Supporting Information

Racemic Hemiacetals as Oxygen-Centered Pronucleophiles Triggering Cascade 1,4-Addition/Michael Reaction through Dynamic Kinetic Resolution under Iminium catalysis. Reaction Development and Mechanistic Insights

Ane Orue,[†] Uxue Uria,[†] David Roca-López,[‡] Ignacio Delso,[§] Efraim Reyes,[†] Luisa Carrillo,[†] Pedro Merino*,[‡] and Jose L. Vicario*,[†]

[†] Department of Organic Chemistry II, University of the Basque Country (UPV/EHU). P.O. Box 644, 48080 Bilbao (Spain).
[‡] Departamento de Síntesis y Estructura de Biomoléculas, Instituto de Síntesis Quimica y Catálisis Homogénea (ISQCH), Universidad de Zaragoza, CSIC, 50009 Zaragoza, Aragón (Spain).
[§] Servicio de Resonancia Magnética Nuclear, Centro de Quimica y Materiales de Aragón (CEQMA), Universidad de Zaragoza, CSIC. Campus San Francisco, 50009 Zaragoza (Spain).

E-mail: pmerino@unizar.es, joseluis.vicario@ehu.es

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1. General Methods and Materials

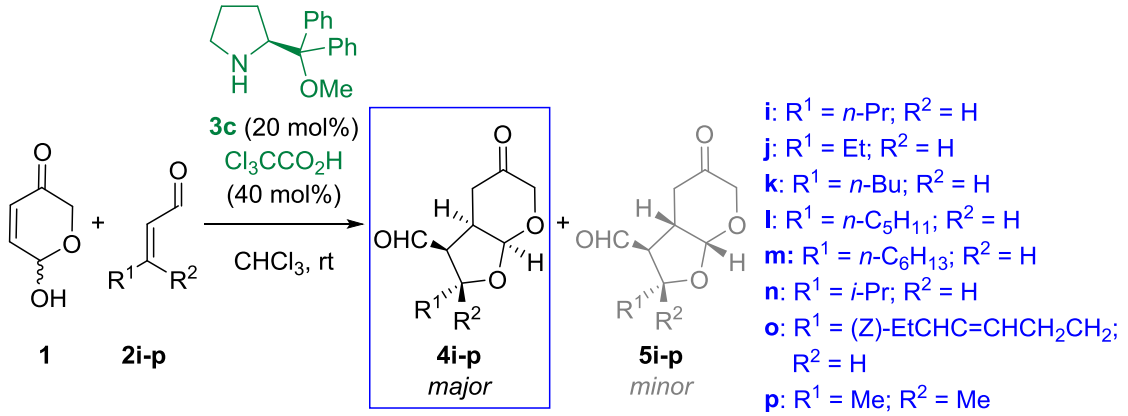
Monodimensional and/or bidimensional nuclear magnetic resonance (NMR) proton and carbon spectra (^{1}H-NMR and ^{13}C-NMR) were acquired at 25ºC on a Bruker AC-300 spectrometer (300 MHz for ^{1}H, 75.5 MHz for ^{13}C and 283 MHz for ^{19}F) and a Bruker AC-500 spectrometer (500 MHz for ^{1}H and and 125.7 MHz ^{13}C). Chemical shifts (δ) are reported in ppm relative to residual solvent signals ($CHCl_3$, 7.26 ppm for ^{1}H NMR, $CDCl_3$, 77.0 ppm for ^{13}C NMR) and coupling constants (*J*) in hertz (Hz). The following abbreviations are used to indicate the multiplicity in ^{1}H NMR spectra: s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet; bs, broad signal. ^{13}C NMR spectra were acquired on a broad band decoupled mode using DEPT experiments (Distortionless Enhancement by Polarization Transfer) for assigning different types of carbon environment. Infrared spectra (IR) were measured in a Jasco FT/IR 4100, a Perkin-Elmer 1600 and a Perkin-Elmer Spectrum BX apparatus, in the interval between 4000 and 400 cm^{-1} with a 4 cm^{-1} resolution. Only characteristic bands are given in each case. Mass spectra (MS) were recorded on an Agilent 7890A gas chromatograph coupled to an Agilent 5975 mass spectrometer under electronic impact (EI) conditions at 70 eV. The obtained data is presented in mass units (m/z) and the values found in brackets belong to the relative intensities comparing to the base peak (100%). High-resolution mass spectra (HRMS) were recorded on a Micromass GCT spectrometer using chemical ionization techniques (CI+) or on an Acquity UPLC coupled to a QTOF mass spectrometer (SYNAPT G2 HDMS) using electrospray ionization (ESI). Melting points (M.p.) were measured in a Büchi B-540 apparatus in open capillary tubes and are uncorrected. High performance liquid chromatography (HPLC) on a chiral stationary phase was performed in a Waters 2695 chromatograph coupled to a Waters 2998 photodiode array detector. Daicel Chiralpak IA, ASH and Chiralcel OZ-3 columns (0.46 cm x 25 cm) were used; specific conditions are indicated for each case. Optical rotations (α value) were measured at 20ºC on a Jasco P-2000 polarimeter with a sodium lamp at 589 nm and a path length of 1 dm. Solvent and concentration are specified in each case. X-ray data collections were performed in an *Agilent Supernova* diffractometer equipped with an *Atlas* CCD area detector, and a CuKα micro-focus source with multilayer optics (λ = 1.54184Å, 250 μm FWHM beam size). The quality of the crystals was checked under a polarizing microscope, and a suitable crystal or fragment was mounted on a MitegenMicromount™ using Paratone-N inert oil and transferred to the diffractometer. Analytical grade solvents and commercially available reagents were used without further purification. Reactions were monitored using analytical thin layer chromatography (TLC), in pre-coated aluminium-backed plates (Merck Kieselgel 60 F254). These were visualized by ultraviolet irradiation, potassium permanganate or *p*-anisaldehyde dips.[1] For flash chromatography Silicycle 40-63, 230-400 mesh silicagel was used.[2] Anhydrous solvents were dried with activated molecular sieves prior to use. For the removal of solvents under reduced pressure Büchi R-210 rotary evaporators were used. For reactions carried out under inert conditions, the argon was previously dried through a column of P_2O_5 and a column of KOH and $CaCl_2$. All the glassware was dried for 12 hours prior to utilizing in an oven at 140ºC, and allowed to cool under a dehumidified atmosphere.

[1] E. Stahl, *Thin Layer Chromatography*, Springer-Verlag, Berlin, 1969.

[2] W. C. Still, H. Kann, A. J. Mitra, *J. Org. Chem*., 1978, **43**, 2923.

2. Experimental Procedures and Characterizations

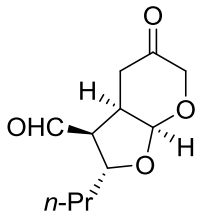
2.1. Preparation of 2-substituted (2*R*,3*S*,3a*R*,7a*S*)-configured 5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-carbaldehyde (4i-o) (R^1 = Alkyl; R^2 = H) and 2,2-disubstituted (3*S*,3a*R*,7a*S*)-configured 5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-carbaldehyde (4p) (R^1 = R^2 = Alkyl)



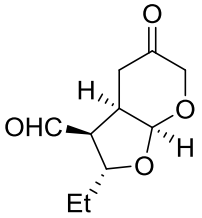
Scheme ESI-1. General overview for the synthesis of **4i-p**.

General procedure

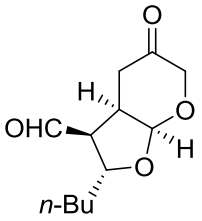
An ordinary vial equipped with a magnetic stirring bar was charged with catalyst **(*S*)-3c (**0.04 mmol, 20 mol%), trichloroacetic acid (0.07 mmol, 40 mol%) and the corresponding *α,β*-unsaturated aldehyde **2i-p** (0.18 mmol) in chloroform (1.0 mL). After stirring the mixture for 15 minutes at 0ºC, 6-hydroxy-2*H*-pyran-3(6*H*)-one **1** (0.36 mmol, 2eq.) was added and the reaction mixture was further stirred at room temperature until completion (tipically 18 h). The crude mixture was quenched with saturated $NaHCO_3$ aqueous solution (1.0 mL), extracted with CH_2Cl_2 (3 × 2.0 mL) and the combined organic fractions were collected, dried over Na_2SO_4, filtered and the solvent removed under reduced pressure. Pure aldehydes **4i-p** were isolated after flash column chromatography purification



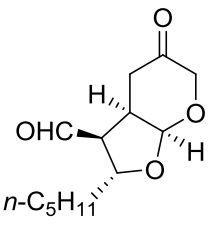
(2*R*,3*S*,3a*R*,7a*S*)-5-Oxo-2-propylhexahydro-4*H*-furo[2,3-*b*]pyran-3-carbaldehyde (4i). Following the general procedure **4i** (29 mg, 0.14 mmol) was isolated by FC (hexanes/EtOAc 7:3) after 18 h in 76% yield as a yellow oil starting from *(E)*-hex-2-enal (18 mg, 0.18 mmol), trichloroacetic acid (12 mg, 0.07 mmol) and pyranone **1** (41 mg, 0.36 mmol) in the presence of catalyst **(*S*)-3c** (19 mg, 0.04 mmol) and using chloroform (1.0 mL) as solvent. Measured d.r. (**4i**:**5i**) before purification: 8:1. ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.76 (d, *J* = 2.3 Hz, 1H, CHO), 5.44 (d, *J* = 5.3 Hz, 1H, OCHO), 4.58 (dt, *J* = 8.1, 6.0 Hz, 1H, *n*-PrC**H**), 4.19 (d, *J* = 18.1 Hz, 1H, C**H**$_a$H$_b$O), 3.91 (d, *J* = 18.1 Hz, 1H, CH$_a$**H**$_b$O), 3.24-3.12 (m, 1H, C**H**CH$_2$CO), 2.88 (ddd, *J* = 9.8, 8.1, 2.3 Hz, 1H, C**H**CHO), 2.71 (dd, *J* = 15.6, 7.5 Hz, 1H, CHC**H**$_a$H$_b$CO), 2.53 (dd, *J* = 15.6, 7.5 Hz, 1H, CHCH$_a$**H**$_b$CO), 1.61-1.33 (m, 4H, CH$_2$CH$_2$), 0.94 (t, *J* = 7.2 Hz, 3H, CH$_3$).^{13}C NMR (75 MHz, $CDCl_3$) δ 208.1 (CO), 199.9 (CHO), 101.0 (OCHO), 78.8 (*n*-Pr**C**H), 69.1 (CH$_2$O), 58.5 (**C**HCHO), 40.1 (**C**HCH$_2$CO), 36.6 (CH**C**H$_2$CO), 36.1 (CH$_3$CH$_2$**C**H$_2$), 19.1 (CH$_3$**C**H$_2$), 13.9 (CH$_3$). IR (ATR): 1731, 1720 (C=O) cm^{-1}. MS (70 eV) *m*/*z* (%): 212 (M$^+$, 3), 169 (17), 111 (100), 81 (26), 55 (31). HRMS: Calculated for [C$_{11}$H$_{17}$O$_4$]$^+$: 213.1127 [(M+H)$^+$]; found: 213.1132. [α]$_D^{rt}$: +14.5, (*c* 0.3, CH_2Cl_2). The enantiomeric excess (e.e.) was measured after transformation into **7i**.



(2*R*,3*S*,3a*R*,7a*S*)-2-Ethyl-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-carbaldehyde (4j). Following the general procedure **4j** (26 mg, 0.13 mmol) was isolated by FC (hexanes/EtOAc 7:3) after 18 h in 72% yield as a yellow oil starting from *(E)*-pent-2-enal (16 mg, 0.18 mmol), trichloroacetic acid (12 mg, 0.07 mmol) and pyranone **1** (41 mg, 0.36 mmol) in the presence of catalyst **(*S*)-3c** (19 mg, 0.04 mmol) and using chloroform (1.0 mL) as solvent. Measured d.r. (**4j**:**5j**) before purification: 9:1. ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.78 (d, *J* = 2.2 Hz, 1H, CHO), 5.46 (d, *J* = 5.3 Hz, 1H, OCHO), 4.54 (dt, *J* = 12.9, 6.4 Hz, 1H, EtC**H**), 4.22 (d, *J* = 18.2 Hz, 1H, C**H**$_a$H$_b$O), 3.94 (d, *J* = 18.2 Hz, 1H, CH$_a$**H**$_b$O), 3.22-3.14 (m, 1H, C**H**CH$_2$CO), 2.98-2.86 (m, 1H, C**H**CHO), 2.73 (dd, *J* = 15.6, 7.3 Hz, 1H, CHC**H**$_a$H$_b$CO), 2.56 (dd, *J* = 15.6, 7.5 Hz, 1H, CHCH$_a$**H**$_b$CO), 1.78-1.56 (m, 2H, CH$_3$C**H**$_2$), 1.01 (t, *J* = 7.4 Hz, 3H, CH$_3$).^{13}C NMR (75 MHz, $CDCl_3$) δ 208.0 (CO), 199.8 (CHO), 101.0 (OCHO), 80.2 (Et**C**H), 69.2 (CH$_2$O), 58.0 (**C**HCHO), 40.2 (**C**HCH$_2$CO), 36.1 (CH**C**H$_2$CO), 27.4 (CH$_3$**C**H$_2$), 10.0 (CH$_3$). IR (ATR): 1732, 1726 (C=O), 1072, 1017 (OCHO) cm^{-1}. MS (70 eV) *m*/*z* (%): 198 (M$^+$, 3), 169 (22), 111 (25), 97 (100), 55 (30). HRMS: Calculated for $[C_{10}H_{15}O_4]^+$: 199.0970 [(M+H)$^+$]; found: 199.0978. $[\alpha]_D^{rt}$: +9.4 (*c* 0.4, CH_2Cl_2). The enantiomeric excess (e.e.) was measured after transformation into **7j**.

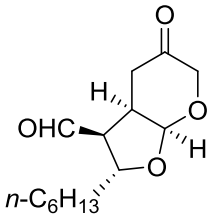


(2*R*,3*S*,3a*R*,7a*S*)-2-Butyl-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-carbaldehyde (4k). Following the general procedure **4k** (30 mg, 0.13 mmol) was isolated by FC (hexanes/EtOAc 7:3) after 18 h in 69% yield as a yellow oil starting from (*E*)-hept-2-enal (22 mg, 0.18 mmol), trichloroacetic acid (12 mg, 0.07 mmol) and pyranone **1f** (41 mg, 0.36 mmol) in the presence of catalyst **(*S*)-3c** (19 mg, 0.04 mmol) and using chloroform (1.0 mL) as solvent. Measured d.r. (**4k**:**5k**) before purification: 9:1. ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.77 (d, *J* = 2.1 Hz, 1H, CHO), 5.45 (d, *J* = 5.3 Hz, 1H, OCHO), 4.58 (dt, *J* = 13.7, 6.3 Hz, 1H, *n*-BuC**H**), 4.21 (d, *J* = 18.2 Hz, 1H, C**H**$_a$H$_b$O), 3.93 (d, *J* = 18.2 Hz, 1H, CH$_a$**H**$_b$O), 3.24-3.12 (m, 1H, C**H**CH$_2$CO), 2.93-2.96 (m, 1H, C**H**CHO), 2.72 (dd, *J* = 15.6, 7.4 Hz, 1H, CHC**H**$_a$H$_b$CO), 2.55 (dd, *J* = 15.6, 7.6 Hz, 1H, CHCH$_a$**H**$_b$CO), 1.74-1.23 (m, 6H, (CH$_2$)$_3$), 0.90 (t, *J* = 6.9 Hz, 3H, CH$_3$).^{13}C NMR (75 MHz, $CDCl_3$) δ 208.1 (CO), 199.8 (CHO), 101.0 (OCHO), 79.0 (*n*-Bu**C**H), 69.2 (CH$_2$O), 58.5 (**C**HCHO), 40.2 (**C**HCH$_2$CO), 36.1 (CH**C**H$_2$CO), 34.2 (*n*-PrCH$_2$), 27.9 (Et**C**H$_2$), 22.5 (CH$_3$**C**H$_2$), 13.9 (CH$_3$). IR (ATR): 1735, 1720 (C=O), 1071, 1009 (OCHO) cm^{-1}. MS (70 eV) *m*/*z* (%): 226 (M$^+$, 4), 169 (20), 125 (100), 81 (25), 55 (28). HRMS: Calculated for $[C_{12}H_{19}O_4]^+$: 227.1283 [(M+H)$^+$]; found: 227.1273. $[\alpha]_D^{rt}$: +14.1 (*c* 0.3, CH_2Cl_2). The enantiomeric excess (e.e.) was measured after transformation into **7k**.

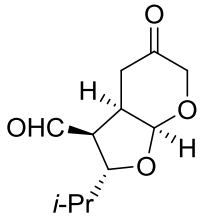


(2*R*,3*S*,3a*R*,7a*S*)-5-Oxo-2-pentylhexahydro-4*H*-furo[2,3-*b*]pyran-3-carbaldehyde (4l). Following the general procedure **4l** (31 mg, 0.13 mmol) was isolated by FC (hexanes/EtOAc 7:3) after 18 h in 73% yield as a white solid starting from (*E*)-oct-2-enal (24 mg, 0.18 mmol), trichloroacetic acid (12 mg, 0.07 mmol) and pyranone **1** (41 mg, 0.36 mmol) in the presence of catalyst **(*S*)-3c** (19 mg, 0.04 mmol) and using chloroform (1.0 mL) as solvent. Measured d.r. (**4l**:**5l**) before purification: 9:1. ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.77 (d, *J* = 2.3 Hz, 1H, CHO), 5.45 (d, *J* = 5.4 Hz, 1H, OCHO), 4.58 (dt, *J* = 8.1, 6.2 Hz, 1H, *n*-C$_5$H$_{11}$C**H**), 4.21 (d, *J* = 18.1 Hz, 1H, C**H**$_a$H$_b$O), 3.92 (d, *J* = 18.1 Hz, 1H, CH$_a$**H**$_b$O), 3.22-3.12 (m, 1H, C**H**CH$_2$CO), 2.88 (ddd, *J* = 9.8, 8.1, 2.3 Hz, 1H, C**H**CHO), 2.72 (dd, *J* = 15.6, 7.5 Hz, 1H, CHC**H**$_a$H$_b$CO), 2.54 (dd, *J* = 15.6, 7.5 Hz, 1H, CHCH$_a$**H**$_b$CO), 1.75-1.16 (m, 8H, (CH$_2$)$_4$), 0.88 (t, *J* = 6.6 Hz, 3H, CH$_3$).^{13}C NMR (75 MHz, $CDCl_3$) δ 208.1 (CO), 199.8 (CHO), 101.0

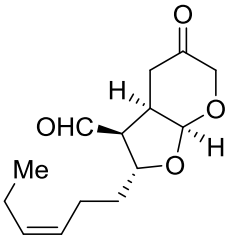
(OCHO), 79.0 (*n*-C_5H_{11}**C**H), 69.1 (CH_2O), 58.5 (**C**HCHO), 40.2 (**C**HCH_2CO), 36.1 (CH**C**H_2CO), 34.5 (*n*-Bu**C**H_2), 31.6 (*n*-Pr**C**H_2), 25.5 (Et**C**H_2), 22.5 (CH_3**C**H_2), 13.9 (CH_3). IR (ATR): 1733 (C=O), 1073 (OCHO) cm^{-1}. MS (70 eV) *m*/*z* (%): 240 (M^+, 3), 169 (20), 139 (100), 111 (18), 81 (30), 55 (36). HRMS: Calculated for $[C_{13}H_{21}O_4]^+$: 241.1440 [$(M+H)^+$]; found: 241.1452. M.p. (hexanes/EtOAc): 118-120ºC. $[\alpha]_D^{rt}$: +8.6 (*c* 0.6, CH_2Cl_2). The enantiomeric excess (e.e.) was measured after transformation into **7l**.



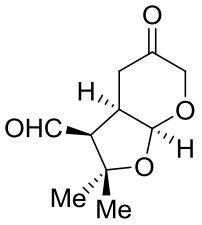
(2*R*,3*S*,3a*R*,7a*S*)-2-Hexyl-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-carbaldehyde (4m). Following the general procedure **4m** (28 mg, 0.11 mmol) was isolated by FC (hexanes/EtOAc 7:3) after 18 h in 61% yield as a white solid starting from *trans*-non-2-enal (26 mg, 0.18 mmol), trichloroacetic acid (12 mg, 0.07 mmol) and pyranone **1** (41 mg, 0.36 mmol) in the presence of catalyst **(*S*)-3c** (19 mg, 0.04 mmol) and using chloroform (1.0 mL) as solvent. Measured d.r. (**4m**:**5m**) before purification: 9:1. ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.77 (d, *J* = 2.1 Hz, 1H, CHO), 5.45 (d, *J* = 5.4 Hz, 1H, OCHO), 4.58 (dt, *J* = 13.9, 6.2 Hz, 1H, *n*-C_6H_{13}C**H**), 4.21 (d, *J* = 18.1 Hz, 1H, C**H**$_a$H$_b$O), 3.93 (d, *J* = 18.1 Hz, 1H, CH$_a$**H**$_b$O), 3.28-3.11 (m, 1H, C**H**CH_2CO), 3.02-2.81 (m, 1H, C**H**CHO), 2.72 (dd, *J* = 15.5, 7.4 Hz, 1H, CHC**H**$_a$H$_b$CO), 2.55 (dd, *J* = 15.5, 7.5 Hz, 1H, CHCH$_a$**H**$_b$CO), 1.69-1.20 (m, 10H, $(CH_2)_5$), 0.88 (t, *J* = 5.6 Hz, 3H, CH_3).^{13}C NMR (75 MHz, $CDCl_3$) δ 208.1 (CO), 199.8 (CHO), 101.0 (OCHO), 79.0 (*n*-C_6H_{13}**C**H), 69.1 (CH_2O), 58.5 (**C**HCHO), 40.2 (**C**HCH_2CO), 36.1 (CH**C**H_2CO), 34.5 (*n*-C_5H_{11}**C**H_2), 31.6 (*n*-Bu**C**H_2), 29.1 (*n*-Pr**C**H_2), 25.7 (Et**C**H_2), 22.5 (CH_3**C**H_2), 14.0 (CH_3). IR (ATR): 1732, 1719 (C=O), 1072, 1010 (OCHO) cm^{-1}. MS (70 eV) *m*/*z* (%): 254 (M^+, 3), 169 (23), 153 (100), 81 (38), 55 (39). HRMS: Calculated for $[C_{14}H_{23}O_4]^+$: 255.1596 [$(M+H)^+$]; found: 255.1587. $[\alpha]_D^{rt}$: +10.3 (*c* 0.3, CH_2Cl_2). The enantiomeric excess (e.e.) was measured after transformation into **7m.**



(2*S*,3*S*,3a*R*,7a*S*)-2-Isopropyl-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-carbaldehyde (4n). Following the general procedure **4n** (22 mg, 0.10 mmol) was isolated by FC (hexanes/EtOAc 7:3) after 48 h in 59% yield as a yellow oil starting from (*E*)-4-methylpent-2-enal (19 mg, 0.18 mmol), trichloroacetic acid (12 mg, 0.07 mmol) and pyranone **1** (41 mg, 0.36 mmol) in the presence of catalyst **(*S*)-3c** (19 mg, 0.04 mmol) and using chloroform (1.0 mL) as solvent. Measured d.r. (**4n**:**5n**) before purification: 9:1. ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.76 (d, *J* = 2.7 Hz, 1H, CHO), 5.45 (d, *J* = 5.0 Hz, 1H, OCHO), 4.40 (dd, *J* = 13.3, 7.2 Hz, 1H, *i*-PrC**H**), 4.21 (d, *J* = 17.9 Hz, 1H, C**H**$_a$H$_b$O), 3.95 (d, *J* = 17.9 Hz, 1H, CH$_a$**H**$_b$O), 3.20-3.09 (m, 1H, C**H**CH_2CO), 2.96 (ddd, *J* = 9.9, 7.2, 2.7 Hz, 1H, C**H**CHO), 2.74 (dd, *J* = 16.1, 6.1 Hz, 1H, CHC**H**$_a$H$_b$CO), 2.56 (dd, *J* = 16.1, 7.8 Hz, 1H, CHCH$_a$**H**$_b$CO), 1.88-1.74 (m, 1H, $(CH_3)_2$C**H**), 0.99 (t, *J* = 6.7 Hz, 3H, CH_3), 0.91 (t, *J* = 6.8 Hz, 3H, CH_3).^{13}C NMR (75 MHz, $CDCl_3$) δ 207.5 (CO), 200.4 (CHO), 101.0 (OCHO), 84.4 (*i*-Pr**C**H), 69.3 (CH_2O), 55.5 (**C**HCHO), 41.0 (**C**HCH_2CO), 36.0 (CH**C**H_2CO), 32.1 (($CH_3)_2$**C**H), 18.6 (CH_3), 18.1 (CH_3). IR (ATR): 1727 (C=O), 1074 (OCHO) cm^{-1}. MS (70 eV) *m*/*z* (%): 182 (7), 140 (46), 111 (100), 98 (49), 83 (44), 55 (37). HRMS: Calculated for $[C_{11}H_{17}O_4]^+$: 213.1127 [$(M+H)^+$]; found: 213.1139. $[\alpha]_D^{rt}$: +13.7 (*c* 0.1, CH_2Cl_2). The enantiomeric excess (e.e.) was measured after transformation into **7n**.

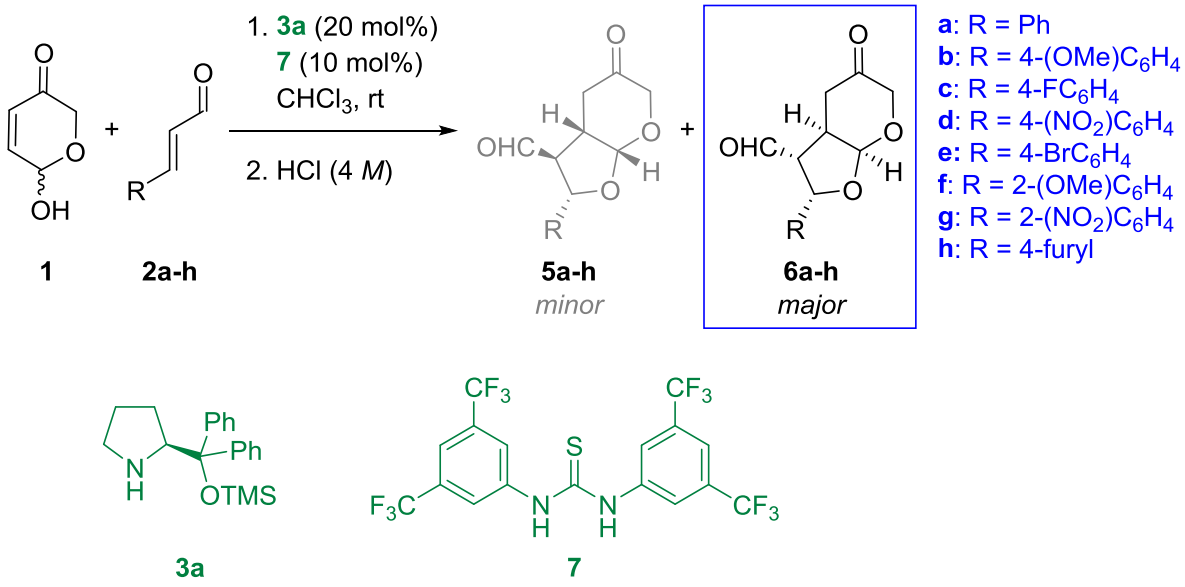


(2*R*,3S,3a*R*,7a*S*)-2-[(*Z*)-Hex-3-en-1-yl]-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-carbaldehyde (4o). Following the general procedure **4o** (27 mg, 0.11 mmol) was isolated by FC (hexanes/EtOAc 7:3) after 18 h in 60% yield as a yellow oil starting from (2*E*,6*Z*)-nona-2,6-dienal (25 mg, 0.18 mmol), trichloroacetic acid (12 mg, 0.07 mmol) and pyranone **1** (41 mg, 0.36 mmol) in the presence of catalyst **(*S*)-3c** (19 mg, 0.04 mmol) and using chloroform (1.0 mL) as solvent. Measured d.r. (**4o**:**5o**) before purification: 9:1. ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.76 (d, *J* = 2.1 Hz, 1H, CHO), 5.46 (d, *J* = 5.3 Hz, 1H, OCHO), 5.45-5.20 (m, 2H, CH=CH), 4.58 (dt, *J* = 13.2, 7.0 Hz, 1H, $CH_2CH_2C\mathbf{H}$), 4.20 (d, *J* = 18.2 Hz, 1H, $C\mathbf{H}_aH_bO$), 3.93 (d, *J* = 18.2 Hz, 1H, $CH_a\mathbf{H}_bO$), 3.37-3.08 (m, 1H, $C\mathbf{H}CH_2CO$), 3.06-2.79 (m, 1H, C**H**CHO), 2.72 (dd, *J* = 15.6, 7.3 Hz, 1H, $CHC\mathbf{H}_aH_bCO$), 2.56 (dd, *J* = 15.6, 7.4 Hz, 1H, $CHCH_a\mathbf{H}_bCO$), 2.34-1.90 (m, 4H, CH_2CH_2), 1.63 (dt, *J* = 8.0, 7.5 Hz, 2H, $CH_3C\mathbf{H}_2$), 0.96 (t, *J* = 7.5 Hz, 3H, CH_3).^{13}C NMR (75 MHz, $CDCl_3$) δ 208.0 (CO), 199.7 (CHO), 133.0 (EtCH=**C**H), 127.3 (Et**C**H), 101.0 (OCHO), 78.4 ($CH_2CH_2\mathbf{C}H$), 69.1 (CH_2O), 58.4 (**C**HCHO), 40.2 (**C**HCH_2CO), 36.1 ($CH\mathbf{C}H_2CO$), 34.5 ($CH_2\mathbf{C}H_2CH$), 23.5 ($\mathbf{C}H_2CH_2CH$), 20.5 ($CH_3\mathbf{C}H_2$), 14.2 (CH_3). IR (ATR): 1732, 1723 (C=O), 1069, 1012 (OCHO) cm^{-1}. MS (70 eV) *m*/*z* (%): 252 (M^+, 3), 140 (70), 111 (41), 95 (69), 81 (100), 55 (77). HRMS: Calculated for $[C_{14}H_{21}O_4]^+$: 253.1440 [$(M+H)^+$]; found: 253.1432. $[\alpha]_D^{rt}$: +9.6 (*c* 0.2, CH_2Cl_2). The enantiomeric excess (e.e.) was measured after transformation into **7o.**



(3*S*,3a*R*,7a*S*)-2,2-Dimethyl-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-carbaldehyde (4p). Following the general procedure **4p** (26 mg, 0.13 mmol) was isolated by FC (hexanes/EtOAc 7:3) after 18h in 73% yield as a yellow oil starting from 3-methylbut-2-enal (16 mg, 0.18 mmol), trichloroacetic acid (12 mg, 0.07 mmol) and pyranone **1** (41 mg, 0.36 mmol) in the presence of catalyst **(*S*)-3c** (19 mg, 0.04 mmol) and using chloroform (1.0 mL) as solvent. Measured d.r. (**4p**:**5p**) before purification: 9:1. ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.86 (d, *J* = 4.0 Hz, 1H, CHO), 5.39 (d, *J* = 5.5 Hz, 1H, OCHO), 4.25 (d, *J* = 18.0 Hz, 1H, $C\mathbf{H}_aH_bO$), 3.92 (d, *J* = 18.0 Hz, 1H, $CH_a\mathbf{H}_bO$), 3.34-3.05 (m, 1H, $C\mathbf{H}CH_2CO$), 2.82 (dd, *J* = 9.1, 4.0 Hz, 1H, C**H**CHO), 2.68 (d, *J* = 7.6 Hz, 2H, $CHC\mathbf{H}_2CO$), 1.51 (s, 3H, CH_3), 1.39 (s, 3H, CH_3). ^{13}C NMR (75 MHz, $CDCl_3$) δ 209.8 (CO), 197.5 (CHO), 99.0 (OCHO), 80.7 ($CH_3\mathbf{C}$), 67.0 (CH_2O), 64.7 (**C**HCHO), 38.2 ($CH\mathbf{C}H_2CO$), 36.4 (**C**HCH_2CO), 28.3 (CH_3), 24.3 (CH_3). IR (ATR): 1720 (C=O), 1009 (OCHO) cm^{-1}. HRMS: Calculated for $[C_{10}H_{15}O_4]^+$: 199.0970 [$(M+H)^+$]; found: 199.0972. $[\alpha]_D^{rt}$: +57.6 (*c* 1.4, CH_2Cl_2). The enantiomeric excess (e.e.) was measured after transformation into **7p**.

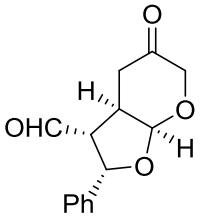
2.2. Preparation of 2-substituted (2*S*,3*R*,3a*R*,7a*S*)-configured 5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-carbaldehyde (6a-h) (R = Aromatic or Heteroaromatic)



Scheme ESI-2. General overview for the synthesis of **6a-h**.

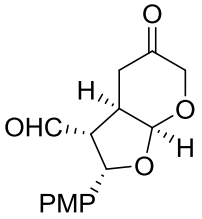
General procedure

An ordinary vial equipped with a magnetic stirring bar was charged with catalyst **(*S*)-3a (**0.10 mmol, 20 mol%), 1,3-bis[3,5-bis(trifluoromethyl)phenyl]thiourea **15** (0.05 mmol, 10 mol%), the corresponding *α,β*-unsaturated aldehyde (0.50 mmol) and $CHCl_3$ (2.0 mL). After stirring the solution for 15 minutes at 0ºC, 6-hydroxy-2*H*-pyran-3(6*H*)-one **1** (1.00 mmol, 2 eq.) was added and the reaction mixture was further stirred at room temperature until completion (tipically 18 h). Once the reaction was completed, aqueous HCl 4 *M* (2.0 mL) was added to the mixture and the crude mixture was stirred 4 h at room temperature, after which was extracted with CH_2Cl_2 (3 × 2.0 mL). The combined organic fractions were collected, dried over anhydrous Na_2SO_4, filtered and the solvent removed under reduced pressure. Pure aldehydes **6a-h** were isolated after flash column chromatography purification.

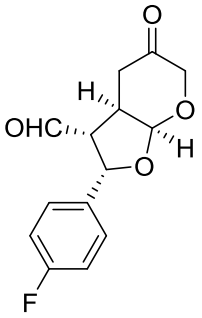


(2*S*,3*R*,3a*R*,7a*S*)-5-Oxo-2-phenylhexahydro-4*H*-furo[2,3-*b*]pyran-3-carbaldehyde (6a). Following the general procedure **6a** (36 mg, 0.15 mmol) was isolated by FC (hexanes/EtOAc 7:3) after 18 h in 74% yield as a yellow oil starting from (*E*)-cinnalmaldehyde (26 mg, 0.20 mmol), thiourea **7** (10 mg, 0.02 mmol) and pyranone **1** (46 mg, 0.40 mmol) in the presence of catalyst **(*S*)-3a** (13 mg, 0.04 mmol) and using chloroform (0.8 mL) as solvent. Measured d.r. (**5a**:**6a**) before purification: 1:4. ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.12 (d, *J* = 1.6 Hz, 1H, CHO), 7.53-7.26 (m, 5H, C_{arom}-H), 5.84 (d, *J* = 6.3 Hz, 1H, OCHO), 5.72 (d, *J* = 7.6 Hz, 1H, PhC**H**), 4.27 (d, *J* = 18.4 Hz, 1H, C**H**$_a$H$_b$O), 4.06 (d, *J* = 18.4 Hz, 1H, CH$_a$**H**$_b$O), 3.52-3.44 (m, 1H, C**H**CH$_2$CO), 3.17 (ddd, *J* = 7.6, 5.2, 1.6 Hz, 1H, C**H**CHO), 2.80 (dd, *J* = 15.6, 6.9 Hz, 1H, CHC**H**$_a$H$_b$CO), 2.58 (dd, *J* = 15.6, 5.9 Hz, 1H, CHCH$_a$**H**$_b$CO).^{13}C NMR (75 MHz, $CDCl_3$) δ 209.3 (CO), 198.4 (CHO), 136.1(**C**$_{arom}$-C), 129.0, 128.6, 125.8 (C_{arom}-H), 101.5 (OCHO), 81.4 (Ph**C**H), 68.8 (CH_2O), 61.0 (**C**HCHO), 38.8 (CH**C**H$_2$CO), 36.8 (**C**HCH$_2$CO). IR (ATR): 1720 (C=O), 1077, 1020 (OCHO) cm^{-1}. MS (70 eV) *m*/*z* (%): 140 (100), 131 (39), 111 (24), 91 (20), 77 (20). HRMS: Calculated for $[C_{14}H_{15}O_4]^+$: 247.0970 $[(M+H)^+]$; found:

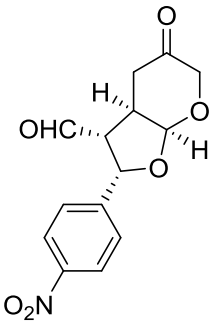
247.0973. $[\alpha]_D^{rt}$: -22.9 (*c* 0.4, CH_2Cl_2). The enantiomeric excess (e.e.) was measured after transformation into **8a**.



(2*S*,3*R*,3a*R*,7a*S*)-2-(4-Methoxyphenyl)-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-carbaldehyde (6b). Following the general procedure 6**b** (86 mg, 0.31 mmol) was isolated by FC (hexanes/EtOAc 7:3) after 18 h in 63% yield as a yellow oil starting from (*E*)-4-methoxycinnalmaldehyde (81 mg, 0.50 mmol), thiourea **7** (25 mg, 0.05 mmol) and pyranone **1** (114 mg, 1.0 mmol) in the presence of catalyst **(*S*)-3a** (32 mg, 0.10 mmol) and using chloroform (2.0 mL) as solvent. Measured d.r. (**5b**:**6b**) before purification: 1:4. ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.14 (d, *J* = 1.6 Hz, 1H, CHO), 7.17 (d, *J* = 8.8 Hz, 2H, C_{arom}-H), 6.89 (d, *J* = 8.8 Hz, 2H, C_{arom}-H), 5.81 (d, *J* = 6.2 Hz, 1H, OCHO), 5.68 (d, *J* = 7.5 Hz, 1H, PMPC**H**), 4.25 (d, *J* = 18.4 Hz, 1H, C**H**$_a$H$_b$O), 4.05 (d, *J* = 18.4 Hz, 1H, CH$_a$**H**$_b$O), 3.80 (s, 3H, CH_3), 3.54-3.34 (m, 1H, C**H**CH_2CO), 3.20-3.11 (m, 1H, C**H**CHO), 2.79 (dd, *J* = 15.6, 6.9 Hz, 1H, CHC**H**$_a$H$_b$CO), 2.56 (dd, *J* = 15.6, 5.9 Hz, 1H, CHCH$_a$**H**$_b$CO). ^{13}C NMR (75 MHz, $CDCl_3$) δ 209.3 (CO), 198.5 (CHO), 159.7 (**C**$_{arom}$-C), 128.0 (**C**$_{arom}$-C), 127.1, 114.3 (C_{arom}-H), 101.4 (OCHO), 81.2 (PMP**C**H), 68.9 (CH_2O), 61.0 (**C**HCHO), 55.3 (CH_3), 38.8 (CH**C**H_2CO), 36.8 (**C**HCH_2CO). IR (ATR): 1722 (C=O), 1025 (OCHO) cm^{-1}. MS (70 eV) *m*/*z* (%): 276 (M^+, 6), 136 (100), 111 (15), 77 (15). HRMS: Calculated for $[C_{15}H_{17}O_5]^+$: 277.1076 [$(M+H)^+$]; found: 277.1079. $[\alpha]_D^{rt}$: -22.9 (*c* 0.2, CH_2Cl_2). The enantiomeric excess (e.e.) was measured after transformation into **8b**.

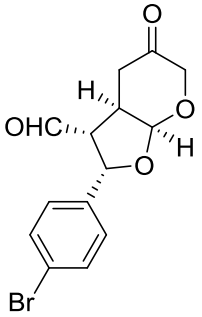


(2*S*,3*R*,3a*R*,7a*S*)-2-(4-Fluorophenyl)-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-carbaldehyde (6c). Following the general procedure **6c** (97 mg, 0.37 mmol) was isolated by FC (hexanes/EtOAc 7:3) after 18 h in 73% yield as a yellow oil starting from (*E*)-4-fluorocinnalmaldehyde (75 mg, 0.50 mmol), thiourea **7** (25 mg, 0.05 mmol) and pyranone **1** (114 mg, 1.0 mmol) in the presence of catalyst **(*S*)-3a** (32 mg, 0.10 mmol) and using chloroform (2.0 mL) as solvent. Measured d.r. (**5c**:**6c**) before purification: 1:2. ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.14 (d, *J* = 1.6 Hz, 1H, CHO), 7.37-7.01 (m, 4H, C_{arom}-H), 5.82 (d, *J* = 6.2 Hz, 1H, OCHO), 5.70 (d, *J* = 7.3 Hz, 1H, 4-FC_6H_4C**H**), 4.26 (d, *J* = 18.4 Hz, 1H, C**H**$_a$H$_b$O), 4.06 (d, *J* = 18.4 Hz, 1H, CH$_a$**H**$_b$O), 3.50-3.44 (m, 1H, C**H**CH_2CO), 3.17 (ddd, *J* = 7.3, 4.9, 1.6 Hz, 1H, C**H**CHO), 2.80 (dd, *J* = 15.5, 7.0 Hz, 1H, CHC**H**$_a$H$_b$CO), 2.58 (dd, *J* = 15.5, 6.1 Hz, 1H, CHCH$_a$**H**$_b$CO).^{13}C NMR (75 MHz, $CDCl_3$) δ 209.0 (CO), 198.2 (CHO), 162.6 (d, *J* = 247.7 Hz, C_{arom}-F), 131.8 (d, *J* = 8.3 Hz, **C**$_{arom}$-C), 127.6 (d, ^3J = 8.3 Hz, C_{arom}-H), 116.0 (d, ^2J = 21.8 Hz, C_{arom}-H), 101.4 (OCHO), 80.8 (4-FC_6H_4**C**H), 68.9 (CH_2O), 61.0 (**C**HCHO), 38.8 (CH**C**H_2CO), 36.9 (**C**HCH_2CO). IR (ATR): 1732, 1723 (C=O), 1280 (C-F) cm^{-1}. MS (70 eV) *m*/*z* (%): 264 (M^+, 3), 240 (36), 151 (100), 109 (49), 28 (37). HRMS: Calculated for $[C_{14}H_{14}FO_4]^+$: 265.0876 [$(M+H)^+$]; found: 265.0886. $[\alpha]_D^{rt}$: -24.4 (*c* 0.8, CH_2Cl_2). The enantiomeric excess (e.e.) was measured after transformation into **8c**.

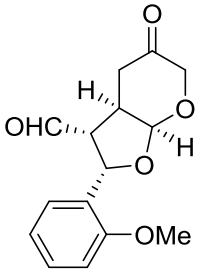


(2*S*,3*R*,3a*R*,7a*S*)-2-(4-Nitrophenyl)-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-carbaldehyde (6d). Following the general procedure **6d** (113 mg, 0. 39 mmol) was isolated by FC (hexanes/EtOAc 7:3) after 18 h in 78% yield as a yellow oil starting from (*E*)-4-nitrocinnalmaldehyde (88 mg, 0.50 mmol), thiourea **7** (25 mg, 0.05 mmol) and pyranone **1** (114 mg, 1.0 mmol) in the presence of catalyst **(*S*)-3a** (32 mg, 0.10 mmol) and using chloroform (2.0 mL) as solvent. Measured d.r. (**5d**:**6d**) before purification: 1:2. ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.14 (d, *J* = 1.5 Hz, 1H, CHO), 8.25 (d,

J = 8.7 Hz, 2H, C_{arom}-H), 7.50 (d, *J* = 8.7 Hz, 2H, C_{arom}-H), 5.85 (d, *J* = 6.2 Hz, 1H, OCHO), 5.79 (d, *J* = 7.2 Hz, 1H, 4-$NO_2C_6H_4C$**H**), 4.28 (d, *J* = 18.4 Hz, 1H, C**H**$_a$H$_b$O), 4.08 (d, *J* = 18.4 Hz, 1H, CH$_a$**H**$_b$O), 3.54-3.42 (m, 1H, C**H**CH_2CO), 3.39-3.11 (m, 1H, C**H**CHO), 2.82 (dd, *J* = 15.5, 7.0 Hz, 1H, CHC**H**$_a$H$_b$CO), 2.62 (dd, *J* = 15.5, 6.4 Hz, 1H, CHCH$_a$**H**$_b$CO).^{13}C NMR (75 MHz, $CDCl_3$) δ 208.5 (CO), 197.3 (CHO), 148.0 (C_{arom}-N), 143.1 (**C**$_{arom}$-C), 126.8, 124.2 (C_{arom}-H), 101.6 (OCHO), 80.3 (4-$NO_2C_6H_4$**C**H), 69.0 (CH_2O), 61.1 (**C**HCHO), 38.7 (CH**C**H_2CO), 37.2 (**C**HCH_2CO). IR (ATR): 1727 (C=O), 1518, 1347 (NO_2) cm^{-1}. MS (70 eV) *m*/*z* (%): 261 (M^+-CHO, 4), 190 (36), 98 (100), 77 (12). HRMS: Calculated for $[C_{14}H_{14}NO_6]^+$: 292.0821 [$(M+H)^+$]; found: 292.0807. $[\alpha]_D^{rt}$: +10.8 (*c* 0.8, CH_2Cl_2). The enantiomeric excess (e.e.) was measured after transformation into **8d**.

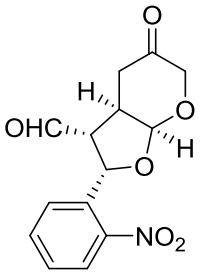


(2*S*,3*R*,3a*R*,7a*S*)-2-(4-Bromophenyl)-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-carbaldehyde (6e). Following the general procedure **6e** (140 mg, 0.43 mmol) was isolated by FC (hexanes/EtOAc 7:3) after 18 h in 87% yield as a yellow oil starting from (*E*)-4-bromocinnalmaldehyde (105 mg, 0.50 mmol), thiourea **7** (25 mg, 0.05 mmol) and pyranone **1** (114 mg, 1.0 mmol) in the presence of catalyst **(*S*)-3a** (32 mg, 0.10 mmol) and using chloroform (2.0 mL) as solvent. Measured d.r. (**5e**:**6e**) before purification: 1:1.5. ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.12 (d, *J* = 1.7 Hz, 1H, CHO), 7.50 (d, *J* = 8.5 Hz, 2H, C_{arom}-H), 7.15 (d, *J* = 8.5 Hz, 2H, C_{arom}-H), 5.80 (d, *J* = 6.2 Hz, 1H, OCHO), 5.66 (d, *J* = 6.9 Hz, 1H, 4-BrC_6H_4C**H**), 4.25 (d, *J* = 18.4 Hz, 1H, C**H**$_a$H$_b$O), 4.05 (d, *J* = 18.4 Hz, 1H, CH$_a$**H**$_b$O), 3.47-3.43 (m, 1H, C**H**CH_2CO), 3.17 (ddd, *J* = 6.9, 4.8, 1.7 Hz, 1H, C**H**CHO), 2.78 (dd, *J* = 15.5, 7.0 Hz, 1H, CHC**H**$_a$H$_b$CO), 2.57 (dd, *J* = 15.5, 6.2 Hz, 1H, CHCH$_a$**H**$_b$CO).^{13}C NMR (75 MHz, $CDCl_3$) δ 208.9 (CO), 198.0 (CHO), 135.0 (C_{arom}-Br), 132.2, 127.5 (C_{arom}-H), 122.6 (**C**$_{arom}$-C), 101.5 (OCHO), 80.7 (4-BrC_6H_4**C**H), 68.9 (CH_2O), 60.9 (**C**HCHO), 38.7 (CH**C**H_2CO), 36.9 (**C**HCH_2CO). IR (ATR): 1724 (C=O), 1070, 1009 (OCHO) cm^{-1}. MS (70 eV) *m*/*z* (%): 323 (M^+, 1), 226 (85), 131 (77), 98 (100). HRMS: Calculated for $[C_{14}H_{14}BrO_4]^+$: 325.0075 [$(M+H)^+$]; found: 325.0091. $[\alpha]_D^{rt}$: -12.1 (*c* 1.9, CH_2Cl_2). The enantiomeric excess (e.e.) was measured after transformation into **8e**.

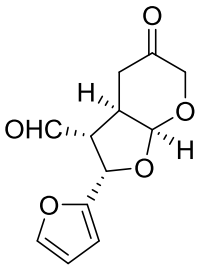


(2*S*,3*R*,3a*R*,7a*S*)-2-(2-Methoxyphenyl)-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-carbaldehyde (6f). Following the general procedure **6f** (84 mg, 0.30 mmol) was isolated by FC (hexanes/EtOAc 7:3) after 18 h in 61% yield as a yellow oil starting from (*E*)-2-methoxycinnalmaldehyde (81 mg, 0.50 mmol), thiourea **7** (25 mg, 0.05 mmol) and pyranone **1** (114 mg, 1.0 mmol) in the presence of catalyst **(*S*)-3a** (32 mg, 0.10 mmol) and using chloroform (2.0 mL) as solvent. Measured d.r. (**5f**:**6f**) before purification: 1:3. ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.08 (d, *J* = 1.8 Hz, 1H, CHO), 7.40-7.17 (m, 2H, C_{arom}-H), 6.98 (dd , *J* = 7.5 Hz, 1H, C_{arom}-H), 6.88 (d, *J* = 8.2 Hz, 1H, C_{arom}-H), 5.88 (d, *J* = 7.6 Hz, 1H, OCHO), 5.84 (d, *J* = 6.4 Hz, 1H, 2-$MeOC_6H_4C$**H**), 4.26 (d, *J* = 18.4 Hz, 1H, C**H**$_a$H$_b$O), 4.05 (d, *J* = 18.4 Hz, 1H, CH$_a$**H**$_b$O), 3.84 (s, 3H, CH_3), 3.41-3.33 (m, 1H, C**H**CH_2CO), 3.29-3.24 (m, 1H, C**H**CHO), 2.76 (dd, *J* = 15.7, 6.7 Hz, 1H, CHC**H**$_a$H$_b$CO), 2.55 (dd, *J* = 15.7, 5.4 Hz, 1H, CHCH$_a$**H**$_b$CO). ^{13}C NMR (75 MHz, $CDCl_3$) δ 209.4 (CO), 198.6 (CHO), 155.2 (C_{arom}-O), 129.4, 126.4 (C_{arom}-H), 124.9 (**C**$_{arom}$-C), 121.1, 110.1 (C_{arom}-H), 101.2 (OCHO), 77.4 (2-$MeOC_6H_4$**C**H), 68.7 (CH_2O), 59.1 (**C**HCHO), 55.2 (CH_3), 38.6 (CH**C**H_2CO), 36.7 (**C**HCH_2CO). IR (ATR): 1724 (C=O), 1010 (OCHO) cm^{-1}. MS (70 eV) *m*/*z* (%): 276 (M^+, 25), 136 (100), 118 (45), 91 (35), 77 (24). HRMS: Calculated for $[C_{15}H_{17}O_5]^+$: 277.1076 [$(M+H)^+$];

found: 277.1067. $[\alpha]_D^{rt}$: -48.5 (*c* 0.5, CH_2Cl_2). The enantiomeric excess (e.e.) was measured after transformation into **8f**.

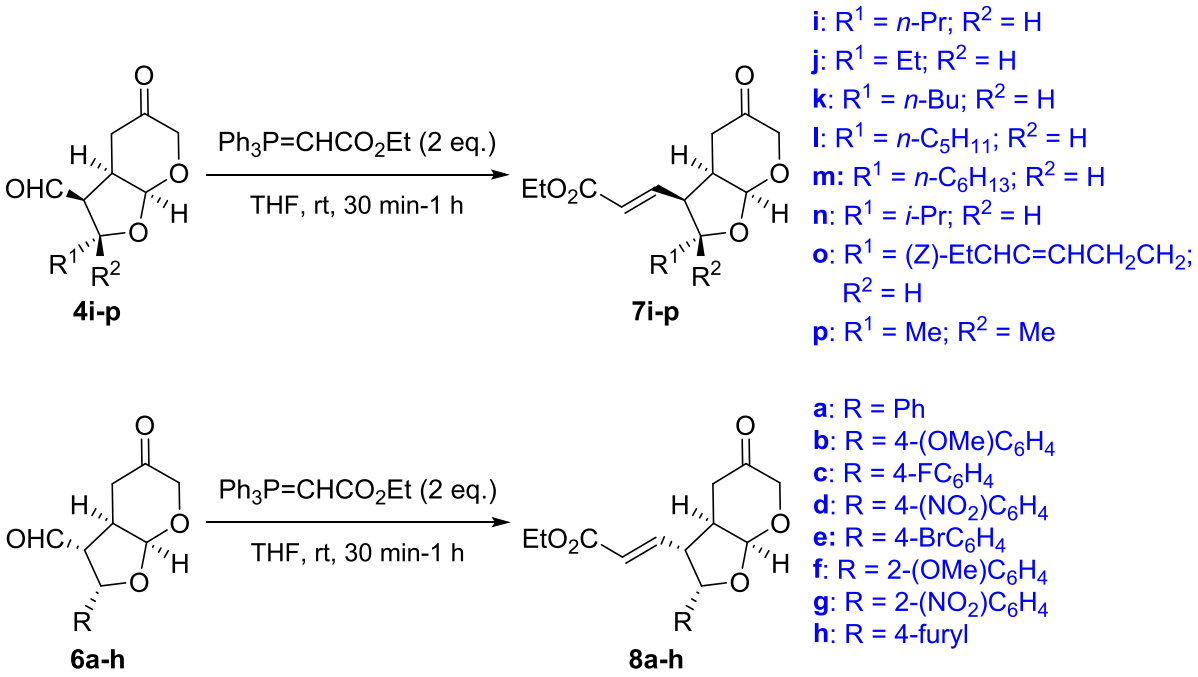


(2*S*,3*R*,3a*R*,7a*S*)-2-(2-Nitrophenyl)-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-carbaldehyde (6g). Following the general procedure **6g** (100 mg, 0.34 mmol) was isolated by FC (hexanes/EtOAc 7:3) after 18 h in 71% yield as a yellow oil starting from (*E*)-2-nitrocinnalmaldehyde (88 mg, 0.50 mmol), thiourea **7** (25 mg, 0.05 mmol) and pyranone **1** (114 mg, 1.0 mmol) in the presence of catalyst **(*S*)-3a** (32 mg, 0.10 mmol) and using chloroform (2.0 mL) as solvent. Measured d.r. (**5g**:**6g**) before purification: 1:3. ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.21 (s, 1H, CHO), 8.12 (d, *J* = 8.2 Hz, 1H, C_{arom}-H), 7.83-7.44 (m, 3H, C_{arom}-H), 6.16 (d, *J* = 7.8 Hz, 1H, OCHO), 5.83 (d, *J* = 6.1 Hz, 1H, 2-$NO_2C_6H_4C\mathbf{H}$), 4.26 (d, *J* = 18.3 Hz, 1H, $C\mathbf{H}_aH_bO$), 4.07 (d, *J* = 18.3 Hz, 1H, $CH_a\mathbf{H}_bO$), 3.87-3.62 (m, 1H, $C\mathbf{H}CH_2CO$), 3.60-3.20 (m, 1H, $C\mathbf{H}CHO$), 2.78 (dd, *J* = 15.8, 6.4 Hz, 1H, $CHC\mathbf{H}_aH_bCO$), 2.64 (dd, *J* = 15.8, 6.4 Hz, 1H, $CHCH_a\mathbf{H}_bCO$).^{13}C NMR (75 MHz, $CDCl_3$) δ 208.2 (CO), 197.8 (CHO), 147.3 (C_{arom}-N), 134.4 (C_{arom}-H), 133.0 ($\mathbf{C}_{arom}$-C), 129.5, 128.3, 125.1 (C_{arom}-H), 101.5 (OCHO), 78.2 (2-$NO_2C_6H_4\mathbf{C}H$), 69.3 (CH_2O), 60.3 ($\mathbf{C}HCHO$), 38.6 ($CH\mathbf{C}H_2CO$), 36.8 ($\mathbf{C}HCH_2CO$). IR (ATR): 1725 (C=O), 1526, 1350 (NO_2) cm^{-1}. MS (70 eV) *m*/*z* (%): 291 (M^+, 1), 172 (43), 135 (100), 92 (87), 78 (93). HRMS: Calculated for $[C_{14}H_{14}NO_6]^+$: 292.0821 $[(M+H)^+]$; found: 292.0839. $[\alpha]_D^{rt}$: +105.5 (*c* 0.3, CH_2Cl_2). The enantiomeric excess (e.e.) was measured after transformation into **8g**.



(2*S*,3*R*,3a*R*,7a*S*)-2-(Furan-2-yl)-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-carbaldehyde (6h). Following the general procedure **6h** (76 mg, 0.32 mmol) was isolated by FC (hexanes/EtOAc 7:3) after 18h in 64% yield as a yellow oil starting from (*E*)-3-(furan-2-yl)acrylaldehyde (61 mg, 0.50 mmol), thiourea **7** (25 mg, 0.05 mmol) and pyranone **1** (114 mg, 1.0 mmol) in the presence of catalyst **(*S*)-3a** (32 mg, 0.1 mmol) and using chloroform (2.0 mL) as solvent. Measured d.r. (**5h**:**6h**) before purification: 1:10. ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.30 (d, *J* = 1.4 Hz, 1H, CHO), 7.48-7.31 (m, 1H, $C_{hetarom}$-H), 6.38-6.29 (m, 2H, $C_{hetarom}$-H), 5.85 (d, *J* = 6.9 Hz, 1H, OCHO), 5.61 (d, *J* = 8.2 Hz, 1H, $C_{hetarom}$-CH), 4.18 (d, *J* = 18.4 Hz, 1H, $C\mathbf{H}_aH_bO$), 4.02 (d, *J* = 18.4 Hz, 1H, $CH_a\mathbf{H}_bO$), 3.75-3.56 (m, 1H, $C\mathbf{H}CH_2CO$), 3.12-3.92 (m, 1H, $C\mathbf{H}CHO$), 2.84 (dd, *J* = 16.1, 6.4 Hz, 1H, $CHC\mathbf{H}_aH_bCO$), 2.51 (dd, *J* = 16.1, 3.4 Hz, 1H, $CHCH_a\mathbf{H}_bCO$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 209.3 (CO), 196.5 (CHO), 150.7 ($\mathbf{C}_{hetarom}$-C), 143.3, 110.5, 109.6 ($C_{hetarom}$-H), 101.0 (OCHO), 73.2 ($C_{hetarom}$-$\mathbf{C}$H), 67.6 (CH_2O), 58.9 ($\mathbf{C}HCHO$), 38.4 ($CH\mathbf{C}H_2CO$), 36.4 ($\mathbf{C}HCH_2CO$). IR (ATR): 1723 (C=O), 1131 (FuranC-O), 1006 (OCHO) cm^{-1}. MS (70 eV) *m*/*z* (%): 236 (M^+, 9), 140 (100), 111 (30), 94 (41). HRMS: Calculated for $[C_{12}H_{13}O_5]^+$: 237.0763 $[(M+H)^+]$; found: 237.0748. $[\alpha]_D^{rt}$: -55.1 (*c* 0.2, CH_2Cl_2). The enantiomeric excess (e.e.) was measured after transformation into **8h**.

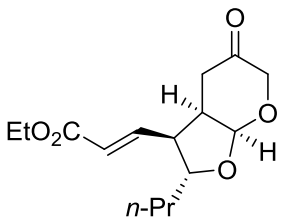
2.3. Preparation of 2-substituted (2*R*,3*S*,3a*R*,7a*S*)-configured 5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-yl acrylates (7i-o) (R^1 = Alkyl; R^2 = H), 2,2-disubstituted (3*S*,3a*R*,7a*S*)-configured 5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-yl acrylate (7p) (R^1 = R^2 = Me) and 2-substituted (2*R*,3*S*,3a*R*,7a*S*)-configured 5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-yl acrylates (8a-h) (R = Aromatic or Heteroaromatic).



Scheme ESI-3. General overview for the synthesis of **7i-p** and **8a-h**.

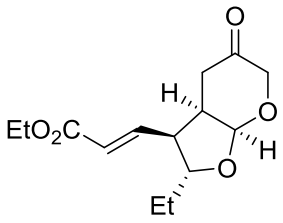
General procedure

An ordinary vial equipped with a magnetic stirring bar was charged with furopyrane **4** or **6**, THF (1.0 mL) and (carbethoxymethylene)triphenylphosphorane (2.0 eq.) was added. The crude mixture was stirred at room temperature until completion (30-60 min) and, once finished monitored by tlc, it was concentrated *in vacuo* and purified by flash column chromatography. *Note:* Racemic standards were prepared starting from racemic furopyranes **4** and **6**, respectively, which were previously synthesized using racemic catalyst **(±)-3a**.

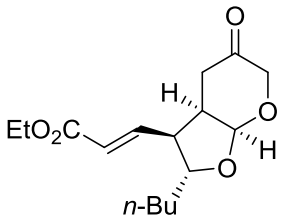


Ethyl (*E*)-3-[(2*R*,3*S*,3a*R*,7a*S*)-5-oxo-2-propylhexahydro-4*H*-furo[2,3-*b*]pyran-3-yl]acrylate (7i). Following the general procedure **7i** (31 mg, 0.11 mmol) was isolated by FC (hexanes/EtOAc 1:1) after 30 min in 78% yield as a yellow oil starting from pure **4i** (30 mg, 0.14 mmol) and (carbethoxymethylene)triphenylphosphorane (97 mg, 0.28 mmol), using THF (1.0 mL) as solvent. ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.77 (dd, *J* = 15.6, 9.3 Hz, 1H, C**H**=CHCO), 5.91 (d, *J* = 15.6 Hz, 1H, C**H**CO), 5.48 (d, *J* = 5.7 Hz, 1H, OCHO), 4.28-4.16 (m, 3H, OC**H**$_a$H$_b$CO, CH_3C**H**$_2$O), 4.16-4.06 (m, 1H, *n*-PrC**H**), 3.89 (d, *J* = 18.4 Hz, 1H, OCH$_a$**H**$_b$CO), 2.99-2.87 (m, 1H, C**H**CH$_2$CO), 2.85-2.57 (m, 2H, C**H**CH=CH, CHC**H**$_a$H$_b$CO), 2.41 (dd, *J* = 14.7, 7.1 Hz, 1H, CHCH$_a$**H**$_b$CO), 1.56-1.40 (m, 4H, CH_2CH_2), 1.30 (t, *J* = 7.1 Hz, 3H, OCH$_2$C**H**$_3$), 0.93 (t, *J* = 6.3 Hz, 3H, C**H**$_3$CH$_2$CH$_2$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 210.2 (CH_2**C**O), 165.5 (COO), 142.4 (COCH=**C**H), 125.6 (CO**C**H=CH), 101.5 (OCHO), 81.4 (*n*-Pr**C**H), 68.9 (CO**C**H$_2$O), 60.7 (CH_3**C**H$_2$O), 50.8 (**C**HCH=CH), 42.4 (**C**HCH$_2$CO), 36.1 (CH**C**H$_2$CO), 35.5 (Et**C**H$_2$), 19.3 (CH_3**C**H$_2$CH$_2$), 14.2 (**C**H$_3$CH$_2$CH$_2$), 14.0

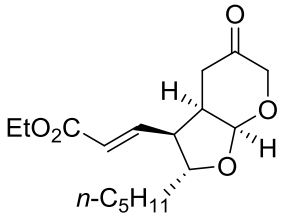
(**C**H_3CH_2O). IR (ATR): 1717, 1654 (C=O) cm^{-1}. MS (70 eV) *m*/*z* (%): 282 (M^+, 3), 237 (16), 210 (76), 136 (56), 79 (100). HRMS: Calculated for $[C_{15}H_{23}O_5]^+$: 283.1545 [$(M+H)^+$]; found: 283.1556. The e.e. was determined by HPLC using a Chiralpak IA column [*n*-hexane /*i*-PrOH (95:5)]; flow rate 1.00 mL/min; τ_{major} = 29.82 min, τ_{minor} = 22.11 min (93% e.e.). $[\alpha]_D^{rt}$: +124.8 (*c* 0.2, CH_2Cl_2).



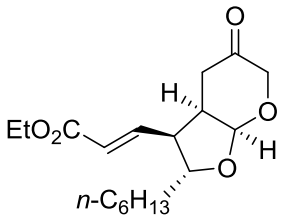
Ethyl (*E*)-3-[(2*R*,3*S*,3a*R*,7a*S*)-2-ethyl-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-yl]acrylate (7j). Following the general procedure **7j** (15 mg, 0.05 mmol) was isolated by FC (hexanes/EtOAc 1:1) after 30 min in 75% yield as a yellow oil starting from pure **4j** (15 mg, 0.07 mmol) and (carbethoxymethylene)triphenylphosphorane (53 mg, 0.15 mmol), using THF (1.0 mL) as solvent. ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.78 (dd, *J* = 15.6, 9.2 Hz, 1H, C**H**=CHCO), 5.91 (d, *J* = 15.6 Hz, 1H, C**H**CO), 5.49 (d, *J* = 5.7 Hz, 1H, OCHO), 4.32-4.15 (m, 3H, OC**H**$_a$H$_b$CO, CH_3C**H**$_2$O), 4.13-4.00 (m, 1H, EtC**H**), 3.90 (d, *J* = 18.4 Hz, 1H, OCH$_a$**H**$_b$CO), 3.05-2.88 (m, 1H, C**H**CH_2CO), 2.98-2.77 (m, 1H, C**H**CH=CH), 2.66 (dd, *J* = 14.7, 8.8 Hz, 1H, CHC**H**$_a$H$_b$CO), 2.41 (dd, *J* = 14.7, 7.1 Hz, 1H, CHCH$_a$**H**$_b$CO), 1.76-1.42 (m, 2H, CH_3C**H**$_2$CH), 1.30 (t, *J* = 7.1 Hz, 3H, OCH_2C**H**$_3$), 1.01 (t, *J* = 7.4 Hz, 3H, CH_2CH_2C**H**$_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 210.2 (CH_2**C**O), 165.5 (COO), 142.4 (COCH=**C**H), 125.6 (CO**C**H=CH), 101.5 (OCHO), 82.7 (Et**C**H), 68.9 (CO**C**H_2O), 60.7 (CH_3**C**H_2O), 50.2 (**C**HCH=CH), 42.5 (**C**HCH_2CO), 36.1 (CH**C**H_2CO), 26.3 (CH_3**C**H_2CH), 14.2 (**C**H_3CH_2O), 10.1 (**C**$H_3CH_2CH_2$). IR (ATR): 1716, 1654 (C=O) cm^{-1}. MS (70 eV) *m*/*z* (%): 268 (M^+, 1), 210 (31), 136 (35), 79 (100). HRMS: Calculated for $[C_{14}H_{21}O_5]^+$: 269.1389 [$(M+H)^+$]; found: 269.1382. The e.e. was determined by HPLC using a Chiralpak IA column [*n*-hexane /*i*-PrOH (95:5)]; flow rate 1.00 mL/min; τ_{major} = 34.04 min, τ_{minor} = 26.85 min (92% e.e.). $[\alpha]_D^{rt}$: +138.3 (*c* 0.1, CH_2Cl_2).



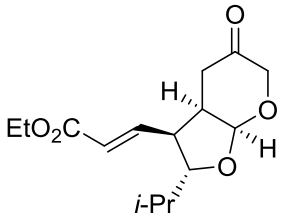
Ethyl (*E*)-3-[(2*R*,3*S*,3a*R*,7a*S*)-2-butyl-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-yl]acrylate (7k). Following the general procedure **7k** (24 mg, 0.08 mmol) was isolated by FC (hexanes/EtOAc 1:1) after 1 h in 87% yield as a yellow oil starting from pure **4k** (21 mg, 0.09 mmol) and (carbethoxymethylene)triphenylphosphorane (65 mg, 0.18 mmol), using THF (1.0 mL) as solvent. ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.78 (dd, *J* = 15.6, 9.2 Hz, 1H, C**H**=CHCO), 5.91 (d, *J* = 15.6 Hz, 1H, C**H**CO), 5.49 (d, *J* = 5.7 Hz, 1H, OCHO), 4.37-4.13 (m, 3H, OC**H**$_a$H$_b$CO, CH_3C**H**$_2$O), 4.13-4.01 (m, 1H, *n*-BuC**H**), 3.90 (d, *J* = 18.4 Hz, 1H, OCH$_a$**H**$_b$CO), 3.02-2.87 (m, 1H, C**H**CH_2CO), 2.99-2.87 (m, C**H**CH=CH), 2.66 (dd, *J* = 14.7, 8.8 Hz, 1H, CHC**H**$_a$H$_b$CO), 2.41 (dd, *J* = 14.7, 7.1 Hz, 1H, CHCH$_a$**H**$_b$CO), 1.73-1.41 (m, 6H, $(CH_2)_3$), 1.30 (t, *J* = 7.1 Hz, 3H, OCH_2C**H**$_3$), 1.01 (t, *J* = 7.4 Hz, 3H, CH_2CH_2C**H**$_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 210.2 (CH_2**C**O), 165.5 (COO), 142.4 (COCH=**C**H), 125.6 (CO**C**H=CH), 101.5 (OCHO), 81.6 (*n*-Bu**C**H), 68.9 (CO**C**H_2O), 60.7 (CH_3**C**H_2O), 50.7 (**C**HCH=CH), 42.4 (**C**HCH_2CO), 36.1 (CH**C**H_2CO), 33.1 (*n*-Pr**C**H_2), 28.2 (Et**C**H_2), 22.6 (CH_3**C**H_2CH_2), 14.2 (**C**H_3CH_2O), 13.9 (**C**$H_3CH_2CH_2$). IR (ATR): 1718, 1653 (C=O) cm^{-1}. MS (70 eV) *m*/*z* (%): 296 (M^+, 1), 210 (73), 136 (66), 79 (100). HRMS: Calculated for $[C_{16}H_{25}O_5]^+$: 297.1702 [$(M+H)^+$]; found: 297.1695. The e.e. was determined by HPLC using a Chiralpak IA column [*n*-hexane /*i*-PrOH (95:5)]; flow rate 1.00 mL/min; τ_{major} = 34.63 min, τ_{minor} = 22.60 min (94% e.e.). $[\alpha]_D^{rt}$: +98.2 (*c* 0.5, CH_2Cl_2).



Ethyl (*E*)-3-[(2*R*,3*S*,3a*R*,7a*S*)-5-oxo-2-pentylhexahydro-4*H*-furo[2,3-*b*]pyran-3-yl]acrylate (7l). Following the general procedure **7l** (20 mg, 0.06 mmol) was isolated by FC (hexanes/EtOAc 1:1) after 30 min in 70% yield as a yellow oil starting from pure **4l** (22 mg, 0.09 mmol) and (carbethoxymethylene)triphenylphosphorane (64 mg, 0.18 mmol), using THF (1.0 mL) as solvent. ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.77 (dd, *J* = 15.7, 9.3 Hz, 1H, C**H**=CHCO), 5.91 (d, *J* = 15.7 Hz, 1H, CHCO), 5.48 (d, *J* = 5.7 Hz, 1H, OCHO), 4.33-4.16 (m, 3H, OC**H**$_a$H$_b$CO, CH_3C**H**$_2$O), 4.16-4.02 (m, 1H, *n*-C_5H_{11}C**H**), 3.89 (d, *J* = 18.4 Hz, 1H, OCH$_a$**H**$_b$CO), 2.98-2.88 (m, 1H, C**H**CH_2CO), 2.84-2.72 (m, 1H, C**H**CH=CH), 2.66 (dd, *J* = 14.7, 8.9 Hz, CHC**H**$_a$H$_b$CO), 2.41 (dd, *J* = 14.7, 7.1 Hz, 1H, CHCH$_a$**H**$_b$CO), 1.56-1.28 (m, 11H, $(CH_2)_4$, OCH_2C**H**$_3$), 0.88 (t, *J* = 6.6 Hz, 3H, CH_2CH_2C**H**$_3$).^{13}C NMR (75 MHz, $CDCl_3$) δ 210.2 (CH_2**C**O), 165.5 (COO), 142.4 (COCH=**C**H), 125.6 (CO**C**H=CH), 101.5 (OCHO), 81.6 (*n*-C_5H_{11}**C**H), 68.9 (CO**C**H_2O), 60.7 (CH_3**C**H_2O), 50.7 (**C**HCH=CH), 42.4 (**C**HCH_2CO), 36.1 (CH**C**H_2CO), 33.4 (*n*-Bu**C**H_2), 31.7 (*n*-Pr**C**H_2), 25.7 (Et**C**H_2), 22.5 (CH_3**C**H_2CH_2), 14.2 (**C**H_3CH_2O), 13.9 (**C**$H_3CH_2CH_2$). IR (ATR): 1733, 1717 (C=O) cm^{-1}. MS (70 eV) *m*/*z* (%): 310 (M^+, 1), 210 (77), 136 (65), 79 (100), 55 (25). HRMS: Calculated for $[C_{17}H_{27}O_5]^+$: 311.1858 [$(M+H)^+$]; found: 311.1855. The e.e. was determined by HPLC using a Chiralpak IA column [*n*-hexane/*i*-PrOH (90:10)]; flow rate 1.00 mL/min; τ_{major} = 20.65 min, τ_{minor} = 10.83 min (95% e.e.). $[\alpha]_D^{rt}$: +79.8 (*c* 0.1, CH_2Cl_2).

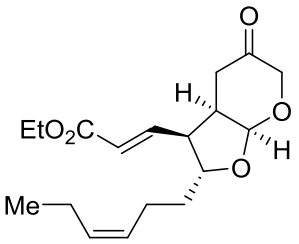


Ethyl (*E*)-3-[(2*R*,3*S*,3a*R*,7a*S*)-2-hexyl-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-yl]acrylate (7m). Following the general procedure **7m** (15 mg, 0.05 mmol) was isolated by FC (hexanes/EtOAc 1:1) after 30 min in 69% yield as a yellow oil starting from pure **4m** (17 mg, 0.07 mmol) and (carbethoxymethylene)triphenylphosphorane (49 mg, 0.14 mmol), using THF (1.0 mL) as solvent. ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.77 (dd, *J* = 15.6, 9.3 Hz, 1H, C**H**=CHCO), 5.90 (d, *J* = 15.6 Hz, 1H, C**H**CO), 5.48 (d, *J* = 5.7 Hz, 1H, OCHO), 4.33-4.15 (m, 3H, OC**H**$_a$H$_b$CO, CH_3C**H**$_2$O), 4.15-4.01 (m, 1H, *n*-C_6H_{13}C**H**), 3.89 (d, *J* = 18.4 Hz, 1H, OCH$_a$**H**$_b$CO), 2.93-2.86 (m, 1H, C**H**CH_2CO), 2.84-2.72 (m, 1H, C**H**CH=CH), 2.66 (dd, *J* = 14.7, 8.8 Hz, 1H, CHC**H**$_a$H$_b$CO), 2.40 (dd, *J* = 14.7, 7.1 Hz, 1H, CHCH$_a$**H**$_b$CO), 1.63-1.21 (m, 13H, $(CH_2)_5$, C**H**$_3CH_2$O), 0.87 (t, *J* = 6.5 Hz, 3H, CH_2CH_2C**H**$_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 210.2 (CH_2**C**O), 165.5 (COO), 142.4 (COCH=**C**H), 125.6 (CO**C**H=CH), 101.5 (OCHO), 81.6 (*n*-C_6H_{13}**C**H), 68.9 (CO**C**H_2O), 60.7 (CH_3**C**H_2O), 50.7 (**C**HCH=CH), 42.4 (**C**HCH_2CO), 36.0 (CH**C**H_2CO), 33.4 (*n*-C_5H_{11}**C**H_2), 31.7 (*n*-Bu**C**H_2), 29.2 (*n*-Pr**C**H_2), 26.0 (Et**C**H_2), 22.5 (CH_3**C**H_2CH_2), 14.2 (**C**H_3CH_2O), 14.0 (**C**$H_3CH_2CH_2$). IR (ATR): 1719 (C=O) cm^{-1}. MS (70 eV) *m*/*z* (%): 324 (M^+, 1), 210 (78), 164 (51), 136 (72), 79 (100). HRMS: Calculated for $[C_{18}H_{29}O_5]^+$: 325.2015 [$(M+H)^+$]; found: 325.2008. The e.e. was determined by HPLC using a Chiralpak AS-H column [*n*-hexane/*i*-PrOH (95:5)]; flow rate 1.00 mL/min; τ_{major} = 27.80 min, τ_{minor} = 16.12 min (96% e.e.). $[\alpha]_D^{rt}$: +112.9 (*c* 0.2, CH_2Cl_2).

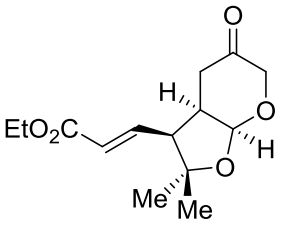


Ethyl (*E*)-3-[(2*R*,3*S*,3a*R*,7a*S*)-2-isopropyl-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-yl]acrylate (7n). Following the general procedure **7n** (13 mg, 0.04 mmol) was isolated by FC (hexanes/EtOAc 1:1) after 1 h 67% yield as a yellow oil starting from pure **4n** (14 mg, 0.07 mmol) and (carbethoxymethylene)triphenylphosphorane (46 mg, 0.13 mmol), using THF (1.0 mL) as solvent. ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.80 (dd, *J* = 15.6, 9.2 Hz, 1H,

C**H**=CHCO), 5.90 (d, *J* = 15.6 Hz, 1H, C**H**CO), 5.46 (d, *J* = 5.1 Hz, 1H, OCHO), 4.33-4.12 (m, 3H, OC**H**$_a$H$_b$CO, CH$_3$C**H**$_2$O), 4.05-3.77 (m, 2H, *i*-PrC**H**, OCH$_a$**H**$_b$CO), 3.03-2.81 (m, 2H, CH=CHC**H**, C**H**CH$_2$CO), 2.64 (dd, *J* = 15.1, 7.2 Hz, 1H, CHC**H**$_a$H$_b$CO), 2.42 (dd, *J* = 15.1, 6.8 Hz, 1H, CHCH$_a$**H**$_b$CO), 1.86-1.70 (m, 1H, (CH$_3$)$_2$C**H**), 1.30 (t, *J* = 7.1 Hz, 3H, OCH$_2$C**H**$_3$), 0.97 (d, *J* = 6.5 Hz, 3H, (C**H**$_3$)$_2$CH), 0.95 (d, *J* = 6.5 Hz, 3H, (C**H**$_3$)$_2$CH). ^{13}C NMR (75 MHz, CDCl$_3$) δ 209.8 (CH$_2$**C**O), 165.5 (COO), 143.8 (COCH=**C**H), 125.1 (CO**C**H=CH), 101.3 (OCHO), 86.6 (*i*-Pr**C**H), 68.9 (CO**C**H$_2$O), 60.7 (CH$_3$**C**H$_2$O), 47.5 (**C**HCH=CH), 42.9 (**C**HCH$_2$CO), 36.0 (CH**C**H$_2$CO), 30.9 (CH$_3$)$_2$**C**), 19.4 (**C**H$_3$CH), 17.2 (**C**H$_3$CH), 14.2 (**C**H$_3$CH$_2$). IR (ATR): 1718 (C=O) cm^{-1}. MS (70 eV) *m*/*z* (%): 282 (M$^+$, 1), 239 (13), 210 (43), 136 (34), 79 (100). HRMS: Calculated for [C$_{15}$H$_{23}$O$_5$]$^+$: 283.1545 [(M+H)$^+$]; found: 283.1539. The e.e. was determined by HPLC using a Chiralpak IA column [*n*-hexane/*i*-PrOH (95:5)]; flow rate 1.00 mL/min; τ_{major} = 18.55 min, τ_{minor} = 17.75 min (84% e.e.). $[\alpha]_D^{rt}$: +30.8 (*c* 0.08, CH$_2$Cl$_2$).

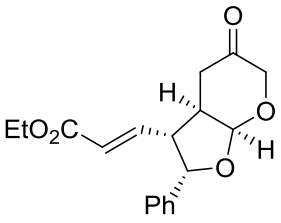


Ethyl (*E*)-3-{(2*R*,3*S*,3a*R*,7a*S*)-2-[(*Z*)-hex-3-en-1-yl]-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-yl]}acrylate (7o) Following the general procedure **7o** (23 mg, 0.07 mmol) was isolated by FC (hexanes/EtOAc 1:1) after 30 min in 74% yield as a yellow oil starting from pure **4o** (24 mg, 0.09 mmol) and (carbethoxymethylene)triphenylphosphorane (66 mg, 0.19 mmol), using THF (1.0 mL) as solvent. ^{1}H NMR (300 MHz, CDCl$_3$) δ 6.77 (dd, *J* = 15.6, 9.2 Hz, 1H, C**H**=CHCO), 5.91 (d, *J* = 15.6 Hz, 1H, C**H**CO), 5.50 (d, *J* = 5.7 Hz, 1H, OCHO), 5.48-5.21 (m, 2H, CH$_2$C**H**=C**H**), 4.25-4.18 (m, 3H, OC**H**$_a$H$_b$CO, CH$_3$C**H**$_2$O), 4.11 (dt, *J* = 9.1, 3.5 Hz, 1H, CH$_2$CH$_2$C**H**), 3.90 (d, *J* = 18.4 Hz, 1H, OCH$_a$**H**$_b$CO), 3.00-2.87 (m, 1H, C**H**CH$_2$CO), 2.86-2.74 (m, 1H, C**H**CH=CH), 2.66 (dd, *J* = 14.8, 8.6 Hz, CHC**H**$_a$H$_b$CO), 2.42 (dd, *J* = 14.8, 7.1 Hz, 1H, CHCH$_a$**H**$_b$CO), 2.11-1.91 (m, 4H, C**H**$_2$C**H**$_2$), 1.67-1.43 (m, 2H, CH$_3$C**H**$_2$CH), 1.30 (t, *J* = 7.1 Hz, 3H, OCH$_2$C**H**$_3$), 0.96 (t, *J* = 7.5 Hz, 3H, CHCH$_2$C**H**$_3$). ^{13}C NMR (75 MHz, CDCl$_3$) δ 210.1 (CH$_2$**C**O), 165.4 (COO), 142.4 (COCH=**C**H), 132.8 (EtCH=**C**H), 127.6 (Et**C**H=CH), 125.7 (CO**C**H=CH), 101.5 (OCHO), 80.9 (CH=CHCH$_2$CH$_2$**C**H), 68.8 (CO**C**H$_2$O), 60.7 (CH$_3$**C**H$_2$O), 50.7 (**C**HCH=CH), 42.4 (**C**HCH$_2$CO), 36.1 (CH**C**H$_2$CO), 33.5 (CH=CHCH$_2$**C**H$_2$CH), 23.7 (CH=CH**C**H$_2$CH$_2$CH), 20.5 (CH$_3$**C**H$_2$CH), 14.3 (**C**H$_3$CH$_2$CO), 14.0 (**C**H$_3$CH$_2$CH). IR (ATR): 1732, 1718 (C=O) cm^{-1}. MS (70 eV) *m*/*z* (%): 322 (M$^+$, 2), 210 (61), 136 (48), 79 (100). HRMS: Calculated for [C$_{18}$H$_{27}$O$_5$]$^+$: 323.1858 [(M+H)$^+$]; found: 323.1866. The e.e. was determined by HPLC using a Chiralpak IA column [hexanes/*i*-PrOH (95:5)]; flow rate 1.00 mL/min; τ_{major} = 45.91 min, τ_{minor} = 18.02 min (96% e.e.). $[\alpha]_D^{rt}$: +25.7 (*c* 0.5, CH$_2$Cl$_2$).

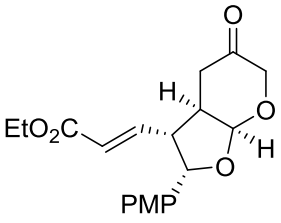


Ethyl (*E*)-3-[(3*S*,3a*R*,7a*S*)-2,2-dimethyl-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-yl]acrylate (7p). Following the general procedure **7p** (29 mg, 0.11 mmol) was isolated by FC (hexanes/EtOAc 1:1) after 30 min in 80% yield as a yellow oil starting from pure **4p** (27 mg, 0.14 mmol) and (carbethoxymethylene)triphenylphosphorane (94 mg, 0.27 mmol), using THF (1.0 mL) as solvent. ^{1}H NMR (300 MHz, CDCl$_3$) δ 6.66 (dd, *J* = 15.5, 9.3 Hz, 1H, C**H**=CHCO), 5.89 (d, *J* = 15.5 Hz, 1H, C**H**CO), 5.62 (d, *J* = 7.1 Hz, 1H, OCHO), 4.39-4.09 (m, 3H, OC**H**$_a$H$_b$CO, CH$_3$C**H**$_2$), 3.98 (d, *J* = 18.3 Hz, 1H, OCH$_a$**H**$_b$CO), 2.97-2.85 (m, 1H, C**H**CH$_2$CO), 2.71 (dd, *J* = 16.1, 6.2 Hz, 1H, CHC**H**$_a$H$_b$CO), 2.34 (dd, *J* = 16.1, 2.3 Hz, 1H, CHCH$_a$**H**$_b$CO), 2.17-2.09 (m, 1H, C**H**CH=CH), 1.33-1.25 (m, 6H, OCH$_2$C**H**$_3$, CH$_3$), 1.16 (s, 3H, CH$_3$).^{13}C NMR (75 MHz, CDCl$_3$) δ 209.9 (CH$_2$**C**O), 165.6 (COO), 143.5

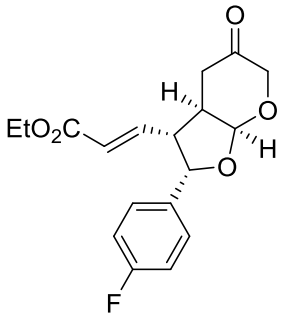
(COCH=**C**H), 125.2 (CO**C**H=CH), 99.0 (OCHO), 82.9 ((CH$_3$)$_2$**C**), 66.9 (CO**C**H$_2$O), 60.7 (CH$_3$**C**H$_2$O), 56.7 (**C**HCH=CH), 41.7 (**C**HCH$_2$CO), 37.3 (CH**C**H$_2$CO), 26.7 (CH$_3$), 23.3 (CH$_3$), 14.2 (**C**H$_3$CH$_2$). IR (ATR): 1718 (C=O) cm^{-1}. HRMS: Calculated for [C$_{14}$H$_{21}$O$_5$]$^+$: 269.1389 [(M+H)$^+$]; found: 269.1388. The e.e. was determined by HPLC using a Chiralpak AS-H column [*n*-hexane/*i*-PrOH (90:10)]; flow rate 1.00 mL/min; τ_{major} = 15.05 min, τ_{minor} = 27.06 min (77% e.e.). $[\alpha]_D^{rt}$: +45.4 (*c* 0.3, CH$_2$Cl$_2$).



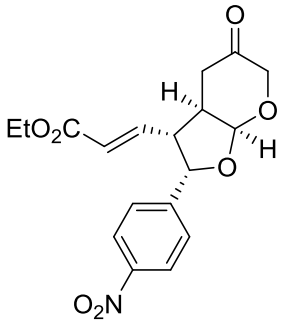
Ethyl (*E*)-3-[(2*S*,3*R*,3a*R*,7a*S*)-5-oxo-2-phenylhexahydro-4*H*-furo[2,3-*b*]pyran-3-yl]acrylate (8a). Following the general procedure **8a** (21 mg, 0.06 mmol) was isolated by FC (hexanes/EtOAc 1:1) after 30 min in 79% as a yellow oil starting from pure **6a** (20 mg, 0.08 mmol) and (carbethoxymethylene)triphenylphosphorane (56 mg, 0.16 mmol), using THF (1.0 mL) as solvent. ^{1}H NMR (300 MHz, CDCl$_3$) δ 7.54-6.90 (m, 5H, C$_{arom}$-H), 6.17 (dd, *J* = 15.7, 9.6 Hz, 1H, C**H**=CHCO), 6.00 (d, *J* = 6.1 Hz, 1H, OCHO), 5.79 (d, *J* = 15.7 Hz, 1H, CH=C**H**CO), 5.52 (d, *J* = 7.4 Hz, PhC**H**), 4.27 (d, *J* = 18.3 Hz, 1H, OC**H**$_a$H$_b$CO), 4.18-3.97 (m, 3H, CH$_3$C**H**$_2$O, OCH$_a$**H**$_b$CO), 2.99-2.91 (m, 1H, C**H**CH$_2$CO), 2.85-2.70 (m, 2H, C**H**CH=CH, CHC**H**$_a$H$_b$CO), 2.47 (dd, *J* = 15.6, 3.5 Hz, 1H, CHCH$_a$**H**$_b$CO), 1.22 (t, *J* = 7.1 Hz, 3H, CH$_3$). ^{13}C NMR (75 MHz, CDCl$_3$) δ 209.0 (CH$_2$**C**O), 165.3 (COO), 144.1 (COCH=**C**H), 137.8 (**C**$_{arom}$-C), 128.5, 128.0, 125.8 (C$_{arom}$-H), 124.2 (CO**C**H=CH), 101.4 (OCHO), 83.7 (Ph**C**H), 68.1 (CO**C**H$_2$O), 60.5 (CH$_3$**C**H$_2$O), 52.1 (**C**HCH=CH), 41.2 (**C**HCH$_2$CO), 37.4 (CH**C**H$_2$CO), 14.1 (CH$_3$). IR (ATR): 1736, 1720 (C=O) cm^{-1}. MS (70 eV) *m*/*z* (%): 271 (M$^+$-CH$_3$CH$_2$O, 2), 210 (100), 136 (43), 79 (83). HRMS: Calculated for [C$_{18}$H$_{21}$O$_5$]$^+$: 317.1389 [(M+H)$^+$]; found: 317.1392. The e.e. was determined by HPLC using a Chiralpak IA column [*n*-hexane/*i*-PrOH (95:5)]; flow rate 1.00 mL/min; τ_{major} = 30.99 min, τ_{minor} = 68.43 min (95% e.e.). $[\alpha]_D^{rt}$: +47.9 (*c* 0.2, CH$_2$Cl$_2$).



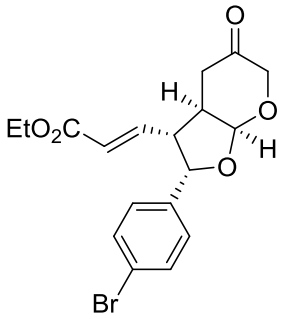
Ethyl (*E*)-3-[(2*S*,3*R*,3a*R*,7a*S*)-2-(4-methoxyphenyl)-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-yl]acrylate (8b). Following the general procedure **8b** (16 mg, 0.046 mmol) was isolated by FC (hexanes/EtOAc 1:1) after 30 min in 83% yield as a yellow oil starting from pure **6b** (15 mg, 0.054 mmol) and (carbethoxymethylene)triphenylphosphorane (38 mg, 0.11 mmol), using THF (1.0 mL) as solvent. ^{1}H NMR (300 MHz, CDCl$_3$) δ 7.05 (d, *J* = 8.7 Hz, 2H, C$_{arom}$-H), 6.87 (d, *J* = 8.7 Hz, 2H, C$_{arom}$-H), 6.22 (dd, *J* = 15.6, 9.5 Hz, 1H, C**H**=CHCO), 5.97 (d, *J* = 6.1 Hz, 1H, OCHO), 5.79 (d, *J* = 15.6 Hz, 1H, CH=C**H**CO), 5.48 (d, *J* = 7.2 Hz, PMPC**H**), 4.26 (d, *J* = 18.3 Hz, 1H, OC**H**$_a$H$_b$CO), 4.21-3.95 (m, 3H, CH$_3$C**H**$_2$O, OCH$_a$**H**$_b$CO), 3.80 (s, 3H, CH$_3$O), 2.96-2.70 (m, 3H, C**H**CH$_2$CO, C**H**CH=CH, CHC**H**$_a$H$_b$CO), 2.47 (dd, *J* = 15.6, 3.5 Hz, 1H, CHCH$_a$**H**$_b$CO), 1.23 (t, *J* = 7.1 Hz, 3H, CH$_3$). ^{13}C NMR (75 MHz, CDCl$_3$) δ 209.1 (CH$_2$**C**O), 165.4 (COO), 159.2 (COCH=**C**H), 144.4 (CO**C**H=CH), 129.9 (**C**$_{arom}$-C), 127.2 (C$_{arom}$-H), 127.1 (**C**$_{arom}$-C), 124.0 (C$_{arom}$-H), 101.3 (OCHO), 83.4 (PMP**C**H), 68.1 (CO**C**H$_2$O), 60.4 (CH$_3$**C**H$_2$), 55.2 (CH$_3$O), 52.1 (**C**HCH=CH), 41.3 (**C**HCH$_2$CO), 37.4 (CH**C**H$_2$CO), 14.1 (**C**H$_3$CH$_2$). IR (ATR): 1713 (C=O) cm^{-1}. MS (70 eV) *m*/*z* (%): 346 (M$^+$, 1), 210 (100), 137 (95), 79 (68). HRMS: Calculated for [C$_{19}$H$_{23}$O$_6$]$^+$: 347.1495 [(M+H)$^+$]; found: 347.1479. The e.e. was determined by HPLC using a Chiralcel OZ-3 column [*n*-hexane/*i*-PrOH (90:10)]; flow rate 1.00 mL/min; τ_{major} = 66.91 min, τ_{minor} = 55.59 min (86% e.e.). $[\alpha]_D^{rt}$: +45.8 (*c* 0.2, CH$_2$Cl$_2$).



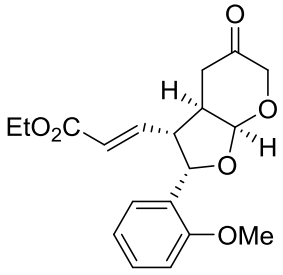
Ethyl (*E*)-3-[(2*S*,3*R*,3a*R*,7a*S*)-2-(4-fluorophenyl)-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-yl]acrylate (8c). Following the general procedure **8c** (24 mg, 0.07 mmol) was isolated by FC (hexanes/EtOAc 1:1) after 30 min in 82% yield as a yellow oil starting from pure **6c** (23 mg, 0.09 mmol) and (carbethoxymethylene)triphenylphosphorane (60 mg, 0.17 mmol), using THF (1.0 mL) as solvent. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.22-6.82 (m, 4H, C_{arom}-H), 6.17 (dd, *J* = 15.6, 9.6 Hz, 1H, C**H**=CHCO), 5.97 (d, *J* = 6.0 Hz, 1H, OCHO), 5.77 (d, *J* = 15.6 Hz, 1H, CH=C**H**CO), 5.50 (d, *J* = 7.3 Hz, 4-FC_6H_4C**H**), 4.25 (d, *J* = 18.3 Hz, 1H, OC**H**$_a$H$_b$CO), 4.19-3.88 (m, 3H, CH_3C**H**$_2$, OCH_a**H**$_b$CO), 2.99-2.90 (m, 1H, C**H**CH_2CO), 2.83-2.70 (m, 2H, C**H**CH=CH, CHC**H**$_a$H$_b$CO), 2.52-2.46 (m, 1H, $CHCH_a$**H**$_b$CO), 1.22 (t, *J* = 7.1 Hz, 3H, CH_3). ^{13}C NMR (75 MHz, $CDCl_3$) δ 208.8 (CH_2**C**O), 165.3 (COO), 162.3 (d, $^{1}J_{CF}$ = 246.6 Hz, C_{arom}-F), 143.9 (COCH=**C**H), 133.5 (d, $^{4}J_{CF}$ = 3.2 Hz, **C**$_{arom}$-C), 127.5 (d, $^{3}J_{CF}$ = 8.2 Hz, C_{arom}-H), 124.3 (CO**C**H=CH), 115.5 (d, $^{2}J_{CF}$ = 21.6 Hz, C_{arom}-H), 101.4 (OCHO), 83.0 (4-FC_6H_4CH), 68.3 (CO**C**H_2O), 60.6 (CH_3**C**H_2), 52.1 (**C**HCH=CH), 41.5 (**C**HCH_2CO), 37.5 (CH**C**H_2CO), 14.1 (CH_3). IR (ATR): 1716 (C=O) cm^{-1}. MS (70 eV) *m*/*z* (%): 289 (M^+-OEt, 2), 210 (96), 136 (52), 79 (100). HRMS: Calculated for $[C_{18}H_{20}FO_5]^+$: 335.1295 [$(M+H)^+$]; found: 335.1287. The e.e. was determined by HPLC using a Chiralpak IA column [*n*-hexane/*i*-PrOH (90:10)]; flow rate 1.00 mL/min; τ_{major} = 20.09 min, τ_{minor} = 47.81 min (92% e.e.). $[\alpha]_D^{rt}$: +37.9 (*c* 0.9, CH_2Cl_2).



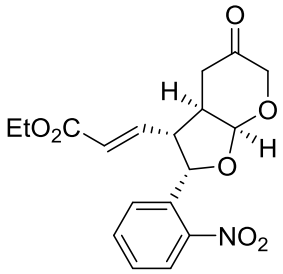
Ethyl (*E*)-3-[(2*S*,3*R*,3a*R*,7a*S*)-2-(4-nitrophenyl)-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-yl]acrylate (8d). Following the general procedure **8d** (48 mg, 0.13 mmol) was isolated by FC (hexanes/EtOAc 1:1) after 30 min in 77% yield as a yellow oil starting from pure **6d** (50 mg, 0.17 mmol) and (carbethoxymethylene)triphenylphosphorane (119 mg, 0.34 mmol), using THF (1.0 mL) as solvent. ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.22 (d, *J* = 8.7 Hz, 2H, C_{arom}-H), 7.35 (d, *J* = 8.7 Hz, 2H, C_{arom}-H), 6.15 (dd, *J* = 15.5, 9.6 Hz, 1H, C**H**=CHCO), 5.97 (d, *J* = 5.8 Hz, 1H, OCHO), 5.80 (d, *J* = 15.5 Hz, 1H, CH=C**H**CO), 5.60 (d, *J* = 7.3 Hz, 4-$NO_2C_6H_4C$**H**), 4.27 (d, *J* = 18.3 Hz, 1H, OC**H**$_a$H$_b$CO), 4.16-4.05 (m, 3H, CH_3C**H**$_2$O, OCH_a**H**$_b$CO), 3.12-3.00 (m, 1H, C**H**CH_2CO), 2.84-2.73 (m, 2H, C**H**CH=CH, CHC**H**$_a$H$_b$CO), 2.58-2.50 (m, 1H, $CHCH_a$**H**$_b$CO), 1.22 (t, *J* = 7.1 Hz, 3H, CH_3). ^{13}C NMR (75 MHz, $CDCl_3$) δ 208.2 (CH_2**C**O), 165.0 (COO), 147.6 (C_{arom}-N), 145.0 (**C**$_{arom}$-C), 142.9 (COCH=**C**H), 126.8 (C_{arom}-H), 124.9 (CO**C**H=CH), 123.8 (C_{arom}-H), 101.5 (OCHO), 82.4 (4-$NO_2C_6H_4$**C**H), 68.5 (CO**C**H_2O), 60.7 (CH_3**C**H_2), 52.5 (**C**HCH=CH), 42.1 (**C**HCH_2CO), 37.6 (CH**C**H_2CO), 14.1 (CH_3). IR (ATR): 1715, 1519 (C=O), 1345 (NO_2) cm^{-1}. HRMS: Calculated for $[C_{18}H_{20}NO_7]^+$: 362.1240 [$(M+H)^+$]; found: 362.1237. The e.e. was determined by HPLC using a Chiralcel OZ-3 column [*n*-hexane/*i*-PrOH (90:10)]; flow rate 1.00 mL/min; τ_{major} = 203.84 min, τ_{minor} = 187.35 min (92% e.e.). $[\alpha]_D^{rt}$: +72.2 (*c* 0.2, CH_2Cl_2).



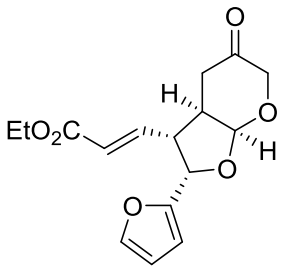
Ethyl (*E*)-3-[(2*S*,3*R*,3a*R*,7a*S*)-2-(4-bromophenyl)-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-yl]acrylate (8e). Following the general procedure **8e** (73 mg, 0.19 mmol) was isolated by FC (hexanes/EtOAc 1:1) after 30 min in 85% yield as a yellow oil starting from pure **6e** (70 mg, 0.22 mmol) and (carbethoxymethylene)triphenylphosphorane (150 mg, 0.43 mmol), using THF (1.0 mL) as solvent. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.47 (d, *J* = 8.4 Hz, 2H, C_{arom}-H), 7.02 (d, *J* = 8.4 Hz, 2H, C_{arom}-H), 6.17 (dd, *J* = 15.5, 9.7 Hz, 1H, C**H**=CHCO), 5.95 (d, *J* = 6.0 Hz, 1H, OCHO), 5.78 (d, *J* = 15.5 Hz, 1H, CH=C**H**CO), 5.47 (d, *J* = 7.3 Hz, 4-BrC_6H_4C**H**), 4.25 (d, *J* = 18.2 Hz, 1H, OC**H**$_a$H$_b$CO), 4.20-3.99 (m, 3H, CH_3C**H**$_2$O, OCH$_a$**H**$_b$CO), 3.01-2.90 (m, 1H, C**H**CH_2CO), 2.87-2.63 (m, 2H, C**H**CH=CH, CHC**H**$_a$H$_b$CO), 2.49 (dd, *J* = 13.2, 5.4 Hz, 1H, CHCH$_a$**H**$_b$CO), 1.23 (t, *J* = 7.1 Hz, 3H, CH_3). ^{13}C NMR (75 MHz, $CDCl_3$) δ 208.7 (CH_2**C**O), 165.2 (COO), 143.6 (COCH=**C**H), 136.8 (**C**$_{arom}$-C), 131.7, 127.5 (C_{arom}-H), 124.5 (CO**C**H=CH), 121.9 (C_{arom}-Br), 101.4 (OCHO), 82.9 (4-BrC_6H_4**C**H), 68.3 (CO**C**H_2O), 60.6 (CH_3**C**H_2), 52.0 (**C**HCH=CH), 41.5 (**C**HCH_2CO), 37.4 (CH**C**H_2CO), 14.1 (CH_3). IR (ATR): 1713 (C=O) cm^{-1}. MS (70 eV) *m*/*z* (%): 210 (100), 136 (68), 79 (89). HRMS: Calculated for [$C_{18}H_{20}BrO_5$]$^+$: 395.0494 [(M+H)$^+$]; found: 395.0483. The e.e. was determined by HPLC using a Chiralpak IA column [*n*-hexane/*i*-PrOH (90:10)]; flow rate 1.00 mL/min; τ_{major} = 59.37 min, τ_{minor} = 23.37 min (88% e.e.). $[\alpha]_D^{rt}$: +51.9 (*c* 1.9, CH_2Cl_2).



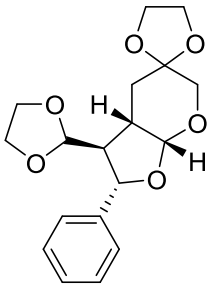
Ethyl (*E*)-3-[(2*S*,3*R*,3a*R*,7a*S*)-2-(2-methoxyphenyl)-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-yl]acrylate (8f). Following the general procedure **8f** (54 mg, 0.16 mmol) was isolated by FC (hexanes/EtOAc 1:1) after 30 min in 86% yield as a yellow oil starting from pure **6f** (50 mg, 0.18 mmol) and (carbethoxymethylene)triphenylphosphorane (125 mg, 0.36 mmol), using THF (1.0 mL) as solvent. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.31-7.21 (m, 2H, C_{arom}-H), 7.02-6.91 (m, 1H, C_{arom}-H), 6.82 (d, *J* = 8.5 Hz, 1H, C_{arom}-H), 6.25 (dd, *J* = 15.5, 9.6 Hz, 1H, C**H**=CHCO), 5.95 (d, *J* = 6.0 Hz, 1H, OCHO), 5.79 (d, *J* = 7.3 Hz, 2-MeOC_6H_4C**H**), 5.71 (d, *J* = 15.5 Hz, CH=C**H**CO), 4.27 (d, *J* = 18.3 Hz, 1H, OC**H**$_a$H$_b$CO), 4.19-3.90 (m, 3H, CH_3C**H**$_2$, OCH$_a$**H**$_b$CO), 3.73 (s, 3H, OCH_3), 3.06-2.94 (m, 1H, C**H**CH_2CO), 2.78-2.65 (m, 2H, C**H**CH=CH, CHC**H**$_a$H$_b$CO), 2.50 (dd, *J* = 17.9, 6.5 Hz, 1H, CHCH$_a$**H**$_b$CO), 1.21 (t, *J* = 7.1 Hz, 3H, CH_2C**H**$_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 209.4 (CH_2**C**O), 165.7 (COO), 155.6 (C_{arom}-O), 145.1 (COCH=**C**H), 129.0 (C_{arom}-H), 126.4 (**C**$_{arom}$-C), 126.1, 122.7 (C_{arom}-H), 120.6 (CO**C**H=CH), 110.1 (C_{arom}-H), 101.1 (OCHO), 79.7 (2-MeOC_6H_4**C**H), 68.3 (CO**C**H_2O), 60.3 (CH_3**C**H_2), 55.0 (**C**HCH=CH), 51.2 (OCH_3), 41.5 (**C**HCH_2CO), 37.6 (CH**C**H_2CO), 14.1 (CH_3). IR (ATR): 1733, 1715 (C=O) cm^{-1}. MS (70 eV) *m*/*z* (%): 346 (M$^+$, 1), 210 (100), 137 (84), 79 (70). HRMS: Calculated for [$C_{19}H_{23}O_6$]$^+$: 347.1495 [(M+H)$^+$]; found: 347.1500. The e.e. was determined by HPLC using a Chiralcel OD-3 column [*n*-hexane/*i*-PrOH (90:10)]; flow rate 1.00 mL/min; τ_{major} = 19.01 min, τ_{minor} = 22.91 min (94% e.e.). $[\alpha]_D^{rt}$: -14.4 (*c* 0.4, CH_2Cl_2).



Ethyl (*E*)-3-[(2*S*,3*R*,3a*R*,7a*S*)-2-(2-nitrophenyl)-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-yl]acrylate (8g). Following the general procedure **8g** (44 mg, 0.12 mmol) was isolated by FC (hexanes/EtOAc 1:1) after 30 min in 79% yield as a yellow oil starting from pure **6g** (50 mg, 0.15 mmol) and (carbethoxymethylene)triphenylphosphorane (107 mg, 0.31 mmol), using THF (1.0 mL) as solvent. ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.10 (dd, *J* = 8.2, 1.0 Hz, 1H, C_{arom}-H), 7.76-7.64 (m, 2H, C_{arom}-H), 7.56-7.38 (m, 1H, C_{arom}-H), 6.33-6.14 (m, 2H, COCH=C**H**, 2-$NO_2C_6H_4$C**H**), 5.89 (d, *J* = 5.4 Hz, 1H, OCHO), 5.71 (d, *J* = 15.5 Hz, COC**H**=CH), 4.28 (d, *J* = 18.2 Hz, 1H, OC**H**$_a$H$_b$CO), 4.19-3.94 (m, 3H, CH_3C**H**$_2$, OCH$_a$**H**$_b$CO), 3.42-3.30 (m, 1H, C**H**CH_2CO), 2.86-2.58 (m, 3H, C**H**CH=CH, CHC**H**$_2$CO), 1.19 (t, *J* = 7.1 Hz, 3H, CH_3). ^{13}C NMR (75 MHz, $CDCl_3$) δ 208.2 (CH_2**C**O), 165.4 (COO), 147.0 (C_{arom}-N), 143.4 (COCH=**C**H), 134.1 (C_{arom}-H), 134.0 (**C**$_{arom}$-C), 128.9, 127.9, 125.3 (C_{arom}-H), 124.1 (CO**C**H=CH), 101.4 (OCHO), 80.2 (2-$NO_2C_6H_4$**C**H), 69.2 (CO**C**H_2O), 60.5 (CH_3**C**H_2), 51.9 (**C**HCH=CH), 43.0 (**C**HCH_2CO), 37.9 (CH**C**H_2CO), 14.1 (CH_3). IR (ATR): 1715, 1525 (C=O) cm^{-1}. MS (70 eV) *m*/*z* (%): 210 (63), 152 (31), 136 (45), 79 (100). HRMS: Calculated for $[C_{18}H_{20}NO_7]^+$: 362.1240 [$(M+H)^+$]; found: 362.1225. The e.e. was determined by HPLC using a Chiralcel OZ-3 column [*n*-hexane/*i*-PrOH (90:10)]; flow rate 1.00 mL/min; τ_{major} = 98.25 min, τ_{minor} = 123.10 min (92% e.e.). $[\alpha]_D^{rt}$: +35.3 (*c* 0.4, CH_2Cl_2).

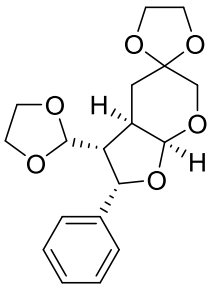


Ethyl (*E*)-3-[(2*S*,3*R*,3a*R*,7a*S*)-2-(furan-2-yl)-5-oxohexahydro-4*H*-furo[2,3-*b*]pyran-3-yl]acrylate (8h). Following the general procedure **8h** (22 mg, 0.07 mmol) was isolated by FC (hexanes/EtOAc 1:1) after 30 min in 75% yield as a yellow oil starting from pure **6h** (22 mg, 0.09 mmol) and (carbethoxymethylene)triphenylphosphorane (63 mg, 0.19 mmol), using THF (1.0 mL) as solvent. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.42-7.38 (m, 1H, $C_{hetarom}$-H), 6.35-6.21 (m, 3H, 2 × $C_{hetarom}$-H, C**H**=CHCO), 5.95 (d, *J* = 7.1 Hz, 1H, OCHO), 5.86 (d, *J* = 15.6 Hz, CH=C**H**CO), 5.28 (d, *J* = 7.6 Hz, $C_{hetarom}$-CH), 4.23 (d, *J* = 18.4 Hz, 1H, OC**H**$_a$H$_b$CO), 4.19-3.96 (m, 3H, CH_3C**H**$_2$, OCH$_a$**H**$_b$CO), 3.36-3.13 (m, 1H, C**H**CH_2CO), 2.95-2.64 (m, 2H, C**H**CH=CH, CHC**H**$_a$H$_b$CO), 2.43 (dd, *J* = 16.2, 2.6 Hz, 1H, CHCH$_a$**H**$_b$CO), 1.24 (t, *J* = 7.1 Hz, 3H, CH_3). ^{13}C NMR (75 MHz, $CDCl_3$) δ 209.5 (CH_2**C**O), 165.4 (COO), 151.8 (**C**$_{hetarom}$-C), 143.0 (COCH=**C**H), 142.5 ($C_{hetarom}$-H), 125.1 (CO**C**H=CH), 110.4, 109.4 ($C_{hetarom}$-H), 101.0 (OCHO), 76.15 ($C_{hetarom}$-**C**H), 67.2 (CO**C**H_2O), 60.5 (CH_3**C**H_2), 55.7 (**C**HCH=CH), 40.9 (**C**HCH_2CO), 37.2 (CH**C**H_2CO), 14.1 (CH_3). IR (ATR): 1716 (C=O) cm^{-1}. MS (70 eV) *m*/*z* (%): 210 (90), 136 (44), 91 (33), 79 (100). HRMS: Calculated for $[C_{16}H_{19}O_6]^+$: 307.1182 [$(M+H)^+$]; found: 307.1202. The e.e. was determined by HPLC using a Chiralcel OZ-3 column [*n*-hexane/*i*-PrOH (90:10)]; flow rate 1.00 mL/min; τ_{major} = 34.63 min, τ_{minor} = 31.09 min (97% e.e.). $[\alpha]_D^{rt}$: +47.3 (*c* 0.3, CH_2Cl_2).



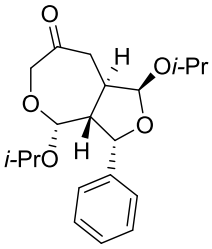
(2*S*,3*S*,3a*S*,7a*R*)-3-(1,3-dioxolan-2-yl)-2-phenyltetrahydro-4*H*,6*H*-spiro[furo[2,3-b]pyran-5,2'-[1,3]dioxolane] (9a).

A solution of **5a** (20 mg, 0.081 mmol) and *p*-TSA (7 mg, 0.04 mmol) was stirred in 2-ethyl-2-methyl-1,3-dioxolane (1.0 mL) at room temperature for 18h. After completion of the reaction compound **9a** (20 mg, 0.06 mmol) was isolated by FC (hexanes/EtOAc 1:1) in 74% yield as a white solid. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.52 (d, *J* = 7.1 Hz, 2H), 7.39-7.24 (m, 3H), 5.27 (d, *J* = 4.1 Hz, 1H), 4.97 (d, *J* = 2.1 Hz, 2H), 4.95 (d, 1.9 Hz, 1H), 4.10-3.75 (m, 5H), 3.49 (d, *J* = 12.0 Hz, 1H), 2.92 (td, *J* = 8.8, 3.9 Hz, 1H), 2.66- 2.50 (m, 1H), 2.11 (ddd, *J* = 10.7, 4.3, 2.1 Hz, 1H), 1.96 (dd, *J* = 14.1, 6.5 Hz, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 142.1, 128.2, 127.4, 126.9, 104.1, 104.0, 101.2, 82.5, 66.5, 65.0, 64.9, 64.6, 64.3, 50.6, 39.8, 32.5. IR (ATR): 1155, 1065 (O-C-O) cm^{-1}. MS (70 eV) *m*/*z* (%): 334 (1), 289 (2), 231 (2), 201 (68), 159 (5), 142 (6), 128 (9), 115 (8), 103 (4), 87 (27), 73 (100), 55 (3). HRMS: Calculated for $[C_{18}H_{23}O_6]^+$: 335.1495 [$(M+H)^+$]; found: 335.1487. $[\alpha]_D^{rt}$: +17.8 (*c* 0.61, CH_2Cl_2).



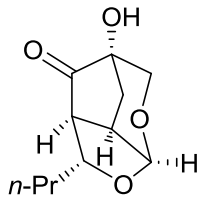
(2*S*,3*R*,3a*R*,7a*S*)-3-(1,3-dioxolan-2-yl)-2-phenyltetrahydro-4*H*,6*H*-spiro[furo[2,3-b]pyran-5,2'-[1,3]dioxolane] (10a).

A solution of **6a** (52 mg, 0.211 mmol) and *p*-TSA (20 mg, 0.12 mmol) was stirred in 2-ethyl-2-methyl-1,3-dioxolane (2.0 mL) at room temperature for 18h. After completion of the reaction compound **10a** (46 mg, 0.14 mmol) was isolated by FC (hexanes/EtOAc 1:1) in 65% yield as a white solid. ^{13}C NMR (75 MHz, $CDCl_3$) δ 138.8, 127.7, 127.3, 127.2, 104.5, 103.9, 101.7, 81.8, 67.0, 64.8, 64.6, 64.3, 64.2, 47.8, 38.2, 32.3. IR (ATR): 1070 (O-C-O) cm^{-1}. MS (70 eV) *m*/*z* (%): 334 (1), 232 (5), 201 (41), 191 (11), 159 (4), 128 (5), 115 (7), 105 (7), 87 (15), 73 (100), 55 (3). HRMS: Calculated for $[C_{18}H_{23}O_6]^+$: 335.1495 [$(M+H)^+$]; found: 335.1490. $[\alpha]_D^{rt}$: -44.8 (*c* 0.15, CH_2Cl_2).



[(1*S*,3*S*,3a*R*,4*S*,8a*R*)-1,4-Isopropoxy-3-phenyltetrahydro-1*H*,3*H*-furo[3,4-*c*]oxepin-7(6*H*)-one (11a).

A solution of **9a** (45 mg, 0.18 mmol) and *p*-TSA (70 mg, 0.39 mmol) was stirred in *i*-PrOH/DCM (1.0/2.0 mL) at room temperature for 18h. After completion of the reaction compound **11a** (34 mg, 0.10 mmol) was isolated by FC (hexanes/EtOAc gradient from 9:1 to 7:3) in 54% yield as a yellow oil. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.42-7.20 (m, 4H, C_{arom}-H), 5.78 (d, *J* = 6.5 Hz, 1H, *i*-PrOC**H**OCH), 5.39 (d, *J* = 7.1 Hz, 1H, *i*-PrOC**H**OCH$_2$), 4.25 (d, *J* = 18.4 Hz, 1H, OC**H**$_a$H$_b$CO), 4.07-3.98 (m, 2H, OCH$_a$**H**$_b$CO, CHPh), 3.60-3.47 (m, 2H, C**H**$_a$(CH$_3$)$_2$, C**H**$_b$(CH$_3$)$_2$), 3.44-3.13 (m, 1H, COCH$_2$CH), 2.88-2.53 (COC**H**$_2$CH), 2.53-2.26 (m, 1H, C**H**CHPh), 1.07 (d, *J* = 6.2 Hz, 6H, CH$_{3ab}$), 0.98 (d, *J* = 6.1 Hz, 3H, CH$_{3c}$), 0.73 (d, *J* = 6.1 Hz, 3H, CH$_{3d}$). ^{13}C NMR (75 MHz, $CDCl_3$) 211.6 (CO), 138.3 (C_{arom}-C), 128.1, 127.4, 126.5 (C_{arom}-H), 102.2 (*i*-PrO**C**HOCH), 97.6 (*i*-PrO**C**HOCH$_2$), 81.8 (**C**HPh), 68.5 (*i*-Pr$_a$), 68.3 (OCH$_2$CO), 68.2 (*i*-Pr$_b$), 54.3 (**C**HCHPh), 40.6 (CO**C**H$_2$CH), 38.1 (COCH$_2$**C**H), 23.3 (CH$_{3a}$), 22.9 (CH$_{3b}$), 22.8 (CH$_{3c}$), 20.9 (CH$_{3d}$). IR (ATR): 1734 cm^{-1}. MS (EI) m/z (%): 289 (1), 210 (33), 141 (92), 128 (52), 115 (59), 89 (100). HRMS: Calculated for $[C_{14}H_{13}O_3]^+$: 229.0844 [(M-(O*i*-Pr)- (O*i*-Pr) $^+$]; found: 229.0896. $[\alpha]_D^{rt}$: -6.8 (*c* = 1.2, CH_2Cl_2).



(2*R*,3*S*,3a*R*,5*S*,7a*S*)-5-hydroxy-2-propylhexahydro-4*H*-3,5-methanofuro[2,3-b]pyran-8-one (12k).

A solution of **4k** (48 mg, 0.226 mmol) was dissolved in CH_2Cl_2 (1 mL) and cooled to 0ºC. Then a solution of 1,3-dimethyl-1*H*-imidazol-3-ium bromide (*N*-heterocyclic carbene, 17 mg, 0.05 mmol) and Et_3N (38 mL, 0.276 mmol) in CH_2Cl_2 (1 mL) was added dropewise and the reaction mixture was further stirred at 0ºC for 18h. After completion of the reaction the crude was directly charged onto silicagel column from where compound **12k** (46 mg, 0.14 mmol) was isolated (hexanes/EtOAc 7:3) in 58% yield. ^{1}H NMR (500 MHz, $CDCl_3$) δ 5.67 (dd, *J* = 11.1, 5.0 Hz, 1H), 4.41-4.30 (m, 1H), 3.72 (d, *J* = 12.6 Hz, 2H), 3.70 (d, *J* = 11.6 Hz, 2H), 3.16 (dt, *J* = 7.1, 5.4 Hz, 1H), 3.04 (s, 1H), 2.59 (dd, *J* = 8.3, 1.0 Hz, 1H), 2.39 (d, *J* = 11.6 Hz, 1H), 1.85 (dd, *J* = 11.6, 4.7 Hz, 1H), 1.54-1.15 (m, 6H), 0.94 (t, *J* = 7.1 Hz, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 102.8, 83.2, 78.2, 68.4, 51.5, 39.6, 39.3, 29.9, 18.6, 13.7. IR (ATR): 1733 (C=O) cm^{-1}. $[\alpha]_D^{rt}$: -69.3 (*c* 0.18, CH_2Cl_2).

3. Determination of the Absolute Configuration of 4l, 6a and 9a (obtained from 5a)

3.1 Determination of the absolute configuration of 4l

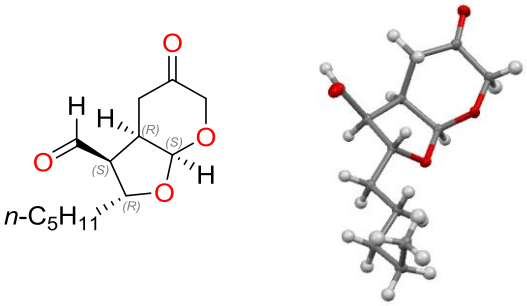


Figure ESI-1. ORTEP diagram for compound **(2*R*,3*S*,3a*R*,7a*S*)-4l**

Crystal data for $C_{13}H_{20}O_4$ (*M* = 240.29 g/mol): CCDC 1525188, orthorhombic, space group $P2_12_12_1$, *a* = 5.56040(10) Å, *b* = 6.68950(10) Å, *c* = 33.0826(5) Å, $\alpha = \beta = \gamma = 90^o$, *V* = 1230.55(3) $Å^3$, *Z* = 4, *T* = 100(2) K, μ(CuKα) = 0.779 mm^{-1}, *Dcalc* = 1.297 g/cm^3, 22597 reflections measured ($5.34^o \leq 2\Theta \leq 142^o$), 2369 unique ($R_{int}$ = 0.0418, R_{sigma} = 0.0191) which were used in all calculations. The final R_1 was 0.0306 ($I > 2\sigma(I)$) and wR_2 was 0.0711 (all data).

Table ESI-1. Crystal data and structure refinement for **4l**.

Empirical formula	$C_{13}H_{20}O_4$
Formula weight	240.29
Temperature/K	100(2)
Crystal system	
Space group	$P2_12_12_1$
a/Å	5.56040(10)
b/Å	6.68950(10)
c/Å	33.0826(5)
α/°	90
β/°	90
γ/°	90
Volume/$Å^3$	1230.55(3)
Z	4
$\rho_{calc}g/cm^3$	1.297
μ/mm^{-1}	0.779
F(000)	520.0
Crystal size/mm^3	0.1821 × 0.0405 × 0.0323
Radiation	CuKα (λ = 1.54184)
2Θ range for data collection/°	5.34 to 142
Index ranges	$-6 \leq h \leq 6$, $-8 \leq k \leq 8$, $-40 \leq l \leq 40$
Reflections collected	22597
Independent reflections	2369 [R_{int} = 0.0418, R_{sigma} = 0.0191]
Data/restraints/parameters	2369/0/155
Goodness-of-fit on F^2	1.088
Final R indexes [I>=2σ (I)]	R_1 = 0.0306, wR_2 = 0.0702
Final R indexes [all data]	R_1 = 0.0327, wR_2 = 0.0711
Largest diff. peak/hole / e $Å^{-3}$	0.18/-0.16
Flack parameter	-0.13(18)

Table ESI-2. Fractional Atomic Coordinates ($\times 10^4$) and Equivalent Isotropic Displacement Parameters ($Å^2 \times 10^3$) for **4l**. U_{eq} is defined as 1/3 of of the trace of the orthogonalised U_{IJ} tensor.

Atom	***x***	***y***	***z***	**U(eq)**
O1	8012(2)	8866(2)	2526.1(3)	33.7(3)
O2	9841(2)	5722.5(14)	1088.7(3)	18.6(2)
O3	11219.7(19)	7200.1(16)	1660.0(3)	20.9(2)
O4	5758(2)	1311.0(16)	1672.2(4)	30.1(3)
C1	8578(3)	7984(2)	2219.7(4)	21.6(3)
C2	7245(3)	6226(2)	2047.4(4)	19.7(3)
C3	6891(3)	6497(2)	1589.1(4)	15.4(3)
C4	6267(3)	4526(2)	1365.5(4)	15.7(3)
C5	8680(3)	3863(2)	1193.5(4)	16.4(3)
C6	9270(3)	7146(2)	1382.7(4)	16.2(3)
C7	10757(3)	8602(2)	1976.1(5)	24.7(3)
C8	5031(3)	2997(2)	1626.5(4)	19.1(3)
C9	8631(3)	2551(2)	822.2(4)	18.6(3)
C10	11130(3)	1847(2)	694.7(4)	19.9(3)
C11	11114(3)	409(2)	336.3(4)	20.7(3)
C12	13603(3)	-477(2)	248.7(4)	21.4(3)
C13	14370(3)	-2023(2)	558.7(5)	25.0(3)

3.2 Determination of the absolute configuration of 6a

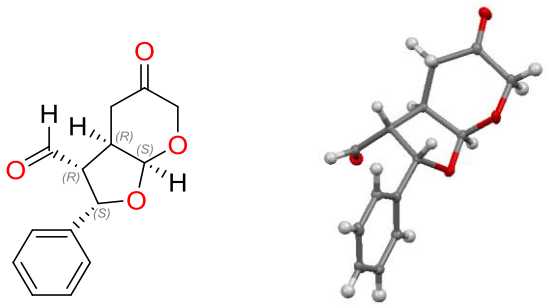


Figure ESI-2. ORTEP diagram for compound **(2*S*,3*R*,3a*R*,7a*S*)-6a**

Crystal data for $C_{14}H_{14}O_4$ (*M* = 246.25 g/mol): CCDC 1525189, monoclynic, space group $P2_1$ (no.4), *a* = 9.16074(6) Å, *b* = 6.01447(4) Å, *c* = 10.6243(1) Å, *γ* = 92.0730(10)º, *V* = 584.984(10) Å^3, *Z* = 2, *T* = 100(2) K, μ(CuKα) = 0.849 mm^{-1}, *Dcalc* = 1.398 g/cm^3, 21603 reflections measured (8.32º ≤ 2Θ ≤ 143.96º), 2281 unique (R_{int} = 0.0556, R_{sigma} = 0.0187) which were used in all calculations. The final R_1 was 0.0266 (I > 2σ(I)) and wR_2 was 0.0716 (all data).

Table ESI-3. Crystal data and structure refinement for **6a**.

Empirical formula	$C_{14}H_{14}O_4$
Formula weight	246.25
Temperature/K	100(2)
Crystal system	
Space group	$P2_1$
a/Å	9.16074(6)
b/Å	6.01447(4)
c/Å	10.6243(1)
α/°	90
β/°	92.0730(10)
γ/°	90
Volume/Å^3	584.984(8)
Z	2
ρ_{calc}g/cm^3	1.398
μ/mm^{-1}	0.849
F(000)	260.0
Crystal size/mm^3	0.234 × 0.1168 × 0.0601
Radiation	CuKα (λ = 1.54184)
2Θ range for data collection/°	8.32 to 143.96
Index ranges	-11 ≤ h ≤ 11, -7 ≤ k ≤ 7, -12 ≤ l ≤ 13
Reflections collected	21603
Independent reflections	2281 [R_{int} = 0.0556, R_{sigma} = 0.0187]
Data/restraints/parameters	2281/1/163
Goodness-of-fit on F^2	1.073
Final R indexes [I>=2σ (I)]	R_1 = 0.0266, wR_2 = 0.0714
Final R indexes [all data]	R_1 = 0.0267, wR_2 = 0.0716
Largest diff. peak/hole / e Å^{-3}	0.21/-0.17
Flack parameter	-0.03(13)

Table ESI-4. Fractional Atomic Coordinates ($\times 10^4$) and Equivalent Isotropic Displacement Parameters ($Å^2 \times 10^3$) for **6a**. U_{eq} is defined as 1/3 of of the trace of the orthogonalised U_{IJ} tensor.

Atom	***x***	***y***	***z***	**U(eq)**
O2	1409.5(9)	3845.0(14)	2425.7(8)	19.66(19)
O1	5804.7(9)	-1290.5(18)	4098.4(9)	29.7(2)
O3	3780.0(9)	2754.4(16)	2329.3(8)	23.1(2)
O4	-595.6(10)	1779.4(15)	4877.0(9)	26.9(2)
C11	-2851.2(12)	2055(2)	-99.4(11)	21.9(3)
C6	2595.5(12)	3050.0(19)	3160.1(11)	17.7(2)
C10	-1528.8(12)	1380(2)	468.3(11)	18.9(2)
C14	-1486.9(13)	4664(2)	1757.8(12)	20.8(2)
C13	-2800.1(14)	5350(2)	1172.7(13)	24.1(3)
C8	-648.4(12)	751.2(19)	3903.3(11)	19.2(2)
C9	-836.7(12)	2687(2)	1392.7(10)	16.4(2)
C1	4799.9(12)	-230(2)	3619.4(11)	19.8(2)
C5	623.2(12)	1937.9(19)	1943.8(11)	16.1(2)
C3	2130.3(11)	826.3(18)	3747.0(11)	14.6(2)
C4	639.3(12)	326.9(17)	3086.7(10)	15.0(2)
C2	3244.8(12)	-1032(2)	3546.4(11)	18.9(2)
C12	-3476.0(13)	4060(2)	244.2(12)	23.7(3)
C7	5053.0(12)	1995(2)	3005.7(12)	22.6(3)

3.2 Determination of the absolute configuration of 9a (obtained from 5a)

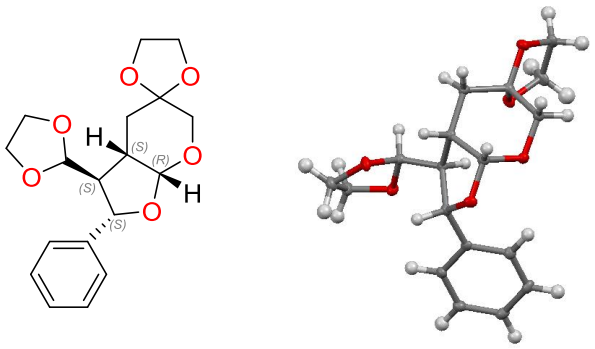


Figure ESI-3. ORTEP diagram for compound **(2*S*,3*S*,3a*S*,7a*R*)-9a**

Crystal data for $C_{14}H_{14}O_4$ (*M* = 246.25 g/mol): CCDC 1525190, monoclynic, space group $P2_1$ (no.4), *a* = 9.16074(6) Å, *b* = 6.01447(4) Å, *c* = 10.6243(1) Å, *γ* = 92.0730(10)°, *V* = 584.984(10) Å^3, *Z* = 2, *T* = 100(2) K, μ(CuKα) = 0.849 mm^{-1}, *Dcalc* = 1.398 g/cm^3, 21603 reflections measured (8.32° ≤ 2Θ ≤ 143.96°), 2281 unique (R_{int} = 0.0556, R_{sigma} = 0.0187) which were used in all calculations. The final R_1 was 0.0266 (I > 2σ(I)) and wR_2 was 0.0716 (all data).

Table ESI-5. Crystal data and structure refinement for **11**.

Empirical formula	$C_{18}H_{22}O_6$
Formula weight	334.37
Temperature/K	100.15
Crystal system	orthorhombic
Space group	$P2_12_12_1$
a/Å	8.96150(9)
b/Å	10.02283(10)
c/Å	17.71277(19)
α/°	90
β/°	90
γ/°	90
Volume/Å^3	1590.95(3)
Z	4
ρ_{calc}g/cm^3	1.3959
μ/mm^{-1}	0.869
F(000)	714.6
Radiation	Cu Kα (λ = 1.54184)
2Θ range for data collection/°	9.98 to 144.88
Index ranges	-11 ≤ h ≤ 11, -12 ≤ k ≤ 12, -22 ≤ l ≤ 22
Reflections collected	31492
Independent reflections	3160 [R_{int} = 0.0406, R_{sigma} = 0.0167]
Data/restraints/parameters	3160/0/216
Goodness-of-fit on F^2	1.063
Final R indexes [I>=2σ (I)]	R_1 = 0.0246, wR_2 = 0.0631
Final R indexes [all data]	R_1 = 0.0255, wR_2 = 0.0638
Largest diff. peak/hole / e Å^{-3}	0.16/-0.19
Flack parameter	0.06(11)

Table ESI-6. Fractional Atomic Coordinates ($\times 10^4$) and Equivalent Isotropic Displacement Parameters ($Å^2 \times 10^3$) for **11**. U_{eq} is defined as 1/3 of of the trace of the orthogonalised U_{IJ} tensor.

Atom	***x***	***y***	***z***	**U(eq)**
O1	-5087.7(10)	-6750.8(8)	-2084.2(5)	22.56(18)
O4	-5669.8(9)	-7465.3(8)	-3261.3(4)	20.22(18)
O12	-10414.8(9)	-8928.2(8)	-2939.8(4)	19.72(18)
O15	-10756.4(10)	-5542.3(9)	-3983.2(5)	22.97(19)
O8	-7985.3(9)	-9191.8(8)	-2588.4(5)	18.85(17)
O16	-9504.7(10)	-6530.9(8)	-4944.9(4)	20.27(17)
C20	-9402.6(14)	-10750.2(11)	-4041.7(6)	20.4(2)
C5	-6739.3(14)	-8653.4(12)	-2188.6(7)	20.4(2)
C17	-10123.7(12)	-9575.9(11)	-4253.6(6)	16.8(2)
C11	-9062.9(12)	-7358.0(11)	-3691.3(6)	15.4(2)
C13	-9381.5(13)	-6155.3(11)	-4179.8(6)	17.4(2)
C21	-10709.7(13)	-9477.4(12)	-4980.1(7)	21.6(2)
C9	-8988.8(12)	-6998.8(11)	-2845.6(6)	16.0(2)
C22	-9293.5(15)	-11811.5(12)	-4544.8(7)	23.0(2)
C1BA	-7563.0(12)	-6353.1(11)	-2544.4(6)	17.0(2)
C24	-9878.5(14)	-11707.1(12)	-5268.5(7)	22.3(2)
C10	-9277.3(13)	-8363.7(11)	-2504.7(7)	18.0(2)
C2	-6259.7(12)	-7311.0(11)	-2524.5(6)	17.4(2)
C14	-10311.2(12)	-8423.4(11)	-3707.9(6)	17.2(2)
C3	-3715.2(13)	-7251.3(13)	-2392.1(8)	24.9(3)
C18	-11437.5(15)	-5089.4(14)	-4670.9(7)	26.2(3)
C23	-10574.2(14)	-10532.7(13)	-5484.8(7)	23.7(2)
C7	-4096.7(14)	-7681.7(17)	-3190.7(8)	33.0(3)
C19	-10318.3(14)	-5453.7(12)	-5280.2(7)	24.0(3)

4. Computational Methods

All of the calculations were performed using the Gaussian09 program.[3] Molecular geometries were optimized with the M06-2X functional,[4] in conjunction with cc-pVTZ basis set, a triple-ζ quality set.[5] This combination of functional and basis has demonstrated to give acceptable geometries and energies quantitatively consistent with higher levels estimating that errors due to BSSE (basis set superposition error) differences between stereoisomers can be of the order of 0.2 kcal/mol for TZVP basis.[6] Therefore is strongly recommended for calculating energy differences between alternative transition states in stereoselective organocatalytic reactions.[7] Moreover, M06-2X functional performs well for systems with dispersion and ionic hydrogen-bonding interactions,[8] and in conjunction with minimally augmented basis sets such as cc-pVTZ.All calculations have been carried out considering solvent effects ($CHCl_3$) with the PCM model.[9] Analytical second derivatives of the energy were calculated to classify the nature of every stationary point, to determine the harmonic vibrational frequencies, and to provide zero-point vibrational energy corrections. The thermal and entropic contributions to the free energies were also obtained from the vibrational frequency calculations, using the unscaled frequencies. All discussions are based on values of free energies (G). However, several of the individual reactions involved on the study are bimolecular processes. In order to avoid errors due to entropic effects when comparing all stationery points in an only energy diagram, we used corrected free energy (G_{corr}) values following Sasaki's model.[10] Translational and rotational degrees of freedom in solution are highly suppressed owing to the interactions with solvent molecules and these interactions are not well-estimated by continuum solvent models like PCM; in consequence, thermodynamic corrections to potential energies calculated by using continuum solvation models overestimate the contributions of translational and rotational degrees of freedom to the entropy.[11] According to Sasaki's model only vibrational contributions to entropy must be considered calculating free energy as follows:

$$\Delta G_{corr} = \Delta H - T \cdot \Delta S_{vib}$$

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[3] M. J. Frisch, G. W. Trucks, H. B. Schlegel, G. E. Scuseria, M. A. Robb, J. R. Cheeseman, G. Scalmani, V. Barone, B. Mennucci, G. A. Petersson, H. Nakatsuji, M. Caricato, X. Li, H. P. Hratchian, A. F. Izmaylov, J. Bloino, G. Zheng, J. L. Sonnenberg, M. Hada, M. Ehara, K. Toyota, R. Fukuda, J. Hasegawa, M. Ishida, T. Nakajima, Y. Honda, O. Kitao, H. Nakai, T. Vreven, J. J. A. Montgomery, J. E. Peralta, F. Ogliaro, M. Bearpark, J. J. Heyd, E. Brothers, K. N. Kudin, V. N. Staroverov, R. Kobayashi, J. Normand, K. Raghavachari, A. Rendell, J. C. Burant, S. S. Iyengar, J. Tomasi, M. Cossi, N. Rega, J. M. Millam, M. Klene, J. E. Knox, J. B. Cross, V. Bakken, C. Adamo, J. Jaramillo, R. Gomperts, R. E. Stratmann, O. Yazyev, A. J. Austin, R. Cammi, C. Pomelli, J. W. Ochterski, R. L. Martin, K. Morokuma, V. G. Zakrzewski, G. A. Voth, P. Salvador, J. J. Dannenberg, S. Dapprich, A. D. Daniels, Ö. Farkas, J. B. Foresman, J. V. Ortiz, J. Cioslowski, D. J. Fox, Gaussian, Inc., Wallingford CT,: 2009.

[4] Y. Zhao, D. G. Truhlar, *Acc. Chem. Res.*, 2008, **41**, 157-167.

[5] (a) T. H. Dunning Jr., *J. Chem. Phys.*, 1989, **90**, 1007-1023. (b) R. A. Kendall, T. H. Dunning Jr., R. J. Harris, *J. Chem. Phys.*, 1992, **96**, 6796-6806. (c) D. E. Woon, T. H. Dunning Jr., *J. Chem. Phys.*, 1993, **98**, 1358-1371.

[6] A. Armstrong, R. A. Boto, P. Dingwall, J. Contreras-Garcia, M. J. Harvey, N. J. Masona, H. S. Rzepa, *Chem. Sci.*, 2014, **4**, 2057-2071.

[7] S. Schenker, C. Schneider, S. B. Tsogoeva, T. Clark, *J. Chem. Theory Comp.*, 2011, **7**, 3586-3595

[8] M. Walker, A. J. A. Harvey, A. Sen, C. E. H. Dessent, *J. Phys. Chem. A*, 2013, **117**, 12590

[9] (a) V. Barone, M. Cossi, J. Tomasi, *J. Comput. Chem.*, 1998, **19**, 404-417. (b) M. Cossi, G. Scalmani, N. Rega, V. Barone, *J. Chem. Phys.*, 2002, **117**, 43-54. (c) J. Tomasi, M. Persico, *Chem. Rev.*, 1994, **94**, 2027-2094.

[10] (a) M. Sumimoto, N. Iwane, T. Takahama, S. Sakaki, *J. Am. Chem. Soc.*, 2004, **126**, 10457-10471. (b) H. Tamura, H. Yamazaki, H. Sato, S. Sakaki, *J. Am. Chem. Soc.*, 2003, **125**, 16114-16126.

[11] E. Buncel, R. A. Stairs, *Solvent effects in Chemistry. 2nd ed*. Wiley: Hoboken, 2016. pp.135-136.

It has been demonstrated that ΔG_{corr} is closer to the experimentally derived ΔG that the uncorrected calculated free energy.[12] All transition structures were characterized by one imaginary frequency. All the located TSs were confirmed to connect to reactants and products by intrinsic reaction coordinate (IRC) calculations.[13] The IRC paths were traced using the Hratchian-Schlegel algorithm.[14] NCI (non-covalent interactions) were computed using the methodology previously described.[15] Data were obtained with the NCIPLOT program.[16] A density cutoff of ρ=0.2 a.u. was applied and the pictures were created for an isosurface value of s=0.5 and colored in the [-0.3,0.3] a.u. sign(λ_2)ρ range using VMD software.[17] Molecular graphics have been performed with CYLview 1.0 software.[18]

[12] C. T. Liu, C. I. Maxwell, D. R. Edwards, A. A. Neverov, N. J. Mosey, R. S. Brown, *J. Am. Chem. Soc.*, 2010, **132**, 16599-16609.

[13] (a) K. Fukui, *J. Phys. Chem.*, 1970, **74**, 4161-4163. (b) K. Fukui, *Acc. Chem. Res.*, 1981, **14**, 363-368.

[14] H. P. Hratchian, H. B. Schlegel, *J. Phys. Chem. A*, 2002, **106**, 165-169.

[15] (a) E. R. Johnson, S. Keinan, P. Mori-Sanchez, J. Contreras-Garcia, A. J. Cohen, W. Yang, *J. Am. Chem. Soc.*, 2010, **132**, 6498-6506. (b) J. R. Lane, J. Contreras-Garcia, J.-P. Piquemal, B. J. Miller, H. G. Kjaergaard, *J. Chem. Theory Comput.*, 2013, **9**, 3263-3266.

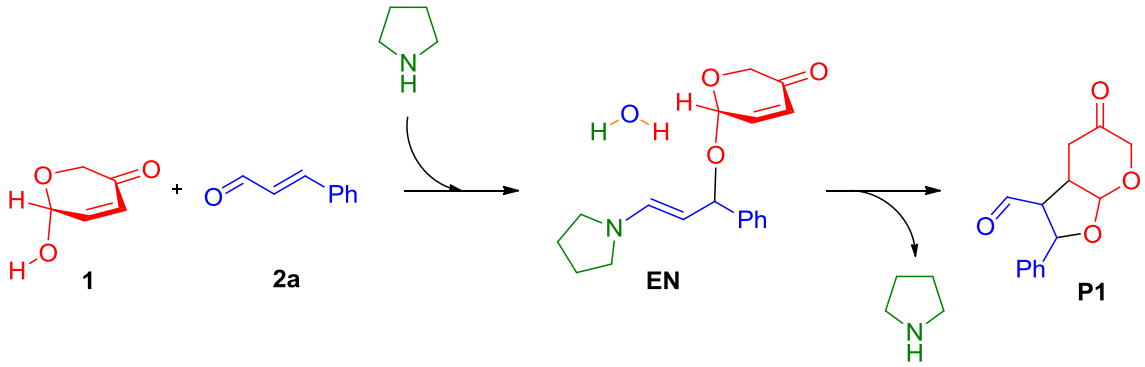
[16] J. Contreras-Garcia, E. R. Johnson, S. Keinan, R. Chaudret, J.-P. Piquemal, D. N. Beratan, W. Yang, *J. Chem. Theory Comput.*, 2011, **7**, 625-632.

[17] W. Humphrey, A. Dalke, K. Schulten, *J. Mol. Graph.*, 1996, **14**.

[18] C. Y. Legault, *Université de Sherbrooke* 2009, http://www.cylview.org.

4.1. Preliminary Studies with racemic and achiral systems

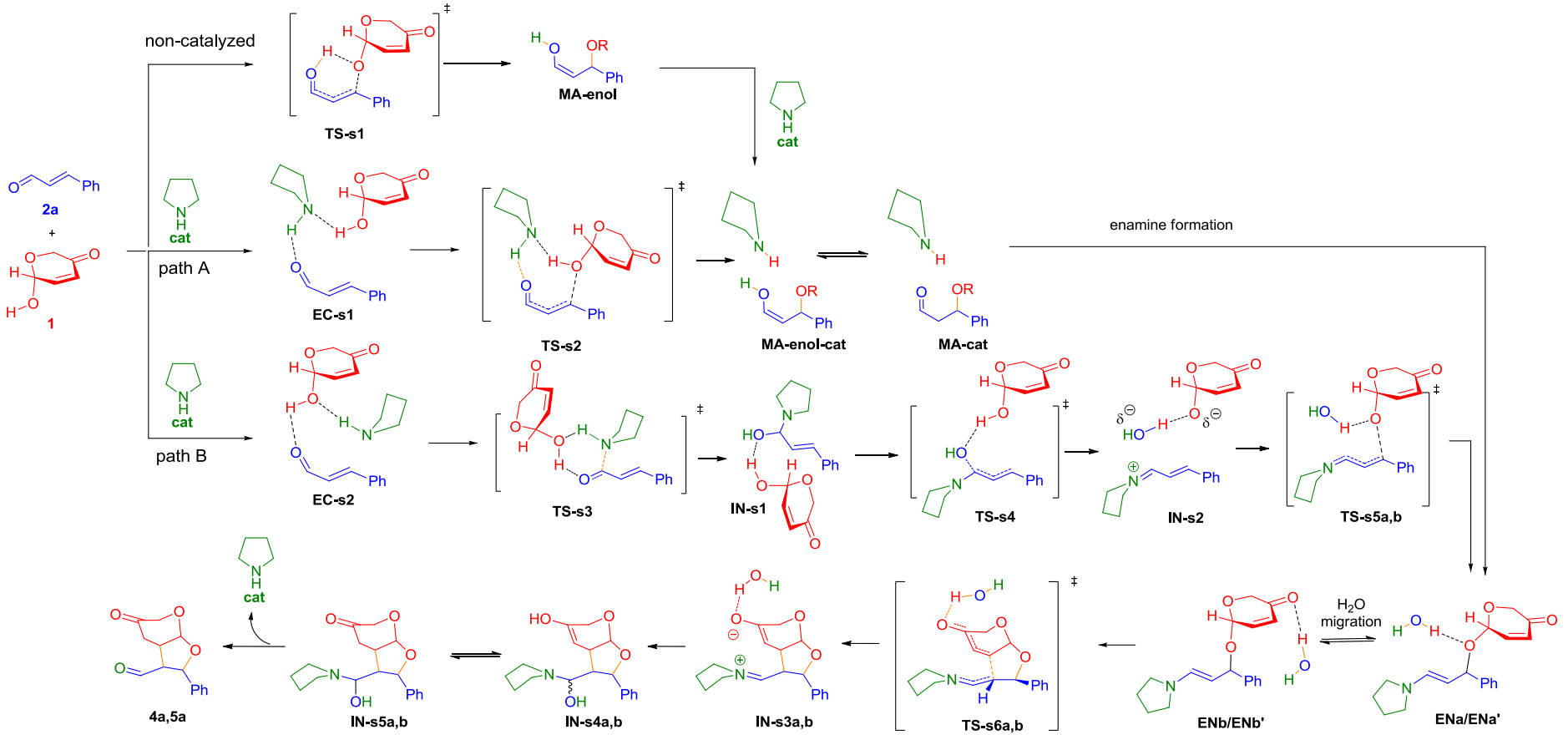
A series of preliminary studies with achiral systems (using pyrrolidine as a catalyst) were carried out in order to determine the exact mechanism of the reaction between **1** and **2a**, and the required approaches to reach the real catalytic system (Scheme ESI-4).



Scheme ESI-4. Reaction between alcohol **1** and aldehyde **2**, catalyzed by pyrrolidine.

Several different pathways are possible for the first step of the reaction (Michael addition) leading to intermediate enamine **ENa** which finally evolves to the final products **P1** (Scheme ESI-5). The uncatalyzed reaction leads to enol **MA-enol**- This enol, after tautomerization can interact with the catalyst to afford the intermediate enamine **EN**. Path A involves participation of the catalyst by forming encounter complex **EC-s1** but without formation of iminium salt, also leading to **MA-enol** through the corresponding transition structure **TS-s2**. A similar situation has been described by Lattanzi, Peluso and co-workers for the epoxidation of enones catalyzed by α,α-L-diarylprolinols.[19] Finally, path B illustrates a different encounter complex **EC-s2** in which formation of the hemiaminal is facilitated by the alcohol. The formation of iminium salt **IN-s2** also required the assistance of the alcohol and formation of enamine **ENa** takes place in two steps through **TS-s4** and **TS-s5a,b**. A direct transition structure from **IN-s1** to **ENa** was not found after exhaustive exploration of PES. It should have been taken into consideration that there are two possible transition structures **TS-s5** since enantiomeric alcohols can generate diastereomeric enamines **ENa** and **ENA'**. After formation of enamine **EN** the second step of the reaction consists of a second intramolecular Michael addition, through **TS-s6a,b** (also two diastereotopic attacks are possible), leading to **IN-s3a,b**. Further evolution of these intermediates furnish the final adducts **P1a,b**. Next, computational analyses of each path is described.

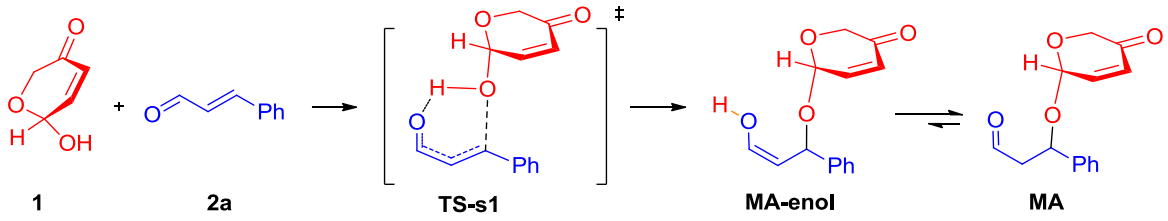
[19] A. Capobianco, A. Russo, A. Lattanzi, A. Peluso, *Adv. Synth. Catal.*, 2012, **354**, 2789-2796.



Scheme ESI-5. Different pathways for the reaction between **1** and **2a**.

4.2.1. Uncatalyzed reaction

The uncatalyzed reaction between **1** and **2a** was calculated (Scheme ESI-6). The reaction showed a typical concerted transfer of proton with a free energy barrier of 20.0 kcal/mol (Table ESI-7, Figure ESI-4).



Scheme ESI-6. Uncatalyzed reaction between alcohol **1** and aldehyde **2a**.

Table ESI-7. Calculated (M06-2X/cc-pVTZ/PCM=$CHCl_3$) absolute (hartrees) and relative (kcal/mol) energies of the stationary points corresponding to the reaction between alcohol **1** and aldehyde **2a**.

	E_0	ΔE_0 [a]	G	ΔG [a]	im. freq
1	-419.671437		-419.668541		
2a	-422.804905		-422.803286		
TS-s1	-842.438973	23.4	-842.439994	20.0	-1022.8
MA-enol	-842.468764	4.8	-842.469374	1.5	
MA	-842.476680	-0.2	-842.478156	-4.0	

[a] Referred to isolated starting materials (**1**+**2a**)

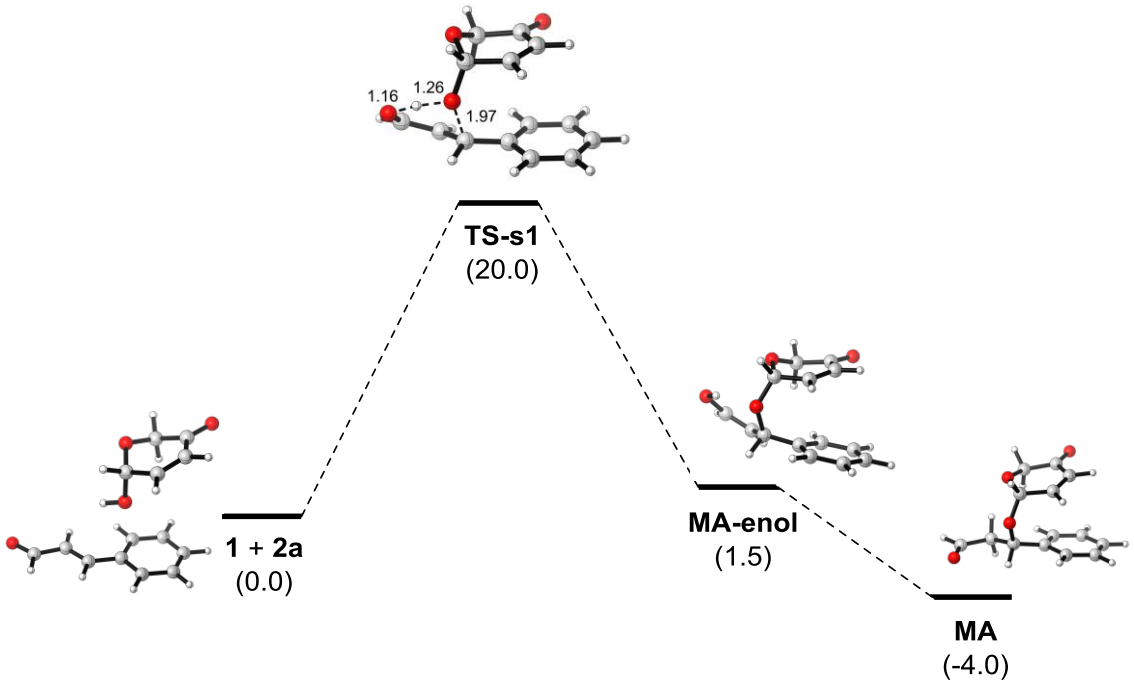


Figure ESI-4. Uncatalyzed reaction between **1** and **2a**. Distances are given in ångstrøms. Relative energies are given in kcal/mol

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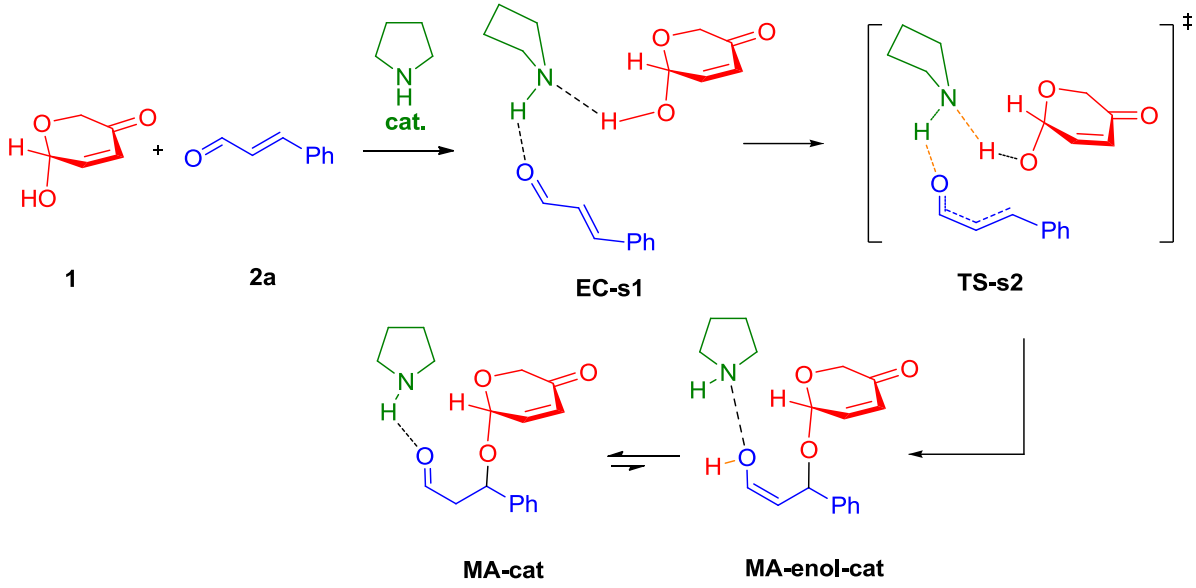
4.2.2. Non-covalent activation of reactants (path A)

Alcohol **1** and aldehyde **2a** form encounter complex **EC-s1** with the catalyst, without barrier and located at 25.9 kcal/mol below the ground state in agreement with that suggested by Lattanzi, Peluso and co-workers for the epoxidation of enones catalyzed by diarylprolinols.[19] That activated encounter complex leads to adduct **MA-enol-cat** through **TS-s2**, located 3 kcal/mol below the ground state. (Scheme ESI-7). This process does not involve the formation of an iminium intermediate but the non-covalent activation of the reactants. The corresponding transition structure showed an energy barrier of 20.0 kcal/mol (Table ESI-8, Figure ESI-5).



Scheme ESI-7. Catalyzed reaction between alcohol **1** and aldehyde **2a** through non-covalent activation of the reactants.

Table ESI-8. Calculated (M06-2X/cc-pVTZ/PCM=$CHCl_3$) absolute (hartrees) and relative (kcal/mol) energies of the stationary points corresponding to the reaction between alcohol **1** and aldehyde **2a** through non-covalent activation of the reactants.

	E_0	ΔE_0 [a]	G	ΔG [a]	im. freq
1	-419.671437		-419.668541		
2a	-422.804905		-422.803286		
Cat.	-212.427811		-212.425118		
EC-s1	-1054.929601	-16.0	-1054.938165	-25.9	
TS-s2	-1054.896396	4.9	-1054.901734	-3.0	-318.0
MA-enol-cat	-1054.916319	-7.6	-1054.921275	-15.3	
MA-cat	-1054.919012	-9.3	-1054.929534	-20.4	

[a] Referred to isolated starting materials (**1**+**2a**). A molecule of catalyst has been added when necessary.

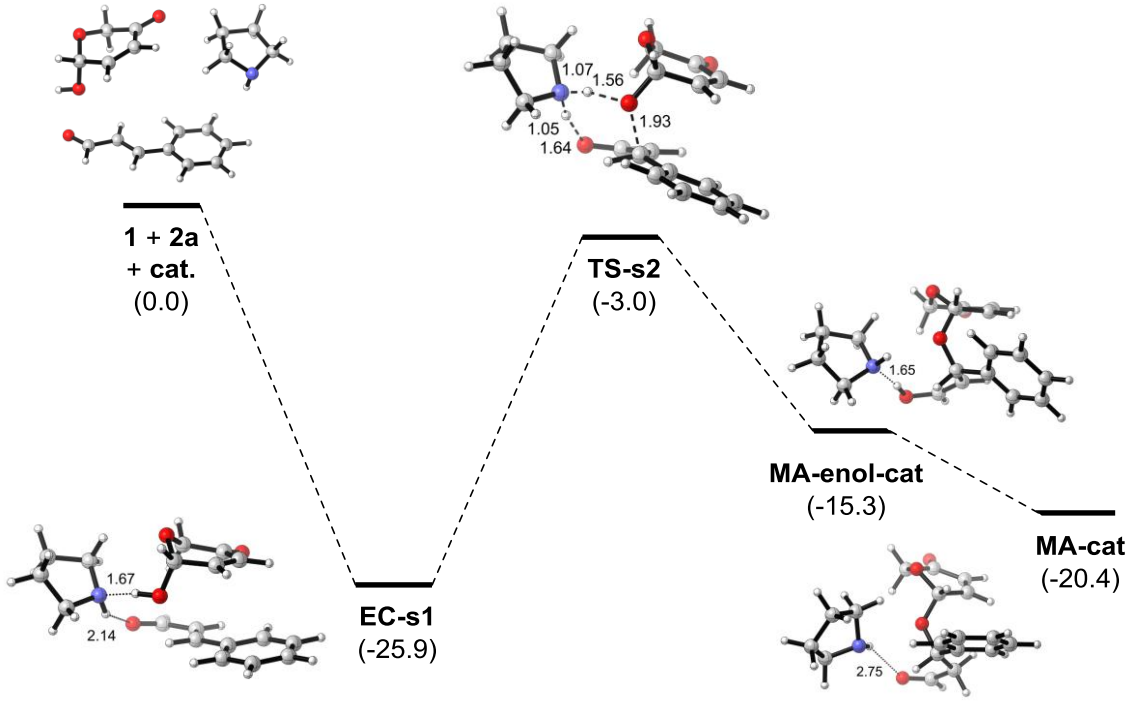


Figure ESI-5. Catalyzed reaction between alcohol **1** and aldehyde **2a** through non-covalent activation of the reactants. Distances are given in ångstrøms. Relative energies are given in kcal/mol.

Given the importance of non-covalent interactions in this approach we also carried out a NCI analysis of **EC-s1** and **TS-s2** (Figure ESI-6). The topological analysis clearly shows H-bond interactions (blue discs) between aldehyde, alcohol and catalyst. Interestingly, important London interactions (π,π-stacking) between the unsaturated systems of alcohol and aldehyde are also evidenced (green surfaces). These interactions are observed in encounter complex **EC-s1** and they are maintained in **TS-s2**. In the transition state the forming bond is also evidenced (blue-red disc).

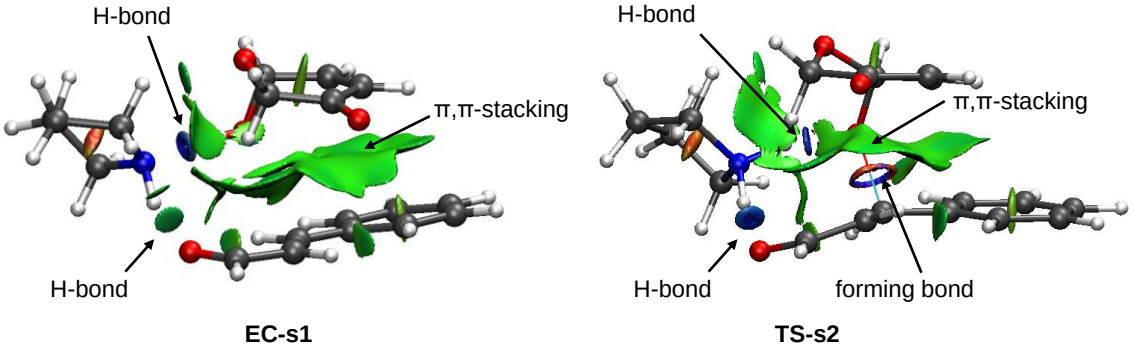
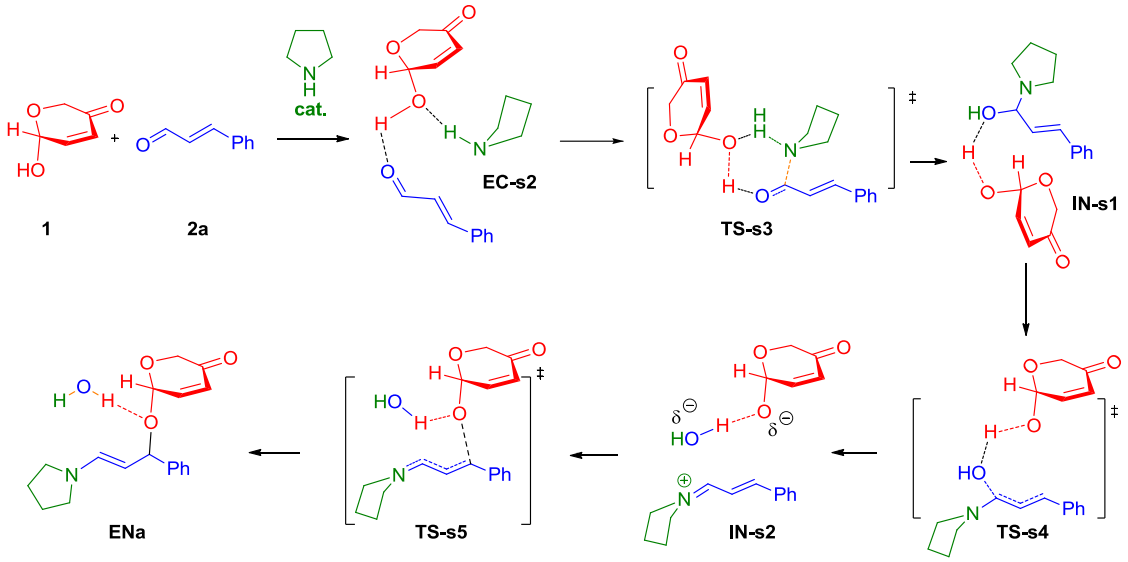


Figure ESI-6. NCI analysis of **TS-s2**.

4.2.3. Hemiaminal route (path B)

Alcohol **1** and aldehyde **2a** form encounter complex **EC-s2** with the catalyst, without barrier and located at 22.3 kcal/mol below the ground state. That activated encounter complex leads to hemiaminal in complex with **1** **IN-s1** through **TS-s3**, located 18.5 kcal/mol below the ground state. (Scheme ESI-8). Complex **IN-s1** further evolves to the intermediate iminium salt **IN-s2** via **TS-s4** (10.3 kcal/mol below the ground state). Thus, alcohol can act as an co-catalyst[20] to promote formation of the iminium salt by i) forming the initial hemiaminal[21] and ii) facilitating elimination of water. In fact, such elimination of water is crucial in the following rate-limiting step in which the Michael addition takes place through **TS-s5** to give enamine **ENa**.



Scheme ESI-8. Catalyzed reaction between alcohol **1** and aldehyde **2a** via formation of iminium salt.

The addition of two enantiomeric alcohols (*R*)-**1** and (*S*)-**1** by one face of the iminium ion (the *trans*-configuration is the most stable one) gives rise to two diastereomers. Consequently, this step is determinant for the diastereoselectivity of the reaction involving a kinetic resolution of the two alcohols. Since both alcohols can racemize (see below) the process is, actually a DKR (Scheme ESI-9).

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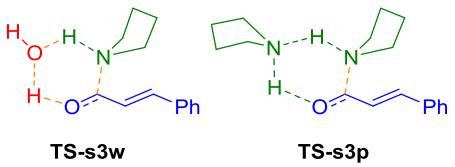
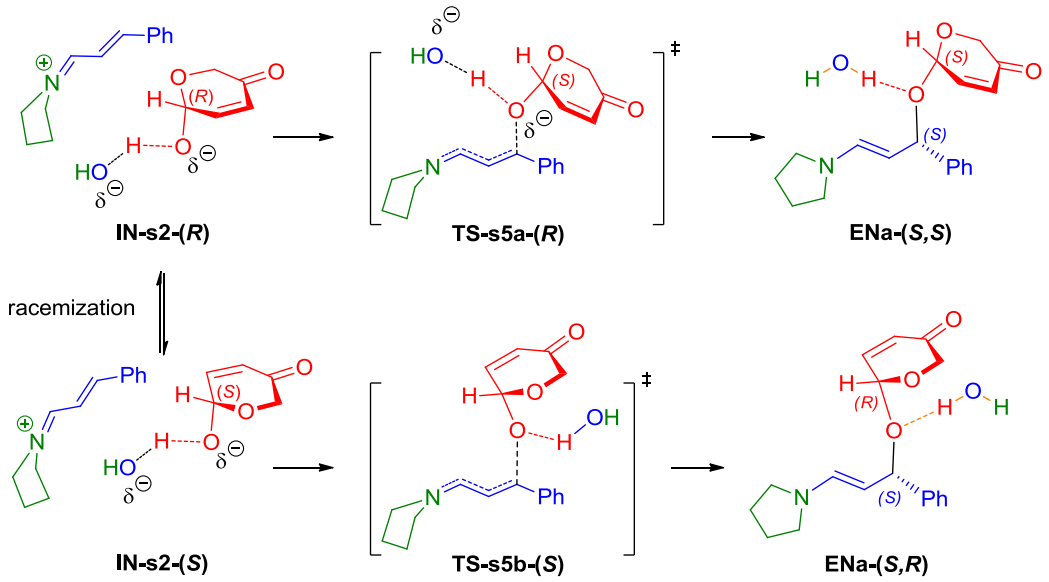
[20] It has been reported and computationally studied that protic co-catalysts can lower the barriers significantly. See: M. P. Patil, R. B. Sunoj, *Chem. Asian J.*, 2009, **4**, 714-724. In our case, compound **1** can also assume the role of a co-catalyst.

[21] We have also calculated alternative transition structures for initial formation of hemiaminal in **IN-s1** promoted by a molecule of water (**TS-s3w**) or by a second molecule of catalyst (pyrrolidine) (**TS-s3p**). However, these transition structures are either less favored or further decoordination of water/pyrrolidine and re-coordination of alcohol to furnish coomplex **IN-s1** requires more energy.





Scheme ESI-9. DKR in the reaction between alcohols (*R*)-**1** and (*S*)-**1**and iminium salt derived from **2a**.

After exhaustive exploration of the PES we determined the most stable transition structures for each approach, resulting in a difference of 0.9 kcal/mol in favor of **TS-s5b-(S)** (Figure ESI-7).[22] Optimized geometries of both transition structures are given in Figure S4. Since we are studying the reactivity in achiral series, we will continue the study with the most stable **TS-s5b-(S)**.[23]

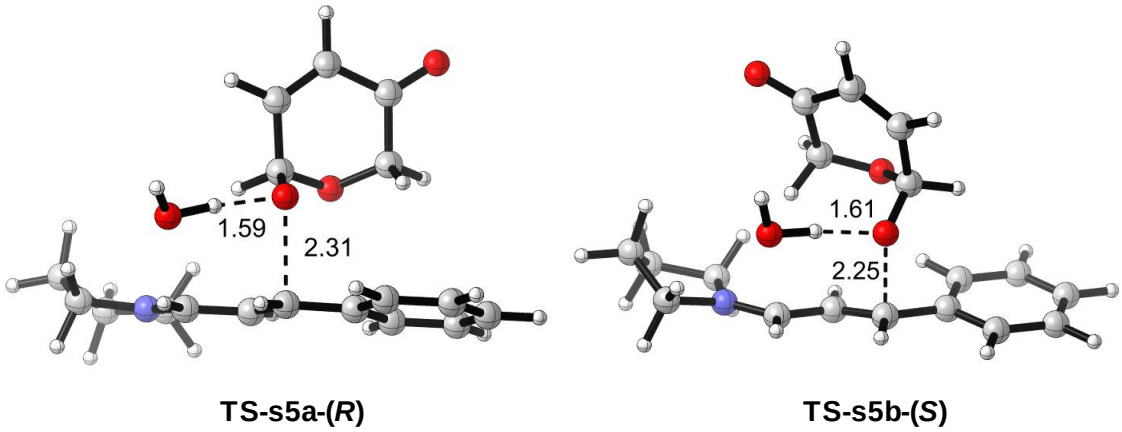


Figure ESI-7. Optimized geometries (M06-2X/cc-pVTZ/PCM=$CHCl_3$) of transition structures corresponding to the DKR in the formation of intermediate enamine.

[22] Although the difference (below 1.0 kcal/mol) is in the limit of error for the used level of theory we can predict a d.r. of ca. 4:1 in favor of **ENa**-(*R*,*R*). During PES exploration we also located up to 3 different transition structures per approach. A Bolztmann's distribution of the totality of transition structures afforded the same d.r value

[23] At this point, it has no sense to evaluate any prediction concerning absolute configurations since the whole system, including chiral catalyst, is required. The achiral study serves to determine the preferred path, relative diastereoselectivity (although it might change) and evaluate the catalytic cycle. Sereoselectivity (both diastereo and eantio) should also be studied with the full chiral model representing the real system studied experimentally.

A diagram energy for the formation of intermediate enamine **ENa-(*R*,*R*)**, including paths A and B for the purpose of comparison, is given in Figure ESI-8.

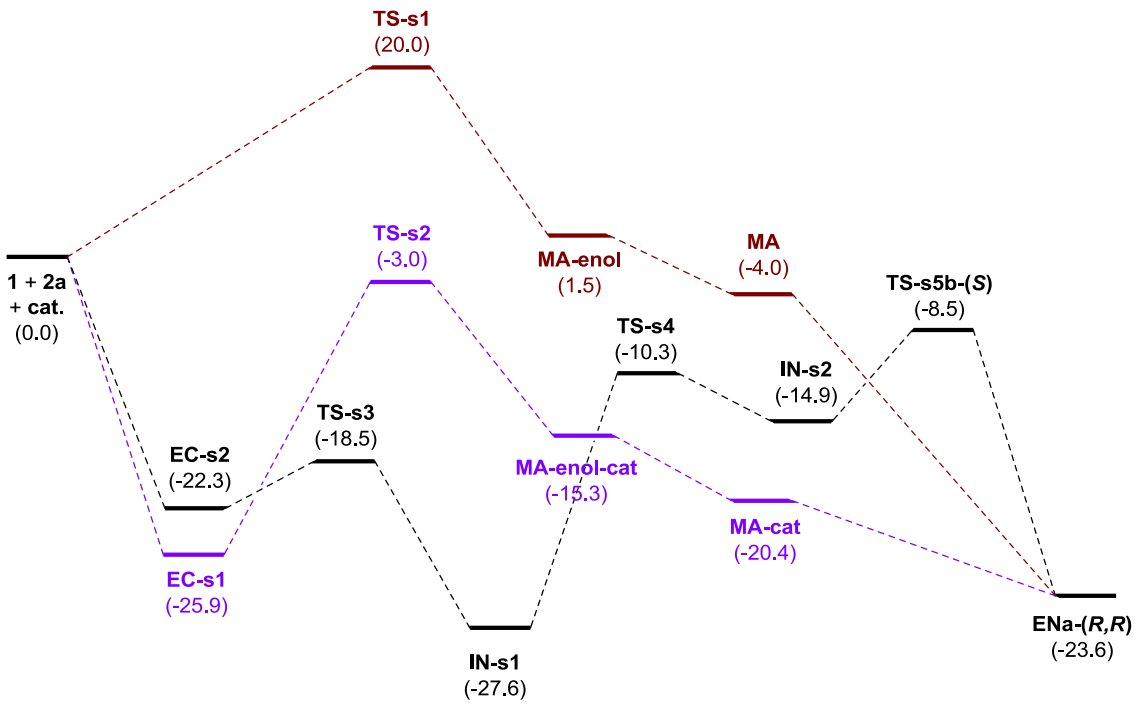
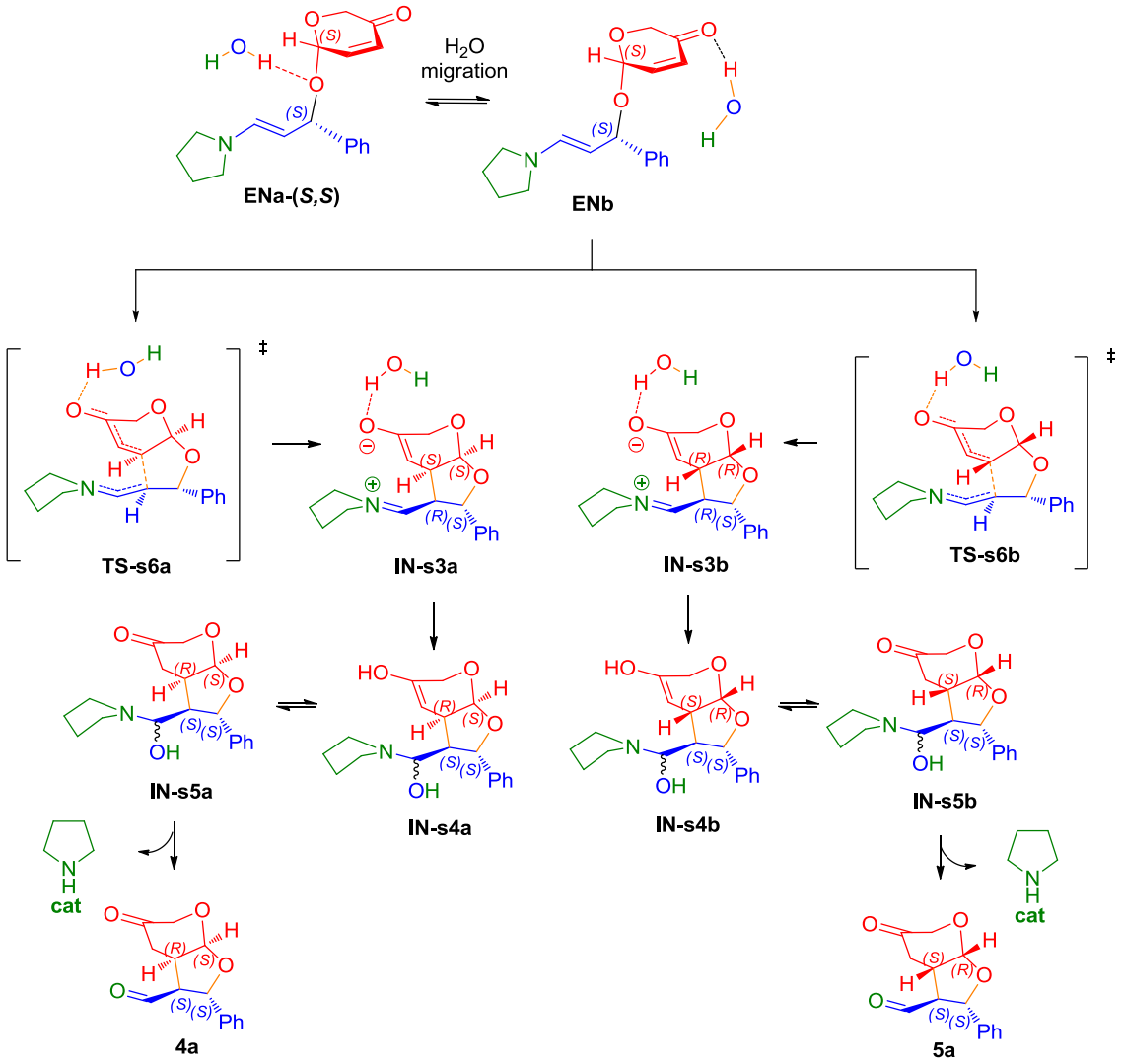


Figure ESI-8. Energy diagram of the reactions between alcohol **1** and aldehyde **2a** to form intermediate enamine. Red: uncatalyzed reaction; magenta: via non-covalent activation of reactants; black: via iminium ion. Relative energies are given in kcal/mol.

Actually, **ENa-(*R*,*R*)** is a complex between enamine and water that after re-coordination of the water moelecule leads to the productive complex **ENb** (Scheme ESI-10, Table ESI-9). This complex is activated towards the intramolecular Michael addition which can take place by two diastereotopic faces of the α,β-unsaturated system. Thus, two channels are possible, through **TS-s6a** -leading to **P1**- being the preferred one. Final products **P1** and **P2** are produced from intermediate iminium salts **IN-s3a,b** through hydrolysis via intermediate tautomeric hemiaminals **IN-s4a,b** and **IN-s5a,b** (Scheme ESI-10). The rate limiting for the whole process is the oxa-Michael reaction to the iminium salt **IN-s2** (Scheme ESI-9). The energy barrier corresponding to such rate-limiting **TS-s5** is 8.5 kcal/mol below the ground state, the lowest one of the above studied paths so, it is confirmed that path C is the preferred one. Optimized geometries of transition structures **TS-s6a** and **TS-s6b** are given in Figure ESI-9. Absolute and relative energies for all stationary points are given in Table ESI-9. A energy diagram for this part of the reaction is given in Figure ESI-10.



Scheme ESI-10. Second step of the reaction between **1** and **2a** catalyzed by pyrrolidine.

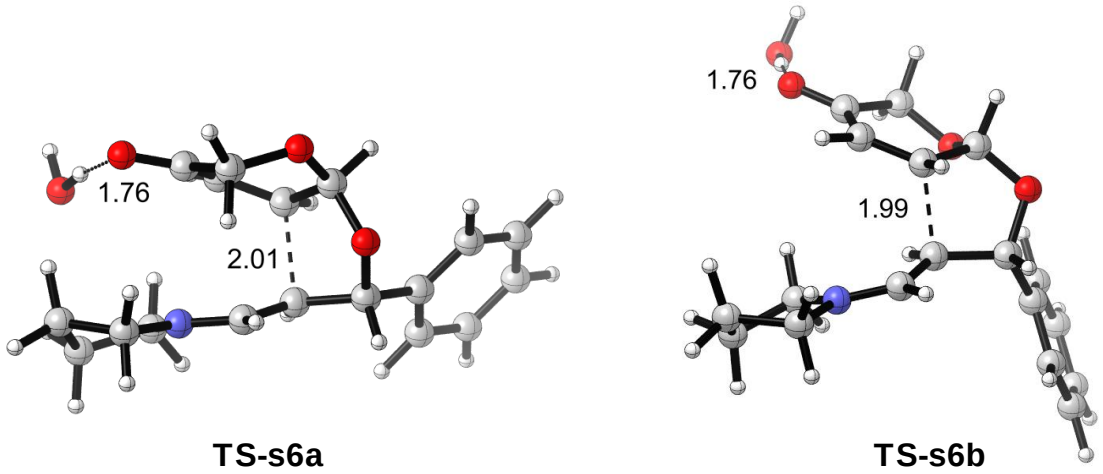


Figure ESI-9. Optimized geometries (M06-2X/cc-pVTZ/PCM=$CHCl_3$) of transition structures corresponding to the second step of the reaction between **1** and **2a**.

Table ESI-9. Calculated (M06-2X/cc-pVTZ/PCM=$CHCl_3$) absolute (hartrees) and relative (kcal/mol) energies of the stationary points corresponding to the reaction between alcohol **1** and aldehyde **2a** via formation of iminium salt.

	E_0	ΔE_0[a]	G	ΔG[a]	im. freq
1	-419.671437		-419.668541		
2a	-422.804905		-422.803286		
Cat.	-212.427811		-212.425118		
EC-s2	-1054.923628	-12.2	-1054.932476	-22.3	
TS-s3	-1054.919995	-9.9	-1054.926400	-18.5	-792.4
IN-s1	-1054.928430	-15.2	-1054.935423	-24.1	
TS-s4	-1054.905854	-1.1	-1054.913418	-10.3	-569.8
IN-s2	-1054.912618	-5.3	-1054.920665	-14.9	
TS-s5-(*S*)	-1054.905280	-0.7	-1054.910526	-8.5	-247.6
ENa-(*R*,*R*)	-1054.928780	-15.5	-1054.934501	-23.6	
ENb	-1054.926833	-14.2	-1054.935265	-24.0	
TS-s6a	-1054.917528	-8.4	-1054.921280	-15.3	-400.3
IN-s3a	-1054.924498	-12.8	-1054.928802	-20.0	
IN-s4a	-1054.948838	-28.0	-1054.952177	-34.7	
IN-s5a	-1054.962341	-36.5	-1054.965070	-42.7	
TS-s6b	-1054.913834	-6.1	-1054.918550	-13.6	-386.1
IN-s3b	-1054.920223	-10.1	-1054.925904	-18.2	
IN-s4b	-1054.953299	-30.8	-1054.956664	-37.5	
IN-s5b	-1054.962955	-36.9	-1054.966801	-43.8	
P1a	-842.508892	-20.4	-842.509948	-23.9	
P1b	-842.510111	-21.2	-842.511516	-24.9	

[a] Referred to isolated starting materials (**1**+**2a**+**cat**). A molecule of catalyst has been added when necessary.

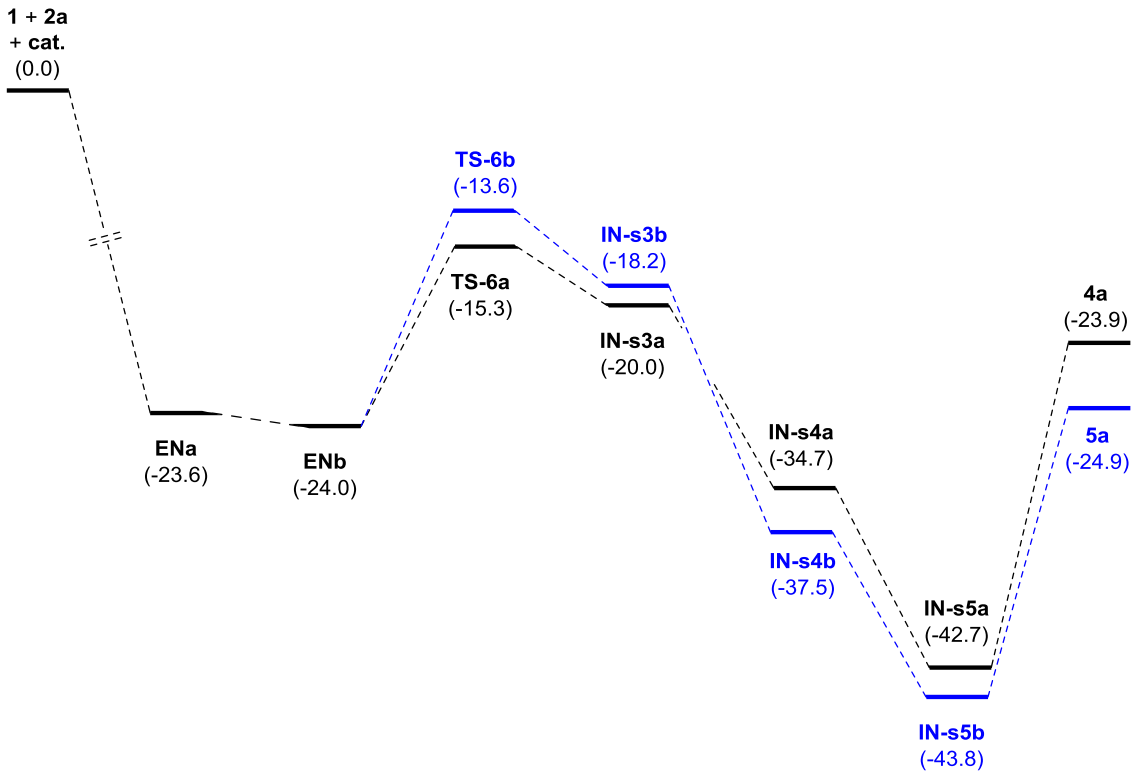


Figure ESI-10. Energy diagram of the second step of the reaction between alcohol **1** and aldehyde **2a**. Relative energies are given in kcal/mol.

From the study of the achiral system it can be concluded that the preferred diastereoselectivity will consist on a relative 2*R**3*R**3*aS**7*aR** configuration, in other words: i) a *trans*-disposition between phenyl and aldehyde groups located at 2- and 3-position, respectively, ii) a *cis* fusion between the six-and five-membered cycles (3a- and 7a-positions), iii) a *cis* disposition between the aldehyde at C-3 and the contiguous bridgehead atom C-3a and iv) a *trans* disposition between the phenyl group at C-3 and the C-7a bridgehead atom. (Figure ESI-11)

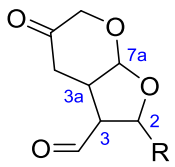


Figure ESI-11. Numbering of final products. Note that absolute configuration can change depending on R

4.3. Real System (path C, chiral catalyst)

We studied two different orientations of the unsaturated chain leading to attacks by different stereofaces of the double bond,[24] the attack of the two enantiomeric alcohols to evaluate DKR and North and South conformations of the pyrrolidine ring[25] Thus, a total of 8 transition structures were located and characterized. Those corresponding to a North conformation of the pyrrolidine ring are always less stable than the corresponding South conformers. Consequently, it remain 4 different approaches to be considered (Figure ESI-12).

The absolute and relative energies as well as the relative abundance of these approaches is collected in Table ESI-10 (South conformations have also been included for comparison). According to the values of free energies it is predicted that essentially only **4** and **5** will be obtained in a ca. 91:9 diastereomeric ratio in qualitative agreement with experimental results since it is necessary to take into account that compound **4** epimerizes to compound **6** (see below). The optimized geometries for the located transition structures corresponding to South conformations of the pyrrolidine ring are given in Figure ESI-13.

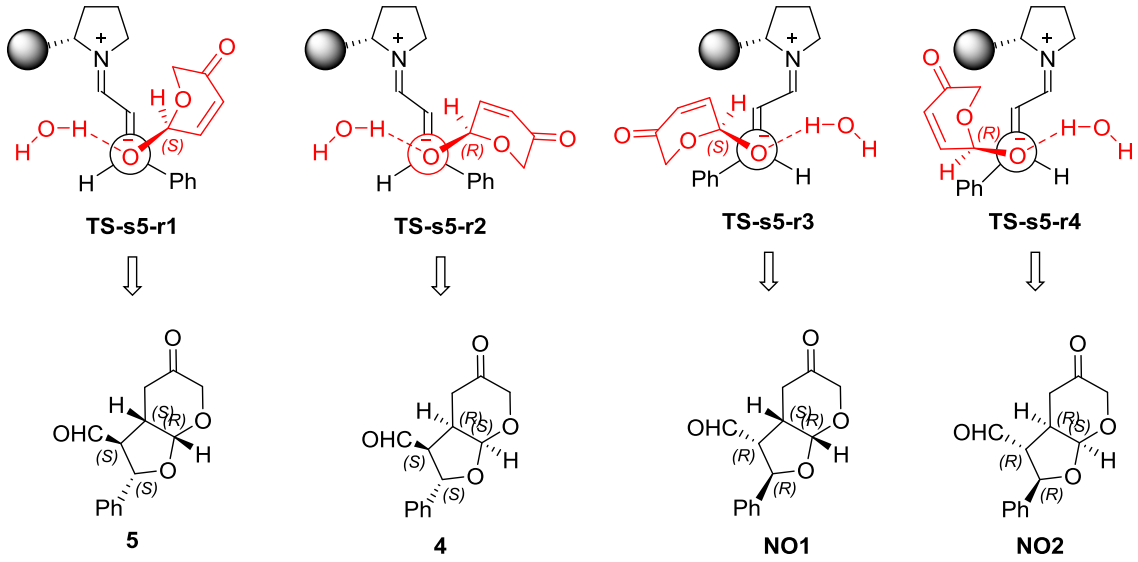


Figure ESI-12. Approaches studied for the real system

[24] Irrelevant in the achiral analysis but necessary with the chiral catalyst

[25] The pyrrolidine ring can adopt two different and almost equivalent conformations, i.e. $^{3}T_{2}$ (called North or N) and $^{2}T_{3}$ (called South or S). The nomenclature is given by analogy with that used in conformational studies of furanoses. See: H. A. Taha, M. R. Richards, T. L. Lowary, *Chem. Rev.*, 2012, **102**, 1851-1876.

Table ESI-10. Calculated (M06-2X/cc-pVTZ/PCM=$CHCl_3$) absolute (hartrees) and relative (kcal/mol) energies of the stationary points corresponding to the reaction between alcohol **1** and aldehyde **2a** via formation of iminium salt.[a]

	E_0	$\Delta\Delta E_0$[b]	G	$\Delta\Delta G$[b]	im. freq	rel. ab. %[c]
TS-s5-r1-S	-2040.596414	0.3	-2039.926213	1.6	-225.6	6.6
TS-s5-r2-S	-2040.595722	0.0	-2039.928691	0.0	-250.3	90.7
TS-s5-r3-S	-2040.594003	2.4	-2039.921494	4.5	-245.0	0.0
TS-s5-r4-S	-2040.591843	3.5	-2039.921176	4.7	-235.5	0.0
TS-s5-r1-N	-2039.909511	1.8	-2039.925163	2.2	-230.8	2.2
TS-s5-r2-N	-2039.909708	1.6	-2039.922972	3.6	-242.1	0.2
TS-s5-r3-N	-2039.909127	2.0	-2039.922934	3.6	-255.5	0.2
TS-s5-r4-N	-2039.906767	3.5	-2039.921477	4.5	-220.2	0.0

[a] **N** and **S** series refer to North and South conformations of the pyrrolidine ring, respectively. [b] Referred to the most stable **TS-s5-r2-S**. [c] According to Boltzmann's distribution: a ratio 5:4:NO1:NO2 of 8.8:90.9:0.2:0 is predicted.

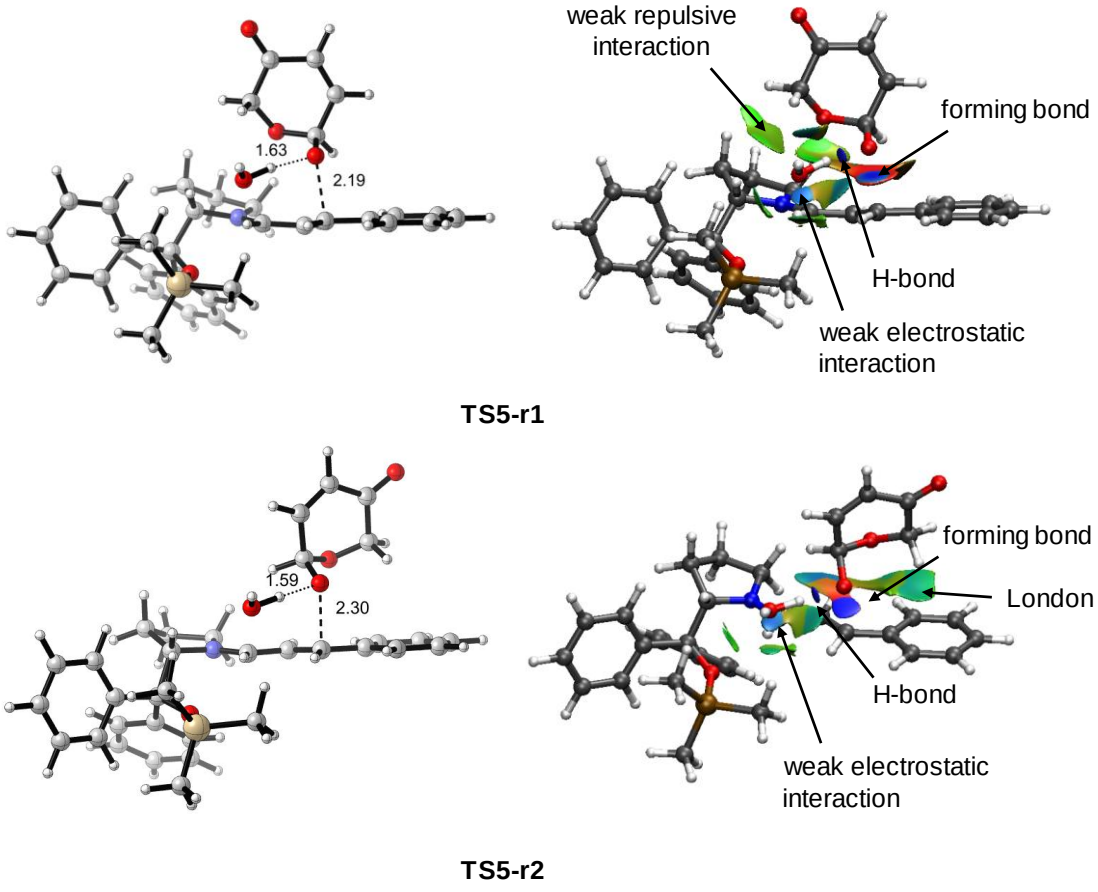


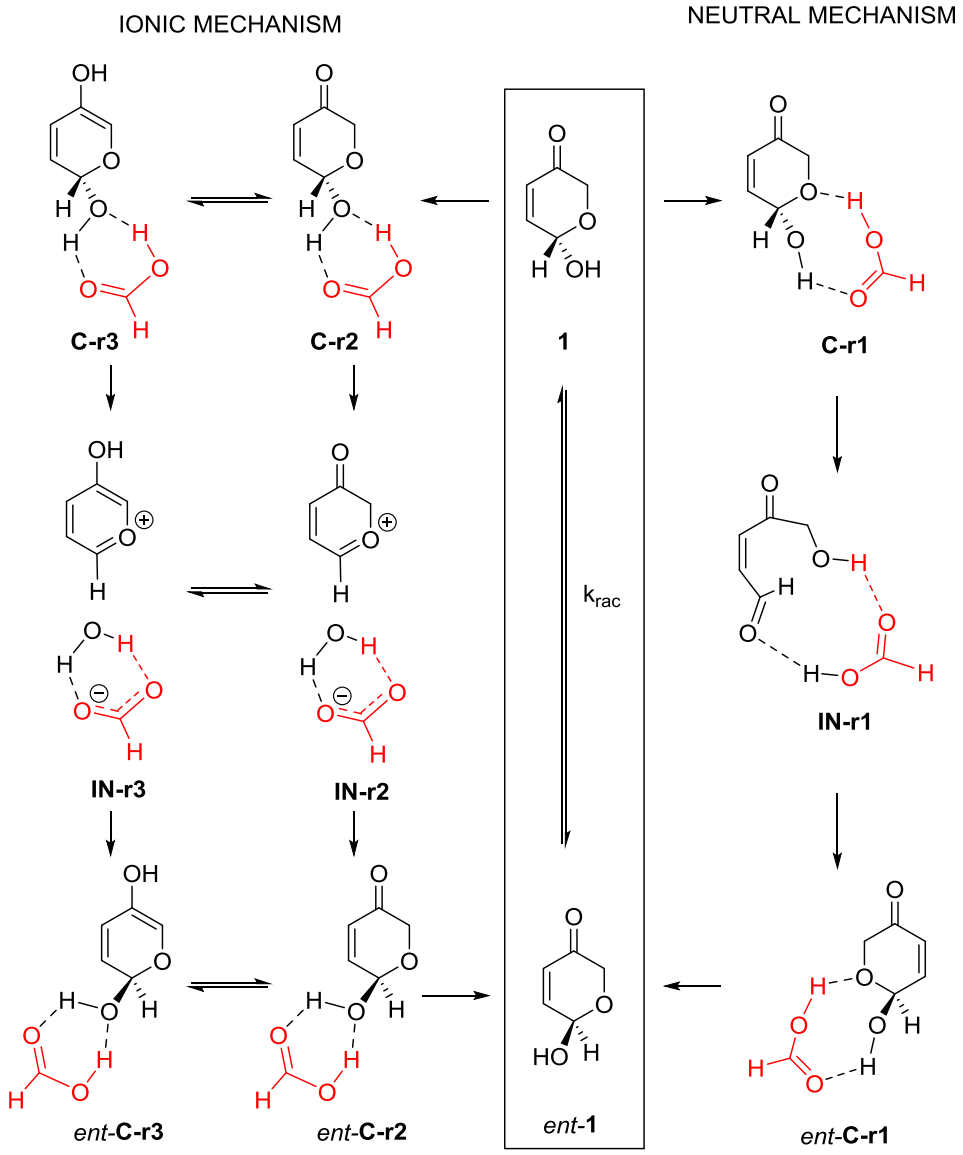
Figure ESI-13. Optimized geometries (M06-2X/cc-pVTZ/PCM=$CHCl_3$) of transition structures corresponding to the rate-limitng step of the reaction between **1** and **2a** catalyzed by **3a**.

Regarding the orientation of the attack, if only the attack of the oxygen atom is exclusively considered, both models present an almost identical geometrical disposition, showing trajectory angles of 104.1° for **TS5-r1** and 104.9° for **TS5-r2**, which is also in good agreement with the Bürgi-Dunitz trajectory.46 Under this situation, **(*R*)-1** (**TS5-r2**), orienting the pyrane ring outside, should present less unfavorable steric interactions with the pyrrolidine ring than **(*S*)-1** in (**TS5-r1**),. Practically the same disposition is appreciated for both TS, with rather similar

weak electrostatic interactions, H-bond and forming bond. However, whereas a weak repulsive steric interaction appears in the former, the latter presents an additional attractive London interaction between the methylene group of the heterocyclic ring and the aromatic ring. Thus, calculations predict a kinetic resolution in favor of the attack of **(*R*)-1** to give compound **4** (which might epimerize, see below) as the major isomer.

4.3.1. Racemization of compound 1.

After elimination of DKR intermediate II and DYKAT intermediate III by means of experiments with deuterated compounds (see main text), two processes remain possible for the racemization of hydroxypyranone **1**: i) racemization through intermediate open-chain aldehyde **IN-r1** (Scheme ESI-11, right) and ii) formation of oxonium cation **IN-r2** which could be estabilized by enolization to give aromatic species **IN-r3** (Scheme ESI-11, left). In the case of ionic mechanism enolization could also take place over the initial complex **C-r2** to give **C-r3** and then aromatic **IN-r3**.



Scheme ESI-11. Racemization of hydroxypyranone **1** through neutral and ionic mechanisms

Essentially, the difference between the two mechanisms starts with the initial formation of different complexes **C-r2** and **C-r3** between compound **1** and the promoter of racemization, initially modeled in our case by formic acid.

Actually, racemization of compounds **1** can be considered as the typical process of mutarotation observed in carbohydrates. The process has been extensively studied experimental and computationally, and all those studies concluded that the process take place through the open-

chain aldehyde through a neutral mechanism.[26] Moreover, these studies were conducted in water as a solvent the most favorable scenario for a ionic mechanism. In any case, the use of chloroform as a solvent and the possibility of aromatization of intermediate **IN-r3** prompted us to calculate both mechanisms.

The energy data of the stationary points are given in Table ESI-11. The results are summarized in the energy diagram illustrated in Scheme ESI-12. Only the formation of intermediates has been studied since further transformation into *ent*-**1** corresponds to an enantiomeric situation.

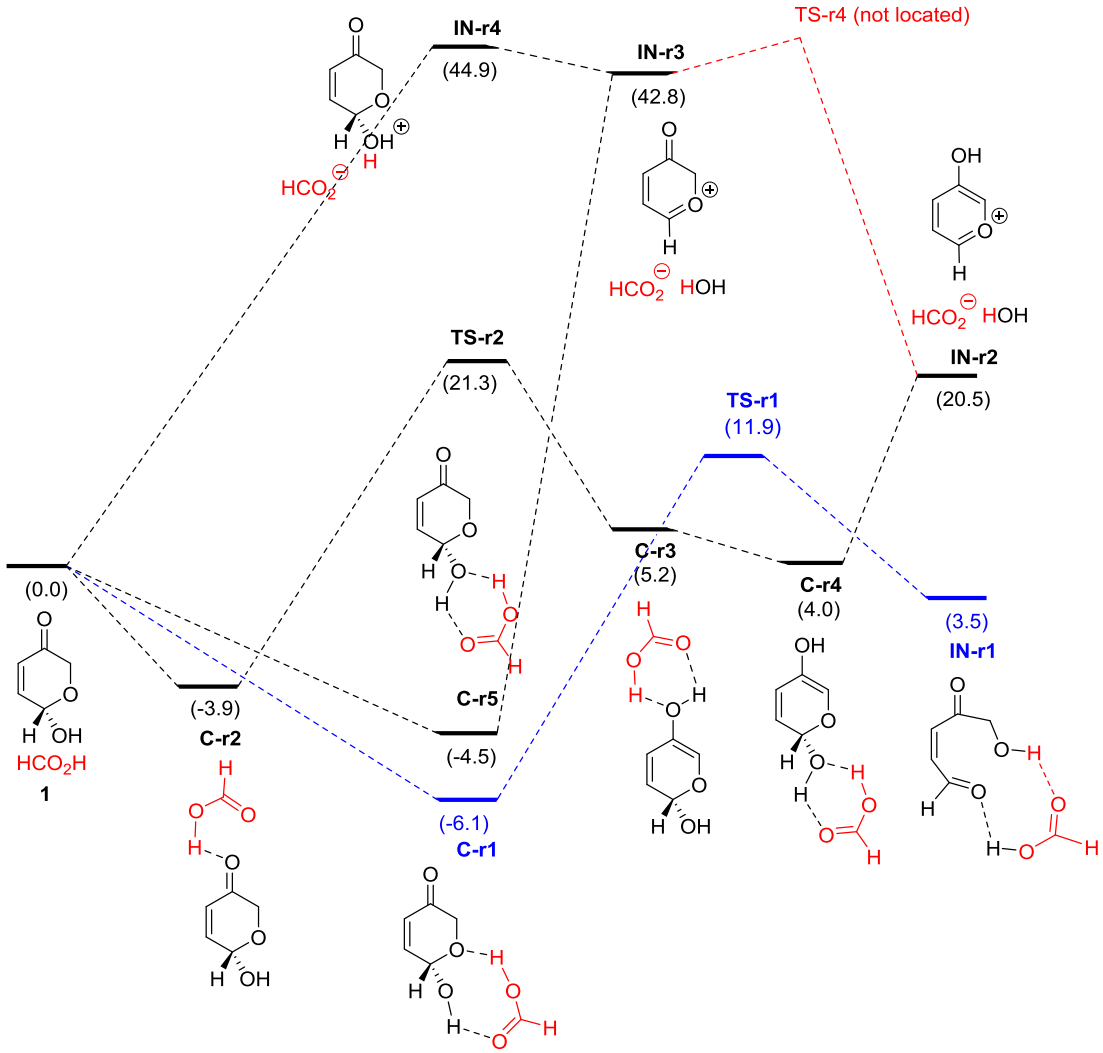
Table ESI-11. Calculated (M06-2X/cc-pVTZ/PCM=$CHCl_3$) absolute (hartrees) and relative (kcal/mol) energies of the stationary points corresponding to the racemization of **1** .

	E_0	ΔE_0[a]	G	ΔG[a]	im. freq
1+HCOOH	-609.411294	0.0	-609.452317	0.0	
C-r1	-609.423358	-7.6	-609.461968	-6.1	
TS-r1	-609.396487	9.3	-609.433282	11.9	-671.1
IN-r1	-609.407469	2.4	-609.446754	3.5	
C-r2	-609.418010	-4.2	-609.458572	-3.9	
TS-r2	-609.382349	18.2	-609.418378	21.3	-1489.4
C-r3	-609.405120	3.9	-609.444095	5.2	
C-r4	-609.405303	3.8	-609.445886	4.0	
IN-r2	-609.379616	19.9	-609.419653	20.5	
C-r5	-609.419103	-4.9	-609.459477	-4.5	
IN-r3	-609.342066	43.4	-609.384111	42.8	
IN-r4	-609.339173	45.3	-609.380686	44.9	

[a] Referred to **1** + HCO_2H

According to this data the preferred path corresponds to the formation of intermediate aldehyde **IN-r1** as in the case of carbohydrates. The barrier for this process is that of the rate-limiting step, i.e. 11.9 kcal/mol. The formation of aromatic intermediate **IN-r2** can be discarded since the corresponding rate-limiting step is 9.4 kcal/mol above. The possibility of formation of ionic species like **IN-r4** or **IN-r3** is negligible due to the high values of energy of such stationary points.

[26] (a) A. M. Silva, E. C. da Silva, C. O. da Silva, *Carbohydr. Res.*, 2006, **341**, 1029-1040 and references cited therein. (b) S.; Morpugo, A. Grandi, C. Zazza, M. Bossa, *J. Mol. Struct. TEOCHEM*, 2005, **79**, 71-82. (c) X. *J.* Qian, *Phys. Chem. B*, 2013, **117**, 11460-11465. For a definitive computational demonstration by using molecular simulations based on the combination of DFT methodology with the molecular dynamics formalism see: (d) W.; Plazinski, A. Plazinska, M. Drach, *Phys. Chem. Chem. Phys*., 2015, **17**, 21622-21629.



Scheme ESI-12. Energy diagram (M06-2X/cc-pVTZ/PCM= $CHCl_3$) for racemization of **1**. Relative energies are given in kcal/mol

The geometries of representative points of the preferred route are given in Figure ESI-14.

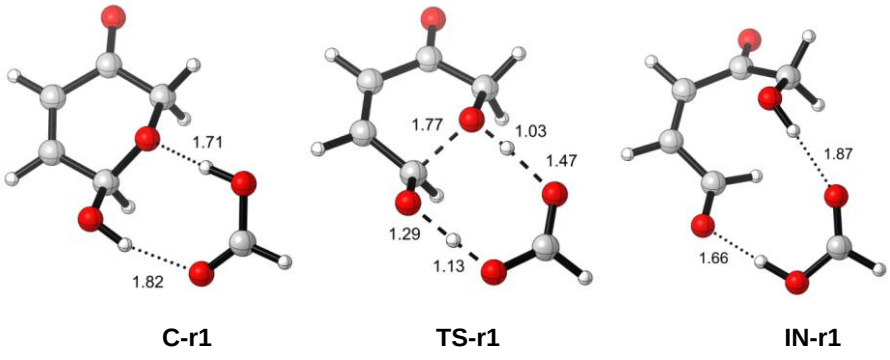


Figure ESI-14 Optimized (M06-2X/cc-pVTZ/PCM=$CHCl_3$) geometries of stationary points corresponding to the racemization of alcohol **1** catalyzed by formic acid. Distances are given in angstroms.

Since the formation of ionic intermediates has been discarded even in the presence of an acid, the most favorable situation, and considering that the process takes place in the presence of water and mediated by thiourea **7**, we also calculate the corresponding transition structures (Figures ESI-15 and ESI-16). In the case of water, two molecules were considered on the basis of previous accurate studies carried out with D-glucose.[10d] Barriers of 21.1 and 28.0 kcal/mol were found for water- and thiourea-mediated processes, respectively (Table ESI-12).

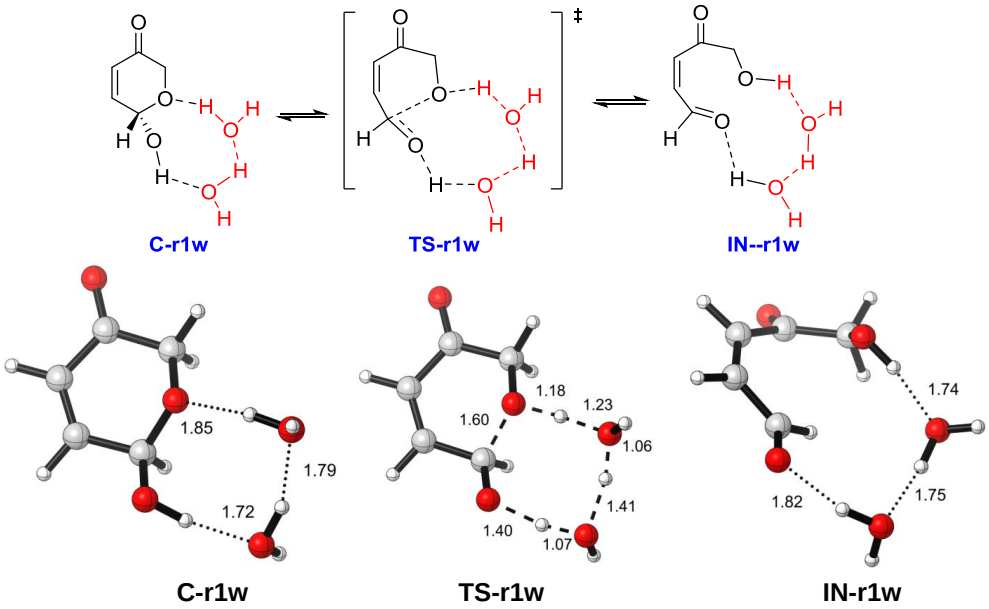


Figure ESI-15. Optimized (M06-2X/cc-pVTZ/PCM=$CHCl_3$) geometries of stationary points corresponding to the racemization of alcohol **1** catalyzed by water. Distances are given in angstroms.

Table ESI-12. Calculated (M06-2X/cc-pVTZ/PCM=$CHCl_3$) absolute (hartrees) and relative (kcal/mol) energies of the stationary points corresponding to the racemization of **1** mediated by water and thiourea .

	E_0	ΔE_0[a]	G	ΔG[a]	im. freq
C-r1w	-572.321248	0.0	-572.360029	0.0	
TS-r1w	-572.290079	23.5	-572.326396	21.1	-587.5
IN-rw1	-572.305199	11.4	-572.345296	9.2	
C-r1t	-2777.316000	0.0	-2777.391839	0.0	
TS-r1t	-2777.272036	27.6	-2777.347265	28.0	-391.9
IN-rwt	-2777.280878	22.0	-2777.358396	21.0	

[a] Referred to the corresp¡ponding complex **C-r1w** or **C-r1t**.

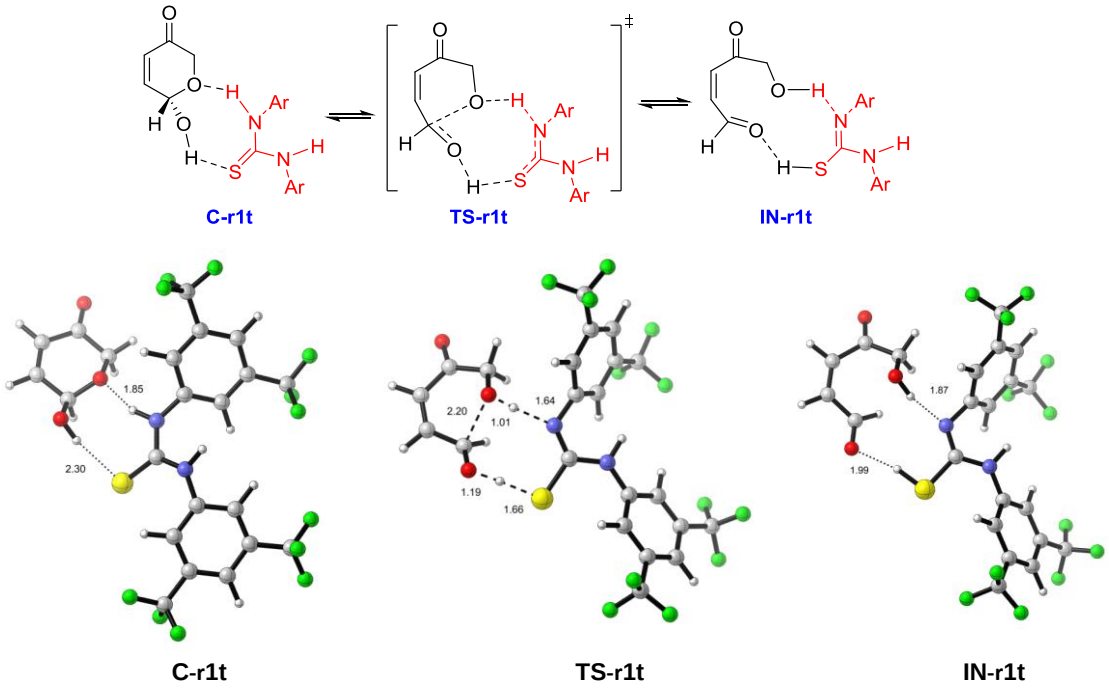


Figure ESI-16. Optimized (M06-2X/cc-pVTZ/PCM=$CHCl_3$) geometries of stationary points corresponding to the racemization of alcohol **1** catalyzed by thiourea **7**. Distances are given in angstroms.

4.3.2. Epimerization of compounds 4.

Conformational analysis

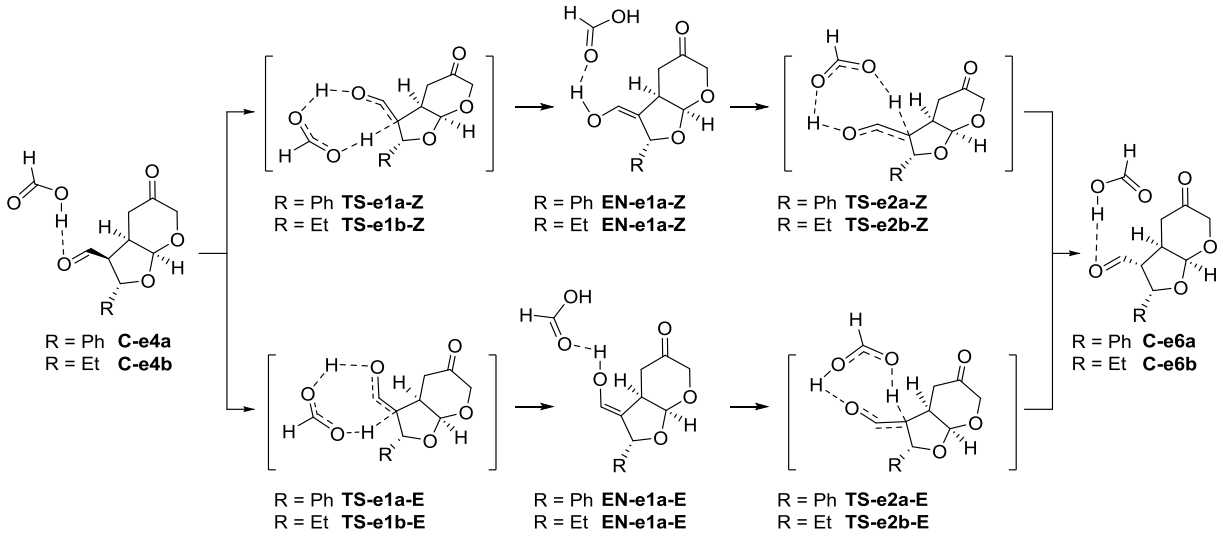
In order to gain insight into the available conformational space we carried out a exhaustive conformational analysis of **4a,b** and **6a,b** using Macromodel (v. 11.1) software.[27] A total of 5000 conformations were generated and minimized using the OPLS_2005 force field[28] with chloroform solvation. Multiple searches were carried out using different starting geometries as well as different ring-closure bond choices. After minimization, a conformer was only saved if its steric energy was within 7 kcal/mol of the instant global minimum (lowest energy structure known during an incomplete conformational search) and did not duplicate a previously stored conformer. After completion of the search, the output files from the conformational searches were then analyzed using by XCluster program in the MacroModel. Finally, structures with energy over 5.0 kcal/mol higher than the current global minimum were optimized at DFT level (M062X/cc-pVDZ/PCM=chloroform). For both aryl and alkyl substituents compounds **6** resulted to be more stable by ca. 3-5 kcal/mol). Consequently, it can be concluded that *epimerization of **4** into **6** is thermodynamically favored independently of the nature of the substituent*.

[27] Schrödinger Release 2016-1: MacroModel, version 11.1, Schrödinger, LLC, New York, NY, 2016.

[28] (a) W. L. Jorgensen, D. S. Maxwell, J. Tirado-Rives, *J. Am. Chem. Soc.*, 1996, **118**, 11225-11236. (b) W. L. Jorgensen, J. Tirado-Rives, *J. Am. Chem. Soc.*, 1988, **110**, 1657-1666.

Kinetic analysis

Epimerization of compounds **4** in acidic media should take place through the formation of the intermediate enol. Enol **EN-e1** has two possible configurations, i.e. E and Z; consequently, two different transition structures **TS-e1** are possible for the transformation of compounds **4** into **EN-e1**. Similarly, two transition structures **TS-e2** are also possible for the transformation of **EN-e1** into compounds **6**. We have studied all the possible paths for the transformation using formic acid as model acid and assuming the formation of initial complexes between **4a**/**6a** and formic acid[29] (Scheme ESI-13).



Scheme ESI-13. Transformation of compounds **4a,b** into **6a,b**.

The study showed that the preferred pathway was in both **a** and **b** series that involving the formation of (*E*)-enolates **EN-e1a-E** and **EN-e1b-E**. Absolute and relative energies are collected in Table ESI-13. The geometries of the transition structures are given in Figure S16. The rate limiting step was the transformation of the intermediate enolate into the most stable compound **6**. When compared the energy barriers of **a** and **b** series, the former (22.9 kcal/mol) - corresponding to R = Ph- was found to be 1.5 kcal/mol lower than that corresponding to epimerization of **4b** (24.4 kcal/mol). (Figure ESI-17 and Figure ESI-18).

[29] By considering transformations between unique entities it can be assumed the processes as unimolecular and estimation of free energy is correct (introduction of error due to translational entropy is avoided)

Table ESI-13. Calculated (M06-2X/cc-pVTZ/PCM=$CHCl_3$) absolute (hartrees) and relative (kcal/mol) energies of the stationary points corresponding to the transformation of **4a,b** into **6a,b**.

R		E_0	ΔE_0[a]	G	ΔG[a]	im. freq
Ph	**4a**	-1032.256997	0.0	-1032.307029	0.0	
	TS-e1a-E	-1032.224107	20.6	-1032.271673	22.2	-1508.3
	TS-e1a-Z	-1032.220821	22.7	-1032.267457	24.8	-1510.3
	EN-e1a-E	-1032.248376	5.4	-1032.298601	5.3	
	EN-e1a-Z	-1032.246400	6.6	-1032.295595	7.2	
	TS-e2a-E	-1032.223282	21.2	-1032.270602	22.9	-1510.7
	TS-e2a-Z	-1032.222453	21.7	-1032.270032	23.2	-1415.8
	6a	-1032.259206	-1.4	-1032.310468	-2.2	
Et	**4b**	-879.862352	0.0	-879.910067	0.0	
	TS-e1b-E	-879.829820	20.4	-879.873682	22.8	-1466.8
	TS-e1b-Z	-879.824474	23.8	-879.868891	25.8	-1636.2
	EN-e1b-E	-879.853790	5.4	-879.900298	6.1	
	EN-e1b-Z	-879.851488	6.8	-879.899670	6.5	
	TS-e2b-E	-879.827785	21.7	-879.871186	24.4	-1507.0
	TS-e2b-Z	-879.827965	21.6	-879.872235	23.7	-1455.1
	6b	-879.865394	-1.9	-879.912423	-1.5	

[a] Referred to **4a** or **4b**

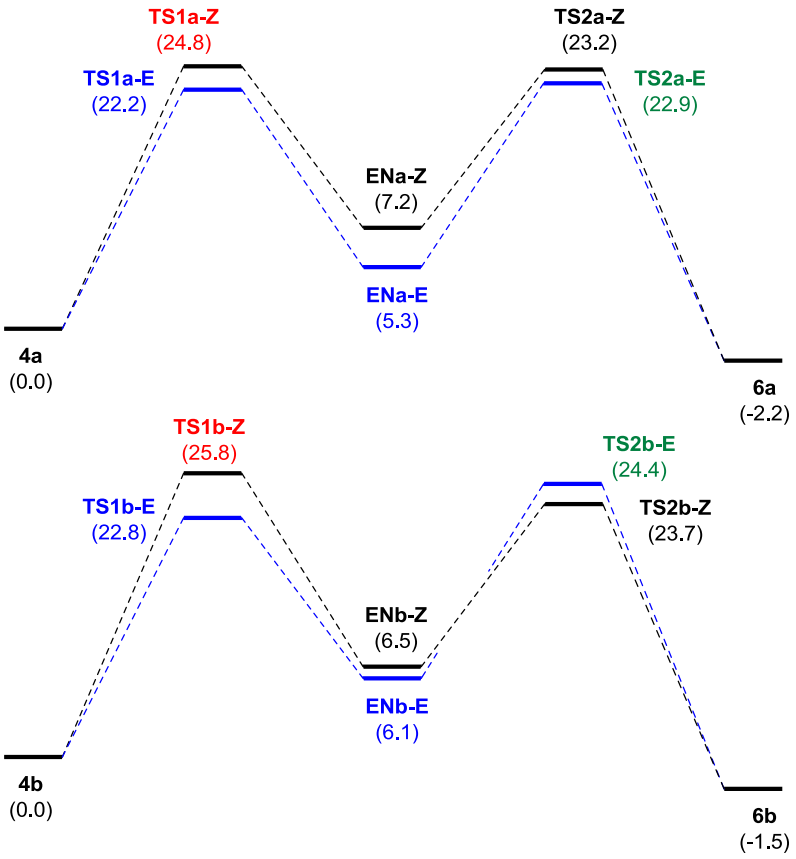


Figure ESI-17. Energy diagram for the transformation of **4a,b** into **6a,b**. Blue: preferred path. Red: Rate-limiting step for the non-preferred path. Green: Rate-limiting step for the preferred step.

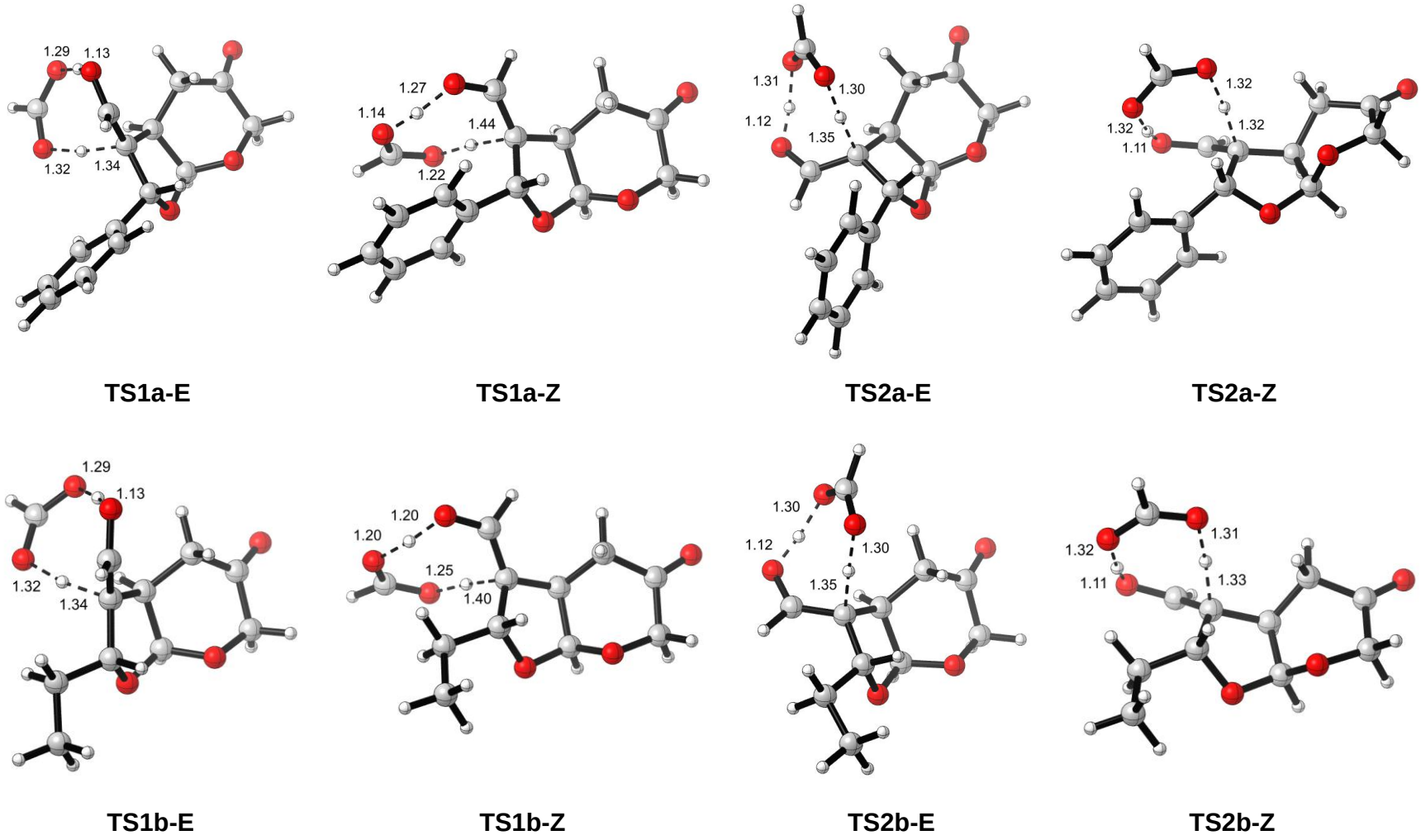
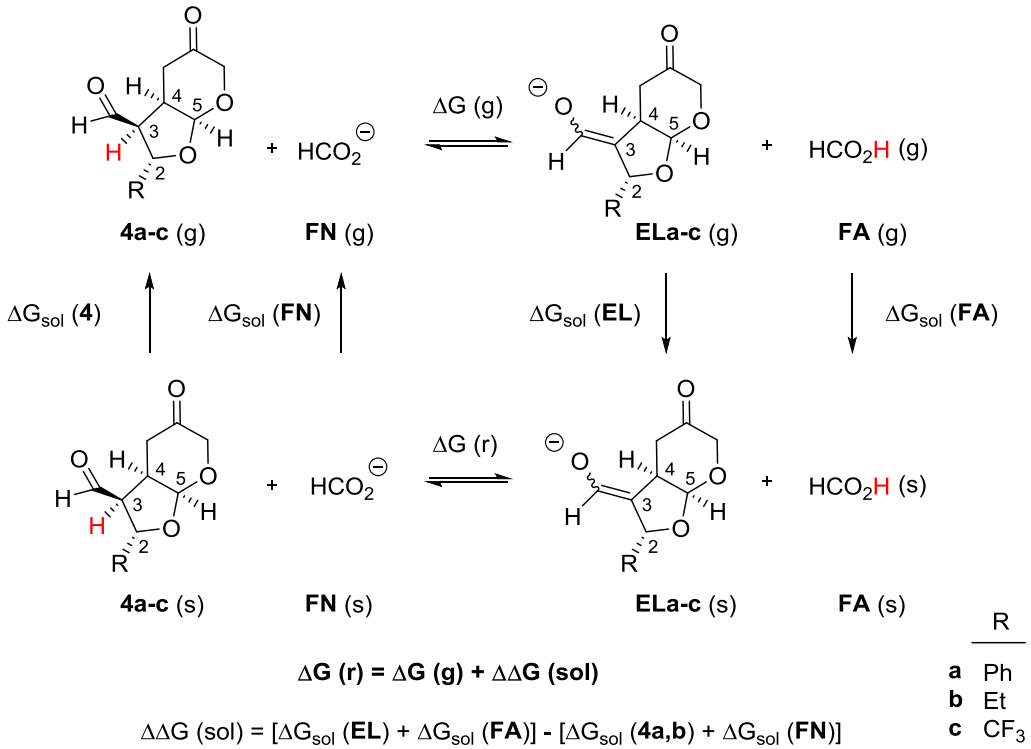


Figure ESI-18. Optimized (M06-2X/cc-pVTZ/PCM=$CHCl_3$) geometries of transition structures corresponding to enolization of **4a,b** and **6a,b.** Distances are given in angstroms

Since the different energy barriers found for the enolization processes of compounds **4** were in the range of 1-2 kcal/mol, within the error of DFT methods (estimated in ca. 3 kcal/mol),[30] we also studied acidity of **4a,b** and introduced R = CF_3 (**4c**) to validate the model. In order to achieve reliable results it is necessary to consider an isodesmic process and to estimate solvation of the species. Thus, we considered the thermodynamic cycle indicated in Scheme ESI-14 corresponding to the deprotonation of compounds **4a-c** by formate anion. The results are collected in Table ESI-14.

The values collected in Table S7 clearly confirm the tendency previously observed (**4a** more easily enolizable than **4b**) and point out that *the acidity of the enolizable proton strongly depends on the R substituent at β position*, predicting that electron-withdrawing substituents like CF_3 should epimerize more easily.



ΔG (r) = ΔG (g) + ΔΔG (sol)

ΔΔG (sol) = [ΔG_{sol} (**EL**) + ΔG_{sol} (**FA**)] - [ΔG_{sol} (**4a,b**) + ΔG_{sol} (**FN**)]

Scheme ESI-14. Thermodynamic cycle for studying deprotonation of compounds **4a,b.** For enolate **EL** the more stable *E/Z*-isomer has been chosen. Calculation level: M06-2X/cc-pVTZ (gas phase and PCM=chloroform).

Table SI.14. Calculated (M06-2X/cc-pVTZ/PCM=$CHCl_3$) free energies (kcal/mol) and pK_a values for the deprotonation of compounds **4a-c**.

	ΔG (g)	ΔΔG (solv)	ΔG (r)	pK_a
4a	-2.9	15.3	**12.4**	9.1
4b	-1.1	14.8	**13.7**	10.1
4c	-11.3	17.4	**6.1**	4.5

[30] S. N. Pieniazek, F. R. Clemente, K. N. Houk, *Angew. Chem. Int. Ed.*, 2008, **47**, 7746-7749.

4.4. Cartesian Coordinates

4.4.1. Achiral System

1

0 1

O	-2.0311173810	-0.0925260925	0.7783094638
H	-2.6951863946	-0.7784669319	0.6510643258
C	0.5530463167	-1.2251123381	0.0339010089
C	-0.5260368841	1.3432602192	-0.2830626900
H	-1.0580599762	2.2842677839	-0.3419137688
C	0.7855108030	1.2938676655	-0.0765869683
H	1.3981900601	2.1804713925	0.0182745823
O	-0.5785267443	-1.0173763483	-0.7896656153
C	1.4500057739	-0.0083549191	0.1124554685
O	2.6240166733	-0.1096500445	0.3884730643
H	0.2544801067	-1.4796873923	1.0567934872
H	1.1130315058	-2.0577836141	-0.3833661548
C	-1.3522332739	0.0953259215	-0.4353479275
H	-2.0577845754	0.2139067081	-1.2596342859

2a

0 1

C	1.3219274372	2.2533185790	-0.0175534024
O	1.5701832046	3.4152187956	-0.2440506935
H	2.1188465789	1.5610933033	0.3095316834
C	-0.0051379988	1.6545925484	-0.1447066586
H	-0.8069630108	2.3080119990	-0.4635289590
C	-0.1755825213	0.3569938130	0.1299568320
H	0.6994888780	-0.2074116923	0.4424755404
C	-1.4176138409	-0.4107099143	0.0603731304
C	-1.3884504372	-1.7666491308	0.3897189119
C	-2.6337563430	0.1620904378	-0.3236759421
C	-2.5415597169	-2.5350833175	0.3384131541
H	-0.4501305927	-2.2172152667	0.6880838514
C	-3.7839518982	-0.6039887150	-0.3749542544
H	-2.6816307783	1.2104659237	-0.5834909801
C	-3.7417510171	-1.9546191794	-0.0442126307
H	-2.5022949169	-3.5841614803	0.5966277766
H	-4.7187452379	-0.1500224421	-0.6734218990
H	-4.6433142288	-2.5501585015	-0.0855854608

4a

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C	-0.5874993732	-0.5091861813	-1.0395512042
C	0.6092700830	-0.2632435880	-0.1422757758
C	1.8545697997	0.1690916194	-0.9330709329
H	1.7927685638	-0.1779360126	-1.9676675799
H	0.7808814120	-1.1743094855	0.4305178293
O	1.8163386966	1.6026455593	-0.9466713330
C	3.1417923995	-0.3319569978	-0.3227780299
C	3.9669841236	0.4926823382	0.4301431113
C	3.4928488887	-1.6684745962	-0.4998942227
C	5.1251838385	-0.0156698152	1.0070583745
H	3.7084770129	1.5354008865	0.5525766560
C	4.6462365808	-2.1759726613	0.0758202966
H	2.8577477650	-2.3140508350	-1.0960125865
C	5.4665887420	-1.3483069210	0.8340592646
H	5.7634716023	0.6350381999	1.5896610076
H	4.9091642650	-3.2147876071	-0.0710432276
H	6.3696222354	-1.7406113429	1.2813962704
H	-0.4238469991	-0.3795652994	-2.1234099828
C	-2.0058277776	1.8030002535	0.6522895485
C	-1.5262638298	2.6894516170	-0.4836576849
C	-0.9384626713	1.1209872562	1.4775447376
O	-3.1755307307	1.7414018655	0.9347159521
O	-0.3552928785	2.2049524721	-1.1073029069
C	0.4108813602	0.9526699867	0.7860171647
H	-1.3370652855	0.1782814402	1.8463339307
C	0.7318931006	2.0584515027	-0.2093105308
H	1.2034973406	0.9219374666	1.5348915272
H	0.9782025191	3.0267774302	0.2358705514
O	-1.6599383450	-0.8527463234	-0.6160759979
H	-0.8052136094	1.7738045599	2.3460796587
H	-1.3584552951	3.6926813759	-0.0673098091
H	-2.3042134842	2.7563472367	-1.2394310865

5a

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C	-1.5855127199	-0.5962311730	-1.3693612763
H	-2.0522239697	-0.1561338411	-2.2520970438
H	-0.1688735061	0.1773698502	0.0953720801
O	-1.0582273899	-1.8774280754	-1.7523444789
C	-2.6137116212	-0.7144209051	-0.2755150713
C	-2.5373678880	-1.7231993492	0.6788197752

C	-3.6323444833	0.2299817157	-0.1958108718
C	-3.4723603055	-1.7834815344	1.7028442118
H	-1.7476709551	-2.4587550939	0.6073024776
C	-4.5623536795	0.1722041641	0.8329573672
H	-3.6914503026	1.0115923842	-0.9432216862
C	-4.4847314422	-0.8359732896	1.7842463066
H	-3.4115359255	-2.5740387637	2.4388050411
H	-5.3518511179	0.9097353050	0.8870519060
H	-5.2126316620	-0.8861356594	2.5827080703
H	0.3948260029	2.3203453978	-1.0541071087
C	2.5839397506	-1.0461213366	-0.0355126823
C	1.9749007740	-2.4340253873	-0.0051064262
C	2.1944346309	-0.1979378928	-1.2244264257
O	3.3726329617	-0.6753428237	0.7964984312
O	0.5936129488	-2.3817726338	-0.2938780326
H	2.5065682551	-3.0607715057	-0.7350713578
H	2.0969747884	-2.8652089382	0.9843670556
C	0.7802191610	-0.4523221378	-1.7399504625
H	2.3732605489	0.8492179003	-0.9850965361
C	0.3176751763	-1.9011534237	-1.5986686461
H	0.7145579477	-0.1836178836	-2.7961324747
H	0.7520571120	-2.5832855403	-2.3354435044
O	-1.4217651642	2.1995030239	-1.8829956811
H	2.9109766839	-0.4688236570	-2.0071548101

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N	0.0183809379	-1.2747198938	0.2906698226
C	1.1533602268	-0.4621595596	-0.1581253171
C	-1.1460216518	-0.4887830552	-0.1292299312
C	0.7623094894	1.0122271567	0.0722899194
H	2.0653389166	-0.7537306570	0.3591804634
H	1.2991255102	-0.6479519002	-1.2246060423
C	-0.7835547237	0.9943142138	0.0917913437
H	-2.0377318860	-0.8012686122	0.4107052834
H	-1.3141643090	-0.6781677616	-1.1917790958
H	1.1616579661	1.6640379627	-0.7028447024
H	1.1540905741	1.3629475917	1.0263664908
H	-1.2173269633	1.6365406290	-0.6727732432
H	-1.1591622349	1.3360512877	1.0555826364
H	0.0314331476	-1.3006524020	1.3055763722

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C	-4.8912940000	0.8873960000	-1.0734230000
H	-5.7830650000	0.8852470000	-1.6964630000
H	-3.9645420000	-0.5149740000	-2.4359840000
C	-4.9917300000	-0.0182800000	0.1525320000
H	-5.4032310000	-0.9879140000	-0.1345040000
H	-5.6073610000	0.3956410000	0.9486530000
C	-3.5251310000	-0.1625790000	0.5523820000
H	-3.3073970000	-1.0823250000	1.0933230000
H	-3.2147050000	0.6803050000	1.1724100000
H	-4.6964330000	1.9145310000	-0.7589320000
N	-2.7640170000	-0.1342520000	-0.7200810000
H	-2.4096360000	-1.0639250000	-0.9119670000
O	-1.5346960000	-2.8442460000	-0.1104570000
C	-0.5113400000	-3.2234060000	0.4232050000
C	0.8028070000	-2.5946560000	0.2624450000
C	0.9869060000	-1.6067950000	-0.6230510000
H	0.1305690000	-1.3051410000	-1.2190400000
H	1.5996660000	-2.9679620000	0.8912510000
O	-0.5101890000	1.2987030000	-0.7899450000
H	-1.4112710000	0.8377730000	-0.7260850000
C	2.2194440000	-0.8658410000	-0.8702170000
C	2.2312460000	0.0825020000	-1.8944420000
C	3.3692440000	-1.0371640000	-0.0940740000
C	3.3651500000	0.8378550000	-2.1459390000
H	1.3297900000	0.2424470000	-2.4700180000
C	4.5006150000	-0.2804130000	-0.3427530000
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C	4.5016660000	0.6588490000	-1.3690630000
H	3.3606940000	1.5703570000	-2.9416550000
H	5.3828490000	-0.4155200000	0.2680520000
H	5.3874170000	1.2498590000	-1.5599820000
H	-0.5416150000	-4.1000280000	1.0894210000
H	-3.1766580000	1.0656390000	-2.4257280000
C	1.1116490000	0.5078040000	2.0871650000
C	-0.3956990000	0.4655770000	1.9345850000
C	1.8169350000	1.5835410000	1.3724450000
O	1.6898750000	-0.3484590000	2.7237560000
O	-0.9447360000	1.6777580000	1.4659660000
H	-0.8395460000	0.2578670000	2.9065460000
H	-0.6388160000	-0.3653460000	1.2603800000
C	1.1532690000	2.3321280000	0.4957340000
H	2.8858110000	1.6593310000	1.5233790000
C	-0.3313930000	2.1556330000	0.2881340000
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C	-1.7071731624	-0.4727541064	-0.7429658093
H	-1.9640817247	-1.1289356166	-1.5642759481
C	-2.5923939665	-0.0343511725	0.1617488613
H	-2.2217064910	0.6238590025	0.9435904712
C	-4.0197232013	-0.3340526747	0.2245201526
C	-4.7877030052	0.2743407960	1.2190873670
C	-4.6455833908	-1.2046785240	-0.6731576628
C	-6.1481367423	0.0268908387	1.3154187226
H	-4.3079102312	0.9465338033	1.9193534331
C	-6.0022202826	-1.4533927152	-0.5756519170
H	-4.0686468887	-1.6913953803	-1.4474438927
C	-6.7574033996	-0.8375621288	0.4176538322
H	-6.7309382204	0.5057074053	2.0899954781
H	-6.4764447671	-2.1296622928	-1.2734619971
H	-7.8181653657	-1.0350315655	0.4900553144
N	1.9714153146	2.0772288617	0.3144310240
C	1.5343577373	2.7384614709	-0.9208345237
C	2.1121166319	3.1694667539	1.2794684427
C	2.1346397715	4.1689218904	-0.9186511687
H	1.8317462771	2.1488420268	-1.7857084256
H	0.4423336430	2.7923986651	-0.9186485544
C	2.7267348635	4.3357666536	0.4956817475
H	2.7060729159	2.8547930132	2.1357004590
H	1.1160934187	3.4421380990	1.6396429608
H	1.3643742496	4.9122665872	-1.1183129179
H	2.9001329791	4.2790799728	-1.6842308451
H	2.5046014348	5.3061328821	0.9365624158
H	3.8108754889	4.2215550088	0.4702334844
H	2.8837108391	1.6626941496	0.1459529219
O	3.3219796839	-0.0881263600	-1.3732597837
H	2.3461042993	-0.1379418844	-1.3843883683
C	3.8383584045	-1.1993610814	-0.6995228124
O	3.7766555519	-1.0701375946	0.6989014473
C	3.1561115070	-2.4624887700	-1.1624859264
H	4.9018808811	-1.2367898046	-0.9281906078
C	2.4739411241	-1.1616419698	1.2425459257
C	2.1661355991	-3.0156001898	-0.4680588499
H	3.4776325132	-2.8684079670	-2.1135841429
C	1.6741622512	-2.3443769254	0.7440556492

H	2.5797776801	-1.2481506683	2.3222755660
H	1.8971841952	-0.2535310449	1.0292510270
H	1.6365730542	-3.8997163823	-0.7973552659
O	0.6397680226	-2.6598858679	1.2941493952

ENa-RR

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C	2.8023581012	-1.4782325570	-0.6383312085
C	4.2605616970	-1.9375213083	-0.5930637271
H	4.8218247598	-1.6182712665	-1.4676031894
H	2.6917126762	-0.5217019397	-1.1610407444
C	4.7786816669	-1.3323219572	0.7141231825
H	4.9833541780	-0.2696826610	0.5769988305
H	5.6811603206	-1.8141198237	1.0826854029
C	3.5917085835	-1.5072605793	1.6562147769
H	3.5645957682	-0.7694072352	2.4571898675
H	3.5937771333	-2.5065778044	2.1035334269
H	4.3034994693	-3.0260426990	-0.5382358816
O	1.2087547430	1.8319964910	2.6997872880
H	1.4528870616	2.7262512176	2.4478042708
N	2.4496988945	-1.3318196489	0.7653638272
C	1.2153170243	-0.9886565497	1.1776714259
C	0.1429421083	-0.7471665881	0.3951120739
C	-1.1203022402	-0.2485522582	1.0030610943
H	-1.1241389610	-0.5383849557	2.0568008467
H	0.2132817183	-0.8367733868	-0.6808086908
O	-1.1948183422	1.2065942758	1.1375464732
H	0.3937682838	1.6689629911	2.2022311568
C	-2.4044512900	-0.7755259028	0.3847617068
C	-3.6171091213	-0.1548076698	0.6853468237
C	-2.4124432943	-1.8906703835	-0.4445795355
C	-4.8059347023	-0.6266553409	0.1523152916
H	-3.6194026586	0.7113863428	1.3342840000
C	-3.6041044006	-2.3658726876	-0.9804965023
H	-1.4826749171	-2.3928033014	-0.6741187392
C	-4.8029030020	-1.7338672102	-0.6885171722
H	-5.7373497463	-0.1318167775	0.3933439397
H	-3.5917511676	-3.2311536202	-1.6297766547
H	-5.7294699019	-2.1023475965	-1.1074706281
H	1.1232673058	-0.8761960108	2.2537373158
H	2.1469636498	-2.2012922736	-1.1307950139
C	0.8580400191	1.6347260144	-1.9608601149
C	1.1602330183	2.2130608344	-0.5984455669
C	-0.5547469849	1.3600047225	-2.2608712636
O	1.7550852272	1.3504071914	-2.7258707065
O	0.0428714999	2.8223452402	0.0187462003

H	1.9210322156	2.9835476756	-0.7093755659
H	1.5686932187	1.4081052189	0.0233392672
C	-1.4720486557	1.4898360802	-1.3071354388
H	-0.7876400799	0.9795072243	-3.2466528794
C	-1.1551773004	2.0913416641	0.0378208808
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C	1.4859514898	2.3040482233	1.1993002392
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H	2.0335935641	1.3614636049	1.1071720812
C	2.7295176162	4.1026478969	0.1848752506
H	3.4997214562	3.5196189926	-0.3218212128
H	3.0657996448	5.1342033962	0.2567764585
C	1.4093813450	3.9630206366	-0.5637452978
H	1.5257005589	3.9516879748	-1.6471006200
H	0.7255801864	4.7771092581	-0.2985116482
H	1.8667285094	4.2003345335	2.1609100140
O	3.7991845033	-3.6334954651	2.2561602223
H	3.9191301067	-2.9804135205	1.5496739553
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C	-0.0817255619	1.9850940038	-0.6745567720
C	-0.6341065979	0.8427607234	-0.2227266930
C	-1.6755174884	0.1256718607	-1.0099429186
H	-1.9933403580	0.7732766717	-1.8311140012
H	-0.3178666560	0.3983832037	0.7112207753
O	-1.2352194079	-1.1069009996	-1.6443606485
H	3.9402834090	-4.4818900970	1.8301675394
C	-2.8904334318	-0.2034856727	-0.1685848936
C	-2.9683982110	-1.3875913889	0.5557858088
C	-3.9280290507	0.7183053773	-0.0766253549
C	-4.0697749511	-1.6426278484	1.3618713246
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C	-5.0302125729	0.4638008733	0.7263514056
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H	-4.1226592805	-2.5679105783	1.9203178784
H	-5.8335530321	1.1860999436	0.7850256297
H	-5.9637217880	-0.9231040152	2.0731849539
H	-0.4188018341	2.4052337936	-1.6187106816
H	0.6986468259	2.1567395296	1.9436401357
C	2.6676964283	-1.6122078139	-0.3557298160
C	1.5456136007	-2.5618911807	0.0164027816

C	2.3583547614	-0.6146990620	-1.3772450419
O	3.7766376023	-1.7300620150	0.1359055674
O	0.2663825223	-2.0013071508	-0.1762361139
H	1.6712331243	-3.4683302021	-0.5944078531
H	1.6420170555	-2.8418918029	1.0625870661
C	1.1354475453	-0.5806098714	-1.9101304747
H	3.1538022886	0.0488876545	-1.6886955855
C	0.0586917905	-1.5545055102	-1.5006521666
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H	0.1261312882	-2.4196184909	-2.1780305114

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C	0.0154098200	0.2368077126	-0.6175726549
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H	0.4016192928	-0.4694143637	0.1262388844
C	-1.4654555868	0.0457894917	-0.7587077809
H	-1.9328838053	0.5616117357	-1.5899288365
C	-2.1778721770	-0.6955136099	0.0846217245
H	-1.6513180152	-1.2132471516	0.8824448447
C	-3.6320749371	-0.9134091223	0.0626080694
C	-4.1939645467	-1.7720343754	1.0077844155
C	-4.4798357675	-0.2981907922	-0.8623979506
C	-5.5596419182	-2.0159676576	1.0313669747
H	-3.5477593390	-2.2542742506	1.7308924299
C	-5.8423187629	-0.5413848342	-0.8414992700
H	-4.0745863794	0.3780516491	-1.6030514116
C	-6.3889075388	-1.4014213730	0.1054635366
H	-5.9737918643	-2.6870752627	1.7715934311
H	-6.4840016748	-0.0576347468	-1.5655704997
H	-7.4539525008	-1.5882664315	0.1186750055
N	0.4075388781	1.5670794145	-0.1285859421
C	-0.1129636025	2.7189438702	-0.9105649655
C	0.0890610359	1.7846434952	1.2988579302
C	-0.9525295532	3.5234970969	0.0764764481
H	0.7308817279	3.3125421110	-1.2681273541
H	-0.6653136727	2.3781899430	-1.7833412959
C	-0.2186041419	3.2737564298	1.3933831870
H	0.9218331331	1.4623171846	1.9246688908
H	-0.7964663545	1.2087992933	1.5851404536
H	-1.9608205186	3.1076933732	0.1347838049
H	-1.0260601623	4.5749853381	-0.1922643429
H	-0.8048731985	3.5192891185	2.2757987326
H	0.7066728830	3.8520524126	1.4213830106
H	2.0870188531	1.4120059230	-0.3369903590
O	2.9974632719	1.0781242948	-0.6063347077

H	1.5432429664	0.1838762285	-1.8059166718
C	3.6107629001	0.5269154415	0.5175839006
O	2.8819636452	-0.5554959546	1.0512876425
C	5.0104545146	0.1336704120	0.1332508255
H	3.6435679341	1.2514493189	1.3359810653
C	2.9276507314	-1.7379932812	0.2774948767
C	5.3604145820	-1.1326736997	-0.0685242011
H	5.7205229777	0.9425284220	0.0152991575
C	4.3411458872	-2.1946750100	-0.0140737739
H	2.4087954177	-2.5143154437	0.8344440318
H	2.4190821353	-1.6091286882	-0.6861910052
H	6.3666989228	-1.4275089041	-0.3350335501
O	4.5877750097	-3.3543592900	-0.2586608150

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O	-1.0171408803	-1.0212838797	1.5822123754
H	-1.0146844387	0.2853376650	2.4196083713
C	1.7180796746	0.0041349008	0.1409349945
C	1.2670112123	1.2340852544	-0.1834287051
H	0.9950639079	-0.6766118662	0.5911783361
C	-0.1091738657	1.4968806222	0.0932597779
H	1.8961831462	1.9977082617	-0.6200001140
H	-0.7020697939	0.6846715394	0.5080437724
O	-1.0498981518	1.2142681932	2.8300215031
C	3.0666519137	-0.5103389633	-0.0364092402
C	3.3351838370	-1.8127117055	0.3930497329
C	4.0966023503	0.2373241655	-0.6182980582
C	4.6009161074	-2.3576248243	0.2480230719
H	2.5394685697	-2.3921863114	0.8438456867
C	5.3584629035	-0.3071820840	-0.7634237491
H	3.9101219676	1.2462519905	-0.9602477859
C	5.6132669951	-1.6053729122	-0.3301267300
H	4.7965542791	-3.3664202074	0.5838561647
H	6.1481353434	0.2764849600	-1.2159795774
H	6.6021139570	-2.0277431909	-0.4463829145
N	-0.7113814237	2.6152901020	-0.1071098786
C	-2.1375394903	2.8222123075	0.2243574822
C	-0.1055934453	3.8402473292	-0.6637613667
C	-2.4913040729	4.0691080219	-0.5714507896
H	-2.1990707421	2.9862482357	1.3003535245
H	-2.6931875155	1.9214500729	-0.0249953265
C	-1.2014441967	4.8897396648	-0.4954926130
H	0.8134952735	4.0738721755	-0.1313595375
H	0.1273394267	3.6610653656	-1.7140897348
H	-3.3499043766	4.5876313342	-0.1542234166

H	-2.7127690504	3.8061372607	-1.6062579855
H	-1.1164214232	5.3590298960	0.4844265970
H	-1.1352160649	5.6642486103	-1.2544062407
H	-1.4096392197	1.0993129237	3.7112074843
C	-2.2794733973	-1.2157883720	1.1894145686
O	-2.6005390975	-0.5818138842	-0.0903743019
C	-2.5856326349	-2.6937604040	1.0781602334
H	-3.0297977767	-0.7442538462	1.8477003804
C	-1.9432552297	-1.1782898484	-1.1772965398
C	-2.5901284250	-3.3578892489	-0.0781652959
H	-2.7421095603	-3.2145650222	2.0162931164
C	-2.2529950522	-2.6546428517	-1.3211414904
H	-2.2455525977	-0.6642991301	-2.0889190082
H	-0.8505012071	-1.0982548888	-1.0838012803
H	-2.7661034205	-4.4239615786	-0.1474772476
O	-2.1496203145	-3.2148108328	-2.3945502456

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H	-4.0698342462	-2.6486351085	0.9915506649
H	-2.1223901492	-1.3257679113	1.1816033252
C	-4.1634145748	-1.3774907424	-0.7812077881
H	-4.3960315453	-0.5268084011	-0.1415226451
H	-5.0567851945	-1.6835610985	-1.3184082339
C	-3.0362267159	-1.0063786109	-1.7311869253
H	-3.0772844220	0.0114825160	-2.1105220650
H	-2.9519582255	-1.7098607870	-2.5594732460
H	-3.5206763564	-3.4305525386	-0.5078147246
N	-1.8288728223	-1.1562682653	-0.8790081129
C	-0.7153435508	-0.5966980931	-1.1418679434
C	0.4583210617	-0.5580142406	-0.2558336341
C	1.6826339202	-0.1116631790	-1.0652329434
H	1.7003576592	-0.5629605112	-2.0597890398
H	0.5812475874	-1.4875061218	0.2948013261
O	1.4541539597	1.2716620063	-1.2526500771
C	2.9914138878	-0.4230477086	-0.3671795469
C	3.9116478991	0.5787823597	-0.0868278950
C	3.2975961584	-1.7391442673	-0.0285978373
C	5.1125166562	0.2727205085	0.5418114127
H	3.6911722088	1.5979547610	-0.3726951201
C	4.4970015175	-2.0460064129	0.5946218469
H	2.5982077143	-2.5340008610	-0.2597609639
C	5.4069108991	-1.0374869608	0.8873595230
H	5.8198158934	1.0620959996	0.7575368550

H	4.7225419006	-3.0721834268	0.8516273066
H	6.3413654147	-1.2742114060	1.3773781086
H	-0.6702949646	-0.0371280414	-2.0720941053
H	-1.3742555787	-2.7582982146	0.4120283266
C	-1.9192631164	1.6450173429	0.6266403064
C	-1.3656195650	2.4321054966	-0.5530797995
C	-1.0087260224	0.9308468727	1.3473671949
O	-3.1836539006	1.7456659387	0.8132080946
O	-0.0071943834	2.8257950530	-0.3926912279
H	-1.9386335120	3.3530411124	-0.6358694264
H	-1.4983726910	1.8884957016	-1.4980443866
C	0.3315720665	0.6662197803	0.7687490844
H	-1.3094093445	0.4019151969	2.2410909427
C	0.8995110092	1.8387450480	-0.0586177139
H	1.0601846446	0.4179158442	1.5409881357
H	1.6970336378	2.3456788274	0.4850011679
H	-3.9360491493	-0.0196900855	3.1814000975
O	-3.9855373526	-0.2806462453	2.2595115976
H	-3.6976344056	0.5325201446	1.7458962869

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H	2.7406444246	3.0426362764	2.3828961390
H	1.9094189405	1.2484785392	0.9983101323
C	2.3204885649	4.0888799888	0.4975972641
H	3.1969925592	3.6325727760	0.0376358809
H	2.5333543797	5.1350820227	0.6967818541
C	1.1116797854	3.9199060250	-0.4087885195
H	1.3037113615	4.0440887264	-1.4701540061
H	0.2961040803	4.5757600120	-0.1029512722
H	1.1961442035	3.8958300141	2.3312177218
O	3.8006252717	-3.2778001303	2.3042419361
H	3.8051217773	-2.7224393721	1.4788159841
N	0.6977343062	2.5234233629	-0.1402067376
C	0.0213890552	1.8064158062	-0.9561596850
C	-0.2471876495	0.3898476181	-0.7727011877
C	-1.5799009499	-0.1275222776	-1.3306715457
H	-1.8889736030	0.4753744330	-2.1907723374
H	-0.1157752954	0.0728069029	0.2586532403
O	-1.2960852522	-1.4493787625	-1.7951266274
H	3.9380209214	-4.1721266152	1.9859450711
C	-2.6794994649	-0.1313267172	-0.3012479227
C	-2.7366970999	-1.1472600436	0.6481113313
C	-3.6072237288	0.9021546001	-0.2579532458

C	-3.7125578881	-1.1232177749	1.6324497564
H	-2.0141180389	-1.9518723336	0.6001532178
C	-4.5820276542	0.9282242600	0.7319628675
H	-3.5756321948	1.6855388280	-1.0067681204
C	-4.6358209390	-0.0851118234	1.6782714206
H	-3.7546436091	-1.9174429943	2.3656187269
H	-5.3045475820	1.7327622191	0.7559812456
H	-5.3988586779	-0.0713846918	2.4446693363
H	-0.2755969483	2.2858715375	-1.8854253683
H	0.3862965740	1.7092829231	1.7843177535
C	2.5887210120	-1.6015470795	-0.3756850292
C	1.5851441055	-2.7264123783	-0.1430850192
C	2.1831848548	-0.5166702315	-1.1045591409
O	3.7505250790	-1.8047261837	0.1110091223
O	0.2270392209	-2.3906594968	-0.4071471285
H	1.8868040982	-3.5859450666	-0.7558587360
H	1.6351139325	-3.0272617511	0.9017076659
C	0.8072383362	-0.4235825320	-1.6438338803
H	2.8924598936	0.2746669564	-1.3152235016
C	0.0594290713	-1.7480492183	-1.6449128283
H	0.7718820883	-0.0164739197	-2.6587615895
H	0.3682549488	-2.4083473762	-2.4610556065

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H	-1.5419132055	-1.8732891689	1.6065983569
C	-3.9525697951	-2.4624829801	-0.2262197716
H	-4.4669311405	-1.7226835156	0.3878240326
H	-4.6962677457	-3.1000029110	-0.6993980765
C	-3.0529384939	-1.7520032683	-1.2240838868
H	-3.5227341596	-0.8948011726	-1.7094331003
H	-2.7414136550	-2.4608833553	-2.0070649936
H	-2.7035279957	-4.1868099343	0.1146153273
N	-1.9413494922	-1.3117593617	-0.3879698554
C	-0.7990864301	-0.8029695299	-1.0875551917
C	0.1790340685	-0.1379248276	-0.1322538164
C	1.4328395439	0.4391297132	-0.8481238398
H	1.3276507896	0.3440756289	-1.9299914160
H	0.5039501744	-0.8932878314	0.5844191340
O	1.4514435838	1.8263269988	-0.5491090226
C	2.7310940650	-0.2273491540	-0.4232682791
C	3.8051294146	0.5297976195	0.0304177012
C	2.8670071828	-1.6129121634	-0.4995094297

C	4.9928348725	-0.0849830665	0.4094181707
H	3.7077119512	1.6051219037	0.0841819636
C	4.0549151944	-2.2248569603	-0.1287599453
H	2.0347812671	-2.2070938671	-0.8546782190
C	5.1229940379	-1.4630933727	0.3303778376
H	5.8177010146	0.5182145527	0.7651493525
H	4.1469806763	-3.3008953031	-0.1952052022
H	6.0474142614	-1.9420409312	0.6236065506
H	-1.1590890679	-0.0623456143	-1.8085938221
H	-0.7873078749	-2.9194763057	0.3990429226
C	-1.4941669471	3.0507552968	-0.3757785253
C	-0.3057314749	3.9116889042	-0.0932364891
C	-1.5572108765	1.7706378446	-0.0351525153
O	-2.4702653361	3.7542867174	-1.0133677787
O	0.5332523724	3.3440797798	0.8955841035
H	-0.6425144062	4.8716311832	0.2959353288
H	0.2521971692	4.0914562355	-1.0167844133
C	-0.4069054368	1.0716819701	0.6372935181
H	-2.4565363580	1.1967683776	-0.2263307410
C	0.8098213496	2.0004635764	0.7014730144
H	-0.7012126599	0.7597730902	1.6403161734
H	1.4833114545	1.7148701995	1.5155774650
H	-3.1997667521	3.1648498851	-1.2327451097
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H	-0.5669456332	-2.0855136212	-2.5601563871

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H	1.4685521013	1.5337371189	1.2061627385
C	1.9698954051	4.4143681693	-0.0402736502
H	2.8773321403	4.0534009450	-0.5246114975
H	2.0328921720	5.4968921338	0.0469988982
C	0.7607504681	3.9488085847	-0.8354339623
H	0.8736760016	4.0529712448	-1.9147555674
H	-0.1259942634	4.5227225285	-0.5218856170
H	1.2025302277	4.3623777611	1.9843567453
N	0.6731944236	2.5404551620	-0.4653942262
C	-0.4904534104	1.8458637965	-0.9414668094
C	-0.3882550784	0.3509234093	-0.6994014603
C	-1.5890613569	-0.4245957419	-1.2772625899
H	-1.9987575168	0.1237300573	-2.1307104533
H	-0.3163577431	0.1570911880	0.3728257113
O	-1.0499382469	-1.6600877090	-1.7823854492

C	-2.7036550514	-0.7088473082	-0.3028253708
C	-2.5432317250	-1.6773290641	0.6838885029
C	-3.8995143665	-0.0064840809	-0.3755179931
C	-3.5641263025	-1.9306657162	1.5882837128
H	-1.6180302254	-2.2387954724	0.7246705718
C	-4.9222327400	-0.2573857459	0.5292624892
H	-4.0244811945	0.7495135281	-1.1401030490
C	-4.7564272391	-1.2207779533	1.5141425478
H	-3.4320476994	-2.6873171550	2.3503188697
H	-5.8491434884	0.2964315819	0.4621278933
H	-5.5534366911	-1.4219938612	2.2173577102
H	-0.5448134693	2.0220376995	-2.0226129345
H	-0.0025483979	2.4497648128	1.5483213899
C	2.6697342276	-1.3178662297	-0.2022559895
C	1.9350111715	-2.6247031179	-0.1426960953
C	2.1446670756	-0.2306651710	-0.7540270192
O	3.8993544113	-1.4138866479	0.3711341834
O	0.5591791345	-2.4619022807	-0.3960225910
H	2.3851457724	-3.3329218410	-0.8507354649
H	2.0333339151	-3.0461489522	0.8571790739
C	0.8047935468	-0.2917395073	-1.4235424676
H	2.6767779196	0.7130953531	-0.7539656978
C	0.3197524520	-1.7239252175	-1.5846761220
H	0.8747489237	0.1511271240	-2.4225094314
H	0.7794147082	-2.2528069721	-2.4259453375
H	4.3751706440	-0.5845311548	0.2551031808
O	-1.7118986934	2.2749756160	-0.3416782664
H	-1.9100795890	3.1669704344	-0.6398373729

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C	-1.8581594199	-2.1566374082	0.2882032372
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H	-1.5977731122	-1.8395121400	1.3021300128
C	-4.1187434517	-1.7051720139	-0.4620003346
H	-4.4391956852	-0.9478572308	0.2544184505
H	-4.9970658945	-2.1124413832	-0.9580156217
C	-3.1210608935	-1.0810039046	-1.4247479911
H	-3.4117707660	-0.0896369713	-1.7724266410
H	-2.9889506742	-1.7387804200	-2.2985698053
H	-3.2446379000	-3.6744962326	-0.3917148883
N	-1.9218279642	-0.9897903136	-0.6018114147
C	-0.7198100760	-0.5922702782	-1.2553282829
C	0.4008867388	-0.2849820815	-0.2621092160
C	1.6652431564	0.2019291984	-0.9979635864

H	1.6461841396	-0.1173827361	-2.0384124003
H	0.6097190345	-1.2205172297	0.2544695214
O	1.5688661960	1.6178209386	-0.9983520621
C	2.9489854296	-0.2908716545	-0.3600643758
C	3.9199892935	0.5870176009	0.1035742513
C	3.1762406420	-1.6630533063	-0.2651997677
C	5.0921034159	0.1025684758	0.6741761849
H	3.7649191699	1.6524963422	0.0027591030
C	4.3464200879	-2.1469494797	0.2973345594
H	2.4318428727	-2.3533524581	-0.6455483798
C	5.3072678351	-1.2631101124	0.7756111127
H	5.8389713311	0.7971380825	1.0348994735
H	4.5115064771	-3.2141327430	0.3623869486
H	6.2193450006	-1.6397221785	1.2184365986
H	-0.9539230220	0.2875638533	-1.8658132664
H	-1.0999691207	-2.8722716793	-0.0410967254
C	-1.9018715797	2.0246276373	0.0066700652
C	-0.9717904884	2.9507453674	-0.7571882266
C	-1.2386653025	1.2859589969	1.1363861036
O	-3.0700356461	1.9366534285	-0.2811111768
O	0.2148541357	3.1938162719	-0.0304947496
H	-1.4662033605	3.9080166538	-0.9068577859
H	-0.7554231086	2.5215872783	-1.7405323470
C	0.1840645192	0.8462202711	0.7703892293
H	-1.8735864798	0.4680334817	1.4593457657
C	0.9818389417	2.0528511125	0.2084292393
H	0.6765632335	0.5304649217	1.6886143814
H	1.7523972495	2.3840591285	0.9060729767
O	-0.1725643854	-1.6048807865	-2.1129314159
H	-0.7732457209	-1.7424567738	-2.8506792036
H	-1.1540401953	2.0083239395	1.9552759819

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C	0.9453900975	2.4017424960	1.0046871247
C	1.6482922016	3.7128267291	1.4058881026
H	2.5393587079	3.5359585416	2.0035529141
H	1.5725286631	1.5300686258	1.2027824453
C	1.9552537858	4.4074556680	0.0742386085
H	2.8947510106	4.0421831504	-0.3416080979
H	2.0119863836	5.4902710545	0.1616996669
C	0.8031015296	3.9390503729	-0.7985175331
H	0.9847959969	4.0483688562	-1.8679043386
H	-0.1038335036	4.5084874214	-0.5416404431
H	0.9719807828	4.3316890528	1.9949168553
N	0.6979979997	2.5265676988	-0.4438648855

C	-0.4524950285	1.8395608873	-0.9554264187
C	-0.3450480025	0.3358531692	-0.7582807332
C	-1.5742887638	-0.4185515970	-1.3066982203
H	-1.9908971784	0.1404060329	-2.1492636295
H	-0.2368026487	0.1186276808	0.3077649197
O	-1.0623216925	-1.6608191613	-1.8345632996
C	-2.6756266467	-0.6929072065	-0.3140290174
C	-2.4823077652	-1.6132368468	0.7122747976
C	-3.8954952389	-0.0363164090	-0.4134714160
C	-3.4919471063	-1.8625974435	1.6296313481
H	-1.5401503238	-2.1422469872	0.7760537468
C	-4.9080227328	-0.2839882138	0.5040393401
H	-4.0483468477	0.6815757257	-1.2093652449
C	-4.7077551929	-1.1977228731	1.5290434356
H	-3.3316941875	-2.5803491324	2.4232238702
H	-5.8536725339	0.2341459491	0.4162991528
H	-5.4956516094	-1.3944274373	2.2436198953
H	-0.4997137693	2.0494891449	-2.0308964463
H	0.0107788767	2.2745043138	1.5563970420
C	2.4776283802	-1.1340731986	0.1519729118
C	1.8709429696	-2.5138403691	-0.0237687803
C	2.2143933275	-0.1899721061	-0.9915460097
O	3.1545011199	-0.8483301081	1.1092804029
O	0.5120412708	-2.4143850495	-0.3951115938
H	2.4490005949	-3.0533825459	-0.7876238561
H	1.9220537622	-3.0624719399	0.9125701459
C	0.7993137956	-0.3050875440	-1.5540311733
H	2.4548629988	0.8314566675	-0.7096555422
C	0.3046180981	-1.7433655429	-1.6318322814
H	0.7823495474	0.1060945000	-2.5667118986
H	0.7549402345	-2.3331727974	-2.4363983534
O	-1.6830586385	2.2386700082	-0.3534467655
H	-1.8682595528	3.1498425210	-0.5978708972
H	2.9210183683	-0.4946822188	-1.7724675203

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0 1

C	-3.9436549571	1.1443419497	0.7893188670
C	-4.8978540732	0.5428123708	-0.2519841951
H	-5.7131691263	1.2244178467	-0.4858153294
H	-3.9609652377	2.2406043223	0.7164718979
C	-3.9940824582	0.2568200276	-1.4764205702
H	-4.3443918909	0.7489875109	-2.3814439339
H	-3.9556534997	-0.8134893241	-1.6765095592
C	-2.6107571274	0.7606104932	-1.0500932436
H	-2.4885443202	1.8143762187	-1.3392679207

H	-1.7866298655	0.2006307142	-1.4896257171
H	-5.3368366780	-0.3800961943	0.1227222394
N	-2.6444931153	0.5977058519	0.4017001855
H	-1.8727159952	1.0832978440	0.8455562411
O	-0.1264619685	1.4197009723	2.9411596049
C	0.9045776859	0.8122191606	3.0629176391
C	0.2907235865	-0.6779359391	1.1406200620
H	-0.7149007558	-0.6241173631	1.5582134051
O	0.3030297518	0.4069359471	0.2045660868
C	0.4206762726	-2.0207091951	0.4594830551
C	-0.6668099798	-2.4693164725	-0.2895681285
C	1.5712398123	-2.7977230537	0.5156607435
C	-0.5991137683	-3.6690941051	-0.9789491936
H	-1.5652836524	-1.8610597825	-0.3148525358
C	1.6397081703	-4.0042340790	-0.1727082119
H	2.4217455851	-2.4748121089	1.1031210254
C	0.5581369282	-4.4387279487	-0.9231679890
H	-1.4483023233	-4.0092202656	-1.5561066954
H	2.5386899210	-4.6032294512	-0.1197648675
H	0.6121212464	-5.3764937597	-1.4592273347
H	1.6526160576	1.1304065990	3.8096639392
H	-4.1966122007	0.8689528110	1.8120812629
C	2.5245503408	2.8529521268	-0.7985383163
C	1.0729914337	2.6997148442	-1.2030763403
C	3.2580037996	1.6038301688	-0.5228934763
O	3.0239827181	3.9471262426	-0.6622794363
O	0.7823340181	1.4245879486	-1.7447105092
H	0.8384234398	3.4373774643	-1.9664803997
H	0.4567470725	2.8997057738	-0.3198733984
C	2.6116242083	0.4420891643	-0.5484577906
H	4.3067912332	1.6911762566	-0.2709966380
C	1.1497920882	0.3625761934	-0.9243151794
H	3.1146212276	-0.4886656577	-0.3122960726
H	0.9642138106	-0.5436726323	-1.5040003228
C	1.2701800501	-0.4145898717	2.2708089814
H	2.3025623755	-0.3020937120	1.9329524389
H	1.2752321597	-1.2531019071	2.9757846302

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0 1

C	-3.3906901313	-2.3611272084	0.8491592976
C	-4.3946731800	-2.5328967382	-0.2882109295
H	-5.2992350045	-3.0560944067	0.0154210534
H	-3.8993049625	-2.0451445596	1.7631068893
C	-4.6590641525	-1.0853144251	-0.7307653303
H	-5.5453359079	-0.6918951271	-0.2352520692

H	-4.8221453974	-1.0089321758	-1.8034936001
C	-3.4017191780	-0.3026893782	-0.2772913085
H	-3.6723025304	0.4811397327	0.4319830499
H	-2.8581778050	0.1598016579	-1.0984813170
H	-3.9296742552	-3.1011688790	-1.0952147608
N	-2.5125708525	-1.2672037735	0.4091511245
H	-1.7639239454	-0.3943522397	1.5896869768
O	-1.5585927927	0.2370249184	2.3611839076
C	-0.3662654124	0.8341629910	2.3246108565
C	0.6747217887	0.5750113905	1.5267019154
C	0.7009559956	-0.5284473779	0.5114152851
H	0.1401844459	-1.3722765392	0.9256869715
H	1.5483651284	1.1981775089	1.6461074590
O	-0.0503603580	-0.2612554955	-0.6900035277
H	-1.8450184774	-1.6173349016	-0.2696749125
C	2.0951563825	-1.0399688624	0.1893131469
C	2.3535503023	-1.6415919860	-1.0407374567
C	3.1218188432	-0.9688763903	1.1261701603
C	3.6149277554	-2.1363196645	-1.3371927647
H	1.5594501120	-1.7212595974	-1.7712068167
C	4.3838558990	-1.4695179920	0.8328894386
H	2.9359857366	-0.5237848873	2.0941493801
C	4.6375253764	-2.0482987705	-0.4017369569
H	3.7984160693	-2.5933803191	-2.3004030748
H	5.1705171530	-1.4026422893	1.5724900457
H	5.6221634300	-2.4314393012	-0.6323969949
H	-0.2882860360	1.6328644873	3.0557455030
H	-2.8090063503	-3.2530989299	1.0719221685
C	-0.0084374228	3.3394013130	-0.4207492657
C	-1.1603851451	2.4278414058	-0.7862160302
C	1.3365752251	2.8510890448	-0.7745756830
O	-0.1911811556	4.3706639147	0.1864231682
O	-0.8384096644	1.5486200738	-1.8445154967
H	-2.0081108668	3.0293390020	-1.1057499512
H	-1.4444325860	1.8725586923	0.1159167996
C	1.4844725550	1.6142219418	-1.2371053144
H	2.1750233473	3.4990941642	-0.5563226865
C	0.2932401485	0.7606098794	-1.6037478391
H	2.4646783555	1.1899522773	-1.4138893329
H	0.4980545203	0.2806148197	-2.5631411776

MA-enol

0 1

C	2.2963682811	-1.9380889789	-1.4875597571
O	3.2811537709	-1.9097046455	-0.5666702612
H	2.6813989178	-2.0874318441	-2.4881178608

C	0.9904139730	-1.8081556195	-1.2639262343
H	0.3358858104	-1.8990219413	-2.1177584546
C	0.3666755058	-1.6913739529	0.0999600592
H	0.3131079942	-2.6932489315	0.5364223552
C	-1.0385530471	-1.1280875218	0.1309340258
C	-1.7499806758	-1.2544852808	1.3232413491
C	-1.6230689287	-0.4481278651	-0.9295750007
C	-2.9956780306	-0.6688942373	1.4728670339
H	-1.3022542998	-1.7978165324	2.1471714491
C	-2.8692411328	0.1483062050	-0.7815865318
H	-1.1082306879	-0.3551205703	-1.8754632001
C	-3.5522995240	0.0498913197	0.4214338116
H	-3.5321724887	-0.7682776477	2.4067169726
H	-3.3032179204	0.6937581713	-1.6085277674
H	-4.5201745765	0.5186152746	0.5357832632
C	0.0870571833	2.3807684225	-0.5086727389
C	1.2143735146	1.5117663142	-1.0183176654
C	-0.3696012386	2.1250842702	0.8623311069
O	-0.4477126808	3.1822080122	-1.2439073112
O	2.0150697026	0.9281113844	-0.0088229874
H	1.8771057425	2.1256528840	-1.6247933098
H	0.7807981965	0.7443365248	-1.6671607336
C	0.1696127096	1.1283112780	1.5565822284
H	-1.2055397476	2.7067118471	1.2271501984
C	1.3971736660	0.3791996846	1.1135719707
H	-0.2126847813	0.8469434816	2.5296672382
O	1.2342689346	-1.0288135502	1.0567155510
H	2.1317380524	0.4812508255	1.9154527206
H	2.8869588052	-1.6689707801	0.2857554806

MA

0 1

C	3.2029088625	-1.6088907098	-1.0133289310
O	3.5861844654	-2.3161464248	-0.1204304346
H	3.9057296117	-1.2637057031	-1.7915526070
C	1.7774543099	-1.1610340215	-1.1990008195
H	1.3952855475	-1.7241798921	-2.0576533725
C	0.9148951130	-1.4198432659	0.0247243985
H	1.1302867825	-2.4368978239	0.3552138890
C	-0.5766662526	-1.3133994136	-0.1997525842
C	-1.4179121059	-1.7980679246	0.8012367006
C	-1.1426391995	-0.7196298871	-1.3203689600
C	-2.7908448610	-1.6464147825	0.7096218994
H	-0.9807663929	-2.2796781582	1.6680060711
C	-2.5196372338	-0.5545281989	-1.4125800939
H	-0.5182198350	-0.3762610472	-2.1341520579

C	-3.3446420103	-1.0060299502	-0.3931971988
H	-3.4305912303	-2.0215954258	1.4969513710
H	-2.9449259280	-0.0722947299	-2.2821386787
H	-4.4157611758	-0.8750394821	-0.4639847370
C	-0.8017630077	2.4777699996	-0.1251008857
C	0.5786222785	2.1402819056	-0.6428649307
C	-1.2348731006	1.8050095309	1.0991573567
O	-1.5139146963	3.2235657332	-0.7622751479
O	1.4719385576	1.5459514285	0.2787599922
H	1.0468203832	3.0634498523	-0.9803938166
H	0.4327784160	1.5068285390	-1.5236990952
C	-0.4255769668	0.9316441975	1.6896467152
H	-2.2425020667	1.9948816204	1.4438494541
C	1.0121648450	0.7123602792	1.3087461002
H	-0.7463542011	0.3638754974	2.5543953824
O	1.3606853703	-0.6400793186	1.1432033333
H	1.6053068247	0.9879621425	2.1845254857
H	1.7893651262	-0.1132034165	-1.4968780684

TS-s1

0 1

C	0.8746989892	-2.1941421872	-1.4677243134
O	1.5648367389	-2.1271535791	-0.3840281244
H	1.4264050277	-2.4140941219	-2.3803139918
C	-0.4744732537	-1.9281270894	-1.4961178369
H	-0.9657995435	-1.7184175369	-2.4331393300
C	-1.1532734052	-1.8472523555	-0.2587606450
H	-0.9103768437	-2.6086610747	0.4724264948
C	-2.4807961673	-1.2552318586	-0.1001893919
C	-3.1470405360	-1.4367988381	1.1131605218
C	-3.0582585601	-0.4516713715	-1.0833843595
C	-4.3608783957	-0.8152833435	1.3474536011
H	-2.6881649243	-2.0501478674	1.8784127181
C	-4.2717601505	0.1731436720	-0.8486789689
H	-2.5563297676	-0.2973170072	-2.0290678156
C	-4.9204431743	-0.0034437796	0.3673016096
H	-4.8681269012	-0.9541837168	2.2921387093
H	-4.7063719634	0.8071954018	-1.6087164339
H	-5.8644248081	0.4916052306	0.5507519412
C	-1.3387593324	2.2499951082	-0.5825248597
C	-0.1019579311	1.5126226338	-1.0485575621
C	-1.7372412686	2.0299991965	0.8137479696
O	-1.9943065100	2.9098190130	-1.3606921305
O	0.7906215828	1.1706084084	-0.0121757666
H	0.4407677579	2.1458957671	-1.7472564291
H	-0.4371930073	0.6209649805	-1.5922661665

C	-1.0437138518	1.1809396946	1.5665609278
H	-2.6446308745	2.5123214289	1.1530154372
C	0.2317295522	0.5243371754	1.1050816088
H	-1.3727141449	0.9168419204	2.5645469792
O	0.0375581426	-0.8426123957	0.9420202611
H	0.9889664565	0.6573173272	1.8856432558
H	0.9481670673	-1.4908158352	0.3624220908

TS-s2

0 1

C	-2.9051645432	-2.2915333287	0.0742601514
C	-4.1405306245	-2.1804416211	-0.8101500651
H	-4.7894441417	-3.0470871020	-0.7145330571
H	-3.1522576458	-2.7121086741	1.0470467528
C	-4.7808274640	-0.8823691991	-0.3217445328
H	-5.2765355611	-1.0459163635	0.6357388788
H	-5.5059150257	-0.4699160313	-1.0184722287
C	-3.5776248782	0.0363639376	-0.1431362541
H	-3.7107262559	0.8026060668	0.6162224358
H	-3.2887467222	0.5082763594	-1.0806198901
H	-3.8457415425	-2.0833453099	-1.8558025613
N	-2.4634226912	-0.8758296447	0.2700873487
H	-2.1677073903	-0.6832876601	1.2580448141
O	-1.5394908466	-0.0578056565	2.6430135855
C	-0.5255883690	0.6748427122	2.6054542681
C	0.6101177900	0.5328362579	1.7925319888
C	0.8144405343	-0.5875413253	0.9867034233
H	0.1619383919	-1.4295767291	1.1934691211
H	1.3394514525	1.3278813774	1.8372156518
O	-0.0740861207	-0.5166179751	-0.7211109136
H	-1.5635532083	-0.6875056661	-0.2794290827
C	2.1660108491	-0.9831540696	0.5121923054
C	2.3034464131	-2.1208291686	-0.2843009289
C	3.3104377812	-0.2659073381	0.8522713465
C	3.5455997218	-2.5177230953	-0.7491582173
H	1.4156175931	-2.6757737328	-0.5560764338
C	4.5573086778	-0.6592741989	0.3850995689
H	3.2360506191	0.6034028564	1.4895325818
C	4.6791042665	-1.7819780293	-0.4203637513
H	3.6319995282	-3.3994834817	-1.3697587740
H	5.4349948414	-0.0880544547	0.6558767074
H	5.6504843194	-2.0887894587	-0.7839127120
H	-0.5046369119	1.5372362000	3.2900646652
H	-2.0891930580	-2.8606689354	-0.3640391082
C	0.2515393988	3.0025029979	-0.3800392409
C	-1.0384391097	2.2516083569	-0.6430328458

C	1.4757774154	2.4082439876	-0.9335921737
O	0.2553441974	4.0024839141	0.3069796858
O	-0.9650635918	1.3727167335	-1.7400391615
H	-1.8291480065	2.9728580768	-0.8424339262
H	-1.2844697987	1.7191543378	0.2852989427
C	1.4240945476	1.2004093060	-1.4889764463
H	2.4013206037	2.9509915321	-0.7894459425
C	0.1238839720	0.4502763501	-1.6706950758
H	2.3247272595	0.6948717334	-1.8177403177
H	0.1230933343	0.0004471561	-2.6709825826

TS-s3

0 1

C	0.1895343003	0.3073078566	-0.2426488943
O	0.9932453167	0.0555290437	-1.2858030264
H	0.4794499190	-0.1891806595	0.6987383353
C	-1.2550011576	0.0418466912	-0.5363815499
H	-1.6013388884	0.3817754379	-1.5062117284
C	-2.0507566314	-0.6329346734	0.2887698316
H	-1.6305451614	-0.9997541259	1.2219745977
C	-3.4647037112	-0.9696154851	0.0707009474
C	-4.0905004706	-1.8461177703	0.9573174854
C	-4.2136356220	-0.4419918703	-0.9842243401
C	-5.4218185868	-2.1993974315	0.7922785723
H	-3.5218279227	-2.2577609606	1.7820110498
C	-5.5422463565	-0.7931674885	-1.1500913200
H	-3.7589458629	0.2538082177	-1.6768743721
C	-6.1518530795	-1.6748276117	-0.2636560152
H	-5.8866599802	-2.8842052494	1.4884804021
H	-6.1081638336	-0.3753165520	-1.9717426184
H	-7.1902779622	-1.9459898460	-0.3962440688
N	0.3830154259	1.8194483079	0.1496633808
C	-0.1031955428	2.7718836064	-0.9035271686
C	-0.2376275980	2.2102654243	1.4549476685
C	-1.3265496267	3.4274320893	-0.2811913265
H	0.6860296221	3.5002910623	-1.0792589946
H	-0.2745838303	2.2205554083	-1.8229215195
C	-0.9190805301	3.5481014157	1.1868135170
H	0.5301634296	2.2380035042	2.2228093402
H	-0.9693505256	1.4458070095	1.7097263787
H	-2.1971235625	2.7765509839	-0.3787863315
H	-1.5537532718	4.3829920438	-0.7464838841
H	-1.7575234648	3.7116686446	1.8587428827
H	-0.2114413655	4.3676528834	1.3140883251
H	1.4178952687	1.8719442094	0.1887951145
O	2.9435562697	1.2026445043	-0.5183961501

H	2.0888750441	0.5215128951	-0.9726411938
C	3.8712288726	0.5777651612	0.2774203305
O	3.2981206747	-0.3150963859	1.2267958473
C	4.9241213776	-0.1079715241	-0.5588909593
H	4.3708855719	1.3250381286	0.9031215529
C	2.9615279923	-1.5987072397	0.7375605907
C	5.0728783237	-1.4283757431	-0.6270540998
H	5.5628788357	0.5563922590	-1.1289301026
C	4.1176715310	-2.3043187997	0.0656232241
H	2.6261085448	-2.1930069327	1.5845853621
H	2.1532902341	-1.5483370744	-0.0033135421
H	5.8407319690	-1.9041621055	-1.2233156478
O	4.1858410217	-3.5145952592	0.0341191172

TS-s4

0 1

O	0.8540232777	-1.6991731977	0.9807118232
H	-0.1184214517	-1.2906544366	1.4643374952
C	0.3381715956	1.5624069256	0.2931827330
C	-0.9895202885	1.4088940526	0.2095715258
H	0.9487651624	0.6678118639	0.1932226300
C	-1.5331181667	0.0982171160	-0.0782834719
H	-1.6761842824	2.2343886686	0.3398254151
H	-0.8580539336	-0.6822425331	-0.4016897786
O	-1.2374787012	-0.8896710387	1.8463455688
C	1.0614940656	2.8061374867	0.5459289606
C	2.4520624413	2.7566498370	0.6617796123
C	0.4205101853	4.0424528548	0.6762841669
C	3.1858722826	3.9077752164	0.9050502594
H	2.9558289352	1.8034636123	0.5623405827
C	1.1520170579	5.1905299636	0.9181304535
H	-0.6548237474	4.1105329213	0.5840873630
C	2.5373286389	5.1271225488	1.0340281593
H	4.2619685413	3.8515045248	0.9940665296
H	0.6438778082	6.1399919713	1.0166169743
H	3.1063326527	6.0271724370	1.2231077538
N	-2.7942214805	-0.1042026327	-0.3121505365
C	-3.3042644009	-1.4423192437	-0.6453482291
C	-3.8846576539	0.8143397918	0.0547546493
C	-4.7705094825	-1.1820329892	-0.9532686121
H	-3.1793301188	-2.0751906479	0.2364359221
H	-2.7292816144	-1.8643646471	-1.4657151833
C	-5.1263493931	-0.0779011598	0.0449071900
H	-3.6867072224	1.2529968991	1.0311568084
H	-3.9502862504	1.6109343292	-0.6873704136
H	-5.3798812830	-2.0738549653	-0.8356331242

H	-4.8795500183	-0.8192842775	-1.9759060006
H	-5.2753529833	-0.5093066112	1.0343942247
H	-6.0213667038	0.4756324838	-0.2259589120
H	-1.0916481233	-0.1853527651	2.4827458019
C	0.5429958013	-2.8918406810	0.4062970711
O	-0.0354563036	-2.7539860178	-0.9055894088
C	1.7771200950	-3.7551813468	0.3311154515
H	-0.2440662046	-3.4244505803	0.9557427285
C	0.8769967268	-2.2900736950	-1.8718222928
C	2.4841127757	-3.9112670302	-0.7864217478
H	2.0912630718	-4.2154643450	1.2605606732
C	2.1022806616	-3.1726110159	-1.9976977778
H	0.3655275272	-2.2566134559	-2.8319260795
H	1.2344620100	-1.2794228870	-1.6327353178
H	3.3818830698	-4.5136049630	-0.8371070257
O	2.7538664243	-3.1964693408	-3.0209626155

TS-s5a-R

0 1

C	2.4343646169	-2.2498104249	-0.8742426018
C	3.9546935772	-2.3410580254	-0.9954339807
H	4.2949738560	-2.1029447325	-1.9993571044
H	2.0221385580	-1.4718301526	-1.5198427073
C	4.4495880085	-1.3529480530	0.0632072379
H	4.3300359049	-0.3280129668	-0.2911333518
H	5.4879053811	-1.5087357769	0.3429209161
C	3.4932023899	-1.6044027324	1.2213871278
H	3.3619448406	-0.7569367628	1.8895671458
H	3.7831085796	-2.4918383986	1.7870691947
H	4.2890268165	-3.3490737615	-0.7495211190
O	1.6869534644	1.0973560493	1.8717210329
H	2.0247512588	1.9943672839	1.9229078256
N	2.2209930787	-1.8585666699	0.5269818158
C	1.0571816689	-1.5746558069	1.0383052954
C	-0.1631616609	-1.5988125749	0.3557074833
C	-1.2454943272	-1.0479383612	0.9919346257
H	-1.1713237522	-0.8737031427	2.0561117705
H	-0.1986064449	-1.8782087576	-0.6869947876
O	-0.8021615365	1.1589529459	1.0747240492
H	0.7327051470	1.1867552155	1.5680430191
C	-2.5850708030	-0.9240884930	0.4295032307
C	-3.6468042806	-0.6336968678	1.2882859008
C	-2.8373301365	-1.0619811025	-0.9370023616
C	-4.9368314037	-0.5086319788	0.7999912951
H	-3.4483673200	-0.5002988175	2.3441010514
C	-4.1265416784	-0.9333224570	-1.4258871557

H	-2.0192142900	-1.2345372997	-1.6212958768
C	-5.1786743252	-0.6612260234	-0.5594347661
H	-5.7514728179	-0.2870767793	1.4756375010
H	-4.3119474078	-1.0354841457	-2.4862947641
H	-6.1837440813	-0.5588334962	-0.9458096610
H	1.0732040231	-1.2282310561	2.0650851067
H	1.9200946573	-3.1859809179	-1.0860504998
C	1.3842473055	2.5809912356	-1.1852159562
C	0.8042644326	1.1897388072	-1.3336399640
C	0.5277976377	3.5782446815	-0.5343763326
O	2.5253678072	2.8156094330	-1.5351772023
O	-0.5961528371	1.1423696673	-1.2620429400
H	1.1077897309	0.7941657319	-2.3031774480
H	1.2723375338	0.5876063274	-0.5441827006
C	-0.6442391038	3.2042454234	-0.0179205205
H	0.9214942706	4.5825418144	-0.4417224247
C	-1.1316439373	1.7713373410	-0.0726062488
H	-1.2552023078	3.9021868982	0.5430316678
H	-2.2142240938	1.7527146797	-0.2772268181

TS-s5b-S

0 1

C	2.8726112989	-2.1284725866	-1.3950916730
C	4.3528488494	-2.4586791444	-1.5706825971
H	4.7508300306	-2.0558372203	-2.4977785918
H	2.6171996709	-1.1500276602	-1.8081945791
C	4.9988716455	-1.8568736259	-0.3205538449
H	5.0845217700	-0.7750161120	-0.4235089960
H	5.9831305758	-2.2649405535	-0.1083691011
C	3.9892839642	-2.1946426934	0.7683525512
H	3.9981369385	-1.5205237267	1.6212038053
H	4.1155547477	-3.2207337780	1.1176586322
H	4.4933543125	-3.5396818098	-1.5777231715
O	1.4354155368	0.1289138821	2.8721712229
H	1.4732387603	0.6865145413	3.6515772010
N	2.7011412803	-2.0775143080	0.0648526025
C	1.5694848656	-1.8435348456	0.6645474874
C	0.3397796675	-1.6348097204	0.0259818853
C	-0.7226540216	-1.2596114339	0.8033038837
H	-0.5917630352	-1.2858935836	1.8769911764
H	0.2771926391	-1.6503092283	-1.0519158520
H	0.7038311278	0.5155683458	2.2966908894
C	-2.0884152865	-1.0519034779	0.3340281371
C	-3.0569120175	-0.6568787303	1.2582505022
C	-2.4585632173	-1.2248680647	-1.0002691512
C	-4.3649495348	-0.4356373277	0.8612591782

H	-2.7630085740	-0.4978248841	2.2877056013
C	-3.7666206840	-1.0065122493	-1.3986060487
H	-1.7218253919	-1.5202648154	-1.7338500488
C	-4.7222150505	-0.6101537405	-0.4700487180
H	-5.1046844513	-0.1234836518	1.5855567793
H	-4.0426589238	-1.1406945596	-2.4356386381
H	-5.7422385776	-0.4355598971	-0.7846237663
H	1.6145985112	-1.7561181849	1.7449989210
H	2.2045947116	-2.8724268719	-1.8255683510
O	-0.3946864436	0.9832509496	1.2491082626
C	-1.3444543129	3.5046022762	-0.9672104657
C	-1.6219655958	2.0227347197	-1.1172094927
C	-0.1450987107	3.8570632778	-0.1935816259
O	-2.1118470743	4.3383416757	-1.4070844577
O	-0.4486120175	1.2498935248	-1.0654610695
H	-2.1071340581	1.8461983690	-2.0759405821
H	-2.3201818851	1.7371770526	-0.3184981688
C	0.5975528809	2.8923715378	0.3497579823
H	0.0478486863	4.9109217897	-0.0366556782
C	0.2701530065	1.4250403689	0.1723322918
H	1.4298093451	3.1241603351	1.0055179403
H	1.2064170409	0.8689468397	-0.0290722643

TS-s6a

0 1

C	-2.0447110000	-2.0298310000	0.2395580000
C	-3.4848600000	-2.4913750000	0.0291370000
H	-3.9628660000	-2.7291840000	0.9751940000
H	-1.9355950000	-1.5086940000	1.1865810000
C	-4.1432880000	-1.3009560000	-0.6700060000
H	-4.3733260000	-0.5266850000	0.0592690000
H	-5.0524960000	-1.5681060000	-1.2024080000
C	-3.0576850000	-0.8047730000	-1.6137210000
H	-3.1242590000	0.2636860000	-1.8158060000
H	-3.0532760000	-1.3545740000	-2.5565430000
H	-3.5085760000	-3.3719450000	-0.6136540000
N	-1.8155960000	-1.0883460000	-0.8743390000
C	-0.6413060000	-0.6589730000	-1.2575890000
C	0.5311550000	-0.7270600000	-0.5085200000
C	1.7504110000	-0.0968330000	-1.1369900000
H	1.8817810000	-0.4266400000	-2.1702350000
H	0.6471680000	-1.5259940000	0.2100130000
O	1.4778800000	1.2971780000	-1.2450710000
C	3.0318660000	-0.3914870000	-0.3800240000
C	3.9303720000	0.6238620000	-0.0741350000
C	3.3459840000	-1.7007450000	-0.0218830000

C	5.1126250000	0.3395340000	0.5978430000
H	3.7067980000	1.6386960000	-0.3732500000
C	4.5292600000	-1.9866060000	0.6422750000
H	2.6667170000	-2.5068210000	-0.2707790000
C	5.4144420000	-0.9646110000	0.9606270000
H	5.7995480000	1.1410100000	0.8340840000
H	4.7600320000	-3.0083720000	0.9122530000
H	6.3347230000	-1.1855680000	1.4837670000
H	-0.6412610000	-0.0628700000	-2.1652250000
H	-1.3154810000	-2.8377050000	0.1797710000
C	-1.9157660000	1.6932950000	0.5408300000
C	-1.3176110000	2.4590900000	-0.6263070000
C	-1.0015280000	0.9534930000	1.3064080000
O	-3.1514300000	1.7703710000	0.7182760000
O	0.0264890000	2.8529910000	-0.4064660000
H	-1.8902720000	3.3717950000	-0.7722770000
H	-1.4053030000	1.8637370000	-1.5441710000
C	0.2943450000	0.7615690000	0.8161780000
H	-1.3510750000	0.4179280000	2.1770280000
C	0.9137870000	1.8408500000	-0.0631830000
H	1.0130040000	0.3118310000	1.4923470000
H	1.7068670000	2.3335390000	0.5042810000
H	-4.0055940000	0.0753920000	3.2864960000
O	-3.8562670000	-0.2717760000	2.4043640000
H	-3.6464120000	0.5131910000	1.8518300000

TS-s6b

0 1

C	1.8680423958	-1.5583755767	-1.3181728549
C	2.9318490111	-2.5016798654	-1.8742029710
H	3.5948520246	-1.9974021065	-2.5715990577
H	2.2465924460	-0.5446333251	-1.2041573169
C	3.6449474767	-3.0046512317	-0.6180868406
H	4.3121286814	-2.2335504111	-0.2317495767
H	4.2197370568	-3.9118900165	-0.7833545267
C	2.4914768705	-3.2230257299	0.3515976198
H	2.7755001215	-3.1569727557	1.3991390562
H	2.0049258631	-4.1845216148	0.1739674792
H	2.4580762501	-3.3363769762	-2.3915134982
O	2.6125803764	4.6758054052	-1.9919881468
H	2.8191638037	3.9686015807	-1.3465606268
N	1.5656014008	-2.1314011811	0.0091353314
C	0.5371029044	-1.7878651257	0.7505251792
C	-0.2421699234	-0.6585096078	0.5428632759
C	-1.5676258457	-0.4768191846	1.2276310899
H	-1.6561217689	-1.1916159001	2.0512383446

H	-0.1461170397	-0.1475799882	-0.4064090047
O	-1.6171330580	0.8447066913	1.7943031029
H	2.5440101585	5.4722581159	-1.4615048867
C	-2.7302911064	-0.6717113957	0.2827492988
C	-3.1734148496	0.3745567163	-0.5191320918
C	-3.3289818823	-1.9212064060	0.1708435783
C	-4.2029725262	0.1670278523	-1.4262289768
H	-2.7082170419	1.3465180256	-0.4206052682
C	-4.3578473054	-2.1290699559	-0.7372426070
H	-2.9887463453	-2.7356045011	0.8001631047
C	-4.7969908923	-1.0835452229	-1.5385622131
H	-4.5443754090	0.9853288160	-2.0460956754
H	-4.8205030487	-3.1038463816	-0.8147899465
H	-5.6017917001	-1.2410905162	-2.2437617082
H	0.3894218008	-2.3828774590	1.6479424851
H	0.9573767513	-1.5283115994	-1.9158794251
C	2.0115424615	2.2015503702	0.3477341748
C	0.7115067664	2.9732126017	0.1578270185
C	1.9735249269	1.0599864315	1.1662041320
O	3.0399809610	2.6739391816	-0.1747090958
O	-0.4632242439	2.2210180234	0.4089545181
H	0.7510014777	3.8524459414	0.8154826415
H	0.6550856656	3.3276302868	-0.8689405299
C	0.7571712739	0.6164420674	1.6974352631
H	2.8993136911	0.5419804139	1.3770266375
C	-0.4331168859	1.5451593092	1.6435838399
H	0.7813412148	0.0185729989	2.6027021455
H	-0.3784559593	2.2713632052	2.4641735289

4.4.2. Chiral system

TS-s5-r1

0 1

O	1.3338640000	1.1837810000	2.1745390000
C	0.7006050000	-0.5889350000	-0.2074460000
C	1.9007480000	-1.2520370000	-0.4736220000
H	0.4821130000	-0.3138390000	0.8164690000
C	2.8181560000	-1.2755270000	0.5529140000
H	2.1550660000	-1.5468580000	-1.4802830000
H	2.4573520000	-1.0881540000	1.5555120000
C	4.1572580000	-1.8530730000	0.4566930000
C	4.8958850000	-2.0336060000	1.6278400000
C	4.7275070000	-2.2202020000	-0.7632810000
C	6.1671590000	-2.5784030000	1.5857960000
H	4.4627400000	-1.7314620000	2.5728030000

C	6.0040620000	-2.7587130000	-0.8070990000
H	4.1782960000	-2.0864100000	-1.6850690000
C	6.7249650000	-2.9414720000	0.3657020000
H	6.7262270000	-2.7157720000	2.5011610000
H	6.4372070000	-3.0382530000	-1.7577840000
H	7.7200110000	-3.3637960000	0.3285200000
H	2.1737400000	1.1143840000	1.6343090000
O	3.4808430000	0.8021180000	0.7204560000
C	3.5114220000	1.2751360000	-0.5349230000
O	2.2839300000	1.9064350000	-0.9695960000
C	4.6669910000	2.2330440000	-0.6961500000
H	3.6230100000	0.4730870000	-1.2891560000
C	2.0560290000	3.1716610000	-0.3953610000
C	4.5220440000	3.5555580000	-0.7732960000
H	5.6501430000	1.7756820000	-0.6976890000
C	3.1864190000	4.1482910000	-0.6376010000
H	1.1431890000	3.5790030000	-0.8277710000
H	1.9124600000	3.0975860000	0.6894520000
H	5.3583480000	4.2369100000	-0.8647410000
O	2.9910120000	5.3475550000	-0.6381580000
H	1.5740720000	1.6460110000	2.9805550000
N	-0.1594480000	-0.1794160000	-1.0981040000
C	-1.3142540000	0.6533880000	-0.7428340000
C	0.1043260000	-0.2314920000	-2.5406010000
C	-1.5806830000	1.4296570000	-2.0372680000
C	-2.4972780000	-0.2075530000	-0.2013630000
H	-0.9992970000	1.3003020000	0.0775180000
C	-1.0580960000	0.5324980000	-3.1675520000
H	1.0658490000	0.2584880000	-2.7116950000
H	0.1641030000	-1.2662240000	-2.8770980000
H	-2.6325410000	1.6760210000	-2.1613710000
H	-1.0161500000	2.3614870000	-2.0089550000
O	-1.9599710000	-1.0180960000	0.8229340000
C	-3.0088010000	-1.1231980000	-1.3112950000
C	-3.6132370000	0.6792930000	0.3509150000
H	-1.8284780000	-0.1601180000	-3.4992050000
H	-0.7327480000	1.1133780000	-4.0265480000
Si	-1.9844010000	-1.0171980000	2.4996070000
C	-4.0565820000	-0.7426760000	-2.1461920000
C	-2.3528340000	-2.3259250000	-1.5626810000
C	-3.5305540000	2.0628100000	0.4543290000
C	-4.7545080000	0.0426130000	0.8377270000
C	-2.0992240000	0.7029480000	3.2211790000
C	-3.3835970000	-2.0943660000	3.1227510000
C	-0.3499180000	-1.7920300000	2.9719390000
C	-4.4261550000	-1.5355490000	-3.2237780000
H	-4.5915110000	0.1793330000	-1.9596810000
C	-2.7203610000	-3.1181510000	-2.6416670000

H	-1.5517510000	-2.6372970000	-0.9062910000
C	-4.5553950000	2.7911990000	1.0489210000
H	-2.6673920000	2.6003750000	0.0885200000
C	-5.7720840000	0.7626150000	1.4398290000
H	-4.8387170000	-1.0331730000	0.7425390000
H	-1.8700470000	0.6470630000	4.2879800000
H	-3.0915900000	1.1394460000	3.1053920000
H	-1.3624180000	1.3623090000	2.7575980000
H	-3.2081290000	-2.3433220000	4.1711560000
H	-3.4306240000	-3.0276830000	2.5591710000
H	-4.3516570000	-1.5997780000	3.0529080000
H	-0.3891640000	-2.1572690000	3.9995300000
H	0.4492660000	-1.0515110000	2.9068990000
H	-0.1067270000	-2.6336050000	2.3210440000
C	-3.7537130000	-2.7222880000	-3.4800110000
H	-5.2423040000	-1.2250120000	-3.8619560000
H	-2.2001290000	-4.0487420000	-2.8251710000
C	-5.6732590000	2.1451190000	1.5505340000
H	-4.4693720000	3.8666400000	1.1244210000
H	-6.6442050000	0.2476080000	1.8197470000
H	-4.0402940000	-3.3396450000	-4.3205050000
H	-6.4658790000	2.7113180000	2.0202790000

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O	-0.9789430000	-2.5899530000	0.1494360000
H	-1.0754470000	-3.5258150000	0.3373610000
C	-0.3611490000	0.3071570000	-0.0335940000
C	-1.5741290000	0.9425250000	0.2550260000
C	-2.4074990000	0.3274210000	1.1524390000
H	-2.0113980000	-0.5062710000	1.7169640000
H	-1.8856660000	1.8100550000	-0.3065070000
H	-1.9165030000	-2.2172380000	0.1218640000
C	-3.6959130000	0.8438620000	1.6012890000
C	-4.4139570000	0.1148000000	2.5501830000
C	-4.2400090000	2.0315620000	1.1091050000
C	-5.6486120000	0.5566390000	2.9967310000
H	-4.0017180000	-0.8165830000	2.9162010000
C	-5.4727490000	2.4754450000	1.5555380000
H	-3.7080250000	2.6058650000	0.3641090000
C	-6.1806120000	1.7391900000	2.4986590000
H	-6.1982510000	-0.0210590000	3.7269320000
H	-5.8869590000	3.3948920000	1.1647980000
H	-7.1454890000	2.0864500000	2.8425410000
H	-0.1095660000	-0.5973520000	0.5023510000
O	-3.3084610000	-1.4513630000	0.0021240000

C	-6.1163140000	-1.1403840000	-2.0390790000
C	-5.5143930000	-0.0596240000	-1.1643950000
C	-5.1820460000	-2.1688260000	-2.5211270000
O	-7.3101000000	-1.1797110000	-2.2634850000
O	-4.1558600000	0.1629140000	-1.4490790000
H	-6.0548820000	0.8720660000	-1.3237430000
H	-5.6537570000	-0.3677100000	-0.1193590000
C	-3.9023940000	-2.1251910000	-2.1496230000
H	-5.6000630000	-2.9742800000	-3.1118260000
C	-3.3575680000	-1.0221440000	-1.2679240000
H	-3.2123460000	-2.9218210000	-2.4052980000
H	-2.3753510000	-0.6968840000	-1.6624960000
N	0.4829310000	0.6776770000	-0.9579140000
C	1.7036900000	-0.0752370000	-1.2785510000
C	0.2122660000	1.7796660000	-1.8898500000
C	2.0224370000	0.3906560000	-2.7041230000
C	2.8227380000	0.1663460000	-0.2179390000
H	1.4484750000	-1.1340210000	-1.2273490000
C	1.4204330000	1.7983920000	-2.8207080000
H	-0.7187160000	1.5582400000	-2.4164160000
H	0.0867570000	2.7112740000	-1.3387170000
H	3.0909030000	0.3847700000	-2.9061510000
H	1.5435860000	-0.2855720000	-3.4120450000
O	2.2412090000	-0.1095580000	1.0385790000
C	3.2346180000	1.6374540000	-0.2389150000
C	4.0188710000	-0.7546500000	-0.4612770000
H	2.1327020000	2.5508100000	-2.4897160000
H	1.1314890000	2.0316620000	-3.8419620000
Si	2.3386380000	-1.3277510000	2.1867210000
C	4.2871350000	2.0906800000	-1.0305640000
C	2.4830030000	2.5678620000	0.4744680000
C	4.0454340000	-1.7687090000	-1.4111590000
C	5.1177660000	-0.6053410000	0.3843870000
C	2.6293830000	-3.0144320000	1.4348350000
C	3.6666310000	-0.9224250000	3.4419700000
C	0.6616780000	-1.2921360000	3.0093090000
C	4.5666110000	3.4465840000	-1.1277320000
H	4.8957610000	1.3839360000	-1.5791770000
C	2.7598880000	3.9245200000	0.3754480000
H	1.6801290000	2.2238560000	1.1120290000
C	5.1371420000	-2.6262880000	-1.4999830000
H	3.2191490000	-1.9205600000	-2.0908970000
C	6.2016500000	-1.4626560000	0.3058960000
H	5.1138600000	0.1929130000	1.1164450000
H	2.4408780000	-3.7707990000	2.2003540000
H	3.6492140000	-3.1437020000	1.0716620000
H	1.9353790000	-3.1954480000	0.6113640000
H	3.4909740000	-1.4932690000	4.3557180000

H	3.6431520000	0.1378600000	3.6990970000
H	4.6645160000	-1.1676850000	3.0802910000
H	0.6946310000	-1.8345170000	3.9556150000
H	-0.0812240000	-1.7735620000	2.3699370000
H	0.3432840000	-0.2686270000	3.2158850000
C	3.7980060000	4.3693720000	-0.4318180000
H	5.3877460000	3.7802570000	-1.7476050000
H	2.1647850000	4.6343330000	0.9342380000
C	6.2126850000	-2.4825060000	-0.6388140000
H	5.1369660000	-3.4129810000	-2.2421280000
H	7.0379990000	-1.3353050000	0.9799420000
H	4.0140500000	5.4262520000	-0.5085700000
H	7.0564220000	-3.1557810000	-0.7036720000

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O	-2.1850135839	-3.9001139956	-0.6256876230
C	-0.6030600655	-1.4927735344	-1.1631125653
C	-1.4411876340	-0.4303494716	-0.8423135165
H	-0.9816711382	-2.2332510379	-1.8588064875
C	-2.7368115312	-0.4779649859	-1.3245943750
H	-1.1232763472	0.3373469016	-0.1529130857
H	-2.9508888849	-1.2164415842	-2.0855934475
C	-3.6795694278	0.6467389225	-1.2701427724
C	-4.9619942352	0.4785879083	-1.7953629786
C	-3.3310022737	1.8822509426	-0.7254593413
C	-5.8795216354	1.5143620139	-1.7623327502
H	-5.2368222704	-0.4870171101	-2.1987814355
C	-4.2482589896	2.9206837860	-0.6910114207
H	-2.3406569099	2.0382080594	-0.3195653965
C	-5.5252349421	2.7383456834	-1.2055484432
H	-6.8719190720	1.3699540173	-2.1670388606
H	-3.9656404754	3.8728687520	-0.2626647444
H	-6.2414403635	3.5483981504	-1.1765199111
H	-2.8495209199	-3.1750541697	-0.4644607233
O	-3.8480353227	-1.8803499892	-0.2149388461
C	-4.2119268414	-1.7786467650	1.0844913058
O	-3.4084157358	-2.5804466794	1.9724031527
C	-4.1902995445	-0.3427498130	1.5666524861
H	-5.2180870859	-2.1866234025	1.2593111856
C	-2.0910735350	-2.1202217012	2.1132231518
C	-3.1679525108	0.1690406725	2.2522483567
H	-5.0306405105	0.2791536021	1.2770113280
C	-1.9868126486	-0.6595872492	2.4905765667
H	-1.6066331407	-2.7106695034	2.8909066165
H	-1.5208479413	-2.2525523535	1.1833625909

H	-3.1218658506	1.2064057344	2.5604600609
O	-0.9317926747	-0.2028583986	2.8982030063
H	-2.3708815909	-4.5407677115	0.0653329013
N	0.5830331115	-1.7770686919	-0.6777293148
C	1.2284388707	-1.0597864020	0.4261496835
C	1.1745098420	-3.1095212611	-0.9231887999
C	1.8729560177	-2.1967194678	1.2263190259
C	2.2018711895	0.0541724399	-0.0645421312
H	0.4435412933	-0.5652592042	0.9955867049
C	2.1948196128	-3.2967857939	0.2022694532
H	0.3641003426	-3.8364182614	-0.8819132277
H	1.6352264464	-3.1392751757	-1.9088870880
H	2.7551689507	-1.8687768284	1.7716823875
H	1.1462011176	-2.5559230016	1.9558555340
O	1.4595015297	0.8498272067	-0.9697229183
C	3.3696172323	-0.5686842395	-0.8305842577
C	2.6925893485	0.8941735313	1.1194144860
H	3.2047724219	-3.1844961372	-0.1832737423
H	2.1118051554	-4.2866036394	0.6437875680
Si	0.9350369882	2.4366554047	-1.0010078006
C	4.5531062624	-0.9380108473	-0.1942943338
C	3.2264408119	-0.8440927480	-2.1874396354
C	2.1466531621	0.8148642450	2.3971929502
C	3.6912633362	1.8389217983	0.8825195968
C	0.1355819253	2.9112698966	0.6297726925
C	2.3005677590	3.6515527943	-1.4196873658
C	-0.2570911800	2.4719217187	-2.4395771938
C	5.5614785372	-1.5854160085	-0.8937707969
H	4.6941241438	-0.7192743724	0.8559088093
C	4.2334486406	-1.4944502926	-2.8883957163
H	2.3181548644	-0.5450764709	-2.6919714678
C	2.5771853925	1.6711793905	3.4045303760
H	1.3652075777	0.1074186906	2.6338626420
C	4.1162802571	2.6983747626	1.8821727442
H	4.1391711918	1.9020842602	-0.1012842892
H	-0.5739488409	3.7277036459	0.4778685665
H	0.8948630485	3.2507069442	1.3373305535
H	-0.3927784839	2.0803338411	1.1052165743
H	1.8512727737	4.5399536814	-1.8686482759
H	2.9836678461	3.2198724933	-2.1538572406
H	2.8775031593	3.9657308308	-0.5521966824
H	-0.7365441480	3.4504229586	-2.5080776708
H	-1.0327201027	1.7119018945	-2.3693110507
H	0.2956323092	2.3065869061	-3.3667055864
C	5.4027066575	-1.8719380865	-2.2429681483
H	6.4731123288	-1.8639201273	-0.3826074051
H	4.1037524073	-1.7026872800	-3.9420677949
C	3.5562978758	2.6183605945	3.1514455058

H	2.1335841891	1.5952774890	4.3880605500
H	4.8865724379	3.4284437948	1.6720291299
H	6.1885784394	-2.3769098857	-2.7881287376
H	3.8859205831	3.2864533192	3.9355371534

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O	-3.1339810000	-1.9811610000	-2.5872360000
C	-0.7566490000	-0.4157100000	-1.5945850000
C	-1.3183190000	0.7029950000	-0.9773970000
H	-1.2426450000	-0.7904680000	-2.4897460000
C	-2.6089230000	1.0030410000	-1.3571830000
H	-0.8364720000	1.1676710000	-0.1327350000
H	-2.9683190000	0.5910970000	-2.2913370000
C	-3.3980100000	2.1098490000	-0.8137200000
C	-4.5901620000	2.4530430000	-1.4539200000
C	-3.0125040000	2.8269910000	0.3200560000
C	-5.3753550000	3.4900230000	-0.9829050000
H	-4.8990570000	1.8867320000	-2.3231930000
C	-3.8023750000	3.8625690000	0.7975220000
H	-2.0951150000	2.5777710000	0.8364960000
C	-4.9827690000	4.1973810000	0.1474580000
H	-6.2949990000	3.7456550000	-1.4911300000
H	-3.4957670000	4.4102180000	1.6783290000
H	-5.5958130000	5.0064670000	0.5207540000
H	-3.4324970000	-1.5071470000	-1.7632310000
O	-3.8031750000	-0.5497950000	-0.4801330000
C	-3.2711290000	-0.7889920000	0.7298190000
O	-2.2158710000	-1.7790800000	0.7424510000
C	-4.3631070000	-1.1940920000	1.6897210000
H	-2.7491560000	0.0931150000	1.1450190000
C	-2.6669920000	-3.0987450000	0.5486370000
C	-4.5569350000	-2.4497090000	2.0929210000
H	-5.0301660000	-0.3967650000	1.9976110000
C	-3.7134690000	-3.5244010000	1.5557550000
H	-1.8086470000	-3.7644640000	0.6349750000
H	-3.0988720000	-3.2320220000	-0.4506430000
H	-5.3619910000	-2.7380200000	2.7568140000
O	-3.8787930000	-4.6962000000	1.8310830000
H	-3.9105980000	-2.4354090000	-2.9204130000
N	0.2395390000	-1.1514470000	-1.1754490000
C	0.8713030000	-1.0343390000	0.1394710000
C	0.6124060000	-2.4003040000	-1.8564830000
C	1.1079250000	-2.4932990000	0.5524950000
C	2.1288620000	-0.1117100000	0.1020960000
H	0.1424660000	-0.5578630000	0.7900180000

C	1.0332290000	-3.3502420000	-0.7293490000
H	-0.2505930000	-2.7530750000	-2.4175270000
H	1.4336880000	-2.2089700000	-2.5475110000
H	2.0542280000	-2.6134130000	1.0734720000
H	0.3187810000	-2.7784410000	1.2457120000
O	1.5991420000	1.1773690000	-0.1371780000
C	3.0141150000	-0.5464640000	-1.0637400000
C	2.8405980000	-0.1159430000	1.4585280000
H	1.9927630000	-3.8072040000	-0.9580080000
H	0.3051070000	-4.1493350000	-0.6123280000
Si	2.2183780000	2.7170630000	0.0969440000
C	3.8516120000	-1.6565670000	-0.9679290000
C	2.8923750000	0.0884160000	-2.2966560000
C	2.0953510000	-0.1741490000	2.6366080000
C	4.2163470000	0.0725380000	1.5594550000
C	2.3155890000	3.1486010000	1.9142500000
C	3.8998740000	2.9245160000	-0.6984350000
C	0.9586500000	3.7953820000	-0.7586800000
C	4.5429000000	-2.1234240000	-2.0768960000
H	3.9737110000	-2.1629890000	-0.0193940000
C	3.5880680000	-0.3720190000	-3.4058310000
H	2.2288030000	0.9360450000	-2.3924690000
C	2.7063220000	-0.0530350000	3.8747440000
H	1.0225700000	-0.3049150000	2.6029670000
C	4.8313390000	0.2013450000	2.7985020000
H	4.8215440000	0.1204750000	0.6651920000
H	2.5189520000	4.2166580000	2.0178310000
H	3.1061410000	2.6008050000	2.4290380000
H	1.3710280000	2.9354860000	2.4173060000
H	4.2743760000	3.9278800000	-0.4847270000
H	3.8472650000	2.8046450000	-1.7805860000
H	4.6257410000	2.2084760000	-0.3133550000
H	1.2456290000	4.8464100000	-0.6992450000
H	-0.0272160000	3.6875340000	-0.3036260000
H	0.8711690000	3.5244590000	-1.8119120000
C	4.4128060000	-1.4829440000	-3.3016890000
H	5.1871530000	-2.9869920000	-1.9814620000
H	3.4776930000	0.1345030000	-4.3552370000
C	4.0786930000	0.1387730000	3.9611500000
H	2.1070370000	-0.1018760000	4.7737340000
H	5.9013390000	0.3503810000	2.8503820000
H	4.9523800000	-1.8449150000	-4.1662100000
H	4.5557100000	0.2377560000	4.9266810000

4.4.3. Epimerization of 1

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O	-0.8278462479	2.3738611595	-0.9766229634
C	0.2040856654	1.7429421092	-0.9496046039
H	0.9648632347	1.9384510291	-1.7199723658
H	-2.2404751678	2.1229088637	0.0454718892
H	-0.1268323874	0.8694400649	0.9354657031
O	-1.8483734550	1.5973907480	2.3155447055
C	-2.9171085288	1.6861804791	1.7676001670
O	-3.1062693200	2.0070512972	0.5031931781
H	-3.8724828209	1.5132414845	2.2745798903
C	0.4733780013	0.6646383162	0.0482718503
C	1.9391207139	0.3978147819	0.4326112831
C	0.0236038632	-0.7176271935	-0.4942973262
C	1.9509393042	-1.1442814246	0.6632975915
C	2.9789025557	0.7938111896	-0.6269377961
H	2.1753832480	0.9116226202	1.3620394893
O	0.6709276974	-1.6117325114	0.3987868090
C	-1.4632346276	-0.9215682339	-0.4701324104
H	0.4033543129	-0.8696418547	-1.5114870752
O	2.8417441479	-1.7878624115	-0.2251688250
H	2.2128789055	-1.4204069162	1.6883181880
C	4.2934690227	0.1325804284	-0.3045933429
H	2.6744773807	0.4220200169	-1.6103077705
H	3.1226954926	1.8699398473	-0.6858365039
C	-2.2131031650	-0.6653743274	-1.6123007102
C	-2.1066042668	-1.3180663496	0.6976006226
C	4.1655927693	-1.3514719682	-0.0210351954
O	5.3522965617	0.7045451647	-0.2617415710
C	-3.5945764146	-0.7982246251	-1.5896639290
H	-1.7150669175	-0.3657318576	-2.5267044218
C	-3.4862542208	-1.4595429652	0.7172230477
H	-1.5225626955	-1.5169158943	1.5857264020
H	4.5052193099	-1.5478215545	1.0035102846
H	4.8101677887	-1.9020431949	-0.7041159577
C	-4.2329714087	-1.1972784598	-0.4245567719
H	-4.1694975268	-0.5954999584	-2.4827420954
H	-3.9794873885	-1.7758212576	1.6267198549
H	-5.3085834162	-1.3077686419	-0.4063343205

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O	-0.8411987756	2.2534806676	-1.1156144609
C	0.1893897307	1.6207999487	-1.0526435192
H	0.9239712839	1.7274682648	-1.8646694562
H	-2.2219915343	2.1680034543	-0.0466909251
H	-0.0952582891	0.9486163897	0.9179286629
O	-1.8831718245	1.6936588507	2.2434071949
C	-2.9372284216	1.8890362966	1.6964971345
O	-3.0965051326	2.1447864653	0.4116254390
H	-3.9004484843	1.8740083334	2.2175067519
C	0.4859682327	0.6531571404	0.0437033938
C	1.9627211538	0.4365065561	0.4229229914
C	0.0312049380	-0.7701939496	-0.3451112679
C	1.9969178699	-1.0787688374	0.7898976635
C	2.9817686341	0.7482098836	-0.6842334307
H	2.2094647200	1.0317141520	1.2993283628
O	0.7171383406	-1.5768759228	0.6086039057
H	0.3823020572	-1.0262275870	-1.3537571528
O	2.8738192268	-1.7903018989	-0.0624138363
H	2.2938589594	-1.2578870199	1.8270041580
C	4.3071243411	0.1282292782	-0.3273362879
H	2.6675319977	0.2883367164	-1.6263164674
H	3.1129636224	1.8164392342	-0.8399381595
C	4.1972742824	-1.3293345131	0.0769049068
O	5.3611074460	0.7107554722	-0.3451693018
H	4.5597865262	-1.4390682341	1.1066509287
H	4.8335306512	-1.9290411463	-0.5719013525
C	-1.4567372551	-1.0050409590	-0.2323938008
H	-1.7541005729	-0.7802774478	0.7945644365
H	-1.9663550334	-0.2884072855	-0.8809612760
C	-1.8511844336	-2.4273676557	-0.6084965567
H	-1.3603849280	-3.1477328915	0.0440812493
H	-2.9275685691	-2.5664075685	-0.5230103134
H	-1.5631107801	-2.6504394274	-1.6366206344

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O	-1.3594344872	1.0451762640	2.0124104036
C	-0.4357861133	0.3162337913	1.7381985569
H	-0.1450841069	-0.4788523085	2.4458125246
H	-2.2286513410	2.1609549414	0.9675937371
H	0.1202038532	1.3448528247	-0.0282001716
O	-1.2518236291	2.9541926813	-1.0411729478
C	-2.3266637447	3.2570671132	-0.5895261281

O	-2.8477064488	2.7914744446	0.5274172400
H	-3.0044006561	3.9685609515	-1.0730004951
C	0.3576902823	0.4062128502	0.4702204859
C	1.8610323712	0.1991307896	0.7258330592
C	0.0213755410	-0.8086738811	-0.4320413624
C	2.0851066326	-1.3030814865	0.3816680814
C	2.7228655281	1.1116048682	-0.1554604597
H	2.1117035619	0.3719007669	1.7724314052
O	0.8375568749	-1.8436639726	0.0977109726
C	-1.4305057348	-1.1932752071	-0.4285211816
H	0.3399239083	-0.5714527332	-1.4522733355
O	2.8973015147	-1.4416890258	-0.7650888555
H	2.5269573596	-1.8731535855	1.2034369298
C	4.1254704905	0.5728104404	-0.2391823784
H	2.3201767052	1.1106157260	-1.1728950444
H	2.7361332803	2.1348150769	0.2102433331
C	-2.3328608972	-0.3613469199	-1.0859065462
C	-1.8974965471	-2.3008232360	0.2665695986
C	4.1852385807	-0.9130845587	-0.5453624324
O	5.1230322463	1.2283751480	-0.0787605905
C	-3.6915181029	-0.6292491023	-1.0401642703
H	-1.9652334382	0.5032975160	-1.6267207034
C	-3.2603211577	-2.5728575084	0.3027218586
H	-1.1958082730	-2.9487780591	0.7726837016
H	4.6973105514	-1.4231938051	0.2797194578
H	4.7677631557	-1.0656298073	-1.4523755077
C	-4.1586730282	-1.7382765686	-0.3446119966
H	-4.3863896683	0.0258353053	-1.5479607975
H	-3.6178185503	-3.4401752721	0.8412507441
H	-5.2185555133	-1.9500174623	-0.3102428856

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O	-1.6366718846	1.4279471048	1.5073188303
C	-0.9020989113	0.4955055065	1.2744088546
H	-0.8366808072	-0.3336070789	1.9986362650
H	-1.3686424687	2.9404520924	0.7349346091
H	-0.1849692150	1.2332213709	-0.5866468180
O	0.9393233913	3.1939534483	1.0135251280
C	0.1789709635	4.0148732611	0.5674900525
O	-1.1174802861	3.8357790509	0.3958255568
H	0.4884378777	5.0147010298	0.2455672780
C	-0.0546584138	0.3590173151	0.0489269143
C	1.4205942886	0.1250602230	0.4434956194
C	-0.3955678051	-0.9570308747	-0.6752021432
C	1.5567846369	-1.4252292555	0.4030086971

C	2.3856060201	0.8032201077	-0.5354681223
H	1.6231880695	0.4958311841	1.4475471748
O	0.3021021903	-1.9345883601	0.0979684890
H	0.0358725873	-0.9193194829	-1.6822381945
O	2.4556770064	-1.8302857276	-0.6098372222
H	1.8804736122	-1.8538275791	1.3555620528
C	3.7572694268	0.1951501780	-0.4183675764
H	2.0483125133	0.6214922474	-1.5611465519
H	2.4309294582	1.8744231217	-0.3627838862
C	3.7491432046	-1.3222839840	-0.3777482978
O	4.7831150655	0.8244462681	-0.3585726751
H	4.1444941918	-1.6497904930	0.5924455188
H	4.4053340812	-1.7048866535	-1.1573433393
C	-1.8602126064	-1.3253589231	-0.7636994902
H	-2.3850446133	-0.4974629637	-1.2451225491
H	-2.2686265402	-1.4205138586	0.2454646223
C	-2.0811306761	-2.6185591860	-1.5370619338
H	-1.5694688617	-3.4473250691	-1.0504195539
H	-3.1411236232	-2.8588769356	-1.5981092147
H	-1.6941851227	-2.5318613343	-2.5530797041

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O	-0.5256131719	2.0139955754	1.9845333860
C	0.1877032780	0.9173256697	1.6426025960
H	1.0658929590	0.7864943120	2.2656265972
H	-1.0701467727	2.3122598833	1.2360657328
H	0.7510553521	1.9206498639	-0.4162992086
O	0.7991718038	2.6154741678	-1.1036193048
C	-0.3152969159	3.3228293487	-1.1381989114
O	-1.2741004937	3.1525877099	-0.4265945780
H	-0.2678516500	4.0935387495	-1.9110931446
C	-0.0978645582	0.0430043915	0.6807399978
C	-1.3229739862	-0.0159659262	-0.2021537432
C	0.7549382023	-1.1861105661	0.3956138576
C	-1.1784825813	-1.4200987660	-0.8170594509
C	-2.6558836951	0.1586720143	0.5519377088
H	-1.2715436034	0.7124803436	-1.0128362532
O	0.1673868958	-1.7366060161	-0.7848454910
C	2.2113329355	-0.8921033059	0.1613343777
H	0.6569861057	-1.9097930984	1.2098321674
O	-1.9013872450	-2.3567508130	-0.0398985769
H	-1.5165187593	-1.4806448739	-1.8556003039
C	-3.7282690387	-0.7509967083	0.0109722669
H	-2.5104078649	-0.1332867323	1.5960491782
H	-3.0156528453	1.1848375889	0.5308694744

C	3.1380280892	-1.1234769183	1.1692977784
C	2.6332317904	-0.3310462694	-1.0408805935
C	-3.2859329797	-2.1824275479	-0.2417780585
O	-4.8650741934	-0.4070193524	-0.1933973536
C	4.4735293532	-0.7848579284	0.9870440532
H	2.8150820833	-1.5746809346	2.0998810731
C	3.9663181742	-0.0008218403	-1.2267555958
H	1.9131635334	-0.1653766684	-1.8322968800
H	-3.5805480675	-2.4605068626	-1.2603069944
H	-3.8110543622	-2.8343780164	0.4554416946
C	4.8891370102	-0.2233837322	-0.2108802460
H	5.1880766912	-0.9674339922	1.7781828218
H	4.2882822789	0.4300652379	-2.1652181748
H	5.9289482481	0.0353760130	-0.3572828988

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O	-1.4768097443	1.5381312181	1.6974125694
C	-0.2597727744	0.9573490937	1.6942406587
H	0.3123504464	1.2219254418	2.5769616840
H	-1.8815165148	1.4844498007	0.8180532882
H	0.4762082936	2.3419726266	0.0123983078
O	0.5059789199	3.0983545447	-0.6064589737
C	-0.6751927430	3.2218301719	-1.1923112761
O	-1.6220325092	2.5086639848	-0.9863873740
H	-0.6820187546	4.0578022991	-1.8962294189
C	0.2636584619	0.1552362148	0.7673839261
C	1.6600224979	-0.4161938952	0.8537207996
C	-0.4147139477	-0.4685814884	-0.4360203029
C	1.6094925906	-1.5677243032	-0.1831629838
C	2.7671469055	0.5945154381	0.4985374378
H	1.8541180316	-0.8242260531	1.8453159435
O	0.2918624352	-1.7110856405	-0.5836387453
C	-1.8812880838	-0.7796892055	-0.2758155257
H	-0.2668319596	0.1342554525	-1.3392665300
O	2.3980879371	-1.2570211361	-1.3183060568
H	1.9485258895	-2.5250404088	0.2231405670
C	4.0163121103	-0.1337854295	0.0836245264
H	2.4510002135	1.1776780101	-0.3712193824
H	2.9791174949	1.2729189267	1.3213582153
C	-2.8105829937	-0.3270438384	-1.2022395596
C	-2.3101135890	-1.5462780440	0.8049586157
C	3.7625883295	-1.1963795637	-0.9715852643
O	5.1179247167	0.0778714542	0.5235563771
C	-4.1594516395	-0.6257470264	-1.0468747835
H	-2.4801837707	0.2731318789	-2.0394058798

C	-3.6520609392	-1.8498983001	0.9585544124
H	-1.5833974069	-1.9006931662	1.5254535401
H	4.1285869066	-2.1598041886	-0.5962472737
H	4.3263296360	-0.9445300266	-1.8686928868
C	-4.5811501030	-1.3860825760	0.0324221761
H	-4.8770739704	-0.2657353547	-1.7715030664
H	-3.9776437995	-2.4448351816	1.8010773876
H	-5.6301582136	-1.6192511401	0.1553930508

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O	-0.6285683595	1.9115588381	2.0532926900
C	0.1122218326	0.8411307304	1.6825804774
H	0.9599690815	0.6847774445	2.3407823625
H	-1.1354899285	2.2504165255	1.2958807181
H	0.7392229907	1.9199997033	-0.2953659423
O	0.8210028567	2.6347200713	-0.9597711211
C	-0.2952291343	3.3372947203	-1.0193474879
O	-1.2775589149	3.1421869975	-0.3470098153
H	-0.2262699423	4.1292168924	-1.7687219241
C	-0.1197127233	0.0178471210	0.6616681349
C	-1.3289837924	-0.0254659166	-0.2448094255
C	0.7700300708	-1.1657595652	0.3370243896
C	-1.2143625376	-1.4540615139	-0.8066387519
C	-2.6746157329	0.2098789531	0.4691310937
H	-1.2349856673	0.6705838831	-1.0808749977
O	0.1225309714	-1.7943939161	-0.7773186955
H	0.7883544146	-1.8746225741	1.1719610667
O	-1.9514486294	-2.3453095687	0.0122224042
H	-1.5688981337	-1.5466716707	-1.8378379288
C	-3.7522159127	-0.7116500504	-0.0414080830
H	-2.5563317298	-0.0274081795	1.5304571603
H	-3.0184217526	1.2381957270	0.3849787593
C	-3.3320549674	-2.1628770591	-0.2036710334
O	-4.8790629890	-0.3600044885	-0.2852547429
H	-3.6306007332	-2.4991512522	-1.2034057533
H	-3.8691497465	-2.7609790657	0.5319315051
C	2.1918108537	-0.8163910708	-0.0635533613
H	2.6485785791	-0.2684516238	0.7635698479
H	2.1472301997	-0.1360755352	-0.9183281045
C	3.0203672860	-2.0470119207	-0.4049976708
H	2.5735169533	-2.5942697505	-1.2336233983
H	4.0344736417	-1.7685341983	-0.6874146718
H	3.0810129253	-2.7208131573	0.4508031900

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O	-1.1096955106	1.3486595822	-1.6039488898
C	-0.0072130683	1.3797756627	-0.8051735635
H	0.4501959002	2.3533994527	-0.6555200867
H	-1.5945799361	2.1767038989	-1.4731031251
H	-1.2875332768	1.4740088432	1.0234043605
O	-1.9462796822	1.8665201372	1.6292140810
C	-2.5066900321	2.9313021830	1.0783669911
O	-2.2741101444	3.3532809039	-0.0247696361
H	-3.2219084070	3.3936120347	1.7636206108
C	0.4955097254	0.2752863416	-0.2675679688
C	1.7778643640	0.1776980656	0.5209849963
C	-0.0661620883	-1.1115245105	-0.4543707466
C	2.0921831080	-1.3220459721	0.3864924812
C	2.9287412828	1.0563711465	0.0006959425
H	1.5986438808	0.3920156629	1.5766397578
O	0.8971550255	-1.9770238137	0.1674853434
H	-0.1265762493	-1.3599175259	-1.5188667366
O	2.9612440967	-1.5263038846	-0.7160654704
H	2.5586763742	-1.7497781564	1.2800631249
C	4.2579394812	0.3559907326	0.1123541326
H	2.7744983762	1.2287159074	-1.0683323600
H	2.9820852675	2.0211519339	0.4981738292
C	4.2567975450	-1.0794794845	-0.3865619355
O	5.2635866973	0.8710407179	0.5326060793
H	4.7182998318	-1.7122377267	0.3806424319
H	4.8688411928	-1.1328400144	-1.2864813245
C	-1.4204128129	-1.3380844897	0.1979838120
H	-1.3316316126	-1.0958746423	1.2605613987
H	-2.1244716016	-0.6321020211	-0.2457771744
C	-1.9171276514	-2.7661996828	0.0185727063
H	-1.2214965524	-3.4758318077	0.4640282828
H	-2.8911201040	-2.9024477876	0.4861835036
H	-2.0145355694	-3.0082658870	-1.0407090477

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O	-0.6033827270	2.1326447238	1.8336076885
C	0.0689837085	1.0856841107	1.5730484772
H	0.8805485208	0.8601938493	2.2696691597
H	-1.0297195734	2.5954655084	0.8934552017
H	0.4250141925	1.3143454732	-0.3248232795
O	0.5400707508	2.3373493730	-1.1479230472
C	-0.4272073147	3.1384066022	-1.1069771014

O	-1.2941963843	3.2137096658	-0.2018736875
H	-0.5279126678	3.8349838148	-1.9456804982
C	-0.0682457233	0.3115273045	0.4214578301
C	-1.4037116992	0.0665554430	-0.2900023075
C	0.7385272386	-0.9830845482	0.3007791986
C	-1.1786794471	-1.3478406623	-0.8817199171
C	-2.6378382915	0.1135320484	0.6276038261
H	-1.5529500260	0.7600375493	-1.1164118891
O	0.1829862291	-1.5950406810	-0.8625291951
C	2.2201331487	-0.7980977293	0.1344639811
H	0.5501007686	-1.6293961250	1.1640715191
O	-1.8346776222	-2.3172034644	-0.0869595674
H	-1.5262694112	-1.4399222894	-1.9144996950
C	-3.7182713872	-0.8025983156	0.1162290478
H	-2.3635912102	-0.2639411822	1.6169946649
H	-3.0341527839	1.1195340652	0.7384400786
C	3.0883586422	-1.1700494118	1.1521306981
C	2.7312908900	-0.2216074096	-1.0257127187
C	-3.2329624715	-2.2005911683	-0.2273522277
O	-4.8754930865	-0.4910218406	-0.0058818452
C	4.4566185005	-0.9631894192	1.0204315719
H	2.6941200922	-1.6295548176	2.0505030348
C	4.0954348404	-0.0250635231	-1.1627512718
H	2.0548283235	0.0708882500	-1.8187389939
H	-3.5570037595	-2.4441125048	-1.2458314500
H	-3.6972451026	-2.9086310979	0.4580461381
C	4.9609895973	-0.3930353530	-0.1378612754
H	5.1250407407	-1.2557938801	1.8186539362
H	4.4871749188	0.4172361958	-2.0686585665
H	6.0256435857	-0.2364875540	-0.2465775182

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O	-0.9803705813	2.2465567584	-1.1946974197
C	0.1465912260	1.9372550869	-0.6969894817
H	0.8997681894	2.7352394144	-0.6721008171
H	-1.9526809141	1.9596376881	-0.4299897474
H	-0.4105802013	1.1382150652	1.0175116637
O	-1.2279672442	1.3409810047	1.8938768834
C	-2.4010822875	1.5958120857	1.5213270729
O	-2.7779272250	1.8702039167	0.3535970504
H	-3.1766928700	1.5888514249	2.2879409475
C	0.4625094721	0.7437418131	-0.0592458734
C	1.8743134630	0.4887448722	0.4549945323
C	-0.0733747114	-0.6442831868	-0.4436069323
C	1.8665323421	-1.0431883986	0.7081756134

C	2.9821882435	0.8783254753	-0.5409766735
H	2.0531926465	1.0033289455	1.3989694559
O	0.5721120174	-1.4947435777	0.5006039319
C	-1.5567738586	-0.8923524991	-0.4168327419
H	0.2960873005	-0.8859497260	-1.4479268410
O	2.7185908329	-1.7129017567	-0.2021733786
H	2.1616456890	-1.3109251174	1.7266421420
C	4.2564612477	0.1506008439	-0.2105045177
H	2.6812887784	0.5614891657	-1.5439997251
H	3.1670259161	1.9495167850	-0.5532432317
C	-2.3148162589	-0.6221668628	-1.5506849913
C	-2.1859674850	-1.3806436392	0.7228279288
C	4.0613339931	-1.3398707945	0.0003284408
O	5.3389011362	0.6706733842	-0.1072637244
C	-3.6893162715	-0.8066717748	-1.5391252878
H	-1.8264088300	-0.2524101663	-2.4436032773
C	-3.5616678026	-1.5680646103	0.7342524663
H	-1.5961875181	-1.6108368869	1.5989485132
H	4.4065139023	-1.5998417470	1.0088517216
H	4.6731610965	-1.8832234217	-0.7182066808
C	-4.3171208815	-1.2763538327	-0.3936875128
H	-4.2684917216	-0.5855025758	-2.4252871933
H	-4.0431307574	-1.9496328635	1.6248276218
H	-5.3884150729	-1.4239852922	-0.3830149372

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O	-1.6162858301	-1.2552020715	1.7602774335
C	-1.4336048750	-0.0139393681	1.5486733621
H	-1.8755763789	0.6572826214	2.2894645726
H	-1.6120331809	-1.8413444569	0.7987276514
H	-1.8784896047	0.1147741480	-0.3345854021
O	-2.6640955387	-0.5390005384	-1.1765922187
C	-2.4480890174	-1.7766028849	-1.1980517425
O	-1.8277460165	-2.4374691662	-0.3293797218
H	-2.8322456735	-2.3311834908	-2.0606114186
C	-0.8455624640	0.5251801606	0.4051538639
C	0.3191715140	-0.1416715741	-0.3389723834
C	-0.6387886623	2.0349330897	0.3208637109
C	1.1358749302	1.0935568255	-0.7856581973
C	1.1685435840	-1.1075564457	0.5063876965
H	-0.0233268098	-0.6606832941	-1.2338924659
O	0.2909930882	2.1846202612	-0.7539591584
H	-0.1751281187	2.4128032283	1.2401586430
O	2.2143831799	1.3083863184	0.1067745715
H	1.5318449504	0.9975106220	-1.8010343764

C	2.6086369545	-1.0847850239	0.0648768001
H	1.1728165109	-0.7680053223	1.5460007044
H	0.7929822982	-2.1271272066	0.4785502458
C	3.1944498017	0.3103425447	-0.0707917907
O	3.2721156773	-2.0679072573	-0.1470983498
H	3.6814532915	0.3933012830	-1.0492206281
H	3.9516854645	0.4445400665	0.7010320191
C	-1.8845486942	2.8378084661	0.0091518845
H	-2.6224794459	2.6325960396	0.7890173695
H	-2.3001905159	2.4687389967	-0.9314049740
C	-1.6082538806	4.3325655661	-0.0726705186
H	-0.8821664581	4.5455483988	-0.8557270232
H	-2.5196601092	4.8863244656	-0.2918424558
H	-1.2058328210	4.7031070186	0.8711746865

TS1-eb-Z

0 1

O	2.2110554698	-1.5241128885	-1.3065507356
C	1.0764465627	-1.4612421690	-0.7286867553
H	0.5682774441	-2.4200340119	-0.5767873248
H	3.0650974267	-0.9231313699	-0.7138933570
H	1.5139817524	-0.3255591950	0.8171230302
O	2.4419380039	-0.2079780243	1.6522608878
C	3.6064655447	-0.2263538284	1.1810475654
O	3.9331185891	-0.5009429830	-0.0000368102
H	4.4192896161	0.0275007187	1.8650828082
C	0.5152773831	-0.3220016304	-0.1650083167
C	-0.8599958289	-0.3863981764	0.4932054050
C	0.6011304445	1.0884006363	-0.7600522042
C	-1.2637121847	1.1122975857	0.5679987548
C	-1.8966372819	-1.2011550990	-0.3004664084
H	-0.7956017752	-0.7869491263	1.5046532435
O	-0.1668839742	1.8568522754	0.1699407587
H	0.0703897233	1.0802844253	-1.7222209067
O	-2.3373375268	1.3910989630	-0.3133303854
H	-1.5470564580	1.4293426502	1.5757110416
C	-3.2901543997	-0.7926677135	0.0920426163
H	-1.7842830722	-0.9726124186	-1.3646319735
H	-1.7792389135	-2.2725333412	-0.1582629275
C	-3.5033897117	0.7101948164	0.0853355806
O	-4.1711802282	-1.5583574516	0.3921012993
H	-3.8354021873	1.0227444799	1.0832036023
H	-4.2927258163	0.9504441715	-0.6256983123
C	1.9413202824	1.7605371338	-0.9532127013
H	2.4356502546	1.8489366610	0.0150113242
H	2.5580592442	1.1253386778	-1.5890748210

C	1.7882171882	3.1390229073	-1.5856304303
H	1.1887920085	3.7902220068	-0.9517371943
H	2.7606496942	3.6053856270	-1.7349227361
H	1.2965833557	3.0654642908	-2.5565772371

TS2-ea-E

0 1

O	-0.0001728032	2.1086099667	1.8994487737
C	-0.6123127020	1.2292493751	1.2164370797
H	-1.6957628085	1.2083046286	1.3430170812
H	0.9202352758	2.4719056060	1.3816658801
H	0.2463822182	1.4808001689	-0.5604460103
O	0.6931718640	2.4996012610	-1.2237596442
C	1.5474294116	3.1731381304	-0.5892737024
O	1.8026503170	3.0843710063	0.6338680431
H	2.1302524384	3.8962622349	-1.1694352101
C	0.0011548421	0.4225406849	0.2462322062
C	1.3658612757	-0.2122997075	0.5480436999
C	-0.8030251968	-0.7188751605	-0.3645065498
C	0.9930991630	-1.7324413180	0.6141177406
C	2.4594500283	0.0304847115	-0.5035662717
H	1.7303817883	0.1198955636	1.5198473153
O	-0.3736258572	-1.8456036667	0.4015049157
C	-2.2976866694	-0.5757915610	-0.3206937278
H	-0.4919263648	-0.8617212648	-1.4053496292
O	1.6463909517	-2.4645368521	-0.4018367330
H	1.2315086231	-2.1795776887	1.5835401448
C	3.5534200749	-0.9957869399	-0.3692709932
H	2.0353042017	-0.0762534801	-1.5062045061
H	2.9001457830	1.0176685805	-0.4099144025
C	-2.9205862920	0.2272029895	-1.2717209021
C	-3.0616187384	-1.1831348607	0.6678930425
C	3.0453083908	-2.4184821199	-0.2502819106
O	4.7299202513	-0.7356312566	-0.3507809451
C	-4.2919314786	0.4273634954	-1.2319174618
H	-2.3263912162	0.6973320478	-2.0469070943
C	-4.4369512837	-0.9876900255	0.7029016552
H	-2.5785590754	-1.8117862069	1.4024773978
H	3.3636104139	-2.8285725804	0.7164688953
H	3.4894516331	-3.0243313991	-1.0382555732
C	-5.0541345827	-0.1815601261	-0.2427061586
H	-4.7662939130	1.0531044839	-1.9755498717
H	-5.0259906575	-1.4689345828	1.4719743958
H	-6.1245743066	-0.0310061379	-0.2130299691

TS2-ea-Z

0 1

O	-1.4705822487	1.5961133956	1.5749997700
C	-0.3875442315	0.9408606392	1.6699258134
H	0.0729433506	0.9433565451	2.6611703457
H	-1.6462005180	1.9546683892	0.5391765265
H	0.5102100378	1.5356792996	0.0200229926
O	0.5523142052	2.6094111287	-0.7507702001
C	-0.5974548582	2.9625527725	-1.1217302514
O	-1.6828564143	2.5879088639	-0.6228039660
H	-0.6506000290	3.6590731326	-1.9657835472
C	0.2988194874	0.3633764816	0.5954748256
C	1.6084688761	-0.3688527661	0.8666237711
C	-0.4254690941	-0.3940140328	-0.5484894278
C	1.6171835153	-1.4371841287	-0.2405459265
C	2.8602604039	0.5276710407	0.7930192424
H	1.5766246160	-0.8712479207	1.8345766384
O	0.3076677456	-1.6192446280	-0.6406207770
C	-1.8734354392	-0.7310601040	-0.3038950384
H	-0.3294566619	0.1474540467	-1.4933504611
O	2.3882881278	-0.9873725264	-1.3392714849
H	2.0046657790	-2.4050981276	0.0911673887
C	4.0477602886	-0.2298484642	0.2619702517
H	2.6783877405	1.3303767907	0.0722349706
H	3.1062633284	0.9775137610	1.7515619200
C	-2.8665977441	-0.2534911609	-1.1453670953
C	-2.2206534180	-1.5424861510	0.7727010277
C	3.7590700102	-1.0135224125	-1.0077424156
O	5.1454273101	-0.2200255054	0.7591068840
C	-4.1992525175	-0.5716264059	-0.9096116213
H	-2.5995981511	0.3779491479	-1.9826128244
C	-3.5461191337	-1.8649444742	1.0078445655
H	-1.4431669905	-1.9243869029	1.4242201513
H	4.1218114326	-2.0394643678	-0.8768611280
H	4.3095819190	-0.5568210089	-1.8294338628
C	-4.5401322164	-1.3756733137	0.1663897866
H	-4.9673253336	-0.1915874429	-1.5692661962
H	-3.8082564058	-2.4957201087	1.8463797970
H	-5.5764507685	-1.6237924817	0.3516985554

TS2-eb-E

0 1

O	2.4630283135	-0.3894522964	1.5418651398
C	2.0912435598	0.6095141319	0.8482758156
H	2.7953245000	1.4420018515	0.8254417075

H	2.0912511144	-1.3587335634	1.1176461722
H	1.5034117914	-0.2822112339	-0.8045384509
O	1.9121640341	-1.3176929409	-1.4776295778
C	1.9735747180	-2.3752509120	-0.7983673659
O	1.9107945280	-2.4606923299	0.4504152658
H	2.0806268762	-3.3113814046	-1.3562377451
C	0.9534675495	0.6277945892	0.0328101794
C	-0.3540419388	-0.0023852489	0.5370336307
C	0.5202697518	1.9387321767	-0.5990309176
C	-1.2855350224	1.2528653858	0.6329531918
C	-0.9806548765	-1.0682938375	-0.3755524489
H	-0.2076821269	-0.4288730565	1.5293093859
O	-0.5419103020	2.3625979659	0.2690625235
H	0.0967113793	1.7397081968	-1.5912526171
O	-2.3774641483	1.1506421080	-0.2599485739
H	-1.6726788832	1.4080475329	1.6444359898
C	-2.4403643521	-1.2452540557	-0.0500995771
H	-0.9173434432	-0.7412901460	-1.4174553095
H	-0.4892370447	-2.0304155360	-0.2763348175
C	-3.2029019860	0.0588583075	0.0664673875
O	-2.9750035912	-2.3132365208	0.1116838661
H	-3.6058079196	0.1435578088	1.0838196614
H	-4.0399709609	0.0467926382	-0.6296586155
C	1.5318299181	3.0587492256	-0.7083688627
H	1.8449730326	3.3496896378	0.2963297624
H	2.4135407819	2.6854229022	-1.2340607745
C	0.9581271552	4.2668426275	-1.4381214305
H	0.0760109826	4.6425902263	-0.9218552857
H	1.6900665239	5.0707918588	-1.4954150871
H	0.6668024256	4.0017822911	-2.4550242222

TS2-eb-Z

0 1

O	2.7709099735	-0.1198761360	1.5494342533
C	1.5026165456	-0.0843374281	1.6384136629
H	1.1049913409	-0.3552778783	2.6202243818
H	3.1210182044	-0.3624023479	0.5241104391
H	1.0412794627	-0.9493760649	-0.1021981862
O	1.5145288490	-1.8322477125	-0.9450810490
C	2.7233824553	-1.6316486448	-1.2330453848
O	3.5142696968	-0.8747113532	-0.6264137710
H	3.1173097999	-2.1722175736	-2.1001698793
C	0.6166085902	0.1165051653	0.5738838998
C	-0.8779221228	0.0556177949	0.8679934625
C	0.7856633778	1.2371432524	-0.4730700078
C	-1.4212023603	1.3352740720	0.1827894380

C	-1.5570641327	-1.2065443124	0.3074263424
H	-1.0631829107	0.1148596511	1.9410147798
O	-0.3268834007	2.0935858010	-0.1860533129
H	0.6529683673	0.8260732089	-1.4807022674
O	-2.1645647324	1.0077625686	-0.9776202778
H	-2.0505433132	1.9410919835	0.8413605972
C	-3.0294337512	-0.9675581908	0.1219914843
H	-1.1468571548	-1.4172425556	-0.6847878041
H	-1.3922253301	-2.0752525848	0.9402058906
C	-3.3410185758	0.3138210553	-0.6317521694
O	-3.9027694558	-1.6976335647	0.5183747458
H	-4.0083512073	0.9305806021	-0.0173011086
H	-3.8641093995	0.0608921655	-1.5531093231
C	2.0419318321	2.0827585364	-0.4236920801
H	2.1658484689	2.4676720263	0.5906283702
H	2.9043519825	1.4569854041	-0.6456507667
C	1.9773753169	3.2306123643	-1.4250353651
H	1.1514572663	3.9008940761	-1.1955897564
H	2.9022252028	3.8050272126	-1.4097897623
H	1.8331569245	2.8511742272	-2.4377550759

4.4.4. Racemization of 4

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O	0.8671228696	1.7696238873	-0.4041735427
H	1.7497425055	1.4779207939	-0.1133439157
H	1.5359213891	-0.9865593300	-0.4553055419
O	2.4187483781	-1.4391484067	-0.4437690019
C	3.3278299188	-0.6618496336	0.0952768275
O	3.1426676217	0.4665470503	0.4900057470
H	4.3015312641	-1.1560321406	0.1540362304
C	-1.0207792368	-1.1735631696	0.2334185937
C	-1.4232955452	1.5988474445	0.0773031495
H	-1.4642010325	2.6805722387	0.0847337097
C	-2.5124589565	0.8501408737	-0.0670723766
H	-3.4982586027	1.2734291969	-0.2039504835
O	-0.0321853264	-0.3180593280	-0.3154418923
C	-2.4166976588	-0.6168407660	0.0313201275
O	-3.3821116437	-1.3445565773	0.0189582862
H	-0.9405010841	-2.1389788108	-0.2589741099
H	-0.8603386504	-1.3113708164	1.3105535001
C	-0.0594203192	0.9971458102	0.2508970981
H	0.1779151095	0.8978356834	1.3214605949

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0 1

O	2.0055746117	4.2265834503	0.4734714140
H	1.1305316081	3.9126152480	0.1658376295
H	1.6996126959	1.6710903134	-0.2147832994
C	-0.2809145765	1.2495054839	-0.1150730436
C	4.3073257920	2.2209277639	-1.3469221484
C	4.1349532308	4.8372868679	-0.3158429154
H	3.9440439110	5.8488688990	0.0488273244
C	5.3699976598	4.3992931573	-0.5851293789
H	6.2598313915	5.0139142337	-0.4402949456
O	3.2957013810	2.5862751537	-0.4238566478
C	5.5673372686	3.0556379981	-1.1717951750
O	6.6461568354	2.6489581552	-1.5461025421
H	4.5543142971	1.1650649058	-1.1766658614
H	3.9549752099	2.3382150464	-2.3901755204
C	2.9231083077	3.9672855224	-0.5172186181
H	2.4989006492	4.1336786202	-1.5298700017
N	1.0314671916	0.9029546101	-0.0933204121
S	-0.7100038428	2.8004002004	-0.6375493427
C	1.6345731070	-0.3600806178	0.0436464213
C	1.0960287171	-1.5287475634	-0.5044725496
C	2.8801063871	-0.4099893258	0.6813096899
C	1.7794487553	-2.7338208395	-0.3599316120
H	0.1649834688	-1.5031070750	-1.0727240070
C	3.5653499492	-1.6155810730	0.7629511776
H	3.3068919170	0.5078816357	1.0915797315
C	3.0183424985	-2.7973577070	0.2676168990
H	3.5504322231	-3.7421836585	0.3616189617
H	-0.7085630368	-0.5525278715	0.6743230037
C	-2.5504632184	0.2111779617	0.2595196128
C	-3.4087734217	1.3121272077	0.2777122958
C	-3.0871724646	-1.0839253914	0.2363982141
C	-4.7863484560	1.0975065413	0.2371671449
H	-3.0125837681	2.3221191406	0.3281828007
C	-4.4620505767	-1.2670835362	0.2228192152
H	-2.4251749173	-1.9520590255	0.2219109184
C	-5.3326948299	-0.1786424682	0.2107763604
H	-6.4114583321	-0.3269509522	0.1844074736
N	-1.1424571320	0.2905838320	0.3082440836
C	-5.0318290423	-2.6583353724	0.2471326283
C	-5.6907832075	2.2989674437	0.1873737589
C	4.9363689890	-1.6035152002	1.3825678732
C	1.1403327539	-3.9690896589	-0.9341801618
F	-4.1466136899	-3.5706663274	-0.1751166242
F	-6.1204738534	-2.7577545349	-0.5273942717
F	-5.4034066143	-3.0150772528	1.4864309631

F	-5.2215429932	3.3051502706	0.9378842867
F	-6.9265942209	2.0133999783	0.6171113945
F	-5.8083980718	2.7707069597	-1.0632087210
F	4.9339608791	-0.9951777089	2.5762653334
F	5.4245230919	-2.8357724353	1.5542816044
F	5.8025814269	-0.9301891902	0.6078797939
F	1.8385412434	-5.0739292526	-0.6579988735
F	1.0204259690	-3.8859537597	-2.2663215121
F	-0.1010838115	-4.1401715325	-0.4475247828

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0 1

O	1.3508477986	1.3263082374	-0.4941860299
H	2.1628965204	0.9883599200	-0.0584255984
H	1.4807130986	-1.5908582189	-0.5054032869
O	2.3230334313	-2.0706049956	-0.4324433673
O	3.4601189205	0.1356523668	0.6933927690
C	-1.1559945686	-1.0461947347	0.3389768885
C	-0.9351482494	1.7059725348	-0.1155543558
H	-0.7362264267	2.7656082373	-0.2166535880
C	-2.1595599691	1.2020344621	-0.2395525847
H	-3.0239316194	1.8115878715	-0.4662640316
O	0.0074530308	-0.4962905635	-0.2463637318
C	-2.3916211453	-0.2314586212	0.0104440696
O	-3.4933049346	-0.7309872293	0.0203075316
H	-1.2788806094	-2.0578454290	-0.0388038195
H	-1.0600255891	-1.0895247373	1.4323041883
C	0.2597203492	0.8429225335	0.1811785045
H	0.4376870815	0.8144752260	1.2686558542
H	3.2240537646	-0.7604842595	0.3815413550
H	3.5487556101	0.0815575204	1.6477080074
H	2.6114345158	-2.2343951309	-1.3339857942

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0 1

O	-2.3317732884	-0.3339327743	0.6106488525
H	-2.9490693022	-1.0341254557	0.3737755547
C	0.3788540992	-1.2495857086	0.0774893077
C	-0.8377304750	1.2600687466	-0.1998699153
H	-1.4228475911	2.1683959471	-0.2657925052
C	0.4427849718	1.2827952687	0.1573562406
H	0.9740095579	2.1999020417	0.3758920982
O	-0.6674993536	-1.0572820690	-0.8504367726
C	1.1560288343	0.0148881489	0.3510635755

O	2.2934897805	-0.0461586424	0.7824302926
H	-0.0025209863	-1.6085272791	1.0400596355
H	1.0496577285	-2.0006385929	-0.3313842654
C	-1.5539070334	-0.0256903248	-0.5133761989
H	-2.1779565148	0.1024271924	-1.3993889076
H	3.1821862672	1.3635883213	1.1741126209
O	3.5857885870	2.2528950747	1.3430814270
C	4.8074883341	2.1170533471	1.8318735419
O	5.3573531729	1.0721795887	2.0500926151
H	5.2651618614	3.0957282897	2.0158445027

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0 1

O	-1.0444427800	-1.6885451050	-0.8851363326
H	-1.5452505485	-1.8805070223	-1.6859770814
C	-1.4026394090	1.2271475932	-0.4097204303
C	-1.1330180093	-0.9045398980	1.3192573036
H	-1.1712119694	-1.7153184353	2.0317802436
C	-0.4018529864	0.1941274171	1.5062690133
H	0.2073169242	0.3386422343	2.3894932227
O	-2.3102770509	0.2114704068	-0.4714396071
C	-0.4439401126	1.2599805612	0.5194170429
O	0.4201024674	2.3187660380	0.6139937200
H	-1.5778521755	2.0179843485	-1.1238752914
C	-1.8919249030	-1.0443075253	0.0357200868
H	-2.8169159916	-1.6060606808	0.1577775660
H	1.3141159339	1.9433378425	0.5931604975
H	3.8884988279	-0.9719752536	-0.9888817280
O	2.9794151918	-1.2605085539	-1.1642050882
C	2.1452493917	-0.4488186745	-0.5293299254
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H	1.1023228726	-0.7366308075	-0.6963276289

C-r4

0 1

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H	-2.5389231604	-0.2209503150	0.8219268993
C	0.6703849310	-1.2966421284	-0.0648377925
C	-0.1597303580	1.2503615937	-0.7093728268
H	-0.5144009429	2.1975416735	-1.0895577570
C	1.1108003809	1.0387502113	-0.3679222820
H	1.8629100526	1.8126766196	-0.4583720619
O	-0.5655502271	-1.1294260734	-0.6153188086
C	1.5182832618	-0.2778561778	0.0862293264

O	2.7953895041	-0.4998130926	0.5379297289
H	0.9146151003	-2.3246189866	0.1561625223
C	-1.1526877795	0.1491301686	-0.5115239599
H	-1.9359893291	0.1549486931	-1.2685586731
H	3.0394340771	0.1946399038	1.1575113574
C	-4.6005649437	1.5322642578	0.9747002803
O	-4.5598235679	0.3339204807	0.8452265116
O	-3.5484047610	2.3249841337	1.0675780393
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C-r5

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C	0.5357857044	-1.3013161561	0.1497166027
C	-0.0386343151	1.2605823791	-0.8306350385
H	-0.3858988657	2.2365784647	-1.1463055259
C	1.2326272582	1.0402828714	-0.5146315902
H	1.9936412629	1.8068273006	-0.5746489185
O	-0.5073015808	-1.1070060821	-0.7874487576
C	1.6397045236	-0.2749219164	0.0150786766
O	2.7651467903	-0.5070184888	0.3931582270
H	0.1562930288	-1.2447892586	1.1757042481
C	-1.0717307661	0.1691100888	-0.7634930113
H	-1.7186174692	0.2091799722	-1.6407594775
C	-4.6436746095	1.4010490349	1.2400343134
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O	-3.6305361859	2.2442439564	1.3226083846
H	-5.5772034500	1.8671606986	1.5680048038
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IN-r1

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H	-0.4239558081	-1.1292378942	1.0695957563
O	-1.9790554968	-1.3575659601	0.0655602821
C	-3.0544017196	-0.9191606464	-0.2763462583
O	-3.3467812697	0.3460825198	-0.4383251298
H	-3.9100723027	-1.5642655786	-0.4949074943
C	1.3007989497	-1.4198375622	0.2366018165
C	1.1317021002	1.7972518382	0.1463344328

H	1.1745792717	2.8404455448	0.4327343290
C	2.2288125226	1.0454890266	0.1107403761
H	3.1931881153	1.4863490847	0.3343192108
O	0.5006058138	-0.9382216402	1.2821878938
C	2.3125207211	-0.4005402465	-0.2706085054
O	3.2286862010	-0.7663719094	-0.9671823879
H	1.8868763087	-2.2874329119	0.5493632217
H	0.7032621328	-1.7315491419	-0.6272417603
C	-0.1968500403	1.2705403101	-0.1852901741
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C	-0.1877078721	1.2685023114	0.0808505958
C	4.3311273543	1.7762713512	-0.4136854269
C	3.9161747194	4.6218190408	-1.7908856901
H	3.8764273765	5.6881857823	-2.0267157691
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H	6.0159682604	4.6001474558	-1.6629756672
O	3.5004411258	2.5754088761	0.3871891637
C	5.3417328452	2.5876305427	-1.2160686075
O	6.3810377408	2.0730252014	-1.5687722963
H	4.9194767547	1.0596284677	0.1849812029
H	3.7581353538	1.1753693286	-1.1475915645
C	2.5986536336	3.9487051434	-1.7259220114
H	2.5707780375	2.8507323366	-1.8773823729
N	1.0981836056	1.1424075186	-0.0079047615
S	-0.9737710197	2.7900271740	-0.3623736445
C	1.6732991166	-0.1336779114	0.1820541740
C	1.4037523936	-1.1890630543	-0.7007598426
C	2.6107283806	-0.3289715120	1.2034678232
C	2.0469892271	-2.4136170673	-0.5433137069
H	0.6961945179	-1.0404796549	-1.5196950312
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H	2.8444097453	0.4951600445	1.8799227581
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C	-3.2604900704	1.1465288153	0.9793099702
C	-2.9722610242	-0.9108297402	-0.2596615554
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H	-6.2826328852	-0.1628253163	0.0839653031
N	-1.0145029398	0.2722838939	0.5280185938
C	-4.9616138971	-2.2354241960	-1.0280167517
C	-5.5252703143	2.0941457344	1.4103571965
C	4.3262110543	-1.6868860197	2.3785001669
C	1.6842527575	-3.5260524668	-1.4872870947
F	-4.0573187081	-2.9407423509	-1.7175232175
F	-5.9348063726	-1.8782574280	-1.8771401409
F	-5.5164397451	-3.0658071877	-0.1324504237
F	-5.0940138985	2.4922720083	2.6159061394
F	-6.7906749813	1.6812610961	1.5471567004
F	-5.5445497862	3.1827078382	0.6271338372
F	3.8915733714	-1.2632674927	3.5737650221
F	4.7405610056	-2.9506210538	2.5219562215
F	5.4068923847	-0.9454845334	2.0783672682
F	2.4402143887	-4.6131680885	-1.3061655131
F	1.8131106388	-3.1491497522	-2.7676185498
F	0.4018136300	-3.8973877053	-1.3267645755

IN-r1w

0 1

O	1.3626587291	2.0780033708	-0.1552604389
H	2.8666927260	1.1666468317	0.3102134285
H	0.6088809759	-1.3177717498	-0.8841790490
O	2.0918273479	-1.7925363185	-0.1135416829
O	3.4749861910	0.4482721899	0.5612458789
C	-1.0866439921	-1.4132346484	0.0309211490
C	-0.9697692193	1.8166035641	-0.2020152322
H	-1.0661936527	2.8281044208	-0.5768506031
C	-2.0407397211	1.0392742838	-0.0666046803
H	-3.0210643700	1.4363928220	-0.3035792761
O	-0.3059714386	-1.0211695513	-1.0620598036
C	-2.0898048188	-0.3585136863	0.4651572009
O	-2.9790453833	-0.6554717986	1.2279182888
H	-1.6787460850	-2.3069816942	-0.1877334496
H	-0.4723822231	-1.6470315817	0.9084504185
C	0.3983338623	1.4079555622	0.1473957652
H	0.5282362074	0.4840055863	0.7277657135
H	2.6635213076	-1.0392691083	0.1424047755
H	3.7030177741	0.6016479765	1.4814110586
H	2.6442267925	-2.3890914808	-0.6241864719

IN-r2

1 1

C	0.9455964090	-0.6280377647	0.0839376173
C	-1.0907604323	1.0362347623	-0.6010840520
H	-1.9239302229	1.6612239227	-0.8807504004
C	0.1246151847	1.5778847235	-0.2107512929
H	0.2561435099	2.6523838213	-0.1809271438
O	-0.2196077808	-1.0990426389	-0.2909564732
C	1.1759332173	0.7323666047	0.1428268846
O	2.3884314098	1.1200563171	0.5342805975
H	1.6728056477	-1.3863144619	0.3305419472
C	-1.2285255664	-0.3241108566	-0.6296826050
H	-2.1104426354	-0.8762968840	-0.9110487971
H	2.4758044094	2.0806461046	0.5514808378

IN-r3

1 1

C	0.6396582065	-1.2409244243	0.0412307060
C	-0.4568145953	1.3538043144	-0.4726893554
H	-0.9761077022	2.2726305999	-0.6985601430
C	0.8127564194	1.3120925903	-0.0444489010
H	1.4119576043	2.2005538866	0.1066046008
O	-0.7166417076	-1.0192786204	-0.4264226034
C	1.4598215241	0.0101041489	0.2458213995
O	2.5922954820	-0.0695395735	0.6300519708
H	0.5397627306	-1.7910908822	0.9755462951
H	1.1032495974	-1.8858780393	-0.7035556369
C	-1.1787109985	0.1285490885	-0.6460353893
H	-2.2076465708	0.1233339111	-0.9910339333

TS-r1

0 1

O	1.1281433455	1.6059537756	-0.3359656842
H	2.2311170907	1.0190011620	-0.0056741230
H	0.8035541304	-0.9168212131	-0.4864316189
O	2.1271400102	-1.4617285086	-0.1346505137
C	3.1149259296	-0.7918323749	0.1818055542
O	3.1761574195	0.4783623338	0.2840614987
H	4.0530649361	-1.3089473930	0.4090055268
C	-1.1412140449	-1.2662675643	-0.0039718347
C	-1.2021299206	1.6744227989	0.0664675323
H	-1.1845245421	2.7567186134	0.0229114726
C	-2.3463369634	1.0029043190	-0.0120335185

H	-3.2936629718	1.5141728699	-0.1196688923
O	-0.1262454975	-0.4834728785	-0.6172509535
C	-2.4288997451	-0.4701033647	0.0751815322
O	-3.4802718107	-1.0425014111	0.2350186976
H	-1.3207414932	-2.1672191019	-0.5875897823
H	-0.8497654716	-1.5553165299	1.0116318015
C	0.1458826518	1.0495124836	0.2344753694
H	0.3148669471	0.5696389839	1.2098869358

TS-r1t

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O	-1.4057725770	4.5243149525	-0.1017601385
H	-0.4705504681	3.7930550517	-0.0388895763
H	-2.3679014909	1.9900822330	-0.6290729757
C	0.2073079819	1.2399934733	-0.1518254665
C	-4.1551657778	1.8453264713	0.1800860209
C	-3.5832625716	4.8292006162	0.7232455430
H	-3.4515001947	5.9137803549	0.7128973642
C	-4.7994369761	4.2862714767	0.8512238410
H	-5.6710301306	4.9303809943	0.9841794209
O	-3.2454311397	2.4932554926	-0.6765792249
C	-5.1231786114	2.8273094172	0.8239874333
O	-6.1604785989	2.4332187775	1.3076836363
H	-4.7633079668	1.0964413055	-0.3539672466
H	-3.6362869289	1.3162552002	1.0045494223
C	-2.3384778984	4.0535639139	0.5734686128
H	-2.1372374182	3.1859944784	1.2231339451
N	-1.0849937807	1.0371470902	-0.2504333431
S	0.8663285006	2.8279197452	0.1428606667
C	-1.6220220838	-0.2630230730	-0.2779660693
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C	-2.0413374209	-2.4235635372	0.7411893169
H	-0.7412690304	-0.9246285248	1.5852128318
C	-3.1754428531	-1.8330552715	-1.2744749997
H	-2.7106563913	0.1084192243	-2.1024153096
C	-2.9389356305	-2.7640875609	-0.2667798539
H	-3.4468225648	-3.7266222920	-0.2623339469
H	0.6545463729	-0.7231084218	-0.3733767234
C	2.4795930275	0.1531093938	-0.0522011937
C	3.3598859208	1.0576569008	-0.6491305236
C	2.9850151197	-0.8853163305	0.7371409493
C	4.7273077049	0.9387555991	-0.4121253510
H	2.9783995699	1.8448724360	-1.2965363397
C	4.3565974425	-1.0037531173	0.9313083671
H	2.3001904130	-1.5986465368	1.1992882743

C	5.2430164889	-0.0857207488	0.3738880422
H	6.3151995816	-0.1731238310	0.5435530071
N	1.0854951899	0.1913283228	-0.2749593236
C	4.8982877070	-2.1574491935	1.7281188638
C	5.6484129880	1.9569863958	-1.0253450975
C	-4.1910920913	-2.1128167212	-2.3464807592
C	-1.7323808747	-3.3869991688	1.8531821930
F	4.0094070431	-2.6109463858	2.6219565342
F	6.0104617644	-1.8204939578	2.3953324669
F	5.2184146811	-3.1936826479	0.9367479646
F	5.3236972593	2.2100565289	-2.3021938596
F	6.9257555409	1.5550913632	-1.0060485914
F	5.5923174167	3.1289013604	-0.3743182954
F	-3.7077684300	-1.8535323545	-3.5701108293
F	-4.6044923161	-3.3850650782	-2.3355326054
F	-5.2797009077	-1.3386729475	-2.1925424530
F	-2.4534591842	-4.5094386397	1.7688398557
F	-1.9674043760	-2.8435062536	3.0568235274
F	-0.4352932084	-3.7410167044	1.8426324683

TS-r1w

0 1

O	1.3889971921	1.4262239282	-0.4024907107
H	2.5872599742	0.8807740216	0.0727553045
H	1.0439940822	-1.1433529213	-0.3664526781
O	2.1062599309	-1.7271439902	-0.1666179787
O	3.4132286895	0.2791761768	0.3765236281
C	-1.0438319326	-1.1812100845	0.1668587673
C	-0.9271523187	1.6625164754	0.0156609633
H	-0.8058740727	2.7383612704	-0.0235765780
C	-2.1281460797	1.1005500216	-0.0963967901
H	-3.0281276401	1.6833647432	-0.2417105758
O	0.0514408905	-0.5170646005	-0.4477003654
C	-2.3064169377	-0.3539405034	0.0357402775
O	-3.3923880494	-0.8830313851	0.0960865354
H	-1.1923768751	-2.1447787152	-0.3152793646
H	-0.8478310053	-1.3445858229	1.2333830606
C	0.3694251195	0.9122854326	0.1963519192
H	0.5142522744	0.6093499867	1.2526497753
H	2.7744228268	-0.9502329875	0.1113409886
H	3.6169188416	0.4674430473	1.2955982854
H	2.4379660893	-2.1488690933	-0.9658514638

TS-r2

0 1

O	1.0779751458	-1.6439232431	-0.2746419234
C	0.0625474231	-0.9067438122	0.0181288918
H	1.9203350714	-1.0540537643	-0.5443793188
H	1.0957288343	0.8346320902	0.3958376763
O	2.2603563779	1.1991767864	0.8327264027
C	3.1772144524	0.7153856423	0.1106276715
O	3.0666483818	-0.2453292900	-0.6756055343
H	4.1588542312	1.1991096256	0.1899945547
C	0.0122958734	0.4582291145	-0.3045049180
H	0.3976076651	0.7363911748	-1.2845545451
C	-1.0181214886	-1.5077699173	0.7791397019
H	-0.8597141625	-2.4809762337	1.2211115254
C	-2.1793547767	-0.8591802899	0.8197018546
H	-3.0538370911	-1.2782660765	1.2987721595
C	-2.3301589004	0.4701822635	0.1286640461
H	-3.0090740945	1.1188504396	0.6824610361
O	-1.1213487652	1.1805440609	0.0933374124
O	-2.8291172258	0.1890039892	-1.1486979031
H	-3.1241569517	1.0121794400	-1.5525197901

5. NMR Spectra

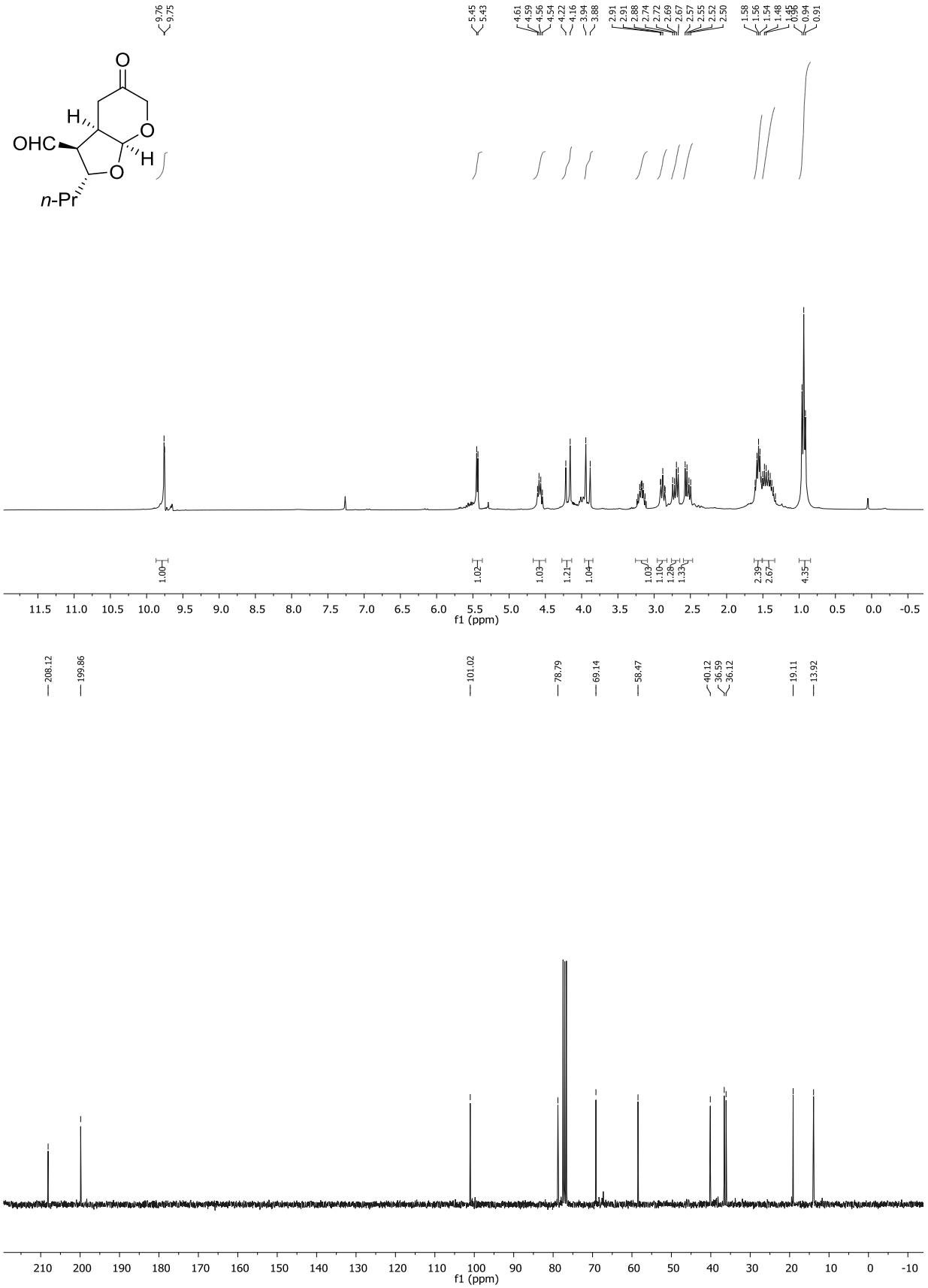


Figure ESI-19. NMR spectra of compound **4i**.

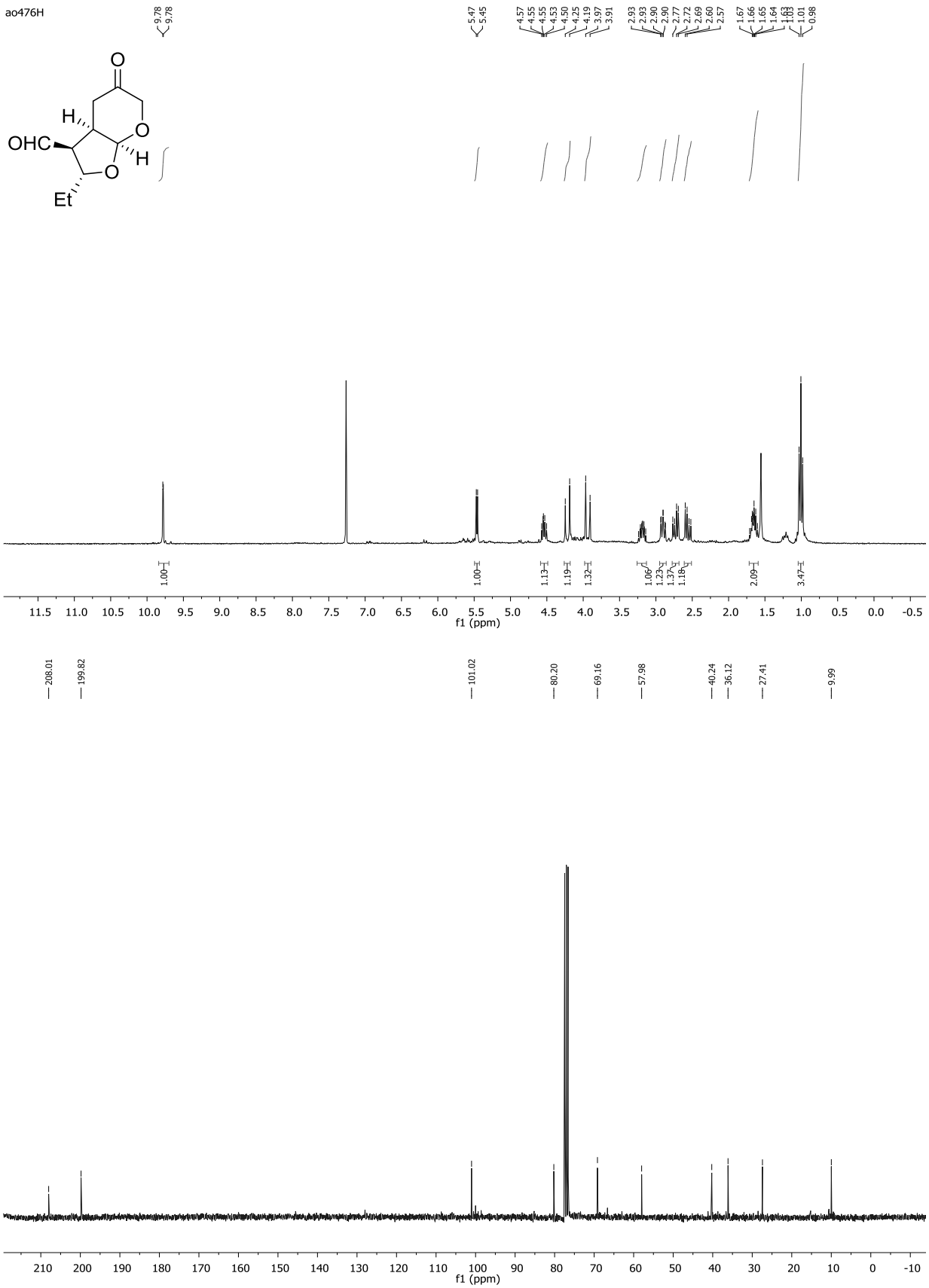


Figure ESI-20. NMR spectra of compound **4j**.

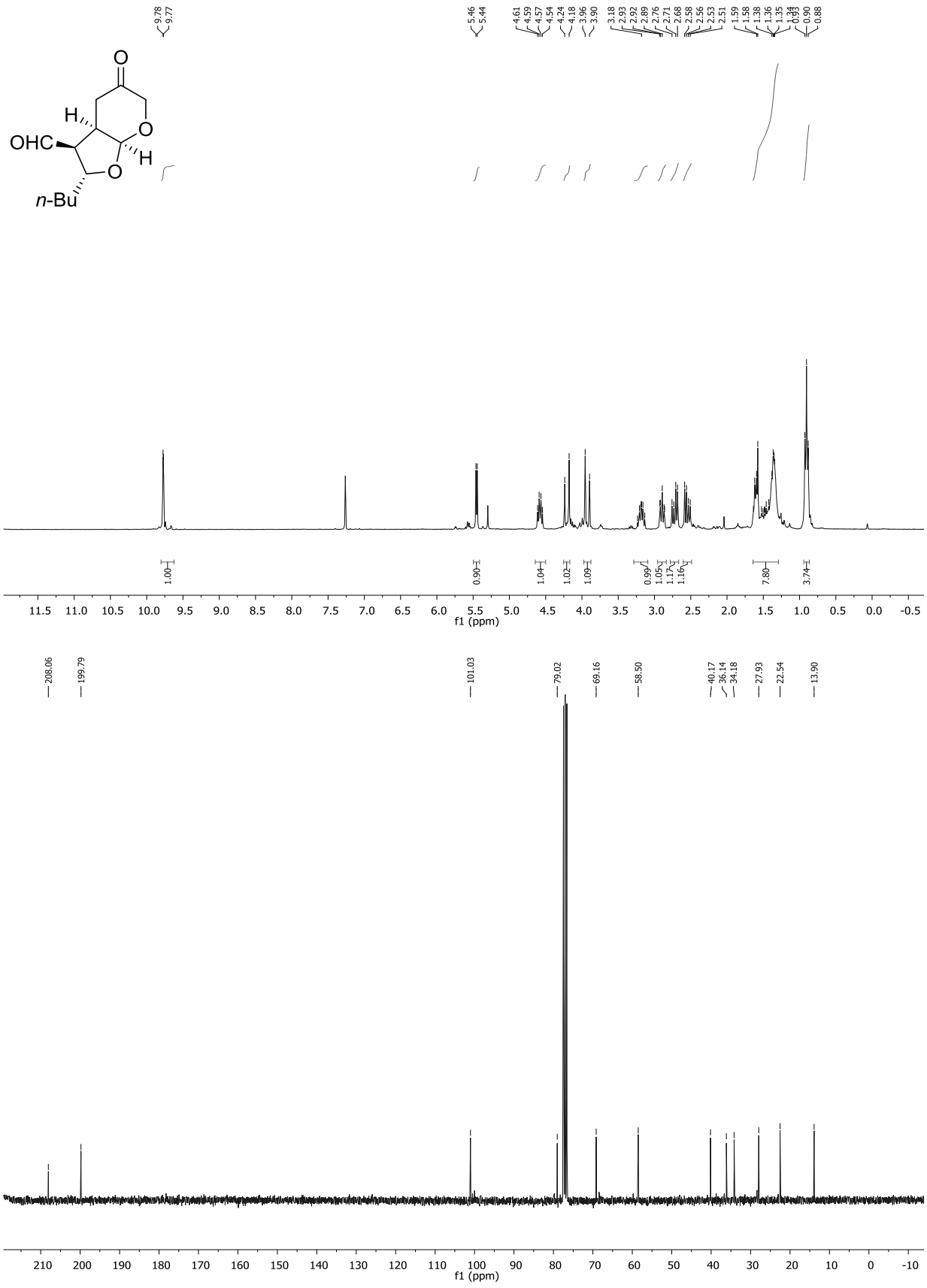


Figure ESI-21. NMR spectra of compound **4k**.

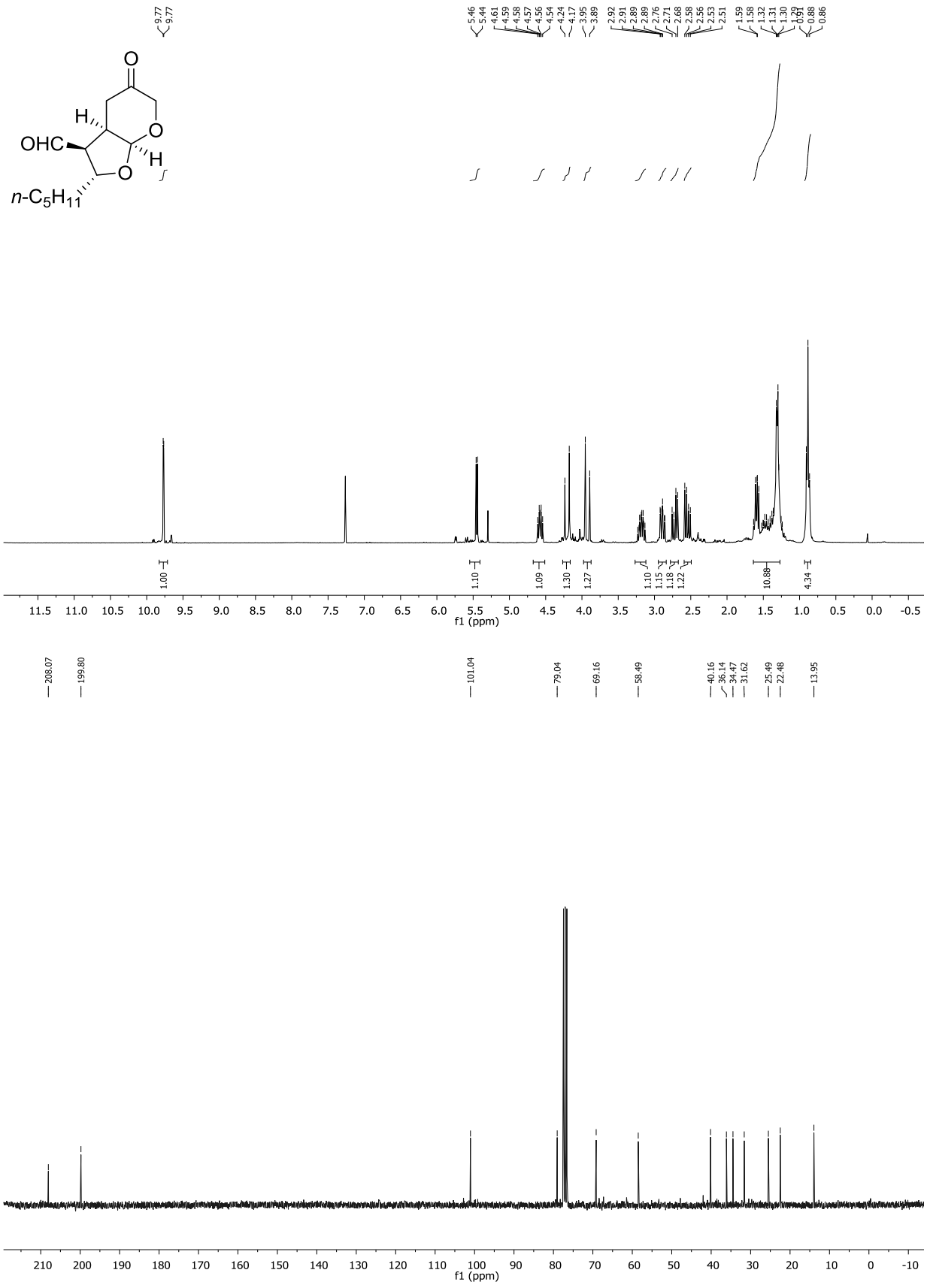


Figure ESI-22. NMR spectra of compound **4l**.

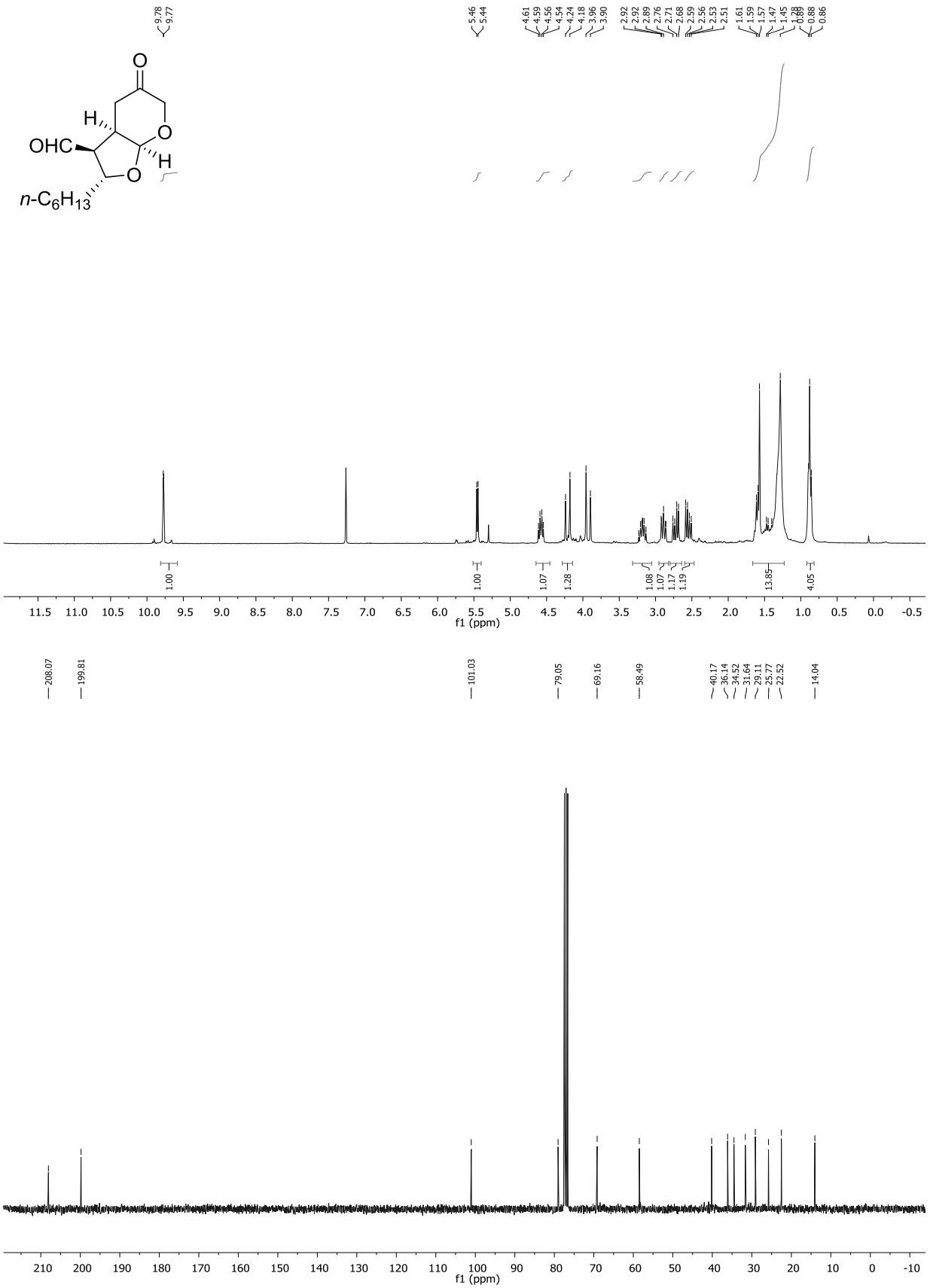


Figure ESI-23. NMR spectra of compound **4m**.

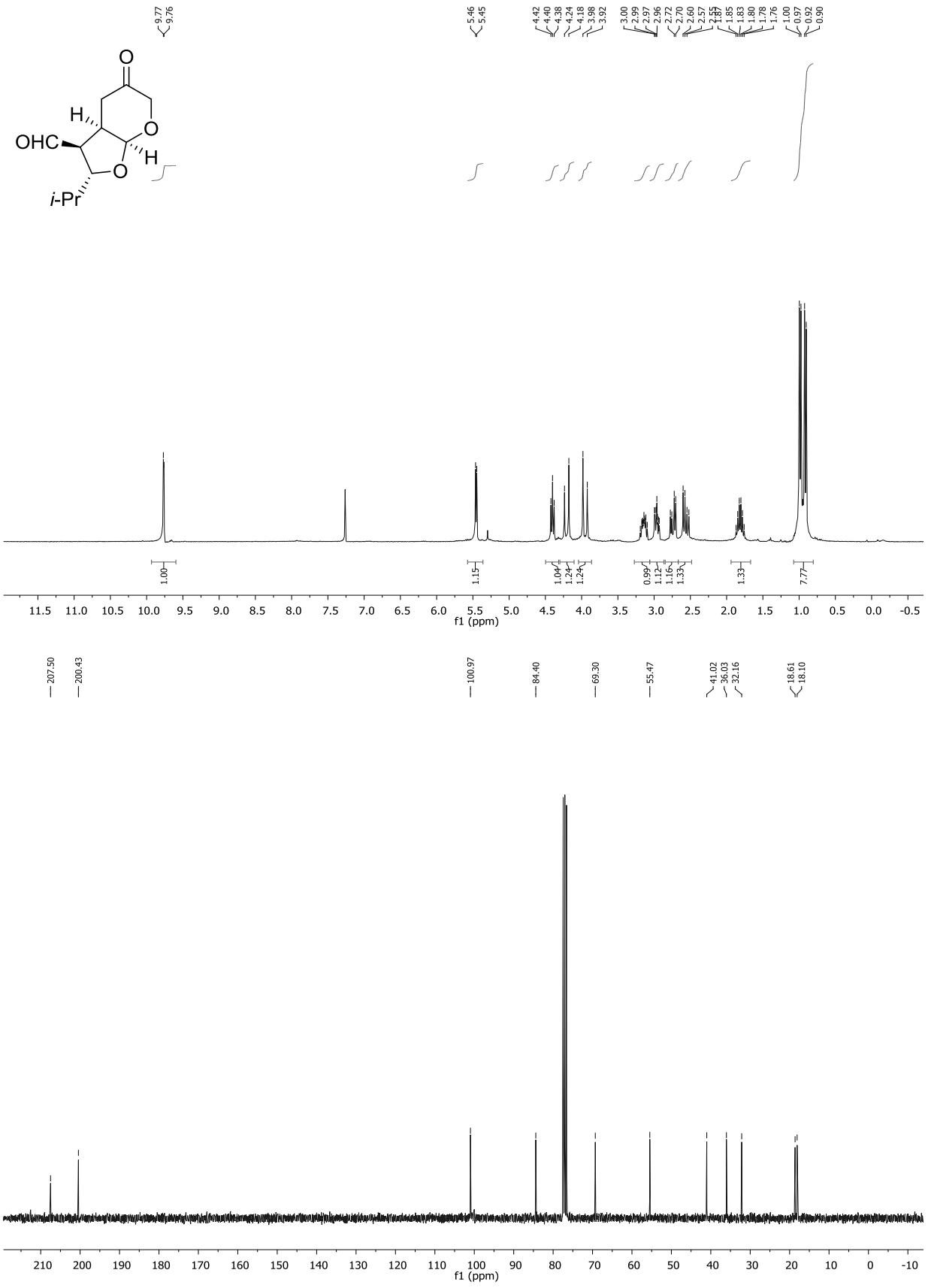


Figure ESI-24. NMR spectra of compound **4n**.

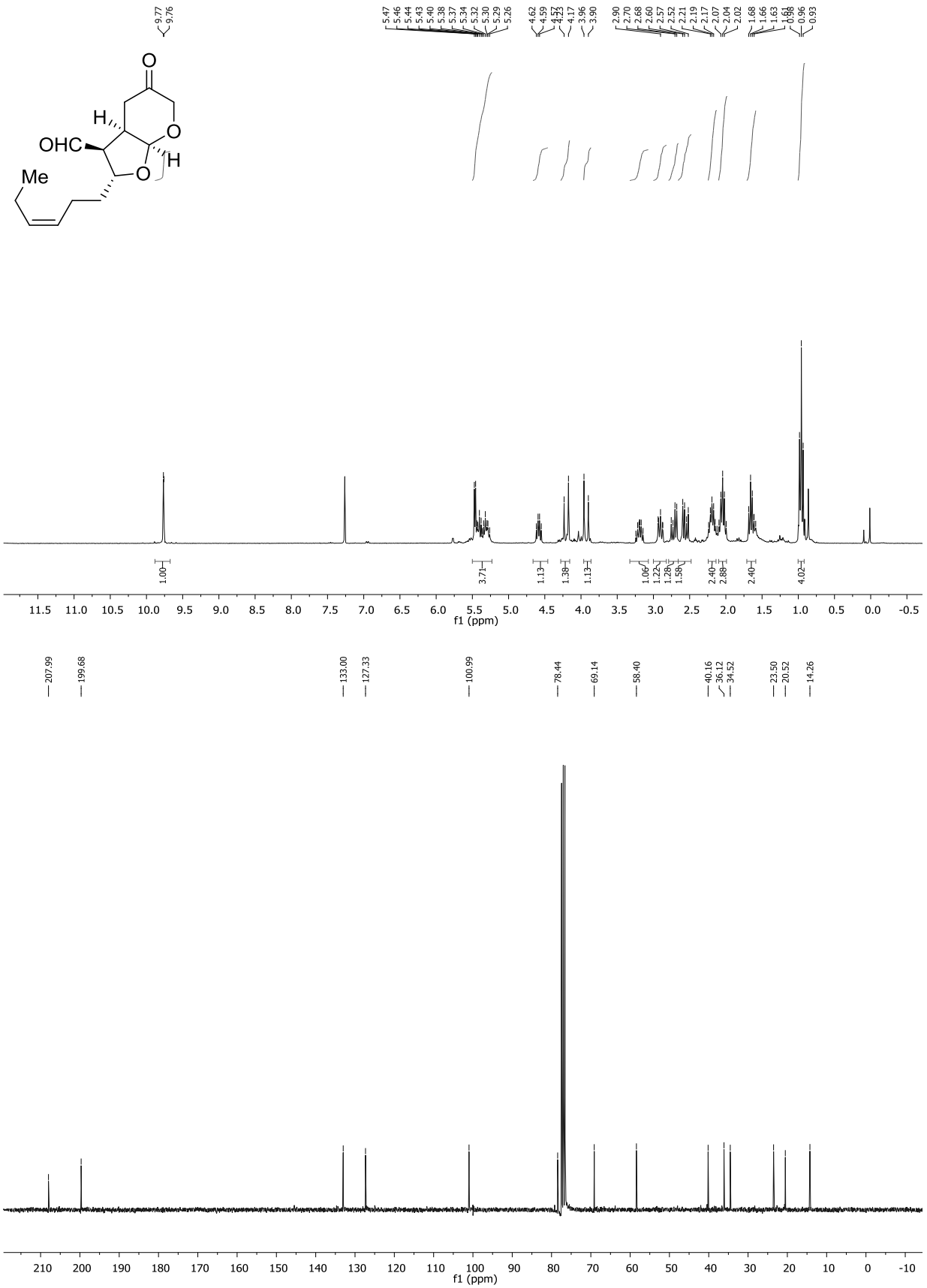


Figure ESI-25. NMR spectra of compound **4o**.

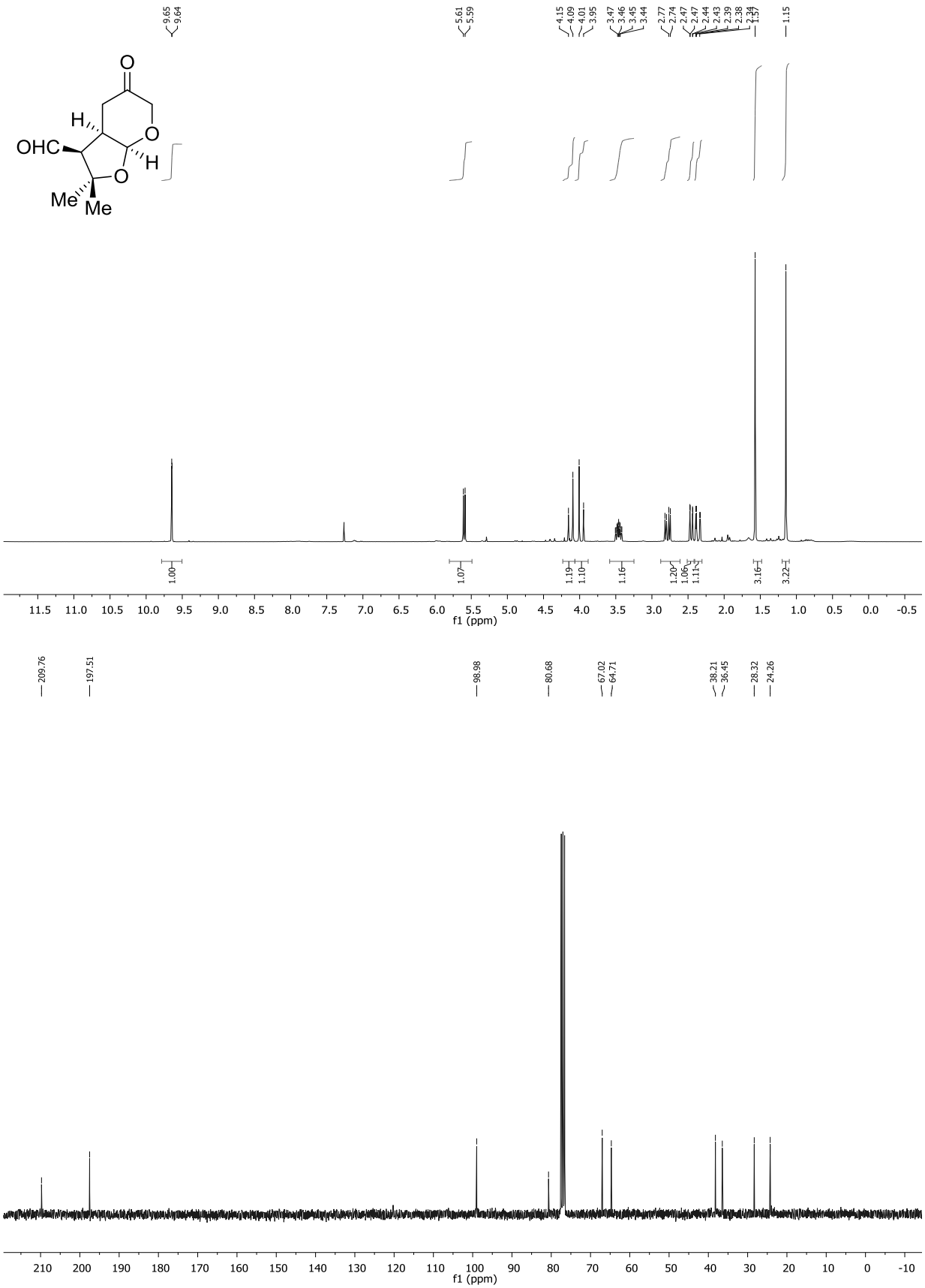


Figure ESI-26. NMR spectra of compound **4p**.

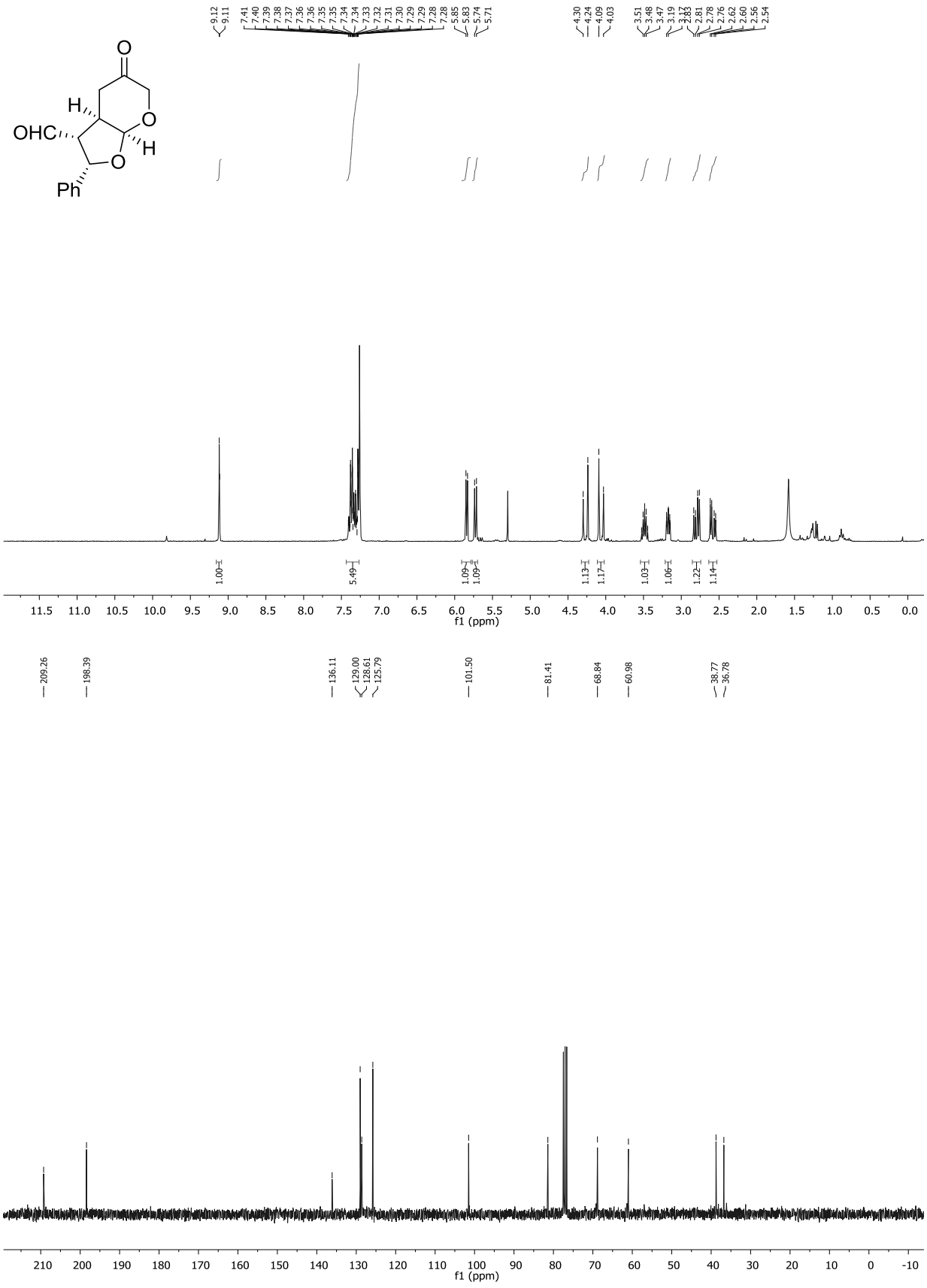


Figure ESI-27. NMR spectra of compound **6a**.

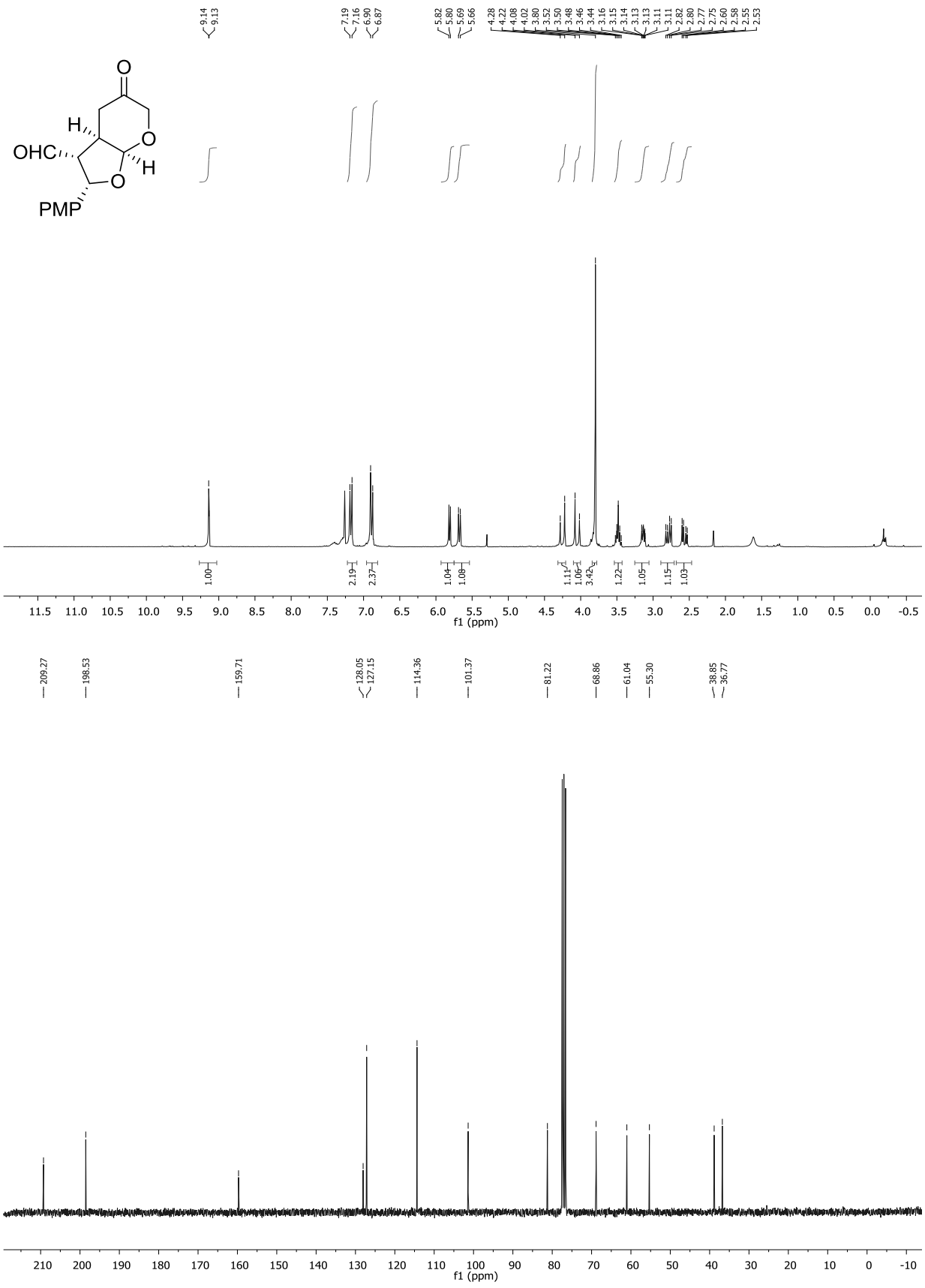


Figure ESI-28. NMR spectra of compound **6b**.

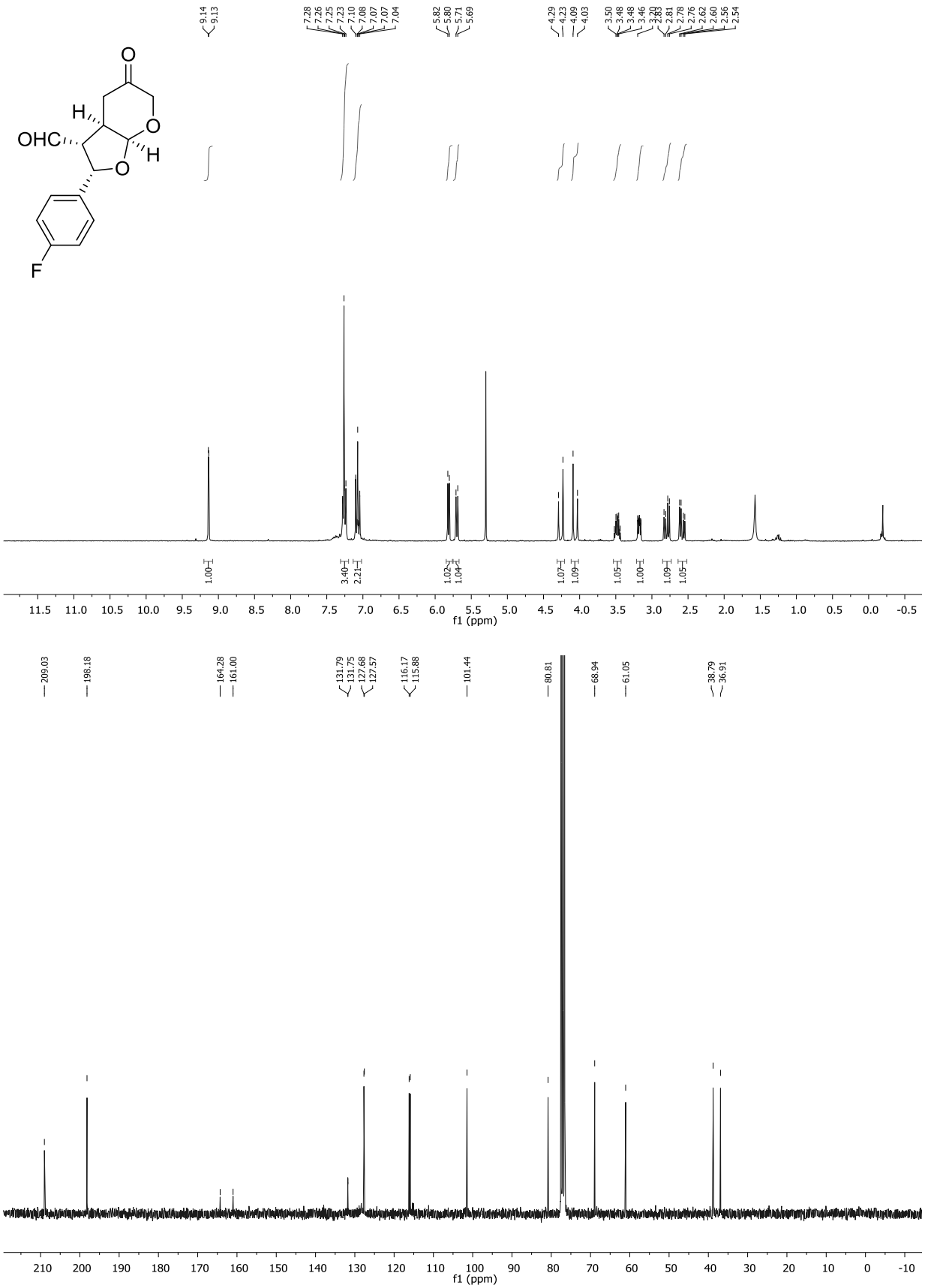


Figure ESI-29. NMR spectra of compound **6c**.

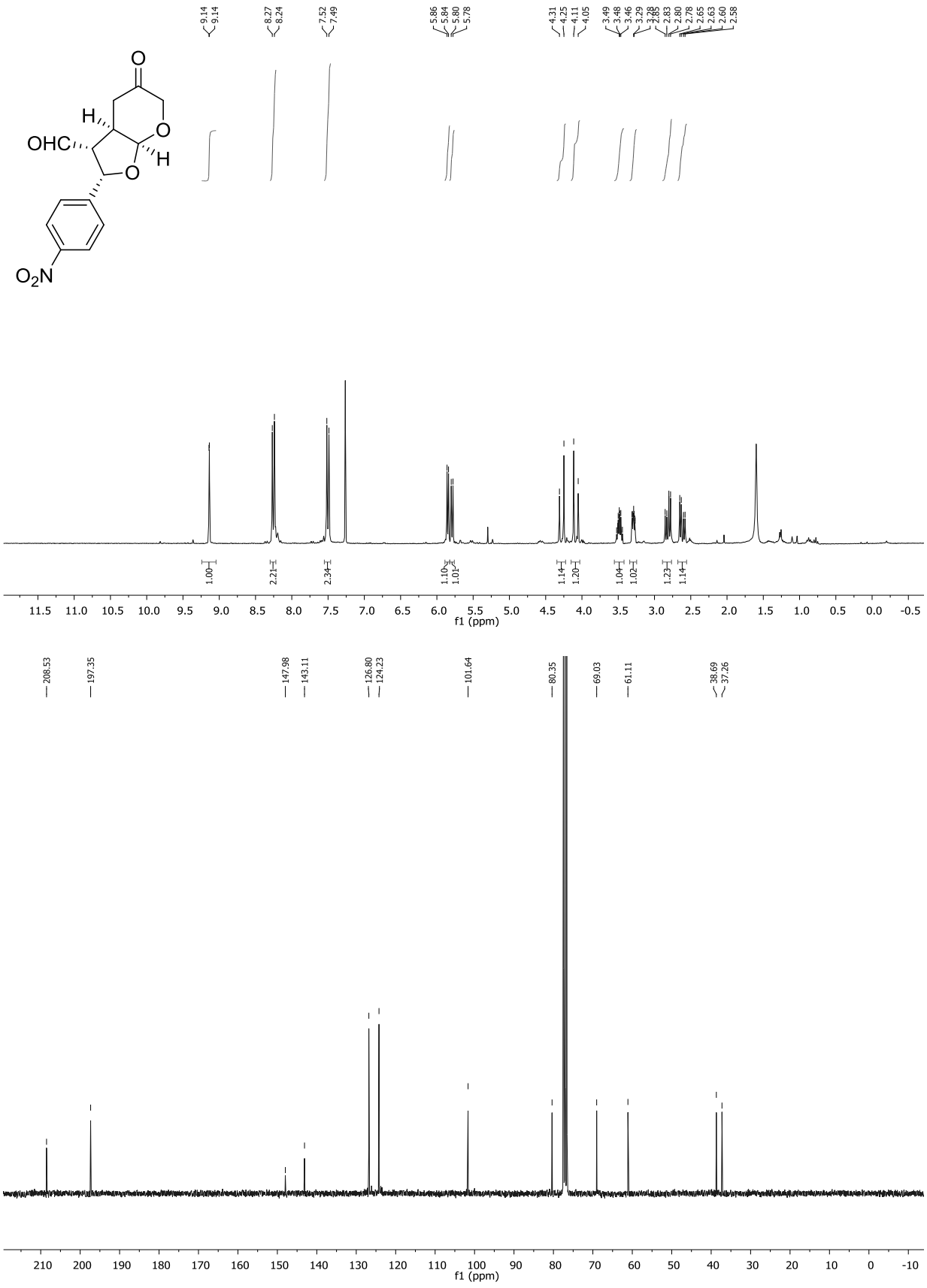


Figure ESI-30. NMR spectra of compound **6d**.

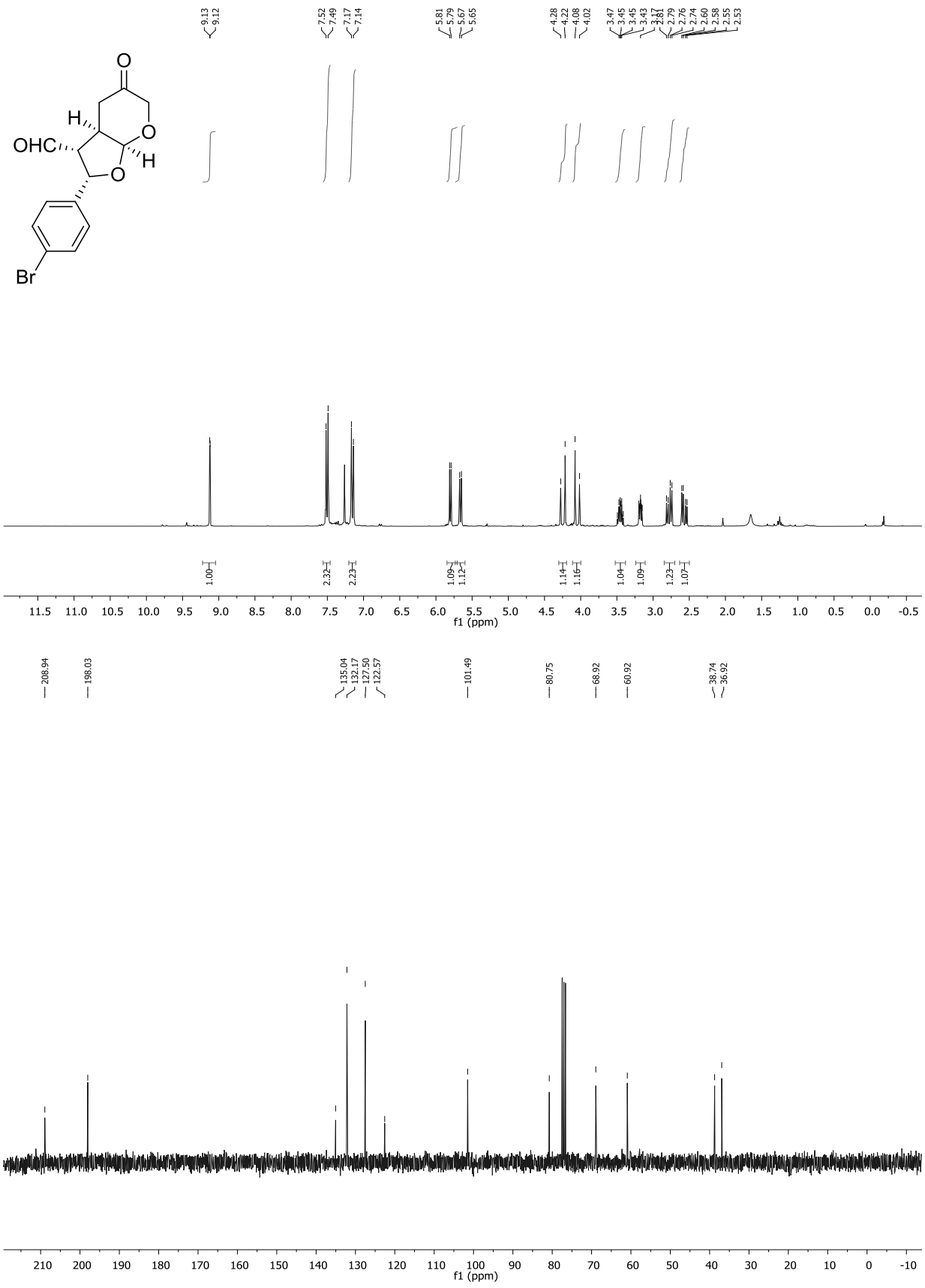


Figure ESI-31. NMR spectra of compound **6e**.

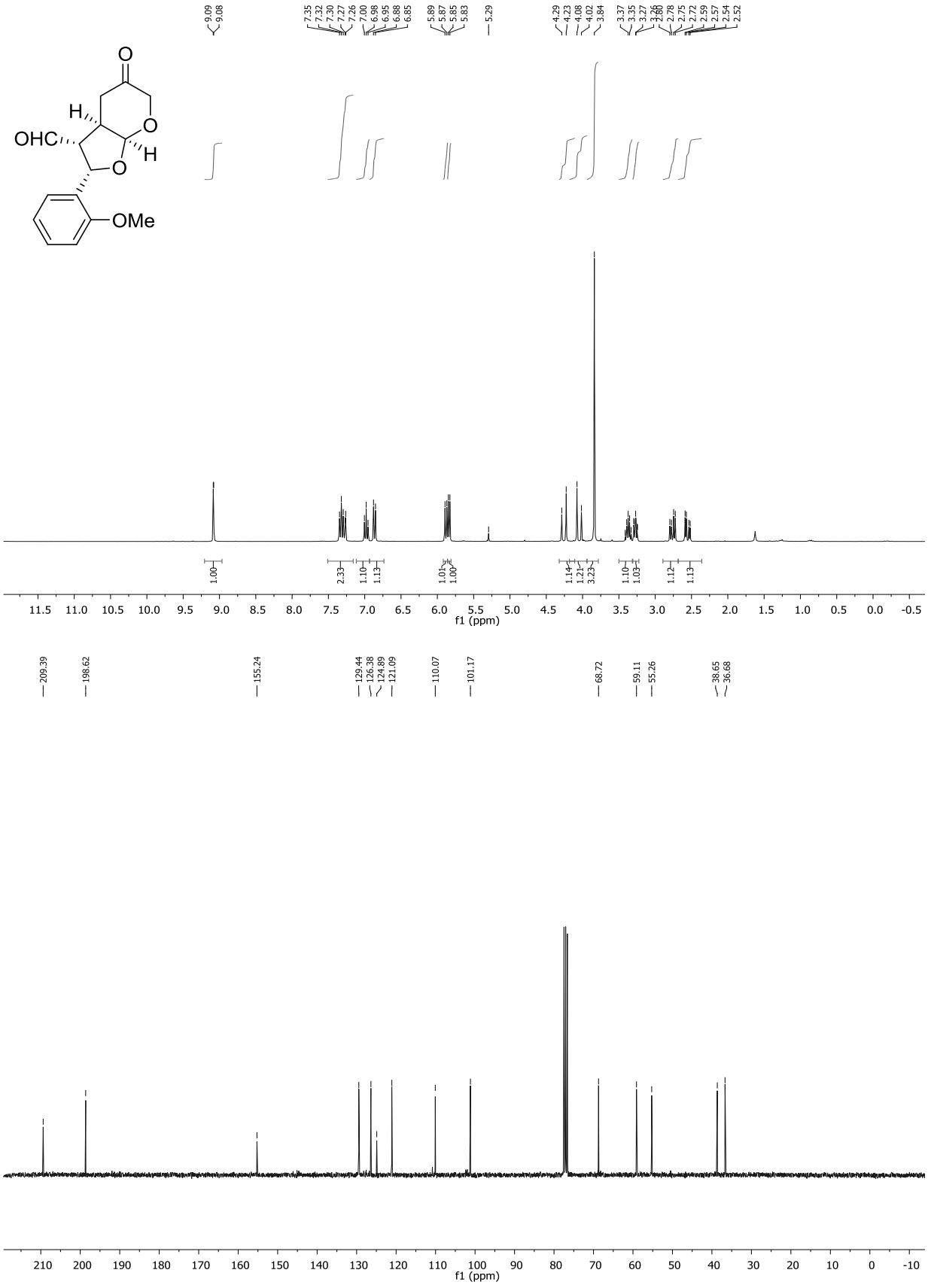


Figure ESI-32. NMR spectra of compound **6f**.

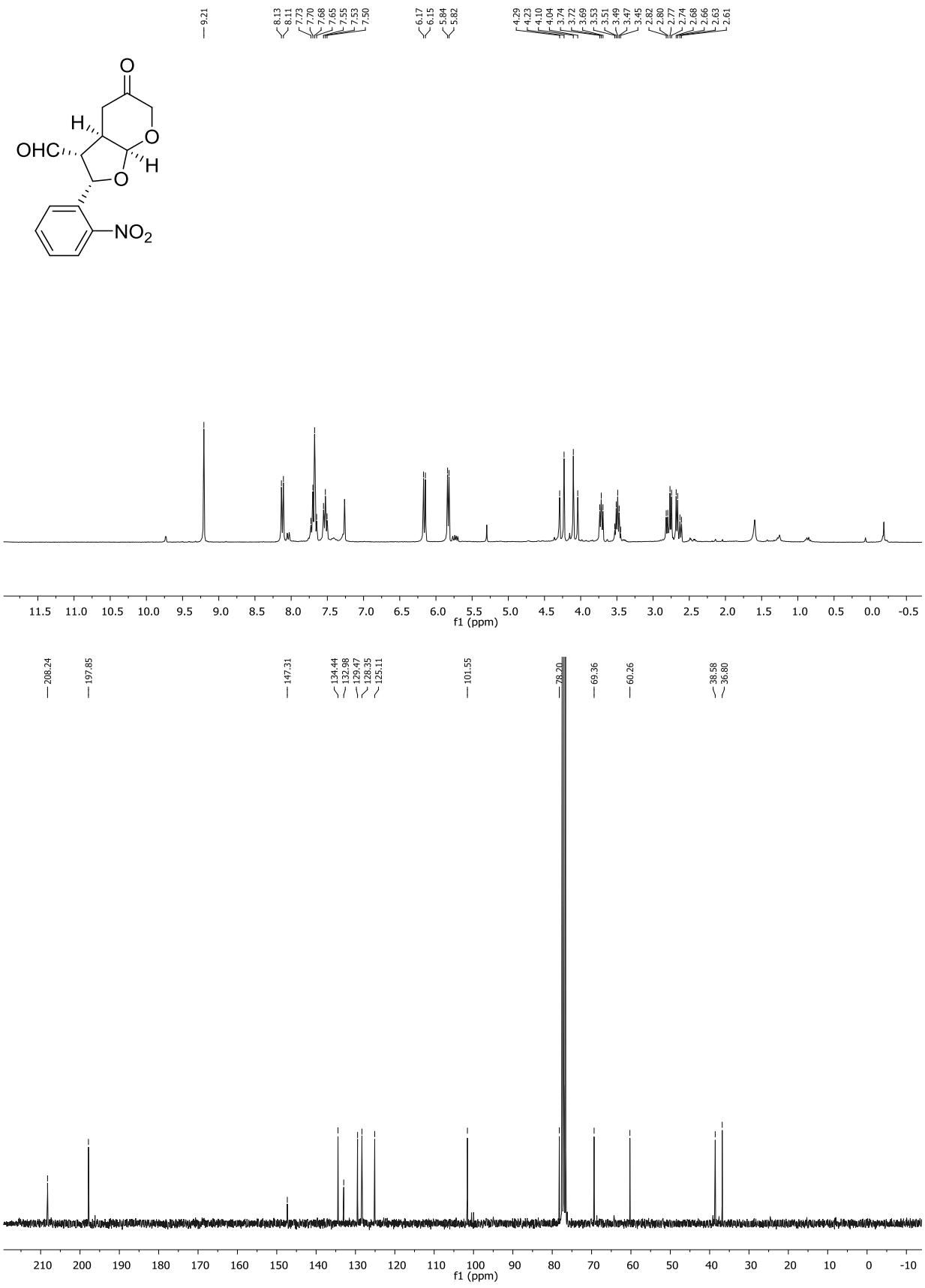


Figure ESI-33. NMR spectra of compound **6g**.

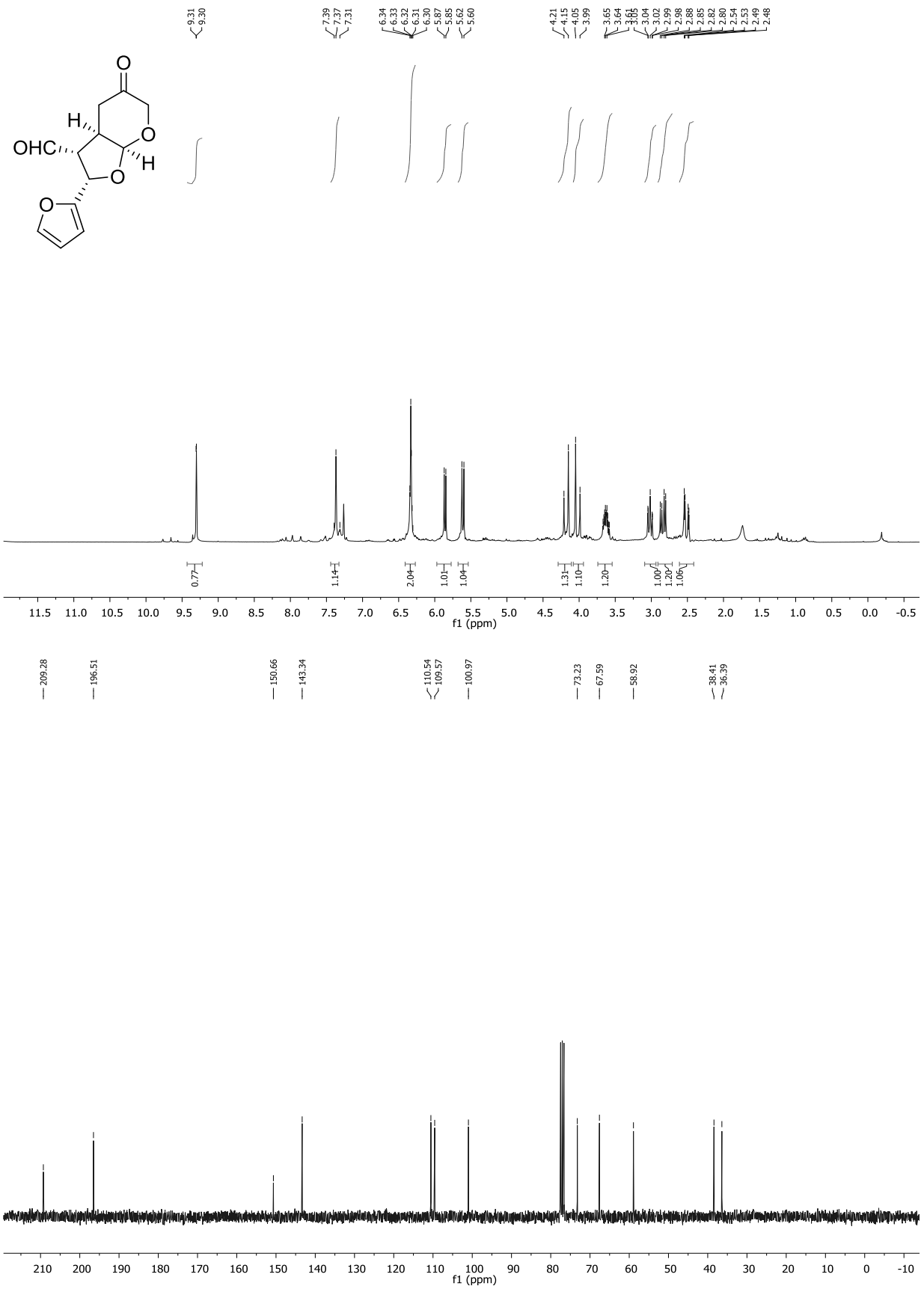


Figure ESI-34. NMR spectra of compound **6h**.

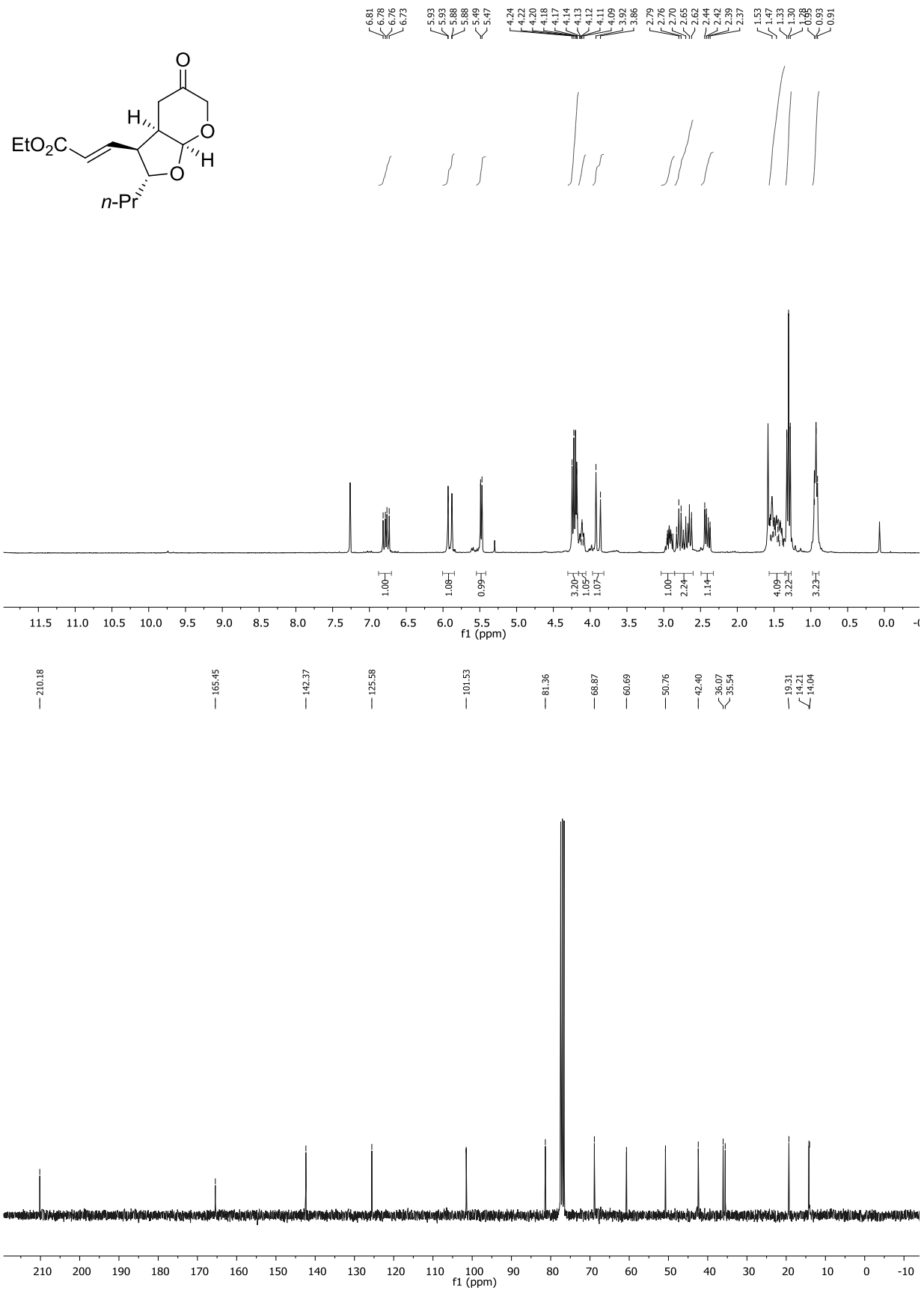


Figure ESI-35. NMR spectra of compound **7i**.

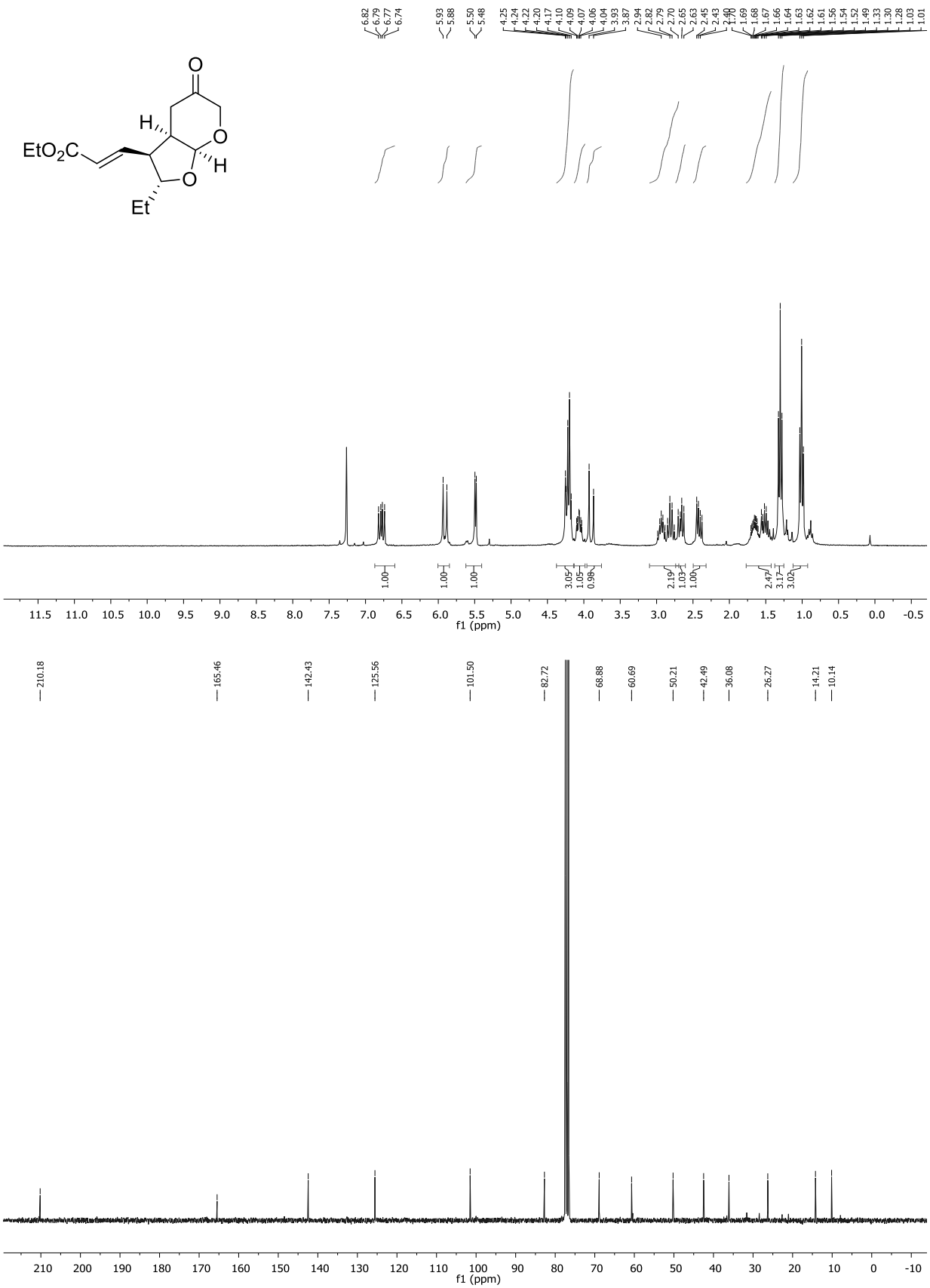


Figure ESI-36. NMR spectra of compound **7j**.

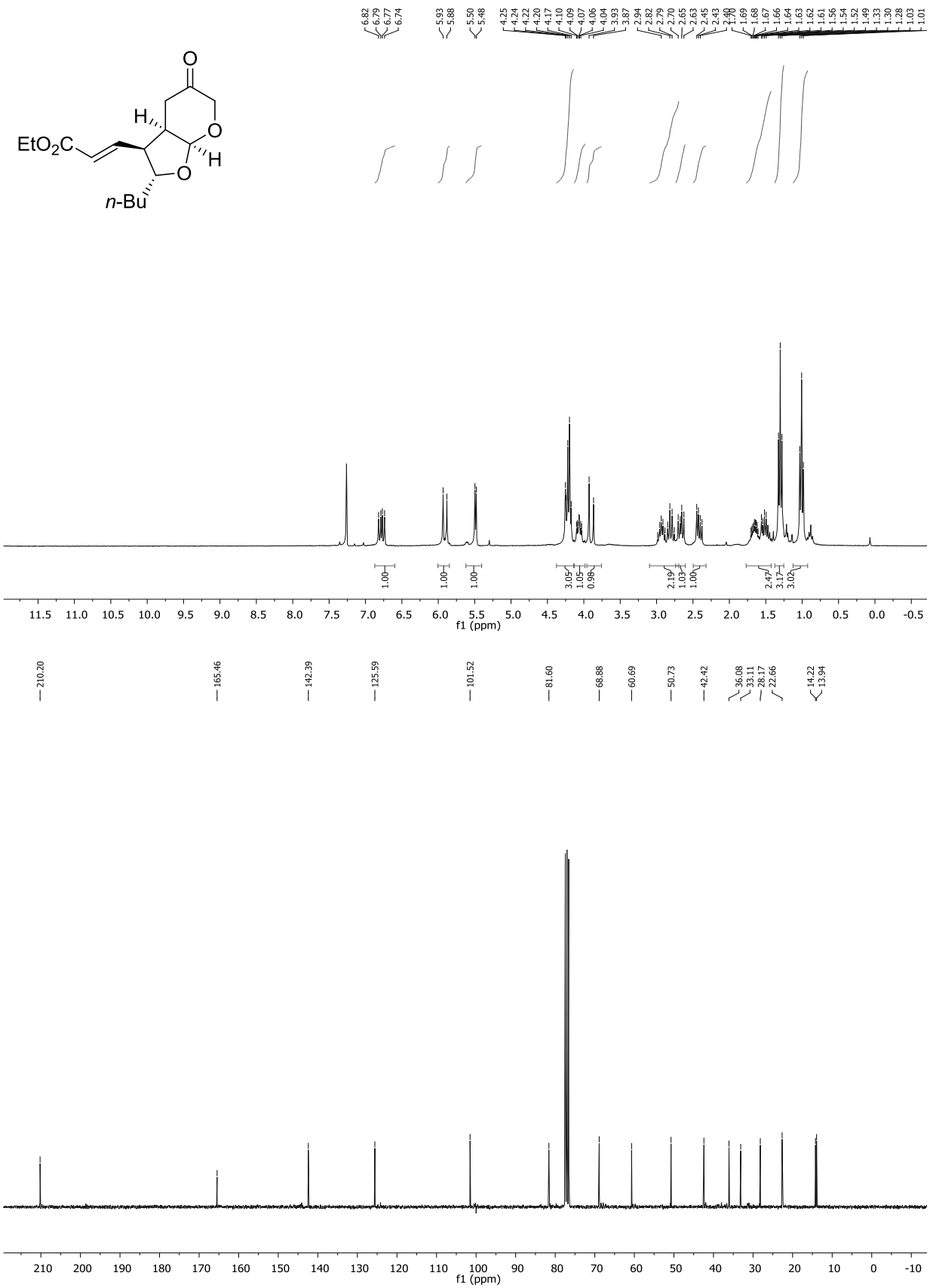


Figure ESI-37. NMR spectra of compound **7k**.

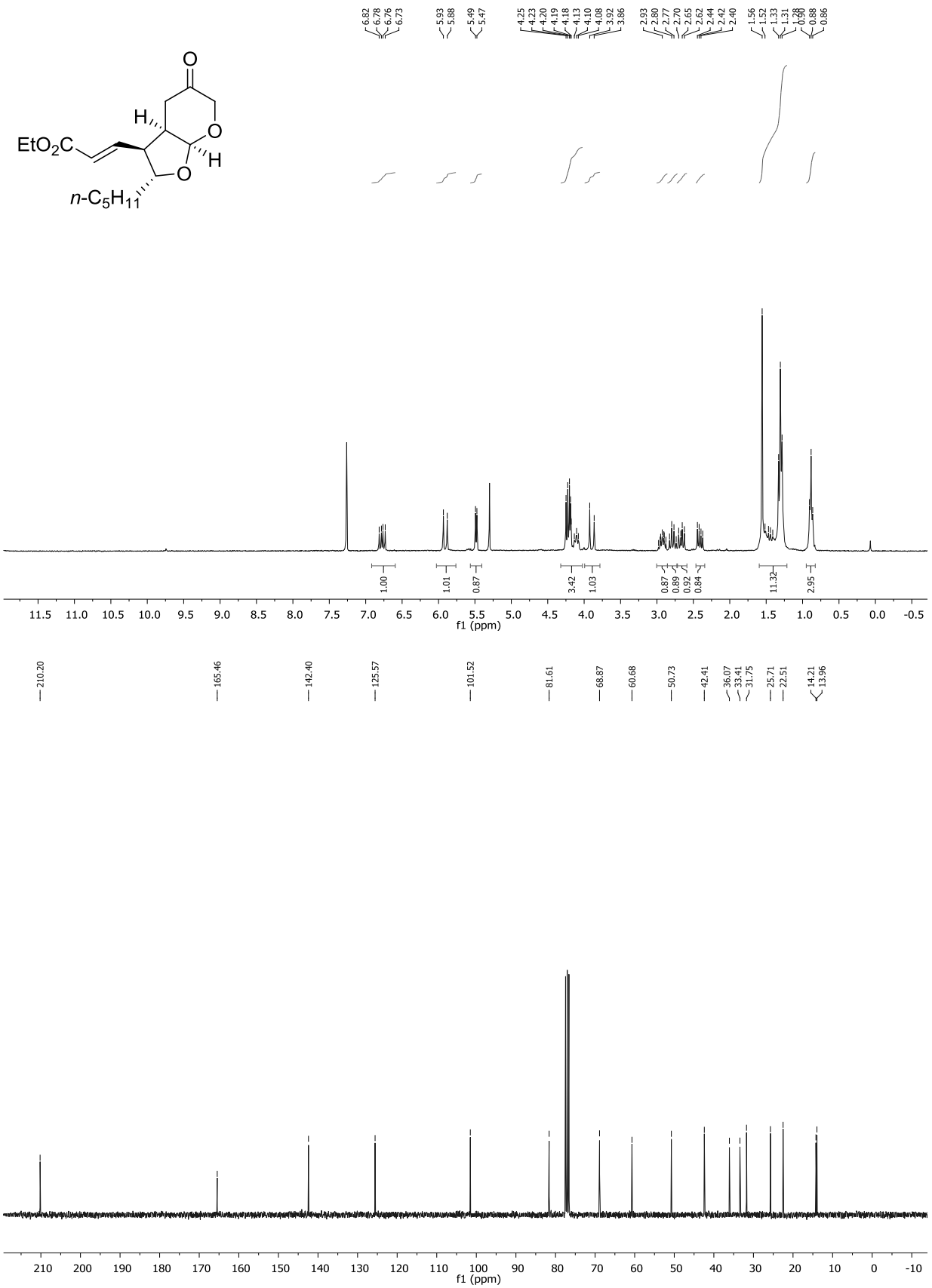


Figure ESI-38. NMR spectra of compound **7l**.

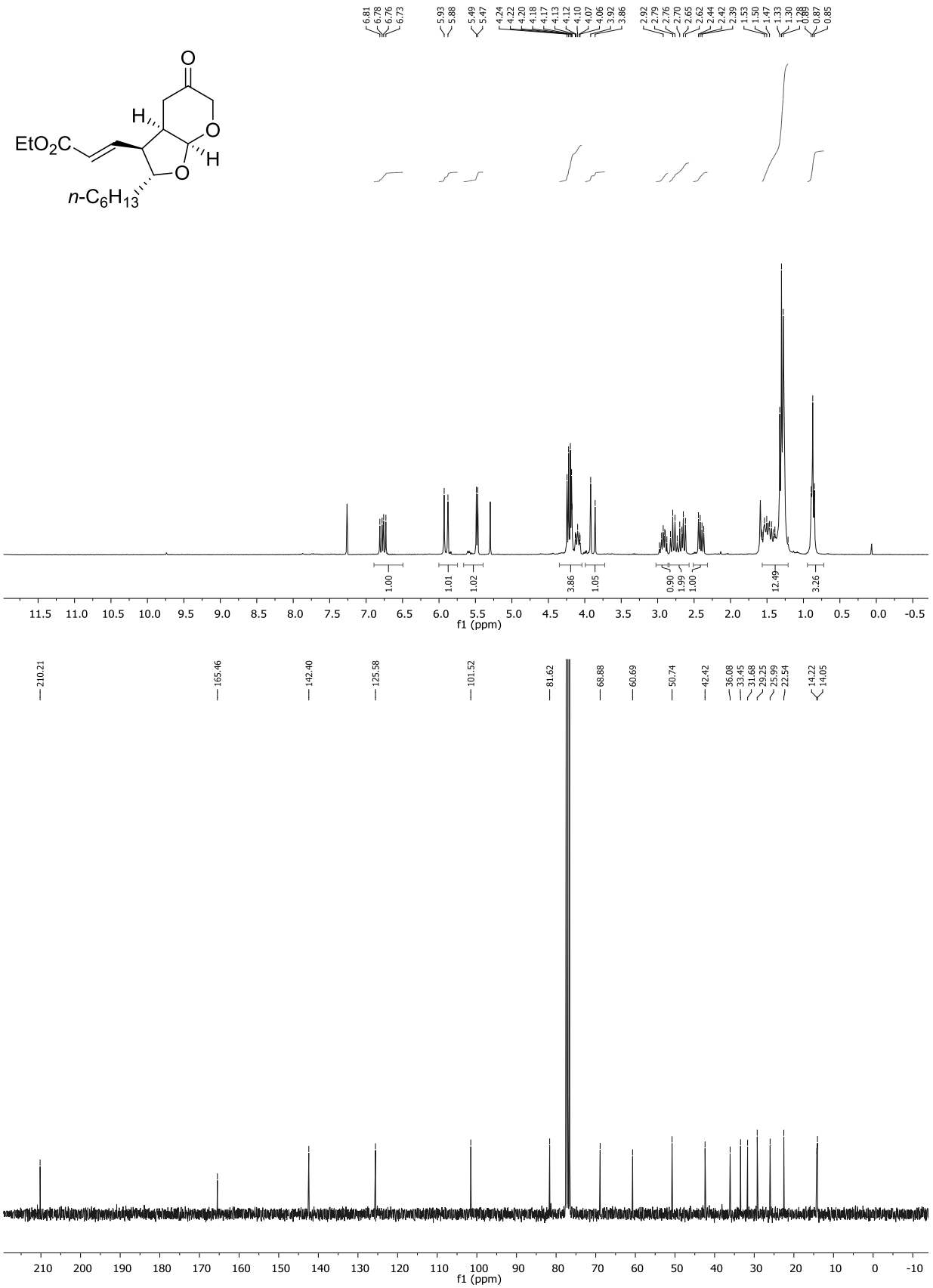


Figure ESI-39. NMR spectra of compound **7m**.

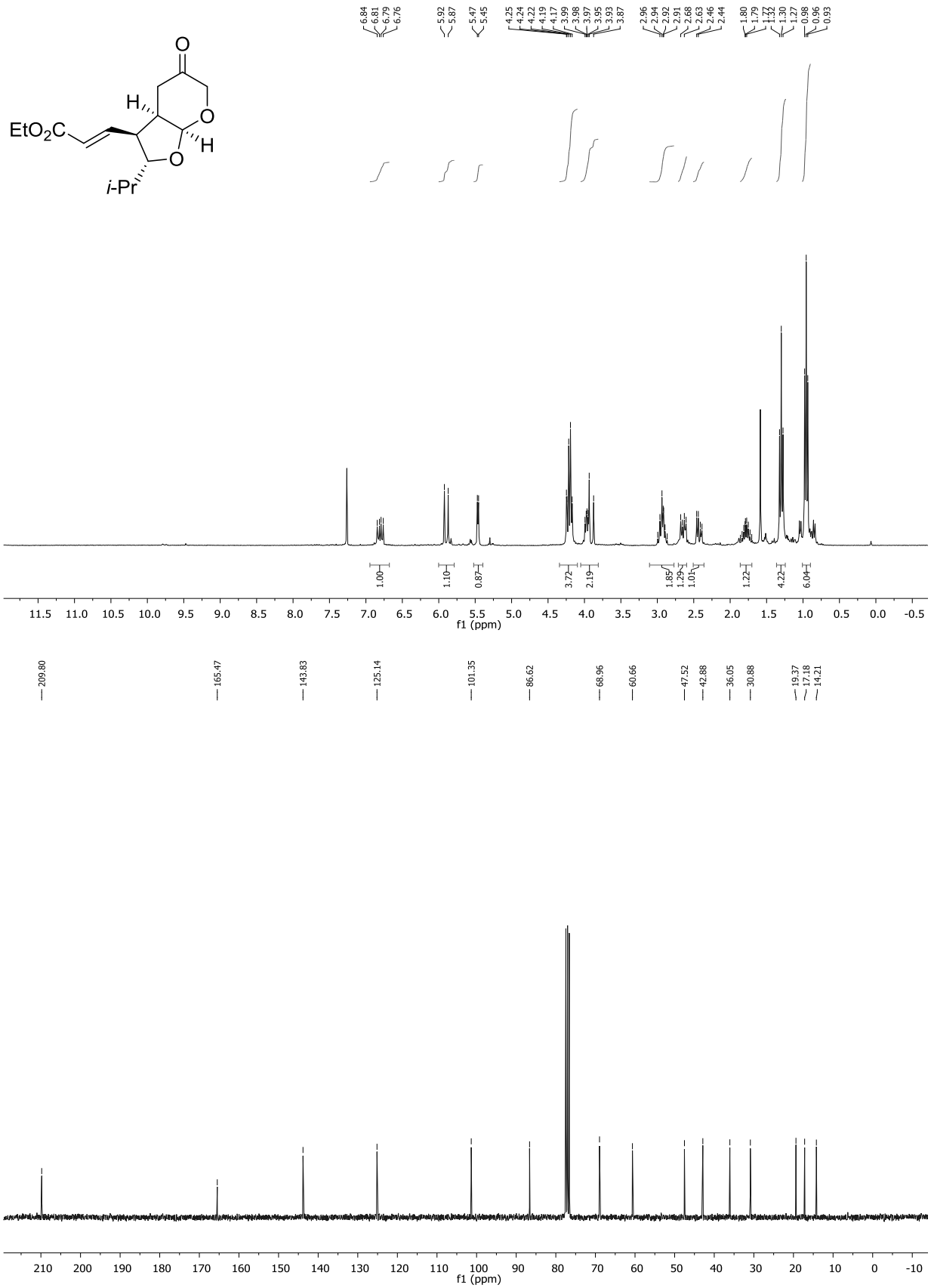


Figure ESI-40. NMR spectra of compound **7n**.

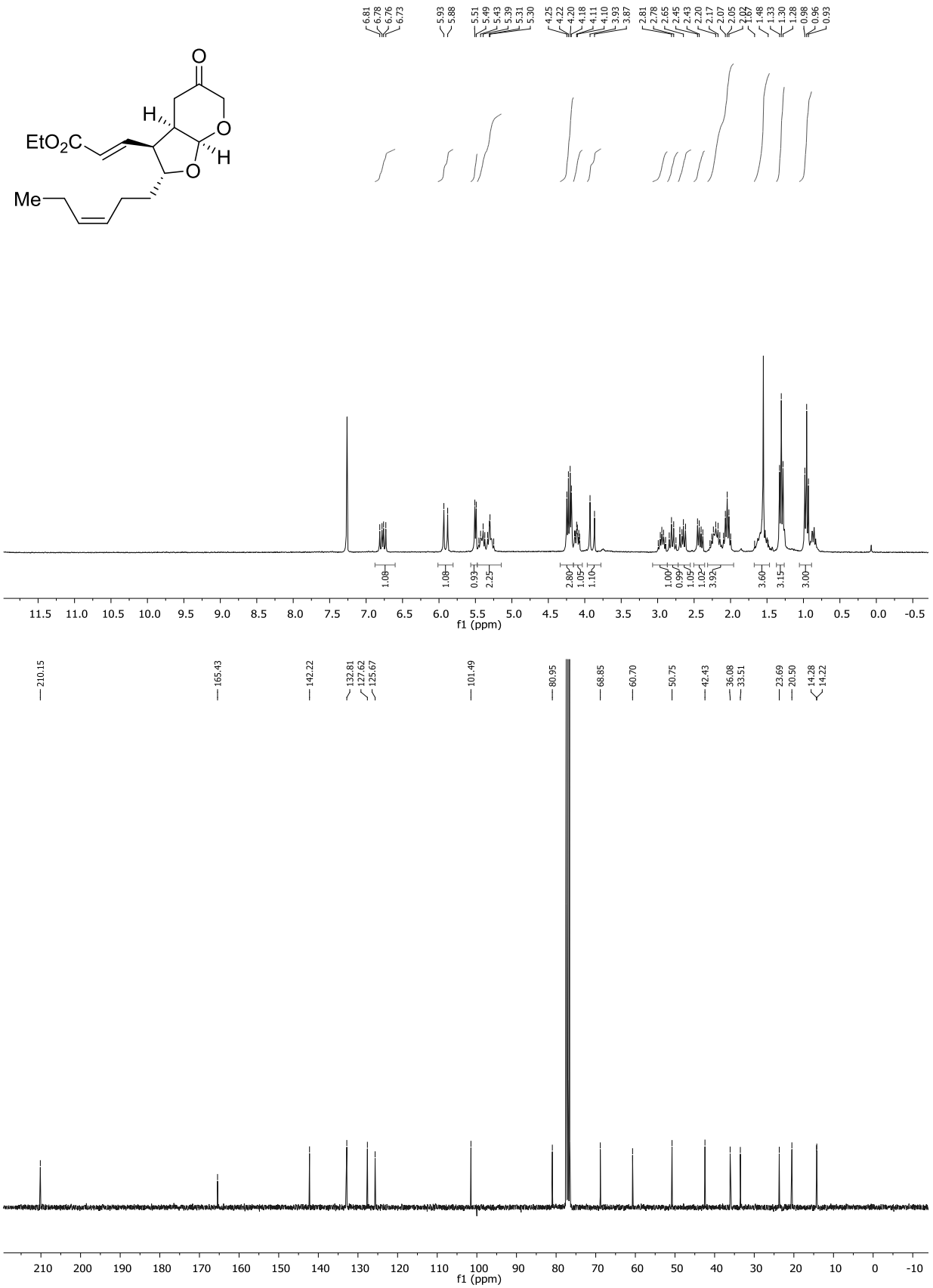


Figure ESI-41. NMR spectra of compound **7o**.

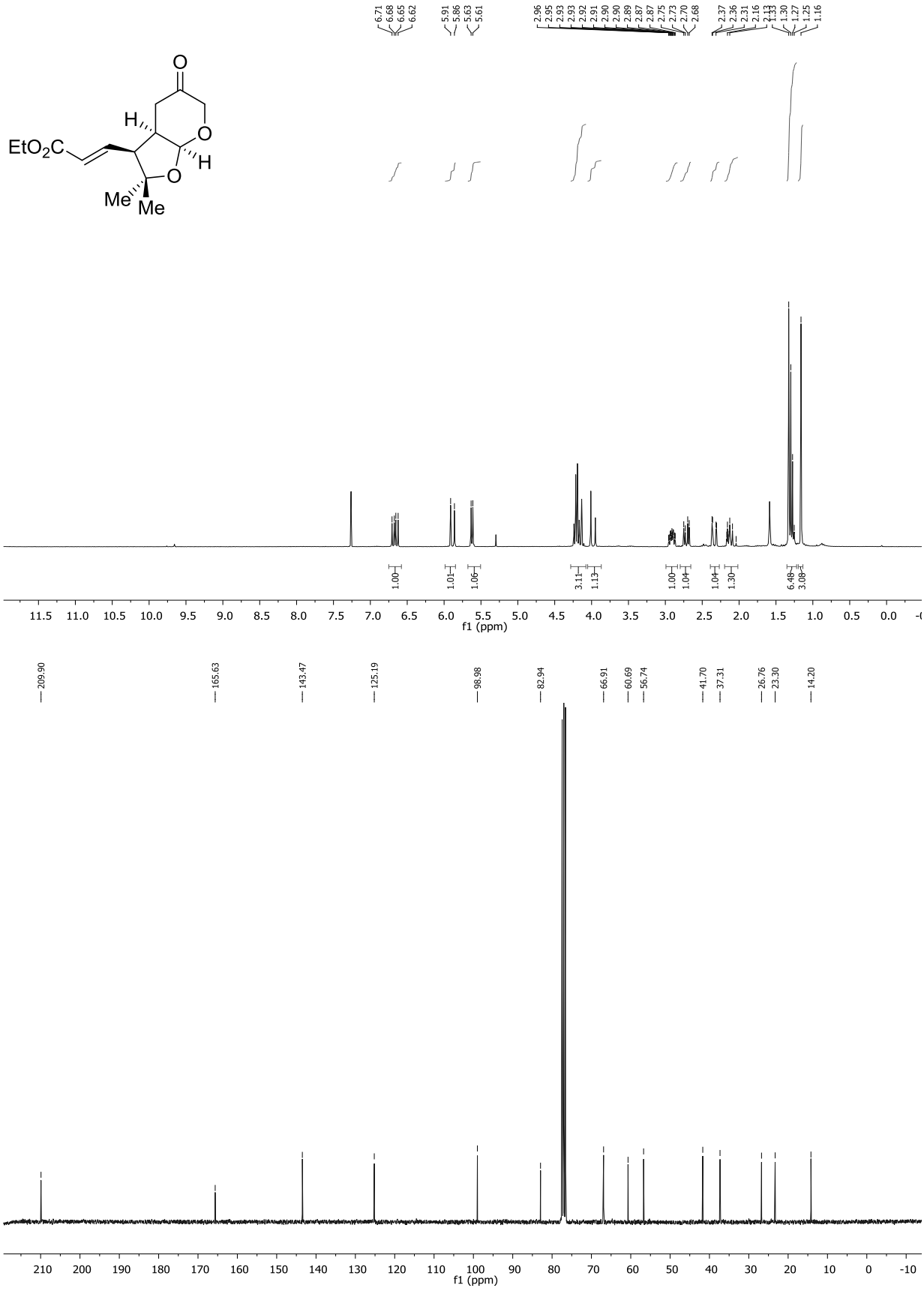


Figure ESI-42. NMR spectra of compound **7p**.

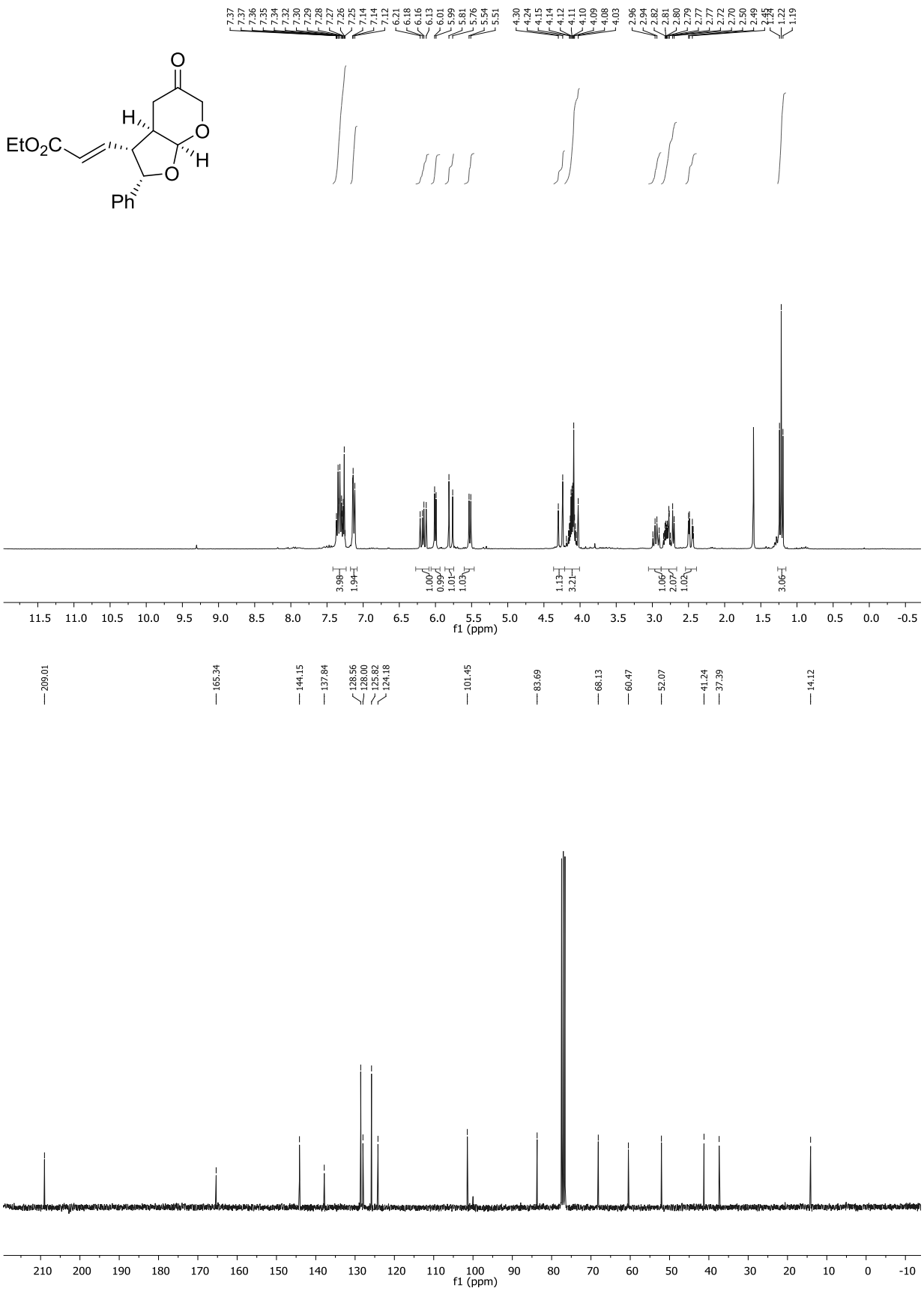


Figure ESI-43. NMR spectra of compound **8a**.

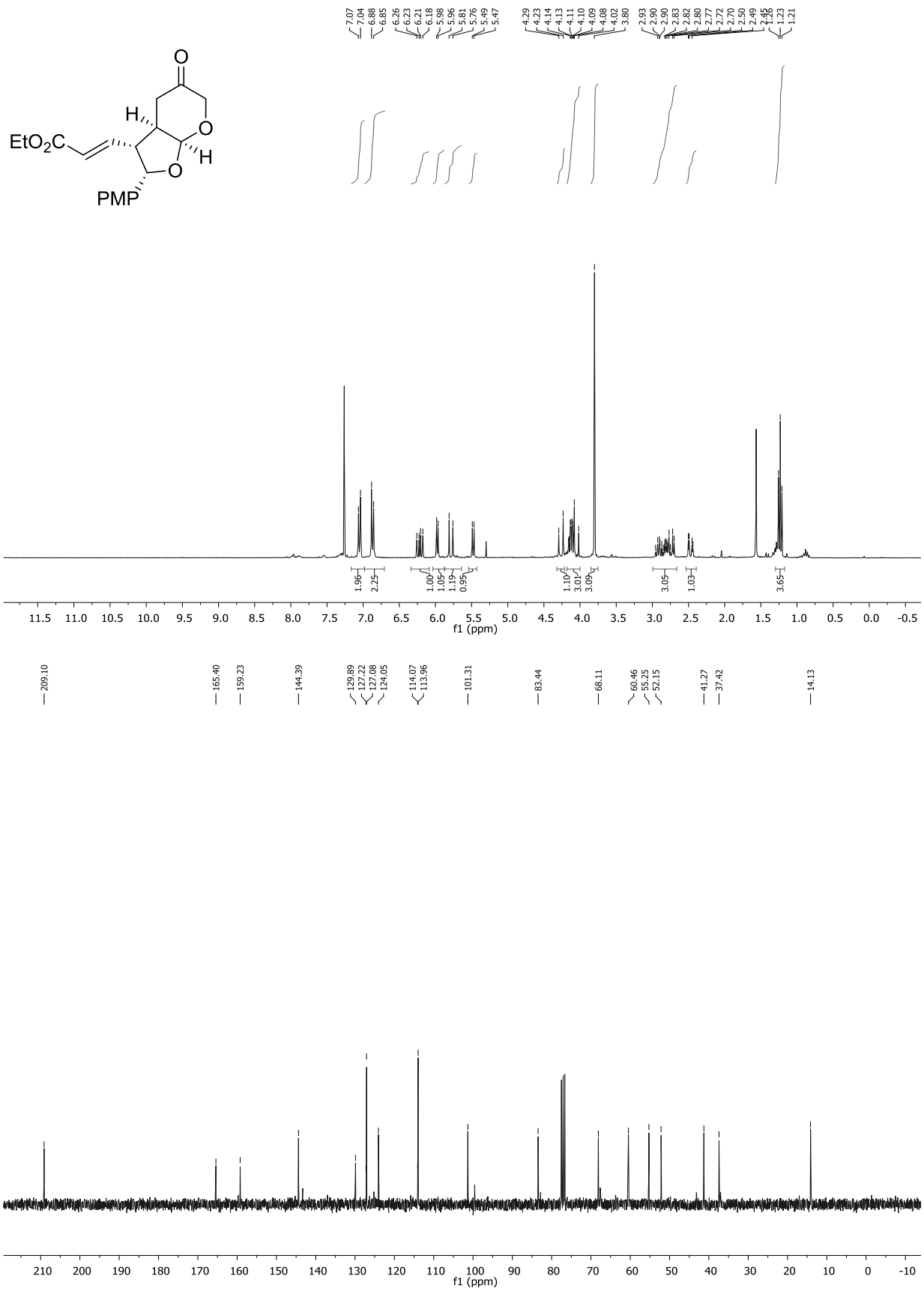


Figure ESI-44. NMR spectra of compound **8b**.

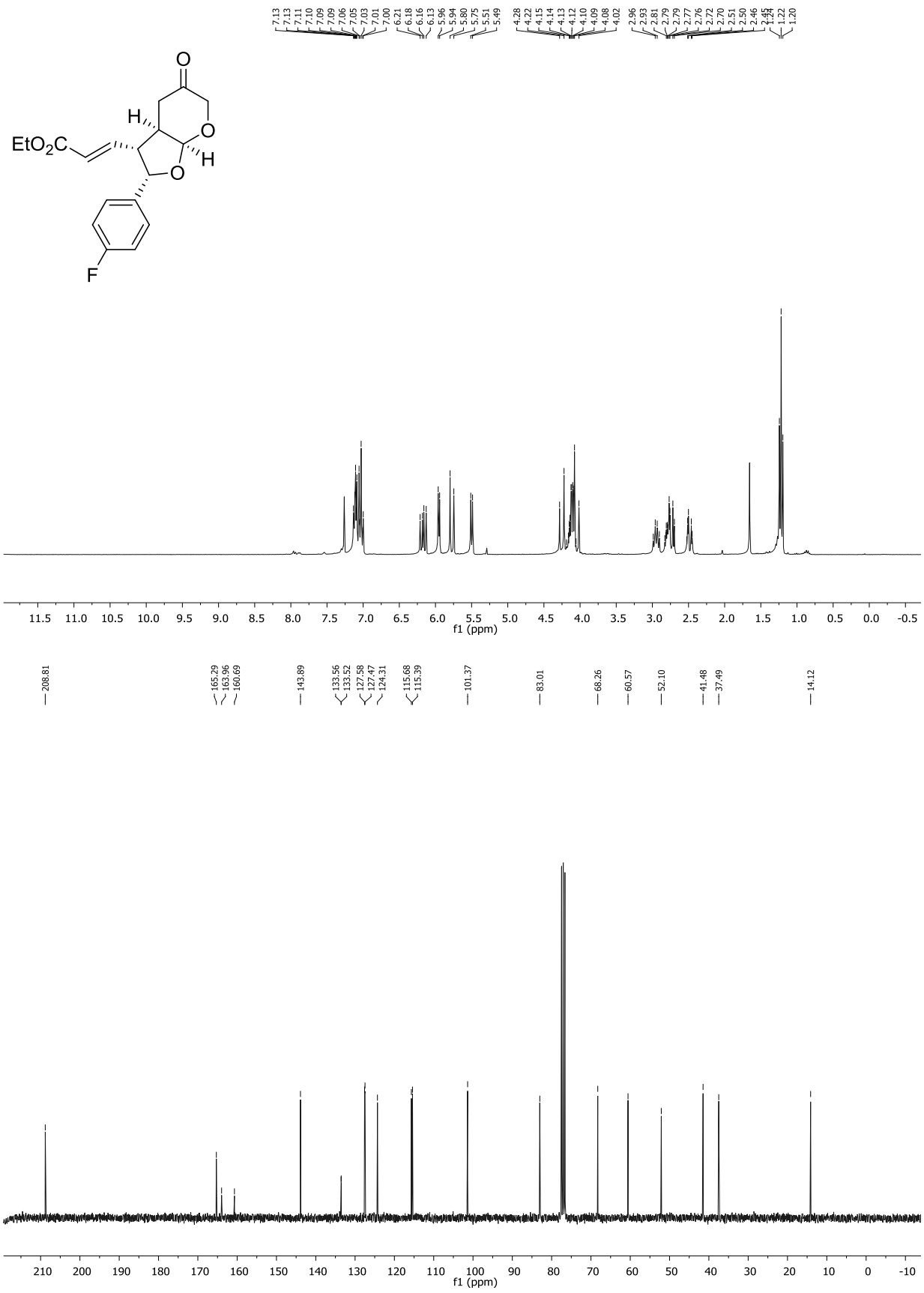


Figure ESI-45. NMR spectra of compound **8c**.

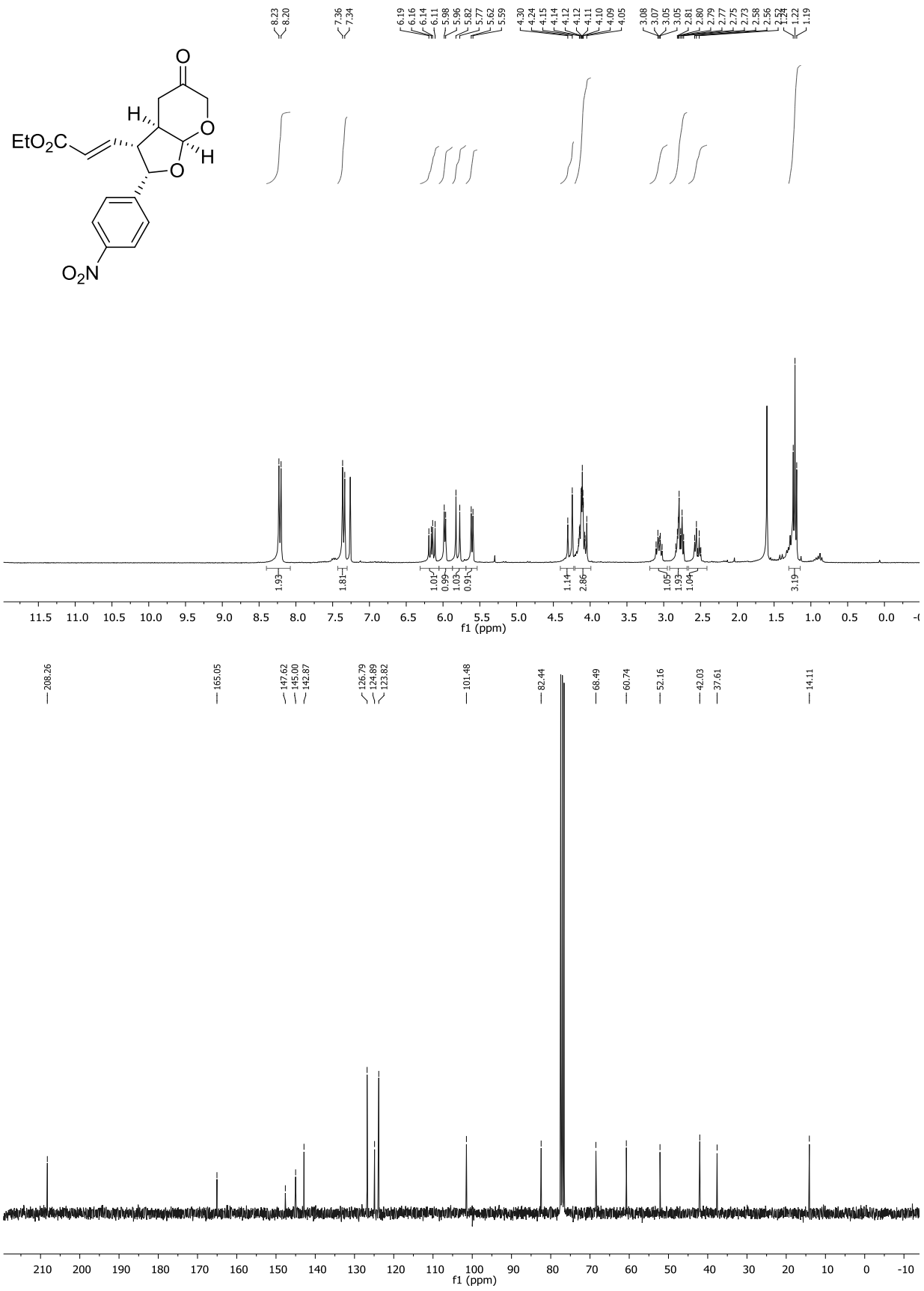


Figure ESI-46. NMR spectra of compound **8d**.

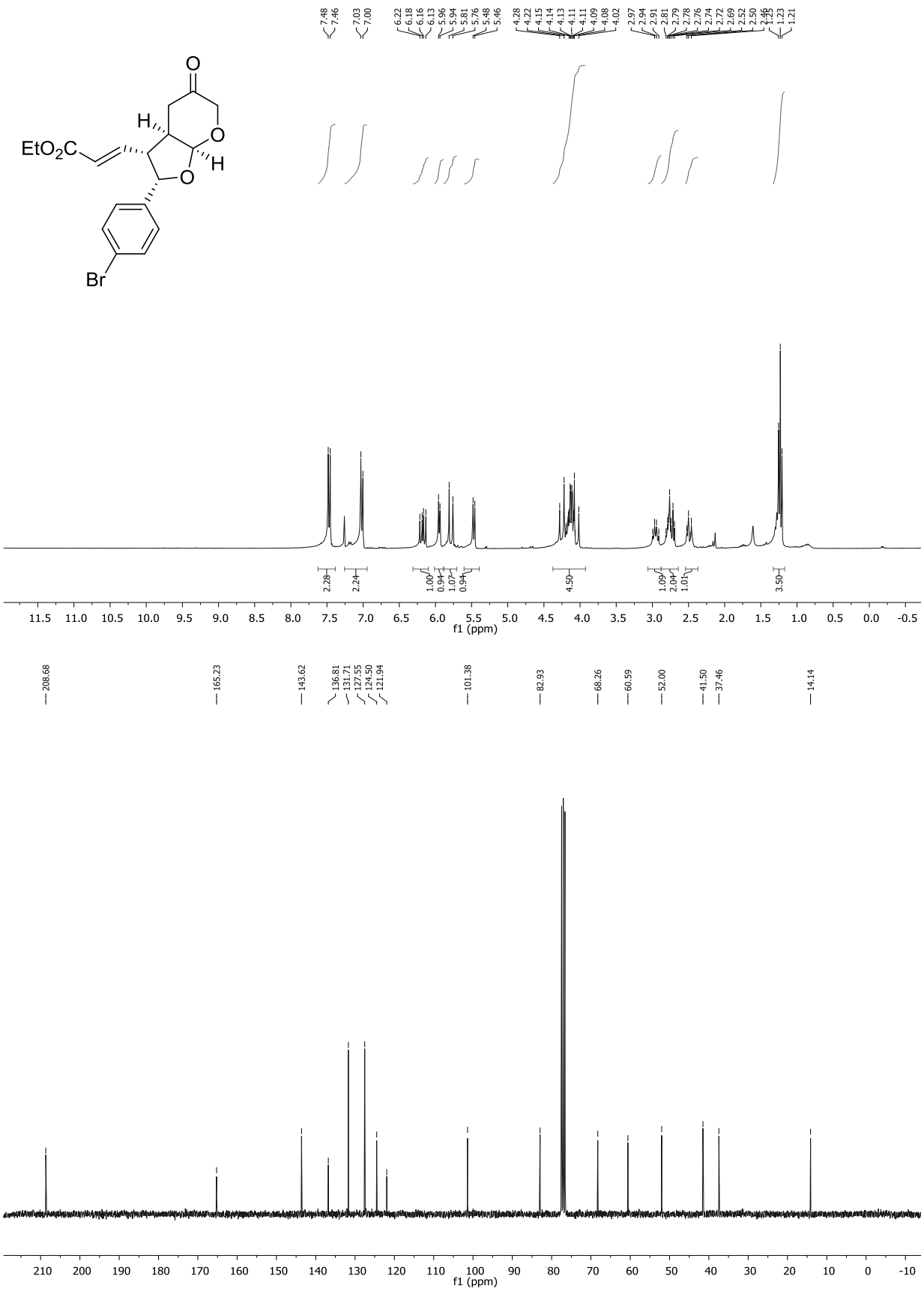


Figure ESI-47. NMR spectra of compound **8e**.

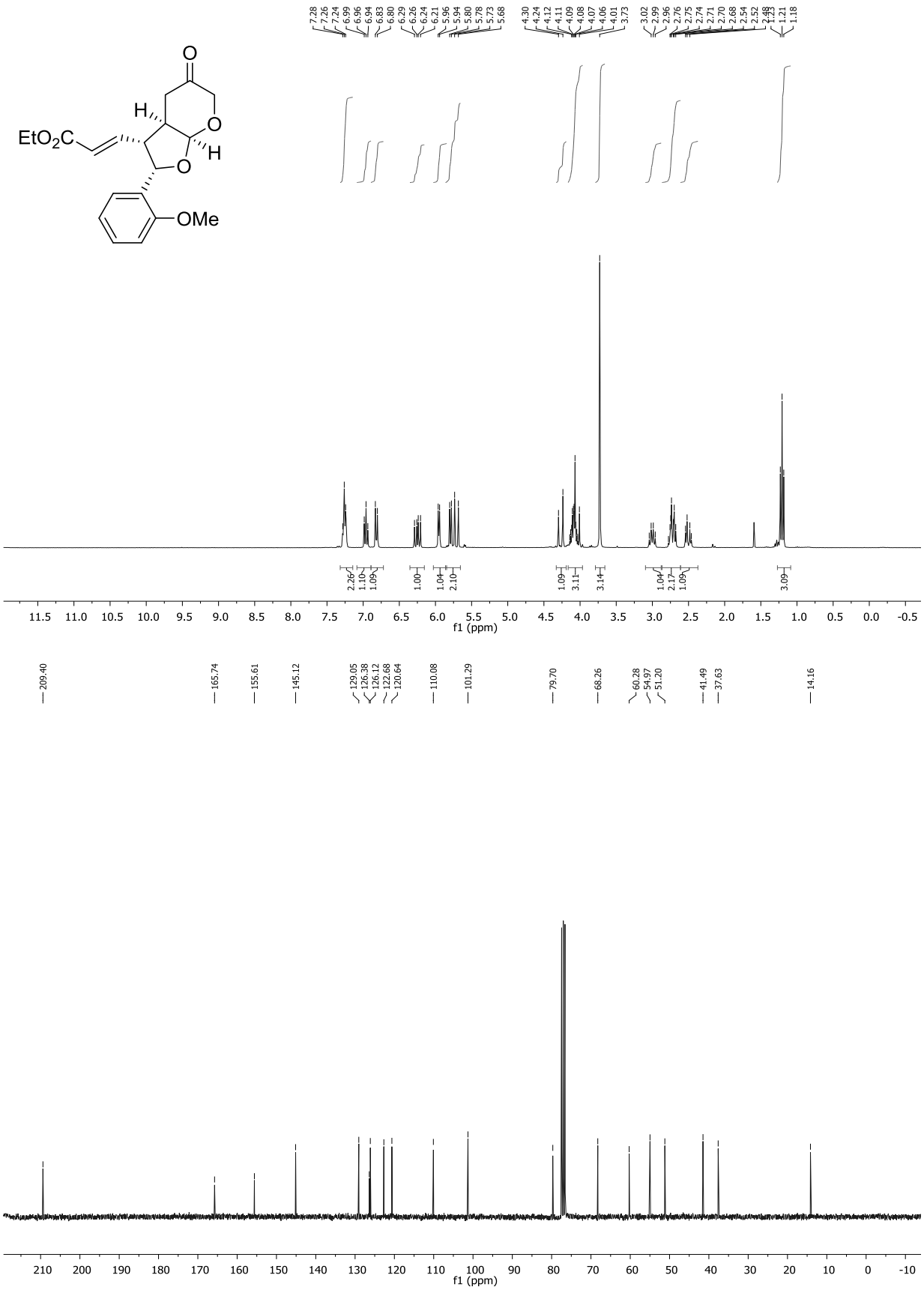


Figure ESI-48. NMR spectra of compound **8f**.

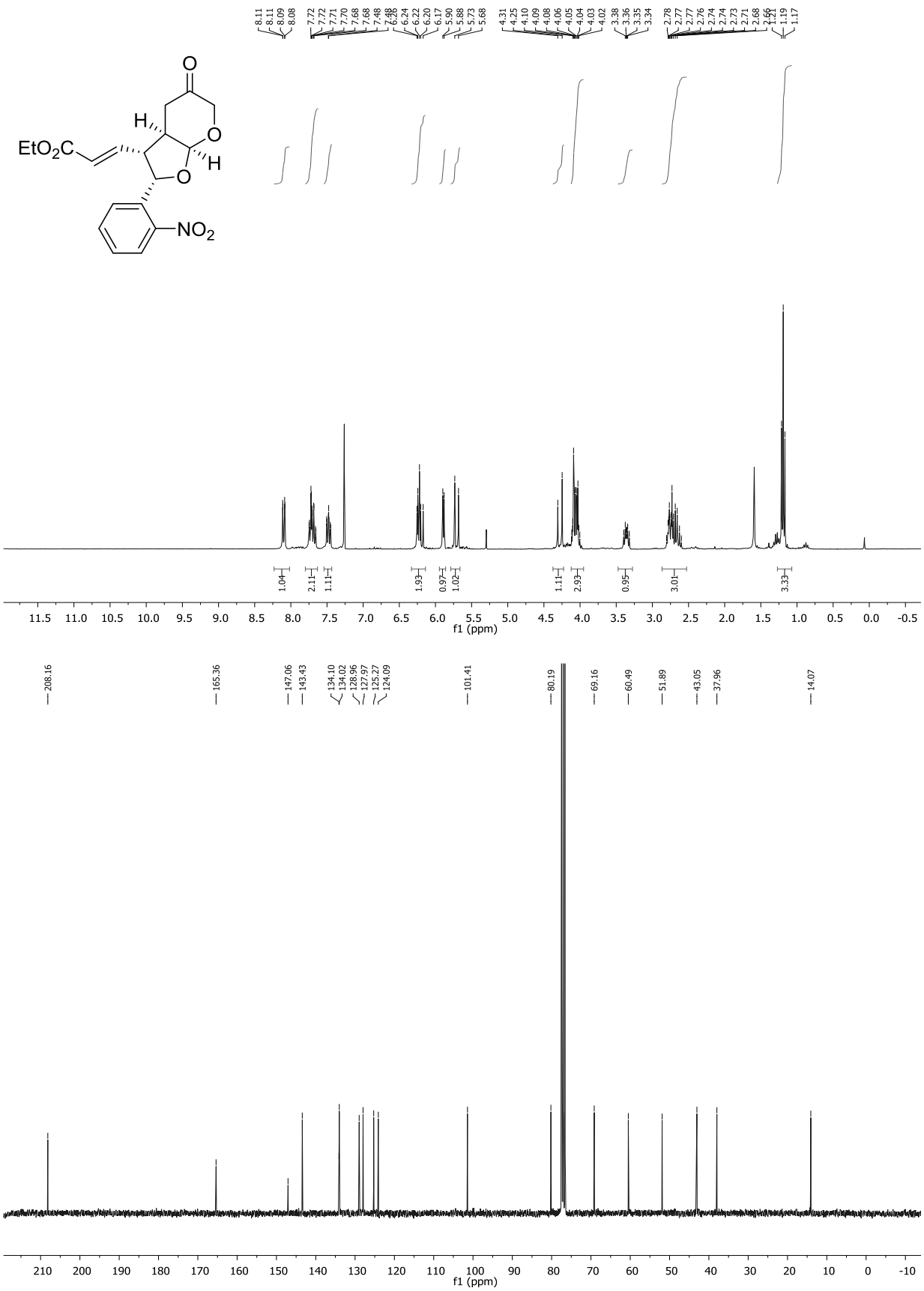


Figure ESI-49. NMR spectra of compound **8g**.

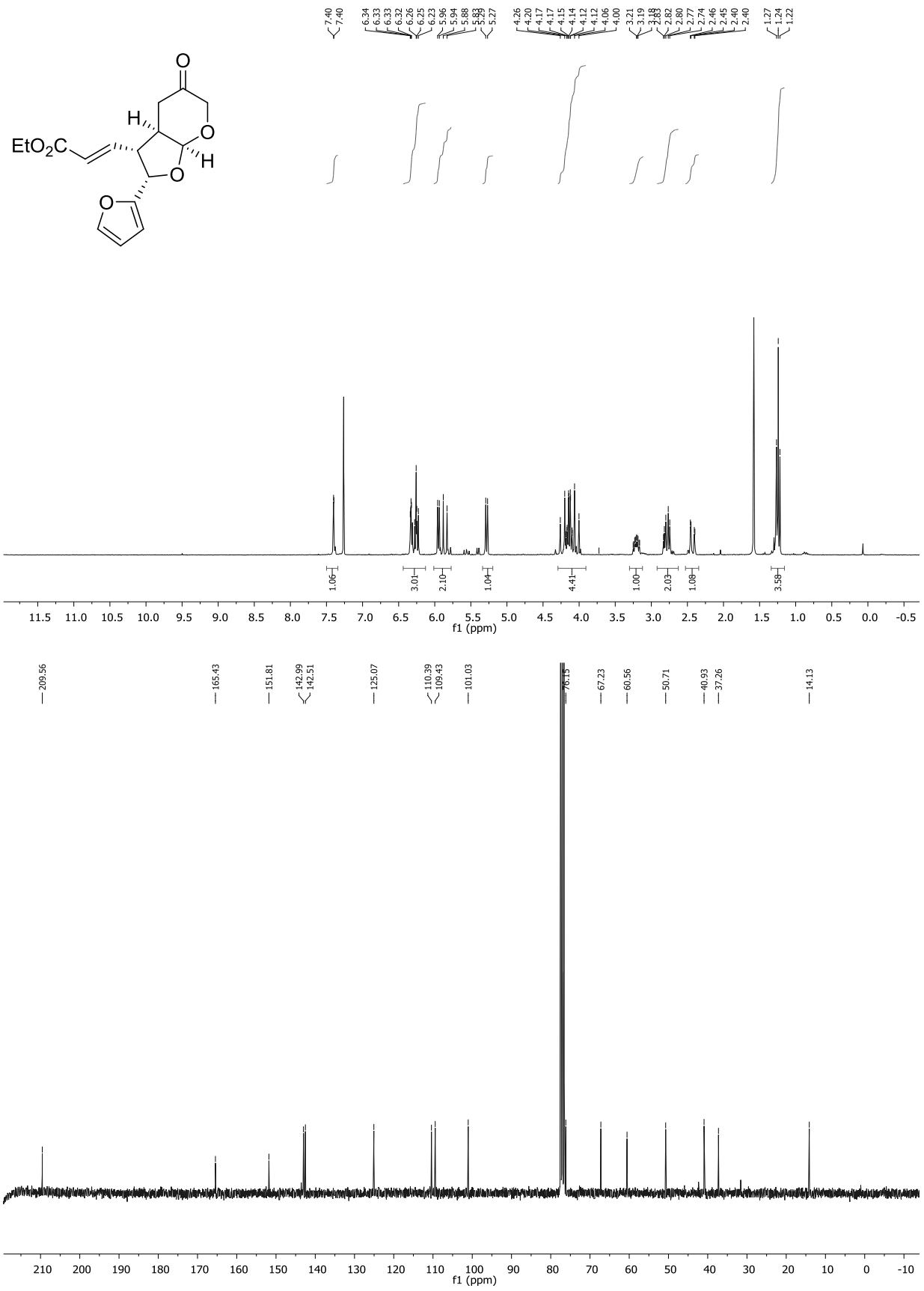


Figure ESI-50. NMR spectra of compound **8h**.

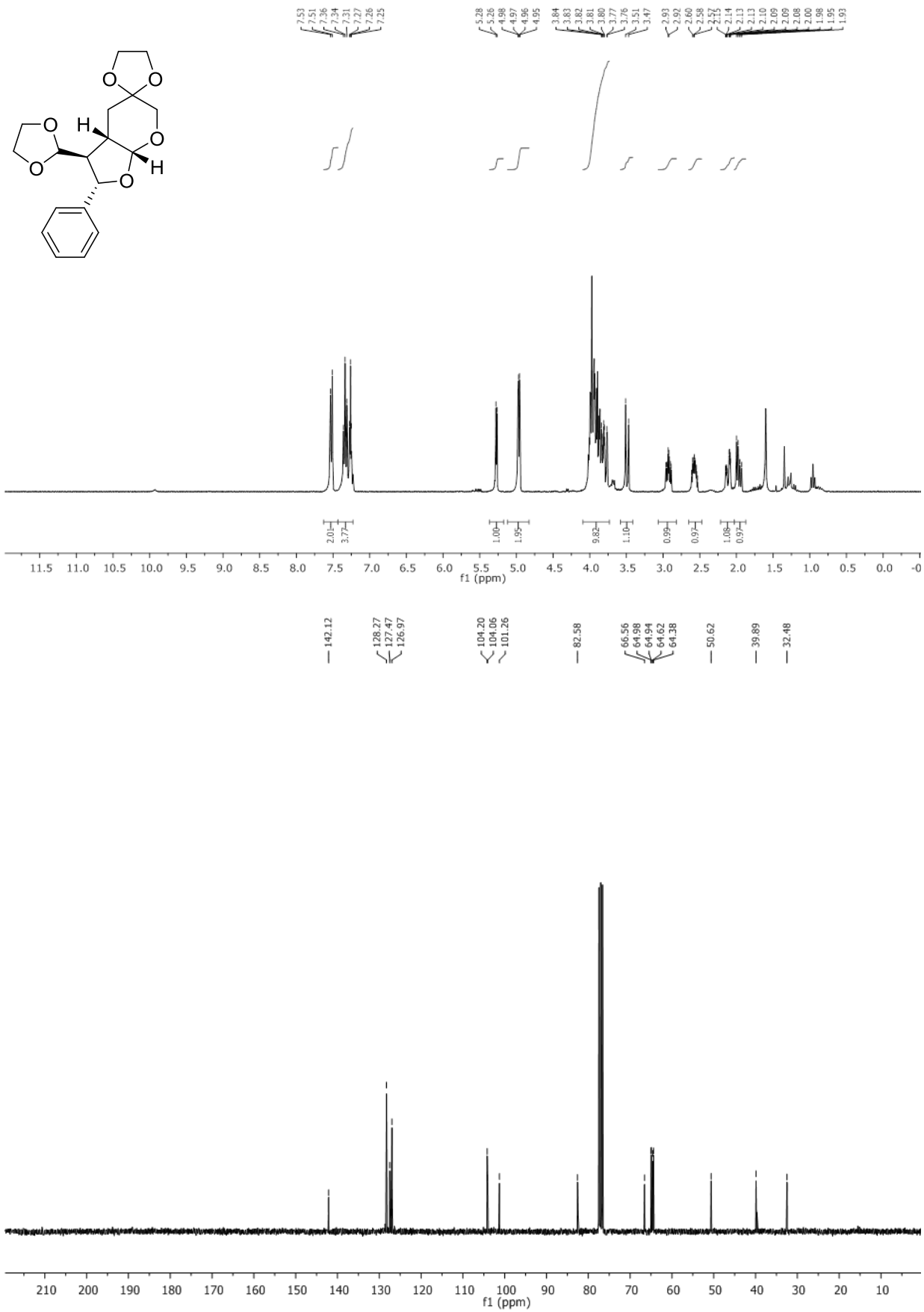


Figure ESI-51. NMR spectra of compound **9a**.

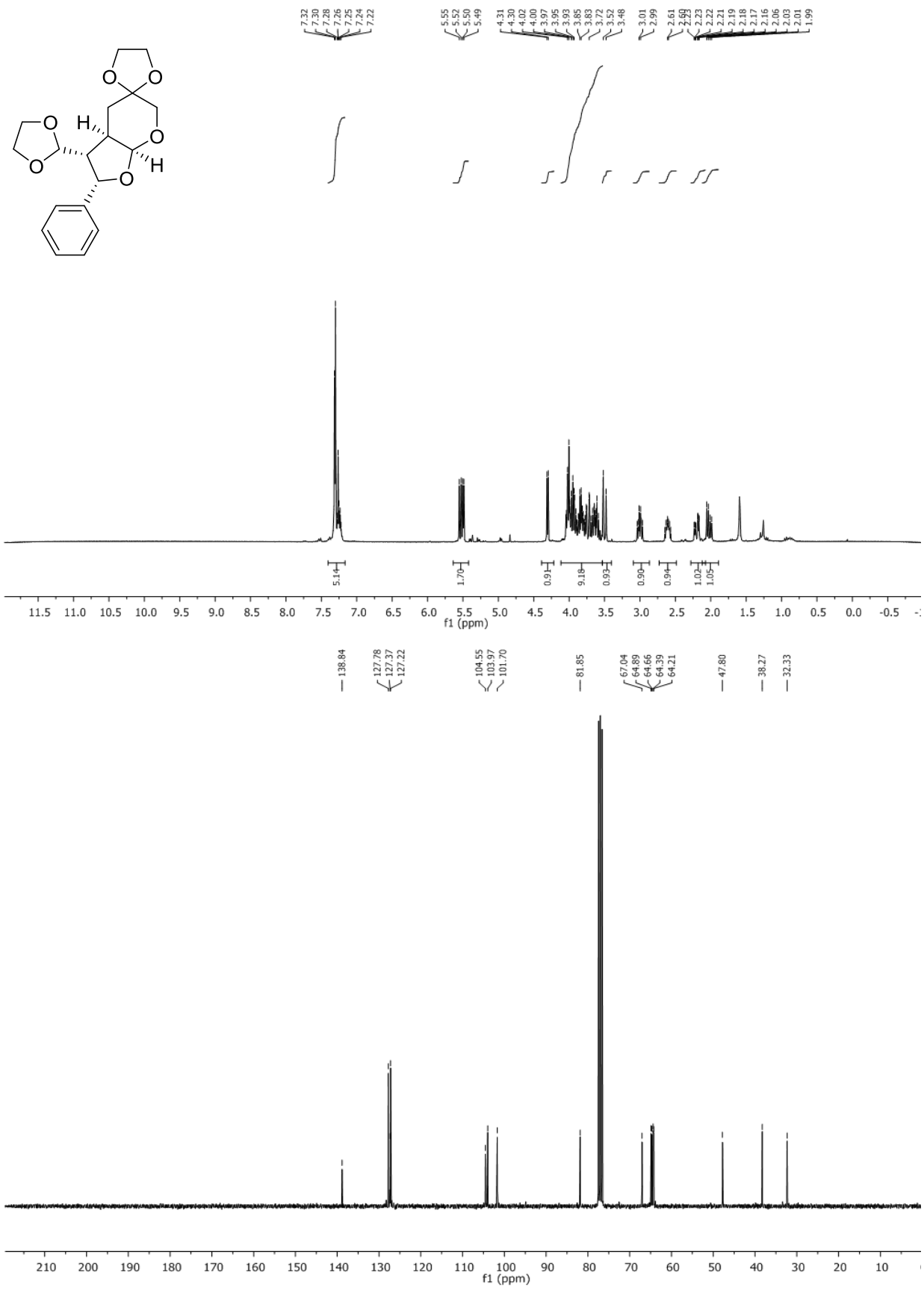


Figure ESI-52. NMR spectra of compound **10a**.

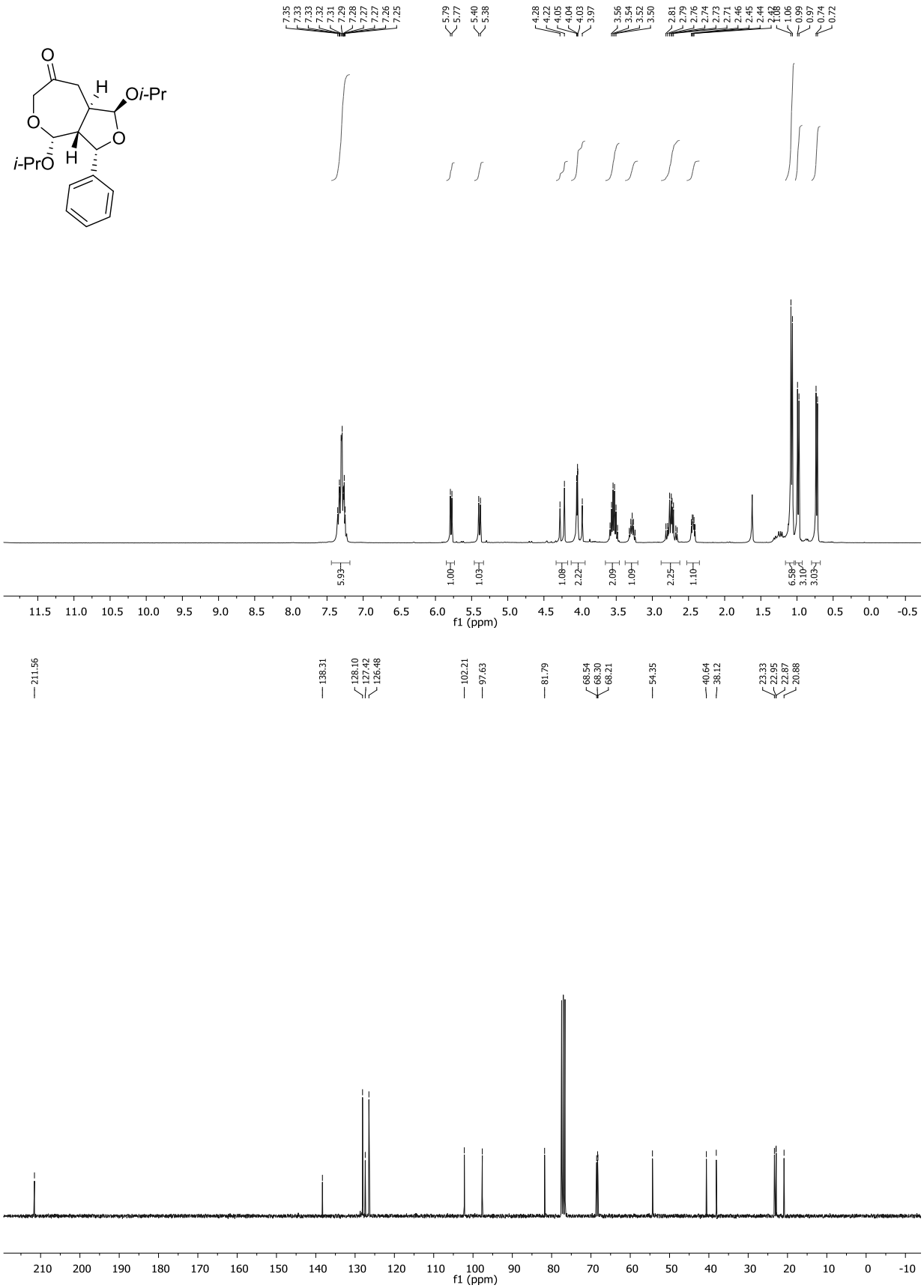


Figure ESI-53. NMR spectra of compound **11a**.

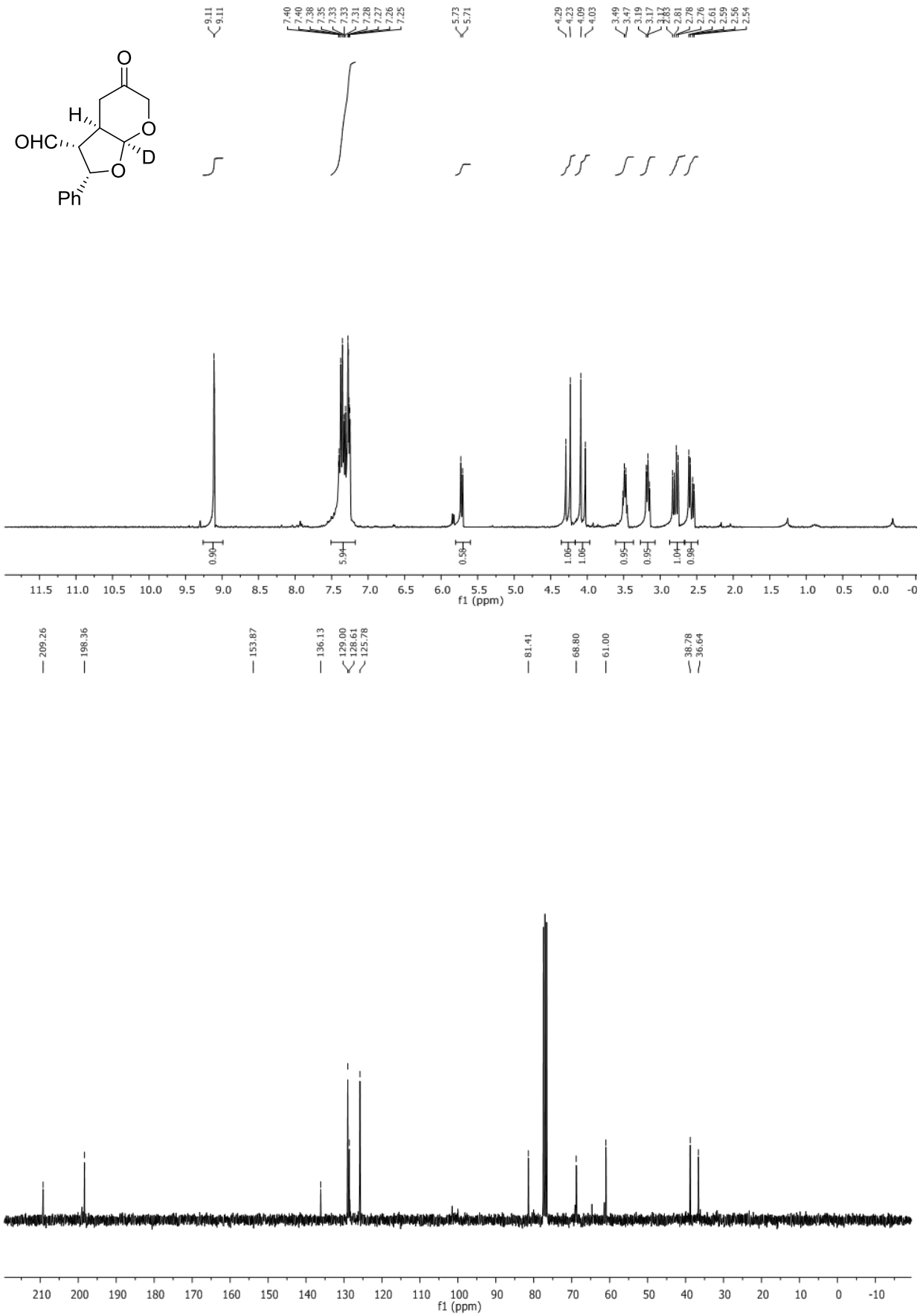


Figure ESI-54. NMR spectra of compound **6a-^{2}H**.

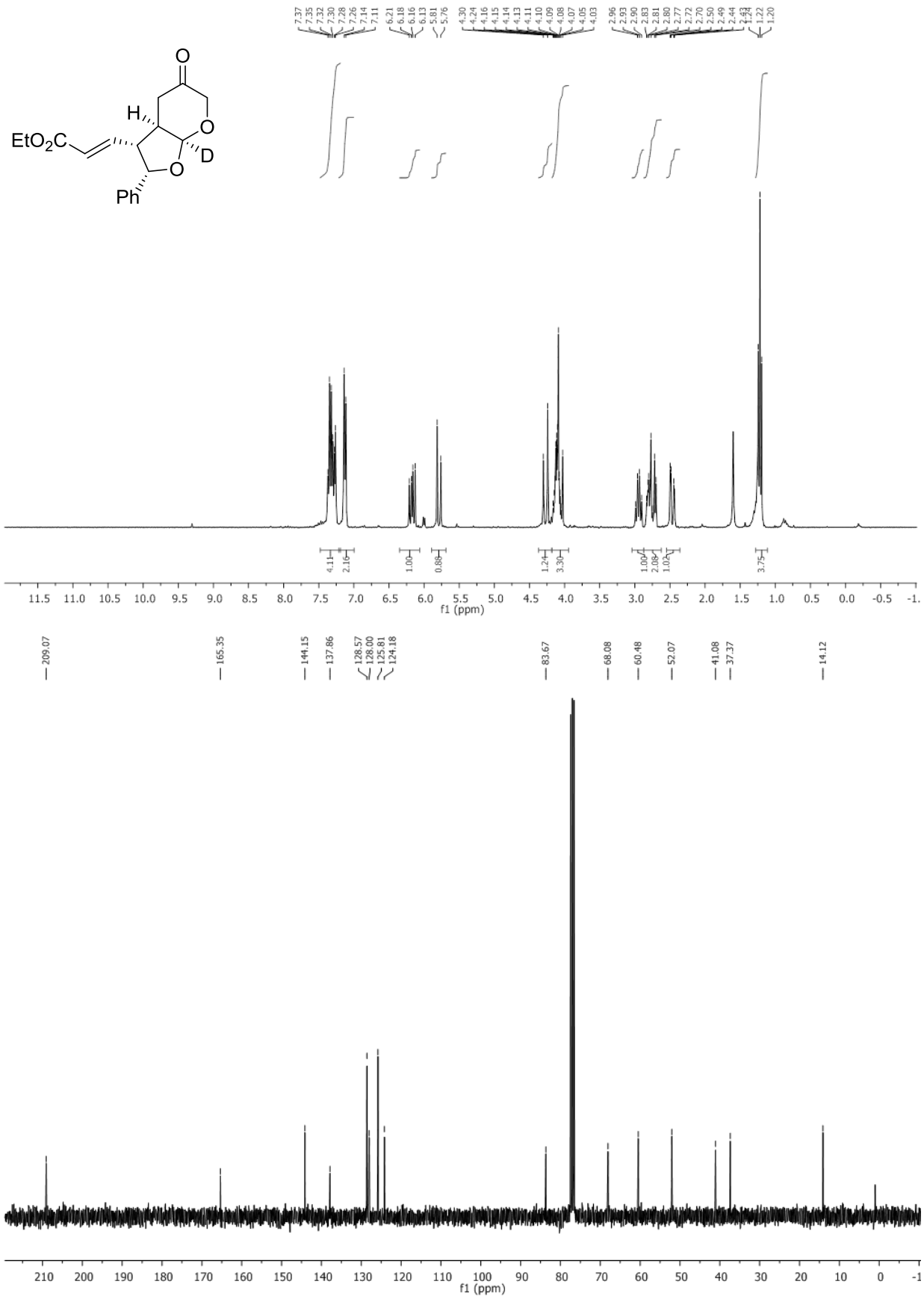


Figure ESI-55. NMR spectra of compound **8a-^{2}H**.

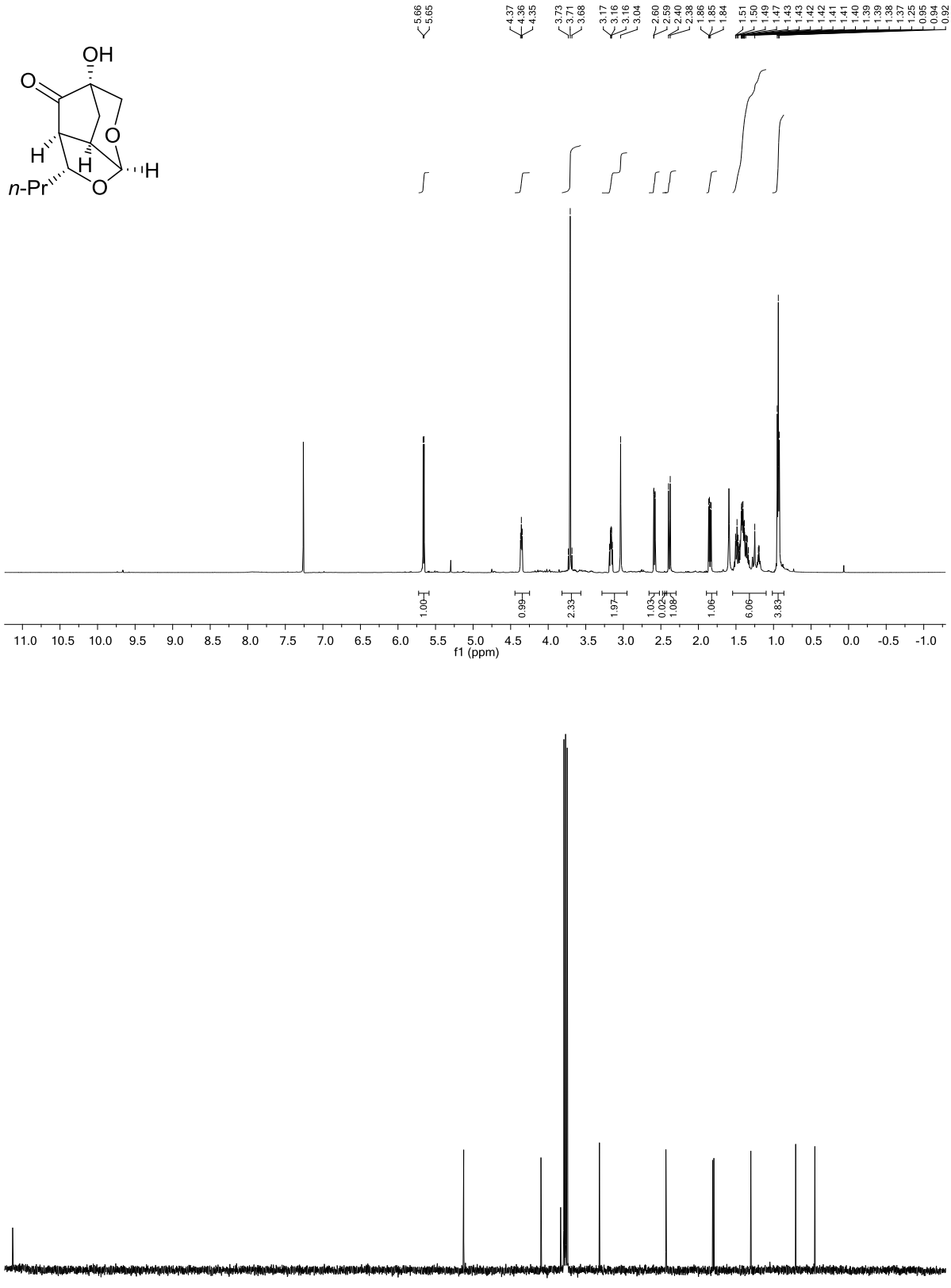
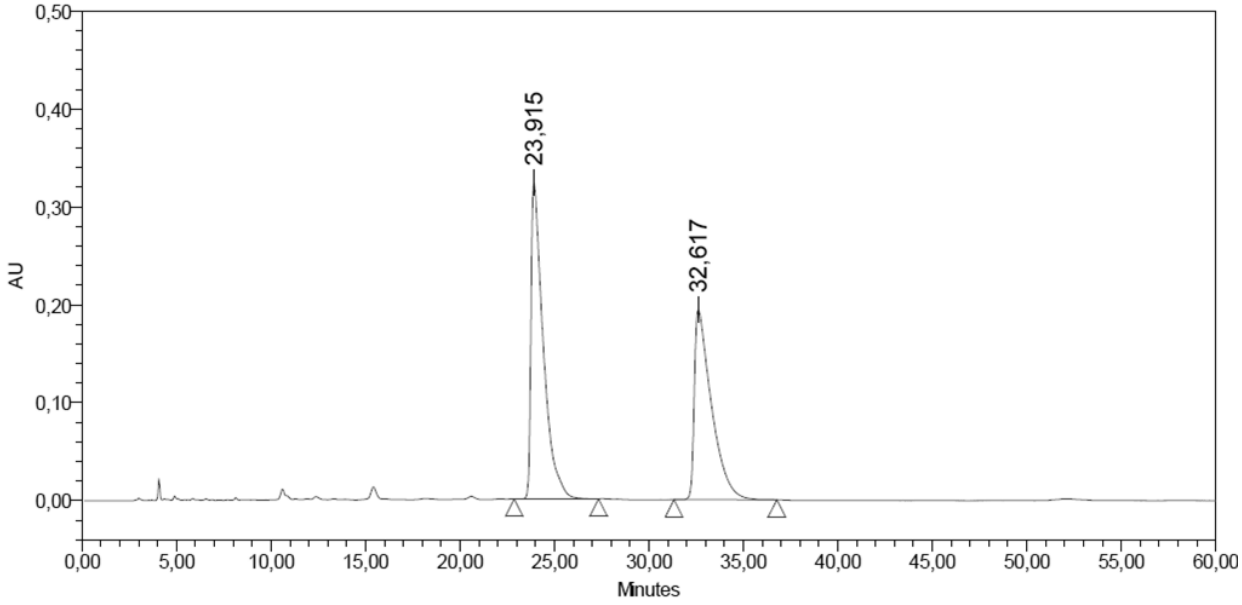
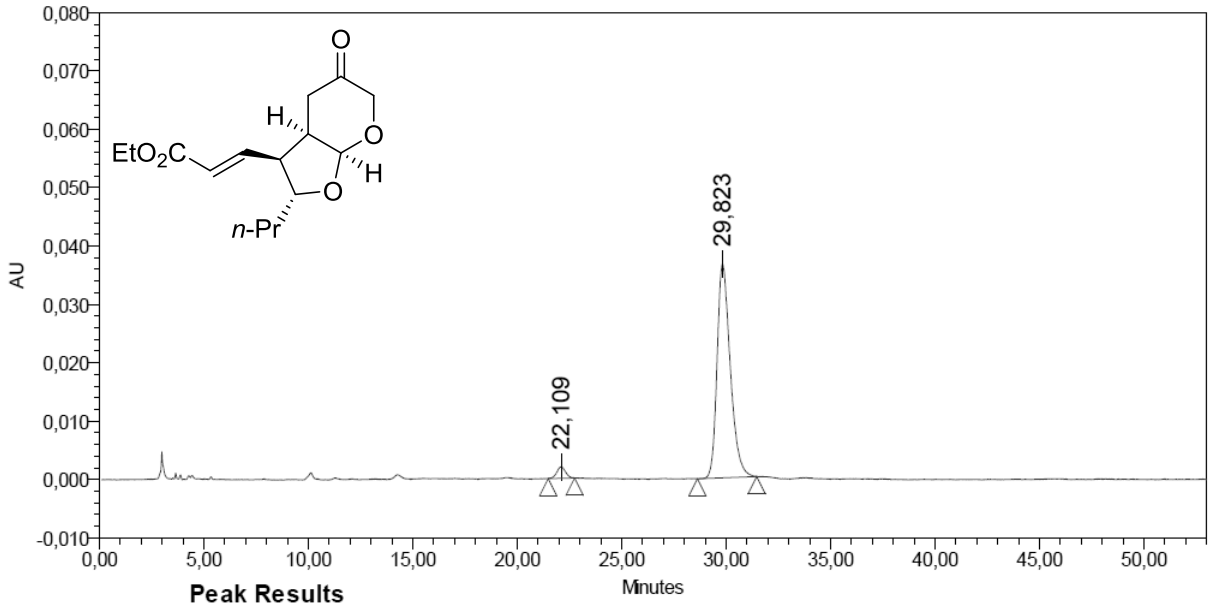


Figure ESI-56. NMR spectra of compound **12k**.

6. HPLC Traces

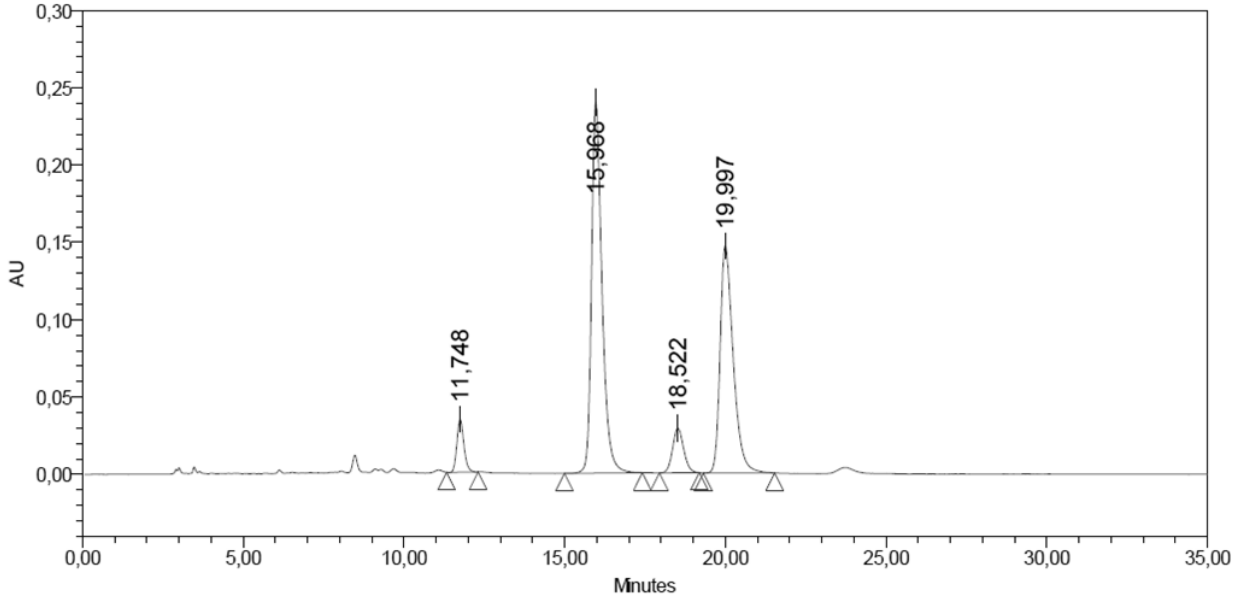


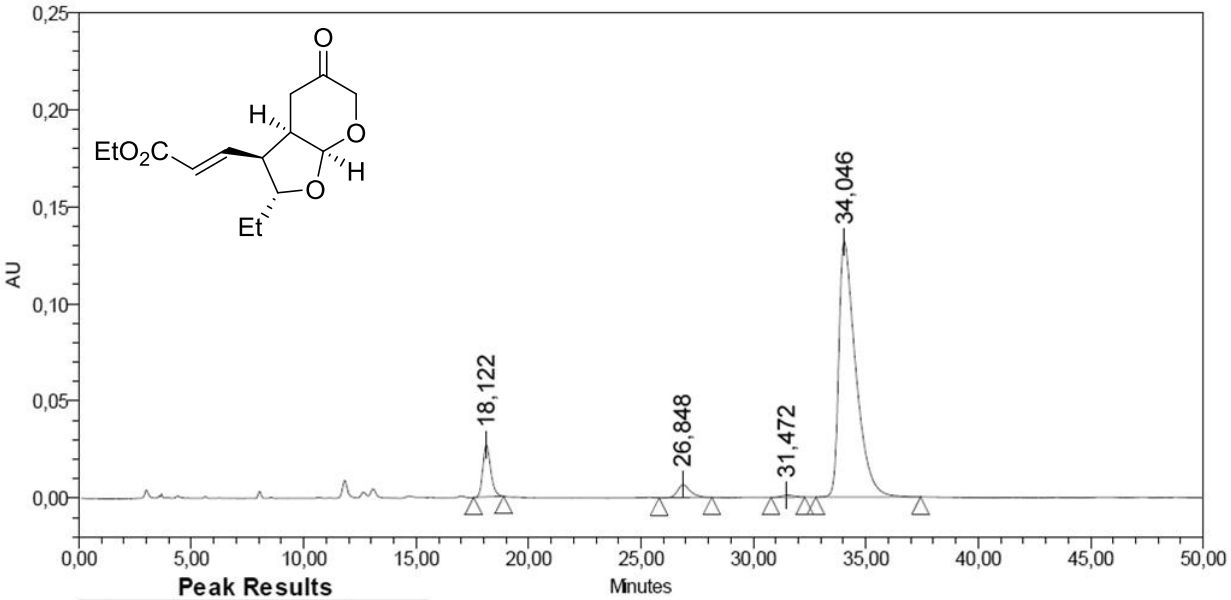


Peak Results

	RT	Area	Height	% Area
1	22,109	56708	1973	3,41
2	29,823	1606265	36632	96,59

Figure ESI-57. HPLC traces of compound **7i**.

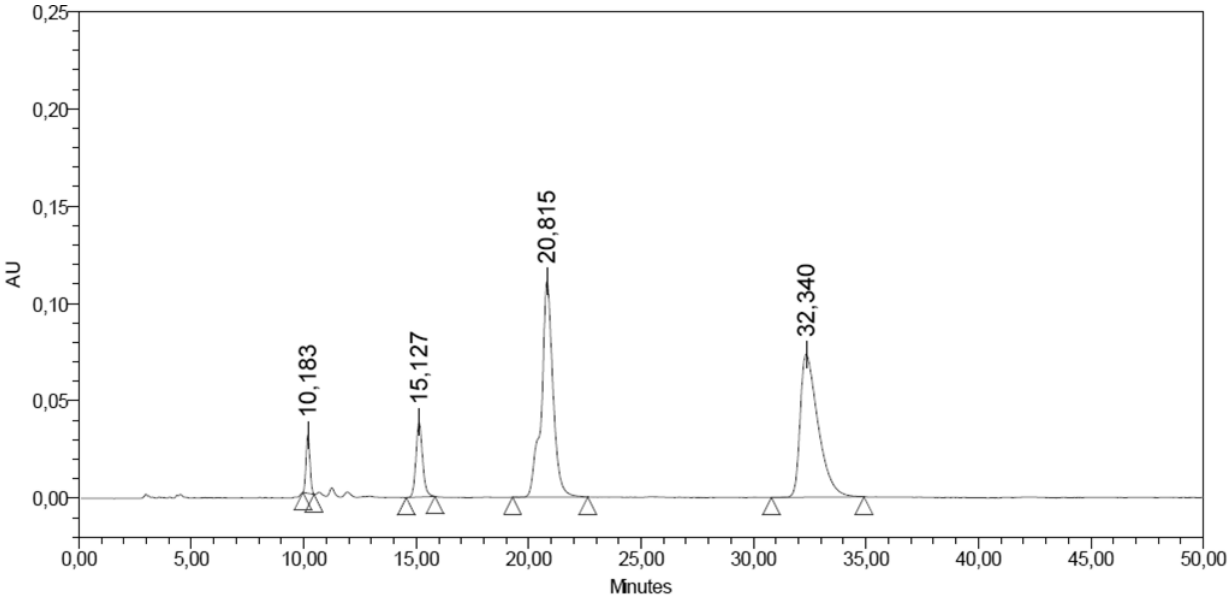


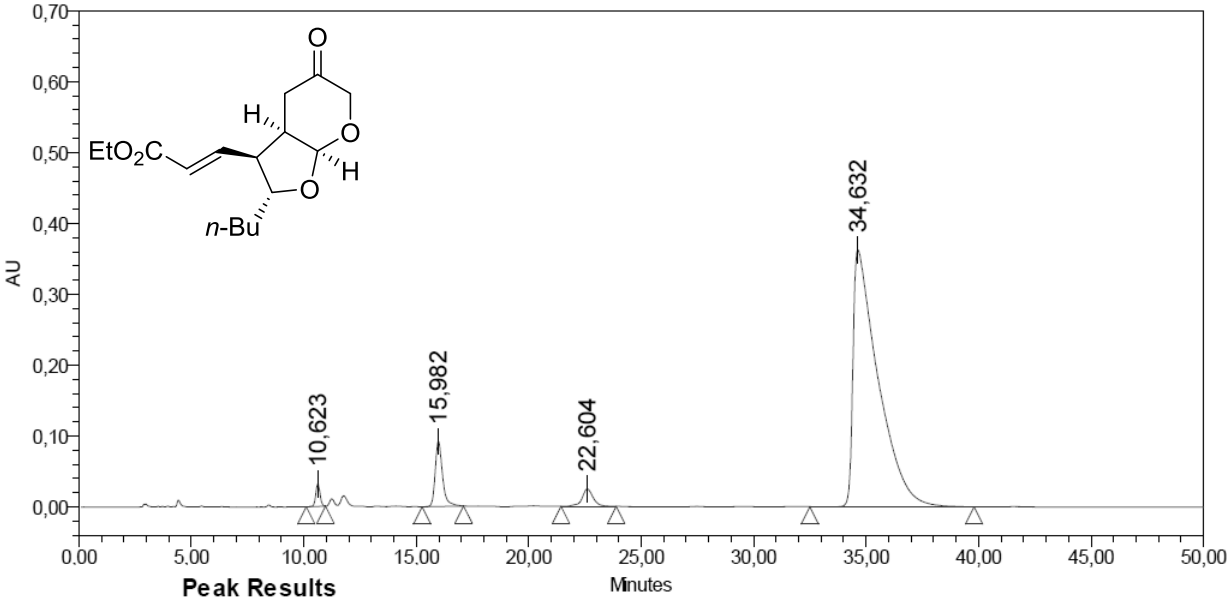


Peak Results

	RT	Area	Height	% Area
1	18,122	659880	26833	8,41
2	26,848	259269	6593	3,31
3	31,472	40004	1052	0,51
4	34,046	6882570	131498	87,77

Figure ESI-58. HPLC traces of compound **7j**.

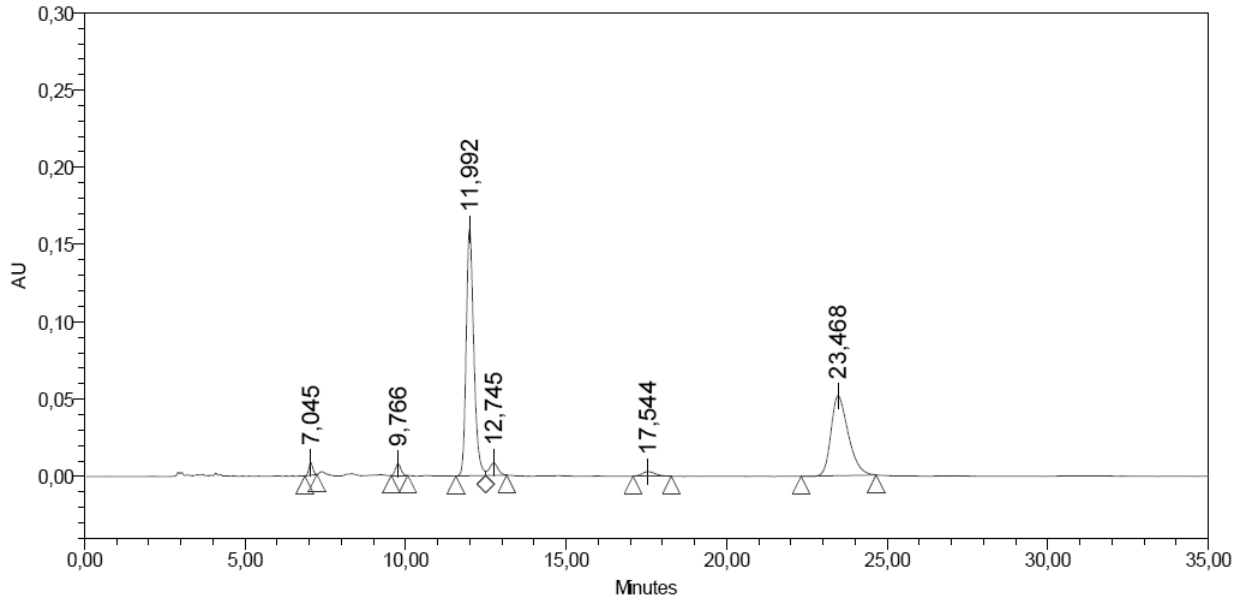


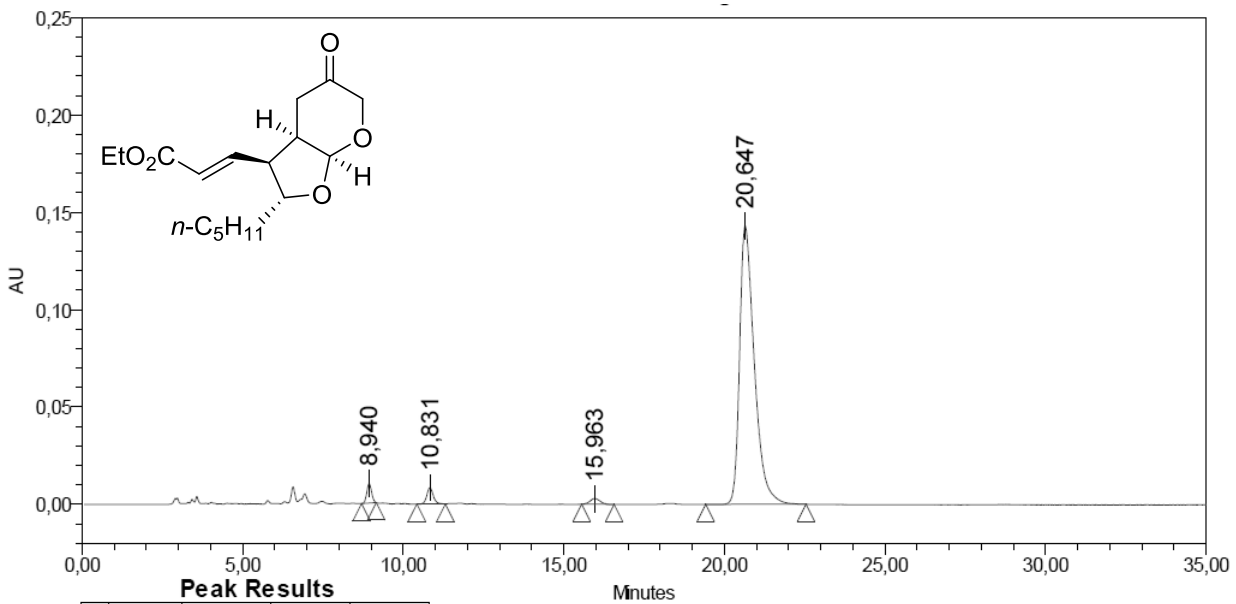


Peak Results

	RT	Area	Height	% Area
1	10,623	421241	31817	1,34
2	15,982	2067112	91694	6,58
3	22,604	840732	24610	2,68
4	34,632	28073280	362256	89,40

Figure ESI-59. HPLC traces of compound **7k**.

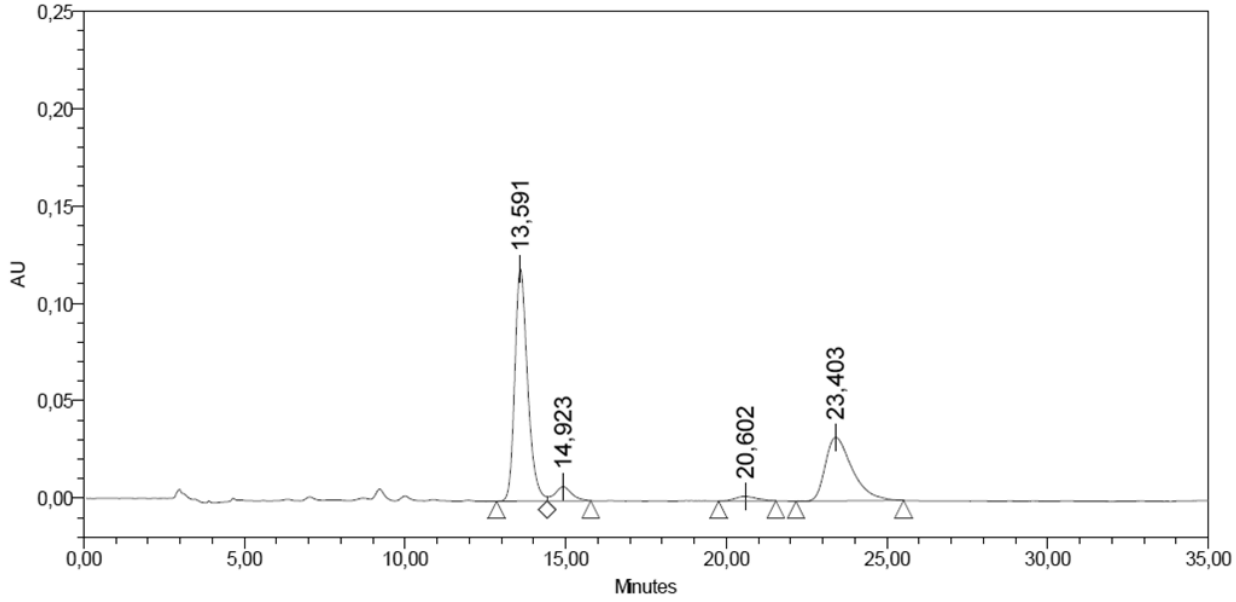


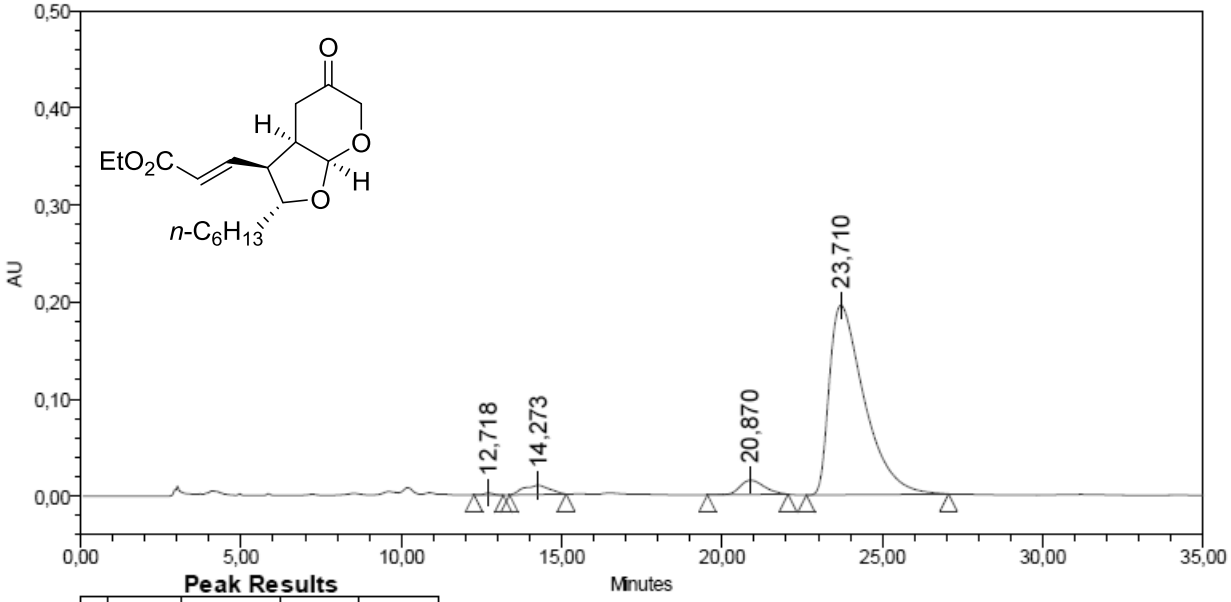


Peak Results

	RT	Area	Height	% Area
1	8,940	104356	9958	2,16
2	10,831	116105	8346	2,40
3	15,963	64019	2931	1,32
4	20,647	4549104	142873	94,11

Figure ESI-60. HPLC traces of compound **7l**.

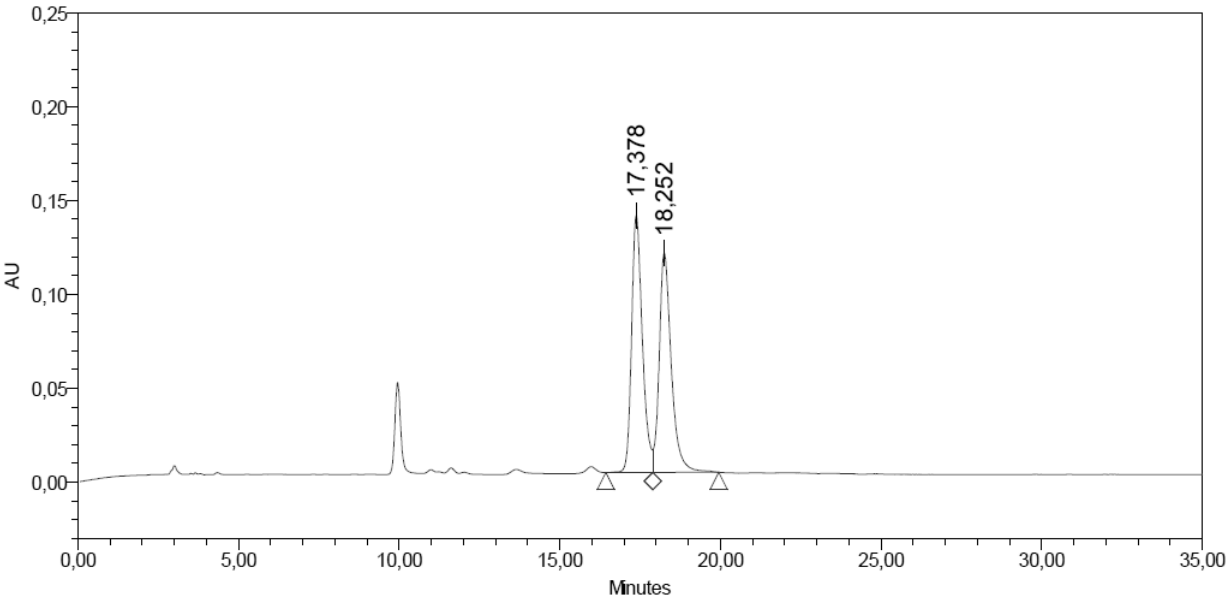


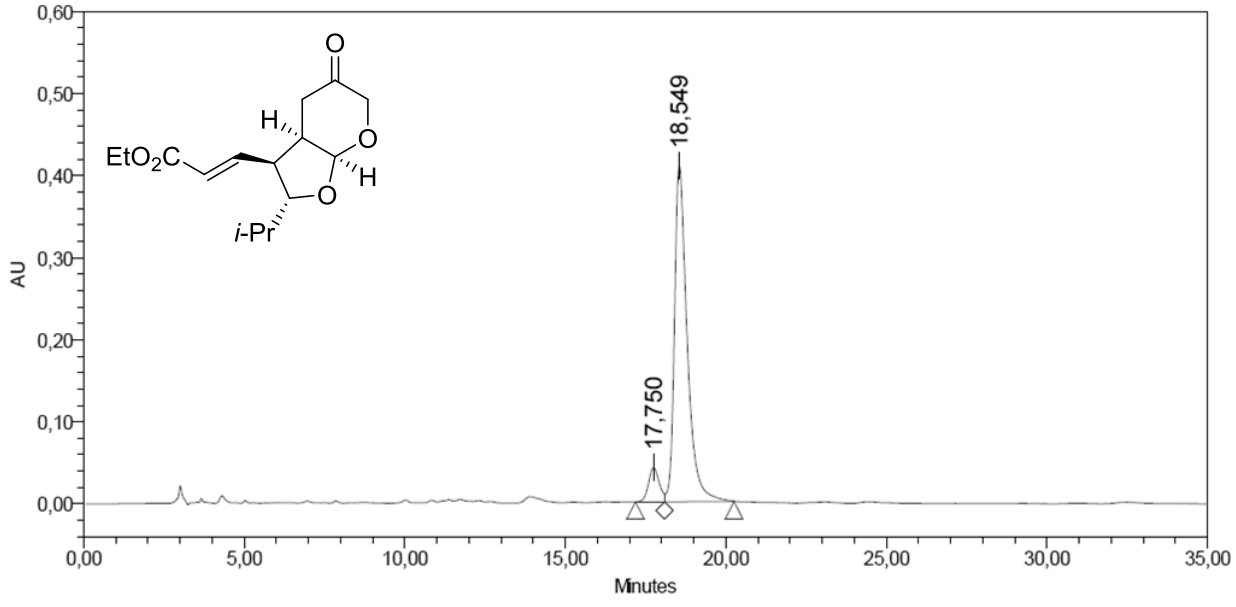


Peak Results

	RT	Area	Height	% Area
1	12,718	37128	2080	0,23
2	14,273	531150	9387	3,29
3	20,870	769935	14656	4,77
4	23,710	14816023	195333	91,72

Figure ESI-61. HPLC traces of compound **7m**.

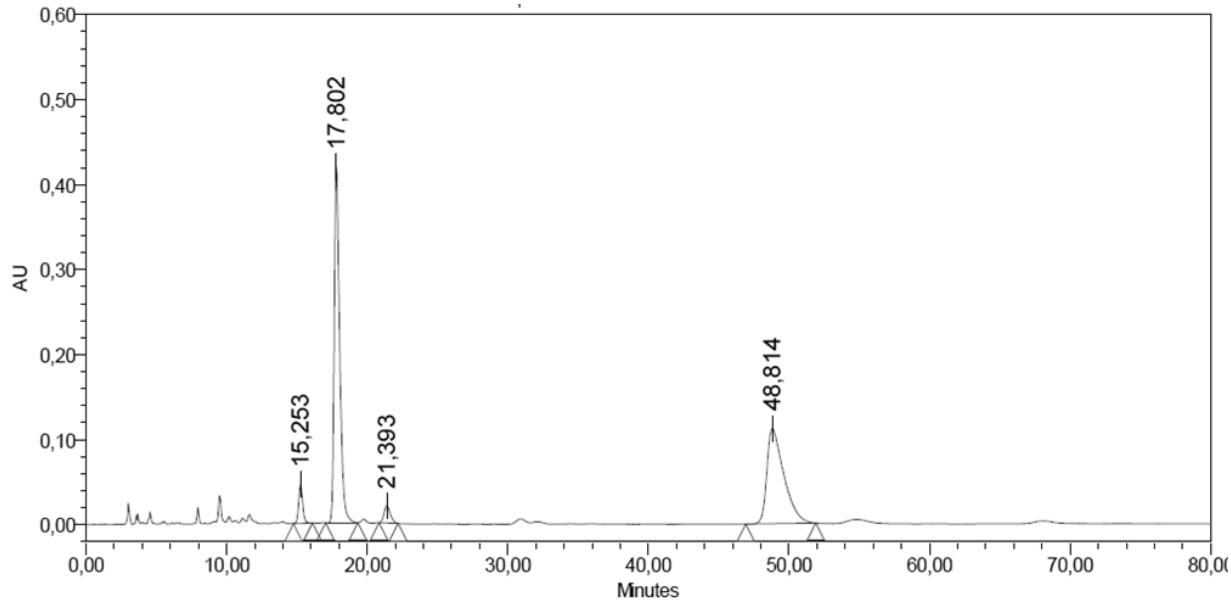


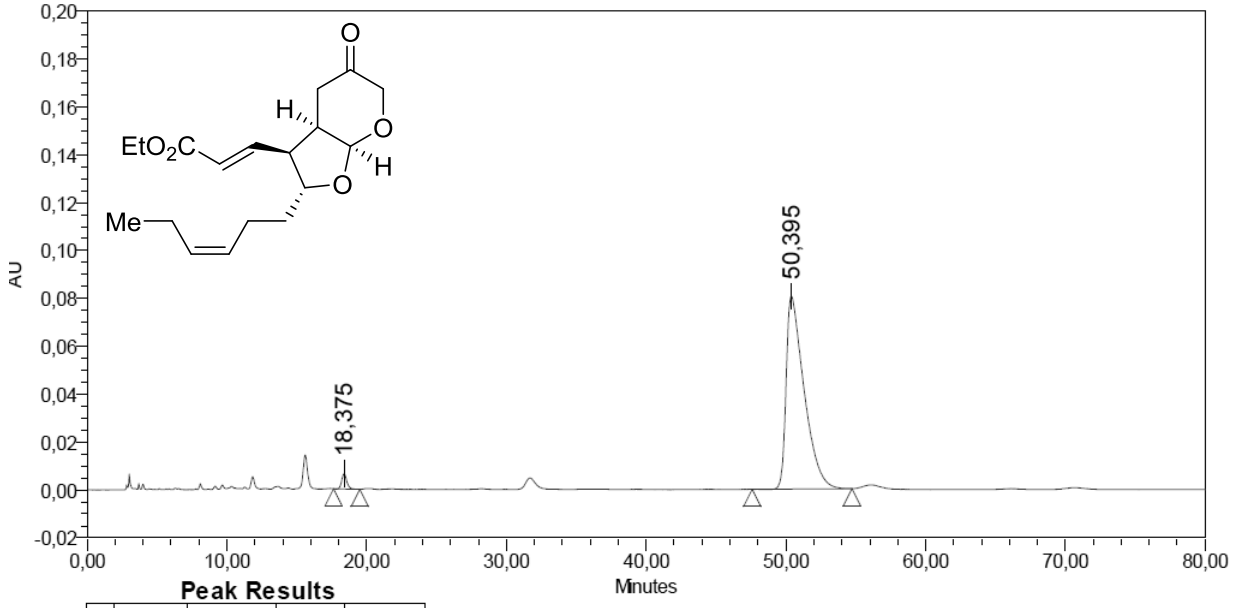


Peak Results

	RT	Area	Height	% Area
1	17,750	964456	41623	7,90
2	18,549	11244769	409480	92,10

Figure ESI-62. HPLC traces of compound **7n**.

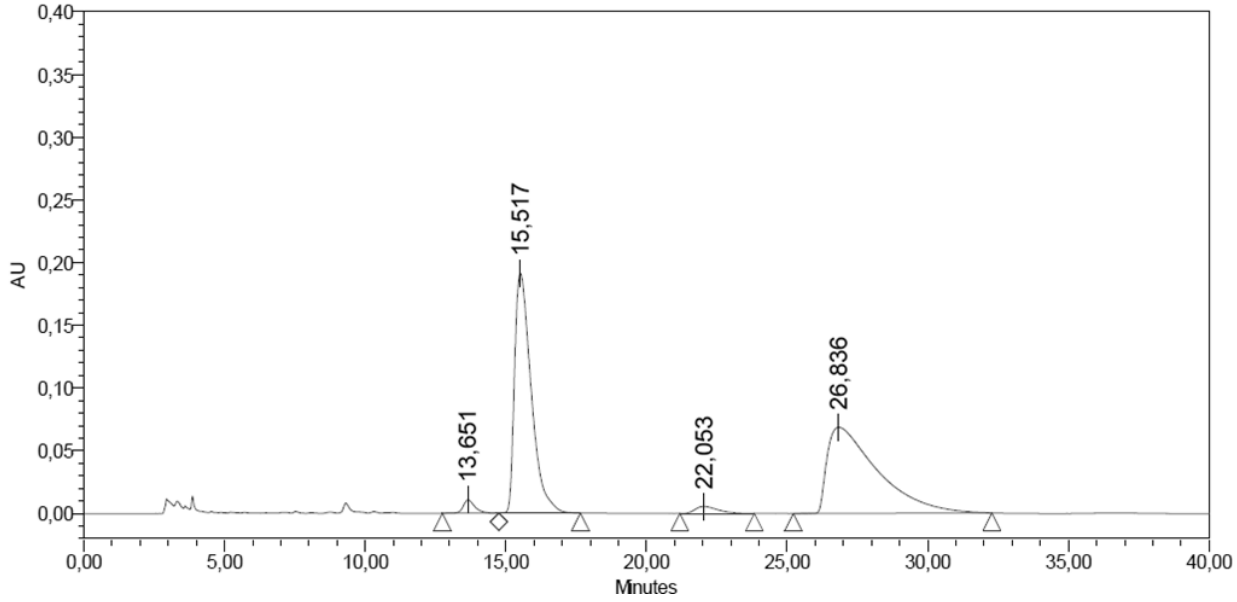


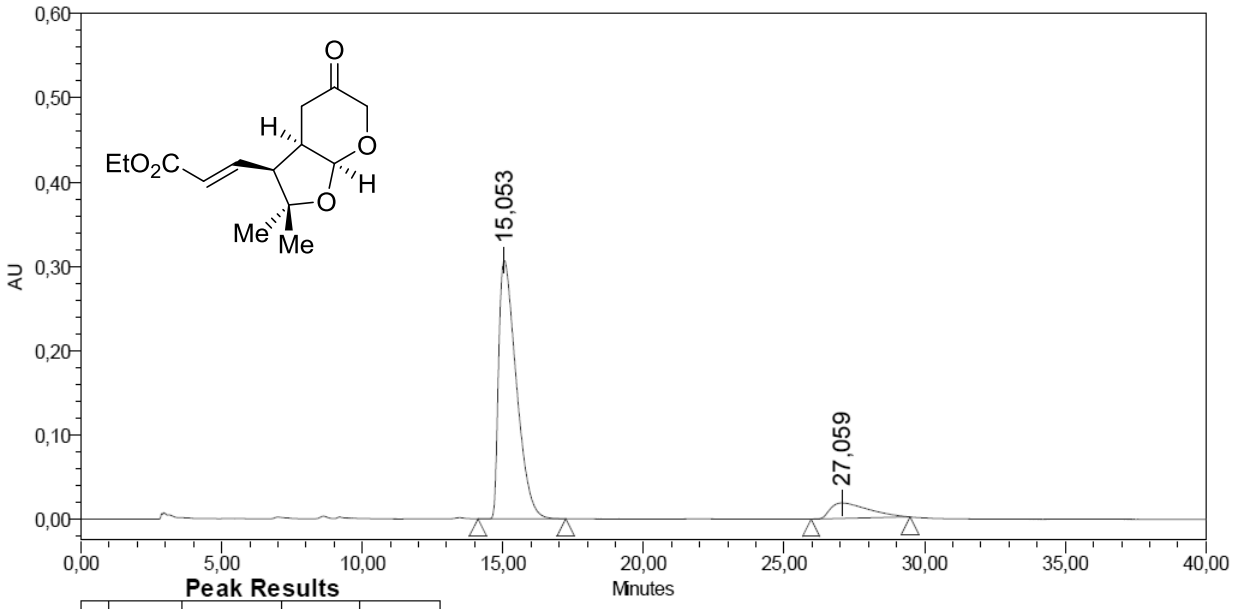


Peak Results

	RT	Area	Height	% Area
1	18,375	161960	6350	2,20
2	50,395	7186485	80584	97,80

Figure ESI-63. HPLC traces of compound **7o**.

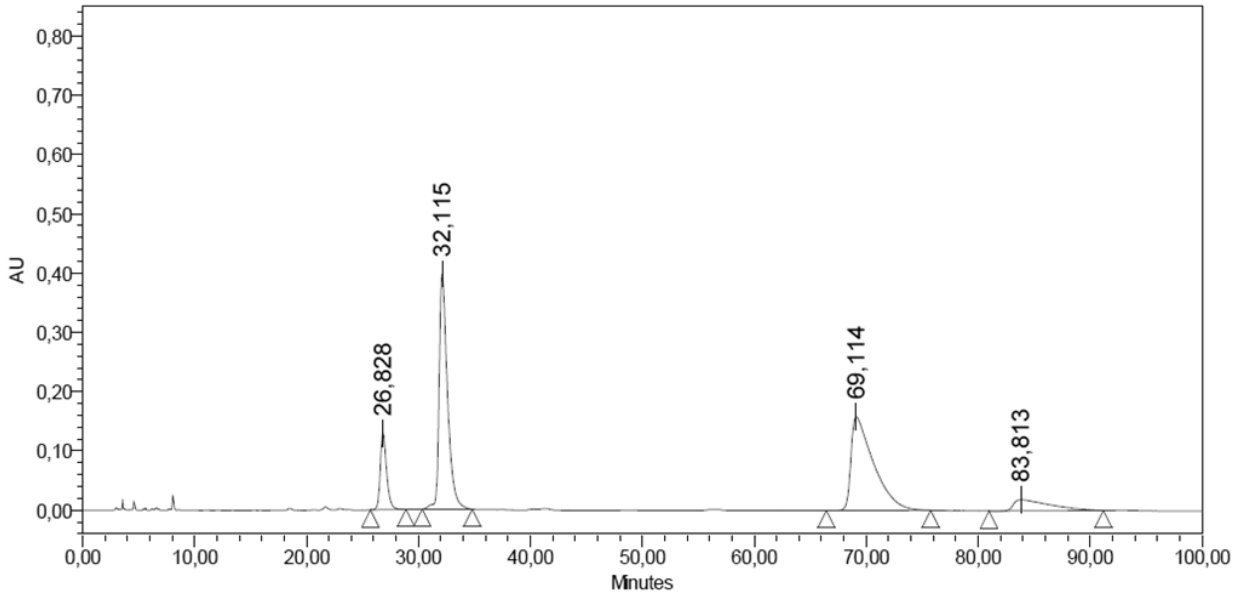


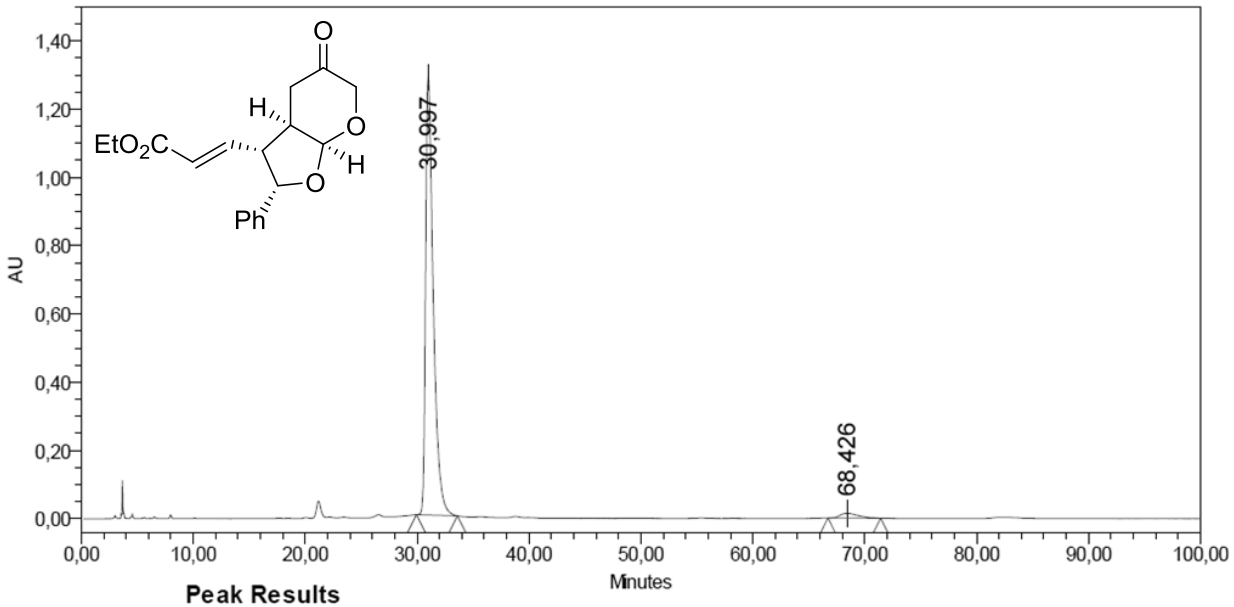


Peak Results

	RT	Area	Height	% Area
1	15,053	13381133	306897	88,60
2	27,059	1721729	18294	11,40

Figure ESI-64. HPLC traces of compound **7p**.

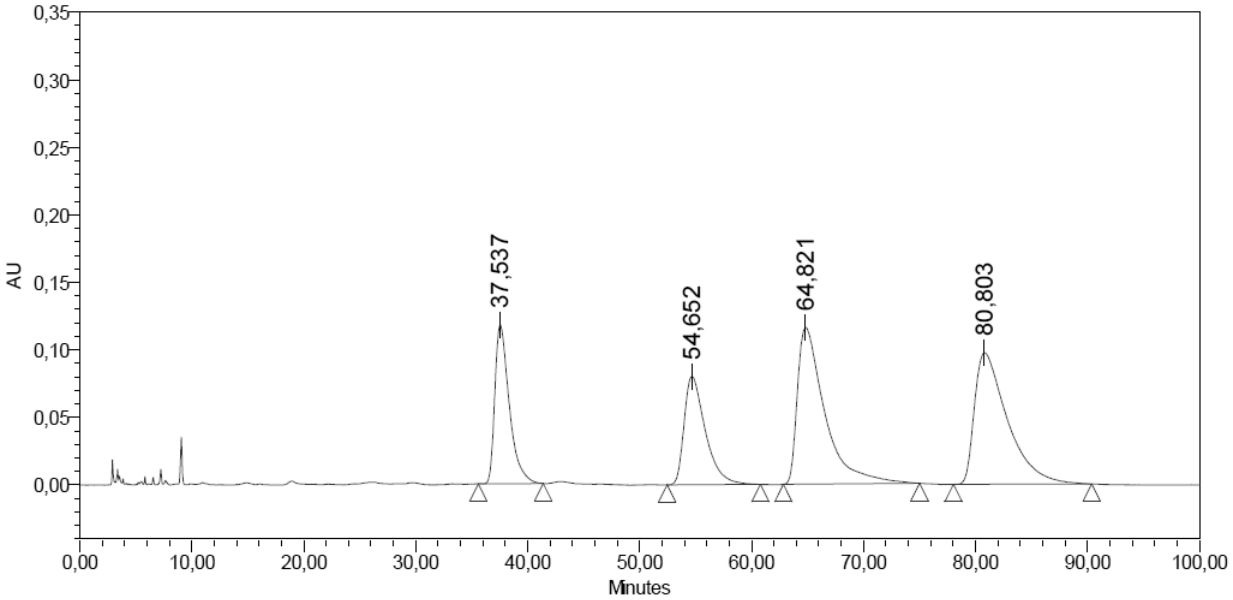


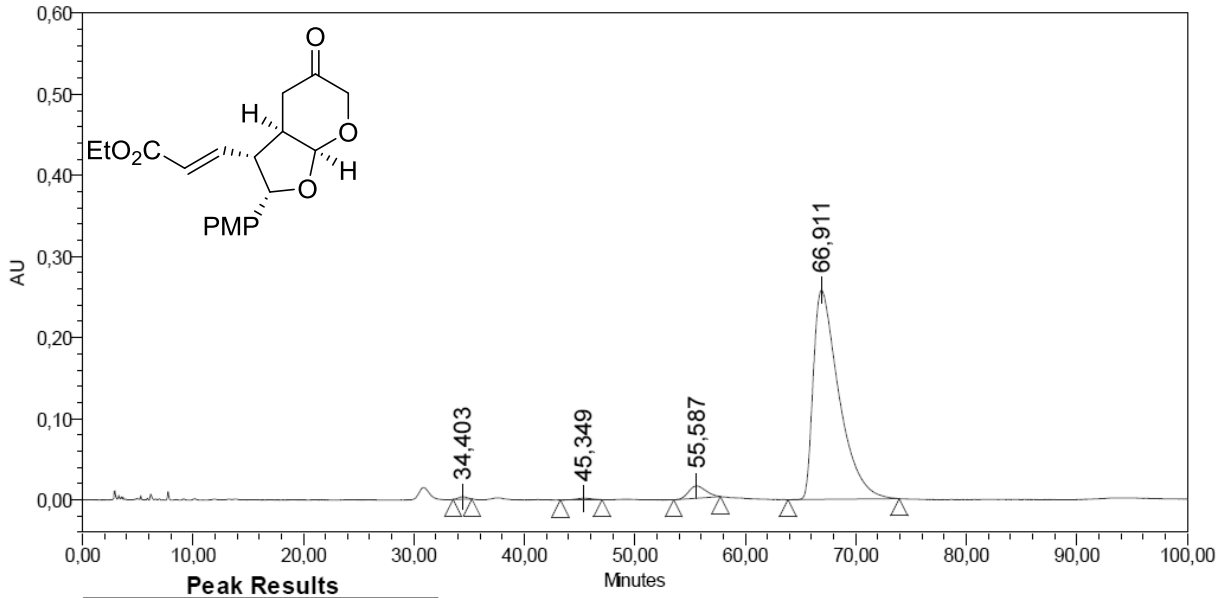


Peak Results

	RT	Area	Height	% Area
1	30,997	61141383	1283003	97,50
2	68,426	1568320	14107	2,50

Figure ESI-65. HPLC traces of compound **8a**.

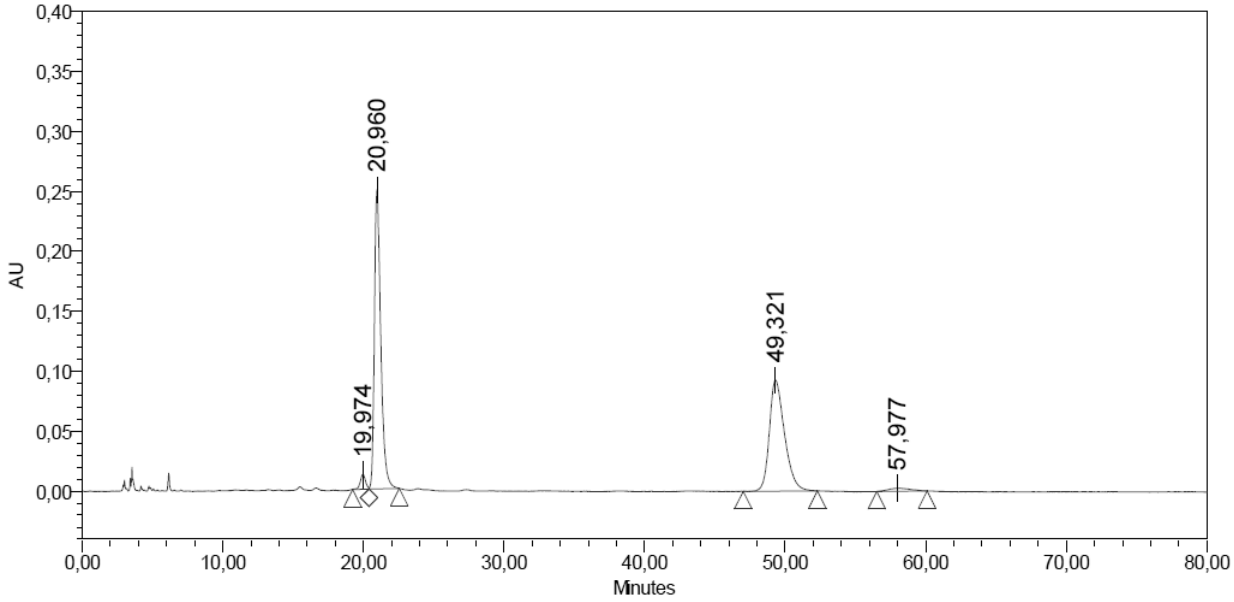


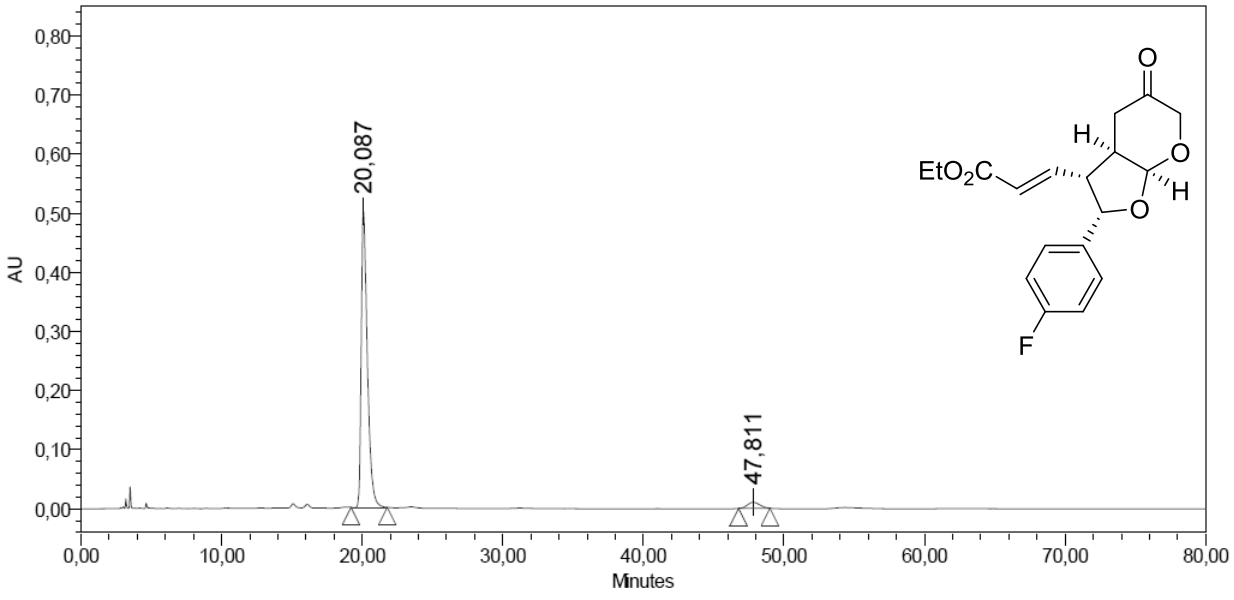


Peak Results

	RT	Area	Height	% Area
1	34,403	165084	3087	0,38
2	45,349	176229	1921	0,40
3	55,587	1627295	15096	3,74
4	66,911	41580164	257867	95,48

Figure ESI-66. HPLC traces of compound **8b**.

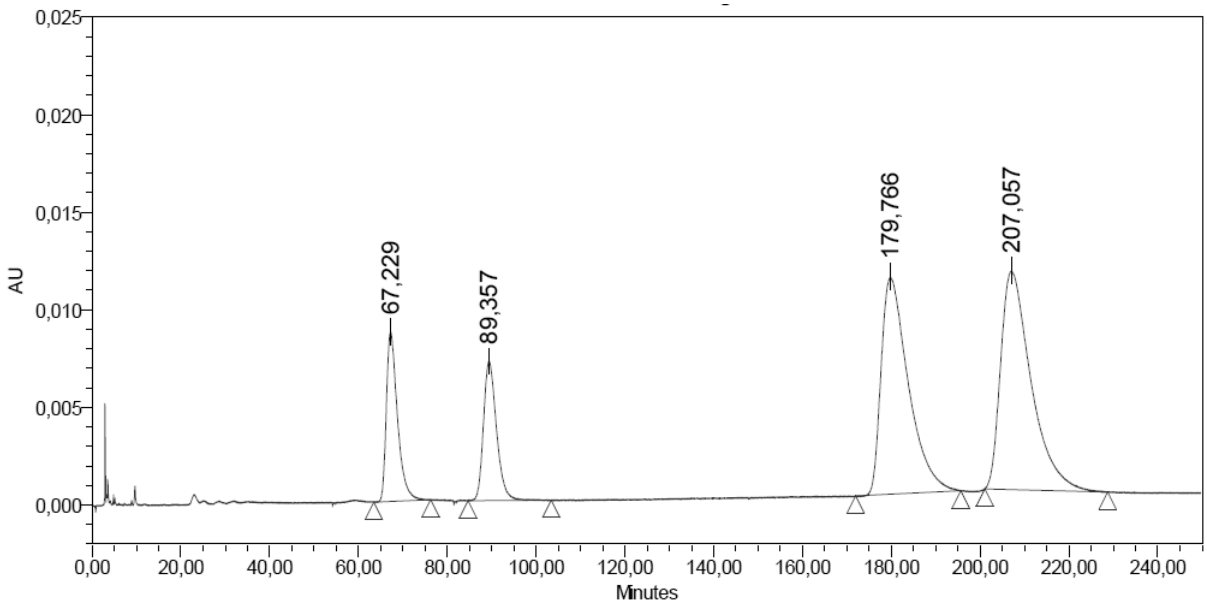


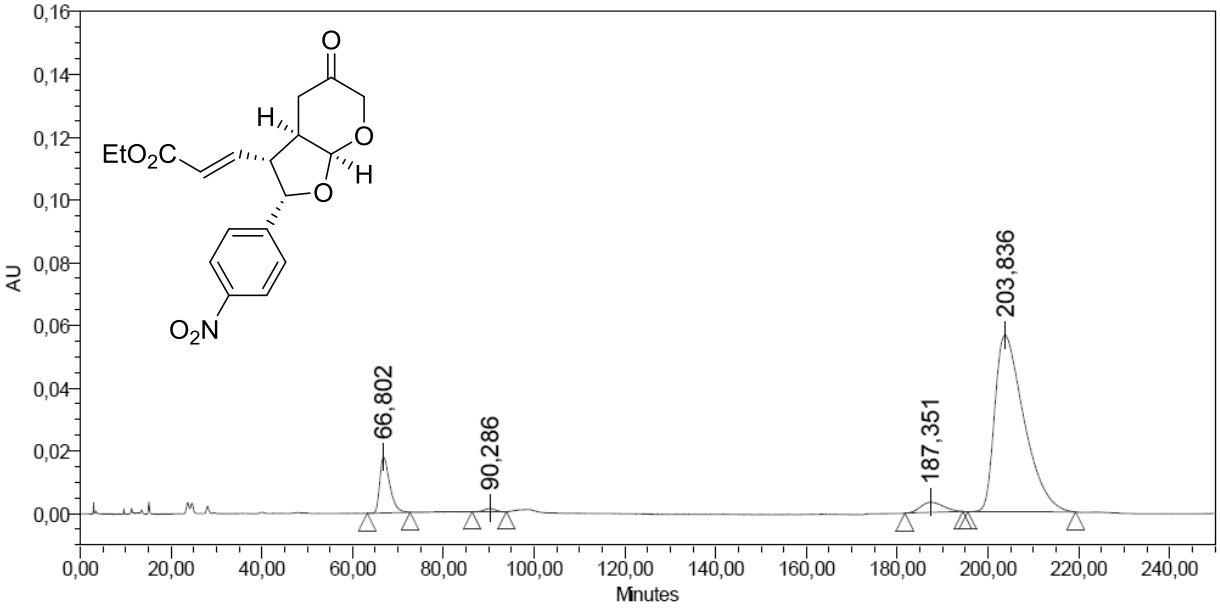


Peak Results

	RT	Area	Height	% Area
1	20,087	15200761	500562	96,02
2	47,811	629292	10324	3,98

Figure ESI-67. HPLC traces of compound **8c**.

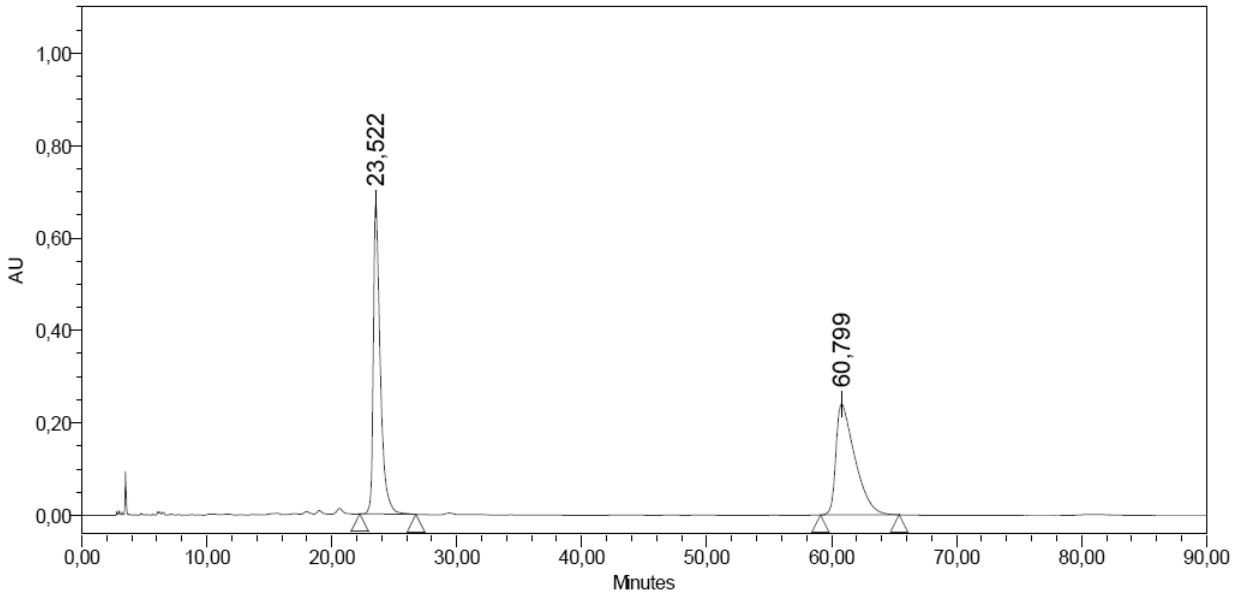


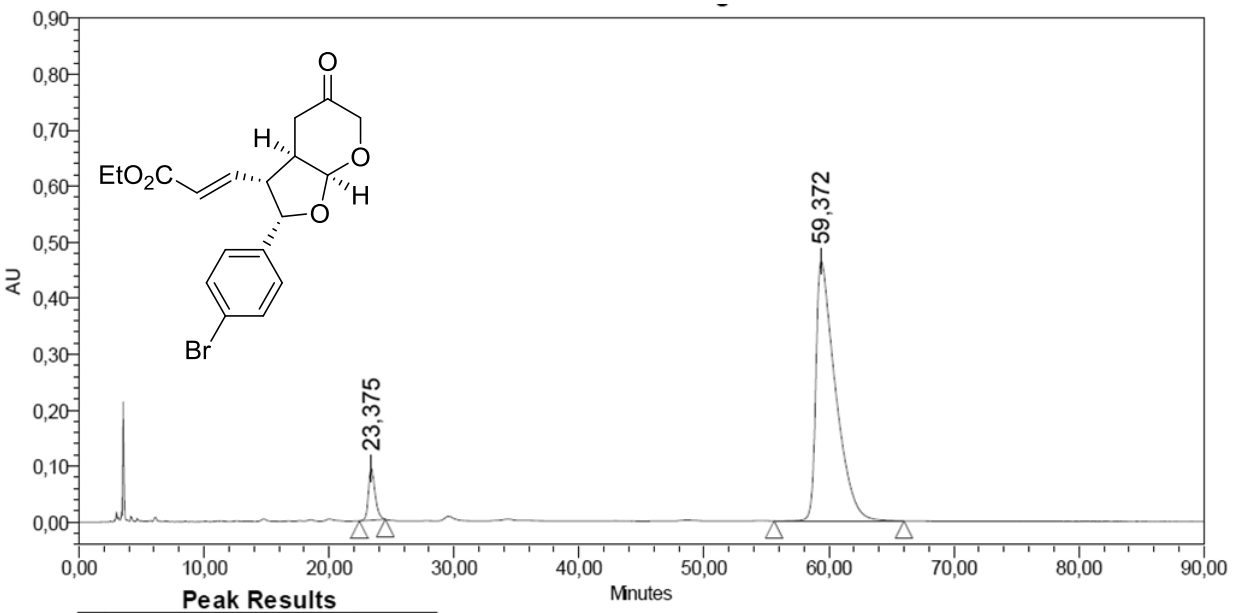


Peak Results

	RT	Area	Height	% Area
1	66,802	2713503	17758	9,25
2	90,286	173844	1075	0,59
3	187,351	1121331	3241	3,82
4	203,836	25321440	56376	86,33

Figure ESI-68. HPLC traces of compound **8d**.

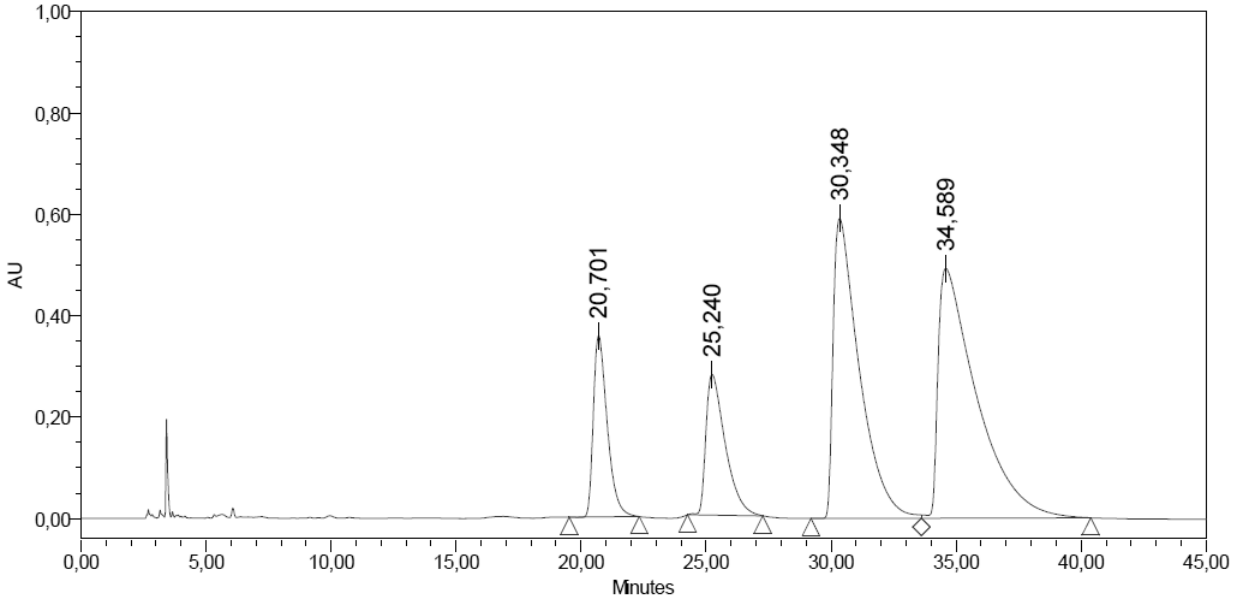


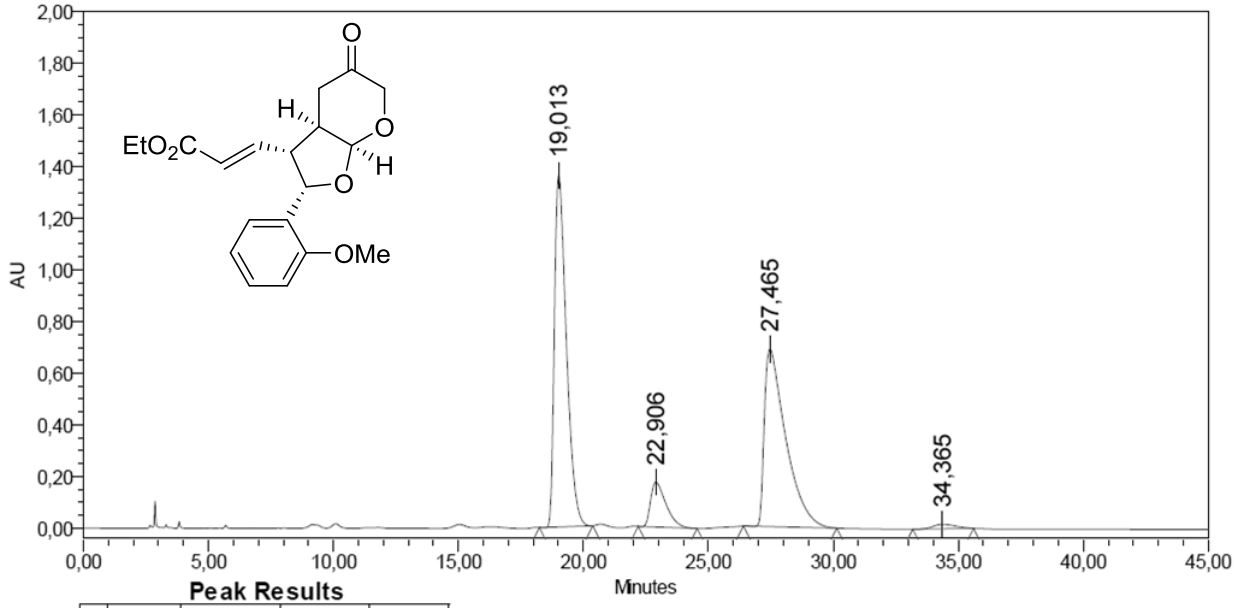


Peak Results

	RT	Area	Height	% Area
1	23,375	3428583	92405	6,38
2	59,372	50336901	463601	93,62

Figure ESI-69. HPLC traces of compound **8e**.

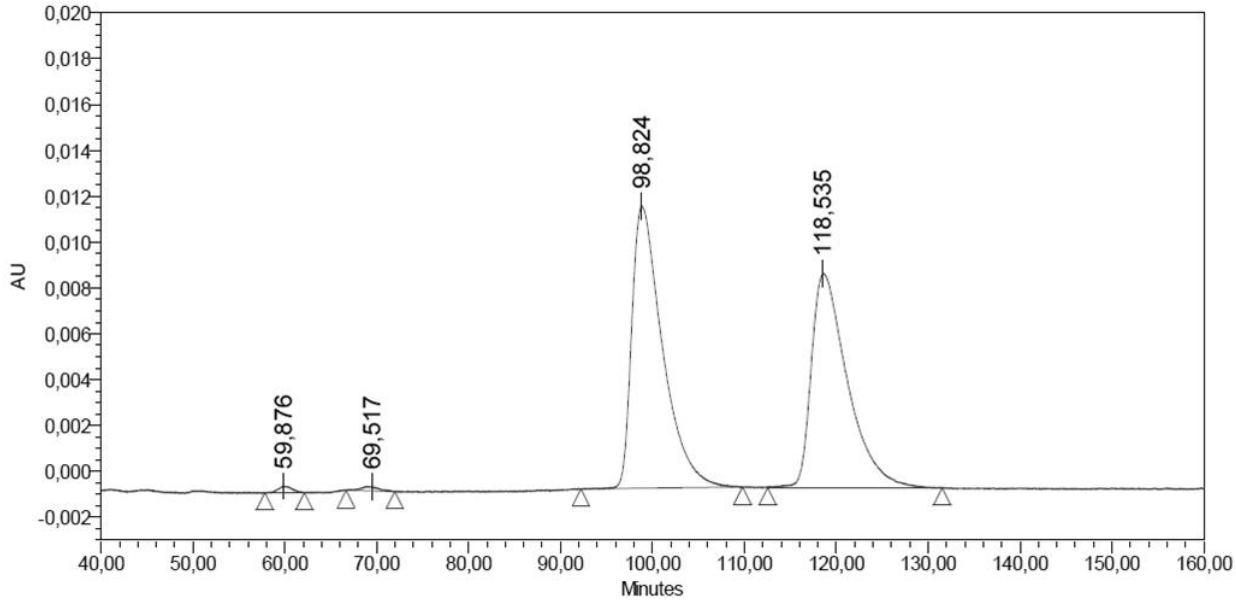


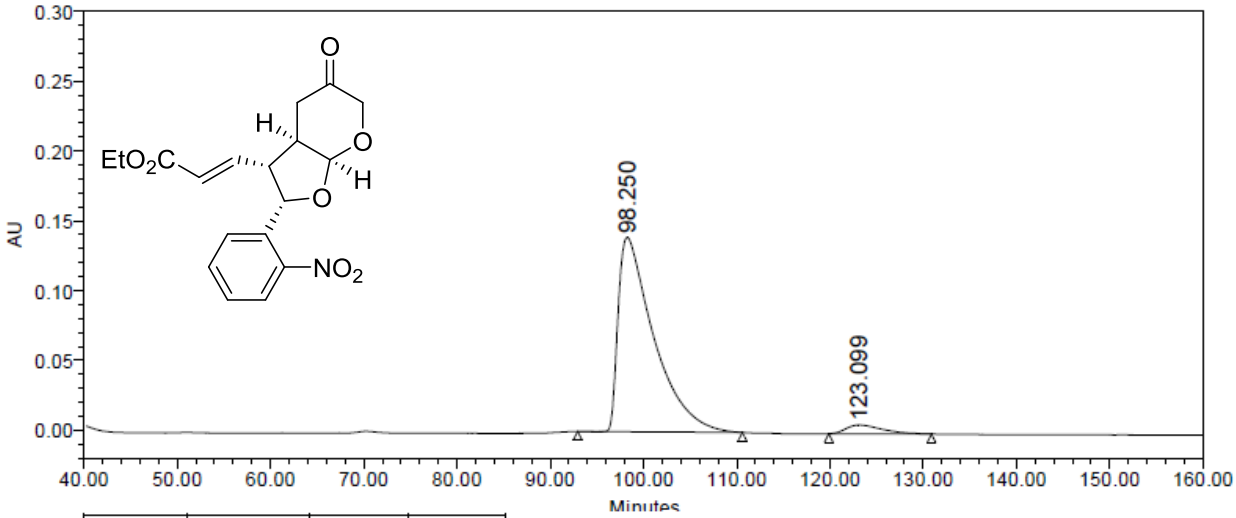


Peak Results

	RT	Area	Height	% Area
1	19,013	45348879	1362358	47,87
2	22,906	7438368	173708	7,85
3	27,465	40875407	687519	43,15
4	34,365	1068398	17352	1,13

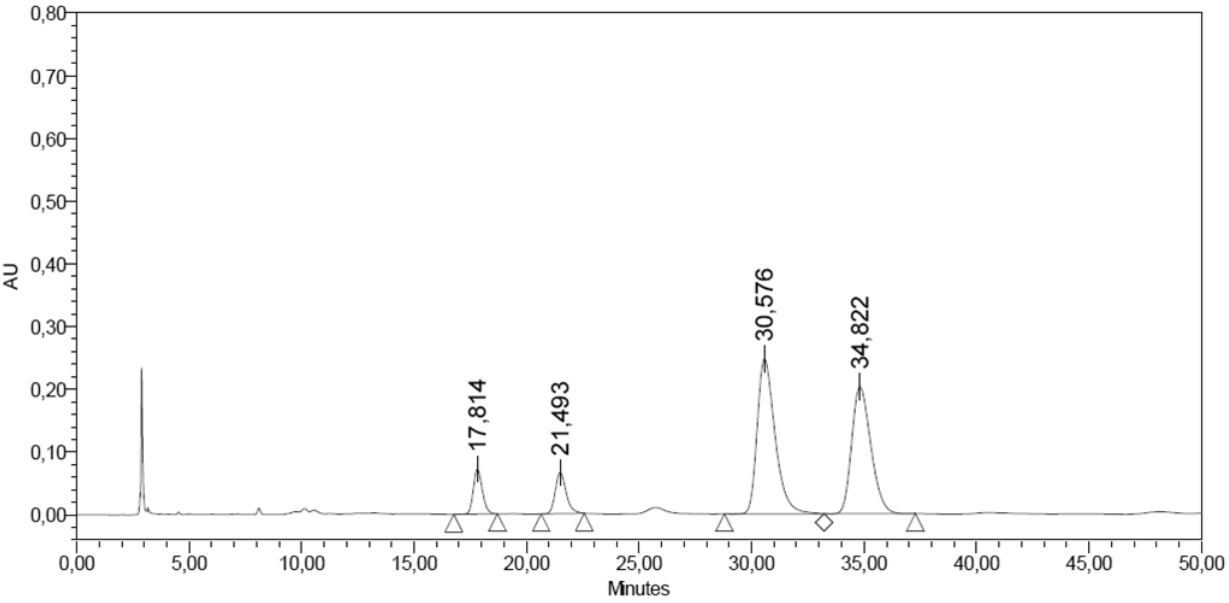
Figure ESI-70. HPLC traces of compound **8f**.

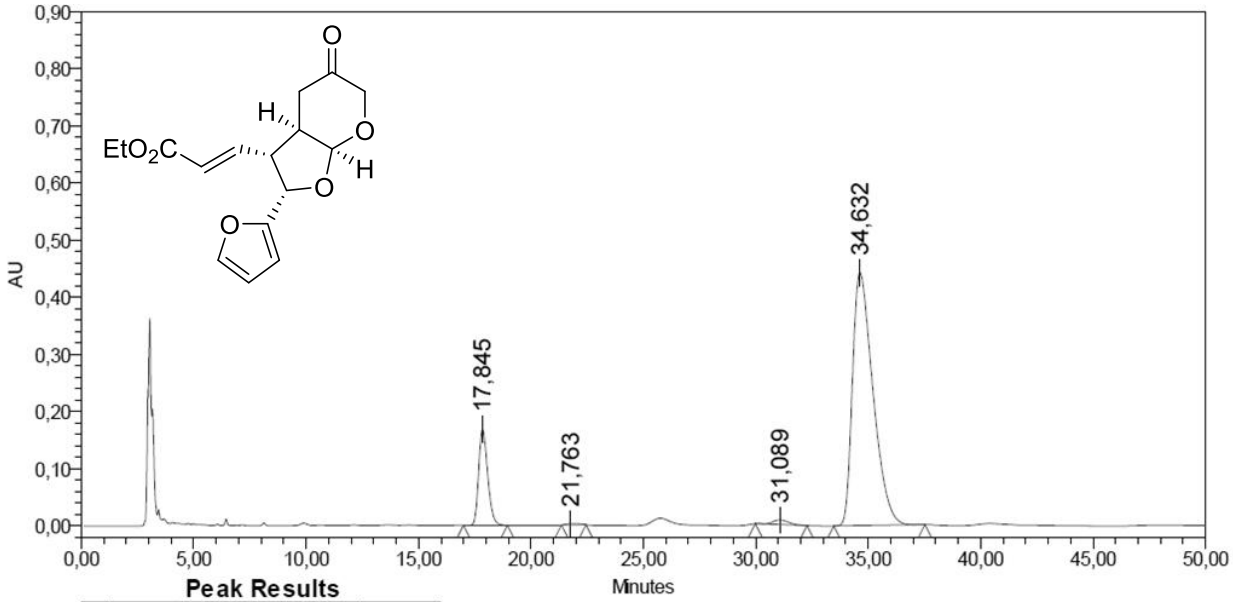




RT	Area	% Area	Height
98.250	36974962	95.64	139320
123.099	1683734	4.36	6264

Figure ESI-71. HPLC traces of compound **8g**.

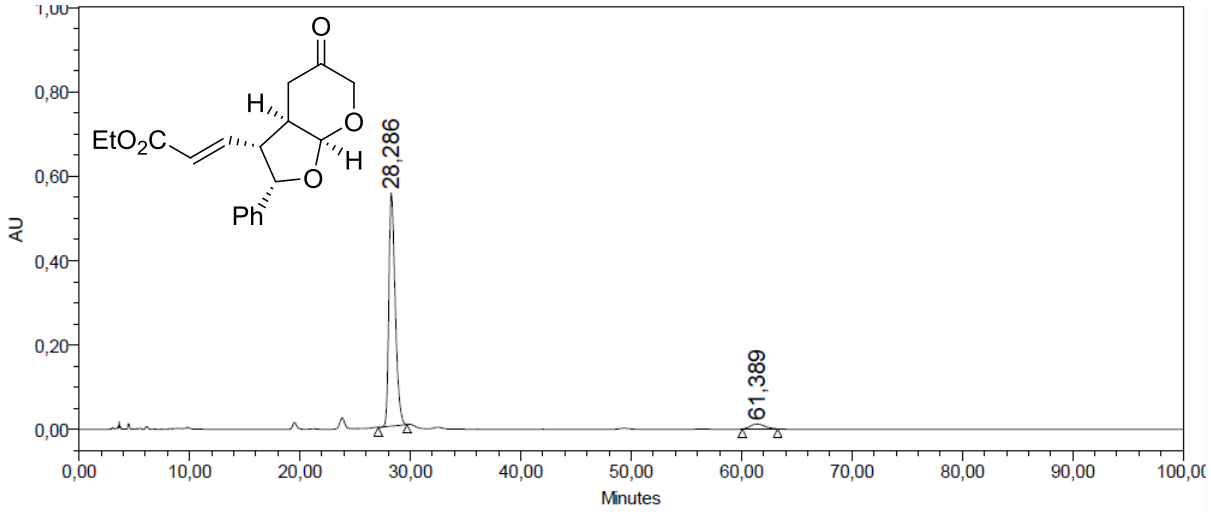




Peak Results

	RT	Area	Height	% Area
1	17,845	4679475	167816	14,08
2	21,763	98017	2155	0,29
3	31,089	391121	8100	1,18
4	34,632	28059902	442371	84,45

Figure ESI-72. HPLC traces of compound **8h**.



	Processed Channel Descr.	RT	Area	% Area	Height
1	PDA 224,3 nm	28,286	22129260	95,52	551237
2	PDA 224,3 nm	61,389	1036871	4,48	11993

Figure ESI-73. HPLC trace of compound **8a-^{2}H**.