Supporting Information

One-Pot, Two-Step Synthesis of Unnatural α-Amino Acids Involving the Exhaustive Aerobic Oxidation of 1,2-Diols

Haruki Inada, Keisuke Furukawa, Masatoshi Shibuya,* and Yoshihiko Yamamoto

Department of Basic Medicinal Sciences, Graduate School of Pharmaceutical Sciences, Nagoya University, Furo-cho, Chikusa, Nagoya 464-8601, Japan

Corresponding author, Email: m-shibu@ps.nagoya-u.ac.jp

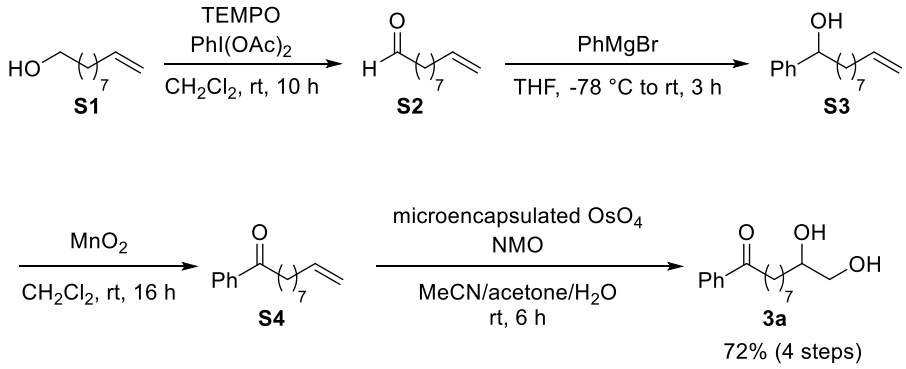
1. General considerations

All reactions were carried out under an argon atmosphere, stirred magnetically, unless otherwise noted. Reactions were monitored by thin-layer chromatography (TLC: Merck Silica Gel 60 F_{254}). Column chromatography was carried out using neutral silica gel (Cica silica gel 60N, particle size 0.040-0.050 mm, neutral, KANTO CHEMICAL CO., INC.). NMR spectra were measured by JEOL ECS-400 (400 MHz). ^{1}H, ^{13}C, and ^{19}F NMR chemical shifts are reported in parts per million (ppm, δ scale) relative to residual solvents or internal/external references (^{1}H NMR: $CHCl_3$ at 7.26 ppm or tetramethylsilane at 0.00 ppm as an internal reference in $CDCl_3$, CD_2HOD at 3.31 ppm in CD_3OD, sodium 2,2-dimethyl-2-silapentane-5-sulfonate at 0.00 ppm as an internal reference in D_2O; ^{13}C NMR: $CDCl_3$ at 77.00 ppm in $CDCl_3$, CD_3OD at 49.00 ppm in CD_3OD, sodium 2,2-dimethyl-2-silapentane-5-sulfonate (DSS) at 0.00 ppm as an internal reference in D_2O; ^{19}F NMR: benzotrifluoride at -63.72 ppm as an external reference in $CDCl_3$ and CD_3OD). Coupling constants (*J*) are reported in Hz. Multiplicities are reported using the following abbreviations; s, singlet; d, doublet; t, triplet; q, quartet; quint, quintet; m, multiplet; br, broad. Infrared (IR) spectra were recorded on a JASCO FT-IR-4200 at 4.0 cm^{-1} resolution and reported in wavenumbers. Mass spectra were measured by JEOL JMS-T100LP using Electrospray Ionization (ESI) and Direct Analysis in Real Time (DART). UV–Vis absorption and fluorescence emission spectra were recorded on JASCO V-530 UV–VIS spectrophotometer and JASCO FP-6200 spectrofluorometer, respectively.

L-Aminoacylase (Acylase H "Amano", >30 kunits/g, mixture of 15% of enzyme and 85% of sodium sulfate) was used for chemoenzymatic resolution. 1,2-Decanediol (**2a**) (TCI), 1,2,10-decanetriol (**8a**) (TCI), and 7-octene-1,2-diol (**16a**) (Wako) were purchased and used as received. ^{13}C NMR spectra of AAs **3e**, **9e**, and **10e** could not be collected owing to their low solubility.

2. Preparation of 1,2-diols.

1,2-Diols **1a** and **4a** were synthesized from corresponding terminal olefins according to the reports.[1,2]



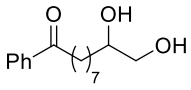
To a solution of alcohol **S1** (2.35 g, 15.1 mmol) and TEMPO (238 mg, 1.52 mmol) in CH_2Cl_2 (75 mL) was added iodobenzene diacetate (5.86 g, 18.2 mmol) at 0 °C. After the reaction mixture was stirred for 10 h at room temperature, it was quenched with saturated aq. $NaHCO_3$ and saturated aq. $Na_2S_2O_3$, Then, it was extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo to provide crude aldehyde **S2**, which was used to the next reaction without further purification.

To a solution of aldehyde **S2** in dry THF (75 mL) was added phenylmagnesium bromide solution (3.0 M in Et_2O, 6.02 mL, 18.1 mol) dropwise at -78 °C. The reaction mixture was stirred for 1 h. Then, the reaction mixture was warmed up to room temperature, and stirred for additional 2 h. It was quenched with saturated aq. NH_4Cl and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 10/1) to afford alcohol **S3** with impurities, which was used to the next reaction without further purification.

To a solution of alcohol **S3** in CH_2Cl_2 (75 mL) was added MnO_2 (26.3 g, 302 mmol) at room temperature. After the reaction mixture was stirred for 16 h, it was filtered through a pad of Celite and the filtrate was concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 15/1) to afford ketone **S4** with impurities, which was used to the next reaction without further purification

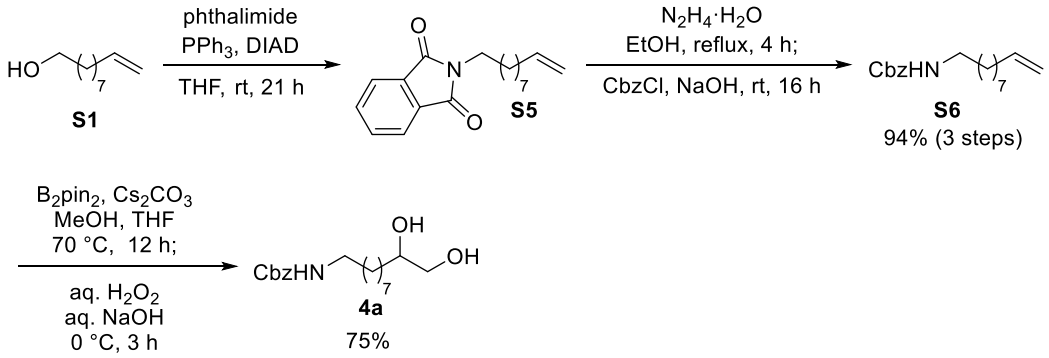
To a solution of ketone **S4** and *N*-methylmorpholine *N*-oxide (2.30 g, 19.6 mmol) in a mixed solvent of acetone, MeCN, and H_2O (1/1/1, 15 mL) was added microencapsulated OsO_4[3] (10%, 378 mg) at

room temperature. After the reaction mixture was stirred for 6 h, it was filtered and washed with MeOH to remove microencapsulated OsO_4, and the filtrate was concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 1/1 to AcOEt only) to afford 1,2-diol **3a** (2.88 g, 72%, 4 steps) as a white solid.



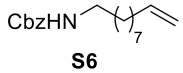
3a

White solid; mp. 83.9-85.4 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.95 (d, J = 8.0 Hz, 2H), 7.54 (t, J = 8.0 Hz, 1H), 7.45 (t, J = 8.0 Hz, 2H), 3.74-3.62 (m, 2H), 3.43 (ddd, J = 11.2, 8.0, 5.2 Hz, 1H), 2.95 (t, J = 7.2 Hz, 2H), 1.97 (d, J = 4.4 Hz, 1H), 1.80 (t, J = 5.2 Hz, 1H), 1.77-1.68 (m, 2H), 1.49-1.26 (m, 10H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 200.7, 136.9, 132.9, 128.5, 128.0, 72.2, 66.8, 38.5, 33.0, 29.4, 29.3, 29.2, 25.4, 24.2; IR (neat, cm^{-1}) 3500-3000, 1684; HRMS (ESI, m/z) Calcd. for $C_{16}H_{24}O_3$·Na ([M+Na]$^+$): 287.1623, found 287.1627.



To a solution of alcohol **S1** (4.71 g, 30.1 mmol), PPh_3 (8.86 g, 39.2 mmol), and phthalimide (4.48 g, 30.4 mmol) in THF (13 mL) was added DIAD (7.58 mL, 39.2 mmol) at 0 °C. The reaction mixture was stirred for 21 h at room temperature, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 10/1) to afford olefin **S5** with impurities, which was used to the next reaction without further purification.

To a solution of olefin **S5** in EtOH (115 mL) was added N_2H_4·H_2O (2.19 mL, 45.2 mmol) at 0 °C. After the reaction mixture was refluxed for 1 h, additional N_2H_4·H_2O (0.730 mL, 15.1 mmol) was added and it was stirred for 3 h. After the reaction mixture was cooled to room temperature, aq. NaOH (2.0 M, 60.3 mL, 121 mmol) and CbzCl (12.9 mL, 90.4 mmol) were added at 0 °C. After the reaction mixture was stirred for 6 h at room temperature, additional aq. NaOH (2.1 M, 22.6 mL, 47.1 mmol) and CbzCl (4.28 mL, 30.1 mmol) were added, and it was stirred for 10 h. Then, it was quenched with saturated H_2O and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 10/1) to afford olefin **S6** (7.66 g, 94%, 3 steps) as a white solid.



S6

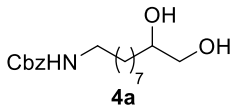
White solid; mp. 28.1-30.4 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40-7.28 (m, 5H), 5.81 (ddt, J = 16.8, 10.0, 6.4 Hz, 1H), 5.10 (s, 2H), 4.99 (dq, J = 16.8, 1.6 Hz, 1H), 4.93 (dd, J = 10.0, 1.6 Hz, 1H), 4.71 (br s, 1H), 3.19 (q, J = 6.4 Hz, 2H), 2.04 (q, J = 6.4 Hz, 2H),

1.54-1.43 (m, 2H), 1.41-1.21 (m, 10H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 156.3, 139.1, 136.7, 128.5, 128.1, 128.0, 114.1, 66.6, 41.1, 33.8, 29.9, 29.3, 29.2, 29.0, 28.9, 26.7; IR (neat, cm^{-1}) 3319, 1687; HRMS (ESI, m/z) Calcd. for $C_{18}H_{27}NO_2 \cdot Na$ ($[M+Na]^+$): 312.1940, found 312.1930.

To a solution of olefin **S6** (2.72 g, 10.0 mmol) in THF (25 mL) were added bis(pinacolato)diboron (5.11 g, 20.1 mmol), Cs_2CO_3 (984 mg, 3.01 mmol), and MeOH (2.03 mL, 50.2 mmol) at 0 °C. After the reaction mixture was stirred for 12 h at 70 °C. After it was cooled to 0 °C, THF (25 mL), aq. H_2O_2 (30%, 5.12 mL, 50.2 mmol), and aq. NaOH (10%, 18.0 mL, 50.2 mmol) were added. After 2 h, additional aq. H_2O_2 (30%, .12 mL, 50.2 mmol) and aq. NaOH (10%, 18.0 mL, 50.2 mmol) were added, and it was stirred for 1 h. Then, it was quenched with saturated aq. $Na_2S_2O_3$ and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo to provide crude 1,2-diol **4a**.

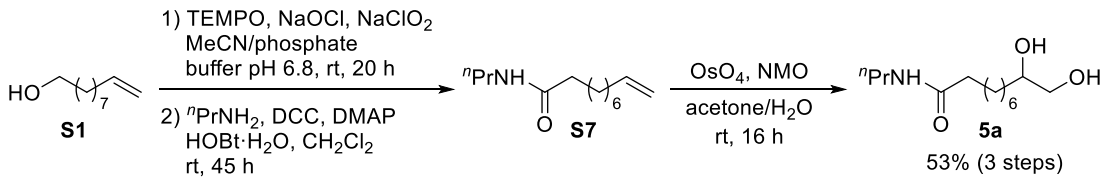
1,2-Diol **4a** was purified by temporary acetonide-protection to remove an impurity originated from the boron reagent as follows. To a solution of the crude **4a** and 2,2-dimethoxypropane (6.13 mL, 50.2 mmol) in CH_2Cl_2 (50 mL) was added $TsOH \cdot H_2O$ (191.8 mg, 1.01 mmol) at room temperature. After 17 h, it was quenched with saturated aq. $Na_2S_2O_3$ and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 4/1) to afford acetonide **4a**.

To a solution of acetonide **4a** in MeOH (40 mL) and H_2O (10 mL) was added DOWEX 50W-8 (200-400 mesh, 637 mg) at room temperature. After the reaction mixture was stirred for 18 h, additional DOWEX 50W-8 (200-400 mesh, 319 mg) was added and the reaction mixture was stirred for additional 6 h. Then, the reaction mixture was filtered through a pad of Celite and the filtrate was concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 1/1) to afford 1,2-diol **4a** (2.44 mg, 75%) as a white solid.



4a

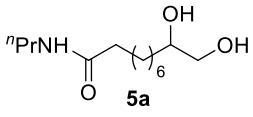
White solid; mp. 81.7-82.0 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.38-7.28 (m, 5H), 5.10 (s, 2H), 4.71 (br s, 1H), 3.75-3.62 (m, 2H), 3.44 (ddd, *J* = 12.8, 7.2, 5.2, 1H), 3.20 (d, *J* = 6.8 Hz, 1H), 3.17(d, *J* = 6.8 Hz, 1H), 1.99 (d, *J* = 4.8 Hz, 1H), 1.82 (dd, *J* = 6.0, 5.2 Hz, 1H), 1.52-1.24 (m, 14H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 156.4, 136.5, 128.4, 128.0 (3C), 72.2, 66.7, 66.5, 41.0, 33.0, 29.8, 29.4, 29.2, 29.0, 26.5, 25.4; IR (neat, cm^{-1}) 3600-3200, 1687; HRMS (ESI, m/z) Calcd. for $C_{18}H_{29}NO_4 \cdot Na$ ($[M+Na]^+$): 346.1994, found 346.1987.



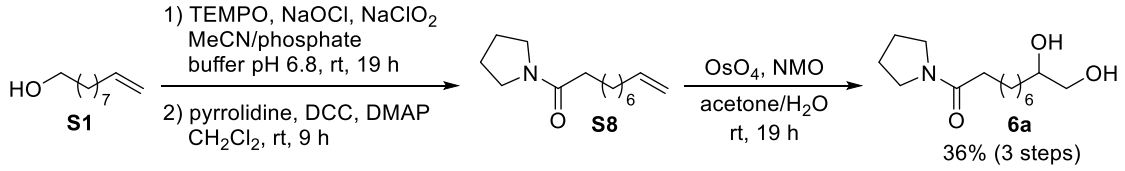
To a solution of alcohol **S1** (2.35 g, 15.1 mmol) and TEMPO (118 mg, 0.757 mmol) in MeCN (75 mL) and sodium phosphate buffer (1 M, pH 6.8, 54 mL) were added aqueous NaOCl solution (0.20 M, 3.77 mL, 0.754 mmol) and aqueous $NaClO_2$ solution (30.1 mmol of 80% $NaClO_2$ dissolved into 22 mL of water) dropwise simultaneously at room temperature. After 20 h, the reaction mixture was quenched with sodium phosphate buffer (1 M, pH 2.1) and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo to provide the corresponding carboxylic acid, which was used to the next reaction without further purification.

To a solution of the carboxylic acid, DCC (3.52 g, 17.1 mmol), and DMAP (370 mg, 3.02 mmol) in CH_2Cl_2 (60 mL) was added $^nPrNH_2$ (1.86 mL, 22.6 mmol) at room temperature. After 7 h, $HOBt·H_2O$ (2.47 g, 16.1 mmol) was added, and it was stirred for 38 h. Then, the reaction mixture was filtered through a pad of Celite. The filtrate was concentrated in vacuo. The residue was washed with saturated aq. Na_2CO_3 and aq. HCl (1 M), dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 3/1) to afford amide **S7** with impurities, which was used to the next reaction without further purification.

To a solution of amide **S7** and *N*-methylmorpholine *N*-oxide (2.15 g, 18.4 mmol) in acetone (108 mL) and H_2O (12 mL) was added osmium tetroxide (4% in H_2O, 743 μL, 0.122 mmol) at 0 °C. After the reaction mixture was stirred for 16 h at room temperature, it was quenched with saturated aq. $Na_2S_2O_3$ and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (AcOEt only to AcOEt/MeOH = 20/1 to 10/1) to afford 1,2-diol **5a** (1.96 g, 53%, 3 steps) as a white solid.



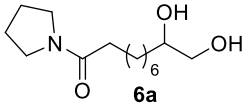
White solid; mp. 87.7-89.3 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.46 (br s, 1H), 3.75-3.65 (m, 1H), 3.65 (dd, J = 10.8, 3.2 Hz, 1H), 3.43 (dd, J = 10.8, 8.0 Hz, 1H), 3.23 (d, J = 6.8 Hz, 1H), 3.19 (d, J = 6.8 Hz, 1H),, 2.29 (br s, 1H), 2.15 (br s, 1H), 2.15 (t, J = 7.2 Hz, 2H), 1.71-1.58 (m, 2H), 1.56-1.47 (m, 2H), 1.47-1.23 (m, 10H), 0.92 (t, J = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.1, 72.2, 66.8, 41.2, 36.8, 33.1, 29.3, 29.1, 29.0, 25.6, 25.3, 22.9, 11.4; IR (neat, cm^{-1}) 3500-3000, 1637, 1547; HRMS (DART, m/z) Calcd. for $C_{13}H_{27}NO_3·H$ ($[M+H]^+$): 246.2069, found 246.2084.



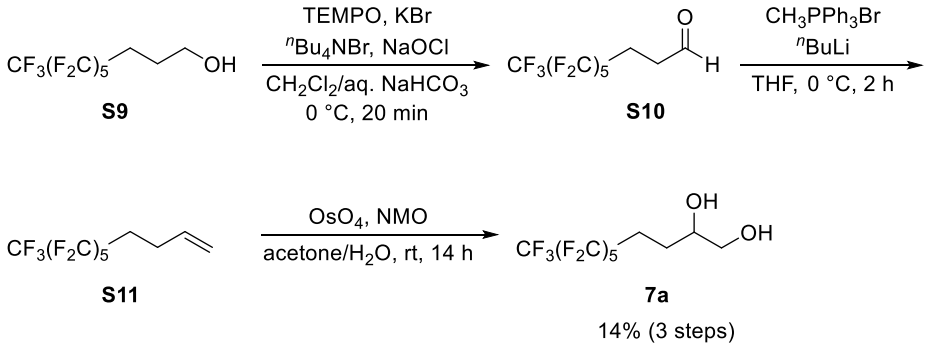
To a solution of alcohol **S1** (2.35 g, 15.0 mmol) and TEMPO (117 mg, 0.751 mmol) in MeCN (75 mL) and sodium phosphate buffer (1 M, pH 6.8, 54 mL) were added aqueous NaOCl solution (0.20 M, 3.77 mL, 0.751 mmol) and aqueous $NaClO_2$ solution (30.1 mmol of 80% $NaClO_2$ dissolved into 22 mL of water) dropwise simultaneously at room temperature. After 19 h, the reaction mixture was quenched with sodium phosphate buffer (1 M, pH = 2.1) and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo to provide the corresponding carboxylic acid, which was used to the next reaction without further purification.

To a solution of the carboxylic acid, DCC (3.41 g, 16.5 mmol) and DMAP (368 mg, 3.01 mmol) in CH_2Cl_2 (60 mL) was added pyrrolidine (1.86 mL, 22.5 mmol) at room temperature. After 9 h, the reaction mixture was filtered through a pad of Celite. The filtrate was concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 1/1) to afford amide **S8** with impurities, which was used to the next reaction without further purification.

To a solution of amide **S8** and *N*-methylmorpholine *N*-oxide (1.18 g, 10.1 mmol) in a mixed solvent of acetone, MeCN, and H_2O (1/1/1, 7.7 mL) was added microencapsulated OsO_4 (10%, 378 mg) at room temperature. After 12 h, additional *N*-methylmorpholine *N*-oxide (1.18 g, 10.1 mmol) was added and it was stirred for 7 h. Then, the reaction mixture was filtered and washing with MeOH to remove microencapsulated OsO_4 and the filtrate was concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (AcOEt only to AcOEt/MeOH 10/1) to afford 1,2-diol **6a** (1.39 g, 36%, 3 steps) as a white solid.



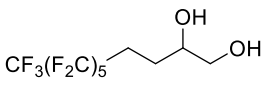
White solid; mp. 59.8-60.4 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.75-3.62 (m, 2H), 3.49-3.37 (m, 5H), 2.25 (t, *J* = 7.6 Hz, 2H), 2.20 (d, *J* = 4.4 Hz, 1H), 2.01 (t, *J* = 5.2 Hz, 1H), 1.99-1.90 (m, 2H), 1.88-1.80 (m, 2H), 1.70-1.59 (m, 2H), 1.50-1.24 (m, 10H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.1, 72.2, 66.9, 46.7, 45.6, 34.7, 33.0, 29.3, 29.2, 29.1, 26.0, 25.4, 24.7, 24.3; IR (neat, cm^{-1}) 3600-3300, 1620; HRMS (ESI, m/z) Calcd. for $C_{14}H_{27}NO_3$·Na ($[M+Na]^+$): 280.1889, found 280.1917.



To a solution of alcohol **S9** (3.35 g, 8.85 mmol), TEMPO (42.3 mg, 0.271 mmol), KBr (111 mg, 0.929 mmol), and ^{n}Bu$_4$NBr (143 mg, 0.443 mmol) in CH_2Cl_2 (23 mL) and saturated aq. $NaHCO_3$ (12 mL) was added a solution of aq. NaOCl (1.77 M, 6.50 mL, 11.5 mmol) and saturated aq. $NaHCO_3$ (9.1 mL) dropwise at 0 °C. After 20 min, it was quenched with saturated aq. $NaHCO_3$ and saturated aq. $Na_2S_2O_3$ and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo to provide crude aldehyde **S10**, which was used to the next reaction without further purification.

To a well-dried round-bottom flask charged with CH_3PPh_3Br (3.80 g, 10.6 mmol) and dry THF (22 mL) was added ^{n}BuLi (15wt% in hexane, 6.23 mL, 9.73 mmol) dropwise at 0 °C. After 20 min, a solution of aldehyde **S10** (0.5 M) in THF was added at -78 °C and the reaction mixture was stirred for 2 h at 0 °C. Then, it was quenched with saturated aq. NH_4Cl and extracted with Et_2O. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo to provide crude olefin **S11,** which was used to the next reaction without further purification

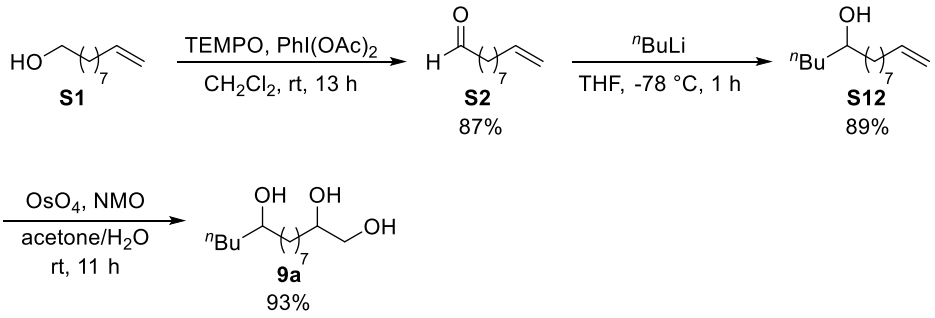
To a solution of olefin **S11** and *N*-methylmorpholine *N*-oxide (1.55 g, 13.3 mmol) in acetone (80 mL) and H_2O (8.8 mL) was added osmium tetroxide (4% in H_2O, 585 μL, 88.5 μmol) at 0 °C. After the reaction mixture was stirred for 14 h at room temperature, it was quenched with saturated aq. $Na_2S_2O_3$ and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 1/1) to afford 1,2-diol **7a** (523 mg, 14%, 3 steps) as a brown solid.



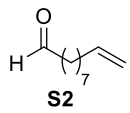
7a

Brown solid; mp. 49.6-51.0 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.81-3.73 (m, 1H), 3.71 (dd, *J* = 14.4, 3.2 Hz, 1H), 3.50 (dd, *J* = 14.4, 6.8 Hz, 1H), 2.54-2.28 (m, 2H), 2.26-1.98 (m, 2H), 1.82-1.58 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 70.9, 66.6, 27.3 (t, *J* = 22.9 Hz), 23.7; ^{19}F NMR (376 MHz, $CDCl_3$) δ -81.7, -115.5, -

122.9, -123.8, -124.4, -127.1; IR (neat, cm^{-1}) 3600-3200, 1238, 1194, 1144; HRMS (DART, m/z) Calcd. for $C_{10}H_9F_{13}O_2 \cdot NH_4$ ($[M+ NH_4]^+$): 426.0739, found 426.0761.

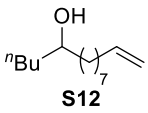


To a solution of alcohol **S1** (1.05 g, 6.72 mmol), TEMPO (105 mg, 0.673 mmol) in CH_2Cl_2 (34 mL) was added iodobenzene diacetate (2.61 g, 8.09 mmol) at 0 °C. After the reaction mixture was stirred for 13 h at room temperature, it was quenched with saturated aq. $NaHCO_3$ and saturated aq. $Na_2S_2O_3$ and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/Et_2O = 20/1) to afford aldehyde **S2** (897 mg, 87%) as a colorless oil.



Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.76 (t, *J* = 2.0 Hz, 1H), 5.81 (ddt, *J* = 16.8, 10.0, 7.2 Hz, 1H), 4.99 (dm, *J* = 16.8 Hz, 1H), 4.93 (dm, *J* = 10.0 Hz, 1H), 2.42 (td, *J* = 7.2, 2.0 Hz, 2H), 2.04 (q, *J* = 7.2 Hz, 2H), 1.68-1.60 (m, 2H), 1.43-1.24 (m, 8H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 202.9, 139.0, 114.2, 43.9, 33.7, 29.2, 29.1, 28.84, 28.78, 22.0; IR (neat, cm^{-1}) 1726; HRMS (DART, m/z) Calcd. for $C_{10}H_{18}O \cdot H$ ($[M+H]^+$): 155.1436, found 155.1431.

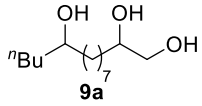
To a solution of aldehyde **S2** (813 mg, 5.27 mmol) in dry THF (26 mL) was added *n*BuLi solution (15wt% in hexane, 8.44 mL, 5.27 mmol) dropwise at -78 °C. After the reaction mixture was stirred for 1 h, it was quenched with saturated aq. NH_4Cl and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 20/1) to afford olefin **S12** (995 mg, 89%) as a colorless oil.



Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.81 (ddt, *J* = 17.2, 10.4, 6.8 Hz, 1H), 4.99 (dm, *J* = 17.2 Hz, 1H), 4.93 (dm, *J* = 10.4 Hz, 1H), 3.63-3.54 (m, 1H), 2.04 (q, *J* = 6.8 Hz, 2H), 1.50-1.23 (m, 18H), 0.91 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (100 MHz,

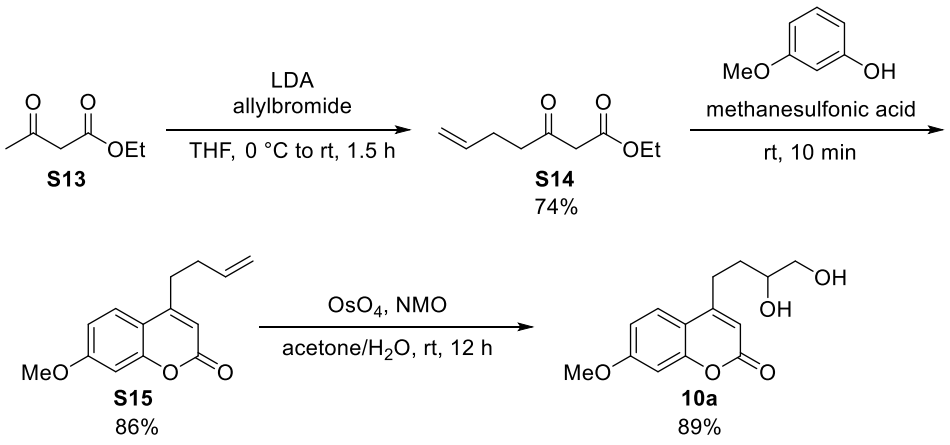
$CDCl_3$) δ 139.2, 114.1, 72.0, 37.4, 37.2, 33.8, 29.6, 29.4, 29.1, 28.9, 27.8, 25.6, 22.7, 14.1; IR (neat, cm^{-1}) 3600-3200; HRMS (ESI, m/z) Calcd. for $C_{14}H_{28}O$·Na ([M+Na]$^+$): 235.2038, found 235.2010.

To a solution of olefin **S12** and *N*-methylmorpholine *N*-oxide (995 mg, 4.68 mmol) in acetone (42 mL) and H_2O (4.7 mL) was added osmium tetroxide (4% in H_2O, 286 μL, 46.8 μmol) at 0 °C. After the reaction mixture was stirred for 11 h at room temperature, it was quenched with saturated aq. $Na_2S_2O_3$ and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 1/1 to AcOEt only) to afford 1,2-diol **9a** (1.07 g, 93%) as a white solid.



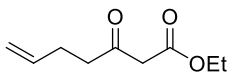
9a

Diastereomixture; White solid; mp. 83.1-85.4 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.75-3.68 (m, 2H), 3.66 (ddd, *J* = 10.8, 6.4, 3.2 Hz, 2H), 3.62-3.54 (m, 2H), 3.44 (ddd, *J* = 10.8, 7.6, 4.8 Hz, 2H), 1.959 (d, *J* = 4.4 Hz, 1H), 1.956 (d, *J* = 4.0 Hz, 1H), 1.80 (dd, *J* = 6.4, 4.8 Hz, 2H), 1.50-1.23 (m, 40H), 1.27 (d, *J* = 5.2 Hz, 2H), 0.91 (t, *J* = 7.2 Hz, 6H); ^{13}C NMR (100 MHz, CD_3OD) δ 73.3 (2C), 72.4 (2C), 67.4 (2C), 38.4 (2C), 38.2 (2C), 34.4 (2C), 30.8 (4C), 30.7 (2C), 29.1 (2C), 26.8 (2C), 26.7 (2C), 23.9 (2C), 14.5 (2C); IR (KBr, cm^{-1}) 3600-3000; HRMS (ESI, m/z) Calcd. for $C_{14}H_{30}O_3$·Na ([M+Na]$^+$): 269.2093, found 269.2081.



To a well-dried round-bottom flask charged with diisopropylamine (4.64 mL, 33.1 mmol) in dry THF (30 mL) was added ^{n}BuLi (15wt% in hexane, 21.2 mL, 33.1 mmol) dropwise at 0 °C. After the solution was stirred for 30 min at 0 °C, a solution of ester **S13** (0.5 M, 1.96 g, 15.0 mmol) in dry THF was added dropwise a t 0 °C. After 15 min, allyl bromide (1.52 mL, 18.0 mmol) was added at the same temperature. After 30 min, the reaction mixture was warmed up to room temperature and stirred for 1 h at the same temperature. Then, it was quenched with saturated aq. NH_4Cl and extracted with AcOEt.

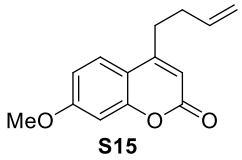
The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 100/1 to 20/1) to afford ester **S14** (1.89 g, 74%) as a colorless oil.



S14

^{1}H NMR data was consistent with the previous report.[4]

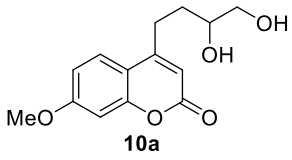
To a round-bottom flask charged with ester **S14** (381 mg, 2.24 mmol) and 3-methoxyphenol (2.78 g, 22.4 mmol) was added methanesulfonic acid (3.63 mL, 56.0 mmol) at 0 °C. The reaction mixture was stirred for 10 min at room temperature. Then, it was quenched with aq. NaOH (10%) and extracted with $CHCl_3$. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 15/1 to 10/1) to afford olefin **S15** (445 mg, 86%) as a pale yellow solid.



S15

Pale yellow solid; mp. 45.6-46.8 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53 (d, *J* = 8.8 Hz, 1H), 6.87 (dd, *J* = 8.8, 2.4 Hz, 1H), 6.84 (d, *J* = 2.4 Hz, 1H), 6.14 (s, 1H), 5.87 (ddt, *J* = 16.8, 10.0, 7.2 Hz, 1H), 5.11 (dd, *J* = 16.8 Hz, 1H), 5.07 (d, *J* = 10.0 Hz, 1H), 3.88 (s, 3H), 2.83 (t, *J* = 7.2 Hz, 2H), 2.45 (q, *J* = 7.2 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.5, 161.4, 155.5, 155.4, 136.3, 125.2, 116.2, 112.7, 112.3, 111.0, 101.0, 55.7, 32.0, 31.0; IR (neat, cm^{-1}) 1720, 1614; HRMS (ESI, m/z) Calcd. for $C_{14}H_{14}O_3$·Na ($[M+Na]^+$): 253.0841, found 253.0831.

To a solution of olefin **S15** (30.0 mg, 0.130 mmol) and *N*-methylmorpholine *N*-oxide (23.2 mg, 0.198 mmol) in acetone (1.2 mL) and H_2O (0.13 mL) was added osmium tetroxide (4% in H_2O, 8.00 μL, 1.30 μmol) at 0 °C. After the reaction mixture was stirred for 12 h at room temperature, it was quenched with saturated aq. $Na_2S_2O_3$ and extracted with $CHCl_3$. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 1/1 to AcOEt only) to afford 1,2-diol **10a** (30.8 mg, 89%) as a white solid.



10a

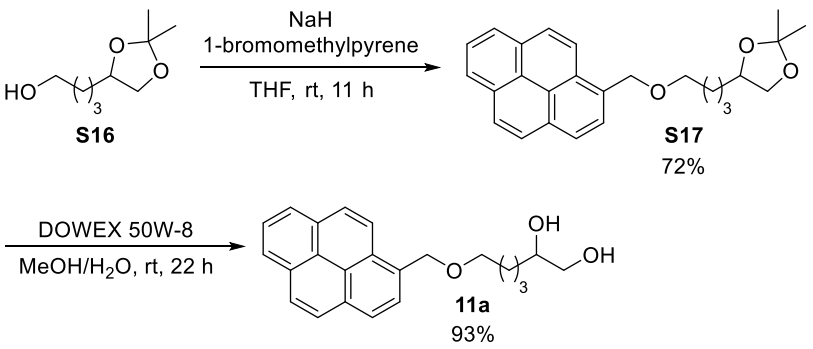
White solid; mp. 112.9-113.7 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.59 (d, *J* = 8.8 Hz, 1H), 6.87 (dd, *J* = 8.8, 2.8 Hz, 1H), 6.83 (d, *J* = 2.8 Hz, 1H), 6.16 (s, 1H), 3.88 (s, 3H), 3.86-3.78 (m, 1H), 3.72 (ddd, *J* = 11.2, 5.2, 4.0 Hz, 1H), 3.52 (ddd, *J* = 11.2, 7.2, 5.6 Hz, 1H), 3.06-2.97 (m, 1H), 2.86-2.77 (m, 1H), 2.28 (d, *J* = 4.0 Hz, 1H), 1.85-1.73 (m, 3H); ^{13}C NMR (100 MHz, CD_3OD) δ 164.4,

163.7, 159.4, 156.8, 127.1, 113.9, 113.7, 111.2, 101.9, 72.4, 67.1, 56.4, 33.4, 28.9; IR (neat, cm^{-1}) 3700-3100, 1703, 1612; HRMS (ESI, m/z) Calcd. for $C_{14}H_{16}O_5 \cdot Na$ ($[M+Na]^+$): 287.0895, found 287.0883.

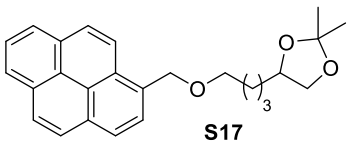
Scale-up of synthesis of 1,2-diol **10a** was carried out by the following procedure. To a well-dried round-bottom flask charged with diisopropylamine (24.7 mL, 176 mmol) in dry THF (160 mL) was added ^{n}BuLi (15wt% in hexane, 113 mL, 176 mmol) dropwise at 0 °C. After the mixture was stirred for 30 min at 0 °C, a solution of ester **S13** (0.5 M, 10.4 g, 80.1 mmol) in dry THF was added over a period of 30 min at 0 °C. After 15 min, allyl bromide (8.13 mL, 96.1 mmol) was added at the same temperature. After 30 min, the reaction mixture was warmed up to room temperature and stirred for 1 h at the same temperature. Then, it was quenched with saturated aq. NH_4Cl and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 100/1 to 20/1) to afford ester **S14**.

To a round-bottom flask charged with ester **S14** and 3-methoxyphenol (69.3 mL, 641 mmol) was added methanesulfonic acid (104 mL, 1.60 mol) at 0 °C. After 5 min, it was quenched with aq. NaOH (10%) and extracted with $CHCl_3$. The organic layer was washed with aq. NaOH (10%), dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 10/1 to 4/1) to afford olefin **S15**.

To a solution of olefin **S15** and *N*-methylmorpholine *N*-oxide (9.49 g, 81.0 mmol) in acetone (243 mL) and H_2O (27 mL) was added osmium tetroxide (4% in H_2O, 3.30 μL, 0.54 mmol) at 0 °C. After the reaction mixture was stirred for 14 h at room temperature, it was quenched with saturated aq. $Na_2S_2O_3$ and extracted with $CHCl_3$. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 1/1 to AcOEt only to AcOEt/MeOH = 1/20 to 1/4) to afford 1,2-diol **10a** (12.4 g, 59%, 3 steps) as a white solid.



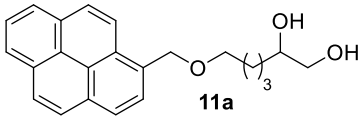
To a well-dried round-bottom flask charged with NaH (60%, 208 mg, 5.19 mmol) in dry THF (6.8 mL) was added a solution of acetonide **S16** (0.5 M, 563 mg, 3.23 mmol) in dry THF dropwise at 0 °C. After the mixture was stirred for 30 min at room temperature, 1-bromomethylpyrene (995 mg, 3.37 mmol) was added at 0 °C. After the reaction mixture was stirred for 2 h at room temperature, it was warmed up to 50 °C and stirred for 9 h at the same temperature. Then, it was quenched with H_2O and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 30/1 to 10/1 to 6/1) to afford acetonide **S17** (1.02 g, 72%) as a yellow oil.



S17

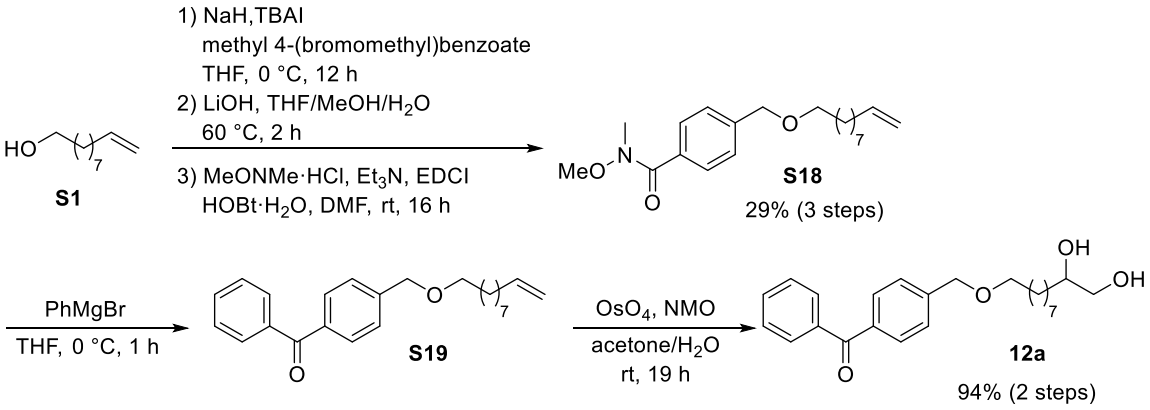
Yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.37 (d, *J* = 9.2 Hz, 1H), 8.20 (t, *J* = 6.8 Hz, 2H), 8.15 (d, *J* = 8.0 Hz, 1H), 8.14 (d, *J* = 9.2 Hz, 1H), 8.07-7.99 (m, 4H), 5.23 (d, *J* = 8.0 Hz, 1H), 5.19 (d, *J* = 8.0 Hz, 1H), 4.06-3.98 (m, 1H), 3.96 (dd, *J* = 8.0, 6.0 Hz, 1H), 3.61 (t, *J* = 6.4 Hz, 2H), 3.44 (t, *J* = 8.0 Hz, 1H), 1.75-1.30 (m, 6H), 1.38 (s, 3H), 1.33 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 131.6, 131.2 (2C), 130.8, 129.3, 127.6, 127.4, 127.3, 126.9, 125.9, 125.2 (2C), 124.9, 124.7, 124.4, 123.5, 108.6, 76.0, 71.5, 70.1, 69.4, 33.3, 29.8, 26.9, 25.7, 22.5; IR (neat, cm^{-1}) 1091, 1057; HRMS (ESI, m/z) Calcd. for $C_{26}H_{28}O_3$·Na ($[M+Na]^+$): 411.1936, found 411.1935.

To a solution of acetonide **S17** (889 mg, 2.29 mmol) in MeOH (9.1 mL) and H_2O (2.3 mL) was added DOWEX 50W-8 (200-400 mesh, 91 mg) at room temperature. After the reaction mixture was stirred for 8 h, additional DOWEX 50W-8 (200-400 mesh, 183 mg) was added and the reaction mixture was stirred for 14 h. Then, it was filtered through a pad of Celite and the filtrate was concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 1/1) to afford 1,2-diol **11a** (740 mg, 93%) as a white solid.



11a

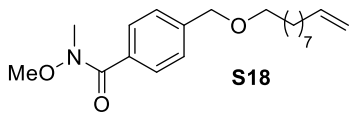
White solid; mp. 74.3-75.0 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.38 (d, *J* = 9.2 Hz, 1H), 8.20 (t, *J* = 6.8 Hz, 2H), 8.17-8.13 (m, 2H), 8.08-7.99 (m, 4H), 5.22 (s, 2H), 3.68-3.59 (m, 1H), 3.62 (t, *J* = 6.4 Hz, 2H), 3.55 (ddd, *J* = 11.2, 6.4, 3.2 Hz, 1H), 3.34 (ddd, *J* = 11.2, 7.6, 4.8 Hz, 1H), 1.96 (d, *J* = 4.8 Hz, 1H), 1.74-1.64 (m, 3H), 1.60-1.35 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 131.5, 131.22, 131.20, 130.8, 129.3, 127.6, 127.4 (2C), 127.0, 125.9, 125.2 (2C), 124.9, 124.7, 124.4, 123.5, 72.0, 71.5, 70.1, 66.7, 32.7, 29.6, 22.2; IR (neat, cm^{-1}) 3700-3100, 1086; HRMS (ESI, m/z) Calcd. for $C_{23}H_{24}O_3$·Na ($[M+Na]^+$): 371.1623, found 371.1618.



To a well-dried round-bottom flask charged with NaH (60%, 1.08 g, 27.1 mmol) in dry THF (30 mL) was added a solution of alcohol **S1** (0.5 M, 2.81 g, 18.0 mmol) in dry THF dropwise at 0 °C. After the reaction mixture was stirred for 30 min at room temperature, methyl 4-(bromomethyl)benzoate (3.44 g, 15.0 mmol) and tetrabutylammonium iodide (5.59 g, 15.1 mmol) were added at 0 °C. After the reaction mixture was stirred at room temperature for 12 h, it was quenched with saturated aq. NH_4Cl and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo to provide crude material, which was used to the next reaction without further purification.

To a solution of the crude material in a mixed solvent of THF (25 mL), MeOH (25 mL), and H_2O (25 mL) was added LiOH (2.89 g, 121 mmol) at room temperature. After the reaction mixture was stirred for 2 h at 60 °C, AcOEt was added. The resultant mixture was separated into the organic layer and the aqueous layer. The aqueous layer was extracted with AcOEt. The resultant combined organic layer was washed with aq. NaOH (1 M) and dried over $MgSO_4$, filtered, and concentrated in vacuo to provide crude carboxylic acid, which was used to the next reaction without further purification.

To a solution of carboxylic acid, *N*,*O*-dimethylhydroxylamine hydrochloride (3.14 g, 32.2 mmol), Et_3N (5.23 mL, 37.6 mmol), and 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide hydrochloride (3.38 17.6 mmol) in DMF (80 mL) was added HOBt·H_2O (1.35 g, 8.90 mmol) at room temperature. After 16 h, the reaction mixture was quenched with H_2O and extracted with a solution of hexane and AcOEt (4/1). The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 8/1 to 4/1) to afford amide **S18** (1.45 g, 29%, 3 steps) as a colorless oil.

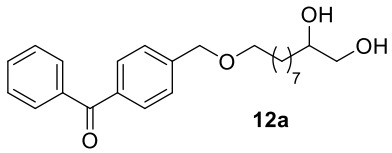


Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.67 (d, J = 8.0 Hz, 2H), 7.37 (d, J = 8.0 Hz, 2H), 5.81 (ddt, J = 16.8, 10.0, 6.8 Hz, 1H), 4.99 (dm, J = 16.8 Hz, 1H), 4.93 (dm, J = 10.0 Hz, 1H), 4.53 (s, 2H),

3.55 (s, 3H), 3.48 (t, J = 6.8 Hz, 2H), 3.36 (s, 3H), 2.04 (q, J = 6.8 Hz, 2H), 1.66-1.59 (m, 2H), 1.42-1.24 (m, 10H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 169.7, 141.4, 139.1, 133.0, 128.2 (2C), 126.8 (2C), 114.1, 72.3, 70.7, 60.9, 33.7 (2C), 29.7, 29.3 (2C), 29.0, 28.8, 26.1; IR (neat, cm^{-1}) 1643; HRMS (ESI, m/z) Calcd. for $C_{20}H_{31}NO_3$·Na ([M+Na]$^+$): 356.2202, found 356.2179.

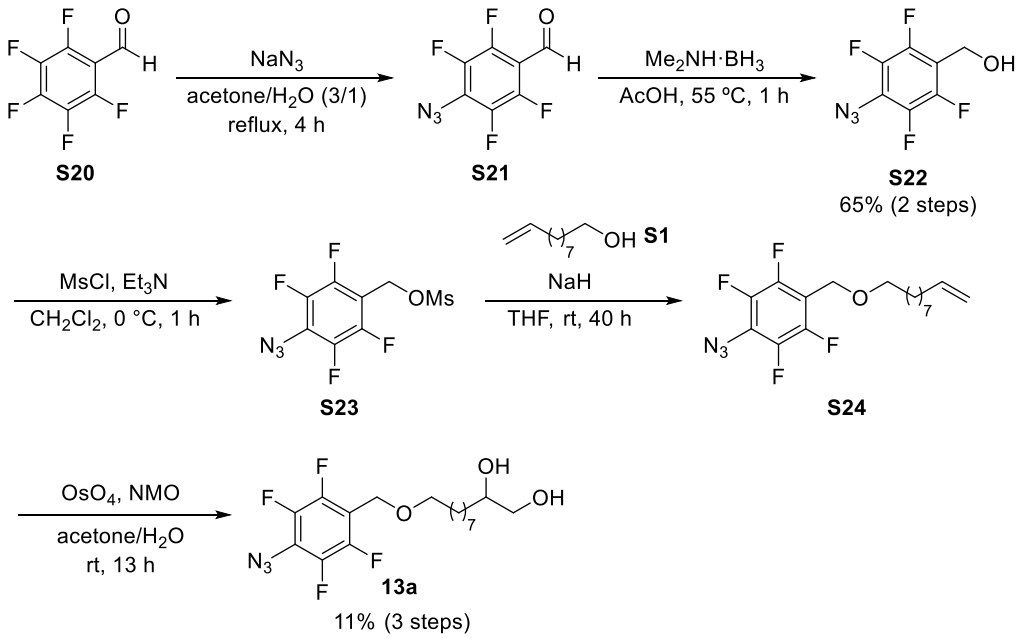
To a solution of amide **S18** (1.79 g, 5.36 mmol) in dry THF (27 mL) and was added phenylmagnesium bromide solution (3.0 M in Et_2O, 7.15 mL, 21.5 mmol) dropwise at 0 °C and stirred for 1 h in the dark. Then, the reaction mixture was quenched with saturated aq. NH_4Cl and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was passed through a flash column chromatography on silica gel (hexane/AcOEt = 15/1) to afford olefin **S19** with impurities.

To a solution of olefin **S19** and *N*-methylmorpholine *N*-oxide (954 mg, 8.14 mmol) in acetone (48 mL) and H_2O (5.4 mL) was added osmium tetroxide (4% in H_2O, 328 μL, 53.6 μmol) at 0 °C. After the reaction mixture was stirred for 19 h at room temperature in the dark, it was quenched with saturated aq. $Na_2S_2O_3$ and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 1/1 to 1/2) to afford 1,2-diol **12a** (1.95 g, 94%, 2 steps) as a white solid.



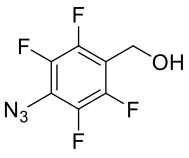
12a

White solid; mp. 62.9-63.5 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.82-7.76 (m, 4H), 7.59 (tm, J = 6.8 Hz, 1H), 7.52-7.42 (m, 4H), 4.59 (s, 2H), 3.75-3.62 (m, 2H), 3.51 (t, J = 6.8 Hz, 2H), 3.43 (ddd, J = 11.2, 8.0, 5.2 Hz, 1H), 2.0 (d, J = 4.0 Hz, 1H), 1.84 (t, J = 5.2 Hz, 1H), 1.68-1.60 (m, J = 7.2 Hz, 2H), 1.48-1.24 (m, 12H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.6, 143.6, 137.5, 136.5, 132.3, 130.2, 129.9, 128.2, 127.0, 72.2, 72.1, 70.8, 66.7, 33.0, 29.6, 29.5, 29.4, 29.3, 26.1, 25.5; IR (neat, cm^{-1}) 3600-3100, 1649; HRMS (ESI, m/z) Calcd. for $C_{24}H_{32}O_4$·Na ([M+Na]$^+$): 407.2198, found 407.2186.



Alcohol **S22** was prepared according to the report.[5] To a solution of aldehyde **S20** (2.01 g, 10.2 mmol) in acetone (15 mL) and H_2O (5.1 mL) was added NaN_3 (708 mg, 10.9 mmol) at room temperature. After the reaction mixture was refluxed for 4 h and cooled to room temperature, it was quenched with H_2O and extracted with Et_2O. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo to provide crude aldehyde **S21**, which was used to the next reaction without further purification.

To a solution of aldehyde **S21** in AcOH (34 mL) was added $Me_2NH{\cdot}BH_3$ (728 mg, 12.3 mmol) at 0 °C. After the reaction mixture was stirred for 1 h at 55 °C and cooled to room temperature, it was quenched with saturated aq. Na_2CO_3 and extracted with Et_2O. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/Et_2O = 4/1) to afford alcohol with an impurity. This material was recrystallized from hexane/Et_2O to afford pure alcohol **S22** as a white solid. The filtrate was concentrated in vacuo and recrystallized from hexane/Et_2O again to afford pure alcohol **S22**. The combined yield is 65% (1.48 g, 2 steps).



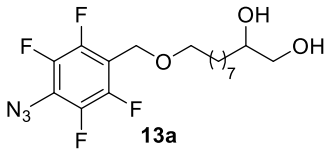
White solid; mp. 68.3-70.8 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.79 (dt, J = 6.8, 1.2 Hz, 2H), 1.90 (t, J = 6.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.2 (dddd, J = 246.9, 12.4, 7.6, 3.8 Hz), 140.4 (ddt, J = 247.9, 17.2, 3.8 Hz), 120.0 (tt, J = 12.4, 2.9 Hz), 114.0 (t, J = 18.1 Hz), 52.6; IR (neat, cm^{-1}) 3800-3100, 2121.

To a solution of alcohol **S22** (1.47 g, 6.65 mmol) and Et_3N (1.84 mL, 13.3 mmol) in CH_2Cl_2 (95 mL) was added MsCl (0.773 mL, 9.98 mmol) at 0 °C. After the reaction mixture was stirred for 1 h at

0 °C in the dark, it was quenched with H_2O and extracted with CH_2Cl_2. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with a flash column chromatography on silica gel (hexane/Et_2O = 1/1) to afford sulfonamide **S23.**

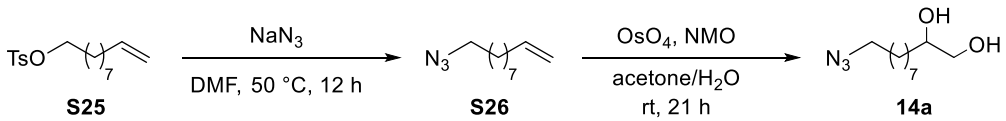
To a well-dried round-bottom flask charged with NaH (60%, 429 mg, 10.7 mmol) and dry THF (13 mL) was added a solution of alcohol **S1** (0.5 M, 1.04 g, 6.67 mmol) in THF at 0 °C. After the mixture was stirred for 30 min at room temperature, sulfonamide **S23** (0.5 M) in dry THF was added dropwise at 0 °C. After the reaction mixture was stirred for 40 h at room temperature in the dark, it was quenched with saturated aq. NH_4Cl and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with a flash column chromatography on silica gel (hexane/AcOEt = 100/1 to 50/1) to afford ether **S24** with impurities, which was used to the next reaction without further purification

To a solution of ether **S24** and *N*-methylmorpholine *N*-oxide (293 mg, 2.50 mmol) in acetone (15 mL) and H_2O (1.66 mL) was added osmium tetroxide (4% in H_2O, 102 μL, 16.6 μmol) at 0 °C. After the reaction mixture was stirred for 13 h at room temperature, it was quenched with saturated aq. $Na_2S_2O_3$ and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 2/1 to 1/1) to afford 1,2-diol **13a** including impurities. This material was recrystallized from hexane/AcOEt to afford pure 1,2-diol **13a** as a white solid. The filtrate was concentrated in vacuo and recrystallized from hexane/Et_2O to afford pure 1,2-diol **13a**. The combined yield is 11% (296 mg, 3 steps).



13a

White solid; mp. 57.2-59.1 °C ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.56 (t, *J* = 1.2 Hz, 2H), 3.75-3.63 (m, 2H), 3.47 (t, *J* = 6.4 Hz, 2H), 3.46-3.40 (m, 1H), 1.96 (d, *J* = 4.4 Hz, 1H), 1.81 (t, *J* = 5.2 Hz, 1H), 1.50-1.23 (m, 14H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 145.5 (dddd, *J* = 247.9, 11.4, 7.6, 3.8 Hz), 140.3 (ddt, *J* = 248.8, 18.1, 2.9 Hz), 119.9 (tt, *J* = 12.4, 2.8 Hz), 112.0 (t, *J* = 18.1 Hz), 72.3, 71.0, 66.8, 59.5, 33.1, 29.49, 29.45, 29.38, 29.2, 25.9, 25.5; IR (neat, cm^{-1}) 3700-3100, 2125; HRMS (DART, m/z) Calcd. for $C_{17}H_{23}F_4N_3O_3$·H ([M+ H]$^+$): 394.1754, found 394.1766.



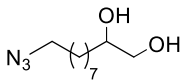
S25 **S26** **14a**

97% (2 steps)

To a solution of olefin **S25** (2.85 g, 9.18 mmol) in DMF (31 mL) was added NaN_3 (900 mg, 13.8

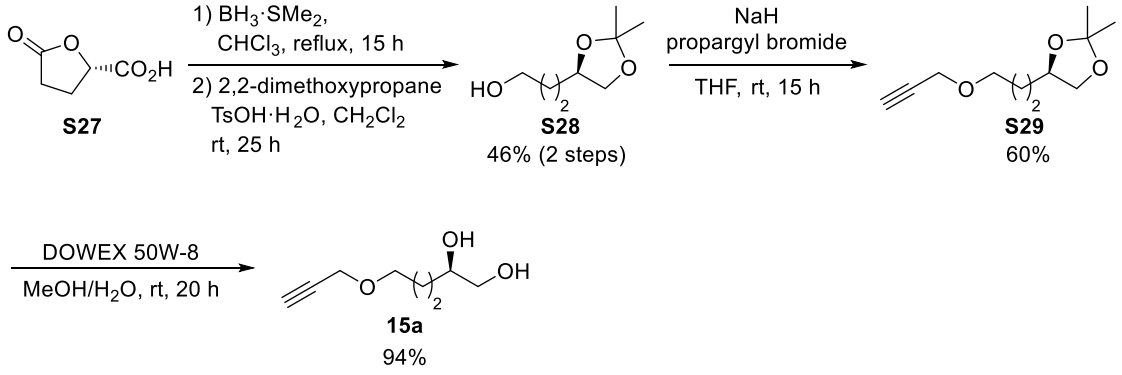
mmol) at 0 °C. After the reaction mixture was stirred for 12 h at 50 °C, it was quenched with H_2O and extracted with a solution of hexane and AcOEt (4/1). The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo to provide crude azide **S26**, which was used to the next reaction without further purification.

To a solution of azide **S26** and *N*-methylmorpholine *N*-oxide (1.65 g, 14.1 mmol) in acetone (83 mL) and H_2O (9.2 mL) was added osmium tetroxide (4% in H_2O, 561 μL, 144 μmol) at 0 °C. After the reaction mixture was stirred for 21 h at room temperature, it was quenched with saturated aq. $Na_2S_2O_3$ and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 1/1) to afford 1,2-diol **14a** (1.91 g, 97%, 2 steps) as a colorless oil.



14a

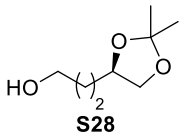
Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.76-3.63 (m, 2H), 3.44 (ddd, *J* = 10.8, 7.6, 5.2 Hz, 1H), 3.26 (t, *J* = 6.8 Hz, 2H), 1.97 (d, *J* = 4.0 Hz, 1H), 1.80 (dd, *J* = 6.4, 5.2 Hz, 1H), 1.60 (quint, *J* = 7.2 Hz, 2H), 1.50-1.24 (m, 12 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 72.3, 66.7, 51.4, 33.0, 29.5, 29.3, 29.0, 28.7, 26.6, 25.5; IR (neat, cm^{-1}) 3800-3100, 2096; HRMS (ESI, m/z) Calcd. for $C_{10}H_{21}N_3O_2$·Na ([M+Na]$^+$): 238.1532, found 238.1511.



To a well-dried round-bottom flask charged with lactone **S27** (73.9 mg, 0.568 mmol) in dry $CHCl_3$ was added BH_3·SMe_2 (90%, 88.8 μL, 0.852 mmol) at 0 °C. After the reaction mixture was stirred for 12 h at room temperature, additional BH_3·SMe_2 (90%, 59.2 μL, 0.568 mmol) was added. After the reaction mixture was stirred for 3 h, it was quenched with MeOH and concentrated in vacuo to provide crude triol, which was used to the next reaction without further purification.

To a solution of triol and 2,2-dimetoxypropane (347 μL, 2.84 mmol) in CH_2Cl_2 was added TsOH·H_2O (12.1 mg, 0.636 mmol) at 0 °C. After the reaction mixture was stirred for 19 h at room temperature, additional 2,2-dimetoxypropane (347 μL, 2.84 mmol) and TsOH·H_2O (12.8 mg, 0.673 mmol) were added and stirred for 6 h. Then, it was quenched with saturated aq. $NaHCO_3$ and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified

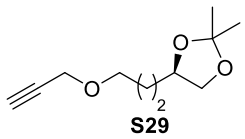
with flash column chromatography on silica gel (hexane/AcOEt = 2/1) to afford acetonide **S28** (41.6 mg, 46%, 2 steps) as a colorless oil.



S28

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.16-4.09 (m, 1H), 4.06 (dd, *J* = 8.0, 6.0 Hz, 1H), 3.71-3.64 (m, 2H), 3.53 (t, *J* = 8.0 Hz, 1H), 1.96 (br s, 1H), 1.73-1.61 (m, 4H), 1.42 (s, 3H), 1.36 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 108.9, 75.9, 69.4, 62.5, 30.2, 29.1, 26.8, 25.7; IR (neat, cm^{-1}) 3700-3100; HRMS (DART, m/z) Calcd. for $C_8H_{16}O_3 \cdot H$ ($[M+H]^+$): 161.1178, found 161.1149.

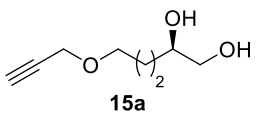
To a well-dried round-bottom flask charged with NaH (60%, 555 mg, 13.9 mmol) in dry THF (18 mL) was added a solution of acetonide **S28** (1 M, 1.48 g, 9.21 mmol) in dry THF dropwise at 0 °C. After the reaction mixture was stirred for 30 min at room temperature, propargyl bromide (1.04 mL, 13.8 mmol) was added dropwise at 0 °C. After the reaction mixture was stirred for 12 h at room temperature, additional propargyl bromide (0.694 mL, 9.21 mmol) was added and the reaction mixture was stirred for 3 h. Then, it was quenched with H_2O and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 10/1) to afford alkyne **S29** (1.10 g, 60%) as a colorless oil.



S29

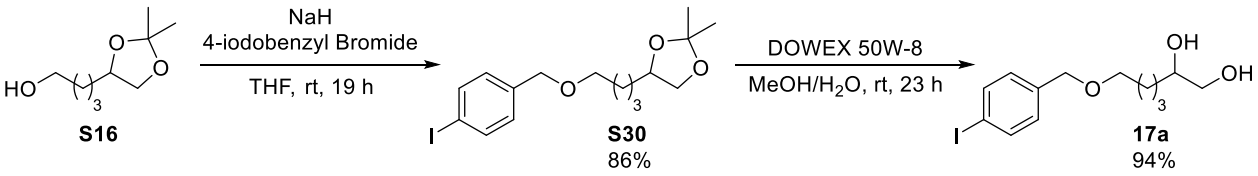
colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.14 (d, *J* = 2.0 Hz, 2H), 4.15-4.07 (m, 1H), 4.04 (dd, *J* = 7.6, 6.4 Hz, 1H), 3.60-3.49 (m, 3H), 2.42 (t, *J* = 2.0 Hz, 1H), 1.79-1.58 (m, 4H), 1.41 (s, 3H), 1.35 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 108.7, 79.9, 75.7, 74.2, 69.7, 69.4, 58.0, 30.2, 26.9, 25.8, 25.7; IR (neat, cm^{-1}) 3278; HRMS (DART, m/z) Calcd. for $C_{11}H_{17}O_3 \cdot H$ ($[M+H]^+$): 199.1334, found 199.1334.

To a solution of acetonide **S29** (1.10 g, 5.53 mmol) in MeOH (22 mL) and H_2O (5.5 mL) was added DOWEX 50W-8 (200-400 mesh, 111 mg) at room temperature. After 20 h, the reaction mixture was filtered through a pad of Celite and the filtrate was concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 1/1) to afford 1,2-diol **15a** (827 mg, 94%) as an orange solid.

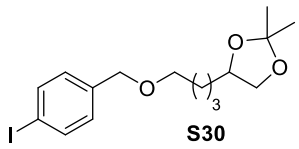


15a

Orange solid; mp. 31.1-33.9 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.16 (d, *J* = 2.4 Hz, 2H), 3.78-3.70 (m, 1H), 3.64 (dd, *J* = 10.8, 3.2 Hz, 1H), 3.58 (t, *J* = 6.0 Hz, 2H), 3.46 (dd, *J* = 10.8, 7.2 Hz, 1H), 2.62 (br s, 1H), 2.43 (t, *J* = 2.4 Hz, 1H), 1.91 (br s, 1H), 1.82-1.67 (m, 2H), 1.66-1.45 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 79.6, 74.5, 71.9, 70.1, 66.7, 58.1, 30.2, 25.7; IR (neat, cm^{-1}) 3700-3100, 3290; HRMS (DART, m/z) Calcd. for $C_8H_{14}O_3 \cdot H$ ($[M+H]^+$): 159.1021, found 159.1044.

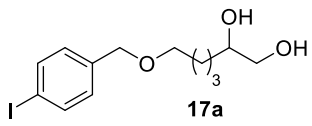


To a well-dried round-bottom flask charged with NaH (60%, 491 mg, 12.3 mmol) in dry THF (16 mL) was added a solution of acetonide **S16** (0.5 M, 1.40 g, 8.03 mmol) in dry THF dropwise at 0 °C. After the mixture was stirred for 30 min at room temperature, 4-iodobenzyl bromide (2.51 mL, 8.45 mmol) was added dropwise at 0 °C. After the reaction mixture was stirred for 5 h at room temperature, it was warmed up to 50 °C and stirred for 14 h at the same temperature. Then, it was quenched with H_2O and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 30/1 to 10/1) to afford acetonide **S30** (2.70 g, 86%) as a pale yellow oil.



Pale yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.67 (d, *J* = 8.4, 2H), 7.08 (d, *J* = 8.4 Hz, 2H), 4.43 (s, 2H), 4.12-4.01 (m, 1H), 4.03 (t, *J* = 7.6 Hz, 1H), 3.50 (t, *J* = 7.6 Hz, 1H), 3.46 (t, *J* = 6.4 Hz, 2H), 1.70-1.58 (m, 3H), 1.55-1.36 (m, 3H), 1.40 (s, 3H), 1.35 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 138.3, 137.4, 129.5, 108.7, 92.9, 76.0, 72.2, 70.3, 69.4, 33.4, 29.7, 26.9, 25.7, 22.5; IR (neat, cm^{-1}) 1099, 1059; HRMS (ESI, m/z) Calcd. for $C_{16}H_{23}IO_3 \cdot Na$ ([M+Na]$^+$): 413.0590, found 413.0586.

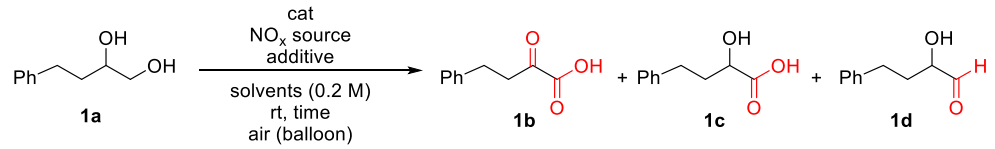
To a solution of acetonide **S30** (2.64 g, 6.76 mmol) in MeOH (27 mL) and H_2O (6.8 mL) was added DOWEX 50W-8 (200-400 mesh, 265 mg) at room temperature. After 23 h, the reaction mixture was filtered through a pad of Celite and the filtrate was concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 1/1) to afford 1,2-diol **17a** (2.22 g, 94%) as a white solid.



White solid; mp. 37.6-38.6 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.67 (d, *J* = 8.4, 2H), 7.08 (d, *J* = 8.4 Hz, 2H), 4.44 (s, 2H), 3.75-3.68 (m, 1H), 3.67 (dd, *J* = 10.4, 2.8 Hz, 1H), 3.47 (t, *J* = 6.4 Hz, 2H), 3.44 (dd, *J* = 10.4, 7.2 Hz, 1H), 1.70-1.40 (m, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 138.1, 137.4, 129.5, 92.9, 72.2, 72.0, 70.3, 66.7, 32.8, 29.5, 22.2; IR (neat, cm^{-1}) 3600-3000, 1095; HRMS (ESI, m/z) Calcd. for $C_{13}H_{19}IO_3 \cdot Na$ ([M+Na]$^+$): 373.0277, found 373.0299.

3. Optimization of the exhaustive oxidation

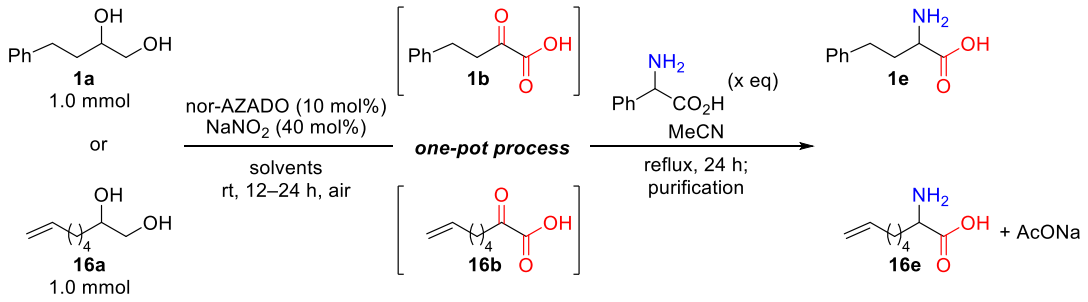
Table S1. the exhaustive oxidation of 1,2-diol to the α-keto acid



cat, NO_x source, and additive	solvents	time [h]	NMR yields [%]			
			1b	**1c**	**1d**	**1a**
AZADOL (5 mol%) $NaNO_2$ (20 mol%)	MeCN/1 M acetate buffer pH 3.9 (1/1)	24	37	6	3	14
AZADO (5 mol%) $NaNO_2$ (20 mol%)	MeCN/1 M acetate buffer pH 3.9 (1/1)	24	68	3	1	3
AZADO (5 mol%) $NaNO_2$ (20 mol%)	MeCN only	24	n.d.	n.d.	<1	96
AZADO (5 mol%) $NaNO_2$ (20 mol%)	MeCN/1 M acetate buffer pH 3.9 (8/2)	24	n.d.	n.d.	6	81
AZADO (5 mol%) $NaNO_2$ (20 mol%)	MeCN/1 M acetate buffer pH 3.9 (2/8)	24	51	7	1	9
AZADO (5 mol%) $NaNO_2$ (20 mol%)	1 M acetate buffer pH 3.9 only	24	31	6	2	16
AZADO (5 mol%) $NaNO_2$ (20 mol%)	MeCN/1 M phosphate buffer pH 6.8 (1/1)	24	n.d.	n.d.	1	96
AZADO (5 mol%) $NaNO_2$ (20 mol%)	MeCN/H_2O (1/1)	24	n.d.	n.d.	<1	100
AZADO (5 mol%) $NaNO_2$ (20 mol%)	MeCN/1 M citrate biffer pH 4.6 (1/1)	24	56	3	2	8
AZADO (5 mol%) $NaNO_2$ (20 mol%)	MeCN/1 M phosphate buffer pH 2.1 (1/1)	24	35	3	2	13
nor-AZADO (5 mol%) $NaNO_2$ (20 mol%)	MeCN/1 M acetate buffer pH 3.9 (1/1)	24	77	3	1	3
nor-AZADO (10 mol%) $NaNO_2$ (40 mol%)	MeCN/1 M acetate buffer pH 3.9 (1/1)	24	81	n.d.	n.d.	n.d.
nor-AZADO (10 mol%) $NaNO_2$ (40 mol%)	MeCN/1 M acetate buffer pH 3.9 (1/1)	48	81	<1	n.d.	n.d.
nor-AZADO (15 mol%) $NaNO_2$ (60 mol%)	MeCN/1 M acetate buffer pH 3.9 (1/1)	24	82	n.d.	n.d.	n.d.
TEMPO (10 mol%) $NaNO_2$ (40 mol%)	MeCN/1 M acetate buffer pH 3.9 (1/1)	24	n.d.	n.d.	6	70
DMN-AZADO (10 mol%) $NaNO_2$ (40 mol%)	MeCN/1 M acetate buffer pH 3.9 (1/1)	24	48	12	<1	<1
nor-AZADO (5 mol%) $NaNO_2$ (20 mol%)	MeCN/1 M acetate buffer pH 3.9 (1/1)	24	n.d.	6	4	39
nor-AZADO (5 mol%) $NaNO_2$ (20 mol%)	MeCN/1 M acetate buffer pH 3.9 (1/1)	24	81	n.d.	n.d.	n.d.
nor-AZADO (10 mol%) $NaNO_2$ (40 mol%)	MeCN/1 M acetate buffer pH 3.9 (1/1)	12	82	n.d.	n.d.	n.d.
nor-AZADO (10 mol%) $NaNO_2$ (40 mol%)	MeCN/0.1 M acetate buffer pH 3.9 (1/1)	12	31	9	9	27
nor-AZADO (10 mol%) $NaNO_2$ (40 mol%)	MeCN/H_2O (1/1) AcOH (1 eq)	12	83	n.d.	n.d.	n.d.
nor-AZADO (10 mol%) $NaNO_2$ (40 mol%)	MeCN/H_2O (1/1) AcOH (2 eq)	12	87	n.d.	n.d.	n.d.
nor-AZADO (10 mol%) ^tBuONO (40 mol%)	MeCN/H_2O (1/1) AcOH (2 eq)	12	75	<1	<1	3

4. Optimization of the one-pot protocol for the synthesis of AAs

Table S2. Optimization of one-pot protocol

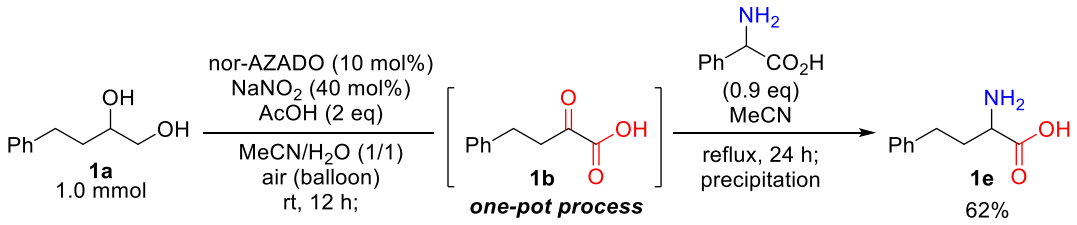


substrate	solvents	x	purification	Yield [%]	AA:AcONa[a]	recovery of DL-2-phenylglycine [%][b]
1a	MeCN/1 M acetate buffer pH 3.9 (1/1)	0.8	neutralization to pH 7 and precipitation	43	no AcONa	none
1a	MeCN/1 M acetate buffer pH 3.9 (1/1)	0.9	neutralization to pH 7 and precipitation	48	no AcONa	none
1a	MeCN/1 M acetate buffer pH 3.9 (1/1)	1.0	neutralization to pH 7 and precipitation	58	no AcONa	none
1a	MeCN/1 M acetate buffer pH 3.9 (1/1)	1.1	neutralization to pH 7 and precipitation	60	no AcONa	none
1a	MeCN/1 M acetate buffer pH 3.9 (1/1)	1.5	neutralization to pH 7 and precipitation	63	no AcONa	5
16a	MeCN/1 M acetate buffer pH 3.9 (1/1)	1.1	precipitation	45	5:1	none
16a	MeCN/H_2O (1/1) AcOH (2 eq)	0.9	precipitation	64	47:1	none
16a	MeCN/H_2O (1/1) AcOH (2 eq)	1.0	precipitation	62	39:1	3

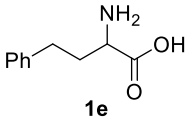
[a] Originated from acetate buffer or $NaNO_2$ and AcOH. [b] An inseparable mixture with AA.

5. One-pot, two-step synthesis of α-amino acids from 1,2-diols

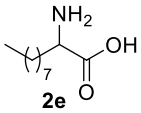
Typical procedure of synthesis of α-amino acids from 1,2-diols



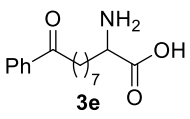
To a 50 mL round-bottom flask charged with 1,2-diol **1a** (168 mg, 1.01 mmol) and nor-AZADO (13.9 mg, 0.101 mmol) in MeCN (2.5 mL) and H_2O (2.5 mL) were added AcOH (115 μL, 2.02 mmol) and $NaNO_2$ (27.8 mg, 0.403 mmol) at room temperature (The initial pH of the reaction mixture was 4.6). After the reaction mixture was stirred under air (balloon) for 12 h, DL-2-phenylglycine (137 mg, 0.907 mmol) and MeCN (3.4 mL) were added at room temperature. The reaction mixture was refluxed for 24 h and cooled to room temperature. After the addition of Et_2O (8.4 mL), the reaction mixture was stirred until AA **1e** was fully precipitated. After filtration, the precipitate was washed with Et_2O and dried under reduced pressure to afford AA **1e** (112 mg, 62%) with high purity.



112 mg (62% yield); White solid; ^{1}H NMR (400 MHz, D_2O with 4 eq of KOH) δ 7.37 (t, J = 6.8 Hz, 2H), 7.31 (d, J = 6.8, 2H), 7.26 (t, J = 6.8, 1H), 3.25 (t, J = 6.4 Hz, 1H), 2.64 (t, J = 8.0 Hz, 2H), 1.95-1.79 (m, 2H); ^{13}C NMR (100 MHz, D_2O with 4 eq of KOH) δ 186.1, 145.1, 131.4, 131.2, 128.8, 58.5, 39.6, 34.2. See our previous report for other chemical data.[1]



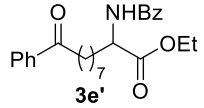
130 mg (69% yield); White solid; 180 °C decomp.; ^{1}H NMR (400 MHz, D_2O with 8 eq of KOH) δ 3.19 (t, J = 7.2 Hz, 1H), 1.65-1.45 (m, 2H), 1.34-1.20 (m, 12H), 0.85 (t, J = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, D_2O with 8 eq of KOH) δ 186.4, 58.7, 37.5, 33.9, 31.5, 31.4, 31.2, 27.7, 24.7, 16.1; IR (KBr, cm^{-1}) 3300-2400, 1656, 1583, 1512; HRMS (DART, m/z) Calcd. for $C_{10}H_{21}NO_2$·H ([M+H]$^+$): 188.1651, found 188.1643.



189 mg (68% yield); White solid; 186 °C decomp.; ^{1}H NMR (400 MHz, 5wt% deuterium chloride solution in D_2O) δ 8.01 (d, J = 7.6 Hz, 2H), 7.70 (t, J = 7.6 Hz, 1H), 7.57 (t, J = 7.6, 2H), 4.11 (t, J = 6.0 Hz, 1H), 3.10 (t, J = 7.6 Hz, 2H), 2.04-1.86 (m, 2H), 1.74-1.64 (m, 2H), 1.50-1.30 (m, 8H); IR (KBr, cm^{-1}) 3300-1900, 1687, 1657, 1581, 1512; HRMS (DART, m/z) Calcd. for $C_{16}H_{23}NO_3$·H ([M+H]$^+$): 278.1756, found 278.1752.

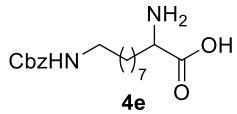
The solubility of **3e** is too low to take ^{13}C NMR in neutral D_2O. Deuteration occurred in the presence

of KOH in D_2O. Thus, after **3e** was converted to the *N*-benzoyl ethyl ester **3e'**, analytical data were also collected.



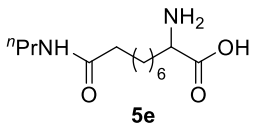
3e'

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.94 (dm, *J* = 7.6 Hz, 2H), 7.81 (dm, *J* = 7.6 Hz, 2H), 7.58-7.48 (m, 2H), 7.47-7.41 (m, 4H), 6.70 (br d, *J* = 7.2 Hz, 1H), 4.80 (dt, *J* = 7.2, 4.8 Hz, 1H), 4.23 (q, *J* = 7.6 Hz, 2H), 2.94 (t, *J* = 7.6 Hz, 2H), 2.02-1.90 (m, 1H), 1.84-1.64 (m, 3H), 1.49-1.26 (m, 8H), 1.30 (t, *J* = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 200.5, 172.7, 166.9, 137.0, 134.0, 132.9, 131.7, 128.6, 128.5, 128.0, 127.0, 61.5, 52.6, 38.5, 32.6, 29.2, 29.1, 29.0, 25.1, 24.2, 14.2; IR (neat, cm^{-1}) 3500-3200, 1739, 1682, 1645; HRMS (ESI, m/z) Calcd. for $C_{25}H_{31}NO_4$·Na ($[M+Na]^+$): 432.2151, found 432.2134.



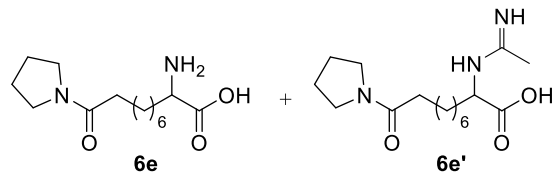
4e

207 mg (61% yield); White solid; 176 °C decomp.; ^{1}H NMR (400 MHz, D_2O with 158 eq of KOH) δ 7.47-7.35 (m, 5H), 5.10 (s, 2H), 3.20 (t, *J* = 6.4 Hz, 1H), 3.10 (t, *J* = 6.4 Hz, 2H), 1.63-1.39 (m, 4H), 1.34-1.19 (m, 10H); ^{13}C NMR (100 MHz, D_2O with 14 eq of KOH) δ 185.6, 159.8, 139.1, 130.8, 130.3, 130.0, 68.7, 58.7, 43.2, 38.0, 31.9, 31.74, 31.65, 31.5, 28.9, 28.1; IR (KBr, cm^{-1}) 3348, 3300-1800, 1687, 1622, 1589, 1506; HRMS (DART, m/z) Calcd. for $C_{18}H_{28}N_2O_4$·H ($[M+H]^+$): 337.2127, found 337.2139.



5e

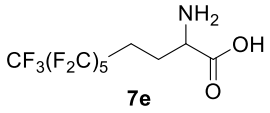
178 mg (69% yield); White solid; 202 °C decomp.; ^{1}H NMR (400 MHz, D_2O with 5 eq of KOH) δ 3.20 (t, *J* = 6.4 Hz, 1H), 3.12 (t, *J* = 6.8, 2H), 2.22 (t, *J* = 7.6 Hz, 2H), 1.63-1.43 (m, 6H), 1.34-1.23 (m, 8H), 0.87 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, D_2O with 5 eq of KOH) δ 186.6, 179.8, 58.7, 43.8, 38.5, 37.3, 31.2, 30.8, 30.7, 28.1, 27.5, 24.5, 13.3; IR (KBr, cm^{-1}) 3282, 3300-1800, 1637, 1583; HRMS (DART, m/z) Calcd. for $C_{13}H_{26}N_2O_3$·H ($[M+H]^+$): 259.2022, found 259.2025.



6e **6e'**

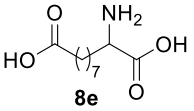
181 mg. An inseparable mixture of AA **6e** (58%) and *N*-iminyl AA **6e'** (8%); Purification of **6e** was carried out by the following procedure. After the transamination step, AcOEt was added to the reaction mixture. It was separated into organic layer and aqueous layer. The aqueous layer was washed with AcOEt. The organic layer was extracted with H_2O. The resultant aqueous layers were combined and charged on a cationic ion exchange chromatography (DOWEX 50W-8, 200-400 mesh). The product was eluted with aq. NH_3 (3%). The eluent was removed by lyophilizer to afford AA **6e** with **6e'** as an inseparable mixture.; White solid; 141 °C decomp.; ^{1}H NMR (400 MHz, D_2O) δ 3.71 (t, *J* = 6.4 Hz, 1H), 3.52 (t, *J* = 6.4 Hz, 2H), 3.37 (t, *J* = 6.4 Hz, 2H), 2.35 (t, *J* = 8.0 Hz, 2H), 1.97-1.80 (m, 6H), 1.63-1.51 (m, 2H), 1.44-1.23 (m, 8H); ^{13}C NMR (100 MHz, D_2O) δ 177.74, 177.72, 57.5, 50.2, 48.3, 36.8, 33.1, 31.0, 30.9, 30.8, 28.0, 27.3,

26.9, 26.7; IR (KBr, cm^{-1}) 3700-1800, 1635, 1581; HRMS (ESI, m/z) Calcd. for $C_{14}H_{26}N_2O_3 \cdot Na$ ($[M+Na]^+$): 293.1841, found 293.1825. HRMS (ESI, m/z) Calcd. for $C_{16}H_{29}N_3O_3 \cdot H$ ($[M+H]^+$): 312.2287, found 312.2266.



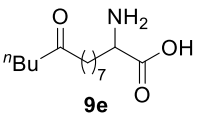
7e

70.8 mg (17% yield); Purification of AA **7e** was carried out by the following procedure referring to Zhao's report.[6] After the transamination step, Et_2O (8.3 mL) was added to the reaction mixture, which was stirred until AA **7e** was fully precipitated. Then, the precipitate was collected by filtration, washed with Et_2O and dried under reduced pressure to afford AA **7e** as an inseparable mixture with unreacted DL-2-phenylglycine. The mixture was dissolved to MeOH and silica gel (1.5 g) was added. The solvent was removed via rotary evaporator under reduced pressure. The residue was purified with flash column chromatography on silica gel (EtOH/AcOEt/28% NH_3 = 100/58/16) and concentrated in vacuo. The resultant AA **7e** was washed with ether to remove CH_3CONH_2 originated from AcOEt and NH_3. AA **7e** was dried under reduced pressure and obtained in pure form.; White solid; 143 °C decomp.; ^{1}H NMR (400 MHz, D_2O with 9 eq of KOH) δ 3.26 (t, J = 6.4 Hz, 1H), 2.33-2.06 (m, 2H), 2.00-1.87 (m, 1H), 1.80-1.69 (m, 1H); ^{13}C NMR (100 MHz, D_2O with 9 eq of KOH) δ 184.4, 58.0, 29.9 (t, J = 22.0 Hz), 28.6; ^{19}F NMR (376 MHz, $CDCl_3$) δ -81.9, -115.3, -122.4, -123.4, -124.0, -126.8; IR (KBr, cm^{-1}) 3300-1800, 1620, 1591, 1508, 1234, 1207, 1192, 1144; HRMS (DART, m/z) Calcd. for $C_{10}H_8F_{13}NO_2 \cdot H$ ($[M+H]^+$): 422.0426, found 422.0439.



8e

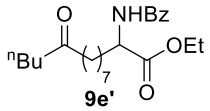
73.6 mg (34% yield); nor-AZADO (27.7 mg, 0.200 mmol), AcOH (229 μL, 4.00 mmol), and $NaNO_2$ (55.3 mg, 0.801 mmol) were used.; Pale brown solid; ^{1}H NMR (400 MHz, D_2O with 5 eq of KOH) δ 3.20 (t, J = 6.4 Hz, 1H), 2.16 (t, J = 7.2 Hz, 2H), 1.65-1.44 (m, 4H), 1.39-1.21 (m, 8H); ^{13}C NMR (100 MHz, D_2O with 5 eq of KOH) δ 187.0, 186.7, 58.7, 40.4, 37.4, 31.4, 31.3, 31.1, 28.6, 27.6. See our previous report for other chemical data.[1]



9e

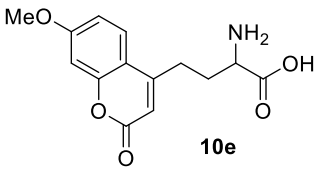
179 mg (69% yield); White solid; 169 °C decomp.; ^{1}H NMR (400 MHz, 5wt% deuterium chloride solution in D_2O) δ 4.12 (t, J = 6.8 Hz, 1H), 2.55 (t, J = 7.2 Hz, 4H), 2.06-1.85 (m, 2H), 1.59-1.22 (m, 14H), 0.86 (t, J = 7.2 Hz, 3H); IR (KBr, cm^{-1}) 3300-2000, 1705, 1657, 1622, 1583; HRMS (ESI, m/z) Calcd. for $C_{14}H_{27}NO_3 \cdot Na$ ($[M+Na]^+$): 280.1889, found 280.1865.

The solubility of **9e** is too low to take ^{13}C NMR in neutral D_2O. Deuteration occurred in the presence of KOH in D_2O. Thus, after **9e** was converted to the *N*-benzoyl ethyl ester **9e'**, analytical data were also collected.



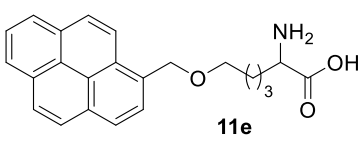
9e'

White solid; mp. 57.7-60.6 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.81 (d, *J* = 7.2 Hz, 2H), 7.51 (t, *J* = 7.2 Hz, 1H), 7.44 (t, *J* = 7.2 Hz, 2H), 6.68 (br d, *J* = 8.0 Hz, 1H), 4.80 (dt, *J* = 7.2, 5.6 Hz, 1H), 4.24 (q, *J* = 6.8 Hz, 2H), 2.37 (td, *J* = 7.2, 2.8 Hz, 4H), 2.01-1.89 (m, 1H), 1.83-1.71 (m, 1H), 1.53 (quint, *J* = 7.2 Hz, 4H), 1.47-1.19 (m, 10H), 1.30 (t, *J* = 7.2 Hz, 3H), 0.89 (t, *J* = 6.8 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 211.6, 172.7, 166.9, 134.1, 131.7, 128.6, 127.0, 61.5, 52.6, 42.7, 42.5, 32.7, 29.14, 29.06, 29.0, 26.0, 25.1, 23.7, 22.3, 14.2, 13.8; IR (neat, cm^{-1}) 3500-3200, 1739, 1712, 1645; HRMS (ESI, m/z) Calcd. for $C_{23}H_{35}NO_4 \cdot Na$ ($[M+Na]^+$): 412.2464, found 412.2439.



10e

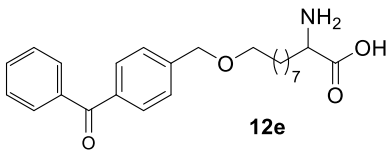
141 mg (51% yield); Purification of AA **10e** was carried out by the following procedure. After the transamination step, Et_2O (8.4 mL) was added. The reaction mixture was stirred until AA **10e** was fully precipitated. After decantation, the precipitate was dried under reduced pressure. MeCN (5.0 mL) and H_2O (5.0 mL) were poured to AA **10e**. Then, it was filtered, washed with MeCN, and dried under reduced pressure to afford AA **10e**.; White solid; 225 °C decomp.; ^{1}H NMR (400 MHz, 5wt% deuterium chloride solution in D_2O) δ 7.72 (d, *J* = 9.2 Hz, 1H), 7.03 (dd, *J* = 9.2, 2.8 Hz, 1H), 6.96 (d, *J* = 2.8 Hz, 1H), 6.28 (s, 1H), 4.30 (t, *J* = 6.4 Hz, 1H), 3.91 (s, 3H), 3.13-2.96 (m, 2H), 2.45-2.27 (m, 2H); IR (KBr, cm^{-1}) 3300-2000, 1701, 1606, 1558; HRMS (DART, m/z) Calcd. for $C_{14}H_{15}NO_5 \cdot H$ ($[M+H]^+$): 278.1029, found 278.1008.



11e

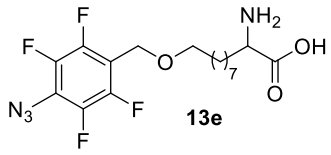
178 mg (49% yield); 0.8 eq of DL-2-phenylglycine was used in transamination step. Purification of AA **11e** was carried out by the following procedure. After the transamination step, Et_2O (8.4 mL) was added to the reaction mixture. It was stirred until AA **11e** was fully precipitated. After filtration, the precipitate was washed with Et_2O and dried under reduced pressure to afford AA **11e** as an inseparable mixture with 8% of unreacted phenylglycine. Then, to the suspension of this mixture in THF (2.0 mL) and H_2O (0.87 mL) was added oxalacetic acid (16.8 mg, 0.127 mmol) at room temperature. The reaction mixture was refluxed for 12 h and cooled to room temperature. After filtration, the precipitate was washed with Et_2O and H_2O and dried under reduced pressure to afford AA **11e**.; Brown solid; 180 °C decomp.; ^{1}H NMR (400 MHz, D_2O with 5 eq of KOH) δ 7.47-7.32 (m, 1H), 7.32-7.03 (m, 6H), 7.03 (d, *J* = 8.0 Hz, 1H) 6.95 (d, *J* = 8.0 Hz, 1H), 4.19 (s, 2H), 3.02 (t, *J* = 6.0 Hz, 1H), 2.82-2.66 (m, 2H), 1.49-1.32 (m, 1H), 1.23-1.00 (m, 3H), 0.98-0.79 (m, 2H); ^{13}C NMR (100 MHz, D_2O with 5 eq of KOH) δ 185.4, 133.01, 132.95, 132.8, 132.6, 130.6,

129.3 (2C), 129.0, 128.5, 127.8, 127.2, 127.0, 126.6, 126.33, 126.29, 124.8, 72.3 (2C), 58.6, 37.8, 31.4, 24.5; IR (KBr, cm^{-1}) 3700-1800, 1655, 1624, 1581; HRMS (ESI, m/z) Calcd. for $C_{23}H_{23}NO_3 \cdot Na$ ($[M+Na]^+$): 384.1576, found 384.1585.



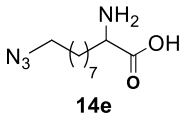
12e

229 mg (58% yield); The reaction was carried out in the dark.; White solid; 193 °C decomp.; ^1H NMR (400 MHz, D_2O with 12 eq of KOH) δ 7.44 (t, *J* = 7.6 Hz, 4H), 7.25 (t, *J* = 7.6 Hz, 1H), 7.18-7.10 (m, 4H), 4.26 (s, 2H), 3.27-3.14 (m, 3H), 1.68-1.56 (m, 1H), 1.49-1.33 (m, 3H), 1.33-1.01 (m, 10H); ^{13}C NMR (100 MHz, D_2O with 12 eq of KOH) δ 198.3, 185.2, 146.0, 139.4, 138.4, 134.8, 132.3, 132.1, 130.6, 129.2, 73.9, 73.0, 58.7, 38.2, 31.9 (2C), 31.8 (2C), 28.4, 28.2; IR (KBr, cm^{-1}) 3400-1800, 1648, 1624, 1583; HRMS (ESI, m/z) Calcd. for $C_{24}H_{31}NO_4 \cdot Na$ ($[M+Na]^+$): 420.2151, found 420.2149.



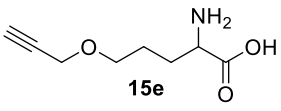
13e

137 mg (70%); Synthesis of AA **13e** was carried out in 0.50 mmol scale by the following procedure. To a 50 mL round-bottom flask charged with 1,2-diol **13a** (197 mg, 0.500 mmol) and nor-AZADO (6.9 mg, 0.0499 mmol) in MeCN (2.5 mL) and H_2O (2.5 mL) were added AcOH (57.2 μL, 1.00 mmol) and $NaNO_2$ (13.8 mg, 0.200 mmol) at room temperature. After the reaction mixture was stirred under air (balloon) for 12 h in the dark, DL-2-phenylglycine (68.0 mg, 0.450 mmol) and MeCN (3.3 mL) were added at room temperature. The reaction mixture was refluxed for 24 h in the dark and cooled to room temperature. After Et_2O (8.3 mL) was added to the reaction mixture, the solution was stirred until AA **13e** was fully precipitated. After filtration, the precipitate was washed with Et_2O and dried under reduced pressure to afford AA **13e** (137 mg, 70%) with high purity.; Pale brown solid; 151 °C decomp.; ^1H NMR (400 MHz, D_2O with 8 eq of KOH) δ 4.47 (s, 2H), 3.37 (t, *J* = 6.4 Hz, 2H), 3.18 (dd, *J* = 7.2, 4.8 Hz, 1H), 1.72-1.58 (m, 1H), 1.57-1.11 (m, 13H); ^{13}C NMR (100 MHz, D_2O with 8 eq of KOH) δ 185.3, 147.8 (d, *J* = 246.9 Hz), 142.5 (dd, *J* = 246.9, 16.2 Hz), 122.3 (t, *J* = 12.4 Hz), 114.3 (t, *J* = 18.1 Hz), 73.1, 61.4, 58.9, 38.4, 32.1, 32.0 (2C), 31.8, 28.4 (2C); IR (KBr, cm^{-1}) 3300-2500, 2129, 1624, 1608, 1581, 1496; HRMS (ESI, m/z) Calcd. for $C_{17}H_{22}F_4N_4O_3 \cdot Na$ ($[M+Na]^+$): 429.1526, found 429.1524.



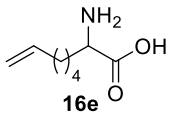
14e

125 mg (55% yield); White solid; 182 °C decomp.; ^1H NMR (400 MHz, D_2O with 5 eq of KOH) δ 3.31 (t, *J* = 6.8 Hz, 2H), 3.20 (dd, *J* = 7.2, 6.0 Hz, 1H), 1.65-1.46 (m, 4H), 1.41-1.23 (m, 10H); ^{13}C NMR (100 MHz, D_2O with 4 eq of KOH) δ 186.7, 58.7, 53.9, 37.4, 31.3, 31.1, 30.9, 30.6, 28.6, 27.6; IR (KBr, cm^{-1}) 3600-1900, 2100, 1655, 1624, 1581; HRMS (ESI, m/z) Calcd. for $C_{10}H_{20}N_4O_2 \cdot Na$ ($[M+Na]^+$): 251.1484, found 251.1472.



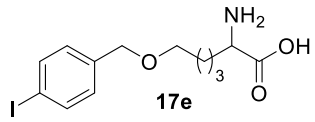
15e

125 mg (73% yield); Purification of AA **15e** was carried out in the similar way with AA **6e**.; White solid; 159 °C decomp.; ^{1}H NMR (400 MHz, D_2O) δ 4.21 (d, *J* = 2.4 Hz, 2H), 3.75 (t, *J* = 6.0, 1H), 3.64 (t, *J* = 6.4 Hz, 2H), 2.88 (t, *J* = 2.4 Hz, 1H), 2.03-1.83 (m, 1H), 1.81-1.60 (m, 3H); ^{13}C NMR (100 MHz, D_2O) δ 177.3, 82.2, 78.5, 72.1, 60.4, 57.2, 30.0, 27.1; IR (KBr, cm^{-1}) 3286, 3200-1800, 1655, 1624, 1581 HRMS (DART, m/z) Calcd. for $C_8H_{13}NO_3$·H ($[M+H]^+$): 172.0974, found 172.0968.



16e

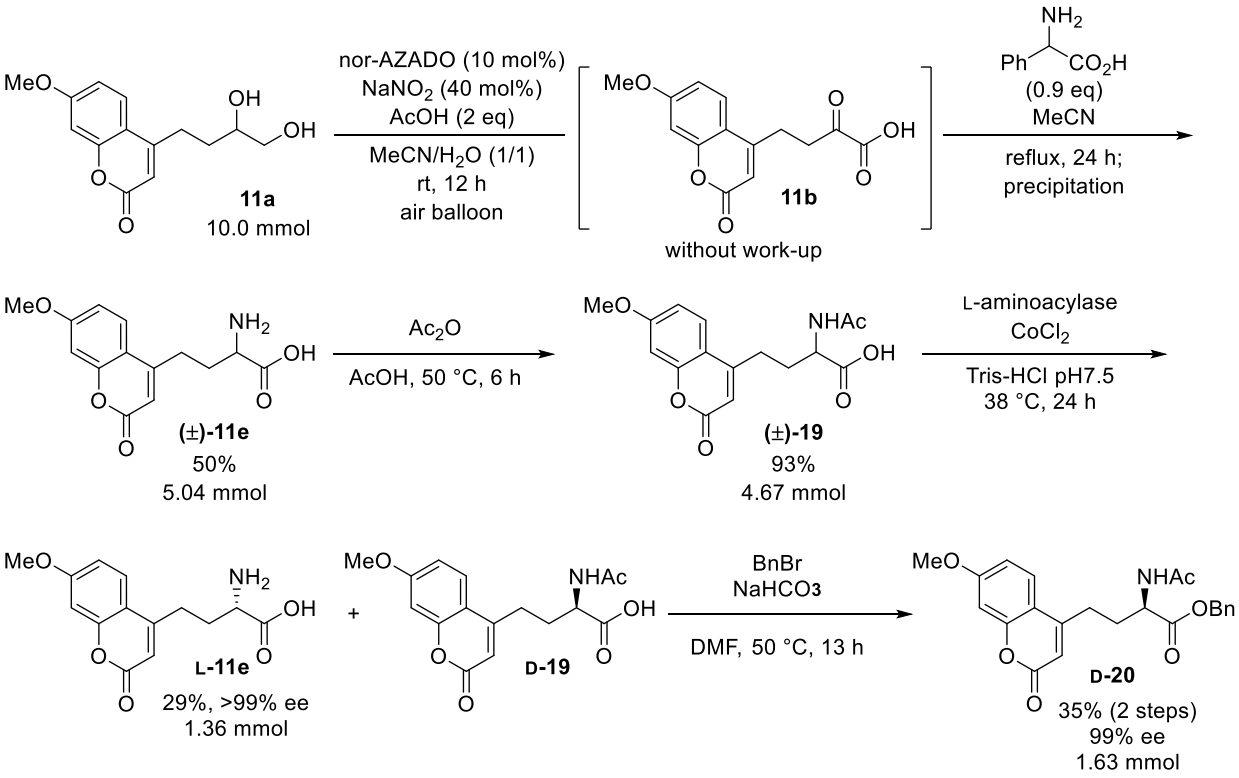
103 mg (64% yield); Precipitation was carried out using MeCN (12.5 mL) instead of Et_2O.; White solid; 158 °C decomp.; ^{1}H NMR (400 MHz, D_2O with 4 eq of KOH) δ 5.90 (ddt, *J* = 16.8, 10.0, 6.4 Hz, 1H), 5.05 (dt, *J* = 16.8, 1.2 Hz, 1H), 4.97 (dt, *J* = 10.0, 1.2 Hz, 1H), 3.20 (t, *J* = 6.8 Hz, 1H), 2.06 (br q, *J* = 6.4 Hz, 2H), 1.65-1.48 (m, 2H), 1.44-1.35 (m, 2H), 1.35-1.26 (m, 2H); ^{13}C NMR (100 MHz, D_2O with 4 eq of KOH) δ 186.6, 142.7, 116.9, 58.7, 37.2, 35.6, 30.7, 27.2; IR (KBr, cm^{-1}) 3300-2200, 1657, 1581, 1514; HRMS (DART, m/z) Calcd. for $C_8H_{15}NO_2$·H ($[M+H]^+$): 158.1181, found 158.1156.



17e

240 mg (65% yield); White solid; 176 °C decomp.; ^{1}H NMR (400 MHz, D_2O with 4 eq of KOH) δ 7.70 (d, *J* = 8.0 Hz, 2H), 7.10 (d, *J* = 8.0 Hz, 2H), 4.42 (s, 2H), 3.48 (t. *J* = 6.4 Hz, 2H), 3.19 (t, *J* = 6.0 Hz, 1H), 1.66-1.44 (m, 4H), 1.37-1.26 (m, 2H); ^{13}C NMR (100 MHz, D_2O with 4 eq of KOH) δ 186.1, 140.2, 139.9, 133.0, 96.1, 74.4, 72.8, 58.6, 37.3, 31.4, 24.4; IR (KBr, cm^{-1}) 3300-1800, 1653, 1610, 1583, 1109; HRMS (DART, m/z) Calcd. for $C_{13}H_{18}INO_3$·H ($[M+H]^+$): 364.0410, found 364.0384.

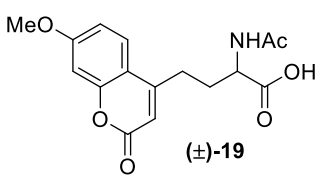
6. Large-scale synthesis and optical resolution of *N*-acetyl α-amino acid



Scale-up of AA synthesis and sequential chemoenzymatic resolution was carried out according for the following procedure.

To a 1 L round-bottom flask charged with 1,2-diol **11a** (2.65 g, 10.0 mmol) and nor-AZADO (138 mg, 1.00 mmol) in MeCN (25 mL) and H_2O (25 mL) were added AcOH (1.14 mL, 20.0 mmol) and $NaNO_2$ (276 mg, 4.00 mmol) at room temperature. After the reaction mixture was stirred under air (balloon) for 12 h, DL-2-phenylglycine (1.36 g, 9.01 mmol) and MeCN (33 mL) were added at room temperature. The reaction mixture was refluxed for 24 h and cooled to room temperature. After MeCN (125 mL) was added to the reaction mixture, the solution was stirred until AA **(±)-11e** was fully precipitated. After the precipitate was collected by filtration, it was washed with MeCN and dried under reduced pressure to afford AA **(±)-11e** (1.34 g, 50%) with high purity.

To a solution of AA **(±)-11e** (1.34 g, 5.04 mmol) in AcOH (25 mL) was added Ac_2O (714 μL, 7.55 mmol) at room temperature. After the reaction mixture was stirred for 6 h at 50 °C, AcOH was removed via rotary evaporator under reduced pressure. After the precipitate was collected by filtration, it was washed with AcOEt and dissolved to MeOH. After the addition of toluene, AcOH was completely removed under reduced pressure. The resultant solid was dried under reduced pressure to afford *N*-acetyl AA **(±)-19** (1.49 g, 93%) as a brown solid.

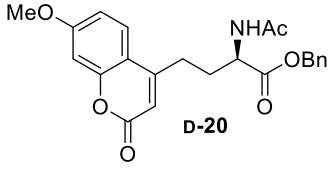


(±)-19

Brown solid; mp. 91.2-92.7 °C; ^{1}H NMR (400 MHz, CD_3OD) δ 7.72 (d, *J* = 9.2 Hz, 1H), 6.98 (dd, *J* = 9.2, 2.0 Hz, 1H), 6.93 (d, *J* = 2.0 Hz, 1H), 6.19 (s, 1H), 4.51 (dd, *J* = 8.4, 4.4, 1H), 3.90 (s, 3H), 2.90 (t, *J* = 7.6 Hz, 2H), 2.30-2.16 (m, 1H), 2.12-1.98 (m, 1H), 2.03 (s, 3H); ^{13}C NMR (100 MHz, CD_3OD) δ 174.8, 173.5, 164.6, 163.5, 157.9, 156.9, 126.9, 113.8, 113.7, 111.5, 102.0, 56.4, 53.3, 31.6, 29.1, 22.4; IR (KBr, cm^{-1}) 3325, 1716, 1658, 1614; HRMS (ESI, m/z) Calcd. for $C_{16}H_{17}NO_6$·Na ([M+Na]$^+$): 342.0954, found 342.0950.

To a solution of *N*-acetyl AA **(±)-19** (1.49 g, 4.67 mmol) and aq. $CoCl_2$ (0.01 M, 1.17 mL, 11.7 μmol) in Tris-HCl buffer (1 M, pH 7.5, 47 mL) was added L-amino acylase (692 mg) at room temperature. After the reaction mixture was stirred for 24 h at 38 °C, MeCN (141 mL) was added. After 1 h, AA **L-11e** was precipitated. Then the reaction mixture was centrifuged, the precipitate was filtered, washed with MeCN and water, and dried under reduced pressure to afford AA **L-11e** (376 mg, 29%).

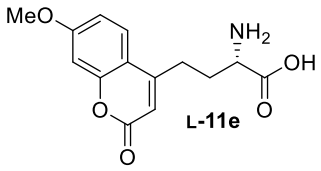
On the other hand, water in filtrate was azeotropically removed with toluene. 10% HCl was added to the residue and the resultant solution was saturated with solid NH_4Cl and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo to afford crude *N*-acetyl AA **D-19**. To a solution of crude *N*-acetyl AA **D-19** and $NaHCO_3$ (5.47 g, 65.1 mmol) in DMF (11 mL) was added benzyl bromide (0.643 mL, 5.42 mmol) at room temperature. After the reaction mixture was stirred for 2 h at 50 °C, additional $NaHCO_3$ (2.75 g, 32.7 mmol) was added and stirred for 11 h. Then, it was quenched with H_2O and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo. The residue was purified with flash column chromatography on silica gel (hexane/AcOEt = 1/1 to AcOEt only) to afford *N*-acetyl amino benzylester **D-20** with small amount of impurities originated from DMF. This material was washed with saturated aq. NH_4Cl and extracted with AcOEt. The organic layer was dried over $MgSO_4$, filtered, and concentrated in vacuo to afford *N*-acetyl amino benzylester **D-20** (669 mg, 35%) in pure form as a brown oil.



D-20

Brown oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41-7.34 (m, 5H), 7.32 (d, *J* = 8.8 Hz, 1H), 6.81 (d, *J* = 2.4 Hz, 1H), 6.78 (dd, *J* = 8.8, 2.4 Hz, 1H), 6.17 (br d, *J* = 6.8 Hz, 1H), 6.02 (s, 1H), 5.28 (d, *J* = 11.6 Hz, 1H), 5.17 (d, *J* = 11.6 Hz, 1H), 4.80 (dt, *J* = 7.2, 5.6 Hz, 1H), 3.86 (s, 3H), 2.79-2.69 (m, 1H), 2.65-2.55 (m, 1H), 2.31-2.16 (m, 1H), 2.08 (s, 3H), 2.08-1.96 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.7, 170.0, 162.6, 161.1, 155.4, 154.7, 134.8, 128.83, 128.77, 128.5, 125.0, 112.4, 112.3, 110.8, 101.1, 67.6, 55.7, 52.0, 31.2, 27.6, 23.2, HRMS (ESI, m/z) Calcd. for $C_{23}H_{23}NO_6$·Na ([M+Na]$^+$): 432.1423, found 432.1439.

Enantiomeric excess of AA **L-11e** and *N*-acetyl amino benzylester **D-20** was measured by chiral HPLC. AA **L-11e** was converted to *N*-benzoyl amino methylester **L-11e'** by using $TMSC_2N_2$ and BzCl. The absolute configuration was determined by comparing optical rotations with the previous report.[7]



$[\alpha]_D^{25}$ = +32.8 (*c* 0.16, 1.0 M HCl), >99% ee.

HPLC Conditions

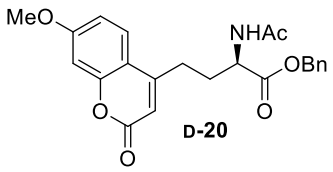
Column: Chiralcel OD-H, Daicel Chemical Industries, Ltd.

Eluent: hexane/isopropanol (70:30)

Flow rate: 1.0 mL/min

Detection: UV 220 nm

Retention time: D-isomer: 26.5 min, L-isomer: 33.7 min.



$[\alpha]_D^{25}$ = -27.7 (*c* 0.91, $CHCl_3$), 99% ee.

HPLC Conditions

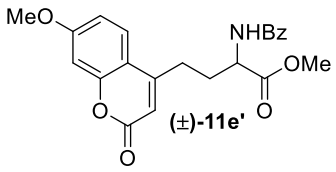
Column: Chiralcel IC, Daicel Chemical Industries, Ltd.

Eluent: hexane/isopropanol (50:50)

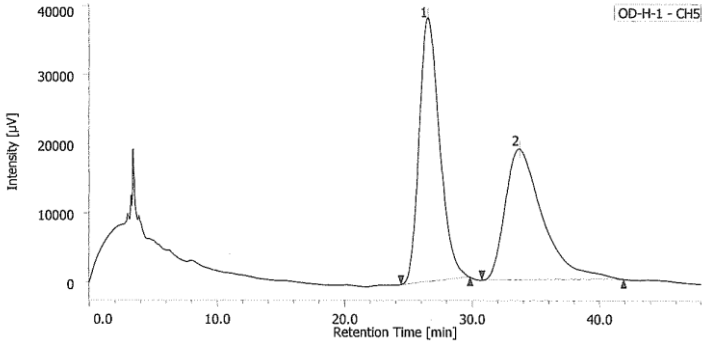
Flow rate: 1.0 mL/min

Detection: UV 220 nm

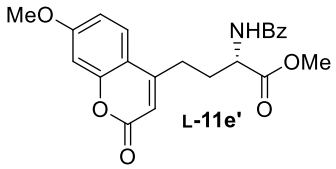
Retention time: D-isomer: 52.0 min, L-isomer: 59.1 min.

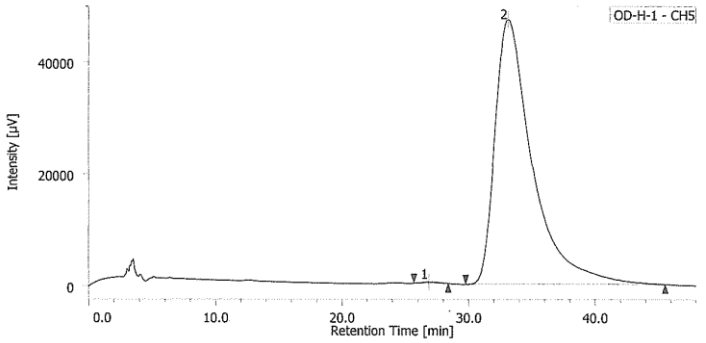


Racemate.

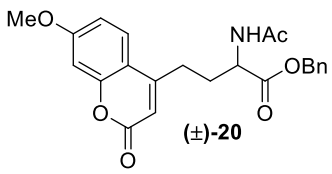


#	Peak Name	CH	tR [min]	Area [μV·sec]	Height [μV]	Area%
1	Unknown	5	26.528	4310271	38169	52.644
2	Unknown	5	33.688	3877314	18953	47.356



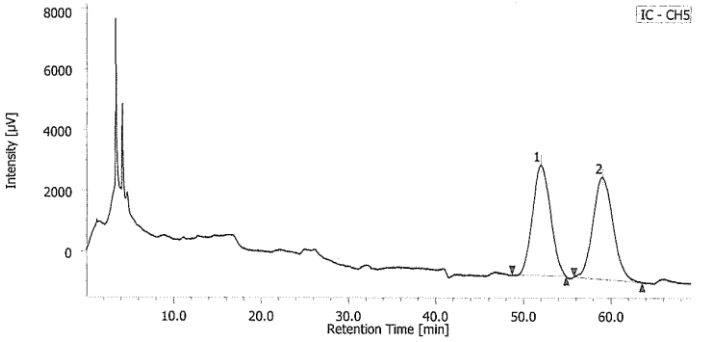


#	Peak Name	CH	tR [min]	Area [μV·sec]	Height [μV]	Area%
1	Unknown	5	26.828	22393	273	0.229
2	Unknown	5	33.085	9749780	47319	99.771

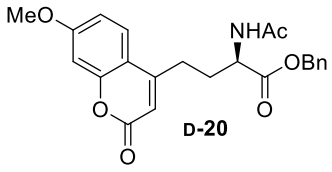


(±)-20

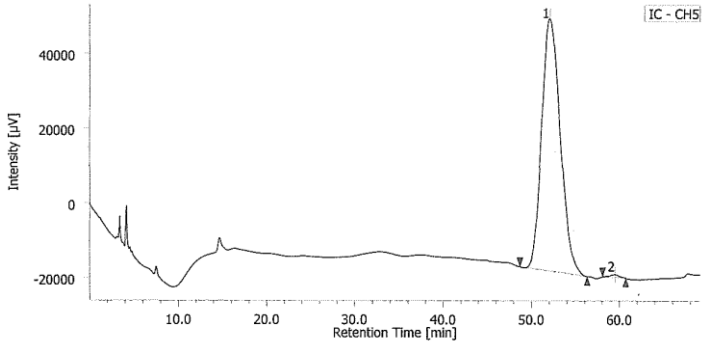
Racemate.



#	Peak Name	CH	tR [min]	Area [μV·sec]	Height [μV]	Area%
1	Unknown	5	51.970	522067	3663	49.107
2	Unknown	5	59.062	541046	3398	50.893



D-20



#	Peak Name	CH	tR [min]	Area [μV·sec]	Height [μV]	Area%
1	Unknown	5	52.098	9868667	67684	99.398
2	Unknown	5	59.517	59766	796	0.602

7. UV-vis absorption and fluorescent emission spectra

UV-vis absorbance spectra of AAs **10e** and **11e** were recorded as a solution (10 μM) in aq. HCl (1.0 M).

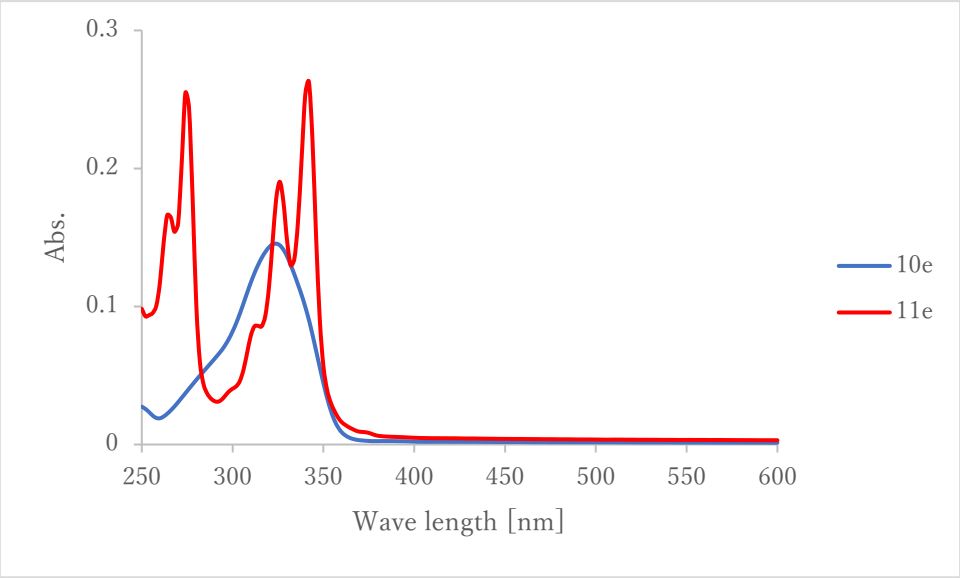


Figure S1. UV–vis absorption spectra of **10e** and **11e**.

Emission spectra of AAs **10e** and **11e** were recorded as a solution (10 μM and 1.0 μM respectively) in aq. HCl (1.0 M) by excitation at 324 and 341 nm respectively.

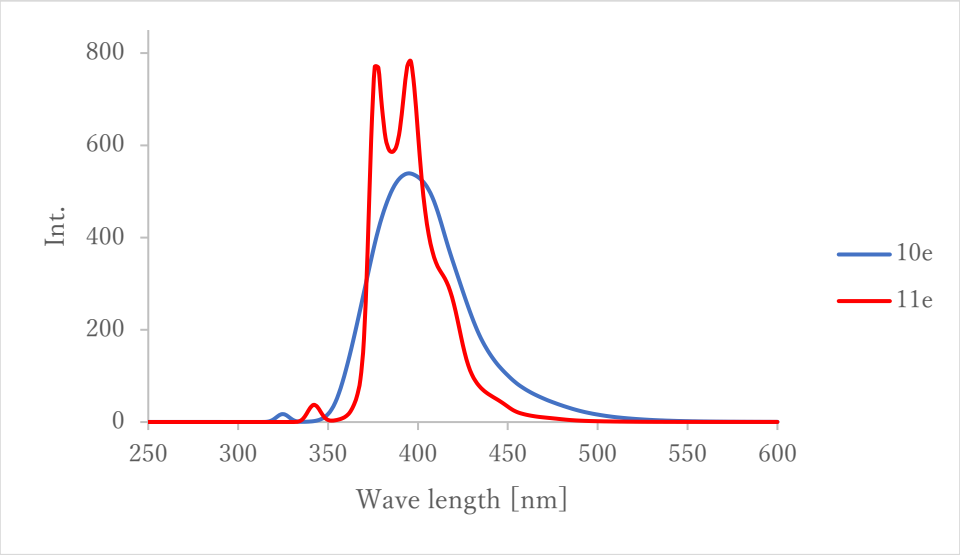


Figure S2. Fluorescent emission spectra of **10e** and **11e**.

8. References

1 H. Inada, M. Shibuya and Y. Yamamoto, *Org. Lett*. 2019, **21**, 709.

2 (*a*) A. Bonet, C. Pubill-Ulldemolins, C. Bo, H. Gulyás and E. Fernández, *Angew. Chem.* 2011, **123**, 7296; *Angew. Chem. Int. Ed.* 2011, **50**, 7158-7161; (*b*) T. P. Blaisdell, T. C. Caya, L. Zhang, A. Sanz-Marco and J. P. Morken, *J. Am. Chem. Soc.* 2014, **136**, 9264.

3 S. Nagayama, M. Endo and S. Kobayashi, *J. Org. Chem.* 1998, **63**, 6094-6095.

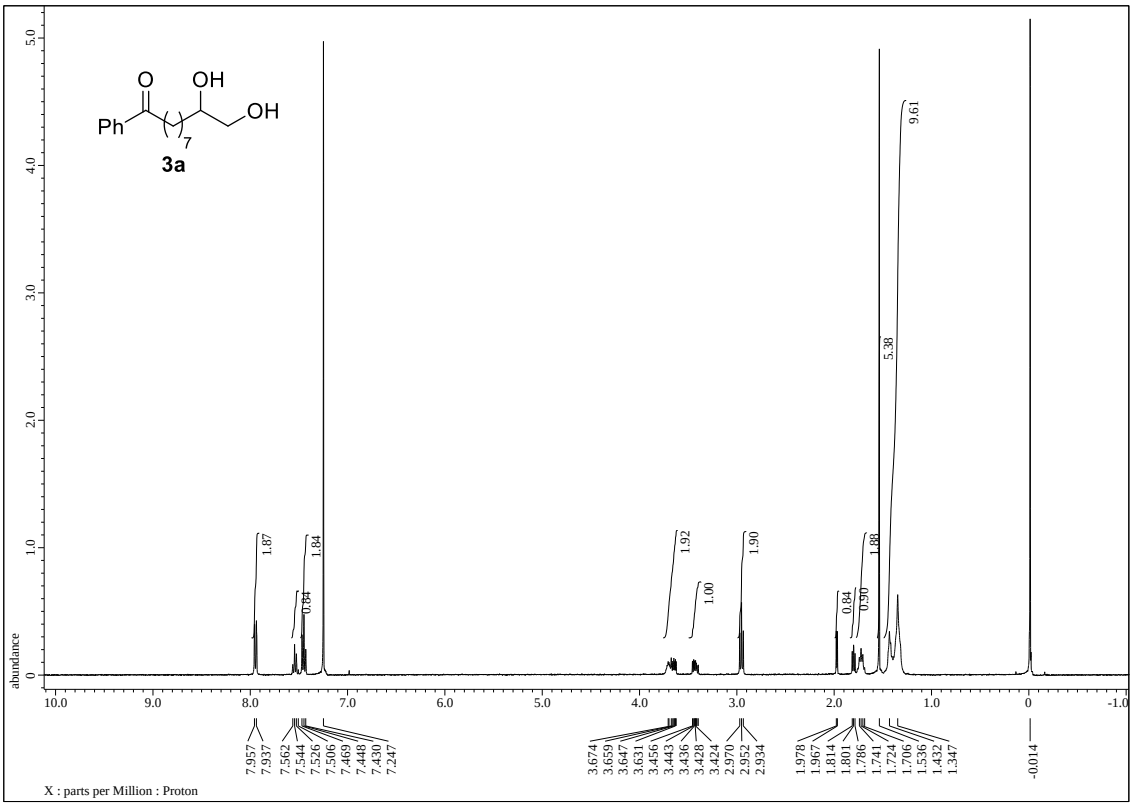
4 S. Pan, S-Y Jang, D Wang, Si Si Liew, Z Li, J-S Lee and S. Q. Yao, *Angew. Chem.* 2017, **129**, 11978; *Angew. Chem. Int. Ed.* 2017, **56**, 11816.

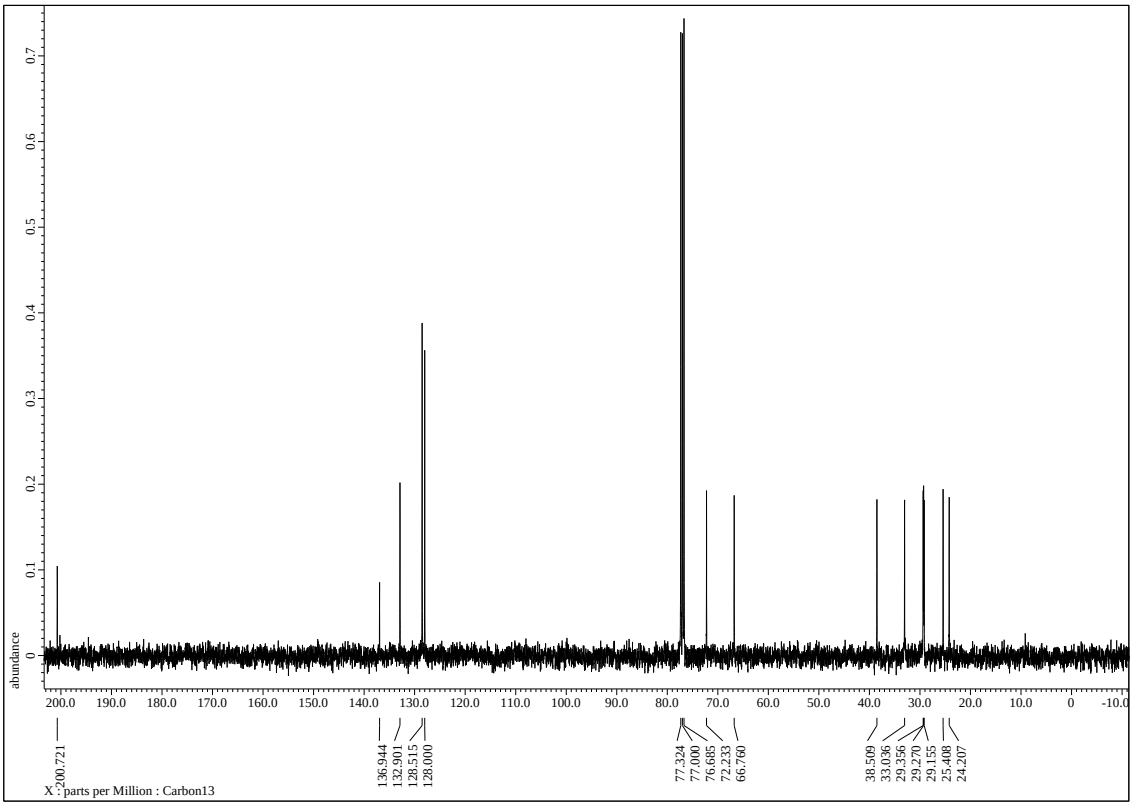
5 J. F. W. Keana and S. X. Cai, *J. Org. Chem.* 1990, **55**, 3640.

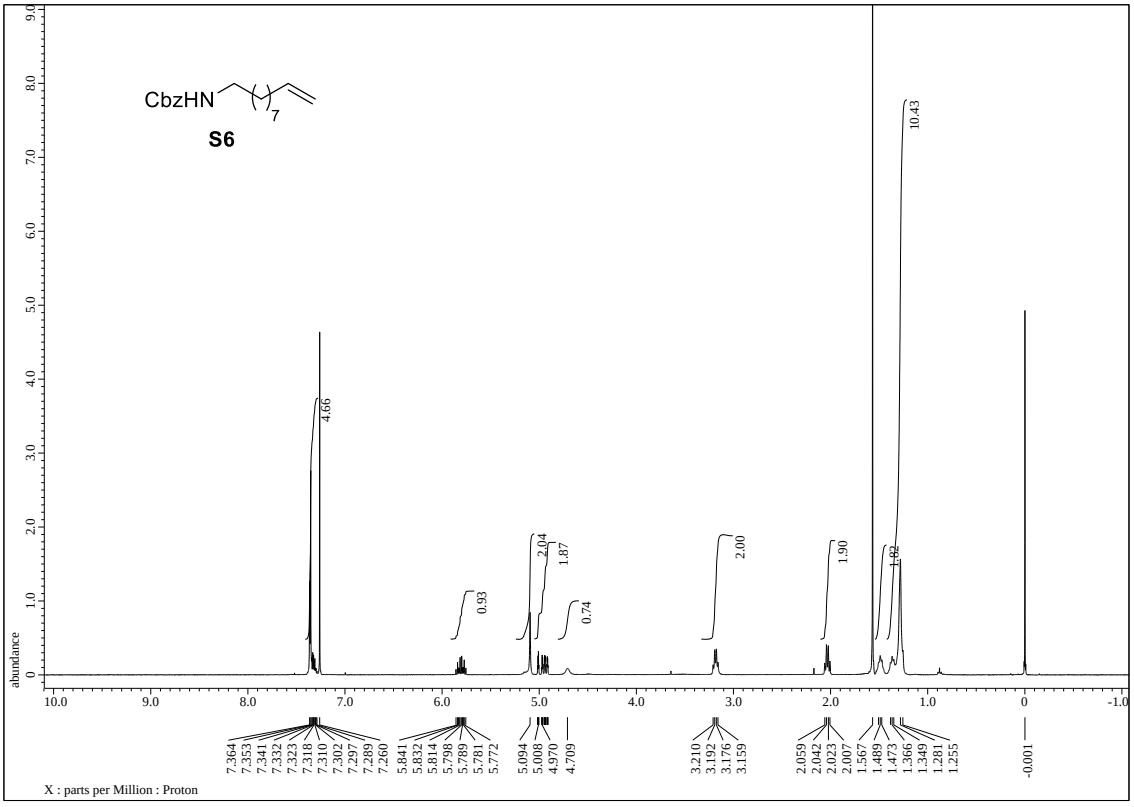
6 Y. E. Liu, Z. Lu, B. Li, J. Tian, F. Liu, J. Zhao, C. Hou, Y. Li, L. Niu and B. Zhao, *J. Am. Chem. Soc.* 2016, **138**, 10730.

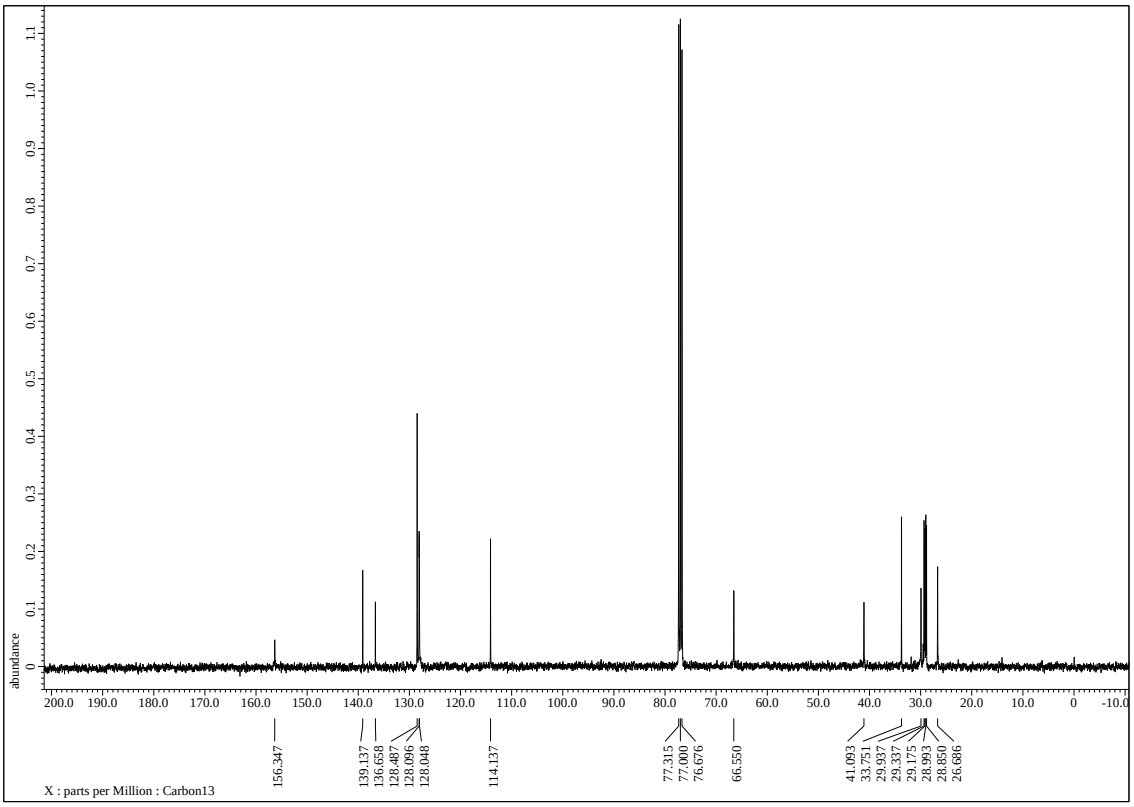
7 M-P Brun, L. Bischoff and C. Garbay, *Angew. Chem.* 2004, **116**, 3514-3518; *Angew. Chem. Int. Ed.* 2004, **43**, 3432.

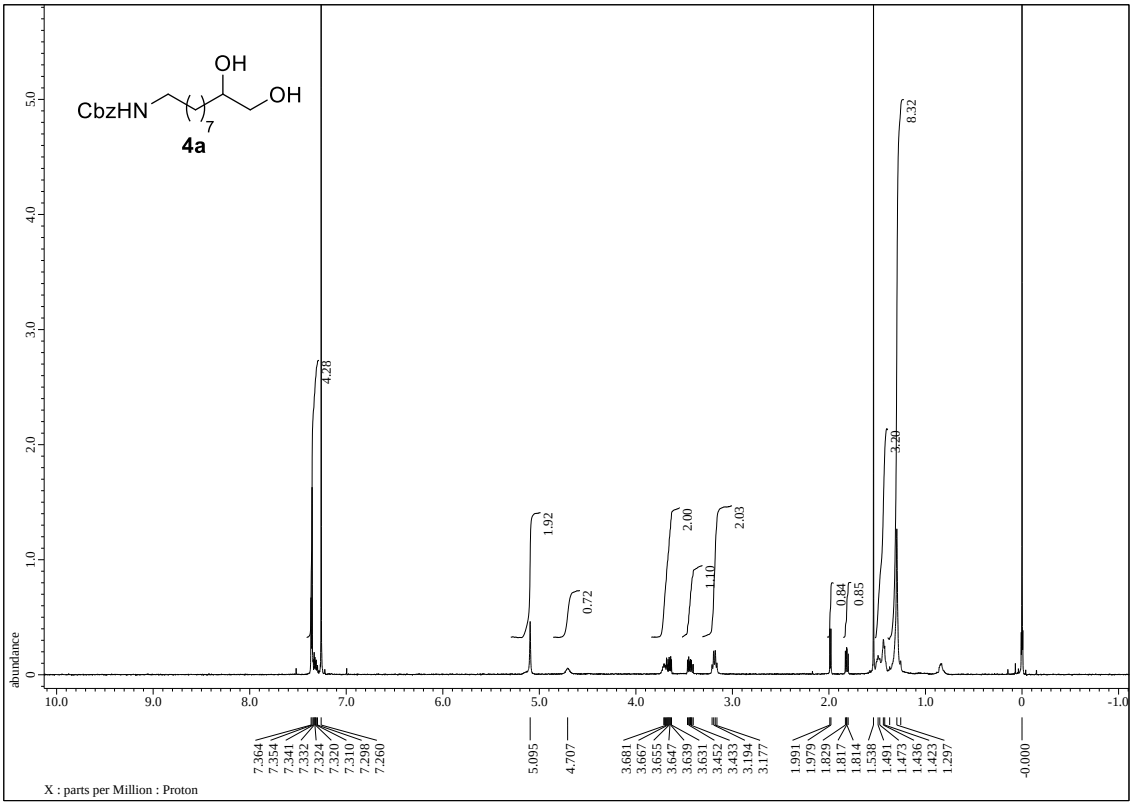
9. NMR spectra

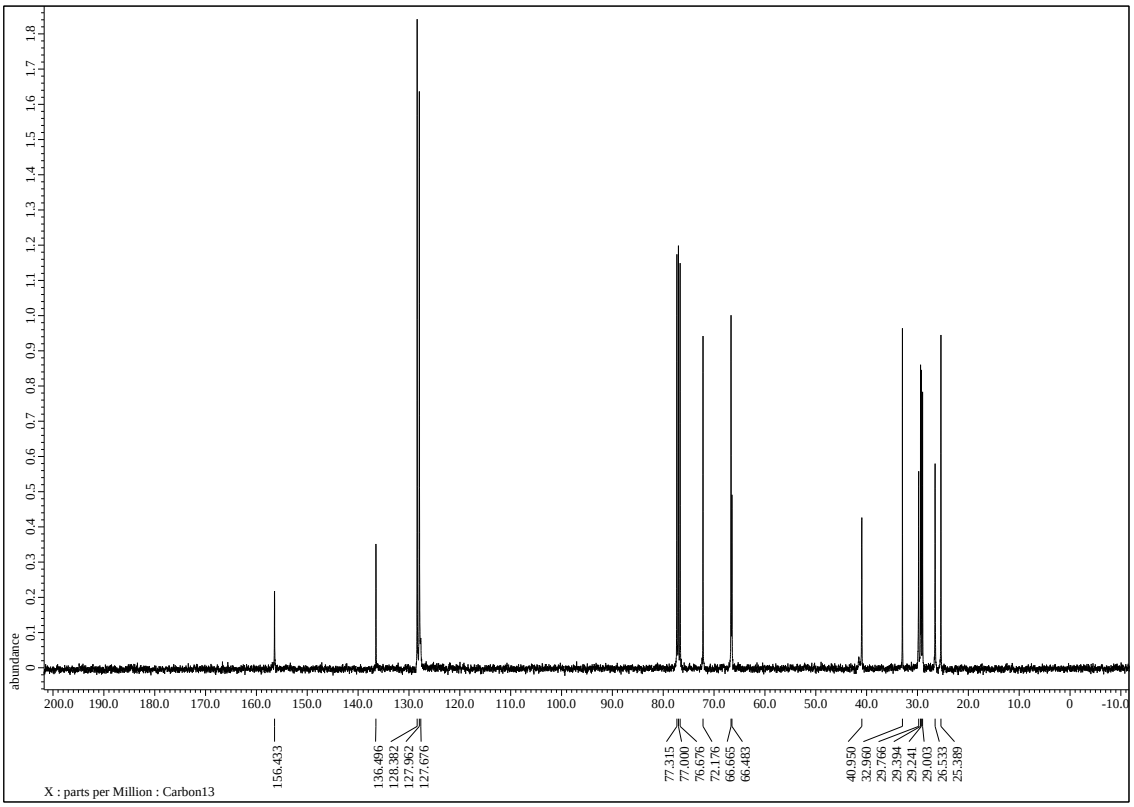


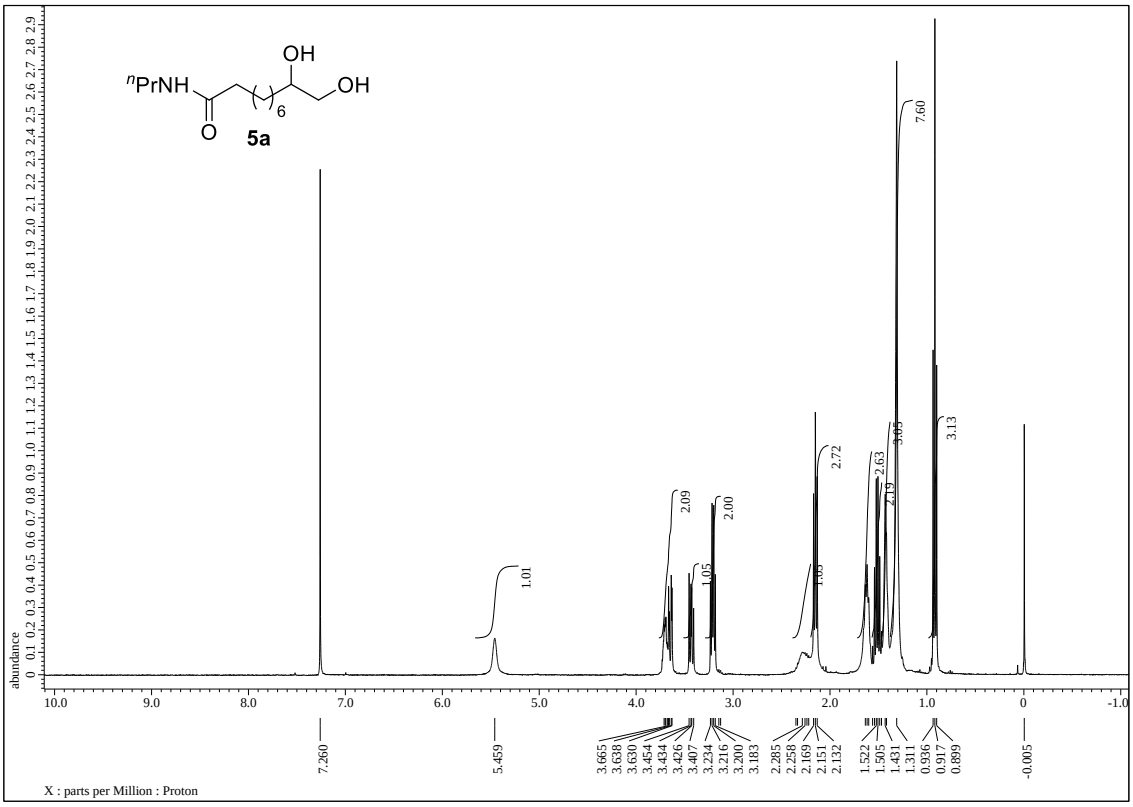


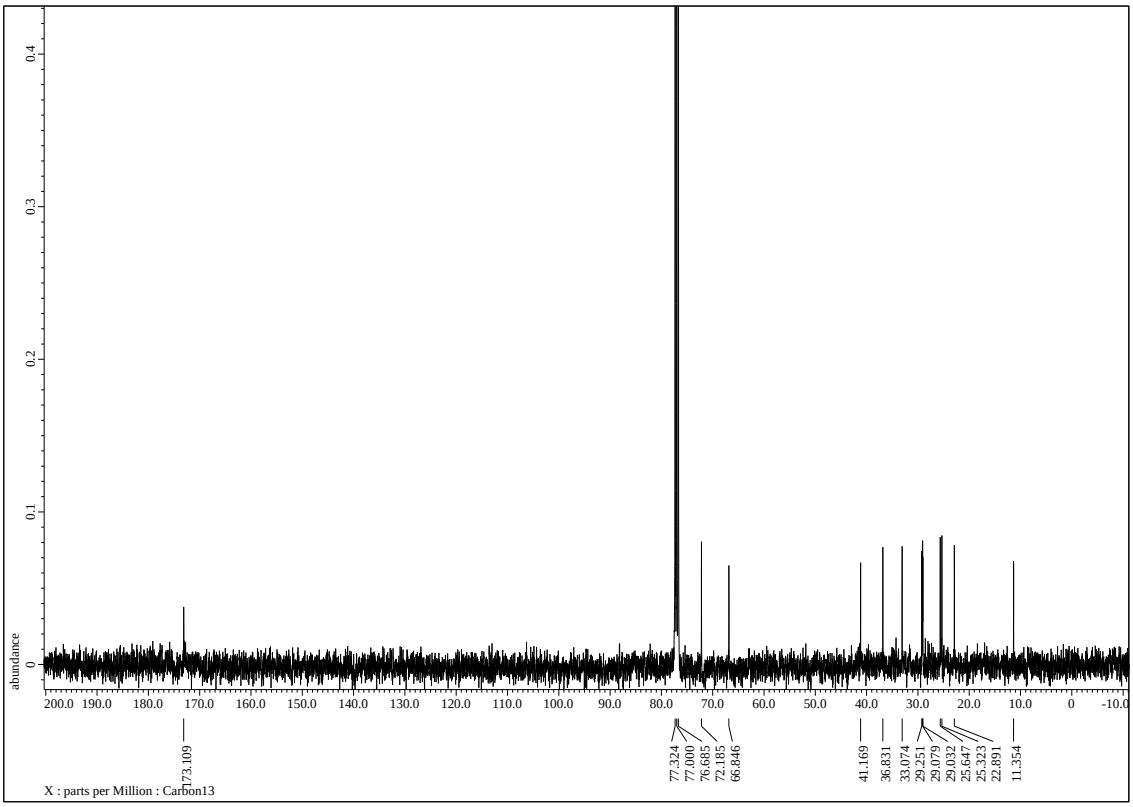

CbzHN
7
S6
abundance
4.66
0.93
2.04
1.87
0.74
2.00
1.90
1.82
10.43
7.364
7.353
7.341
7.332
7.323
7.318
7.310
7.302
7.297
7.289
7.260
5.841
5.832
5.814
5.798
5.789
5.781
5.772
5.094
5.008
4.970
4.709
3.210
3.192
3.176
3.159
2.059
2.042
2.023
2.007
1.567
1.489
1.473
1.366
1.349
1.281
1.255
-0.001
X : parts per Million : Proton

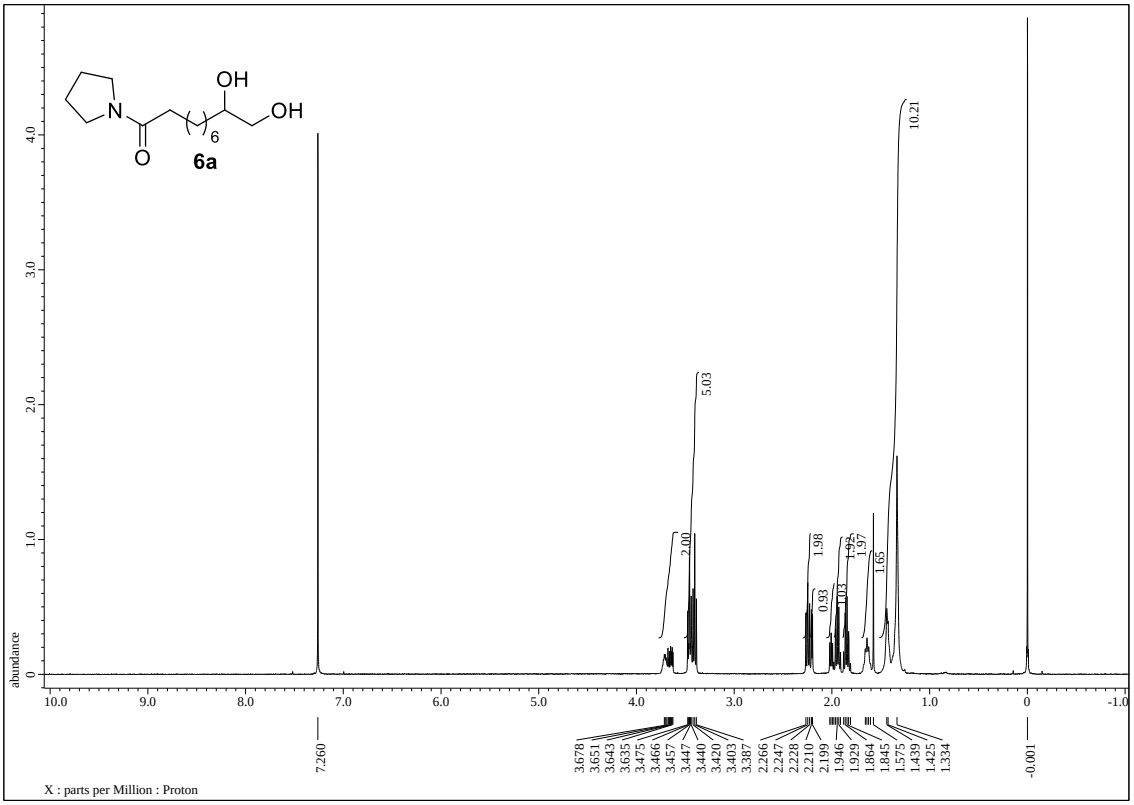

abundance
156.347
139.137
136.658
128.487
128.096
128.048
114.137
77.315
77.000
76.676
66.550
41.093
33.751
29.937
29.337
29.175
28.993
28.850
26.686
X : parts per Million : Carbon13

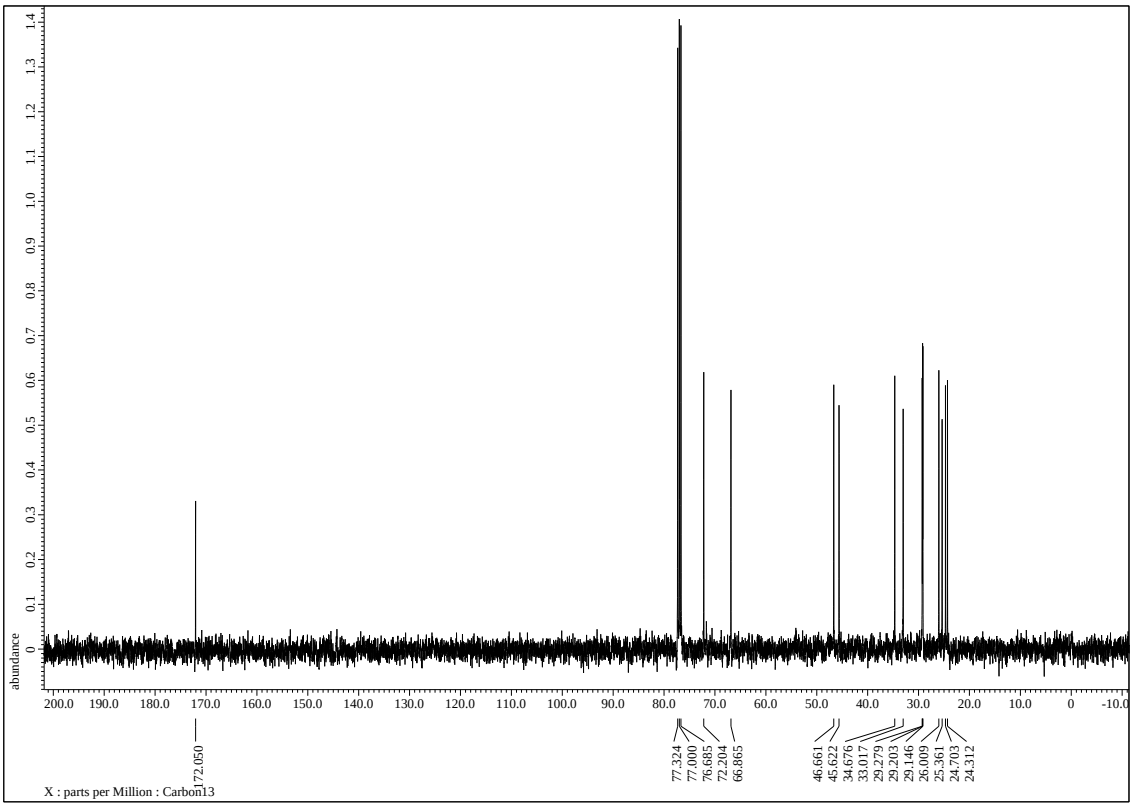

OH
CbzHN
OH
7
4a
abundance
X : parts per Million : Proton

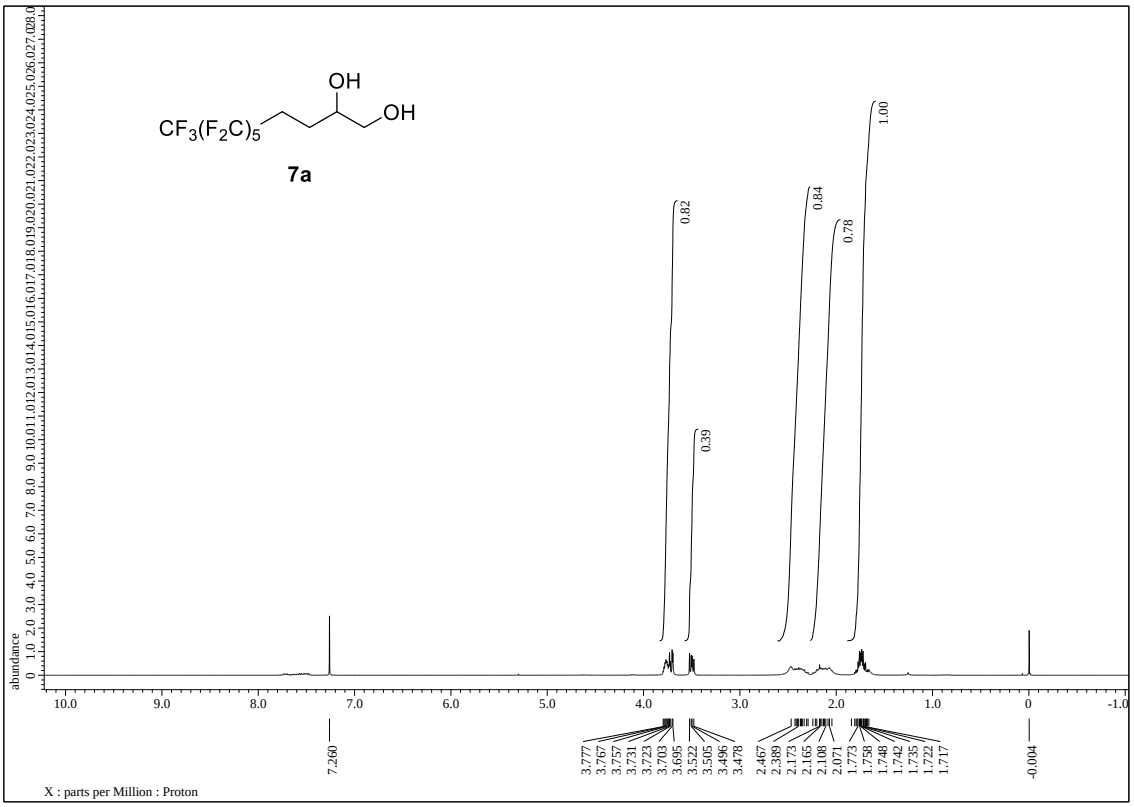

abundance
X : parts per Million : Carbon13

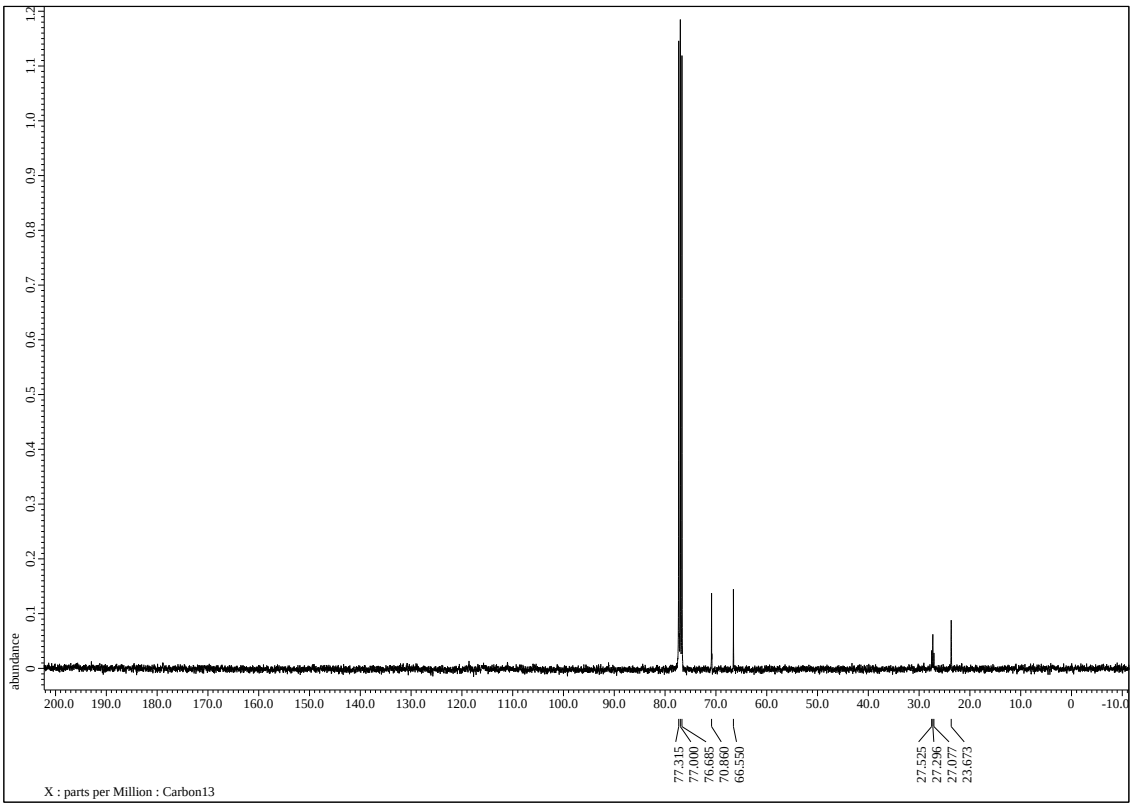

OH
nPrNH
OH
6
O
5a
abundance
1.01
2.09
1.05
2.00
1.00
2.72
2.63
2.19
3.05
7.60
3.13
7.260
5.459
3.665
3.638
3.630
3.454
3.434
3.426
3.407
3.234
3.216
3.200
3.183
2.285
2.258
2.169
2.151
2.132
1.522
1.505
1.431
1.311
0.936
0.917
0.899
-0.005
X : parts per Million : Proton

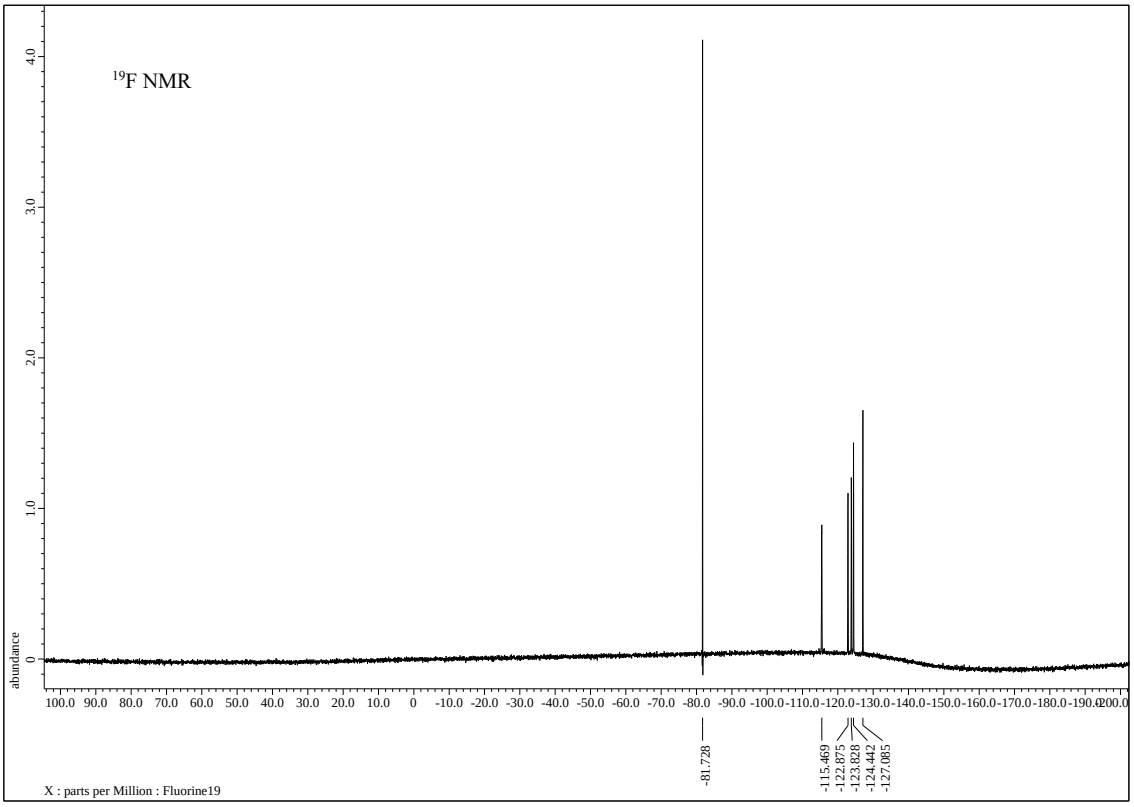

abundance
173.109
77.324
77.000
76.685
72.185
66.846
41.169
36.831
33.074
29.251
29.079
29.032
25.647
25.323
22.891
11.354
X : parts per Million : Carbon13

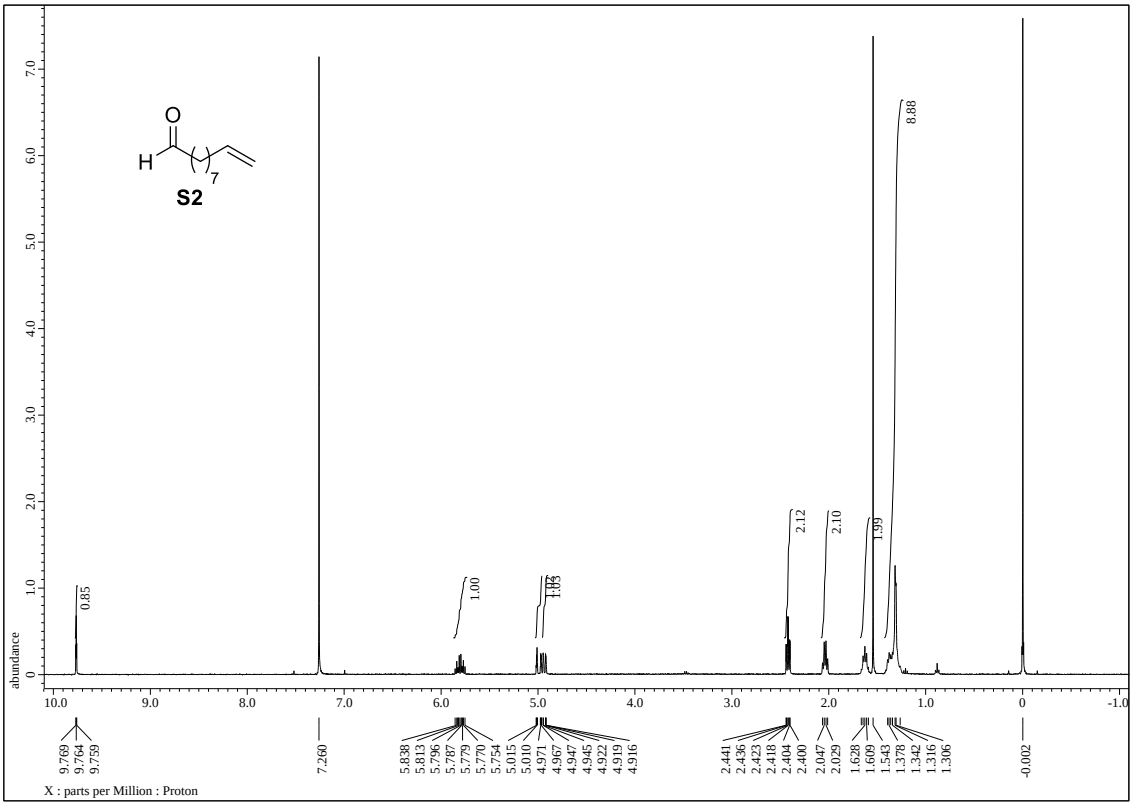

OH
OH
N
O
6
6a
abundance
X : parts per Million : Proton
7.260
5.03
2.00
1.98
1.92
1.97
1.65
0.93
1.03
10.21
-0.001
3.678
3.651
3.643
3.635
3.475
3.466
3.457
3.447
3.440
3.420
3.403
3.387
2.266
2.247
2.228
2.210
2.199
1.946
1.929
1.864
1.845
1.575
1.439
1.425
1.334

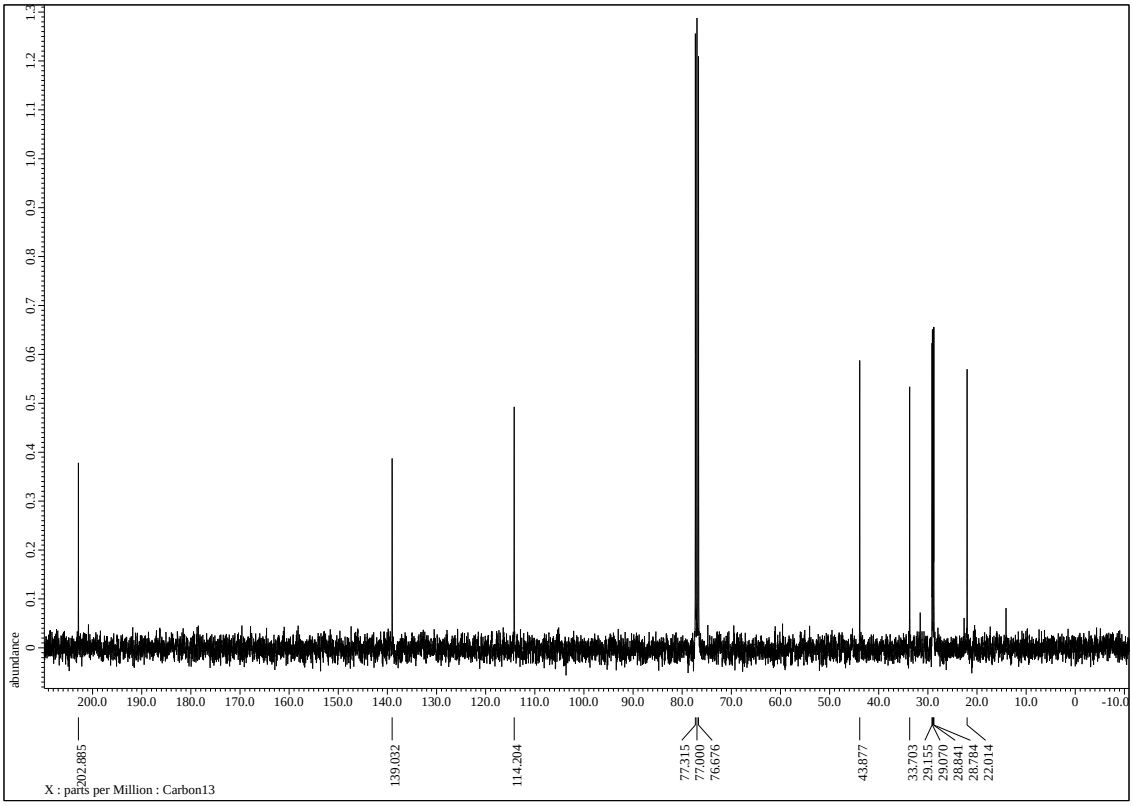

abundance
X : parts per Million : Carbon13
172.050
77.324
77.000
76.685
72.204
66.865
46.661
45.622
34.676
33.017
29.279
29.203
29.146
26.009
25.361
24.703
24.312

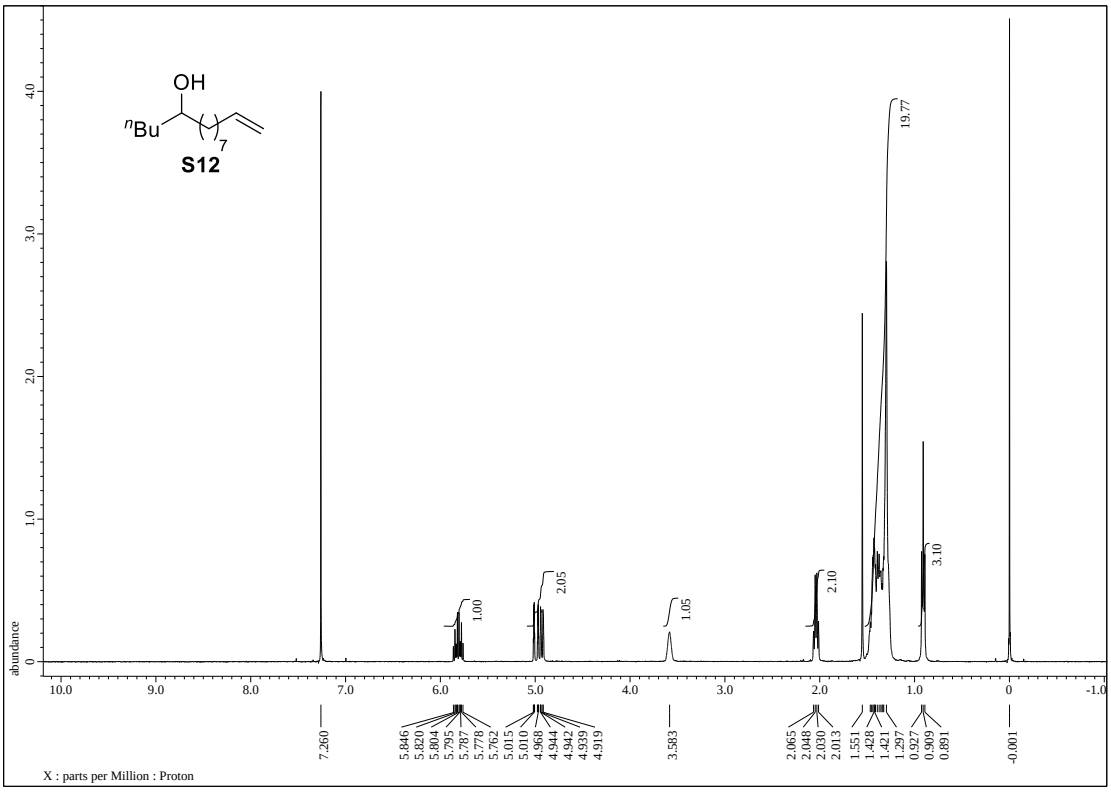

OH
OH
CF3(F2C)5
7a
0.82
0.39
0.84
0.78
1.00
abundance
7.260
3.777
3.767
3.757
3.731
3.723
3.703
3.695
3.522
3.505
3.496
3.478
2.467
2.389
2.173
2.165
2.108
2.071
1.773
1.758
1.748
1.742
1.735
1.722
1.717
-0.004
X : parts per Million : Proton

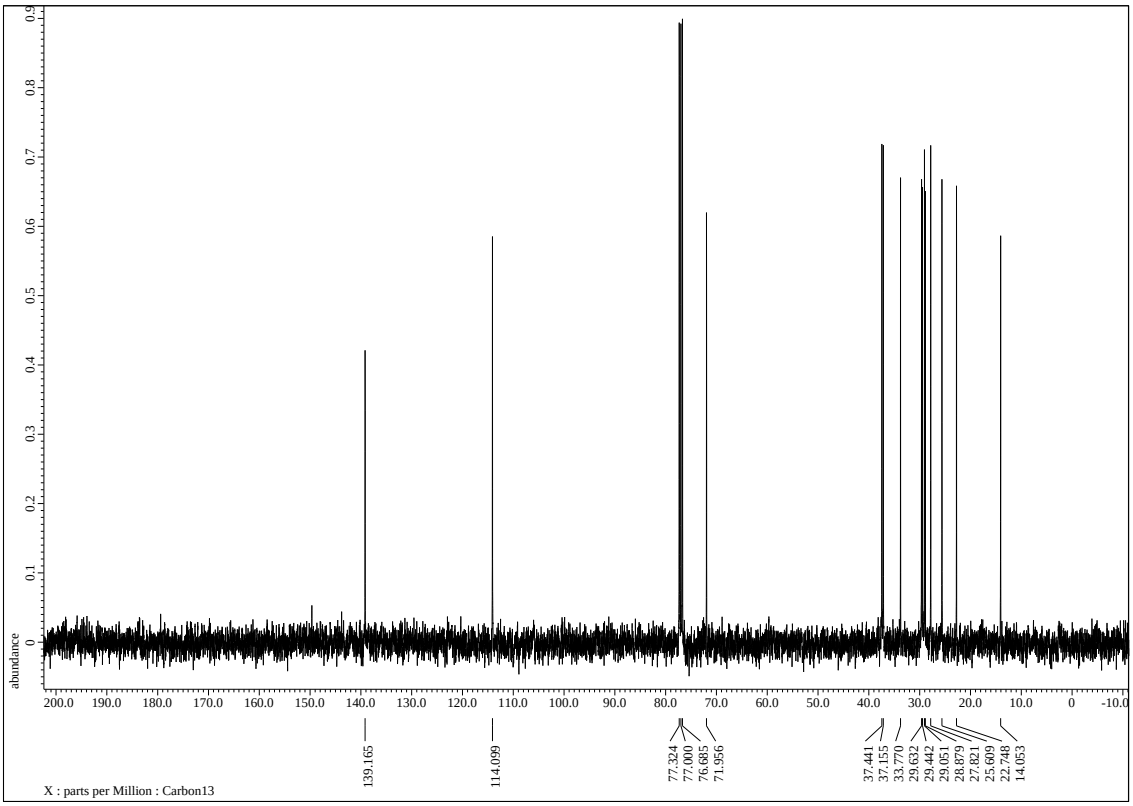

abundance
77.315
77.000
76.685
70.860
66.550
27.525
27.296
27.077
23.673
X : parts per Million : Carbon13

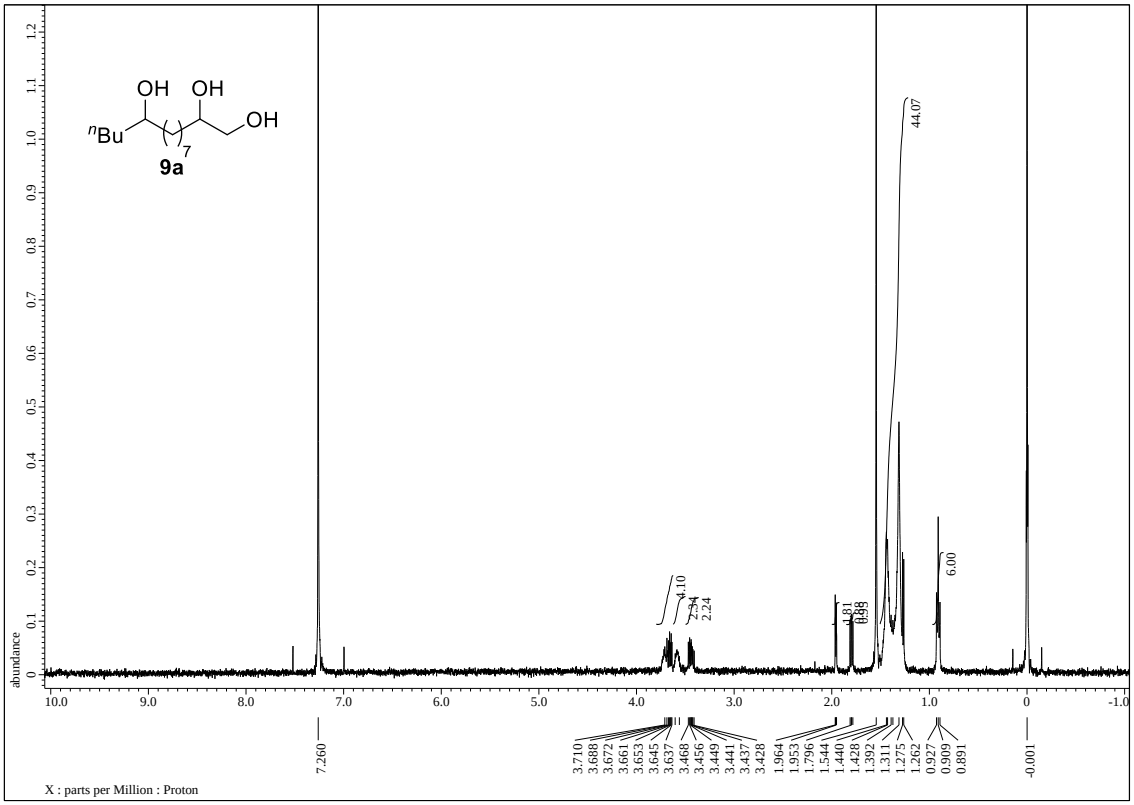

19F NMR
abundance
4.0
3.0
2.0
1.0
0
100.0 90.0 80.0 70.0 60.0 50.0 40.0 30.0 20.0 10.0 0 -10.0 -20.0 -30.0 -40.0 -50.0 -60.0 -70.0 -80.0 -90.0 -100.0 -110.0 -120.0 -130.0 -140.0 -150.0 -160.0 -170.0 -180.0 -190.0 -200.0
-81.728
-115.469
-122.875
-123.828
-124.442
-127.085
X : parts per Million : Fluorine19

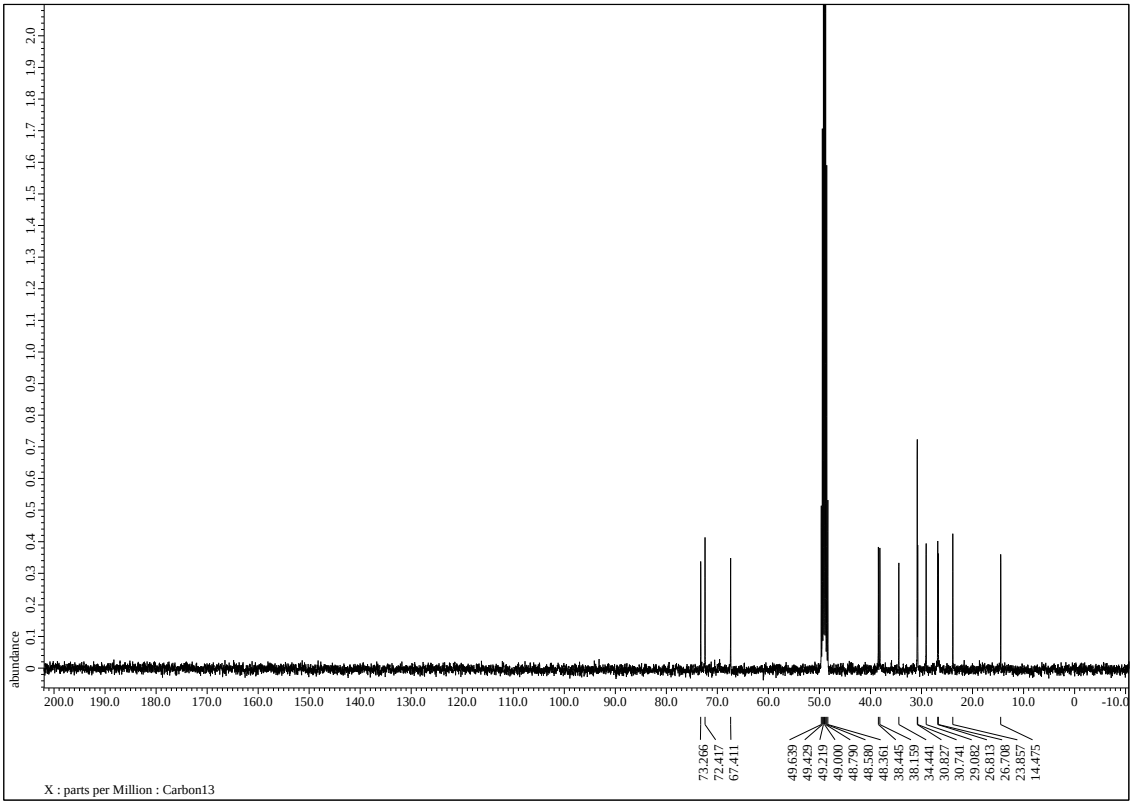

S2
abundance
0.85
1.00
1.03
2.12
2.10
1.99
8.88
9.769
9.764
9.759
7.260
5.838
5.813
5.796
5.787
5.779
5.770
5.754
5.015
5.010
4.971
4.967
4.947
4.945
4.922
4.919
4.916
2.441
2.436
2.423
2.418
2.404
2.400
2.047
2.029
1.628
1.609
1.543
1.378
1.342
1.316
1.306
-0.002
X : parts per Million : Proton

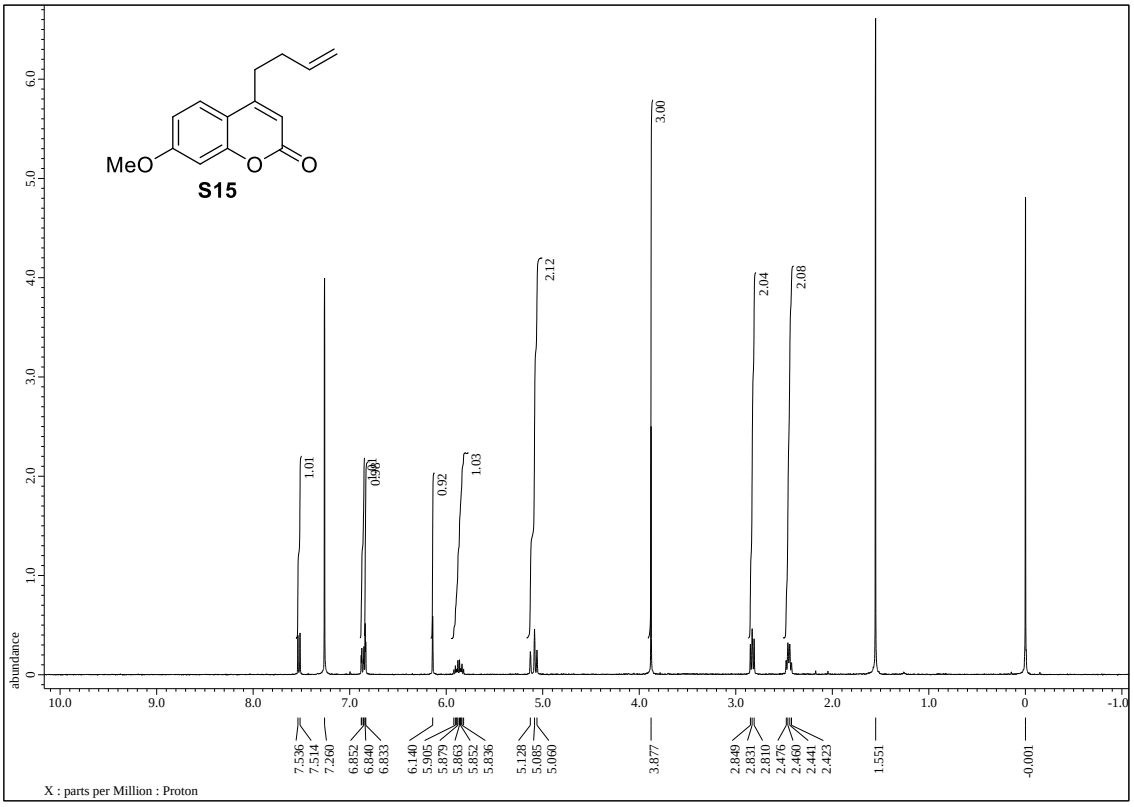

abundance
202.885
139.032
114.204
77.315
77.000
76.676
43.877
33.703
29.155
29.070
28.841
28.784
22.014
X : parts per Million : Carbon13

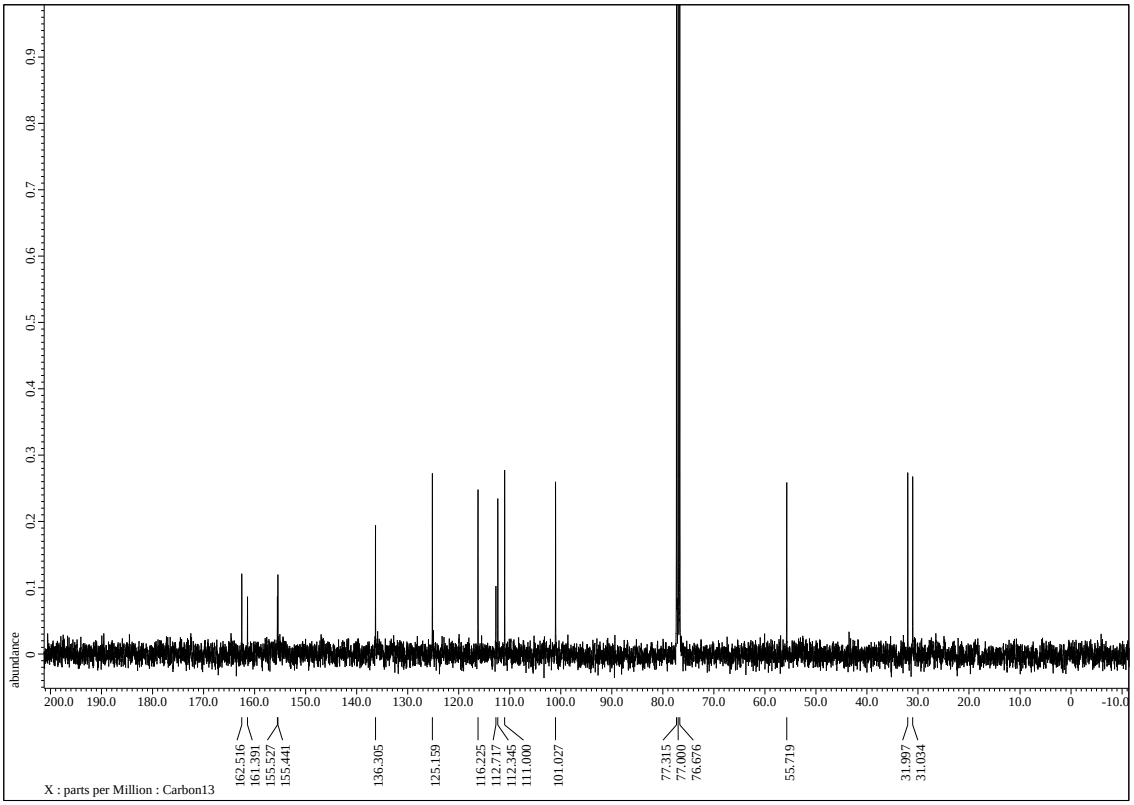

OH
nBu
7
S12
19.77
3.10
2.10
2.05
1.05
1.00
abundance
10.0 9.0 8.0 7.0 6.0 5.0 4.0 3.0 2.0 1.0 0 -1.0
7.260
5.846 5.820 5.804 5.795 5.787 5.778 5.762
5.015 5.010 4.968 4.944 4.942 4.939 4.919
3.583
2.065 2.048 2.030 2.013
1.551 1.428 1.421 1.297
0.927 0.909 0.891
-0.001
X : parts per Million : Proton

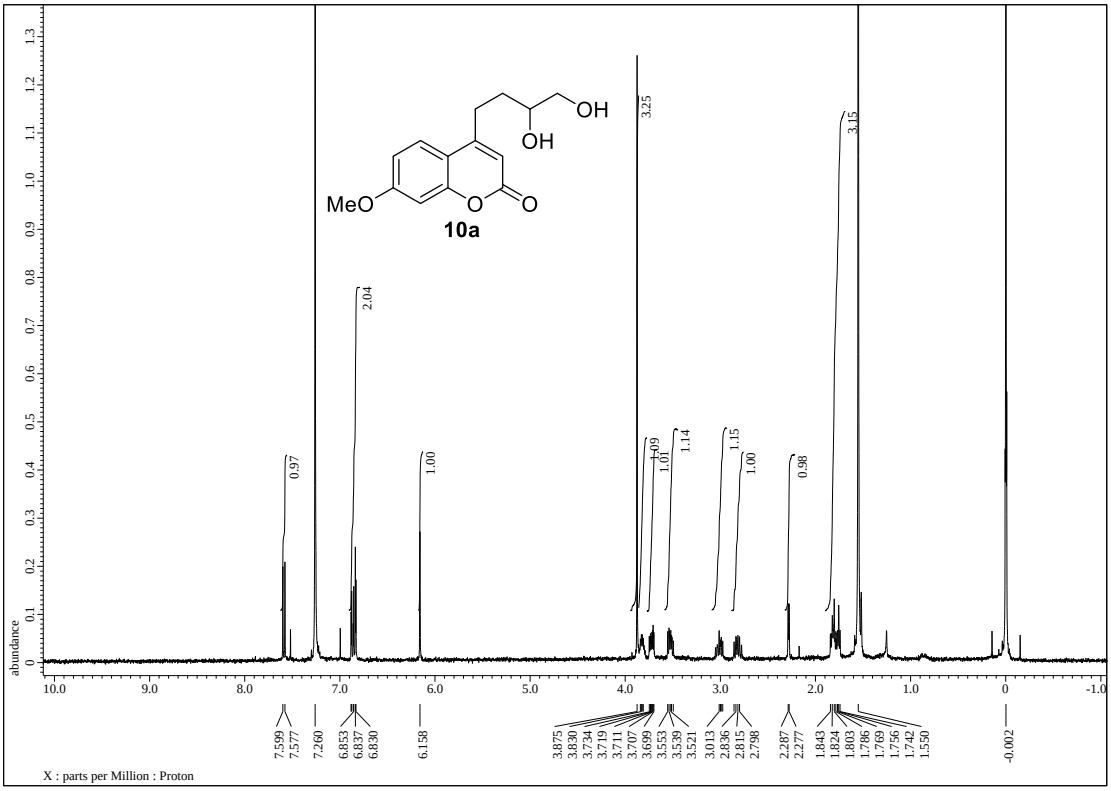

abundance
200.0 190.0 180.0 170.0 160.0 150.0 140.0 130.0 120.0 110.0 100.0 90.0 80.0 70.0 60.0 50.0 40.0 30.0 20.0 10.0 0 -10.0
139.165
114.099
77.324
77.000
76.685
71.956
37.441
37.155
33.770
29.632
29.442
29.051
28.879
27.821
25.609
22.748
14.053
X : parts per Million : Carbon13

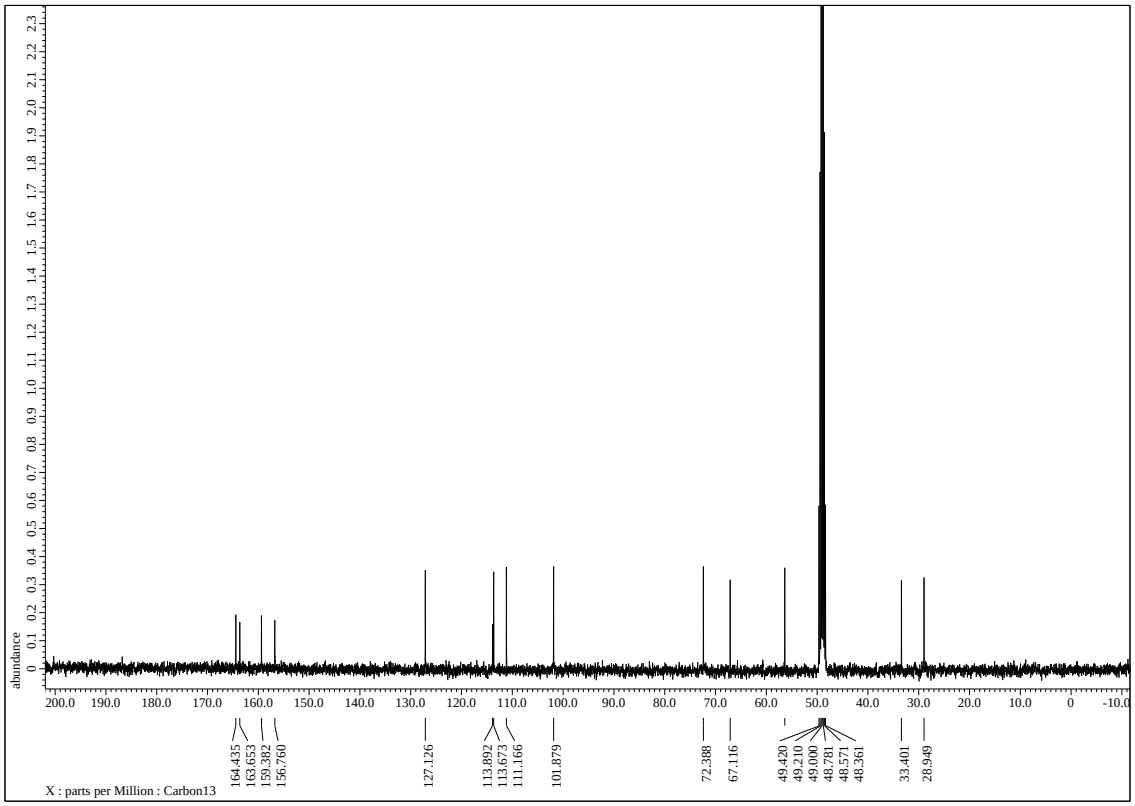

OH
OH
OH
nBu
7
9a
44.07
6.00
4.10
2.34
2.24
1.81
0.88
abundance
7.260
3.710
3.688
3.672
3.661
3.653
3.645
3.637
3.468
3.456
3.449
3.441
3.437
3.428
1.964
1.953
1.796
1.544
1.440
1.428
1.392
1.311
1.275
1.262
0.927
0.909
0.891
-0.001
X : parts per Million : Proton

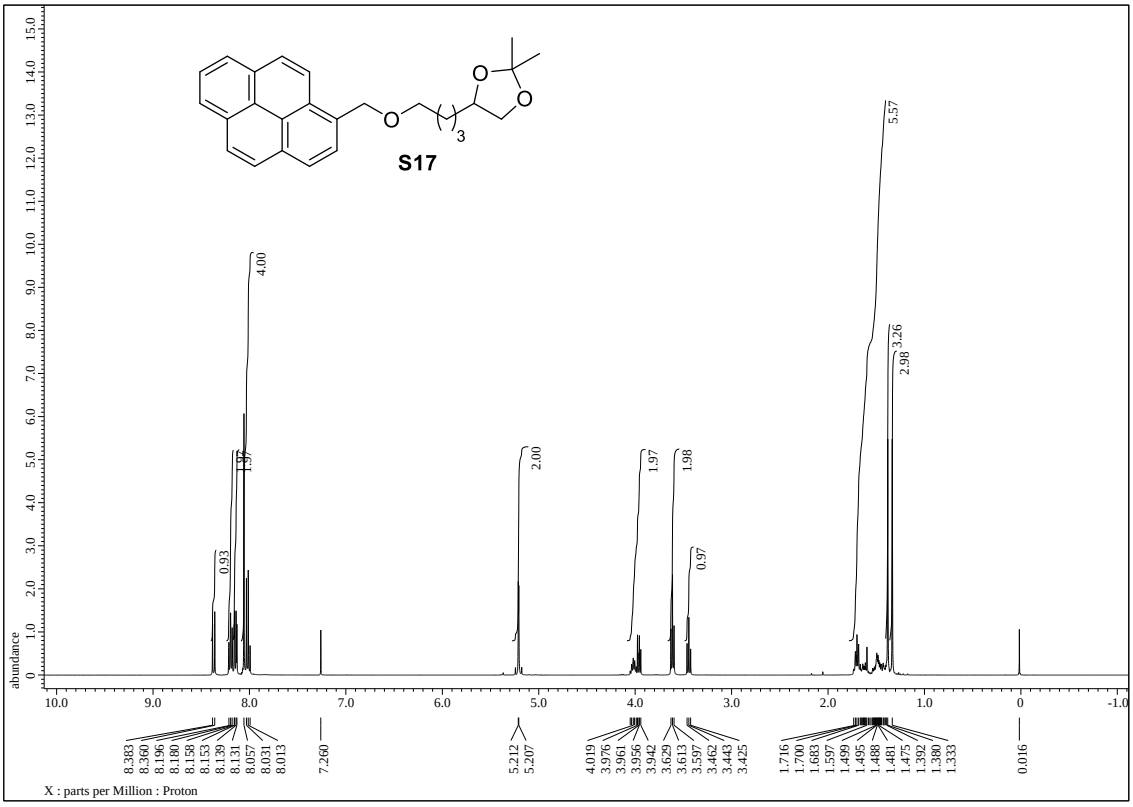

abundance
73.266
72.417
67.411
49.639
49.429
49.219
49.000
48.790
48.580
48.361
38.445
38.139
34.441
30.827
30.741
29.082
26.813
26.708
23.857
14.475
X : parts per Million : Carbon13

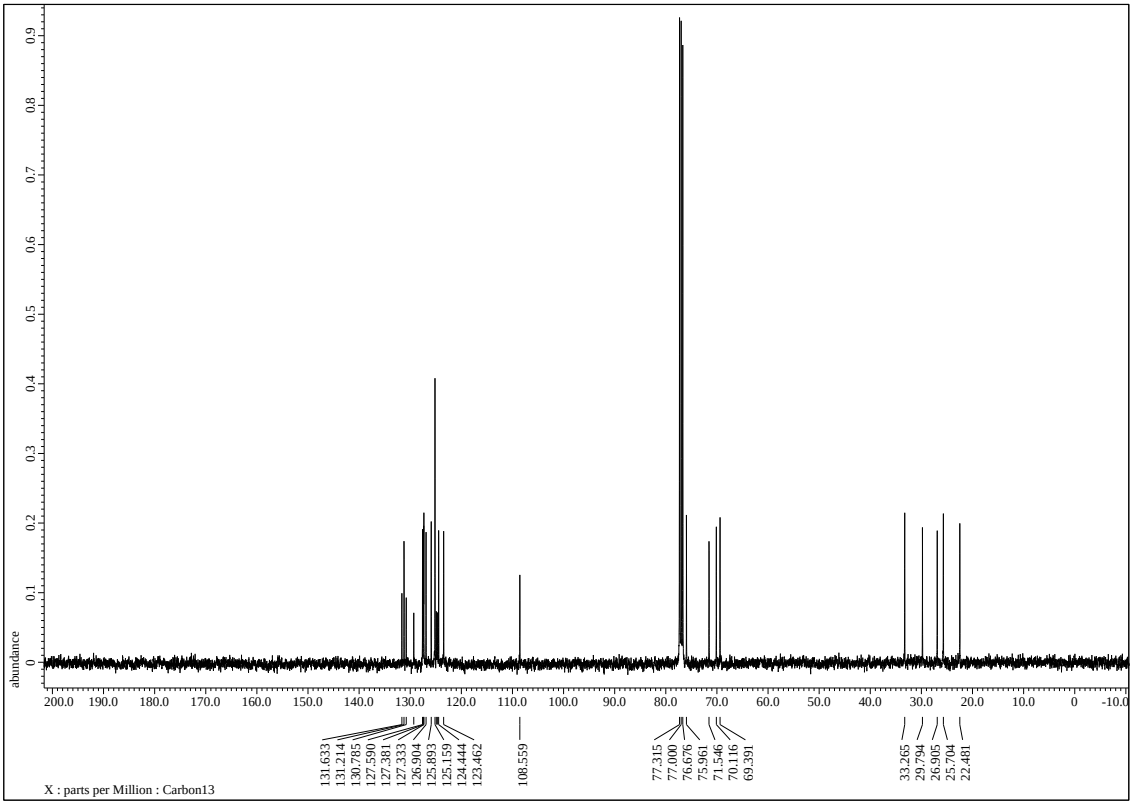

MeO
O
O
S15
abundance
X : parts per Million : Proton

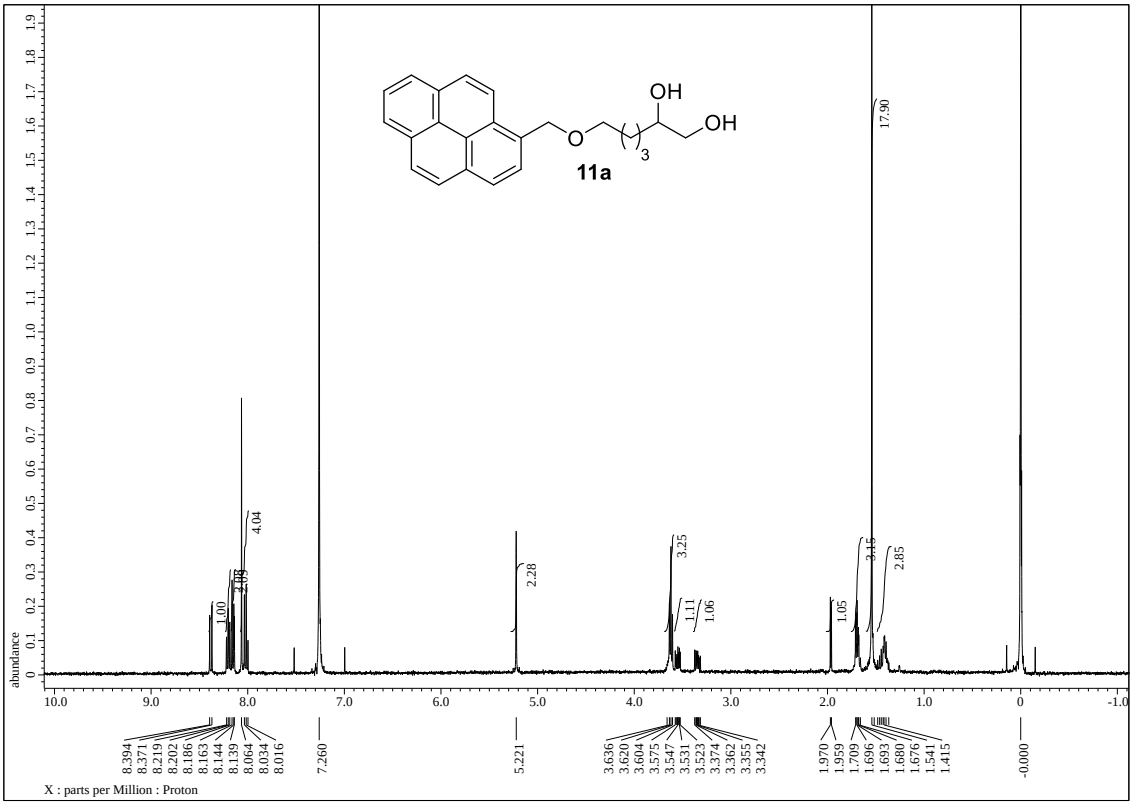

abundance
X : parts per Million : Carbon13

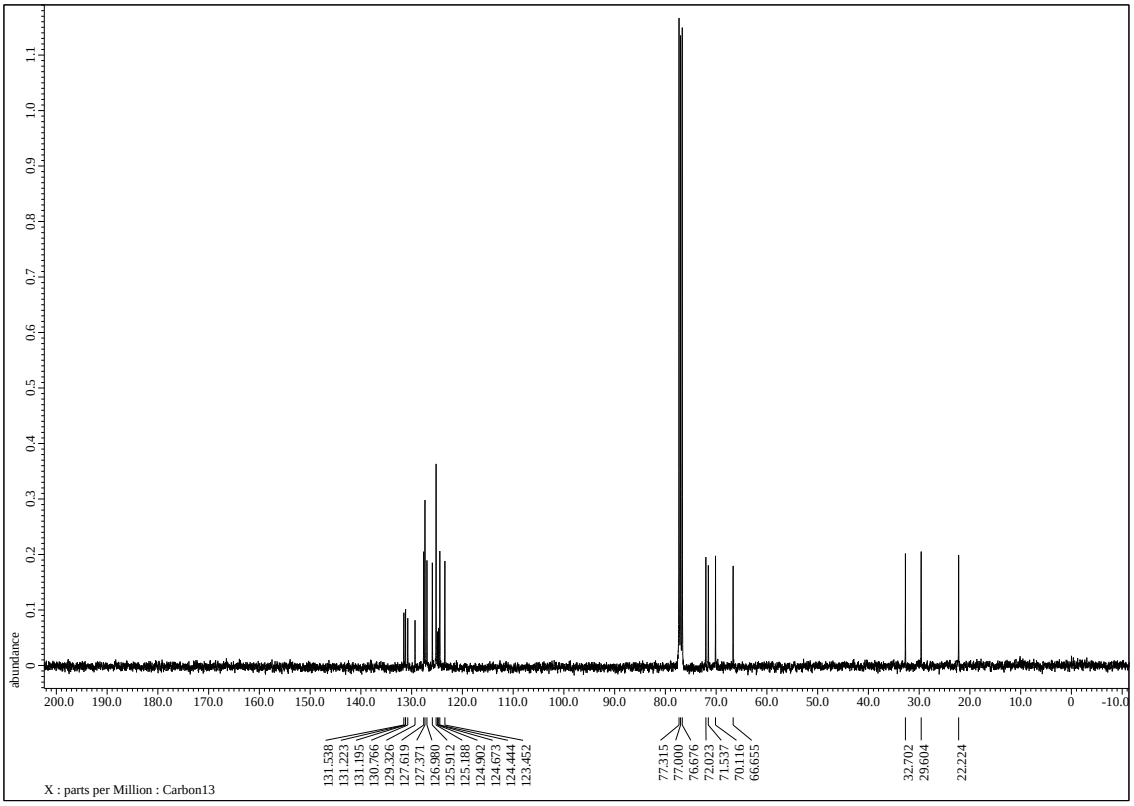

OH
OH
MeO
O
O
10a
3.25
3.15
2.04
0.97
1.00
1.09
1.01
1.14
1.15
1.00
0.98
abundance
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
-1.0
7.599
7.577
7.260
6.853
6.837
6.830
6.158
3.875
3.830
3.734
3.719
3.711
3.707
3.699
3.553
3.539
3.521
3.013
2.836
2.815
2.798
2.287
2.277
1.843
1.824
1.803
1.786
1.769
1.756
1.742
1.550
-0.002
X : parts per Million : Proton

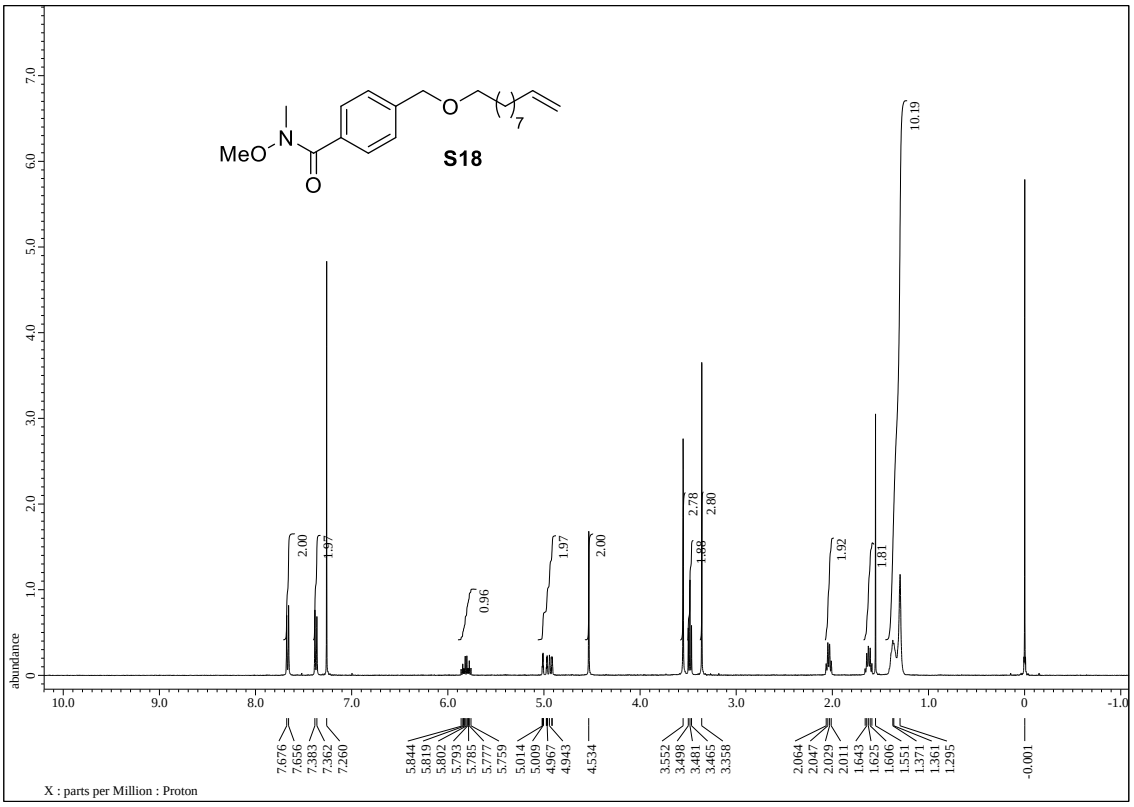

abundance
200.0
190.0
180.0
170.0
160.0
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0
-10.0
164.435
163.653
159.382
156.760
127.126
113.892
113.673
111.166
101.879
72.388
67.116
49.420
49.210
49.000
48.781
48.571
48.361
33.401
28.949
X : parts per Million : Carbon13

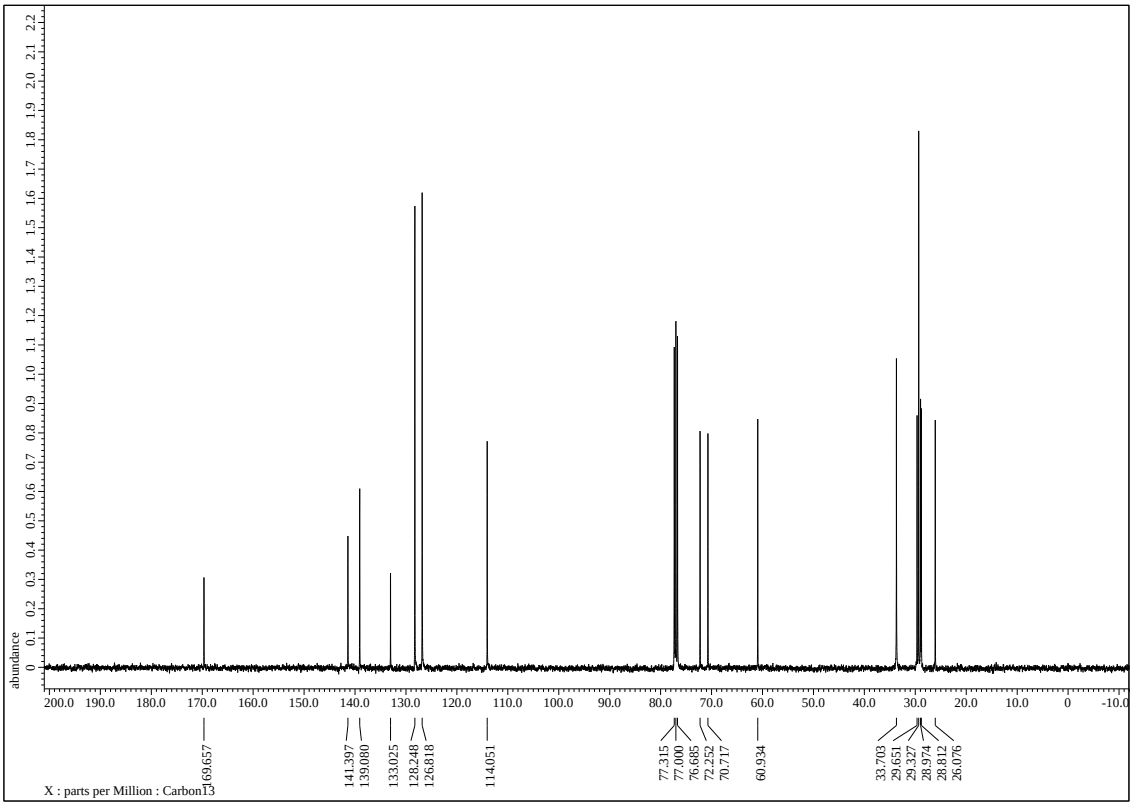

S17
abundance
X : parts per Million : Proton

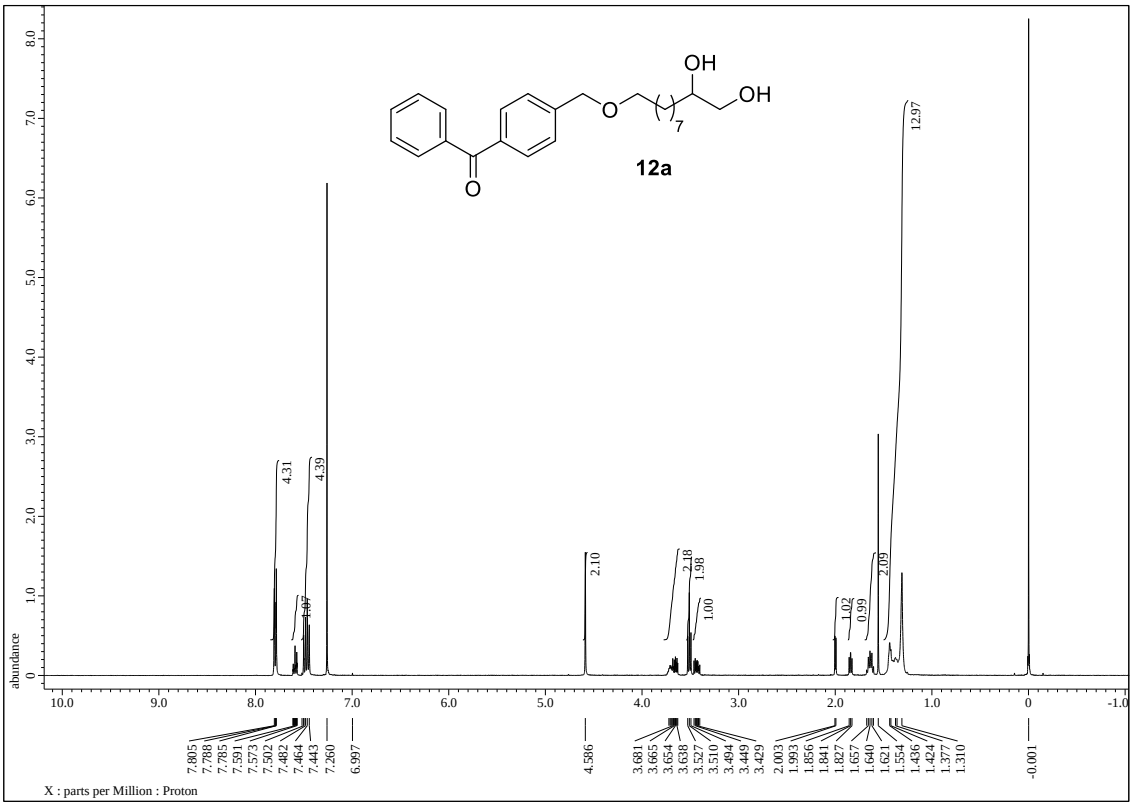

abundance
X : parts per Million : Carbon13

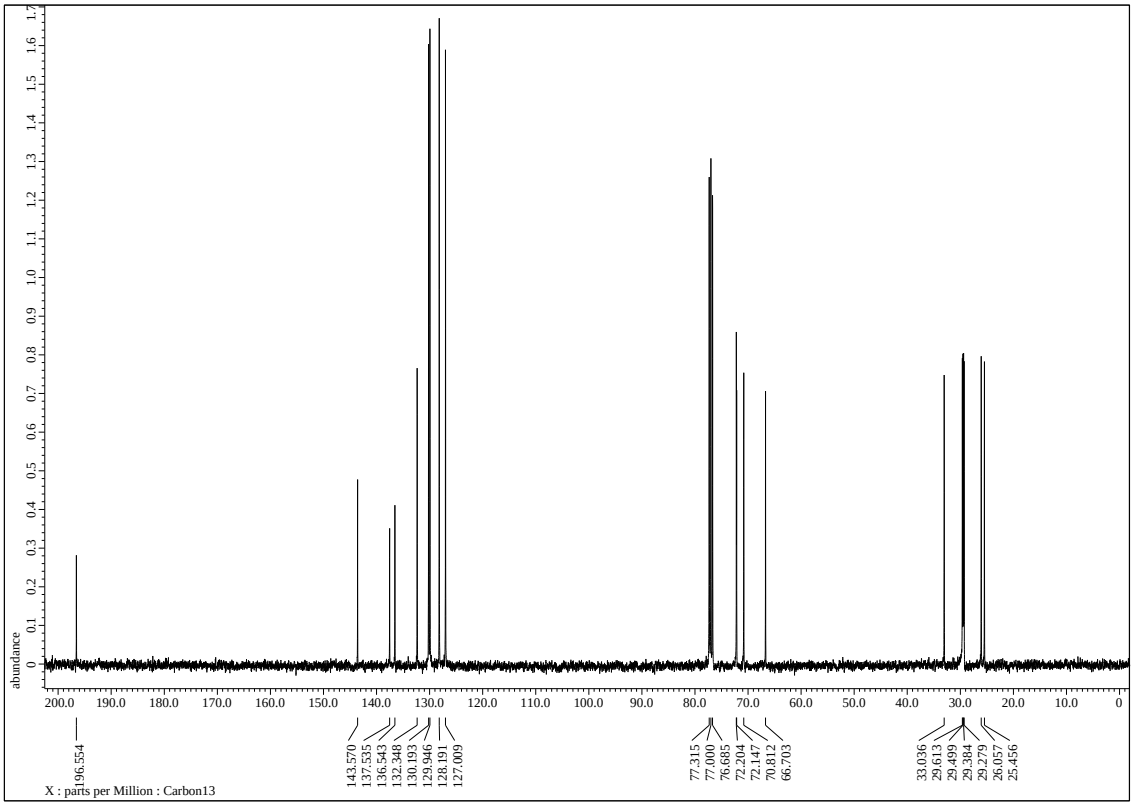

OH
OH
O
3
11a
17.90
4.04
3.25
2.28
3.15
2.85
1.11
1.06
1.05
1.00
abundance
X : parts per Million : Proton

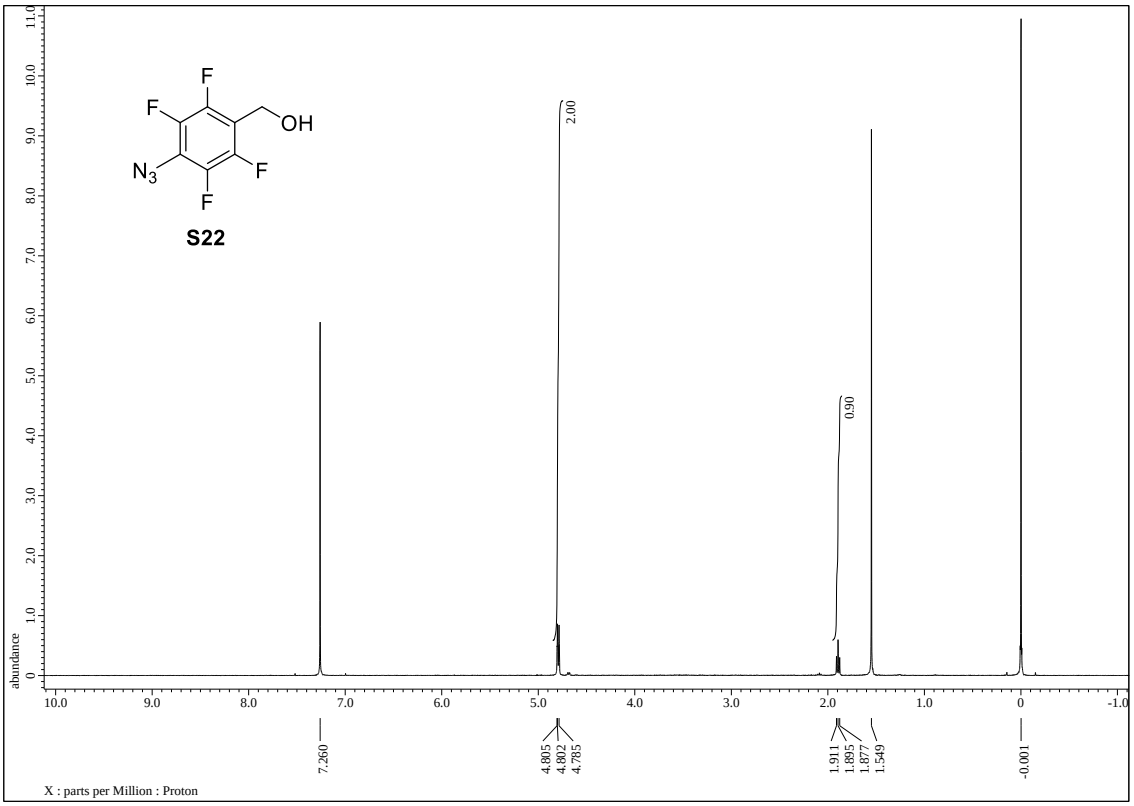

abundance
X : parts per Million : Carbon13

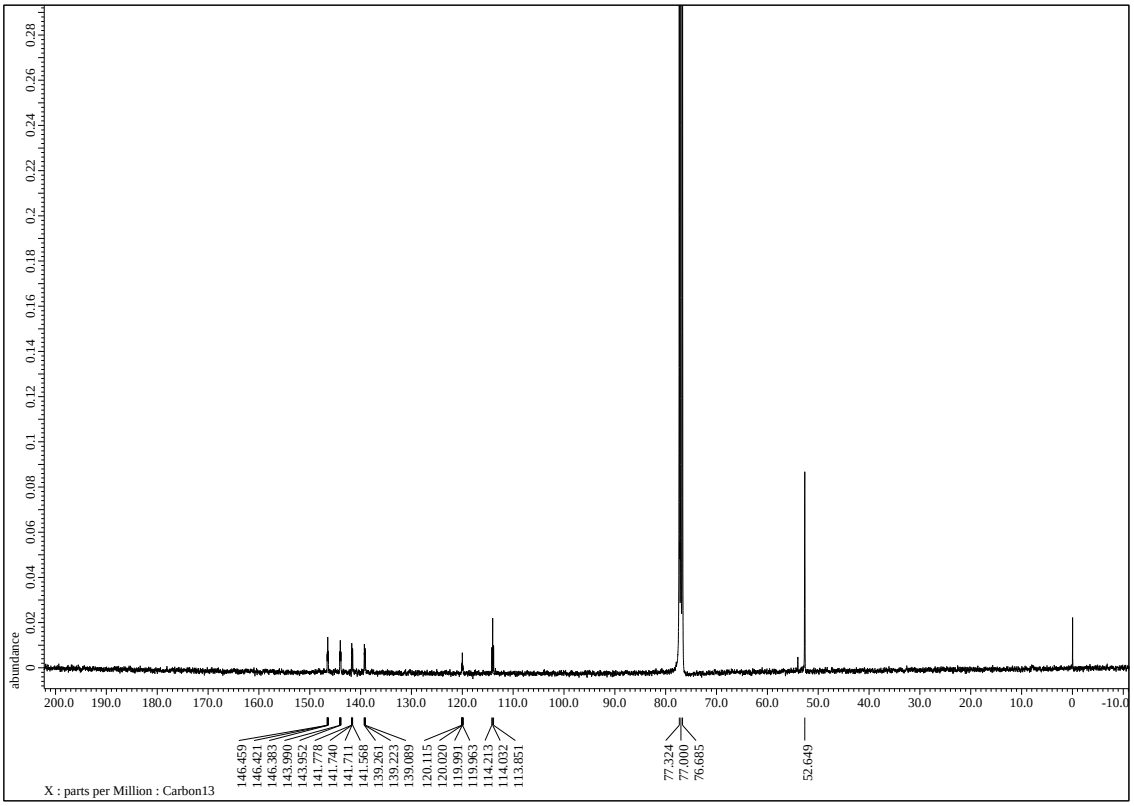

MeO
N
O
O
7
S18
abundance
10.19
2.78
2.80
2.00
1.97
1.97
2.00
1.88
1.92
1.81
0.96
7.676
7.656
7.383
7.362
7.260
5.844
5.819
5.802
5.793
5.785
5.777
5.759
5.014
5.009
4.967
4.943
4.534
3.552
3.498
3.481
3.465
3.358
2.064
2.047
2.029
2.011
1.643
1.625
1.606
1.551
1.371
1.361
1.295
-0.001
X : parts per Million : Proton

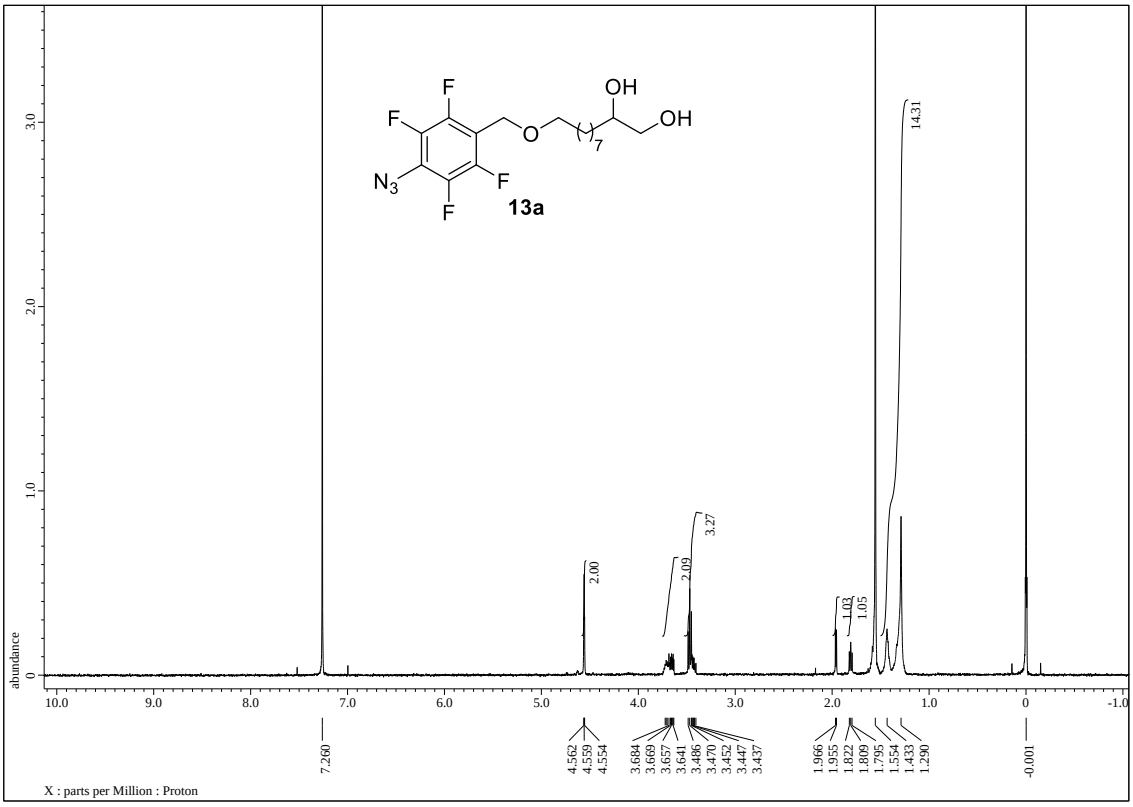

abundance
169.657
141.397
139.080
133.025
128.248
126.818
114.051
77.315
77.000
76.685
72.252
70.717
60.934
33.703
29.651
29.327
28.974
28.812
26.076
X : parts per Million : Carbon13

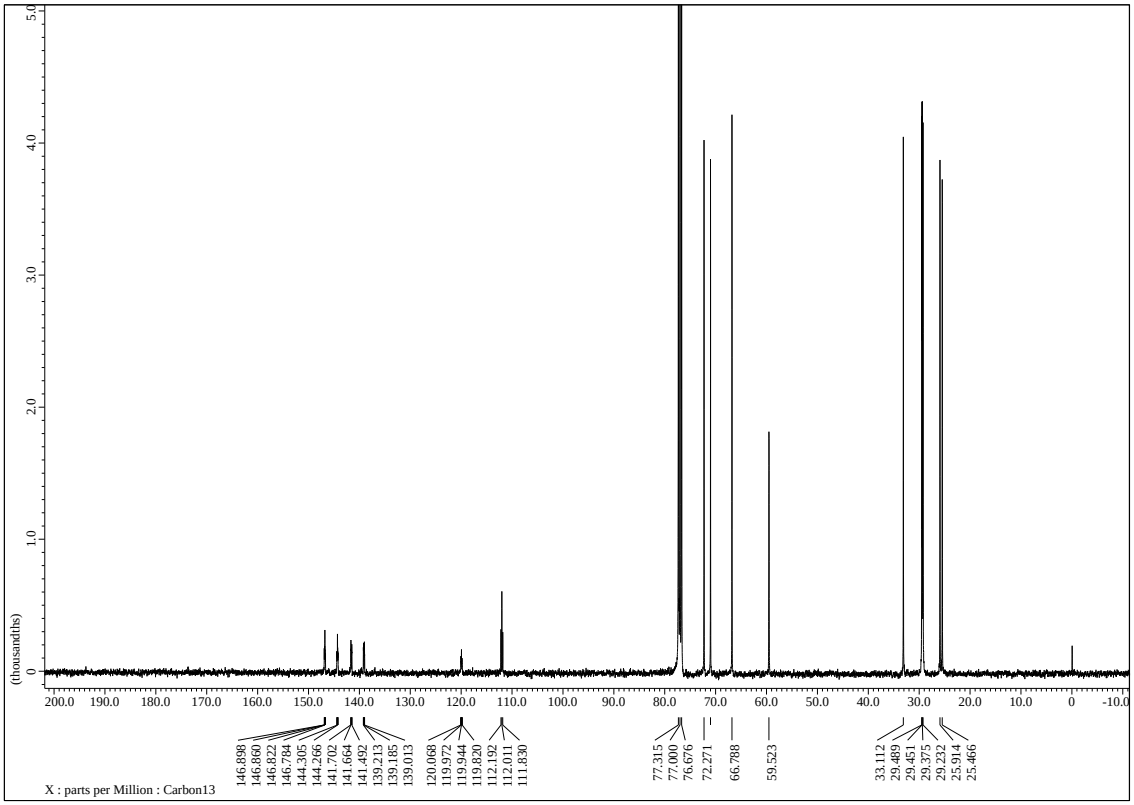

OH
OH
O
7
O
12a
abundance
4.31
4.39
2.10
2.18
1.98
1.00
1.02
0.99
2.09
12.97
7.805
7.788
7.785
7.591
7.573
7.502
7.482
7.464
7.443
7.260
6.997
4.586
3.681
3.665
3.654
3.638
3.527
3.510
3.494
3.449
3.429
2.003
1.993
1.856
1.841
1.027
1.657
1.640
1.621
1.554
1.436
1.424
1.377
1.310
-0.001
X : parts per Million : Proton

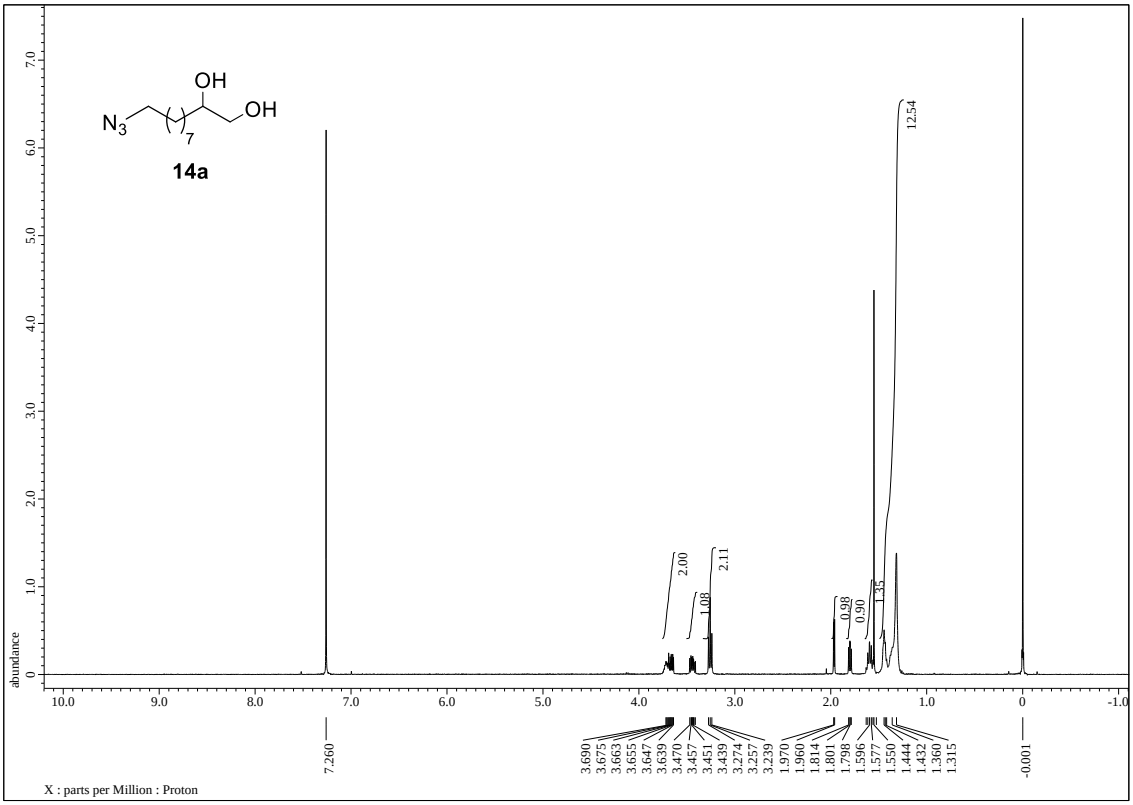

abundance
196.554
143.570
137.535
136.543
132.348
130.193
129.946
128.191
127.009
77.315
77.000
76.685
72.204
72.147
70.812
66.703
33.036
29.613
29.499
29.384
29.279
26.057
25.456
X : parts per Million : Carbon13

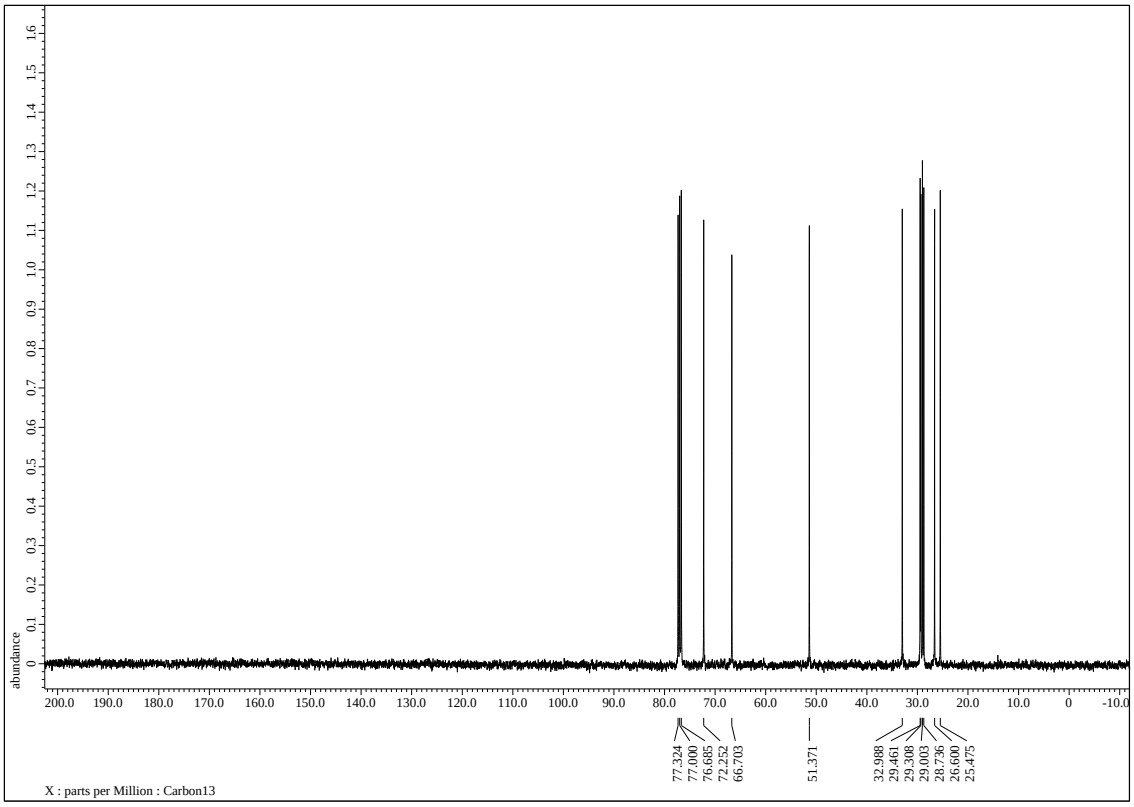

F
F
OH
N3
F
F
S22
2.00
0.90
abundance
7.260
4.805
4.802
4.785
1.911
1.895
1.877
1.549
-0.001
X : parts per Million : Proton

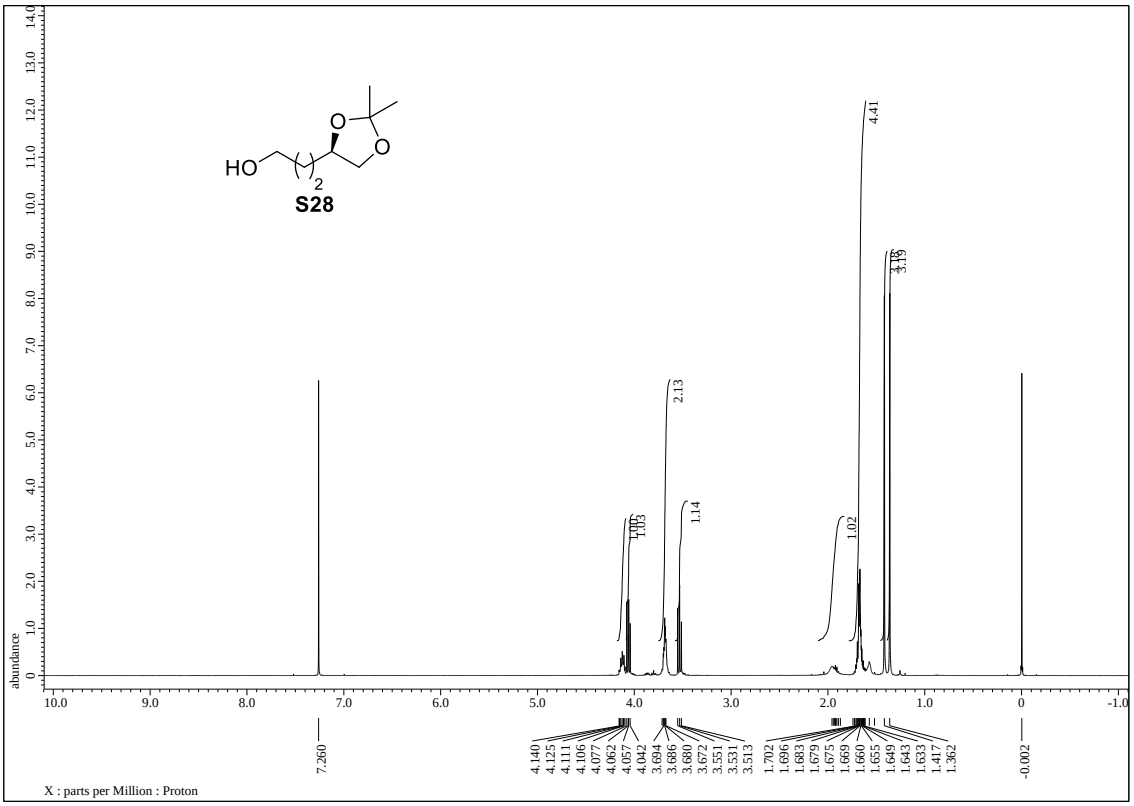

abundance
146.459
146.421
146.383
143.990
143.952
141.778
141.740
141.711
141.568
139.261
139.223
139.089
120.115
120.020
119.991
119.963
114.213
114.032
113.851
77.324
77.000
76.685
52.649
X : parts per Million : Carbon13

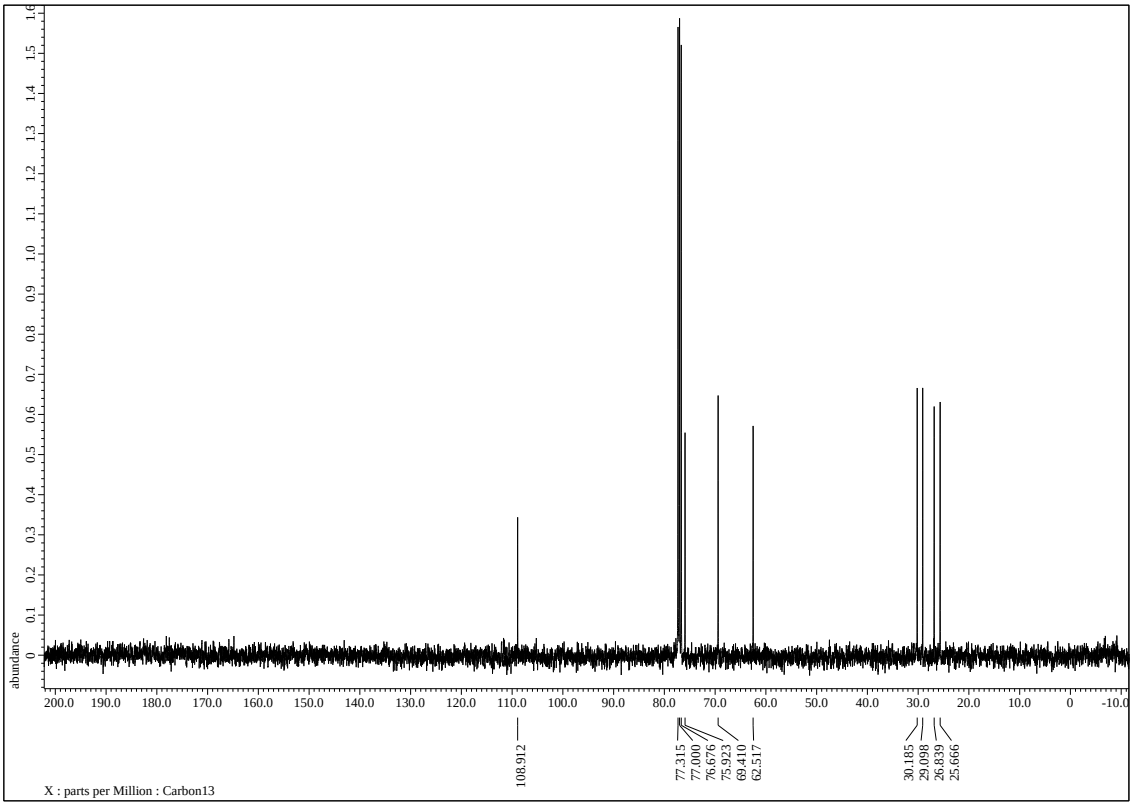

F
F
OH
OH
O
7
N3
F
F
13a
14.31
3.27
2.09
2.00
1.05
1.03
abundance
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
-1.0
7.260
4.562
4.559
4.554
3.684
3.669
3.657
3.641
3.486
3.470
3.452
3.447
3.437
1.966
1.955
1.822
1.809
1.795
1.554
1.433
1.290
-0.001
X : parts per Million : Proton

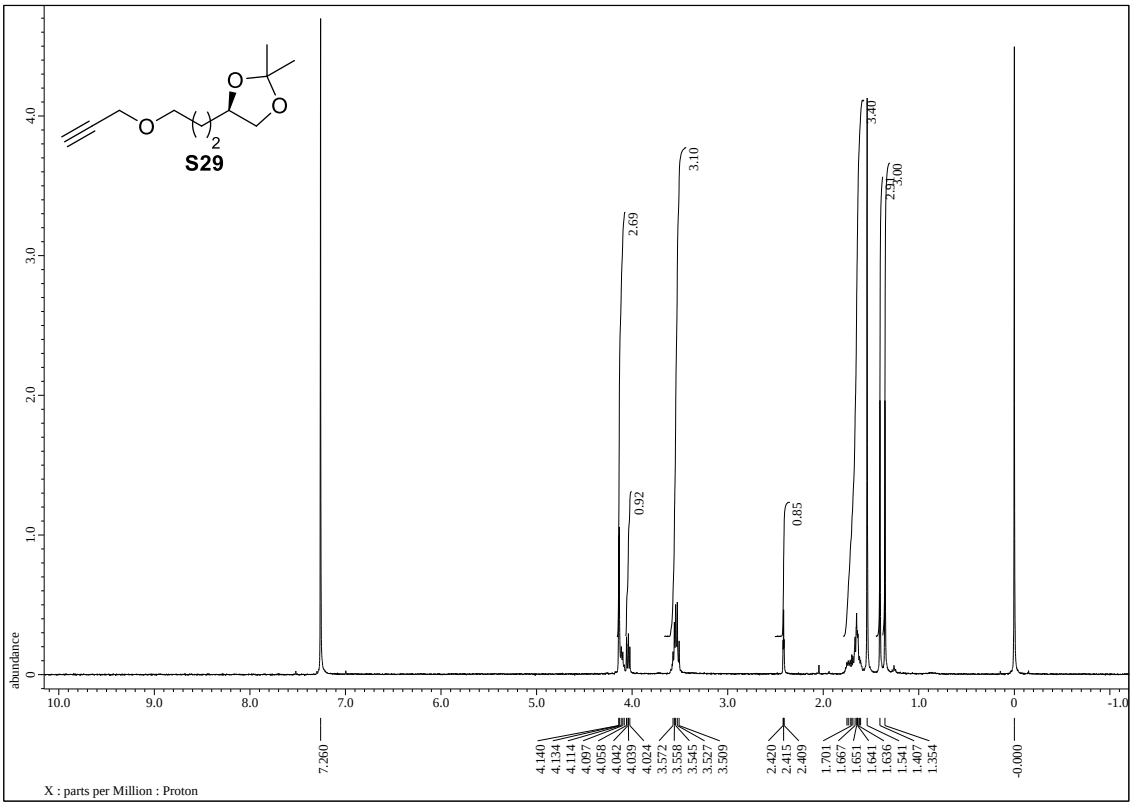

(thousandths)
5.0
4.0
3.0
2.0
1.0
0
200.0
190.0
180.0
170.0
160.0
150.0
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0
-10.0
146.898
146.860
146.822
146.784
144.305
144.266
141.702
141.664
141.492
139.213
139.185
139.013
120.068
119.972
119.944
119.820
112.192
112.011
111.830
77.315
77.000
76.676
72.271
66.788
59.523
33.112
29.489
29.451
29.375
29.232
25.914
25.466
X : parts per Million : Carbon13

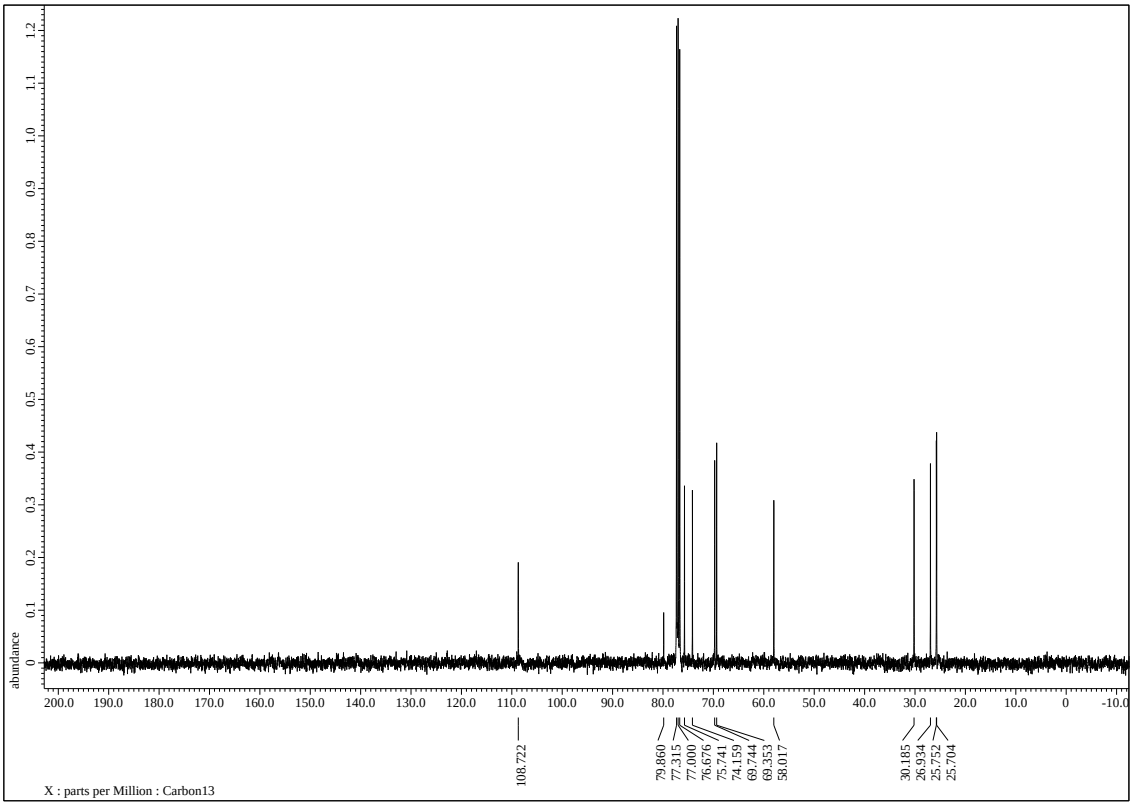

OH
OH
N3
7
14a
12.54
2.00
1.08
2.11
0.98
0.90
1.35
abundance
7.260
3.690
3.675
3.663
3.655
3.647
3.639
3.470
3.457
3.451
3.439
3.274
3.257
3.239
1.970
1.960
1.814
1.801
1.798
1.596
1.577
1.550
1.444
1.432
1.360
1.315
-0.001
X : parts per Million : Proton

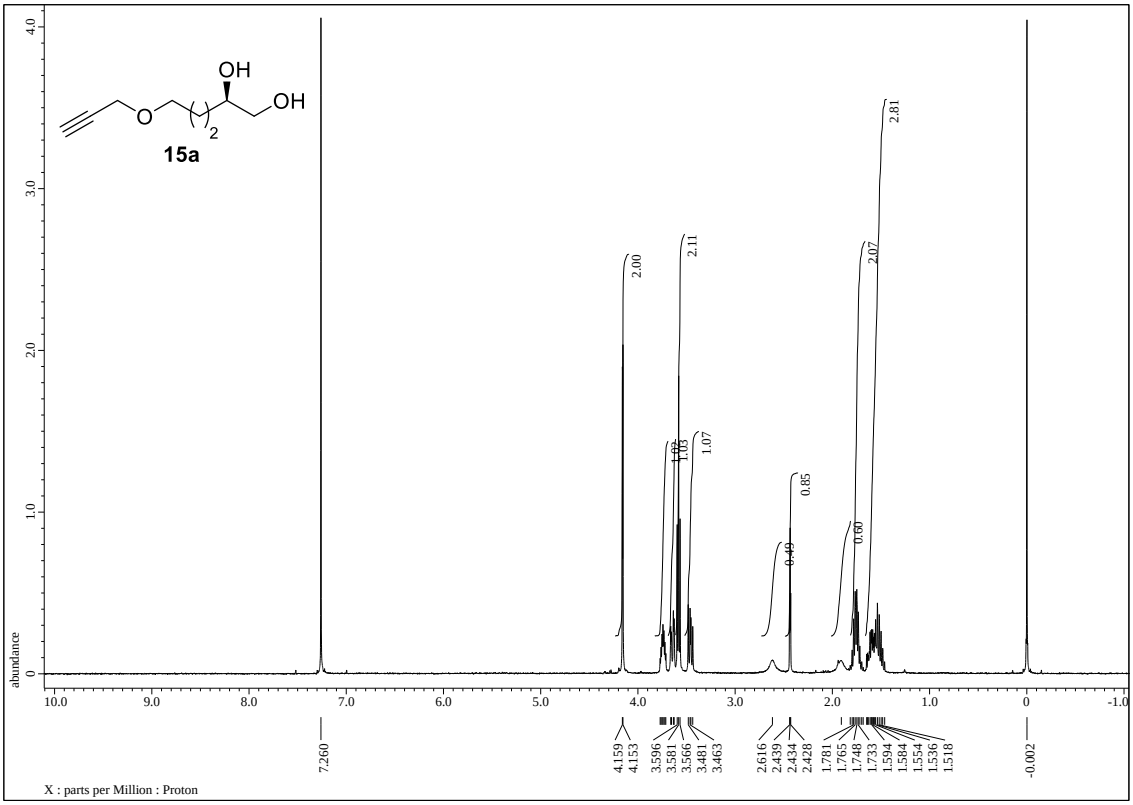

abundance
77.324
77.000
76.685
72.252
66.703
51.371
32.988
29.461
29.308
29.003
28.736
26.600
25.475
X : parts per Million : Carbon13

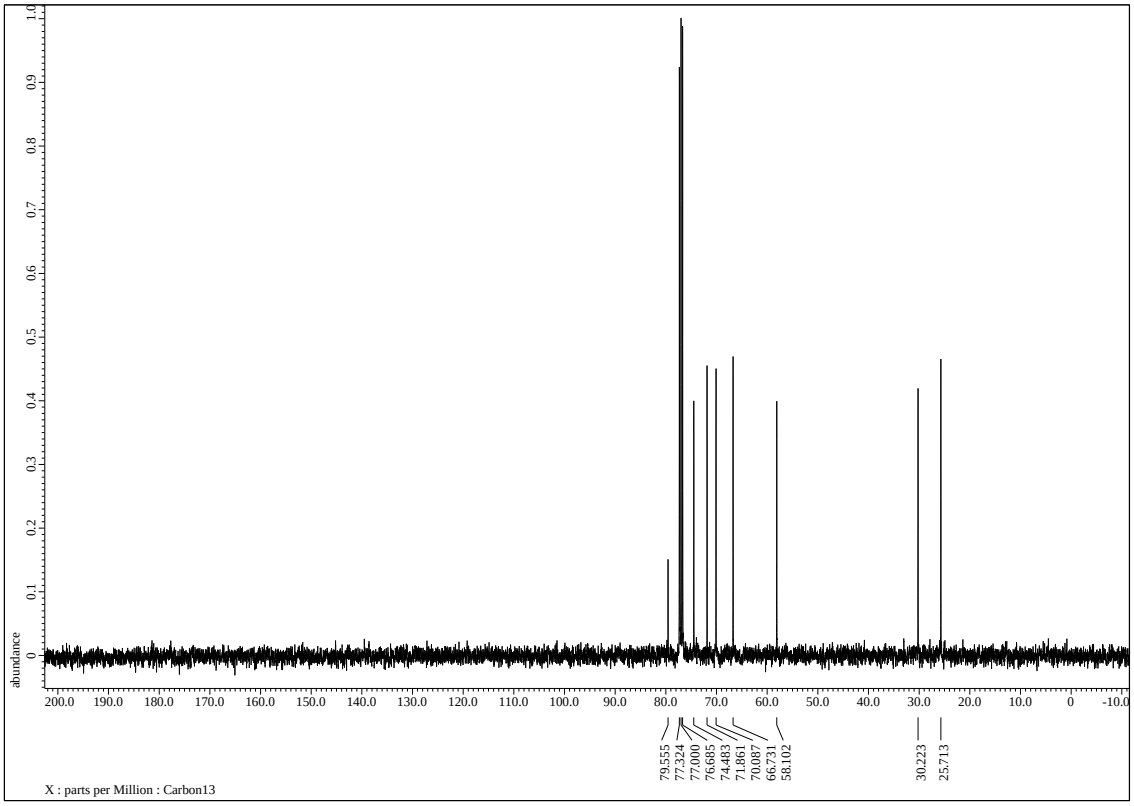

HO
2
O
O
S28
4.41
2.13
1.14
1.02
1.03
abundance
7.260
4.140
4.125
4.111
4.106
4.077
4.062
4.057
4.042
3.694
3.686
3.680
3.672
3.551
3.531
3.513
1.702
1.696
1.683
1.679
1.675
1.669
1.660
1.655
1.649
1.643
1.633
1.417
1.362
-0.002
X : parts per Million : Proton

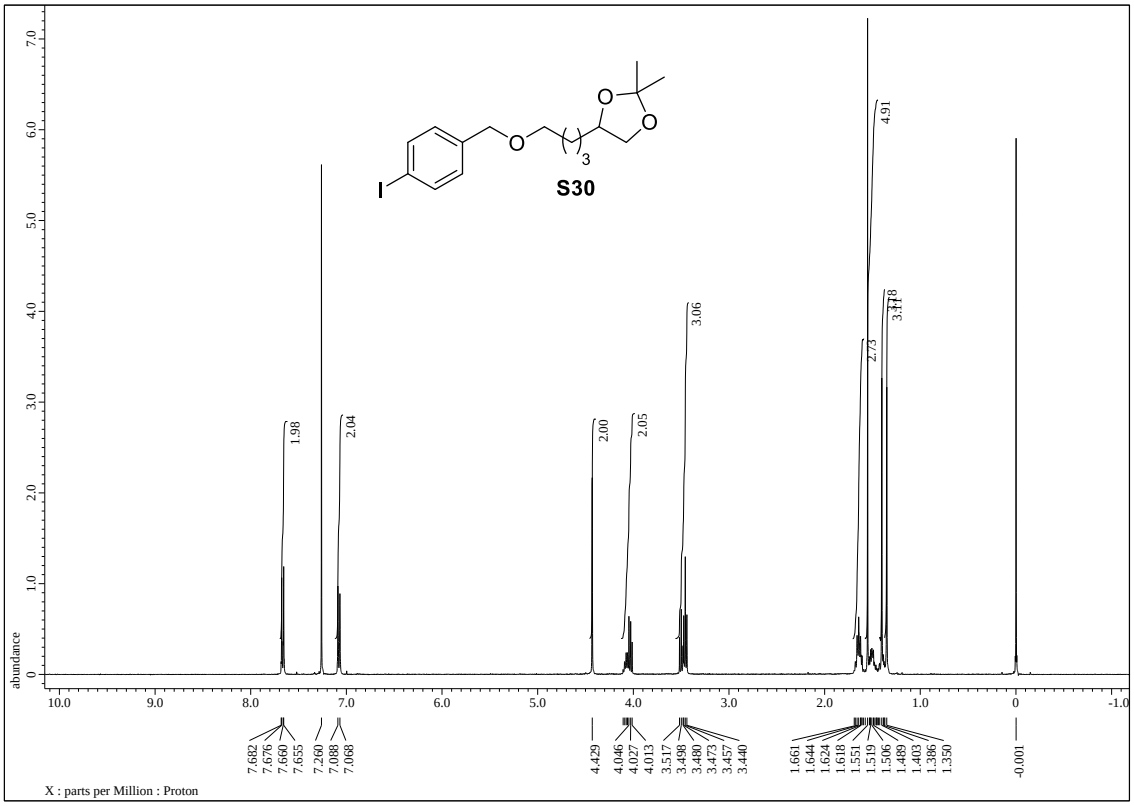

abundance
108.912
77.315
77.000
76.676
75.923
69.410
62.517
30.185
29.098
26.839
25.666
X : parts per Million : Carbon13

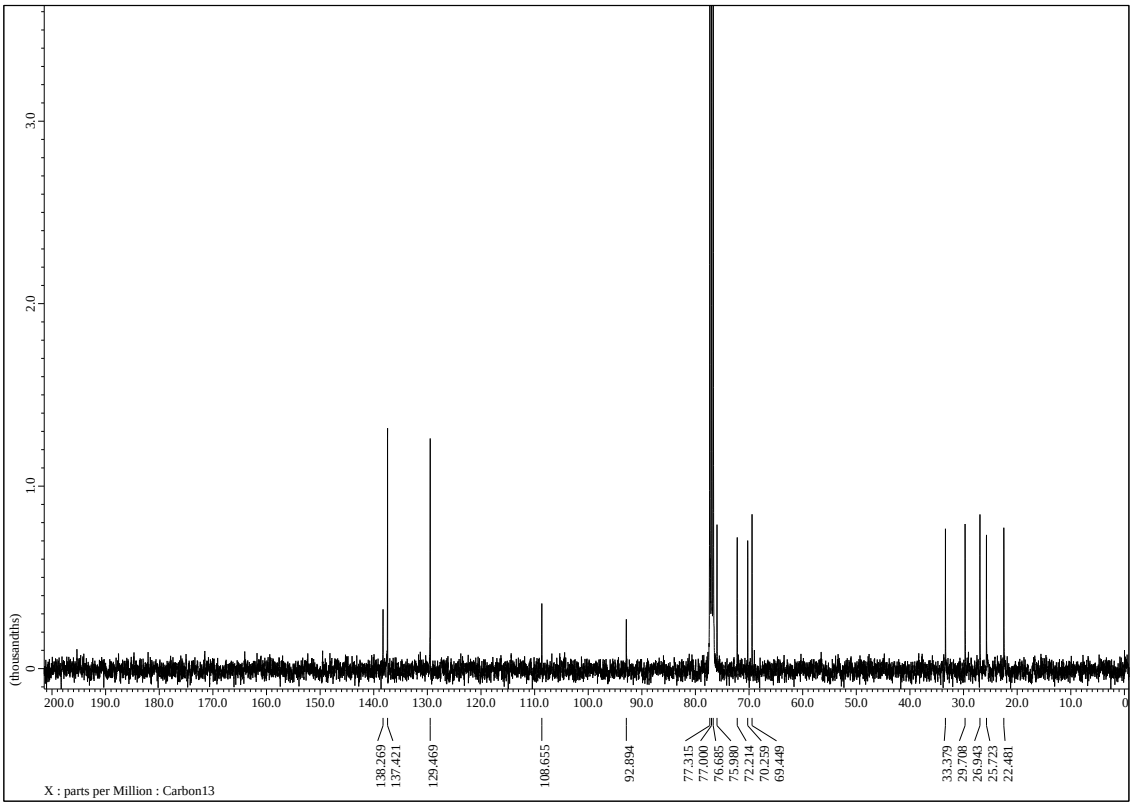

S29
abundance
2.69
3.10
3.40
2.91
3.00
0.92
0.85
7.260
4.140
4.134
4.114
4.097
4.058
4.042
4.039
4.024
3.572
3.558
3.545
3.527
3.509
2.420
2.415
2.409
1.701
1.667
1.651
1.641
1.636
1.541
1.407
1.354
-0.000
X : parts per Million : Proton

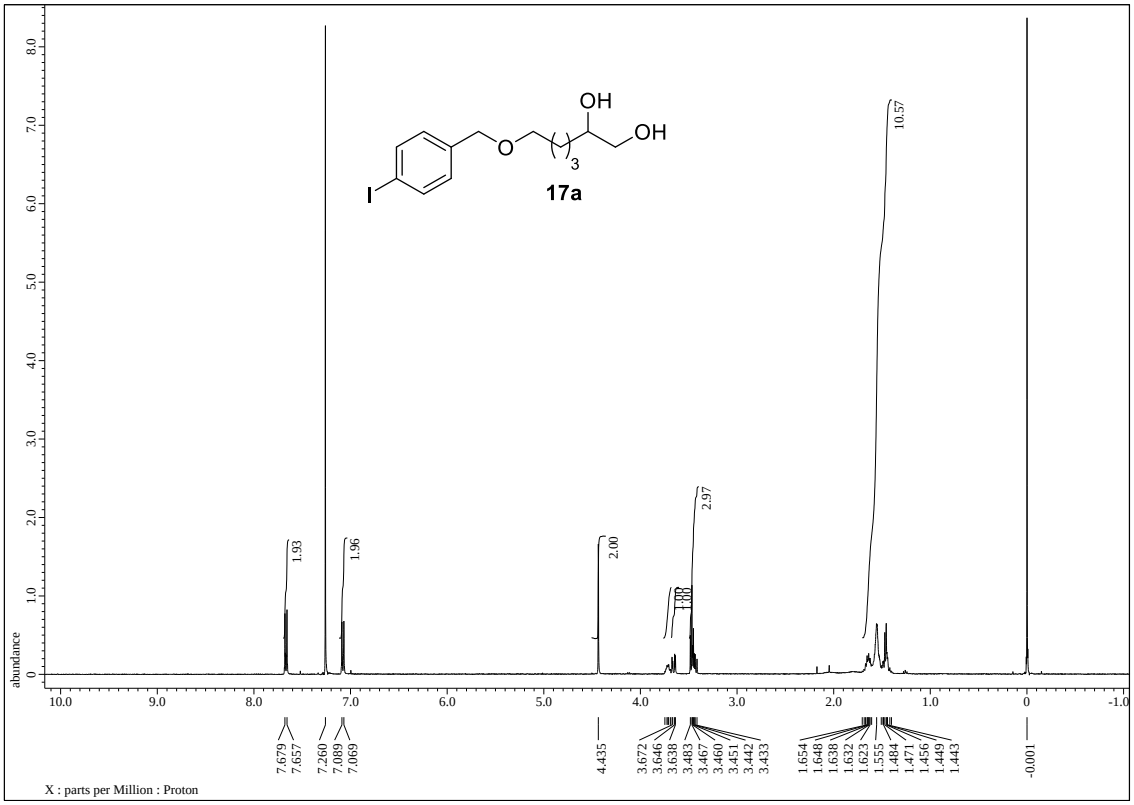

abundance
108.722
79.860
77.315
77.000
76.676
75.741
74.159
69.744
69.353
58.017
30.185
26.934
25.752
25.704
X : parts per Million : Carbon13

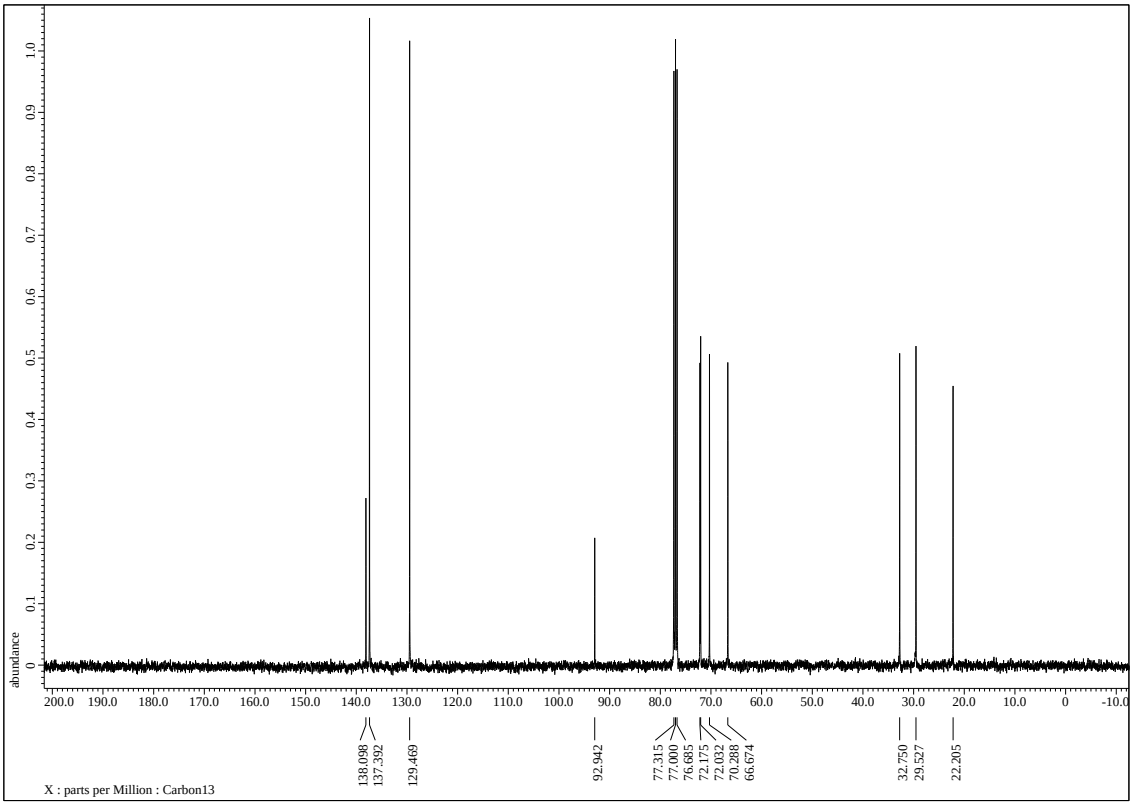

OH
OH
O
2
15a
2.00
2.11
1.03
1.03
1.07
0.85
0.49
0.60
2.07
2.81
abundance
7.260
4.159
4.153
3.596
3.581
3.566
3.481
3.463
2.616
2.439
2.434
2.428
1.781
1.765
1.748
1.733
1.594
1.584
1.554
1.536
1.518
-0.002
X : parts per Million : Proton

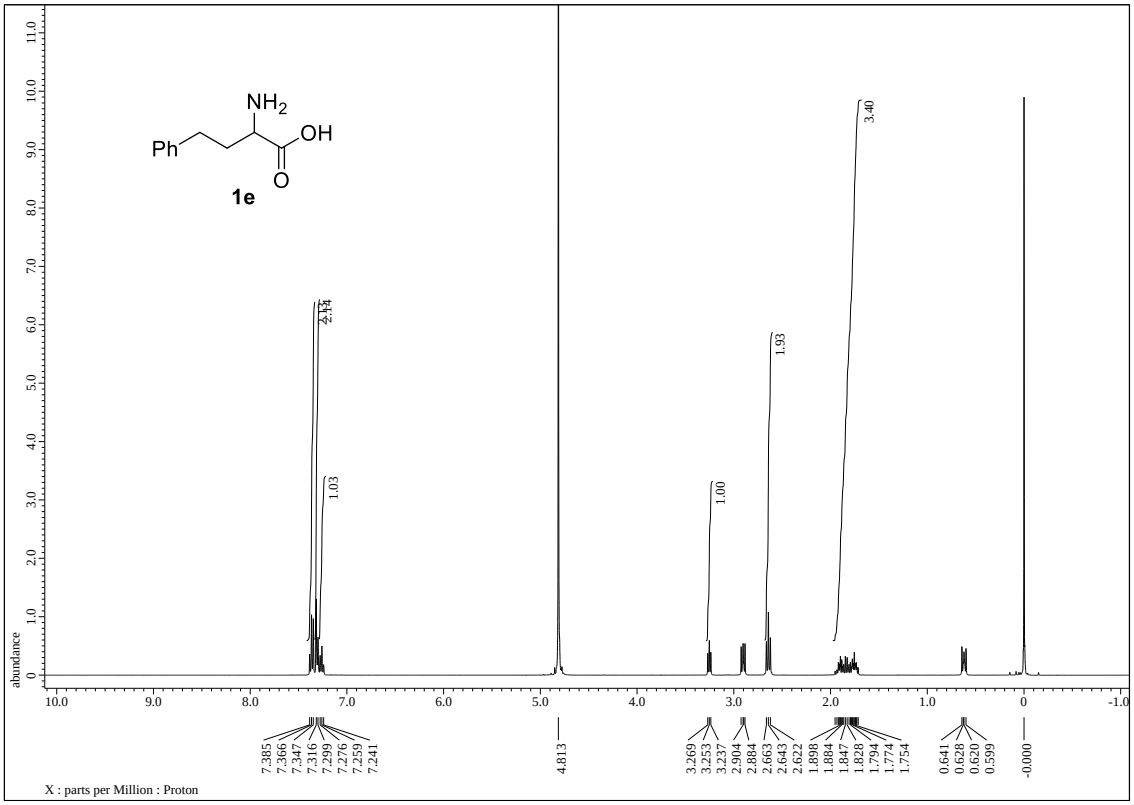

abundance
79.555
77.324
77.000
76.685
74.483
71.861
70.087
66.731
58.102
30.223
25.713
X : parts per Million : Carbon13

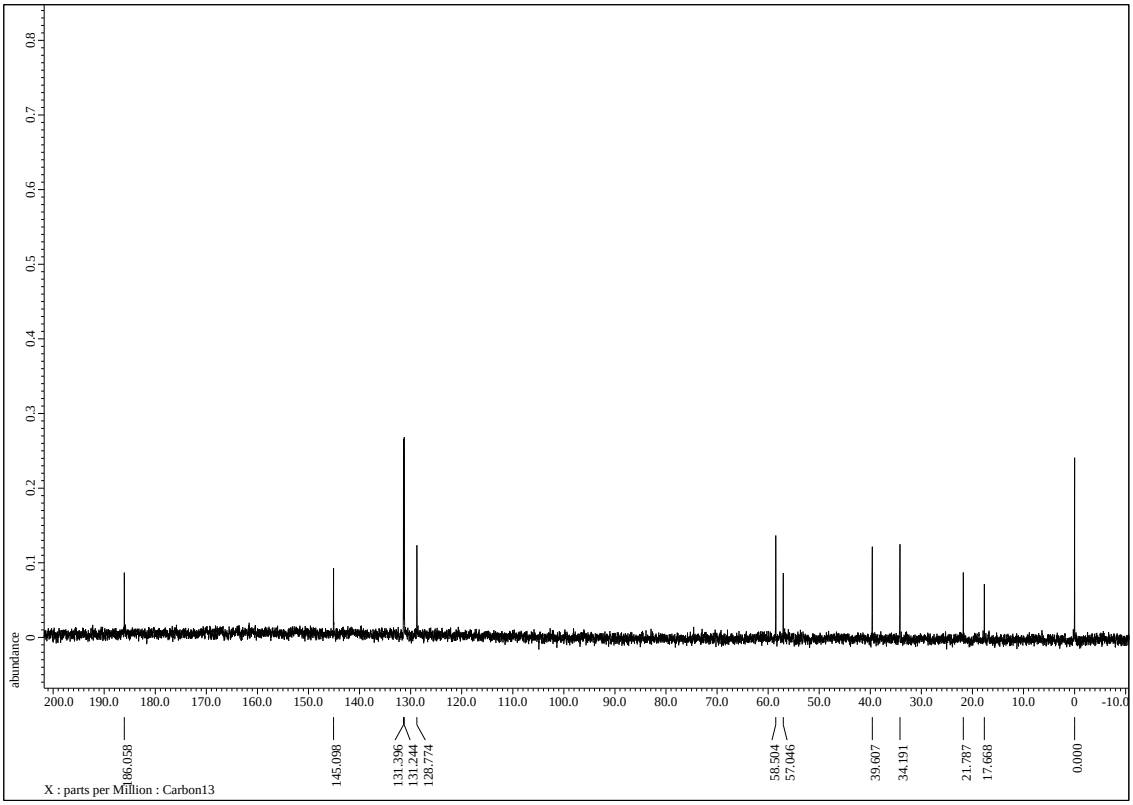

S30
abundance
X : parts per Million : Proton
7.682
7.676
7.660
7.655
7.260
7.088
7.068
4.429
4.046
4.027
4.013
3.517
3.498
3.480
3.473
3.457
3.440
1.661
1.644
1.624
1.618
1.551
1.519
1.506
1.489
1.403
1.386
1.350
-0.001
1.98
2.04
2.00
2.05
3.06
2.73
3.178
3.171
4.91

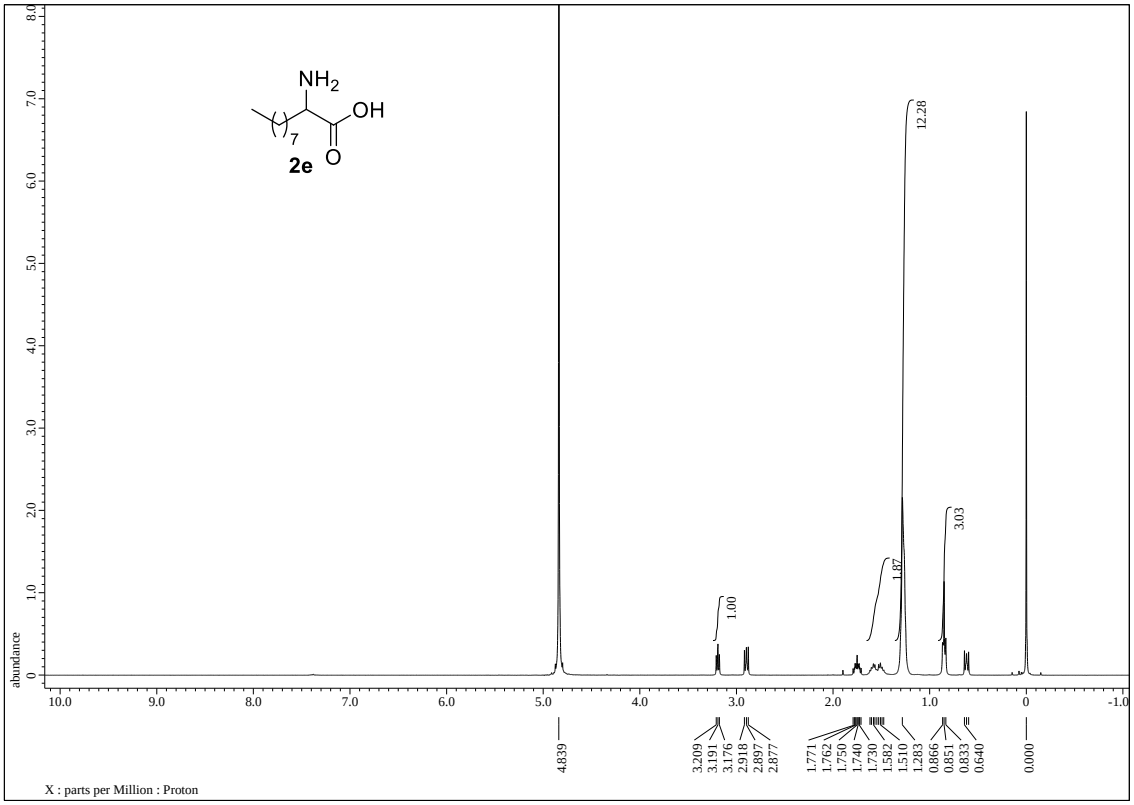

(thousandths)
X : parts per Million : Carbon13
138.269
137.421
129.469
108.655
92.894
77.315
77.000
76.685
75.980
72.214
70.259
69.449
33.379
29.708
26.943
25.723
22.481

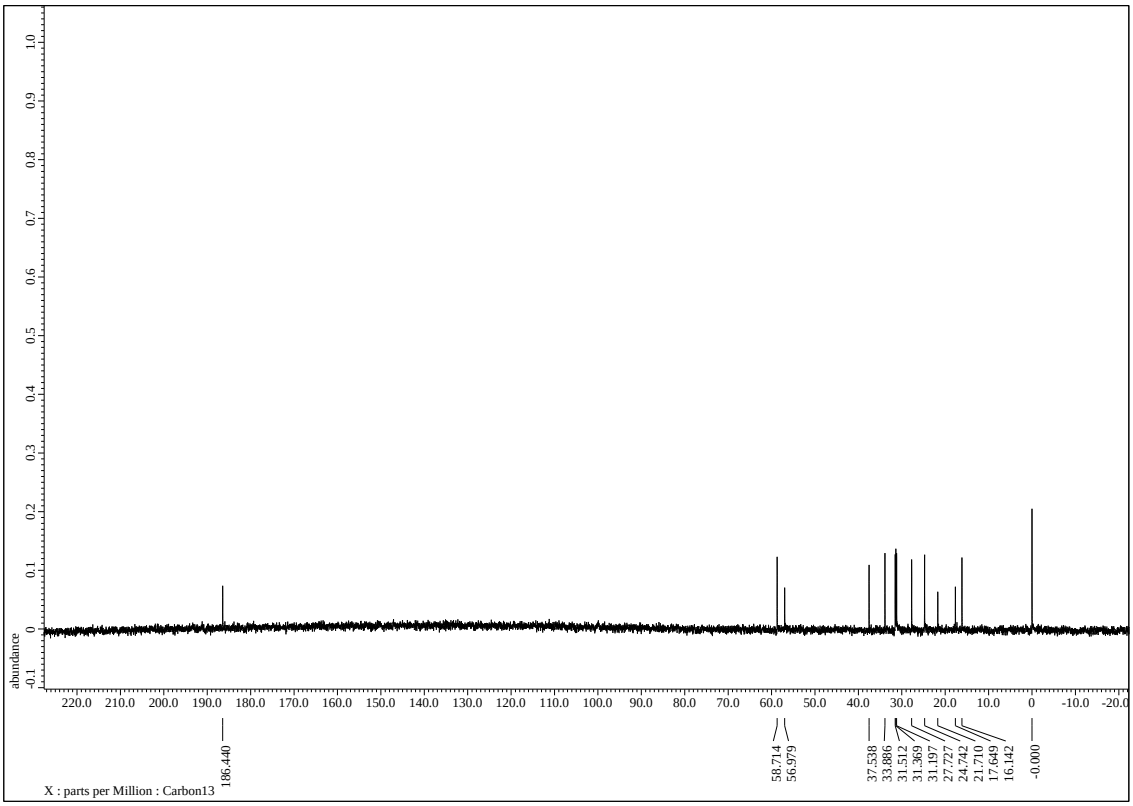

OH
OH
O
3
I
17a
10.57
2.97
2.00
1.96
1.93
abundance
X : parts per Million : Proton

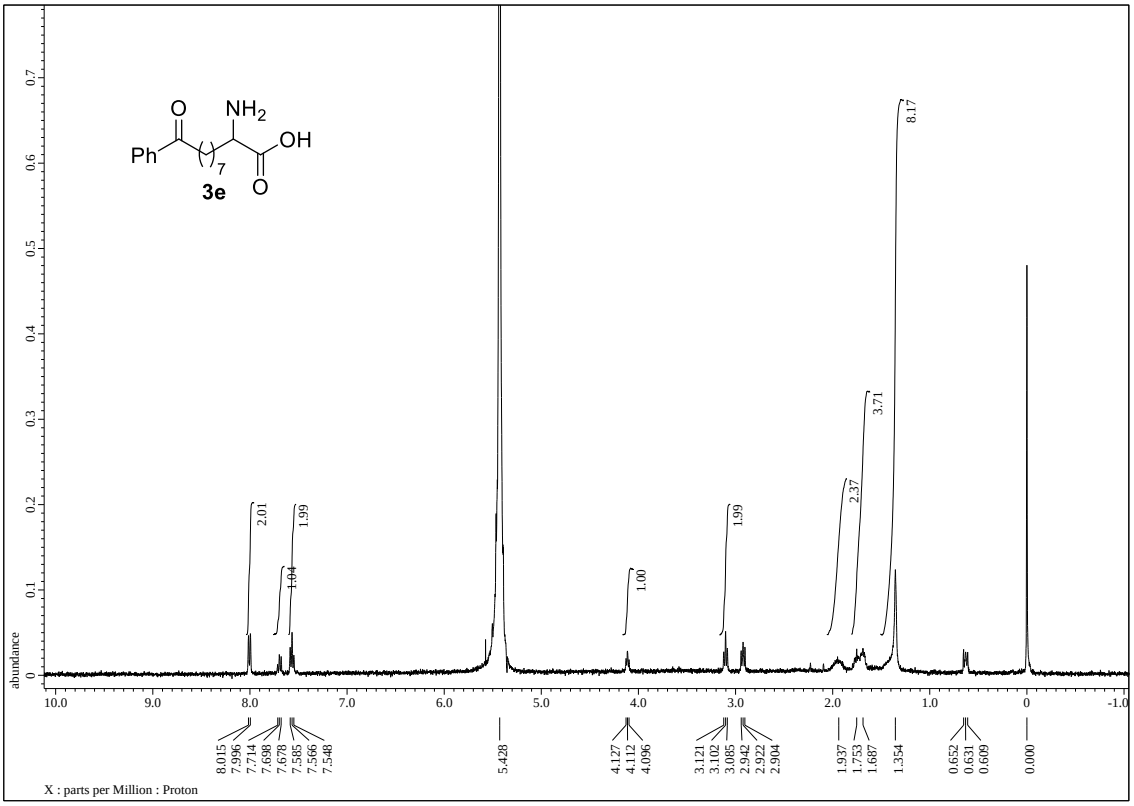

abundance
X : parts per Million : Carbon13

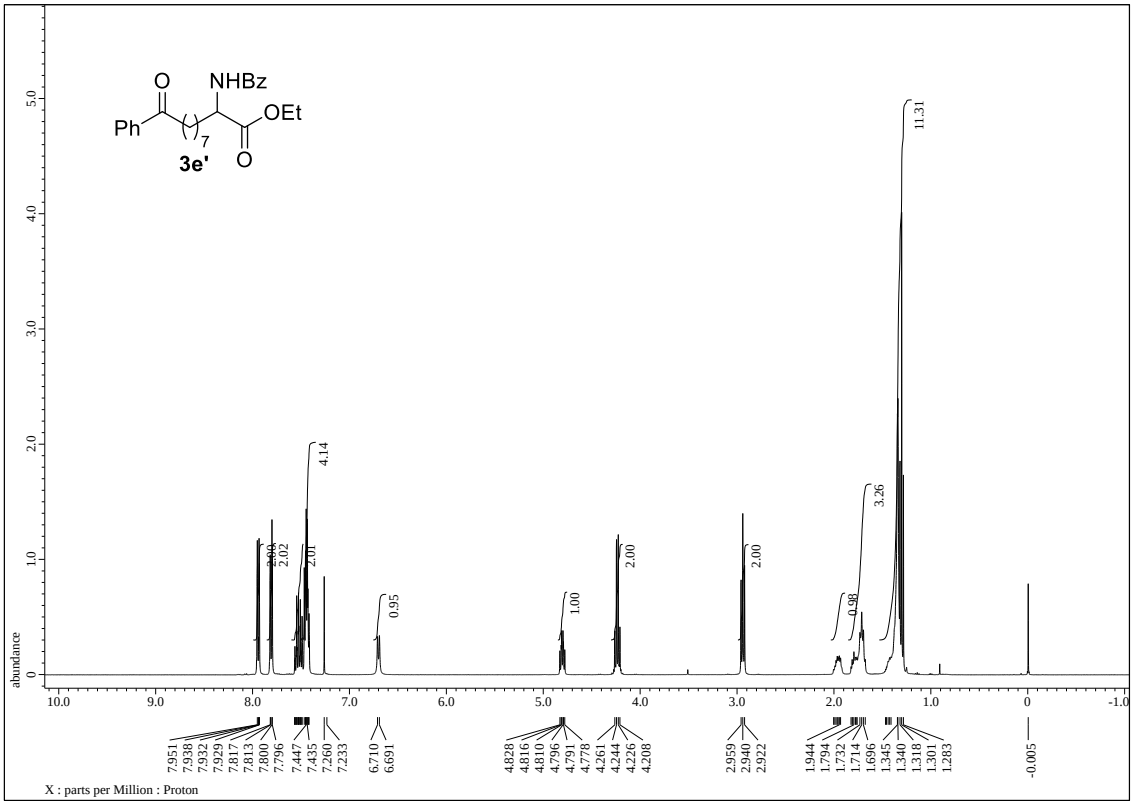

NH2
OH
Ph
O
1e
3.40
2.14
2.13
1.93
1.03
1.00
abundance
X : parts per Million : Proton

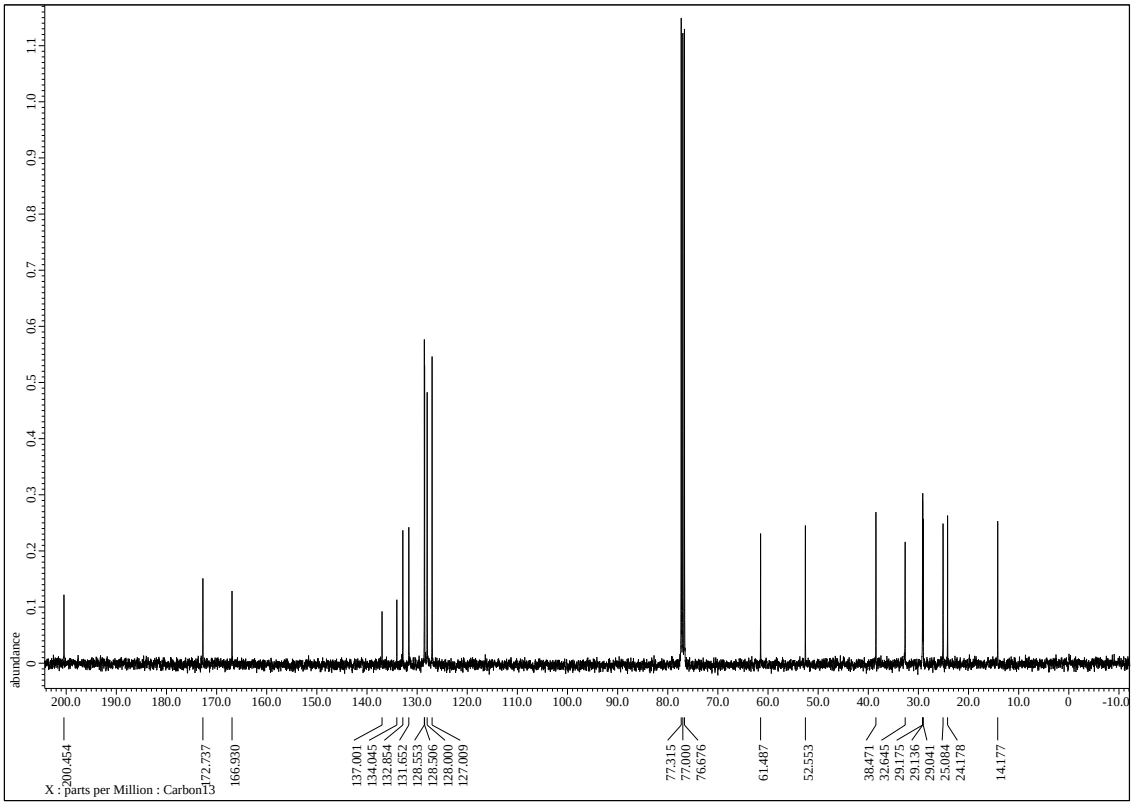

abundance
X : parts per Million : Carbon13

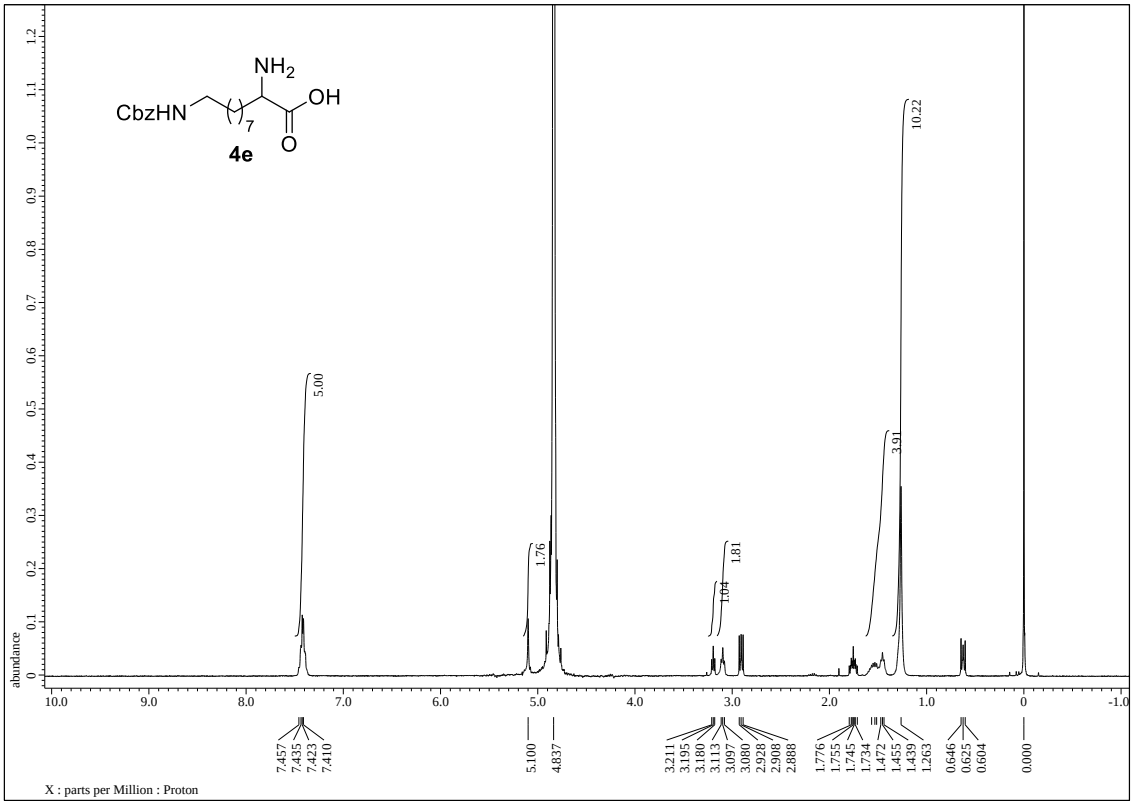

NH2
OH
7
O
2e
12.28
3.03
1.87
1.00
abundance
X : parts per Million : Proton
4.839
3.209
3.191
3.176
2.918
2.897
2.877
1.771
1.762
1.750
1.740
1.730
1.582
1.510
1.283
0.866
0.851
0.833
0.640
0.000

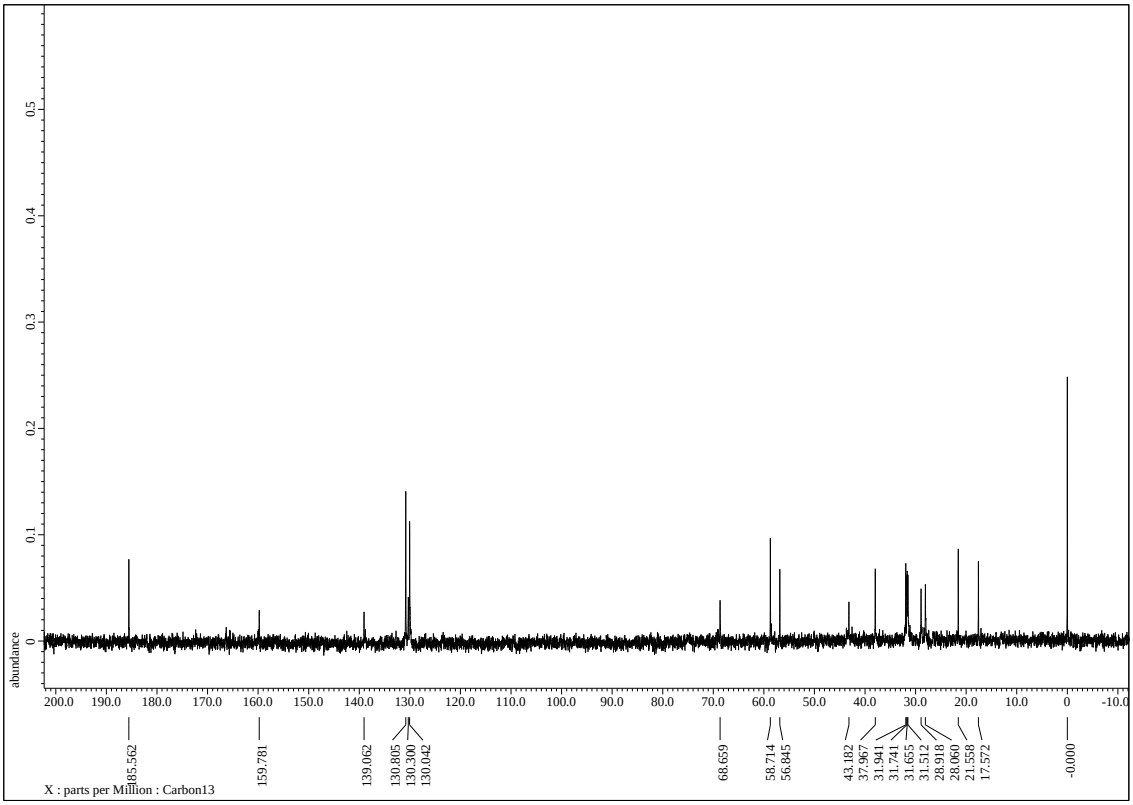

abundance
X : parts per Million : Carbon13
186.440
58.714
56.979
37.538
33.886
31.512
31.369
31.197
27.727
24.742
21.710
17.649
16.142
-0.000

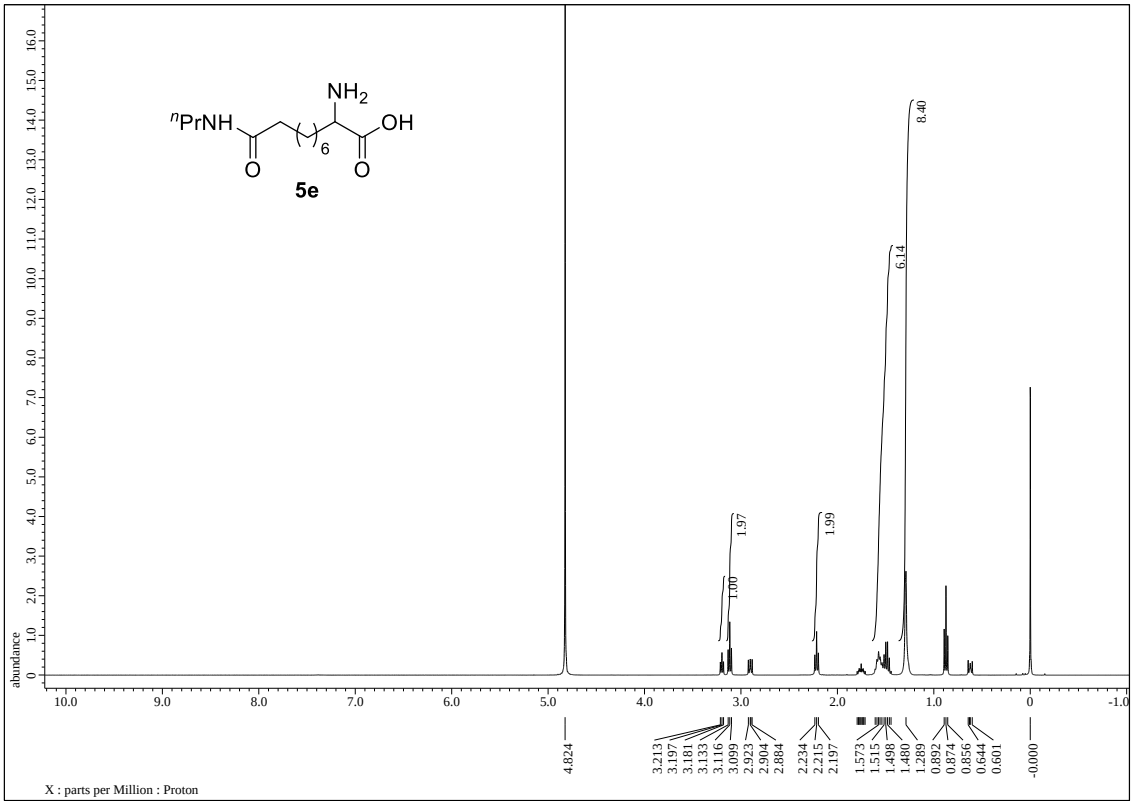

O
NH2
Ph
OH
7
O
3e
abundance
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2.01
1.99
1.04
1.00
1.99
2.37
3.71
8.17
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
-1.0
8.015
7.996
7.714
7.698
7.678
7.585
7.566
7.548
5.428
4.127
4.112
4.096
3.121
3.102
3.085
2.942
2.922
2.904
1.937
1.753
1.687
1.354
0.652
0.631
0.609
0.000
X : parts per Million : Proton

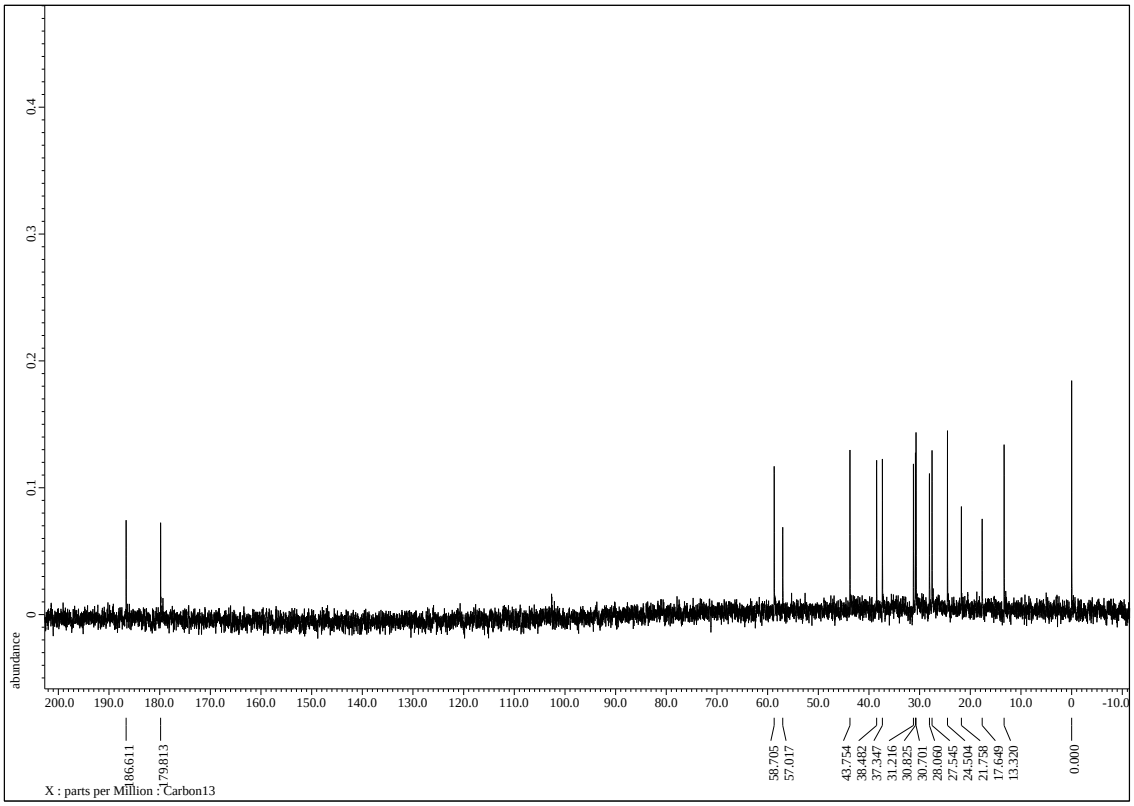

O
NHBz
Ph
OEt
7
O
3e'
abundance
X : parts per Million : Proton

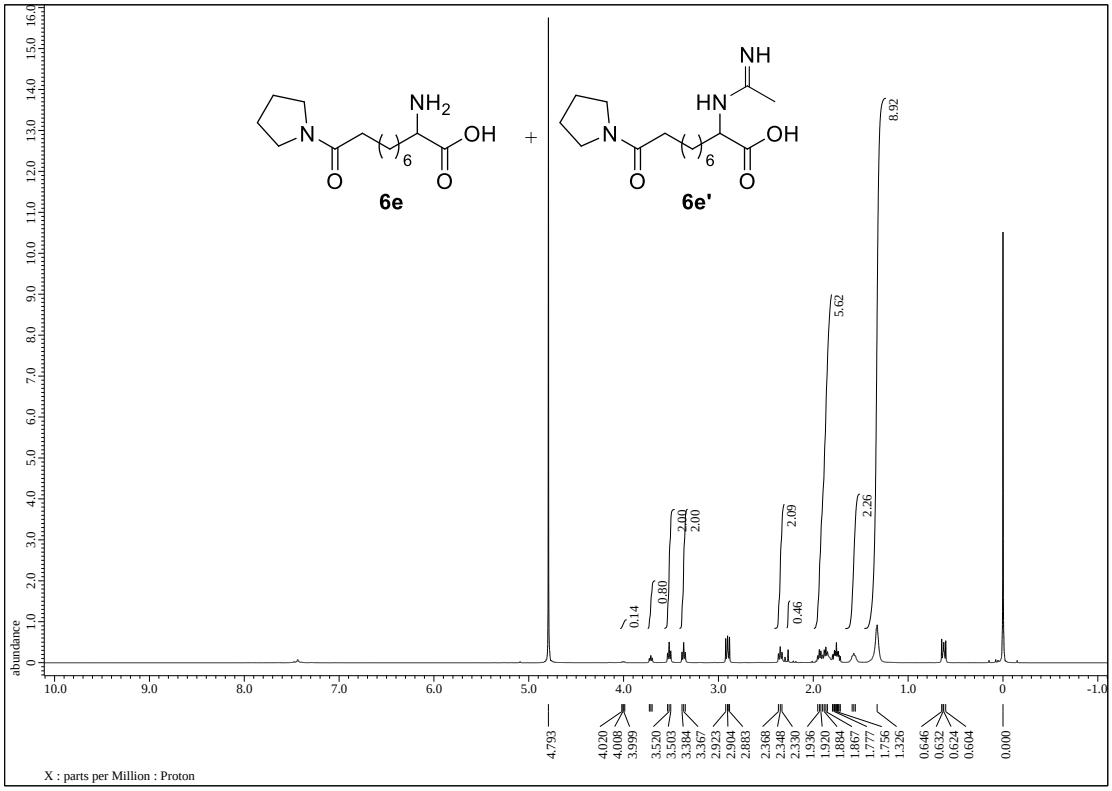

abundance
X : parts per Million : Carbon13

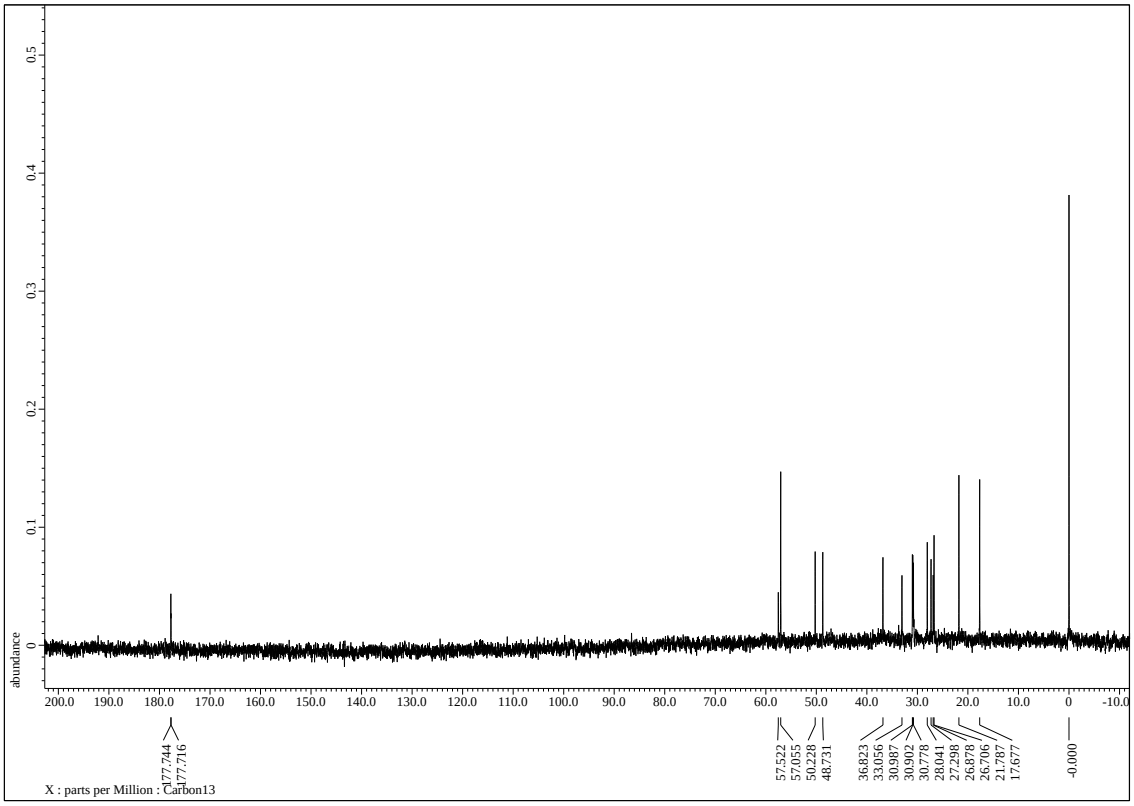

NH2
CbzHN
OH
O
7
4e
abundance
X : parts per Million : Proton

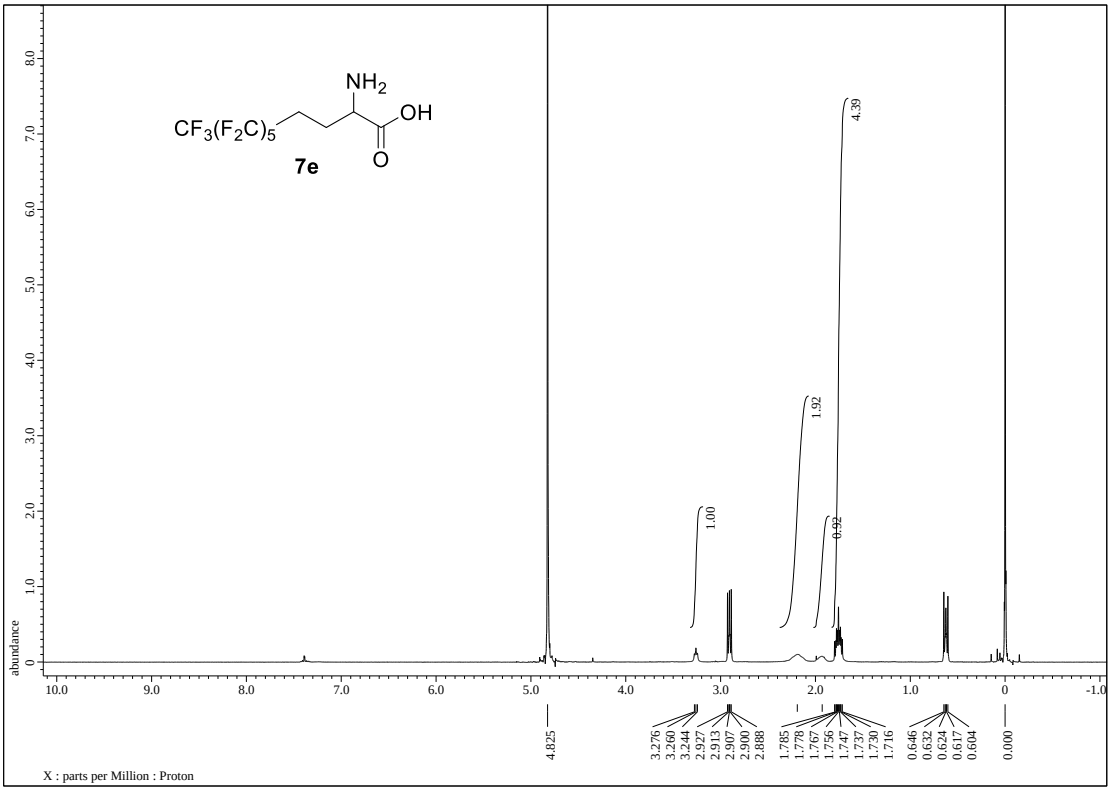

abundance
X : parts per Million : Carbon13

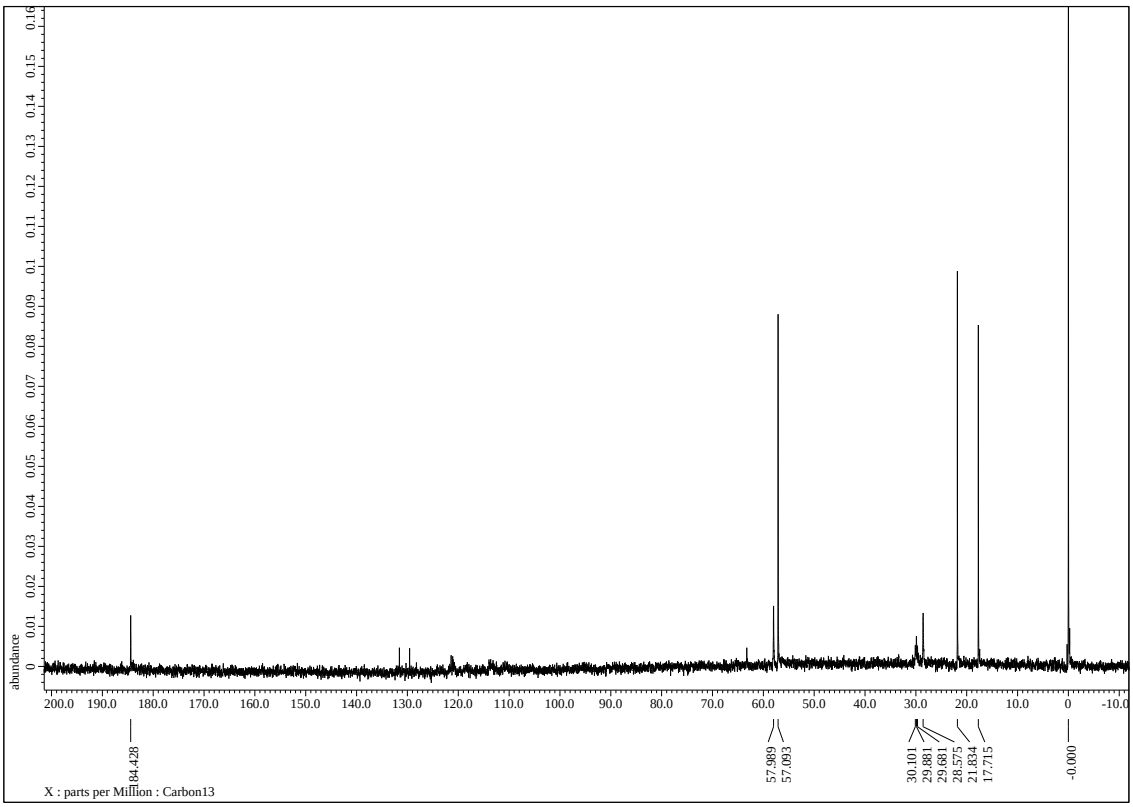

NH2
nPrNH
OH
6
O
O
5e
abundance
X : parts per Million : Proton
8.40
6.14
1.97
1.99
1.00
4.824
3.213
3.197
3.181
3.133
3.116
3.099
2.923
2.904
2.884
2.234
2.215
2.197
1.573
1.515
1.498
1.480
1.269
0.892
0.874
0.856
0.644
0.601
-0.000

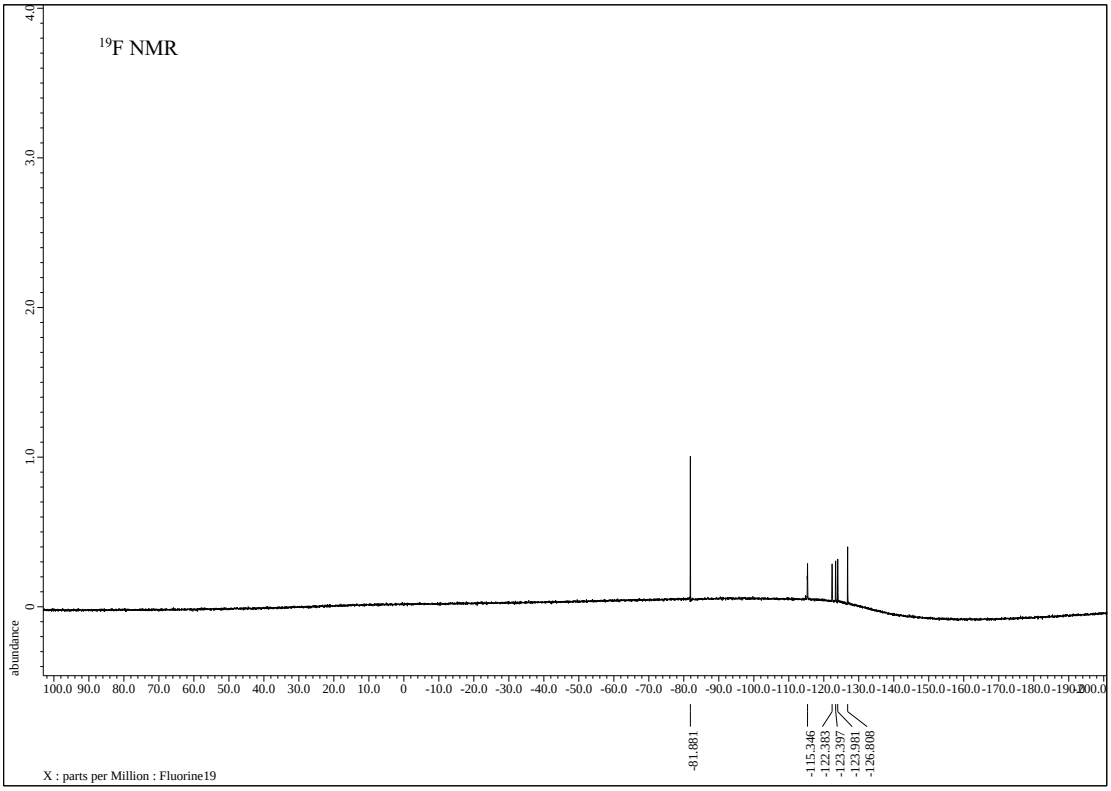

abundance
X : parts per Million : Carbon13
186.611
179.813
58.705
57.017
43.754
38.482
37.347
31.216
30.825
30.701
28.060
27.545
24.504
21.758
17.649
13.320
0.000

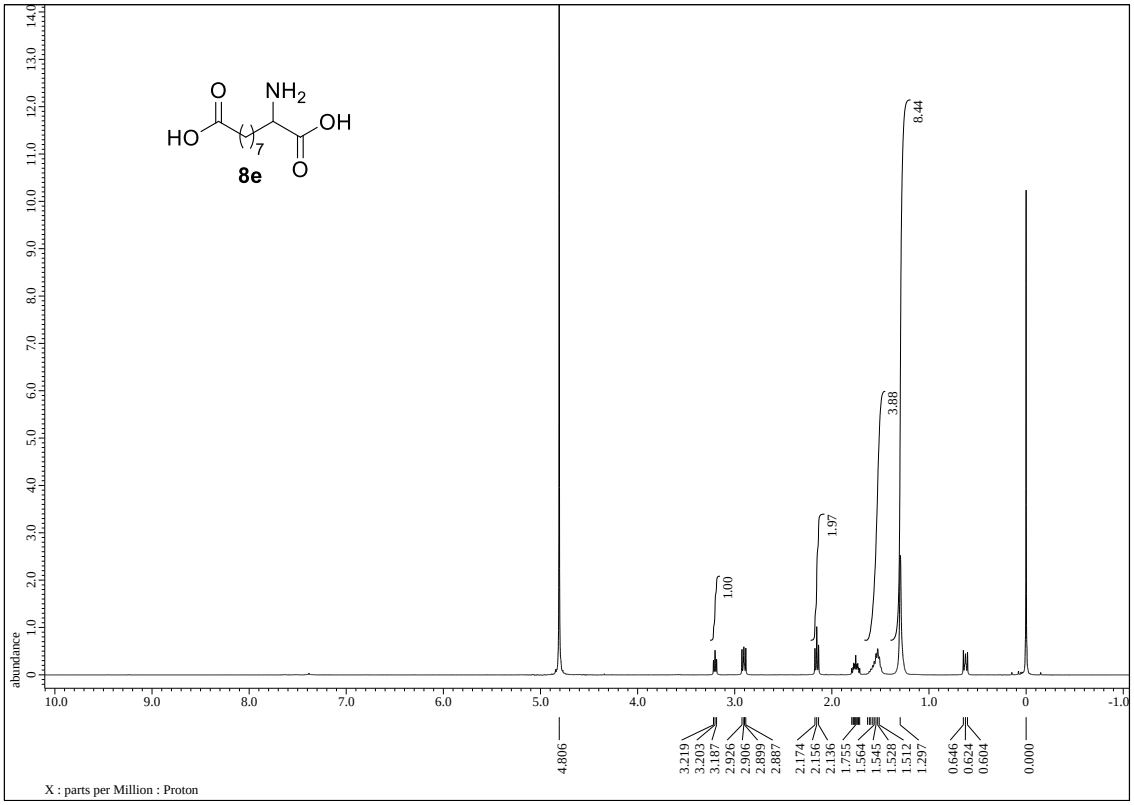

NH2
OH
N
O
O
6
6e
+
NH
HN
OH
N
O
O
6
6e'
8.92
5.62
2.26
2.09
2.00
2.00
0.80
0.46
0.14
abundance
X : parts per Million : Proton

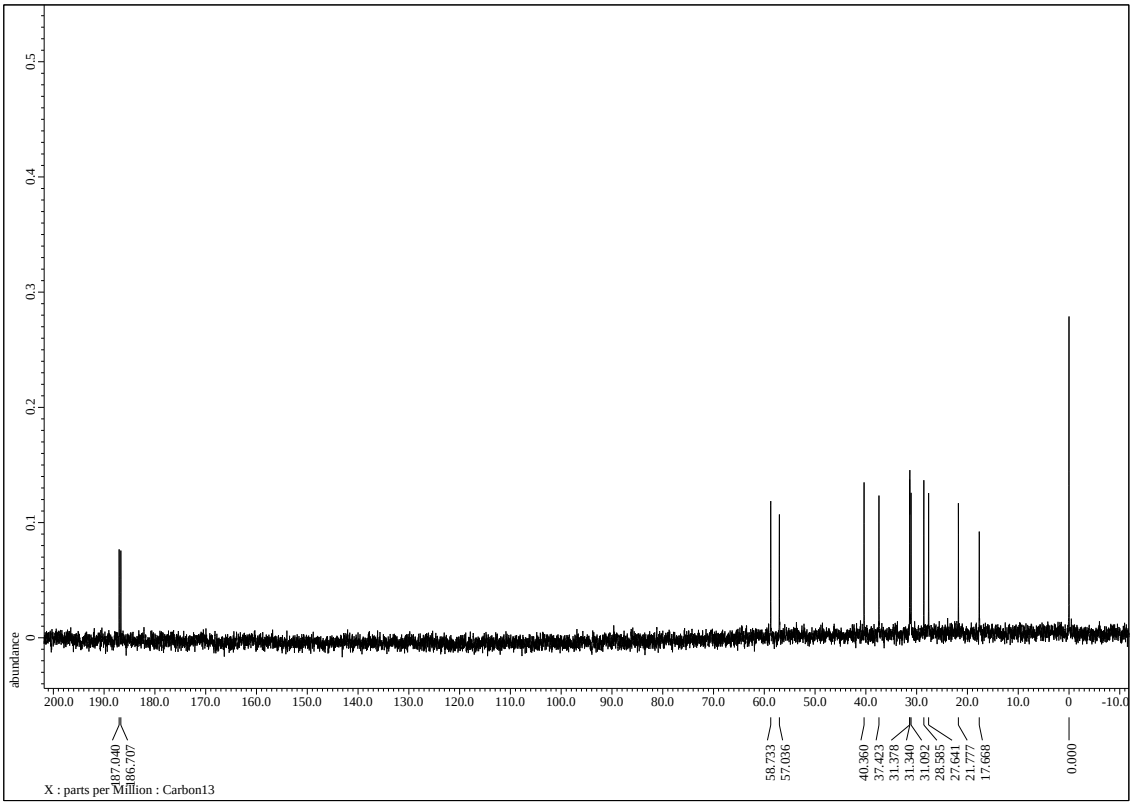

abundance
X : parts per Million : Carbon13

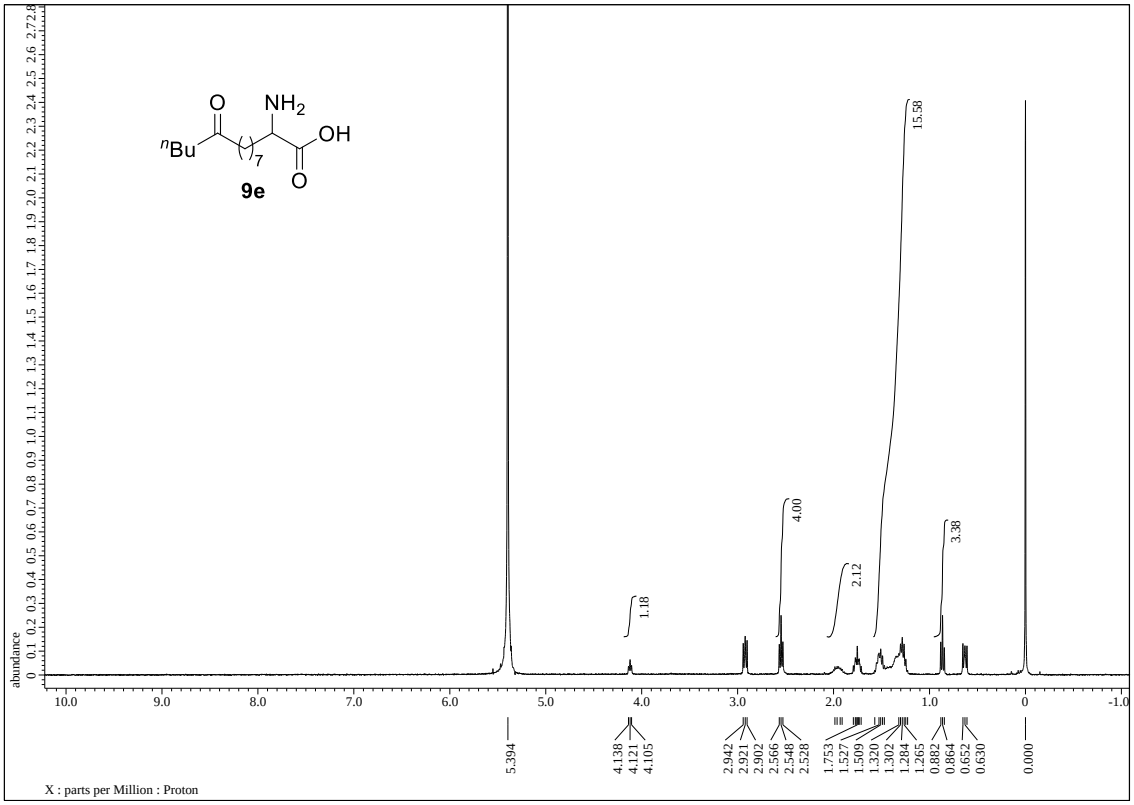

NH2
OH
O
CF3(F2C)5
7e
4.39
1.92
1.00
0.92
abundance
X : parts per Million : Proton
4.825
3.276
3.260
3.244
2.927
2.913
2.907
2.900
2.888
1.785
1.778
1.767
1.756
1.747
1.737
1.730
1.716
0.646
0.632
0.624
0.617
0.604
0.000

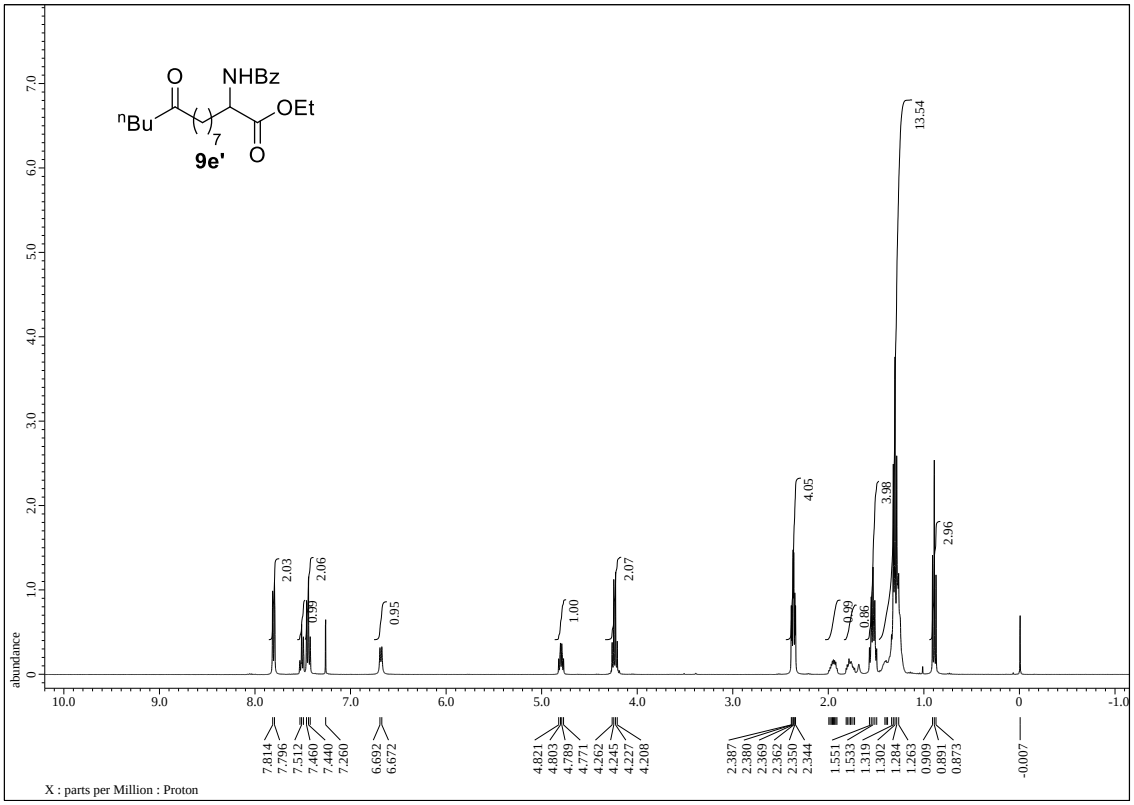

abundance
X : parts per Million : Carbon13
184.428
57.989
57.093
30.101
29.881
29.681
28.575
21.834
17.715
-0.000

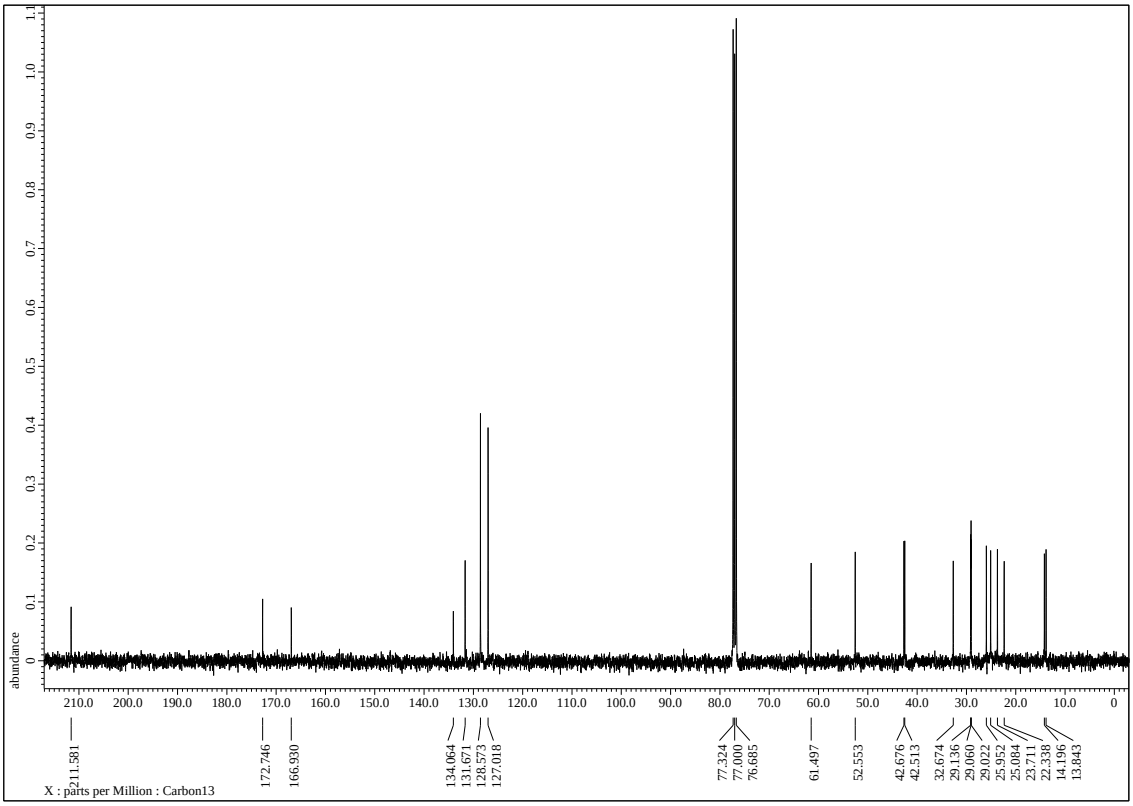

19F NMR
abundance
4.0
3.0
2.0
1.0
0
100.0 90.0 80.0 70.0 60.0 50.0 40.0 30.0 20.0 10.0 0 -10.0 -20.0 -30.0 -40.0 -50.0 -60.0 -70.0 -80.0 -90.0 -100.0 -110.0 -120.0 -130.0 -140.0 -150.0 -160.0 -170.0 -180.0 -190.0 -200.0
-81.881
-115.346
-122.383
-123.397
-123.981
-126.808
X ; parts per Million : Fluorine19

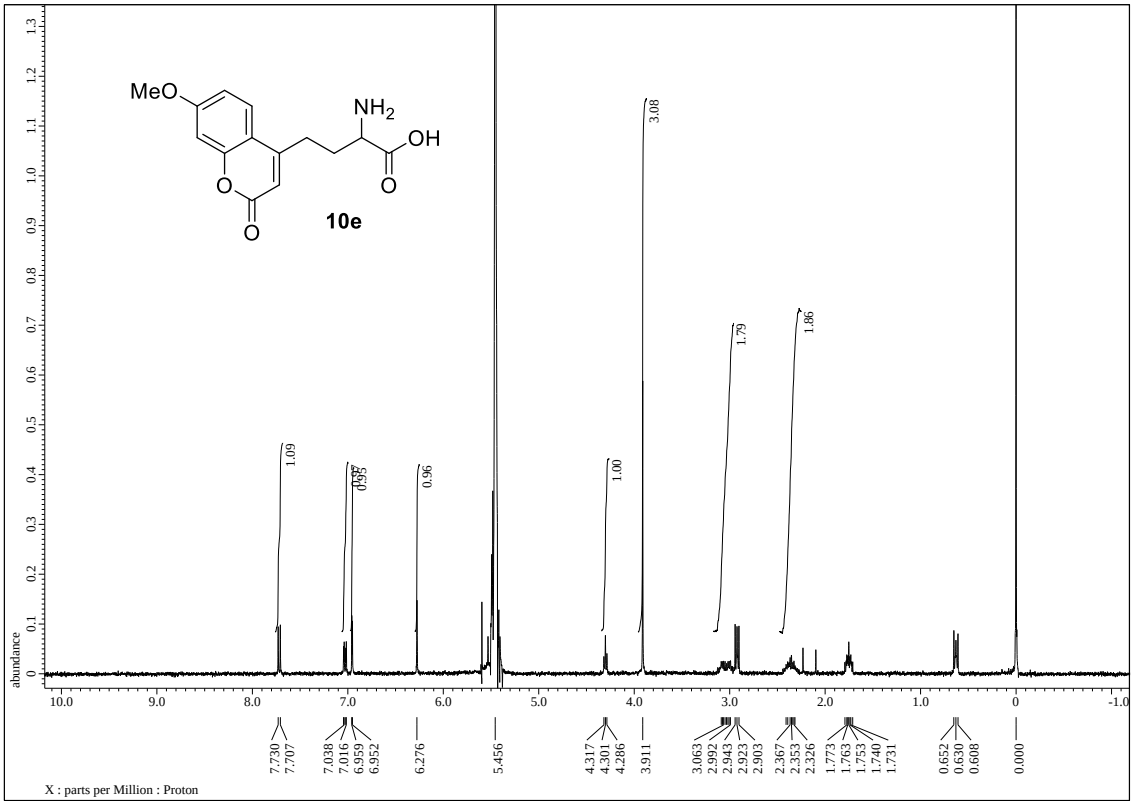

O
NH2
HO
OH
7
O
8e
8.44
3.88
1.97
1.00
abundance
4.806
3.219
3.203
3.187
2.926
2.906
2.899
2.887
2.174
2.156
2.136
1.755
1.564
1.545
1.528
1.512
1.297
0.646
0.624
0.604
0.000
X : parts per Million : Proton

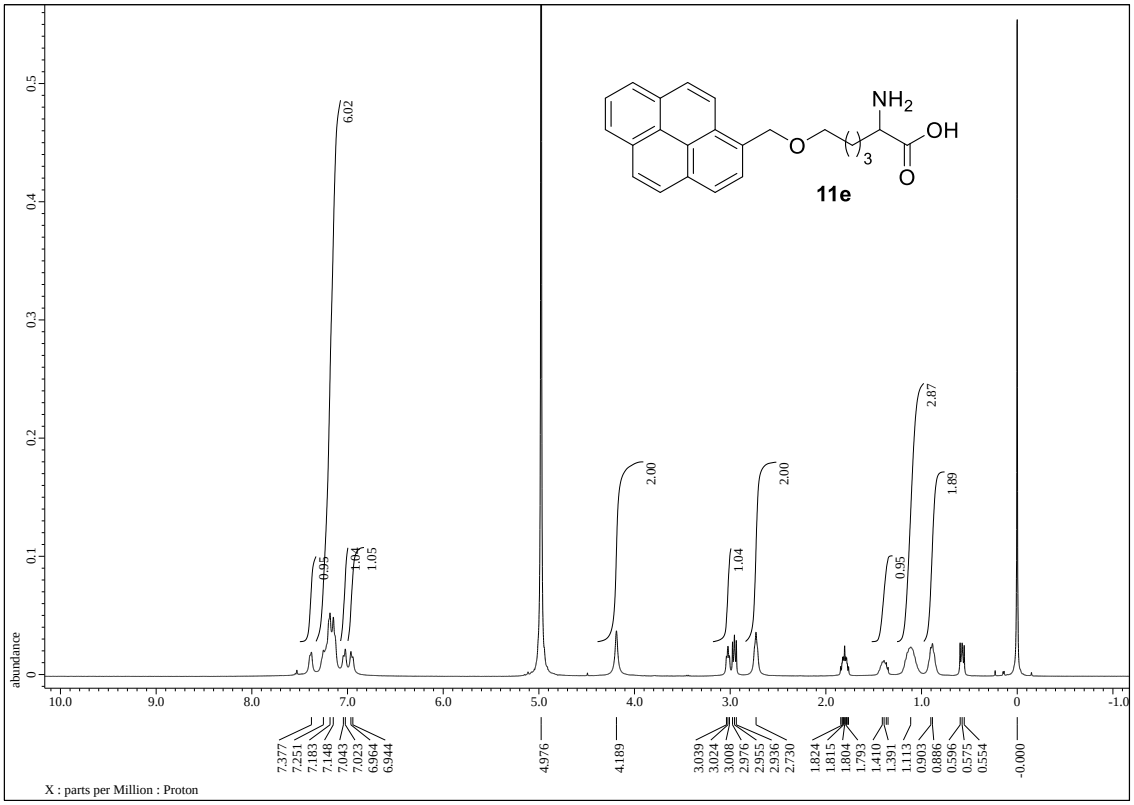

abundance
187.040
186.707
58.733
57.036
40.360
37.423
31.378
31.340
31.092
28.585
27.641
21.777
17.668
0.000
X : parts per Million : Carbon13

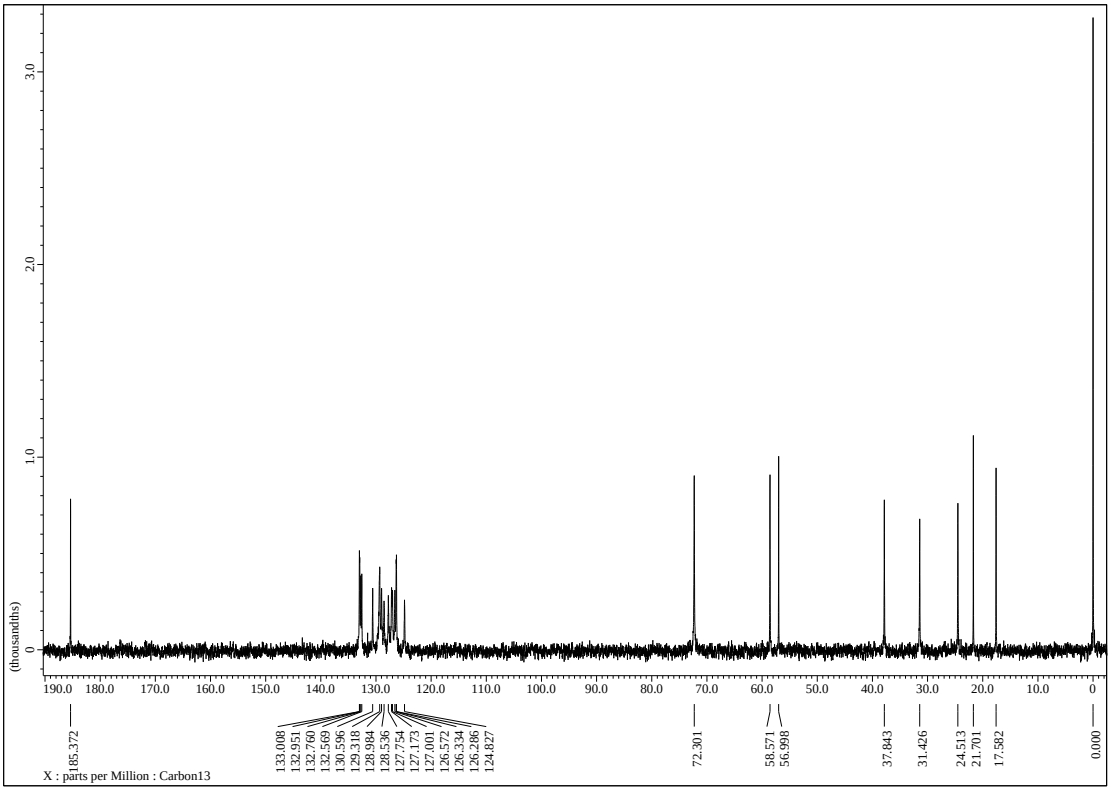

O
NH2
OH
nBu
7
O
9e
15.58
4.00
3.38
2.12
1.18
abundance
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
-1.0
5.394
4.138
4.121
4.105
2.942
2.921
2.902
2.566
2.548
2.528
1.753
1.527
1.509
1.320
1.302
1.284
1.265
0.882
0.864
0.652
0.630
0.000
X : parts per Million : Proton

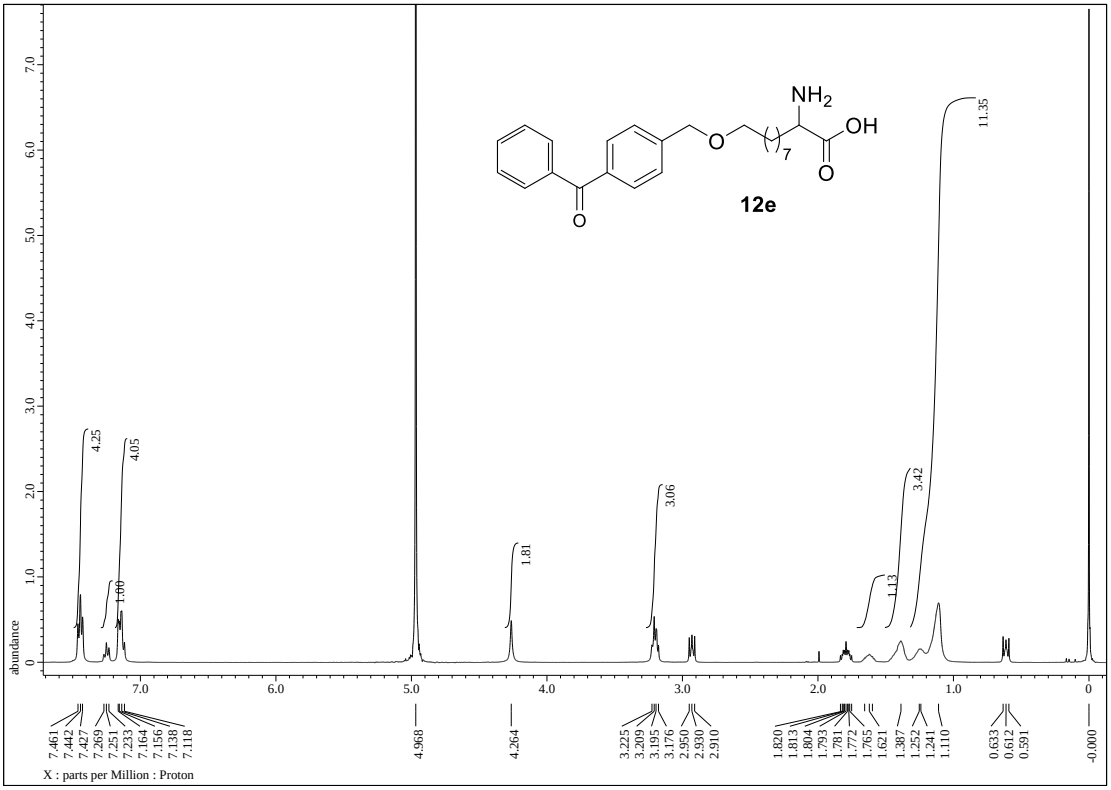

O
NHBz
OEt
nBu
7
O
9e'
13.54
4.05
3.98
2.96
2.03
2.06
0.99
0.95
1.00
2.07
0.99
0.86
abundance
X : parts per Million : Proton

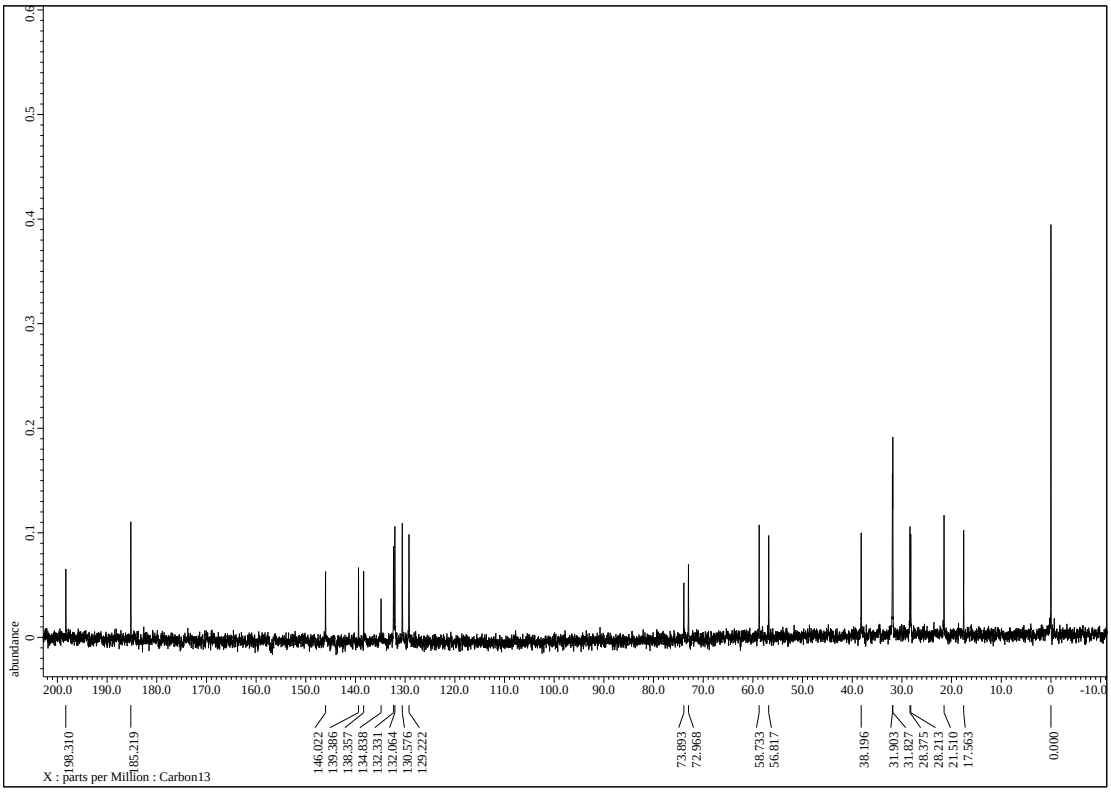

abundance
X : parts per Million : Carbon13

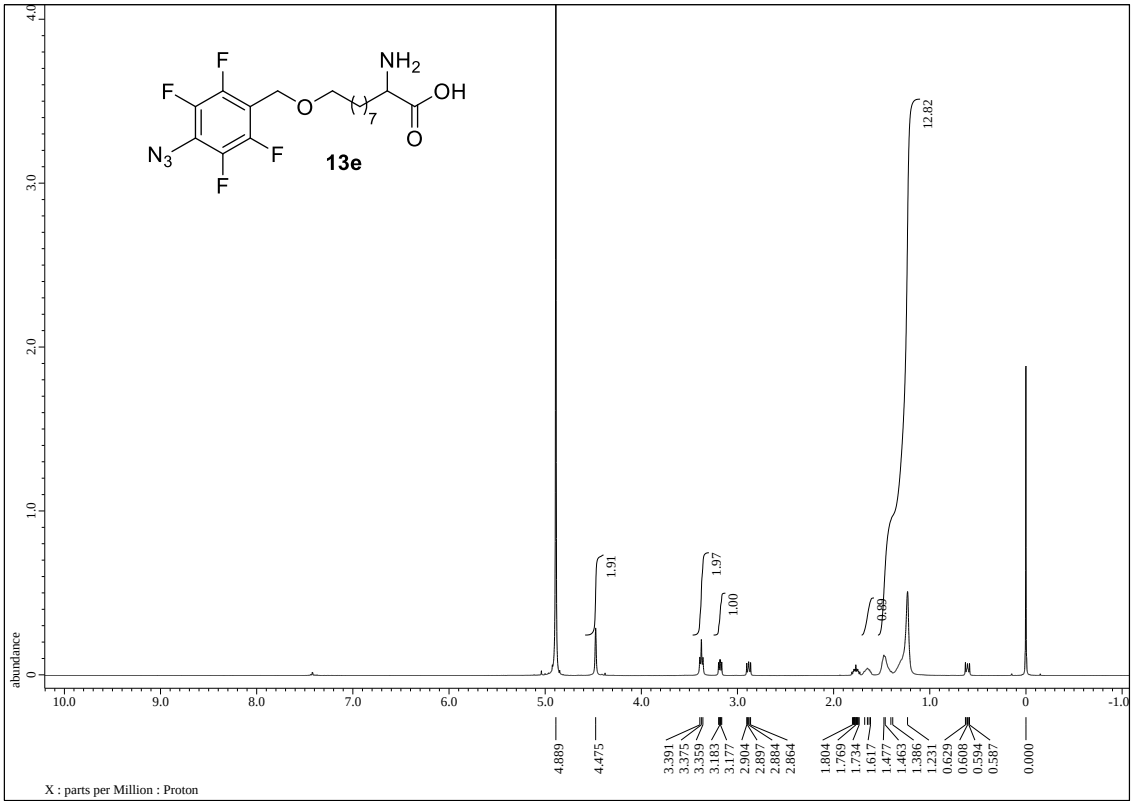

MeO
NH2
OH
O
O
O
10e
abundance
X : parts per Million : Proton

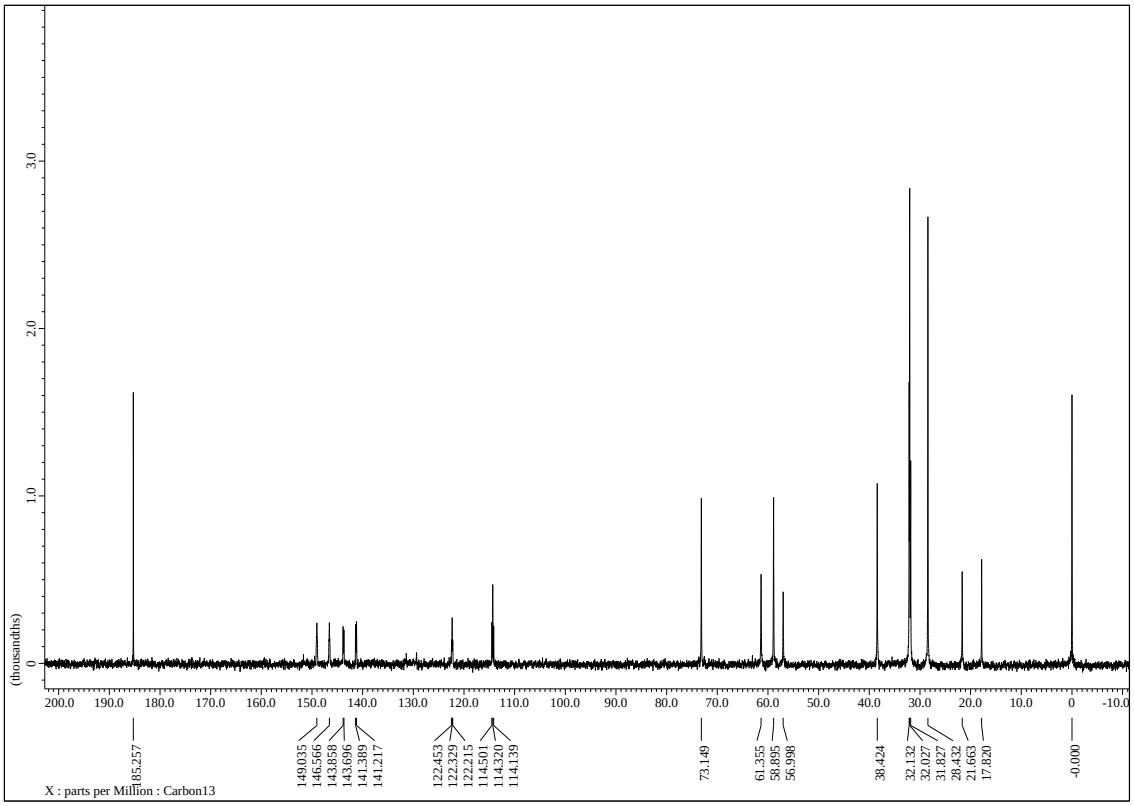

NH2
OH
O
3
O
11e
abundance
X : parts per Million : Proton

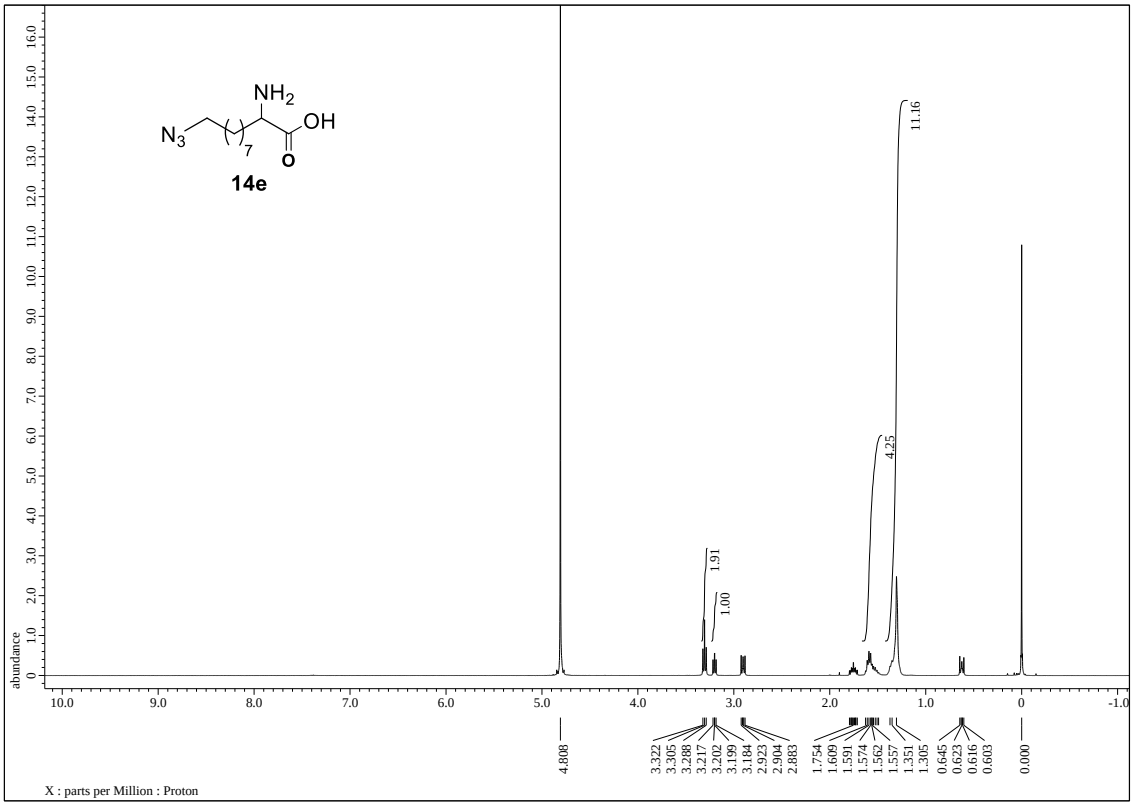

(thousandths)
X : parts per Million : Carbon13

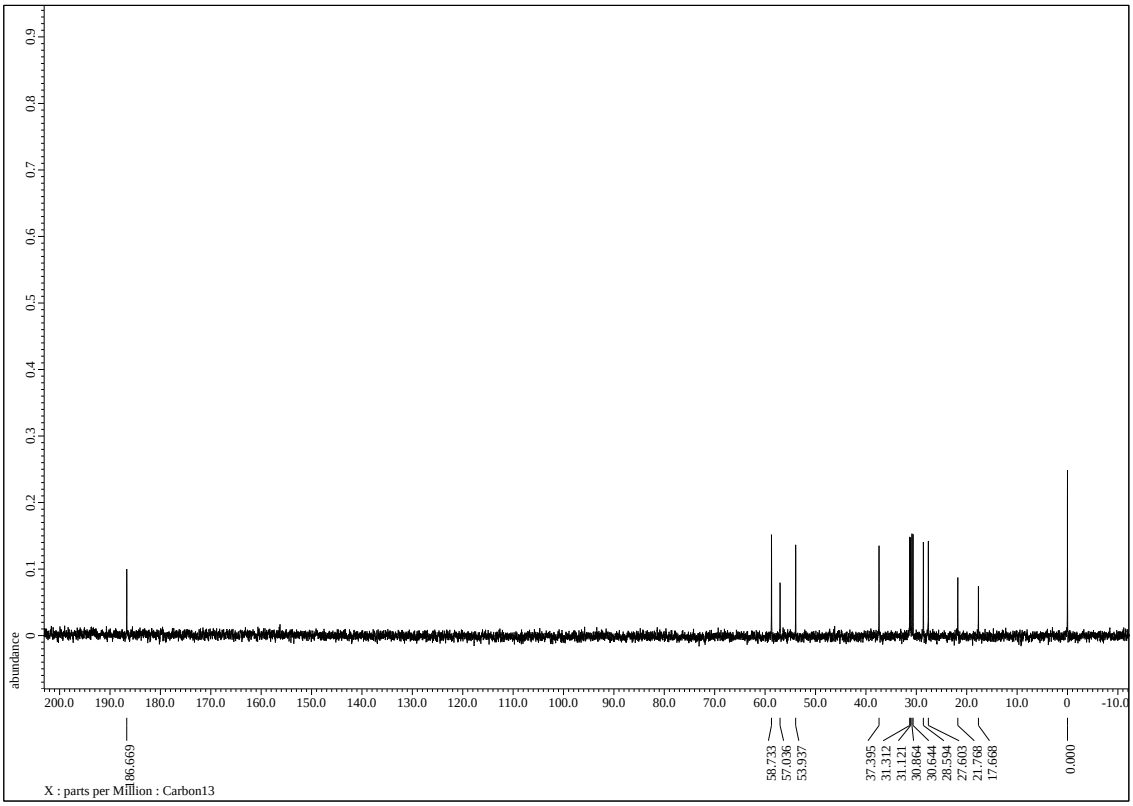

NH2
OH
O
O
O
7
12e
11.35
4.25
4.05
1.00
1.81
3.06
1.13
3.42
abundance
X : parts per Million : Proton

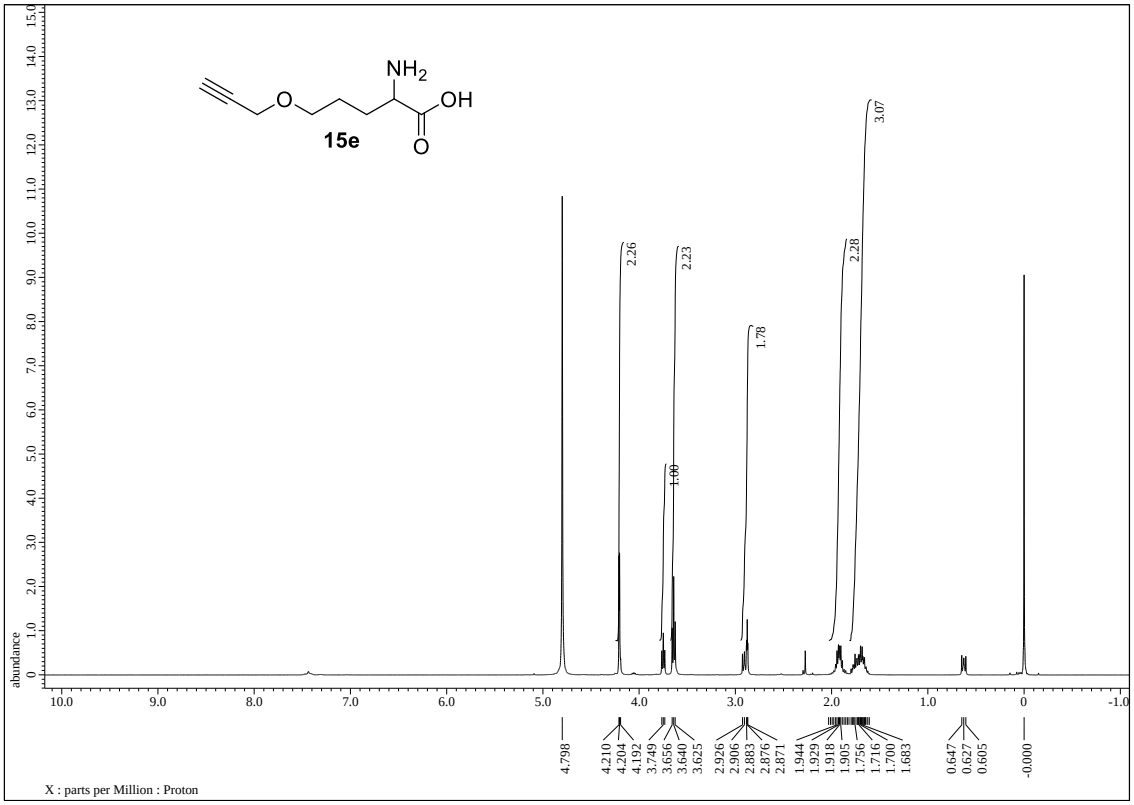

abundance
X : parts per Million : Carbon13

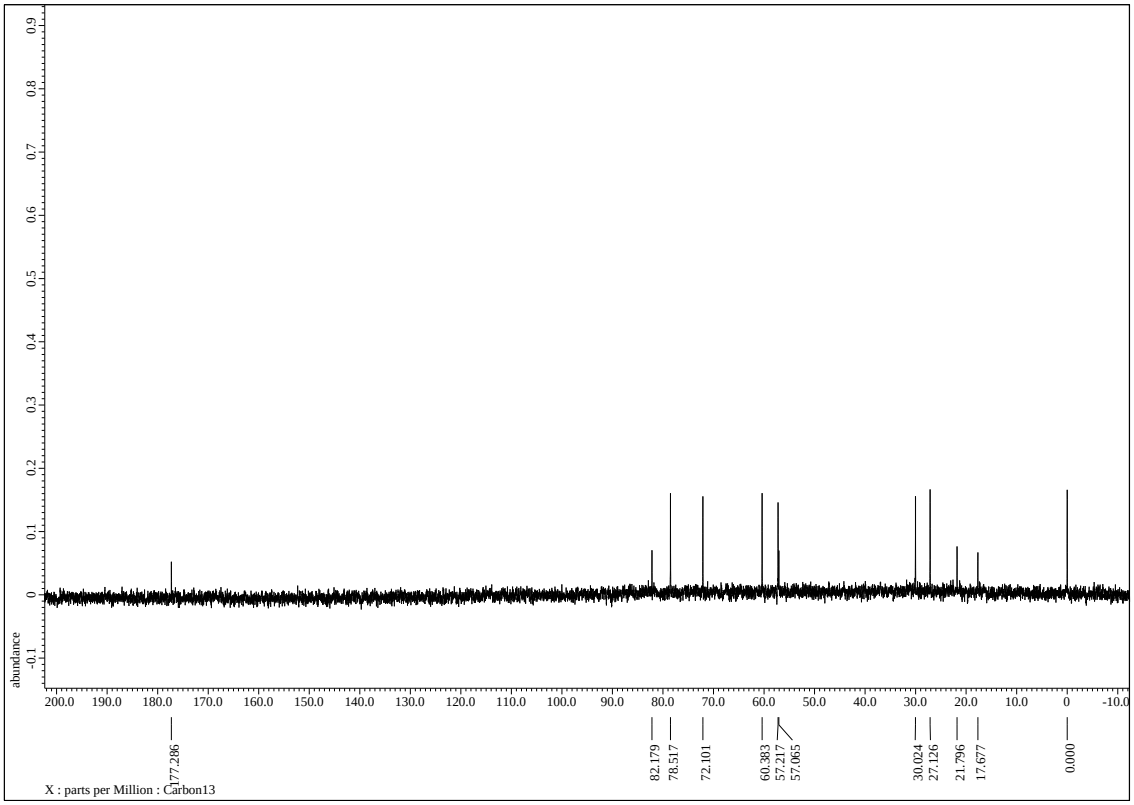

F
F
F
N3
NH2
OH
O
O
7
13e
12.82
1.91
1.97
1.00
0.89
abundance
4.889
4.475
3.391
3.375
3.359
3.183
3.177
2.904
2.897
2.884
2.864
1.804
1.769
1.734
1.617
1.477
1.463
1.386
1.231
0.629
0.608
0.594
0.587
0.000
X : parts per Million : Proton

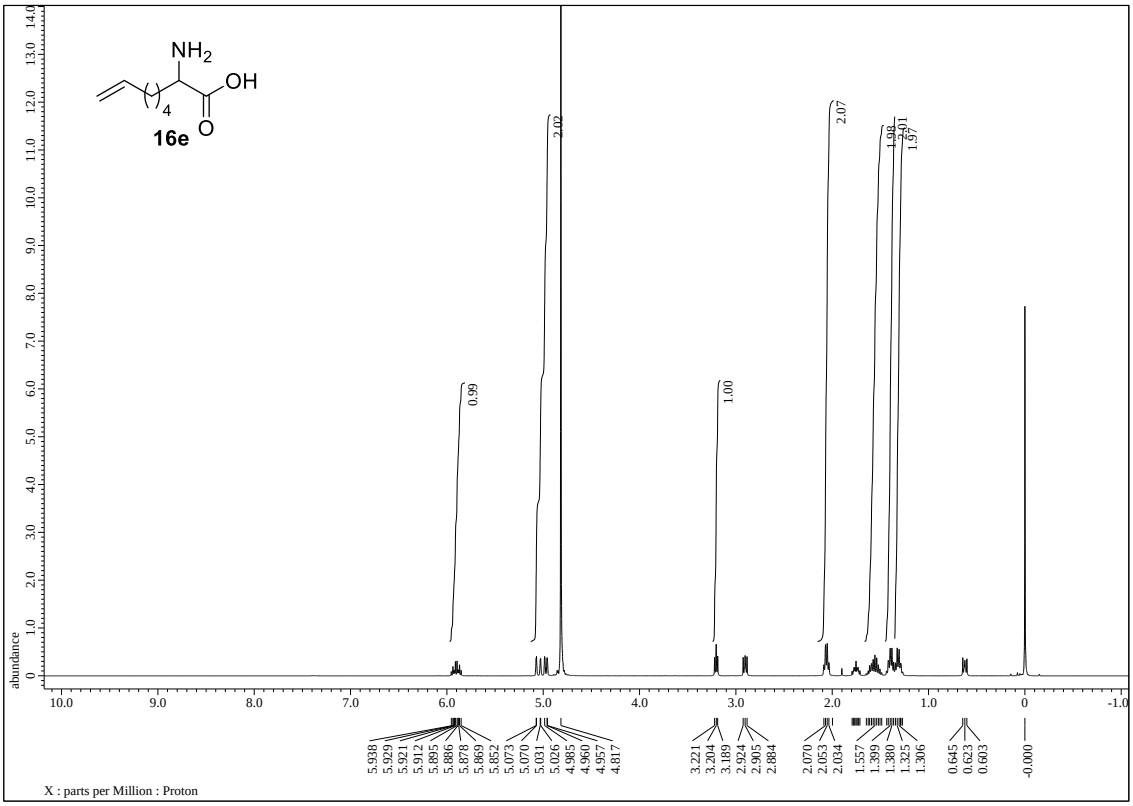

(thousandths)
185.257
149.035
146.566
143.858
143.696
141.389
141.217
122.453
122.329
122.215
114.501
114.320
114.139
73.149
61.355
58.895
56.998
38.424
32.132
32.027
31.827
28.432
21.663
17.820
-0.000
X : parts per Million : Carbon13

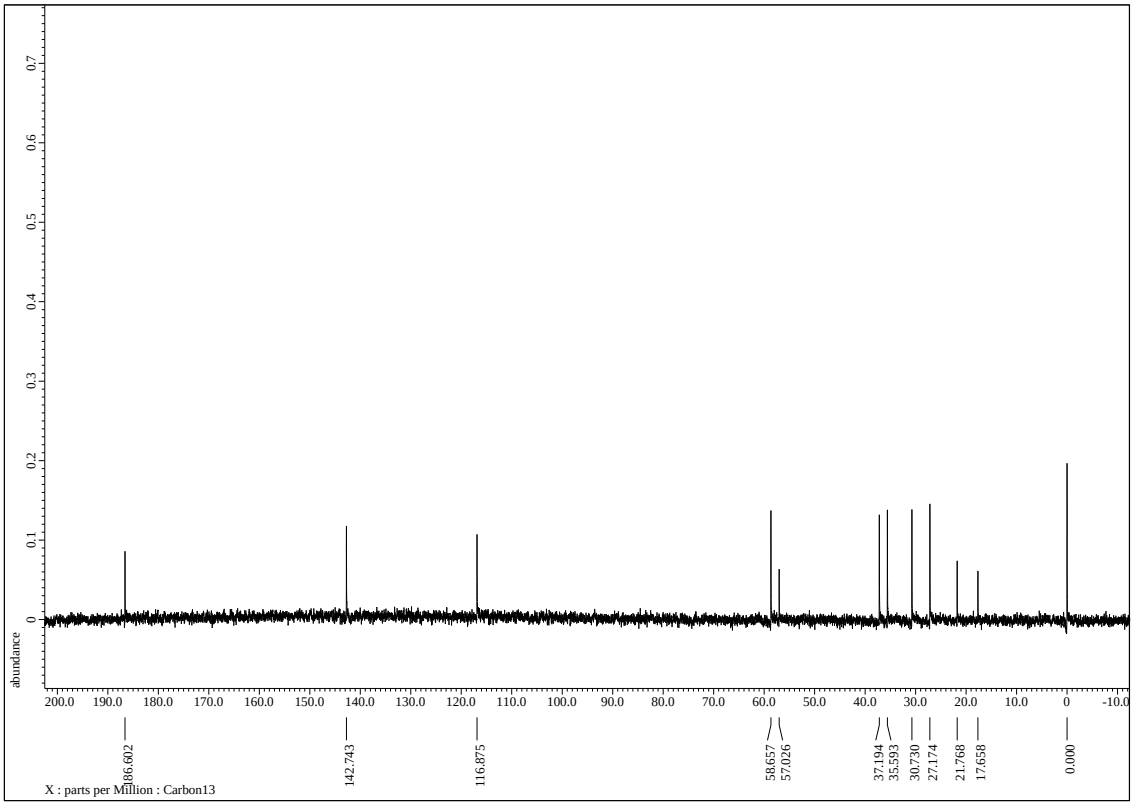

NH2
OH
N3
7
O
14e
abundance
X : parts per Million : Proton
11.16
4.25
1.91
1.00
4.808
3.322
3.305
3.288
3.217
3.202
3.199
3.184
2.923
2.904
2.883
1.754
1.609
1.591
1.574
1.562
1.557
1.351
1.305
0.645
0.623
0.616
0.603
0.000

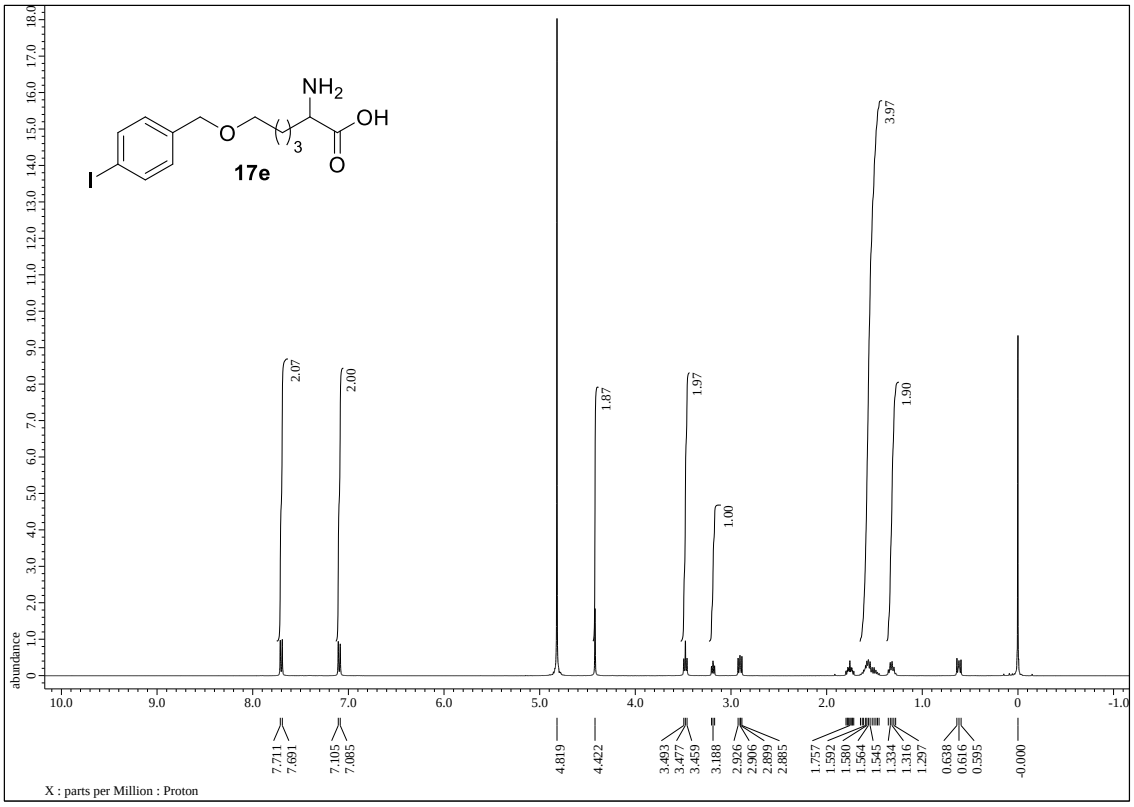

abundance
X : parts per Million : Carbon13
86.669
58.733
57.036
53.937
37.395
31.312
31.121
30.864
30.644
28.594
27.603
21.768
17.668
0.000

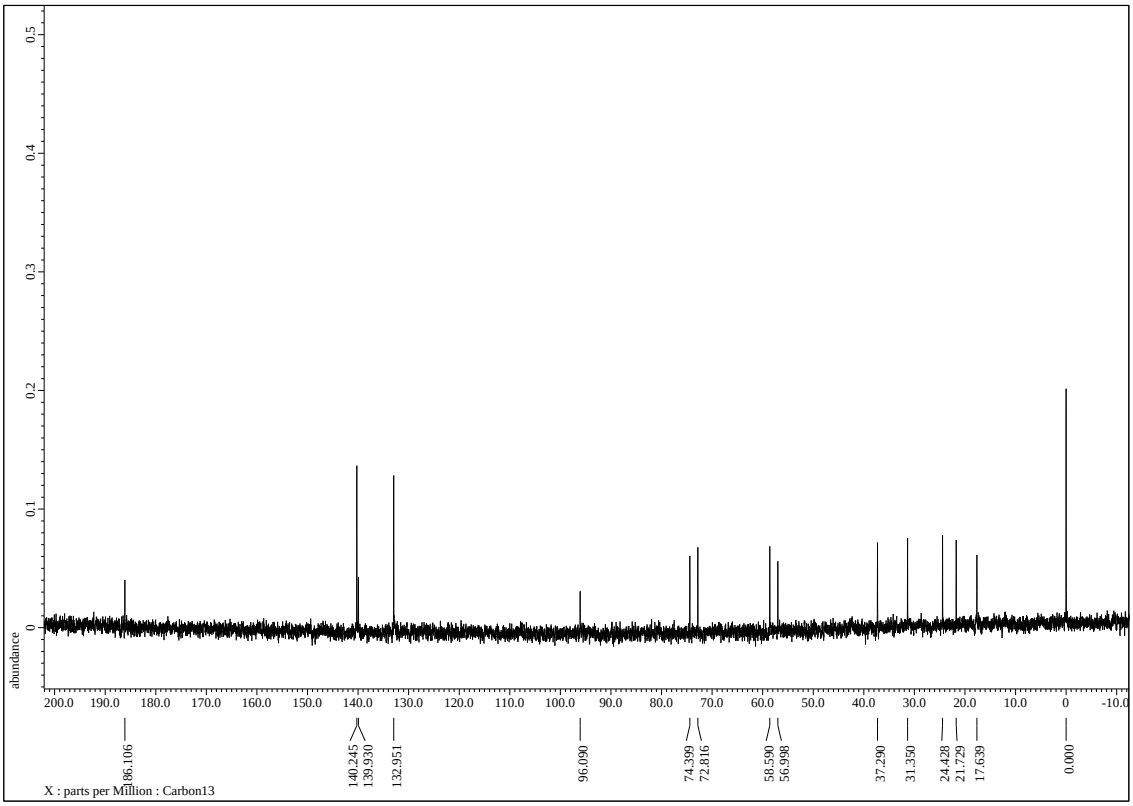

NH2
OH
O
O
15e
abundance
X : parts per Million : Proton
4.798
4.210
4.204
4.192
3.749
3.656
3.640
3.625
2.926
2.906
2.883
2.876
2.871
1.944
1.929
1.918
1.905
1.756
1.716
1.700
1.683
0.647
0.627
0.605
-0.000
2.26
2.23
1.78
2.28
3.07
1.00

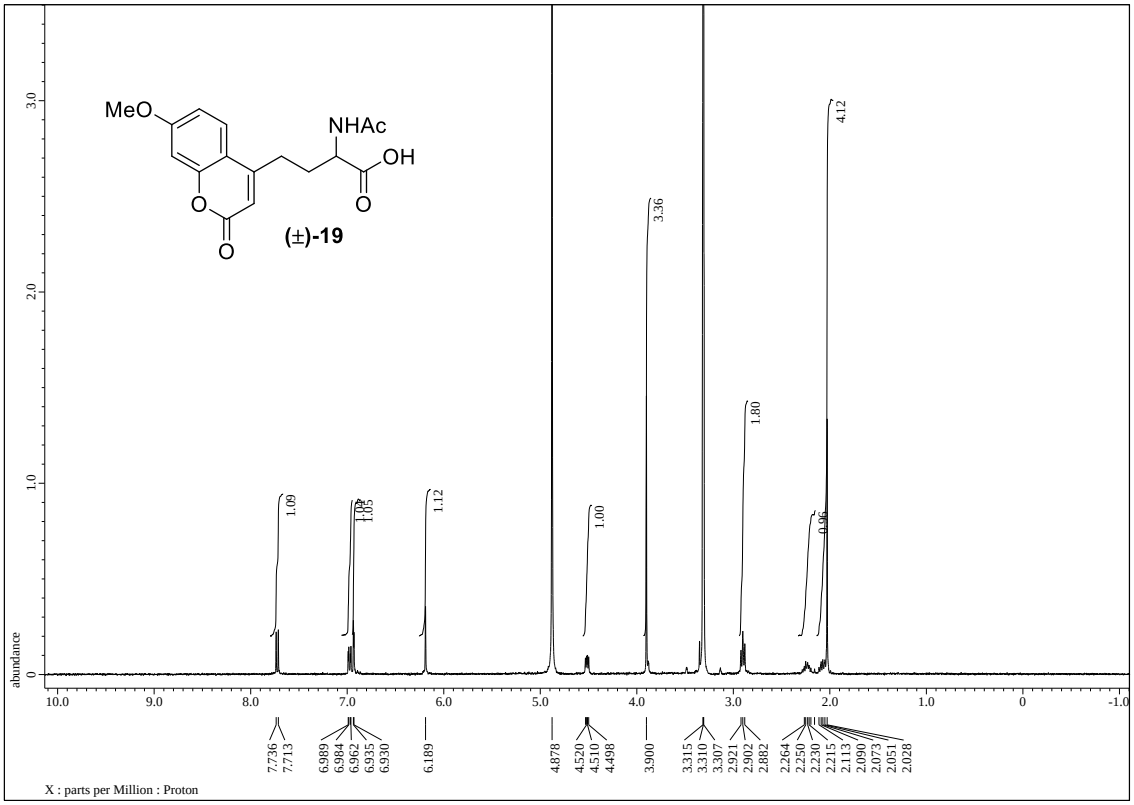

abundance
X : parts per Million : Carbon13
177.286
82.179
78.517
72.101
60.383
57.217
57.065
30.024
27.126
21.796
17.677
0.000

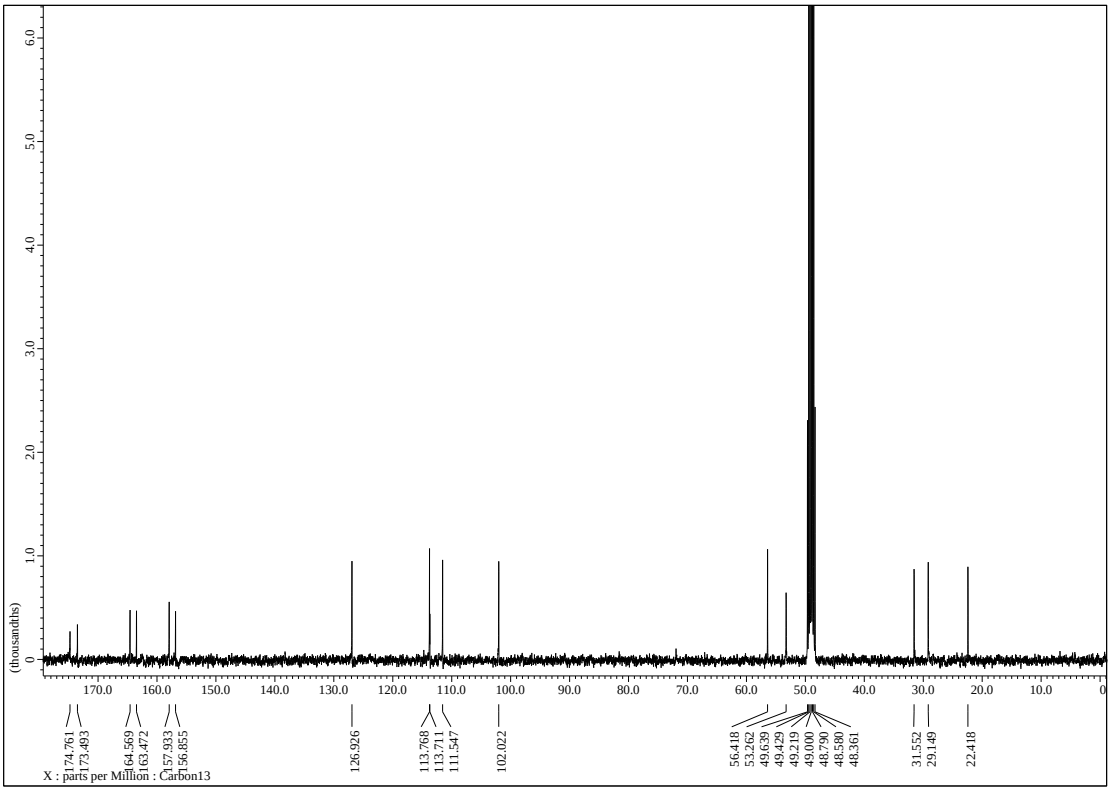

NH2
OH
O
4
16e
abundance
X : parts per Million : Proton

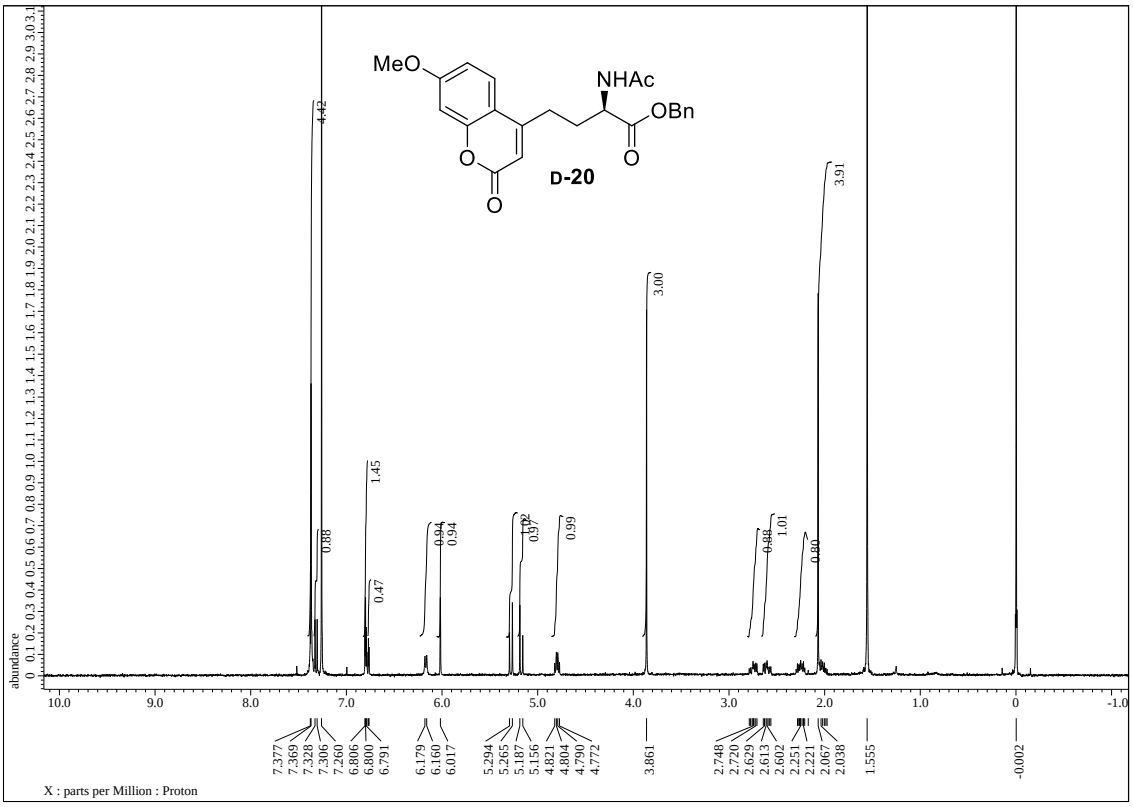

abundance
X : parts per Million : Carbon13

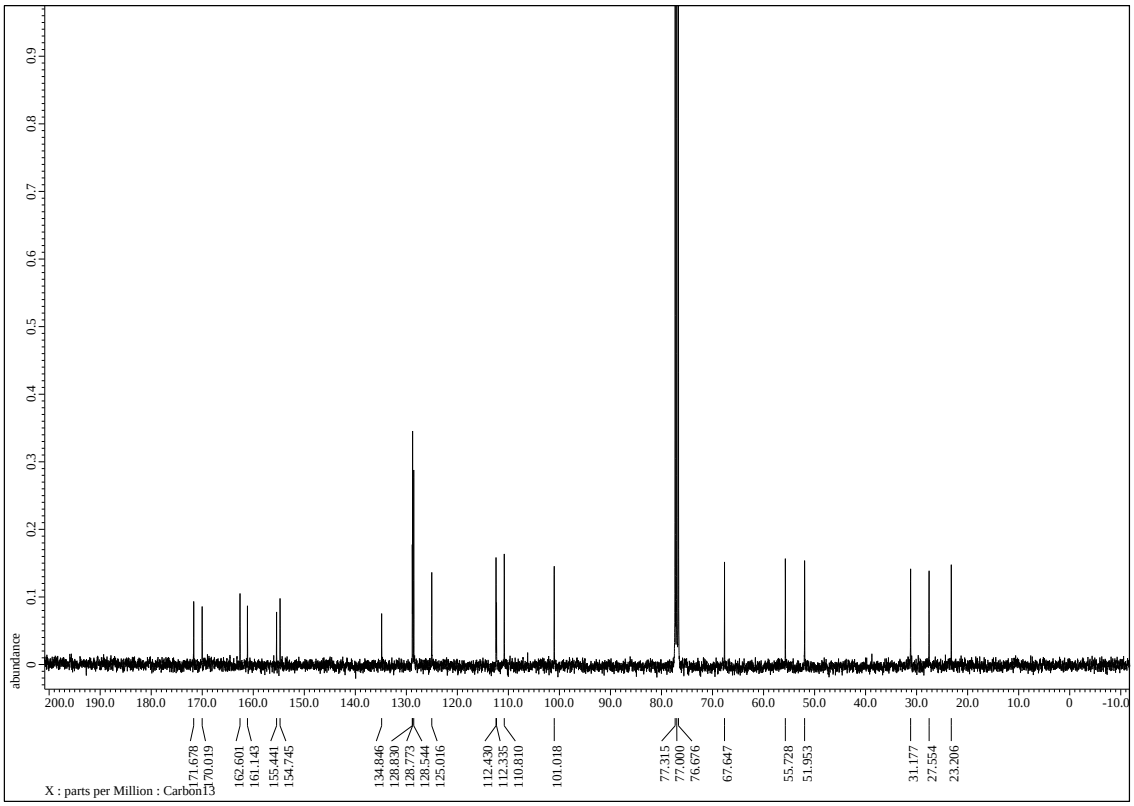

NH2
OH
O
3
O
I
17e
abundance
X : parts per Million : Proton


abundance
X : parts per Million : Carbon13


MeO
NHAc
OH
O
O
O
(±)-19
abundance
X : parts per Million : Proton


(thousandths)
X : parts per Million : Carbon13


MeO
NHAc
OBn
O
O
O
O
D-20
4.42
3.91
3.00
1.45
0.88
0.47
0.94
0.94
0.97
1.02
0.99
1.01
0.88
0.80
abundance
X : parts per Million : Proton


abundance
X : parts per Million : Carbon13