

Supplementary Information

Diastereoselective hydrogenation of arenes and pyridines using supported ruthenium nanoparticles under mild conditions

Florian Bourriquen,^a Julien Hervochon,^{a,b} Ruiyang Qu,^a Stephan Bartling,^a Nils Rockstroh,^a Kathrin Junge,^{*,a} Cédric Fischmeister^b and Matthias Beller^{*,a}

^a Leibniz-Institut für Katalyse e.V., Albert-Einstein-Straße 29a, 18059 Rostock, Germany

^b Univ Rennes, CNRS, ISCR (Institut des Sciences Chimiques de Rennes) UMR 6226, F-35000 Rennes (France)

Correspondence to: kathrin.junge@catalysis.de, matthias.beller@catalysis.de

Content:

1. General information	2
2. Counting of the marketed compounds	3
3. Characterisation of Ru:Phen(1:2)@TiO ₂ -800.....	4
3.1. Scanning transmission electron microscopy	4
3.2. X-ray Photoelectron Spectroscopy	6
3.3. Elemental analysis	6
4. General procedures.....	7
5. Different batches of commercially available catalysts under the optimised conditions	8
6. Catalyst recycling.....	9
7. Diastereoselective reduction of <i>ortho</i> , <i>meta</i> , and <i>para</i> -xylene at different temperatures.....	10
8. Hydrogenation of quinoline	11
9. Unreactive substrates.....	11
10. Products characterisation	12
11. References	16
12. GC and GC-MS traces.....	17
13. NMR Spectra	49
14. Scaled up reaction	64

1. General information

All reagents were obtained from various chemical suppliers and were used without previous purification.

^1H NMR and ^{13}C NMR spectra were recorded on an AV-300, AV-400, or Fourier-300 Bruker equipment. All chemical shifts (δ) are reported in parts per million (ppm) downfield of tetramethylsilane and coupling constants (J) in hertz (Hz). The residual solvent signals were used as references for ^1H and ^{13}C NMR spectra (CDCl_3 : $\delta\text{H} = 7.26$ ppm, $\delta\text{C} = 77.16$ ppm; Abbreviations used in the reported NMR experiments: b, broad; s, singlet; d, doublet; t, triplet; q, quartet; hept, heptuplet; m, multiplet. All measurements were carried out at room temperature.

Gas chromatography was performed on Agilent 7890A equipped with FID detector and HP5 column. High resolution mass spectra measurements were recorded on MAT 95XP ThermoFisher Mass Spectrometer using Electrospray Ionisation mode.

Scanning transmission electron microscopy (STEM) measurements were performed at 200 kV on a probe aberration-corrected JEM-ARM200F (JEOL, corrector: CEOS). The microscope is further equipped with a JED-2300 energy dispersive x-ray spectrometer (JEOL) having a silicon drift detector (dry SD60GV). For general imaging a high-angle annular dark field (HAADF) and an annular bright field (ABF) detector were used. Sample preparation was conducted by dry deposition of the catalyst powder on a Cu grid (mesh 300) covered by a holey carbon film, which was then transferred into the microscope.

The XPS (X-ray Photoelectron Spectroscopy) measurements were performed on an ESCALAB 220iXL (Thermo Fisher Scientific) with monochromated Al K α radiation ($E = 1486.6$ eV). Samples are prepared on a stainless-steel holder with conductive double-sided adhesive carbon tape. The electron binding energies were obtained with charge compensation using a flood electron source, no further charge referencing is applied. For quantitative analysis the peaks were deconvoluted with Gaussian-Lorentzian curves using the software Unifit 2021. The peak areas were normalised by the transmission function of the spectrometer and the element specific sensitivity factor of Scofield.

Determination of the diastereoselective ratio was performed using the GC-FID area (A) of the isomers and was calculated using the following formula:

$$d.r. = \frac{A_{major\ isomer}}{\sum A_{isomers}}$$

In the case isomers have the same retention time on the GC under the conditions of analysis, the diastereoselective ratio was calculated using the intensity of signals corresponding to the different isomers in the NMR spectra of the product.

2. Counting of the marketed compounds

The counting of the marketed compounds was performed using the “Availability in other databases: SigmaAldrich” feature from the search engine Reaxys (www.reaxys.com) on the 15.12.2021. The search settings and number of results are presented in Table S1.

Table S1. Counting of the marketed compounds.

Entry	Search settings	Number of results
1	 <p>The screenshot shows the Reaxys search interface. The central structure editor contains a benzene ring structure. The search settings panel on the right is configured with the following options: "Search this structure as:" with "As substructure" selected; "On all atoms" selected; "On heteroatoms" unselected; "Similar" unselected; "Tautomers" selected; "Stereo" selected; "Additional ring closures" unselected; "Related Markush" unselected; "Salts" selected; "Mixtures" selected; "Isotopes" selected; "Charges" selected; "Radicals" selected. The "Transfer to query" button is visible at the bottom right of the editor.</p>	186,622
2	 <p>The screenshot shows the Reaxys search interface. The central structure editor contains a benzene ring structure. The search settings panel on the right is configured with the following options: "Search this structure as:" with "As substructure" selected; "On all atoms" selected; "On heteroatoms" unselected; "Similar" unselected; "Tautomers" selected; "Stereo" selected; "Additional ring closures" unselected; "Related Markush" unselected; "Salts" selected; "Mixtures" selected; "Isotopes" selected; "Charges" selected; "Radicals" selected. The "Transfer to query" button is visible at the bottom right of the editor.</p>	138,309
3	 <p>The screenshot shows the Reaxys search interface. The central structure editor contains a benzene ring structure. The search settings panel on the right is configured with the following options: "Search this structure as:" with "As substructure" selected; "On all atoms" selected; "On heteroatoms" unselected; "Similar" unselected; "Tautomers" selected; "Stereo" selected; "Additional ring closures" unselected; "Related Markush" unselected; "Salts" selected; "Mixtures" selected; "Isotopes" selected; "Charges" selected; "Radicals" selected. The "Transfer to query" button is visible at the bottom right of the editor.</p>	9,897

3. Characterisation of Ru:Phen(1:2)@TiO₂-800

3.1. Scanning transmission electron microscopy

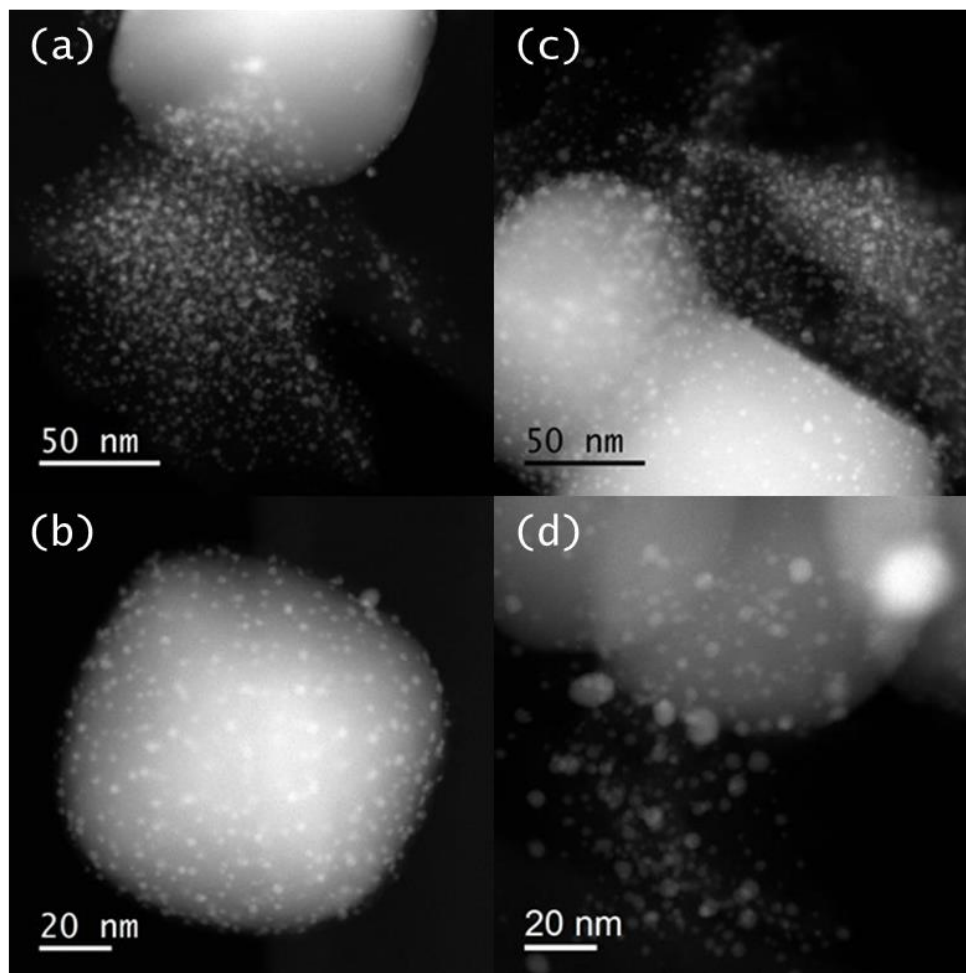


Figure S1. STEM-HAADF images of the fresh Ru@TiO₂-800 catalyst (a, b) and of the recycled catalyst after one run (c, d). The observed changes in the material by the applied reaction conditions are minimal and only few larger Ru particles can be seen.

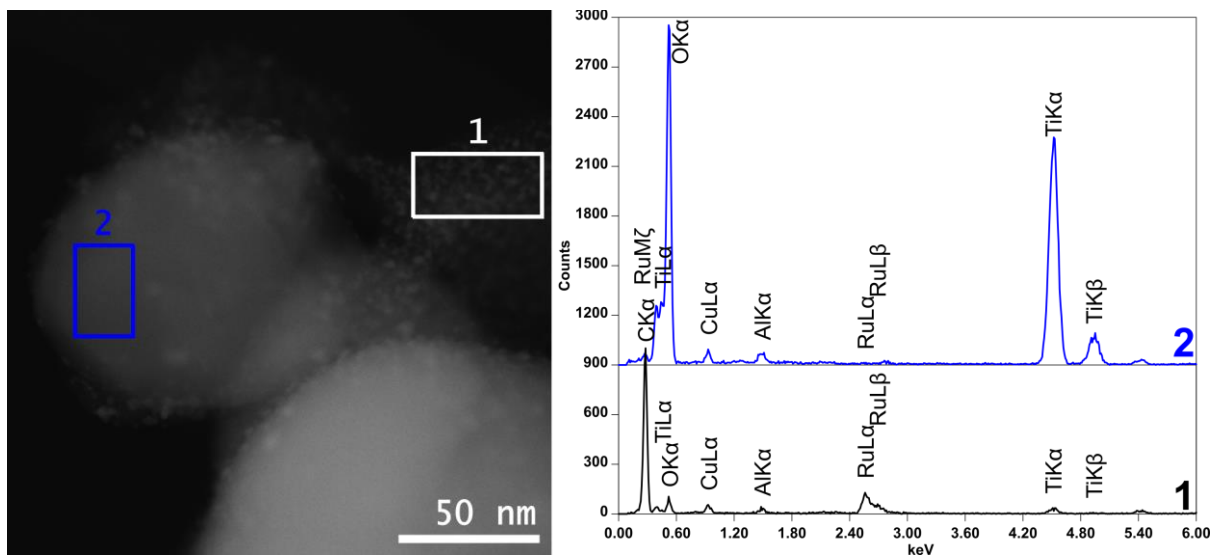


Figure S2. Selected EDX spectra of the marked areas of the fresh catalyst (left) are shown on the right. While area 1 shows almost exclusively ruthenium and carbon, area 2 highlights TiO_2 . Note that aluminium was also found in the material, which may arise from the ceramic crucible used for the catalyst synthesis.

3.2. X-ray Photoelectron Spectroscopy

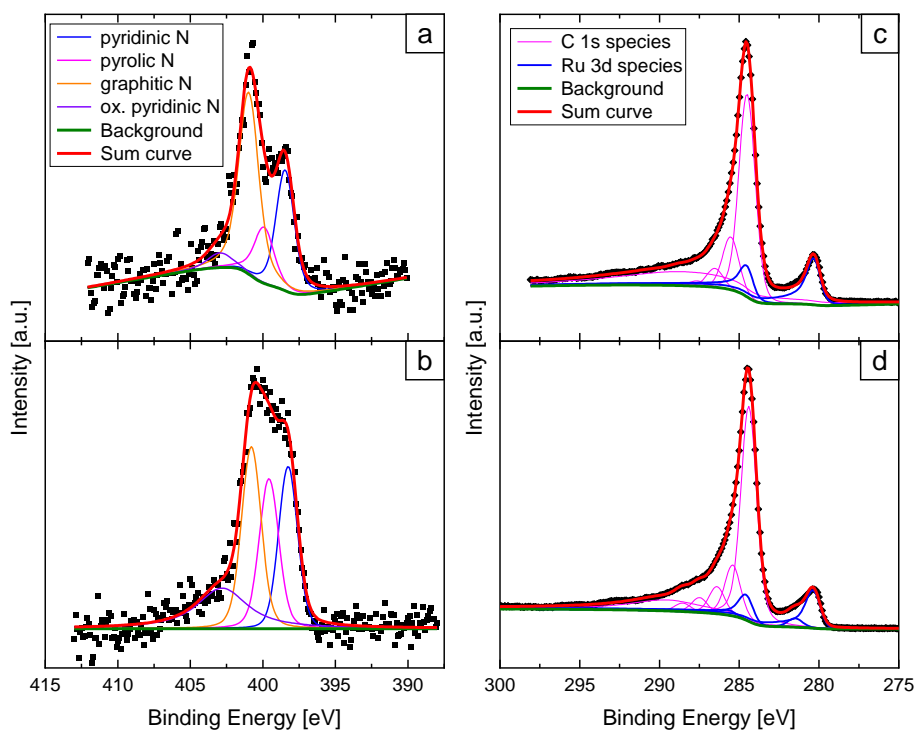


Figure S3. XP spectra of the N 1s (a, b), C 1s and Ru 3d (c, d) region for the fresh (a, c) and recycled (b, d) catalyst, respectively.

Table S2. XPS quantification of detected elements at the surface of the fresh and recycled catalyst

	C [at.%]	O [at.%]	Ti [at.%]	N [at.%]	Ru [at.%]	Si [at.%]	P [at.%]	Cl [at.%]	F [at.%]
fresh	67.5	18.6	7.8	1.9	1.7	0.5	0.3	0.6	1.0
recycled	64.0	23.2	7.2	2.4	1.5	0.8	0.4	-	0.5

3.3. Elemental analysis

Table S3. Elemental analysis of the fresh catalyst

Ru [wt. %]	C [wt. %]	H [wt. %]	N [wt. %]
2.06	5.87	0.44	0.16

4. General procedures

Ru:Phen(1:2)@TiO₂-1000

A 100 mL round bottomed flask was charged with RuCl₃ (61.6 mg, 0.30 mmol), 1,10-phenanthroline monohydrate (108.2 mg, 0.55 mmol) and absolute ethanol (40 mL). After stirring at room temperature for 30 min, TiO₂ anatase (830.2 mg) was added to the reaction mixture *via* a funnel, and the resulting heterogeneous mixture was stirred at room temperature overnight. The solvent was removed *in vacuo* and dried under high vacuum for 4 hours. The sample was ground to a fine powder which was transferred to a ceramic crucible and placed in an oven. The furnace was heated to 800 °C at a rate of 25 °C/min and held at 800 °C for 2 hours under argon atmosphere. After the heating was switched off, the oven was allowed to reach room temperature, giving the Ru-Phen(1:2)@TiO₂-800 as a black powder. Note that during the whole process, argon was constantly passed through the oven.

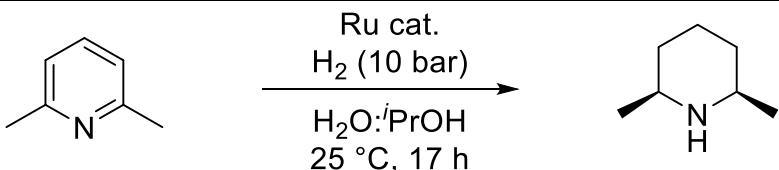
Hydrogenation of arenes and pyridines

A 4 mL glass vial equipped with a Teflon coated oval magnetic stirring bar and a plastic screwcap was charged with a substrate (0.5 mmol), the Ru:Phen(1:2)@TiO₂-800 catalyst (10 mg), water (1 mL) and ^tPrOH (1 mL). The silicone septum was punctured with a syringe needle and the vial was placed in an aluminium plate (up to 8 vials), which was then transferred into the 300 mL steel Parr autoclave. Once sealed, the autoclave was placed into an aluminium block and purged two times with hydrogen (at around 20 bar). Then, it was pressurised with H₂ (10 bar) and heated up to the required temperature under thorough stirring (700 rpm). After 16 hours, the autoclave was removed from the aluminium block and cooled to room temperature in a water bath. The remaining hydrogen was discharged, and the vials containing reaction products were removed from the autoclave. The crude media was diluted with ethyl acetate to fill the 4 mL vial and the resulting mixture was intensively stirred for 30 s. The solid catalyst was separated by filtration over a celite pad (~2 cm), and the organic phase was dried over Na₂SO₄ and subjected to GC analysis to determine the diastereoisomeric ratio in the crude reaction mixture. For isolation of the products, the reaction media was diluted with ethyl acetate to fill the 4 mL vial and the resulting mixture was intensively stirred for 30 s. The solid catalyst was separated by filtration over a celite pad (~2 cm), and the aqueous phase was further extracted with EtOAc (3 x 2 mL). The combined organic phases were dried over Na₂SO₄, filtered and concentrated under *vacuo*. The products were isolated in sufficient purity without further purification necessary.

Volatile piperidines were isolated as their hydrochloride salts: the combined organic phases were stirred for 1 h in presence of 0.5 mL of 1.25M HCl in methanol followed by removal of the solvents under reduced pressure.

5. Different batches of commercially available catalysts under the optimised conditions

Table S4. Catalyst screening for the diastereoselective reduction of 2,6-lutidine.

				
Entry ^a	Catalyst	Conversion (%) ^b	Yield (%) ^b	d.r. ^c
1	Ru:Phen(1:2)@TiO ₂ -800	>99	93	97:3
2	Alfa Aesar reference 11748 – “Ruthenium, 5% on activated carbon powder, reduced”	99	92	97:3
3	Sigma-Aldrich reference 908045 – “Ruthenium on carbon Evonik Noblyst® P3059 5% Ru”	6	0	-
4	Strem reference 44-4050 – “Ruthenium, 5% on carbon”	>99	91	97:3
5	TCI reference R0076 – “Ruthenium 5% on Carbon (wetted with ca. 50% Water)”	>99	96	96:4

^a 2,6-lutidine (53.6 mg, 0.5 mmol), Ru:Phen(1:2)@TiO₂-800 (0.4 mol%, 10 mg) or Ru@C (0.4 mol%, 4 mg), H₂O:iPrOH (1:1, 2 mL), H₂ (10 bar), 25 °C, 17 h.

^b Determined by GC-FID using hexadecane as internal standard, average of two runs.

^c Diastereoisomeric ratio corresponding to the *cis* stereoisomer calculated by GC-FID, average of two runs.

6. Catalyst recycling

The catalyst was filtered after each cycle, washed with ethanol, dried under high vacuum, and used for the following run without reactivation.

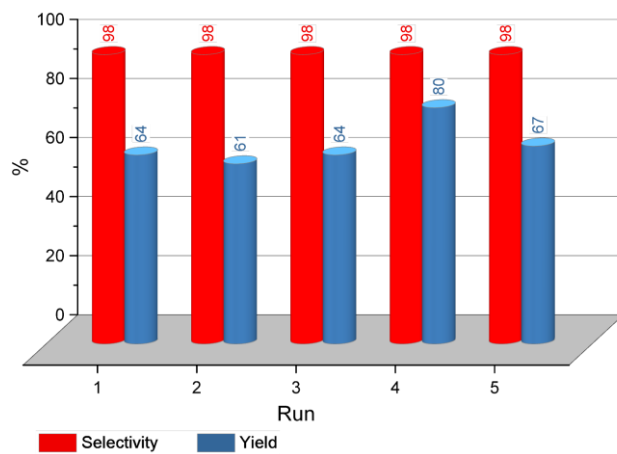


Figure S4. Catalyst recycling. 2,6-lutidine (53.6 mg, 0.5 mmol), catalyst (5 mg), H₂O (1 mL), ^tPrOH (1 mL), H₂ (10 bar), 25 °C, 17 h.

7. Diastereoselective reduction of *ortho*, *meta*, and *para*-xylene at different temperatures

Table S5. Xylene reduction at different temperatures.

Temperature (°C)	Product	Product	Product
25	93:7	83:17	76:24
60	93:7	83:17	74:26
80	92:8	80:20	73:27
120 ^a	88:12	81:19	71:29

Reaction conditions: substrate (0.5 mmol), Ru:Phen(1:2)@TiO₂-800 (10 mg), H₂O (1 mL), *i*PrOH (1 mL), H₂ (10 bar), 17 h. Conversions >98 %.
d.r. determined by GC-FID.
^a 1 h reaction time.

8. Hydrogenation of quinoline

Hydrogenation of quinoline under our standard reaction conditions provided 1,2,3,4-tetrahydroquinoline as main product (Table S6). While 5,6,7,8-tetrahydroquinoline was not detected here, trace amounts of *cis*-decahydroquinoline were formed and no *trans*-decahydroquinoline was observed.

Table S6 Hydrogenation of quinoline.

Entry ^a	Reaction temperature	Conversion (%) ^b	1,2,3,4-Tetrahydroquinoline (%) ^b
1	25	7	4
2	40	13	10
3	60	33	29
4	80	94	94

^a Reaction conditions: quinoline (64.6 mg, 0.5 mmol), Ru:Phen(1:2)@TiO₂-800 (0.4 mol%, 10 mg), H₂O:*i*PrOH (1:1, 2 mL), H₂ (10 bar), 25 °C, 17 h.
^b Determined by NMR.

9. Unreactive substrates

The following substrates were tested under our standard reaction conditions (0.5 mmol scale, Ru:Phen(1:2)@TiO₂-800 (10 mg, 0.4 mol% Ru, 10 bar H₂, 17 h) and did not provide high conversion / yield when the reaction was performed at either 25 °C, 40 °C, 60 °C or 80 °C.

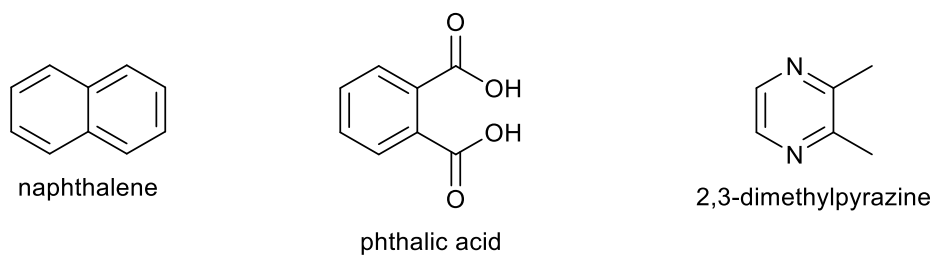
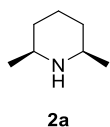
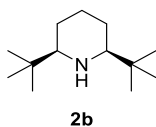


Figure S5 Unreactive substrates of the diastereoselective hydrogenation methodology.

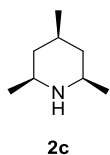
10. Products characterisation



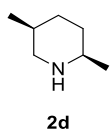
m/z $[M+H]^+$ calculated for $C_7H_{16}N$: 114.1283; observed: 114.1286. The product was converted to its hydrochloride salt for isolation. White solid. 91%. 1H NMR (400 MHz, DMSO) δ 9.30 (s, 1H), 8.63 (s, 1H), 3.47 – 3.32 (m, 0.12H, *trans*- NH_2CH), 3.19 – 2.84 (m, 1.86H, *cis*- NH_2CH), 1.85 – 1.63 (m, 3H), 1.63 – 1.31 (m, 3H), 1.24 (d, $J = 6.5$ Hz, 6H). ^{13}C NMR (101 MHz, DMSO) δ 52.2, 29.5, 22.1, 18.8.



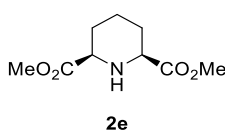
Off-white solid. 93%. 1H NMR (300 MHz, $CDCl_3$) δ 2.12 (dd, $J = 11.1, 2.3$ Hz, 2H), 1.92 – 1.76 (m, 1H), 1.65 – 1.49 (m, 2H), 1.36 – 0.92 (m, 4H), 0.87 (s, 18H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 66.8, 33.9, 26.8, 26.7, 25.8. m/z $[M+H]^+$ calculated for $C_{13}H_{28}N$: 198.2222; observed: 198.2225. Characterisation data in accordance with previously reported literature.¹



m/z $[M+H]^+$ calculated for $C_8H_{18}N$: 128.1439; observed: 128.1443. The product was converted to its hydrochloride salt for isolation. White solid. 94%. 1H NMR (400 MHz, DMSO) δ 9.33 (s, 1H), 8.52 (s, 1H), 3.07 (q, $J = 9.1$ Hz, 2H), 1.85 – 1.60 (m, 3H), 1.24 (d, $J = 6.5$ Hz, 6H), 1.07 (dt, $J = 13.3, 11.6$ Hz, 2H), 0.89 (d, $J = 6.4$ Hz, 3H). ^{13}C NMR (101 MHz, DMSO) δ 51.8, 38.0, 28.7, 21.3, 18.7.



m/z $[M+H]^+$ calculated for $C_7H_{16}N$: 114.1283; observed: 114.1286. The product was converted to its hydrochloride salt for isolation. White solid. 85%. 1H NMR (400 MHz, DMSO) δ 9.49 (br s, 1H), 9.10 (br s, 0.2H), 8.78 (br s, 1H), 3.29 (br s, 0.18H, *cis*- NCH), 3.06 (d, $J = 12.3$ Hz, 0.18H, *trans*- NCH_2), 2.98 – 2.83 (m, 0.82H, *cis*- NCH_2), 2.82 – 2.64 (m, 0.82H, *cis*- NCH_2), 2.42 (m, 0.18H, *trans*- NCH_2), 2.04 – 1.29 (m, 4.82H), 1.26 (d, $J = 6.8$ Hz, 2.46H, *cis*- $NCHCH_3$), 1.23 (d, $J = 6.4$ Hz, 0.54H, *trans*- $NCHCH_3$), 1.16 – 1.05 (m, 0.18H), 0.97 (d, $J = 7.0$ Hz, 2.46H, *cis*- NCH_2CHCH_3), 0.86 (d, $J = 6.7$ Hz, 0.54H, *trans*- NCH_2CHCH_3). ^{13}C NMR (101 MHz, DMSO) *cis*-product δ 48.6, 45.0, 26.6, 26.2, 26.1, 17.7, 15.7. ^{13}C NMR (101 MHz, DMSO) *trans*-product δ 51.4, 49.2, 30.7, 29.9, 27.5, 18.6, 18.4.



White solid. 88%. 1H NMR (300 MHz, $CDCl_3$) δ 3.65 (s, 6H), 3.30 (dd, $J = 11.0, 2.8$ Hz, 2H), 2.33 (s, 1H), 2.00 – 1.80 (m, 3H), 1.65 – 0.79 (m, 4H). ^{13}C NMR (75 MHz, $CDCl_3$) *cis*-product δ 172.9, 58.3, 52.0, 28.6, 24.1. m/z $[M+H]^+$ calculated for $C_9H_{16}NO_4$: 202.1079; observed: 202.1083. Characterisation data in accordance with previously reported literature.²



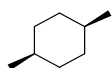
2f

GC yield with internal calibration: 82%. EI m/z (%): 112 (43), 97 (100), 83 (48), 70 (34), 55 (77), 41 (32). Characterisation data in accordance with previously reported literature.³



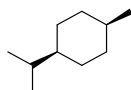
2g

GC yield with internal calibration: 75%. EI m/z (%): 112 (30), 97 (100), 69 (14), 55 (47), 41 (14).



2h

GC yield with internal calibration: 57%. EI m/z (%): 112 (37), 97 (100), 83 (9), 69 (15), 55 (60), 41 (19).



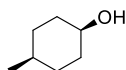
2i

GC yield with internal calibration: 76%. EI m/z (%): 140 (14), 97 (100), 96 (66), 81 (33), 69 (18), 55 (78), 41 (19). Characterisation data in accordance with previously reported literature.⁴



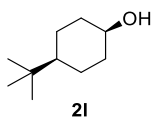
2j

Colourless liquid. 75%. ¹H NMR (300 MHz, CDCl₃) δ 3.76 (m, 0.64H, *cis*-CHOH), 3.10 (m, 0.35H, *trans*-CHOH), 2.00 – 1.08 (m, 9H), 0.99 (d, J = 6.4 Hz, 1.28H, *trans*-CHCH₃), 0.92 (d, J = 6.9 Hz, 2.17H, *cis*-CHCH₃). ¹³C NMR (75 MHz, CDCl₃) *cis*-product δ 71.2, 35.9, 32.6, 28.9, 24.6, 20.8, 17.0. ¹³C NMR (75 MHz, CDCl₃) *trans*-product δ 76.6, 40.4, 35.6, 33.8, 25.8, 25.3, 18.7. EI m/z (%): 114 (11), 96 (76), 81 (100), 71 (52), 68 (75), 57 (87), 55 (36), 41 (31), 93 (20), 29 (13). Characterisation data in accordance with previously reported literature.^{5,6}

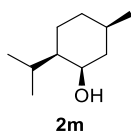


2k

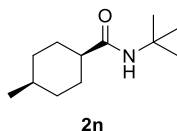
Colourless liquid. 98%. ¹H NMR (300 MHz, CDCl₃) δ 3.95 – 3.87 (m, 0.56H, *cis*-CHOH), 3.51 (m, 0.43H, *trans*-CHOH), 2.00 – 1.12 (m, 9H), 0.89 (d, J = 6.1 Hz, 1.79H, *cis*-CHCH₃), 0.85 (d, J = 6.5 Hz, 1.49H, *trans*-CHCH₃). ¹³C NMR (75 MHz, CDCl₃) *cis*-product δ 67.0, 32.3, 31.2, 29.1, 21.8. ¹³C NMR (75 MHz, CDCl₃) *trans*-product δ 71.0, 35.7, 33.4, 31.9, 22.0. EI m/z (%): 114 (8), 96 (33), 81 (54), 70 (38), 57 (100), 41 (26). Characterisation data in accordance with previously reported literature.^{5,6}



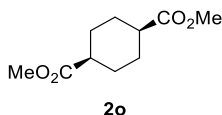
White solid. 99%. $^1\text{H NMR}$ (300 MHz, CDCl_3) δ 4.06 – 3.94 (m, 0.58H, *cis*-CHOH), 3.61 – 3.36 (m, 0.42H, *trans*-CHOH), 2.07 – 0.87 (m, 10H), 0.83 (s, 5H), 0.82 (s, 4H). $^{13}\text{C NMR}$ (75 MHz, CDCl_3) *cis*-product δ 65.9, 48.1, 33.5, 32.6, 27.6, 21.0. $^{13}\text{C NMR}$ (75 MHz, CDCl_3) *trans*-product δ 71.2, 47.3, 36.1, 32.4, 27.7, 25.7. GC-MS m/z (%) 141 (2), 123 (22), 99 (38), 82 (53), 67 (58), 57 (100). Characterisation data in accordance with previously reported literature.⁷



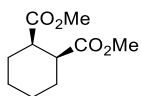
Colourless oil. 88%. $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 4.10 – 4.05 (m, , 0.05H neomenthol CHOH), 3.99 (dt, $J = 6.5, 3.4$ Hz, 0.73, neoisomenthol CHOH), 3.76 (td, $J = 7.8, 3.8$ Hz, 0.21H, isomenthol CHOH), 3.37 (td, $J = 10.4, 4.3$ Hz, 0.02H, menthol CHOH), 2.03 – 1.16 (m, 13H), 1.15 – 1.06 (m, 1H), 1.04 (d, $J = 7.1$ Hz, 2.2H neoisomenthol methyl- CH_3), 0.97 (d, $J = 6.6$ Hz, 2.2H neoisomenthol $^i\text{Pr-CH}_3$), 0.90 (m, 4H, neoisomenthol $^i\text{Pr-CH}_3$, isomenthol $^i\text{Pr-CH}_3$), 0.84 (m, 1H, isomenthol methyl- CH_3). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) neoisomenthol δ 70.9, 47.5, 39.1, 31.1, 28.4, 27.6, 22.1, 21.9, 21.6, 21.6. $^{13}\text{C NMR}$ (101 MHz, CDCl_3) isomenthol δ 68.1, 49.7, 40.2, 30.6, 27.7, 26.2, 21.2, 20.1, 19.7, 18.2. $^{13}\text{C NMR}$ (101 MHz, CDCl_3) neomenthol δ 67.8, 48.1, 42.7, 35.2, 29.3, 24.3, 22.5, 21.3, 20.8. $^{13}\text{C NMR}$ (101 MHz, CDCl_3) menthol δ 50.2, 45.2, 34.7, 31.8, 25.9, 23.2, 22.3, 21.1, 16.2. EI m/z (%): 156 (0.34), 139 (4), 138 (26), 123 (40), 109 (21), 95 (82), 81 (73), 71 (100), 39 (31), 55 (37), 41 (31). Strong overlap of the signals, assignment performed taking advantage of reported literature and 2D NMR.^{8,9}



White solid. 99%. $^1\text{H NMR}$ (400 MHz, CDCl_3) δ 5.37 (s, 1H), 2.04 (hept, $J = 4.1$ Hz, 0.77H, *cis*-CHCONH), 1.82 (tt, $J = 8.5, 3.4$ Hz, 0.23H, *trans*-CHCONH), 1.78 – 1.28 (m, 9H), 1.26 (s, 6.93H, *cis*- ^tBu), 1.25 (s, 2.07H, *trans*- ^tBu), 0.86 (d, $J = 7.0$ Hz, 2.31H, *cis*- CH_3), 0.79 (d, $J = 6.6$ Hz, 0.69H, *trans*- CH_3). $^{13}\text{C NMR}$ (101 MHz, CDCl_3) *cis*-product δ 175.2, 50.8, 43.7, 31.2, 28.9, 25.8, 19.6. $^{13}\text{C NMR}$ (101 MHz, CDCl_3) *trans*-product δ 175.7, 46.1, 34.5, 32.1, 29.8, 29.1, 22.6. m/z $[\text{M}+\text{Na}]^+$ calculated for $\text{C}_{12}\text{H}_{23}\text{NO}$: 220.1672; observed: 220.1678.



Colourless liquid. 89%. $^1\text{H NMR}$ (300 MHz, CDCl_3) δ 3.61 (s, 5H, *cis*- CO_2CH_3), 3.60 (s, 1H, *trans*- CO_2CH_3), 2.53 – 2.31 (m, 1.66H, *cis*- CHCO_2CH_3), 2.06 – 1.91 (m, 0.33H, *trans*- CHCO_2CH_3), 2.32 – 2.15 (m, 0.74H, *trans*- CH_2), 2.09 – 1.71 (m, 3.46H, *cis*- CH_2), 1.71 – 1.49 (m, 3.46H, *cis*- CH_2), 1.49 – 1.25 (m, 0.74H, *trans*- CH_2). $^{13}\text{C NMR}$ (75 MHz, CDCl_3) *cis*-product δ 175.4, 51.6, 40.6, 26.0. $^{13}\text{C NMR}$ (75 MHz, CDCl_3) *trans*-product δ 175.9, 51.6, 42.4, 28.0. m/z $[\text{M}+\text{Na}]^+$ calculated for $\text{C}_{10}\text{H}_{16}\text{O}_4\text{Na}$: 223.0946; observed: 223.0946. Characterisation data in accordance with previously reported literature.¹⁰



2p

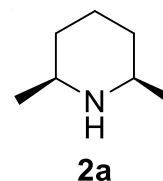
Colourless liquid. 82%. ^1H NMR (300 MHz, CDCl_3) δ 3.62 (s, 5.76H, *cis*- CO_2CH_3), 3.61 (s, 0.24H, *trans*- CO_2CH_3), 2.93 – 2.66 (m, 1.92H, *cis*- CHCO_2CH_3), 2.61 – 2.51 (m, 0.08H, *trans*- CHCO_2CH_3), 2.11 – 1.82 (m, 2H), 1.82 – 1.57 (m, 2H), 1.57 – 1.10 (m, 4H). ^{13}C NMR (75 MHz, CDCl_3) *cis*-product δ 174.2, 51.6, 42.6, 26.2, 23.8. ^{13}C NMR (75 MHz, CDCl_3) *trans*-product δ 175.5, 51.8, 44.8, 28.9, 25.2. m/z $[\text{M}+\text{Na}]^+$ calculated for $\text{C}_{10}\text{H}_{16}\text{O}_4\text{Na}$: 223.0946; observed: 223.0948. Characterisation data in accordance with previously reported literature.¹¹

11. References

- 1 R. F. Francis and E. L. Colling, *J. Org. Chem.*, 1986, **51**, 1889.
- 2 R. Chênevert and M. Dickman, *J. Org. Chem.*, 1996, **61**, 3332.
- 3 P. Natalis, *Bull. Soc. Chim. Belg.*, 1964, **73**, 961.
- 4 Y. Song, X. Feng, J. S. Chen, C. Brzezinski, Z. Xu and W. Lin, *J. Am. Chem. Soc.*, 2020, **142**, 4872.
- 5 T. Hattori, T. Ida, A. Tsubone, Y. Sawama, Y. Monguchi and H. Sajiki, *Eur. J. Org. Chem.*, 2015, **2015**, 2492.
- 6 K. W. Wiitala, Z. F. Al-Rashid, V. Dvornikovs, T. R. Hoye and C. J. Cramer, *J. Phys. Org. Chem.*, 2007, **20**, 345.
- 7 H. Li, L. Wang, Y. Zhang and J. Wang, *Angew. Chem., Int. Ed.*, 2012, **51**, 2943.
- 8 Y. Senda and S. Imaizumi, *Tetrahedron*, 1975, **31**, 2905.
- 9 F. Bohlmann, R. Zeisberg and E. Klein, *Org. Magn. Reson.*, 1975, **7**, 426.
- 10 A. Tortajada, R. Ninokata and R. Martin, *J. Am. Chem. Soc.*, 2018, **140**, 2050.
- 11 Y. Kawamata, M. Yan, Z. Liu, D.-H. Bao, J. Chen, J. T. Starr and P. S. Baran, *J. Am. Chem. Soc.*, 2017, **139**, 7448.

12.GC and GC-MS traces

Data File C:\CHEM32\1\DATA\202110\2021-10-19 10-12-55\FB-485-1-2.D
 Sample Name: FB-485-1-2

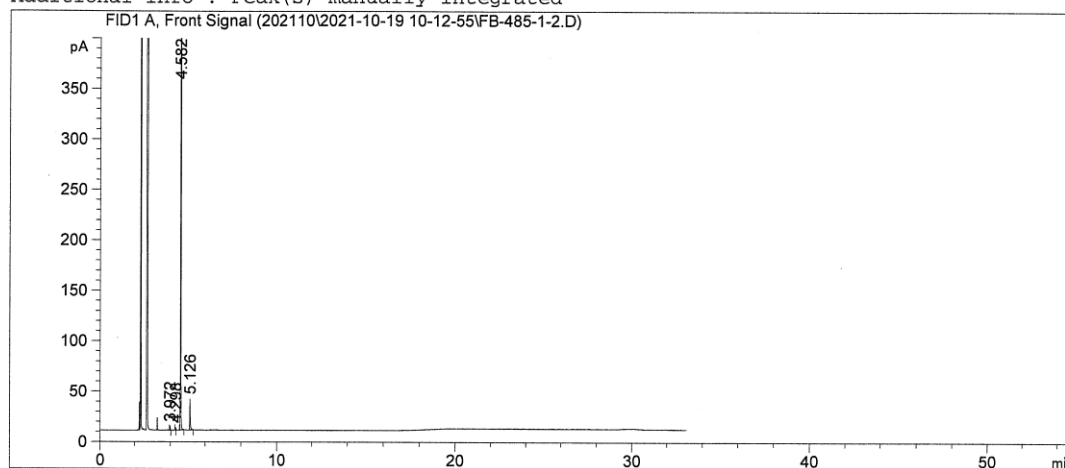


```

=====
Acq. Operator   : Lab 2.112                      Seq. Line :    1
Acq. Instrument : GC Lab.133                      Location  : Vial 111
Injection Date  : 10/19/2021 10:18:07 AM         Inj       :    1
                                                    Inj Volume: 1 µl

Acq. Method     : C:\CHEM32\1\DATA\202110\2021-10-19 10-12-55\STANDARDMTH.M
Last changed    : 6/25/2020 1:31:14 PM by Lab 2.112
Analysis Method : C:\CHEM32\1\METHODS\STANDARDMTH.M
Last changed    : 10/19/2021 10:38:20 AM by Lab 2.112
                  (modified after loading)
Method Info     : HP5 (30x0.25x0.25): 50/8-120/0/15-200/0/25-300/10/50-310/5
                  ramped flow: 1/29/1-2; 260i320d; Split 100/1
  
```

Additional Info : Peak(s) manually integrated



Area Percent Report

```

Sorted By      : Signal
Multiplier     : 1.0000
Dilution       : 1.0000
Use Multiplier & Dilution Factor with ISTDs
  
```

Signal 1: FID1 A, Front Signal

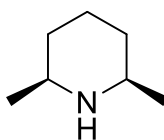
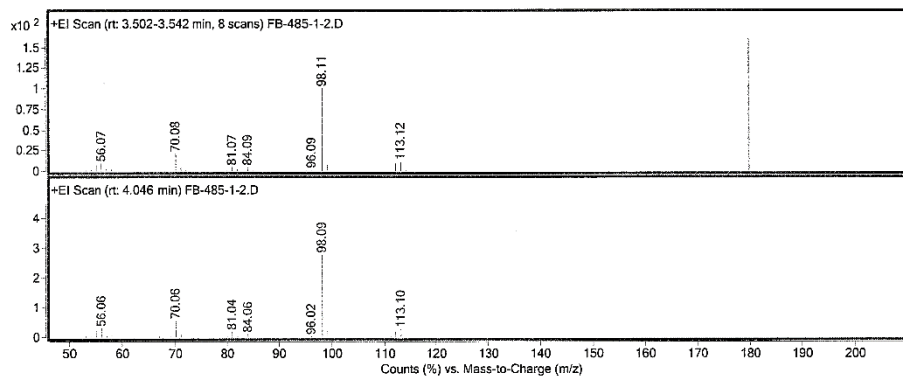
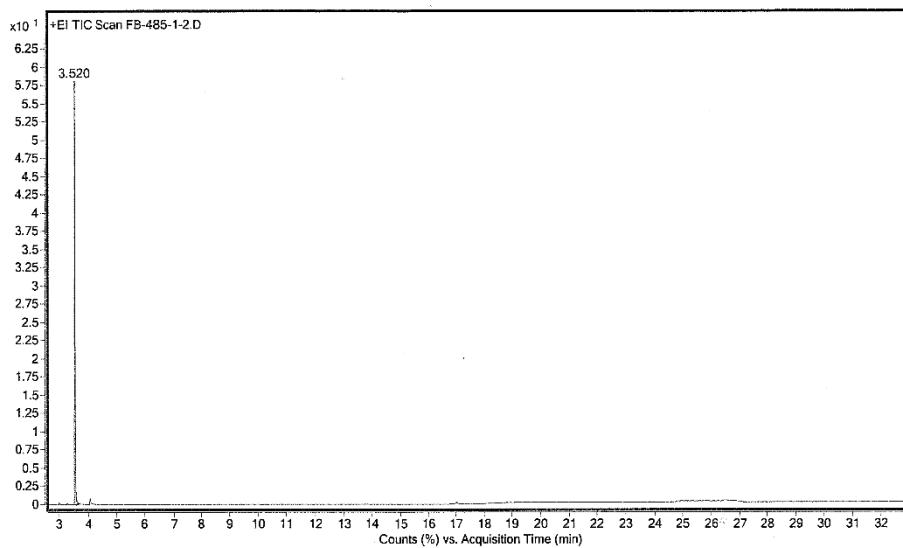
Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Height [pA]	Area %
1	3.972	BB	0.0250	6.72378	4.04314	0.30732
2	4.298	BB	0.0226	3.77454	2.59128	0.17252
3	4.582	BB	0.0247	2114.55151	1349.18359	96.64998
4	5.126	BB	0.0301	62.79492	30.96748	2.87017

Major isomer

Minor isomer

Totals : 2187.84476 1386.78550

*** End of Report ***



2a

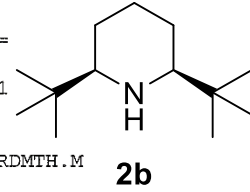
Chemical Formula: $C_7H_{15}N$

Exact Mass: 113.12

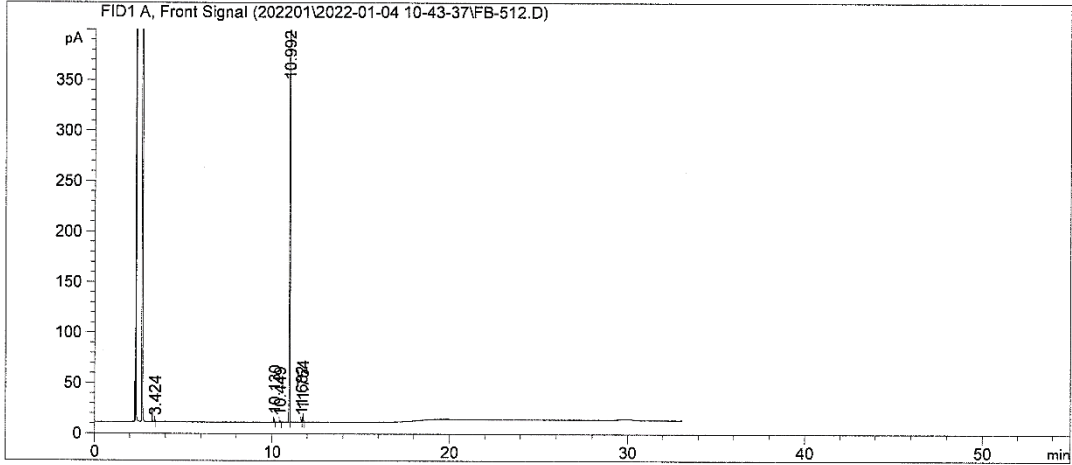
```

=====
Acq. Operator   : Lab 2.112                      Seq. Line :    1
Acq. Instrument : GC Lab.133                    Location  : Vial 111
Injection Date  : 1/4/2022 10:45:43 AM         Inj       :    1
                                                Inj Volume: 1 µl

Acq. Method     : C:\CHEM32\1\DATA\202201\2022-01-04 10-43-37\STANDARDMTH.M
Last changed    : 6/25/2020 1:31:14 PM by Lab 2.112
Analysis Method : C:\CHEM32\1\METHODS\STANDARDMTH.M
Last changed    : 1/4/2022 1:10:45 PM by Lab 2.112
                 (modified after loading)
Method Info     : HP5 (30x0.25x0.25): 50/8-120/0/15-200/0/25-300/10/50-310/5
                 ramped flow: 1/29/1-2; 260i320d; Split 100/1
  
```



Additional Info : Peak(s) manually integrated



=====
 Area Percent Report
 =====

```

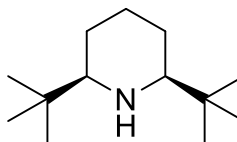
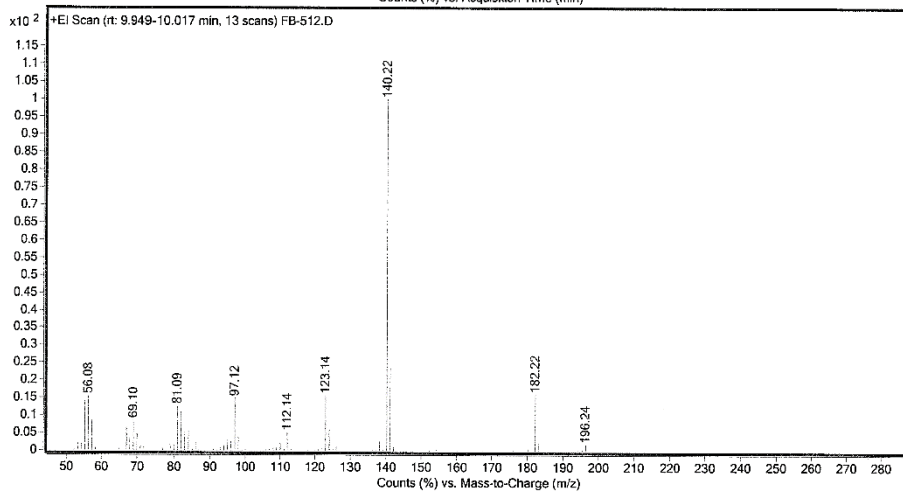
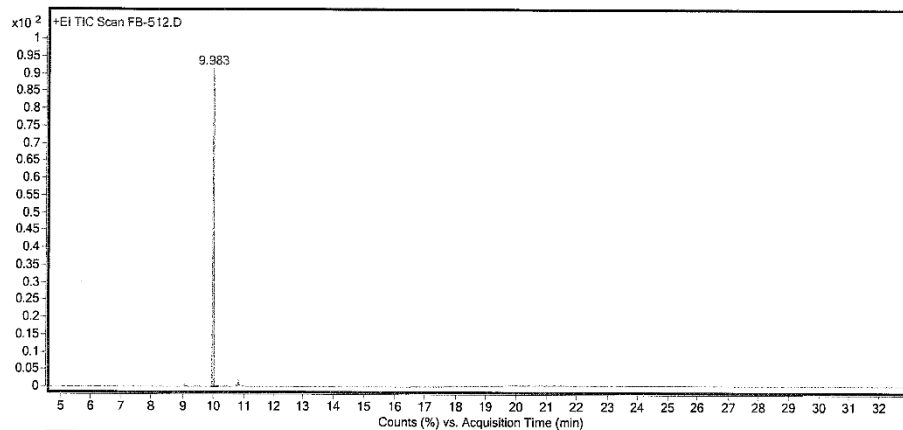
Sorted By      :      Signal
Multiplier     :      1.0000
Dilution       :      1.0000
Use Multiplier & Dilution Factor with ISTDs
  
```

Signal 1: FID1 A, Front Signal

Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Height [pA]	Area %
1	3.424	BB	0.0191	2.52424	2.05377	0.09047
2	10.130	BB	0.0309	7.26205	3.70553	0.26029
3	10.449	BB	0.0363	4.02603	1.66174	0.14430
4	10.992	BB	0.0332	2753.23999	1315.87952	98.68291
5	11.682	BV	0.0277	4.41343	2.50609	0.15819
6	11.754	VB	0.0330	18.52086	8.36995	0.66383
Totals :				2789.98660	1334.17659	

Major isomer
 Minor isomer

=====
 *** End of Report ***



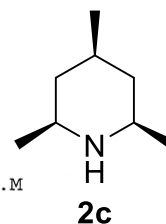
2b

Chemical Formula: $C_{13}H_{27}N$

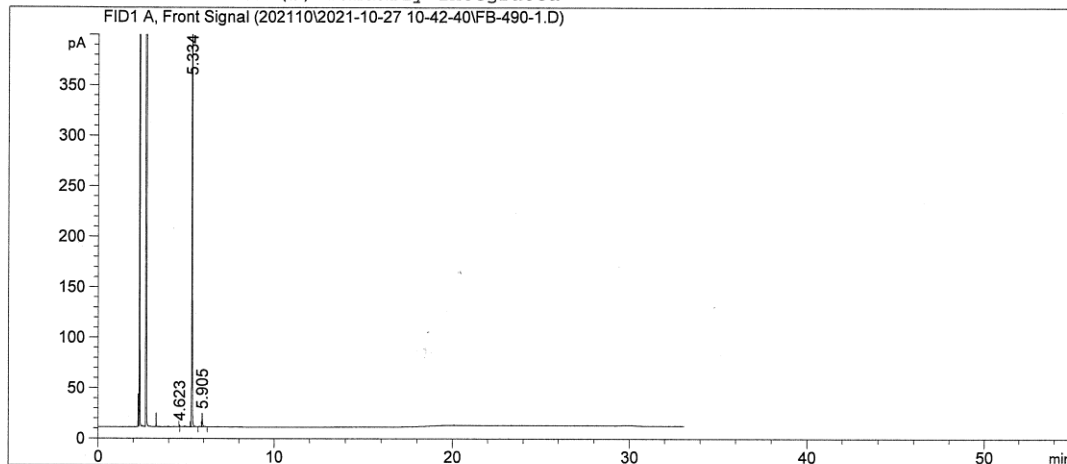
Exact Mass: 197.21

Data File C:\CHEM32\1\DATA\202110\2021-10-27 10-42-40\FB-490-1.D
Sample Name: FB-490-1

```
=====
Acq. Operator   : Lab 2.112                      Seq. Line :    1
Acq. Instrument : GC Lab.133                     Location  : Vial 111
Injection Date  : 10/27/2021 10:44:48 AM         Inj       :    1
                                                    Inj Volume: 1 µl
Acq. Method     : C:\CHEM32\1\DATA\202110\2021-10-27 10-42-40\STANDARDMTH.M
Last changed    : 6/25/2020 1:31:14 PM by Lab 2.112
Analysis Method : C:\CHEM32\1\METHODS\STANDARDMTH.M
Last changed    : 6/25/2020 1:31:14 PM by Lab 2.112
Method Info     : HP5 (30x0.25x0.25): 50/8-120/0/15-200/0/25-300/10/50-310/5
                  ramped flow: 1/29/1-2; 260i320d; Split 100/1
=====
```



Additional Info : Peak(s) manually integrated



=====
Area Percent Report
=====

Sorted By : Signal
Multiplier : 1.0000
Dilution : 1.0000
Use Multiplier & Dilution Factor with ISTDs

Signal 1: FID1 A, Front Signal

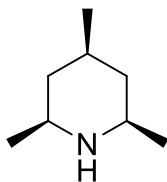
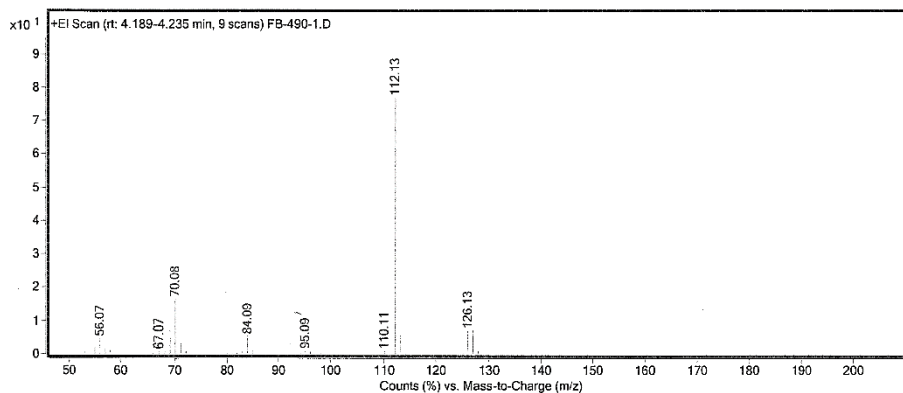
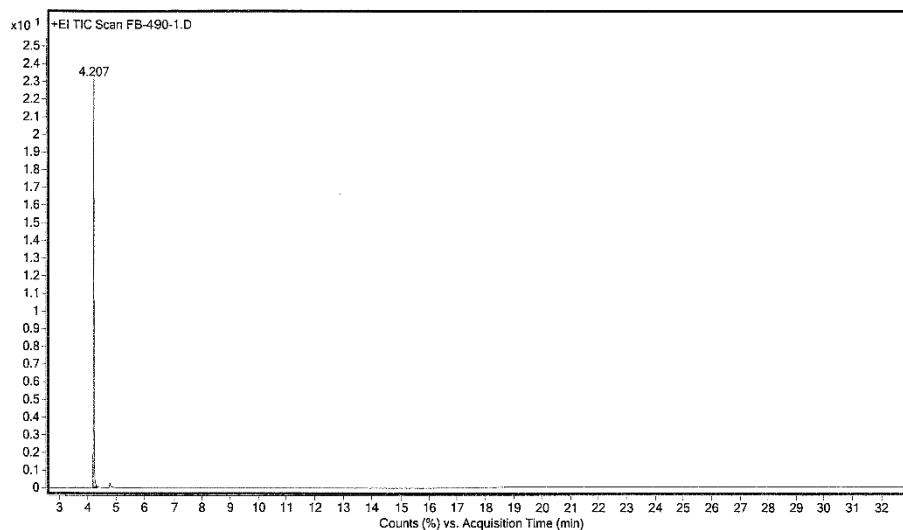
Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Height [pA]	Area %
1	4.623	BB	0.0245	2.51681	1.62352	0.12324
2	5.334	BB	0.0272	2008.91626	1129.44104	98.36858
3	5.905	BB	0.0343	30.80061	13.26650	1.50818

Major isomer

Minor isomer

Totals : 2042.23368 1144.33106

=====
*** End of Report ***



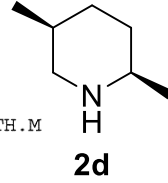
2c

Chemical Formula: C₈H₁₇N

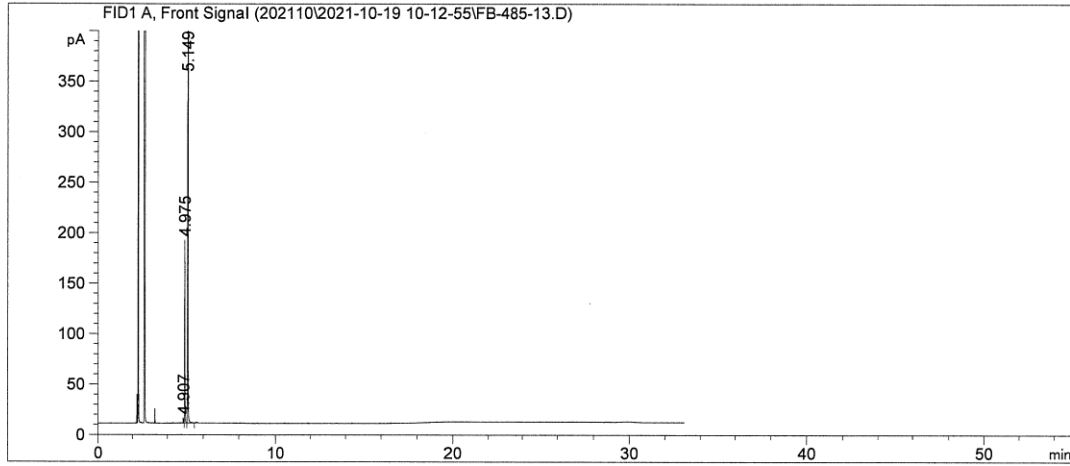
Exact Mass: 127.14

```

=====
Acq. Operator   : Lab 2.112                      Seq. Line : 13
Acq. Instrument : GC Lab.133                    Location  : Vial 123
Injection Date  : 10/19/2021 6:17:50 PM         Inj       : 1
                                                Inj Volume: 1 µl
Acq. Method     : C:\CHEM32\1\DATA\202110\2021-10-19 10-12-55\STANDARDMTH.M
Last changed    : 6/25/2020 1:31:14 PM by Lab 2.112
Analysis Method : C:\CHEM32\1\METHODS\STANDARDMTH.M
Last changed    : 10/19/2021 10:38:20 AM by Lab 2.112
                : (modified after loading)
Method Info     : HP5 (30x0.25x0.25): 50/8-120/0/15-200/0/25-300/10/50-310/5
                : ramped flow: 1/29/1-2; 260i320d; Split 100/1
  
```



Additional Info : Peak(s) manually integrated



=====
 Area Percent Report
 =====

```

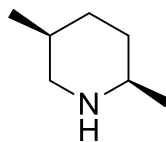
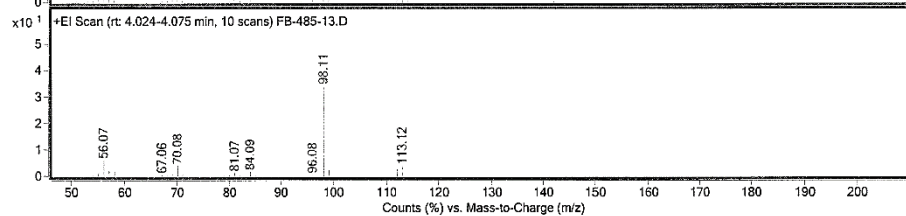
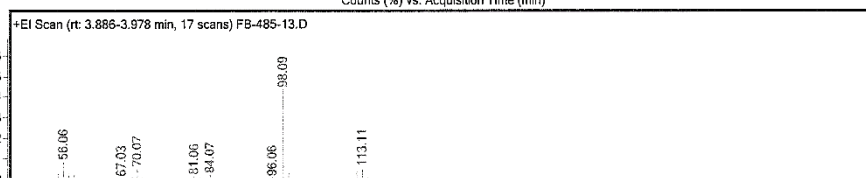
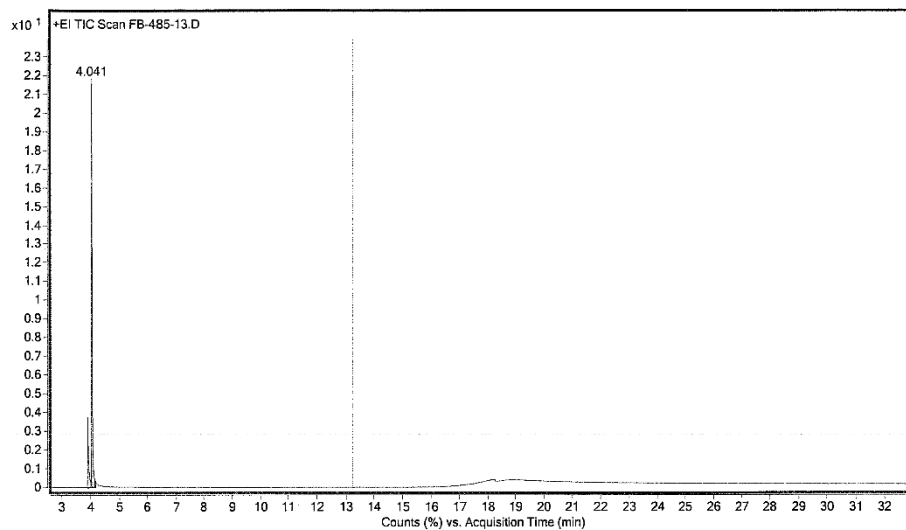
Sorted By      : Signal
Multiplier     : 1.0000
Dilution       : 1.0000
Use Multiplier & Dilution Factor with ISTDs
  
```

Signal 1: FID1 A, Front Signal

Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Height [pA]	Area %
1	4.907	BV	0.0225	6.57610	4.33842	0.39693
2	4.975	VB	0.0251	290.46887	180.75932	17.53271
3	5.149	BB	0.0266	1359.68030	816.28961	82.07035
Totals :				1656.72527	1001.38735	

Minor isomer
 Major isomer

=====
 *** End of Report ***



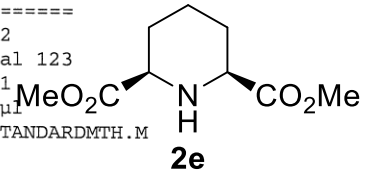
2d

Chemical Formula: C₇H₁₅N

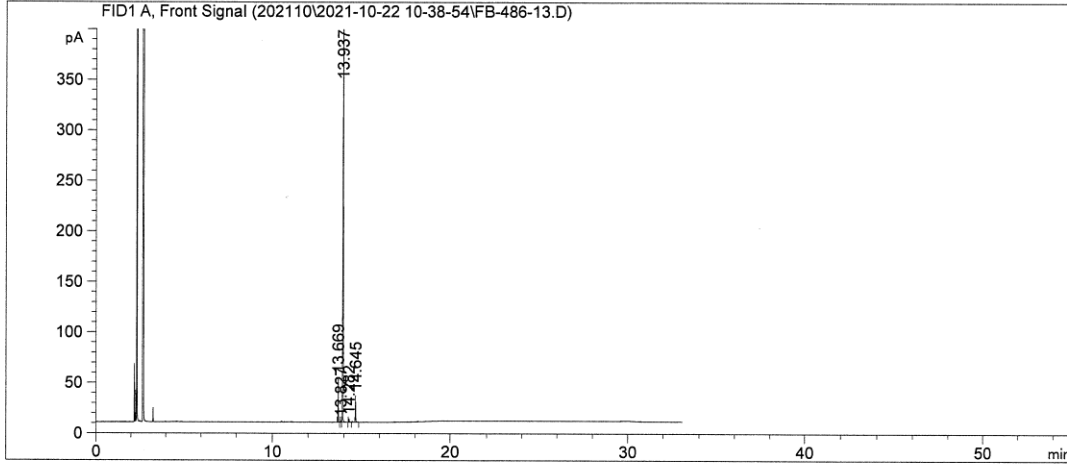
Exact Mass: 113.12


```

=====
Acq. Operator   : Lab 2.112                      Seq. Line : 12
Acq. Instrument : GC Lab.133                    Location  : Vial 123
Injection Date  : 10/22/2021 6:03:36 PM        Inj       : 1
                                                    Inj Volume: 1 µl
Acq. Method     : C:\CHEM32\1\DATA\202110\2021-10-22 10-38-54\STANDARDMTH.M
Last changed    : 6/25/2020 1:31:14 PM by Lab 2.112
Analysis Method : C:\CHEM32\1\METHODS\STANDARDMTH.M
Last changed    : 6/25/2020 1:31:14 PM by Lab 2.112
Method Info     : HP5 (30x0.25x0.25): 50/8-120/0/15-200/0/25-300/10/50-310/5
                  ramped flow: 1/29/1-2; 260i320d; Split 100/1
  
```



Additional Info : Peak(s) manually integrated



=====
 Area Percent Report
 =====

```

Sorted By      : Signal
Multiplier     : 1.0000
Dilution       : 1.0000
Use Multiplier & Dilution Factor with ISTDs
  
```

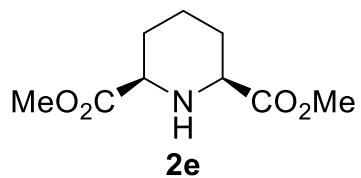
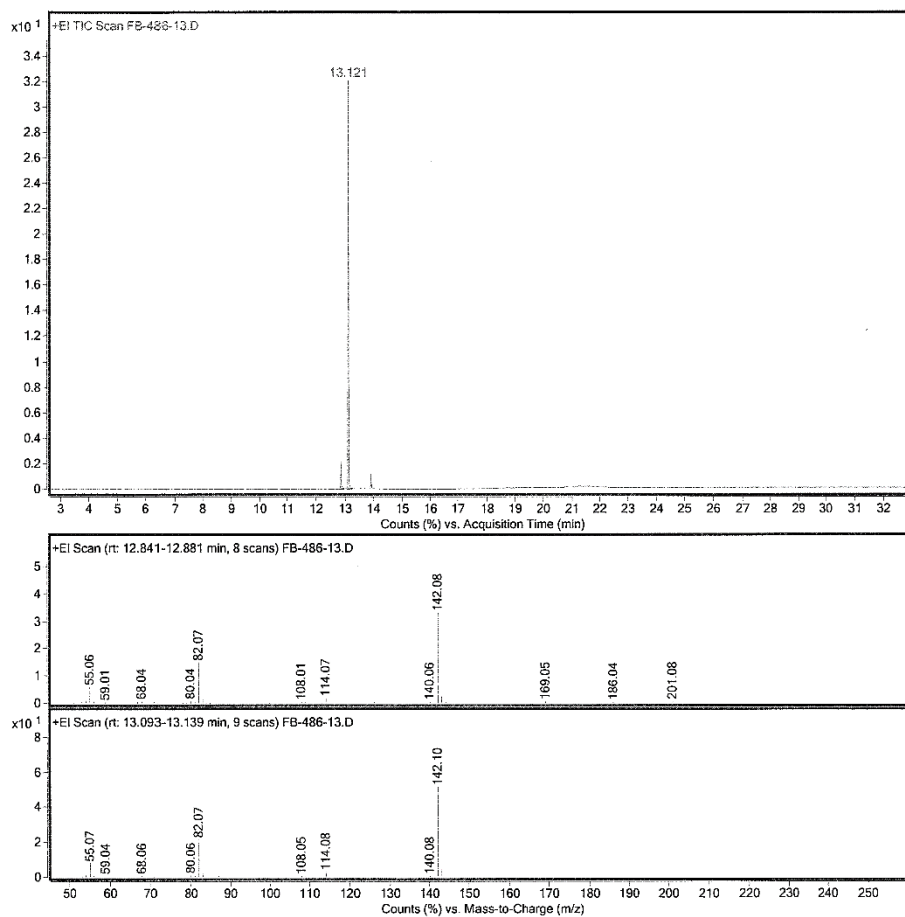
Signal 1: FID1 A, Front Signal

Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Height [pA]	Area %
1	13.669	BB	0.0241	66.70072	43.93755	6.04239
2	13.827	BV	0.0251	1.96088	1.22400	0.17764
3	13.937	VB	0.0276	989.72742	523.94629	89.65897
4	14.282	BB	0.0263	5.60542	3.16343	0.50779
5	14.645	BB	0.0233	39.88549	26.31268	3.61321
Totals :				1103.87993	598.58394	

Major isomer

Minor isomer

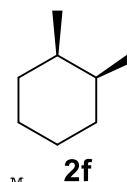
=====
 *** End of Report ***



Chemical Formula: C₉H₁₅NO₄

Exact Mass: 201.10

Data File C:\CHEM32\1\DATA\202110\2021-10-19 10-12-55\FB-485-3.D
 Sample Name: FB-485-3

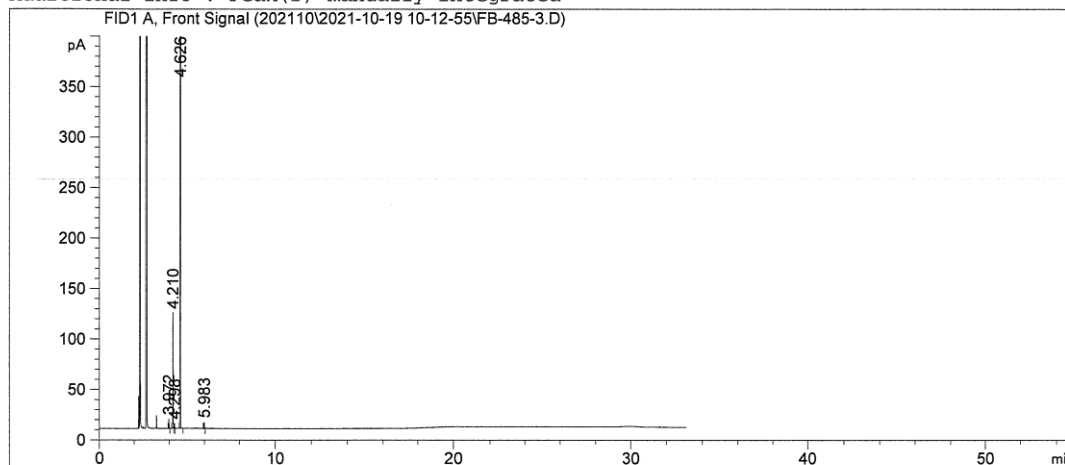


```

=====
Acq. Operator   : Lab 2.112                      Seq. Line :    3
Acq. Instrument : GC Lab.133                     Location  : Vial 113
Injection Date  : 10/19/2021 11:38:01 AM        Inj       :    1
                                                    Inj Volume: 1 µl

Acq. Method     : C:\CHEM32\1\DATA\202110\2021-10-19 10-12-55\STANDARDMTH.M
Last changed    : 6/25/2020 1:31:14 PM by Lab 2.112
Analysis Method : C:\CHEM32\1\METHODS\STANDARDMTH.M
Last changed    : 10/19/2021 10:38:20 AM by Lab 2.112
                  (modified after loading)
Method Info     : HP5 (30x0.25x0.25): 50/8-120/0/15-200/0/25-300/10/50-310/5
                  ramped flow: 1/29/1-2; 260i320d; Split 100/1
  
```

Additional Info : Peak(s) manually integrated



Area Percent Report

```

Sorted By      : Signal
Multiplier     : 1.0000
Dilution       : 1.0000
Use Multiplier & Dilution Factor with ISTDs
  
```

Signal 1: FID1 A, Front Signal

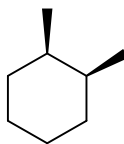
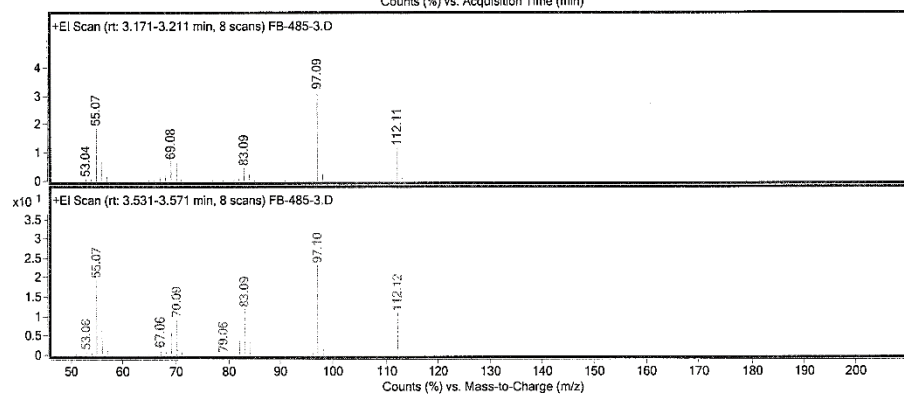
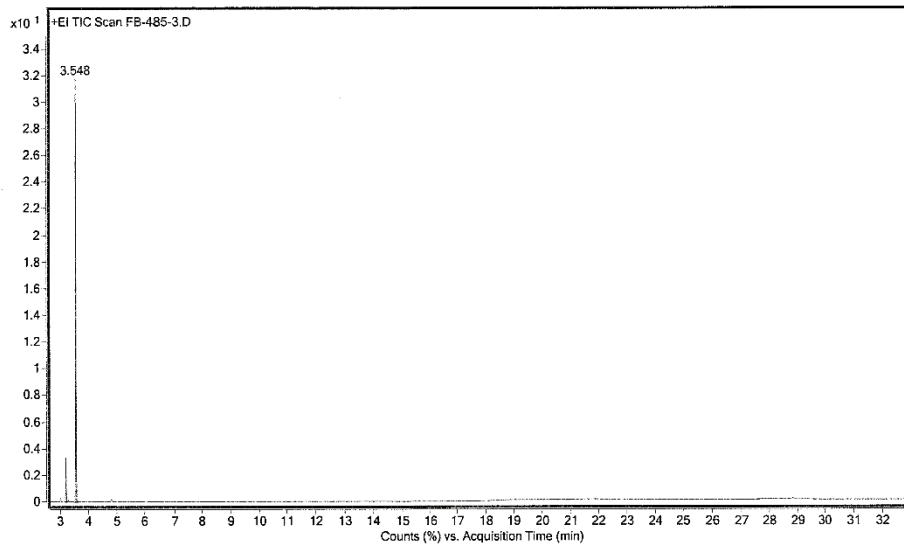
Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Height [pA]	Area %
1	3.972	BB	0.0237	14.14544	9.09770	0.57993
2	4.210	BB	0.0222	162.48473	114.21162	6.66147
3	4.298	BB	0.0226	6.87270	4.70320	0.28176
4	4.626	BB	0.0245	2244.78589	1448.83557	92.03069
5	5.983	BB	0.0283	10.88226	6.01377	0.44615

Minor isomer

Major isomer

Totals : 2439.17101 1582.86187

*** End of Report ***



2f

Chemical Formula: C₈H₁₆

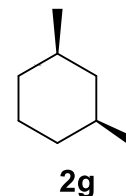
Exact Mass: 112.13

Data File C:\CHEM32\1\DATA\202110\2021-10-19 10-12-55\FB-485-4.D
 Sample Name: FB-485-4

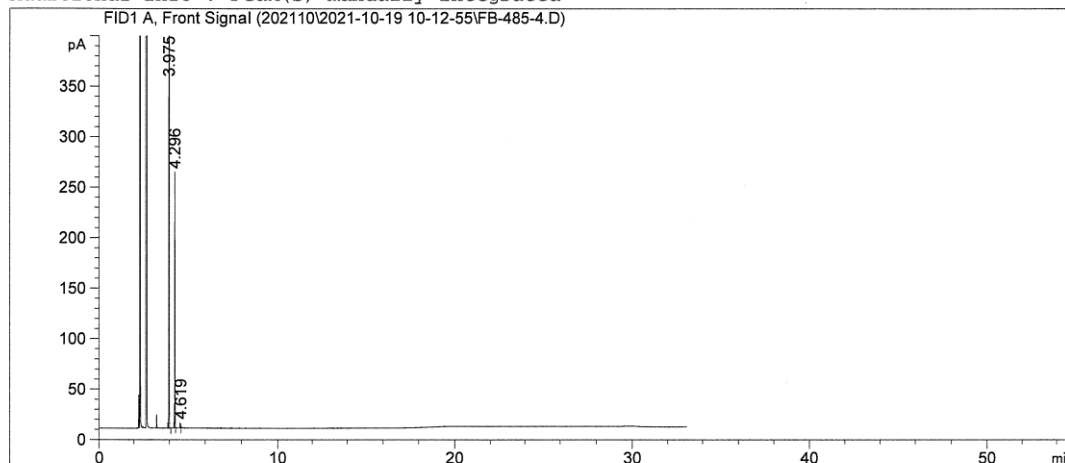
```

=====
Acq. Operator   : Lab 2.112                      Seq. Line :    4
Acq. Instrument : GC Lab.133                     Location  : Vial 114
Injection Date  : 10/19/2021 12:17:55 PM        Inj       :    1
                                                Inj Volume: 1 µl

Acq. Method     : C:\CHEM32\1\DATA\202110\2021-10-19 10-12-55\STANDARDMTH.M
Last changed    : 6/25/2020 1:31:14 PM by Lab 2.112
Analysis Method : C:\CHEM32\1\METHODS\STANDARDMTH.M
Last changed    : 10/19/2021 10:38:20 AM by Lab 2.112
                  (modified after loading)
Method Info     : HP5 (30x0.25x0.25): 50/8-120/0/15-200/0/25-300/10/50-310/5
                  ramped flow: 1/29/1-2; 260i320d; Split 100/1
  
```



Additional Info : Peak(s) manually integrated



Area Percent Report

```

Sorted By      : Signal
Multiplier     : 1.0000
Dilution       : 1.0000
Use Multiplier & Dilution Factor with ISTDs
  
```

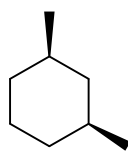
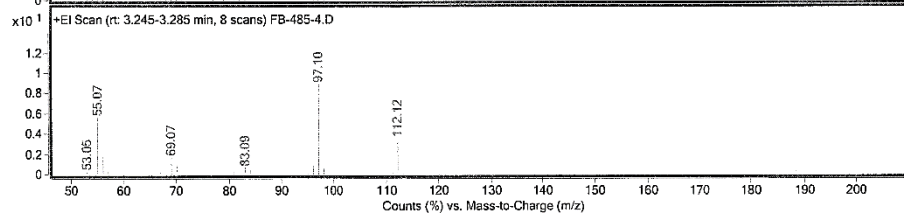
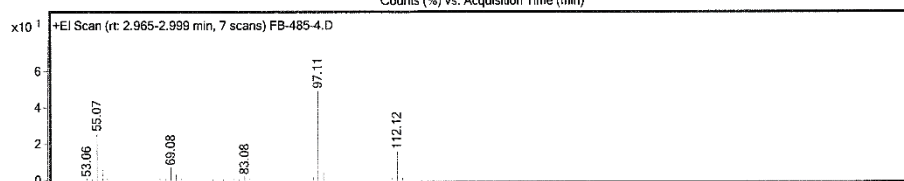
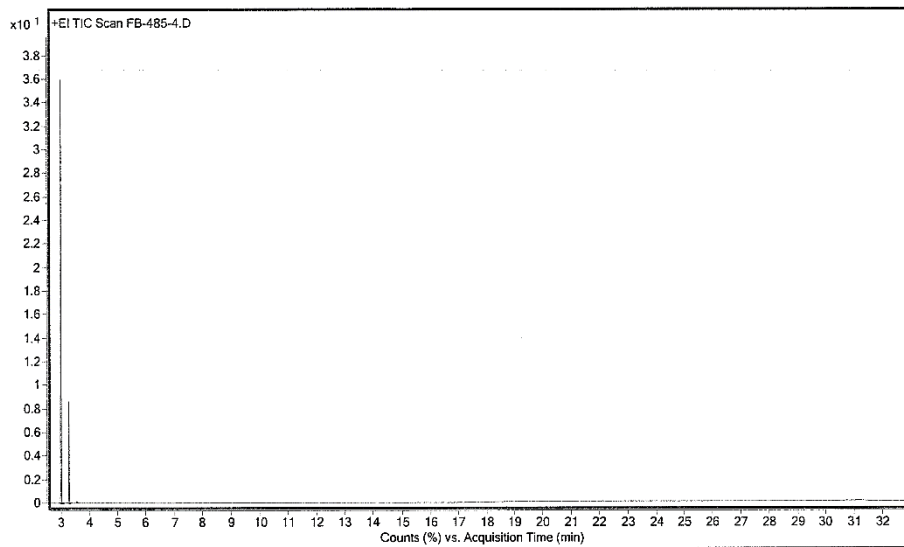
Signal 1: FID1 A, Front Signal

Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Height [pA]	Area %
1	3.975	BB	0.0214	1821.75989	1348.57605	83.20954
2	4.296	BB	0.0231	361.31216	252.41537	16.50306
3	4.619	BB	0.0239	6.29218	4.19018	0.28740

Major isomer
 Minor isomer

Totals : 2189.36423 1605.18160

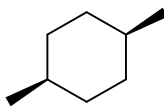
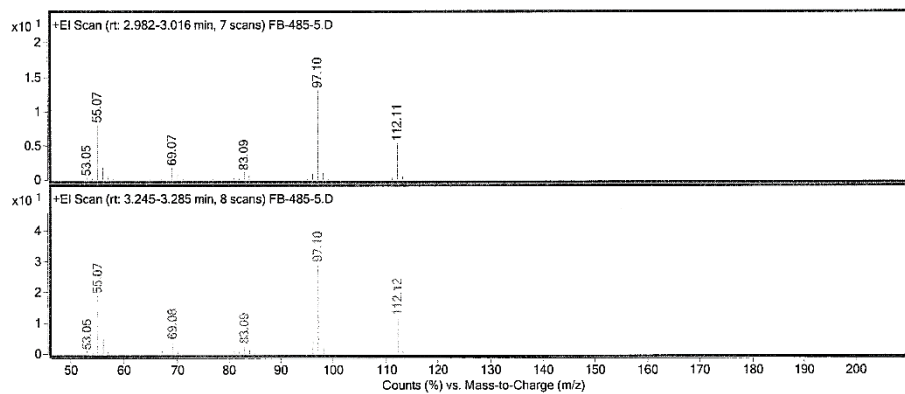
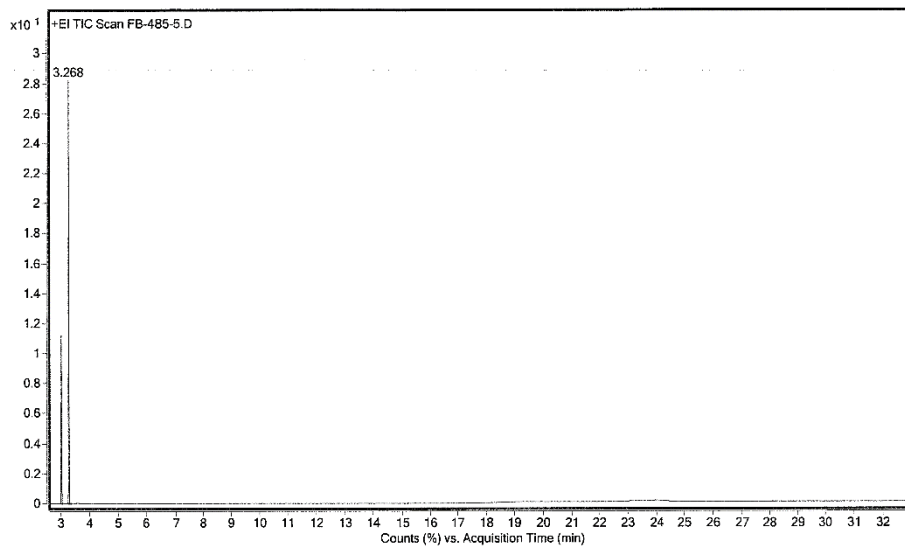
*** End of Report ***



2g

Chemical Formula: C₈H₁₆

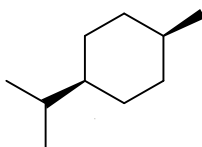
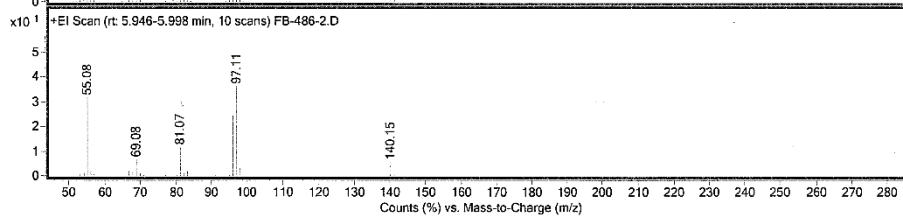
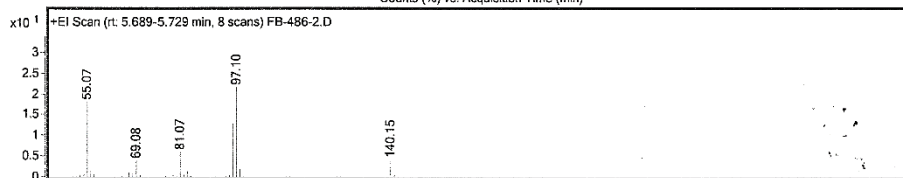
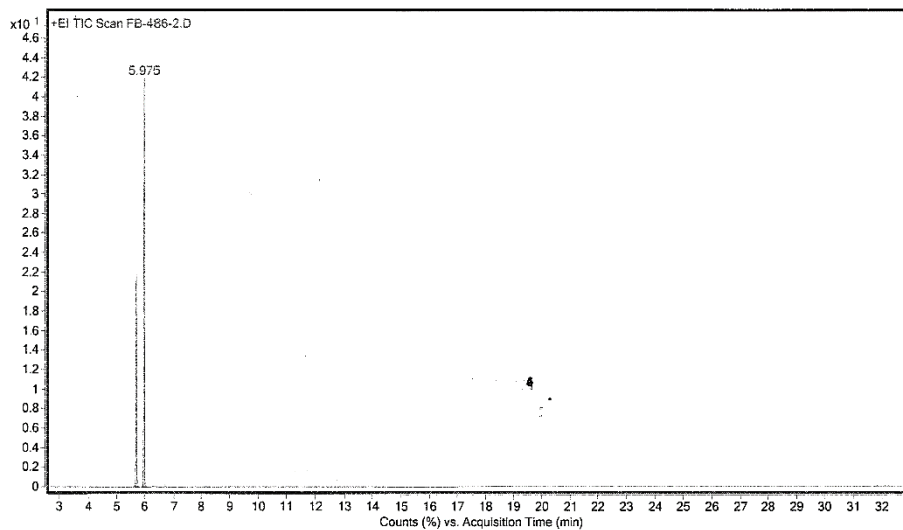
Exact Mass: 112.13



2h

Chemical Formula: C₈H₁₆

Exact Mass: 112.13



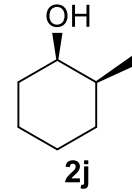
2i

Chemical Formula: C₁₀H₂₀

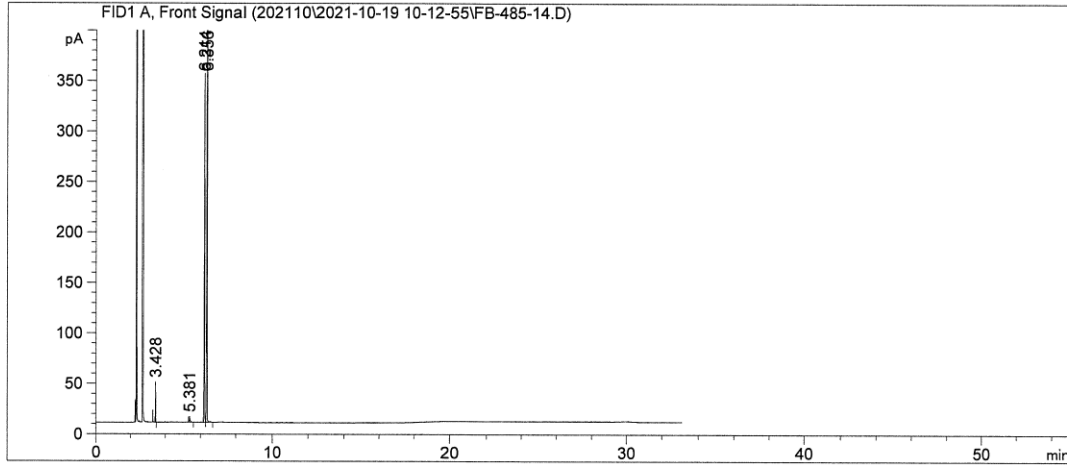
Exact Mass: 140.16

```

=====
Acq. Operator   : Lab 2.112                      Seq. Line : 14
Acq. Instrument : GC Lab.133                     Location  : Vial 124
Injection Date  : 10/19/2021 6:57:46 PM          Inj       : 1
                                                Inj Volume: 1 µl
Acq. Method     : C:\CHEM32\1\DATA\202110\2021-10-19 10-12-55\STANDARDMTH.M
Last changed    : 6/25/2020 1:31:14 PM by Lab 2.112
Analysis Method : C:\CHEM32\1\METHODS\STANDARDMTH.M
Last changed    : 10/19/2021 10:38:20 AM by Lab 2.112
                  (modified after loading)
Method Info     : HP5 (30x0.25x0.25): 50/8-120/0/15-200/0/25-300/10/50-310/5
                  ramped flow: 1/29/1-2; 260i320d; Split 100/1
  
```



Additional Info : Peak(s) manually integrated



=====
 Area Percent Report
 =====

```

Sorted By      : Signal
Multiplier     : 1.0000
Dilution       : 1.0000
Use Multiplier & Dilution Factor with ISTDs
  
```

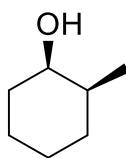
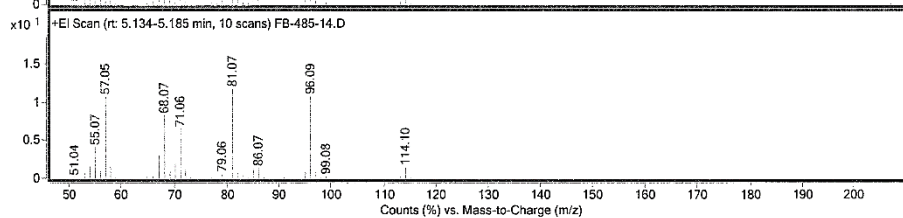
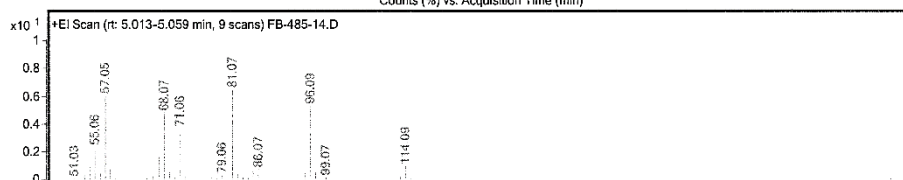
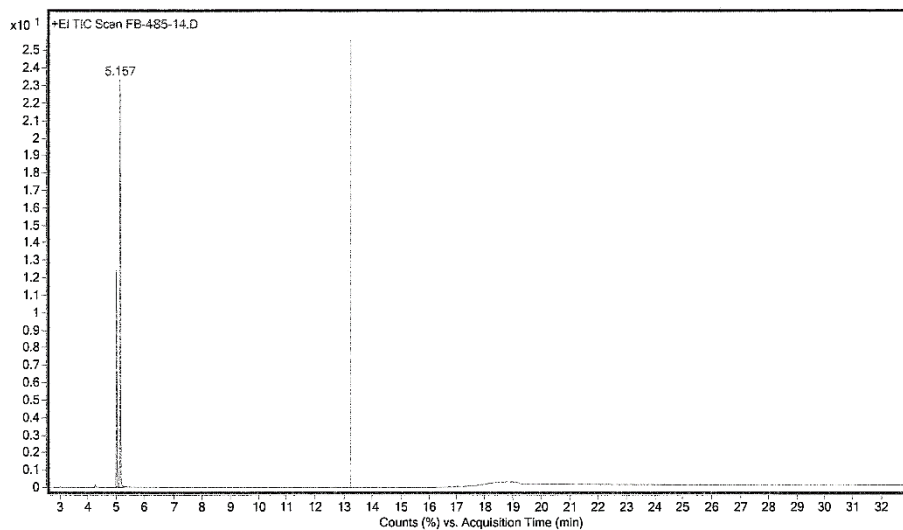
Signal 1: FID1 A, Front Signal

Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Height [pA]	Area %
1	3.428	BB	0.0185	46.96034	39.94128	2.14923
2	5.381	BB	0.0383	15.63956	5.72065	0.71577
3	6.214	BV	0.0309	676.78888	344.72583	30.97457
4	6.356	VB	0.0324	1445.59363	715.04388	66.16042
Totals :				2184.98240	1105.43164	

Minor isomer

Major isomer

=====
 *** End of Report ***



2j

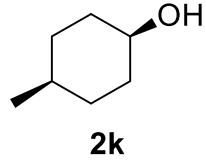
Chemical Formula: C₇H₁₄O

Exact Mass: 114.10

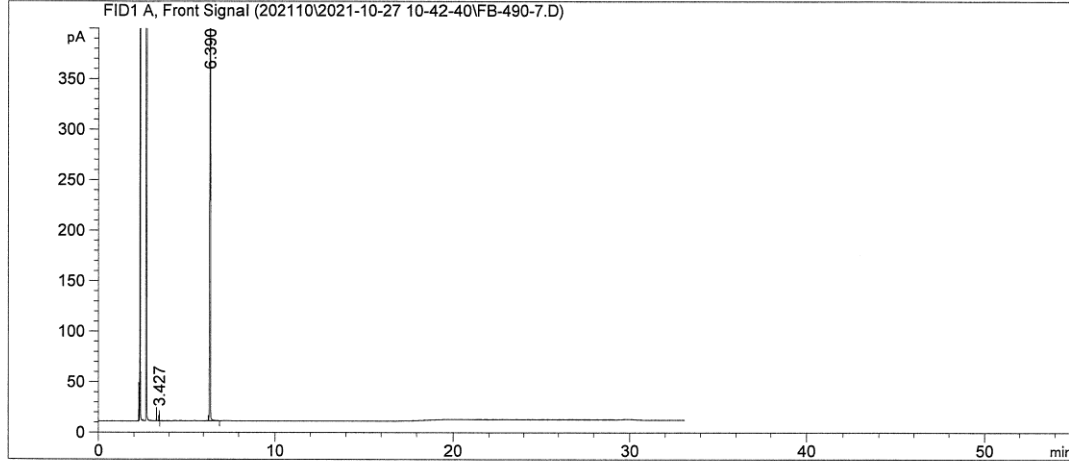
Data File C:\CHEM32\1\DATA\202110\2021-10-27 10-42-40\FB-490-7.D
 Sample Name: FB-490-7

```

=====
Acq. Operator   : Lab 2.112                      Seq. Line :    7
Acq. Instrument : GC Lab.133                     Location  : Vial 117
Injection Date  : 10/27/2021 2:44:31 PM          Inj       :    1
                                                    Inj Volume: 1 µl
Acq. Method    : C:\CHEM32\1\DATA\202110\2021-10-27 10-42-40\STANDARDMTH.M
Last changed   : 6/25/2020 1:31:14 PM by Lab 2.112
Analysis Method: C:\CHEM32\1\METHODS\STANDARDMTH.M
Last changed   : 6/25/2020 1:31:14 PM by Lab 2.112
Method Info    : HP5 (30x0.25x0.25): 50/8-120/0/15-200/0/25-300/10/50-310/5
                ramped flow: 1/29/1-2; 260i320d; Split 100/1
  
```



Additional Info : Peak(s) manually integrated



=====
 Area Percent Report
 =====

```

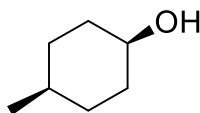
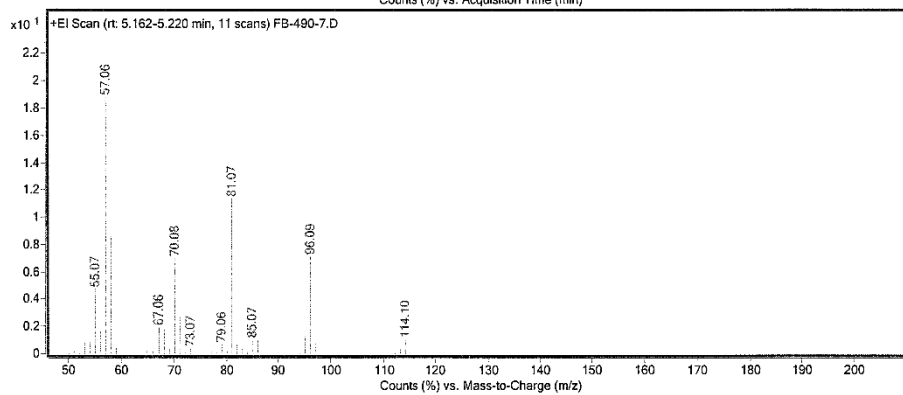
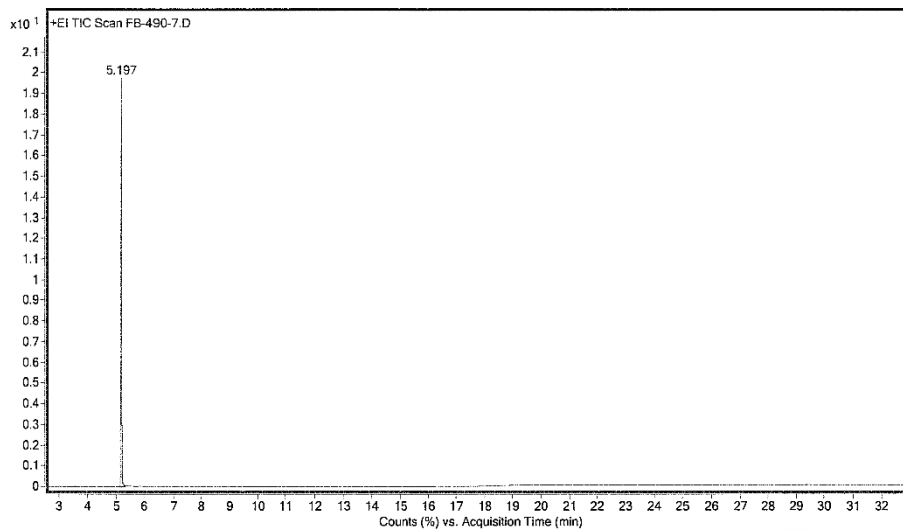
Sorted By      :      Signal
Multiplier     :      1.0000
Dilution       :      1.0000
Use Multiplier & Dilution Factor with ISTDs
  
```

Signal 1: FID1 A, Front Signal

Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Height [pA]	Area %
1	3.427	BB	0.0186	11.92049	10.04867	0.54980
2	6.390	BB	0.0343	2156.21558	875.12555	99.45020
Totals :				2168.13606	885.17422	

In this case it is assumed the two isomers have the same GC retention time under the conditions of the analysis. The diastereoselective ratio is thus determined by NMR.

=====
 *** End of Report ***



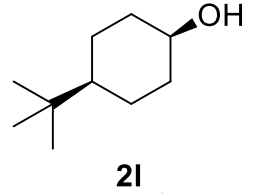
2k

Chemical Formula: C₇H₁₄O

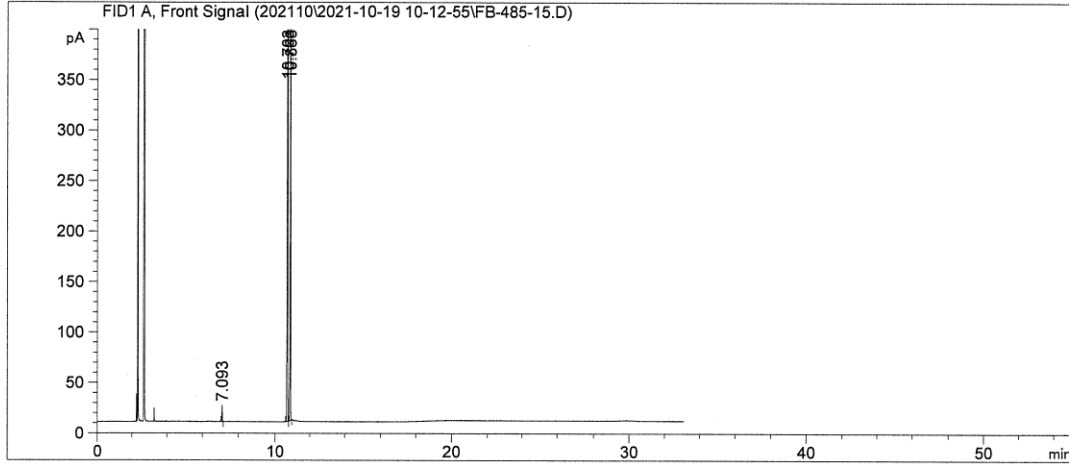
Exact Mass: 114.10

```

=====
Acq. Operator   : Lab 2.112                      Seq. Line : 15
Acq. Instrument : GC Lab.133                     Location  : Vial 125
Injection Date  : 10/19/2021 7:37:49 PM         Inj       : 1
                                                Inj Volume: 1 µl
Acq. Method     : C:\CHEM32\1\DATA\202110\2021-10-19 10-12-55\STANDARDMTH.M
Last changed    : 6/25/2020 1:31:14 PM by Lab 2.112
Analysis Method : C:\CHEM32\1\METHODS\STANDARDMTH.M
Last changed    : 10/19/2021 10:38:20 AM by Lab 2.112
                  (modified after loading)
Method Info     : HP5 (30x0.25x0.25): 50/8-120/0/15-200/0/25-300/10/50-310/5
                  ramped flow: 1/29/1-2; 260i320d; Split 100/1
  
```



Additional Info : Peak(s) manually integrated



=====
 Area Percent Report
 =====

```

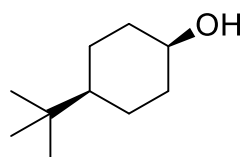
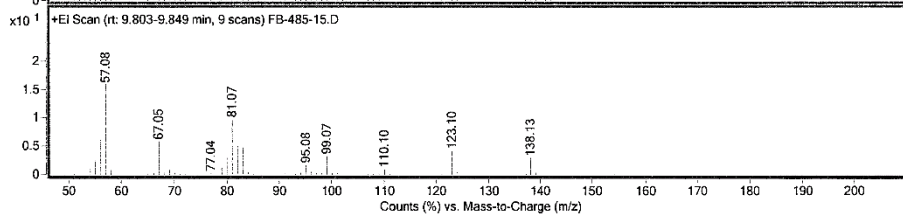
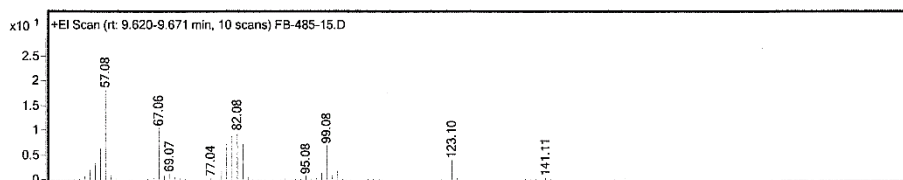
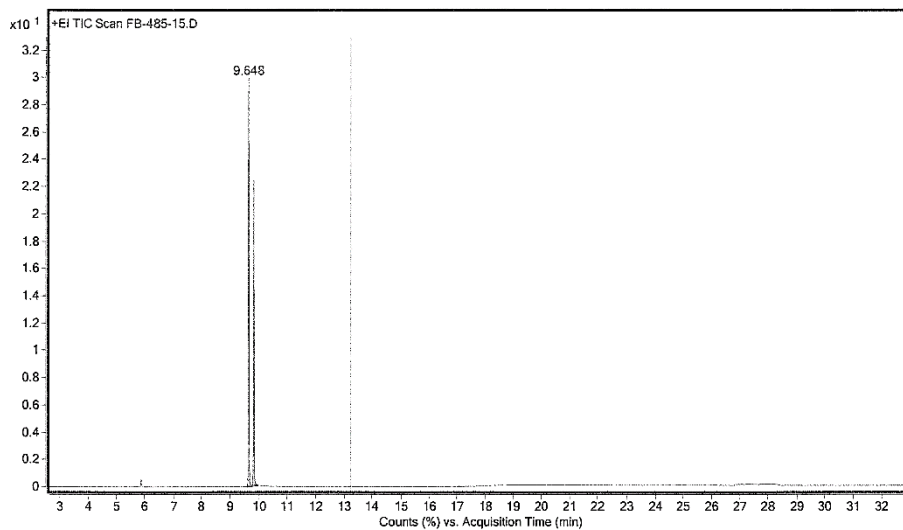
Sorted By      :      Signal
Multiplier     :      1.0000
Dilution       :      1.0000
Use Multiplier & Dilution Factor with ISTDs
  
```

Signal 1: FID1 A, Front Signal

Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Height [pA]	Area %
1	7.093	BB	0.0311	31.36236	15.83591	1.01663
2	10.703	BB	0.0306	1787.68042	833.88367	57.94883
3	10.866	BB	0.0308	1265.88660	647.17603	41.03454
Totals :				3084.92938	1496.89561	

Major isomer
 Minor isomer

=====
 *** End of Report ***



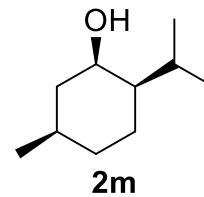
2I

Chemical Formula: C₁₀H₂₀O
 Exact Mass: 156.15

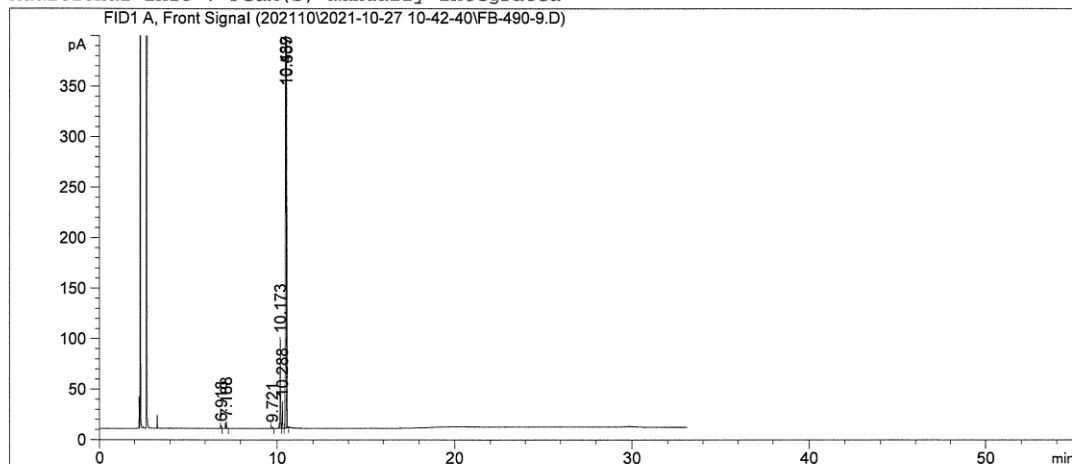
Data File C:\CHEM32\1\DATA\202110\2021-10-27 10-42-40\FB-490-9.D
 Sample Name: FB-490-9

```

=====
Acq. Operator   : Lab 2.112                      Seq. Line :    9
Acq. Instrument : GC Lab.133                    Location  : Vial 119
Injection Date  : 10/27/2021 4:04:25 PM         Inj       :    1
                                                Inj Volume: 1 µl
Acq. Method     : C:\CHEM32\1\DATA\202110\2021-10-27 10-42-40\STANDARDMTH.M
Last changed    : 6/25/2020 1:31:14 PM by Lab 2.112
Analysis Method : C:\CHEM32\1\METHODS\STANDARDMTH.M
Last changed    : 6/25/2020 1:31:14 PM by Lab 2.112
Method Info     : HP5 (30x0.25x0.25): 50/8-120/0/15-200/0/25-300/10/50-310/5
                  ramped flow: 1/29/1-2; 260i320d; Split 100/1
  
```



Additional Info : Peak(s) manually integrated



=====
 Area Percent Report
 =====

```

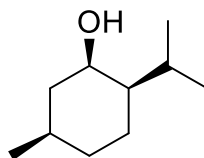
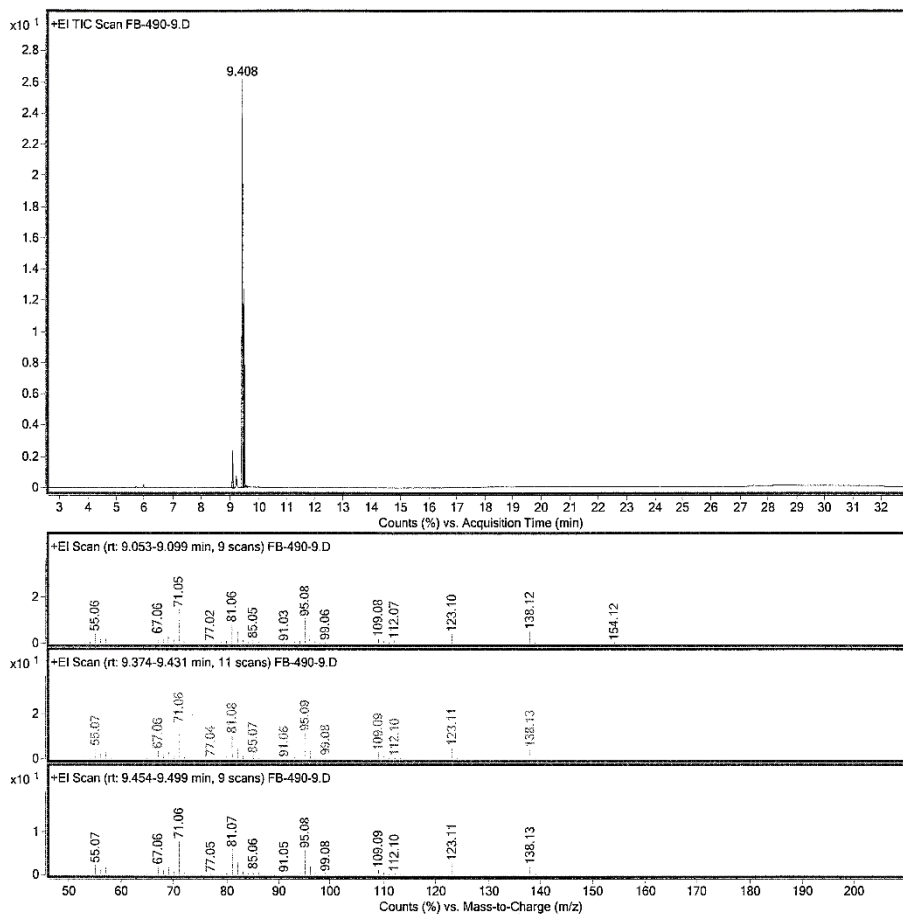
Sorted By      :      Signal
Multiplier     :      1.0000
Dilution       :      1.0000
Use Multiplier & Dilution Factor with ISTDs
  
```

Signal 1: FID1 A, Front Signal

Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Height [pA]	Area %
1	6.918	BB	0.0301	5.61551	2.86615	0.17775
2	7.188	BB	0.0316	14.09221	6.96992	0.44605
3	9.721	BB	0.0335	3.67109	1.62879	0.11620
4	10.173	BV	0.0291	168.53304	89.97670	5.33450
5	10.288	VB	0.0318	51.99598	26.36761	1.64580
6	10.489	BV	0.0321	2272.14526	1064.27356	71.91914
7	10.537	VB	0.0261	643.25226	380.25970	20.36056
Totals :				3159.30535	1572.34243	

Minor isomer
 Minor isomer
 Major isomer
 Minor isomer

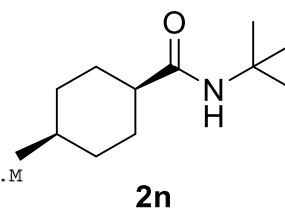
=====
 *** End of Report ***



2m

Chemical Formula: C₁₀H₂₀O

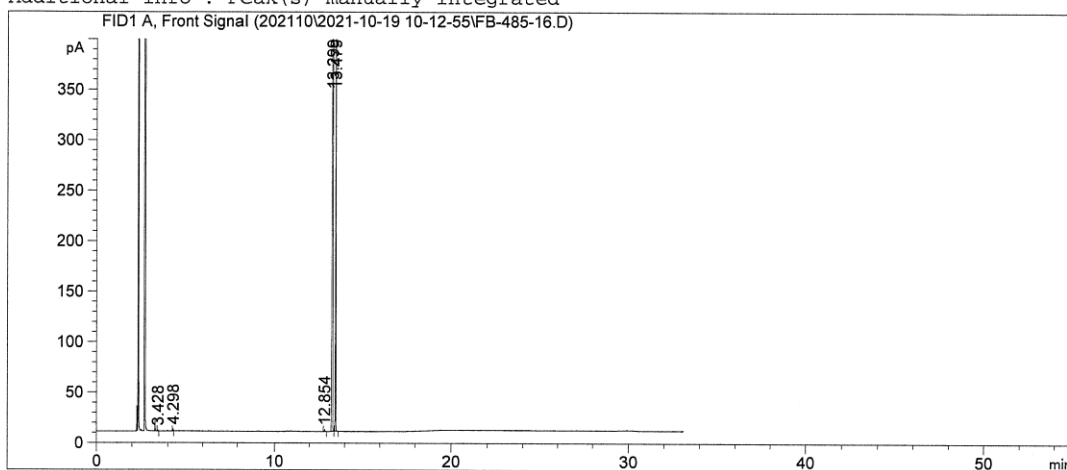
Exact Mass: 156.15



```

=====
Acq. Operator   : Lab 2.112                      Seq. Line : 16
Acq. Instrument : GC Lab.133                     Location  : Vial 126
Injection Date  : 10/19/2021 8:17:47 PM         Inj       : 1
                                                Inj Volume: 1 µl
Acq. Method     : C:\CHEM32\1\DATA\202110\2021-10-19 10-12-55\STANDARDMTH.M
Last changed    : 6/25/2020 1:31:14 PM by Lab 2.112
Analysis Method : C:\CHEM32\1\METHODS\STANDARDMTH.M
Last changed    : 10/19/2021 10:38:20 AM by Lab 2.112
                (modified after loading)
Method Info     : HP5 (30x0.25x0.25): 50/8-120/0/15-200/0/25-300/10/50-310/5
                ramped flow: 1/29/1-2; 260i320d; Split 100/1
  
```

Additional Info : Peak(s) manually integrated



=====
 Area Percent Report
 =====

Sorted By : Signal
 Multiplier : 1.0000
 Dilution : 1.0000
 Use Multiplier & Dilution Factor with ISTDs

Signal 1: FID1 A, Front Signal

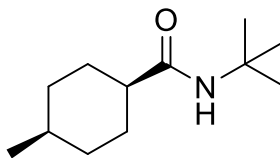
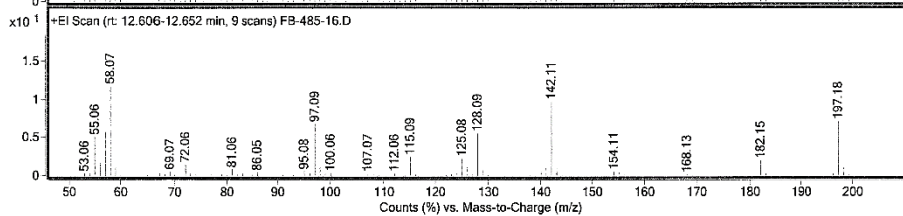
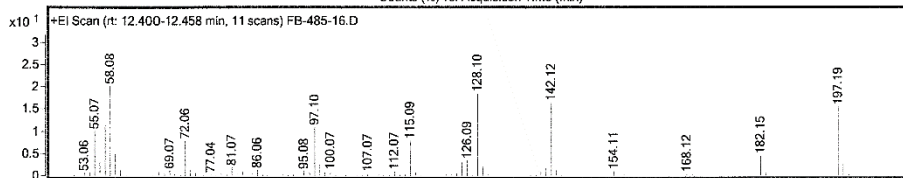
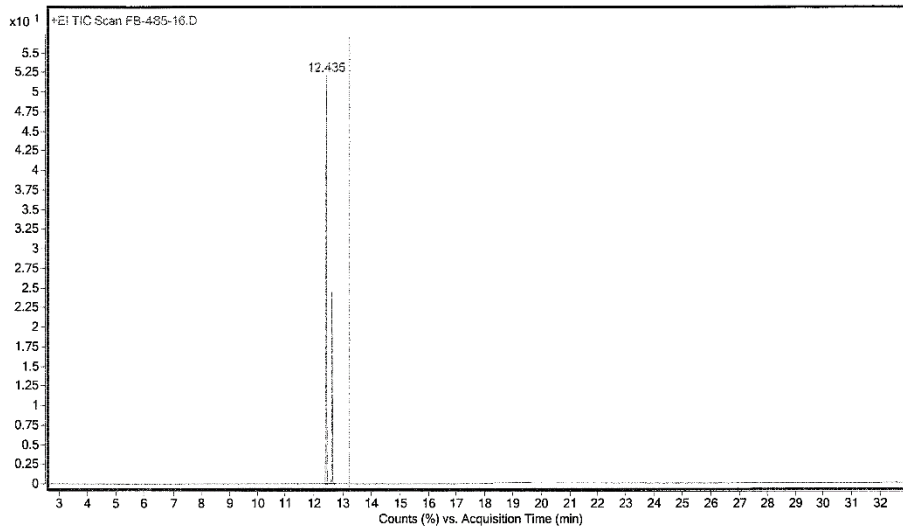
Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Height [pA]	Area %
1	3.428	BB	0.0200	1.40677	1.02860	0.03843
2	4.298	BB	0.0228	3.10197	2.09901	0.08474
3	12.854	BB	0.0332	4.26904	1.97709	0.11663
4	13.299	BB	0.0340	2804.69897	1183.88403	76.62218
5	13.479	BB	0.0277	846.95007	464.42343	23.13801

Major isomer

Minor isomer

Totals : 3660.42683 1653.41216

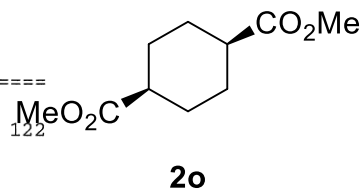
=====
 *** End of Report ***



2n

Chemical Formula: C₁₂H₂₃NO

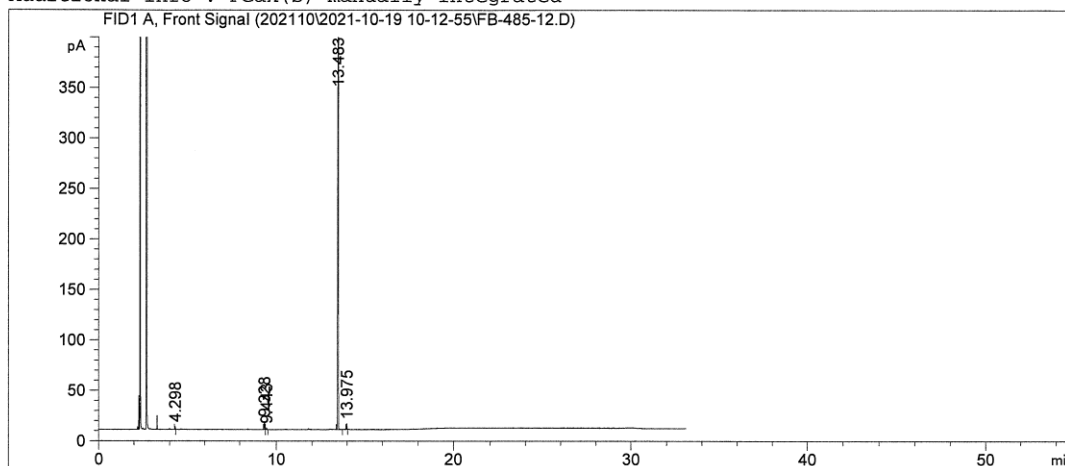
Exact Mass: 197.18



```

=====
Acq. Operator   : Lab 2.112                      Seq. Line : 12
Acq. Instrument : GC Lab.133                     Location  : Vial 122
Injection Date  : 10/19/2021 5:37:51 PM          Inj       : 1
                                                    Inj Volume: 1 µl
Acq. Method     : C:\CHEM32\1\DATA\202110\2021-10-19 10-12-55\STANDARDMTH.M
Last changed    : 6/25/2020 1:31:14 PM by Lab 2.112
Analysis Method : C:\CHEM32\1\METHODS\STANDARDMTH.M
Last changed    : 10/19/2021 10:38:20 AM by Lab 2.112
                  (modified after loading)
Method Info     : HP5 (30x0.25x0.25): 50/8-120/0/15-200/0/25-300/10/50-310/5
                  ramped flow: 1/29/1-2; 260i320d; Split 100/1
  
```

Additional Info : Peak(s) manually integrated



=====
 Area Percent Report
 =====

```

Sorted By      : Signal
Multiplier     : 1.0000
Dilution       : 1.0000
Use Multiplier & Dilution Factor with ISTDs
  
```

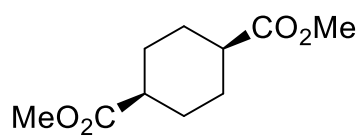
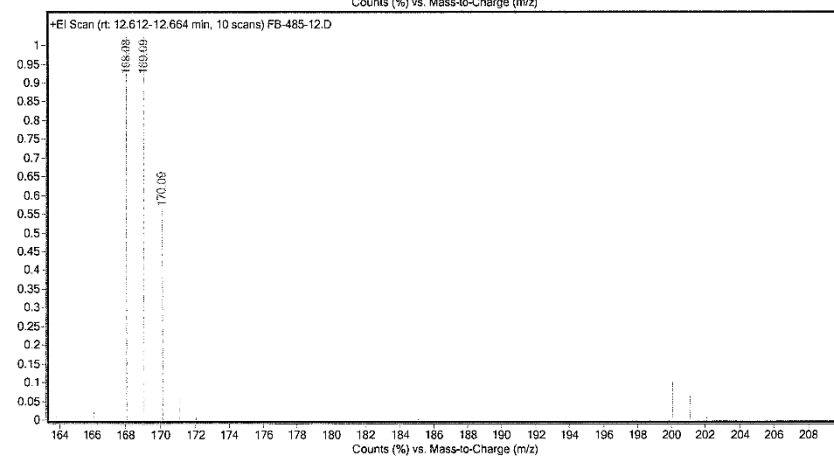
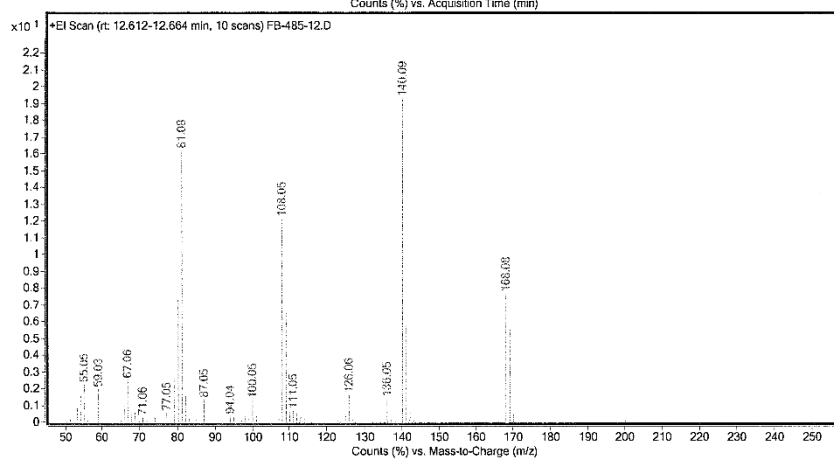
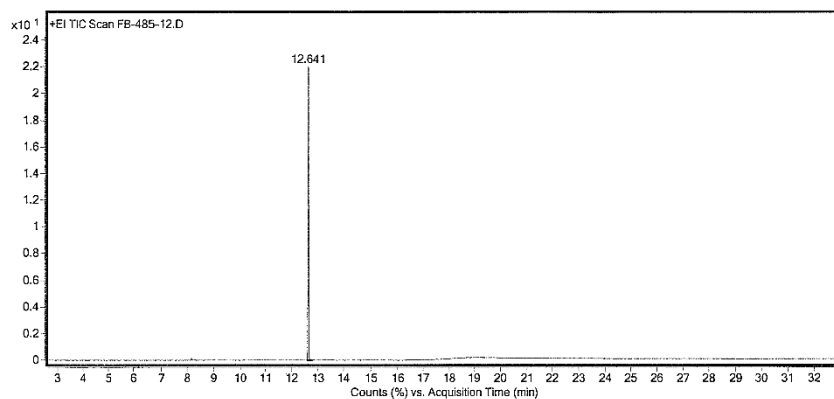
Signal 1: FID1 A, Front Signal

Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Height [pA]	Area %
1	4.298	BB	0.0226	4.20372	2.88682	0.17501
2	9.328	BB	0.0306	15.84037	8.18725	0.65949
3	9.443	BB	0.0339	3.51295	1.58207	0.14626
4	13.483	BB	0.0344	2369.54907	1015.98779	98.65204
5	13.975	BB	0.0236	8.82001	5.73210	0.36721

Totals : 2401.92613 1034.37604

In this case it is assumed the two isomers have the same GC retention time under the conditions of the analysis. The diastereoselective ratio is thus determined by NMR.

=====
 *** End of Report ***
 =====



2o

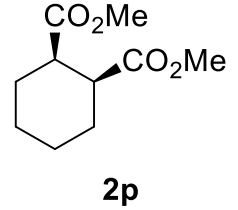
Chemical Formula: $C_{10}H_{16}O_4$
 Exact Mass: 200.10

Data File C:\CHEM32\1\DATA\202110\2021-10-27 10-42-40\FB-490-3.D
 Sample Name: FB-490-3

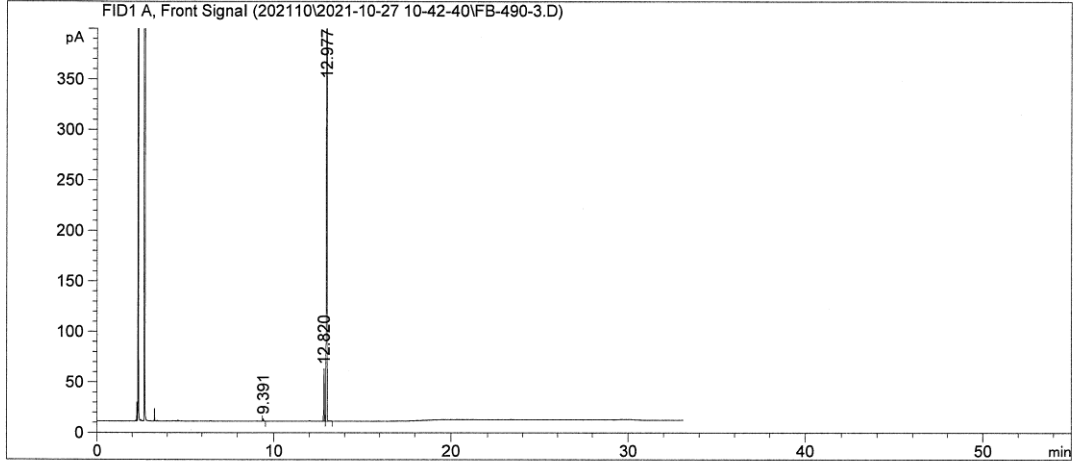
```

=====
Acq. Operator   : Lab 2.112                      Seq. Line :    3
Acq. Instrument : GC Lab.133                     Location  : Vial 133
Injection Date  : 10/27/2021 12:04:36 PM        Inj       :    1
                                                    Inj Volume: 1 µl

Acq. Method     : C:\CHEM32\1\DATA\202110\2021-10-27 10-42-40\STANDARDMTH.M
Last changed    : 6/25/2020 1:31:14 PM by Lab 2.112
Analysis Method : C:\CHEM32\1\METHODS\STANDARDMTH.M
Last changed    : 6/25/2020 1:31:14 PM by Lab 2.112
Method Info     : HP5 (30x0.25x0.25): 50/8-120/0/15-200/0/25-300/10/50-310/5
                  ramped flow: 1/29/1-2; 260i320d; Split 100/1
  
```



Additional Info : Peak(s) manually integrated



=====
 Area Percent Report
 =====

```

Sorted By      :      Signal
Multiplier     :      1.0000
Dilution       :      1.0000
Use Multiplier & Dilution Factor with ISTDs
  
```

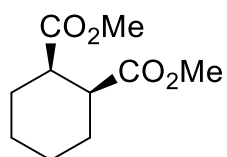
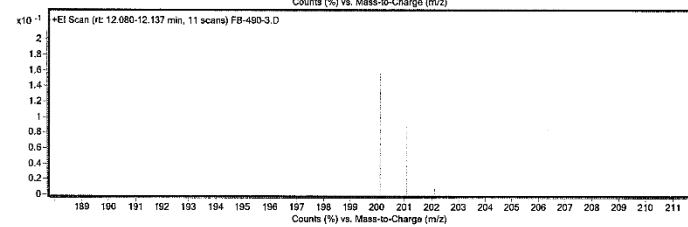
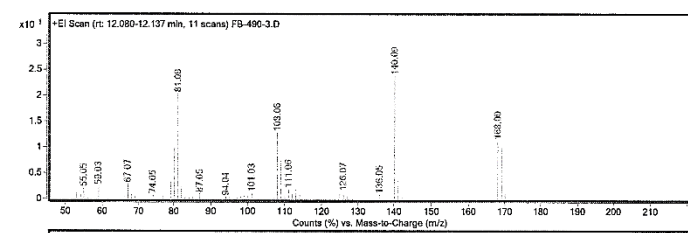
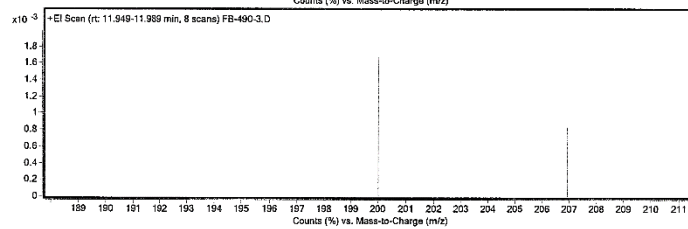
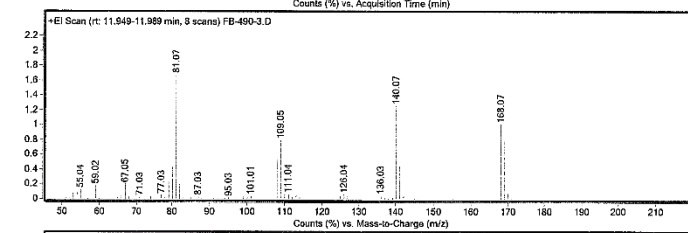
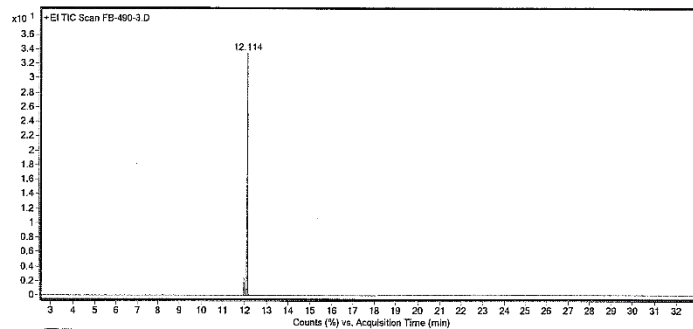
Signal 1: FID1 A, Front Signal

Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Height [pA]	Area %
1	9.391	BB	0.0324	5.49160	2.54459	0.21009
2	12.820	BV	0.0257	86.02828	51.89289	3.29113
3	12.977	VB	0.0343	2522.42065	1151.82837	96.49878

Minor isomer
 Major isomer

Totals : 2613.94054 1206.26585

=====
 *** End of Report ***



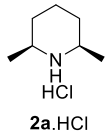
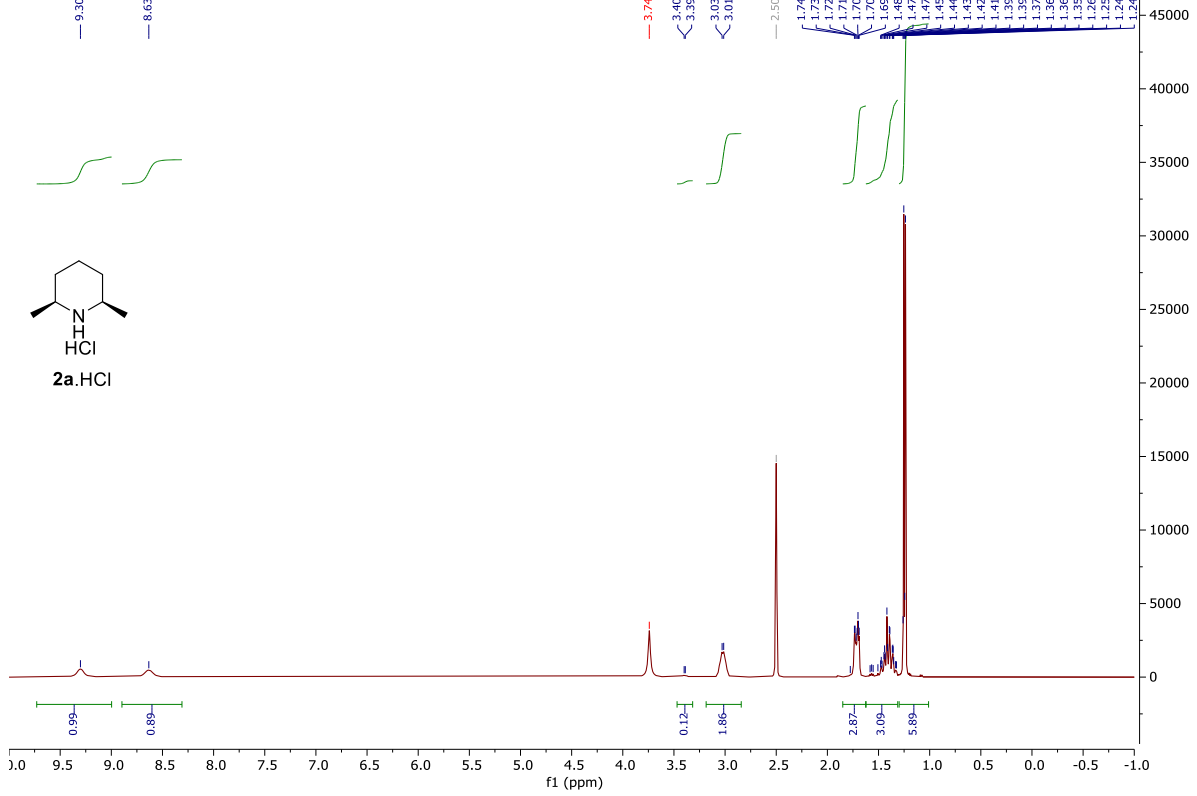
2p

Chemical Formula: $C_{10}H_{16}O_4$

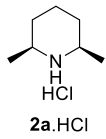
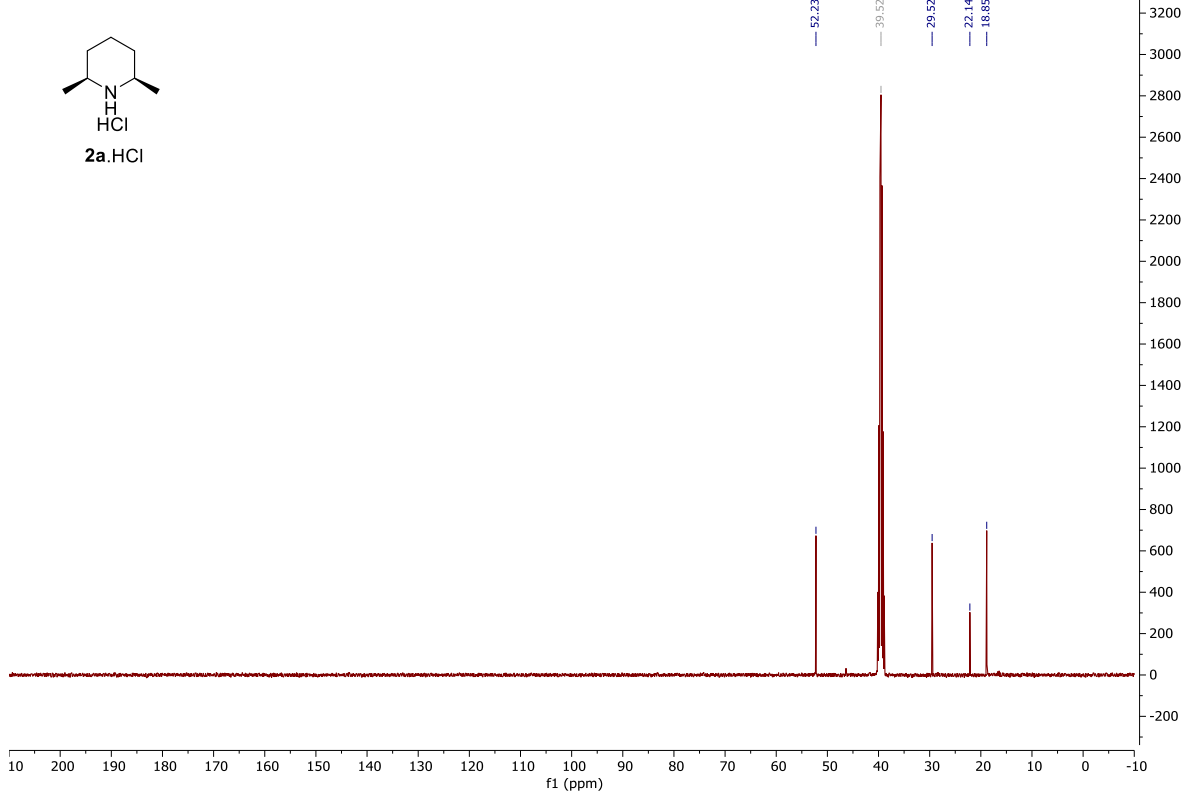
Exact Mass: 200.10

13. NMR Spectra

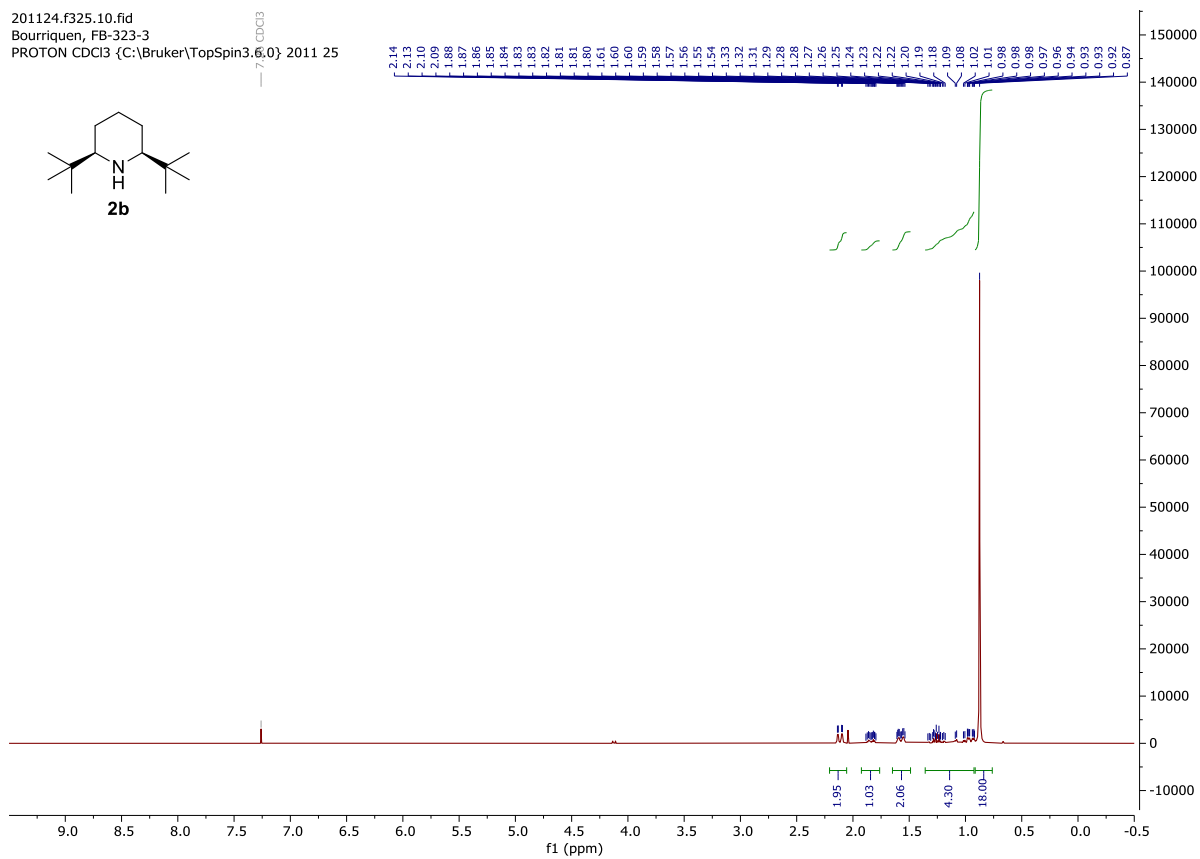
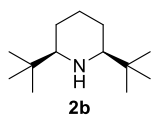
201208.405.10.fid
 Florian Bourriquen FB-333-5
 Au1H DMSO {C:\Bruker\TopSpin3.5pl6} 2012 7



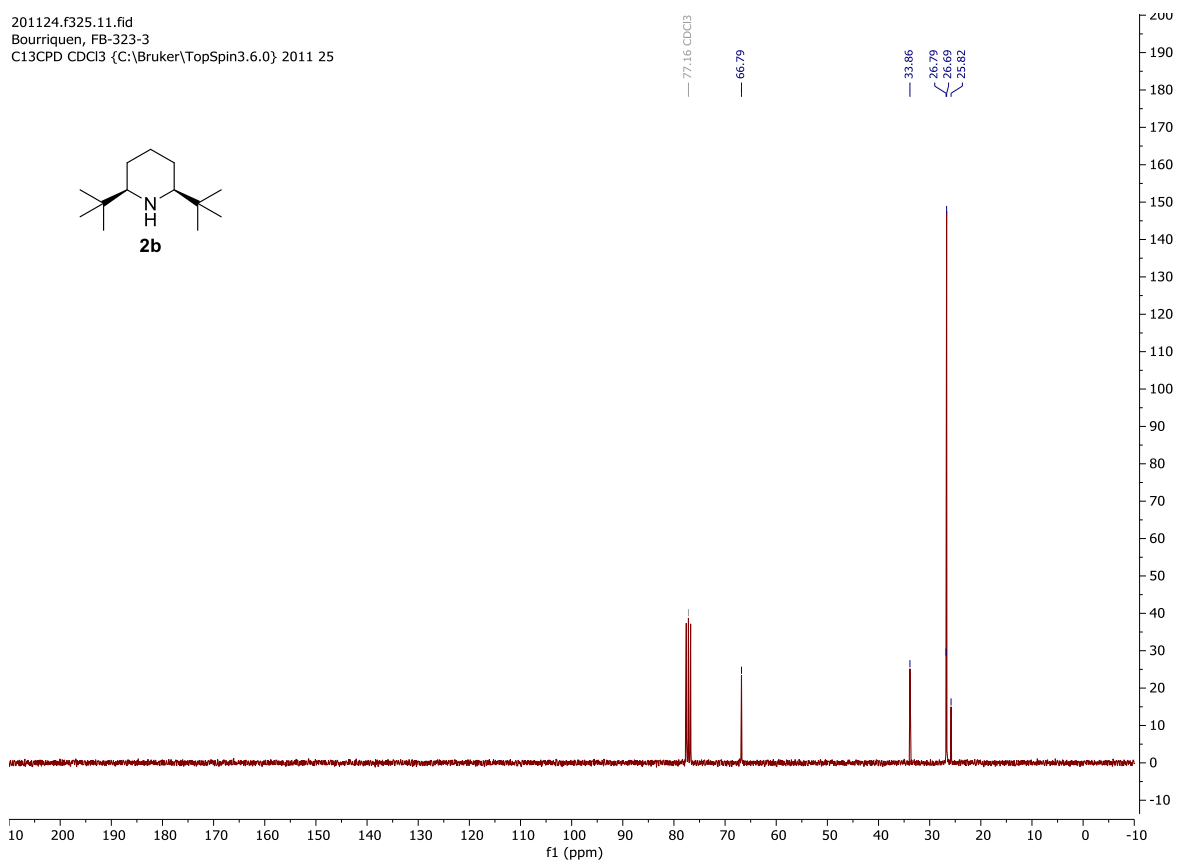
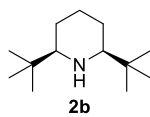
201208.405.11.fid
 Florian Bourriquen FB-333-5
 Au13C DMSO {C:\Bruker\TopSpin3.5pl6} 2012 7



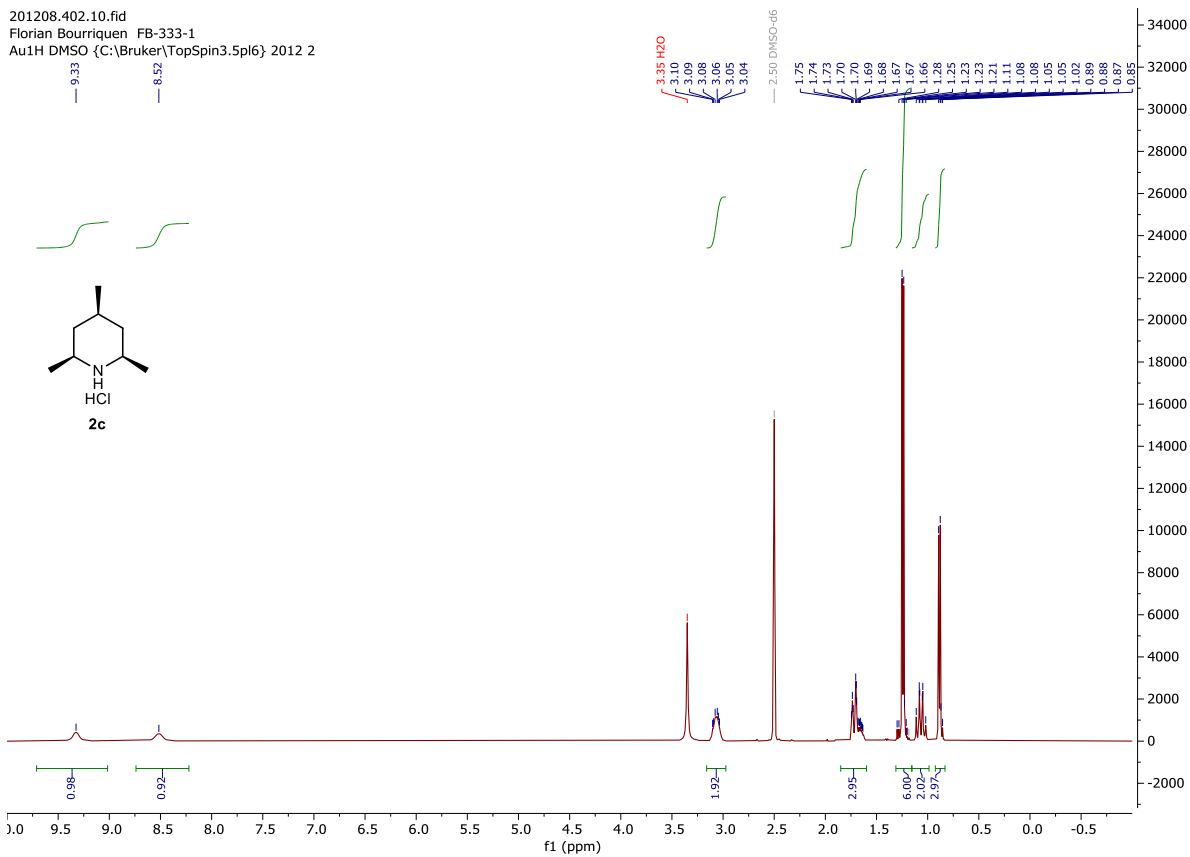
201124.f325.10.fid
Bourriquen, FB-323-3
PROTON CDCl3 {C:\Bruker\TopSpin3.6.0} 2011 25



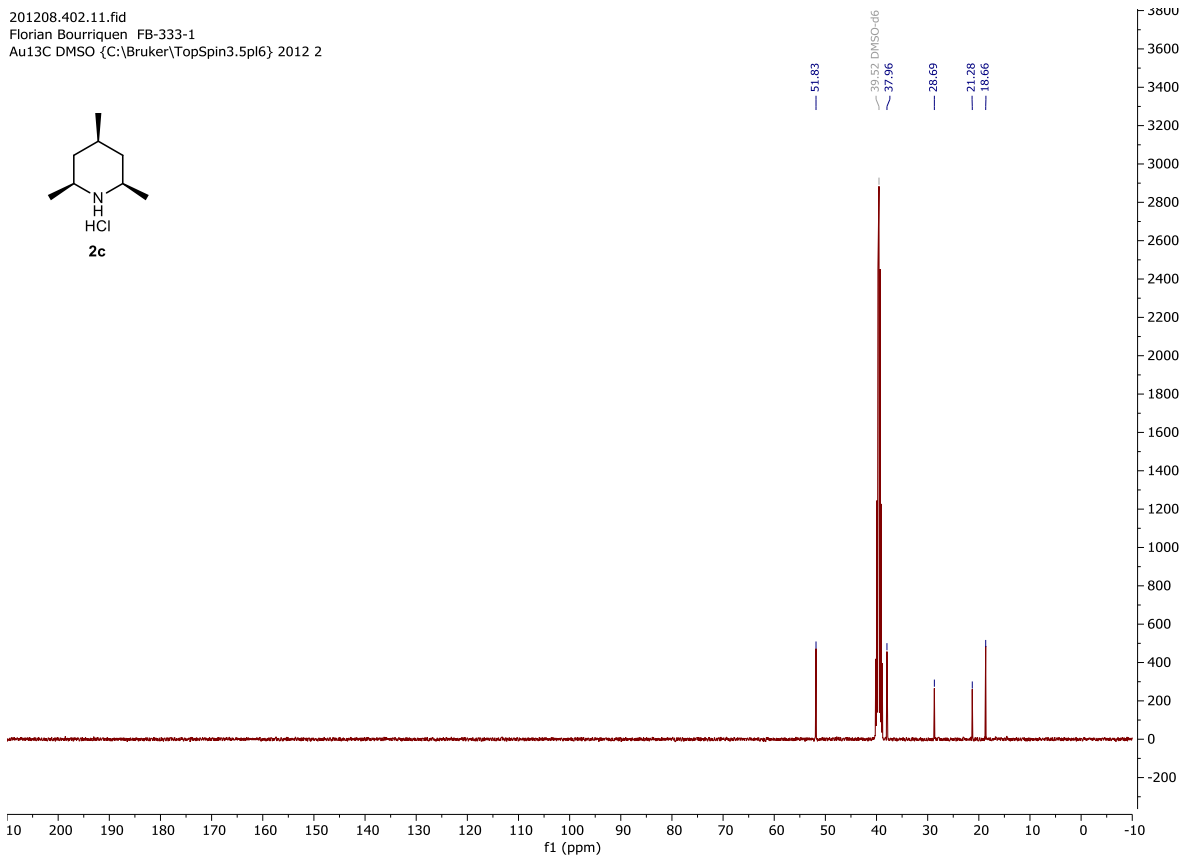
201124.f325.11.fid
Bourriquen, FB-323-3
C13CPD CDCl3 {C:\Bruker\TopSpin3.6.0} 2011 25

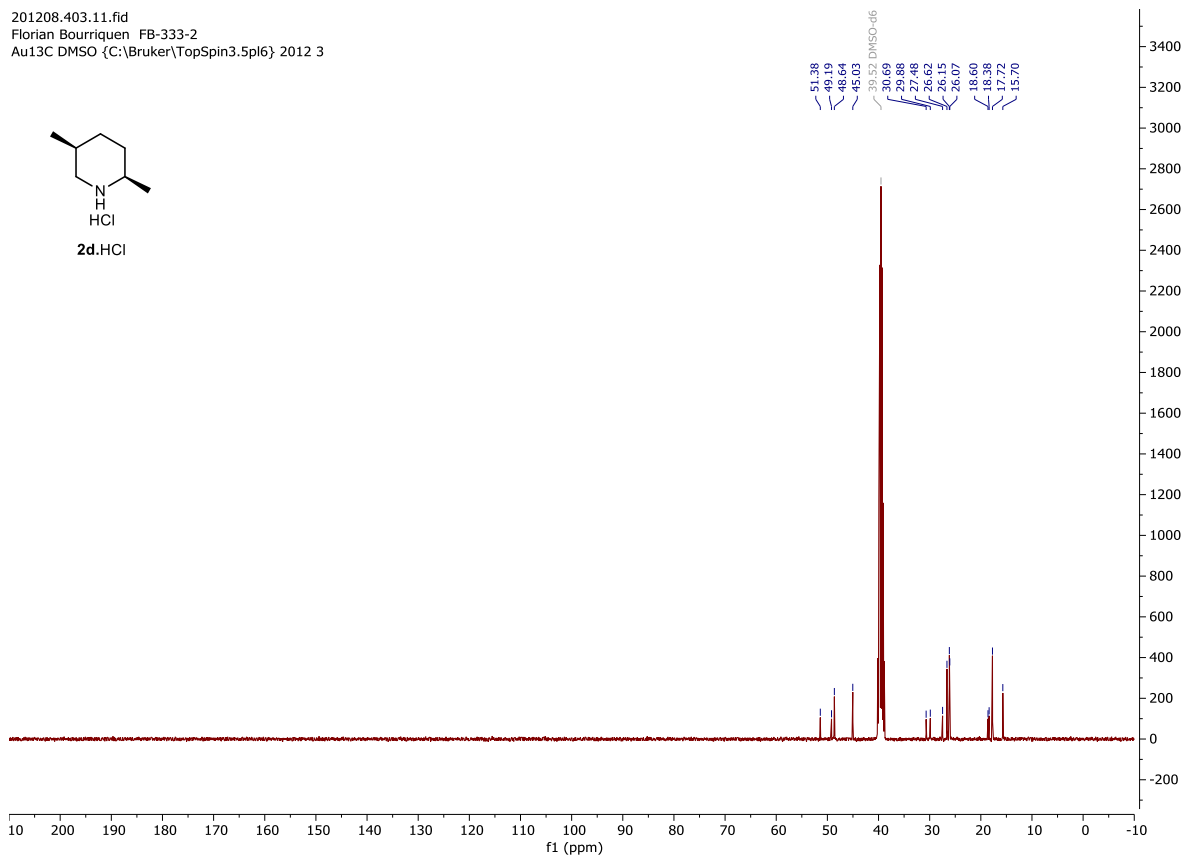
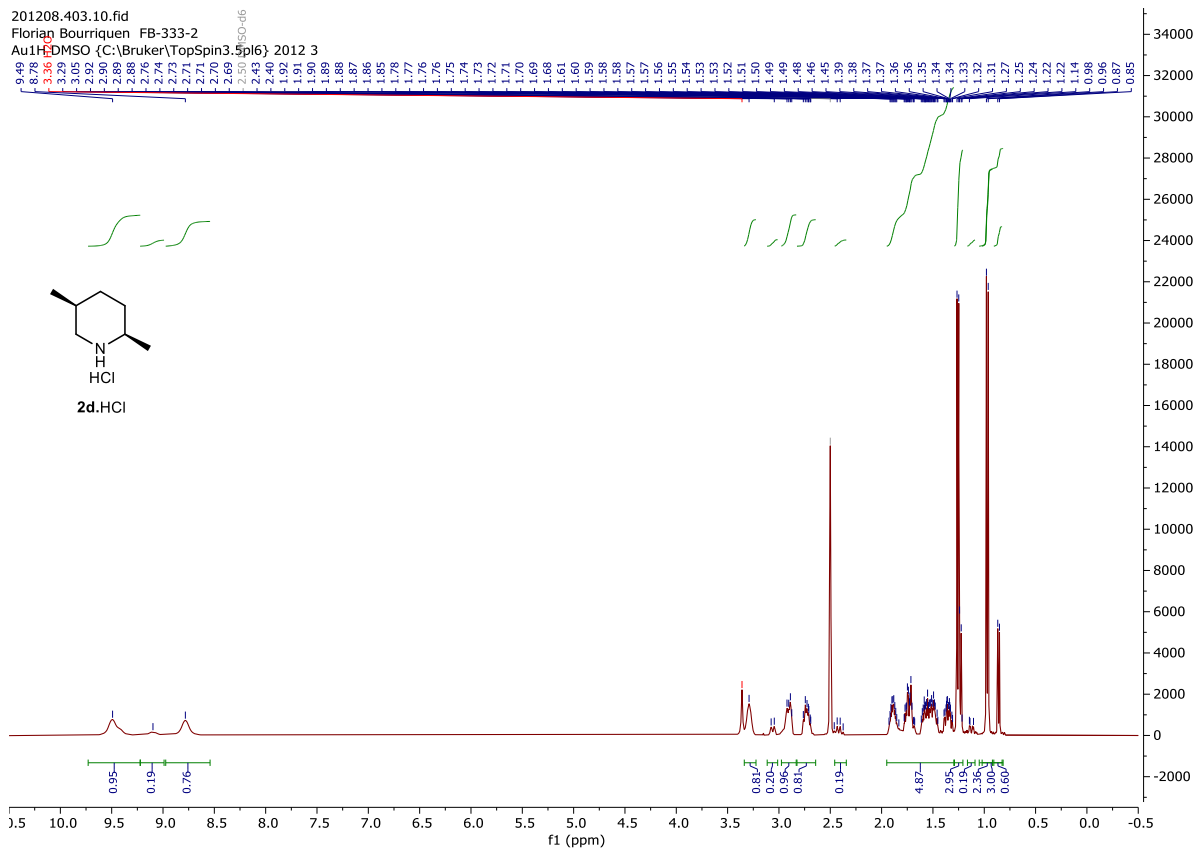


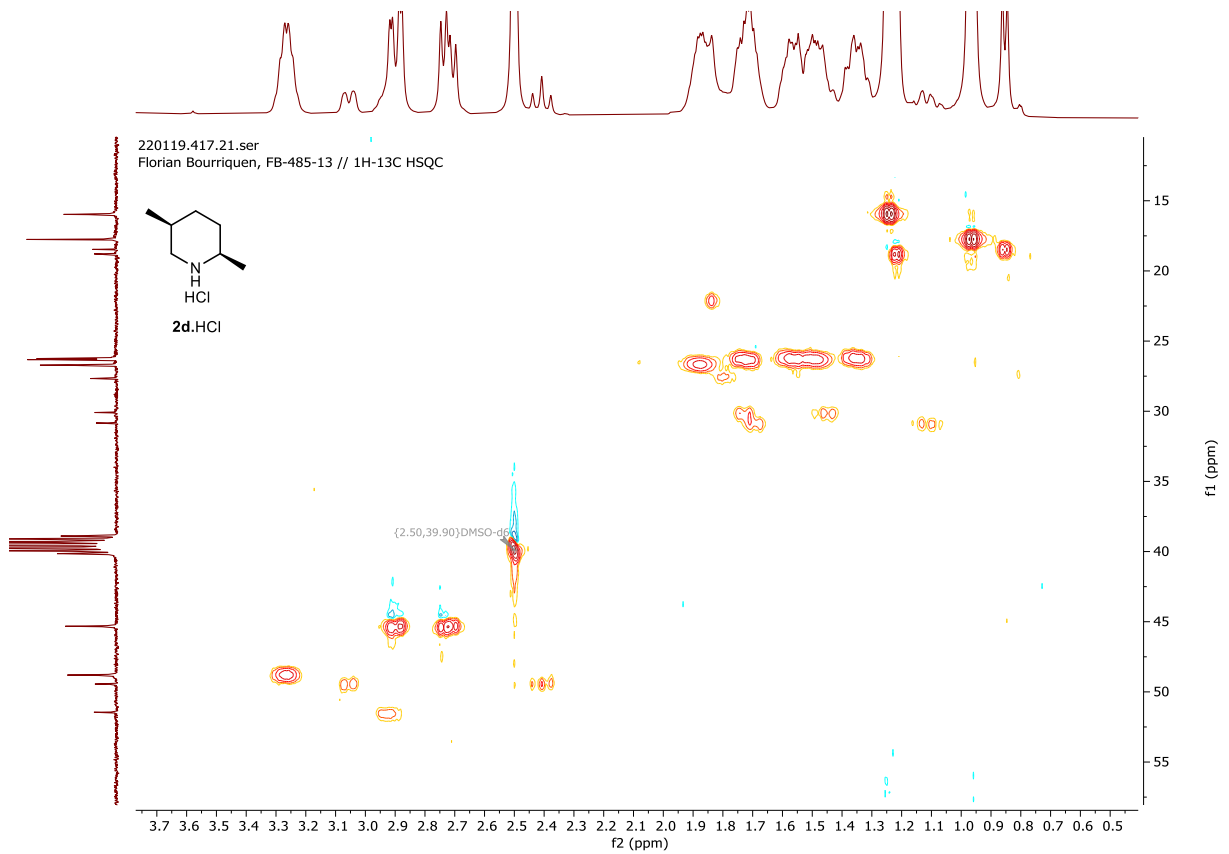
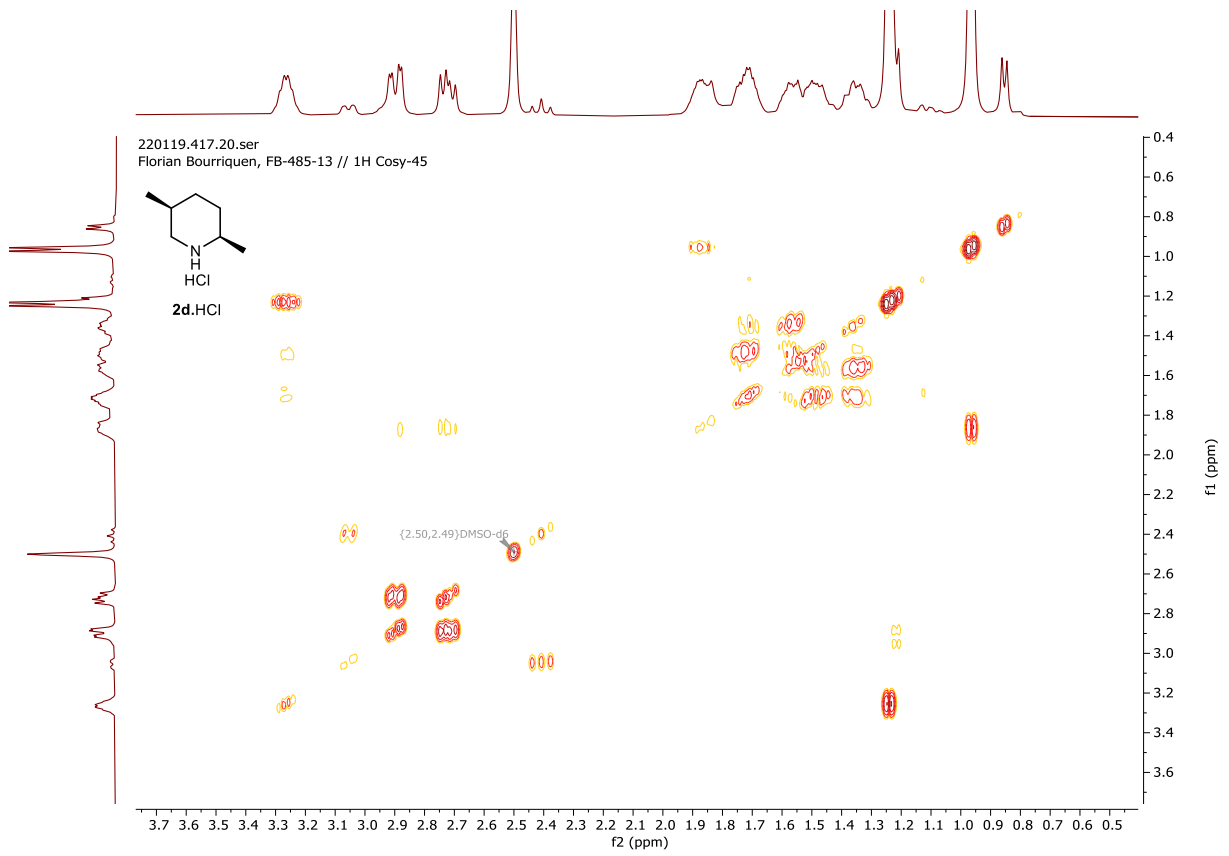
201208.402.10.fid
Florian Bourriquen FB-333-1
Au1H DMSO {C:\Bruker\TopSpin3.5pl6} 2012 2

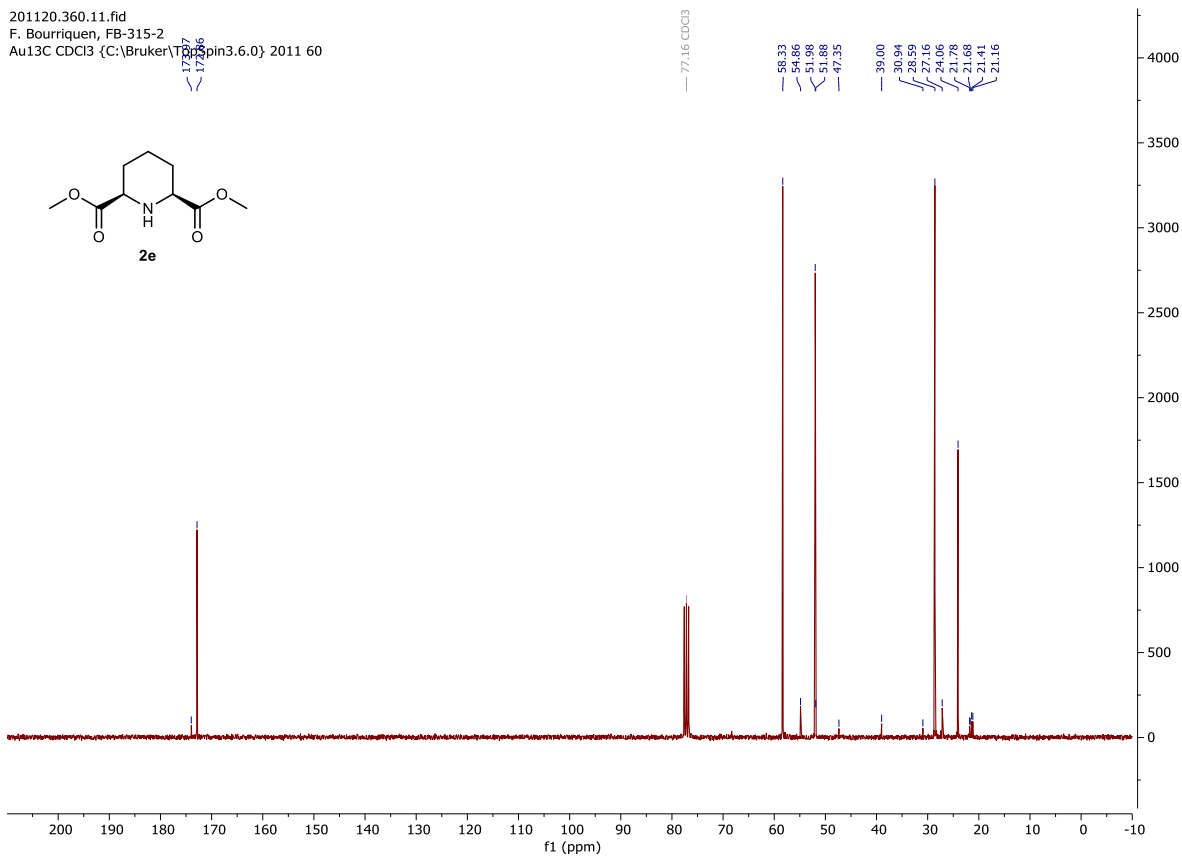
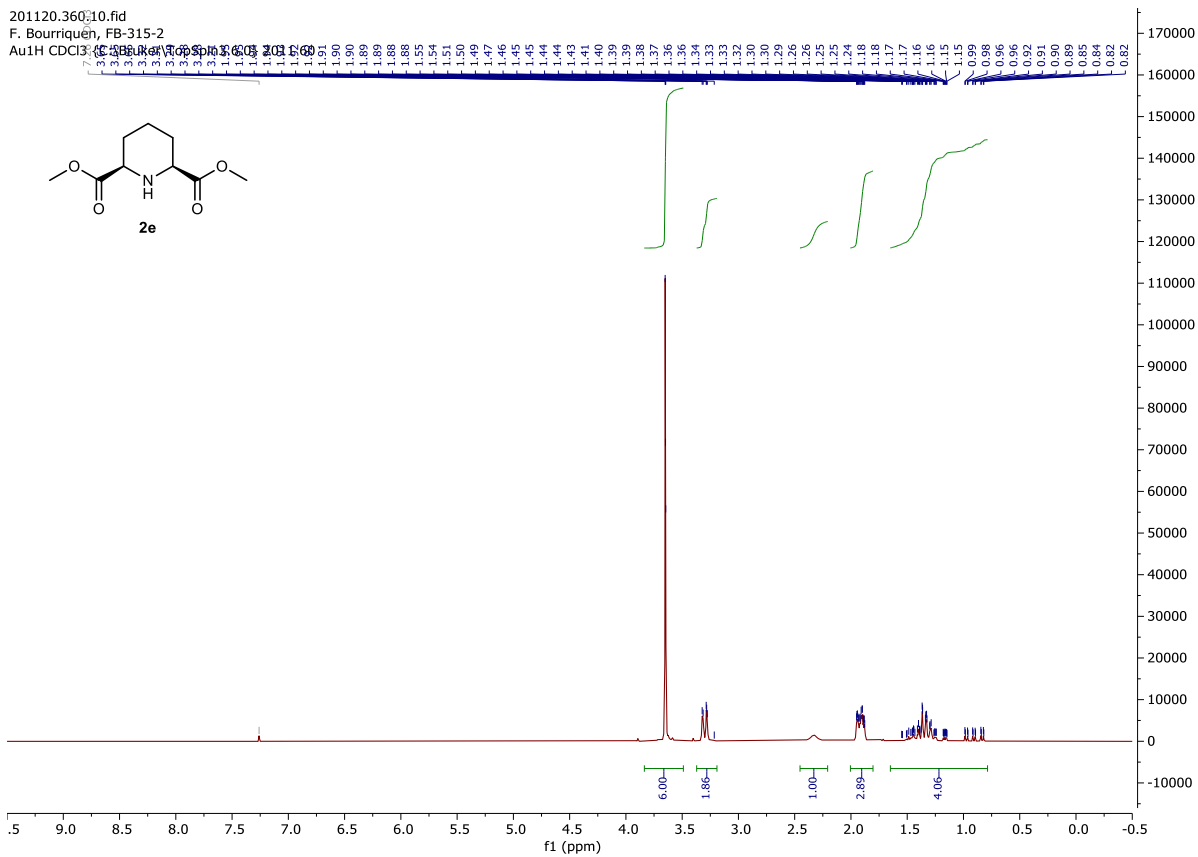


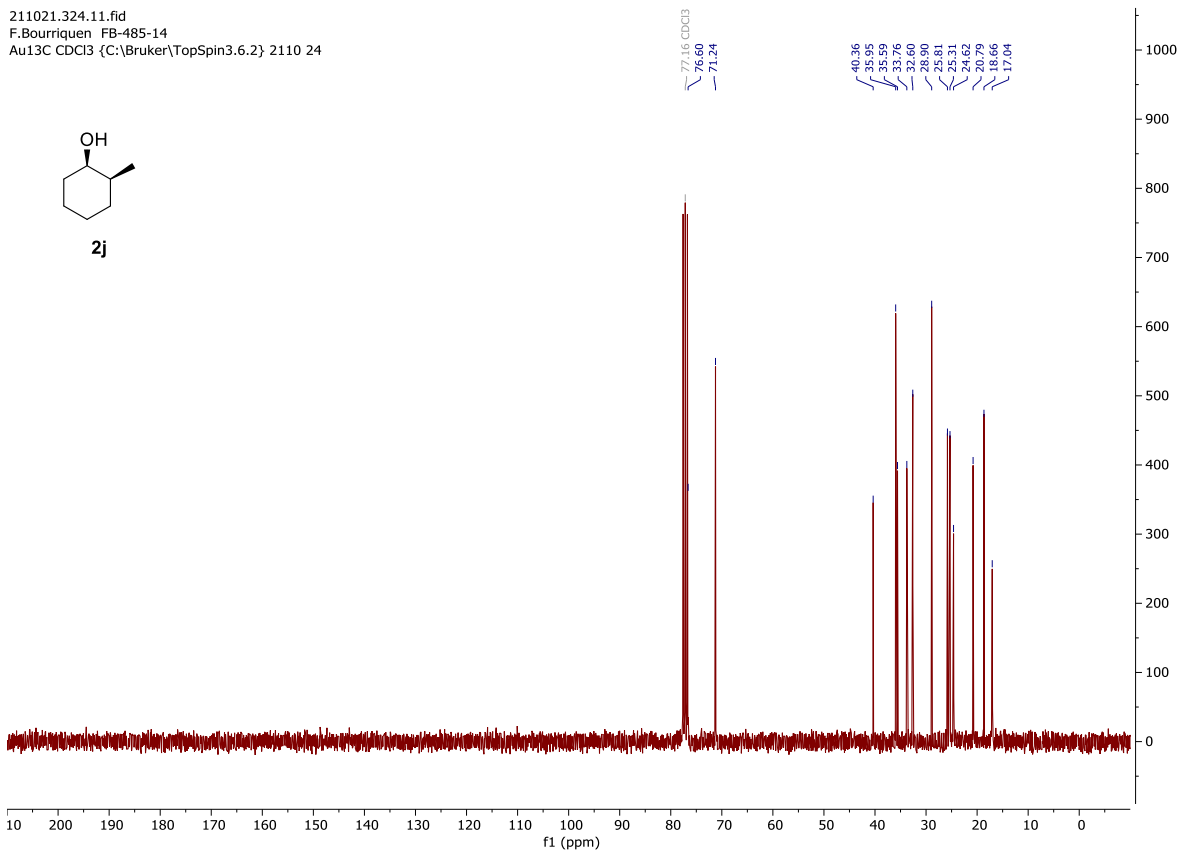
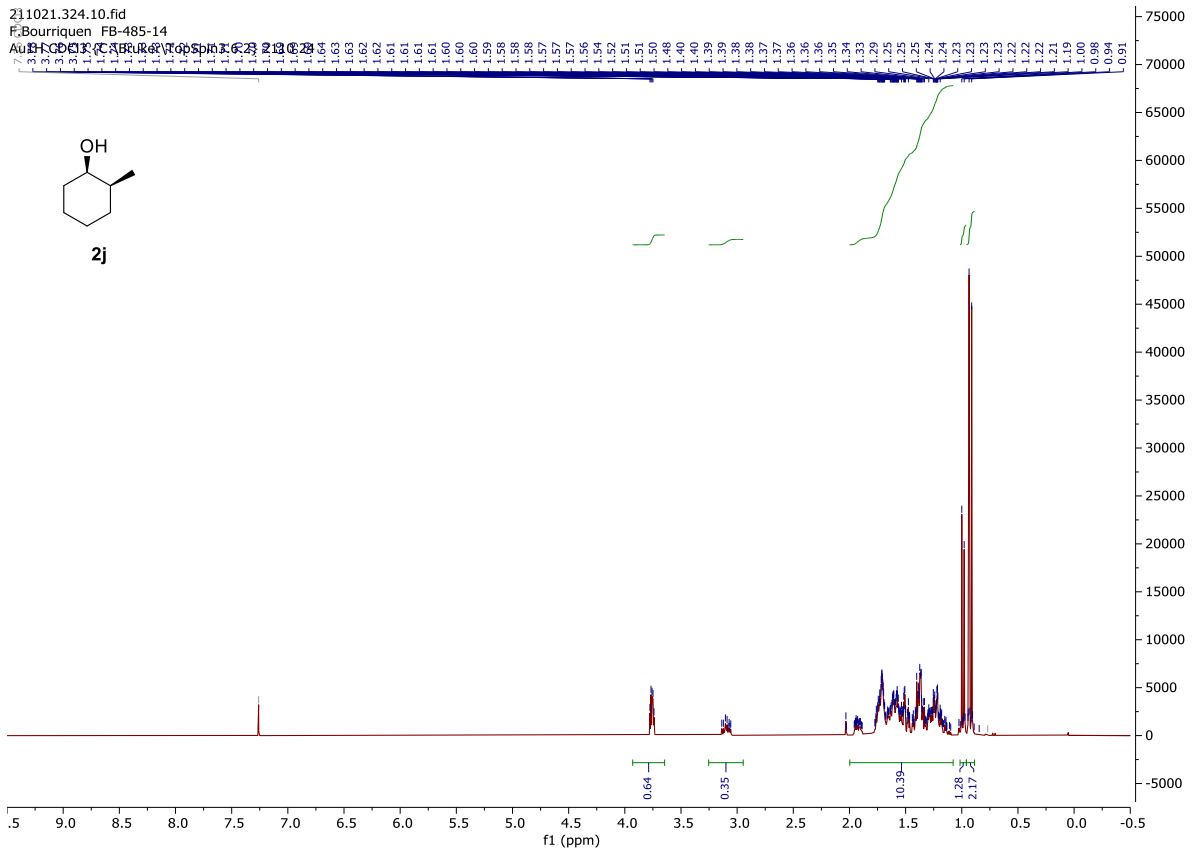
201208.402.11.fid
Florian Bourriquen FB-333-1
Au13C DMSO {C:\Bruker\TopSpin3.5pl6} 2012 2

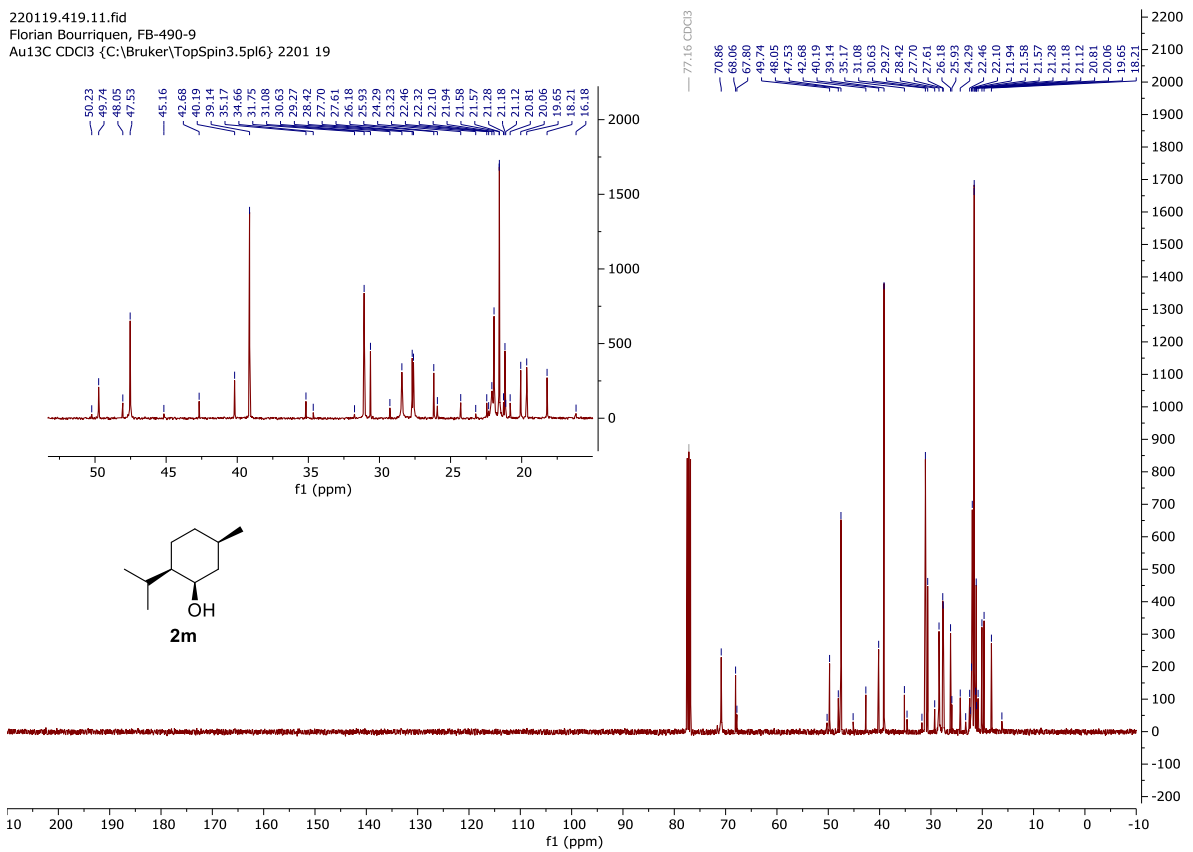
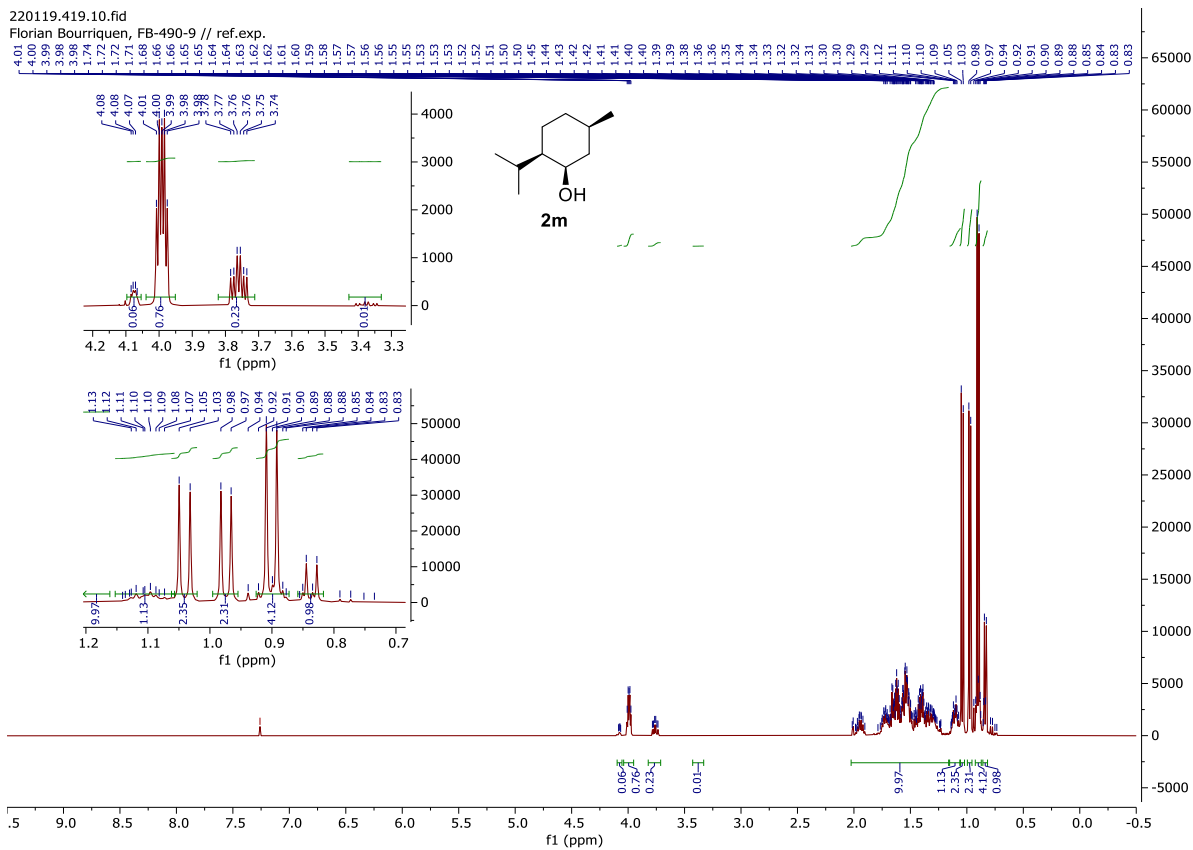


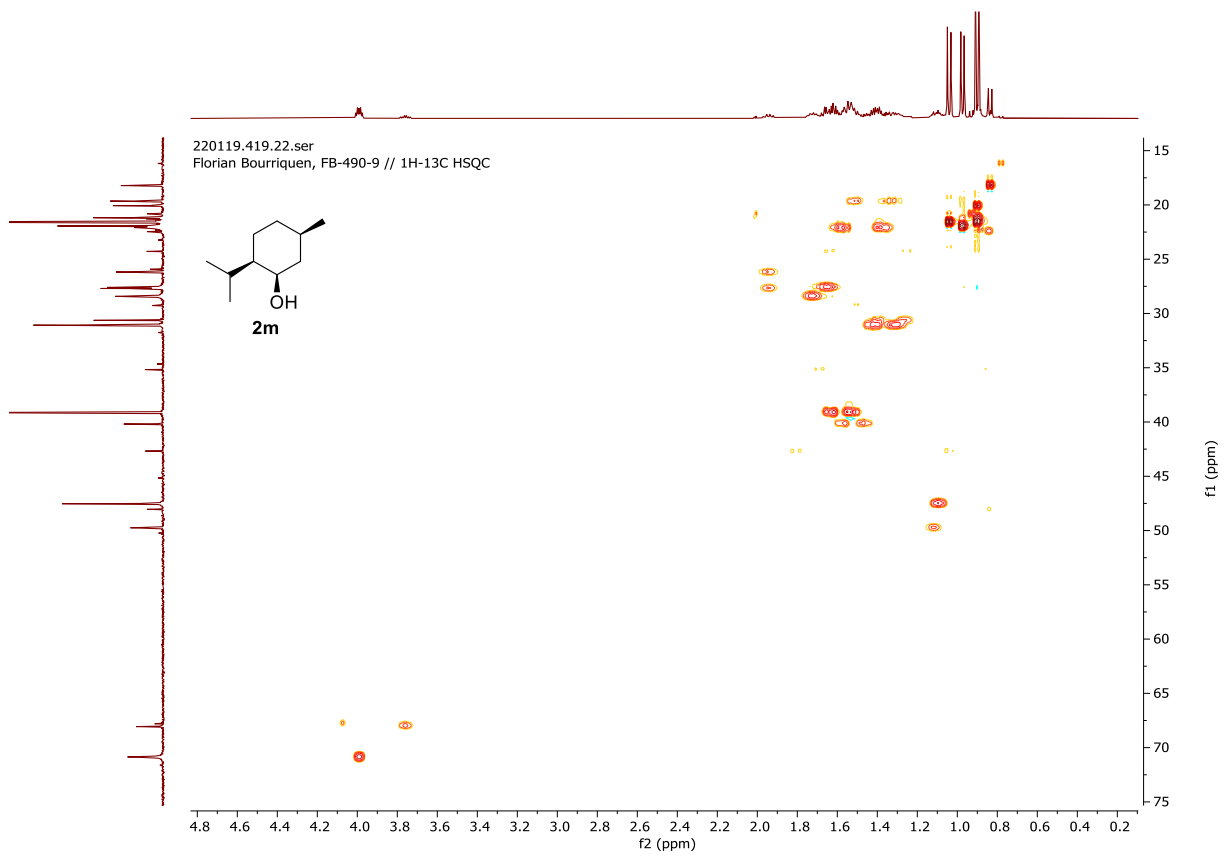
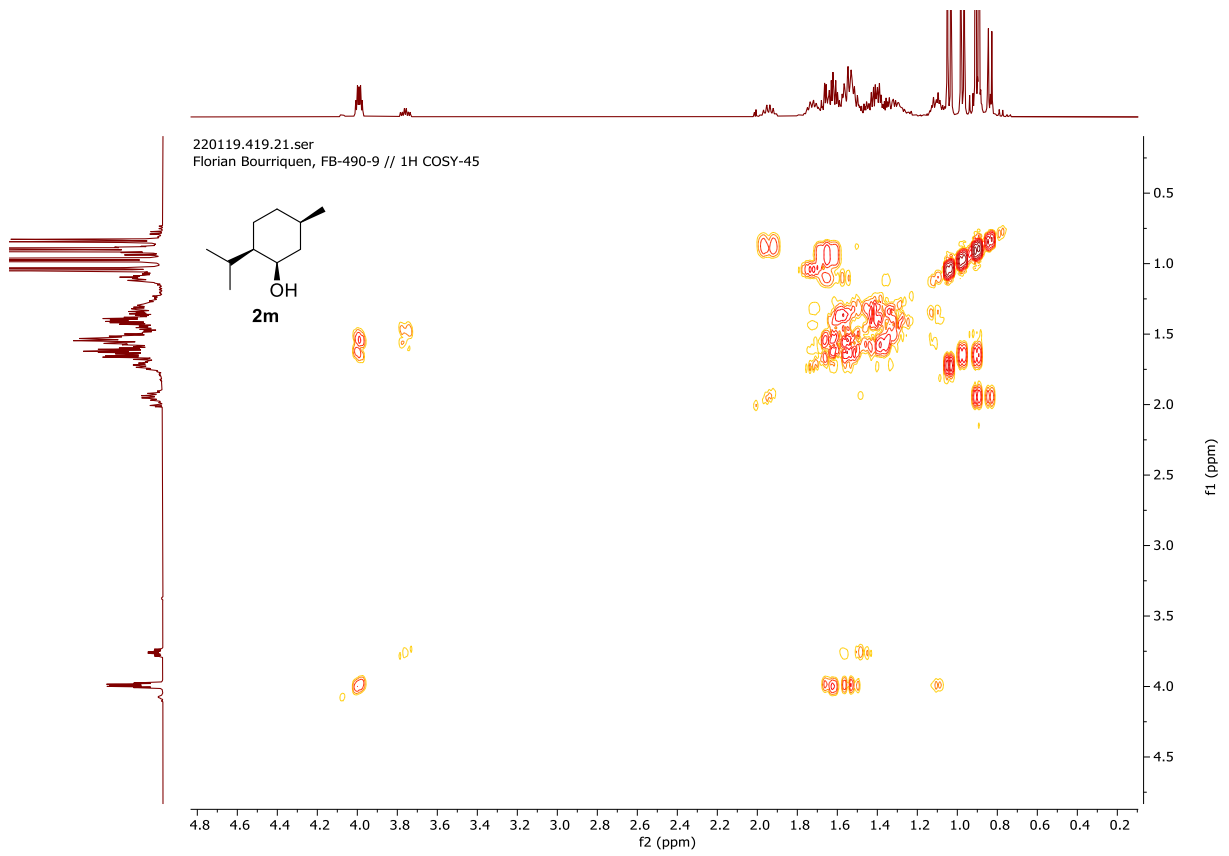




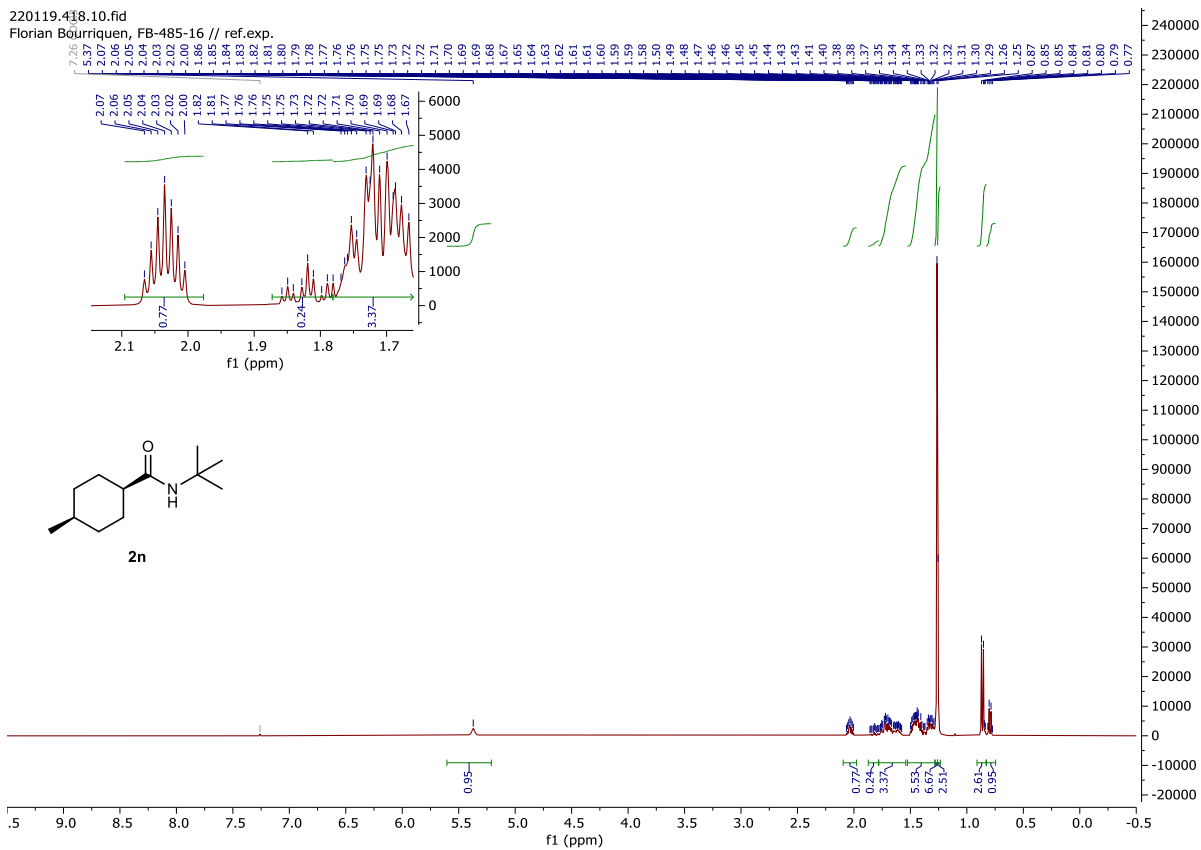




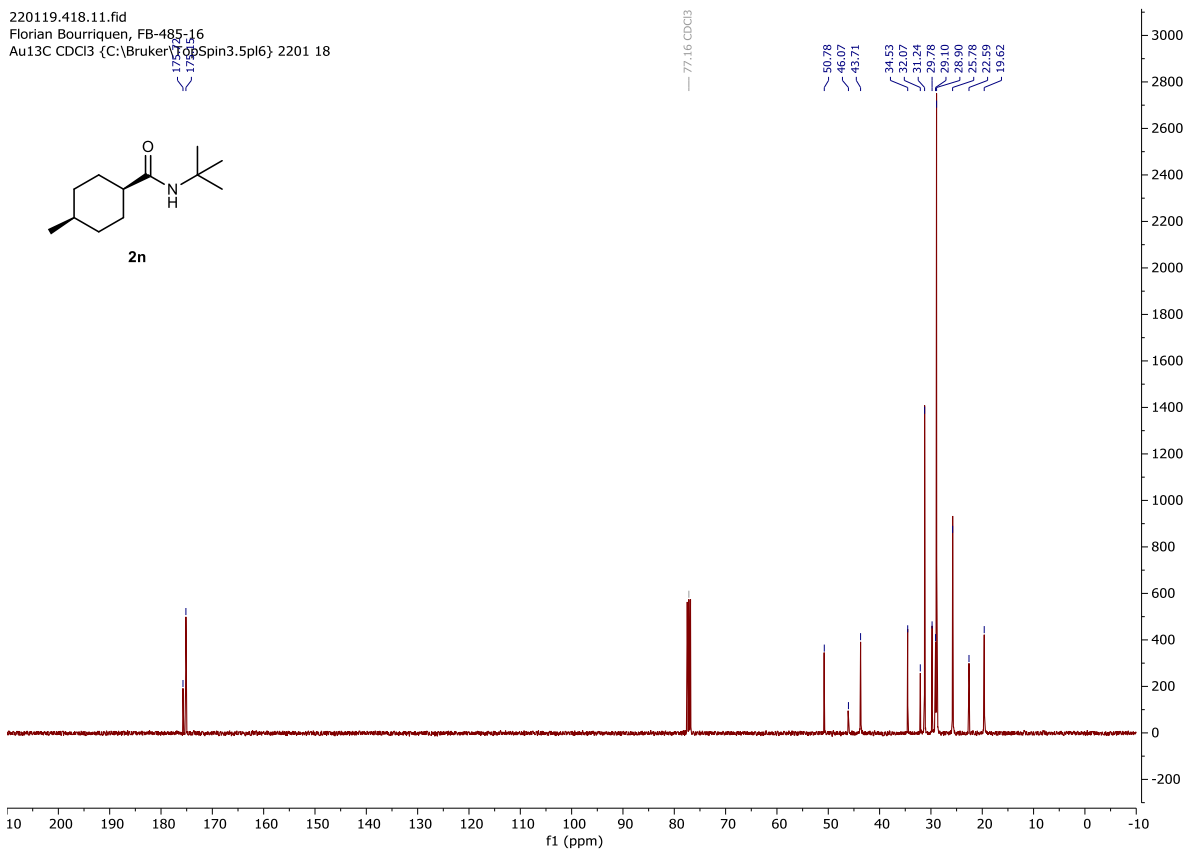


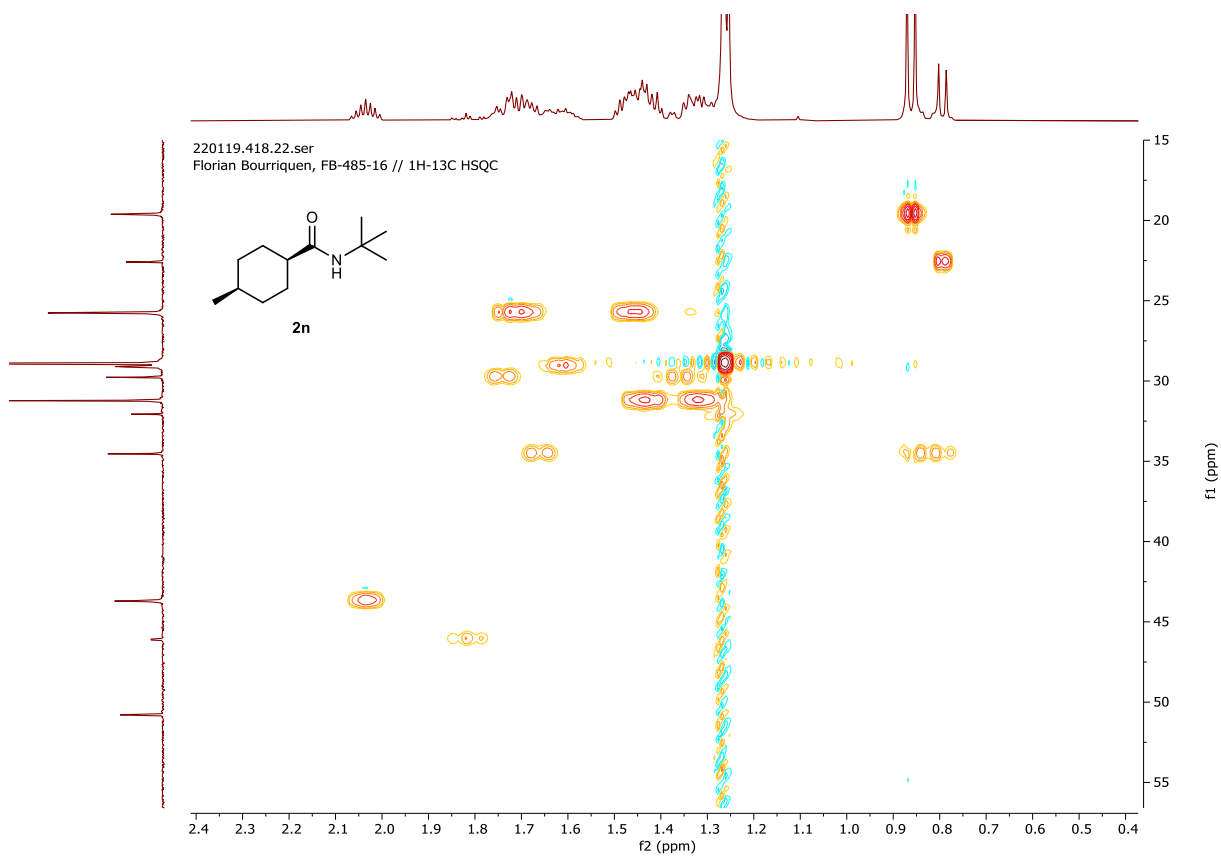
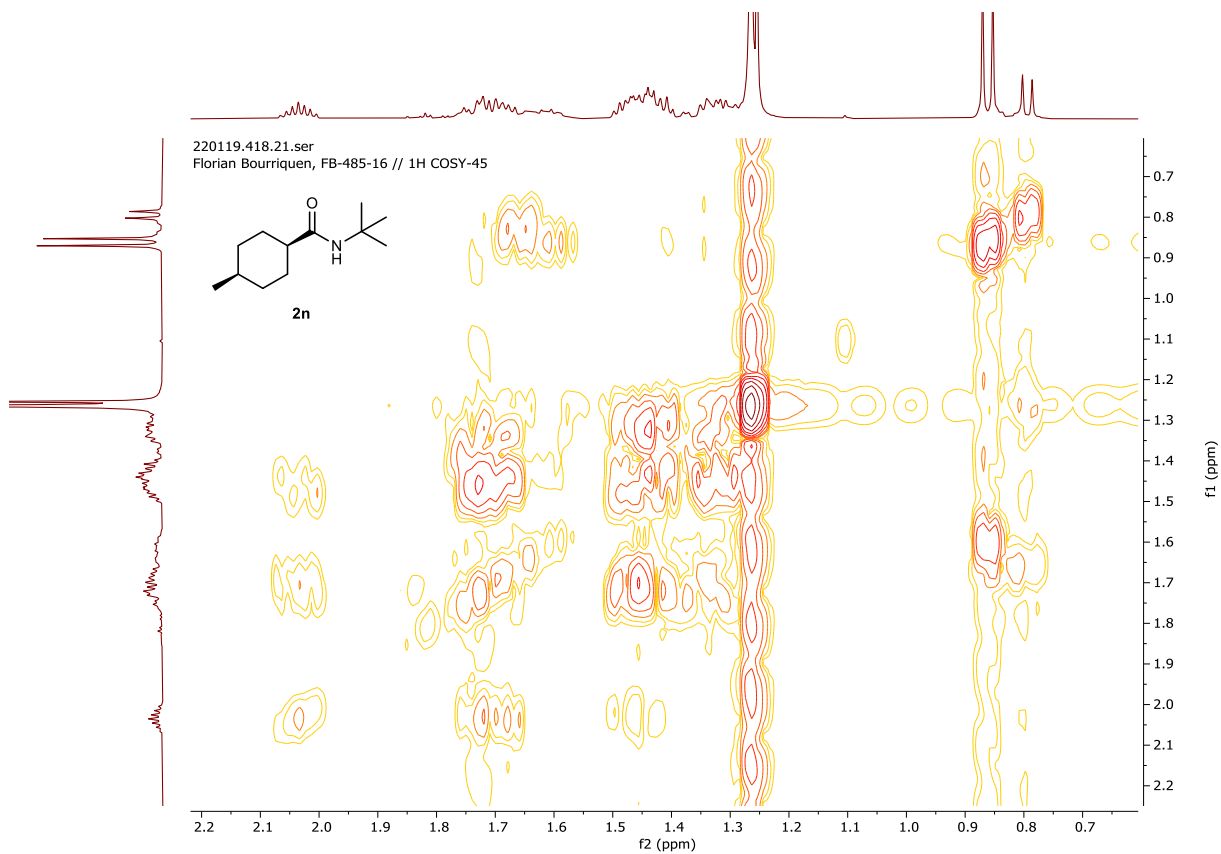


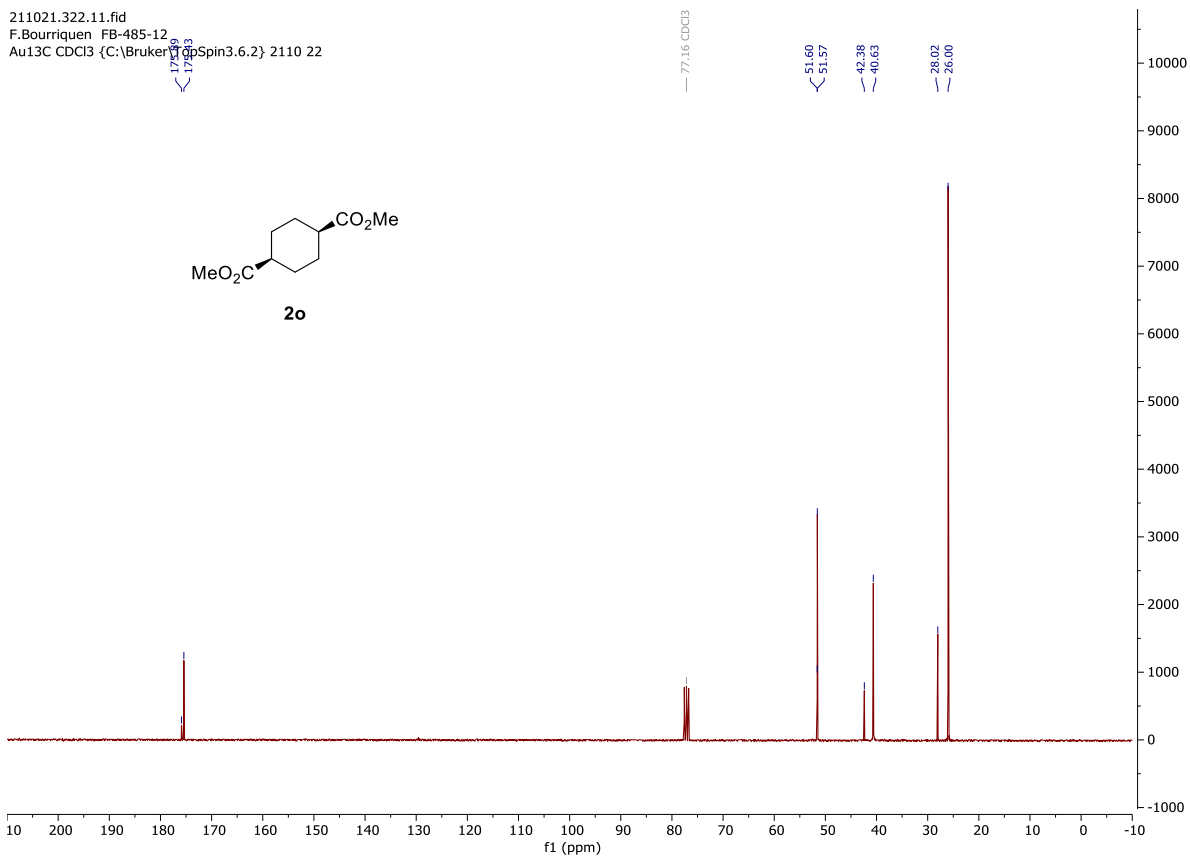
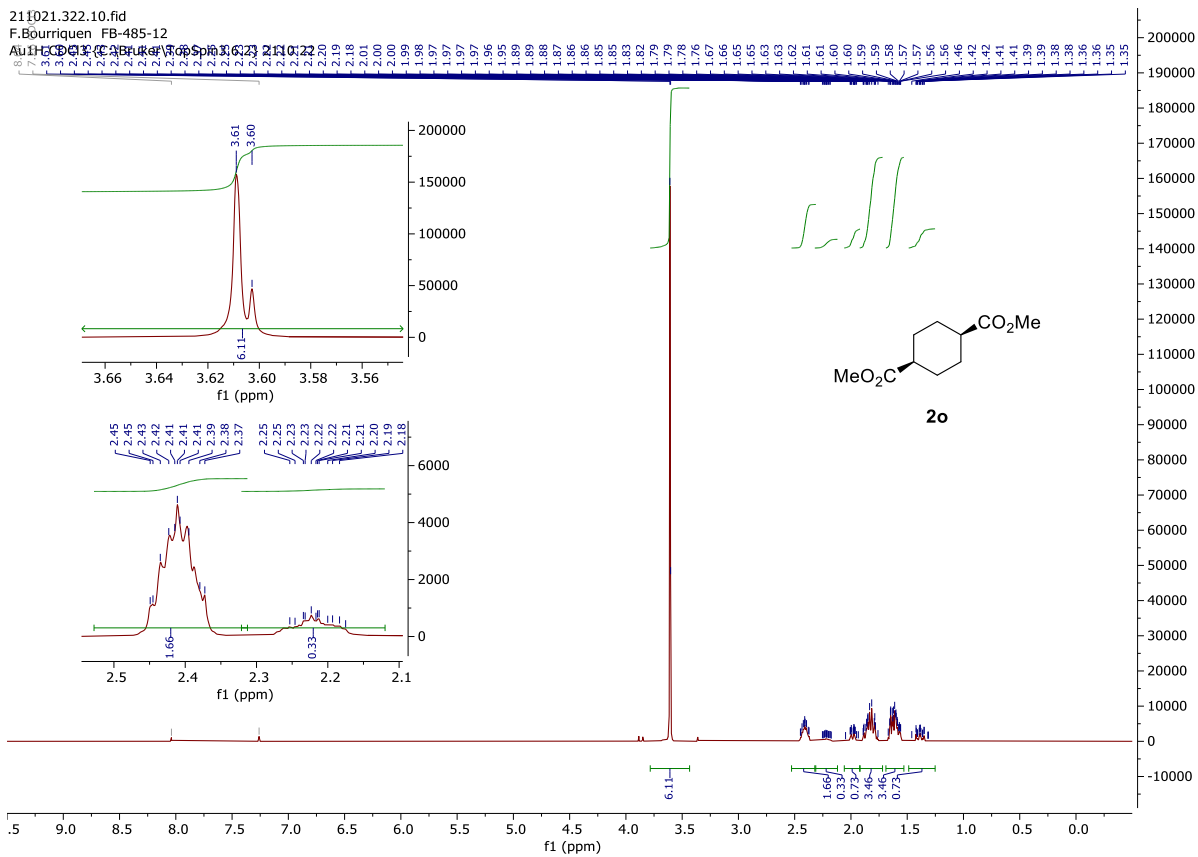
220119.418.10.fid
 Florian Bourriquen, FB-485-16 // ref.exp.

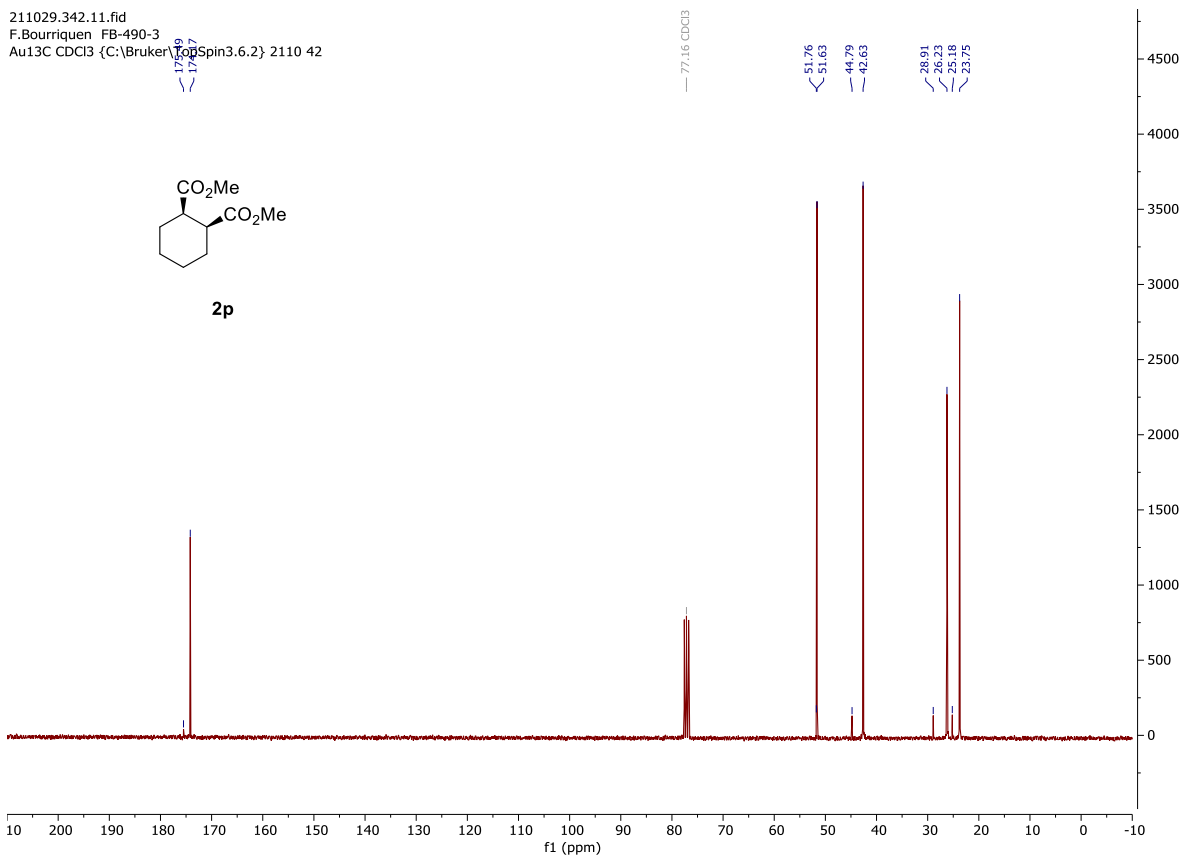
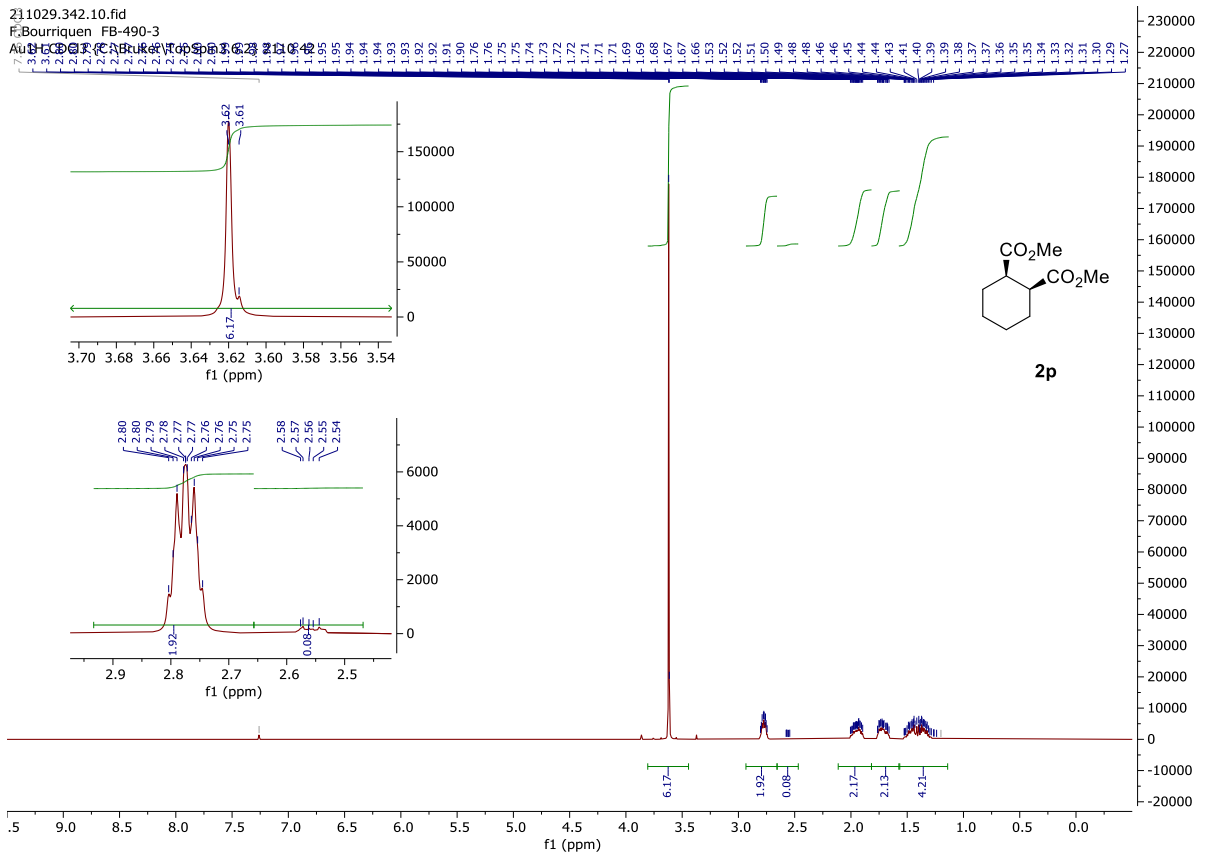


220119.418.11.fid
 Florian Bourriquen, FB-485-16
 Au13C CDCl3 (C:\Bruker\TopSpin3.5\pl6} 2201 18

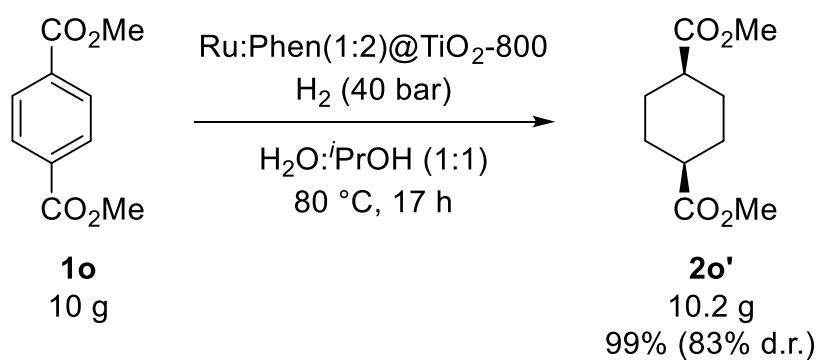








14. Scaled up reaction

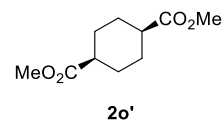


A 300 mL Parr autoclave equipped with a Teflon coated magnetic stirring bar was charged with the substrate (10.0034 g), Ru:Phen(1:2)@TiO₂-800 (516 mg), H₂O (50 mL) and *i*PrOH (50 mL). The autoclave was closed, flushed with H₂ (2 x 20 bar) and pressurised with H₂ (40 bar). The autoclave was placed into an aluminium block and heated to 80 °C under thorough stirring for 17 h. The autoclave was removed from the block and cooled in an ice-water bath. The remaining hydrogen was carefully discharged. The media was diluted with EtOAc (100 mL), and the catalyst was removed by filtration over Celite. The aqueous phase was extracted with EtOAc (3 x 20 mL), the combined organic phases were dried over Na₂SO₄, filtered, and concentrated under reduced pressure.

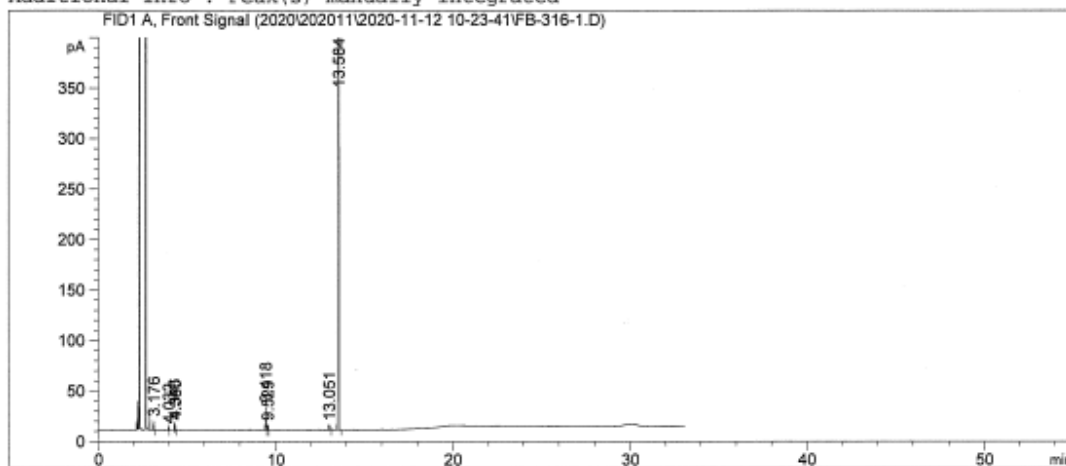

```

=====
Acq. Operator   : Lab 2.112                      Seq. Line :    1
Acq. Instrument : GC Lab.133                    Location  : Vial 119
Injection Date  : 11/12/2020 10:26:39 AM        Inj       :    1
                                                Inj Volume: 1 µl

Acq. Method     : C:\CHEM32\1\DATA\202011\2020-11-12 10-23-41\STANDARDMTHNEW.M
Last changed    : 6/25/2020 1:31:14 PM by Lab 2.112
Analysis Method : C:\CHEM32\1\METHODS\STANDARDMTH.M
Last changed    : 6/25/2020 1:31:14 PM by Lab 2.112
Method Info     : HP5 (30x0.25x0.25): 50/8-120/0/15-200/0/25-300/10/50-310/5
                  ramped flow: 1/29/1-2; 260i320d; Split 100/1
  
```



Additional Info : Peak(s) manually integrated



=====
 Area Percent Report
 =====

```

Sorted By      :      Signal
Multiplier     :      1.0000
Dilution       :      1.0000
Use Multiplier & Dilution Factor with ISTDs
  
```

Signal 1: FID1 A, Front Signal

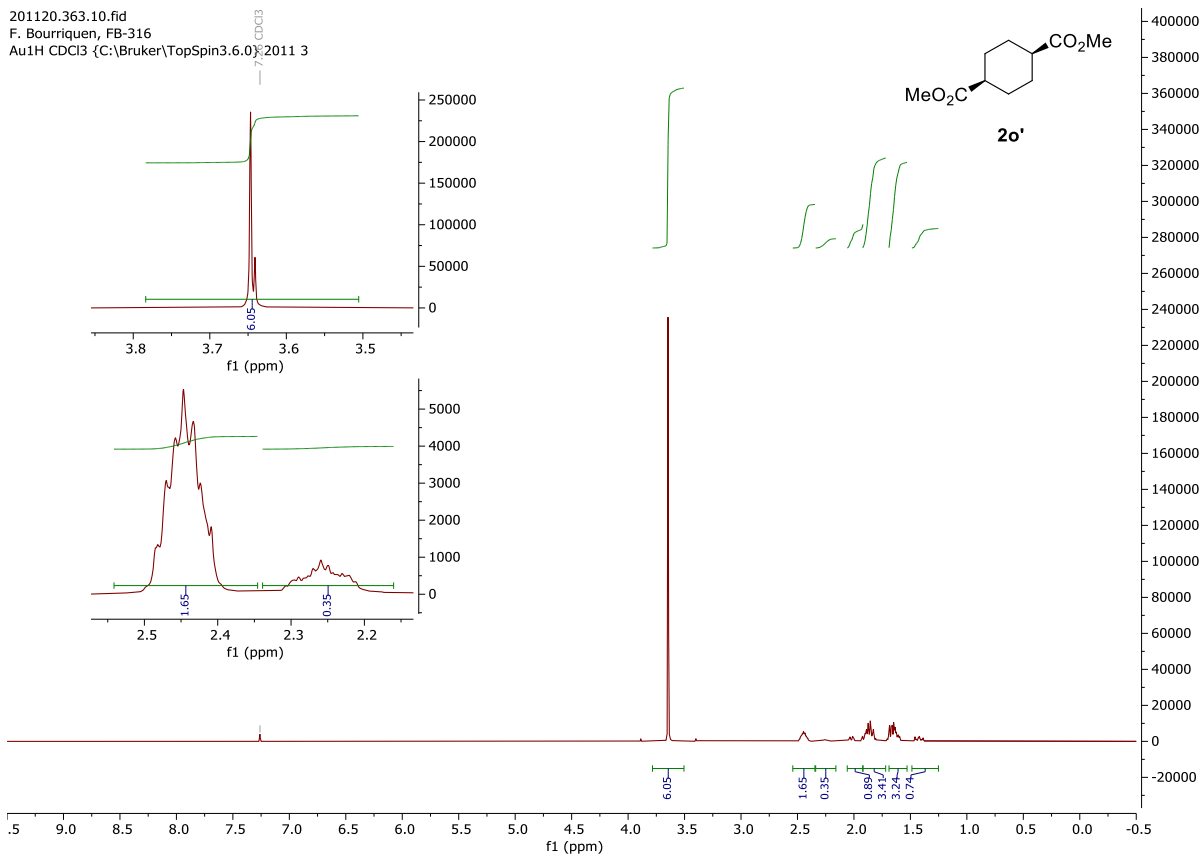
Peak #	RetTime [min]	Type	Width [min]	Area [pA*s]	Height [pA]	Area %
1	3.176	BB	0.0176	9.85620	8.99765	0.20413
2	4.032	BB	0.0228	3.57927	2.32081	0.07413
3	4.346	BV	0.0222	9.29100	6.51128	0.19242
4	4.380	VB	0.0237	8.60168	5.55505	0.17814
5	9.418	BB	0.0296	44.76400	23.34316	0.92708
6	9.529	BB	0.0308	10.12196	5.17061	0.20963
7	13.051	BB	0.0306	10.55927	5.08204	0.21869
8	13.584	BB	0.0442	4731.71191	1558.07520	97.99578

Totals : 4828.48531 1615.05579

=====
 *** End of Report ***

In this case it is assumed the two isomers have the same GC retention time under the conditions of the analysis. The diastereoselective ratio is thus determined by NMR.

201120.363.10.fid
F. Bourriquen, FB-316
Au1H CDCl3 {C:\Bruker\TopSpin3.6.0} 2011 3



201120.363.11.fid
F. Bourriquen, FB-316
Au13C CDCl3 {C:\Bruker\TopSpin3.6.0} 2011 3

