Supplementary Materials

Tandem Rh-Catalysis: Decarboxylative β-Keto Acid and Alkyne Cross-Coupling

Faben A. Cruz, Zhiwei Chen, Sarah I. Kurtoic, Vy M. Dong*

Department of Chemistry, University of California Irvine, California 92697-2025 (USA)

*To whom correspondence should be addressed at e-mail: dongv@uci.edu

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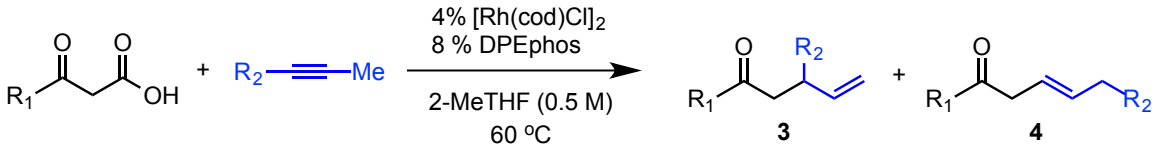
1. Materials and Methods

All reactions were run in oven-dried or flame-dried glassware under an atmosphere of N_2. Tetrahydrofuran, dichloromethane, toluene and diethyl ether were purified using an Innovative Technologies Pure Solv system, degassed by three freeze-pump-thaw cycles, and stored over 3A MS within an N_2 filled glove box. 1,4-Dioxane, 1,2-dimethoxyethane and dimethylsulfoxide were refluxed with CaH_2 and distilled prior to use. The molarity of organolithium reagents was determined by titration with *iso*-propanol/1,10-phenanthroline. Reactions were monitored either *via* gas chromatography using an Agilent Technologies 7890A GC system equipped with an Agilent Technologies 5975C inert XL EI/CI MSD or by analytical thin-layer chromatography on EMD Silica Gel 60 F_{254} plates. Visualization of the developed plates was performed under UV light (254 nm) or using either $KMnO_4$ or *p*-anisaldehyde stain. Column chromatography was performed with Silicycle Silia-P Flash Silica Gel using glass columns. Automated column chromatography was performed using either a Biotage SP1 or Teledyne Isco CombiFlash Rf 200 purification system. ^1H, ^{13}C, and ^{19}F NMR spectra were recorded on a Bruker DRX-400 (400 MHz ^1H, 100 MHz ^{13}C, 376.5 MHz ^{19}F), GN-500 (500 MHz ^1H, 125.7 MHz ^{13}C) or CRYO-500 (500 MHz ^1H, 125.7 MHz ^{13}C) spectrometer. ^1H NMR spectra were internally referenced to the residual solvent signal or TMS. ^{13}C NMR spectra were internally referenced to the residual solvent signal. Data for ^1H NMR are reported as follows: chemical shift (δ ppm), multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br = broad), coupling constant (Hz), integration. Data for ^{13}C NMR are reported in terms of chemical shift (δ, ppm). Infrared spectra were obtained on a Thermo Scientific Nicolet iS5 FT-IR spectrometer equipped with an iD5 ATR accessory. High resolution mass spectra (HRMS) was performed by the University of California, Irvine Mass Spectrometry Center.

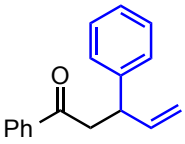
2. Ketone Synthesis

General Procedure for Alkyne and β-keto acid Coupling



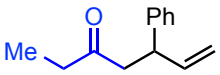
To a 1 dram vial equipped with a magnetic stir bar was added $[Rh(cod)Cl]_2$ (3.9 mg, 0.008 mmol), DPEphos (8.6 mg, 0.016 mmol), β-keto acid (0.40 mmol), alkyne (0.20 mmol), and 2-MeTHF (0.40 mL). In some cases, benzoic acid was added (12.2 mg, 0.10 mmol). The vial was then sealed with a Teflon-lined screw cap and heated to 60 °C for 24 hours. The resulting mixture was then cooled to room temperature. Chemo- and regioselectivities were determined by analysis of the crude reaction mixture by ^{1}H NMR spectroscopy. Ketone products were isolated by flash column chromatography or preparatory TLC.

1,3-diphenylpent-4-en-1-one (Figure 1, **3a**)



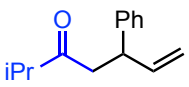
The title compound was synthesized according to the general procedure using $[Rh(cod)Cl]_2$ (2.0 mg, 0.004 mmol, 4 mol%), DPEphos (4.3 mg, 0.008 mmol, 8 mol%), benzoylacetic acid (32.8 mg, 0.2 mmol, 2 equiv), 1-phenyl-1-propyne (12.5 µL, 0.1 mmol, 1 equiv) and 2-MeTHF (200 µL, 0.5 M). After stirring at 60 °C for 7 hours, the yield was determined by GC-FID analysis using 1,3,5-trimethoxybenzene as an internal standard and branched to linear selectivity was determined by ^{1}H NMR analysis of the crude reaction mixture (97% yield, >20:1 branched:linear). **^{1}H NMR** (400 MHz, CDCl3) δ 8.03 – 7.91 (m, 2H), 7.64 – 7.56 (m, 1H), 7.53 – 7.44 (m, 2H), 7.41 – 7.30 (m, 4H), 7.30 – 7.19 (m, 1H), 6.12 (ddd, *J* = 17.1, 10.4, 6.8 Hz, 1H), 5.12 (tt, *J* = 17.2, 1.3 Hz, 2H), 4.21 (q, *J* = 6.7 Hz, 1H), 3.47 (qd, *J* = 16.6, 7.1 Hz, 2H).

5-phenylhept-6-en-3-one (Figure 2, **3b**)



The title compound was synthesized according to the general procedure with benzoic acid, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a yellow oil (33.8 mg, 90% yield). The ^{1}H NMR spectrum is in accordance with the literature.[1] **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.32–7.27 (m, 2H), 7.22–7.18 (m, 3H), 5.97 (ddd, *J* = 17.1, 10.3, 6.8 Hz, 1H), 5.07–4.99 (m, 2H), 3.93 (q, *J* = 7.2 Hz, 1H), 2.89–2.76 (m, 2H), 2.44–2.25 (m, 2H), 0.98 (d, *J* = 14.6 Hz, 3H).

2-methyl-5-phenylhept-6-en-3-one (Figure 2, **3c**)

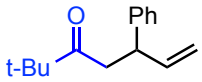


The title compound was synthesized according to the general procedure with benzoic acid, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the

[1] E. C. Burger, J. A. Tunge, *Org. Lett.*, 2004**, 6**, 2603.

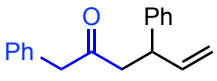
branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a yellow oil (32.4 mg, 80% yield). The ^{1}H NMR spectrum is in accordance with the literature.[2] **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.31–7.27 (m, 2H), 7.20 (t, *J* = 7.1 Hz, 3H), 5.98 (ddd, *J* = 17.1, 10.4, 6.8 Hz, 1H), 5.06–4.99 (m, 2H), 3.96 (q, *J* = 7.1 Hz, 1H), 2.93–2.81 (m, 2H), 2.50 (7, *J* = 6.9 Hz, 1H), 1.04 (d, *J* = 6.9 Hz, 3H), 0.98 (d, *J* = 6.9 Hz, 3H).

2,2-dimethyl-5-phenylhept-6-en-3-one (Figure 2, **3d**)



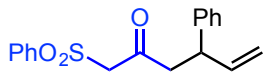
The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a yellow oil (36.5 mg, 85% yield). The ^{1}H NMR spectrum is in accordance with the literature.[3] **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.31–7.27 (m, 2H), 7.21–7.17 (m, 3H), 5.98 (ddd, *J* = 17.1, 10.4, 6.8 Hz, 1H), 5.06–4.99 (m, 2H), 3.99 (q, *J* = 7.0 Hz, 1H), 2.96–2.84 (m, 2H), 1.05 (s, 9H).

1,4-diphenylhex-5-en-2-one (Figure 2, **3e**)



The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (5% ethyl acetate in hexanes) as a yellow oil (30.6 mg, 61% yield). The ^{1}H NMR spectrum is in accordance with the literature.[4] **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.33–7.26 (m, 5H), 7.25–7.18 (m, 1H), 7.16–7.13 (m, 2H), 7.11–7.09 (m, 2H), 5.93 (ddd, *J* = 17.1, 10.3, 6.8 Hz, 1H), 5.05–4.95 (m, 2H), 3.93 (q, *J* = 7.1 Hz, 1H), 3.60 (d, *J* = 1.3 Hz, 2H), 2.92–2.82 (m, 2H).

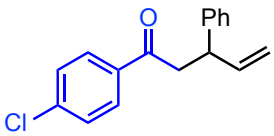
4-phenyl-1-(phenylsulfonyl)hex-5-en-2-one (Figure 2, **3f**)



The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (5% ethyl acetate in hexanes) as a yellow oil (57.9 mg, 92% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.71–7.62 (m, 3H), 7.52–7.48 (m, 2H), 7.34–7.30 (m, 2H), 7.27–7.21 (m, 3H), 5.97 (ddd, *J* = 17.2, 10.4, 6.8 Hz, 1H), 5.10–5.03 (m, 2H), 4.06 (q, *J* = 13.4 Hz, 2H), 3.89 (q, *J* = 7.1 Hz, 1H), 3.20 (qd, *J* = 17.6, 7.4 Hz, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 196.5, 142.2, 140.1, 138.3, 134.4, 129.4, 128.8, 128.4, 128.0, 127.0, 115.2, 67.4, 49.6, 44.2. **IR** (ATR): 3062, 1721, 1447, 1320, 1310, 1151, 1085, 912, 734, 686 cm^{-1}. **HRMS** calculated for $C_{18}H_{18}O_3SNa$ $[M+Na]^+$ 337.0874, found 337.0881.

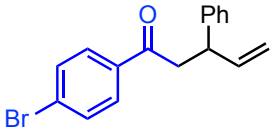
[2] G. W. Daub, M. A. McCoy, M. G. Sanchez, J. S. Carter, *J. Org. Chem.,* 1983**, 48**, 3876.
[3] T. Hirao, T. Fujii, Y. Oshiro, *Tetrahedron* 1994, **50**, 10207.
[4] E. C. Burger, J. A. Tunge, *Chem. Commun.,* 2005, **22**, 2835.

1-(4-chlorophenyl)-3-phenylpent-4-en-1-one (Figure 2, **3g**)



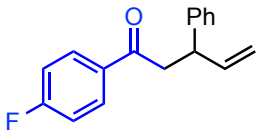
The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (5% ethyl acetate in hexanes) as a yellow oil (38.1 mg, 70% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.87 (d, *J* = 8.6 Hz, 2H), 7.43 (d, *J* = 8.6 Hz, 2H), 7.34–7.30 (m, 2H), 7.28–7.20 (m, 3H), 6.06 (ddd, *J* = 17.2, 10.4, 6.8 Hz, 1H), 5.11–5.02 (m, 2H), 4.13 (q, *J* = 6.8 Hz, 1H), 3.38 (qd, *J* = 16.5, 7.7 Hz, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 197.3, 143.1, 140.7, 139.7, 135.6, 129.7, 129.1, 128.8, 127.9, 126.9, 115.0, 44.8, 44.2. **IR** (ATR): 3028, 1684, 1588, 1488, 1399, 1202, 1090, 987, 815, 699 cm^{-1}. **HRMS** calculated for $C_{17}H_{19}ClNO$ $[M+NH_4]^+$ 288.1155, found 288.1154.

1-(4-bromophenyl)-3-phenylpent-4-en-1-one (Figure 2, **3h**)



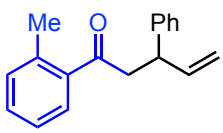
The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a colorless oil (47.6 mg, 76% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.84 (d, *J* = 8.7 Hz, 2H), 7.64 (d, *J* = 8.9 Hz, 2H), 7.38–7.35 (m, 2H), 7.32–7.25 (m, 3H), 6.10 (ddd, *J* = 17.2, 10.4, 6.7 Hz, 1H), 5.15–5.08 (m, 2H), 4.18 (q, *J* = 6.9 Hz, 1H), 3.42 (qd, *J* = 16.5, 7.6 Hz, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 197.4, 143.1, 140.7, 136.0, 132.1, 130.0, 128.8, 128.4, 127.9, 126.8, 115.0, 44.7, 44.2. **IR** (ATR): 3028, 1685, 1568, 1484, 1396, 1201, 1070, 987, 811, 699 cm^{-1}. **HRMS** calculated for $C_{17}H_{15}BrONa$ $[M+Na]^+$ 337.0204, found 337.0211.

1-(4-fluorophenyl)-3-phenylpent-4-en-1-one (Figure 2, **3i**)



The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (5% ethyl acetate in hexanes) as a colorless oil (46.4 mg, 91% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 8.03 (dd, *J* = 8.9, 5.4 Hz, 2H), 7.40–7.37 (m, 2H), 7.35–7.32 (m, 2H), 7.30–7.27 (m, 1H), 7.18 (t, *J* = 8.6 Hz, 2H), 6.13 (ddd, *J* = 17.2, 10.4, 6.9 Hz, 1H), 5.17–5.09 (m, 2H), 4.21 (q, *J* = 6.9 Hz, 1H), 3.45 (qd, *J* = 16.7, 7.6 Hz, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 196.8, 165.9 (d, *J* = 253.9 Hz), 143.2, 140.8, 133.7 (d, *J* = 2.9 Hz), 130.9 (d, *J* = 9.0 Hz), 128.8, 127.9, 126.8, 115.8 (d, *J* = 21.6 Hz), 115.0, 44.8, 44.1. **^{19}F NMR** (376 MHz, $CDCl_3$) δ -105.7. **IR** (ATR): 3028, 1683, 1596, 1505, 1408, 1232, 1155, 989, 829, 699 cm^{-1}. **HRMS** calculated for $C_{17}H_{15}FONa$ $[M+Na]^+$ 277.1005, found 277.0999.

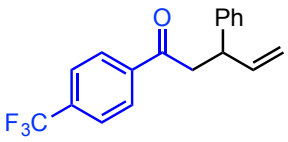
3-phenyl-1-(*o*-tolyl)pent-4-en-1-one (Figure 2, **3j**)



The title compound was synthesized according to the general, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (5% ethyl acetate in hexanes) as a yellow oil

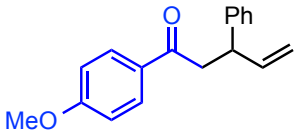
(35.1 mg, 70% yield). The ^{1}H NMR spectrum is in accordance with the literature.[5] **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.56–7.54 (m, 1H), 7.34 (dd, *J* = 7.5, 1.3 Hz, 1H), 7.32–7.28 (m, 2H), 7.24–7.19 (m, 5H), 6.04 (ddd, *J* = 17.1, 10.3, 6.8 Hz, 1H), 5.09–5.02 (m, 2H), 4.08 (q, *J* = 7.1 Hz, 1H), 3.39–3.27 (m, 2H), 2.35 (s, 3H).

3-phenyl-1-(4-(trifluoromethyl)phenyl)pent-4-en-1-one (Figure 2, **3k**)



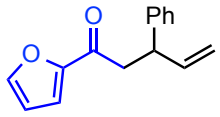
The title compound was synthesized according to the general, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a colorless oil (38.2 mg, 63% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 8.02 (d, *J* = 8.2 Hz, 2H), 7.72 (d, *J* = 8.2 Hz, 2H), 7.34–7.30 (m, 2H), 7.28–7.20 (m, 3H), 6.06 (ddd, *J* = 17.2, 10.4, 6.7 Hz, 1H), 5.12–5.03 (m, 2H), 4.14 (q, *J* = 6.8 Hz, 1H), 3.43 (qd, *J* = 16.7, 7.5 Hz, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 197.6, 143.0, 140.54, 140.53, 139.9 (q, *J* = 0.9 Hz), 134.5 (q, *J* = 32.6 Hz), 128.9, 128.6, 127.9, 126.9, 125.9 (q, *J* = 3.8 Hz), 115.2, 44.7, 44.5. **^{19}F NMR** (376 MHz, $CDCl_3$) δ –63.5. **IR** (ATR): 3029, 1692, 1511, 1410, 1322, 1167, 1126, 1065, 846, 700 cm^{-1}. **HRMS** calculated for $C_{18}H_{16}F_3O$ $[M+H]^+$ 305.1153, found 305.1153.

1-(4-methoxyphenyl)-3-phenylpent-4-en-1-one (Figure 2, **3l**)



The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a yellow oil (32.4 mg, 61% yield). The ^{1}H NMR spectrum is in accordance with the literature.[6] **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.94–7.91 (m, 2H), 7.32–7.25 (m, 4H), 7.22–7.18 (m, 1H), 6.94–6.90 (m, 2H), 6.05 (ddd, *J* = 17.1, 10.4, 6.8 Hz, 1H), 5.08–5.00 (m, 2H), 4.13 (q, *J* = 7.1 Hz, 1H), 3.86 (s, 3H), 3.35 (qd, *J* = 16.3, 7.1 Hz, 2H).

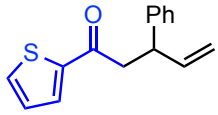
1-(furan-2-yl)-3-phenylpent-4-en-1-one (Figure 2, **3m**)



The title compound was synthesized according to the general procedure with benzoic acid, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a colorless oil (40.7 mg, 90% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.56 (s, 1H), 7.31–7.25 (m, 4H), 7.20 (t, *J* = 7.0 Hz, 1H), 7.15 (d, *J* = 3.2 Hz, 1H), 6.04 (ddd, *J* = 17.0, 10.2, 7.0 Hz, 1H), 5.08–5.04 (m, 2H), 4.11 (q, *J* = 6.8 Hz, 1H), 3.29 (dd, *J* = 15.7, 7.9 Hz, 1H), 3.21 (dd, *J* = 15.7, 6.6 Hz, 1H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 187.7, 153.1, 146.5, 143.0, 140.6, 128.7, 127.9, 126.8, 117.3, 115.0, 112.4, 44.7, 44.0. **IR** (ATR): 3028, 1671, 1567, 1466, 1393, 1268, 1156, 915, 759, 699 cm^{-1}. **HRMS** calculated for $C_{15}H_{14}O_2Na$ $[M+Na]^+$ 249.0892, found 249.0895.

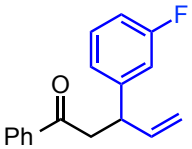
[5] S. Chen, G. Lu, C. Cai, *Chem. Commun.*, 2015, **51**,11512.
[6] H. He, X.-J. Zheng, Y. Li, L.-X. Dai, S.-L. You, *Org. Lett.*, 2007, **9**, 4339.

3-phenyl-1-(thiophen-2-yl)pent-4-en-1-one (Figure 2, **3n**)



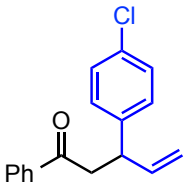
The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a colorless oil (43.2 mg, 89% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.69 (d, *J* = 3.9 Hz, 1H), 7.60 (d, *J* = 5.4 Hz, 1H), 7.32–7.25 (m, 4H), 7.20 (t, *J* = 6.9 Hz, 1H), 7.09 (t, *J* = 3.7 Hz, 1H), 6.05 (ddd, *J* = 17.0, 10.3, 6.8 Hz, 1H), 5.09–5.04 (m, 2H), 4.13 (q, *J* = 6.9 Hz, 1H), 3.36 (dd, *J* = 15.9, 7.8 Hz, 1H), 3.28 (dd, *J* = 15.9, 6.6 Hz, 1H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 191.3, 144.7, 143.0, 140.5, 133.9, 132.0, 128.8, 128.3, 127.9, 126.8, 115.1, 45.0. **IR** (ATR): 3081, 3027, 1657, 1413, 1258, 1061, 916, 857, 723, 699 cm^{-1}. **HRMS** calculated for $C_{15}H_{14}OSNa$ $[M+Na]^+$ 265.0663, found 265.0667.

3-(3-fluorophenyl)-1-phenylpent-4-en-1-one (Figure 3, **3o**)



The title compound was synthesized according to the general, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a colorless oil (15.8 mg, 68% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.95–7.92 (m, 2H), 7.58–7.54 (m, 1H), 7.48–7.43 (m, 2H), 7.29–7.23 (m, 1H), 7.05 (dddd, *J* = 7.7, 1.6, 1.0, 0.5 Hz, 1H), 6.99–6.95 (m, 1H), 6.89 (tdd, *J* = 8.4, 2.5, 0.9 Hz, 1H), 6.02 (ddd, *J* = 17.1, 10.4, 6.8 Hz, 1H), 5.11–5.03 (m, 2H), 4.15 (q, *J* = 6.9 Hz, 1H), 3.39 (qd, *J* = 14.5, 7.1 Hz, 2H). **^{19}F NMR** (376 MHz, $CDCl_3$): δ -113.5. **^{13}C NMR** (101 MHz, $CDCl_3$): δ 198.0, 164.3, 161.9, 145.92, 145.85, 140.2, 137.1, 133.3, 130.19, 130.11, 128.8, 128.2, 123.61, 123.58, 115.4, 114.9, 114.7, 113.7, 113.5, 77.2, 44.3, 43.9. **HRMS** calculated for C17H19FON $[M+NH_4]^+$ 272.1451, found 272.1449. **IR** (ATR): 3061, 2927, 1684, 1588, 1447, 1260, 1239, 988, 912, 784, 756, 732, 688 cm^{-1}.

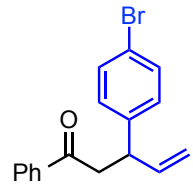
3-(4-chlorophenyl)-1-phenylpent-4-en-1-one (Figure 3, **3p**)



The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (5% ethyl acetate in hexanes) as a colorless oil (40.6 mg, 75% yield). The ^{1}H NMR spectrum is in accordance with the literature.[7] **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.91–7.89 (m, 2H), 7.56–7.52 (m, 1H), 7.46–7.41 (m, 2H), 7.27–7.23 (m, 3H), 7.19–7.16 (m, 2H), 6.00 (ddd, *J* = 17.1, 10.4, 6.7 Hz, 1H), 5.09–4.99 (m, 2H), 4.11 (q, *J* = 6.9 Hz, 1H), 3.36 (qd, *J* = 15.3, 7.1 Hz, 2H).

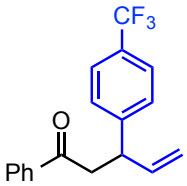
[7] S. Chen, G. Lu, C. Cai, *Chem. Commun.*, 2015, **51**,11512.

3-(4-bromophenyl)-1-phenypent-4-en-1-one (Figure 3, **3q**)



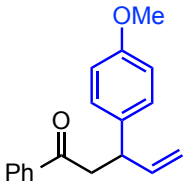
The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (5% ethyl acetate in hexanes) as a colorless oil (38.5 mg, 57% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.93–7.91 (m, 2H), 7.58–7.54 (m, 1H), 7.47–7.40 (m, 4H), 7.16–7.12 (m, 2H), 6.01 (ddd, *J* = 17.1, 10.4, 6.7 Hz, 1H), 5.11–5.01 (m, 2H), 4.11 (q, *J* = 6.9 Hz, 1H), 3.38 (qd, *J* = 15.3, 7.1 Hz, 2H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 198.0, 142.3, 140.3, 137.1, 133.3, 131.8, 129.7, 128.8, 128.2, 120.5, 115.3, 77.2, 43.99, 43.90. **HRMS** calculated for $C_17H_{16}BrO$ $[M+H]^+$ 315.0396, found 315.0385. **IR** (ATR): 1683, 1487, 1010, 989, 908, 823, 750, 729, 688, 648 cm^{-1}.

1-phenyl-3-(4-trifluoromethyl-phenyl)pent-4-en-1-one (Figure 3, **3r**)



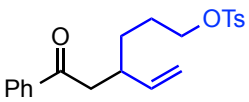
The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (5% ethyl acetate in hexanes) as a colorless oil (49.4 mg, 81% yield). The ^{1}H NMR spectrum is in accordance with the literature.[8] **^{1}H NMR** (400 MHz; $CDCl_3$): δ 7.95–7.92 (m, 2H), 7.58–7.54 (m, 3H), 7.48–7.38 (m, 4H), 6.04 (ddd, *J* = 17.1, 10.4, 6.7 Hz, 1H), 5.14–5.04 (m, 2H), 4.25–4.20 (m, 1H), 3.50–3.37 (m, 2H).

3-(4-methoxyphenyl)-1-phenylpent-4-en-1-one (Figure 3, **3s**)



The title compound was synthesized according to the general, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (5% ethyl acetate in hexanes) as a colorless oil (29.0 mg, 55% yield). The ^{1}H NMR spectrum is in accordance with the literature.[9] **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.94–7.92 (m, 2H), 7.57–7.53 (m, 1H), 7.46–7.43 (m, 2H), 7.19–7.16 (m, 2H), 6.87–6.83 (m, 2H), 6.04 (ddd, *J* = 17.1, 10.4, 6.7 Hz, 1H), 5.07–4.99 (m, 2H), 4.10 (q, *J* = 7.0 Hz, 1H), 3.78 (s, 3H), 3.37 (qd, *J* = 14.9, 7.2 Hz, 2H).

4-(2-oxo-2-phenylethyl_hex-5-en-1-yl 4-methylbenzenesulfonate (Figure 3, **3t**)

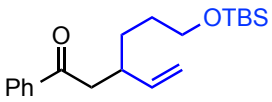


The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (20% ethyl acetate in hexanes) as a yellow oil (60.4 mg, 85% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.93–7.90 (m, 2H), 7.79–7.76 (m, 2H), 7.58–7.54 (m, 1H), 7.48–7.43 (m, 2H), 7.33 (dd, *J* = 8.6, 0.6 Hz, 2H), 5.64–5.55 (m, 1H), 4.99 (s, 1H), 4.96 (ddd, *J* = 6.5, 1.6, 0.8 Hz, 1H), 4.06–3.97 (m, 2H), 2.94 (qd, *J* = 14.6, 6.8 Hz, 2H), 2.73–2.64 (m, 1H), 2.43 (s, 3H), 1.78–1.66 (m, 1H), 1.65–1.59 (m, 1H), 1.57–1.44 (m, 1H), 1.41–1.30 (m, 2H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ

[8] T. Graening, J. F. Hartwig, *J. Am. Chem. Soc.*, 2005, **127**, 17192.
[9] T. Graening, J. F. Hartwig, *J. Am. Chem. Soc.*, 2005, **127**, 17192.

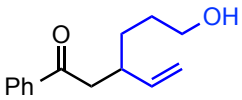
198.9, 144.8, 140.7, 137.3, 133.3, 133.2, 130.0, 128.8, 128.2, 128.03, 115.8, 70.7, 43.9, 39.3, 30.4, 26.8, 21.8. **HRMS** calculated for $C_{21}H_{24}O_4SNa$ $[M+Na]^+$ 395.1293, found 395.1282. **IR** (ATR): 1682, 1355, 1174, 913, 813, 689, 661 cm^{-1}.

6-((*tert*-butyldimethylsilyl)oxy)-1-phenyl-3-vinylhexan-1-one (Figure 3, **3u**)



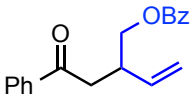
The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (2% ethyl acetate in hexanes) as a yellow oil (38.5 mg, 58% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.93 (dd, *J* = 7.2, 1.1 Hz, 2H), 7.57–7.53 (m, 1H), 7.47–7.43 (m, 2H), 5.72–5.63 (m, 1H), 5.02–4.97 (m, 2H), 3.61–3.58 (m, 2H), 2.99–2.97 (m, 2H), 2.79–2.72 (m, 1H), 1.61–1.47 (m, 3H), 1.43–1.37 (m, 1H), 0.88 (s, 9H), 0.03 (s, 6H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 199.5, 141.5, 137.5, 133.0, 128.7, 128.2, 115.1, 63.2, 44.1, 39.7, 31.0, 30.5, 26.1, 18.5, -5.1. **HRMS** calculated for $C_{20}H_{33}O_2Si$ $[M+H]^+$ 333.2250, found 333.2257. **IR** (ATR): 2928, 2856, 1683, 1448, 1250, 1095, 914, 833, 774, 688 cm^{-1}.

6-hydroxy-1-phenyl-3-vinylhexan-1-one (Figure 3, **3v**)



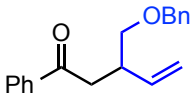
The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (40% ethyl acetate in hexanes) as a yellow oil (22.1 mg, 53% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.95–7.92 (m, 2H), 7.58–7.54 (m, 1H), 7.46 (tt, *J* = 7.5, 1.4 Hz, 2H), 5.69 (ddd, *J* = 17.1, 10.3, 8.3 Hz, 1H), 5.05–4.99 (m, 2H), 3.66 (t, *J* = 6.1 Hz, 2H), 3.01 (dd, *J* = 6.8, 1.8 Hz, 2H), 2.78 (s, 1H), 1.72 (d, *J* = 17.3 Hz, 1H), 1.68–1.52 (m, 3H), 1.45–1.38 (m, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 199.5, 141.3, 137.4, 133.2, 128.7, 128.2, 115.3, 62.8, 44.0, 39.2, 30.7, 30.2. **HRMS** calculated for $C_{14}H_{18}O_2Na$ $[M+Na]^+$ 241.1205, found 241.1197. **IR** (ATR): 3367, 2927, 1681, 1596, 1448, 1211, 1055, 1000, 914, 751, 688, 657 cm^{-1}.

2-(2-oxo-2-phenylethyl)but-3-en-1-yl benzoate (Figure 3, **3w**)



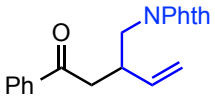
The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (5% ethyl acetate in hexanes) as a yellow oil (30.1 mg, 51% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 8.01–7.94 (m, 4H), 7.58–7.53 (m, 2H), 7.47–7.40 (m, 4H), 5.89 (ddd, *J* = 17.3, 10.4, 7.5 Hz, 1H), 5.23–5.13 (m, 2H), 4.45–4.34 (m, 2H), 3.40–3.32 (m, 1H), 3.19 (qd, *J* = 18.5, 6.7 Hz, 2H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 198.3, 166.5, 137.6, 137.1, 133.3, 133.1, 130.2, 129.7, 128.8, 128.5, 128.2, 117.0, 67.1, 40.2, 38.6. **HRMS** calculated for $C_{19}H_{19}O_3$ $[M+H]^+$ 295.1334, found 295.1324. **IR** (ATR): 1716, 1683, 1268, 1112, 752, 733, 710, 687 cm^{-1}.

3-((benzyloxy)methyl)-1-phenylpent-4-en-1-one (Figure 3, **3x**)



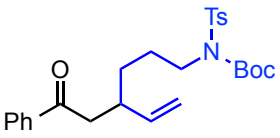
The title compound was synthesized according to the general procedure with benzoic acid, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (5% ethyl acetate in hexanes) as a colorless oil (50.5 mg, 90% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.96–7.94 (m, 2H), 7.57–7.53 (m, 1H), 7.47–7.43 (m, 2H), 7.34–7.25 (m, 5H), 5.85 (ddd, *J* = 17.4, 10.4, 7.4 Hz, 1H), 5.14–5.06 (m, 2H), 4.51 (s, 2H), 3.57–3.46 (m, 2H), 3.28 (dd, *J* = 16.2, 5.8 Hz, 1H), 3.20–3.11 (m, 1H), 3.00 (dd, *J* = 16.2, 7.3 Hz, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 199.3, 138.7, 138.5, 137.4, 133.1, 128.7, 128.5, 128.3, 127.7, 123.0, 116.0, 73.2, 73.0, 40.4, 39.7. **HRMS** calculated for $C_{19}H_{21}O_2$ $[M+H]^+$ 281.1541, found 281.1537. **IR** (ATR): 1682, 1448, 1359, 1208, 1099, 1001, 915, 750, 689, 655 cm^{-1}.

2-(2-(2-oxo-2-phenylethyl)but-3-en-1-yl)isoindoline-1,3-dione (Figure 3, **3y**)



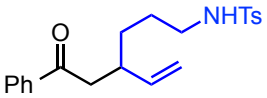
The title compound was synthesized according to the general procedure with benzoic acid, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (20% ethyl acetate in hexanes) as a white solid (33.0 mg, 52% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.91–7.89 (m, 2H), 7.82–7.79 (m, 2H), 7.72–7.67 (m, 2H), 7.56–7.52 (m, 1H), 7.43 (t, *J* = 7.7 Hz, 2H), 5.81–5.72 (m, 1H), 5.08–5.00 (m, 2H), 3.85–3.76 (m, 2H), 3.41–3.32 (m, 1H), 3.11 (d, *J* = 6.7 Hz, 2H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 198.1, 168.5, 138.1, 137.1, 134.1, 133.2, 132.1, 128.7, 128.2, 123.4, 117.4, 41.8, 41.3, 39.0. **HRMS** calculated for $C_{20}H_{17}NO_3Na$ $[M+Na]^+$ 342.1106, found 342.1107. **IR** (ATR): 1771, 1707, 1392, 1357, 753, 723, 713, 689 cm^{-1}.

***Tert*-butyl (4-(2-oxo-2-phenylethyl)hex-5-en-1-yl)(tosyl)carbamate** (Figure 3, **3z**)



The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a colorless oil (55.0 mg, 59% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.95–7.93 (m, 2H), 7.76 (d, *J* = 8.3 Hz, 2H), 7.57–7.53 (m, 1H), 7.47–7.43 (m, 2H), 7.29–7.27 (m, 2H), 5.69 (ddd, *J* = 17.1, 10.3, 8.3 Hz, 1H), 5.05–5.00 (m, 2H), 3.84–3.79 (m, 2H), 3.00 (d, *J* = 6.8 Hz, 2H), 2.84–2.77 (m, 1H), 2.42 (s, 3H), 1.87–1.70 (m, 2H), 1.58–1.50 (m, 1H), 1.47–1.38 (m, 1H), 1.32 (s, 9H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 199.3, 151.1, 144.1, 141.0, 137.6, 137.4, 133.1, 129.3, 128.7, 128.2, 127.9, 115.6, 84.2, 47.2, 44.0, 39.5, 31.7, 28.0, 27.9, 21.7. **HRMS** calculated for $C_{26}H_{33}NO_5SNa$ $[M+Na]^+$ 494.1977, found 494.1985. **IR** (ATR): 1720, 1683, 1352, 1283, 1255, 1153, 1087, 914, 813, 753, 722, 689, 671, 597 cm^{-1}.

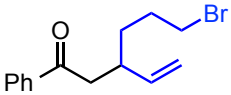
4-methyl-*N*-(4-(2-oxo-2-phenylethyl_hex-5-en-1-yl)benzenesulfonamide (Figure 3, **3aa**)



The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (20% ethyl

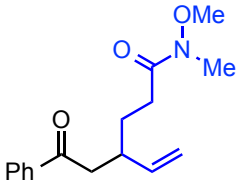
acetate in hexanes) as a yellow oil (60.6 mg, 82% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.92–7.89 (m, 2H), 7.75–7.73 (m, 2H), 7.57–7.53 (m, 1H), 7.47–7.43 (m, 2H), 7.29–7.26 (m, 2H), 5.63–5.54 (m, 1H), 4.96–4.92 (m, 2H), 2.99–2.87 (m, 4H), 2.69–2.61 (m, 1H), 2.39 (s, 3H), 1.56–1.39 (m, 3H), 1.33–1.25 (m, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 199.3, 143.4, 140.8, 137.19, 137.16, 133.2, 129.8, 128.7, 128.2, 127.2, 115.5, 43.9, 43.0, 38.8, 31.2, 27.1, 21.6. **HRMS** calculated for $C_{21}H_{25}NO_3SNa$ $[M+Na]^+$ 394.1453, found 394.1449 **IR** (ATR): 1679, 1324, 1155, 1092, 911, 813, 730, 689, 660 cm^{-1}.

6-bromo-1-phenyl-3-vinylhexan-1-one (Figure 3, **3ab**)



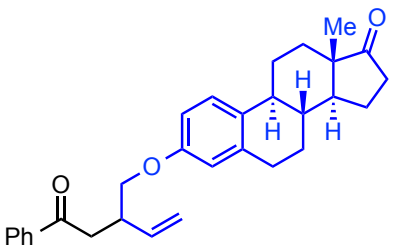
The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (20% ethyl acetate in hexanes) as a colorless oil (34.5 mg, 61% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.95–7.92 (m, 2H), 7.58–7.54 (m, 1H), 7.49–7.44 (m, 2H), 5.67 (ddd, *J* = 17.1, 10.3, 8.4 Hz, 1H), 5.06–5.01 (m, 2H), 3.45–3.35 (m, 2H), 3.07–2.94 (m, 2H), 2.83–2.74 (m, 1H), 1.97–1.80 (m, 2H), 1.69–1.60 (m, 1H), 1.53–1.43 (m, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 199.1, 140.9, 137.3, 133.2, 128.8, 128.2, 115.7, 44.0, 39.2, 33.9, 33.2, 30.6. **HRMS** calculated for $C_{14}H_{18}BrO$ $[M+H]^+$ 281.0541, found 281.0537. **IR** (ATR): 1682, 1447, 1210, 1000, 914, 751, 734, 688, 657 cm^{-1}.

***N*-methoxy-*N*-methyl-4-(2-oxo-2-phenylethyl)hex-5-enamide** (Figure 3, **3ac**)



The title compound was synthesized according to the general procedure with benzoic acid, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (30% ethyl acetate in hexanes) as a yellow oil (43.5 mg, 79% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.94–7.91 (m, 2H), 7.57–7.52 (m, 1H), 7.47–7.42 (m, 2H), 5.67 (ddd, *J* = 17.1, 10.3, 8.5 Hz, 1H), 5.06–5.00 (m, 2H), 3.66 (s, 3H), 3.15 (s, 3H), 3.02 (d, *J* = 6.7 Hz, 2H), 2.84–2.76 (m, 1H), 2.48–2.42 (m, 2H), 1.86 (dddd, *J* = 13.7, 9.6, 6.4, 4.3 Hz, 1H), 1.74-1.64 (m, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 199.1, 140.8, 137.4, 133.1, 128.7, 128.2, 123.1, 115.9, 61.4, 44.1, 39.7, 29.9, 29.4. **HRMS** calculated for $C_{16}H_{21}NO_3Na$ $[M+Na]^+$ 298.1419, found 298.1417. **IR** (ATR): 1682, 1659, 1447, 1179, 994, 916, 752, 732, 690 cm^{-1}.

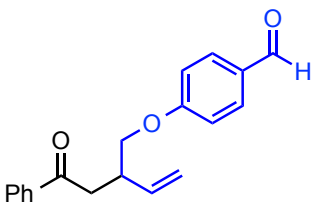
(8*R*,9*S*,13*S*,14*S*)-13-methyl-3-((2-(2-oxo-2-phenylethyl)but-3-en-1-yl)oxy)-6,7,8,9,11,12,13,14,15,16-decahydro-17*H*-cyclopenta[*a*]phenanthren-17-one (Figure 3, **3ad**)



The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a colorless oil (40.4 mg, 46% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.99–7.96 (m, 2H), 7.58–7.54 (m, 1H), 7.48–7.44 (m, 2H), 7.19–7.17 (m, 1H), 6.70 (dd, *J* = 8.6, 2.8 Hz, 1H), 6.63 (d, *J* = 2.6 Hz, 1H), 5.93 (ddd, *J* = 17.4, 10.3, 7.2 Hz, 1H), 5.20–5.11 (m, 2H), 4.06–4.02 (m, 1H), 3.95

(ddd, *J* = 9.3, 6.3, 3.2 Hz, 1H), 3.37 (dd, *J* = 16.0, 5.9 Hz, 1H), 3.33–3.28 (m, 1H), 3.10 (dd, *J* = 16.2, 6.7 Hz, 1H), 2.88–2.86 (m, 2H), 2.53–2.47 (m, 1H), 2.40–2.36 (m, 1H), 2.27–2.21 (m, 1H), 2.18–1.93 (m, 4H), 1.65–1.42 (m, 6H), 0.90 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 221.1, 198.9, 157.0, 138.1, 137.9, 137.3, 133.2, 132.3, 128.7, 128.3, 126.5, 116.5, 114.7, 112.3, 70.3, 50.6, 48.2, 44.1, 40.2, 39.1, 38.5, 36.0, 31.7, 29.8, 26.7, 26.1, 21.7, 14.0. **HRMS** calculated for $C_{30}H_{34}O_3Na$ $[M+Na]^+$ 465.2406, found 465.2416. **IR** (ATR): 2924, 1587, 2359, 1736, 1683, 1608, 1233, 1002, 917, 753, 689 cm^{-1}.

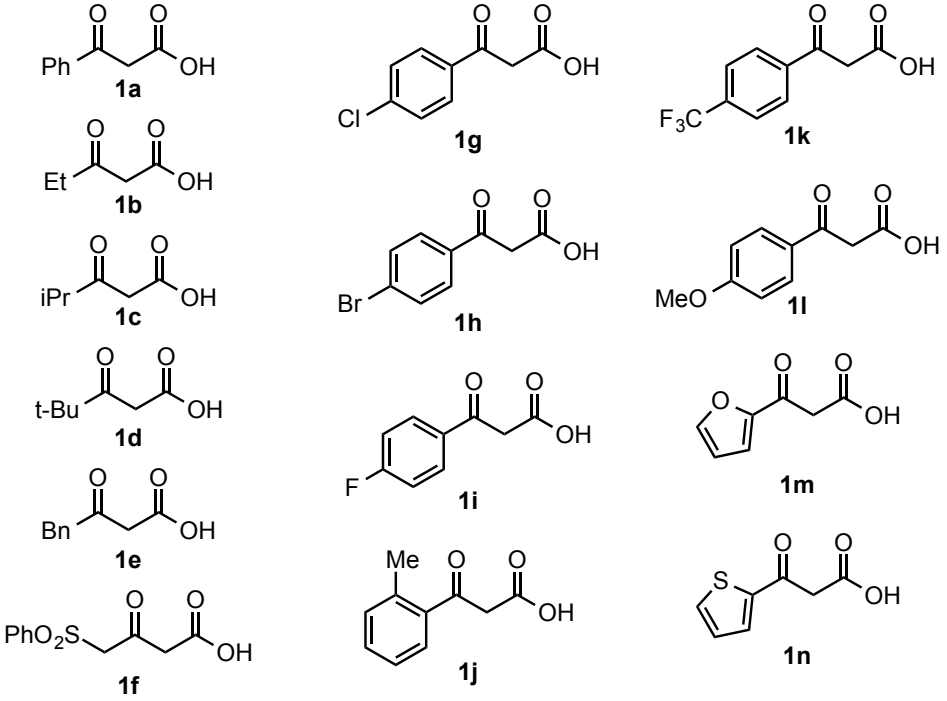
4-((2-(2-oxo-2-phenylethyl)but-3-en-1-yl)oxy)benzaldehyde (Figure 3, **3ae**)



The title compound was synthesized according to the general procedure with benzoic acid, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (20% ethyl acetate in hexanes) as a colorless oil (35.8 mg, 61% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.88 (s, 1H), 7.99–7.96 (m, 2H), 7.83–7.80 (m, 2H), 7.59–7.55 (m, 1H), 7.49–7.45 (m, 2H), 7.01–6.97 (m, 2H), 5.94 (ddd, *J* = 17.4, 10.4, 7.0 Hz, 1H), 5.23–5.15 (m, 2H), 4.16–4.08 (m, 2H), 3.38–3.32 (m, 2H), 3.16 (q, *J* = 9.4 Hz, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 198.6, 190.9, 163.9, 137.6, 137.1, 133.4, 132.1, 130.2, 128.8, 128.2, 123.0, 117.0, 115.0, 70.6, 39.9, 38.8. **HRMS** calculated for $C_{19}H_{18}O_3Na$ $[M+Na]^+$ 317.1154, found 317.1161. **IR** (ATR): 2926, 1682, 1597, 1576, 1500, 1252, 1213, 1157, 1001, 831, 752, 689, 648, 615 cm^{-1}.

3. Substrate Preparation

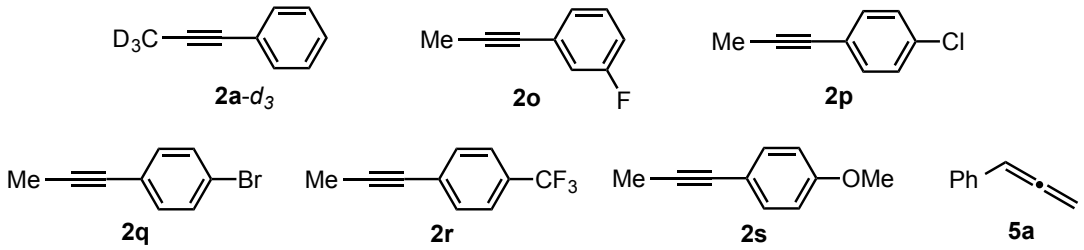
Preparation of β-Keto Acids



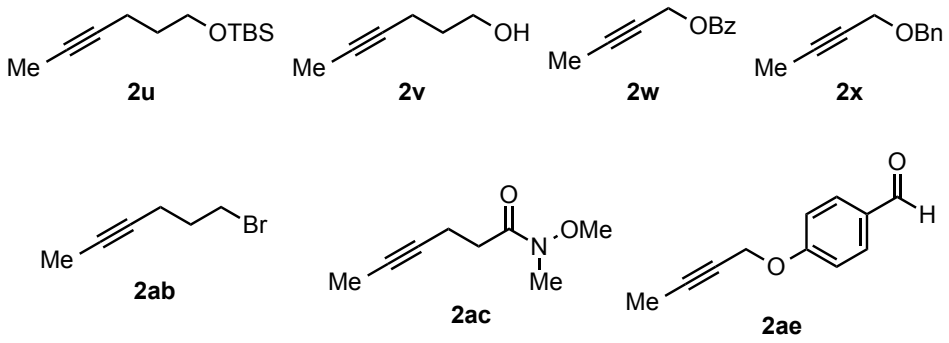
β-Keto acids **1a**-**1n** were prepared from the corresponding *β*-Keto esters according to literature procedure.[10]

Preparation of Alkynes and 1-Phenylallene

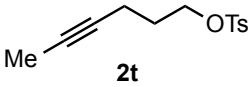
Alkynes **2a**-d_3 and **2o**-**2s** were prepared from the corresponding terminal alkyne according to literature procedure.[11] 1-Phenylallene was prepared from styrene according to literature procedure.[12]



[10] D. A. Evans, S. Mito, D. Seidel, *J. Am. Chem. Soc*. 2007, **129**, 11583.
[11] T. Fujihara, Y. Tani, K. Semba, J. Terao,Y. Tsuji, *Angew. Chem. Int. Ed.,* **2012,** *51,* 11487.
[12] T. Kippo, T. Fukuyama, I. Ryu, *Org. Lett.,* **2011,** *13,* 11487.

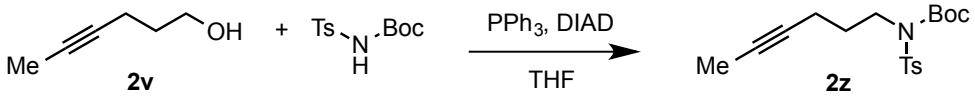


Alkyne **2u**[13] and **2ab**[14] were prepared according to literature procedure from **2v**. Alkyne **2v** was prepared according to literature procedure from 5-hexyn-1-ol.[15] Alkyne **2w**[16] and **2x**[17] were prepared according to literature procedure from 2-butyn-1-ol. Alkyne **2ac** was prepared according to literature procedure from hex-4-ynoic acid.[18] Alkyne **2ae** was prepared according to literature procedure from 4-hydroxy benzaldehyde.[19]



Prepared according to literature procedure from alcohol **2v** in 69% yield as a colorless oil.[20]

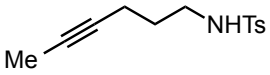
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.81–7.79 (m, 2H), 7.35–7.33 (m, 2H), 4.13 (t, *J* = 6.2 Hz, 2H), 2.45 (s, 3H), 2.18 (tq, *J* = 6.9, 2.4 Hz, 2H), 1.79 (quintet, *J* = 6.5 Hz, 2H), 1.68 (t, *J* = 2.6 Hz, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 144.8, 133.2, 129.9, 128.1, 123.1, 76.9, 69.3, 28.3, 21.8, 15.1, 3.5. **HRMS** calculated for $C_{13}H_{16}O_3SNa$ $[M+Na]^+$ 275.0718, found 275.0713. **IR** (ATR): 1597, 1439, 1357,1173, 1096, 970, 927, 813, 661, 574 cm^{-1}.



To a solution of alcohol **2v** (500 mg, 5.1 mmol, 1.0 equiv.) in THF (20 mL, 0.3 M) at room temperature under nitrogen was added N-[(tert-butoxy)carbonyl]-4-methylbenzenesulfonamide (1.52 g, 5.6 mmol, 1.1 equiv.) and triphenyl phosphine (1.47 g, 5.6 mmol, 1.1 equiv.). The resulting mixture was cooled to 0° C. Diisopropyl azodicarboxylate was added at 0° C, then the reaction mixture was allowed to warm to room temperature. After

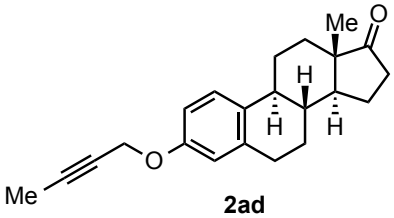
[13] H. Guo, G. A. O'Doherty, *Org. Lett.,* 2005, **7**, 3921.
[14] G. Zheng, S. P. Sumithran, A. G. Deaciuc, L. P. Dwoskin, P. A. Crooks, *Bioorg. Med. Chem. Lett.,* 2007, **24**, 6701.
[15] S. Hoetline, B. Haberlag, M. Tamm, J. Collatz, P. Mack, J. L. M. Steidle, M. Venes, S. Schulz, *Chem. Eur. J.,* 2014, **11**, 3183.
[16] F. R. Wuest, M. Berndt, *J. Label Compd. Radiopharm.,* 2006, **49**, 91.
[17] K. Semba, T. Fujihara, J. Terao, Y. Tsuji, *Chem. Eur. J.,* 2012, **14**, 4179.
[18] H. Kusama, K. Ishida, H. Funami, N. Iwasawa, *Angew. Chem. Int. Ed.,* 2008, **26**, 4903.
[19] K. Bera, S. Sarkar, S. Biswas, S. Maiti, U. Jana, *J. Org. Chem.,* 2011, **9**, 3539.
[20] F. Fang, M. Vogel, J. V. Hines, S. C. Bergmeier, *Org. Biomol. Chem.,* 2012, **10**, 3080.

stirring for 24 hours at room temperature, the crude reaction mixture was concentrated *in vacuo*. The resulting residue was purified by column chromatography using 30% ethyl acetate in hexanes to yield 2z as a white solid (1.5 g, 4.3 mmol, 84% yield). **^{1}H NMR** (400 MHz; $CDCl_3$): δ 7.78–7.75 (m, 2H), 7.29–7.27 (m, 2H), 3.88 (dd, *J* = 8.2, 6.8 Hz, 2H), 2.42 (s, 3H), 2.19 (tq, *J* = 7.1, 2.5 Hz, 2H), 1.91 (quintet, *J* = 7.4 Hz, 2H), 1.75 (t, *J* = 2.5 Hz, 3H), 1.33 (s, 9H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 151.0, 144.2, 137.5, 129.3, 127.9, 84.2, 77.9, 76.3, 46.6, 29.5, 28.0, 21.7, 16.4, 3.6. **HRMS** calculated for $C_{18}H_{25}NO_4SNa$ $[M+Na]^+$ 374.1402, found 374.1409. **IR** (ATR): 1716, 1355, 1288, 1157, 1085, 990, 670 cm^{-1}.



2aa

To a solution of alkyne **2z** (703 mg, 2 mmol, 1 equiv.) in DCM (10 mL, 0.2 M) at room temperature was added trifluoroacetic acid (3.1 mL, 40 mmol, 20 equiv.). After stirring for 45 minutes at room temperature, a saturated aqueous solution of $NaHCO_3$ was added. The aqueous layer was extracted with DCM. The combined organic layers were washed with brine, dried with anhydrous $MgSO_4$, filter, and concentrated *in vacuo*. The resulting residue was purified by column chromatography using 20% ethyl acetate in hexanes to yield **2aa** as a pale yellow solid (360 mg, 72% yield). Spectroscopic data were in accordance with the literature.[21]



2ad

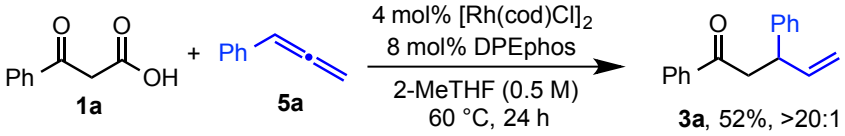
Prepared using a literature procedure from estrone and 1-bromo-2-butyne in 62% yield.[22] **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.21 (d, *J* = 8.2 Hz, 1H), 6.78 (dd, *J* = 8.6, 2.8 Hz, 1H), 6.70 (d, *J* = 2.8 Hz, 1H), 4.61 (q, *J* = 2.3 Hz, 2H), 2.92–2.88 (m, 2H), 2.50 (dd, *J* = 18.7, 8.4 Hz, 1H), 2.40 (ddd, *J* = 9.1, 7.0, 4.3 Hz, 1H), 2.29–2.22 (m, 1H), 2.19–1.93 (m, 4H), 1.86 (d, *J* = 4.7 Hz, 3H), 1.68–1.38 (m, 6H), 0.91 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 221.0, 156.0, 137.9, 132.7, 126.4, 115.0, 112.4, 83.6, 74.3, 56.4, 50.5, 48.1, 44.1, 38.4, 36.0, 31.7, 29.8, 26.6, 26.0, 21.7, 14.0, 3.9. **HRMS** calculated for $C_{22}H_{26}O_2Na$ $[M+Na]^+$ 345.1830, found 345.1836. **IR** (ATR): 2916, 1737, 1609, 1572, 1494, 1371, 1282, 1254, 1155, 1005, 869, 806, 776 cm^{-1}.

[21] F.-T. Luo, R.-T. Wang, *Tetrahedron Lett.,* 1992, **33**, 6835.

[22] P. Ramirez-Lopez, M. C. De La Torre, H. E. Montenegro, M. Asenjo, M. A. Sierra, *Org. Lett.,* 2008, **16**, 3555.

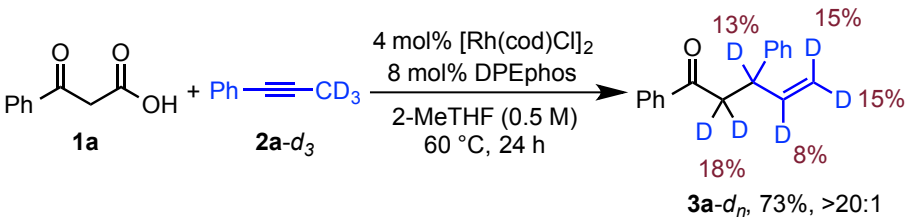
4. Mechanistic Experiments

Procedure for the Coupling of Benzoylacetic acid 1a and 1-Phenylallene 5a



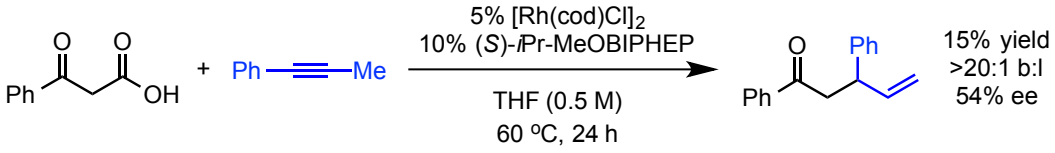
To a 1 dram vial equipped with a magnetic stir bar was added $[Rh(cod)Cl]_2$ (3.9 mg, 0.008 mmol), DPEphos (8.6 mg, 0.016 mmol), β-keto acid **1a** (0.40 mmol), 1-phenylallene **5a** (0.20 mmol), and 2-MeTHF (0.40 mL). The vial was then sealed with a Teflon-lined screw cap and heated to 60 °C for 24 hours. The resulting mixture was then cooled to room temperature. ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a colorless oil (24.6 mg, 52% yield).

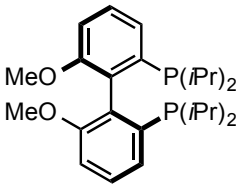
Procedure for the Coupling of Benzoylacetic acid 1a and Deuterated 1-Phenyl-1-propyne 2a-d_3

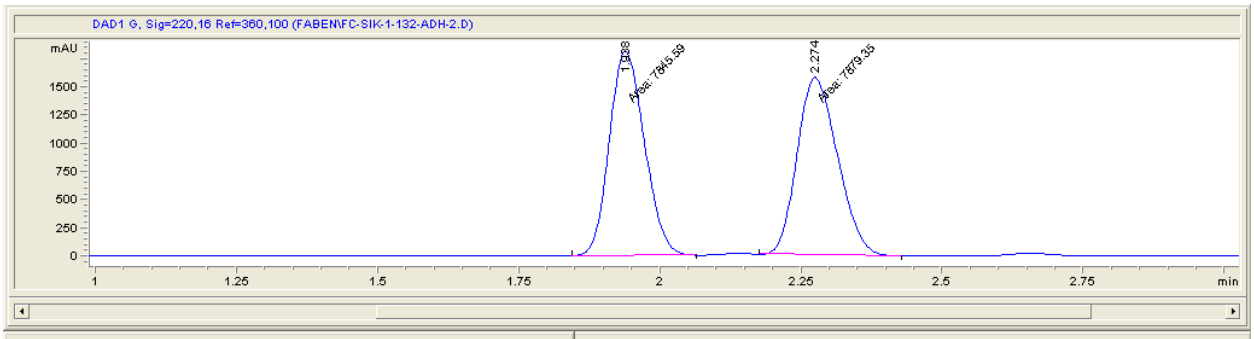


To a 1 dram vial equipped with a magnetic stir bar was added $[Rh(cod)Cl]_2$ (3.9 mg, 0.008 mmol), DPEphos (8.6 mg, 0.016 mmol), β-keto acid **1a** (0.40 mmol), deuterated 1-phenyl-1-propyne **2a**-d_3 (0.20 mmol), and 2-MeTHF (0.40 mL). The vial was then sealed with a Teflon-lined screw cap and heated to 60 °C for 24 hours. The resulting mixture was then cooled to room temperature. ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a colorless oil (34.3 mg, 73% yield). **^{1}H NMR** (400 MHz, CDCl3) δ 8.03 – 7.96 (m, 2H), 7.61 (t, J = 7.4 Hz, 1H), 7.51 (t, J = 7.7 Hz, 2H), 7.41 – 7.30 (m, 4H), 7.30 – 7.22 (m, 1H), 6.13 (ddd, J = 22.4, 10.4, 6.7 Hz, 0.92H), 5.18 – 5.03 (m, 1.43H), 4.22 (q, J = 6.9 Hz, 0.87H), 3.47 (qd, J = 16.6, 7.1 Hz, 1.65H). **^{13}C NMR** (101 MHz, CDCl3) δ 198.5, 143.4, 140.9, 133.2, 128.78, 128.78, 128.3, 127.9, 126.8, 123.5, 114.9, 44.7, 44.2. **^{2}H NMR** (61 MHz, $CDCl_3$) δ 6.24, 5.24, 4.28, 3.57.

5. Enantioselective Alkyne and β-keto acid Coupling







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Barcode	
Operator	FC
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Sampling Rate	0.0033 min (0.198 sec), 1023 datapoints

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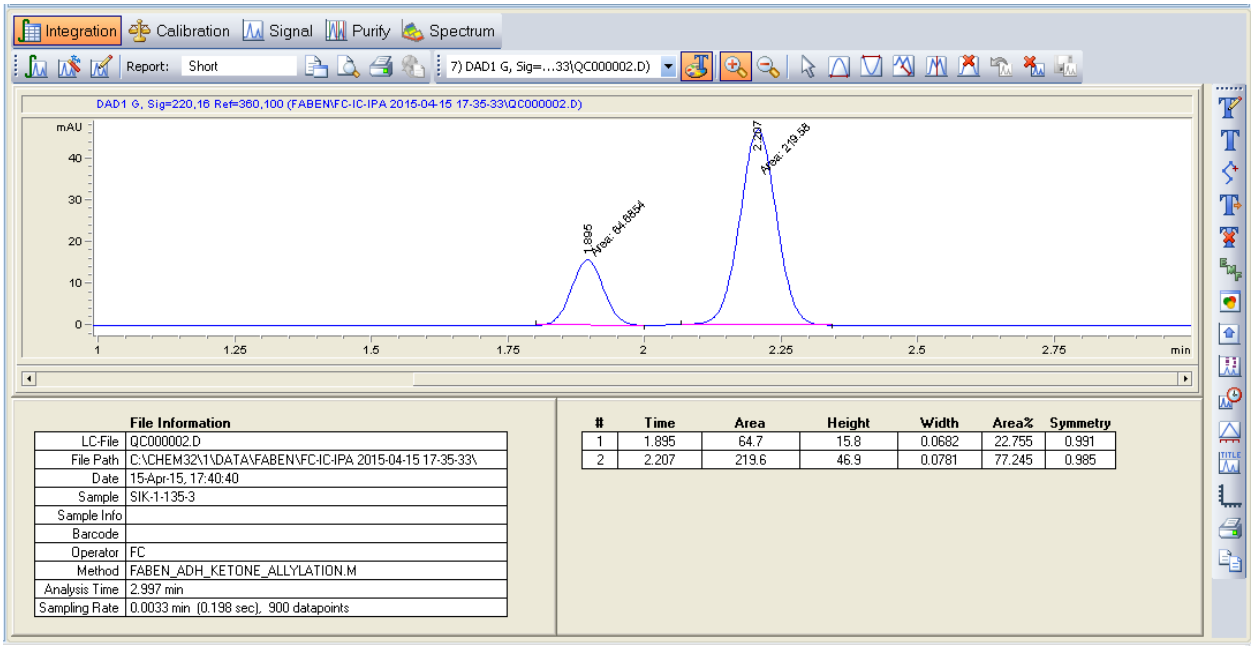

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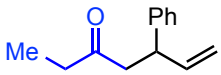
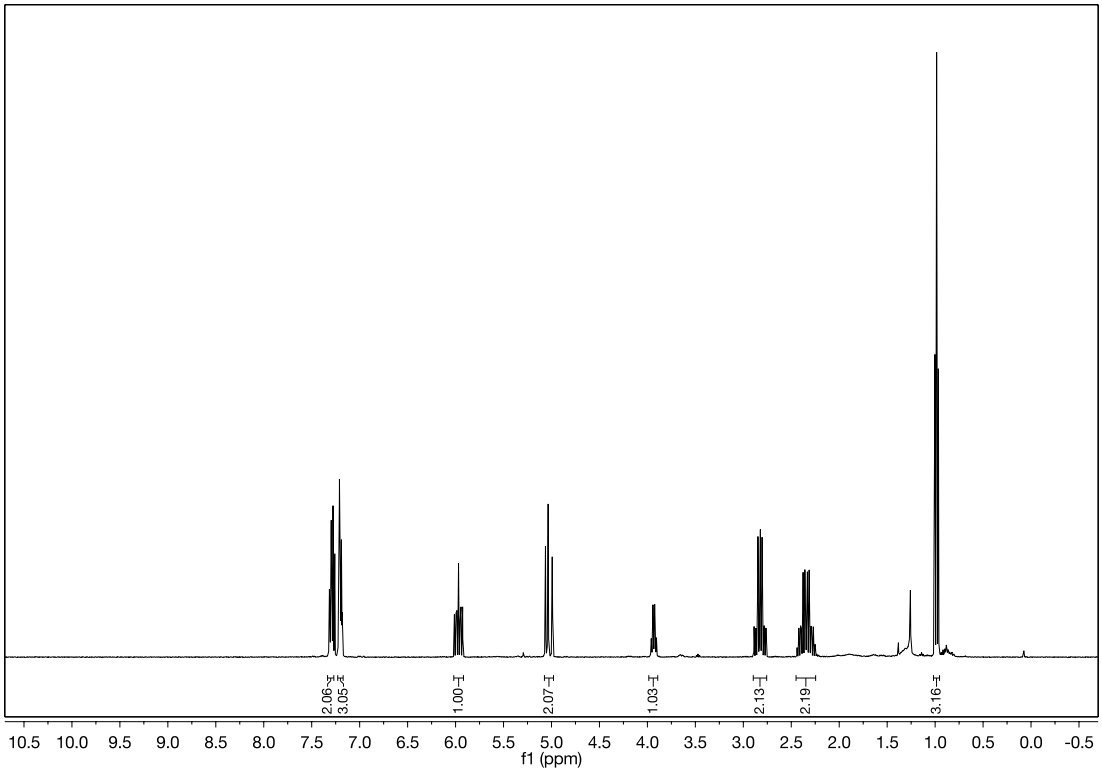
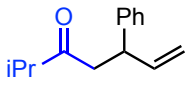
6. NMR Spectra

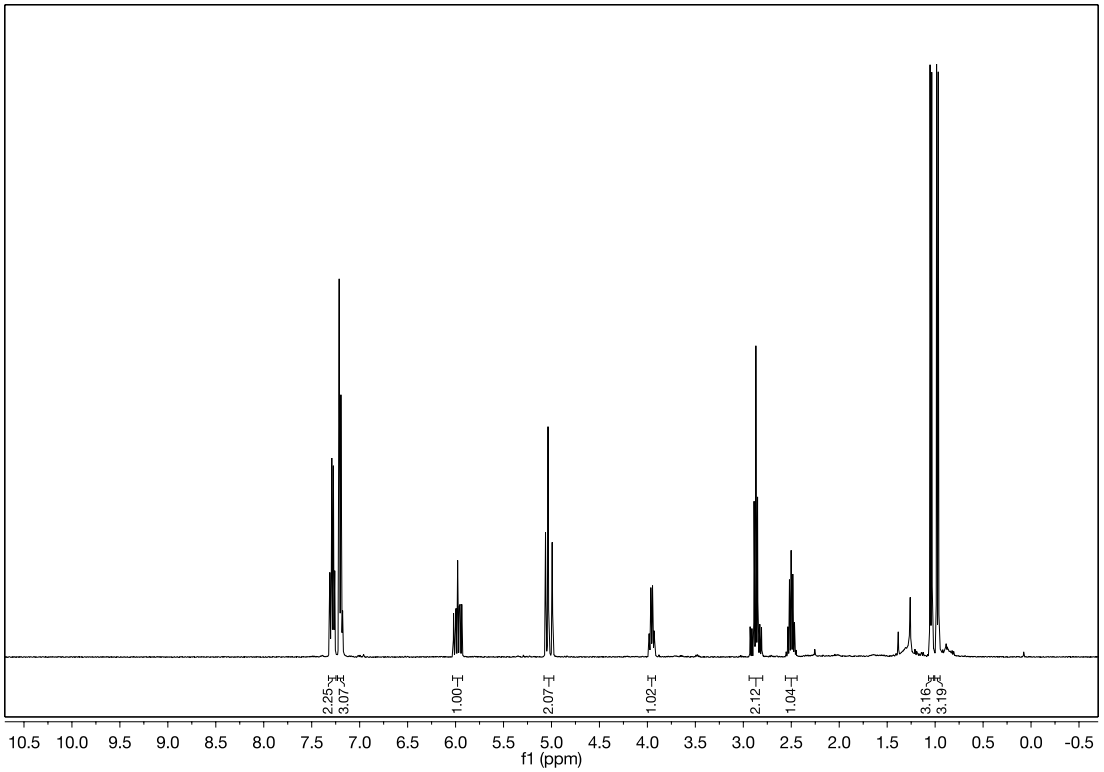


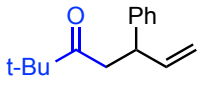
(**3b**)



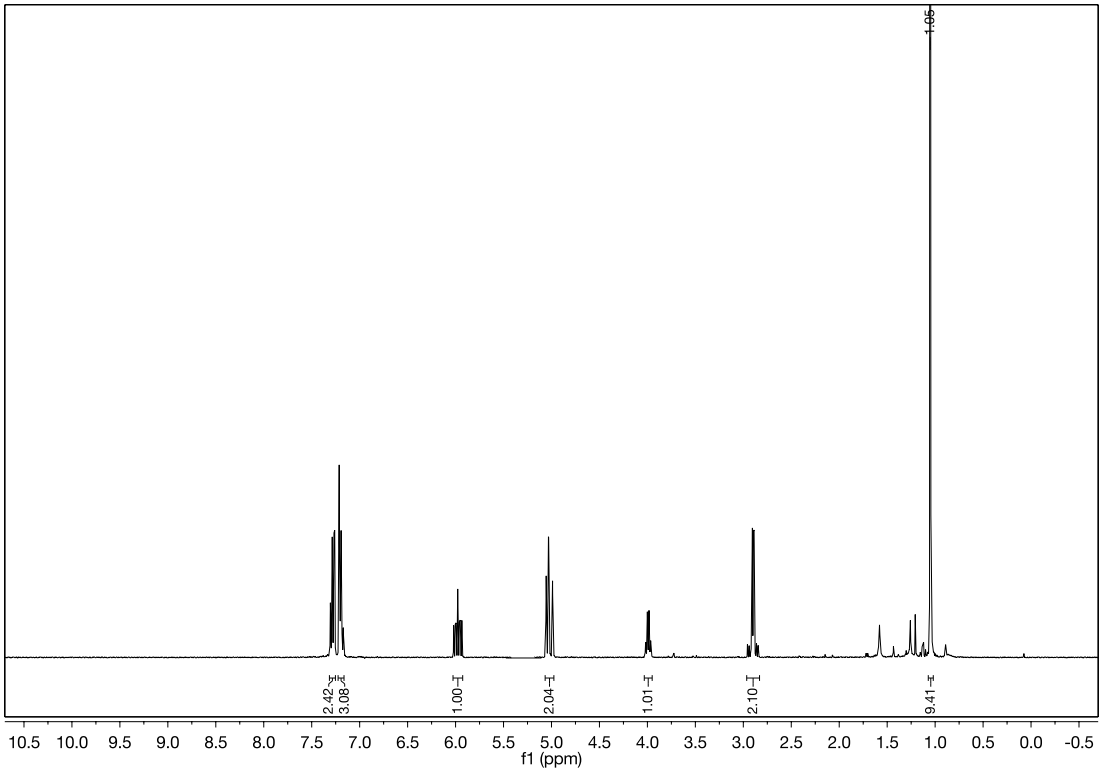

O
Ph
iPr

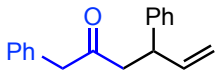
(**3c**)


2.25
3.07
1.00
2.07
1.02
2.12
1.04
3.16
3.19
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

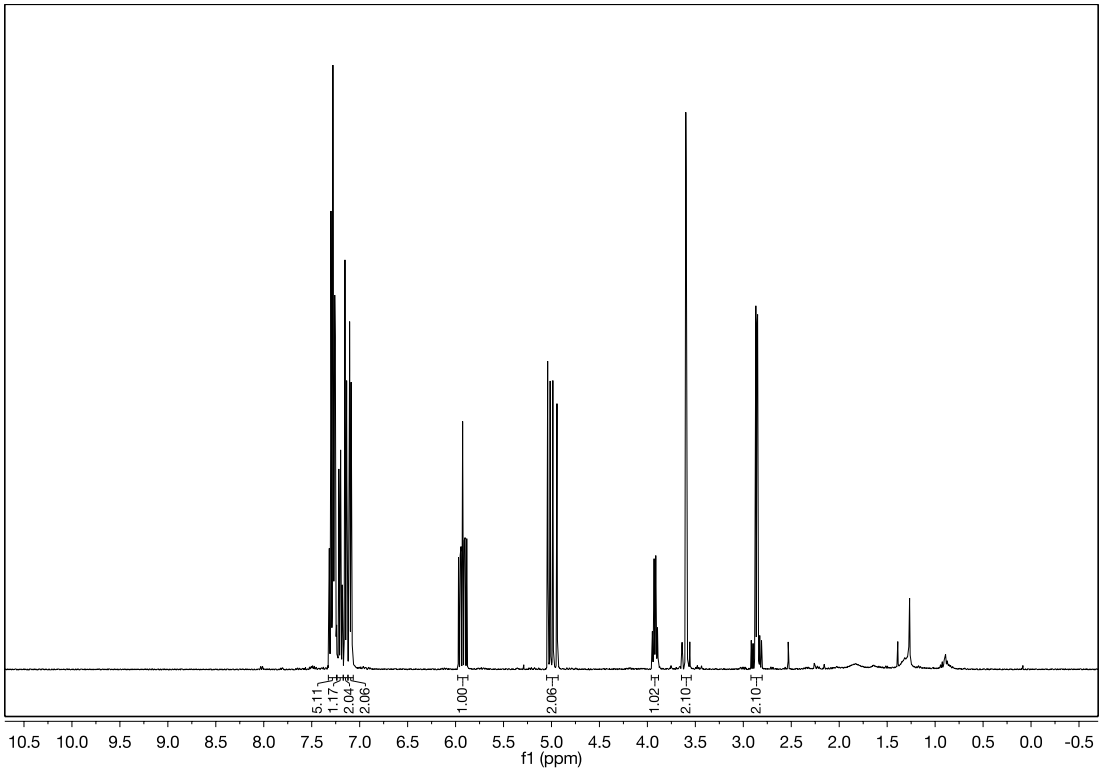

O
Ph
t-Bu

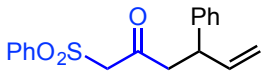
(**3d**)


1.86
2.42
3.08
1.00
2.04
1.01
2.10
9.41
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

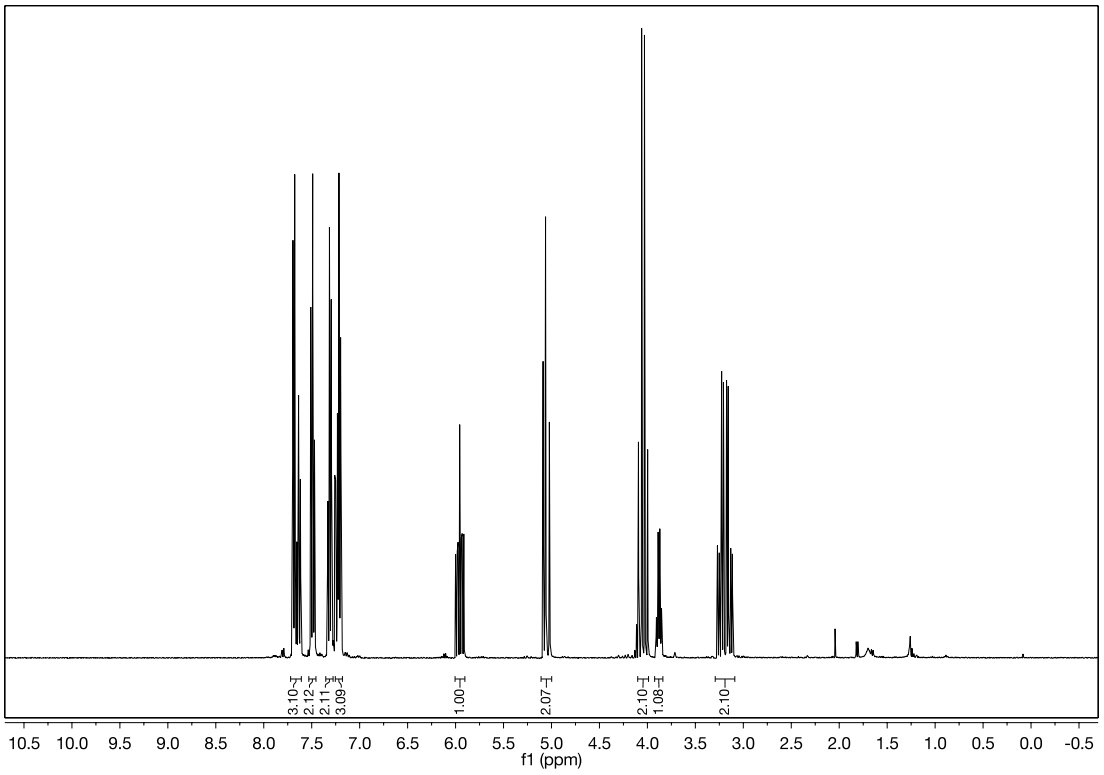

O
Ph
Ph

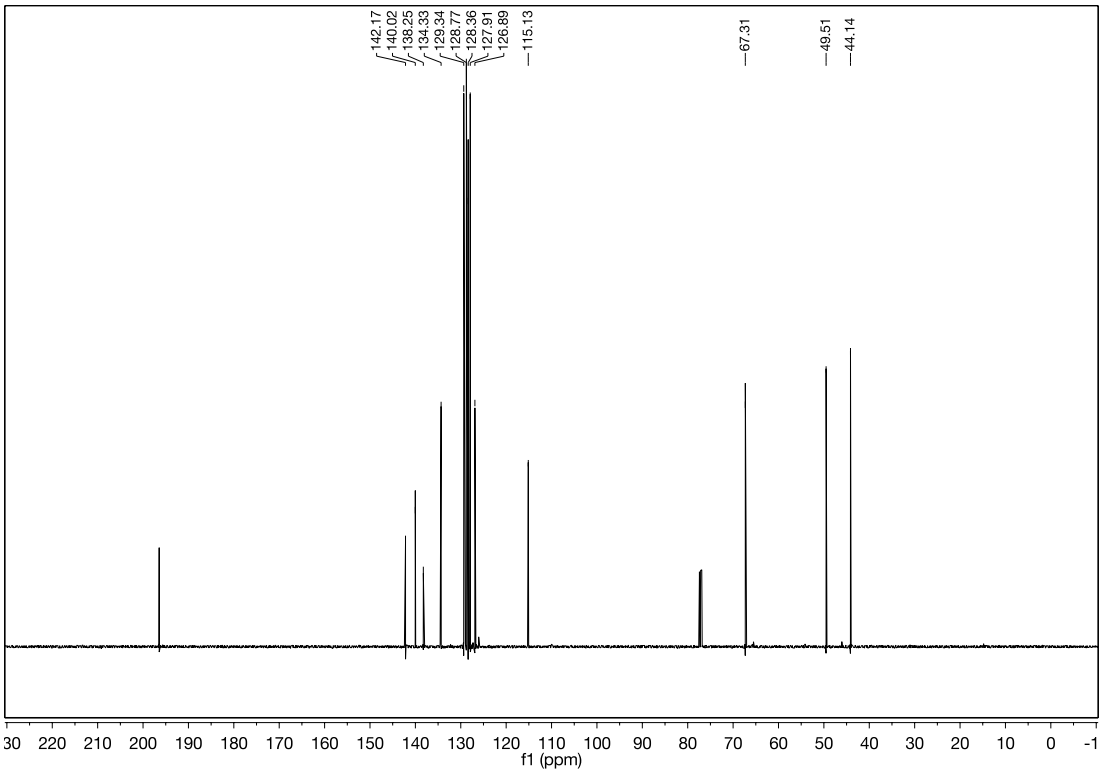
(**3e**)

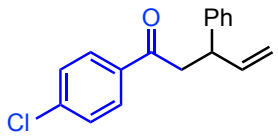

5.11
1.17
2.04
2.06
1.00
2.06
1.02
2.10
2.10
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)


O
Ph
PhO2S

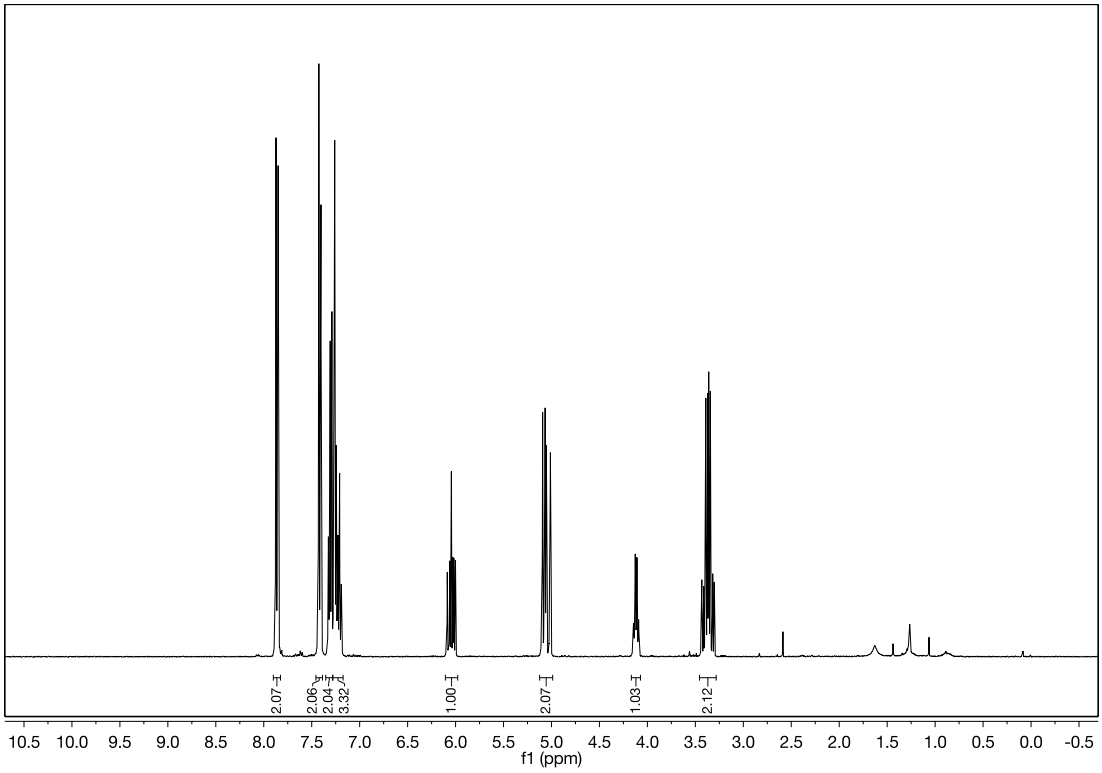
(**3f**)

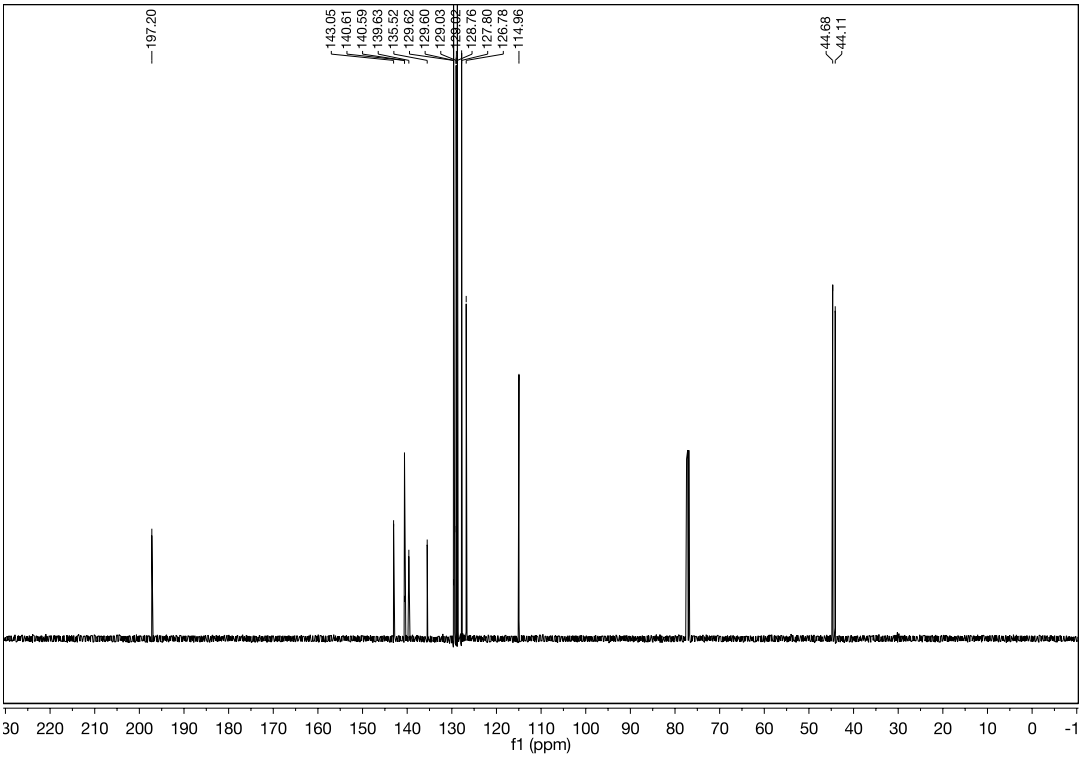

3.10
2.12
2.11
3.09
1.00
2.07
2.10
1.08
2.10
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

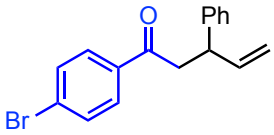

142.17
140.02
138.25
134.33
129.34
128.77
128.36
127.91
126.89
115.13
67.31
49.51
44.14
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


O
Ph
Cl

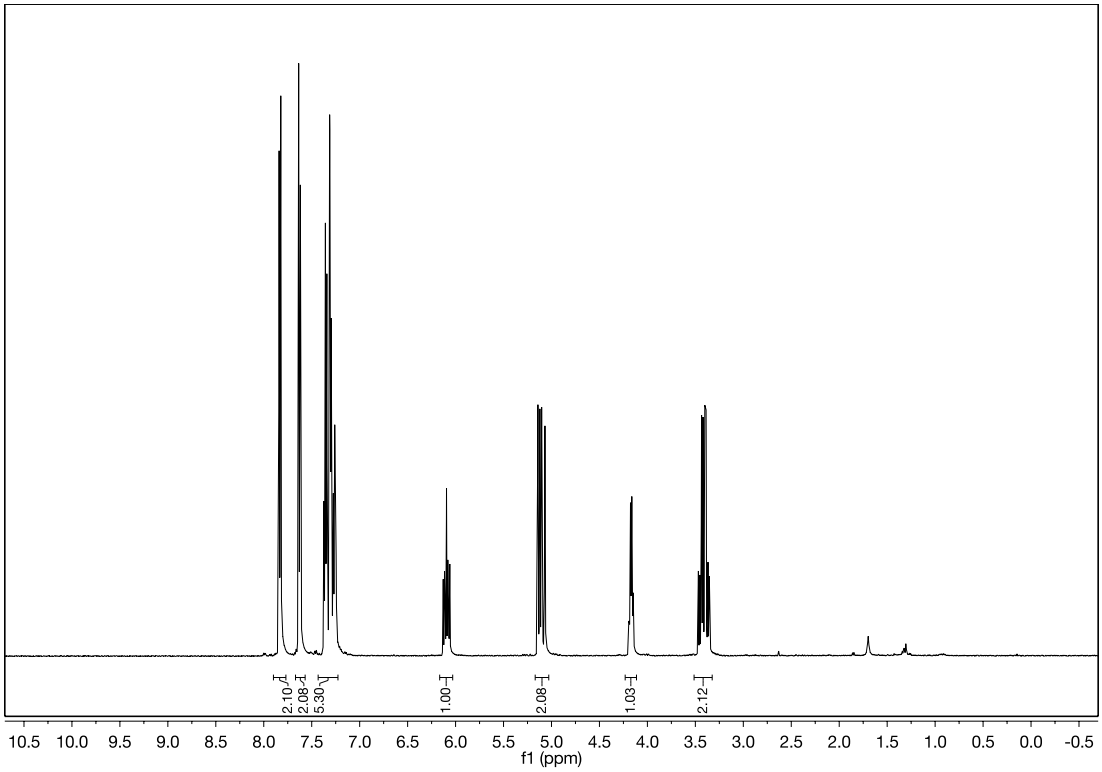
(3g)

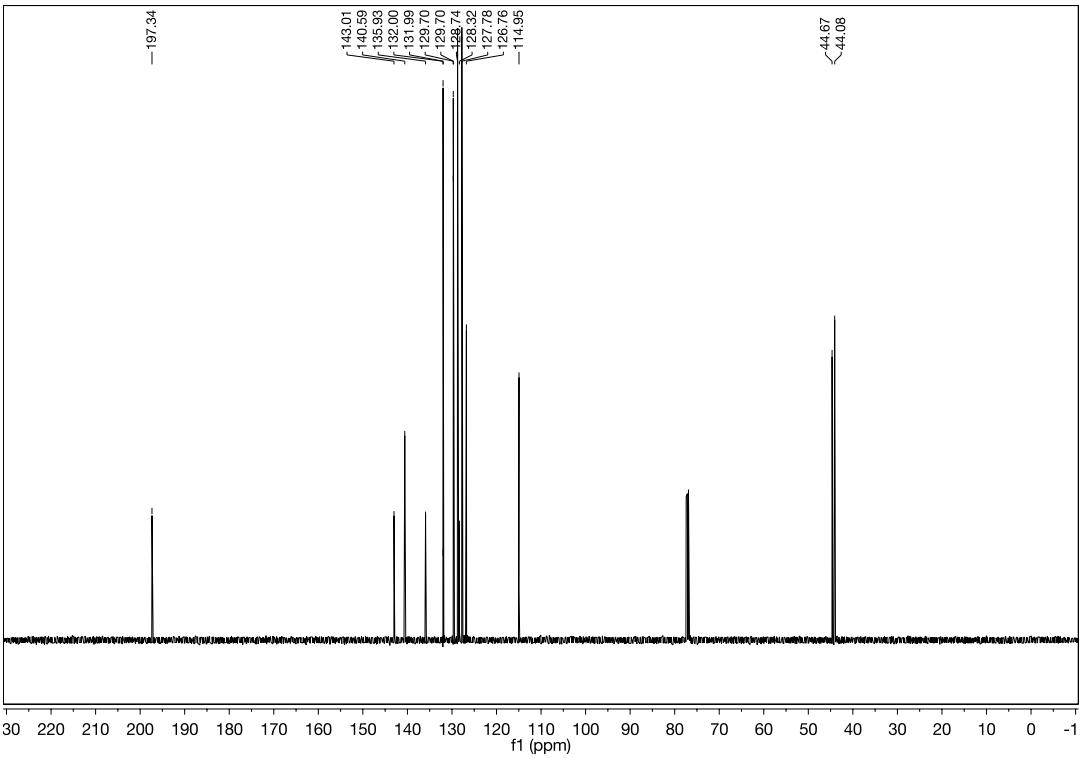

2.07
2.06
2.04
3.32
1.00
2.07
1.03
2.12
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

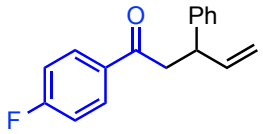

197.20
143.05
140.61
140.59
139.63
135.52
129.62
129.60
129.03
128.76
127.80
126.78
114.96
44.68
44.11
30 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


O
Ph
Br

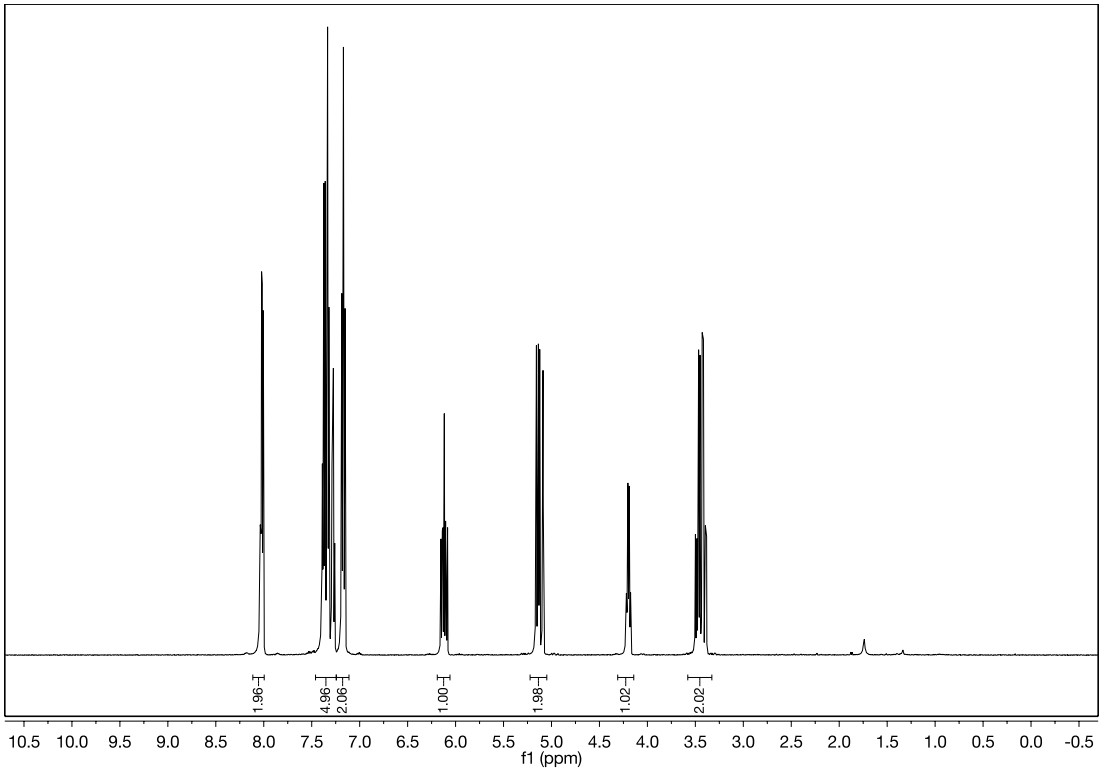
(**3h**)

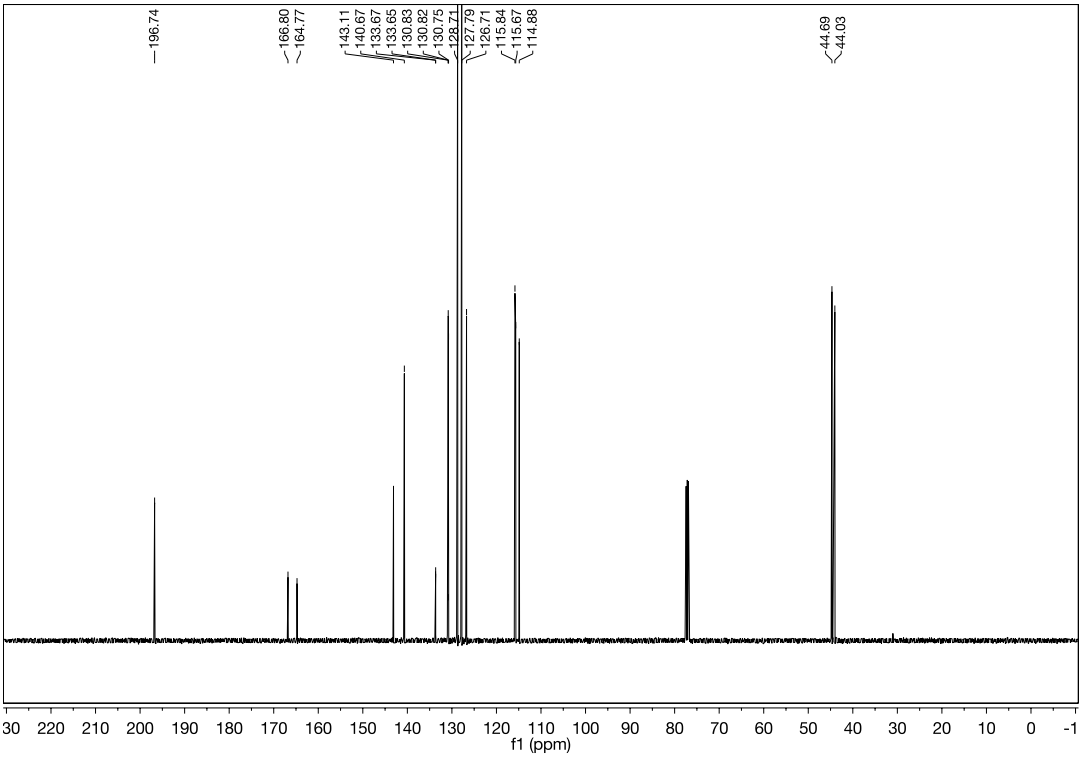

2.10
2.08
5.30
1.00
2.08
1.03
2.12
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

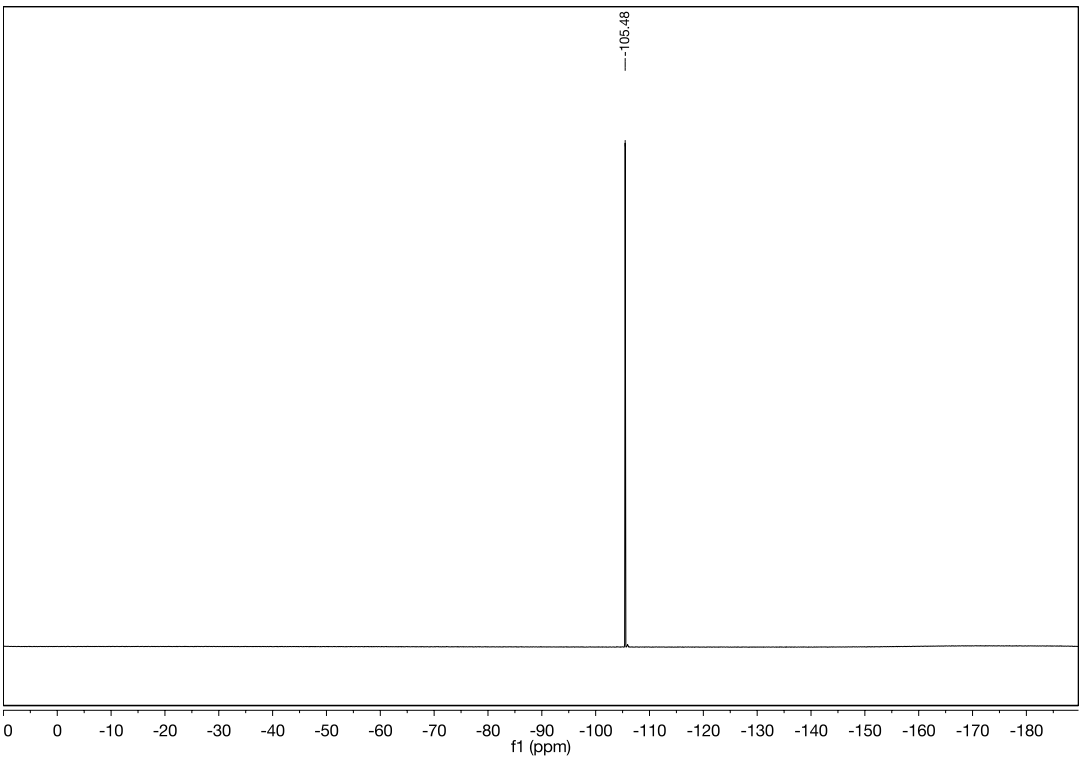

197.34
143.01
140.59
135.93
132.00
131.99
129.70
129.70
128.74
128.32
127.78
126.76
114.95
44.67
44.08
30 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)

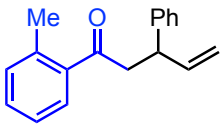

O
Ph
F

(**3i**)

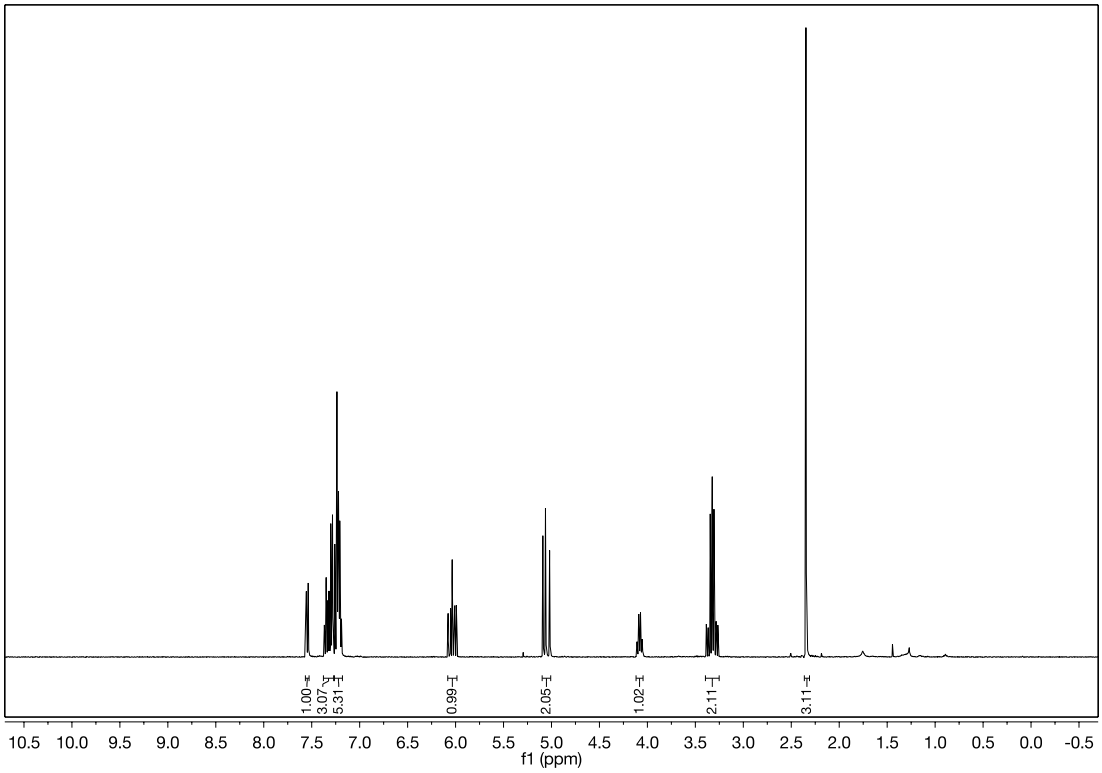

1.96
4.96
2.06
1.00
1.98
1.02
2.02
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

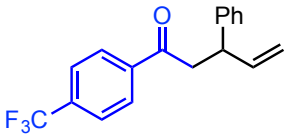

196.74
166.80
164.77
143.11
140.67
133.67
133.65
130.83
130.82
130.75
128.71
127.79
126.71
115.84
115.67
114.88
44.69
44.03
30 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


-105.48
0
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
-180
f1 (ppm)

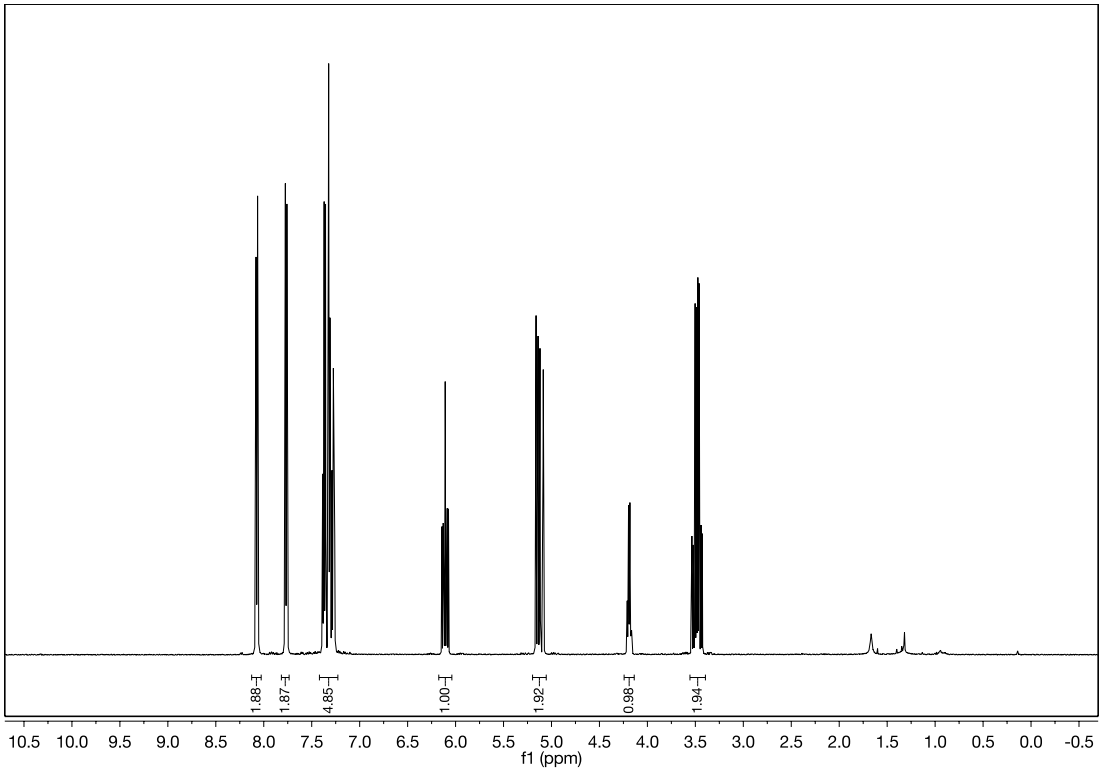

Me
O
Ph

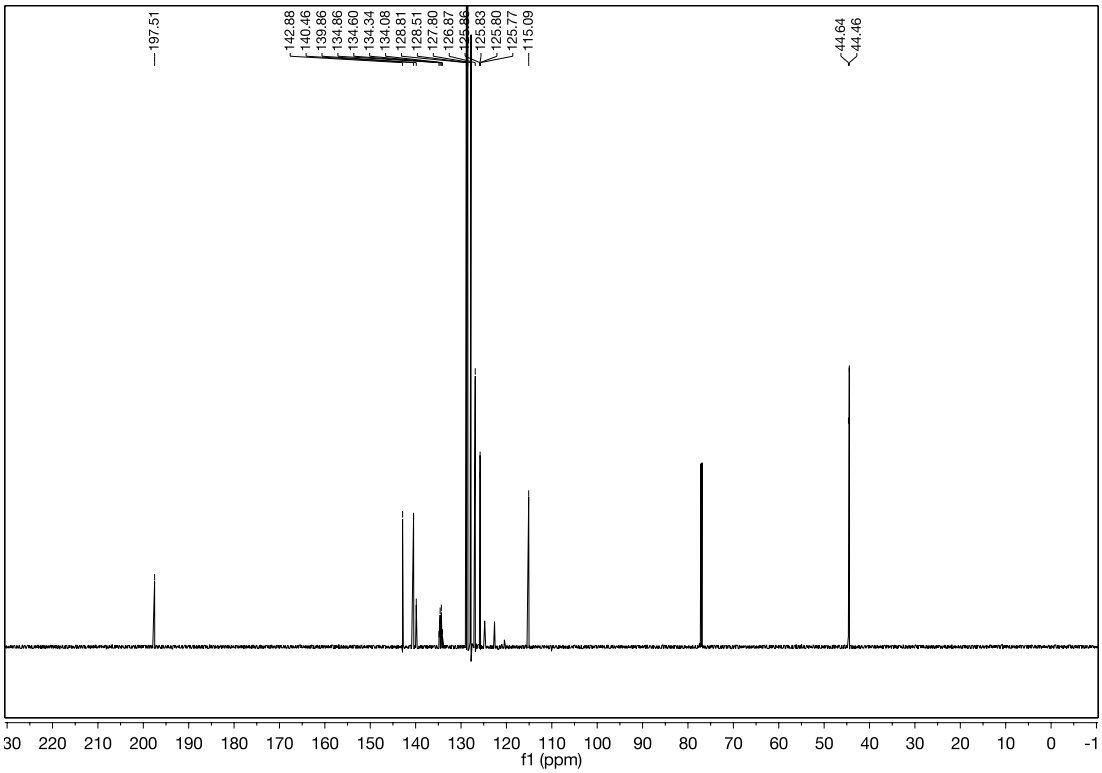
(**3j**)

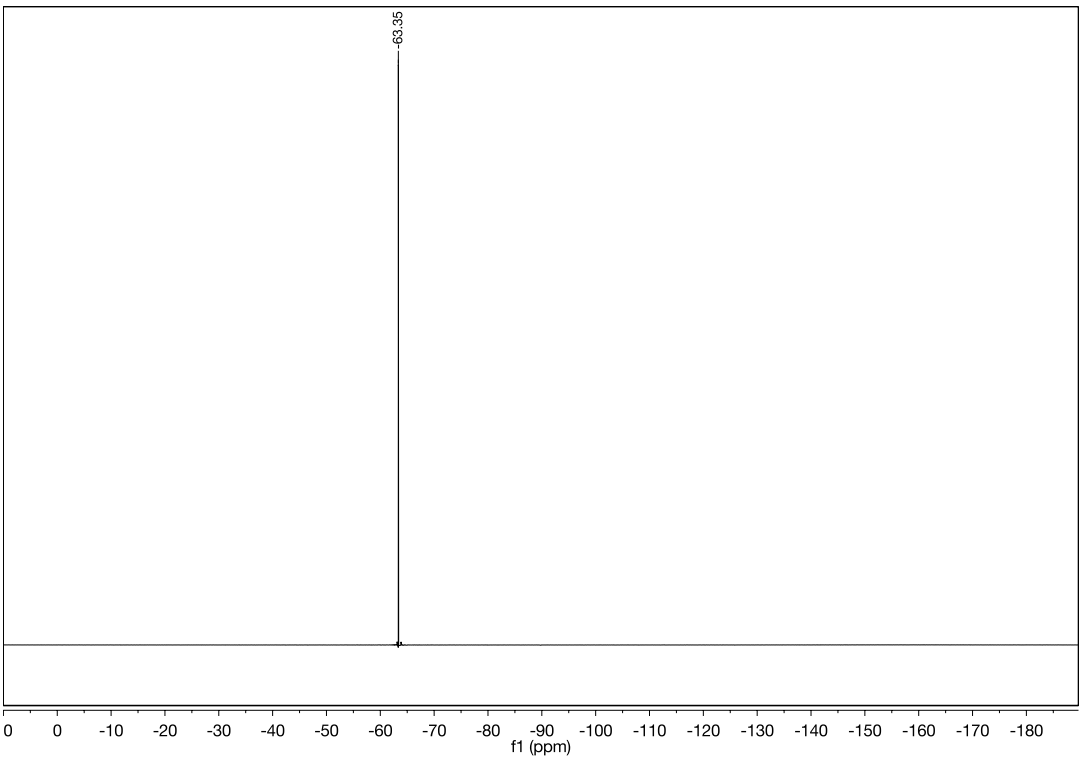

1.00
3.07
5.31
0.99
2.05
1.02
2.11
3.11
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

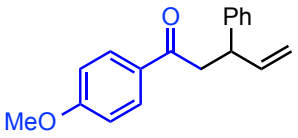

O
Ph
F3C

(**3k**)

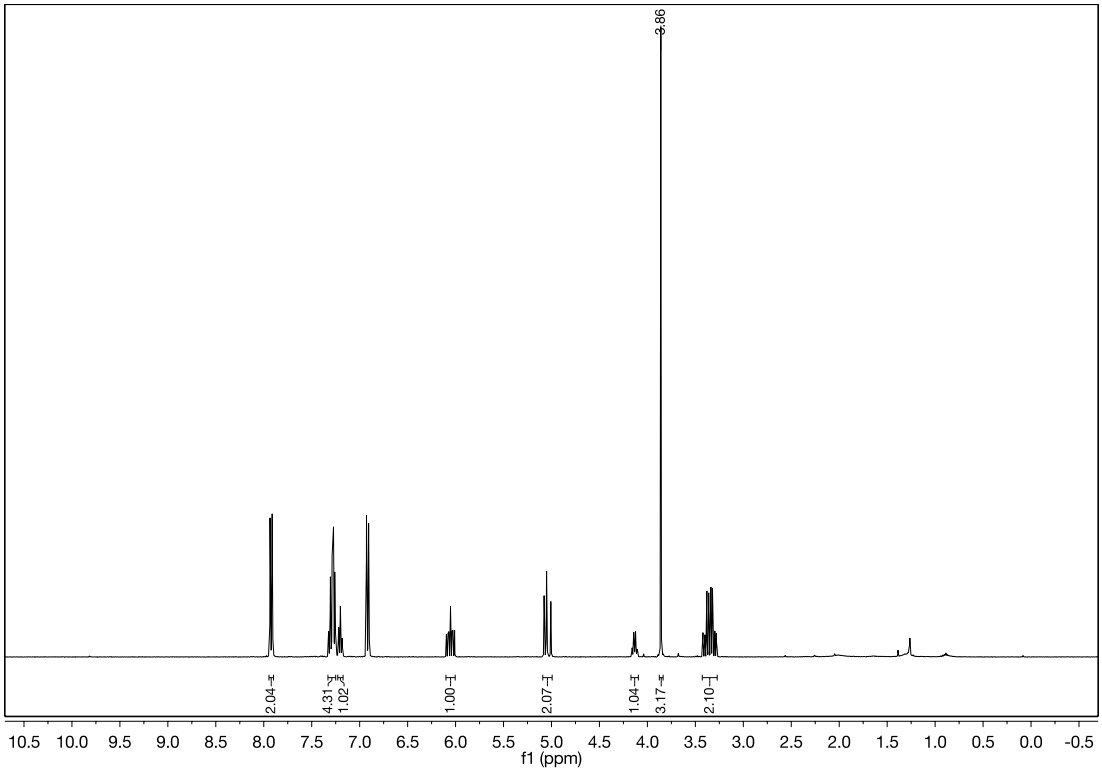

1.88
1.87
4.85
1.00
1.92
0.98
1.94
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

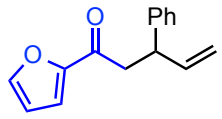

197.51
142.88
140.46
139.86
134.86
134.60
134.34
134.08
128.81
128.51
127.80
126.87
125.86
125.83
125.80
125.77
115.09
44.64
44.46
30 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


-63.35
0
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
-180
f1 (ppm)

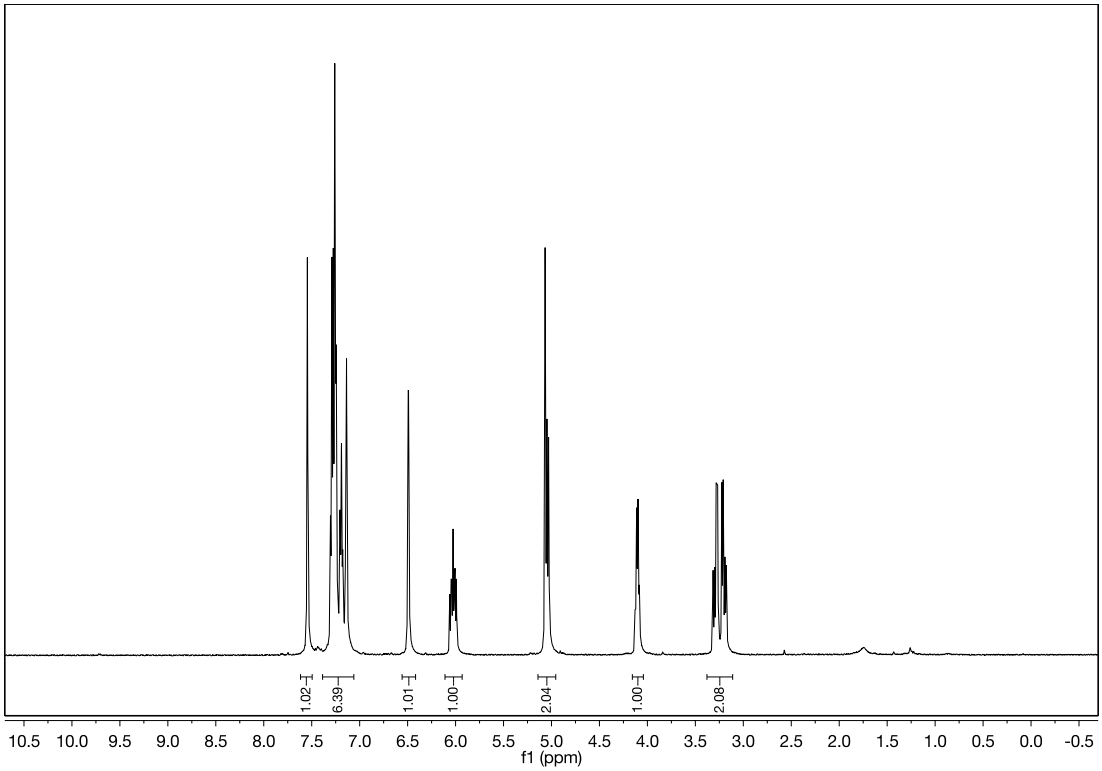

O
Ph
MeO

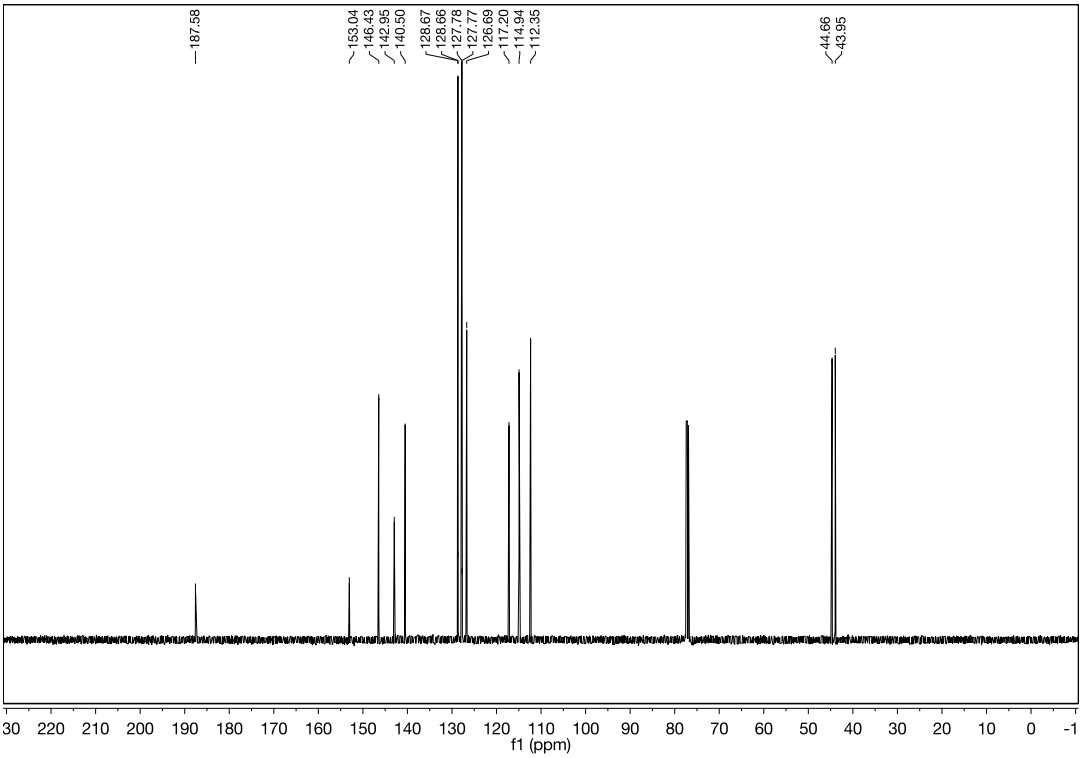
(**3l**)

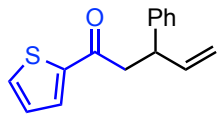

3.86
2.04
4.31
1.02
1.00
2.07
1.04
3.17
2.10
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)


O
Ph
O

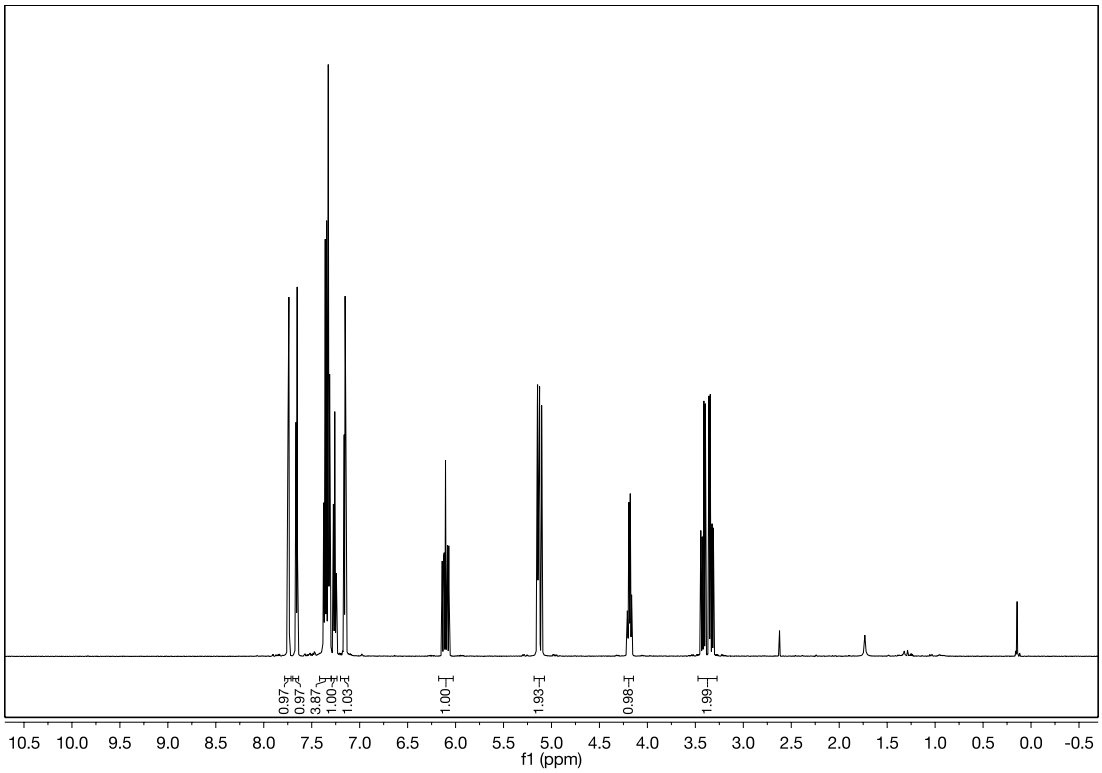
(**3m**)

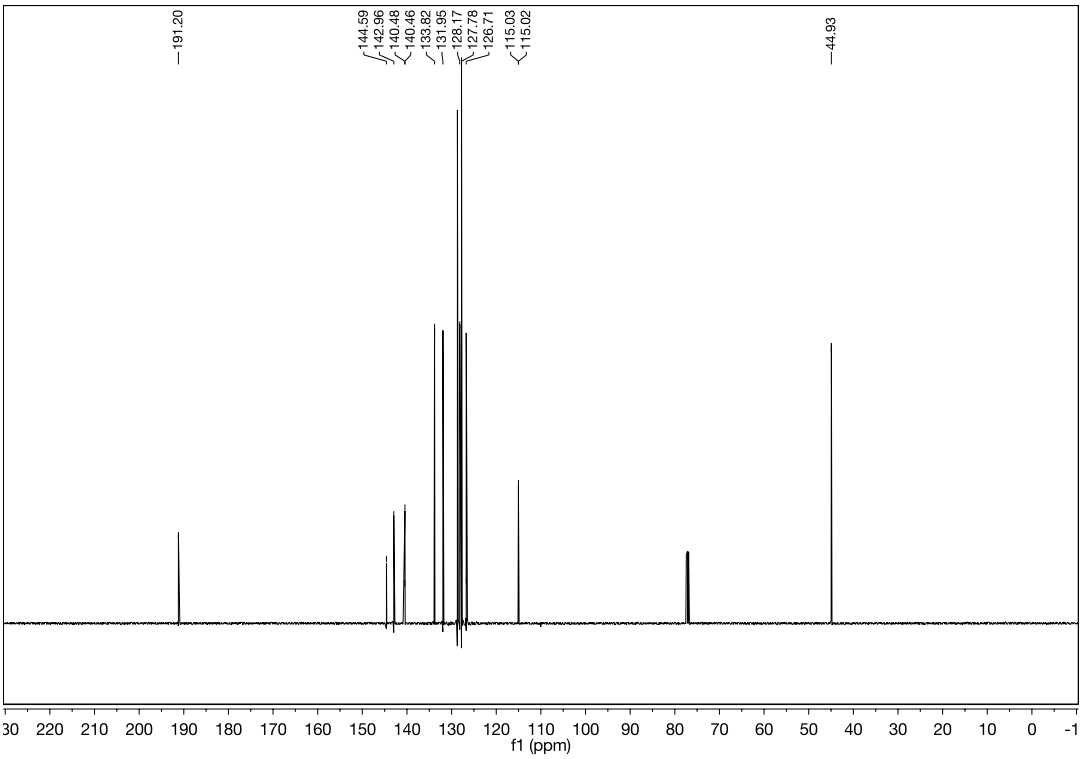

1.02
6.39
1.01
1.00
2.04
1.00
2.08
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

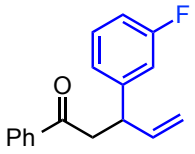

187.58
153.04
146.43
142.95
140.50
128.67
128.66
127.78
127.77
126.69
117.20
114.94
112.35
44.66
43.95
30 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


O
Ph
S

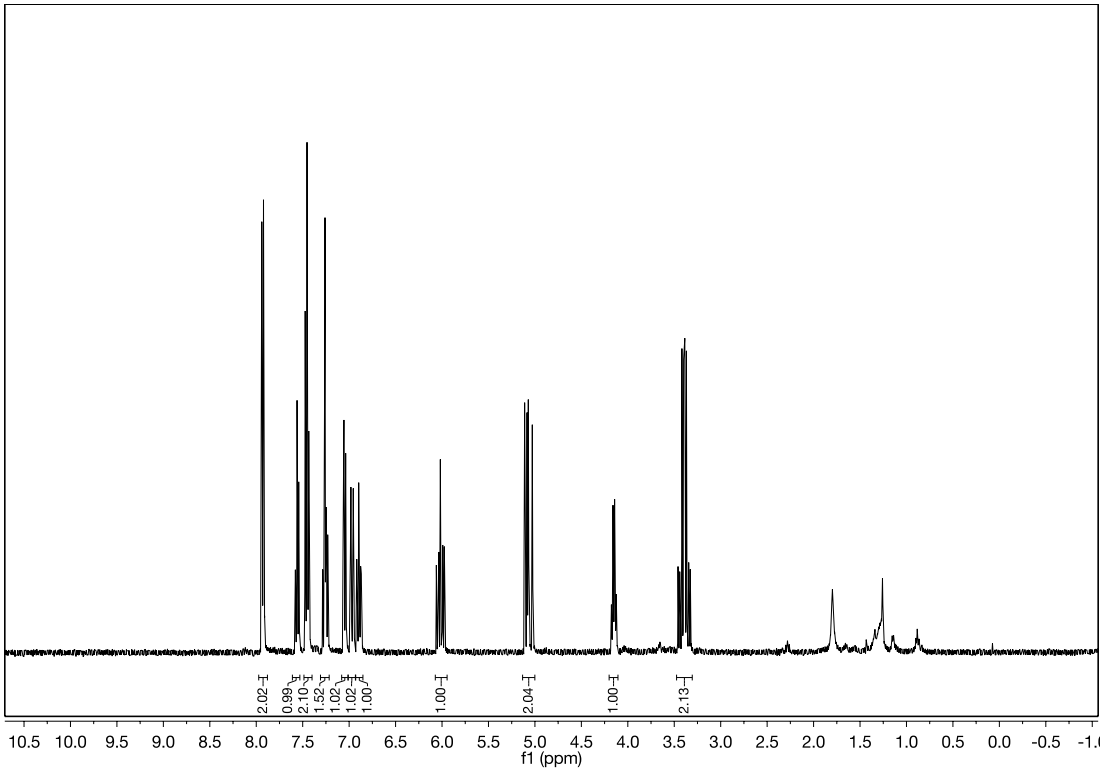
(**3n**)

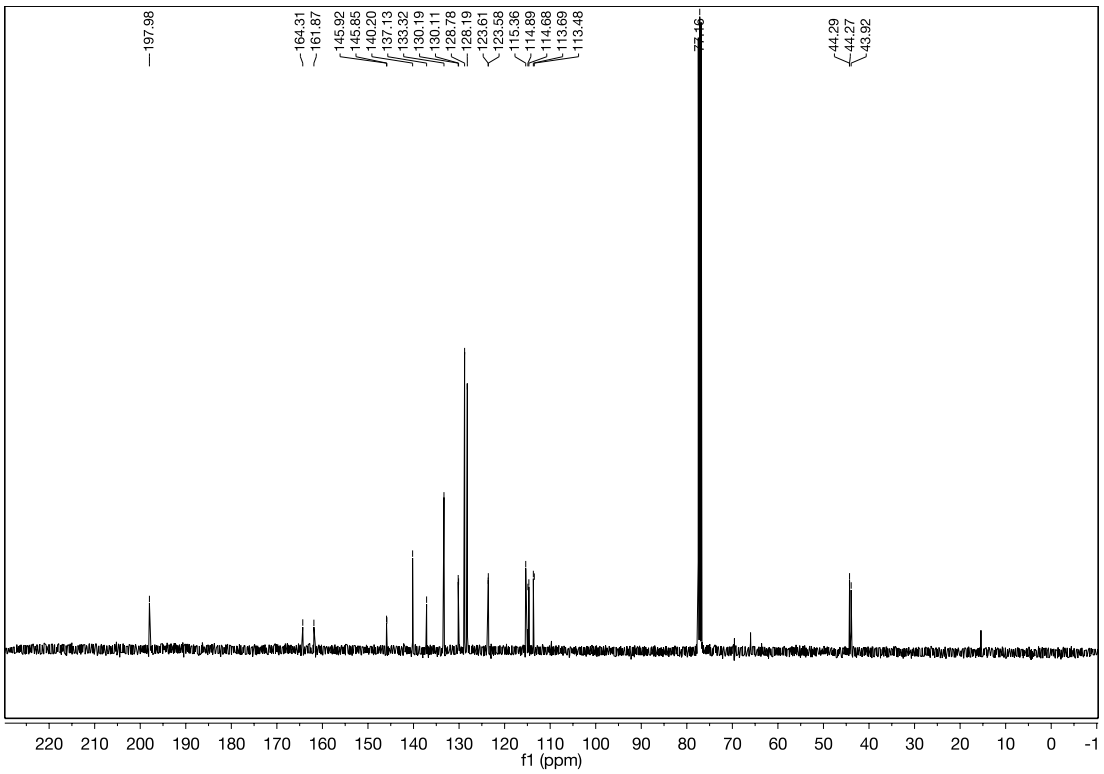

0.97
0.97
3.87
1.00
1.03
1.00
1.93
0.98
1.99
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

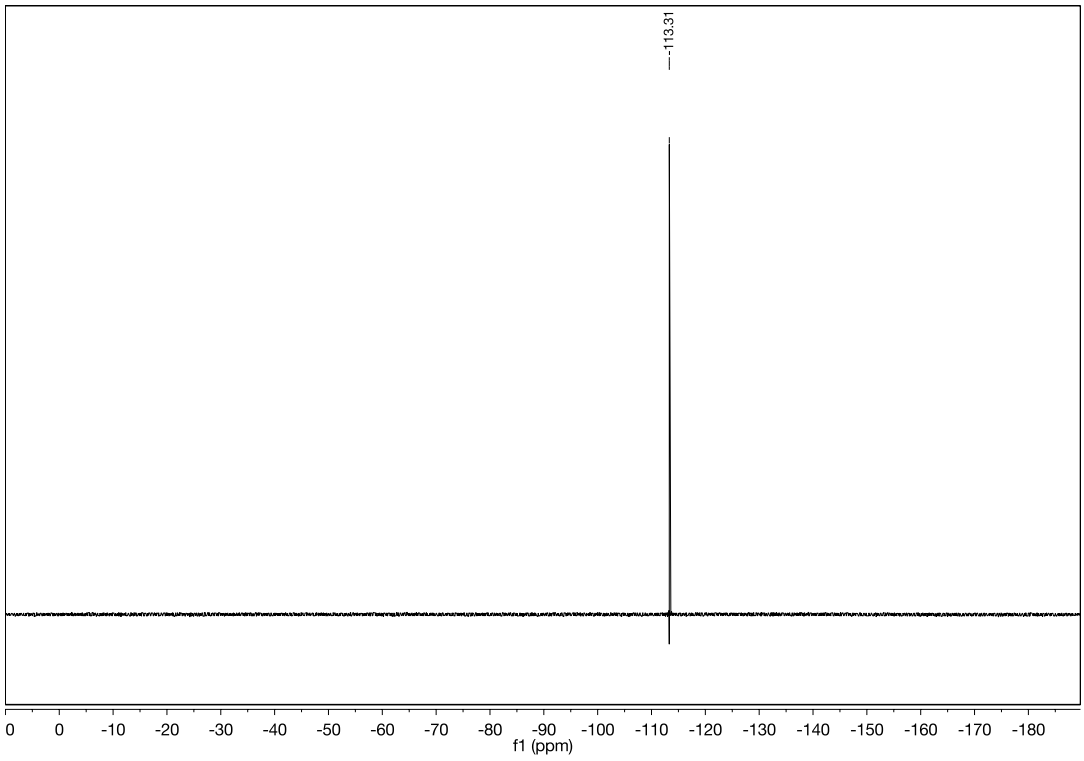

191.20
144.59
142.96
140.48
140.46
133.82
131.95
128.17
127.78
126.71
115.03
115.02
44.93
30 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)

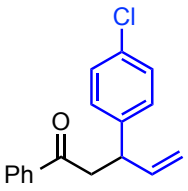

F
O
Ph

(**3o**)

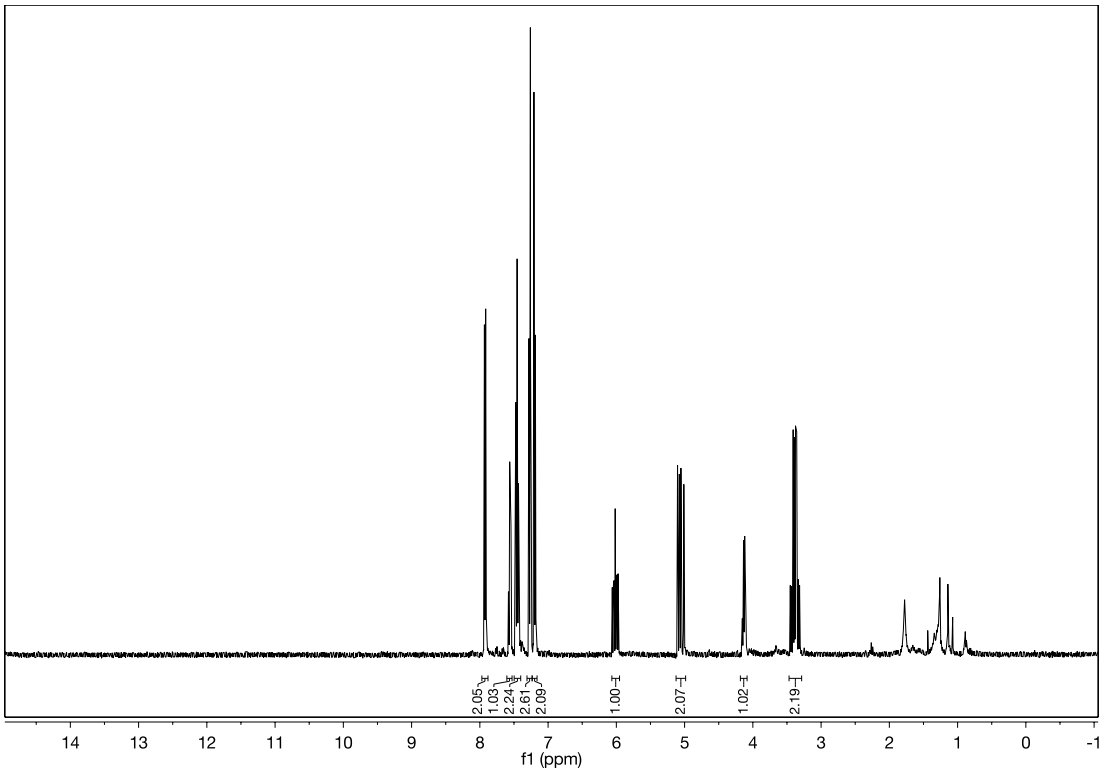

2.02
0.99
2.10
1.52
1.02
1.02
1.00
1.00
2.04
1.00
2.13
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

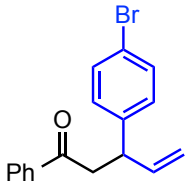

197.98
164.31
161.87
145.92
145.85
140.20
137.13
133.32
130.19
130.11
128.78
128.19
123.61
123.58
115.36
114.89
114.68
113.89
113.48
77.16
44.29
44.27
43.92
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)


-113.31
0 0 -10 -20 -30 -40 -50 -60 -70 -80 -90 -100 -110 -120 -130 -140 -150 -160 -170 -180
f1 (ppm)

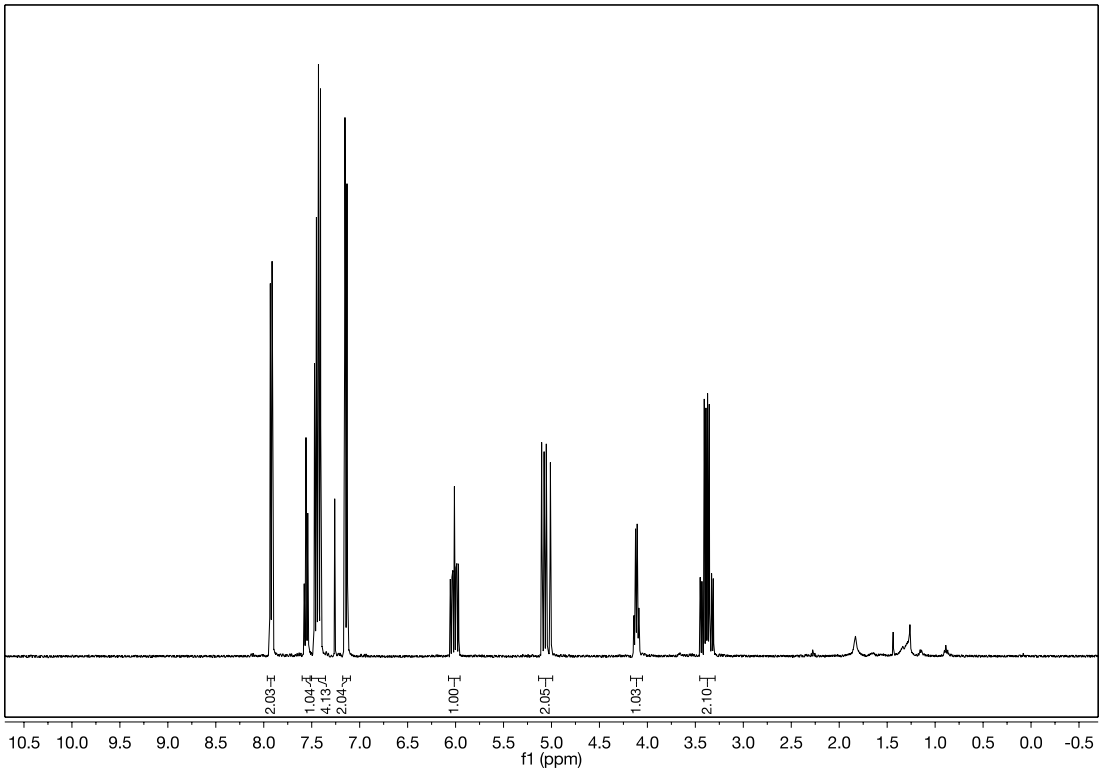

Cl
O
Ph

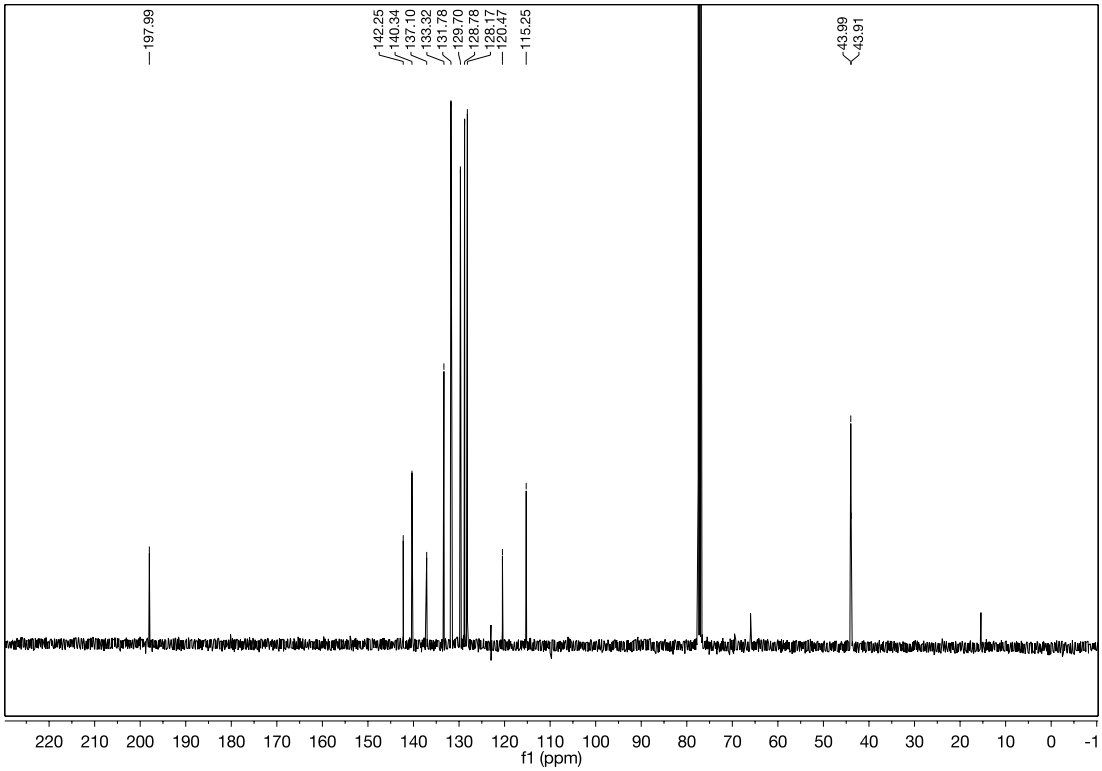
(**3p**)

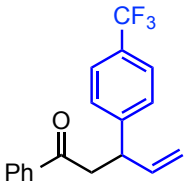

2.05
1.03
2.24
2.61
2.09
1.00
2.07
1.02
2.19
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
f1 (ppm)


Br
O
Ph

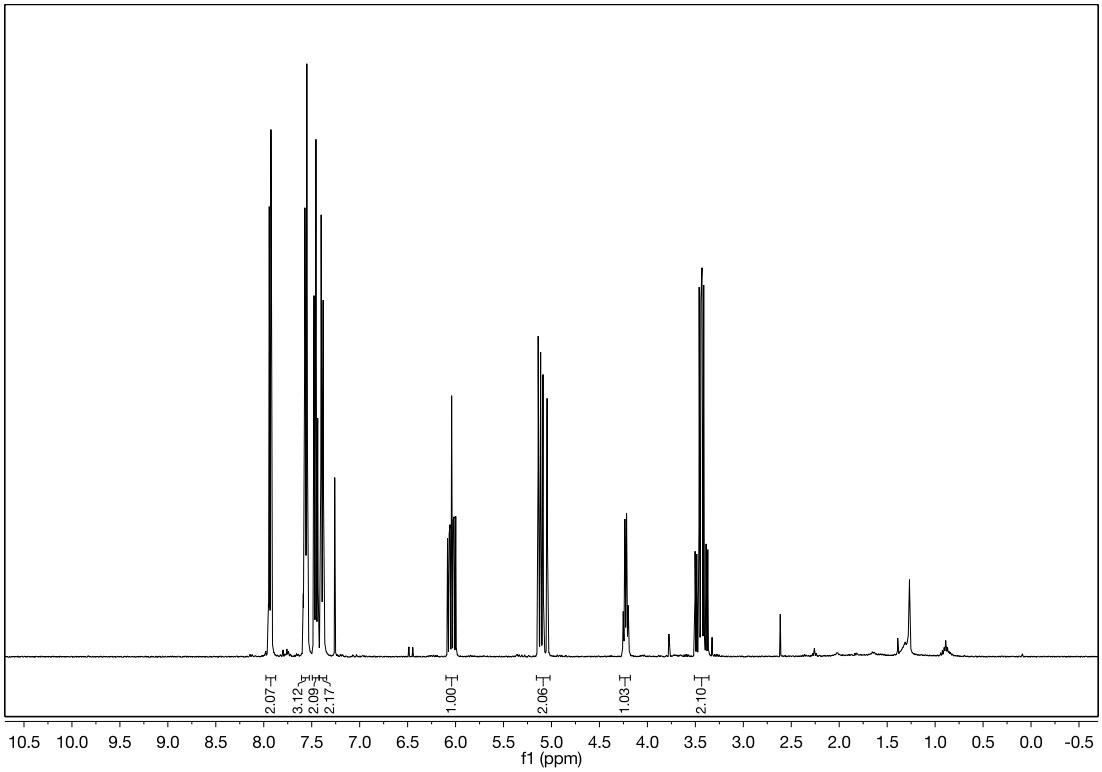
(**3q**)

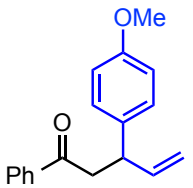

2.03
1.04
4.13
2.04
1.00
2.05
1.03
2.10
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)


197.99
142.25
140.34
137.10
133.32
131.78
129.70
128.78
128.17
120.47
115.25
43.99
43.91
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)

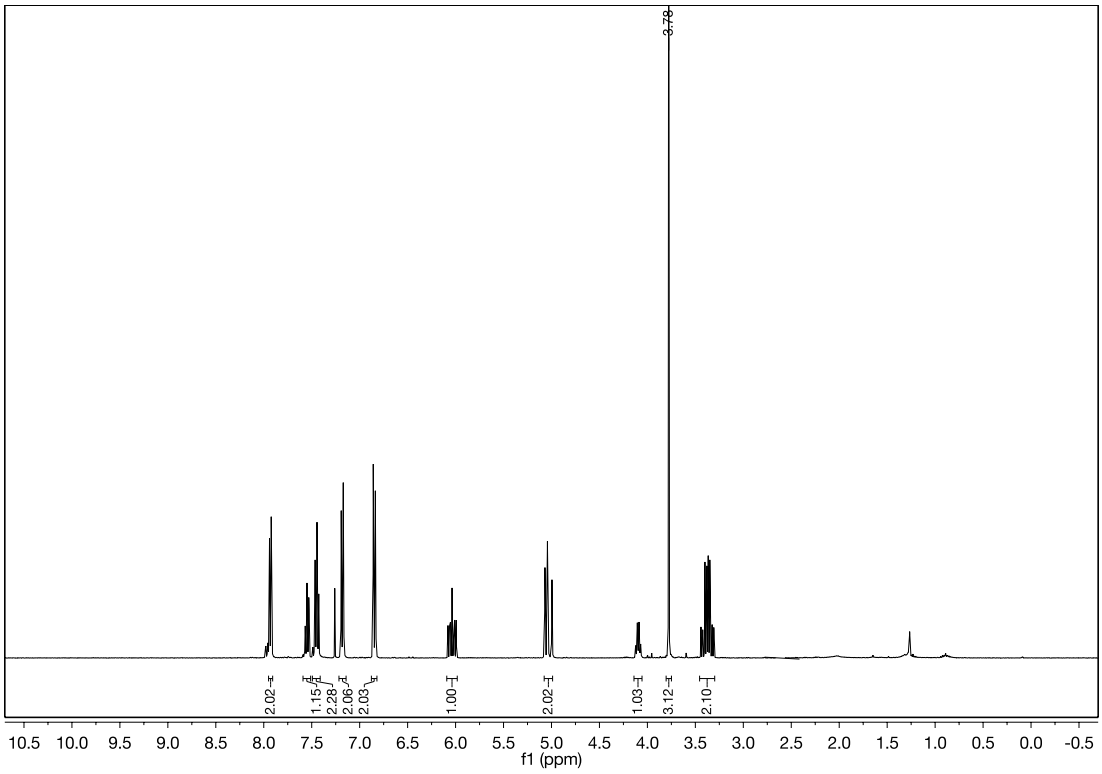

CF3
O
Ph

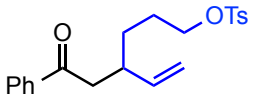
(**3r**)


2.07
3.12
2.09
2.17
1.00
2.06
1.03
2.10
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

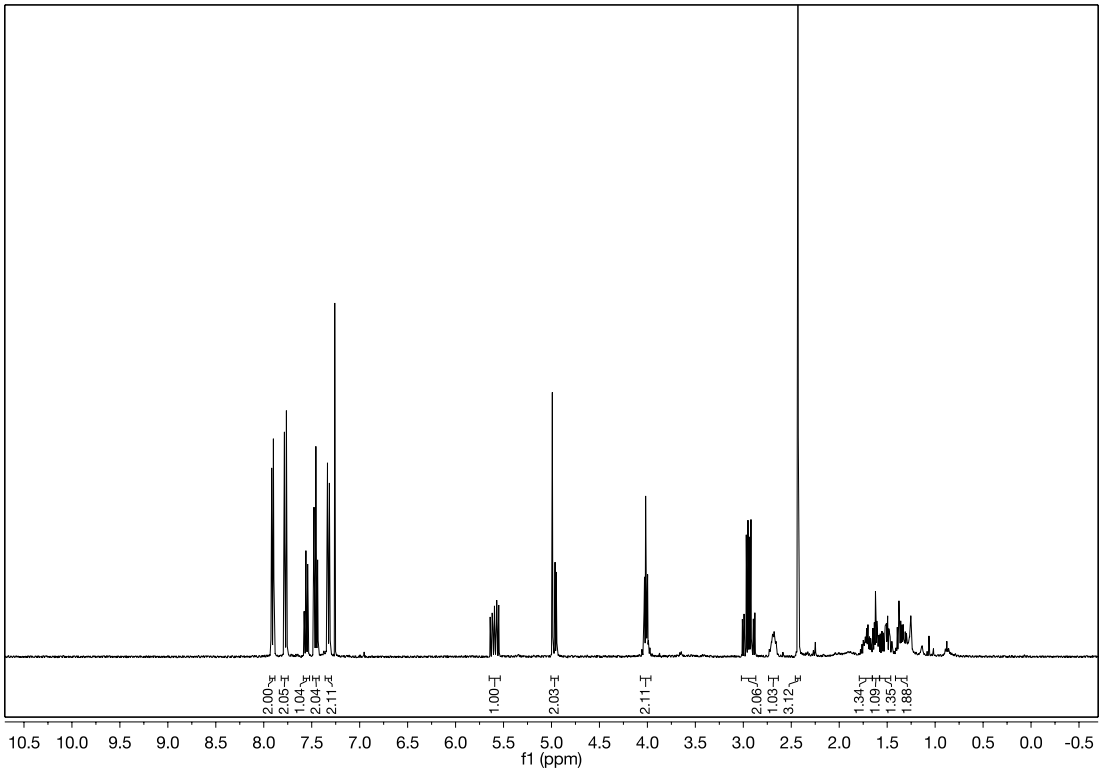

OMe
O
Ph

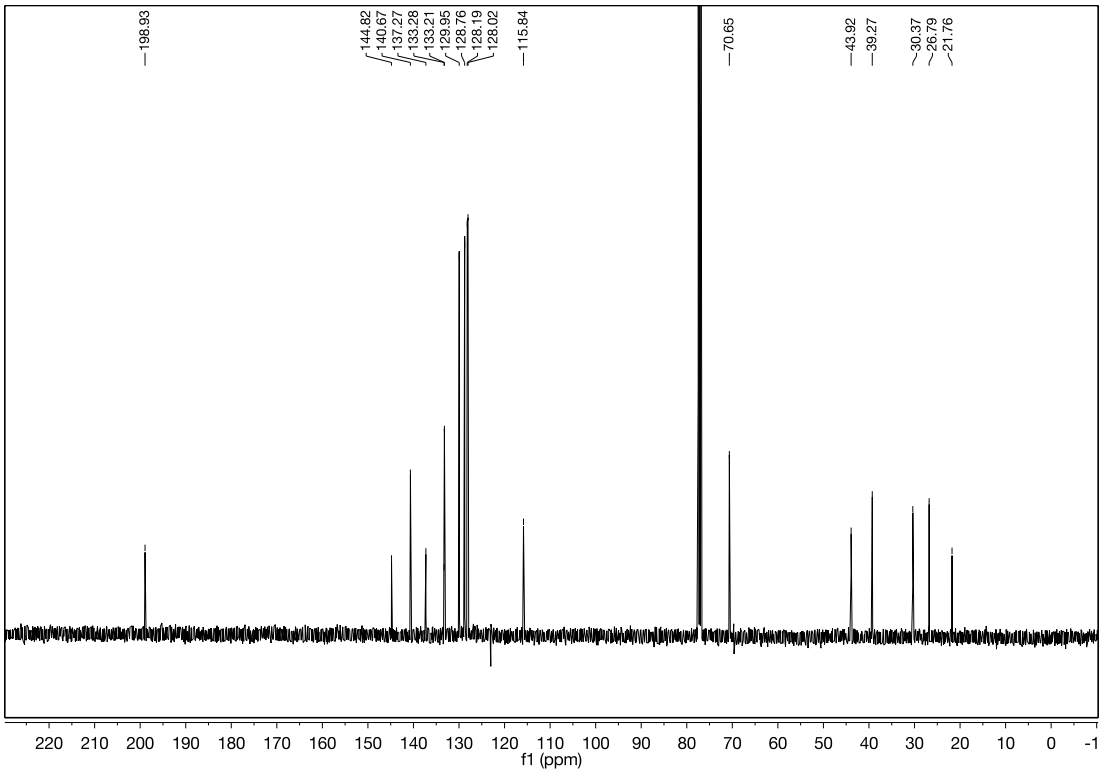
(**3s**)

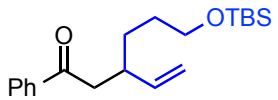

3.79
2.02
1.15
2.28
2.06
2.03
1.00
2.02
1.03
3.12
2.10
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)


O
OTs
Ph

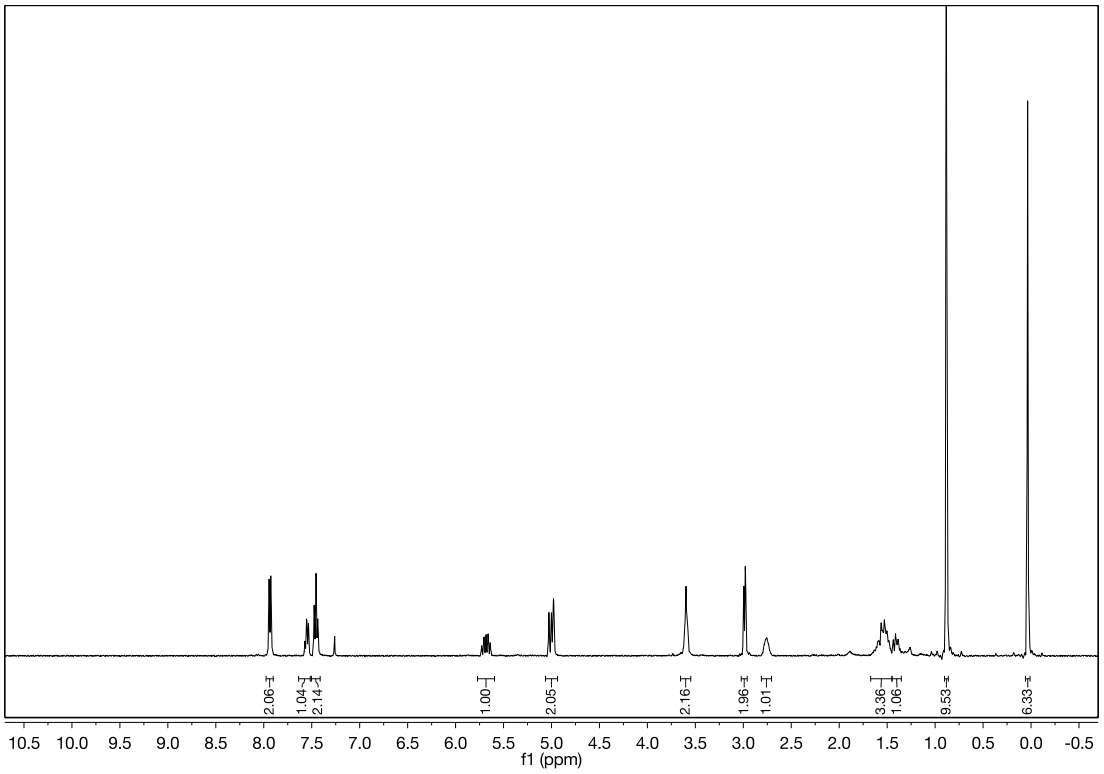
(**3t**)

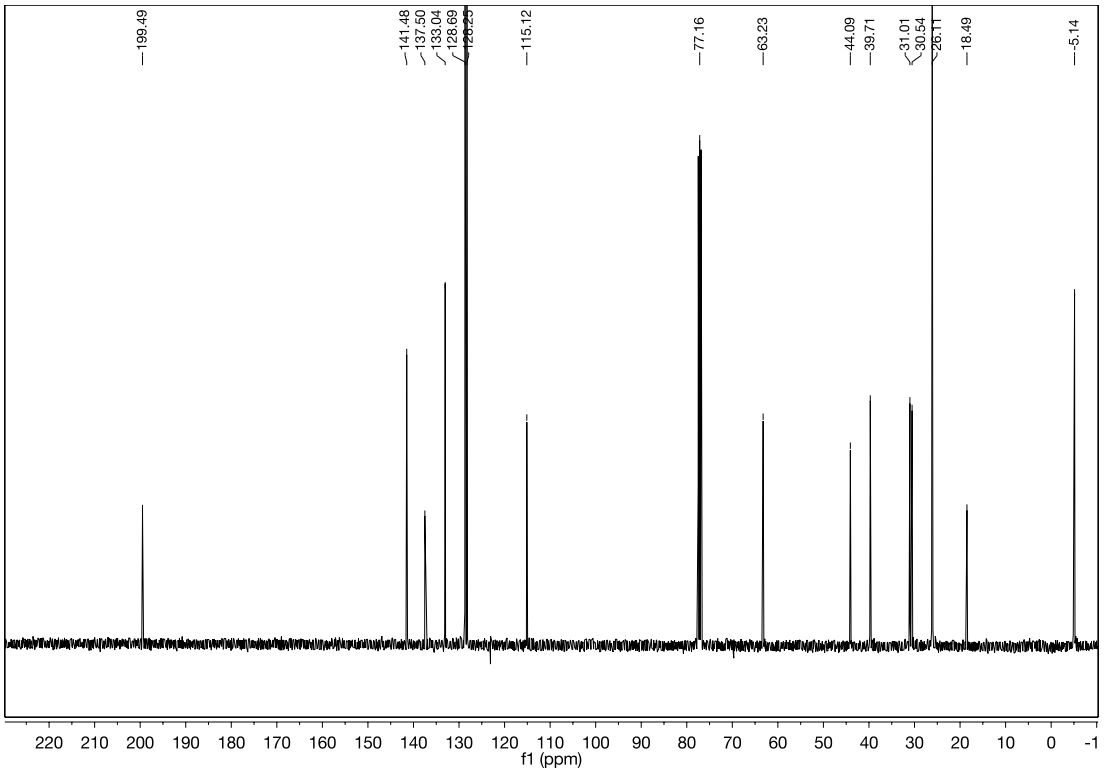

2.00
2.05
1.04
2.04
2.11
1.00
2.03
2.11
2.06
1.03
3.12
1.34
1.09
1.35
1.88
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

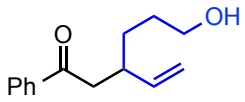

198.93
144.82
140.67
137.27
133.28
133.21
129.95
128.76
128.19
128.02
115.84
70.65
43.92
39.27
30.37
26.79
21.76
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


OTBS
O
Ph

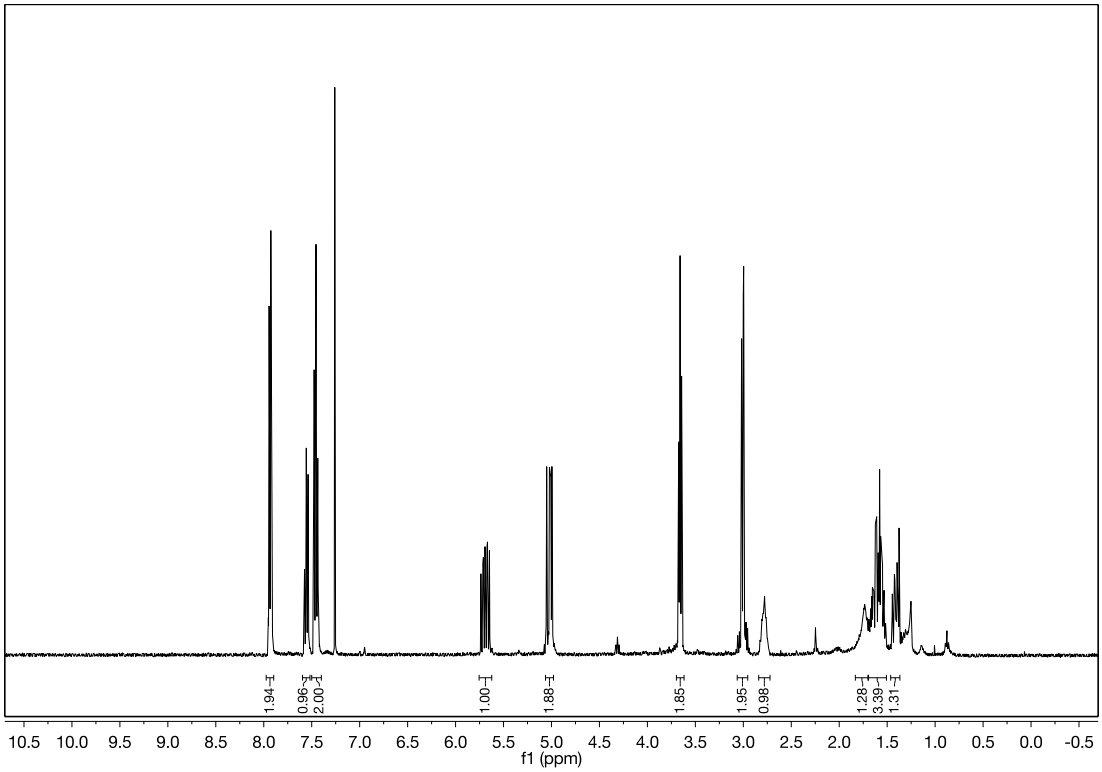
(**3u**)

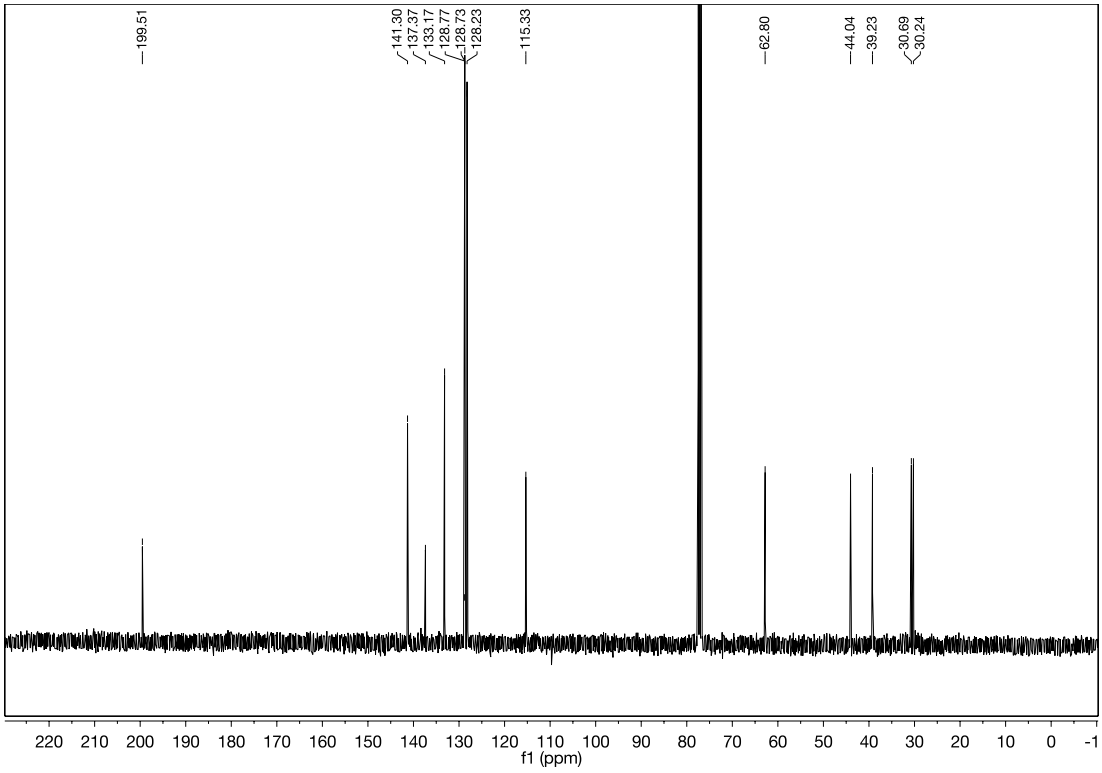

2.06
1.04
2.14
1.00
2.05
2.16
1.96
1.01
3.36
1.06
9.53
6.33
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

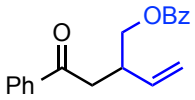

199.49
141.48
137.50
133.04
128.69
128.23
115.12
77.16
63.23
44.09
39.71
31.01
30.54
26.11
18.49
-5.14
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


O
OH
Ph

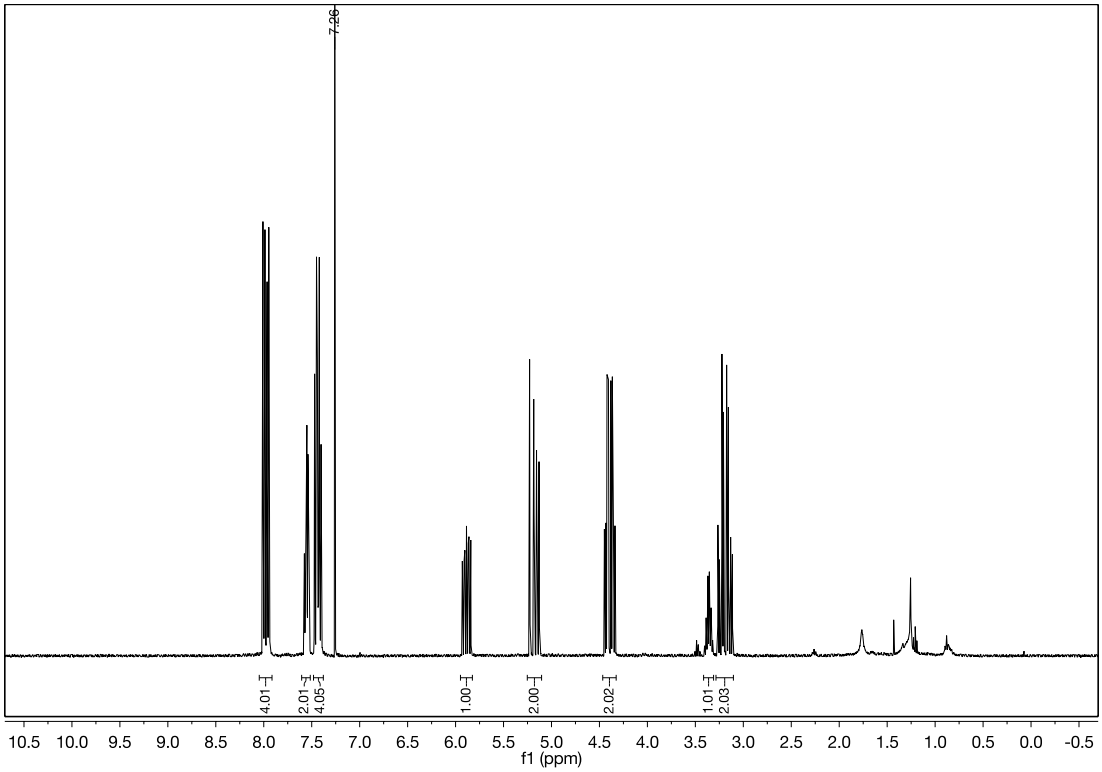
(**3v**)

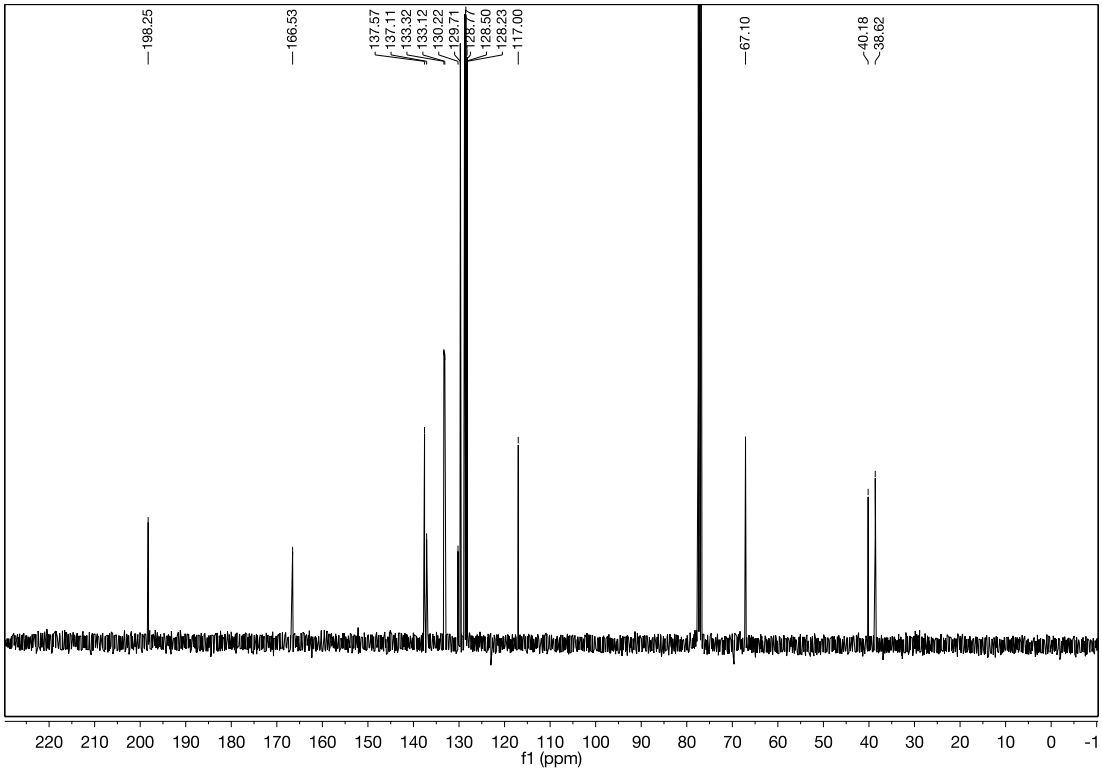

1.94
0.96
2.00
1.00
1.88
1.85
1.95
0.98
1.28
3.39
1.31
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

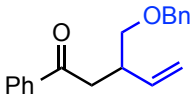

199.51
141.30
137.37
133.17
128.77
128.73
128.23
115.33
62.80
44.04
39.23
30.69
30.24
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


OBz
O
Ph

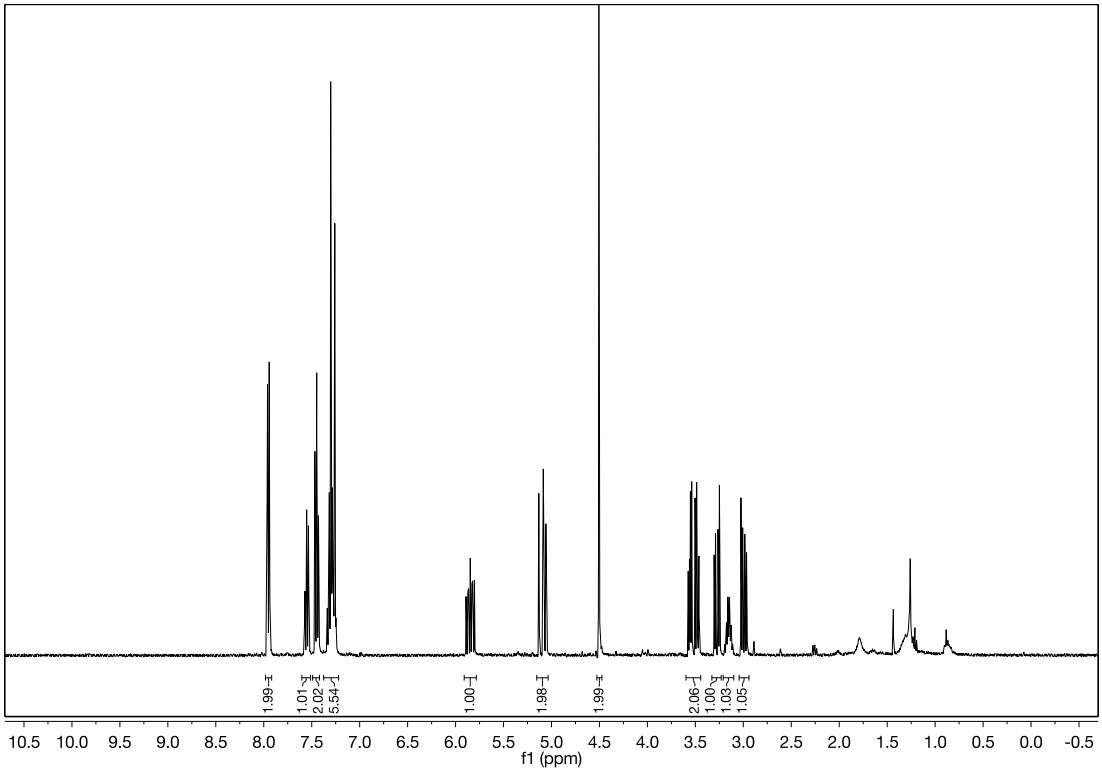
(**3w**)

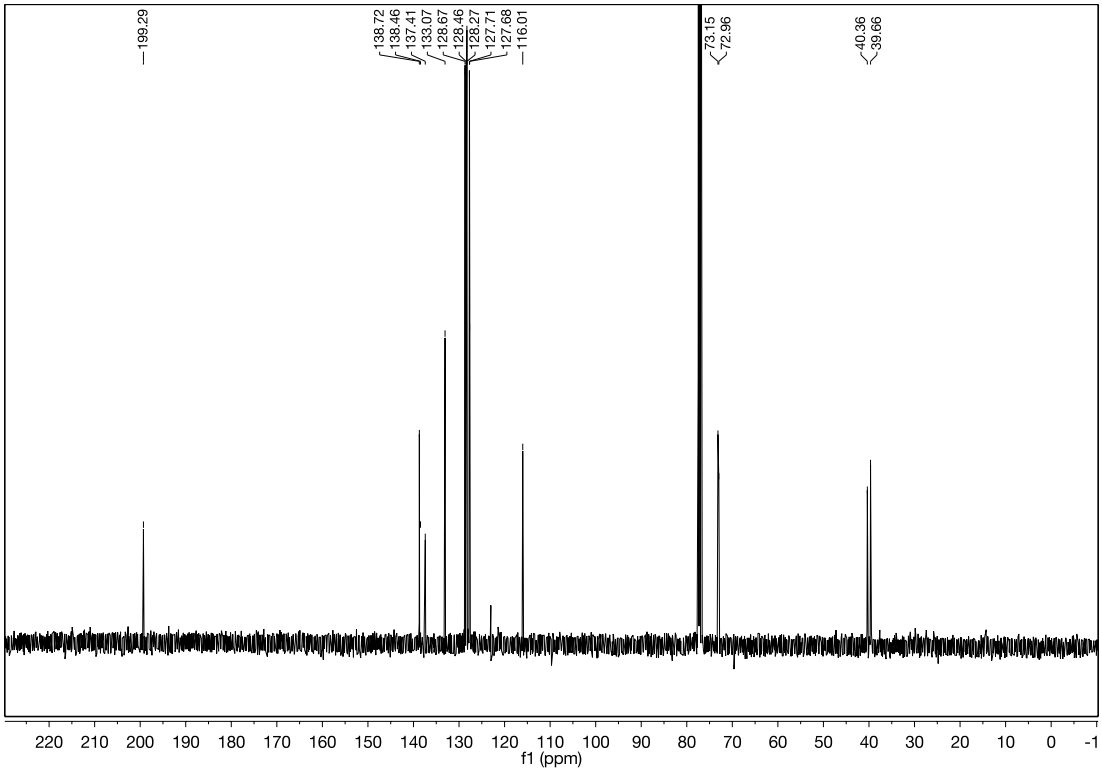

7.26
4.01
2.01
4.05
1.00
2.00
2.02
1.01
2.03
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

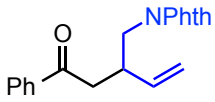

198.25
166.53
137.57
137.11
133.32
133.12
130.22
129.71
128.77
128.50
128.23
117.00
67.10
40.18
38.62
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


O
OBn
Ph

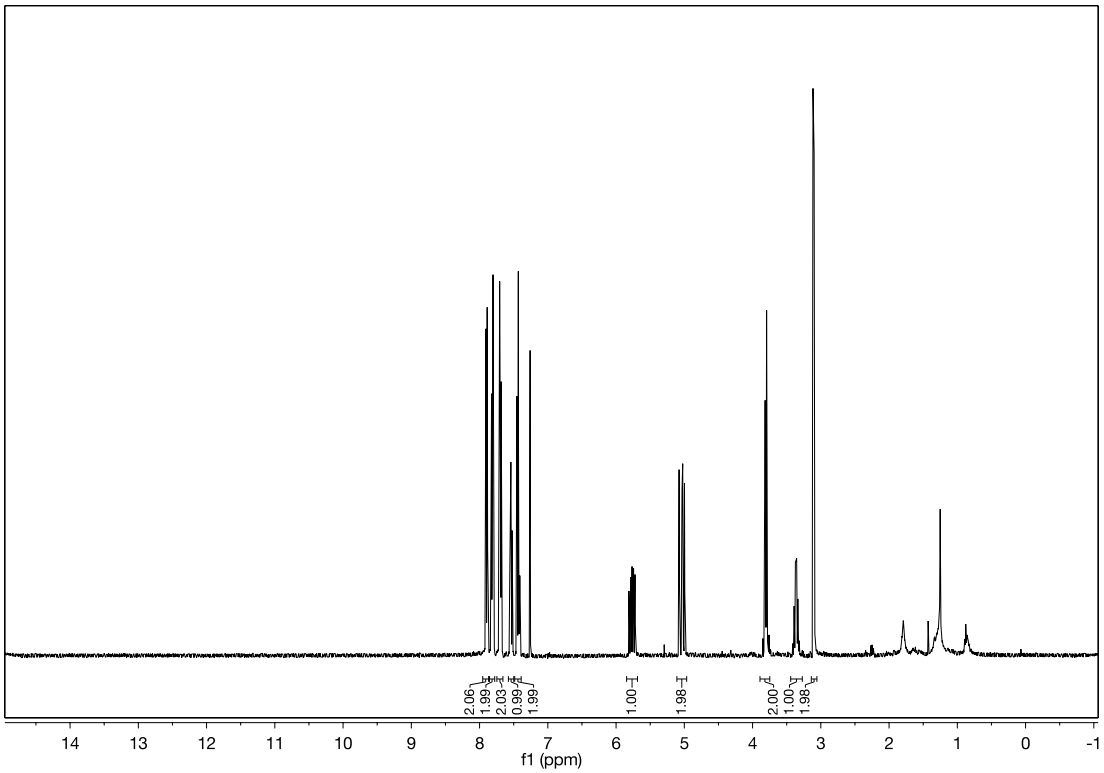
(**3x**)

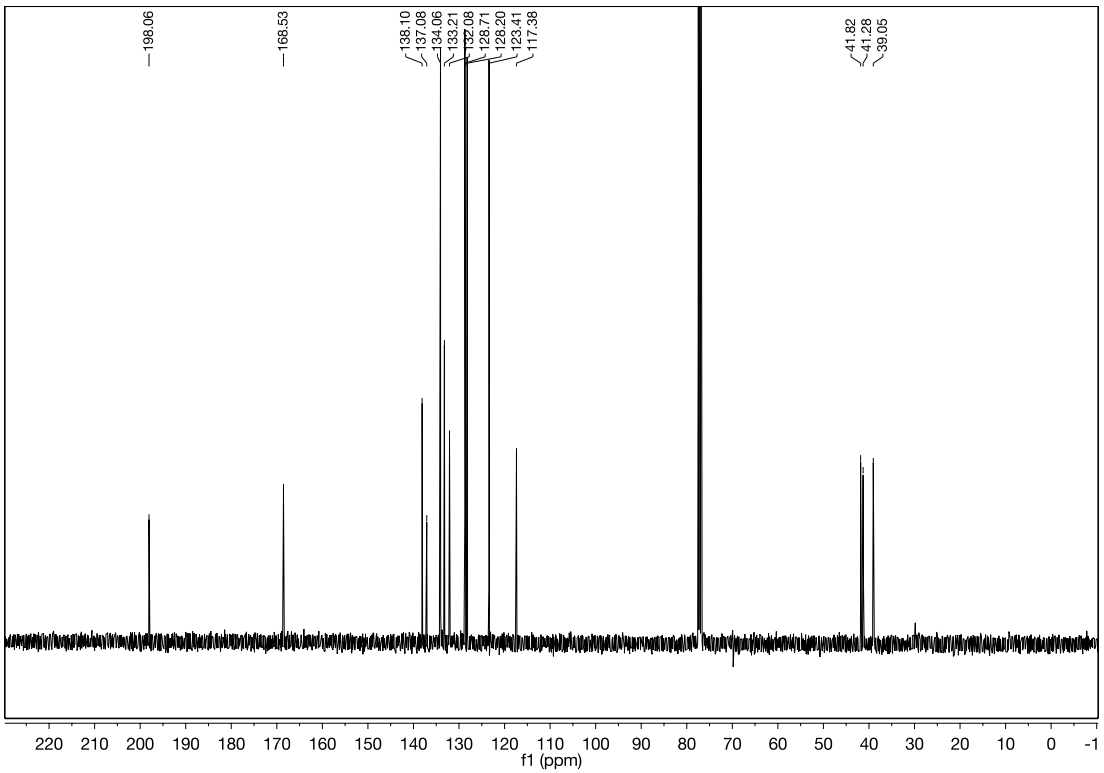

1.99
1.01
2.02
5.54
1.00
1.98
1.99
2.06
1.00
1.03
1.05
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

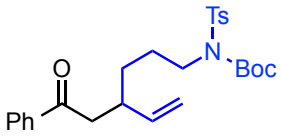

199.29
138.72
138.46
137.41
133.07
128.67
128.46
128.27
127.71
127.68
116.01
73.15
72.96
40.36
39.66
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


NPhth
O
Ph

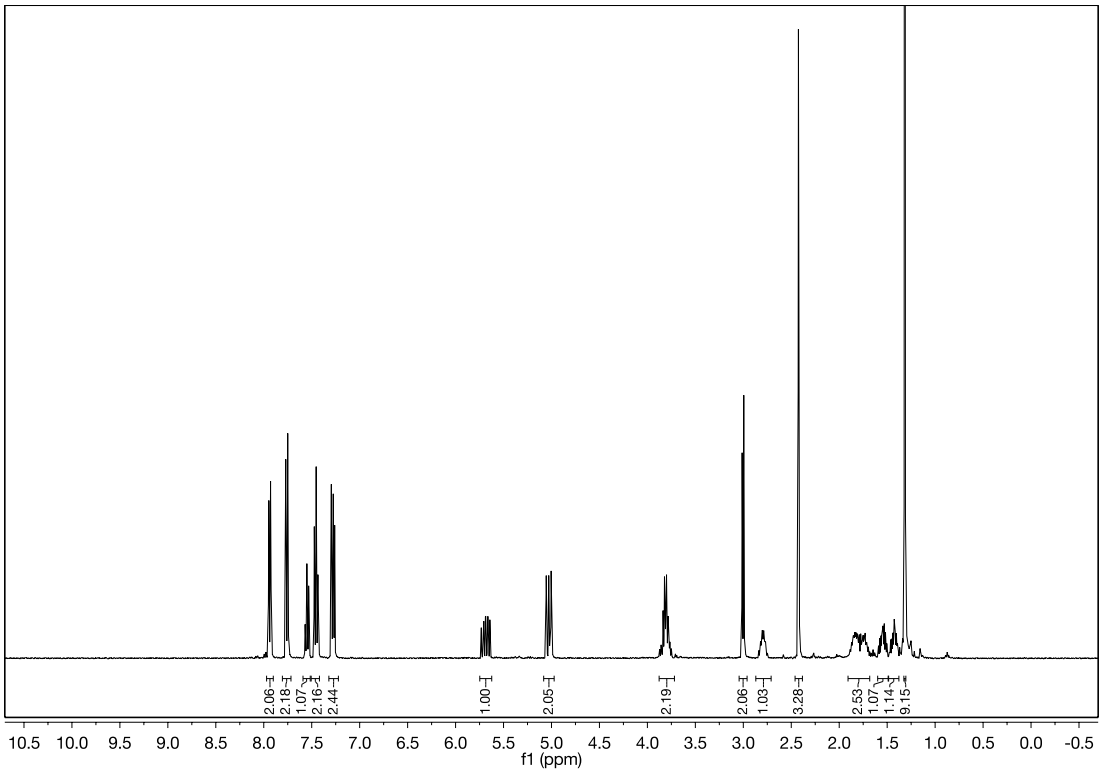
(**3y**)

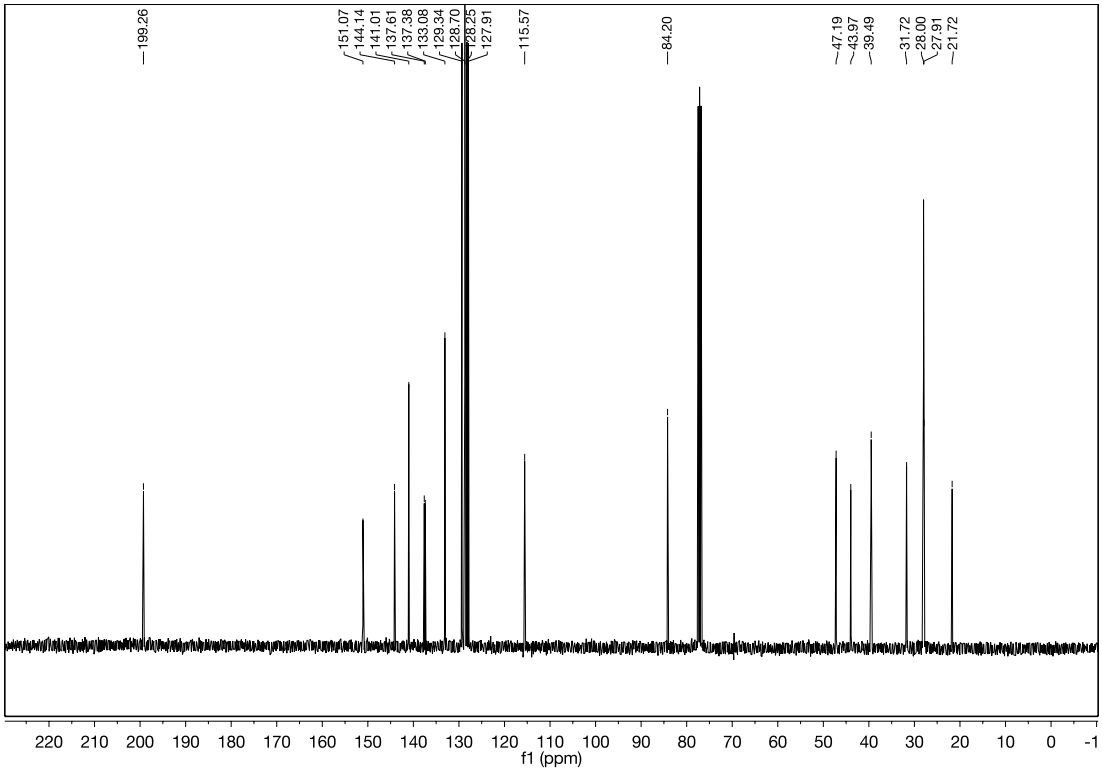

2.06
1.99
2.03
0.99
1.99
1.00
1.98
2.00
1.00
1.98
14 13 12 11 10 9 8 7 6 5 4 3 2 1 0 -1
f1 (ppm)

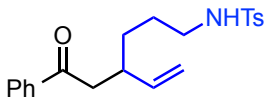

198.06
168.53
138.10
137.08
134.06
133.21
132.08
128.71
128.20
123.41
117.38
41.82
41.28
39.05
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


Ts
N
Boc
O
Ph

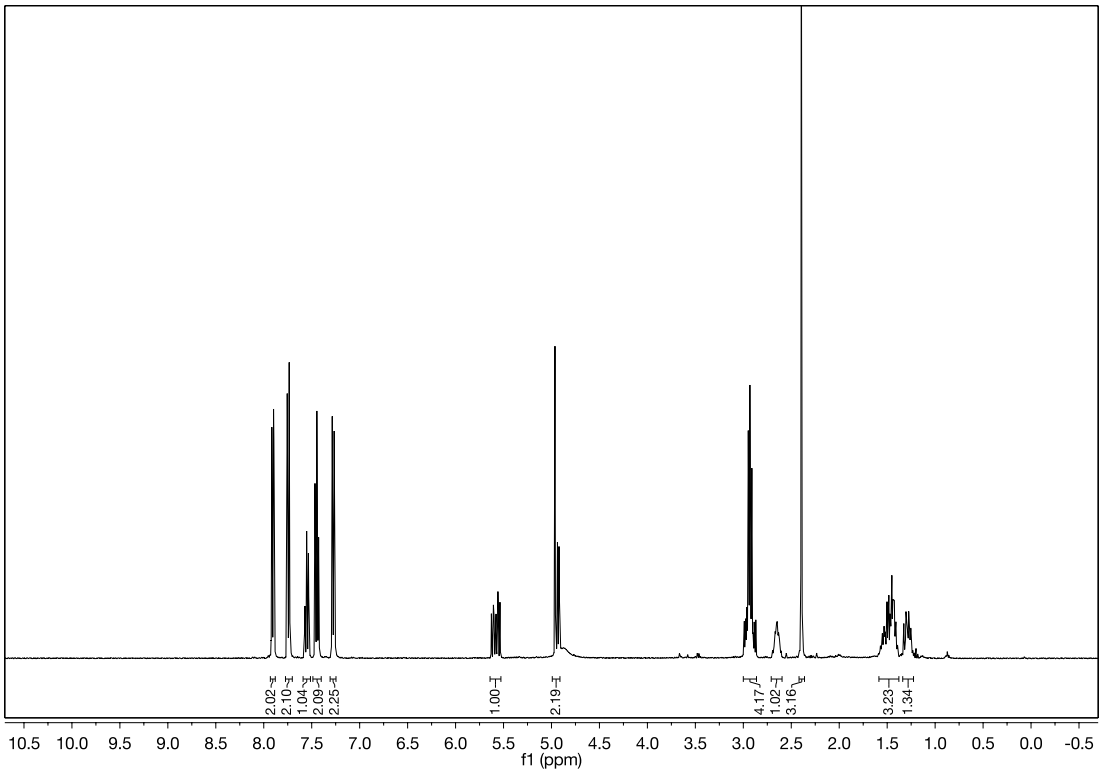
(**3z**)

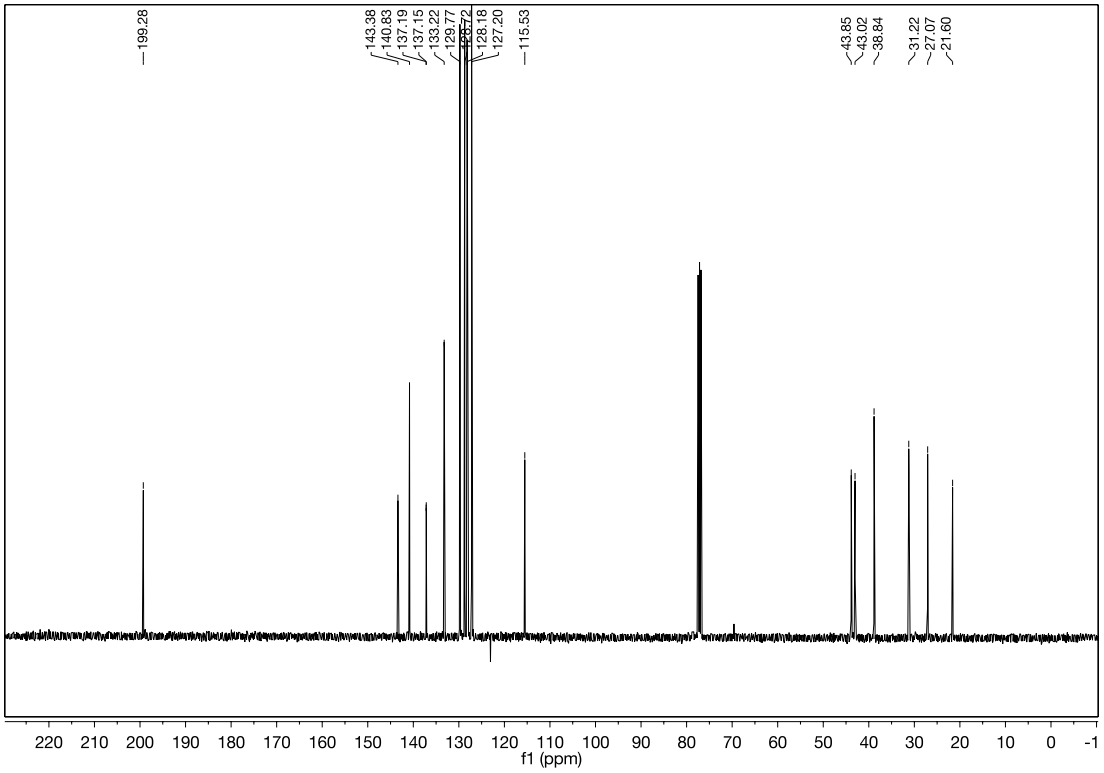

2.06
2.18
1.07
2.16
2.44
1.00
2.05
2.19
2.06
1.03
3.28
2.53
1.07
1.14
9.15
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

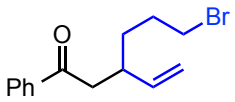

199.26
151.07
144.14
141.01
137.61
137.38
133.08
129.34
128.70
128.25
127.91
115.57
84.20
47.19
43.97
39.49
31.72
28.00
27.91
21.72
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


NHTs
O
Ph

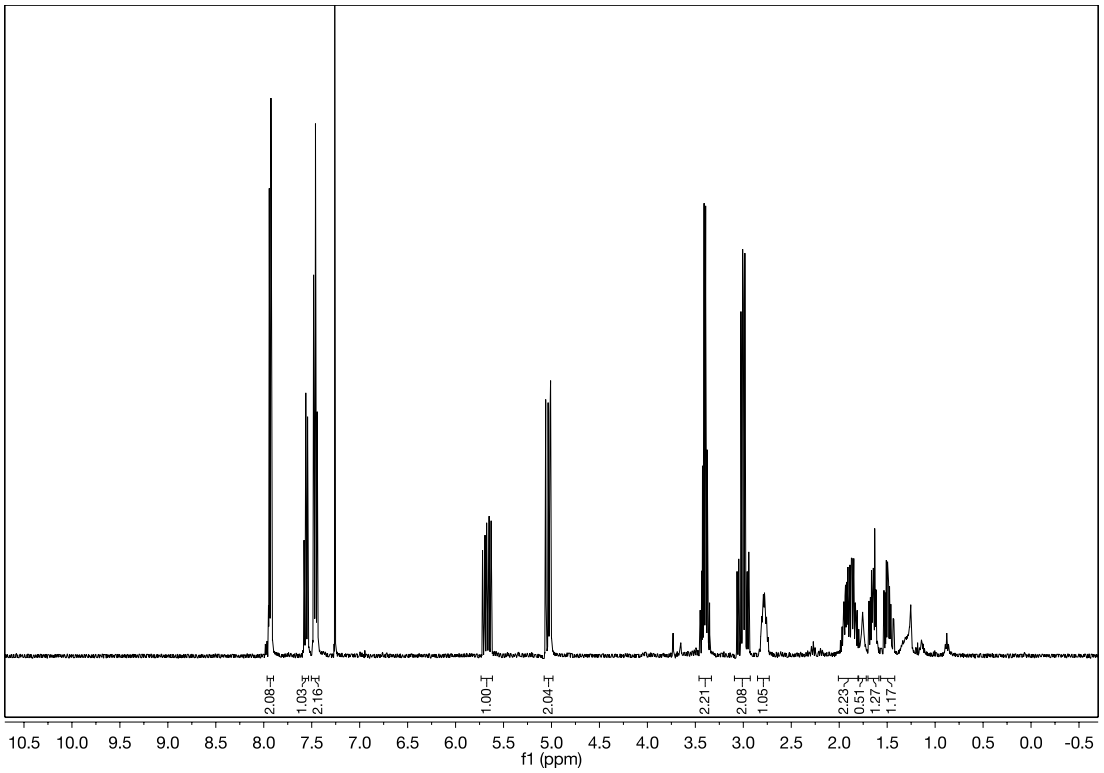
(**3aa**)

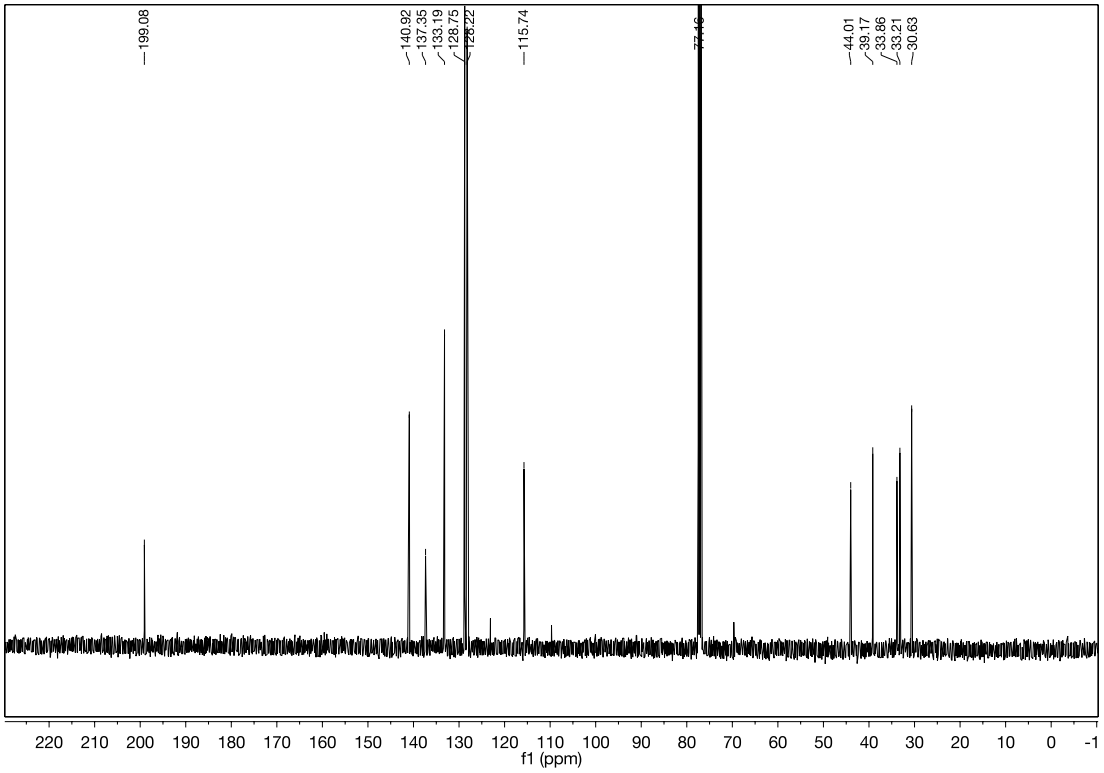

2.02
2.10
1.04
2.09
2.25
1.00
2.19
4.17
1.02
3.16
3.23
1.34
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

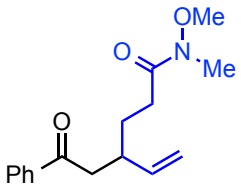

199.28
143.38
140.83
137.19
137.15
133.22
129.77
128.72
128.18
127.20
115.53
43.85
43.02
38.84
31.22
27.07
21.60
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


O
Br
Ph

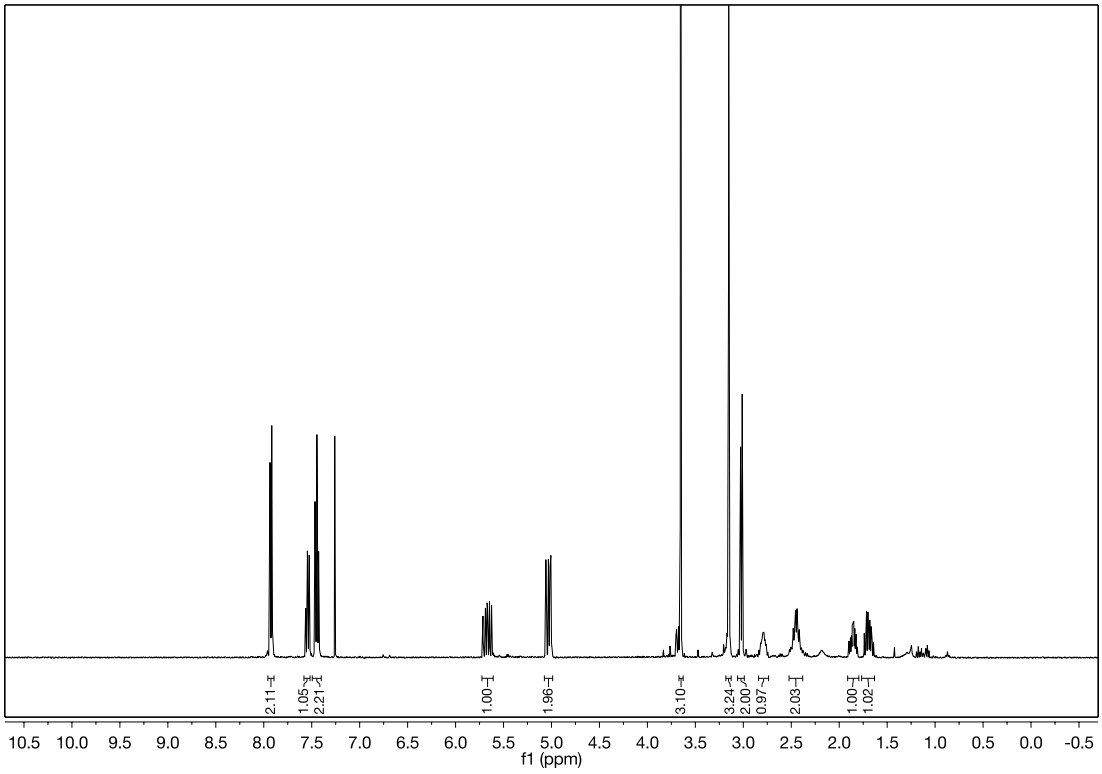
(3ab)

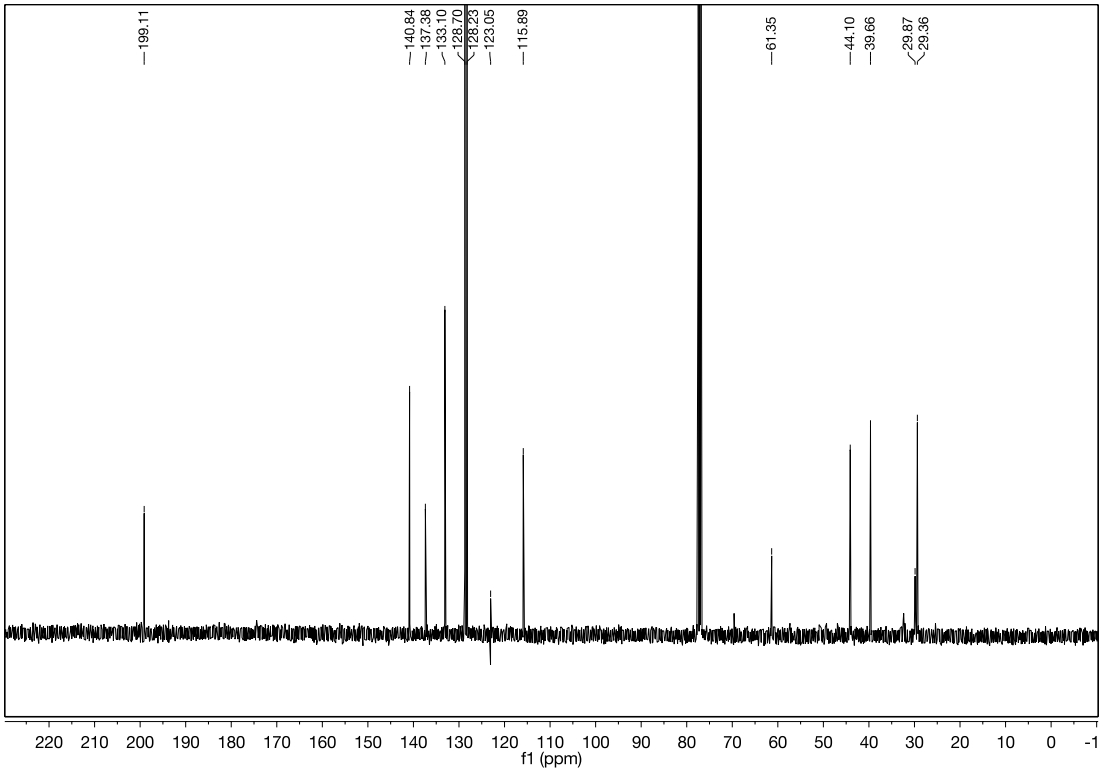

2.08
1.03
2.16
1.00
2.04
2.21
2.08
1.05
2.23
0.51
1.27
1.17
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

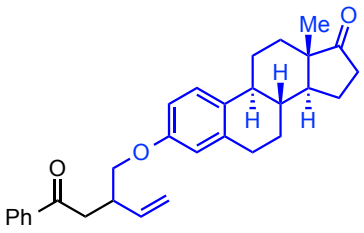

199.08
140.92
137.35
133.19
128.75
128.22
115.74
77.16
44.01
39.17
33.86
33.21
30.63
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


OMe
O
N
Me
O
Ph

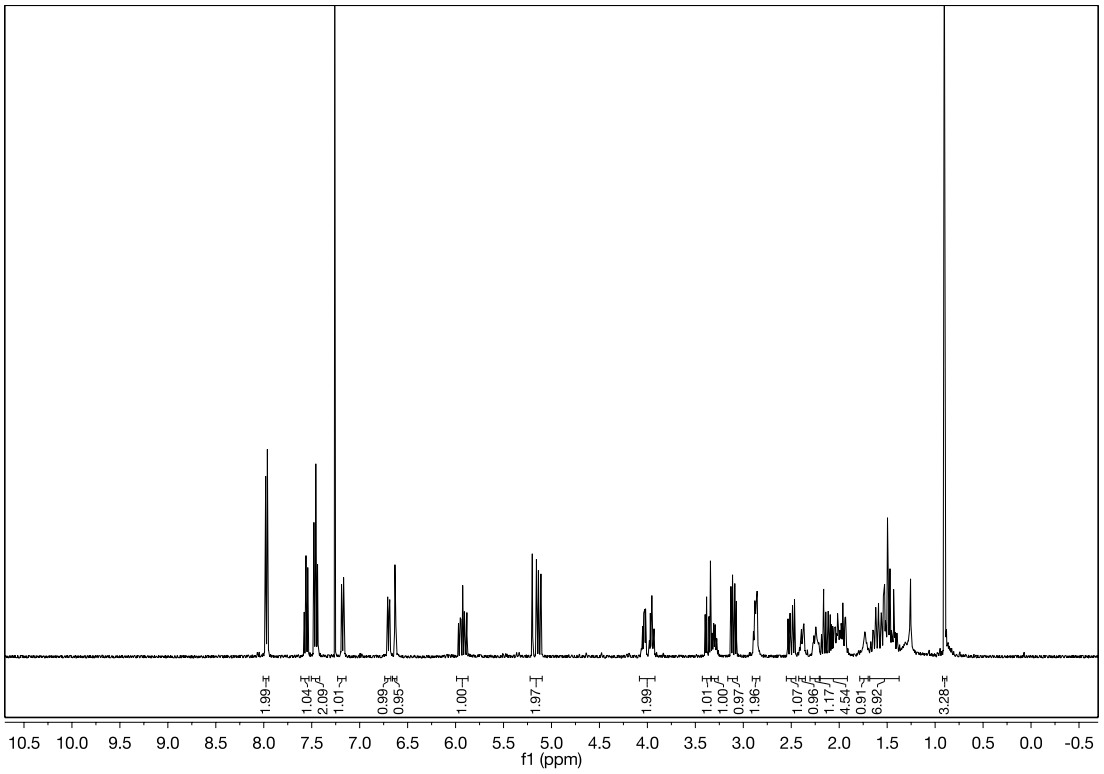
(**3ac**)

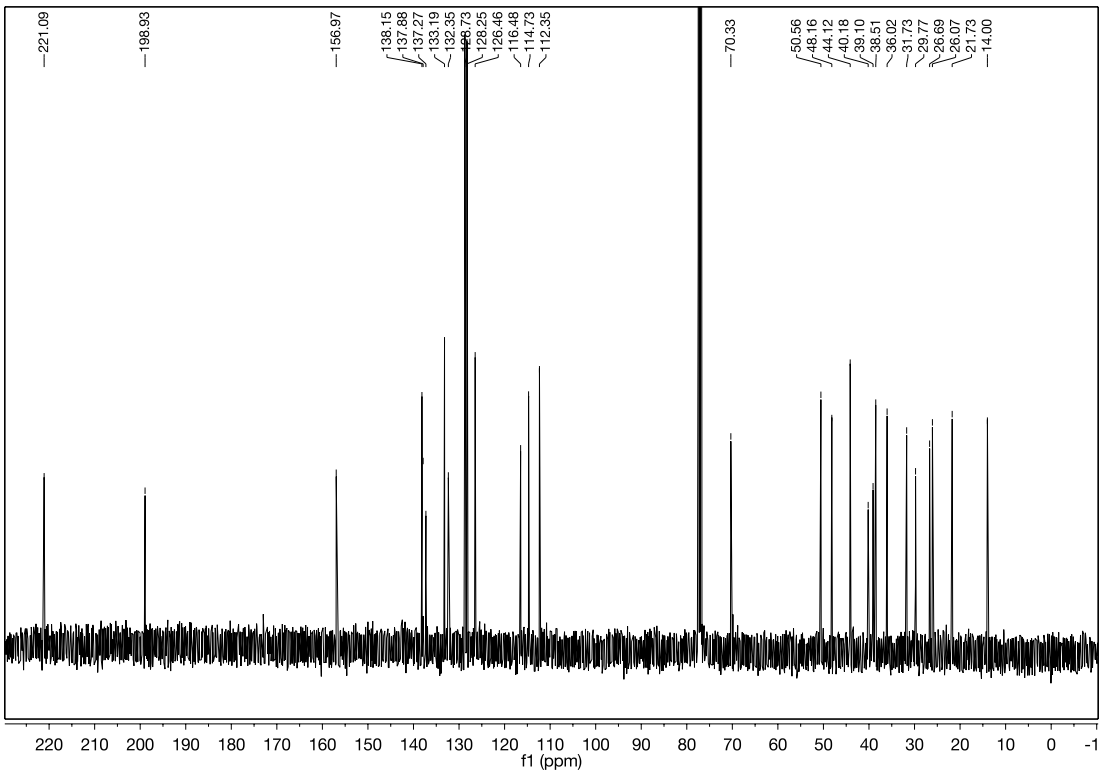

2.11
1.05
2.21
1.00
1.96
3.10
3.24
2.00
0.97
2.03
1.00
1.02
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

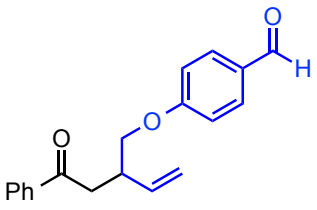

199.11
140.84
137.38
133.10
128.70
128.23
123.05
115.89
61.35
44.10
39.66
29.87
29.36
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


Me
O
H
H
H
O
O
Ph

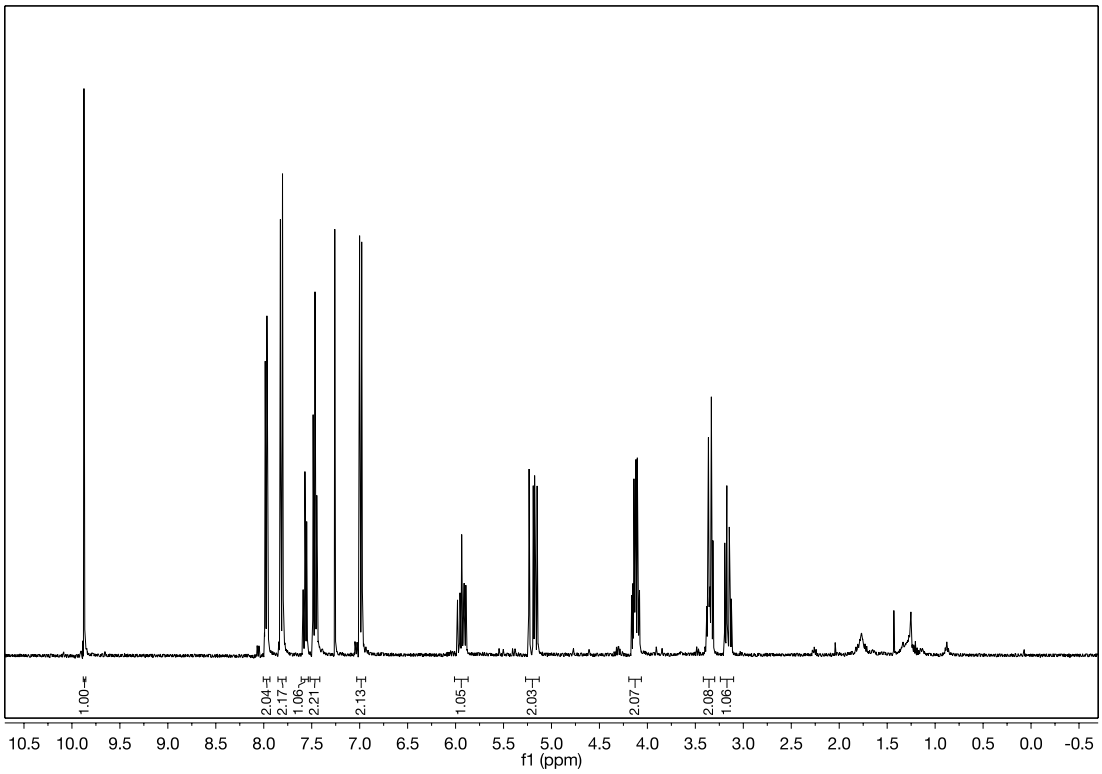
(**3ad**)

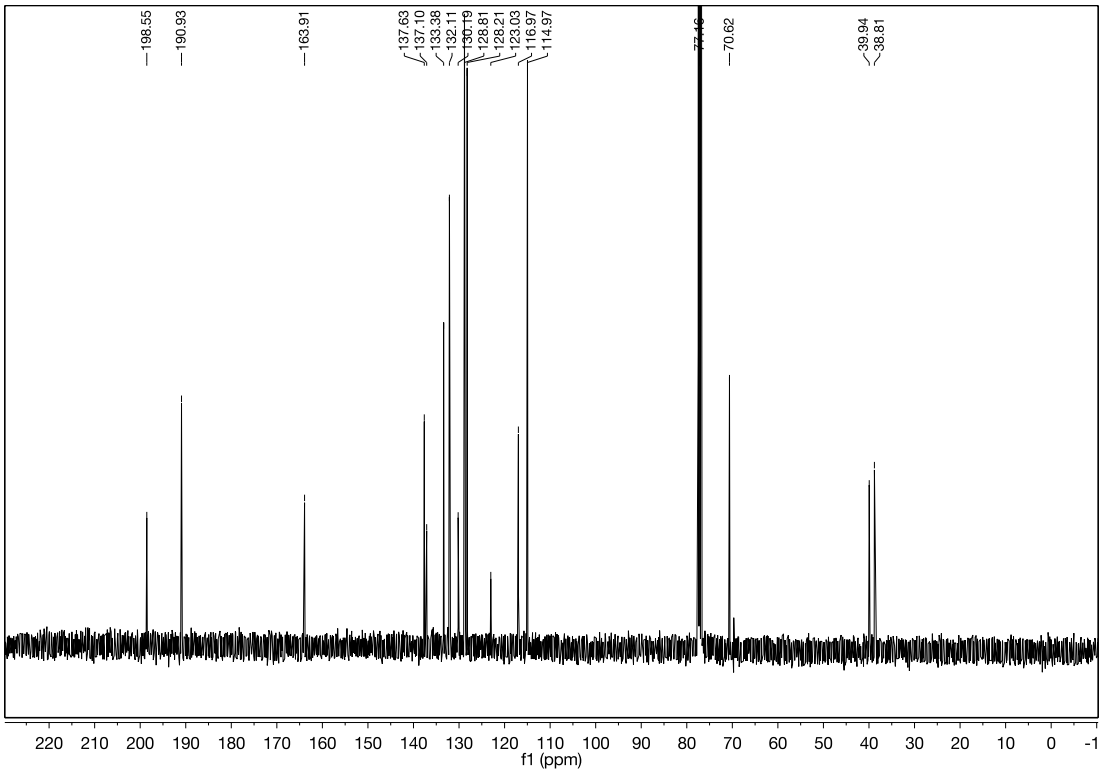

1.99
1.04
2.09
1.01
0.99
0.95
1.00
1.97
1.99
1.01
1.00
0.97
1.96
1.07
0.96
1.17
4.54
0.91
6.92
3.28
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

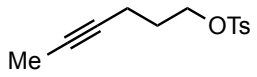

221.09
198.93
156.97
138.15
137.88
137.27
133.19
132.35
128.73
128.25
126.46
116.48
114.73
112.35
70.33
50.56
48.16
44.12
40.18
39.10
38.51
36.02
31.73
29.77
26.69
26.07
21.73
14.00
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


O
H
O
O
Ph

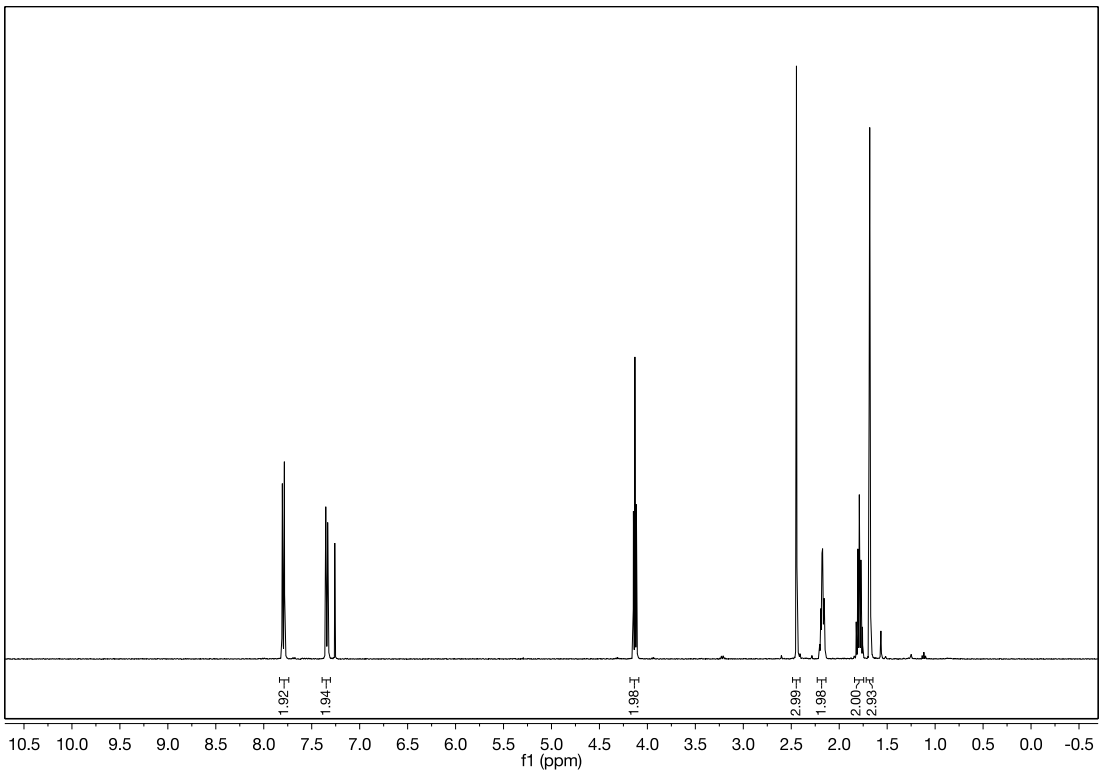
(**3ae**)

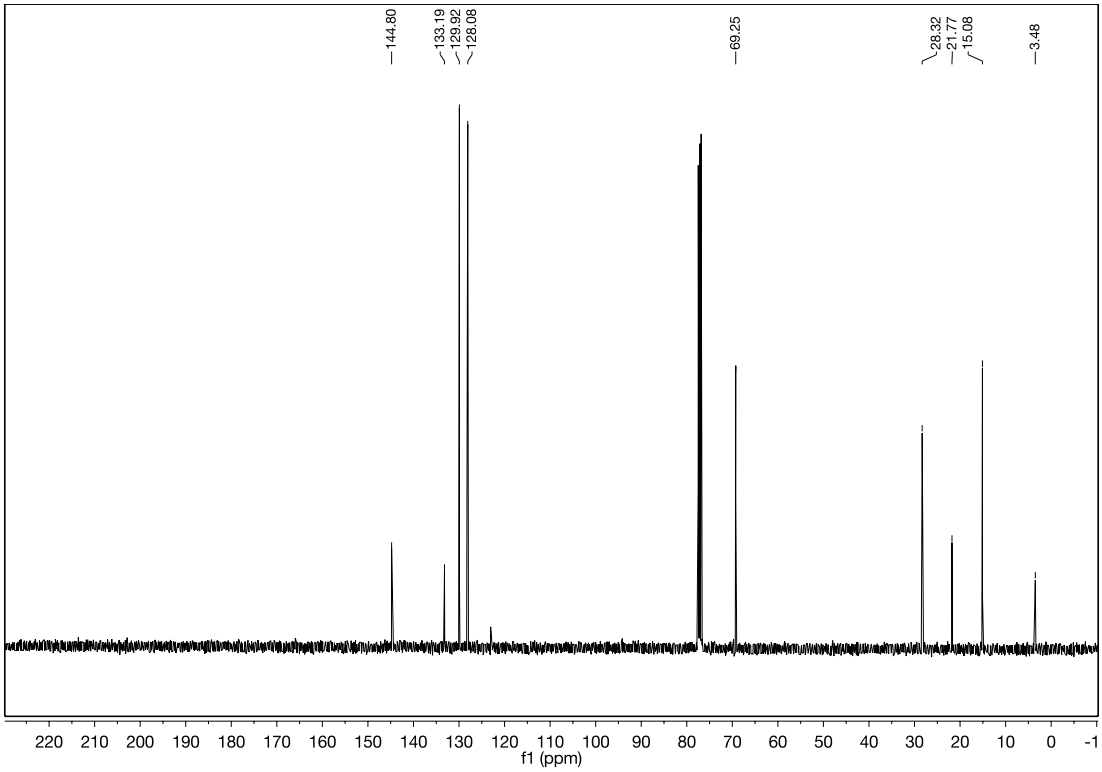

1.00
2.04
2.17
1.06
2.21
2.13
1.05
2.03
2.07
2.08
1.06
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

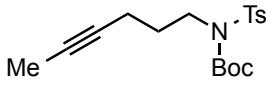

198.55
190.93
163.91
137.63
137.10
133.38
132.11
130.19
128.81
128.21
123.03
116.97
114.97
77.48
70.62
39.94
38.81
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


Me
OTs

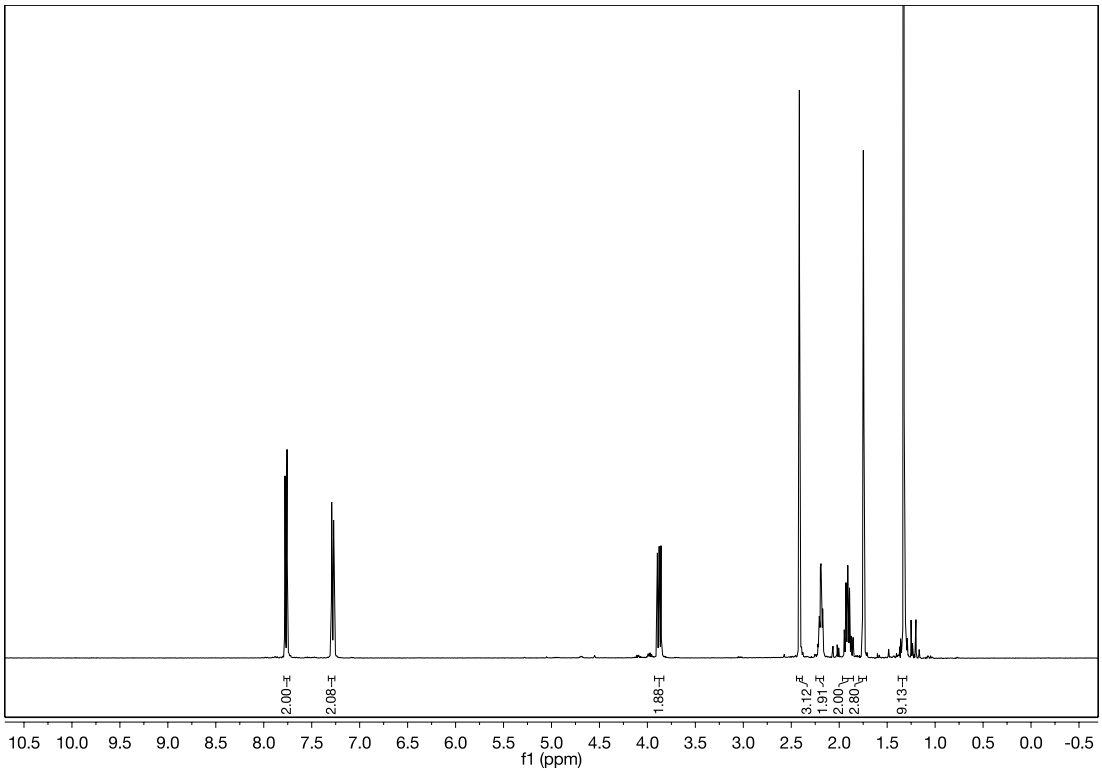
(**2t**)

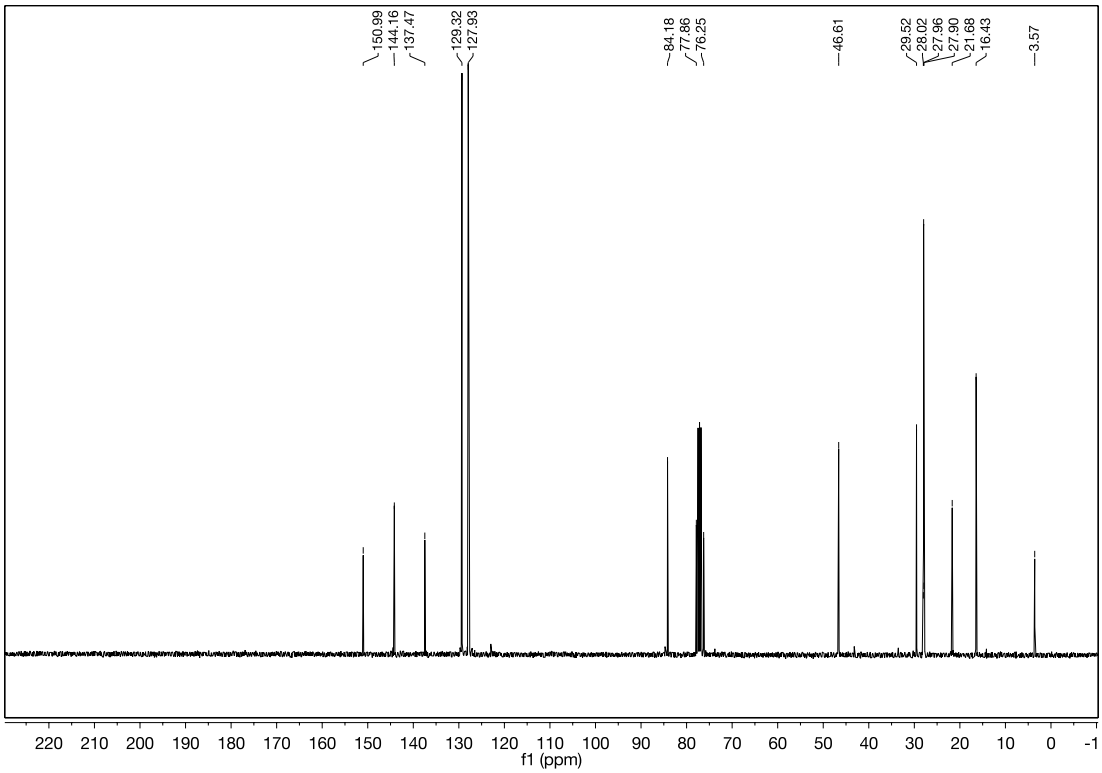

1.92
1.94
1.98
2.99
1.98
2.00
2.93
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

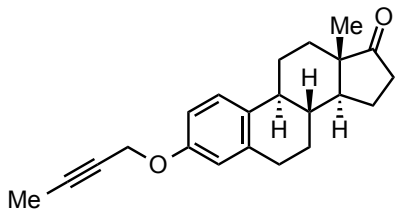

144.80
133.19
129.92
128.08
69.25
28.32
21.77
15.08
3.48
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


Ts
N
Me
Boc

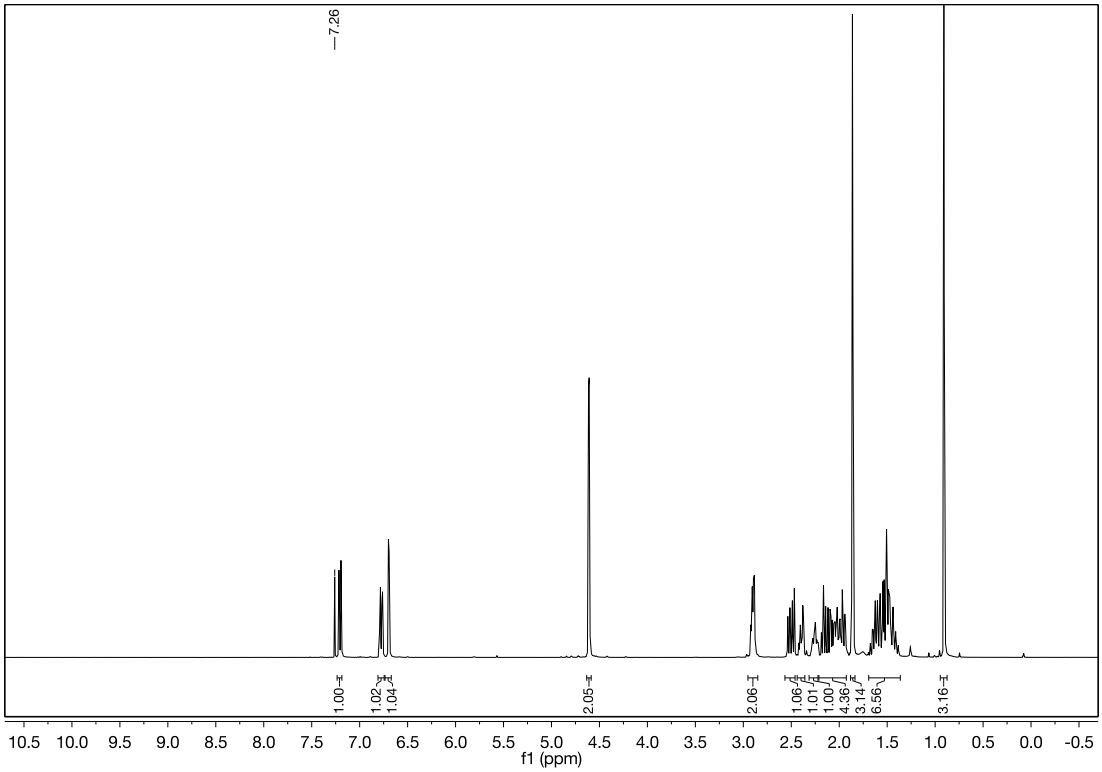
(**2z**)

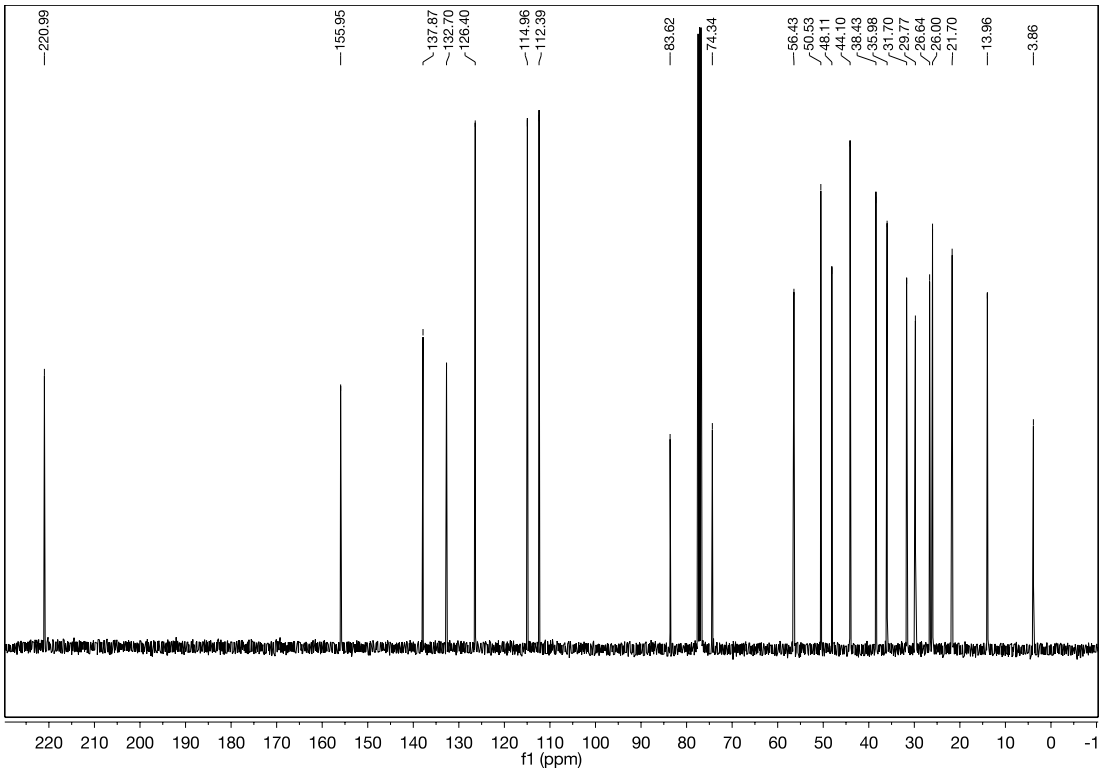

2.00
2.08
1.88
3.12
1.91
2.00
2.80
9.13
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

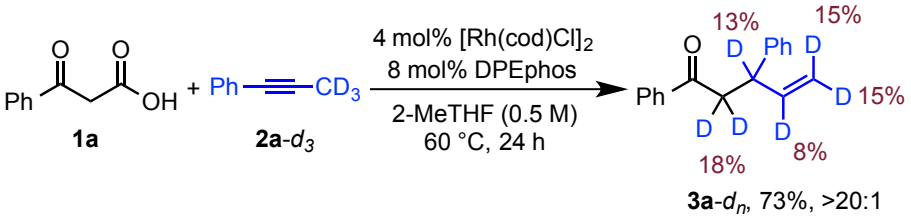

150.99
144.16
137.47
129.32
127.93
84.18
77.86
76.25
46.61
29.52
28.02
27.96
27.90
21.68
16.43
3.57
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


Me
O
H
H
H
O
Me

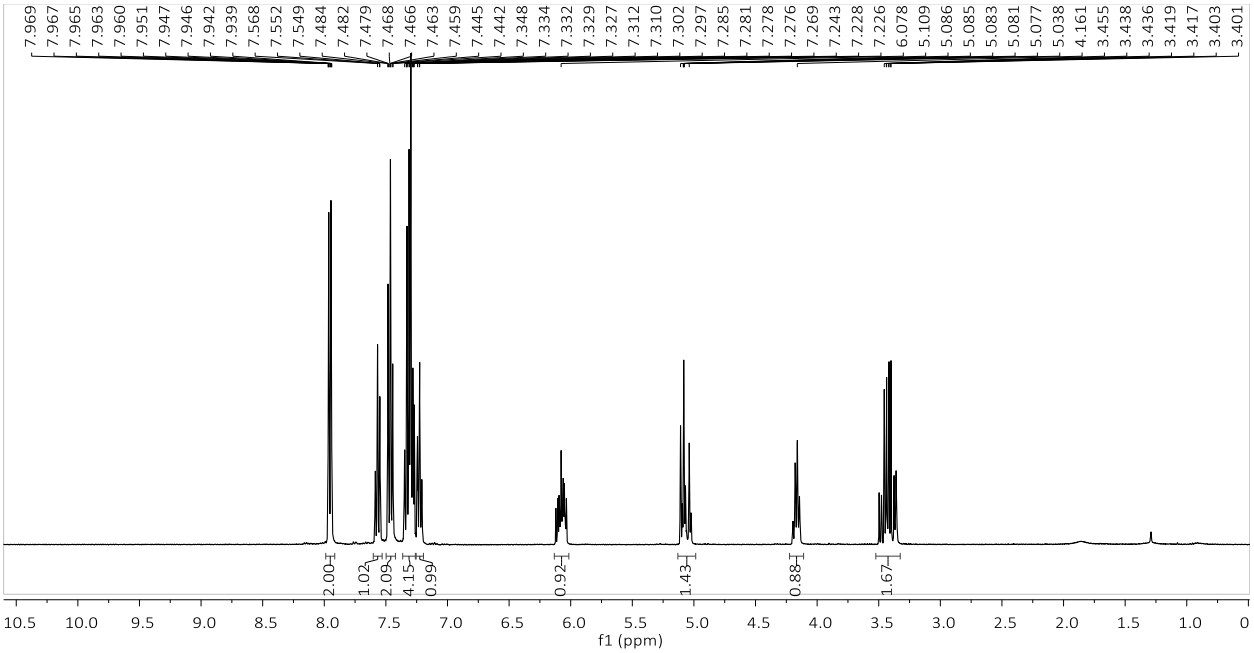
(**2ad**)

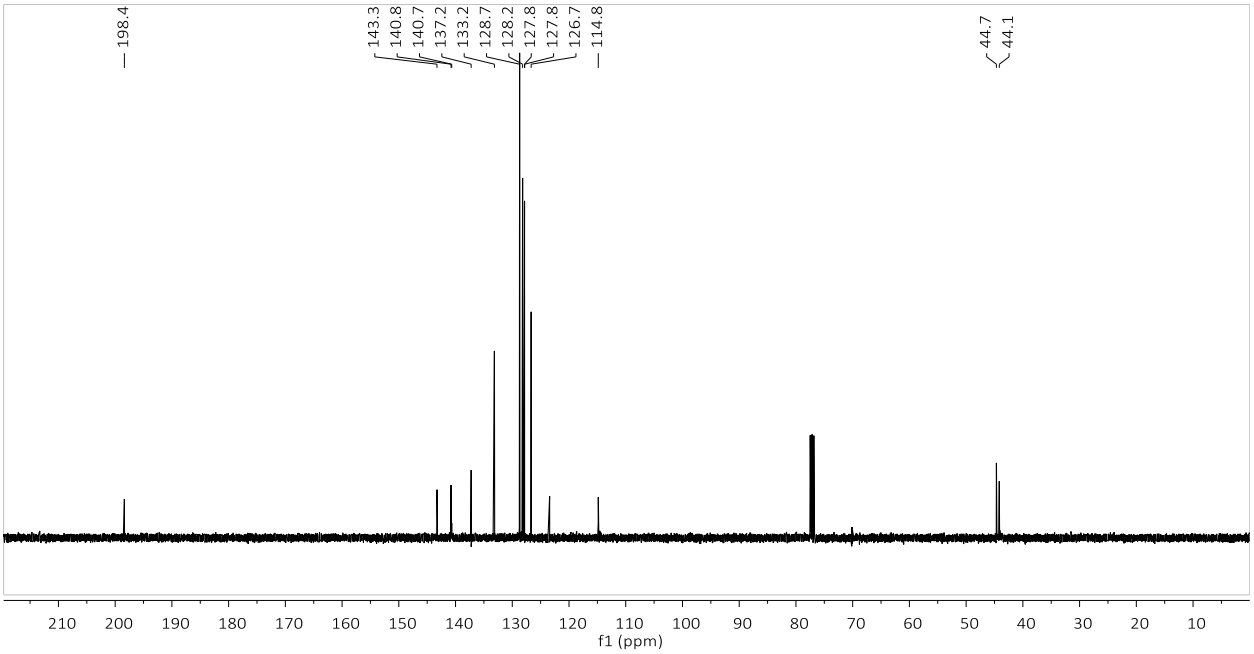

7.26
1.00
1.02
1.04
2.05
2.06
1.06
1.01
1.00
4.36
3.14
6.56
3.16
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

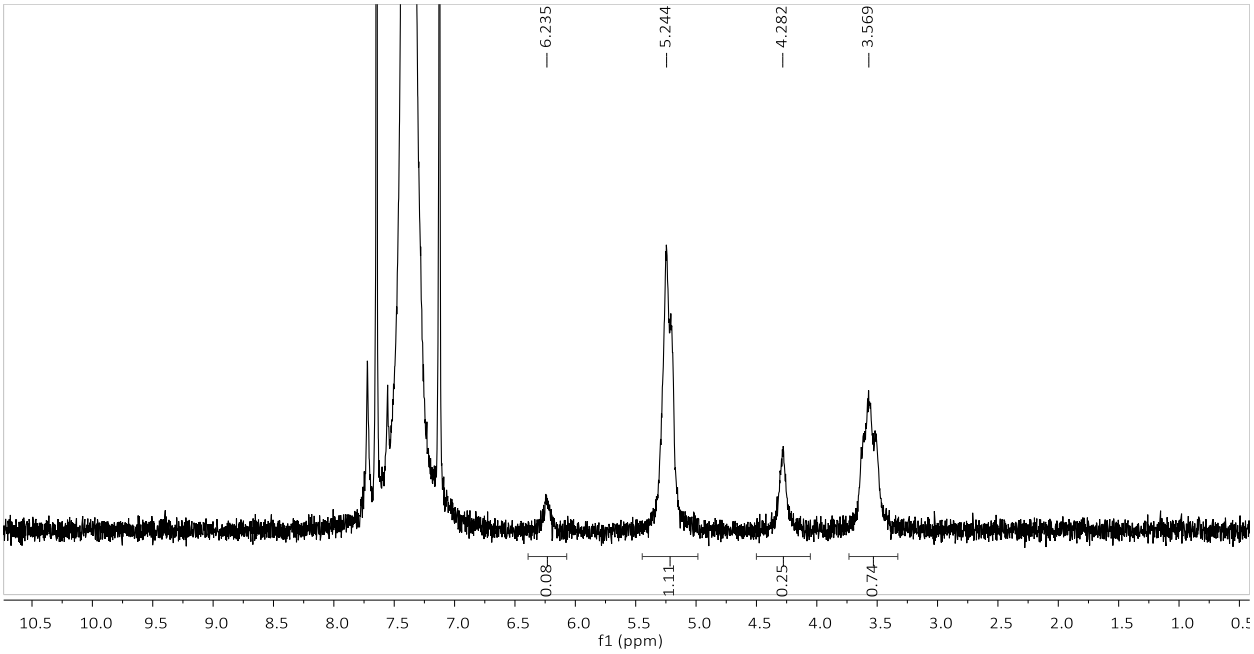

220.99
155.95
137.87
132.70
126.40
114.96
112.39
83.62
74.34
56.43
50.53
48.11
44.10
38.43
35.98
31.70
29.77
26.64
26.00
21.70
13.96
3.86
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)



1a **2a**-d_3 **3a**-d_n, 73%, >20:1






6.235
5.244
4.282
3.569
0.08
1.11
0.25
0.74
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0
f1 (ppm)