m, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 144.6 – 141.4 (m), 131.2 (d, *J* = 11.4 Hz), 129.2 (d, *J* = 100.8 Hz), 38.1 (d, *J* = 66.4 Hz), 26.3 – 25.8 (m), 23.0 (d, *J* = 4.5 Hz), 20.9 (d, *J* = 0.9 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 48.7, 24.0 (d, *J* = 11.9 Hz). HRMS (ESI) calcd for $C_{32}H_{47}O_2P_2^+$ $[M+H]^+$ 525.3046, found 525.3043.



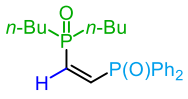
(7ar) Colorless oil; 52% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.83 (dd, *J* = 11.1, 7.7 Hz, 2H), 7.42 – 7.35 (m, 3H), 7.05 – 6.89 (m, 1H), 6.44 – 6.26 (m, 1H), 2.53 – 2.46 (m, 2H), 1.94 – 1.87 (m, 2H), 1.73 – 1.63 (m, 7H), 1.53 – 1.31 (m, 9H), 1.16 – 0.99 (m, 8H), 0.80 (t, *J* = 7.2 Hz, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 146.4 (d, *J* = 86.4 Hz), 139.2 (d, *J* = 75.7 Hz), 132.9 (d, *J* = 100.4 Hz), 131.6, 131.2 (d, *J* = 9.6 Hz), 128.3 (d, *J* = 11.9 Hz), 36.2 (dd, *J* = 67.9, 13.7 Hz), 29.8 (d, *J* = 71.9 Hz), 26.4 – 25.6 (m), 25.0 (d, *J* = 3.2 Hz), 24.8 (d, *J* = 3.2 Hz), 24.0 (d, *J* = 16.1 Hz), 23.5 (d, *J* = 4.4 Hz), 13.7; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 45.5 (d, *J* = 13.3 Hz), 31.2 (d, *J* = 15.8 Hz). HRMS (ESI) calcd for $C_{24}H_{39}O_2P_2^+$ $[M+H]^+$ 421.2420, found 421.2423.



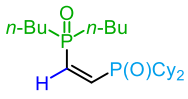
(7as) White solid (m.p.: 188 - 190 °C); 90% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.69 (dd, *J* = 12.1, 7.1 Hz, 4H), 7.51 (t, *J* = 7.6 Hz, 2H), 7.45 (td, *J* = 7.7, 2.8 Hz, 4H), 7.13 – 6.72 (m, 2H), 2.52 – 2.44 (m, 2H), 1.96 – 1.92 (m, 2H), 1.75 – 1.71 (m, 2H), 1.67 – 1.56 (m, 6H), 1.52 – 1.31 (m, 4H), 1.29 – 0.96 (m, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 146.7 (d, *J* = 72.6 Hz), 138.9 (d, *J* = 94.6 Hz), 132.5 (d, *J* = 106.2 Hz), 132.2 (d, *J* = 2.6 Hz), 131.0 (d, *J* = 9.7 Hz), 128.8 (d, *J* = 12.2 Hz), 37.9 (d, *J* = 66.2 Hz), 26.4 (d, *J* = 3.5 Hz), 26.2 (d, *J* = 13.3 Hz), 25.82 – 25.77 (m); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 49.6, 19.5 (d, *J* = 16.5 Hz). HRMS (ESI) calcd for $C_{26}H_{35}O_2P_2^+$ $[M+H]^+$ 441.2107, found 441.2107.



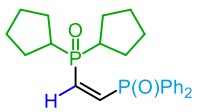
(7at) White solid (m.p.: 199 - 201 °C); 80% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 6.63 – 6.50 (m, 2H), 2.22 – 2.12 (m, 4H), 1.97 – 1.94 (m, 4H), 1.80 – 1.72 (m, 12H), 1.67 – 1.62 (m, 4H), 1.46 – 1.36 (m, 8H), 1.28 – 1.15 (m, 12H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 143.4 (d, *J* = 77.9 Hz), 37.5 (d, *J* = 68.2 Hz), 26.4 – 26.2 (m), 25.8, 25.7; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 46.3. HRMS (ESI) calcd for $C_{26}H_{47}O_2P_2^+$ $[M+H]^+$ 453.3046, found 453.3044.



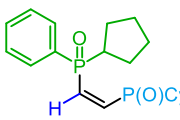
(7au) Colorless oil; 60% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.65 (dd, *J* = 12.0, 7.2 Hz, 4H), 7.52 (t, *J* = 7.6 Hz, 2H), 7.46 (td, *J* = 7.6, 2.8 Hz, 4H), 7.02 – 6.88 (m, 2H), 2.42 – 2.31 (m, 2H), 2.18 – 2.07 (m, 2H), 1.67 – 1.54 (m, 2H), 1.46 – 1.34 (m, 2H), 1.33 – 1.15 (m, 4H), 0.76 (t, *J* = 7.3 Hz, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 148.2 (d, *J* = 77.2 Hz), 138.0 (d, *J* = 94.1 Hz), 132.33 (d, *J* = 2.6 Hz), 132.32 (d, *J* = 106.2 Hz), 130.9 (d, *J* = 9.9 Hz), 128.9 (d, *J* = 12.1 Hz), 30.3 (d, *J* = 68.0 Hz), 24.1 (d, *J* = 15.4 Hz), 23.8 (d, *J* = 4.8 Hz), 13.6; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 44.4 (d, *J* = 18.4 Hz), 19.7 (d, *J* = 18.8 Hz). HRMS (ESI) calcd for $C_{22}H_{31}O_2P_2^+$ $[M+H]^+$ 389.1794, found 389.1791.



(7av) White solid (m.p.: 53 - 55 °C); 85% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 6.98 – 6.83 (m, 1H), 6.37 – 6.18 (m, 1H), 2.28 – 2.08 (m, 4H), 1.91 – 1.88 (m, 2H), 1.79 – 1.58 (m, 12H), 1.52 – 1.43 (m, 2H), 1.39 – 1.15 (m, 14H), 0.84 (t, *J* = 7.2 Hz, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 149.7 (d, *J* = 77.4 Hz), 136.8 (dd, *J* = 74.8, 3.3 Hz), 35.6 (d, *J* = 67.1 Hz), 30.2 (d, *J* = 66.5 Hz), 26.4 – 26.0 (m), 25.7, 24.7, 24.1 (d, *J* = 15.5 Hz), 23.7 (d, *J* = 4.3 Hz), 13.6; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 44.2 (d, *J* = 16.7 Hz), 43.8 (d, *J* = 14.1 Hz). HRMS (ESI) calcd for $C_{22}H_{43}O_2P_2^+$ $[M+H]^+$ 401.2733, found 401.2730.

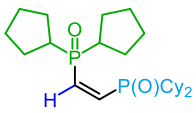


(7aw) White solid (m.p.: 175 - 177 °C); 83% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.67 – 7.62 (m, 4H), 7.54 – 7.50 (m, 2H), 7.48 – 7.43 (m, 4H), 7.15 – 6.83 (m, 2H), 3.04 – 2.95 (m, 2H), 1.92 – 1.83 (m, 4H), 1.74 – 1.62 (m, 4H), 1.60 – 1.47 (m, 6H), 1.42 – 1.34 (m, 2H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 149.0 (d, *J* = 76.0 Hz), 136.9 (d, *J* = 94.8 Hz), 132.3 (d, *J* = 2.5 Hz), 132.3 (d, *J* = 106.3 Hz), 130.9 (d, *J* = 9.8 Hz), 128.9 (d, *J* = 12.3 Hz), 38.6 (d, *J* = 69.7 Hz), 27.5 (d, *J* = 1.9 Hz), 26.8 (d, *J* = 10.1 Hz), 26.2 (d, *J* = 0.9 Hz), 26.0 (d, *J* = 10.4 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 48.8, 20.0 (d, *J* = 18.1 Hz). HRMS (ESI) calcd for $C_{24}H_{31}O_2P_2^+$ $[M+H]^+$ 413.1794, found 413.1794.

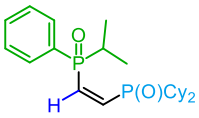


(7ax) White solid (m.p.: 77 - 79 °C); 82% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.86 – 7.81 (m, 2H), 7.48 – 7.40 (m, 3H), 6.97 (dt, *J* = 36.2, 14.8 Hz, 1H), 6.46 (dt, *J* = 39.3, 15.3 Hz, 1H), 3.16 – 3.09 (m, 1H), 2.62 (s, 1H), 2.19 – 2.10 (m, 1H), 2.02 – 1.86 (m, 4H), 1.82 – 1.77 (m, 3H), 1.74 – 1.52 (m, 10H), 1.48 – 1.32 (m, 4H), 1.24 – 1.19 (m, 2H), 1.15 – 0.84 (m, 5H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 144.2 (d, *J* = 86.0 Hz), 141.5 (d, *J* = 75.5 Hz), 132.8 (d,

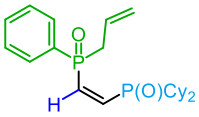
J = 97.4 Hz), 131.6 (d, *J* = 2.1 Hz), 131.3 (d, *J* = 9.2 Hz), 128.3 (d, *J* = 11.6 Hz), 37.8 – 36.4 (m), 27.0 (d, *J* = 8.7 Hz), 26.6 (d, *J* = 8.7 Hz), 26.5 – 26.1 (m), 25.9 (d, *J* = 3.1 Hz), 25.8, 25.7, 25.4 (d, *J* = 3.1 Hz), 25.1 (d, *J* = 3.3 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 46.9 (d, *J* = 14.0 Hz), 33.5 (d, *J* = 13.7 Hz). HRMS (ESI) calcd for $C_{25}H_{39}O_2P_2^+$ $[M+H]^+$ 433.2420, found 433.2419.



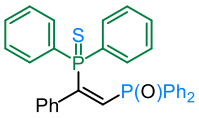
(7ay) White solid (m.p.: 160 - 162 ℃); 70% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 6.95 – 6.81 (m, 1H), 6.35 – 6.16 (m, 1H), 2.83 – 2.73 (m, 2H), 1.87 – 1.27 (m, 32H), 1.21 – 1.12 (m, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 149.7 (d, *J* = 77.4 Hz), 136.9 (d, *J* = 77.3 Hz), 38.8 (d, *J* = 69.8 Hz), 36.4 (d, *J* = 68.2 Hz), 27.6 (d, *J* = 2.2 Hz), 26.5 – 25.9 (m), 25.7 (d, *J* = 0.9 Hz), 25.0 (d, *J* = 3.2 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 46.9, 44.5. HRMS (ESI) calcd for $C_{24}H_{43}O_2P_2^+$ $[M+H]^+$ 425.2733, found 425.2740.



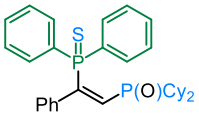
(7az) White solid (m.p.: 114 - 116 ℃); 70% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.77 – 7.72 (m, 2H), 7.44 – 7.36 (m, 3H), 7.00 – 6.82 (m, 1H), 6.63 – 6.45 (m, 1H), 2.76 – 2.67 (m, 1H), 2.22 – 2.14 (m, 1H), 2.08 – 2.00 (m, 1H), 1.93 – 1.88 (m, 1H), 1.73 – 1.59 (m, 6H), 1.49 – 1.14 (m, 12H), 1.07 – 0.77 (m, 7H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 143.4 (d, *J* = 74.7 Hz), 142.2 (d, *J* = 85.0 Hz), 131.7 (d, *J* = 2.5 Hz), 131.3 (d, *J* = 95.9 Hz), 131.2 (d, *J* = 8.8 Hz), 128.4 (d, *J* = 11.5 Hz), 37.5 (d, *J* = 67.1 Hz), 36.7 (d, *J* = 67.0 Hz), 28.1 (d, *J* = 73.3 Hz), 26.4 – 25.3 (m), 15.3 (d, *J* = 3.1 Hz), 14.9 (d, *J* = 2.4 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 47.9, 35.3 (d, *J* = 11.8 Hz). HRMS (ESI) calcd for $C_{23}H_{37}O_2P_2^+$ $[M+H]^+$ 407.2263, found 407.2257.



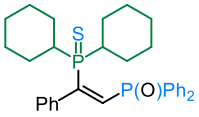
(7ba) White solid (m.p.: 74 - 76 ℃); 37% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.90 – 7.85 (m, 2H), 7.47 – 7.39 (m, 3H), 7.14 – 6.97 (m, 1H), 6.54 – 6.35 (m, 1H), 5.80 – 5.68 (m, 1H), 5.19 – 5.11 (m, 2H), 3.63 – 3.54 (m, 1H), 3.40 – 3.30 (m, 1H), 1.96 – 1.90 (m, 2H), 1.81 – 1.24 (m, 14H), 1.16 – 1.01 (m, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 145.9 (d, *J* = 87.8 Hz), 139.6 (d, *J* = 75.2 Hz), 132.3 (d, *J* = 104.4 Hz) (overlap one peak of 131.8), 131.8, 131.3 (d, *J* = 9.5 Hz), 128.3 (d, *J* = 12.1 Hz), 127.0 (d, *J* = 10.1 Hz), 121.1 (d, *J* = 12.6 Hz), 36.5 (d, *J* = 68.6 Hz), 36.21 (d, *J* = 67.9 Hz), 36.18 (d, *J* = 68.3 Hz), 26.4 – 25.7 (m), 25.1 (d, *J* = 3.2 Hz), 24.8 (d, *J* = 3.2 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 45.9, 27.6 (d, *J* = 14.5 Hz). HRMS (ESI) calcd for $C_{23}H_{35}O_2P_2^+$ $[M+H]^+$ 405.2107, found 405.2109.



(8a) White solid (m.p.: 176 - 178 ℃); 70% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.85 (dd, *J* = 13.7, 7.5 Hz, 4H), 7.58 (dd, *J* = 12.0, 7.3 Hz, 4H), 7.46 (t, *J* = 7.5 Hz, 2H), 7.39 (td, *J* = 7.6, 2.8 Hz, 4H), 7.31 – 7.09 (m, 11H) (overlap one peak of 7.26), 6.97 (dd, *J* = 38.0, 19.3 Hz, 1H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 157.3 (d, *J* = 66.8 Hz), 141.7 (dd, *J* = 16.2, 10.4 Hz), 137.2 (dd, *J* = 92.5, 8.8 Hz), 133.6(d, *J* = 107.8 Hz), 132.6 (d, *J* = 86.2 Hz), 132.4 (d, *J* = 10.8 Hz), 131.7 (d, *J* = 2.6 Hz), 131.0 – 130.9 (m), 128.6 (d, *J* = 12.3 Hz), 128.1, 128.0 (d, *J* = 3.7 Hz), 127.9 – 127.7 (m); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 40.5 (d, *J* = 13.0 Hz), 16.2 (d, *J* = 13.6 Hz). HRMS (ESI) calcd for $C_{32}H_{27}OP_2S^+$ $[M+H]^+$ 521.1252, found 521.1252.

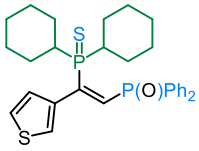


(8b) White solid (m.p.: 242 - 243 ℃); 83% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.88 (dd, *J* = 13.4, 7.4 Hz, 4H), 7.35 – 7.29 (m, 6H), 7.12 (s, 5H), 6.40 (dd, *J* = 39.2, 19.2 Hz, 1H), 1.87 – 1.69 (m, 12H), 1.47 – 1.35 (m, 4H), 1.27 – 1.14 (m, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 158.3 (d, *J* = 68.0 Hz), 142.3 (dd, *J* = 14.1, 10.8 Hz), 137.8 (dd, *J* = 73.9, 10.3 Hz), 133.6 (d, *J* = 86.1 Hz), 132.2 (d, *J* = 10.4 Hz), 130.9 (d, *J* = 2.8 Hz), 127.9 – 127.7 (m), 37.6 (d, *J* = 68.7 Hz), 26.7 – 26.4 (m), 25.9, 25.8 (d, *J* = 2.2 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 40.2, 39.4 (d, *J* = 11.6 Hz). HRMS (ESI) calcd for $C_{32}H_{39}OP_2S^+$ $[M+H]^+$ 533.2191, found 533.2189.

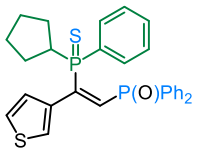


(8c) White solid (m.p.: 253 - 255 ℃); 68% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.77 – 7.72 (m, 4H), 7.59 – 7.49 (m, 6H), 7.34 – 7.30 (m, 3H), 7.21 – 7.19 (m, 2H), 6.94 (dd, *J* = 31.5, 21.6 Hz, 1H), 3.56 – 3.46 (m, 2H), 1.96 – 1.93 (m, 2H), 1.78 – 1.48 (m, 12H), 1.42 – 1.32 (m, 2H), 1.20 – 1.10 (m, 2H), 1.01 – 0.92 (m, 2H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 156.8 (d, *J* = 44.4 Hz), 142.7 (dd, *J* = 17.2, 8.1 Hz), 133.8 (dd, *J* = 92.7, 7.8 Hz), 133.5, 132.4 (d, *J* =

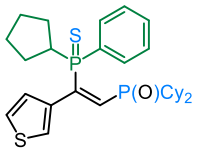
2.6 Hz), 130.9 (d, *J* = 9.5 Hz), 129.1 (d, *J* = 12.2 Hz), 128.7 (d, *J* = 2.9 Hz), 128.0, 127.3, 40.5 (d, *J* = 45.9 Hz), 27.8 (d, *J* = 2.3 Hz), 27.3 (d, *J* = 3.0 Hz), 26.2 – 26.0 (m), 25.6; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 67.8 (d, *J* = 9.8 Hz), 18.1 (d, *J* = 8.9 Hz). HRMS (ESI) calcd for $C_{32}H_{39}OP_2S^+$ $[M+H]^+$ 533.2191, found 533.2190.



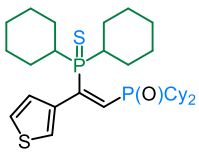
(8d) Yellow solid (m.p.: 212 - 214 ℃); 89% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.78 – 7.73 (m, 4H), 7.60 – 7.50 (m, 6H), 7.28 (d, *J* = 1.4 Hz, 1H), 7.21 (dd, *J* = 4.9, 3.1 Hz, 1H), 7.10 (d, *J* = 5.0 Hz, 1H), 6.98 (dd, *J* = 31.3, 21.1 Hz, 1H), 3.56 – 3.48 (m, 2H), 1.95 (d, *J* = 12.4 Hz, 2H), 1.78 – 1.76 (m, 2H), 1.72 – 1.49 (m, 10H), 1.42 – 1.32 (m, 2H), 1.20 – 1.10 (m, 2H), 0.98 – 0.88 (m, 2H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 151.9 (d, *J* = 45.9 Hz), 142.9 (dd, *J* = 18.1, 8.8 Hz), 133.4 – 132.4 (m), 130.9 (d, *J* = 9.6 Hz), 129.1 (d, *J* = 12.2 Hz), 129.0, 124.84 (d, *J* = 4.4 Hz), 123.9, 40.4 (d, *J* = 46.0 Hz), 27.6 (d, *J* = 2.3 Hz), 27.0 (d, *J* = 3.0 Hz), 26.1 (d, *J* = 9.9 Hz), 26.0 (d, *J* = 10.1 Hz), 25.6; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 67.8 (d, *J* = 8.3 Hz), 18.4 (d, *J* = 8.7 Hz). HRMS (ESI) calcd for $C_{30}H_{37}OP_2S_2$ $[M+H]^+$ 539.1756, found 539.1749.



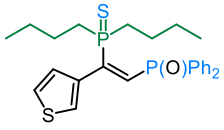
(8e) Yellow oil; 75% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.99 – 7.94 (m, 2H), 7.71 – 7.66 (m, 2H), 7.54 – 7.42 (m, 6H), 7.37 – 7.26 (m, 6H) (overlap one peak of 7.26), 7.21 (dd, *J* = 4.9, 3.1 Hz, 1H), 7.07 (d, *J* = 4.9 Hz, 1H), 6.85 (dd, *J* = 35.2, 19.2 Hz, 1H), 4.32 – 4.22 (m, 1H), 1.85 – 1.74 (m, 2H), 1.69 – 1.65 (m, 1H), 1.59 – 1.45 (m, 5H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 153.0 (d, *J* = 57.7 Hz), 142.2 (dd, *J* = 17.9, 10.7 Hz), 134.6 (dd, *J* = 93.0, 8.9 Hz), 134.1 – 132.5 (m) (overlap one peak of 134.6), 132.1 – 132.0 (m), 131.8 (d, *J* = 2.6 Hz), 131.1 (d, *J* = 2.9 Hz), 130.9 (d, *J* = 9.7 Hz), 130.7 (d, *J* = 9.8 Hz), 128.9 (d, *J* = 12.2 Hz), 128.8 (d, *J* = 2.3 Hz), 128.6 (d, *J* = 12.4 Hz), 128.0 (d, *J* = 12.1 Hz), 124.7, 124.6 (d, *J* = 4.5 Hz), 38.7 (d, *J* = 53.9 Hz), 28.3, 27.6, 26.7 (d, *J* = 10.9 Hz), 26.6 (d, *J* = 10.3 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 54.2 (d, *J* = 11.9 Hz), 17.8 (d, *J* = 12.0 Hz). HRMS (ESI) calcd for $C_{29}H_{29}OP_2S_2^+$ $[M+H]^+$ 519.1130, found 519.1129.



(8f) Yellow solid (m.p.: 164 - 166 ℃); 76% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.94 (dd, *J* = 12.5, 7.6 Hz, 2H), 7.41 – 7.38 (m, 3H), 7.26 – 7.25 (m, 1H) (overlap one peak of 7.26), 7.17 (s, 1H), 7.08 (d, *J* = 4.8 Hz, 1H), 6.20 (dd, *J* = 35.9, 18.5 Hz, 1H), 4.44 – 4.35 (m, 1H), 1.98 – 1.79 (m, 9H), 1.72 – 1.61 (m, 8H), 1.50 – 1.41 (m, 5H), 1.25 (s, 3H), 1.09 – 0.97 (m, 5H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 154.0 (d, *J* = 57.7 Hz), 142.8 (dd, *J* = 15.4, 11.3 Hz), 135.0 (d, *J* = 78.9 Hz), 134.5 (dd, *J* = 74.8, 10.3 Hz), 132.3 (d, *J* = 10.1 Hz), 130.8 (d, *J* = 2.8 Hz), 129.0 (d, *J* = 1.7 Hz), 127.8 (d, *J* = 12.1 Hz), 124.3, 124.0 (d, *J* = 4.5 Hz), 38.0 (d, *J* = 53.4 Hz), 37.2 (dd, *J* = 69.1, 2.8 Hz), 28.1, 27.9, 26.9 – 25.7 (m), 25.4 (d, *J* = 2.8 Hz), 25.1 (d, *J* = 2.7 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 54.2 (d, *J* = 10.3 Hz), 41.8 (d, *J* = 8.9 Hz). HRMS (ESI) calcd for $C_{29}H_{41}OP_2S_2^+$ $[M+H]^+$ 531.2069, found 531.2067.

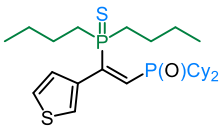


(8g) Yellow solid (m.p.: 215 - 217 ℃); 88% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.22 – 7.20 (m, 2H), 7.06 – 7.05 (m, 1H), 6.28 (dd, *J* = 31.9, 20.3 Hz, 1H), 3.41 (s, 2H), 2.04 – 1.87 (m, 12H), 1.75 – 1.63 (m, 14H), 1.47 – 1.36 (m, 6H), 1.26 – 1.15 (m, 10H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 153.3 (d, *J* = 47.0 Hz), 142.4 (dd, *J* = 15.7, 8.8 Hz), 131.2 (d, *J* = 71.3 Hz), 128.0 (d, *J* = 1.9 Hz), 123.3 (d, *J* = 4.3 Hz), 122.8, 39.8 (d, *J* = 45.7 Hz), 36.4 (d, *J* = 69.2 Hz), 26.4 (d, *J* = 2.7 Hz), 26.1 (d, *J* = 2.9 Hz), 25.7 – 25.4 (m), 25.1 (d, *J* = 2.6 Hz), 24.9 (d, *J* = 2.5 Hz), 24.8, 24.8 (d, *J* = 3.0 Hz), 24.6; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 68.1, 42.1. HRMS (ESI) calcd for $C_{30}H_{49}OP_2S_2^+$ $[M+H]^+$ 551.2695, found 551.2691.

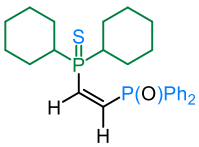


(8h) Yellow solid (m.p.: 91 - 93 ℃); 75% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.76 – 7.71 (m, 4H), 7.57 – 7.47 (m, 6H), 7.41 – 7.40 (m, 1H), 7.25 (dd, *J* = 5.0, 3.1 Hz, 1H), 7.16 (d, *J* = 4.9 Hz, 1H), 6.92 (dd, *J* = 33.3, 20.1 Hz, 1H), 2.90 – 2.79 (m, 2H), 2.39 – 2.29 (m, 2H), 1.73 – 1.60 (m, 2H), 1.46 – 1.35 (m, 2H), 1.33 – 1.24 (m, 2H), 1.20 – 1.13 (m, 2H), 0.78 (t, *J* = 7.3 Hz, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 151.8 (d, *J* = 52.0 Hz), 142.3 (dd, *J* = 18.0, 10.1 Hz), 133.9 (dd, *J* = 92.8, 8.6 Hz), 133.1 (d, *J* = 107.8 Hz), 132.3 (d, *J* = 2.7 Hz), 130.9 (d, *J* = 9.6 Hz), 129.0 (d, *J* = 12.3 Hz), 128.8 (d, *J* = 2.2 Hz), 125.0 (d, *J* = 4.5 Hz), 124.6, 33.8 (d, *J* = 50.9 Hz), 24.7 (d, *J* = 4.1 Hz), 23.7

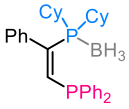
(d, J = 17.5 Hz), 13.7; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 51.9 (d, J = 11.8 Hz), 18.6 (d, J = 10.6 Hz). HRMS (ESI) calcd for $C_{26}H_{33}OP_2S_2^+$ $[M+H]^+$ 487.1433, found 487.1433.



(8i) White solid (m.p.: 174 - 176 ℃); 73% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.24 – 7.23 (m, 2H), 7.08 – 7.06 (m, 1H), 6.19 (dd, J = 33.6, 20.1 Hz, 1H), 2.83 – 2.73 (m, 2H), 2.45 – 2.34 (m, 2H), 2.01 – 1.98 (m, 2H), 1.87 – 1.73 (m, 12H), 1.57 – 1.30 (m, 12H), 1.25 – 1.17 (m, 4H), 0.90 (t, J = 7.2 Hz, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 153.4 (d, J = 51.8 Hz), 143.0 (dd, J = 15.5, 10.4 Hz), 132.8 (dd, J = 74.3, 9.4 Hz), 128.9 (d, J = 1.9 Hz), 124.2 – 124.1 (m), 36.5 (d, J = 69.7 Hz), 34.1 (d, J = 50.9 Hz), 26.6 – 26.2 (m), 25.8, 25.2 (d, J = 3.0 Hz), 24.9 (d, J = 4.0 Hz), 23.9 (d, J = 18.2 Hz), 13.9; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 51.3 (d, J = 10.0 Hz), 42.4 (d, J = 7.3 Hz). HRMS (ESI) calcd for $C_{26}H_{45}OP_2S_2^+$ $[M+H]^+$ 499.2382, found 499.2372.

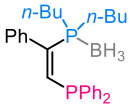


(8j) White solid (m.p.: 199 - 201 ℃); 59% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.71 – 7.66 (m, 4H), 7.58 – 7.54 (m, 2H), 7.50 – 7.46 (m, 4H), 6.99 – 6.74 (m, 2H), 3.13 – 3.04 (m, 2H), 1.91 – 1.88 (m, 2H), 1.78 – 1.75 (m, 2H), 1.59 – 1.41 (m, 10H), 1.38 – 1.27 (m, 2H), 1.18 – 0.97 (m, 4H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 148.6 (d, J = 56.1 Hz), 135.8 (dd, J = 94.1, 2.3 Hz), 132.4 (d, J = 2.6 Hz), 132.2 (d, J = 106.7 Hz), 130.9 (d, J = 9.7 Hz), 129.0 (d, J = 12.3 Hz), 39.0 (d, J = 46.8 Hz), 27.1 (d, J = 3.3 Hz), 27.0 (d, J = 2.3 Hz), 26.1 (d, J = 5.0 Hz), 26.0 (d, J = 4.7 Hz), 25.6 (d, J = 1.2 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 60.7 (d, J = 18.0 Hz), 18.8 (d, J = 18.0 Hz). HRMS (ESI) calcd for $C_{26}H_{35}OP_2S^+$ $[M+H]^+$ 457.1878, found 457.1877.

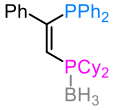


(10a) White solid (m.p.: 160 - 162 ℃); 60% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.35 – 7.12 (m, 16H), 2.84 – 2.73 (m, 2H), 1.90 – 1.87 (m, 2H), 1.76 – 1.69 (m, 4H), 1.60 – 1.36 (m, 8H), 1.20 – 1.04 (m, 4H), 0.93 – 0.83 (m, 2H), 0.54 – -0.22 (m, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 150.4 (dd, J = 34.4, 26.1 Hz), 147.2 (d, J = 18.8 Hz), 143.7 (dd, J = 13.4, 10.7 Hz), 137.9 (d, J = 8.8 Hz), 132.7 (d, J = 19.1 Hz), 129.2, 128.9 (d, J = 6.9 Hz), 128.3 (d, J = 3.1 Hz), 127.61, 127.59, 36.5 (dd, J = 29.8, 15.0 Hz), 28.5, 28.0, 26.9 (d, J = 11.9 Hz), 26.7 (d, J = 11.5 Hz), 25.8 (d, J = 1.1 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 35.0, -30.2; **^{11}B NMR** (128 MHz, $CDCl_3$) δ -42.0. HRMS (ESI) calcd for $C_{32}H_{42}BP_2^+$ $[M+H]^+$ 499.2849, found 499.2846.

(10b) White solid (m.p.: 100 - 102 ℃); 70% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.32 – 7.17 (m, 13H), 7.13 – 7.05 (m, 3H), 3.17 – 3.04 (m, 2H), 1.87 – 1.77 (m, 4H), 1.70 – 1.42 (m, 10H), 1.34 – 1.26 (m, 2H), 0.69 – -0.09 (m, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 151.1 (dd, J = 36.5, 25.0 Hz), 146.0 (dd, J = 19.8, 1.5 Hz), 142.5 (dd, J = 13.0, 10.6 Hz), 137.1 (d, J = 9.0 Hz), 131.5 (d, J = 18.9 Hz), 128.0, 127.8 (d, J = 6.7 Hz), 127.2 (d, J = 2.9 Hz), 126.55, 126.50, 35.5 (dd, J = 33.1, 15.2 Hz), 28.3 (d, J = 2.5 Hz), 27.4 (d, J = 3.9 Hz), 25.7 (d, J = 9.8 Hz), 24.7 (d, J = 10.1 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 35.0, -30.1; **^{11}B NMR** (128 MHz, $CDCl_3$) δ -43.9. HRMS (ESI) calcd for $C_{30}H_{38}BP_2^+$ $[M+H]^+$ 471.2536, found 471.2535.

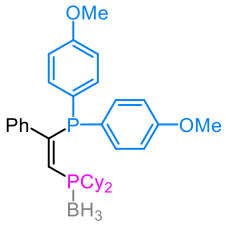


(10c) Colorless oil; 64% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.52 – 7.48 (m, 4H), 7.42 – 7.31 (m, 11H), 7.18 (dd, J = 30.0, 3.7 Hz, 1H), 2.12 – 2.05 (m, 4H), 1.54 – 1.45 (m, 4H), 1.34 – 1.25 (m, 4H), 1.06 – 0.27 (m, 9H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 150.2 (dd, J = 37.7, 27.1 Hz), 146.7 (dd, J = 20.8, 7.3 Hz), 142.6 – 142.4 (m), 138.2 (d, J = 9.7 Hz), 132.8 (d, J = 19.0 Hz), 129.0, 128.8 (d, J = 6.6 Hz), 128.2, 128.0, 127.8 (d, J = 2.7 Hz), 25.6 (dd, J = 34.2, 12.0 Hz), 25.2 (d, J = 2.2 Hz), 24.3 (d, J = 13.7 Hz), 13.6; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 20.6, -29.6 (d, J = 5.7 Hz); **^{11}B NMR** (128 MHz, $CDCl_3$) δ -36.6. HRMS (ESI) calcd for $C_{28}H_{38}BP_2^+$ $[M+H]^+$ 447.2536, found 447.2531.

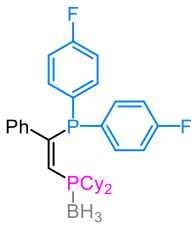


(10d) White solid (m.p.: 158 - 160 ℃); 60% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.36 – 7.27 (m, 10H), 7.12 (t, J = 7.2 Hz, 1H), 7.04 (t, J = 7.4 Hz, 2H), 6.80 (d, J = 7.4 Hz, 2H), 6.53 (dd, J = 36.7, 12.8 Hz, 1H), 2.38 – 2.29 (m, 2H), 2.06 – 1.96 (m, 4H), 1.88 – 1.82 (m, 4H), 1.76 – 1.71 (m, 2H), 1.61 – 1.52 (m, 4H), 1.31 – 1.21 (m, 6H), 0.91 – 0.61 (m, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 160.1 (d, J = 32.7 Hz), 142.8 (dd, J = 12.8, 4.3 Hz), 136.8 (dd, J = 42.9, 39.7 Hz), 135.4

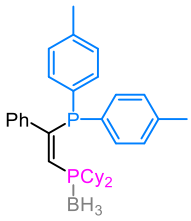
(d, *J* = 13.1 Hz), 133.4 (d, *J* = 19.3 Hz), 128.6, 128.2 (d, *J* = 6.4 Hz), 127.8, 127.5, 127.4, 34.7 (dd, *J* = 32.9, 6.3 Hz), 27.4 (d, *J* = 9.7 Hz), 26.9 (d, *J* = 11.3 Hz), 26.0; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 21.7, -5.7 (d, *J* = 13.8 Hz); **^{11}B NMR** (128 MHz, $CDCl_3$) δ -39.6. HRMS (ESI) calcd for $C_{32}H_{42}BP_2^+$ $[M+H]^+$ 499.2849, found 499.2838.



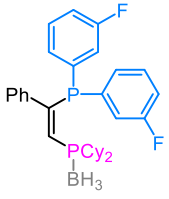
(10e) White solid (m.p.: 133 - 135 ℃); 45% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.22 (t, *J* = 15.4 Hz, 4H), 7.12 (t, *J* = 7.3 Hz, 1H), 7.04 (t, *J* = 7.6 Hz, 2H), 6.79 (d, *J* = 8.1 Hz, 4H), 6.74 (d, *J* = 7.3 Hz, 2H), 6.40 (dd, *J* = 36.5, 13.6 Hz, 1H), 3.78 (s, 6H), 2.39 – 2.30 (m, 2H), 2.04 – 1.94 (m, 4H), 1.87 – 1.80 (m, 4H), 1.74 – 1.69 (m, 2H), 1.55 – 1.52 (m, 4H), 1.30 – 1.21 (m, 6H), 0.98 – 0.33 (m, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 161.2 (d, *J* = 33.5 Hz), 160.2, 143.2 (dd, *J* = 13.0, 4.6 Hz), 135.8 (dd, *J* = 43.2, 40.1 Hz), 135.0 (d, *J* = 20.9 Hz), 127.8, 127.5, 127.3, 126.4 (d, *J* = 10.2 Hz), 113.9 (d, *J* = 7.4 Hz), 55.2, 34.7 (dd, *J* = 32.9, 6.9 Hz), 27.6, 27.4, 27.0, 26.9, 26.0; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 21.6, -8.9 (d, *J* = 13.8 Hz); **^{11}B NMR** (128 MHz, $CDCl_3$) δ -39.6. HRMS (ESI) calcd for $C_{34}H_{46}BO_2P_2^+$ $[M+H]^+$ 559.3061, found 559.3053.



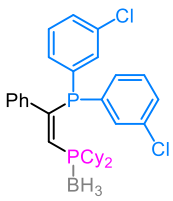
(10f) White solid (m.p.: 128 - 130 ℃); 63% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.29 – 7.23 (m, 4H) (overlap one peak of 7.26), 7.12 (t, *J* = 7.4 Hz, 1H), 7.04 (t, *J* = 7.8 Hz, 2H), 6.96 – 6.92 (m, 4H), 6.69 (d, *J* = 7.2 Hz, 2H), 6.47 (dd, *J* = 36.1, 10.1 Hz, 1H), 2.24 – 2.16 (m, 2H), 2.05 – 1.73 (m, 10H), 1.57 – 1.47 (m, 4H), 1.30 – 1.21 (m, 6H), 0.94 – 0.34 (m, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 163.3 (d, *J* = 250.2 Hz), 160.4 (dd, *J* = 33.4, 2.9 Hz), 142.7 (dd, *J* = 12.9, 4.5 Hz), 137.1 – 136.3 (m), 135.4 (dd, *J* = 21.1, 8.0 Hz), 130.9 (dd, *J* = 13.6, 3.4 Hz), 127.7, 127.58, 127.55, 115.5 (dd, *J* = 21.0, 7.0 Hz), 34.6 (dd, *J* = 33.2, 4.8 Hz), 27.34, 27.28, 27.0 (d, *J* = 4.3 Hz), 26.9 (d, *J* = 5.1 Hz), 26.0; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 21.6, -7.53 – -7.69 (m); **^{19}F NMR** (376 MHz, $CDCl_3$) δ -112.0 (d, *J* = 4.9 Hz); **^{11}B NMR** (128 MHz, $CDCl_3$) δ -39.4. HRMS (ESI) calcd for $C_{32}H_{40}BF_2P_2^+$ $[M-BH_2]^+$ 521.2334, found 521.2329.



(10g) White solid (m.p.: 148 - 150 ℃); 56% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.21 – 7.00 (m, 11H), 6.77 (d, *J* = 7.4 Hz, 2H), 6.45 (dd, *J* = 36.8, 13.9 Hz, 1H), 2.39 – 2.31 (m, 8H), 2.03 – 1.93 (m, 4H), 1.84 – 1.79 (m, 4H), 1.73 – 1.68 (m, 2H), 1.57 – 1.50 (m, 4H), 1.29 – 1.22 (m, 6H), 0.84 – 0.23 (m, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 160.5 (d, *J* = 32.9 Hz), 143.0 (dd, *J* = 12.7, 4.5 Hz), 138.5, 136.5 (dd, *J* = 43.2, 40.0 Hz), 133.5 (d, *J* = 19.6 Hz), 131.9 (d, *J* = 11.7 Hz), 129.0 (d, *J* = 6.6 Hz), 127.8, 127.5, 127.3, 34.7 (dd, *J* = 32.9, 6.9 Hz), 27.5 (d, *J* = 13.0 Hz), 26.9 (d, *J* = 11.3 Hz), 26.0, 21.3; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 21.8, -7.1 (d, *J* = 13.2 Hz); **^{11}B NMR** (128 MHz, $CDCl_3$) δ -40.1. HRMS (ESI) calcd for $C_{34}H_{46}BP_2^+$ $[M-BH_2]^+$ 513.2835, found 513.2844.

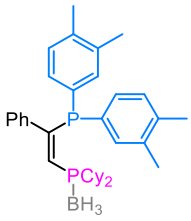


(10h) White solid (m.p.: 155 - 156 ℃); 57% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.27 – 7.21 (m, 2H), 7.15 – 7.11 (m, 3H), 7.07 – 7.03 (m, 2H), 7.01 – 6.94 (m, 4H), 6.77 (d, *J* = 7.2 Hz, 2H), 6.57 (dd, *J* = 36.5, 9.4 Hz, 1H), 2.23 – 2.14 (m, 2H), 2.06 – 1.74 (m, 10H), 1.58 – 1.49 (m, 4H), 1.34 – 1.20 (m, 6H), 1.01 – 0.25 (m, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 162.5 (dd, *J* = 249.8, 7.3 Hz), 159.4 (dd, *J* = 33.3, 2.9 Hz), 142.4 (dd, *J* = 12.6, 4.3 Hz), 138.1 – 137.1 (m), 130.0 - 129.8 (m), 129.2 (dd, *J* = 21.6, 2.9 Hz), 127. 8, 127.5, 119.8 (dd, *J* = 21.8, 18.2 Hz), 115.8 (d, *J* = 21.3 Hz), 34.6 (dd, *J* = 33.2, 4.4 Hz), 27.31, 27.25, 27.0 (d, *J* = 4.9 Hz), 26.9 (d, *J* = 5.8 Hz), 26.0; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 21.9, -5.0 (d, *J* = 15.4 Hz); **^{19}F NMR** (376 MHz, $CDCl_3$) δ -112.3; **^{11}B NMR** (128 MHz, $CDCl_3$) δ -39.4. HRMS (ESI) calcd for $C_{32}H_{40}BF_2P_2^+$ $[M+H]^+$ 535.2661, found 535.2671.

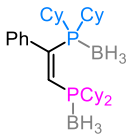


(10i) White solid (m.p.: 161 - 163 ℃); 54% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.25 – 7.03 (m, 11H), 6.73 – 6.71 (m, 2H), 6.55 (dd, *J* = 36.1, 9.2 Hz, 1H), 2.20 – 2.11 (m, 2H), 2.04 – 1.73 (m, 10H), 1.56 – 1.47 (m, 4H), 1.33 – 1.20 (m, 6H), 1.09 – 0.20 (m, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 159.4 (dd, *J* = 33.4, 3.1 Hz), 142.3 (dd, *J* = 12.8, 4.3 Hz), 137.6 (d, *J* = 17.5 Hz), 137.8 – 137.0 (m), 134.5 (d, *J* = 6.3 Hz), 132.9 (d, *J* = 18.9 Hz), 131.5 (d, *J* = 21.1 Hz), 129.6 (d, *J* = 7.0 Hz), 128.9, 127.8, 127.5, 34.5 (dd, *J* = 33.4, 4.3 Hz), 27.3, 27.2, 27.0 (d, *J* =

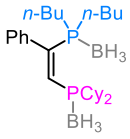
5.8 Hz), 26.9 (d, J = 6.9 Hz), 26.0; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 21.9, -4.8 (d, J = 15.0 Hz); **^{11}B NMR** (128 MHz, $CDCl_3$) δ -39.7. HRMS (ESI) calcd for $C_{32}H_{40}BCl_2P_2^+$ $[M+H]^+$ 567.2070, found 567.2072.



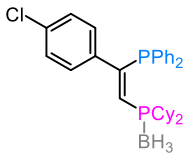
(10j) White solid (m.p.: 115 - 117 °C); 61% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.12 – 6.98 (m, 9H), 6.78 – 6.76 (m, 2H), 6.43 (dd, J = 37.1, 15.4 Hz, 1H), 2.46 – 2.37 (m, 2H), 2.23 (s, 6H), 2.15 (s, 6H), 2.06 – 1.95 (m, 4H), 1.86 – 1.72 (m, 4H), 1.72 – 1.70 (m, 2H), 1.60 – 1.49 (m, 4H), 1.30 – 1.24 (m, 6H), 0.98 – 0.31 (m, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 160.8 (d, J = 32.8 Hz), 143.2 (dd, J = 12.8, 4.5 Hz), 137.2, 136.8 – 136.0 (m), 134.7 (d, J = 20.5 Hz), 132.2 (d, J = 11.0 Hz), 131.0 (d, J = 18.6 Hz), 129.5 (d, J = 6.7 Hz), 127.9, 127.4, 127.3, 34.8 (dd, J = 32.8, 7.8 Hz), 27.6 (d, J = 17.0 Hz), 26.9 (d, J = 11.4 Hz), 26.0, 19.7, 19.6; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 21.8, -7.2 (d, J = 12.9 Hz); **^{11}B NMR** (128 MHz, $CDCl_3$) δ -40.4. HRMS (ESI) calcd for $C_{36}H_{50}BP_2^+$ $[M-BH_2]^+$ 541.3148, found 541.3138.



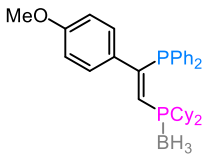
(10k) White solid (m.p.: 173 - 175 °C); 40% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.34 – 7.26 (m, 3H), 7.12 (d, J = 6.1 Hz, 2H), 6.48 (d, J = 24.8 Hz, 1H), 3.12 – 3.03 (m, 2H), 2.01 – 1.44 (m, 29H), 1.38 – -0.20 (m, 19H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 157.9 (dd, J = 30.5, 2.4 Hz), 145.0 (t, J = 13.0 Hz), 135.5 (d, J = 32.8 Hz), 127.9, 127.7, 35.2 (d, J = 29.3 Hz), 35.1 (d, J = 35.7 Hz), 28.23, 28.16, 27.2, 27.0 – 26.8 (m), 26.4 – 26.2 (m), 26.0, 25.7; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 33.7, 19.1, **^{11}B NMR** (128 MHz, $CDCl_3$) δ -39.1, -42.9. HRMS (ESI) calcd for $C_{32}H_{54}BP_2^+$ $[M-BH_2]^+$ 511.3789, found 511.3782.



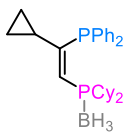
(10l) White solid (m.p.: 120 - 122 °C); 65% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.39 – 7.34 (m, 3H), 7.16 – 7.14 (m, 2H), 6.38 (d, J = 28.6 Hz, 1H), 2.14 – 1.72 (m, 16H), 1.47 – 1.38 (m, 8H), 1.34 – 1.21 (m, 10H), 0.93 – 0.17 (m, 12H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 156.0 (dd, J = 32.8, 1.9 Hz), 143.8 (dd, J = 12.4, 9.7 Hz), 136.7 (dd, J = 33.8, 4.7 Hz), 128.2, 128.1, 127.3 (d, J = 1.9 Hz), 34.7 (d, J = 34.8 Hz), 27.1 – 26.7 (m), 26.0, 25.30, 25.28, 25.0, 24.2 (d, J = 14.5 Hz), 13.7; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 19.7, 19.0; **^{11}B NMR** (128 MHz, $CDCl_3$) δ -37.4, -39.3. HRMS (ESI) calcd for $C_{28}H_{50}BP_2^+$ $[M-BH_2]^+$ 459.3476, found 459.3470.



(10m) White solid (m.p.: 160 - 162 °C); 65% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.32 – 7.22 (m, 10H), 6.97 (d, J = 8.6 Hz, 2H), 6.69 (d, J = 8.5 Hz, 2H), 6.48 (dd, J = 36.5, 12.7 Hz, 1H), 2.35 – 2.26 (m, 2H), 2.02 – 1.69 (m, 10H), 1.57 – 1.47 (m, 4H), 1.26 – 1.15 (m, 6H), 0.95 – 0.40 (m, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 158.8 (d, J = 33.5 Hz), 141.1 (dd, J = 12.9, 4.6 Hz), 137.6 (dd, J = 41.9, 39.7 Hz), 135.0 (d, J = 13.3 Hz), 133.5 – 133.2 (m), 129.1, 128.8, 128.4 (d, J = 6.4 Hz), 127.7, 34.7 (dd, J = 32.7, 6.5 Hz), 27.53, 27.45, 27.0, 26.9, 26.0; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 22.6, -6.2 (d, J = 13.6 Hz); **^{11}B NMR** (128 MHz, $CDCl_3$) δ -39.8. HRMS (ESI) calcd for $C_{32}H_{41}BClP_2^+$ $[M-BH_2]^+$ 519.2132, found 519.2127.

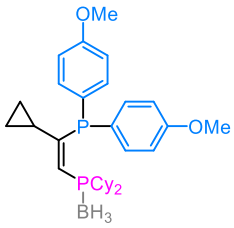


(10n) Colorless oil; 63% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.27 – 7.23 (m, 4H), 7.19 – 7.15 (m, 6H), 6.70 (d, J = 8.7 Hz, 2H), 6.49 – 6.35 (m, 3H), 3.60 (s, 3H), 2.29 – 2.20 (m, 2H), 1.93 – 1.83 (m, 4H), 1.74 – 1.68 (m, 4H), 1.61 – 1.60 (m, 2H), 1.49 – 1.39 (m, 4H), 1.17 – 1.03 (m, 6H), 0.80 – 0.33 (m, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 159.18, 159.15 (d, J = 31.6 Hz), 136.0 (dd, J = 43.5, 40.3 Hz), 135.5 (d, J = 13.2 Hz), 135.1 (dd, J = 13.0, 4.3 Hz), 133.2 (d, J = 19.2 Hz), 129.3, 128.5, 128.2 (d, J = 6.4 Hz), 113.0, 55.2, 34.8 (dd, J = 32.9, 7.0 Hz), 27.6, 27.5, 27.0, 26.8, 26.0; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 21.9, -5.8 (d, J = 14.6 Hz); **^{11}B NMR** (128 MHz, $CDCl_3$) δ -39.9. HRMS (ESI) calcd for $C_{33}H_{44}BOP_2^+$ $[M+H]^+$ 529.2955, found 529.2953.

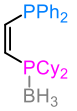


(10o) White solid (m.p.: 136 - 138 °C); 64% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.44 – 7.39 (m, 4H), 7.38 – 7.34 (m, 6H), 5.82 (dd, J = 39.1, 15.8 Hz, 1H), 2.39 – 2.30 (m, 2H), 1.92 – 1.89 (m, 2H), 1.76 – 1.62 (m, 8H), 1.54 – 1.34 (m, 5H), 1.22 – 1.00 (m, 6H), 0.87 – 0.18 (m, 7H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 162.5 (d, J = 24.9 Hz), 136.0 (d,

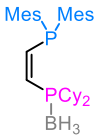
J = 12.8 Hz), 133.3 (d, J = 18.7 Hz), 128.6, 128.5 (d, J = 6.4 Hz), 125.3 (dd, J = 49.8, 36.6 Hz), 34.6 (dd, J = 33.0, 8.9 Hz), 27.7–25.9 (m), 18.9 (dd, J = 13.0, 3.2 Hz), 11.1; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 20.9, -6.7 (d, J = 13.2 Hz); **^{11}B NMR** (128 MHz, $CDCl_3$) δ -40.7. HRMS (ESI) calcd for $C_{29}H_{42}BP_2^+$ $[M+H]^+$ 463.2849, found 463.2842.



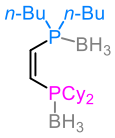
(10p) White solid (m.p.: 130 - 132 °C); 55% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.32 (dd, J = 8.7, 6.9 Hz, 4H), 6.89 (d, J = 7.9 Hz, 4H), 5.73 (dd, J = 38.6, 16.5 Hz, 1H), 3.80 (s, 6H), 2.40 – 2.31 (m, 2H), 1.91 – 1.87 (m, 2H), 1.76 – 1.61 (m, 8H), 1.54 – 1.31 (m, 5H), 1.21 – 1.00 (m, 6H), 0.85 – 0.29 (m, 7H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 163.5 (d, J = 25.3 Hz), 160.2, 134.7 (d, J = 20.2 Hz), 127.1 (d, J = 10.0 Hz), 124.2 (dd, J = 50.5, 36.5 Hz), 114.2 (d, J = 7.2 Hz), 55.2, 34.6 (dd, J = 33.2, 9.6 Hz), 27.7, 27.4, 26.8 (d, J = 12.1 Hz), 26.7 (d, J = 11.0 Hz), 25.9, 18.6 (dd, J = 13.2, 3.3 Hz), 11.0; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 20.5, -9.5 (d, J = 12.1 Hz); **^{11}B NMR** (128 MHz, $CDCl_3$) δ -40.7. HRMS (ESI) calcd for $C_{31}H_{46}BO_2P_2^+$ $[M+H]^+$ 523.3061, found 523.3057.



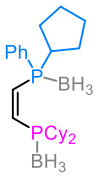
(10q) White solid (m.p.: 93 - 95 °C); 64% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.45 – 7.26 (m, 11H), 6.51 (dt, J = 31.8, 14.6 Hz, 1H), 2.25 – 2.17 (m, 2H), 1.94 – 1.68 (m, 10H), 1.42 – 1.34 (m, 4H), 1.26 – 1.14 (m, 6H), 0.89 – 0.22 (m, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 150.7 (d, J = 20.4 Hz), 138.4 (d, J = 10.7 Hz), 135.3 (dd, J = 42.9, 27.6 Hz), 132.8 (d, J = 18.9 Hz), 128.9, 128.7 (d, J = 6.6 Hz), 33.4 (dd, J = 32.9, 6.2 Hz), 27.1 – 26.7 (m), 25.9; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 24.0 (d, J = 57.0 Hz), -26.5 (d, J = 2.5 Hz); **^{11}B NMR** (193 MHz, $CDCl_3$) δ -41.1. HRMS (ESI) calcd for $C_{26}H_{38}BP_2^+$ $[M+H]^+$ 423.2536, found 423.2528.



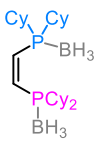
(10r) White solid (m.p.: 98 - 100 °C); 20% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.64 (dd, J = 35.2, 14.2 Hz, 1H), 6.80 (d, J = 2.7 Hz, 4H), 6.23 (ddd, J = 31.2, 14.2, 11.4 Hz, 1H), 2.30 (s, 12H), 2.24 (s, 6H), 1.97 – 1.89 (m, 2H), 1.82 – 1.64 (m, 10H), 1.31 – 1.27 (m, 4H), 1.18 – 1.11 (m, 6H), 0.88 – 0.44 (m, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 154.4 (d, J = 23.1 Hz), 142.5 (d, J = 15.2 Hz), 138.2, 132.4 (d, J = 19.1 Hz), 130.7 - 129.9 (m), 33.2 (dd, J = 33.5, 3.8 Hz), 27.0, 26.9, 26.8, 26.7, 25.9, 23.6, 23.5, 20.8; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 22.5, -36.7; **^{11}B NMR** (128 MHz, $CDCl_3$) δ -41.7. HRMS (ESI) calcd for $C_{32}H_{47}P_2^+$ $[M-BH_2]^+$ 493.3148, found 493.3158.



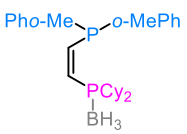
(10s) White solid (m.p.: 121 - 123 °C); 70% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 6.88 – 6.51 (m, 2H), 2.10 – 1.70 (m, 16H), 1.60 – 1.33 (m, 12H), 1.28 – 1.16 (m, 6H), 0.92 – 0.16 (m, 12H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 143.0 (d, J = 40.6 Hz), 138.8 (dd, J = 38.2, 3.7 Hz), 33.8 (d, J = 34.4 Hz), 26.9 – 26.6 (m), 25.9 (d, J = 1.1 Hz), 25.2 (d, J = 1.5 Hz), 25.2 (d, J = 35.4 Hz), 24.2 (d, J = 14.1 Hz), 13.7; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 21.1, 10.5 (d, J = 59.0 Hz); **^{11}B NMR** (193 MHz, $CDCl_3$) δ -38.3, -40.9. HRMS (ESI) calcd for $C_{22}H_{49}B_2P_2^+$ $[M+Na]^+$ 419.3310, found 419.3331.



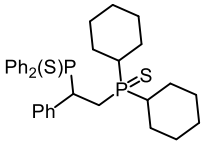
(10t) White solid (m.p.: 149 - 151 °C); 60% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.73 (t, J = 8.9 Hz, 2H), 7.49 (t, J = 7.1 Hz, 1H), 7.43 (t, J = 7.5 Hz, 2H), 7.12 – 6.98 (m, 1H), 6.78 – 6.62 (m, 1H), 2.67 – 2.58 (m, 1H), 2.41 – 2.32 (m, 1H), 2.06 – 1.97 (m, 1H), 1.93 – 1.86 (m, 1H), 1.76 – 1.54 (m, 14H), 1.49 – 1.17 (m, 11H), 1.13 – 0.00 (m, 8H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 141.5 (d, J = 39.5 Hz), 139.5 (dd, J = 45.0, 3.5 Hz), 132.7 (d, J = 8.7 Hz), 131.6 (d, J = 2.4 Hz), 129.0 (d, J = 53.1 Hz), 128.8 (d, J = 9.9 Hz), 37.2 (d, J = 40.5 Hz), 33.1 (dd, J = 32.0, 29.4 Hz), 27.8 (d, J = 2.2 Hz), 27.7, 27.54 (d, J = 1.9 Hz), 27.45 (d, J = 1.5 Hz), 27.3, 27.0, 26.7 – 26.3 (m), 25.9 – 25.6 (m); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 23.8 (d, J = 41.9 Hz), 15.0; **^{11}B NMR** (193 MHz, $CDCl_3$) δ -40.2, -42.1. HRMS (ESI) calcd for $C_{25}H_{42}BP_2^+$ $[M+H]^+$ 415.2849, found 415.2841.



(10u) White solid (m.p.: 106 - 108 °C); 62% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 6.74 – 6.63 (m, 2H), 2.33 – 2.24 (m, 4H), 1.89 – 1.70 (m, 20H), 1.44 – 1.15 (m, 20H), 0.87 – 0.44 (m, 6H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 140.1 (d, J = 37.6 Hz), 33.8 (d, J = 32.9 Hz), 27.4, 27.3, 26.7 – 26.5 (m), 25.8; **^{31}P NMR** (162 MHz, $CDCl_3$) δ 21.6; **^{11}B NMR** (128 MHz, $CDCl_3$) δ -41.0. HRMS (ESI) calcd for $C_{26}H_{50}BP_2^+$ $[M-BH_2]^+$ 435.3476, found 435.3480.



(10v) White solid (m.p.: 97 - 99 ℃); 57% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.38 – 7.15 (m, 9H), 6.56 (dt, *J* = 30.6, 13.8 Hz, 1H), 2.47 (s, 6H), 2.18 – 2.09 (m, 2H), 1.93 – 1.66 (m, 10H), 1.45 – 1.09 (m, 10H), 0.97 – 0.24 (m, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 151.4 (d, *J* = 20.8 Hz), 142.2 (d, *J* = 26.5 Hz), 136.7 (d, *J* = 11.6 Hz), 135.3 (dd, *J* = 43.1, 27.4 Hz), 132.3, 130.3 (d, *J* = 4.8 Hz), 128.9, 126.2 (d, *J* = 0.7 Hz), 33.5 (dd, *J* = 33.2, 5.4 Hz), 27.1 – 26.7 (m), 25.9 (d, *J* = 1.1 Hz), 21.5 (d, *J* = 20.9 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 23.8, -43.3; **^{11}B NMR** (128 MHz, $CDCl_3$) δ -41.4. HRMS (ESI) calcd for $C_{28}H_{42}BP_2^+$ $[M+H]^+$ 451.2849, found 451.2847.



(10aa) White solid (m.p.: 220 - 222 ℃); 61% yield; **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.37 – 8.33 (m, 2H), 7.57 (s, 3H), 7.47 – 7.15 (m, 10H), 5.01 – 4.92 (m, 1H), 2.61 – 2.55 (m, 1H), 2.17 – 2.07 (m, 1H), 1.73 – 1.43 (m, 10H), 1.28 – 1.11 (m, 6H), 1.02 – 0.82 (m, 3H), 0.73 – 0.56 (m, 3H); **^{13}C NMR** (101 MHz, $CDCl_3$) δ 134.6 (d, *J* = 4.0 Hz), 132.7 (d, *J* = 9.2 Hz), 131.9 (d, *J* = 2.8 Hz), 131.5 (d, *J* = 80.0 Hz), 131.3 (d, *J* = 9.7 Hz), 131.1 (d, *J* = 2.8 Hz), 130.6 (br), 130.4 (d, *J* = 76.9 Hz), 128.9 (d, *J* = 11.7 Hz), 128.0 – 127.8 (m), 127.8 (d, *J* = 3.0 Hz), 40.2 (d, *J* = 50.4 Hz), 39.0 (d, *J* = 45.2 Hz), 37.1 (d, *J* = 47.8 Hz), 26.9 (d, *J* = 13.5 Hz), 26.5 (d, *J* = 13.2 Hz), 26.3 – 26.1 (m), 25.6 (d, *J* = 14.1 Hz), 25.3 (d, *J* = 3.3 Hz), 24.6 (dd, *J* = 41.4, 2.8 Hz); **^{31}P NMR** (162 MHz, $CDCl_3$) δ 64.0 (d, *J* = 50.6 Hz), 53.9 (d, *J* = 50.5 Hz). HRMS (ESI) calcd for $C_{32}H_{41}P_2S_2^+$ $[M+H]^+$ 551.2119, found 551.2127.

12. DFT calculation

12.1 Computational details

All calculations were implemented in Gaussian 16C. Geometries are optimized in implicit IEFPCM($CHCl_3$) solvent at M06-2X/def2-SVP level of theory. Minima and transition structures on the potential energy surface (PES) were confirmed as such by harmonic frequency analysis, showing respectively zero or one imaginary frequency at the same level of theory. The Gibbs energies were further corrected with IEFPCM($CHCl_3$)-M06-2X/def2-TZVP single-point energy evaluations. The final IEFPCM ($CHCl_3$)-M06-2X/def2- TZVP// IEFPCM ($CHCl_3$)-M06-2X/def2-SVP free energies are used for discussion of reaction mechanisms throughout the main text and these supplementary materials. The molecular structures were visualized using PyMOL software.

12.2 Cartesian coordinates of optimized structures.

Ph_2PHO

P	-0.03139300	1.20954700	-0.74634300
C	-1.44620500	0.17790300	-0.25741700
C	-1.50647000	-1.19604600	-0.51585100
C	-2.50129800	0.81747300	0.39802100
C	-2.62659700	-1.92528800	-0.12336300
H	-0.67745700	-1.70356000	-1.01564100
C	-3.62066400	0.08292400	0.79110900
H	-2.42869700	1.88875300	0.59564800
C	-3.68311400	-1.28523400	0.52925200
H	-2.67510100	-2.99665900	-0.32268300
H	-4.44500300	0.58043000	1.30406800
H	-4.55831700	-1.85939000	0.83732300
C	1.46138400	0.31358800	-0.24533000
C	2.03487100	-0.67804500	-1.04735700
C	2.03408500	0.64070800	0.98815400
C	3.16721100	-1.36023600	-0.60296000
H	1.60824200	-0.91367500	-2.02603200
C	3.16752600	-0.04108600	1.42708800
H	1.59119800	1.43723800	1.59003600
C	3.72977000	-1.04321900	0.63416700
H	3.61666400	-2.13377300	-1.22701800
H	3.61702000	0.21240500	2.38818000
H	4.61791000	-1.57494800	0.97897200
O	-0.13293900	2.60134400	-0.20011700
H	0.00495300	1.08856000	-2.15985000

Syn-Tf_2O

O	-0.02104000	-0.65166600	0.69442000
S	1.57864900	-0.82962000	0.31415100
O	2.23749100	-1.03493200	1.56501500
O	1.70178700	-1.68783300	-0.82428100
C	1.87903200	0.92630100	-0.21071600
F	1.58989400	1.72064000	0.79198700
F	1.11558200	1.20043800	-1.24224400
F	3.14503200	1.03772800	-0.53461300
S	-1.32552100	-0.84761200	-0.31399500
O	-0.90787600	-0.70581000	-1.67696300
O	-2.08786500	-1.94812000	0.18640100
C	-2.13428000	0.73540000	0.22798300
F	-1.28940400	1.72336800	0.03456400
F	-2.45320500	0.64653700	1.49461400
F	-3.20773500	0.90377800	-0.50684500

Ph-C≡CH-P(O)Ph_2

C	3.99478800	1.23370600	0.07508300
C	3.30407400	0.01698500	0.19949400
C	3.99764500	-1.19735000	0.06777300
C	5.36602000	-1.18930400	-0.18480900
C	6.04941000	0.02173200	-0.30789600
C	5.36310800	1.23041500	-0.17805100
H	3.45037500	2.17272300	0.18035200
H	3.45522000	-2.13814900	0.16680500
H	5.90285000	-2.13333700	-0.28527500
H	7.12234200	0.02356700	-0.50502200
H	5.89770200	2.17626200	-0.27320000
C	1.89284700	0.01378600	0.46186600
C	0.69655200	0.01014800	0.68379800
P	-1.04117300	-0.01232400	1.04054900
O	-1.41273200	-0.05482000	2.49038500
C	-1.65120000	-1.46447200	0.13745500
C	-1.35379600	-1.69475800	-1.21038500
C	-2.46155700	-2.35580700	0.84441400
C	-1.87335200	-2.81758200	-1.84946200
H	-0.71159700	-1.00340500	-1.76172300
C	-2.97932200	-3.47988800	0.19938300
H	-2.67407400	-2.15784500	1.89663300
C	-2.68644300	-3.70882600	-1.14430100
H	-1.64293200	-3.00091000	-2.89975800
H	-3.61132500	-4.17885400	0.74900100
H	-3.09135600	-4.58820400	-1.64757700
C	-1.67863200	1.46074100	0.19490400
C	-2.77919800	2.08904200	0.78615500
C	-1.14037800	1.95604200	-0.99757100
C	-3.35086800	3.20415600	0.17466800
H	-3.17049800	1.70169000	1.72892100
C	-1.71643900	3.07033300	-1.60519100
H	-0.26119500	1.48471000	-1.44346300
C	-2.82205600	3.69134300	-1.02090300
H	-4.20794300	3.69715000	0.63550200
H	-1.29661500	3.46014600	-2.53341600
H	-3.26873200	4.56524000	-1.49762800

H_2O

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H	0.00000000	0.75468900	-0.47969000

H	0.00000000	-0.75468900	-0.47969000

TS1

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C	3.21881800	0.13431000	-0.82937400
C	4.18290000	1.14106500	-0.68777000
C	3.58885300	-1.21307700	-0.88519600
C	5.52693100	0.78963000	-0.60355500
H	3.89033000	2.19260200	-0.63621200
C	4.93749500	-1.55278900	-0.79446200
H	2.82662500	-1.98643000	-0.99081300
C	5.90162500	-0.55497000	-0.65596400
H	6.28373000	1.56659300	-0.49258400
H	5.23305600	-2.60155700	-0.83141900
H	6.95596900	-0.82576200	-0.58559500
C	1.02699900	1.69163300	0.34797700
C	0.05178700	2.66983200	0.10883400
C	1.65294400	1.59190800	1.59825300
C	-0.29713900	3.54676900	1.13161000
H	-0.44644700	2.72536400	-0.85965500
C	1.29533100	2.47614500	2.61154500
H	2.40419800	0.82164800	1.77928300
C	0.32229400	3.44930500	2.37826500
H	-1.05939500	4.30593300	0.95428000
H	1.77560000	2.40194400	3.58742200
H	0.04370600	4.13830300	3.17694800
O	0.66407700	-0.79735900	-1.07734800
H	1.22413600	1.20719700	-2.18256900
S	-2.03849100	0.03800600	-1.30695300
O	-2.45494500	-1.20970200	-1.90980400
O	-1.33887900	1.01795700	-2.13110600
O	-1.37915100	-0.14779200	0.05725500
S	0.04212500	-1.73889800	0.33337700
O	-0.03706800	-2.96289100	-0.42978700
O	1.08666800	-1.33608200	1.26215200
C	-3.57190000	0.89238400	-0.74393500
C	-1.34876300	-2.08496300	1.56846200
F	-2.47781800	-2.31243500	0.94732400
F	-1.46609800	-1.10113900	2.42274700
F	-0.97364200	-3.17643400	2.21067200
F	-4.22300900	0.13058500	0.11455900
F	-3.25989700	2.03904300	-0.16212900
F	-4.34562400	1.13428600	-1.78760700

I

P	-0.92731900	-0.68448400	-0.48581200
C	-2.60654300	-1.15937800	-0.87809300
C	-3.12089200	-2.34954600	-0.34647700
C	-3.37445300	-0.36934000	-1.74396700
C	-4.41187800	-2.74579500	-0.68555000
H	-2.52325100	-2.96132800	0.33208800
C	-4.66620200	-0.77333800	-2.06867700
H	-2.97496000	0.55772400	-2.15918400
C	-5.18162800	-1.95865900	-1.54265800
H	-4.81851400	-3.66933300	-0.27322000
H	-5.27123200	-0.15818300	-2.73483500
H	-6.19464800	-2.27015200	-1.80027200
C	-0.52658900	-1.09942000	1.19186500
C	0.73031400	-1.67254900	1.43392400
C	-1.45071600	-0.90442000	2.23176700
C	1.07019900	-2.03386700	2.73401000
H	1.42788100	-1.83033900	0.61284300
C	-1.09092200	-1.26289300	3.52551100
H	-2.43116400	-0.47000800	2.03260300
C	0.16626400	-1.82109800	3.77471900
H	2.04696400	-2.47675000	2.92956000
H	-1.79425100	-1.10824500	4.34380000
H	0.43997500	-2.09831000	4.79378900
O	-0.86833100	0.92073100	-0.86292500
H	0.05744900	-1.20453800	-1.34734500
S	2.58449000	-0.28005900	-1.41049300
O	3.10944800	0.50847000	-2.51423900
O	1.98159600	-1.58186100	-1.77179000
O	1.78567800	0.44555800	-0.40657500
S	-1.53996800	2.17097500	-0.07681200
O	-1.88425000	3.14056000	-1.07114500
O	-2.47612800	1.65470000	0.88777300
C	4.09170000	-0.77557400	-0.46863400
C	-0.03214500	2.75954700	0.83570300
F	0.87737200	3.13655300	-0.01967200
F	0.40108300	1.79002600	1.60337500
F	-0.41686900	3.78084000	1.57371100
F	4.72908200	0.29465700	-0.01622200
F	3.76426800	-1.53632100	0.57628200
F	4.91951200	-1.46633500	-1.23916600

TS2

P	-0.72563200	-0.83514300	-0.16185300
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C	-2.79635100	-2.61889200	0.24681100
C	-3.03658100	-1.15559700	-1.68107700
C	-4.00093200	-3.23701000	-0.07857700
H	-2.23850000	-2.94669100	1.12691400
C	-4.24375700	-1.77696100	-1.99287900
H	-2.66569300	-0.34793000	-2.31474500
C	-4.72406200	-2.81522500	-1.19512000
H	-4.37717900	-4.04769100	0.54588800
H	-4.80915300	-1.44634700	-2.86445200
H	-5.66966200	-3.29851100	-1.44388000
C	-0.65846700	-0.48206000	1.58953100
C	0.60091400	-0.53535800	2.20491300
C	-1.80971200	-0.18525100	2.33597400
C	0.70735300	-0.27815500	3.56884000
H	1.48898700	-0.75664100	1.61444600
C	-1.68931400	0.07108400	3.69726700
H	-2.78633100	-0.14641500	1.85191000
C	-0.43415700	0.02689700	4.30998000
H	1.68468000	-0.31604300	4.05017100
H	-2.57755800	0.30740500	4.28355800
H	-0.34766000	0.23017700	5.37839400
O	-0.72614300	0.57451300	-1.06563500
H	0.58608500	-1.46972900	-0.70242300
S	2.71404600	-0.50881400	-1.15273800
O	3.31715400	-0.15177300	-2.41904400
O	1.85752200	-1.75009800	-1.20087600
O	2.07377700	0.54290900	-0.36099700
S	-1.58941300	1.92020500	-0.86221800
O	-1.87237800	2.43954200	-2.16788800

O	-2.60744800	1.69358600	0.13056400
C	4.12138900	-1.08214300	-0.10855000
C	-0.25660900	2.95922800	-0.09796800
F	0.70615900	3.13616200	-0.96508000
F	0.18875000	2.35754400	0.98043500
F	-0.79805300	4.11591700	0.22426700
F	4.98761700	-0.09701100	0.05815100
F	3.67967200	-1.46473600	1.08597400
F	4.73494900	-2.10440400	-0.67873600

II

P	0.65886800	0.42837100	-1.51438500
C	2.17353500	0.07259400	-0.55115600
C	3.00034500	1.13795700	-0.17051000
C	2.60156900	-1.24234100	-0.32944300
C	4.22610500	0.89008500	0.44569000
H	2.68488900	2.16980100	-0.34420900
C	3.82535900	-1.48497900	0.29165100
H	1.98025700	-2.08814800	-0.63245900
C	4.63929200	-0.42114800	0.68062200
H	4.85761600	1.72702800	0.74689300
H	4.14285500	-2.51295100	0.47142100
H	5.59656500	-0.61415600	1.16667000
C	-0.20742700	1.68289300	-0.50792200
C	-1.15437700	2.44971200	-1.20231500
C	-0.01057000	1.90440000	0.86343500
C	-1.91465000	3.40805100	-0.53411000
H	-1.29997500	2.29044400	-2.27369200
C	-0.76542400	2.86829900	1.52608800
H	0.72148100	1.31109000	1.41192900
C	-1.71973300	3.61485800	0.83074700
H	-2.65384600	3.99561100	-1.07989200
H	-0.61279400	3.03526300	2.59315700
H	-2.31114100	4.36570500	1.35722500
O	-0.25533500	-1.01673500	-1.15752000
S	-0.66803700	-1.70310200	0.20997500
O	-0.55583700	-3.12897000	0.04639200
O	-0.10946800	-1.02337800	1.35221300
C	-2.47373300	-1.30826500	0.17973700
F	-3.01929400	-1.80599000	-0.90966000
F	-2.64580100	-0.00249500	0.20721300
F	-3.03012200	-1.85103300	1.24415400

a_TS3

P	0.14097100	0.69842000	-0.07821100
C	0.22846400	-0.57777700	-1.38664900
C	0.97795300	-1.73491200	-1.15389000
C	-0.55225300	-0.47371800	-2.54310300
C	0.94736700	-2.78095600	-2.07398500
H	1.59644600	-1.80923700	-0.25677100
C	-0.57165200	-1.51714400	-3.46675600
H	-1.15395000	0.42175700	-2.71428700
C	0.17566800	-2.67203200	-3.23088400
H	1.53521200	-3.68120800	-1.88915600
H	-1.17761500	-1.43044400	-4.36998200
H	0.15518600	-3.49084000	-3.95208900
C	0.28906500	2.35327500	-0.84876600
C	1.04300000	2.55990800	-2.00731000
C	-0.35267100	3.43161800	-0.23031900
C	1.14628200	3.84254100	-2.54578700
H	1.54847000	1.72208000	-2.49376600
C	-0.24153800	4.71174400	-0.76974000
H	-0.94182000	3.26865900	0.67508400
C	0.50712800	4.91772000	-1.92935300
H	1.73407500	3.99918100	-3.45121800
H	-0.73934800	5.55083100	-0.28155200
H	0.59476400	5.91984800	-2.35160100
O	2.21308300	0.65781600	0.09204500
S	3.45161500	0.68676900	-0.77467100
O	3.28339000	0.03555700	-2.06609900
O	4.13928900	1.96425600	-0.74115100
C	4.53277500	-0.46113300	0.19205300
F	3.85242500	-1.53118800	0.58211700
F	5.01677600	0.14925500	1.26153900
F	5.54612100	-0.85707000	-0.56368900
C	1.88623300	0.20716600	2.89985600
C	1.03759800	-0.84787500	2.54131300
C	1.40315800	-2.17114200	2.83302200
C	2.60718400	-2.43059900	3.48255200
C	3.44202600	-1.37622200	3.85175500
C	3.07707000	-0.05912800	3.56558100
H	1.61041600	1.22887700	2.63599000
H	0.73427400	-2.98509600	2.54856000
H	2.89284500	-3.46011600	3.70208700
H	4.38595500	-1.58065400	4.35928600
H	3.73595400	0.76391500	3.84387000
C	-0.25233000	-0.61601100	1.91418000
C	-1.49159800	-0.89392600	1.88676900
P	-2.50755300	-0.24553100	0.64549300
O	-1.66213400	0.81734000	-0.17504900
C	-3.93902800	0.63272800	1.27185800
C	-4.83320300	-0.03157400	2.12031900
C	-4.15401700	1.96325000	0.90058800
C	-5.94930500	0.64727900	2.60060200
H	-4.65488800	-1.07051500	2.40787000
C	-5.27758300	2.63277800	1.38522800
H	-3.44501100	2.46355300	0.23873600
C	-6.17018900	1.97672200	2.23211000
H	-6.64869600	0.13948600	3.26542500
H	-5.45362500	3.67064700	1.10062400
H	-7.04651800	2.50481200	2.61060100
C	-3.04188400	-1.55734400	-0.46034500
C	-4.06295800	-1.28956800	-1.38065200
C	-2.36986100	-2.78357000	-0.47570200
C	-4.40776900	-2.25616700	-2.32183500
H	-4.58698500	-0.33080900	-1.36227700
C	-2.72172600	-3.74477100	-1.42101200
H	-1.57038100	-2.97900700	0.24235300
C	-3.73640100	-3.48031000	-2.34132600
H	-5.20266900	-2.05477300	-3.04069700
H	-2.19748100	-4.70091500	-1.44132900
H	-4.00870200	-4.23548900	-3.08017100

b_TS3

P	1.09124500	0.33065000	0.10955400
C	0.44699100	1.97524600	-0.35198000
C	-0.42748900	2.71499500	0.44943100
C	0.87857600	2.48236200	-1.58414800

C	-0.88360900	3.95670200	0.00537000	H	-2.17187100	0.75005700	-2.15373100
H	-0.77952800	2.31017300	1.40207100	C	-4.21354200	3.46409600	-1.90057100
C	0.40649900	3.71640500	-2.02580700	H	-5.21473300	4.11600200	-0.10053300
H	1.59545100	1.91632100	-2.18479800	H	-3.08884700	2.59795100	-3.52956100
C	-0.47550700	4.45249500	-1.23189900	H	-4.60335400	4.28409200	-2.50565500
H	-1.57581600	4.52820900	0.62556200				
H	0.73599100	4.10808900	-2.98907400	**b_III**			
H	-0.84346000	5.41928800	-1.57925000	P	0.38914200	0.41626700	0.52188300
C	0.93785100	0.04627400	1.90718900	C	0.76872700	1.46243300	-0.88171400
C	0.61287900	-1.22560800	2.39262500	C	0.83620600	2.84597500	-0.69657800
C	1.24300400	1.07685700	2.80181200	C	0.90436800	0.89373300	-2.15122700
C	0.55989200	-1.45261300	3.76543800	C	1.04383400	3.66856900	-1.80197500
H	0.39309700	-2.04333900	1.70342200	H	0.72865400	3.28073300	0.29969200
C	1.17957300	0.84417200	4.17483900	C	1.10835700	1.72592800	-3.24836900
H	1.53631900	2.05876400	2.42752500	H	0.88185400	-0.19086900	-2.27885800
C	0.83313100	-0.41645300	4.65860700	C	1.17737900	3.10948500	-3.07294600
H	0.30331100	-2.44533900	4.13751200	H	1.10144500	4.74919700	-1.66812300
H	1.40590200	1.65516500	4.86815800	H	1.23019900	1.29081800	-4.24070100
H	0.78322600	-0.59446800	5.73365600	H	1.34524000	3.75678400	-3.93487700
O	2.91582600	1.18707200	0.43737100	C	1.04015100	0.98497700	2.09657600
S	4.09317200	0.86001300	-0.46711100	C	0.15146100	1.06075600	3.17709500
O	3.66848900	0.48827700	-1.81142000	C	2.37209700	1.40308100	2.22411800
O	5.18198300	1.79591100	-0.30501100	C	0.61227800	1.53282500	4.40491600
C	4.66680000	-0.71922800	0.29407600	H	-0.89929000	0.77922300	3.06113400
F	3.64977300	-1.57299000	0.35686000	C	2.81154000	1.88343300	3.45485600
F	5.11869300	-0.50425100	1.51507400	H	3.05380600	1.35117300	1.37459600
F	5.62726000	-1.25407800	-0.43901700	C	1.93895000	1.93979300	4.54348700
C	-0.62225500	-3.15047100	-1.86375300	H	-0.07338400	1.59090100	5.25072400
C	0.27888200	-2.10501100	-1.59699200	H	3.84604800	2.21070600	3.56341300
C	1.55951200	-2.10945800	-2.16075800	H	2.29501000	2.31158700	5.50546000
C	1.93404600	-3.16222800	-2.99300000	O	2.54567600	-0.61173200	0.10352700
C	1.04376500	-4.20251400	-3.25912200	S	3.64670700	-0.27537200	-0.84545100
C	-0.23418500	-4.19571400	-2.69395800	O	3.49830700	-0.89152900	-2.16089500
H	-1.61658600	-3.13362900	-1.41248700	O	4.05712500	1.12568800	-0.80192400
H	2.25199400	-1.29276000	-1.95042600	C	5.05002100	-1.18452300	-0.07580600
H	2.93089200	-3.16748400	-3.43506100	F	5.26450900	-0.74237000	1.15684000
H	1.34603400	-5.02493000	-3.90900800	F	6.15695200	-1.01136300	-0.78425300
H	-0.92978600	-5.01021800	-2.89902200	F	4.78433500	-2.48288700	-0.01797700
C	-0.19596000	-1.03895600	-0.73286100	C	-1.55328300	-3.31642400	0.16791200
C	-1.04682300	-0.40884300	-0.06466900	C	-0.43376500	-2.49923000	-0.06971400
P	-2.54735800	0.11478100	0.75822500	C	0.71861600	-3.03574500	-0.66659100
O	-2.35088800	0.58014900	2.16725500	C	0.73545500	-4.37739400	-1.03980900
C	-3.58584400	-1.36556100	0.65164500	C	-0.37929700	-5.18489800	-0.81124000
C	-4.13250900	-1.80561800	-0.55934500	C	-1.52101200	-4.65551400	-0.20347600
C	-3.79768000	-2.08448100	1.83131600	H	-2.44028600	-2.90115100	0.64894700
C	-4.88576000	-2.97714700	-0.58740700	H	1.58951700	-2.39836700	-0.82299500
H	-3.97641700	-1.23370600	-1.47788800	H	1.62779400	-4.79408800	-1.50788200
C	-4.55339500	-3.25649500	1.79559700	H	-0.35798000	-6.23613600	-1.10262700
H	-3.37046400	-1.71406700	2.76529400	H	-2.38886200	-5.28927900	-0.01674000
C	-5.09316400	-3.70203000	0.58903300	C	-0.48690400	-1.08963100	0.28368300
H	-5.31753900	-3.32358100	-1.52724200	C	-1.30535500	-0.07500500	0.60602900
H	-4.72277300	-3.82185700	2.71294400	P	-2.99251900	0.51930300	0.87980400
H	-5.68455000	-4.61851100	0.56362900	O	-3.22832300	0.92869700	2.30374100
C	-3.20530700	1.38051100	-0.35468600	C	-4.05727900	-0.84175900	0.34798800
C	-4.05108000	2.33145900	0.22633000	C	-4.12939800	-1.27329700	-0.98155000
C	-2.85848600	1.47299200	-1.70673000	C	-4.74006700	-1.53075200	1.35540900
C	-4.55780900	3.37090300	-0.55129100	C	-4.87311000	-2.40788000	-1.29717700
H	-4.28834600	2.26476600	1.29009200	H	-3.60462800	-0.73518100	-1.77334700
C	-3.36633100	2.51694900	-2.47780900	C	-5.48290500	-2.66654300	1.03239600

H	-4.67347400	-1.17217700	2.38429800
C	-5.54319100	-3.10678100	-0.29018200
H	-4.92789200	-2.75027500	-2.33113600
H	-6.01442900	-3.20900900	1.81530500
H	-6.12071400	-3.99784600	-0.54075100
C	-3.06526300	1.88773900	-0.30085000
C	-3.64030300	3.08171600	0.14407600
C	-2.51296600	1.80506500	-1.58598100
C	-3.67529900	4.18852400	-0.70412300
H	-4.04146200	3.13596700	1.15798800
C	-2.55031400	2.91349700	-2.42827600
H	-2.02517900	0.88876700	-1.92816400
C	-3.13229500	4.10359800	-1.98623900
H	-4.12091000	5.12236700	-0.35910400
H	-2.11192900	2.85124400	-3.42527400
H	-3.15484000	4.97340000	-2.64446800

b_TS4

P	-0.32275700	-0.15366300	-0.44674100
C	0.31370500	-1.46563500	-1.50642700
C	-0.08863500	-1.57969300	-2.84403200
C	1.25455800	-2.35260800	-0.97332000
C	0.46108700	-2.57792900	-3.64365300
H	-0.83197200	-0.89610500	-3.25374100
C	1.78604500	-3.35900200	-1.77559500
H	1.58648900	-2.24854900	0.05957300
C	1.39375300	-3.46858700	-3.10924100
H	0.15557300	-2.66384000	-4.68693700
H	2.51775300	-4.05115100	-1.35824600
H	1.81793100	-4.25287000	-3.73793800
C	0.07404300	1.57100100	-0.75615400
C	0.94772200	2.21284800	0.12871300
C	-0.47455300	2.26131600	-1.84360600
C	1.28822400	3.54432600	-0.08717300
H	1.40001900	1.67110500	0.96044300
C	-0.13469700	3.59751900	-2.04506600
H	-1.17138300	1.76234200	-2.51666100
C	0.74501300	4.23646400	-1.17080900
H	1.99500900	4.02970200	0.58608700
H	-0.55897300	4.14025600	-2.89035800
H	1.01357800	5.28052300	-1.33818700
C	0.01334800	-1.33070500	3.58842200
C	0.63334500	-0.92610800	2.39618000
C	2.03023700	-0.87525000	2.30958100
C	2.80376300	-1.22873100	3.41343700
C	2.18667300	-1.63525700	4.59623300
C	0.79054900	-1.68685300	4.68359600
H	-1.07759600	-1.36048500	3.63574300
H	2.49921200	-0.54503700	1.38274200
H	3.89076900	-1.17770200	3.34228000
H	2.79365200	-1.91246100	5.45959700
H	0.31312800	-2.00516100	5.61124900
C	-0.19901400	-0.53359900	1.25845200
C	-1.54229300	-0.37884000	1.15259000
P	-2.79574200	-0.07949700	0.03760900
O	-1.98141400	-0.12828500	-1.34680500
C	-3.52433100	1.53240400	0.34043200
C	-2.79484600	2.50951400	1.03009300
C	-4.77602600	1.83282600	-0.21074300
C	-3.32216600	3.79076800	1.16348800
H	-1.81960400	2.27113800	1.46077300
C	-5.29678100	3.11737200	-0.06758700
H	-5.34378400	1.06977400	-0.74768500
C	-4.57027300	4.09310600	0.61548800
H	-2.75693500	4.55414400	1.69881200
H	-6.27229600	3.35574600	-0.49231400
H	-4.98071900	5.09792800	0.72388100
C	-4.05804900	-1.34854700	-0.05183400
C	-5.03872500	-1.43578700	0.94530600
C	-4.01704900	-2.26894400	-1.10390400
C	-5.98916100	-2.44934400	0.87755800
H	-5.05847500	-0.71636500	1.76726000
C	-4.97351100	-3.28221000	-1.15961300
H	-3.24248800	-2.18647200	-1.86799500
C	-5.95502800	-3.37018600	-0.17342800
H	-6.75793300	-2.52436400	1.64713400
H	-4.95019400	-4.00360900	-1.97688400
H	-6.70177200	-4.16398600	-0.22103300
O	2.77635500	0.07855000	-0.72787400
S	3.91485900	0.95554900	-0.38818400
O	4.36002300	1.84677100	-1.45460800
O	3.85227500	1.53831300	0.95880500
C	5.28588500	-0.26838200	-0.22694800
F	5.47850800	-0.92589800	-1.36447700
F	4.99704600	-1.16372500	0.72014600
F	6.42510800	0.32714700	0.10672900

IV

P	0.14067600	-0.13677400	0.47872200
C	0.03767300	1.65487500	0.82336300
C	0.73265100	2.57809400	0.03365900
C	-0.84600400	2.10757800	1.81183800
C	0.53127000	3.94343100	0.22505500
H	1.42122300	2.23333100	-0.73625600
C	-1.02298300	3.47466900	2.01327800
H	-1.40526300	1.39199800	2.41508800
C	-0.34207900	4.39342300	1.21469600
H	1.06519900	4.65801700	-0.40257400
H	-1.70460300	3.82105500	2.79121600
H	-0.49275100	5.46365500	1.36451100
C	0.56123100	-1.23588000	1.85821500
C	1.19750400	-0.75087100	3.00237900
C	0.20742500	-2.58488700	1.75404600
C	1.49367100	-1.63100500	4.04330400
H	1.47568700	0.30205500	3.08002500
C	0.52064500	-3.45841500	2.79265000
H	-0.30814300	-2.95315700	0.86296400
C	1.16268400	-2.98094200	3.93674500
H	1.99071600	-1.25676500	4.93892200
H	0.26002100	-4.51411900	2.70908900
H	1.40536000	-3.66651600	4.74974300
O	2.01783800	0.13325000	0.08927500
S	3.36058200	0.16546000	0.81624100
O	3.41158900	1.17905300	1.85407300
O	3.87767200	-1.15916700	1.08965400
C	4.37254300	0.84448300	-0.56792800
F	3.90348900	2.03166100	-0.92363000
F	4.34469800	0.04041400	-1.61116600

F	5.62140300	0.98252000	-0.15560800
C	1.99629800	-2.11432600	-1.57787500
C	1.13011900	-1.14292800	-2.09949300
C	1.33304200	-0.68836500	-3.40682300
C	2.38334600	-1.18864300	-4.17591500
C	3.23228000	-2.16355500	-3.65334800
C	3.03244100	-2.62733400	-2.35187000
H	1.87027700	-2.46170000	-0.54988900
H	0.64834000	0.05705800	-3.81480200
H	2.53500600	-0.81785800	-5.19105900
H	4.05136400	-2.55862300	-4.25641800
H	3.69617100	-3.38350200	-1.92981900
C	-0.05971100	-0.67154400	-1.33517600
C	-1.28931400	-0.57159300	-1.88034900
P	-2.42352200	-0.25707800	-0.59757900
O	-1.57369400	-0.36806400	0.77253600
C	-3.71567700	-1.49206200	-0.44725600
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C	-5.61535800	-2.63176100	-1.39870500
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C	-4.80375600	-3.24435900	0.79980300
H	-3.08279000	-2.13721300	1.51435600
C	-5.70719000	-3.41856000	-0.24802800
H	-6.32065000	-2.77455400	-2.21803300
H	-4.87725000	-3.86208400	1.69555000
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C	-3.16532100	1.38089600	-0.65820800
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C	-2.51541400	2.39151900	-1.37599100
C	-4.76170400	2.98116100	0.18566900
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C	-2.99010100	3.69912100	-1.30352200
H	-1.63926700	2.15177800	-1.98319000
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H	-2.48433800	4.49084500	-1.85754900
H	-4.47903600	5.01701100	-0.46764600

V

P	-1.20107200	0.84809300	0.09107000
C	-1.02779800	0.73653600	1.89757100
C	-1.26268300	-0.46863200	2.56979200
C	-0.57666900	1.86141900	2.60161600
C	-1.03076000	-0.54723400	3.94088400
H	-1.61362800	-1.34589900	2.02921100
C	-0.37815300	1.77976100	3.97704500
H	-0.37206000	2.79484100	2.07660100
C	-0.59585300	0.57462200	4.64525300
H	-1.19701000	-1.49184600	4.45958300
H	-0.03822200	2.65939900	4.52478000
H	-0.42280700	0.50938800	5.72043900
C	-2.23632500	2.13488800	-0.63926100
C	-3.14754900	2.83130200	0.15733300
C	-2.10204400	2.42358800	-2.00097100
C	-3.94400600	3.81634600	-0.42619100
H	-3.25339400	2.59976900	1.21900100
C	-2.91218400	3.40043400	-2.57441800
H	-1.38006300	1.88343600	-2.61900600
C	-3.83174200	4.09544000	-1.78705400
H	-4.65860100	4.36334200	0.18935600
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H	-4.46441700	4.86018100	-2.23908700
O	-2.64328300	-0.34410200	0.18309300
S	-4.16721700	-0.21942000	0.40322800
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F	-3.82544700	-2.43544100	1.73064200
F	-4.12921200	-2.71528500	-0.38221100
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C	-0.60991100	-2.81722700	-1.68582400
C	-1.24113500	-3.81934500	-2.42108000
C	-2.37190800	-3.52359200	-3.18006700
C	-2.87963300	-2.22281900	-3.19463200
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H	-0.84404400	-4.83483600	-2.39828900
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C	1.82459300	3.09910400	-2.15911400
C	4.61958100	3.07839400	-2.25941600
H	4.51653300	1.48909300	-0.79301600
C	2.49741600	3.97009800	-3.01216900
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C	2.90788200	2.15387600	1.92598700
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C	3.34641000	2.12394200	3.24729900
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Product 3a

P	1.88556000	-0.87075500	-0.45366600
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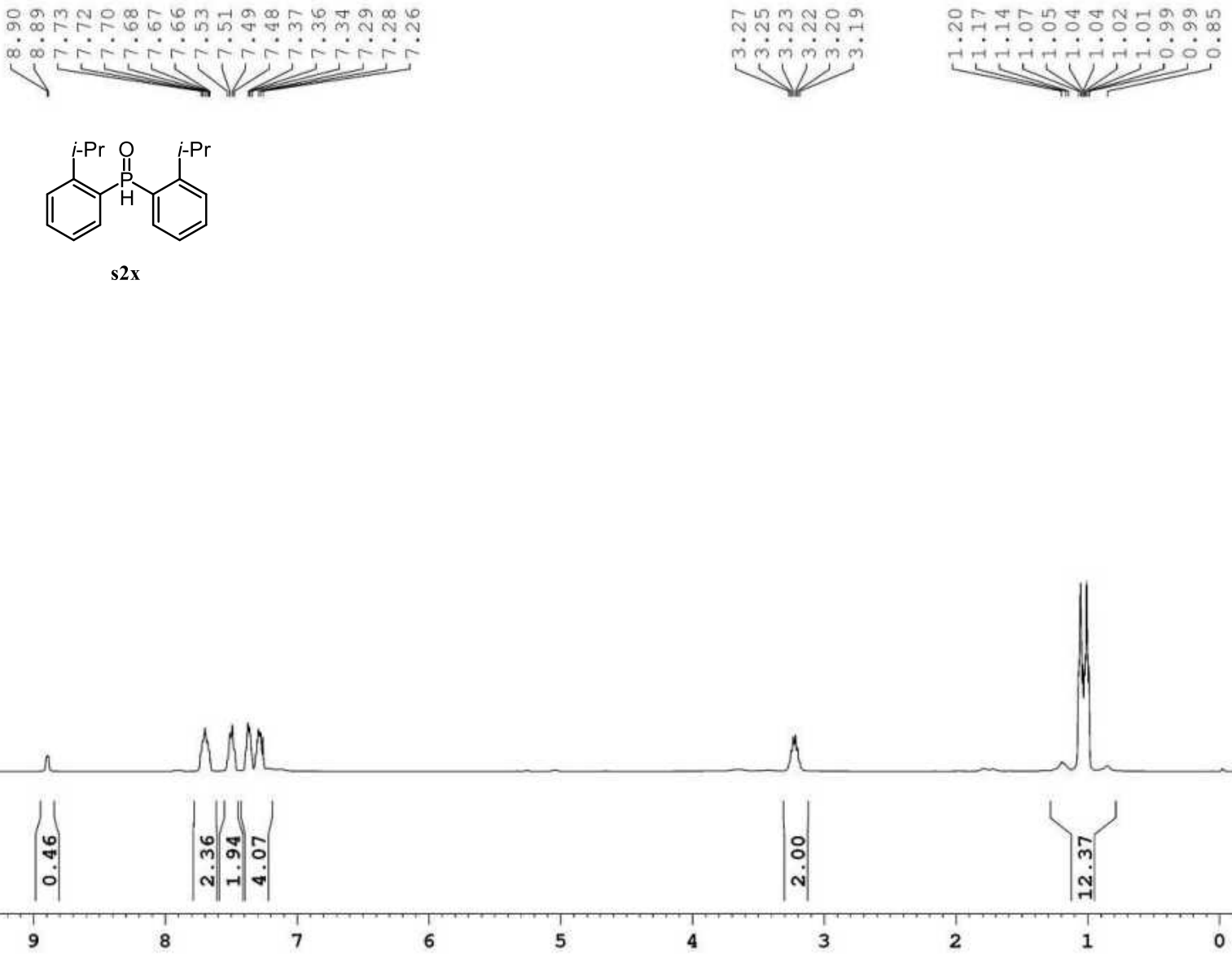
NMR spectra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7.28
7.26
3.27
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3.22
3.20
3.19
1.20
1.17
1.14
1.07
1.05
1.04
1.04
1.02
1.01
0.99
0.99
0.85
i-Pr
O
P
H
i-Pr
0.46
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9
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5
4
3
2
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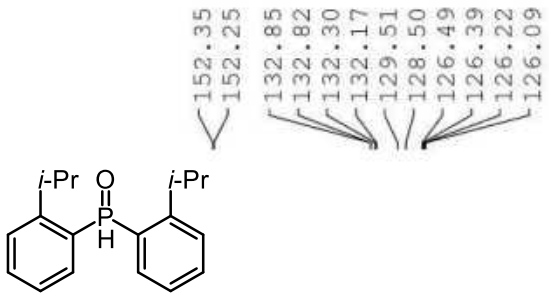
0
ppm

s2x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31.01
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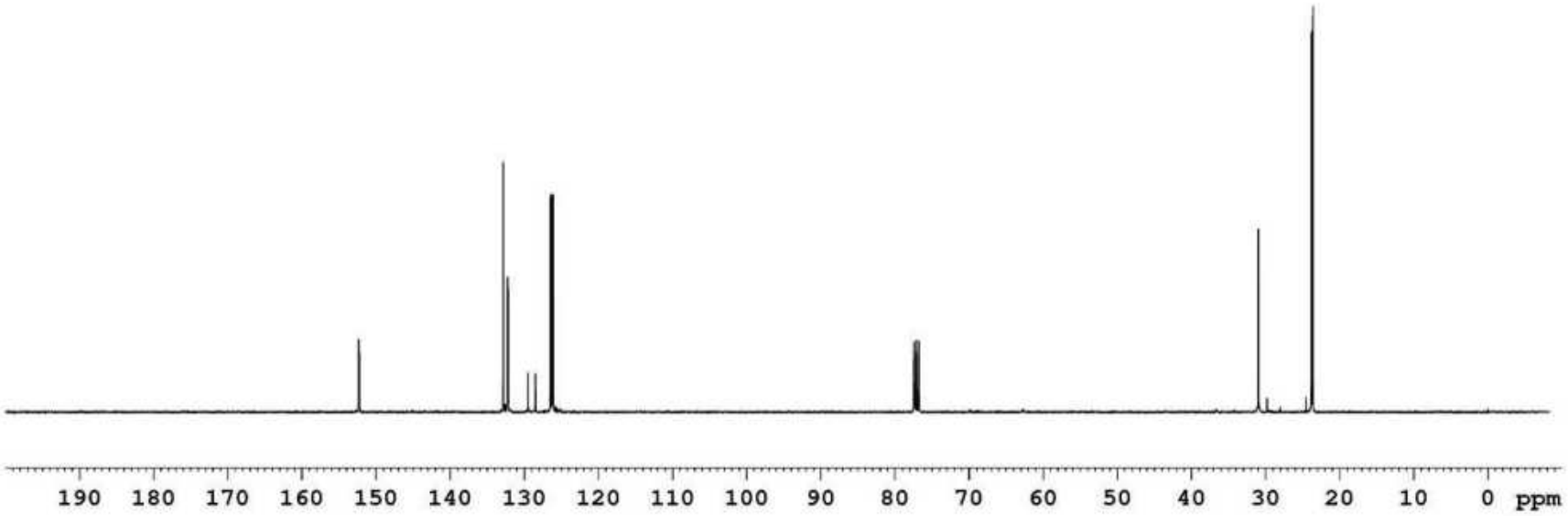
23.80
23.59
i-Pr
O
P
H
i-Pr

s2x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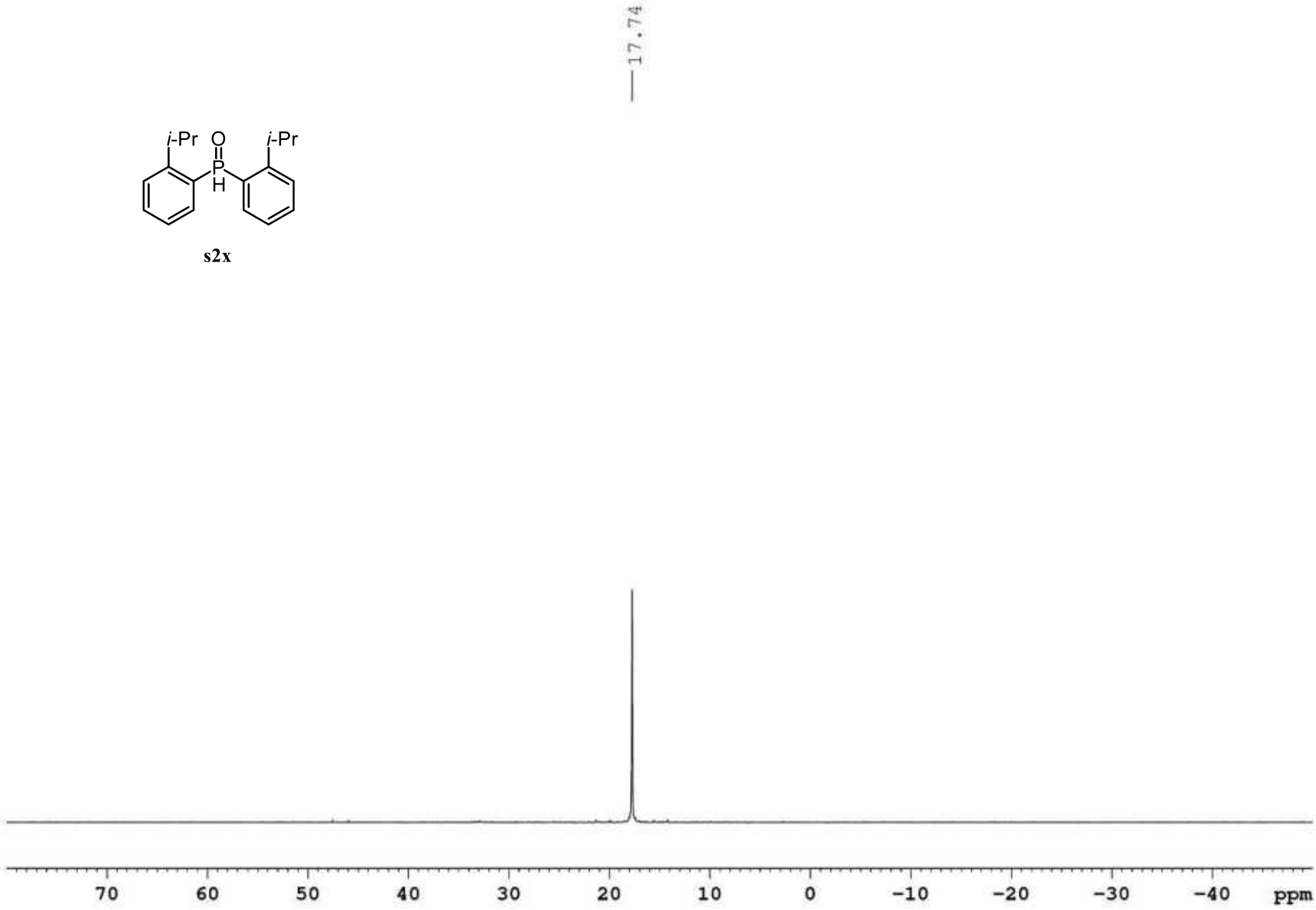
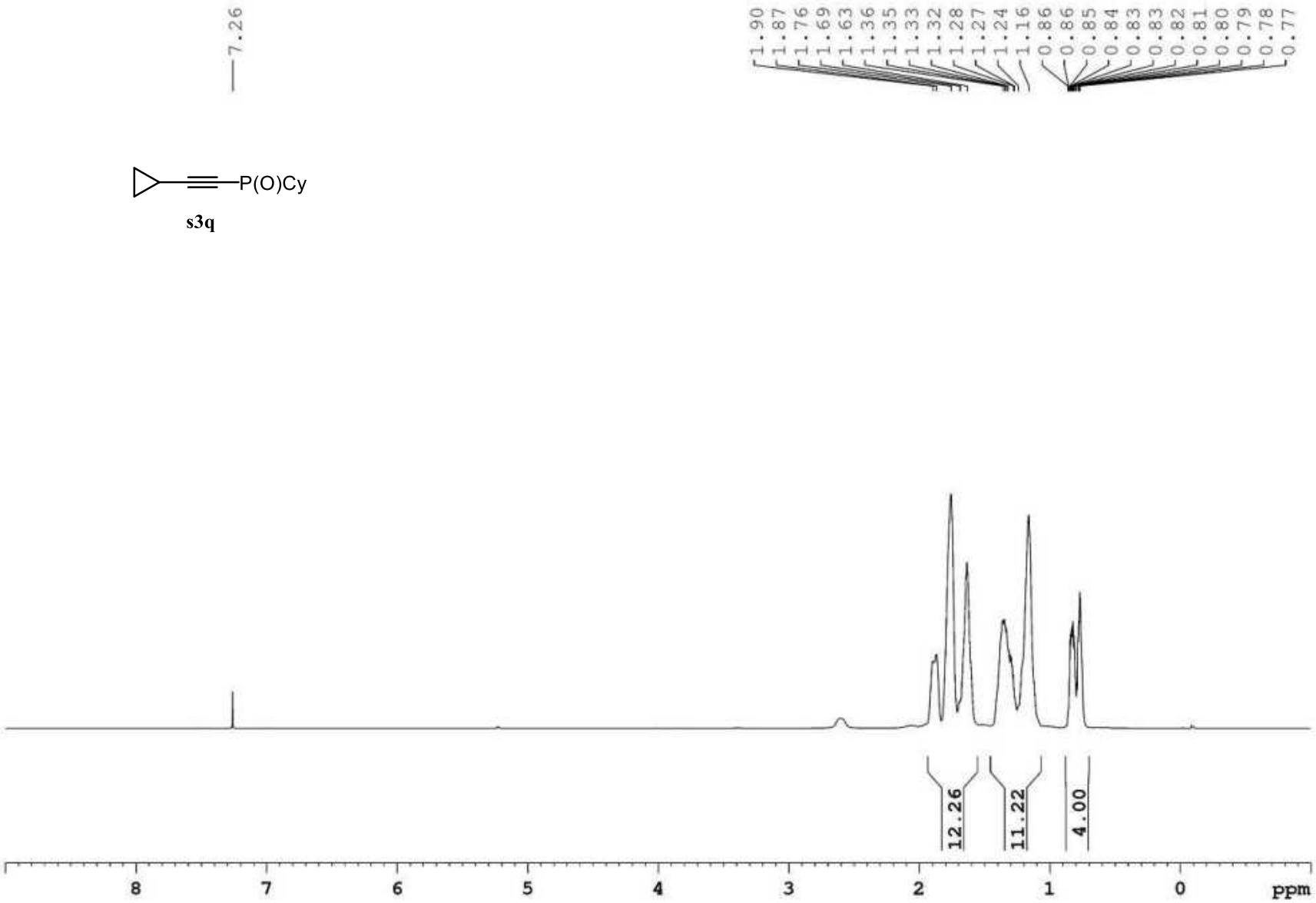
ppm

s2x

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1.16
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0.86
0.85
0.84
0.83
0.83
0.82
0.81
0.80
0.79
0.78
0.77
P(O)Cy
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4
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1
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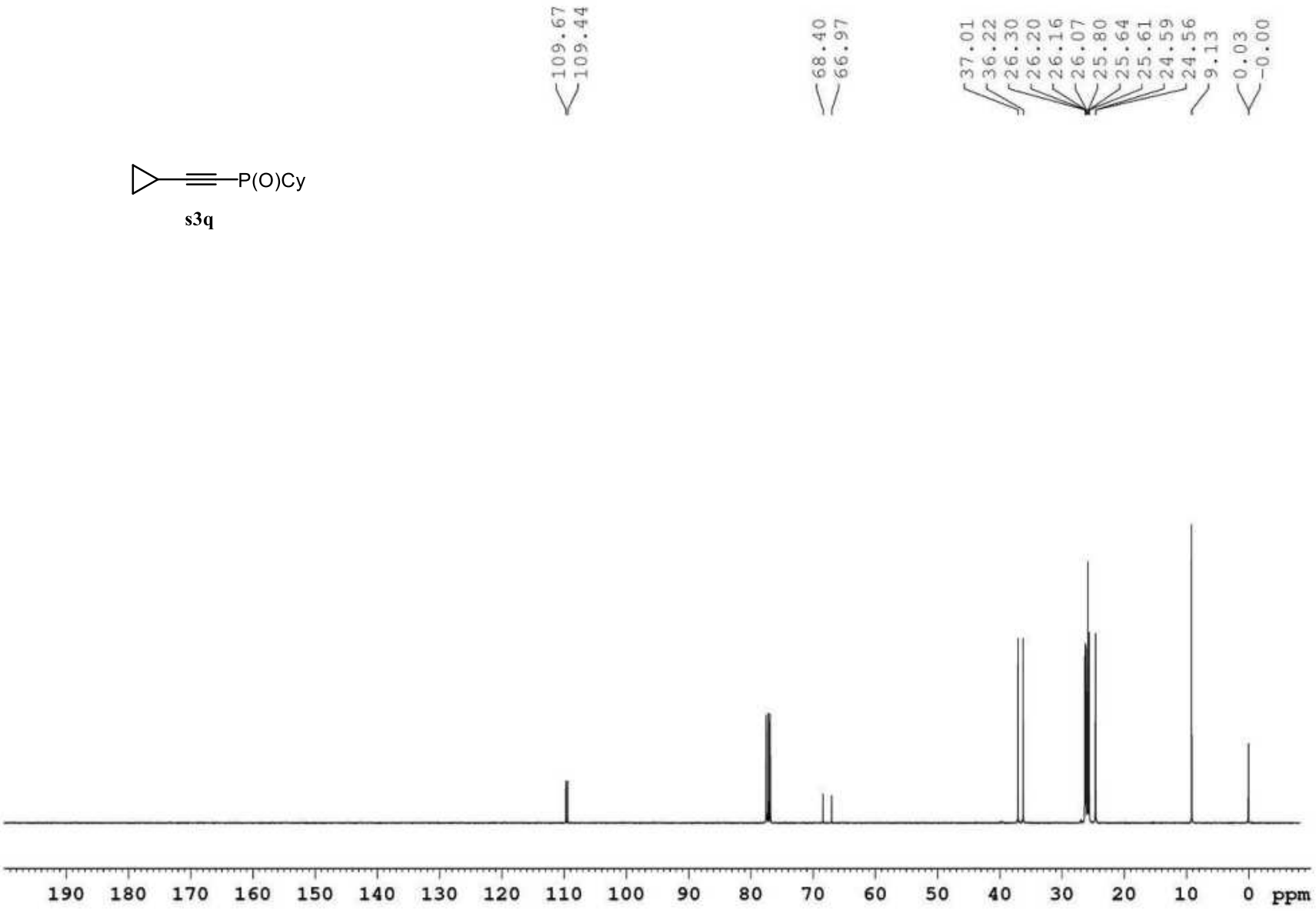
s3q

P(O)Cy

s3q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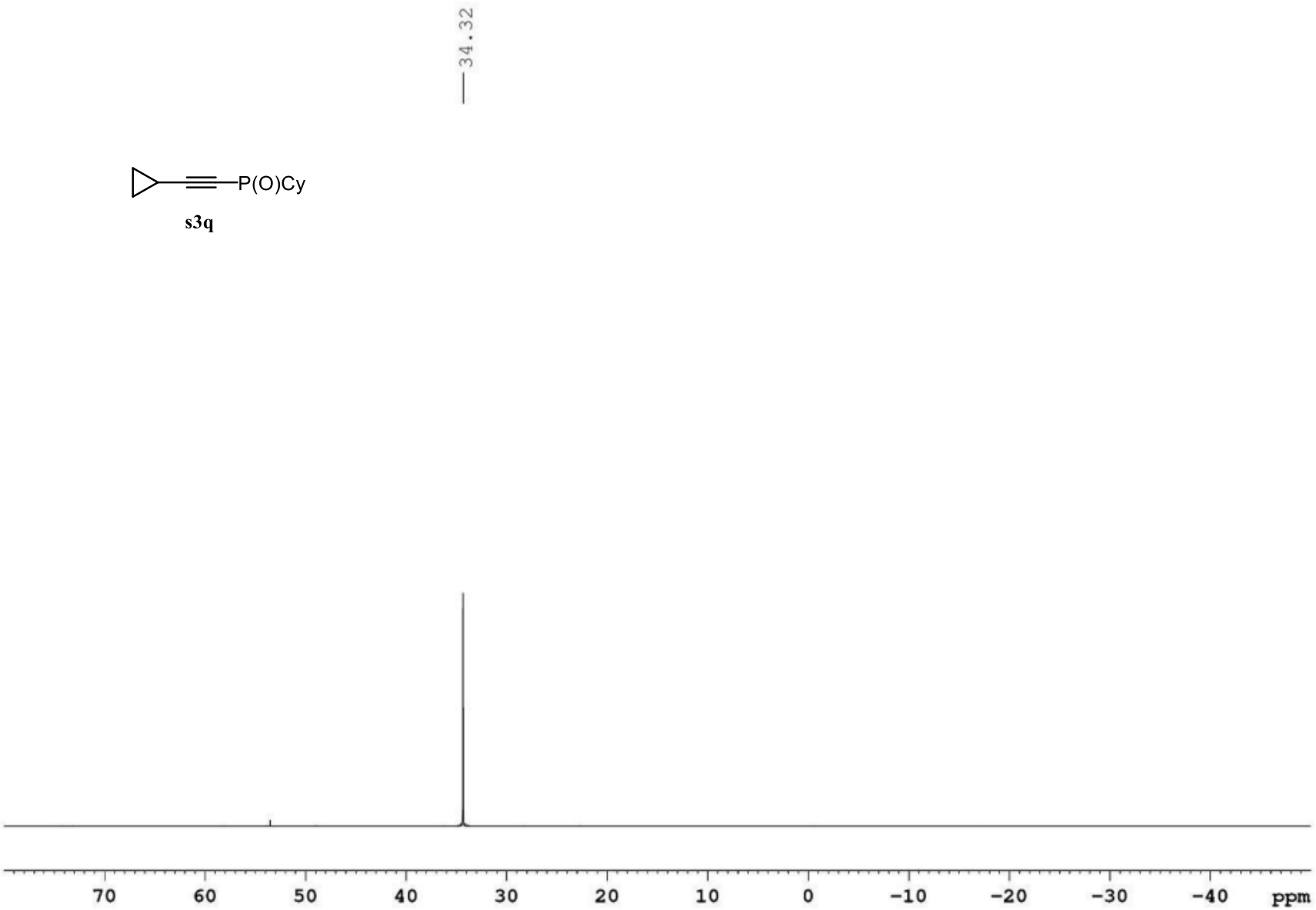

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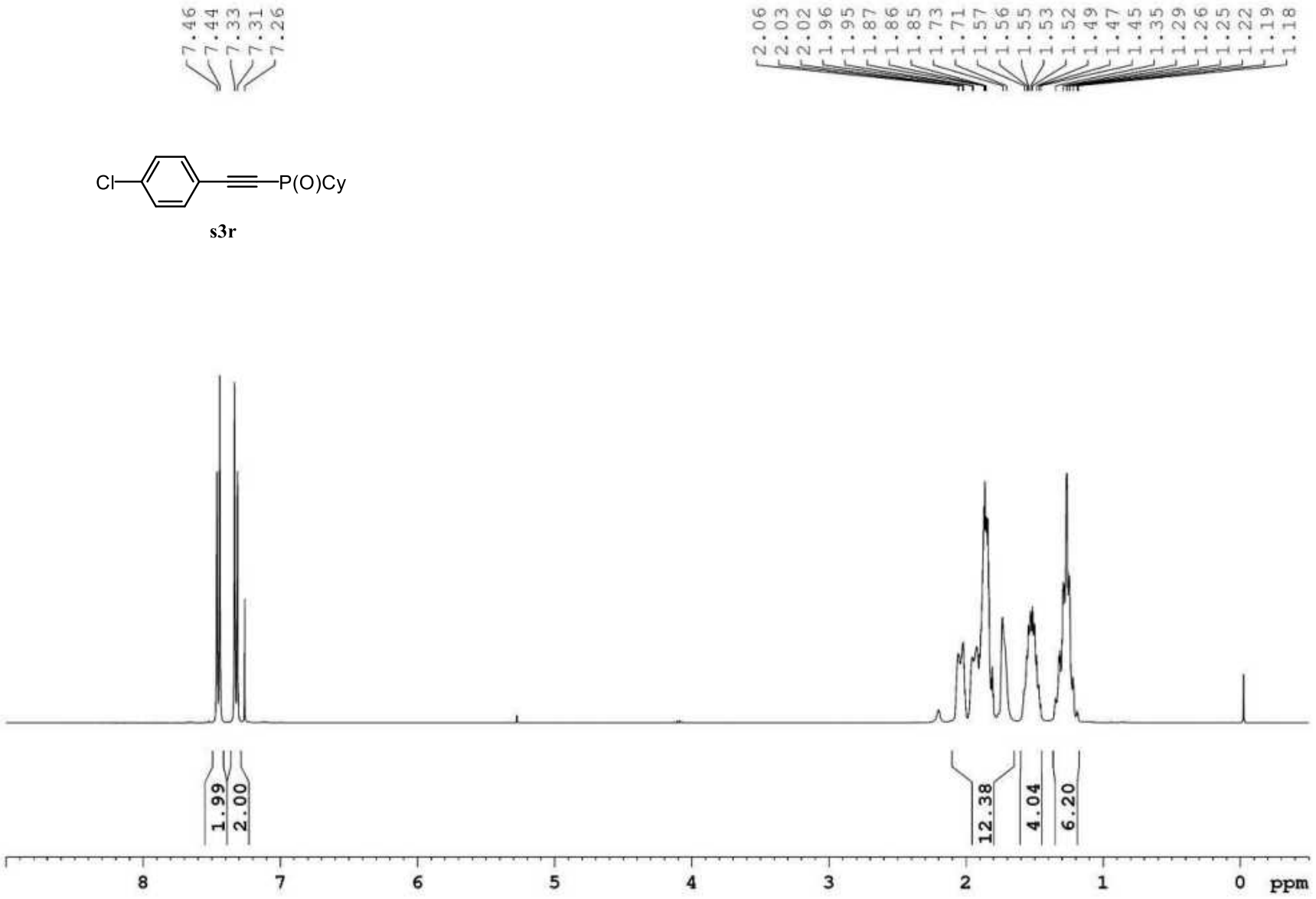
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1.71
1.57
1.56
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1.49
1.47
1.45
1.35
1.29
1.26
1.25
1.22
1.19
1.18
Cl
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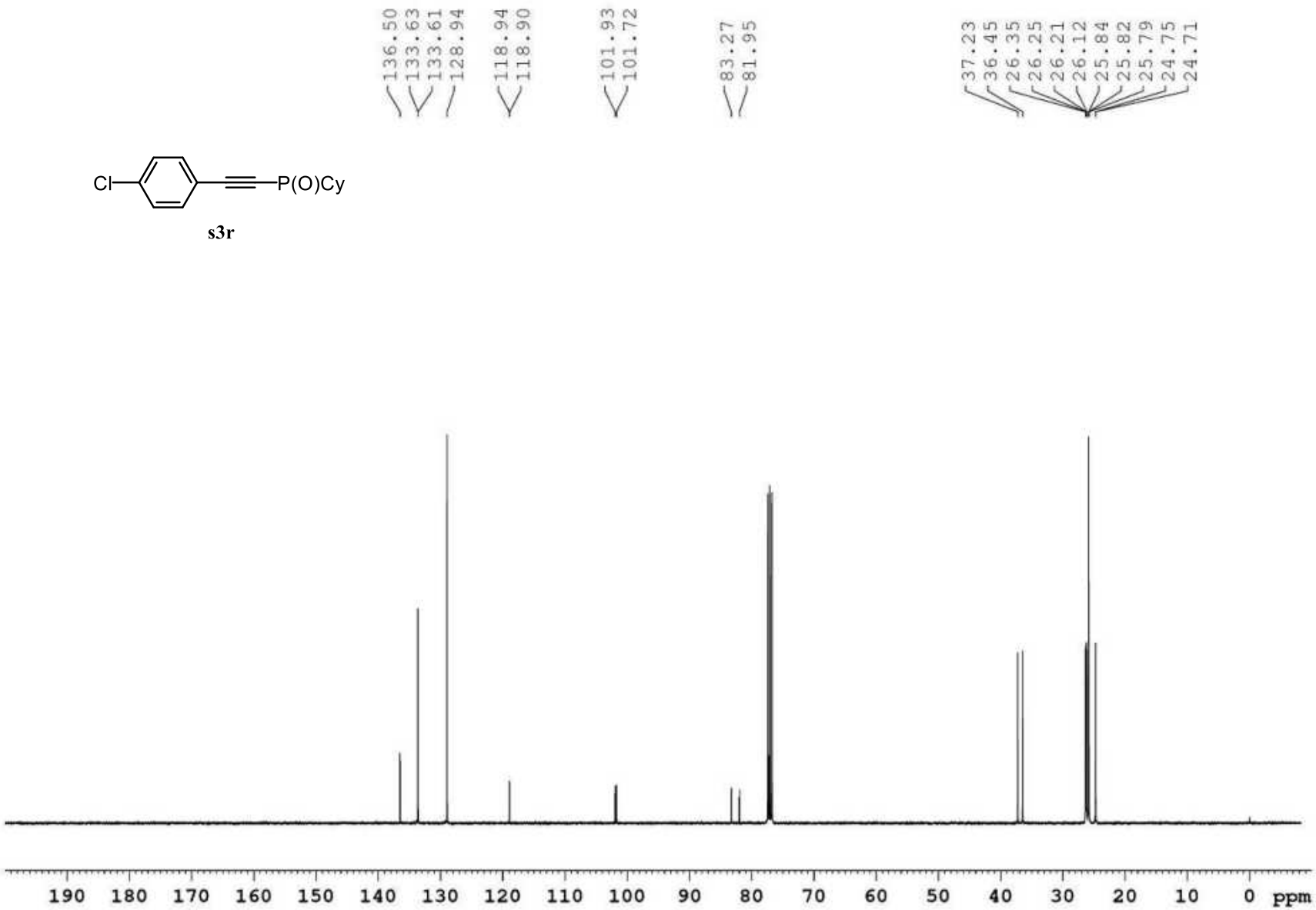
ppm

s3r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26.35
26.25
26.21
26.12
25.84
25.82
25.79
24.75
24.71
Cl
P(O)Cy
190
180
170
160
150
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70
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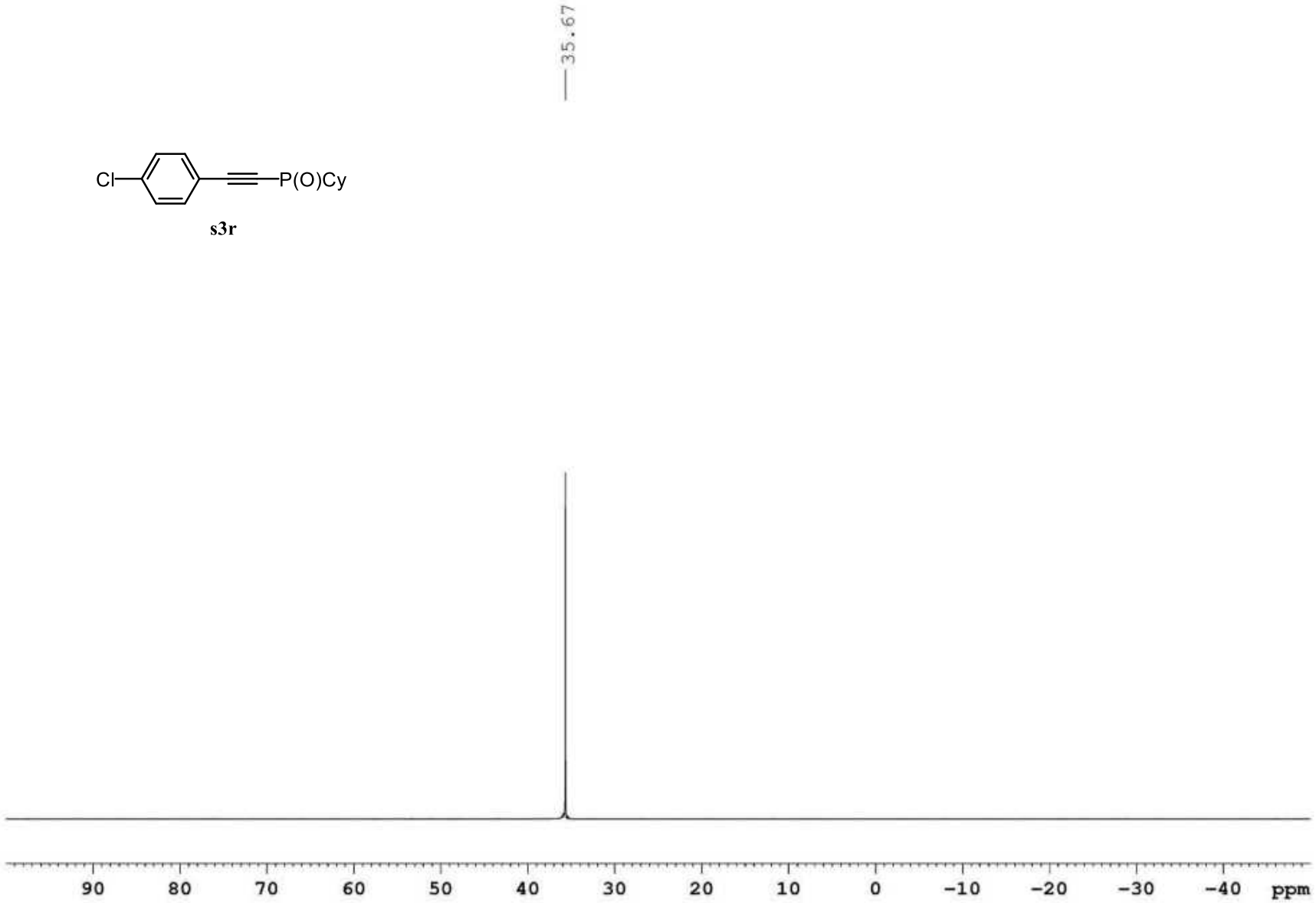
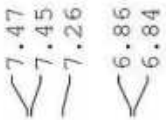
ppm

s3r

s3r

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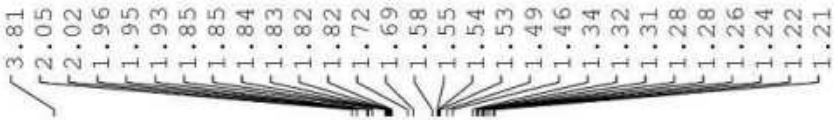
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1.31
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1.28
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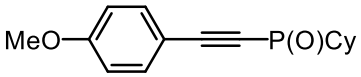
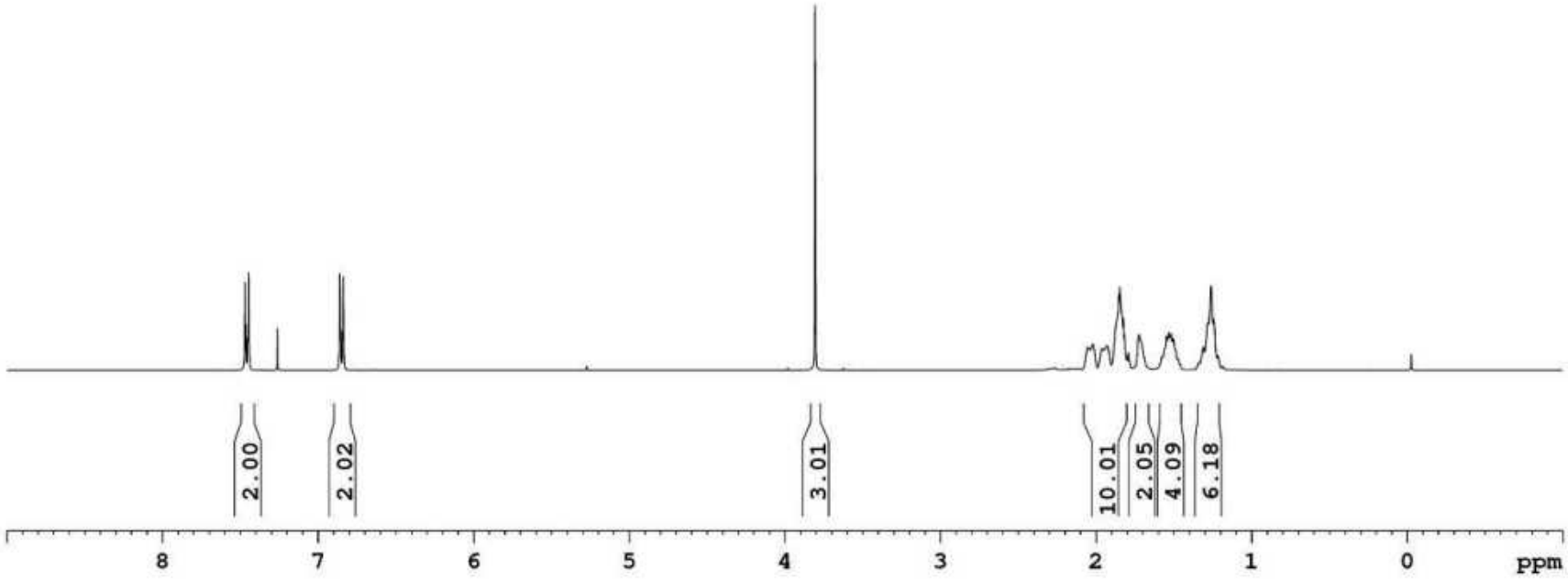
1.24
1.22
1.21


MeO
P(O)Cy

s3s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2.05
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6.18
8
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6
5
4
3
2
1
0
ppm


161.05
134.11
134.09
114.16
112.42
112.38
103.71
103.49
80.86
79.49
55.39
37.27
36.49
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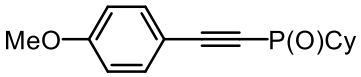
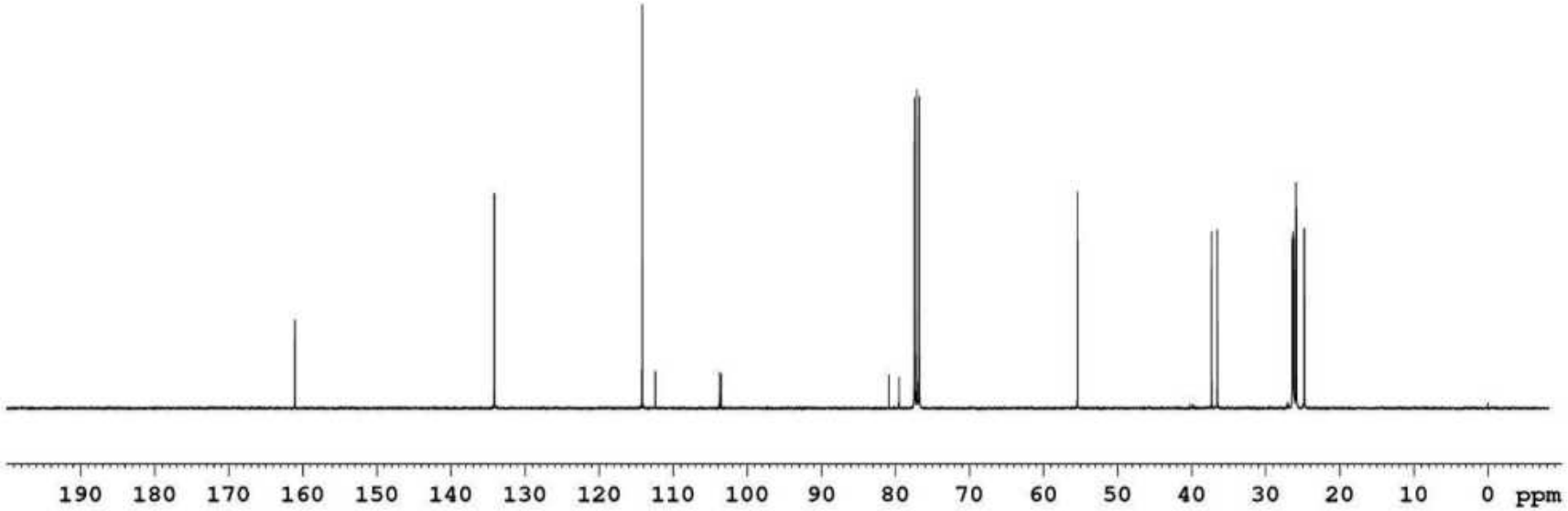
25.88
25.87
25.84
25.81
24.78
24.75


MeO
P(O)Cy

s3s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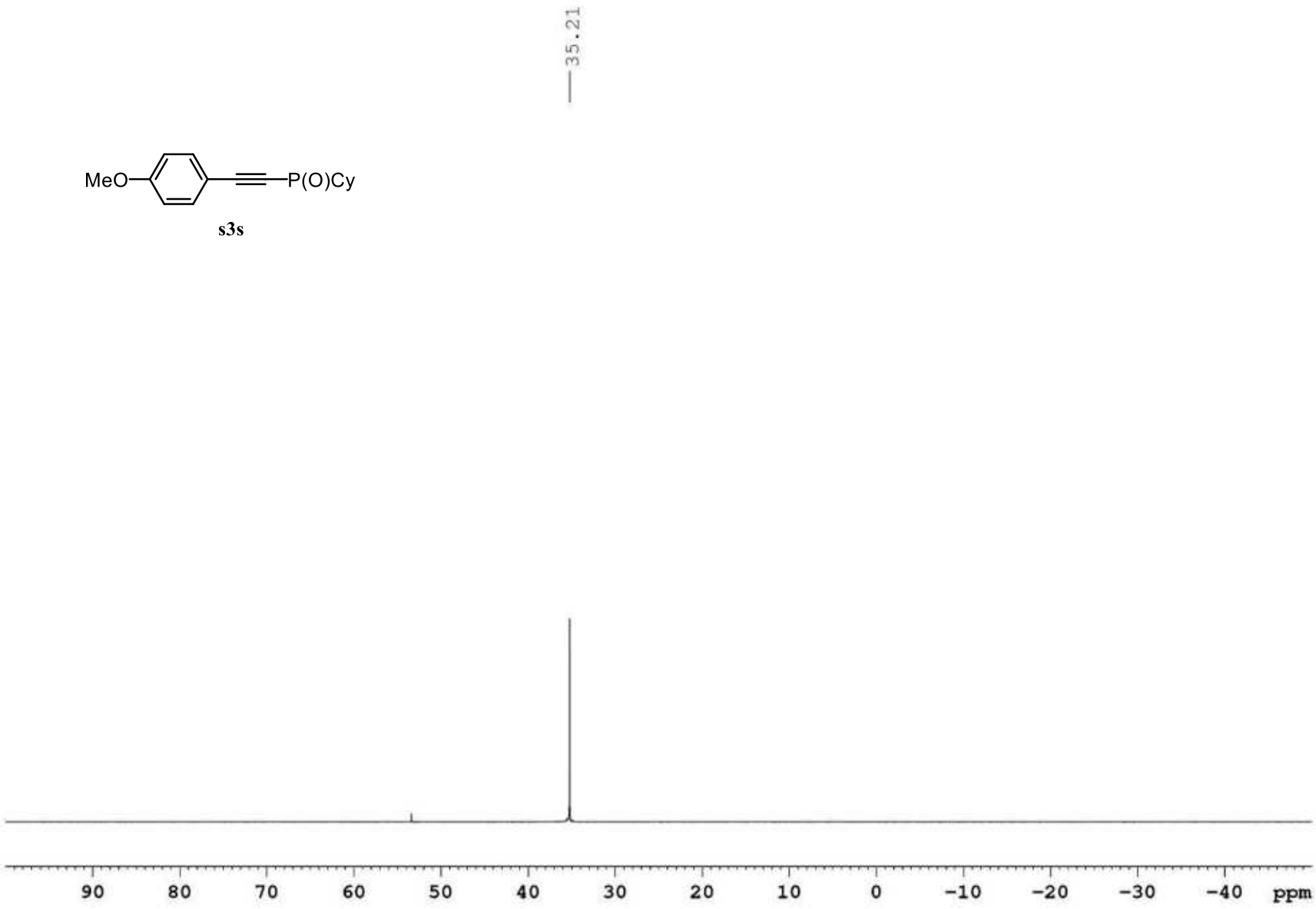
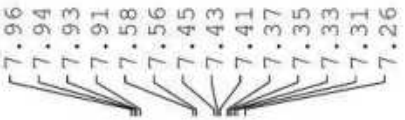
s3s

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7.43
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7.37
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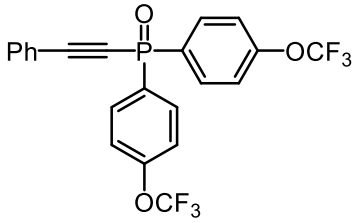
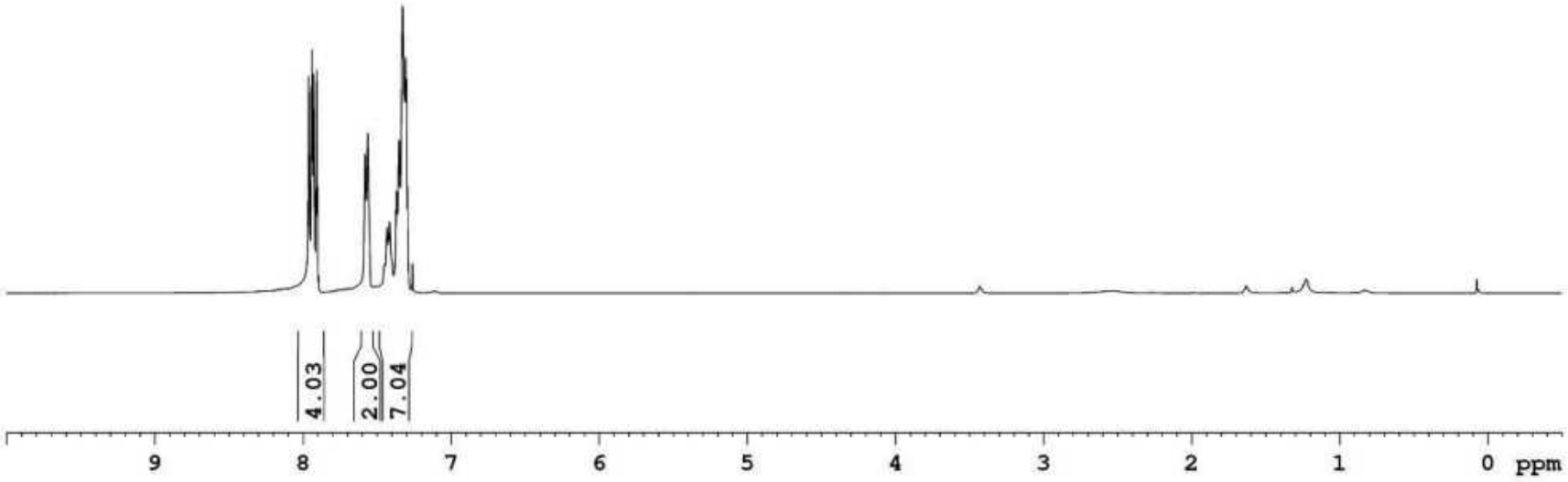
7.33
7.31
7.26


O
Ph
P
OCF3
OCF3

s3y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6
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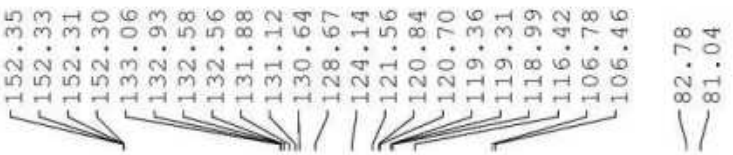
4
3
2
1
0
ppm


152.35
152.33
152.31
152.30
133.06
132.93
132.58
132.56
131.88
131.12
130.64
128.67
124.14
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118.99
116.42
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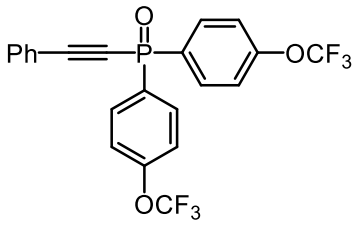
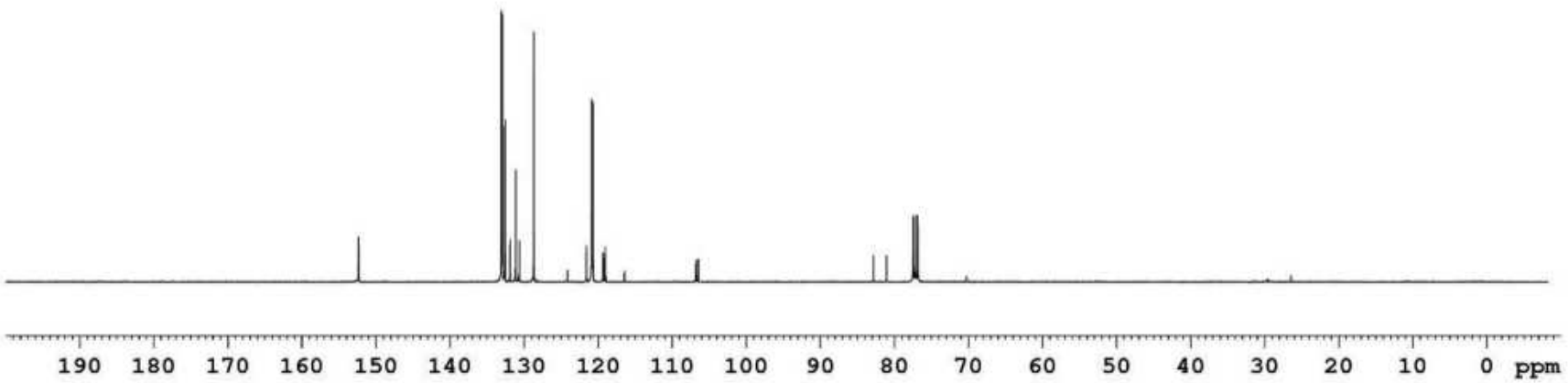
106.46
82.78
81.04


O
Ph
P
OCF3
OCF3

s3y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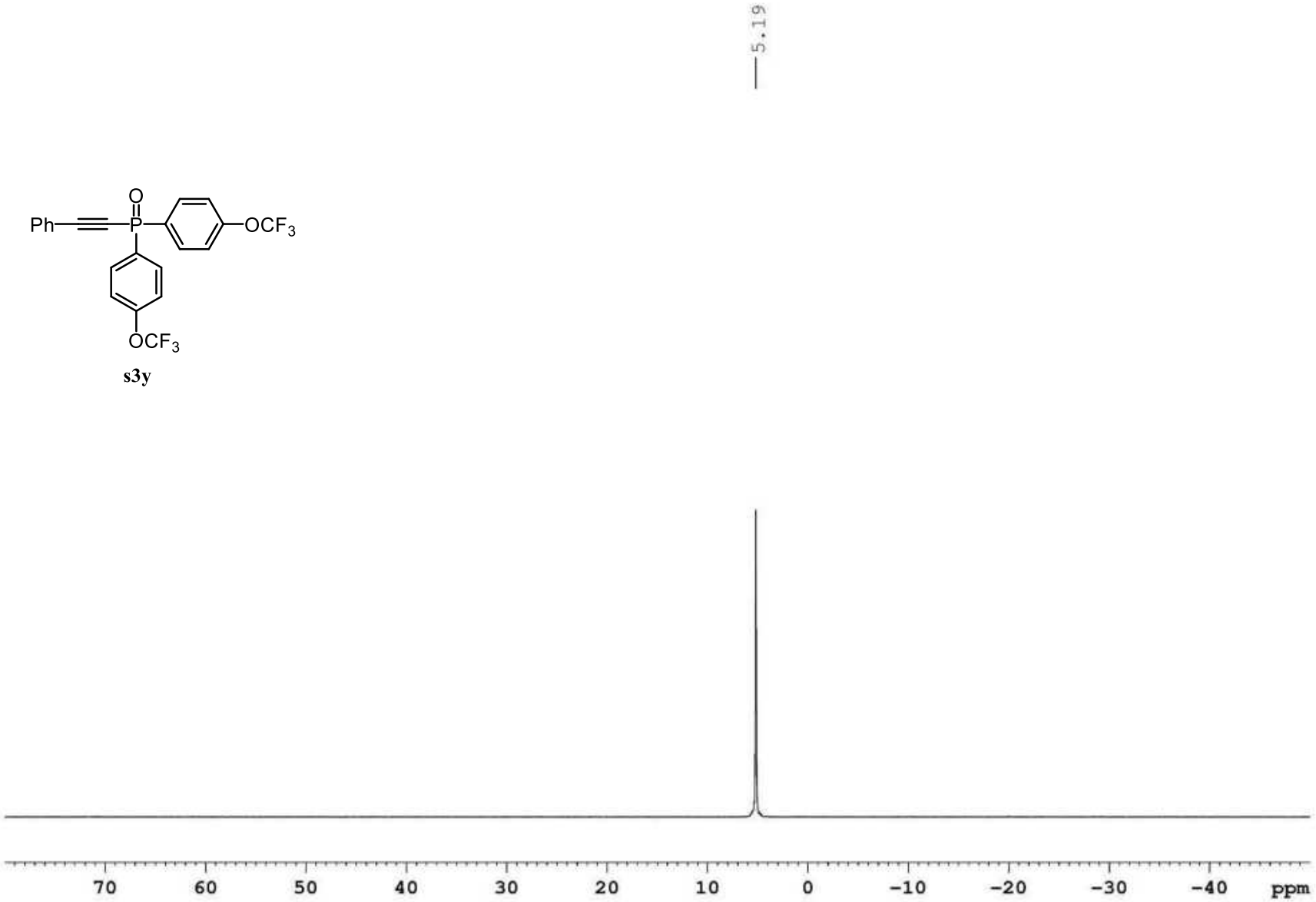
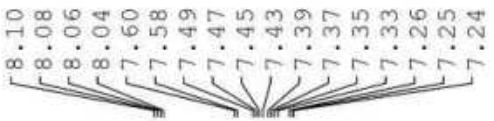
10
0
ppm

s3y

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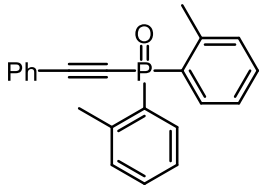
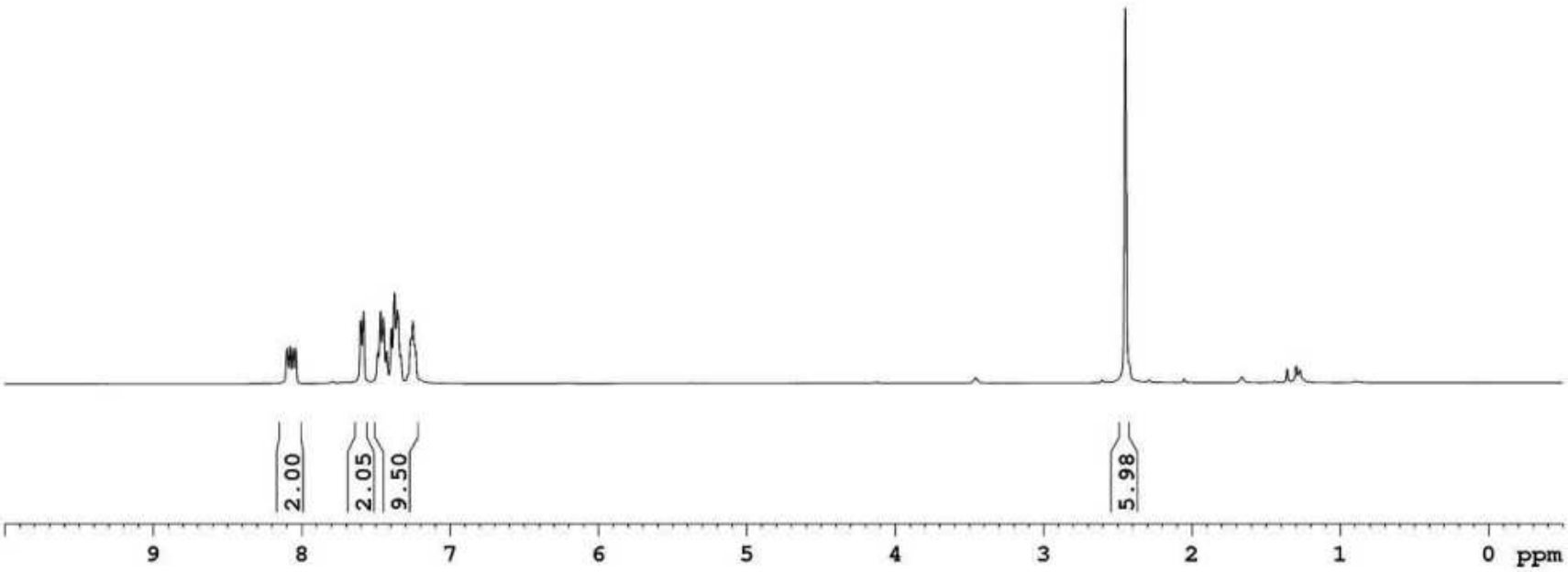
8.08
8.06
8.04
7.60
7.58
7.49
7.47
7.45
7.43
7.39
7.37
7.35
7.33
7.26
7.25
7.24


2.45


O
Ph
P

s3z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2.05
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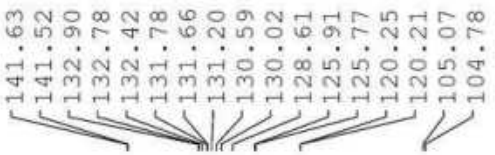
6
5
4
3
2
1
0
ppm


141.63
141.52
132.90
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132.42
131.78
131.66
131.20
130.59
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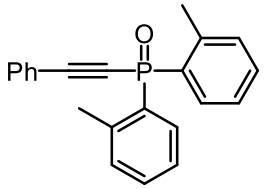
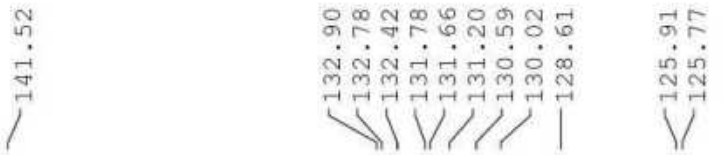
125.77
120.25
120.21
105.07
104.78


84.02
82.36


21.28
21.23


Ph
O
P

s3z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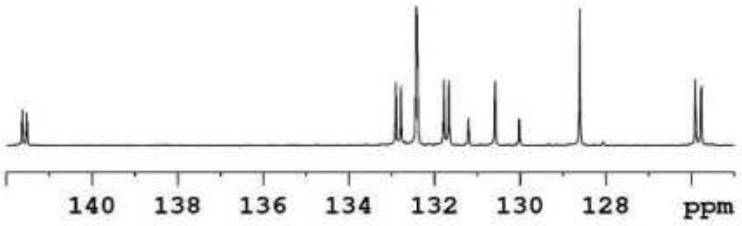
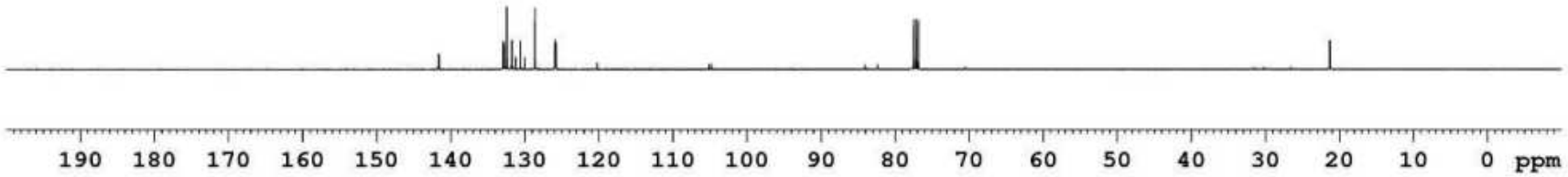
132.90
132.78
132.42
131.78
131.66
131.20
130.59
130.02
128.61
125.91
125.77


140
138
136
134
132
130
128
ppm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180
170
160
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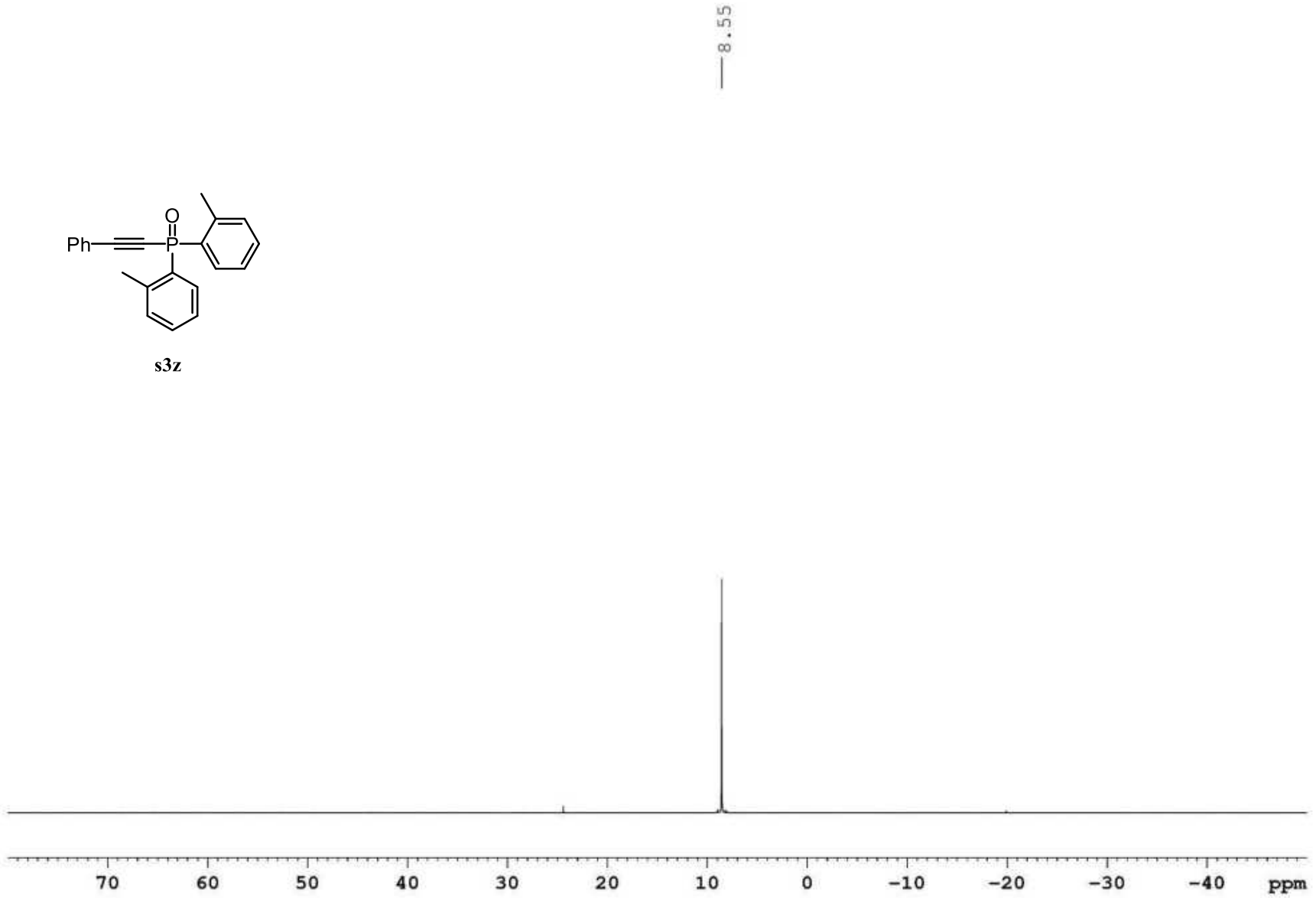
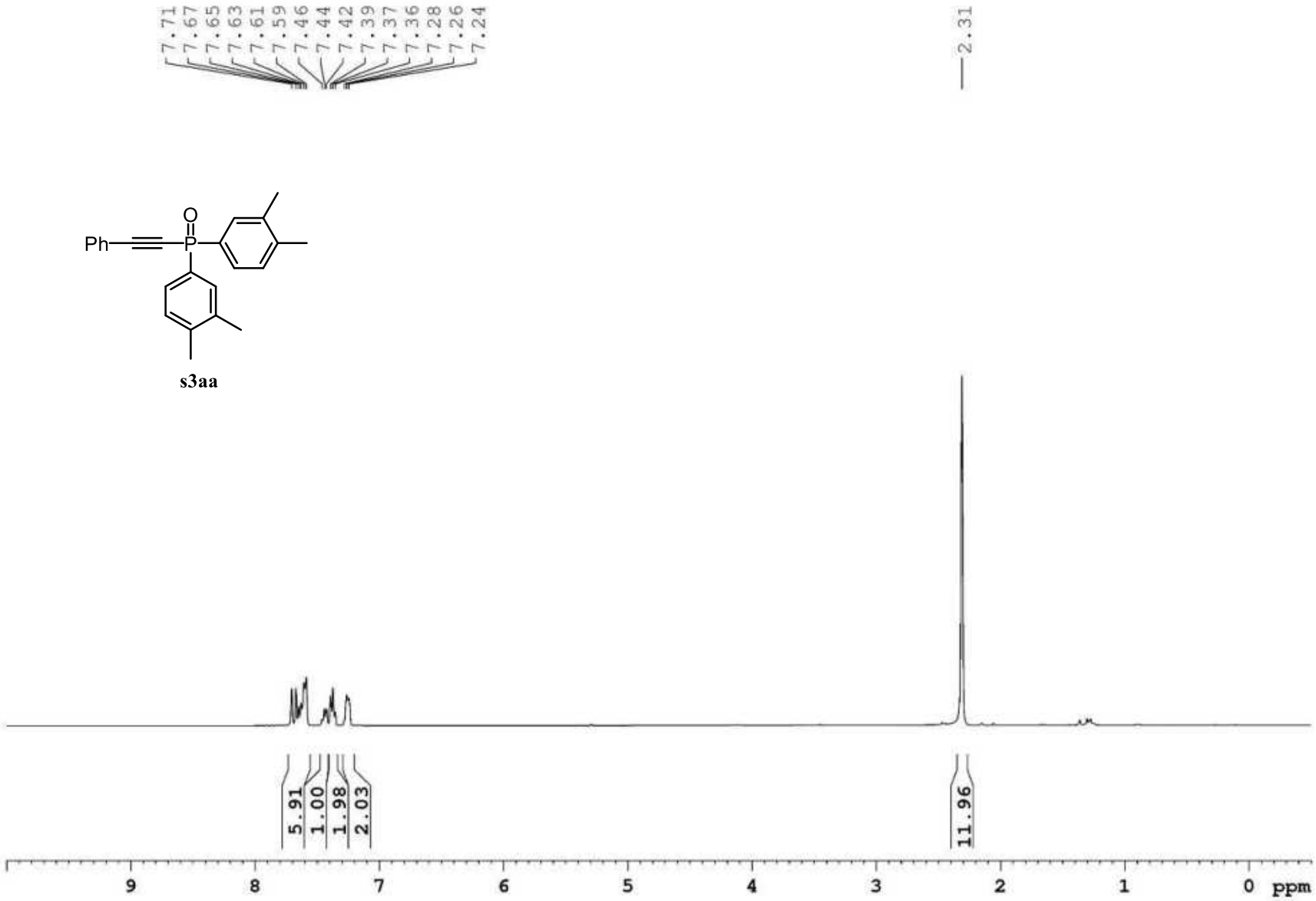
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

s3z

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7.59
7.46
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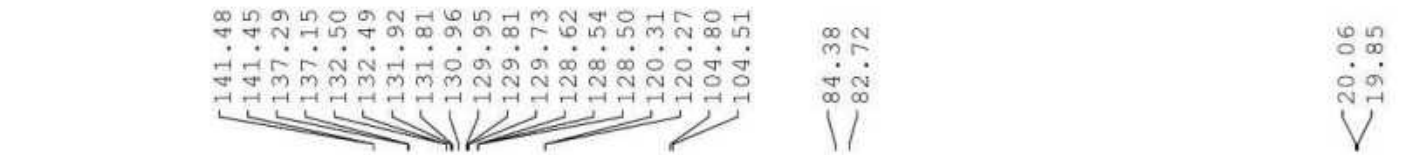
7.39
7.37
7.36
7.28
7.26
7.24
2.31
O
Ph
P
5.91
1.00
1.98
2.03
11.96
9
8
7
6
5
4
3
2
1
0
ppm

s3aa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129.95
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104.51
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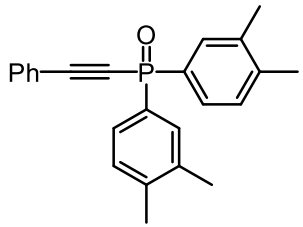
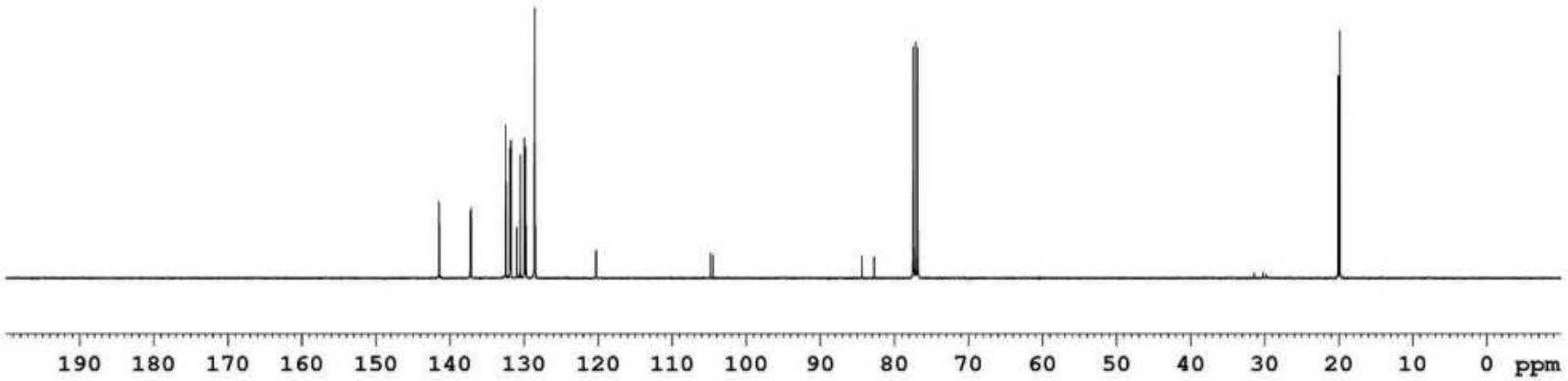
82.72
20.06
19.85


O
Ph
P

s3aa


190
180
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110
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80
70
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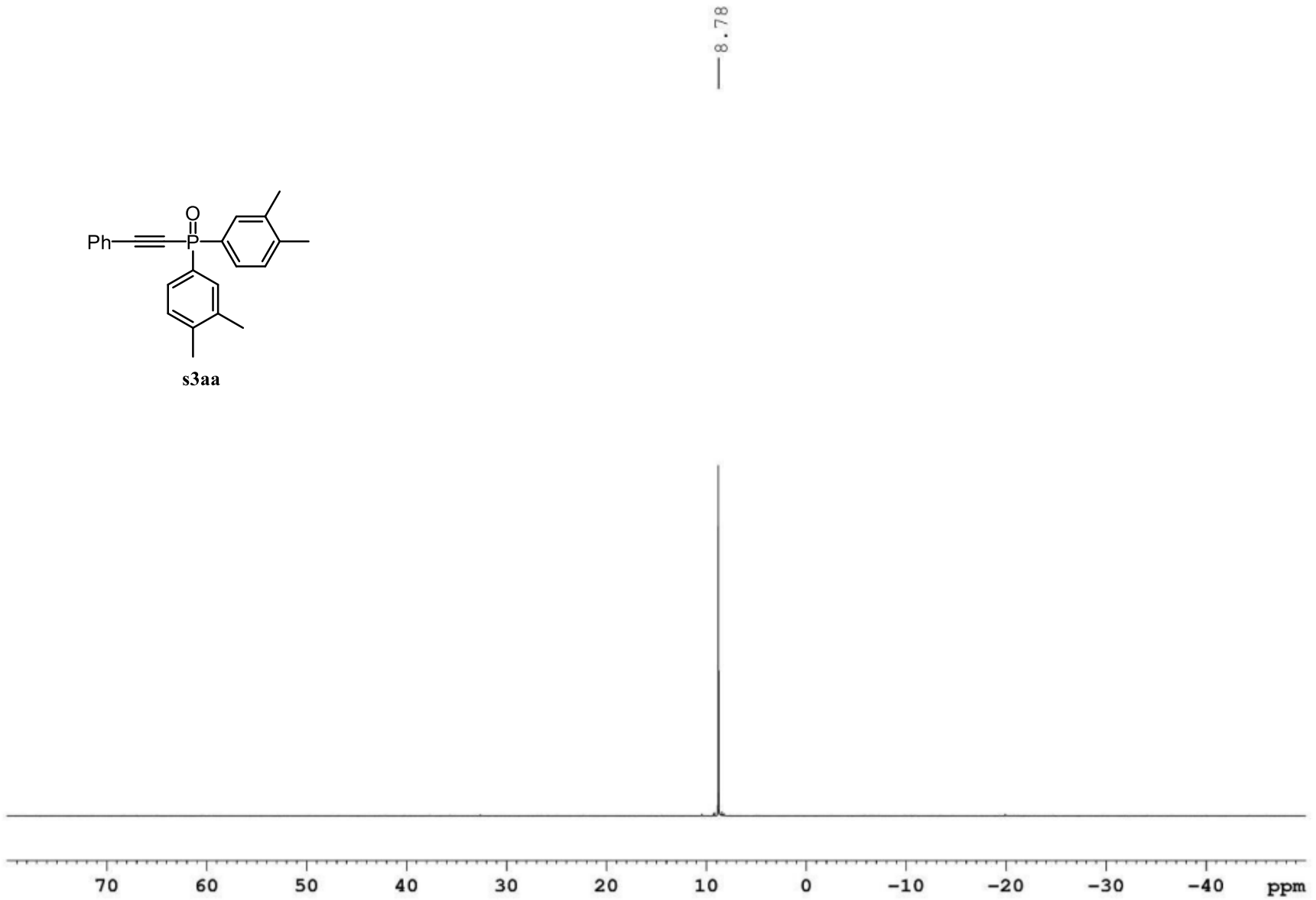
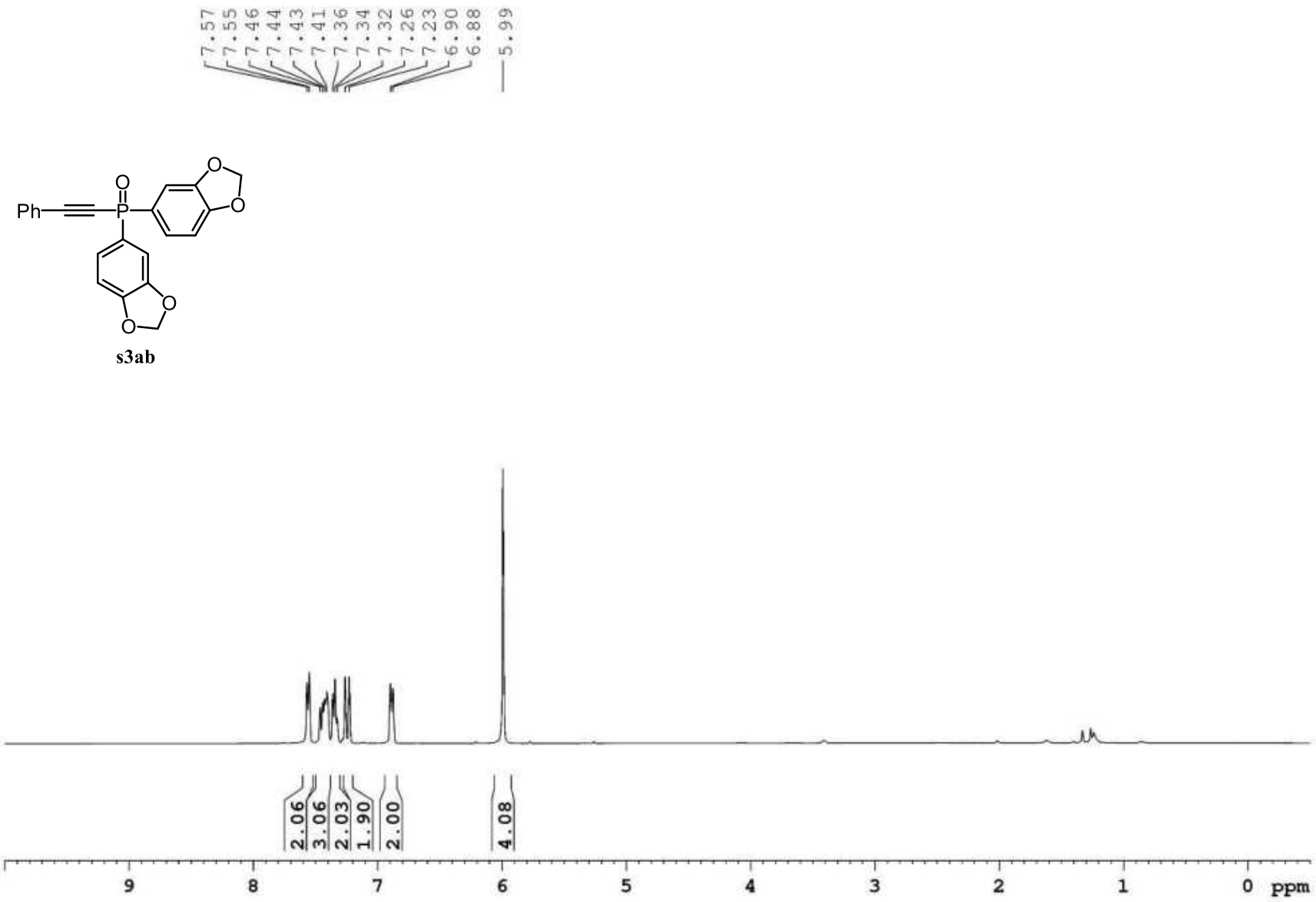
50
40
30
20
10
0
ppm

s3aa

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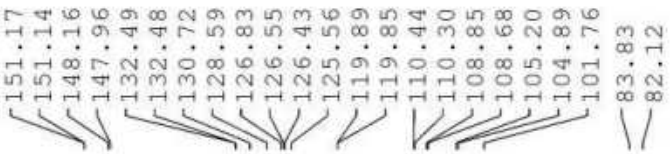
7.46
7.44
7.43
7.41
7.36
7.34
7.32
7.26
7.23
6.90
6.88
5.99
Ph
P
O
O
O
O
O
2.06
3.06
2.03
1.90
2.00
4.08
9
8
7
6
5
4
3
2
1
0
ppm

s3ab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132.48
130.72
128.59
126.83
126.55
126.43
125.56
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110.44
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108.85
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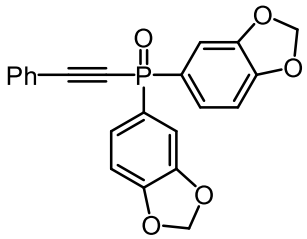
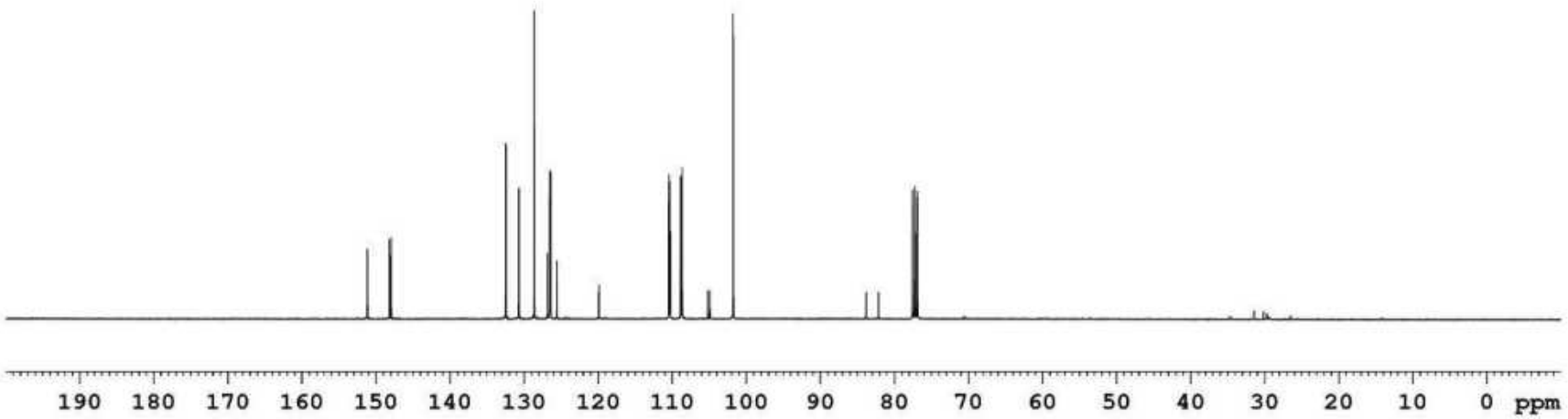
83.83
82.12


Ph
O
P
O
O
O
O

s3ab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180
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150
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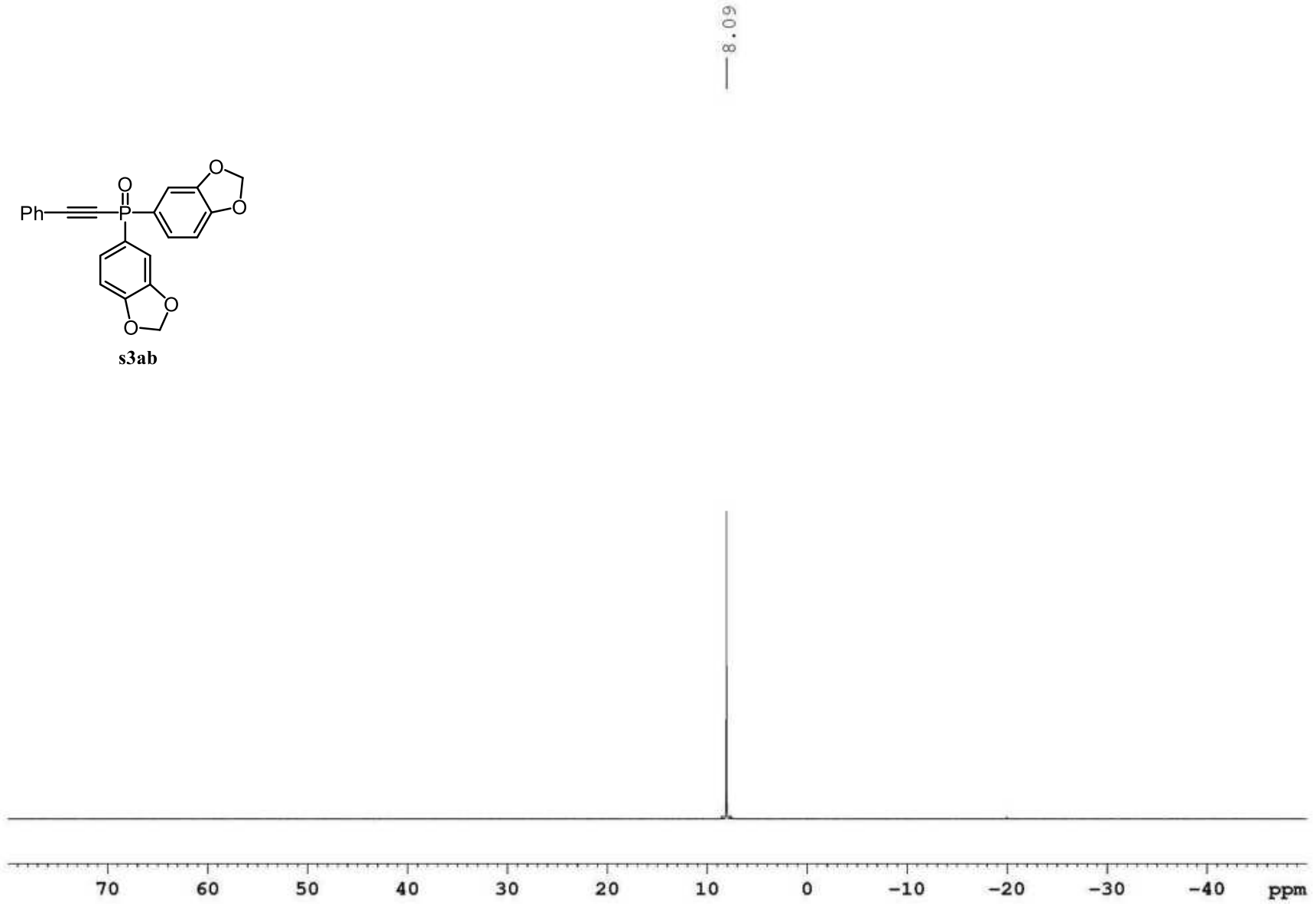
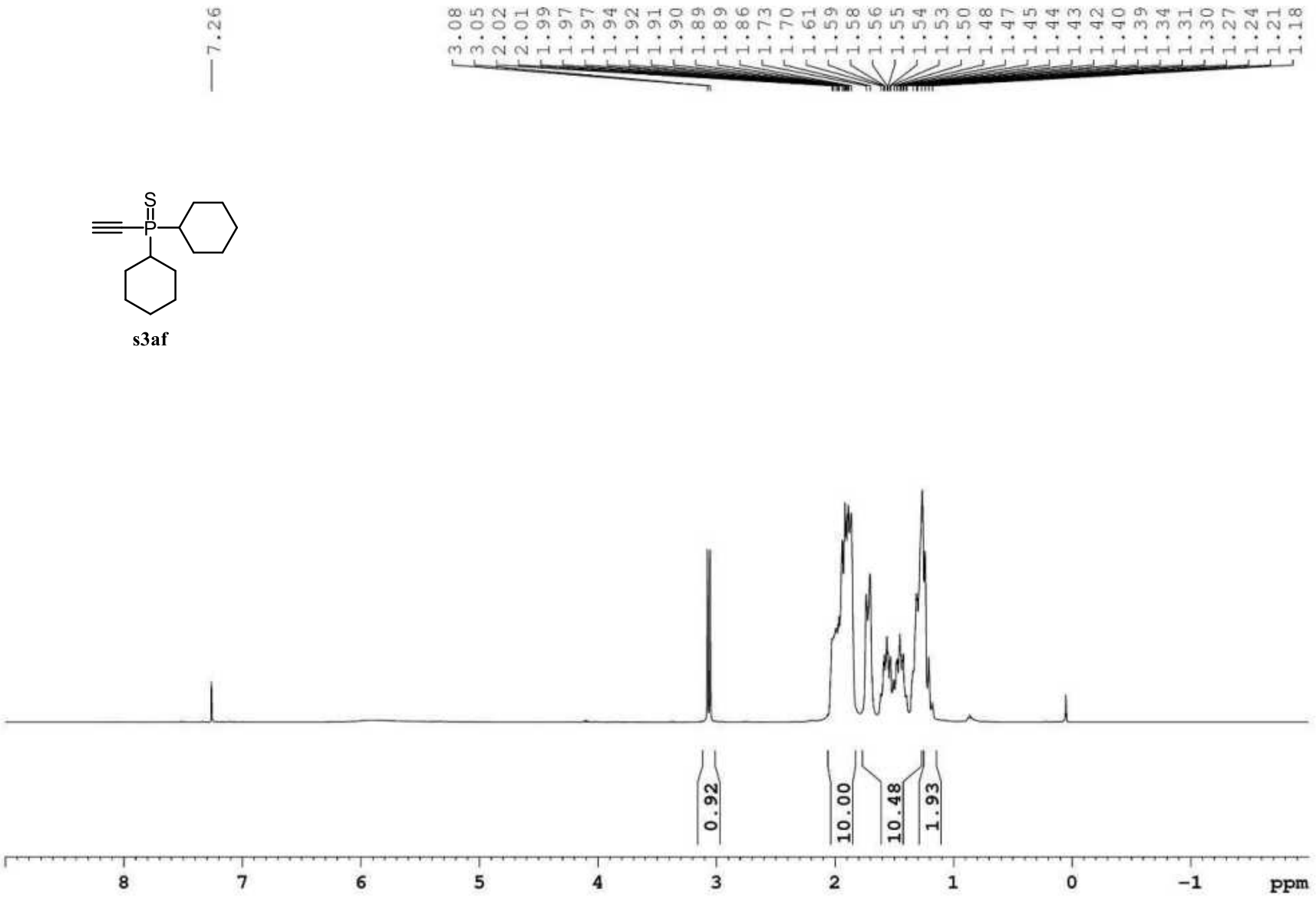
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

s3ab

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2.01
1.99
1.97
1.97
1.94
1.92
1.91
1.90
1.89
1.89
1.86
1.73
1.70
1.61
1.59
1.58
1.56
1.55
1.54
1.53
1.50
1.48
1.47
1.45
1.44
1.43
1.42
1.40
1.39
1.34
1.31
1.30
1.27
1.24
1.21
1.18
S
P
0.92
10.00
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8
7
6
5
4
3
2
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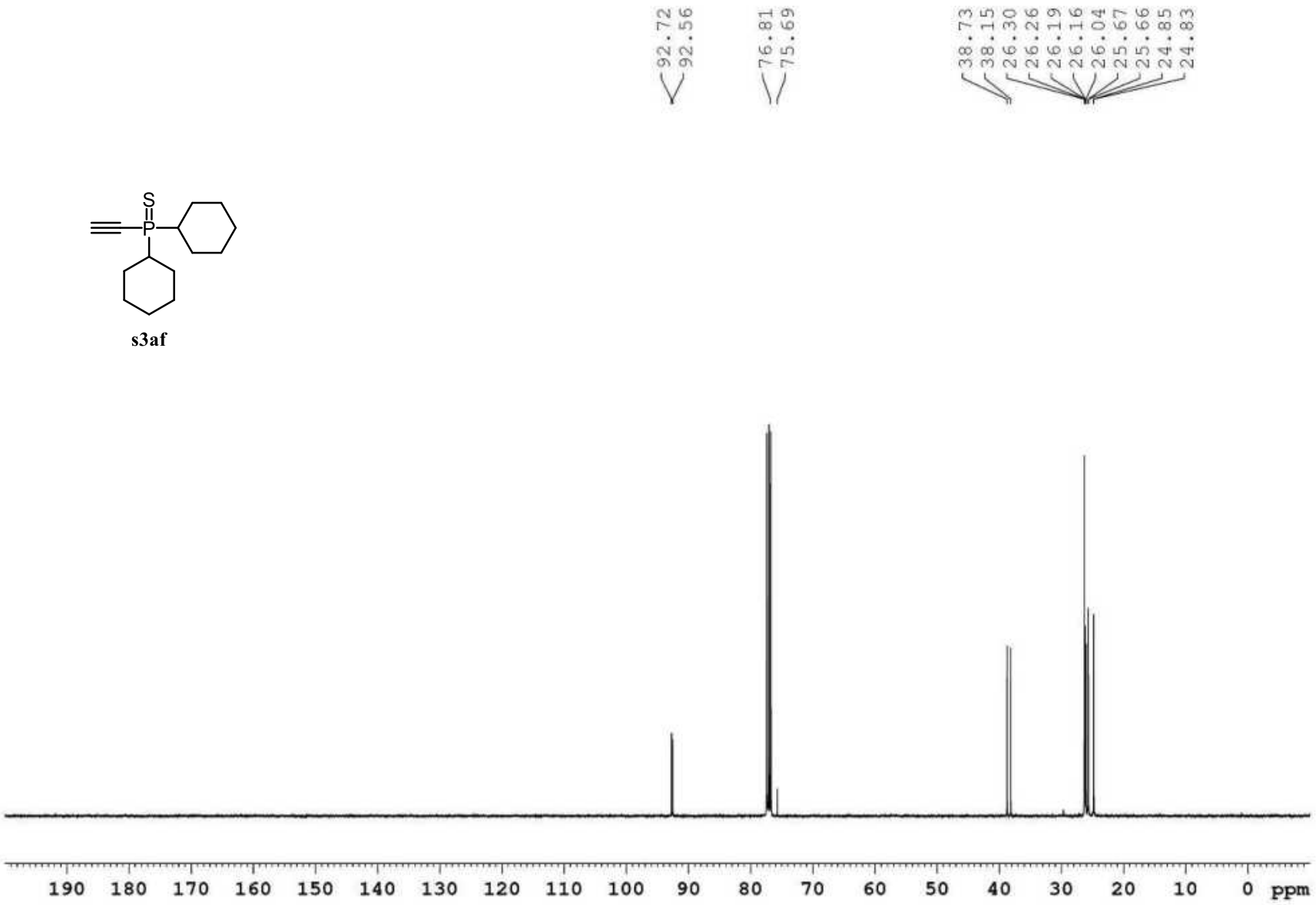
0
−1
ppm

s3af

S
P

s3af


92.72
92.56
76.81
75.69
38.73
38.15
26.30
26.26
26.19
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26.04
25.67
25.66
24.85
24.83
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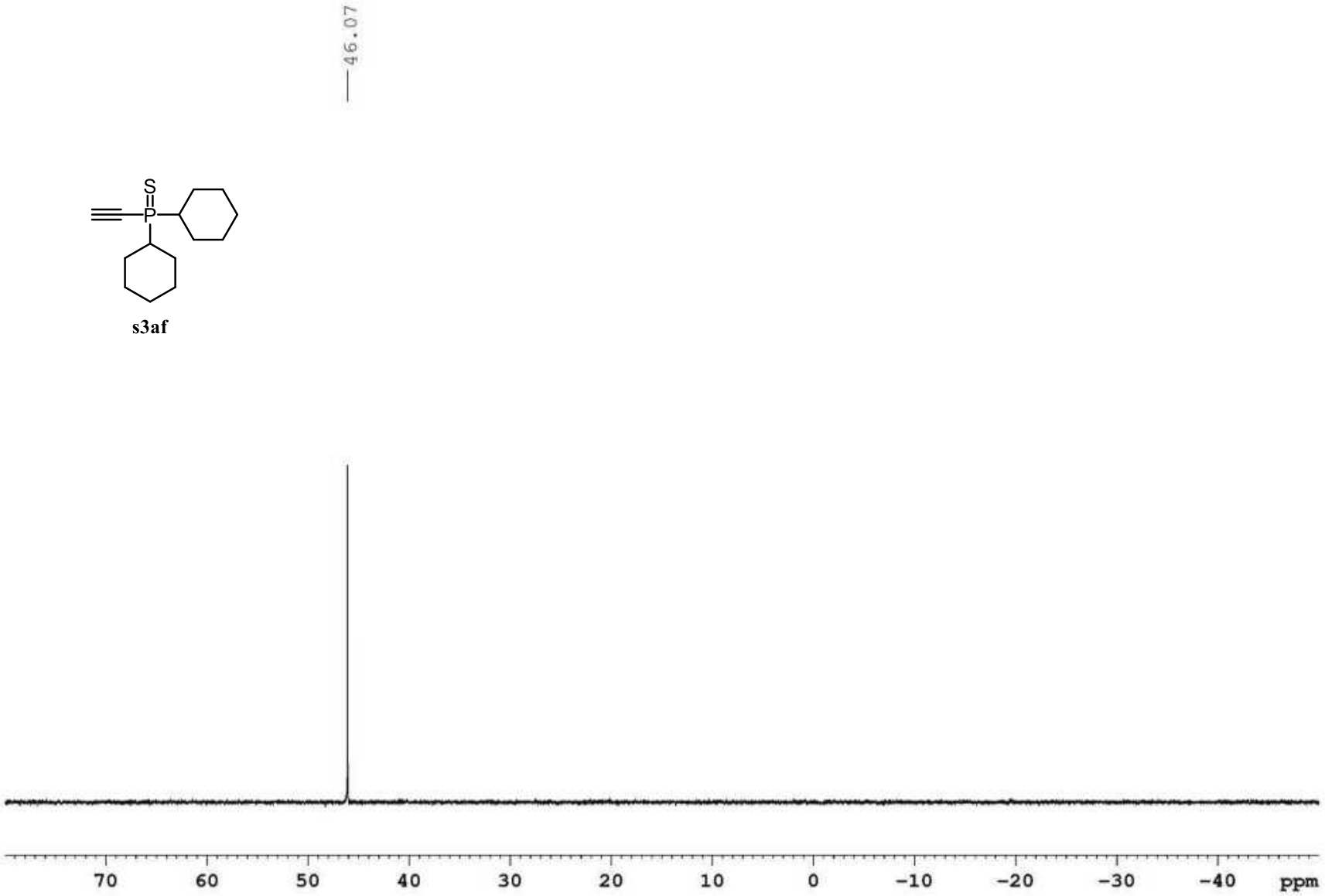
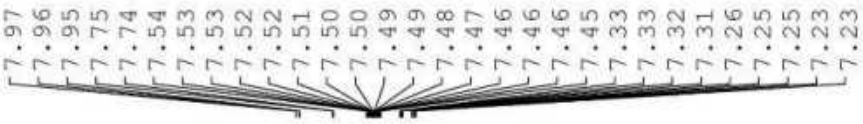
s3af

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7.47
7.46
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7.32
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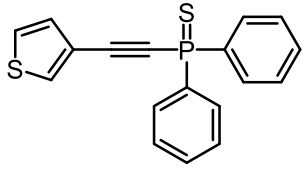
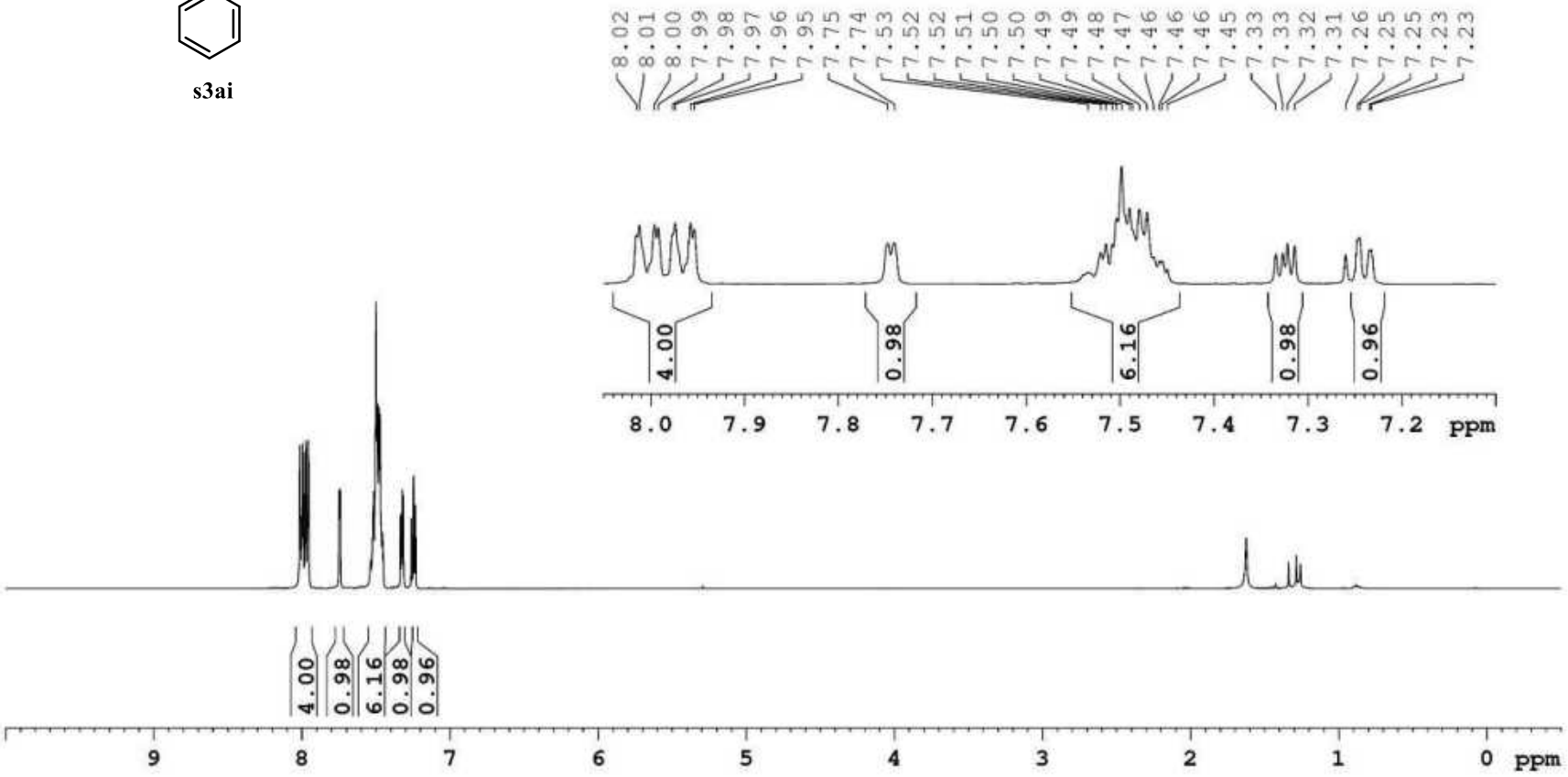
7.26
7.25
7.25
7.23
7.23


S
S
P

s3ai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8.00
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7.97
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7.95
7.75
7.74
7.53
7.52
7.52
7.51
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7.46
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7.46
7.45
7.33
7.33
7.32
7.31
7.26
7.25
7.25
7.23
7.23
4.00
0.98
6.16
0.98
0.96
8.0
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
ppm
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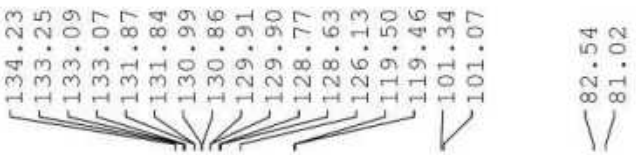
6.16
0.98
0.96
9
8
7
6
5
4
3
2
1
0
ppm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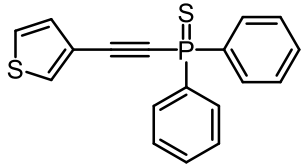
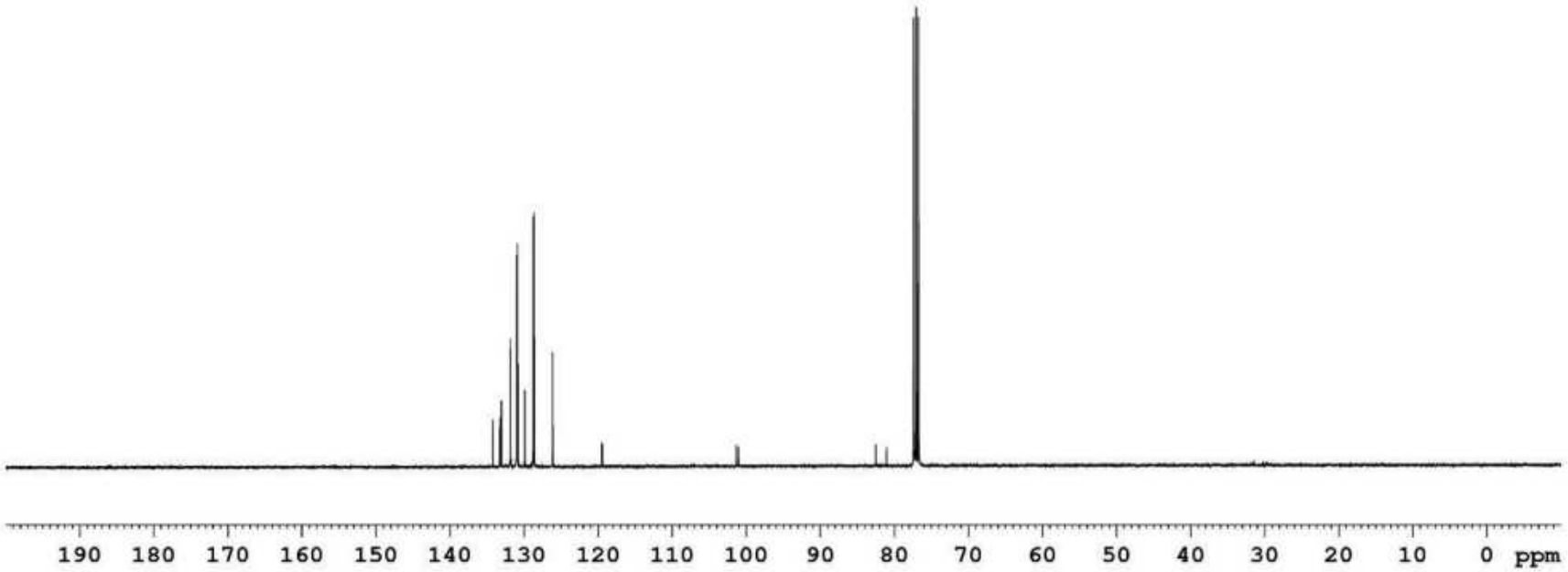
101.07
82.54
81.02


S
S
P

s3ai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40
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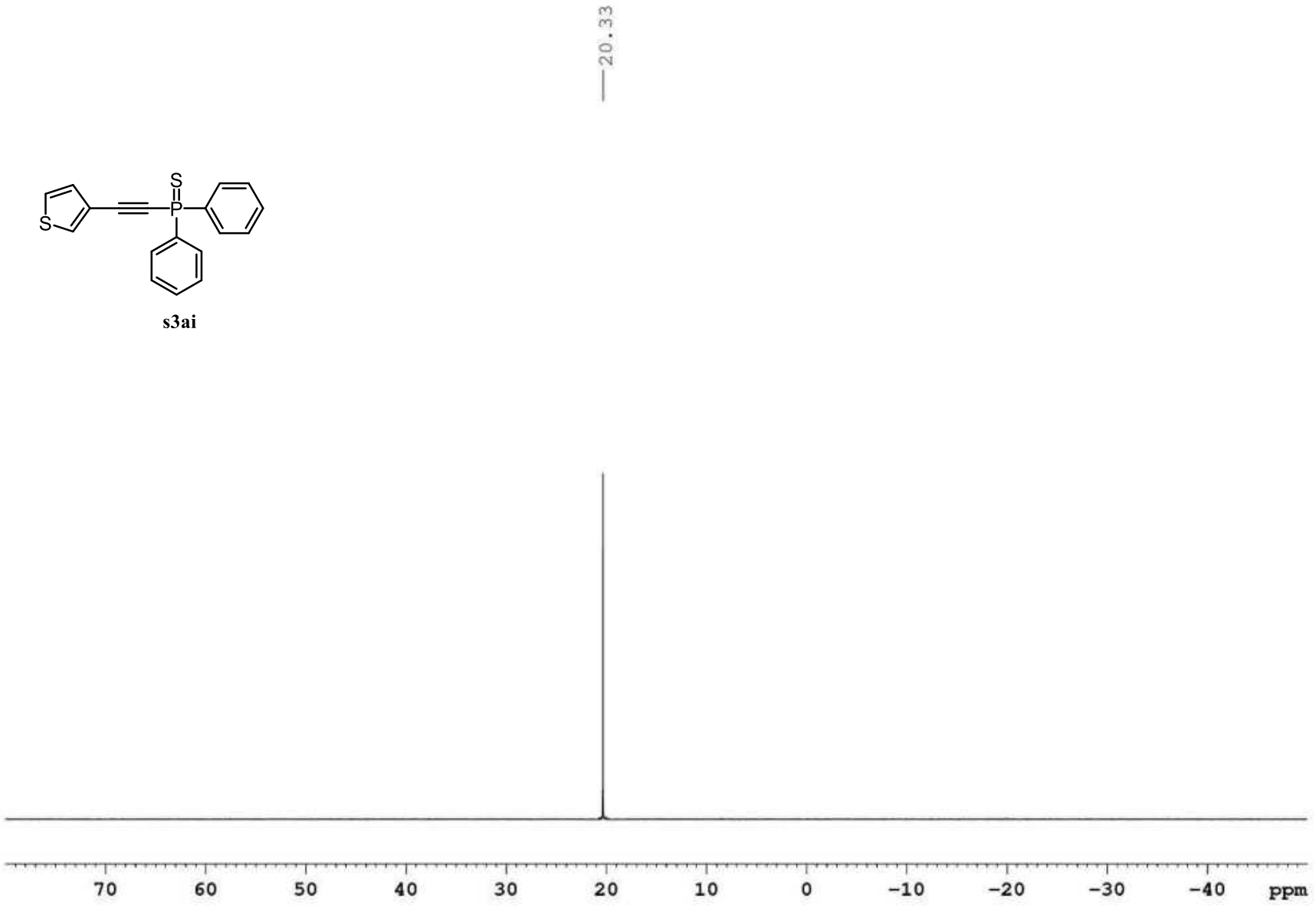
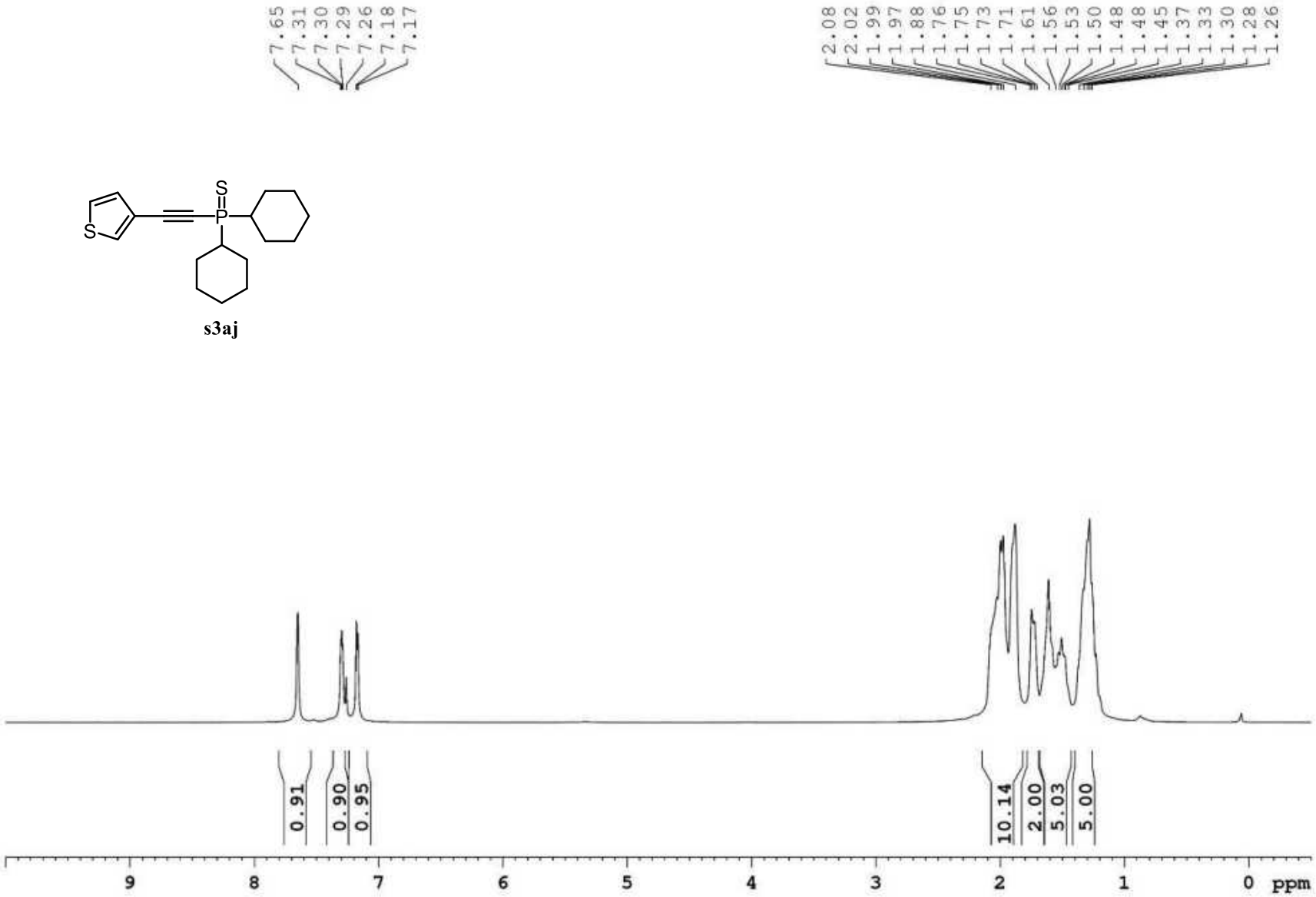
0
ppm

s3ai

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7.17
2.08
2.02
1.99
1.97
1.88
1.76
1.75
1.73
1.71
1.61
1.56
1.53
1.50
1.48
1.48
1.45
1.37
1.33
1.30
1.28
1.26
S
S
P
0.91
0.90
0.95
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5.03
5.00
9
8
7
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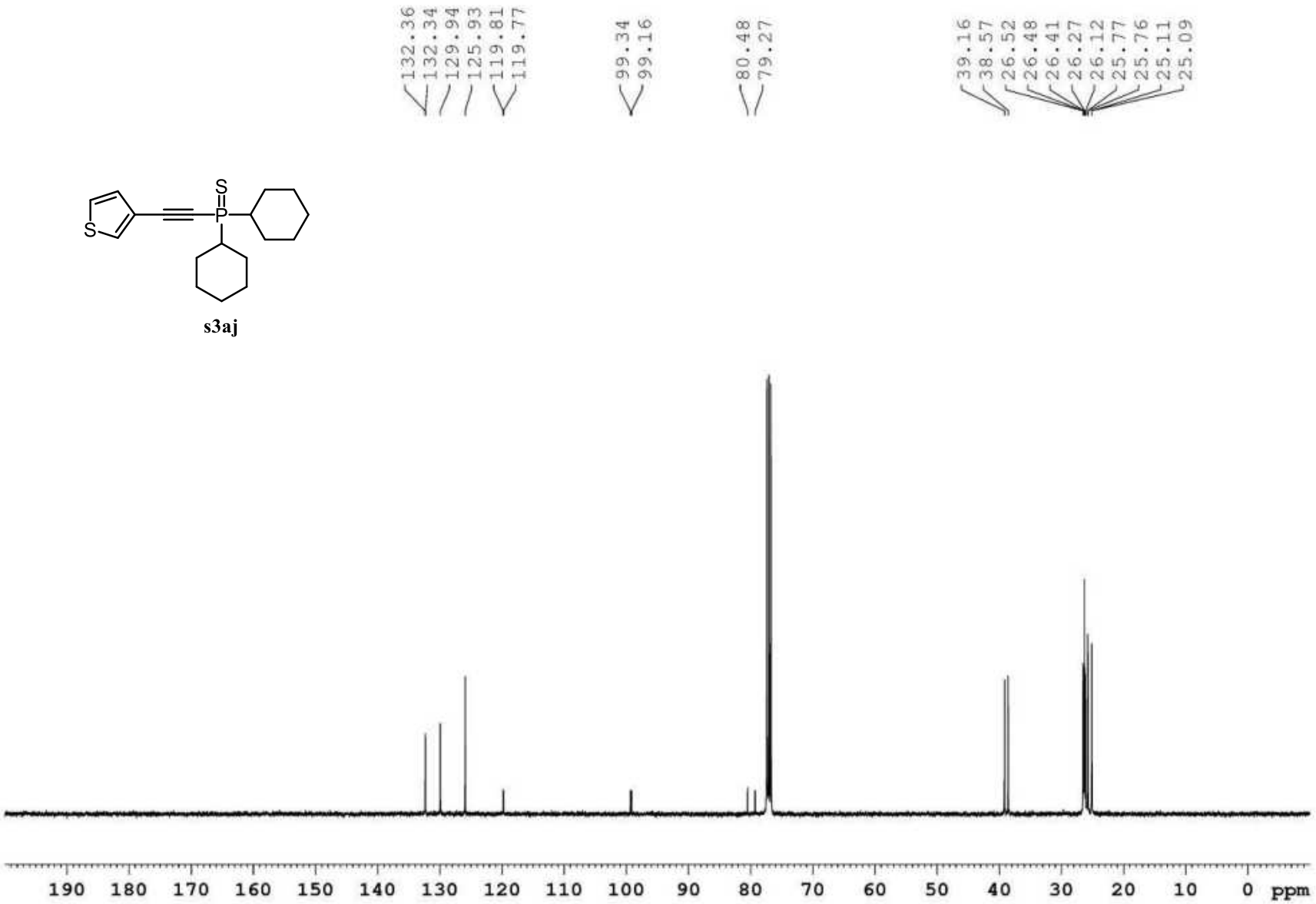
5
4
3
2
1
0
ppm

s3aj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132.34
129.94
125.93
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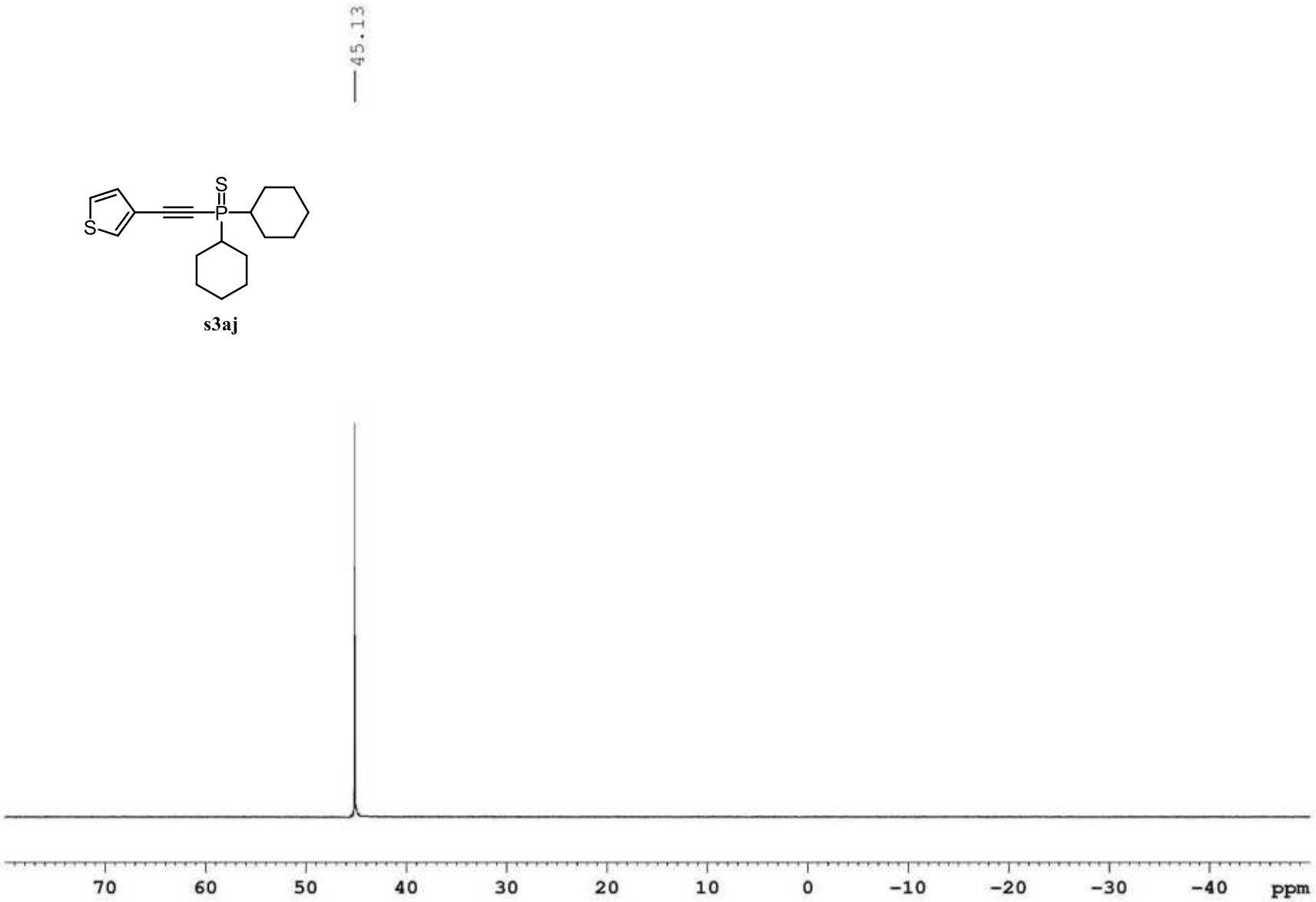
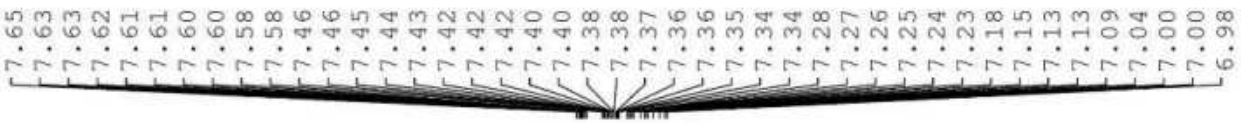
119.77
99.34
99.16
80.48
79.27
39.16
38.57
26.52
26.48
26.41
26.27
26.12
25.77
25.76
25.11
25.09
S
S
P
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm

s3aj

s3aj

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7.45
7.44
7.43
7.42
7.42
7.42
7.40
7.40
7.38
7.38
7.37
7.36
7.36
7.35
7.34
7.34
7.28
7.27
7.26
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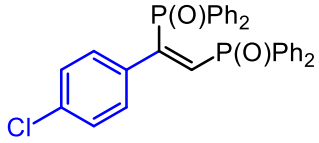
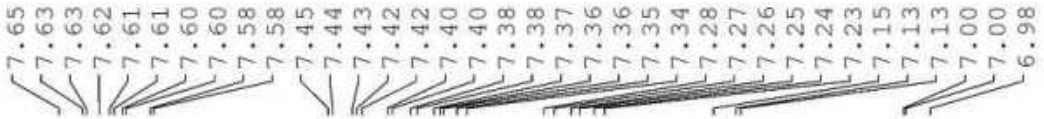
7.23
7.18
7.15
7.13
7.13
7.09
7.04
7.00
7.00
6.98


P(O)Ph2
P(O)Ph2
Cl

4a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7.63
7.63
7.62
7.61
7.61
7.60
7.60
7.58
7.58
7.45
7.44
7.43
7.42
7.42
7.40
7.40
7.38
7.38
7.37
7.36
7.36
7.35
7.34
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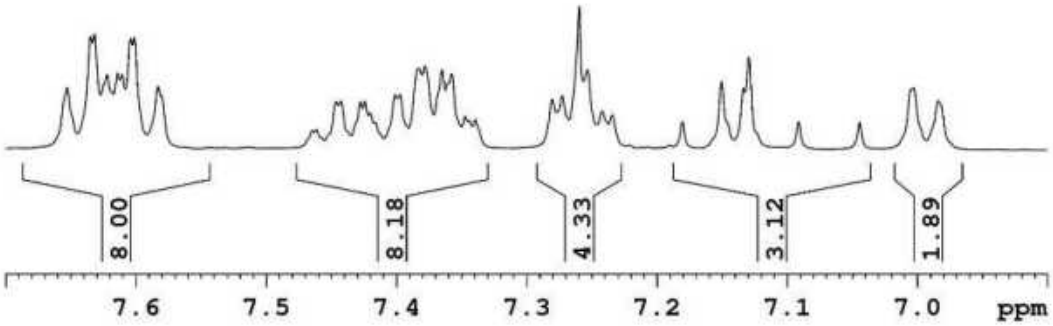
7.15
7.13
7.13
7.00
7.00
6.98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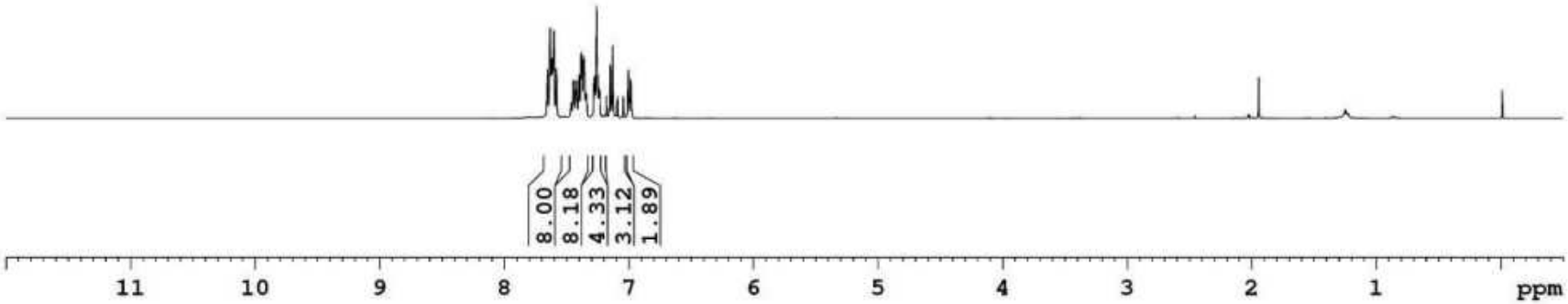
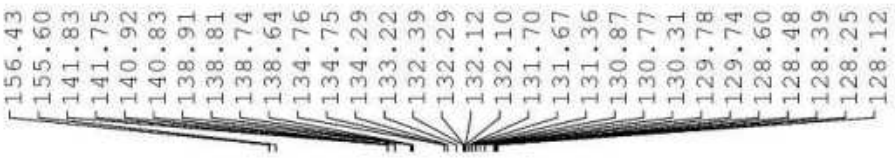
8.18
4.33
3.12
1.89
7.6
7.5
7.4
7.3
7.2
7.1
7.0
ppm


8.00
8.18
4.33
3.12
1.89
11
10
9
8
7
6
5
4
3
2
1
ppm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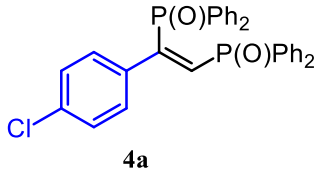
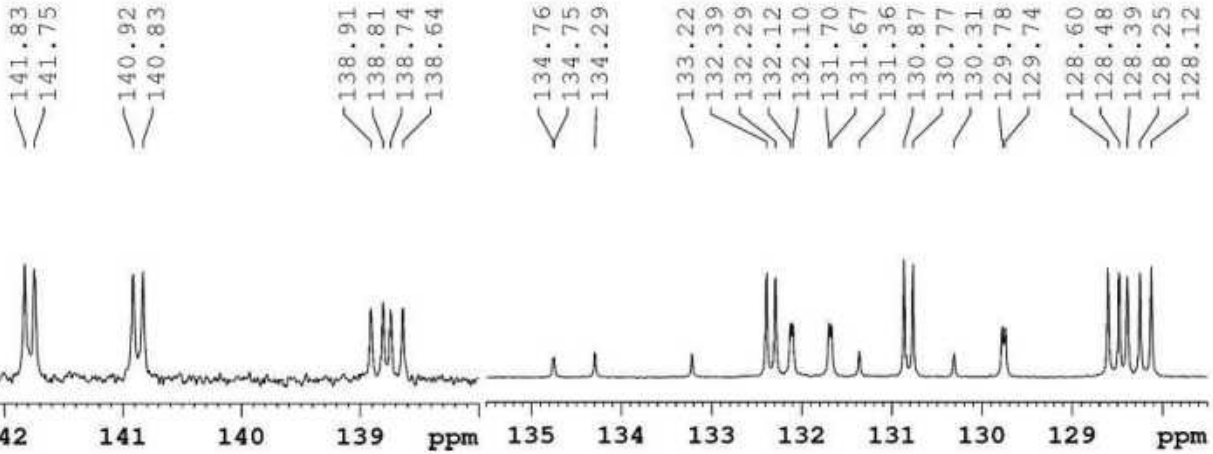
155.60
141.83
141.75
140.92
140.83
138.91
138.81
138.74
138.64
134.76
134.75
134.29
133.22
132.39
132.29
132.12
132.10
131.70
131.67
131.36
130.87
130.77
130.31
129.78
129.74
128.60
128.48
128.39
128.25
128.12


P(O)Ph2
P(O)Ph2
Cl

4a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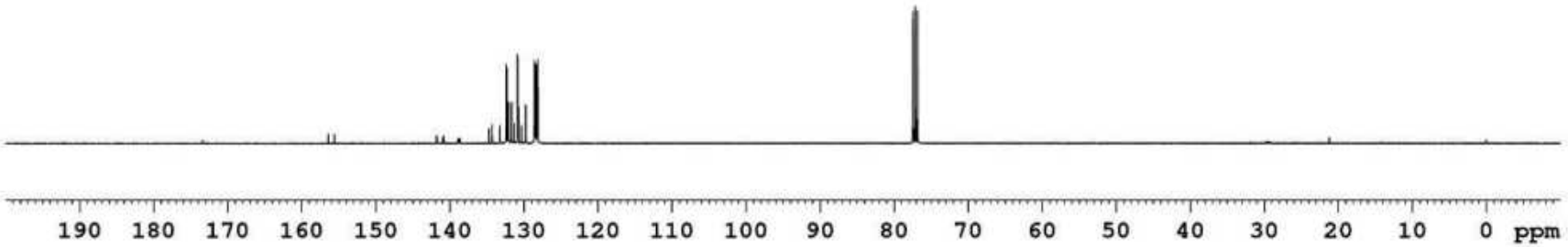
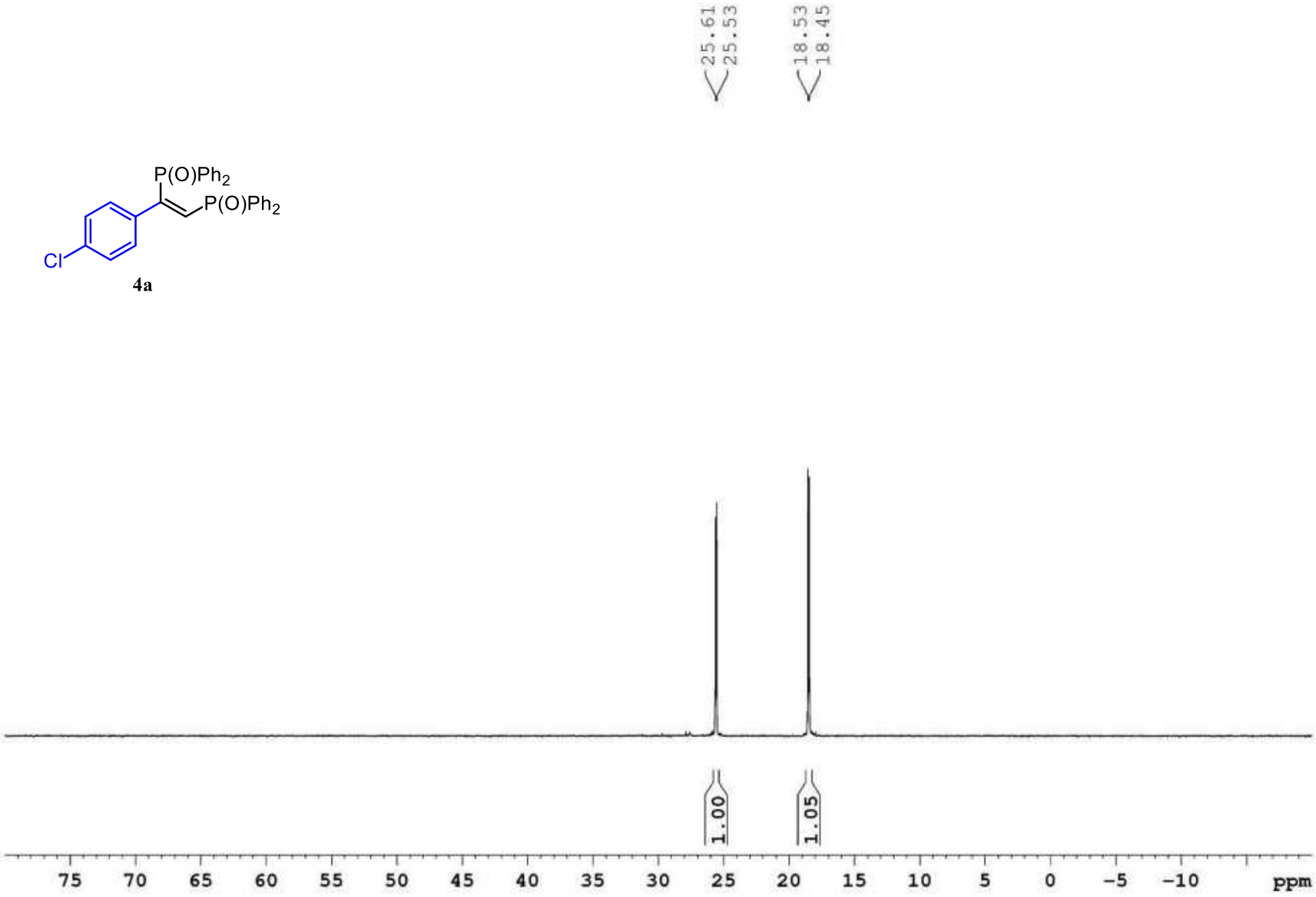
141.75
140.92
140.83
138.91
138.81
138.74
138.64
134.76
134.75
134.29
133.22
132.39
132.29
132.12
132.10
131.70
131.67
131.36
130.87
130.77
130.31
129.78
129.74
128.60
128.48
128.39
128.25
128.12
142
141
140
139
ppm
135
134
133
132
131
130
129
ppm


190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

P(O)Ph2
P(O)Ph2
Cl

4a


25.61
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18.53
18.45
1.00
1.05
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70
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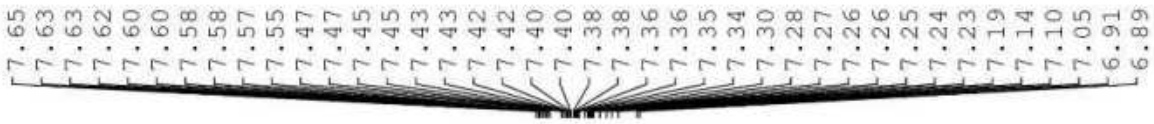
60
55
50
45
40
35
30
25
20
15
10
5
0
−5
−10
ppm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7.63
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7.60
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7.58
7.57
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7.45
7.43
7.43
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7.40
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7.38
7.36
7.36
7.35
7.34
7.30
7.28
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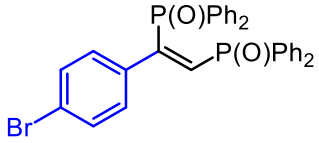
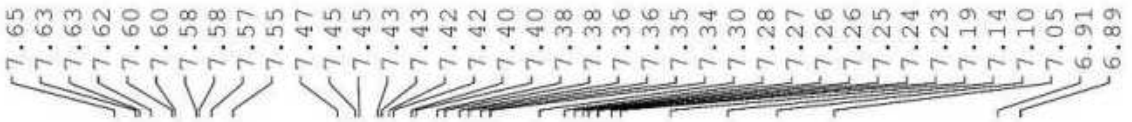
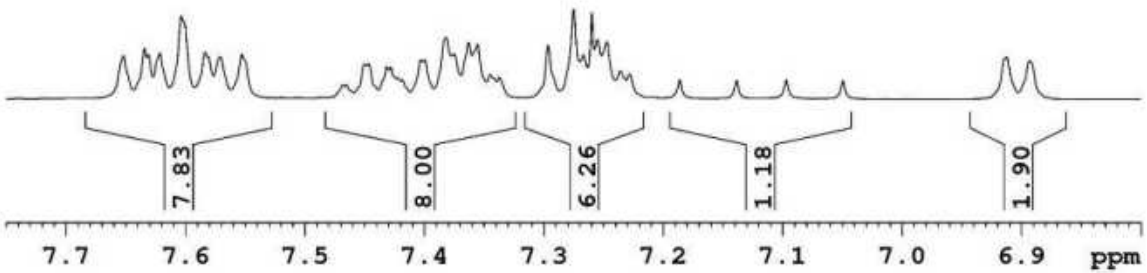
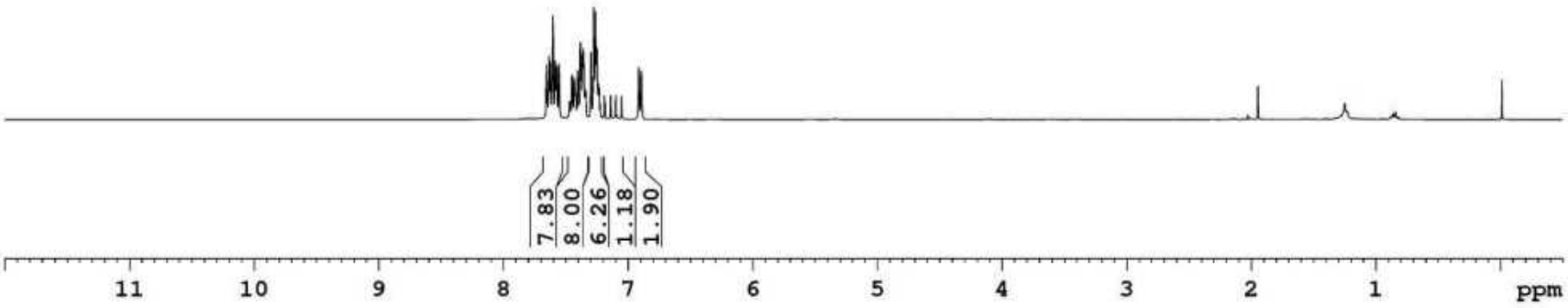
7.26
7.26
7.25
7.24
7.23
7.19
7.14
7.10
7.05
6.91
6.89

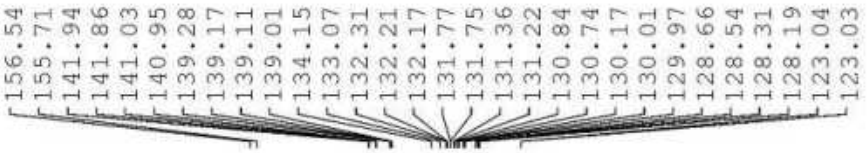

P(O)Ph2
P(O)Ph2
Br

4b


7.65
7.63
7.63
7.62
7.60
7.60
7.58
7.58
7.57
7.55
7.47
7.45
7.45
7.43
7.43
7.42
7.42
7.40
7.40
7.38
7.38
7.36
7.36
7.35
7.34
7.30
7.28
7.27
7.26
7.26
7.25
7.24
7.23
7.19
7.14
7.10
7.05
6.91
6.89


7.83
8.00
6.26
1.18
1.90
7.7
7.6
7.5
7.4
7.3
7.2
7.1
7.0
6.9
ppm


7.83
8.00
6.26
1.18
1.90
11
10
9
8
7
6
5
4
3
2
1
ppm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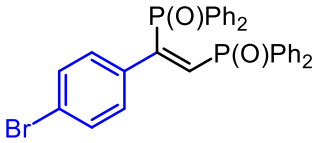
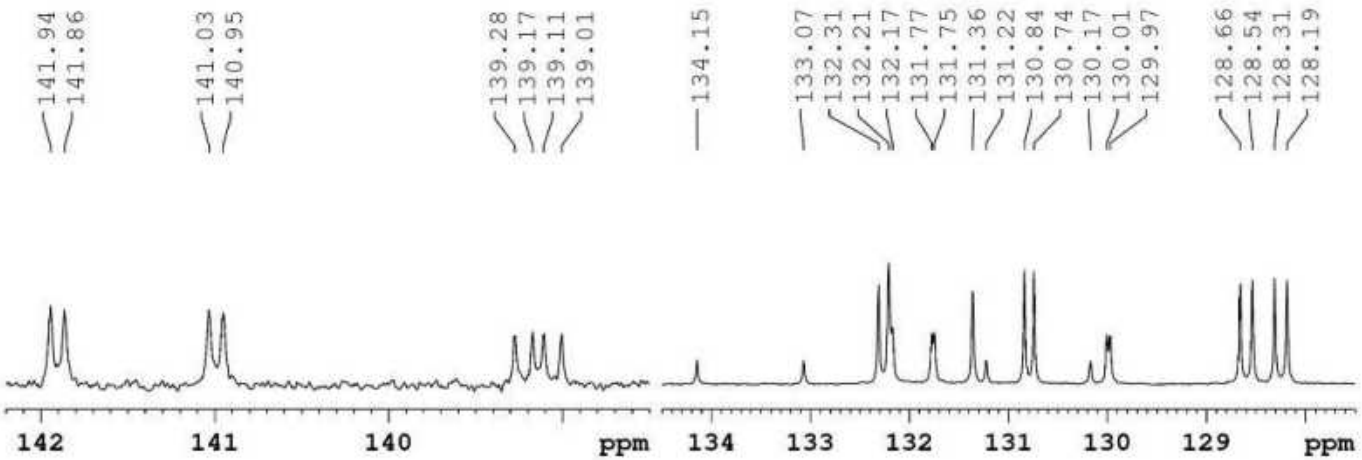
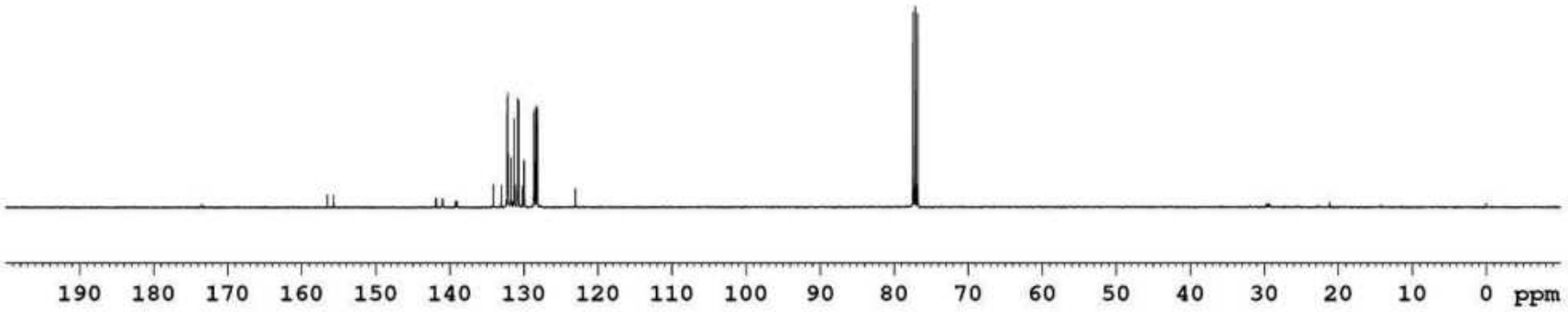
155.71
141.94
141.86
141.03
140.95
139.28
139.17
139.11
139.01
134.15
133.07
132.31
132.21
132.17
131.77
131.75
131.36
131.22
130.84
130.74
130.17
130.01
129.97
128.66
128.54
128.31
128.19
123.04
123.03


P(O)Ph2
P(O)Ph2
Br

4b


141.94
141.86
141.03
140.95
139.28
139.17
139.11
139.01
134.15
133.07
132.31
132.21
132.17
131.77
131.75
131.36
131.22
130.84
130.74
130.17
130.01
129.97
128.66
128.54
128.31
128.19
142
141
140
ppm
134
133
132
131
130
129
ppm


190
180
170
160
150
140
130
120
110
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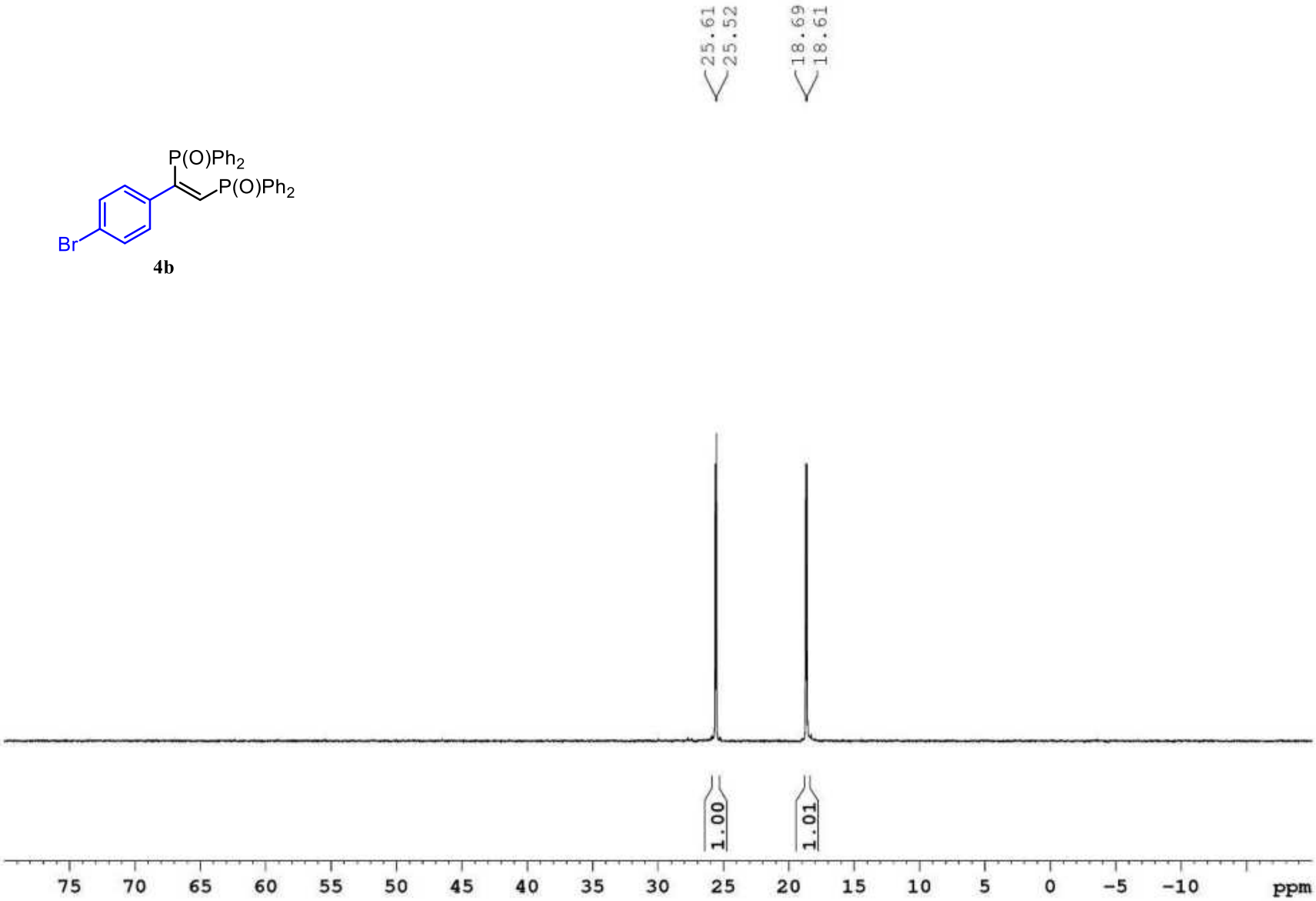
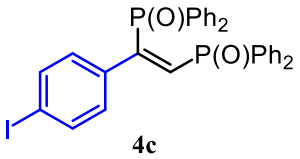
90
80
70
60
50
40
30
20
10
0
ppm

P(O)Ph2
P(O)Ph2
Br

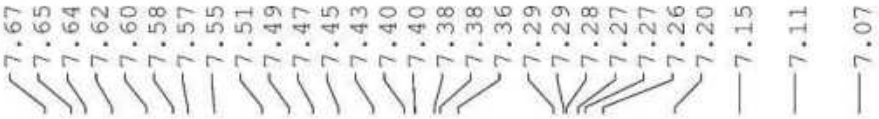
4b


25.61
25.52
18.69
18.61
1.00
1.01
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm


7.67
7.65
7.64
7.62
7.60
7.58
7.57
7.55
7.51
7.49
7.47
7.45
7.43
7.40
7.40
7.38
7.38
7.36
7.29
7.29
7.28
7.27
7.27
7.26
7.20
7.15
7.11
7.07
6.77
6.75


P(O)Ph2
P(O)Ph2
I

4c


7.67
7.65
7.64
7.62
7.60
7.58
7.57
7.55
7.51
7.49
7.47
7.45
7.43
7.40
7.40
7.38
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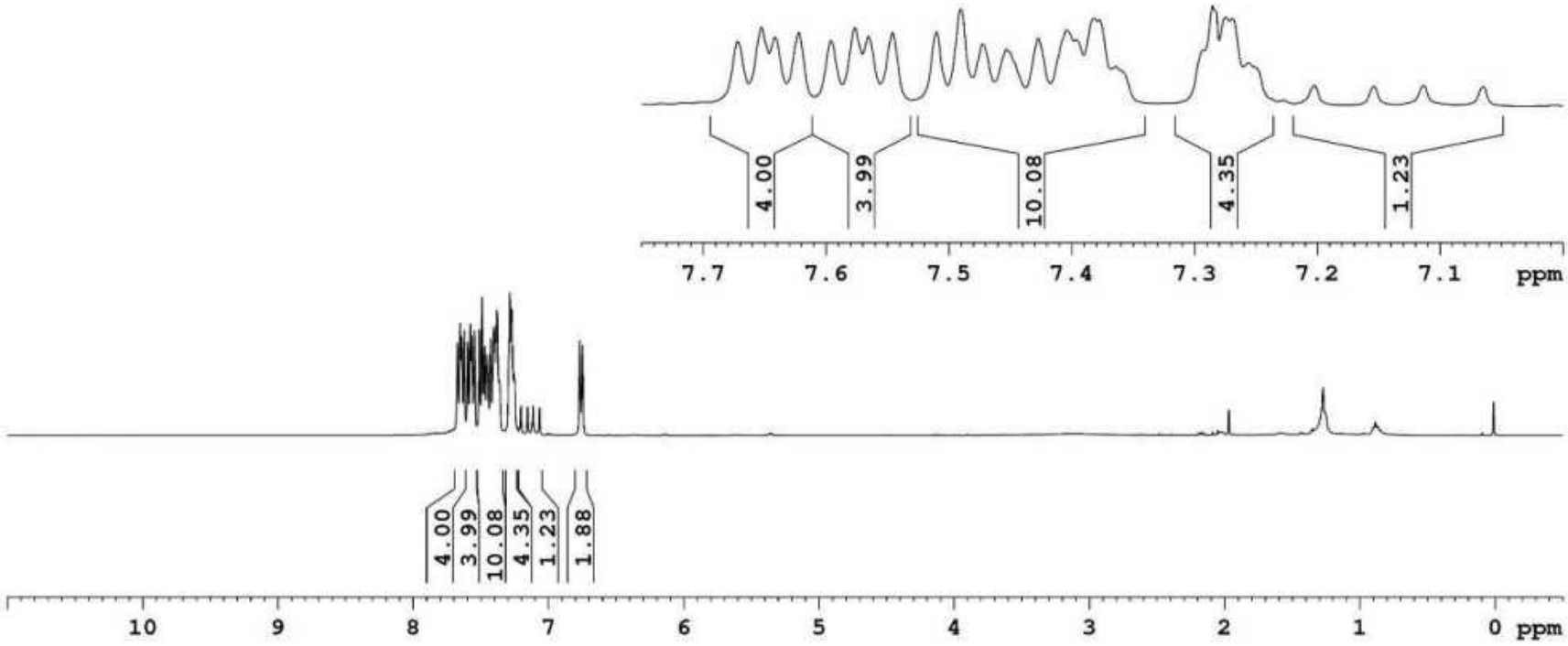
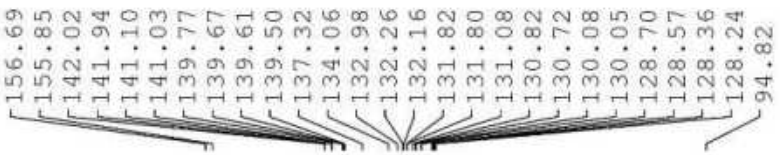
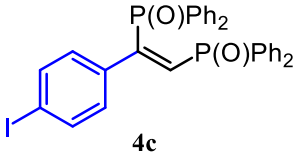
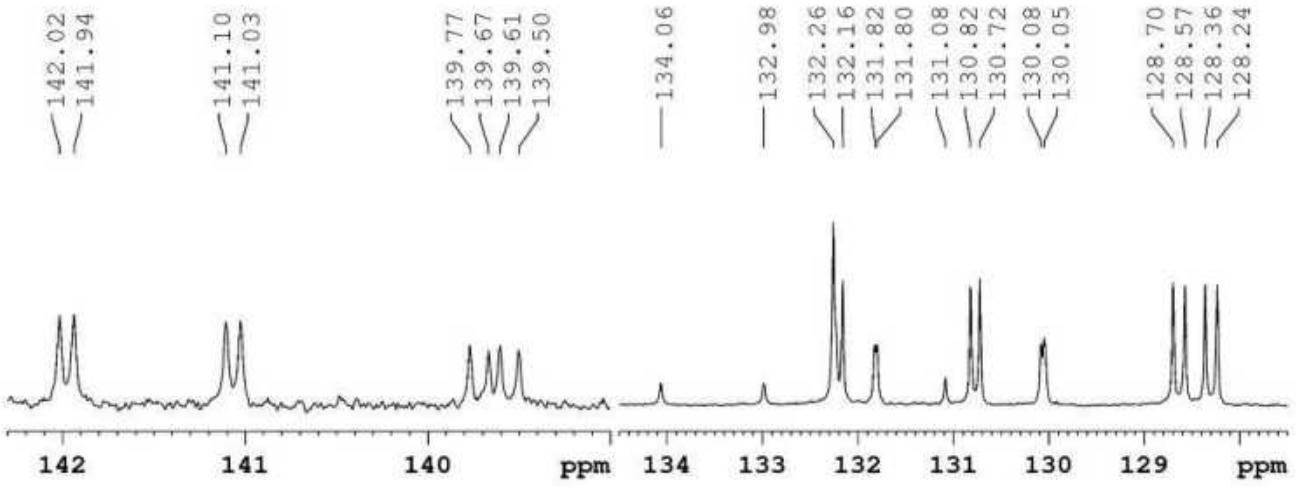
7.27
7.26
7.20
7.15
7.11
7.07

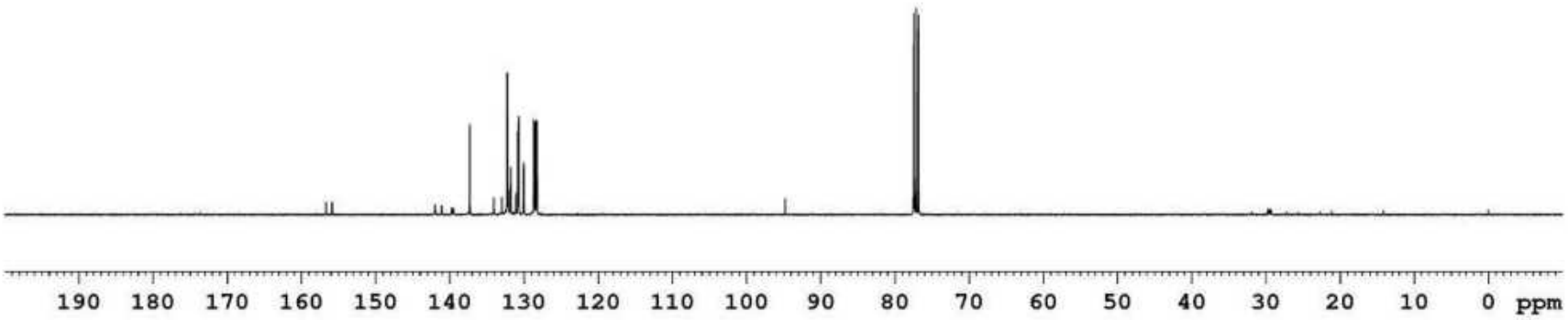

4.00
3.99
10.08
4.35
1.23
7.7
7.6
7.5
7.4
7.3
7.2
7.1
ppm
4.00
3.99
10.08
4.35
1.23
1.88
10
9
8
7
6
5
4
3
2
1
0
ppm


156.69
155.85
142.02
141.94
141.10
141.03
139.77
139.67
139.61
139.50
137.32
134.06
132.98
132.26
132.16
131.82
131.80
131.08
130.82
130.72
130.08
130.05
128.70
128.57
128.36
128.24
94.82


P(O)Ph2
P(O)Ph2
I

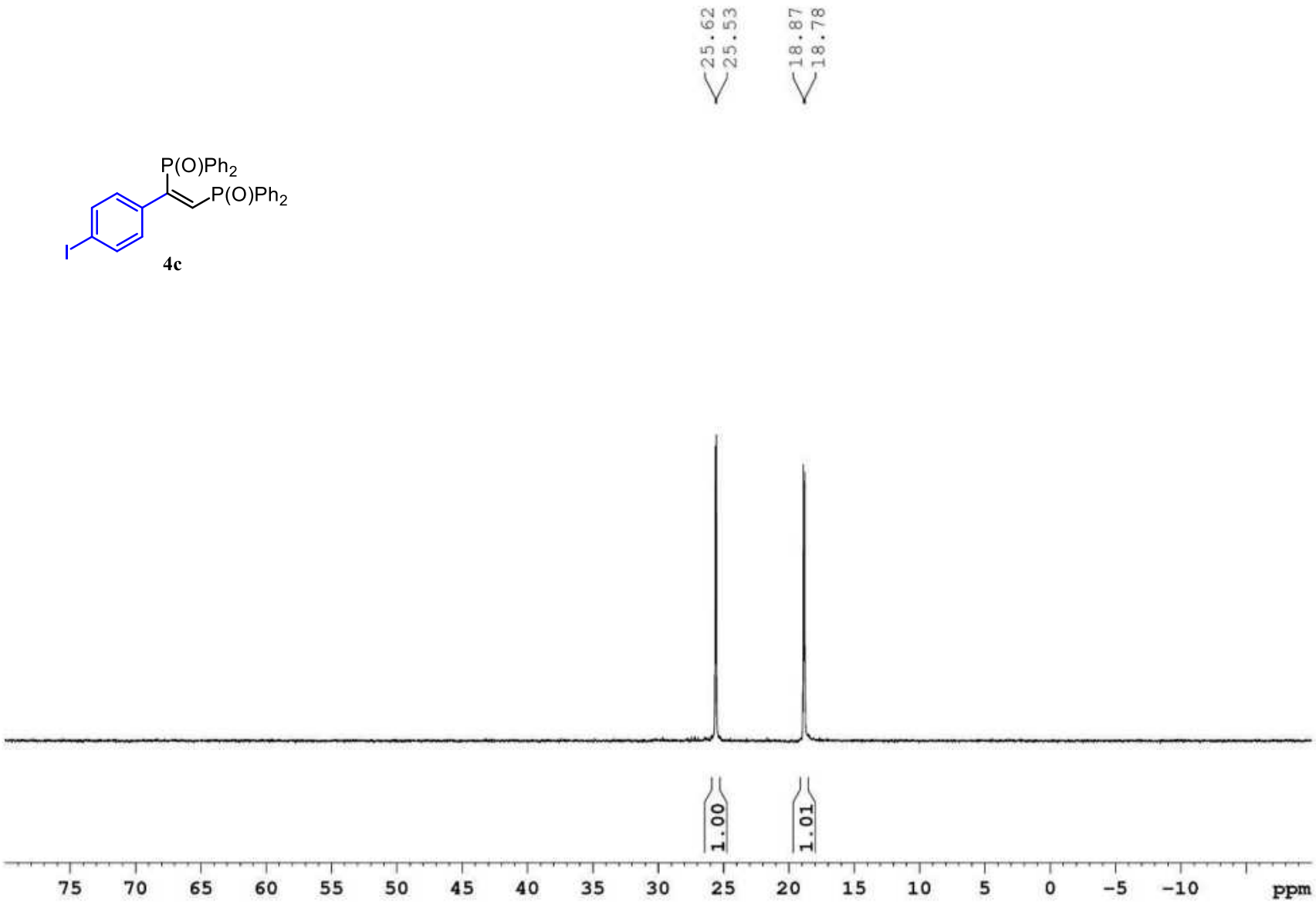
4c


142.02
141.94
141.10
141.03
139.77
139.67
139.61
139.50
134.06
132.98
132.26
132.16
131.82
131.80
131.08
130.82
130.72
130.08
130.05
128.70
128.57
128.36
128.24
142
141
140
ppm
134
133
132
131
130
129
ppm


190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

P(O)Ph2
P(O)Ph2
I

4c


25.62
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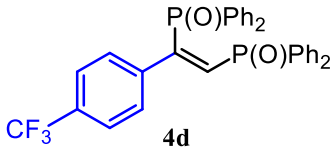
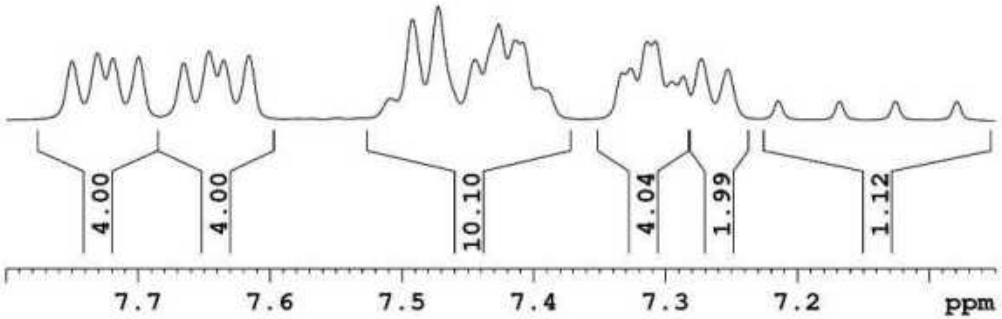
18.78
1.00
1.01
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm

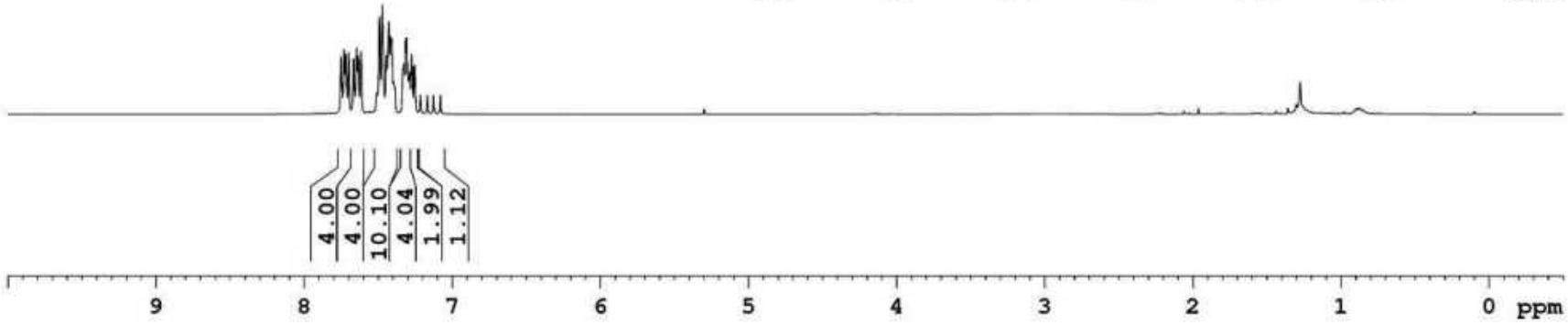

7.75
7.73
7.72
7.70
7.67
7.65
7.64
7.62
7.51
7.49
7.47
7.44
7.43
7.41
7.41
7.40
7.33
7.33
7.31
7.31
7.30
7.29
7.27
7.25
7.21
7.17
7.13
7.08

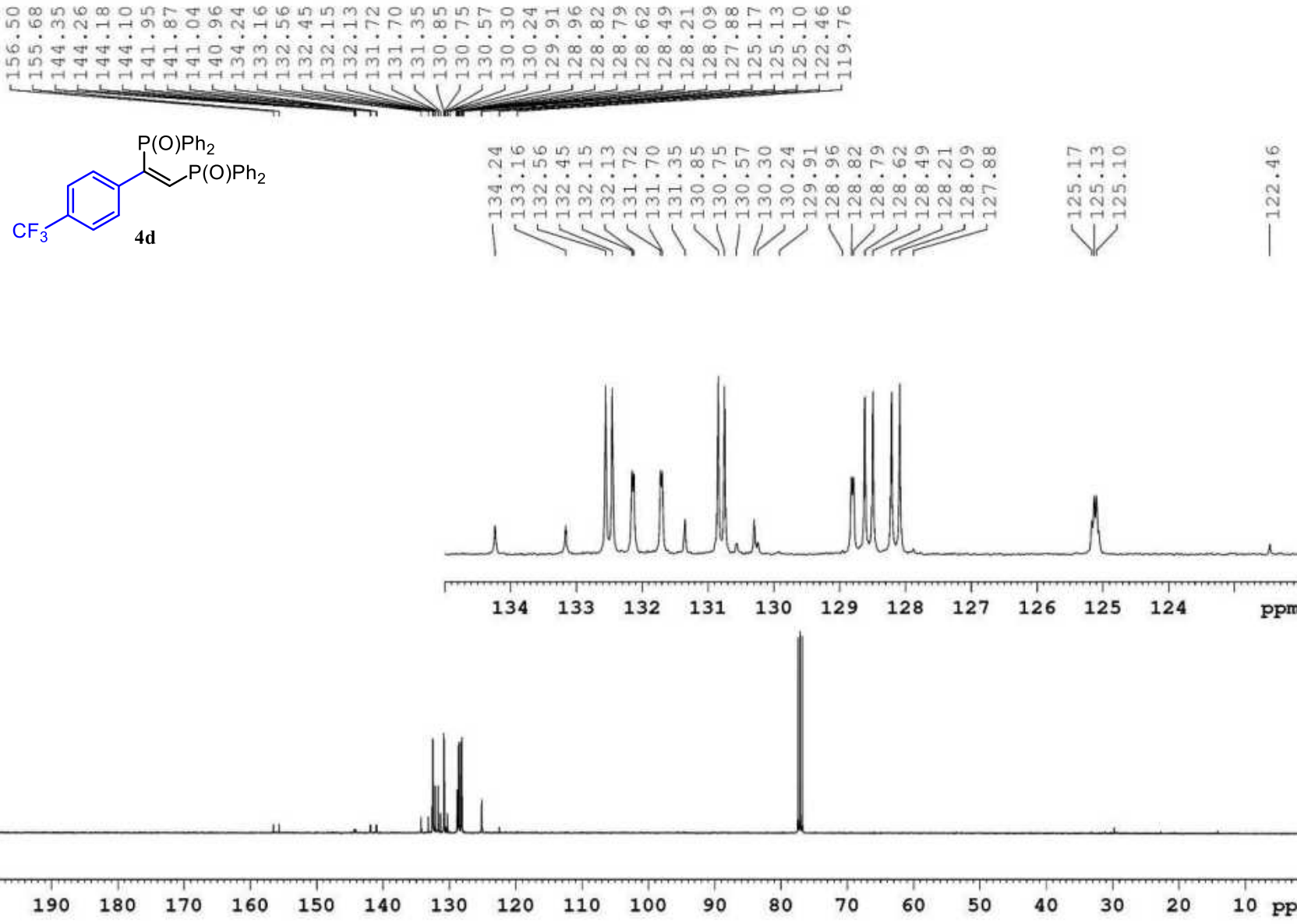

P(O)Ph2
P(O)Ph2
CF3

4d


7.75
7.73
7.72
7.70
7.67
7.65
7.64
7.62
7.51
7.49
7.47
7.44
7.43
7.41
7.41
7.40
7.33
7.33
7.31
7.31
7.30
7.29
7.27
7.25
7.21
7.17
7.13
7.08


4.00
4.00
10.10
4.04
1.99
1.12
7.7
7.6
7.5
7.4
7.3
7.2
ppm


4.00
4.00
10.10
4.04
1.99
1.12
9
8
7
6
5
4
3
2
1
0
ppm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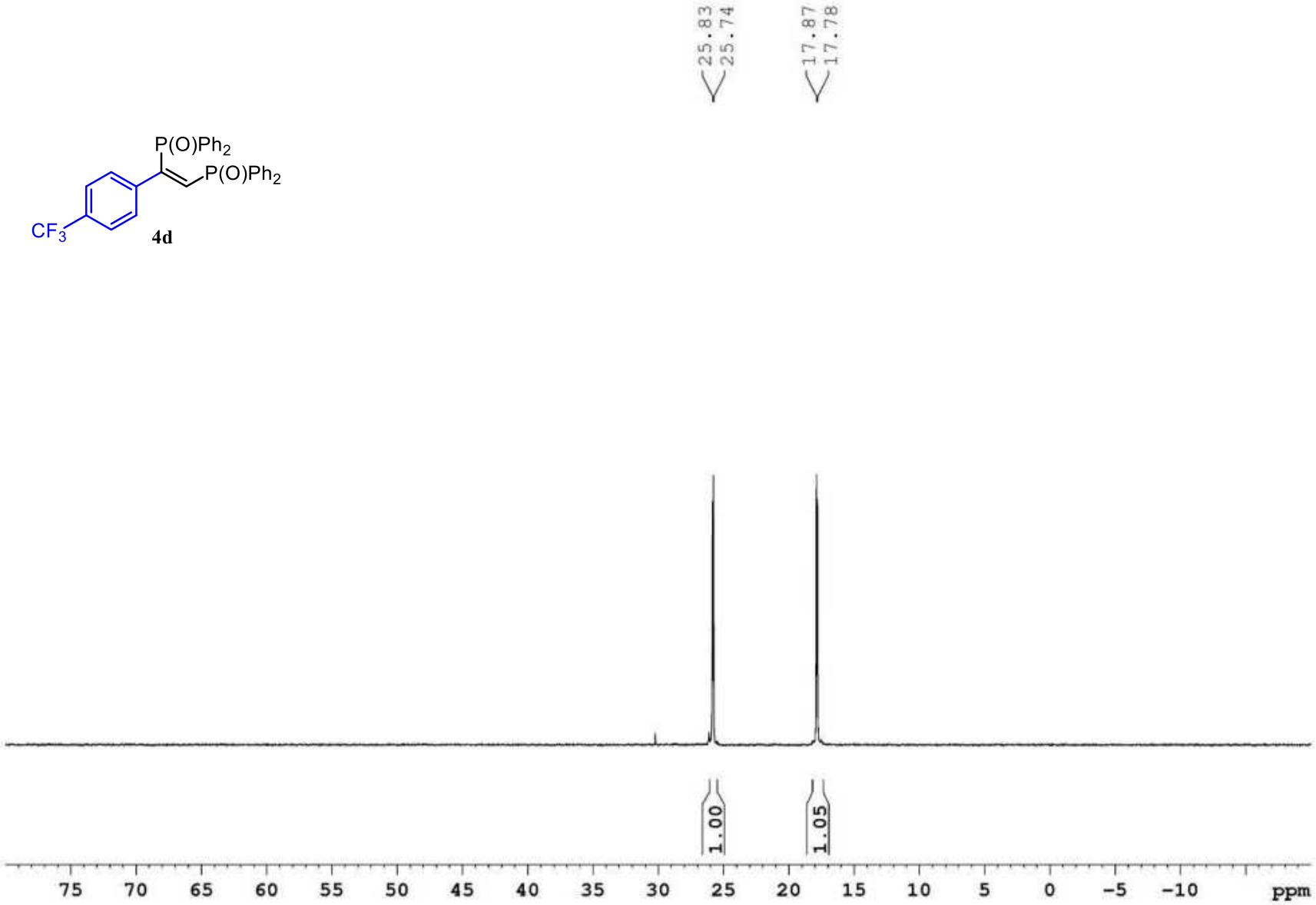
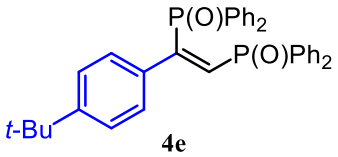
155.68
144.35
144.26
144.18
144.10
141.95
141.87
141.04
140.96
134.24
133.16
132.56
132.45
132.15
132.13
131.72
131.70
131.35
130.85
130.75
130.57
130.30
130.24
129.91
128.96
128.82
128.79
128.62
128.49
128.21
128.09
127.88
125.17
125.13
125.10
122.46
119.76
P(O)Ph2
P(O)Ph2
CF3
4d
134
133
132
131
130
129
128
127
126
125
124
ppm
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm

P(O)Ph2
P(O)Ph2
CF3

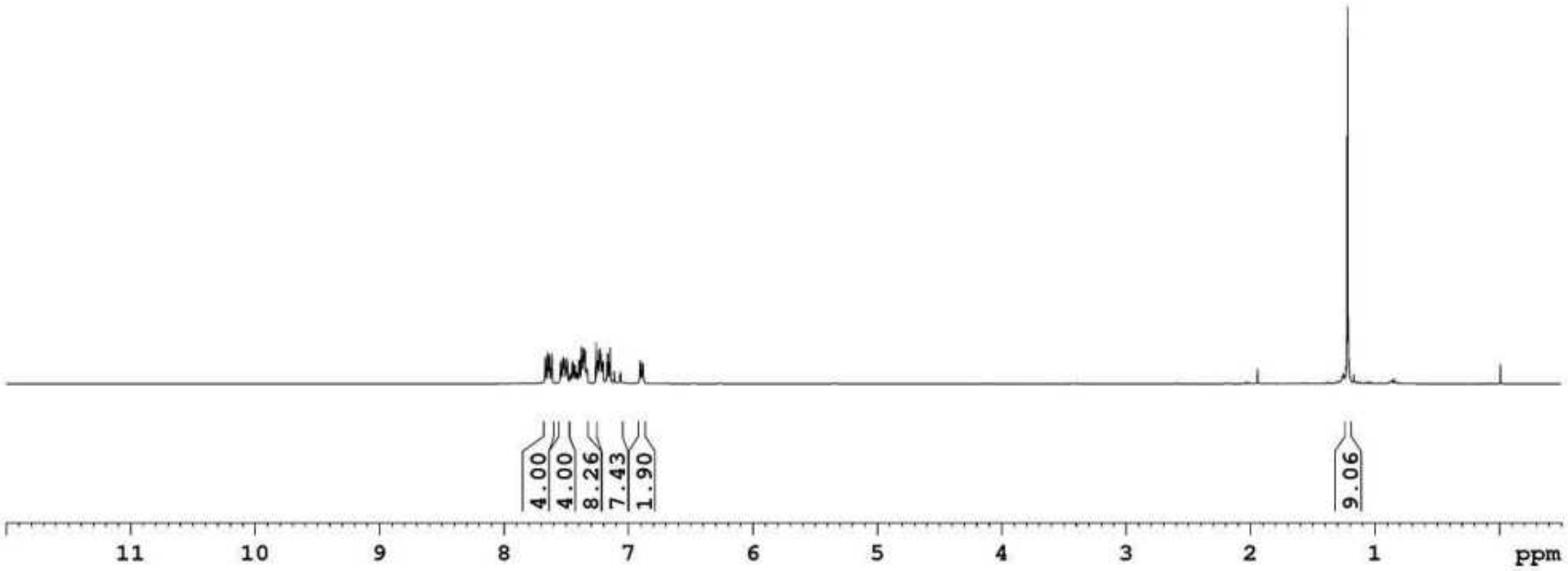
4d

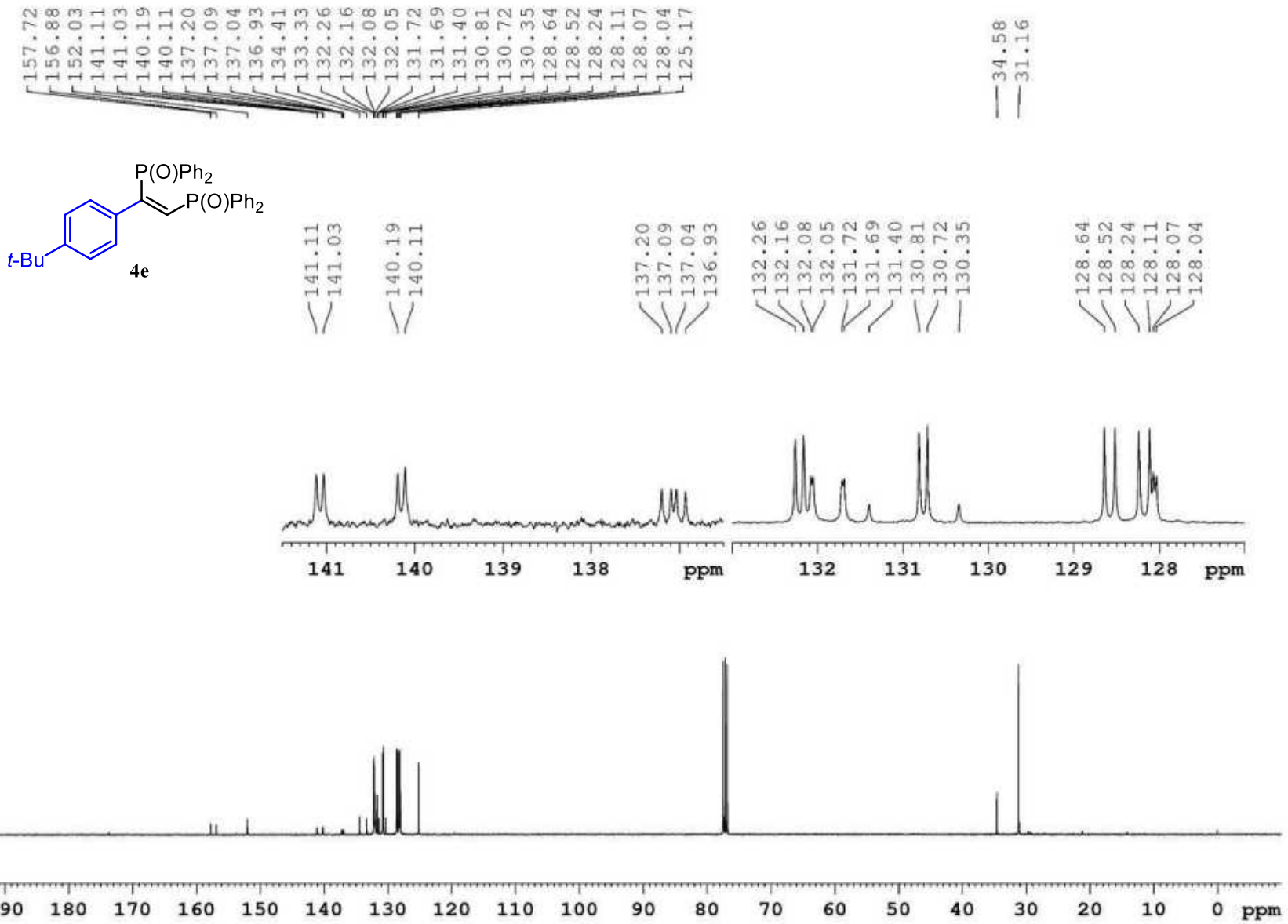

25.83
25.74
17.87
17.78
1.00
1.05
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm


7.67
7.65
7.64
7.63
7.62
7.61
7.54
7.52
7.51
7.49
7.47
7.46
7.45
7.45
7.43
7.43
7.41
7.41
7.40
7.39
7.37
7.37
7.36
7.35
7.34
7.33
7.26
7.25
7.24
7.23
7.22
7.21
7.20
7.17
7.15
7.15
7.11
7.06
6.90
6.88
1.22


P(O)Ph2
P(O)Ph2
t-Bu

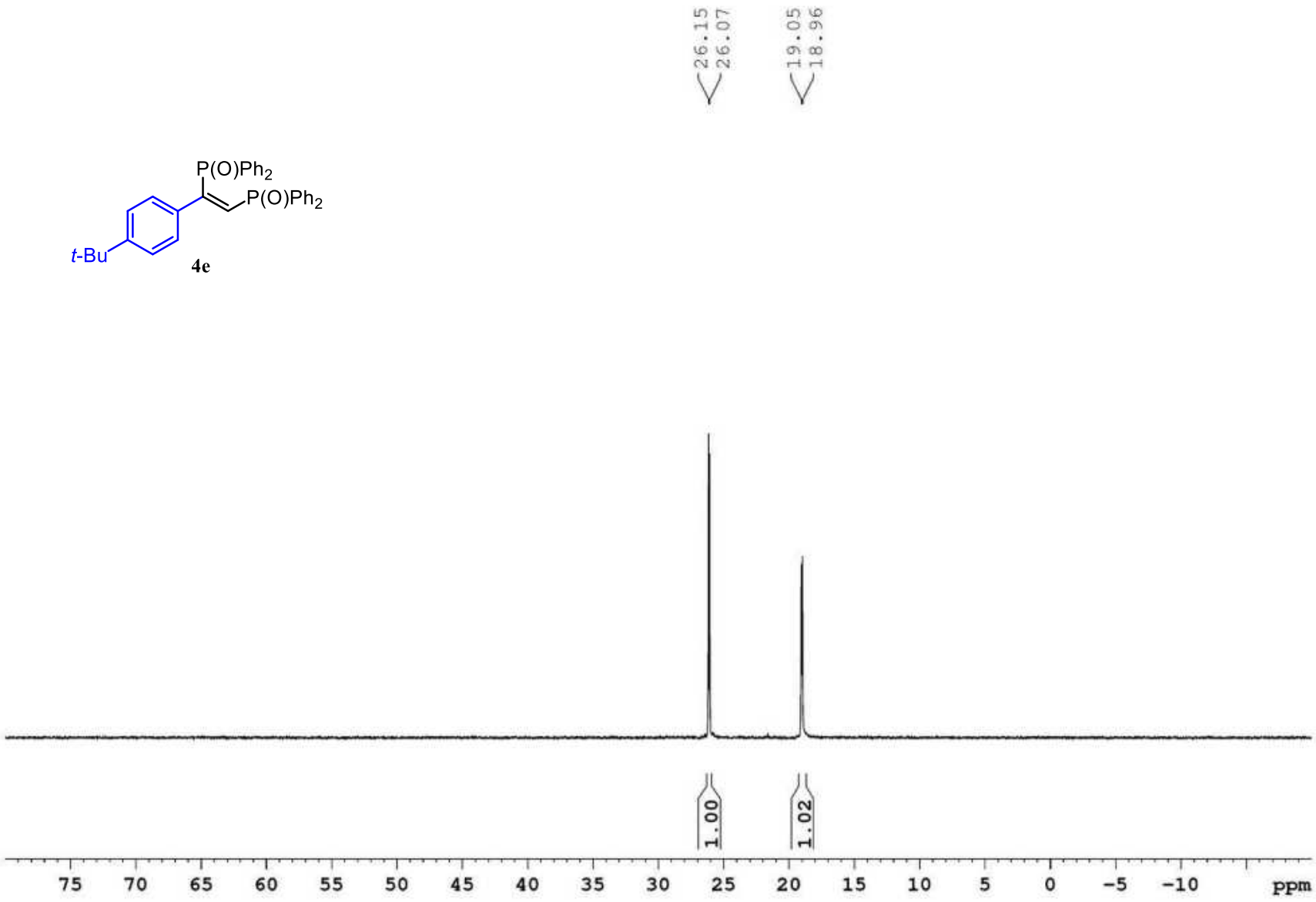
4e

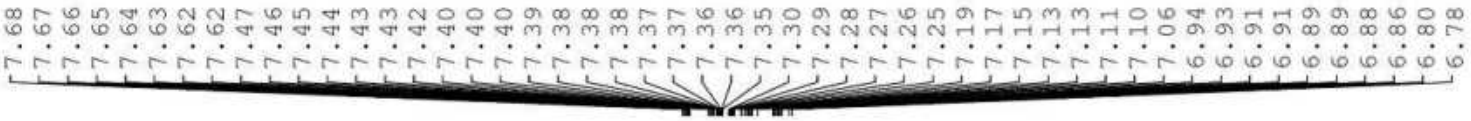

4.00
4.00
8.26
7.43
1.90
9.06
11
10
9
8
7
6
5
4
3
2
1
ppm

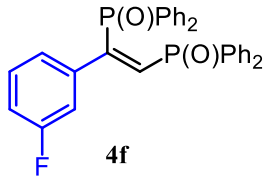

157.72
156.88
152.03
141.11
141.03
140.19
140.11
137.20
137.09
137.04
136.93
134.41
133.33
132.26
132.16
132.08
132.05
131.72
131.69
131.40
130.81
130.72
130.35
128.64
128.52
128.24
128.11
128.07
128.04
125.17
34.58
31.16
P(O)Ph2
P(O)Ph2
t-Bu
4e
141.11
141.03
140.19
140.11
137.20
137.09
137.04
136.93
132.26
132.16
132.08
132.05
131.72
131.69
131.40
130.81
130.72
130.35
128.64
128.52
128.24
128.11
128.07
128.04
141
140
139
138
ppm
132
131
130
129
128
ppm
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

P(O)Ph2
P(O)Ph2
t-Bu

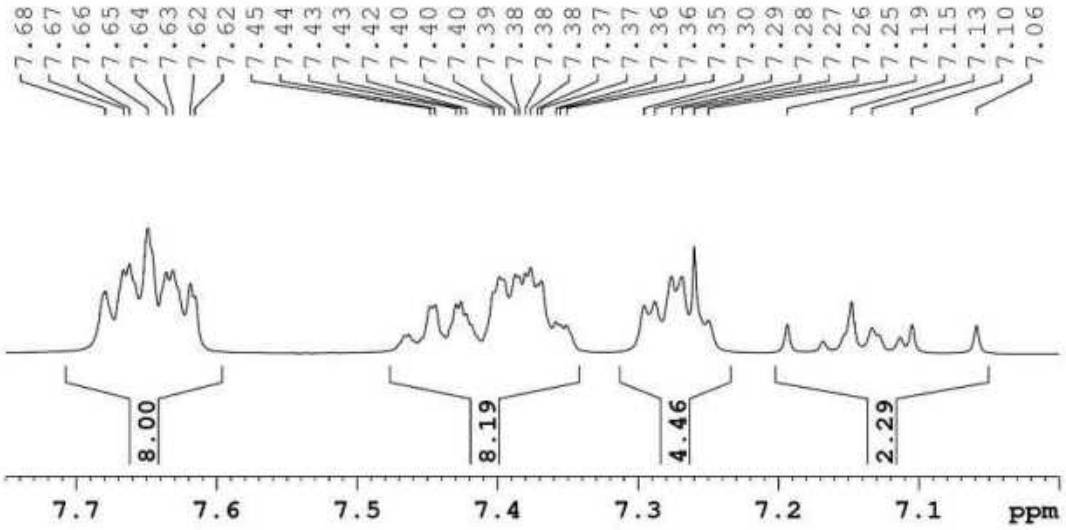
4e

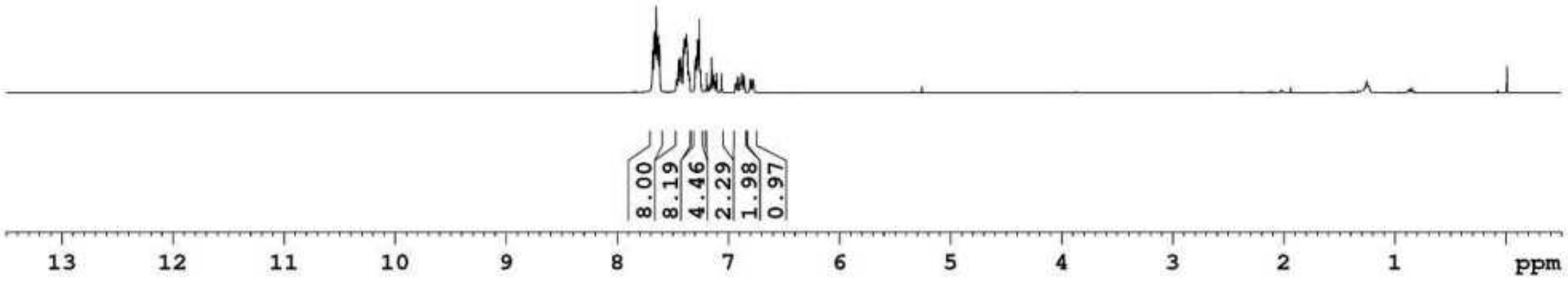

26.15
26.07
19.05
18.96
1.00
1.02
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm

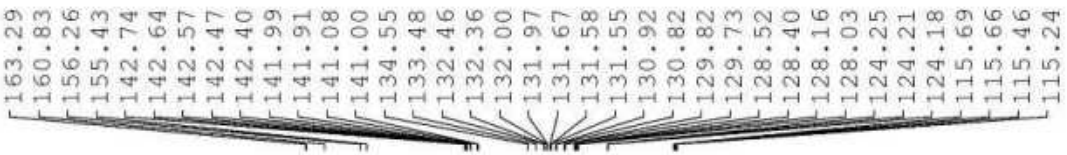

7.68 7.67 7.66 7.65 7.64 7.63 7.62 7.62 7.47 7.46 7.45 7.44 7.43 7.43 7.42 7.40 7.40 7.40 7.39 7.38 7.38 7.38 7.37 7.37 7.36 7.36 7.35 7.30 7.29 7.28 7.27 7.26 7.25 7.19 7.17 7.15 7.13 7.13 7.11 7.10 7.06 6.94 6.93 6.91 6.91 6.89 6.89 6.88 6.86 6.80 6.78


P(O)Ph2
P(O)Ph2
F

4f


7.68 7.67 7.66 7.65 7.64 7.63 7.62 7.62 7.45 7.44 7.43 7.43 7.42 7.40 7.40 7.40 7.39 7.38 7.38 7.38 7.37 7.37 7.36 7.36 7.35 7.30 7.29 7.28 7.27 7.26 7.25 7.19 7.15 7.13 7.10 7.06
8.00
8.19
4.46
2.29
7.7 7.6 7.5 7.4 7.3 7.2 7.1 ppm


8.00
8.19
4.46
2.29
1.98
0.97
13 12 11 10 9 8 7 6 5 4 3 2 1 ppm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160.83
156.26
155.43
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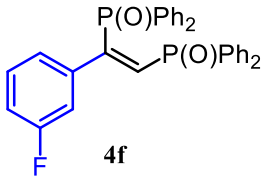
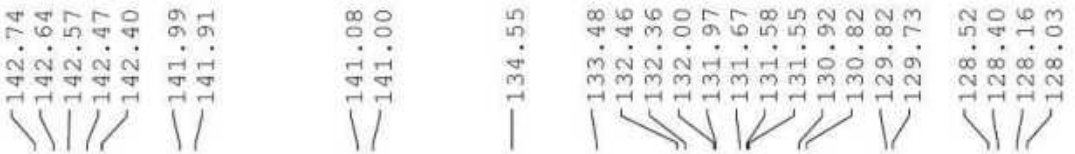
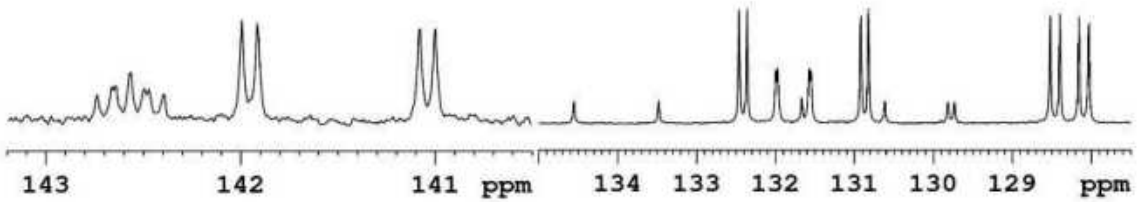
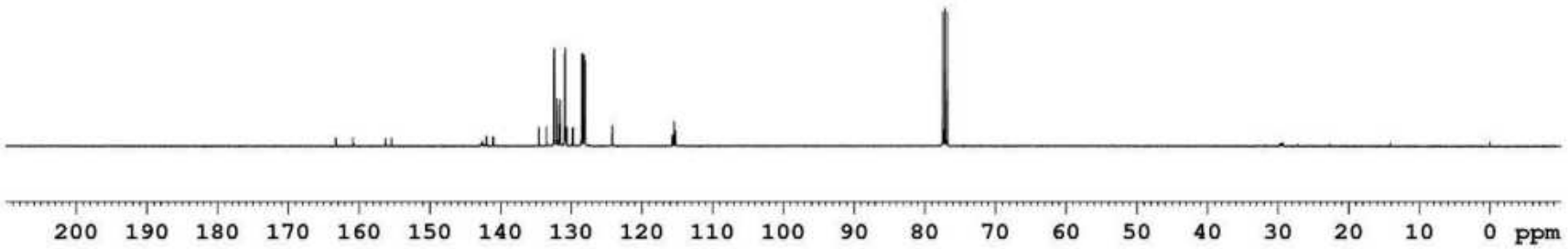
142.64
142.57
142.47
142.40
141.99
141.91
141.08
141.00
134.55
133.48
132.46
132.36
132.00
131.97
131.67
131.58
131.55
130.92
130.82
129.82
129.73
128.52
128.40
128.16
128.03
124.25
124.21
124.18
115.69
115.66
115.46
115.24


P(O)Ph2
P(O)Ph2
F

4f

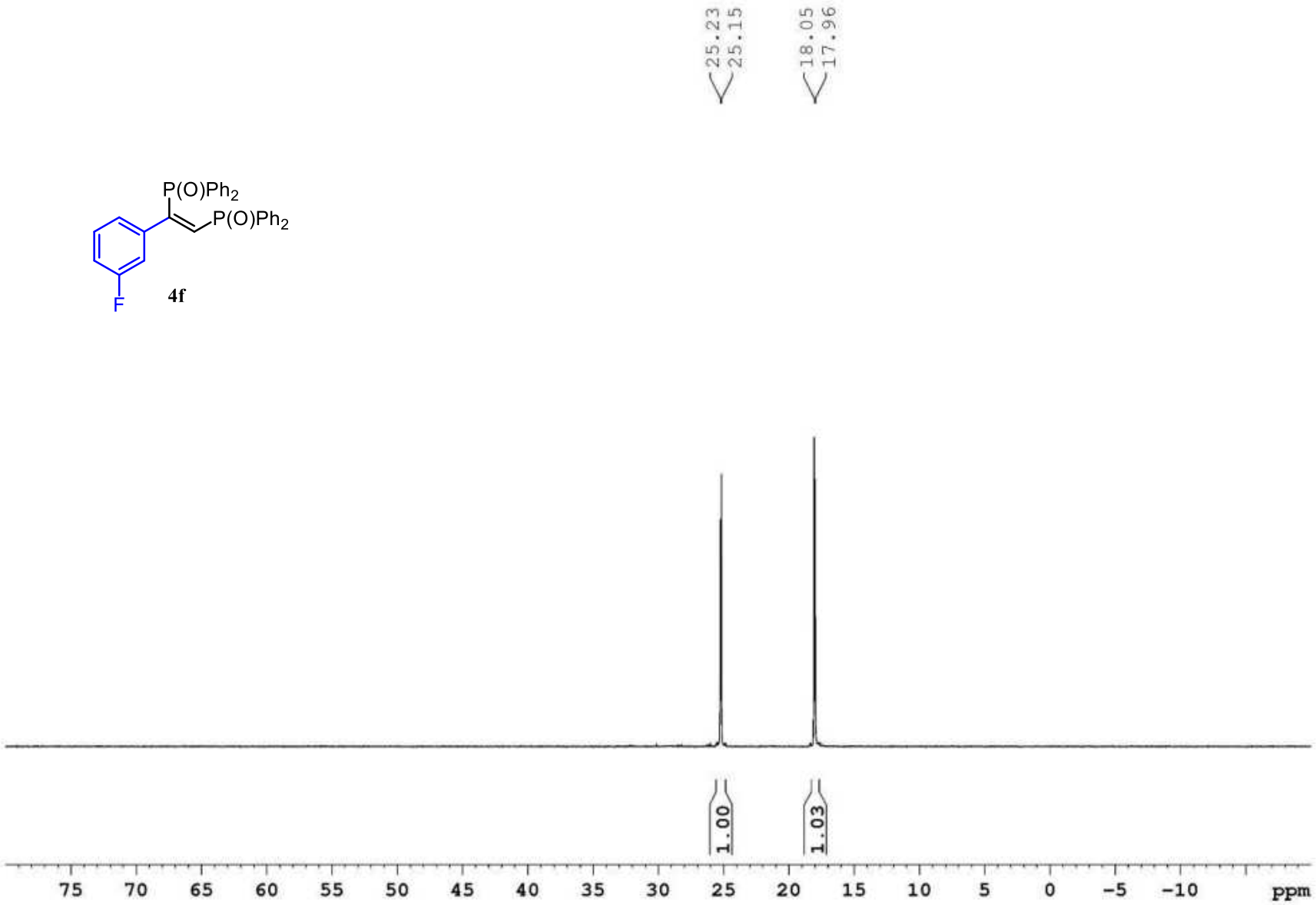

142.74
142.64
142.57
142.47
142.40
141.99
141.91
141.08
141.00
134.55
133.48
132.46
132.36
132.00
131.97
131.67
131.58
131.55
130.92
130.82
129.82
129.73
128.52
128.40
128.16
128.03


143
142
141
ppm
134
133
132
131
130
129
ppm


200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

P(O)Ph2
P(O)Ph2
F

4f


25.23
25.15
18.05
17.96
1.00
1.03
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm


7.71
7.69
7.67
7.67
7.66
7.64
7.50
7.48
7.48
7.46
7.46
7.45
7.45
7.43
7.42
7.41
7.40
7.39
7.39
7.38
7.36
7.34
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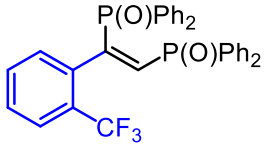
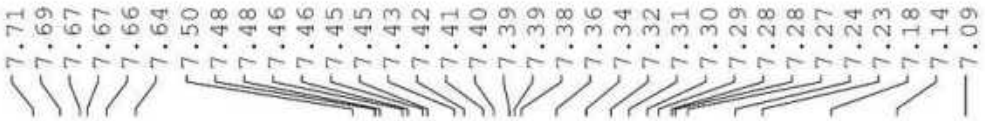
7.27
7.24
7.23
7.18
7.14
7.09


P(O)Ph2
P(O)Ph2
CF3

4g


7.71
7.69
7.67
7.67
7.66
7.64
7.50
7.48
7.48
7.46
7.46
7.45
7.45
7.43
7.42
7.41
7.40
7.39
7.39
7.38
7.36
7.34
7.32
7.31
7.30
7.29
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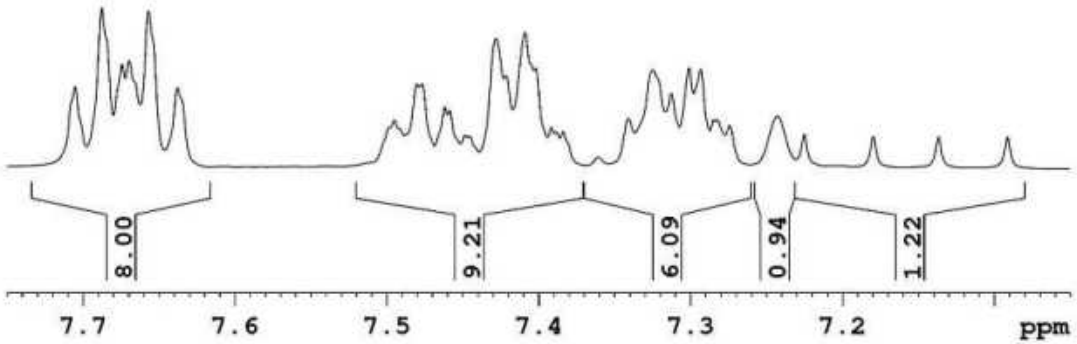
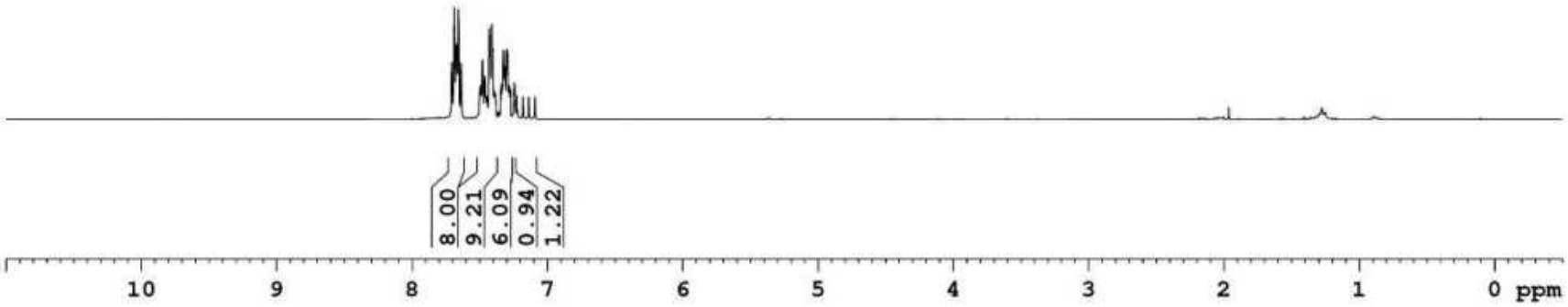
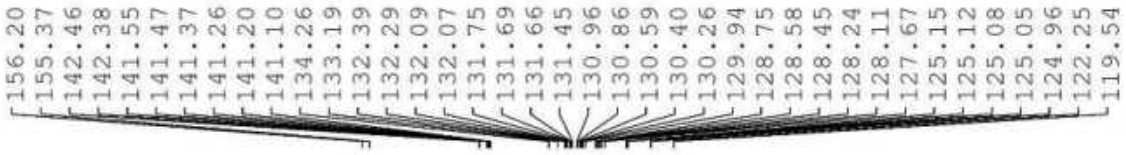
7.27
7.24
7.23
7.18
7.14
7.09


8.00
9.21
6.09
0.94
1.22
7.7
7.6
7.5
7.4
7.3
7.2
ppm


8.00
9.21
6.09
0.94
1.22
10
9
8
7
6
5
4
3
2
1
0
ppm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155.37
142.46
142.38
141.55
141.47
141.37
141.26
141.20
141.10
134.26
133.19
132.39
132.29
132.09
132.07
131.75
131.69
131.66
131.45
130.96
130.86
130.59
130.40
130.26
129.94
128.75
128.58
128.45
128.24
128.11
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125.15
125.12
125.08
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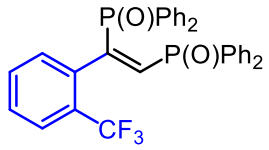
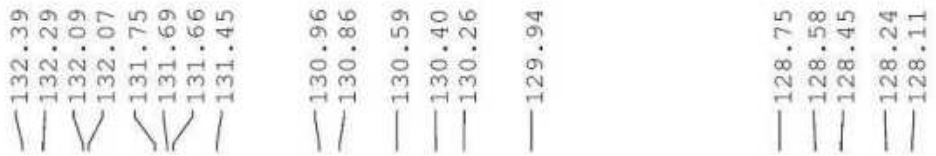
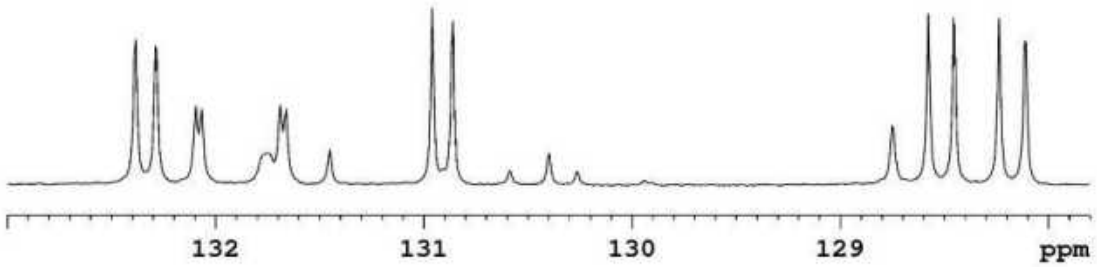
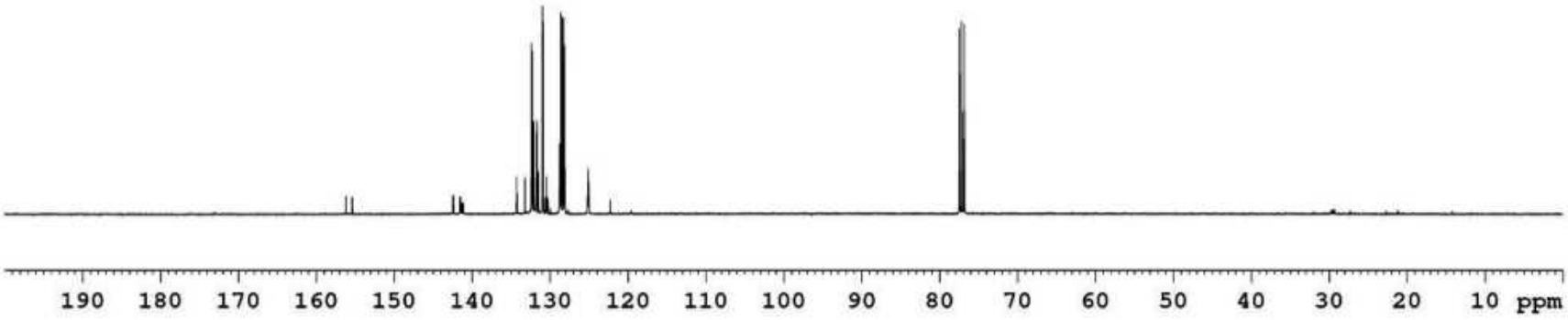
124.96
122.25
119.54


P(O)Ph2
P(O)Ph2
CF3

4g

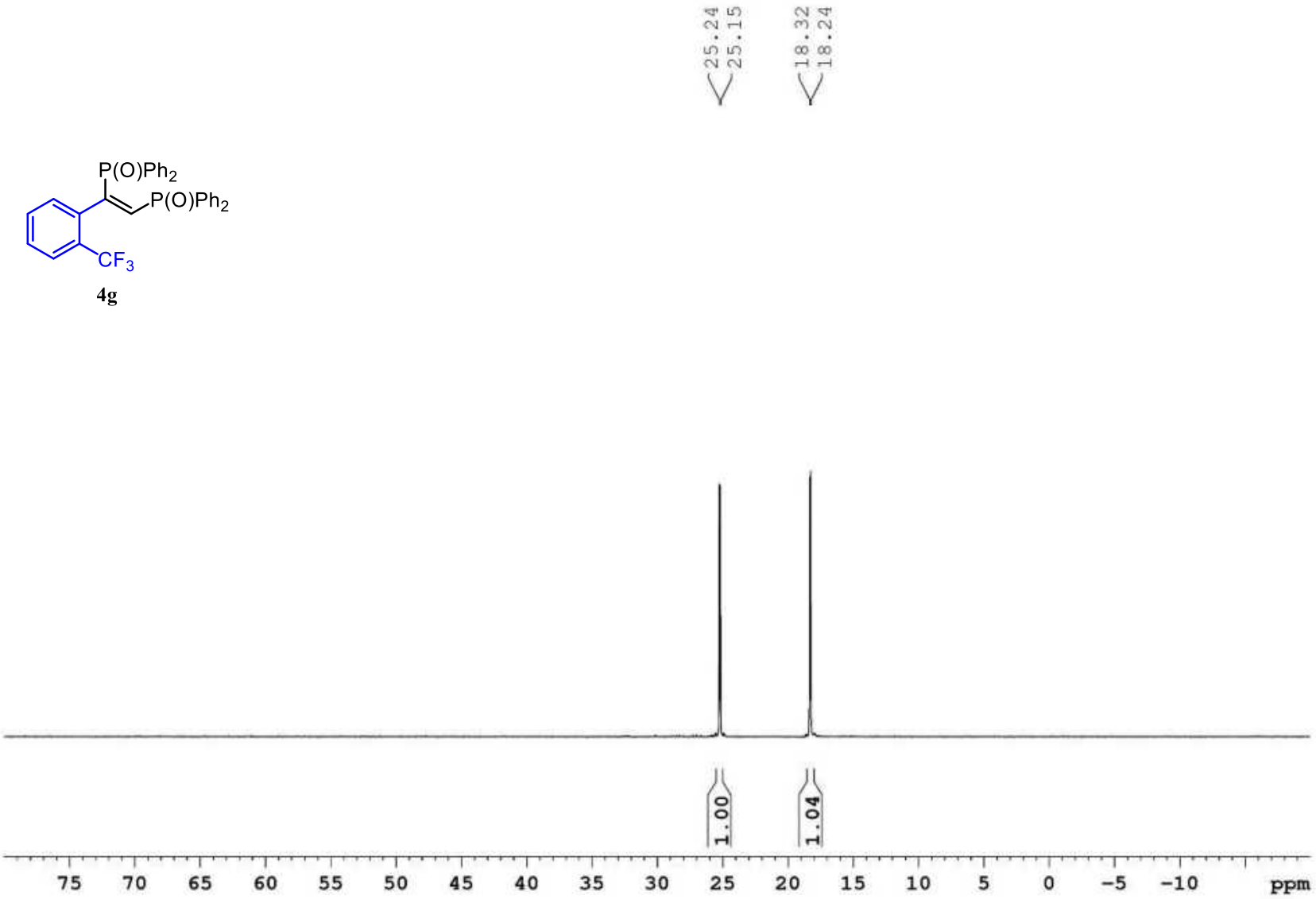

132.39
132.29
132.09
132.07
131.75
131.69
131.66
131.45
130.96
130.86
130.59
130.40
130.26
129.94
128.75
128.58
128.45
128.24
128.11


132
131
130
129
ppm


190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm

P(O)Ph2
P(O)Ph2
CF3

4g


25.24
25.15
18.32
18.24
1.00
1.04
75
70
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60
55
50
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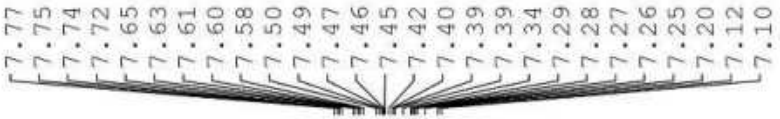
40
35
30
25
20
15
10
5
0
-5
-10
ppm


7.77
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7.74
7.72
7.65
7.63
7.61
7.60
7.58
7.50
7.49
7.47
7.46
7.45
7.42
7.40
7.39
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7.34
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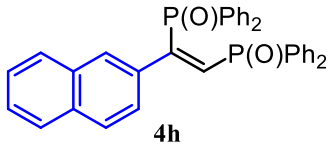
7.28
7.27
7.26
7.25
7.20
7.12
7.10


P(O)Ph2
P(O)Ph2

4h


7.77
7.75
7.74
7.72
7.65
7.63
7.61
7.60
7.58
7.50
7.49
7.47
7.46
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7.39
7.34
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7.28
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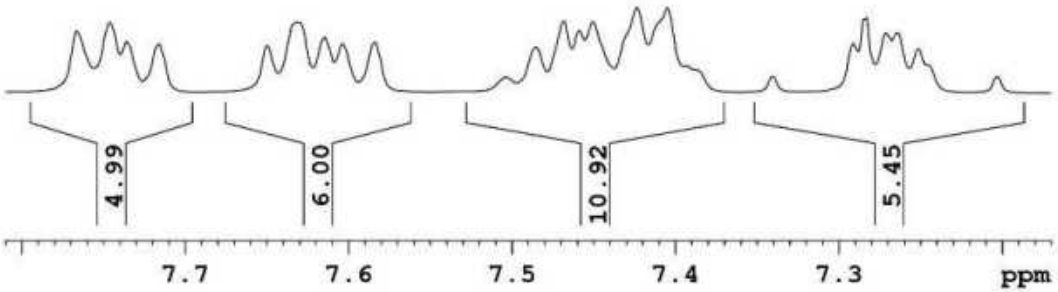
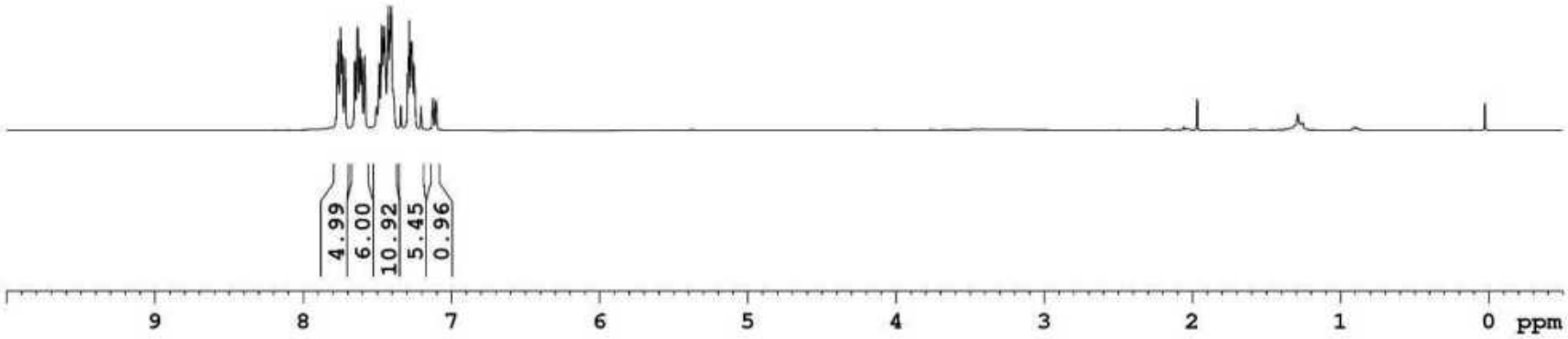
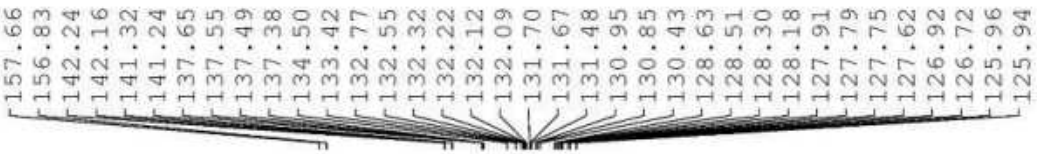
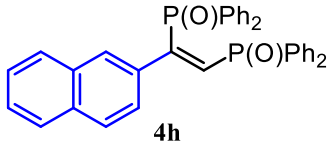
7.26
7.25
7.20

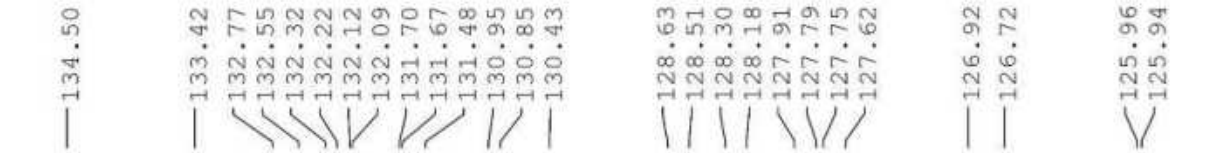

4.99
6.00
10.92
5.45
7.7
7.6
7.5
7.4
7.3
ppm


4.99
6.00
10.92
5.45
0.96
9
8
7
6
5
4
3
2
1
0
ppm


157.66
156.83
142.24
142.16
141.32
141.24
137.65
137.55
137.49
137.38
134.50
133.42
132.77
132.55
132.32
132.22
132.12
132.09
131.70
131.67
131.48
130.95
130.85
130.43
128.63
128.51
128.30
128.18
127.91
127.79
127.75
127.62
126.92
126.72
125.96
125.94


P(O)Ph2
P(O)Ph2

4h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132.22
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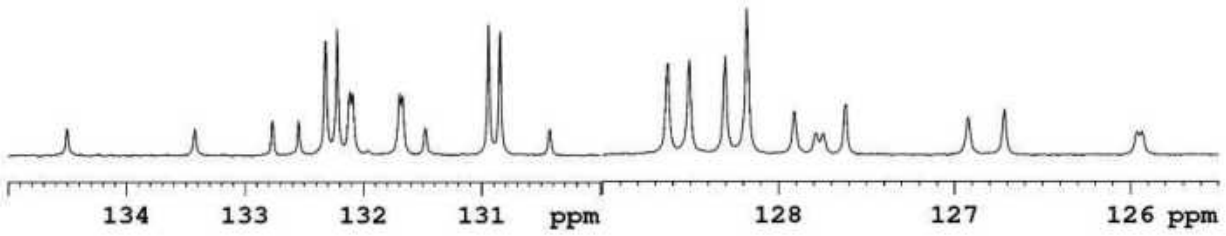
132.09
131.70
131.67
131.48
130.95
130.85
130.43
128.63
128.51
128.30
128.18
127.91
127.79
127.75
127.62
126.92
126.72
125.96
125.94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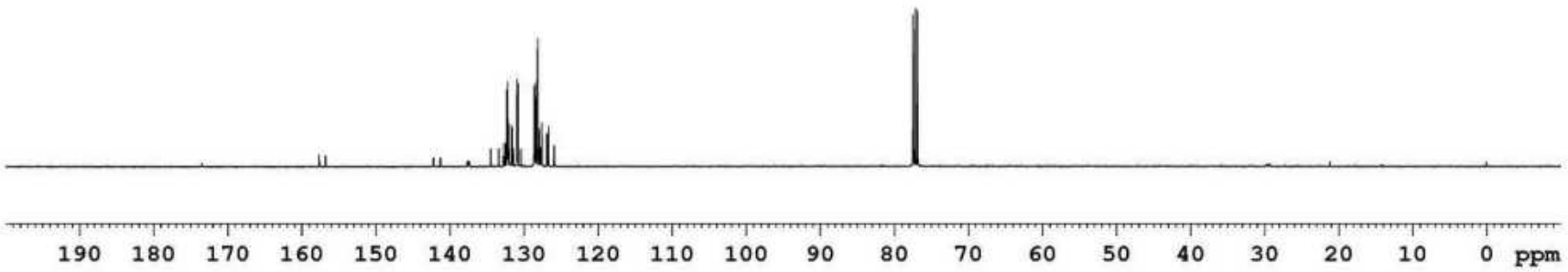
133
132
131
ppm
128
127
126 ppm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100
90
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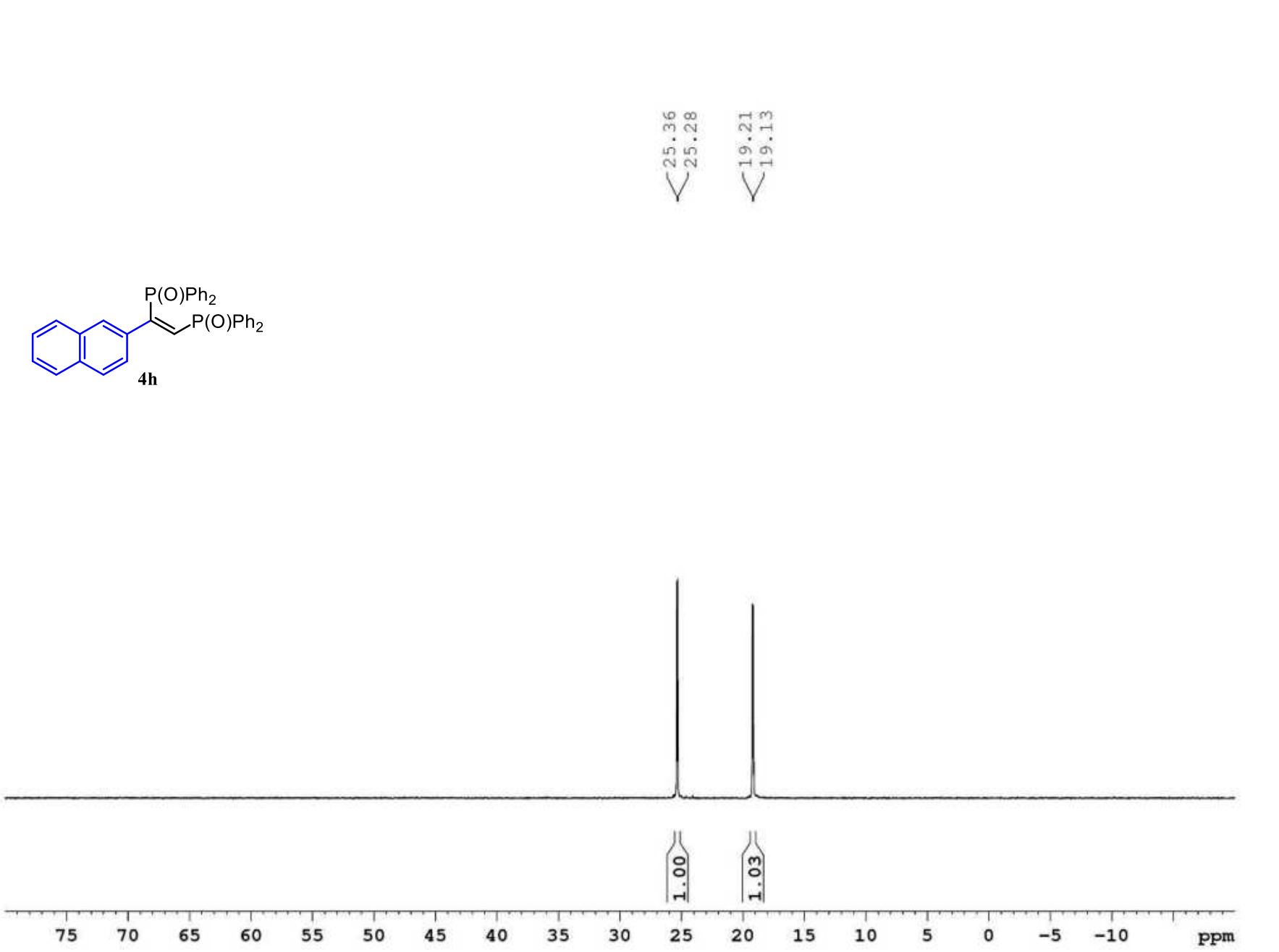
0
ppm


25.36
25.28
19.21
19.13
P(O)Ph2
P(O)Ph2
4h
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1.03
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm


8.46
8.45
8.37
7.73
7.71
7.71
7.70
7.68
7.68
7.63
7.61
7.61
7.60
7.58
7.58
7.51
7.49
7.46
7.46
7.44
7.44
7.42
7.42
7.42
7.41
7.40
7.39
7.39
7.38
7.37
7.36
7.36
7.35
7.35
7.34
7.29
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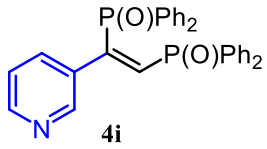
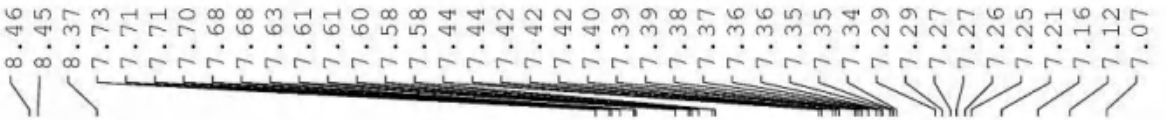
7.10
7.09
7.07


P(O)Ph2
P(O)Ph2
N

4i


8.46
8.45
8.37
7.73
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7.70
7.68
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7.61
7.61
7.60
7.58
7.58
7.44
7.44
7.42
7.42
7.42
7.40
7.39
7.39
7.38
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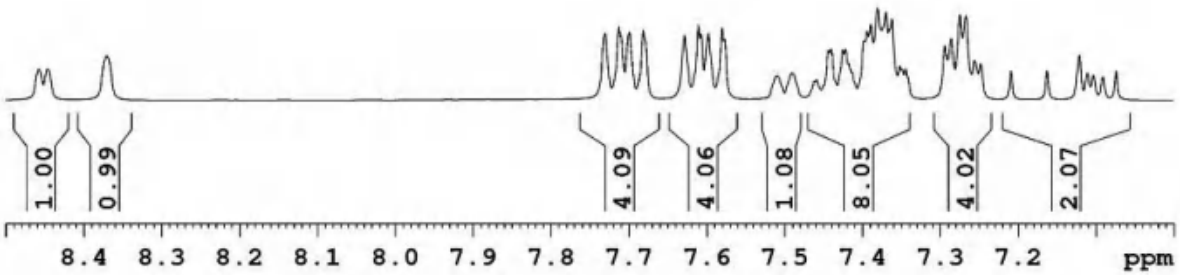
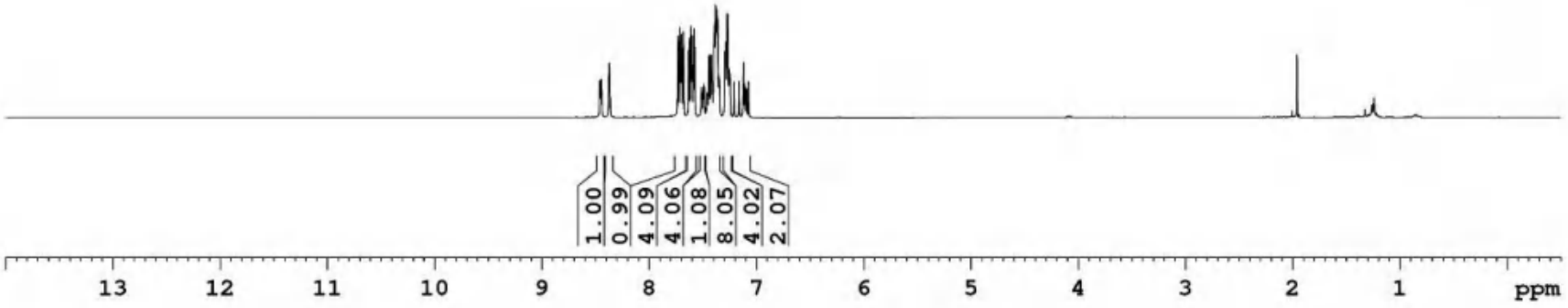
7.21
7.16
7.12
7.07


1.00
0.99
4.09
4.06
1.08
8.05
4.02
2.07
8.4
8.3
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
ppm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0.99
4.09
4.06
1.08
8.05
4.02
2.07
13
12
11
10
9
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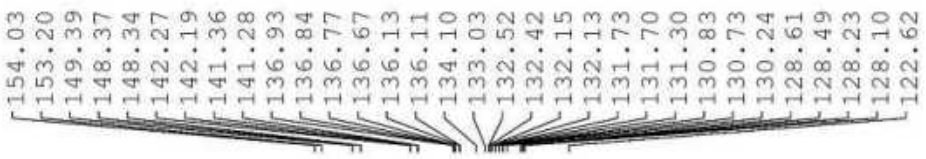
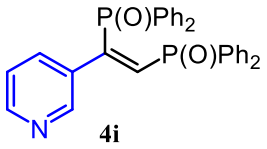
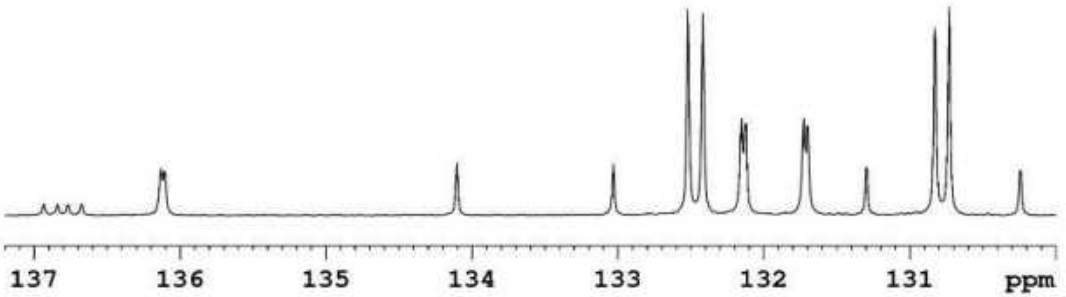
7
6
5
4
3
2
1
ppm

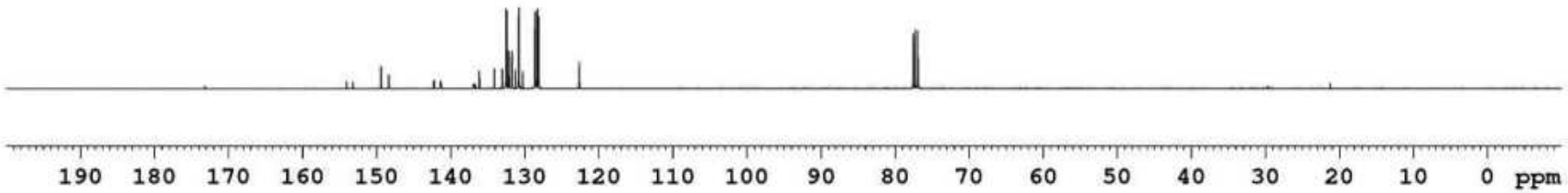

154.03
153.20
149.39
148.37
148.34
142.27
142.19
141.36
141.28
136.93
136.84
136.77
136.67
136.13
136.11
134.10
133.03
132.52
132.42
132.15
132.13
131.73
131.70
131.30
130.83
130.73
130.24
128.61
128.49
128.23
128.10
122.62


P(O)Ph2
P(O)Ph2
N

4i

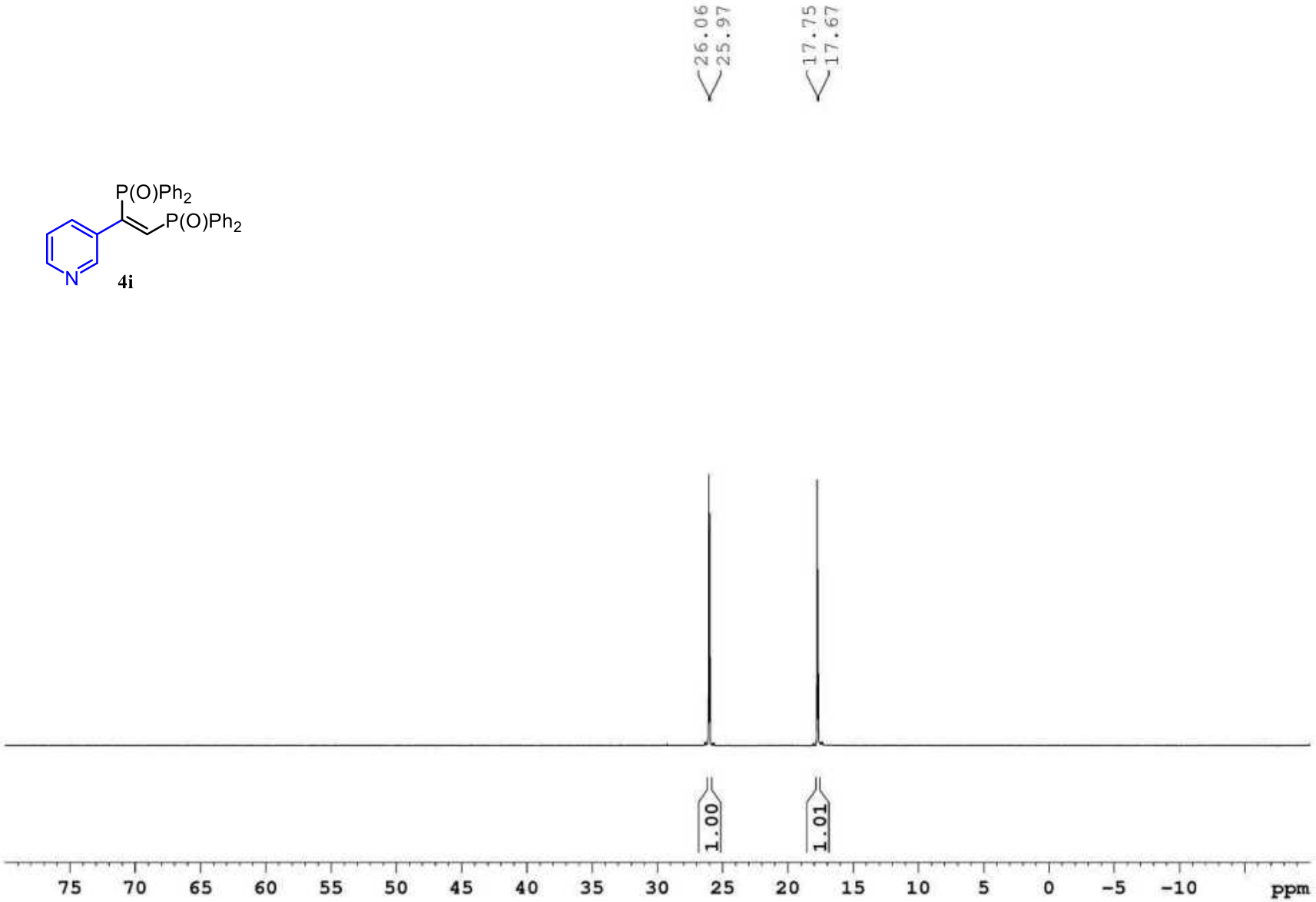

136.93
136.84
136.77
136.67
136.13
136.11
134.10
133.03
132.52
132.42
132.15
132.13
131.73
131.70
131.30
130.83
130.73
130.24


137
136
135
134
133
132
131
ppm


190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

P(O)Ph2
P(O)Ph2
N

4i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25.97
17.75
17.67
1.00
1.01
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm


7.73
7.71
7.69
7.68
7.57
7.55
7.54
7.52
7.44
7.42
7.41
7.39
7.37
7.36
7.35
7.34
7.33
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7.31
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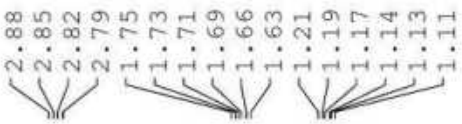
7.29
7.28
7.27
7.08
7.04
6.98
6.94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2.85
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1.73
1.71
1.69
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1.63
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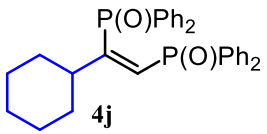
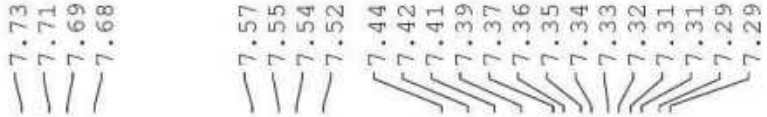
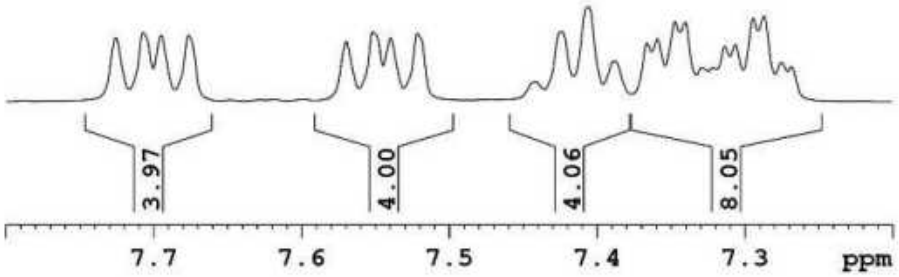
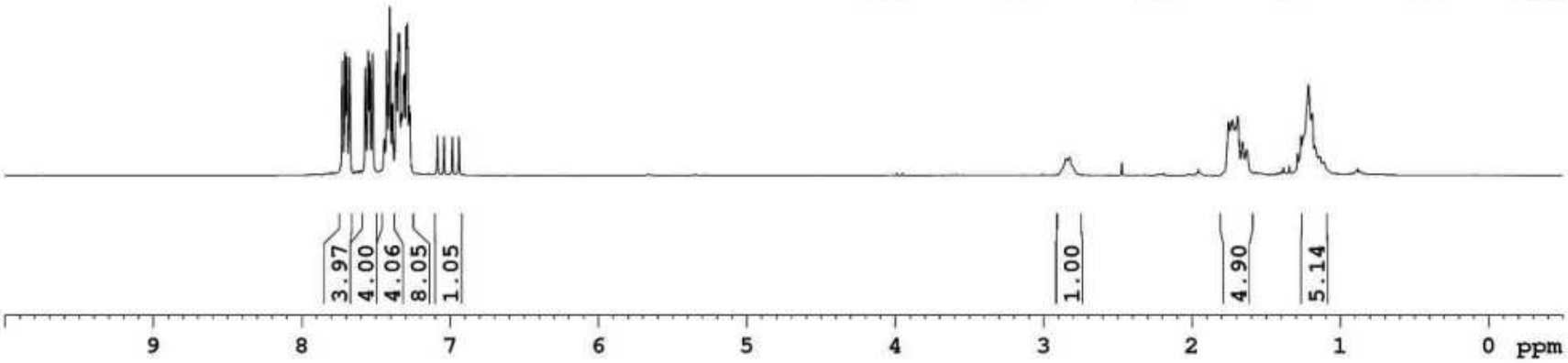
1.19
1.17
1.14
1.13
1.11

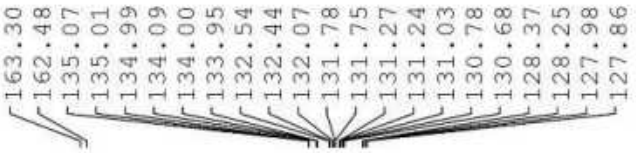

P(O)Ph2
P(O)Ph2

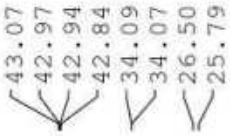
4j


7.73
7.71
7.69
7.68
7.57
7.55
7.54
7.52
7.44
7.42
7.41
7.39
7.37
7.36
7.35
7.34
7.33
7.32
7.31
7.31
7.29
7.29


3.97
4.00
4.06
8.05
7.7
7.6
7.5
7.4
7.3
ppm


3.97
4.00
4.06
8.05
1.05
1.00
4.90
5.14
9
8
7
6
5
4
3
2
1
0
ppm


163.30
162.48
135.07
135.01
134.99
134.09
134.00
133.95
132.54
132.44
132.07
131.78
131.75
131.27
131.24
131.03
130.78
130.68
128.37
128.25
127.98
127.86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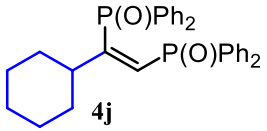
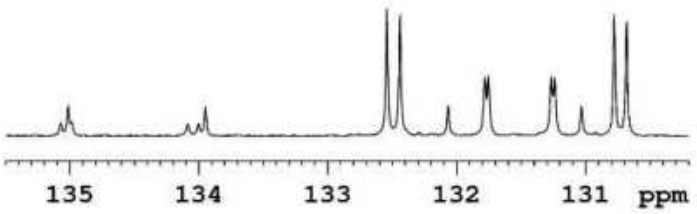
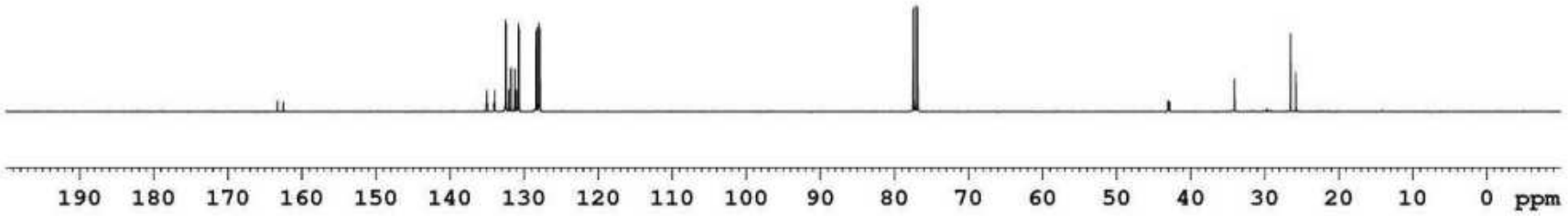
42.94
42.84
34.09
34.07
26.50
25.79


P(O)Ph2
P(O)Ph2
4j


135.07
135.01
134.99
134.09
134.00
133.95
132.54
132.44
132.07
131.78
131.75
131.27
131.24
131.03
130.78
130.68


135
134
133
132
131
ppm


190
180
170
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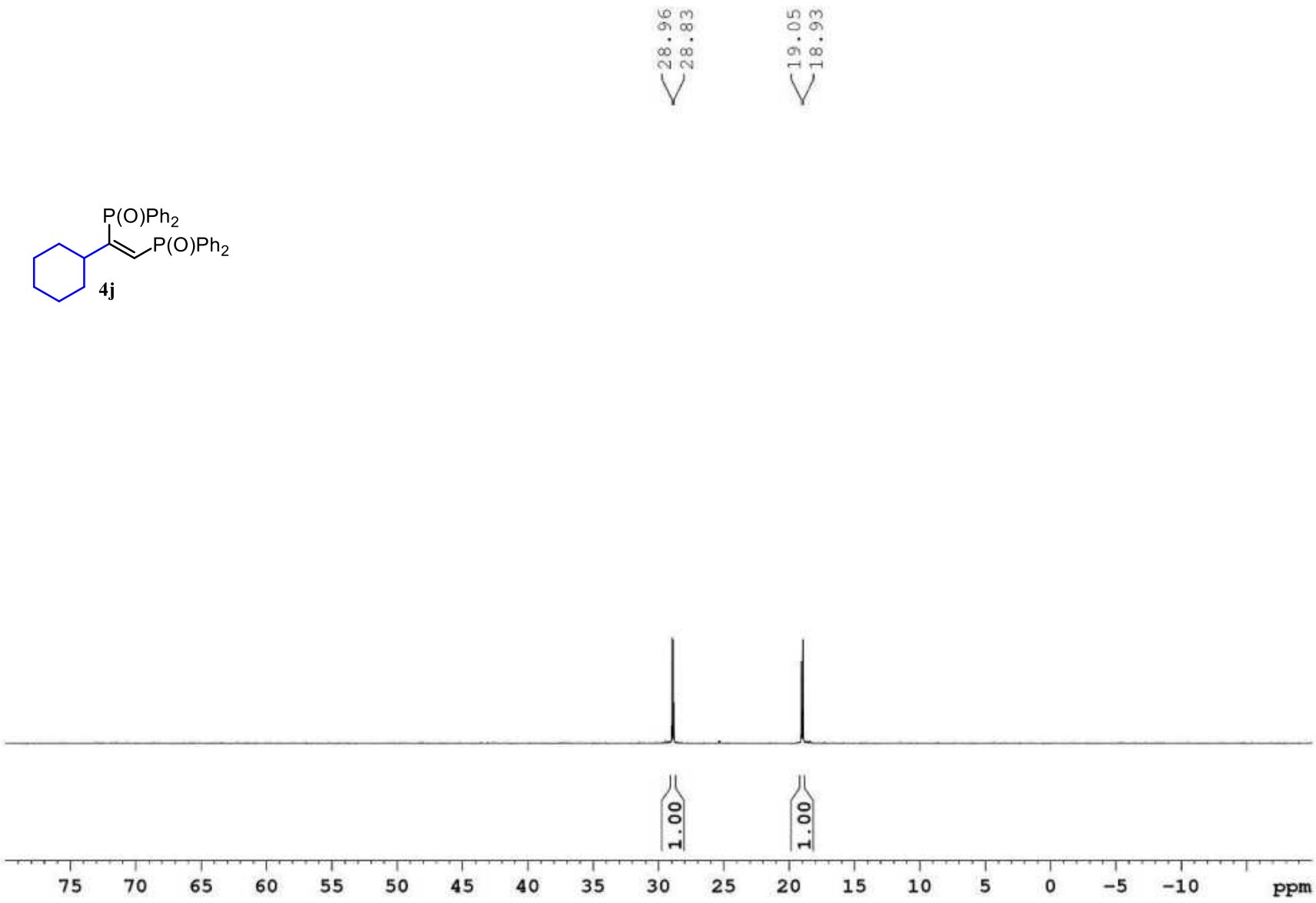
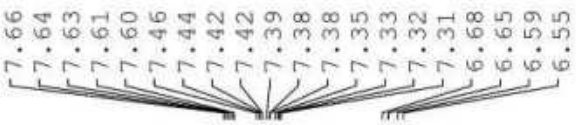
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


28.96
28.83
19.05
18.93
P(O)Ph2
P(O)Ph2
4j
1.00
1.00
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm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7.64
7.63
7.61
7.60
7.46
7.44
7.42
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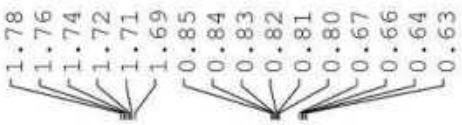
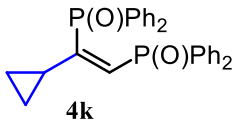
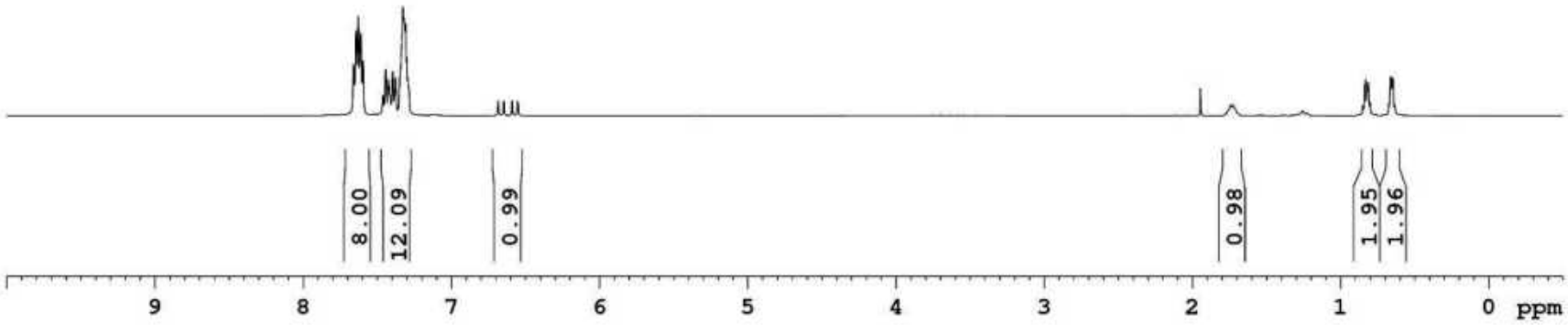
7.38
7.38
7.35
7.33
7.32
7.31
6.68
6.65
6.59
6.55


1.78
1.76
1.74
1.72
1.71
1.69
0.85
0.84
0.83
0.82
0.81
0.80
0.67
0.66
0.64
0.63


P(O)Ph2
P(O)Ph2

4k


8.00
12.09
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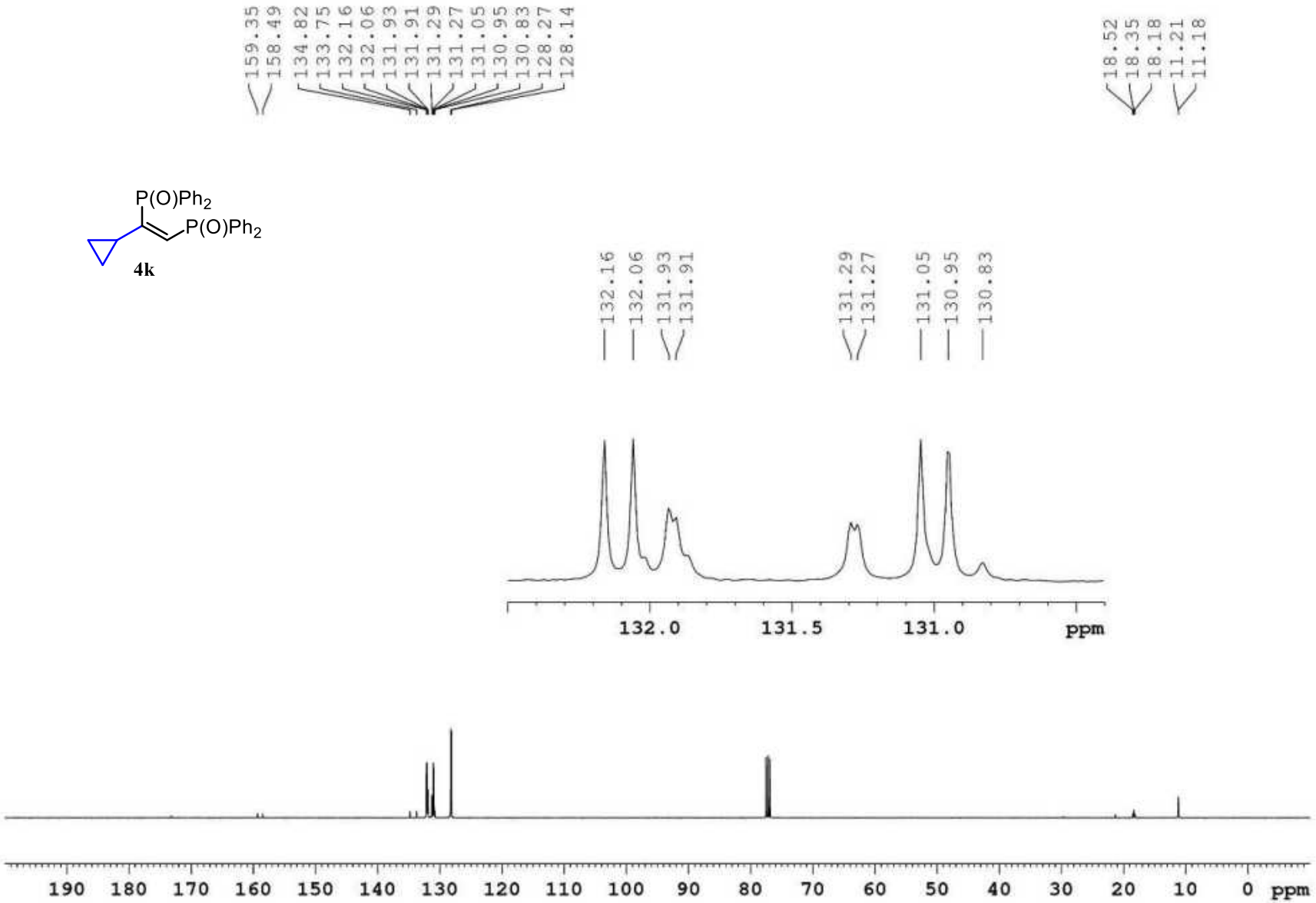
0.98
1.95
1.96
9
8
7
6
5
4
3
2
1
0
ppm


159.35
158.49
134.82
133.75
132.16
132.06
131.93
131.91
131.29
131.27
131.05
130.95
130.83
128.27
128.14
18.52
18.35
18.18
11.21
11.18
P(O)Ph2
P(O)Ph2
4k
132.16
132.06
131.93
131.91
131.29
131.27
131.05
130.95
130.83
132.0
131.5
131.0
ppm
190
180
170
160
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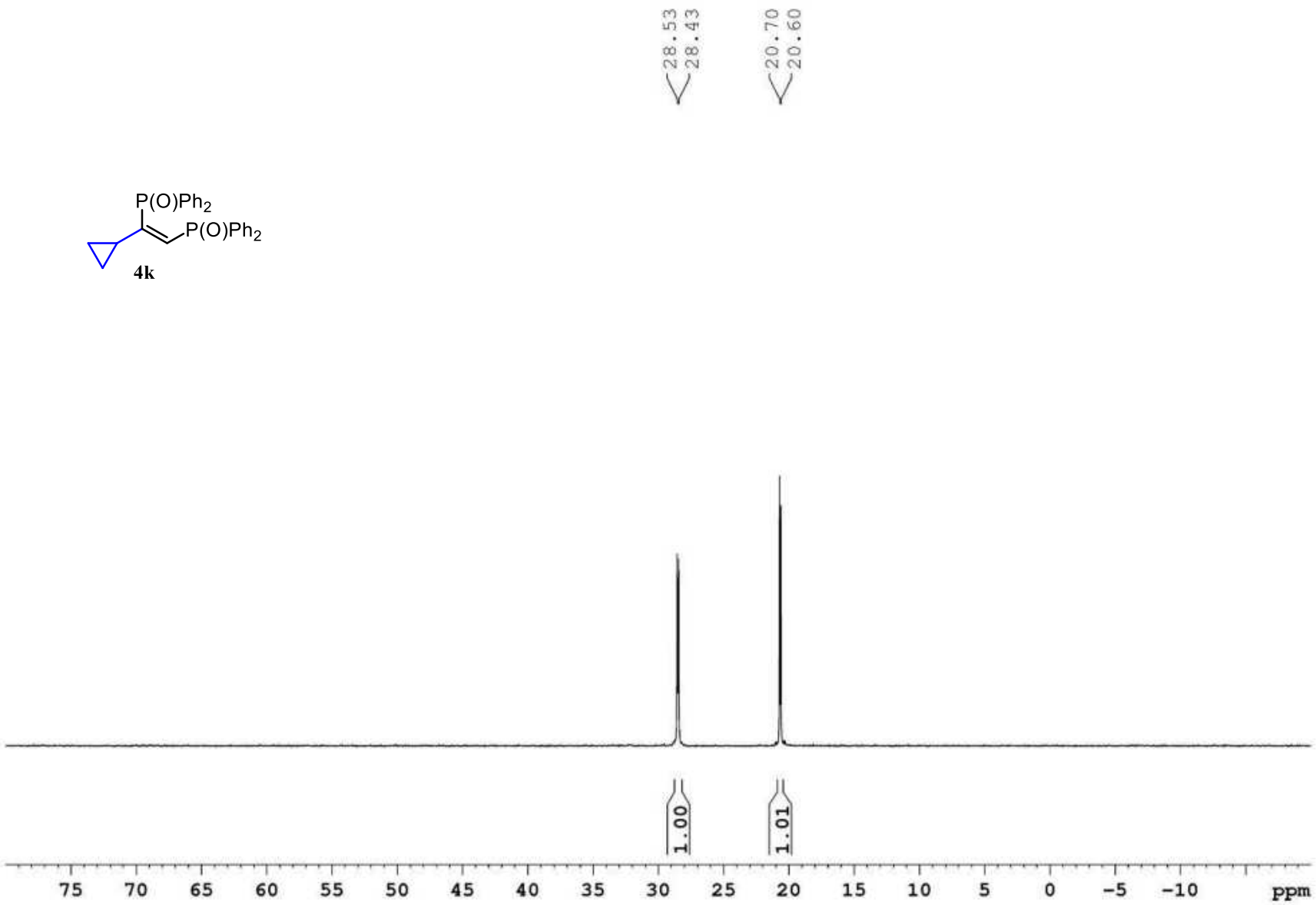
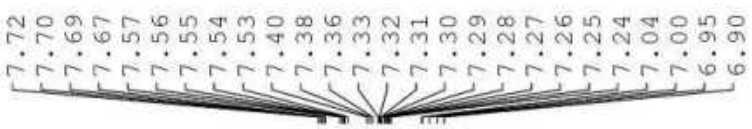
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


28.53
28.43
20.70
20.60
P(O)Ph2
P(O)Ph2
4k
1.00
1.01
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm


7.72
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7.69
7.67
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7.56
7.55
7.54
7.53
7.40
7.38
7.36
7.33
7.32
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7.28
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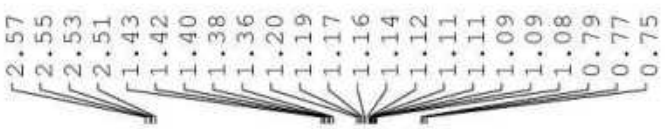
7.26
7.25
7.24
7.04
7.00
6.95
6.90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1.42
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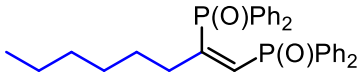
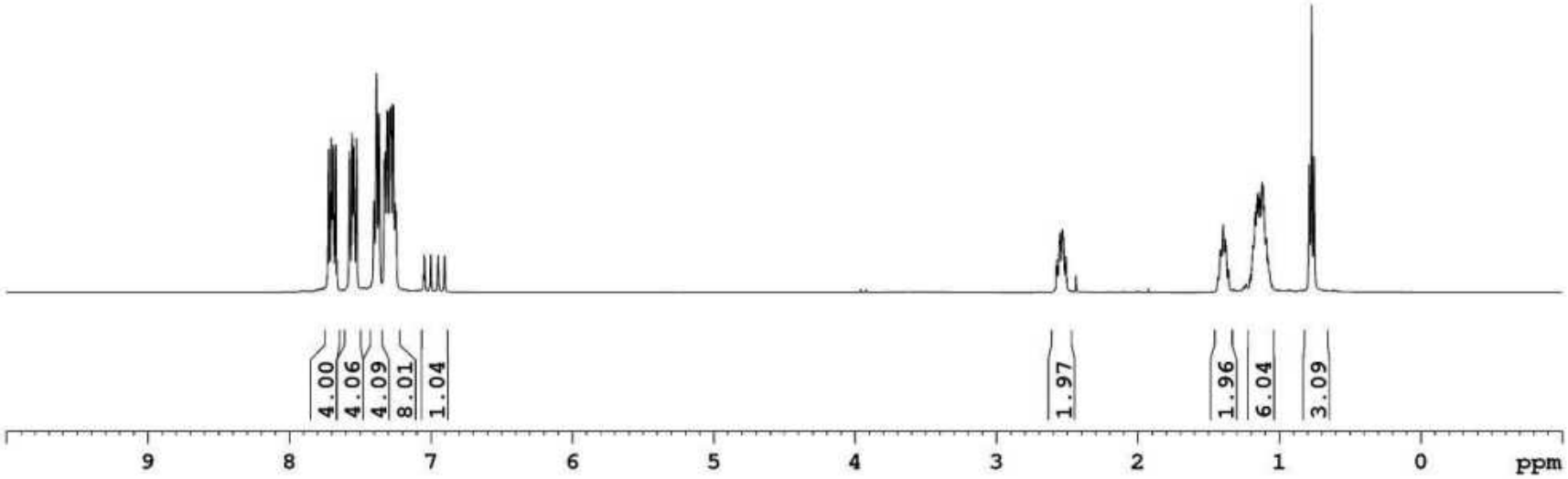
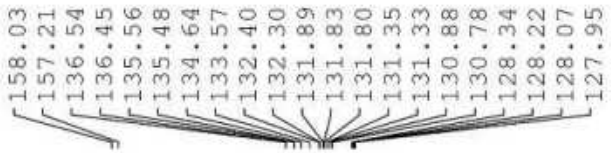
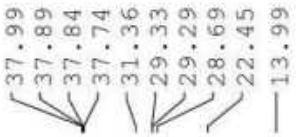
1.38
1.36
1.20
1.19
1.17
1.16
1.14
1.12
1.11
1.11
1.09
1.09
1.08
0.79
0.77
0.75


P(O)Ph2
P(O)Ph2

4l


4.00
4.06
4.09
8.01
1.04
1.97
1.96
6.04
3.09
9
8
7
6
5
4
3
2
1
0
ppm


158.03
157.21
136.54
136.45
135.56
135.48
134.64
133.57
132.40
132.30
131.89
131.83
131.80
131.35
131.33
130.88
130.78
128.34
128.22
128.07
127.95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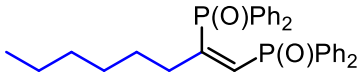
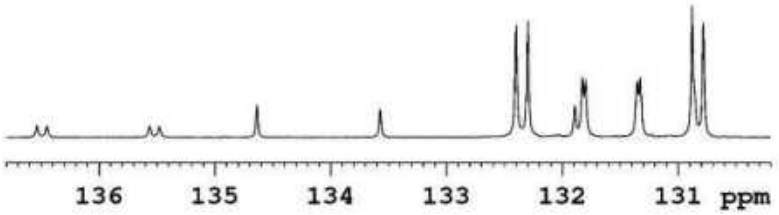
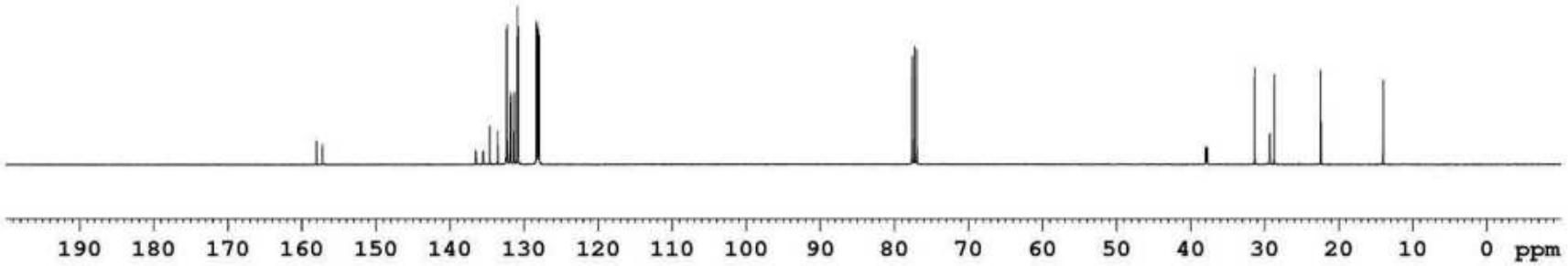
37.89
37.84
37.74
31.36
29.33
29.29
28.69
22.45
13.99


P(O)Ph2
P(O)Ph2

4l


136.54
136.45
135.56
135.48
134.64
133.57
132.40
132.30
131.89
131.83
131.80
131.35
131.33
130.88
130.78


136
135
134
133
132
131
ppm


190
180
170
160
150
140
130
120
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100
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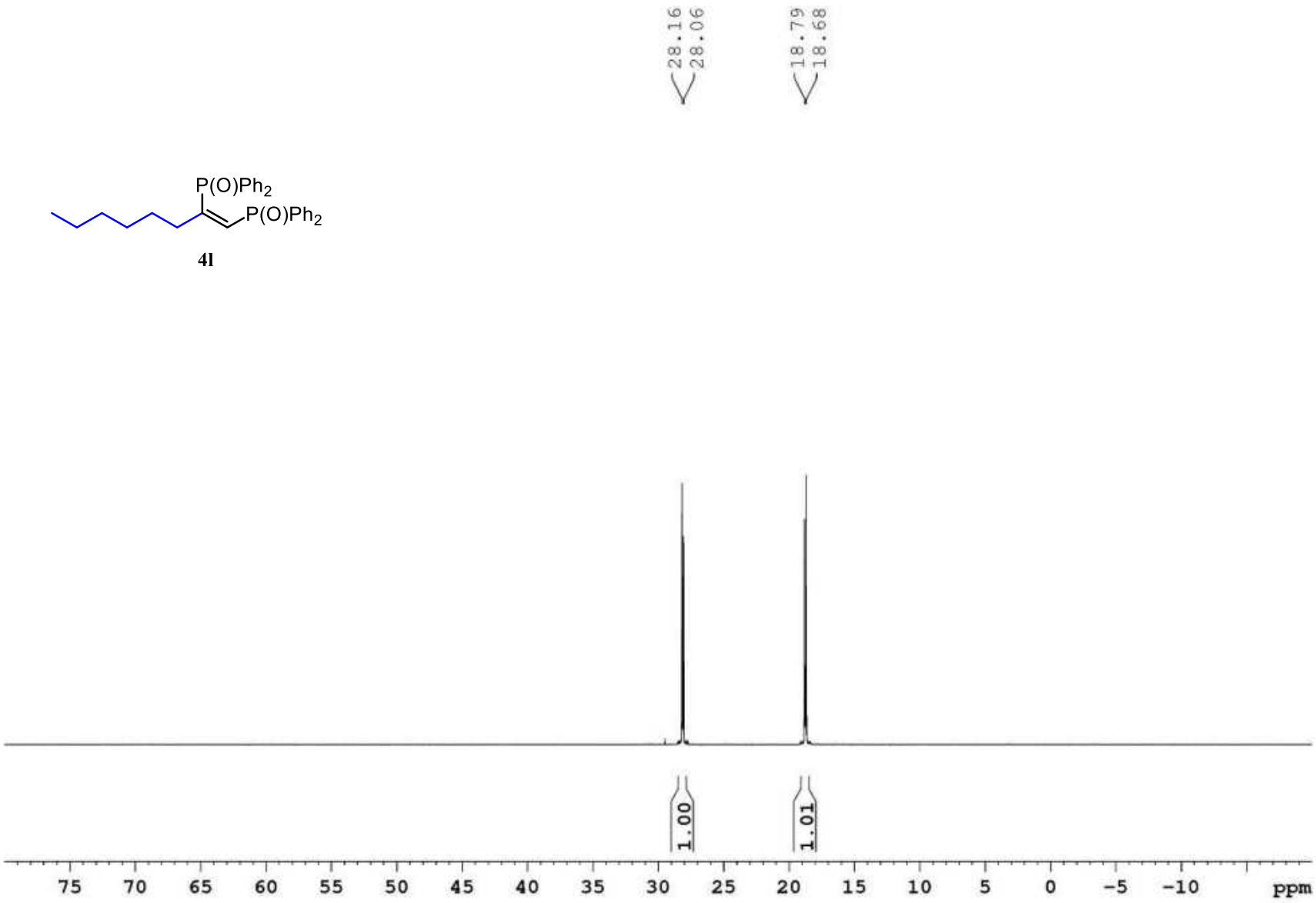
80
70
60
50
40
30
20
10
0
ppm

P(O)Ph2
P(O)Ph2

4l


28.16
28.06
18.79
18.68
1.00
1.01
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
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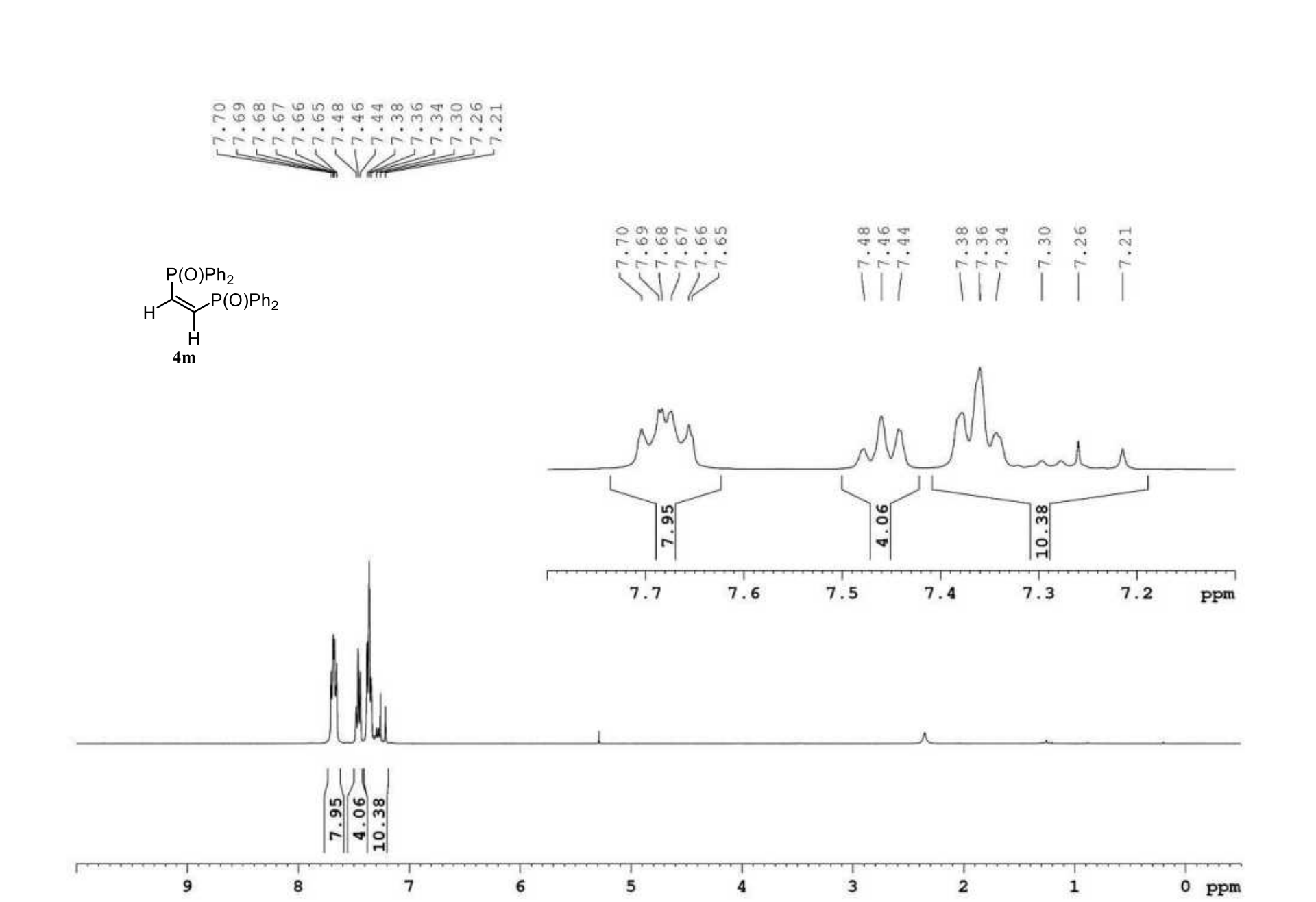
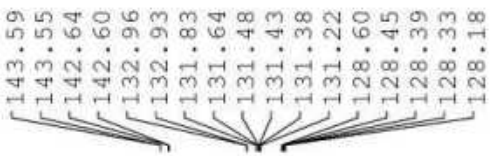
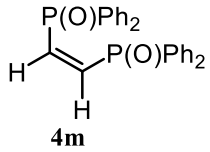
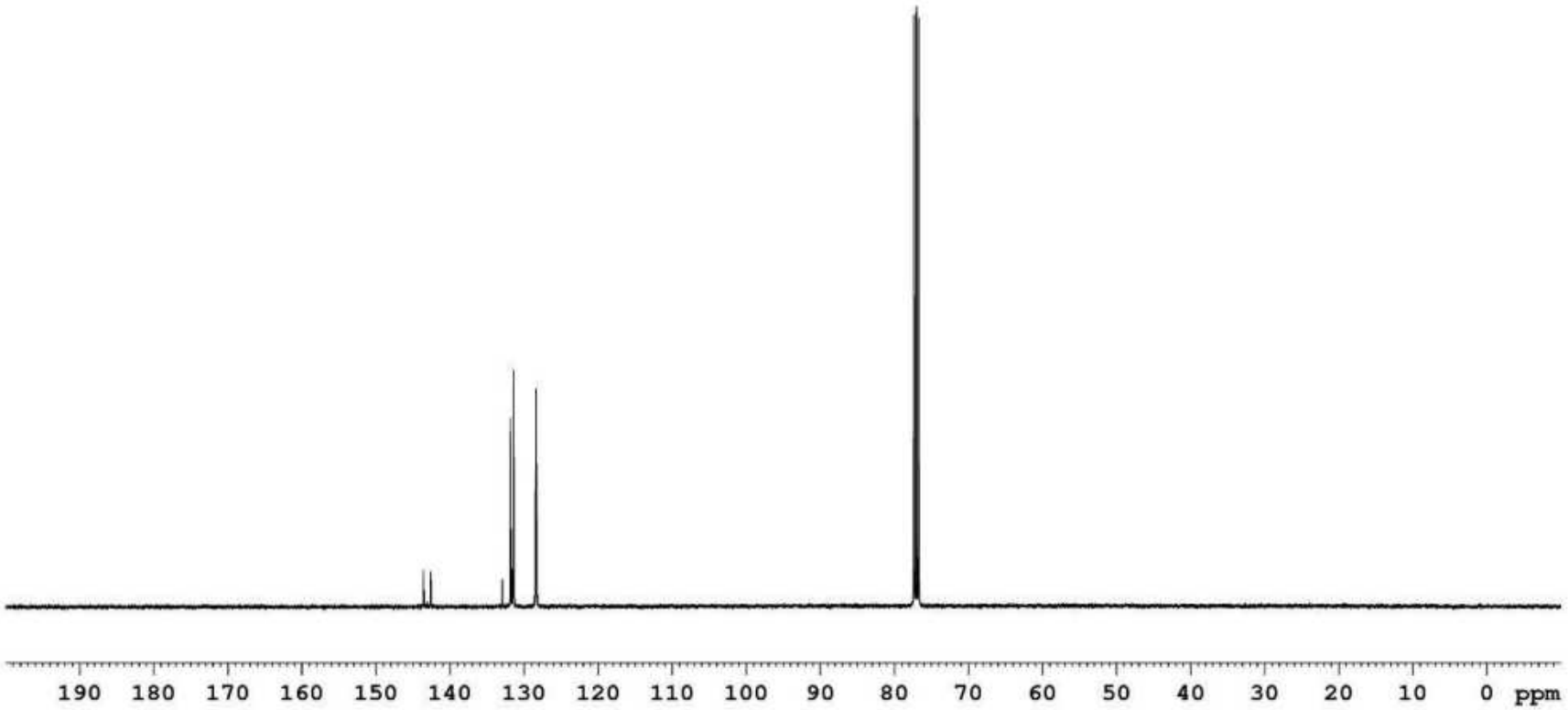
-5
-10
ppm


7.70
7.69
7.68
7.67
7.66
7.65
7.48
7.46
7.44
7.38
7.36
7.34
7.30
7.26
7.21
P(O)Ph2
P(O)Ph2
H
H
4m
7.95
4.06
10.38
7.7
7.6
7.5
7.4
7.3
7.2
ppm
9
8
7
6
5
4
3
2
1
0
ppm


143.59
143.55
142.64
142.60
132.96
132.93
131.83
131.64
131.48
131.43
131.38
131.22
128.60
128.45
128.39
128.33
128.18

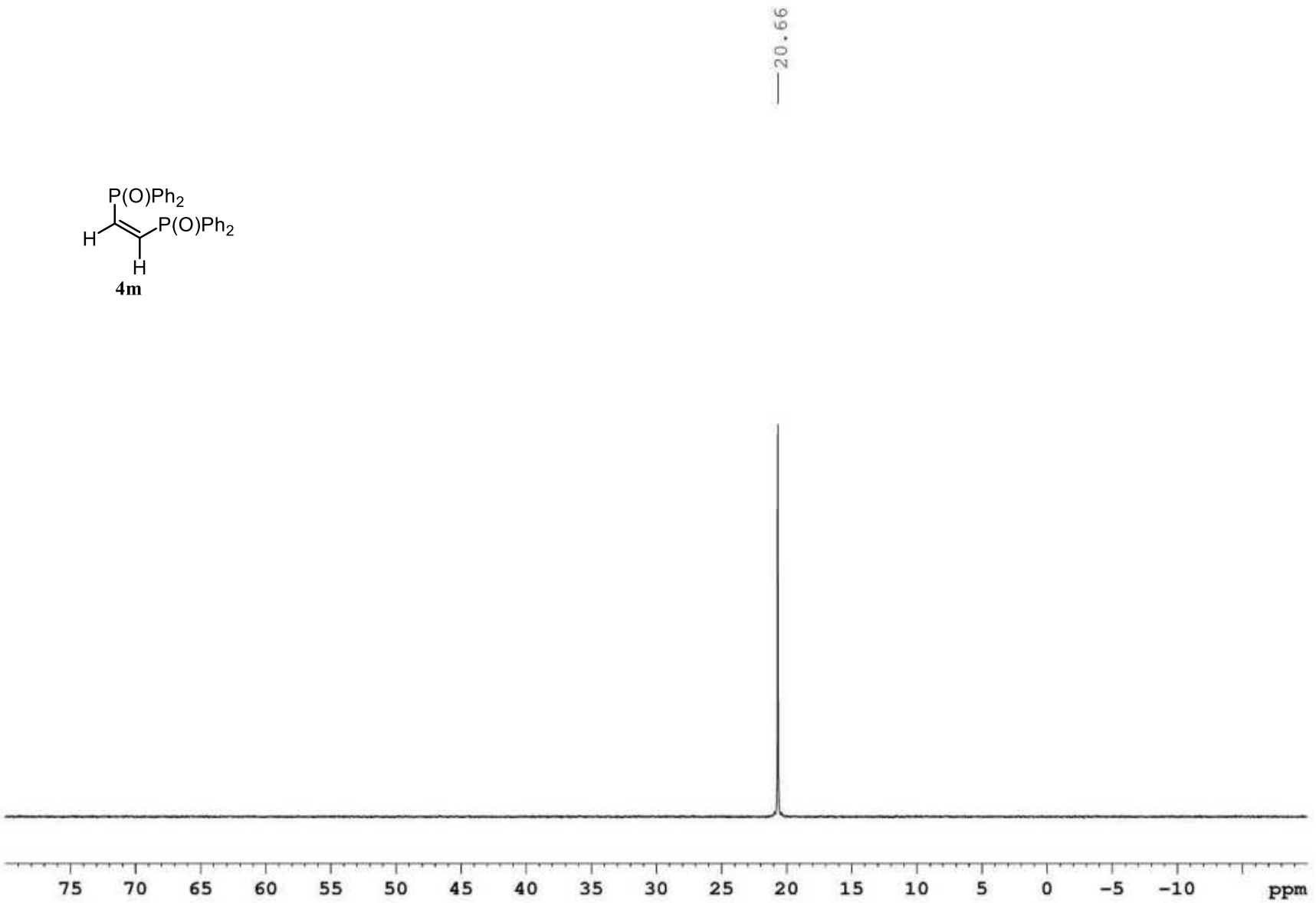

P(O)Ph2
H
P(O)Ph2
H

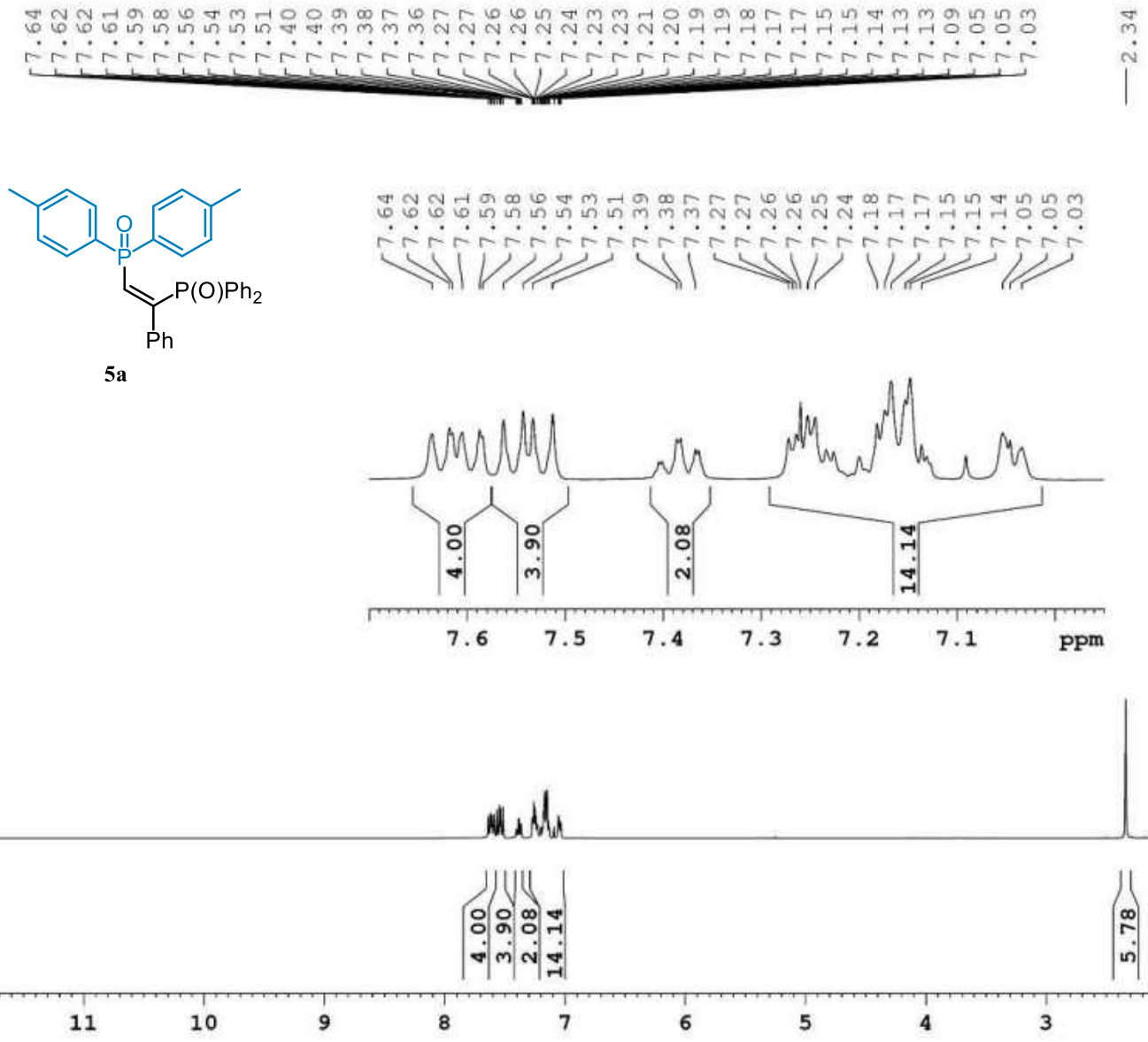
4m

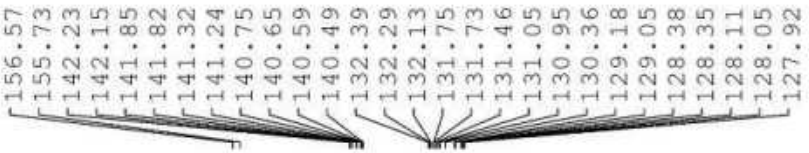

190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

P(O)Ph2
H
P(O)Ph2
H

4m


20.66
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm


7.64 7.62 7.62 7.61 7.59 7.58 7.56 7.54 7.53 7.51 7.40 7.40 7.39 7.38 7.37 7.36 7.27 7.27 7.26 7.26 7.25 7.24 7.23 7.23 7.21 7.20 7.19 7.19 7.18 7.17 7.17 7.15 7.15 7.14 7.13 7.13 7.09 7.05 7.05 7.03
2.34
P(O)Ph2
Ph
5a
4.00
3.90
2.08
14.14
7.6 7.5 7.4 7.3 7.2 7.1 ppm
5.78
11 10 9 8 7 6 5 4 3 2 1 ppm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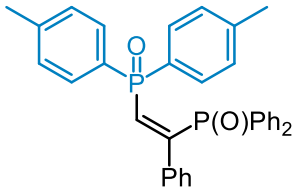
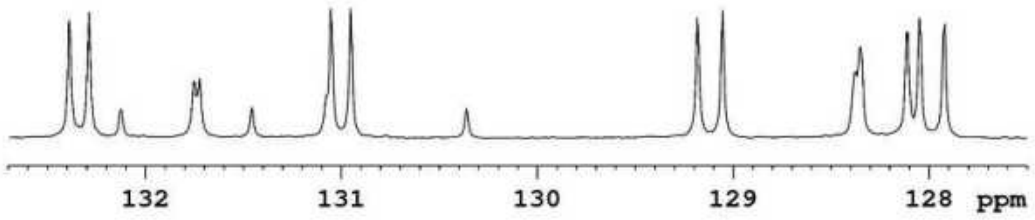
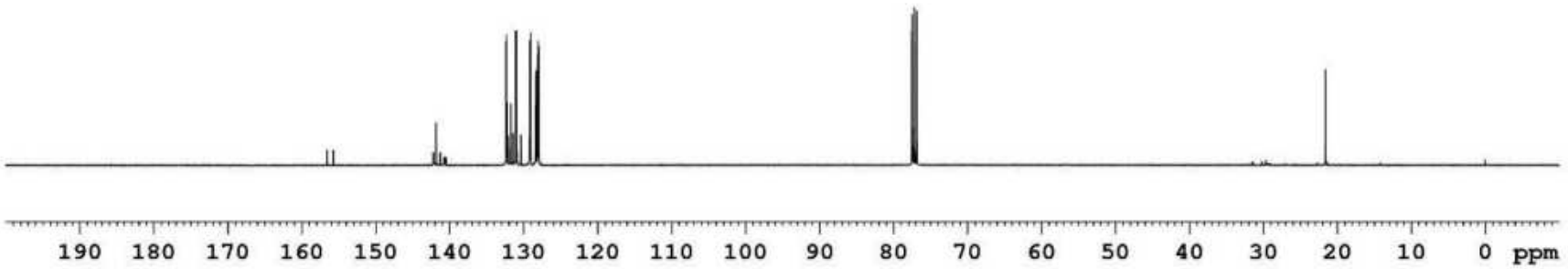
155.73
142.23
142.15
141.85
141.82
141.32
141.24
140.75
140.65
140.59
140.49
132.39
132.29
132.13
131.75
131.73
131.46
131.05
130.95
130.36
129.18
129.05
128.38
128.35
128.11
128.05
127.92
21.60


O
P
P(O)Ph2
Ph

5a

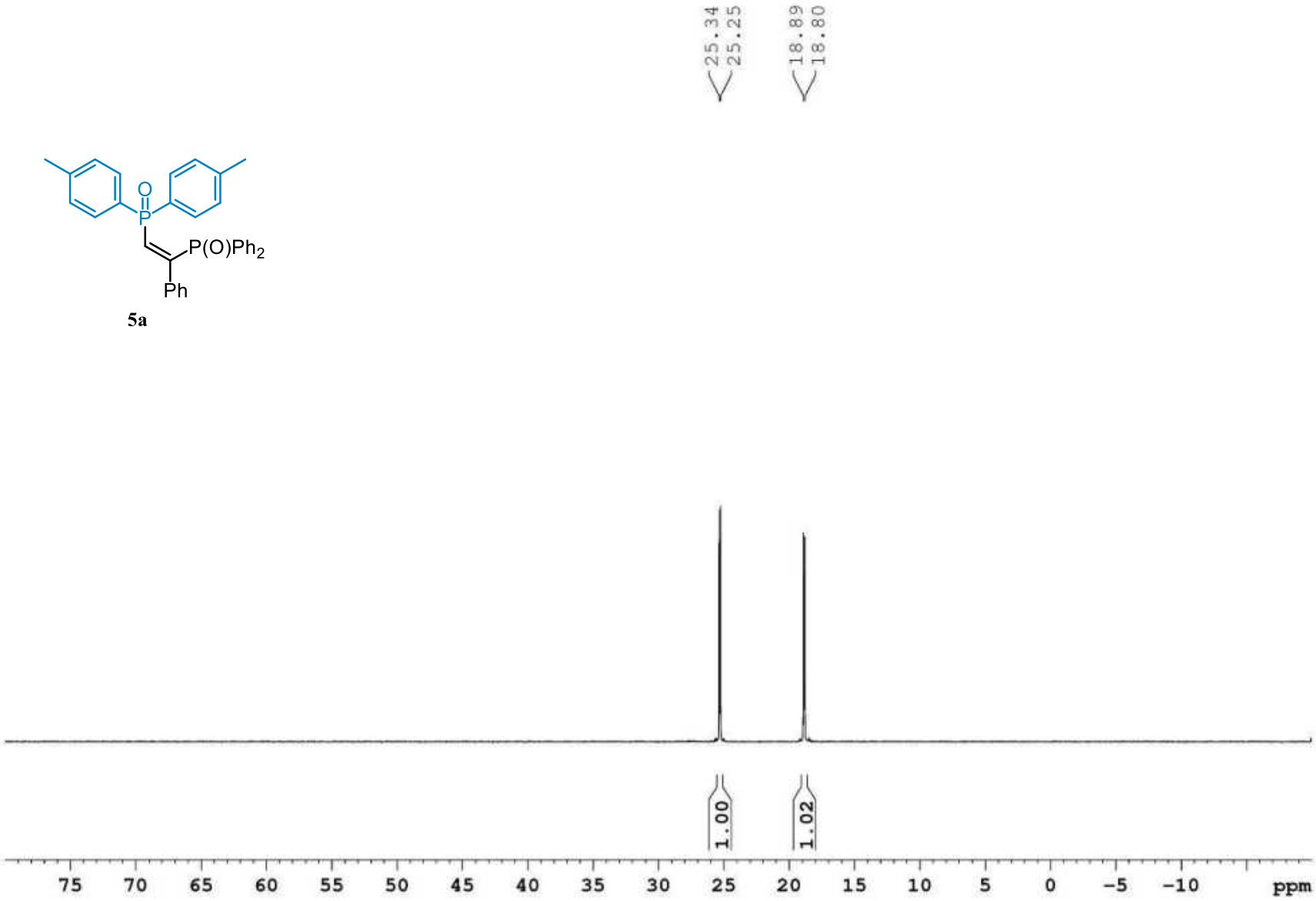

132.39
132.29
132.13
131.75
131.73
131.46
131.05
130.95
130.36
129.18
129.05
128.38
128.35
128.11
128.05
127.92

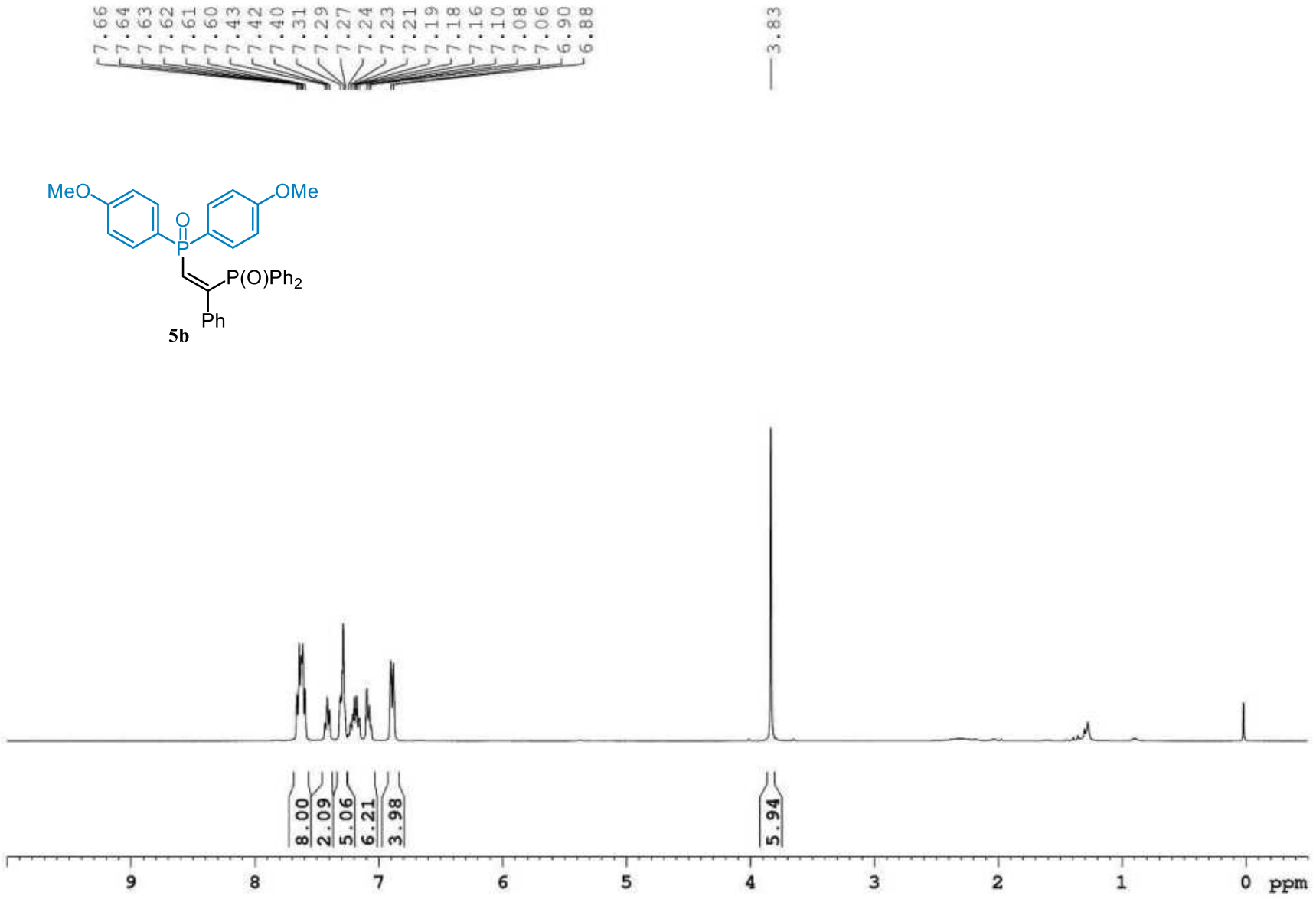

132
131
130
129
128
ppm

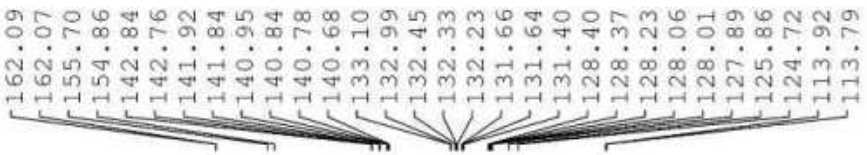

190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

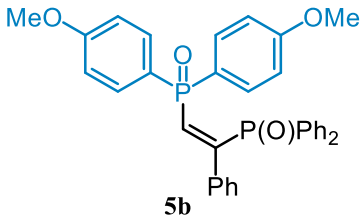
O
P
P(O)Ph2
Ph

5a

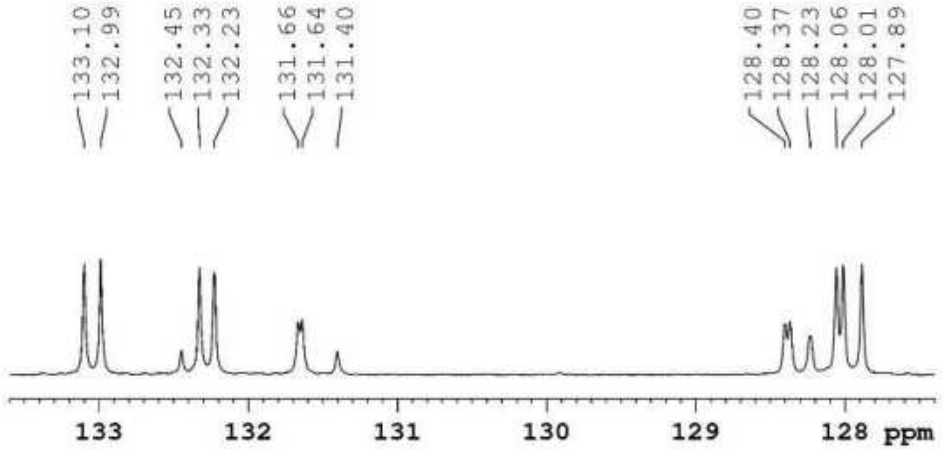

25.34
25.25
18.89
18.80
1.00
1.02
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm

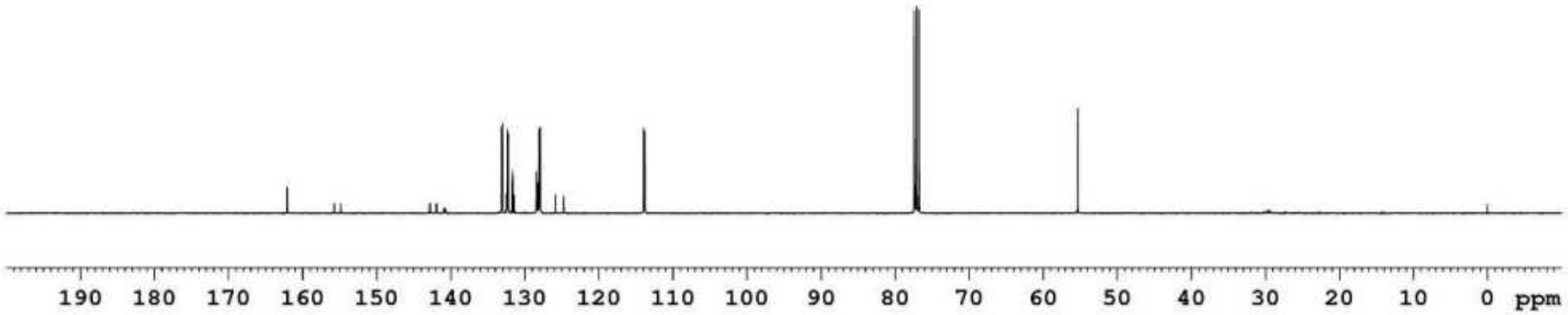

7.66
7.64
7.63
7.62
7.61
7.60
7.43
7.42
7.40
7.31
7.29
7.27
7.24
7.23
7.21
7.19
7.18
7.16
7.10
7.08
7.06
6.90
6.88
3.83
MeO
OMe
O
P
P(O)Ph2
Ph
5b
8.00
2.09
5.06
6.21
3.98
5.94
9
8
7
6
5
4
3
2
1
0
ppm


162.09
162.07
155.70
154.86
142.84
142.76
141.92
141.84
140.95
140.84
140.78
140.68
133.10
132.99
132.45
132.33
132.23
131.66
131.64
131.40
128.40
128.37
128.23
128.06
128.01
127.89
125.86
124.72
113.92
113.79
55.31


MeO
OMe
O
P
P(O)Ph2
Ph

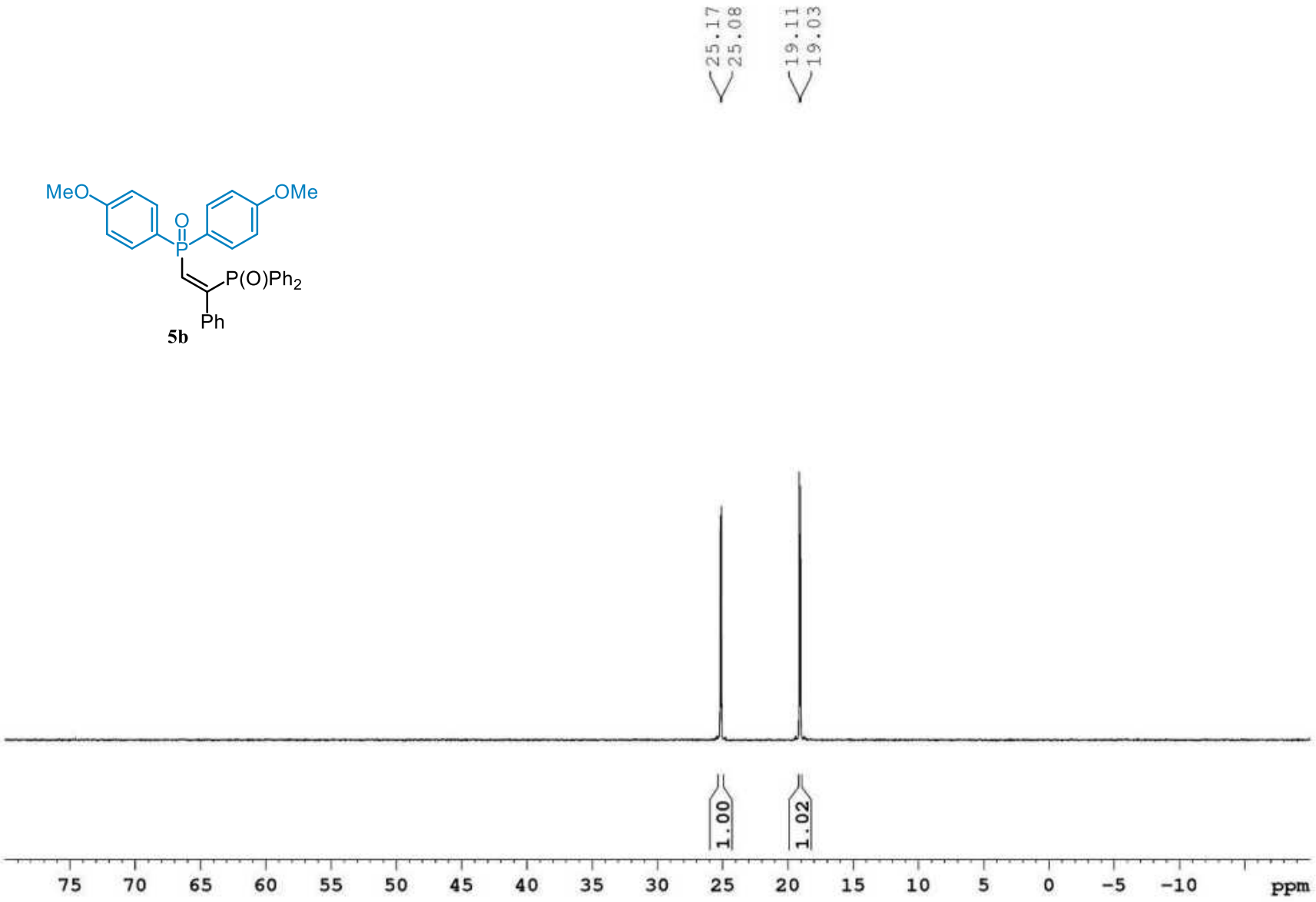
5b

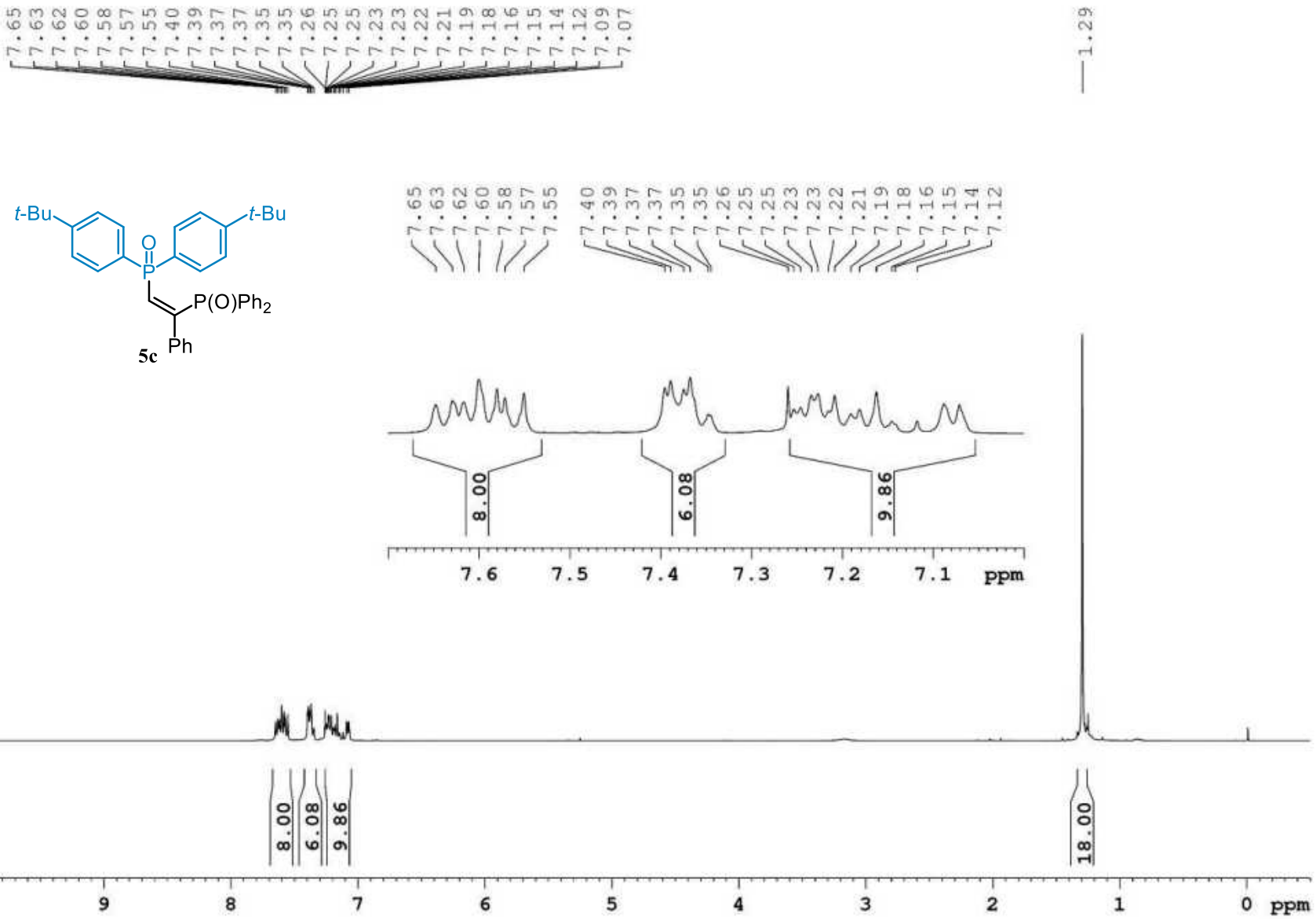

133.10
132.99
132.45
132.33
132.23
131.66
131.64
131.40
128.40
128.37
128.23
128.06
128.01
127.89
133
132
131
130
129
128
ppm

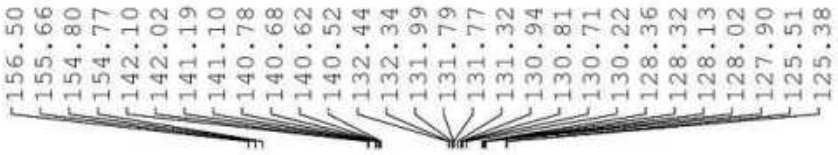

190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

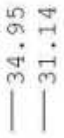
MeO
OMe
O
P
P(O)Ph2
Ph

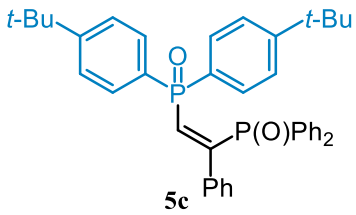
5b


25.17
25.08
19.11
19.03
1.00
1.02
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm

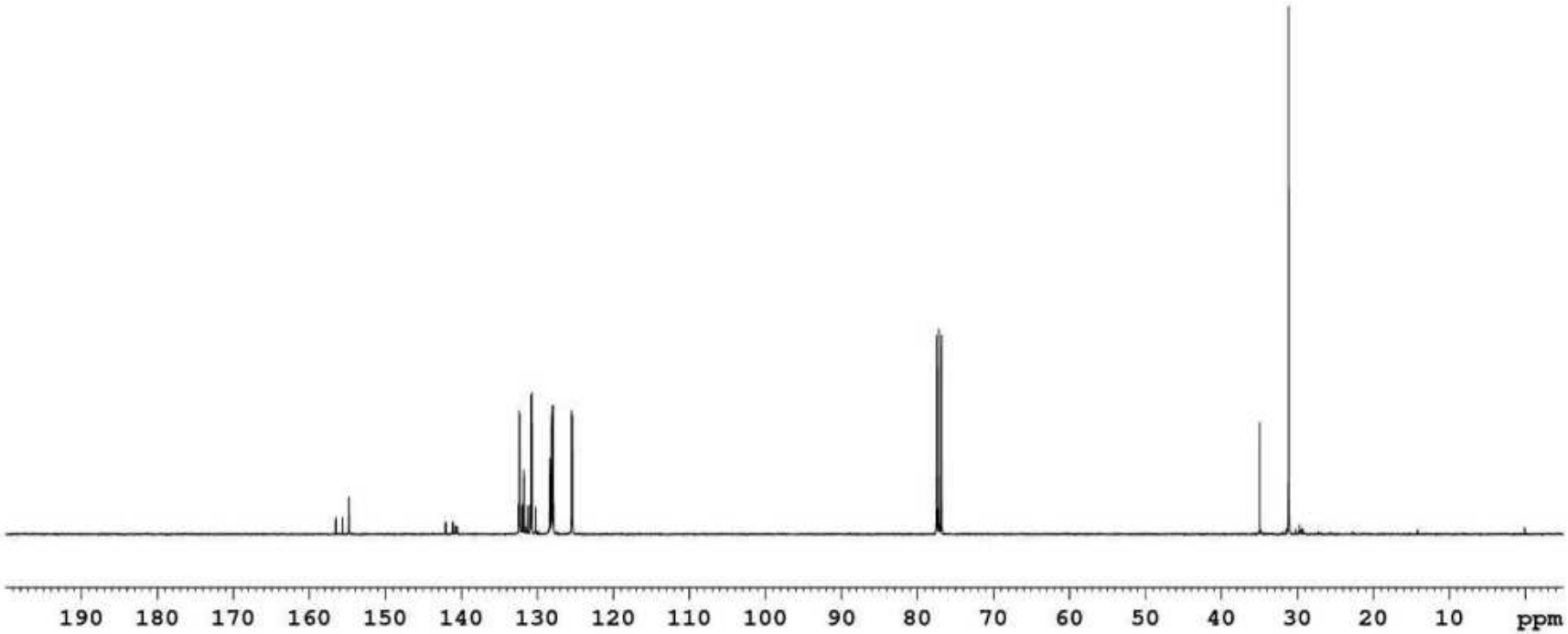

7.65
7.63
7.62
7.60
7.58
7.57
7.55
7.40
7.39
7.37
7.37
7.35
7.35
7.26
7.25
7.25
7.23
7.23
7.22
7.21
7.19
7.18
7.16
7.15
7.14
7.12
7.09
7.07
1.29
t-Bu
t-Bu
O
P
P(O)Ph2
Ph
5c
8.00
6.08
9.86
7.6
7.5
7.4
7.3
7.2
7.1
ppm
8.00
6.08
9.86
18.00
9
8
7
6
5
4
3
2
1
0
ppm


156.50
155.66
154.80
154.77
142.10
142.02
141.19
141.10
140.78
140.68
140.62
140.52
132.44
132.34
131.99
131.79
131.77
131.32
130.94
130.81
130.71
130.22
128.36
128.32
128.13
128.02
127.90
125.51
125.38


34.95
31.14

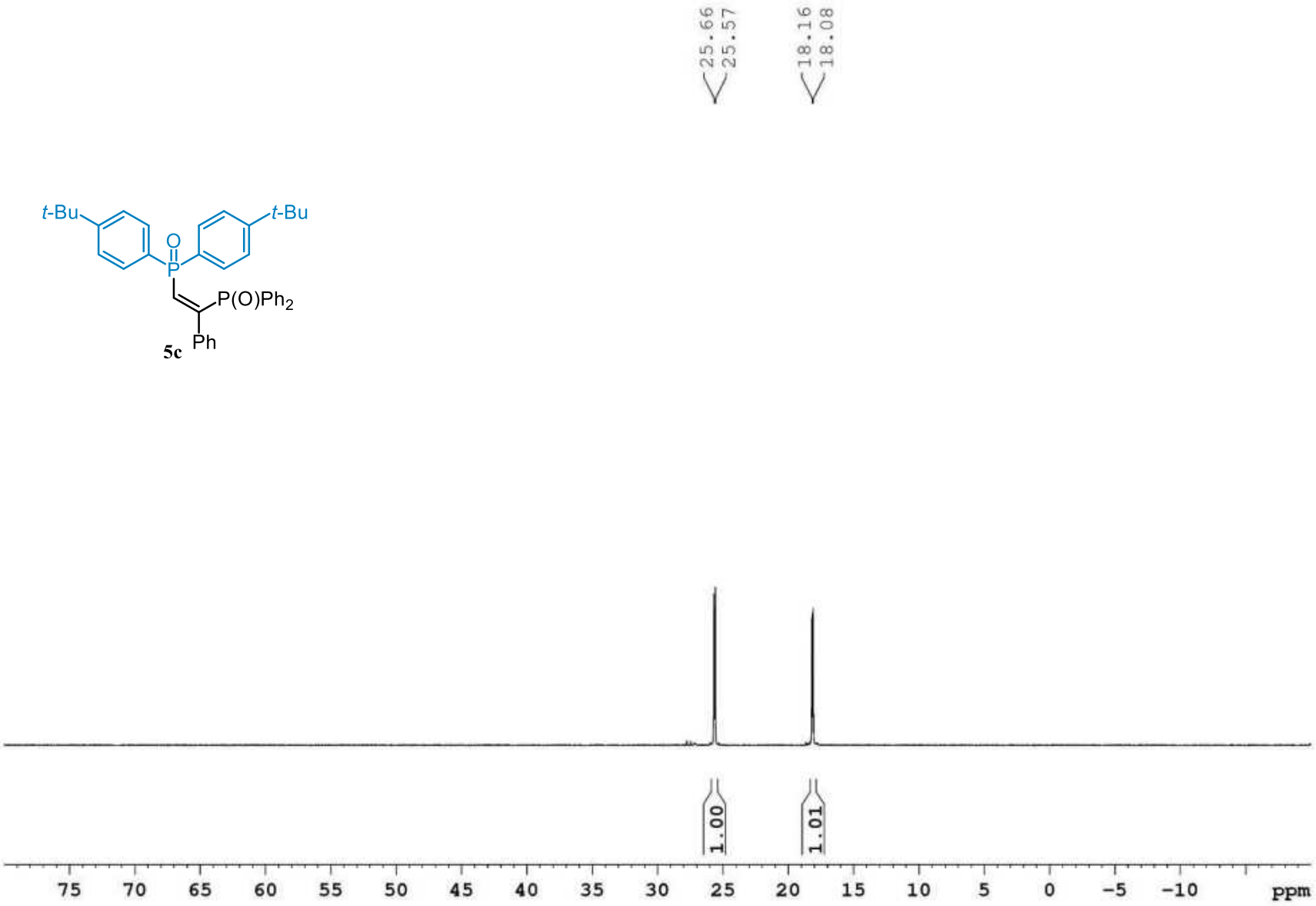

t-Bu
t-Bu
O
P
P(O)Ph2
Ph

5c

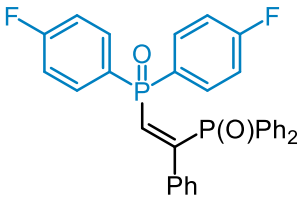

190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm

t-Bu
t-Bu
O
P
P(O)Ph2
Ph

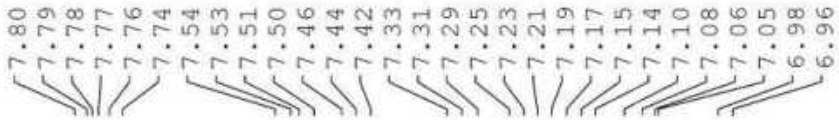
5c

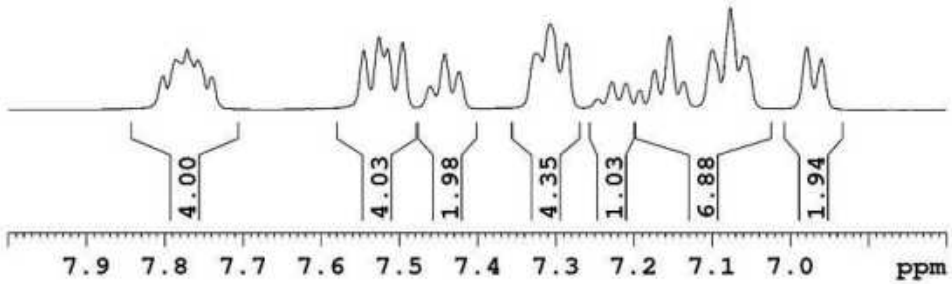

25.66
25.57
18.16
18.08
1.00
1.01
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm

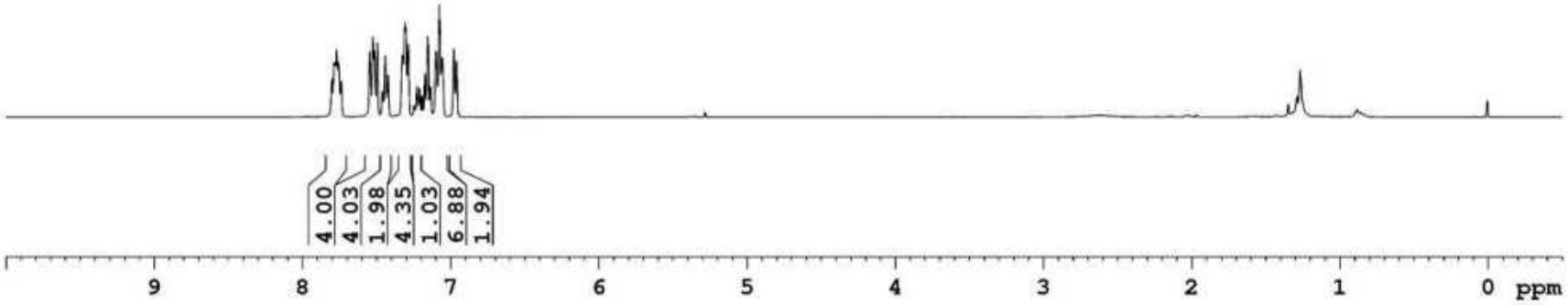

7.80
7.79
7.78
7.77
7.76
7.74
7.54
7.53
7.51
7.50
7.46
7.44
7.42
7.33
7.31
7.29
7.25
7.23
7.21
7.19
7.17
7.15
7.14
7.10
7.08
7.06
7.05
6.98
6.96

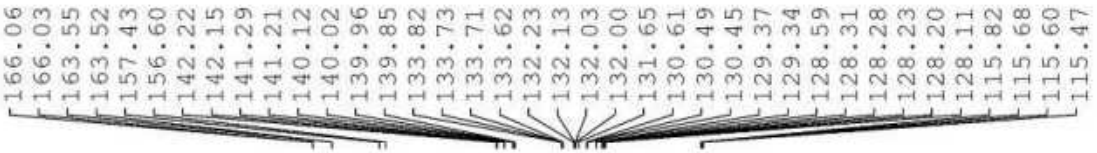

F
F
O
P
P(O)Ph2
Ph

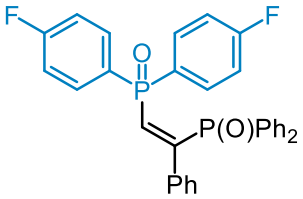
5d


7.80
7.79
7.78
7.77
7.76
7.74
7.54
7.53
7.51
7.50
7.46
7.44
7.42
7.33
7.31
7.29
7.25
7.23
7.21
7.19
7.17
7.15
7.14
7.10
7.08
7.06
7.05
6.98
6.96

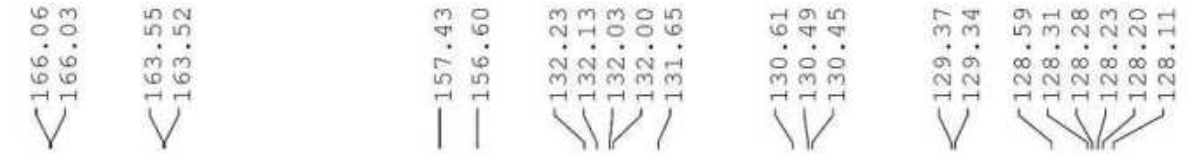

4.00
4.03
1.98
4.35
1.03
6.88
1.94
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
7.1
7.0
ppm

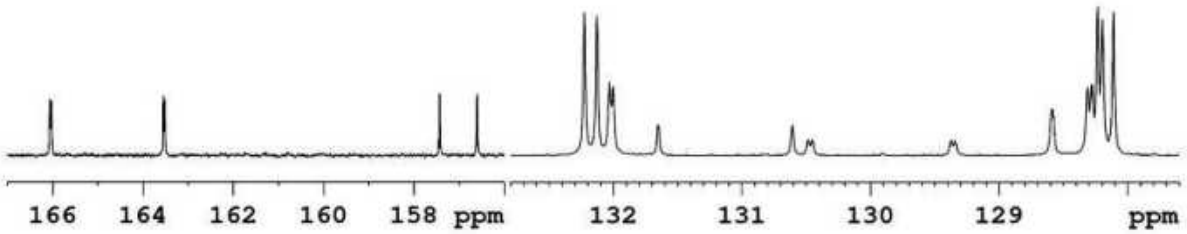

4.00
4.03
1.98
4.35
1.03
6.88
1.94
9
8
7
6
5
4
3
2
1
0
ppm


166.06
166.03
163.55
163.52
157.43
156.60
142.22
142.15
141.29
141.21
140.12
140.02
139.96
139.85
133.82
133.73
133.71
133.62
132.23
132.13
132.03
132.00
131.65
130.61
130.49
130.45
129.37
129.34
128.59
128.31
128.28
128.23
128.20
128.11
115.82
115.68
115.60
115.47


F
F
O
P
P(O)Ph2
Ph

5d


166.06
166.03
163.55
163.52
157.43
156.60
132.23
132.13
132.03
132.00
131.65
130.61
130.49
130.45
129.37
129.34
128.59
128.31
128.28
128.23
128.20
128.11


166
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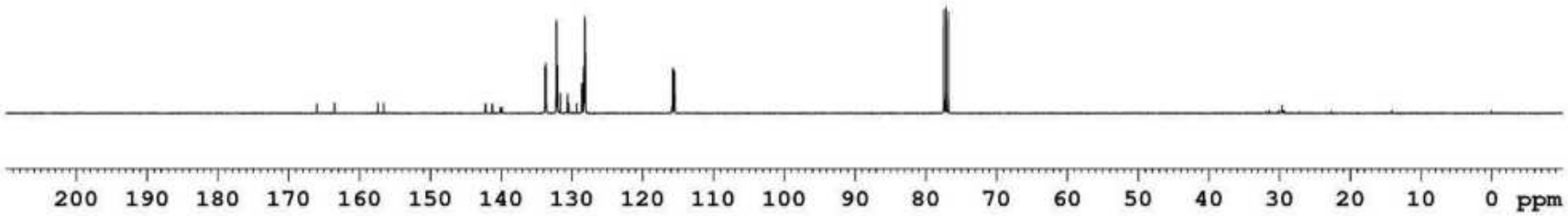
162
160
158
ppm
132
131
130
129
ppm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180
170
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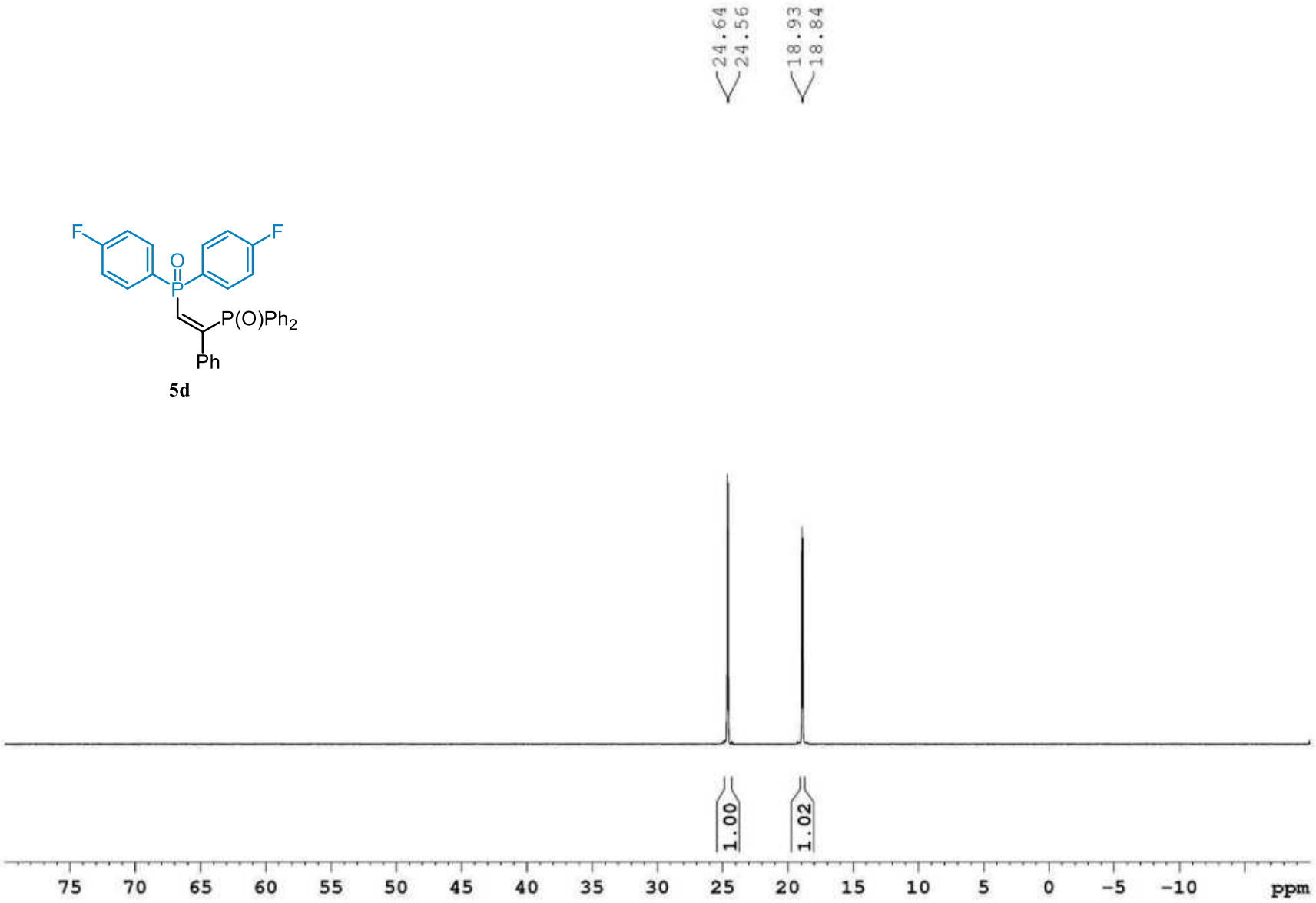
50
40
30
20
10
0
ppm

F
F
O
P
P(O)Ph2
Ph

5d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1.02
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45
40
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25
20
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10
5
0
-5
-10
ppm


7.85
7.83
7.82
7.80
7.49
7.47
7.46
7.44
7.42
7.31
7.29
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7.17
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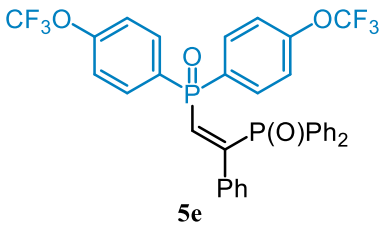
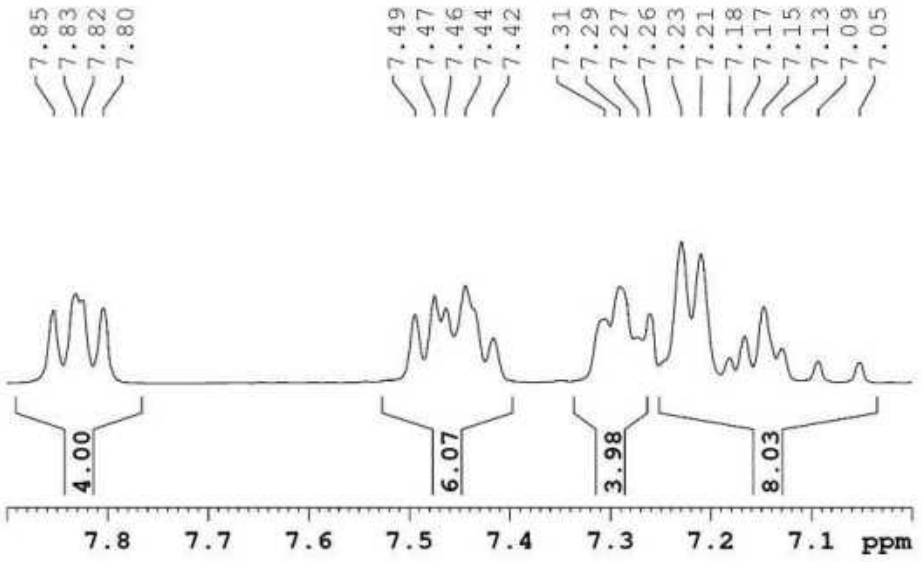
7.13
7.09
7.05
6.95
6.93


CF3O
OCF3
O
P
P(O)Ph2
Ph

5e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7.83
7.82
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7.26
7.23
7.21
7.18
7.17
7.15
7.13
7.09
7.05
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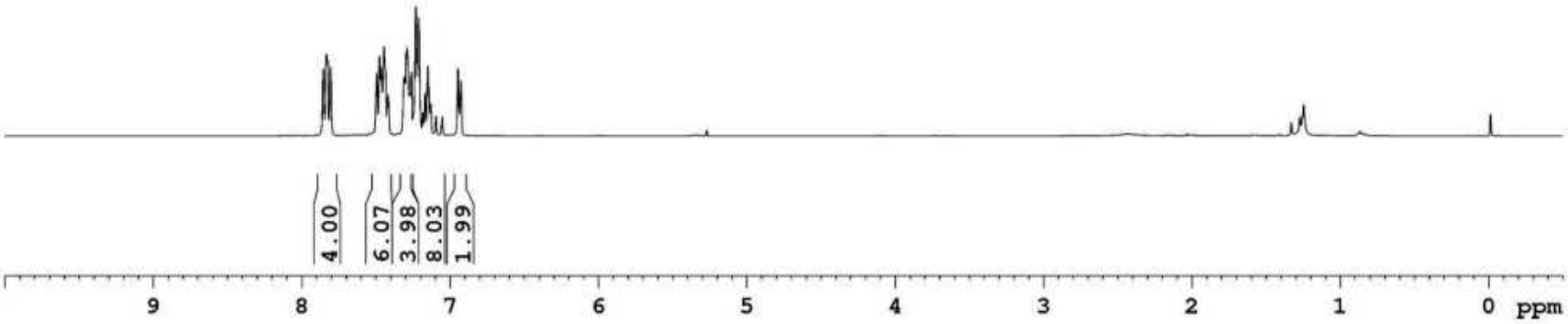
8.03
7.8
7.7
7.6
7.5
7.4
7.3
7.2
7.1
ppm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3.98
8.03
1.99
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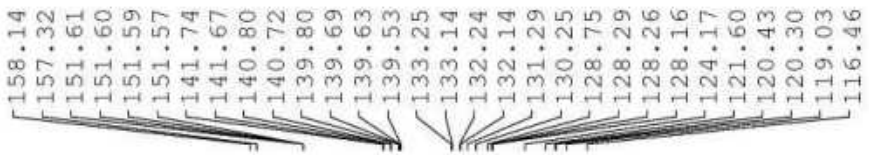
8
7
6
5
4
3
2
1
0
ppm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157.32
151.61
151.60
151.59
151.57
141.74
141.67
140.80
140.72
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139.69
139.63
139.53
133.25
133.14
132.24
132.14
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128.26
128.16
124.17
121.60
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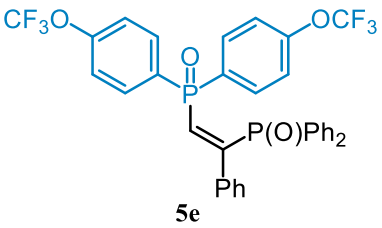
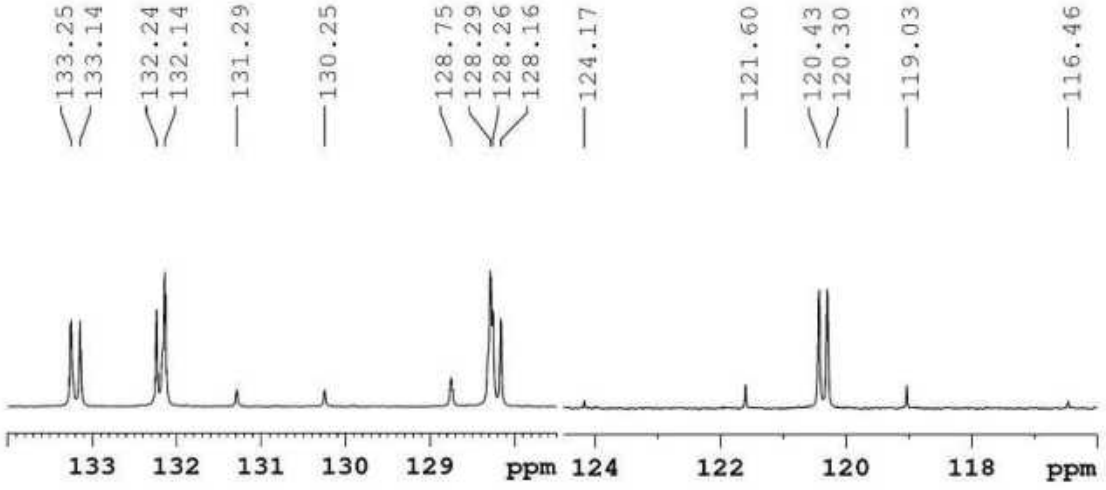
119.03
116.46


CF3O
OCF3
O
P
P(O)Ph2
Ph

5e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128.75
128.29
128.26
128.16
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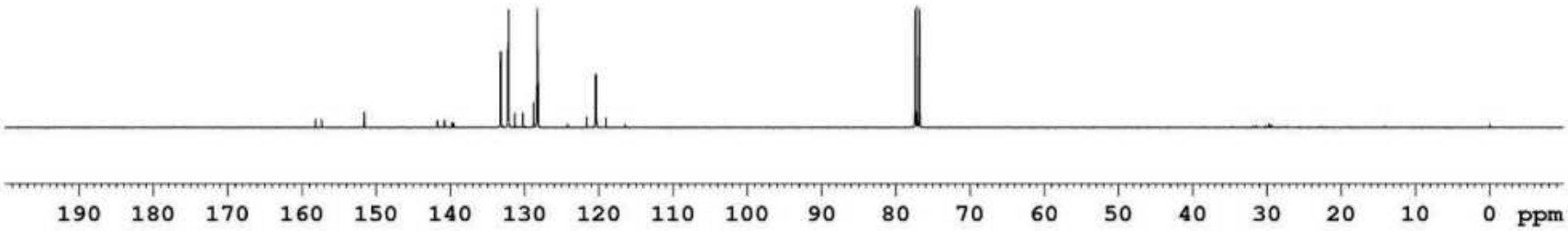
120.30
119.03
116.46
133
132
131
130
129
ppm
124
122
120
118
ppm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180
170
160
150
140
130
120
110
100
90
80
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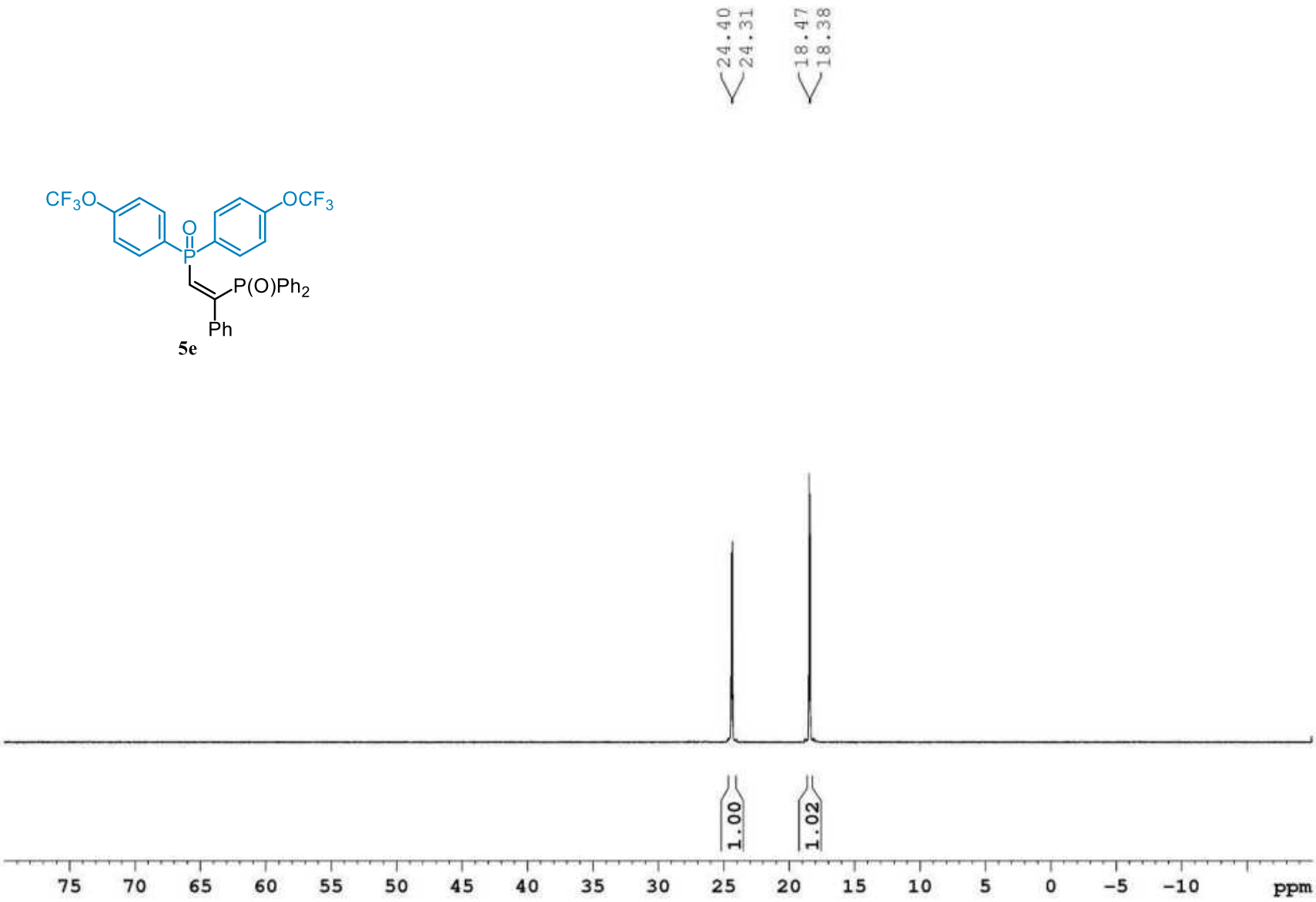
60
50
40
30
20
10
0
ppm

CF3O
OCF3
O
P
P(O)Ph2
Ph

5e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24.31
18.47
18.38
1.00
1.02
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70
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60
55
50
45
40
35
30
25
20
15
10
5
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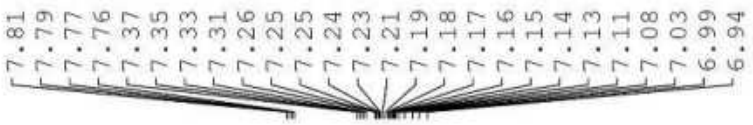
-5
-10
ppm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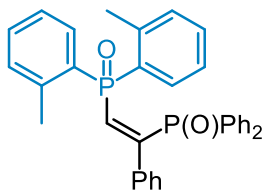
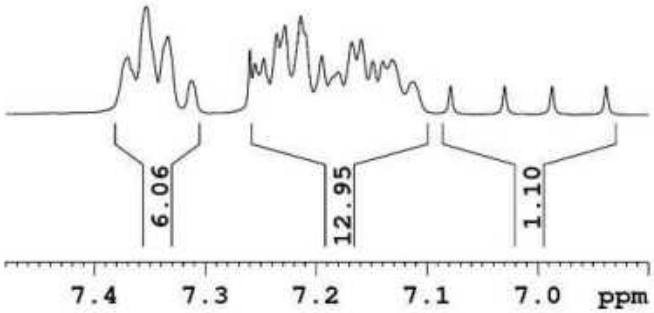
7.79
7.77
7.76
7.37
7.35
7.33
7.31
7.26
7.25
7.25
7.24
7.23
7.21
7.19
7.18
7.17
7.16
7.15
7.14
7.13
7.11
7.08
7.03
6.99
6.94

2.42


O
P
P(O)Ph2
Ph

5f


7.37
7.35
7.33
7.31
7.26
7.25
7.25
7.24
7.23
7.21
7.19
7.18
7.17
7.16
7.15
7.14
7.13
7.11
7.08
7.03
6.99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12.95
1.10
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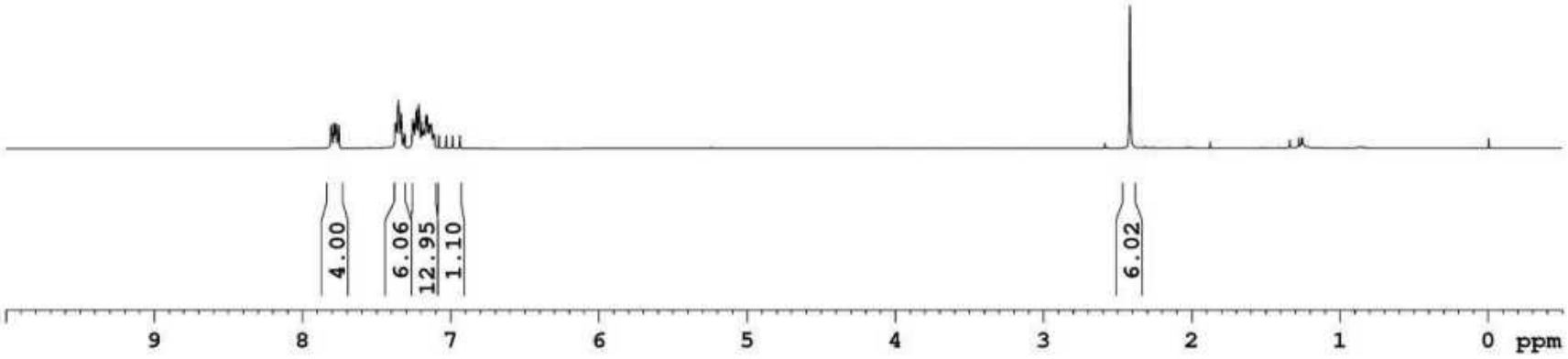
7.3
7.2
7.1
7.0
ppm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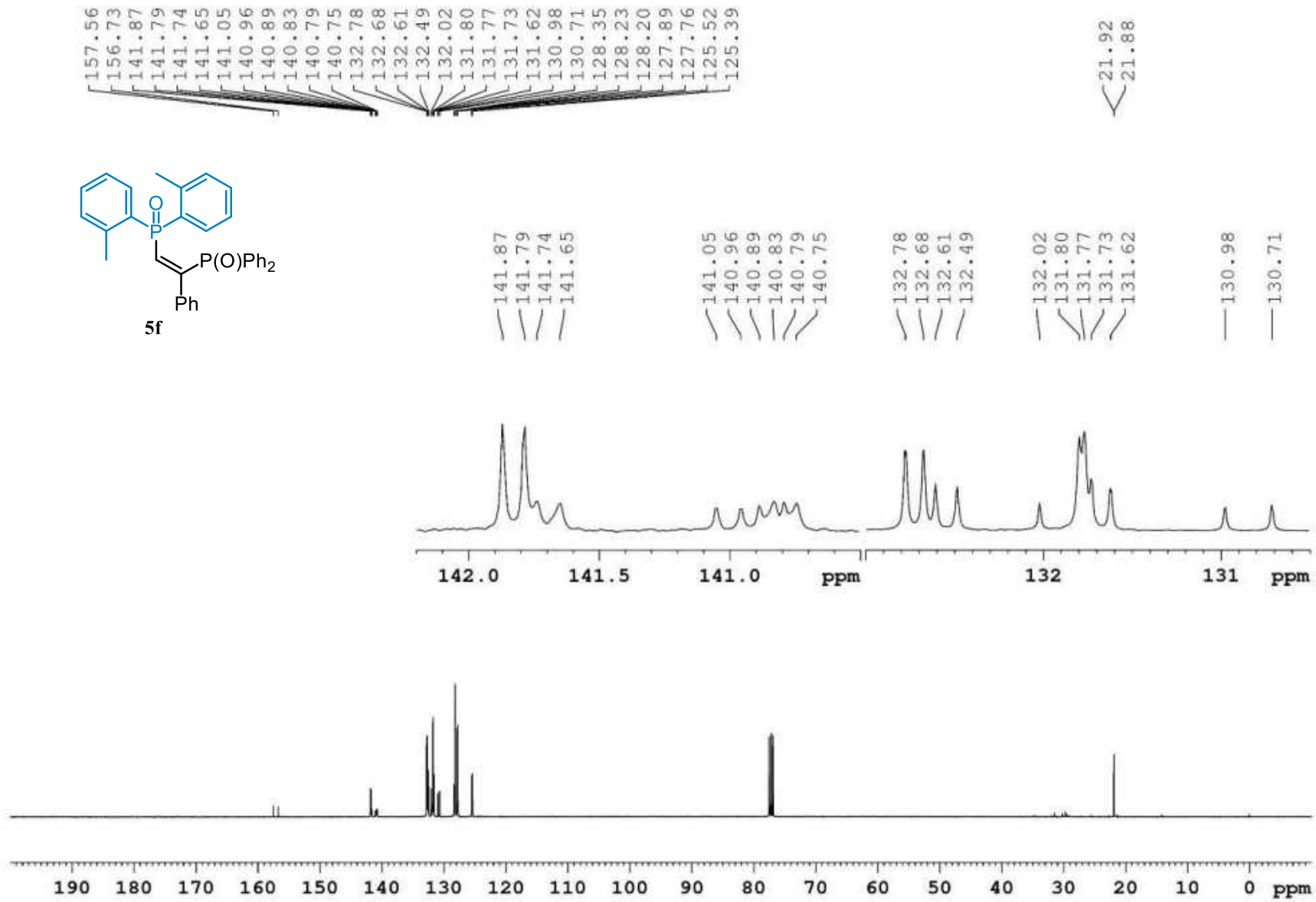
12.95
1.10
6.02
9
8
7
6
5
4
3
2
1
0
ppm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141.74
141.65
141.05
140.96
140.89
140.83
140.79
140.75
132.78
132.68
132.61
132.49
132.02
131.80
131.77
131.73
131.62
130.98
130.71
128.35
128.23
128.20
127.89
127.76
125.52
125.39
21.92
21.88
O
P
P(O)Ph2
Ph
5f
141.87
141.79
141.74
141.65
141.05
140.96
140.89
140.83
140.79
140.75
132.78
132.68
132.61
132.49
132.02
131.80
131.77
131.73
131.62
130.98
130.71
142.0
141.5
141.0
ppm
132
131
ppm
190
180
170
160
150
140
130
120
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70
60
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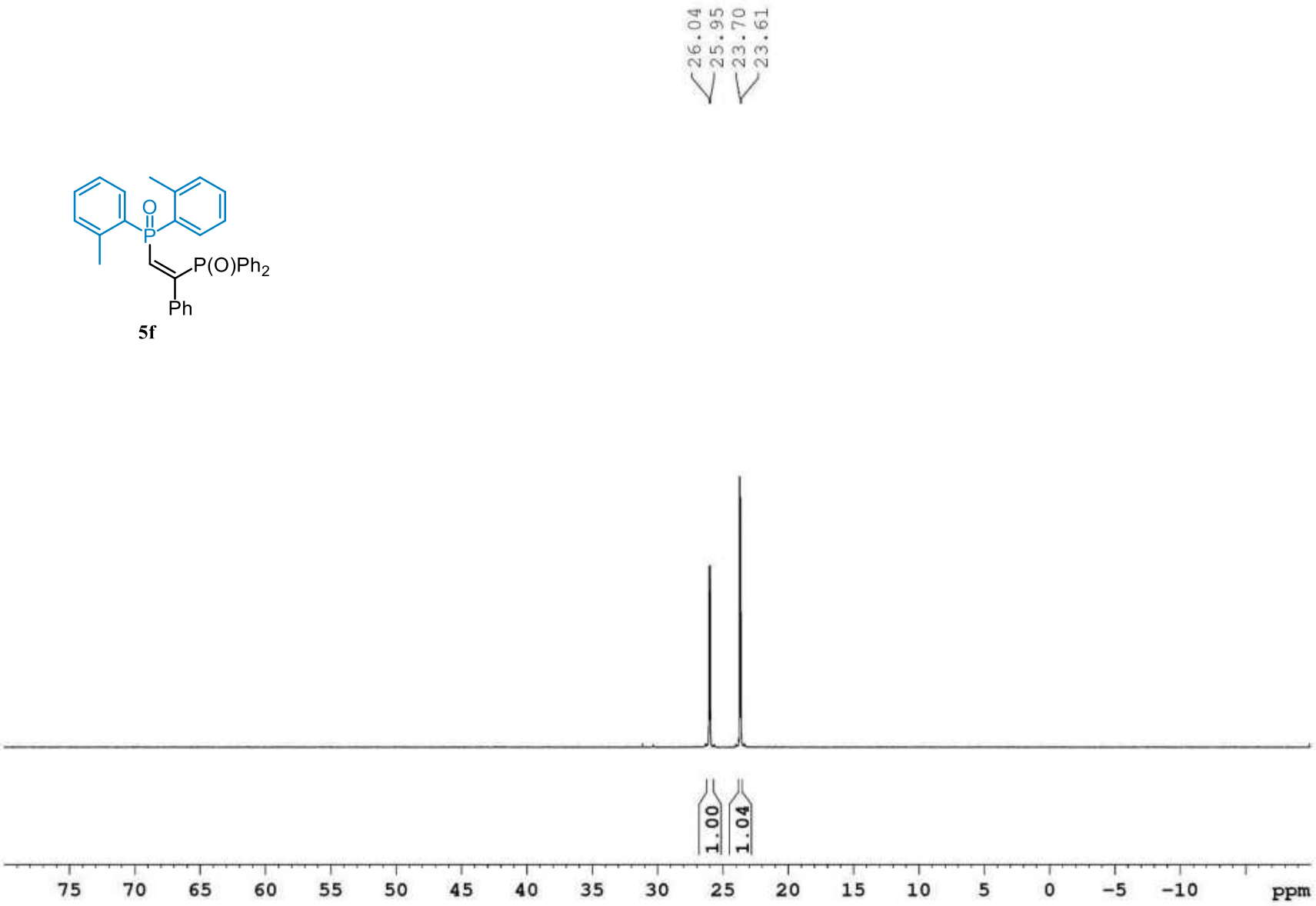
30
20
10
0
ppm

O
P
P(O)Ph2
Ph

5f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25.95
23.70
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1.00
1.04
75
70
65
60
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50
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40
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15
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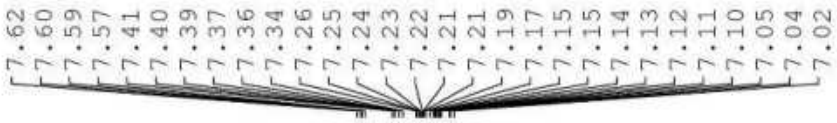
-5
-10
ppm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7.37
7.36
7.34
7.26
7.25
7.24
7.23
7.22
7.21
7.21
7.19
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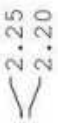
7.15
7.15
7.14
7.13
7.12
7.11
7.10
7.05
7.04
7.02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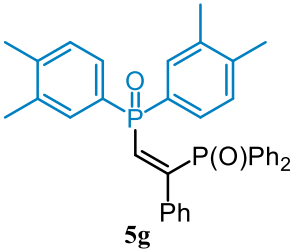
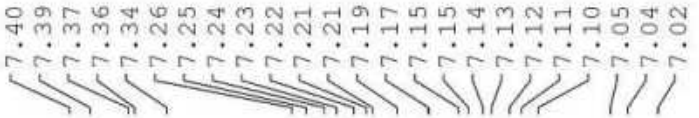

O
P
P(O)Ph2
Ph

5g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7.37
7.36
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7.26
7.25
7.24
7.23
7.22
7.21
7.21
7.19
7.17
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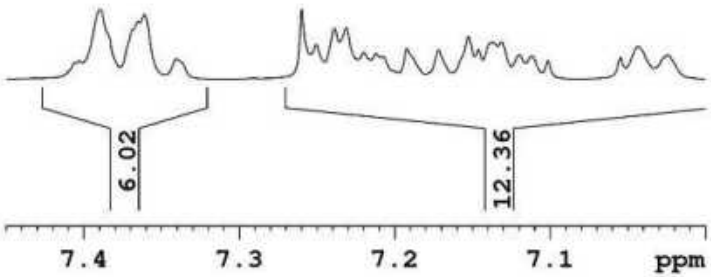
7.15
7.14
7.13
7.12
7.11
7.10
7.05
7.04
7.02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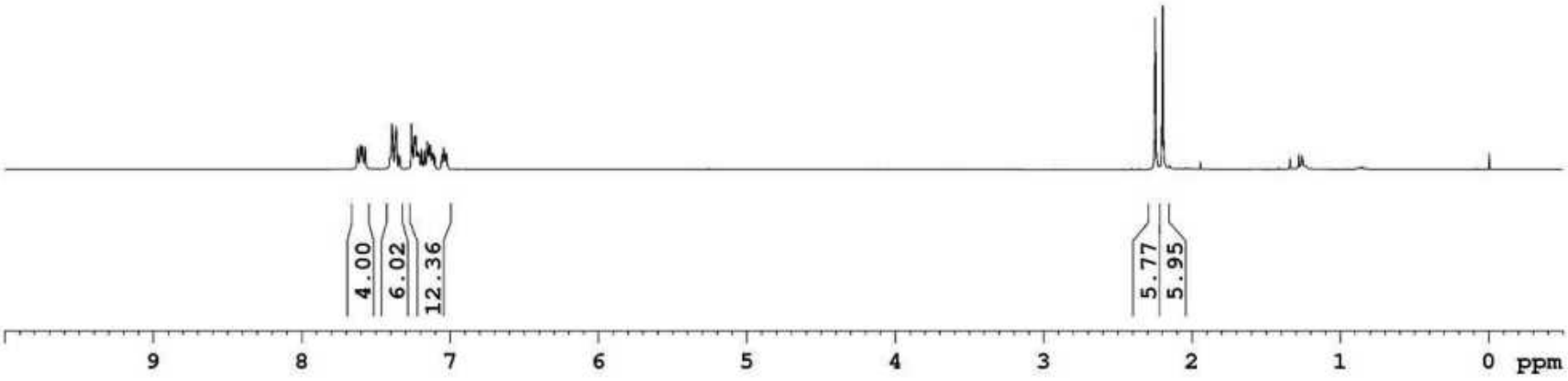
ppm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6
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4
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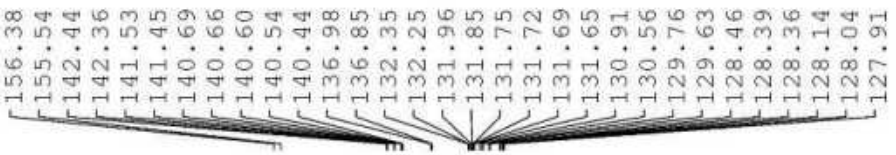
1
0
ppm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141.45
140.69
140.66
140.60
140.54
140.44
136.98
136.85
132.35
132.25
131.96
131.85
131.75
131.72
131.69
131.65
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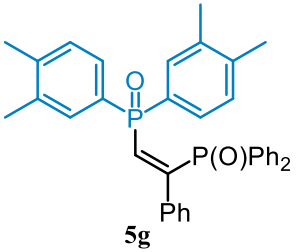
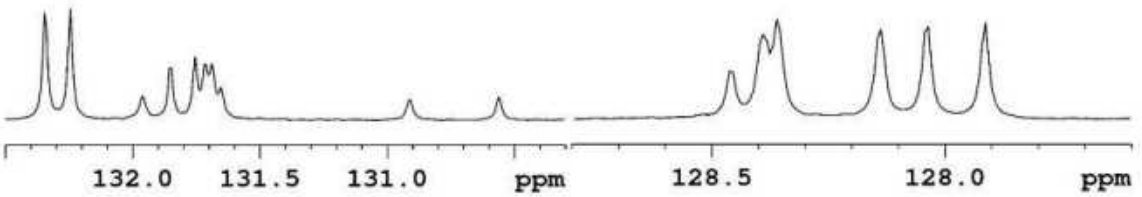
129.76
129.63
128.46
128.39
128.36
128.14
128.04
127.91


19.94
19.81


O
P
P(O)Ph2
Ph

5g


132.35
132.25
131.96
131.85
131.75
131.72
131.69
131.65
130.91
130.56
128.46
128.39
128.36
128.14
128.04
127.91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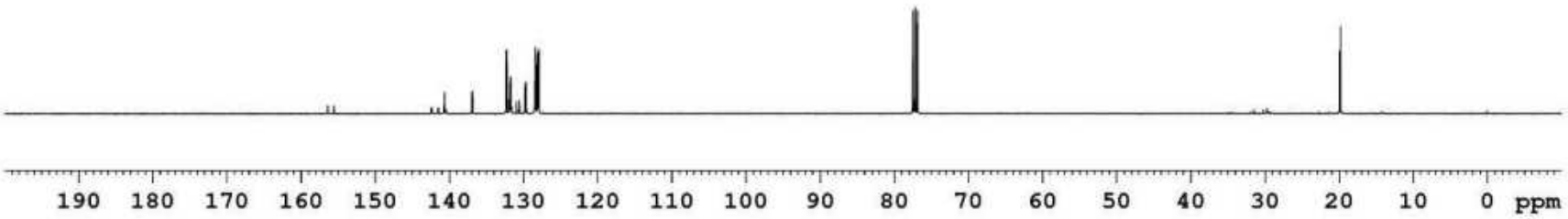
131.0
ppm
128.5
128.0
ppm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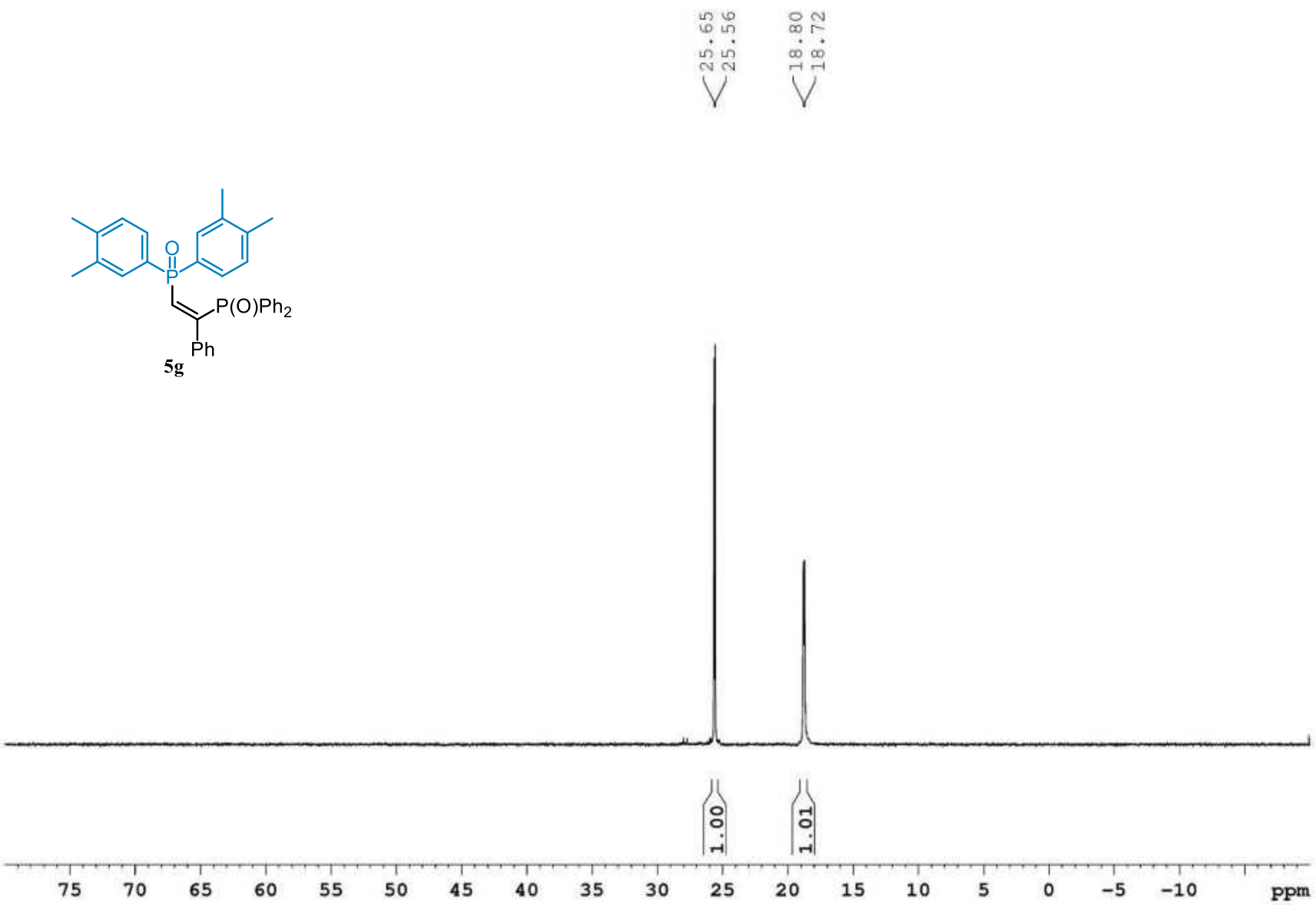
20
10
0
ppm


25.65
25.56
18.80
18.72
O
P
P(O)Ph2
Ph
5g
1.00
1.01
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55
50
45
40
35
30
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20
15
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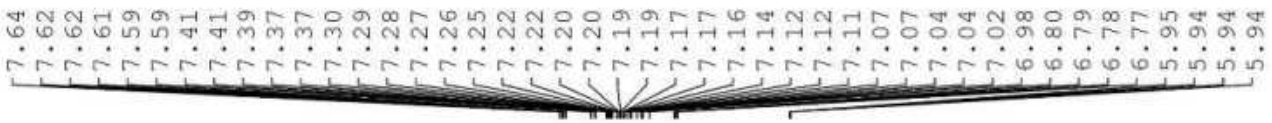
0
-5
-10
ppm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7.59
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7.37
7.37
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7.29
7.28
7.27
7.26
7.25
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7.22
7.20
7.20
7.19
7.19
7.17
7.17
7.16
7.14
7.12
7.12
7.11
7.07
7.07
7.04
7.04
7.02
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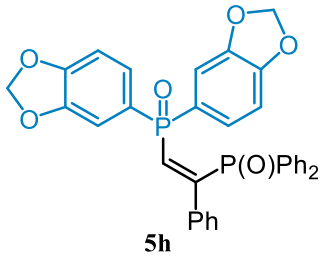
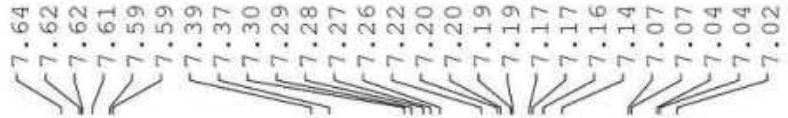
6.79
6.78
6.77
5.95
5.94
5.94
5.94


P(O)Ph2
Ph

5h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7.62
7.62
7.61
7.59
7.59
7.39
7.37
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7.28
7.27
7.26
7.22
7.20
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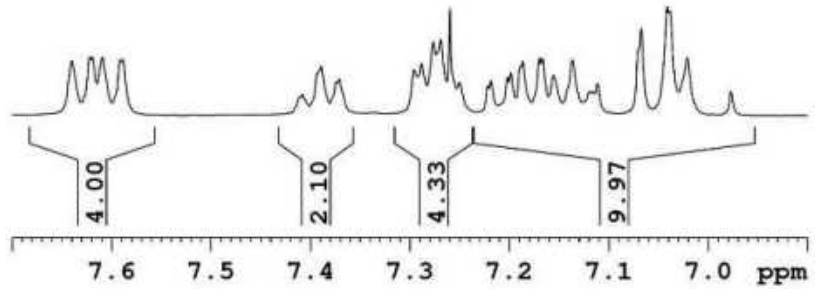
7.16
7.14
7.07
7.07
7.04
7.04
7.02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4.33
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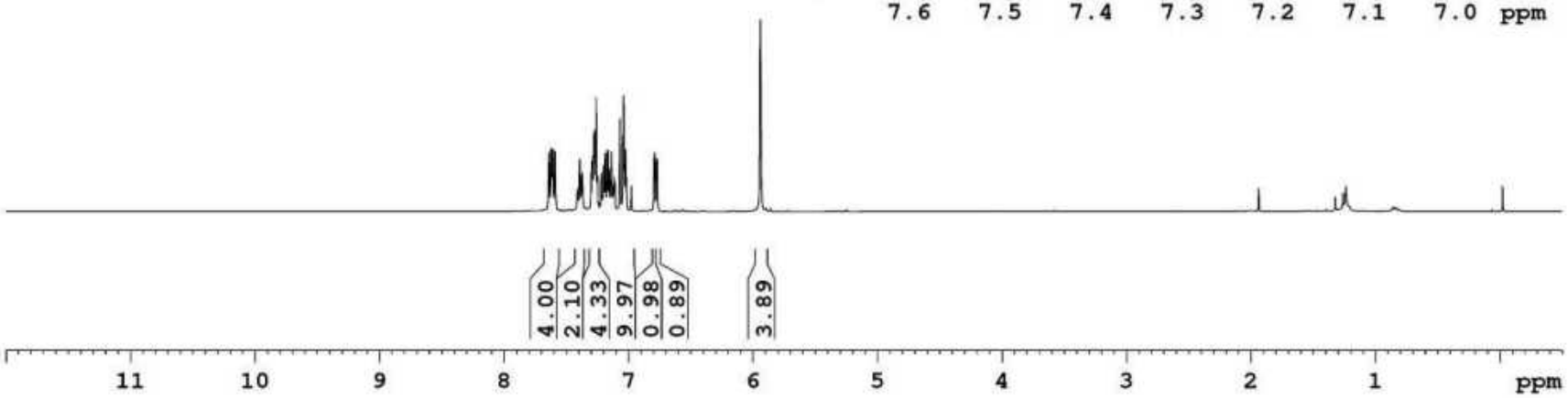
7.6
7.5
7.4
7.3
7.2
7.1
7.0
ppm


4.00
2.10
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0.89
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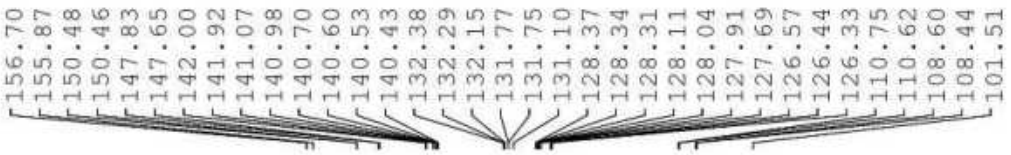
11
10
9
8
7
6
5
4
3
2
1
ppm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147.65
142.00
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141.07
140.98
140.70
140.60
140.53
140.43
132.38
132.29
132.15
131.77
131.75
131.10
128.37
128.34
128.31
128.11
128.04
127.91
127.69
126.57
126.44
126.33
110.75
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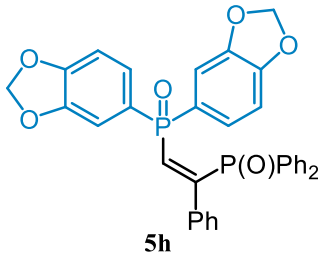
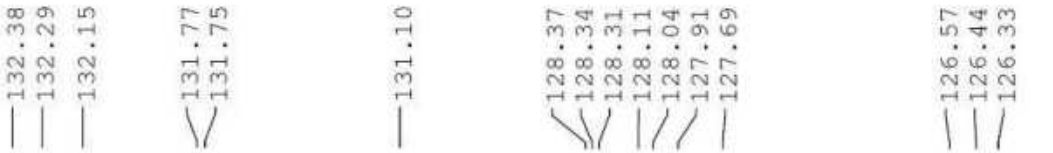
108.60
108.44
101.51


O
O
O
O
P
O
P(O)Ph2
Ph

5h


132.38
132.29
132.15
131.77
131.75
131.10
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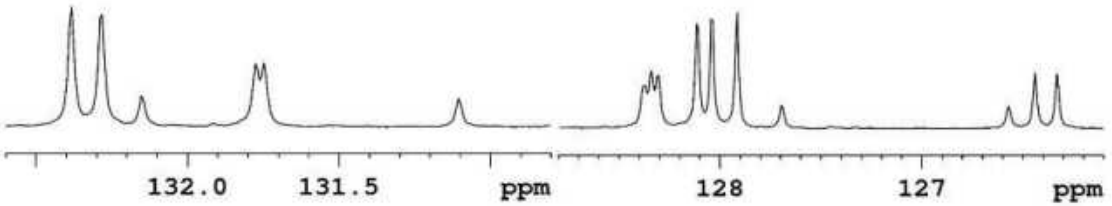
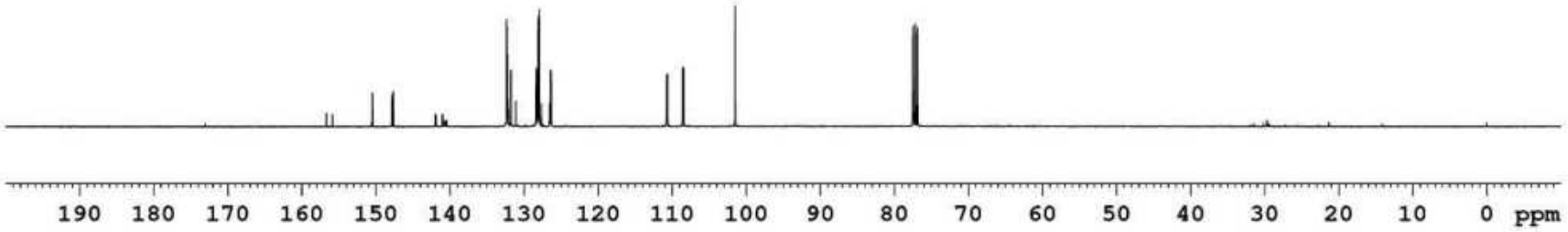
128.34
128.31
128.11
128.04
127.91
127.69
126.57
126.44
126.33


132.0
131.5
ppm
128
127
ppm


190
180
170
160
150
140
130
120
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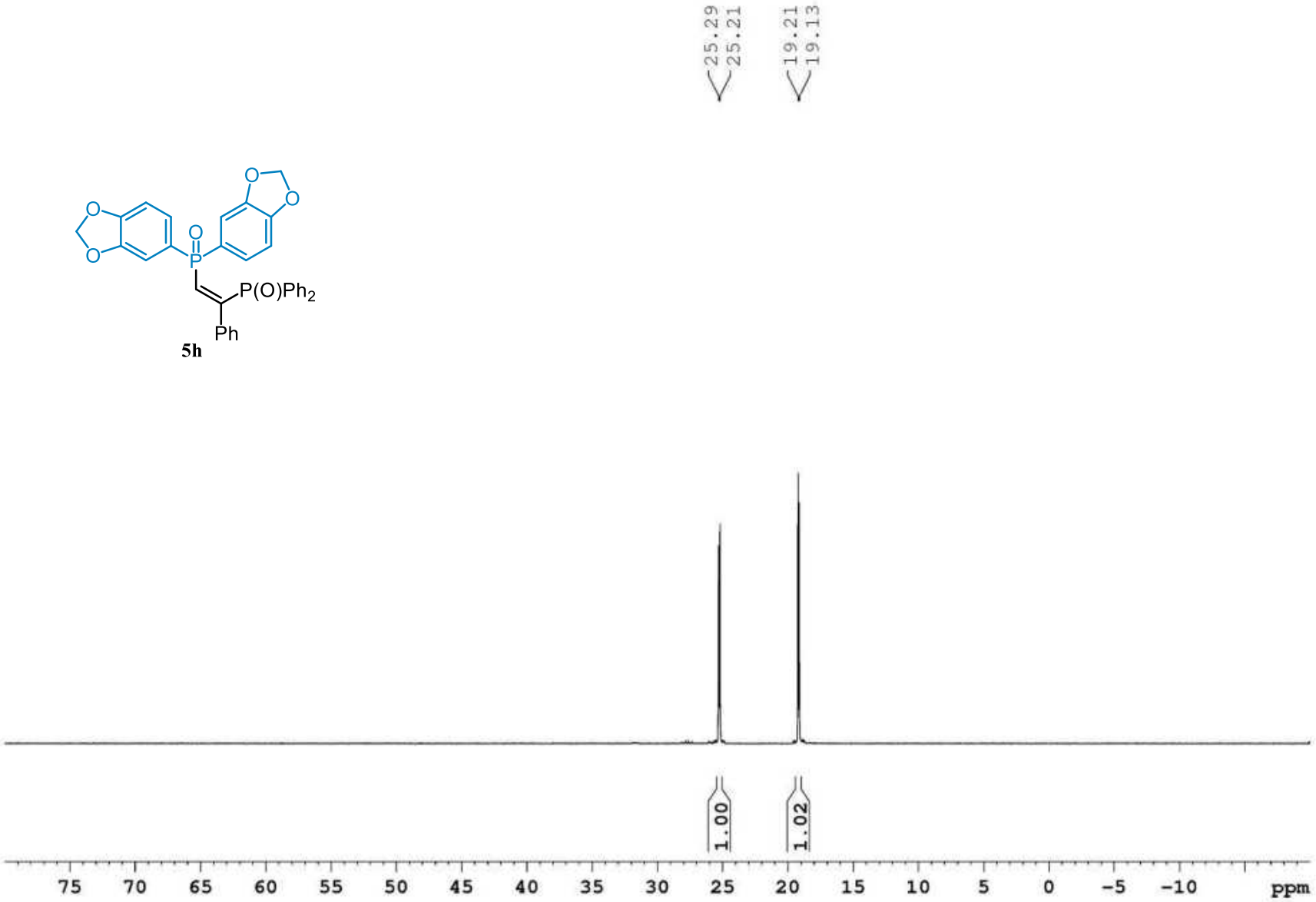
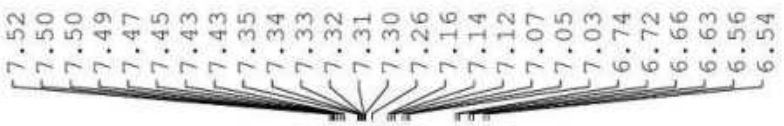
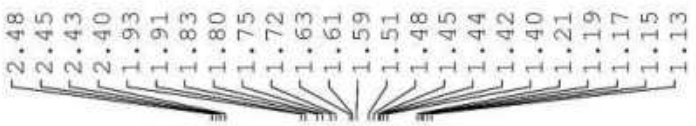
90
80
70
60
50
40
30
20
10
0
ppm

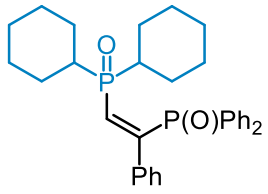
P(O)Ph2
Ph

5h

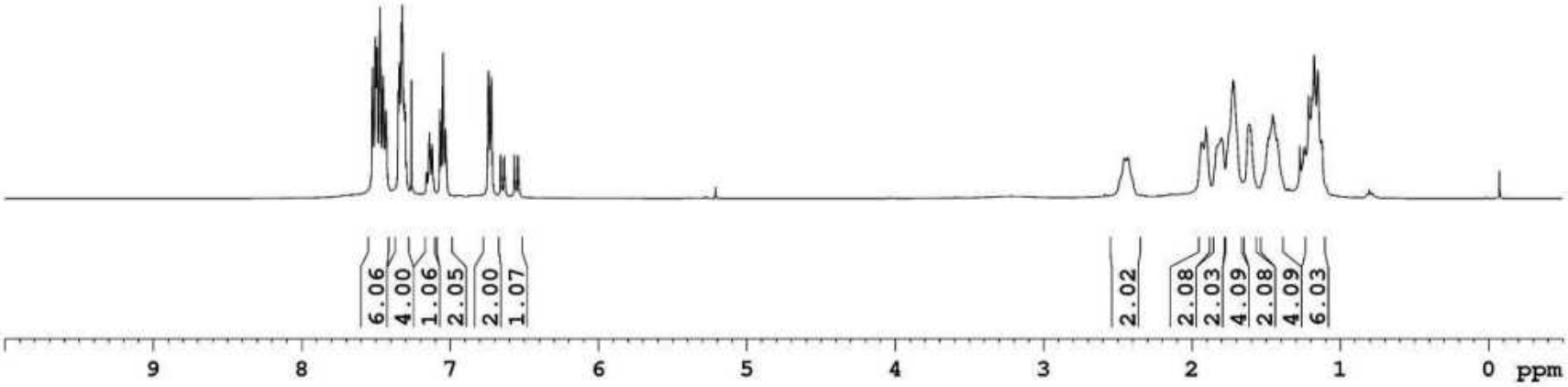

25.29
25.21
19.21
19.13
1.00
1.02
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm

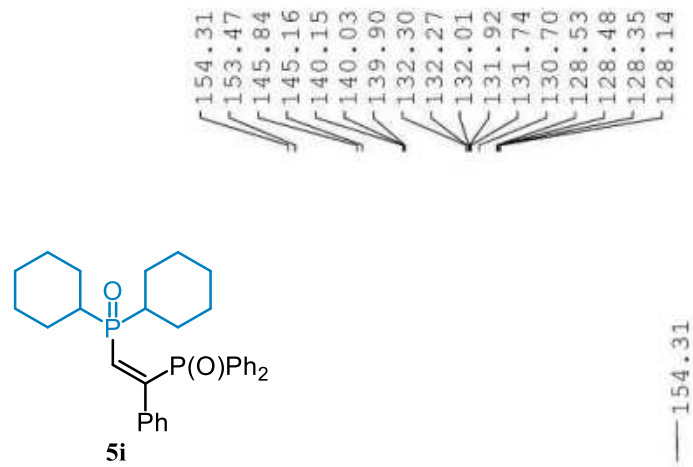

7.52
7.50
7.50
7.49
7.47
7.45
7.43
7.43
7.35
7.34
7.33
7.32
7.31
7.30
7.26
7.16
7.14
7.12
7.07
7.05
7.03
6.74
6.72
6.66
6.63
6.56
6.54


2.48
2.45
2.43
2.40
1.93
1.91
1.83
1.80
1.75
1.72
1.63
1.61
1.59
1.51
1.48
1.45
1.44
1.42
1.40
1.21
1.19
1.17
1.15
1.13


O
P
P(O)Ph2
Ph

5i


6.06
4.00
1.06
2.05
2.00
1.07
2.02
2.08
2.03
4.09
2.08
4.09
6.03
9
8
7
6
5
4
3
2
1
0
ppm


154.31
153.47
145.84
145.16
140.15
140.03
139.90
132.30
132.27
132.01
131.92
131.74
130.70
128.53
128.48
128.35
128.14
38.59
37.92
26.69
26.66
26.51
26.38
26.24
26.10
26.07
25.81
O
P
P(O)Ph2
Ph
5i
154.31
153.47
145.84
145.16
140.15
140.03
139.90
132.30
132.27
132.01
131.92
131.74
130.70
128.53
128.48
128.35
128.14
150
145
140
135
130
ppm
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180
170
160
150
140
130
120
110
100
90
80
70
60
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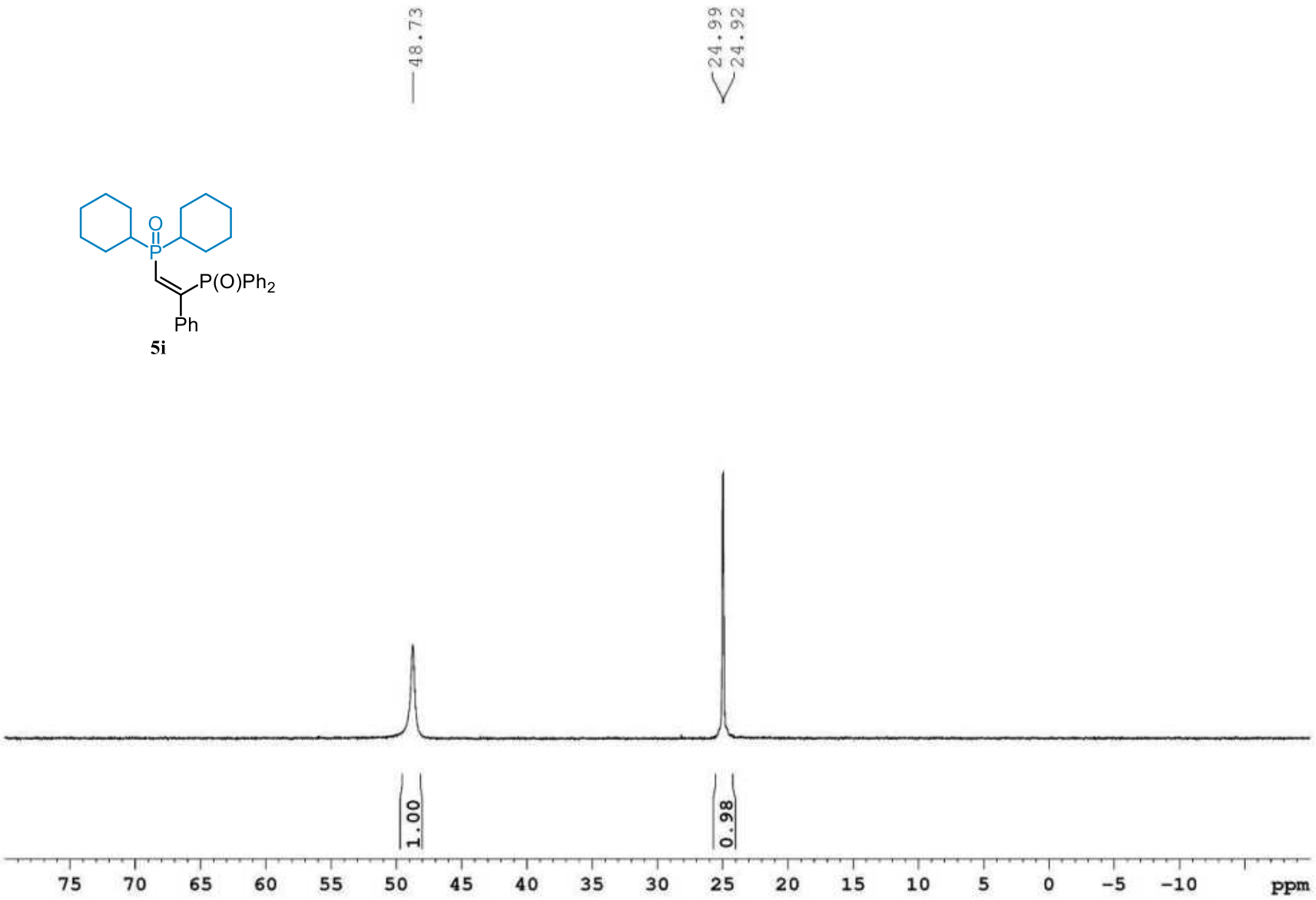
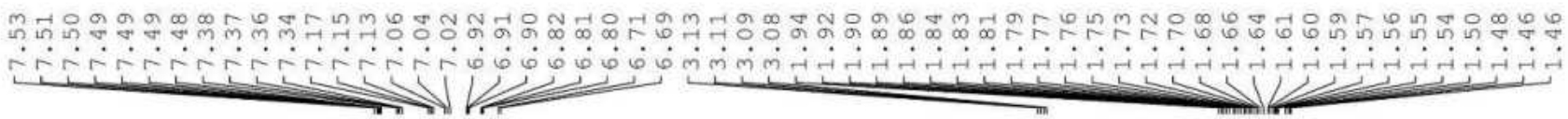
30
20
10
0
ppm


48.73
24.99
24.92
O
P
P(O)Ph2
Ph
1.00
0.98
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm

5i


7.53
7.51
7.50
7.49
7.49
7.49
7.48
7.38
7.37
7.36
7.34
7.17
7.15
7.13
7.06
7.04
7.02
6.92
6.91
6.90
6.82
6.81
6.80
6.71
6.69
3.13
3.11
3.09
3.08
1.94
1.92
1.90
1.89
1.86
1.84
1.83
1.81
1.79
1.77
1.76
1.75
1.73
1.72
1.70
1.68
1.66
1.64
1.61
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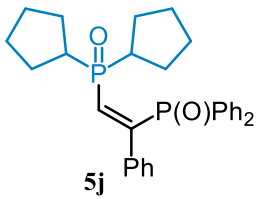
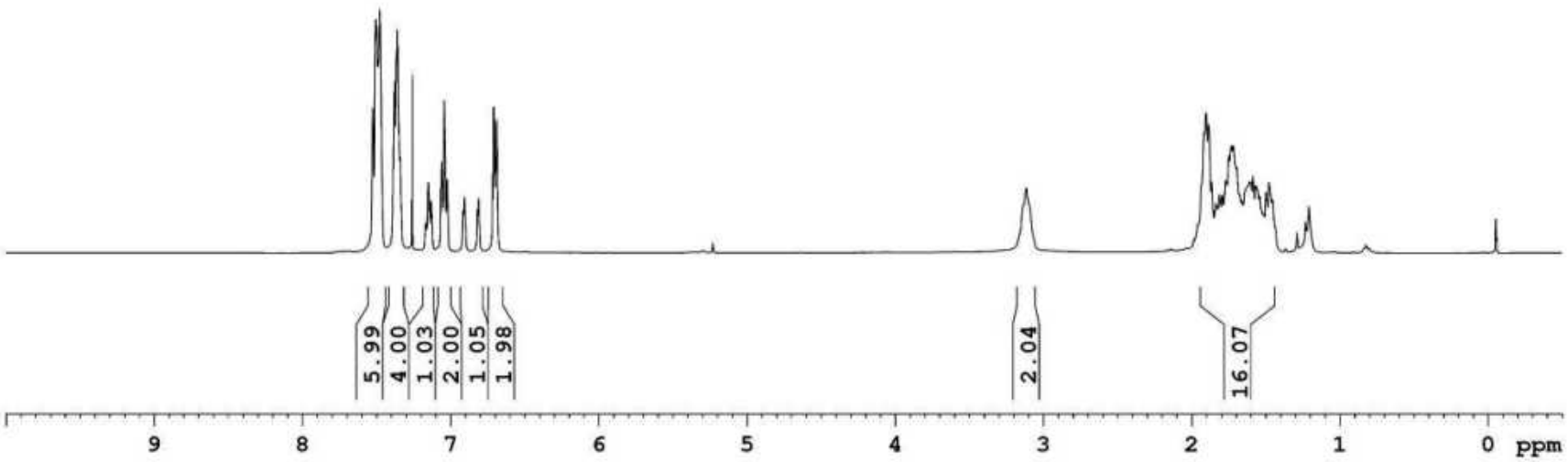
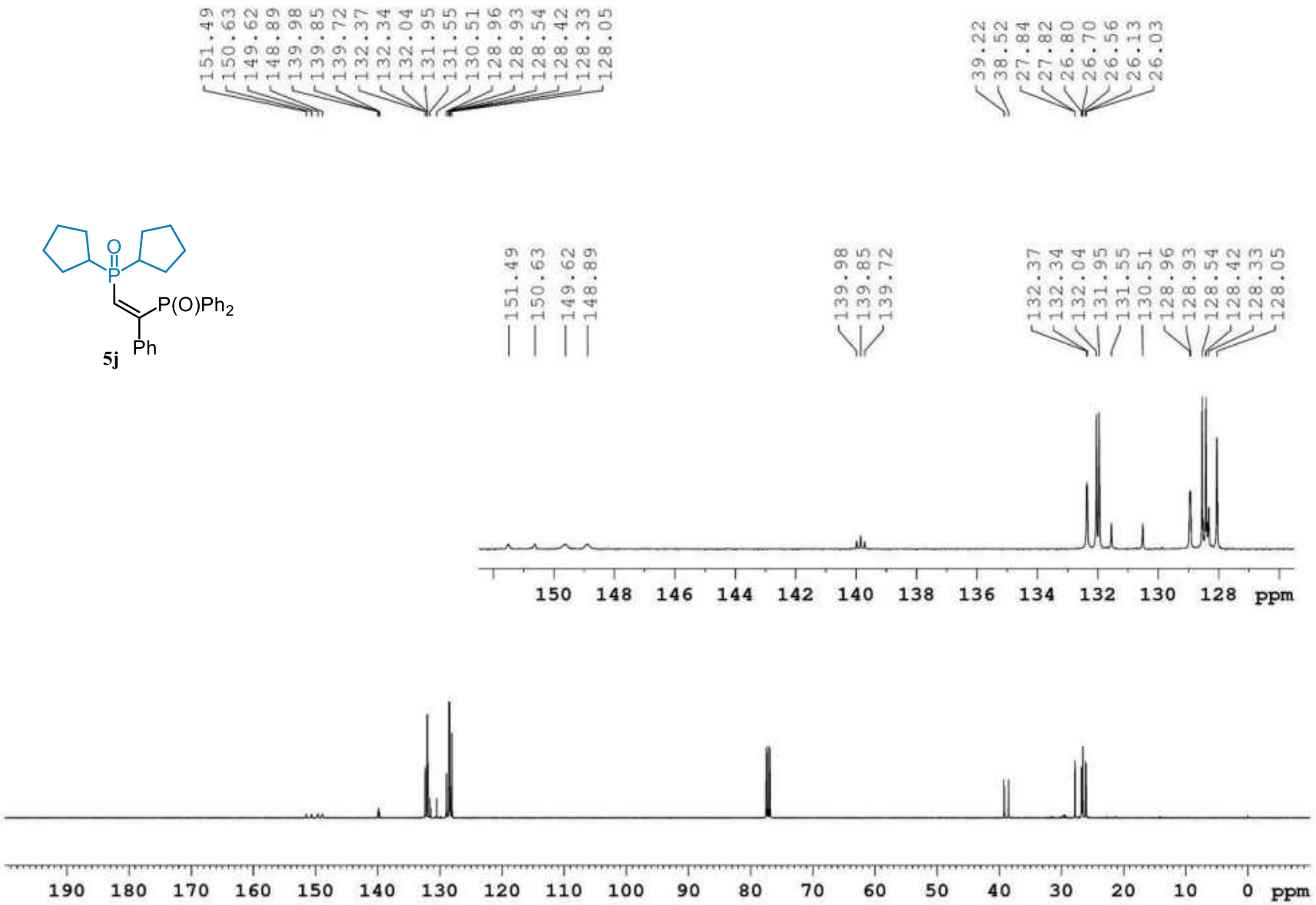
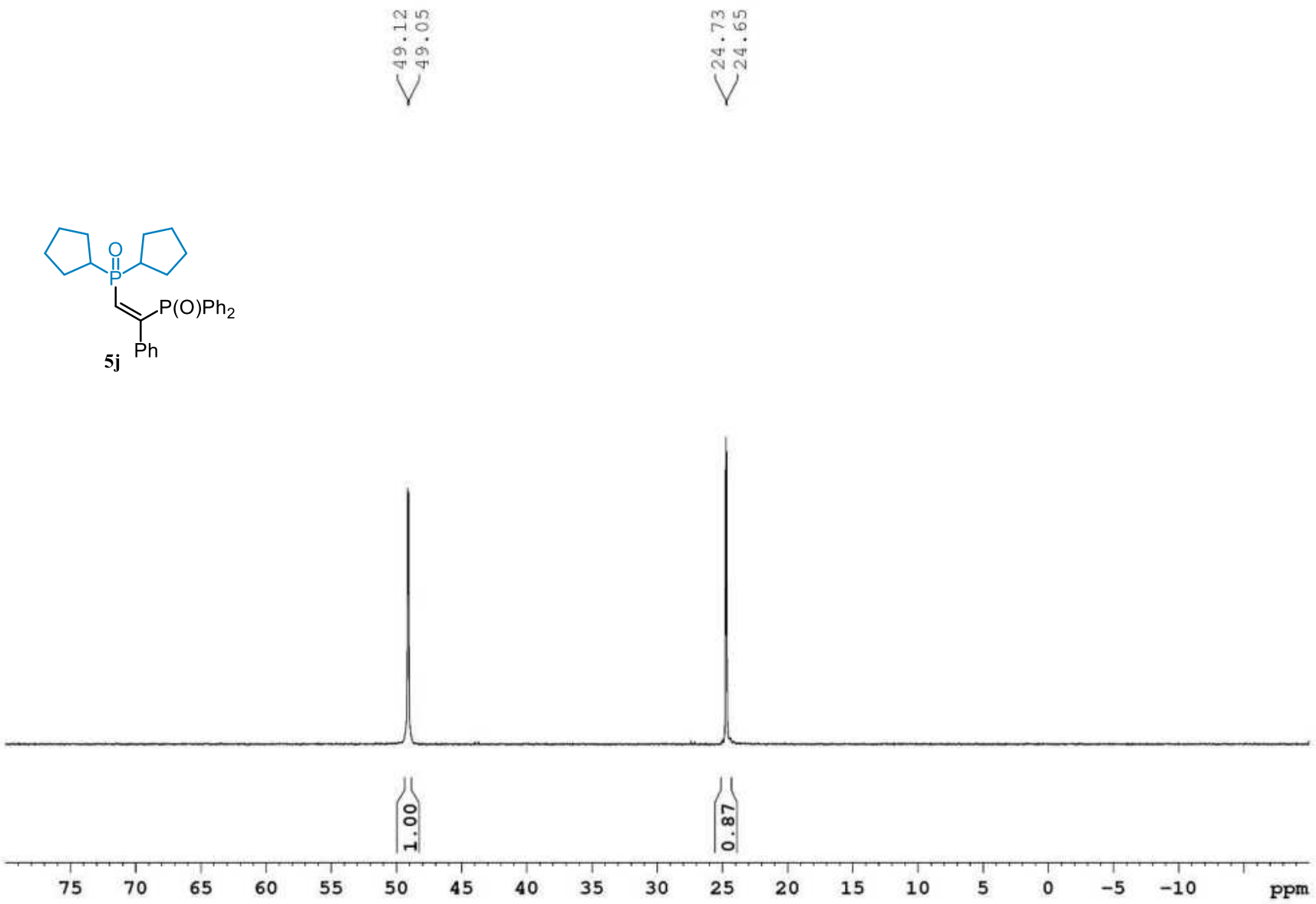
1.55
1.54
1.50
1.48
1.46
1.46

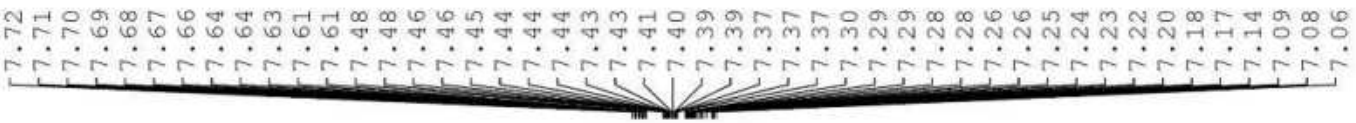

O
P
P(O)Ph2
Ph

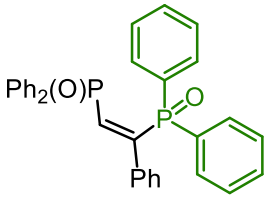
5j


5.99
4.00
1.03
2.00
1.05
1.98
2.04
16.07
9
8
7
6
5
4
3
2
1
0
ppm


151.49
150.63
149.62
148.89
139.98
139.85
139.72
132.37
132.34
132.04
131.95
131.55
130.51
128.96
128.93
128.54
128.42
128.33
128.05
39.22
38.52
27.84
27.82
26.80
26.70
26.56
26.13
26.03
O
P
P(O)Ph2
Ph
5j
ppm
ppm

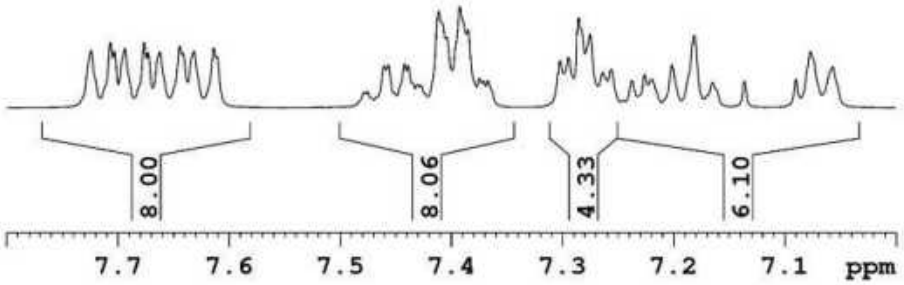

49.12
49.05
24.73
24.65
O
P
P(O)Ph2
Ph
5j
1.00
0.87
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm

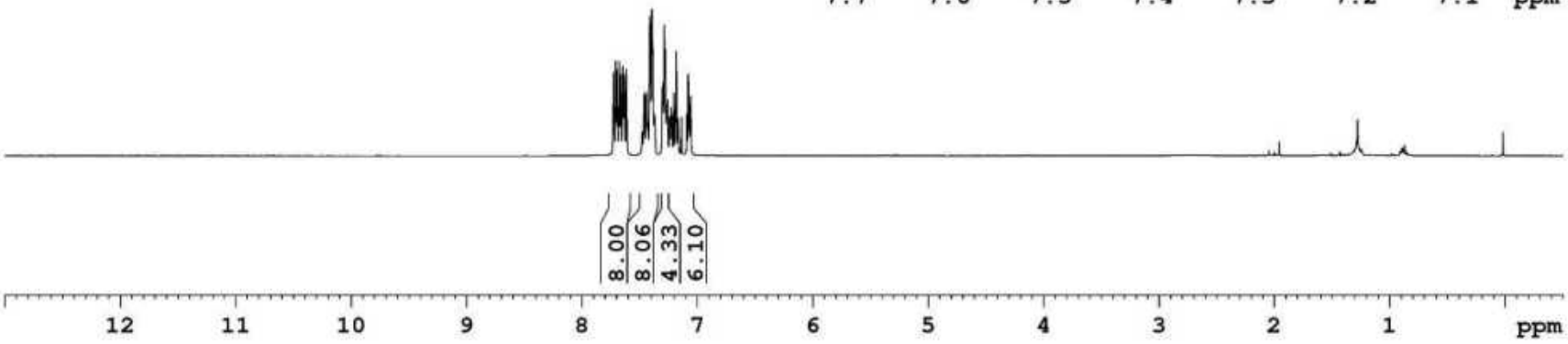

7.72 7.71 7.70 7.69 7.68 7.67 7.66 7.64 7.64 7.63 7.61 7.61 7.48 7.48 7.46 7.46 7.45 7.44 7.44 7.44 7.43 7.43 7.41 7.40 7.39 7.39 7.37 7.37 7.37 7.30 7.29 7.29 7.28 7.28 7.26 7.26 7.25 7.24 7.23 7.22 7.20 7.18 7.17 7.14 7.09 7.08 7.06

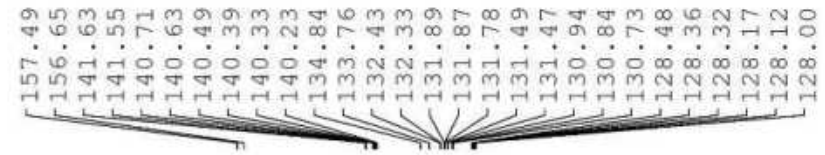

Ph2(O)P
P
O
Ph

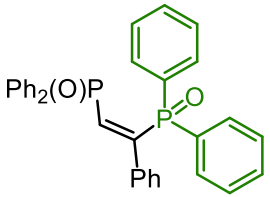
6a


7.72 7.71 7.70 7.69 7.68 7.67 7.66 7.64 7.64 7.63 7.61 7.61 7.46 7.46 7.44 7.44 7.41 7.40 7.39 7.39 7.30 7.29 7.29 7.28 7.28 7.26 7.20 7.18 7.08 7.06

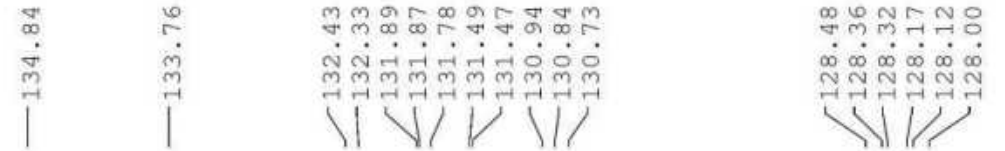

8.00
8.06
4.33
6.10
7.7 7.6 7.5 7.4 7.3 7.2 7.1 ppm

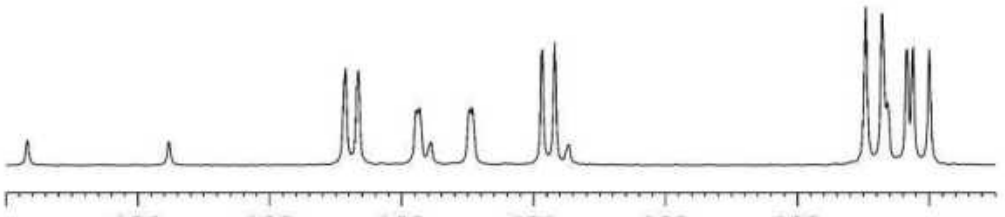

8.00
8.06
4.33
6.10
12 11 10 9 8 7 6 5 4 3 2 1 ppm

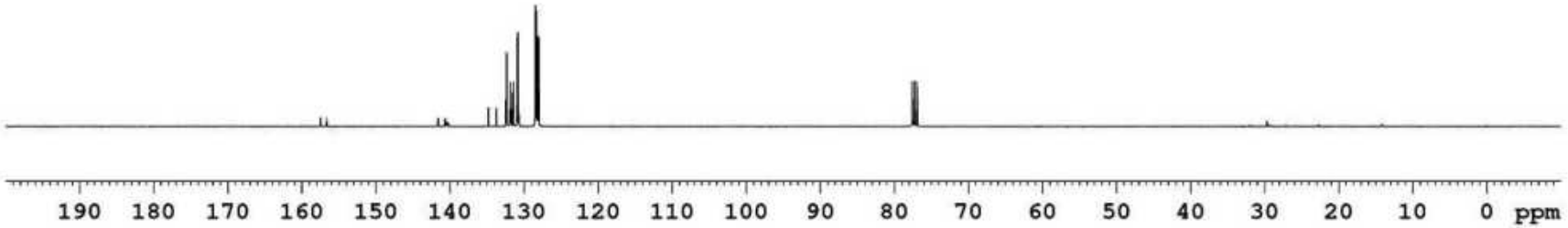

157.49
156.65
141.63
141.55
140.71
140.63
140.49
140.39
140.33
140.23
134.84
133.76
132.43
132.33
131.89
131.87
131.78
131.49
131.47
130.94
130.84
130.73
128.48
128.36
128.32
128.17
128.12
128.00


Ph2(O)P
P
O
Ph

6a

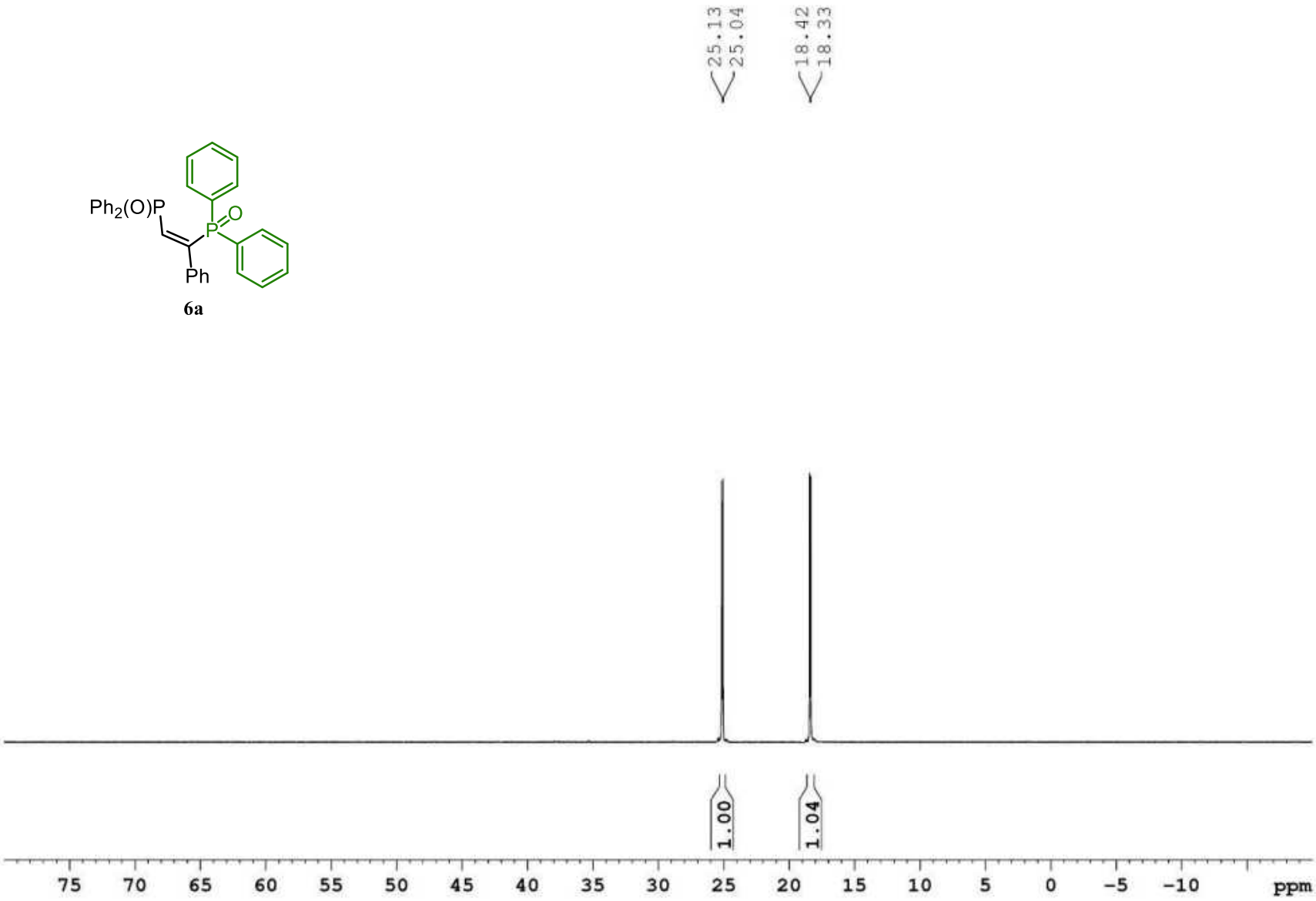

134.84
133.76
132.43
132.33
131.89
131.87
131.78
131.49
131.47
130.94
130.84
130.73
128.48
128.36
128.32
128.17
128.12
128.00

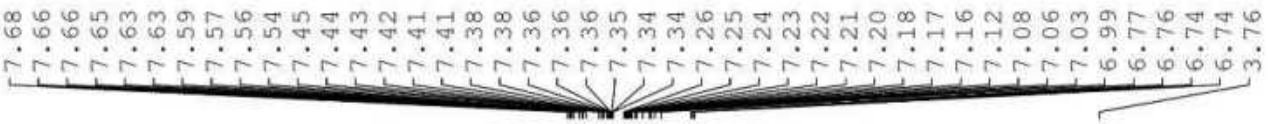

134
133
132
131
130
129
ppm

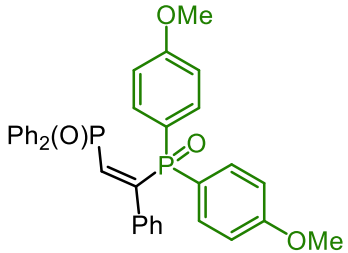

190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

Ph2(O)P
P
O
Ph

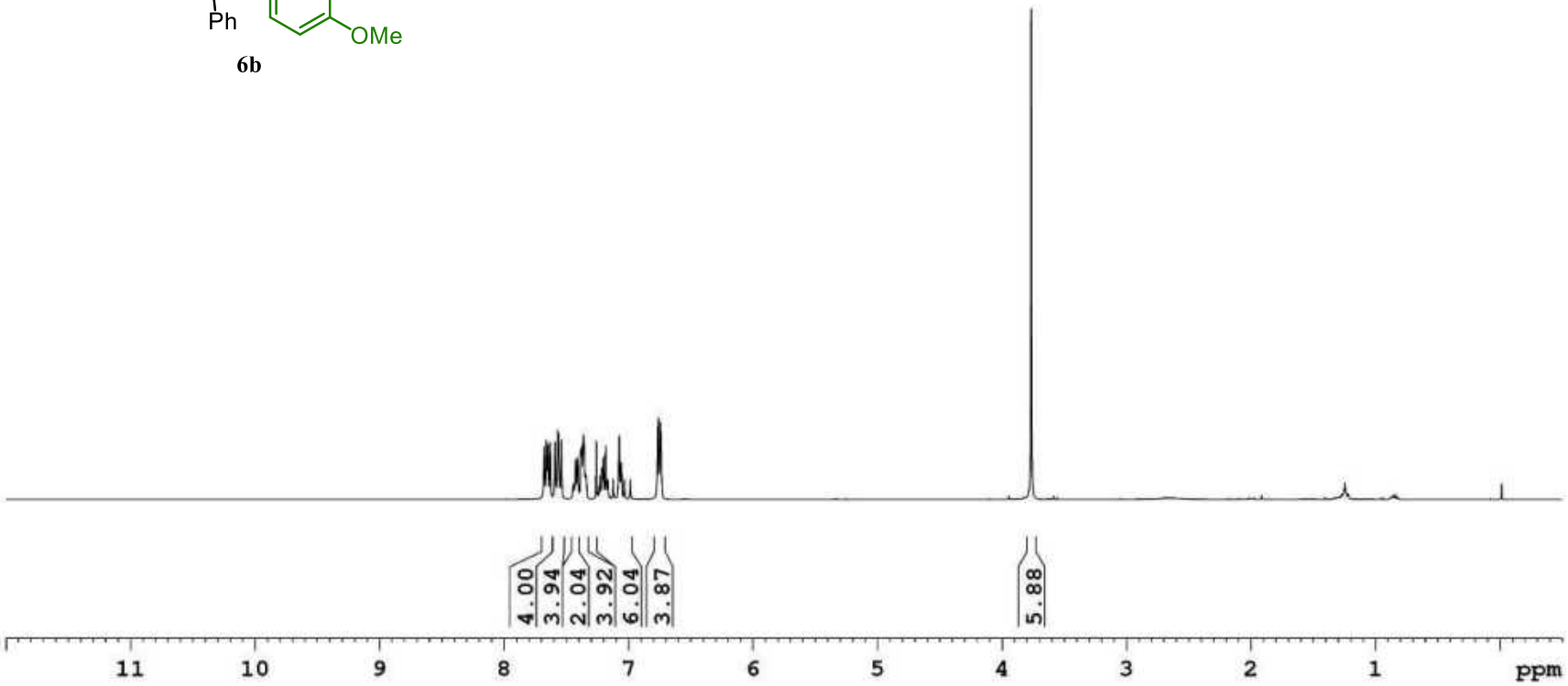
6a

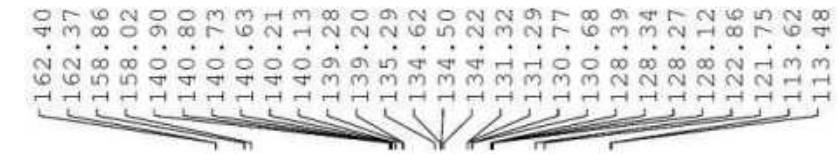

25.13
25.04
18.42
18.33
1.00
1.04
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm

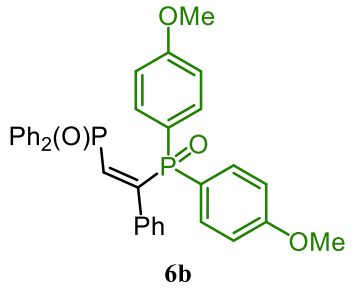

7.68
7.66
7.66
7.65
7.63
7.63
7.59
7.57
7.56
7.54
7.45
7.44
7.43
7.42
7.41
7.41
7.38
7.38
7.36
7.36
7.36
7.35
7.34
7.34
7.26
7.25
7.24
7.23
7.22
7.21
7.20
7.18
7.17
7.16
7.12
7.08
7.06
7.03
6.99
6.77
6.76
6.74
6.74
3.76


OMe
Ph2(O)P
O
P
Ph
OMe

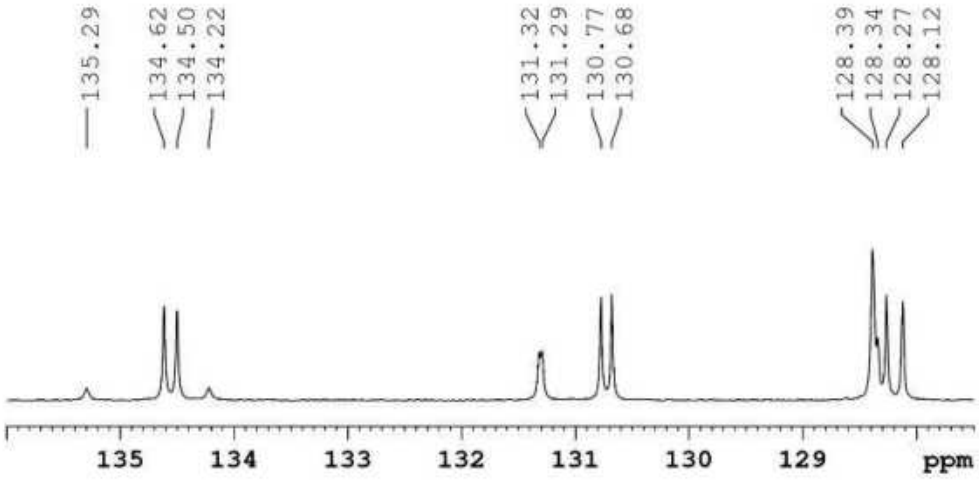
6b

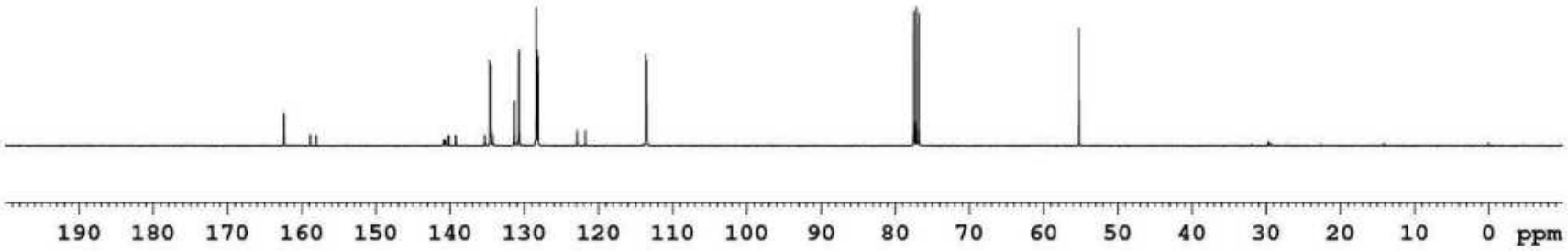

4.00
3.94
2.04
3.92
6.04
3.87
5.88
11
10
9
8
7
6
5
4
3
2
1
ppm


162.40
162.37
158.86
158.02
140.90
140.80
140.73
140.63
140.21
140.13
139.28
139.20
135.29
134.62
134.50
134.22
131.32
131.29
130.77
130.68
128.39
128.34
128.27
128.12
122.86
121.75
113.62
113.48
55.23


OMe
Ph2(O)P
P
O
Ph
OMe

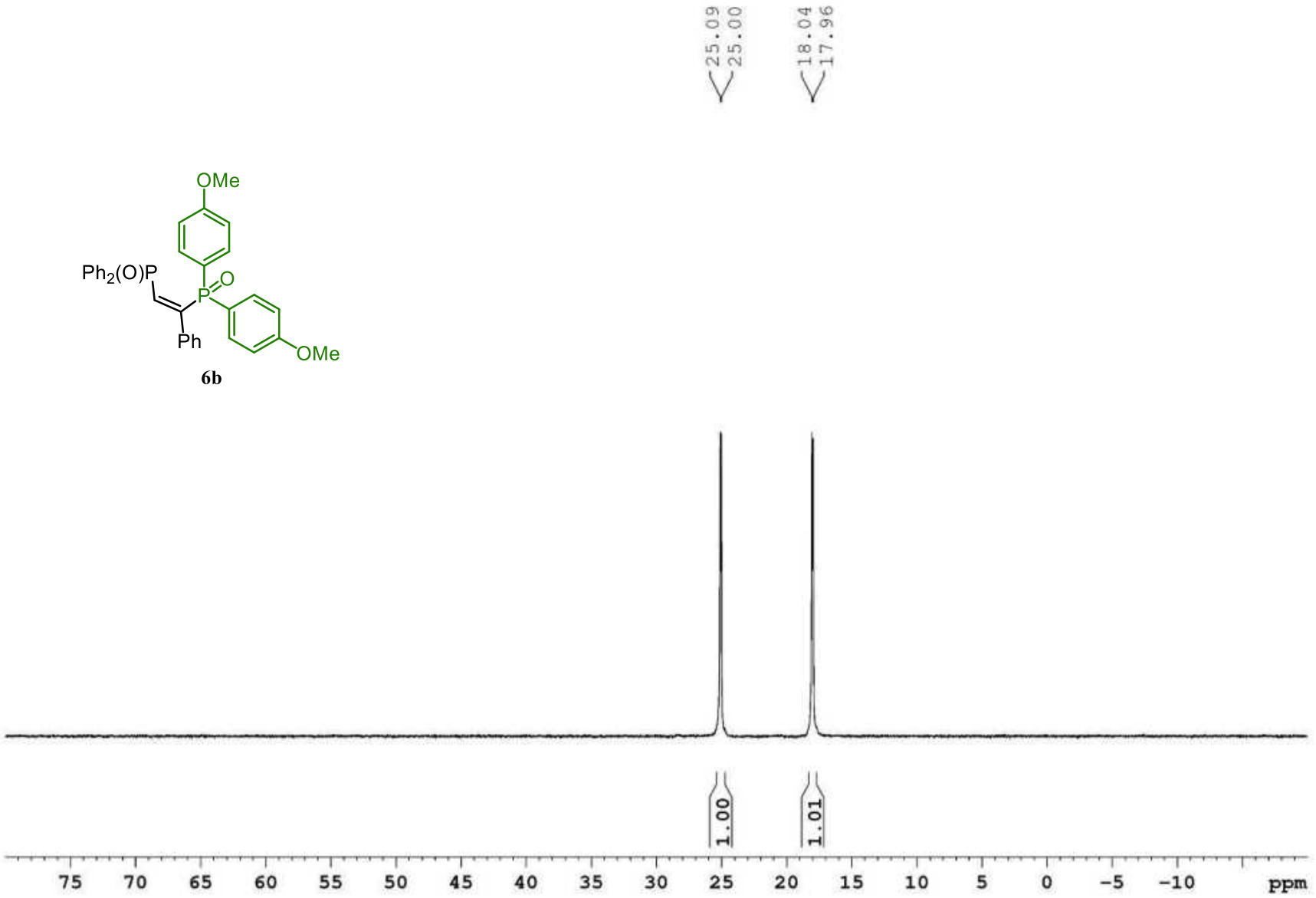
6b

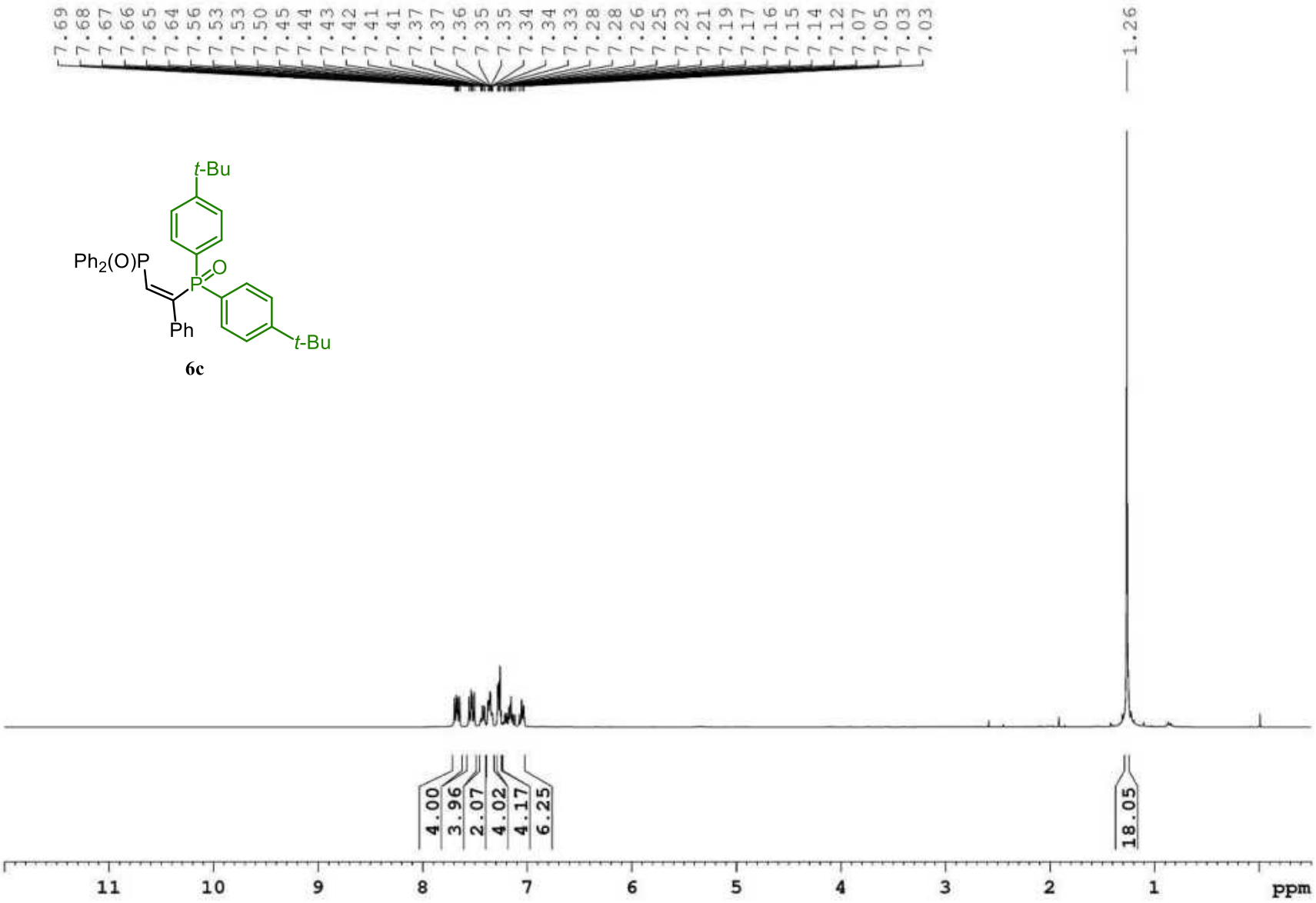

135.29
134.62
134.50
134.22
131.32
131.29
130.77
130.68
128.39
128.34
128.27
128.12
135
134
133
132
131
130
129
ppm


190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

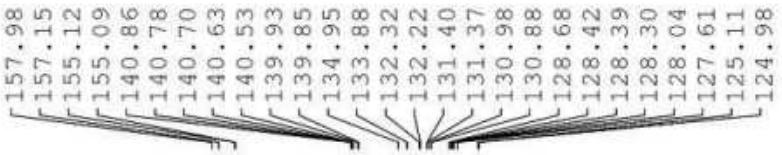
OMe
Ph2(O)P
O
P
Ph
OMe

6b

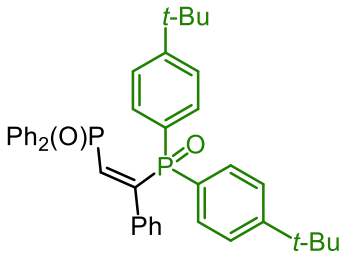

25.09
25.00
18.04
17.96
1.00
1.01
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm


7.69
7.68
7.67
7.66
7.65
7.64
7.56
7.53
7.53
7.50
7.45
7.44
7.43
7.42
7.41
7.41
7.37
7.37
7.36
7.35
7.35
7.34
7.34
7.33
7.28
7.28
7.26
7.25
7.23
7.21
7.19
7.17
7.16
7.15
7.14
7.12
7.07
7.05
7.03
7.03
1.26
t-Bu
Ph2(O)P
P
O
Ph
t-Bu
4.00
3.96
2.07
4.02
4.17
6.25
18.05
11
10
9
8
7
6
5
4
3
2
1
ppm

6c


157.98
157.15
155.12
155.09
140.86
140.78
140.70
140.63
140.53
139.93
139.85
134.95
133.88
132.32
132.22
131.40
131.37
130.98
130.88
128.68
128.42
128.39
128.30
128.04
127.61
125.11
124.98


34.91
31.10


t-Bu
Ph2(O)P
P
O
Ph
t-Bu

6c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131.37
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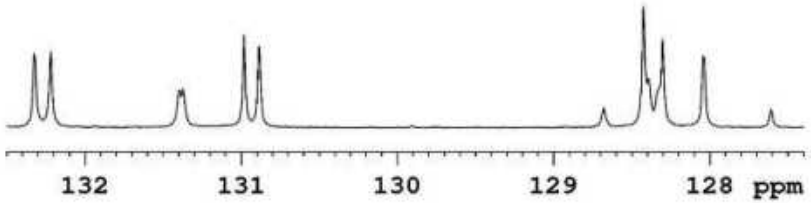
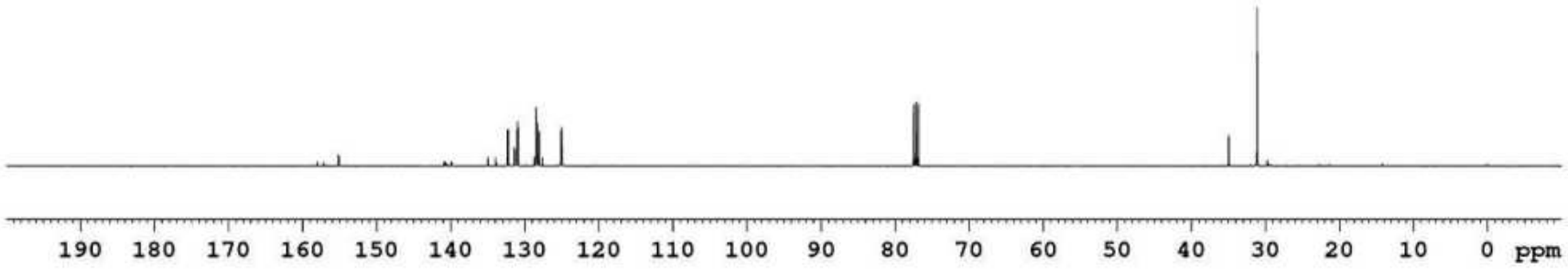
130.88
128.68
128.42
128.39
128.30
128.04
127.61


132
131
130
129
128
ppm


190
180
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110
100
90
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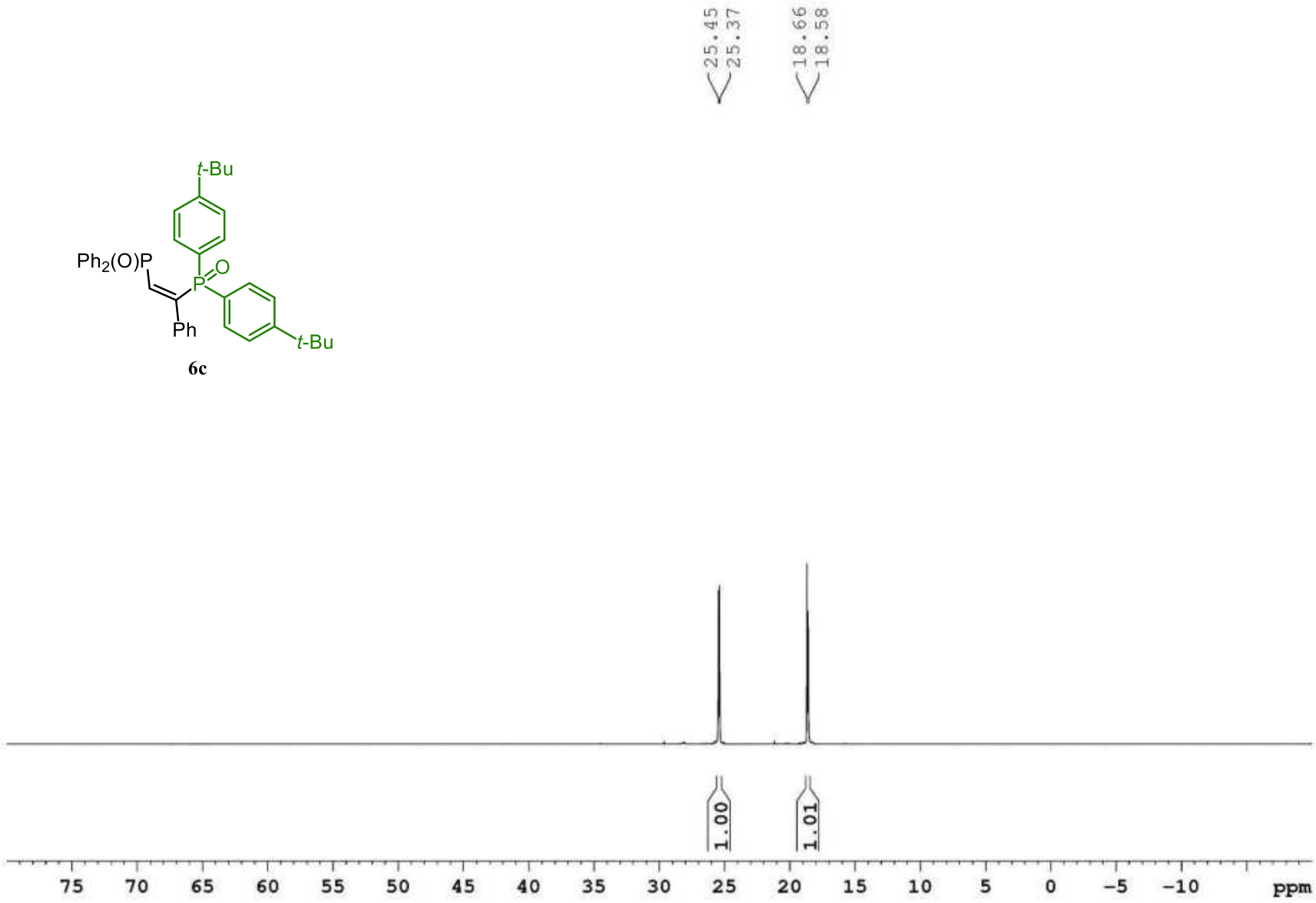
30
20
10
0
ppm

t-Bu
Ph2(O)P
P
O
Ph
t-Bu

6c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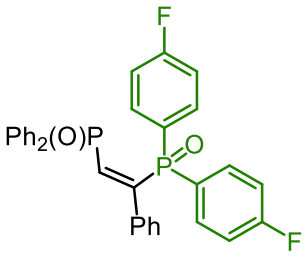
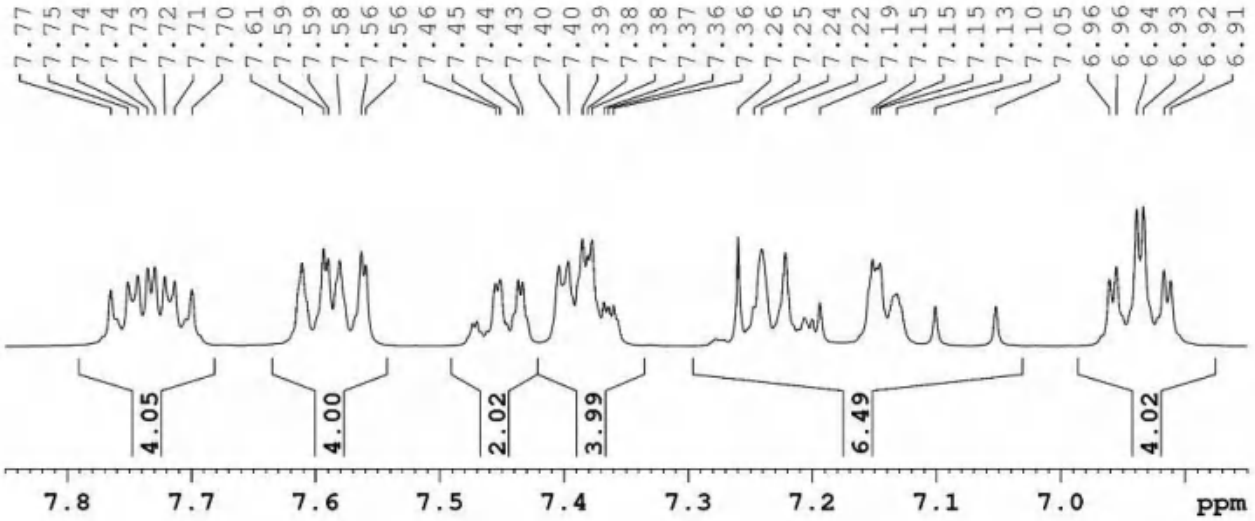
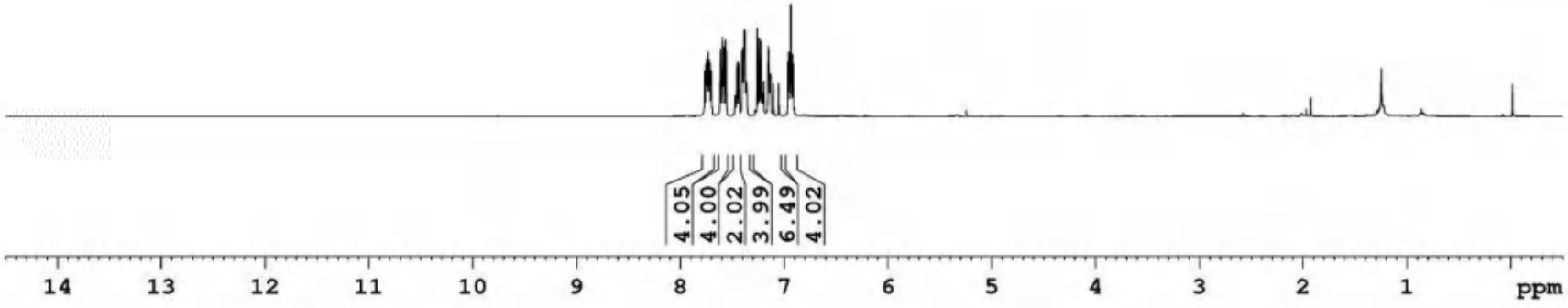
25.37
18.66
18.58
1.00
1.01
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
−5
−10
ppm

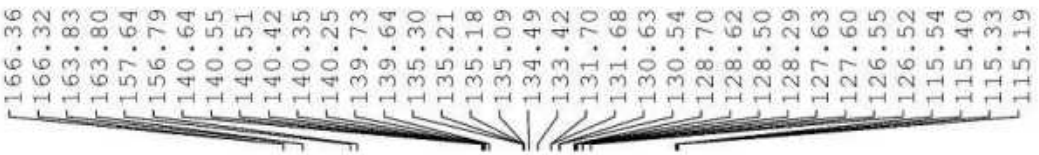

7.77 7.76 7.75 7.74 7.74 7.73 7.72 7.71 7.70 7.70 7.61 7.59 7.59 7.58 7.56 7.56 7.47 7.47 7.47 7.46 7.46 7.45 7.45 7.44 7.43 7.40 7.40 7.39 7.38 7.38 7.37 7.36 7.36 7.28 7.27 7.26 7.25 7.24 7.22 7.21 7.21 7.20 7.19 7.15 7.15 7.15 7.13 7.10 7.05 6.96 6.96 6.94 6.93 6.92 6.92 6.91


F
Ph2(O)P
P
O
Ph
F

6d


7.77 7.75 7.74 7.74 7.73 7.72 7.71 7.70 7.61 7.59 7.59 7.58 7.56 7.56 7.46 7.45 7.44 7.43 7.40 7.40 7.39 7.38 7.38 7.37 7.36 7.36 7.26 7.25 7.24 7.22 7.19 7.15 7.15 7.15 7.13 7.10 7.05 6.96 6.96 6.94 6.93 6.92 6.91
4.05
4.00
2.02
3.99
6.49
4.02
7.8 7.7 7.6 7.5 7.4 7.3 7.2 7.1 7.0 ppm


4.05
4.00
2.02
3.99
6.49
4.02
14 13 12 11 10 9 8 7 6 5 4 3 2 1 ppm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166.32
163.83
163.80
157.64
156.79
140.64
140.55
140.51
140.42
140.35
140.25
139.73
139.64
135.30
135.21
135.18
135.09
134.49
133.42
131.70
131.68
130.63
130.54
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126.55
126.52
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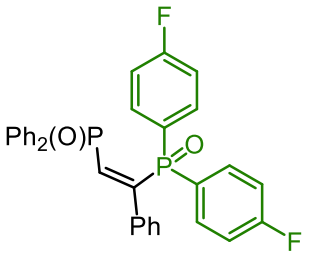
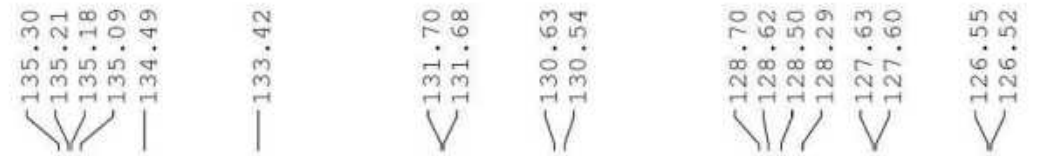
115.40
115.33
115.19


F
Ph2(O)P
P
O
Ph
F

6d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135.18
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134.49
133.42
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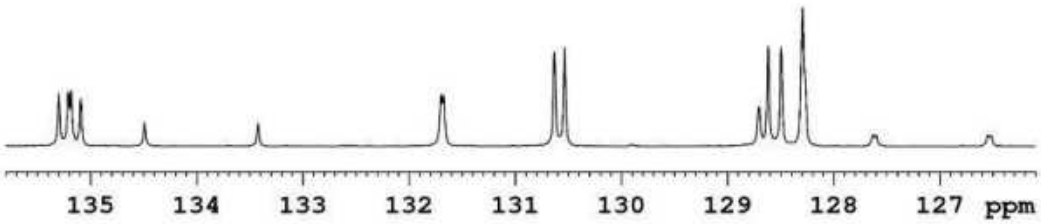
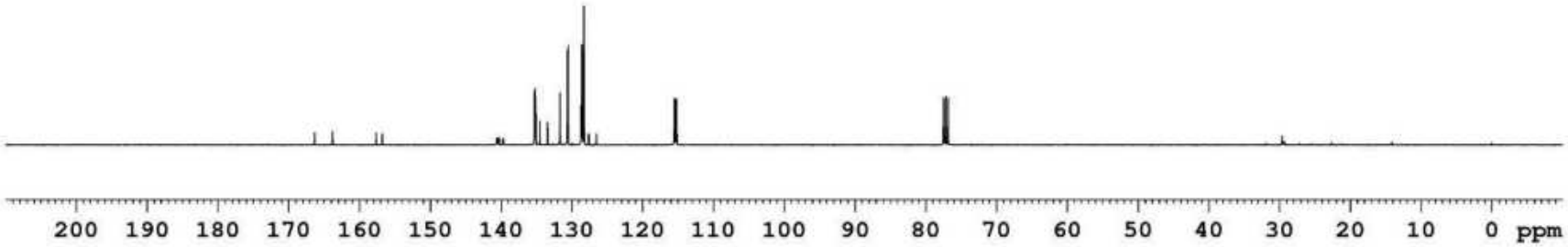
131.68
130.63
130.54
128.70
128.62
128.50
128.29
127.63
127.60
126.55
126.52


135
134
133
132
131
130
129
128
127
ppm


200
190
180
170
160
150
140
130
120
110
100
90
80
70
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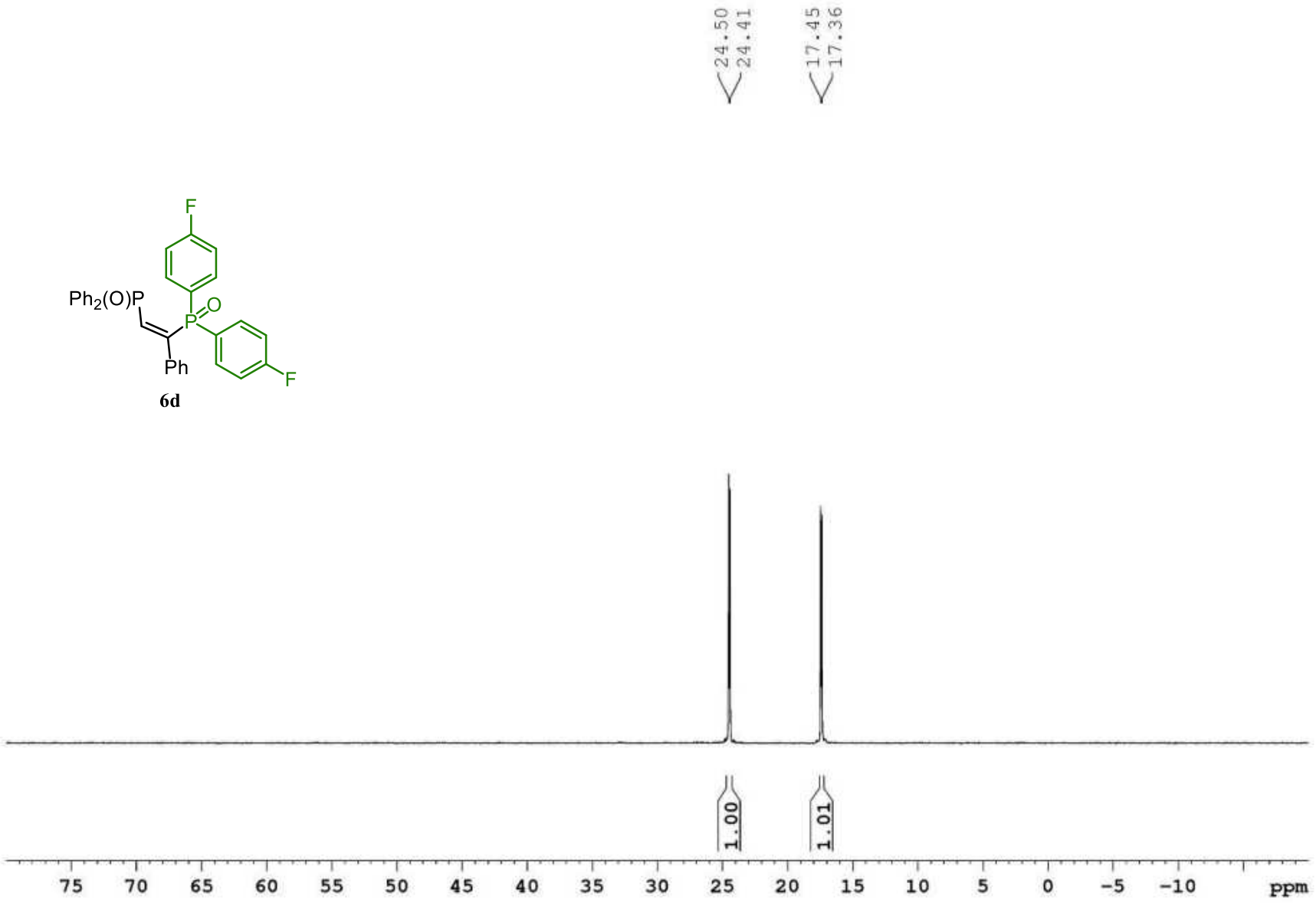
50
40
30
20
10
0
ppm

F
Ph2(O)P
P
O
Ph
F

6d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1.01
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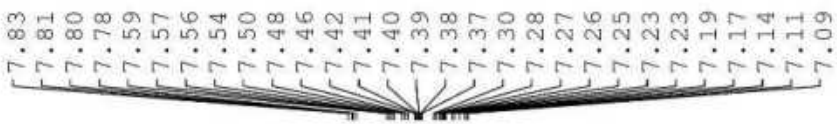
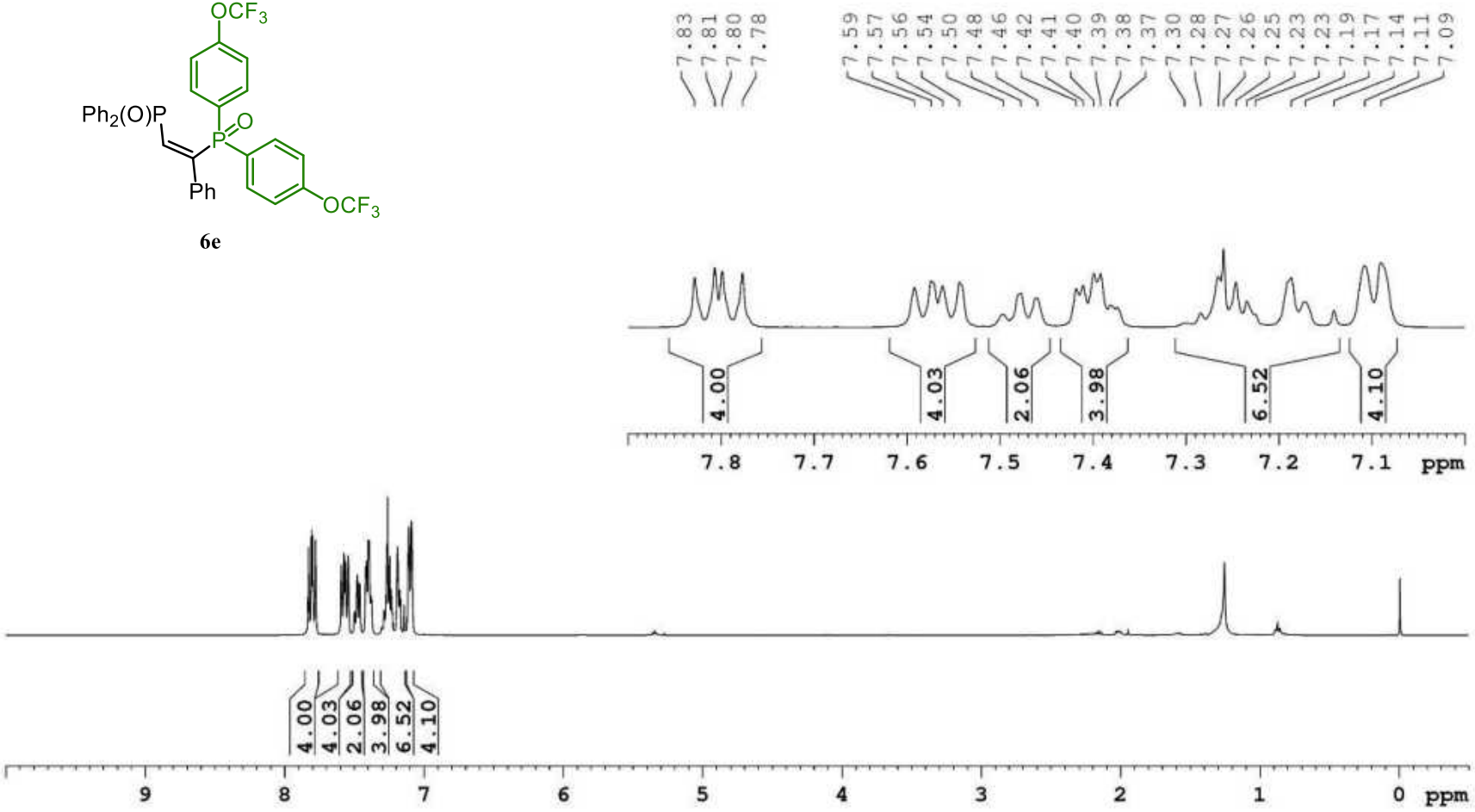
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm


7.83
7.81
7.80
7.78
7.59
7.57
7.56
7.54
7.50
7.48
7.46
7.42
7.41
7.40
7.39
7.38
7.37
7.30
7.28
7.27
7.26
7.25
7.23
7.23
7.19
7.17
7.14
7.11
7.09

OCF3
Ph2(O)P
P
O
Ph
OCF3

6e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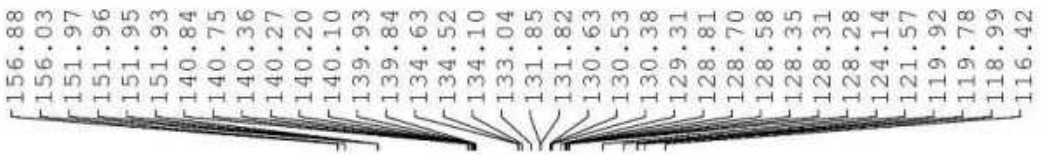
7.81
7.80
7.78
7.59
7.57
7.56
7.54
7.50
7.48
7.46
7.42
7.41
7.40
7.39
7.38
7.37
7.30
7.28
7.27
7.26
7.25
7.23
7.23
7.19
7.17
7.14
7.11
7.09
4.00
4.03
2.06
3.98
6.52
4.10
7.8
7.7
7.6
7.5
7.4
7.3
7.2
7.1
ppm
4.00
4.03
2.06
3.98
6.52
4.10
9
8
7
6
5
4
3
2
1
0
ppm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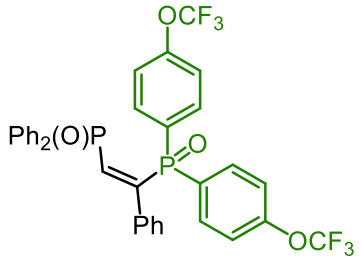
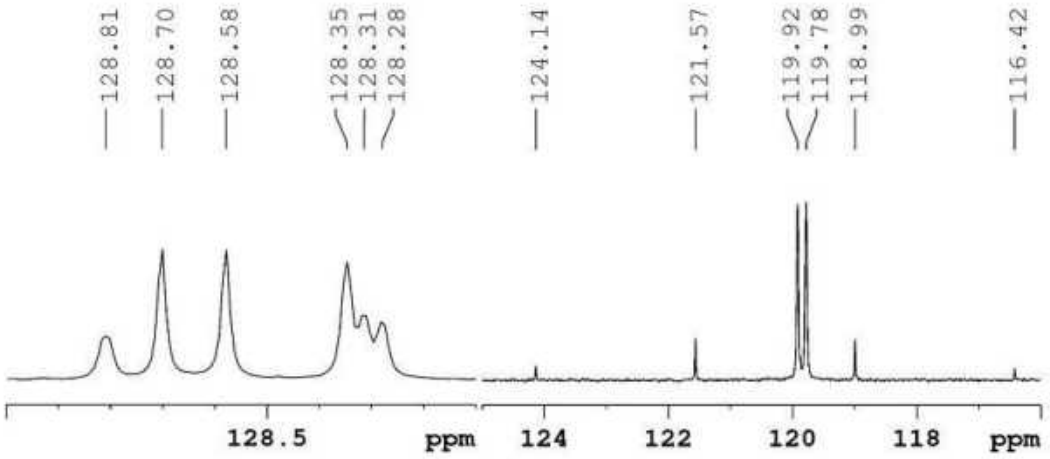
156.03
151.97
151.96
151.95
151.93
140.84
140.75
140.36
140.27
140.20
140.10
139.93
139.84
134.63
134.52
134.10
133.04
131.85
131.82
130.63
130.53
130.38
129.31
128.81
128.70
128.58
128.35
128.31
128.28
124.14
121.57
119.92
119.78
118.99
116.42


OCF3
Ph2(O)P
P
O
Ph
OCF3

6e


128.81
128.70
128.58
128.35
128.31
128.28
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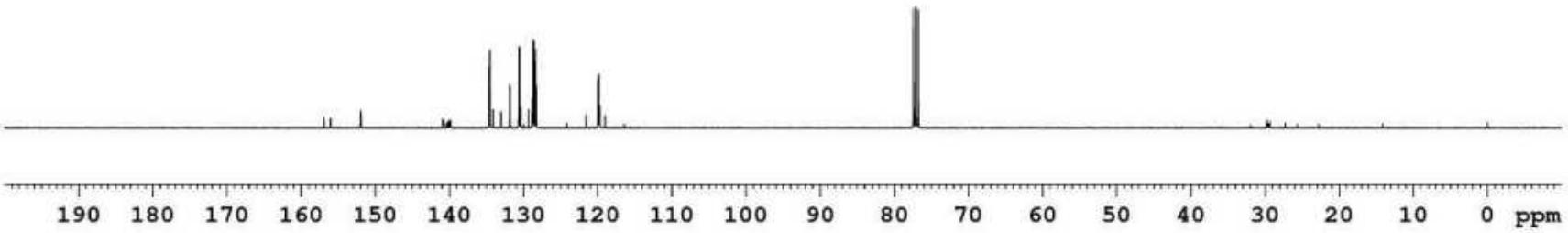
121.57
119.92
119.78
118.99
116.42
128.5
ppm
124
122
120
118
ppm


190
180
170
160
150
140
130
120
110
100
90
80
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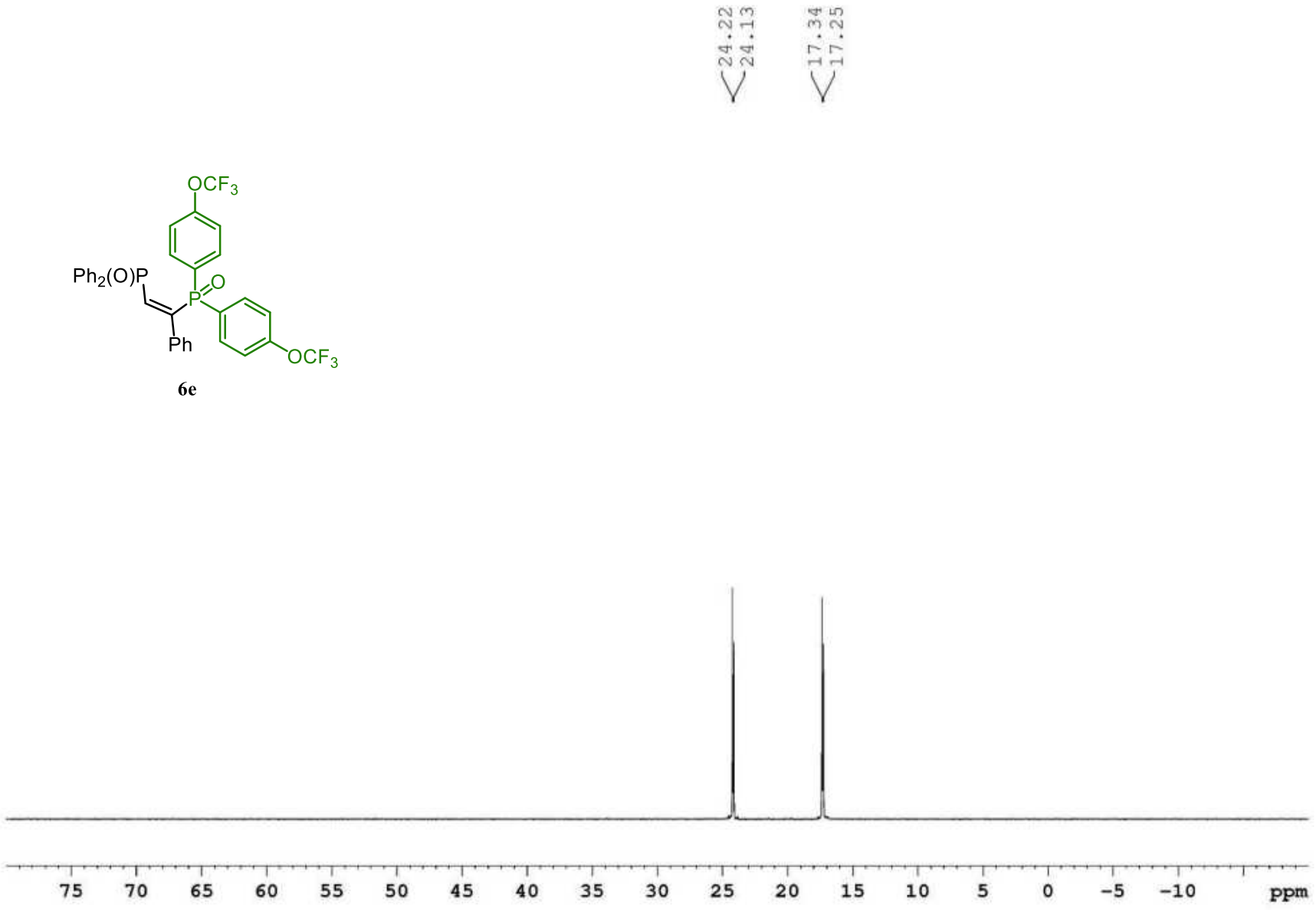
40
30
20
10
0
ppm

OCF3
Ph2(O)P
P
O
Ph
OCF3

6e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24.13
17.34
17.25
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70
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50
45
40
35
30
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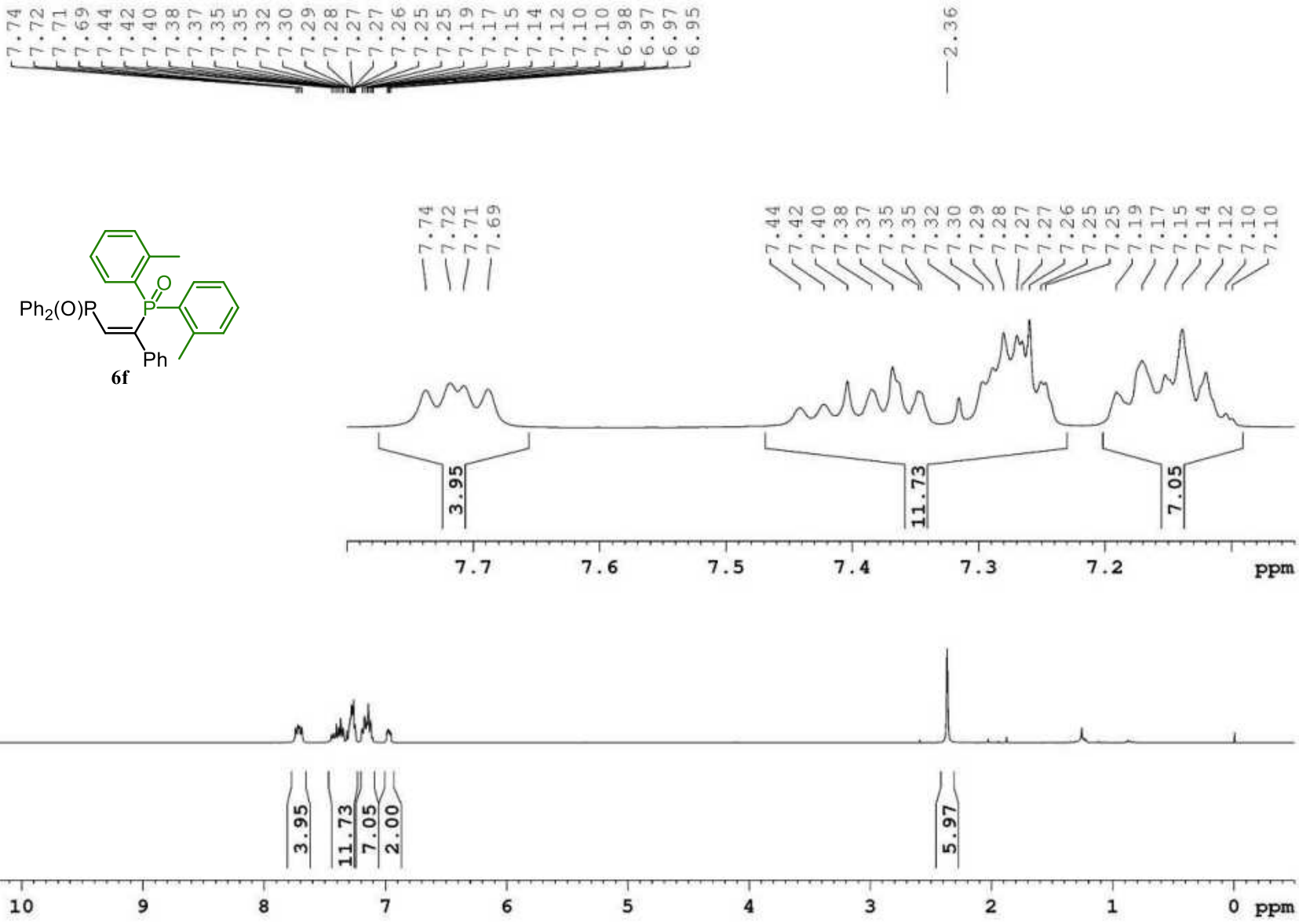
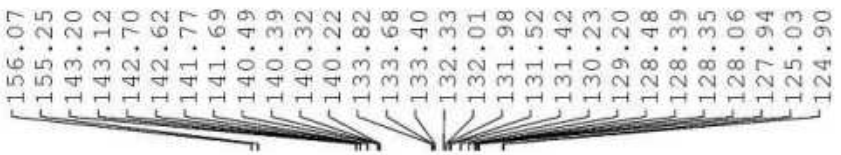
15
10
5
0
-5
-10
ppm


7.74
7.72
7.71
7.69
7.44
7.42
7.40
7.38
7.37
7.35
7.35
7.32
7.30
7.29
7.28
7.27
7.27
7.26
7.25
7.25
7.19
7.17
7.15
7.14
7.12
7.10
7.10
6.98
6.97
6.97
6.95
2.36
Ph2(O)P
O
P
Ph
6f
3.95
11.73
7.05
2.00
5.97
ppm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155.25
143.20
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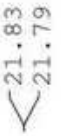
142.70
142.62
141.77
141.69
140.49
140.39
140.32
140.22
133.82
133.68
133.40
132.33
132.01
131.98
131.52
131.42
130.23
129.20
128.48
128.39
128.35
128.06
127.94
125.03
124.90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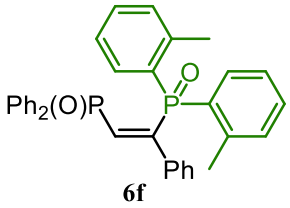
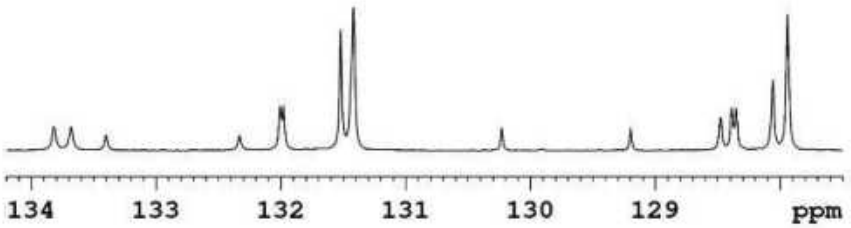
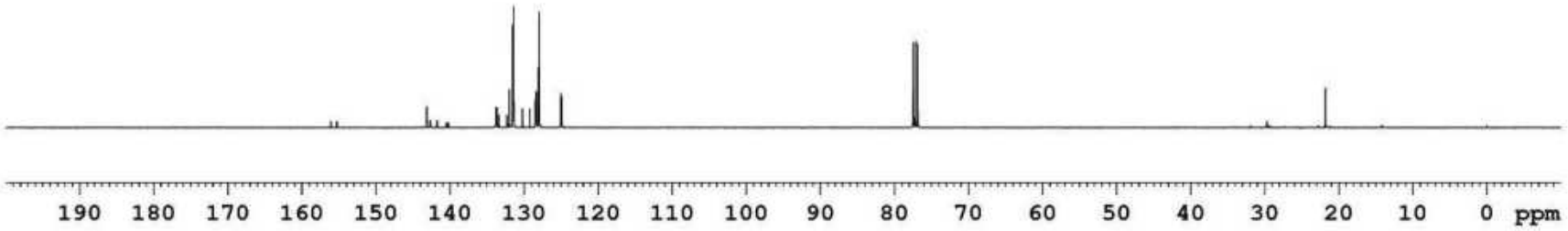
21.79


Ph2(O)P
P
O
Ph

6f


133.82
133.68
133.40
132.33
132.01
131.98
131.52
131.42
130.23
129.20
128.48
128.39
128.35
128.06
127.94


134
133
132
131
130
129
ppm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100
90
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60
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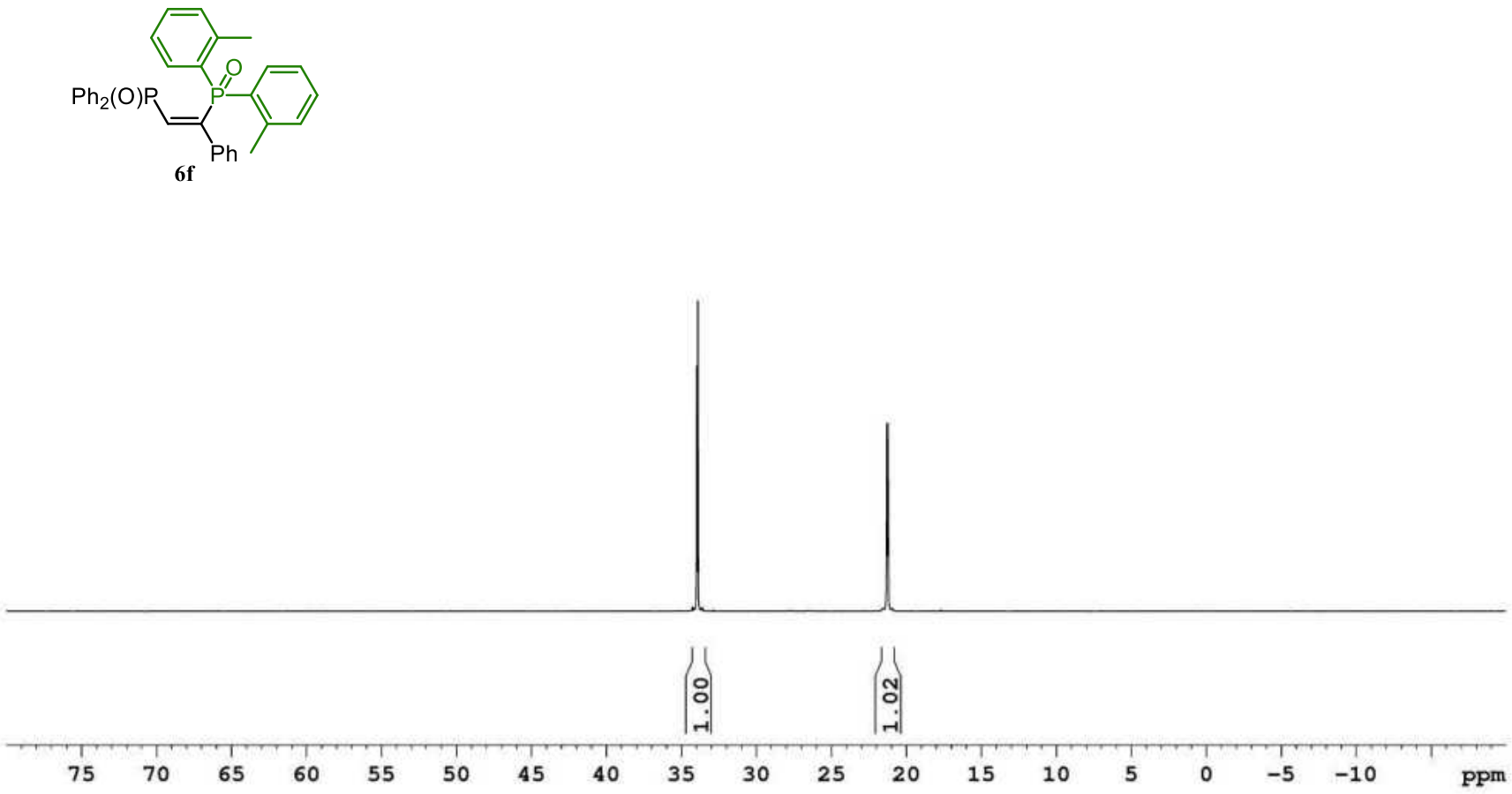
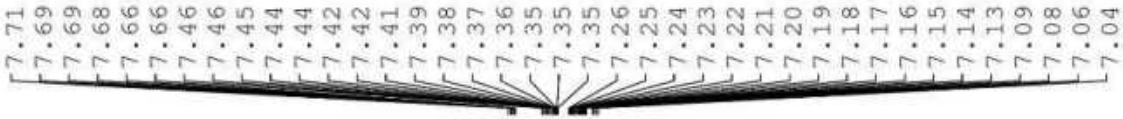
30
20
10
0
ppm


33.96
33.87
21.28
21.20
Ph2(O)P
O
P
Ph
1.00
1.02
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm

6f


7.71
7.69
7.69
7.68
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7.66
7.46
7.46
7.45
7.44
7.44
7.42
7.42
7.41
7.39
7.38
7.37
7.36
7.35
7.35
7.35
7.26
7.25
7.24
7.23
7.22
7.21
7.20
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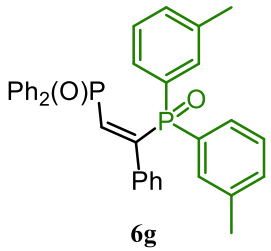
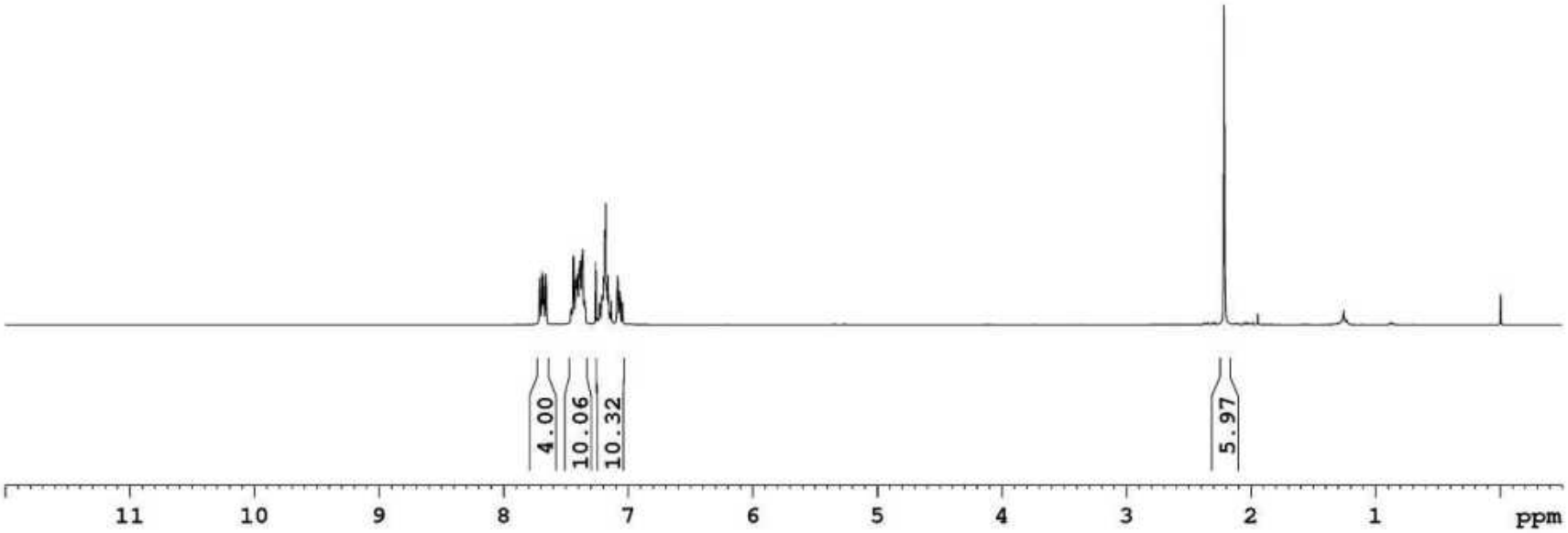
7.16
7.15
7.14
7.13
7.09
7.08
7.06
7.04
2.21


Ph2(O)P
P
O
Ph

6g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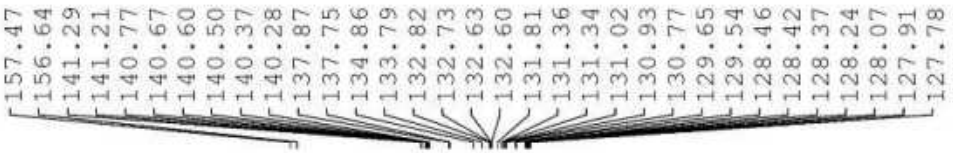
10.32
5.97
11
10
9
8
7
6
5
4
3
2
1
ppm


157.47
156.64
141.29
141.21
140.77
140.67
140.60
140.50
140.37
140.28
137.87
137.75
134.86
133.79
132.82
132.73
132.63
132.60
131.81
131.36
131.34
131.02
130.93
130.77
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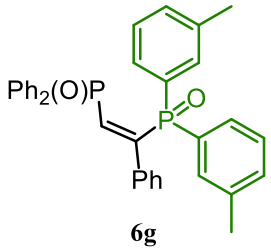
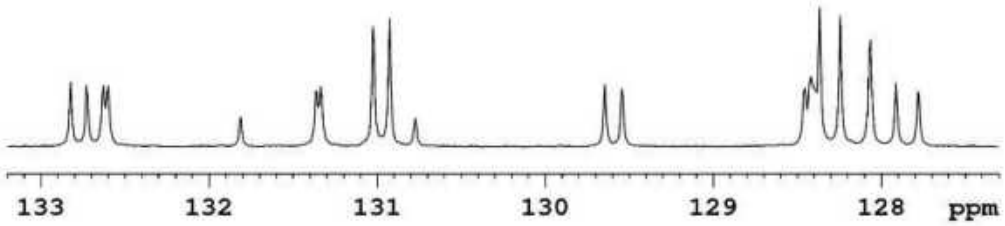
129.54
128.46
128.42
128.37
128.24
128.07
127.91
127.78

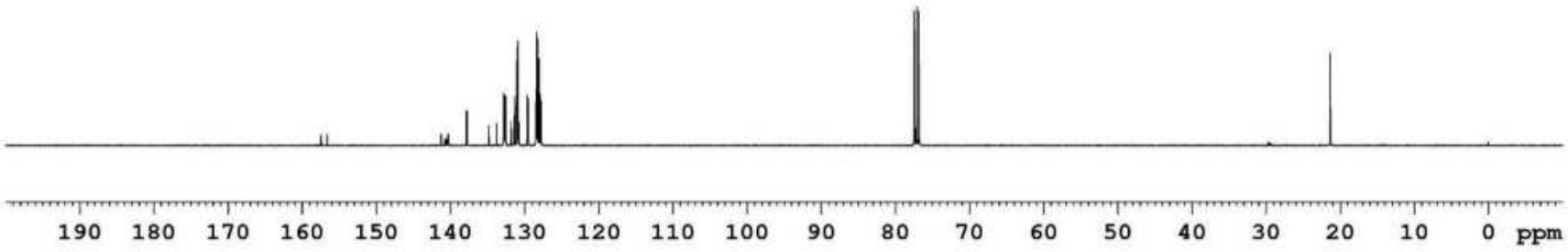

21.37


Ph2(O)P
P
O
Ph

6g


132.82
132.73
132.63
132.60
131.81
131.36
131.34
131.02
130.93
130.77
129.65
129.54
128.46
128.42
128.37
128.24
128.07
127.91
127.78


133
132
131
130
129
128
ppm


190
180
170
160
150
140
130
120
110
100
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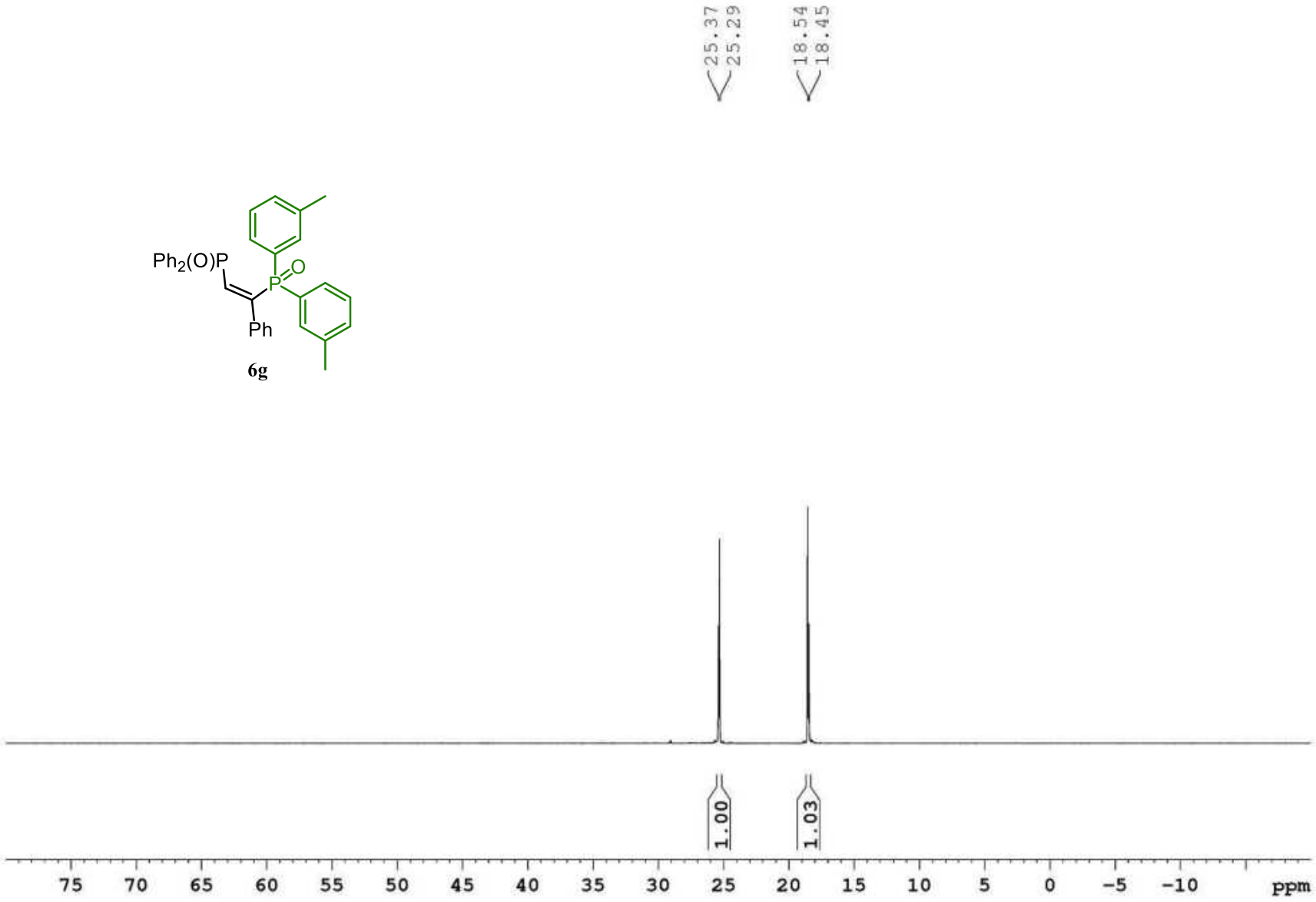
70
60
50
40
30
20
10
0
ppm

Ph2(O)P
P
O
Ph

6g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25.29
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1.03
75
70
65
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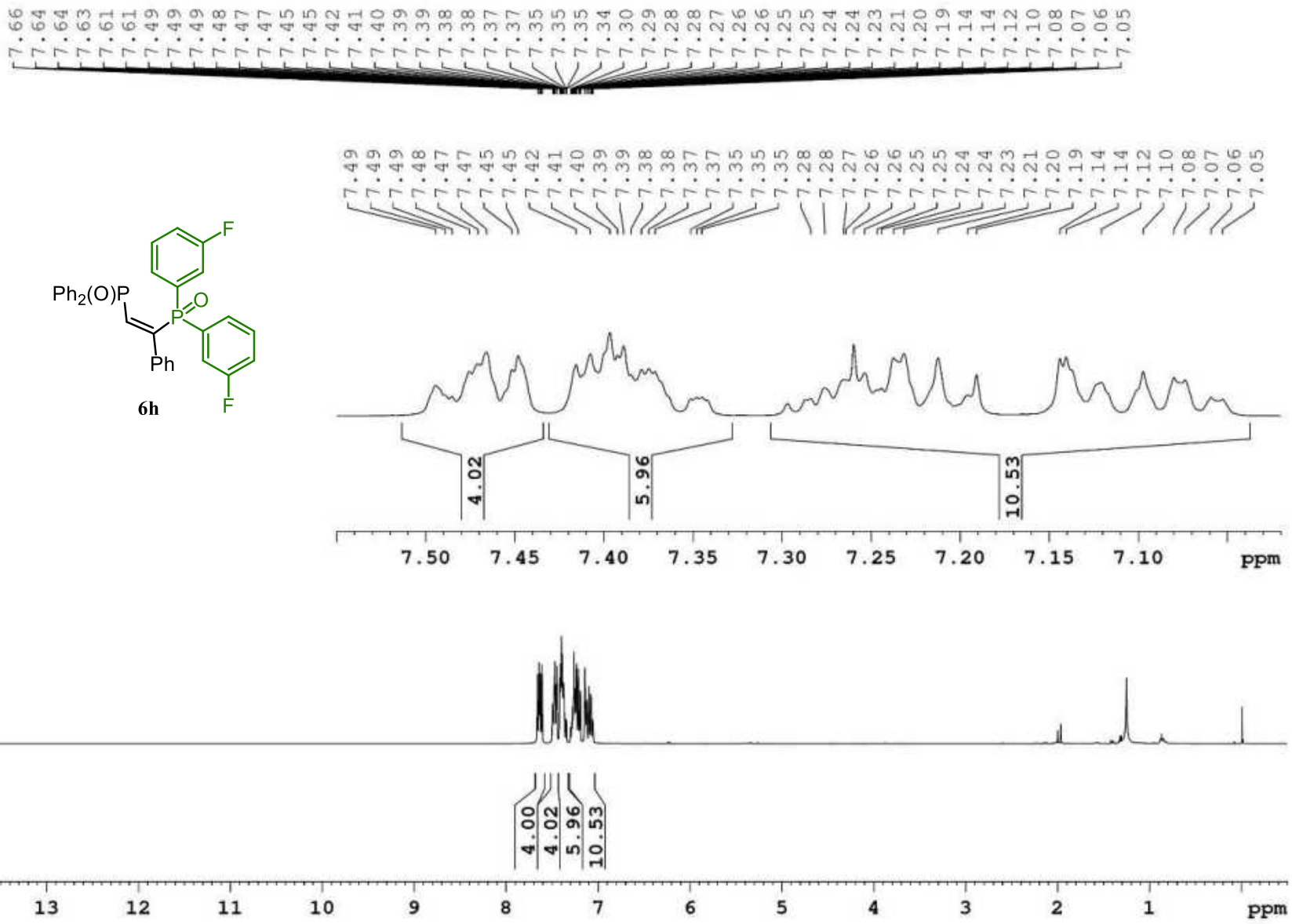
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm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7.49 7.49 7.49 7.48 7.47 7.47 7.45 7.45 7.42 7.41 7.40 7.39 7.39 7.38 7.38 7.37 7.37 7.35 7.35 7.35 7.28 7.28 7.27 7.26 7.26 7.25 7.25 7.24 7.24 7.23 7.21 7.20 7.19 7.14 7.14 7.12 7.10 7.08 7.07 7.06 7.05
F
Ph2(O)P
P
O
Ph
F
6h
4.02
5.96
10.53
7.50 7.45 7.40 7.35 7.30 7.25 7.20 7.15 7.10 ppm
4.00
4.02
5.96
10.53
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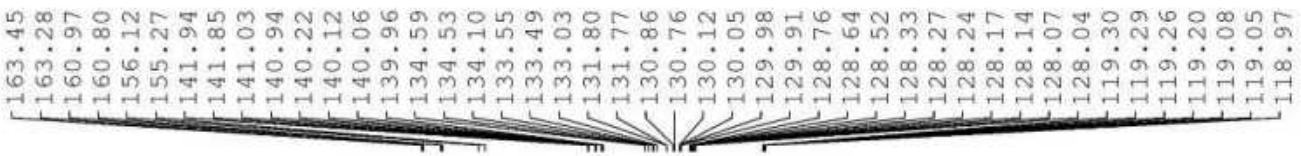
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140.06
139.96
134.59
134.53
134.10
133.55
133.49
133.03
131.80
131.77
130.86
130.76
130.12
130.05
129.98
129.91
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128.64
128.52
128.33
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119.05
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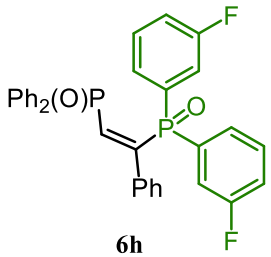
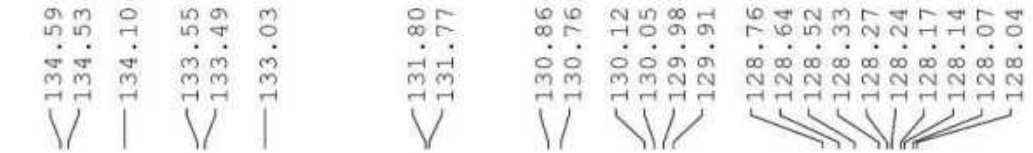

F
Ph2(O)P
P
O
Ph
F

6h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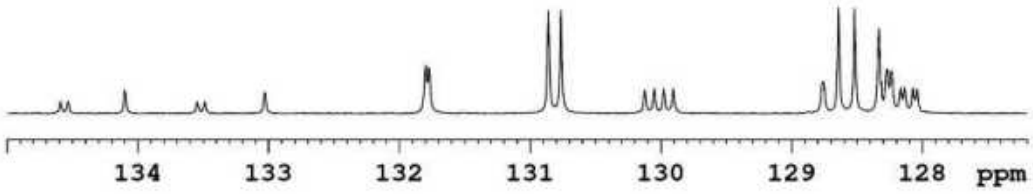
128.14
128.07
128.04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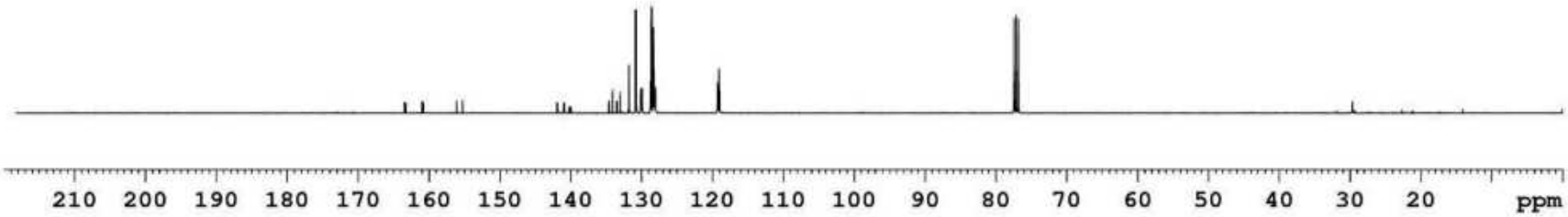
131
130
129
128
ppm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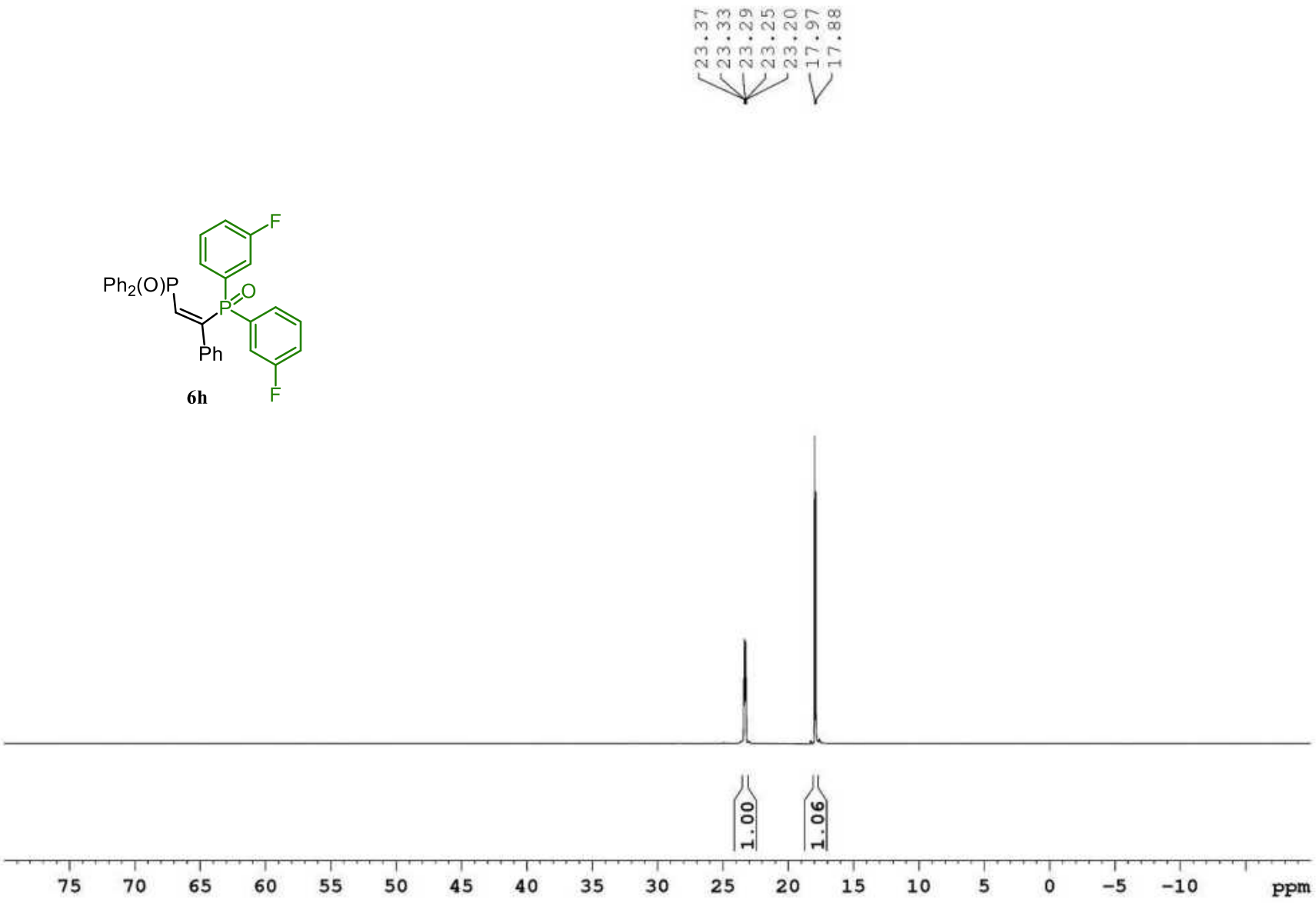
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23.29
23.25
23.20
17.97
17.88
F
Ph2(O)P
O
P
Ph
F
6h
1.00
1.06
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm


7.71
7.67
7.67
7.66
7.65
7.64
7.63
7.62
7.60
7.58
7.52
7.52
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7.50
7.49
7.48
7.45
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7.31
7.29
7.29
7.28
7.27
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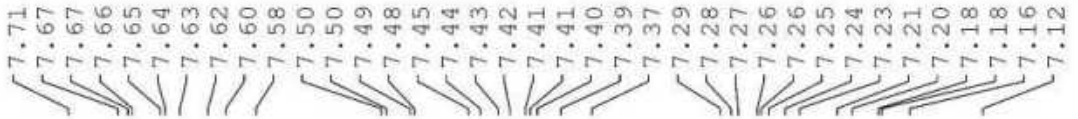
7.16
7.12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7.62
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7.50
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7.48
7.45
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7.43
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7.28
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7.23
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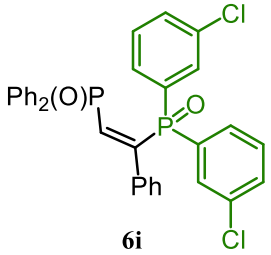
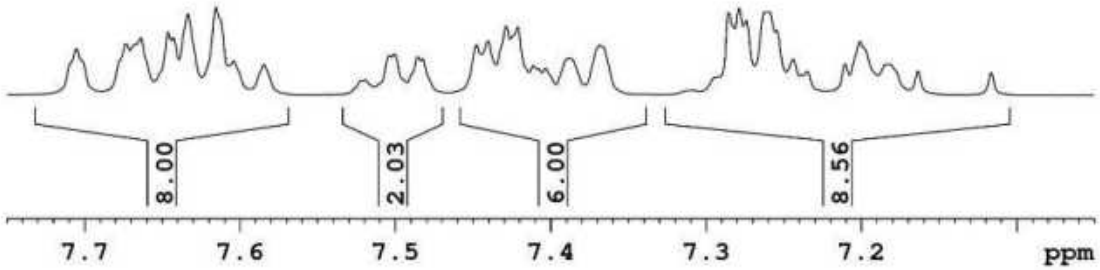
7.20
7.18
7.18
7.16
7.12


Cl
Ph2(O)P
P
O
Ph
Cl

6i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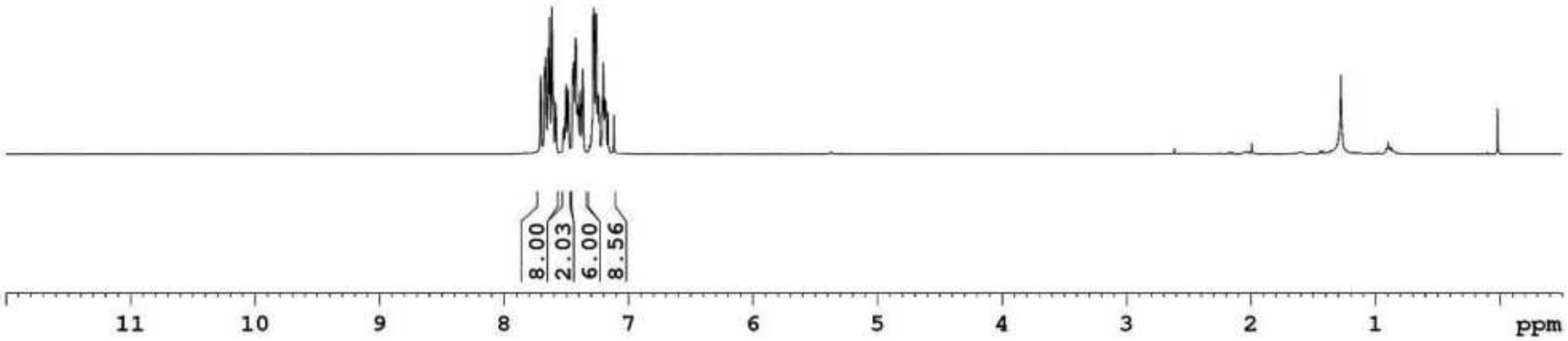
2.03
6.00
8.56
7.7
7.6
7.5
7.4
7.3
7.2
ppm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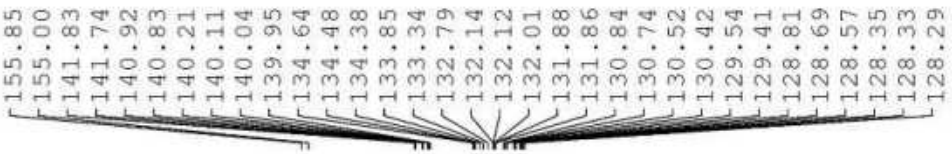
2.03
6.00
8.56
11
10
9
8
7
6
5
4
3
2
1
ppm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155.00
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141.74
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140.83
140.21
140.11
140.04
139.95
134.64
134.48
134.38
133.85
133.34
132.79
132.14
132.12
132.01
131.88
131.86
130.84
130.74
130.52
130.42
129.54
129.41
128.81
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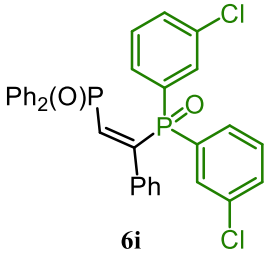
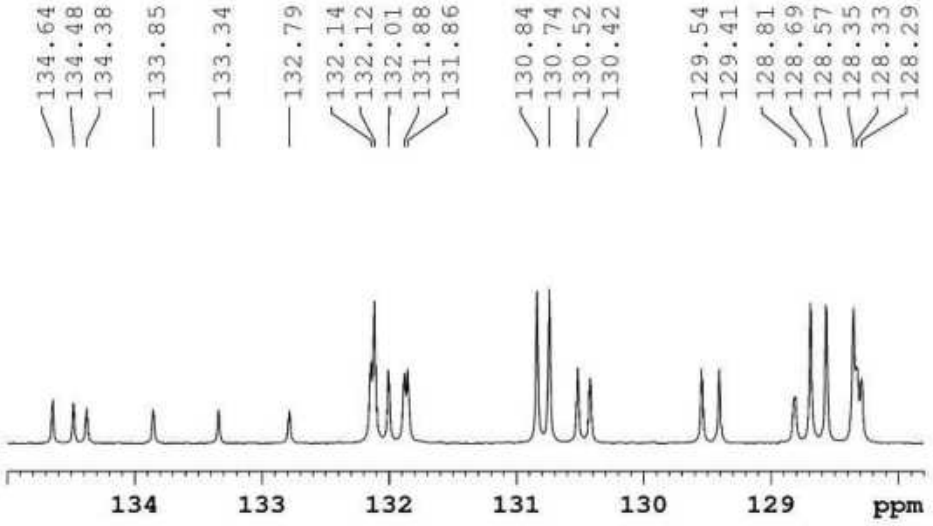
128.57
128.35
128.33
128.29


Cl
Ph2(O)P
P
O
Ph
Cl

6i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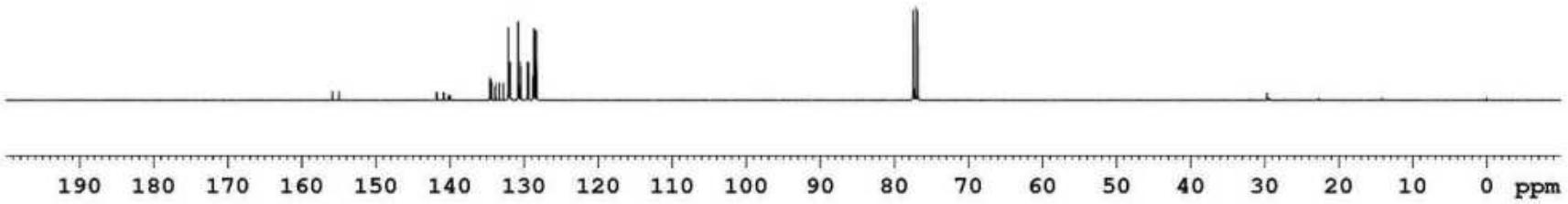
134.48
134.38
133.85
133.34
132.79
132.14
132.12
132.01
131.88
131.86
130.84
130.74
130.52
130.42
129.54
129.41
128.81
128.69
128.57
128.35
128.33
128.29
134
133
132
131
130
129
ppm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100
90
80
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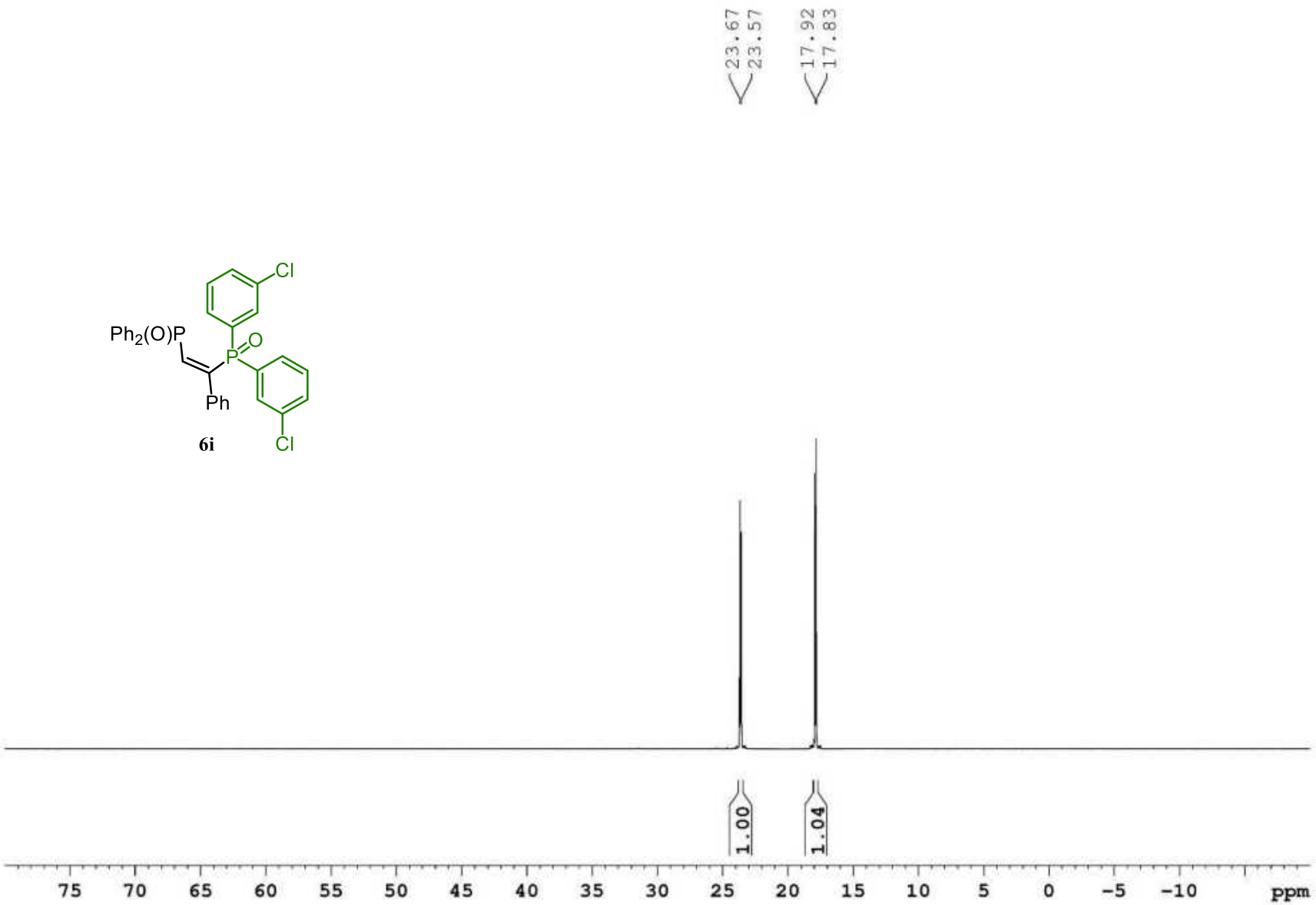
20
10
0
ppm


23.67
23.57
17.92
17.83
Cl
Ph2(O)P
P
O
Ph
Cl
6i
1.00
1.04
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60
55
50
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40
35
30
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20
15
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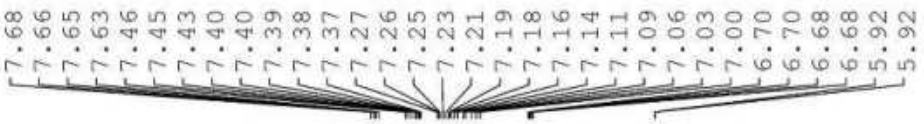
-5
-10
ppm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7.65
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7.40
7.40
7.39
7.38
7.37
7.27
7.26
7.25
7.23
7.21
7.19
7.18
7.16
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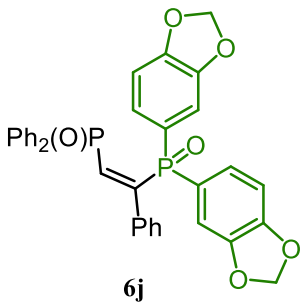
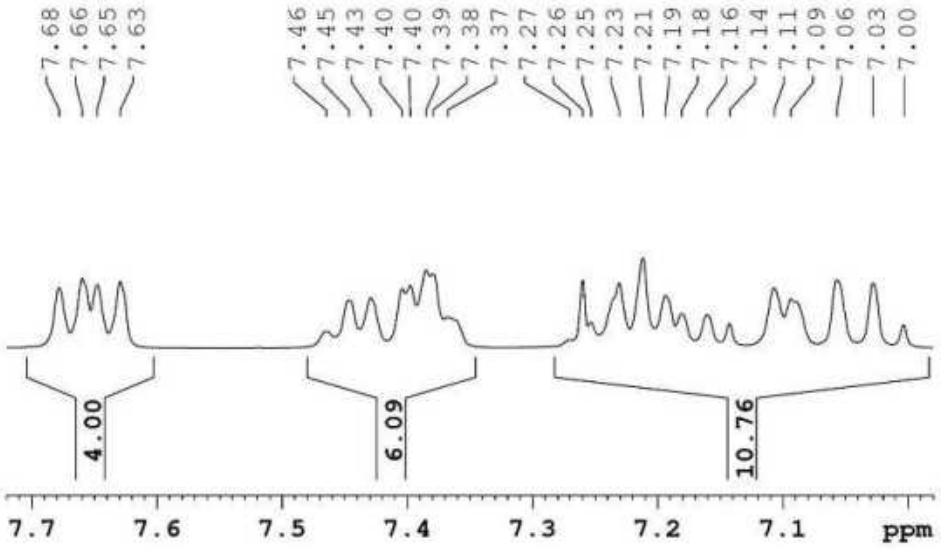
7.09
7.06
7.03
7.00
6.70
6.70
6.68
6.68
5.92
5.92


Ph2(O)P
P
O
Ph
O
O
O
O

6j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7.63
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7.27
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7.25
7.23
7.21
7.19
7.18
7.16
7.14
7.11
7.09
7.06
7.03
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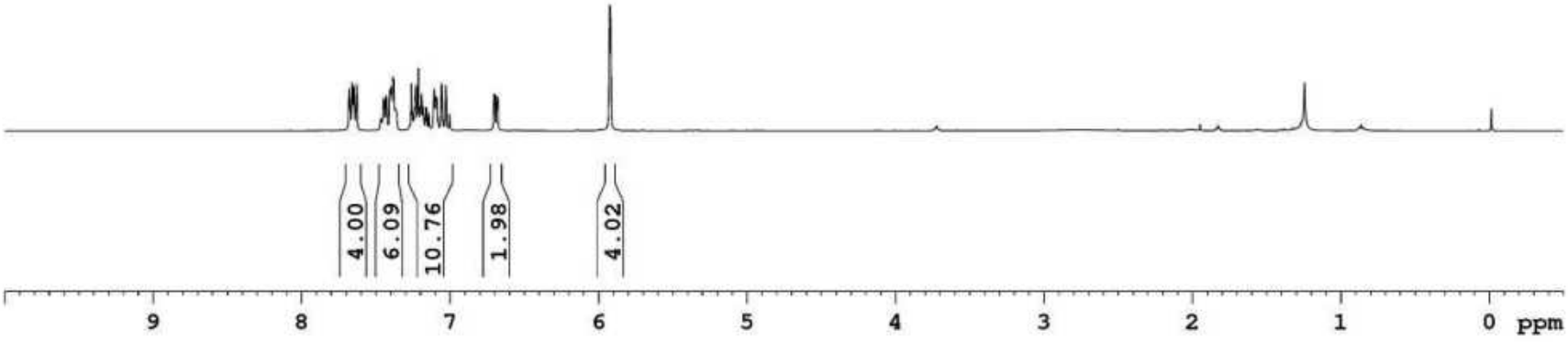
6.09
10.76
7.7
7.6
7.5
7.4
7.3
7.2
7.1
ppm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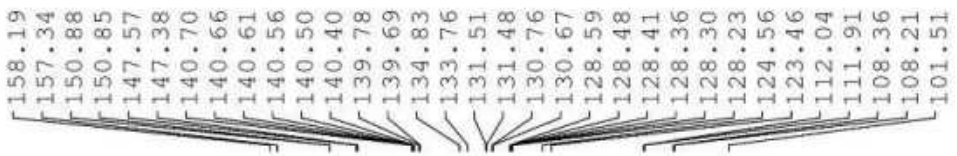
10.76
1.98
4.02
9
8
7
6
5
4
3
2
1
0
ppm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140.40
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139.69
134.83
133.76
131.51
131.48
130.76
130.67
128.59
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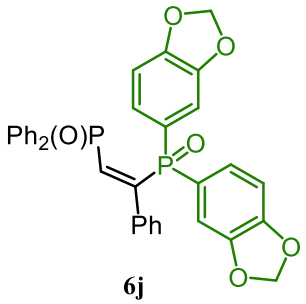
128.30
128.23
124.56
123.46
112.04
111.91
108.36
108.21
101.51


Ph2(O)P
P
O
Ph
O
O
O
O

6j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140.66
140.61
140.56
140.50
140.40
139.78
139.69
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131.51
131.48
130.76
130.67
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128.48
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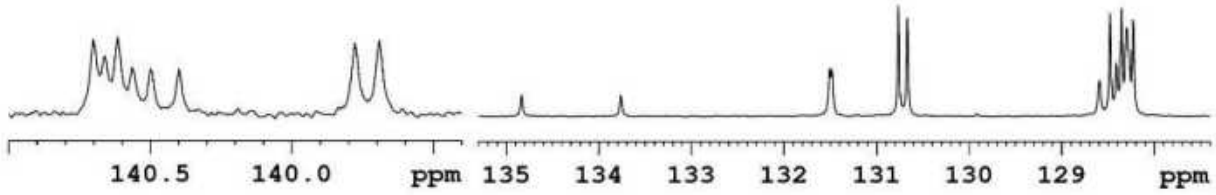
128.36
128.30
128.23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ppm
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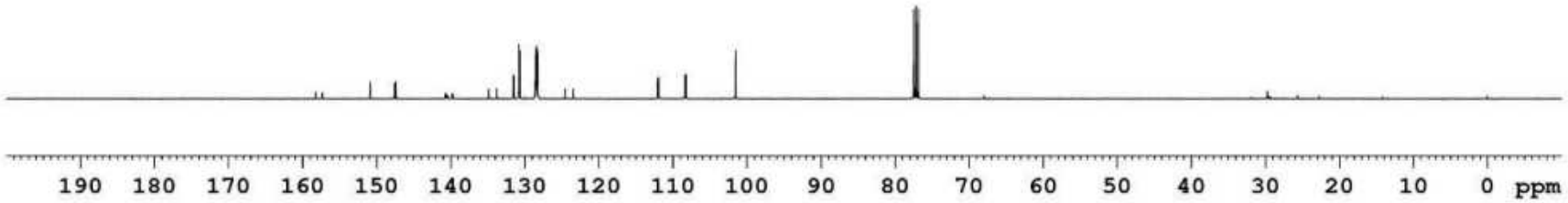
131
130
129
ppm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180
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120
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100
90
80
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60
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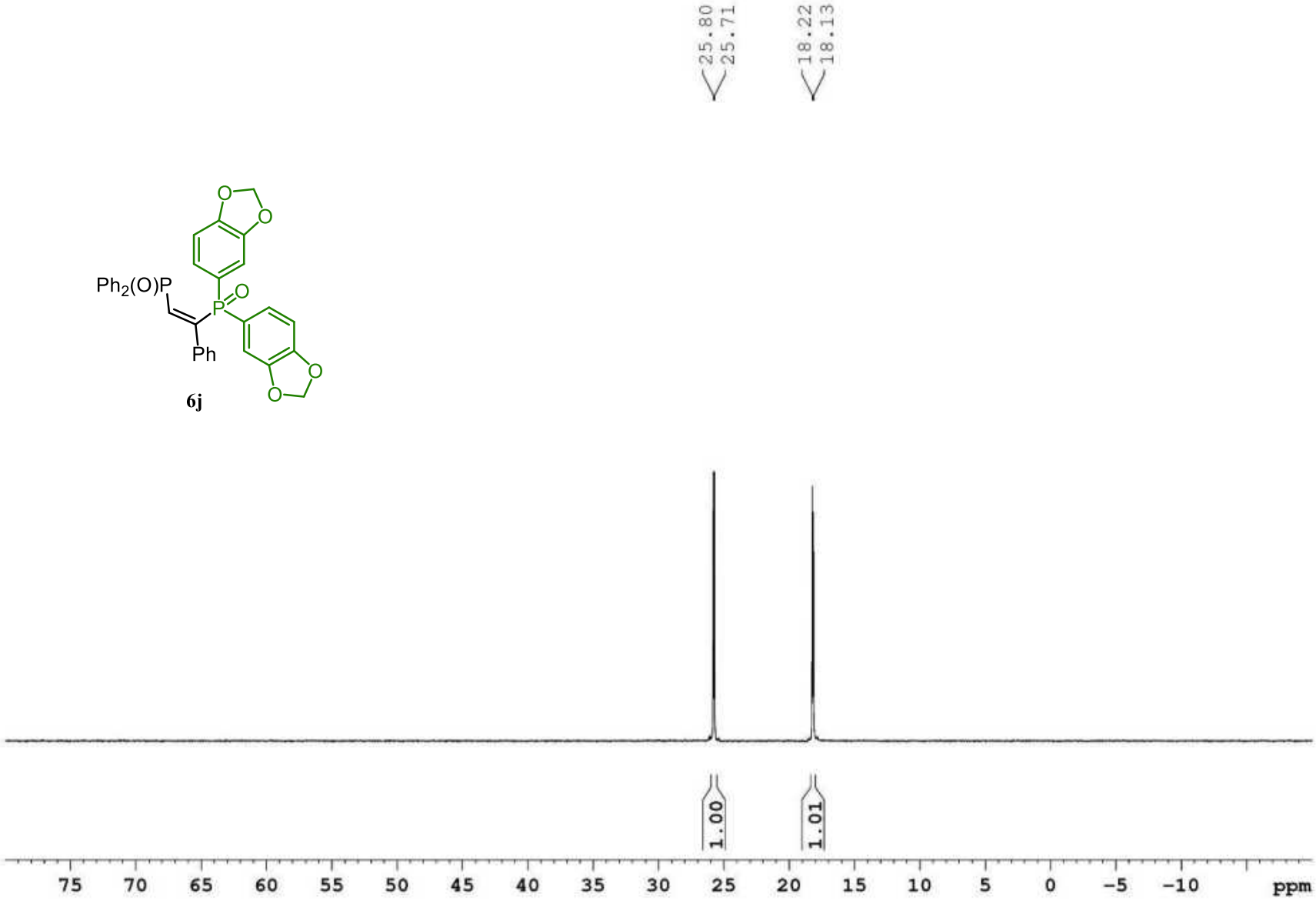
30
20
10
0
ppm

Ph2(O)P
P
O
Ph
O
O
O
O

6j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1.01
75
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60
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50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm


8.31
8.28
7.91
7.53
7.52
7.51
7.50
7.50
7.49
7.48
7.46
7.43
7.42
7.41
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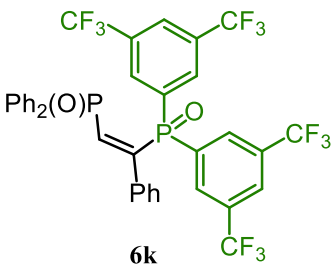
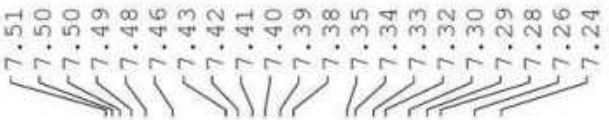
7.28
7.26
7.24


CF3
CF3
Ph2(O)P
P
O
CF3
Ph
CF3

6k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7.49
7.48
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7.30
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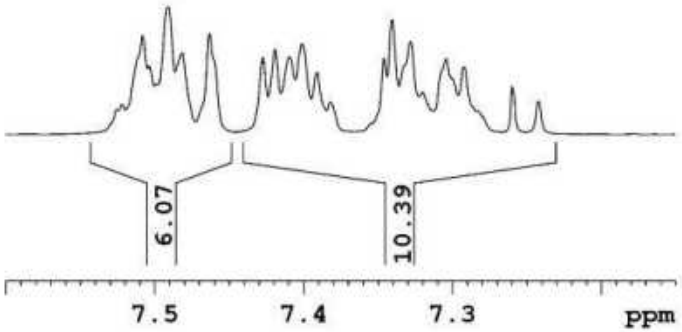
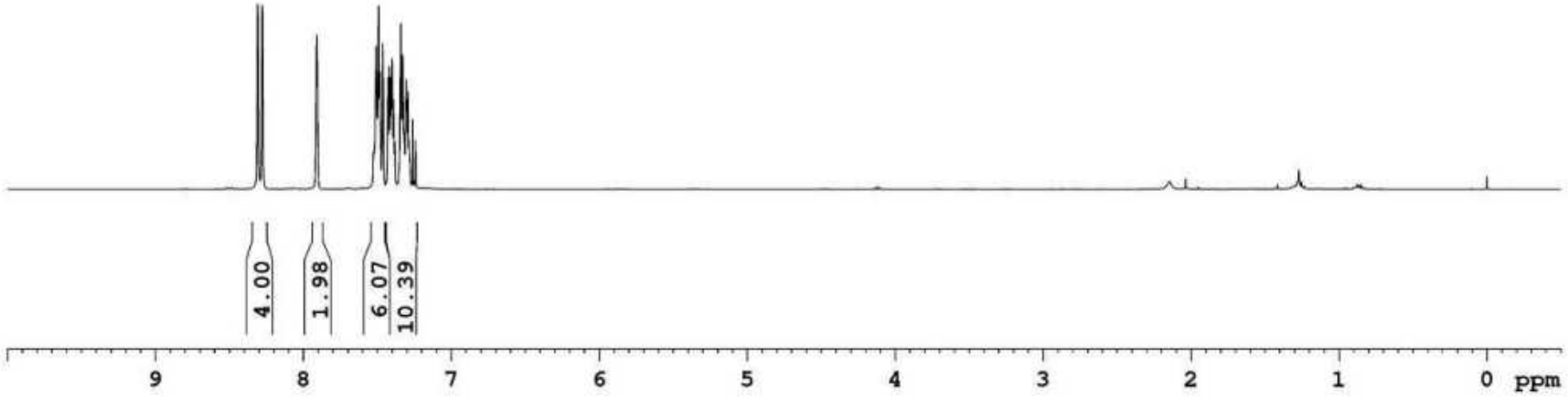
7.26
7.24


6.07
10.39
7.5
7.4
7.3
ppm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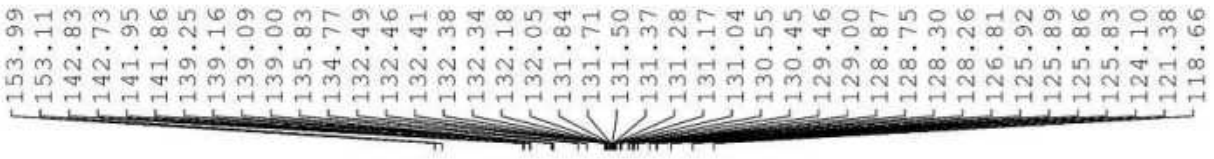
1.98
6.07
10.39
9
8
7
6
5
4
3
2
1
0
ppm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134.77
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132.34
132.18
132.05
131.84
131.71
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131.37
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131.17
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129.46
129.00
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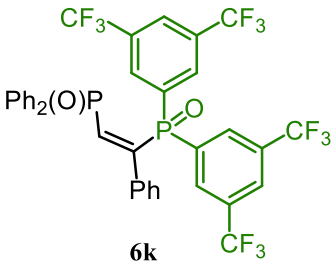
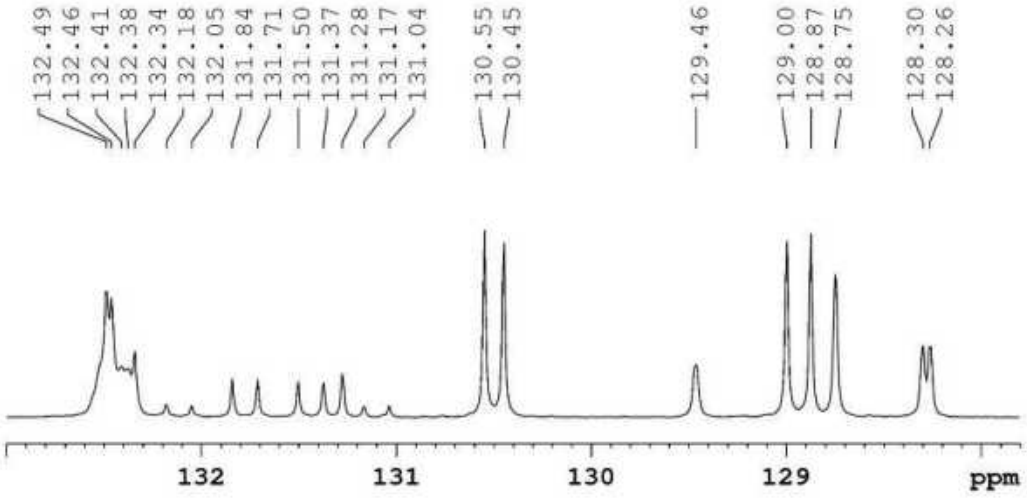
125.89
125.86
125.83
124.10
121.38
118.66


CF3
CF3
Ph2(O)P
P
O
CF3
Ph
CF3

6k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131.28
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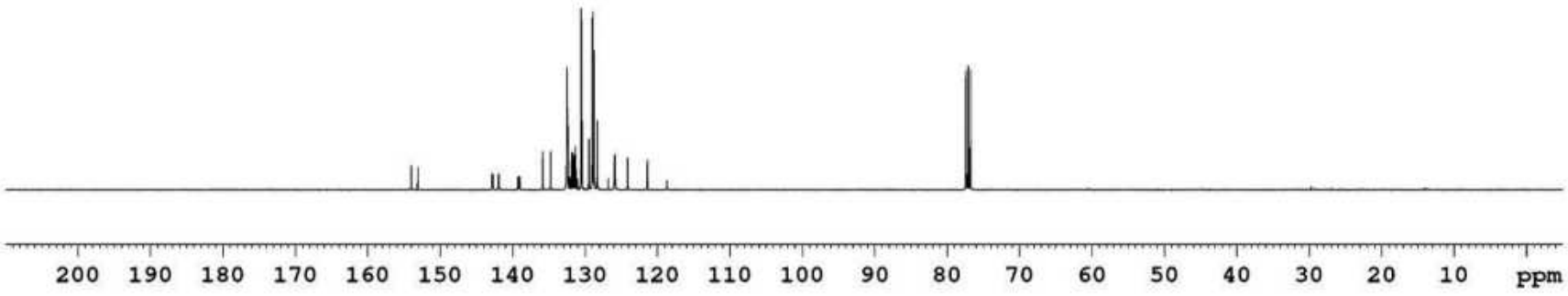
132
131
130
129
ppm


200
190
180
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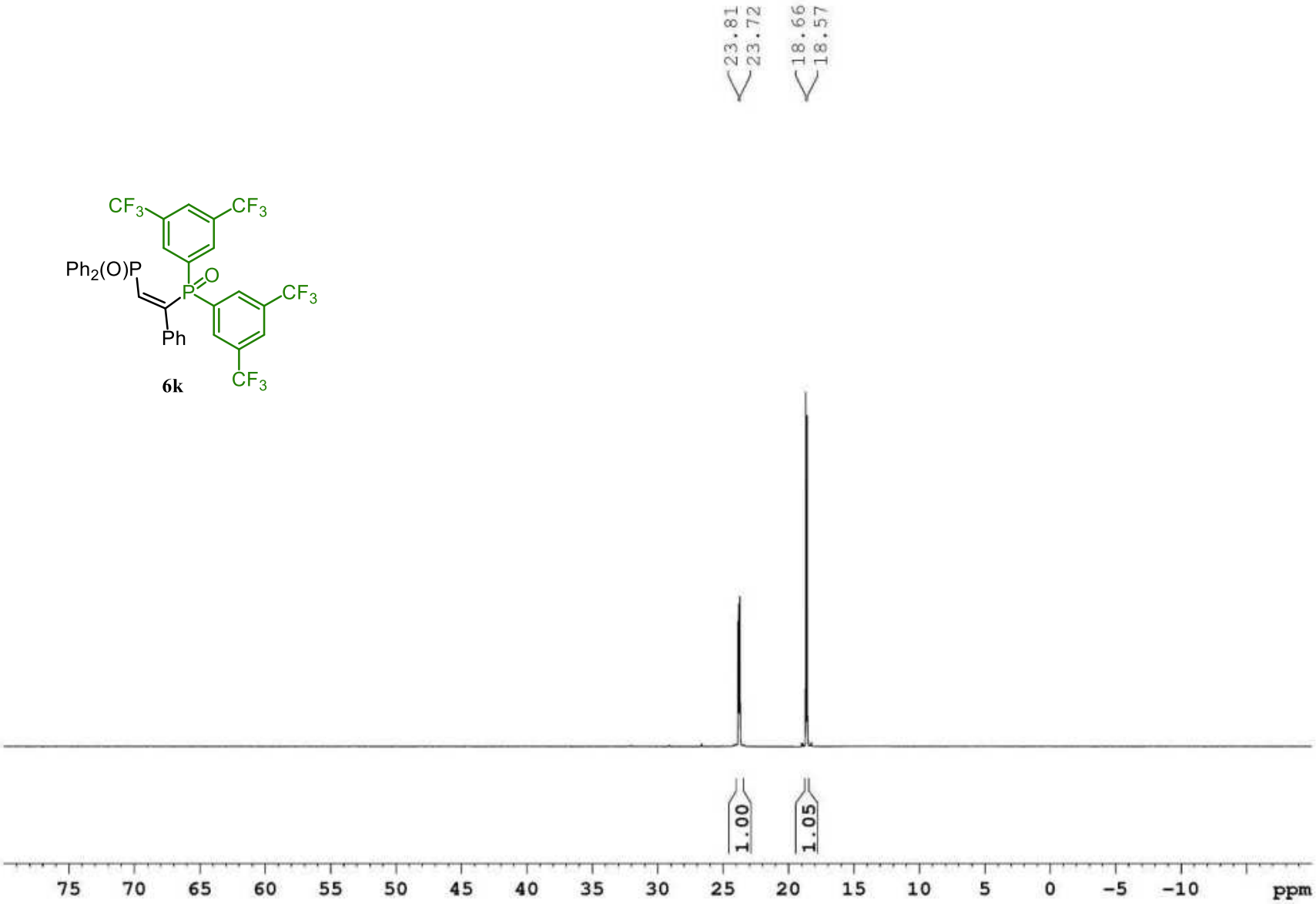
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm

CF3
CF3
Ph2(O)P
P
O
CF3
Ph
CF3

6k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23.72
18.66
18.57
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1.05
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70
65
60
55
50
45
40
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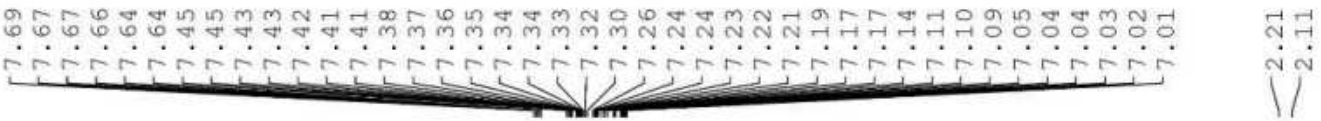
-5
-10
ppm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7.67
7.66
7.64
7.64
7.45
7.45
7.43
7.43
7.42
7.41
7.41
7.38
7.37
7.36
7.35
7.34
7.34
7.33
7.32
7.30
7.26
7.24
7.24
7.23
7.22
7.21
7.19
7.17
7.17
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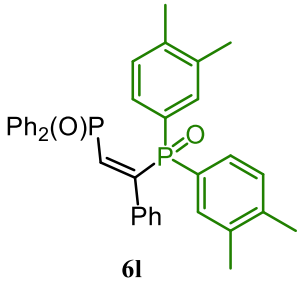
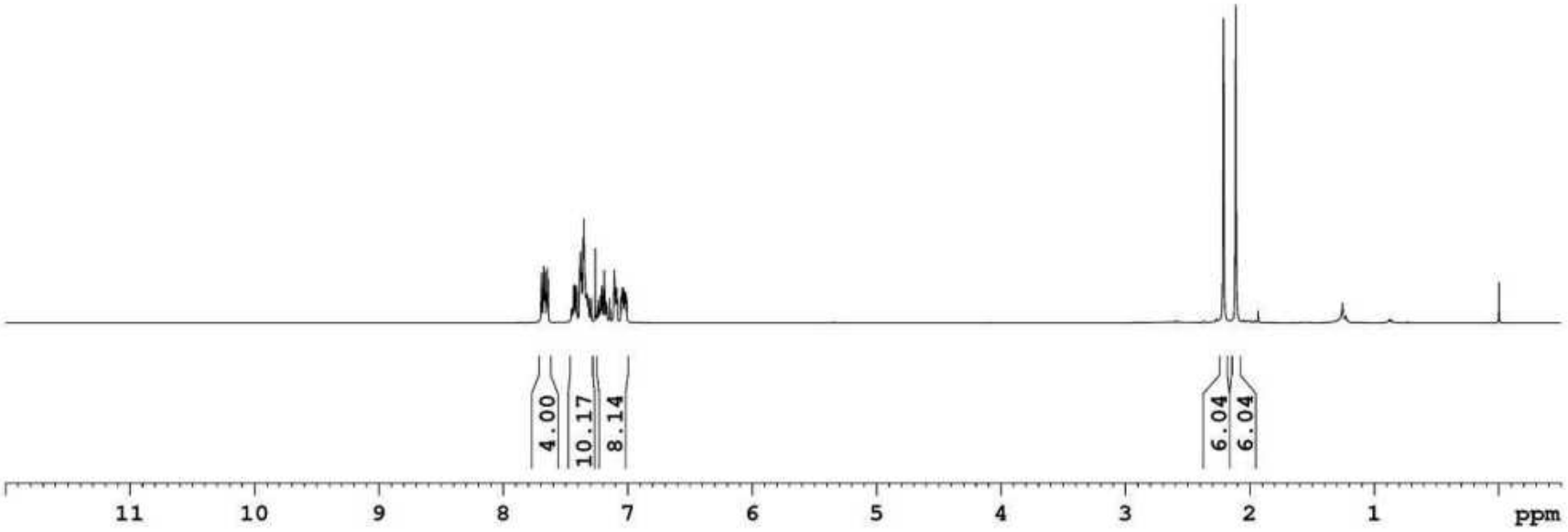
7.09
7.05
7.04
7.04
7.03
7.02
7.01
2.21
2.11


Ph2(O)P
P
O
Ph

6l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6.04
11
10
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8
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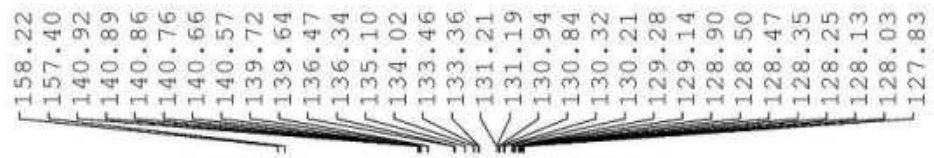
4
3
2
1
ppm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157.40
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140.76
140.66
140.57
139.72
139.64
136.47
136.34
135.10
134.02
133.46
133.36
131.21
131.19
130.94
130.84
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129.28
129.14
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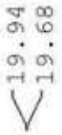
128.50
128.47
128.35
128.25
128.13
128.03
127.83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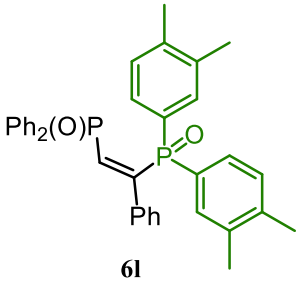
19.68


Ph2(O)P
P
O
Ph

6l


136.47
136.34
135.10
134.02
133.46
133.36
131.21
131.19
130.94
130.84
130.32
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129.28
129.14
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128.50
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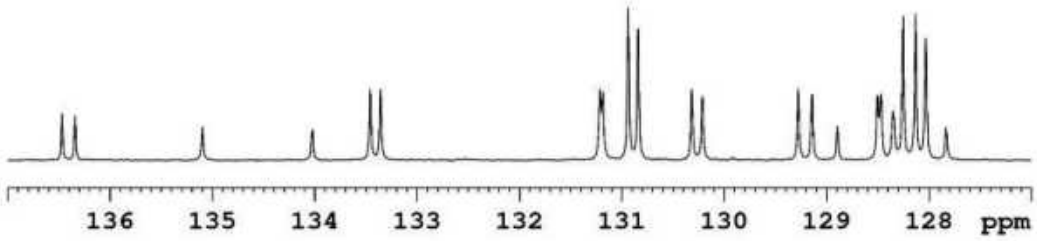
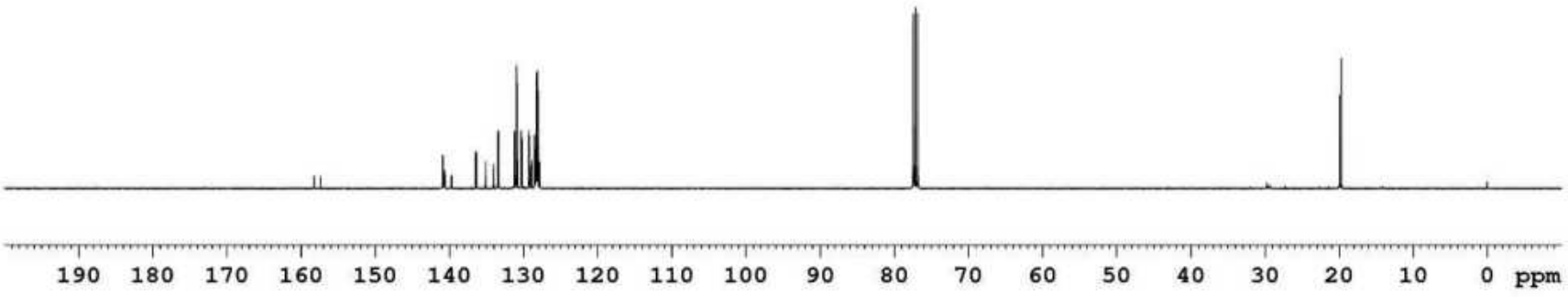
128.35
128.25
128.13
128.03
127.83


136
135
134
133
132
131
130
129
128
ppm


190
180
170
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150
140
130
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100
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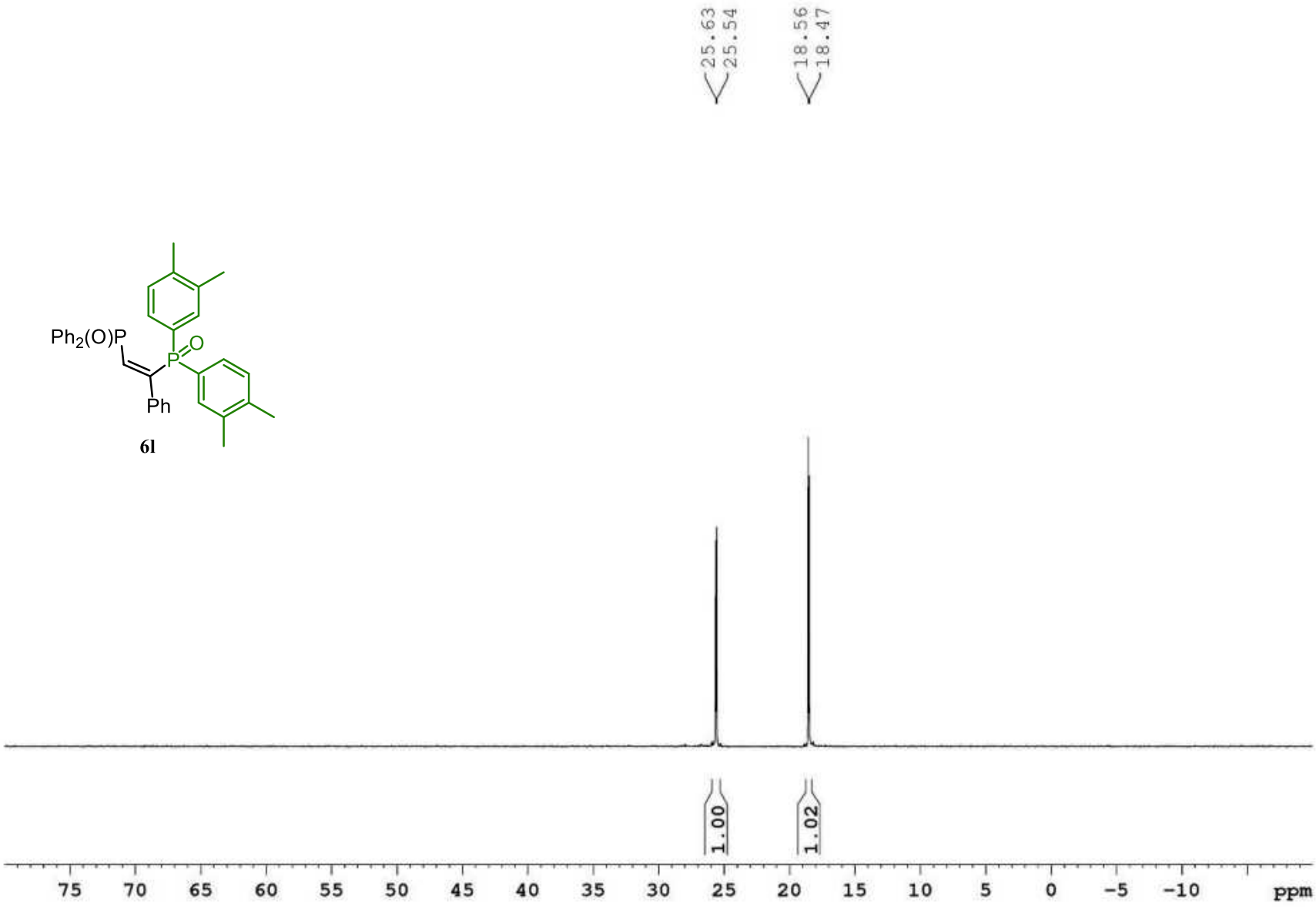
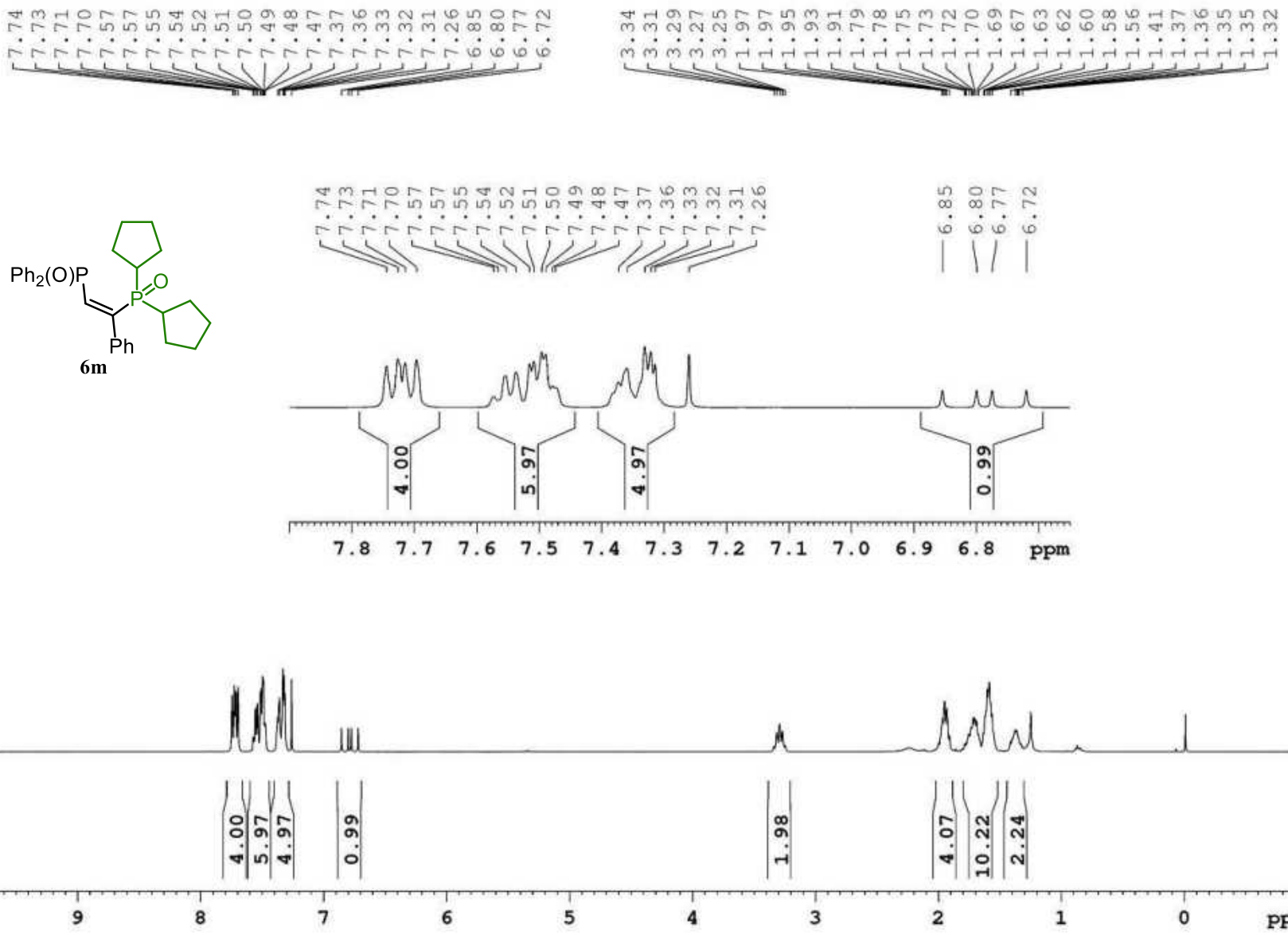
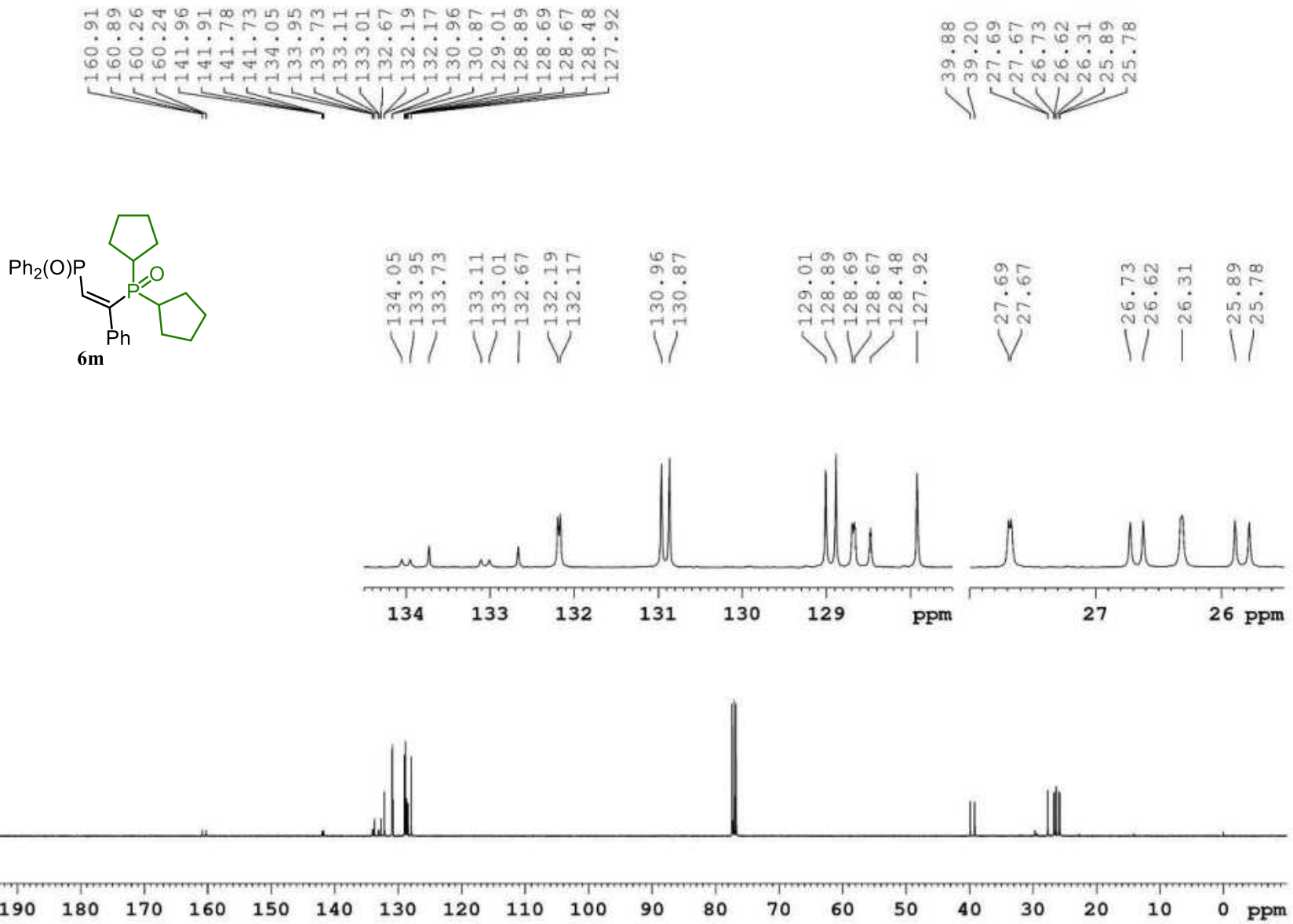
70
60
50
40
30
20
10
0
ppm

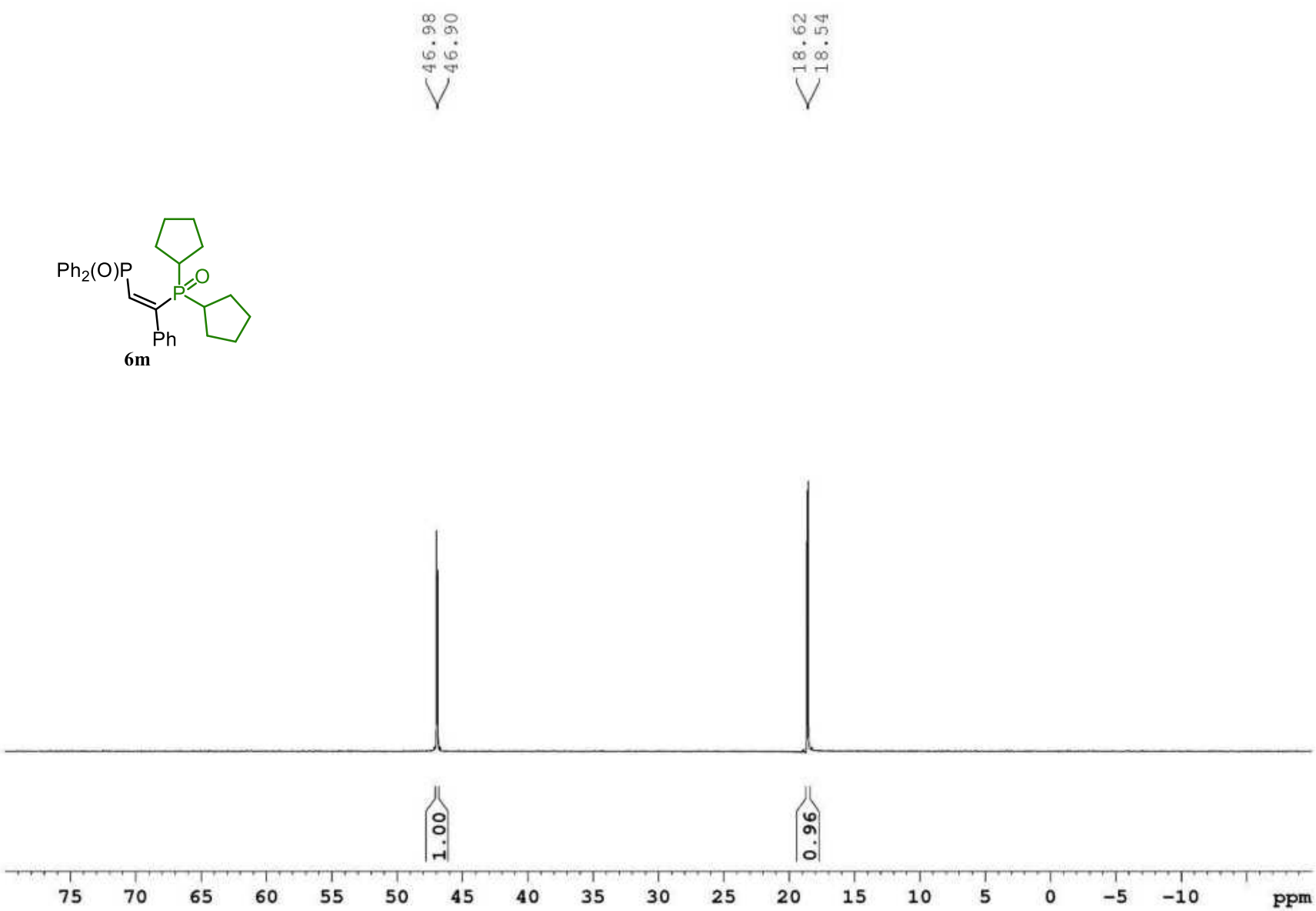
Ph2(O)P
P
O
Ph

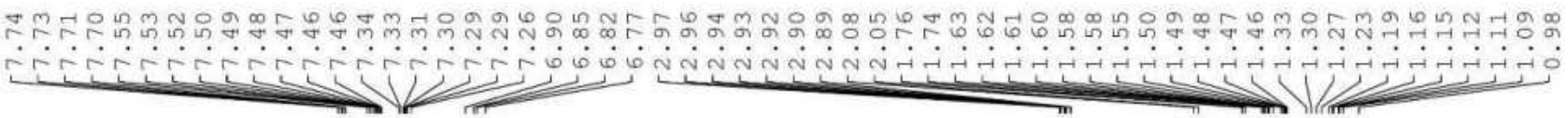
6l

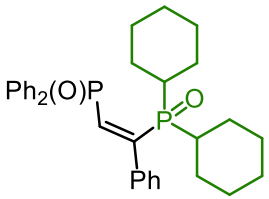

25.63
25.54
18.56
18.47
1.00
1.02
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm


7.74 7.73 7.71 7.70 7.57 7.57 7.55 7.54 7.52 7.51 7.50 7.49 7.48 7.47 7.37 7.36 7.33 7.32 7.31 7.26 6.85 6.80 6.77 6.72
3.34 3.31 3.29 3.27 3.25 1.97 1.97 1.95 1.93 1.91 1.79 1.78 1.75 1.73 1.72 1.70 1.69 1.67 1.63 1.62 1.60 1.58 1.56 1.41 1.37 1.36 1.35 1.35 1.32
Ph2(O)P
P
O
Ph
6m
4.00
5.97
4.97
0.99
7.8 7.7 7.6 7.5 7.4 7.3 7.2 7.1 7.0 6.9 6.8 ppm
4.00
5.97
4.97
0.99
1.98
4.07
10.22
2.24
9 8 7 6 5 4 3 2 1 0 ppm

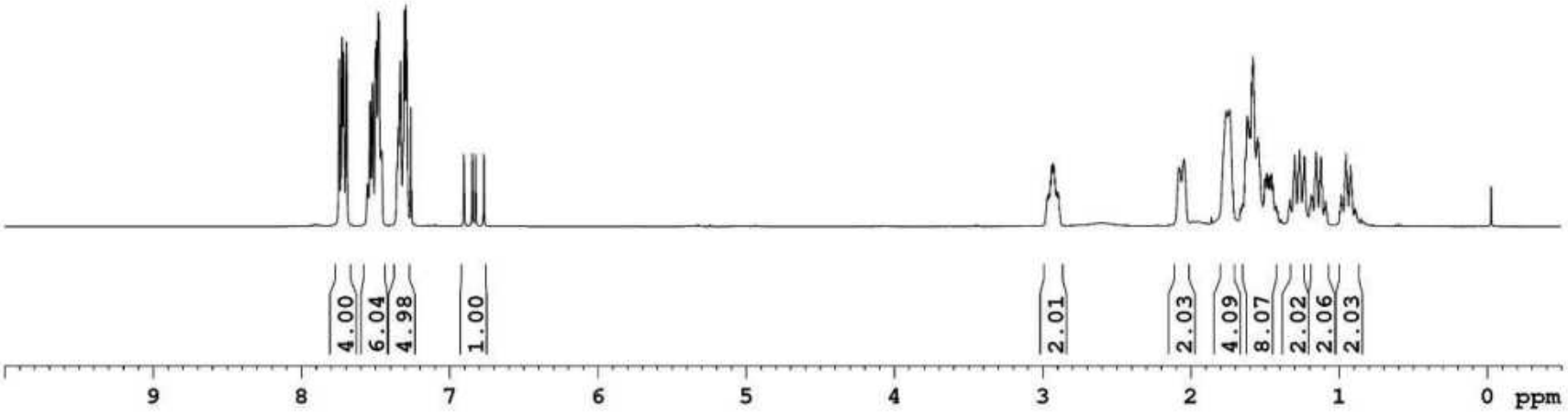

160.91
160.89
160.26
160.24
141.96
141.91
141.78
141.73
134.05
133.95
133.73
133.11
133.01
132.67
132.19
132.17
130.96
130.87
129.01
128.89
128.69
128.67
128.48
127.92
39.88
39.20
27.69
27.67
26.73
26.62
26.31
25.89
25.78
Ph2(O)P
Ph
6m
ppm
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm

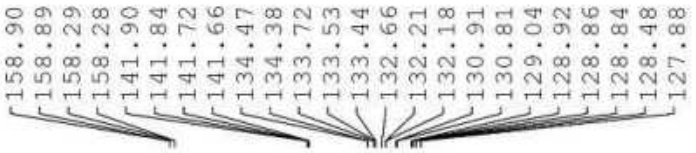

46.98
46.90
18.62
18.54
Ph2(O)P
P
O
Ph
6m
1.00
0.96
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm


7.74
7.73
7.71
7.70
7.55
7.53
7.52
7.50
7.49
7.48
7.47
7.46
7.46
7.34
7.33
7.31
7.30
7.29
7.29
7.26
6.90
6.85
6.82
6.77
2.97
2.96
2.94
2.93
2.92
2.90
2.89
2.08
2.05
1.76
1.74
1.63
1.62
1.61
1.60
1.58
1.58
1.55
1.50
1.49
1.48
1.47
1.46
1.33
1.30
1.27
1.23
1.19
1.16
1.15
1.12
1.11
1.09
0.98


Ph2(O)P
P
O
Ph

6n


4.00
6.04
4.98
1.00
2.01
2.03
4.09
8.07
2.02
2.06
2.03
9
8
7
6
5
4
3
2
1
0
ppm


158.90
158.89
158.29
158.28
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141.84
141.72
141.66
134.47
134.38
133.72
133.53
133.44
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132.18
130.91
130.81
129.04
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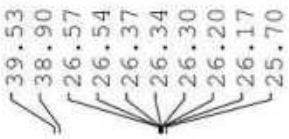
128.84
128.48
127.88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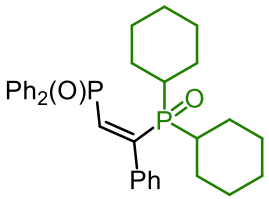
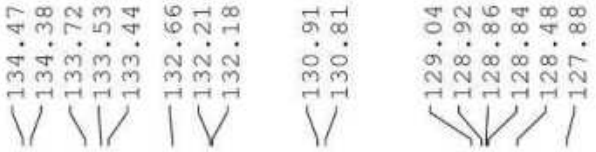
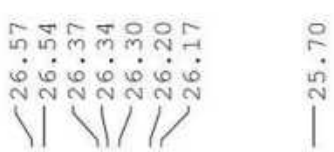
26.54
26.37
26.34
26.30
26.20
26.17
25.70


Ph2(O)P
P
O
Ph

6n


134.47
134.38
133.72
133.53
133.44
132.66
132.21
132.18
130.91
130.81
129.04
128.92
128.86
128.84
128.48
127.88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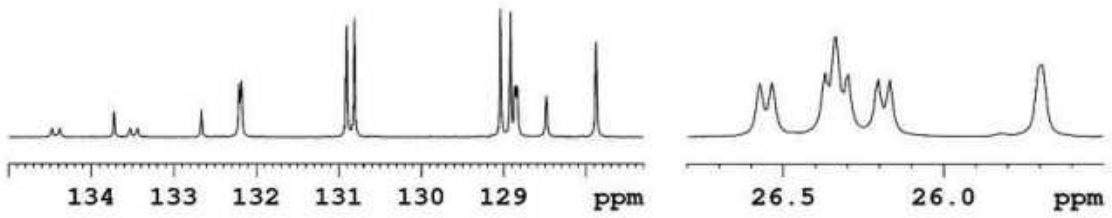
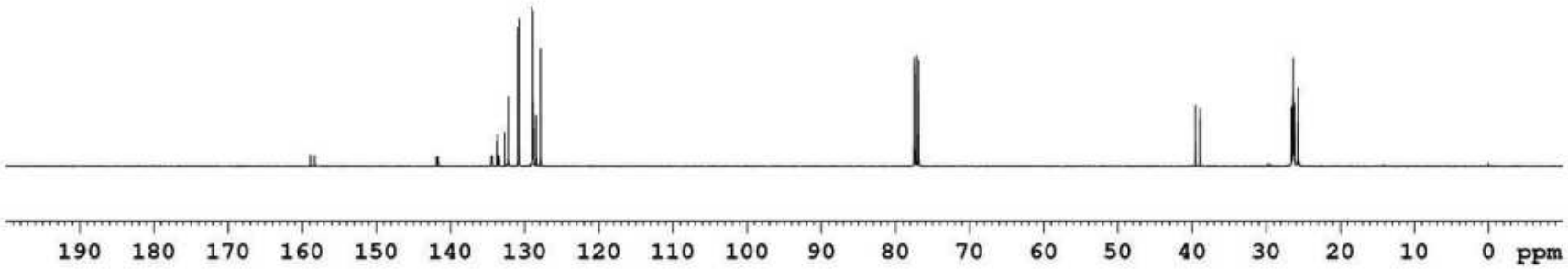
26.54
26.37
26.34
26.30
26.20
26.17

25.70


134
133
132
131
130
129
ppm
26.5
26.0
ppm


190
180
170
160
150
140
130
120
110
100
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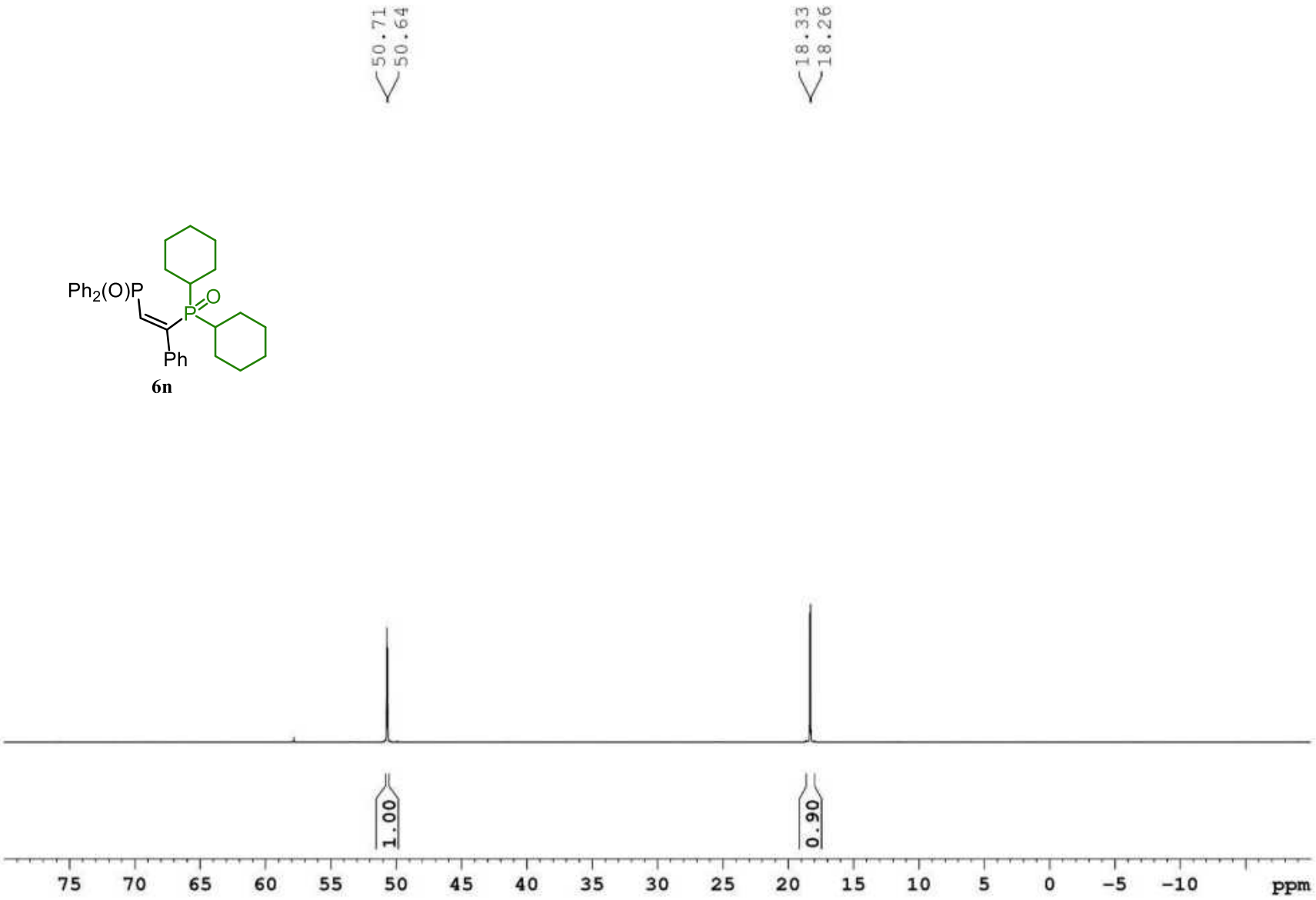
80
70
60
50
40
30
20
10
0
ppm

Ph2(O)P
P
O
Ph

6n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50.64
18.33
18.26
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0.90
75
70
65
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50
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40
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30
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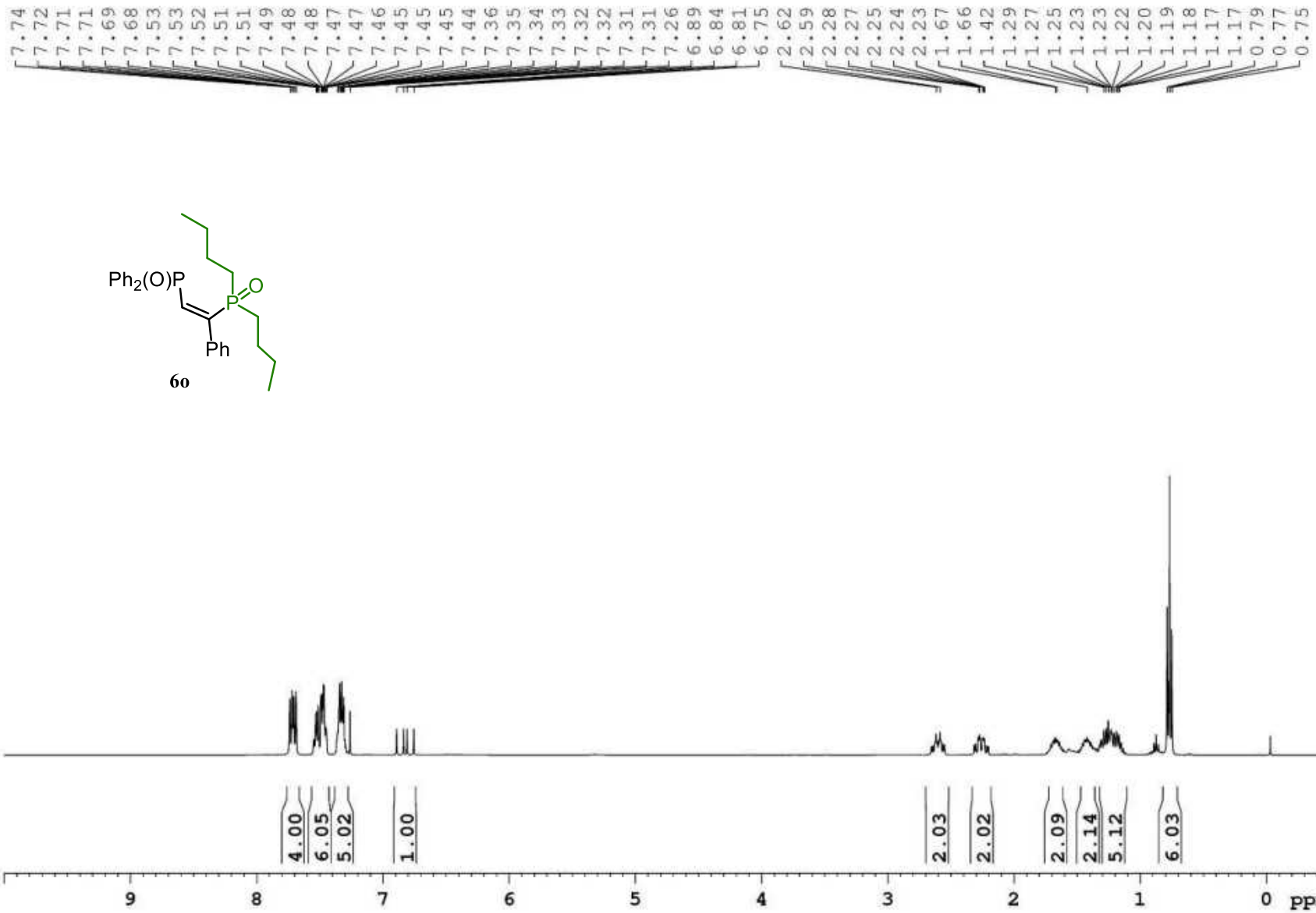
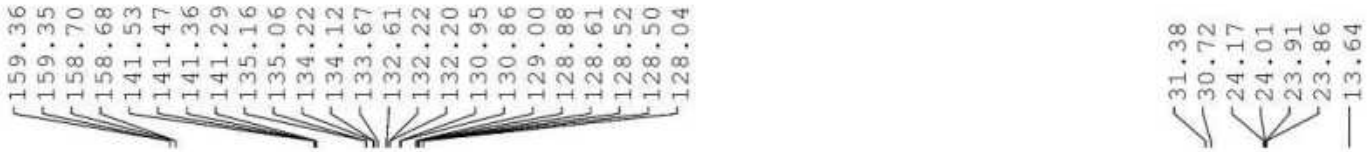
20
15
10
5
0
-5
-10
ppm


7.74 7.72 7.71 7.71 7.69 7.68 7.53 7.53 7.52 7.51 7.51 7.49 7.48 7.48 7.47 7.47 7.46 7.45 7.45 7.45 7.44 7.36 7.35 7.34 7.33 7.32 7.32 7.31 7.31 7.26 6.89 6.84 6.81 6.75
2.62 2.59 2.28 2.27 2.25 2.24 2.23 1.67 1.66 1.42 1.29 1.27 1.25 1.23 1.23 1.22 1.20 1.19 1.18 1.17 1.17 0.79 0.77 0.75
Ph2(O)P
P
O
Ph
4.00
6.05
5.02
1.00
2.03
2.02
2.09
2.14
5.12
6.03
9
8
7
6
5
4
3
2
1
0
ppm

6o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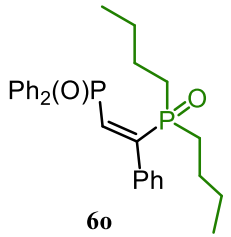
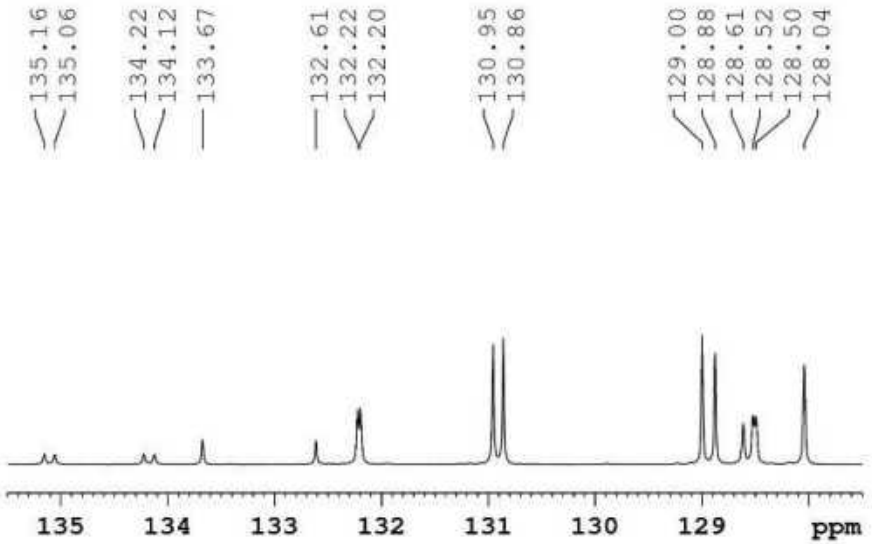
141.47
141.36
141.29
135.16
135.06
134.22
134.12
133.67
132.61
132.22
132.20
130.95
130.86
129.00
128.88
128.61
128.52
128.50
128.04
31.38
30.72
24.17
24.01
23.91
23.86
13.64


Ph2(O)P
P
O
Ph

6o


135.16
135.06
134.22
134.12
133.67
132.61
132.22
132.20
130.95
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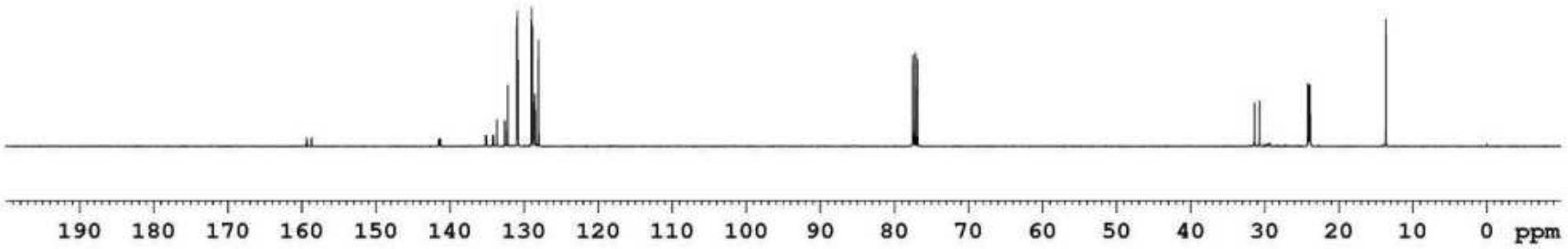
128.88
128.61
128.52
128.50
128.04
135
134
133
132
131
130
129
ppm


190
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170
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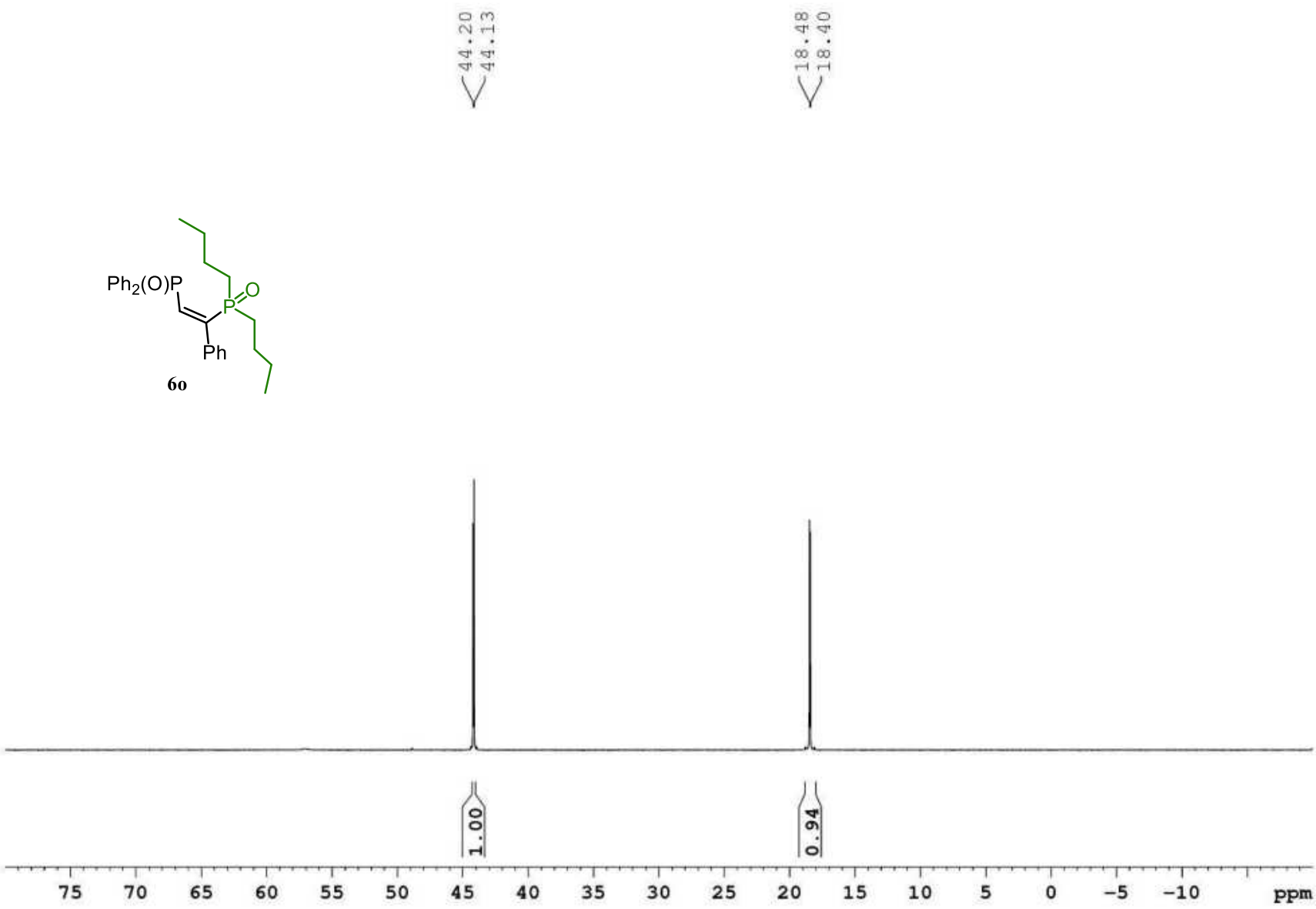
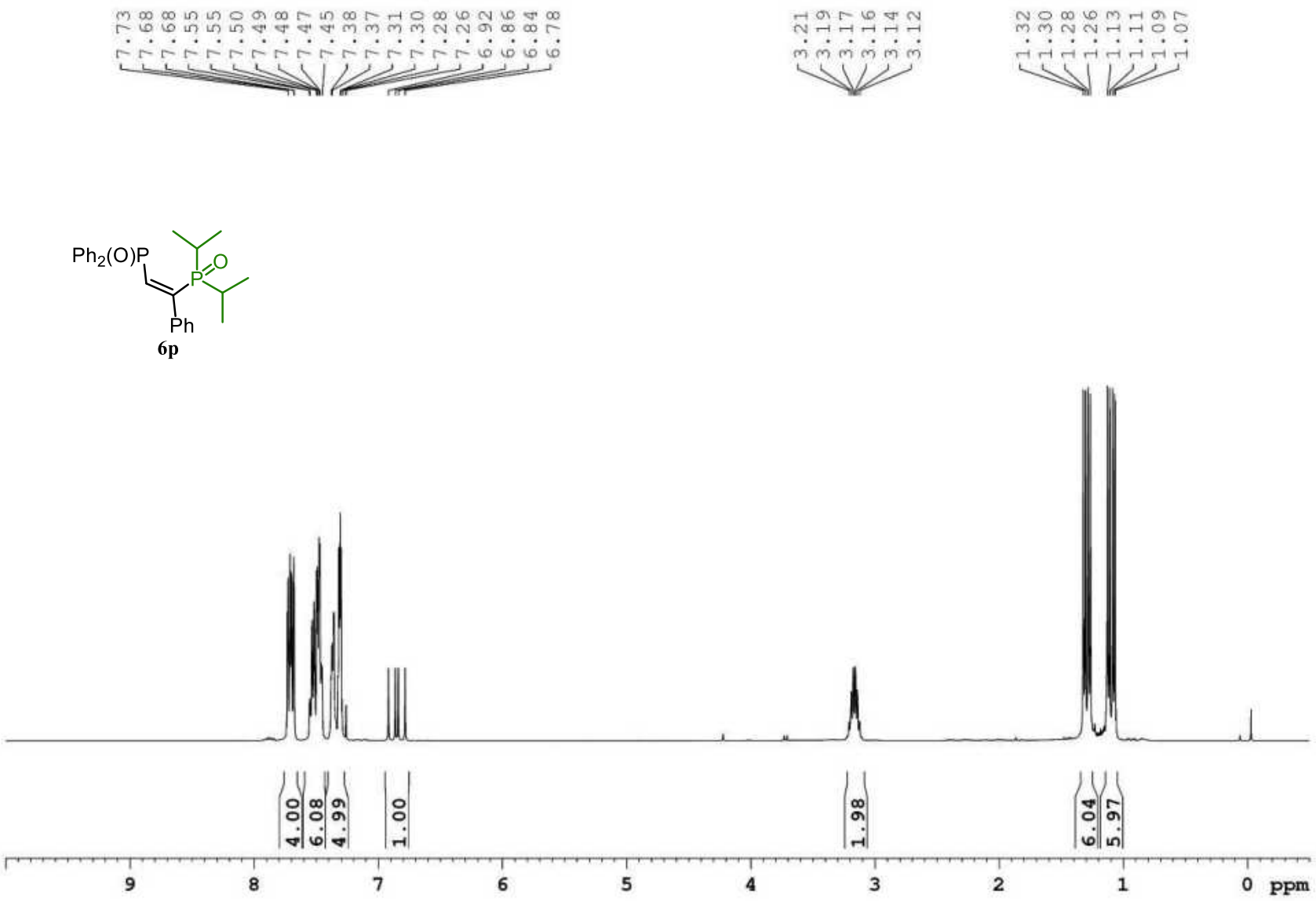
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


44.20
44.13
18.48
18.40
Ph2(O)P
P
O
Ph
1.00
0.94
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
−5
−10
ppm

6o


7.73
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7.68
7.55
7.55
7.50
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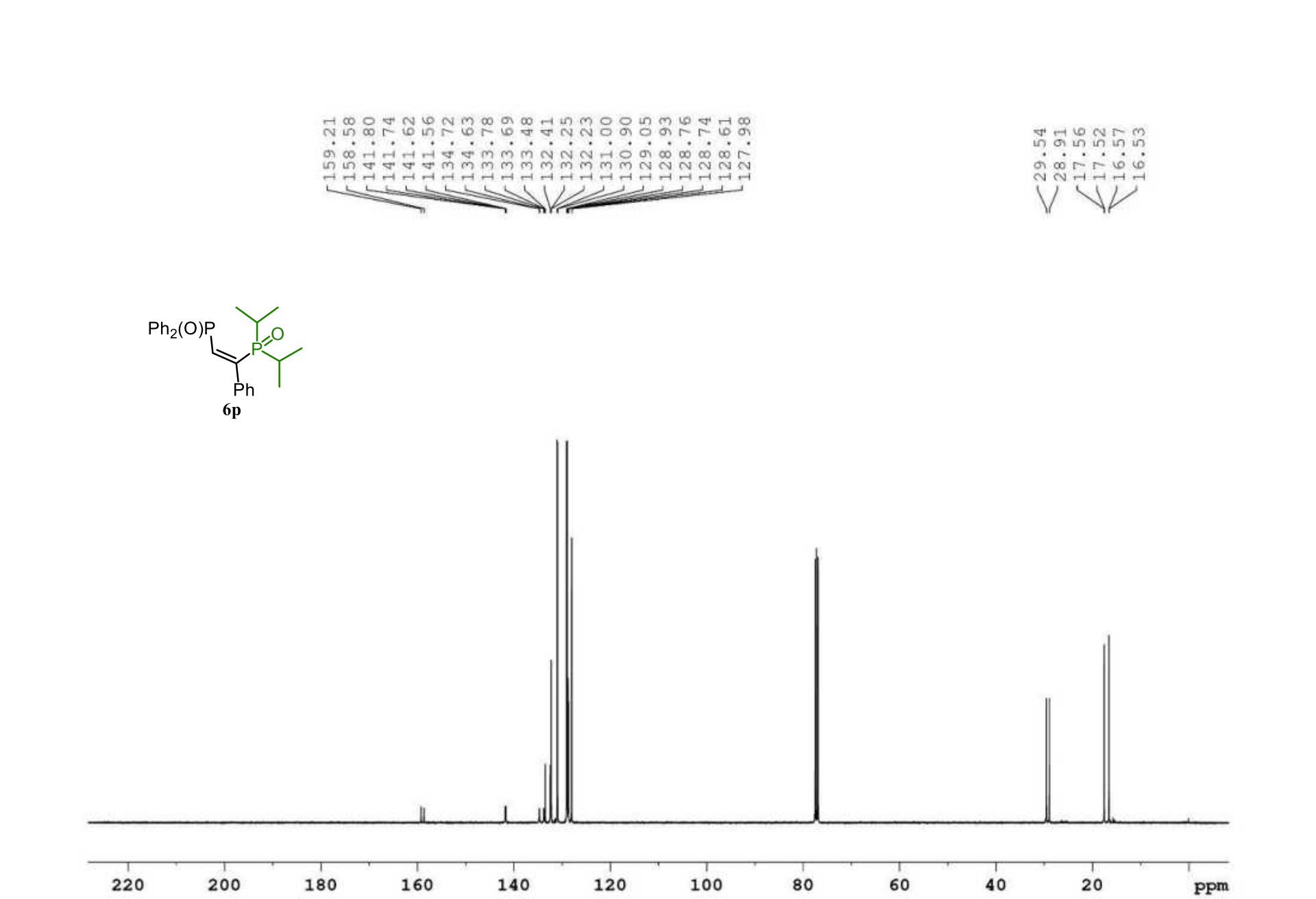
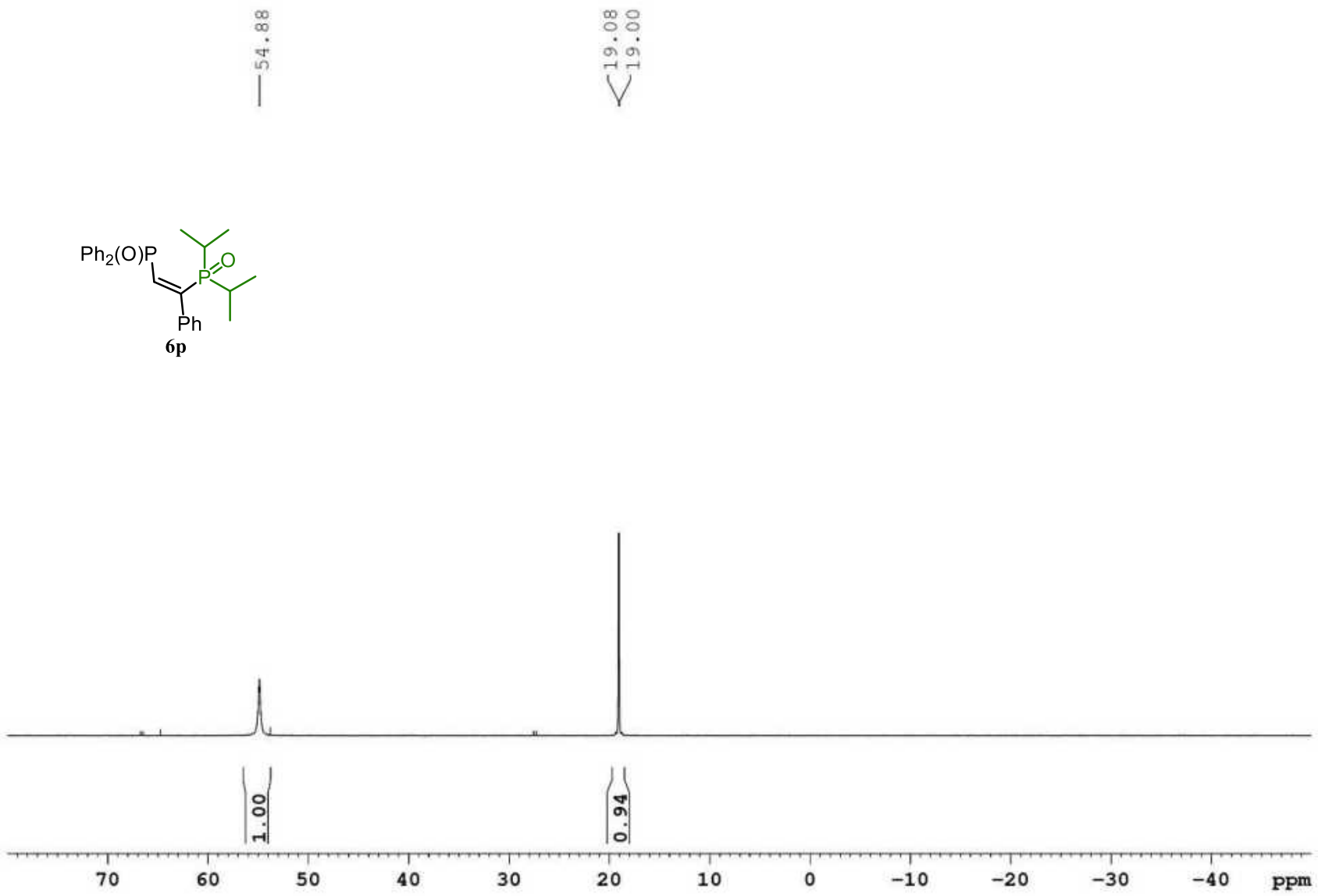
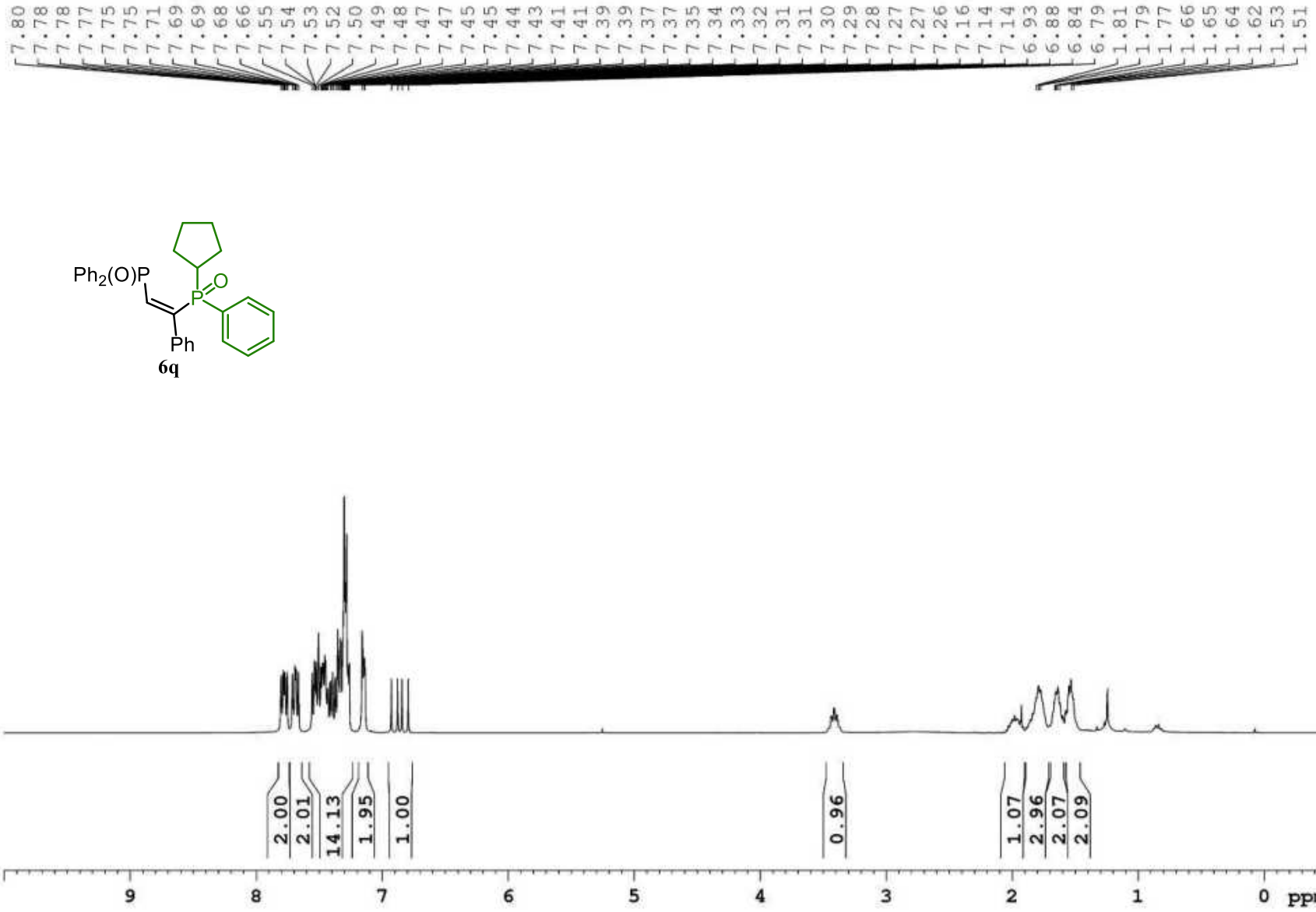
7.48
7.47
7.45
7.38
7.37
7.31
7.30
7.28
7.26
6.92
6.86
6.84
6.78
3.21
3.19
3.17
3.16
3.14
3.12
1.32
1.30
1.28
1.26
1.13
1.11
1.09
1.07
Ph2(O)P
P
O
Ph
6p
4.00
6.08
4.99
1.00
1.98
6.04
5.97
9
8
7
6
5
4
3
2
1
0
ppm


159.21
158.58
141.80
141.74
141.62
141.56
134.72
134.63
133.78
133.69
133.48
132.41
132.25
132.23
131.00
130.90
129.05
128.93
128.76
128.74
128.61
127.98
29.54
28.91
17.56
17.52
16.57
16.53
Ph2(O)P
P
O
Ph
6p
220
200
180
160
140
120
100
80
60
40
20
ppm


54.88
19.08
19.00
Ph2(O)P
P
O
Ph
6p
1.00
0.94
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm


7.80
7.78
7.78
7.77
7.75
7.75
7.71
7.69
7.69
7.68
7.66
7.55
7.54
7.53
7.52
7.50
7.49
7.48
7.47
7.47
7.45
7.45
7.44
7.43
7.41
7.41
7.39
7.39
7.37
7.37
7.35
7.34
7.33
7.32
7.31
7.31
7.30
7.29
7.28
7.27
7.27
7.26
7.16
7.14
7.14
6.93
6.88
6.84
6.79
1.81
1.79
1.77
1.66
1.65
1.64
1.62
1.53
1.51
Ph2(O)P
P
O
Ph
6q
2.00
2.01
14.13
1.95
1.00
0.96
1.07
2.96
2.07
2.09
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6
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2
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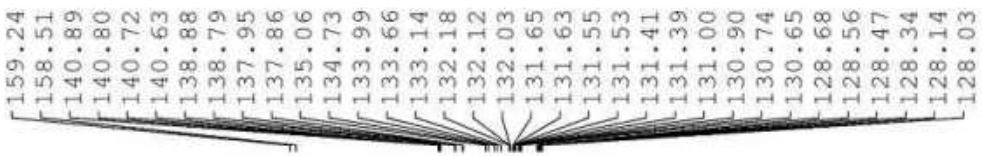
0
ppm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140.63
138.88
138.79
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137.86
135.06
134.73
133.99
133.66
133.14
132.18
132.12
132.03
131.65
131.63
131.55
131.53
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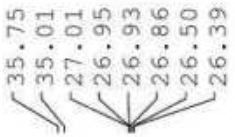
128.14
128.03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35.01
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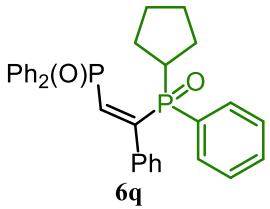
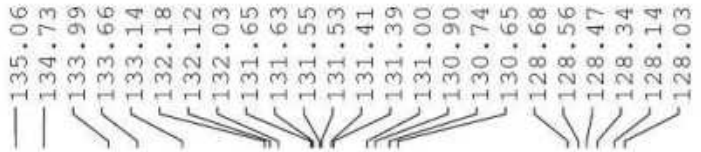
26.95
26.93
26.86
26.50
26.39


Ph2(O)P
P
O
Ph

6q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132.18
132.12
132.03
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131.63
131.55
131.53
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131.00
130.90
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128.68
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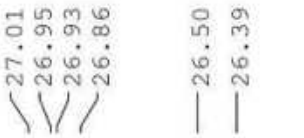
128.34
128.14
128.03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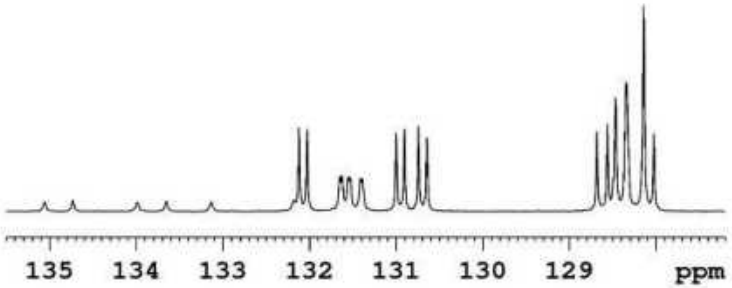
26.93
26.86
26.50
26.39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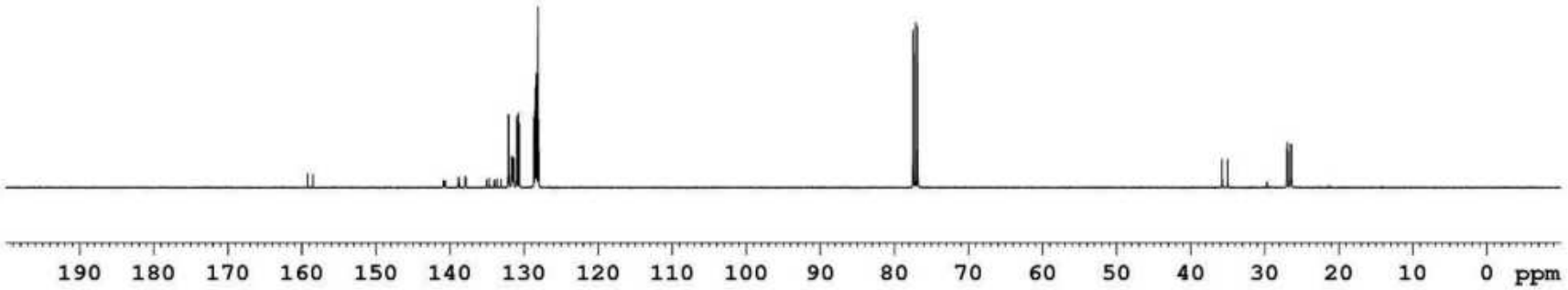
134
133
132
131
130
129
ppm


27.0
26.5 ppm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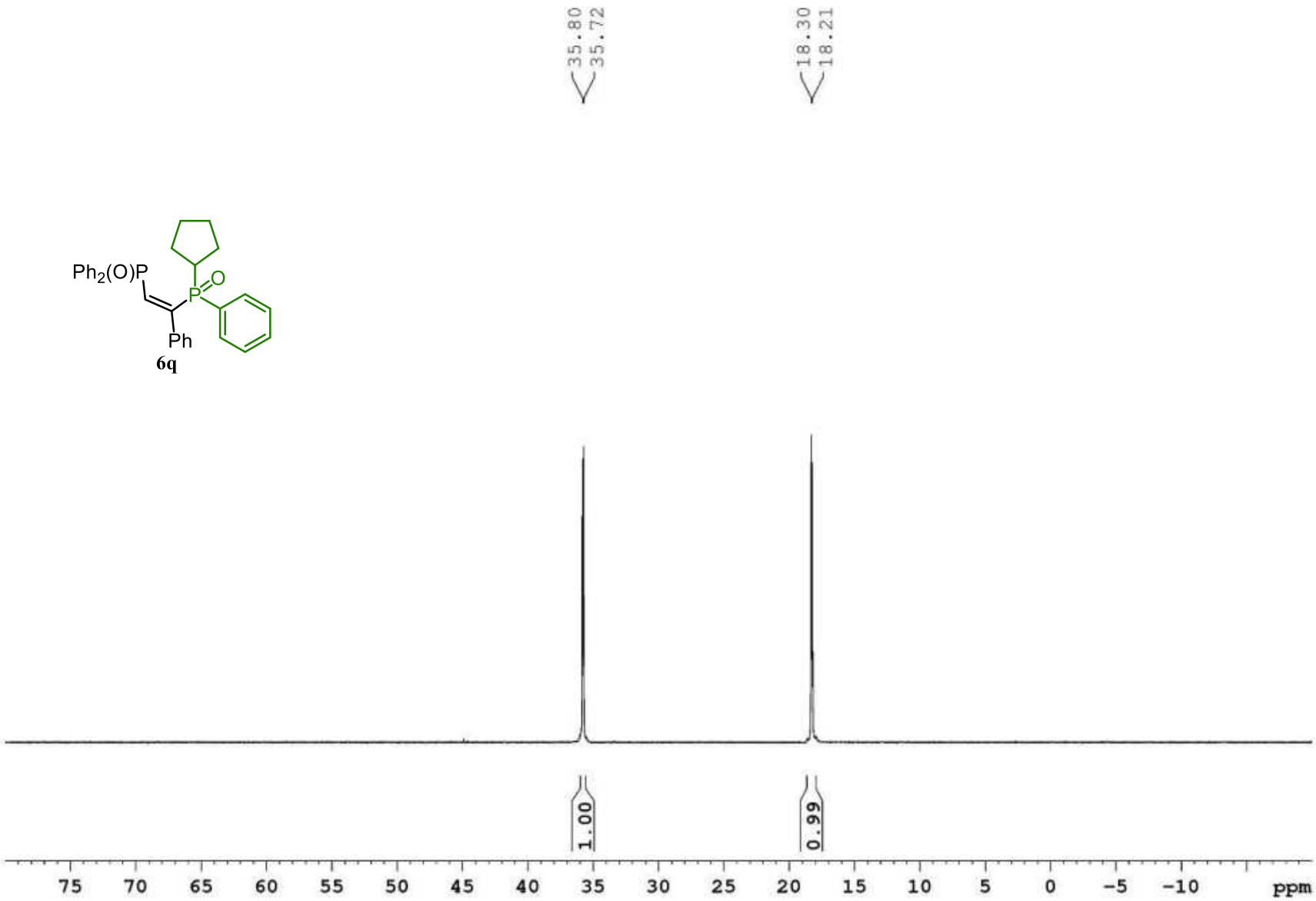
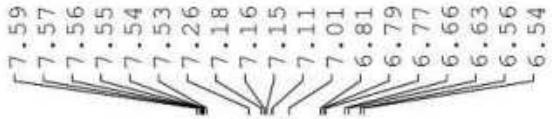
30
20
10
0 ppm


35.80
35.72
18.30
18.21
Ph2(O)P
P
O
Ph
6q
1.00
0.99
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm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7.57
7.56
7.55
7.54
7.53
7.26
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7.16
7.15
7.11
7.01
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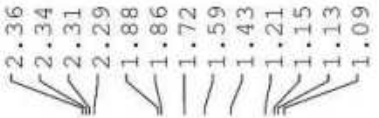
6.79
6.77
6.66
6.63
6.56
6.54


2.36
2.34
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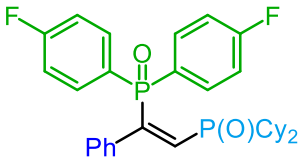
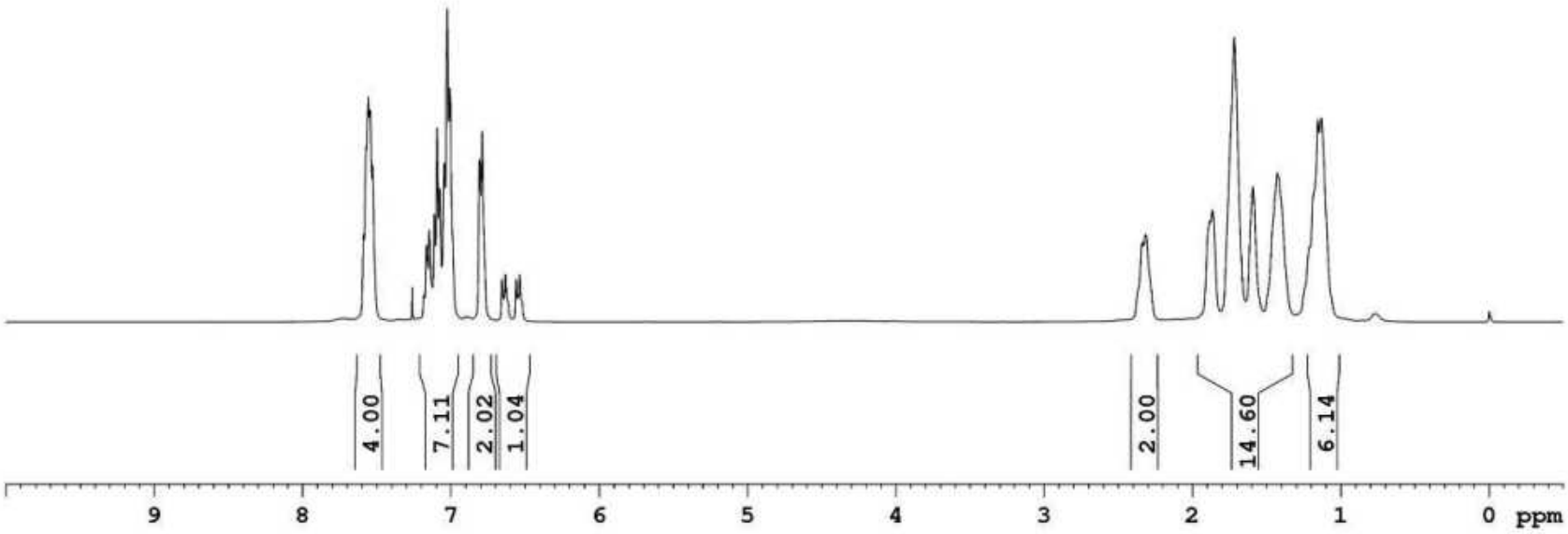
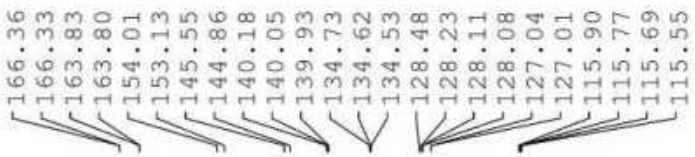
1.86
1.72
1.59
1.43
1.21
1.15
1.13
1.09


F
F
O
P
Ph
P(O)Cy2

7a


4.00
7.11
2.02
1.04
2.00
14.60
6.14
9
8
7
6
5
4
3
2
1
0
ppm


166.36
166.33
163.83
163.80
154.01
153.13
145.55
144.86
140.18
140.05
139.93
134.73
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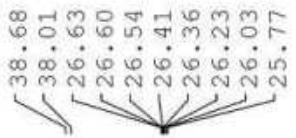
134.53
128.48
128.23
128.11
128.08
127.04
127.01
115.90
115.77
115.69
115.55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38.01
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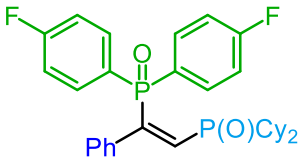
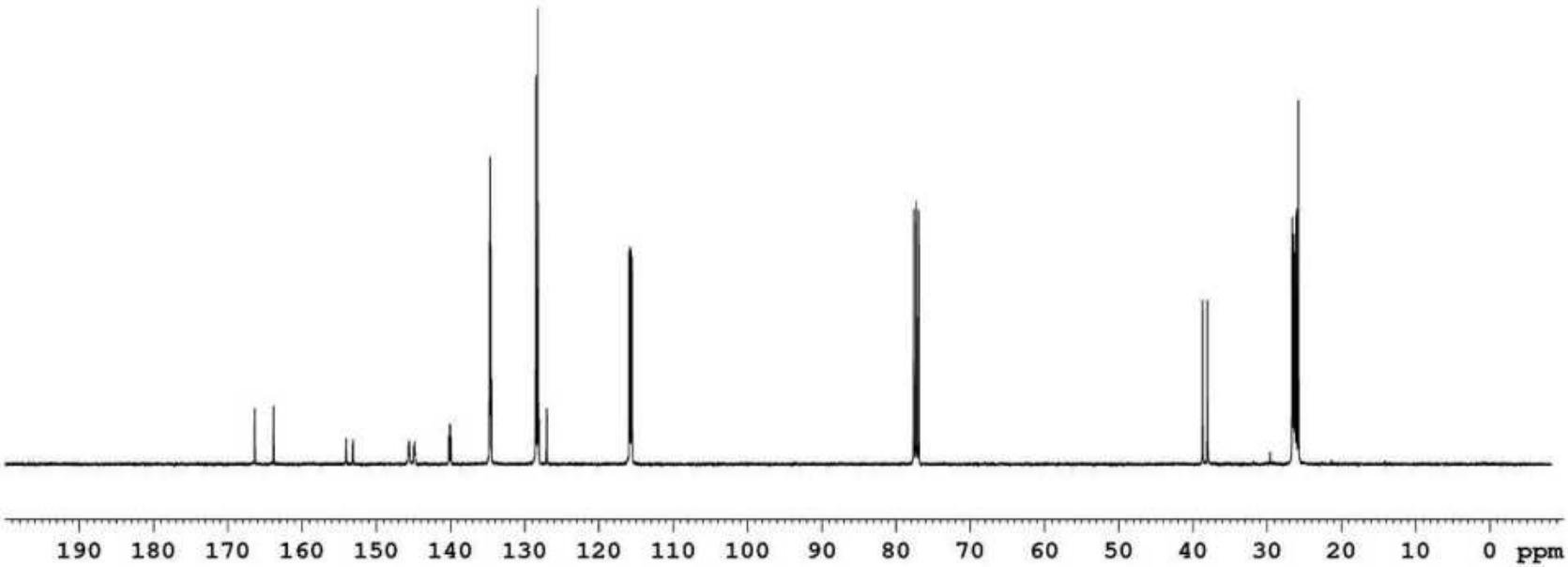
26.41
26.36
26.23
26.03
25.77


F
F
O
P
Ph
P(O)Cy2

7a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130
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110
100
90
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70
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30
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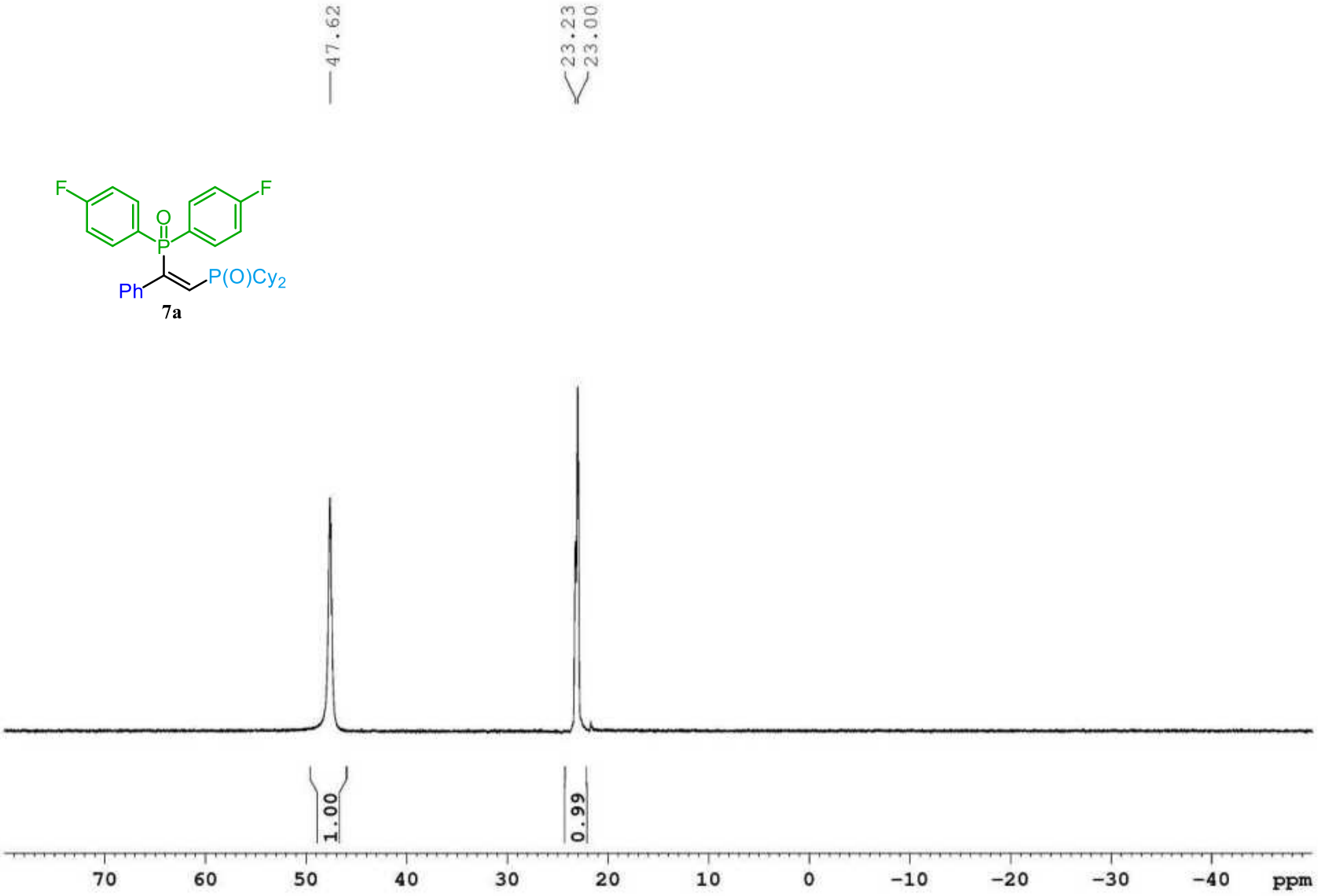
0
ppm


47.62
23.23
23.00
F
F
O
P
Ph
P(O)Cy2
7a
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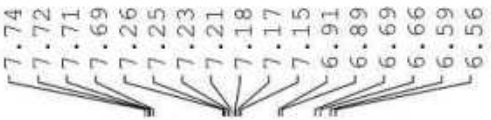
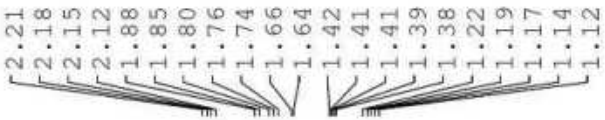
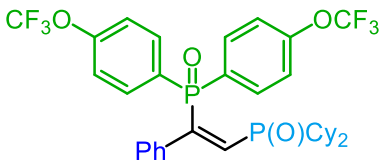
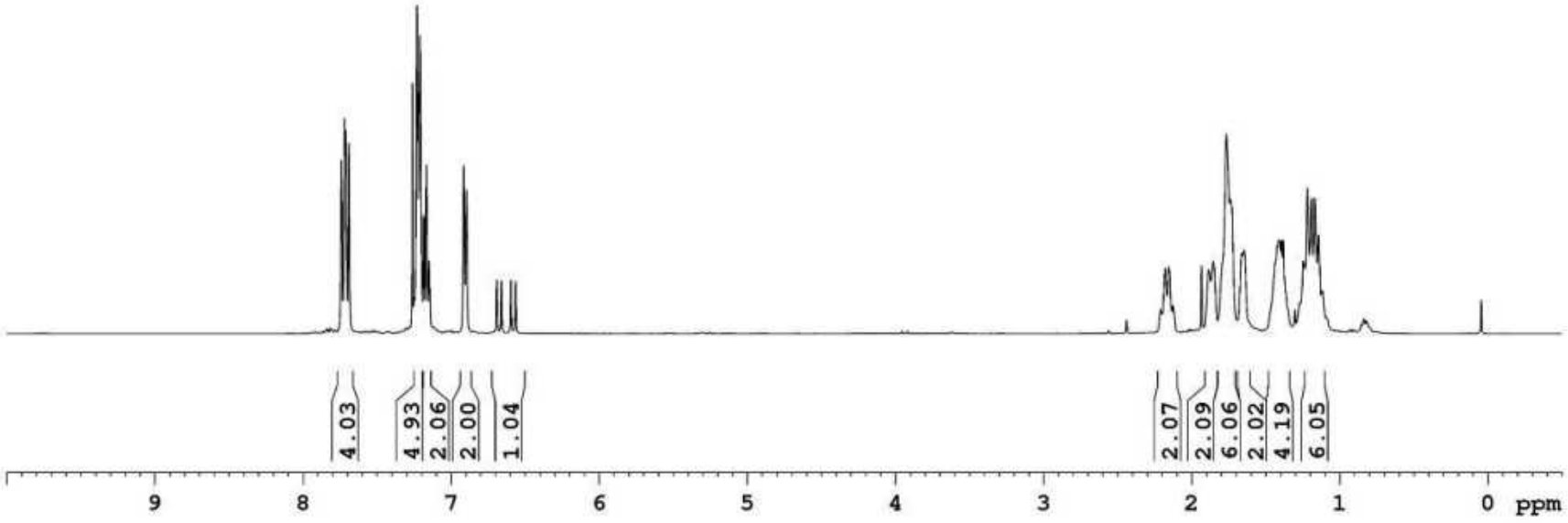
0.99
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm

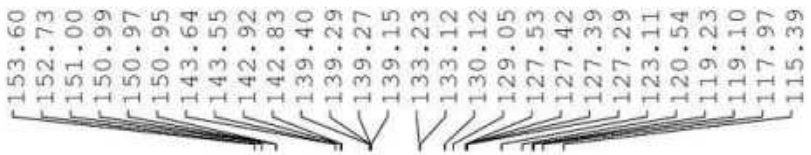

7.74
7.72
7.71
7.69
7.26
7.25
7.23
7.21
7.18
7.17
7.15
6.91
6.89
6.69
6.66
6.59
6.56


2.21
2.18
2.15
2.12
1.88
1.85
1.80
1.76
1.74
1.66
1.64
1.42
1.41
1.41
1.39
1.38
1.22
1.19
1.17
1.14
1.12


CF3O
OCF3
O
P
Ph
P(O)Cy2

7b


4.03
4.93
2.06
2.00
1.04
2.07
2.09
6.06
2.02
4.19
6.05
9
8
7
6
5
4
3
2
1
0
ppm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151.00
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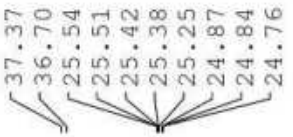
150.95
143.64
143.55
142.92
142.83
139.40
139.29
139.27
139.15
133.23
133.12
130.12
129.05
127.53
127.42
127.39
127.29
123.11
120.54
119.23
119.10
117.97
115.39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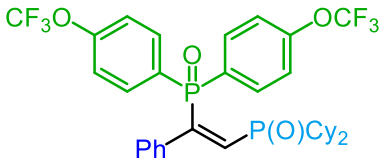
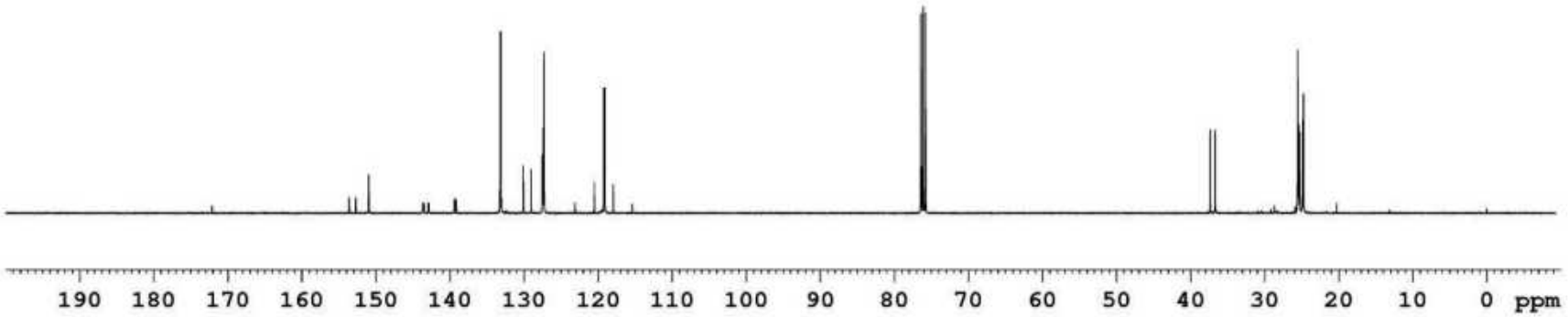
36.70
25.54
25.51
25.42
25.38
25.25
24.87
24.84
24.76


CF3O
OCF3
O
P
Ph
P(O)Cy2

7b


190
180
170
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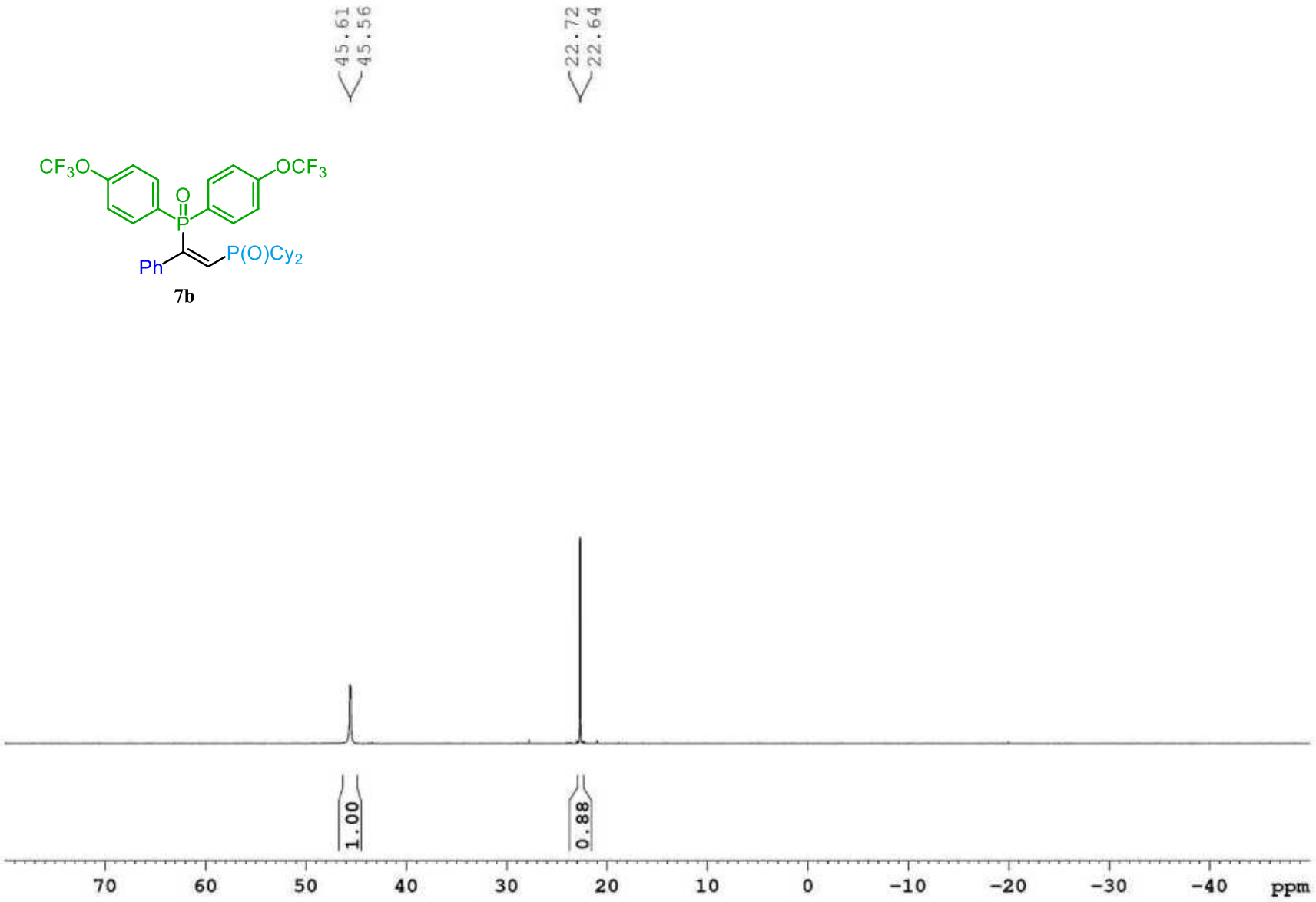
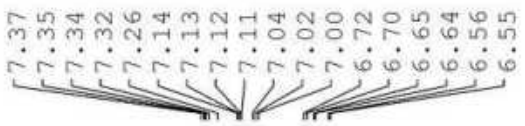
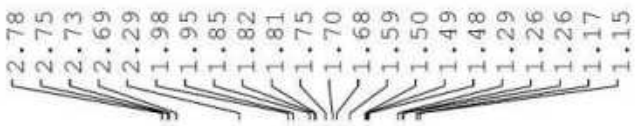
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


45.61
45.56
22.72
22.64
CF3O
OCF3
O
P
Ph
P(O)Cy2
1.00
0.88
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm

7b


7.37
7.35
7.34
7.32
7.26
7.14
7.13
7.12
7.11
7.04
7.02
7.00
6.72
6.70
6.65
6.64
6.56
6.55


2.78
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2.29
1.98
1.95
1.85
1.82
1.81
1.75
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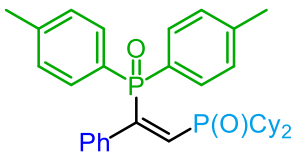
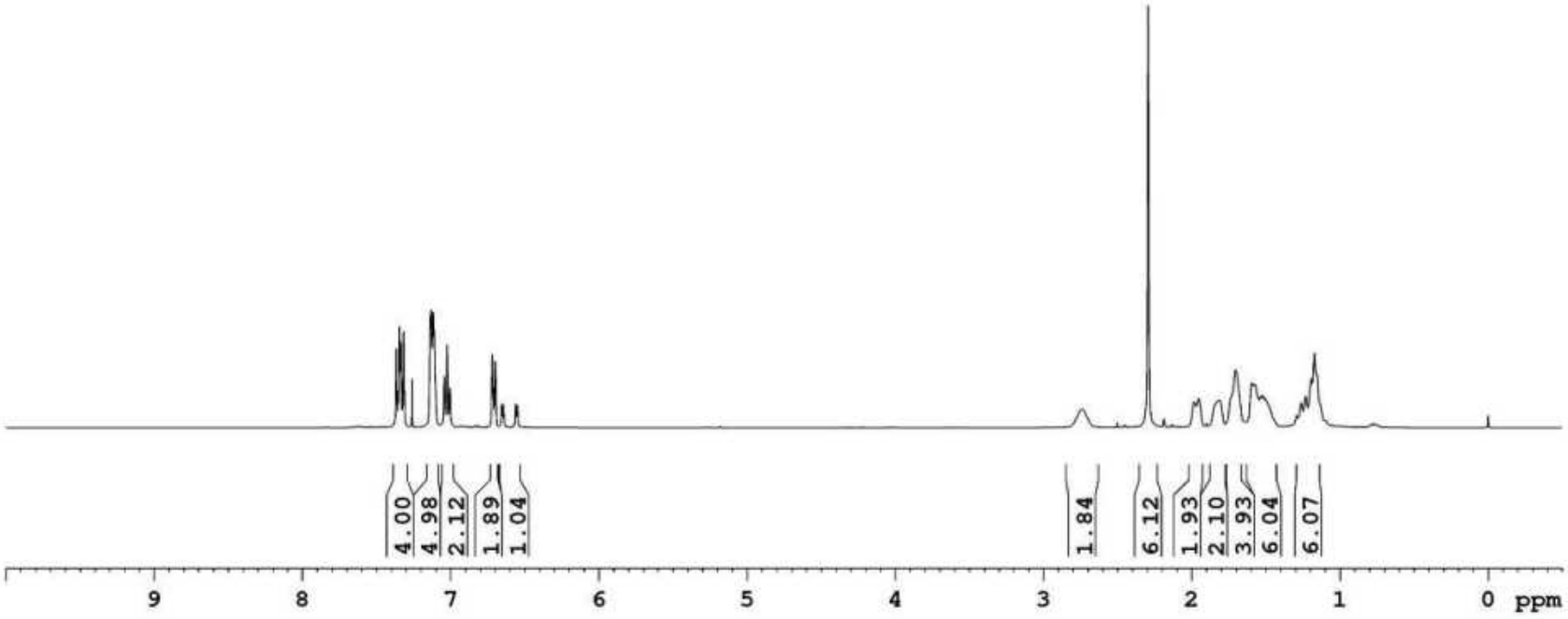
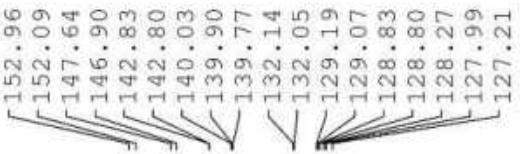
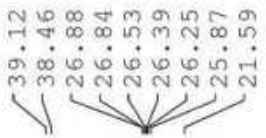
1.48
1.29
1.26
1.26
1.17
1.15

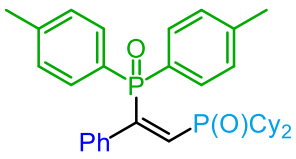

O
P
Ph
P(O)Cy2

7c

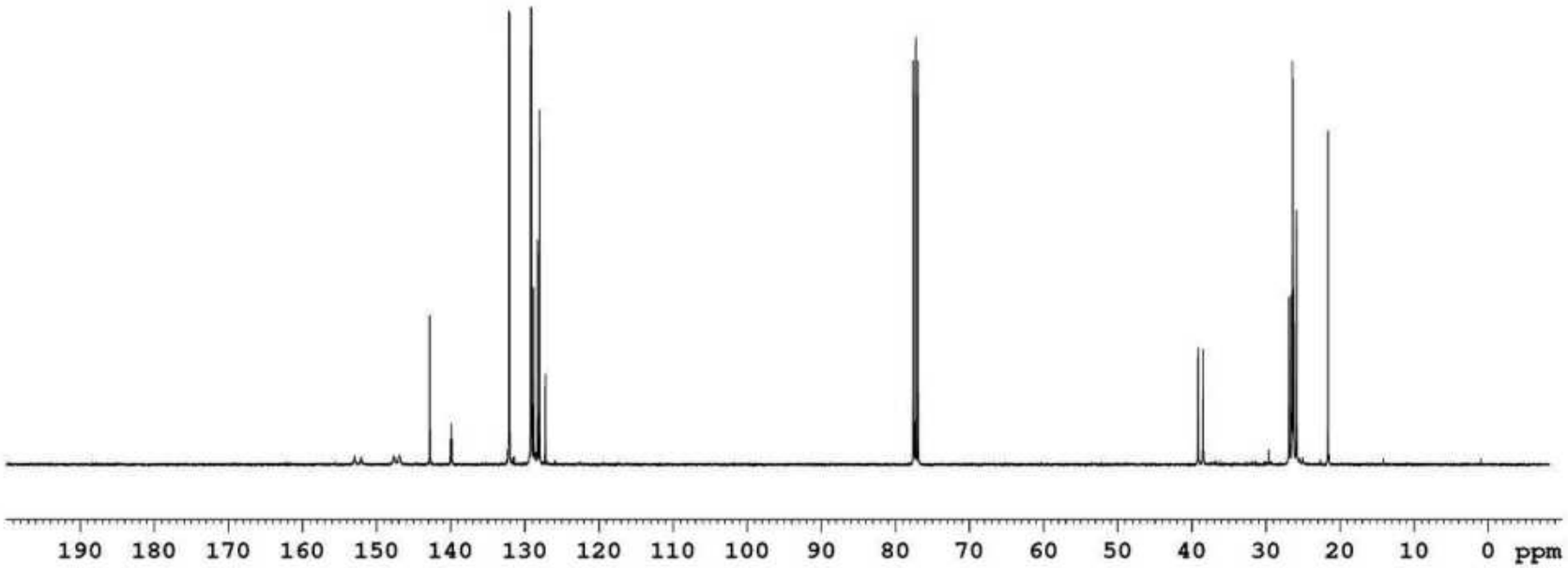

4.00
4.98
2.12
1.89
1.04
1.84
6.12
1.93
2.10
3.93
6.04
6.07
9
8
7
6
5
4
3
2
1
0
ppm


152.96
152.09
147.64
146.90
142.83
142.80
140.03
139.90
139.77
132.14
132.05
129.19
129.07
128.83
128.80
128.27
127.99
127.21


39.12
38.46
26.88
26.84
26.53
26.39
26.25
25.87
21.59

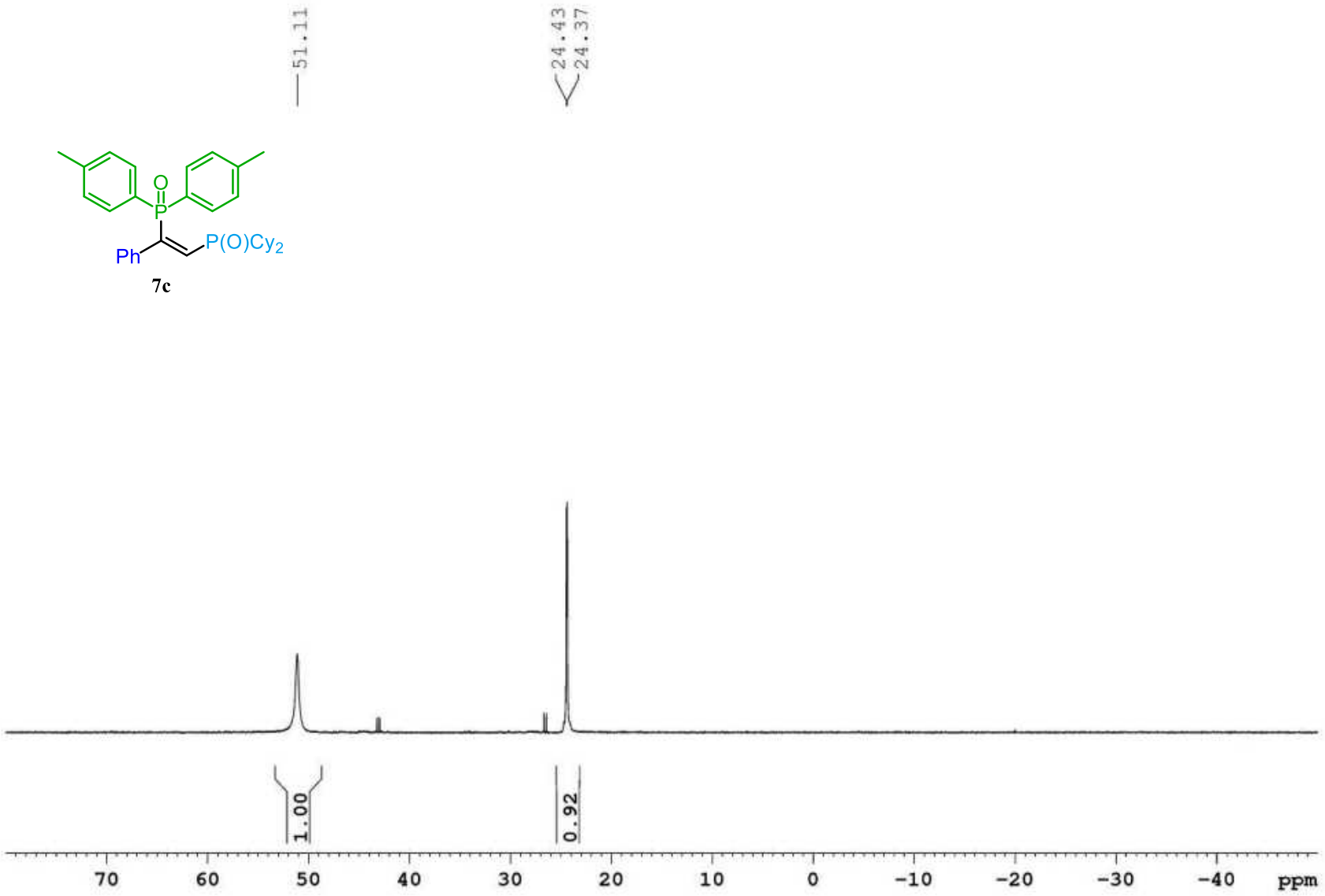

O
P
Ph
P(O)Cy2

7c


190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

O
P
Ph
P(O)Cy2

7c


51.11
24.43
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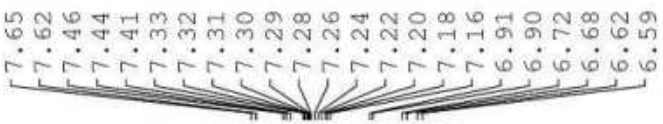
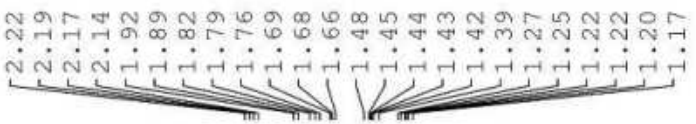
0.92
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm


7.65
7.62
7.46
7.44
7.41
7.33
7.32
7.31
7.30
7.29
7.28
7.26
7.24
7.22
7.20
7.18
7.16
6.91
6.90
6.72
6.68
6.62
6.59


2.22
2.19
2.17
2.14
1.92
1.89
1.82
1.79
1.76
1.69
1.68
1.66
1.48
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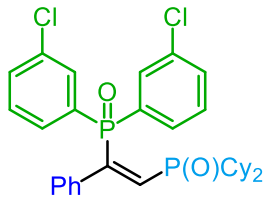
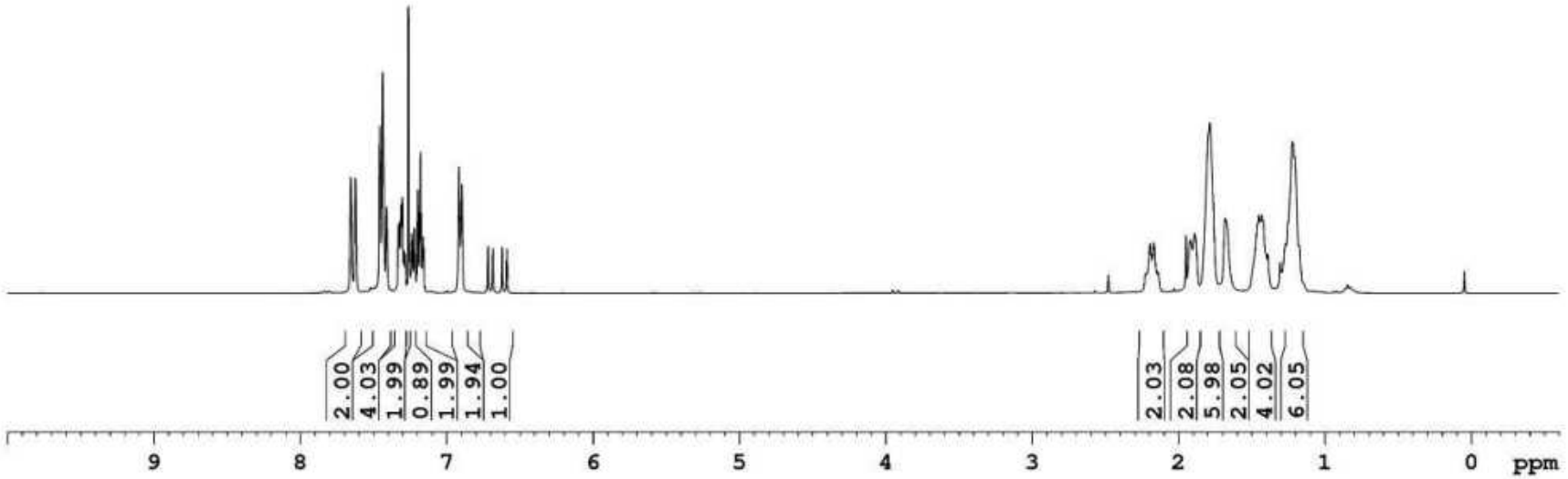
1.44
1.43
1.42
1.39
1.27
1.25
1.22
1.22
1.20
1.17


Cl
Cl
O
P
Ph
P(O)Cy2

7d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4.03
1.99
0.89
1.99
1.94
1.00
2.03
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2.05
4.02
6.05
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8
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6
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0
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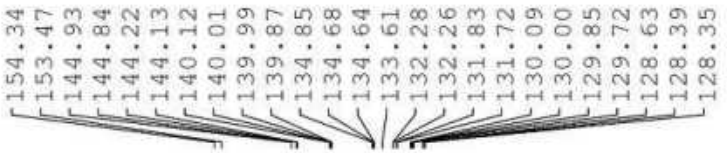
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144.22
144.13
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140.01
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134.85
134.68
134.64
133.61
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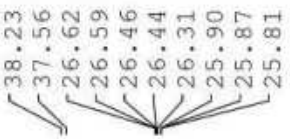
132.26
131.83
131.72
130.09
130.00
129.85
129.72
128.63
128.39
128.35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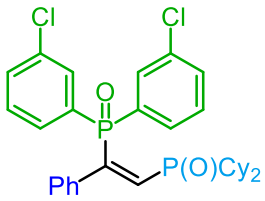
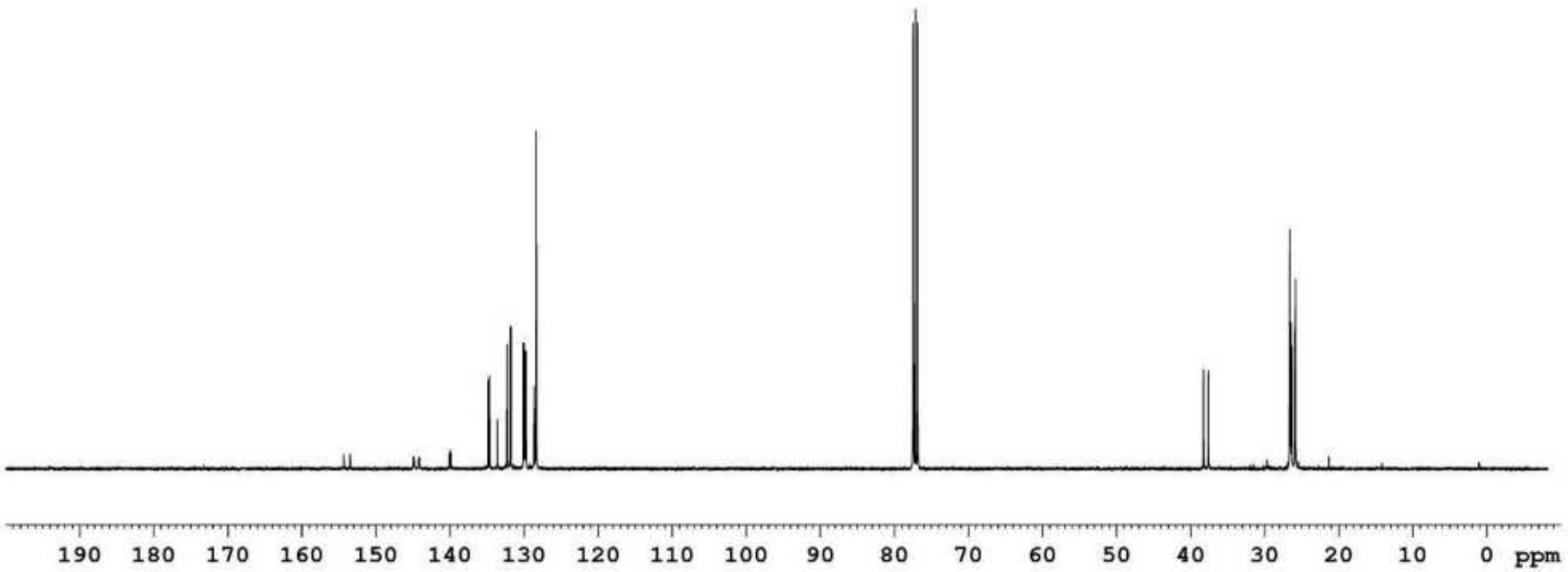
26.44
26.31
25.90
25.87
25.81


Cl
Cl
O
P
Ph
P(O)Cy2

7d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20
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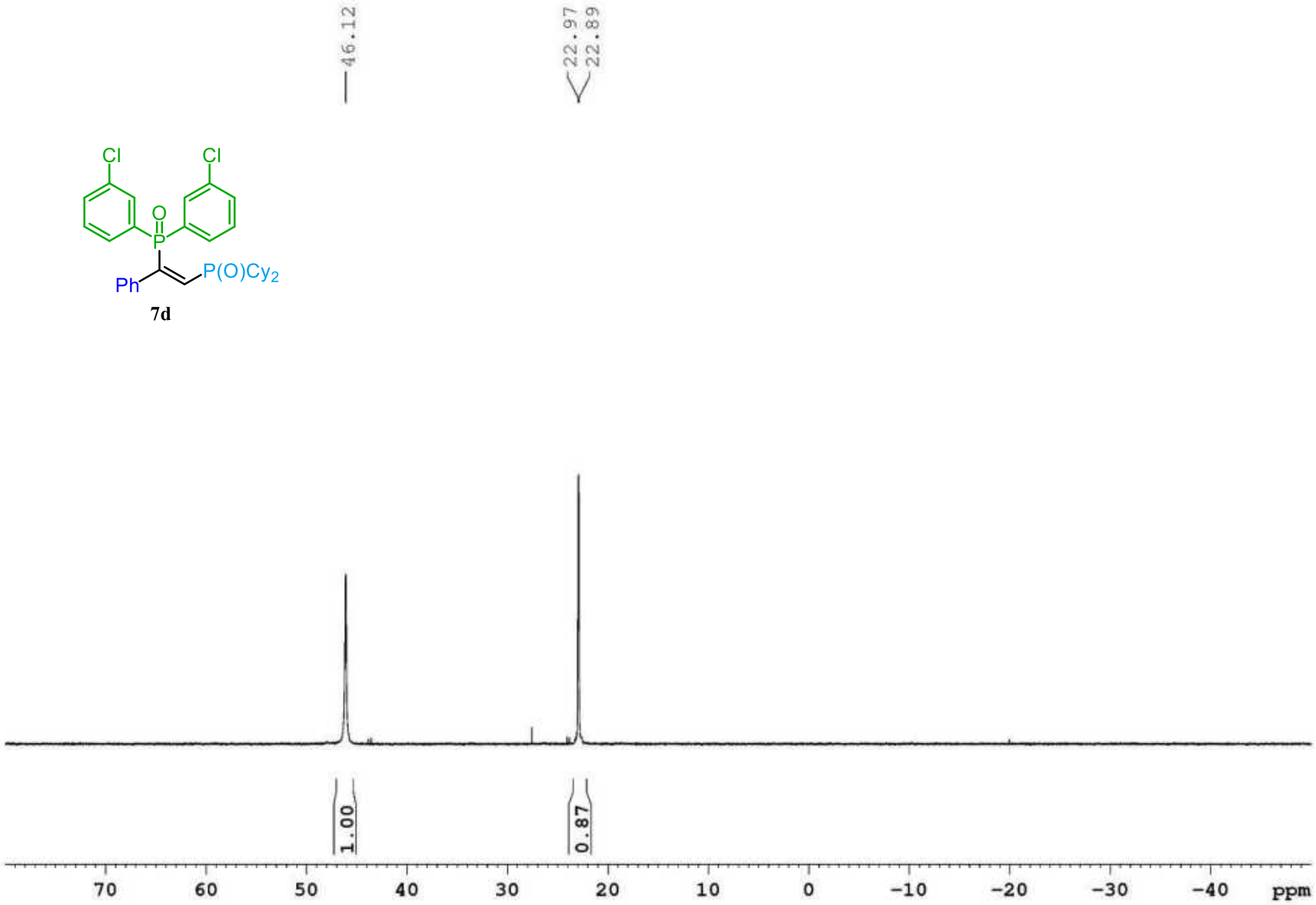
0
ppm


46.12
22.97
22.89
Cl
Cl
O
P
Ph
P(O)Cy2
1.00
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70
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30
20
10
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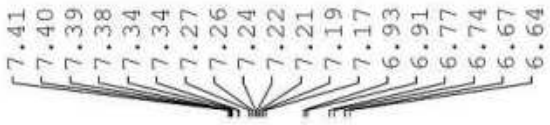
-10
-20
-30
-40
ppm

7d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7.40
7.39
7.38
7.34
7.34
7.27
7.26
7.24
7.22
7.21
7.19
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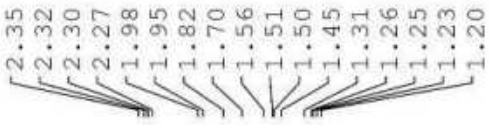
6.93
6.91
6.77
6.74
6.67
6.64


2.35
2.32
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1.70
1.56
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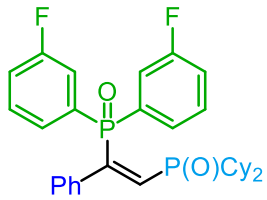
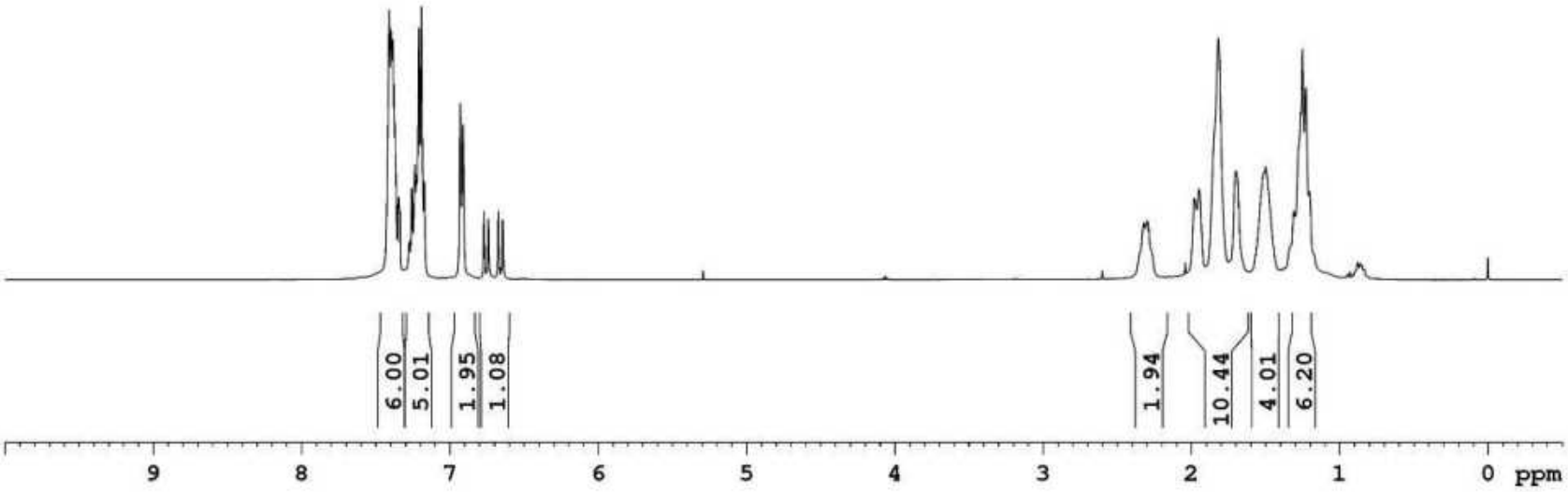
1.50
1.45
1.31
1.26
1.25
1.23
1.20


F
F
O
P
Ph
P(O)Cy2

7e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5.01
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1.08
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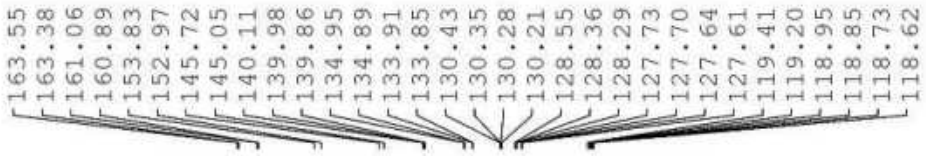
4.01
6.20
9
8
7
6
5
4
3
2
1
0
ppm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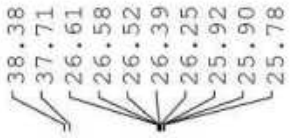
161.06
160.89
153.83
152.97
145.72
145.05
140.11
139.98
139.86
134.95
134.89
133.91
133.85
130.43
130.35
130.28
130.21
128.55
128.36
128.29
127.73
127.70
127.64
127.61
119.41
119.20
118.95
118.85
118.73
118.62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37.71
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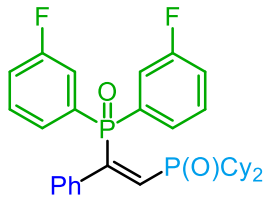
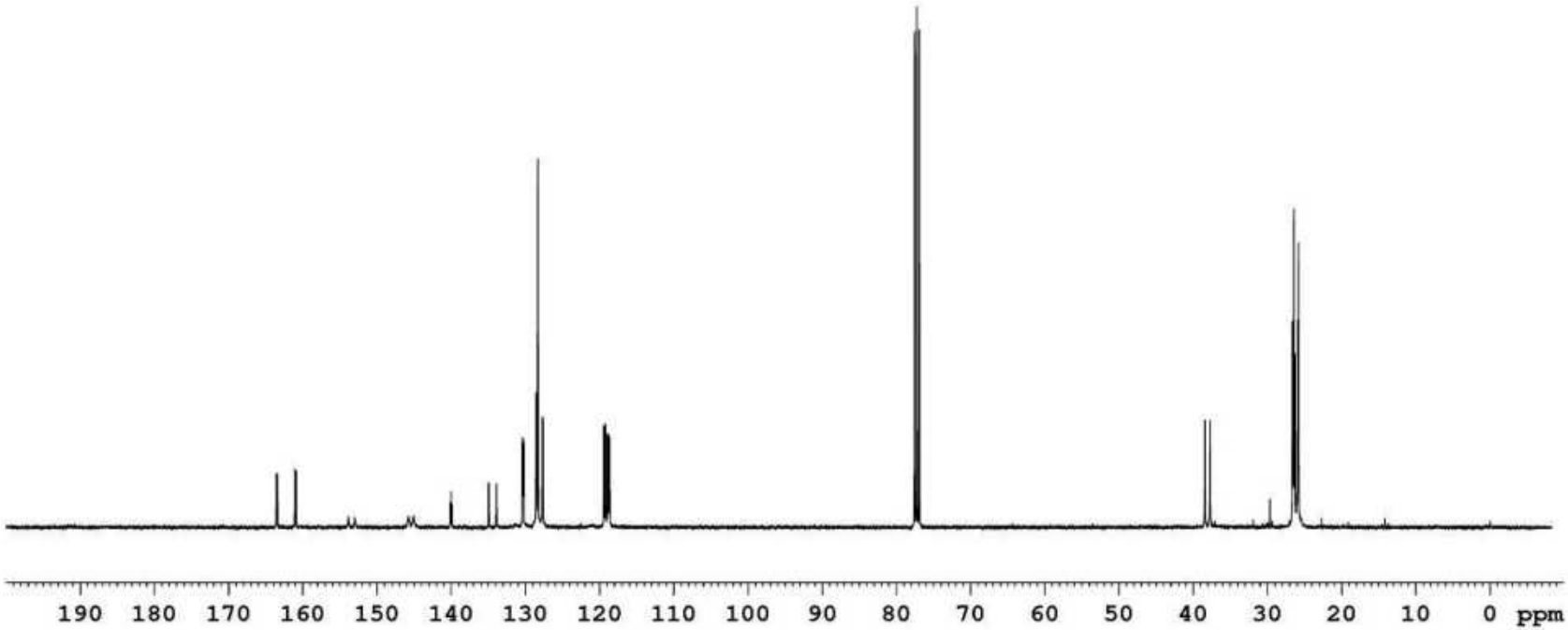
26.58
26.52
26.39
26.25
25.92
25.90
25.78


F
F
O
P
Ph
P(O)Cy2

7e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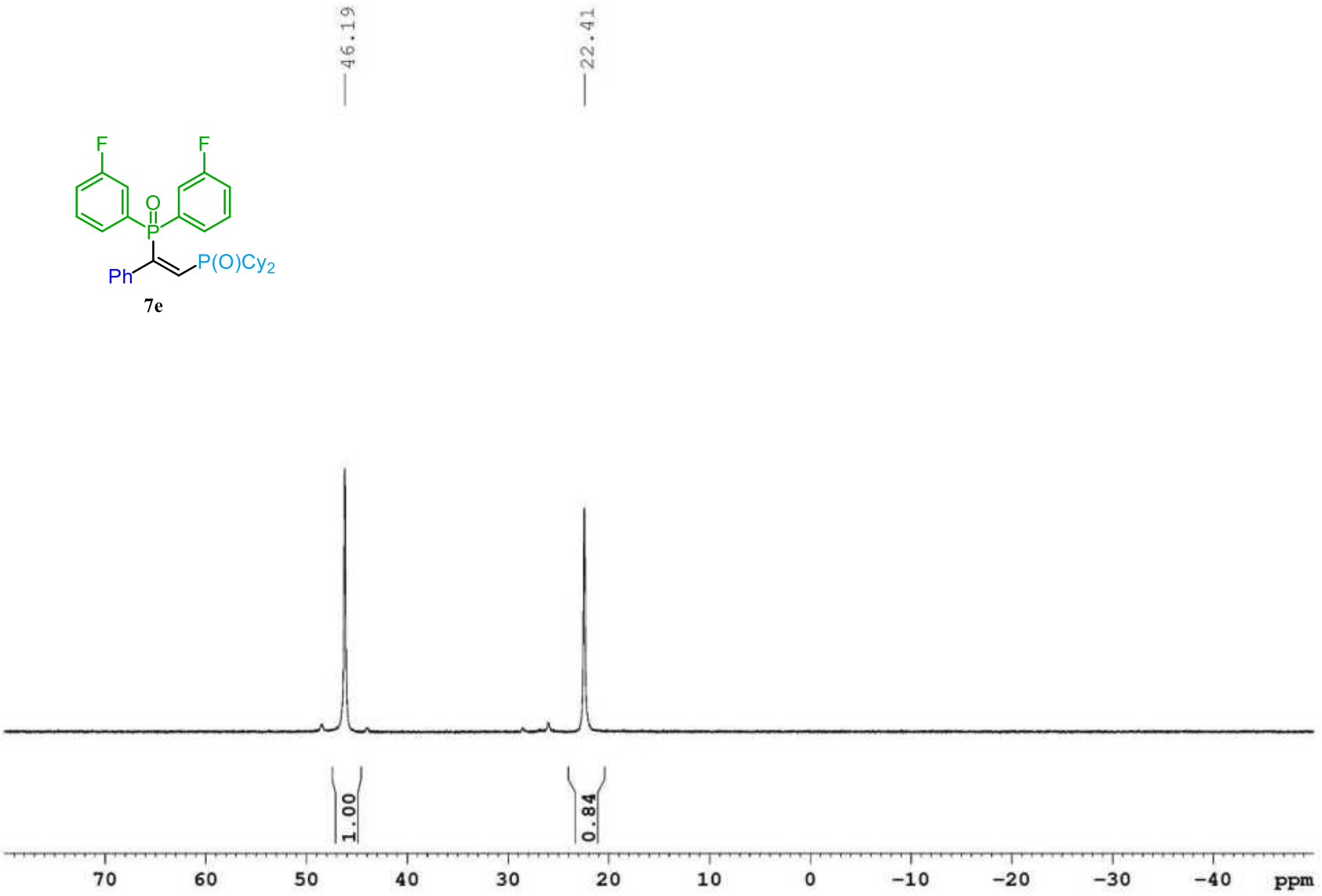
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


46.19
22.41
F
F
O
P
Ph
P(O)Cy2
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0.84
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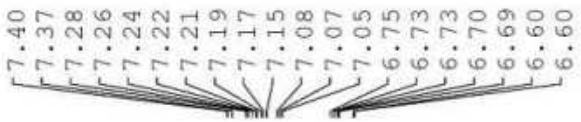
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm

7e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7.24
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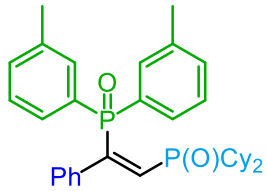
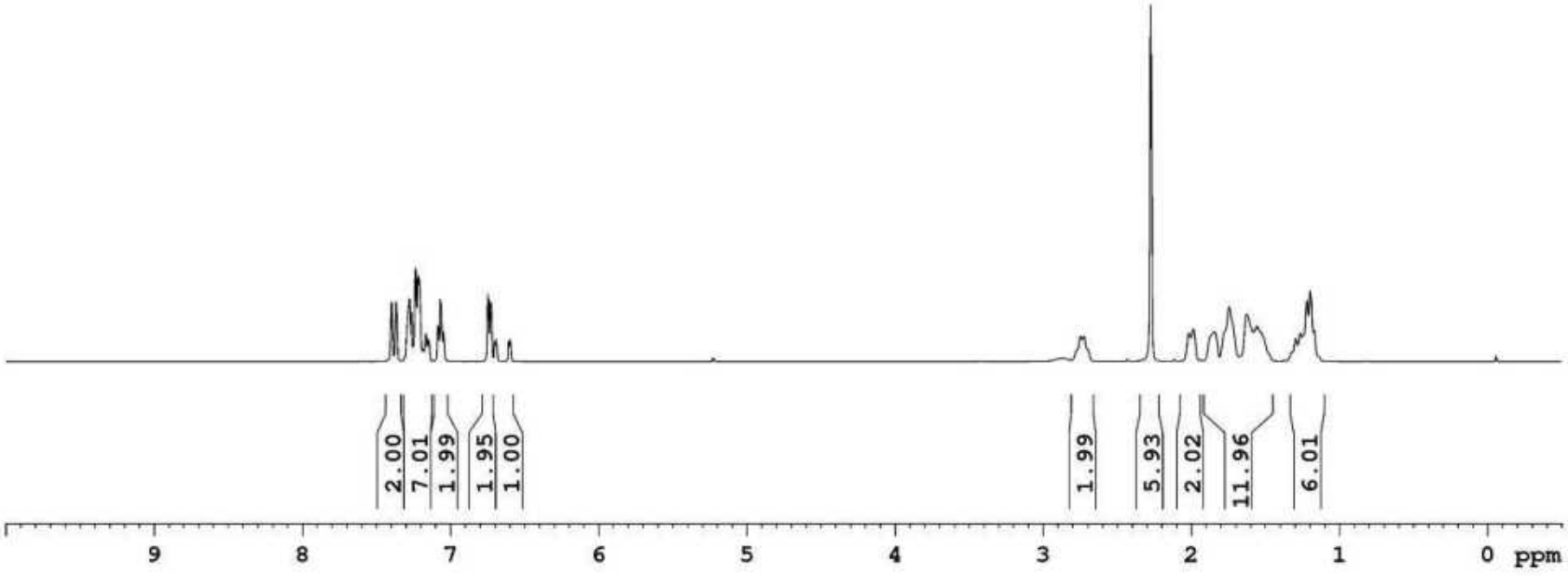
7.21
7.19
7.17
7.15
7.08
7.07
7.05
6.75
6.73
6.73
6.70
6.69
6.60
6.60


2.75
2.72
2.70
2.27
2.01
1.98
1.84
1.74
1.62
1.55
1.53
1.32
1.30
1.26
1.22
1.20
1.17
1.14


O
P
Ph
P(O)Cy2

7f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1.95
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1.99
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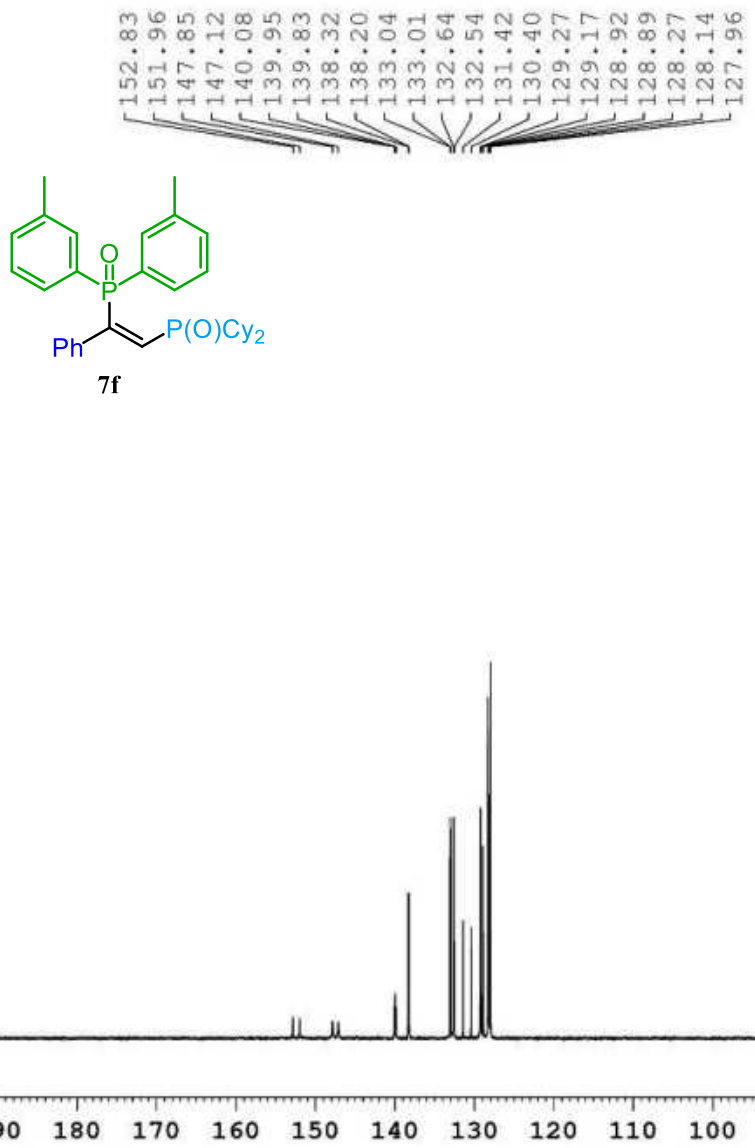
2.02
11.96
6.01
9
8
7
6
5
4
3
2
1
0
ppm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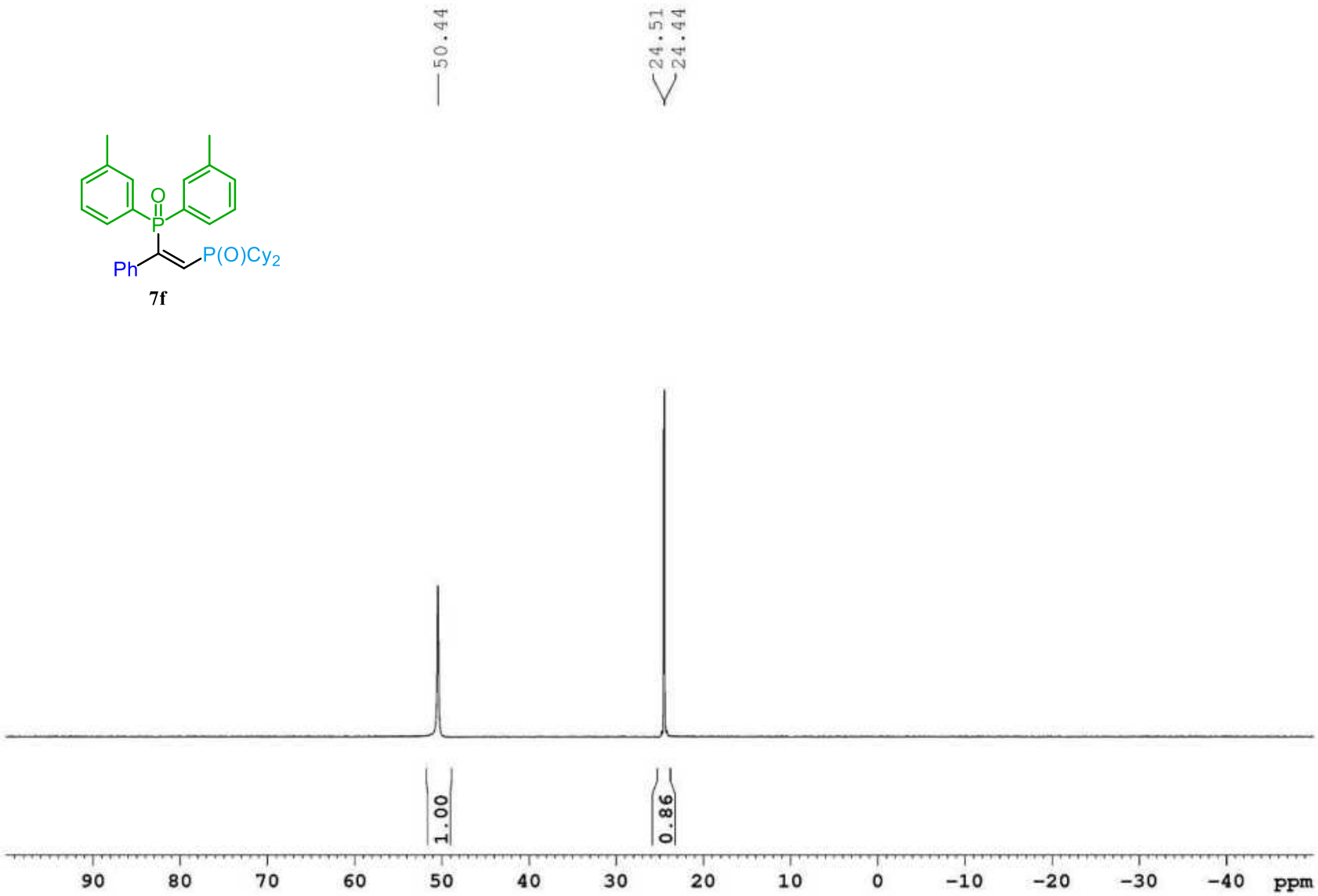
151.96
147.85
147.12
140.08
139.95
139.83
138.32
138.20
133.04
133.01
132.64
132.54
131.42
130.40
129.27
129.17
128.92
128.89
128.27
128.14
127.96
39.13
38.47
26.94
26.91
26.59
26.46
26.42
26.38
26.29
25.89
21.39
O
P
Ph
P(O)Cy2
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

7f

O
P
Ph
P(O)Cy2

7f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24.51
24.44
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80
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50
40
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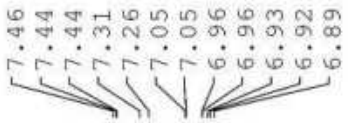
-20
-30
-40
ppm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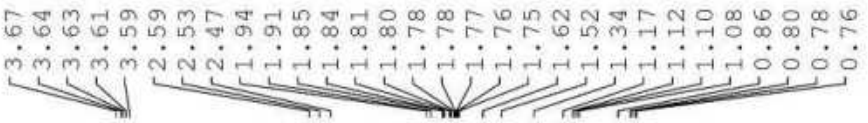
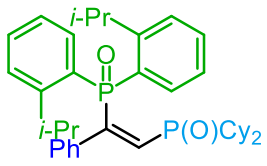
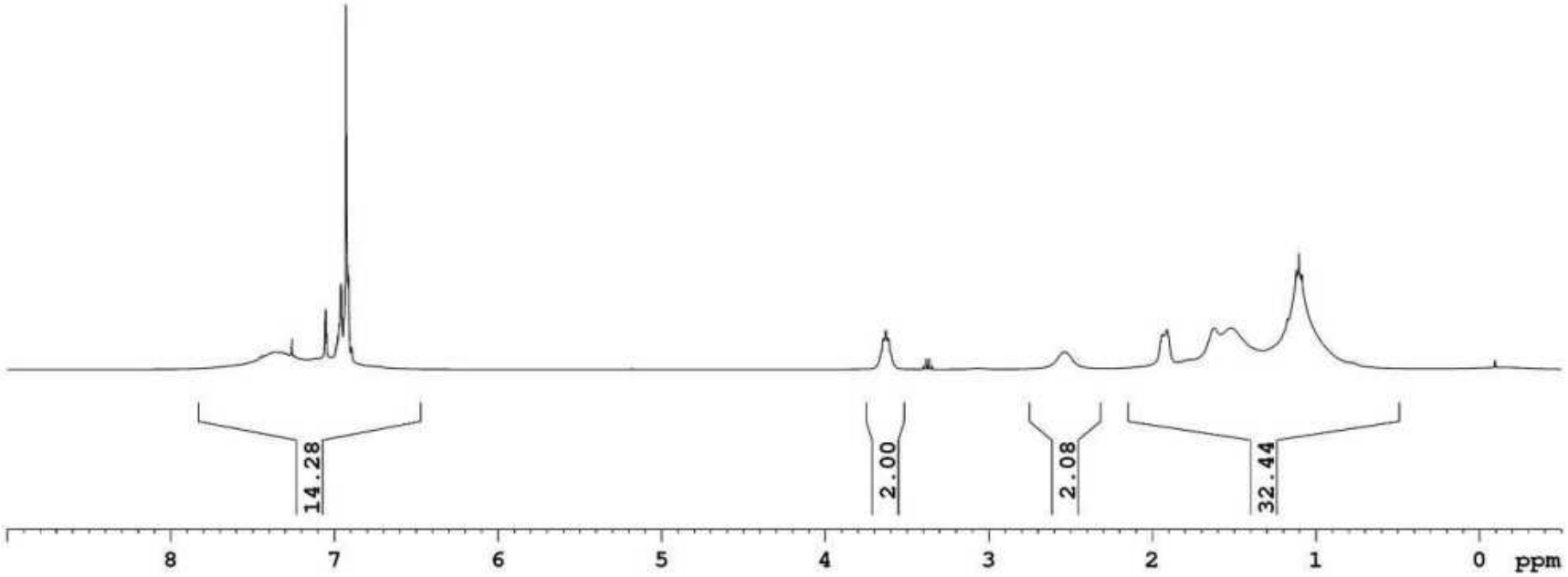
7.44
7.44
7.31
7.26
7.05
7.05
6.96
6.96
6.93
6.92
6.89


3.67
3.64
3.63
3.61
3.59
2.59
2.53
2.47
1.94
1.91
1.85
1.84
1.81
1.80
1.78
1.78
1.77
1.76
1.75
1.62
1.52
1.34
1.17
1.12
1.10
1.08
0.86
0.80
0.78
0.76


i-Pr
O
P
i-Pr
Ph
P(O)Cy2

7g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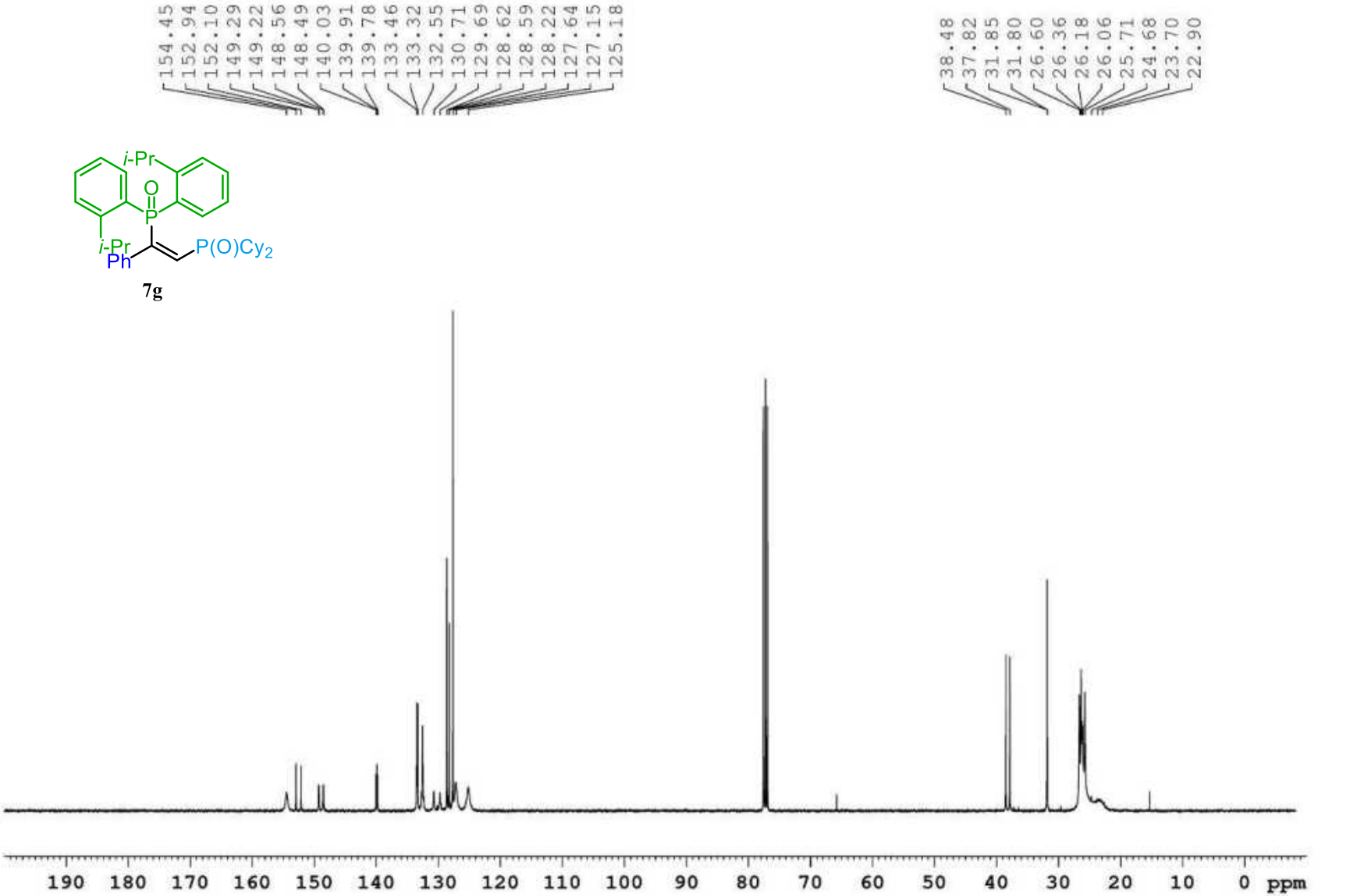
2.00
2.08
32.44
8
7
6
5
4
3
2
1
0
ppm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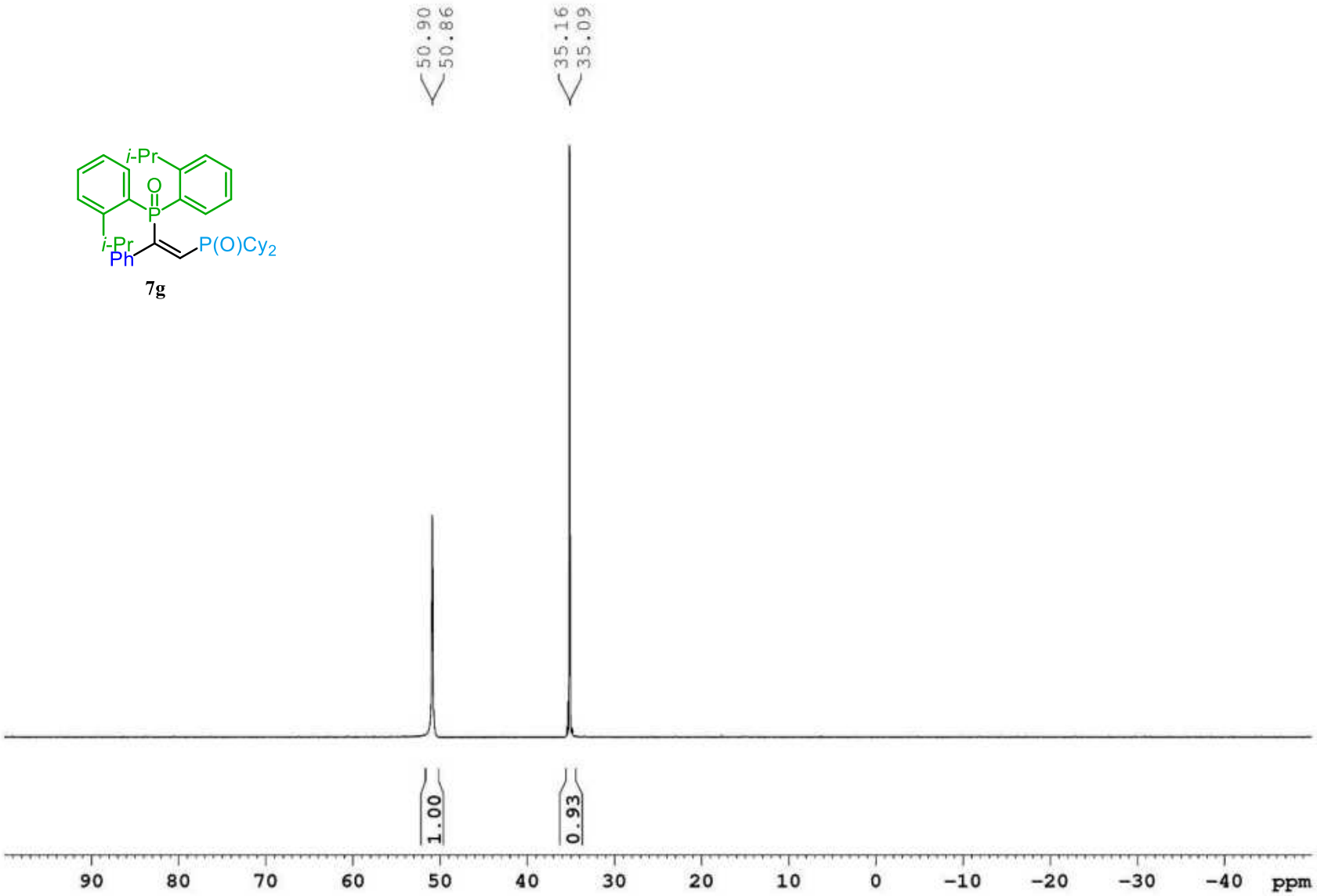
152.94
152.10
149.29
149.22
148.56
148.49
140.03
139.91
139.78
133.46
133.32
132.55
130.71
129.69
128.62
128.59
128.22
127.64
127.15
125.18
38.48
37.82
31.85
31.80
26.60
26.36
26.18
26.06
25.71
24.68
23.70
22.90
i-Pr
O
P
i-Pr
Ph
P(O)Cy2
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

7g


50.90
50.86
35.16
35.09
i-Pr
O
P
i-Pr
Ph
P(O)Cy2
7g
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90
80
70
60
50
40
30
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10
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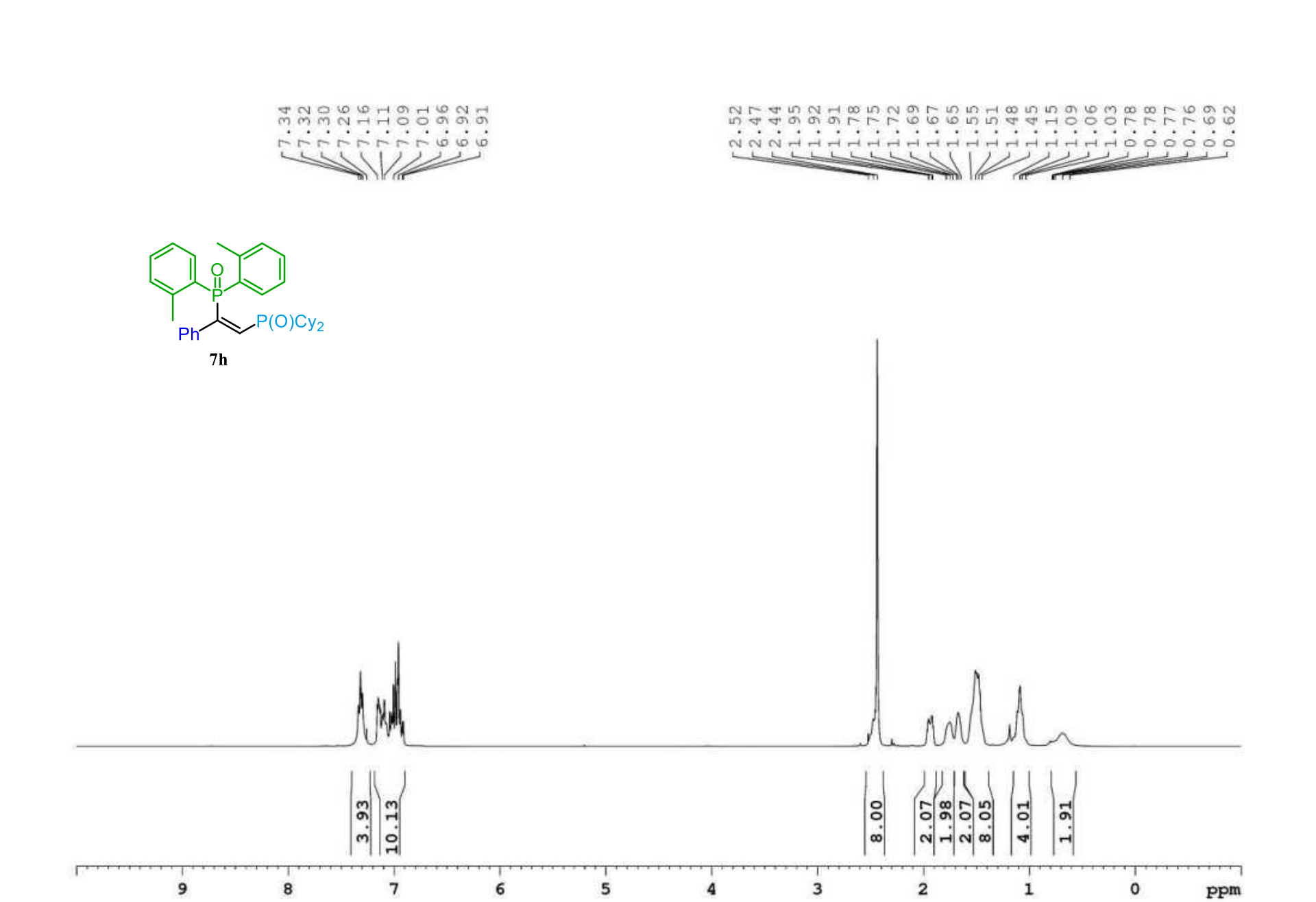
-30
-40
ppm


7.34
7.32
7.30
7.26
7.16
7.11
7.09
7.01
6.96
6.92
6.91
2.52
2.47
2.44
1.95
1.92
1.91
1.78
1.75
1.72
1.69
1.67
1.65
1.55
1.51
1.48
1.45
1.15
1.09
1.06
1.03
0.78
0.78
0.77
0.76
0.69
0.62
O
P
Ph
P(O)Cy2
7h
3.93
10.13
8.00
2.07
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2.07
8.05
4.01
1.91
9
8
7
6
5
4
3
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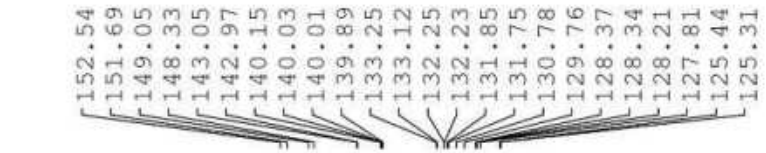
0
ppm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151.69
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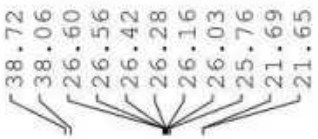
148.33
143.05
142.97
140.15
140.03
140.01
139.89
133.25
133.12
132.25
132.23
131.85
131.75
130.78
129.76
128.37
128.34
128.21
127.81
125.44
125.31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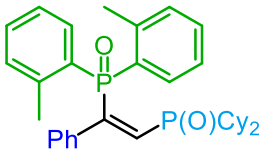
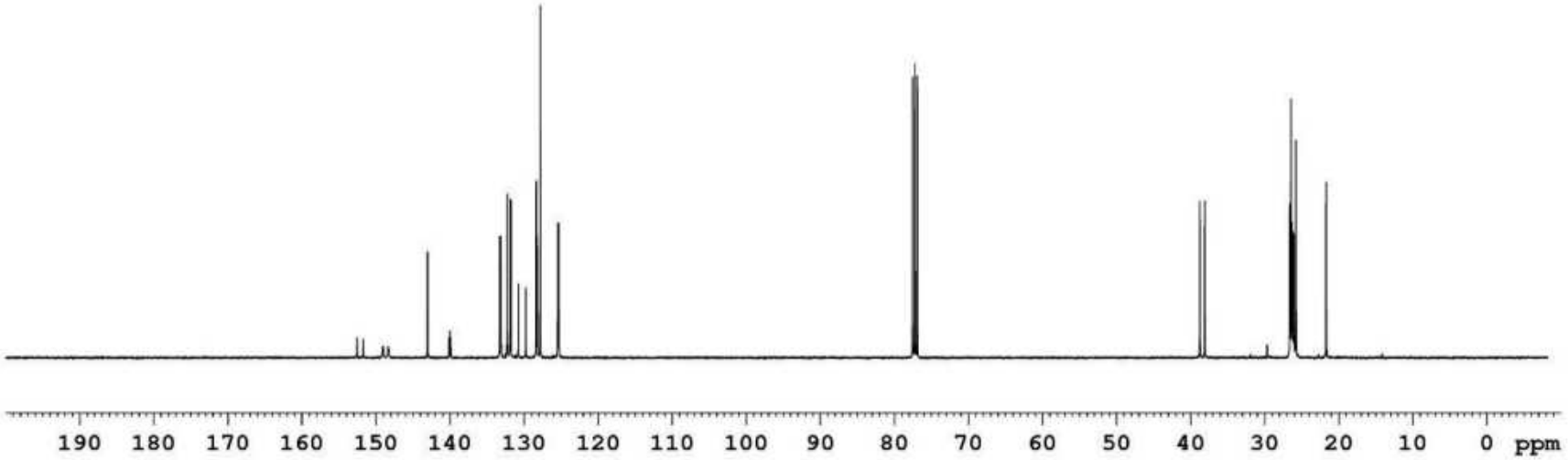
26.42
26.28
26.16
26.03
25.76
21.69
21.65


O
P
Ph
P(O)Cy2

7h


190
180
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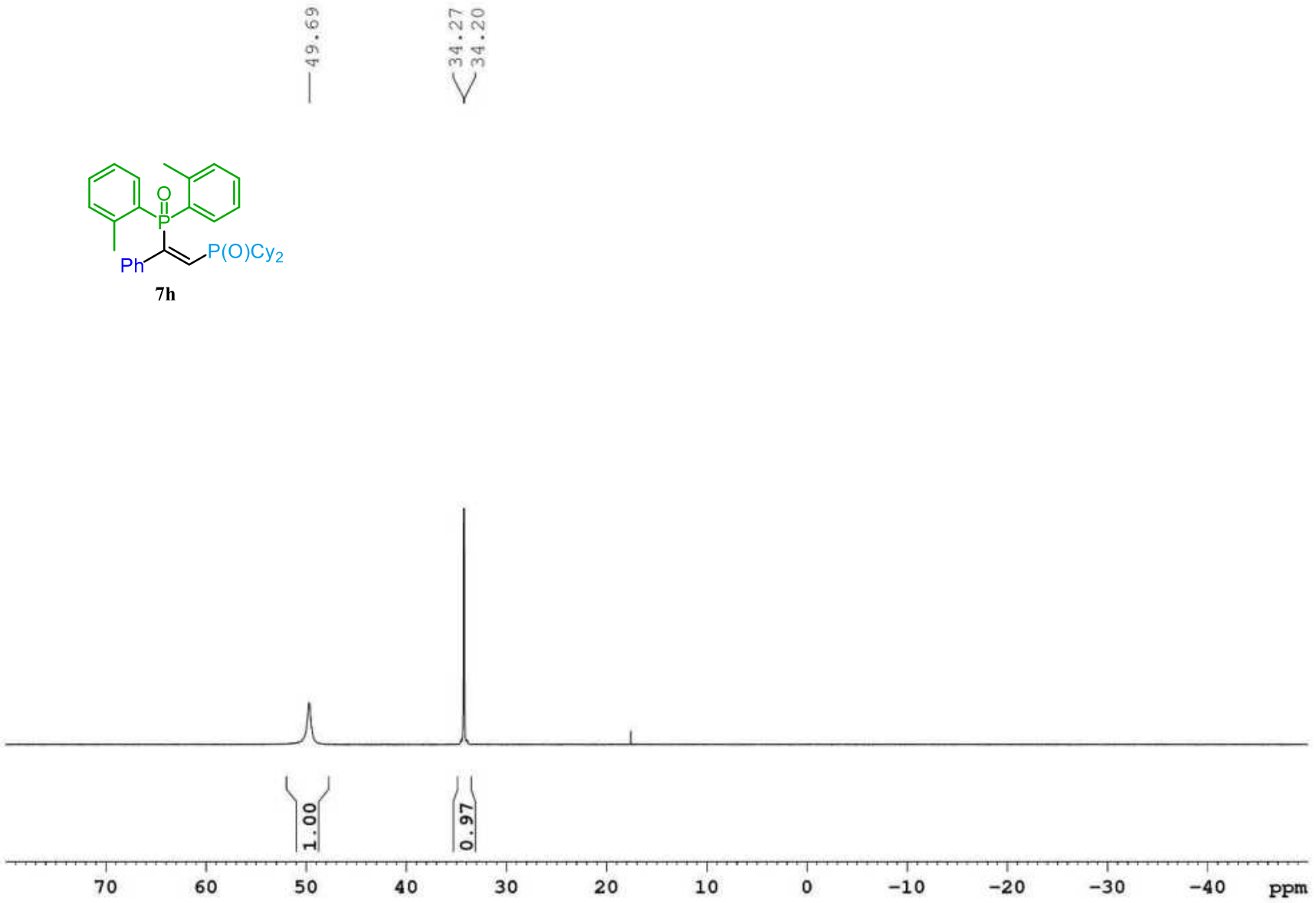
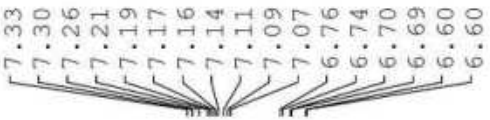
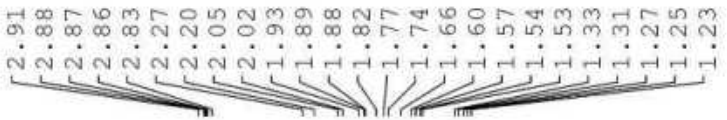
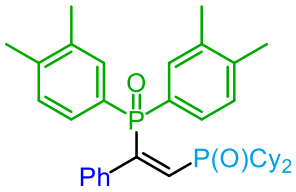
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

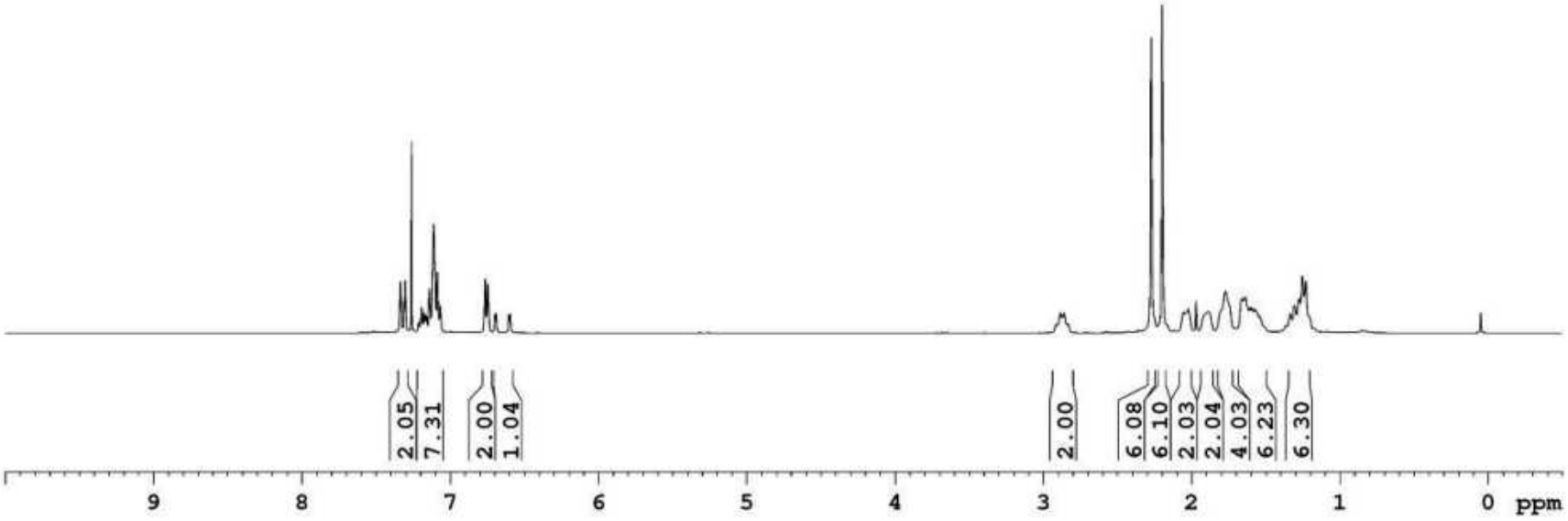

49.69
34.27
34.20
O
P
Ph
P(O)Cy2
7h
1.00
0.97
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm

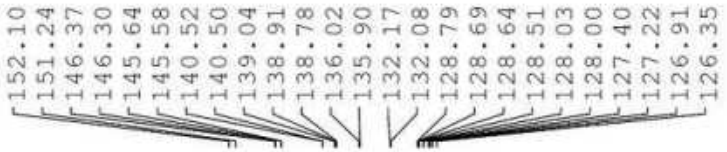

7.33
7.30
7.26
7.21
7.19
7.17
7.16
7.14
7.11
7.09
7.07
6.76
6.74
6.70
6.69
6.60
6.60


2.91
2.88
2.87
2.86
2.83
2.27
2.20
2.05
2.02
1.93
1.89
1.88
1.82
1.77
1.74
1.66
1.60
1.57
1.54
1.53
1.33
1.31
1.27
1.25
1.23


O
P
Ph
P(O)Cy2

7i


2.05
7.31
2.00
1.04
2.00
6.08
6.10
2.03
2.04
4.03
6.23
6.30
9
8
7
6
5
4
3
2
1
0
ppm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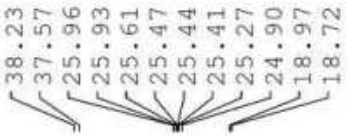
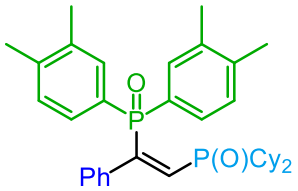
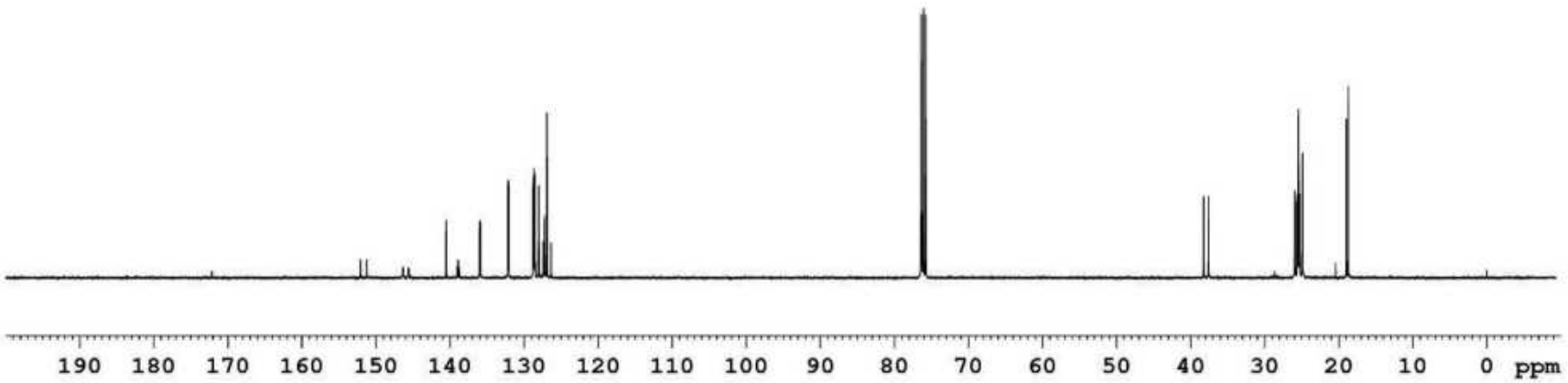
151.24
146.37
146.30
145.64
145.58
140.52
140.50
139.04
138.91
138.78
136.02
135.90
132.17
132.08
128.79
128.69
128.64
128.51
128.03
128.00
127.40
127.22
126.91
126.35


38.23
37.57
25.96
25.93
25.61
25.47
25.44
25.41
25.27
24.90
18.97
18.72

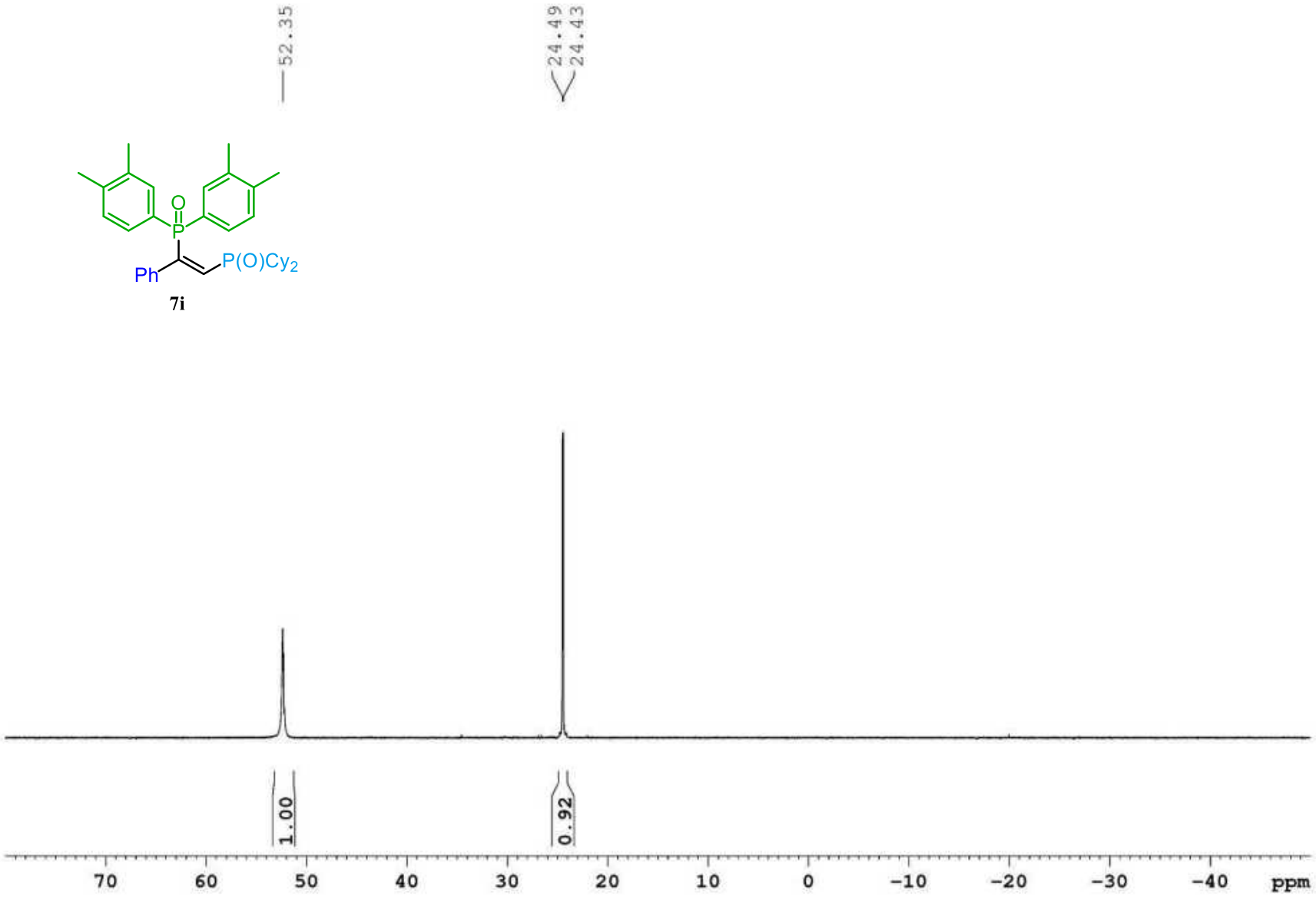

O
P
Ph
P(O)Cy2

7i


190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

O
P
Ph
P(O)Cy2

7i


52.35
24.49
24.43
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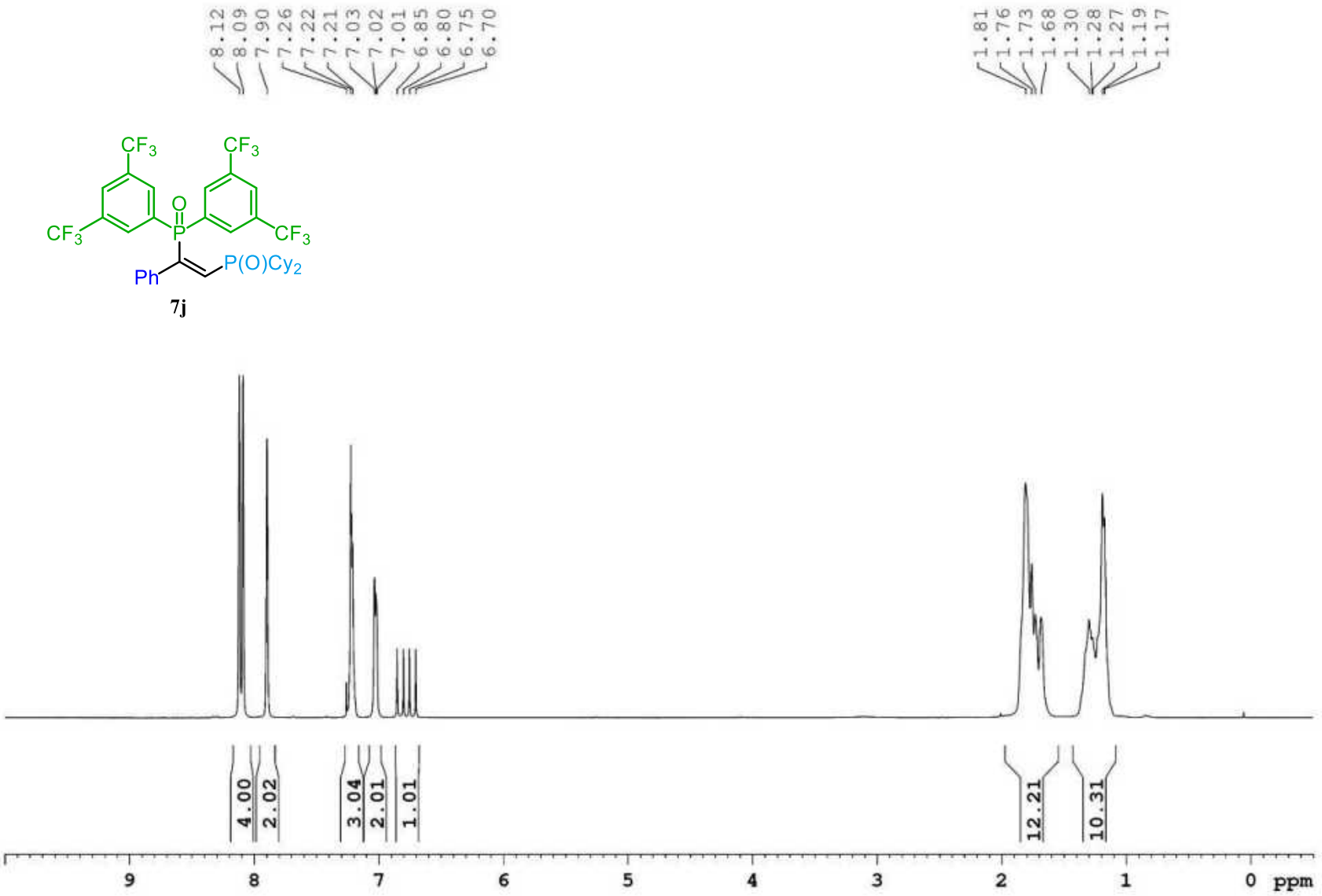
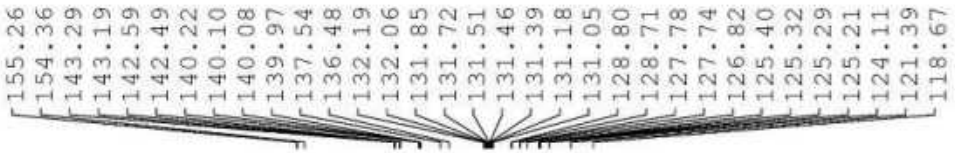
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm


8.12
8.09
7.90
7.26
7.22
7.21
7.03
7.02
7.01
6.85
6.80
6.75
6.70
1.81
1.76
1.73
1.68
1.30
1.28
1.27
1.19
1.17
CF3
CF3
CF3
CF3
O
P
Ph
P(O)Cy2
4.00
2.02
3.04
2.01
1.01
12.21
10.31
9
8
7
6
5
4
3
2
1
0
ppm

7j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154.36
143.29
143.19
142.59
142.49
140.22
140.10
140.08
139.97
137.54
136.48
132.19
132.06
131.85
131.72
131.51
131.46
131.39
131.18
131.05
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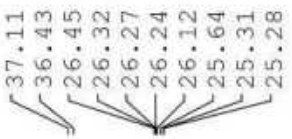
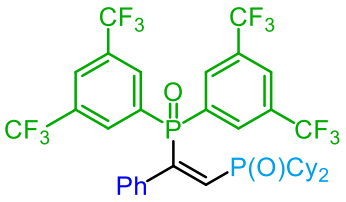
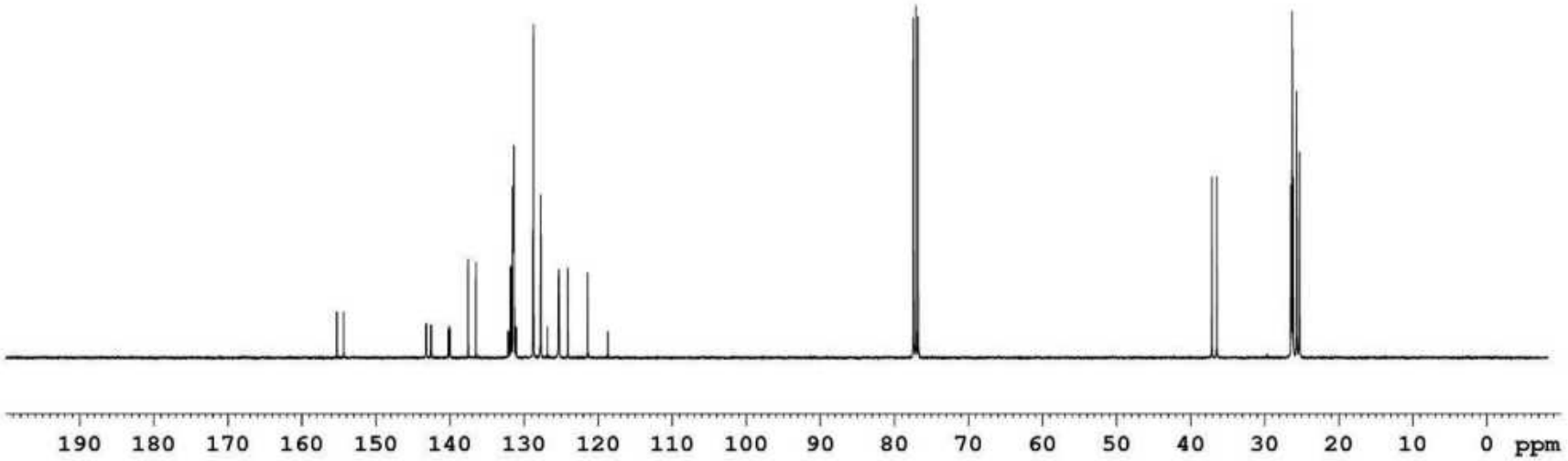
128.71
127.78
127.74
126.82
125.40
125.32
125.29
125.21
124.11
121.39
118.67


37.11
36.43
26.45
26.32
26.27
26.24
26.12
25.64
25.31
25.28

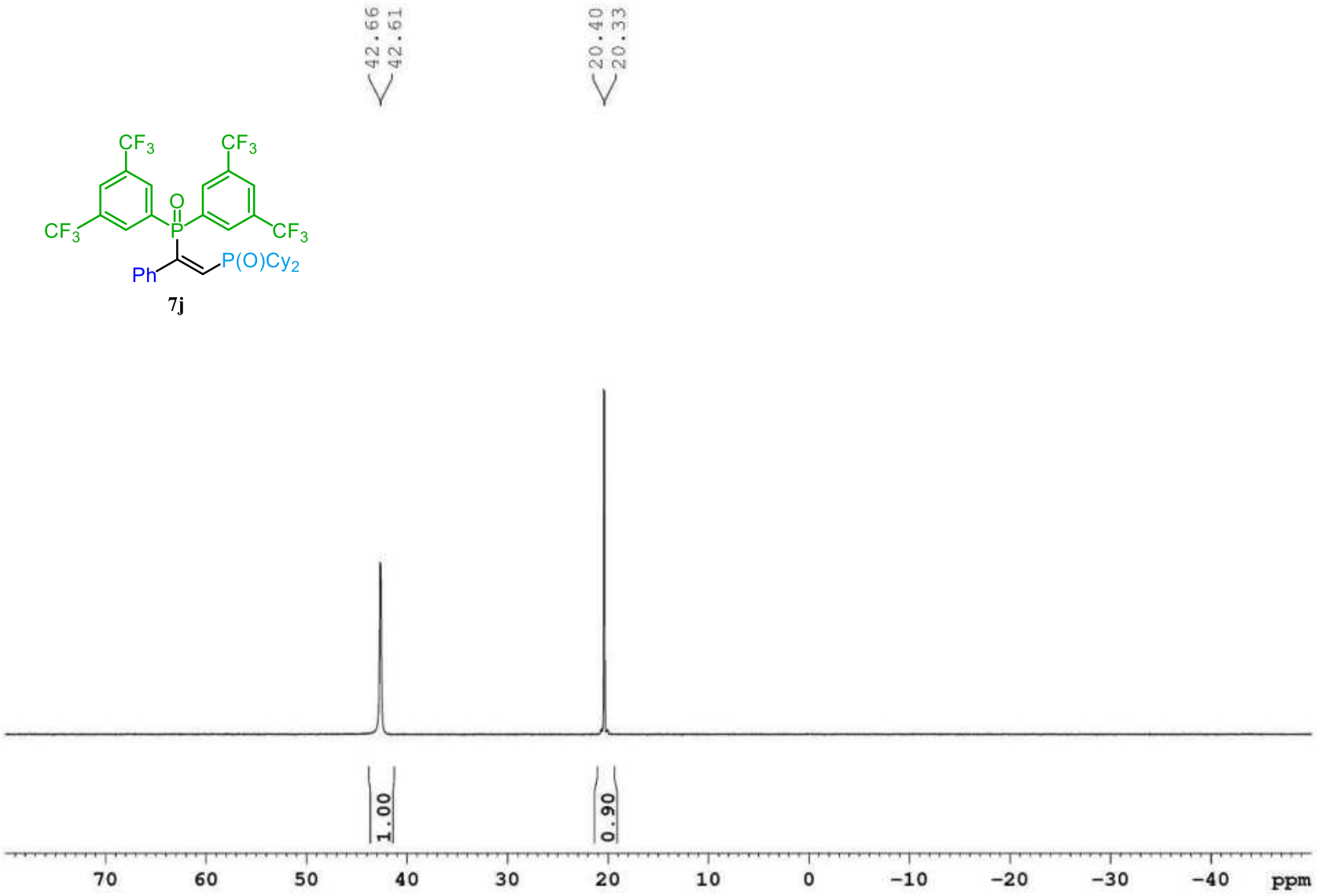

CF3
CF3
CF3
CF3
O
P
Ph
P(O)Cy2

7j


190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

CF3
CF3
CF3
CF3
O
P
Ph
P(O)Cy2

7j


42.66
42.61
20.40
20.33
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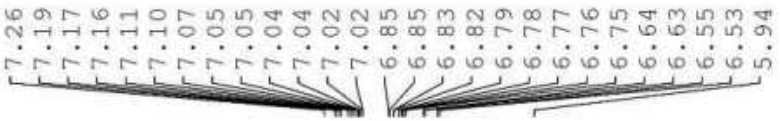
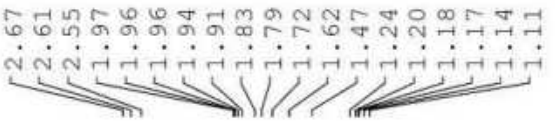
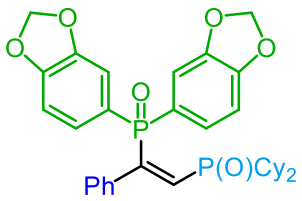
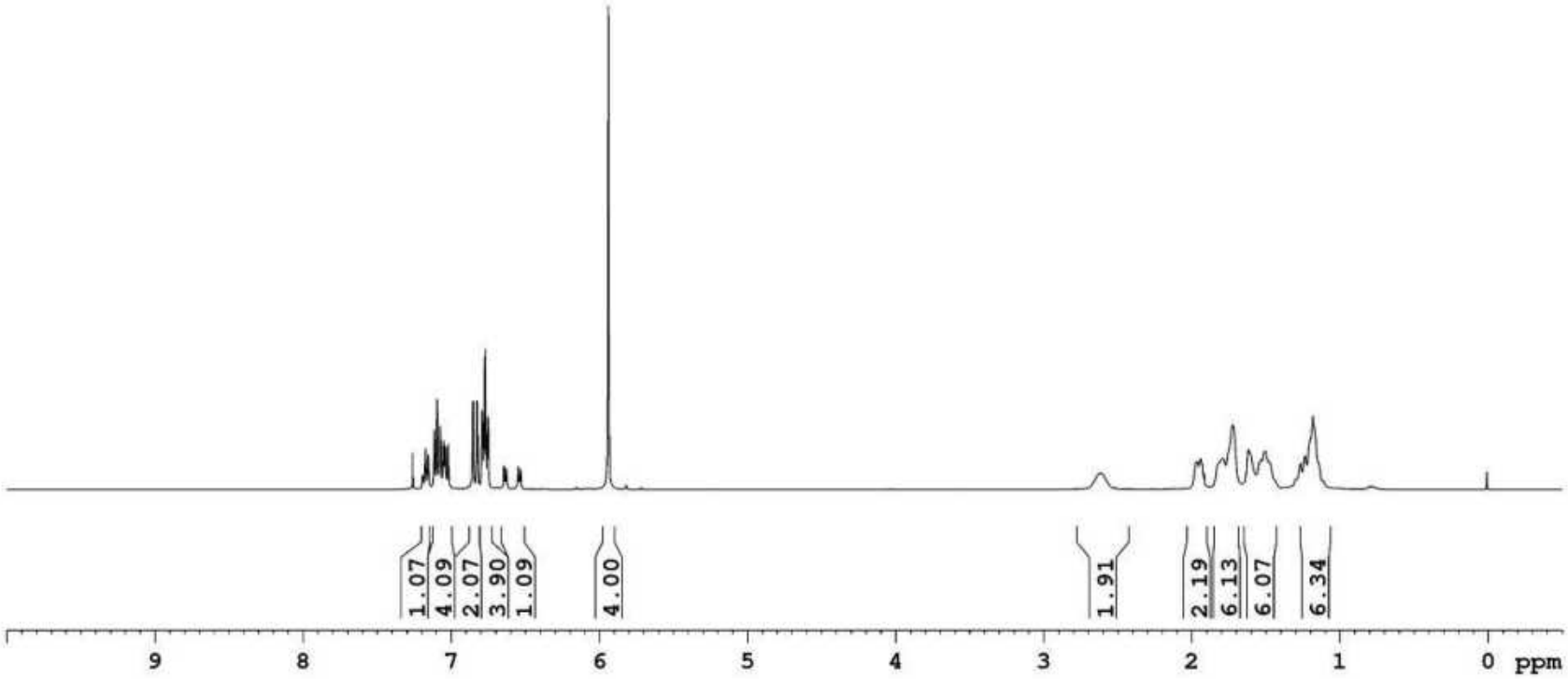
0.90
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm

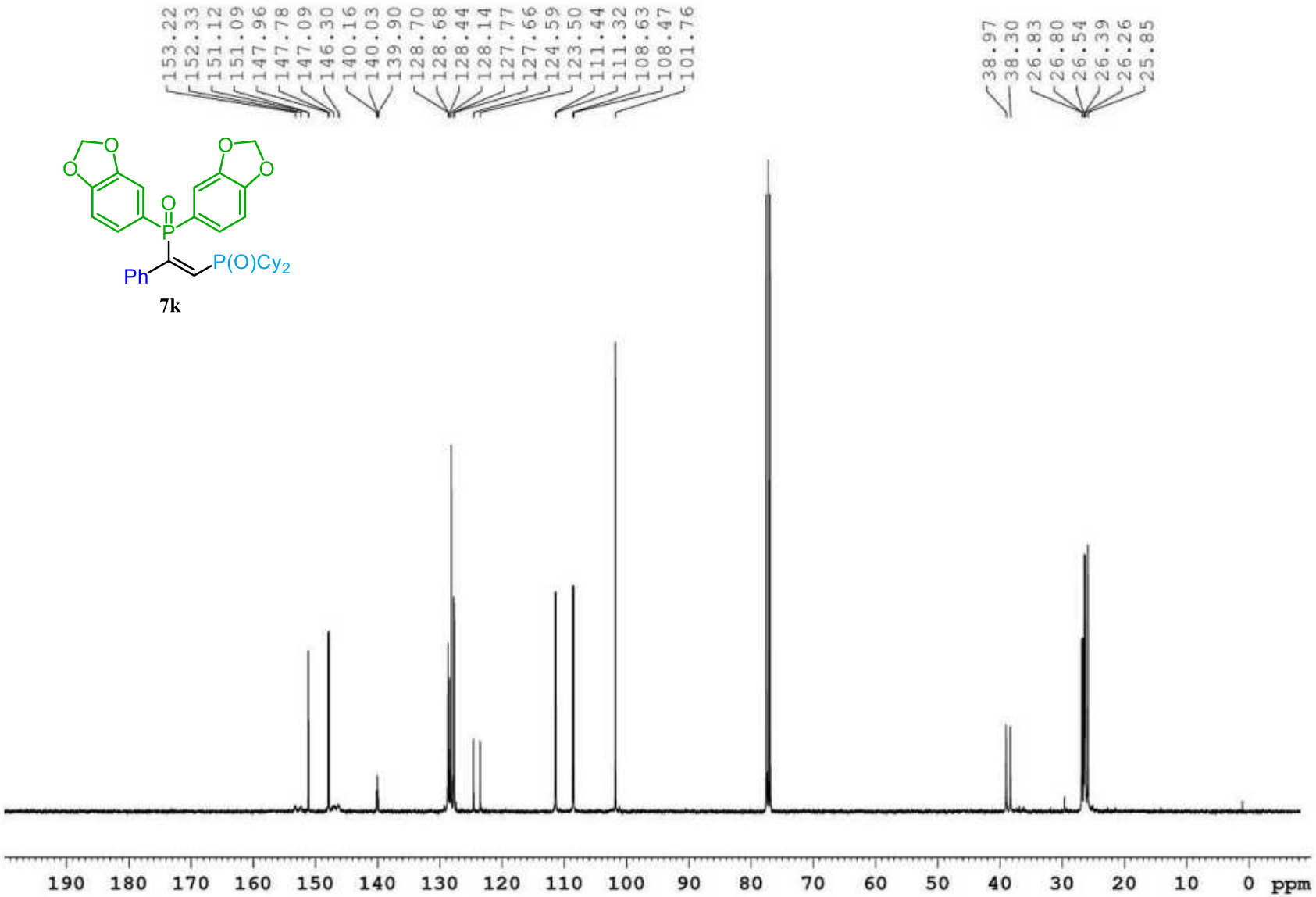

7.26
7.19
7.17
7.16
7.11
7.10
7.07
7.05
7.05
7.04
7.04
7.02
7.02
6.85
6.85
6.83
6.82
6.79
6.78
6.77
6.76
6.75
6.64
6.63
6.55
6.53
5.94


2.67
2.61
2.55
1.97
1.96
1.96
1.94
1.91
1.83
1.79
1.72
1.62
1.47
1.24
1.20
1.18
1.17
1.14
1.11


O
O
O
O
O
P
Ph
P(O)Cy2

7k

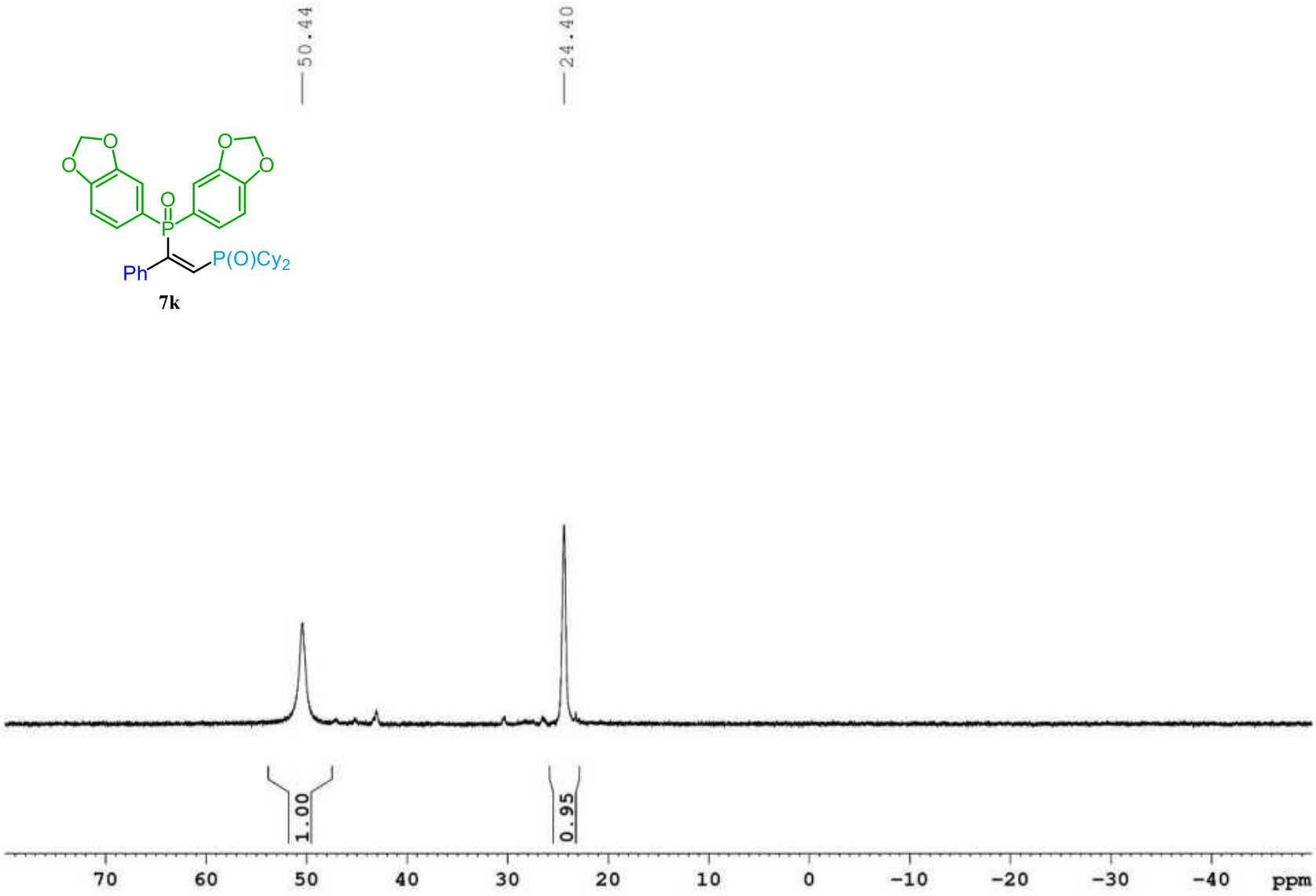

1.07
4.09
2.07
3.90
1.09
4.00
1.91
2.19
6.13
6.07
6.34
9
8
7
6
5
4
3
2
1
0
ppm

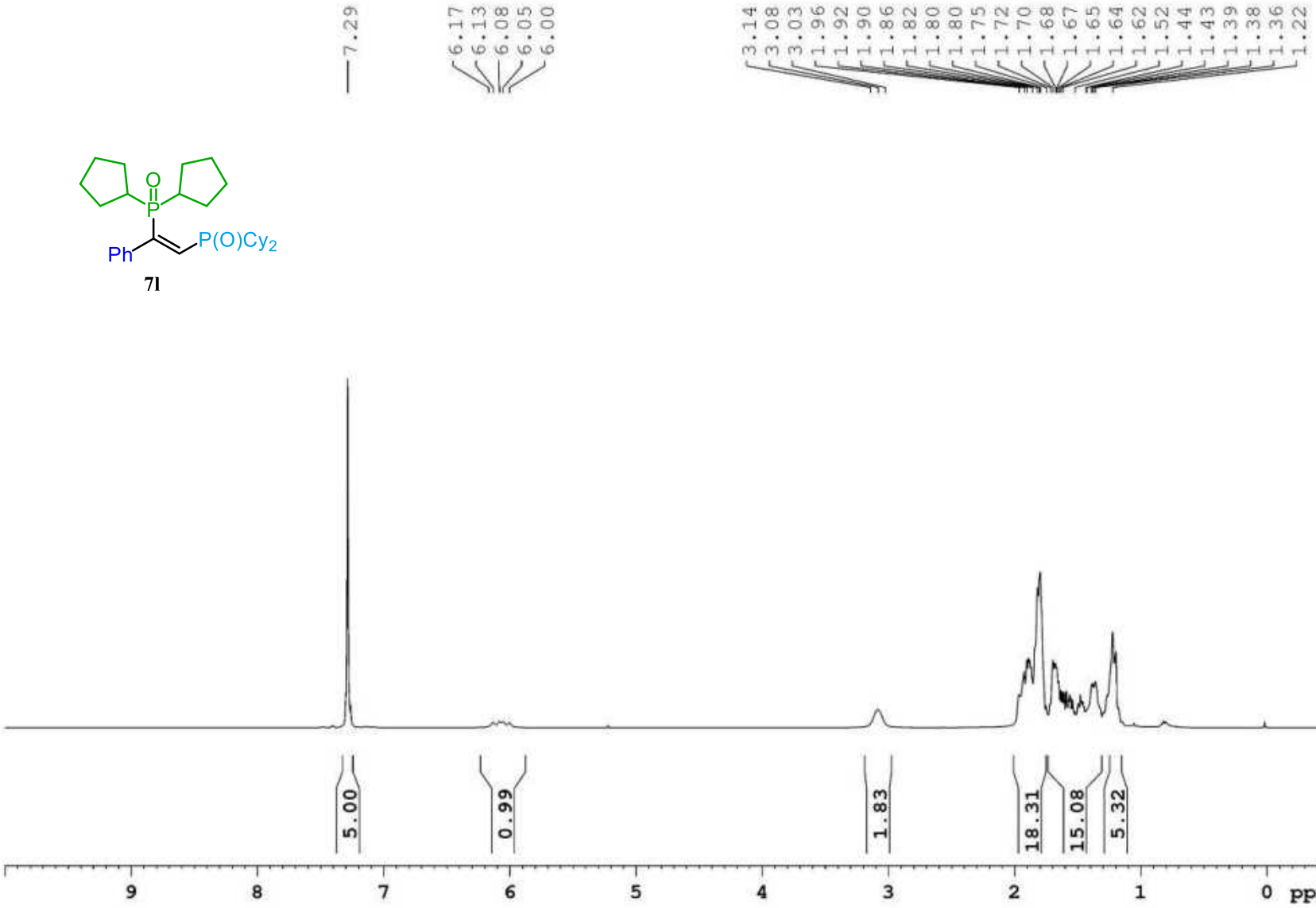

153.22
152.33
151.12
151.09
147.96
147.78
147.09
146.30
140.16
140.03
139.90
128.70
128.68
128.44
128.14
127.77
127.66
124.59
123.50
111.44
111.32
108.63
108.47
101.76
38.97
38.30
26.83
26.80
26.54
26.39
26.26
25.85
O
O
O
O
P
O
Ph
P(O)Cy2
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

7k

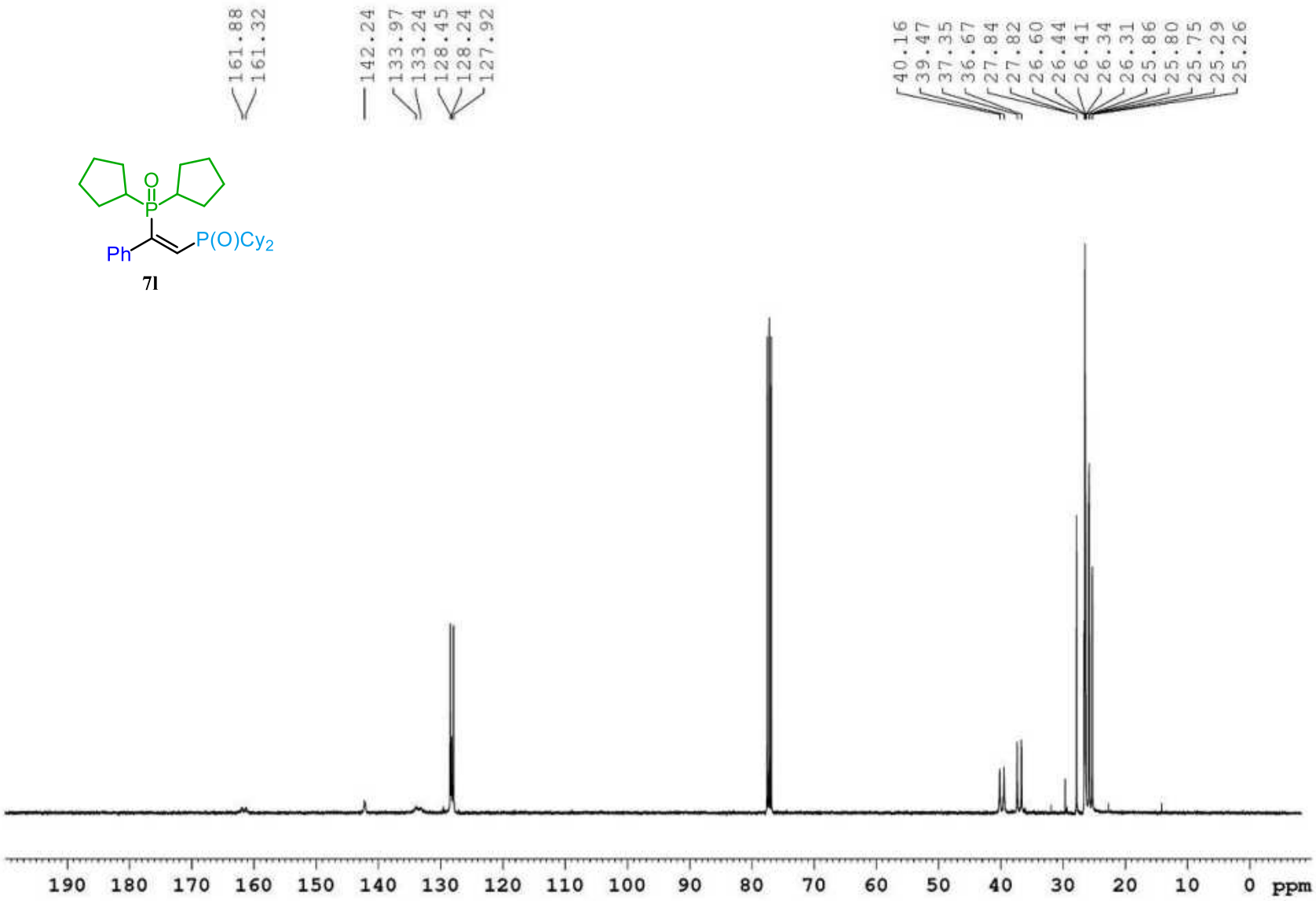
O
O
O
O
P
O
Ph
P(O)Cy2

7k

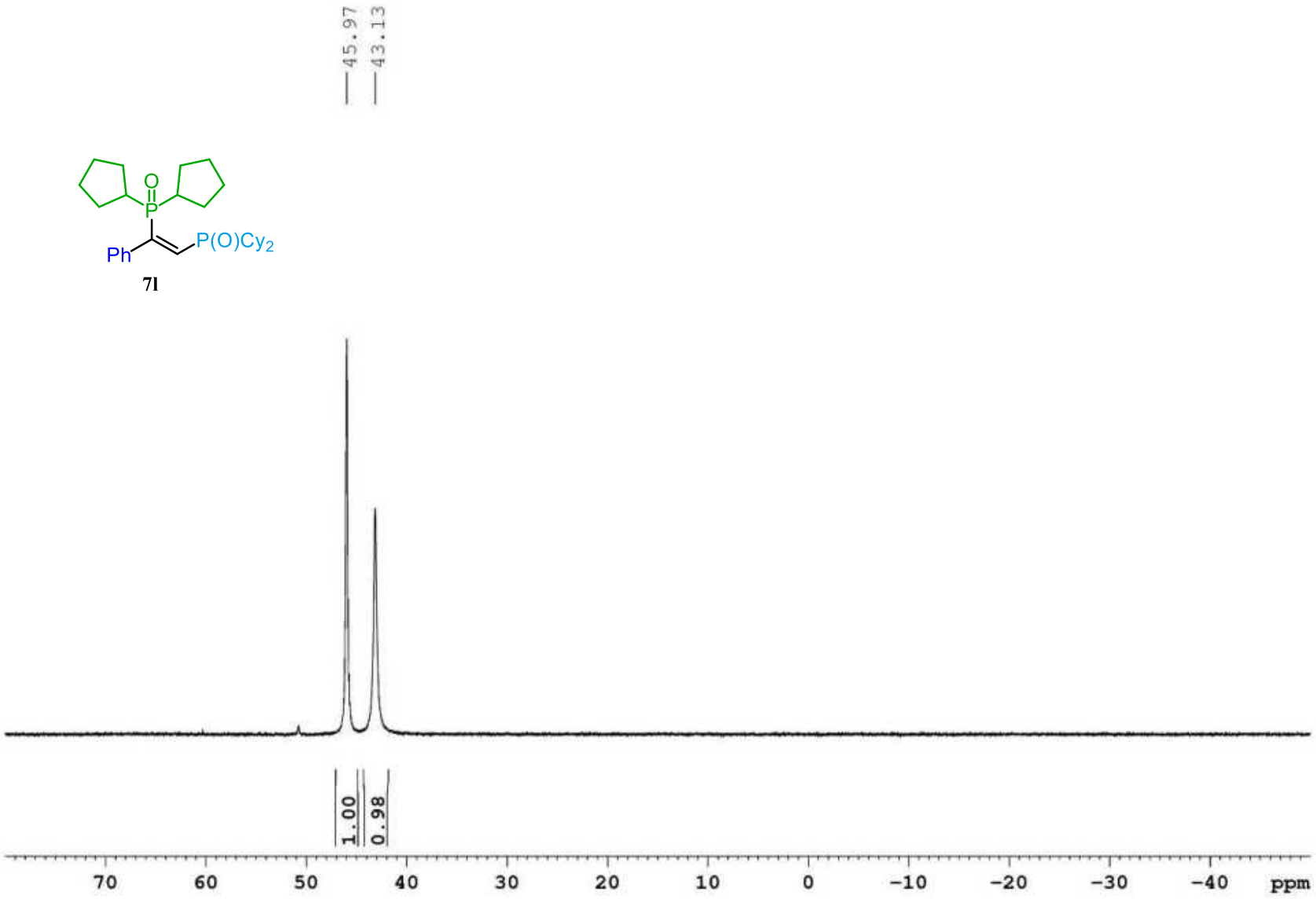

50.44
24.40
1.00
0.95
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm


7.29
6.17
6.13
6.08
6.05
6.00
3.14
3.08
3.03
1.96
1.92
1.90
1.86
1.82
1.80
1.80
1.75
1.72
1.70
1.68
1.67
1.65
1.64
1.62
1.52
1.44
1.43
1.39
1.38
1.36
1.22
O
P
Ph
P(O)Cy2
5.00
0.99
1.83
18.31
15.08
5.32
9
8
7
6
5
4
3
2
1
0
ppm

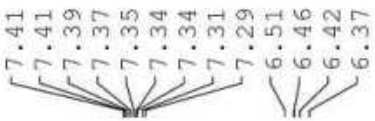
7l

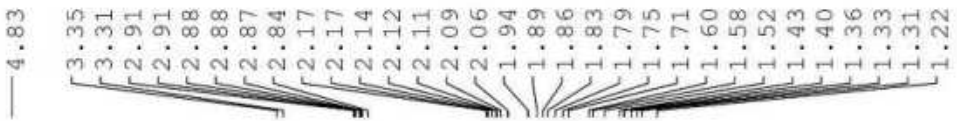

161.88
161.32
142.24
133.97
133.24
128.45
128.24
127.92
40.16
39.47
37.35
36.67
27.84
27.82
26.60
26.44
26.41
26.34
26.31
25.86
25.80
25.75
25.29
25.26
O
P
Ph
P(O)Cy2
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm

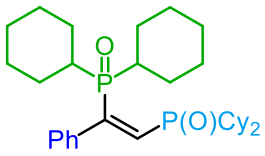
7l



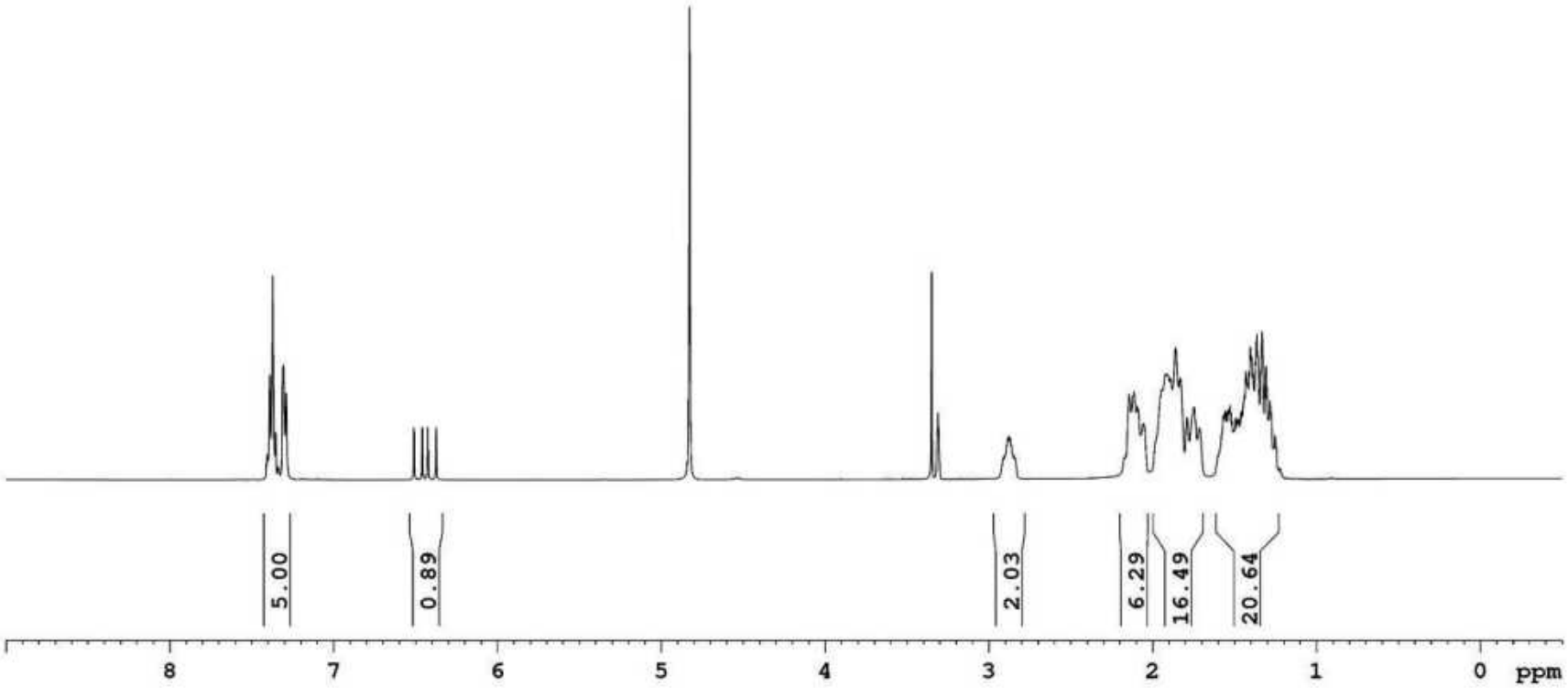
7l

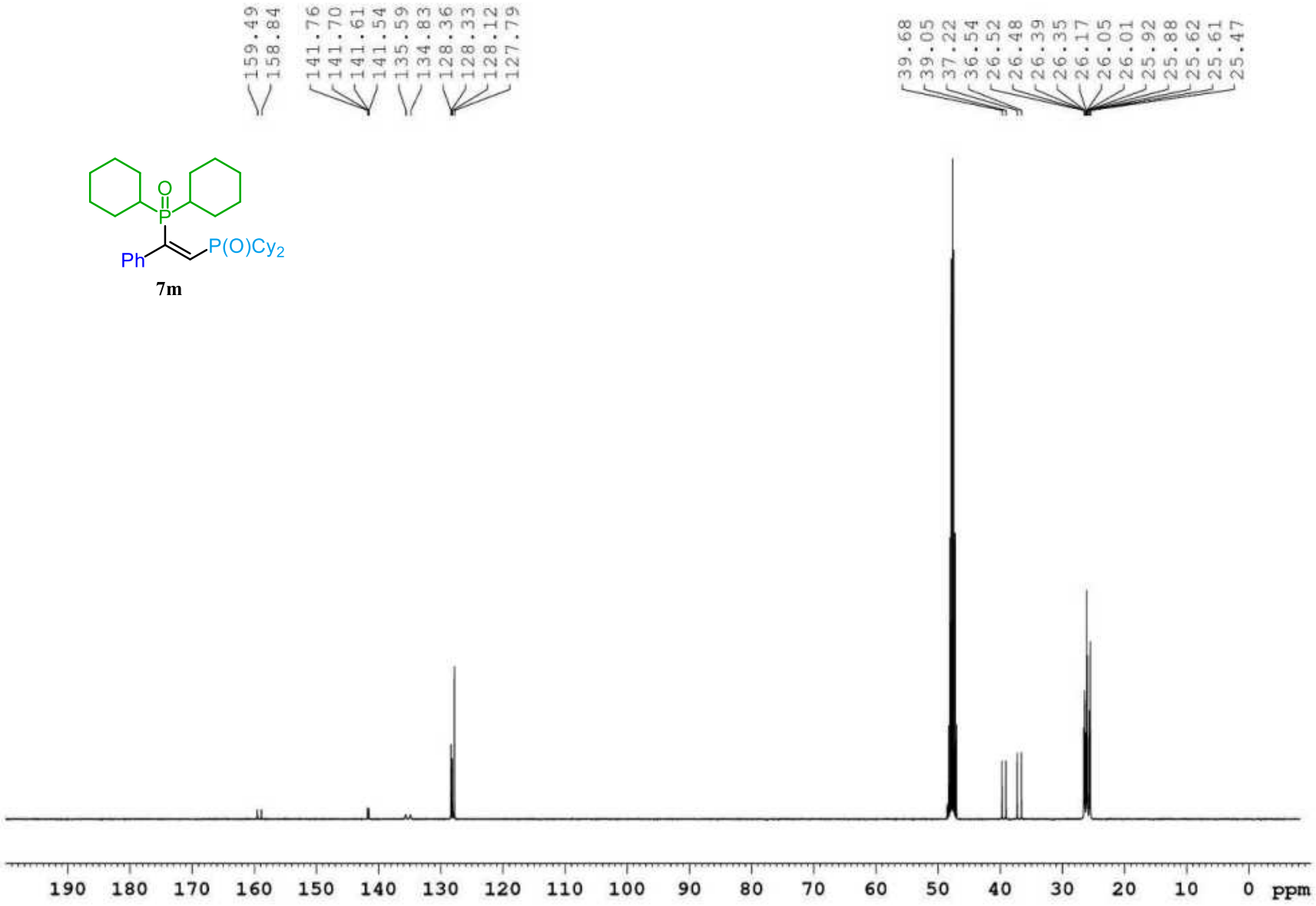

7.41
7.41
7.39
7.37
7.35
7.34
7.34
7.31
7.29
6.51
6.46
6.42
6.37

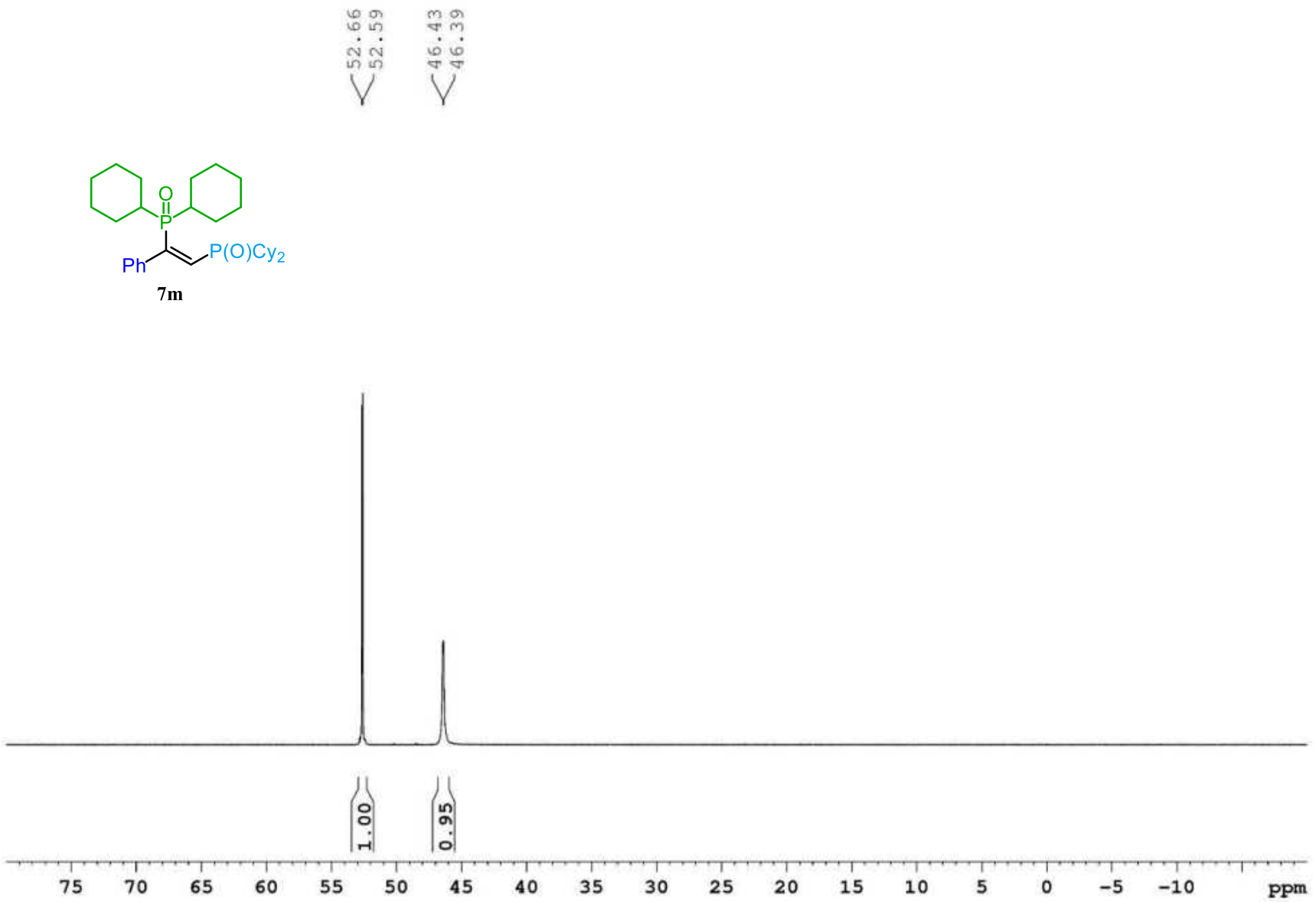

4.83
3.35
3.31
2.91
2.91
2.88
2.88
2.87
2.84
2.17
2.17
2.14
2.12
2.11
2.09
2.06
1.94
1.89
1.86
1.83
1.79
1.75
1.71
1.60
1.58
1.52
1.43
1.40
1.36
1.33
1.31
1.22


O
P
Ph
P(O)Cy2

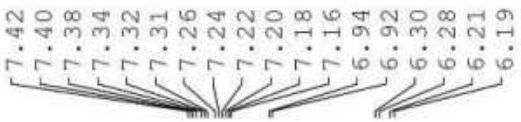
7m

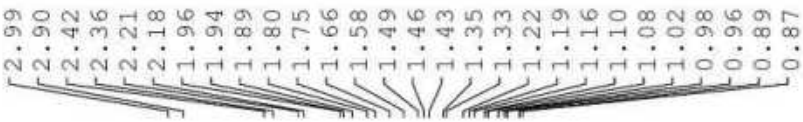

5.00
0.89
2.03
6.29
16.49
20.64
8
7
6
5
4
3
2
1
0
ppm

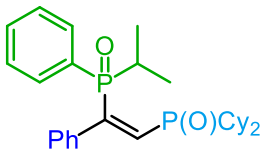

159.49
158.84
141.76
141.70
141.61
141.54
135.59
134.83
128.36
128.33
128.12
127.79
39.68
39.05
37.22
36.54
26.52
26.48
26.39
26.35
26.17
26.05
26.01
25.92
25.88
25.62
25.61
25.47
O
P
Ph
P(O)Cy2
7m
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


52.66
52.59
46.43
46.39
O
P
Ph
P(O)Cy2
1.00
0.95
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm

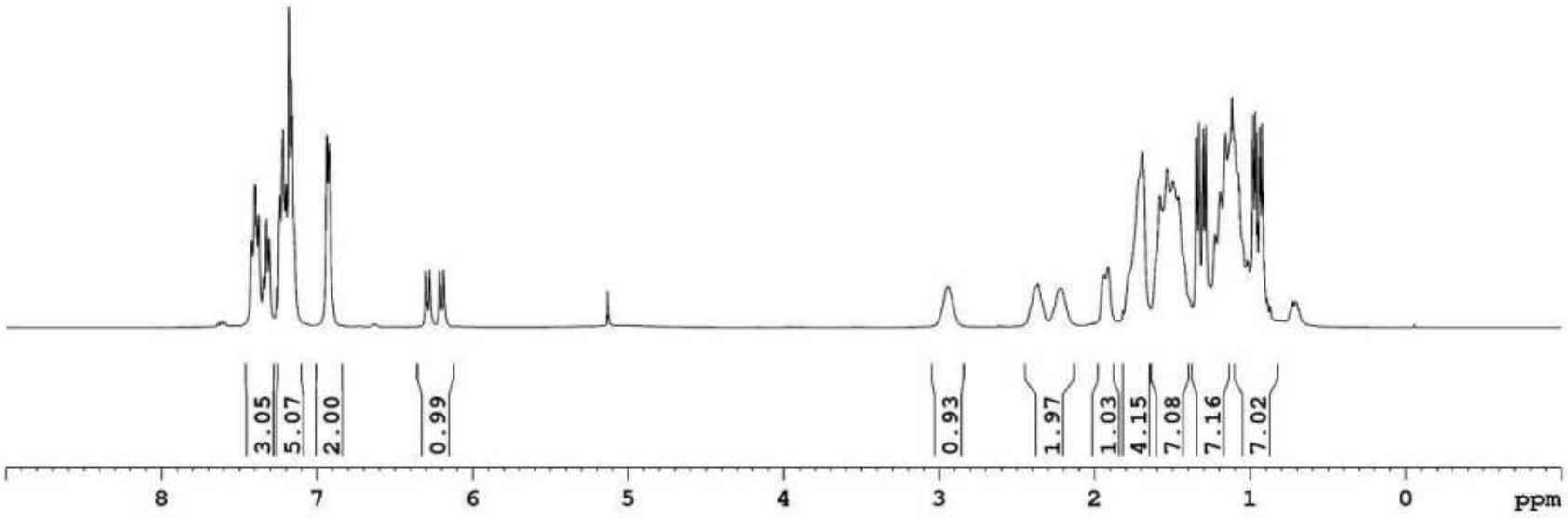
7m


7.42
7.40
7.38
7.34
7.32
7.31
7.26
7.24
7.22
7.20
7.18
7.16
6.94
6.92
6.30
6.28
6.21
6.19


2.99
2.90
2.42
2.36
2.21
2.18
1.96
1.94
1.89
1.80
1.75
1.66
1.58
1.49
1.46
1.43
1.35
1.33
1.22
1.19
1.16
1.10
1.08
1.02
0.98
0.96
0.89
0.87

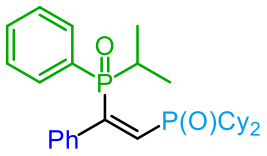

O
P
Ph
P(O)Cy2

7n

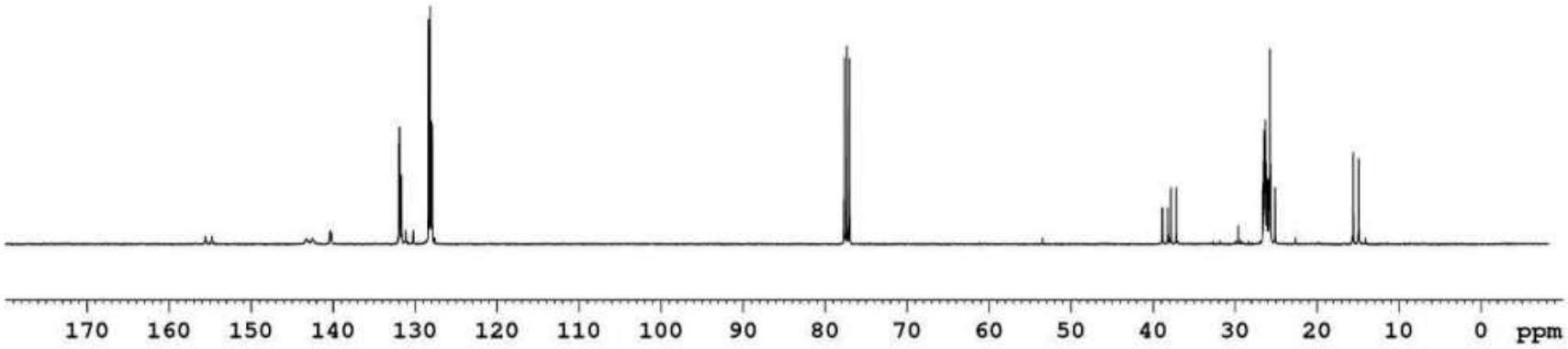

3.05
5.07
2.00
0.99
0.93
1.97
1.03
4.15
7.08
7.16
7.02
8
7
6
5
4
3
2
1
0
ppm

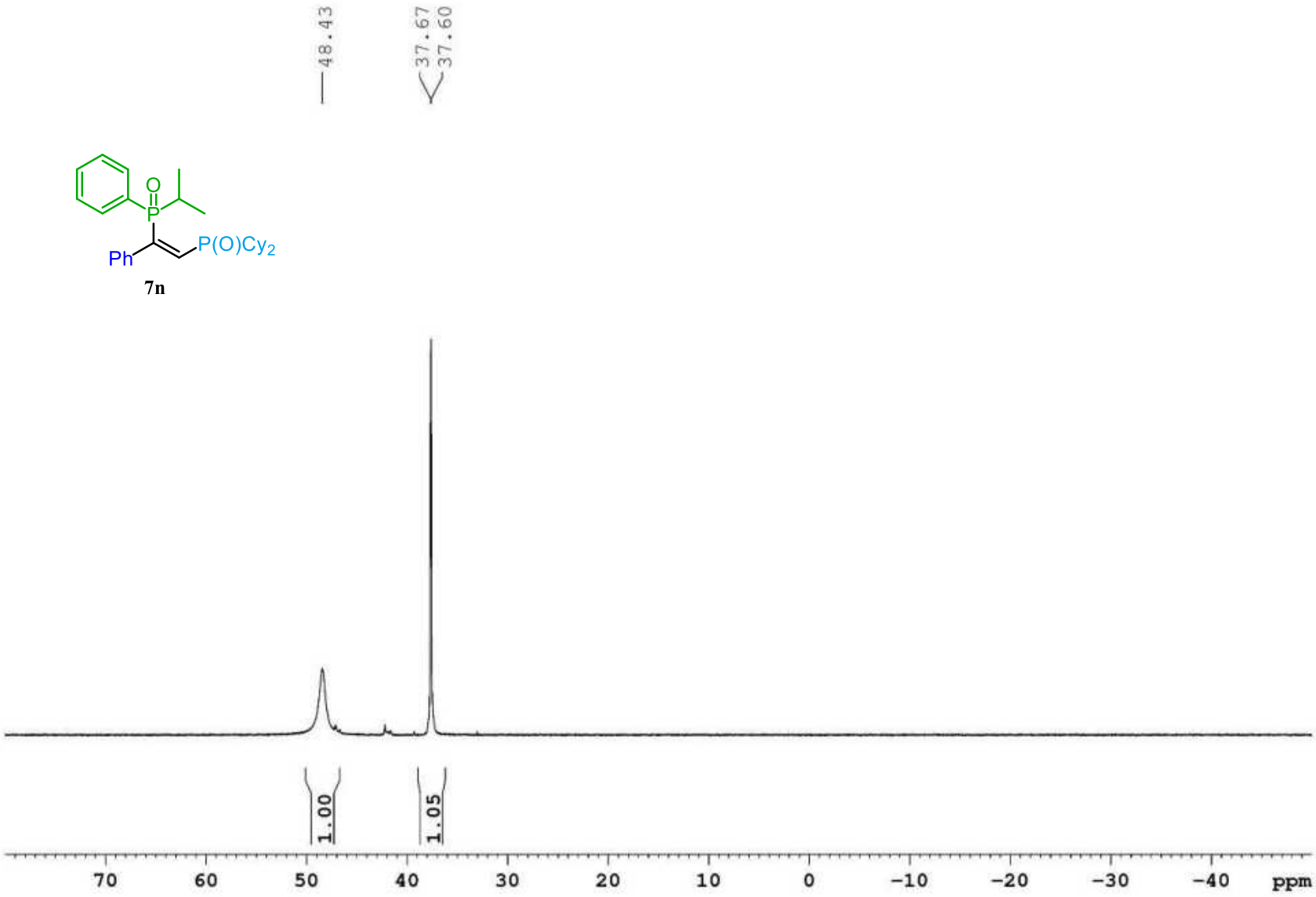
155.53
154.78
143.21
142.48
140.41
140.27
140.16
131.93
131.85
131.67
131.65
131.14
130.20
128.34
128.13
128.02
127.90

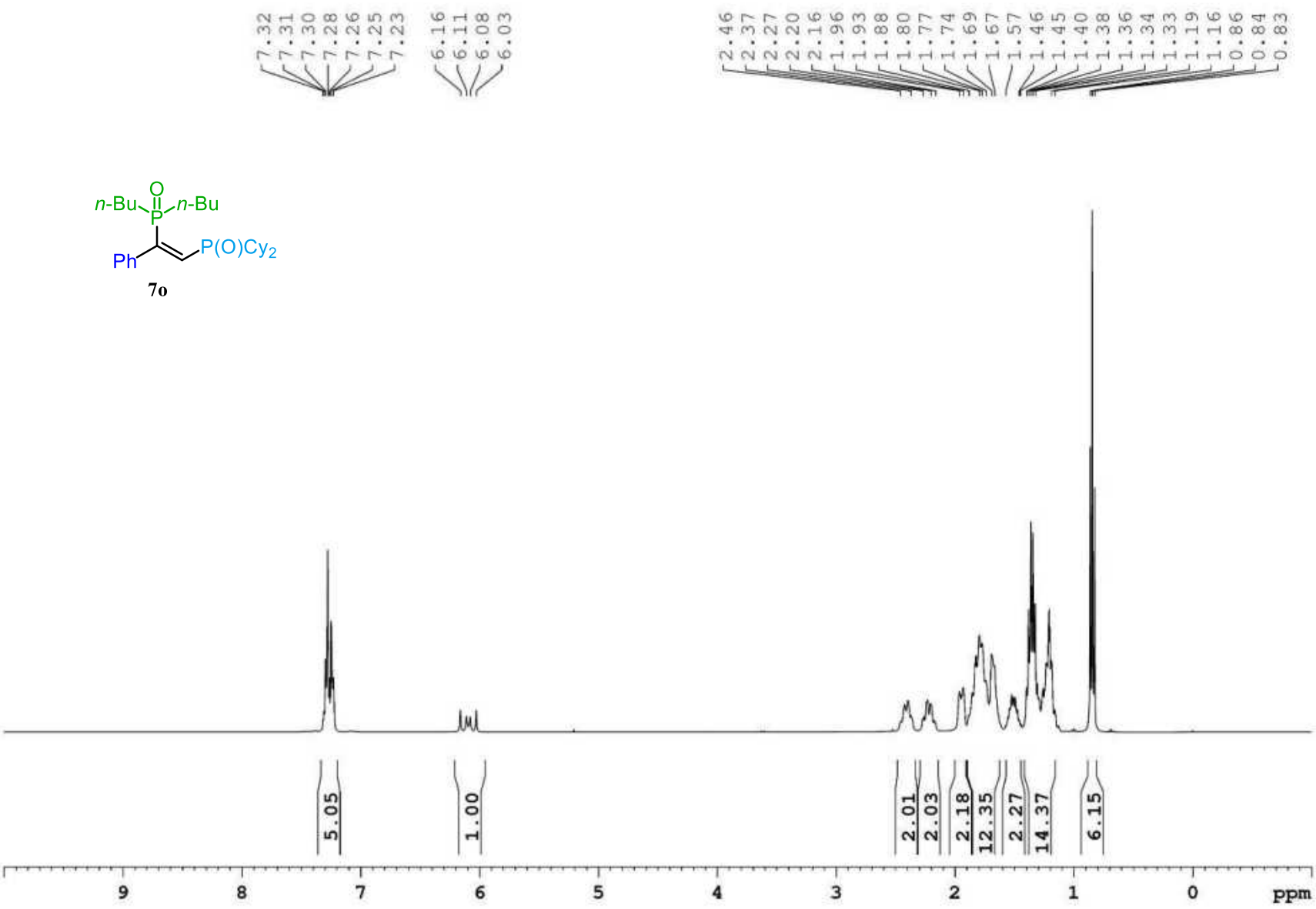
38.83
38.16
37.81
37.14
26.59
26.46
26.37
26.29
26.24
26.21
26.18
26.08
25.95
25.92
25.78
25.71
25.64
25.08
15.55
15.52
14.89
14.86



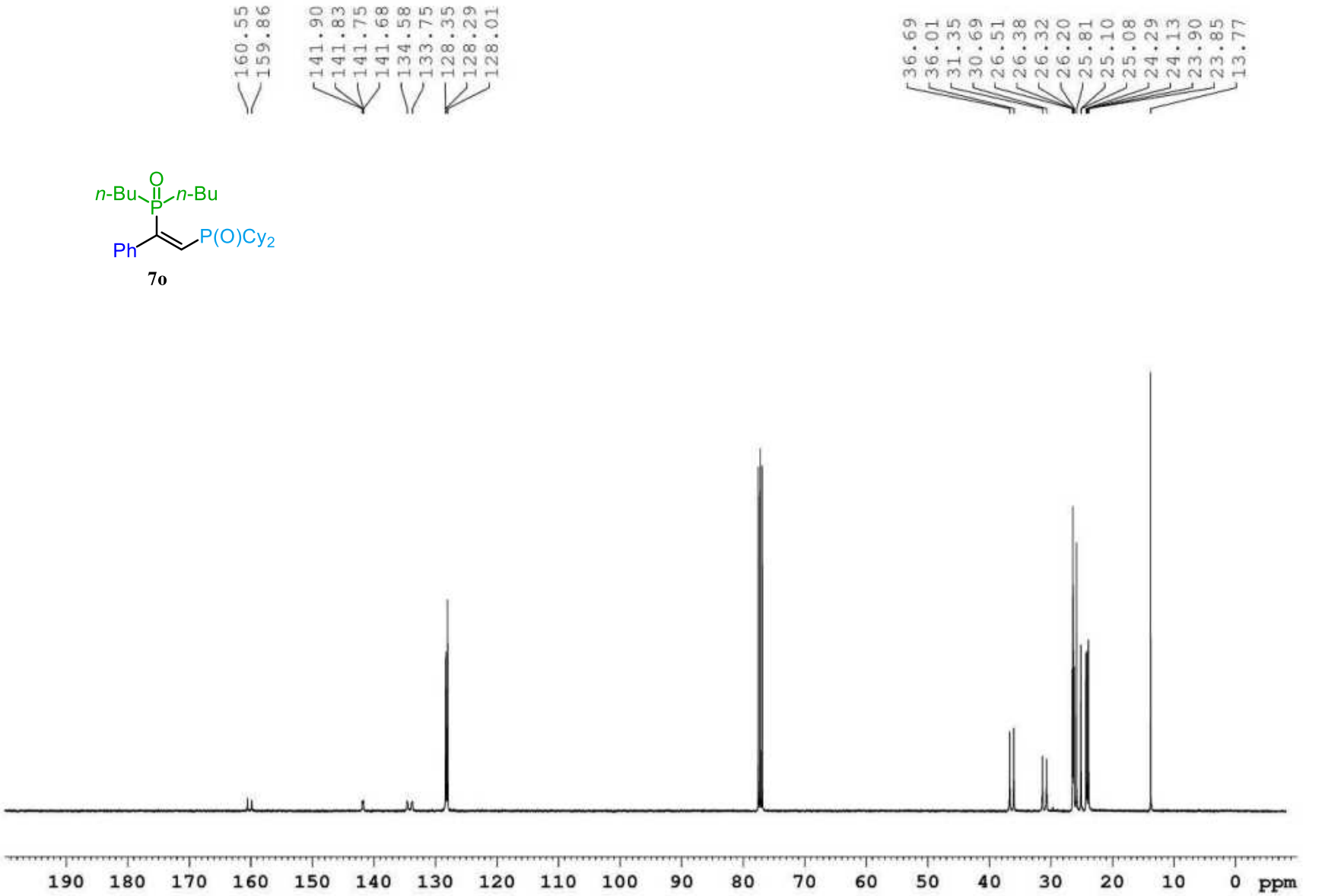
7n




48.43
37.67
37.60
O
P
Ph
P(O)Cy2
7n
1.00
1.05
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm

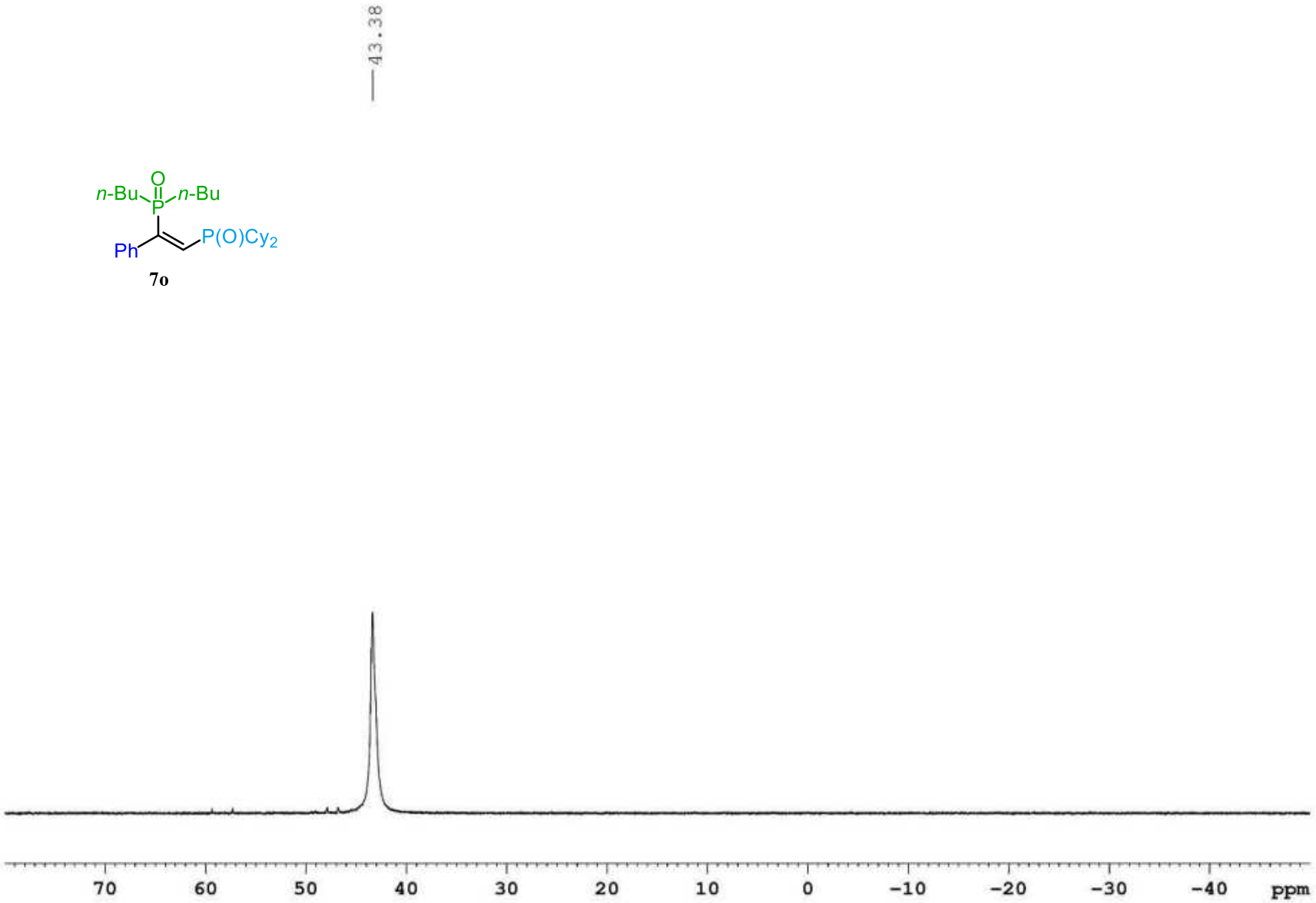

7.32
7.31
7.30
7.28
7.26
7.25
7.23
6.16
6.11
6.08
6.03
2.46
2.37
2.27
2.20
2.16
1.96
1.93
1.88
1.80
1.77
1.74
1.69
1.67
1.57
1.46
1.45
1.40
1.38
1.36
1.34
1.33
1.19
1.16
0.86
0.84
0.83
n-Bu
n-Bu
O
P
Ph
P(O)Cy2
5.05
1.00
2.01
2.03
2.18
12.35
2.27
14.37
6.15
9
8
7
6
5
4
3
2
1
0
ppm

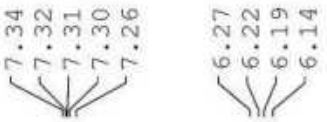
7o


160.55
159.86
141.90
141.83
141.75
141.68
134.58
133.75
128.35
128.29
128.01
36.69
36.01
31.35
30.69
26.51
26.38
26.32
26.20
25.81
25.10
25.08
24.29
24.13
23.90
23.85
13.77
n-Bu
O
P
n-Bu
Ph
P(O)Cy2
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

7o

7o

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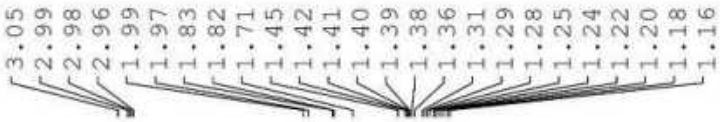
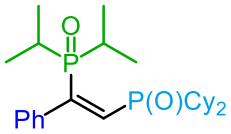
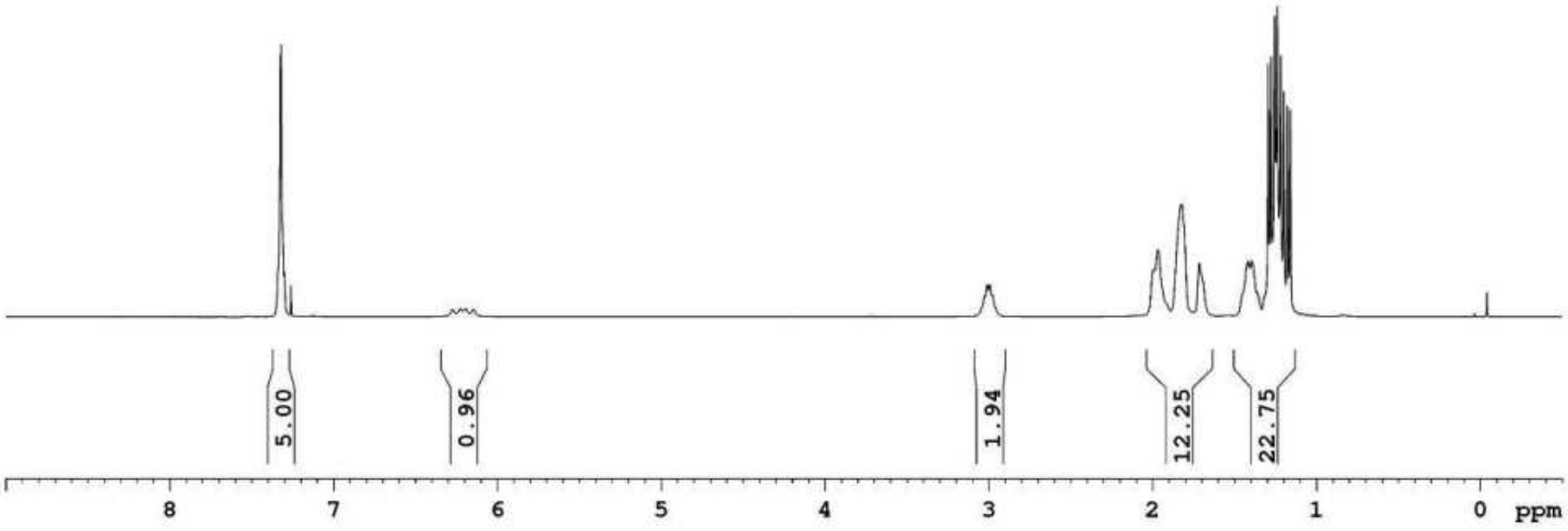
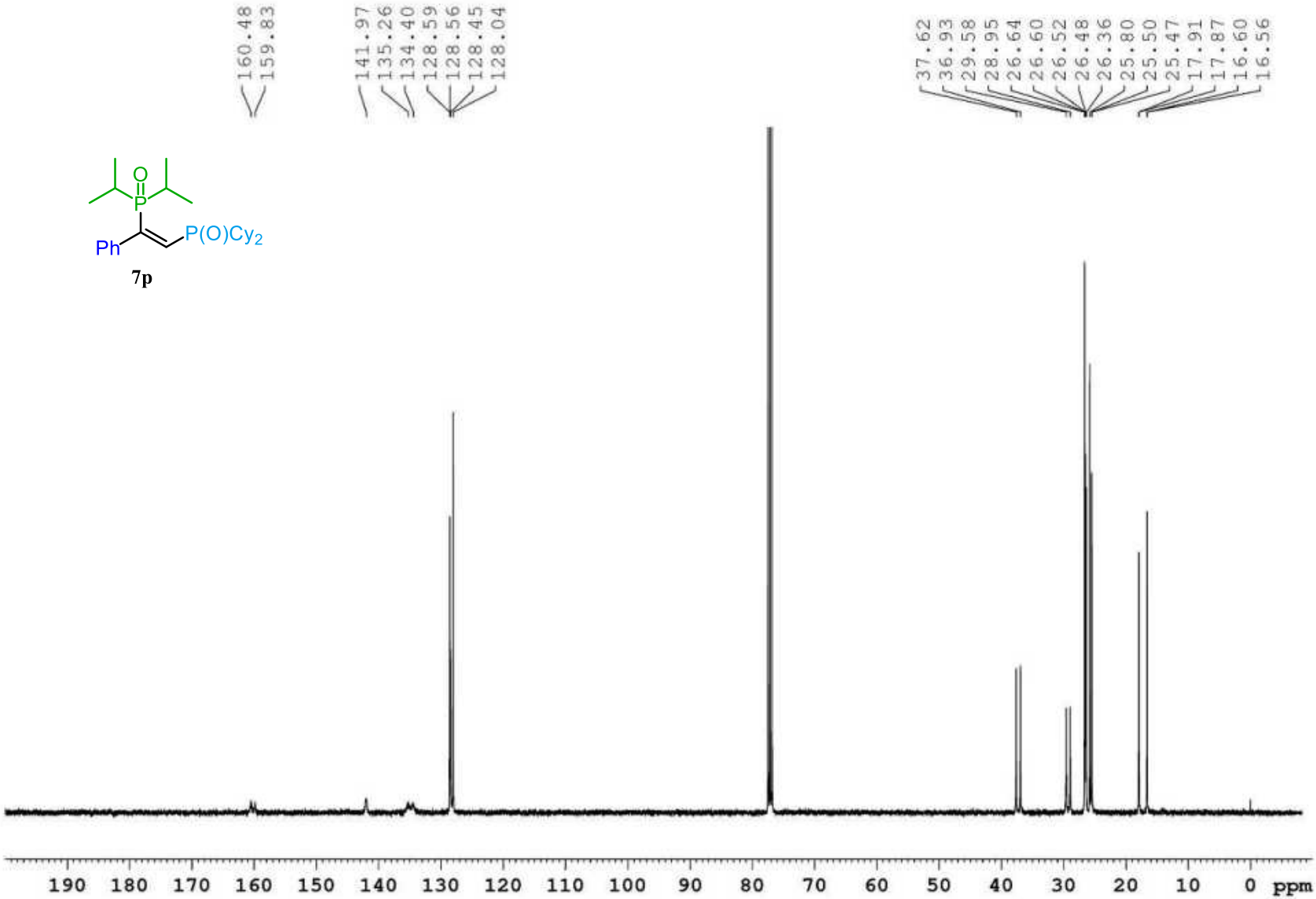
7.32
7.31
7.30
7.26
6.27
6.22
6.19
6.14


3.05
2.99
2.98
2.96
1.99
1.97
1.83
1.82
1.71
1.45
1.42
1.41
1.40
1.39
1.38
1.36
1.31
1.29
1.28
1.25
1.24
1.22
1.20
1.18
1.16


O
P
Ph
P(O)Cy2

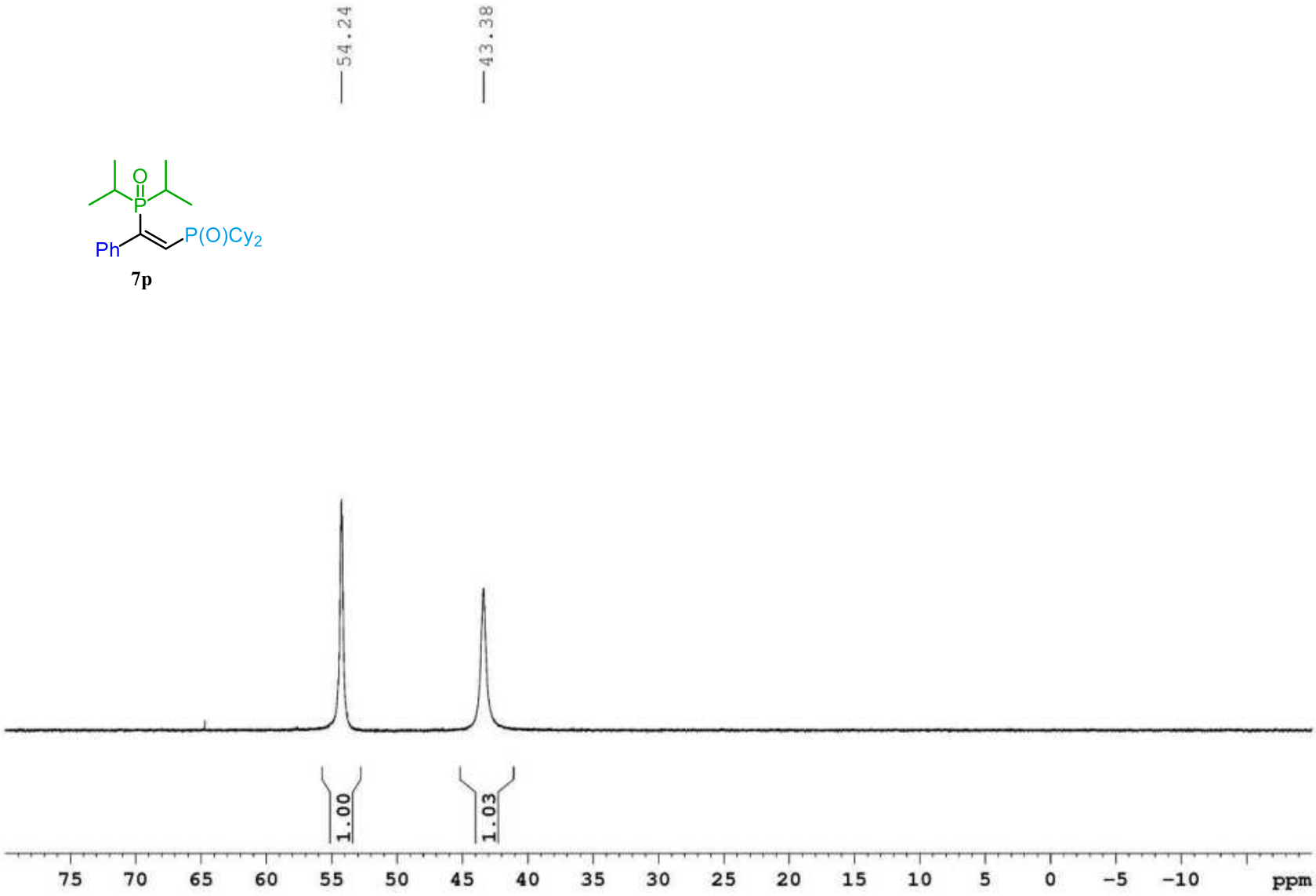
7p

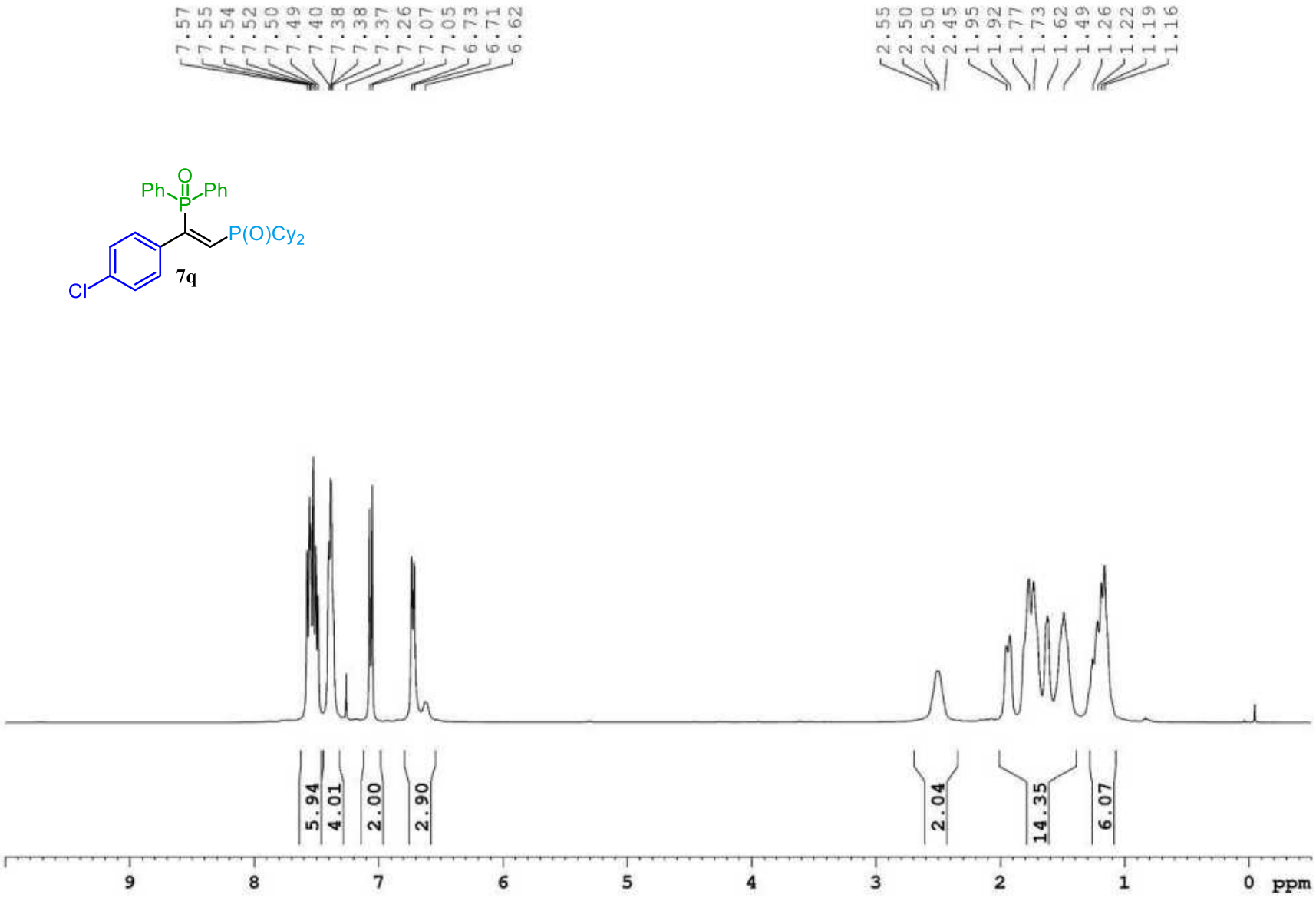

5.00
0.96
1.94
12.25
22.75
8
7
6
5
4
3
2
1
0
ppm

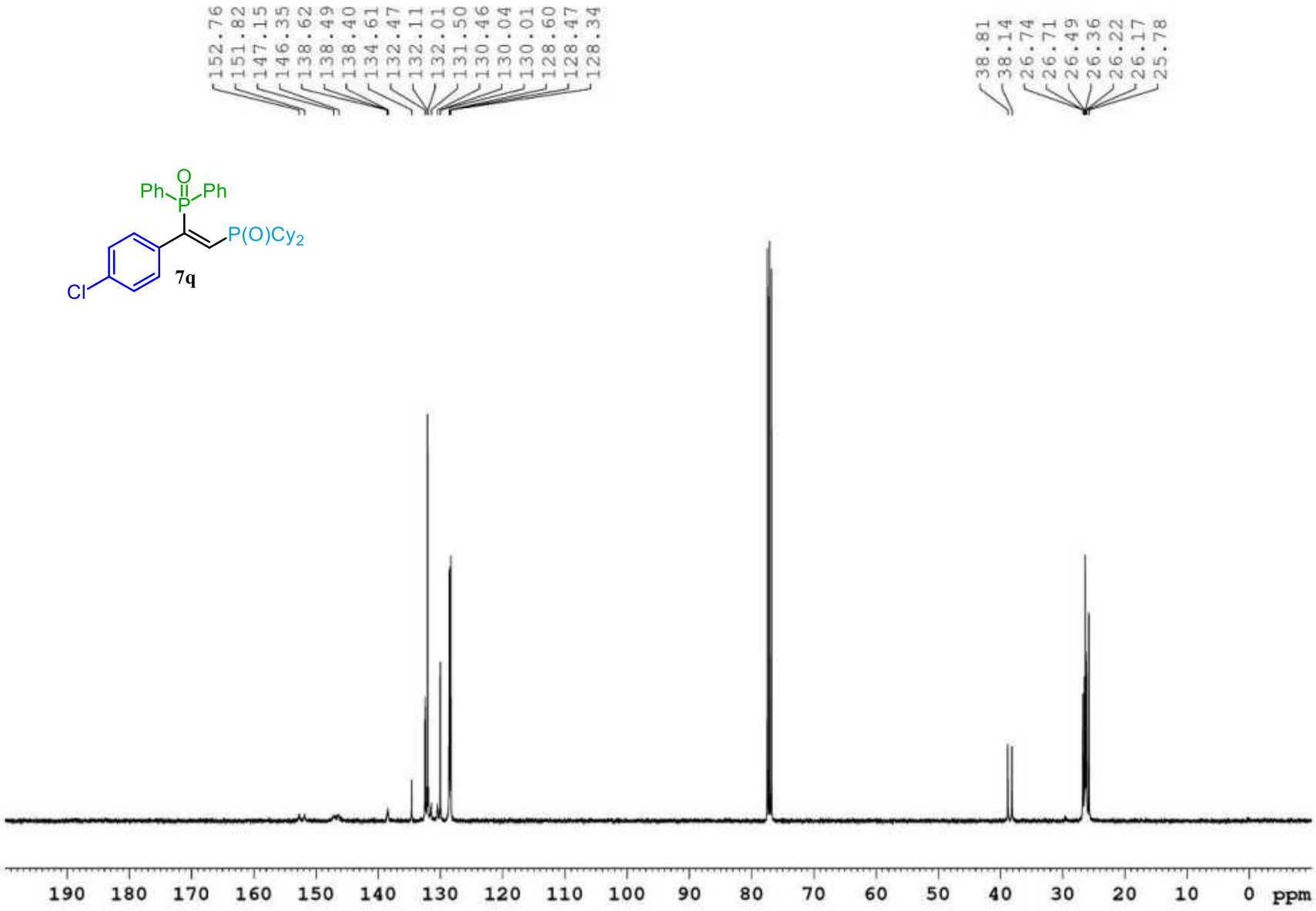

160.48
159.83
141.97
135.26
134.40
128.59
128.56
128.45
128.04
37.62
36.93
29.58
28.95
26.64
26.60
26.52
26.48
26.36
25.80
25.50
25.47
17.91
17.87
16.60
16.56
O
P
Ph
P(O)Cy2
7p
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm

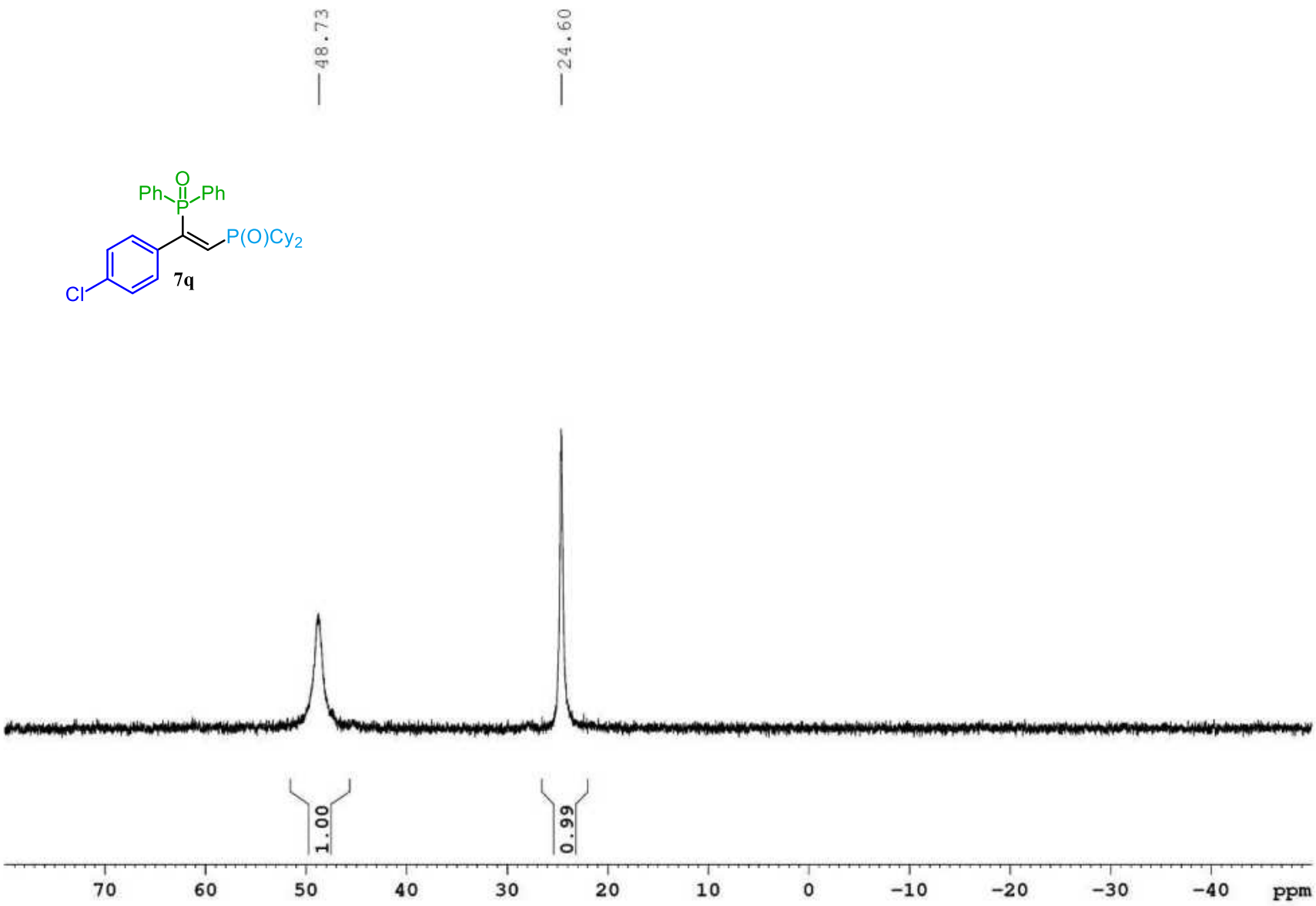
O
P
Ph
P(O)Cy2

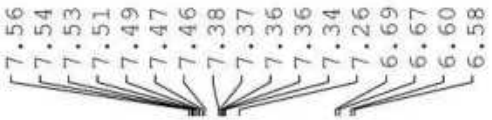
7p

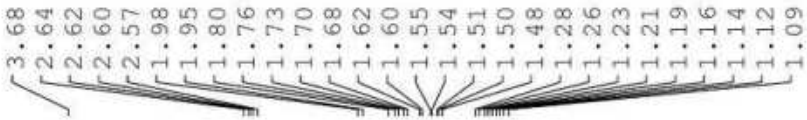

54.24
43.38
1.00
1.03
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm


7.57
7.55
7.54
7.52
7.50
7.49
7.40
7.38
7.38
7.37
7.26
7.07
7.05
6.73
6.71
6.62
2.55
2.50
2.50
2.45
1.95
1.92
1.77
1.73
1.62
1.49
1.26
1.22
1.19
1.16
Ph
O
P
Ph
P(O)Cy2
Cl
7q
5.94
4.01
2.00
2.90
2.04
14.35
6.07
9
8
7
6
5
4
3
2
1
0
ppm


152.76
151.82
147.15
146.35
138.62
138.49
138.40
134.61
132.47
132.11
132.01
131.50
130.46
130.04
130.01
128.60
128.47
128.34
38.81
38.14
26.74
26.71
26.49
26.36
26.22
26.17
25.78
Ph
O
P
Ph
P(O)Cy2
Cl
7q
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


48.73
24.60
Ph
O
Ph
P
P(O)Cy2
Cl
7q
1.00
0.99
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm


7.56
7.54
7.53
7.51
7.49
7.47
7.46
7.38
7.37
7.36
7.36
7.34
7.26
6.69
6.67
6.60
6.58


3.68
2.64
2.62
2.60
2.57
1.98
1.95
1.80
1.76
1.73
1.70
1.68
1.62
1.60
1.55
1.54
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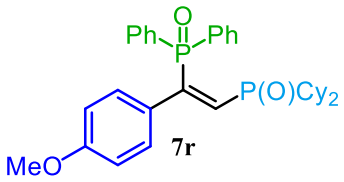
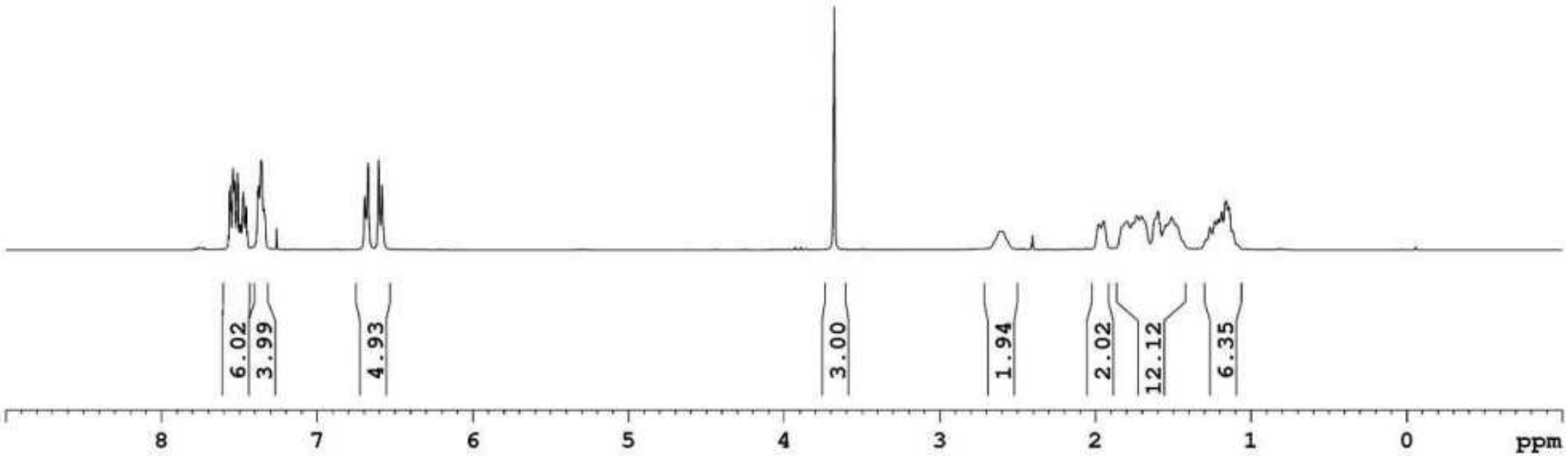
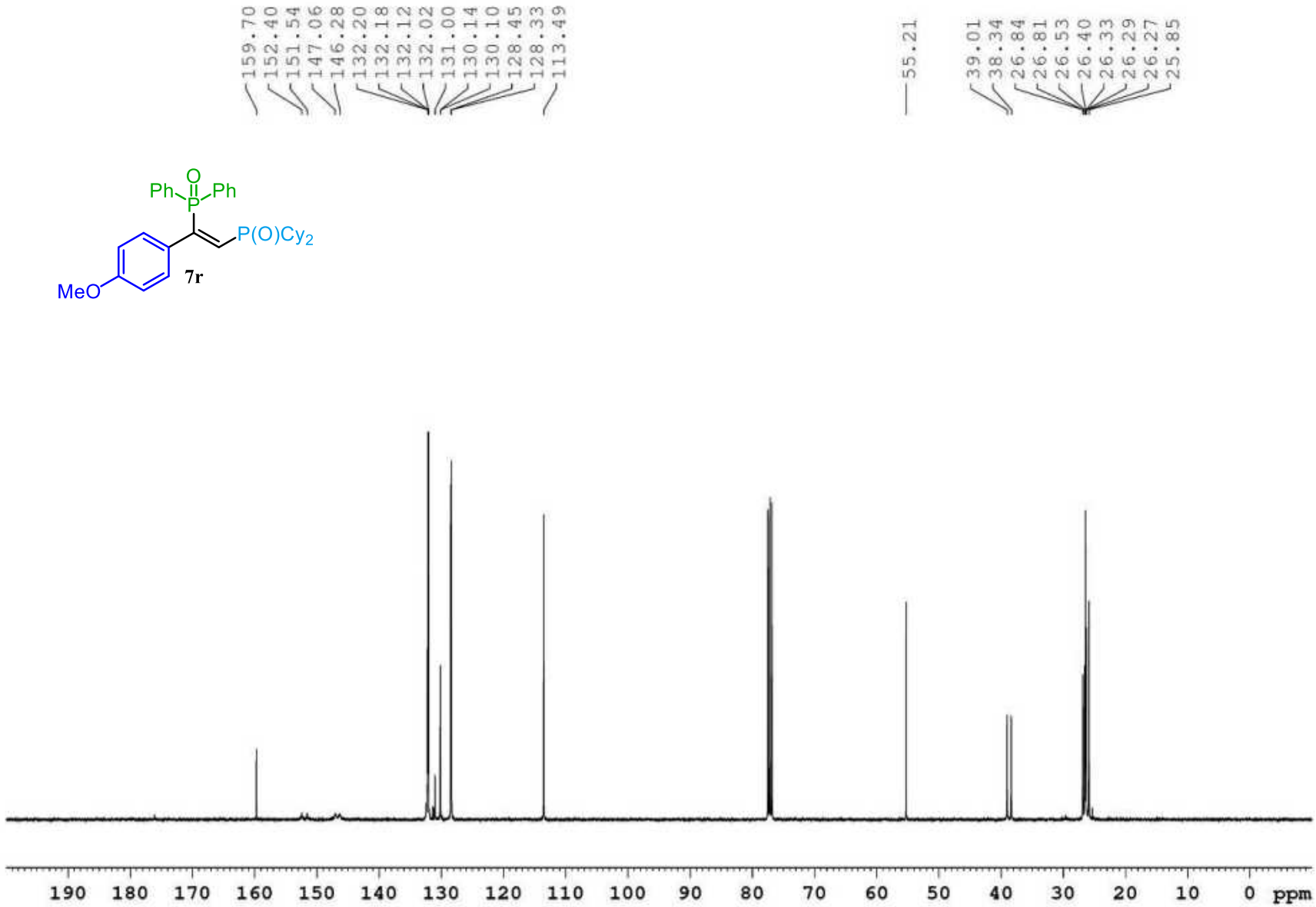
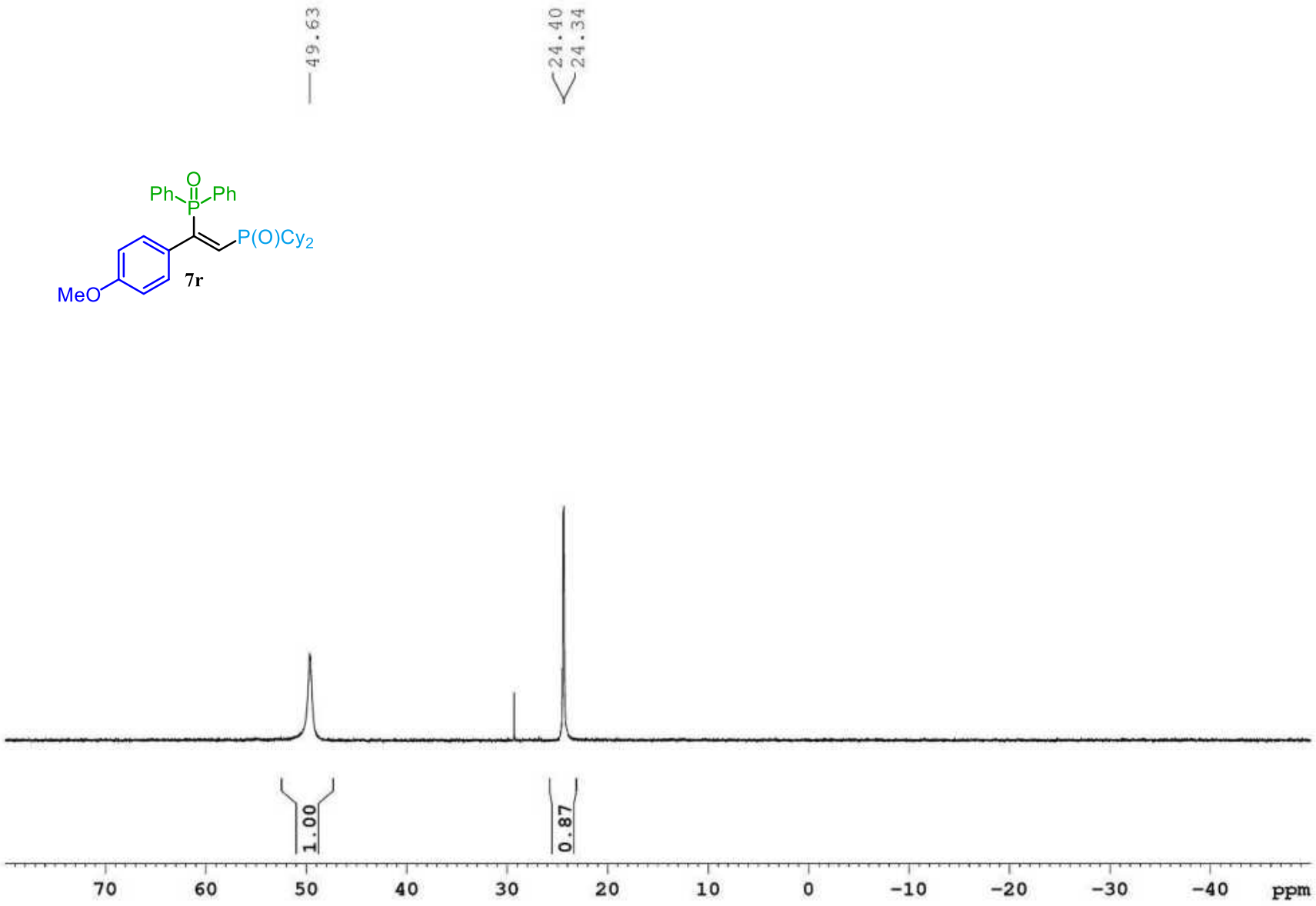
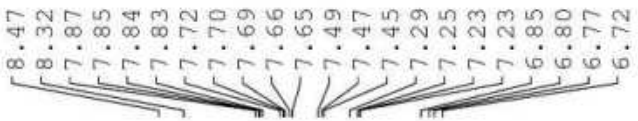
1.21
1.19
1.16
1.14
1.12
1.09

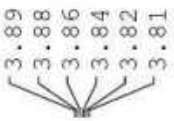

Ph
O
P
Ph
P(O)Cy2
MeO
7r

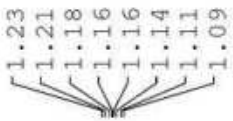

6.02
3.99
4.93
3.00
1.94
2.02
12.12
6.35
8
7
6
5
4
3
2
1
0
ppm

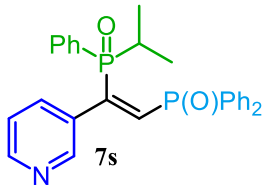

159.70
152.40
151.54
147.06
146.28
132.20
132.18
132.12
132.02
131.00
130.14
130.10
128.45
128.33
113.49
55.21
39.01
38.34
26.84
26.81
26.53
26.40
26.33
26.29
26.27
25.85
Ph
O
P
Ph
P(O)Cy2
MeO
7r
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


49.63
24.40
24.34
Ph
O
Ph
P
P(O)Cy2
MeO
7r
1.00
0.87
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm

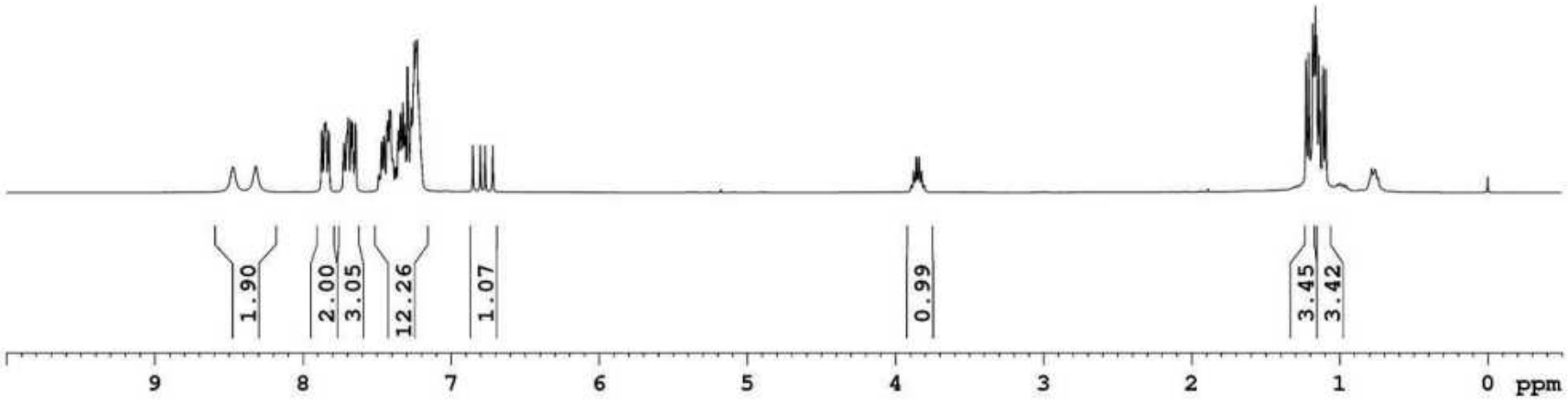

8.47
8.32
7.87
7.85
7.84
7.83
7.72
7.70
7.69
7.66
7.65
7.49
7.47
7.45
7.29
7.25
7.23
7.23
6.85
6.80
6.77
6.72

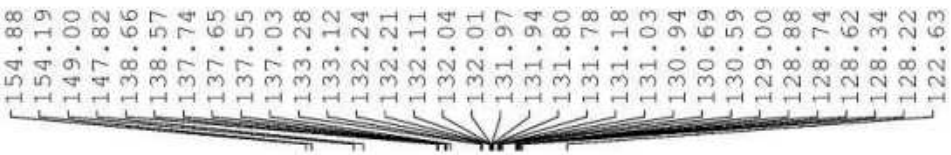

3.89
3.88
3.86
3.84
3.82
3.81

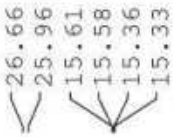

1.23
1.21
1.18
1.16
1.16
1.14
1.11
1.09

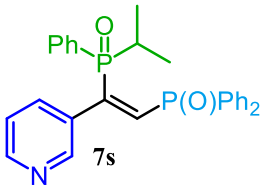

Ph
O
P
P(O)Ph2
N

7s

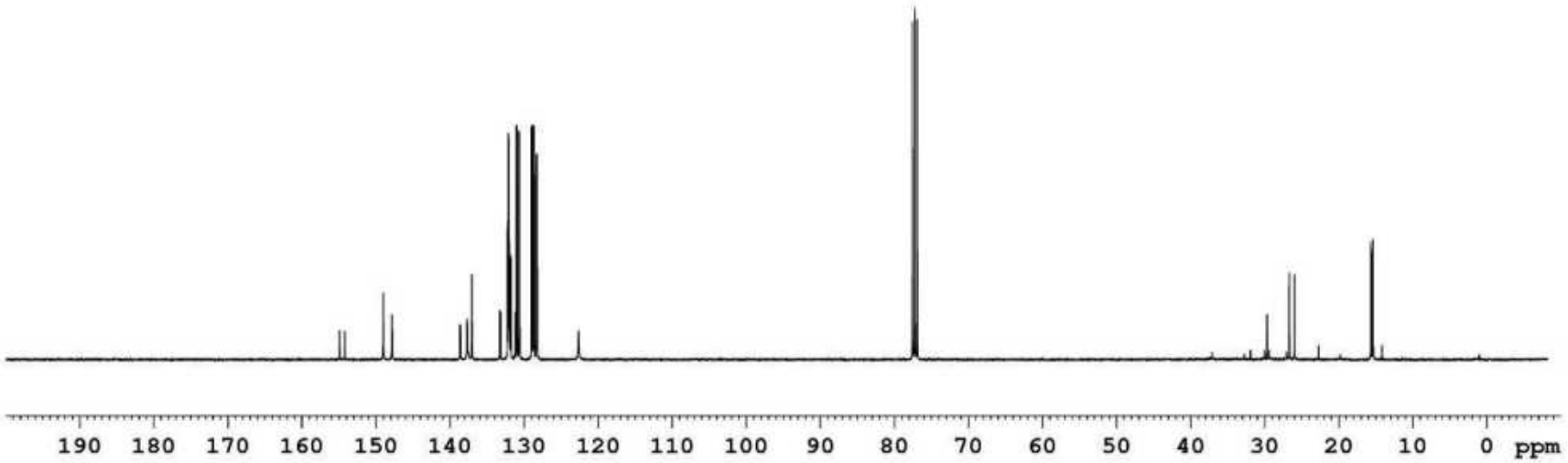

1.90
2.00
3.05
12.26
1.07
0.99
3.45
3.42
9
8
7
6
5
4
3
2
1
0
ppm

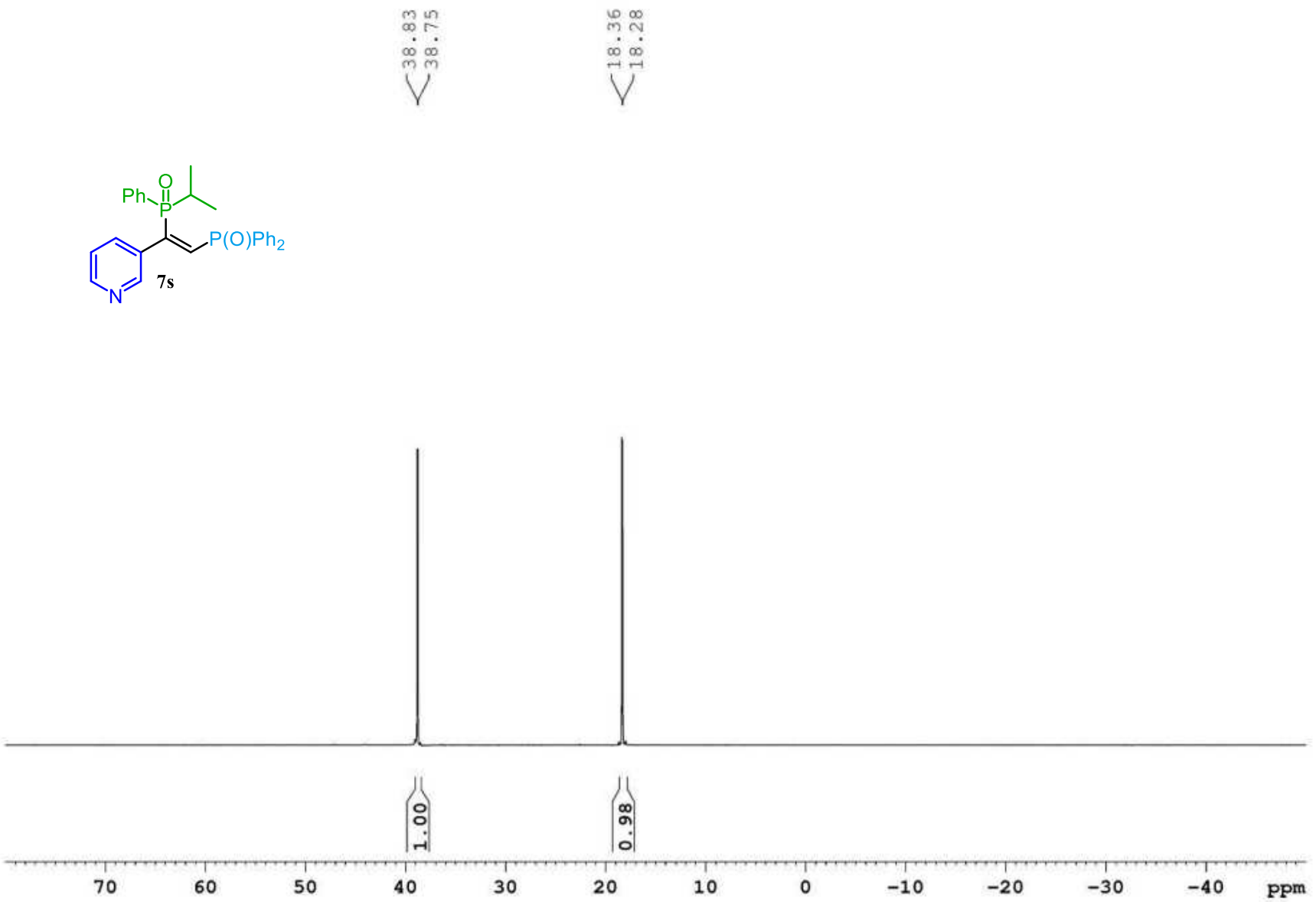

154.88
154.19
149.00
147.82
138.66
138.57
137.74
137.65
137.55
137.03
133.28
133.12
132.24
132.21
132.11
132.04
132.01
131.97
131.94
131.80
131.78
131.18
131.03
130.94
130.69
130.59
129.00
128.88
128.74
128.62
128.34
128.22
122.63


26.66
25.96
15.61
15.58
15.36
15.33

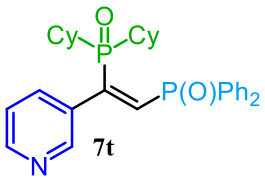

Ph
O
P
P(O)Ph2
N

7s

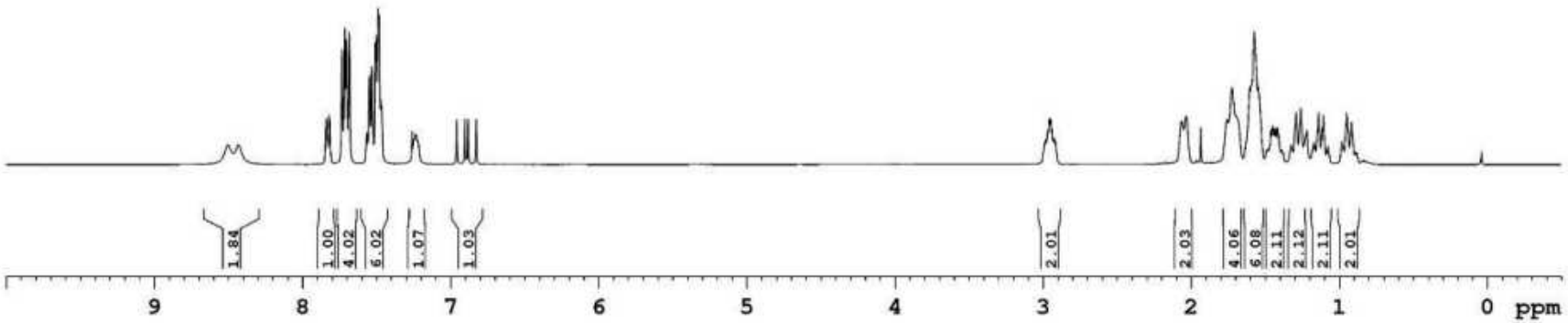

190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

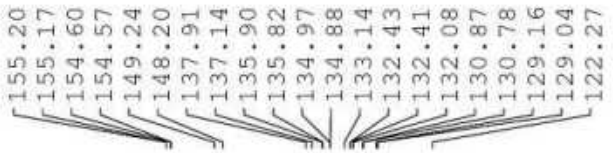

38.83
38.75
18.36
18.28
Ph
O
P
P(O)Ph2
N
7s
1.00
0.98
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm

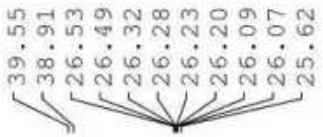

8.50
8.43
7.84
7.82
7.73
7.71
7.71
7.70
7.68
7.68
7.57
7.56
7.55
7.55
7.53
7.53
7.51
7.50
7.49
7.48
7.48
7.47
7.47
7.46
7.26
7.25
7.24
7.23
7.22
6.96
6.90
6.88
6.83
2.99
2.98
2.98
2.97
2.96
2.95
2.95
2.94
2.93
2.92
2.91
2.06
2.03
1.75
1.72
1.69
1.60
1.60
1.59
1.57
1.55
1.46
1.45
1.45
1.44
1.43
1.42
1.42
1.41
1.32
1.29
1.26
1.23
1.22
1.17
1.15
1.14
1.13
1.12
1.11
1.10
0.98
0.95
0.94
0.92

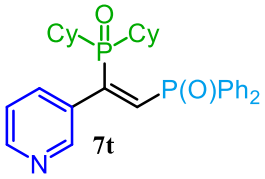

Cy
O
P
Cy
P(O)Ph2
N

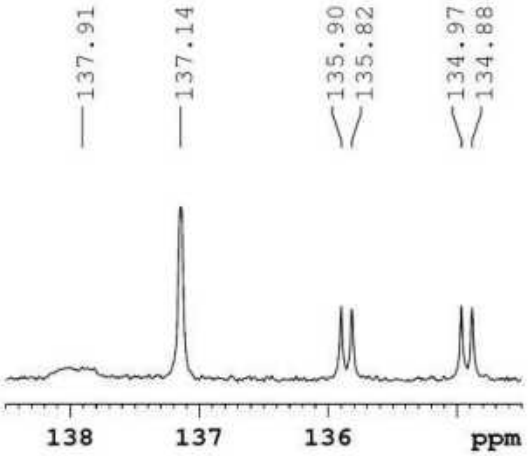
7t

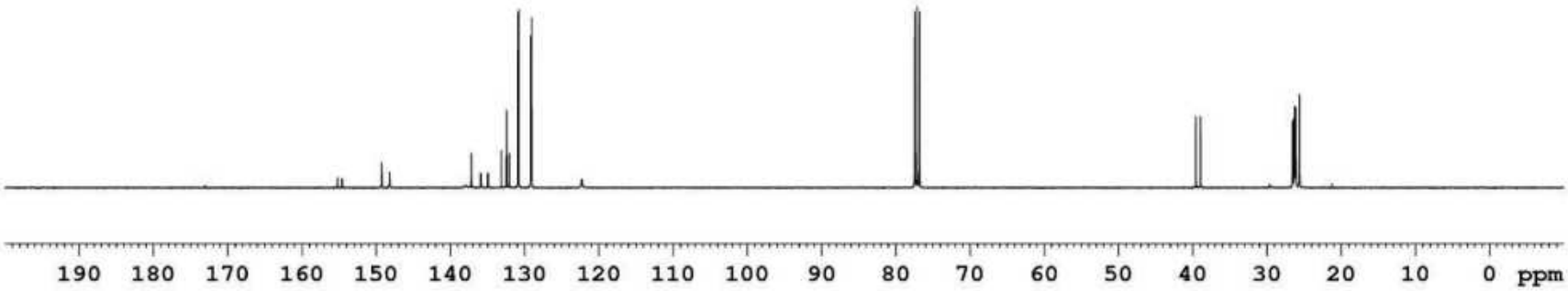

1.84
1.00
4.02
6.02
1.07
1.03
2.01
2.03
4.06
6.08
2.11
2.12
2.11
2.01
9
8
7
6
5
4
3
2
1
0
ppm

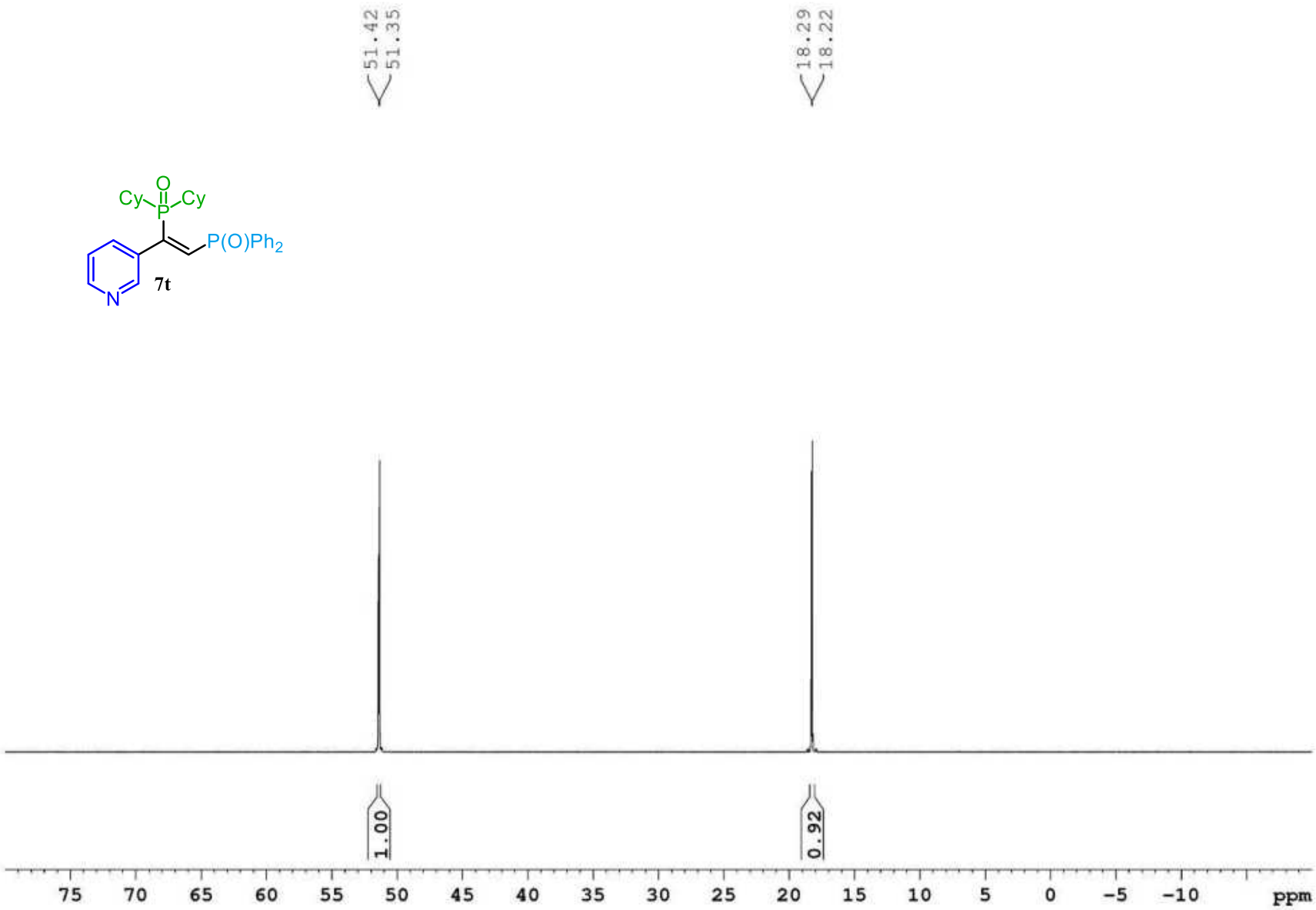

155.20
155.17
154.60
154.57
149.24
148.20
137.91
137.14
135.90
135.82
134.97
134.88
133.14
132.43
132.41
132.08
130.87
130.78
129.16
129.04
122.27

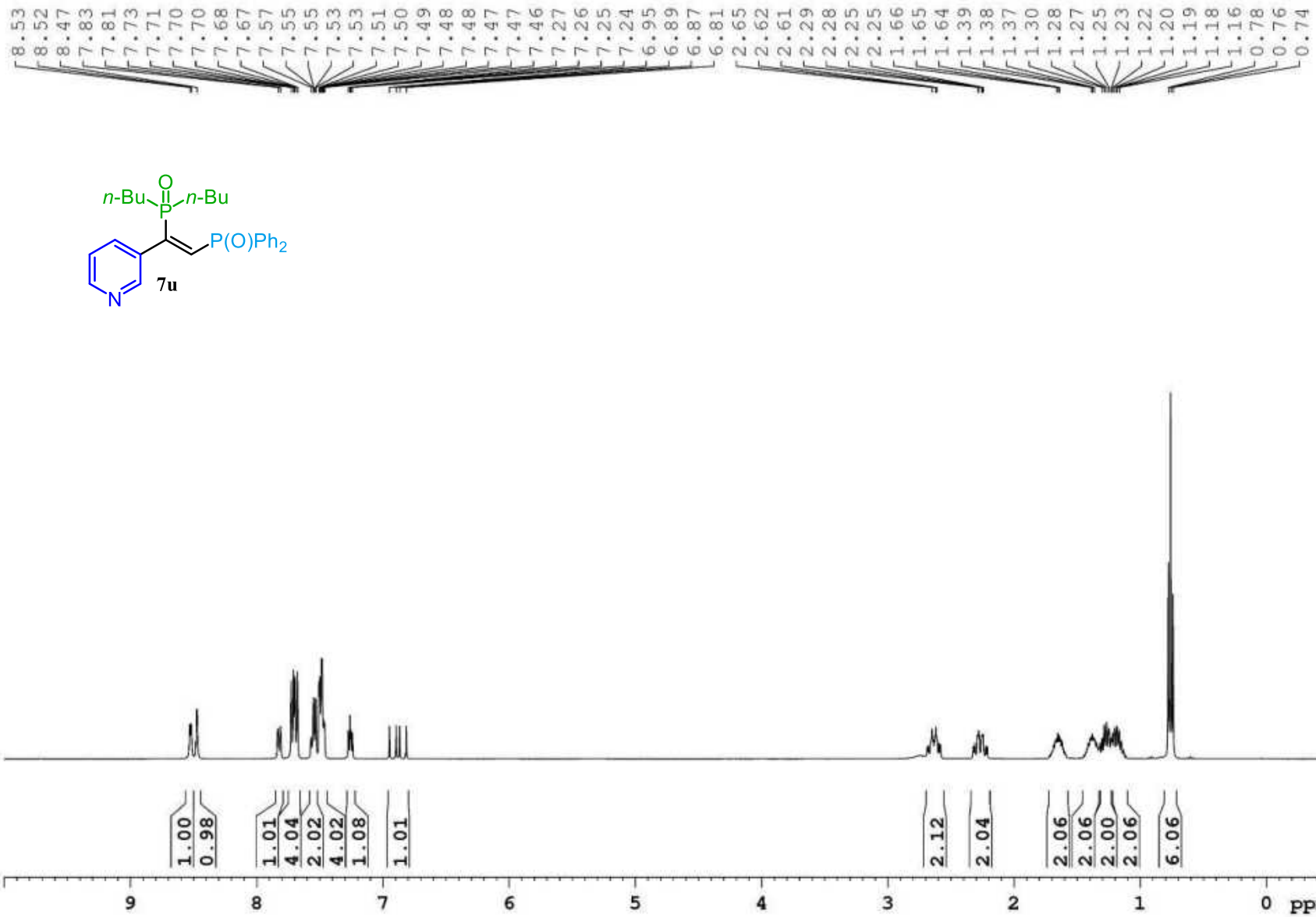

39.55
38.91
26.53
26.49
26.32
26.28
26.23
26.20
26.09
26.07
25.62

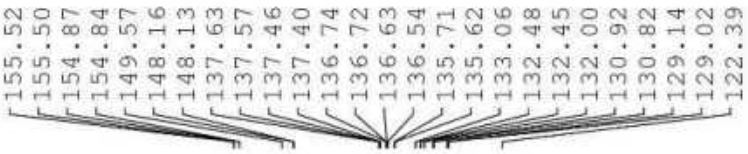

Cy
O
P
Cy
P(O)Ph2
N
7t


137.91
137.14
135.90
135.82
134.97
134.88
138
137
136
ppm


190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


51.42
51.35
18.29
18.22
Cy
O
P
Cy
P(O)Ph2
N
7t
1.00
0.92
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm


8.53 8.52 8.47 7.83 7.81 7.73 7.71 7.70 7.70 7.68 7.67 7.57 7.55 7.55 7.53 7.53 7.51 7.50 7.49 7.48 7.48 7.47 7.47 7.46 7.27 7.26 7.25 7.24 6.95 6.89 6.87 6.81
2.65 2.62 2.61 2.29 2.28 2.25 2.25 1.66 1.65 1.64 1.39 1.38 1.37 1.30 1.28 1.27 1.25 1.23 1.22 1.20 1.19 1.18 1.16 0.78 0.76 0.74
n-Bu
O
P
n-Bu
P(O)Ph2
N
7u
1.00 0.98 1.01 4.04 2.02 4.02 1.08 1.01 2.12 2.04 2.06 2.06 2.00 2.06 6.06
9 8 7 6 5 4 3 2 1 0 ppm


155.52
155.50
154.87
154.84
149.57
148.16
148.13
137.63
137.57
137.46
137.40
136.74
136.72
136.63
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133.06
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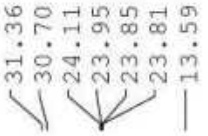
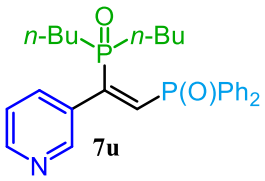
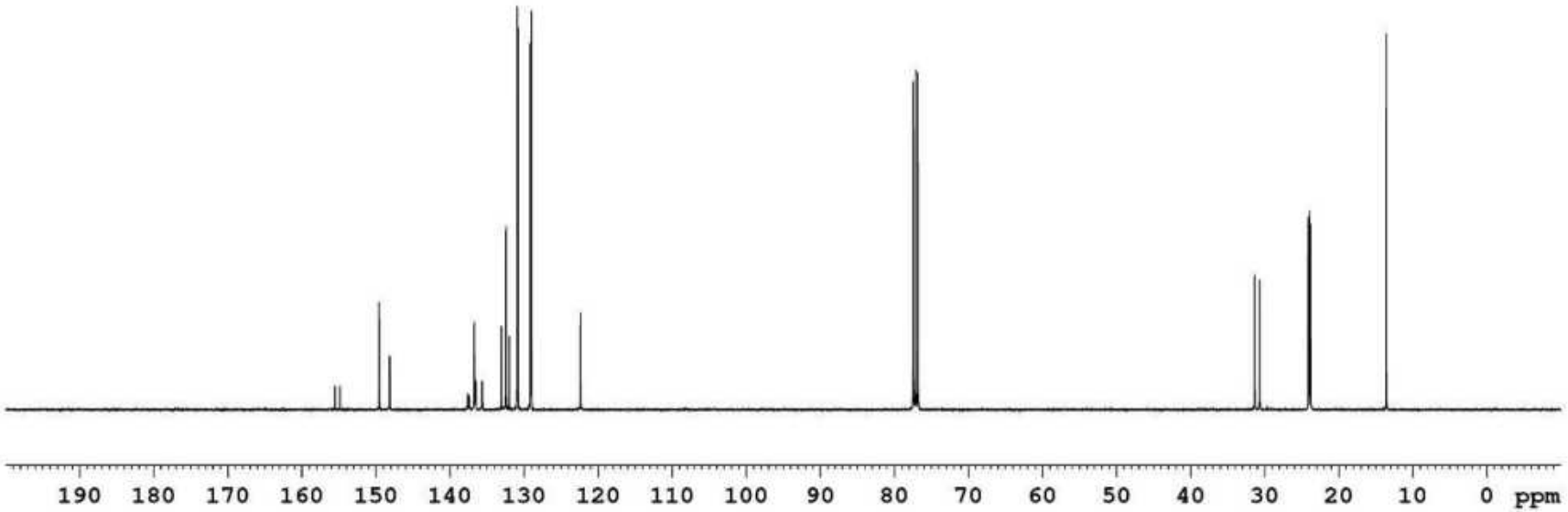
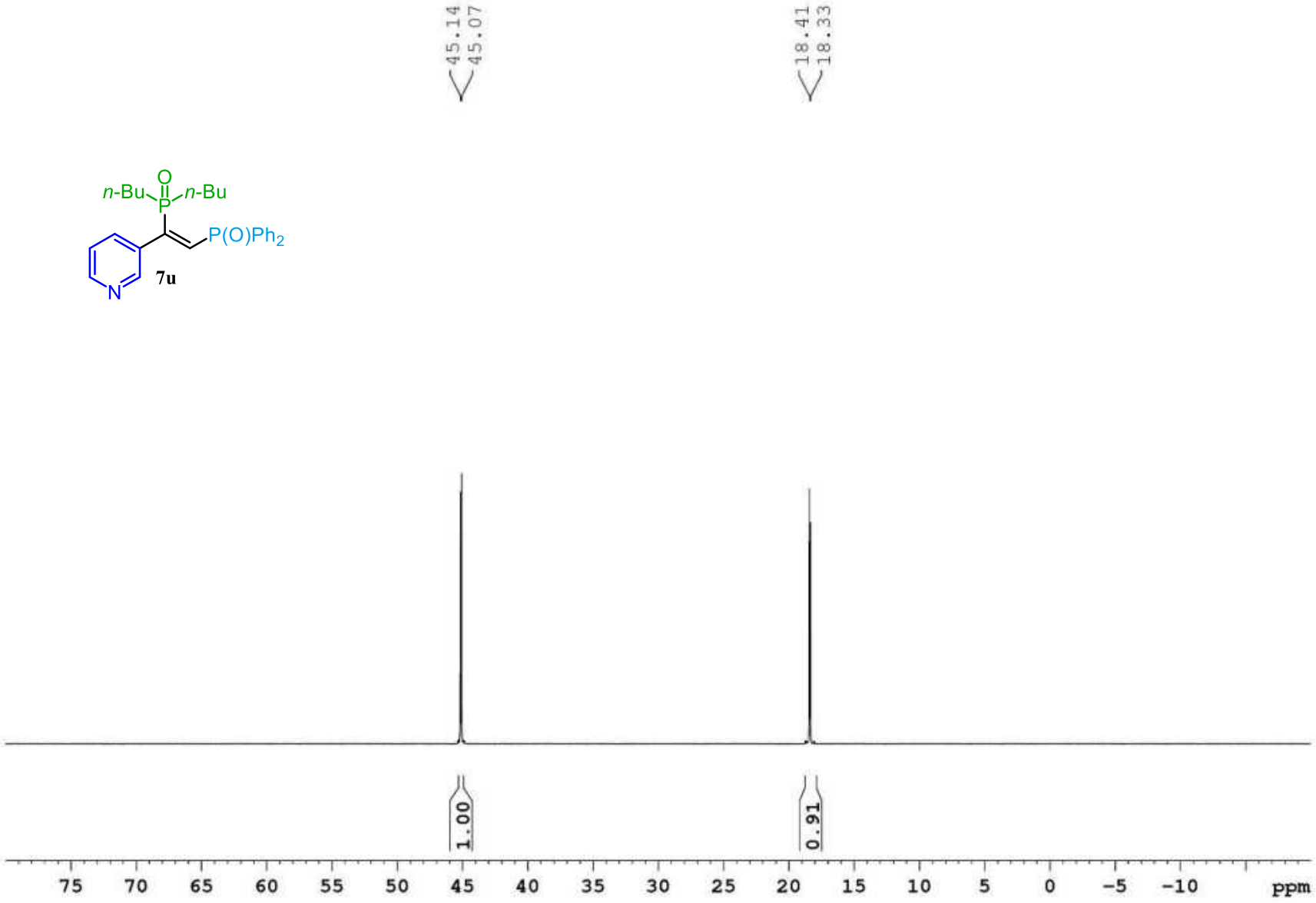
132.00
130.92
130.82
129.14
129.02
122.39

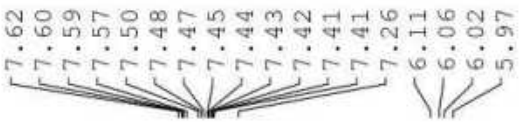

31.36
30.70
24.11
23.95
23.85
23.81
13.59

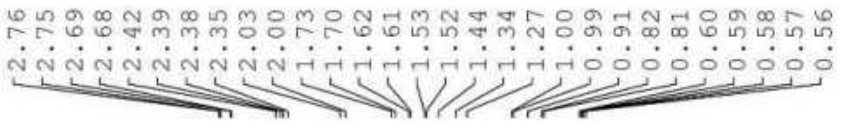

n-Bu
O
P
n-Bu
P(O)Ph2
N

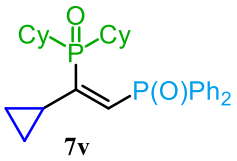
7u


190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

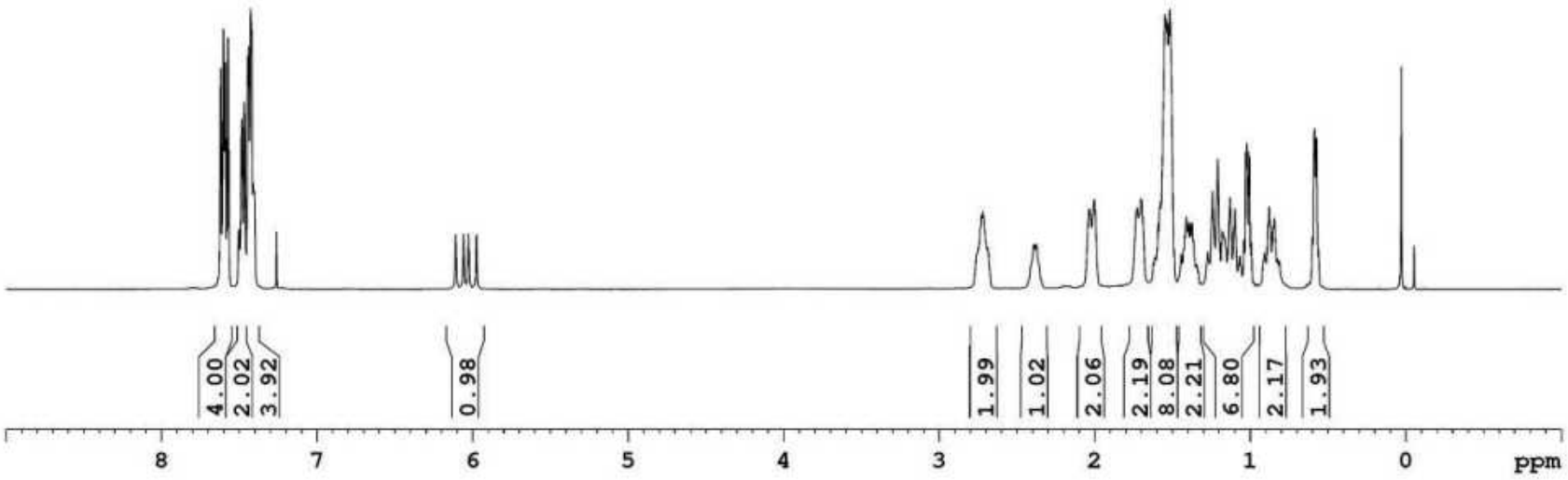

45.14
45.07
18.41
18.33
n-Bu
O
P
n-Bu
P(O)Ph2
N
7u
1.00
0.91
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm

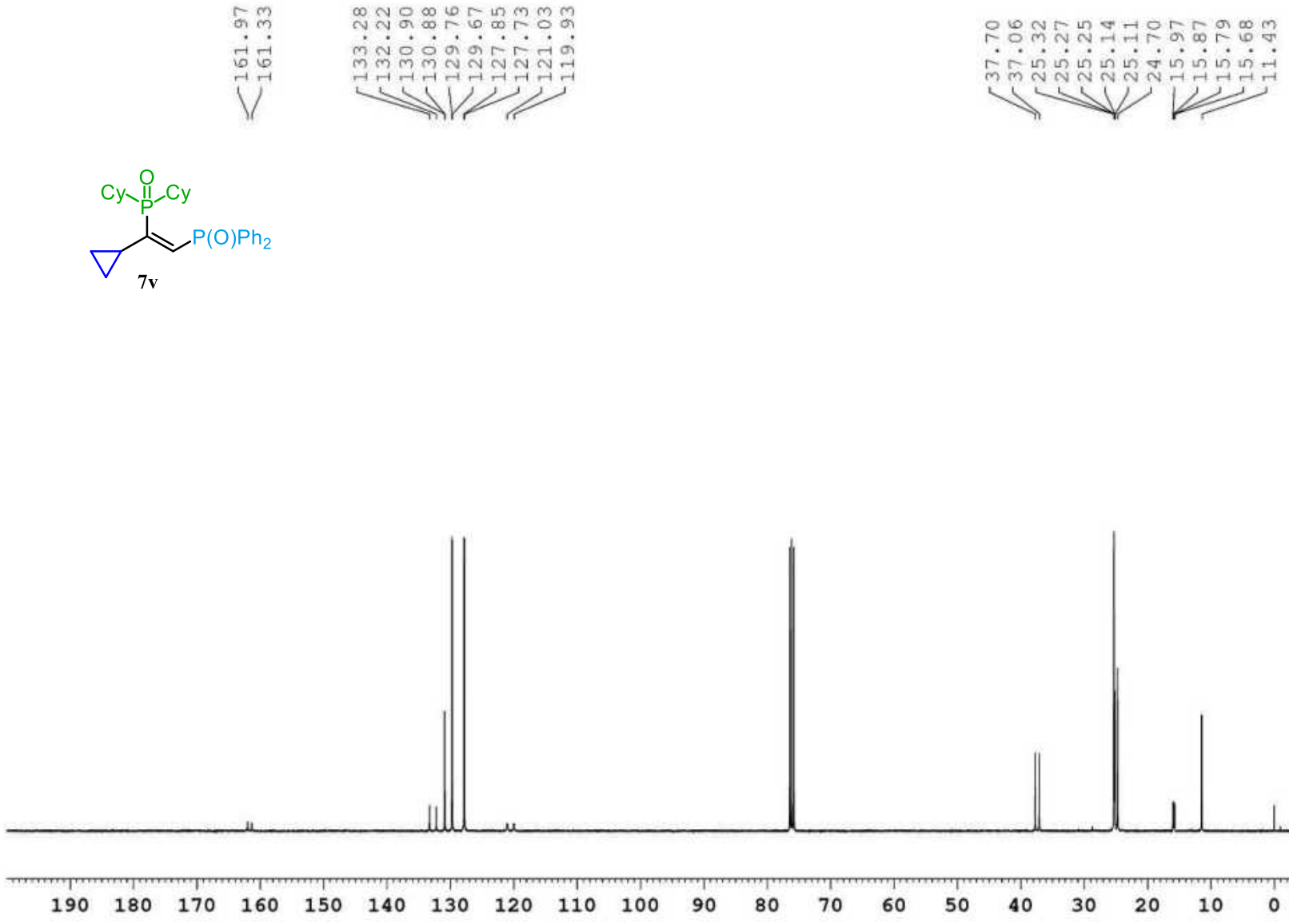

7.62
7.60
7.59
7.57
7.50
7.48
7.47
7.45
7.44
7.43
7.42
7.41
7.41
7.26
6.11
6.06
6.02
5.97

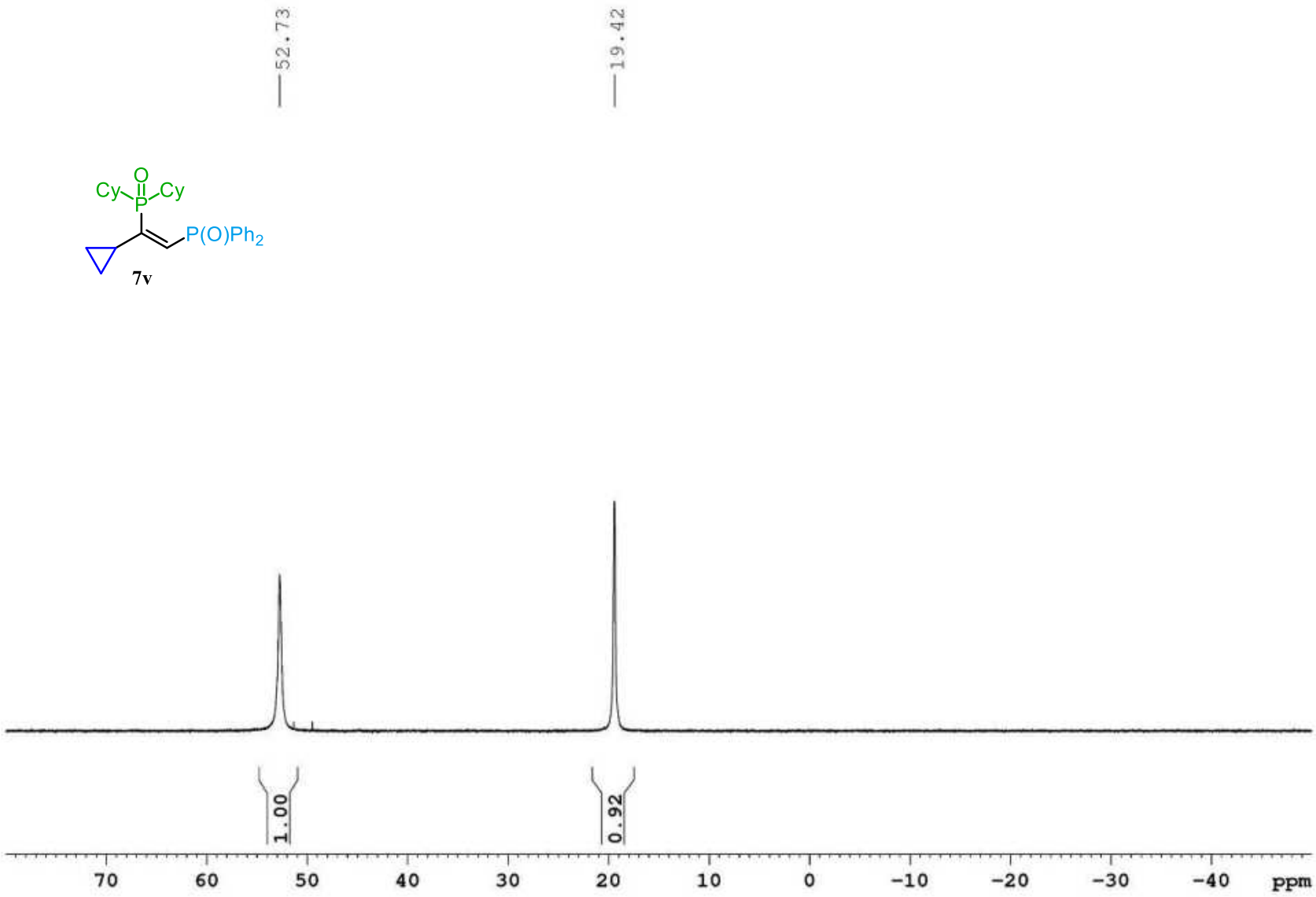

2.76
2.75
2.69
2.68
2.42
2.39
2.38
2.35
2.03
2.00
1.73
1.70
1.62
1.61
1.53
1.52
1.44
1.34
1.27
1.00
0.99
0.91
0.82
0.81
0.60
0.59
0.58
0.57
0.56

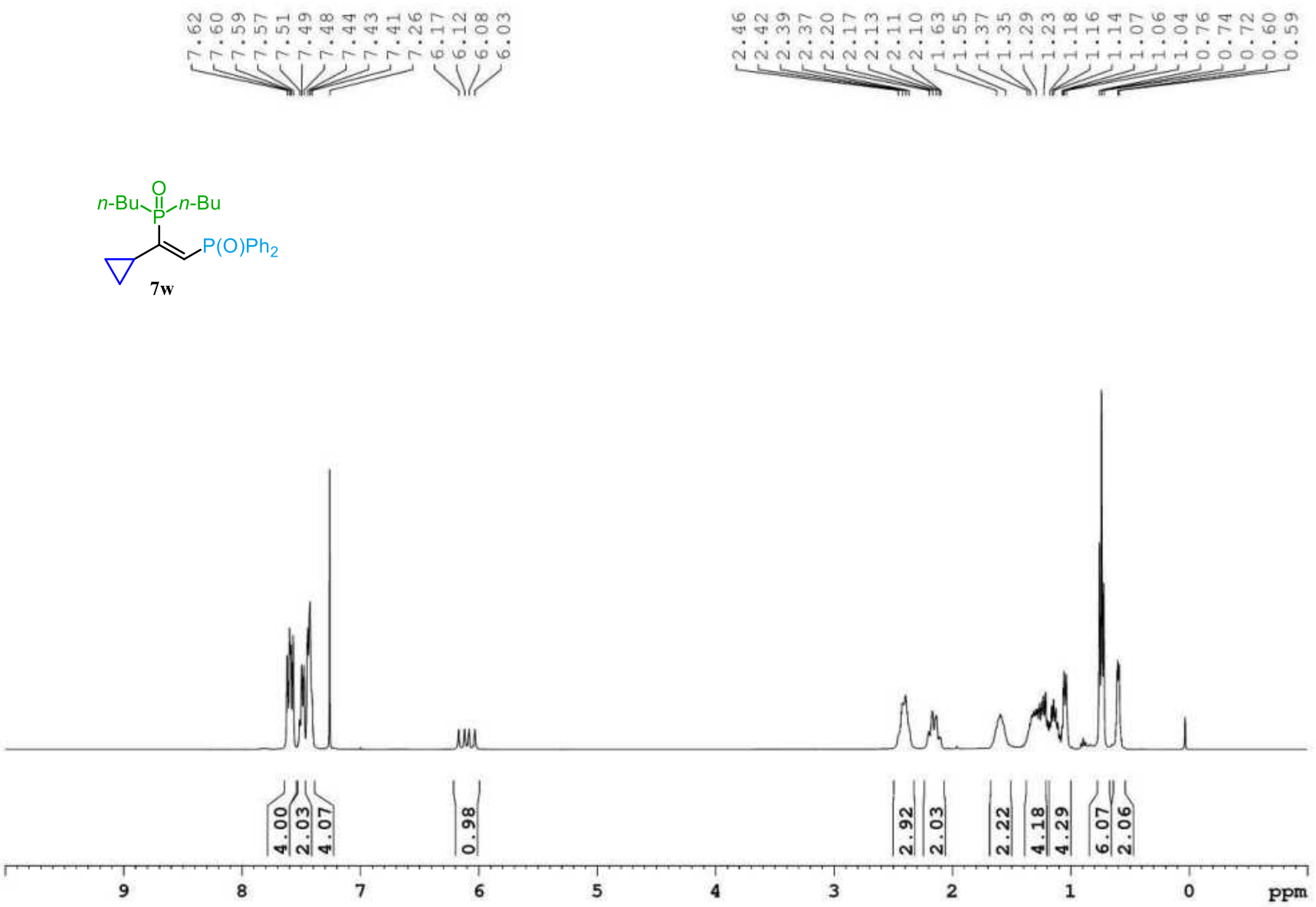

O
Cy
Cy
P
P(O)Ph2

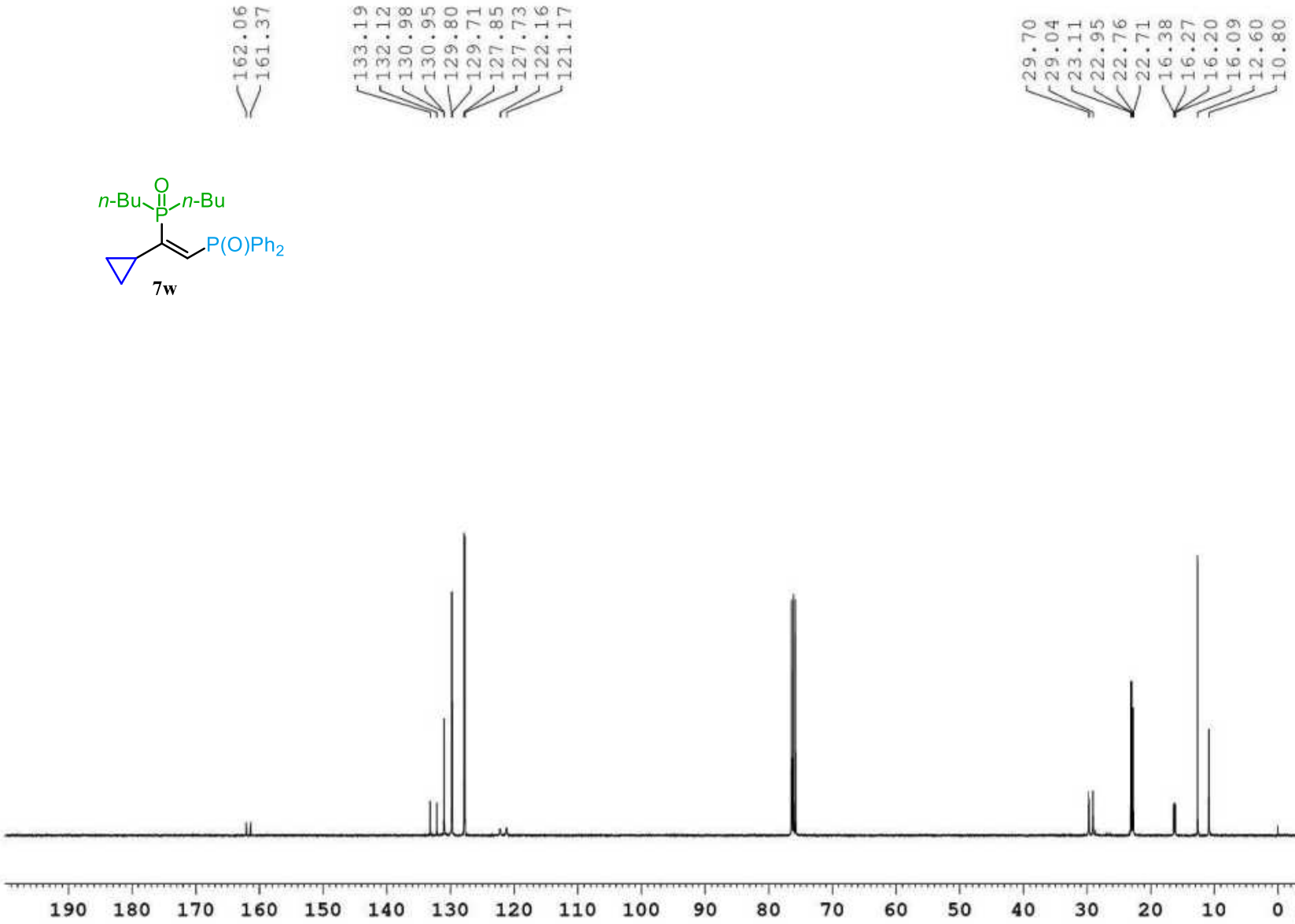
7v

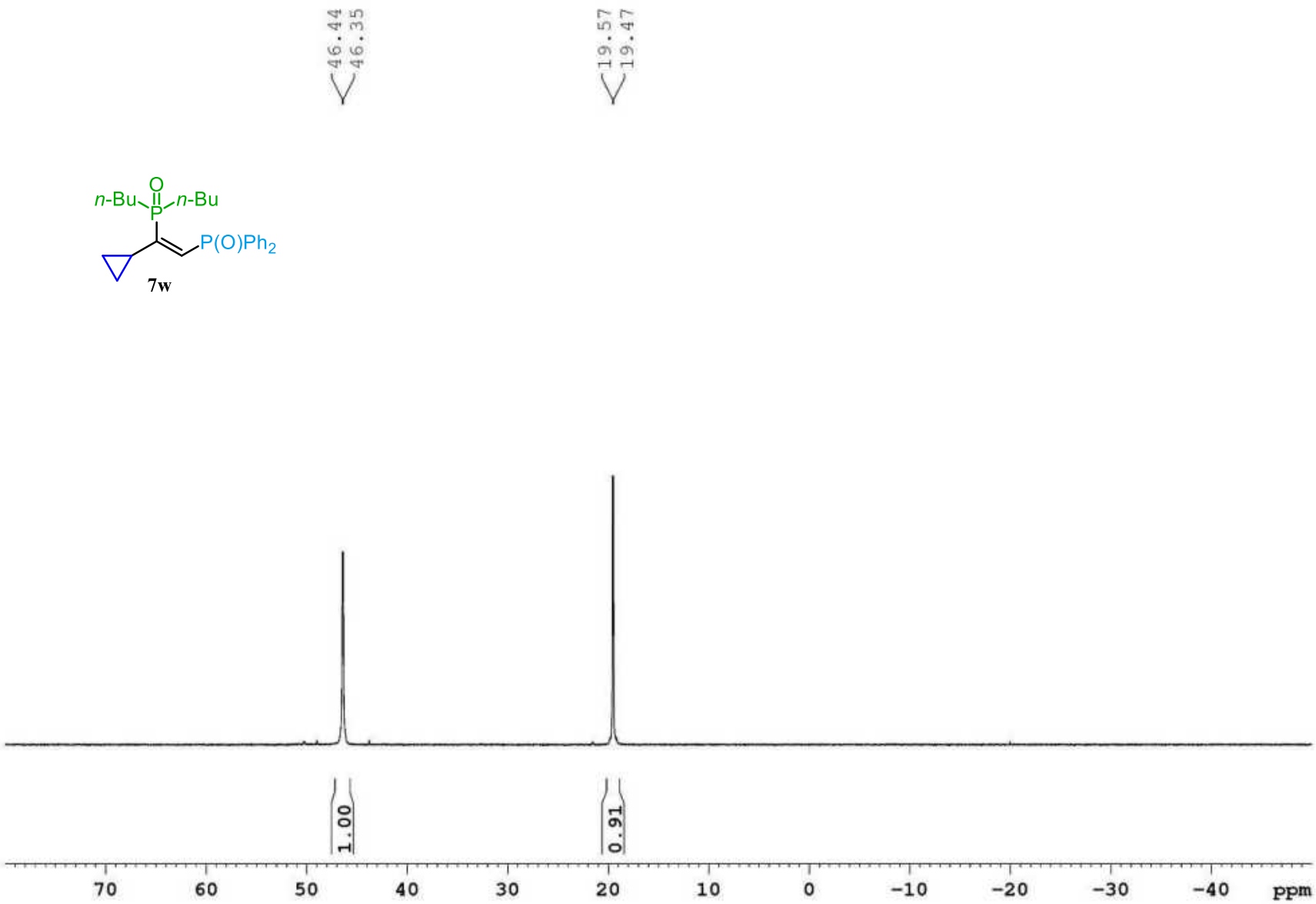

4.00
2.02
3.92
0.98
1.99
1.02
2.06
2.19
8.08
2.21
6.80
2.17
1.93
8
7
6
5
4
3
2
1
0
ppm

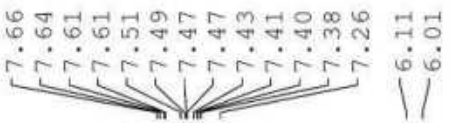

161.97
161.33
133.28
132.22
130.90
130.88
129.76
129.67
127.85
127.73
121.03
119.93
37.70
37.06
25.32
25.27
25.25
25.14
25.11
24.70
15.97
15.87
15.79
15.68
11.43
Cy
O
P
Cy
P(O)Ph2
7v
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

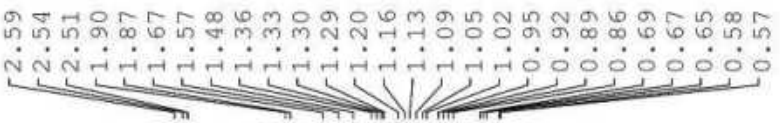

52.73
19.42
Cy
O
P
Cy
P(O)Ph2
7v
1.00
0.92
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm

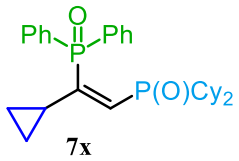

7.62
7.60
7.59
7.57
7.51
7.49
7.48
7.44
7.43
7.41
7.26
6.17
6.12
6.08
6.03
2.46
2.42
2.39
2.37
2.20
2.17
2.13
2.11
2.10
1.63
1.55
1.37
1.35
1.29
1.23
1.18
1.16
1.14
1.07
1.06
1.04
0.76
0.74
0.72
0.60
0.59
n-Bu
n-Bu
P(O)Ph2
7w
4.00
2.03
4.07
0.98
2.92
2.03
2.22
4.18
4.29
6.07
2.06
9
8
7
6
5
4
3
2
1
0
ppm


162.06
161.37
133.19
132.12
130.98
130.95
129.80
129.71
127.85
127.73
122.16
121.17
29.70
29.04
23.11
22.95
22.76
22.71
16.38
16.27
16.20
16.09
12.60
10.80
n-Bu
n-Bu
P(O)Ph2
7w
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

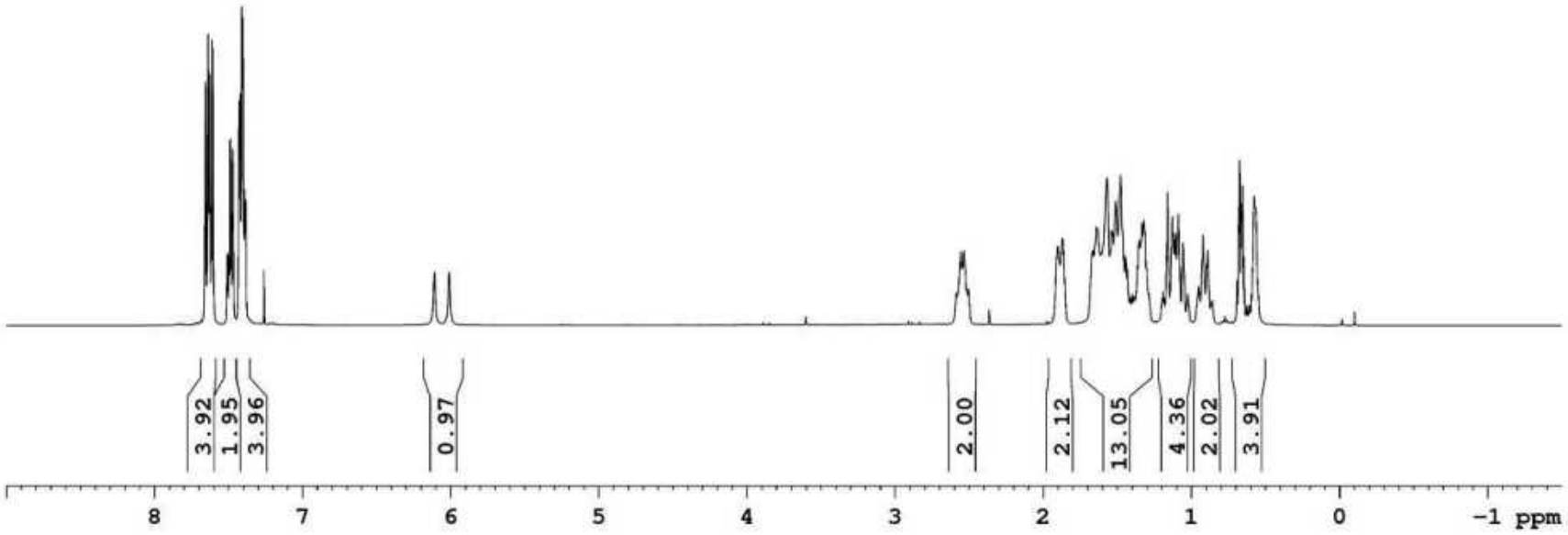

46.44
46.35
19.57
19.47
n-Bu
O
P
n-Bu
P(O)Ph2
7w
1.00
0.91
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm

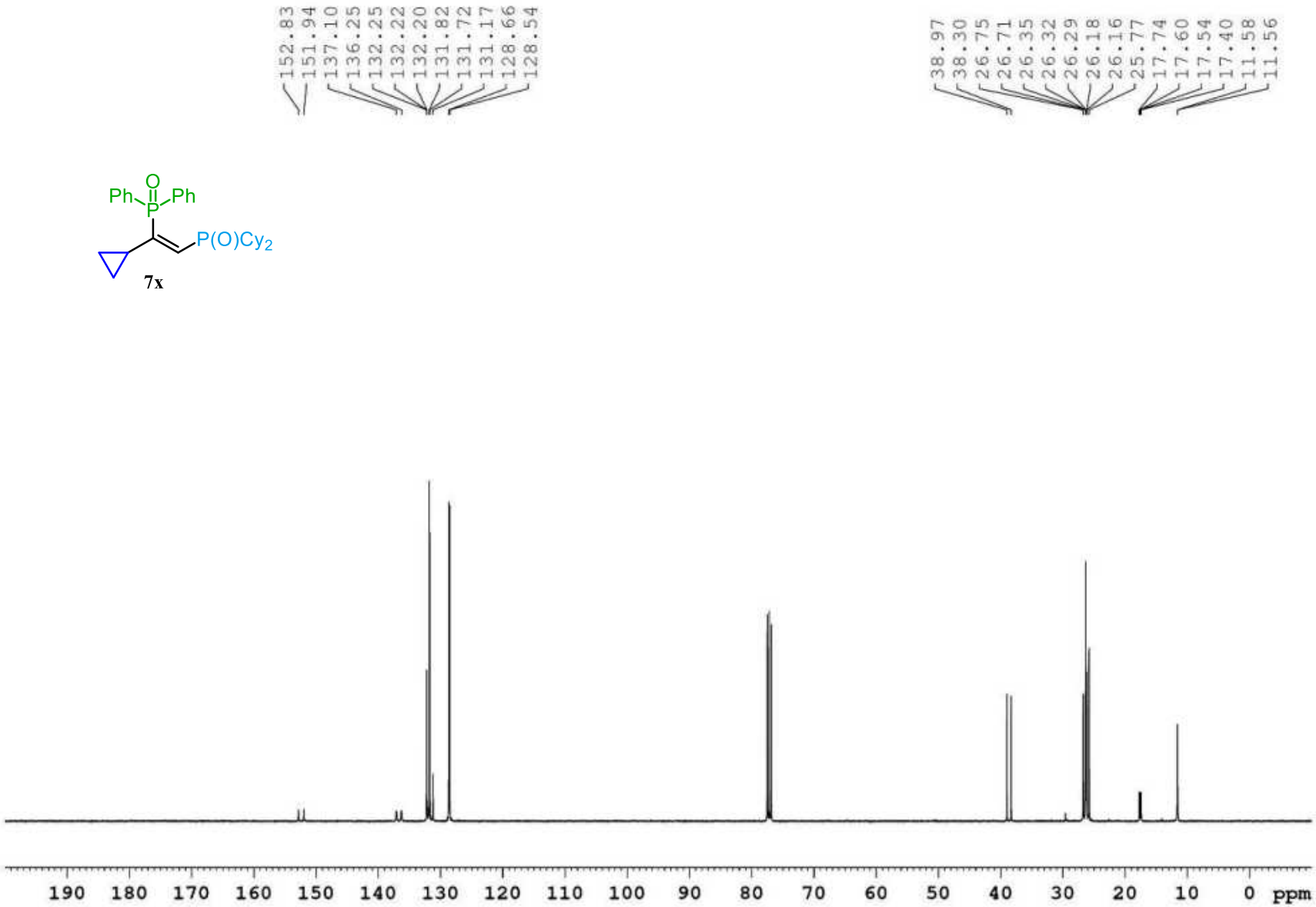

7.66
7.64
7.61
7.61
7.51
7.49
7.47
7.47
7.43
7.41
7.40
7.38
7.26
6.11
6.01

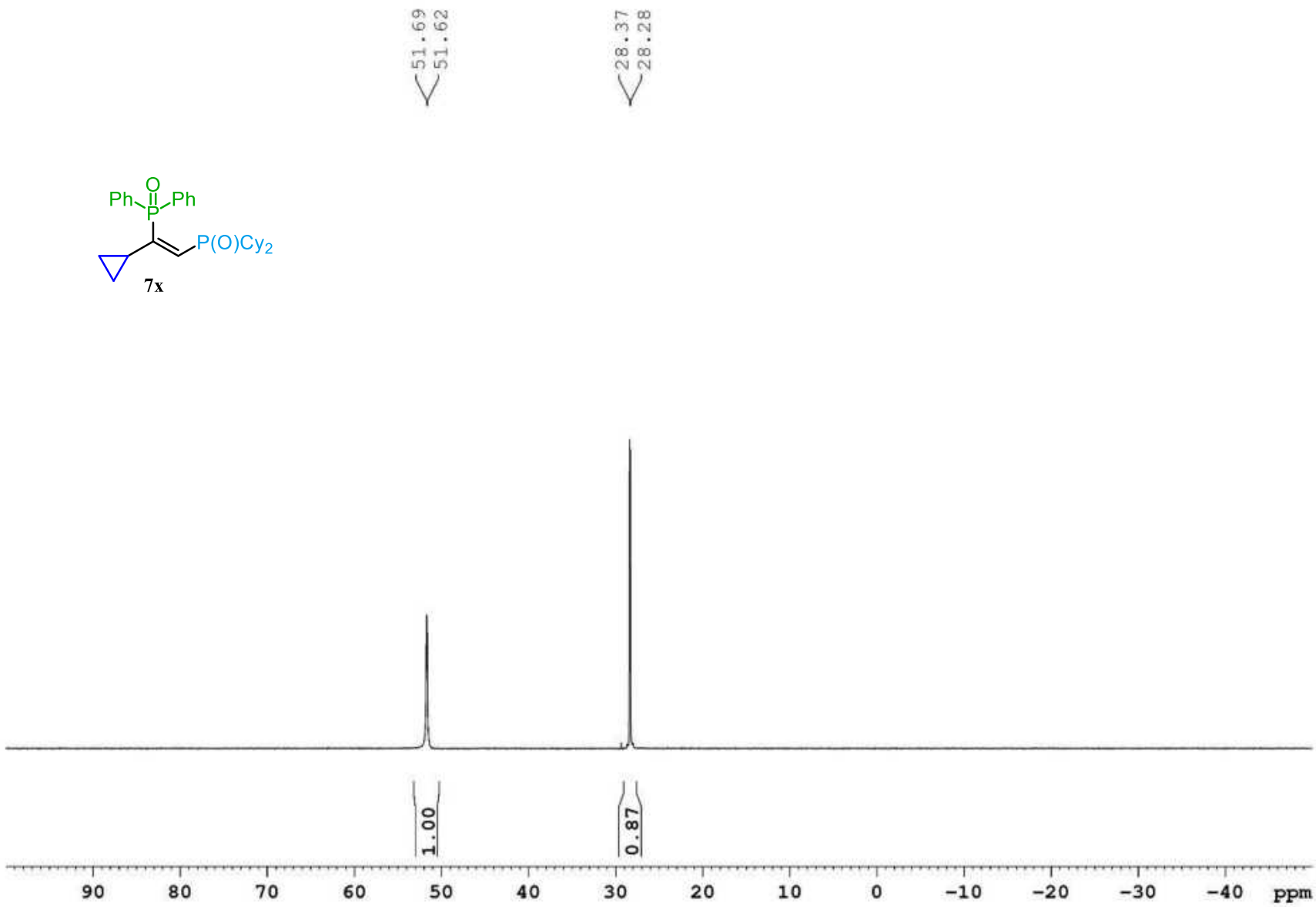

2.59
2.54
2.51
1.90
1.87
1.67
1.57
1.48
1.36
1.33
1.30
1.29
1.20
1.16
1.13
1.09
1.05
1.02
0.95
0.92
0.89
0.86
0.69
0.67
0.65
0.58
0.57

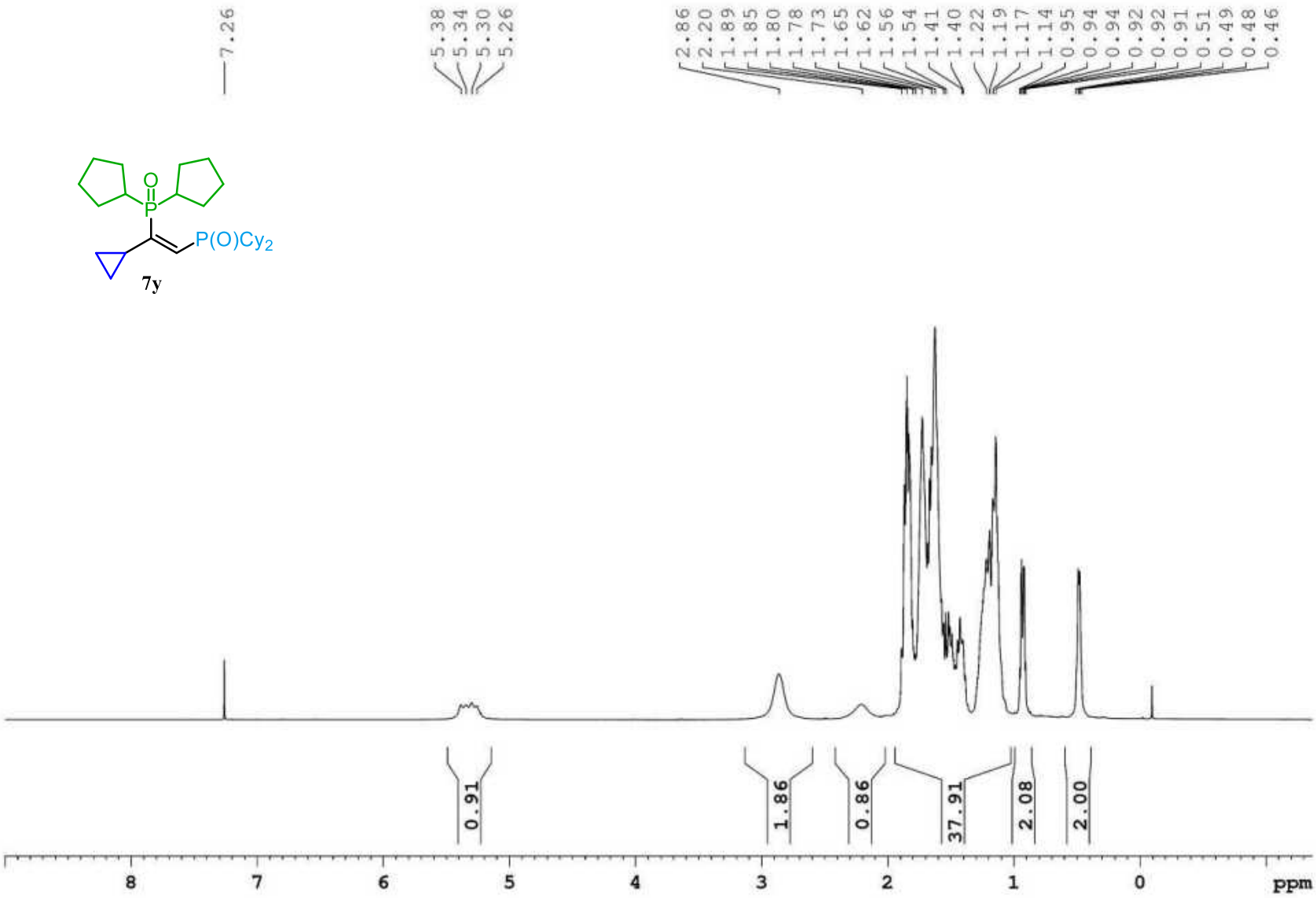

O
Ph
Ph
P
P(O)Cy2

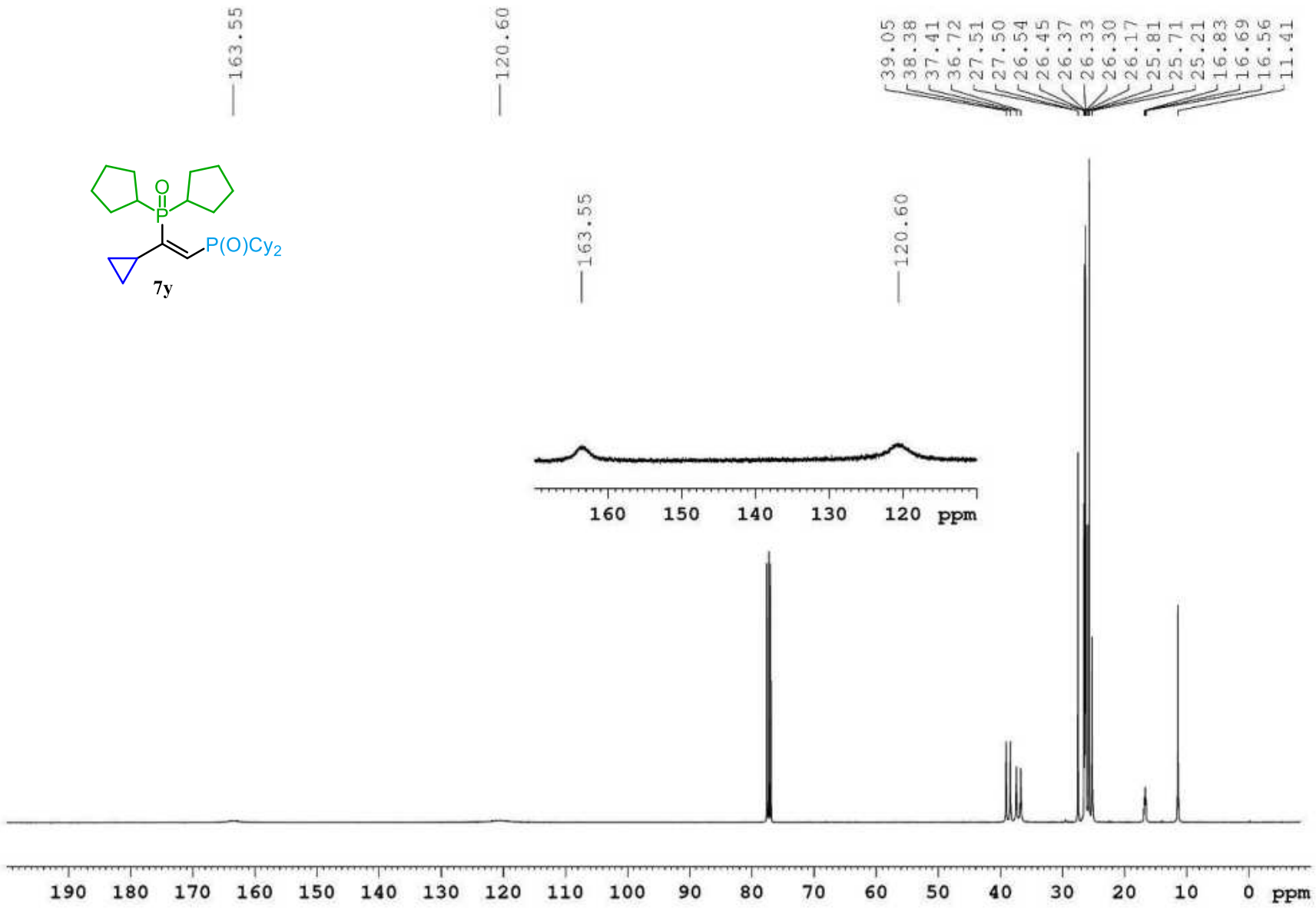
7x

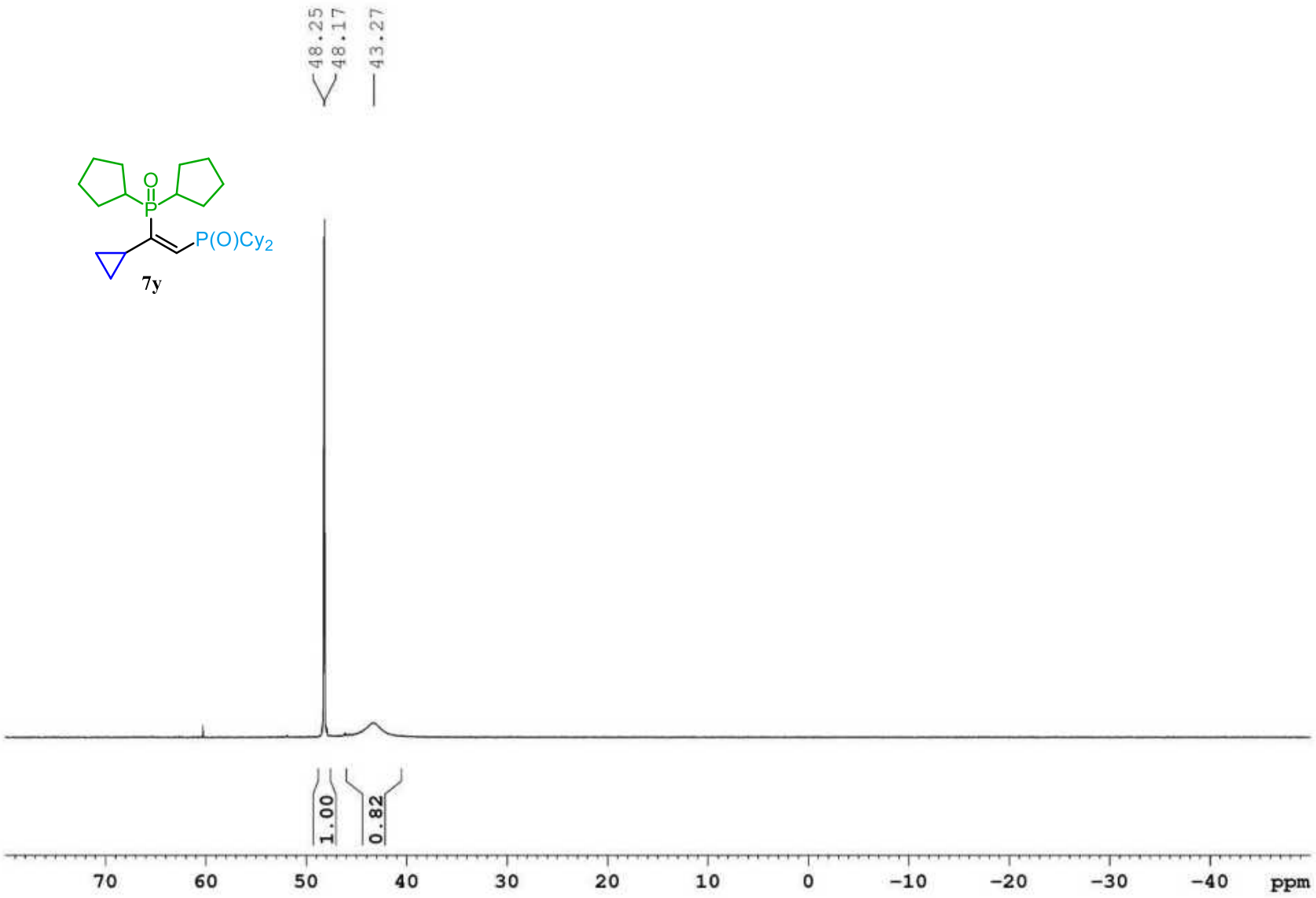

3.92
1.95
3.96
0.97
2.00
2.12
13.05
4.36
2.02
3.91
8
7
6
5
4
3
2
1
0
−1 ppm

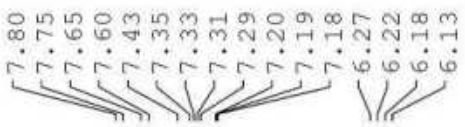

152.83
151.94
137.10
136.25
132.25
132.22
132.20
131.82
131.72
131.17
128.66
128.54
38.97
38.30
26.75
26.71
26.35
26.32
26.29
26.18
26.16
25.77
17.74
17.60
17.54
17.40
11.58
11.56
Ph
O
P
Ph
P(O)Cy2
7x
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

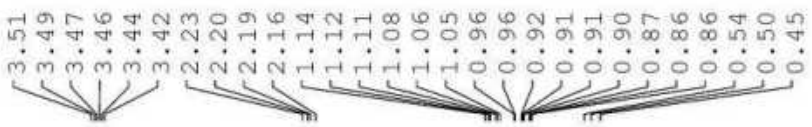

51.69
51.62
28.37
28.28
O
Ph
P
Ph
P(O)Cy2
7x
1.00
0.87
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm

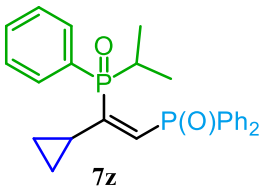

7.26
5.38
5.34
5.30
5.26
2.86
2.20
1.89
1.85
1.80
1.78
1.73
1.65
1.62
1.56
1.54
1.41
1.40
1.22
1.19
1.17
1.14
0.95
0.94
0.94
0.92
0.92
0.91
0.51
0.49
0.48
0.46
O
P
P(O)Cy2
7y
0.91
1.86
0.86
37.91
2.08
2.00
8
7
6
5
4
3
2
1
0
ppm


163.55
120.60
39.05
38.38
37.41
36.72
27.51
27.50
26.54
26.45
26.37
26.33
26.30
26.17
25.81
25.71
25.21
16.83
16.69
16.56
11.41
P(O)Cy2
7y
160 150 140 130 120 ppm
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm

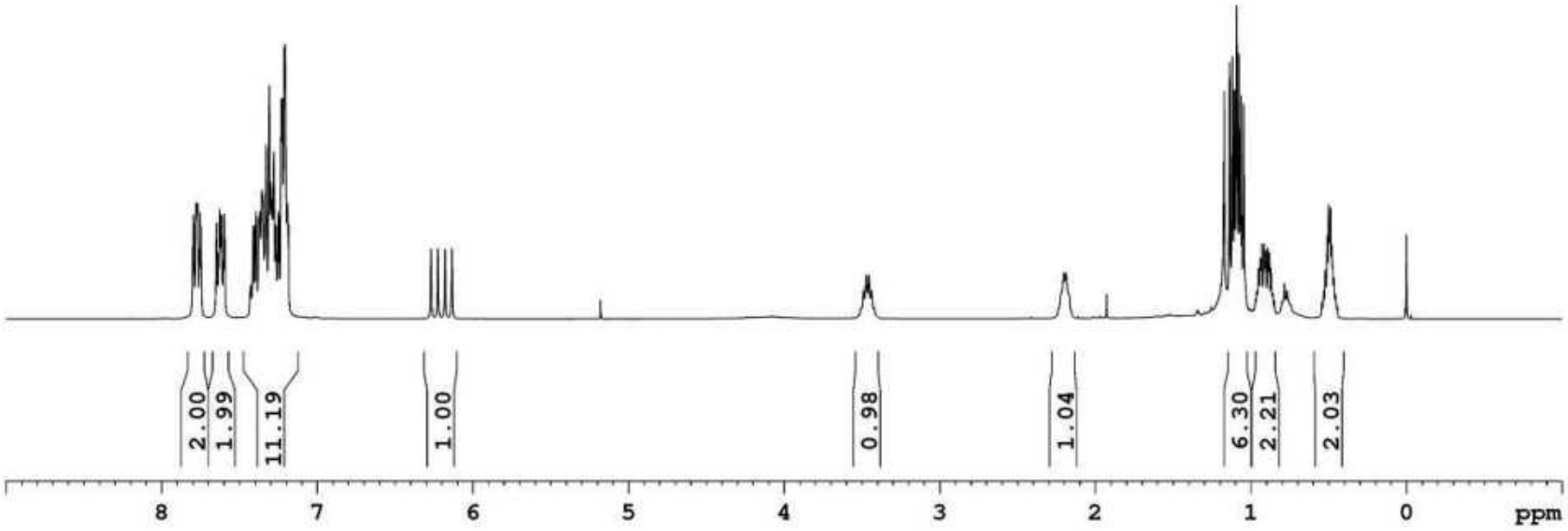

48.25
48.17
43.27
O
P
P(O)Cy2
7y
1.00
0.82
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm

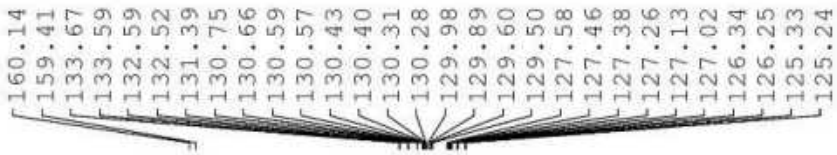

7.80
7.75
7.65
7.60
7.43
7.35
7.33
7.31
7.29
7.20
7.19
7.18
6.27
6.22
6.18
6.13

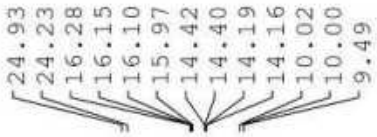

3.51
3.49
3.47
3.46
3.44
3.42
2.23
2.20
2.19
2.16
1.14
1.12
1.11
1.08
1.06
1.05
0.96
0.96
0.92
0.91
0.91
0.90
0.87
0.86
0.86
0.54
0.50
0.45

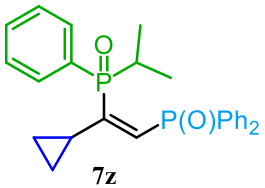

O
P
P(O)Ph2

7z

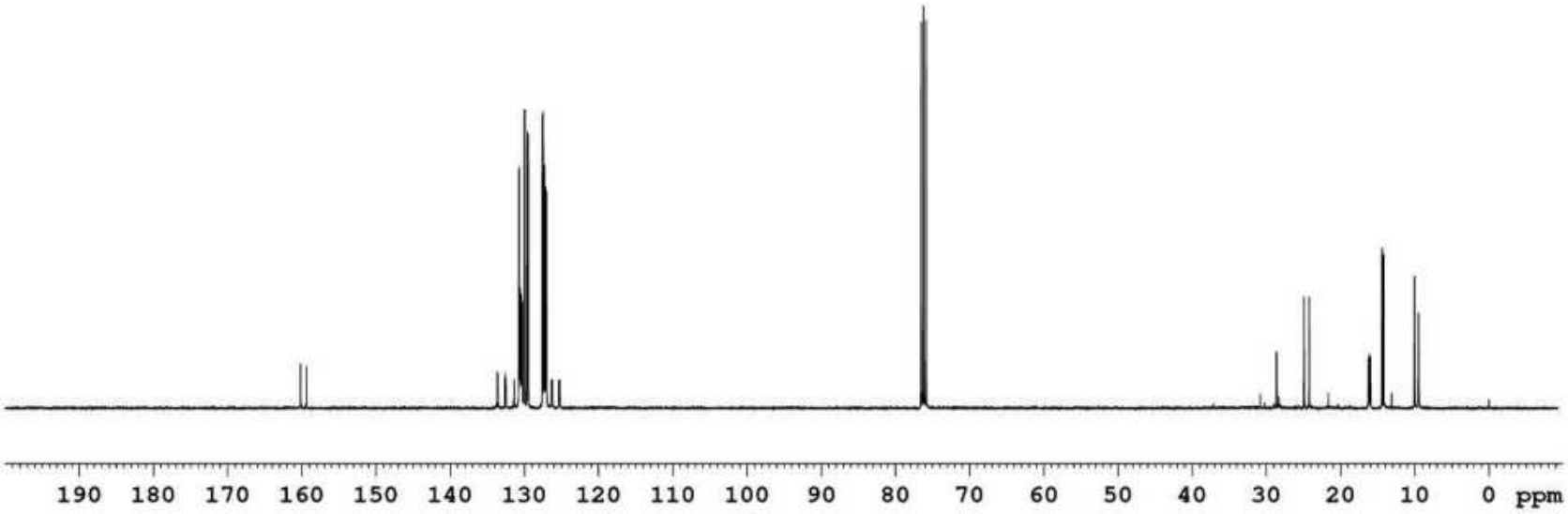

2.00
1.99
11.19
1.00
0.98
1.04
6.30
2.21
2.03
8
7
6
5
4
3
2
1
0
ppm

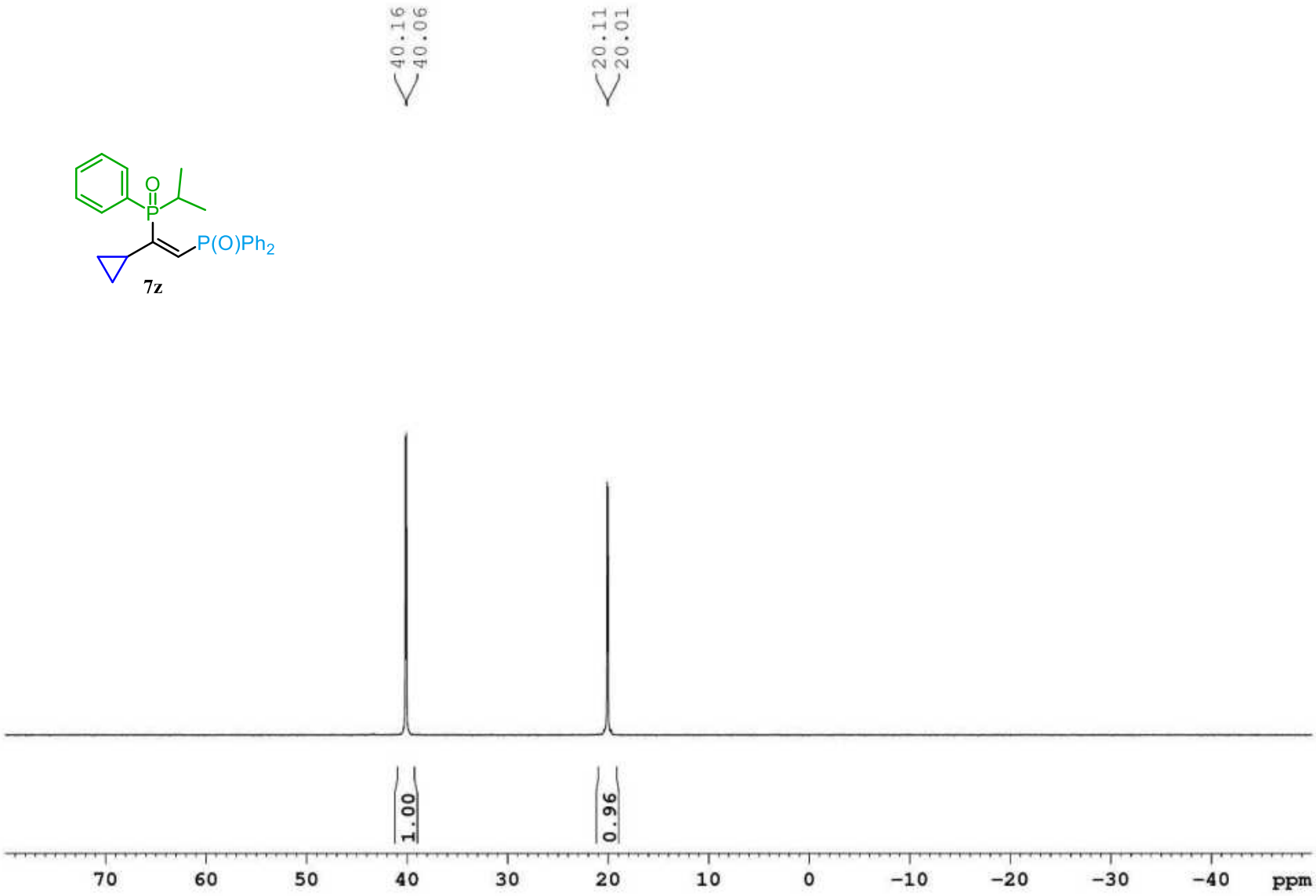

160.14
159.41
133.67
133.59
132.59
132.52
131.39
130.75
130.66
130.59
130.57
130.43
130.40
130.31
130.28
129.98
129.89
129.60
129.50
127.58
127.46
127.38
127.26
127.13
127.02
126.34
126.25
125.33
125.24

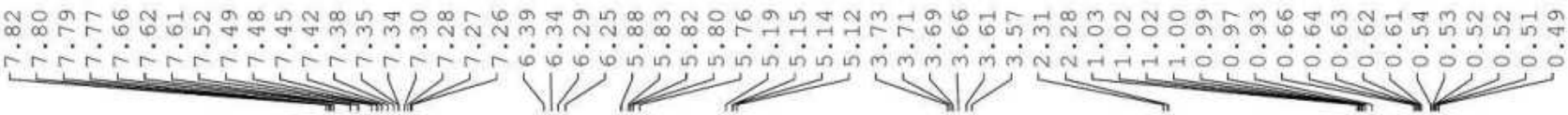

24.93
24.23
16.28
16.15
16.10
15.97
14.42
14.40
14.19
14.16
10.02
10.00
9.49

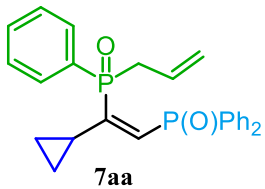

O
P
P(O)Ph2

7z

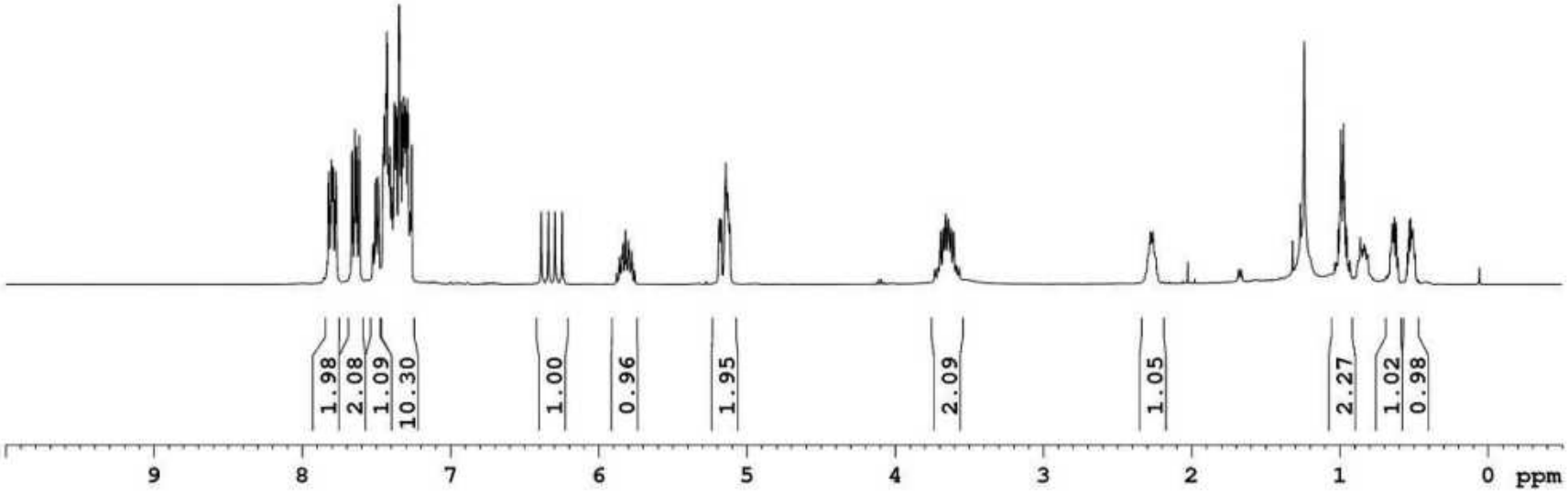

190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

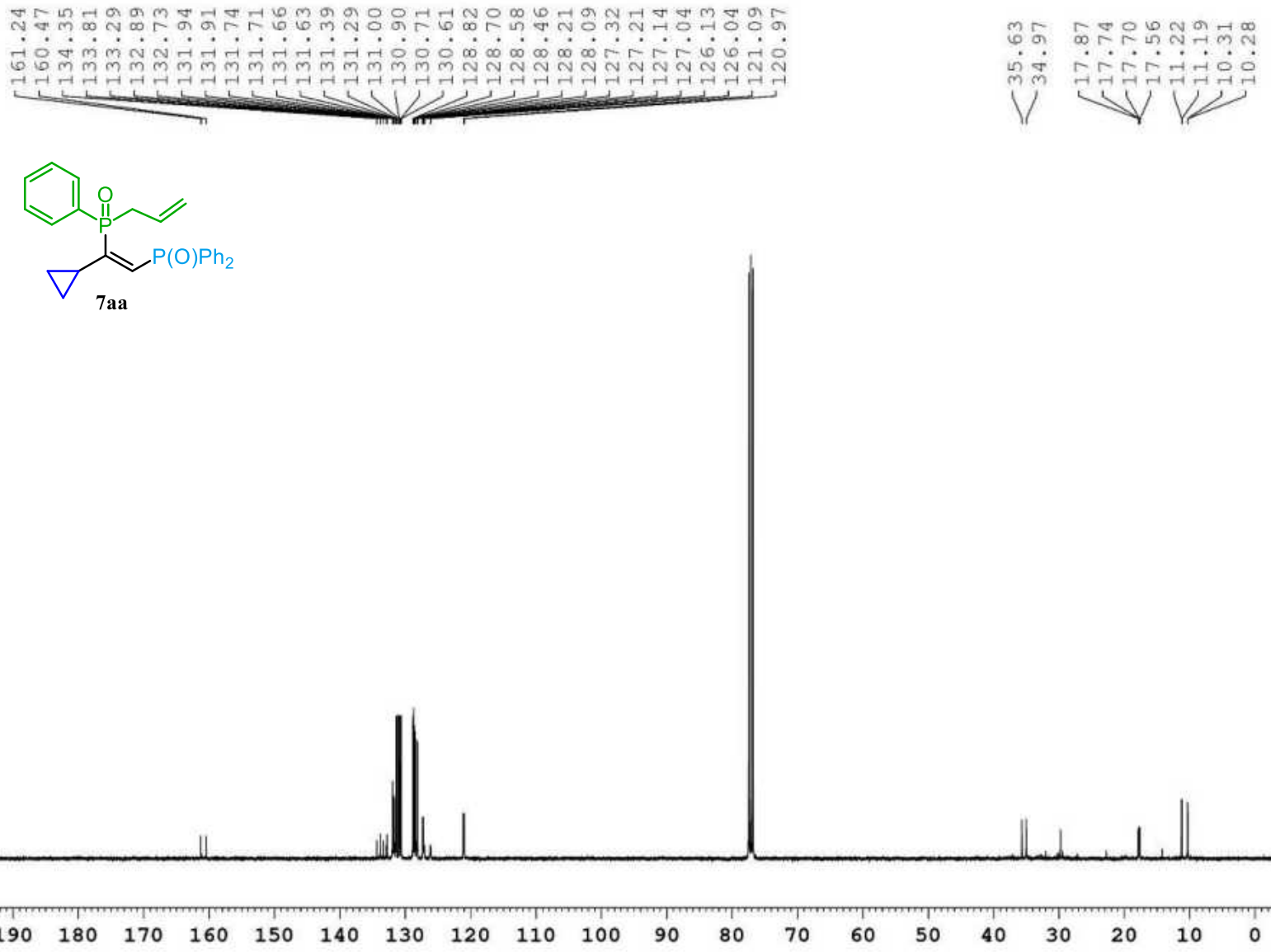

40.16
40.06
20.11
20.01
O
P
P(O)Ph2
7z
1.00
0.96
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm

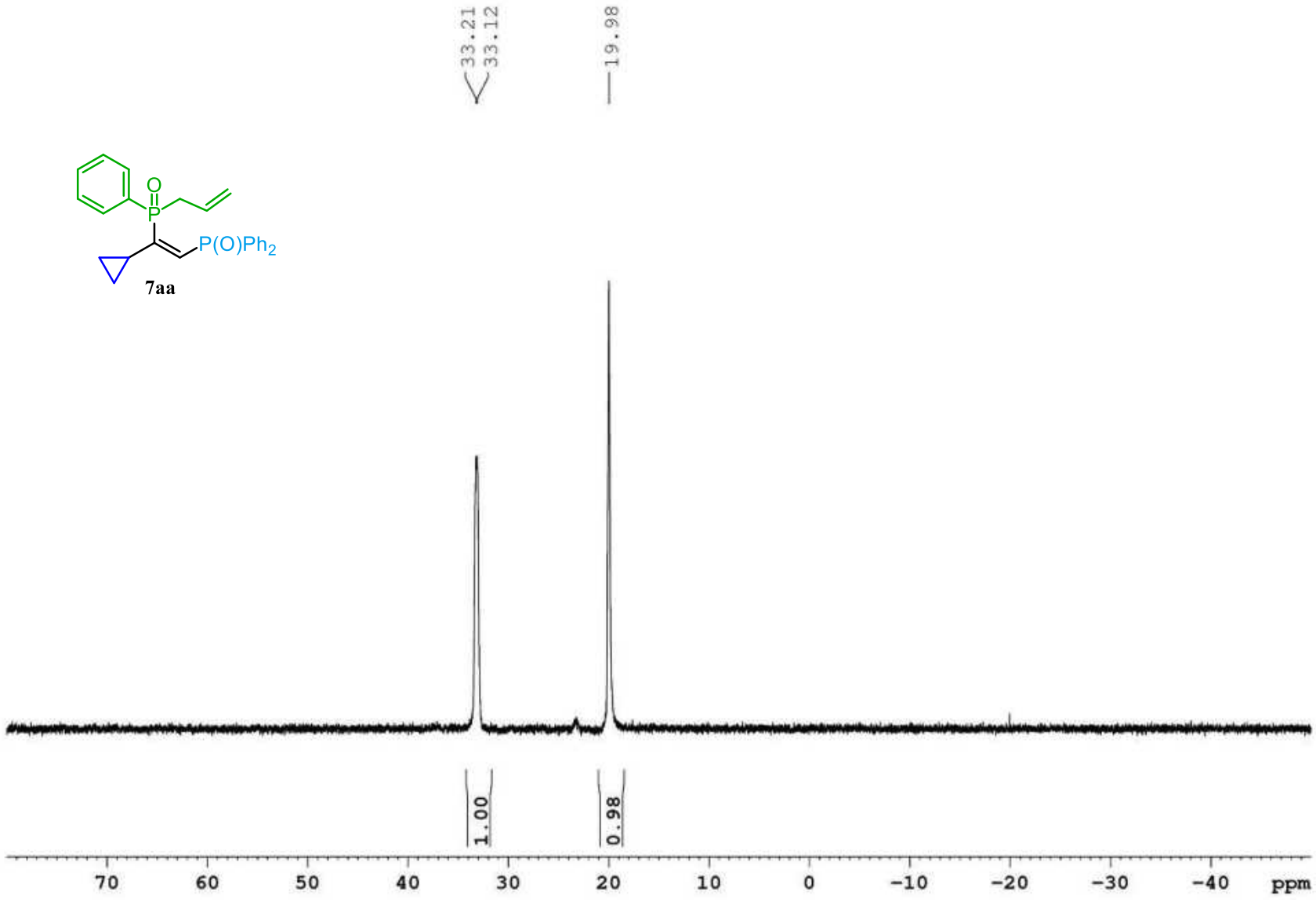

7.82
7.80
7.79
7.77
7.66
7.62
7.61
7.52
7.49
7.48
7.45
7.42
7.38
7.35
7.34
7.30
7.28
7.27
7.26
6.39
6.34
6.29
6.25
5.88
5.83
5.82
5.80
5.76
5.19
5.15
5.14
5.12
3.73
3.71
3.69
3.66
3.61
3.57
2.31
2.28
1.03
1.02
1.02
1.00
0.99
0.97
0.93
0.66
0.64
0.63
0.62
0.61
0.54
0.53
0.52
0.52
0.51
0.49


O
P
P(O)Ph2

7aa


1.98
2.08
1.09
10.30
1.00
0.96
1.95
2.09
1.05
2.27
1.02
0.98
9
8
7
6
5
4
3
2
1
0
ppm


161.24
160.47
134.35
133.81
133.29
132.89
132.73
131.94
131.91
131.74
131.71
131.66
131.63
131.39
131.29
131.00
130.90
130.71
130.61
128.82
128.70
128.58
128.46
128.21
128.09
127.32
127.21
127.14
127.04
126.13
126.04
121.09
120.97
35.63
34.97
17.87
17.74
17.70
17.56
11.22
11.19
10.31
10.28
O
P
P(O)Ph2
7aa
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm


33.21
33.12
19.98
O
P
P(O)Ph2
7aa
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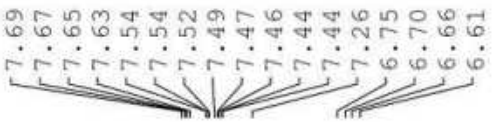
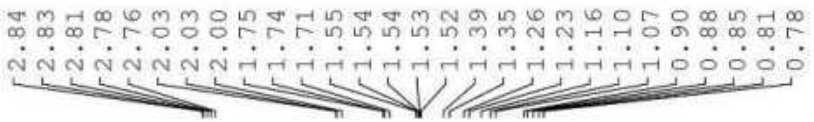
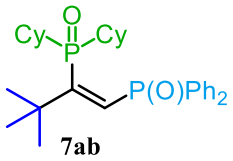
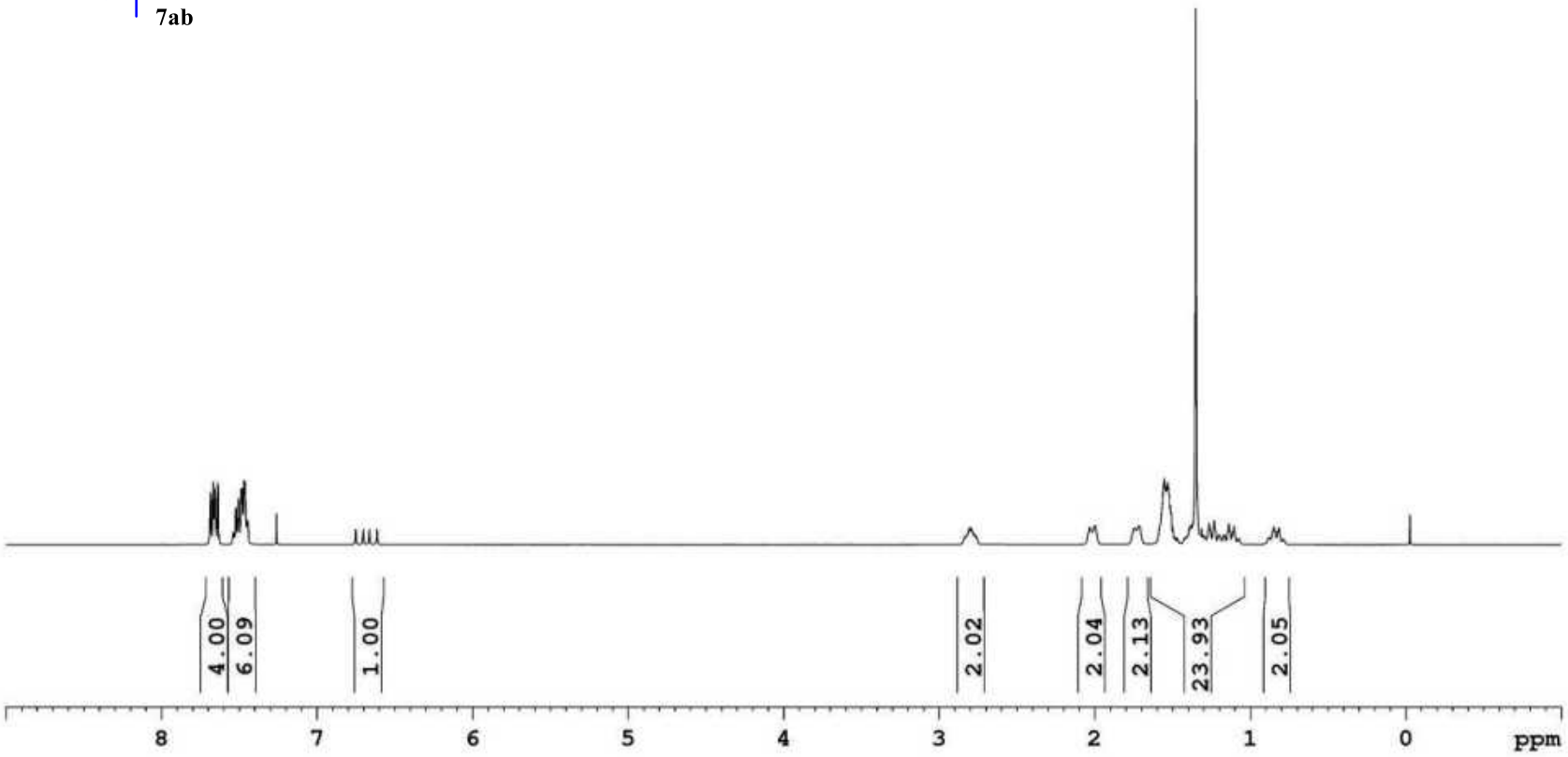
0.98
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm

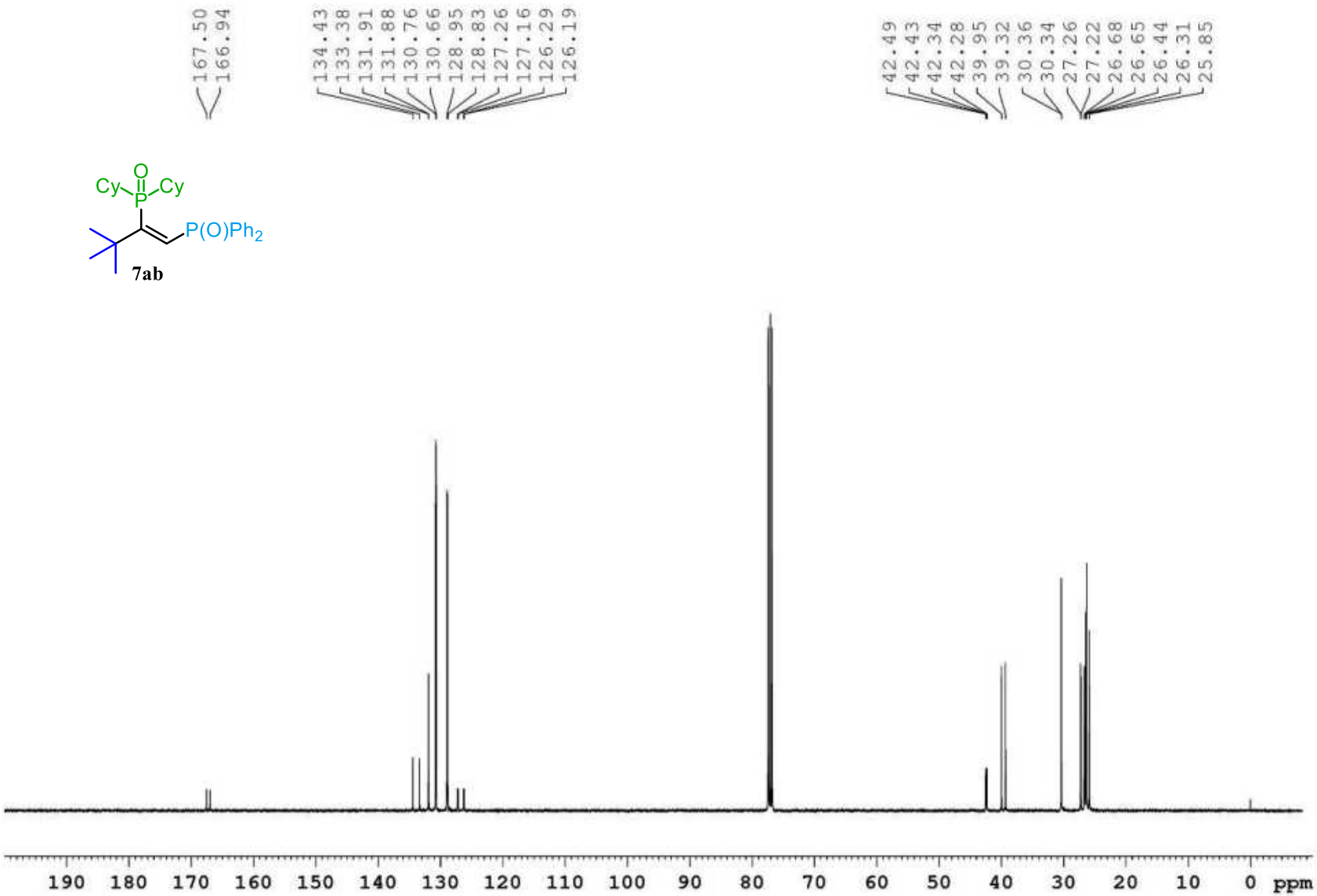

7.69
7.67
7.65
7.63
7.54
7.54
7.52
7.49
7.47
7.46
7.44
7.44
7.26
6.75
6.70
6.66
6.61

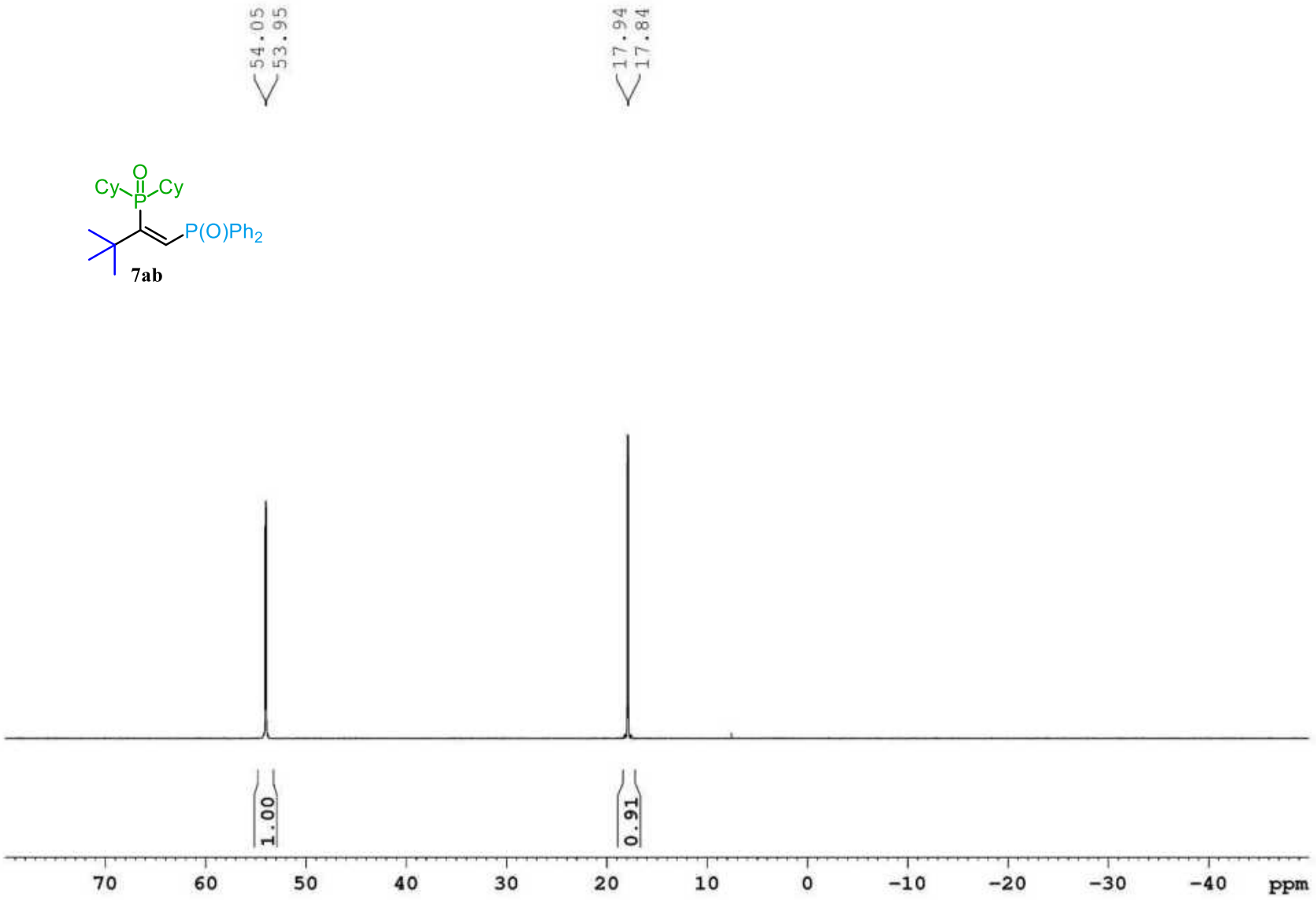

2.84
2.83
2.81
2.78
2.76
2.03
2.03
2.00
1.75
1.74
1.71
1.55
1.54
1.54
1.53
1.52
1.39
1.35
1.26
1.23
1.16
1.10
1.07
0.90
0.88
0.85
0.81
0.78

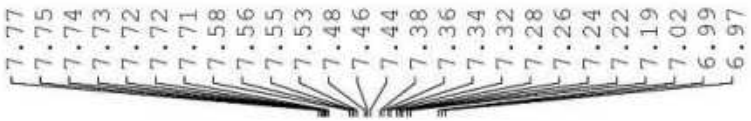

Cy
O
Cy
P
P(O)Ph2

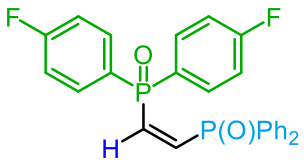
7ab


4.00
6.09
1.00
2.02
2.04
2.13
23.93
2.05
8
7
6
5
4
3
2
1
0
ppm


167.50
166.94
134.43
133.38
131.91
131.88
130.76
130.66
128.95
128.83
127.26
127.16
126.29
126.19
42.49
42.43
42.34
42.28
39.95
39.32
30.36
30.34
27.26
27.22
26.68
26.65
26.44
26.31
25.85
Cy
O
P
Cy
P(O)Ph2
7ab
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

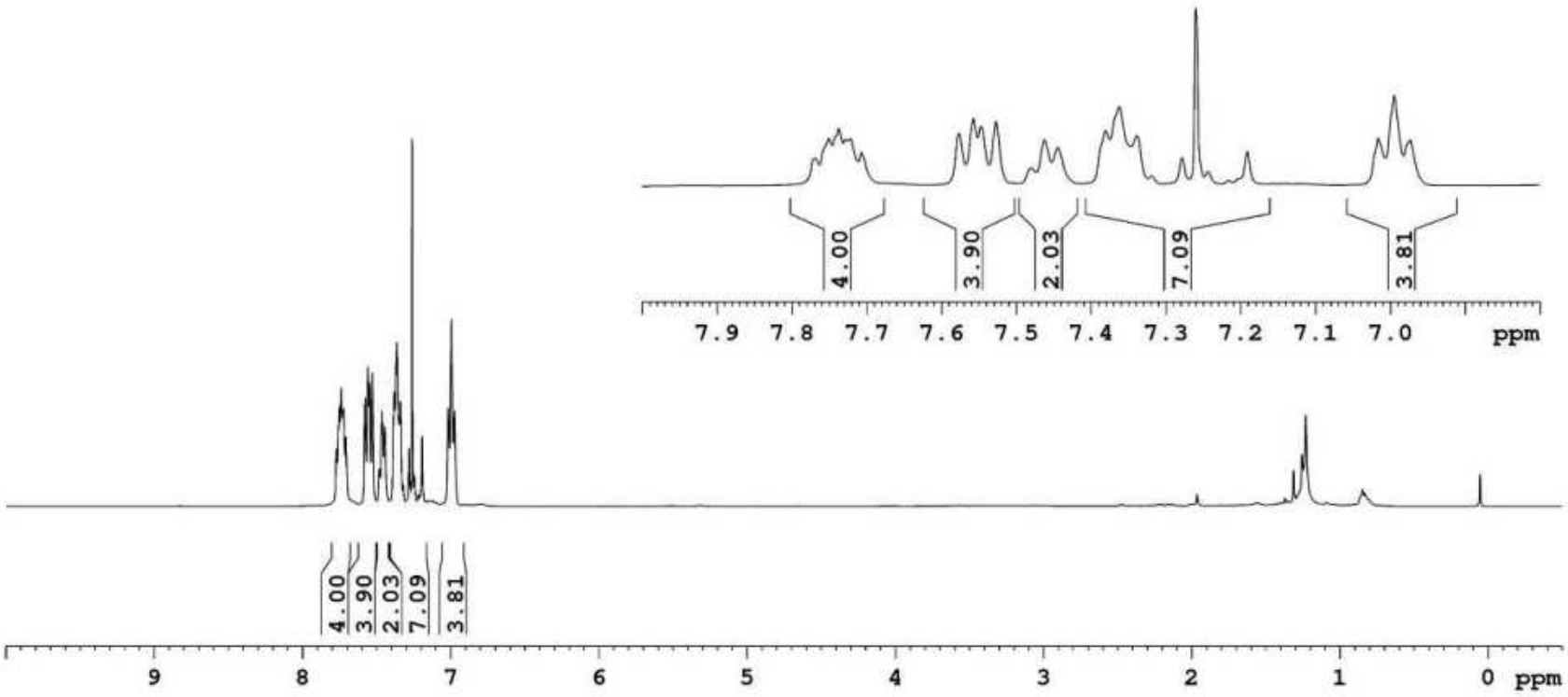

54.05
53.95
17.94
17.84
Cy
O
P
Cy
P(O)Ph2
7ab
1.00
0.91
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm

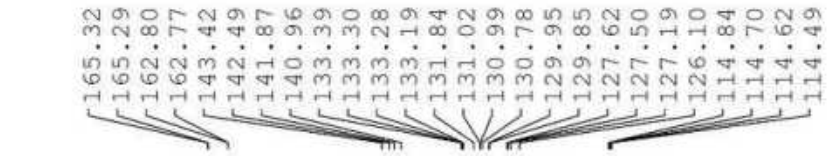

7.77
7.75
7.74
7.73
7.72
7.72
7.71
7.58
7.56
7.55
7.53
7.48
7.46
7.44
7.38
7.36
7.34
7.32
7.28
7.26
7.24
7.22
7.19
7.02
6.99
6.97

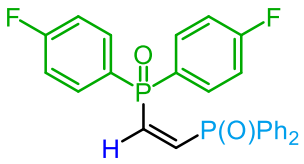

F
F
O
P
H
P(O)Ph2

7ac


7.77
7.75
7.74
7.73
7.72
7.72
7.71
7.58
7.56
7.55
7.53
7.48
7.46
7.44
7.38
7.36
7.34
7.32
7.28
7.26
7.24
7.22
7.19
7.02
6.99
6.97

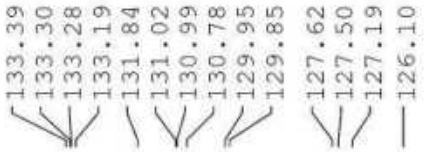

4.00
3.90
2.03
7.09
3.81
7.9 7.8 7.7 7.6 7.5 7.4 7.3 7.2 7.1 7.0 ppm
9 8 7 6 5 4 3 2 1 0 ppm

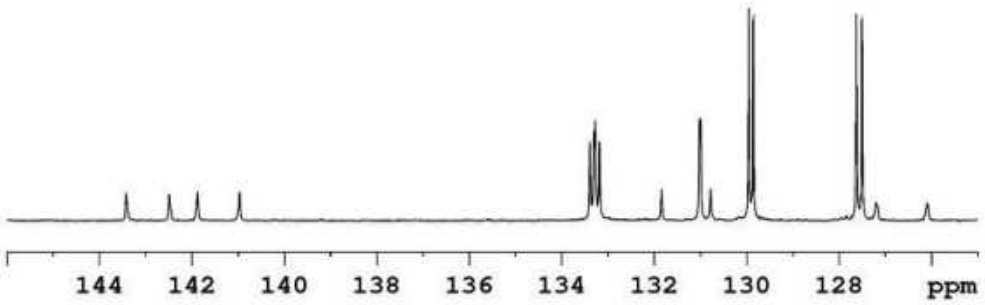

165.32
165.29
162.80
162.77
143.42
142.49
141.87
140.96
133.39
133.30
133.28
133.19
131.84
131.02
130.99
130.78
129.95
129.85
127.62
127.50
127.19
126.10
114.84
114.70
114.62
114.49

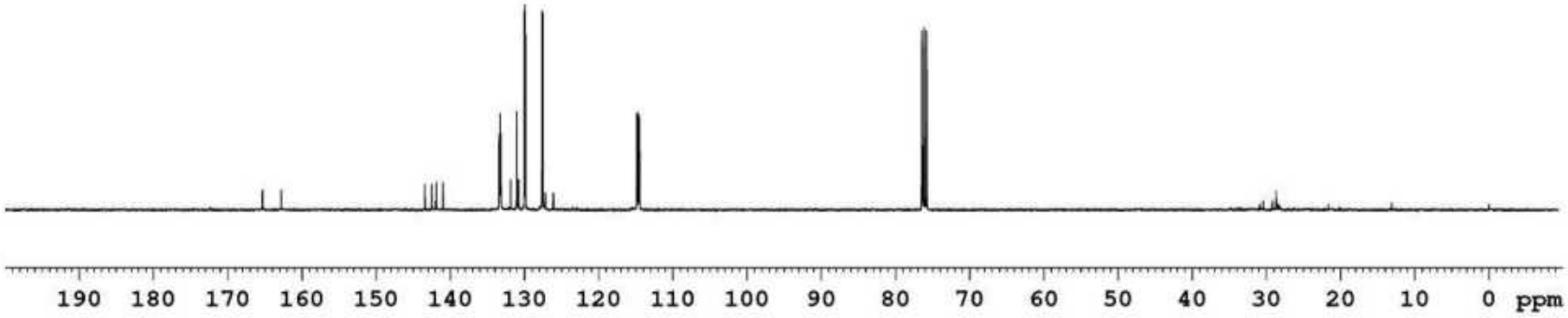

F
F
O
P
H
P(O)Ph2

7ac


143.42
142.49
141.87
140.96

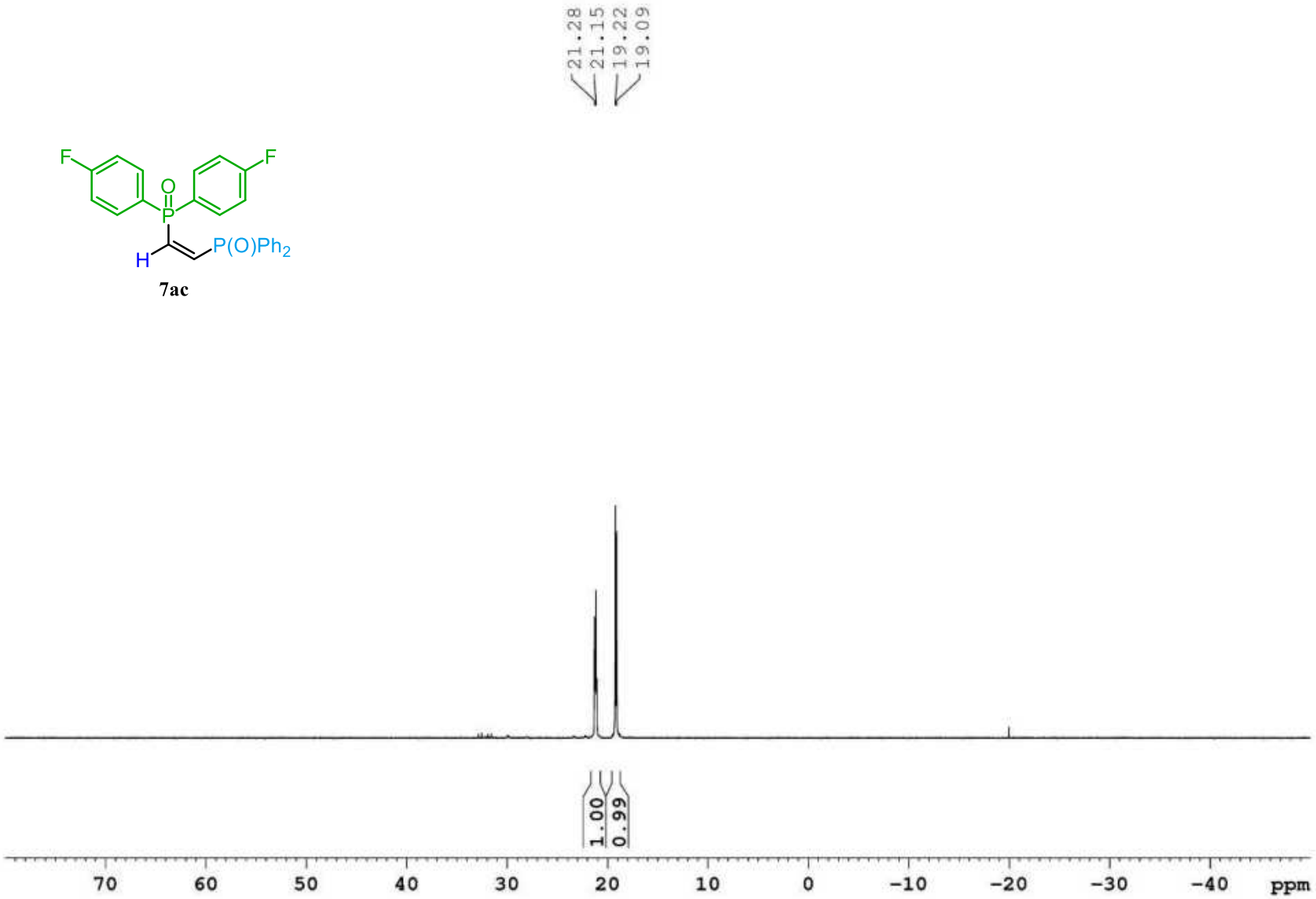

133.39
133.30
133.28
133.19
131.84
131.02
130.99
130.78
129.95
129.85
127.62
127.50
127.19
126.10

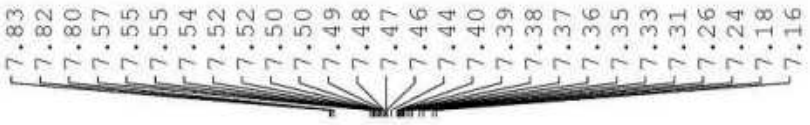

144
142
140
138
136
134
132
130
128
ppm

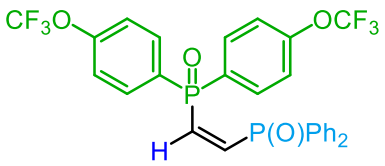

190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

F
F
O
P
H
P(O)Ph2

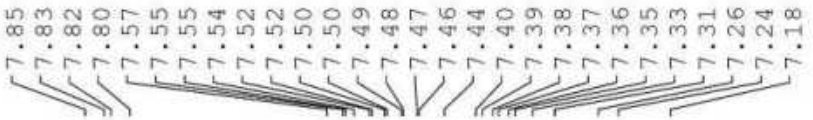
7ac


21.28
21.15
19.22
19.09
1.00
0.99
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm


7.83
7.82
7.80
7.57
7.55
7.55
7.54
7.52
7.52
7.50
7.50
7.49
7.48
7.47
7.46
7.44
7.40
7.39
7.38
7.37
7.36
7.35
7.33
7.31
7.26
7.24
7.18
7.16


CF3O
OCF3
O
P
H
P(O)Ph2

7ad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7.83
7.82
7.80
7.57
7.55
7.55
7.54
7.52
7.52
7.50
7.50
7.49
7.48
7.47
7.46
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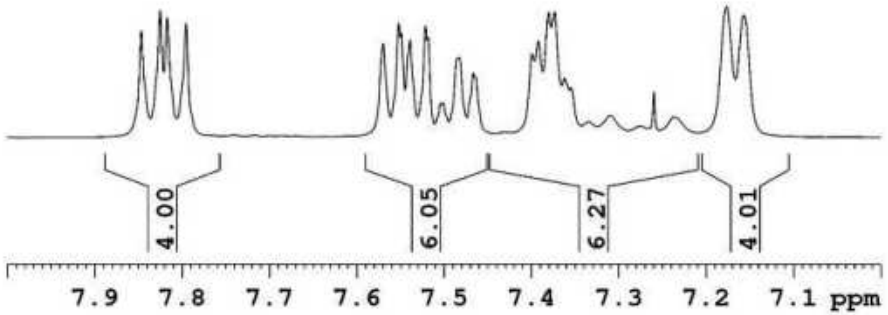
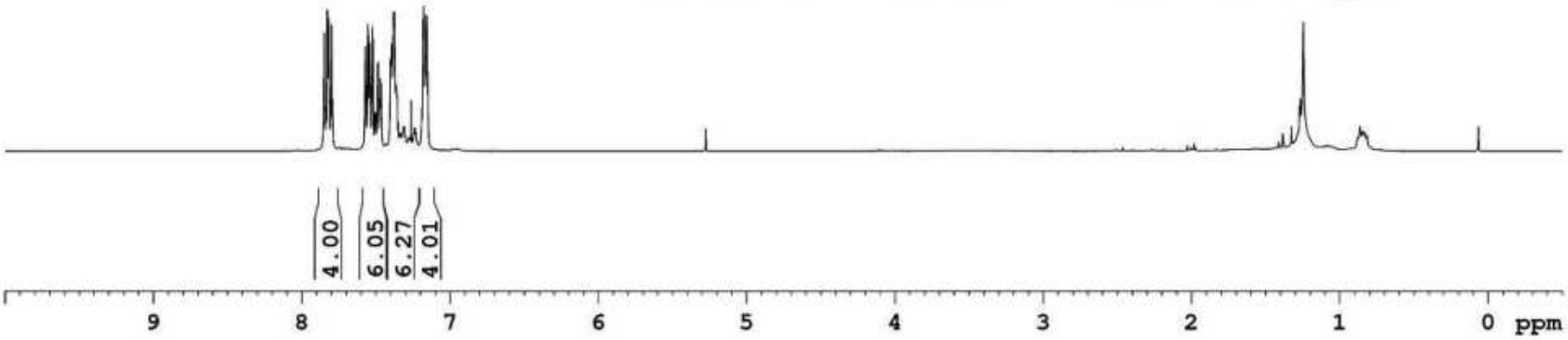
7.35
7.33
7.31
7.26
7.24
7.18


4.00
6.05
6.27
4.01
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
7.1
ppm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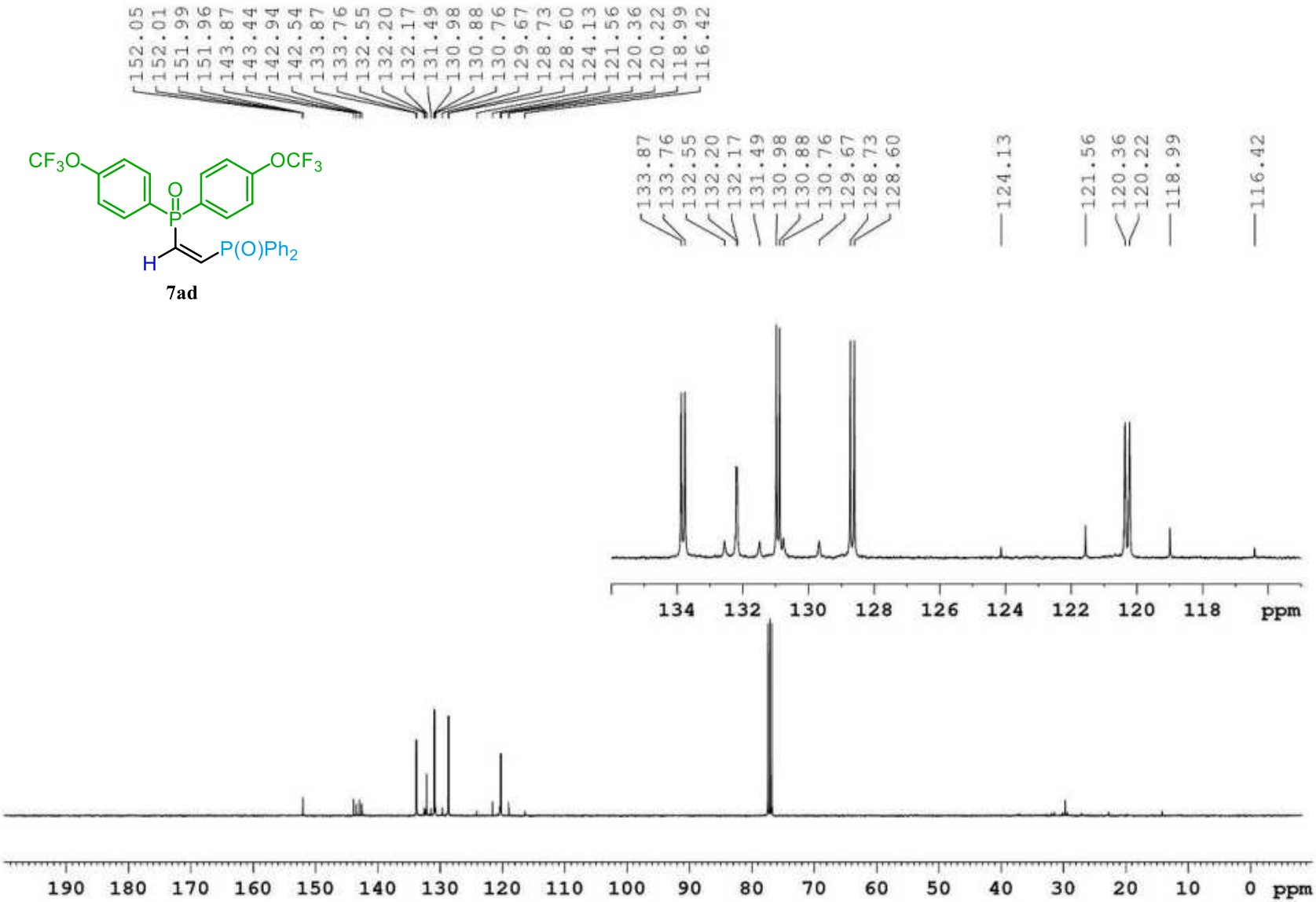
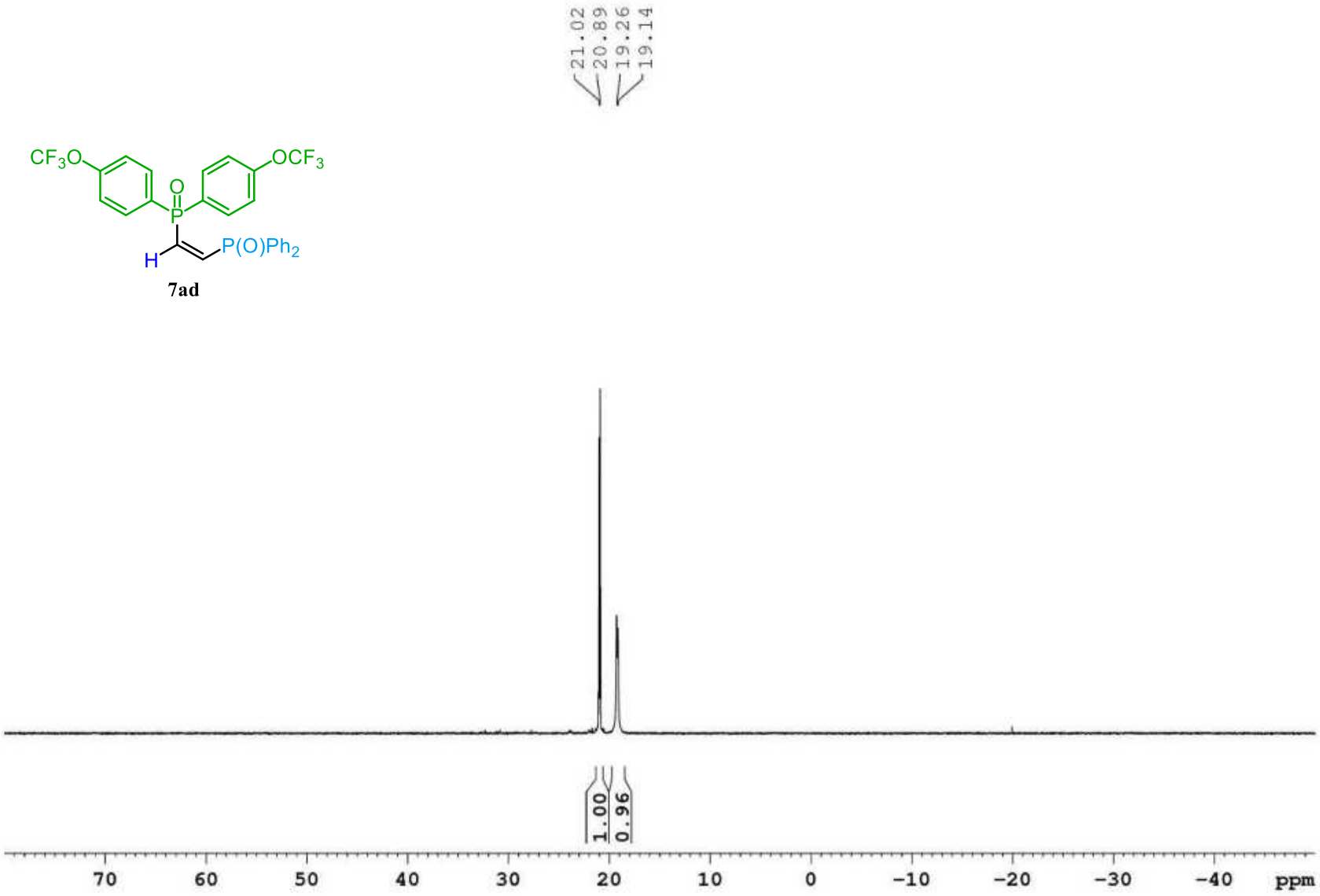
6.05
6.27
4.01
9
8
7
6
5
4
3
2
1
0
ppm


152.05
152.01
151.99
151.96
143.87
143.44
142.94
142.54
133.87
133.76
132.55
132.20
132.17
131.49
130.98
130.88
130.76
129.67
128.73
128.60
124.13
121.56
120.36
120.22
118.99
116.42
CF3O
OCF3
O
P
H
P(O)Ph2
7ad
134
132
130
128
126
124
122
120
118
ppm
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

CF3O
OCF3
O
P
H
P(O)Ph2

7ad


21.02
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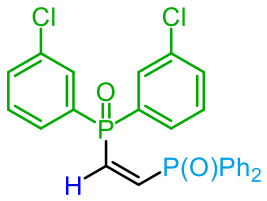
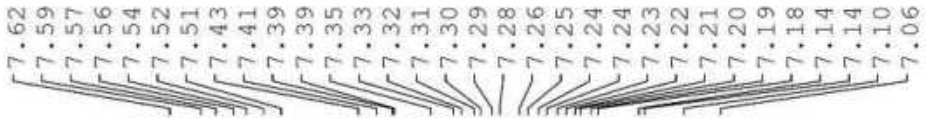
0.96
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm


7.62
7.59
7.57
7.56
7.54
7.52
7.51
7.43
7.41
7.39
7.39
7.35
7.33
7.32
7.31
7.30
7.29
7.28
7.26
7.25
7.24
7.24
7.23
7.22
7.21
7.20
7.19
7.18
7.14
7.14
7.10
7.06


Cl
Cl
O
P
H
P(O)Ph2

7ae


7.62
7.59
7.57
7.56
7.54
7.52
7.51
7.43
7.41
7.39
7.39
7.35
7.33
7.32
7.31
7.30
7.29
7.28
7.26
7.25
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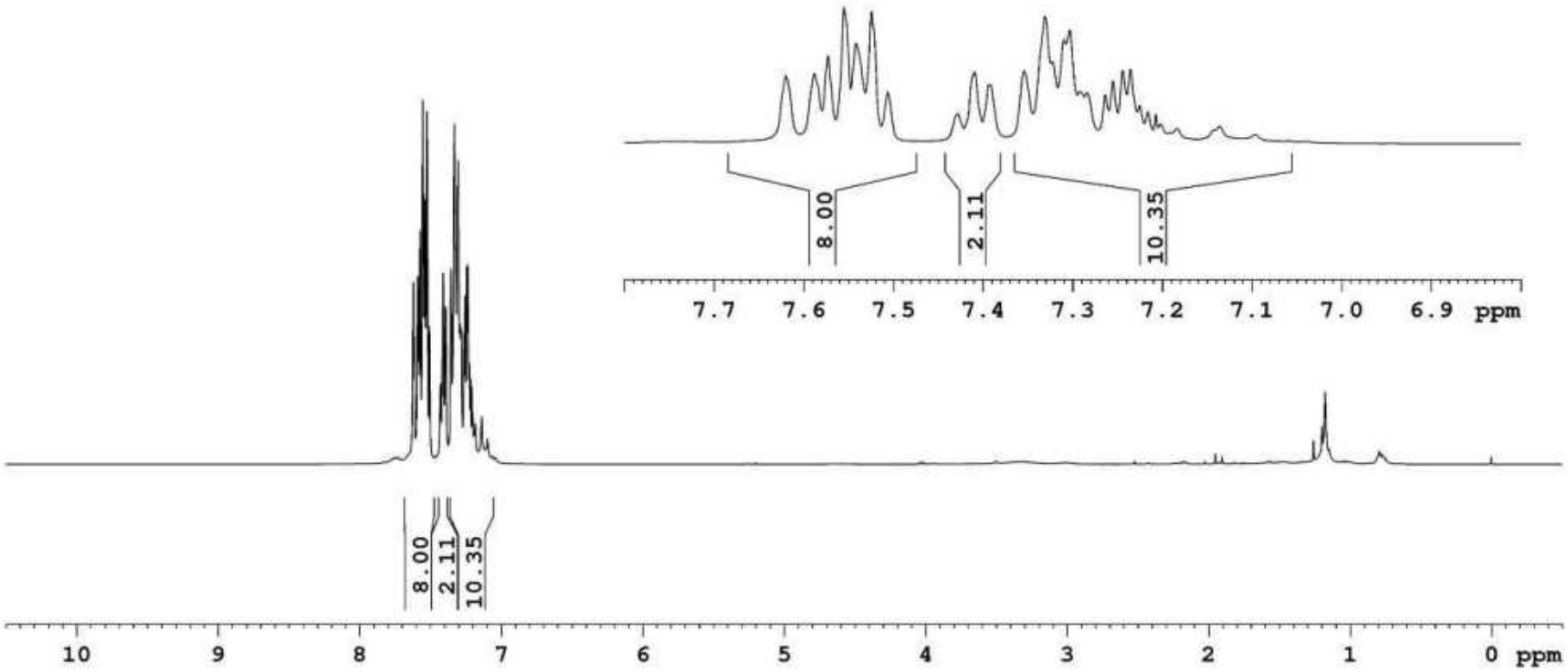
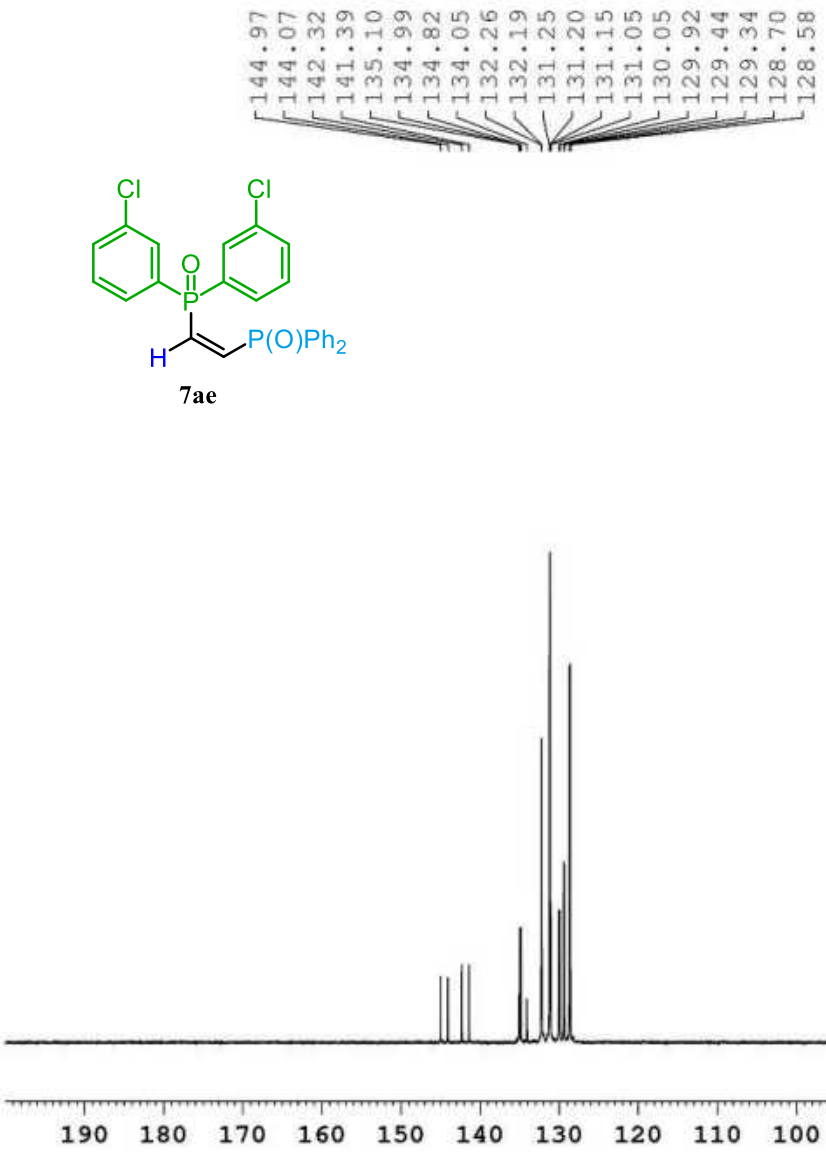
7.20
7.19
7.18
7.14
7.14
7.10
7.06

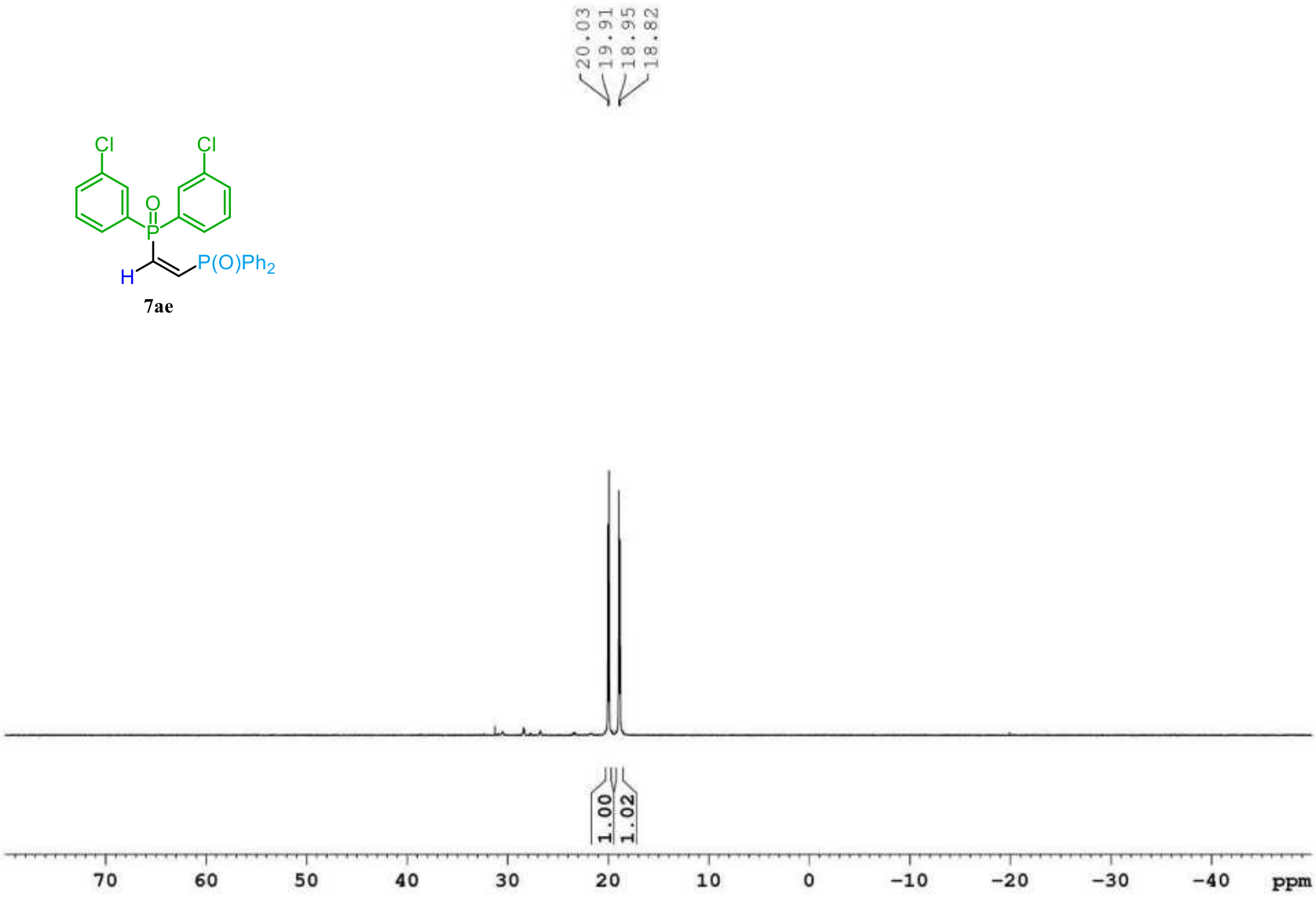

8.00
2.11
10.35
7.7
7.6
7.5
7.4
7.3
7.2
7.1
7.0
6.9
ppm
8.00
2.11
10.35
10
9
8
7
6
5
4
3
2
1
0
ppm


144.97
144.07
142.32
141.39
135.10
134.99
134.82
134.05
132.26
132.19
131.25
131.20
131.15
131.05
130.05
129.92
129.44
129.34
128.70
128.58
Cl
Cl
O
P
H
P(O)Ph2
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

7ae

Cl
Cl
O
P
H
P(O)Ph2

7ae


20.03
19.91
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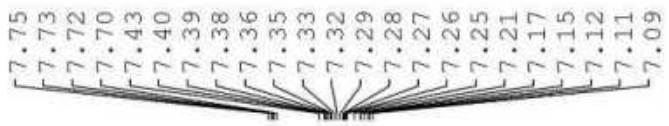
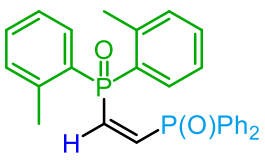
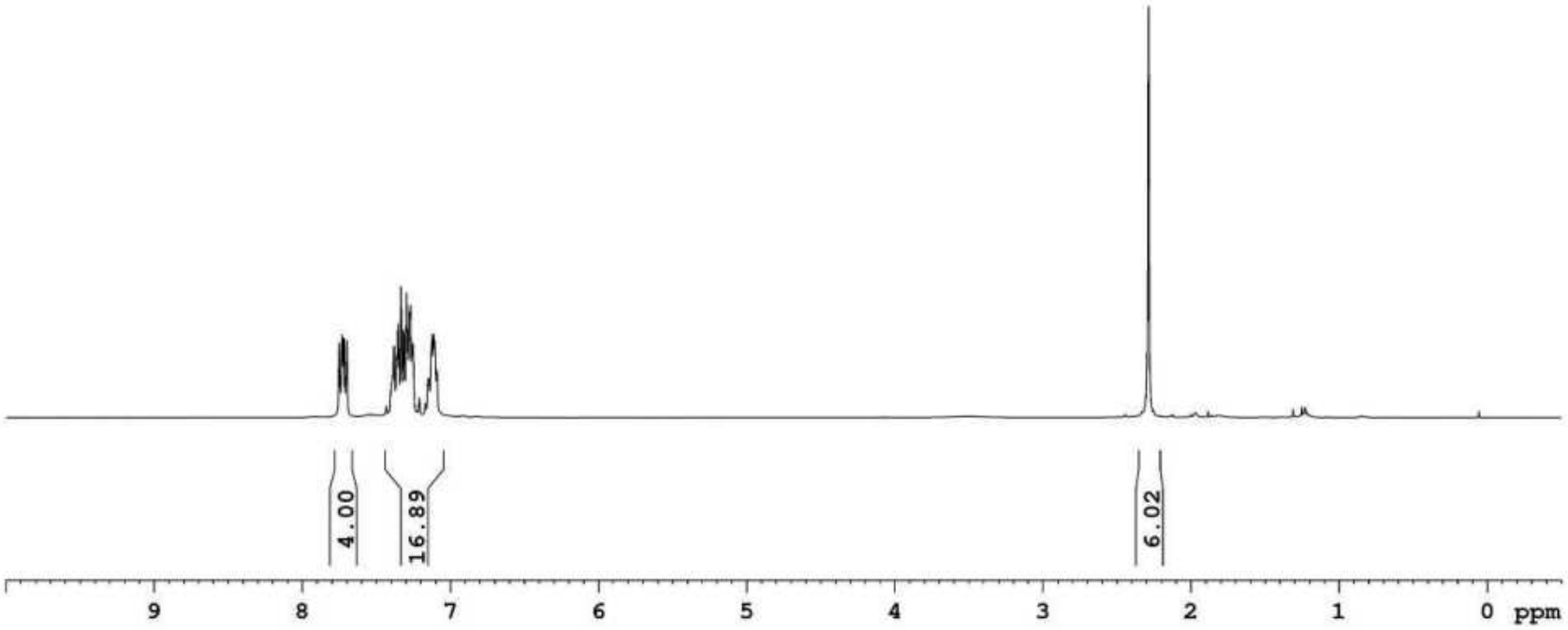
1.02
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm


7.75
7.73
7.72
7.70
7.43
7.40
7.39
7.38
7.36
7.35
7.33
7.32
7.29
7.28
7.27
7.26
7.25
7.21
7.17
7.15
7.12
7.11
7.09


2.29


O
P
H
P(O)Ph2

7af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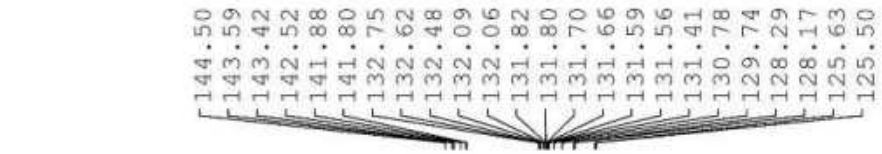
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132.75
132.62
132.48
132.09
132.06
131.82
131.80
131.70
131.66
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131.56
131.41
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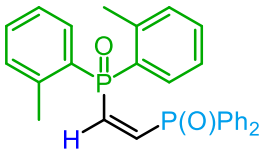
129.74
128.29
128.17
125.63
125.50

21.68
21.64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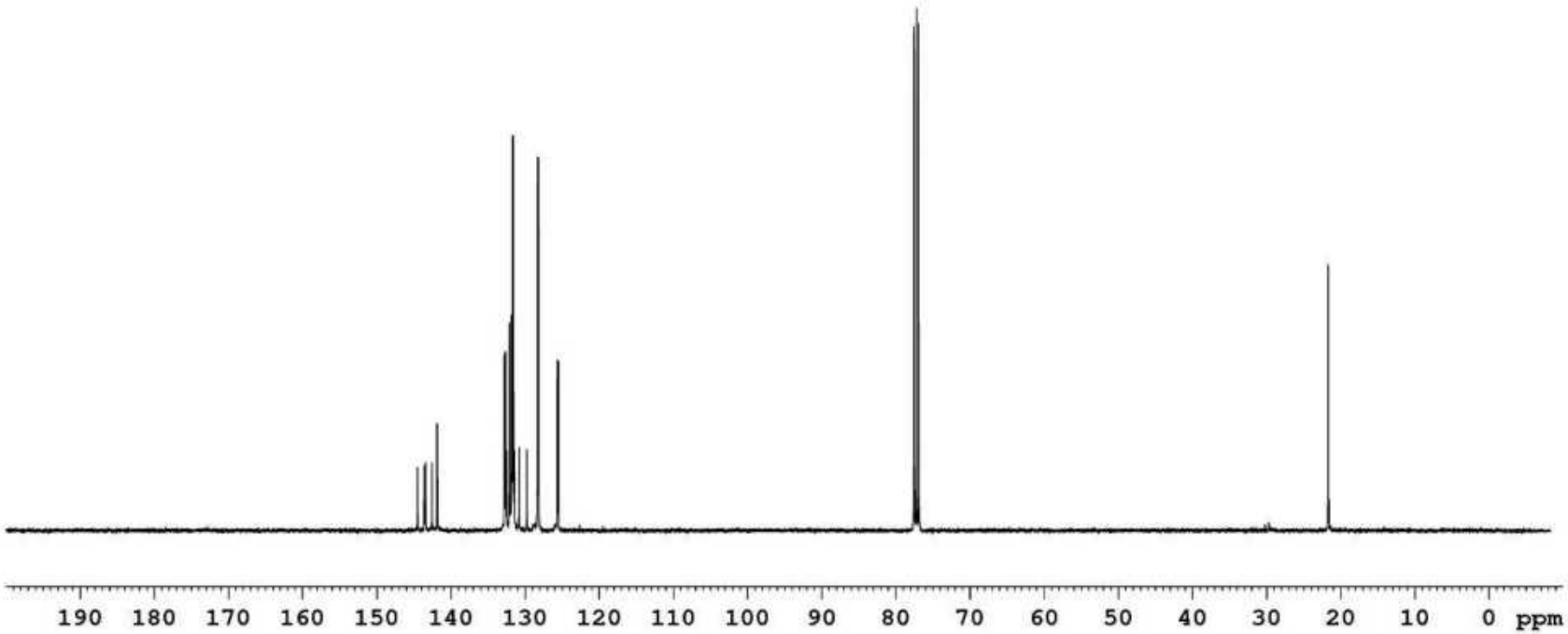
P
H
P(O)Ph2

7af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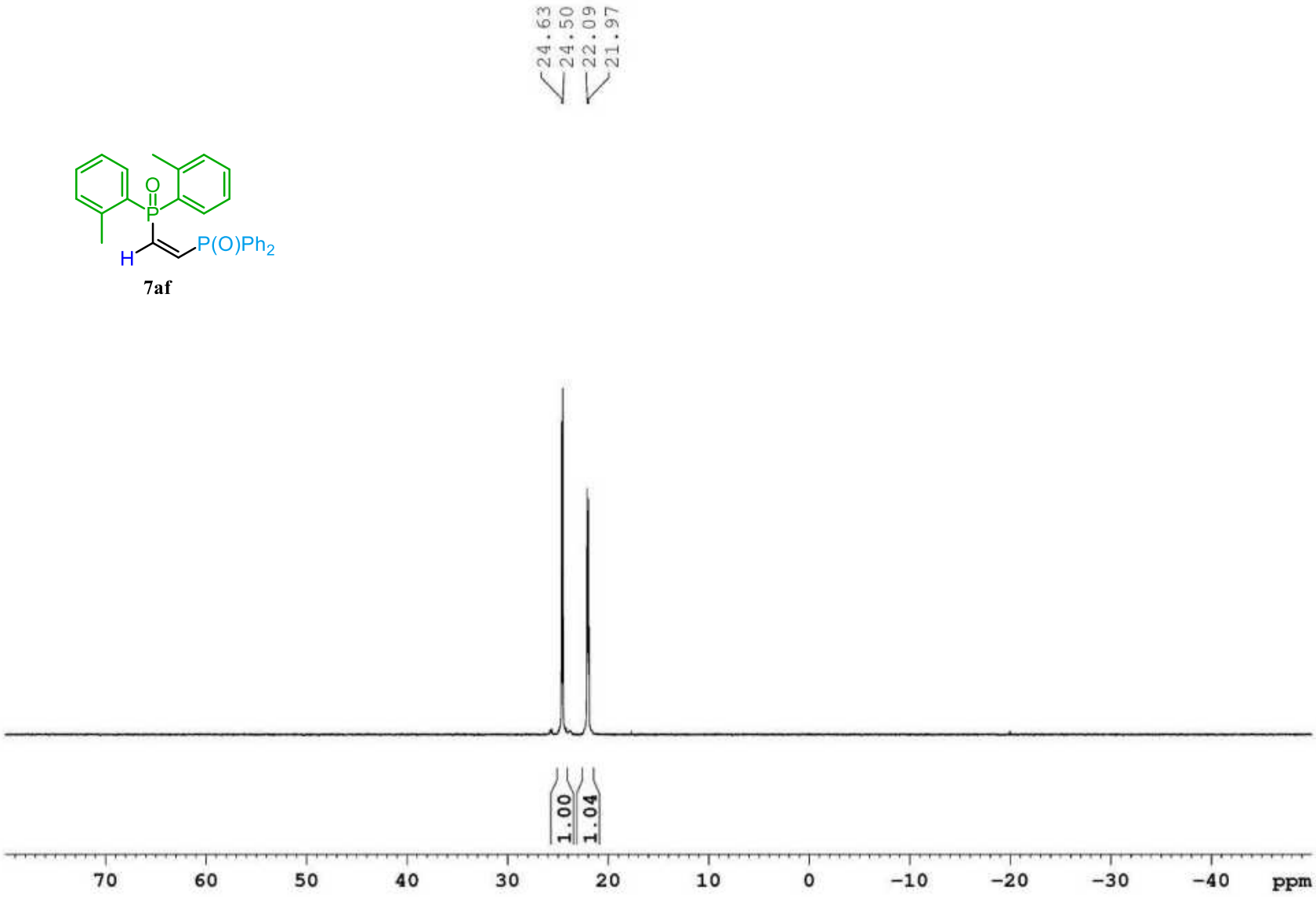
24.63
24.50
22.09
21.97
O
P
H
P(O)Ph2
1.00
1.04
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm

7af


7.77
7.76
7.75
7.74
7.74
7.73
7.72
7.71
7.26
7.17
7.15
7.13
7.13
7.11
7.08
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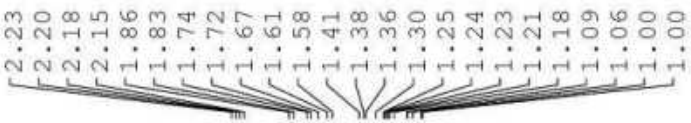
6.81
6.80
6.77
6.74
6.71
6.70
6.67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2.20
2.18
2.15
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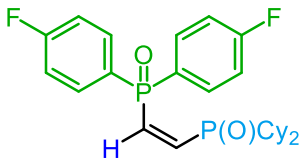
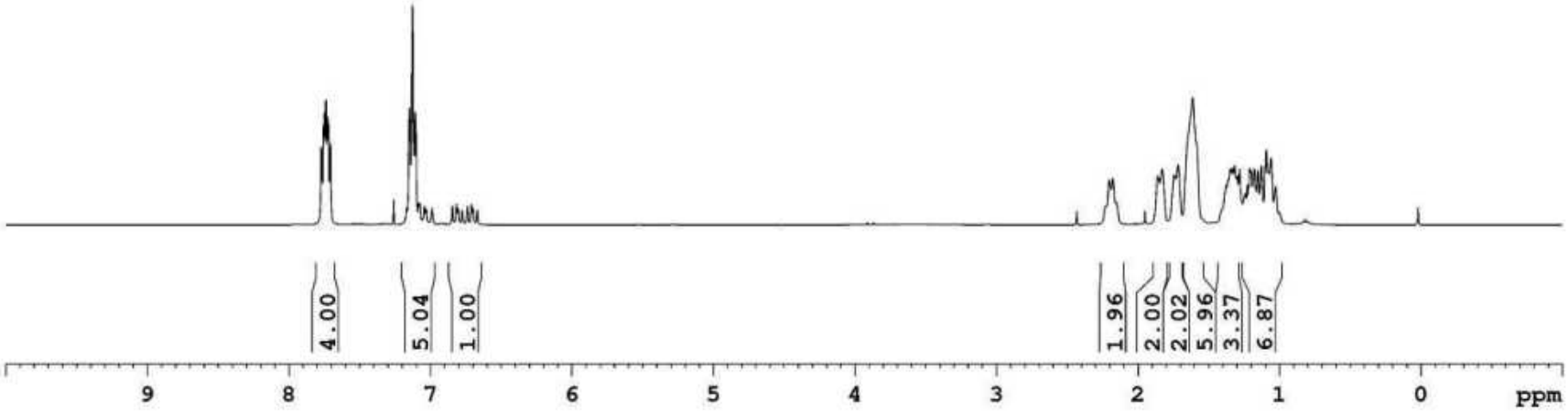
1.83
1.74
1.72
1.67
1.61
1.58
1.41
1.38
1.36
1.30
1.25
1.24
1.23
1.21
1.18
1.09
1.06
1.00
1.00


F
F
O
P
H
P(O)Cy2

7ag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5.04
1.00
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2.00
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5.96
3.37
6.87
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6
5
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2
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0
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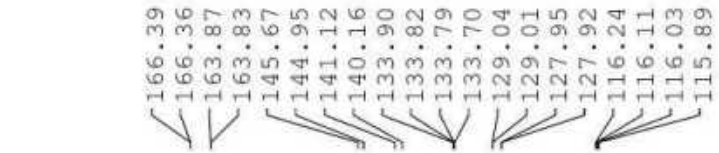
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166.36
163.87
163.83
145.67
144.95
141.12
140.16
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133.70
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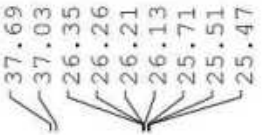
127.95
127.92
116.24
116.11
116.03
115.89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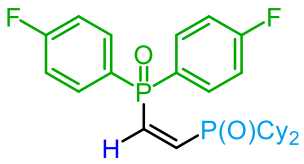
37.03
26.35
26.26
26.21
26.13
25.71
25.51
25.47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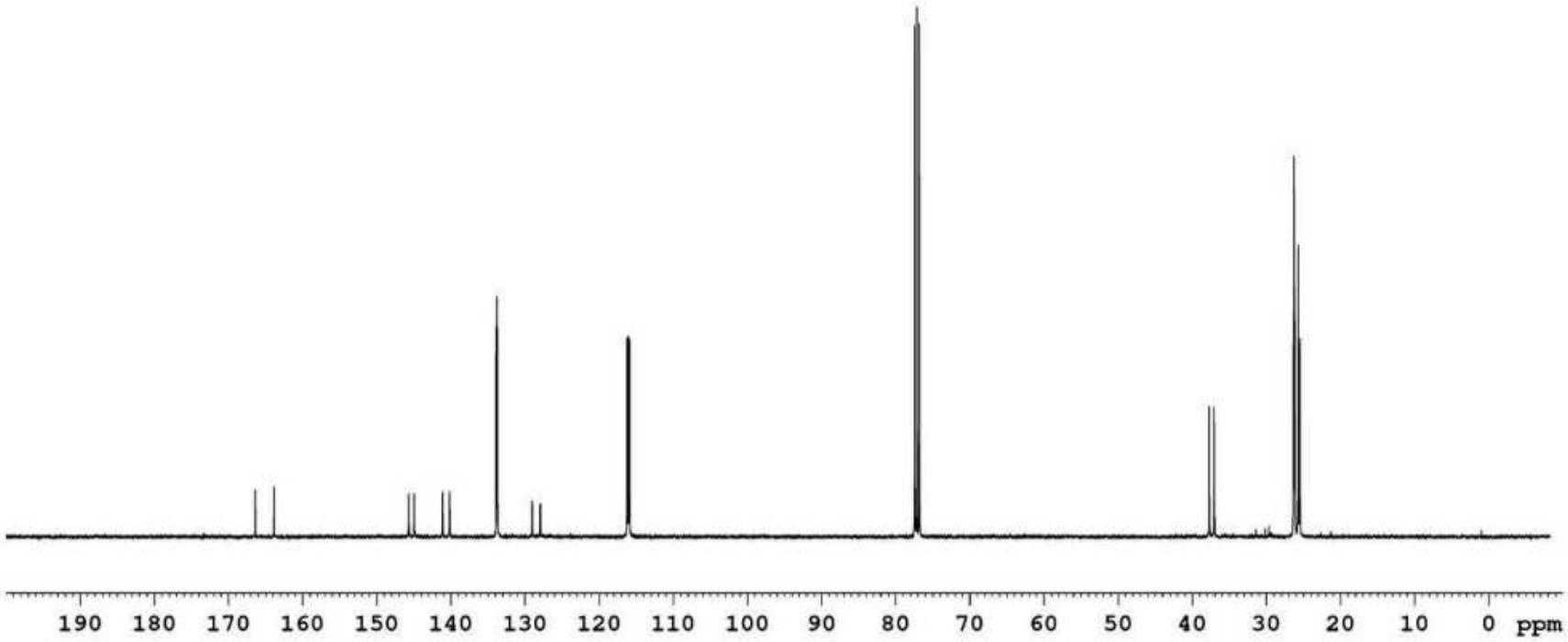
F
O
P
H
P(O)Cy2

7ag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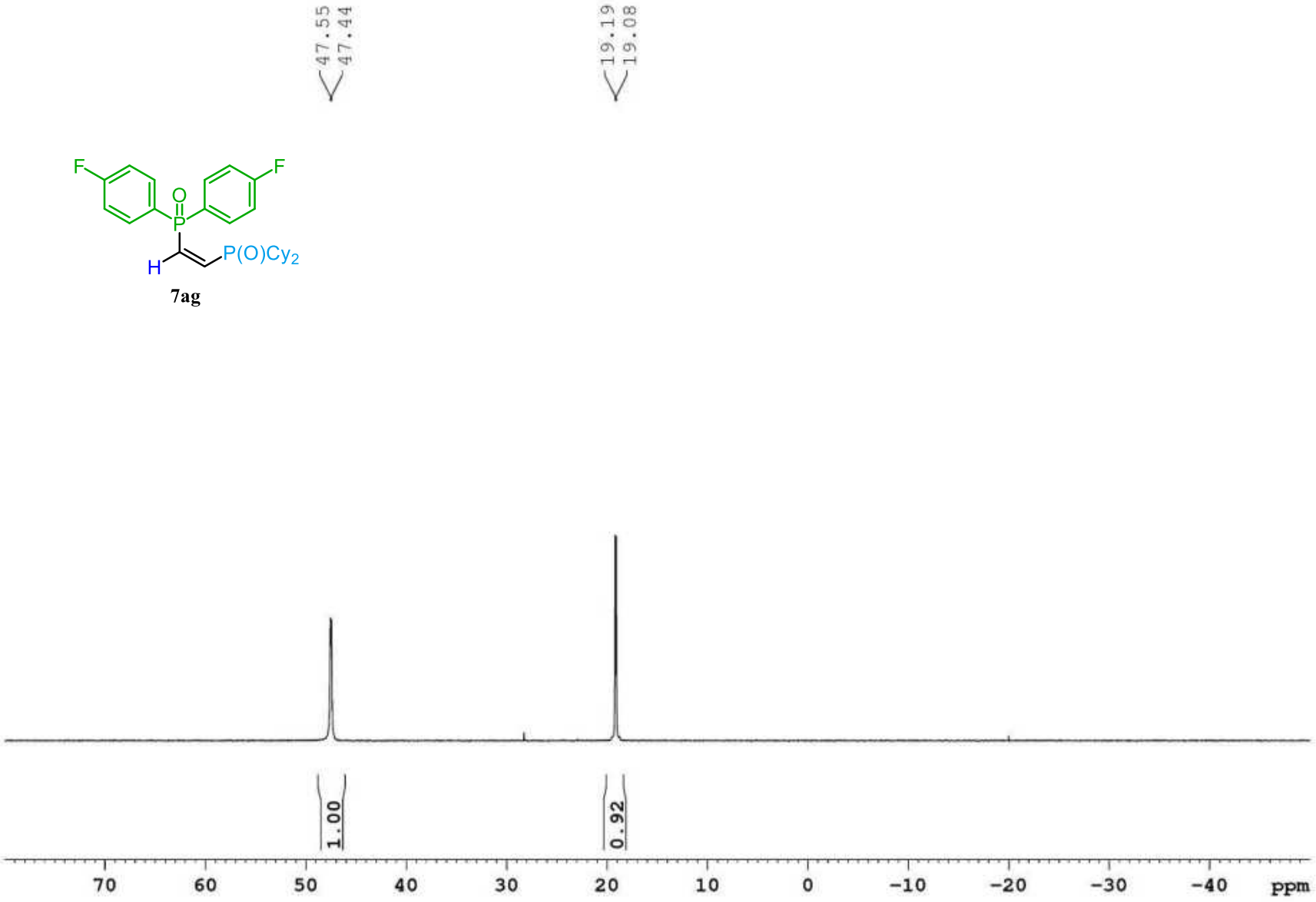
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

F
F
O
P
H
P(O)Cy2

7ag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47.44
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50
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30
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10
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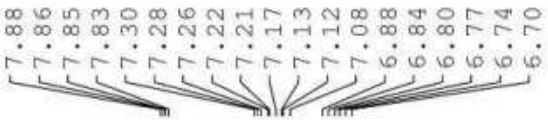
-20
-30
-40
ppm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7.86
7.85
7.83
7.30
7.28
7.26
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7.17
7.13
7.12
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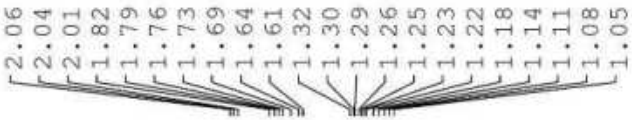
6.88
6.84
6.80
6.77
6.74
6.70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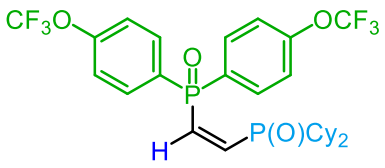
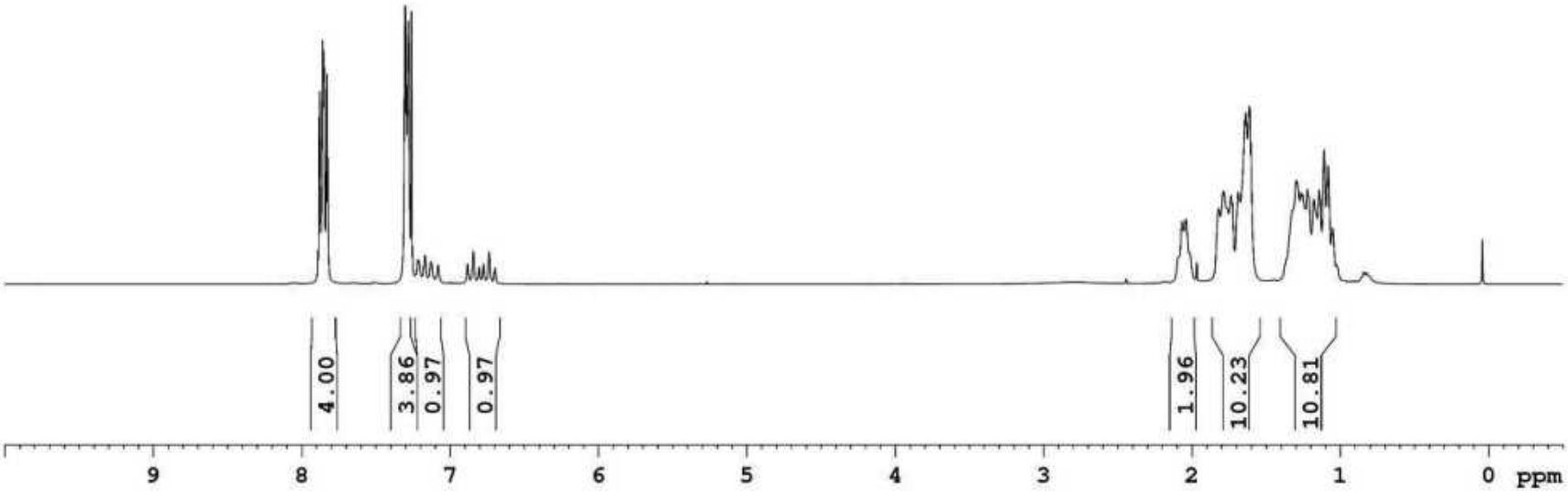
2.04
2.01
1.82
1.79
1.76
1.73
1.69
1.64
1.61
1.32
1.30
1.29
1.26
1.25
1.23
1.22
1.18
1.14
1.11
1.08
1.05


CF3O
OCF3
O
P
H
P(O)Cy2

7ah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1.96
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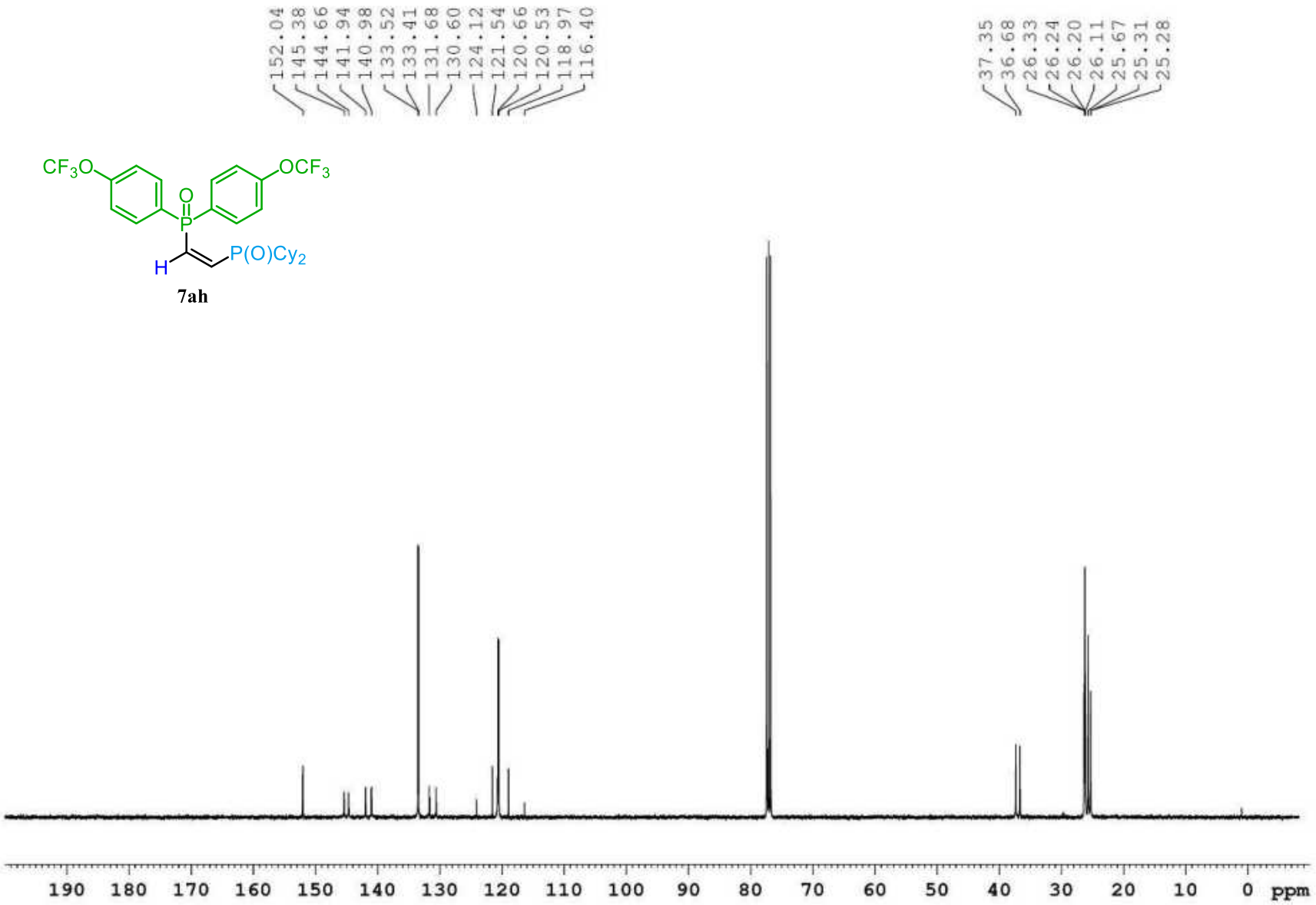
10.81
9
8
7
6
5
4
3
2
1
0
ppm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131.68
130.60
124.12
121.54
120.66
120.53
118.97
116.40
37.35
36.68
26.33
26.24
26.20
26.11
25.67
25.31
25.28
CF3O
OCF3
O
P
H
P(O)Cy2
7ah
190
180
170
160
150
140
130
120
110
100
90
80
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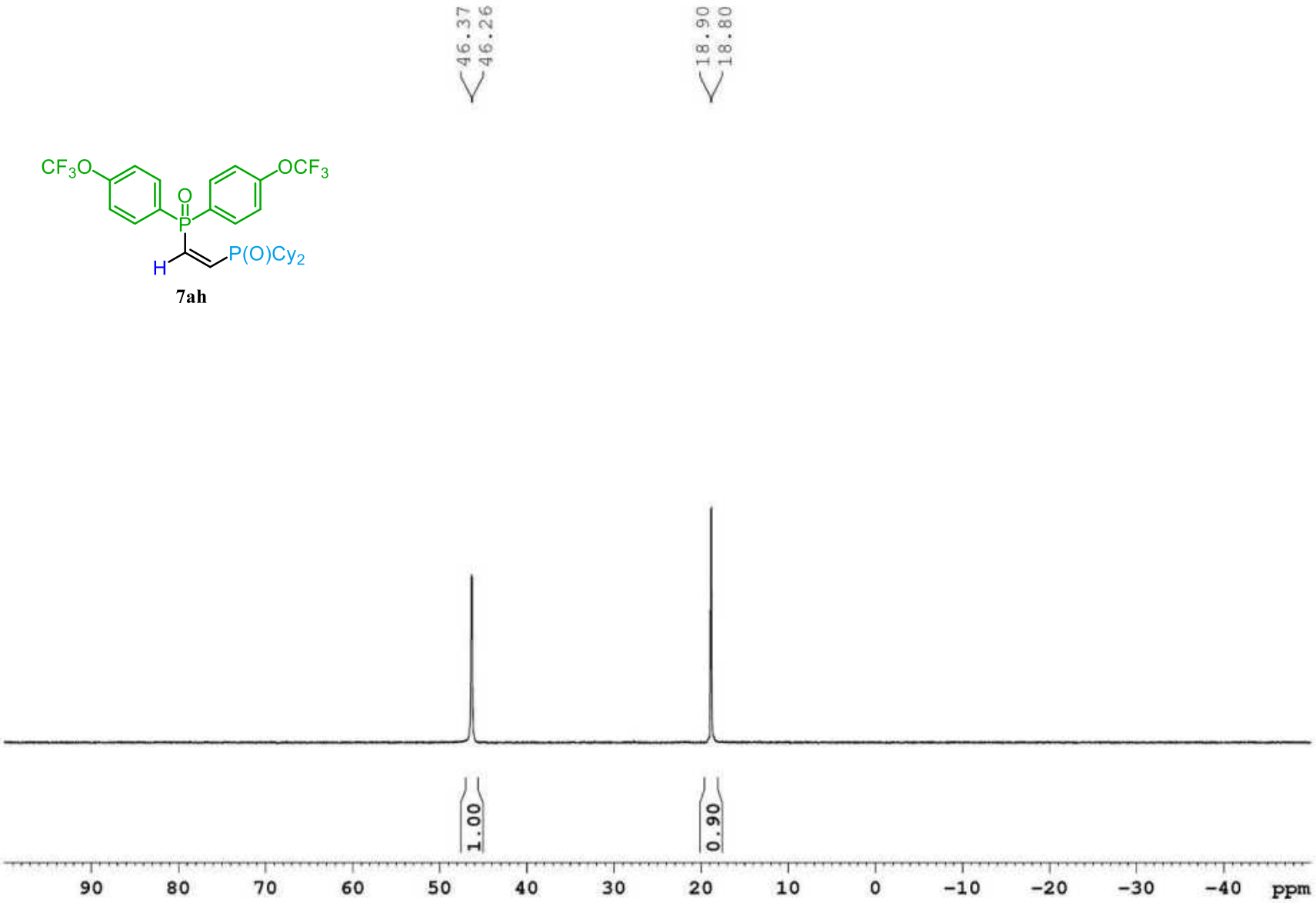
40
30
20
10
0
ppm

CF3O
OCF3
O
P
H
P(O)Cy2

7ah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46.26
18.90
18.80
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80
70
60
50
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30
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10
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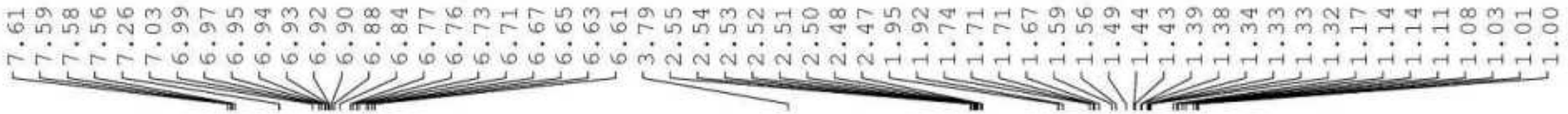
-20
-30
-40
ppm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7.59
7.58
7.56
7.26
7.03
6.99
6.97
6.95
6.94
6.93
6.92
6.90
6.88
6.84
6.77
6.76
6.73
6.71
6.67
6.65
6.63
6.61
3.79
2.55
2.54
2.53
2.52
2.51
2.50
2.48
2.47
1.95
1.92
1.74
1.71
1.71
1.67
1.59
1.56
1.49
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1.43
1.39
1.38
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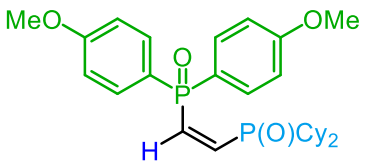
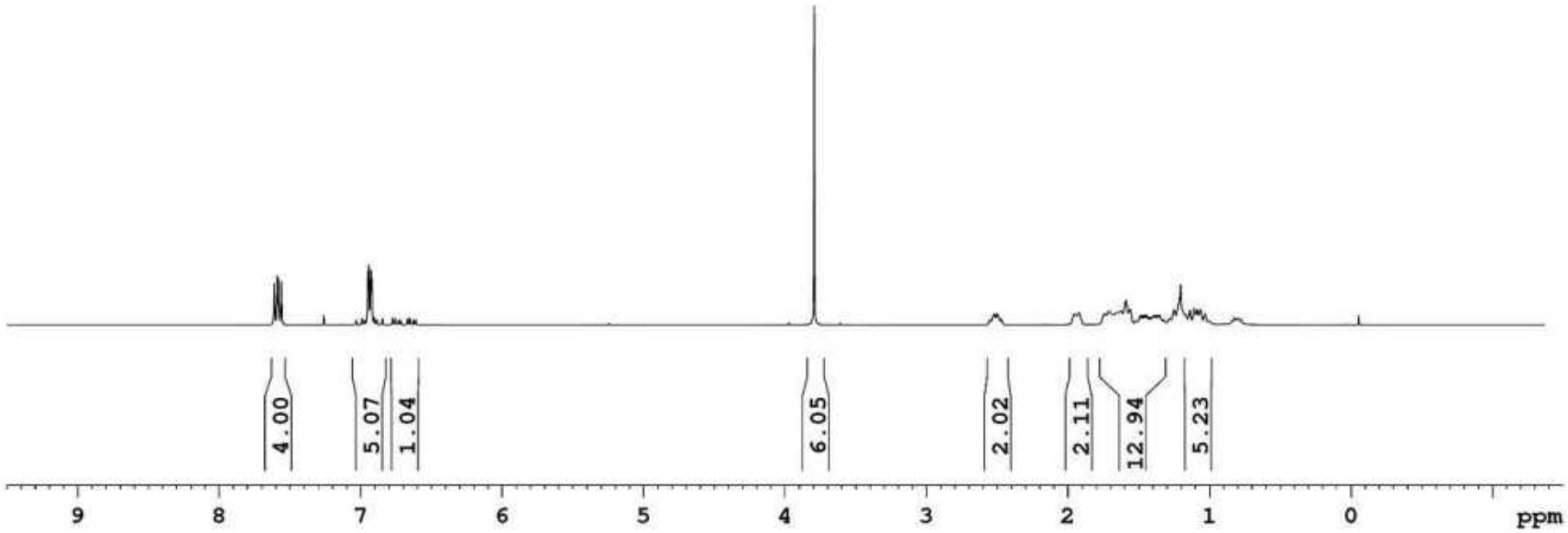
1.03
1.01
1.00


MeO
OMe
O
P
H
P(O)Cy2

7ai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6.05
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2.11
12.94
5.23
9
8
7
6
5
4
3
2
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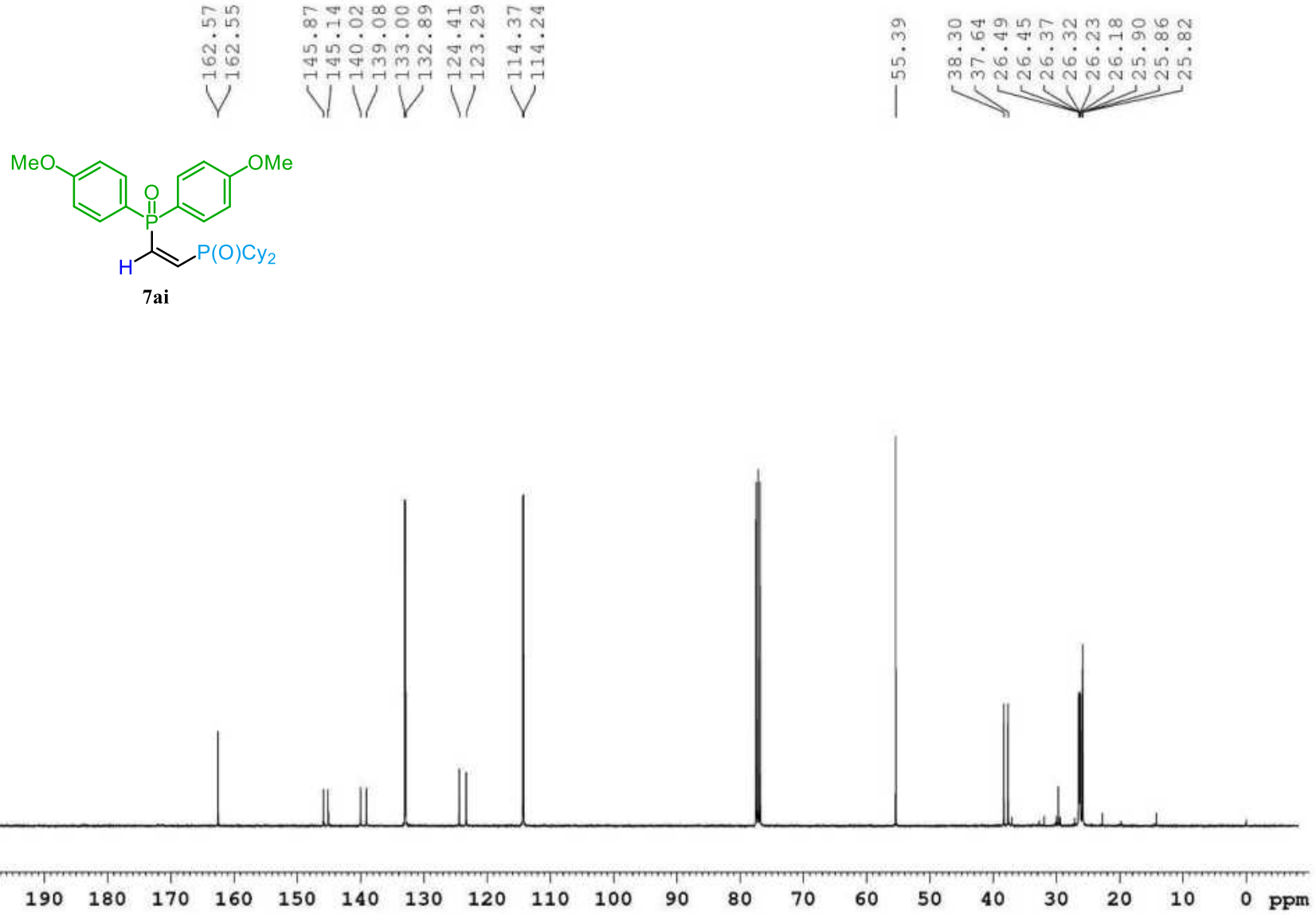
0
ppm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162.55
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145.14
140.02
139.08
133.00
132.89
124.41
123.29
114.37
114.24
55.39
38.30
37.64
26.49
26.45
26.37
26.32
26.23
26.18
25.90
25.86
25.82
MeO
OMe
O
P
H
P(O)Cy2
190
180
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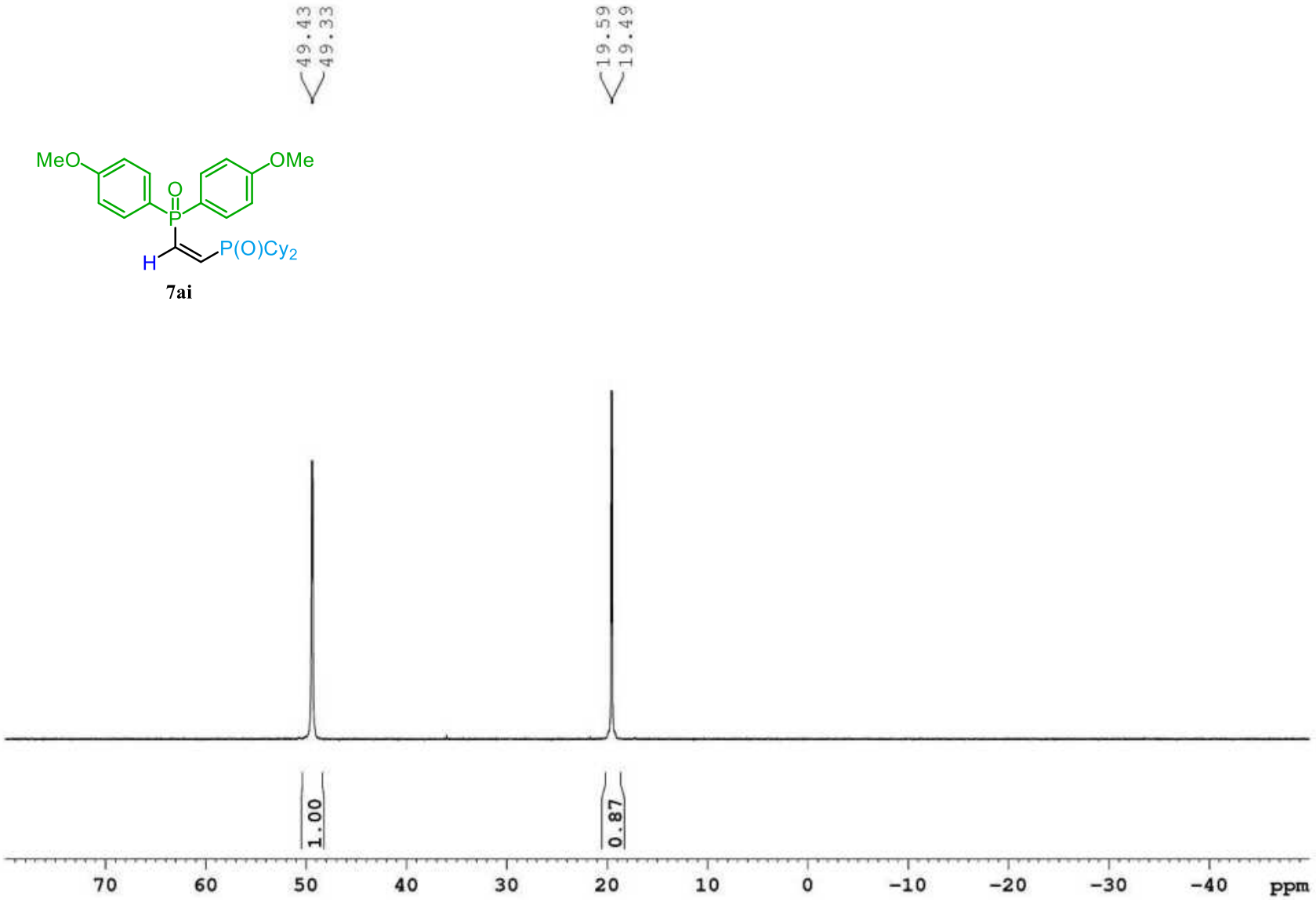
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

7ai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49.33
19.59
19.49
MeO
OMe
O
P
H
P(O)Cy2
7ai
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50
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10
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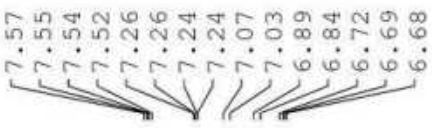
-20
-30
-40
ppm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7.54
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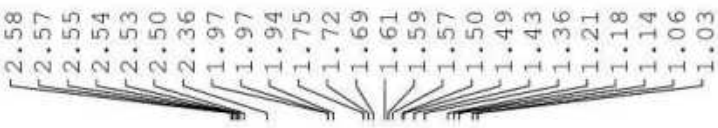
7.26
7.24
7.24
7.07
7.03
6.89
6.84
6.72
6.69
6.68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2.50
2.36
1.97
1.97
1.94
1.75
1.72
1.69
1.61
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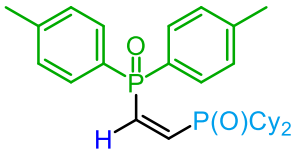
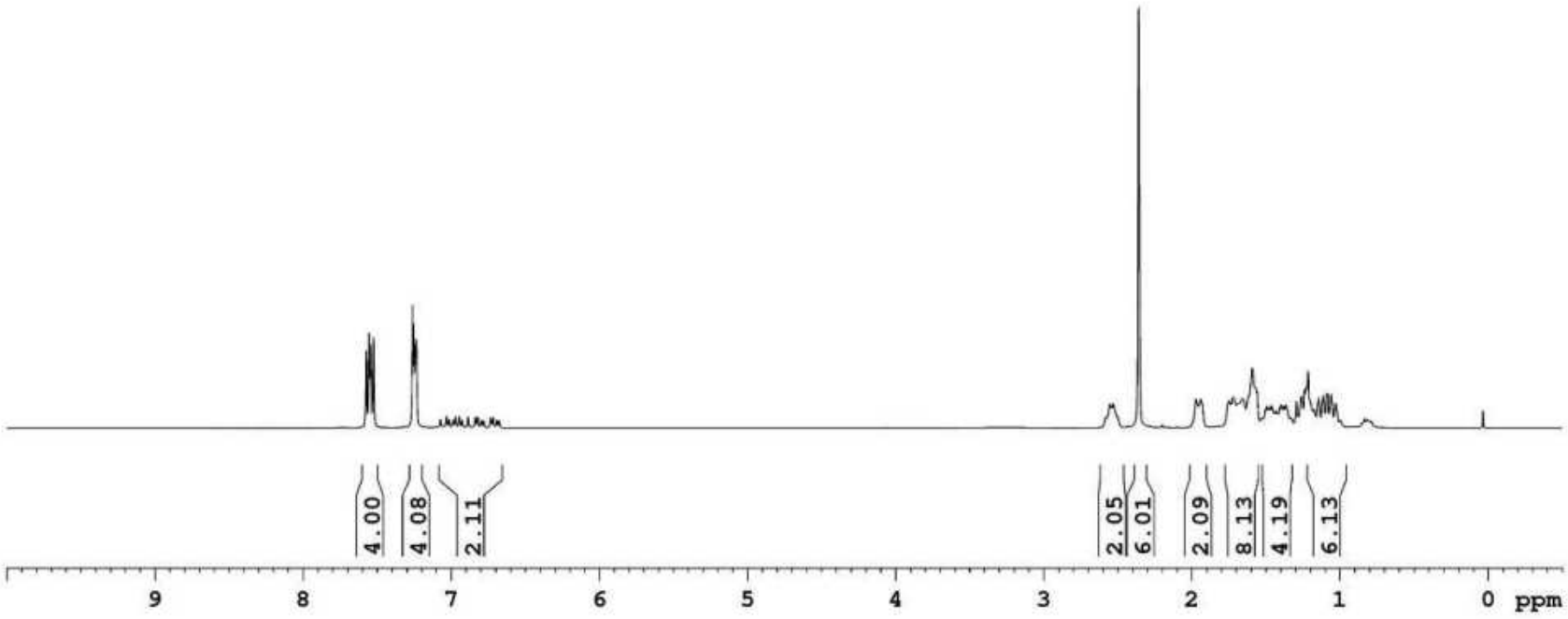
1.50
1.49
1.43
1.36
1.21
1.18
1.14
1.06
1.03


O
P
H
P(O)Cy2

7aj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2.11
2.05
6.01
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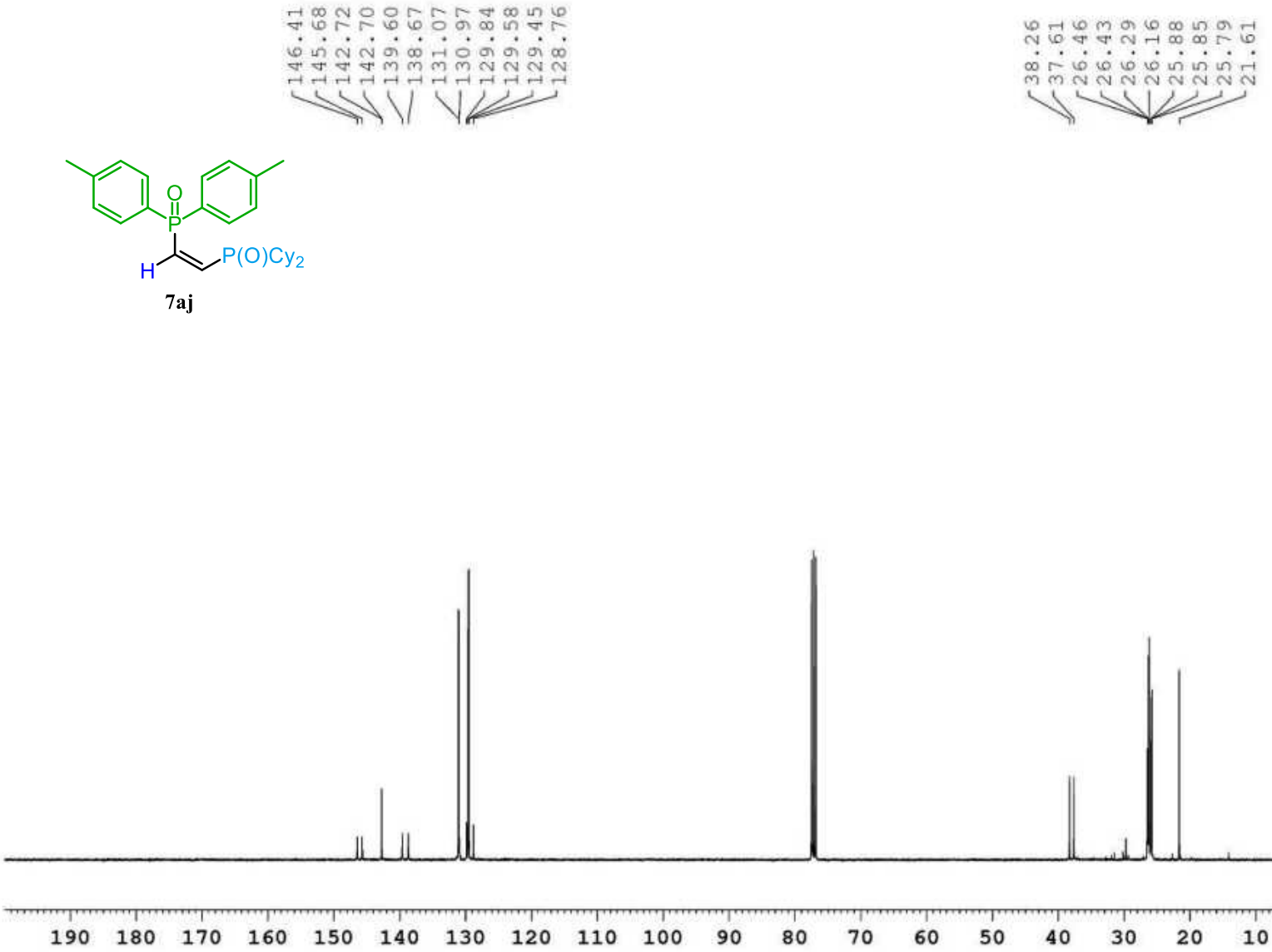
8.13
4.19
6.13
9
8
7
6
5
4
3
2
1
0
ppm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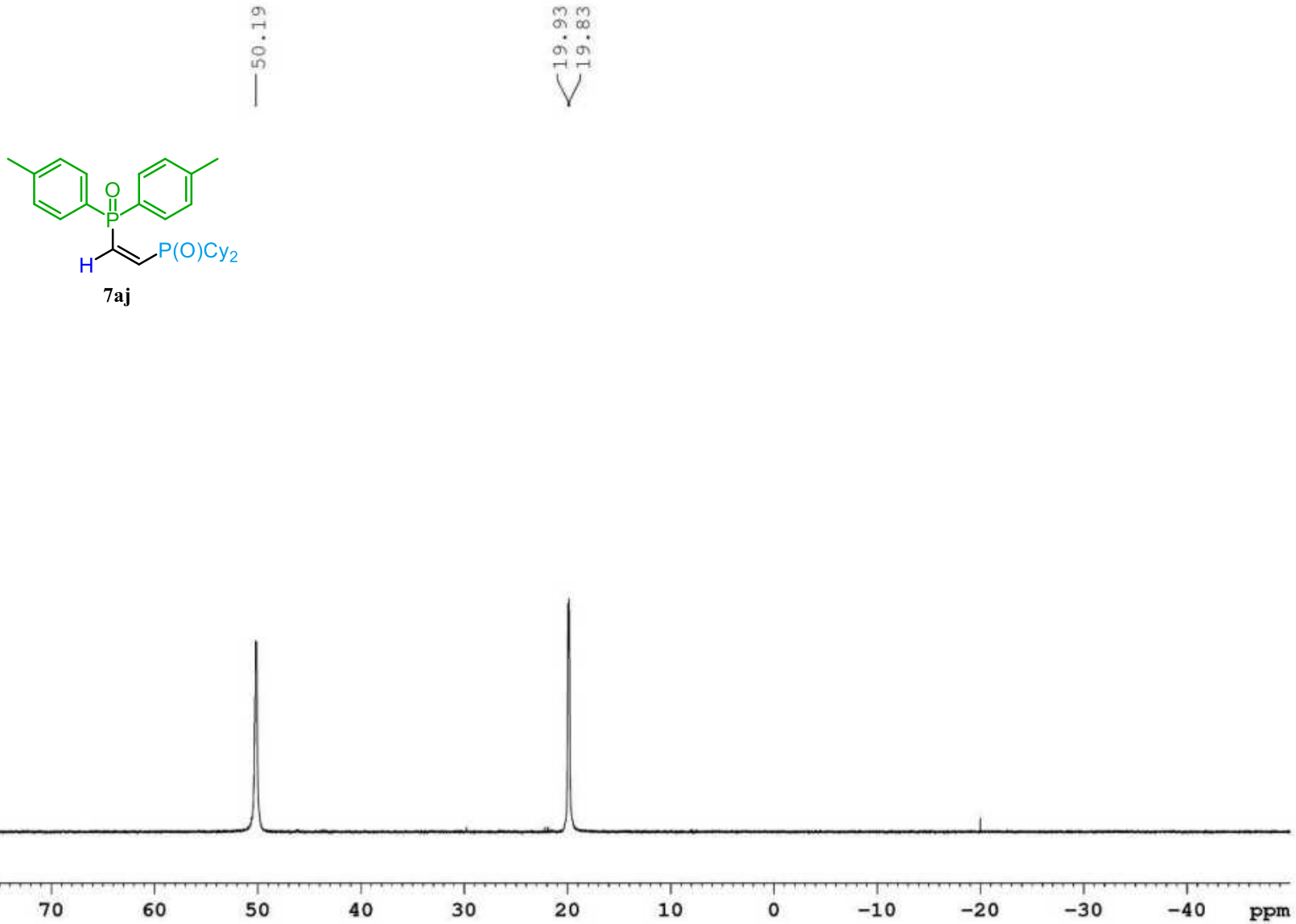
142.70
139.60
138.67
131.07
130.97
129.84
129.58
129.45
128.76
38.26
37.61
26.46
26.43
26.29
26.16
25.88
25.85
25.79
21.61
O
P
H
P(O)Cy2
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

7aj



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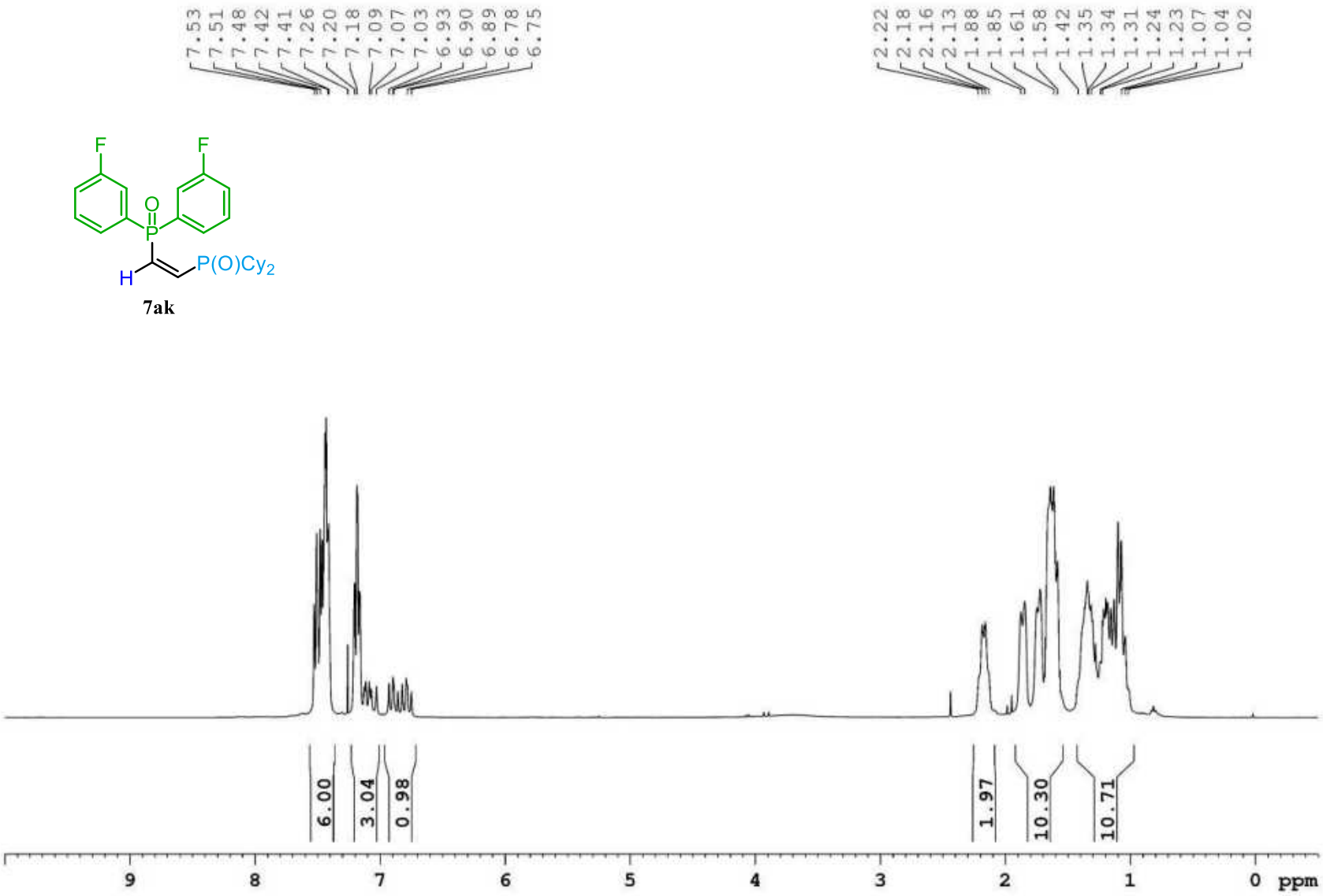
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7.18
7.09
7.07
7.03
6.93
6.90
6.89
6.78
6.75
2.22
2.18
2.16
2.13
1.88
1.85
1.61
1.58
1.42
1.35
1.34
1.31
1.24
1.23
1.07
1.04
1.02
F
F
O
P
H
P(O)Cy2
7ak
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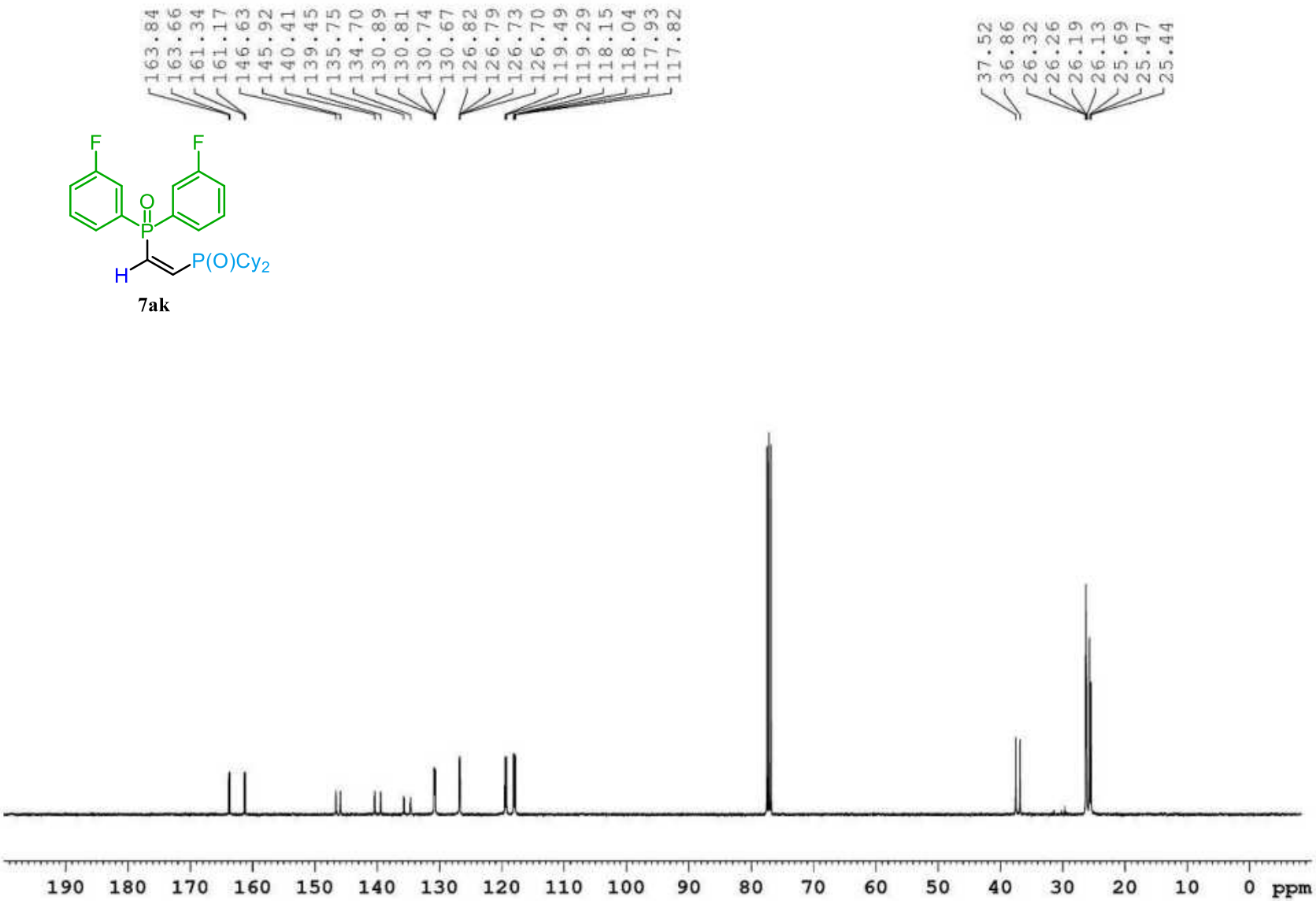
1.97
10.30
10.71
9
8
7
6
5
4
3
2
1
0
ppm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161.17
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139.45
135.75
134.70
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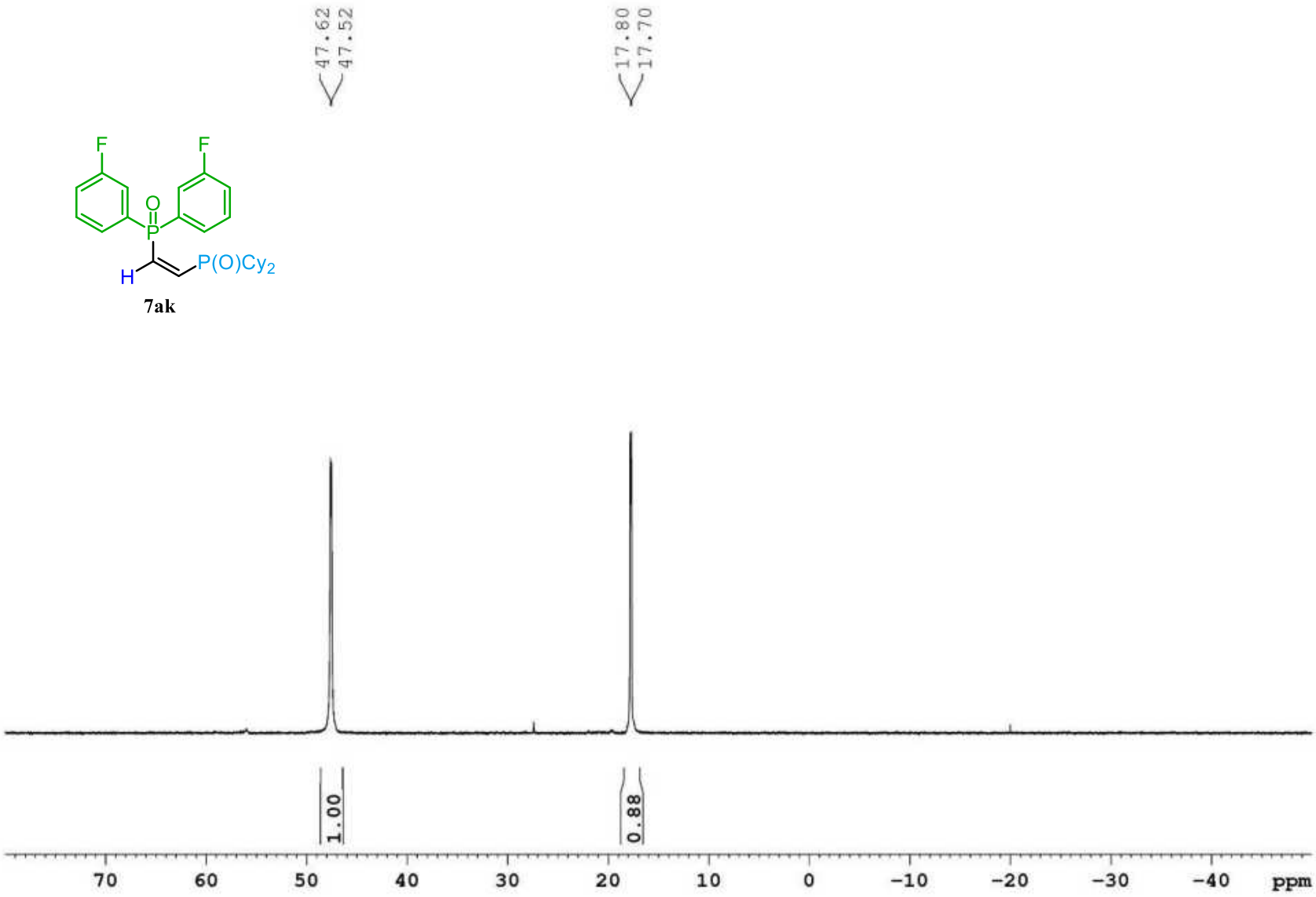
130.81
130.74
130.67
126.82
126.79
126.73
126.70
119.49
119.29
118.15
118.04
117.93
117.82
37.52
36.86
26.32
26.26
26.19
26.13
25.69
25.47
25.44
F
F
O
P
H
P(O)Cy2
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

7ak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47.52
17.80
17.70
F
F
O
P
H
P(O)Cy2
7ak
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0.88
70
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50
40
30
20
10
0
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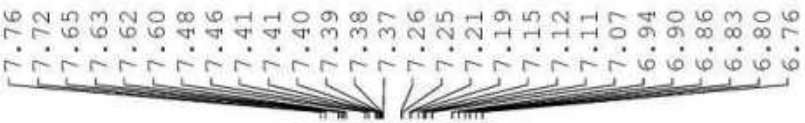
-20
-30
-40
ppm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7.63
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7.60
7.48
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7.41
7.41
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7.39
7.38
7.37
7.26
7.25
7.21
7.19
7.15
7.12
7.11
7.07
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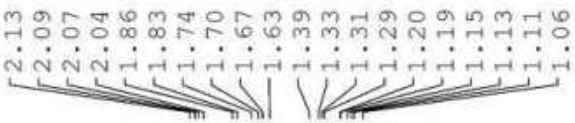
6.80
6.76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1.70
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1.29
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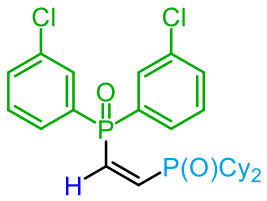
1.19
1.15
1.13
1.11
1.06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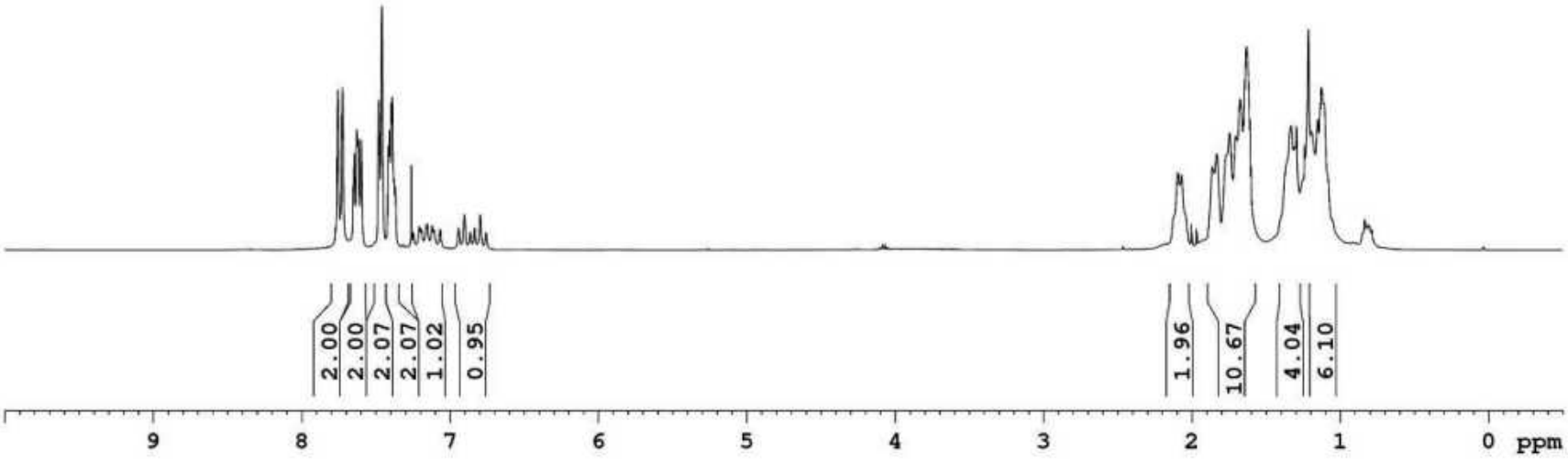
Cl
O
P
H
P(O)Cy2

7al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2.00
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2.07
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6.10
9
8
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6
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4
3
2
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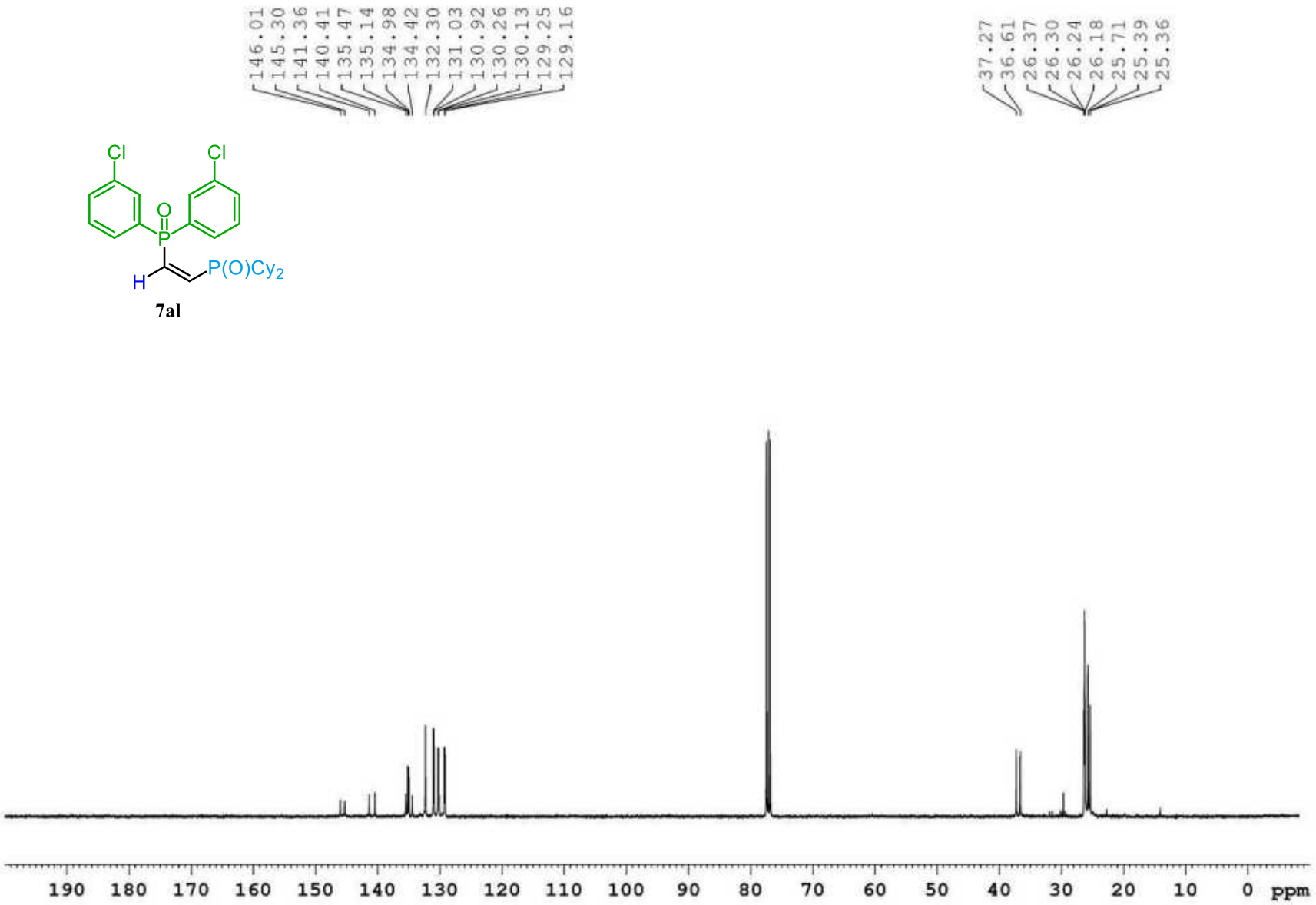
ppm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134.98
134.42
132.30
131.03
130.92
130.26
130.13
129.25
129.16
37.27
36.61
26.37
26.30
26.24
26.18
25.71
25.39
25.36
Cl
Cl
O
P
H
P(O)Cy2
7al
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180
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140
130
120
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100
90
80
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60
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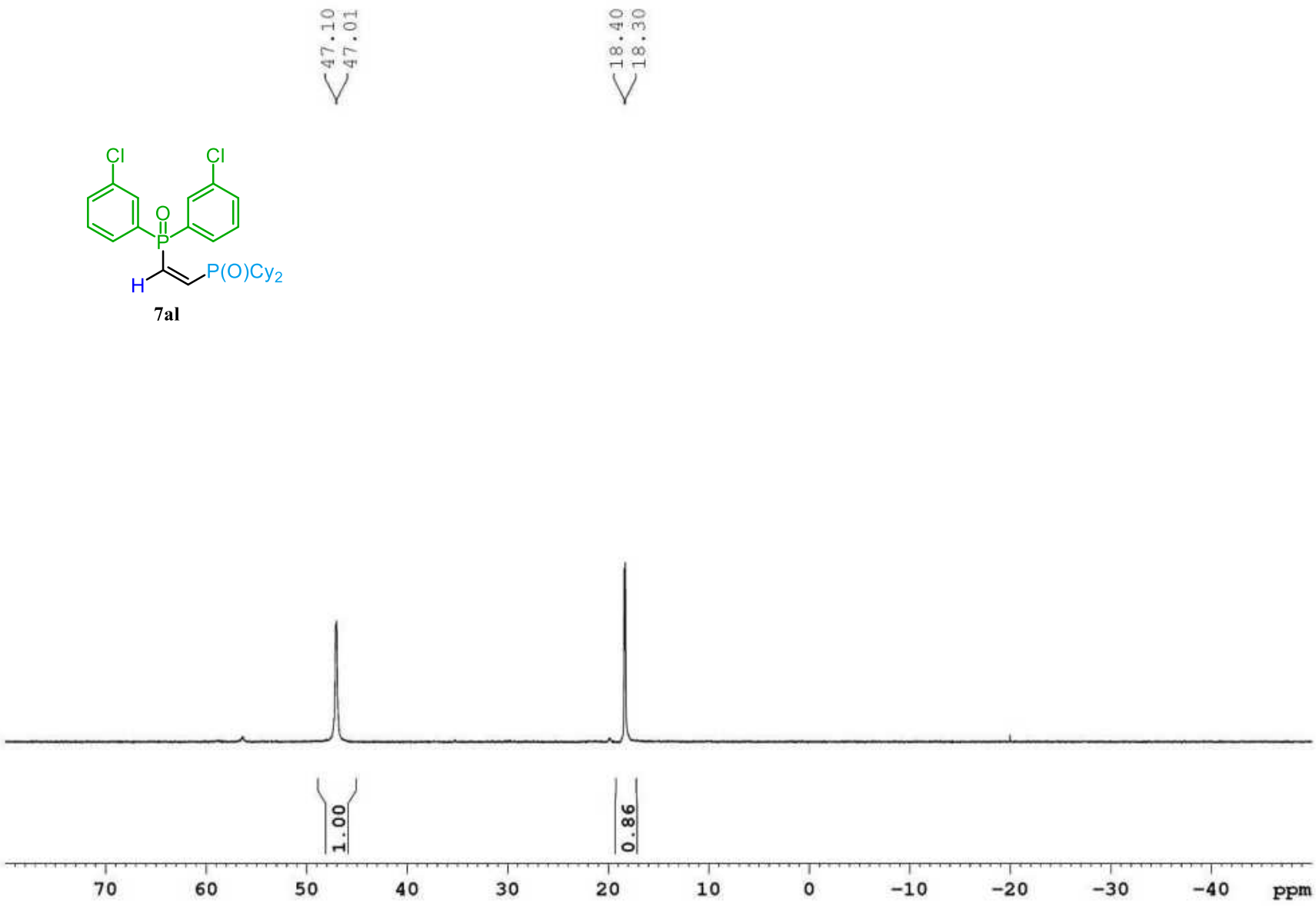
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Cl
Cl
O
P
H
P(O)Cy2
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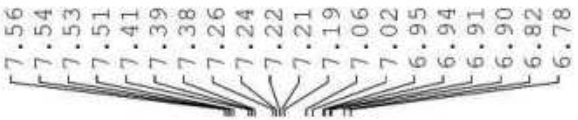
-20
-30
-40
ppm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7.38
7.26
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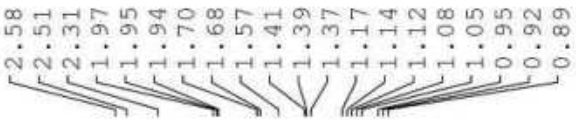
7.19
7.06
7.02
6.95
6.94
6.91
6.90
6.82
6.78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1.68
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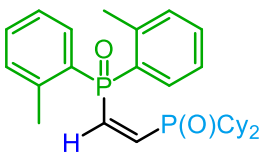
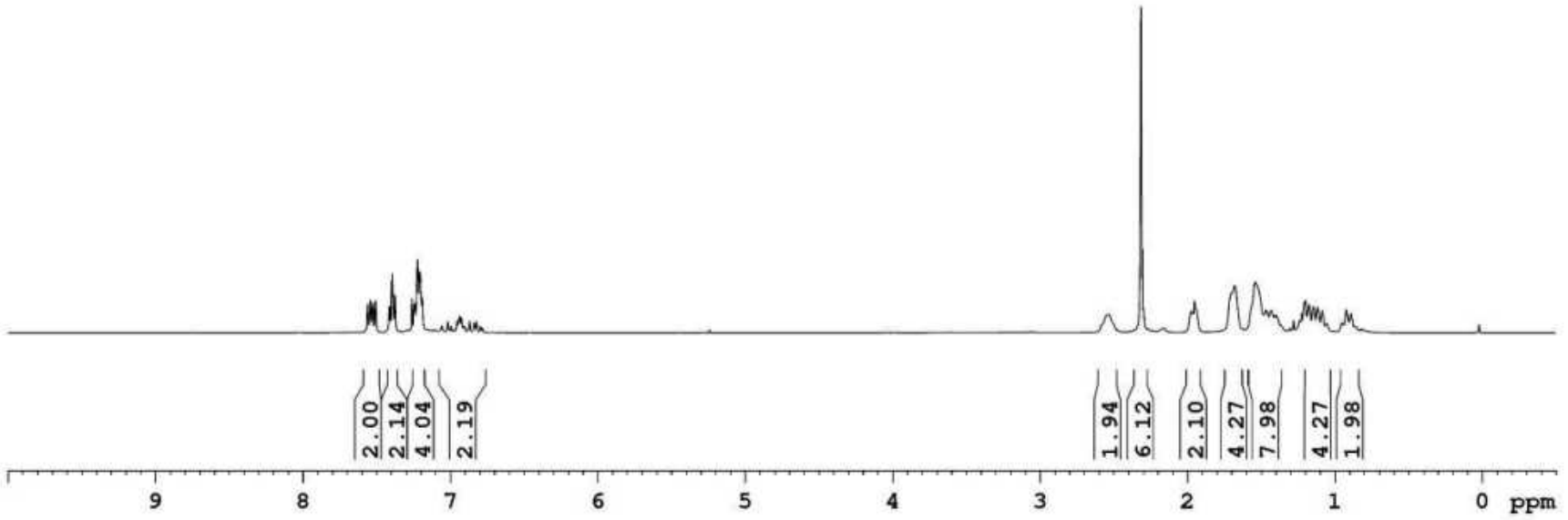
1.14
1.12
1.08
1.05
0.95
0.92
0.89


O
P
H
P(O)Cy2

7am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2.19
1.94
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1.98
9
8
7
6
5
4
3
2
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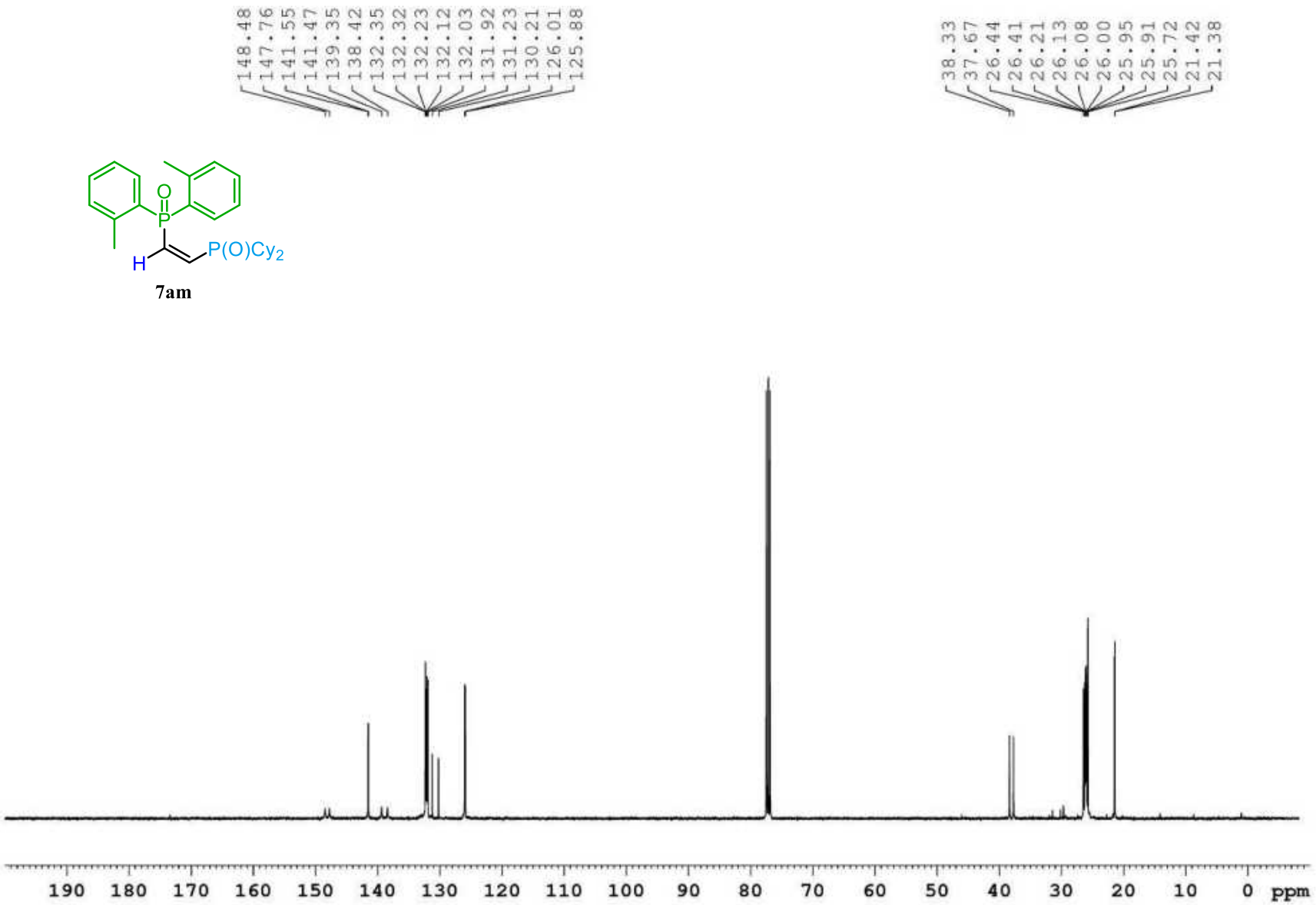
0
ppm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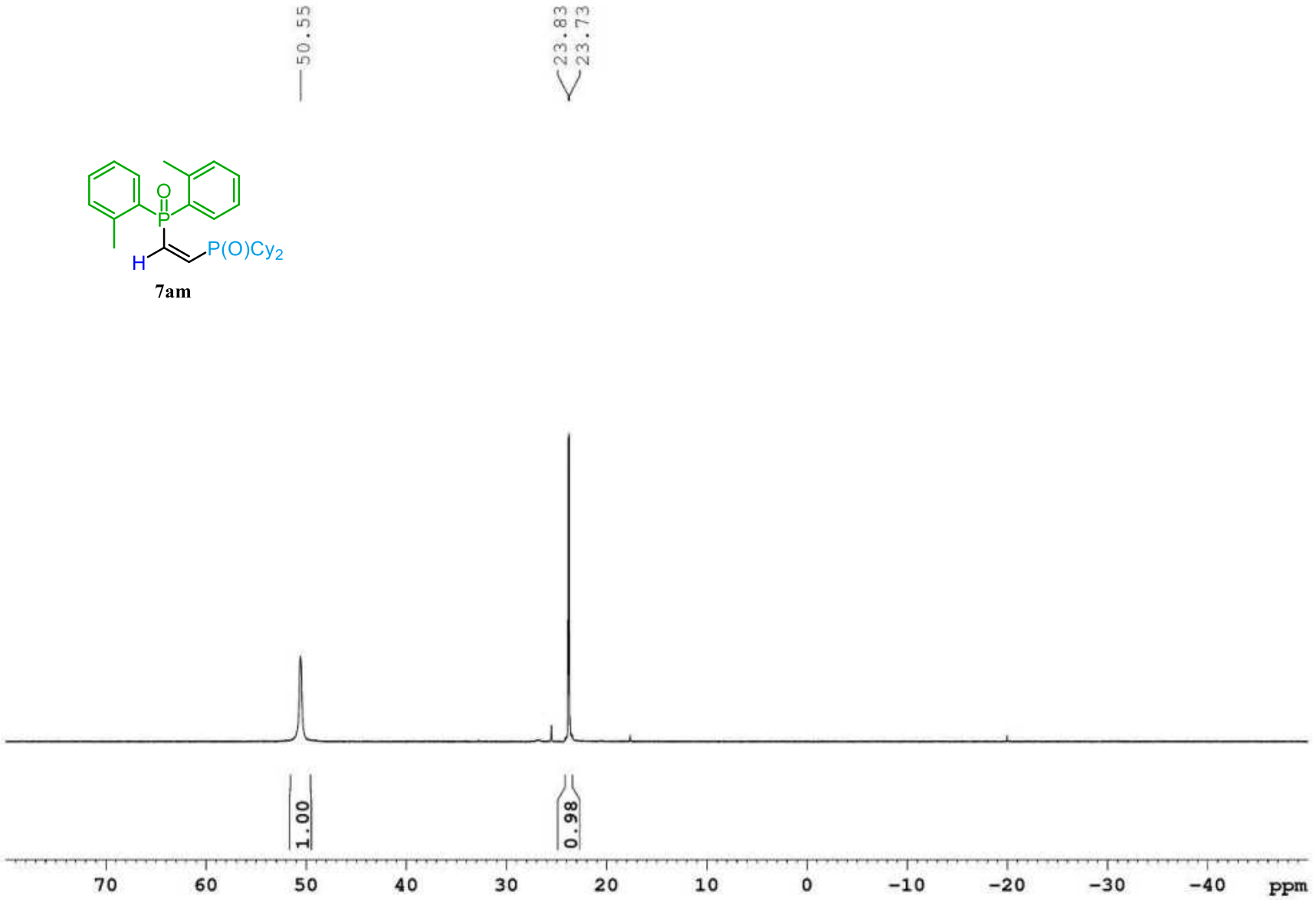
147.76
141.55
141.47
139.35
138.42
132.35
132.32
132.23
132.12
132.03
131.92
131.23
130.21
126.01
125.88
38.33
37.67
26.44
26.41
26.21
26.13
26.08
26.00
25.95
25.91
25.72
21.42
21.38
O
P
H
P(O)Cy2
7am
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm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23.83
23.73
O
P
H
P(O)Cy2
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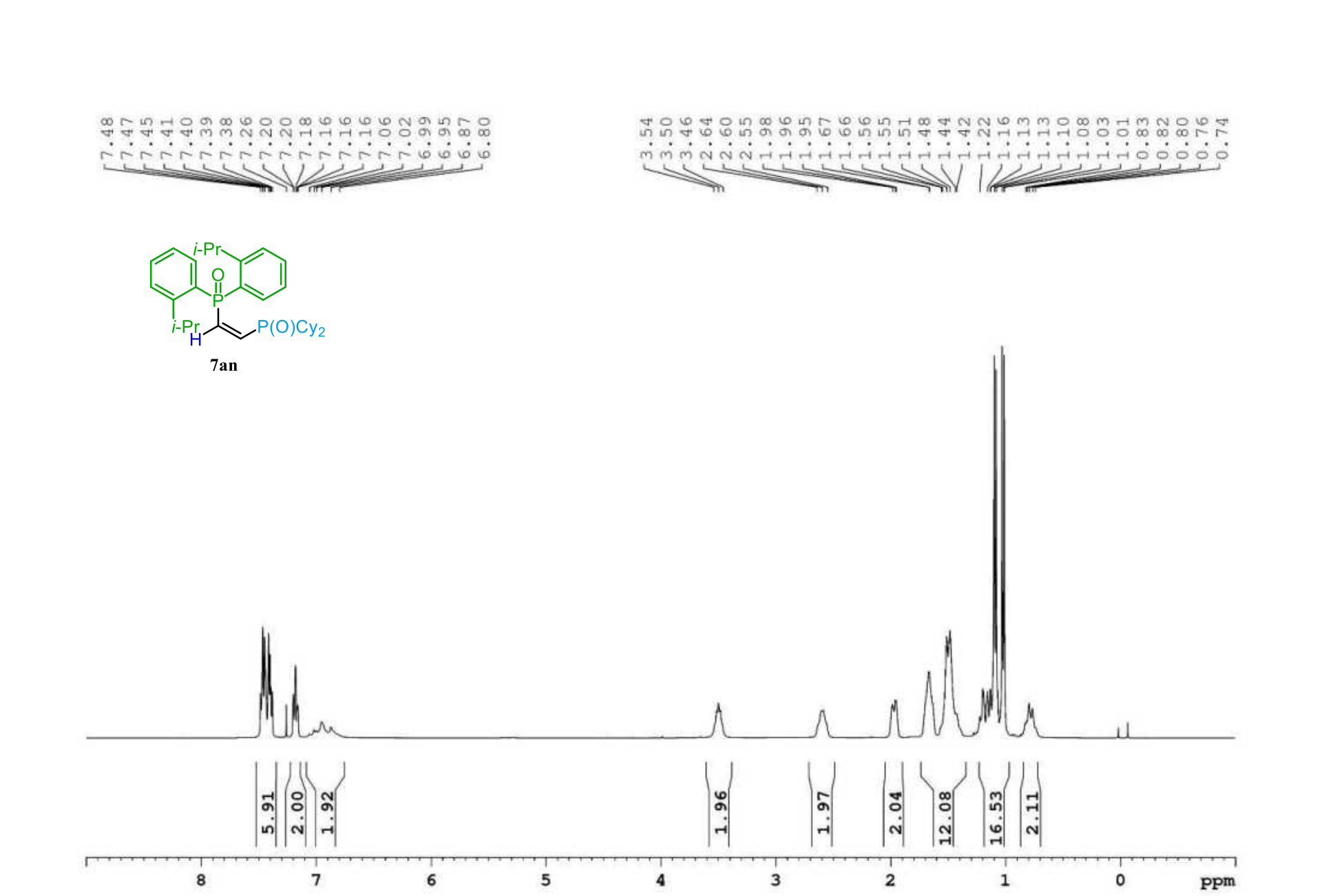
0.98
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm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7.47
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7.39
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7.20
7.18
7.16
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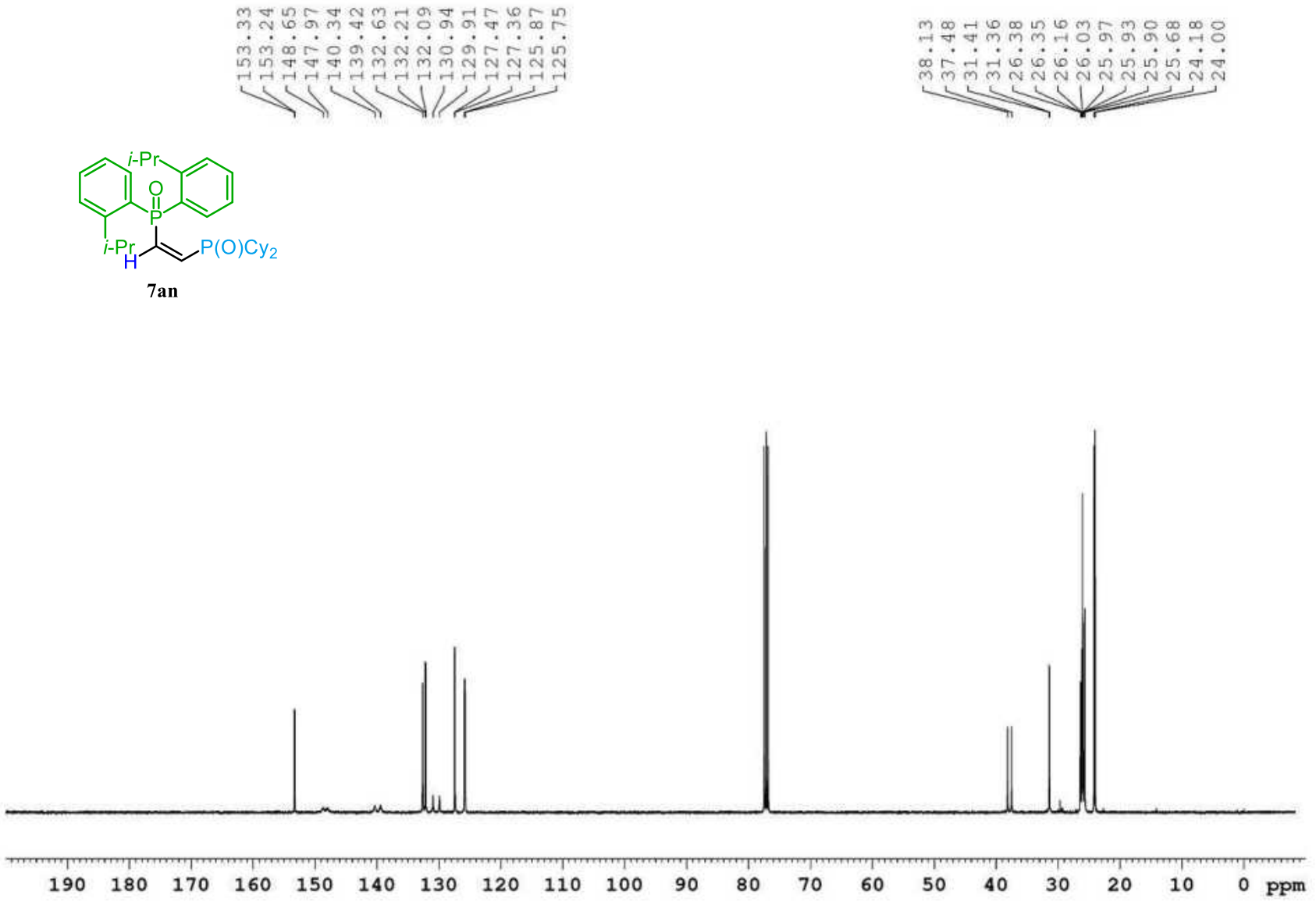
7.16
7.06
7.02
6.99
6.95
6.87
6.80
3.54
3.50
3.46
2.64
2.60
2.55
1.98
1.96
1.95
1.67
1.66
1.56
1.55
1.51
1.48
1.44
1.42
1.22
1.16
1.13
1.13
1.10
1.08
1.03
1.01
0.83
0.82
0.80
0.76
0.74
i-Pr
O
P
i-Pr
H
P(O)Cy2
7an
5.91
2.00
1.92
1.96
1.97
2.04
12.08
16.53
2.11
8
7
6
5
4
3
2
1
0
ppm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153.24
148.65
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140.34
139.42
132.63
132.21
132.09
130.94
129.91
127.47
127.36
125.87
125.75
38.13
37.48
31.41
31.36
26.38
26.35
26.16
26.03
25.97
25.93
25.90
25.68
24.18
24.00
i-Pr
O
P
i-Pr
H
P(O)Cy2
7an
190
180
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160
150
140
130
120
110
100
90
80
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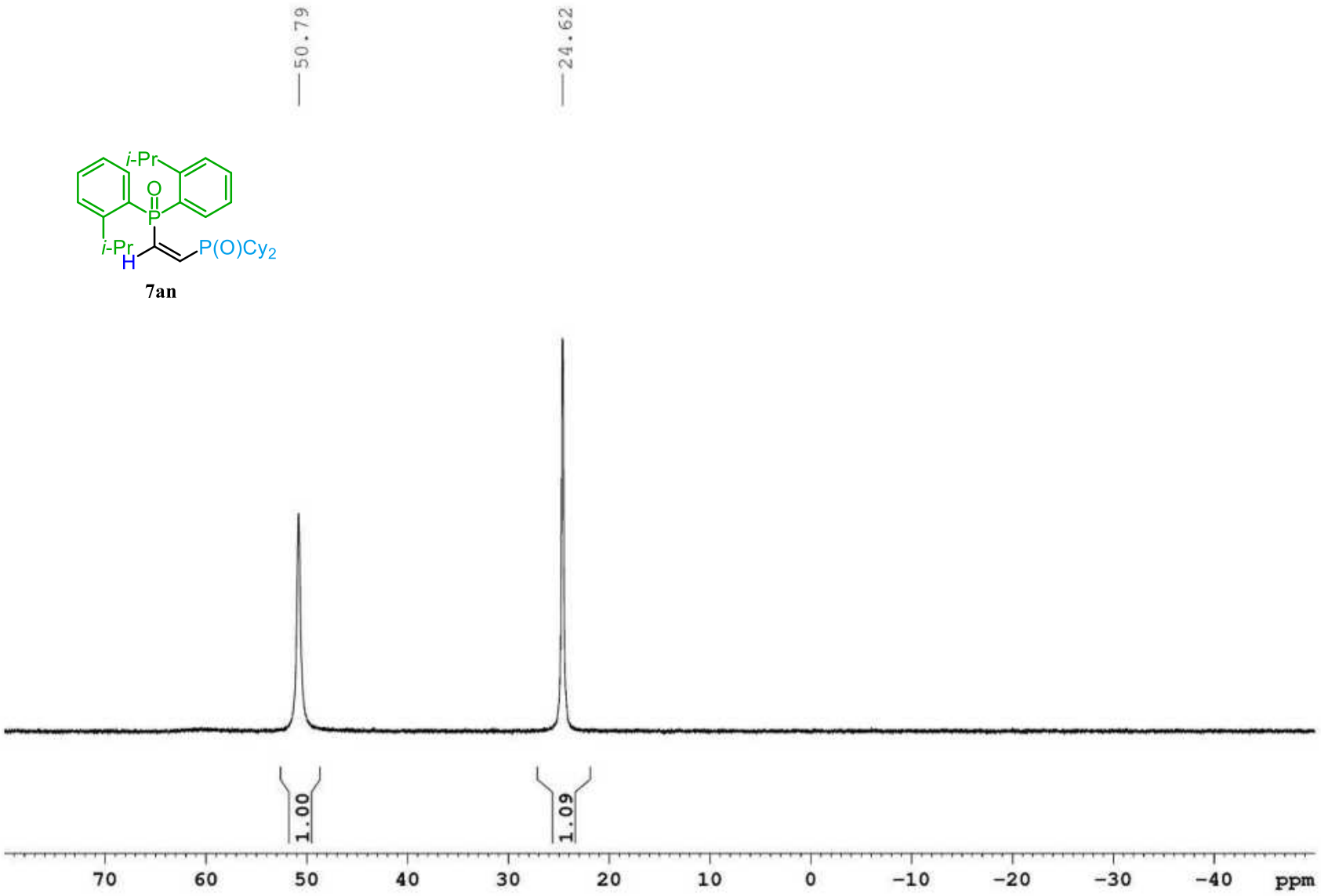
ppm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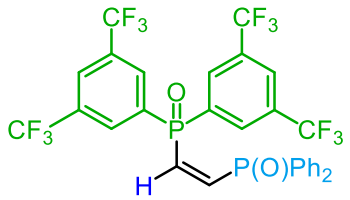
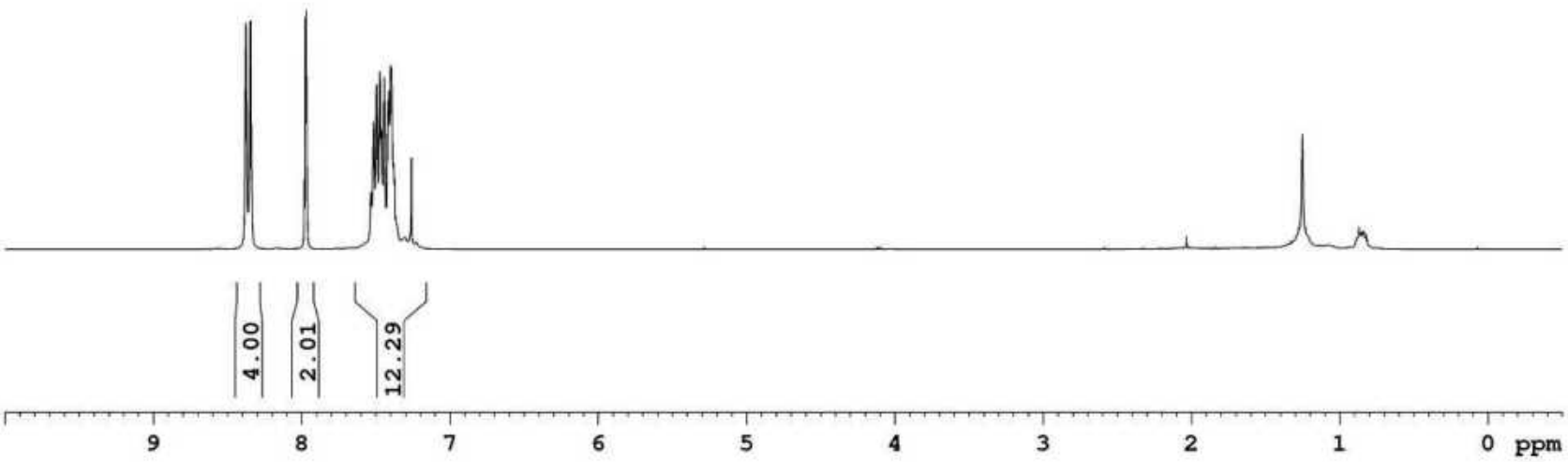
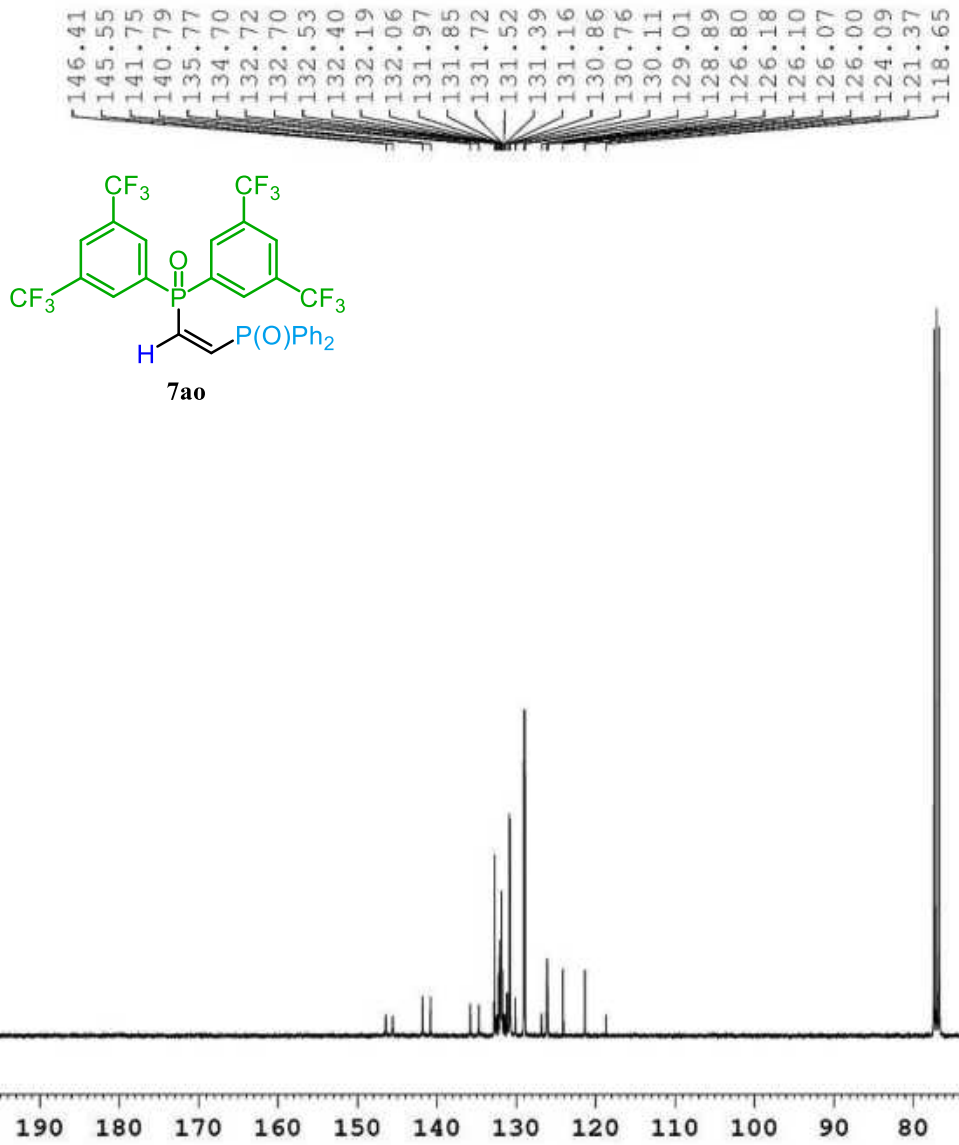
24.62
i-Pr
O
P
i-Pr
H
P(O)Cy2
7an
1.00
1.09
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm


8.37
8.34
7.97
7.53
7.51
7.49
7.47
7.46
7.44
7.41
7.40
7.39
7.38
7.26
7.23


CF3
CF3
CF3
CF3
O
P
H
P(O)Ph2

7ao


4.00
2.01
12.29
9
8
7
6
5
4
3
2
1
0
ppm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145.55
141.75
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135.77
134.70
132.72
132.70
132.53
132.40
132.19
132.06
131.97
131.85
131.72
131.52
131.39
131.16
130.86
130.76
130.11
129.01
128.89
126.80
126.18
126.10
126.07
126.00
124.09
121.37
118.65
CF3
CF3
CF3
CF3
O
P
H
P(O)Ph2
190
180
170
160
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130
120
110
100
90
80
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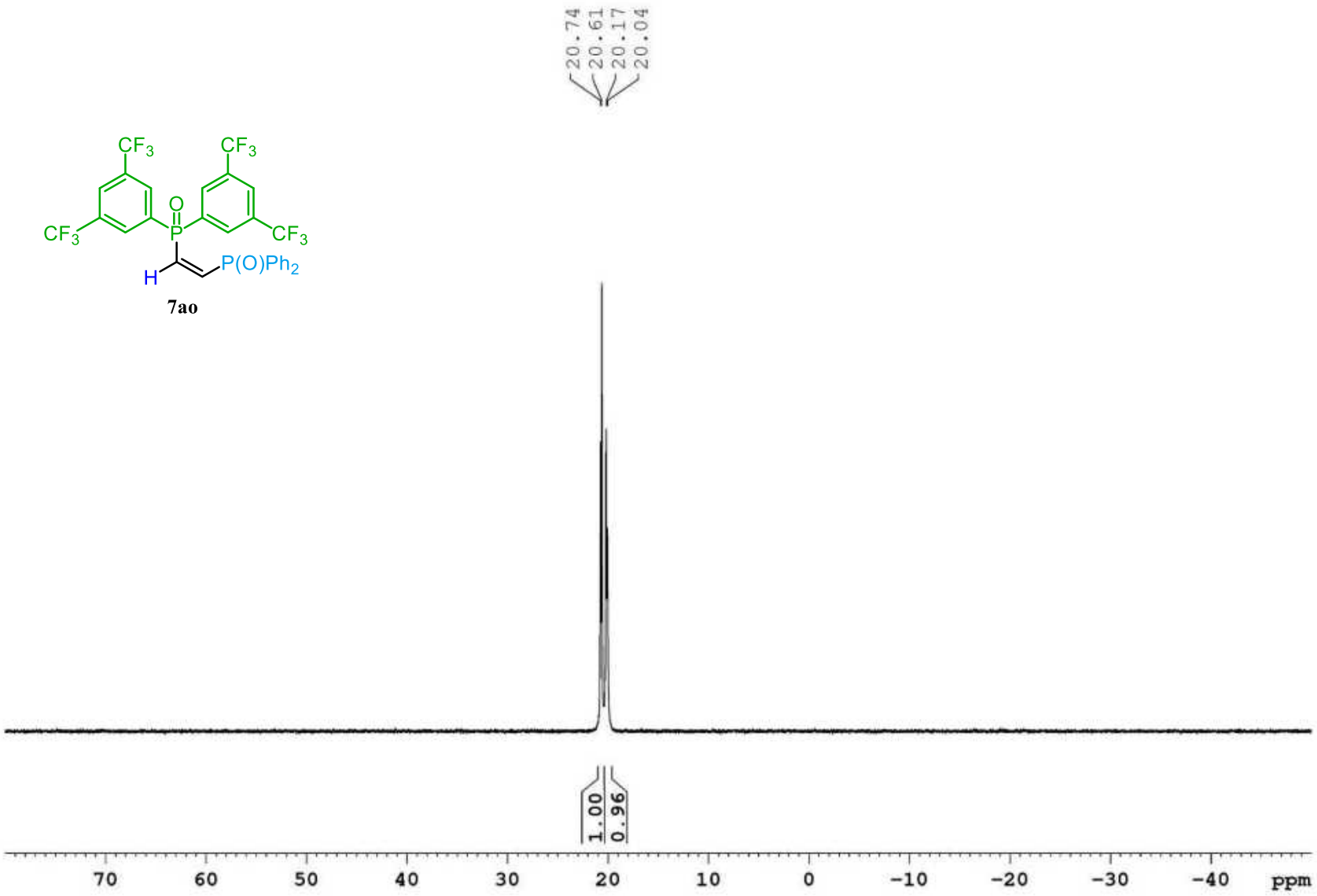
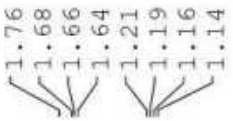
50
40
30
20
10
0
ppm

7ao


20.74
20.61
20.17
20.04
CF3
CF3
CF3
CF3
O
P
H
P(O)Ph2
7ao
1.00
0.96
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm


8.33
8.30
8.01
7.40
7.36
7.35
7.31
7.27
7.26
7.23
7.11
7.07
7.05
7.01
7.00
6.96
6.94
6.90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1.64
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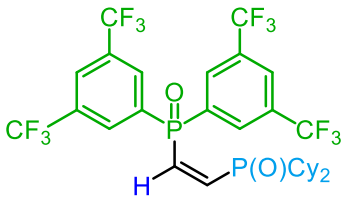
1.19
1.16
1.14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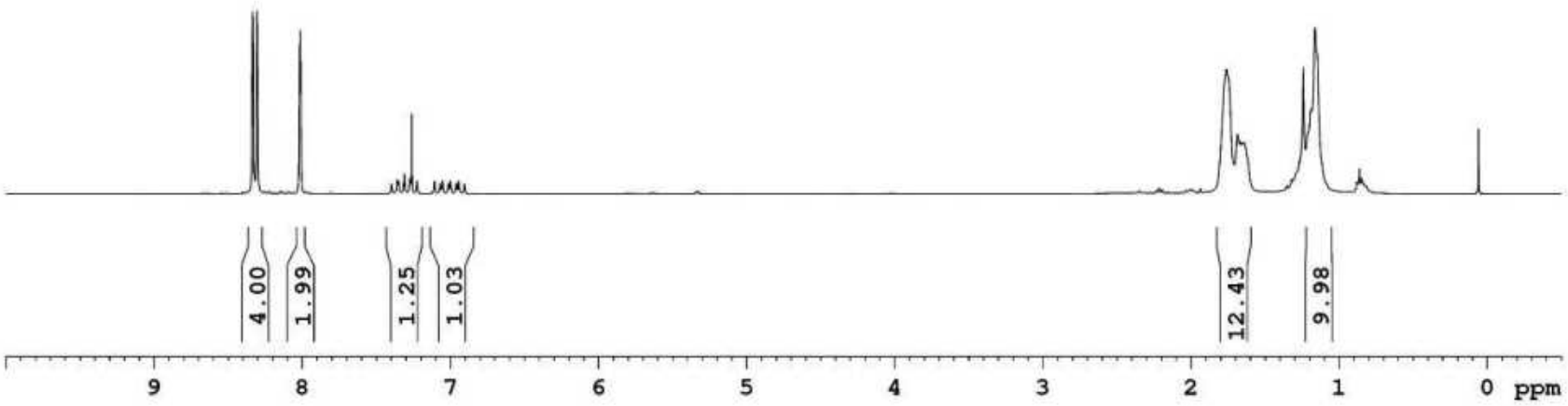
CF3
CF3
CF3
O
P
H
P(O)Cy2

7ap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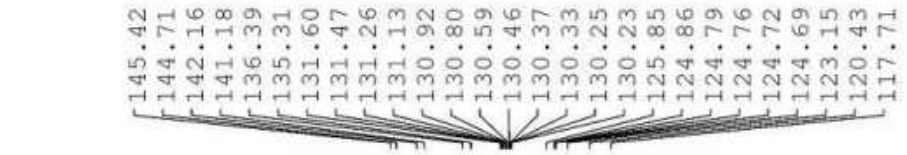
9
8
7
6
5
4
3
2
1
0
ppm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131.60
131.47
131.26
131.13
130.92
130.80
130.59
130.46
130.37
130.33
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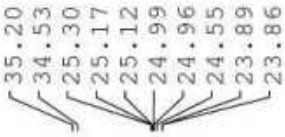
130.23
125.85
124.86
124.79
124.76
124.72
124.69
123.15
120.43
117.71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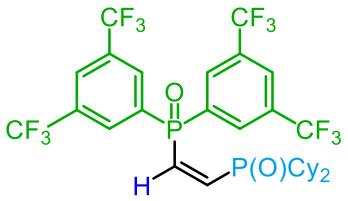
24.55
23.89
23.86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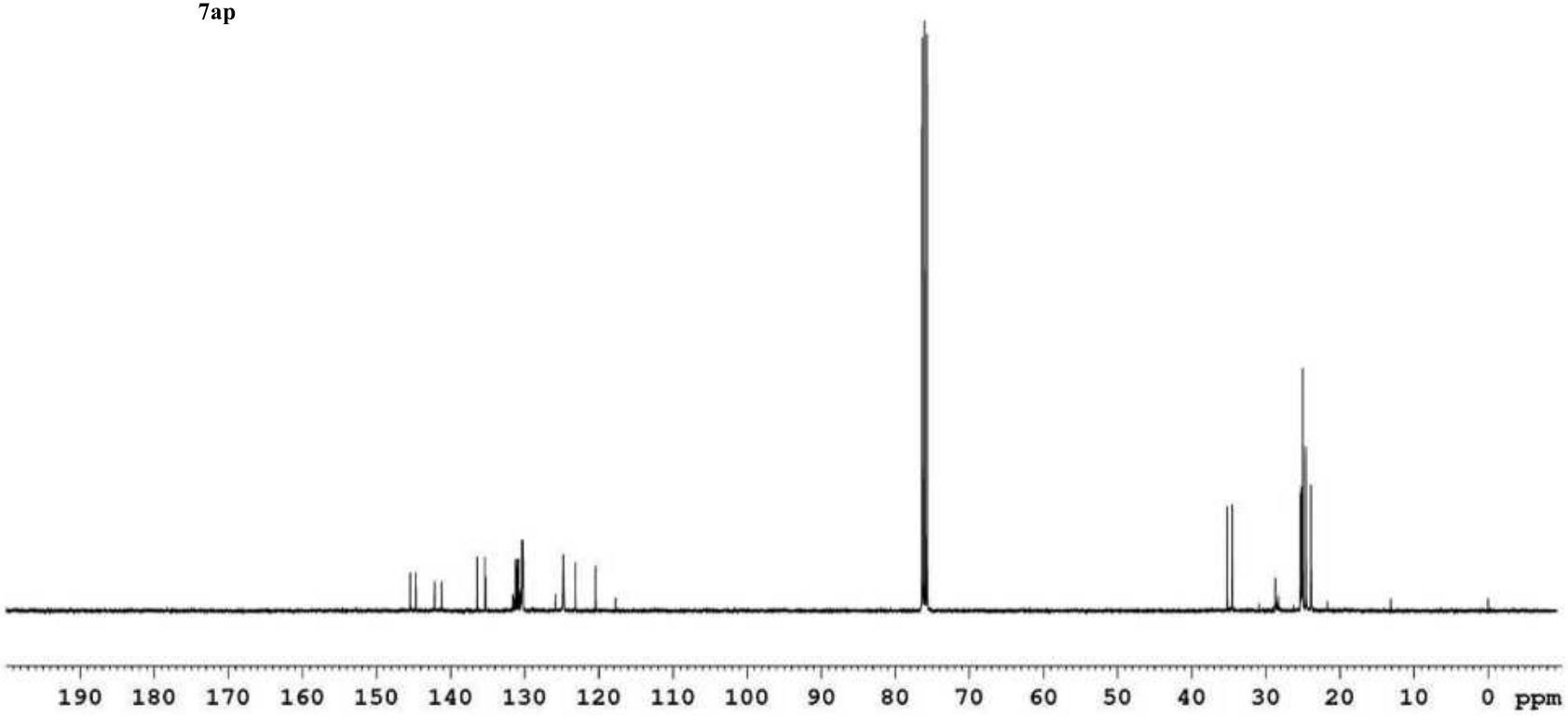
CF3
CF3
CF3
O
P
H
P(O)Cy2

7ap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120
110
100
90
80
70
60
50
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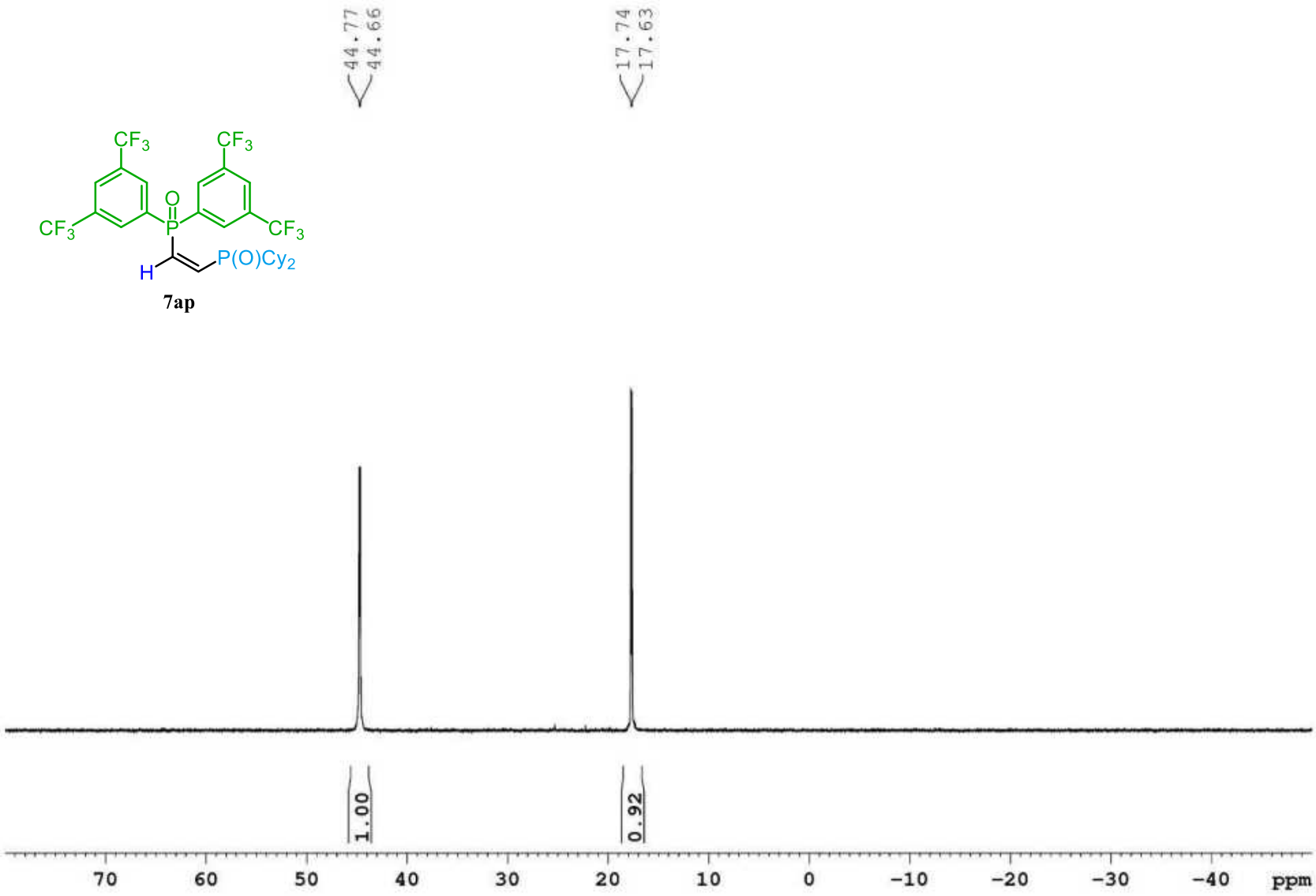
30
20
10
0
ppm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44.66
17.74
17.63
CF3
CF3
CF3
CF3
O
P
H
P(O)Cy2
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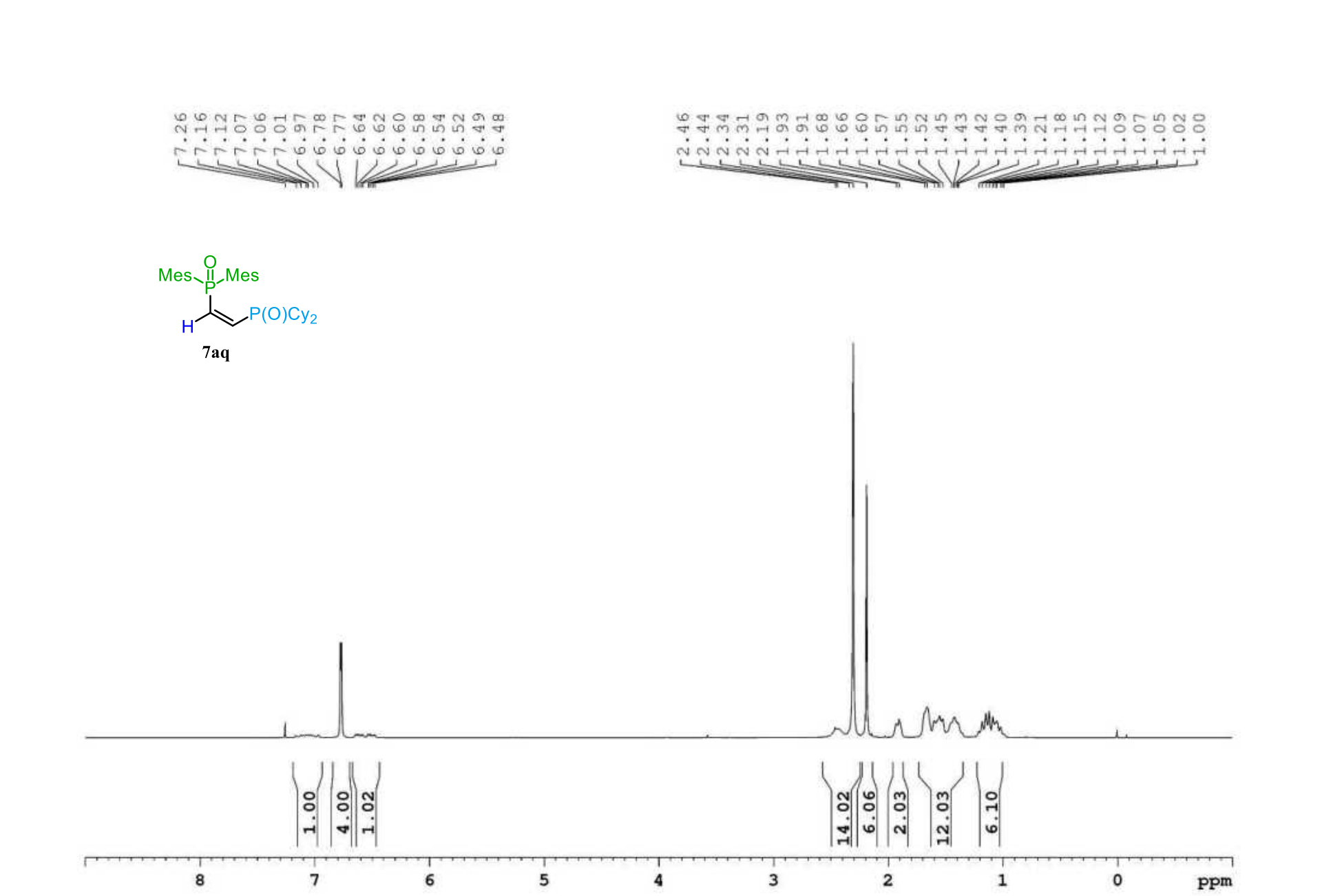
50
40
30
20
10
0
-10
-20
-30
-40
ppm

7ap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6.78
6.77
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6.62
6.60
6.58
6.54
6.52
6.49
6.48
2.46
2.44
2.34
2.31
2.19
1.93
1.91
1.68
1.66
1.60
1.57
1.55
1.52
1.45
1.43
1.42
1.40
1.39
1.21
1.18
1.15
1.12
1.09
1.07
1.05
1.02
1.00
Mes
O
P
Mes
H
P(O)Cy2
7aq
1.00
4.00
1.02
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6.06
2.03
12.03
6.10
8
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6
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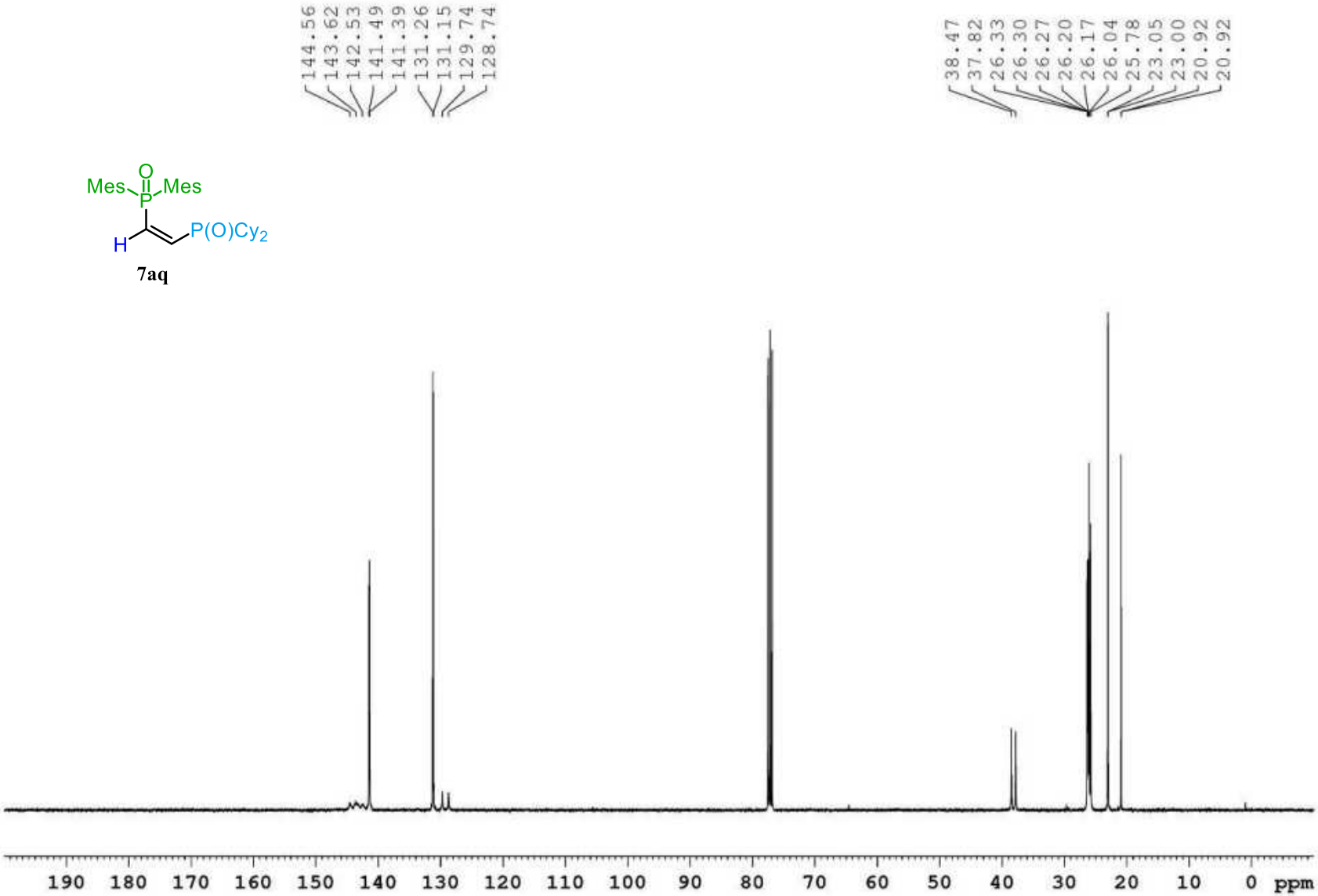
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142.53
141.49
141.39
131.26
131.15
129.74
128.74
38.47
37.82
26.33
26.30
26.27
26.20
26.17
26.04
25.78
23.05
23.00
20.92
20.92
O
Mes
P
Mes
H
P(O)Cy2
190
180
170
160
150
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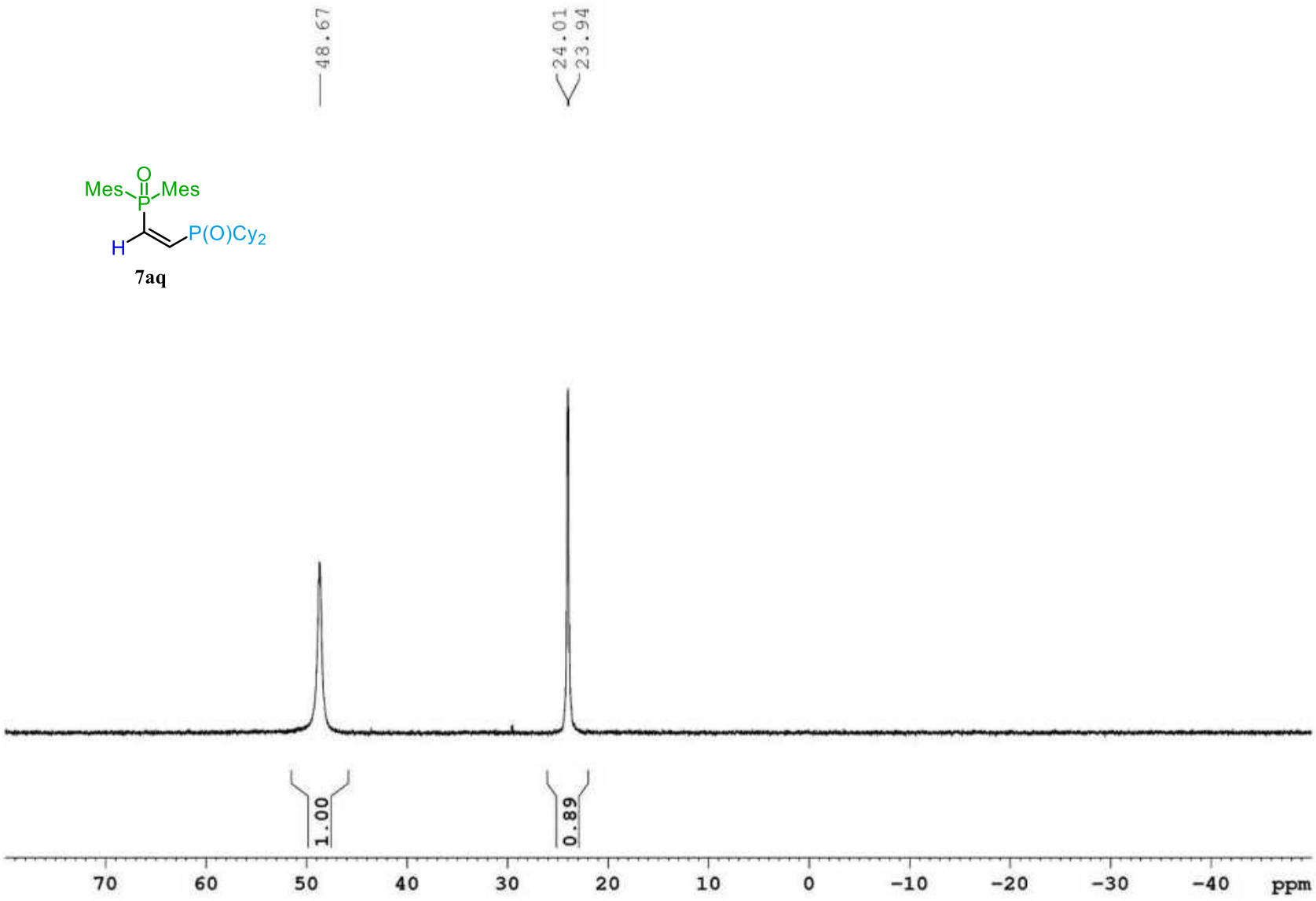
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

7aq


48.67
24.01
23.94
Mes
O
P
Mes
H
P(O)Cy2
7aq
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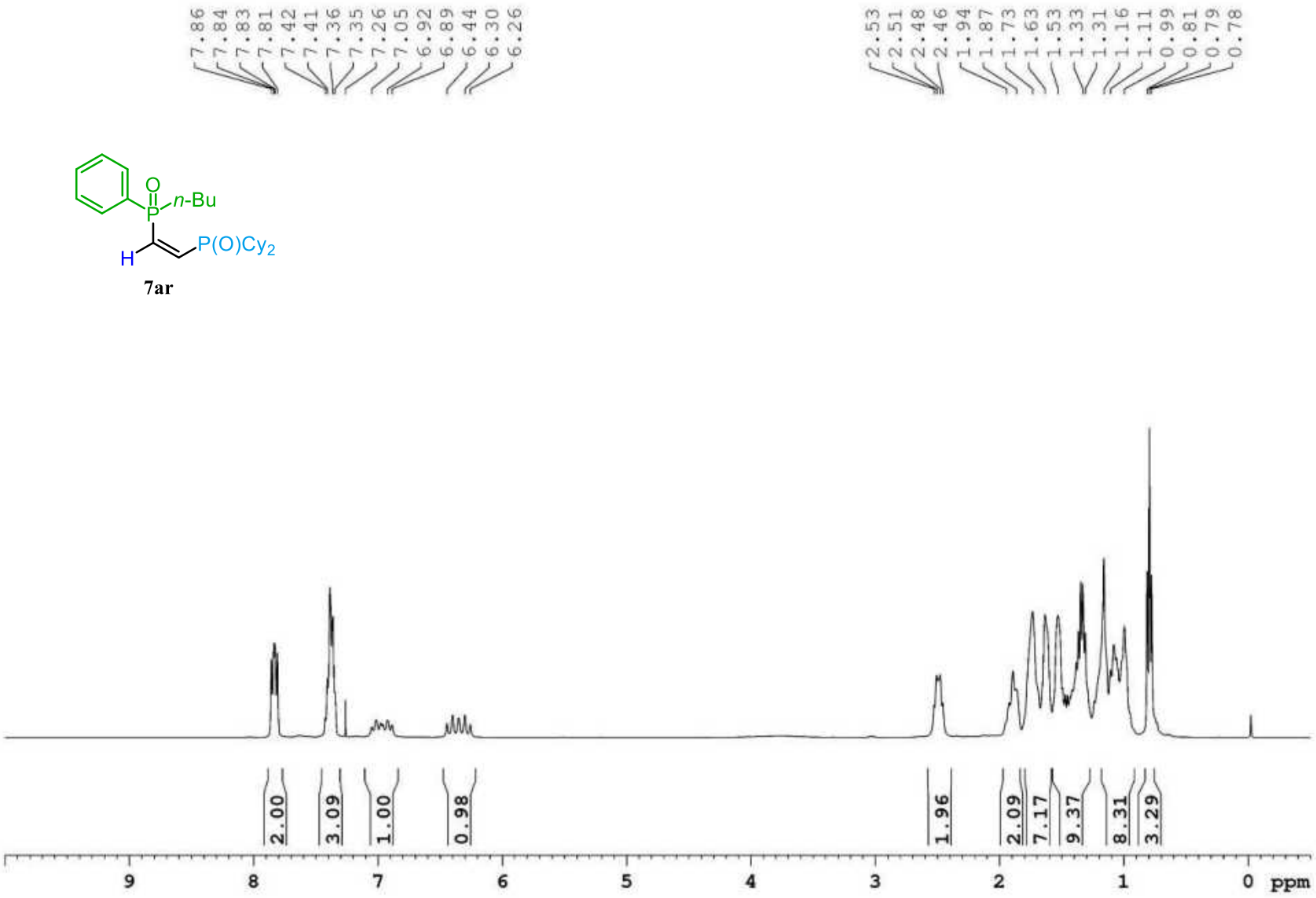
0.89
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm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7.41
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7.35
7.26
7.05
6.92
6.89
6.44
6.30
6.26
2.53
2.51
2.48
2.46
1.94
1.87
1.73
1.63
1.53
1.33
1.31
1.16
1.11
0.99
0.81
0.79
0.78
O
P
n-Bu
H
P(O)Cy2
7ar
2.00
3.09
1.00
0.98
1.96
2.09
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9.37
8.31
3.29
9
8
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6
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3
2
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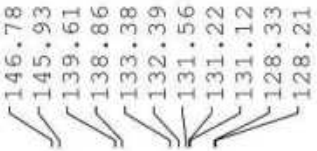
0
ppm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132.39
131.56
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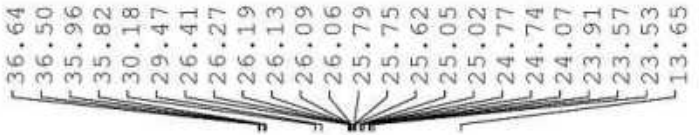
131.12
128.33
128.21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35.82
30.18
29.47
26.41
26.27
26.19
26.13
26.09
26.06
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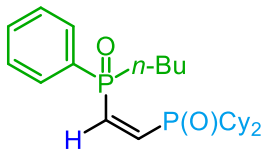
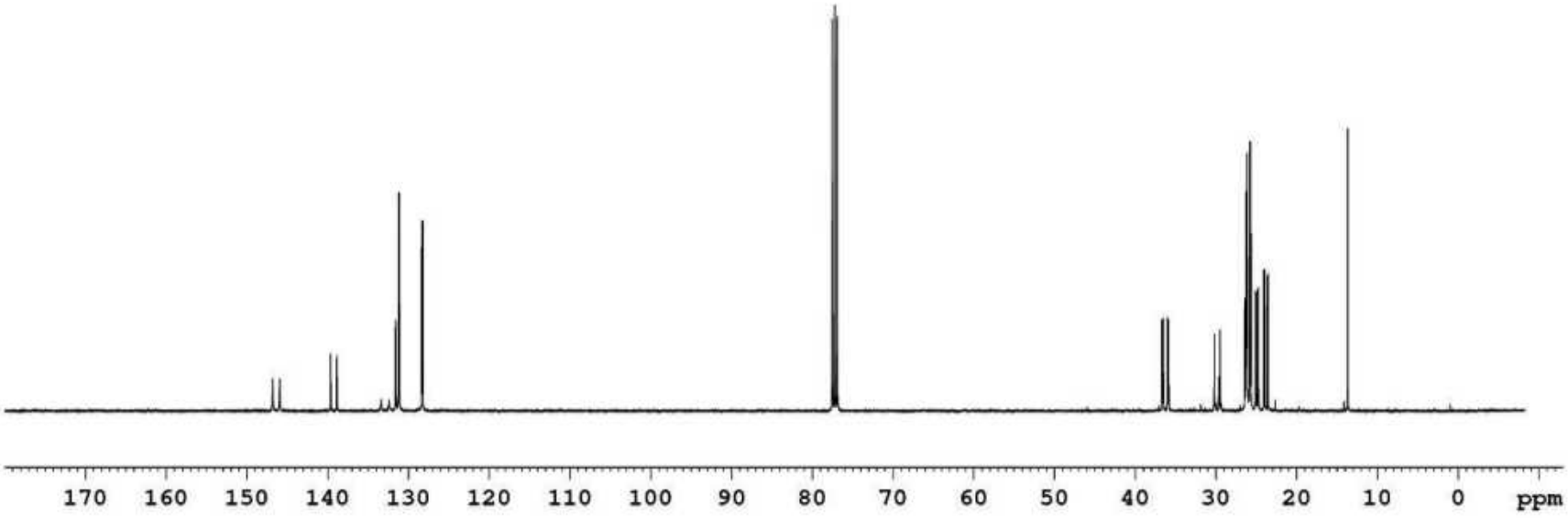
25.75
25.62
25.05
25.02
24.77
24.74
24.07
23.91
23.57
23.53
13.65


O
P
n-Bu
H
P(O)Cy2

7ar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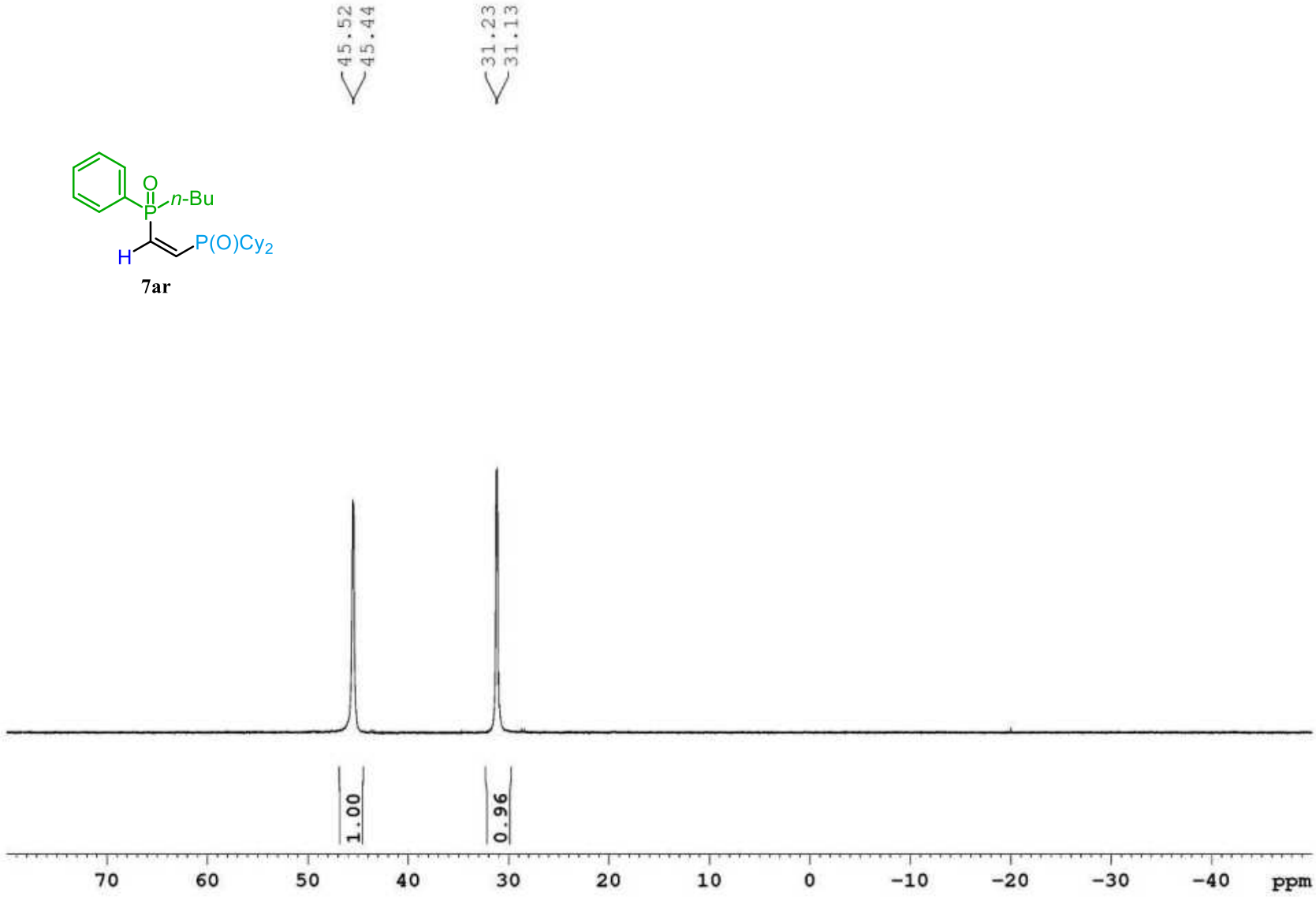
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


45.52
45.44
31.23
31.13
O
P
n-Bu
H
P(O)Cy2
7ar
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0.96
70
60
50
40
30
20
10
0
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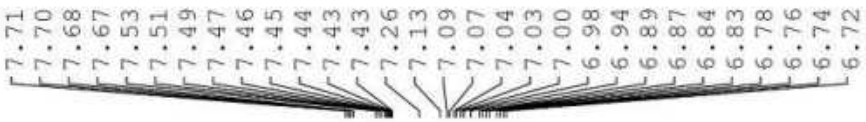
-20
-30
-40
ppm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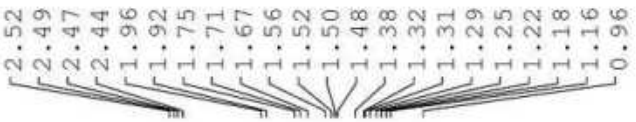
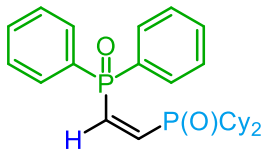
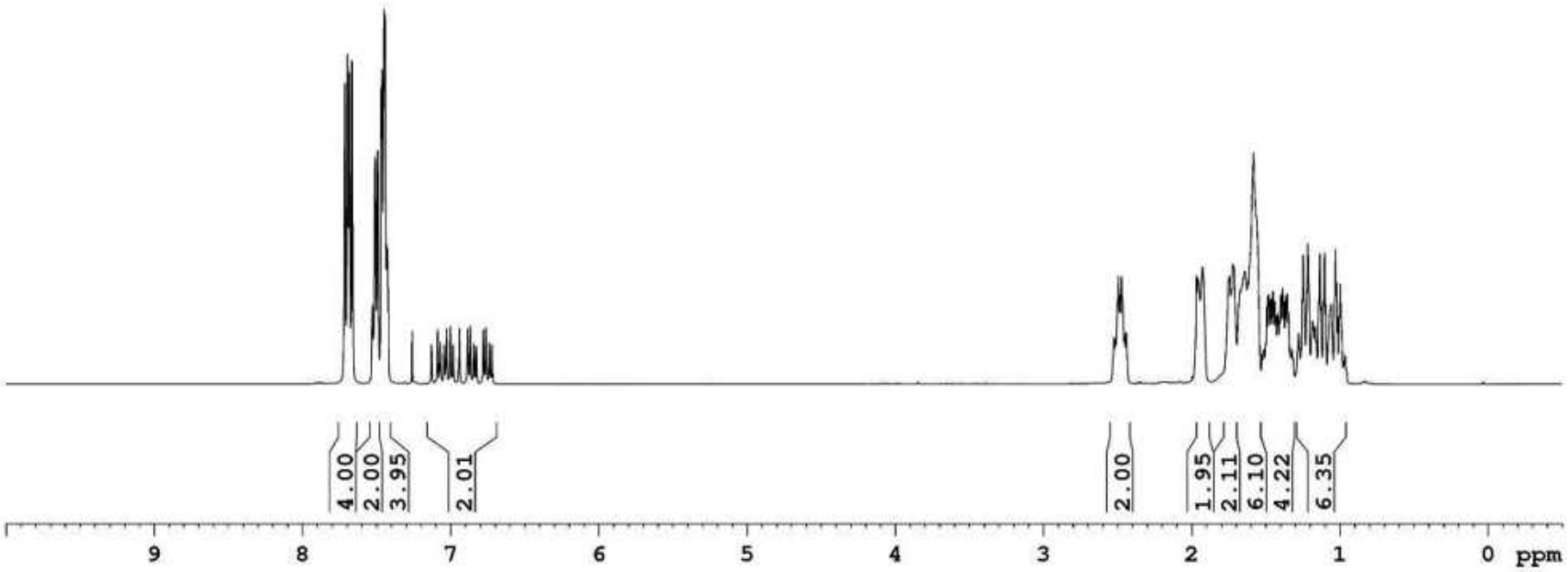
7.70
7.68
7.67
7.53
7.51
7.49
7.47
7.46
7.45
7.44
7.43
7.43
7.26
7.13
7.09
7.07
7.04
7.03
7.00
6.98
6.94
6.89
6.87
6.84
6.83
6.78
6.76
6.74
6.72


2.52
2.49
2.47
2.44
1.96
1.92
1.75
1.71
1.67
1.56
1.52
1.50
1.48
1.38
1.32
1.31
1.29
1.25
1.22
1.18
1.16
0.96

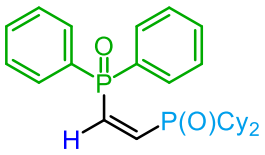

O
P
H
P(O)Cy2

7as


4.00
2.00
3.95
2.01
2.00
1.95
2.11
6.10
4.22
6.35
9
8
7
6
5
4
3
2
1
0
ppm

147.08
146.36
139.33
138.39
133.06
132.19
132.17
132.00
131.07
130.97
128.85
128.73

38.18
37.53
26.45
26.41
26.28
26.15
25.82
25.78
25.77



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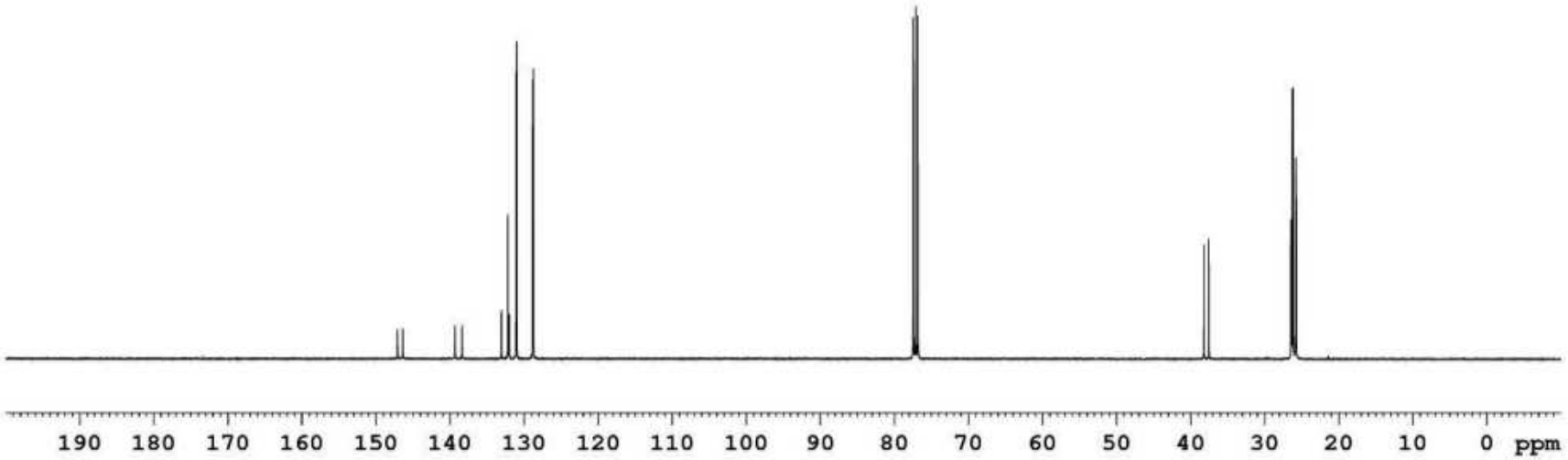
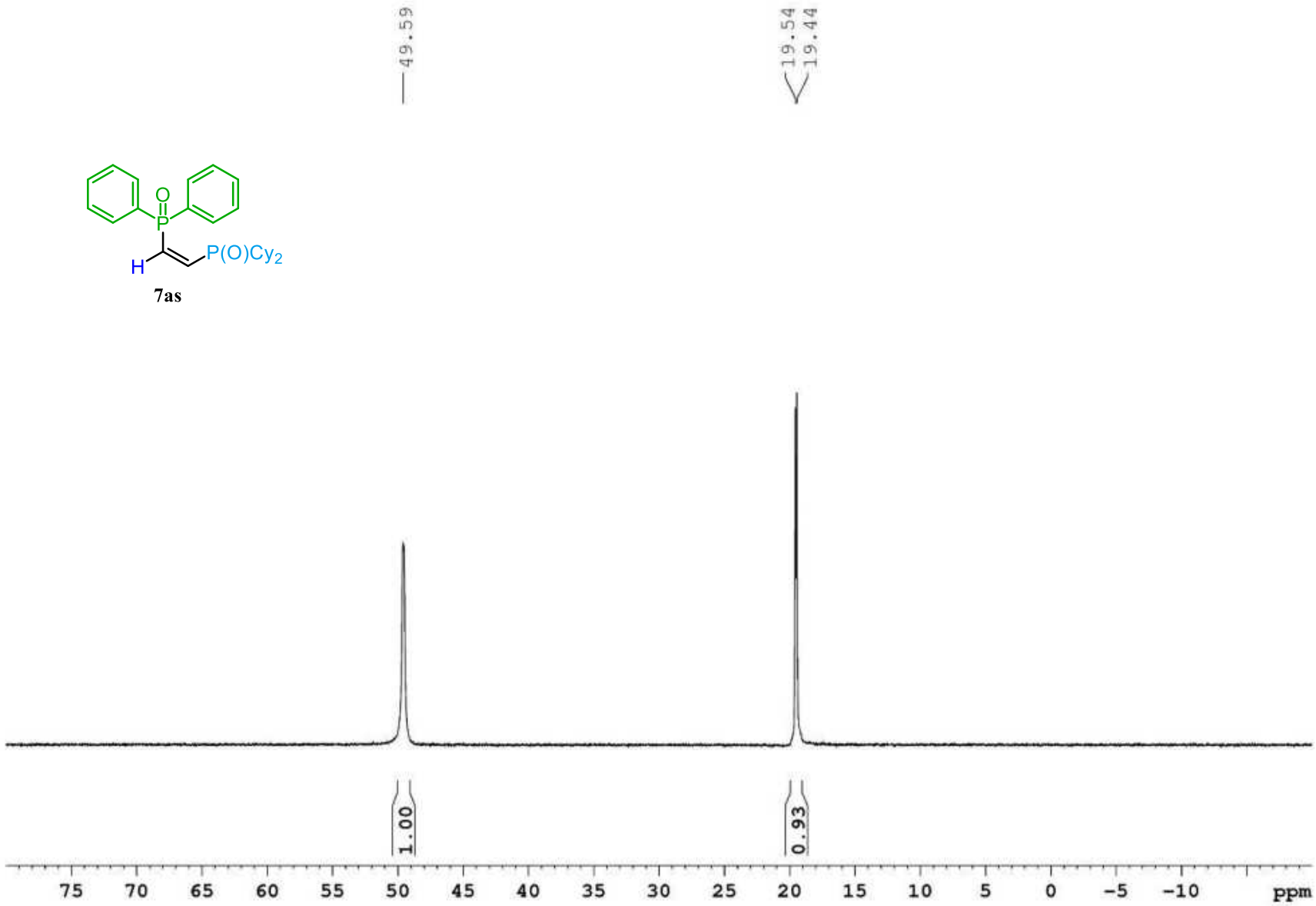
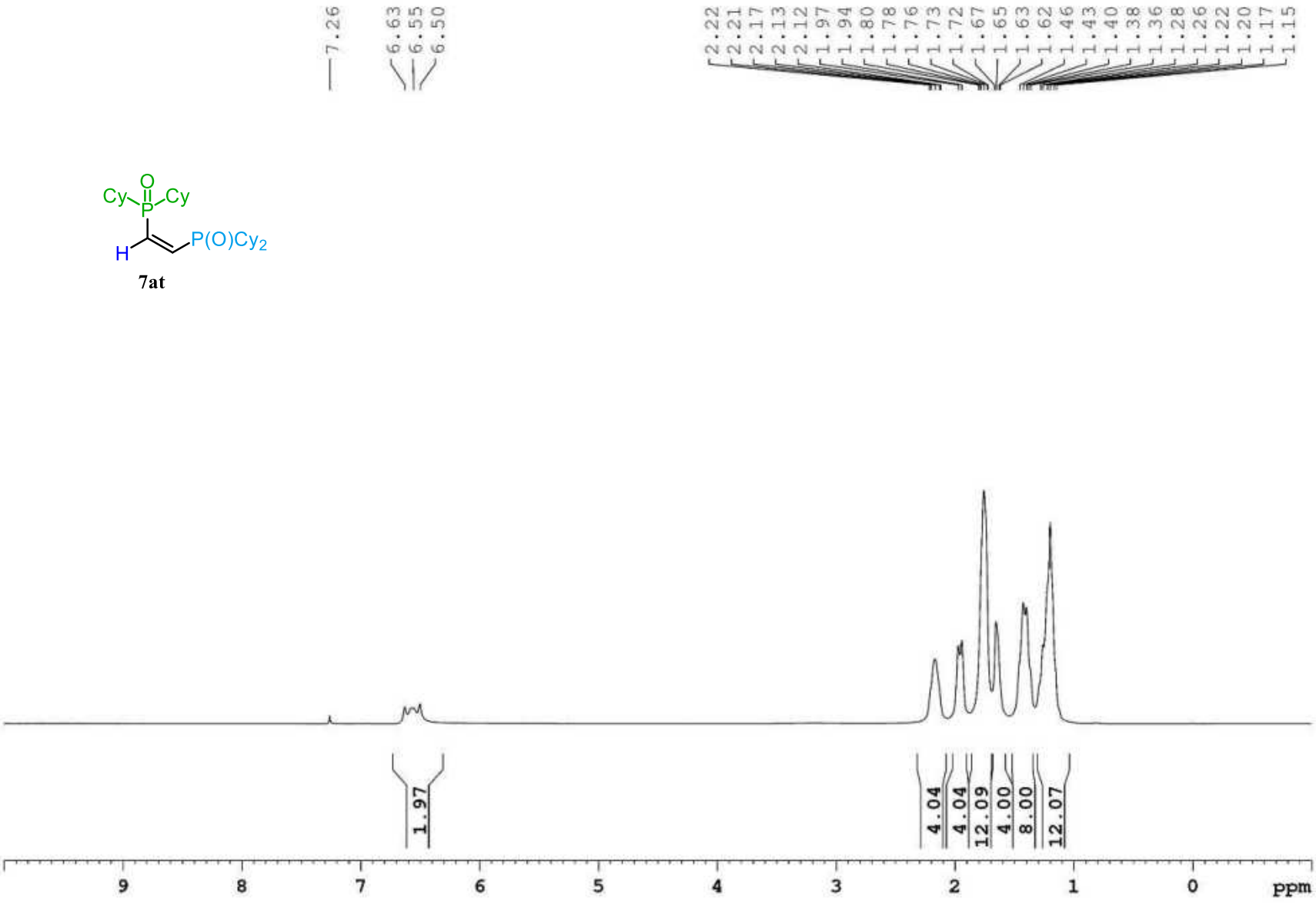


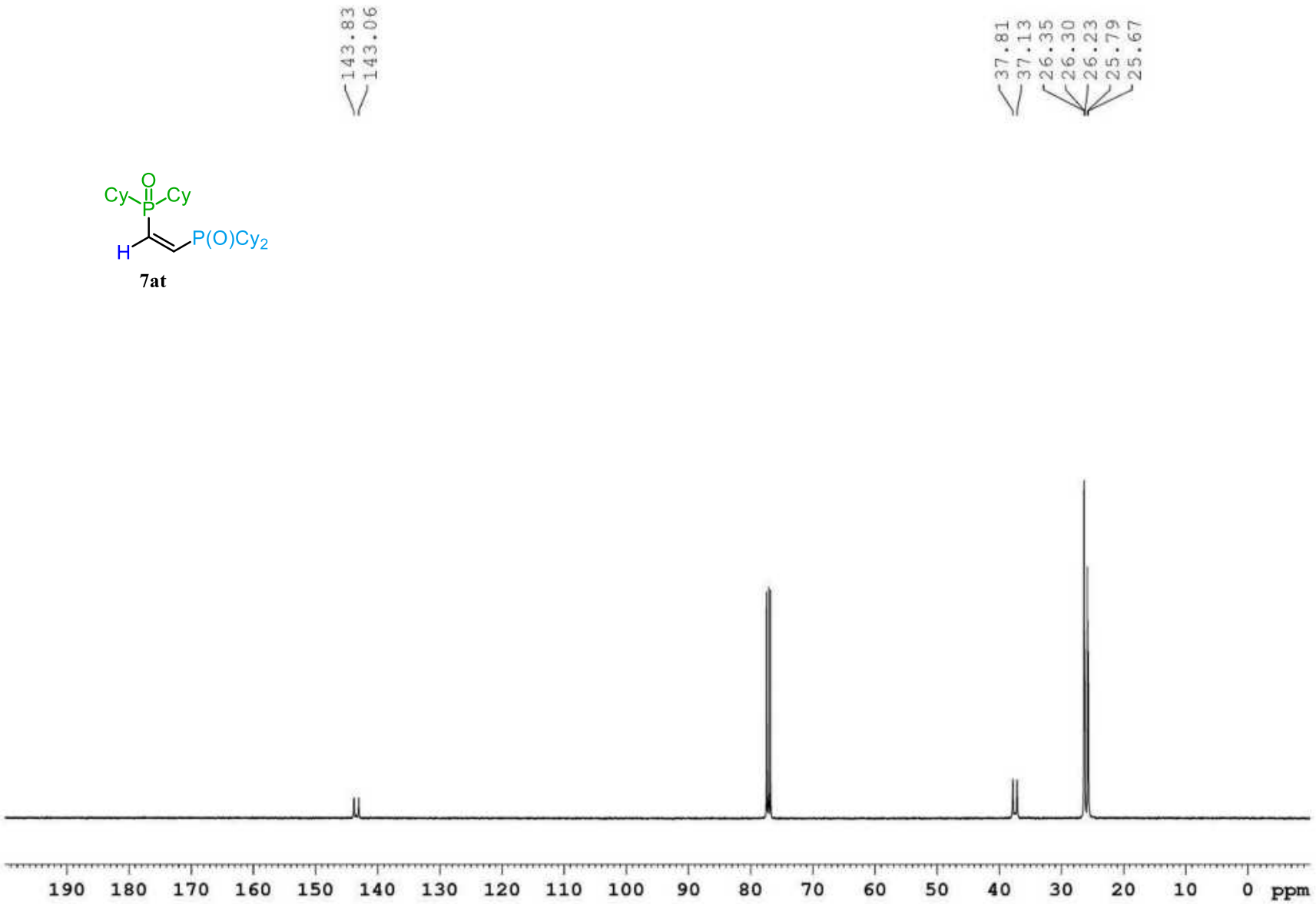

49.59
19.54
19.44
O
P
H
P(O)Cy2
1.00
0.93
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm

7as

Cy
O
Cy
P
H
P(O)Cy2

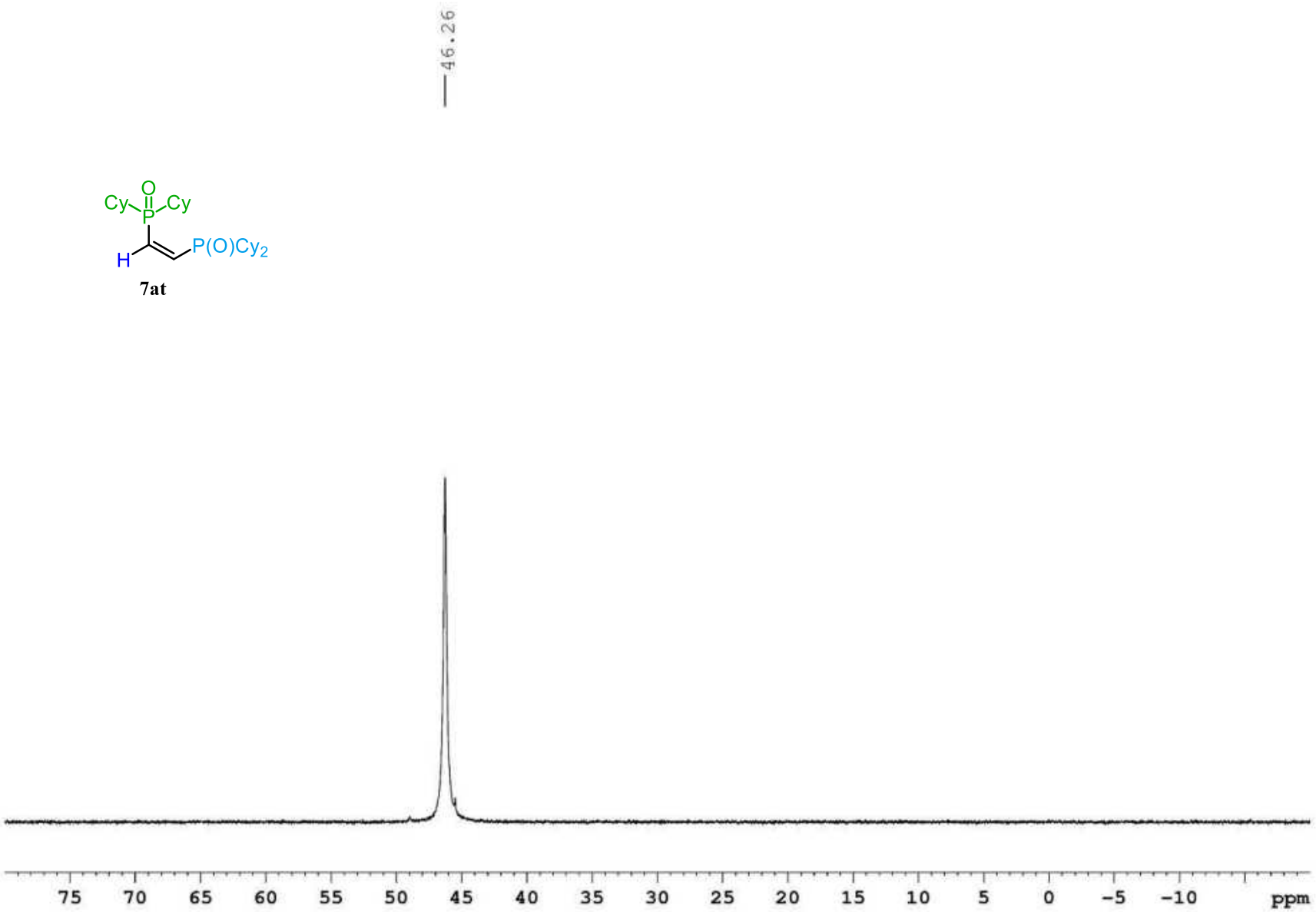
7at


7.26
6.63
6.55
6.50
2.22
2.21
2.17
2.13
2.12
1.97
1.94
1.80
1.78
1.76
1.73
1.72
1.67
1.65
1.63
1.62
1.46
1.43
1.40
1.38
1.36
1.28
1.26
1.22
1.20
1.17
1.15
1.97
4.04
4.04
12.09
4.00
8.00
12.07
9
8
7
6
5
4
3
2
1
0
ppm

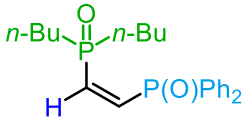

143.83
143.06
37.81
37.13
26.35
26.30
26.23
25.79
25.67
Cy
O
Cy
P
H
P(O)Cy2
7at
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm

O
Cy
Cy
P
H
P(O)Cy2

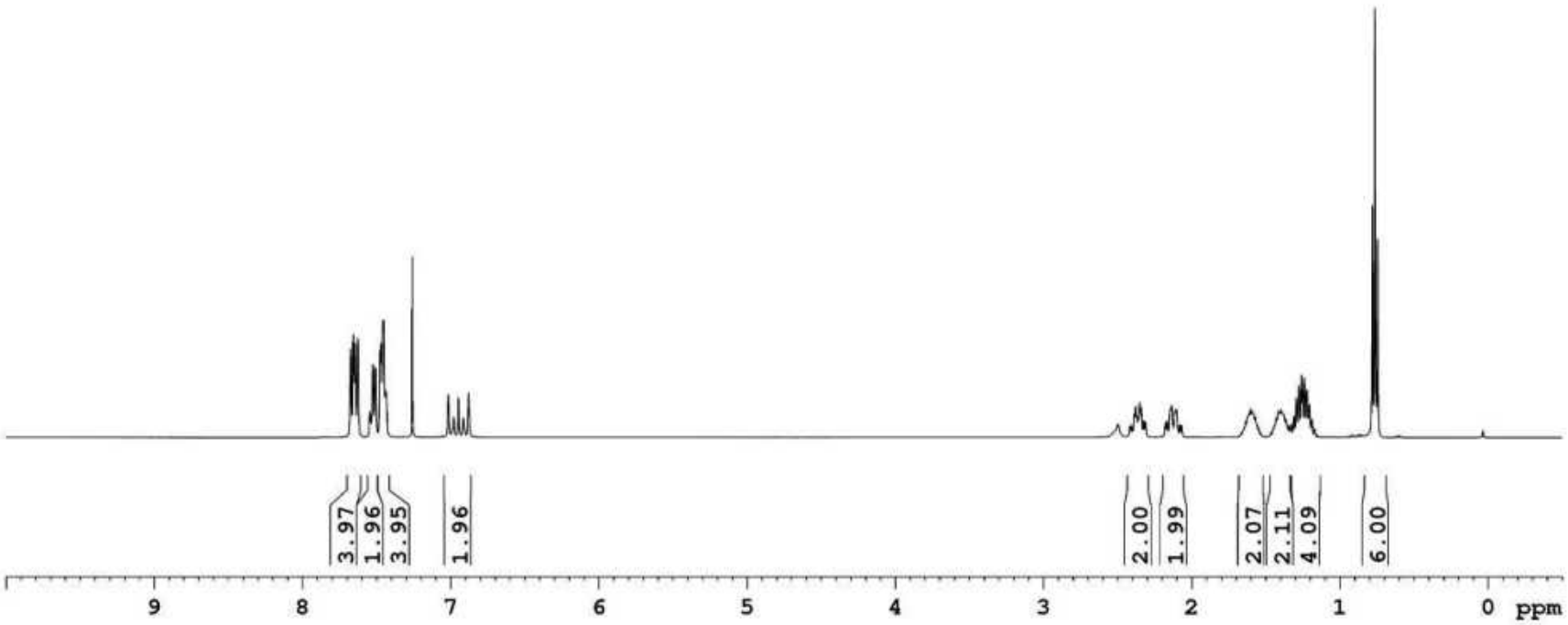
7at

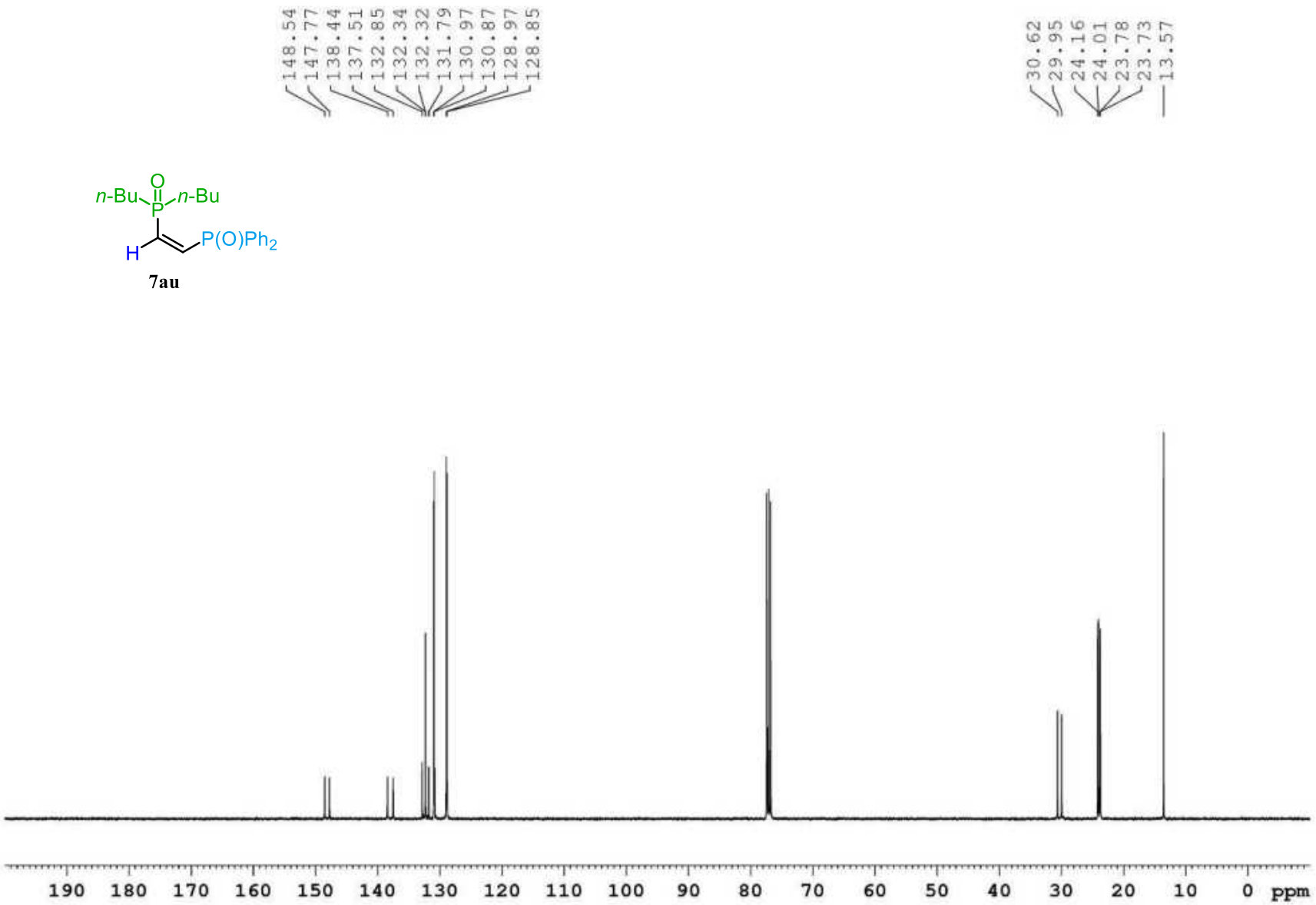

46.26
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm


7.68
7.66
7.65
7.63
7.54
7.52
7.51
7.48
7.47
7.46
7.45
7.44
7.43
7.02
6.98
6.95
6.91
6.88
2.40
2.39
2.38
2.37
2.35
2.34
2.32
2.31
2.18
2.17
2.14
2.14
2.11
2.10
2.08
1.63
1.61
1.60
1.59
1.58
1.57
1.43
1.41
1.41
1.40
1.39
1.38
1.36
1.33
1.31
1.29
1.27
1.26
1.24
1.22
1.20
1.19
0.78
0.76
0.74


n-Bu
O
P
n-Bu
H
P(O)Ph2

7au

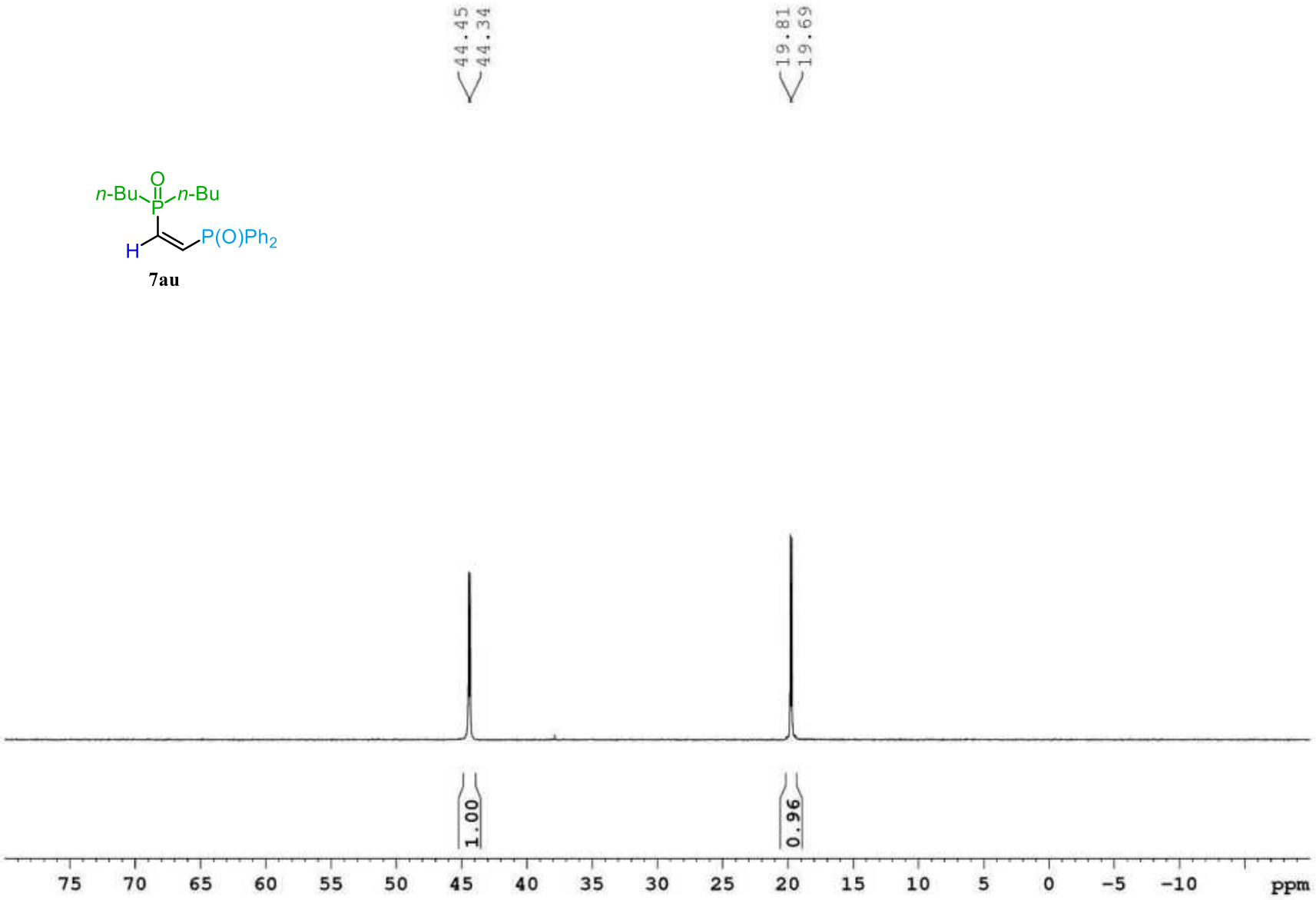

3.97
1.96
3.95
1.96
2.00
1.99
2.07
2.11
4.09
6.00
9
8
7
6
5
4
3
2
1
0
ppm

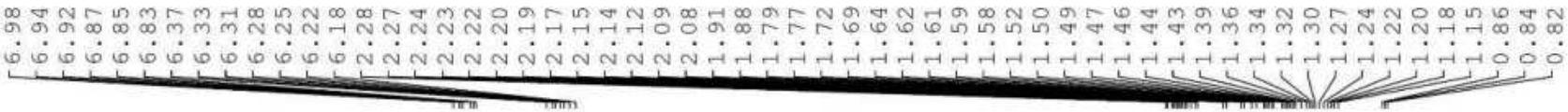

148.54
147.77
138.44
137.51
132.85
132.34
132.32
131.79
130.97
130.87
128.97
128.85
30.62
29.95
24.16
24.01
23.78
23.73
13.57
n-Bu
O
P
n-Bu
H
P(O)Ph2
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

7au

n-Bu
O
P
n-Bu
H
P(O)Ph2

7au


44.45
44.34
19.81
19.69
1.00
0.96
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm


6.98
6.94
6.92
6.87
6.85
6.83
6.37
6.33
6.31
6.28
6.25
6.22
6.18
2.28
2.27
2.24
2.23
2.22
2.20
2.19
2.17
2.15
2.14
2.12
2.09
2.08
1.91
1.88
1.79
1.77
1.72
1.69
1.64
1.62
1.61
1.59
1.58
1.52
1.50
1.49
1.47
1.46
1.44
1.43
1.39
1.36
1.34
1.32
1.30
1.27
1.24
1.22
1.20
1.18
1.15
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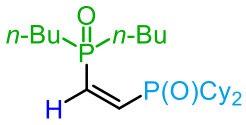
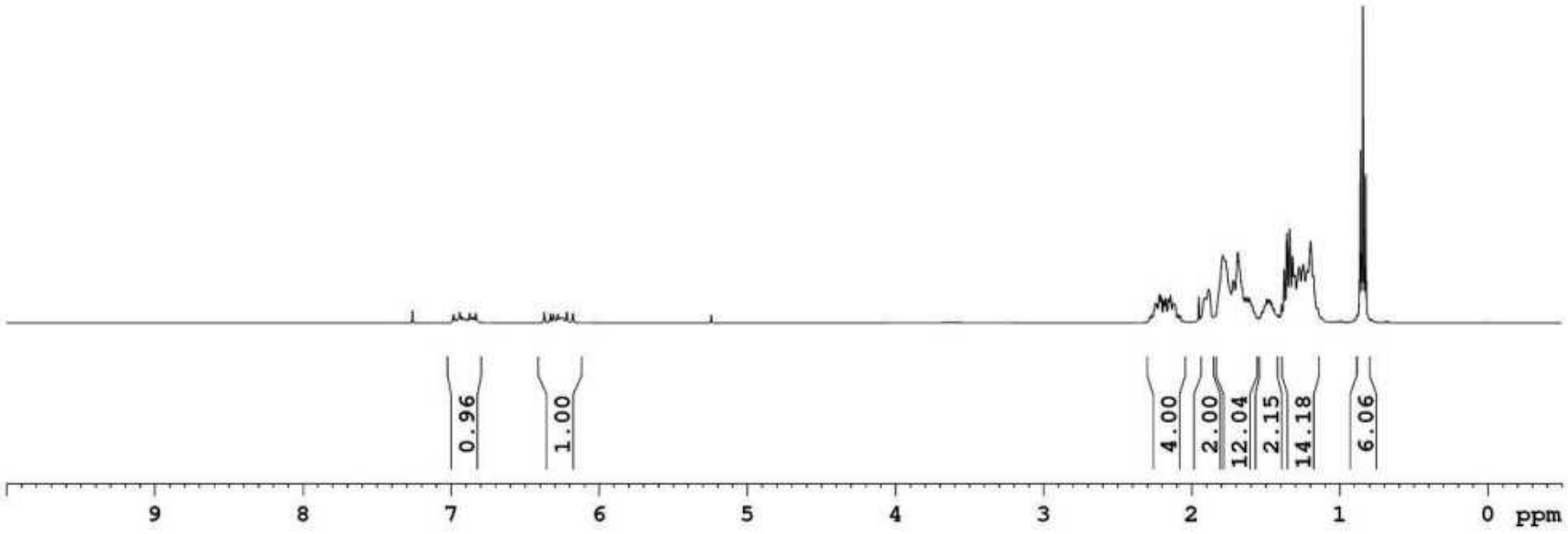
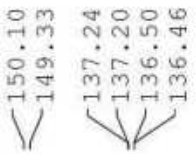
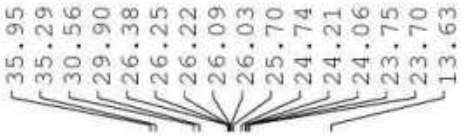
0.84
0.82

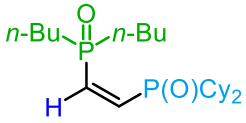

n-Bu
O
P
n-Bu
H
P(O)Cy2

7av

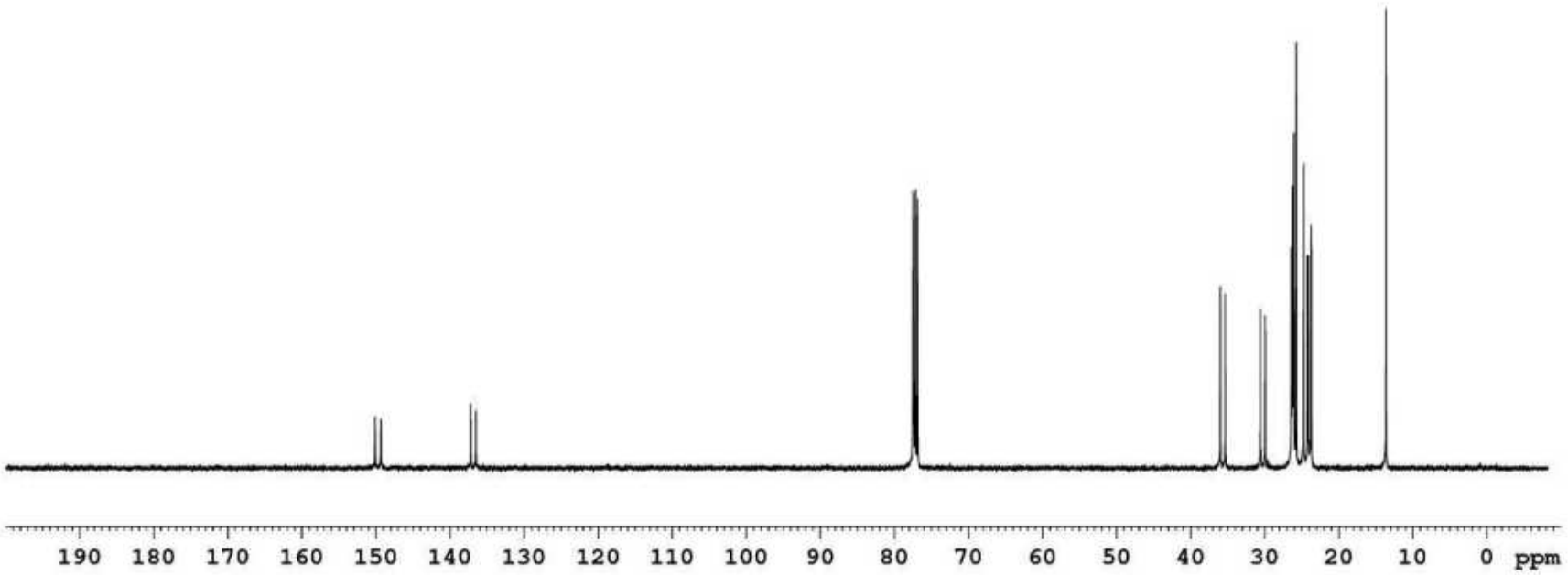

0.96
1.00
4.00
2.00
12.04
2.15
14.18
6.06
9
8
7
6
5
4
3
2
1
0
ppm


150.10
149.33
137.24
137.20
136.50
136.46


35.95
35.29
30.56
29.90
26.38
26.25
26.22
26.09
26.03
25.70
24.74
24.21
24.06
23.75
23.70
13.63


n-Bu
n-Bu
O
P
H
P(O)Cy2

7av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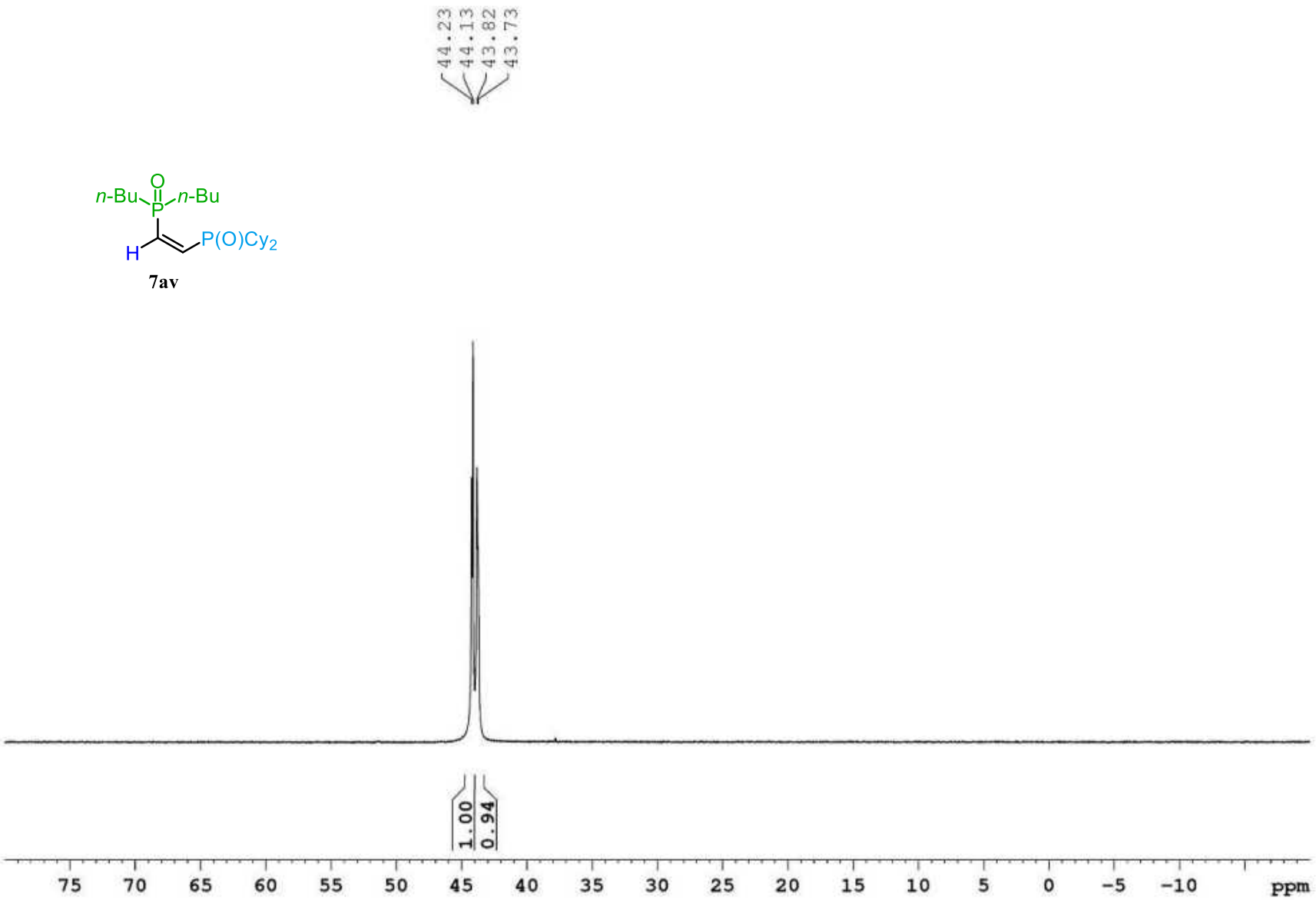
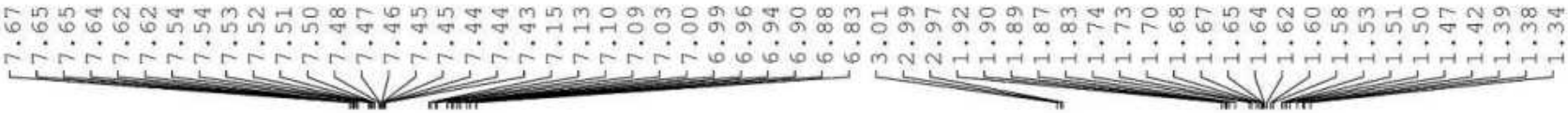
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


44.23
44.13
43.82
43.73
n-Bu
O
P
n-Bu
H
P(O)Cy2
1.00
0.94
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm

7av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7.65
7.65
7.64
7.62
7.62
7.54
7.54
7.53
7.52
7.51
7.50
7.48
7.47
7.46
7.45
7.45
7.44
7.44
7.43
7.15
7.13
7.10
7.09
7.03
7.00
6.99
6.96
6.94
6.90
6.88
6.83
3.01
2.99
2.97
1.92
1.90
1.89
1.87
1.83
1.74
1.73
1.70
1.68
1.67
1.65
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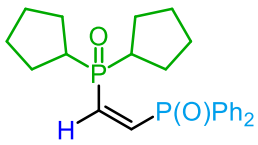
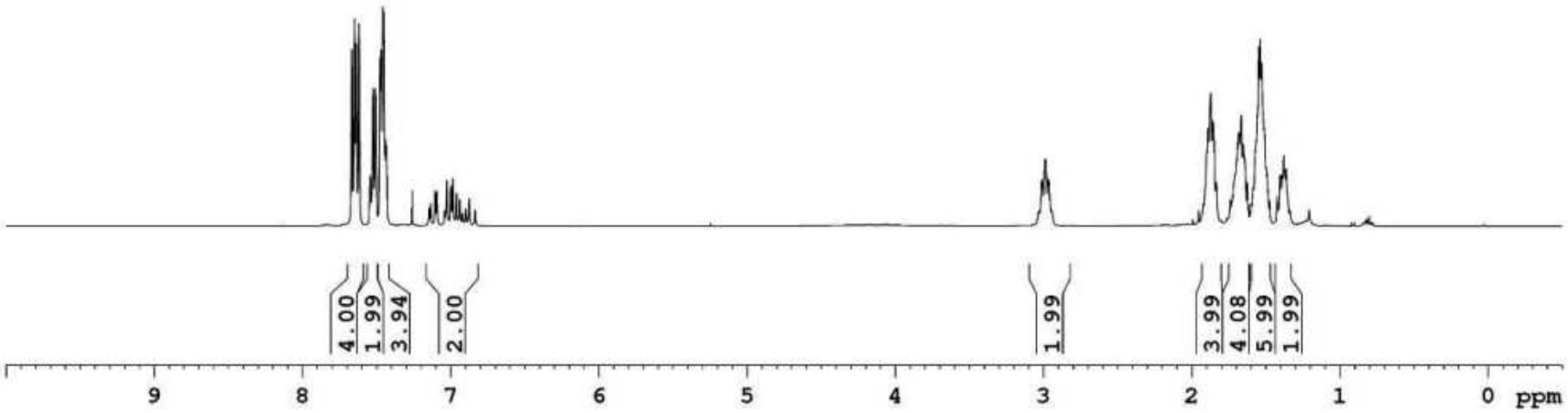
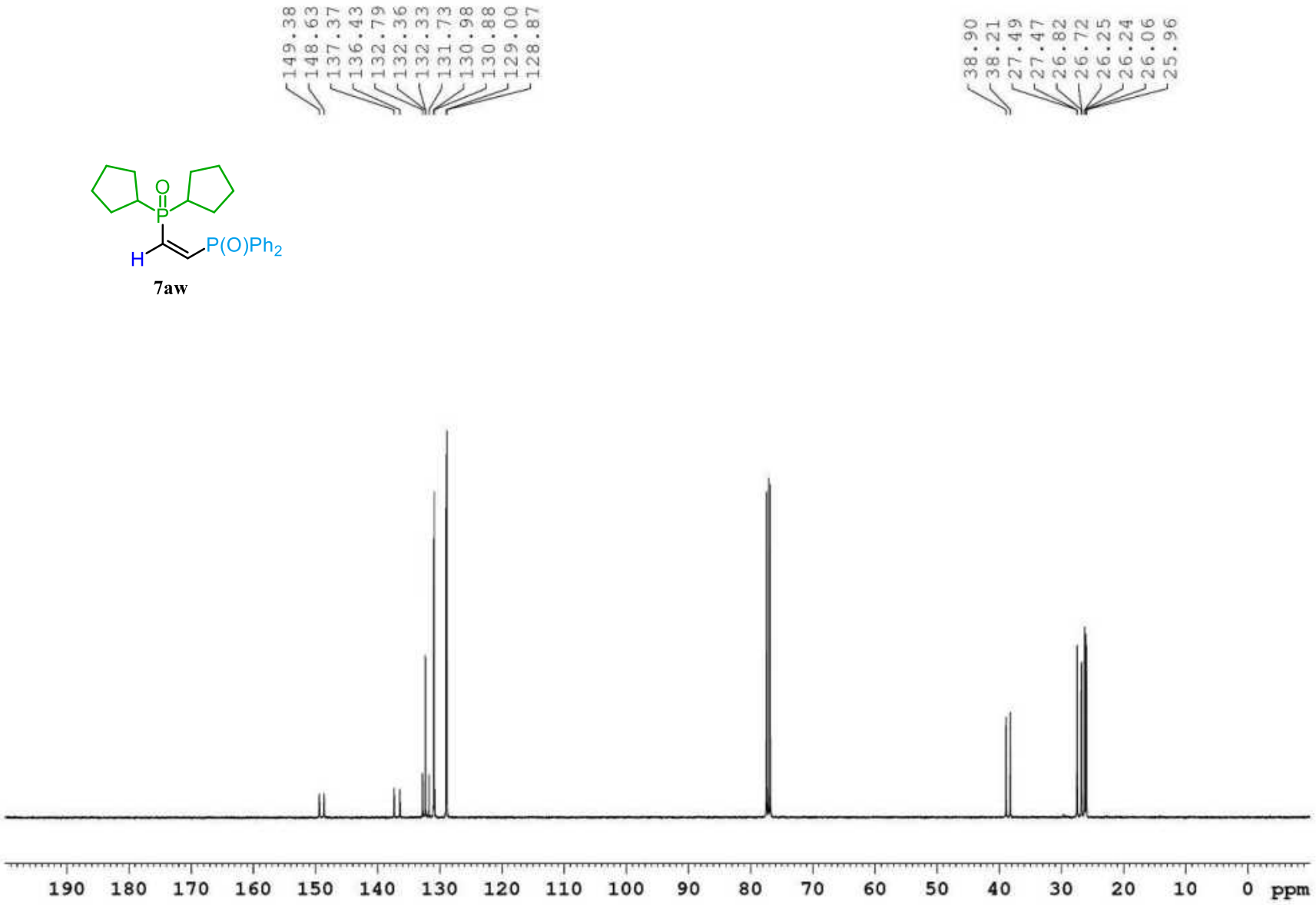
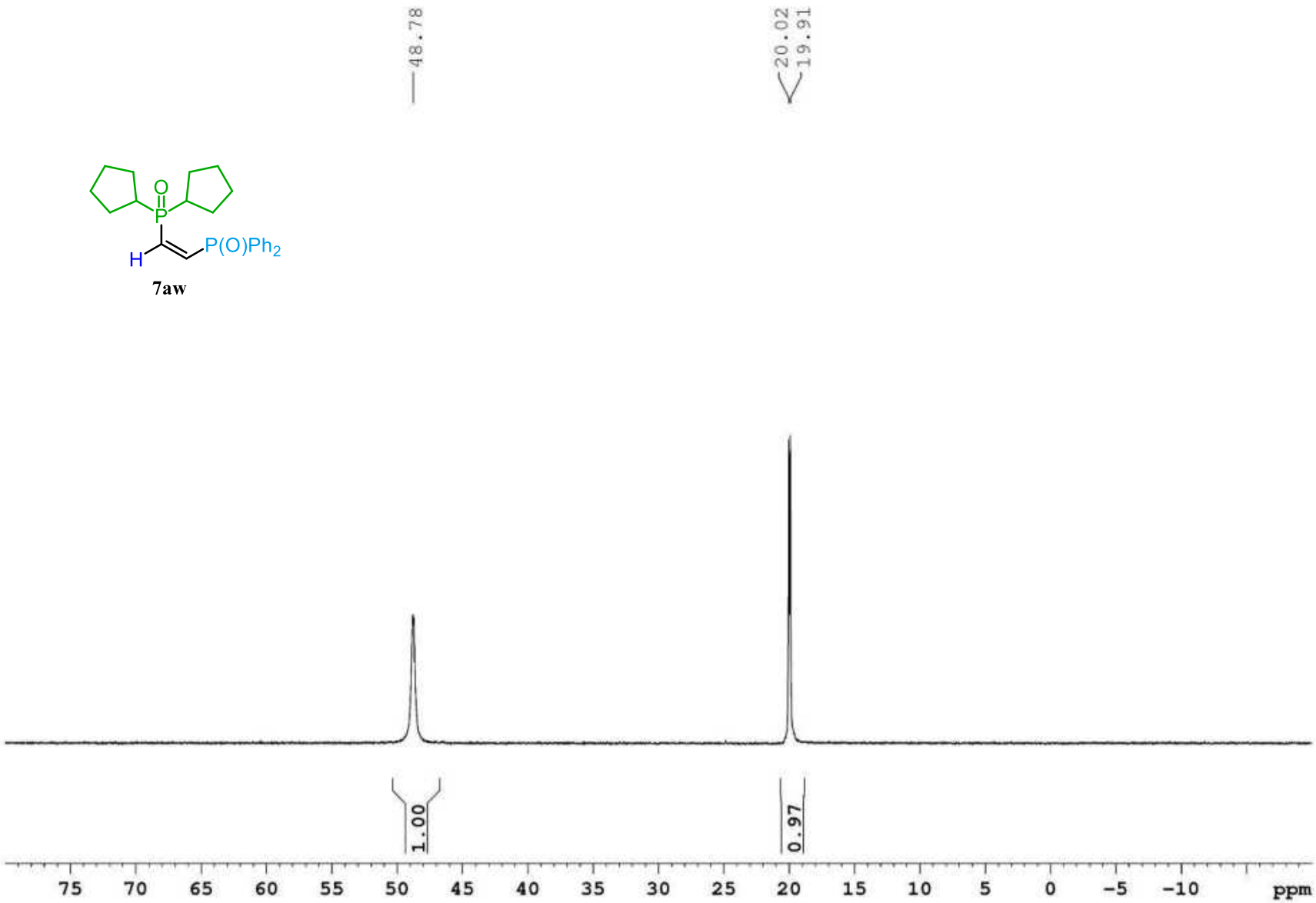
1.50
1.47
1.42
1.39
1.38
1.34


O
P
H
P(O)Ph2

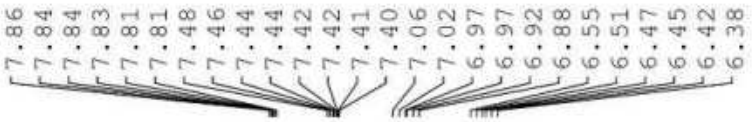
7aw

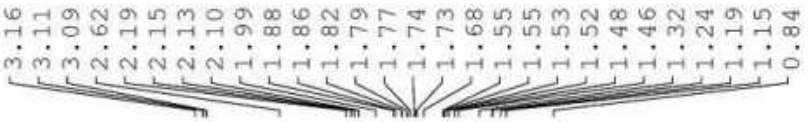

4.00
1.99
3.94
2.00
1.99
3.99
4.08
5.99
1.99
9
8
7
6
5
4
3
2
1
0
ppm

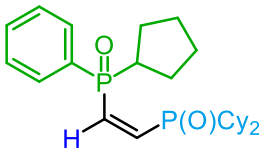

149.38
148.63
137.37
136.43
132.79
132.36
132.33
131.73
130.98
130.88
129.00
128.87
38.90
38.21
27.49
27.47
26.82
26.72
26.25
26.24
26.06
25.96
O
P
H
P(O)Ph2
7aw
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


48.78
20.02
19.91
O
P
H
P(O)Ph2
1.00
0.97
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm

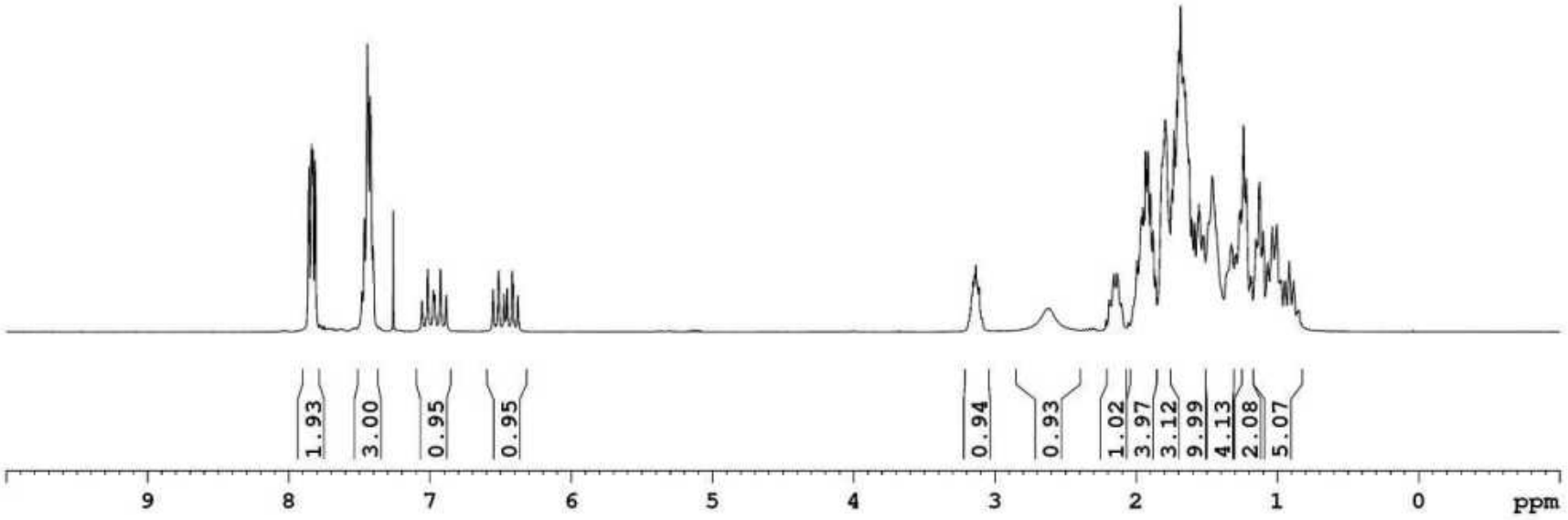
7aw


7.86
7.84
7.84
7.83
7.81
7.81
7.48
7.46
7.44
7.44
7.42
7.42
7.41
7.40
7.06
7.02
6.97
6.97
6.92
6.88
6.55
6.51
6.47
6.45
6.42
6.38


3.16
3.11
3.09
2.62
2.19
2.15
2.13
2.10
1.99
1.88
1.86
1.82
1.79
1.77
1.74
1.73
1.68
1.55
1.55
1.53
1.52
1.48
1.46
1.32
1.24
1.19
1.15
0.84


O
P
H
P(O)Cy2

7ax


1.93
3.00
0.95
0.95
0.94
0.93
1.02
3.97
3.12
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2.08
5.07
9
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6
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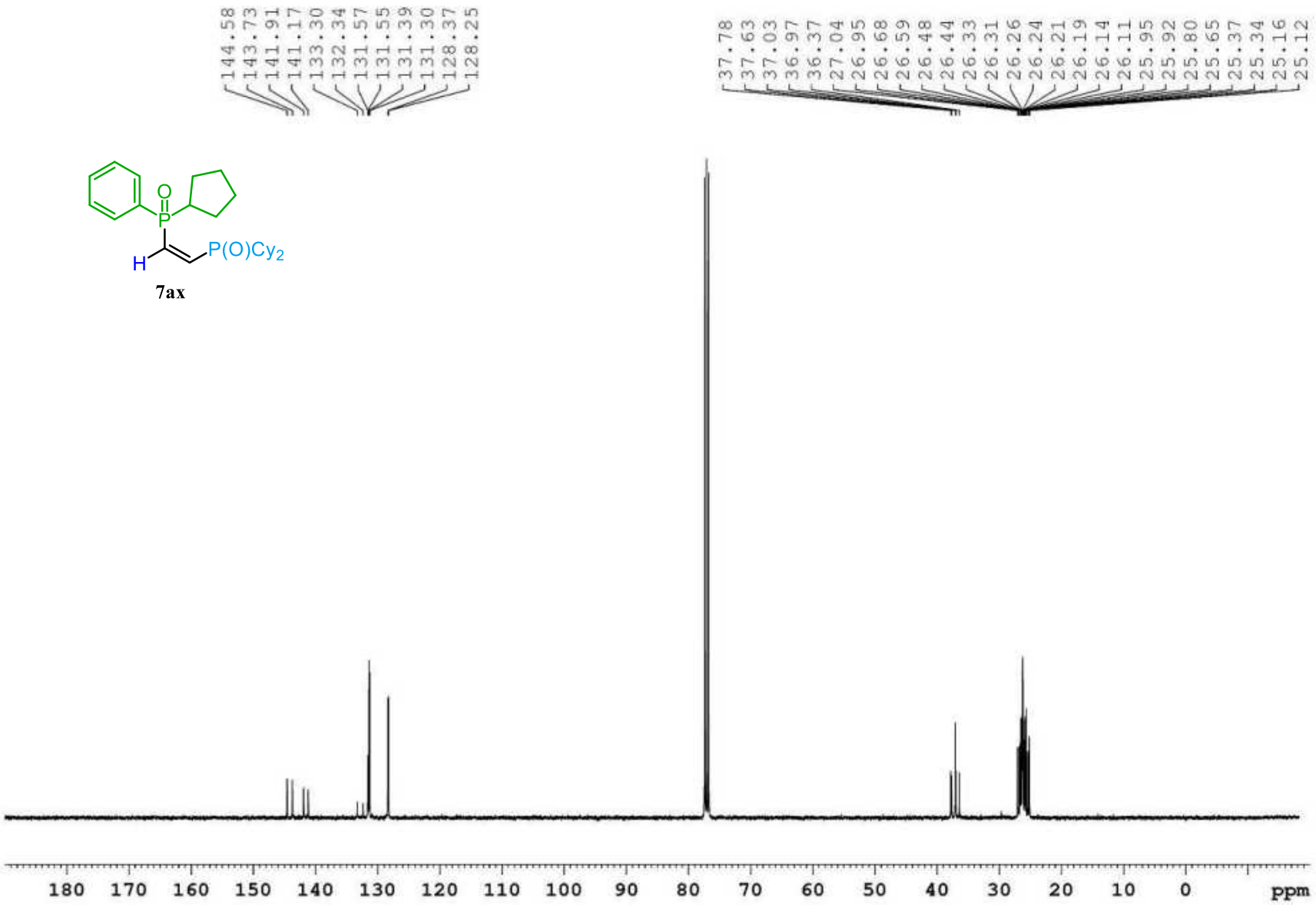
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143.73
141.91
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132.34
131.57
131.55
131.39
131.30
128.37
128.25
37.78
37.63
37.03
36.97
36.37
27.04
26.95
26.68
26.59
26.48
26.44
26.33
26.31
26.26
26.24
26.21
26.19
26.14
26.11
25.95
25.92
25.80
25.65
25.37
25.34
25.16
25.12
O
P
H
P(O)Cy2
7ax
180
170
160
150
140
130
120
110
100
90
80
70
60
50
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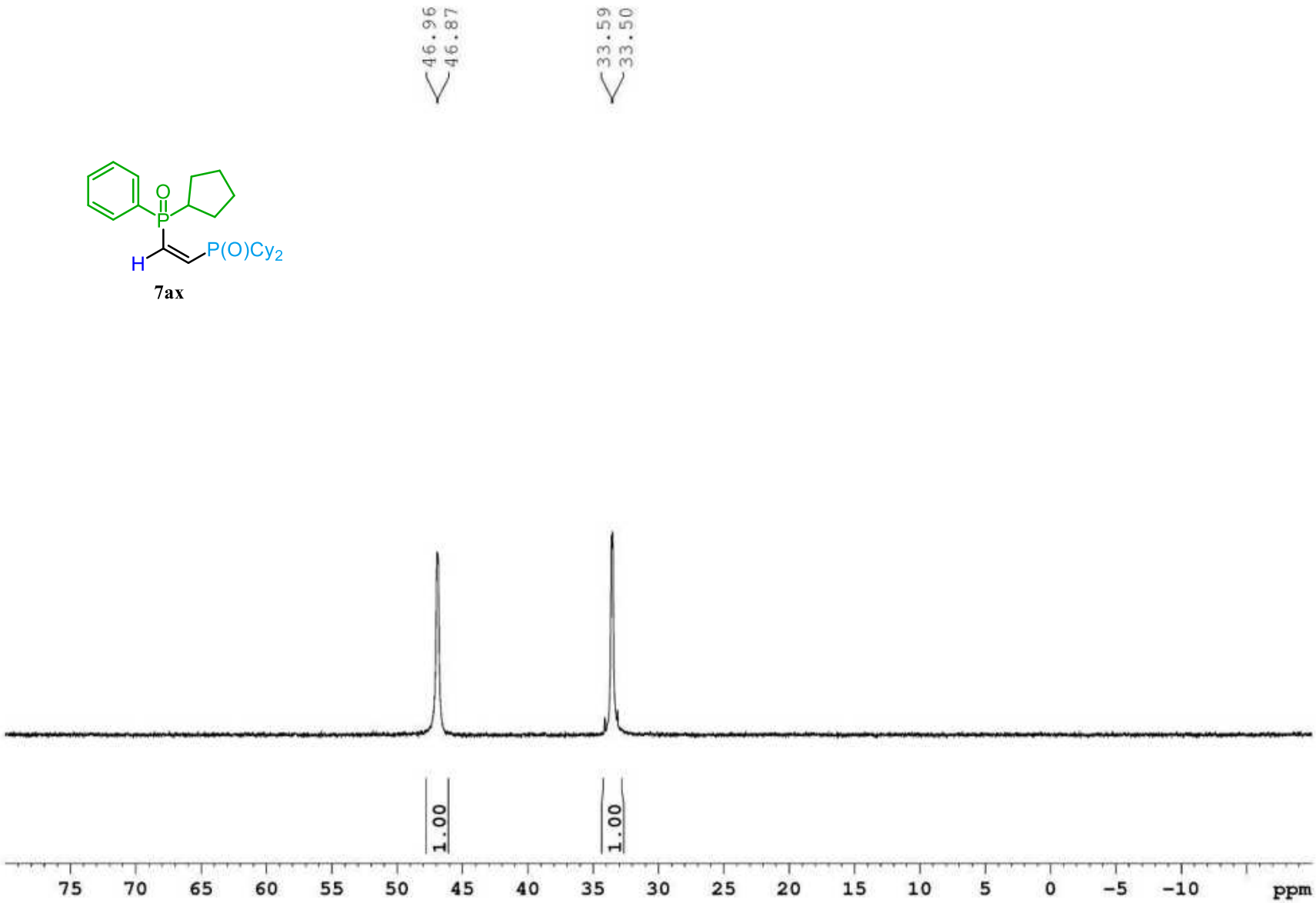
30
20
10
0
ppm


46.96
46.87
33.59
33.50
O
P
H
P(O)Cy2
1.00
1.00
75
70
65
60
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50
45
40
35
30
25
20
15
10
5
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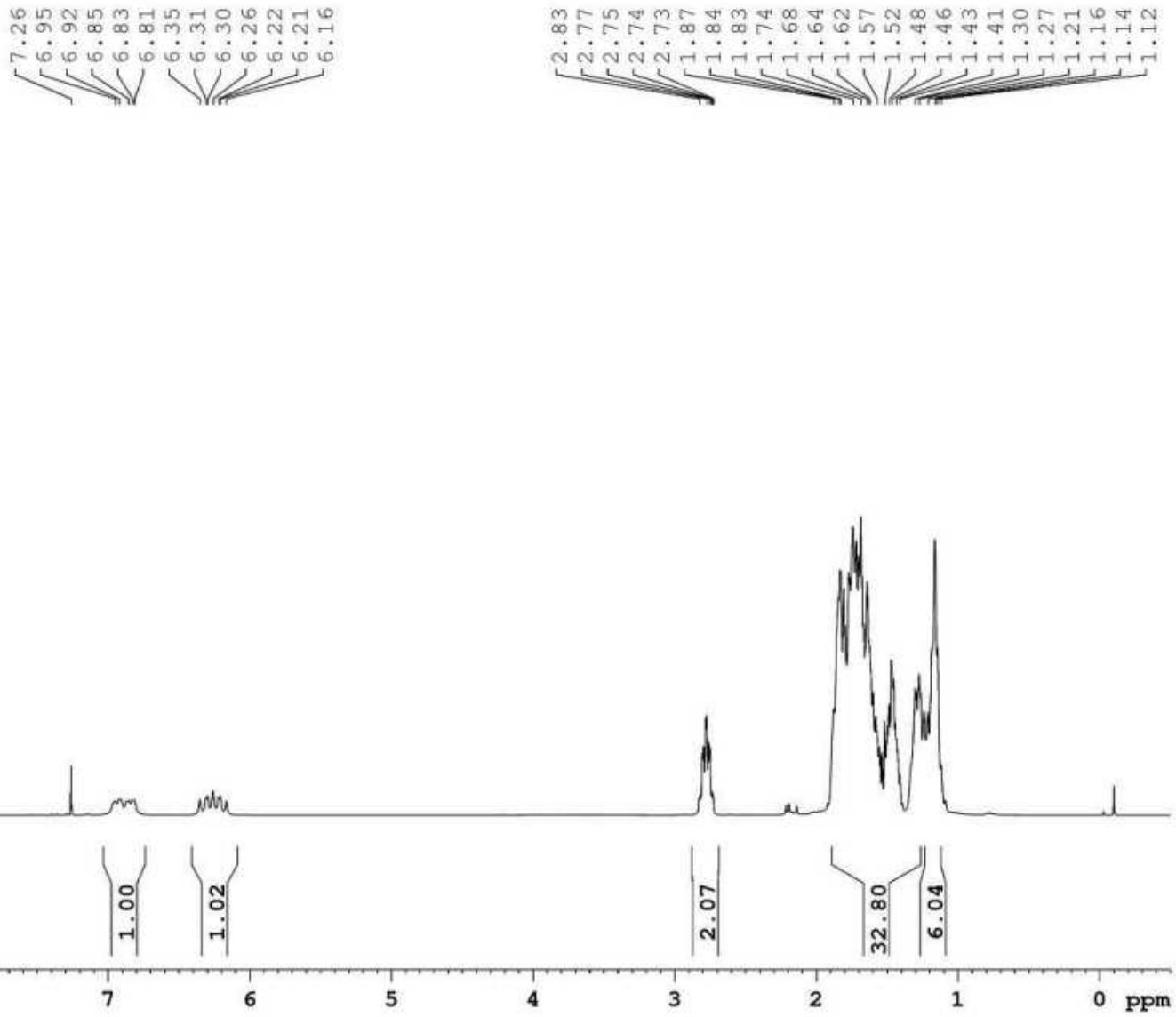
-5
-10
ppm

7ax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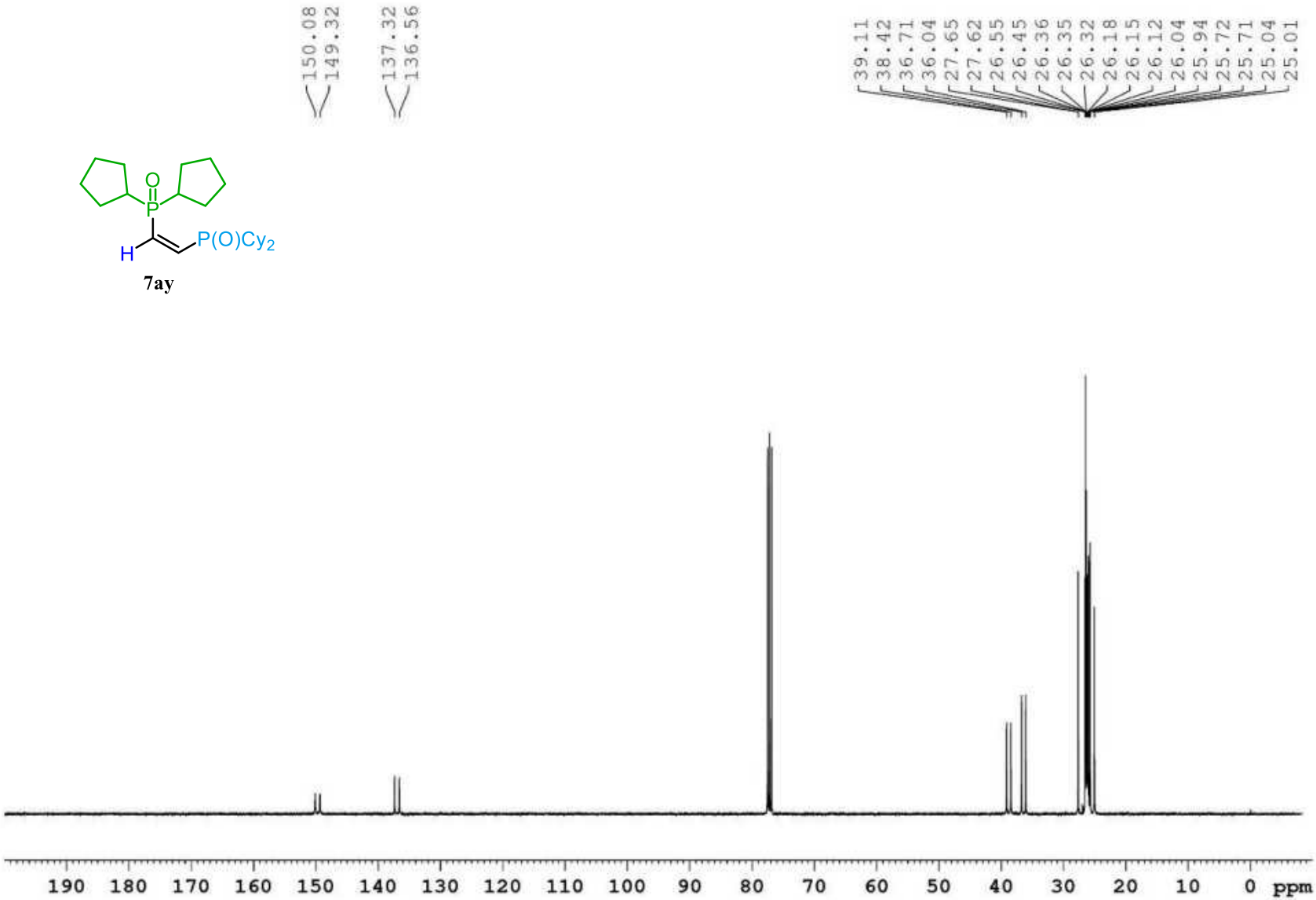
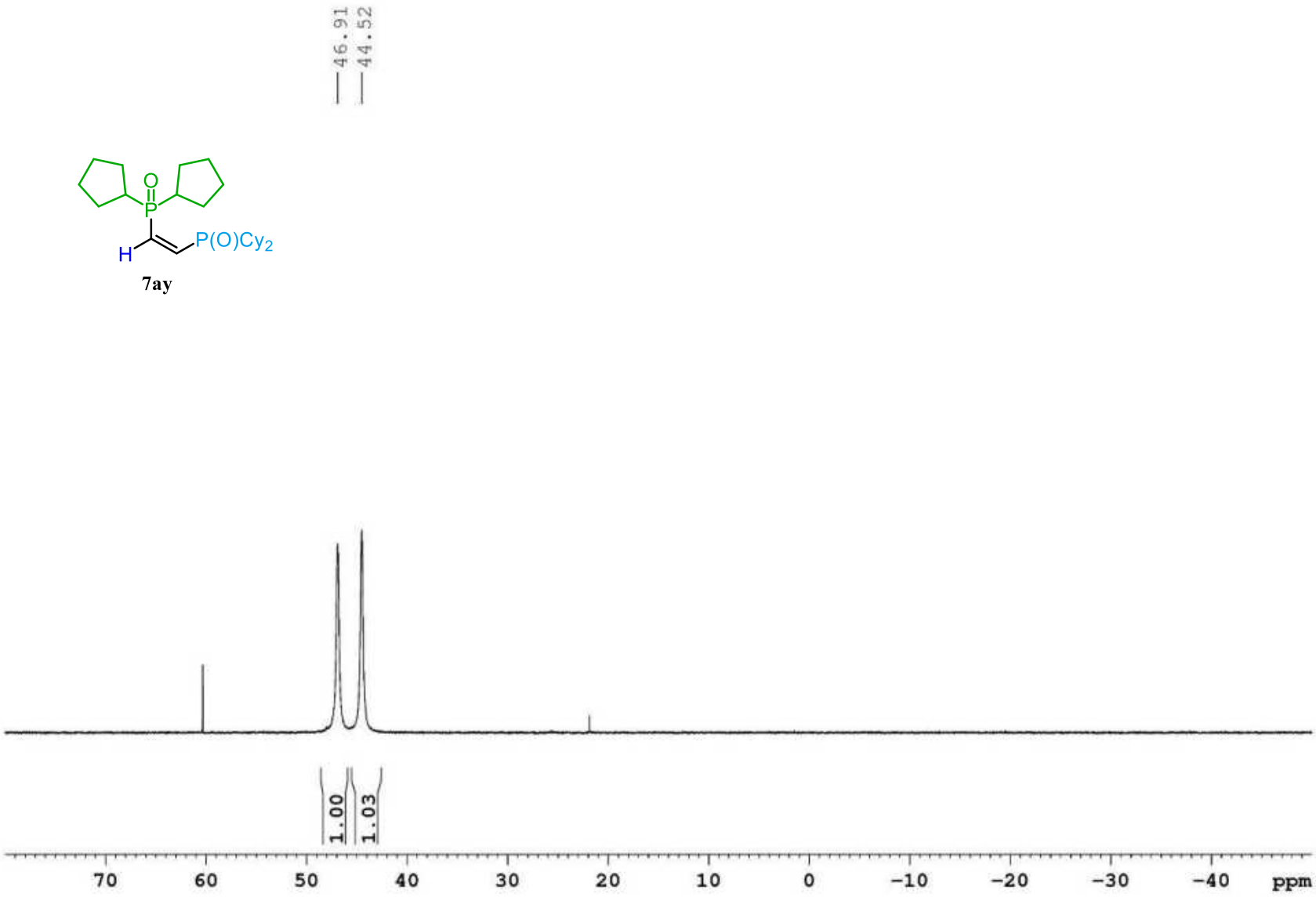
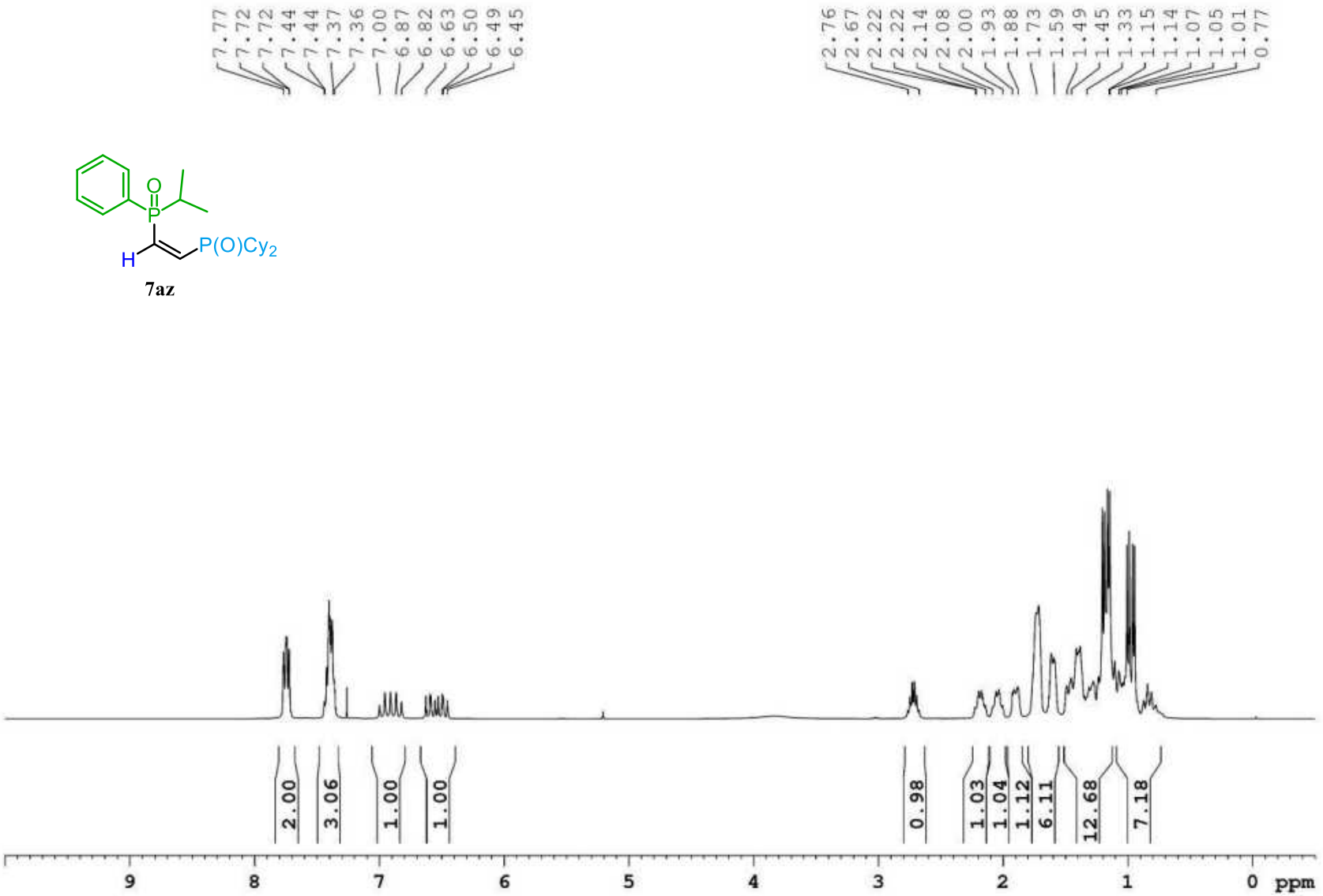
6.95
6.92
6.85
6.83
6.81
6.35
6.31
6.30
6.26
6.22
6.21
6.16
2.83
2.77
2.75
2.74
2.73
1.87
1.84
1.83
1.74
1.68
1.64
1.62
1.57
1.52
1.48
1.46
1.43
1.41
1.30
1.27
1.21
1.16
1.14
1.12
O
P
H
P(O)Cy2
1.00
1.02
2.07
32.80
6.04
9
8
7
6
5
4
3
2
1
0
ppm

7ay

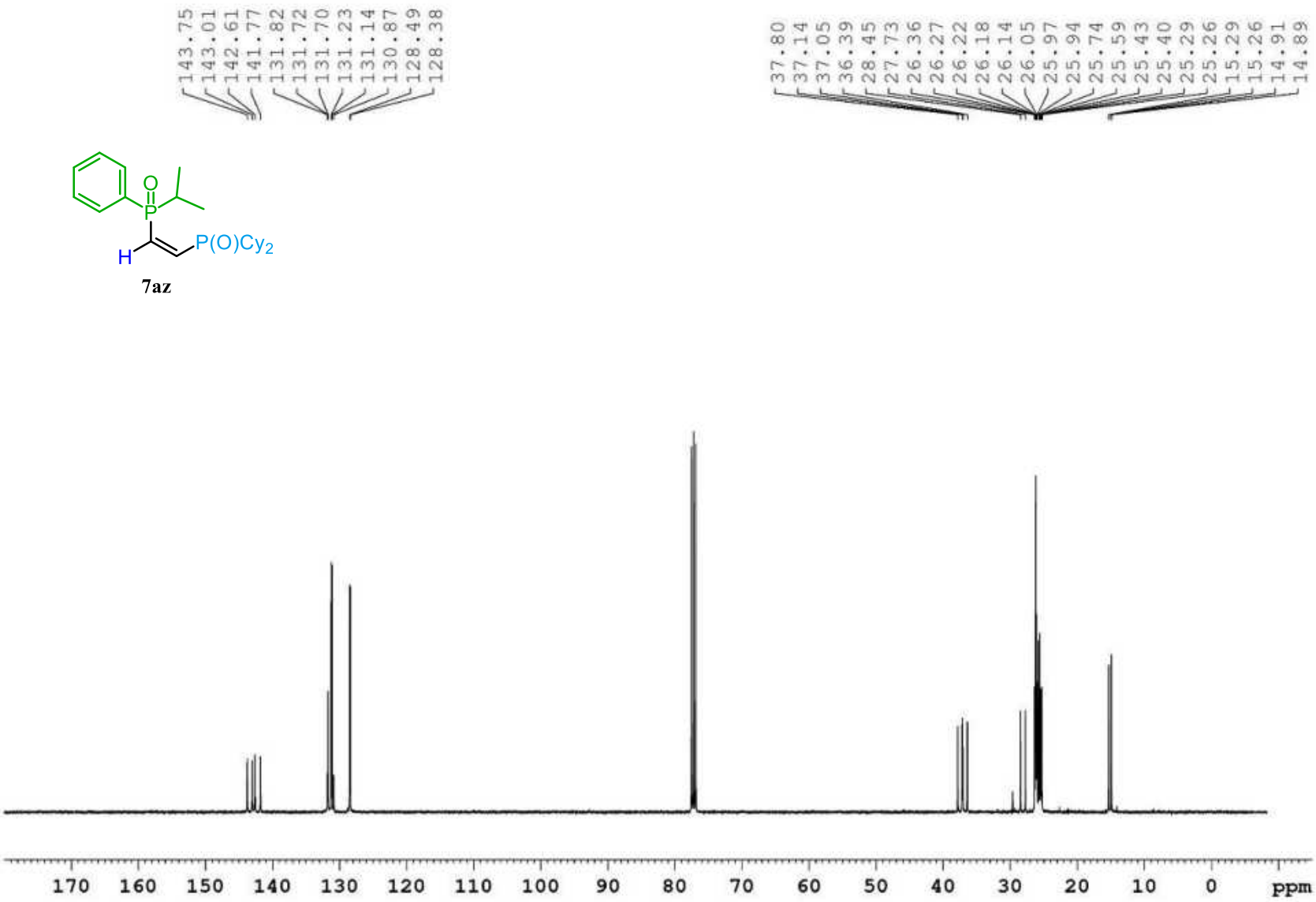

150.08
149.32
137.32
136.56
39.11
38.42
36.71
36.04
27.65
27.62
26.55
26.45
26.36
26.35
26.32
26.18
26.15
26.12
26.04
25.94
25.72
25.71
25.04
25.01
O
P
H
P(O)Cy2
7ay
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm



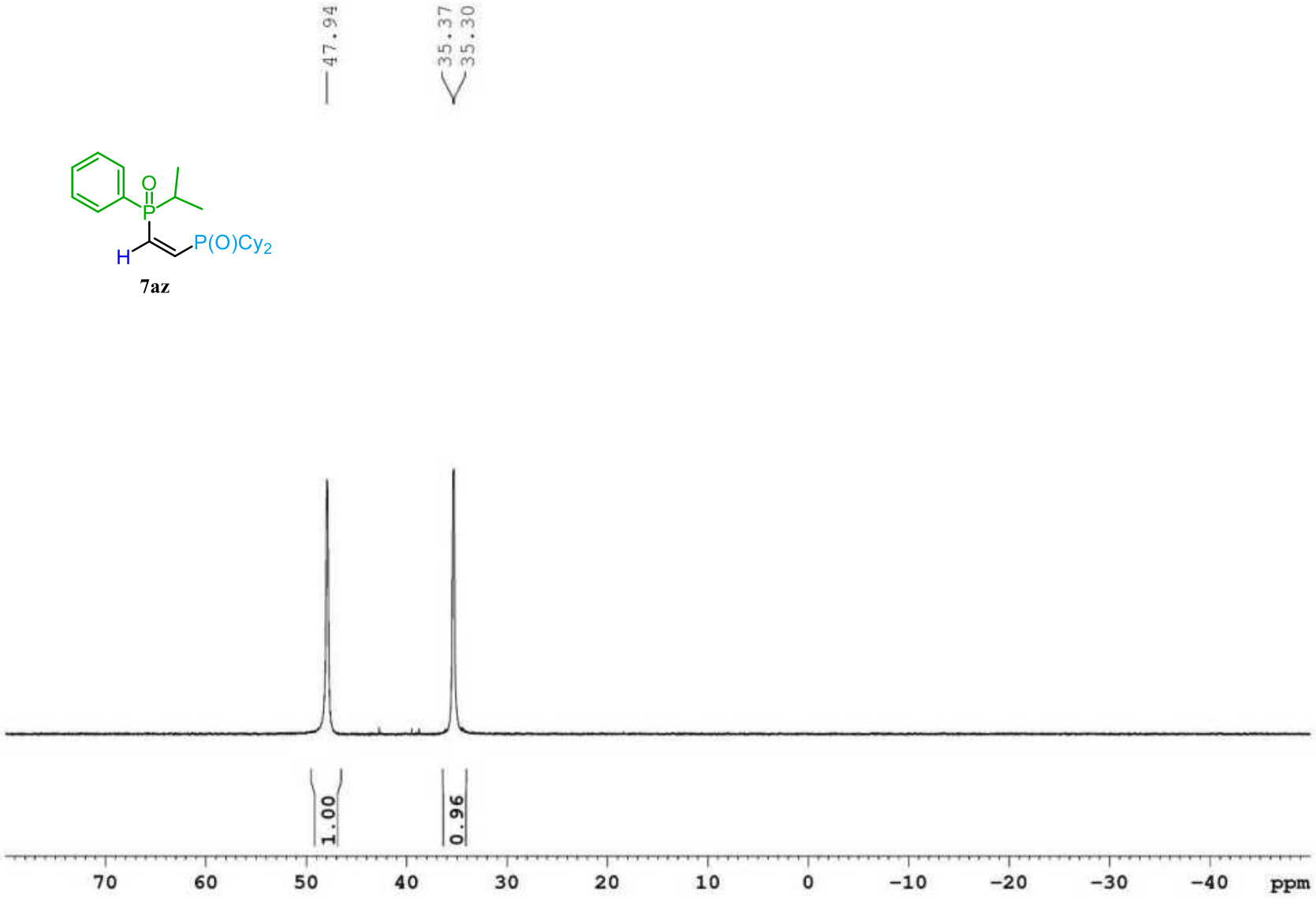
7ay


7.77
7.72
7.72
7.44
7.44
7.37
7.36
7.00
6.87
6.82
6.63
6.50
6.49
6.45
2.76
2.67
2.22
2.22
2.14
2.08
2.00
1.93
1.88
1.73
1.59
1.49
1.45
1.33
1.15
1.14
1.07
1.05
1.01
0.77
O
P
H
P(O)Cy2
2.00
3.06
1.00
1.00
0.98
1.03
1.04
1.12
6.11
12.68
7.18
9
8
7
6
5
4
3
2
1
0
ppm

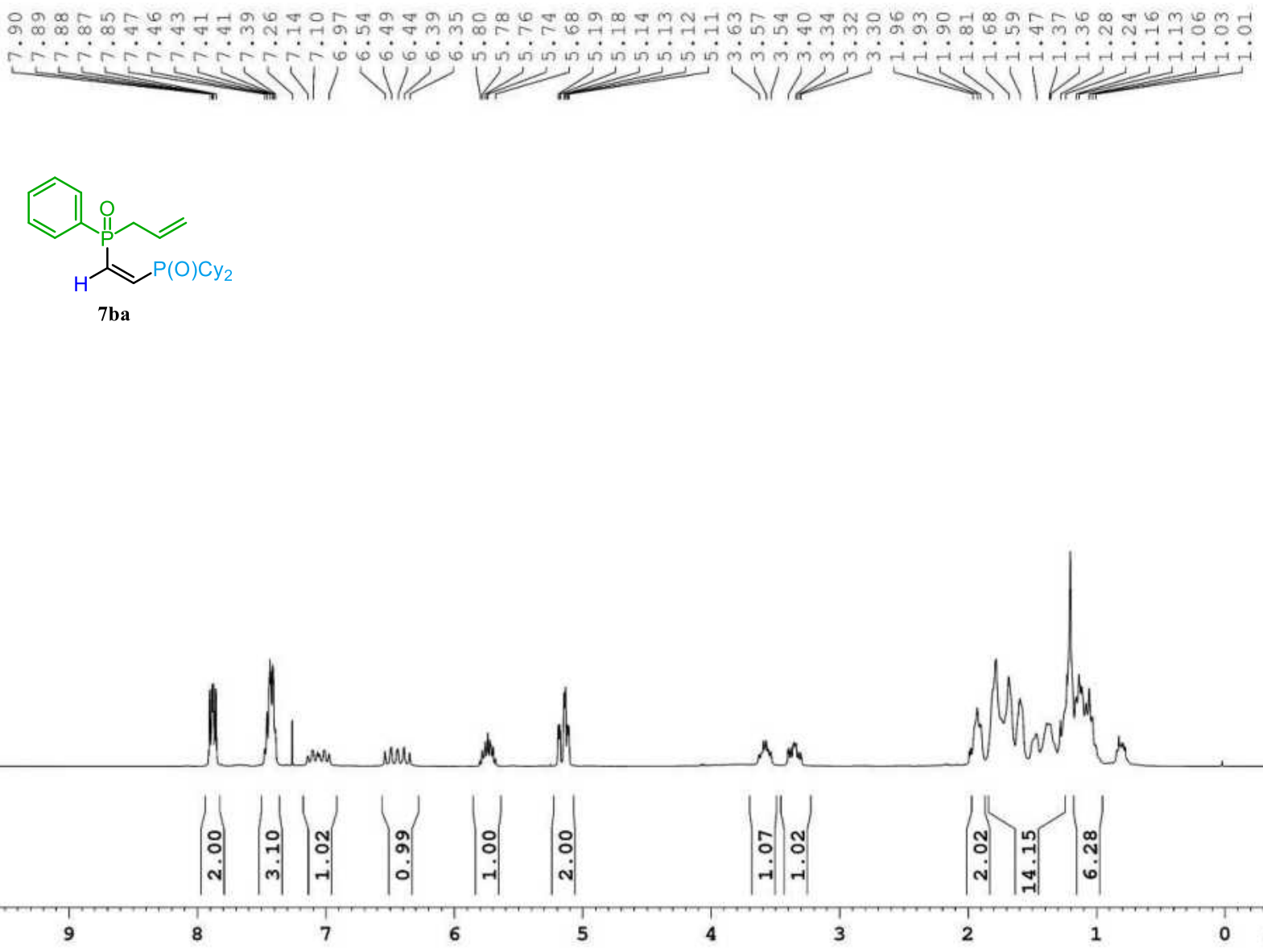
7az

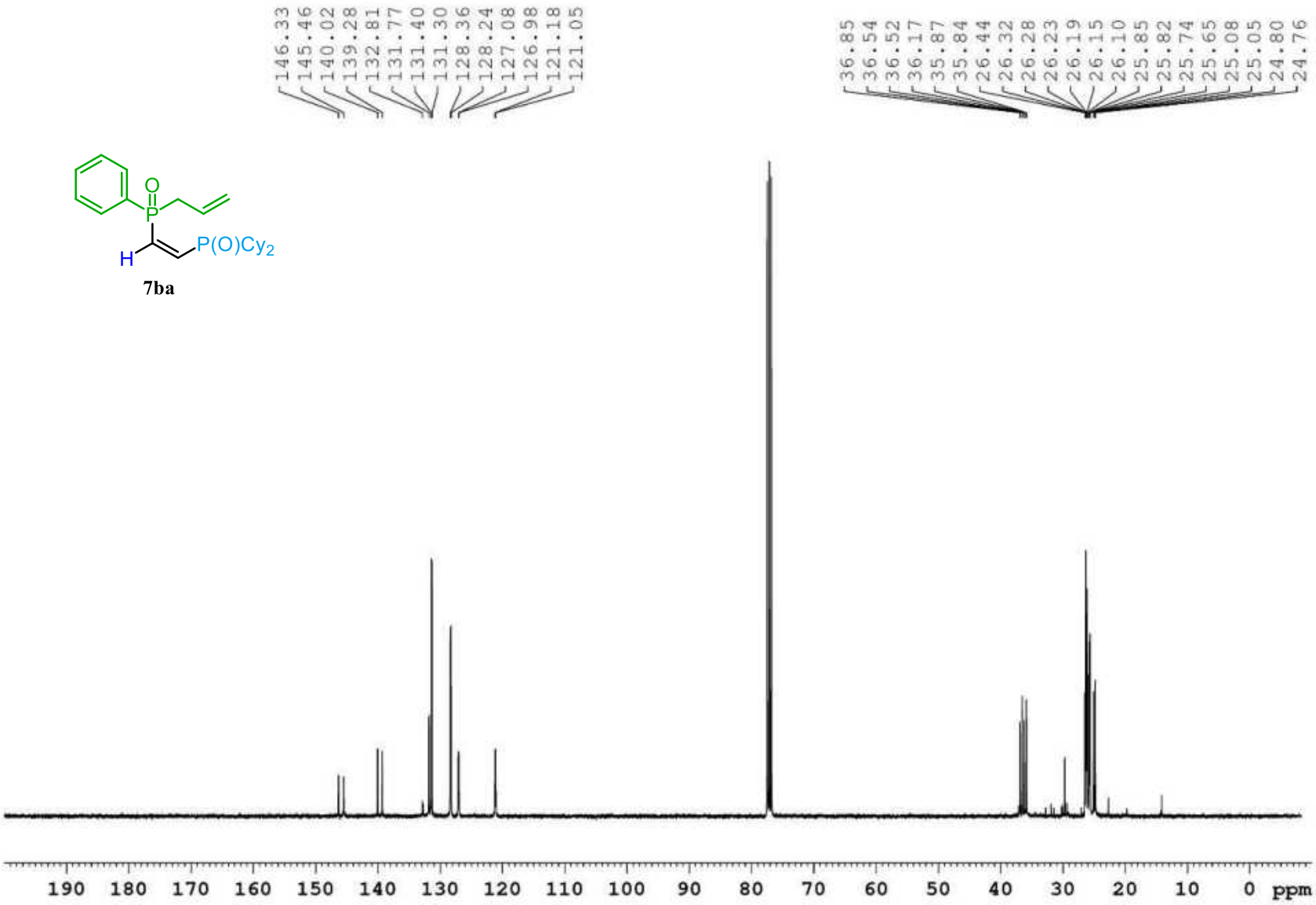

143.75
143.01
142.61
141.77
131.82
131.72
131.70
131.23
131.14
130.87
128.49
128.38
37.80
37.14
37.05
36.39
28.45
27.73
26.36
26.27
26.22
26.18
26.14
26.05
25.97
25.94
25.74
25.59
25.43
25.40
25.29
25.26
15.29
15.26
14.91
14.89
O
P
H
P(O)Cy2
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

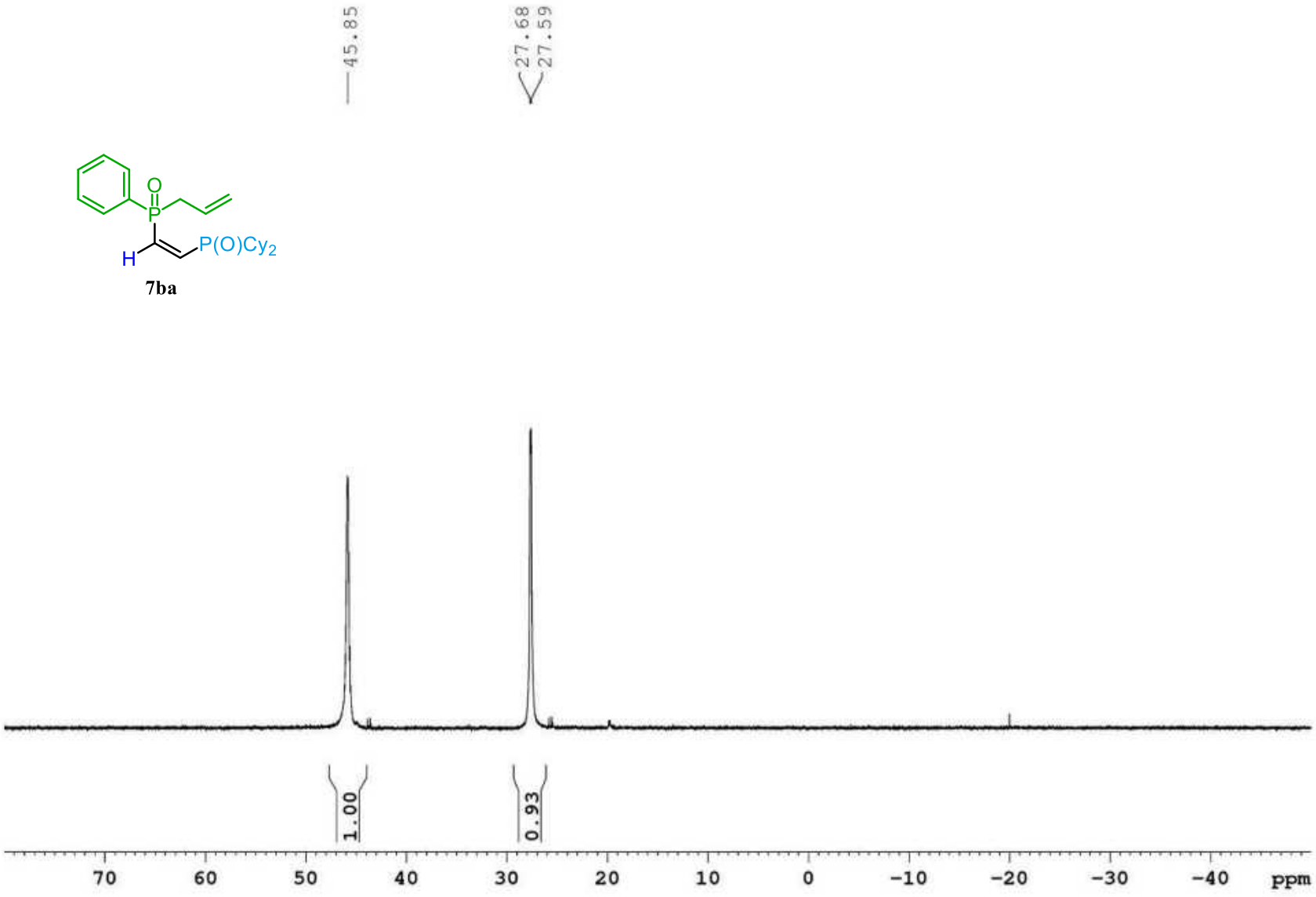
7az

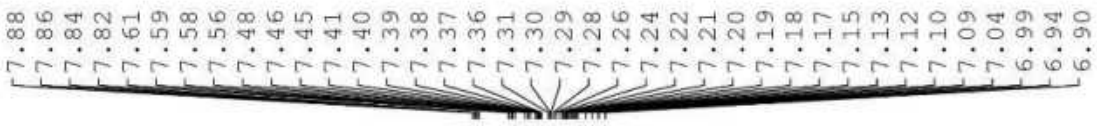

47.94
35.37
35.30
O
P
H
P(O)Cy2
1.00
0.96
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm

7az


7.90
7.89
7.88
7.87
7.85
7.47
7.46
7.43
7.41
7.41
7.39
7.26
7.14
7.10
6.97
6.54
6.49
6.44
6.39
6.35
5.80
5.78
5.76
5.74
5.68
5.19
5.18
5.14
5.13
5.12
5.11
3.63
3.57
3.54
3.40
3.34
3.32
3.30
1.96
1.93
1.90
1.81
1.68
1.59
1.47
1.37
1.36
1.28
1.24
1.16
1.13
1.06
1.03
1.01
O
P
H
P(O)Cy2
7ba
2.00
3.10
1.02
0.99
1.00
2.00
1.07
1.02
2.02
14.15
6.28
9
8
7
6
5
4
3
2
1
0
ppm


146.33
145.46
140.02
139.28
132.81
131.77
131.40
131.30
128.36
128.24
127.08
126.98
121.18
121.05
36.85
36.54
36.52
36.17
35.87
35.84
26.44
26.32
26.28
26.23
26.19
26.15
26.10
25.85
25.82
25.74
25.65
25.08
25.05
24.80
24.76
O
P
H
P(O)Cy2
7ba
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 ppm


45.85
27.68
27.59
O
P
H
P(O)Cy2
7ba
1.00
0.93
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm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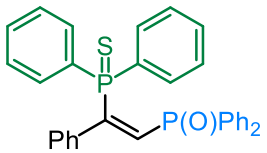
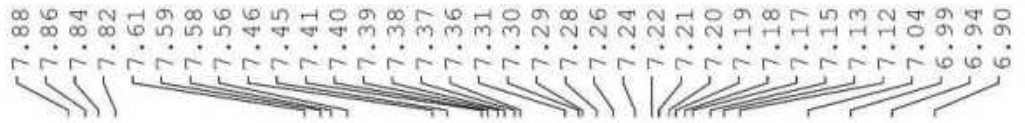
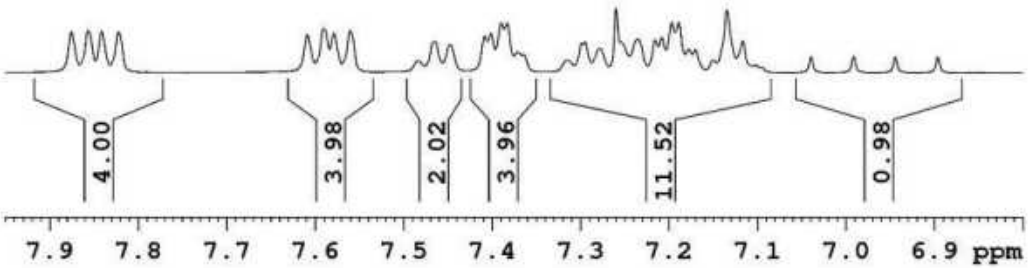
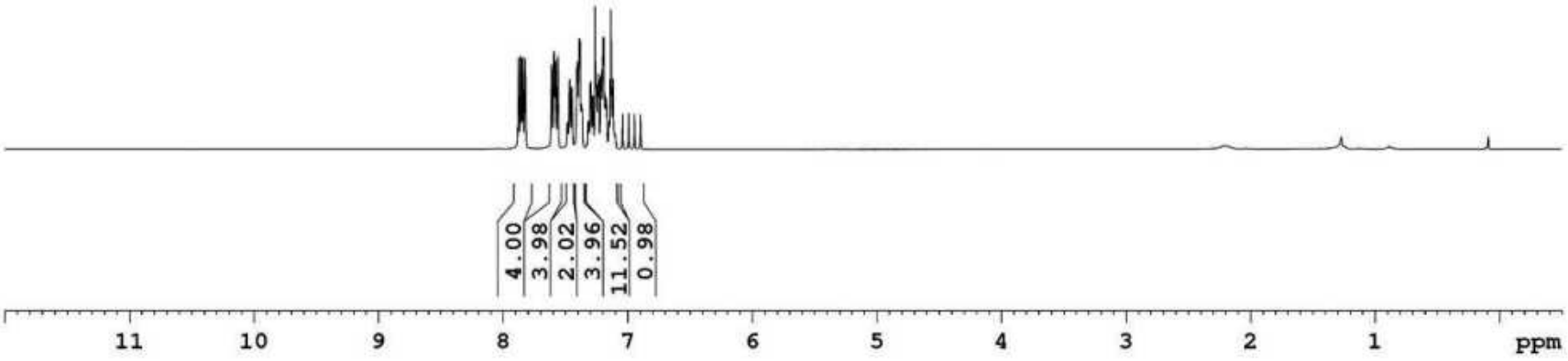
7.86
7.84
7.82
7.61
7.59
7.58
7.56
7.48
7.46
7.45
7.41
7.40
7.39
7.38
7.37
7.36
7.31
7.30
7.29
7.28
7.26
7.24
7.22
7.21
7.20
7.19
7.18
7.17
7.15
7.13
7.12
7.10
7.09
7.04
6.99
6.94
6.90

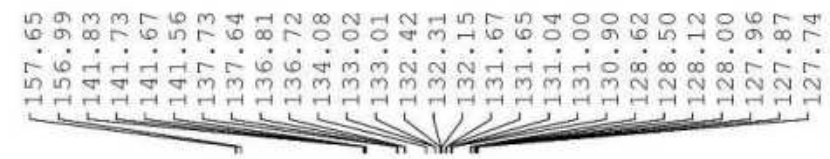

S
P
Ph
P(O)Ph2

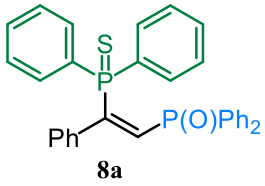
8a


7.88
7.86
7.84
7.82
7.61
7.59
7.58
7.56
7.46
7.45
7.41
7.40
7.39
7.38
7.37
7.36
7.31
7.30
7.29
7.28
7.26
7.24
7.22
7.21
7.20
7.19
7.18
7.17
7.15
7.13
7.12
7.04
6.99
6.94
6.90

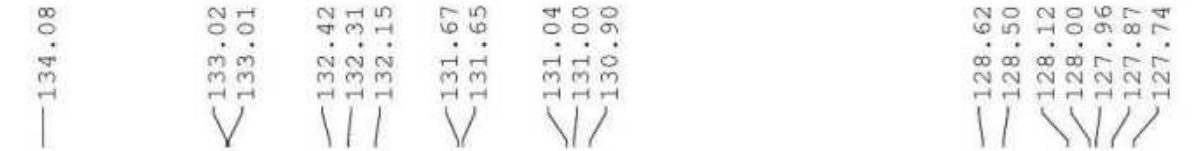

4.00
3.98
2.02
3.96
11.52
0.98
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
7.1
7.0
6.9
ppm

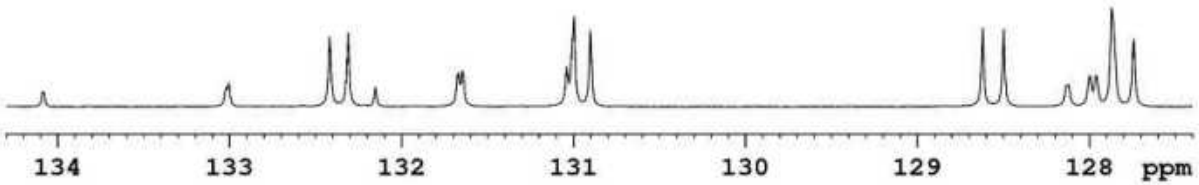

4.00
3.98
2.02
3.96
11.52
0.98
11
10
9
8
7
6
5
4
3
2
1
ppm

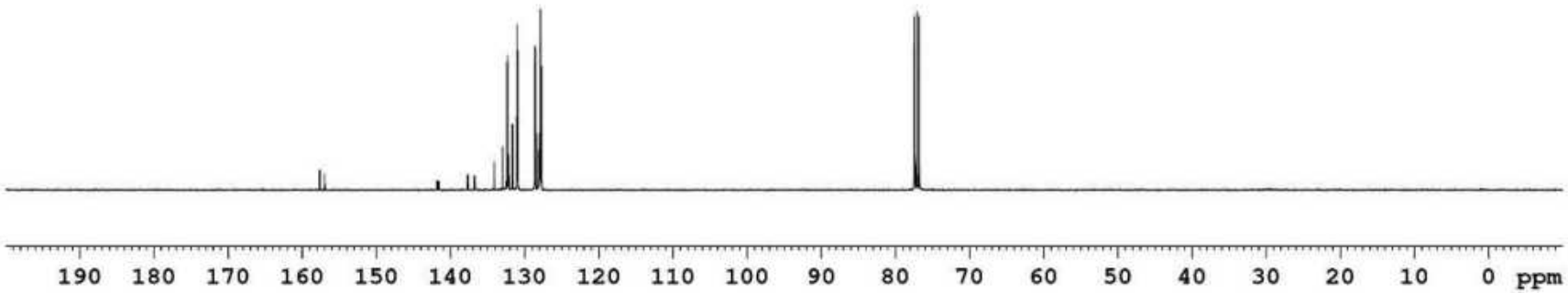

157.65
156.99
141.83
141.73
141.67
141.56
137.73
137.64
136.81
136.72
134.08
133.02
133.01
132.42
132.31
132.15
131.67
131.65
131.04
131.00
130.90
128.62
128.50
128.12
128.00
127.96
127.87
127.74

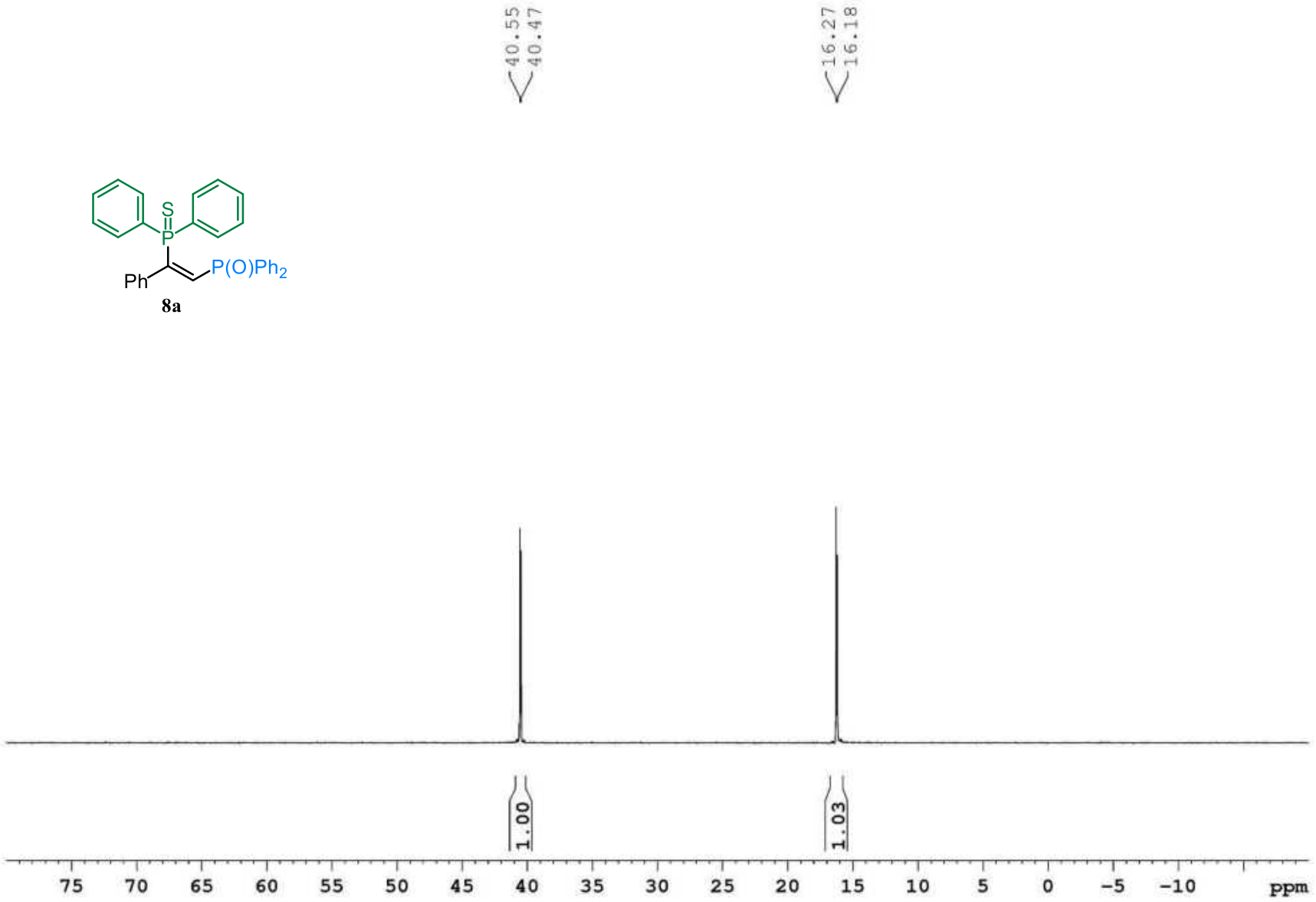

S
P
P(O)Ph2
Ph

8a

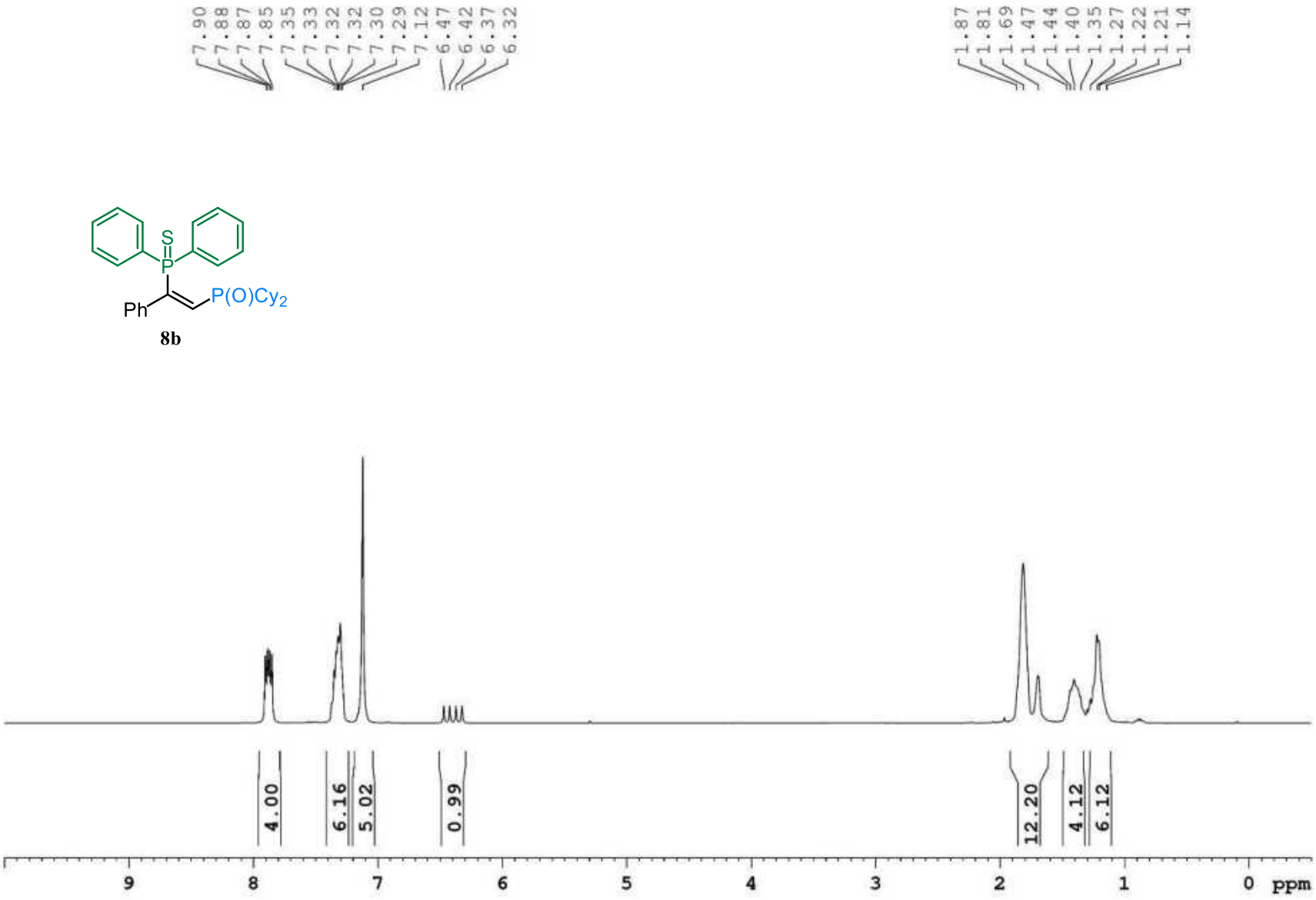

134.08
133.02
133.01
132.42
132.31
132.15
131.67
131.65
131.04
131.00
130.90
128.62
128.50
128.12
128.00
127.96
127.87
127.74


134
133
132
131
130
129
128
ppm

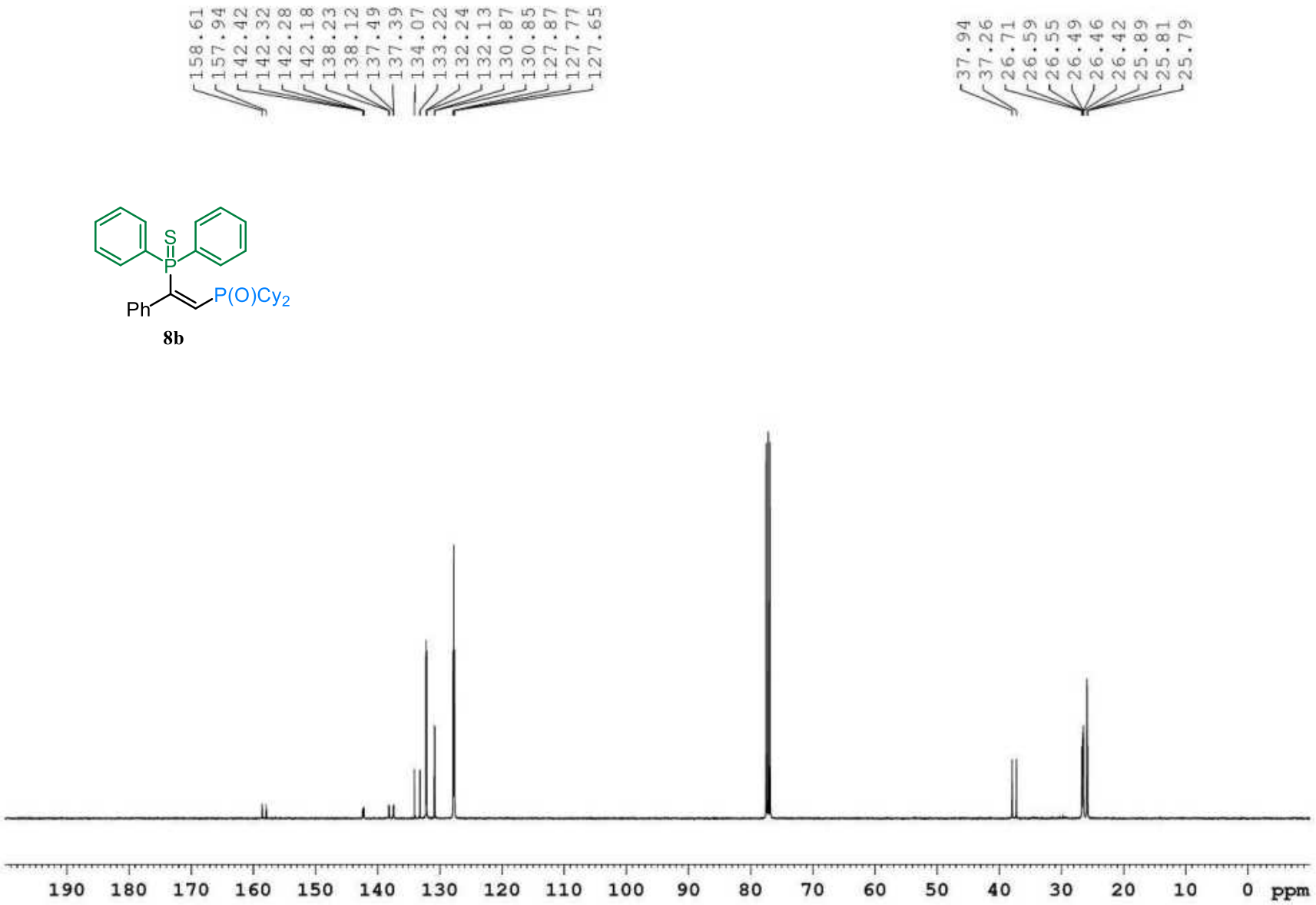

190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


40.55
40.47
16.27
16.18
S
P
Ph
P(O)Ph2
1.00
1.03
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm

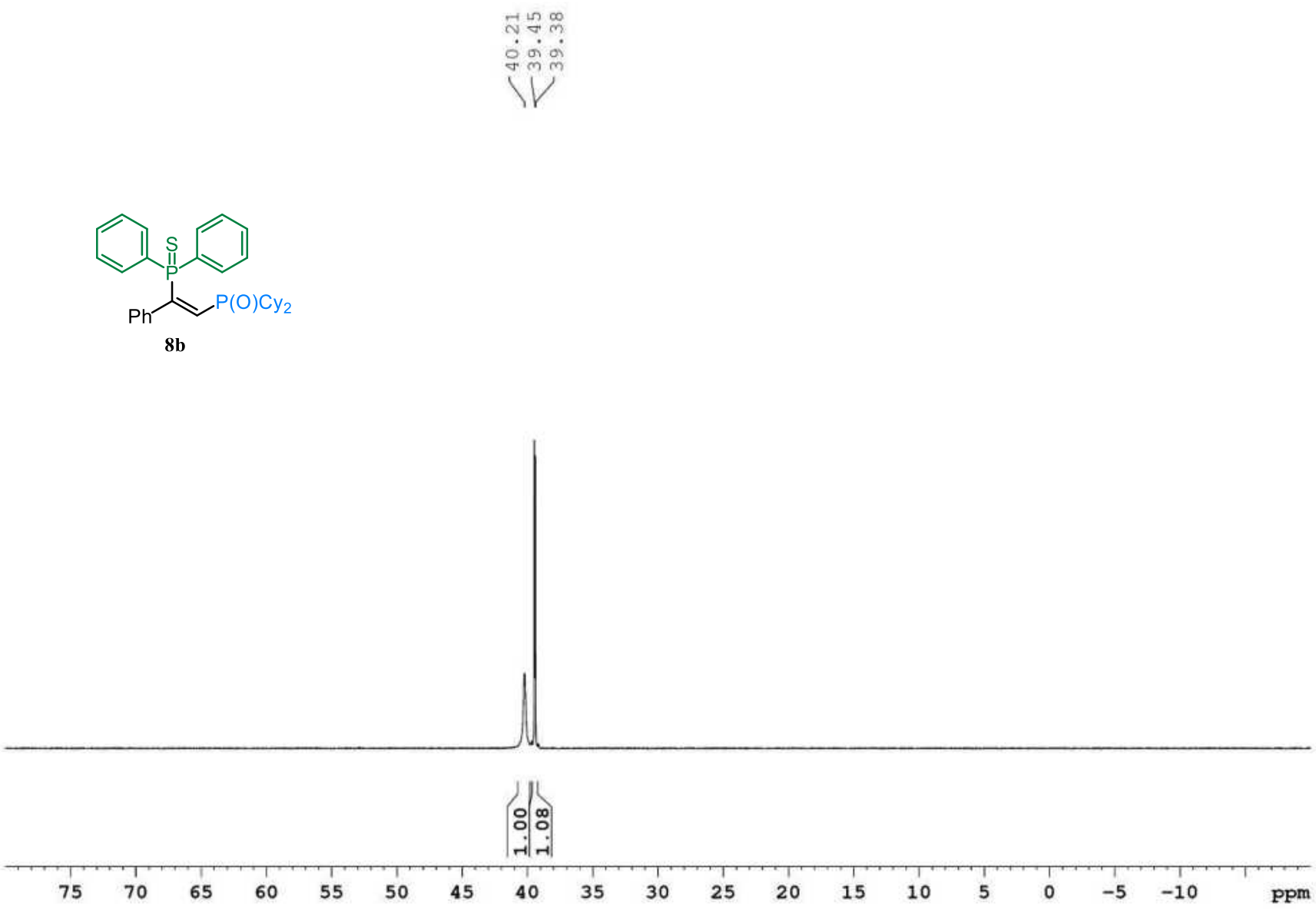
8a


7.90
7.88
7.87
7.85
7.35
7.33
7.32
7.32
7.30
7.29
7.12
6.47
6.42
6.37
6.32
1.87
1.81
1.69
1.47
1.44
1.40
1.35
1.27
1.22
1.21
1.14
S
P
Ph
P(O)Cy2
4.00
6.16
5.02
0.99
12.20
4.12
6.12
9
8
7
6
5
4
3
2
1
0
ppm

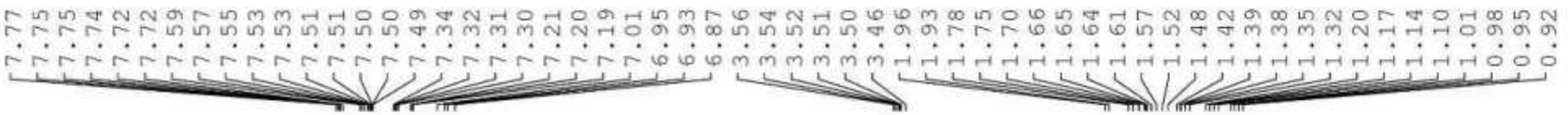
8b

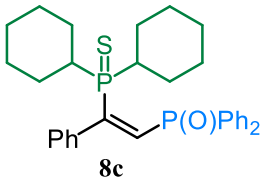

158.61
157.94
142.42
142.32
142.28
142.18
138.23
138.12
137.49
137.39
134.07
133.22
132.24
132.13
130.87
130.85
127.87
127.77
127.65
37.94
37.26
26.71
26.59
26.55
26.49
26.46
26.42
25.89
25.81
25.79
S
P
Ph
P(O)Cy2
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

8b

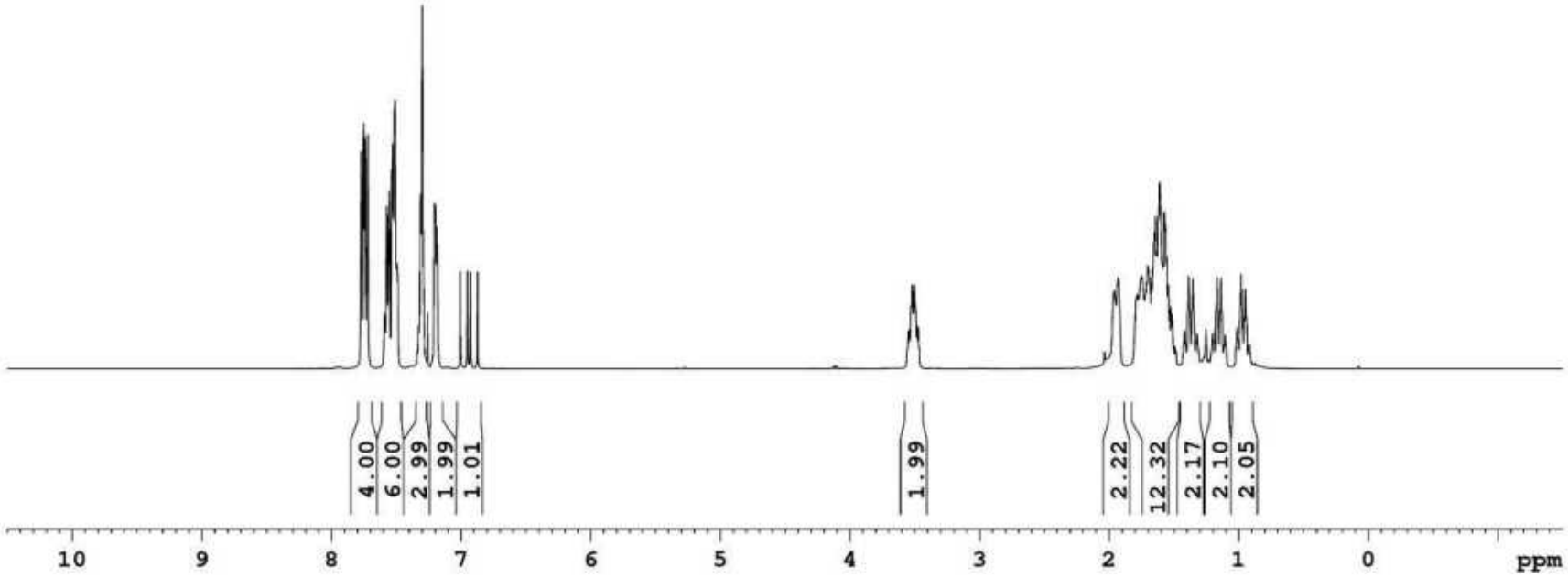

40.21
39.45
39.38
S
P
Ph
P(O)Cy2
1.00
1.08
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm

8b


7.77
7.75
7.75
7.74
7.72
7.72
7.59
7.57
7.55
7.53
7.53
7.51
7.51
7.50
7.50
7.49
7.34
7.32
7.31
7.30
7.21
7.20
7.19
7.01
6.95
6.93
6.87
3.56
3.54
3.52
3.51
3.50
3.46
1.96
1.93
1.78
1.75
1.70
1.66
1.65
1.64
1.61
1.57
1.52
1.48
1.42
1.39
1.38
1.35
1.32
1.20
1.17
1.14
1.10
1.01
0.98
0.95
0.92

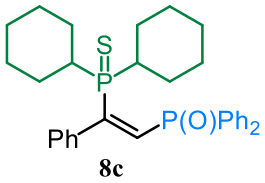

S
P
Ph
P(O)Ph2

8c

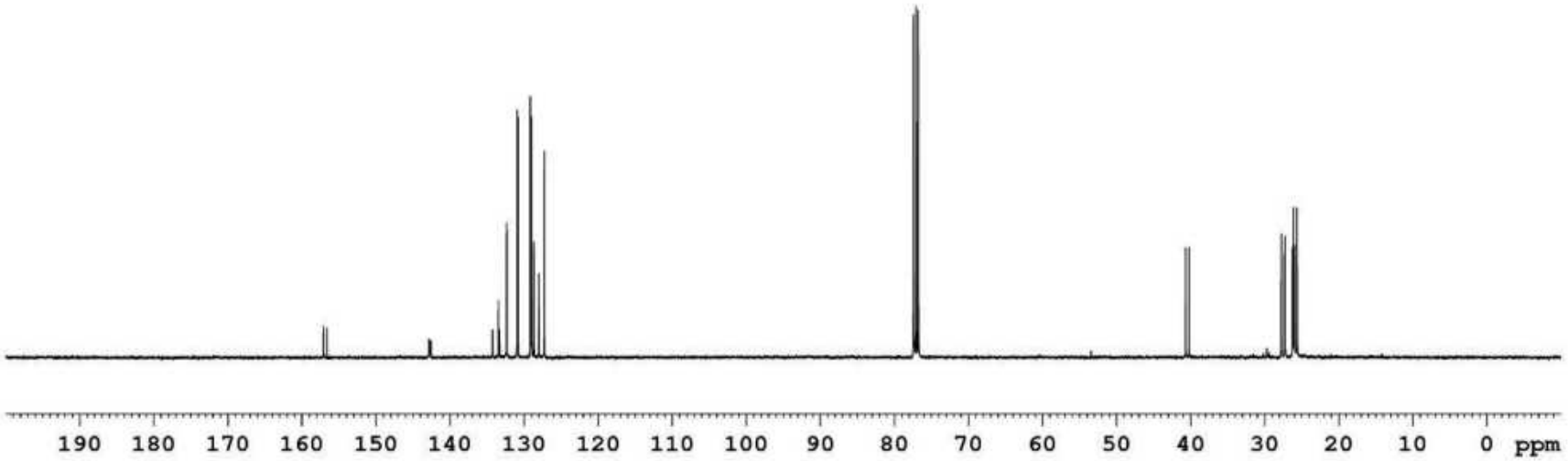

4.00
6.00
2.99
1.99
1.01
1.99
2.22
12.32
2.17
2.10
2.05
10
9
8
7
6
5
4
3
2
1
0
ppm

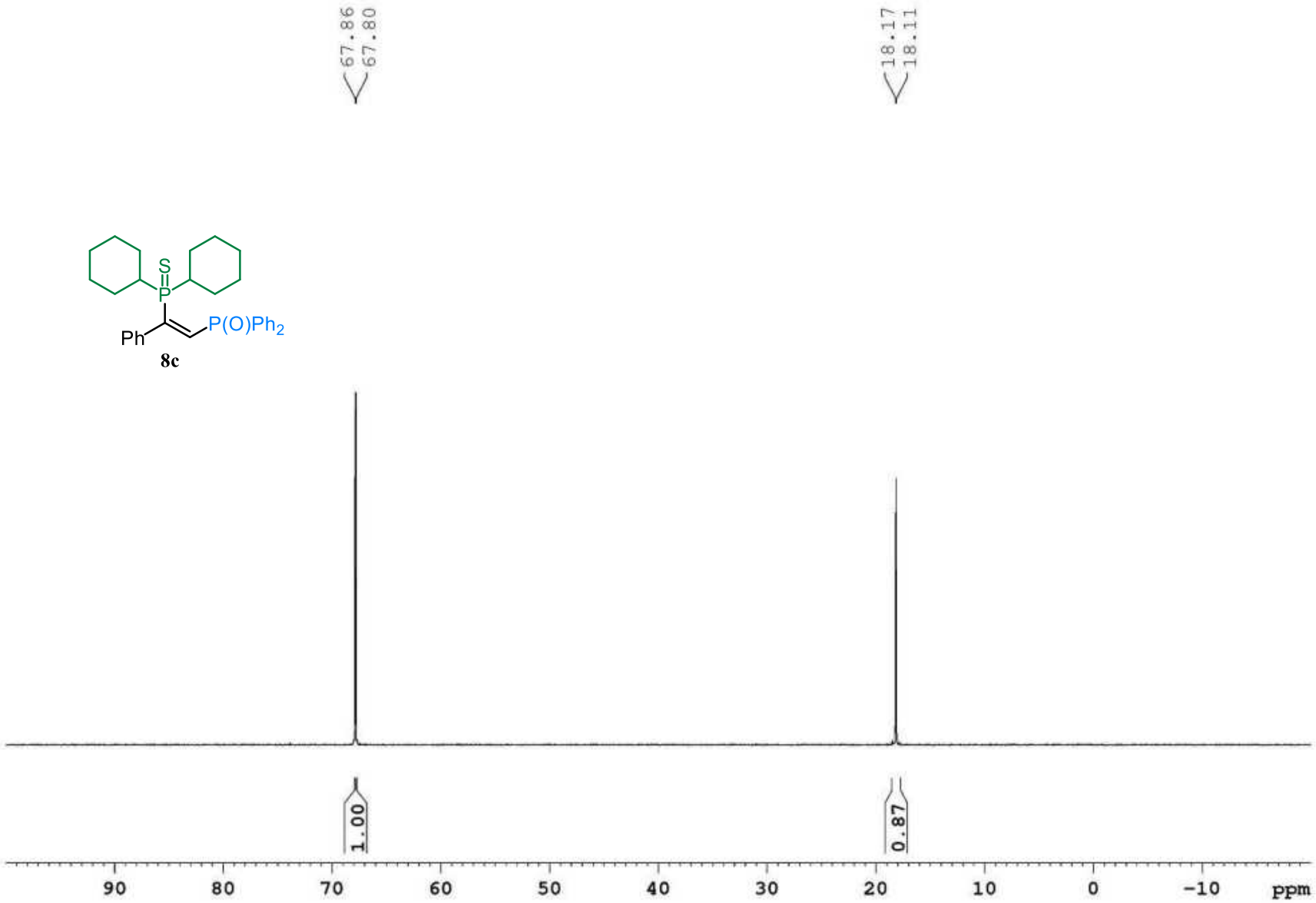
157.06
156.62
142.84
142.76
142.67
142.59
134.30
134.23
133.45
133.39
133.31
132.36
132.34
130.91
130.82
129.13
129.01
128.69
128.66
128.00
127.27

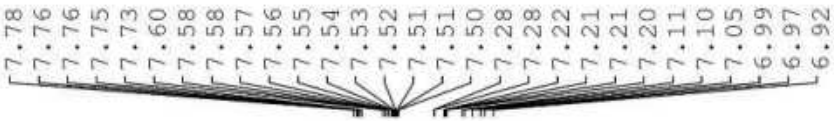
40.69
40.23
27.77
27.75
27.29
27.27
26.24
26.11
25.97
25.63



8c




67.86
67.80
18.17
18.11
S
P
Ph
P(O)Ph2
8c
1.00
0.87
90
80
70
60
50
40
30
20
10
0
−10
ppm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7.76
7.76
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7.60
7.58
7.58
7.57
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7.54
7.53
7.52
7.51
7.51
7.50
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7.21
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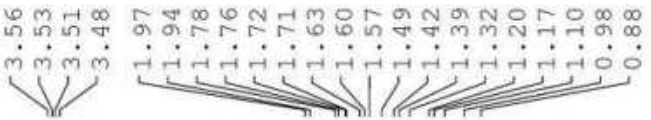
7.20
7.11
7.10
7.05
6.99
6.97
6.92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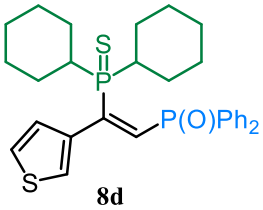
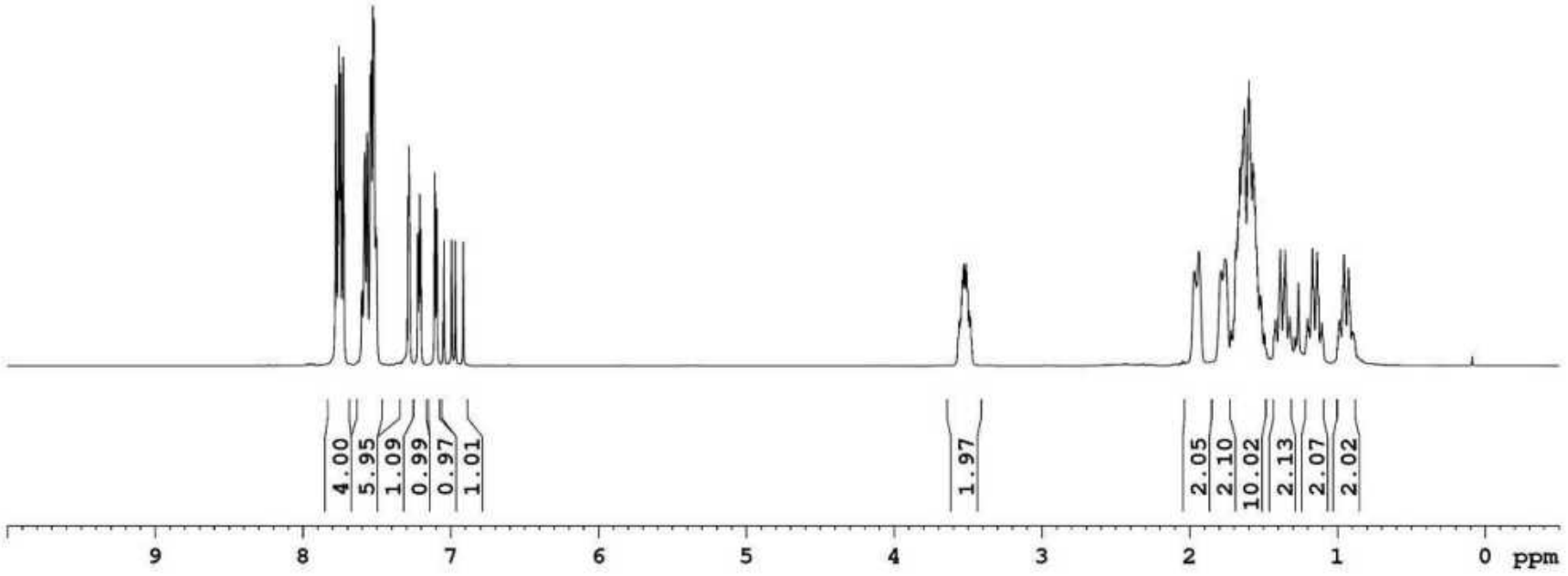
3.53
3.51
3.48
1.97
1.94
1.78
1.76
1.72
1.71
1.63
1.60
1.57
1.49
1.42
1.39
1.32
1.20
1.17
1.10
0.98
0.88


S
P
P(O)Ph2
S

8d


4.00
5.95
1.09
0.99
0.97
1.01
1.97
2.05
2.10
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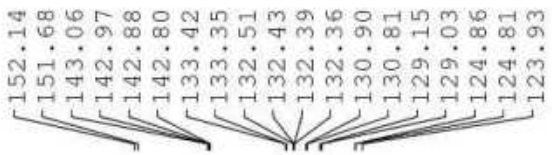
2.13
2.07
2.02
9
8
7
6
5
4
3
2
1
0
ppm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151.68
143.06
142.97
142.88
142.80
133.42
133.35
132.51
132.43
132.39
132.36
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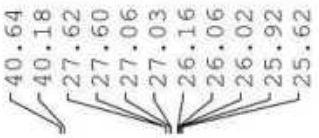
130.81
129.15
129.03
124.86
124.81
123.93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40.18
27.62
27.60
27.06
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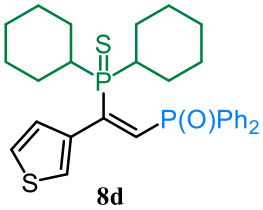
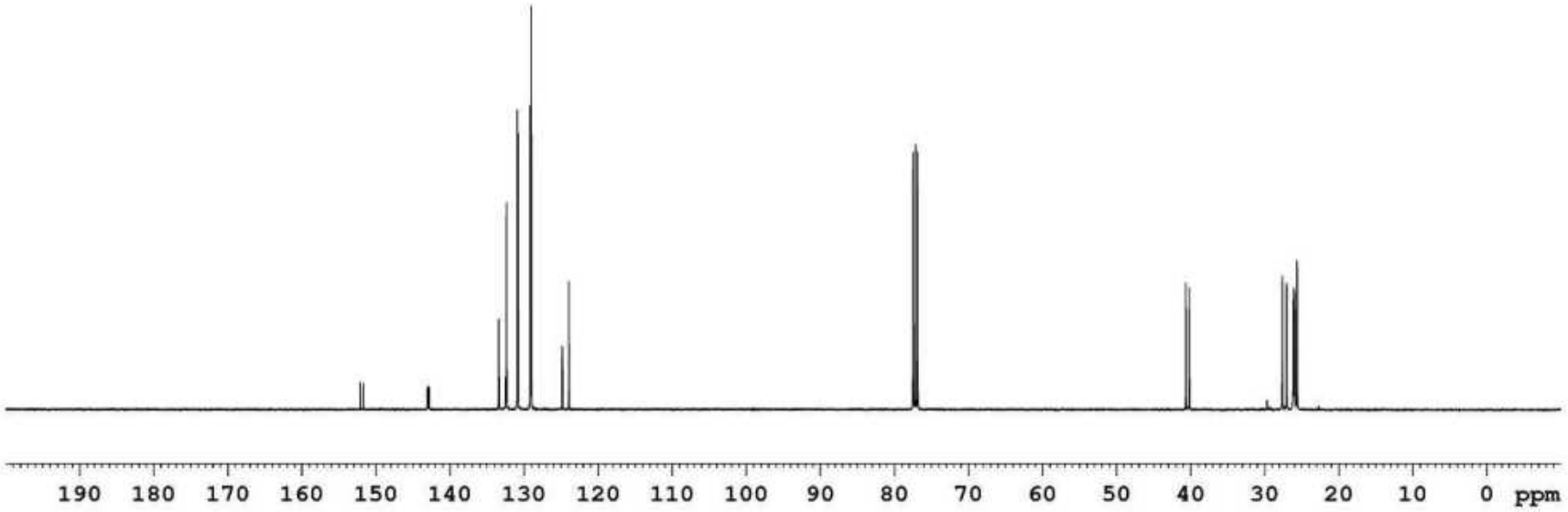
26.16
26.06
26.02
25.92
25.62


S
P
P(O)Ph2
S

8d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130
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110
100
90
80
70
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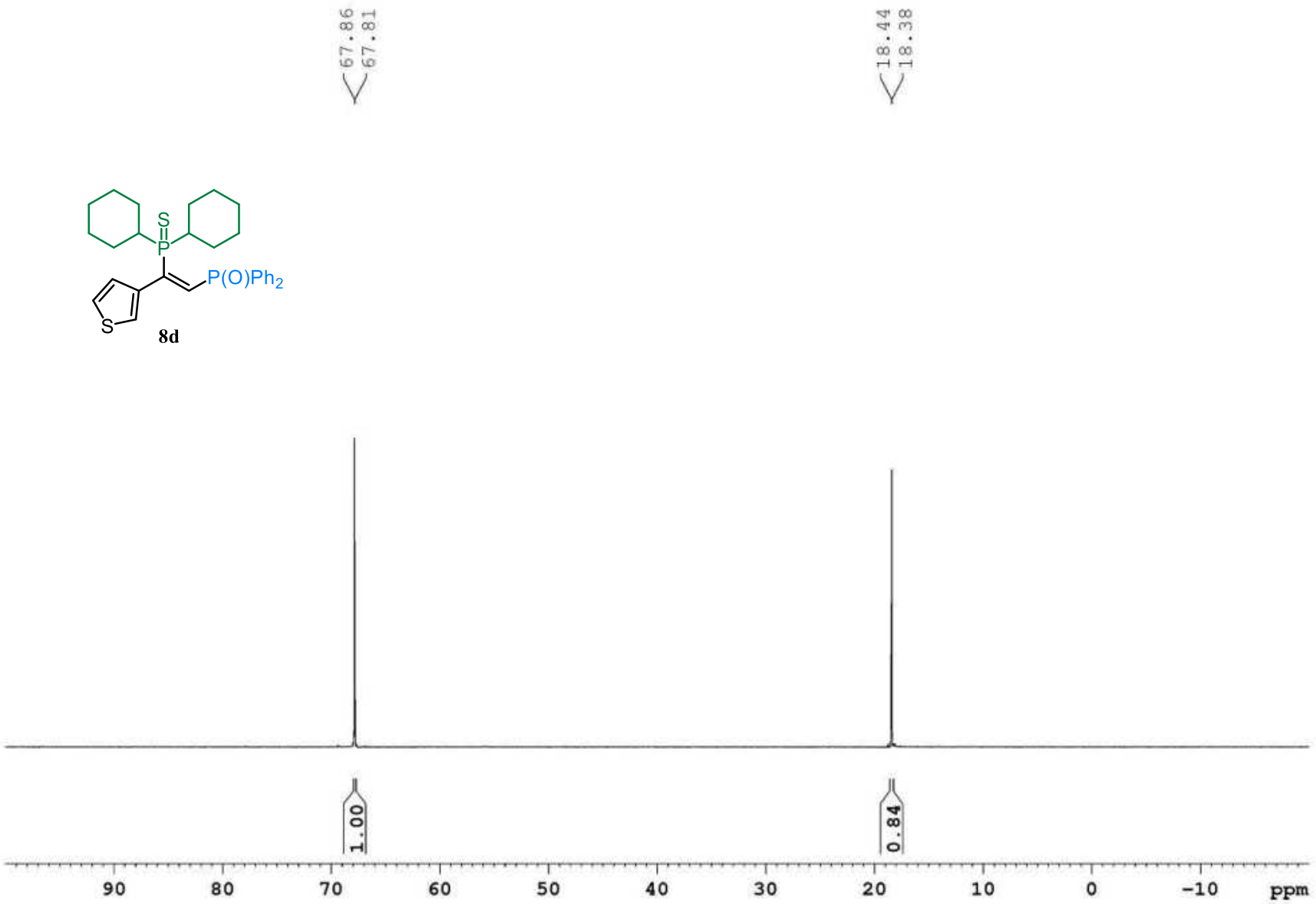
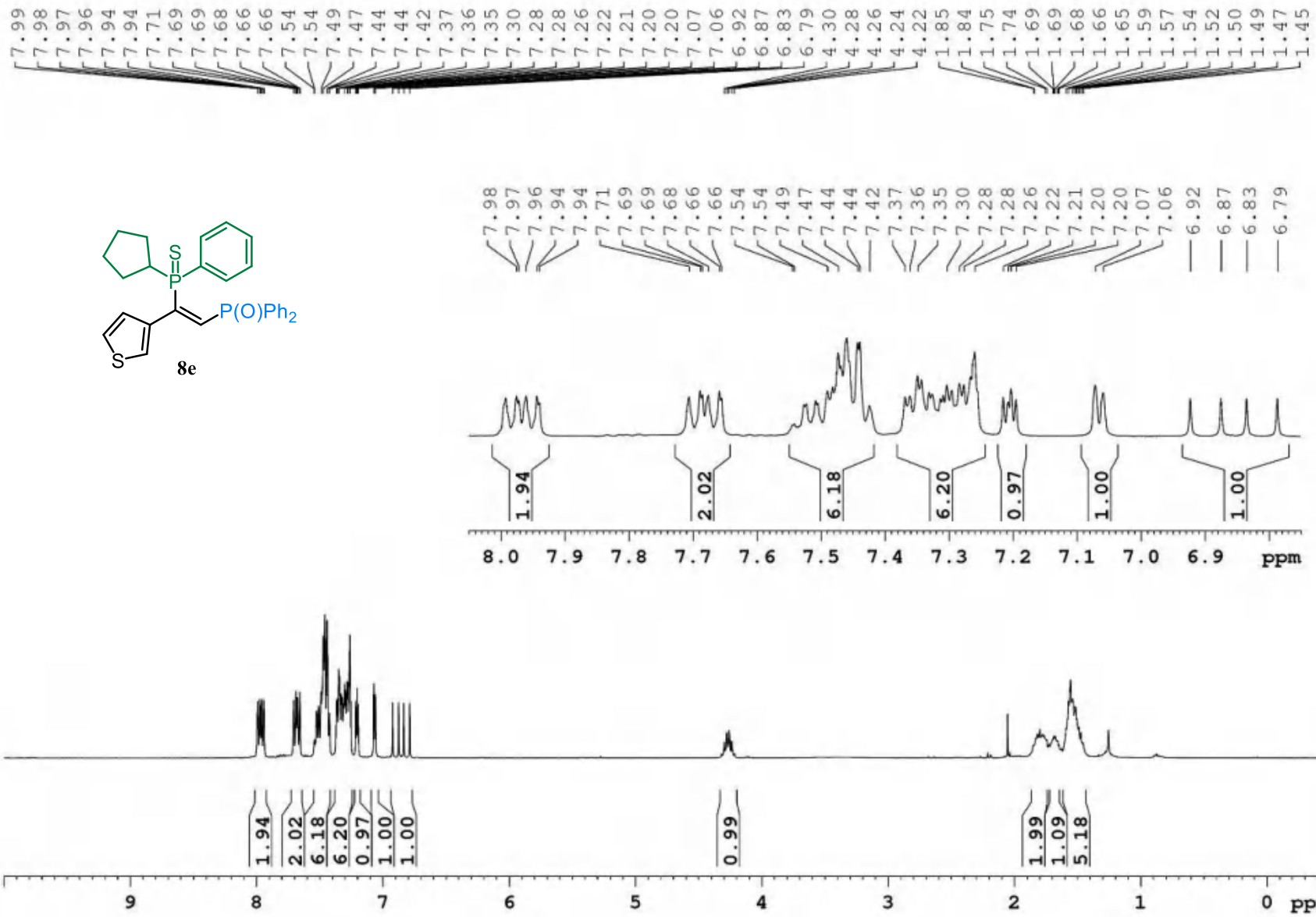
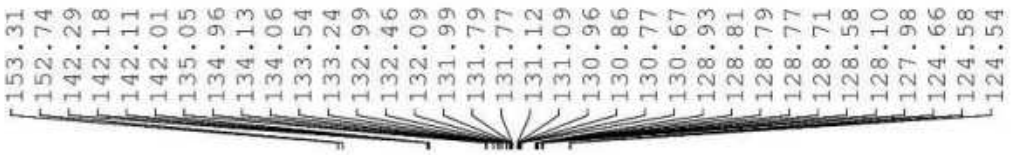
30
20
10
0
ppm


67.86
67.81
18.44
18.38
S
P
P(O)Ph2
S
8d
1.00
0.84
90
80
70
60
50
40
30
20
10
0
-10
ppm


7.99 7.98 7.97 7.96 7.94 7.94 7.71 7.69 7.69 7.68 7.66 7.66 7.54 7.54 7.49 7.47 7.44 7.44 7.42 7.37 7.36 7.35 7.30 7.28 7.28 7.26 7.22 7.21 7.20 7.20 7.07 7.06 6.92 6.87 6.83 6.79 4.30 4.28 4.26 4.24 4.22 1.85 1.84 1.75 1.74 1.69 1.69 1.68 1.66 1.65 1.59 1.57 1.54 1.52 1.50 1.49 1.47 1.45
S
P
P(O)Ph2
S
8e
1.94 2.02 6.18 6.20 0.97 1.00 1.00
8.0 7.9 7.8 7.7 7.6 7.5 7.4 7.3 7.2 7.1 7.0 6.9 ppm
1.94 2.02 6.18 6.20 0.97 1.00 1.00 0.99 1.99 1.09 5.18
9 8 7 6 5 4 3 2 1 0 ppm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134.96
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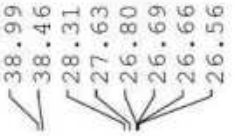
134.06
133.54
133.24
132.99
132.46
132.09
131.99
131.79
131.77
131.12
131.09
130.96
130.86
130.77
130.67
128.93
128.81
128.79
128.77
128.71
128.58
128.10
127.98
124.66
124.58
124.54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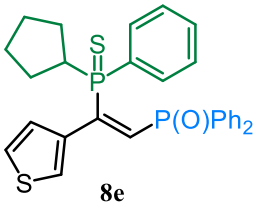
26.69
26.66
26.56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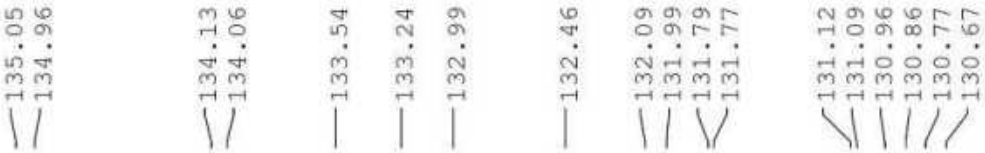
P
P(O)Ph2
S

8e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132.46
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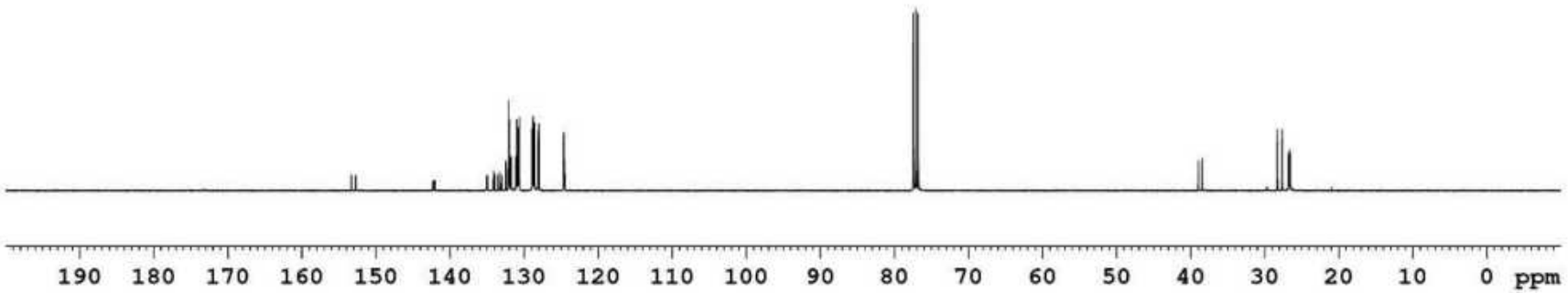
131.09
130.96
130.86
130.77
130.67


135
134
133
132
131
ppm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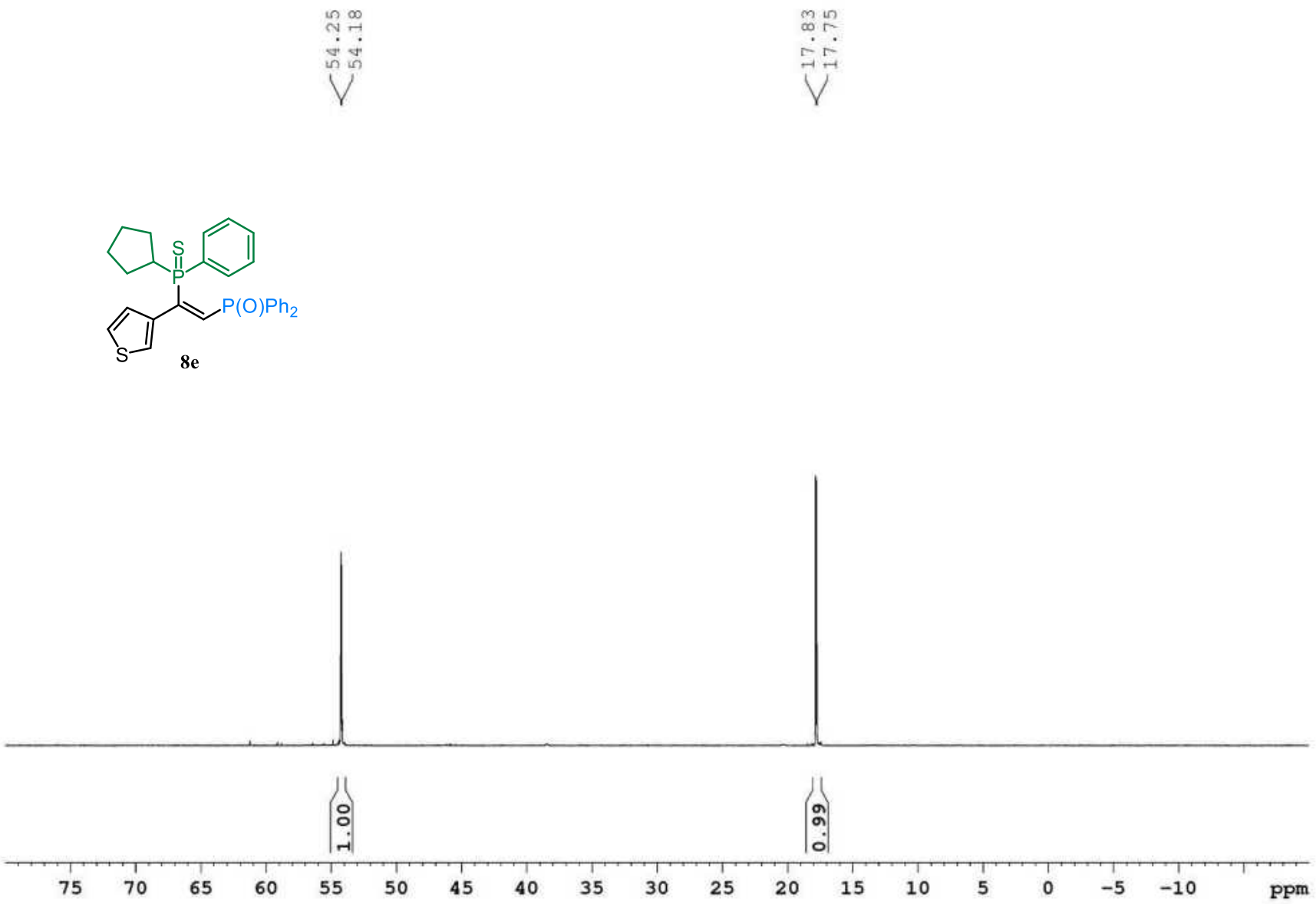
20
10
0
ppm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54.18
17.83
17.75
S
P
P(O)Ph2
S
1.00
0.99
75
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65
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50
45
40
35
30
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20
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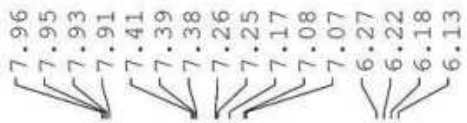
10
5
0
-5
-10
ppm

8e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7.91
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7.38
7.26
7.25
7.17
7.08
7.07
6.27
6.22
6.18
6.13
4.44
4.42
4.40
4.38
4.35
1.98
1.94
1.92
1.91
1.89
1.88
1.86
1.83
1.79
1.72
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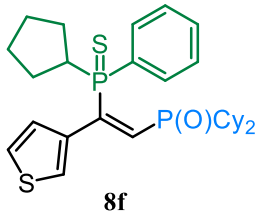
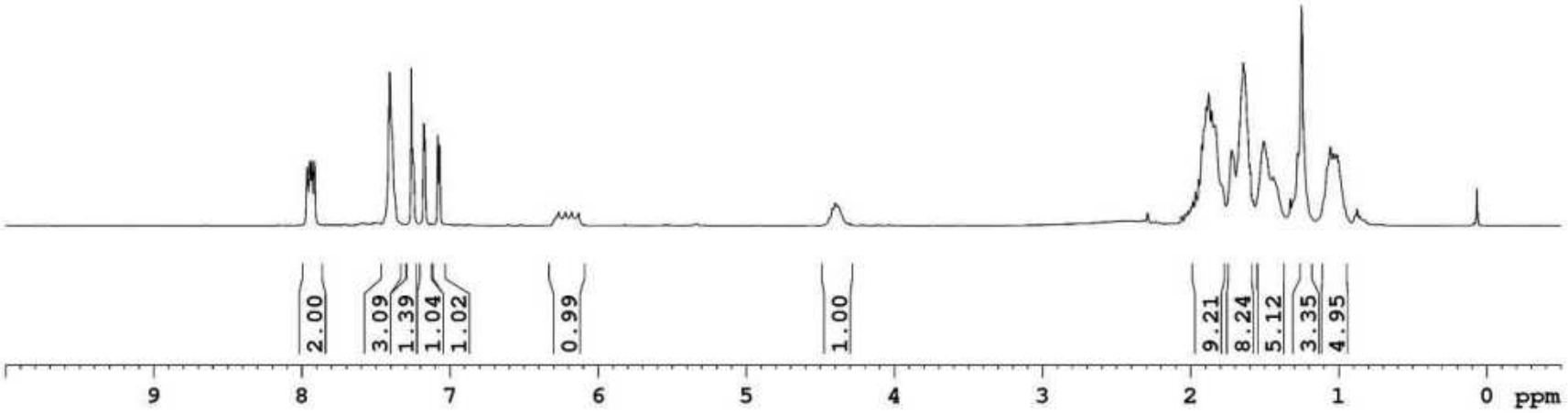
1.25
1.09
1.06
1.03
1.01
0.97


S
P
P(O)Cy2
S

8f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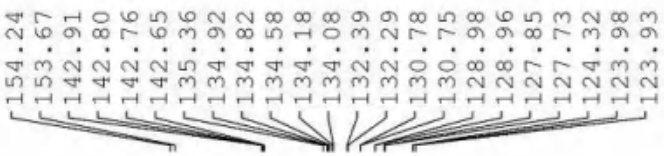
3.09
1.39
1.04
1.02
0.99
1.00
9.21
8.24
5.12
3.35
4.95
9
8
7
6
5
4
3
2
1
0
ppm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142.65
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134.92
134.82
134.58
134.18
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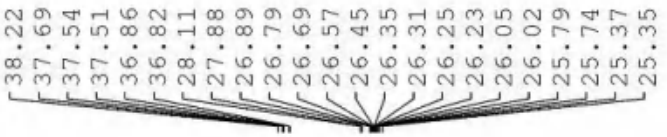
132.29
130.78
130.75
128.98
128.96
127.85
127.73
124.32
123.98
123.93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26.79
26.69
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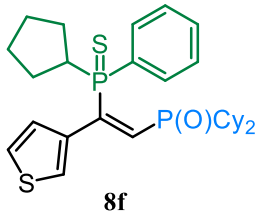
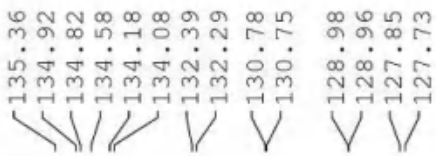
26.31
26.25
26.23
26.05
26.02
25.79
25.74
25.37
25.35


S
P
P(O)Cy2
S

8f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134.18
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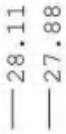
130.75
128.98
128.96
127.85
127.73


124.32
123.98
123.93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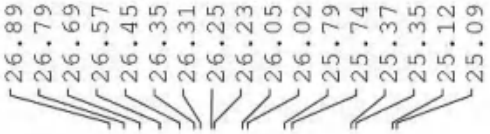
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26.79
26.69
26.57
26.45
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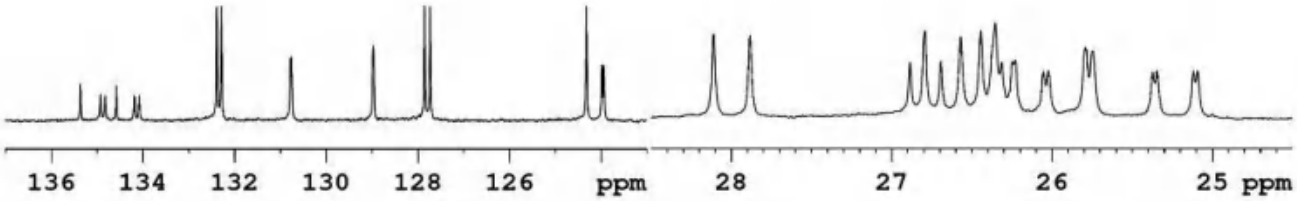
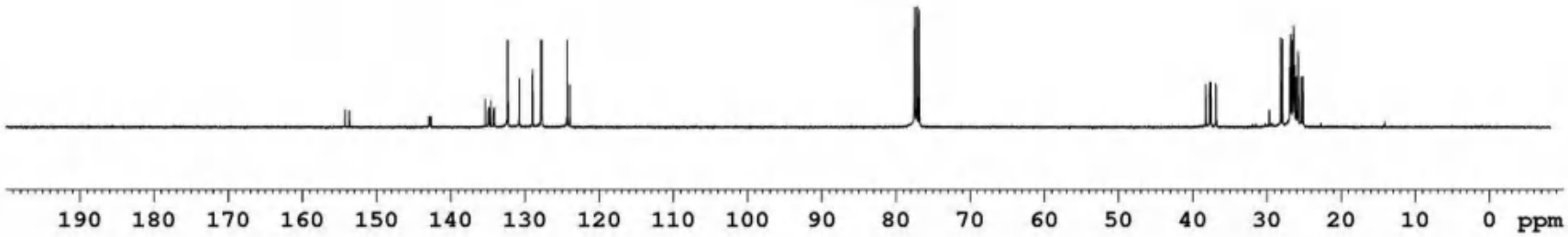
26.02
25.79
25.74
25.37
25.35
25.12
25.09


136
134
132
130
128
126
ppm
28
27
26
25 ppm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150
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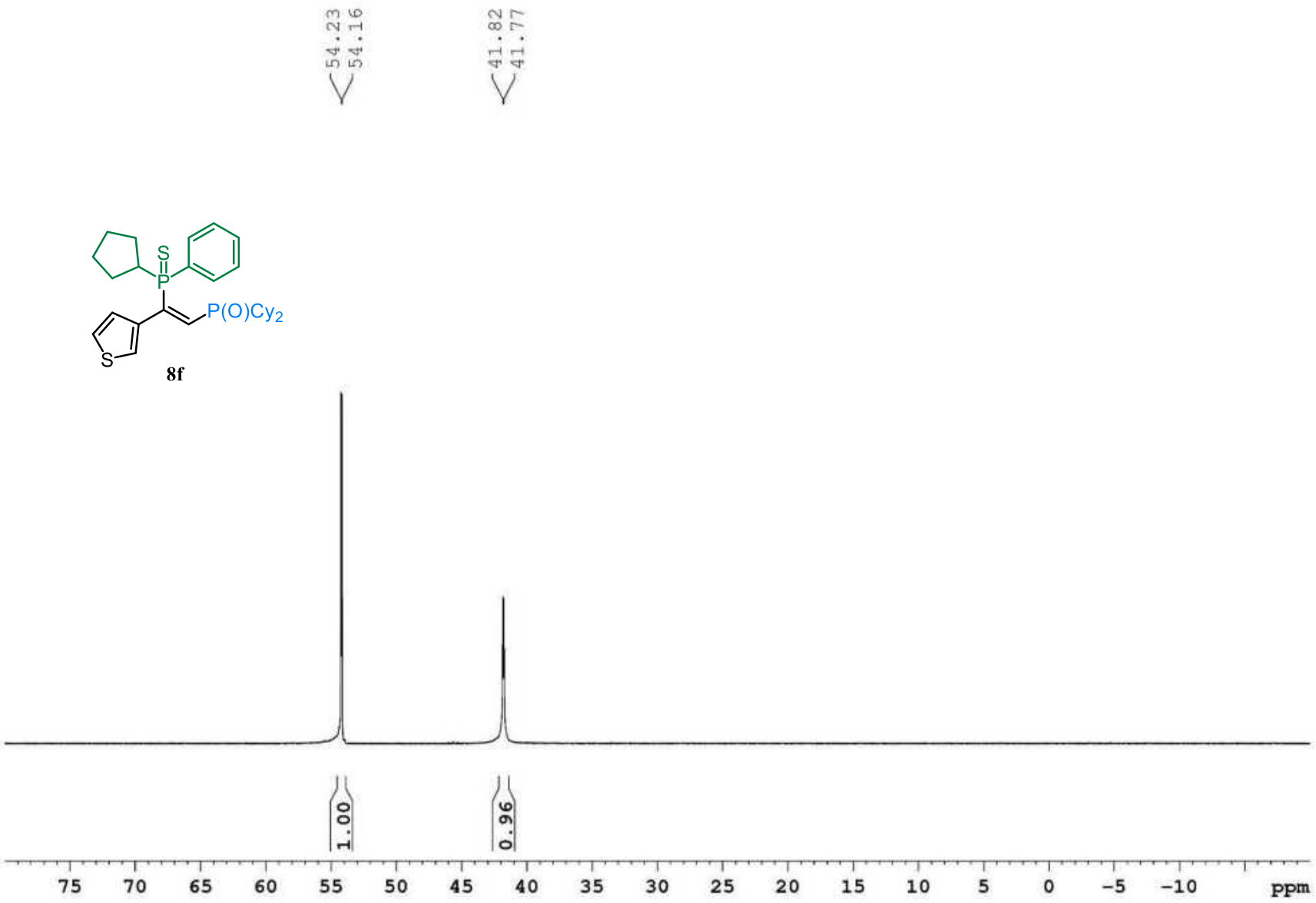
80
70
60
50
40
30
20
10
0 ppm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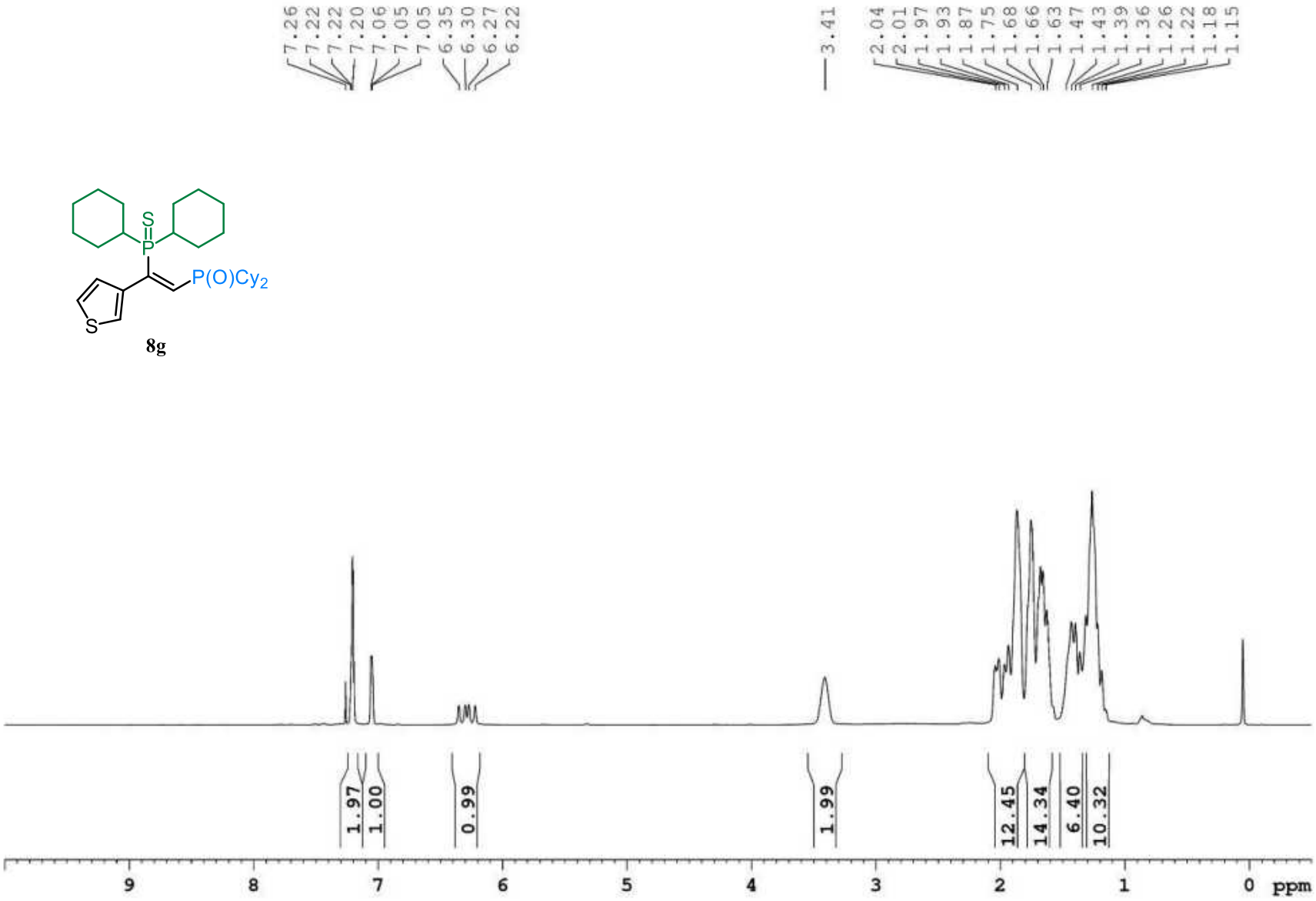
41.82
41.77
S
P
P(O)Cy2
S
8f
1.00
0.96
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm

S
P
P(O)Cy2
S

8g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7.22
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7.05
7.05
6.35
6.30
6.27
6.22
3.41
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2.01
1.97
1.93
1.87
1.75
1.68
1.66
1.63
1.47
1.43
1.39
1.36
1.26
1.22
1.18
1.15
1.97
1.00
0.99
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14.34
6.40
10.32
9
8
7
6
5
4
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2
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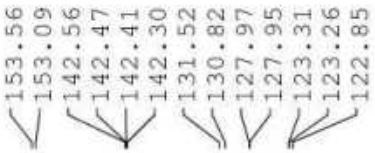
ppm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127.97
127.95
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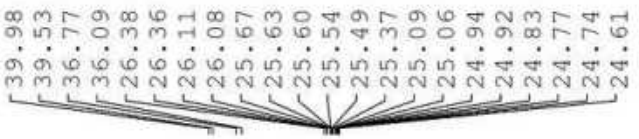
123.26
122.85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26.08
25.67
25.63
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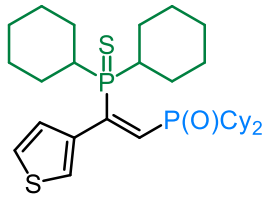
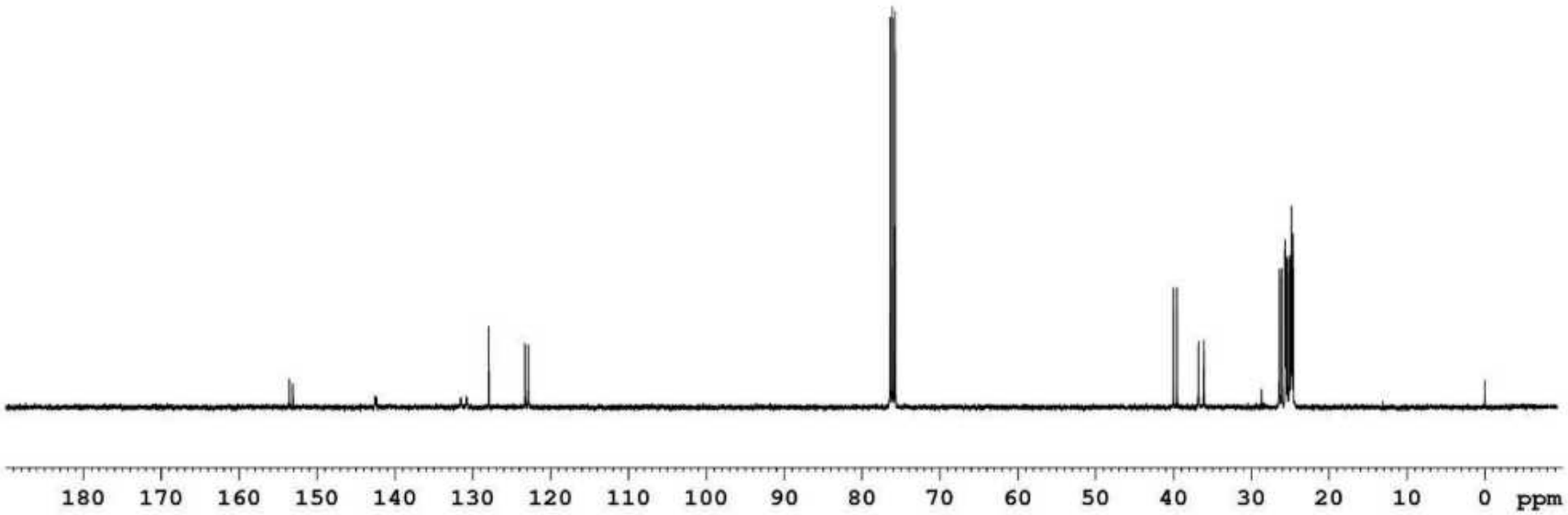
25.49
25.37
25.09
25.06
24.94
24.92
24.83
24.77
24.74
24.61


S
P
P(O)Cy2
S

8g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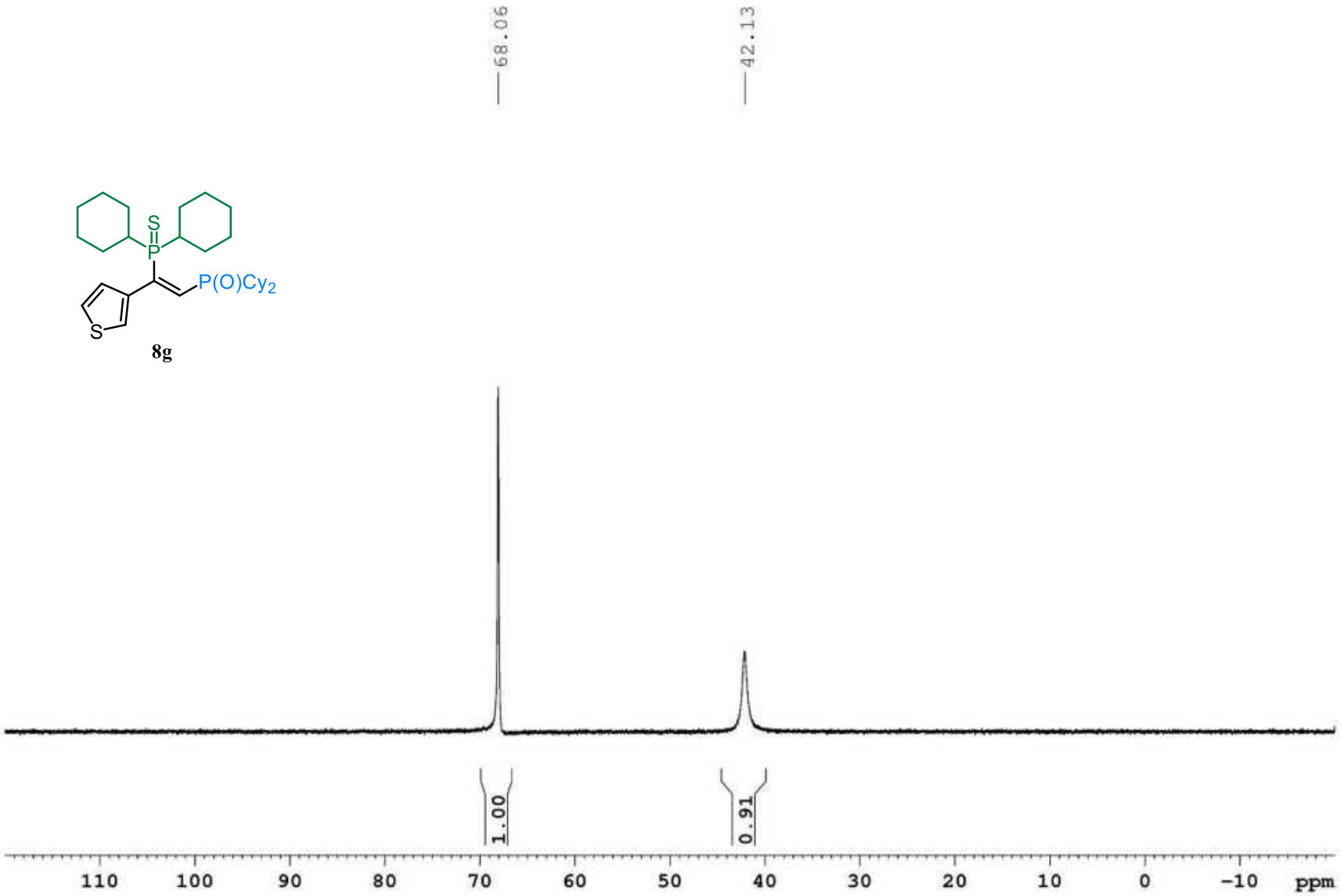
30
20
10
0
ppm

S
P
P(O)Cy2
S

8g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0.91
110
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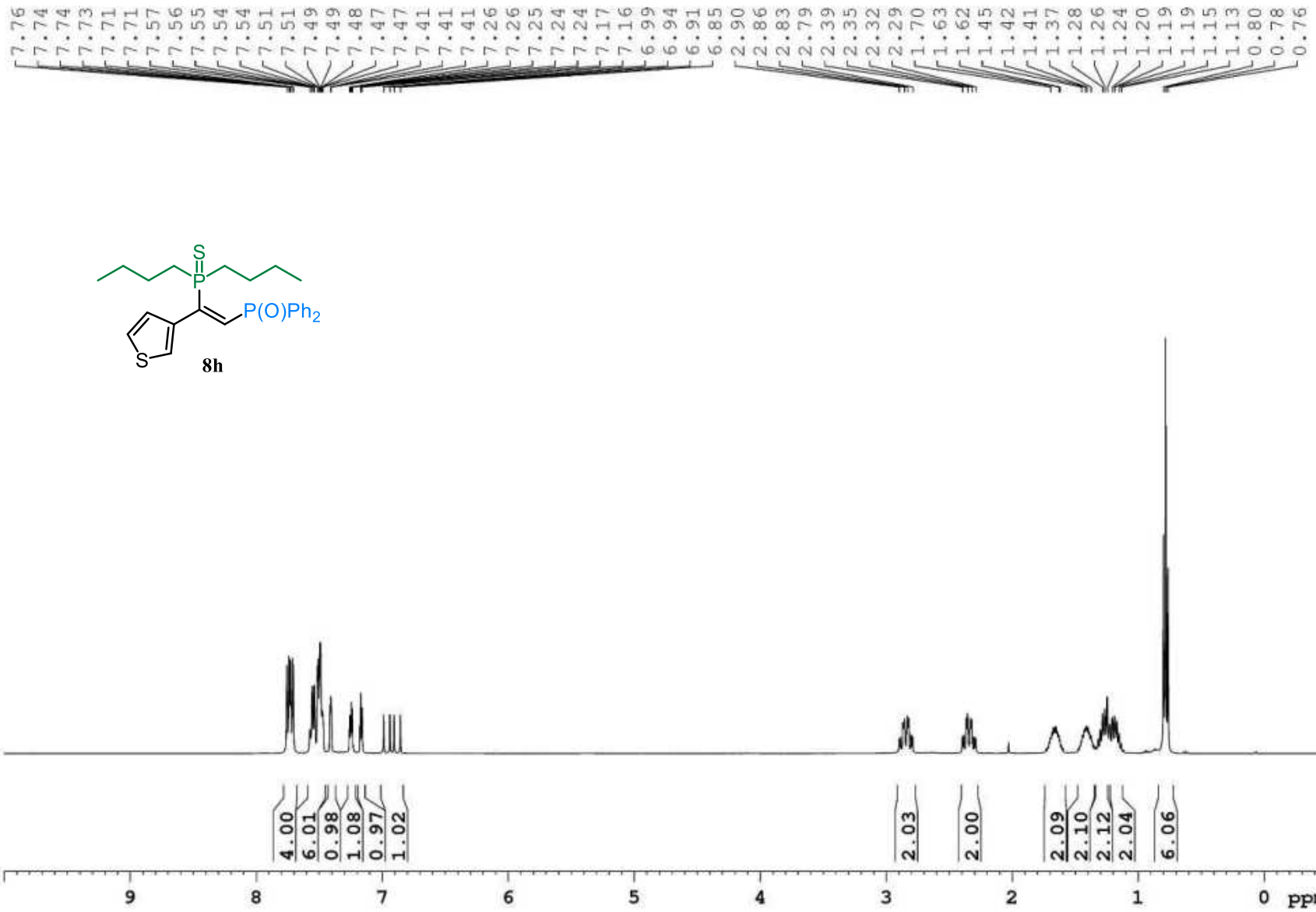
90
80
70
60
50
40
30
20
10
0
−10
ppm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7.74
7.74
7.73
7.71
7.71
7.57
7.56
7.55
7.54
7.54
7.51
7.51
7.49
7.49
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7.47
7.47
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7.41
7.41
7.26
7.26
7.25
7.24
7.24
7.17
7.16
6.99
6.94
6.91
6.85
2.90
2.86
2.83
2.79
2.39
2.35
2.32
2.29
1.70
1.63
1.62
1.45
1.42
1.41
1.37
1.28
1.26
1.24
1.20
1.19
1.19
1.15
1.13
0.80
0.78
0.76
S
P
P(O)Ph2
S
8h
4.00
6.01
0.98
1.08
0.97
1.02
2.03
2.00
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2.12
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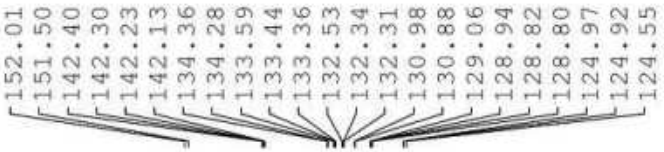
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129.06
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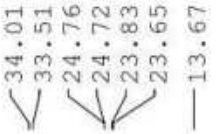
124.92
124.55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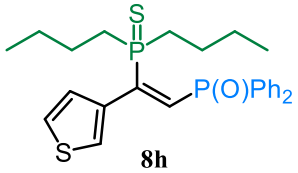
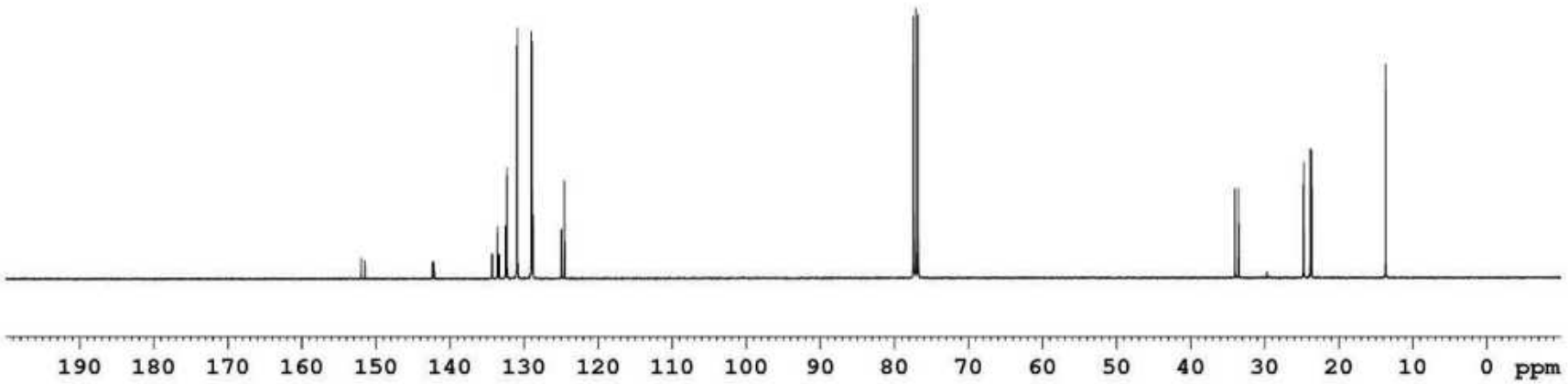

S
P
P(O)Ph2
S

8h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0
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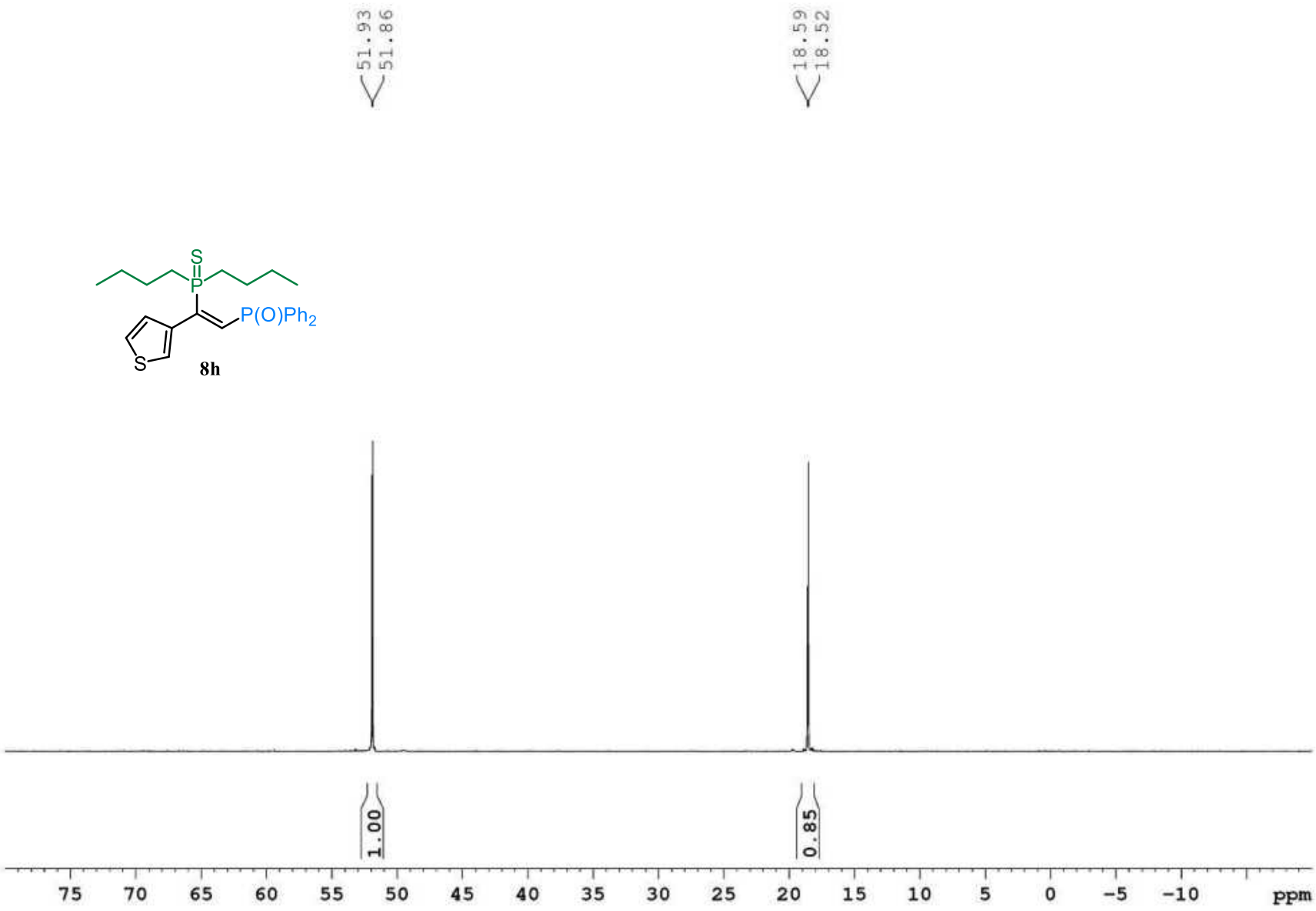
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51.86
18.59
18.52
S
P
P(O)Ph2
S
8h
1.00
0.85
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35
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15
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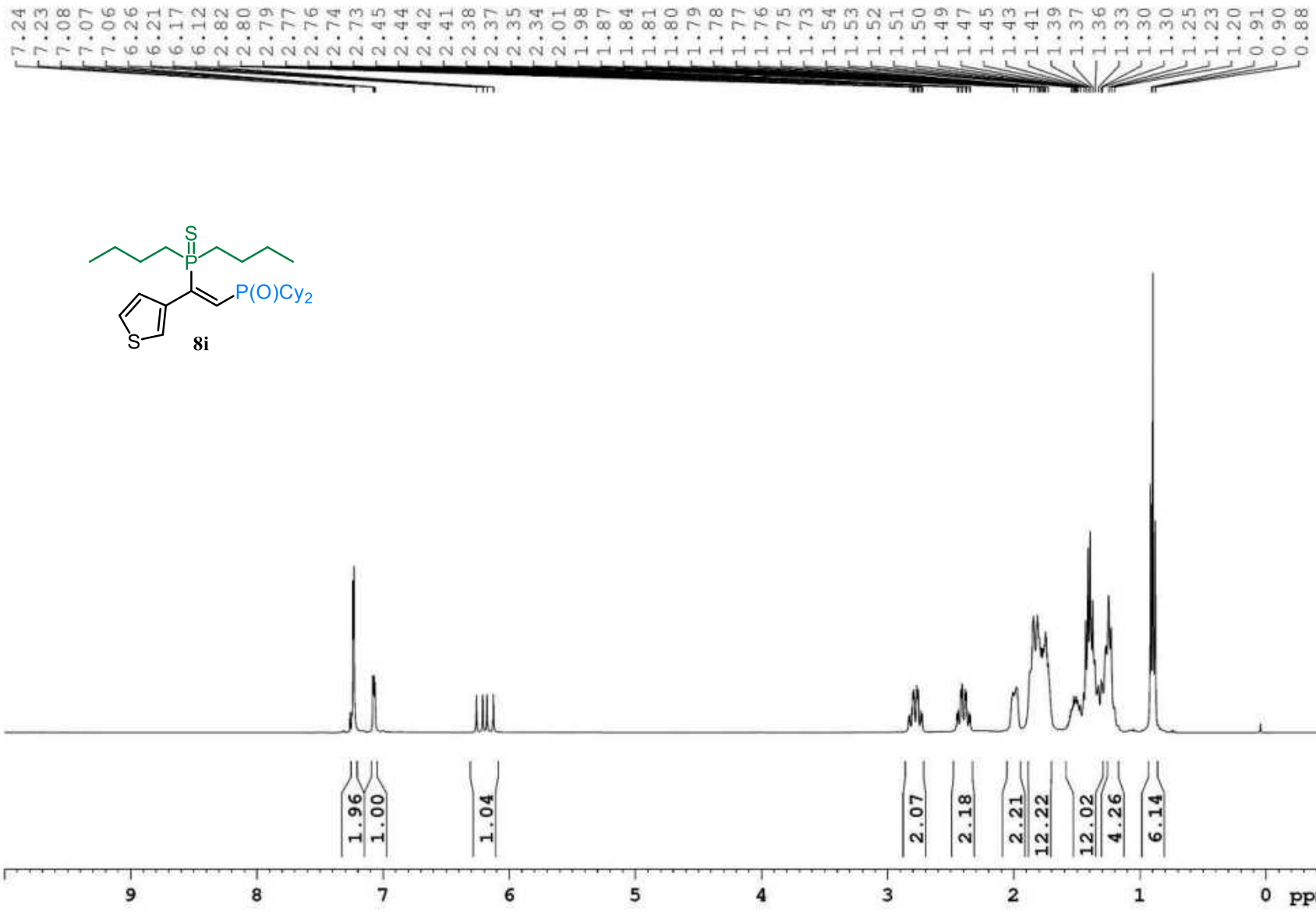
-10
ppm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6.17
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2.79
2.77
2.76
2.74
2.73
2.45
2.44
2.42
2.41
2.38
2.37
2.35
2.34
2.01
1.98
1.87
1.84
1.81
1.80
1.79
1.78
1.77
1.76
1.75
1.73
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1.53
1.52
1.51
1.50
1.49
1.47
1.45
1.43
1.41
1.39
1.37
1.36
1.33
1.30
1.30
1.25
1.23
1.20
0.91
0.90
0.88
S
P
P(O)Cy2
S
8i
1.96
1.00
1.04
2.07
2.18
2.21
12.22
12.02
4.26
6.14
9
8
7
6
5
4
3
2
1
0
ppm

153.70
153.18
143.13
143.03
142.98
142.87
133.22
133.13
132.49
132.39
128.90
128.88
124.20
124.15

36.81
36.12
34.39
33.89
26.55
26.49
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24.00
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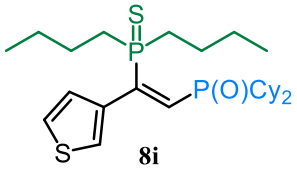
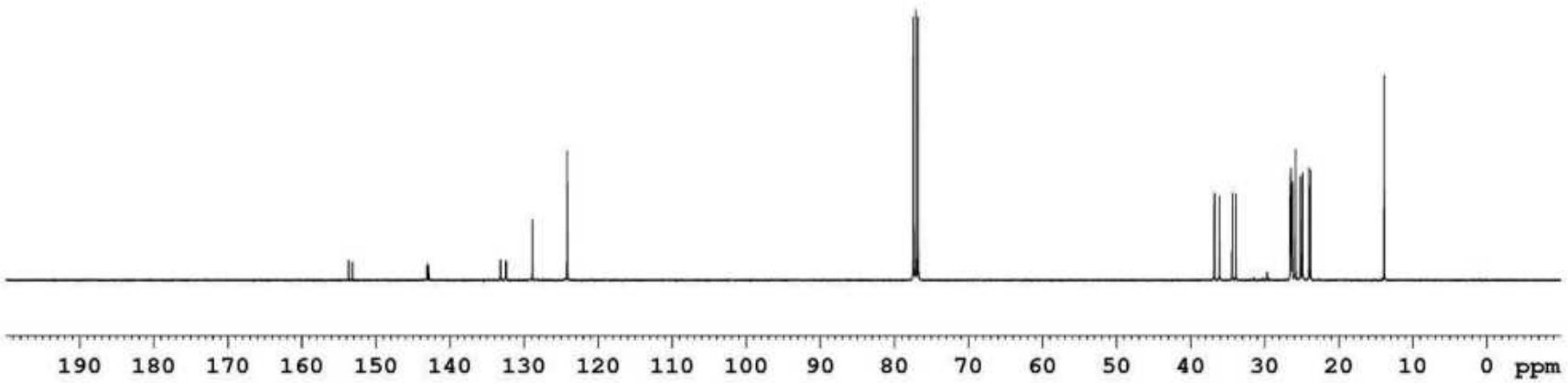
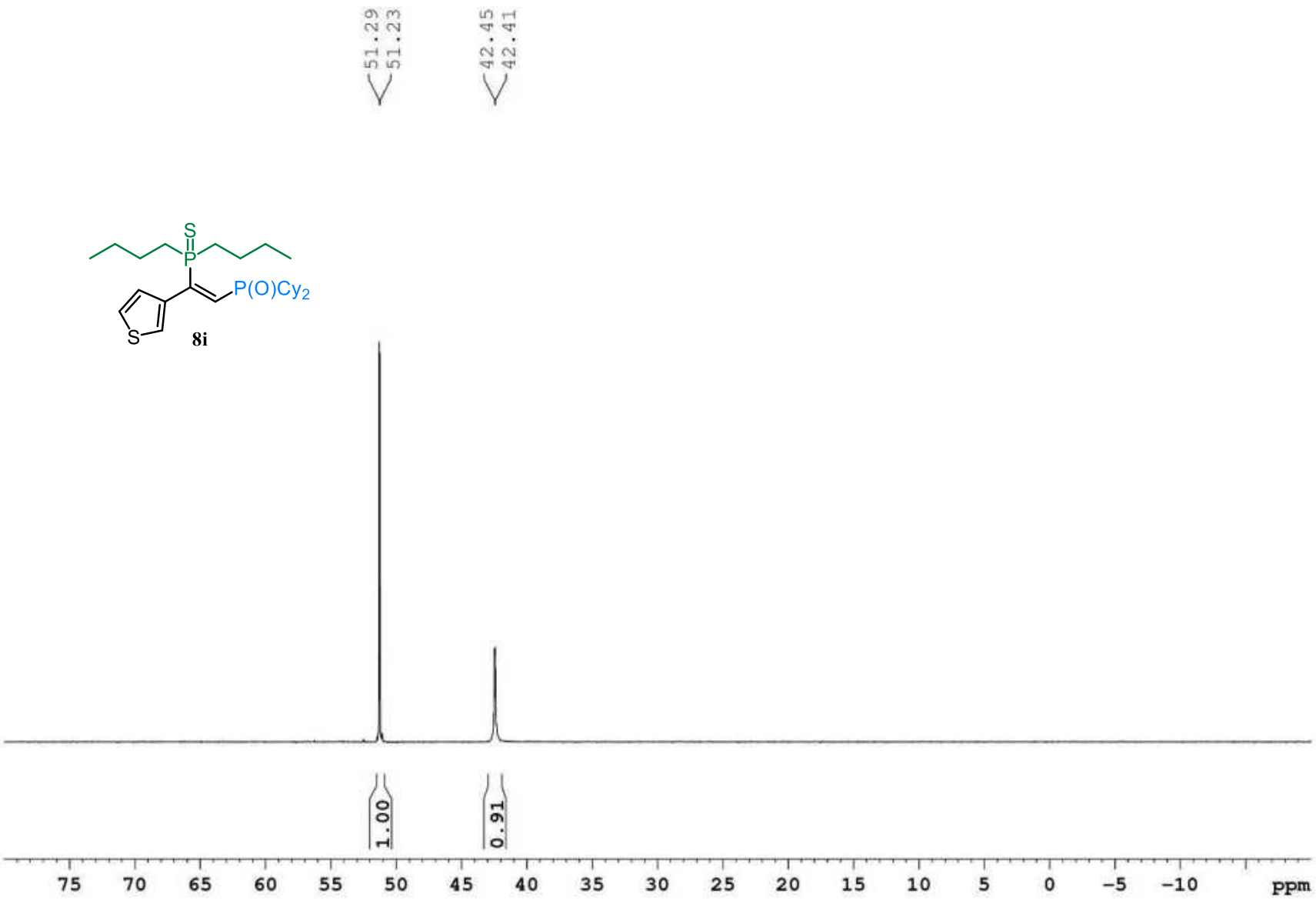
13.86



8i

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42.45
42.41
S
P
P(O)Cy2
S
8i
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0.91
75
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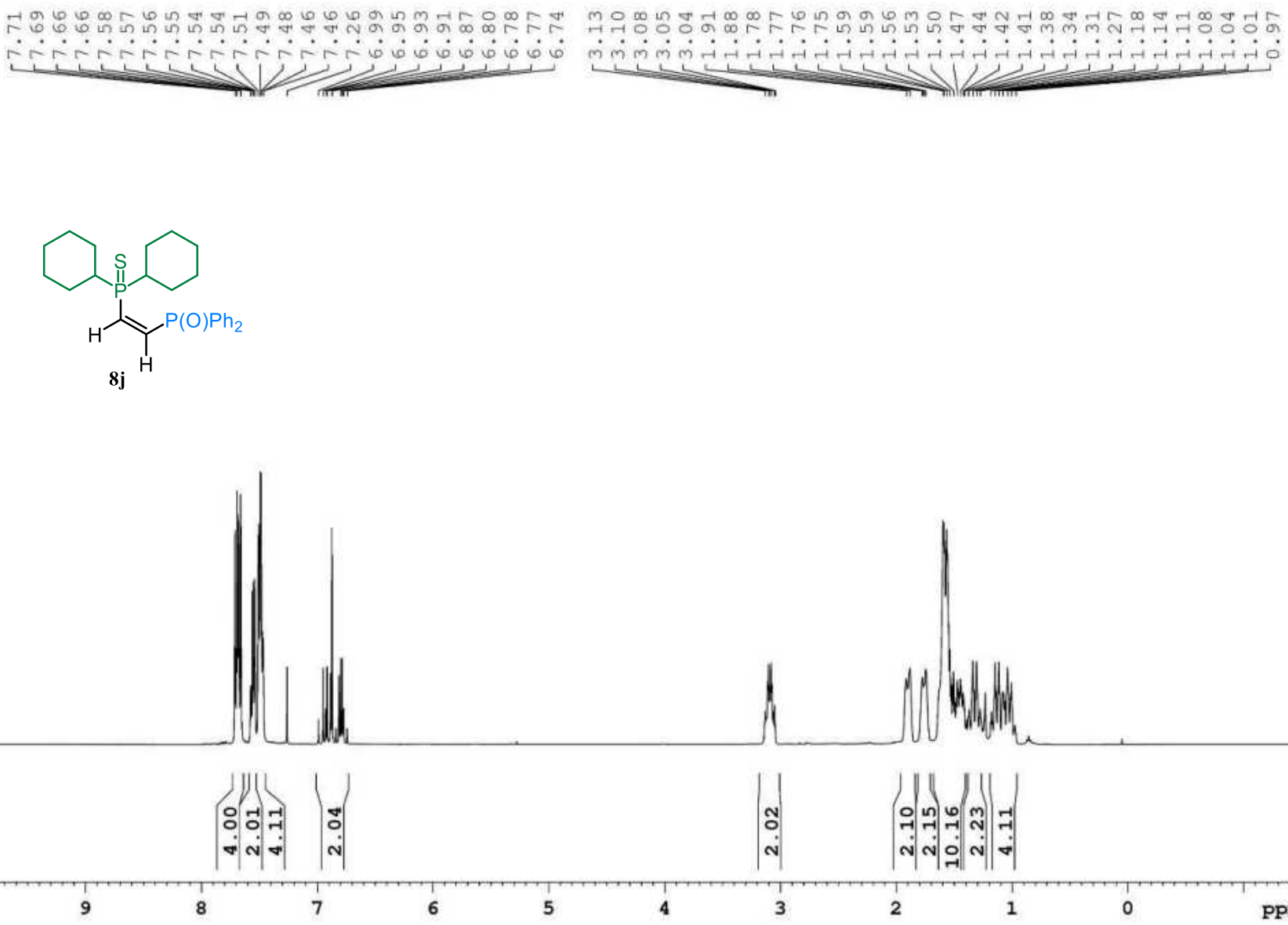
60
55
50
45
40
35
30
25
20
15
10
5
0
−5
−10
ppm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7.58
7.57
7.56
7.55
7.54
7.54
7.51
7.49
7.48
7.46
7.46
7.26
6.99
6.95
6.93
6.91
6.87
6.80
6.78
6.77
6.74
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3.10
3.08
3.05
3.04
1.91
1.88
1.78
1.77
1.76
1.75
1.59
1.59
1.56
1.53
1.50
1.47
1.44
1.42
1.41
1.38
1.34
1.31
1.27
1.18
1.14
1.11
1.08
1.04
1.01
0.97
S
P
H
P(O)Ph2
H
8j
4.00
2.01
4.11
2.04
2.02
2.10
2.15
10.16
2.23
4.11
9
8
7
6
5
4
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2
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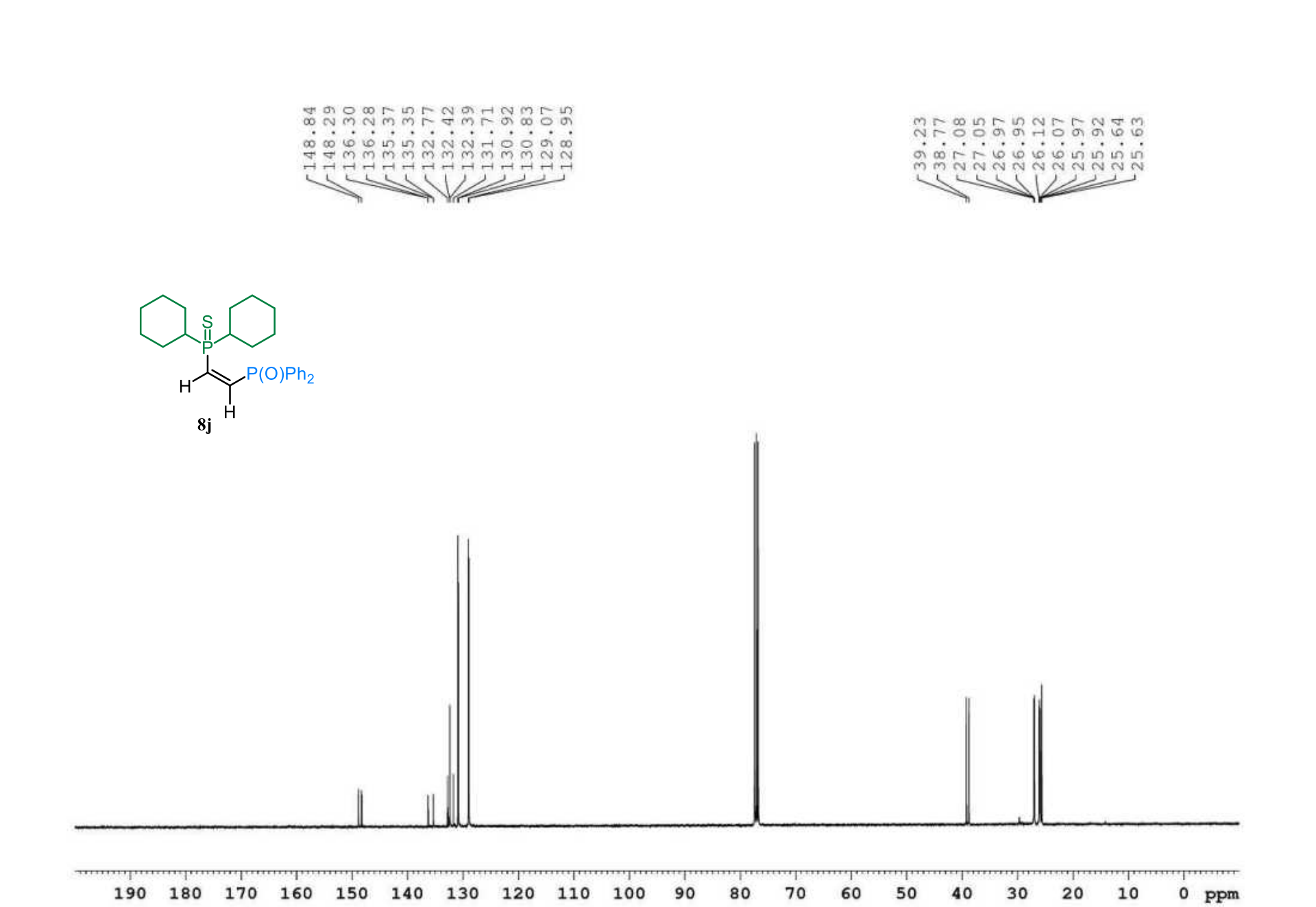
0
ppm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132.77
132.42
132.39
131.71
130.92
130.83
129.07
128.95
39.23
38.77
27.08
27.05
26.97
26.95
26.12
26.07
25.97
25.92
25.64
25.63
S
P
H
P(O)Ph2
H
8j
190
180
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140
130
120
110
100
90
80
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60
50
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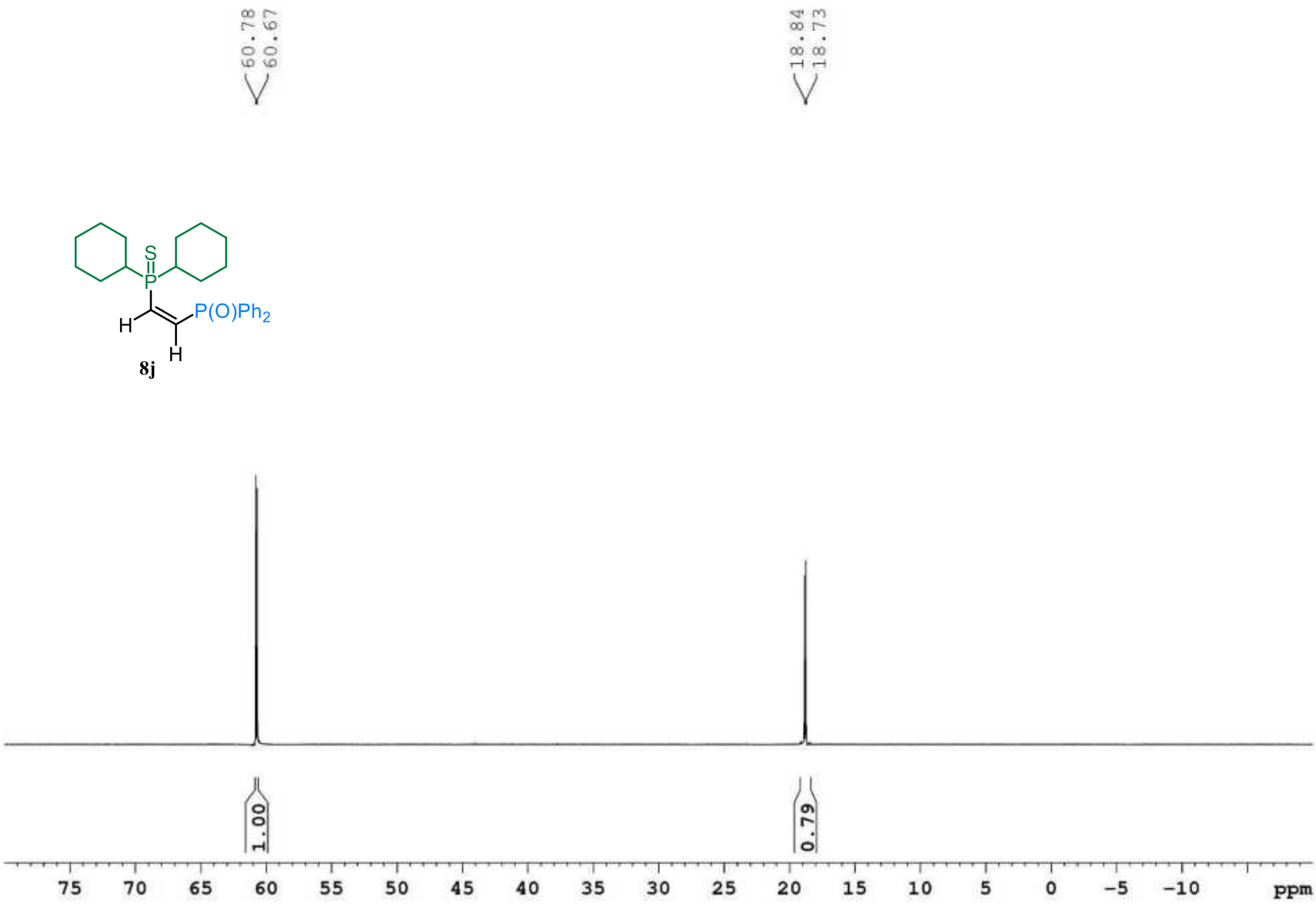
30
20
10
0
ppm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18.84
18.73
S
P
H
P(O)Ph2
H
8j
1.00
0.79
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55
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40
35
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20
15
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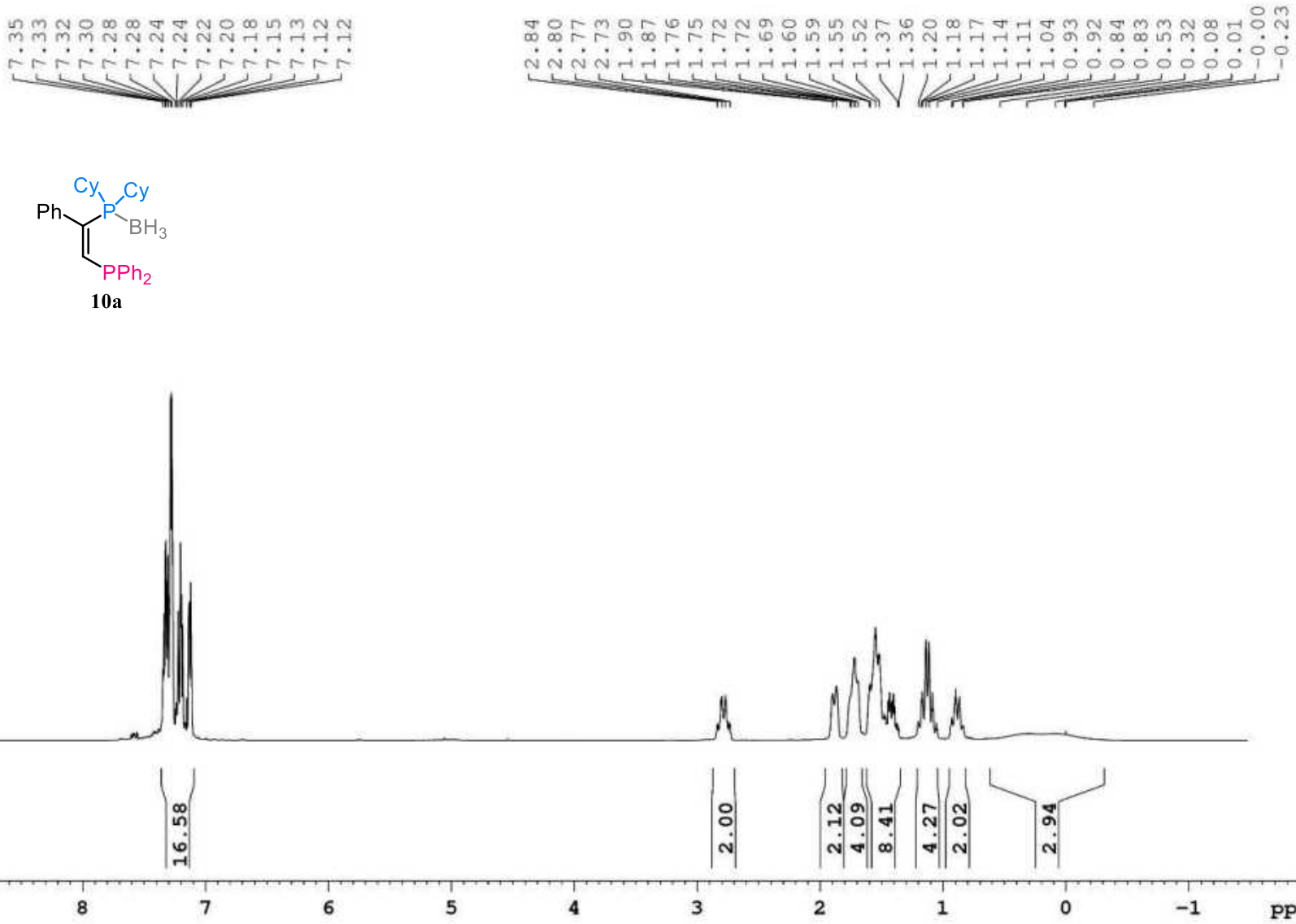
−5
−10
ppm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7.28
7.24
7.24
7.22
7.20
7.18
7.15
7.13
7.12
7.12
2.84
2.80
2.77
2.73
1.90
1.87
1.76
1.75
1.72
1.72
1.69
1.60
1.59
1.55
1.52
1.37
1.36
1.20
1.18
1.17
1.14
1.11
1.04
0.93
0.92
0.84
0.83
0.53
0.32
0.08
0.01
-0.00
-0.23
Cy
Cy
Ph
P
BH3
PPh2
10a
16.58
2.00
2.12
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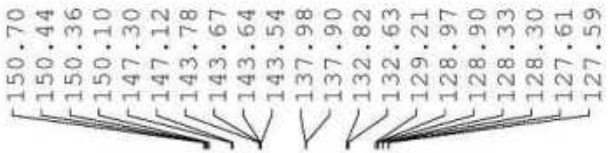
4.27
2.02
2.94
8
7
6
5
4
3
2
1
0
-1
ppm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143.64
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128.90
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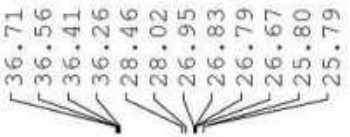
128.30
127.61
127.59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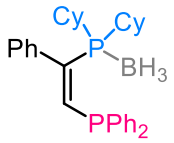
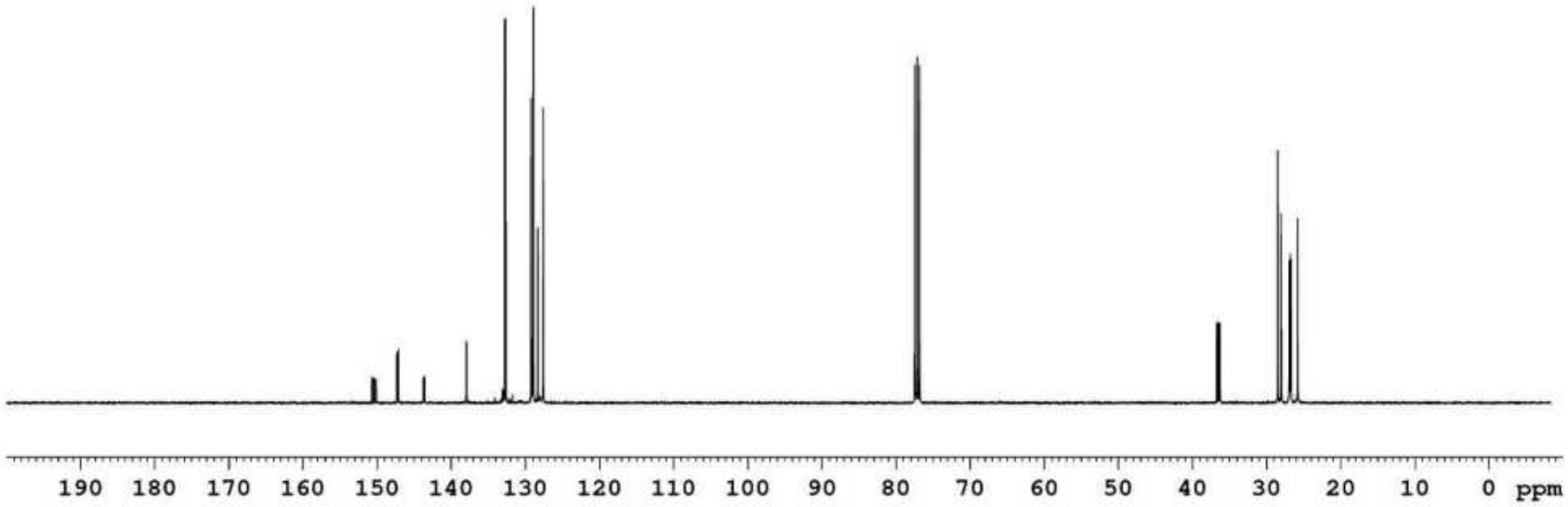
28.02
26.95
26.83
26.79
26.67
25.80
25.79


Cy
Cy
Ph
P
BH3
PPh2

10a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100
90
80
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60
50
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30
20
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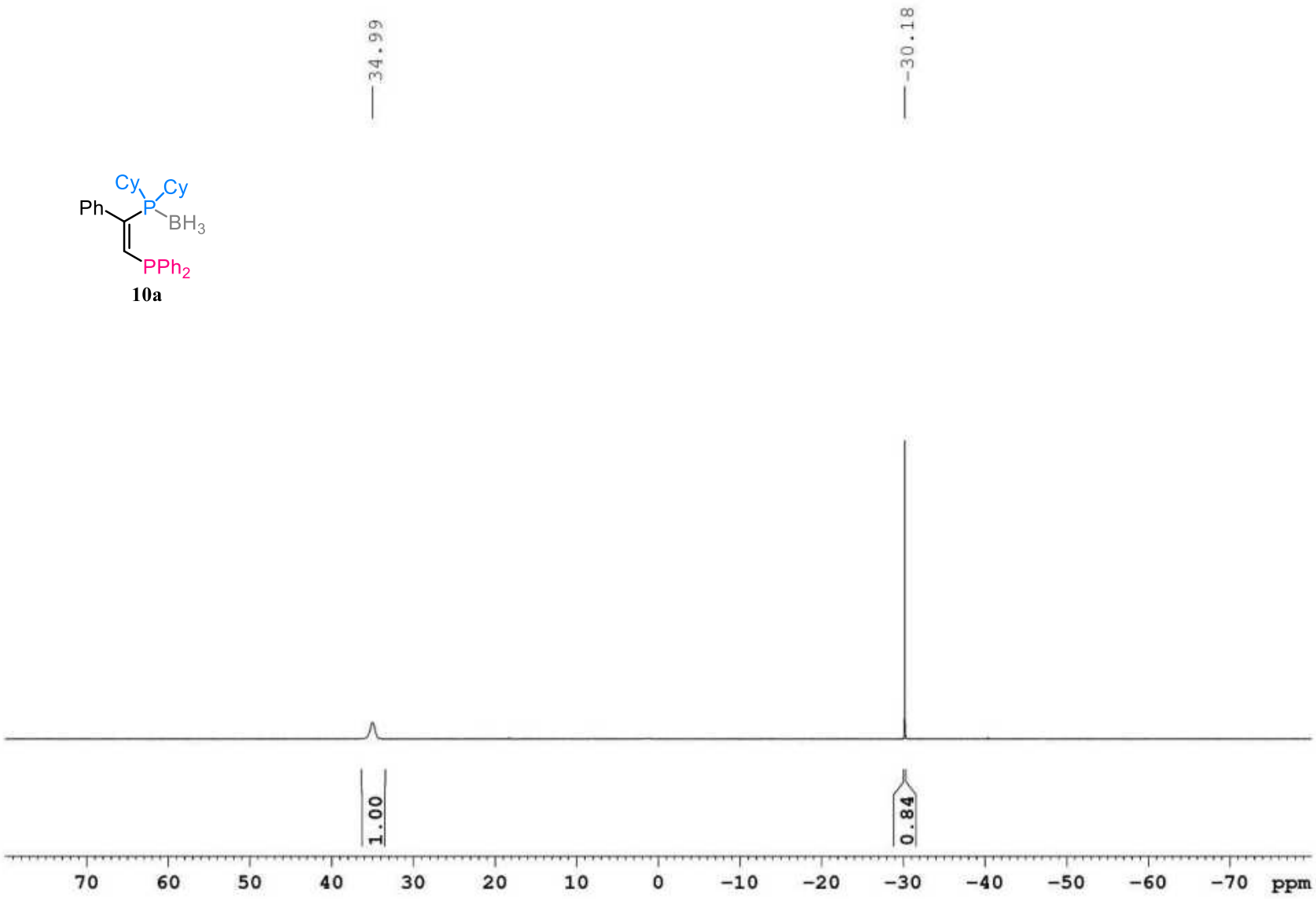
0
ppm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Cy
Cy
Ph
P
BH3
PPh2
10a
1.00
0.84
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60
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40
30
20
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0
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-20
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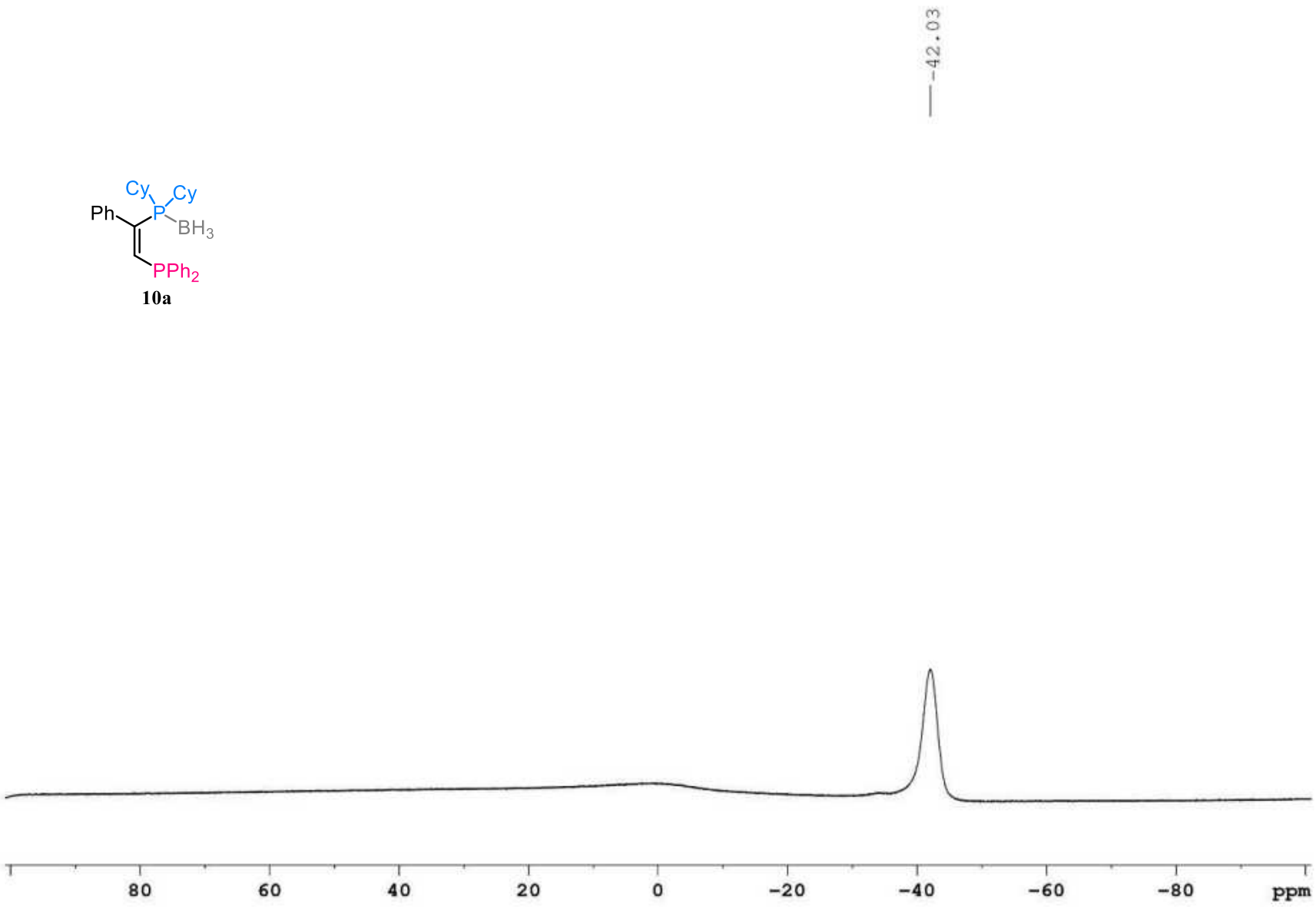
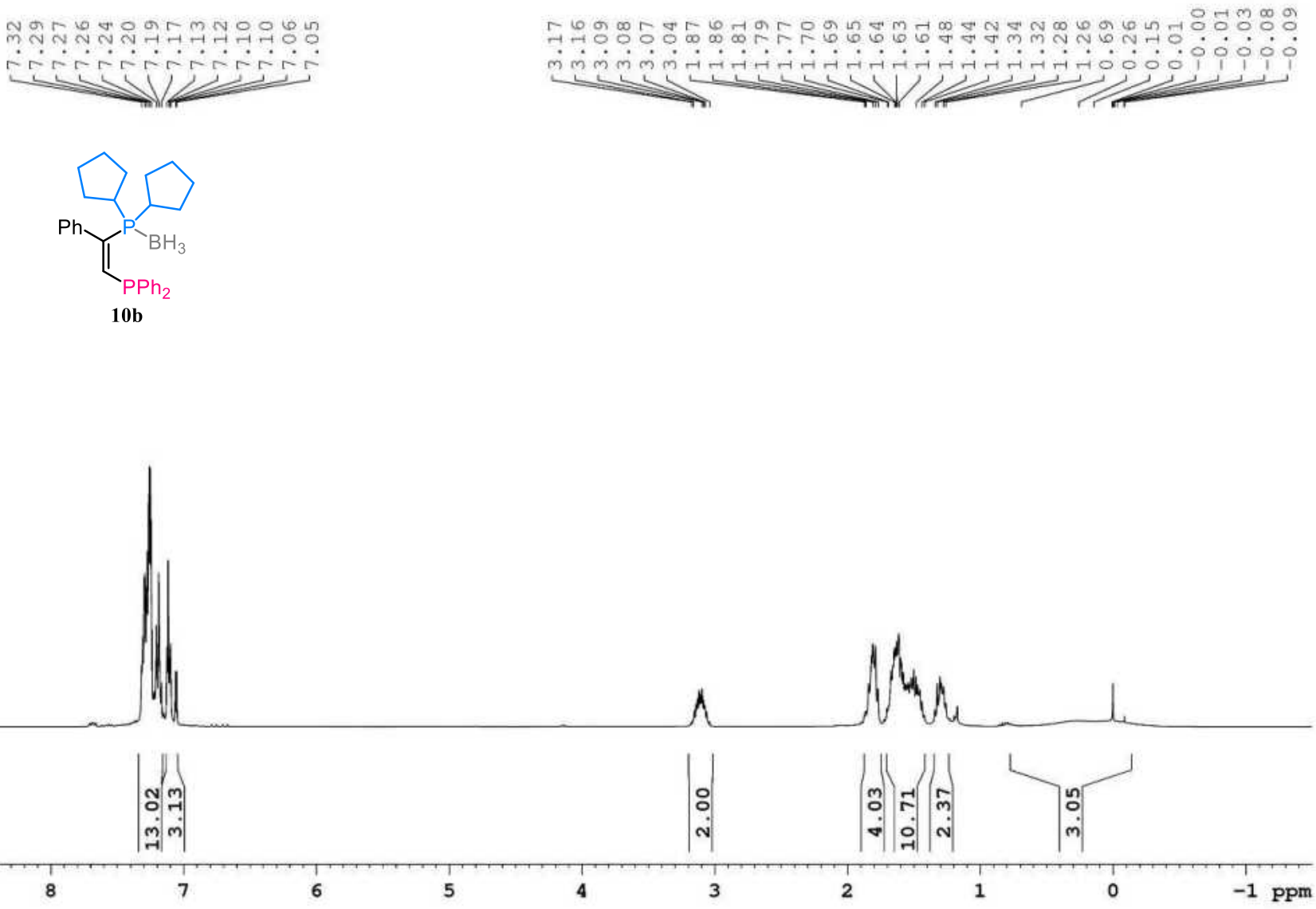
-40
-50
-60
-70
ppm

10a

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7.05
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3.16
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1.64
1.63
1.61
1.48
1.44
1.42
1.34
1.32
1.28
1.26
0.69
0.26
0.15
0.01
-0.00
-0.01
-0.03
-0.08
-0.09
Ph
P
BH3
PPh2
10b
13.02
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10.71
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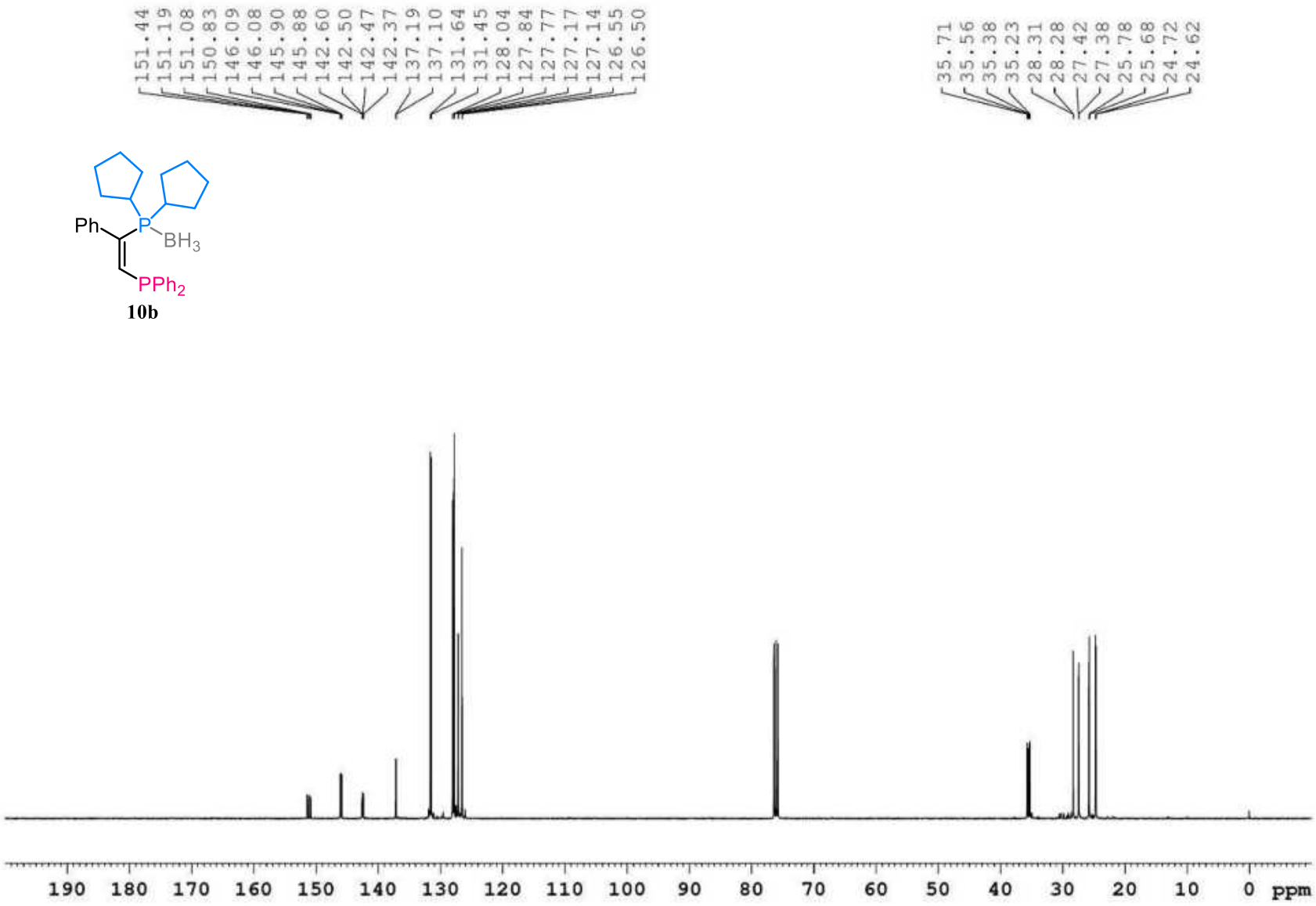
8
7
6
5
4
3
2
1
0
-1 ppm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146.08
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142.60
142.50
142.47
142.37
137.19
137.10
131.64
131.45
128.04
127.84
127.77
127.17
127.14
126.55
126.50
35.71
35.56
35.38
35.23
28.31
28.28
27.42
27.38
25.78
25.68
24.72
24.62
Ph
P
BH3
PPh2
190
180
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130
120
110
100
90
80
70
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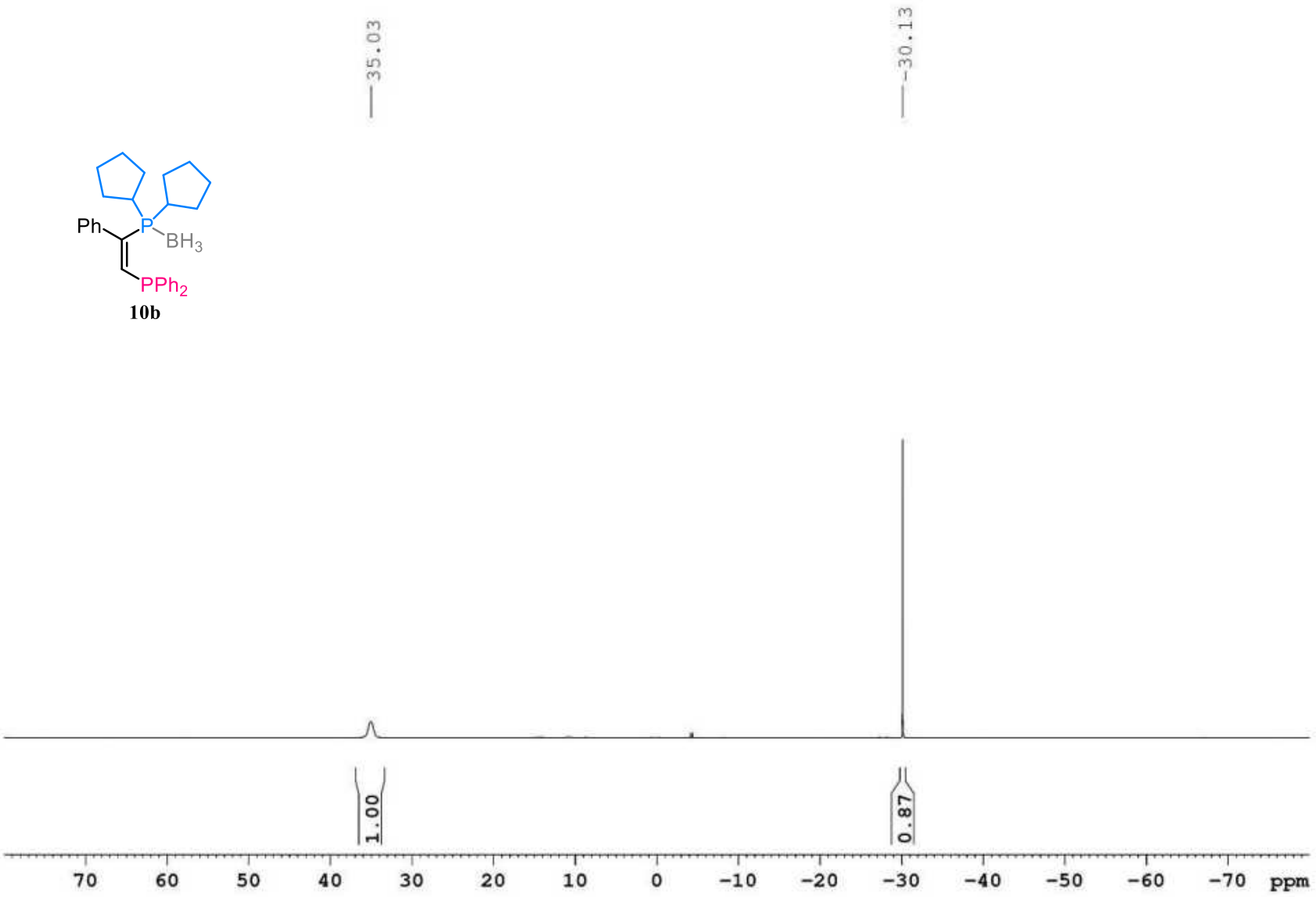
50
40
30
20
10
0
ppm

10b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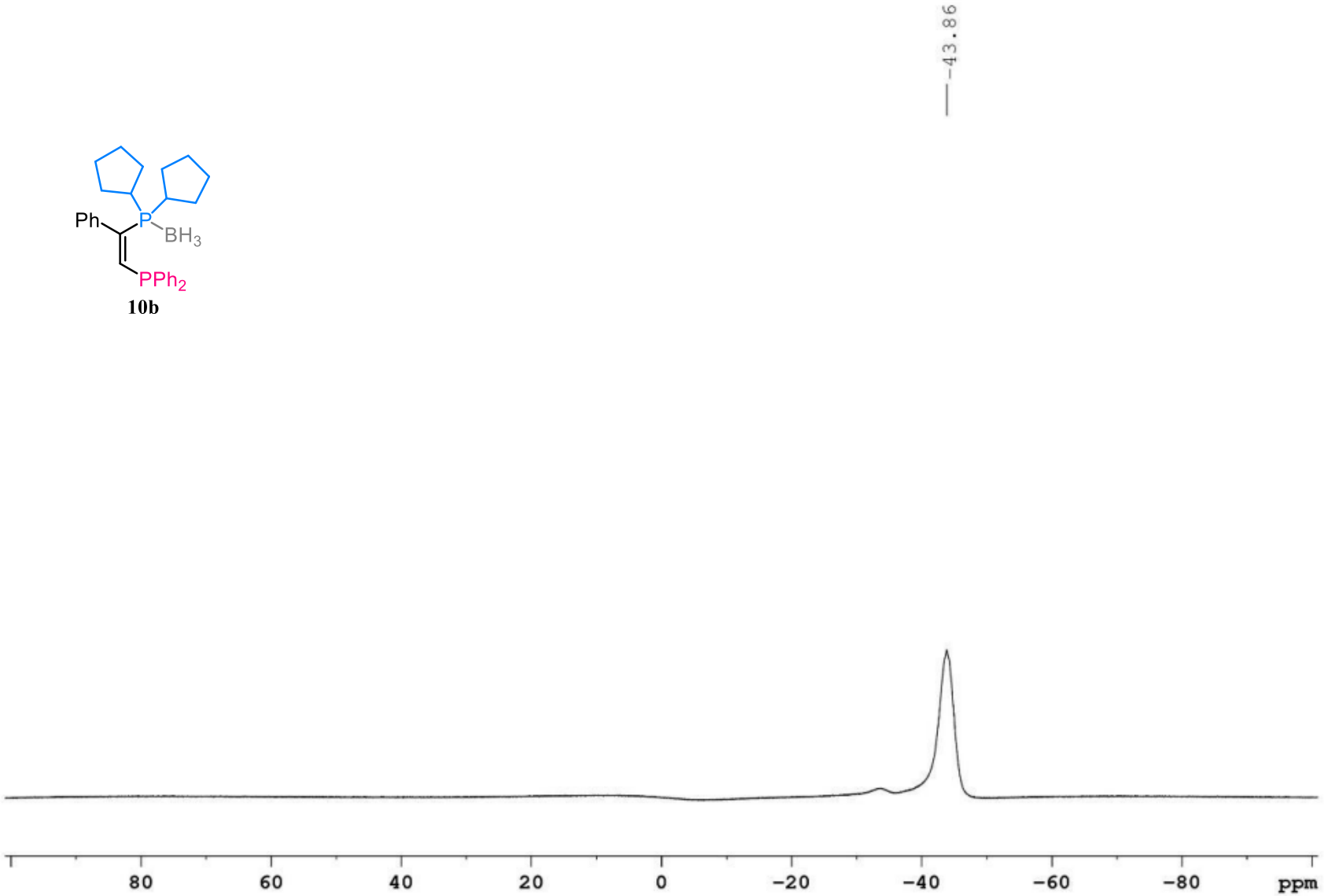
-30.13
Ph
P
BH3
PPh2
10b
1.00
0.87
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
ppm

10b




7.52
7.50
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7.48
7.48
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7.38
7.37
7.35
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7.33
7.31
7.26
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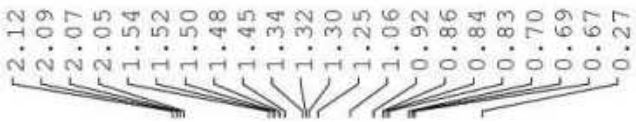
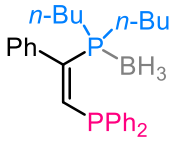
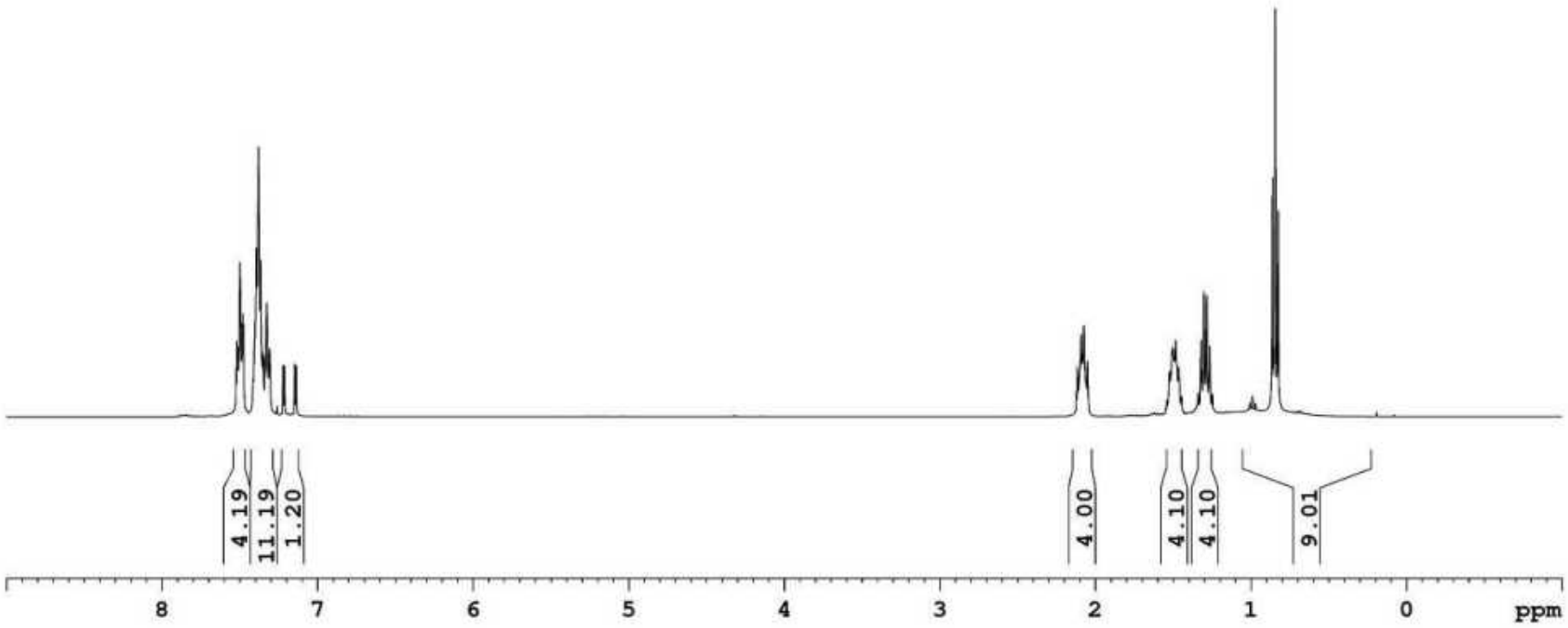
7.21
7.15
7.14


2.12
2.09
2.07
2.05
1.54
1.52
1.50
1.48
1.45
1.34
1.32
1.30
1.25
1.06
0.92
0.86
0.84
0.83
0.70
0.69
0.67
0.27


n-Bu
n-Bu
Ph
P
BH3
PPh2

10c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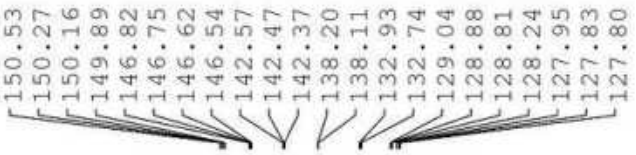
11.19
1.20
4.00
4.10
4.10
9.01
8
7
6
5
4
3
2
1
0
ppm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149.89
146.82
146.75
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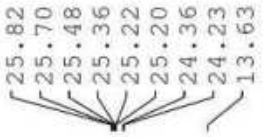
146.54
142.57
142.47
142.37
138.20
138.11
132.93
132.74
129.04
128.88
128.81
128.24
127.95
127.83
127.80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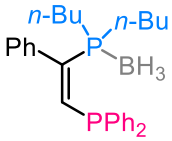
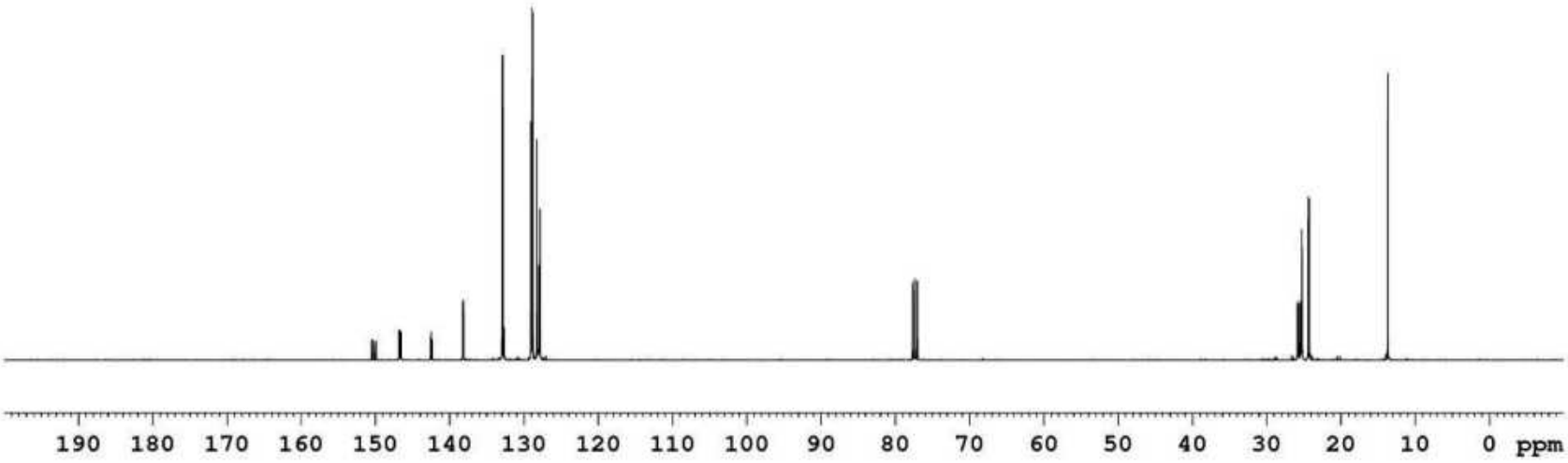
25.22
25.20
24.36
24.23
13.63


n-Bu
n-Bu
Ph
P
BH3
PPh2

10c


190
180
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140
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100
90
80
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60
50
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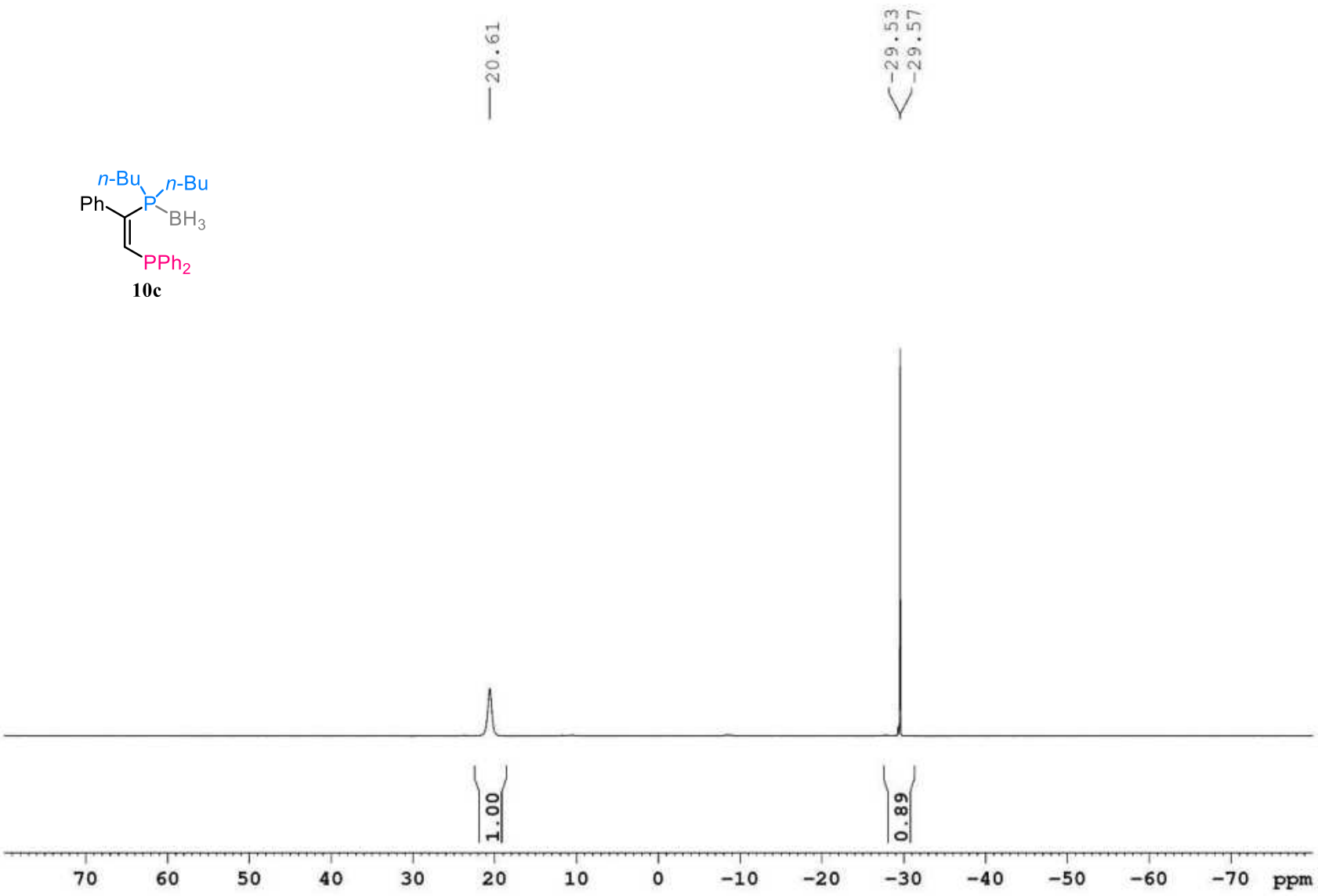
30
20
10
0
ppm


20.61
-29.53
-29.57
n-Bu
n-Bu
Ph
P
BH3
PPh2
10c
1.00
0.89
70
60
50
40
30
20
10
0
-10
-20
-30
-40
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-60
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n-Bu
n-Bu
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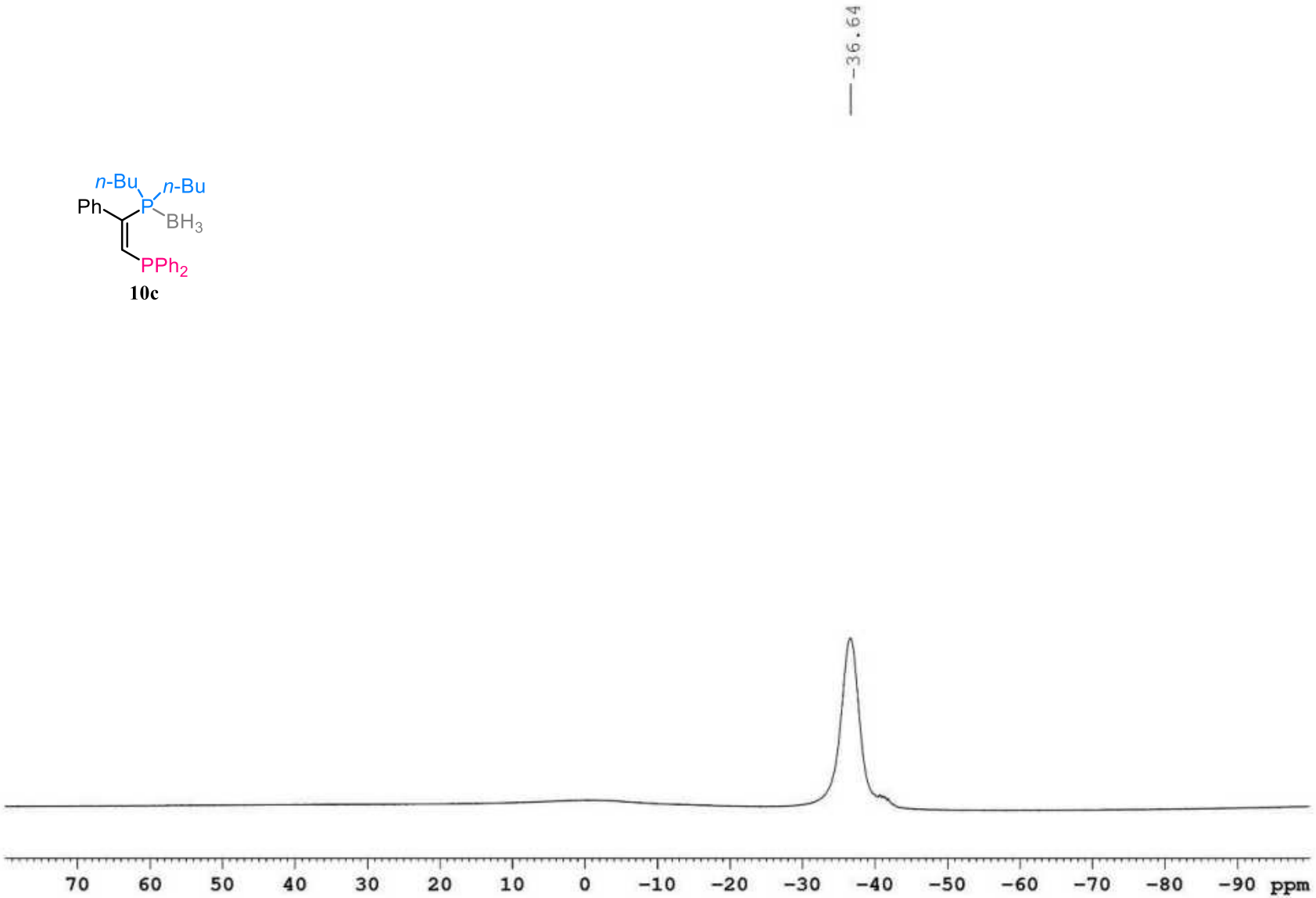
P
BH3
PPh2

10c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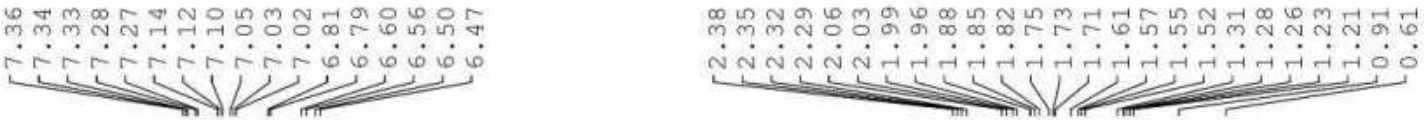
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6.79
6.60
6.56
6.50
6.47
2.38
2.35
2.32
2.29
2.06
2.03
1.99
1.96
1.88
1.85
1.82
1.75
1.73
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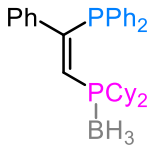
Ph
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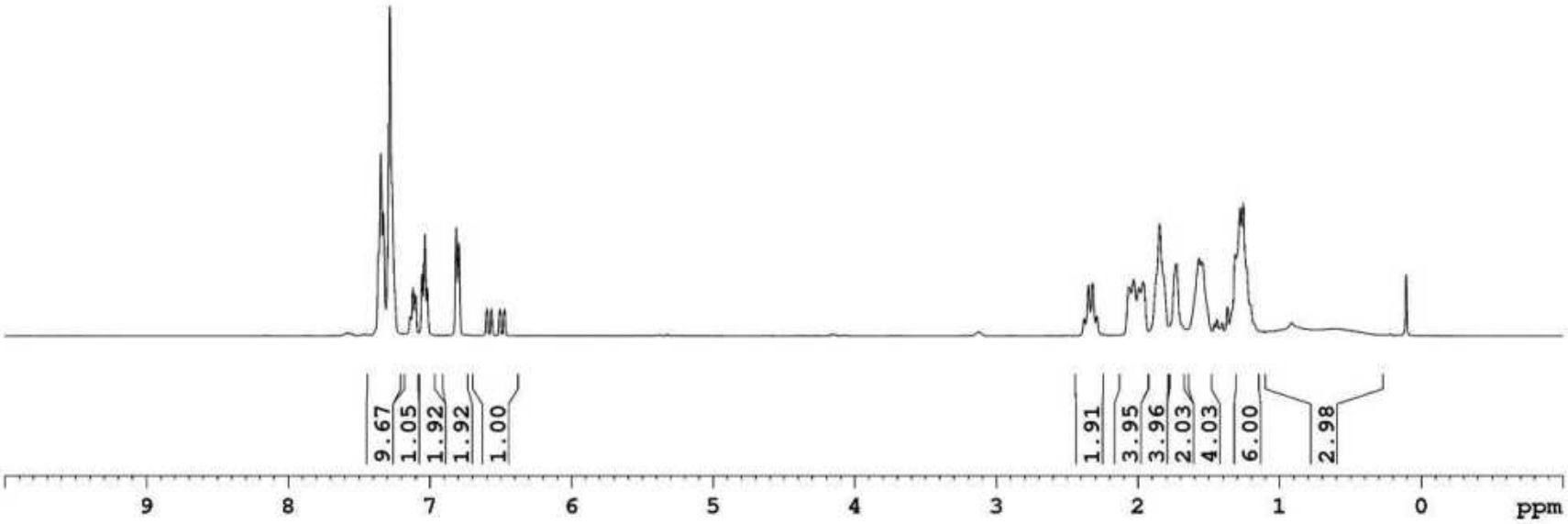
PCy2
BH3

10d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6
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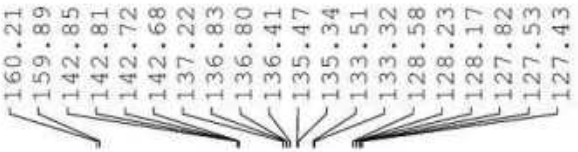
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128.23
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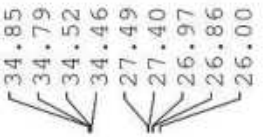
127.82
127.53
127.43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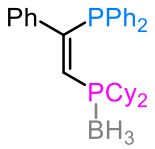
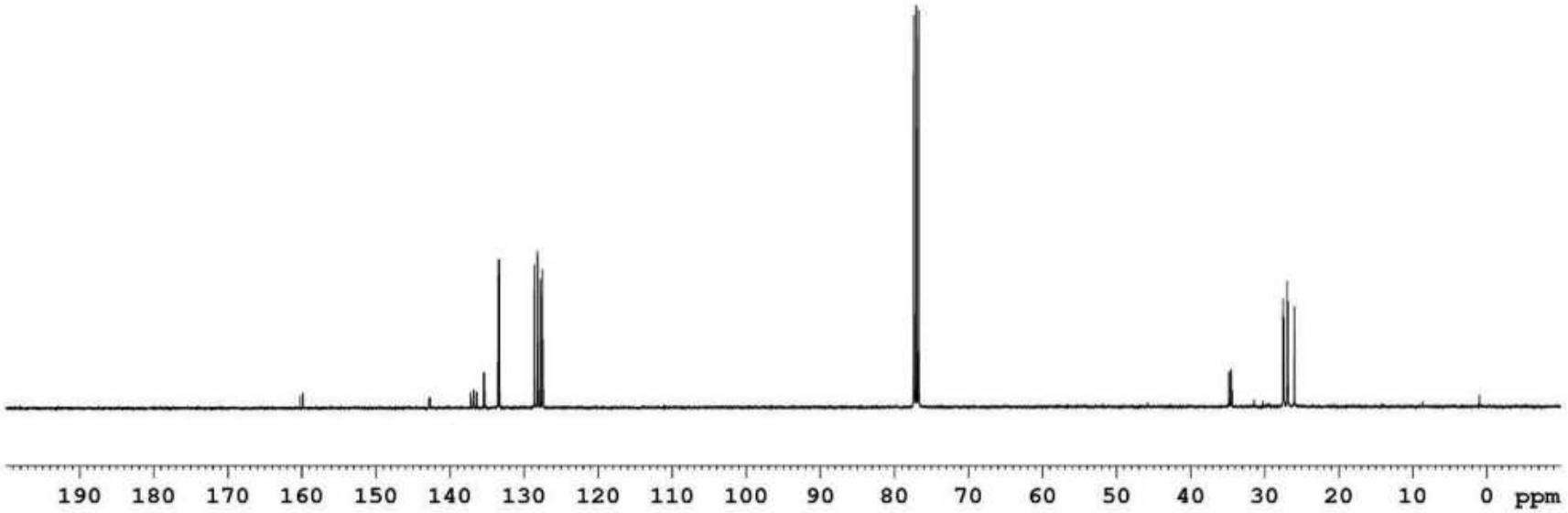
26.00


Ph
PPh2
PCy2
BH3

10d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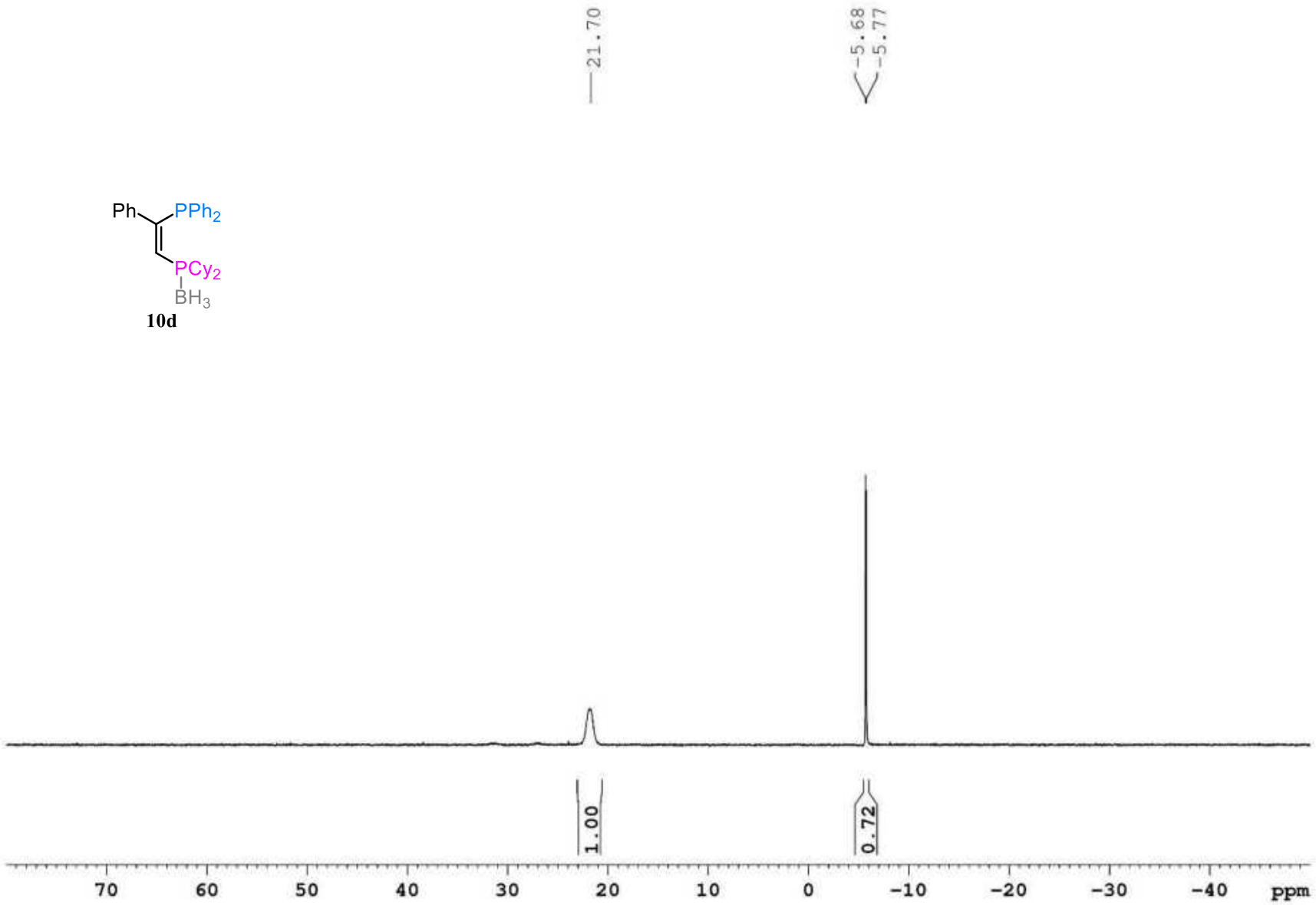
ppm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Ph
PPh2
PCy2
BH3
10d
1.00
0.72
70
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10
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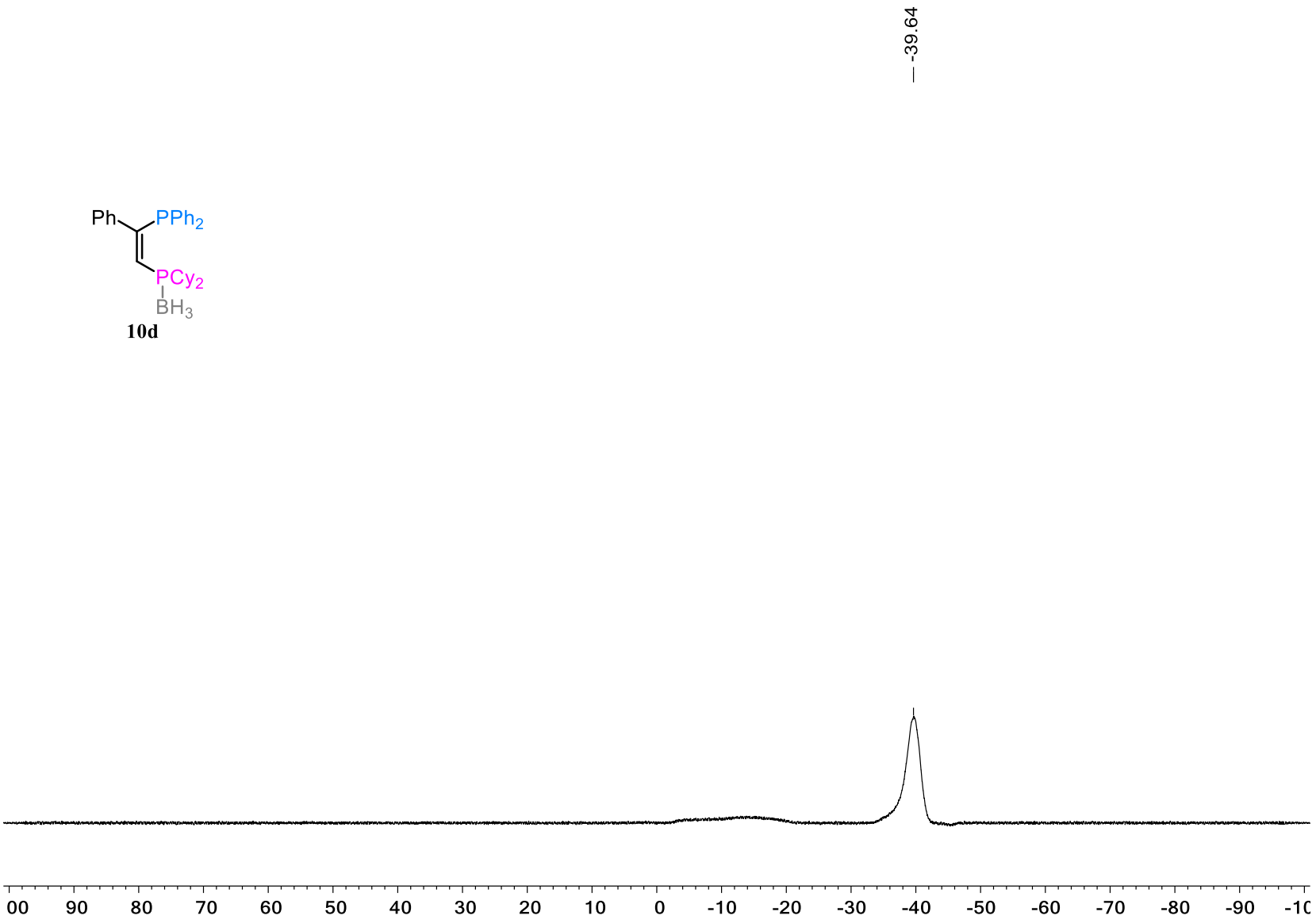
-20
-30
-40
ppm

Ph
PPh2
PCy2
BH3

10d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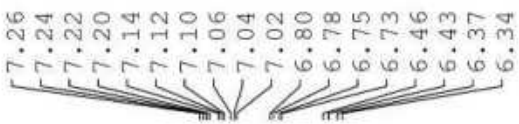
-80
-90
-10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7.14
7.12
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7.02
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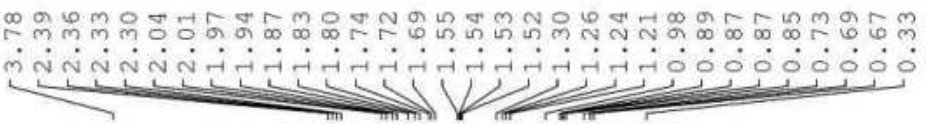
6.78
6.75
6.73
6.46
6.43
6.37
6.34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2.01
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1.94
1.87
1.83
1.80
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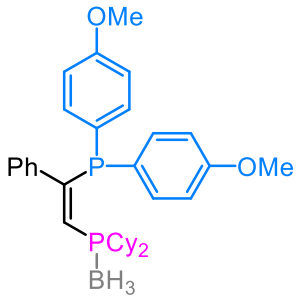
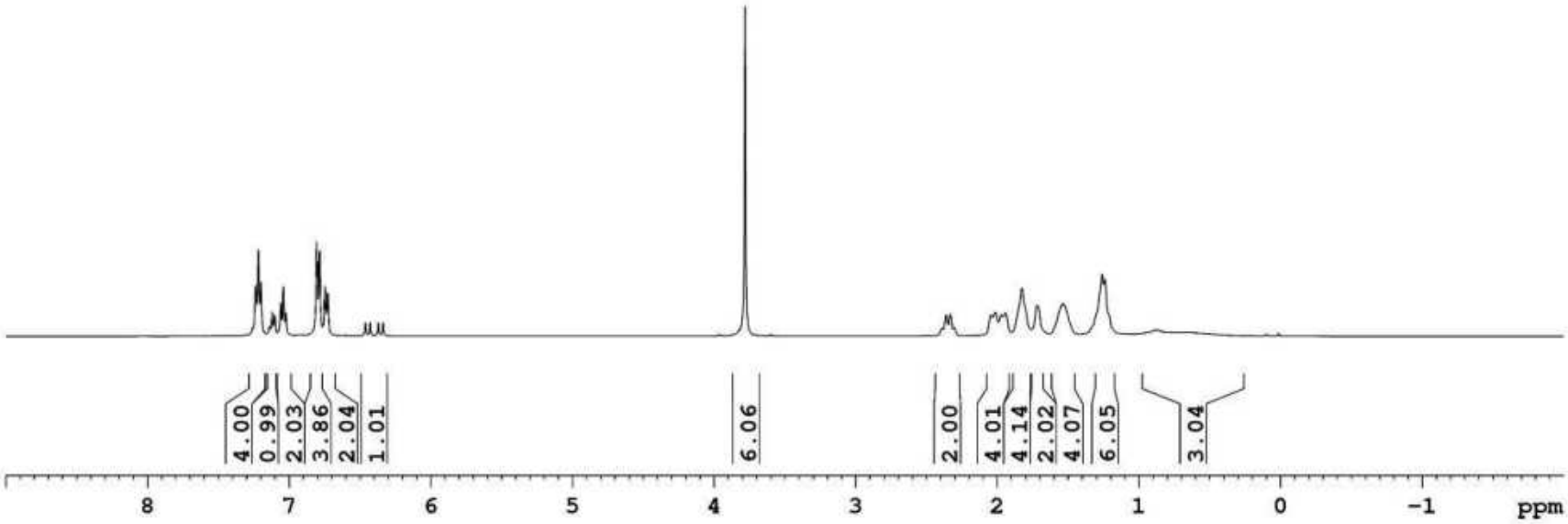
1.72
1.69
1.55
1.54
1.53
1.52
1.30
1.26
1.24
1.21
0.98
0.89
0.87
0.87
0.85
0.73
0.69
0.67
0.33


OMe
Ph
P
OMe
PCy2
BH3

10e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2.00
4.01
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6.05
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5
4
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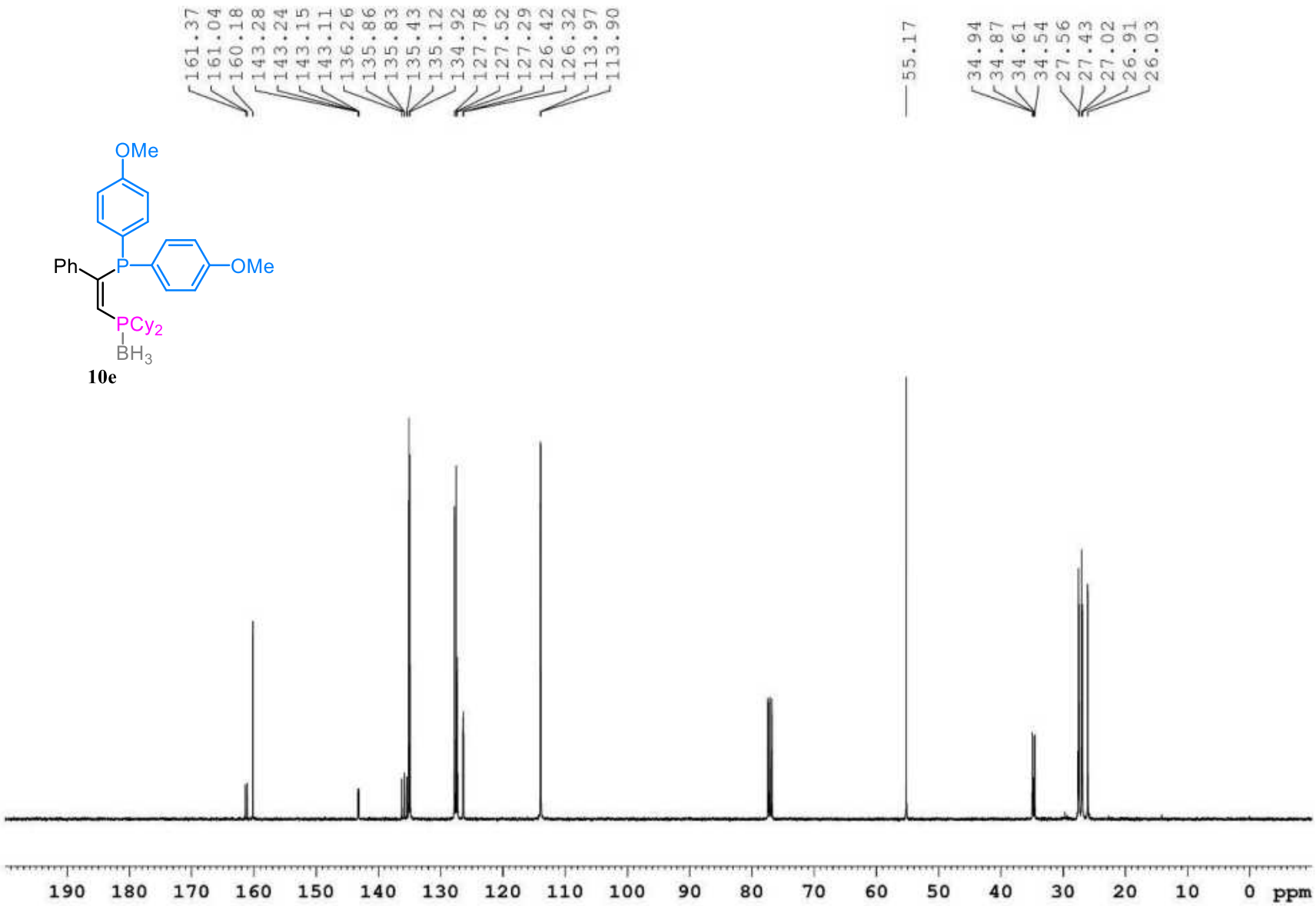
1
0
-1
ppm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143.24
143.15
143.11
136.26
135.86
135.83
135.43
135.12
134.92
127.78
127.52
127.29
126.42
126.32
113.97
113.90
55.17
34.94
34.87
34.61
34.54
27.56
27.43
27.02
26.91
26.03
OMe
Ph
P
OMe
PCy2
BH3
10e
190
180
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140
130
120
110
100
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60
50
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20
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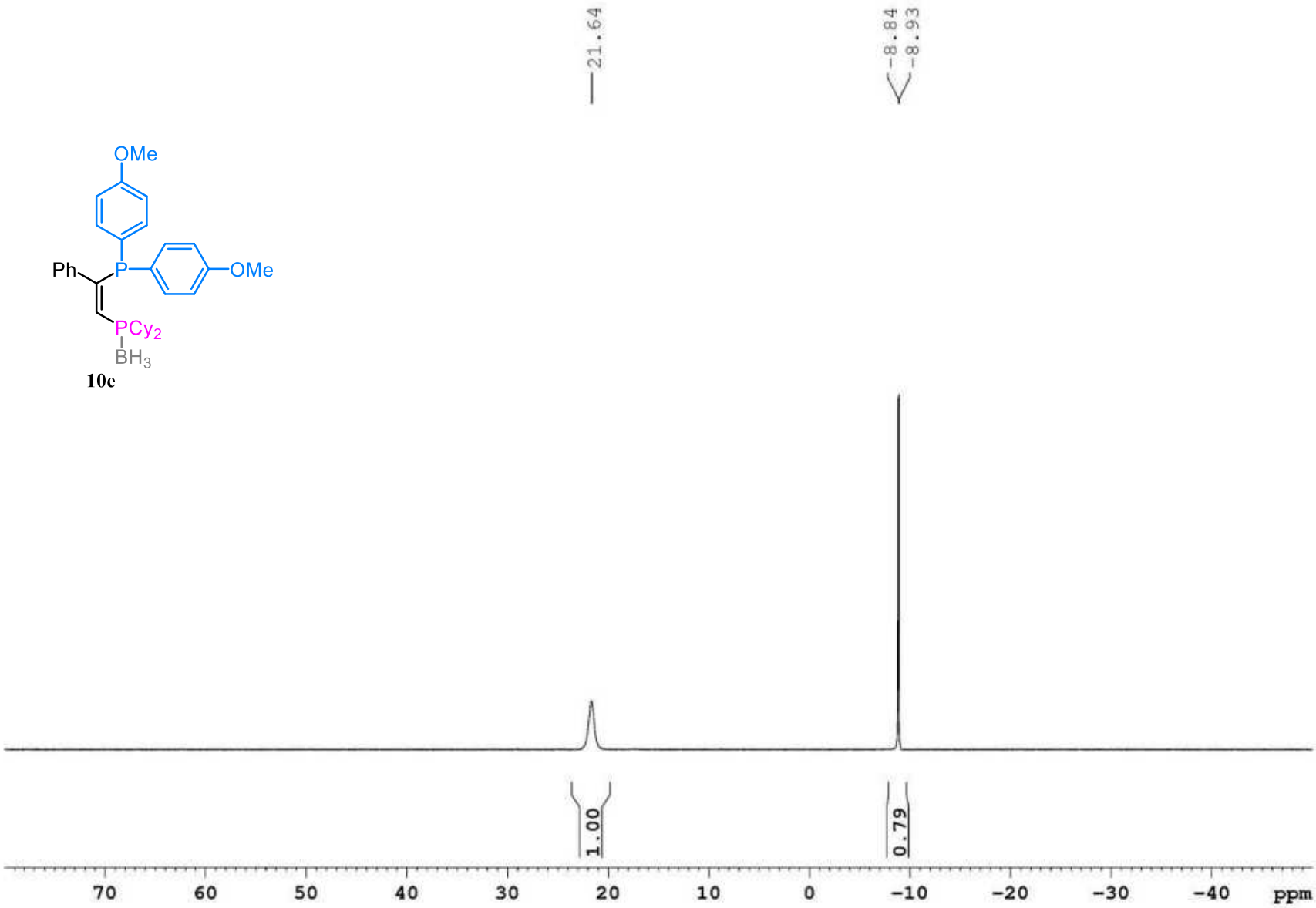
0
ppm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-8.84
-8.93
OMe
Ph
P
OMe
PCy2
BH3
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50
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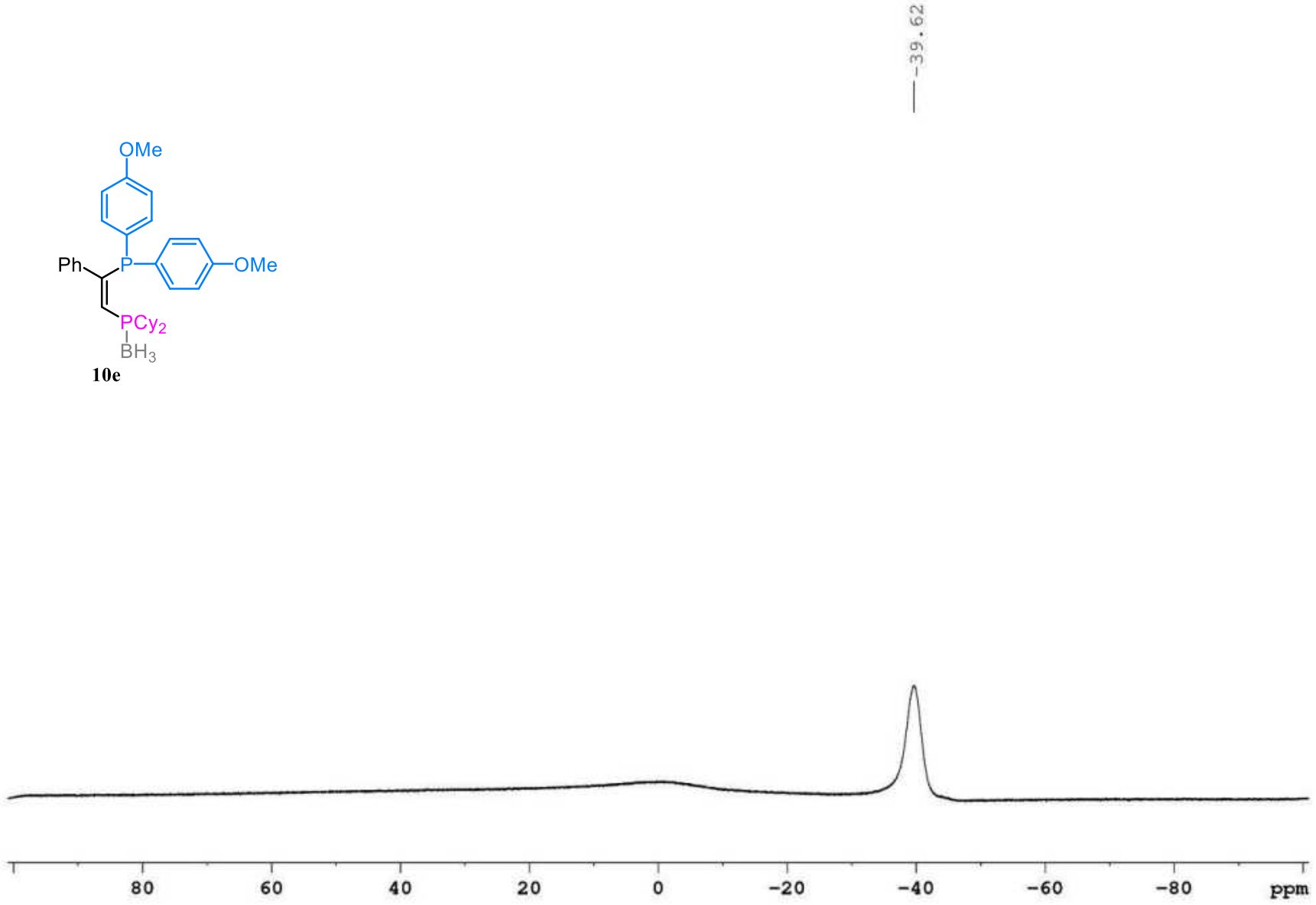
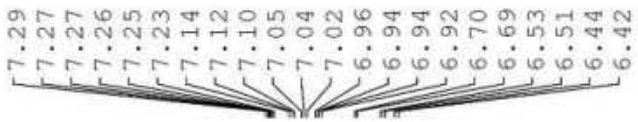
30
20
10
0
-10
-20
-30
-40
ppm

10e

10e

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7.26
7.25
7.23
7.14
7.12
7.10
7.05
7.04
7.02
6.96
6.94
6.94
6.92
6.70
6.69
6.53
6.51
6.44
6.42


2.24
2.21
2.19
2.16
2.05
2.03
2.01
1.95
1.92
1.84
1.73
1.57
1.53
1.47
1.30
1.24
1.21
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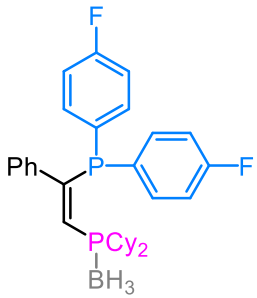
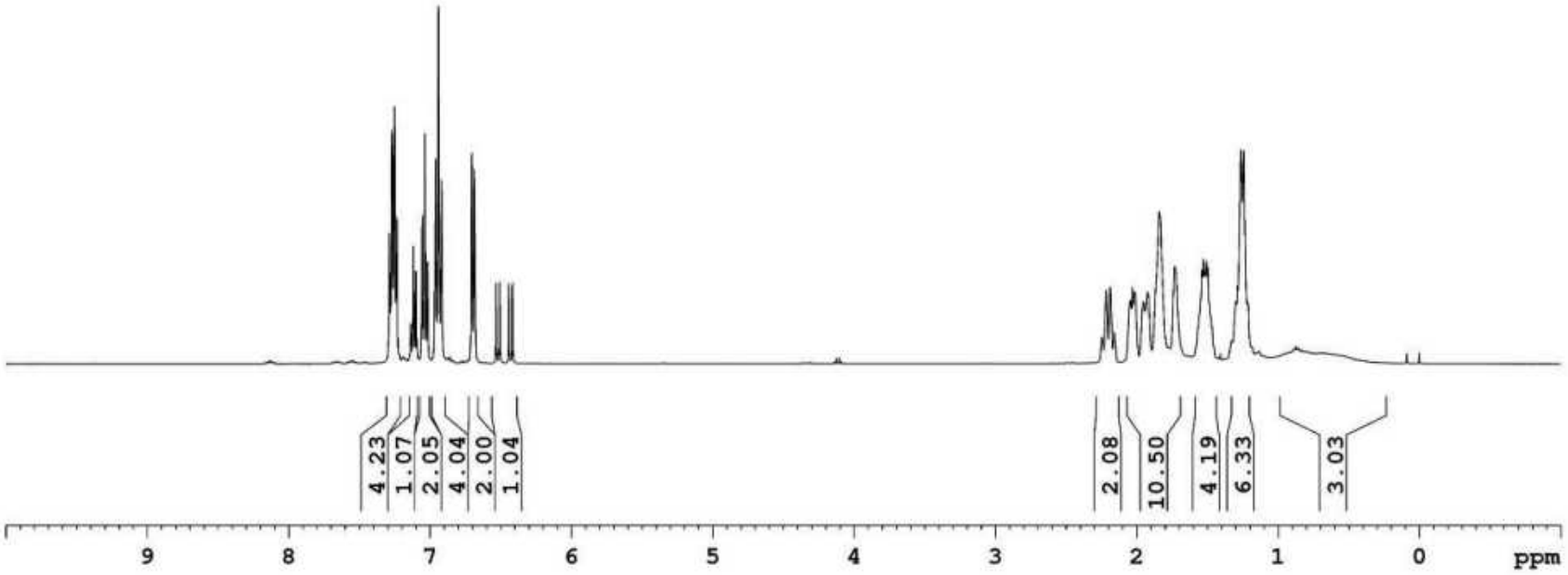
0.92
0.92
0.76
0.55
0.34


F
Ph
P
F
PCy2
BH3

10f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4.04
2.00
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4.19
6.33
3.03
9
8
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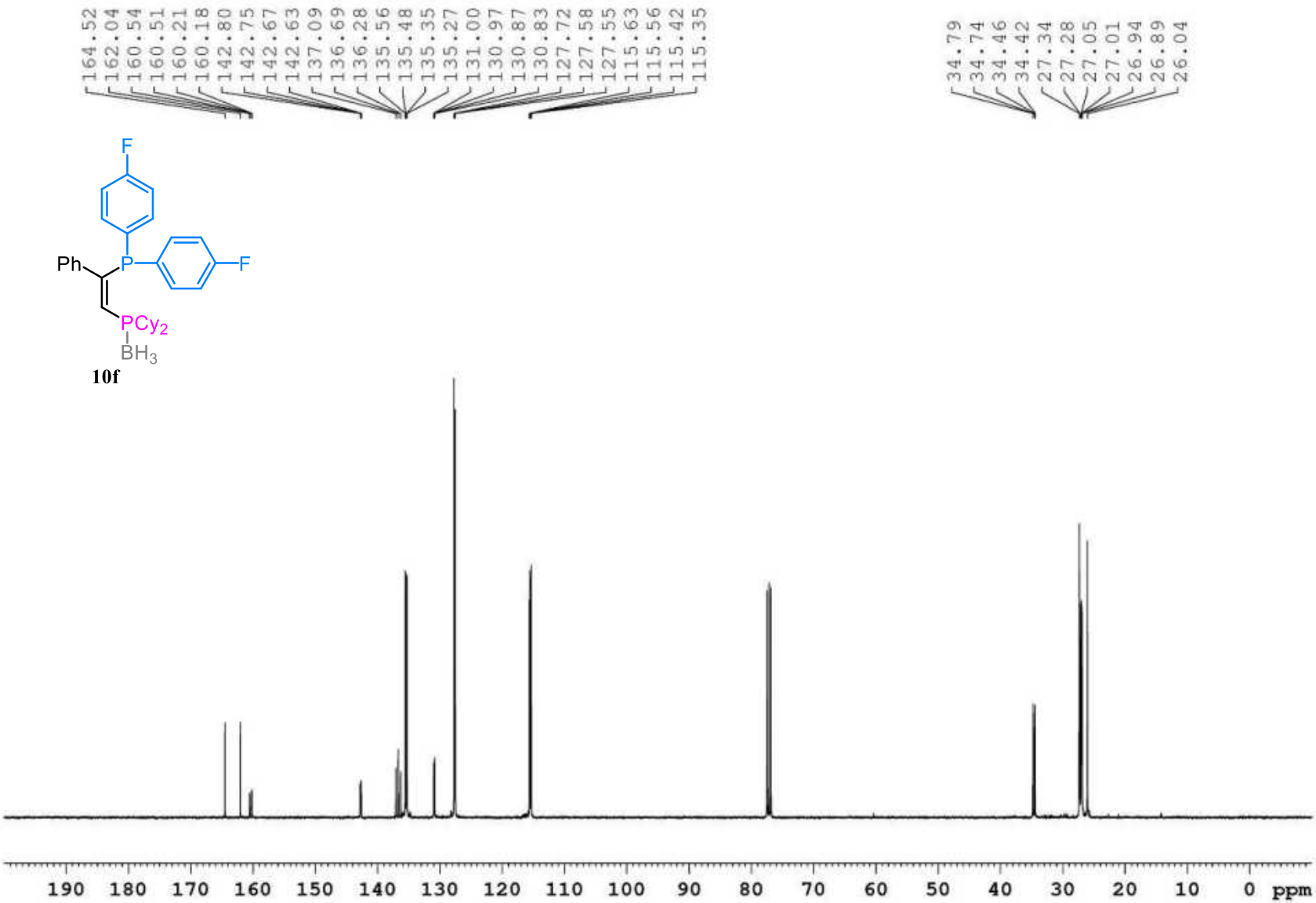
6
5
4
3
2
1
0
ppm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136.28
135.56
135.48
135.35
135.27
131.00
130.97
130.87
130.83
127.72
127.58
127.55
115.63
115.56
115.42
115.35
34.79
34.74
34.46
34.42
27.34
27.28
27.05
27.01
26.94
26.89
26.04
F
Ph
P
F
PCy2
BH3
10f
190
180
170
160
150
140
130
120
110
100
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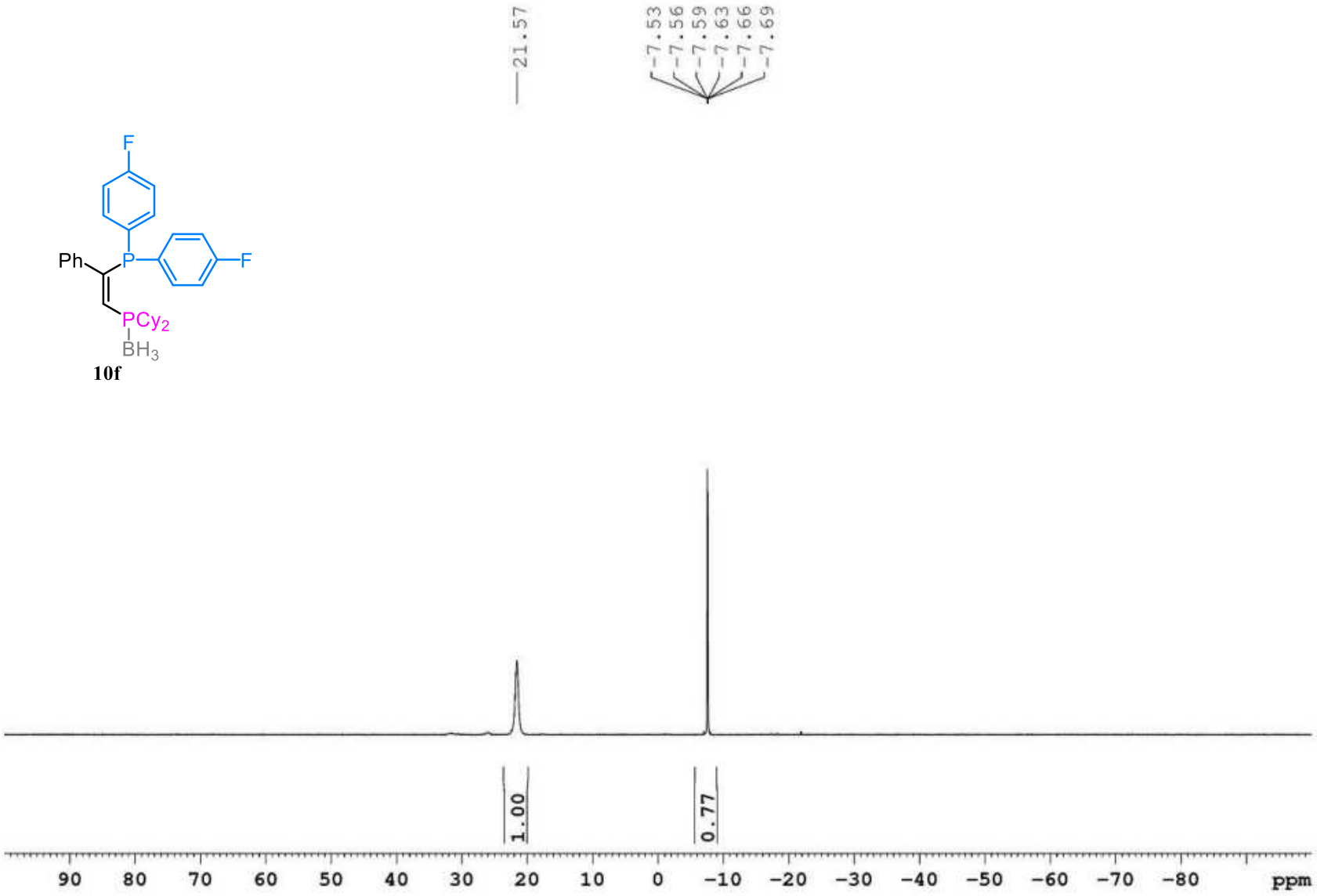
30
20
10
0
ppm

F
Ph
P
F
PCy2
BH3

10f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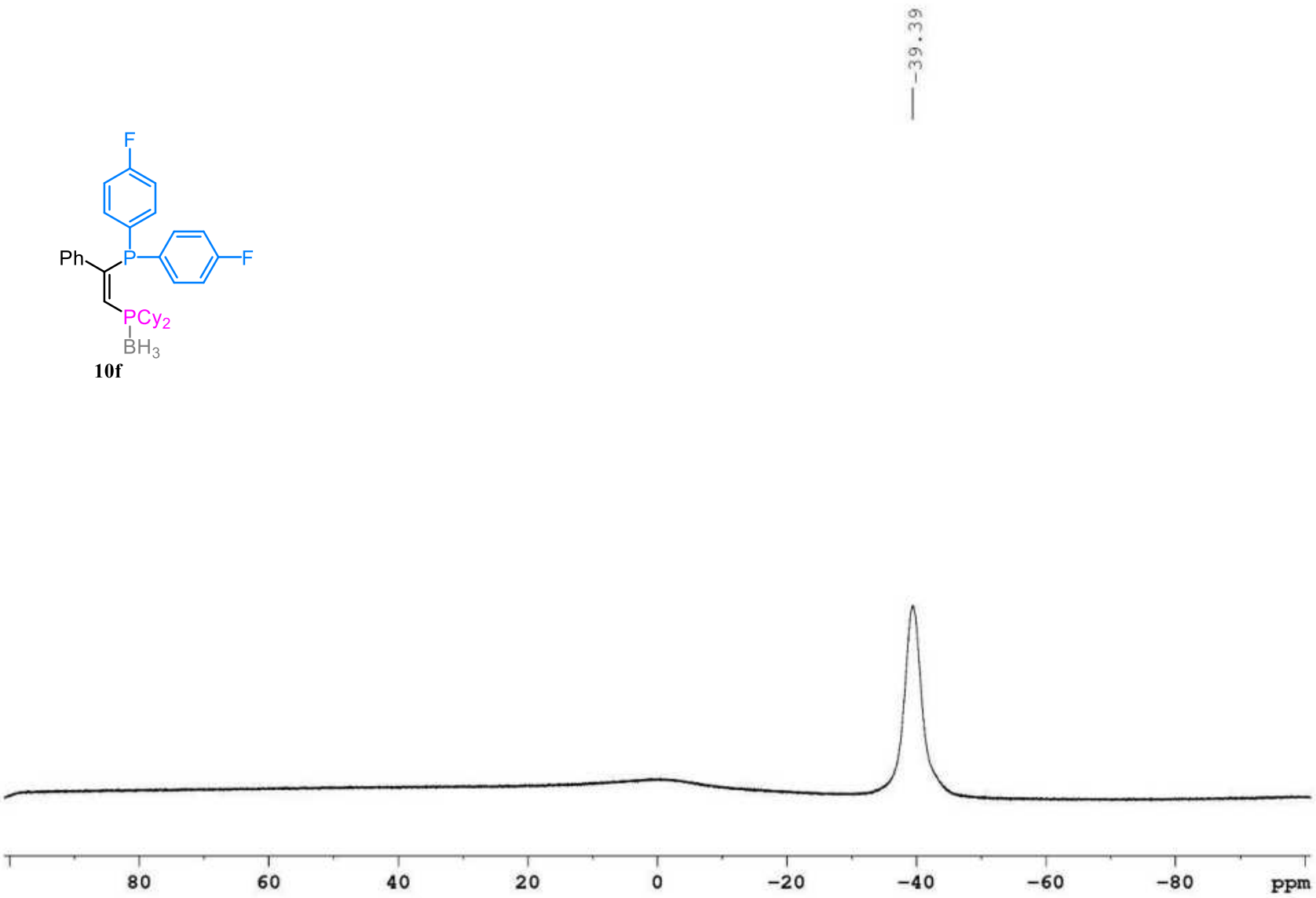
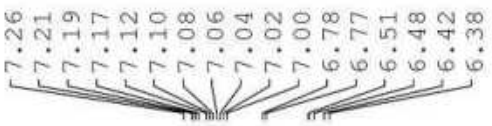
ppm

10f

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6.77
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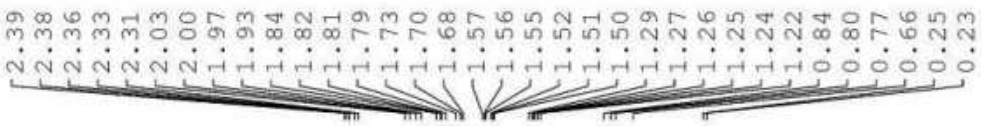
6.42
6.38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2.03
2.00
1.97
1.93
1.84
1.82
1.81
1.79
1.73
1.70
1.68
1.57
1.56
1.55
1.52
1.51
1.50
1.29
1.27
1.26
1.25
1.24
1.22
0.84
0.80
0.77
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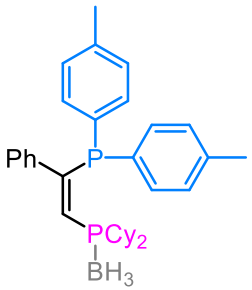
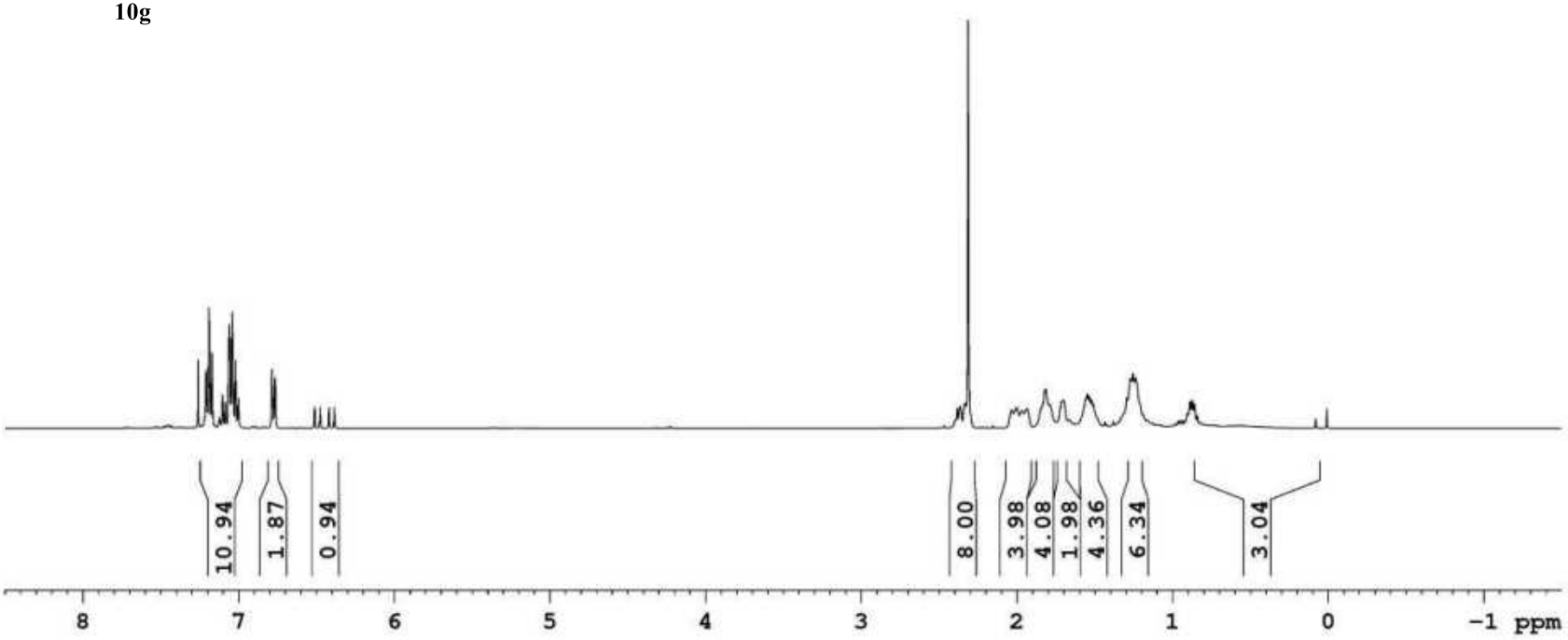
0.25
0.23


Ph
P
PCy2
BH3

10g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8
7
6
5
4
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2
1
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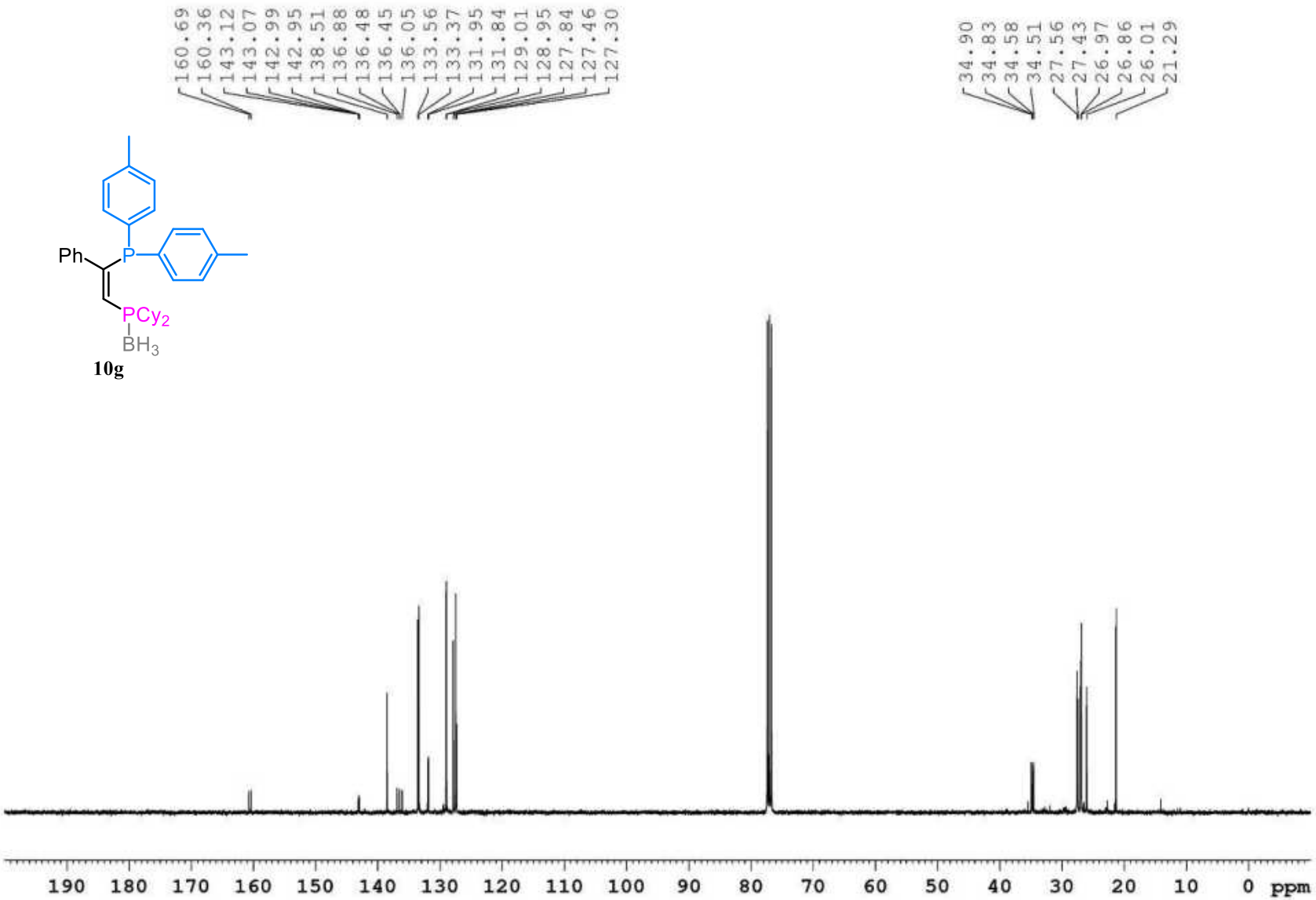
−1
ppm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136.88
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136.45
136.05
133.56
133.37
131.95
131.84
129.01
128.95
127.84
127.46
127.30
34.90
34.83
34.58
34.51
27.56
27.43
26.97
26.86
26.01
21.29
Ph
P
PCy2
BH3
10g
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140
130
120
110
100
90
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60
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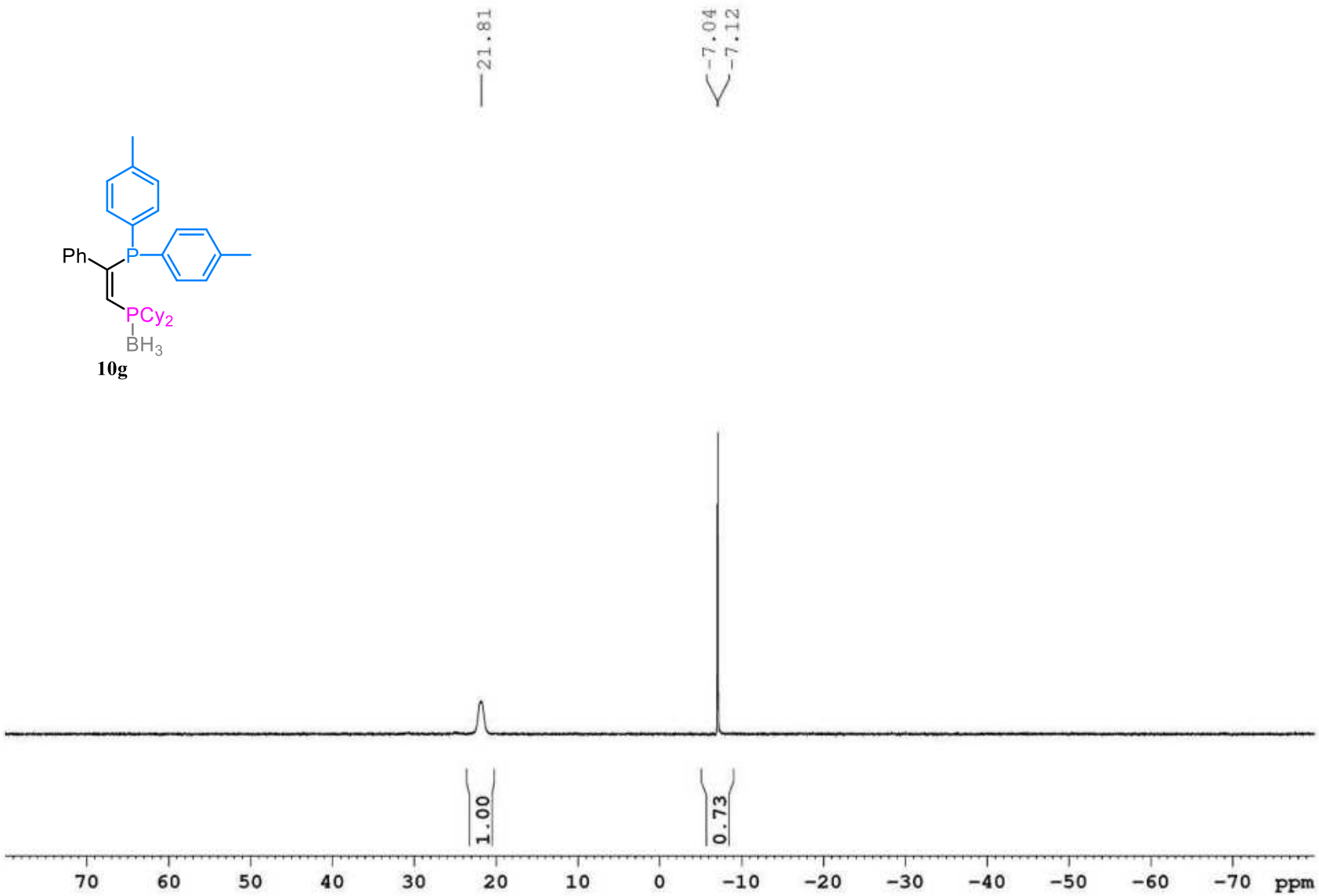
20
10
0
ppm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7.04
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Ph
P
PCy2
BH3
10g
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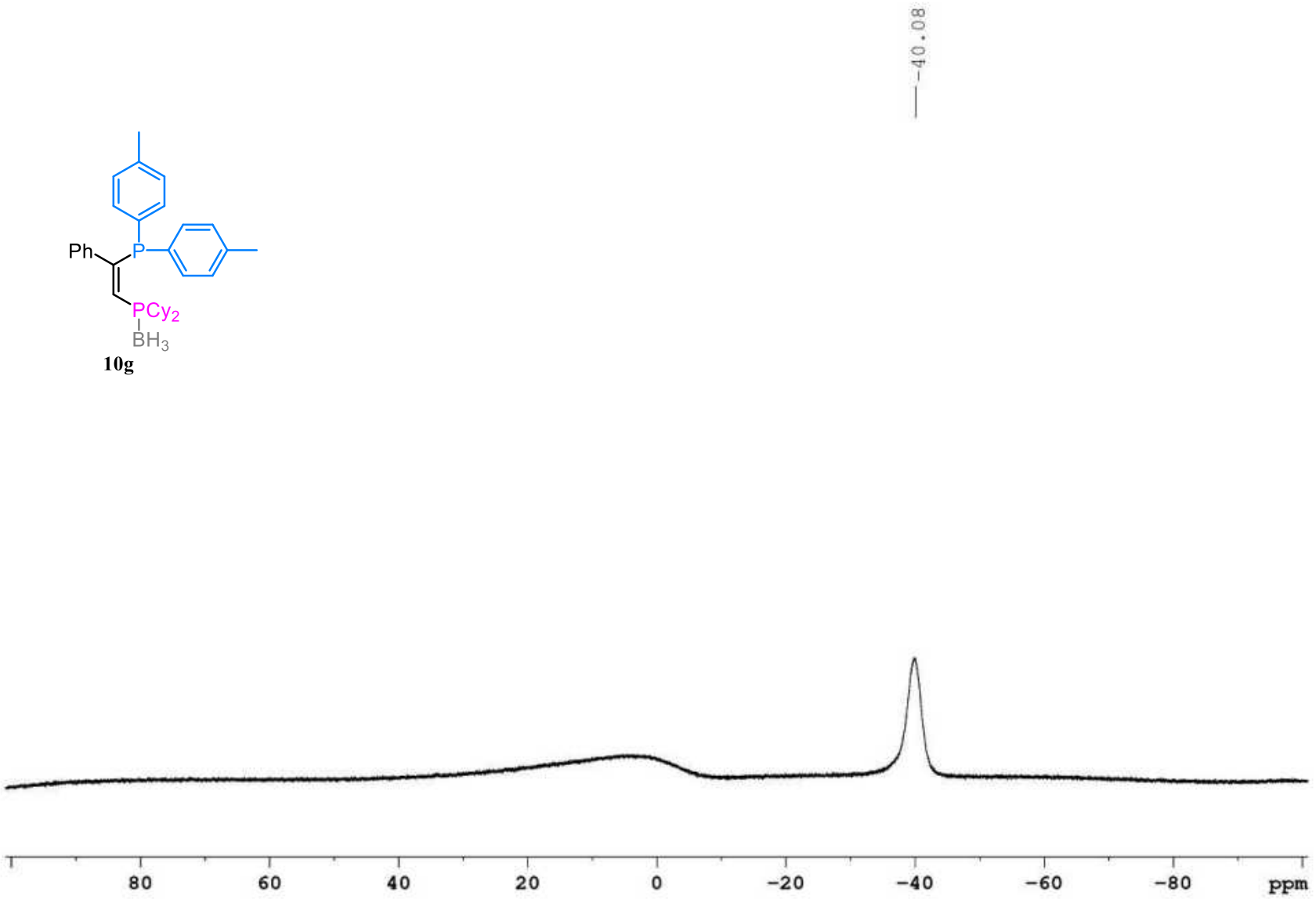
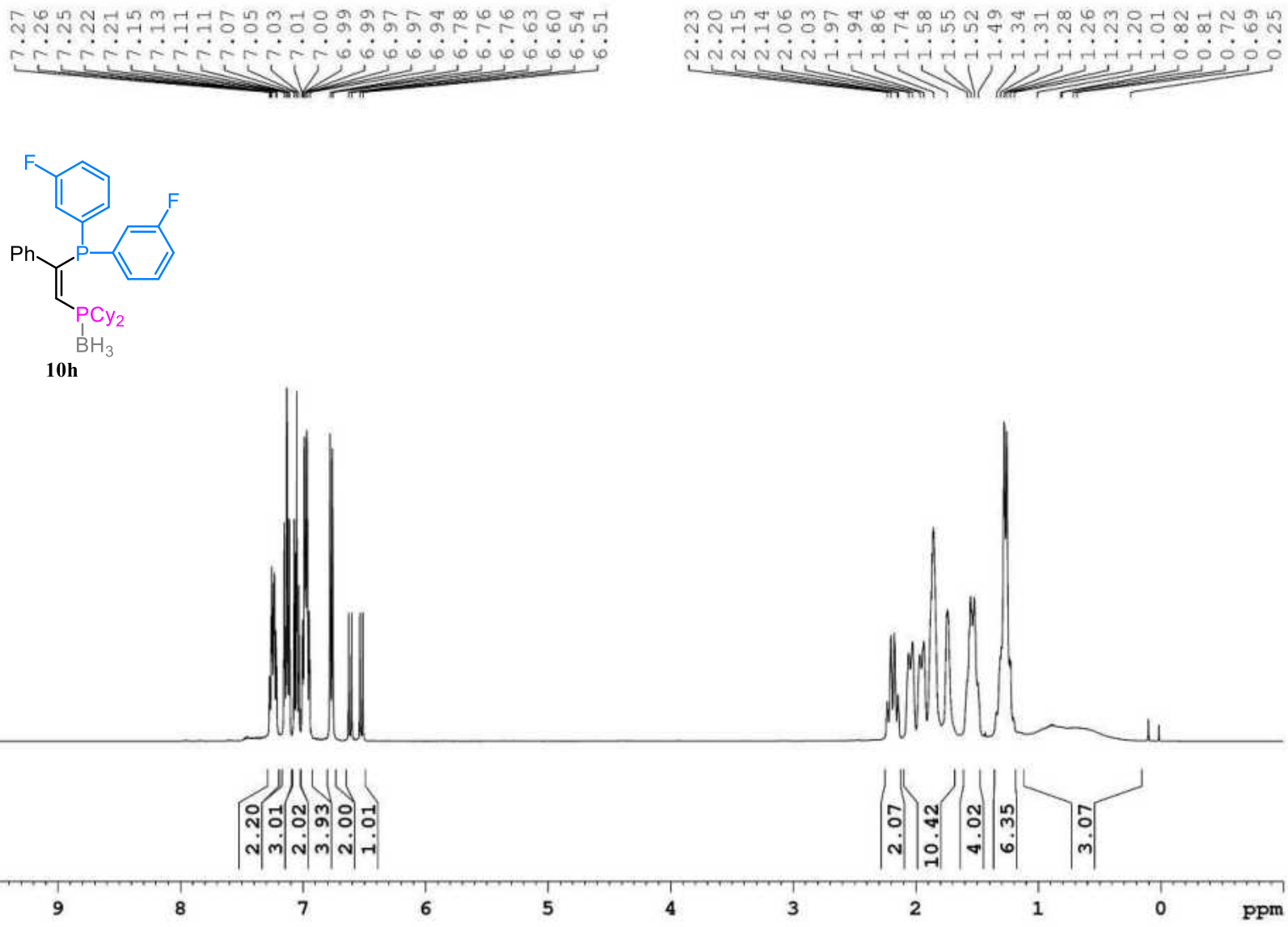
-10
-20
-30
-40
-50
-60
-70
ppm

10g

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7.11
7.11
7.07
7.05
7.03
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7.00
6.99
6.99
6.97
6.97
6.94
6.78
6.76
6.76
6.63
6.60
6.54
6.51
2.23
2.20
2.15
2.14
2.06
2.03
1.97
1.94
1.86
1.74
1.58
1.55
1.52
1.49
1.34
1.31
1.28
1.26
1.23
1.20
1.01
0.82
0.81
0.72
0.69
0.25
F
F
Ph
P
PCy2
BH3
10h
2.20
3.01
2.02
3.93
2.00
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6
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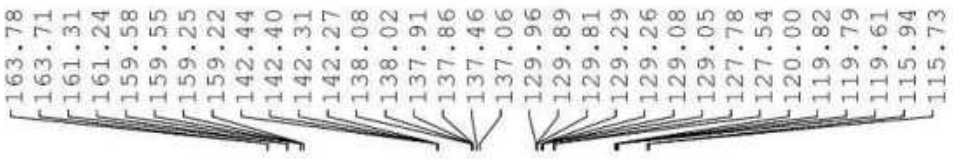
ppm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142.40
142.31
142.27
138.08
138.02
137.91
137.86
137.46
137.06
129.96
129.89
129.81
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127.54
120.00
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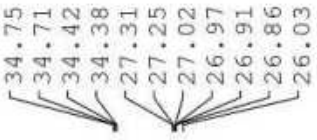
115.94
115.73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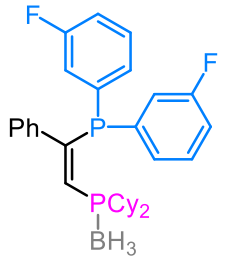
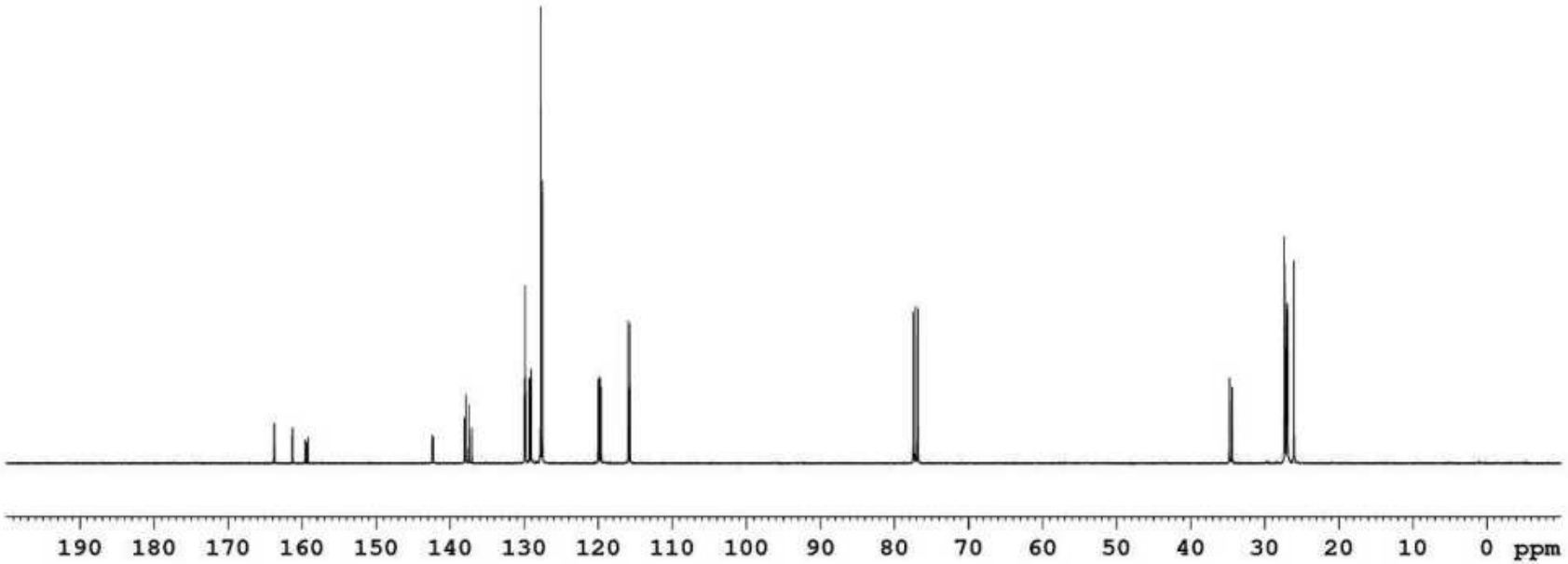
27.25
27.02
26.97
26.91
26.86
26.03


F
F
Ph
P
PCy2
BH3

10h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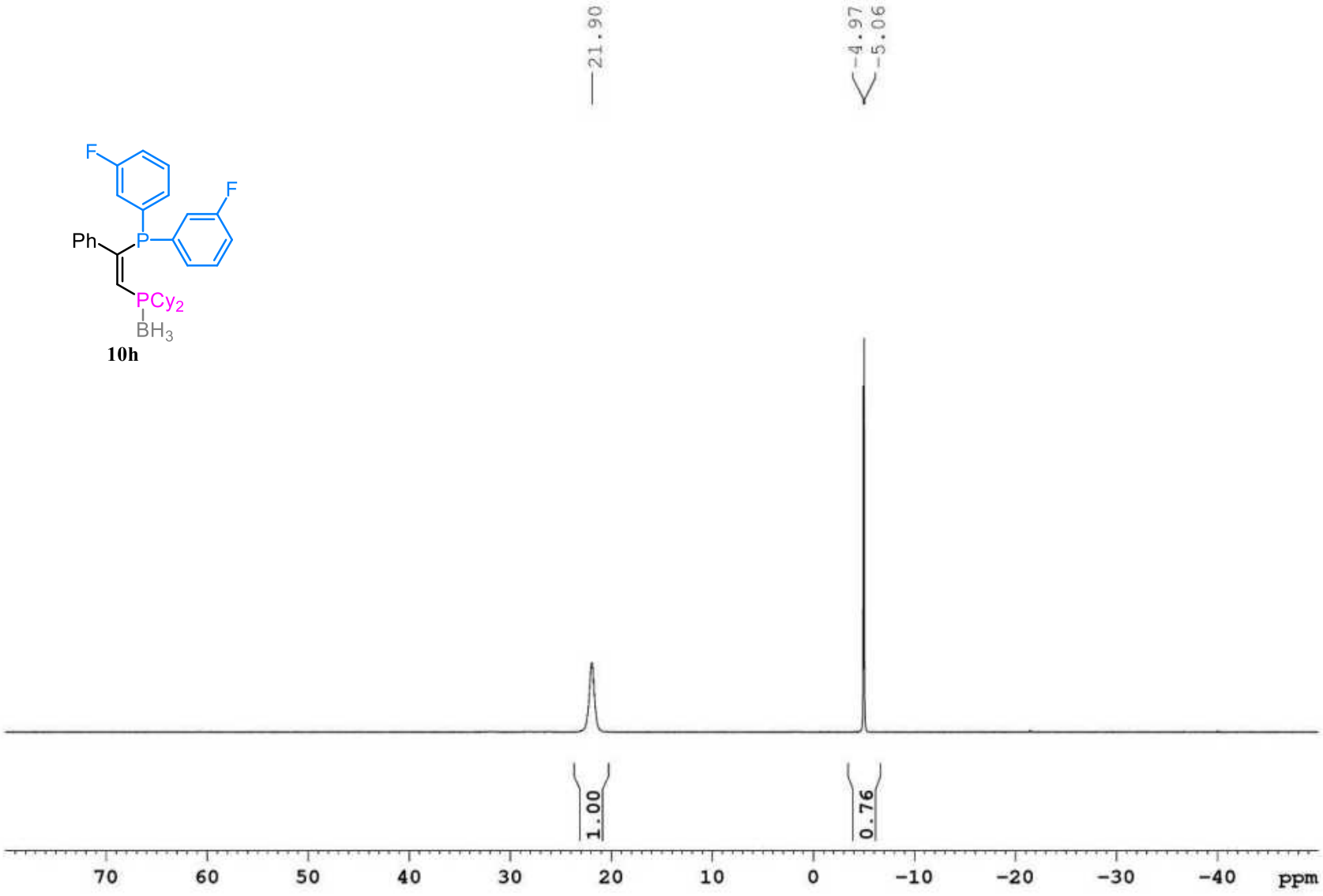
ppm


21.90
-4.97
-5.06
F
F
Ph
P
PCy2
BH3
10h
1.00
0.76
70
60
50
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30
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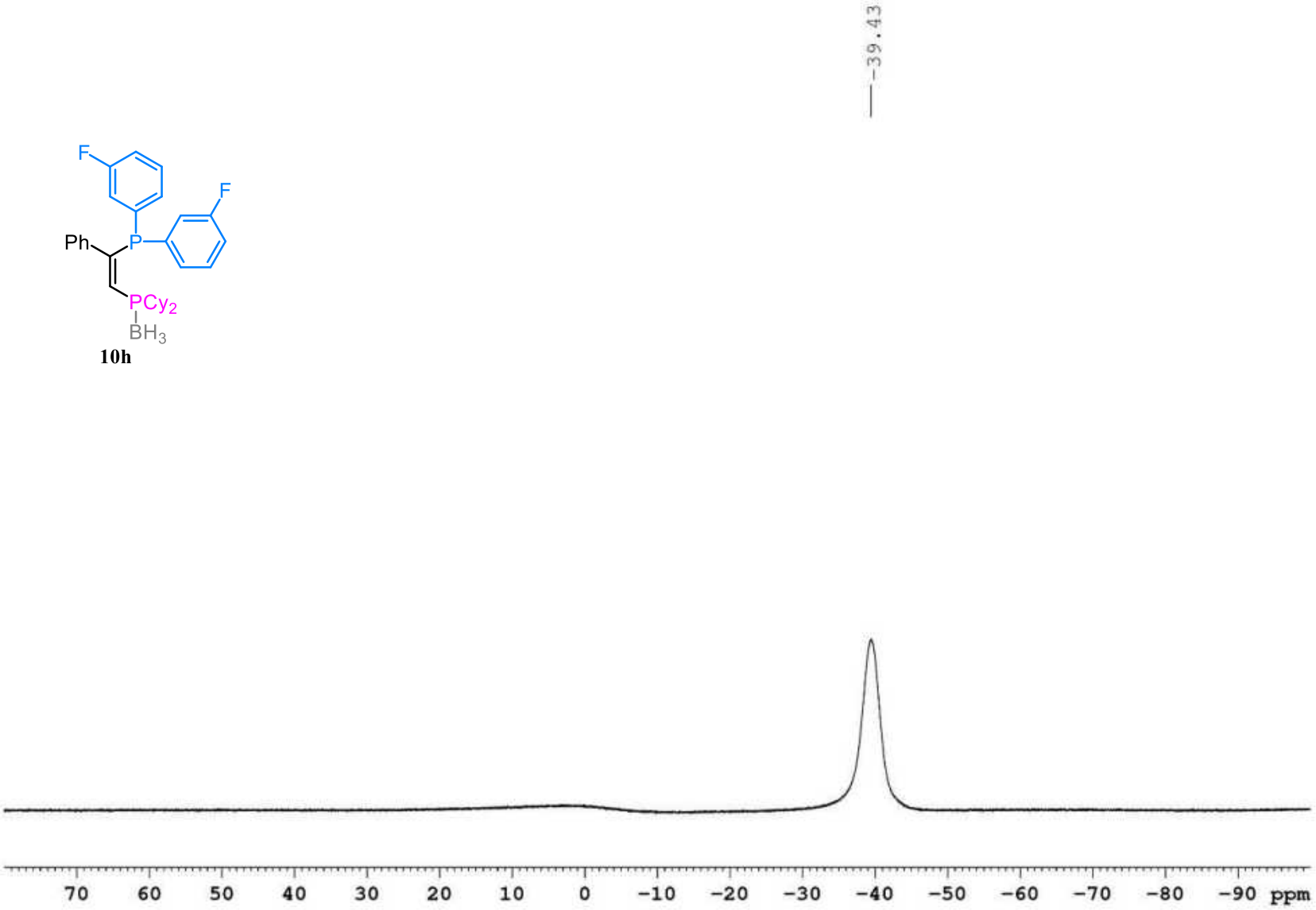
10
0
-10
-20
-30
-40
ppm

F
F
Ph
P
PCy2
BH3

10h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-20
-30
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-50
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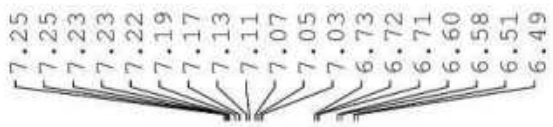
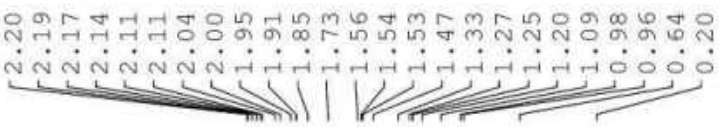
-70
-80
-90
ppm


7.25
7.25
7.23
7.23
7.22
7.19
7.17
7.13
7.11
7.07
7.05
7.03
6.73
6.72
6.71
6.60
6.58
6.51
6.49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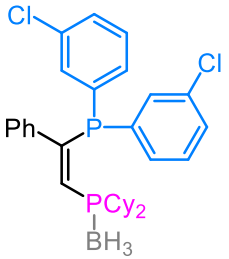
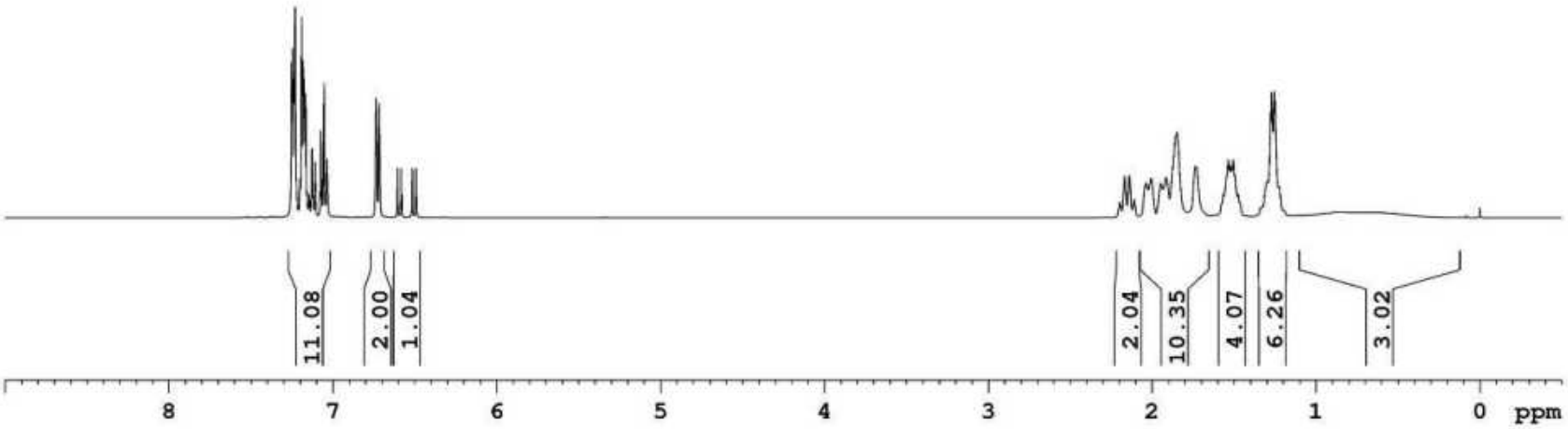
2.19
2.17
2.14
2.11
2.11
2.04
2.00
1.95
1.91
1.85
1.73
1.56
1.54
1.53
1.47
1.33
1.27
1.25
1.20
1.09
0.98
0.96
0.64
0.20


Cl
Cl
Ph
P
PCy2
BH3

10i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2.00
1.04
2.04
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4.07
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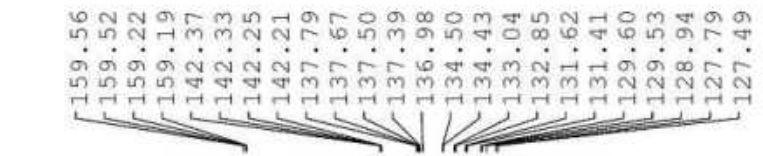
3.02
8
7
6
5
4
3
2
1
0
ppm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159.52
159.22
159.19
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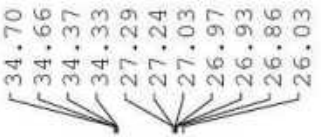
142.33
142.25
142.21
137.79
137.67
137.50
137.39
136.98
134.50
134.43
133.04
132.85
131.62
131.41
129.60
129.53
128.94
127.79
127.49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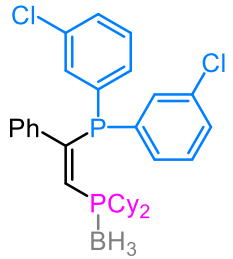
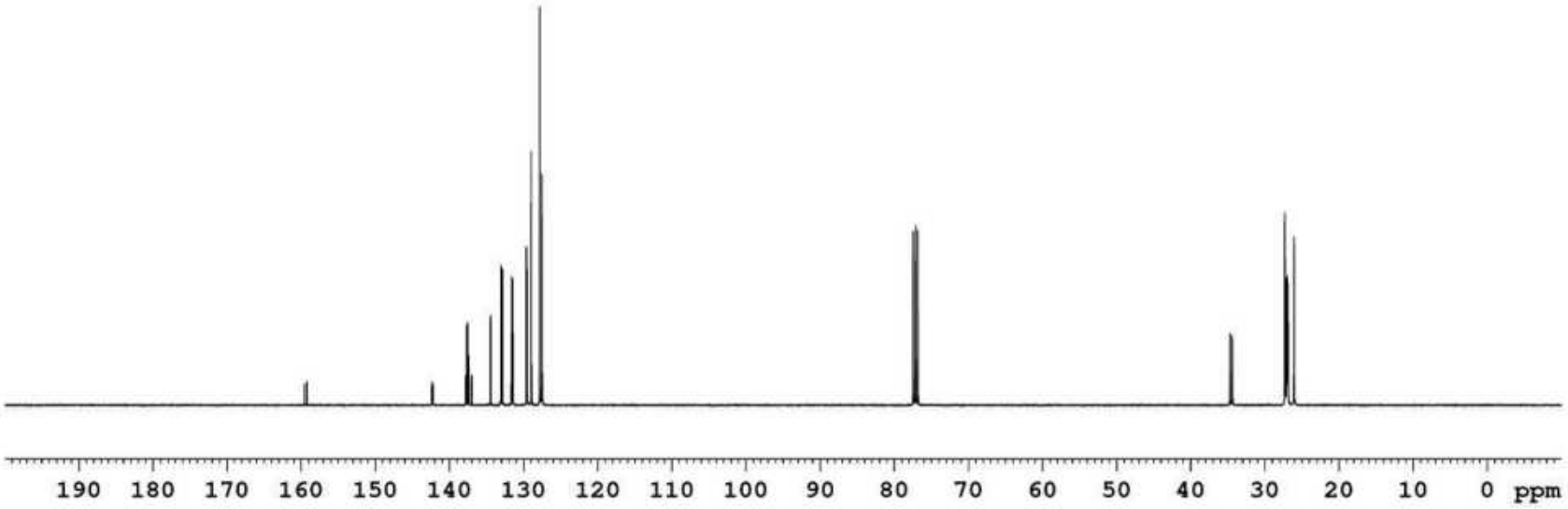
34.66
34.37
34.33
27.29
27.24
27.03
26.97
26.93
26.86
26.03

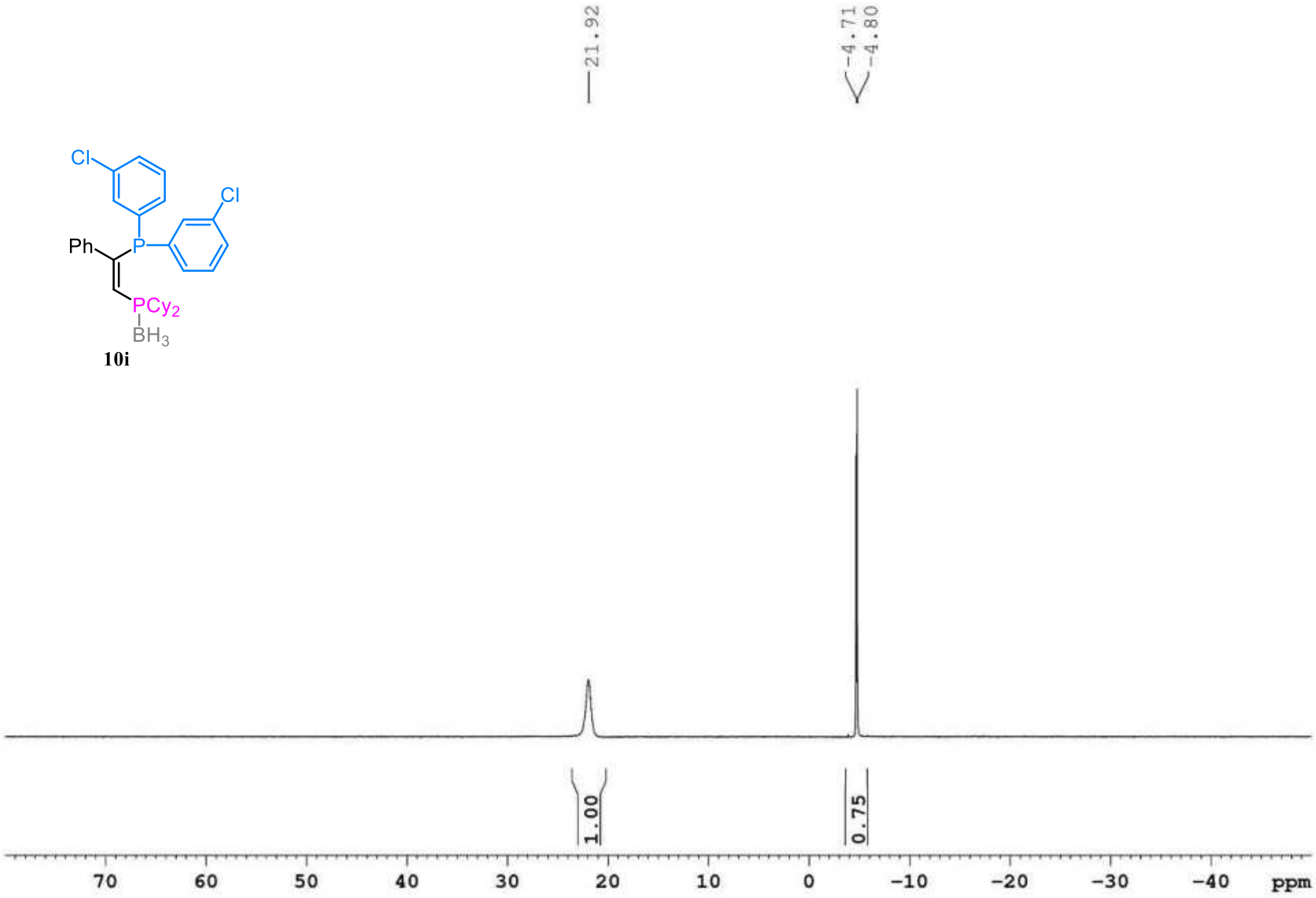

Cl
Cl
Ph
P
PCy2
BH3

10i


190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

Cl
Cl
Ph
P
PCy2
BH3

10i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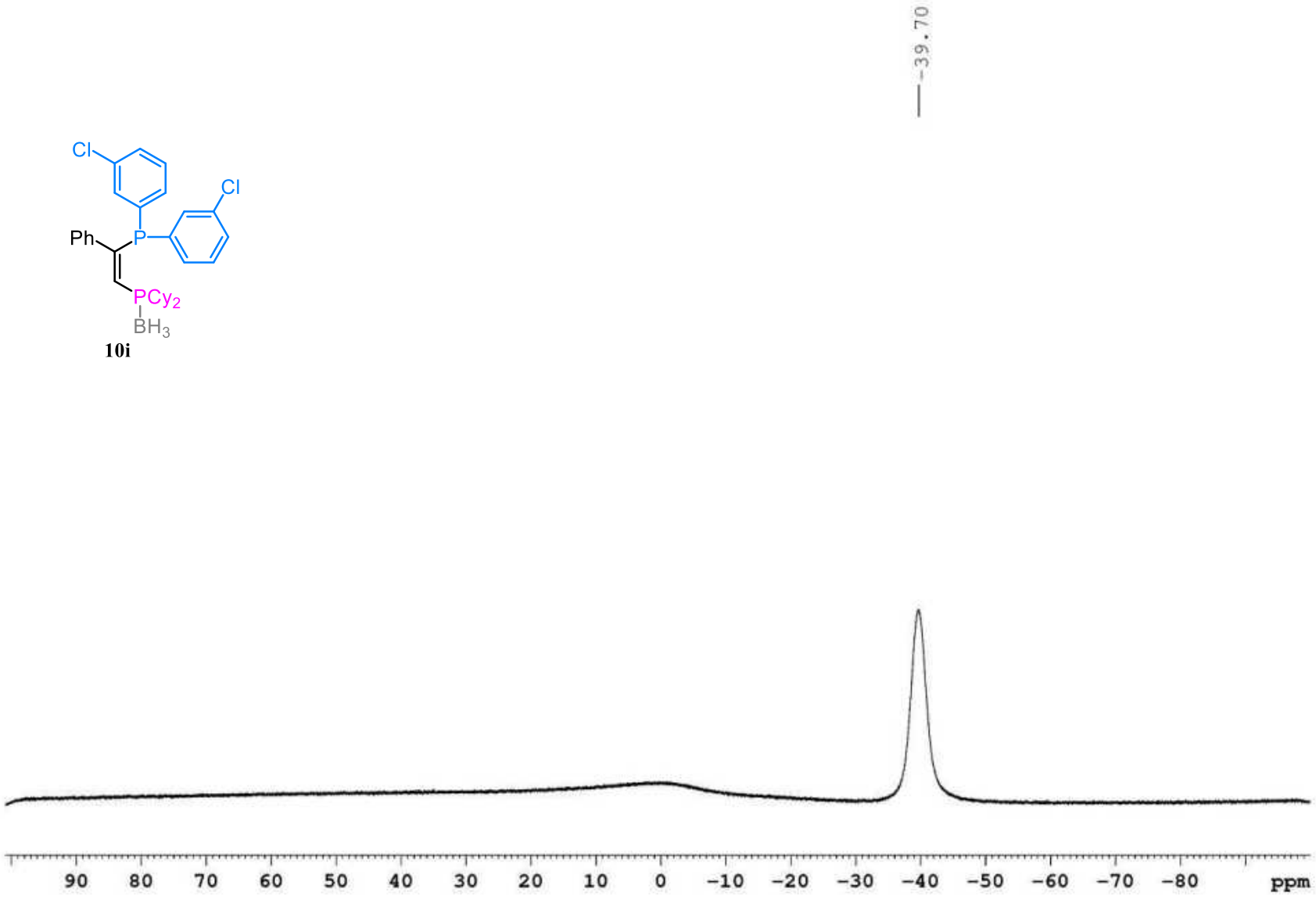
-4.71
-4.80
1.00
0.75
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm

Cl
Cl
Ph
P
PCy2
BH3

10i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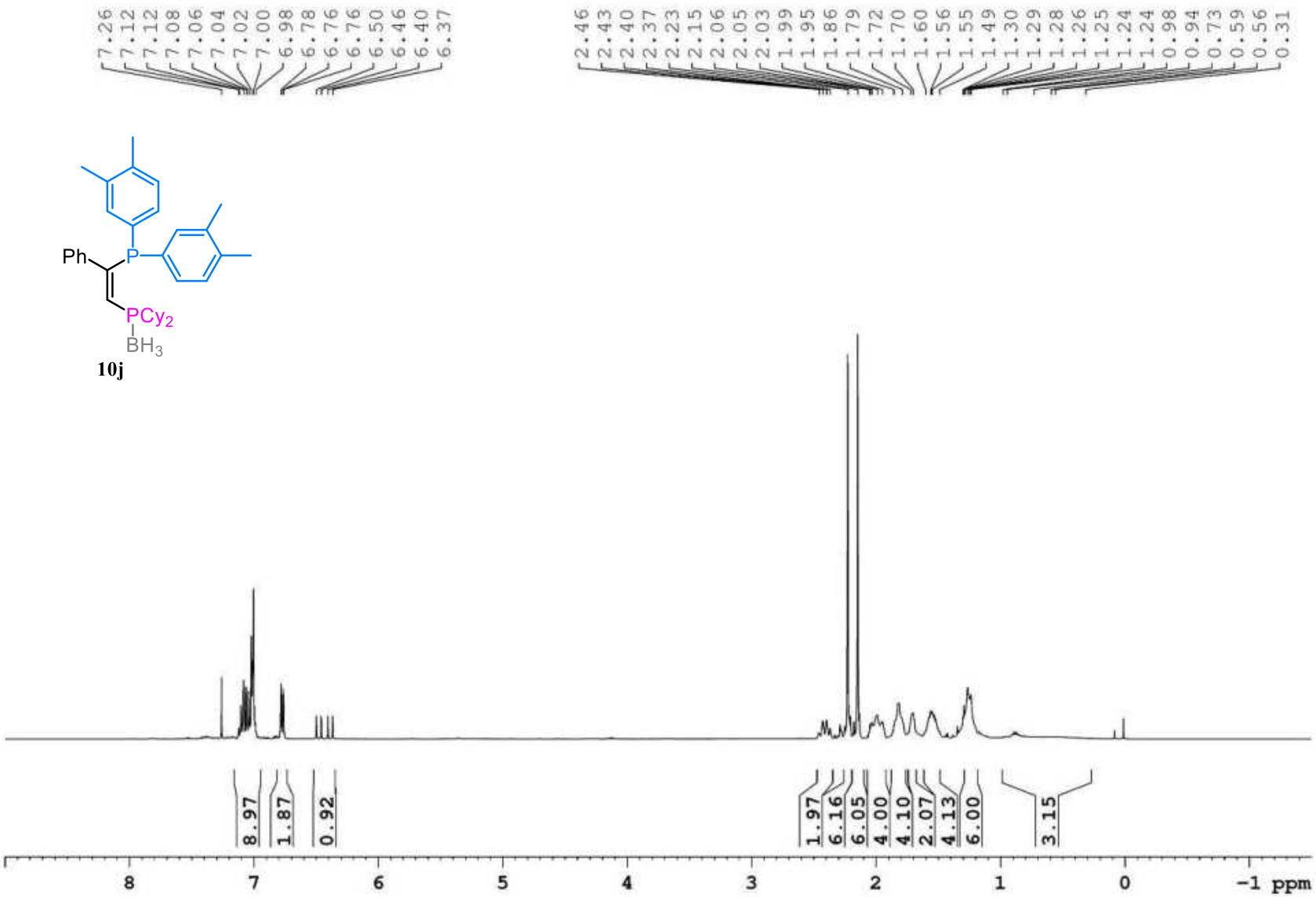
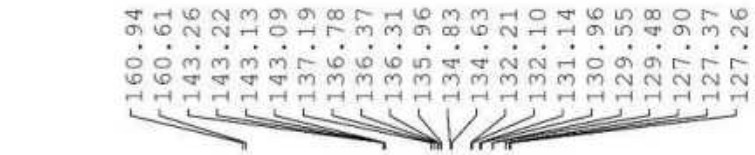
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
ppm


7.26
7.12
7.12
7.08
7.06
7.04
7.02
7.00
6.98
6.78
6.76
6.76
6.50
6.46
6.40
6.37
2.46
2.43
2.40
2.37
2.23
2.15
2.06
2.05
2.03
1.99
1.95
1.86
1.79
1.72
1.70
1.60
1.56
1.55
1.49
1.30
1.29
1.28
1.26
1.25
1.24
1.24
0.98
0.94
0.73
0.59
0.56
0.31
Ph
P
PCy2
BH3
8.97
1.87
0.92
1.97
6.16
6.05
4.00
4.10
2.07
4.13
6.00
3.15
8
7
6
5
4
3
2
1
0
-1 ppm

10j


160.94
160.61
143.26
143.22
143.13
143.09
137.19
136.78
136.37
136.31
135.96
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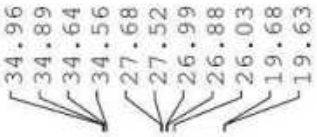
130.96
129.55
129.48
127.90
127.37
127.26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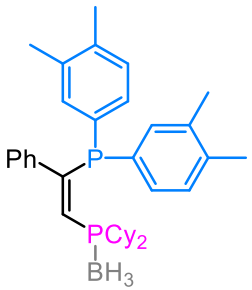
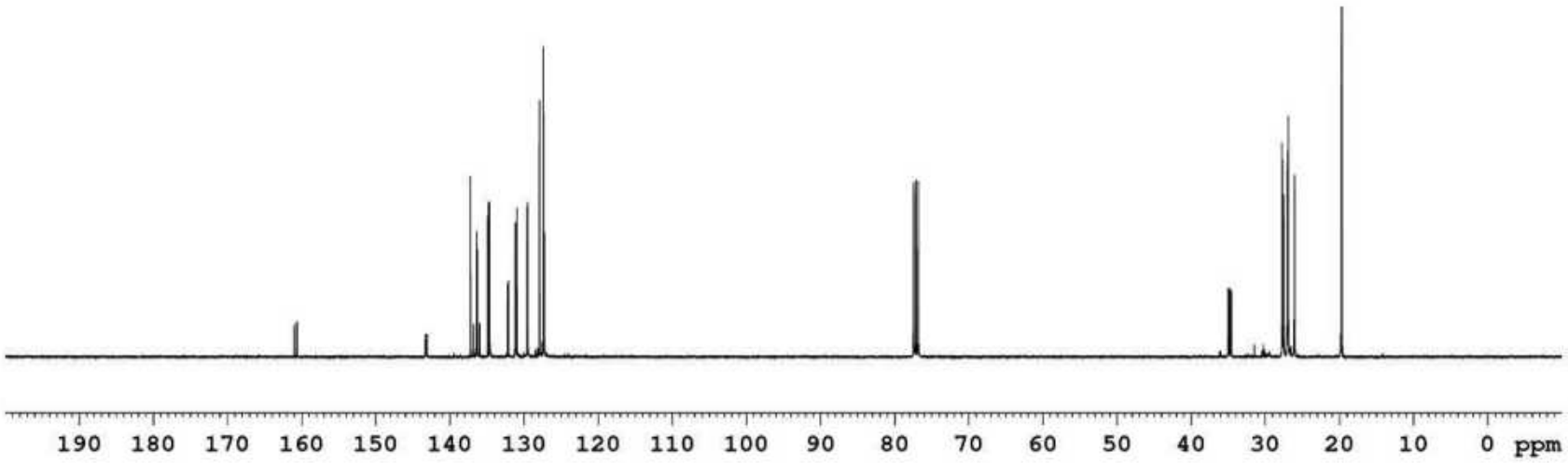
34.89
34.64
34.56
27.68
27.52
26.99
26.88
26.03
19.68
19.63


Ph
P
PCy2
BH3

10j


190
180
170
160
150
140
130
120
110
100
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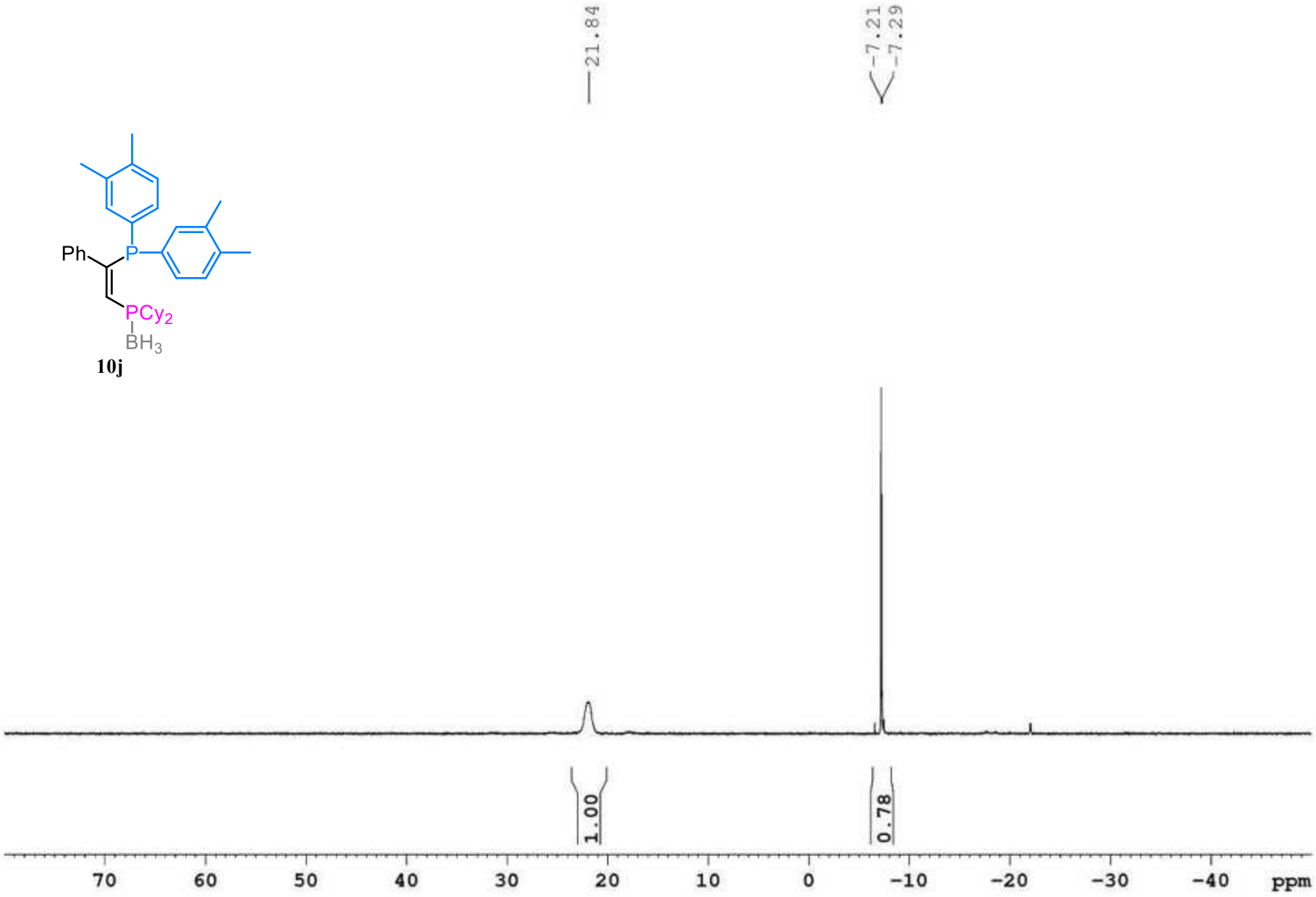
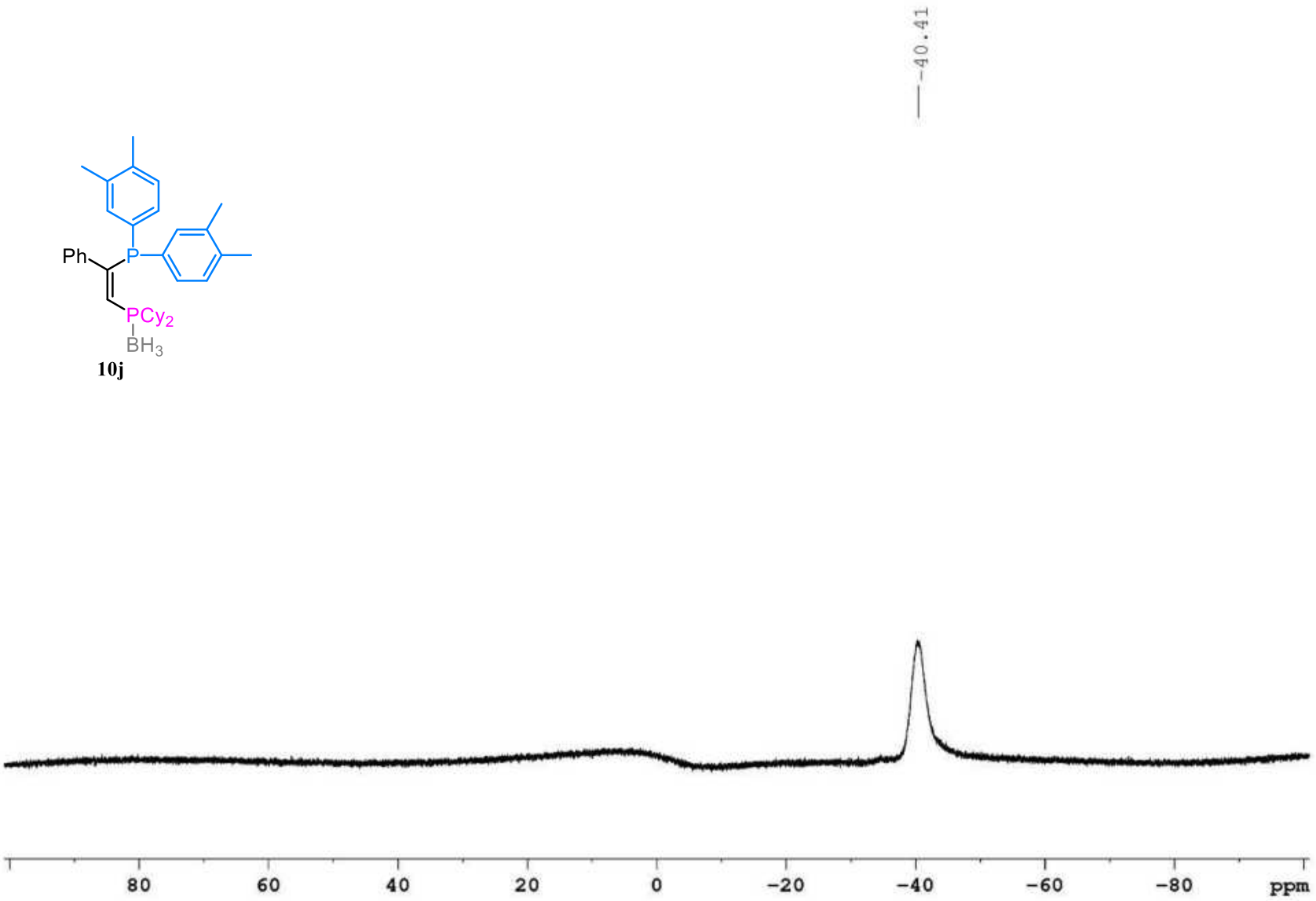
80
70
60
50
40
30
20
10
0
ppm

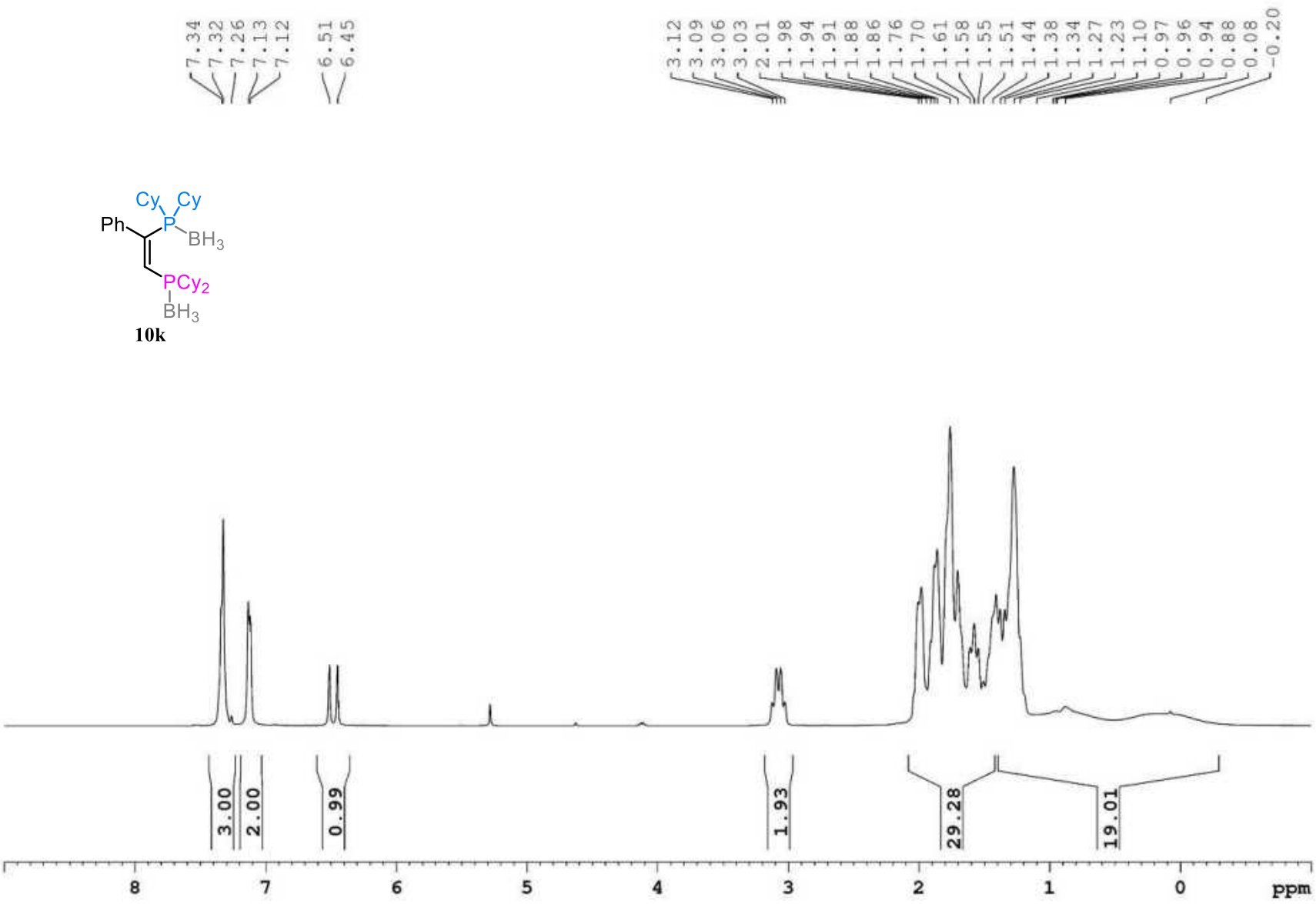
Ph
P
PCy2
BH3

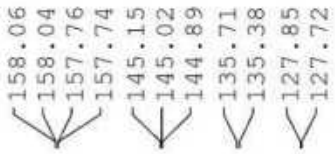
10j


21.84
7.21
7.29
1.00
0.78
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm

10j




7.34
7.32
7.26
7.13
7.12
6.51
6.45
3.12
3.09
3.06
3.03
2.01
1.98
1.94
1.91
1.88
1.86
1.76
1.70
1.61
1.58
1.55
1.51
1.44
1.38
1.34
1.27
1.23
1.10
0.97
0.96
0.94
0.88
0.08
-0.20
Cy
Cy
Ph
P
BH3
PCy2
BH3
10k
3.00
2.00
0.99
1.93
29.28
19.01
8
7
6
5
4
3
2
1
0
ppm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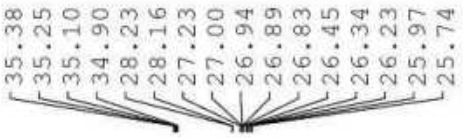
158.04
157.76
157.74
145.15
145.02
144.89
135.71
135.38
127.85
127.72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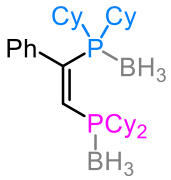
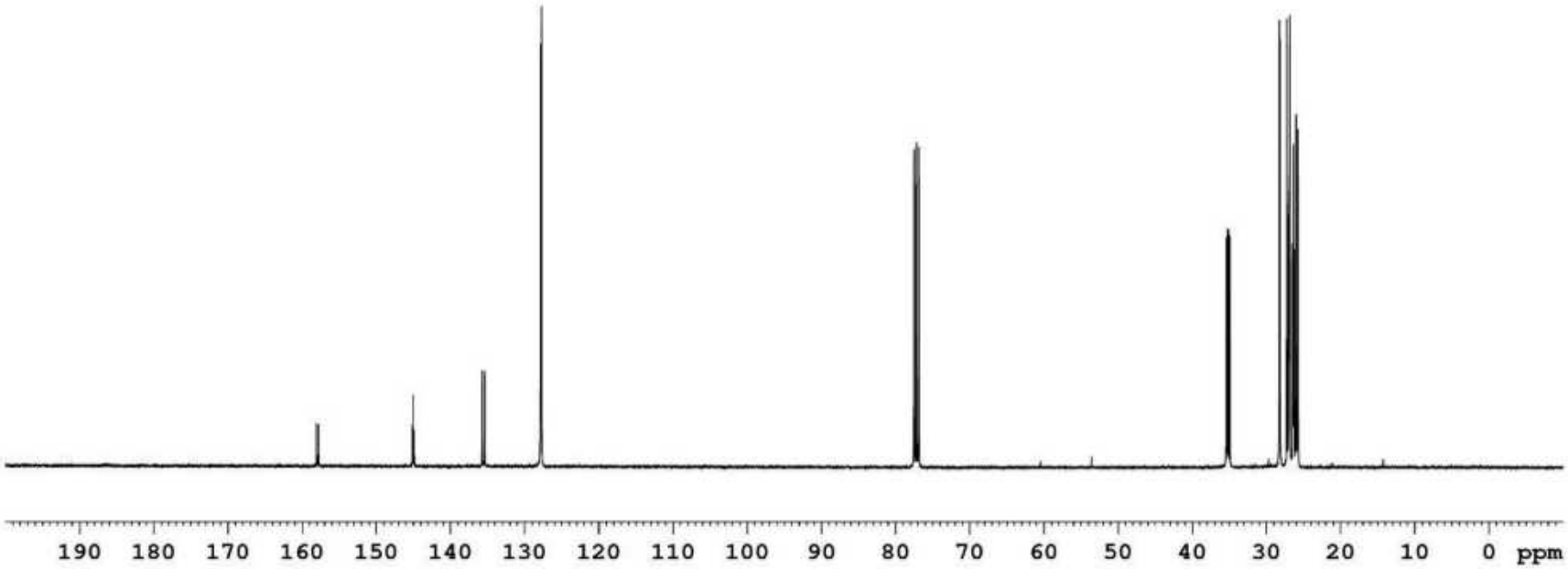
35.25
35.10
34.90
28.23
28.16
27.23
27.00
26.94
26.89
26.83
26.45
26.34
26.23
25.97
25.74


Cy
Cy
Ph
P
BH3
PCy2
BH3

10k


190
180
170
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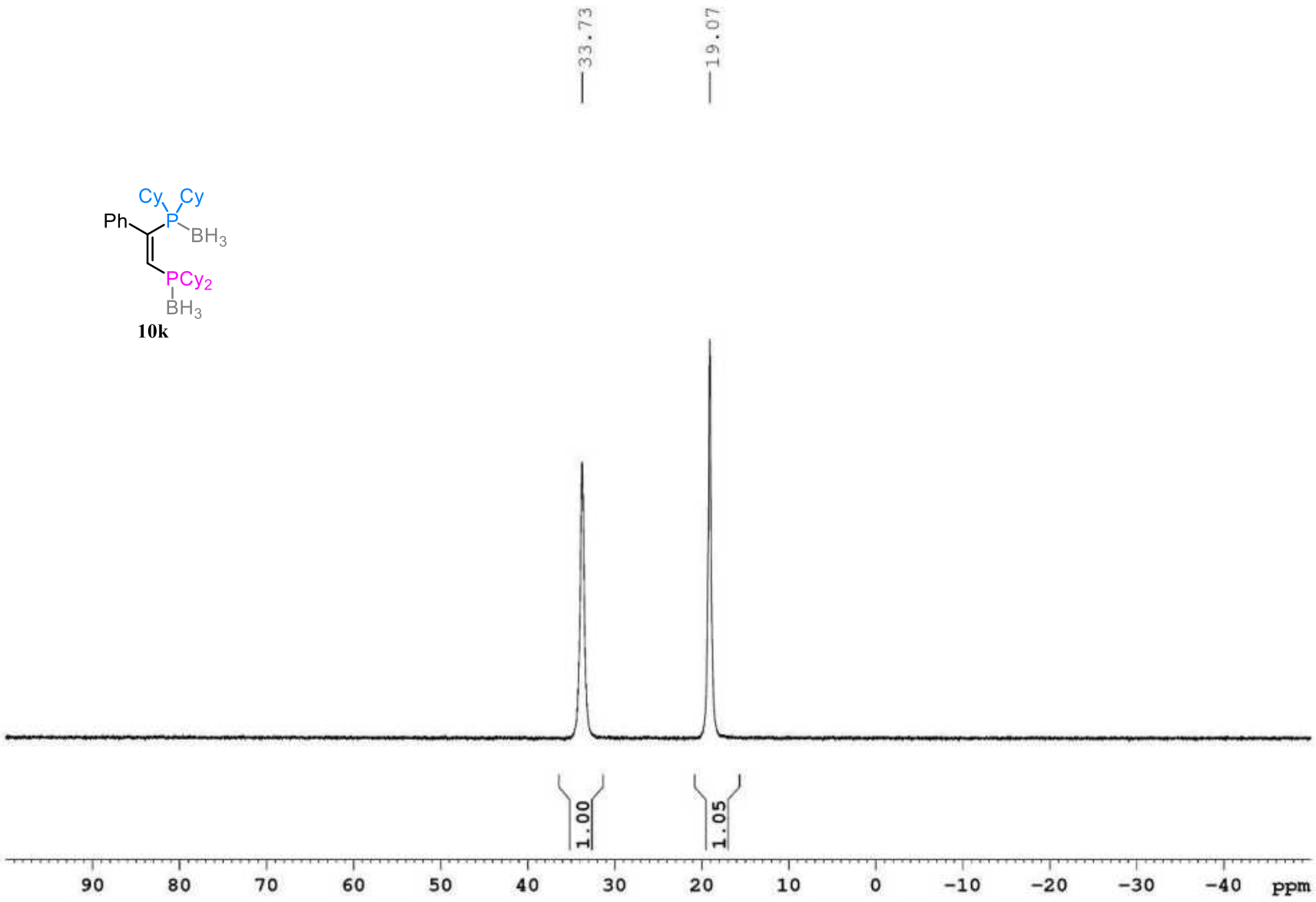
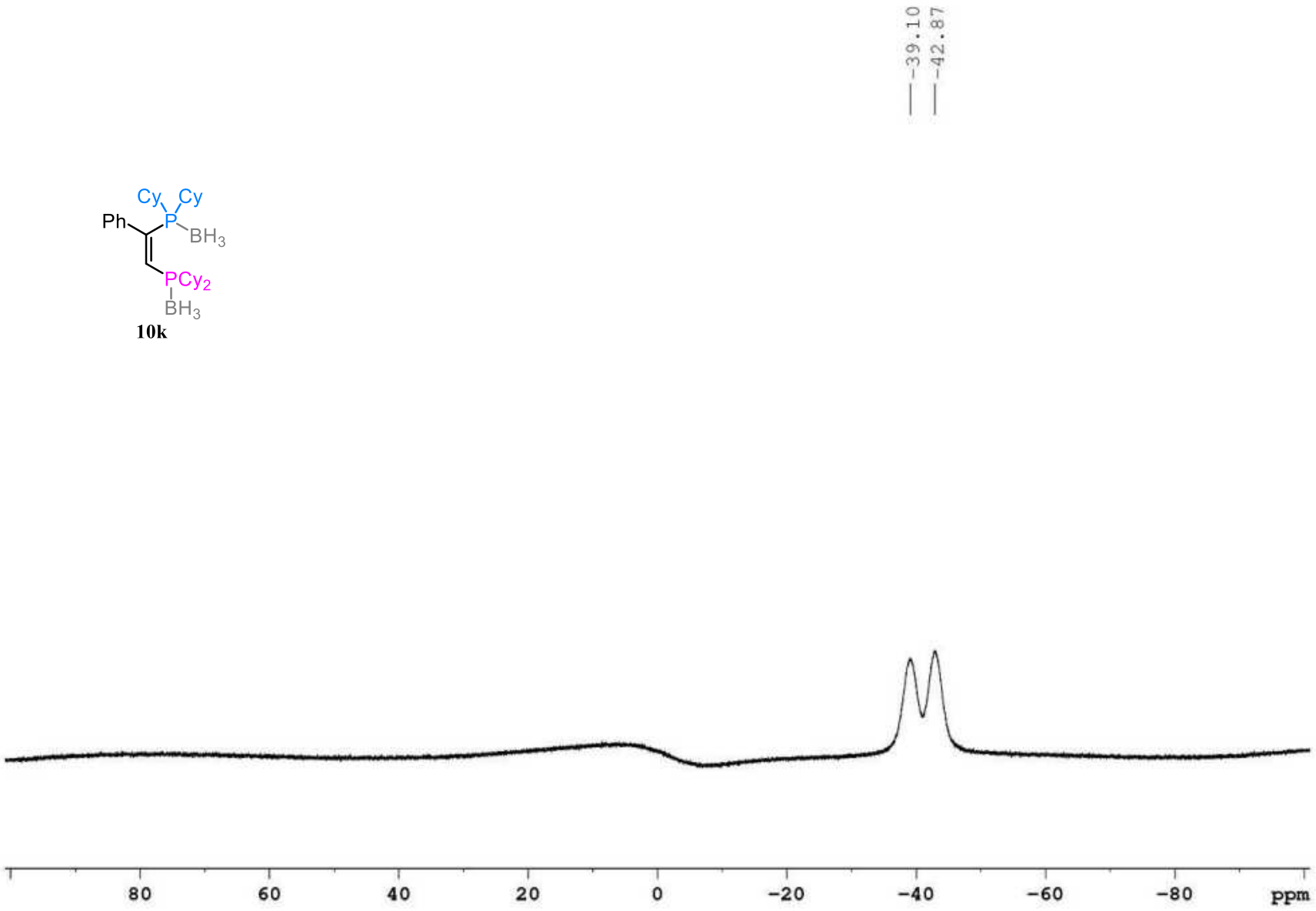
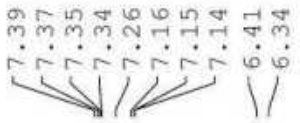
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


33.73
19.07
Cy
Cy
Ph
P
BH3
PCy2
BH3
10k
1.00
1.05
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm

10k

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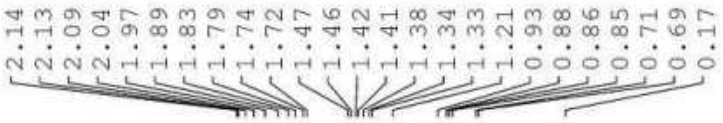
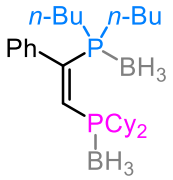
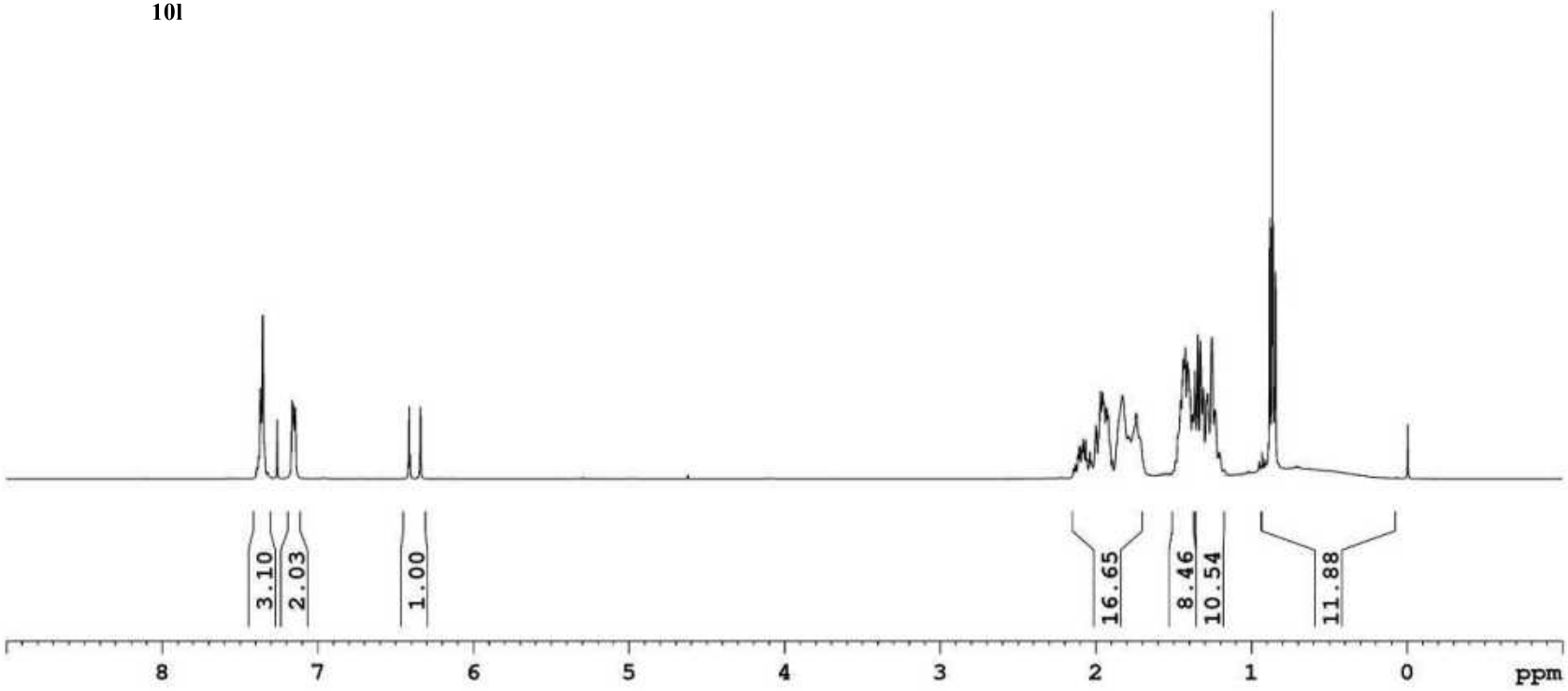
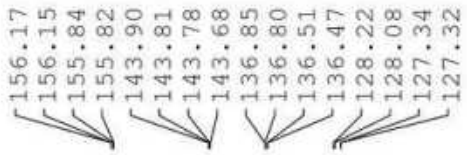
7.37
7.35
7.34
7.26
7.16
7.15
7.14
6.41
6.34


2.14
2.13
2.09
2.04
1.97
1.89
1.83
1.79
1.74
1.72
1.47
1.46
1.42
1.41
1.38
1.34
1.33
1.21
0.93
0.88
0.86
0.85
0.71
0.69
0.17


n-Bu
n-Bu
Ph
P
BH3
PCy2
BH3

10l


3.10
2.03
1.00
16.65
8.46
10.54
11.88
8
7
6
5
4
3
2
1
0
ppm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156.15
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155.82
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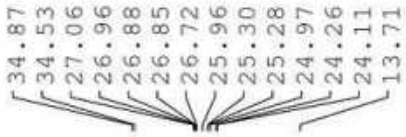
143.78
143.68
136.85
136.80
136.51
136.47
128.22
128.08
127.34
127.32


34.87
34.53
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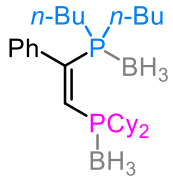
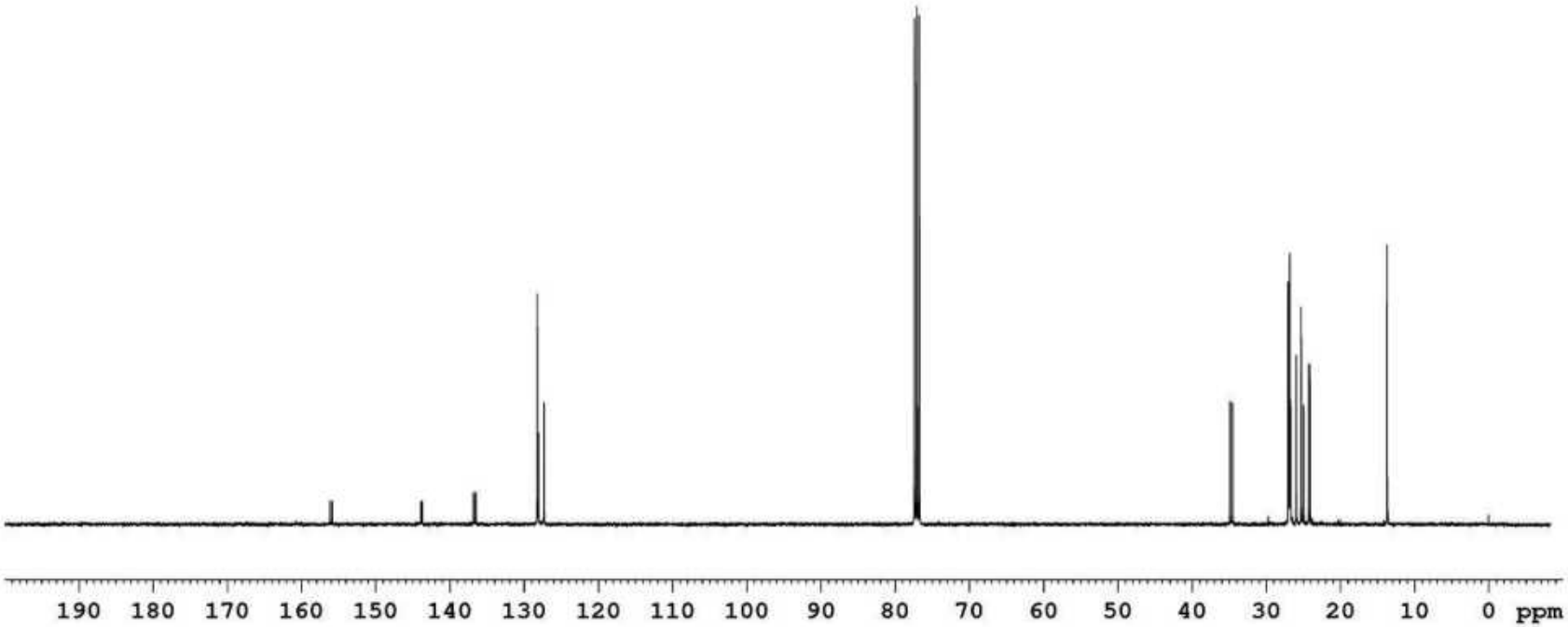
26.88
26.85
26.72
25.96
25.30
25.28
24.97
24.26
24.11
13.71

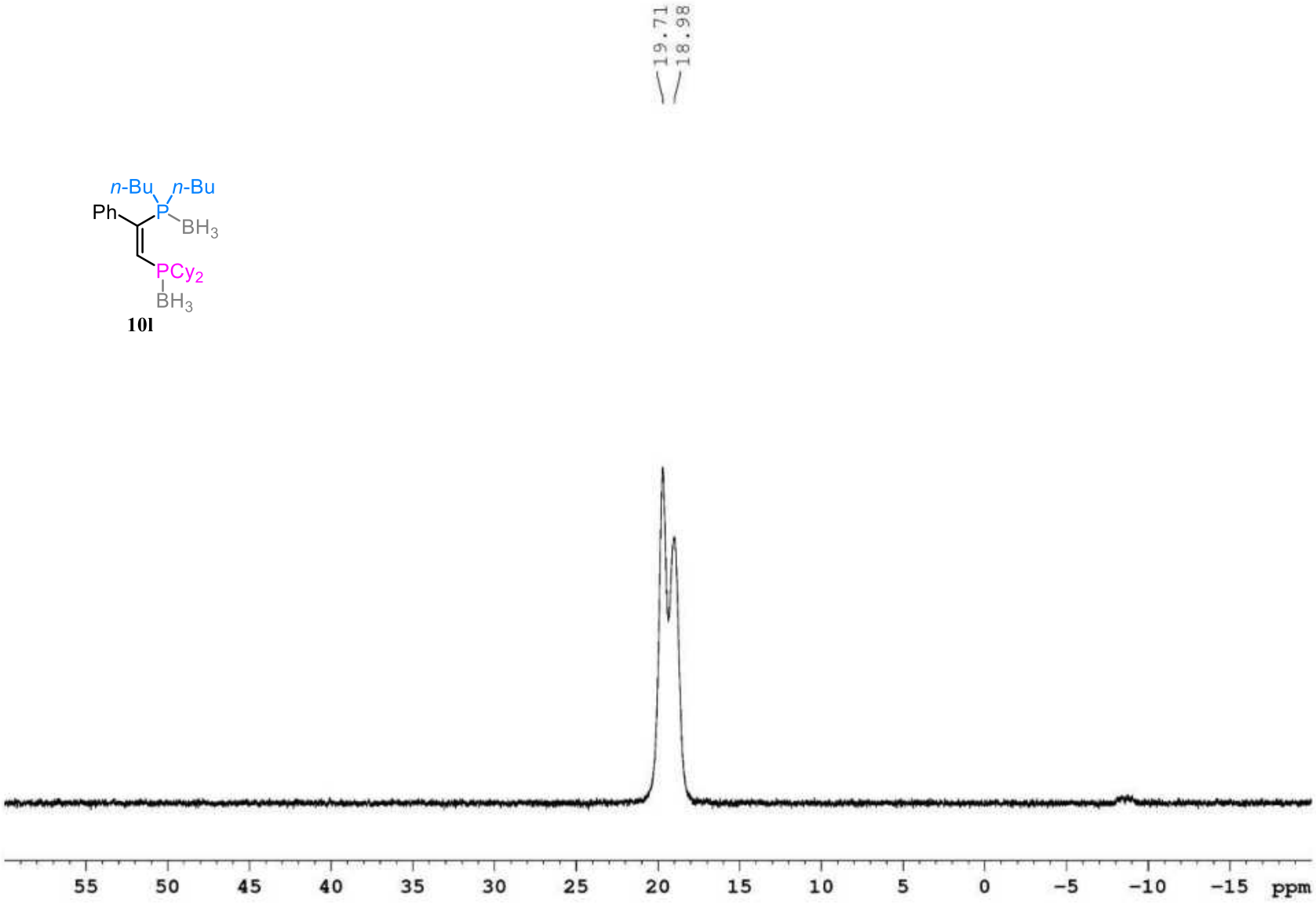

n-Bu
n-Bu
Ph
P
BH3
PCy2
BH3

10l


190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

n-Bu
n-Bu
Ph
P
BH3
PCy2
BH3

10l


19.71
18.98
55
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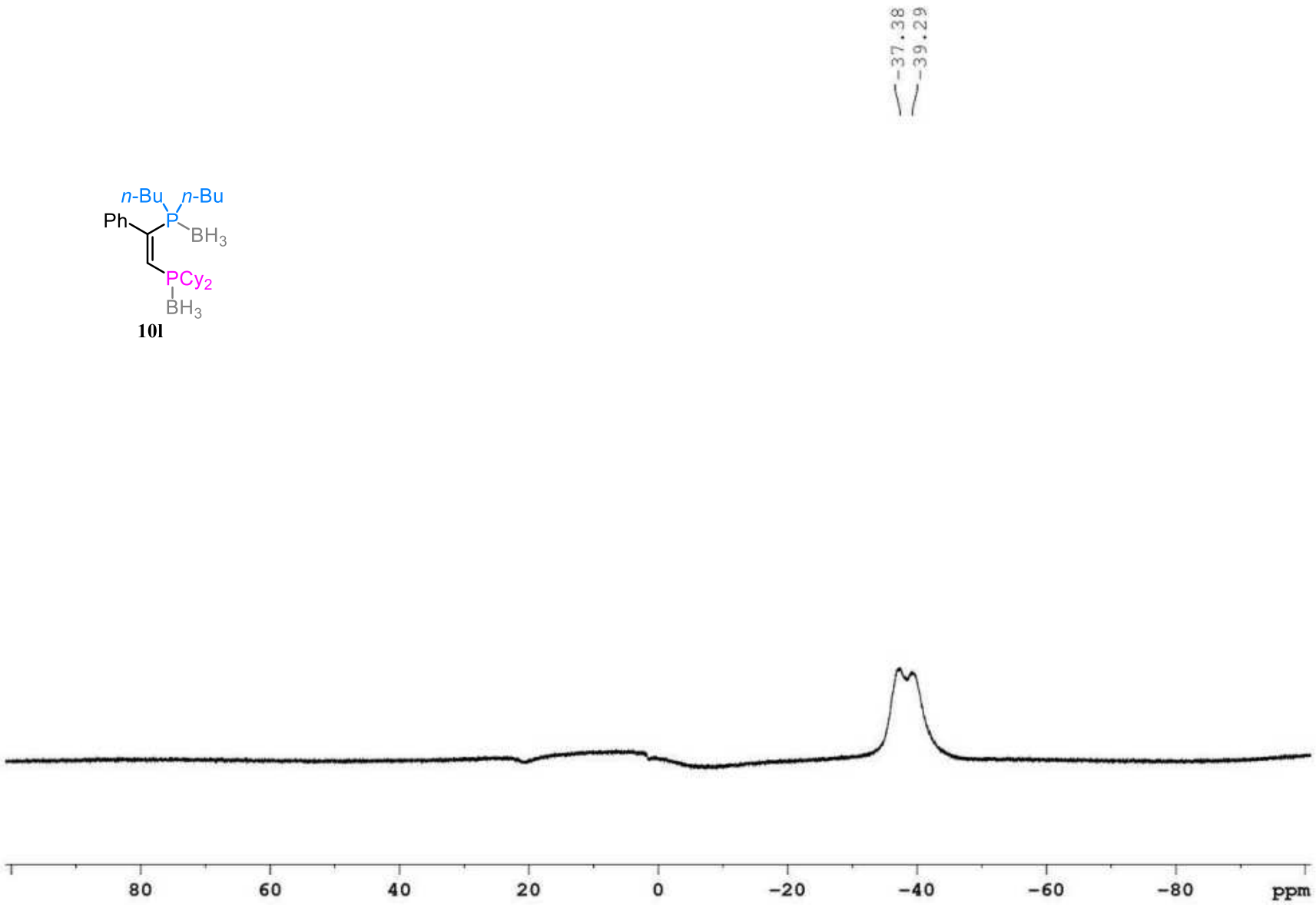
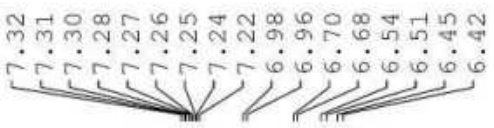
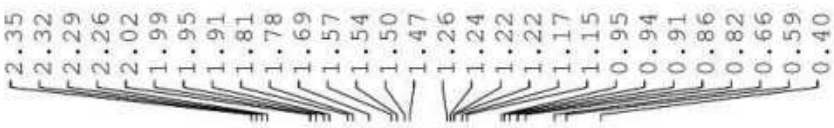
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
ppm

10l




7.32
7.31
7.30
7.28
7.27
7.26
7.25
7.24
7.22
6.98
6.96
6.70
6.68
6.54
6.51
6.45
6.42


2.35
2.32
2.29
2.26
2.02
1.99
1.95
1.91
1.81
1.78
1.69
1.57
1.54
1.50
1.47
1.26
1.24
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1.15
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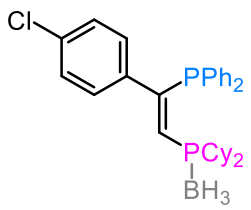
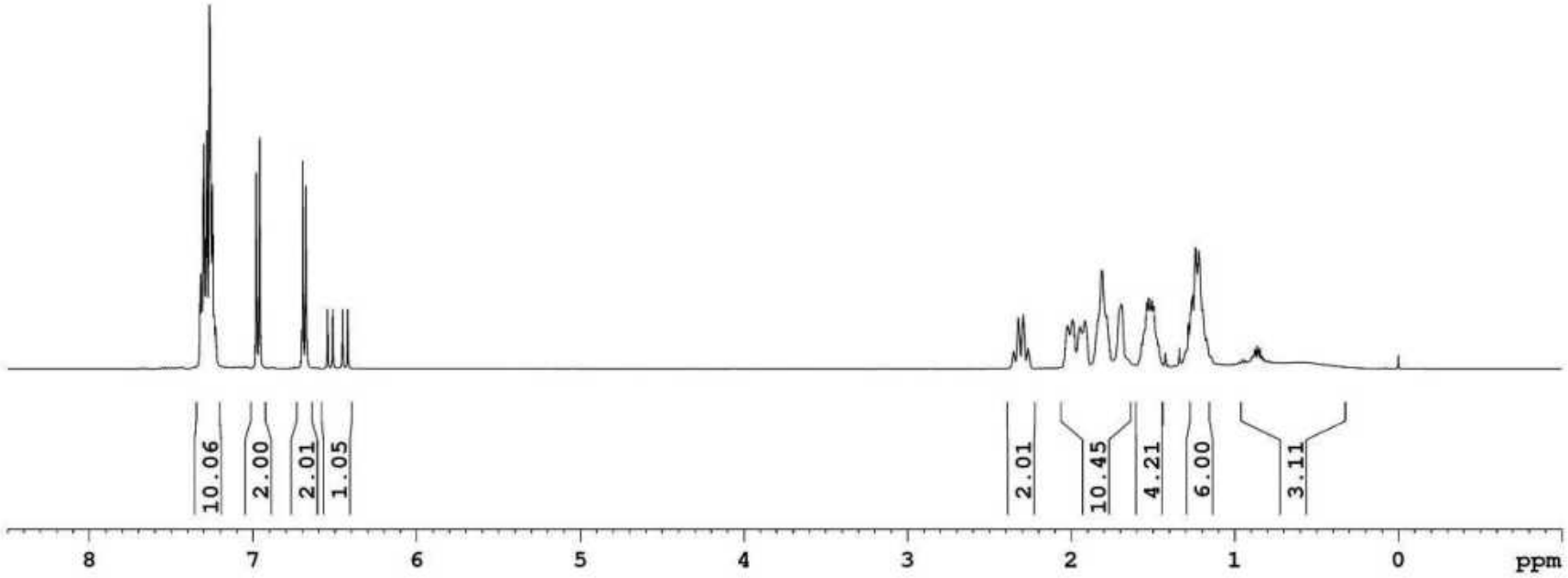
0.59
0.40


Cl
PPh2
PCy2
BH3

10m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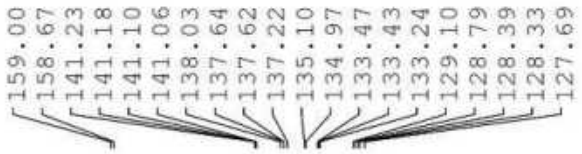
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134.97
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133.24
129.10
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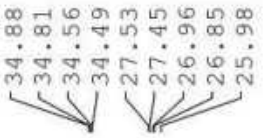
128.33
127.69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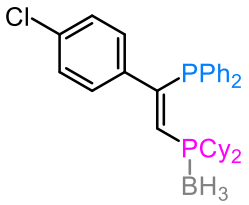
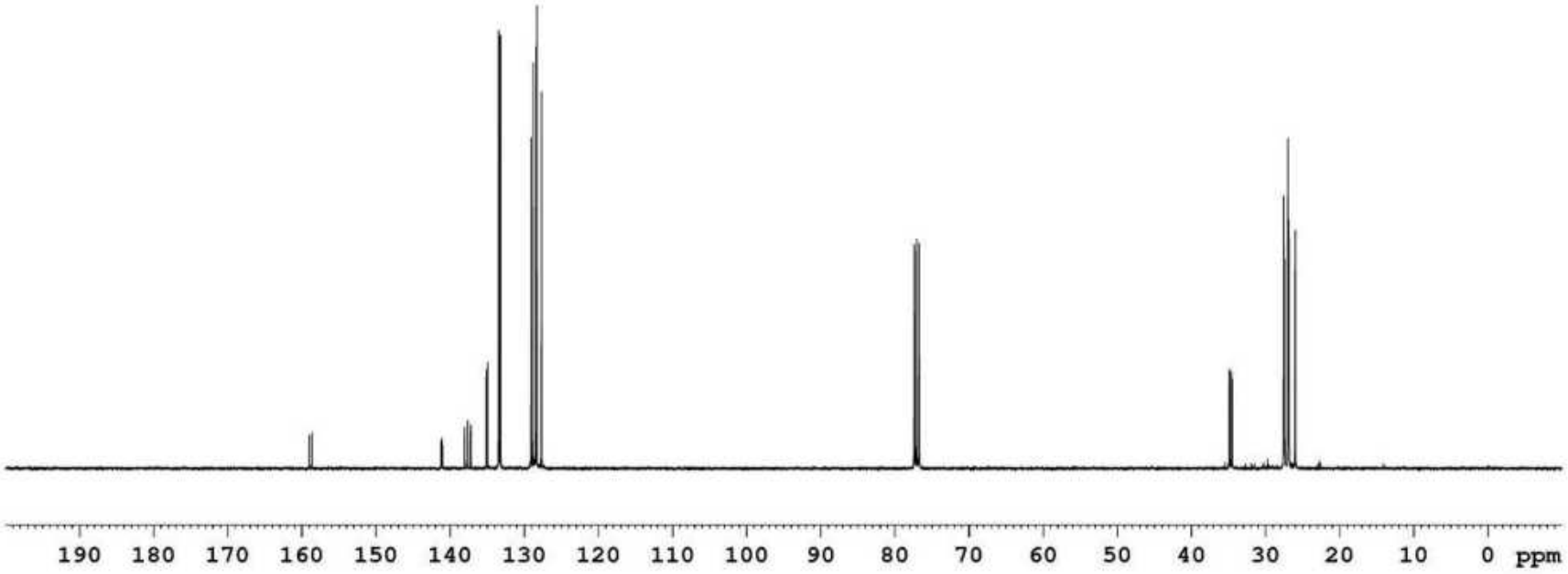
25.98


Cl
PPh2
PCy2
BH3

10m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20
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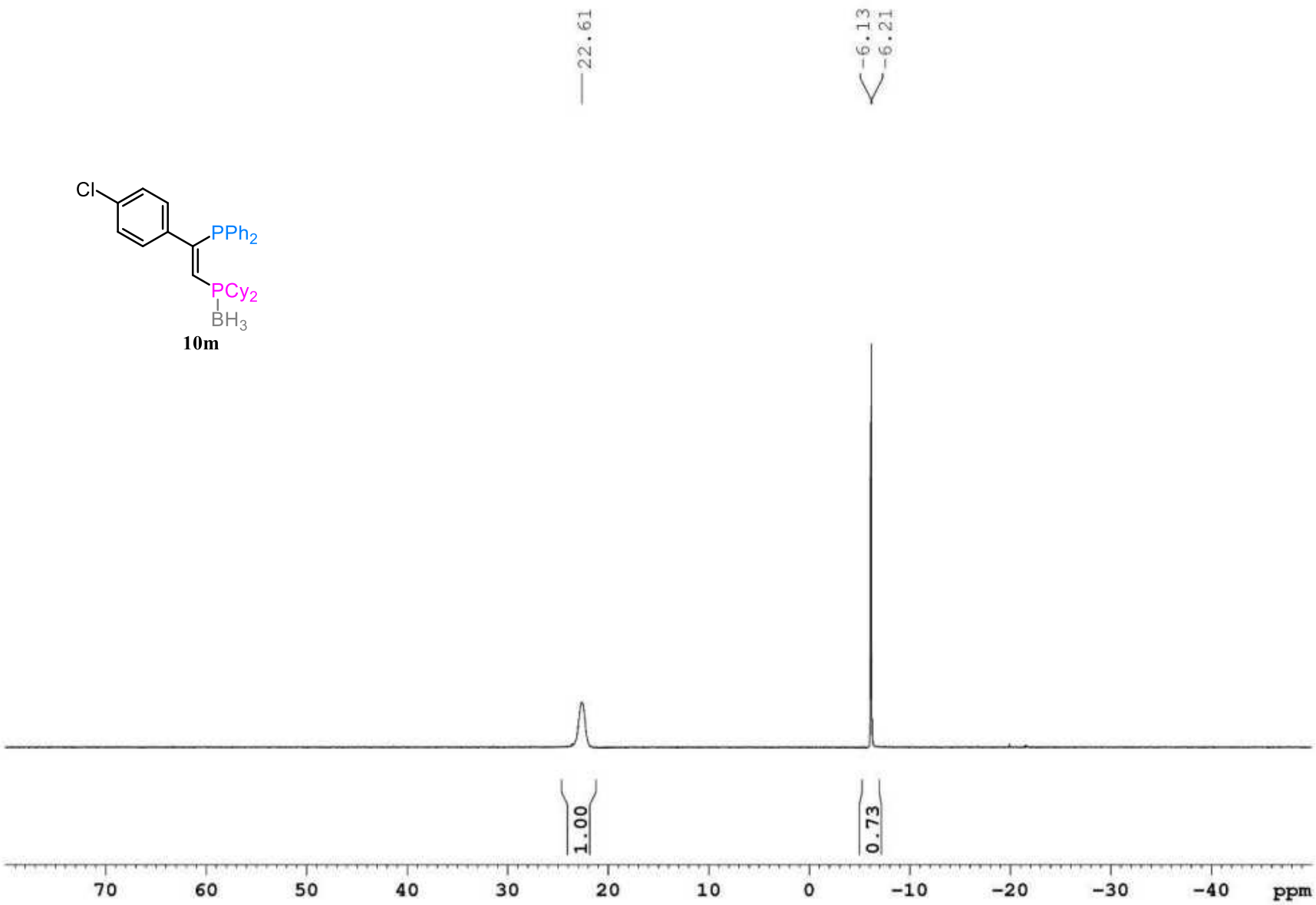
0
ppm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6.13
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Cl
PPh2
PCy2
BH3
10m
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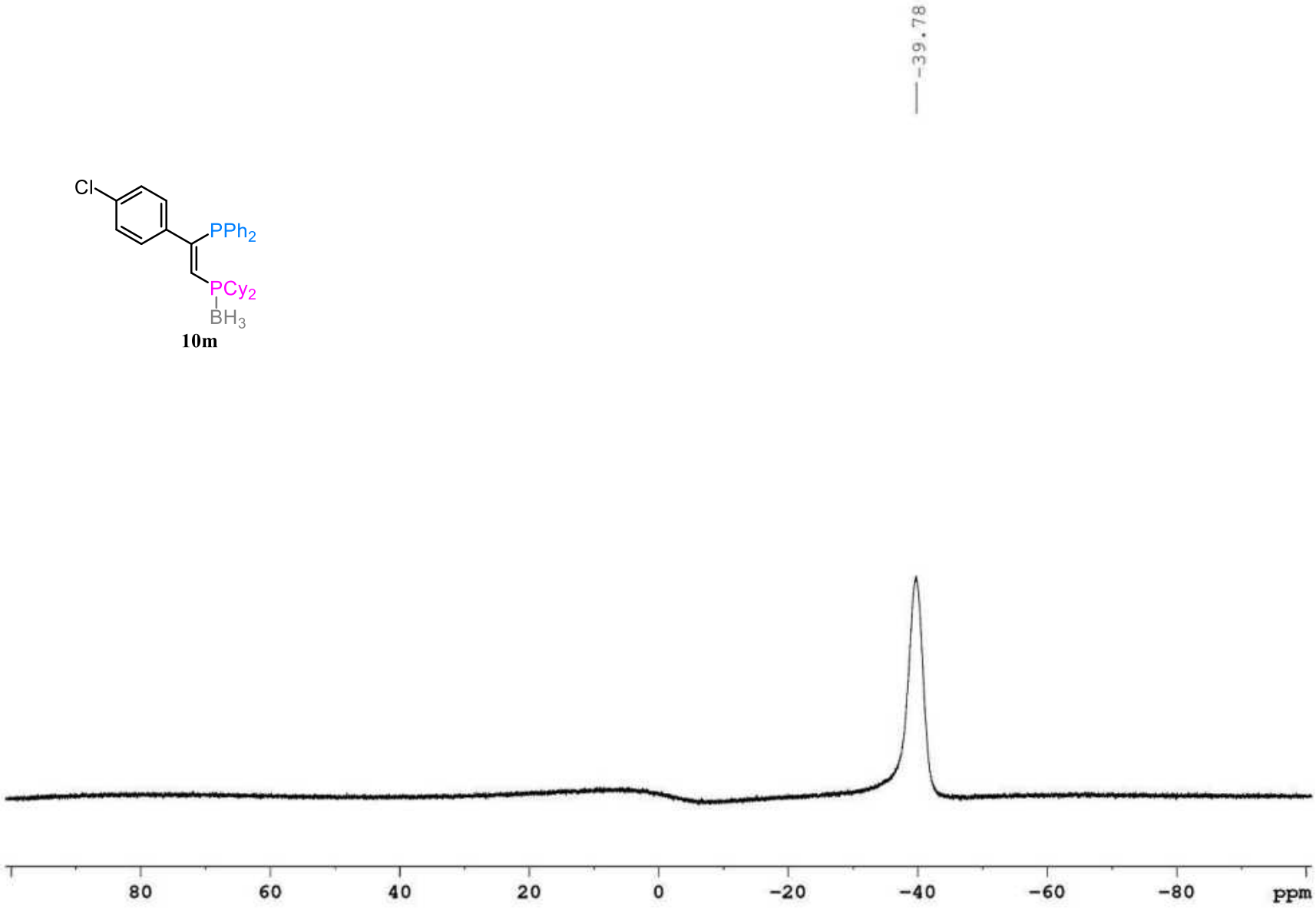
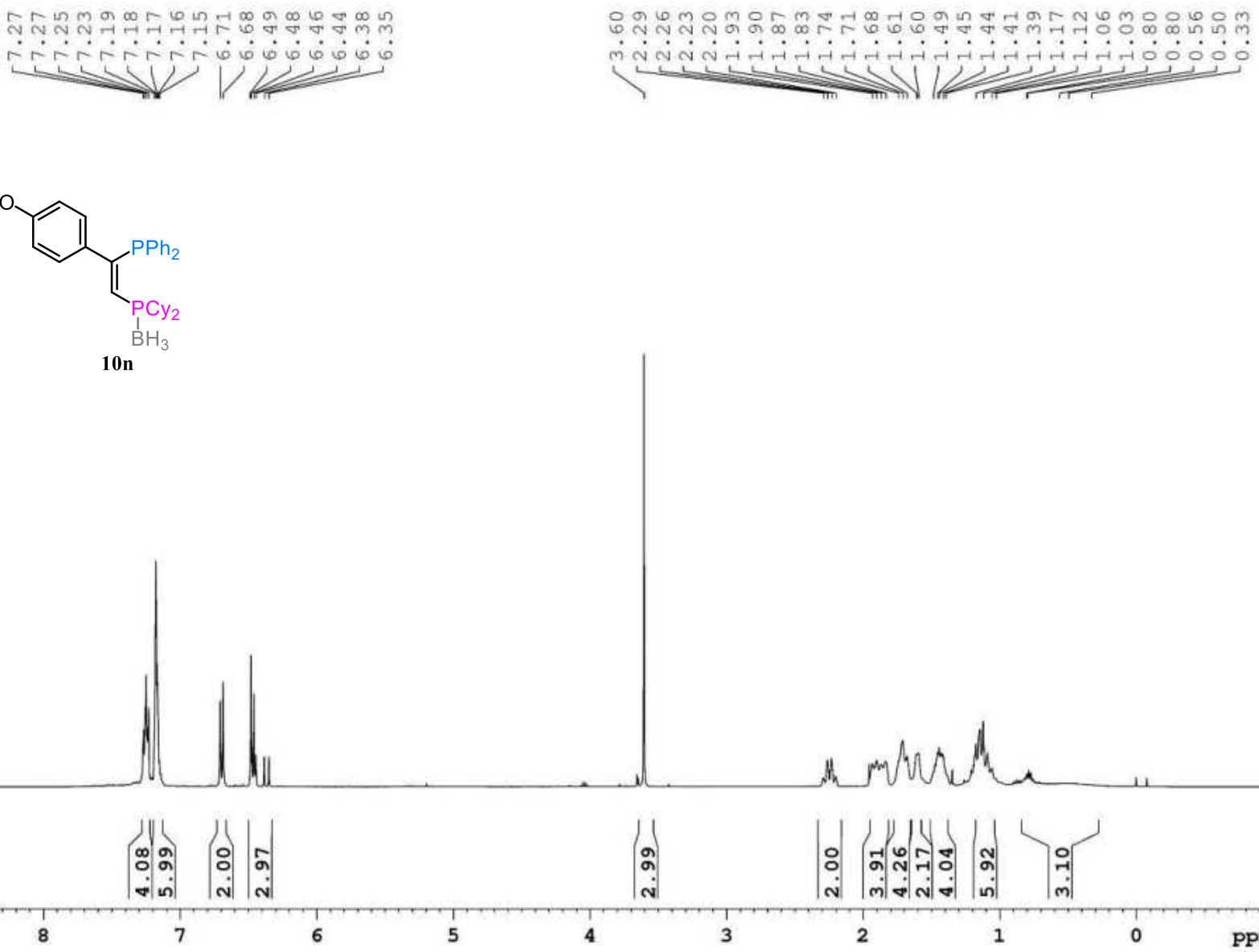
-30
-40
ppm

10m

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6.49
6.48
6.46
6.44
6.38
6.35
3.60
2.29
2.26
2.23
2.20
1.93
1.90
1.87
1.83
1.74
1.71
1.68
1.61
1.60
1.49
1.45
1.44
1.41
1.39
1.17
1.12
1.06
1.03
0.80
0.80
0.56
0.50
0.33
MeO
PPh2
PCy2
BH3
10n
4.08
5.99
2.00
2.97
2.99
2.00
3.91
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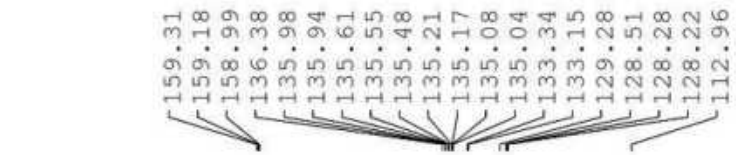
4.04
5.92
3.10
8
7
6
5
4
3
2
1
0
ppm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135.08
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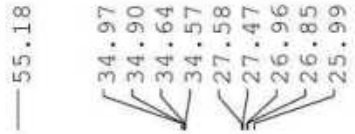
133.34
133.15
129.28
128.51
128.28
128.22
112.96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34.97
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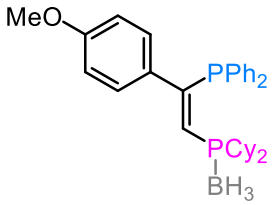
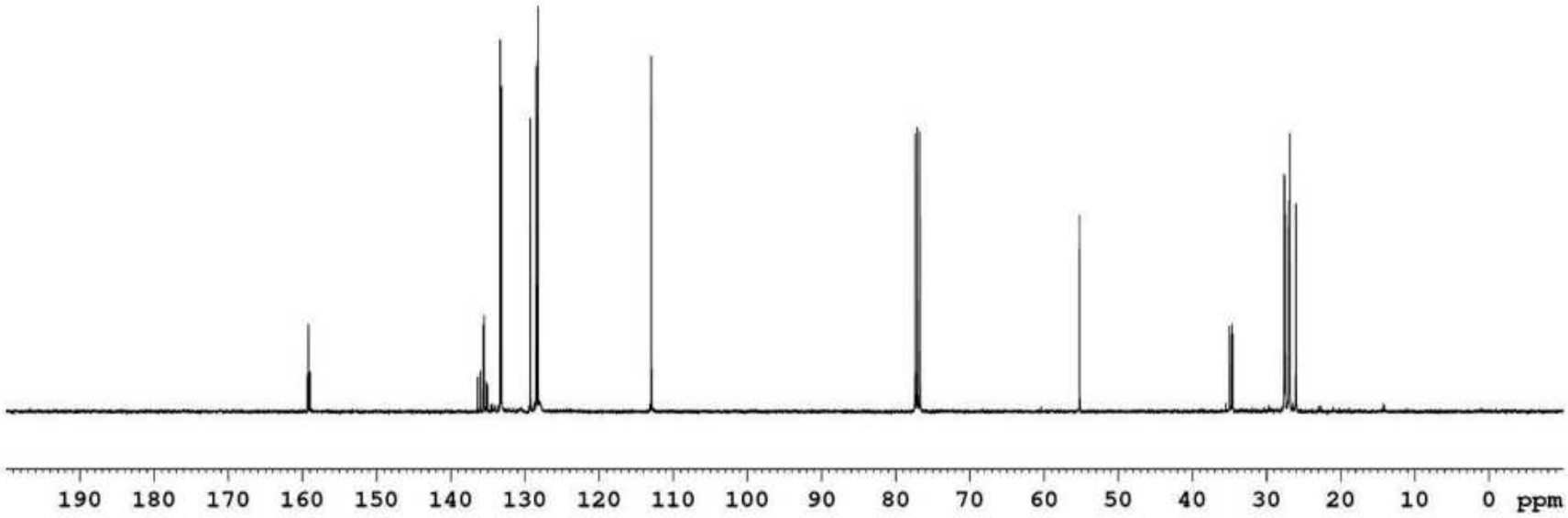
34.64
34.57
27.58
27.47
26.96
26.85
25.99


MeO
PPh2
PCy2
BH3

10n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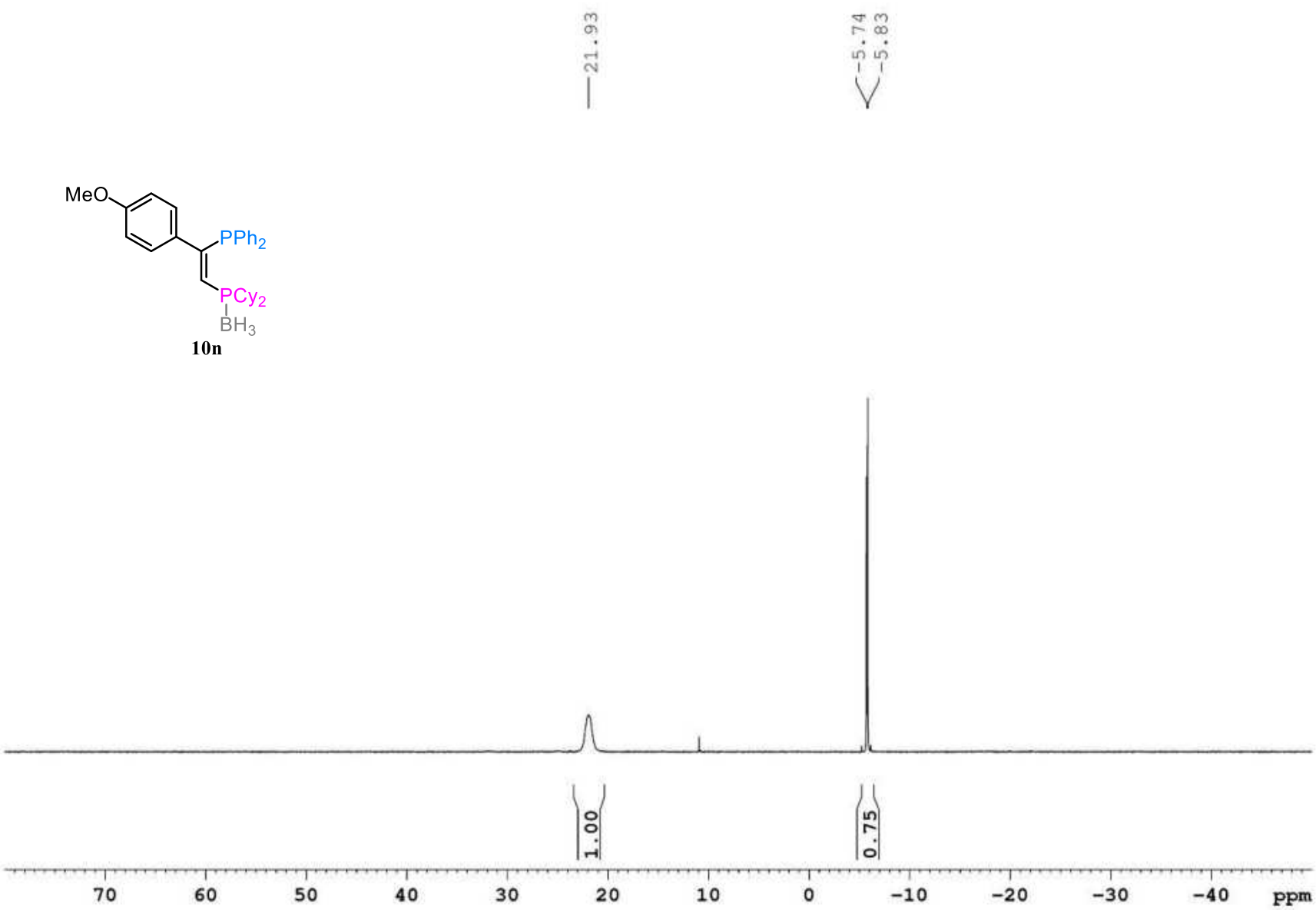
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm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-5.83
MeO
PPh2
PCy2
BH3
10n
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20
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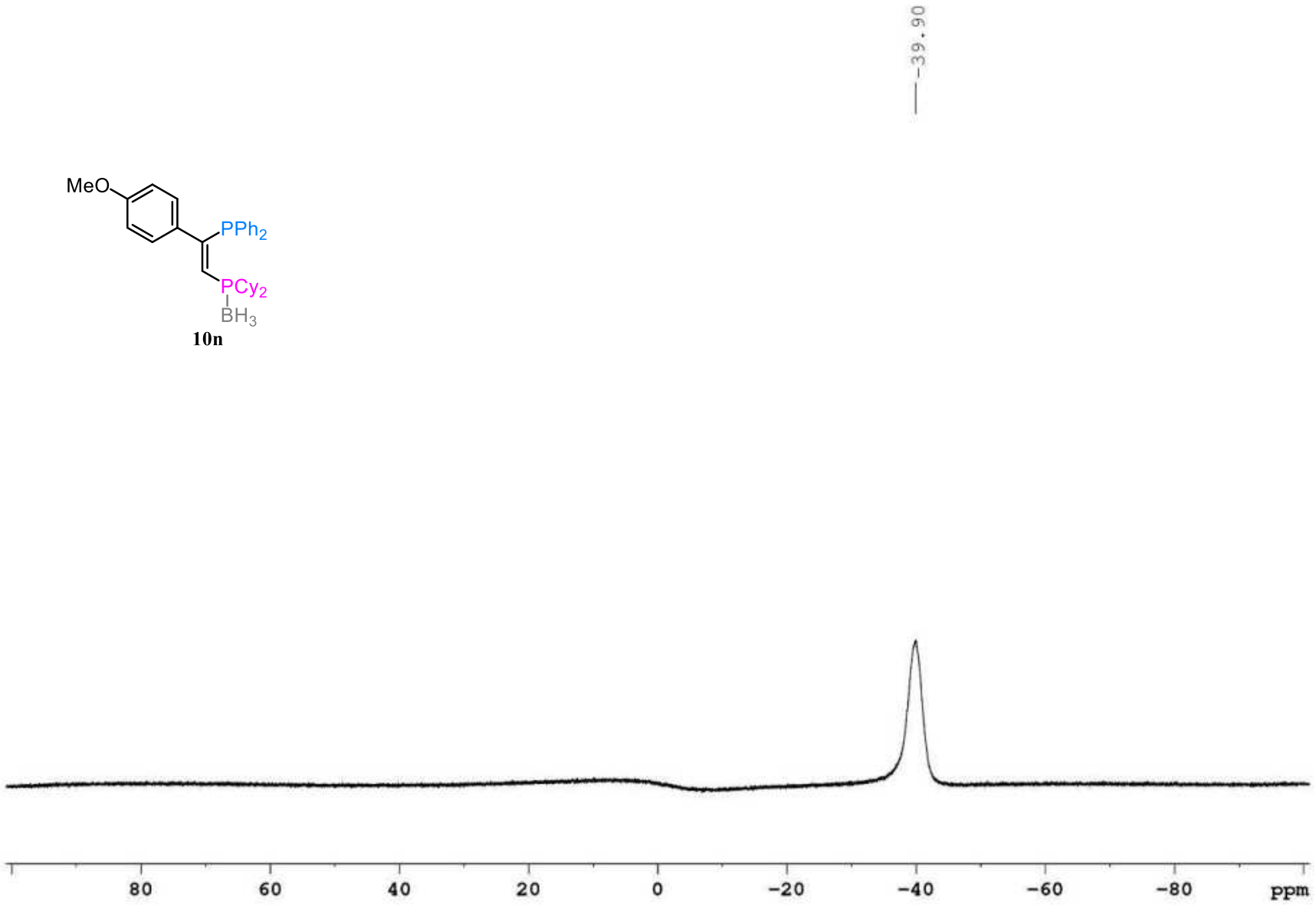
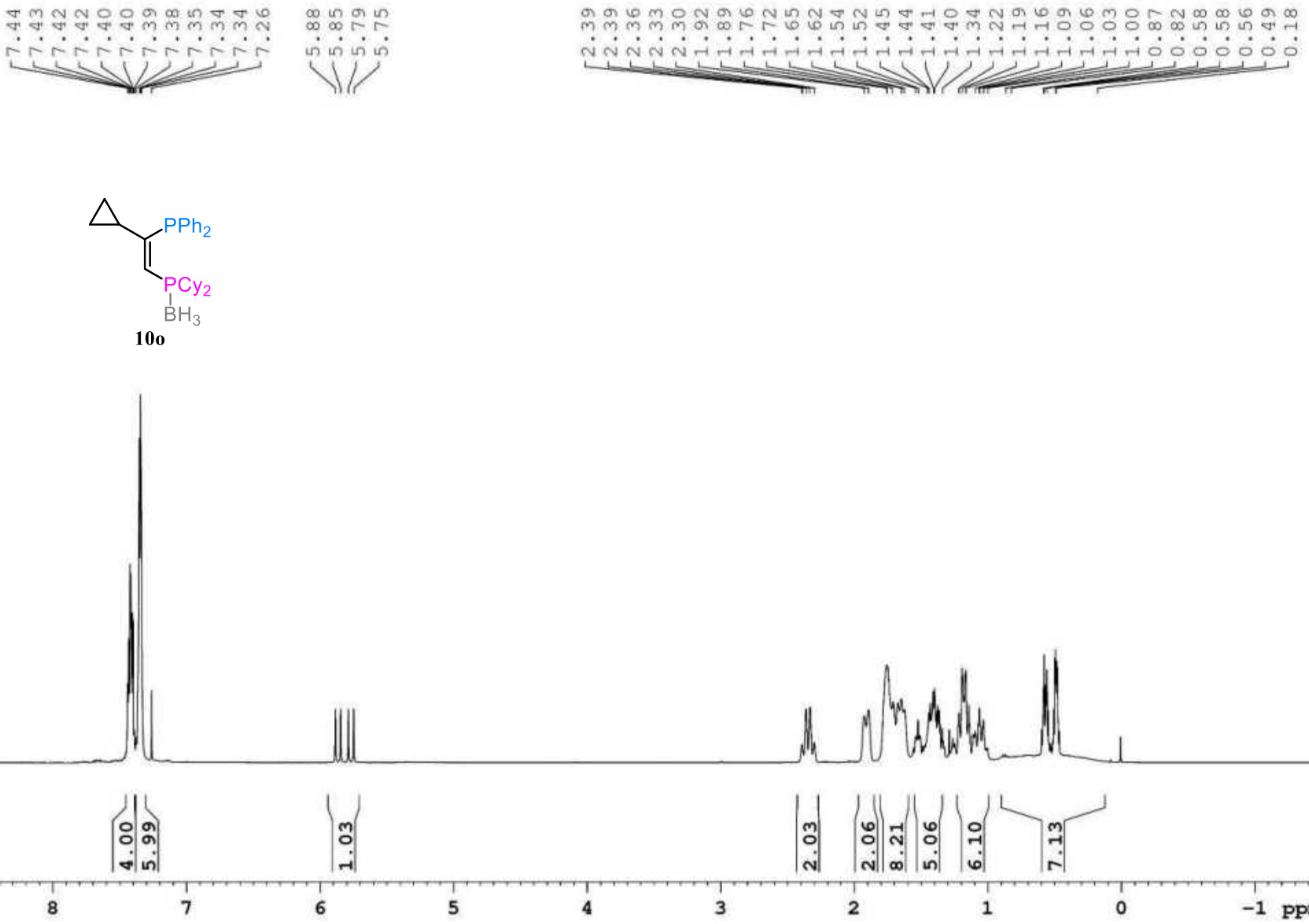
0
-10
-20
-30
-40
ppm

10n

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7.34
7.34
7.26
5.88
5.85
5.79
5.75
2.39
2.39
2.36
2.33
2.30
1.92
1.89
1.76
1.72
1.65
1.62
1.54
1.52
1.45
1.44
1.41
1.40
1.34
1.22
1.19
1.16
1.09
1.06
1.03
1.00
0.87
0.82
0.58
0.58
0.56
0.49
0.18
PPh2
PCy2
BH3
4.00
5.99
1.03
2.03
2.06
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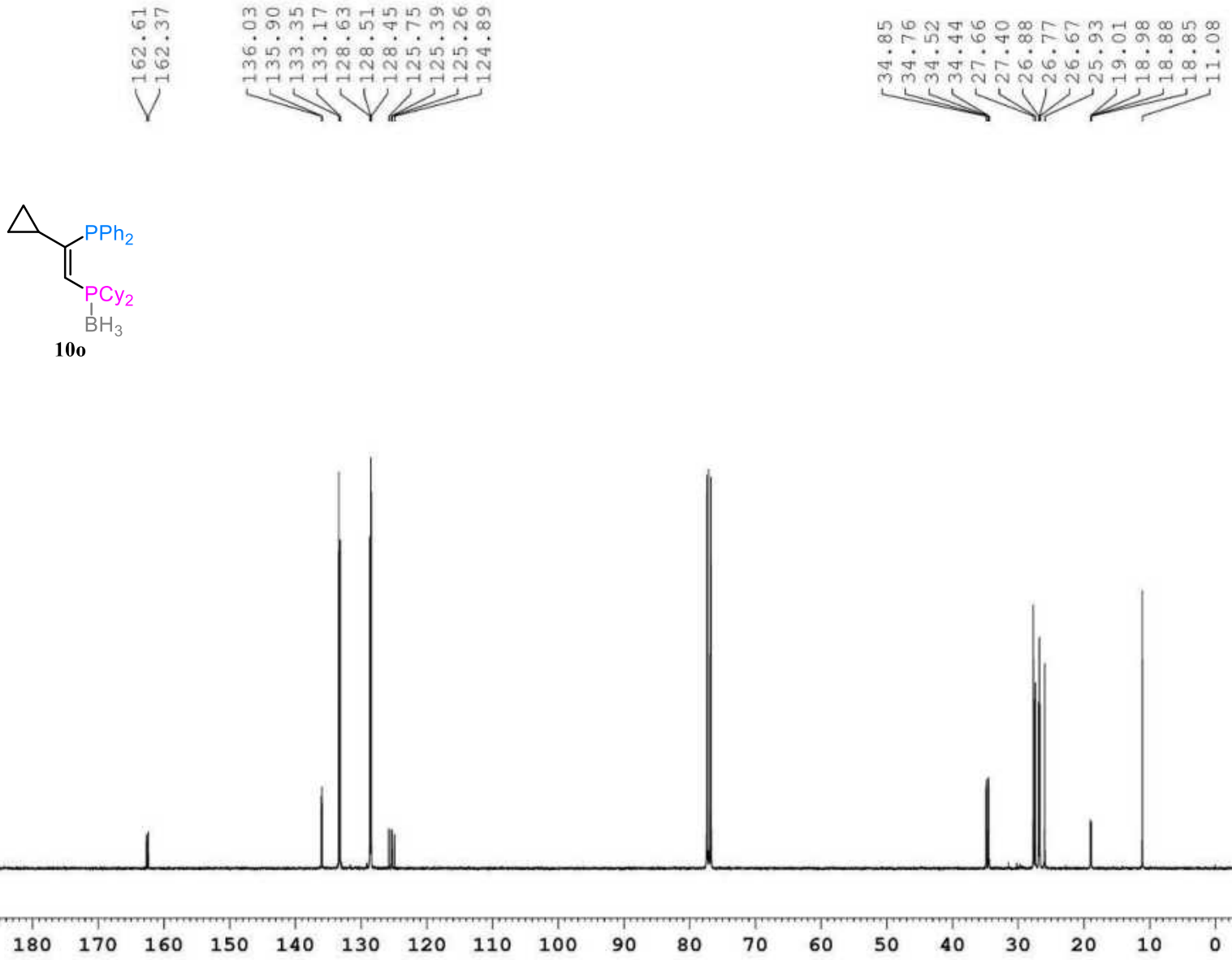
6.10
7.13
8
7
6
5
4
3
2
1
0
−1
ppm

10o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135.90
133.35
133.17
128.63
128.51
128.45
125.75
125.39
125.26
124.89
34.85
34.76
34.52
34.44
27.66
27.40
26.88
26.77
26.67
25.93
19.01
18.98
18.88
18.85
11.08
PPh2
PCy2
BH3
190
180
170
160
150
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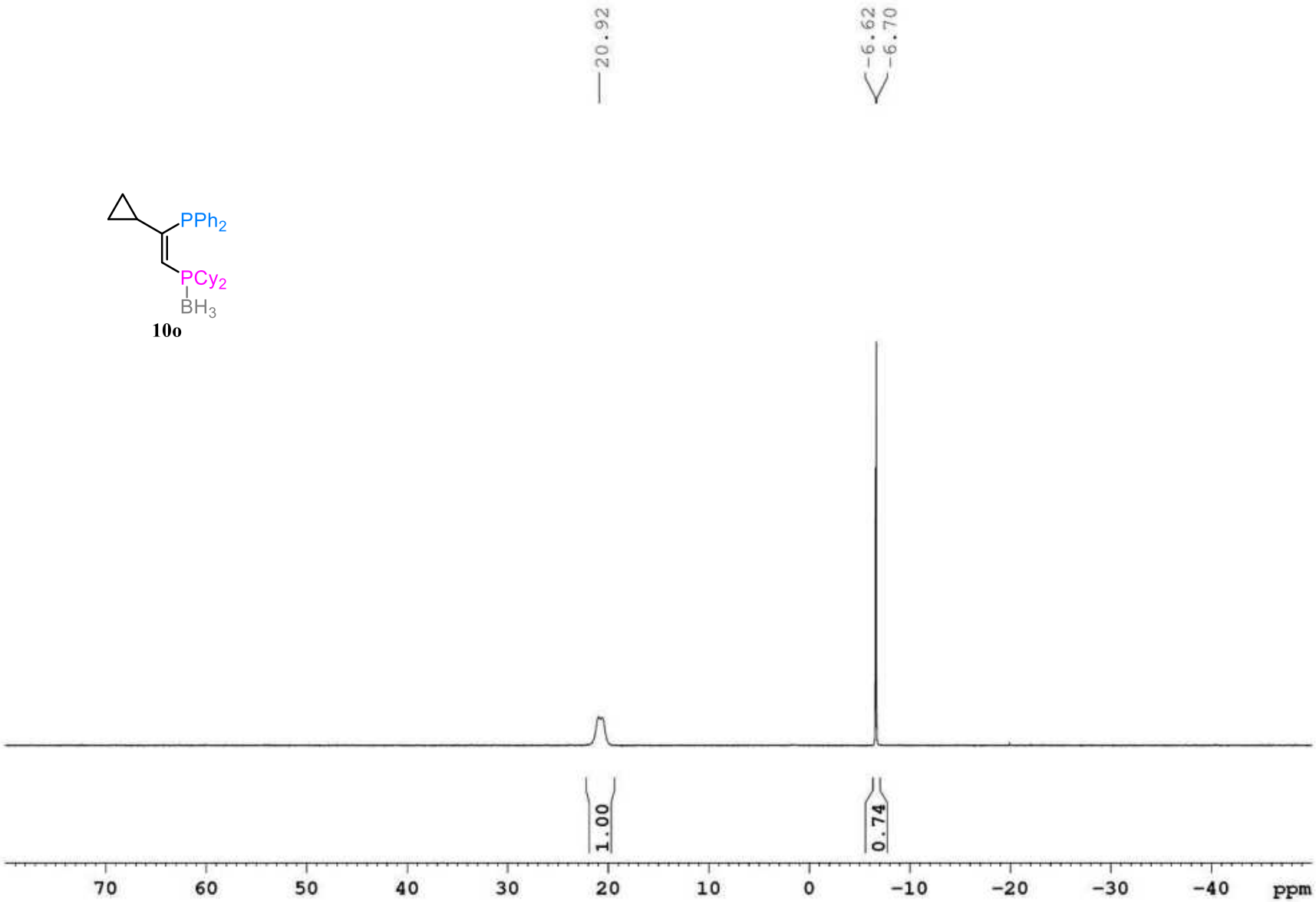
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

10o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-6.62
-6.70
PPh2
PCy2
BH3
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0.74
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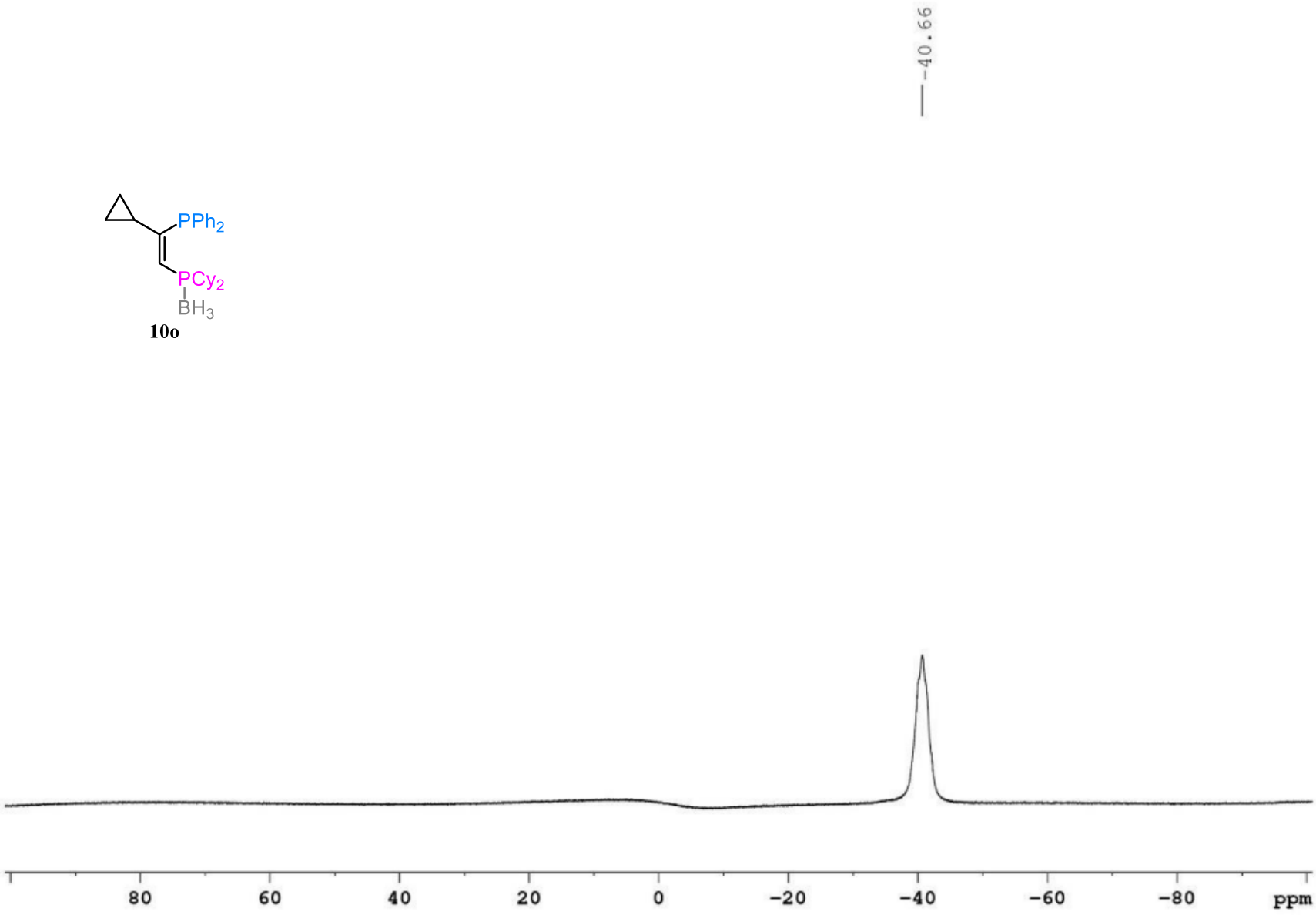
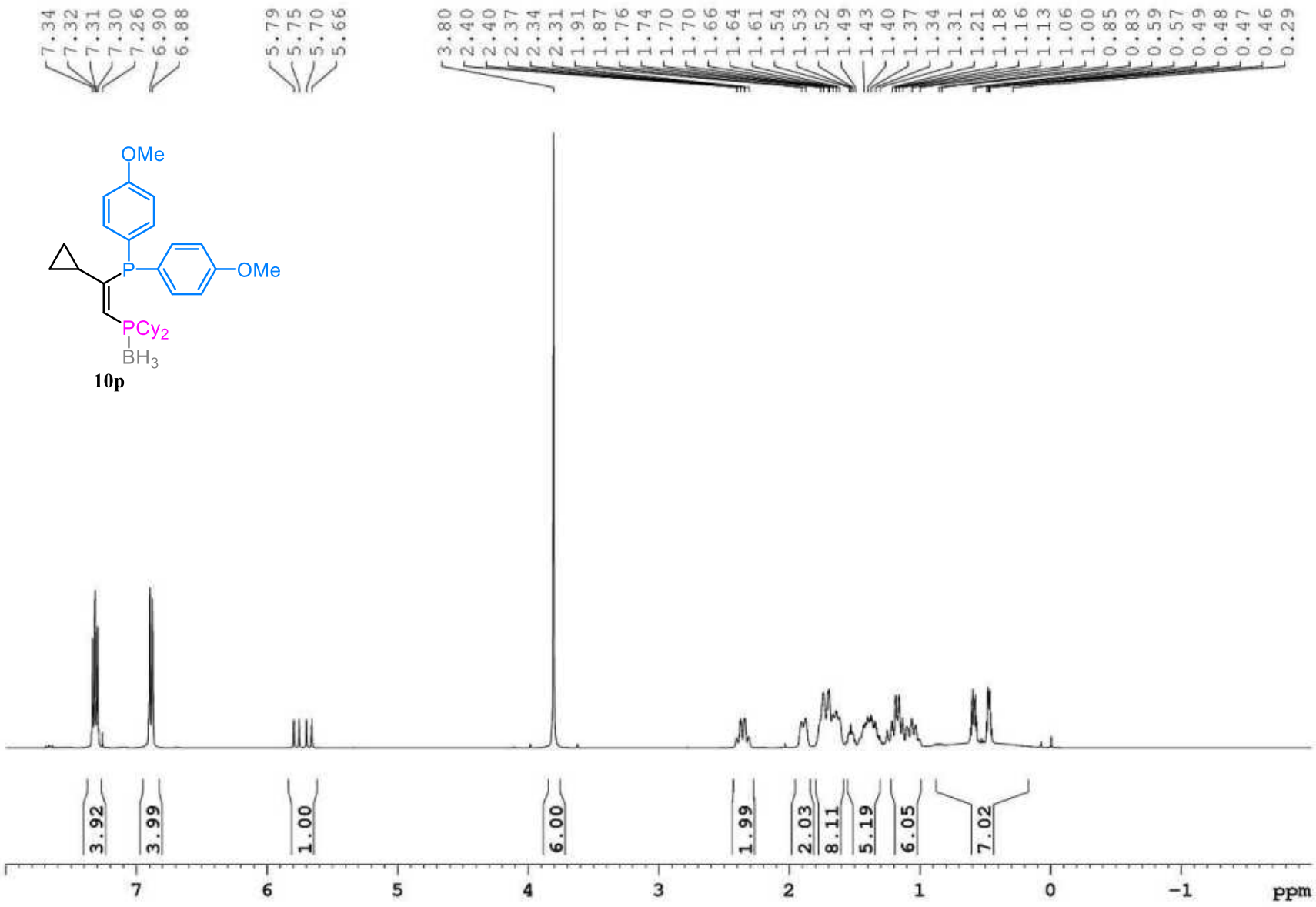
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm

10o

10o

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6.88
5.79
5.75
5.70
5.66
3.80
2.40
2.40
2.37
2.34
2.31
1.91
1.87
1.76
1.74
1.70
1.70
1.66
1.64
1.61
1.54
1.53
1.52
1.49
1.43
1.40
1.37
1.34
1.31
1.21
1.18
1.16
1.13
1.06
1.00
0.85
0.83
0.59
0.57
0.49
0.48
0.47
0.46
0.29
OMe
P
OMe
PCy2
BH3
3.92
3.99
1.00
6.00
1.99
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6.05
7.02
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3
2
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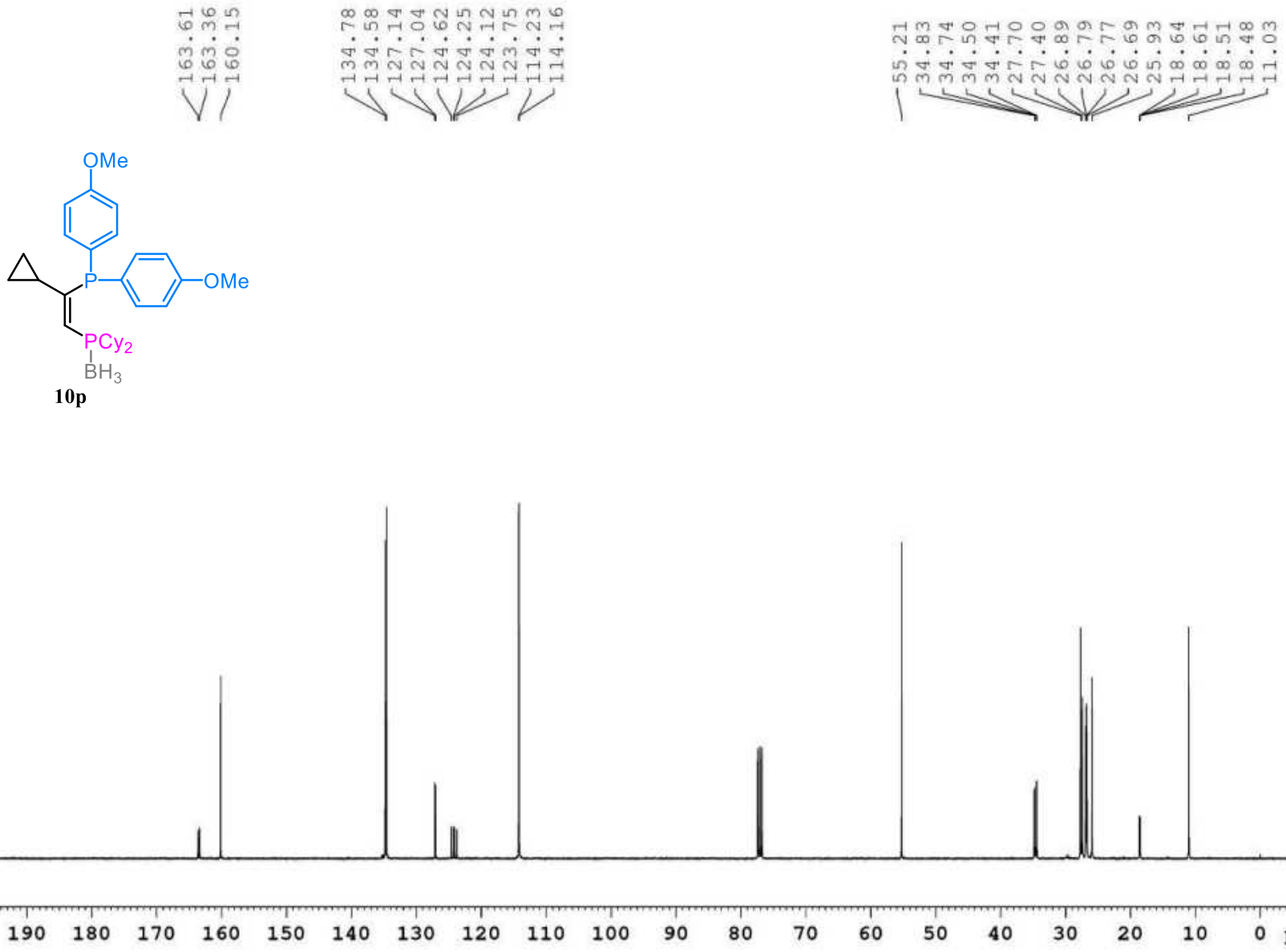
-1
ppm

10p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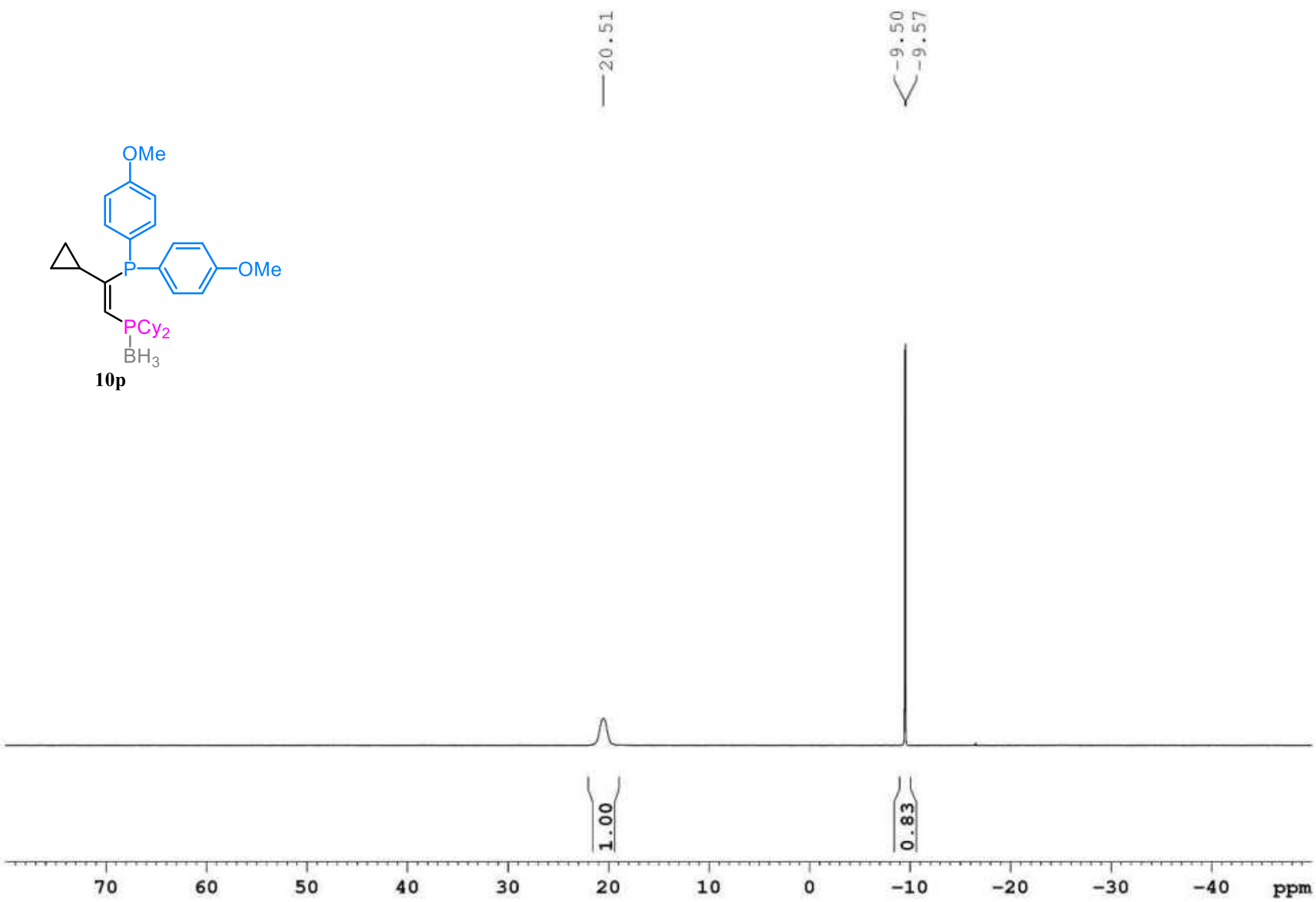
134.58
127.14
127.04
124.62
124.25
124.12
123.75
114.23
114.16
55.21
34.83
34.74
34.50
34.41
27.70
27.40
26.89
26.79
26.77
26.69
25.93
18.64
18.61
18.51
18.48
11.03
OMe
P
OMe
PCy2
BH3
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

10p


OMe
P
OMe
PCy2
BH3
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-9.50
-9.57
1.00
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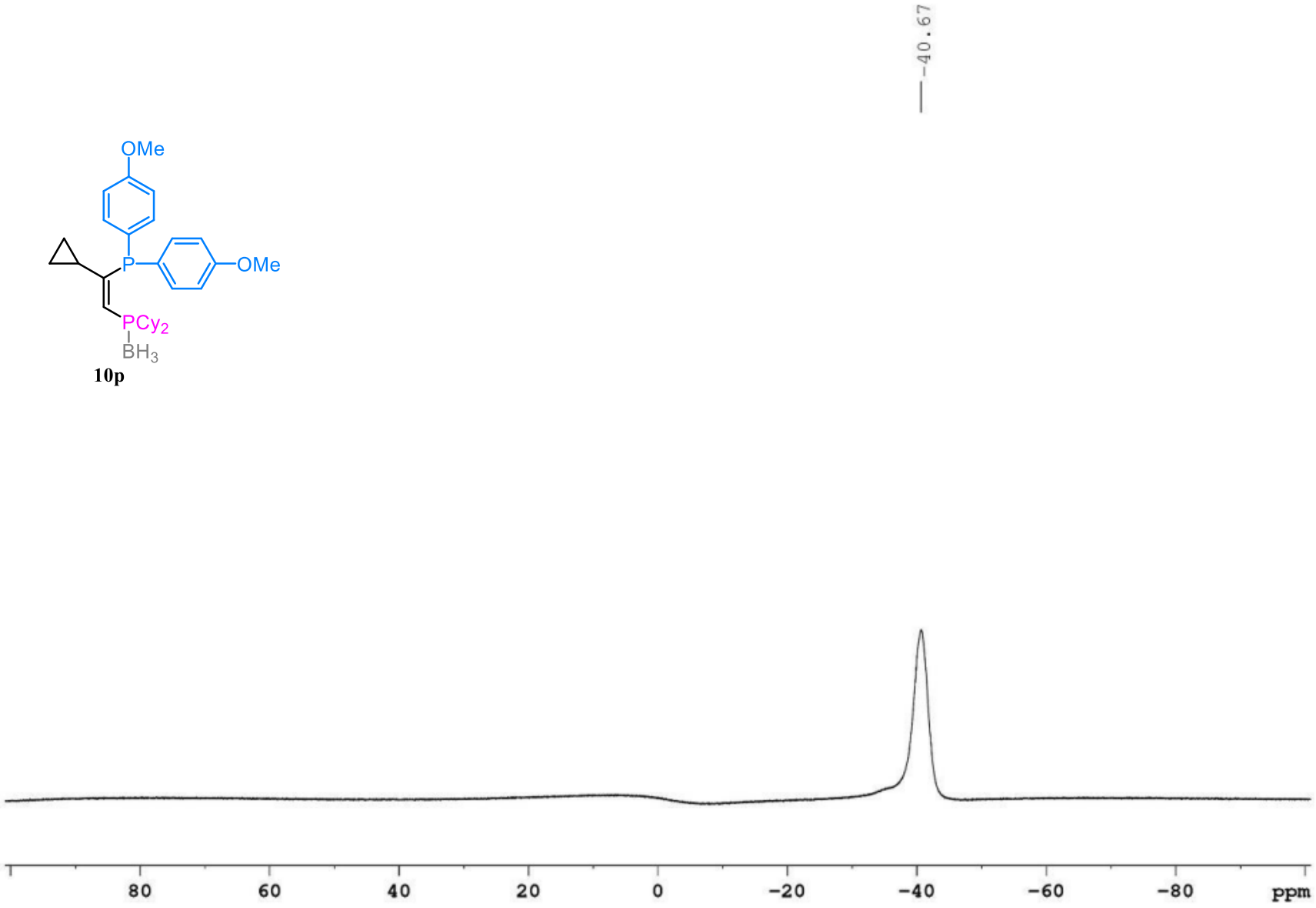
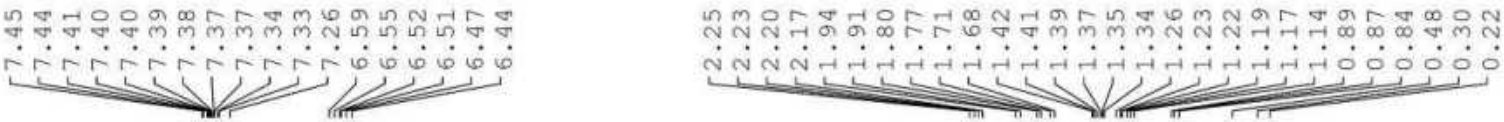
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm

10p

10p

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7.41
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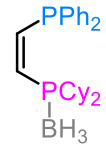
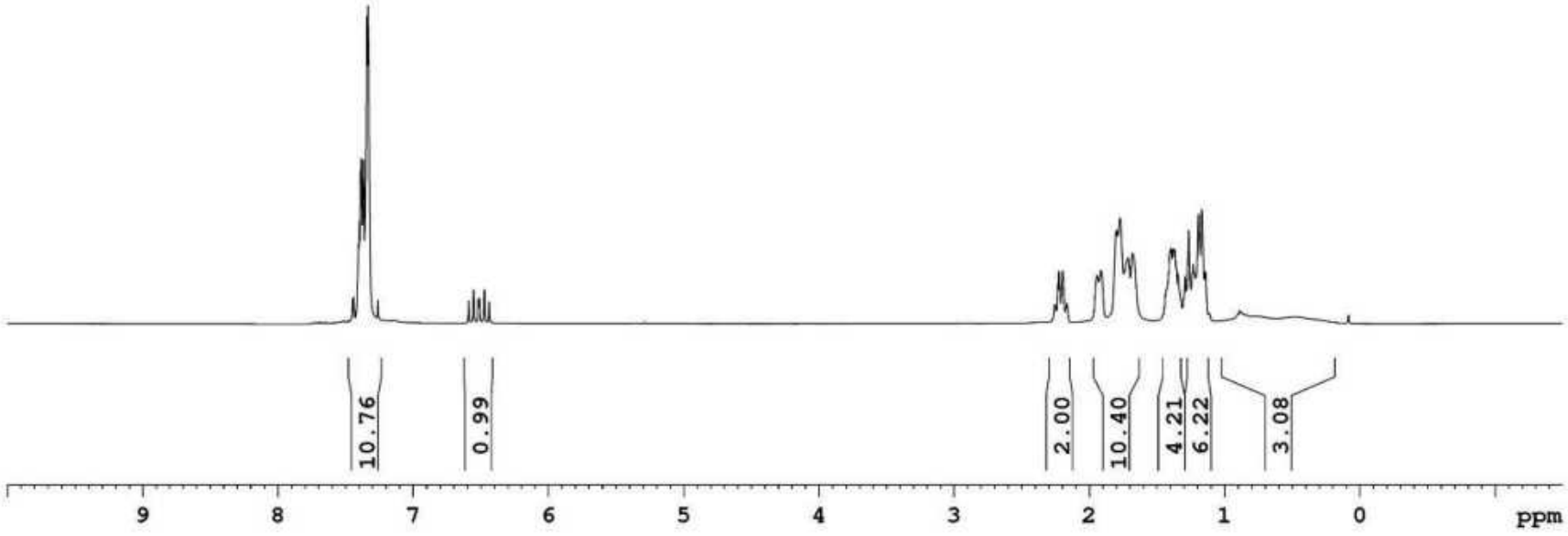
7.40
7.39
7.38
7.37
7.37
7.34
7.33
7.26
6.59
6.55
6.52
6.51
6.47
6.44
2.25
2.23
2.20
2.17
1.94
1.91
1.80
1.77
1.71
1.68
1.42
1.41
1.39
1.37
1.35
1.34
1.26
1.23
1.22
1.19
1.17
1.14
0.89
0.87
0.84
0.48
0.30
0.22


PPh2
PCy2
BH3

10q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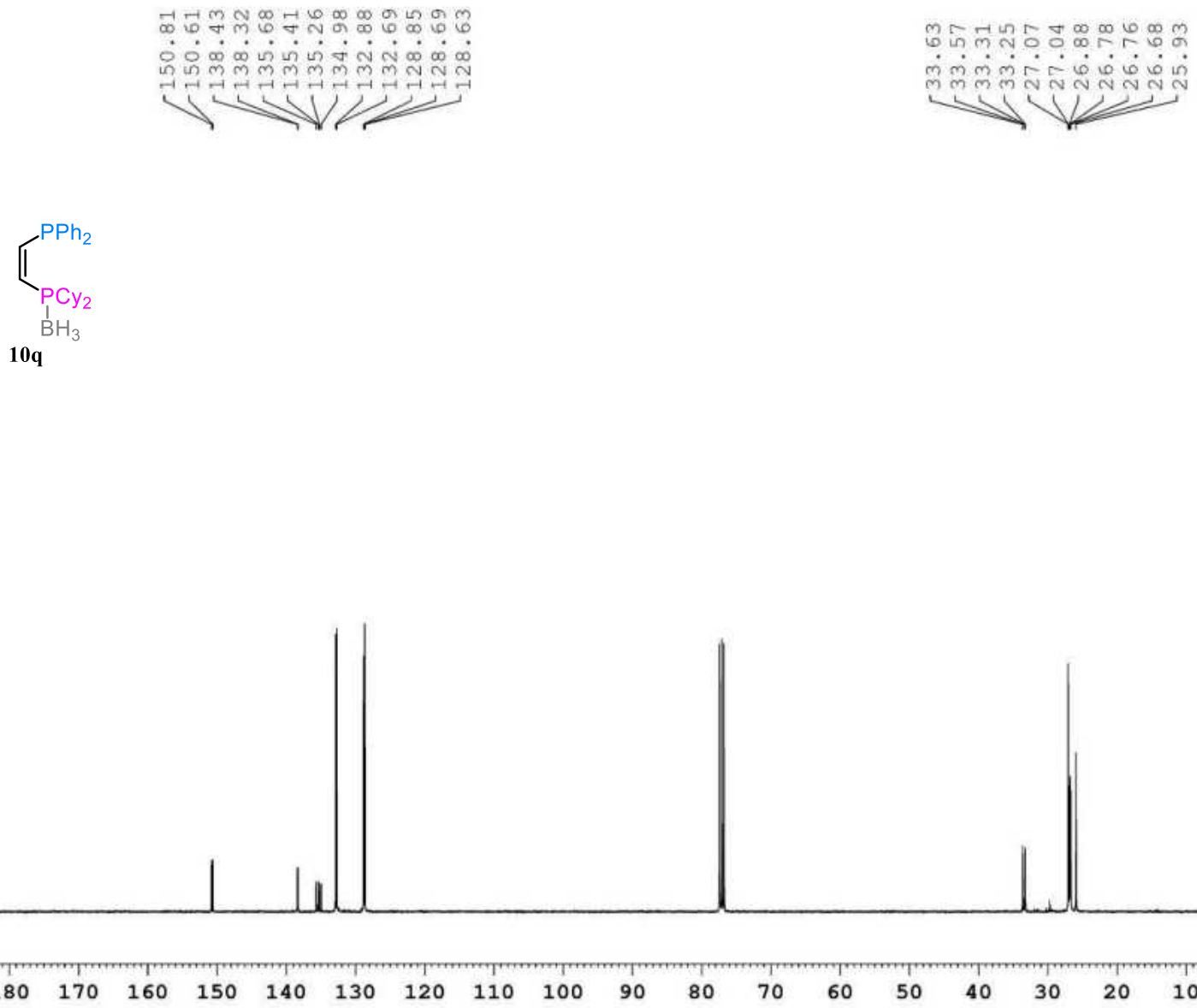
3.08
9
8
7
6
5
4
3
2
1
0
ppm


150.81
150.61
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135.41
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134.98
132.88
132.69
128.85
128.69
128.63
33.63
33.57
33.31
33.25
27.07
27.04
26.88
26.78
26.76
26.68
25.93
PPh2
PCy2
BH3
10q
190
180
170
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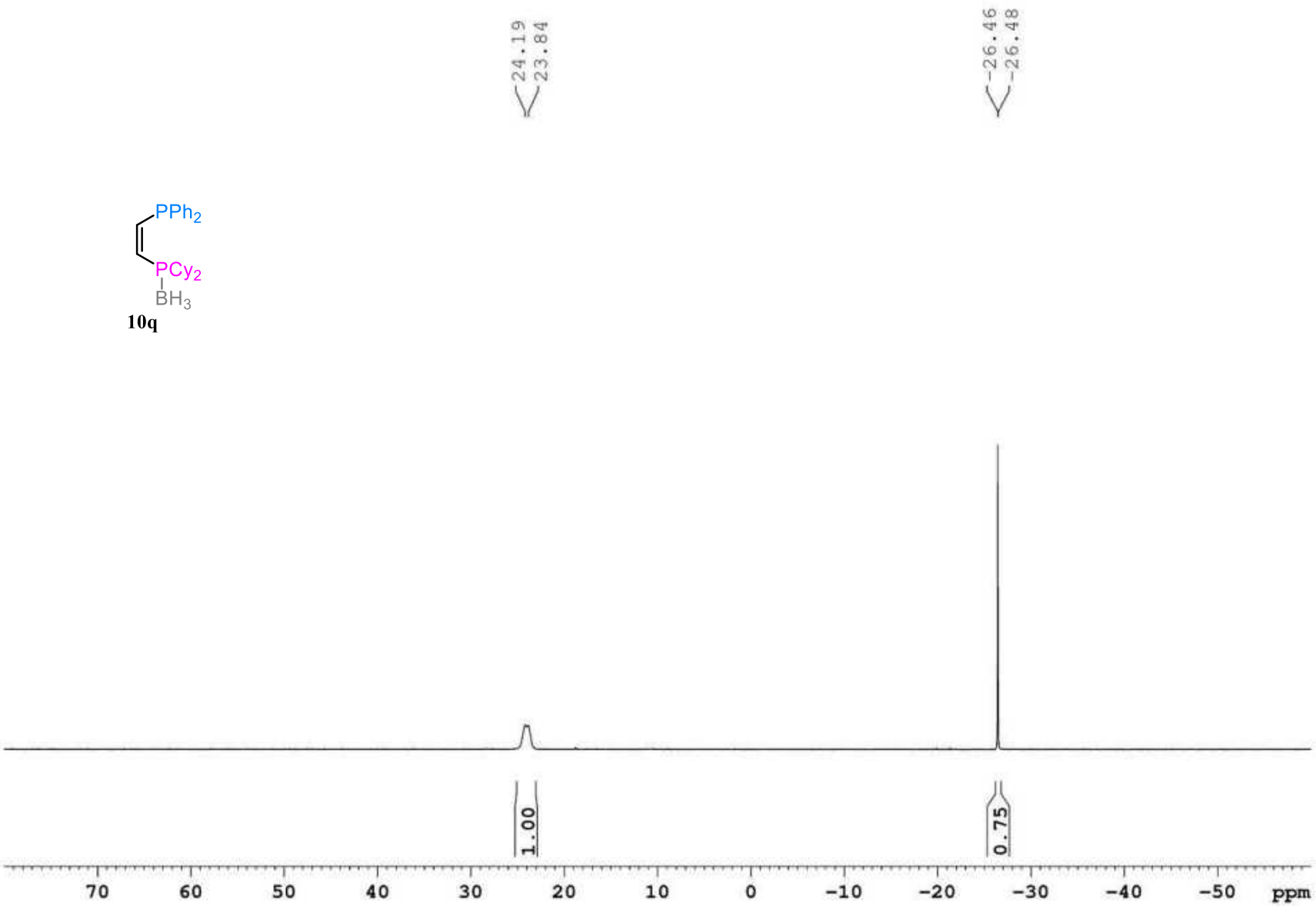
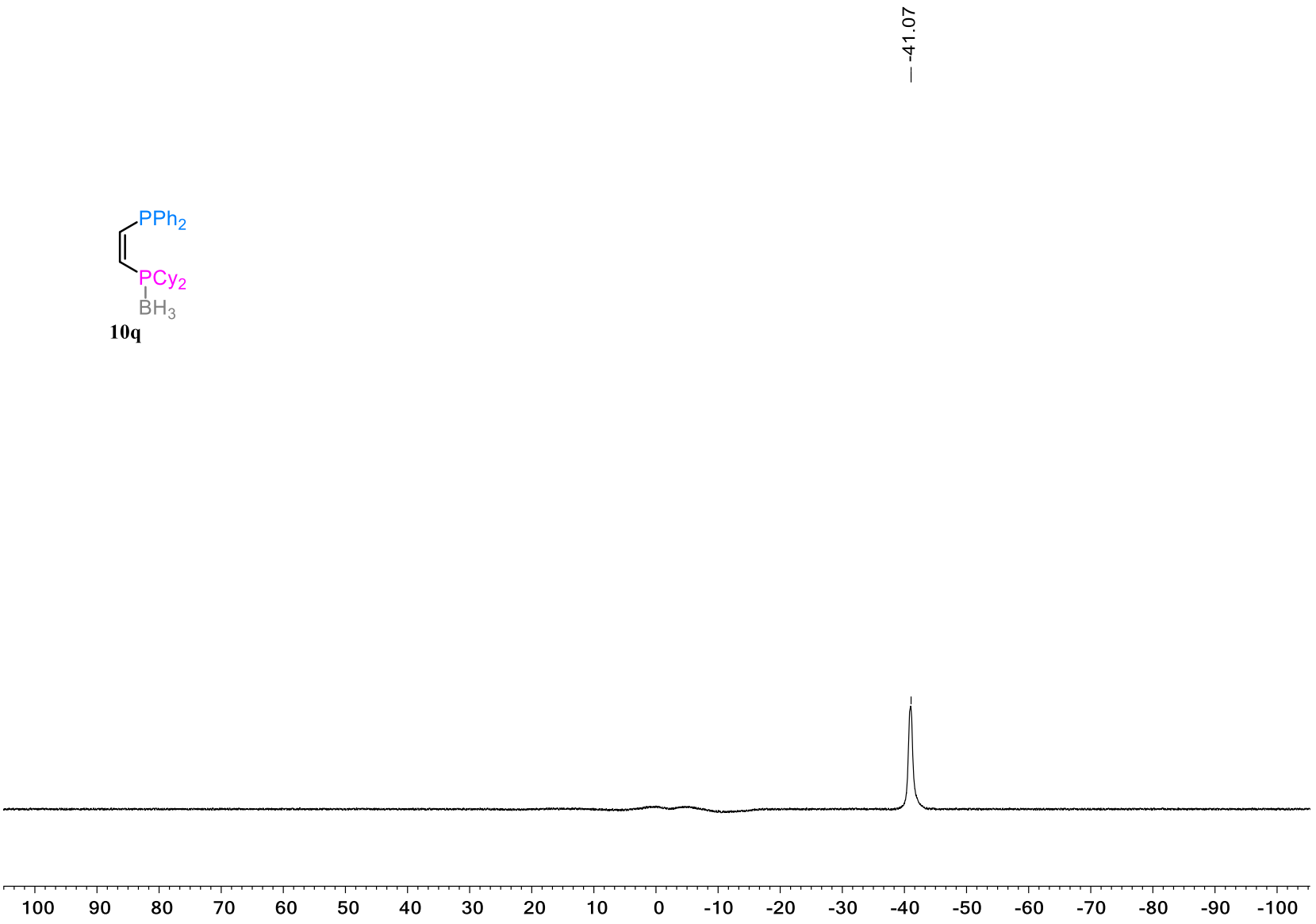
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


24.19
23.84
-26.46
-26.48
PPh2
PCy2
BH3
10q
1.00
0.75
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
ppm

PPh2
PCy2
BH3

10q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80
70
60
50
40
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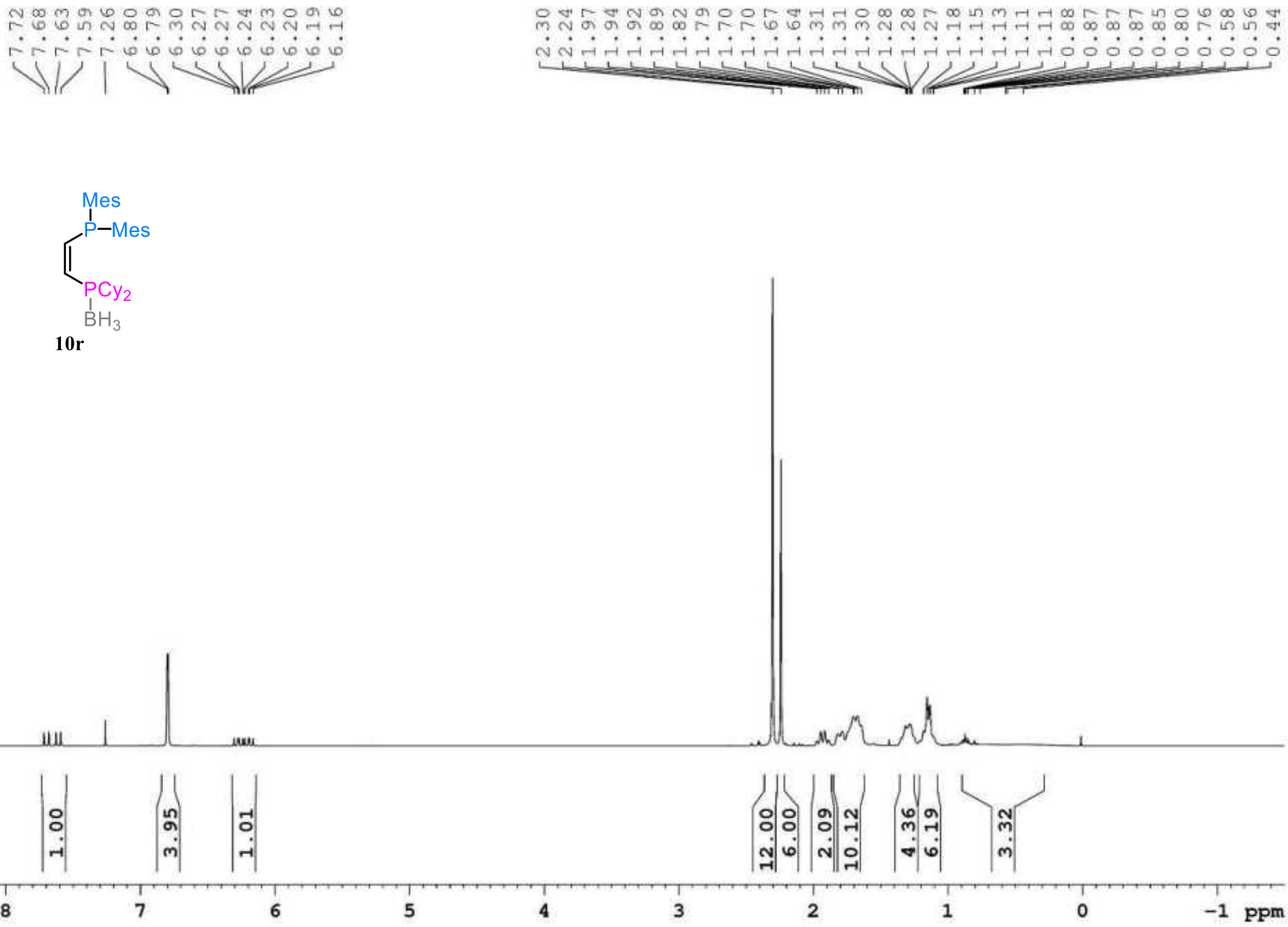
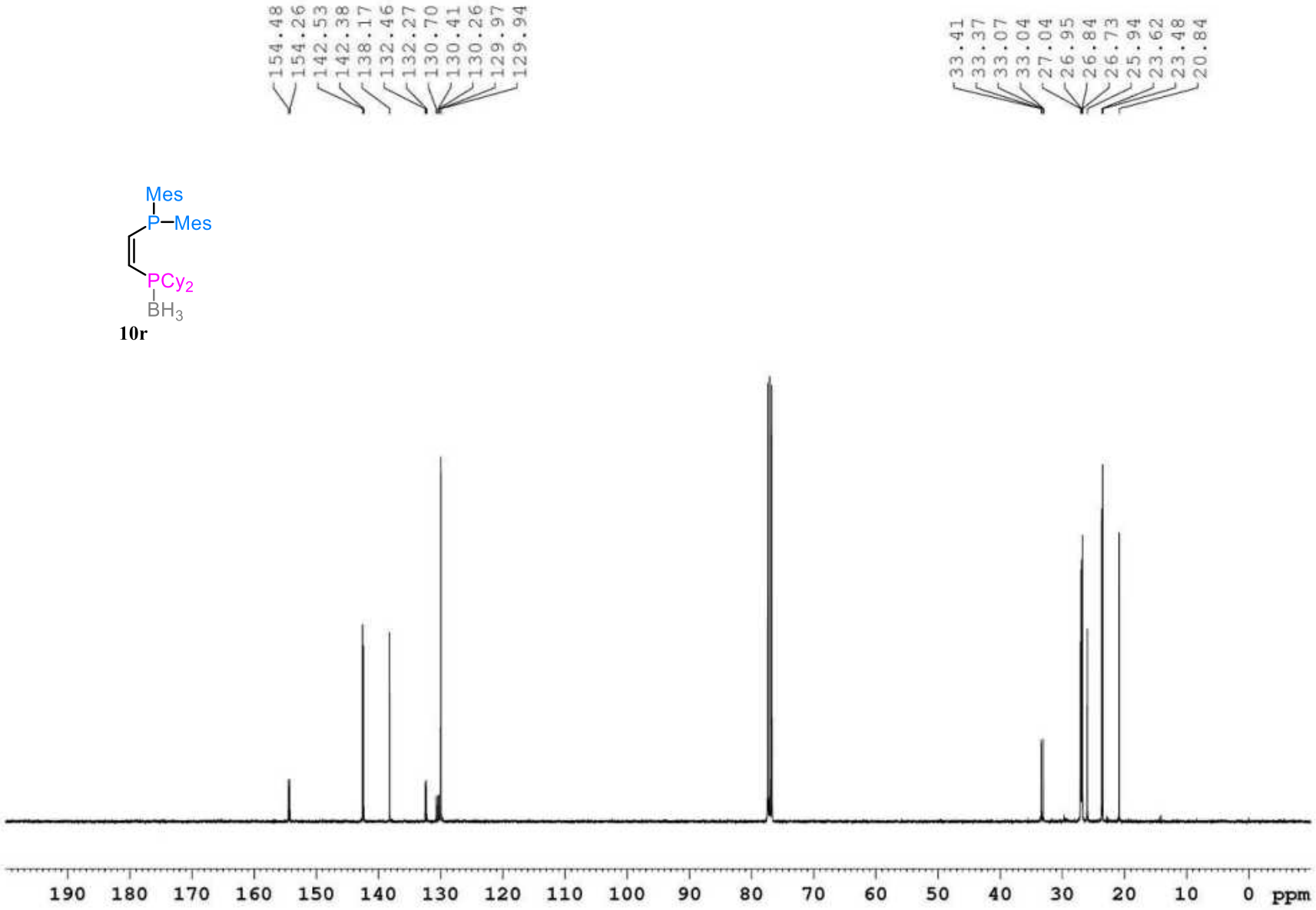
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100


7.72
7.68
7.63
7.59
7.26
6.80
6.79
6.30
6.27
6.27
6.24
6.23
6.20
6.19
6.16
2.30
2.24
1.97
1.94
1.92
1.89
1.82
1.79
1.70
1.70
1.67
1.64
1.31
1.31
1.30
1.28
1.28
1.27
1.18
1.15
1.13
1.11
1.11
0.88
0.87
0.87
0.87
0.85
0.80
0.76
0.58
0.56
0.44
Mes
P
Mes
PCy2
BH3
10r
1.00
3.95
1.01
12.00
6.00
2.09
10.12
4.36
6.19
3.32
8
7
6
5
4
3
2
1
0
−1
ppm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154.26
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142.38
138.17
132.46
132.27
130.70
130.41
130.26
129.97
129.94
33.41
33.37
33.07
33.04
27.04
26.95
26.84
26.73
25.94
23.62
23.48
20.84
Mes
P
Mes
PCy2
BH3
190
180
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160
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120
110
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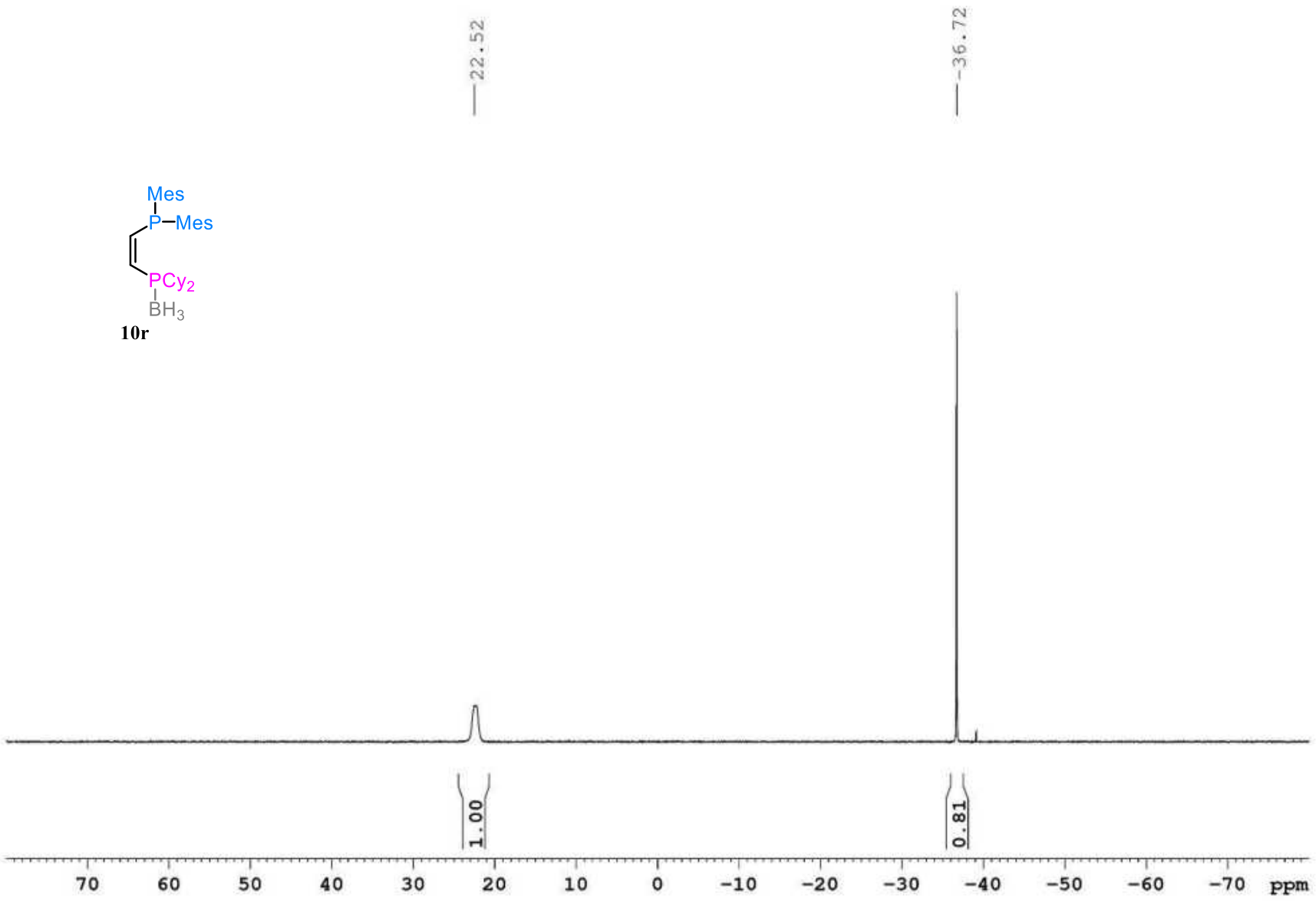
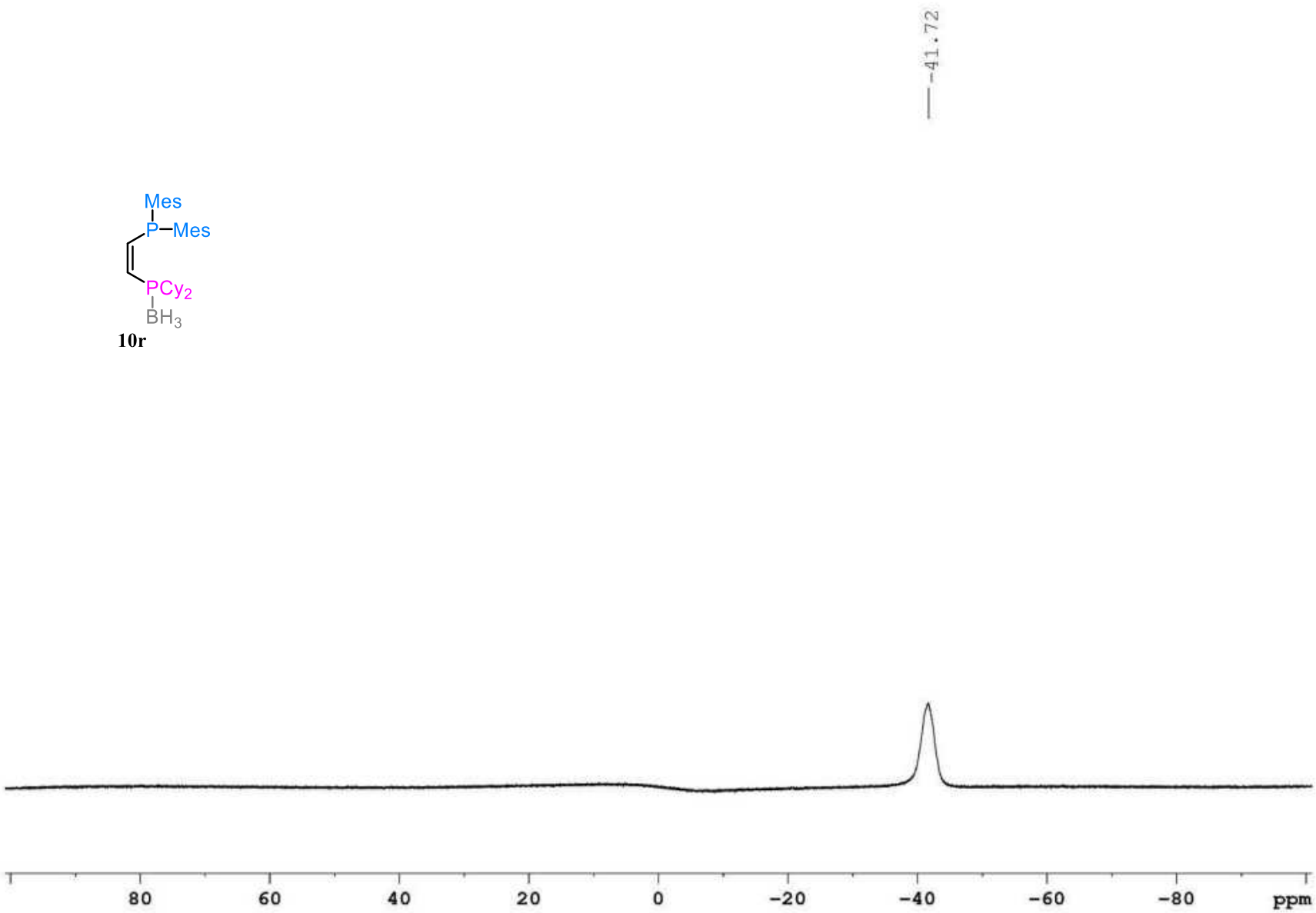
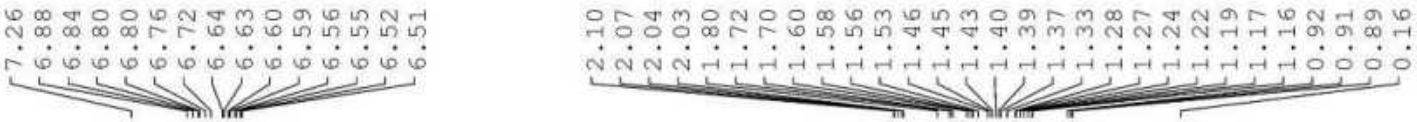
90
80
70
60
50
40
30
20
10
0
ppm

10r


22.52
-36.72
Mes
P
Mes
PCy2
BH3
10r
1.00
0.81
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
ppm

10r

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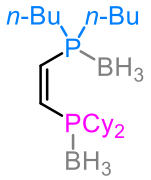
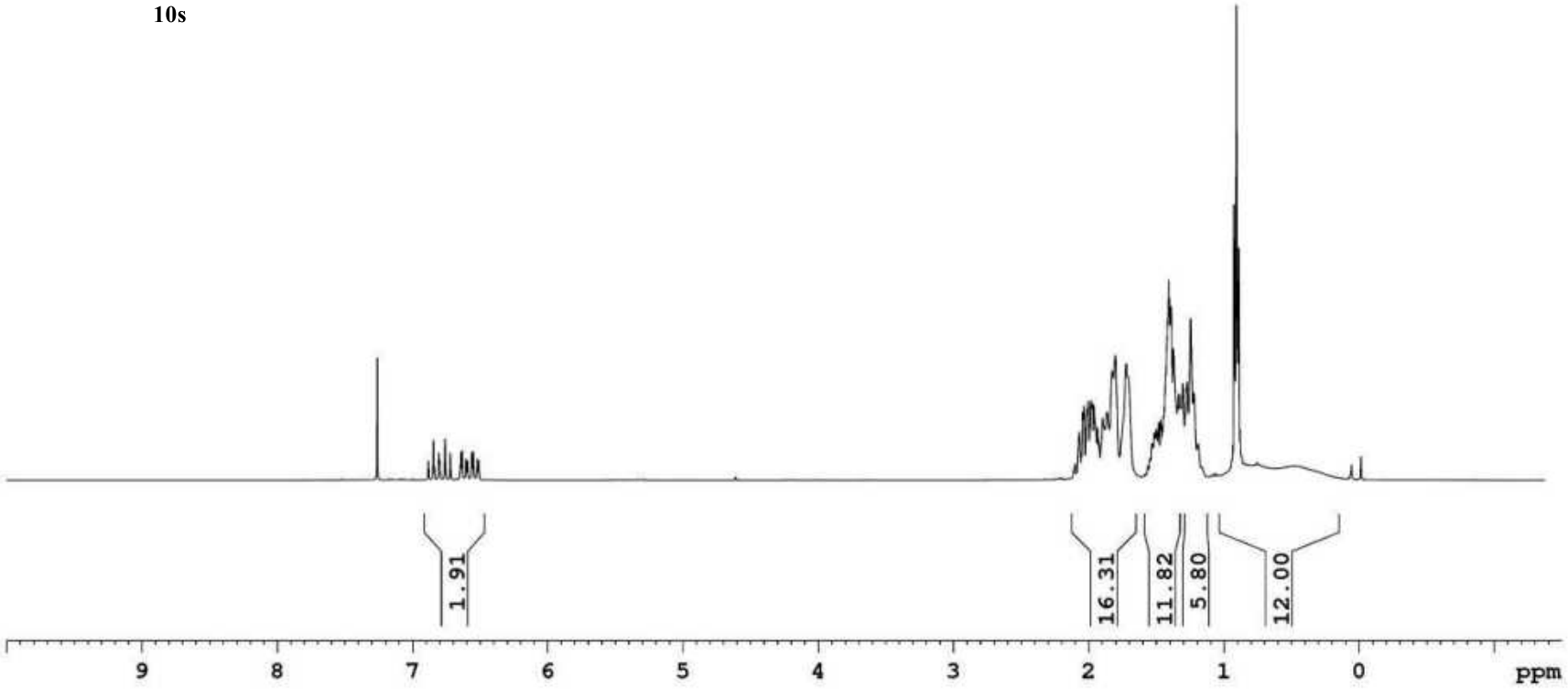
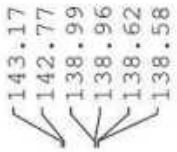
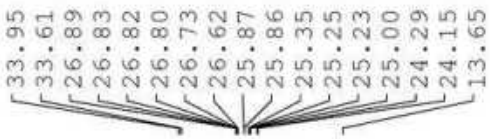
6.88
6.84
6.80
6.80
6.76
6.72
6.64
6.63
6.60
6.59
6.56
6.55
6.52
6.51
2.10
2.07
2.04
2.03
1.80
1.72
1.70
1.60
1.58
1.56
1.53
1.46
1.45
1.43
1.40
1.39
1.37
1.33
1.28
1.27
1.24
1.22
1.19
1.17
1.16
0.92
0.91
0.89
0.16

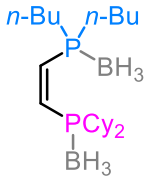

n-Bu
n-Bu
P
BH3
PCy2
BH3

10s

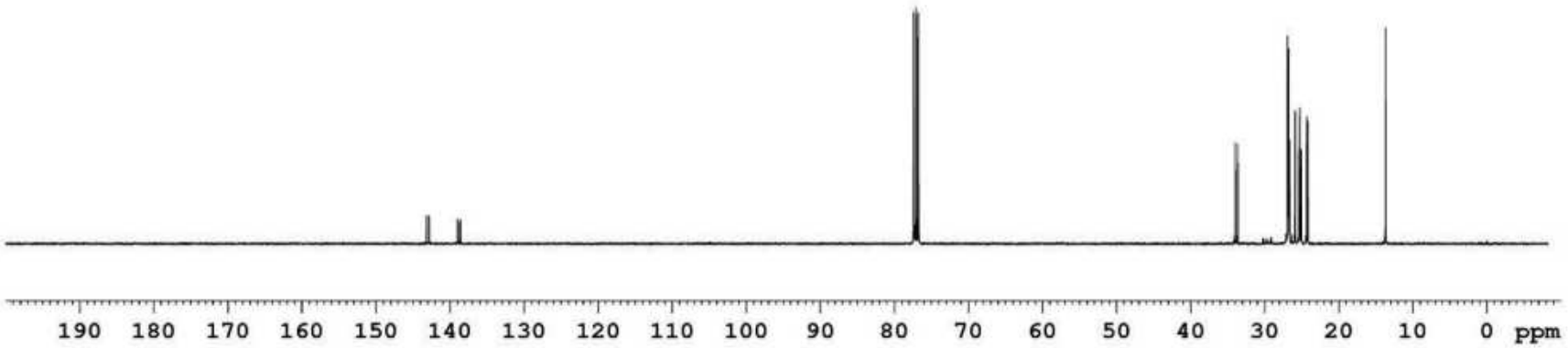

1.91
16.31
11.82
5.80
12.00
9
8
7
6
5
4
3
2
1
0
ppm


143.17
142.77
138.99
138.96
138.62
138.58


33.95
33.61
26.89
26.83
26.82
26.80
26.73
26.62
25.87
25.86
25.35
25.25
25.23
25.00
24.29
24.15
13.65


n-Bu
n-Bu
P
BH3
PCy2
BH3

10s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180
170
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130
120
110
100
90
80
70
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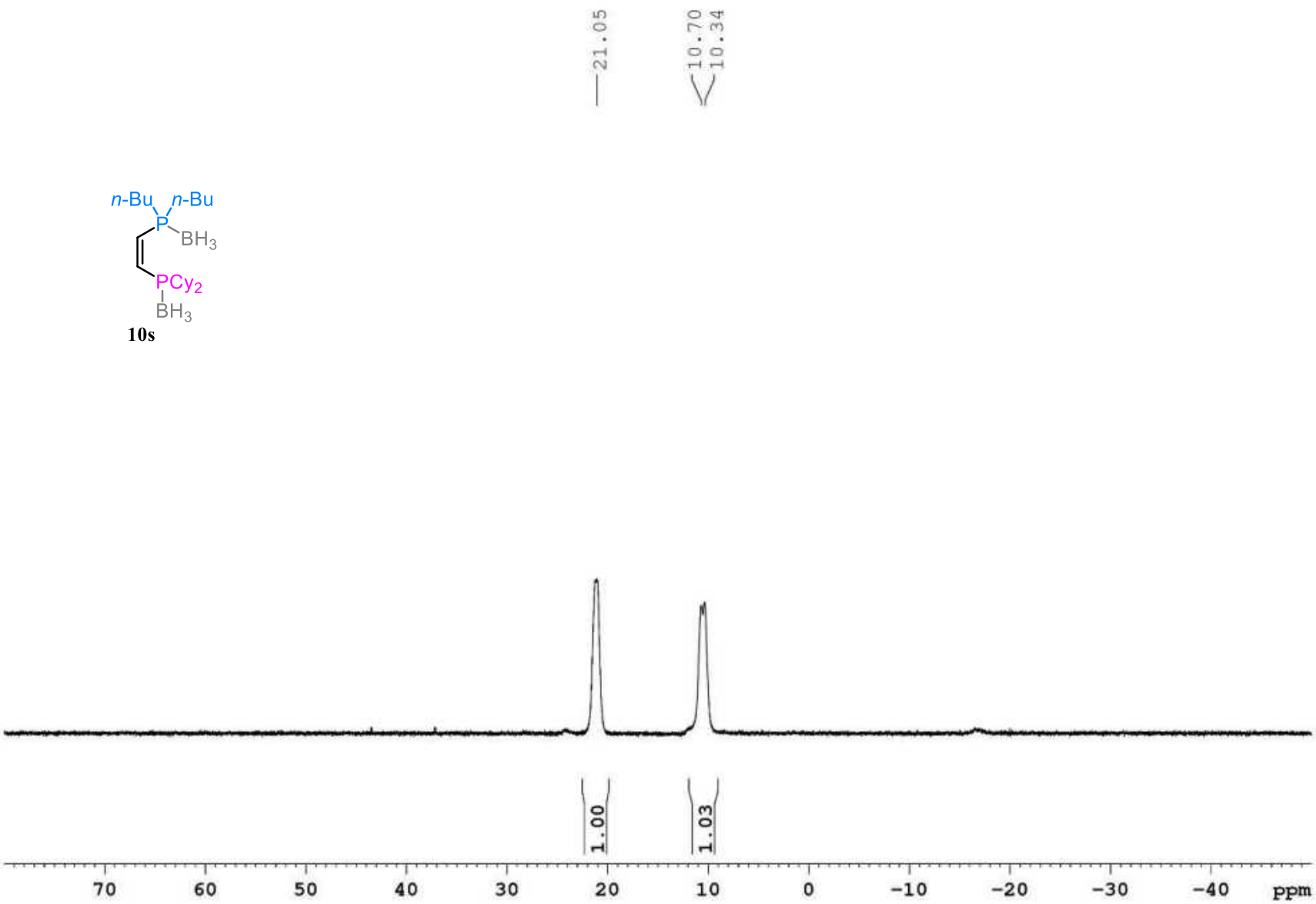
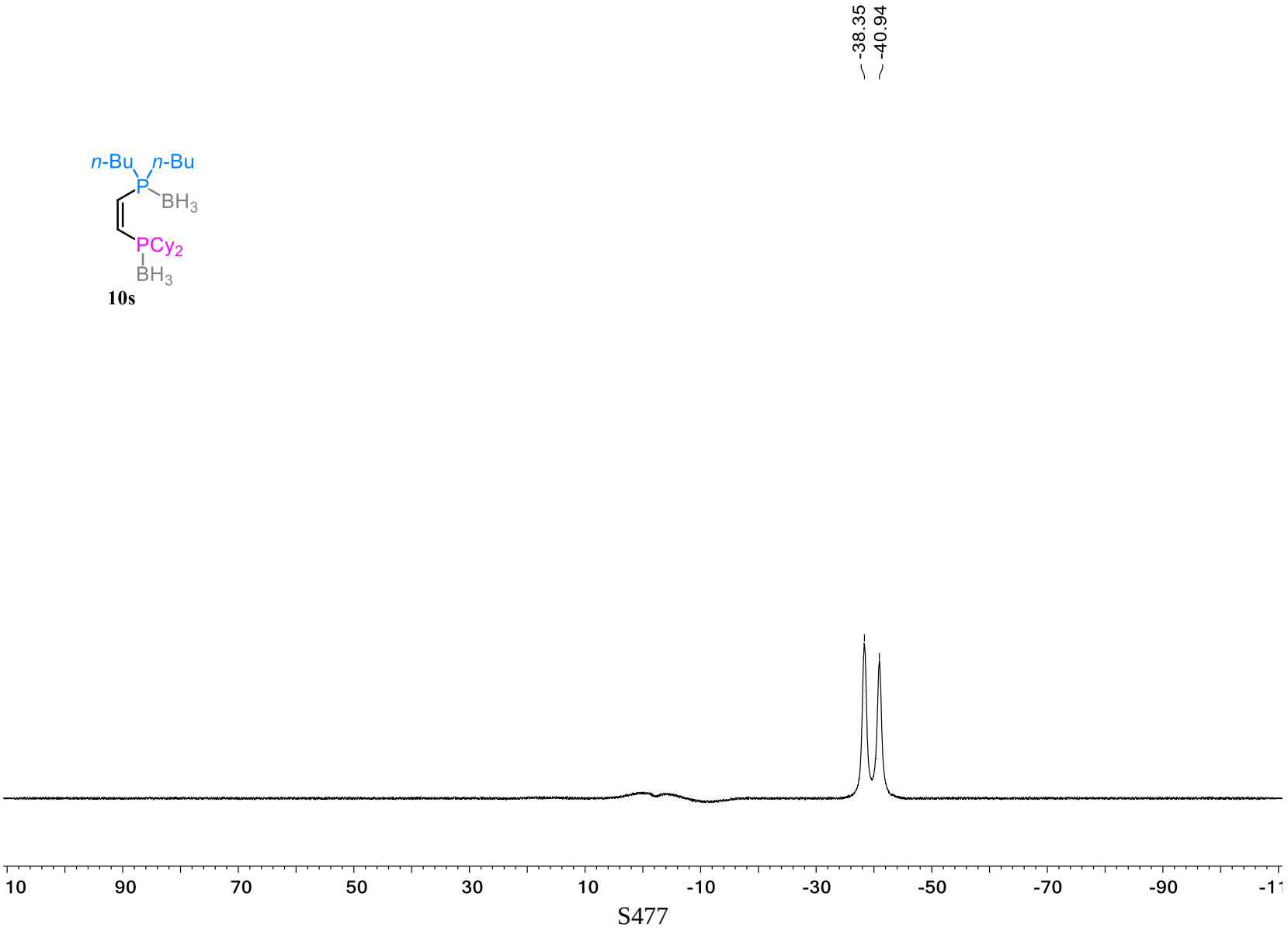
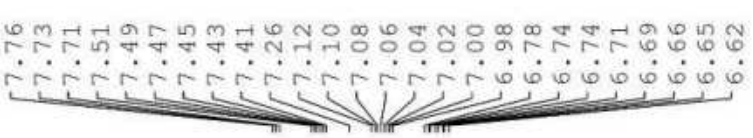
40
30
20
10
0
ppm

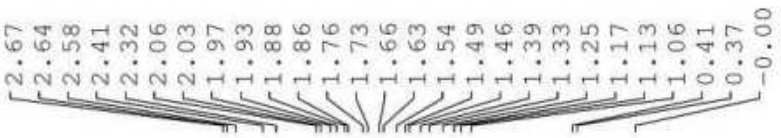

21.05
10.70
10.34
n-Bu
n-Bu
P
BH3
PCy2
BH3
1.00
1.03
70
60
50
40
30
20
10
0
-10
-20
-30
-40
ppm

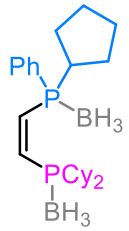
10s

10s

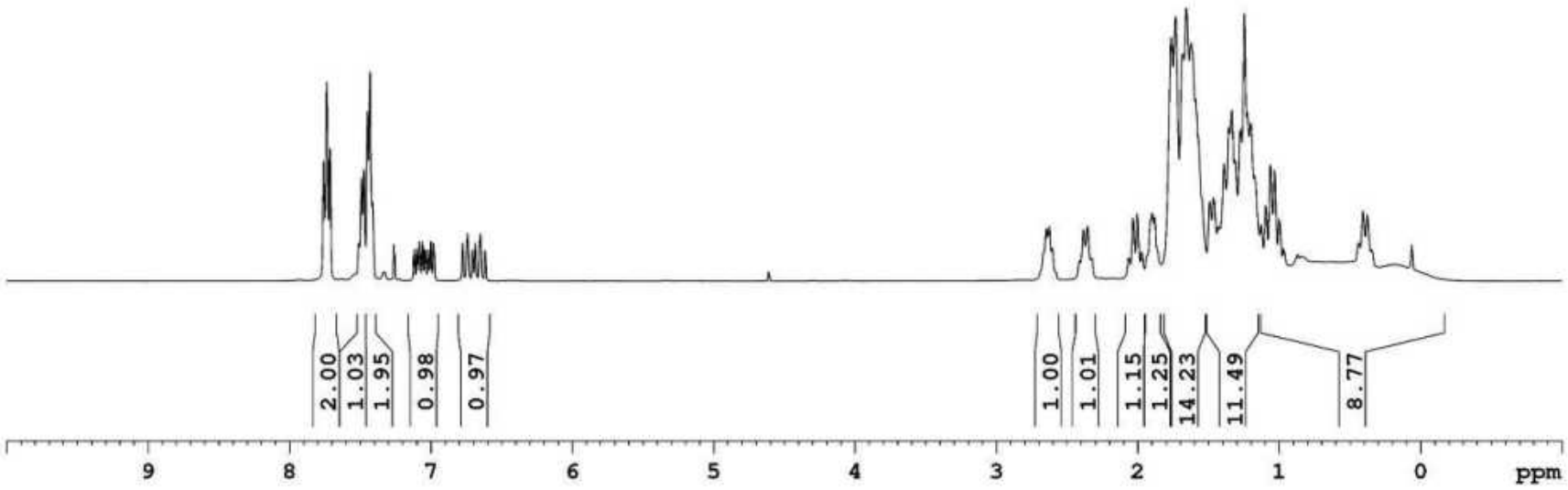


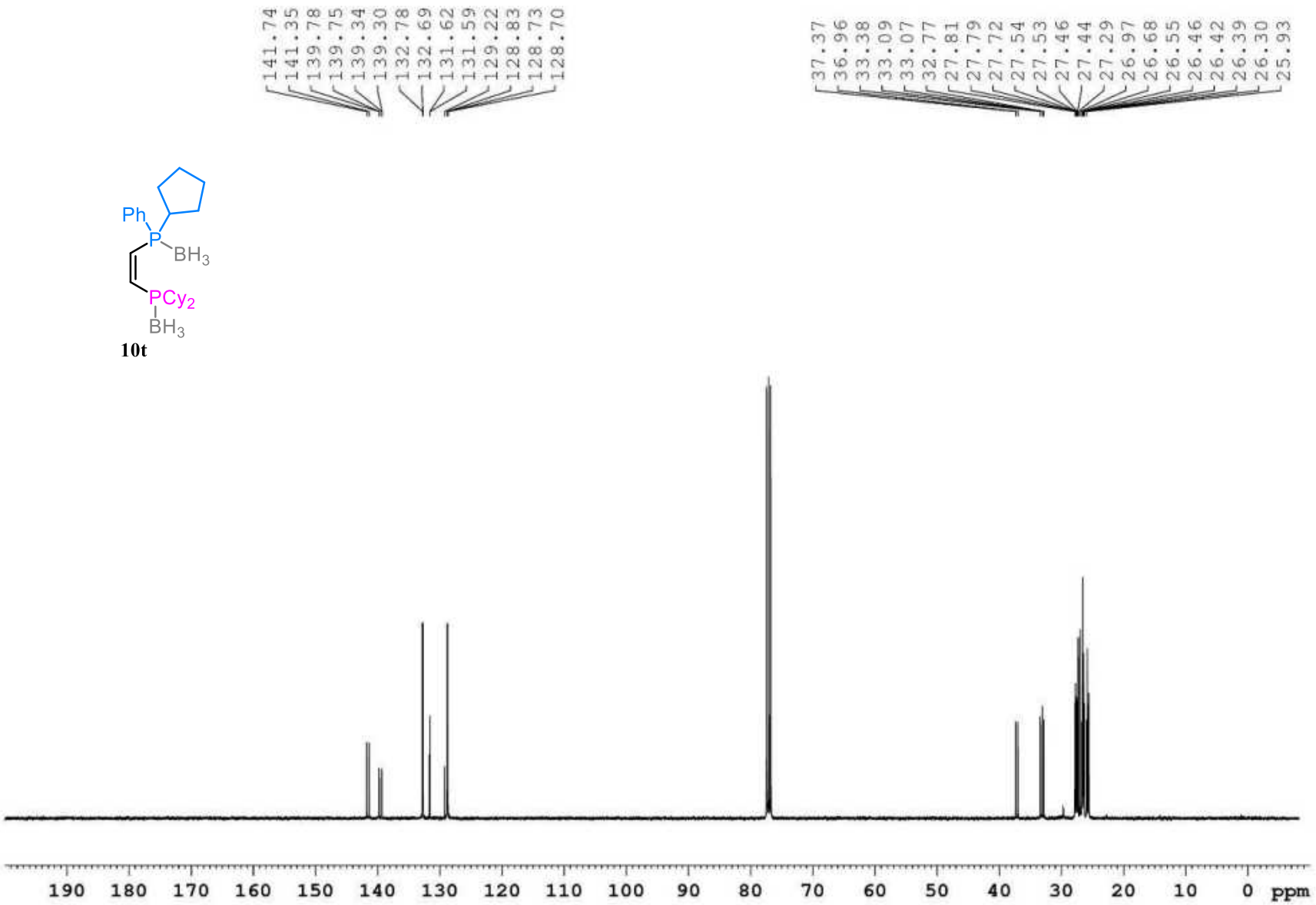

7.76
7.73
7.71
7.51
7.49
7.47
7.45
7.43
7.41
7.26
7.12
7.10
7.08
7.06
7.04
7.02
7.00
6.98
6.78
6.74
6.74
6.71
6.69
6.66
6.65
6.62


2.67
2.64
2.58
2.41
2.32
2.06
2.03
1.97
1.93
1.88
1.86
1.76
1.73
1.66
1.63
1.54
1.49
1.46
1.39
1.33
1.25
1.17
1.13
1.06
0.41
0.37
-0.00


Ph
P
BH3
PCy2
BH3

10t

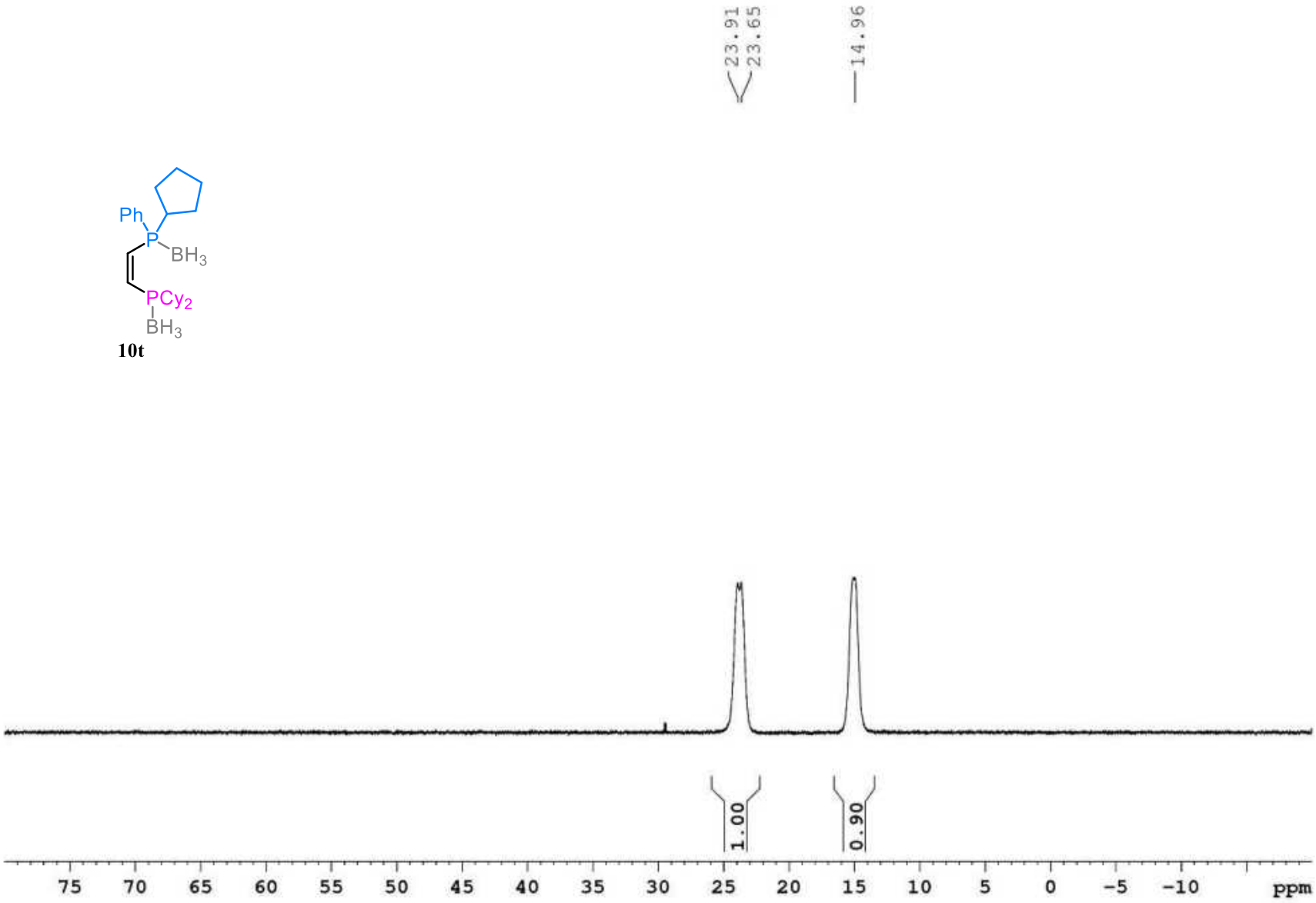

2.00
1.03
1.95
0.98
0.97
1.00
1.01
1.15
1.25
14.23
11.49
8.77
9
8
7
6
5
4
3
2
1
0
ppm


141.74
141.35
139.78
139.75
139.34
139.30
132.78
132.69
131.62
131.59
129.22
128.83
128.73
128.70
37.37
36.96
33.38
33.09
33.07
32.77
27.81
27.79
27.72
27.54
27.53
27.46
27.44
27.29
26.97
26.68
26.55
26.46
26.42
26.39
26.30
25.93
Ph
P
BH3
PCy2
BH3
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

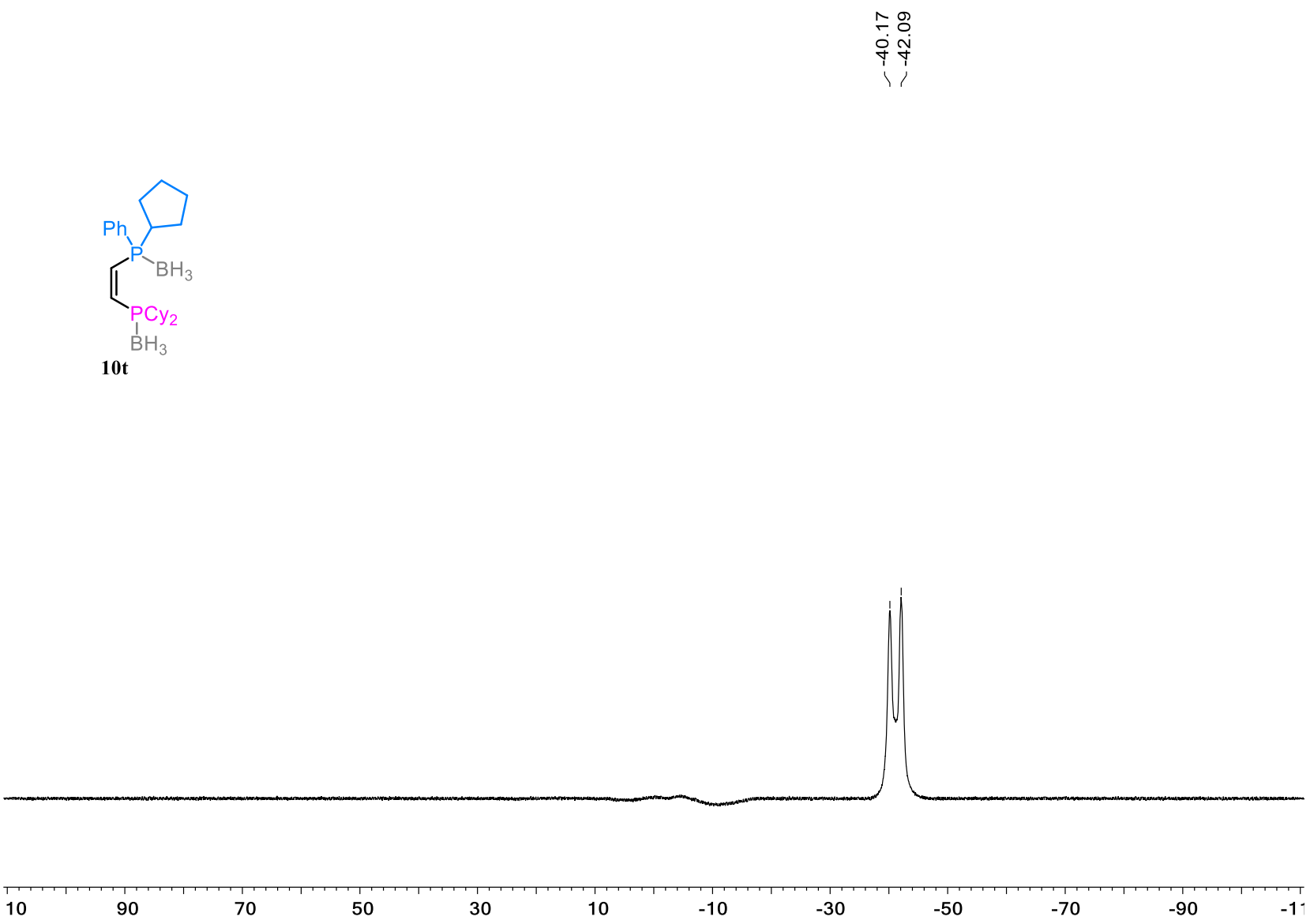
10t

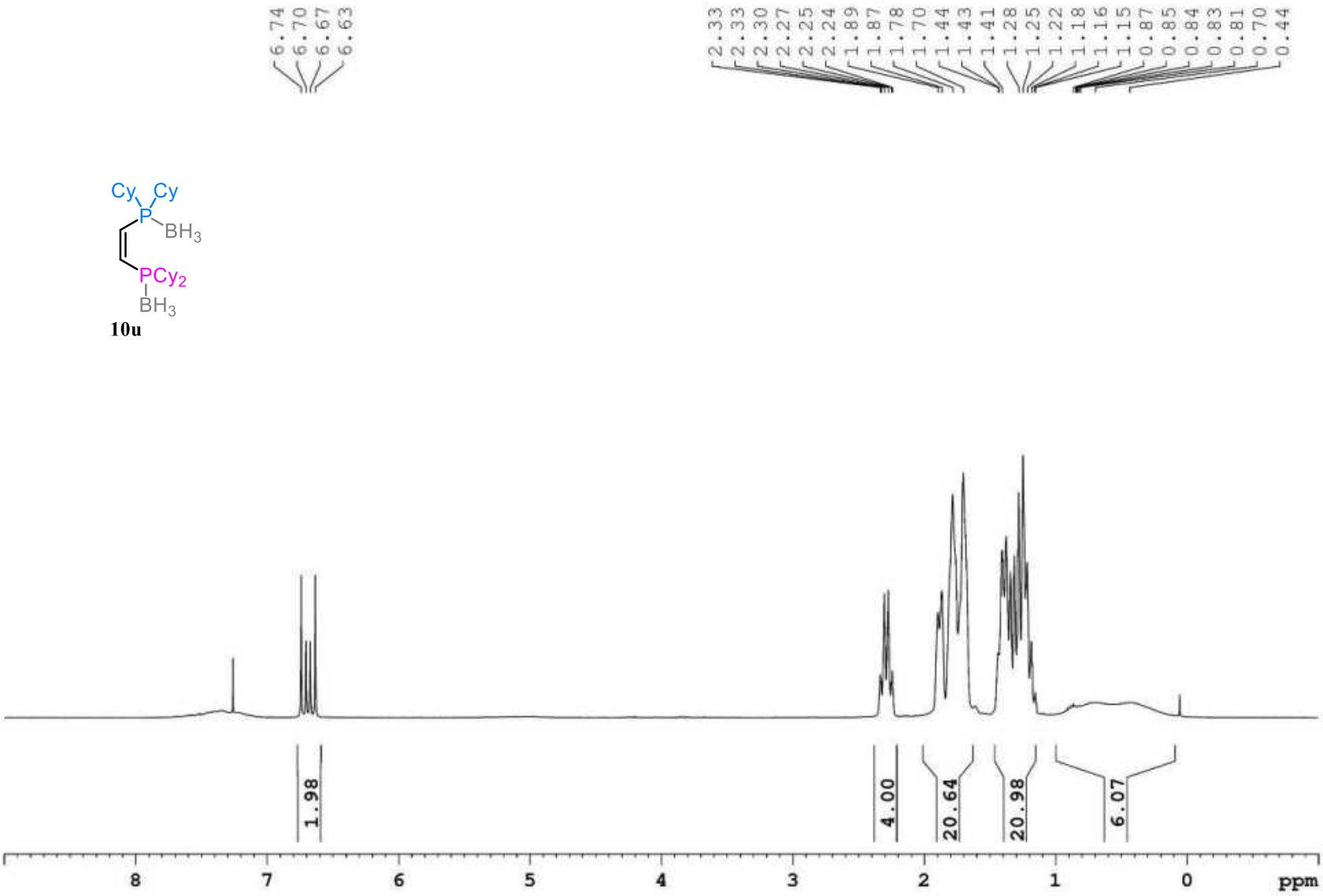
Ph
P
BH3
PCy2
BH3

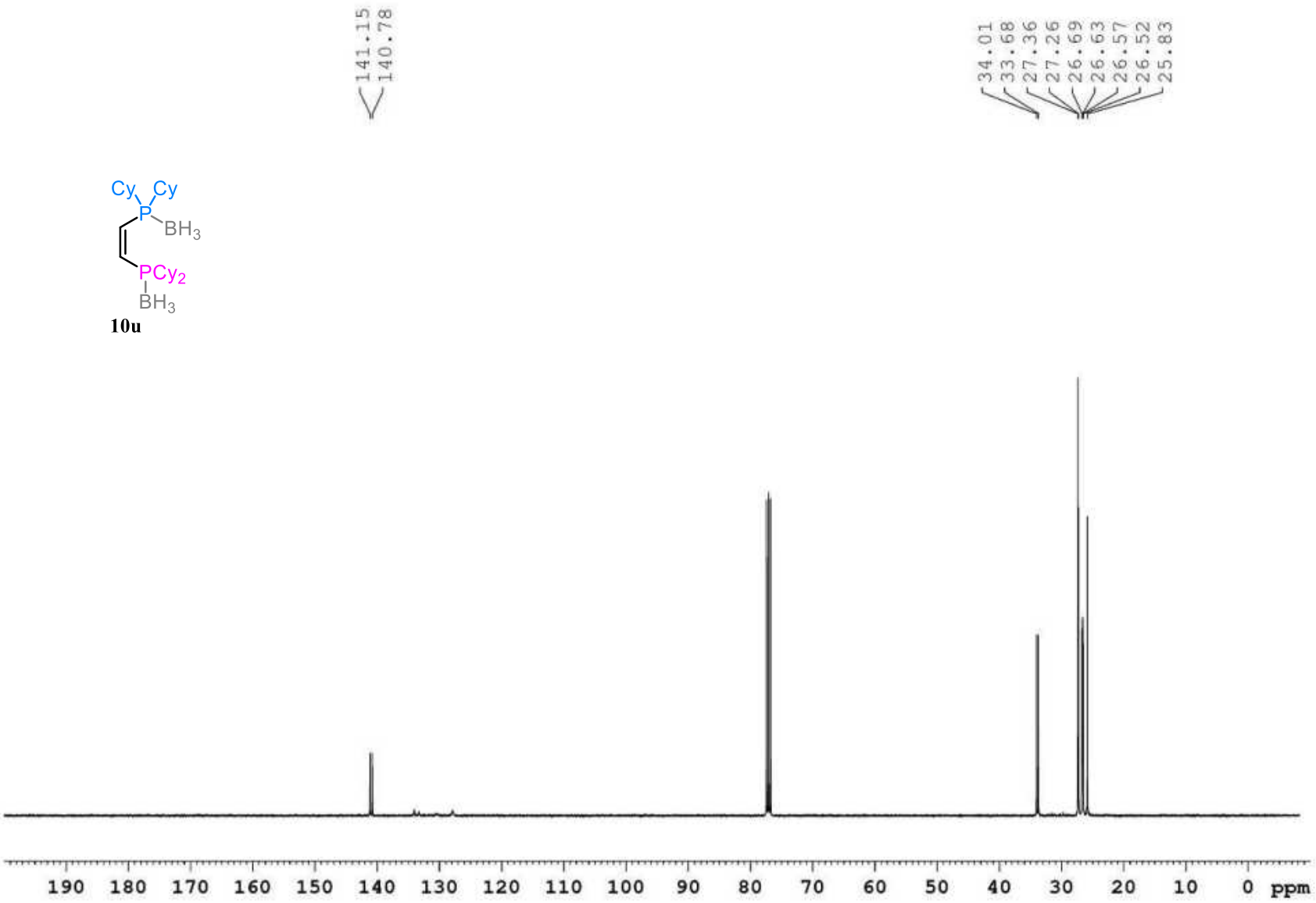
10t

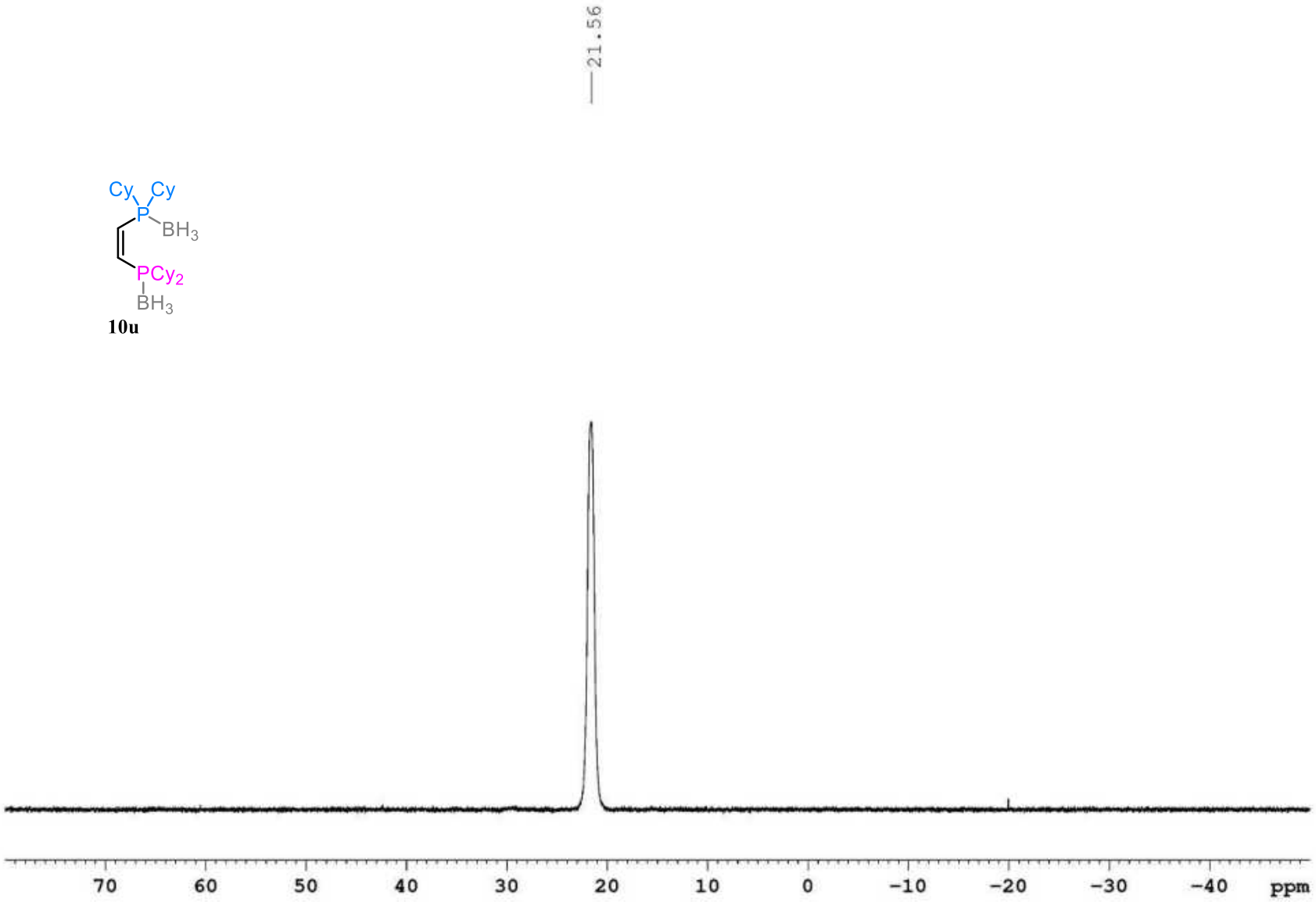

23.91
23.65
14.96
1.00
0.90
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
ppm

10t



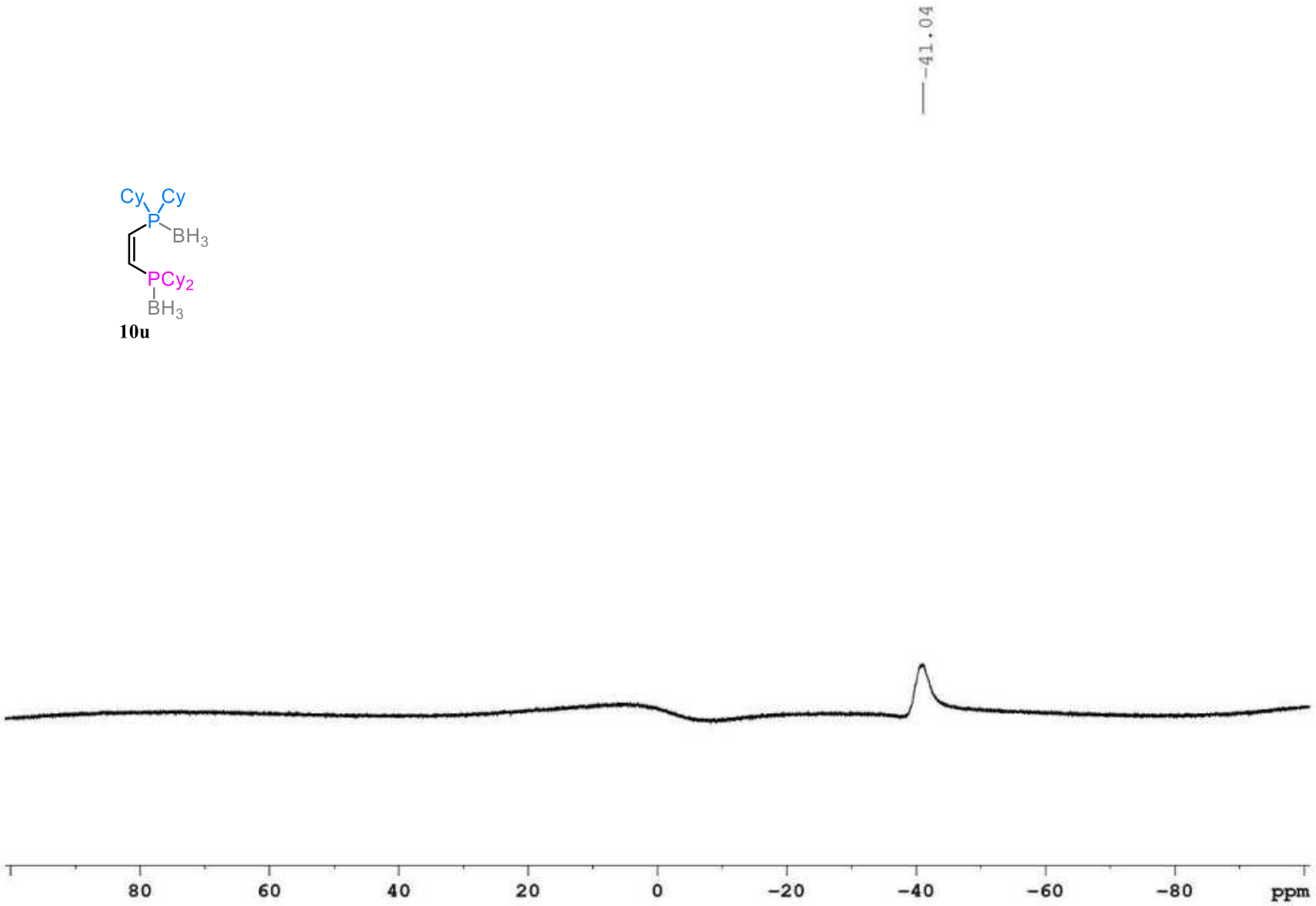

6.74
6.70
6.67
6.63
2.33
2.33
2.30
2.27
2.25
2.24
1.89
1.87
1.78
1.70
1.44
1.43
1.41
1.28
1.25
1.22
1.18
1.16
1.15
0.87
0.85
0.84
0.83
0.81
0.70
0.44
Cy
Cy
P
BH3
PCy2
BH3
10u
1.98
4.00
20.64
20.98
6.07
8
7
6
5
4
3
2
1
0
ppm

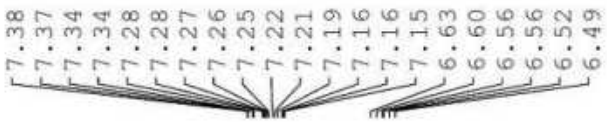

141.15
140.78
34.01
33.68
27.36
27.26
26.69
26.63
26.57
26.52
25.83
Cy
Cy
P
BH3
PCy2
BH3
10u
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

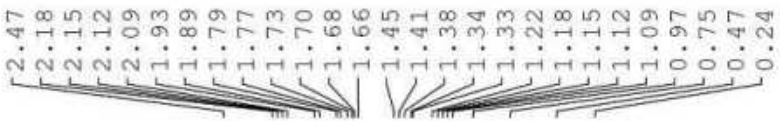


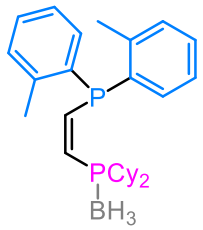
10u

10u

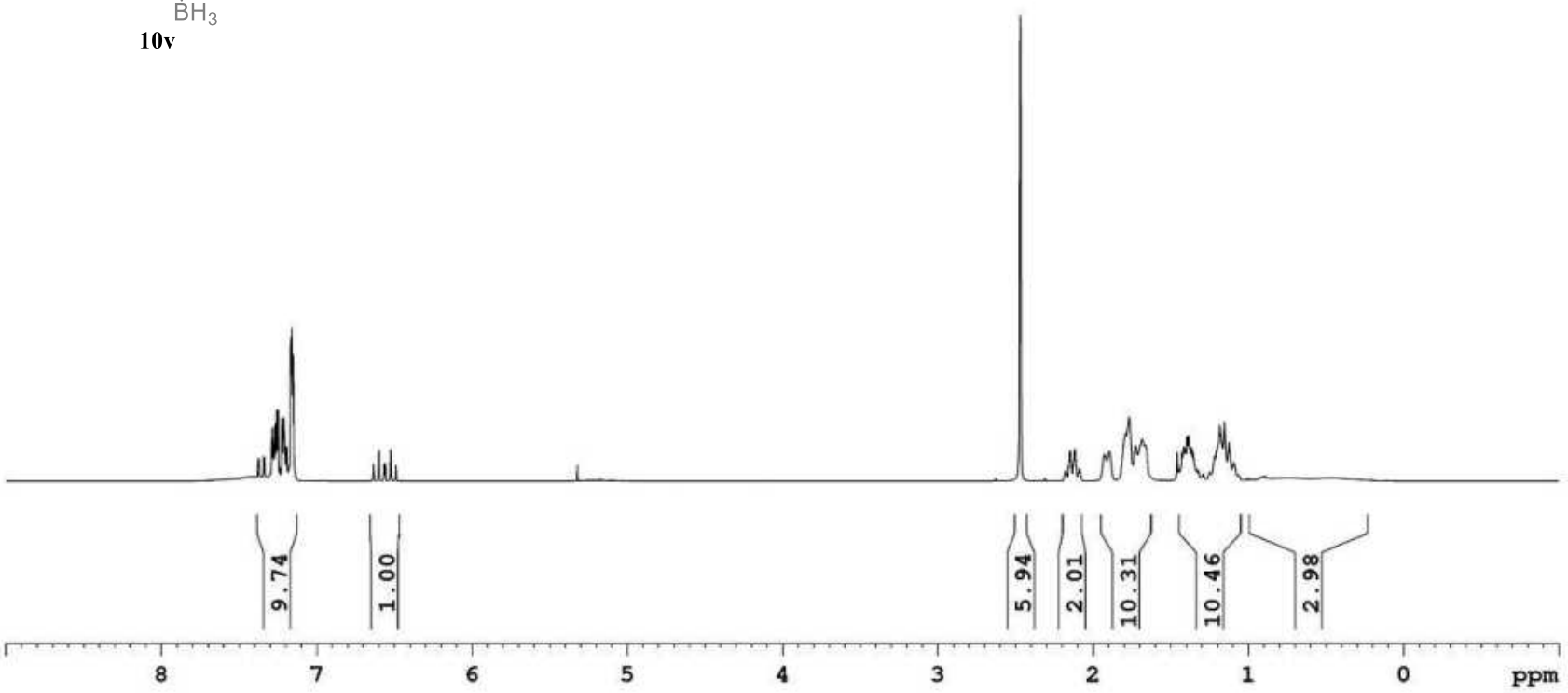


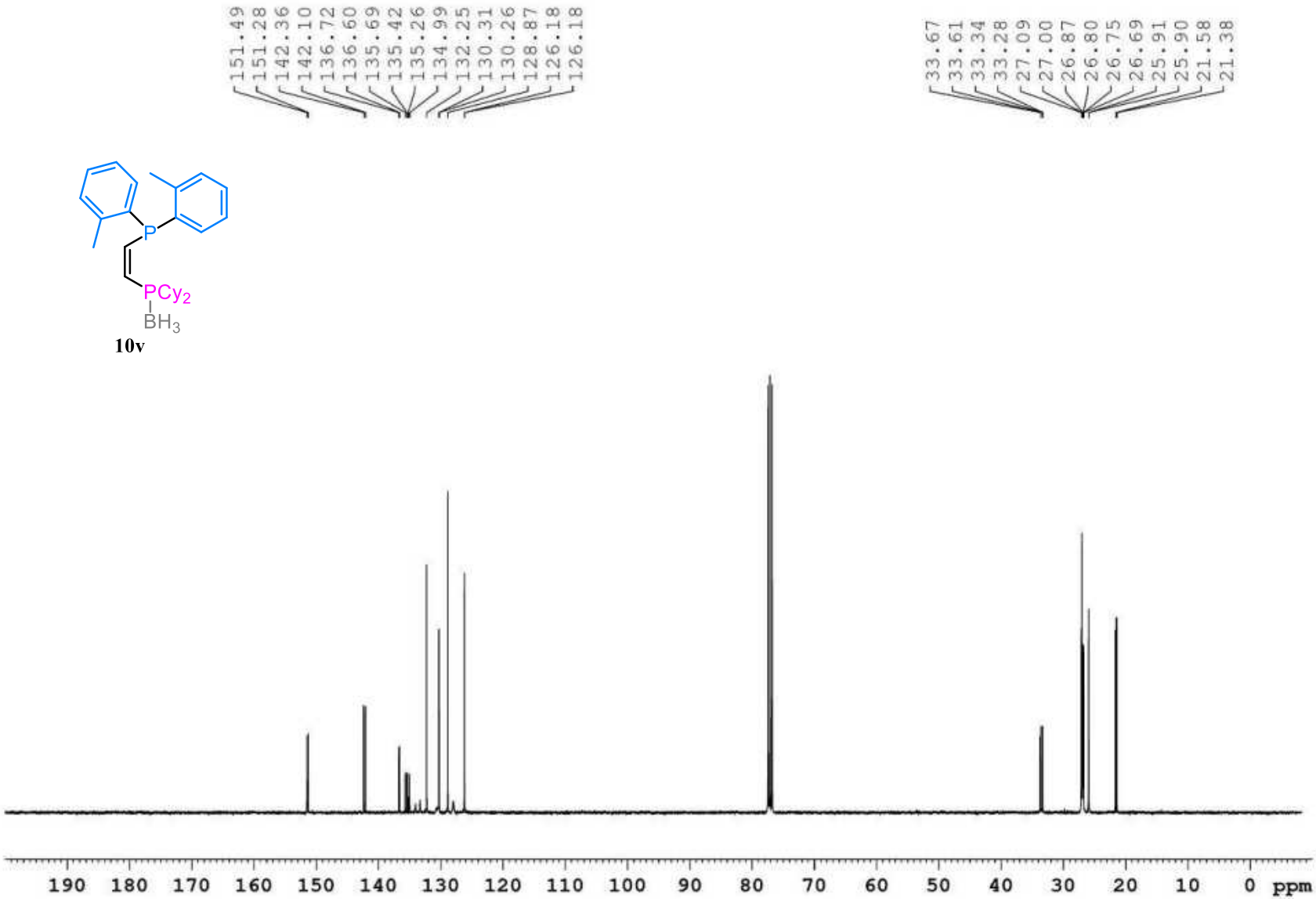

7.38
7.37
7.34
7.34
7.28
7.28
7.27
7.26
7.25
7.22
7.21
7.19
7.16
7.16
7.15
6.63
6.60
6.56
6.56
6.52
6.49


2.47
2.18
2.15
2.12
2.09
1.93
1.89
1.79
1.77
1.73
1.70
1.68
1.66
1.45
1.41
1.38
1.34
1.33
1.22
1.18
1.15
1.12
1.09
0.97
0.75
0.47
0.24


P
PCy2
BH3

10v

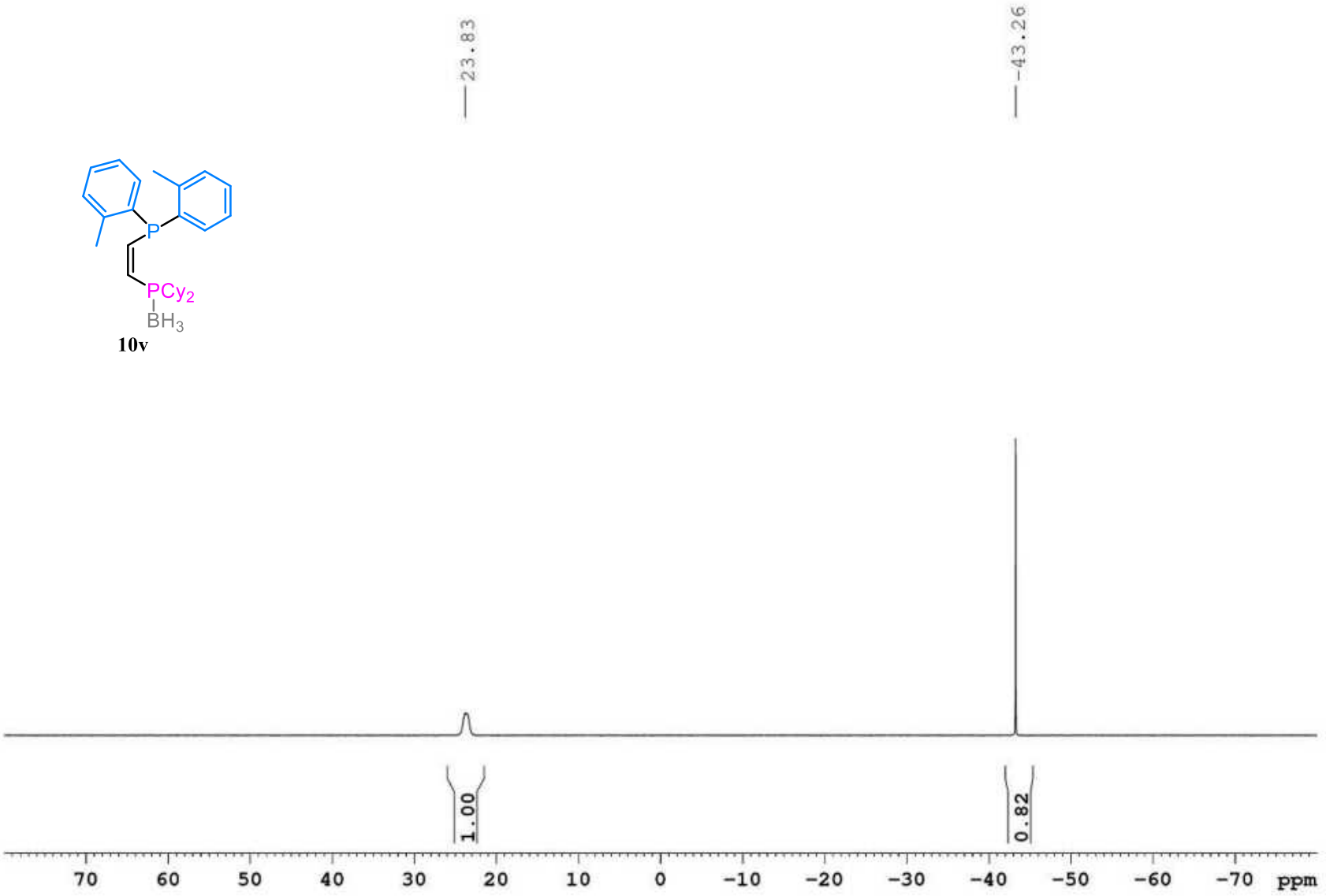

9.74
1.00
5.94
2.01
10.31
10.46
2.98
8
7
6
5
4
3
2
1
0
ppm


151.49
151.28
142.36
142.10
136.72
136.60
135.69
135.42
135.26
134.99
132.25
130.31
130.26
128.87
126.18
126.18
33.67
33.61
33.34
33.28
27.09
27.00
26.87
26.80
26.75
26.69
25.91
25.90
21.58
21.38
P
PCy2
BH3
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

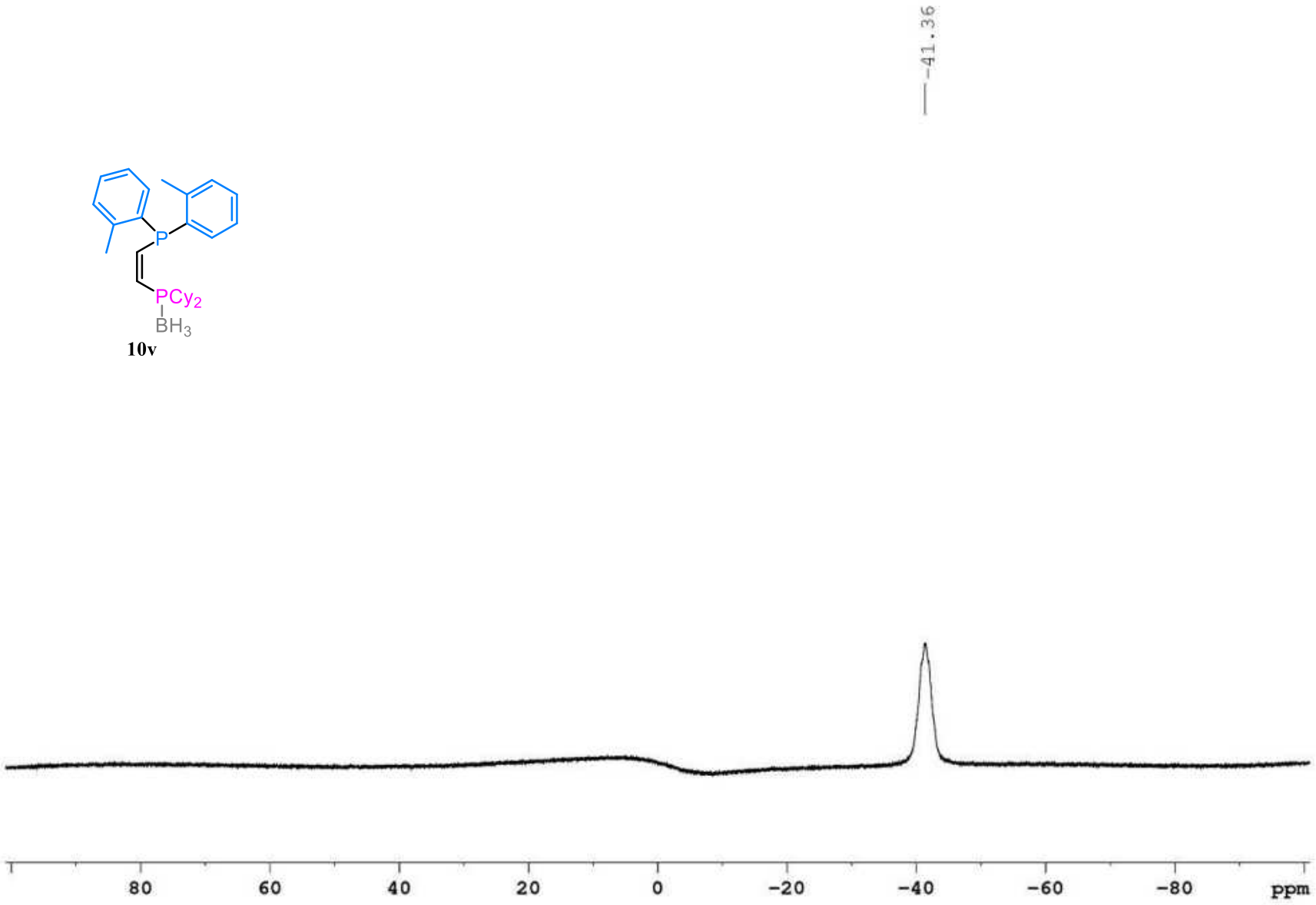
10v

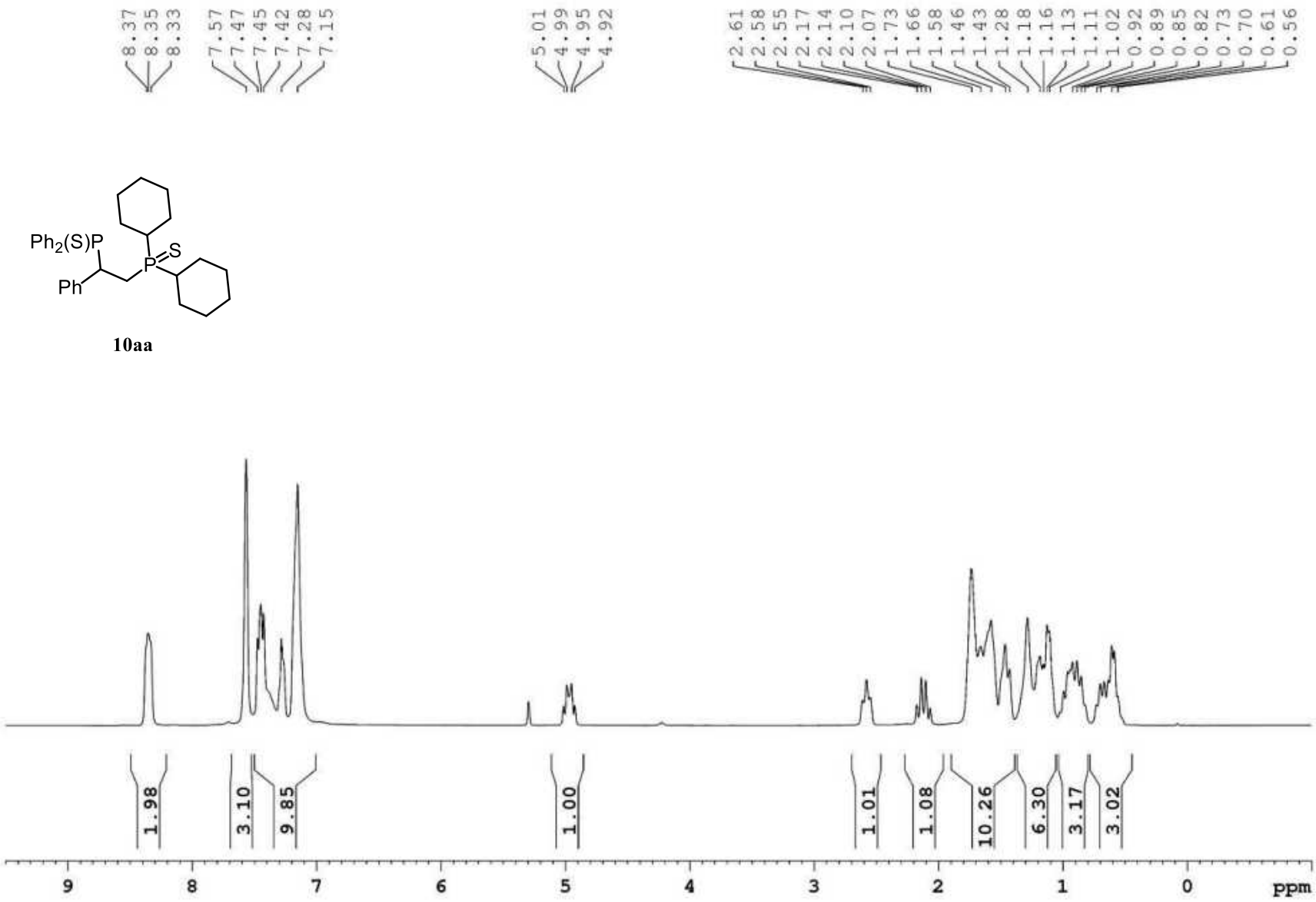
P
PCy2
BH3

10v

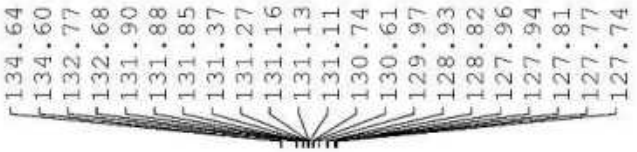

23.83
-43.26
1.00
0.82
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
ppm

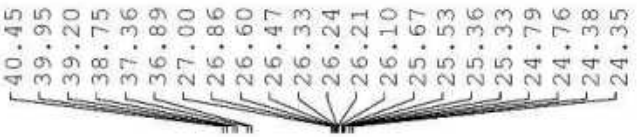
10v

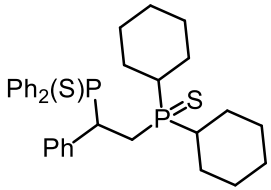



8.37
8.35
8.33
7.57
7.47
7.45
7.42
7.28
7.15
5.01
4.99
4.95
4.92
2.61
2.58
2.55
2.17
2.14
2.10
2.07
1.73
1.66
1.58
1.46
1.43
1.28
1.18
1.16
1.13
1.11
1.02
0.92
0.89
0.85
0.82
0.73
0.70
0.61
0.56
Ph2(S)P
P
S
Ph
1.98
3.10
9.85
1.00
1.01
1.08
10.26
6.30
3.17
3.02
9
8
7
6
5
4
3
2
1
0
ppm

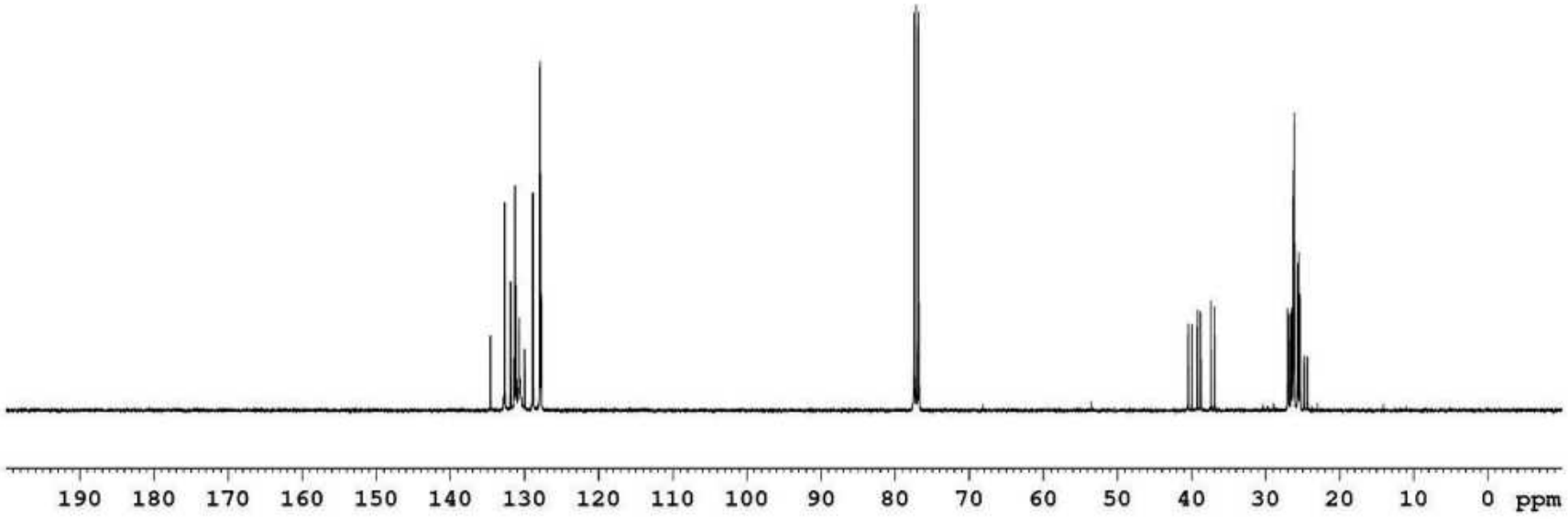
10aa

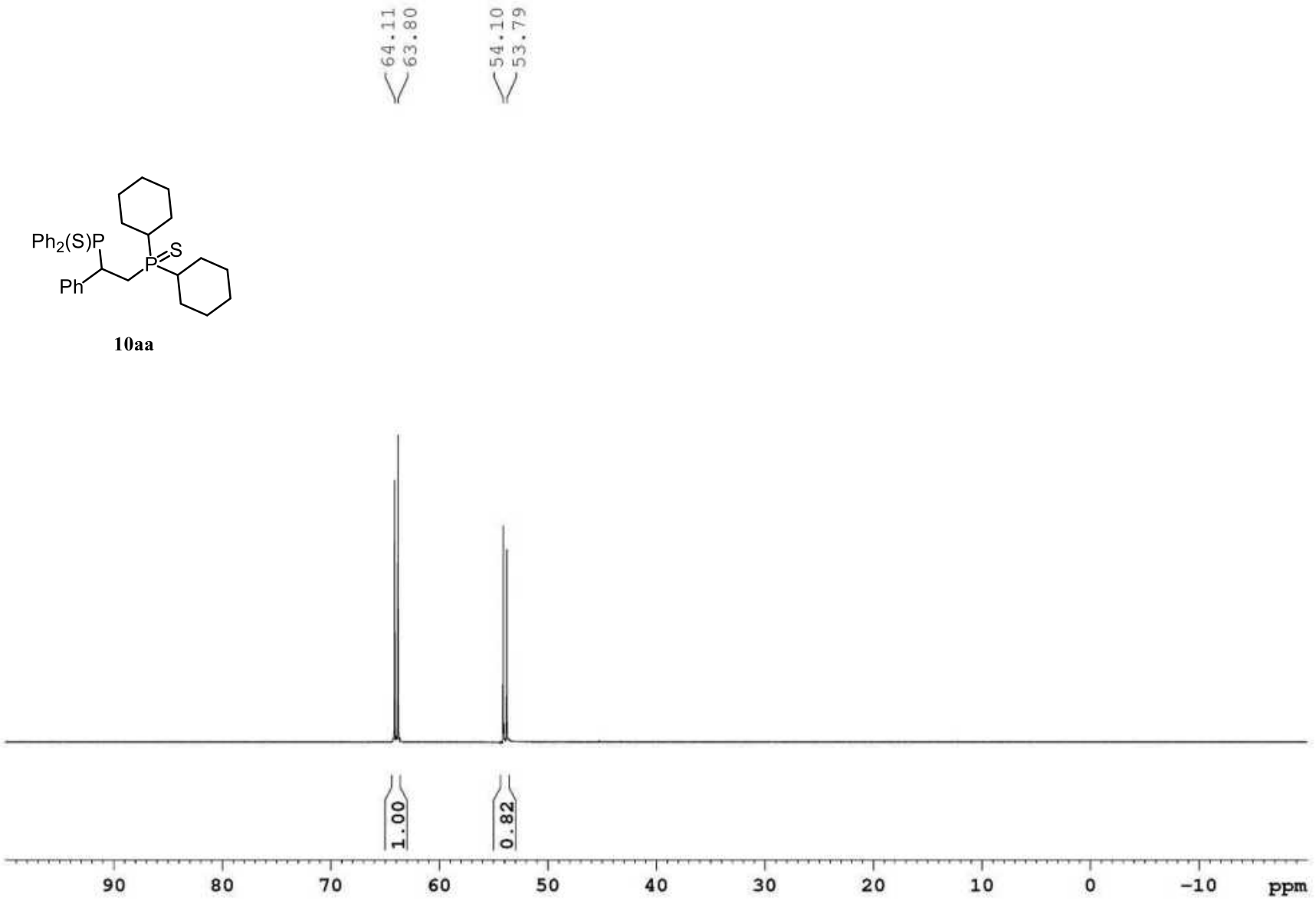

134.64
134.60
132.77
132.68
131.90
131.88
131.85
131.37
131.27
131.16
131.13
131.11
130.74
130.61
129.97
128.93
128.82
127.96
127.94
127.81
127.77
127.74


40.45
39.95
39.20
38.75
37.36
36.89
27.00
26.86
26.60
26.47
26.33
26.24
26.21
26.10
25.67
25.53
25.36
25.33
24.79
24.76
24.38
24.35


Ph2(S)P
P
S
Ph

10aa


190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm


64.11
63.80
54.10
53.79
Ph2(S)P
P
S
Ph
1.00
0.82
90
80
70
60
50
40
30
20
10
0
-10
ppm

10aa