Structural Assignment of a *bis*-Cyclopentenyl-β-cyanohydrin Formed *via* Alkene Metathesis from either a Triene or a Tetraene Precursor

Keith G. Andrews[a], Christopher S. Frampton[b] and Alan C. Spivey[a]*

Department of Chemistry, Imperial College London, South Kensington, London, SW7 2AZ.
Pharmorphix Limited, 250 Cambridge Science Park Milton Road, Cambridge, CB4 0WE, United Kingdom
**Corresponding Author - Email: a.c.spivey@imperial.ac.uk. Tel: +44 (0)20 7594 5841*

SUPPORTING INFORMATION

Computational Methods

All structures were optimised to their lowest energy gas phase conformers with the MM2 or MMFF4 forcefield. The molecules examined here have few rotatable bonds, and the possible conformers were easily identified manually. All further calculations were performed using Gaussian (version G09W; release C.01) employing the popular DFT functional, B3LYP, which has precedent for both accurate geometry optimisation and NMR shielding tensor calculation. The conformers from the initial searches were optimised using the 6-31G** basis set[3] for all atoms, and NMR calculations performed at the same level of theory, using the GIAO[4] method. Structures were optimised in the gas phase and for unique conformers, their validity as true minima confirmed with a vibrational analysis calculation to ascertain that no imaginary modes existed. The energies were recovered with a single point energy (SPE) calculation in solution, using the CPCM (conductor-like polarisable continuum model) solvation model as implemented in Gaussian, with chloroform ($CHCl_3$) as the solvent. Although it is appreciated that the zero-point-energy-corrected Gibbs free energies should be used for the Boltzmann weightings, it was considered that the errors in the final MAE values using the SPE values was sufficiently suitably small for our purposes. The NMR calculations were also completed in solvent at the B3LYP/6-31G** level.

The chemical shift values for each isomer were obtained by using Boltzmann weighted average shifts over the set of conformers, calculated by first averaging the chemical shifts for degenerate symmetry related carbon environments within each conformer. Each conformer then contributed a percentage of its chemical shift value to the final total value per environment depending on its Boltzmann weighted energy contribution. A general equation is shown below, where σ^x is the weighted average shielding tensor of the atom(s), σ_i^x is the raw shielding tensor of the atom(s) in conformer i and E_i is the energy of the associated conformer.

$$\sigma^x = \frac{\sum_i \sigma_i^x \exp(-\frac{E_i}{RT})}{\sum_i \exp(-\frac{E_i}{RT})}$$

Finally, tetramethylsilane (TMS) was optimised in a symmetry restricted (tetrahedral) geometry optimisation calculation in chloroform and the single NMR shielding tensor for all carbon atoms obtained again in chloroform ($CHCl_3$) at the B3LYP/6-31G** level. The value obtained was σ_C = 192.172 and σ_H = 31.736. All final shifts were then calculated as $\sigma_{TMS} - \sigma_{calc}$.

The corrected mean absolute error (CMAE) is calculated by performing a linear regression on the experimental/predicted shifts for each isomer. The predicted shifts are then scaled using the parameters from this linear regression, according to:

$$\delta_{scaled} = \frac{\delta_{calc} - intercept}{slope}$$

The absolute error between each scaled shift and the corresponding experimental shift is obtained, and these values are used to calculate the mean error, which is the CMAE.

Predicted chemical shifts for compounds 9 and 10

^{1}H predicted and experimental shifts

DFT/B3LYP/6-31G**

GIAO method (CPCM, $CHCl_3$)

Referenced to TMS (σ = 31.736)

Experiment: δ_H ($CDCl_3$, 400 MHz) /ppm

	^{1}H predicted shifts	
δ_H **Experiment**	δ_H ***bis*-cyclopentene 10**	δ_H ***cis*-dehydrodecalin 9**
5.73	5.98	5.88
5.69	5.89	5.83
2.88	3.13	2.60
2.75	2.85	2.36
2.74	2.74	2.31
2.46	2.46	2.29
2.23	1.71	1.96

^{13}C predicted and experimental shifts

DFT/B3LYP/6-31G**

GIAO method (CPCM, $CHCl_3$)

Referenced to TMS (σ = 192. 172)

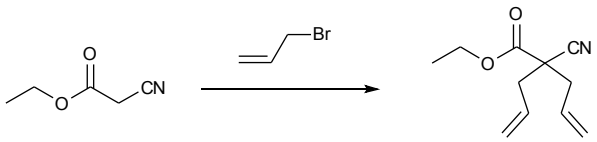
Experiment: δ_C ($CDCl_3$, 100 MHz) /ppm

	^{13}C predicted shifts	
δ_C **Experiment**	δ_C ***bis*-cyclopentene 10**	δ_C ***cis*-dehydrodecalin 9**
128.48	126.24	122.56
128.47	125.73	120.45
125.53	118.89	117.48
83.12	85.09	72.18
49.24	52.46	44.14
44.86	46.35	37.93
41.57	43.51	35.79

General Directions

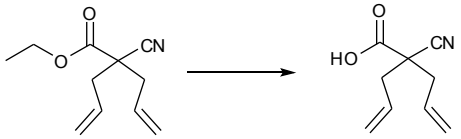
All reactions were performed under an atmosphere of nitrogen and anhydrous conditions in flame or oven-dried glassware unless stated. Yields refer to chromatographically homogenous materials, unless otherwise indicated. All reagents were used as received from commercial suppliers. Anhydrous solvents were used directly following passage under nitrogen through Al_2O_3 columns in a Grubbs dry-solvent system (Innovative Technology Inc.). Flash chromatography (FC) was performed on silica gel (Merck Kieselgel 60 $_{F254\ 230}$-400 mesh). Thin Layer Chromatography (TLC) was performed on Merck aluminium-backed plates pre-coated with silica (0.2 mm, 60 F_{254}). Melting points were determined on a Reichardt hot stage apparatus and are uncorrected. Infra-red (IR) spectra were recorded neat on a Perkin-Elmer Paragon 1000 Fourier transform spectrometer. Only selected absorbances (υ_{max}) are reported. ^{1}H NMR spectra were recorded at ambient temperature at 400 MHz (unless stated otherwise) on a Bruker DRX-400 (or DRX-500) instrument. Chemical shifts (δ_H) are quoted in parts per million (ppm), referenced to the residual solvent peak ($CDCl_3$ at δ_H 7.27 ppm and MeOD at δ_H 3.35 ppm). The multiplicities of ^{1}H signals are designated by the following abbreviations: s = singlet; d = doublet; dd = doublet of doublets; ddt = doublet of doublets of triplets; t = triplet; q = quartet; br = board; m = multiplet. Coupling constants, *J*, are reported to the nearest 0.1 Hz. ^{13}C NMR spectra were recorded at 100 MHz on a Bruker AMX-400 instrument at ambient temperature. Chemical shifts (δ_C) are quoted in ppm referenced to ($CDCl_3$ at δ_C 77.1 ppm). Low resolution mass spectra (*m/z*) were recorded on either a VG platform II or VG AutoSpec spectrometers; molecular ions (M^+, MH^+, MNH_4^+) are reported. High Resolution Mass Spectrometry (HRMS) measurements are valid to ±5.2 ppm.

Ethyl 2-allyl-2-cyanopent-4-enoate 12[5]



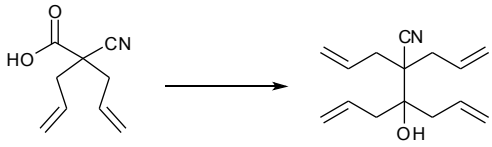
To a stirred solution of *ethyl cyanoacetate* (500 mg, 4.42 mmol) in DMF (20 mL) was added allyl bromide (1.12 g, 9.28 mmol) and caesium carbonate (2.88 g, 8.84 mmol). The reaction mixture was stirred at 0 °C for 15 min warming to RT over 3 h. The reaction mixture was concentrated *in vacuo* and the crude residue partitioned between sat. aqueous sodium hydrogen carbonate solution (10 mL) and ethyl acetate (40 mL) and extracted with further ethyl acetate (2 × 40 mL). The combined organics were washed with sat. aqueous sodium chloride solution (3 × 40 mL) and dried over magnesium sulfate. The crude residue was purified by flash column chromatography eluting with 1:9 EtOAc:pet ether to give *diene* **12** as a colourless oil (840 mg, 98%). IR (neat) 2246 (CN), 1741(C=O), 1644 (C=C) cm^{-1}. ^{1}H NMR ($CDCl_3$, 400 MHz): δ 5.84 (ddt, *J* = 17.1, 9.8, 7.3 Hz, 2H, =CH), 5.32 – 5.21 (m, 4H, CH_2), 4.28 (q, *J* = 7.1 Hz, 2H, OCH_2CH_3), 2.68 (dd, *J* = 14.0, 7.3 Hz, 2H, 2 × C*H*H), 2.58 (dd, *J* = 14.0, 7.3 Hz, 2H, 2 × CH*H*), 1.33 (t, *J* = 7.1 Hz, 3H, OCH_2CH_3) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz): δ 168.0, 130.5, 121.0, 118.5, 62.8, 49.3, 40.7, 14.2 ppm; MS(CI$^+$) *m/z* 211 (MNH_4^+); HRMS (CI$^+$) calcd. for $C_{11}H_{19}N_2O_2$ (MNH_4^+); 211.1447, found 211.1453, Δ = 2.8 ppm.

2-Allyl-2-cyanopent-4-enoic acid 13



Ester **12** (3170 mg, 16.4 mmol) was dissolved in ethanol (20 mL) and cooled to 0 °C. Separately, potassium *tert*-butoxide (2760 mg, 24.6 mmol) was dissolved in water (10 mL), in an exothermic reaction, and the resulting solution was added dropwise to the stirred ethanol solution. After 15-30 min, the reaction mixture was concentrated *in vacuo*. The resulting residue was diluted with 1 M NaOH solution, extracted with diethyl ether (5 mL), and the aqueous made acidic (pH 3) with 1 M HCl. The acidic solution was extracted with ethyl acetate (6 × 50 mL) and the combined organic phases dried and concentrated to give *acid* **13** as a white crystalline solid (2.5 g, 74%). IR (neat) ν_{max} 2253 (CN), 1727 (C=O), 1645 (C=C), 1420 (OH) cm^{-1}; ^1H NMR (400 MHz, Methanol-d_4) δ 5.86 (ddt, J = 17.0, 10.0, 7.3 Hz, 2H, 2 × CH), 5.27 (dd, J = 17.0, 1.6 Hz, 2H, 2 × = C*H*H), 5.26 (dd, J = 10.0, 1.6 Hz, 2H, 2 × = CH*H*), 2.67 (dd, J = 13.9, 7.3 Hz, 2H, 2 × C*H*H), 2.58 (dd, J = 13.9, 7.3 Hz, 2H, 2 × CH*H*) ppm; ^{13}C NMR (methanol-d_4, 100 MHz): δ 169.4, 131.0, 119.5, 118.6, 49.8, 40.3 ppm; MS(CI^+) *m/z* 183 (MNH_4^+); HRMS (CI^+) calcd. for $C_9H_{15}N_2O_2$ (MNH_4^+); 183.1134, found 183.1127, Δ = - 3.8 ppm.

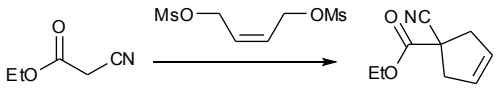
2,2,3-Triallyl-3-hydroxyhex-5-enenitrile 6



Dry magnesium turnings (824 mg, 33.92 mmol) were sonicated before covering in THF and refluxing briefly with iodine (20.3 mg, 0.08 mmol). A few drops of allyl bromide were added, and the reaction heated gently until the yellow colour disappeared. A solution of the remaining allyl bromide (2565 mg, 21.2 mmol) in tetrahydrofuran (20 mL) was added dropwise over 1 h and stirred for a further 2 h at RT. Meanwhile, *acid* **13** (1400 mg, 8.48 mmol) was dissolved in CH_2Cl_2 (35 mL) and stirred at 0 °C during cautious addition of oxalyl chloride (1399 mg, 11.02 mmol). Two drops of DMF were added and the reaction mixture stirred at RT for 3 h. After this time, the solvent was evaporated *in vacuo*, and the resulting residue redissolved in THF (5 mL). To this solution was added the Grignard reagent solution formed above, dropwise at 0 °C. After 3 h stirring at RT, the reaction mixture was quenched with sat. aqueous ammonium chloride solution (40 mL) and extracted with CH_2Cl_2 (3 × 50 mL). The combined organic layers were washed with aqueous HCl and brine, dried over sodium sulfate, filtered, concentrated, and purified by flash column chromatography eluting with 15:1 pet ether:EtOAc to give *tetraene* **6** as a pale yellow oil (120 mg, 9%). IR (neat) ν_{max} 3471 (OH), 3079, 2233 (CN), 1639 (C=C) cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz): δ 6.07 – 5.88 (m, 4H, 4 × =CH), 5.28 – 5.19 (m, 8H, 4 × =CH_2), 2.70 – 2.62 (m, 2H, 2 × C*H*H), 2.55 (d, J = 7.3 Hz, 4H, 2 × CH_2), 2.50 (dd, J = 14.4, 7.8 Hz, 2H, 2 × CH*H*), 2.15 (s, 1H) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz): δ 133.5, 132.9, 121.6, 120.0, 119.4, 75.9, 50.4, 41.3, 37.3 ppm; MS(CI^+) *m/z*

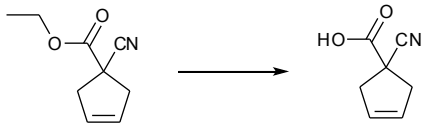
249 (MNH_4^+); HRMS (CI^+) calcd. for $C_{15}H_{25}N_2O$ (MNH_4^+); 249.1967, found 249.1966, Δ = -0.4 ppm.

Ethyl 1-cyanocyclopent-3-ene-1-carboxylate 14[6]



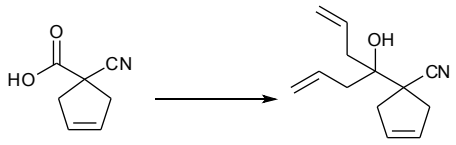
Ethyl cyanoacetate (47.0 µ L, 0.44 mmol) and *(Z)-but-2-en-1,4-diol dimethanesulfonate*[7] (73.1 mg, 0.40 mmol) were added to caesium carbonate (260 mg, 0.80 mmol) in DMF (10 mL) and the reaction mixture stirred for 30 min without restricting the temperature rise. Sat. aqueous sodium hydrogen carbonate solution (100 mL) was added to the reaction mixture before extracting with ethyl acetate (4 × 50 mL). The combined organic layers were washed with sat. aqueous sodium chloride solution (3 × 20 mL), dried over sodium sulfate and concentrated *in vacuo*. The crude residue was purified by flash column chromatography eluting with 1:10 EtOAc:pet ether to give the *cyclopentene* **14** as a colourless oil (55.4 mg, 84%). IR (neat) 2246 (CN), 1739 (C=O) cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz): δ 5.72 (s, 2H, HC=CH), 4.31 (q, J = 7.1 Hz, 1H, OCH_2CH_3), 3.15 (m, ^2J = 15.4 Hz, 1H, C*H*H), 3.09 (m, ^2J = 15.4 Hz, 1H, CH*H*), 1.36 (t, J = 7.2 Hz, 2H, OCH_2CH_3) ppm; ^{13}C NMR ($CDCl_3$, 400 MHz): δ 169.2, 127.5, 121.2, 63.1, 45.4, 44.0, 14.0 ppm; MS(CI^+) *m/z* 183 (MNH_4^+); HRMS (CI^+) calcd. for $C_9H_{15}N_2O_2$ (MNH_4^+); 183.1134, found 183.1143, Δ = 4.9 ppm.

1-Cyanocyclopent-3-ene-1-carboxylic acid 15



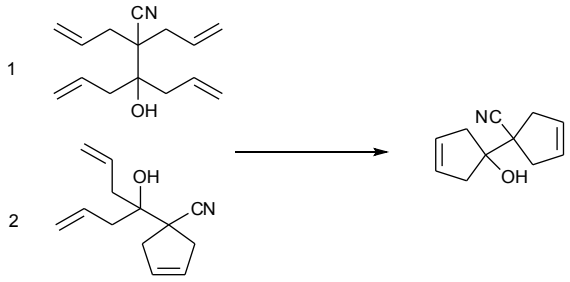
To a solution of *ester* **14** (40 mg, 0.24 mmol) in ethanol (4 mL) was added a solution of potassium *tert*-butoxide (29.2 mg, 0.26 mmol) in water (1 mL). The reaction mixture was stirred at RT for 1 h before being concentrated to an oil, redissolved in dilute sodium hydroxide (5 mL) and extracted once with diethyl ether (1 mL). The aqueous phase was acidified to pH 2 and extracted with ethyl acetate (4 × 20 mL). The combined organic layers were dried and concentrated to give *acid* **15** as a white powder (29.3 mg, 90%). IR (neat) ν_{max} 2252 (CN), 1721 (C=O) cm^{-1}; ^1H NMR (400MHz, Methanol-d_4) δ 5.72 (s, 2H, HC=CH), 3.15 (m, ^2J = 14.8 Hz, 2H, 2 × C*H*H), 2.97 (m, ^2J = 14.8 Hz, 2H, 2 × CH*H*) ppm; ^{13}C NMR (400 MHz, Methanol-d_4) δ 172.4, 127.4, 123.1, 47.1, 44.0 ppm; MS(CI^+) *m/z* 155 (MNH_4^+); HRMS (CI^+) calcd. for $C_7H_{11}N_2O_2$ (MNH_4^+); 155.0821, found 155.0826, Δ = 3.2 ppm.

1-(4-Hydroxyhepta-1,6-dien-4-yl)cyclopent-3-ene-1-carbonitrile 7



Dry magnesium turnings (306 mg, 12.6 mmol) were sonicated before covering in THF and refluxing briefly with iodine (20.3 mg, 0.08 mmol). Allyl bromide (762 mg, 6.3 mmol) was dropped in slowly over 90 min while stirring rapidly at RT. Meanwhile, *acid* **15** (288 mg, 2.1 mmol) was dissolved in CH_2Cl_2 (6 mL) and stirred at 0 °C during cautious addition of a solution of oxalyl chloride (216 μ L, 2.52 mmol) in CH_2Cl_2 (1 mL). A drop of DMF was added and the reaction mixture was heated at reflux for 3 h. After this time, the solvent was evaporated *in vacuo* and the resulting yellow oil redissolved in THF (3 mL). To this was added the Grignard reagent solution formed above, dropwise at 0 °C. After 3 h stirring at RT, the reaction mixture was quenched with sat. aqueous ammonium chloride solution (40 mL) and extracted with CH_2Cl_2 (3 × 50 mL). The combined organic layers were washed with aqueous HCl and brine, dried over sodium sulfate, filtered, concentrated and purified by flash column chromatography eluting with 15:1 pet ether:EtOAc to give *triene* **7** as a pale yellow oil. IR (neat) ν_{max} 3467 (OH), 2235 (CN), 1640 (C=C) cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz): δ 5.95 (ddt, J = 17.6, 10.3, 7.4 Hz, 2H, 2 × =CH), 5.71 (s, 2H, HC=CH), 5.31 – 5.16 (m, 4H, 2 × $=CH_2$), 2.92 (d, J = 14.8 Hz, 2H, 2 × C*H*H), 2.78 (d, J = 14.8 Hz, 2H, 2 × CH*H*), 2.58 (dd, J = 14.1, 7.5 Hz, 2H, 2 × C*H*H), 2.47 (dd, J = 14.1, 7.5 Hz, 2H, 2 × CH*H*), 2.00 (s, 1H) ppm; ^{13}C NMR ($CDCl_3$, 100 MHz): δ 132.8, 128.2, 125.3, 120.2, 74.2, 51.5, 41.8, 40.7 ppm; MS(CI^+) *m/z* 221 (MNH_4^+); HRMS (CI^+) calcd. for $C_{13}H_{21}N_2O$ (MNH_4^+); 221.1654, found 221.1647, Δ = -3.2 ppm.

1'-Hydroxy-[1,1'-bi(cyclopentane)]-3,3'-diene-1-carbonitrile 10



Method 1 – from tetraene **6**: To a solution of *tetraene* **6** (80 mg, 0.35 mmol) in CH_2Cl_2 (15 mL) was added Grubbs II catalyst {Trnka, 2000 #708} (17.0 mg, 0.02 mmol) and the resulting reaction mixture stirred at RT for 14 h. After concentration *in vacuo*, analysis of the ^1H NMR spectrum of the crude residue revealed the formation of two products in a ratio of 2:1. The major product corresponds to *bis-cyclopentene* **10** (see below) and the minor product corresponds to the known *trans-2,3,6,7-dehydrodecalin* **8**.{Webber, 2013 #78}

Method 2 – from triene **7**: To a solution of *triene* **7** (300 mg, 1.48 mmol) in CH_2Cl_2 (30 mL) at 0 °C was added Grubbs II catalyst{Trnka, 2000 #708} (59.4 mg, 0.07 mmol) and the resulting

reaction mixture stirred at RT for 18 h. After concentration *in vacuo*, analysis of the ^{1}H NMR spectrum of the crude residue revealed the formation of a single product. Purification by flash column chromatography eluting with 1:11 EtOAc:pet ether gave *bis*-cyclopentene **10** as a white crystalline solid (190 mg, 73%). Mp. 54.5-56.0 °C; IR (neat) ν_{max} 3461 (OH), 3060, 2925, 2860, 2237 (CN), 1622 (C=C), 1431, 1368, 1340 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 5.73 (m, 2H, HC=CH), 5.69 (m, 2H, HC=CH), 2.97 – 2.86 (m, 2H, 2 × C*H*H), 2.83 – 2.71 (m, 4H, 2 × CH_2), 2.53 – 2.42 (m, 2H, 2 × CH*H*), 2.08 (br, s, 1H, OH) ppm; ^{1}H NMR (acetone-d_6, 500 MHz) δ 5.70 (m, 2H, HC=CH), 5.68 (m, 2H, HC=CH), 4.43 (s, 1H, OH), 2.83 – 2.66 (m, 6H, CH_2), 2.51 – 2.41 (m, 2H, CH_2). ^{1}H-^{1}H TOCSY NMR (acetone-d_6, 500 MHz): no cross-peak between alkene proton environments at δ 5.70 and 5.68; ^{13}C NMR ($CDCl_3$, 100 MHz): δ 128.48-128.47 (overlapping signals), 125.3, 83.1, 49.2, 44.9, 41.6 ppm; MS(CI$^+$) *m/z* 193 (MNH_4^+); HRMS (CI$^+$) calcd. for $C_{11}H_{17}N_2O$ (MNH_4^+); 193.1341, found 193.1331, Δ = -5.2 ppm. Further re-crystallisation of a portion of this product *via* the vapour diffusion method using EtOAc:pentane gave white needles suitable for X-ray crystallography.

Crystal data for **10**: $C_{11}H_{13}NO$.

Chemical formula	$C_{11}H_{13}NO$
M_r	175.22
Crystal system, space group	Monoclinic, $P2_1/n$
Temperature (K)	100
a, b, c (Å)	6.2966 (6), 25.416 (4), 11.7111 (13)
β (°)	90.162 (8)
V (Å^3)	1874.1 (4)
Z	8
Radiation type	Cu $K\alpha$
μ (mm^{-1})	0.63
Crystal size (mm)	0.50 × 0.06 × 0.06
Data collection	
Diffractometer	SuperNova, Dual, Cu at zero, Atlas diffractometer
Absorption correction	Multi-scan *CrysAlis PRO*, Agilent Technologies, Version 1.171.35.19 (release 27-10-2011 CrysAlis171 .NET) (compiled Oct 27 2011,15:02:11) Empirical absorption correction using spherical harmonics, implemented in SCALE3 ABSPACK scaling algorithm.
T_{min}, T_{max}	0.822, 1.000
No. of measured, independent and observed [$I > 2\sigma(I)$] reflections	8275, 3793, 3151
R_{int}	0.032
$(\sin \theta/\lambda)_{max}$ (Å^{-1})	0.625
Refinement	
$R[F^2 > 2\sigma(F^2)]$, $wR(F^2)$, S	0.045, 0.141, 1.01
No. of reflections	3793
No. of parameters	281
No. of restraints	0

H-atom treatment	H atoms treated by a mixture of independent and constrained refinement
$\Delta\rho_{max}$, $\Delta\rho_{min}$ (e Å^{-3})	0.30, –0.21

Computer programs: *CrysAlis PRO*, Agilent Technologies, Version 1.171.35.19 (release 27-10-2011 CrysAlis171 .NET) (compiled Oct 27 2011,15:02:11), *SHELXTL* (Sheldrick, 2008), Mercury 2.4 (Macrae *et al.*, 1998).

Table 1 Selected geometric parameters (Å, º)

O1A—C6A	1.4270 (17)	C1B—C6B	1.545 (5)
N1A—C11A	1.146 (2)	C1B—C5B	1.556 (3)
C1A—C11A	1.4693 (18)	C1B—C2B	1.581 (3)
C1A—C5A	1.5543 (19)	C2B—C3B	1.501 (2)
C1A—C6A	1.5579 (19)	C3B—C4B	1.313 (3)
C1A—C2A	1.5624 (19)	C4B—C5B	1.495 (2)
C2A—C3A	1.494 (2)	C6B—C7B	1.552 (3)
C3A—C4A	1.314 (2)	C6B—C10B	1.575 (3)
C4A—C5A	1.496 (2)	C7B—C8B	1.490 (3)
C6A—C7A	1.5453 (18)	C8B—C9B	1.313 (3)
C6A—C10A	1.5472 (19)	C9B—C10B	1.499 (3)
C7A—C8A	1.500 (2)	O1B—H1B	0.87 (3)
C8A—C9A	1.324 (2)	O1B—H1C	0.87 (3)
C9A—C10A	1.490 (2)	O1C—C1C	1.418 (9)
O1A—H1A	0.90 (3)	C1C—C6C	1.543 (7)
O1B—C6B	1.419 (4)	C6C—C11C	1.492 (7)
N1B—C11B	1.180 (4)	O1C—H1B	0.95 (3)
C1B—C11B	1.476 (6)	O1C—H1C	0.95 (3)

C5A—C1A—C2A	105.72 (11)	C11B—C1B—C2B	111.1 (2)
C5A—C1A—C6A	111.77 (12)	C11B—C1B—C5B	110.5 (2)
C6A—C1A—C2A	112.28 (11)	C11B—C1B—C6B	108.9 (3)
C11A—C1A—C2A	110.05 (12)	C3B—C2B—C1B	103.77 (15)
C11A—C1A—C5A	109.36 (11)	C4B—C3B—C2B	112.39 (15)
C11A—C1A—C6A	107.66 (11)	C3B—C4B—C5B	112.70 (15)
C3A—C2A—C1A	103.41 (12)	C4B—C5B—C1B	104.53 (15)
C4A—C3A—C2A	113.25 (14)	C1B—C6B—C7B	109.7 (2)
C3A—C4A—C5A	112.82 (13)	C1B—C6B—C10B	110.9 (2)
C4A—C5A—C1A	103.72 (12)	C7B—C6B—C10B	103.82 (18)
C7A—C6A—C1A	112.63 (11)	O1B—C6B—C1B	108.7 (3)
C7A—C6A—C10A	105.71 (11)	O1B—C6B—C7B	109.3 (2)
C10A—C6A—C1A	112.38 (11)	O1B—C6B—C10B	114.2 (2)
O1A—C6A—C1A	109.83 (11)	C8B—C7B—C6B	103.69 (17)
O1A—C6A—C7A	106.07 (11)	C9B—C8B—C7B	112.06 (16)
O1A—C6A—C10A	109.96 (11)	C8B—C9B—C10B	113.14 (17)
C8A—C7A—C6A	103.67 (12)	C9B—C10B—C6B	102.19 (16)
C9A—C8A—C7A	112.44 (14)	N1B—C11B—C1B	176.9 (4)
C8A—C9A—C10A	112.44 (14)	C6B—O1B—H1B	113.3 (19)
C9A—C10A—C6A	104.05 (11)	C6B—O1B—H1C	113.3 (19)
N1A—C11A—C1A	178.51 (15)	O1C—C1C—C6C	108.0 (5)
C6A—O1A—H1A	113.3 (16)	C11C—C6C—C1C	109.0 (5)
C5B—C1B—C2B	103.36 (19)	C1C—O1C—H1C	115.9 (18)
C6B—C1B—C2B	111.5 (3)	C1C—O1C—H1B	115.9 (18)
C6B—C1B—C5B	111.4 (3)		

C11A—C1A—C2A—C3A	127.62 (13)	C6B—C1B—C2B—C3B	−136.6 (2)
C5A—C1A—C2A—C3A	9.63 (15)	C5B—C1B—C2B—C3B	−16.8 (3)
C6A—C1A—C2A—C3A	−112.49 (13)	C1B—C2B—C3B—C4B	11.1 (2)
C1A—C2A—C3A—C4A	−5.79 (18)	C2B—C3B—C4B—C5B	0.1 (2)
C2A—C3A—C4A—C5A	−0.8 (2)	C3B—C4B—C5B—C1B	−11.5 (2)
C3A—C4A—C5A—C1A	7.08 (18)	C11B—C1B—C5B—C4B	−102.0 (2)
C11A—C1A—C5A—C4A	−128.51 (13)	C6B—C1B—C5B—C4B	136.8 (2)
C6A—C1A—C5A—C4A	112.38 (13)	C2B—C1B—C5B—C4B	17.0 (3)
C2A—C1A—C5A—C4A	−10.06 (15)	C11B—C1B—C6B—O1B	−177.0 (2)

C11A—C1A—C6A—O1A	67.25 (14)	C5B—C1B—C6B—O1B	−54.9 (3)
C5A—C1A—C6A—O1A	−172.64 (11)	C2B—C1B—C6B—O1B	60.0 (3)
C2A—C1A—C6A—O1A	−54.03 (14)	C11B—C1B—C6B—C7B	−57.5 (3)
C11A—C1A—C6A—C7A	−174.77 (11)	C5B—C1B—C6B—C7B	64.6 (4)
C5A—C1A—C6A—C7A	−54.66 (15)	C2B—C1B—C6B—C7B	179.54 (19)
C2A—C1A—C6A—C7A	63.95 (15)	C11B—C1B—C6B—C10B	56.6 (3)
C11A—C1A—C6A—C10A	−55.50 (15)	C5B—C1B—C6B—C10B	178.76 (19)
C5A—C1A—C6A—C10A	64.61 (14)	C2B—C1B—C6B—C10B	−66.3 (4)
C2A—C1A—C6A—C10A	−176.78 (11)	O1B—C6B—C7B—C8B	−100.8 (2)
O1A—C6A—C7A—C8A	−104.46 (13)	C1B—C6B—C7B—C8B	140.0 (2)
C10A—C6A—C7A—C8A	12.29 (15)	C10B—C6B—C7B—C8B	21.4 (3)
C1A—C6A—C7A—C8A	135.37 (12)	C6B—C7B—C8B—C9B	−14.4 (3)
C6A—C7A—C8A—C9A	−7.82 (18)	C7B—C8B—C9B—C10B	0.4 (2)
C7A—C8A—C9A—C10A	−0.30 (19)	C8B—C9B—C10B—C6B	13.5 (2)
C8A—C9A—C10A—C6A	8.30 (17)	O1B—C6B—C10B—C9B	98.0 (2)
O1A—C6A—C10A—C9A	101.58 (13)	C1B—C6B—C10B—C9B	−138.7 (2)
C7A—C6A—C10A—C9A	−12.50 (14)	C7B—C6B—C10B—C9B	−20.9 (2)
C1A—C6A—C10A—C9A	−135.74 (12)	C11B—C1B—C2B—C3B	101.6 (2)
O1C—C1C—C6C—C11C	176.9 (3)		

Figure S1 Molecule A Gauche Form

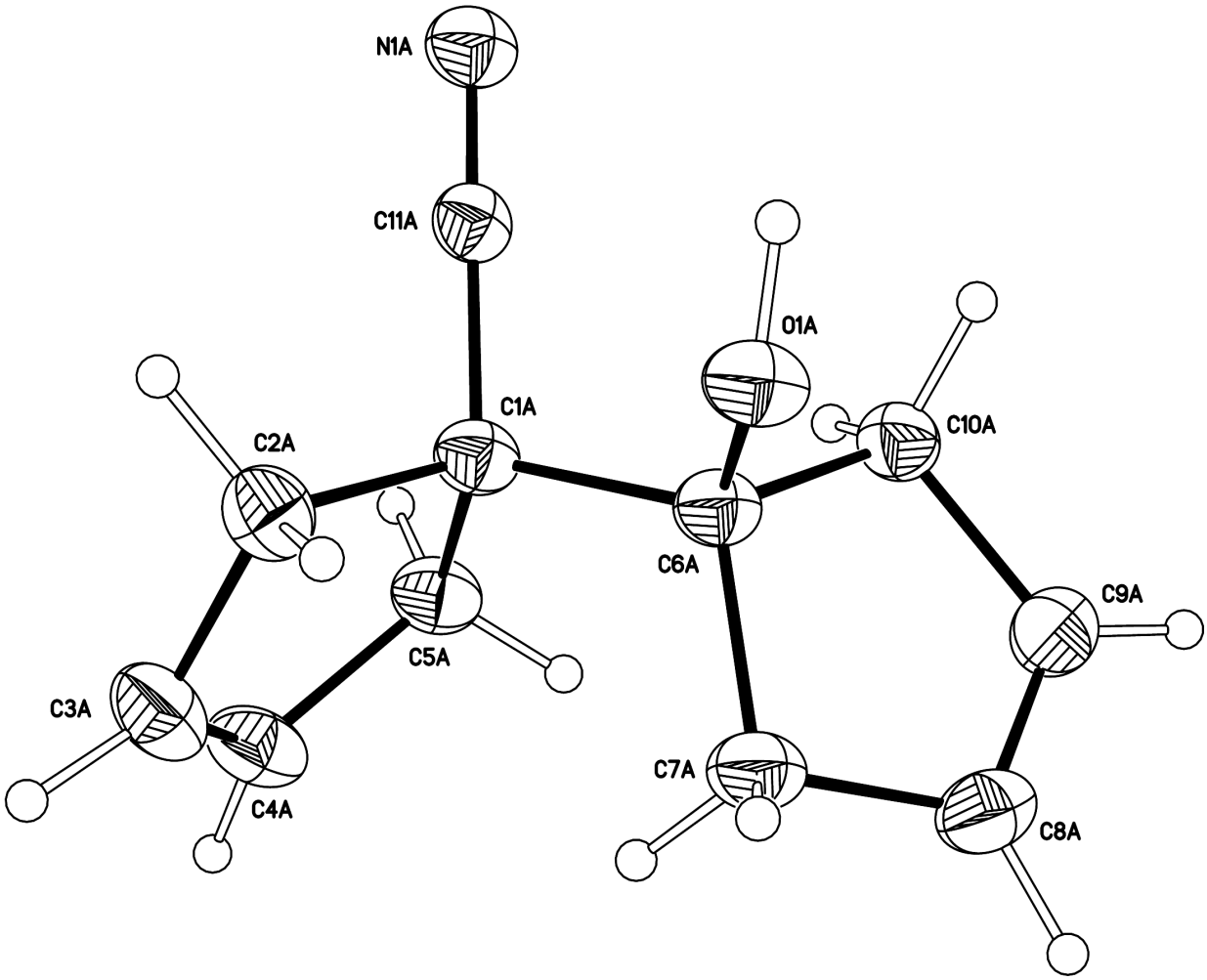


Figure S2 Molecule B and C Major and Minor components of the Anti Form

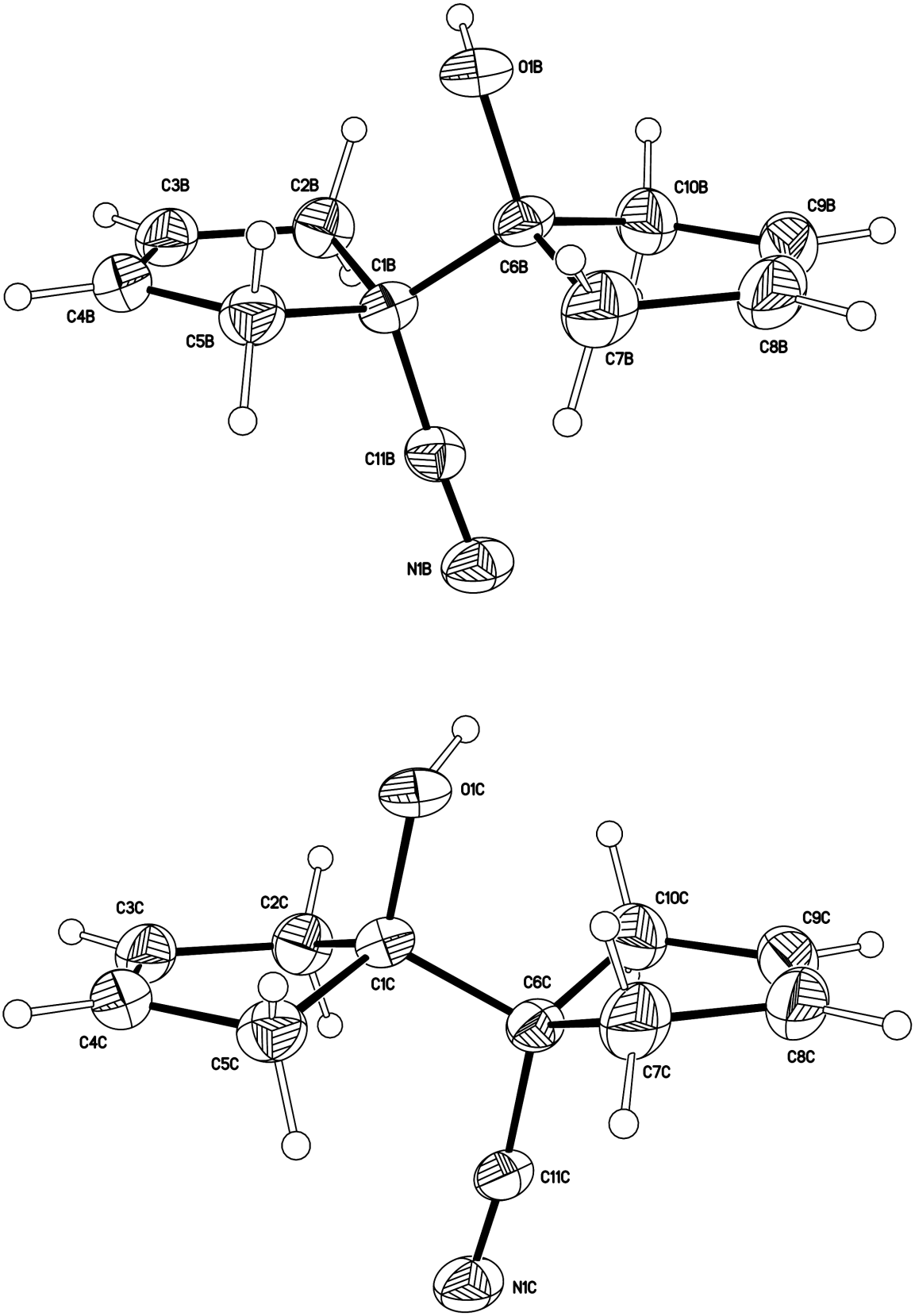
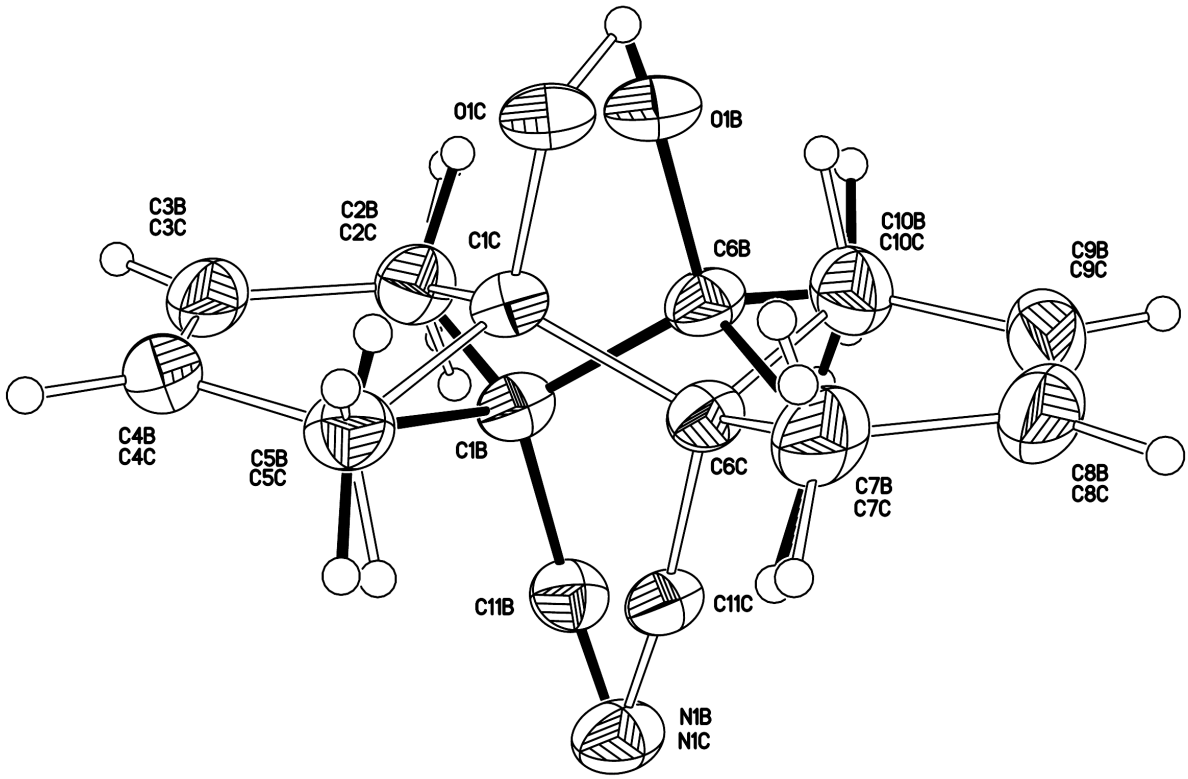
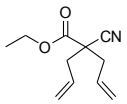


Figure S3 Molecules B and C Major and Minor components of the Anti Form showing disorder model

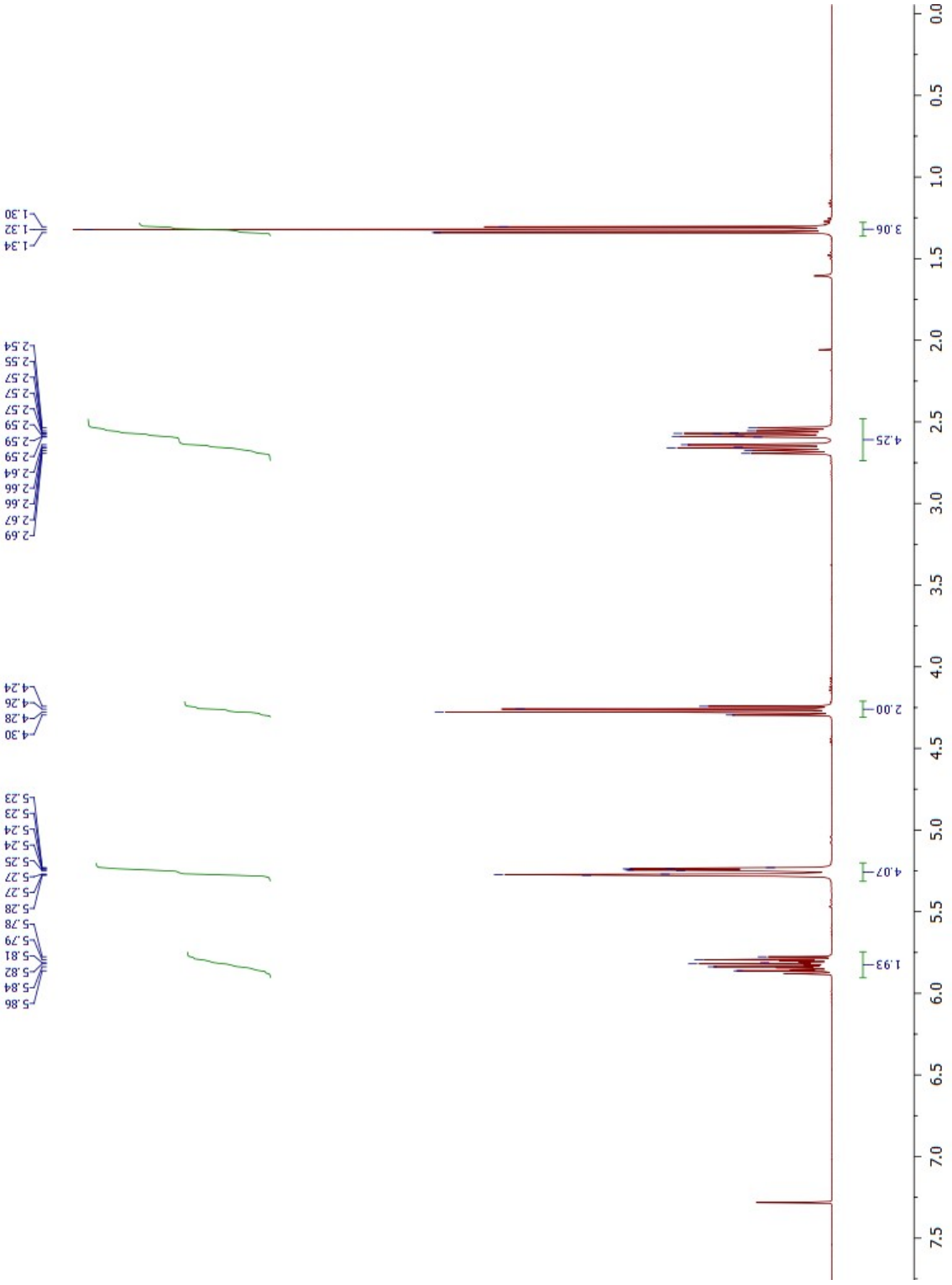


NMR spectra of all Compounds

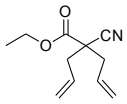
^{1}H NMR ($CDCl_3$, 400 MHz) Ethyl 2-allyl-2-cyanopent-4-enoate **12**.[5]



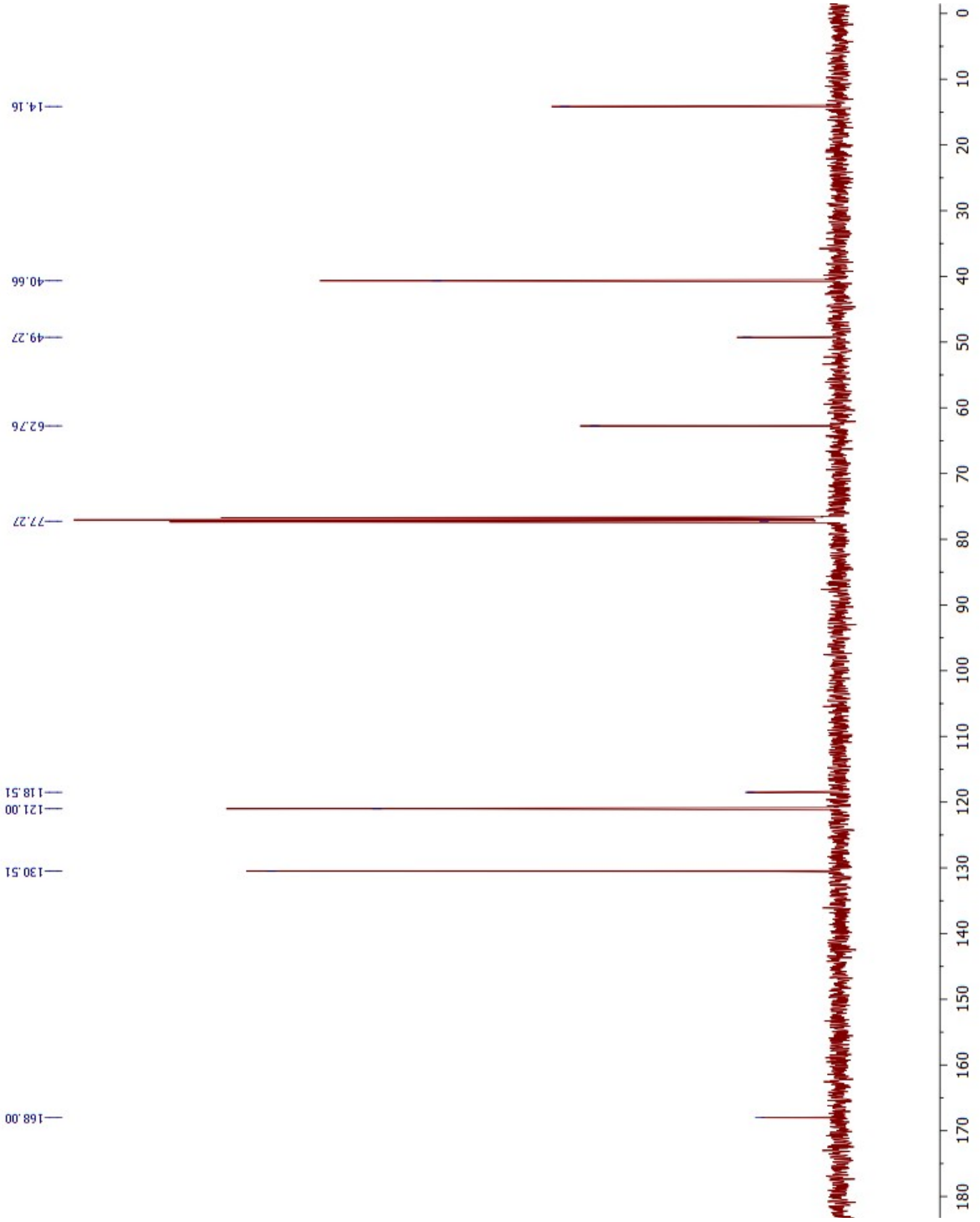
12



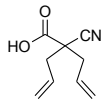
^{13}C NMR ($CDCl_3$, 100 MHz) Ethyl 2-allyl-2-cyanopent-4-enoate **12**.[5]



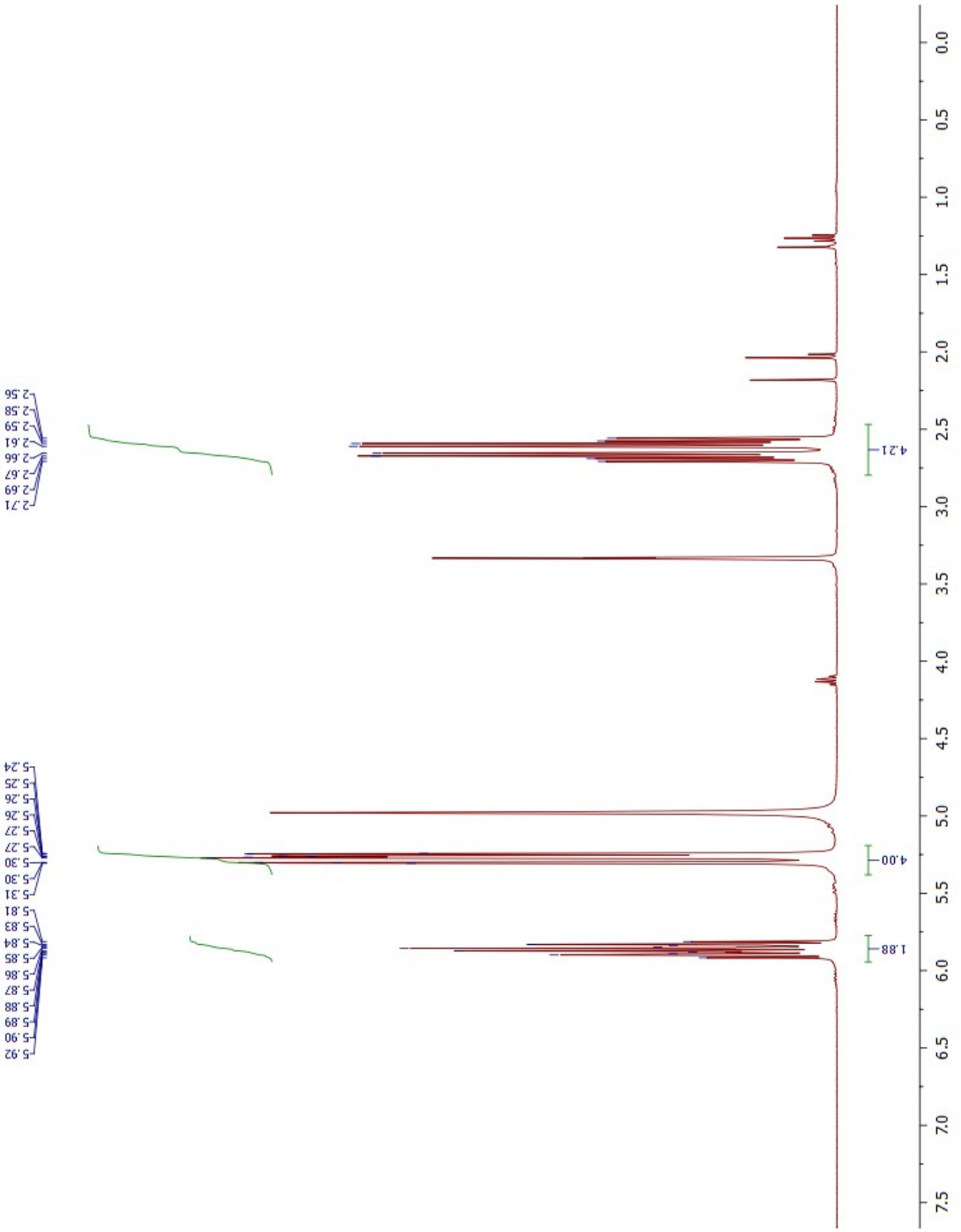
12



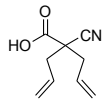
^{1}H NMR (Methanol-d_4, 400 MHz) 2-Allyl-2-cyanopent-4-enoic acid **13**.



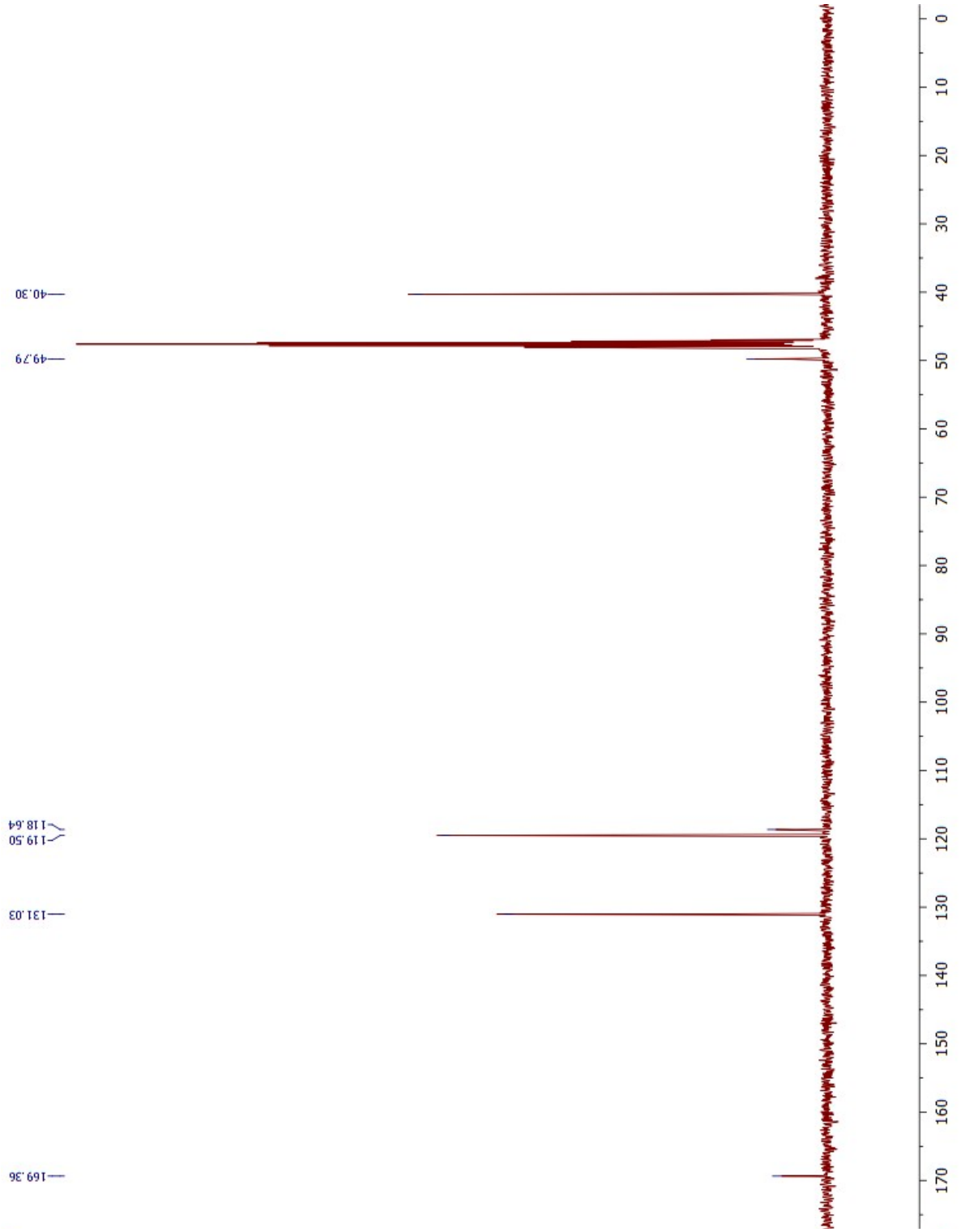
13



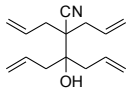
^{13}C NMR (Methanol-d_4, 100 MHz) 2-Allyl-2-cyanopent-4-enoic acid **13**.



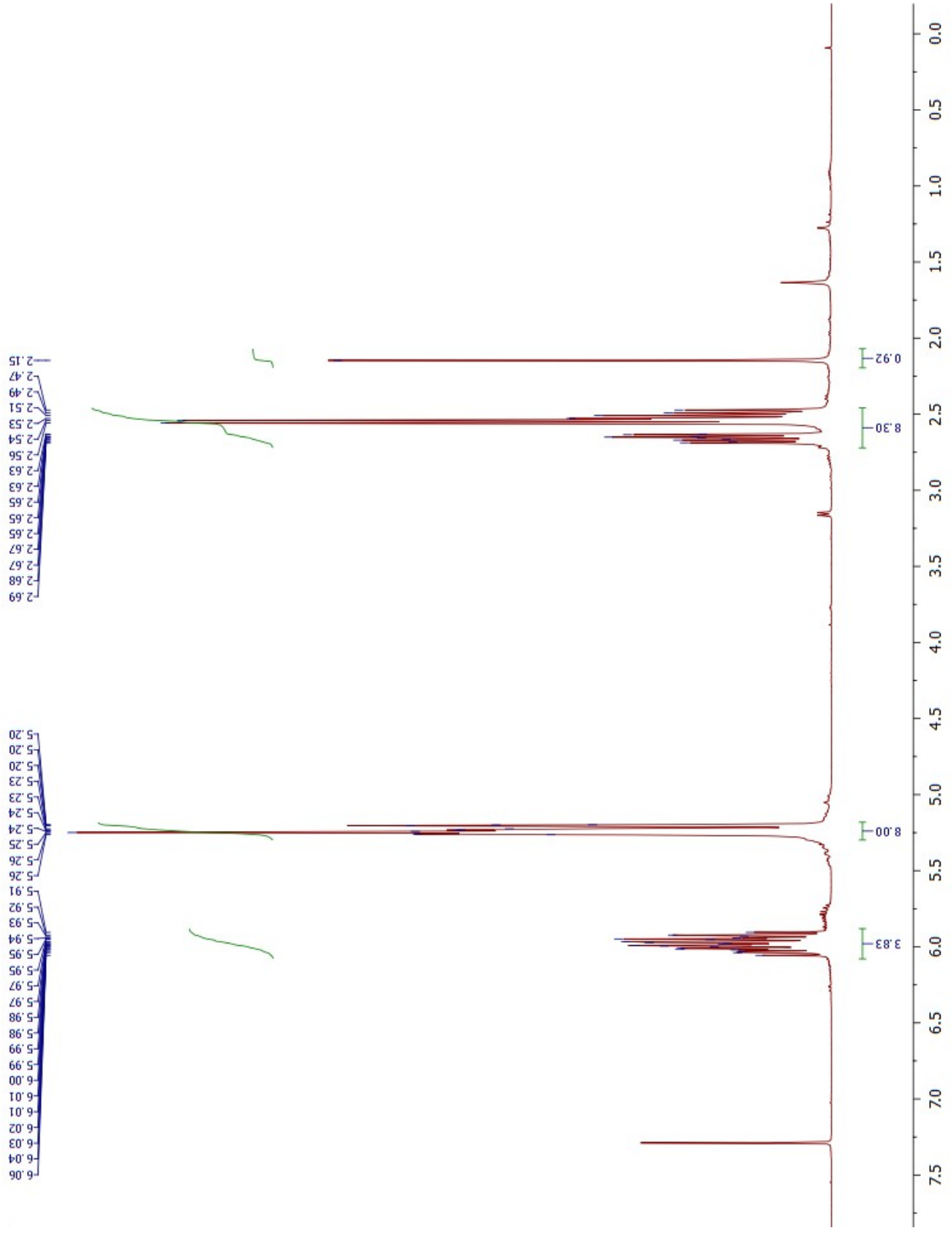
13



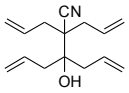
^{1}H NMR ($CDCl_3$, 400 MHz) 2,2,3-Triallyl-3-hydroxyhex-5-enenitrile **6**.



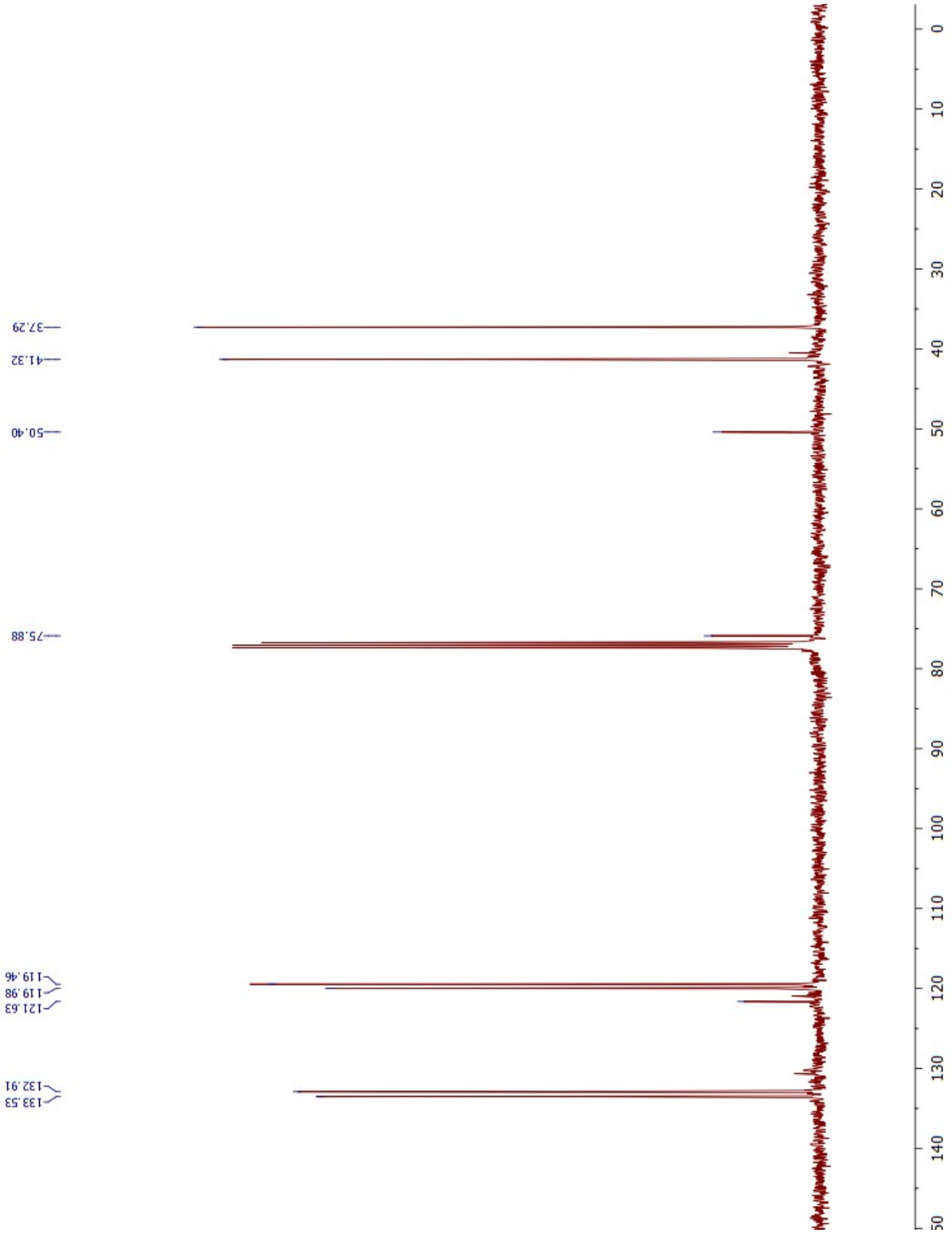
6



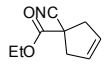
^{13}C NMR ($CDCl_3$, 100 MHz) 2,2,3-Triallyl-3-hydroxyhex-5-enenitrile **6**.



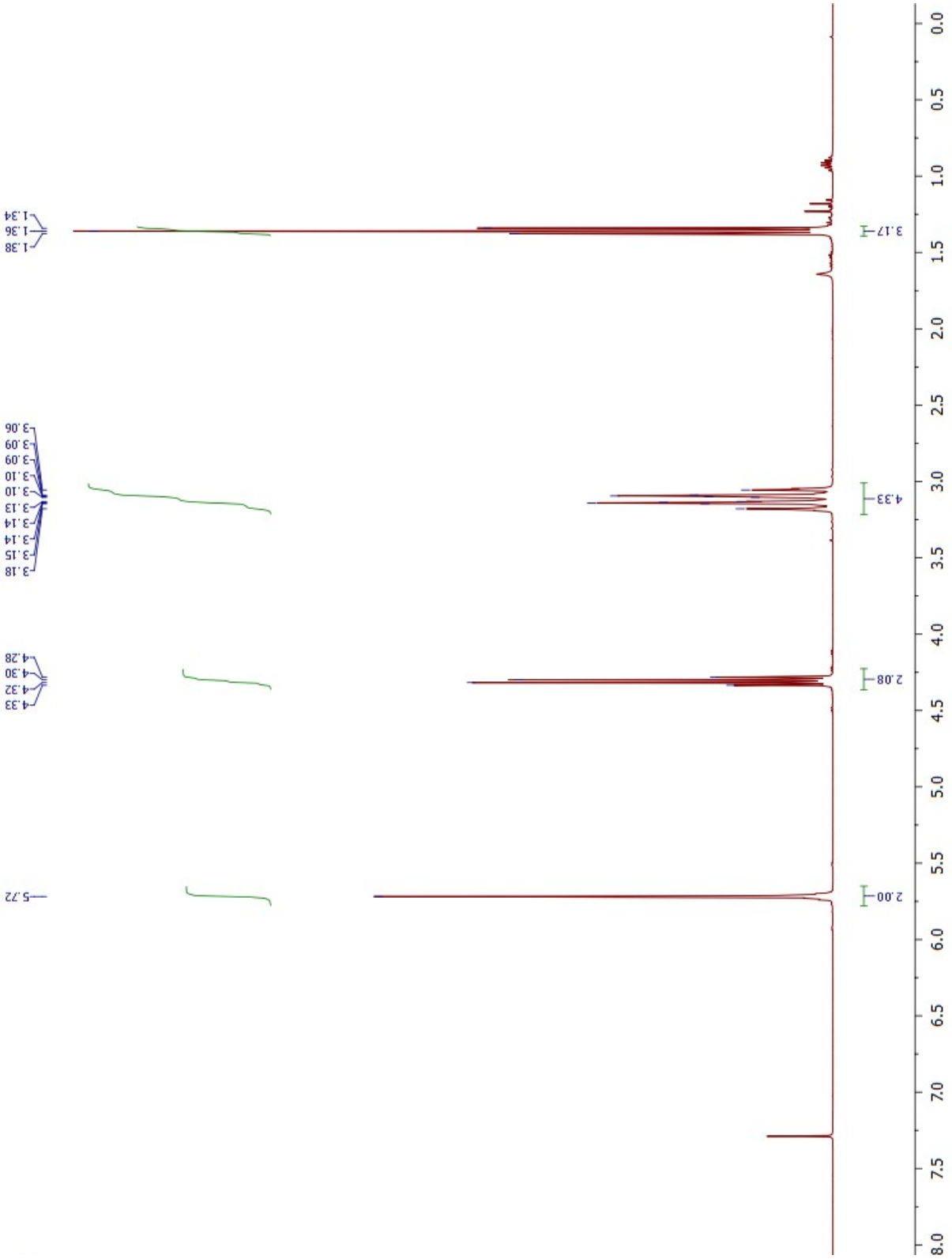
6



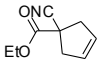
^{1}H NMR ($CDCl_3$, 400 MHz) Ethyl 1-cyanocyclopent-3-ene-1-carboxylate **14**.[6]



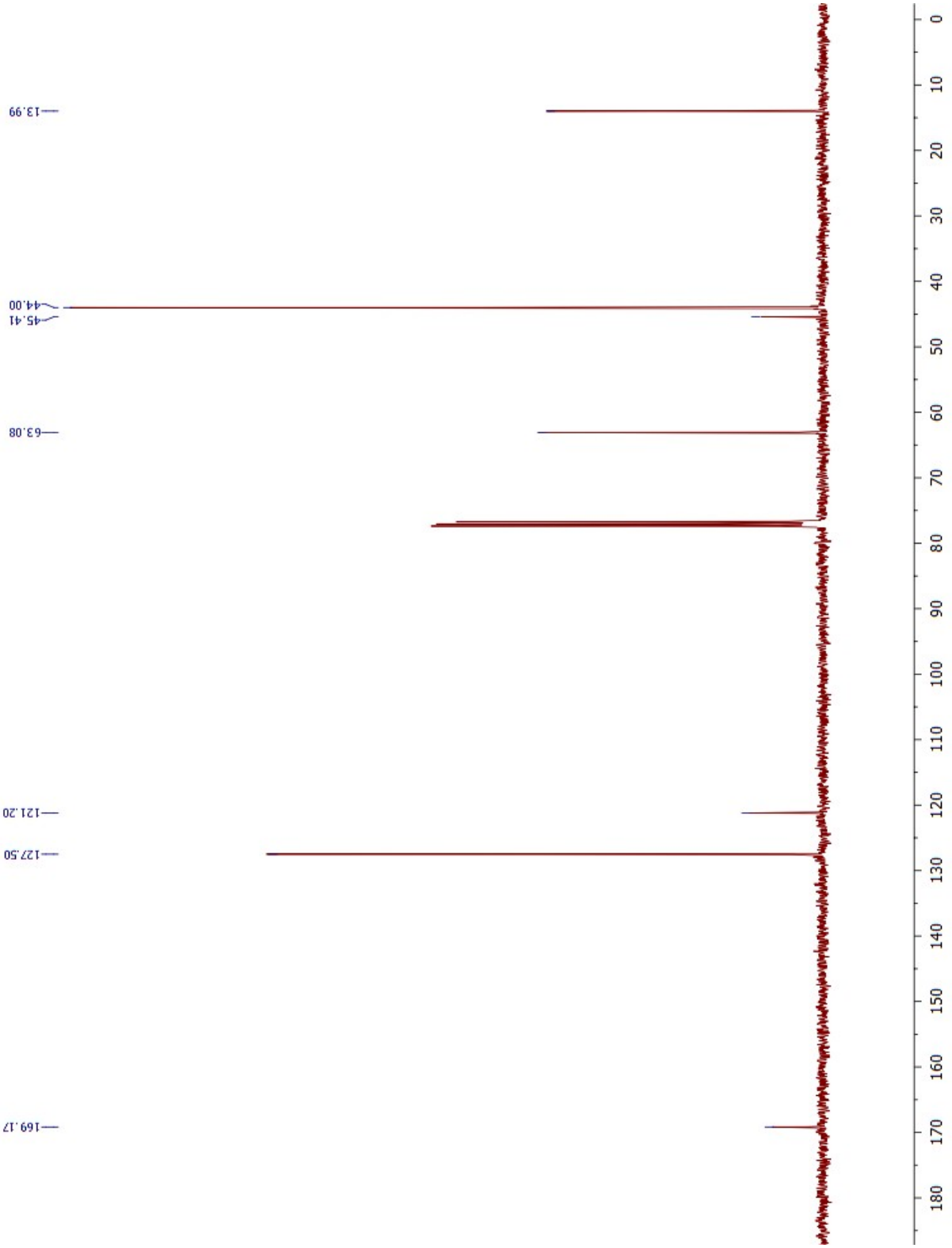
14



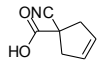
^{13}C NMR ($CDCl_3$, 100 MHz) Ethyl 1-cyanocyclopent-3-ene-1-carboxylate **14.**[6]



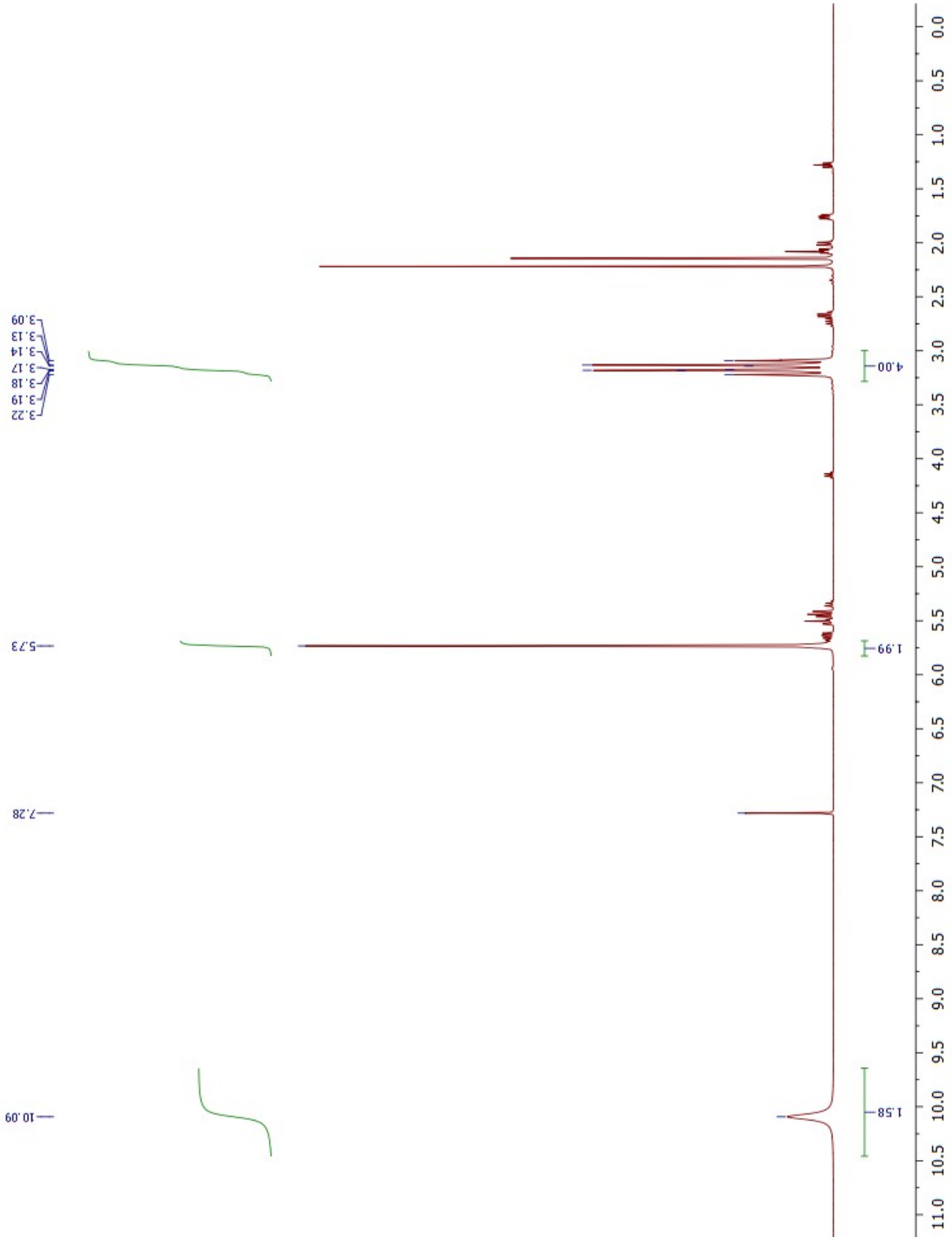
14



^{1}H NMR ($CDCl_3$, 400 MHz) 1-Cyanocyclopent-3-ene-1-carboxylic acid **15**.

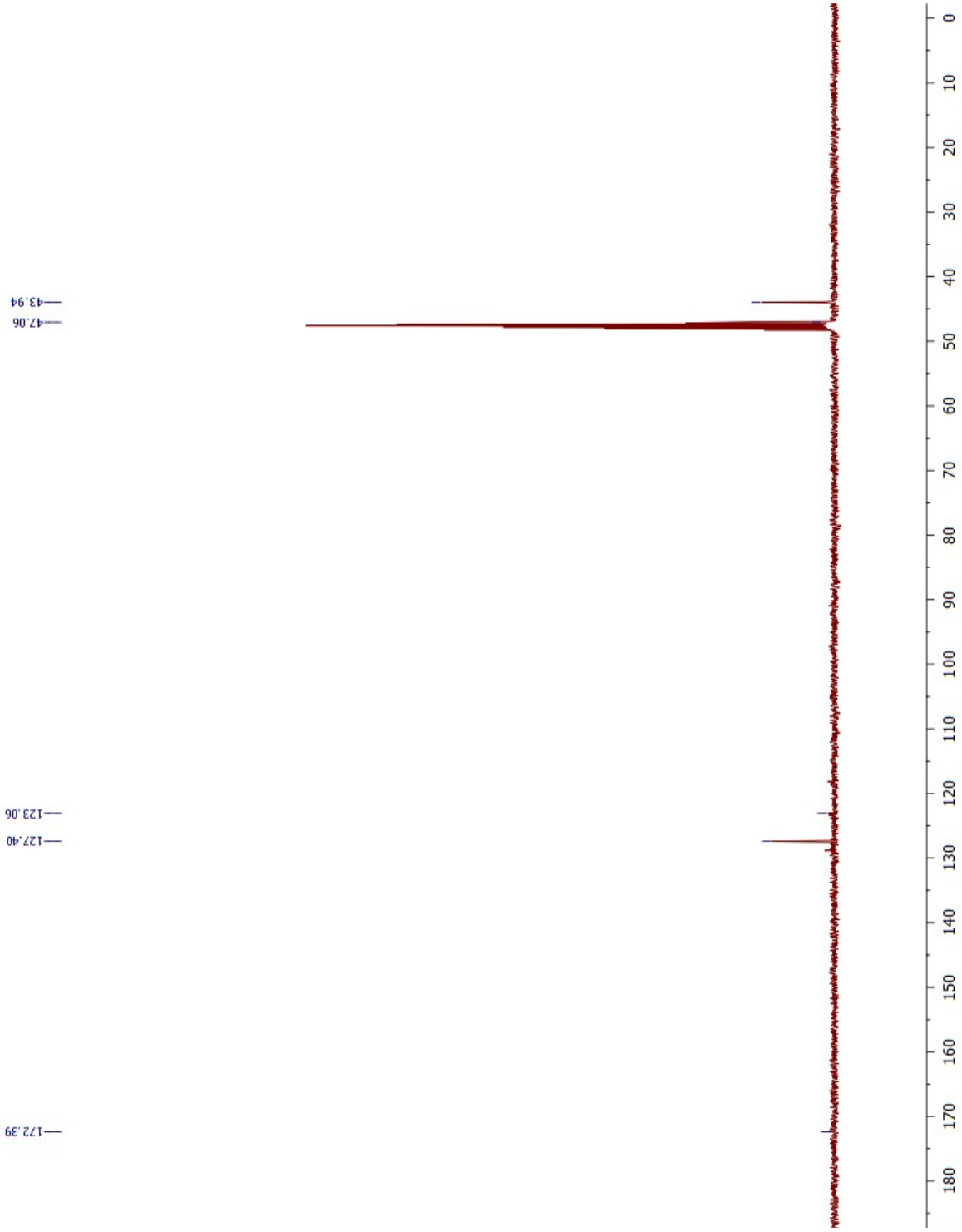


15

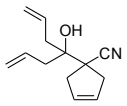


^{13}C NMR (Methanol-d_4, 100 MHz) 1-Cyanocyclopent-3-ene-1-carboxylic acid **15**.

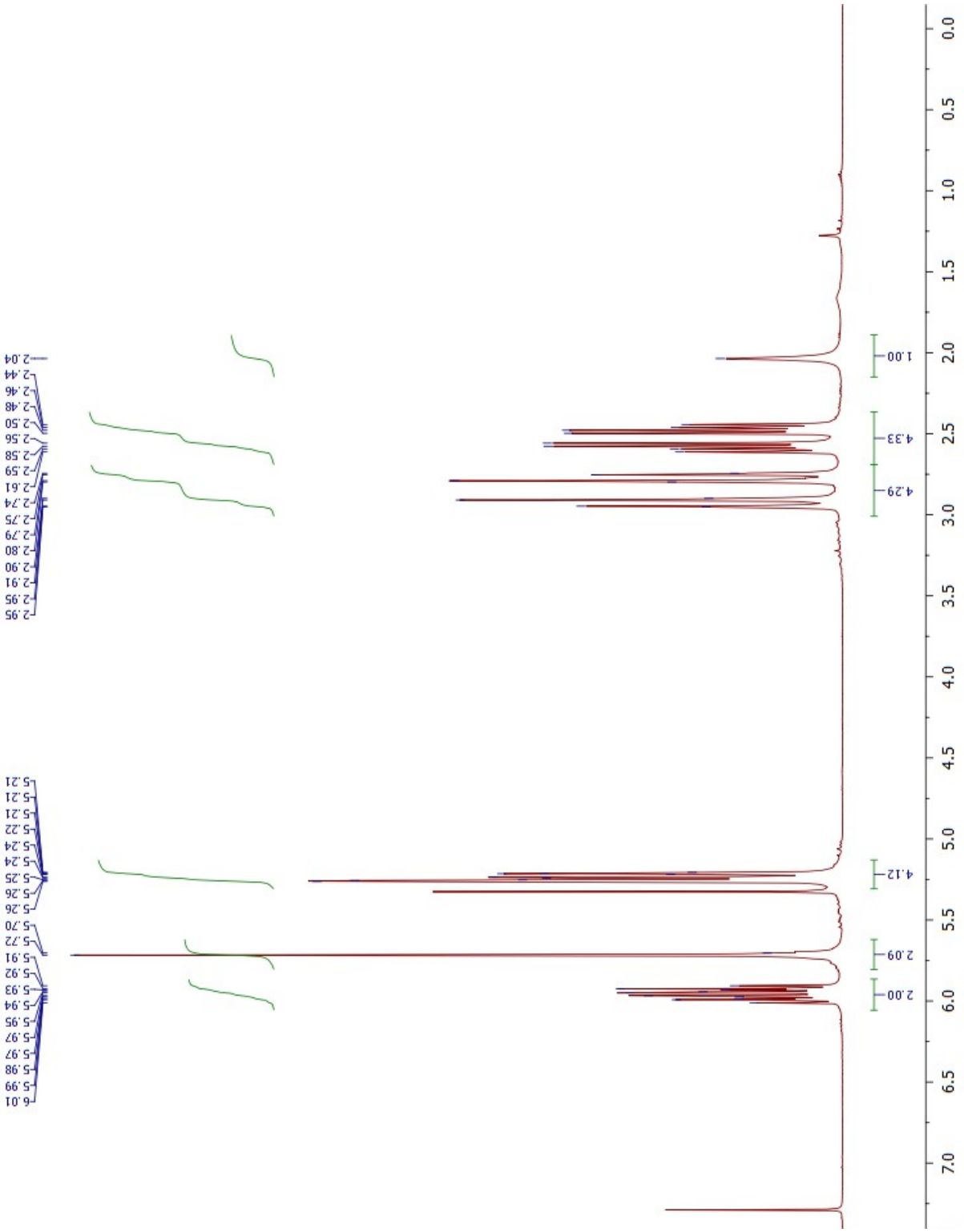
15



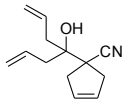
^{1}H NMR ($CDCl_3$, 400 MHz) 1-(4-Hydroxyhepta-1,6-dien-4-yl)cyclopent-3-ene-1-carbonitrile **7**.



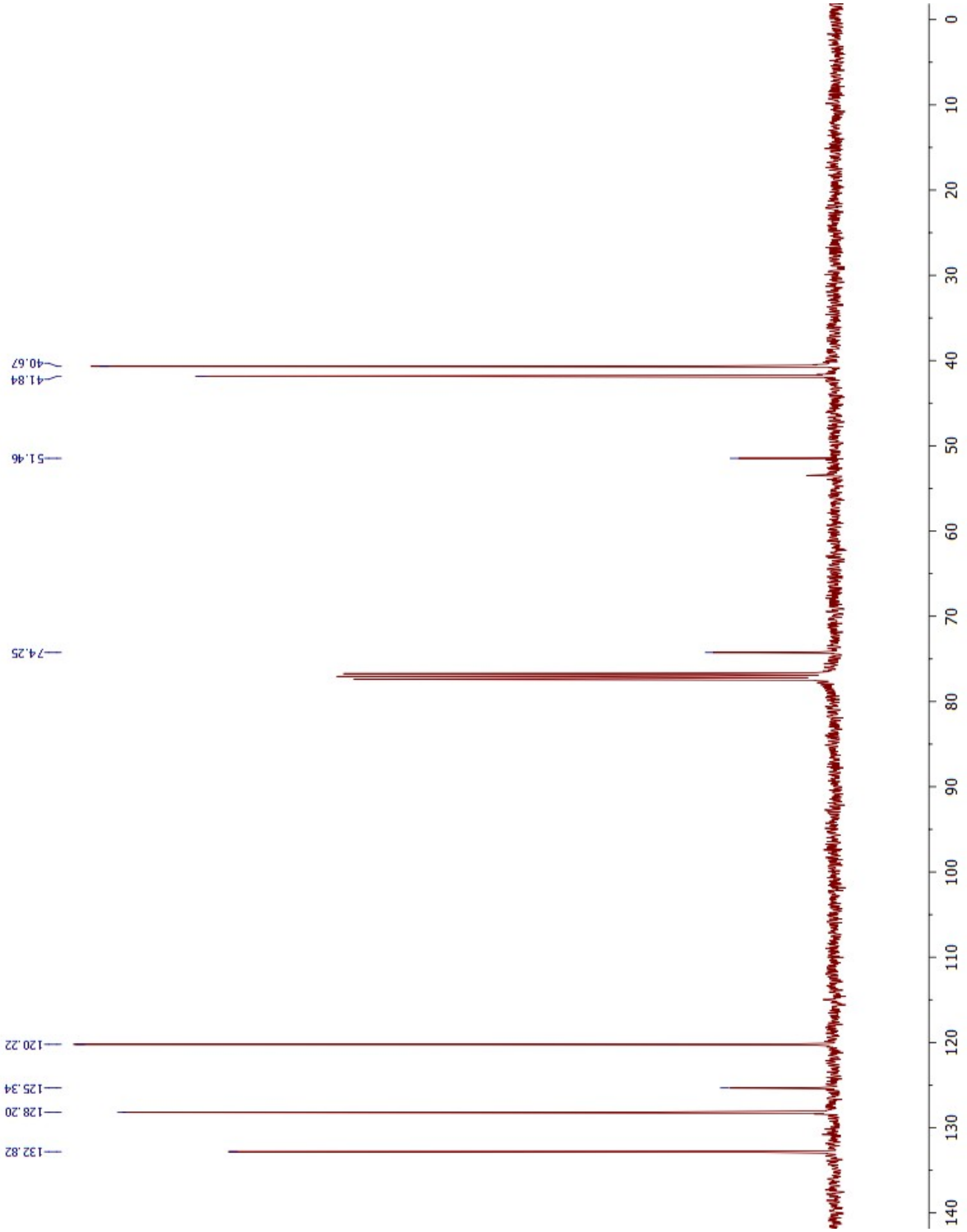
7



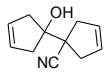
^{13}C NMR (CDCl$_3$, 100 MHz) 1-(4-Hydroxyhepta-1,6-dien-4-yl)cyclopent-3-ene-1-carbonitrile **7**.



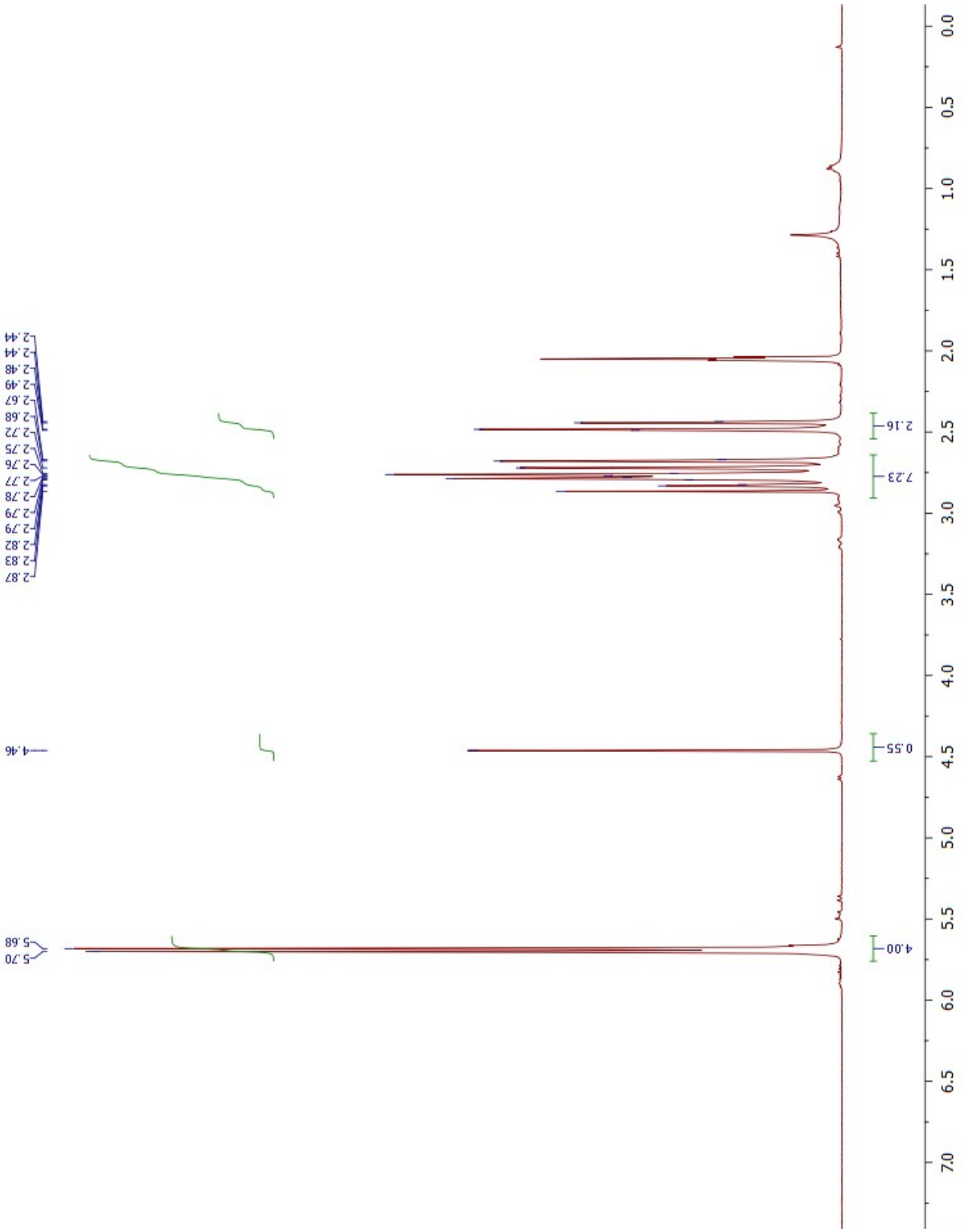
7



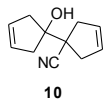
^{1}H NMR (acetone-d_6, 400 MHz) 1'-Hydroxy-[1,1'-bi(cyclopentane)]-3,3'-diene-1-carbonitrile **10**.



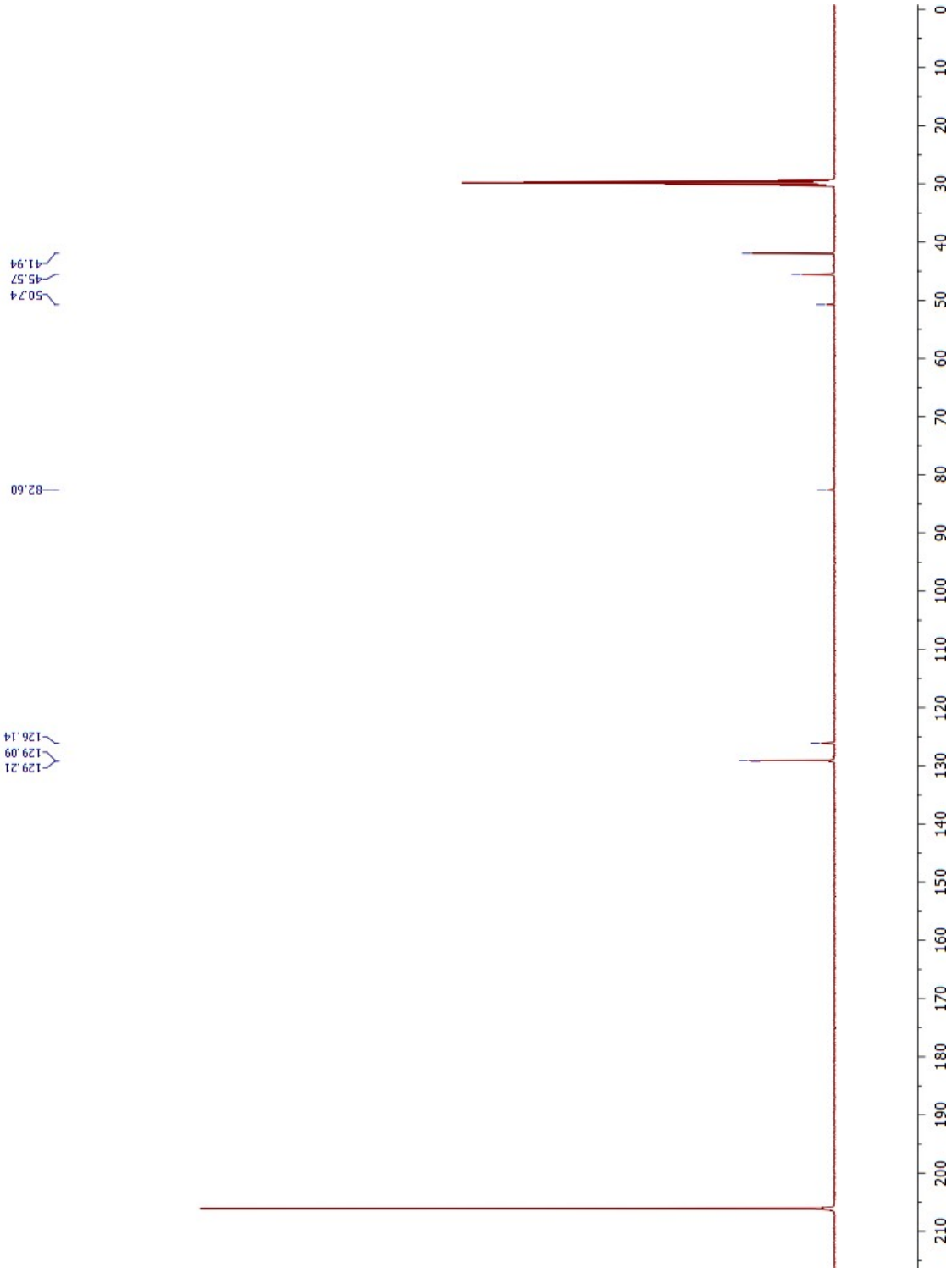
10



^{13}C NMR (acetone-d_6, 125 MHz) 1'-Hydroxy-[1,1'-bi(cyclopentane)]-3,3'-diene-1-carbonitrile **10**.

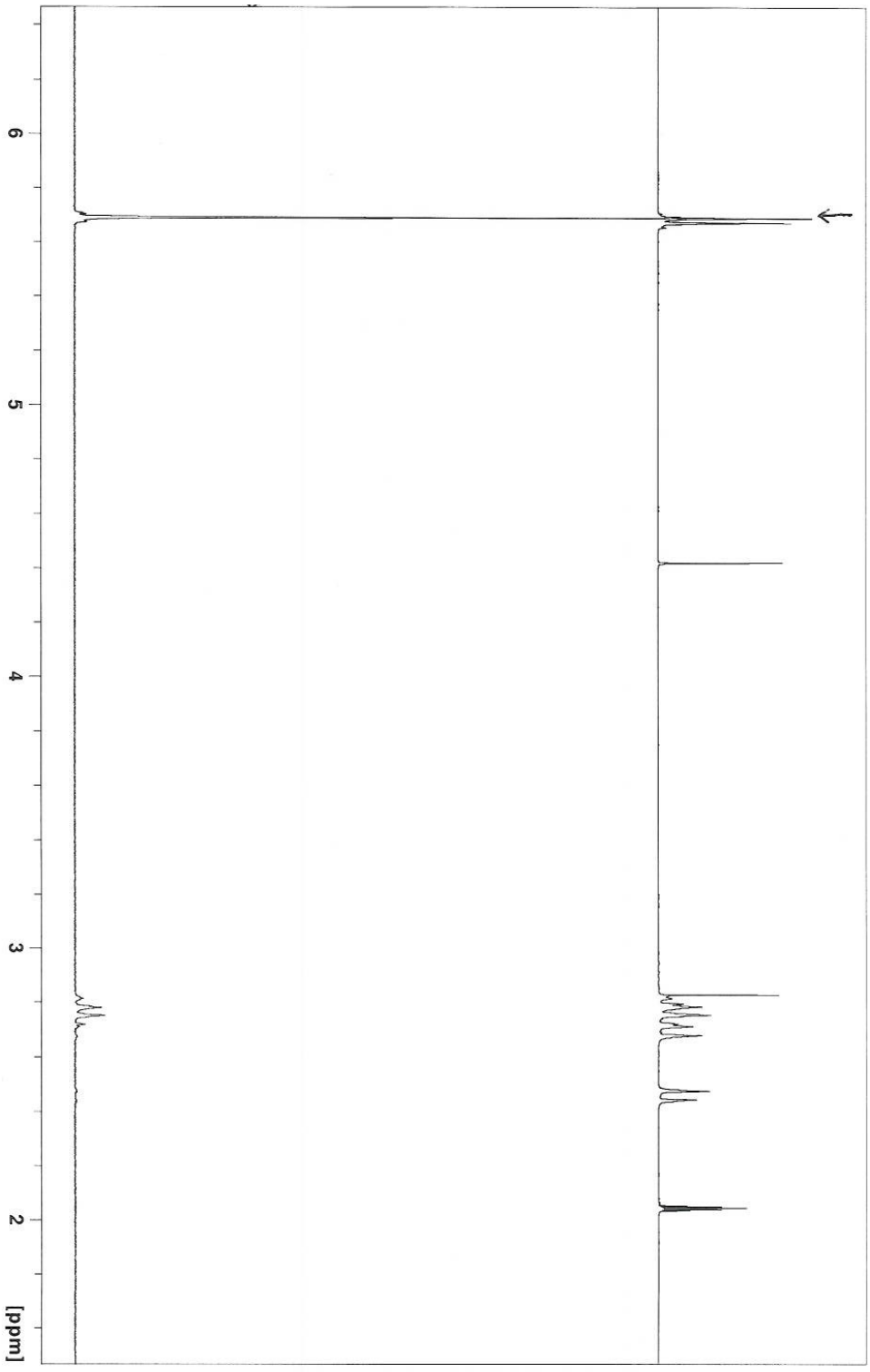


10



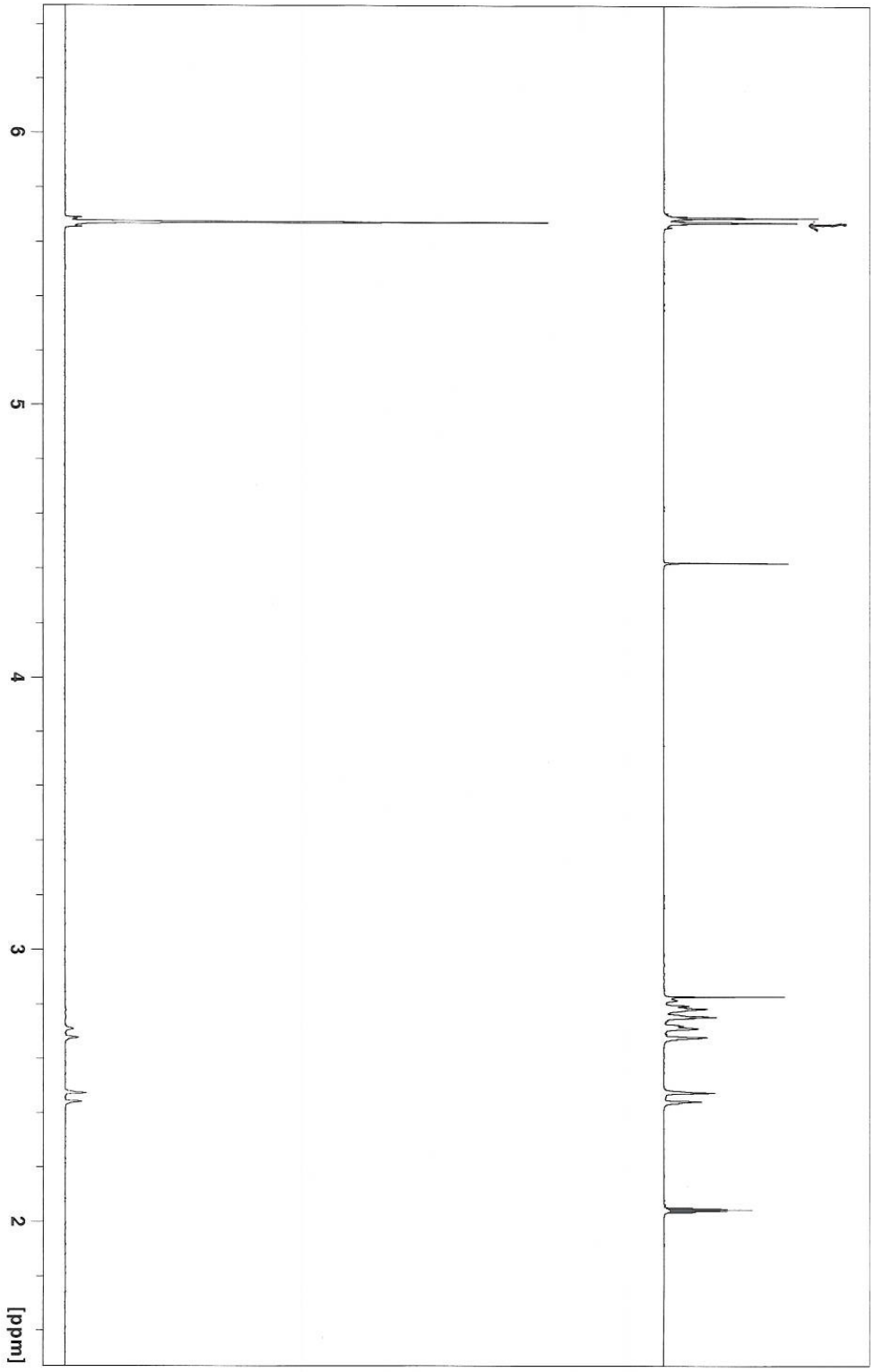
^{1}H-^{1}H TOCSY-NMR (acetone-d_6, 500 MHz) 1'-Hydroxy-[1,1'-bi(cyclopentane)]-3,3'-diene-1-carbonitrile **10**.

Irradiation/excitation of one =C**H** alkene environment results in no observed transfer to the other =C**H** alkene environment. Transfer to one CH_2 environment is observed.



^{1}H-^{1}H TOCSY-NMR (acetone-d_6, 500 MHz) 1'-Hydroxy-[1,1'-bi(cyclopentane)]-3,3'-diene-1-carbonitrile **10**.

Complimentary experiment to the previous one.



References

(1) Becke, A. D. *Physical Review A* **1988**, *38*, 3098.
(2) Lee, C.; Yang, W.; Parr, R. G. *Physical Review B* **1988**, *37*, 785.
(3) Hehre, W. J. R., L.; Schleyer, P. v. R.; Pople, J. A. *Ab Initio Molecular Orbital Theory*; Wiley: New York, 1986.
(4) Gauss, J. *J. Chem. Phys.* **1993**, *99*, 3629.
(5) Lamberto, M.; Kilburn, J. D. *Tetrahedron Letters* **2008**, *49*, 6364.
(6) Çetinkaya, B.; Demir, S.; Özdemir, I.; Toupet, L.; Sémeril, D.; Bruneau, C.; Dixneuf, P. H. *Chem. – Eur. J.* **2003**, *9*, 2323.
(7) Ding, Z.; Tufariello, J. J. *Synth. Commun.* **1990**, *20*, 227.