Single Isomer Iodochlorination of Alkynes and Chlorination of Alkenes Using Tetrabutylammonium Iodide and Dichloroethane

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General. Reactions were performed under nitrogen in oven-dried glassware equipped with a magnetic stirbar and a rubber septum unless otherwise indicated. Solvents were freshly distilled prior to use as follows: THF over sodium/benzophenone; dichloroethane, dichloromethane and DMF over calcium hydride. Triethylamine and diisopropylethylamine were freshly distilled over calcium hydride. All other were purchased and used without further purification unless otherwise indicated. Reactions were monitored by TLC analysis using glass plates precoated (250 μm thickness) with silica gel 60 F254. TLC plates were visualized using ultraviolet light and potassium permanganate stain. Flash chromatography was carried out on 230-400 mesh silica gel 60, or preparatory TLC glass plates precoated with silica gel (Si250F). NMR spectra

were acquired on 300 MHz, 400 MHz or 500 MHz spectrometers in the specified solvent. Infrared spectra were acquired on a FTIR spectrometer.

Synthetic Methods

General procedure for the halogenation of alkenes and alkynes using Bu_4NI/DCE.

(*E*)-Methyl 3-chloro-2-iodoacrylate (9).[1] A solution of methyl-2-propiolate **4** (250 mg, 2.98 mmol, 1.0 equiv) and tetrabutylammonium iodide (3.25 g, 8.95 mmol, 3.0 equiv) in dichloroethane (25 mL) was heated at reflux for 18 h. The reaction mixture was cooled, diluted with Et_2O and washed with $NaHSO_3$ (20 % wt solution), saturated $NaHCO_3$ and brine. The organic phase was then dried over anhydrous $MgSO_4$, filtered and concentrated *in vacuo*. The pure product was obtained by flash chromatography eluting with hexanes then 5 % EtOAc in hexanes to give the title product as a colorless oil (528 mg, 72 %). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.00 (s, 1H), 3.79 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 162.6 (C), 129.4 (CH), 84.3 (C), 53.2 (CH_3); IR (neat) 1728, 1567cm^{-1}; MS (EI) 246 (M^+); HRMS Calcd for $C_4H_4ClIO_2$ (M^+) 245.8945, found 245.8926.

(*E*)-Ethyl 4-(tert-butyldimethylsilyloxy)-3-chloro-2-iodobut-2-enoate (17). Prepared from ethyl 4-(tert-butyldimethylsilyloxy)but-2-ynoate (100 mg, 0.41 mmol) using a procedure similar to that described above for compound **9** that provided the title compound as a colorless oil (152 mg, 92 %). ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.53 (s, 2H), 4.31 (q, J = 7.2 Hz, 2H), 1.34 (t, J = 7.2 Hz, 3H), 0.93 (s, 9H), 0.13 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 164.6 (C), 137.1 (C), 80.1 (C), 68.6 (CH_2), 62.6 (CH_2), 25.8 (CH_3), 18.3 (C), 13.9 (CH_3); IR (neat) 2956, 1733, 1472 cm^{-1}; HRMS Calcd for $C_8H_{13}ClIO_3Si$

(M^+ - *t*-Bu) 346.9367, found 346.9352; Calcd for $C_{11}H_{19}ClIO_3Si$ (M^+ - CH_3) 388.9837, found 388.9830.

N-Methoxy-N-methylnon-2-ynamide (25). To a solution of 1-hexyne (2.6 mL, 17.7 mmol, 1.0 equiv) in hexanes (150 mL) at -78 °C was added a solution of butyllithium (2.26 M in THF, 8.63 mL, 19.5 mmol, 1.1 equiv). After 1 hour a solution of N-methoxy-N-methylcarbamoyl chloride[2] (2.40 g, 19.4 mmol, 1.1 equiv) in THF (20 mL) was slowly added *via* canula. The reaction was stirred for 1 hour at -78 °C then allowed to warm to room temperature for 1 hour. The reaction was quenched by the dropwise addition of 10 % HCl and diluted with ether. The organic layer was washed sequentially with a saturated solution of sodium bicarbonate and brine, then dried over anhydrous $MgSO_4$, filtered and concentrated. The pure product was obtained by chromatography eluting with 5% EtOAc in hexanes then 20% EtOAc in hexanes to give the title product as a pale yellow oil (3.02 g, 77%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.40 (s, 3H), 2.94 (s, 3H), 2.03 (t, *J* = 6.4 Hz, 2H), 1.36 – 1.14 (m, 8H), 0.93 (t, *J* = 6.8 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 73.0 (CH_3), 61.8 (CH_3), 31.1 (CH_2), 30.8 (CH_2), 28.4 (CH_2), 27.6 (CH_2), 22.4 (CH_2), 18.8 (CH_2), 13.6 (CH_3); IR (neat) 2237, 1644 cm^{-1}; HRMS Calcd for $C_{11}H_{19}NO_2$ (M^+) 197.1416, found 197.1405.

(*E*)-3-Chloro-2-iodo-N-methoxy-N-methylnon-2-enamide (26). Prepared from N-methoxy-N-methylnon-2-ynamide (3.02 g, 15.3 mmol) using a procedure similar to that described above for compound **9** that provided the title compound as a colorless oil (5.05 g, 92 %). ^{1}H NMR (400 MHz, C_6D_6) δ 3.22 (s, 3H), 2.82 (s, 3H), 2.46 (br s, 2H), 1.48 – 1.45 (m, 2H), 1.19 – 1.14 (m, 6H), 0.84 (t, *J* = 6.8 Hz, 3H); ^{13}C NMR (100 MHz, C_6D_6) δ 166.3 (C), 135.1 (C), 82.7 (C), 60.8 (CH_3), 40.4 (CH_2), 32.4 (CH_3), 31.8 (CH_2), 28.3

(CH_2), 27.1 (CH_2), 22.8 (CH_2), 14.1 (CH_3); IR (neat) 2954, 2930, 2858, 1654, 1459 cm^{-1}; HRMS Calcd for $C_{11}H_{10}ClIO_2$ (M^+) 359.0149, found 359.0201.

(*E*)-5-Chloro-6-iododec-5-ene (28). Prepared from 5-decyne (0.13 mL, 0.76 mmol) using a procedure similar to that described above for compound **9** that provided the title compound as a colorless oil (210 mg, 92 %). ^1H NMR (400 MHz, acetone-d_6) δ 2.68 (t, *J* = 7.2 Hz, 4H), 1.60 – 1.48 (m, 4H), 1.39 – 1.32 (m, 4H), 0.94 (t, *J* = 7.2 Hz, 3H), 0.93 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, acetone-d_6) δ 133.0 (C), 100.6 (C), 44.3 (CH_2), 43.2 (CH_2), 32.2 (CH_2), 30.9 (CH_2), 23.3 (CH_2), 23.0 (CH_2), 15.2 (CH_3), IR (neat) 2957, 2860, 1623, 1464 cm^{-1}; MS (EI) 300 (M^+); HRMS Calcd for $C_{10}H_{18}ClI$ (M^+) 300.0142, found 300.0132.

(*E*)-(2-Chloro-3-iodobut-2-ene-1,4-diyl)bis(oxy)bis(methylene)dibenzene (30). Prepared from 1,4-bis(benzyloxy)but-2-yne[3] (50 mg, 0.19 mmol) using a procedure similar to that described above for compound **9** that provided the title compound as a colorless oil (75 mg, 93 %). ^1H NMR (400 MHz, acetone-d_6) δ 7.42 – 7.29 (m, 10 H), 4.57 (s, 2H), 4.55 (s, 2H), 4.51 (s, 2H), 4.44 (s, 2H); ^{13}C NMR (100 MHz, acetone-d_6) δ 139.9 (C), 139.8 (C), 132.7 (C), 130.03 (CH), 130.01 (CH), 129.63 (CH), 129.56 (CH), 129.41 (CH), 129.38 (CH), 102.6 (C), 77.9 (CH_2), 74.8 (CH_2), 73.5 (CH_2), 73.2 (CH_2); IR (nujol) 2957, 1640, 1458 cm^{-1}; MS (EI) 428 (M^+); HRMS Calcd for $C_{18}H_{18}ClIO_2$ (M^+) 428.0040, found 428.0043.

(2,3-Dichloropropoxy)benzene (33).[4] Prepared from allyloxybenzene (100 mg, 0.75 mmol) using a procedure similar to that described above for compound **9** that provided the title compound as a colorless oil (151 mg, 99%). ^1H NMR (400 MHz, $CDCl_3$) δ 7.34 – 7.31 (m, 2H), 7.05 – 6.94 (m, 3H), 4.41 – 4.35 (m, 1H), 4.30 (dd, *J* = 6.4, 1.2 Hz, 2H),

4.02 – 3.89 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 157.9 (C), 129.6 (CH), 121.6 (CH), 114.7 (CH), 68.1 (CH_2), 57.3 (CH), 45.0 (CH_2); IR (neat) 2959, 2933, 1599, 1496 cm^{-1}; MS (EI) 204 (M^+); HRMS Calcd for $C_9H_{10}Cl_2O$ (M^+) 204.0109, found 204.0105.

4,5-Dichloropentyl benzoate (36). Prepared from pent-4-enyl benzoate[5] (100 mg, 0.53 mmol) using a procedure similar to that described above for compound **9** that provided the title compound as a colorless oil (118 mg, 99%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.05 (dd, *J* = 6.4, 1.2 Hz, 2H), 7.55 – 7.54 (m, 1H), 7.44 (dd, *J* = 8.0, 1.6 Hz, 2H), 4.38 – 4.35 (m, 2H), 4.13 – 4.10 (m, 1H), 3.79 (dd, *J* = 11.0, 5.0 Hz, 1H), 3.66 (dd, *J* = 11.4, 7.8 Hz, 1H), 2.22 – 1.84 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.4 (C), 132.9 (CH), 130.0 (C), 129.5 (CH), 128.3 (CH), 63.9 (CH_2), 60.4 (CH), 47.9 (CH_2), 31.7 (CH_2), 25.2 (CH_2); IR (neat) 2956, 2849, 1718, 1451 cm^{-1}; MS (EI) 260 (M^+); HRMS Calcd for $C_{12}H_{14}ClO_2$ (M^+ - Cl) 225.0682, found 225.0700.

2-(2,3-Dichloropropyl)phenol (39). Prepared from 2-allylphenol[6] (100 mg, 0.74 mmol) using a procedure similar to that described above for compound **9** that provided the title compound as a colorless oil (135 mg, 89%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.23 – 7.16 (m, 2H), 6.94 (dd, *J* = 7.4, 7.4 Hz, 1H), 6.79 (d, *J* = 8.0 Hz, 1H), 5.42 (br s, 1H), 4.53 – 4.66 (m, 1H), 3.78 (dd, *J* = 11.7, 5.5 Hz, 1H), 3.76 (dd, *J*= 11.7, 5.36 Hz, 1H), 3.35 (dd, *J* = 14.0, 6.0 Hz, 1H), 3.09 (dd, *J* = 14.0, 7.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 153.6 (C), 131.8 (CH), 128.6 (CH), 123.1 (C), 120.9 (CH), 115.5 (CH), 60.3 (CH), 48.4 (CH_2), 36.5 (CH_2); IR (neat) 3540, 2951, 1609, 1502 cm^{-1}; MS (EI) 204 (M^+); HRMS Calcd for $C_9H_{10}Cl_2O$ (M^+) 204.0109, found 204.0121.

Butyl 2,3-dichloropropanoate[7] (48): Prepared from *n*-butyl acrylate (50 mg, 0.39 mmol) using a procedure similar to that described above for compound **9** that provided

the title compound as a colorless oil (15.5 mg, 20%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.42 (dd, *J* = 8.7, 5.2 Hz, 1H), 4.24 (t, *J* = 6.8 Hz, 2H), 3.96 (dd, *J* = 11.1, 8.7 Hz, 1H), 3.80 (dd, *J* = 11.1, 5.2 Hz, 1H), 1.71 – 1.64 (m, 2H), 1.44 – 1.39 (m, 2H), 0.95 (t, *J* = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.1 (C), 66.5 (CH_2), 55.1 (CH), 43.9 (CH_2), 30.4 (CH_2), 18.9 (CH_2), 13.6 (CH_3); IR (neat) 2936, 1750 cm^{-1}.

General procedure for the halogenation of alkenes and alkynes using ICl.

Reaction of methyl-2-propiolate with ICl. To a solution of methyl-2-propiolate **4** (50 mg, 0.60 mmol, 1.0 equiv) in dichloroethane (25 mL) was added iodine monochloride (1.0 M solution in DCM, 0.60 mL, 0.60 mmol, 1 equiv) and the resulting mixture was stirred for 2 h. The reaction was diluted with Et_2O and washed sequentially with $NaHSO_3$ (20 % wt solution), saturated $NaHCO_3$ and brine. The organic phase was then dried over anhydrous $MgSO_4$, filtered and concentrated *in vacuo*. The pure product was obtained by flash chromatography eluting with hexanes then 5 % EtOAc in hexanes to give an inseparable mixture of compounds **9**, **10**, **6**, and **7** as a pale yellow oil (100 mg, 68 %).

(**10**) ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.89 (s, 1H), 3.85 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.4 (C), 142.6 (CH), 87.7 (C), 53.9 (CH_3). **(6/7)** ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.76 (s, 1H), 3.849 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.9 (C), 128.3 (C), 85.5 (CH), 53.4 (CH_3); **(6/7)** ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.35 (s, 1H), 3.85 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 164.0 (C), 97.5 (C), 87.4 (CH), 53.4 (CH_3); IR (neat) 1725, 1563 cm^{-1}; MS (EI) 246 (M^+).

Reaction of ethyl 2-butynoate with ICl. Prepared from ethyl 2-butynoate (50 mg, 0.45 mmol) using a procedure similar to that described above for compound **10** that provided an inseparable mixture of **12**, **13**, **14**, and **15** as a yellow oil (110 mg, 90%).

(13) ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.27 (q, *J* = 7.2 Hz, 2H), 2.54 (s, 3H), 1.34 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 166.1 (C), 128.3 (C), 84.9 (C), 62.6 (CH_2), 38.3 (CH_3), 13.9 (CH_3). **(14/15)** ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.36 (q, *J* = 7.2 Hz, 2H), 2.66 (s, 3H), 1.35, (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 163.2 (C), 96.9 (C), 64.6 (C), 60.9 (CH_2), 25.2 (CH_3), 13.7 (CH_3). **(14/15)** ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.18 (t, *J* = 7.2 Hz, 2H), 2.48, (s, 3H), 1.24 (t, *J* = 7.2 Hz, 3H); IR (neat) 1728, 1627 cm^{-1}; MS (EI) 274 (M^+).

Reaction of 3-cyclohexylpropiolate with ICl. Prepared from ethyl 3-cyclohexylpropiolate (50 mg, 0.28 mmol) using a procedure similar to that described above for compound **10** that provided an inseparable mixture of **20** and **21** as a yellow oil (95 mg, 99%). **(21)** ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.29 (q, *J* = 7.2 Hz, 2H), 2.96 (tt, *J* = 11.1, 3.3 Hz, 1H), 2.20 – 1.16 (m, 10H), 1.33 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 165.6 (C), 143.0 (C), 68.5 (C), 62.9 (CH_2), 52.0 (CH), 32.8 (CH_2), 26.4 (CH_2), 23.2 (CH_2), 14.3 (CH_3); IR (neat) 1732, 1611 cm^{-1}; MS (EI) 342 (M^+).

Reaction of ethyl phenylpropiolate with ICl. Prepared from ethyl phenylpropiolate (50 mg, 0.29 mmol) using a procedure similar to that described above for compound **10** that provided an inseparable mixture of **23** and **24** as a yellow oil (89 mg, 93%). **(24)** ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.47 – 7.26 (m, 5H), 3.99 (q, *J* = 7.0 Hz, 2H), 0.94 (t, *J* = 7.0 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.6 (C), 149.0 (C), 138.6 (C), 134.7 (CH),

129.8 (CH), 127.9 (CH), 81.2 (C), 62.5 (CH_2), 13.4 (CH_3); IR (neat) 1728, 1615 cm^{-1}; MS (EI) 336 (M^+).

Prepared from 1,4-bis(benzyloxy)but-2-yne (50 mg, 0.19 mmol) using a procedure similar to that described above for compound **10** that provided an inseparable mixture of compounds **30** and **31** as a yellow oil (81 mg, 99 %). **(31)** ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.49 – 7.29 (m, 10H), 4.57 (s, 2H), 4.54 (s, 2H), 4.51 (s, 2H), 4.47 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 131.3 (C), 128.6 (C), 128.5 (C), 128.4 (CH), 127.92 (CH), 127.88 (CH), 100.8 (C), 81.5 (CH_2), 76.3 (CH_2), 73.1 (CH_2), 71.9 (CH_2); IR (neat) 1461, 1376 cm^{-1}; MS (EI) 393 (M^+ - Cl), 301 (M^+ - I).

Reaction of alloxybenzene with ICl. Prepared from allyloxybenzene (50 mg, 0.37 mmol) using a procedure similar to that described above for compound **10** that provided an inseparable mixture of compounds **33** and **34** as a yellow oil (89.8 mg, 82%). **(34)** ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.37 – 7.33 (m, 2H), 7.06 – 7.02 (m, 1H), 6.99 – 6.96 (m, 2H), 4.54 – 4.29 (m, 1H), 4.07 (d, J = 6.8 Hz, 2H), 3.74 (dd, J = 10.7, 6.4 Hz, 1H), 3.67 (dd, J = 10.7, 4.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 157.8 (C), 129.3 (CH), 121.6 (CH), 114.7 (CH), 70.2 (CH_2), 54.1 (CH), 6.7 (CH_2); IR (neat) 1594, 1500 cm^{-1}; MS (EI) 296 (M^+).

Reaction of pent-4-enyl benzoate with ICl. Prepared from pent-4-enyl benzoate[8] (50 mg, 0.26 mmol) using a procedure similar to that described above for compound **10** that provided an inseparable mixture of compounds **36** and **37** as a colorless oil (85 mg, 92%). **(37)** ^{1}H NMR (400 MHz, acetone-d_6) δ 8.06 (d, J = 10.4 Hz, 2H), 7.57 (dd, J = 10.0, 10.0 Hz), 7.44 (dd, J = 10.4, 10.4 Hz), 4.37 (t, J = 8.0 Hz, 2H), 4.35 – 4.23 (m, 1H), 4.09 – 3.86 (dd, J = 17.2, 5.6 Hz, 1H), 3.83 (dd, J = 14.4, 14.4 Hz, 1H), 2.33 – 1.86 (m, 4H); ^{13}C

NMR (100 MHz, acetone-d_6) δ 166.5 (C), 133.0 (CH), 130.1 (C), 129.5 (CH), 128.4 (CH), 63.7 (CH_2), 33.9 (CH), 33.1 (CH_2), 28.2 (CH_2), 10.3 (CH_2); IR (neat) 1718, 1615 cm^{-1}; MS (EI) 225 (M^+ - I), 317 (M^+ - Cl).

2-(2-chloro-3-iodopropyl)phenol (40). Prepared from 2-allylphenol[6] (50 mg, 0.37 mmol) using a procedure similar to that described above for compound **10** that provided compound **40** as a yellow oil (109 mg, 99%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.17 – 7.11 (m, 2H), 6.87 (ddd, J = 8.0, 7.6, 0.8 Hz, 1H), 6.78 (d, J = 8.0 Hz), 4.92 – 4.85 (m, 1H), 3.45 (dd, J_{AB} = 8.8, J_{AX} = 6.4 Hz, 1H), 3.34 (dd, J_{AB} = 8.8, J_{BX} = 6.1 Hz, 1H), 3.40 (dd, J = 15.7, 8.9 Hz, 1H), 3.05 (dd, J = 15.7, 6.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.1 (C), 128.2 (CH), 125.7 (C), 125.0 (CH), 120.8 (CH), 109.6 (CH), 81.6 (CH), 36.1 (CH_2), 8.9 (CH_2); IR (neat) 1506, 1479 cm^{-1}; **HRMS** calc'd for $C_9H_{10}ClIO$ (M^+) 295.9465, found 295.9467.

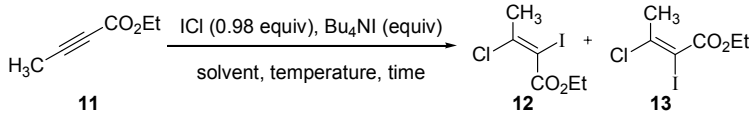
Reaction of 5-decene with ICl.[9] Prepared from 5-decene (0.135 mL, 0.71 mmol) using a procedure similar to that described above for compound **7** that provided compound **43** as an inseparable mixture of 5,6-dichlorodecane (**42**) and 5-chloro-6-iododecane (**43**) as a colorless oil (142 mg, 66%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.26 – 4.21 (m, 1H), 3.93 – 3.88 (m, 1H), 2.11 – 2.03 (m, 1H), 1.98 – 1.80 (m, 3H), 1.62 – 1.52 (m, 2H), 1.46 – 1.27 (m, 6H), 0.93 (t, J = 7.3 Hz, 3H); ^{13}C NMR (100 MHz, acetone-d_6) δ 66.9 (CH), 42.5 (CH), 37.5 (CH_2), 36.8 (CH), 31.3 (CH_2), 28.2 (CH_2), 22.1 (CH_2), 21.9 (CH_2), 13.9 (CH_3); IR (neat) 2957, 2931, 1465 cm^{-1}; MS (EI) 302 (M^+); HRMS calc'd for $C_{10}H_{20}ClI$ (M+) 302.0298, found 302.0218.

Reaction of ((3-methylbut-3-enyloxy)methyl)benzene with ICl. Prepared from ((3-methylbut-3-enyloxy)methyl)benzene[10] (50 mg, 0.28 mmol) using a procedure similar to

that described above for compound **10** that provided an inseparable mixture of compounds **45** and **46** as a colorless oil (12 mg, 14%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.36 – 7.36 (m, 5H), 4.51 (s, 2H), 3.81 – 3.60 (m, 4H), 2.29 – 2.15 (m, 2H), 1.66 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 138.1 (C), 128.4 (CH), 127.6 (CH), 127.5 (CH), 73.1 (CH_2), 70.2 (C), 66.7 (CH_2), 41.2 (CH_2), 28.6 (CH_3), 18.9 (CH_2); IR (neat) 2925, 1273 cm^{-1}; MS (EI) 338 (M^+).

Reaction of *n*-butyl acrylate with ICl. Prepared from *n*-butyl acrylate (50 mg, 0.39 mmol) using a procedure similar to that described above for compound **10** that provided an inseparable mixture of compounds **48** and **49** as a yellow oil (67 mg, 61 %).[7]

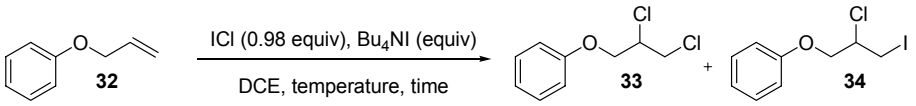
Summary of variable Bu_4NI amount control reactions:



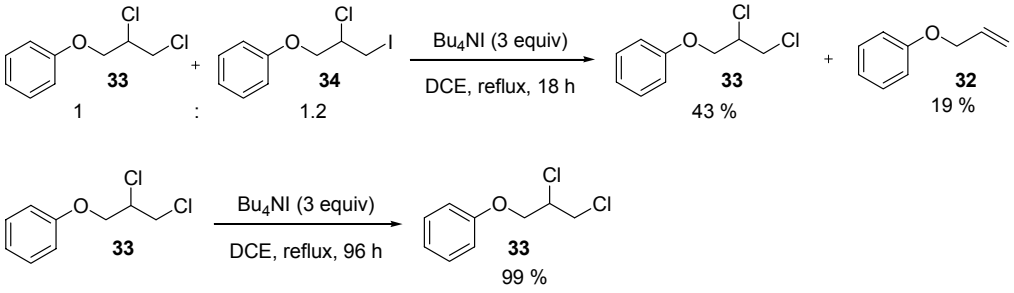
11 12 13

General procedure: To a solution of alkyne **11** (50 mg, 0.45 mmol, 1 equiv) in DCE (4.0 mL) was added Bu_4NI (41 mg, 0.11 mmol, 0.25 equiv). To this was added ICl (1 M solution in DCM, 0.44 mL, 0.44 mmol, 0.98 equiv). The reaction was stirred for 2 hours, upon which time the solution was diluted with Et_2O and washed sequentially with $NaHSO_3$ (20 % solution), a saturated solution of $NaHCO_3$ and brine. The organic layer was dried over anhydrous $MgSO_4$, filtered and concentrated to give a mixture of compounds **12**:**13** (28 mg, 23 % combined yield).

Equiv Bu_4NI	Temperature	Time	Solvent	Yield (%)	12:13 Ratio
0.25	rt	2 h	DCE	23	19:1
0.50	rt	2 h	DCE	6	19:1
1.05	rt	2 h	DCE	trace	-
3.00	rt	2 h	DCE	no reaction	-
3.00	reflux	18 h	DCE	30	12 exclusively
3.00	reflux	18 h	benzene	2	12 exclusively



Equiv Bu_4NI	Temperature	Time	Solvent	Yield (%)	33:34
0.25	rt	5 h	DCE	62	1:1
0.50	rt	5 h	DCE	11	1.2:1
1.05	rt	5 h	DCE	6	1:1
3.00	rt	5 h	DCE	trace	1:1
3.00	reflux	18 h	DCE	32	**33** exclusively
3.00	reflux	18 h	benzene	9	**33** exclusively



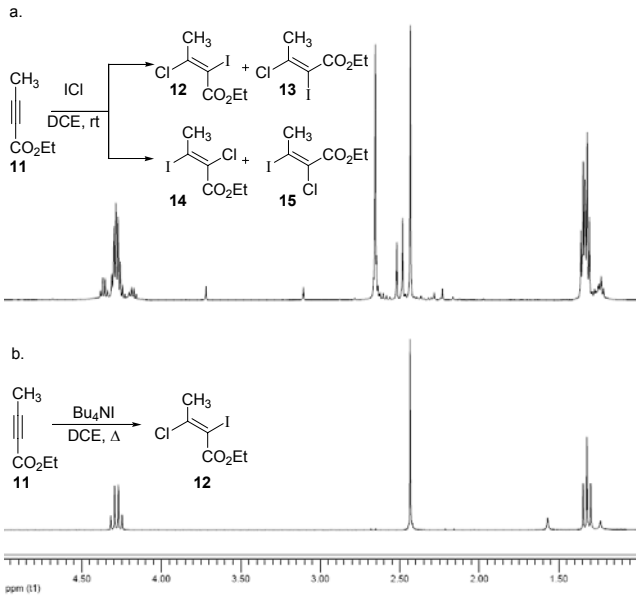
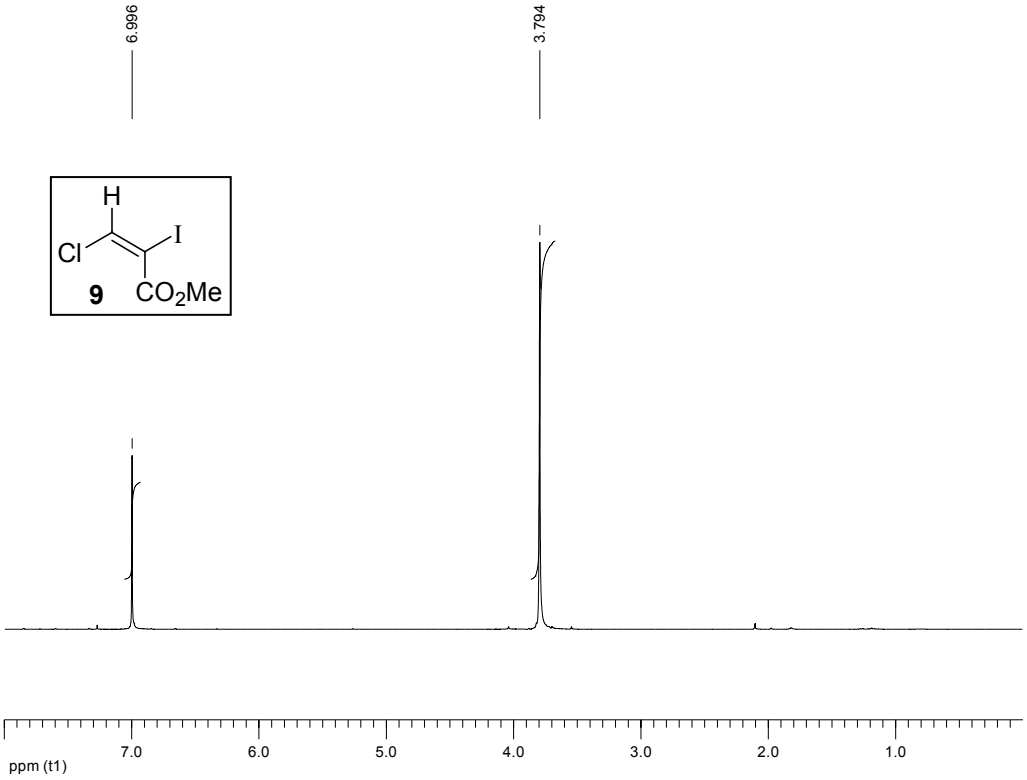
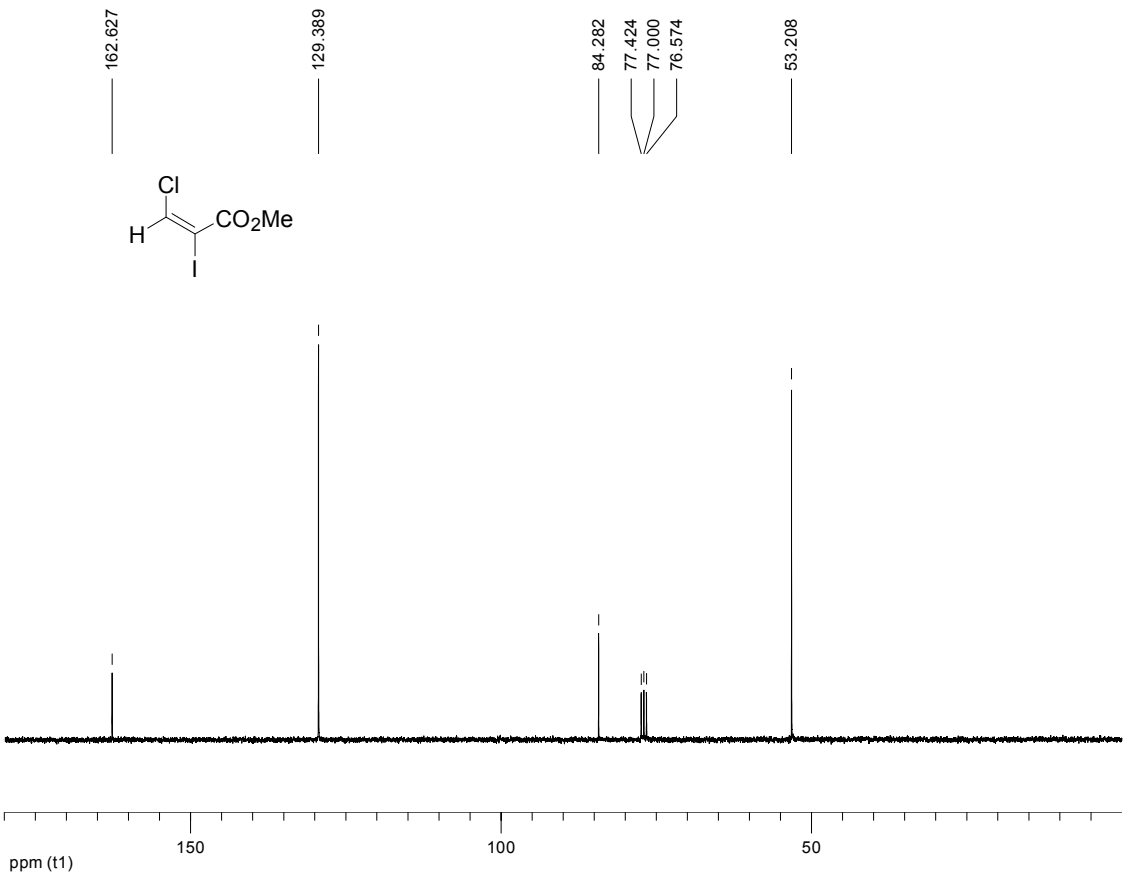
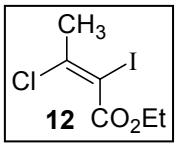


Figure 1. Comparison of the crude products obtained from the reaction of **11** with ICl (1a) and with Bu_4NI/DCE (1b).

NMR Spectra


6.996
3.794
H
Cl
I
9
CO2Me
7.0
6.0
5.0
4.0
3.0
2.0
1.0
ppm (t1)

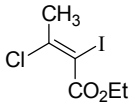

162.627
129.389
84.282
77.424
77.000
76.574
53.208
Cl
CO2Me
H
I
150
100
50
ppm (t1)


CH3
Cl
I
CO2Et

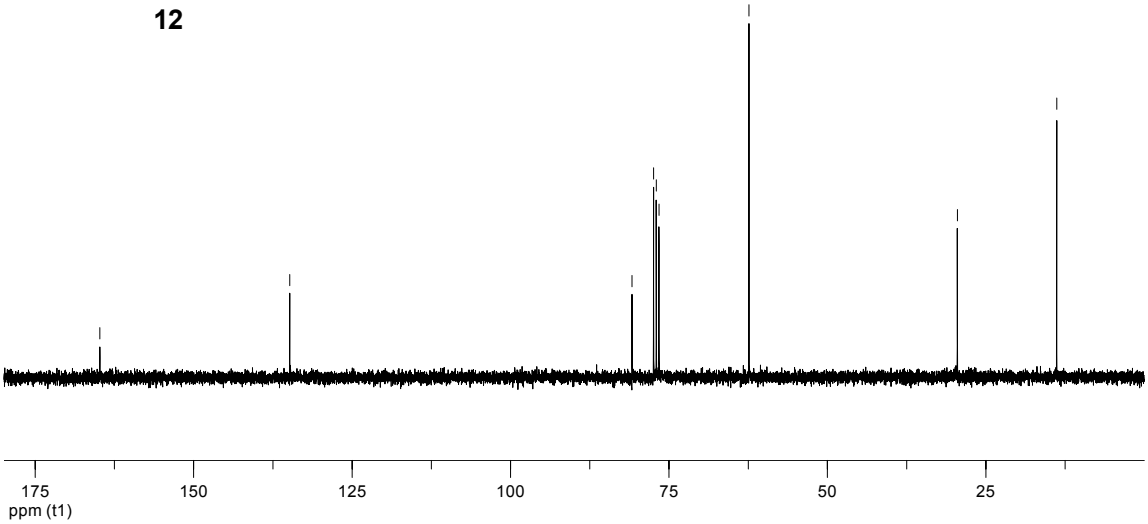
12

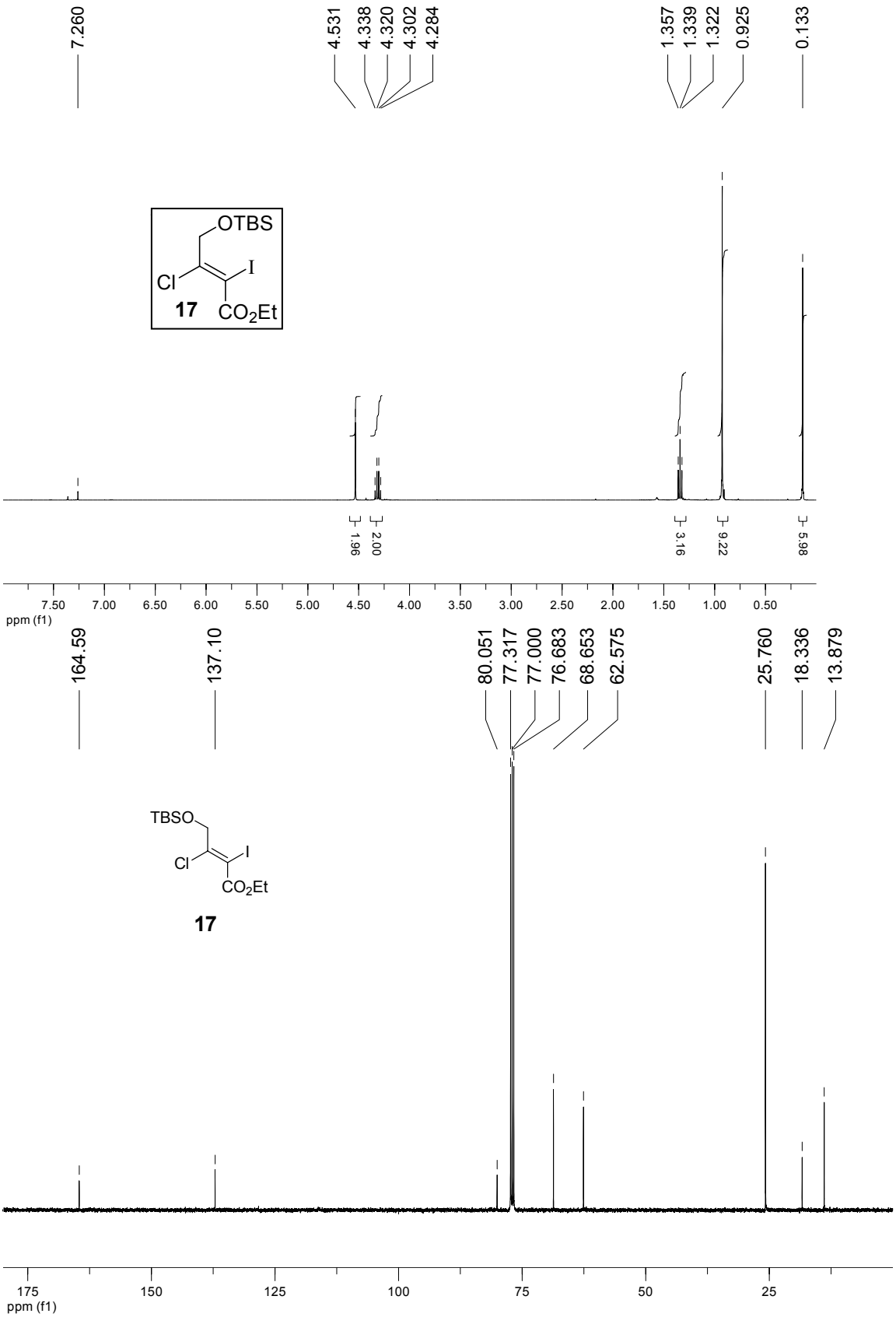
4.312
4.289
4.265
4.241
2.432
1.343
1.319
1.296
7.0
6.0
5.0
4.0
3.0
2.0
1.0
ppm (t1)

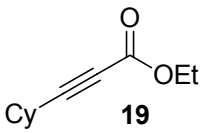
164.78
134.83
80.828
77.423
77.000
76.575
62.369
29.495
13.818


CH3
Cl
I
CO2Et

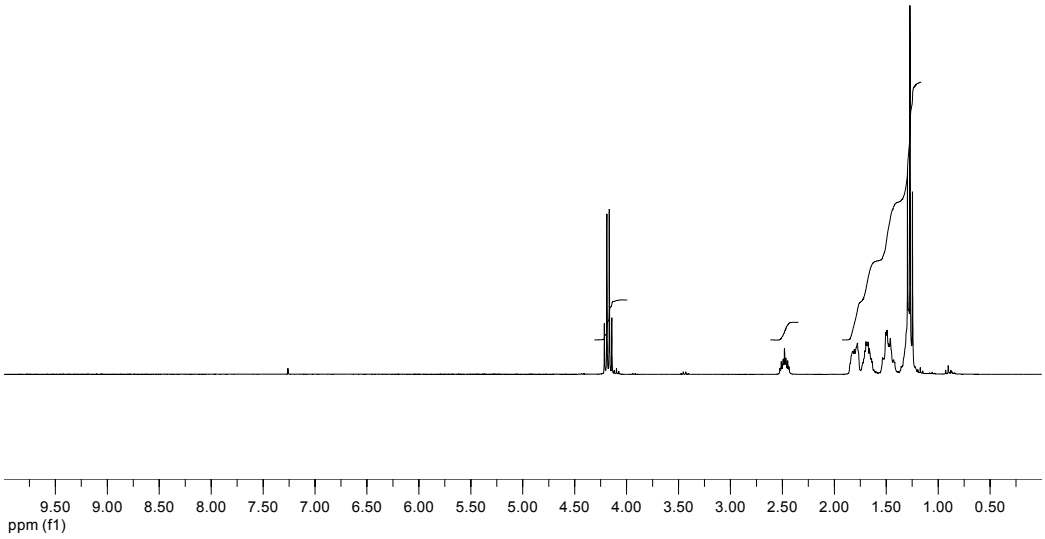
12

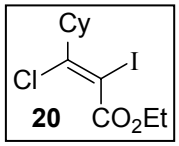

175
150
125
100
75
50
25
ppm (t1)


7.260
4.531
4.338
4.320
4.302
4.284
1.357
1.339
1.322
0.925
0.133
OTBS
Cl
I
17
CO2Et
1.96
2.00
3.16
9.22
5.68
7.50 7.00 6.50 6.00 5.50 5.00 4.50 4.00 3.50 3.00 2.50 2.00 1.50 1.00 0.50
ppm (f1)
164.59
137.10
80.051
77.317
77.000
76.683
68.653
62.575
25.760
18.336
13.879
TBSO
Cl
I
CO2Et
17
175 150 125 100 75 50 25
ppm (f1)


O
OEt
Cy

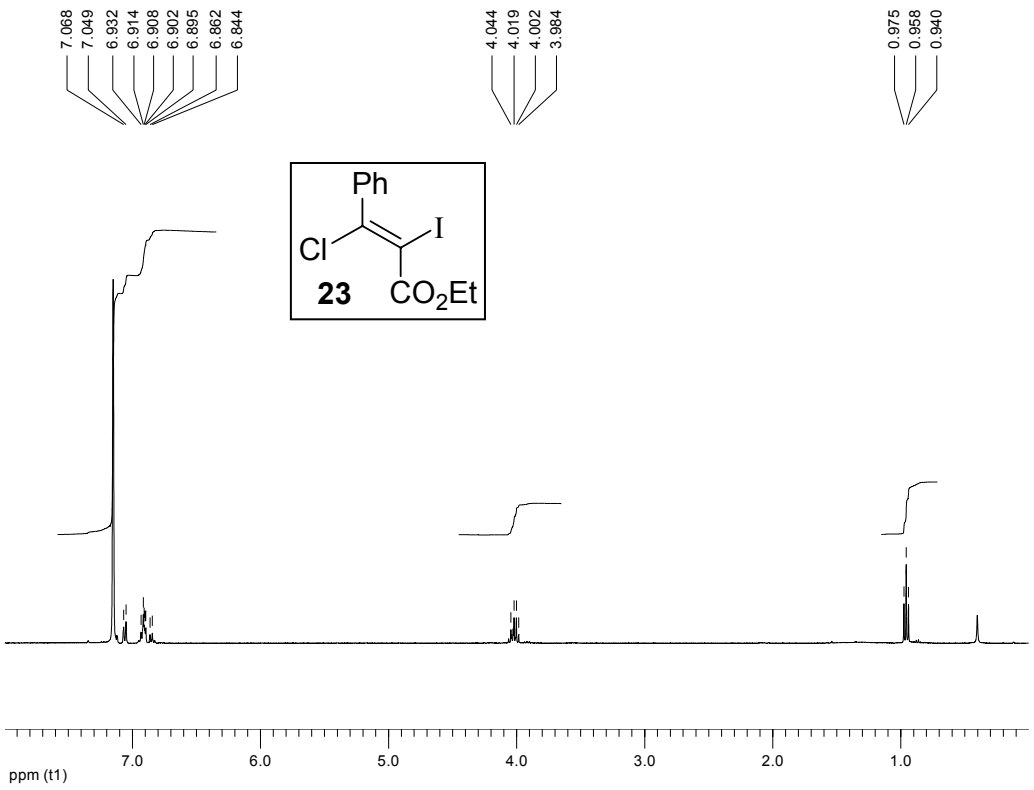
19

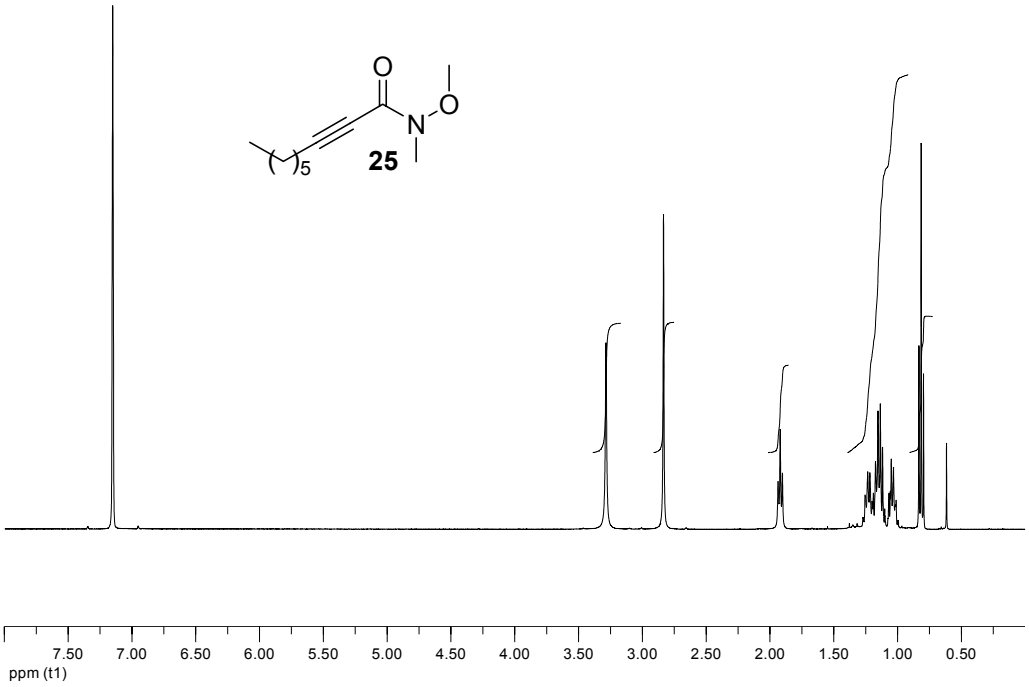

9.50 9.00 8.50 8.00 7.50 7.00 6.50 6.00 5.50 5.00 4.50 4.00 3.50 3.00 2.50 2.00 1.50 1.00 0.50
ppm (f1)

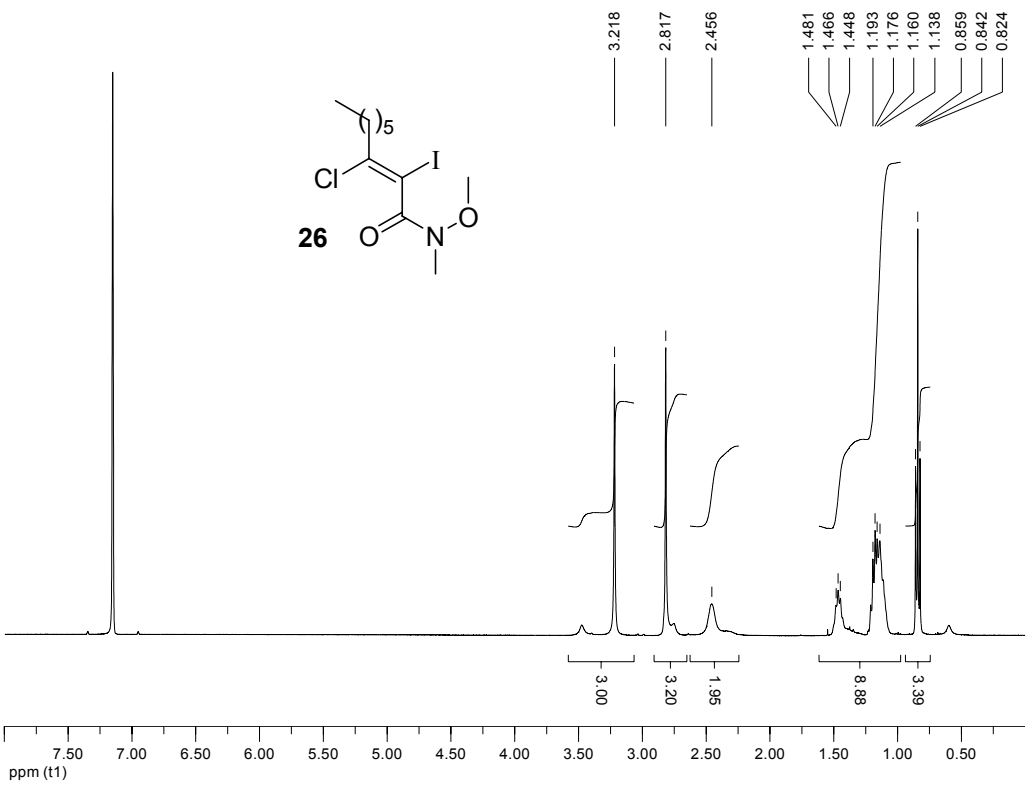

Cy
Cl
I
CO2Et

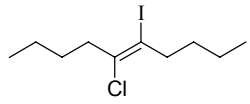
20

2.00
0.94
7.55
6.60
7.0 6.0 5.0 4.0 3.0 2.0 1.0
ppm (t1)

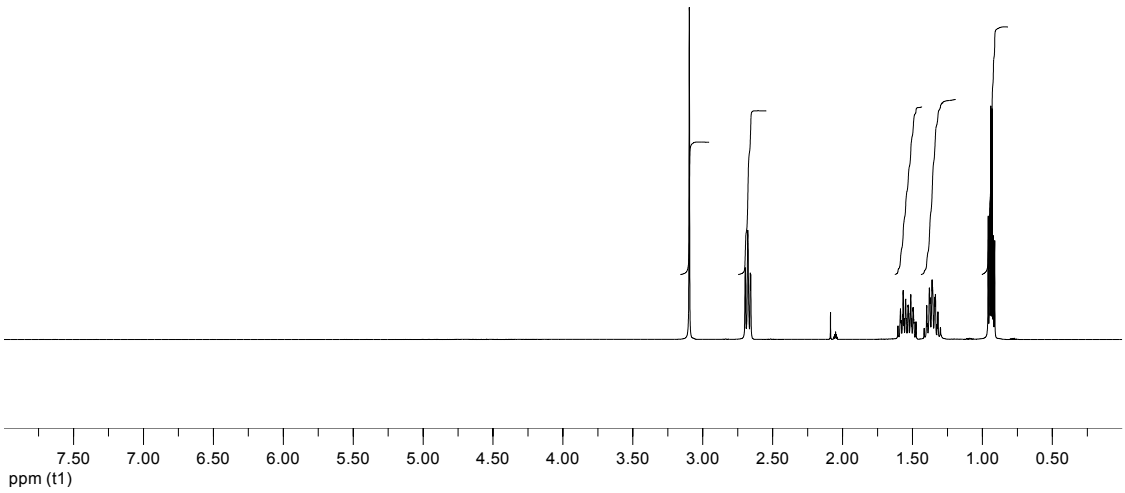

7.068
7.049
6.932
6.914
6.908
6.902
6.895
6.862
6.844
4.044
4.019
4.002
3.984
0.975
0.958
0.940
Ph
Cl
I
23
CO2Et
7.0
6.0
5.0
4.0
3.0
2.0
1.0
ppm (t1)


O
N
O
5
25
7.50 7.00 6.50 6.00 5.50 5.00 4.50 4.00 3.50 3.00 2.50 2.00 1.50 1.00 0.50
ppm (t1)

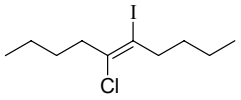

3.218
2.817
2.456
1.481
1.466
1.448
1.193
1.176
1.160
1.138
0.859
0.842
0.824
5
Cl
I
O
N
O
26
3.00
3.20
1.95
8.88
3.39
7.50 7.00 6.50 6.00 5.50 5.00 4.50 4.00 3.50 3.00 2.50 2.00 1.50 1.00 0.50
ppm (t1)


I
Cl

28

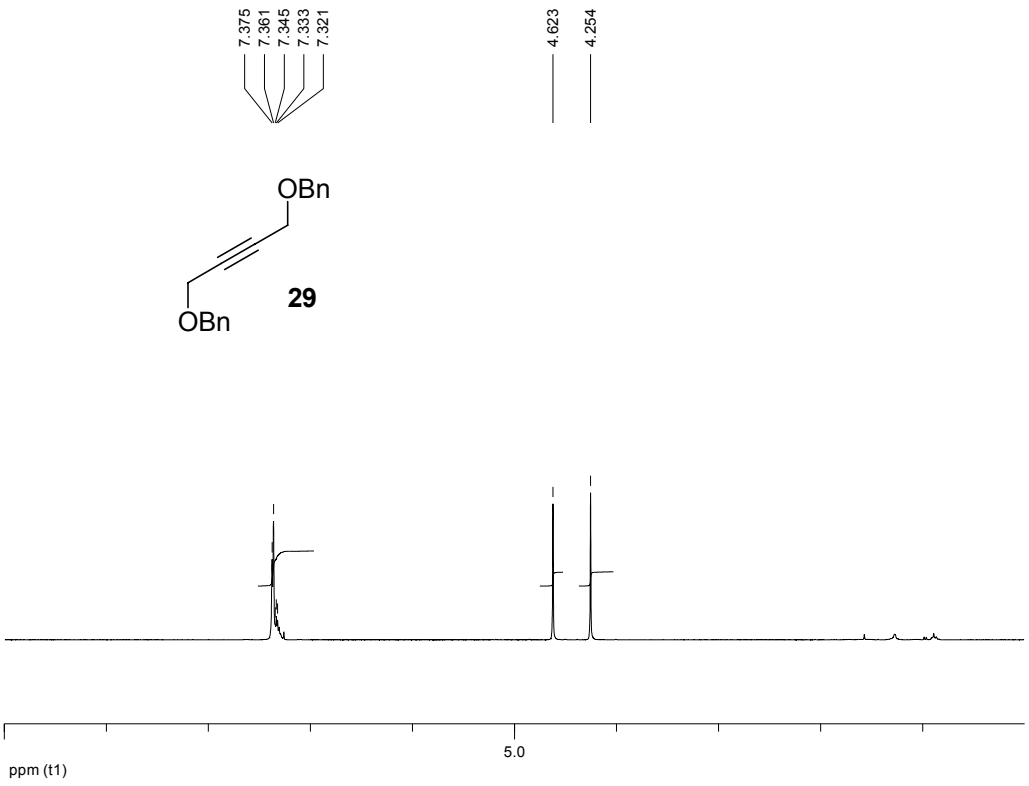

7.50
7.00
6.50
6.00
5.50
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
ppm (t1)

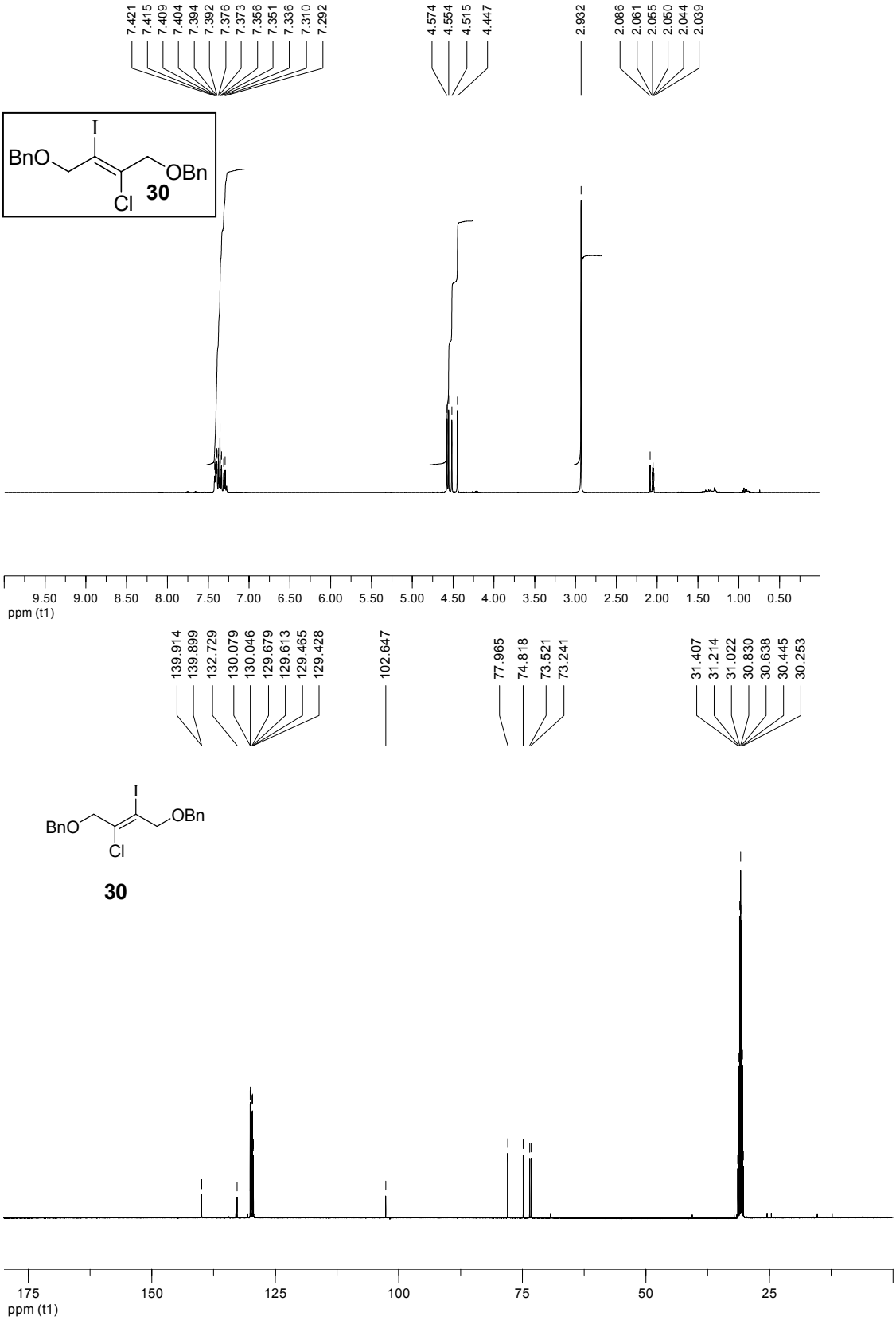

132.981
100.633
44.260
43.160
32.202
31.407
31.215
31.022
30.899
30.830
30.638
30.445
30.253
23.289
23.033

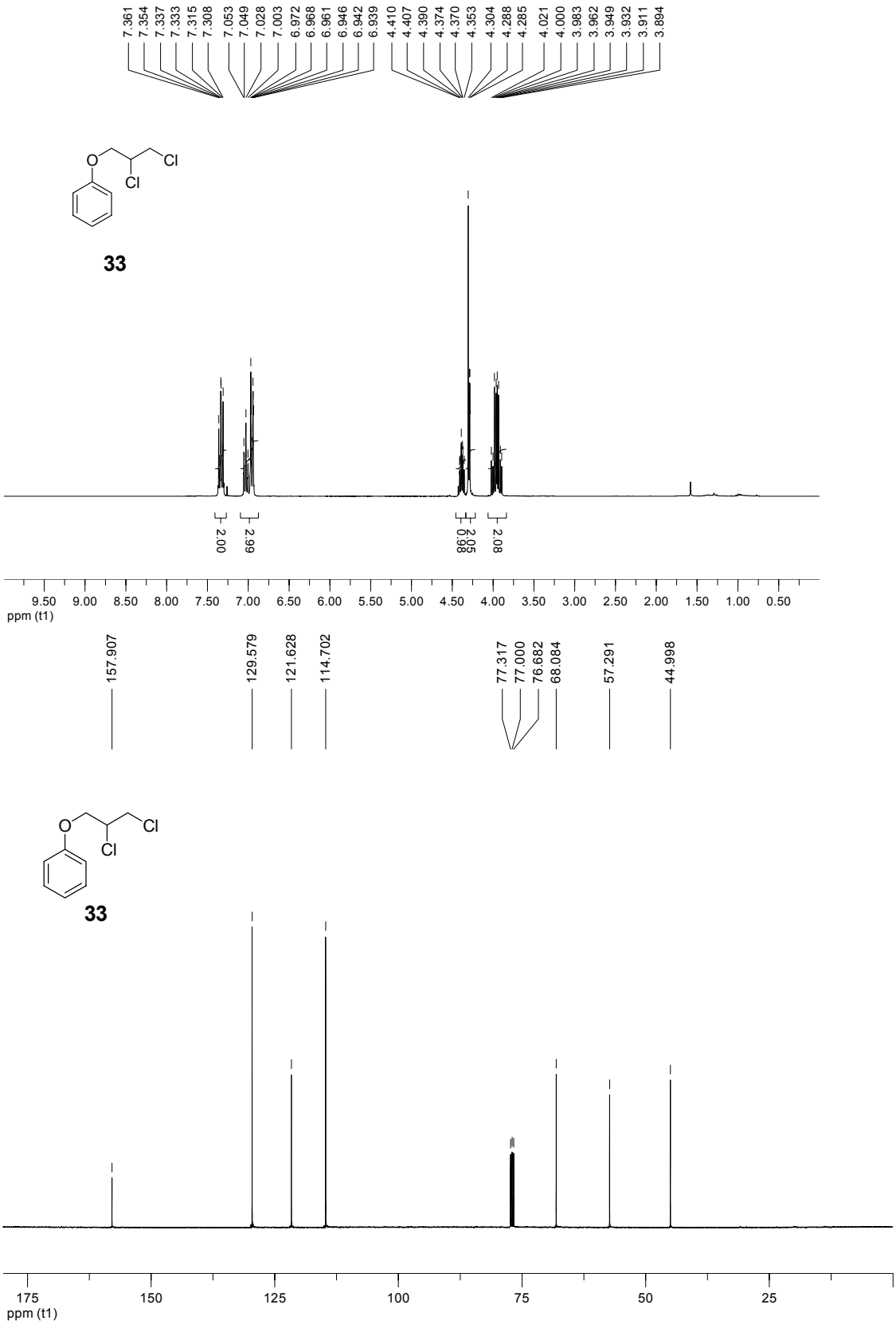

I
Cl

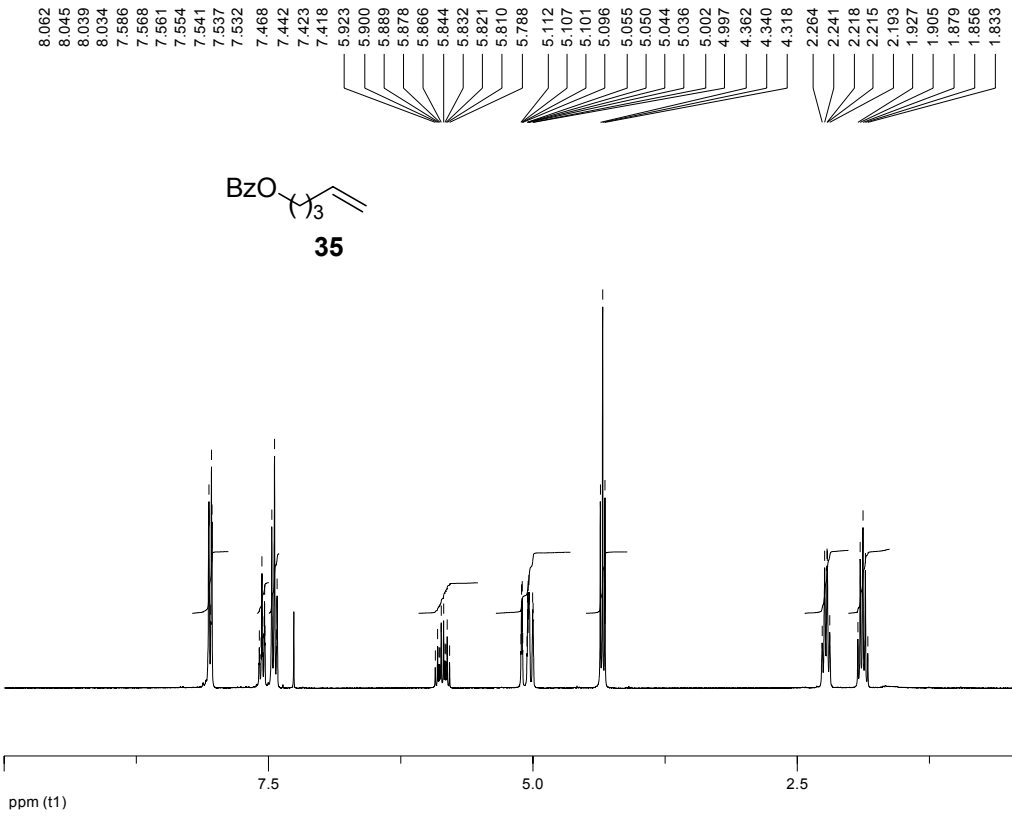
28

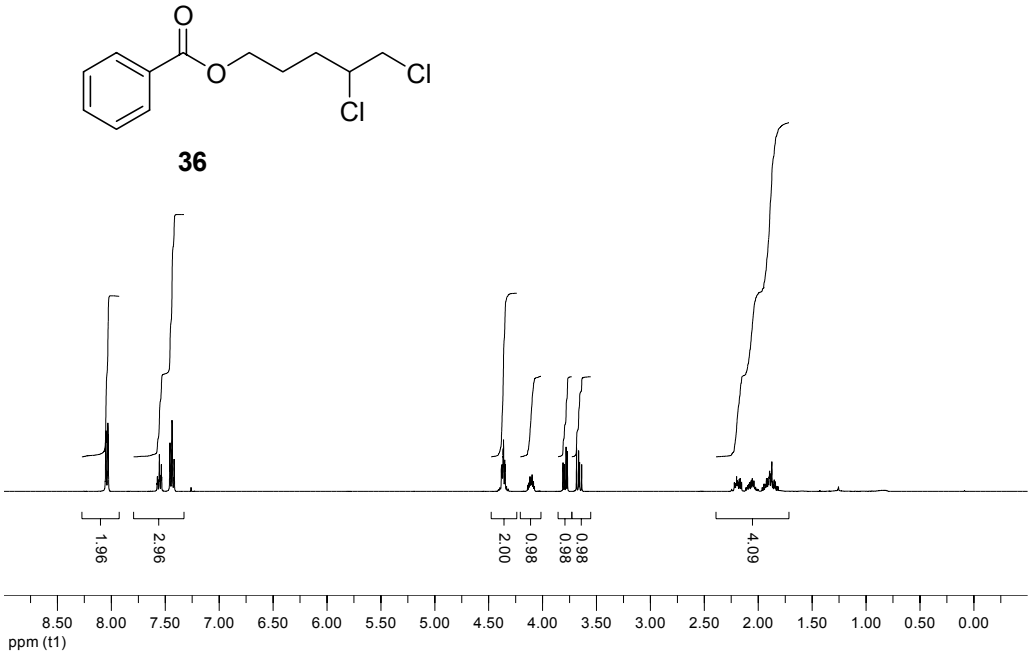
175
150
125
100
75
50
25
ppm (t1)

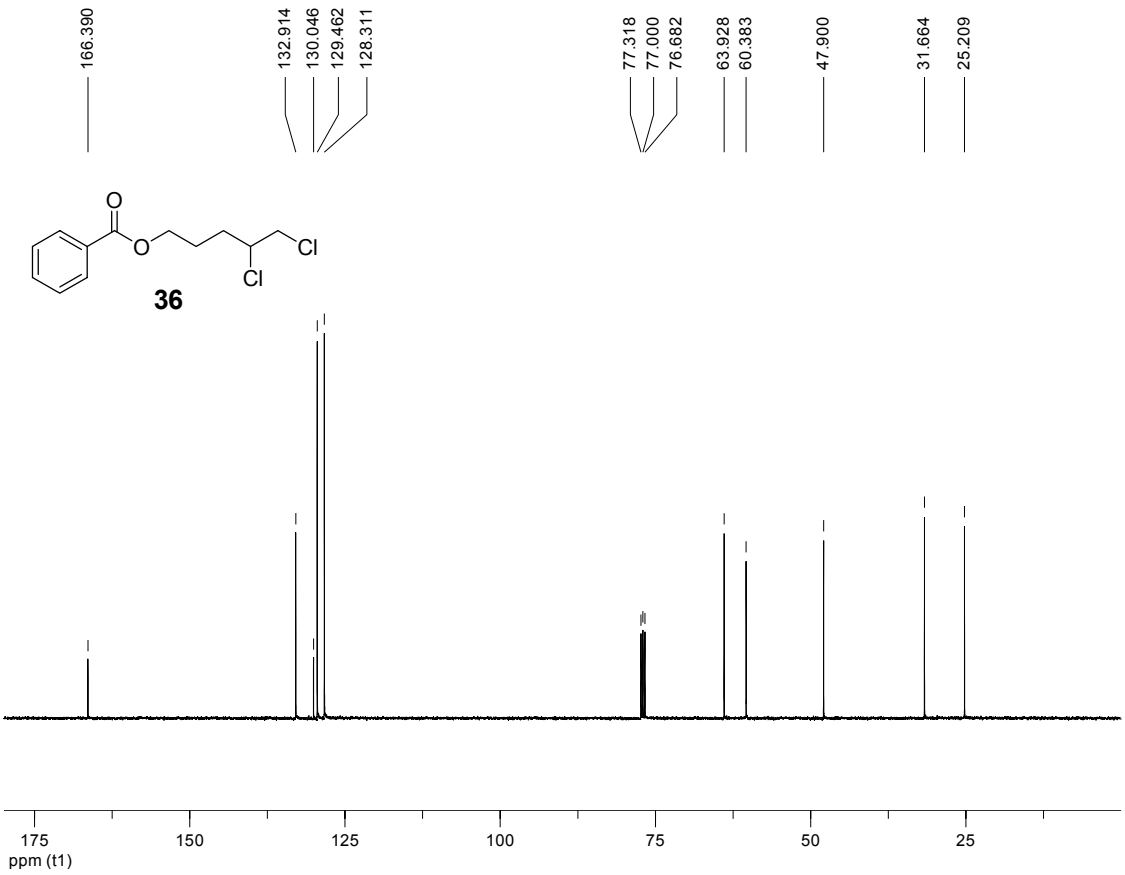

7.375
7.361
7.345
7.333
7.321
4.623
4.254
OBn
OBn
29
5.0
ppm (t1)

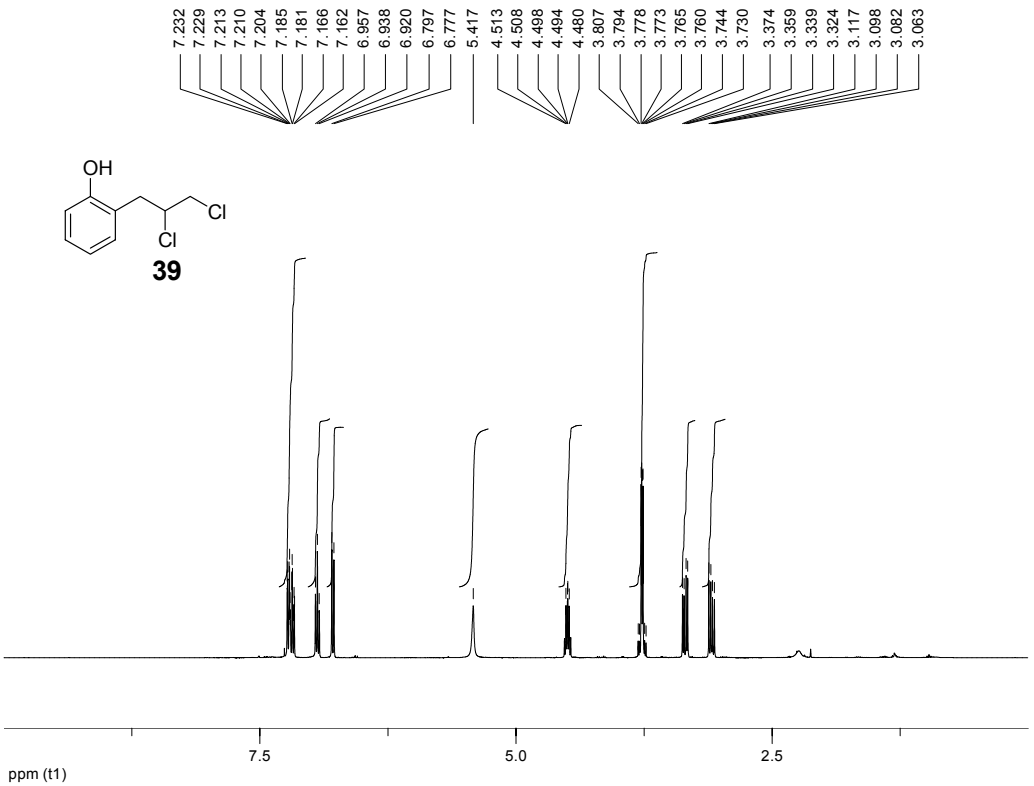

7.421
7.415
7.409
7.404
7.394
7.392
7.376
7.373
7.356
7.351
7.336
7.310
7.292
4.574
4.554
4.515
4.447
2.932
2.086
2.061
2.055
2.050
2.044
2.039
I
BnO
OBn
Cl
30
9.50 9.00 8.50 8.00 7.50 7.00 6.50 6.00 5.50 5.00 4.50 4.00 3.50 3.00 2.50 2.00 1.50 1.00 0.50
ppm (t1)
139.914
139.899
132.729
130.079
130.046
129.679
129.613
129.465
129.428
102.647
77.965
74.818
73.521
73.241
31.407
31.214
31.022
30.830
30.638
30.445
30.253
I
BnO
OBn
Cl
30
175
150
125
100
75
50
25
ppm (t1)

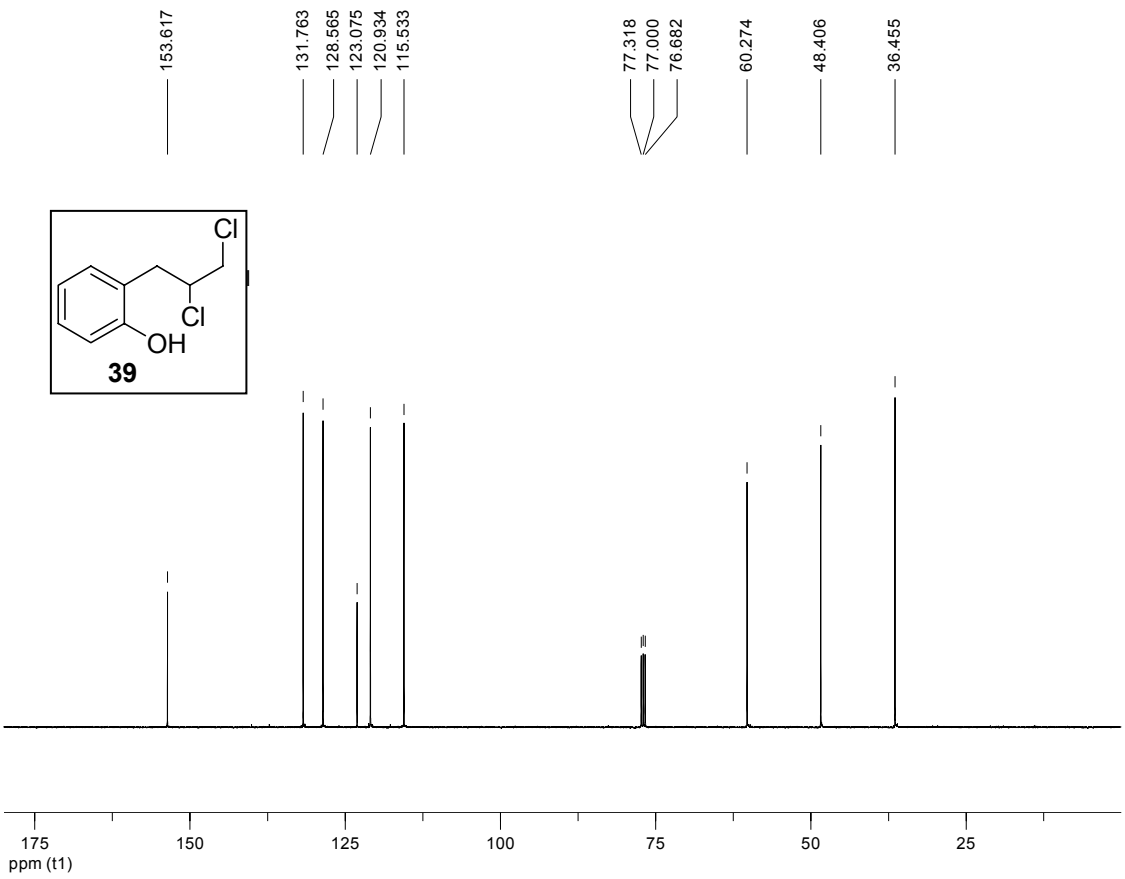

7.361
7.354
7.337
7.333
7.315
7.308
7.053
7.049
7.028
7.003
6.972
6.968
6.961
6.946
6.942
6.939
4.410
4.407
4.390
4.374
4.370
4.353
4.304
4.288
4.285
4.021
4.000
3.983
3.962
3.949
3.932
3.911
3.894
O
Cl
Cl
33
2.00
2.99
0.88
2.05
2.08
9.50 9.00 8.50 8.00 7.50 7.00 6.50 6.00 5.50 5.00 4.50 4.00 3.50 3.00 2.50 2.00 1.50 1.00 0.50
ppm (t1)
157.907
129.579
121.628
114.702
77.317
77.000
76.682
68.084
57.291
44.998
O
Cl
Cl
33
175
150
125
100
75
50
25
ppm (t1)

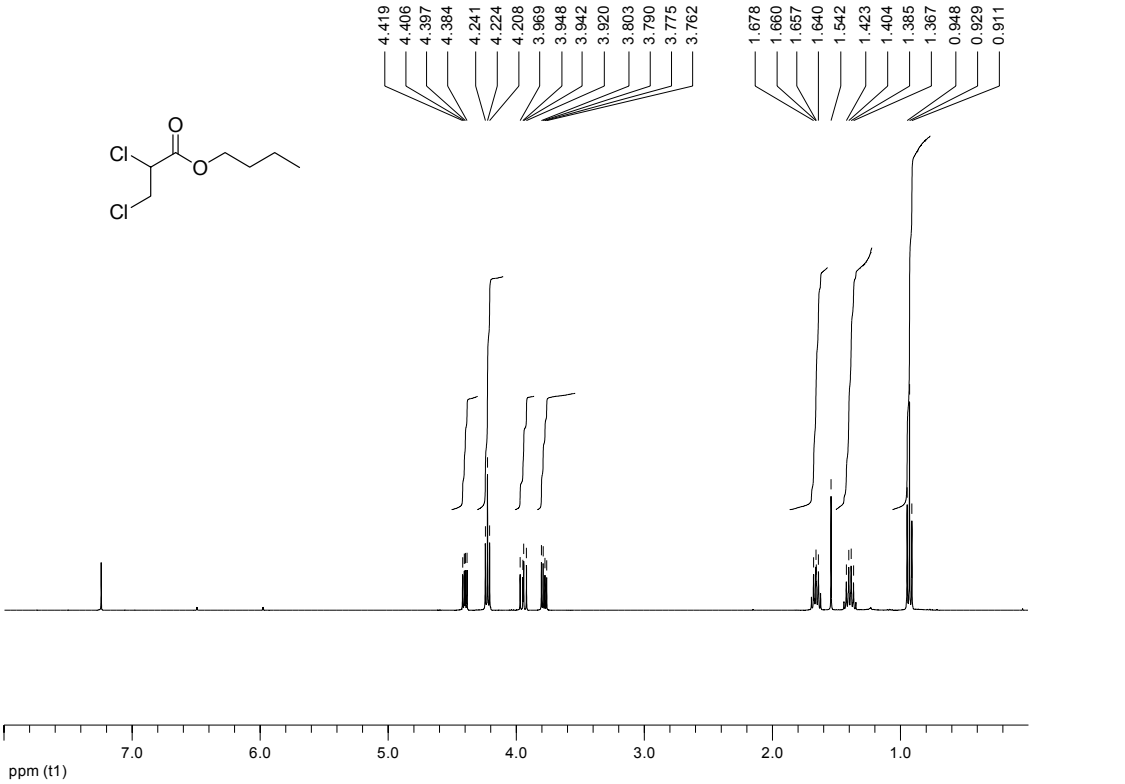

8.062
8.045
8.039
8.034
7.586
7.568
7.561
7.554
7.541
7.537
7.532
7.468
7.442
7.423
7.418
5.923
5.900
5.889
5.878
5.866
5.844
5.832
5.821
5.810
5.788
5.112
5.107
5.101
5.096
5.055
5.050
5.044
5.036
5.002
4.997
4.362
4.340
4.318
2.264
2.241
2.218
2.215
2.193
1.927
1.905
1.879
1.856
1.833
BzO
3
35
7.5
5.0
2.5
ppm (t1)

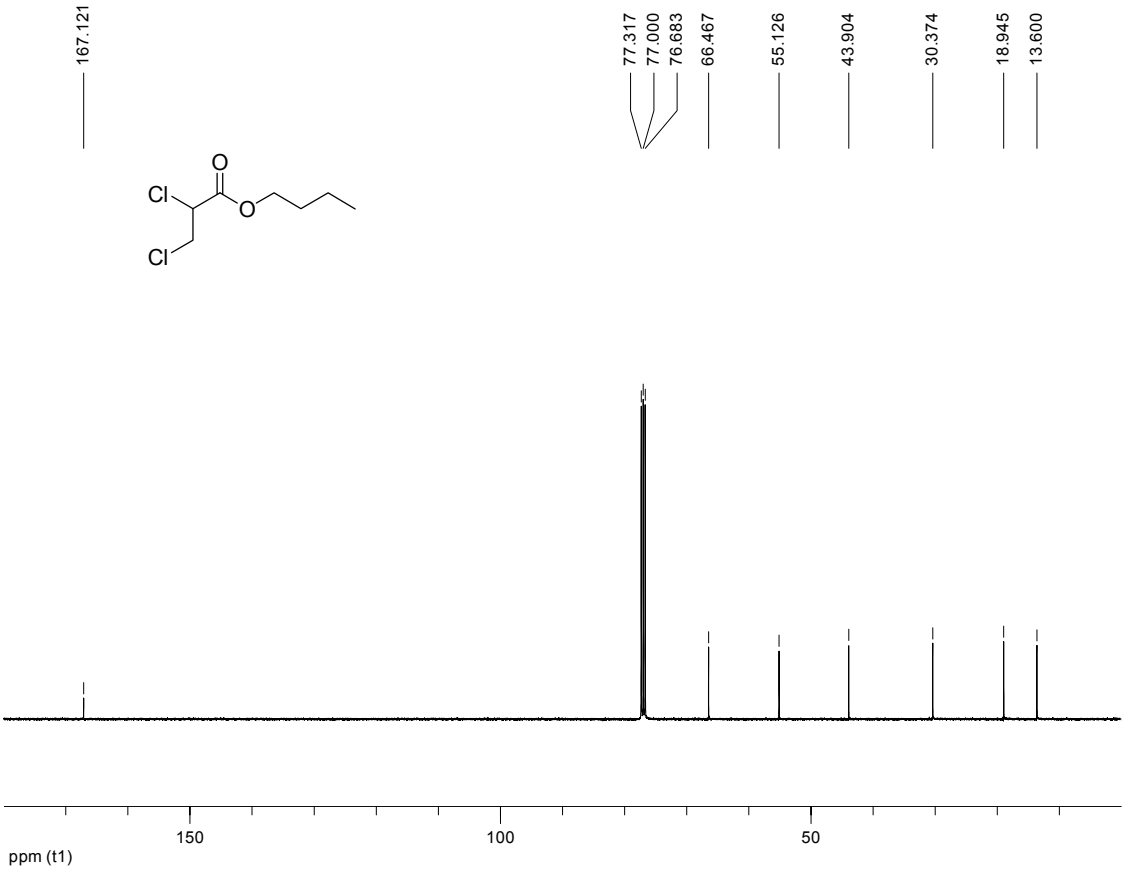

O
O
Cl
Cl
36
1.96
2.96
2.00
0.98
0.98
0.98
4.09
8.50
8.00
7.50
7.00
6.50
6.00
5.50
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
ppm (t1)

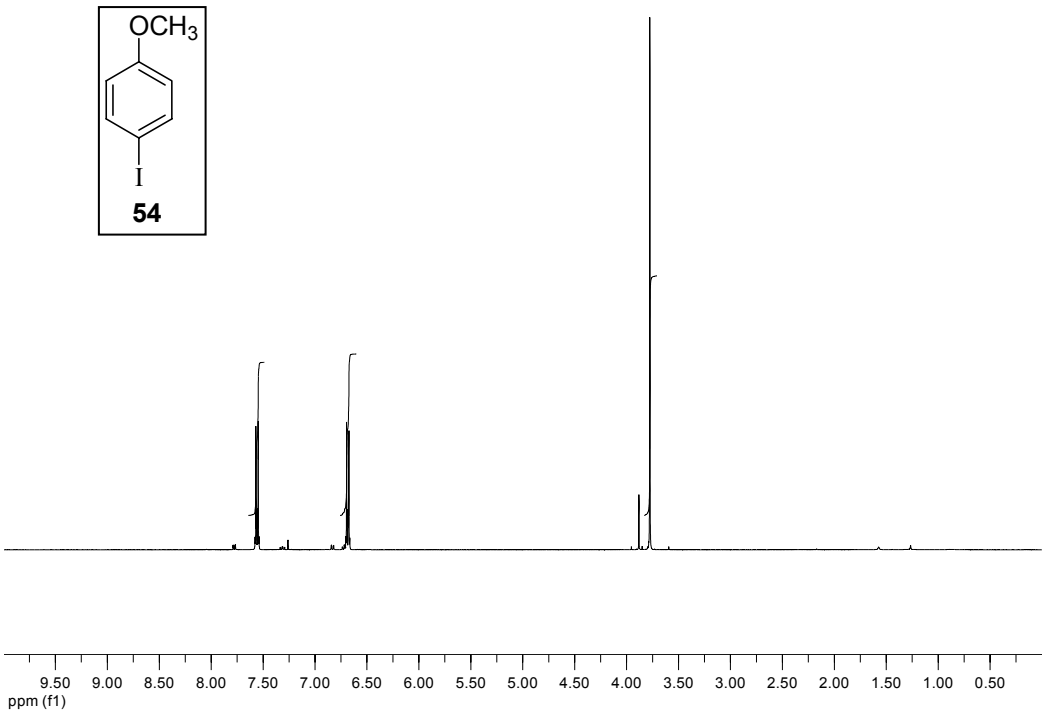

166.390
132.914
130.046
129.462
128.311
77.318
77.000
76.682
63.928
60.383
47.900
31.664
25.209
O
O
Cl
Cl
36
175
150
125
100
75
50
25
ppm (t1)


7.232
7.229
7.213
7.210
7.204
7.185
7.181
7.166
7.162
6.957
6.938
6.920
6.797
6.777
5.417
4.513
4.508
4.498
4.494
4.480
3.807
3.794
3.778
3.773
3.765
3.760
3.744
3.730
3.374
3.359
3.339
3.324
3.117
3.098
3.082
3.063
OH
Cl
Cl
39
7.5
5.0
2.5
ppm (t1)


153.617
131.763
128.565
123.075
120.934
115.533
77.318
77.000
76.682
60.274
48.406
36.455
Cl
Cl
OH
39
175
150
125
100
75
50
25
ppm (t1)


4.419
4.406
4.397
4.384
4.241
4.224
4.208
3.969
3.948
3.942
3.920
3.803
3.790
3.775
3.762
1.678
1.660
1.657
1.640
1.542
1.423
1.404
1.385
1.367
0.948
0.929
0.911
O
Cl
O
Cl
7.0
6.0
5.0
4.0
3.0
2.0
1.0
ppm (t1)


167.121
77.317
77.000
76.683
66.467
55.126
43.904
30.374
18.945
13.600
O
Cl
O
Cl
150
100
50
ppm (t1)



(1) Lemay, A. B.; Vulic, K. S.; Ogilvie, W. W. *J. Org. Chem.* **2006**, *71*, 3615.

(2) Smith, A. B. III; Beiger, J. J.; Davulcu, A. H.; Cox, J. M. *Org. Syn.* **2005**, *82*, 147.

(3) Hecht, S.; Frechet, J. M. J. *J. Am. Chem. Soc.* **1999**, *121*, 4084.

(4) Alternative preparation from epoxides: (a) Iranpoor, N.; Firouzabadi, H.; Azadi, R.; Ebrahimzadeh, F. *Can. J. Chem.* **2006**, *84,* 69. (b) Firouzabadi, H.; Shiriny, F. *Tetrahedron*, **1996**, *52*, 14929. (c) Iranpoor, N.; Firouzabadi, H.; Aghapour, G.; Nahid, A. *Bull. Chem. Soc. Jap.* **2004**, *77*, 1885.

(5) Kabalka, G. W. and Gooch, E. E. III. *J. Org. Chem.*, **1980**, *45*, 3578.

(6) Van, T. N.; Debenedetti, S.; De Kimpe, N. *Tetrahedron Lett.* **2003**, *44*, 4199.

(7) Horna, A.; Taborsky, J.; Churacek, J.; Dufka, O. *J. Chromatography* **1985**, *348*, 141.

(8) Kabalka, G. W.; Gooch, E. E. III. *J. Org. Chem.* **1980**, *45*, 3578.

(9) Zavada, J.; Kruipicka, J.; Kocian, O.; Pankova, M. *Collection of Czechoslovak Chemical Communications* **1983**, *48*, 3552.

(10) Bondar, D.; Liu, J.; Müller, T.; Paquette, L. A. *Org. Lett.* **2005**, *7*, 1813.