Applications of benchtop NMR: organic chemistry, polymer chemistry, teaching, and many others

Thursday 9th of April 2026, 10h00

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Application scientist– Magritek GmbH
Helene@magritek.com

https://www.linkedin.com/company/magritek-ltd/
https://X.com/magritek

The Magritek company

Magritek - Worldwide leader in Benchtop NMR Spectroscopy

- Founded in 2004 – operating for more than 20 years
- Introduced Spinsolve Benchtop NMR in 2012
- Large base of customers (> 2500), more than 600 publications

Aachen (Cáchy)

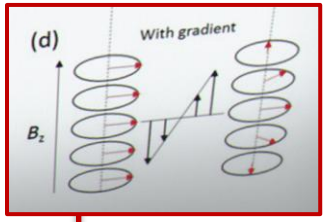
Our production site in Aachen, Germany

The Spinsolve Journey

2013
Reaction monitoring

2014
Spinsolve Double channel

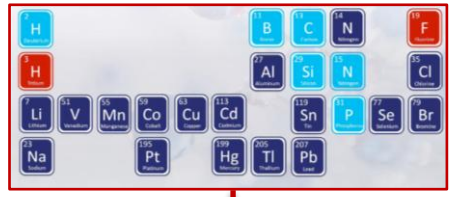
2015
Spinsolve Diffusion



2018
Autosampler

2021
Spinsolve Multi X

2025
Spinsolve Multi X^n



Advanced Autosampler

2026

2012

Spinsolve

2016

Spinsolve™ 60

2017

Spinsolve 80

2021

Spinsolve™ 90

2025

Spinsolve^{STC}

Spinsolve 100

Spinsolve features (for all models)

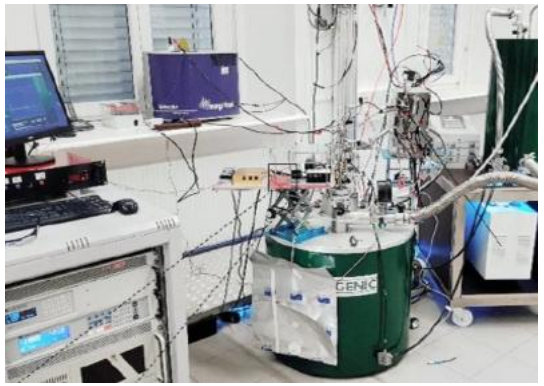
Benchtop NMR spectrometers designed to work in **ANY** lab: easily moved next to the reactor or under the fumehood

Room temperature variation robust (18-28°C)
No stray field outside of the box (<2G)

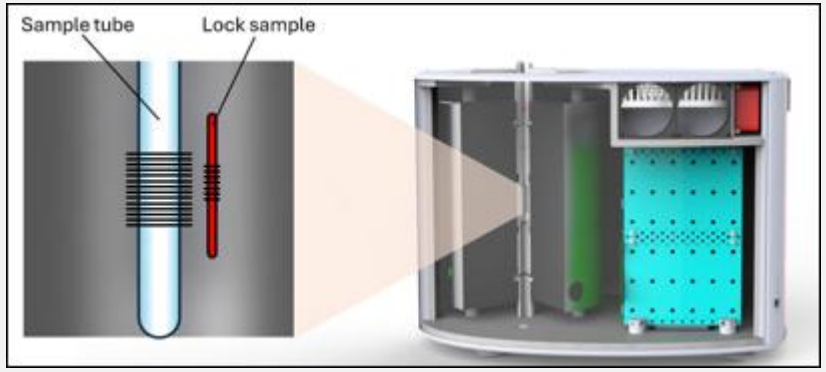
Intuitive interface. The system cannot be damaged by wrong parameter selection.

Highly automatable and flow compatible

3d PFG-gradients for 2D & advanced pulse sequences



Spinsolve integrated in complex/constrained environment



Spinsolve External lock technology

External AND Hardware lock
- **Deuterium-free** samples
- System always ready to measure
- Automatic spectrum reference

No setting time
- Instant & automatic tuning/matching/locking
- 30s shimming procedure once or twice a day
- Can measure **instantly** after sample insertion

Ever linear and constant response factor for fast and accurate **quantification**

Bringing NMR to the table

GC-MS

Raman spectrocopy

IR spectroscopy

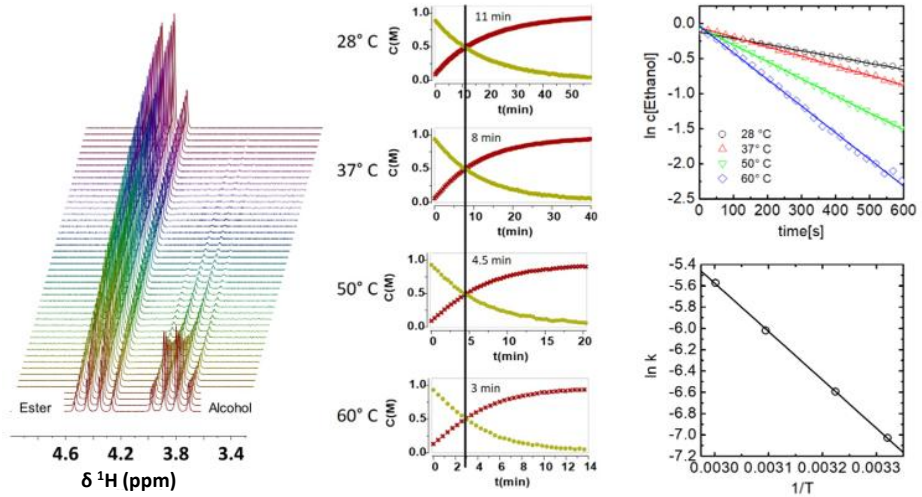
LC-MS

NMR spectroscopy

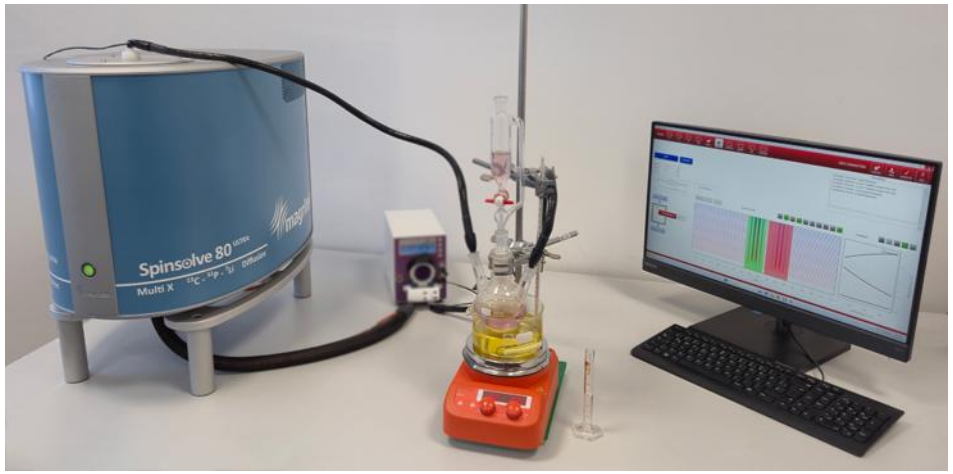
- Negligible-cost consumable
- No maintenance/long lifespan (> 10y)
- Low solvent volume (< 0.5 mL)
- Non-destructive
- Universal liquid detector (No-D)
- Immediate/real-time analysis
- Flow compatible
- Quantitative

Spinsolve variable temperature option

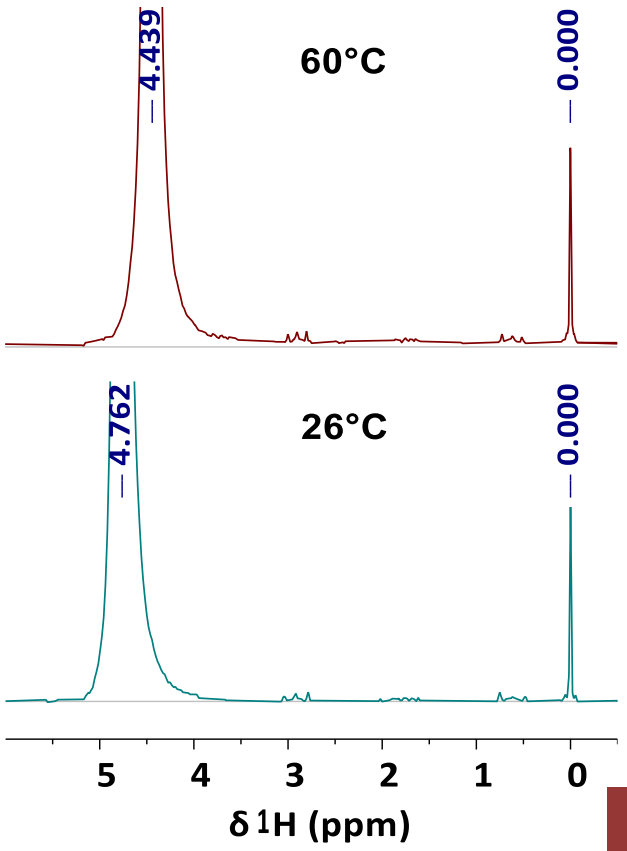
- No external accessory or gas supply needed
- Change working temperature through software selection
- High stability, can stay weeks/months at higher temperature
- Electrical heating provides high temperature control without temperature gradient
- Compatible with all other options (Multi-X, Ultra…) , without performance loss



Esterification kinetics at different temperature



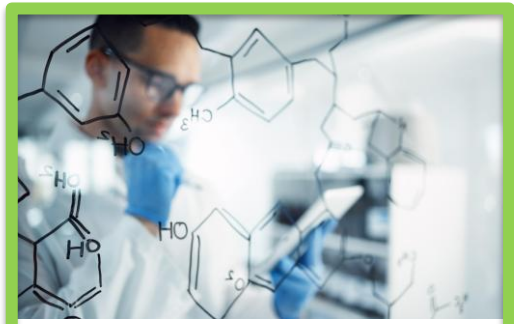
Ideal with fully regulated temperature line



"NMR thermometer"
DSS in H_2O

Hardware

Benchtop NMR applications



Synthesis

Pharma

Macromolecules

Education

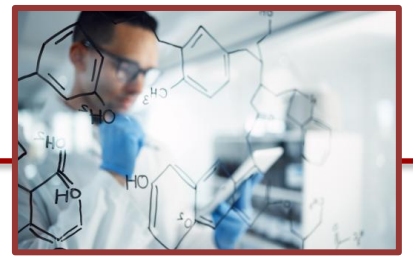
Flow chemistry

Batteries

Food & Agriculture

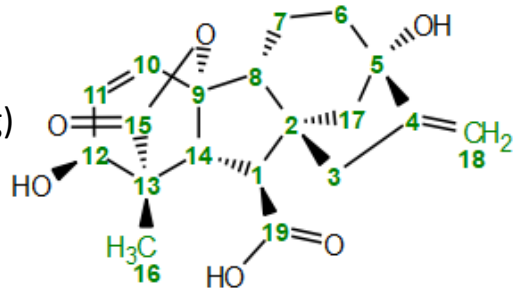
Forensics

Analytics

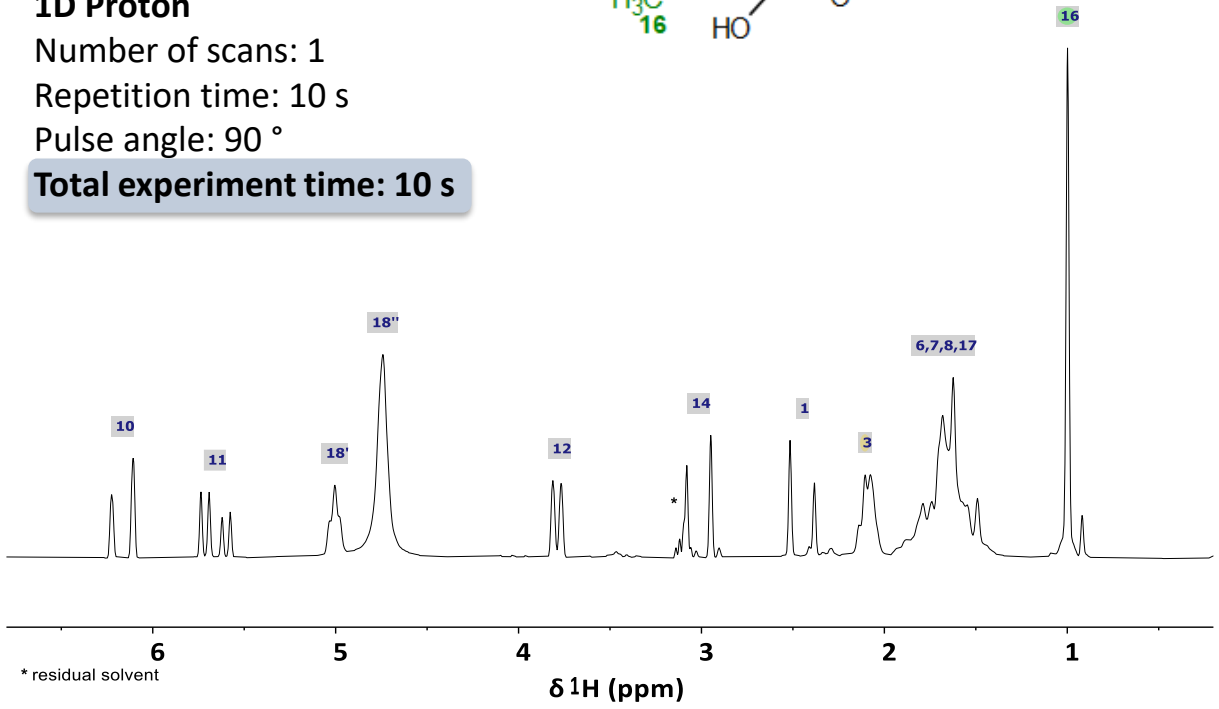


High quality 1D data for structure confirmation

Gibberellic acid
Solvent: MeOH-d4
Concentration: 250 mM (20 mg)
Spinsolve 80

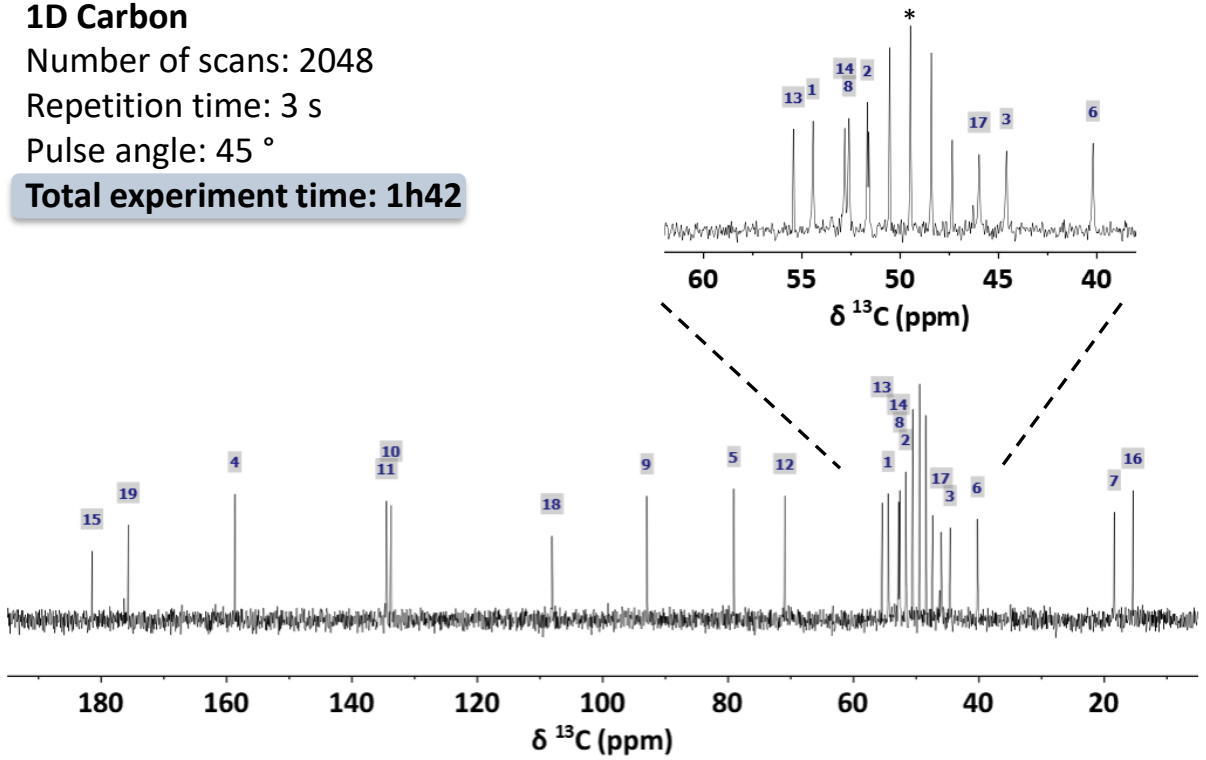


1D Proton
Number of scans: 1
Repetition time: 10 s
Pulse angle: 90 °
Total experiment time: 10 s



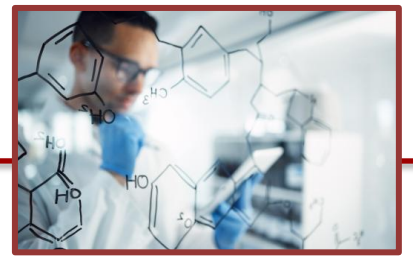
Gibberellic acid
Solvent: MeOH-d4
Concentration: 250 mM (20 mg)
Spinsolve 80

1D Carbon
Number of scans: 2048
Repetition time: 3 s
Pulse angle: 45 °
Total experiment time: 1h42



Free resources available online: https://magritek.com/resources/spectra-library/

Synthesis

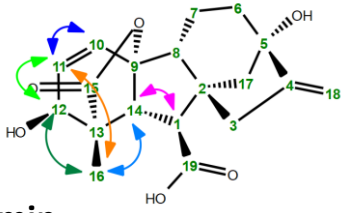


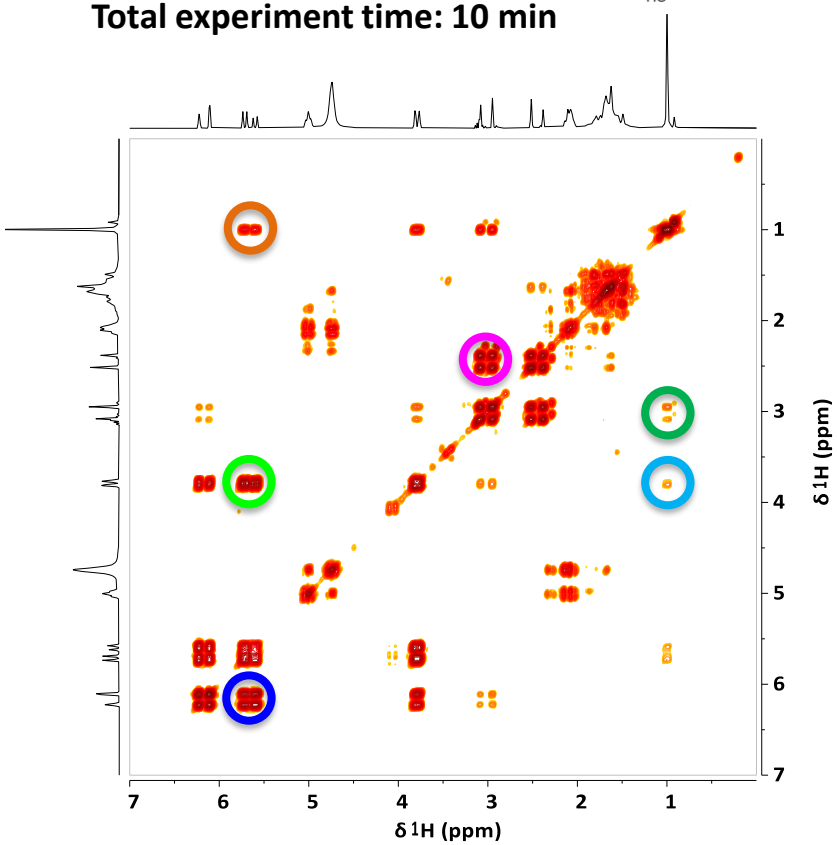
High quality 2D data for structure confirmation

- **Sample: Gibberellic acid** / Solvent: MeOH-d_4 / Concentration: 250 mM (20 mg)

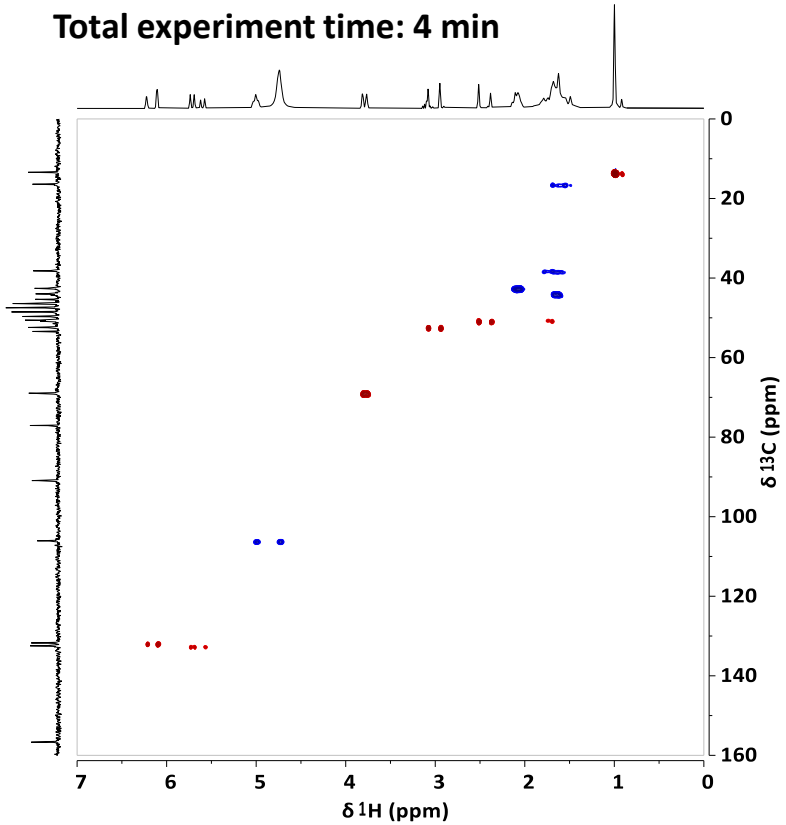
Spinsolve 80 ULTRA

2D ^{1}H-^{1}H gsCOSY
Number of scans: 1
Repetition time: 1 s
Number of steps: 512
Total experiment time: 10 min

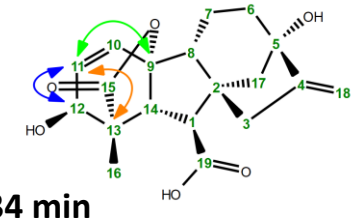


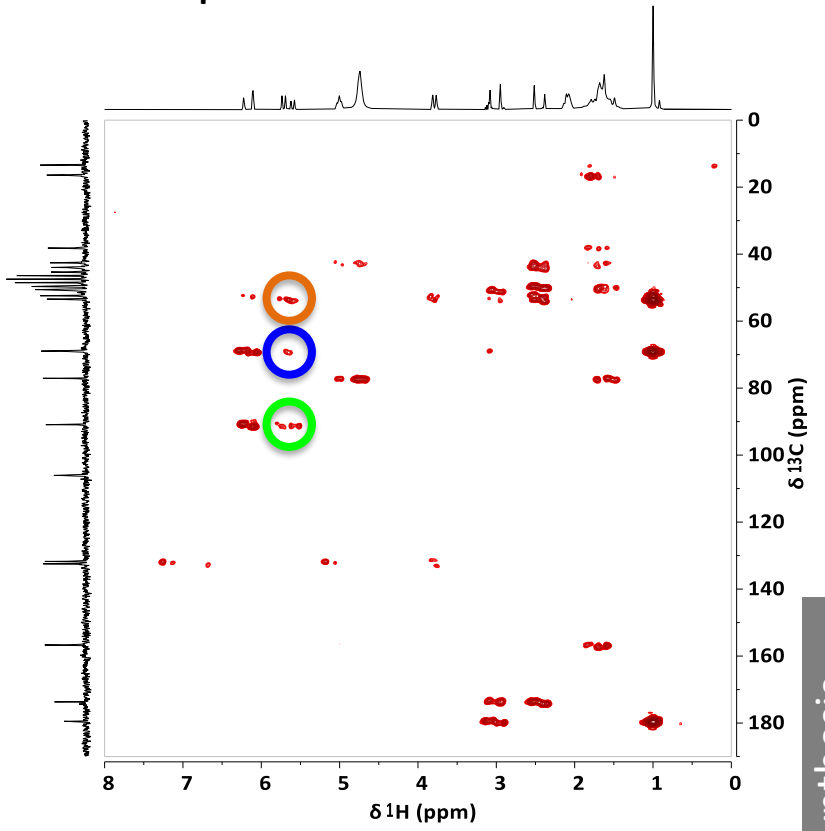


2D ^{1}H-^{13}C gsHSQC-ME
Number of scans: 2
Repetition time: 1 s
Number of steps: 128
NUS rate: 50%
Total experiment time: 4 min



2D ^{1}H-^{13}C gsHMBC
Number of scans: 2
Repetition time: 1 s
Number of steps: 256
Total experiment time: 34 min





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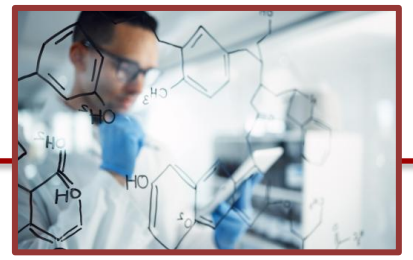
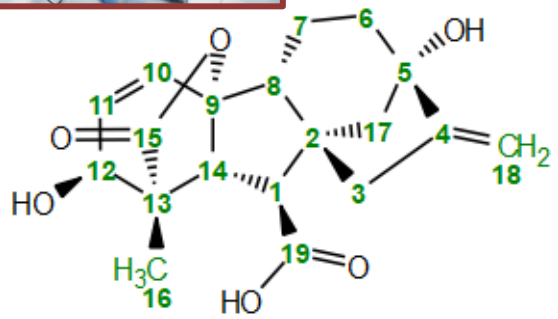
Synthesis



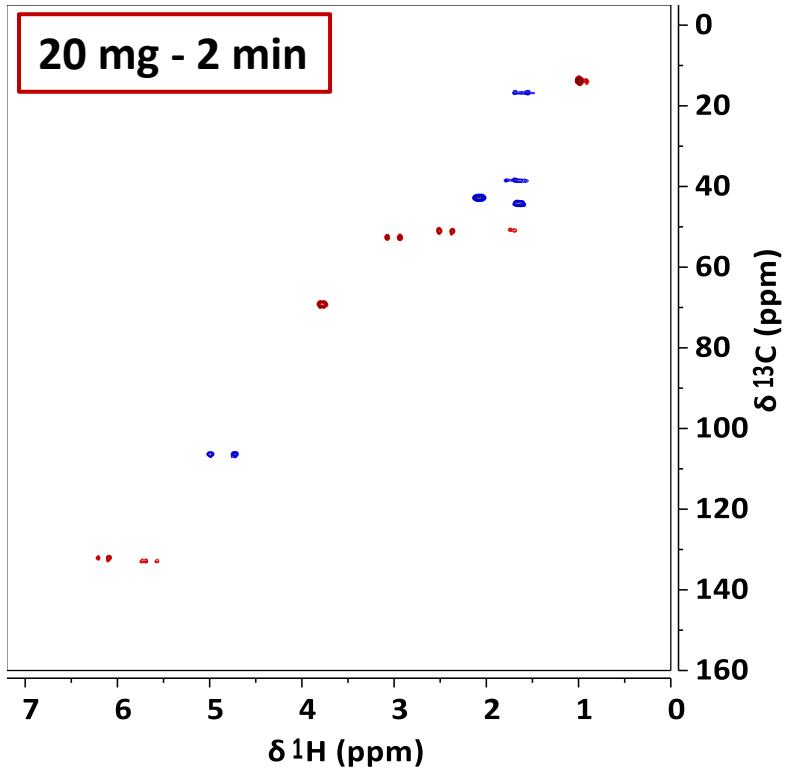
Measurement time & concentration relation

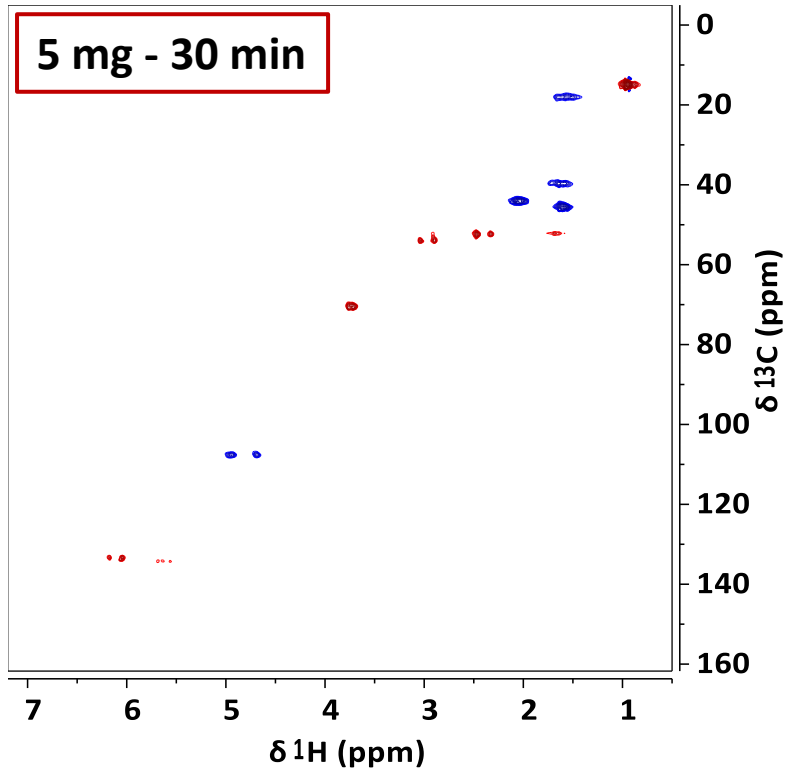


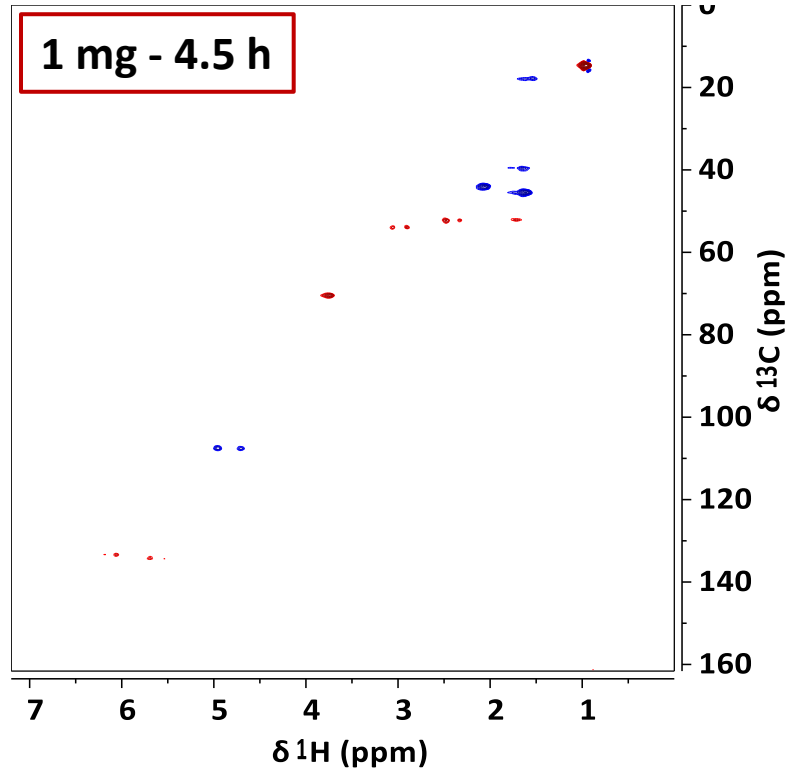
Spinsolve 80 ULTRA **Gibberellic acid**/Solvent: MeOH-d4 **gsHSQC-ME**

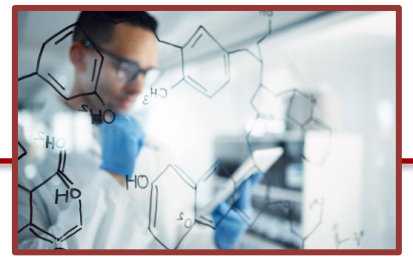
Quadratic relation between concentration and measurement time

Peak separation is independent from sample concentration









When can I get the information about my synthesis ?

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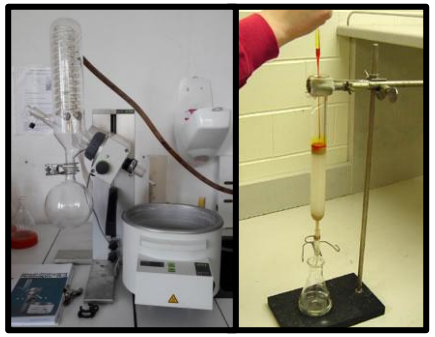
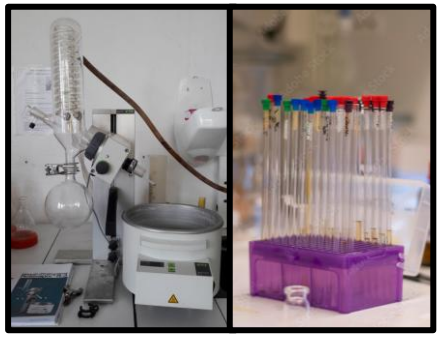
Synthesis



Evaporation + separation



Evaporation + NMR tube preparation in deuterated solvent

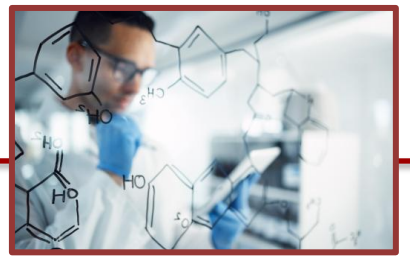
High-field NMR analysis

Chromatography fraction characterization "TLC check"

Raw mixture characterization (in protonated solvent) "TLC check"

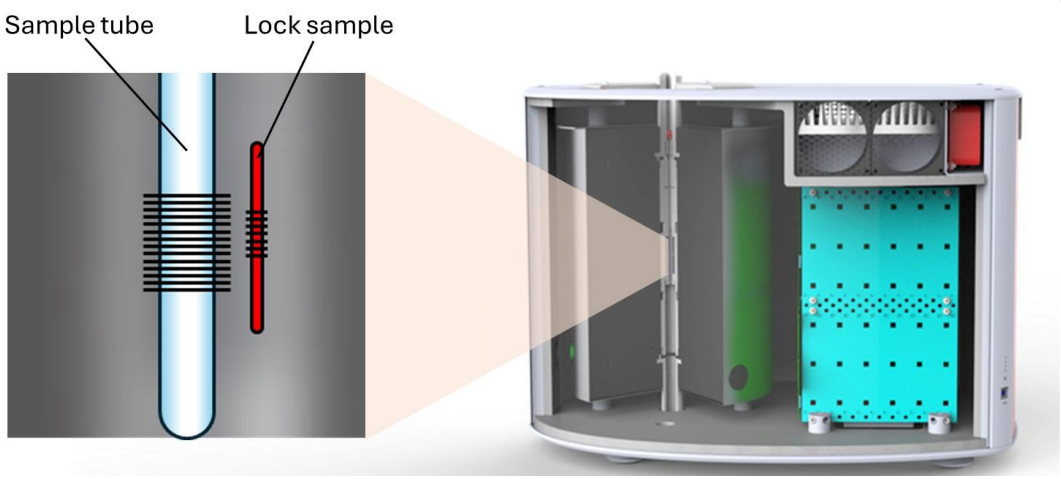
Purified compound in deuterated solvent characterization

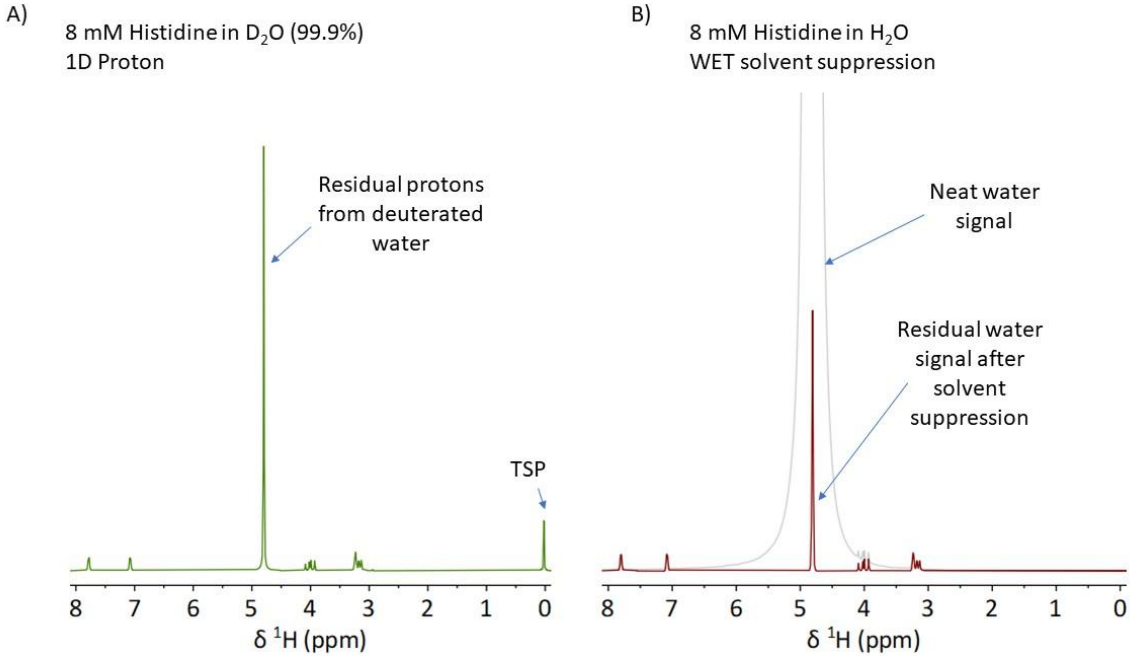
Synthesis

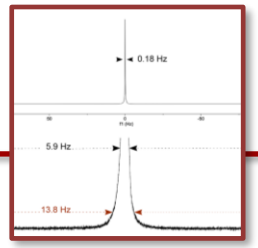


The challenge of protonated solvents – NoD NMR

- Each Spinsolve makes use of a Hardware Lock system
- This lock runs in a fully automatic way in the background and the user does not need to take care on it.
- It is always engaged and also works when no sample is in the NMR.
- Consequently, deuterated solvents are not required for the locking of the NMR
- This means that any type of sample can be measured: neat samples, samples in protonated solvents, aqueous solutions … and of course also samples in deuterated solvents
- Powerful solvent suppression sequences are in place (Wet, Pre-Sat – all perfectly adapted to the Spinsolve hardware)





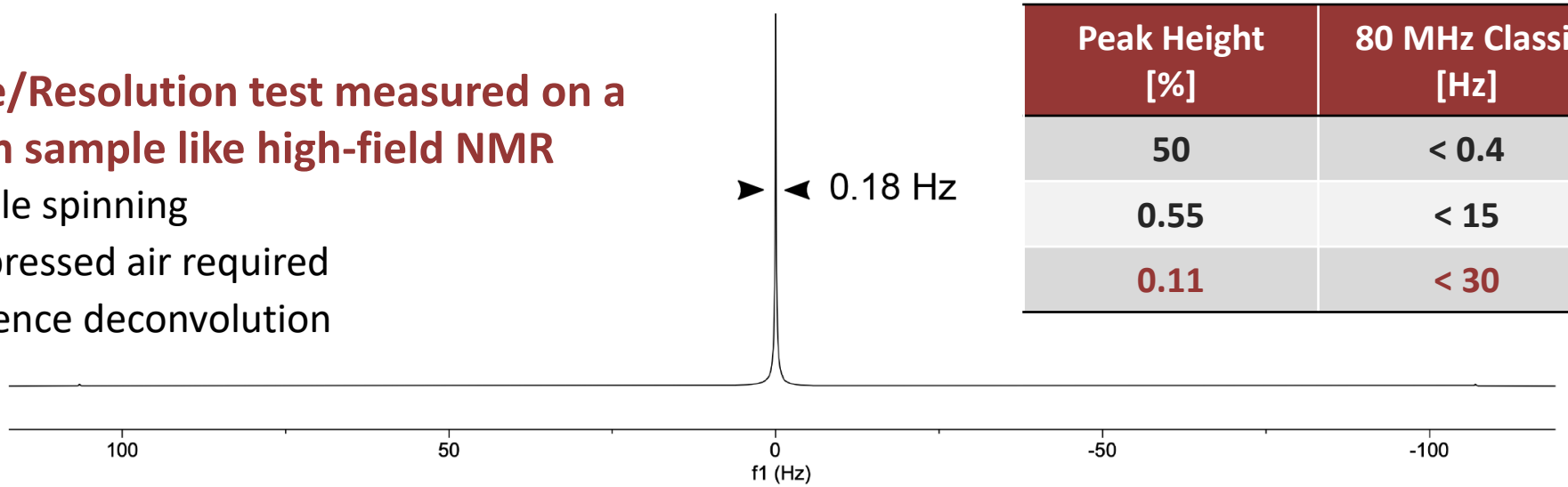


ULTRA Magnet homogeneity

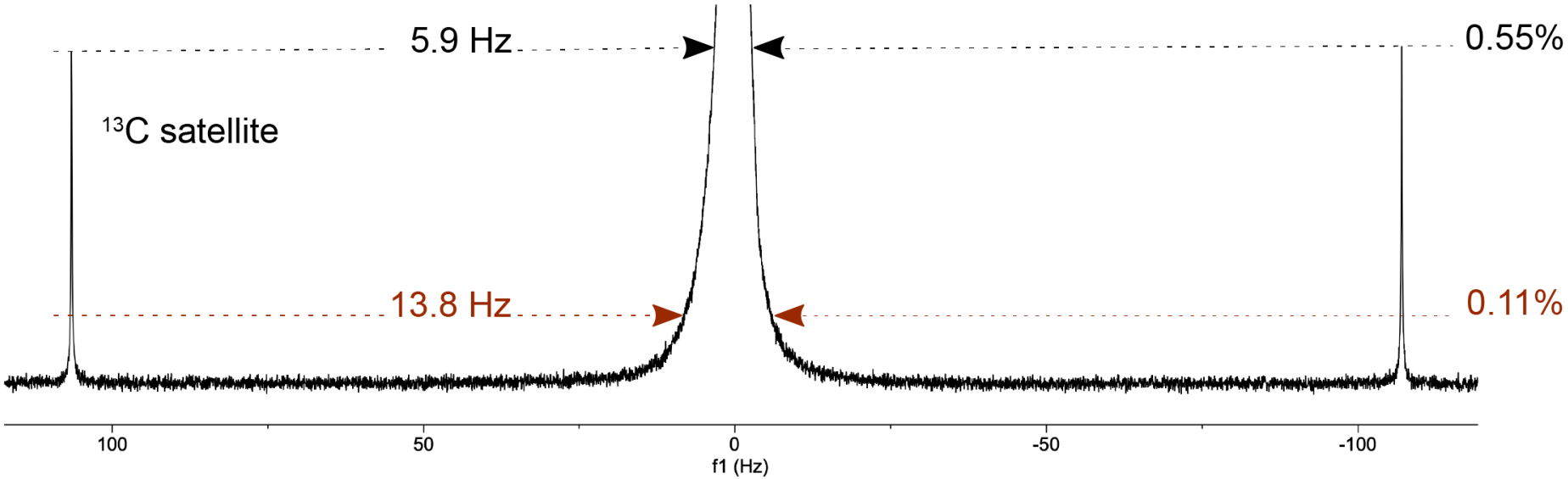
Line Shape/Resolution test measured on a chloroform sample like high-field NMR

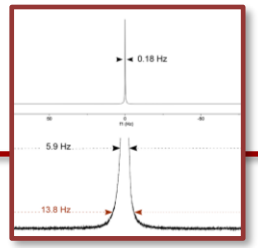
- No sample spinning
- No compressed air required
- No reference deconvolution

Peak Height [%]	80 MHz Classic [Hz]	80 MHz ULTRA [Hz]
50	< 0.4	< 0.2
0.55	< 15	< 8
0.11	< 30	< 16



Zoom x 200



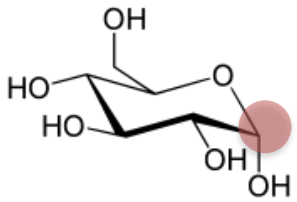


No-D NMR: Remove the interference of protonated solvents

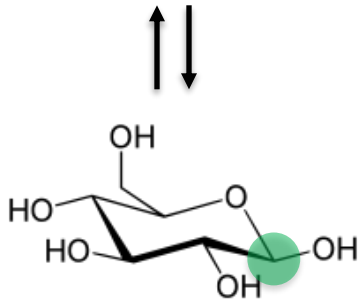
1D ^{1}H (WET)/Repetition time: 10 s/Number of scans: 16/**Measurement time: 3 min**

Glucose/Concentration: 20 mmol.L^{-1} (1 mg) / Solvent: H_2O

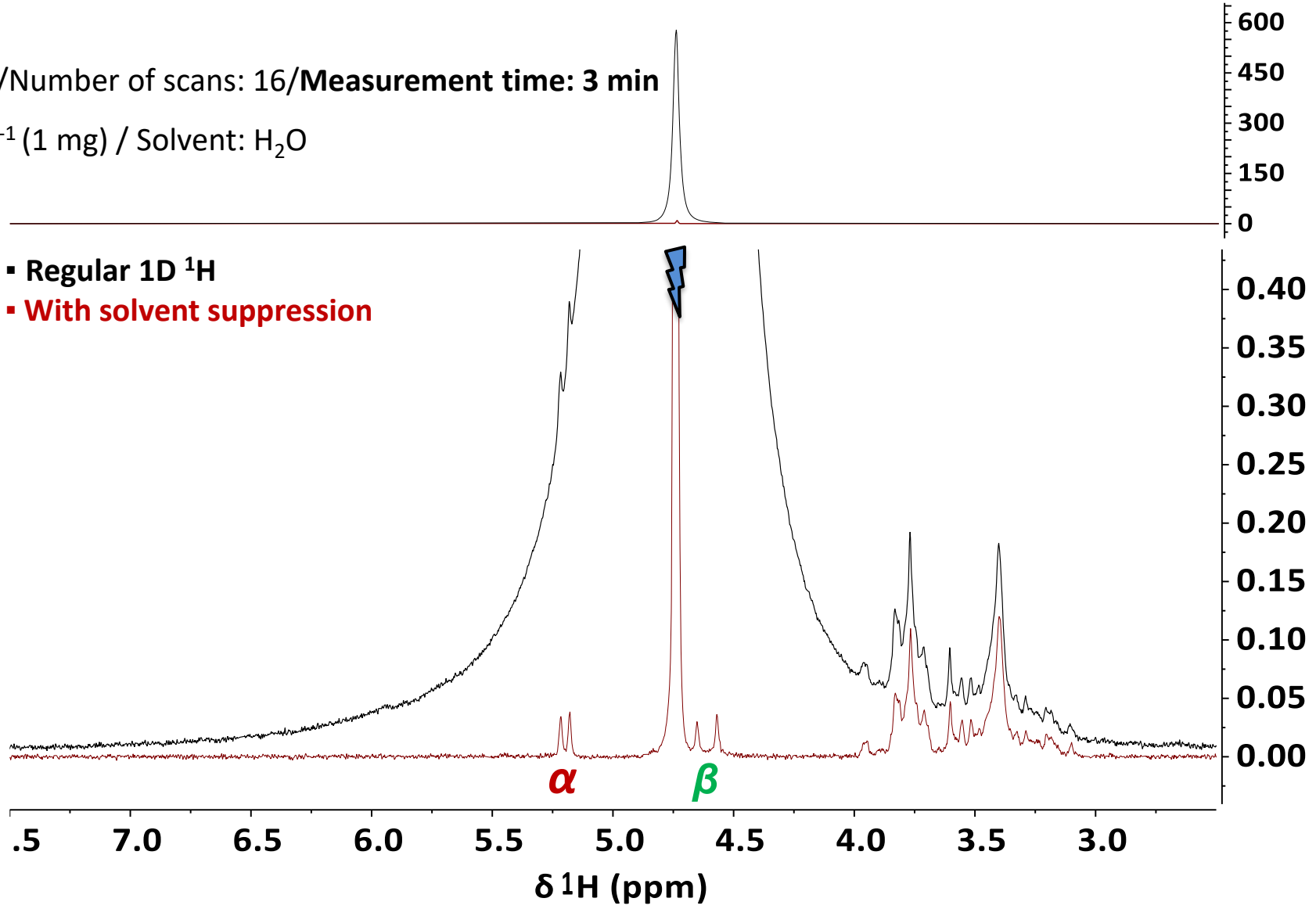
Spinsolve 90 ULTRA

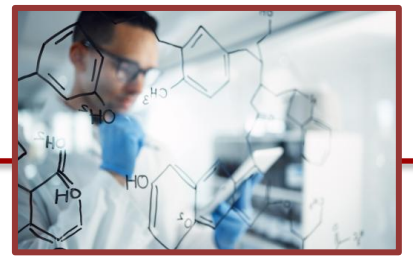


α-Glucose



β-Glucose



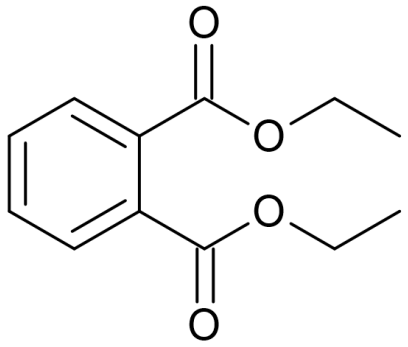


No-D NMR: Remove the interference of protonated solvents

1D ^{1}H (WET)/Repetition time: 10 s/Number of scans: 8/**Measurement time: 2 min**

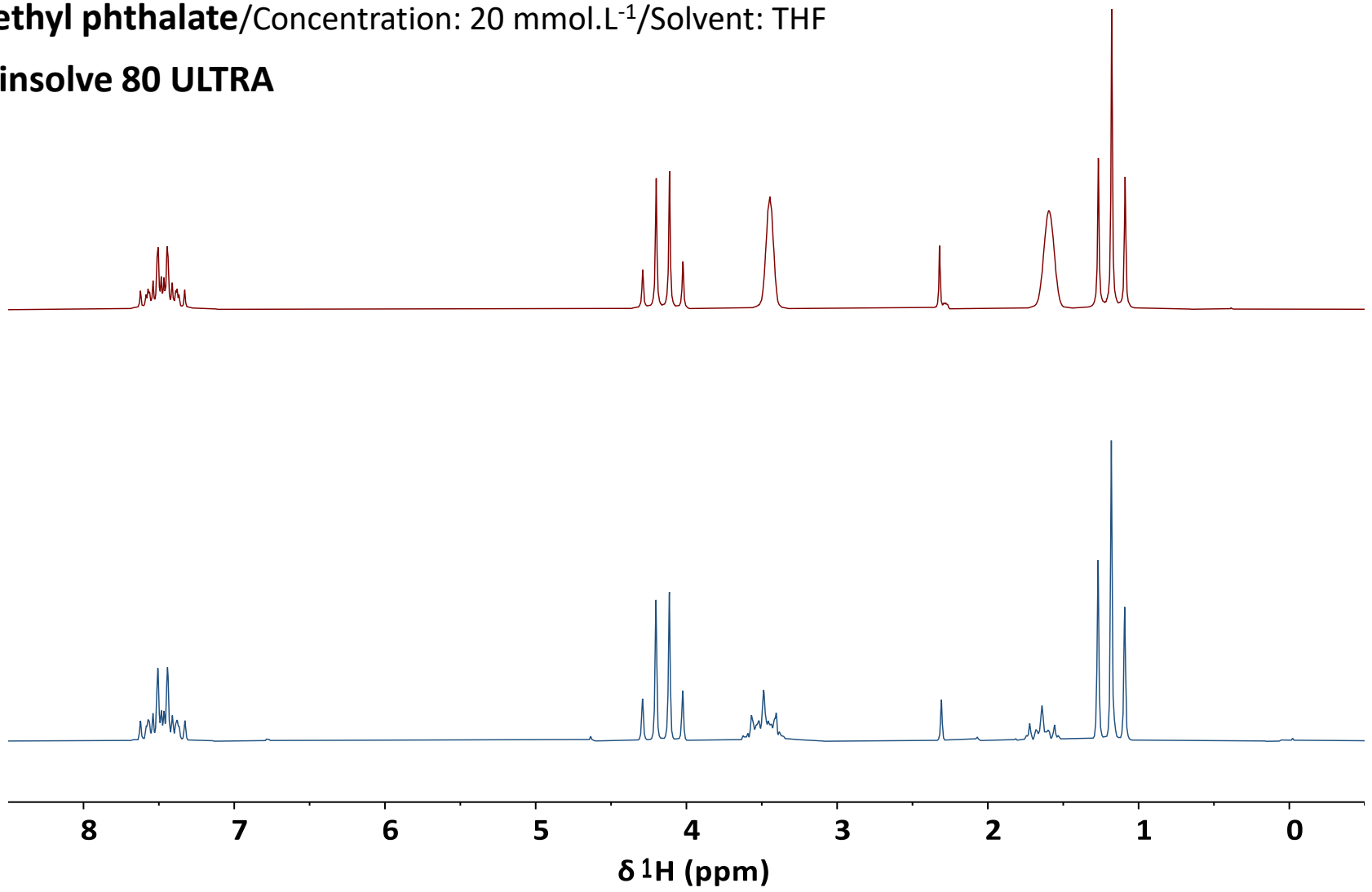
Diethyl phthalate/Concentration: 20 mmol.L^{-1}/Solvent: THF

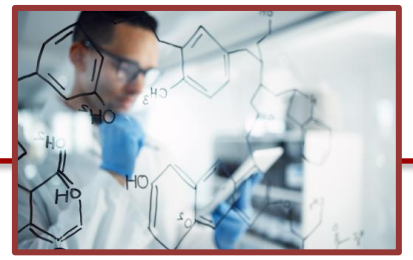
Spinsolve 80 ULTRA



Diethyl phthalate

2 mg in THF-D8 or THF-H8 ?





No-D NMR: Remove the interference of protonated solvents

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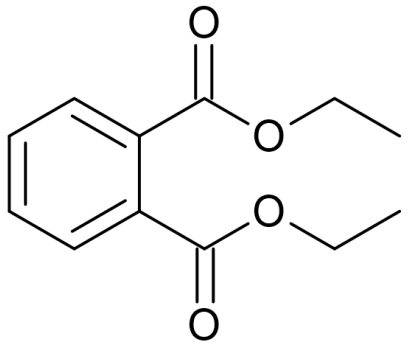
Diethyl phthalate/Concentration: 20 mmol.L^{-1}/Solvent: THF

Spinsolve 80 ULTRA



Diethyl phthalate

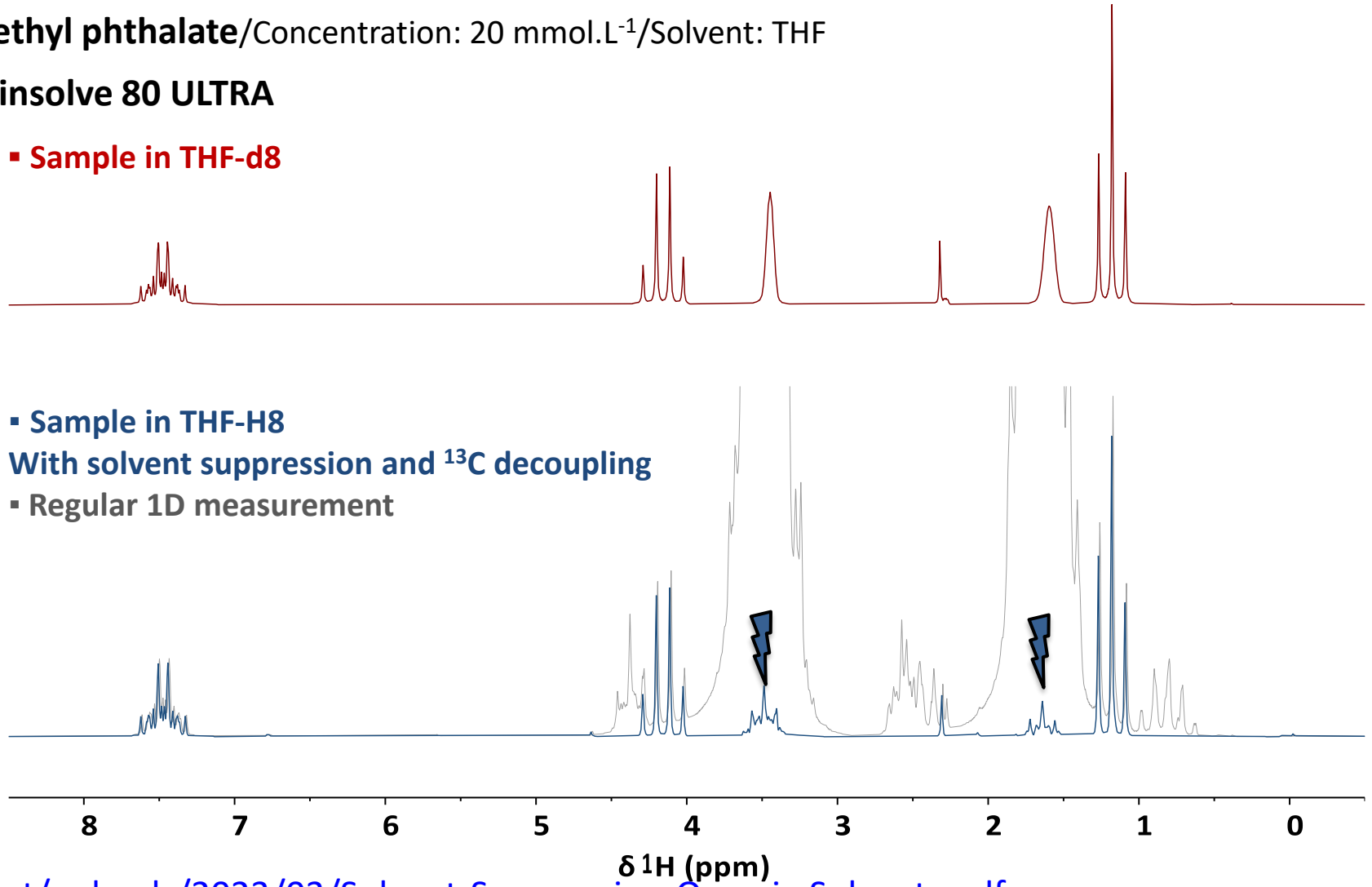
2 mg in THF-D8 or THF-H8 ?

- **Sample in THF-d8**

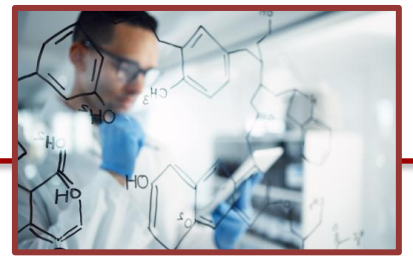
- **Sample in THF-H8**

With solvent suppression and ^{13}C decoupling

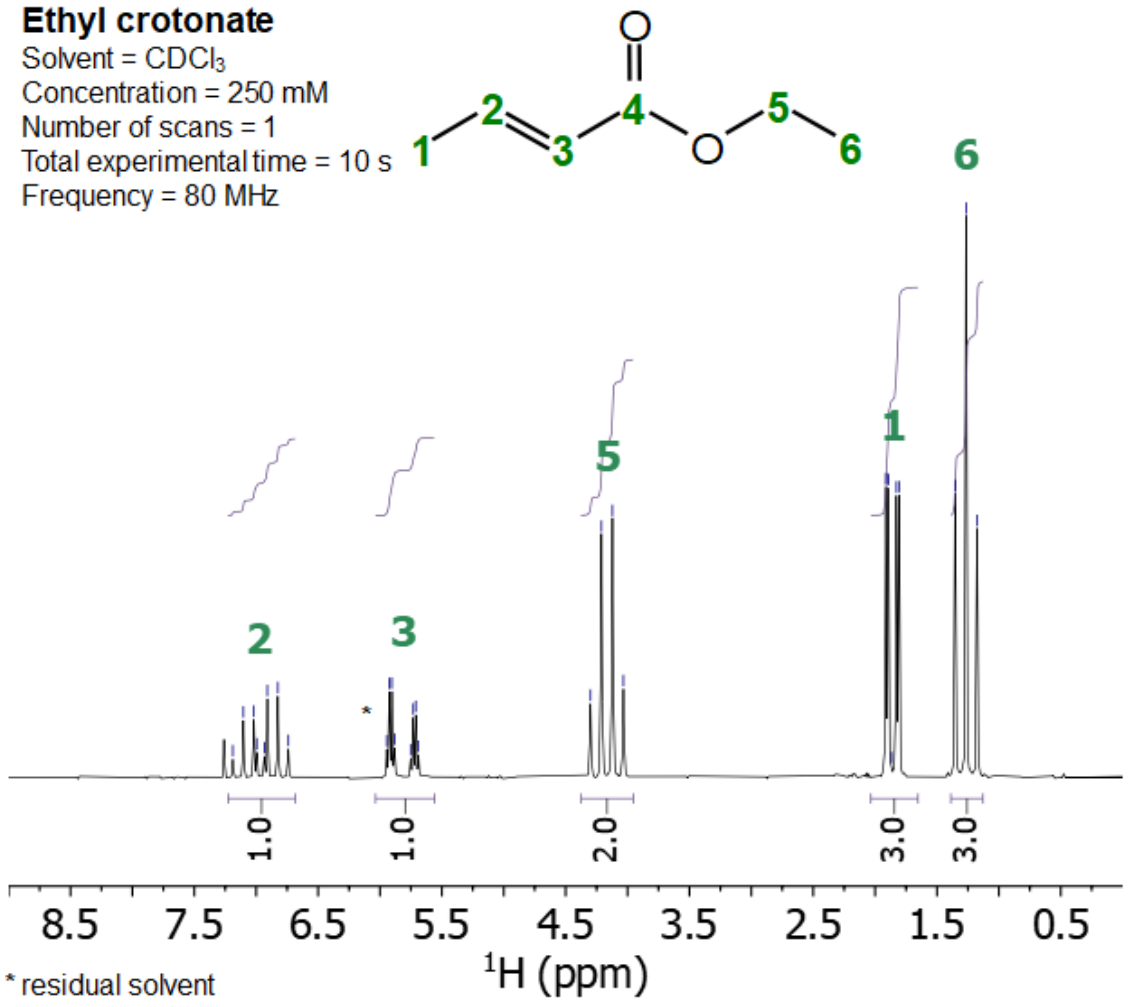
- **Regular 1D measurement**



https://magritek.com/wp-content/uploads/2023/03/Solvent-Suppression-Organic-Solvents.pdf

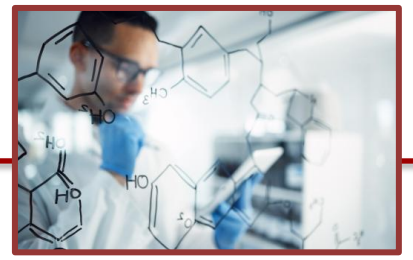


Relative quantification with NMR



Specificity

- Each chemical group of a compound does give a signal at a distinct position
- The position and the pattern of the signals give you information about the chemical environment
- The ratio of the peaks gives information about how many hydrogen nuclei contribute to a signal
- Hence, a single signal can be used to quantify the compound



Spinsolve quantification in different tubes & different solvents

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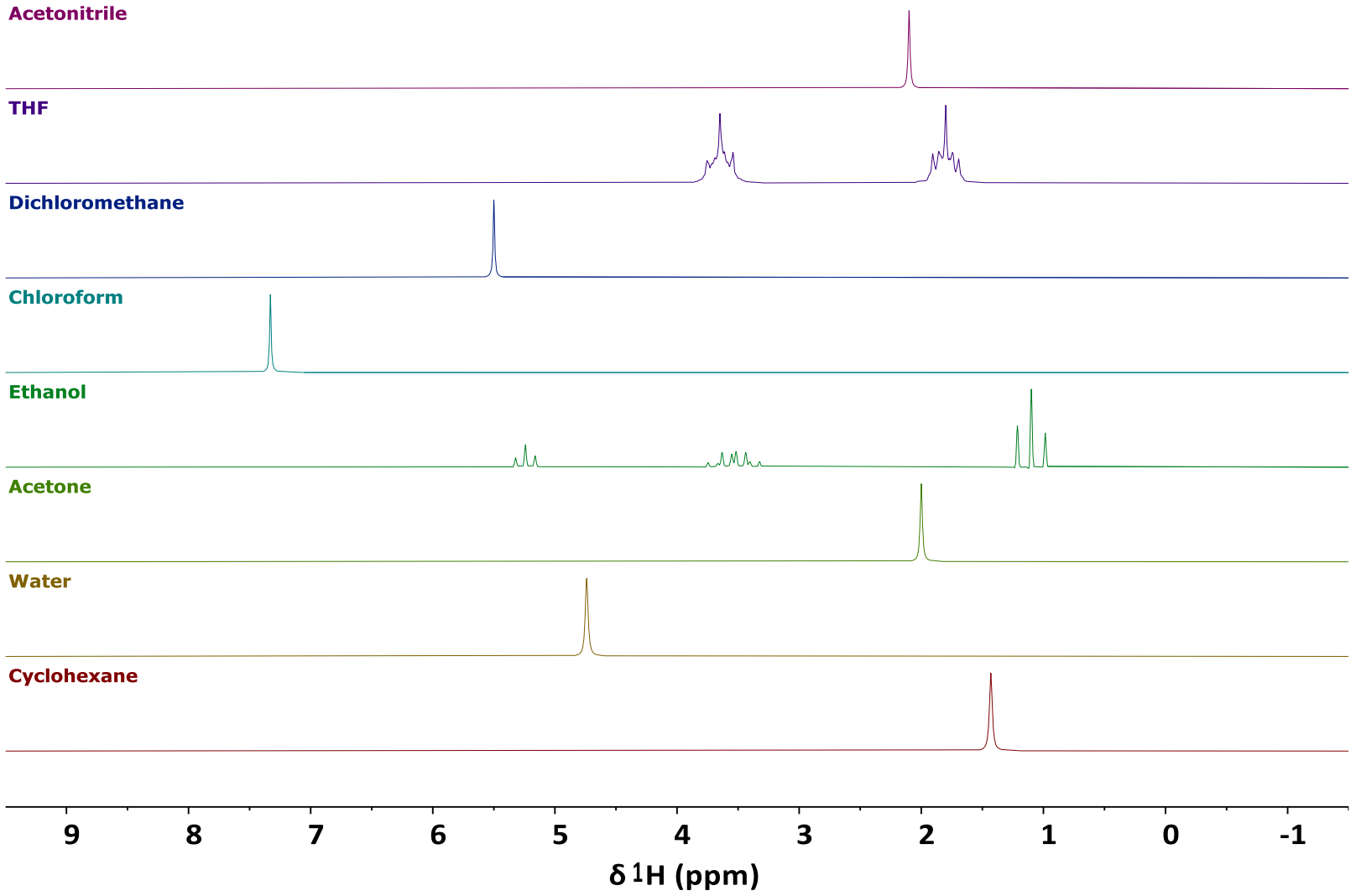
- Unlike high-field systems, Spinsolve systems work with a fixed receiver gain

- Spinsolve NMR has this unique feature that every proton in ~~the same~~ any sample (including different solvents) gives the same "amount" of signal, **if relaxation is fulfilled**

Common solvents (analytical grade, neat) **1D ^{1}H** **Spinsolve 60**



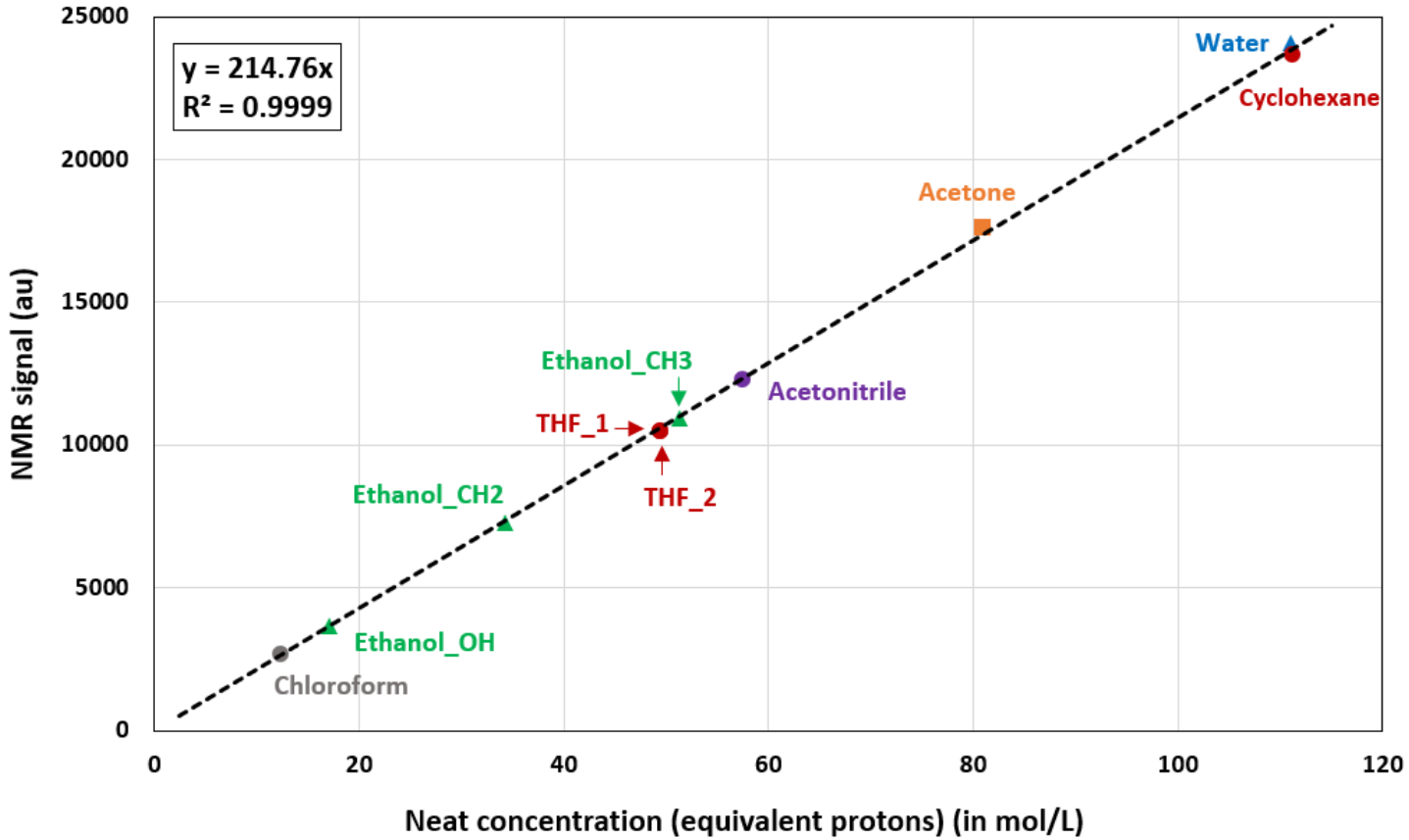
Spinsolve quantification in different samples

Common solvents (analytical grade, neat)

1D ^{1}H (Single scan)

Spinsolve 60

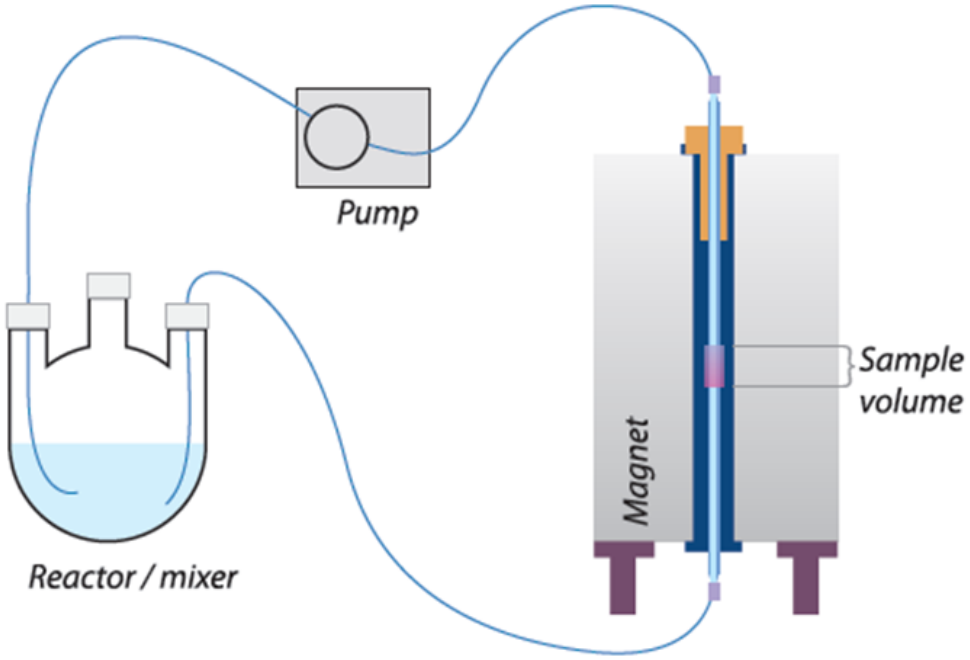
Solvent	Density (g/L)	M (g/mol)	C_{neat} (mol/L)	Heq	C_{perH} (mol/L)	NMR signal (au)
Water	1000	18.01	55.50	2	111.0	24035
Chloroform	1480	119.3	12.39	1	12.4	2682
Ethanol_CH3	789	46.0	17.12	3	51.4	10917
Ethanol_CH2	789	46.0	17.12	2	34.3	7269
Ethanol_OH	789	46.0	17.12	1	17.1	3637
Acetone	784	58.0	13.49	6	81.0	17589
Acetonitrile	786	41.0	19.14	3	57.4	12299
THF_1	890	72.1	12.34	4	49.4	10524
THF_2	890	72.1	12.34	4	49.4	10517
Cyclohexane	779	84.15	9.25	12	111.1	23696

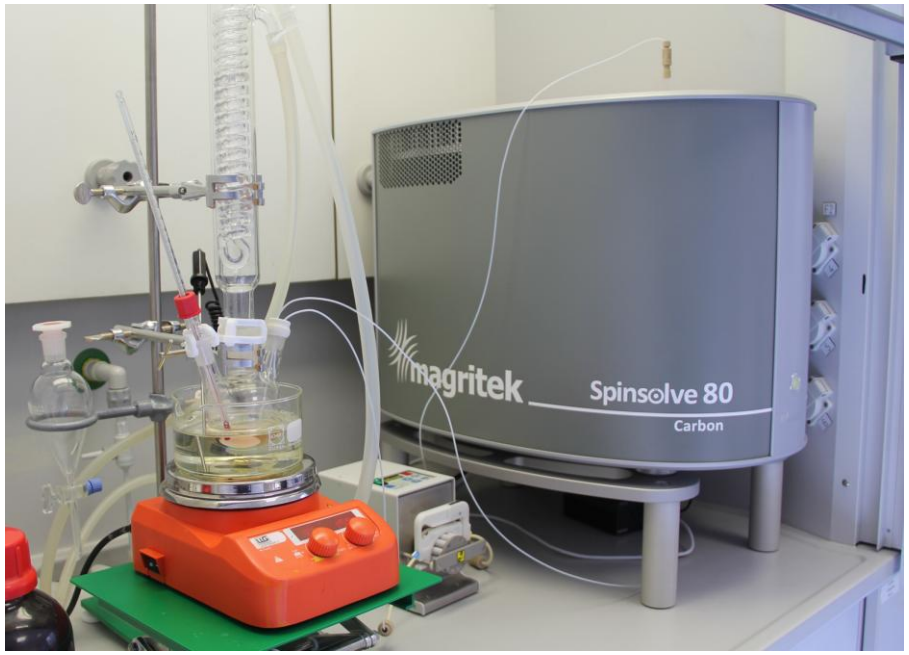


➢ Any peak that can be integrated can be quantified, **allowing to convert integrals into yields in raw mixtures**

Reaction monitoring kit

Following the progress of a reaction from starting material to end-point



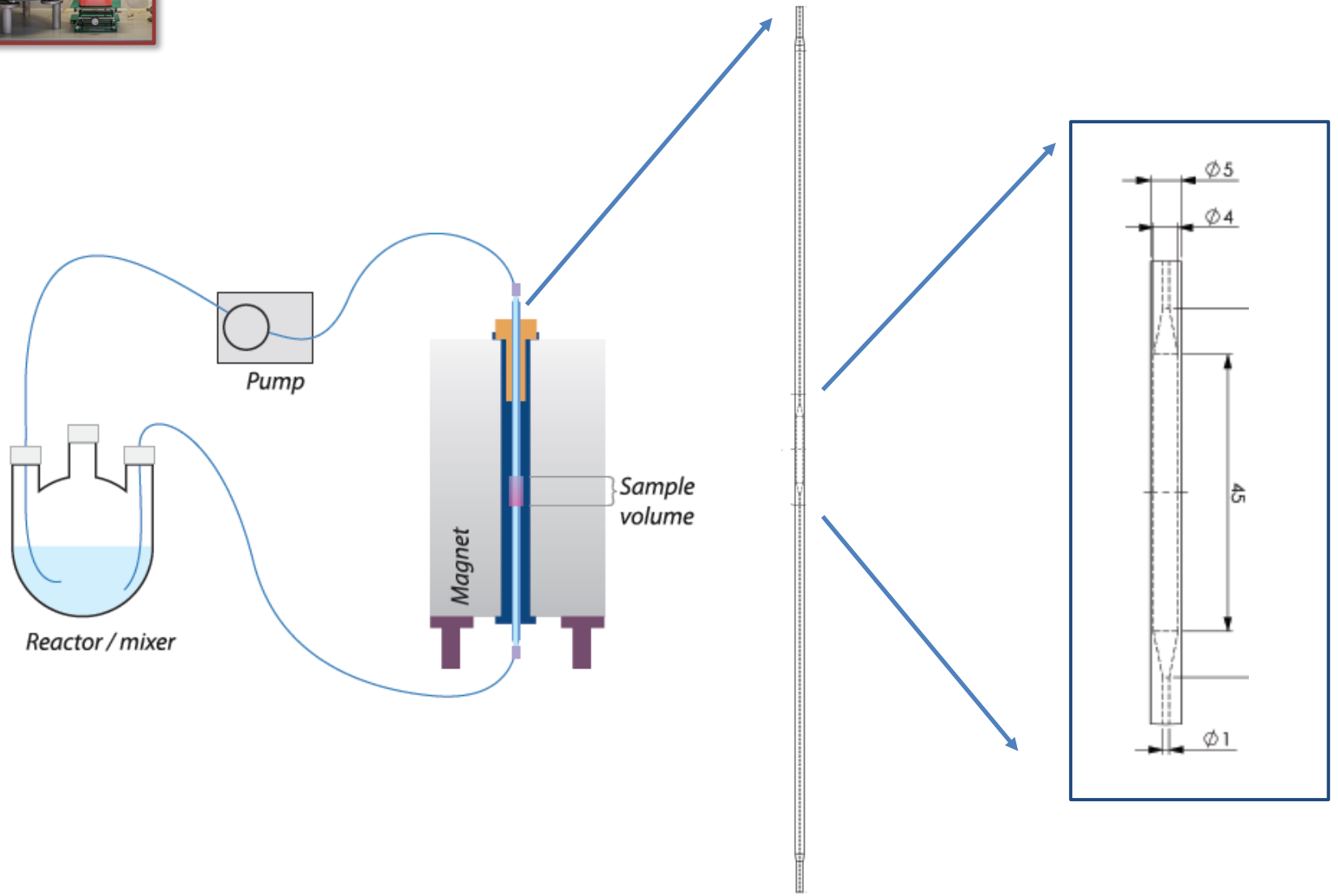


Flow reaction monitoring setup under a fumehood

- Every Spinsolve system has an opening all the way from top to bottom
- So a flow cell can be positioned into the NMR spectrometer
- Take an NMR spectrum all 30 … 60 seconds
- Run the setup either in continuous or stop-flow mode
- No Need for Deuterated Solvents / External Lock in Operation

Accessory

Optimized glass flow-cell for maximum SNR

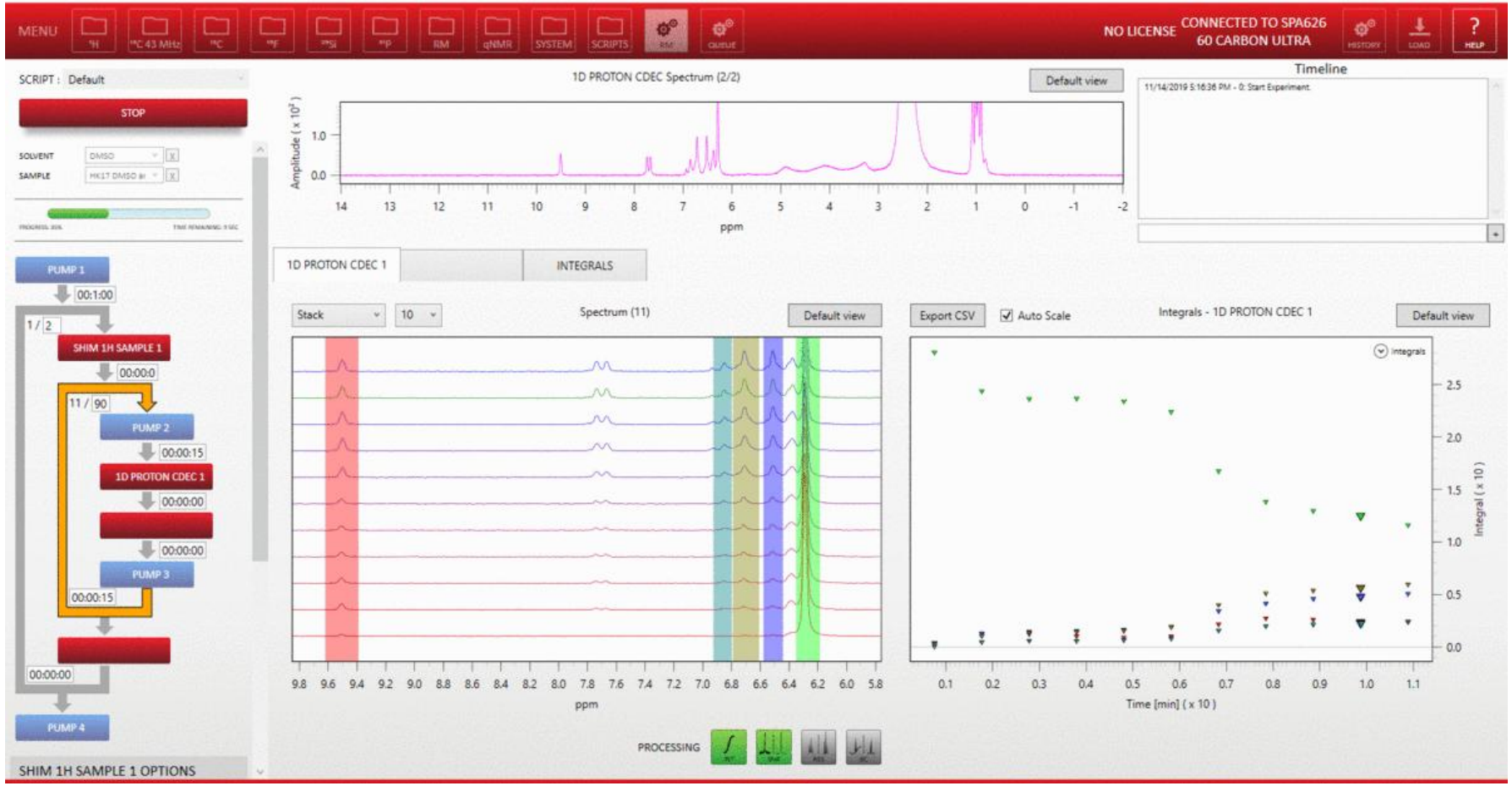


The Spinsolve Glass Flow cell is volume-optimized to achieve the best possible SNR with the minimum dead time / volume.

- Maximum diameter in the center of the cell (rf coil region) to use full sample volume and match the SNR specified for 5 mm NMR tubes
- Total volume of the cell cell kept to the minimum to reduce the dead volume of the setup and minimize the pumping time from the reactor to the system.

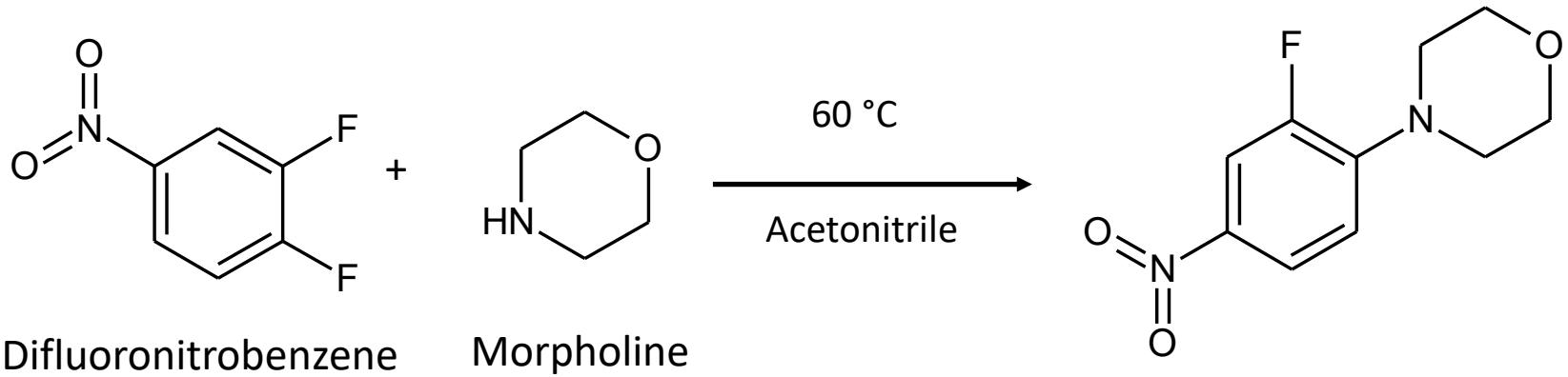
Accessory

RMX software module for on-line monitoring



Accessory*

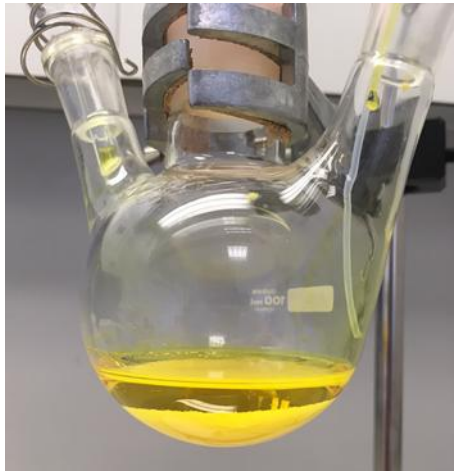
Reaction monitoring - SNAr reaction



3,4-Difluoronitrobenzene

(Dropwise addition)

Morpholine



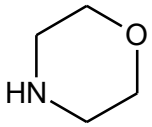
- Continuous flow with ~0.8 mL/min
- Dropwise addition of 3,4-FNB to solution of Morpholine in ACN
- Heating to 60 °C in waterbath after addition was complete
- Reaction was monitored for ~2 h, after that mixture was stirred over night
- Precipitation of white solid

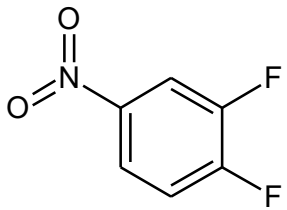
https://magritek.com/wp-content/uploads/2020/09/App-Note-RM-1H-19F.pdf

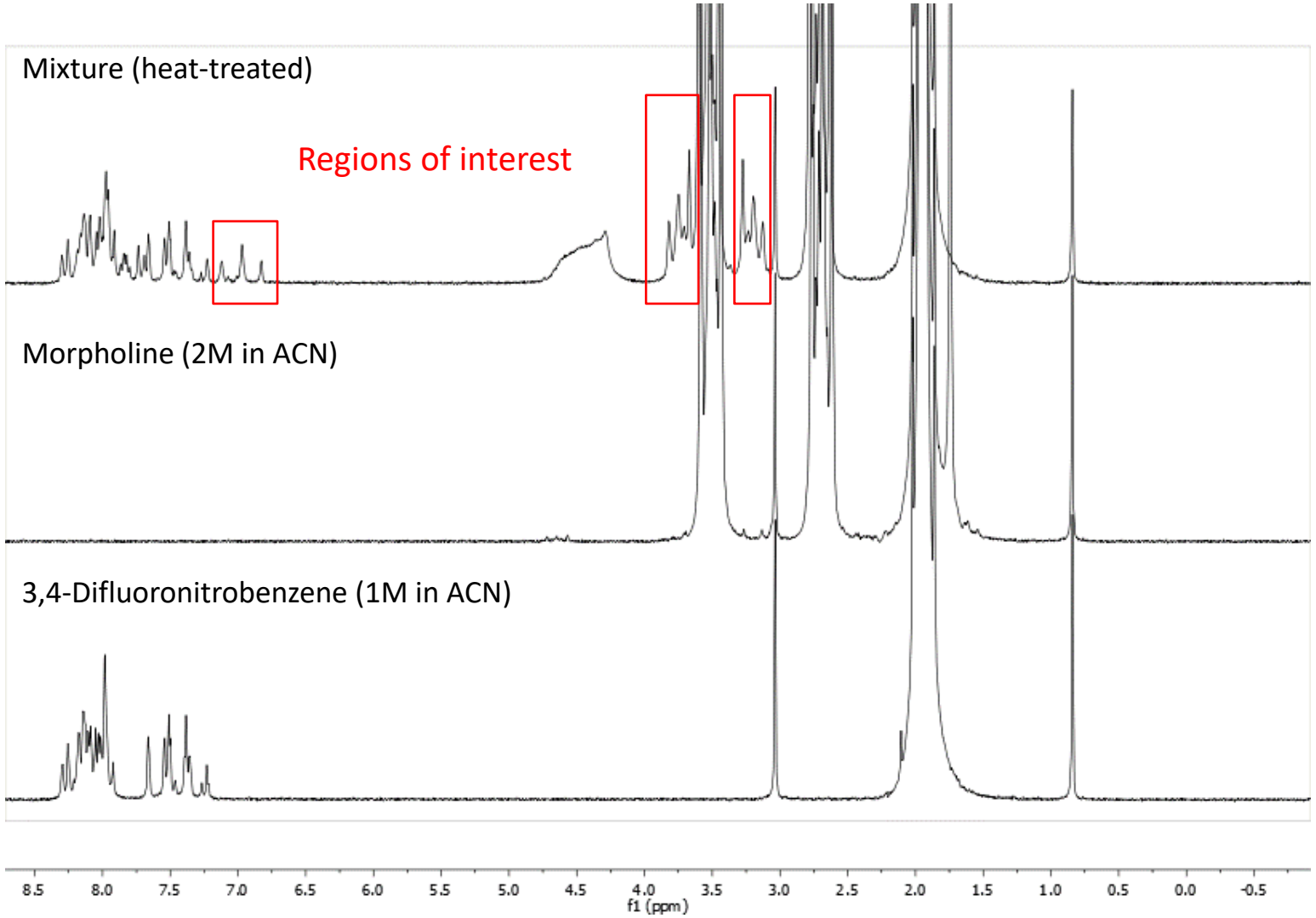
Preliminary experiments in 5 mm NMR tube

1D ^{1}H/Repetition time: 10 s/Number of scans: 2/**Measurement time: 20 s**

Spinsolve 60







Reaction Monitoring – Stacked plot 1H and 19F NMR

124 spectra were acquired over the time of the study

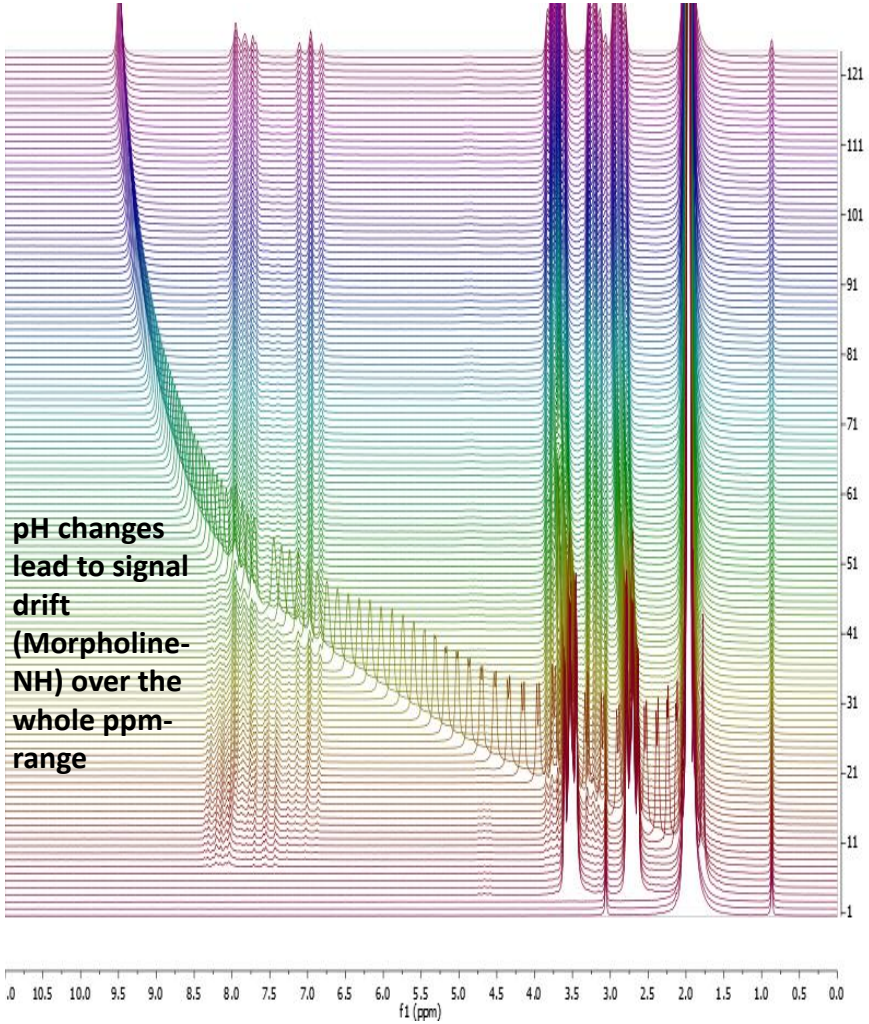
1D ^{1}H/Repetition time: 10 s/Number of scans: 2/**Measurement time: 20 s**

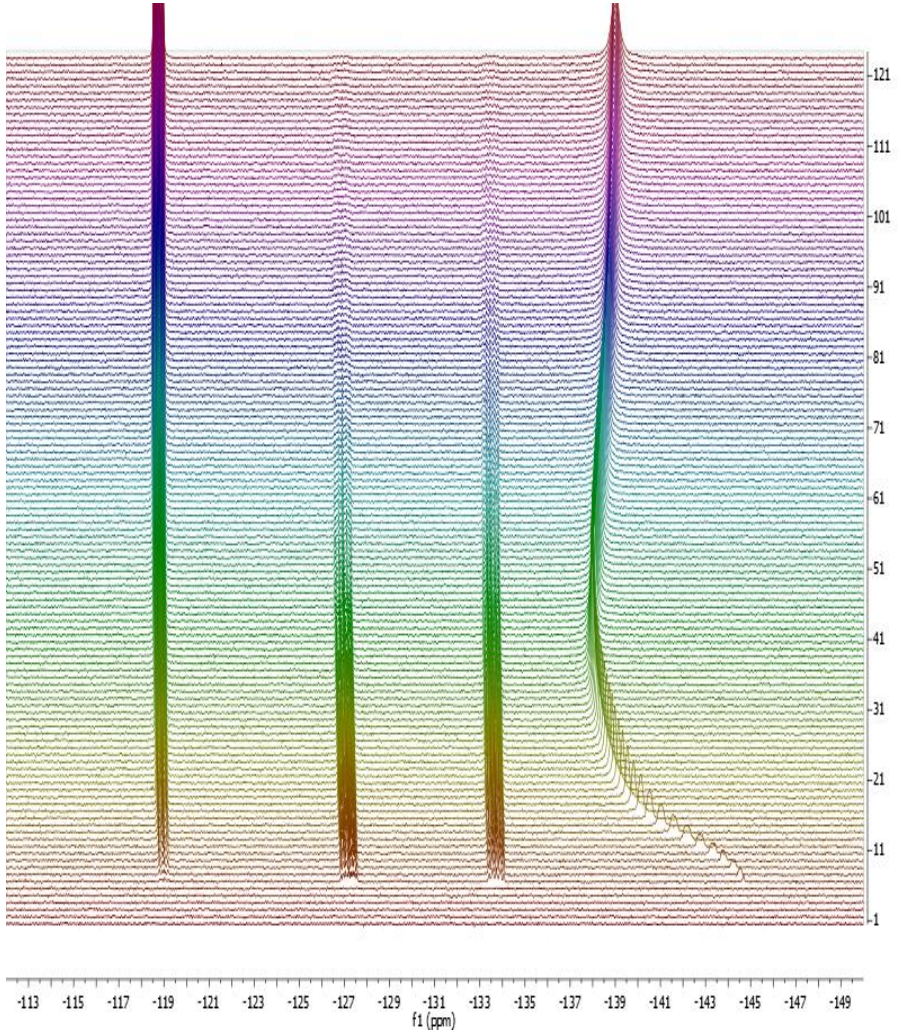
1D ^{19}F/Repetition time: 4 s/Number of scans: 8/**Measurement time: 32 s**

1 H proton

19 F fluorine

Spinsolve 60





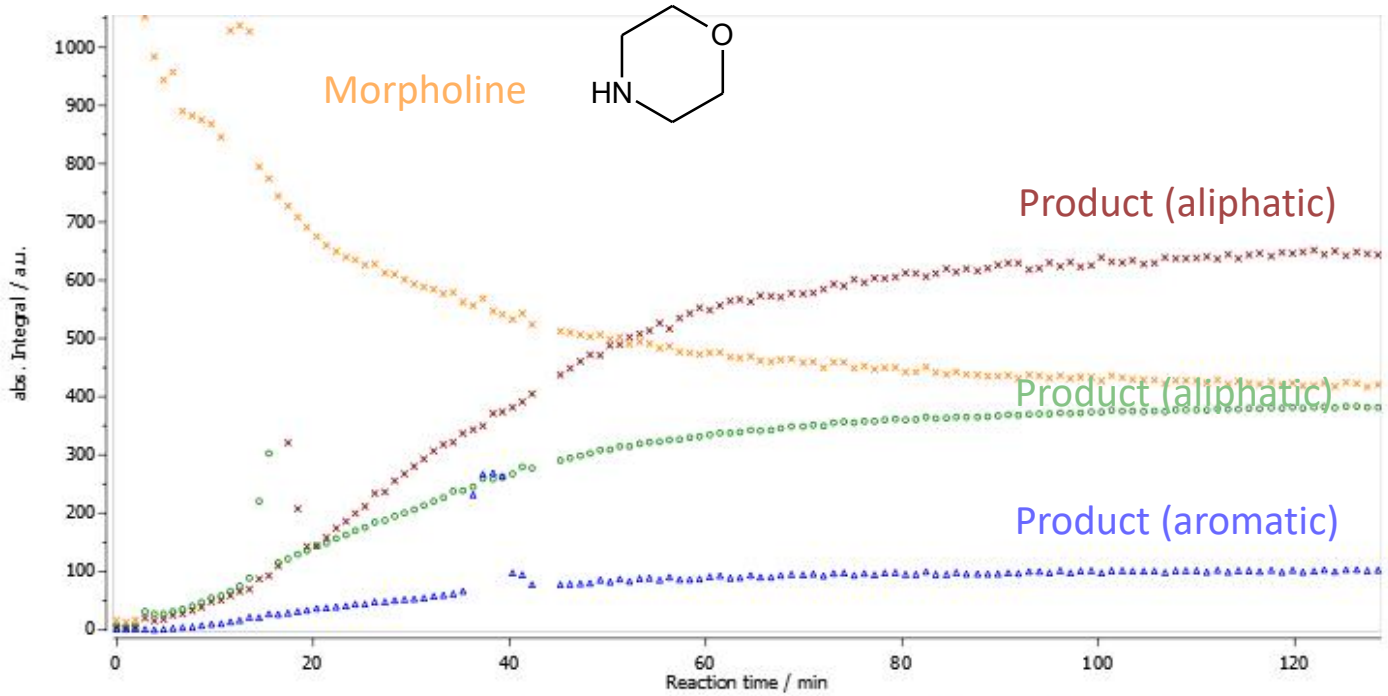
Reaction Monitoring – Regions of Interest 1H NMR

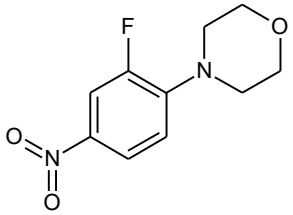
1D ^{1}H/Repetition time: 10 s/Number of scans: 2/**Measurement time: 20 s**

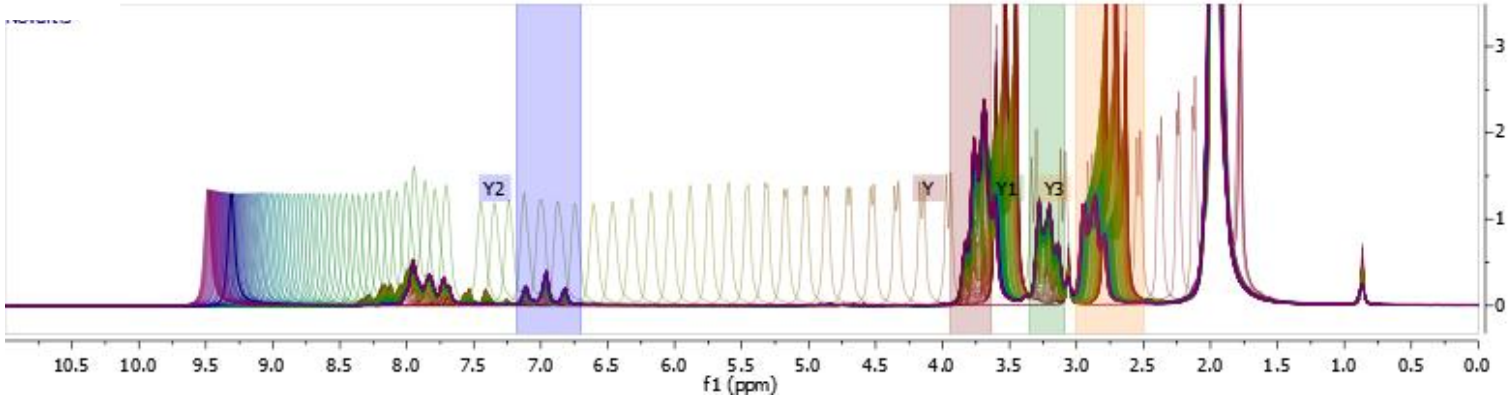
Spinsolve 60

1 H proton

Spinsolve 60







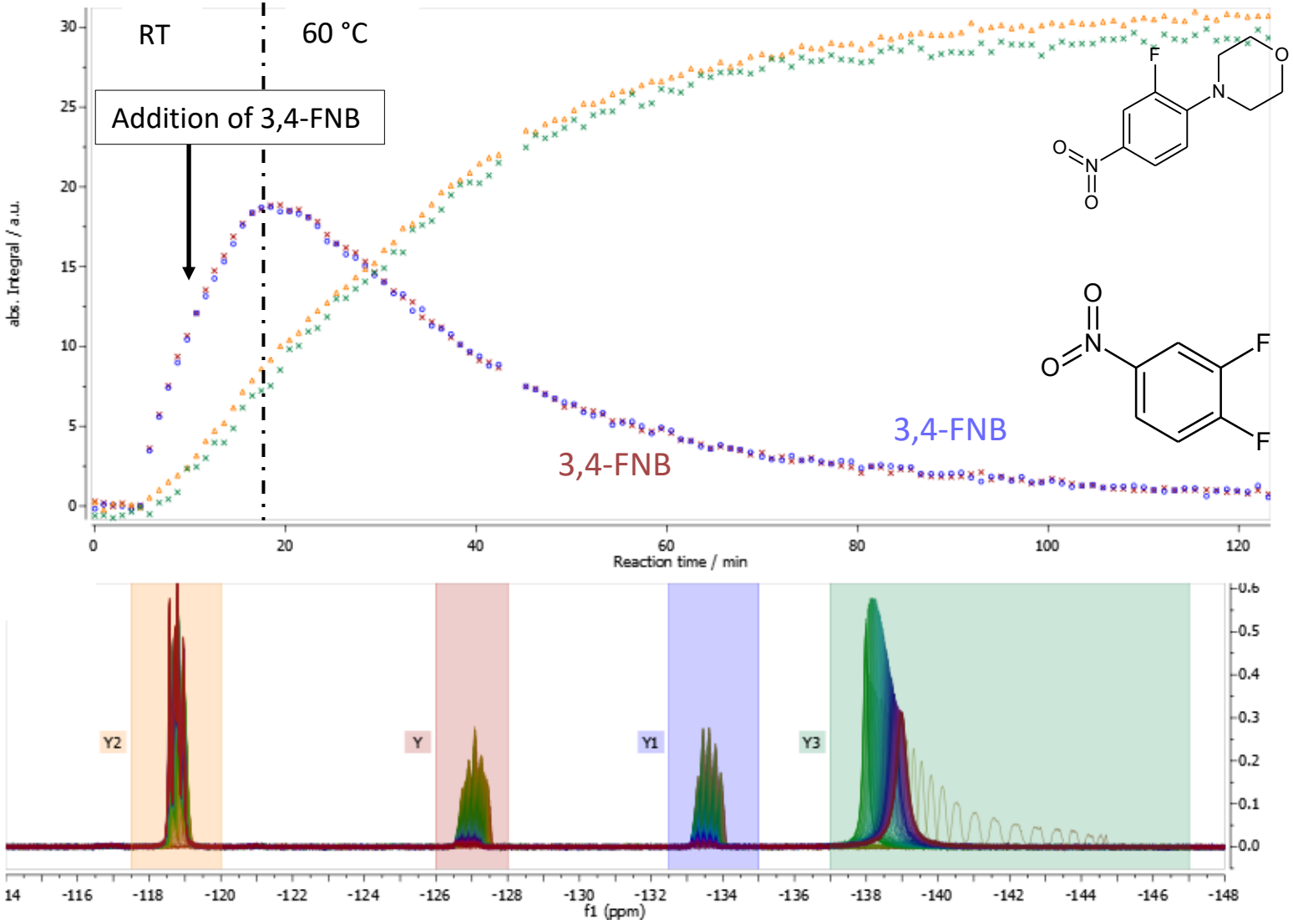
Reaction Monitoring – Regions of Interest 19F NMR

1D ^{19}F/Repetition time: 4 s/Number of scans: 8/**Measurement time: 32 s**

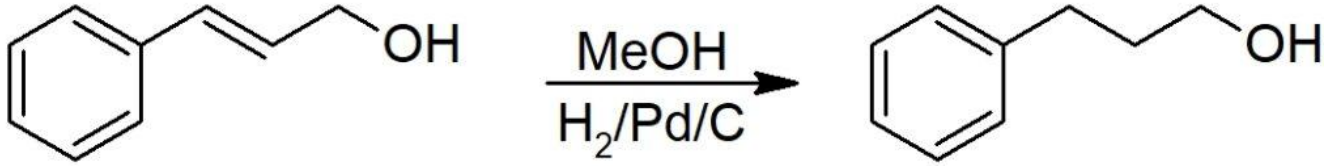
Spinsolve 60

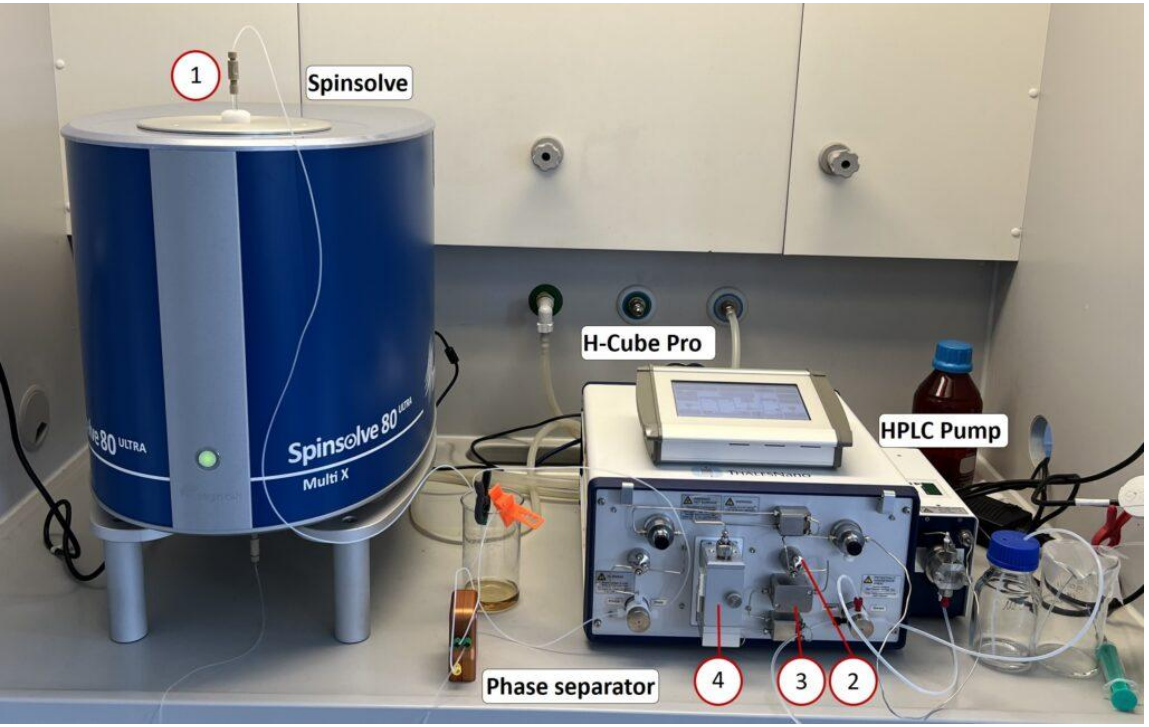
19 F fluorine

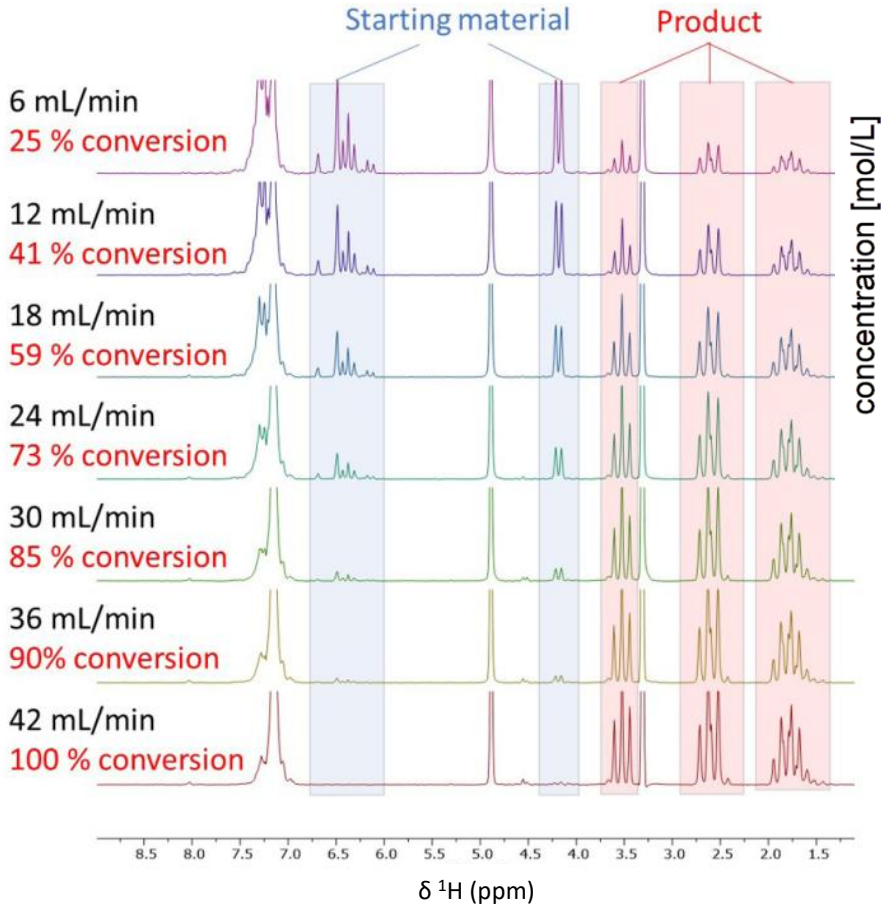
Spinsolve 60

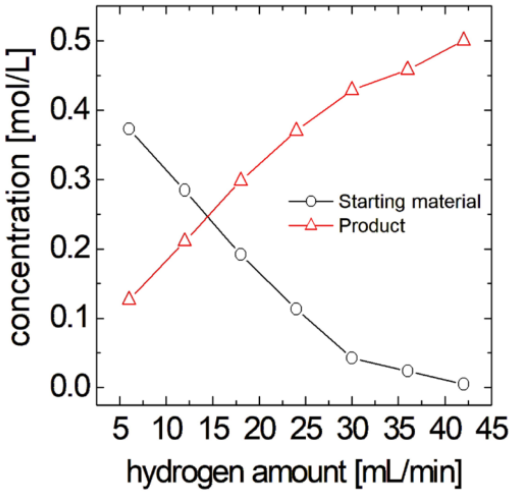


Spinsolve hyphenation with an H-Cube Pro® from ThalesNano©







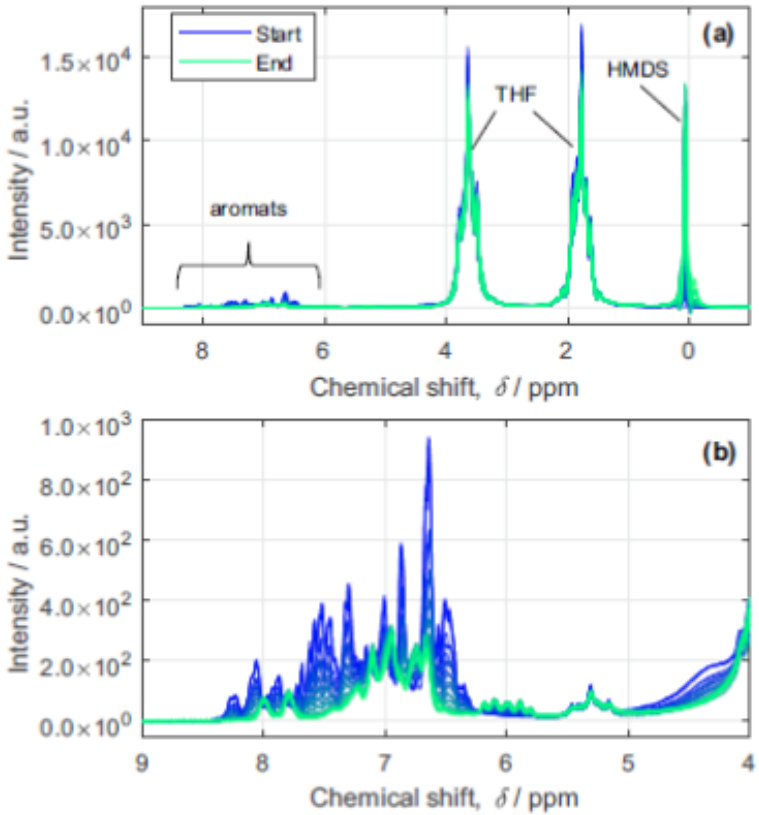


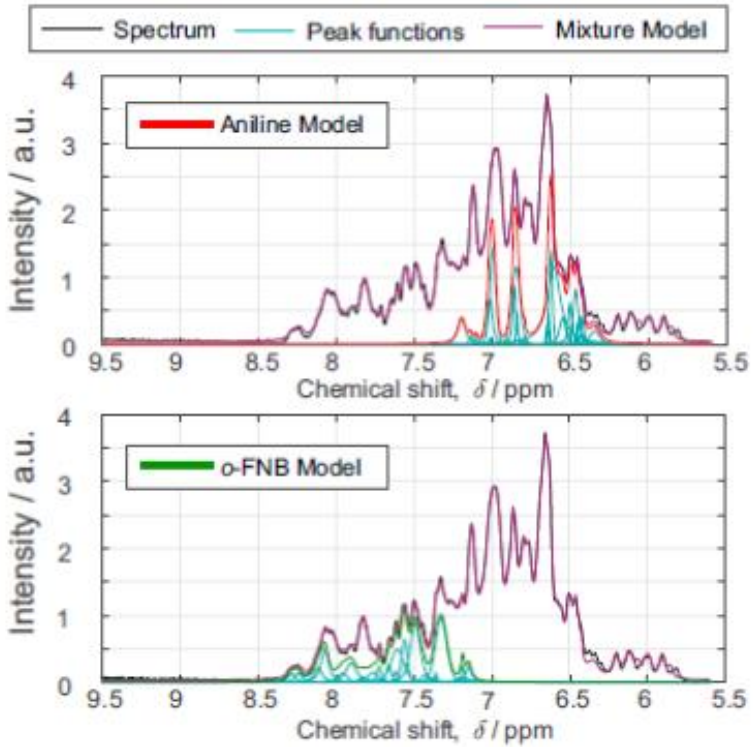
Free resources available online: https://magritek.com/applications/reaction-monitoring/

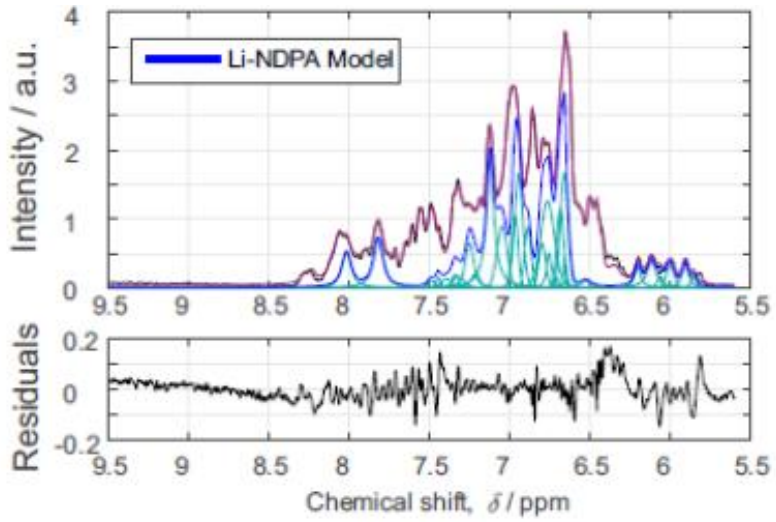
Flow chemistry

Models to demystify complex mixtures

- Indirect Hard Modelling





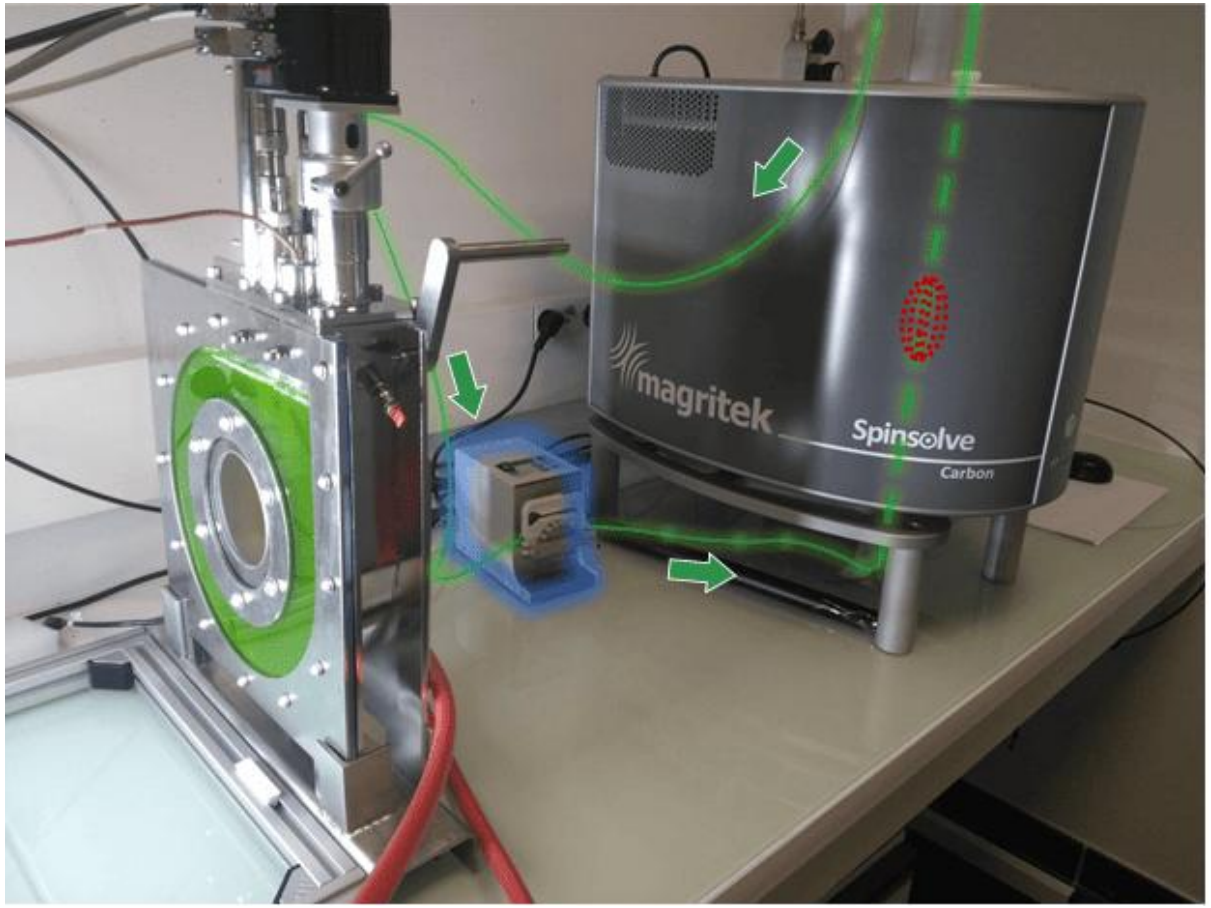


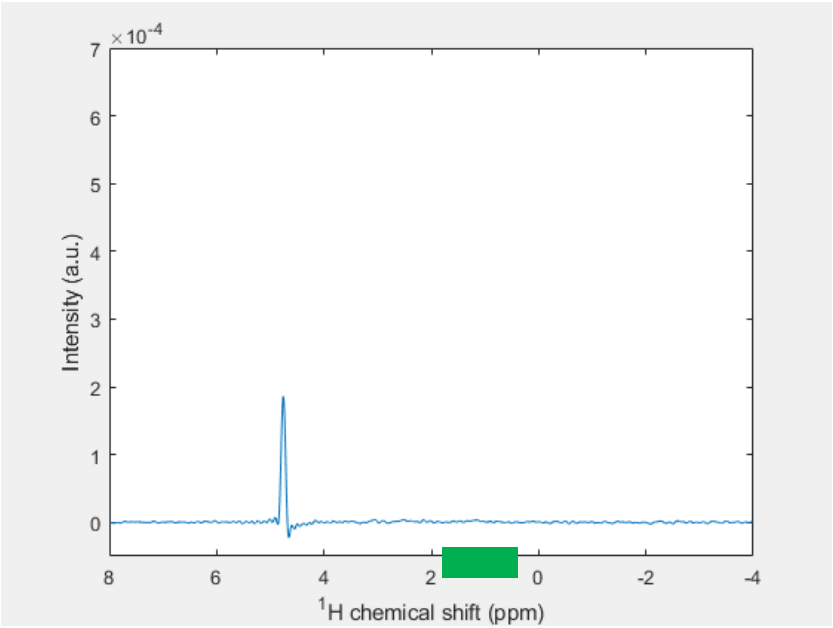
Online low-field NMR spectroscopy for process control of an industrial lithiation reaction-automated data analysis,
S. Kern, K. Meyer, S. Guhl, P. GräBer, A. Paul, R. King, M. Maiwald, *Anal. Bioanal. Chem.*, **2018,** *410*, 3349
10.1007/s00216-018-1020-z

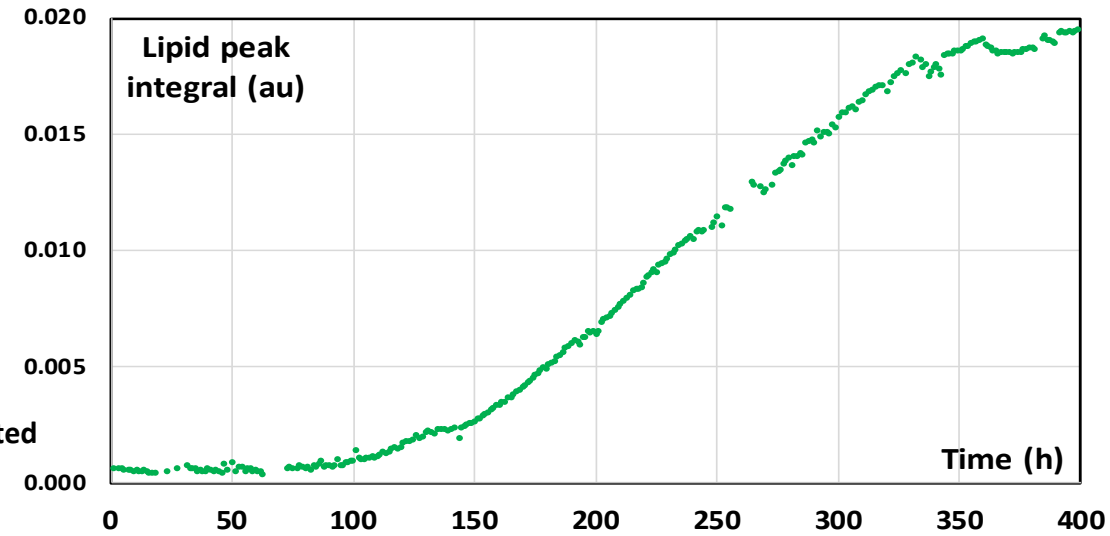
Flow chemistry

Monitoring intracellular lipid content

Spinsolve 43







Using benchtop NMR spectroscopy as an online non-invasive in vivo lipid sensor for microalgae cultivated in photobioreactors, D. Bouillaud, D. Drouin, B. Charrier, C. Jacquemmoz, J. Farjon, P. Giraudeau, O. Gonçalves, *Process Biochemistry*, Volume 93, (2020), https://doi.org/10.1016/j.procbio.2020.03.016

Organic chemistry robots

- Combination of different online detectors
- Feedback loop coupled with algorithm for self-automatizing chemistry

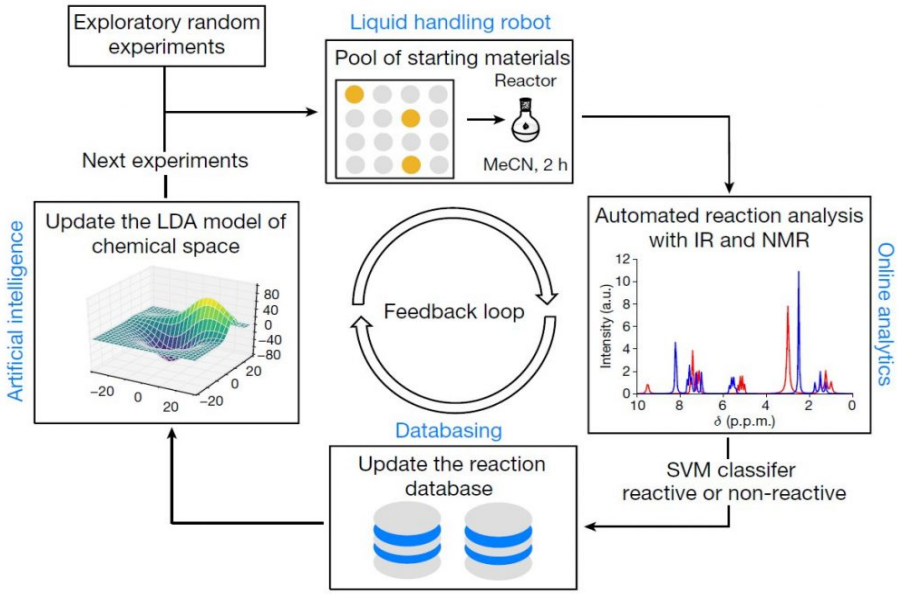
UNIVERSITY OF AMSTERDAM

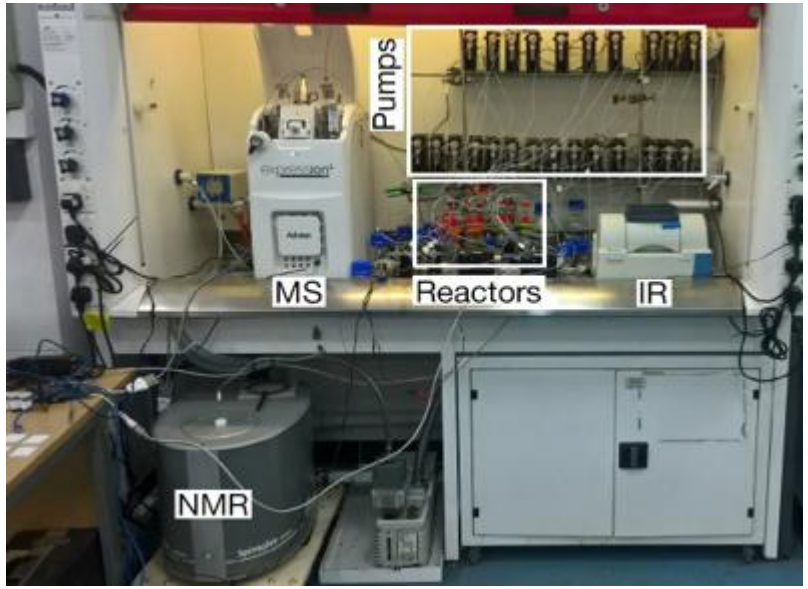
RoboChem: multipurpose robotic platform for the self-optimization, intensification and scale-up of photocatalytic transformations

Bayesian Optimization & Graphical User Interface → Sample Preparation → Photochemical Reactor → Inline NMR

Closed-loop, multiobjective optimization

fast optimization · reproducible · captures complex intercorrelations · generation of detailed datasets · scalable process





Controlling an organic synthesis robot with machine learning to search for new reactivity; J. M. Granda, L. Donina, V. Dragone, D.-L. Long and L. Cronin, *Nature* , 559, 377–381 (2018)
DOI: 10.1038/s41586-018-0307-8
Automated self-optimization, intensification, and scale-up of photocatalysis in flow; A. Slattery, Z. Wen, P. Tenblad, J. Sanjosé-Orduna, D. Pintossi, T. den Hartog and T. Noël*, Science,* 383, (2024).
DOI:10.1126/science.adj1817

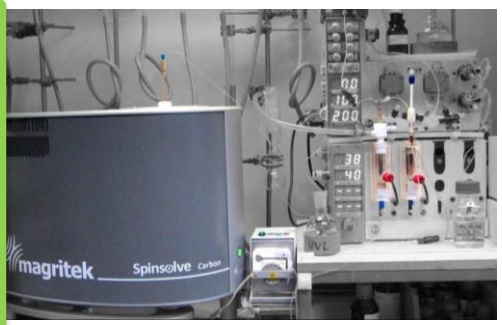
Benchtop NMR applications

Synthesis

Pharma

Macromolecules

Education



Flow chemistry

Batteries

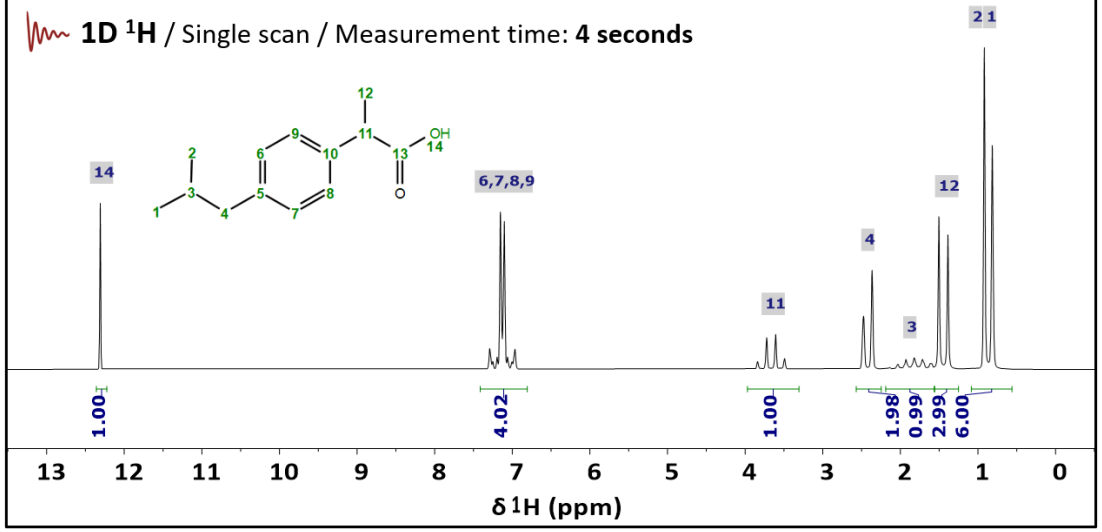
Food & Agriculture

Forensics

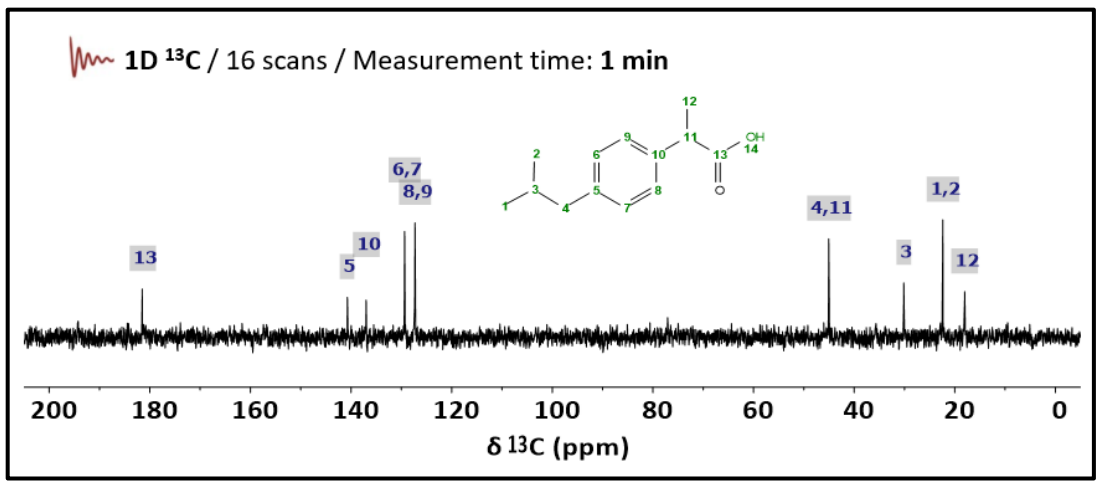
Analytics

Teaching structural elucidation

1D ^{1}H / Single scan / Measurement time: **4 seconds**



1D ^{13}C / 16 scans / Measurement time: **1 min**

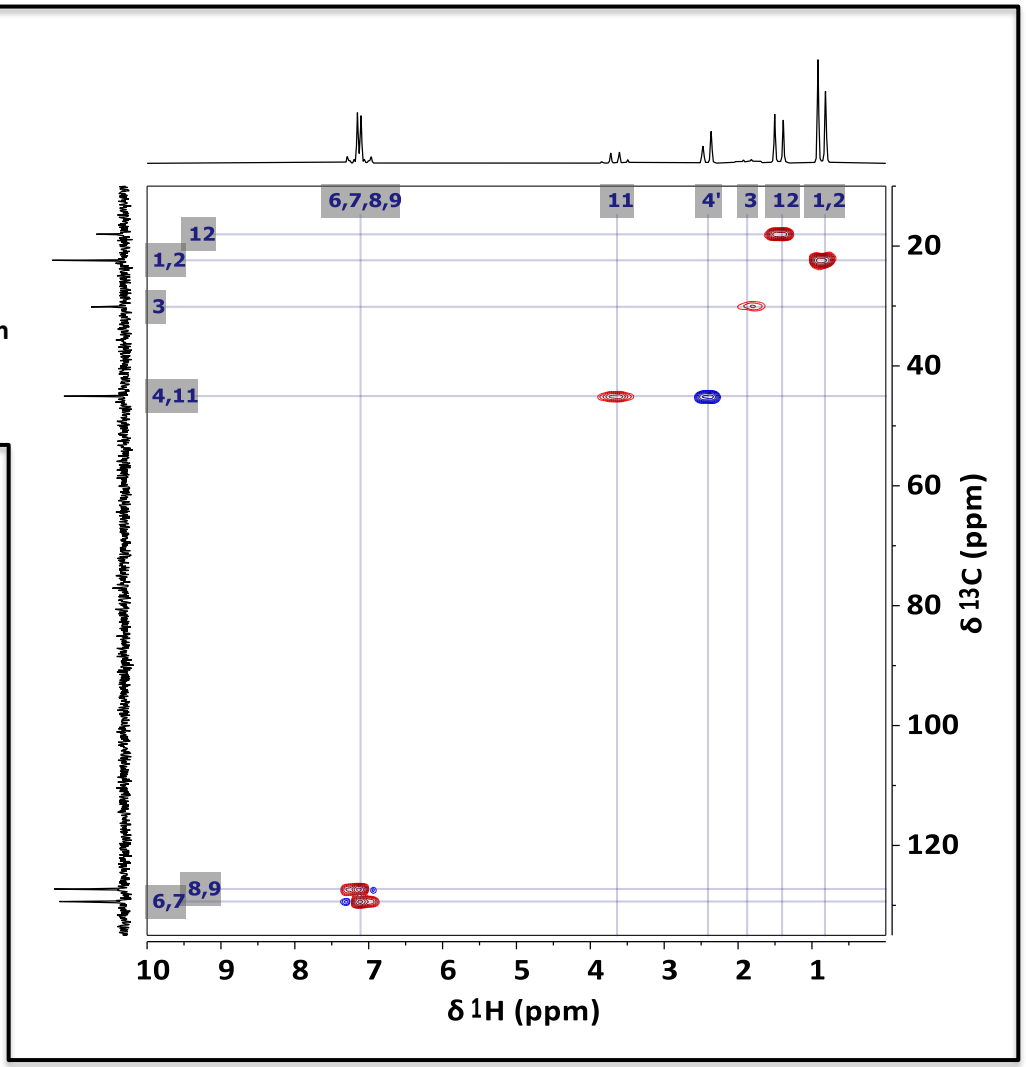


^{1}H-^{13}C gsHSQC-ME
Number of scans: 2
Number of steps: 128
Repetition time: 0.5s
NUS rate: 25%
Measurement time: 1 min

Ibuprofen (100 mg)
$CDCl_3$

Spinsolve 60

All spectra in less than 2 minutes !



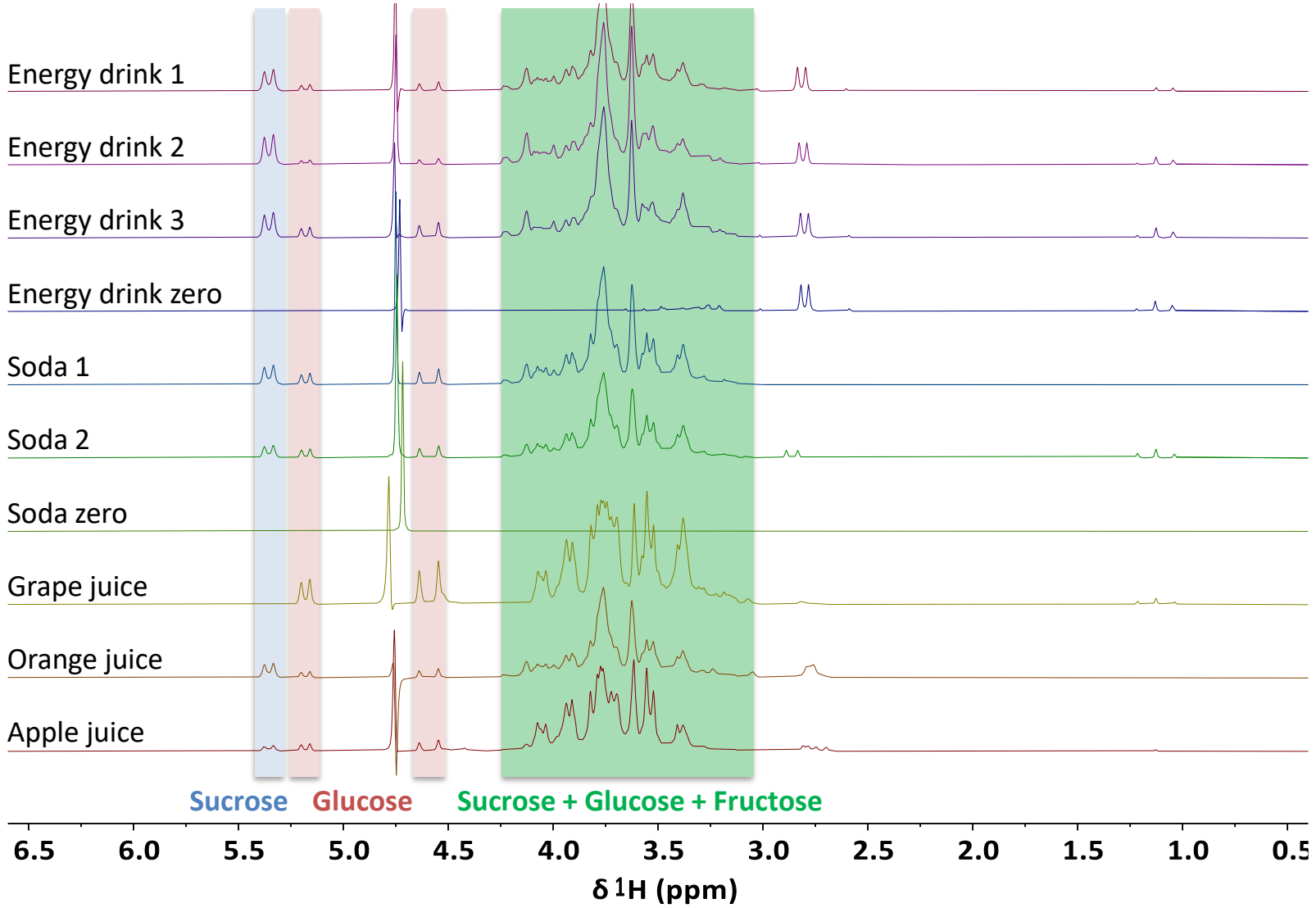
Teaching qNMR - Soft drink analysis

magritek
www.magritek.com

- Low sample preparation

Name	Glucose [g/100 mL]	Sucrose [g/100 mL]	Fructose [g/100 mL]	Total sugars [g/100 mL]
Energy Drink 1	5.20	2.10	2.05	8.88
Energy Drink 2	7.00	1.39	1.94	9.86
Energy Drink 3	6.03	3.24	1.56	10.36
Energy Drink zero	0.01	0.01	0.47	0.01
Cola 1	4.46	3.20	2.91	10.57
Cola 2	2.51	2.33	2.15	6.99
Cola without sugar	0.00	0.01	0.03	0.05
Grape Juice	0.08	8.03	7.99	16.10
Orange Juice	3.77	2.11	2.78	8.65
Apple Juice	1.53	2.47	6.18	10.18

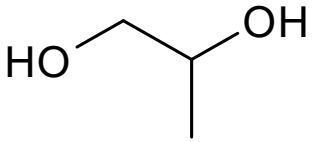
1D ^{1}H (WET)/Repetition time: 10 s/Number of scans: 8/**Measurement time: 2 min each**



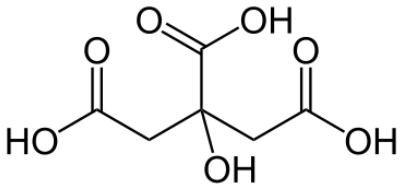
Education

Teaching qNMR - Soft drink analysis

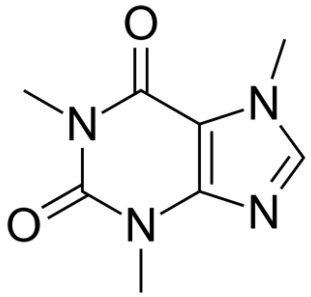
Ethanol



Propylene glycol (E1520)



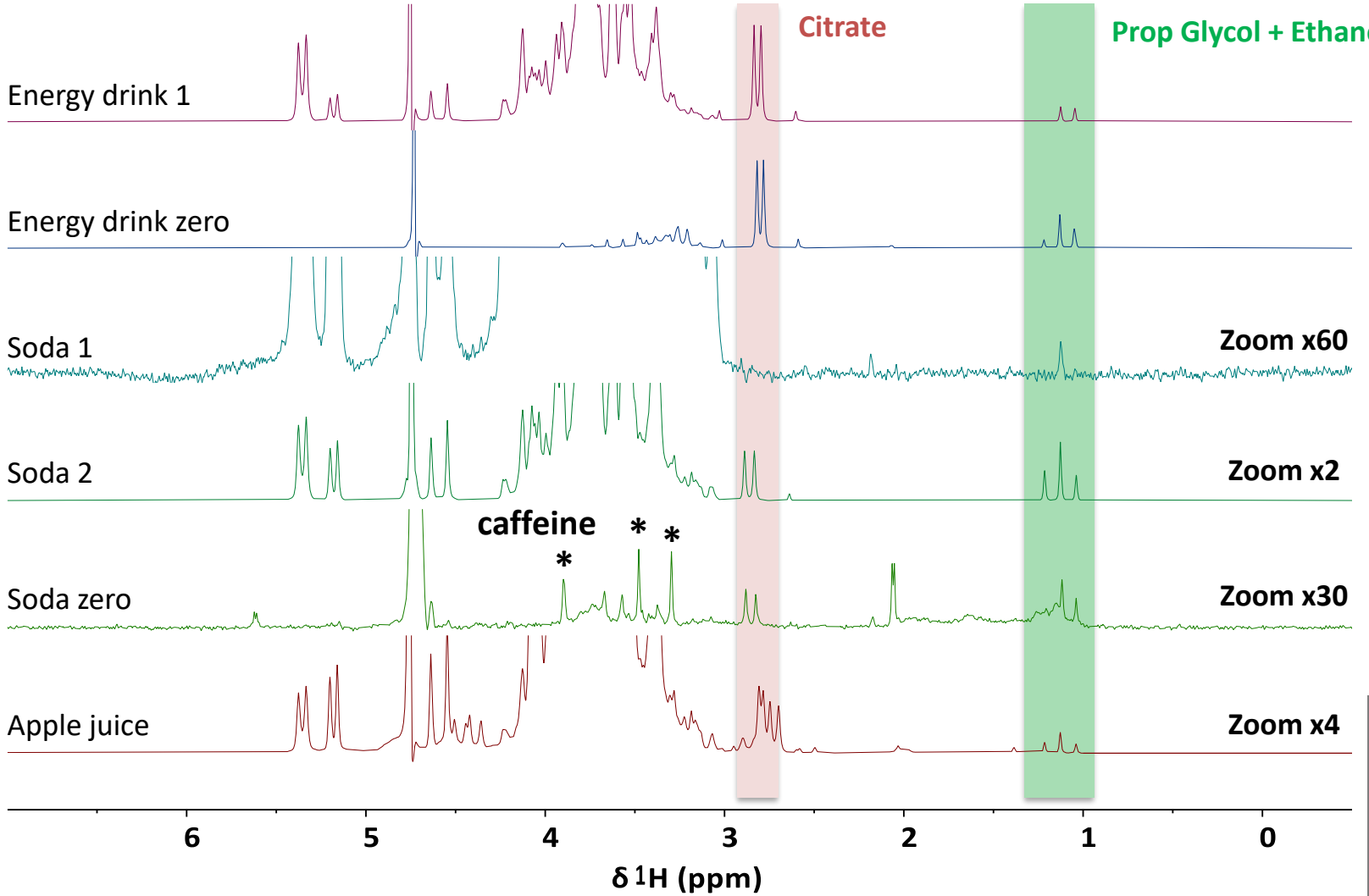
Citrate



Caffeine

- Different quantification approaches possible: internal/external standard, standard addition

1D ^{1}H (WET)/Repetition time: 10 s/Number of scans: 128/**Measurement time: 20 min each**

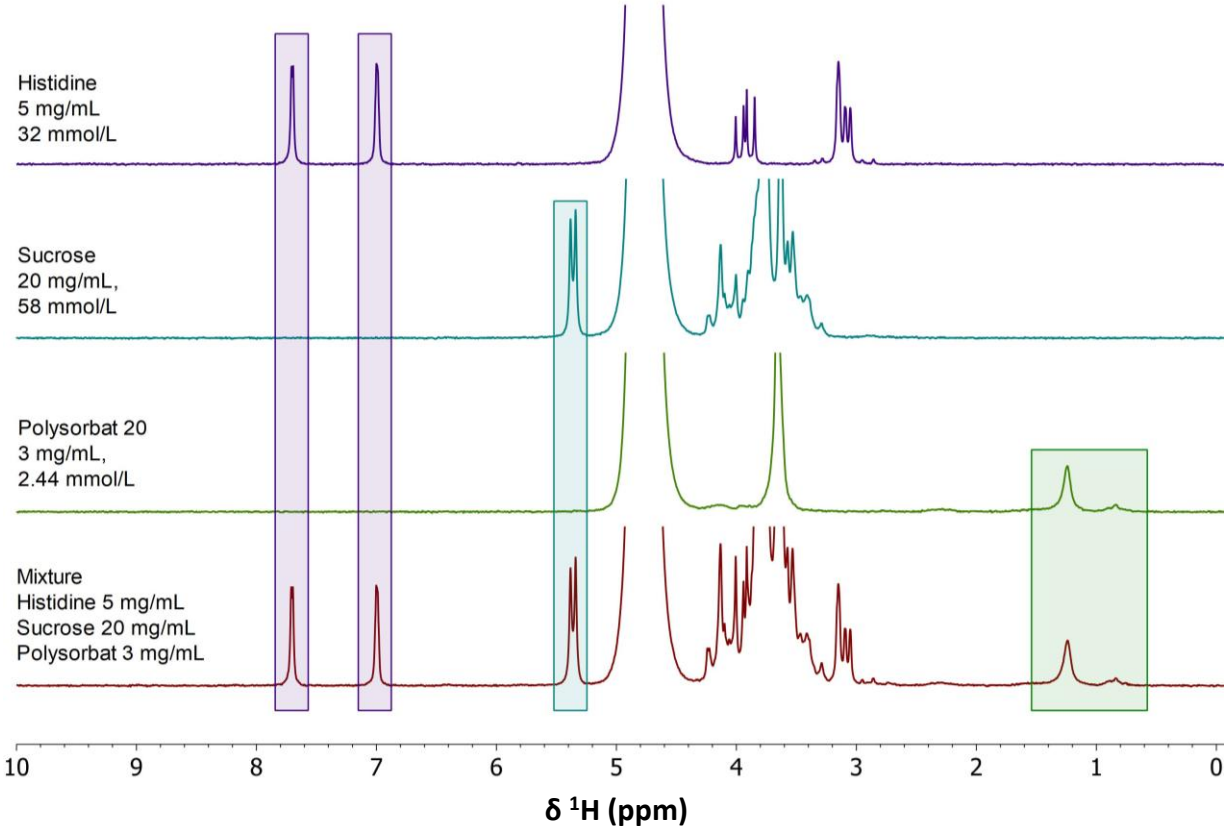


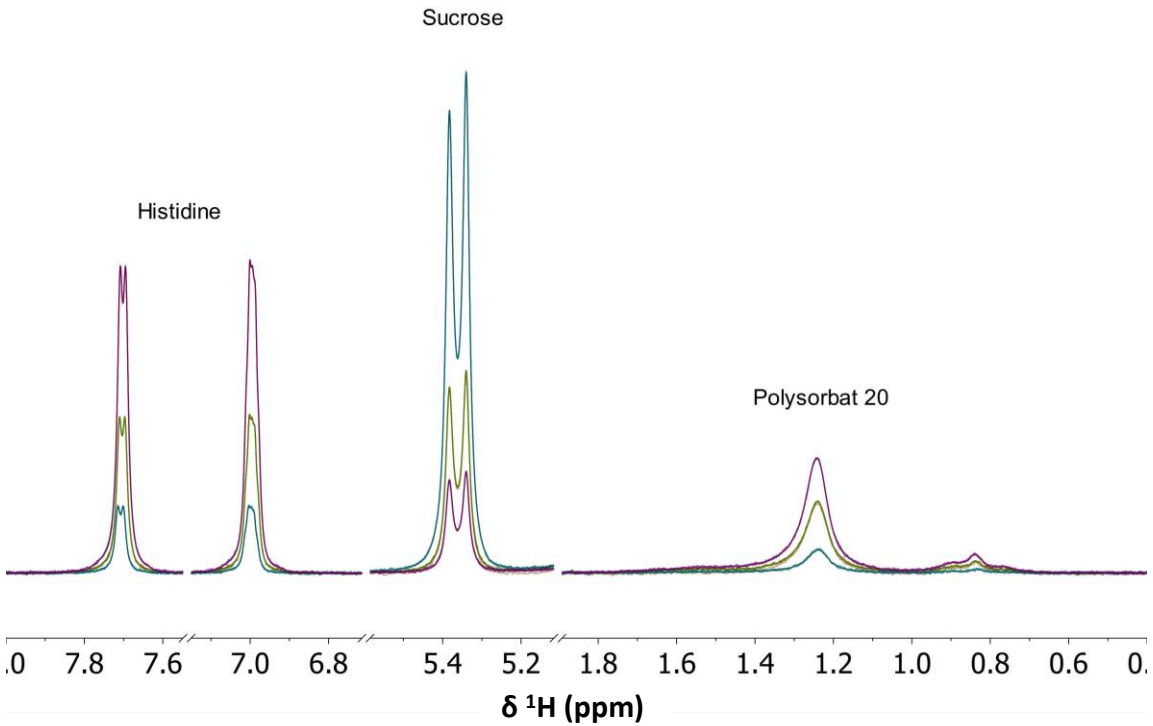
Free resources available online: https://magritek.com/2023/12/08/quantifying-residual-solvents-in-active-pharmaceutical-ingredients/

Education

Teaching qNMR - Pharmaceutical formulation

1D ^{1}H (PRESAT)/Repetition time: 10 s/Number of scans: 32/**Measurement time: 6 min each**





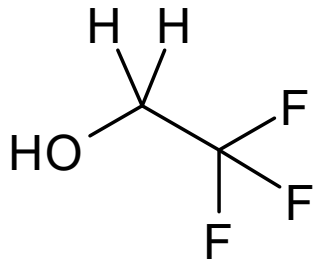
• 3 reference spectra (known concentrations) and a spectrum of a mixture measured on a Spinsolve 80 spectrometer.

• Superposition of three mixtures with different concentrations of histidine, sucrose and polysorbate 20.

Free resources available online: https://magritek.com/2021/02/22/qnmr-on-samples-from-the-production-plant/

Education

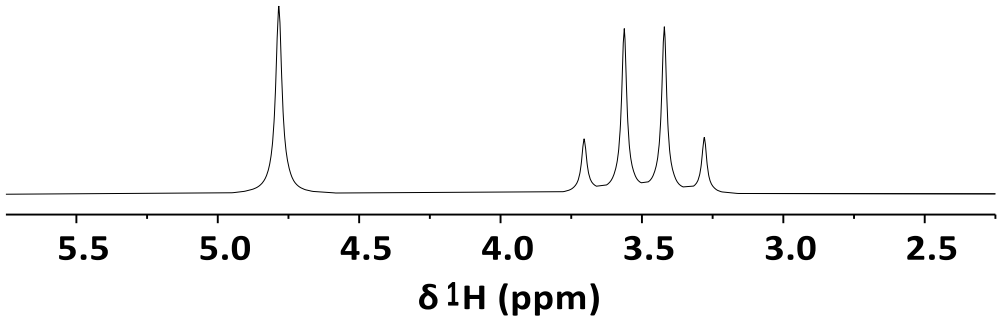
Teaching NMR - Couplings with ^{19}F



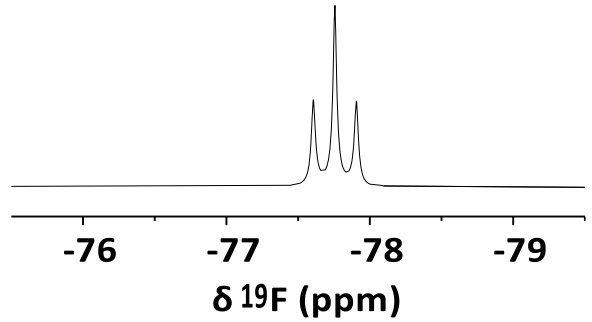
2,2,2-trifluoroethanol

- Full $^{1}H/^{19}F$ decoupling options to understand the couplings, simplify the spectra and get higher SNR

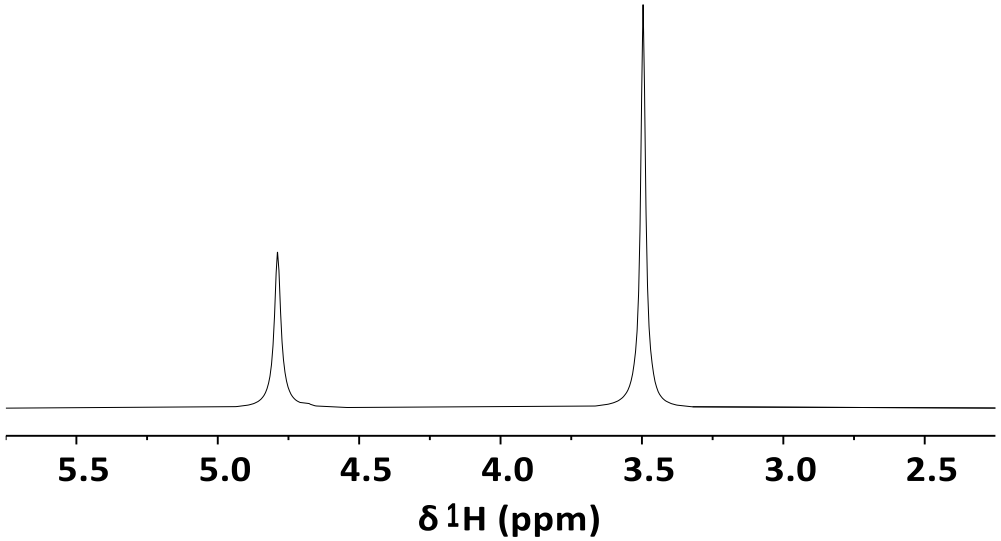
^{1}H/Single scan/**Measurement time: 5 s**



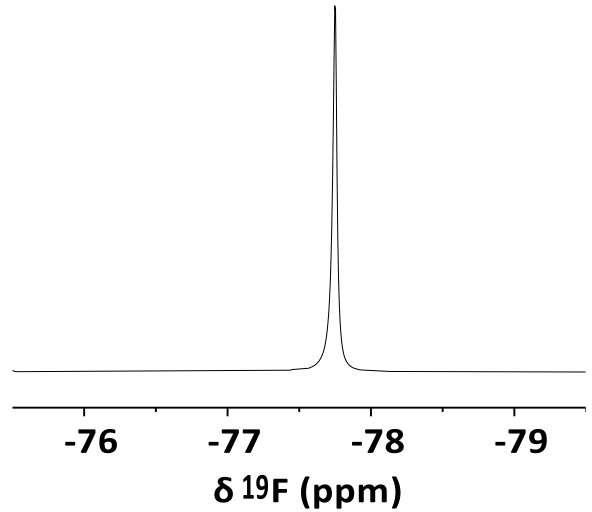
^{19}F/Single scan/**Measurement time: 5 s**



$^{1}H\{^{19}F\}$/Single scan/**Measurement time: 5 s**

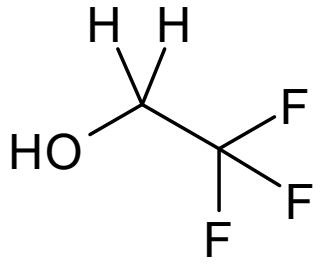


$^{19}F\{^{1}H\}$/Single scan/**Measurement time: 5 s**



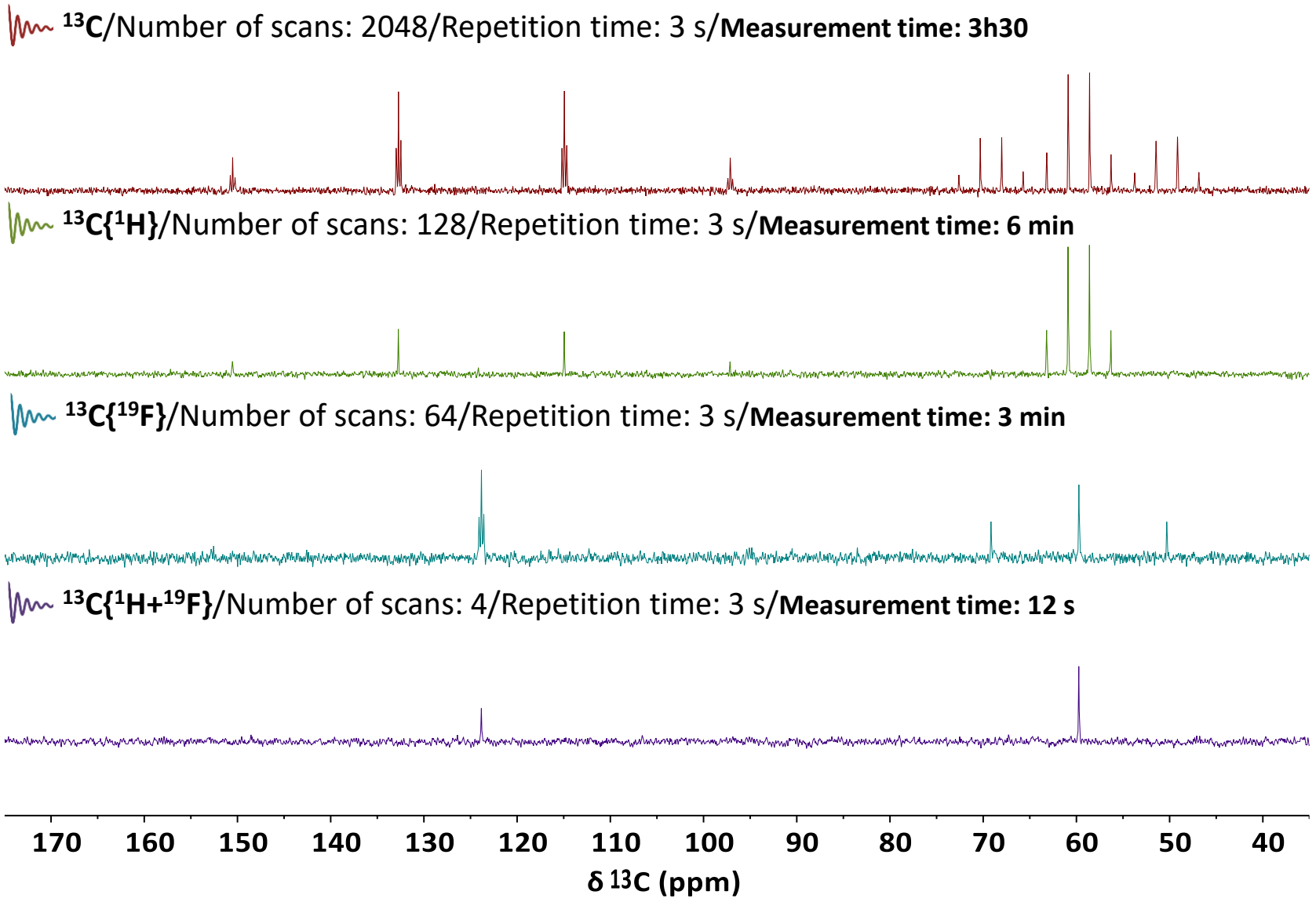
Education

Teaching NMR - Couplings with ^{19}F



2,2,2-trifluoroethanol

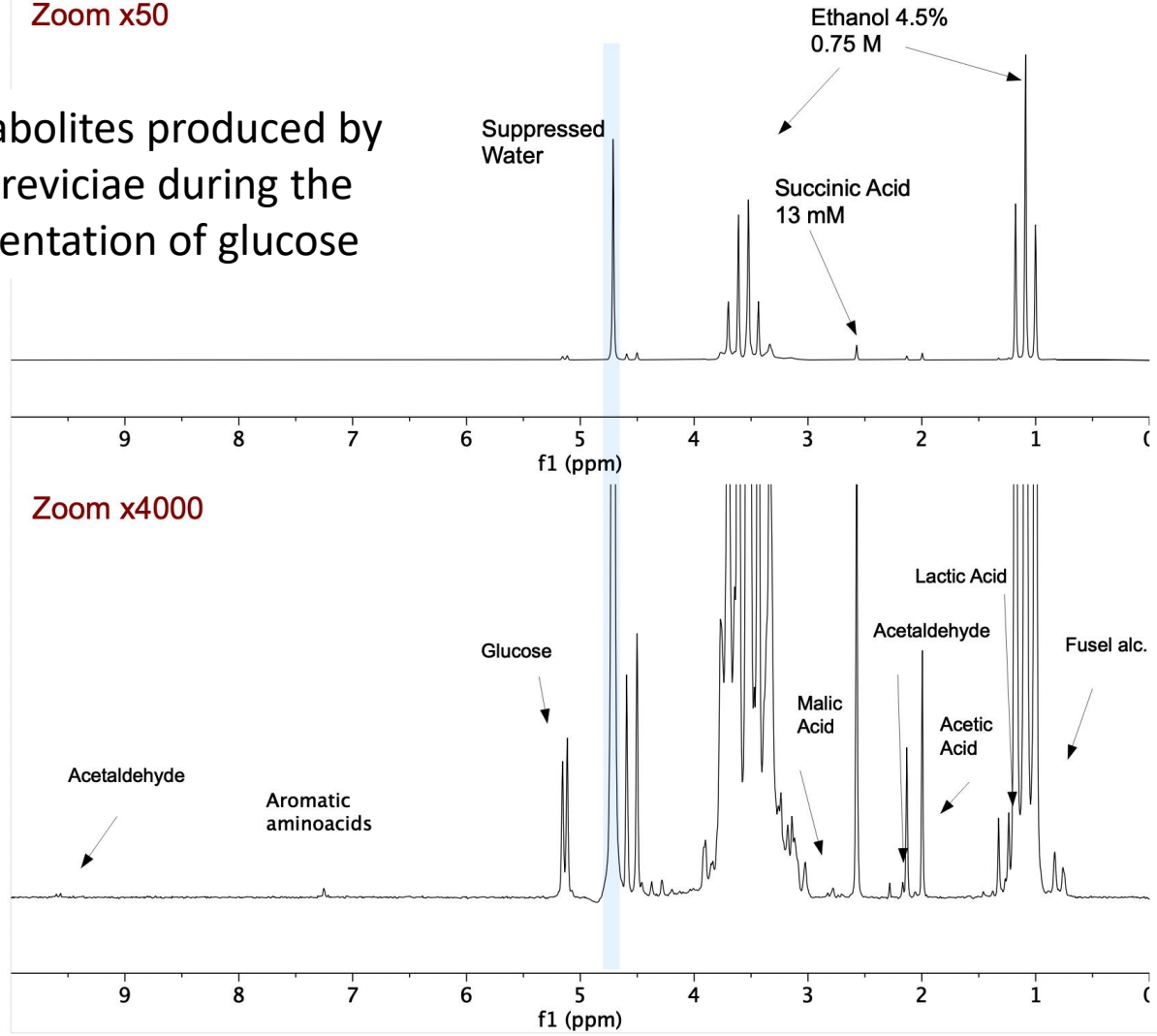
- ^{1}H **AND** ^{19}F decoupling for ^{13}C spectra
- Speeding up fluorinated molecules analysis

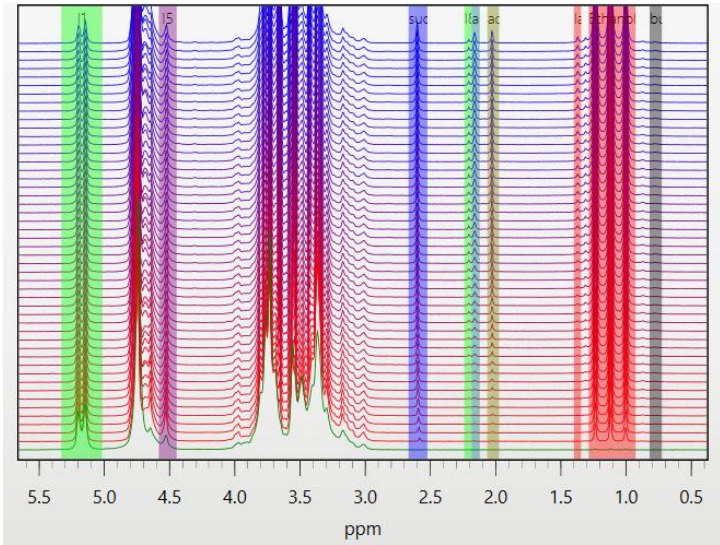


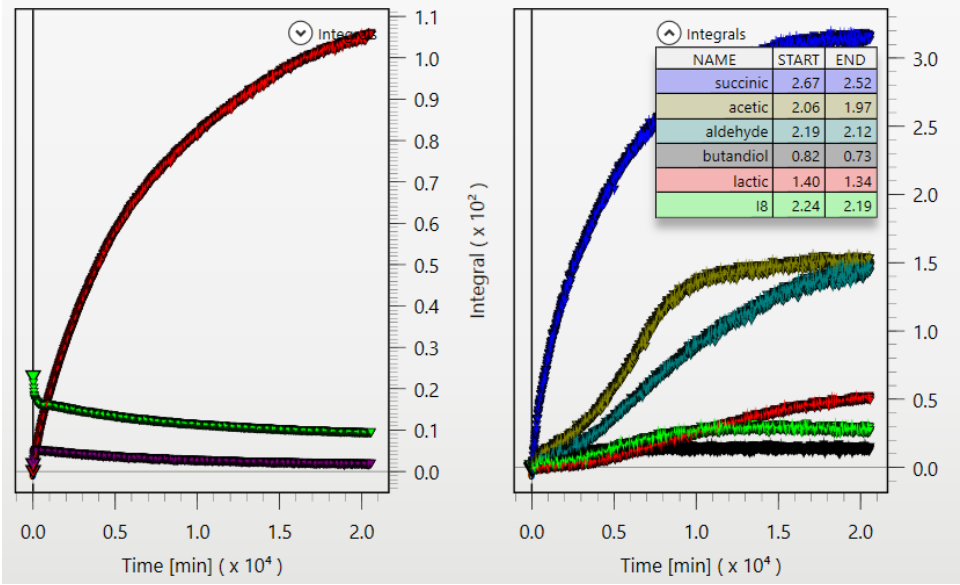
Education

Teaching biochemistry: monitoring fermentations

Metabolites produced by S. Cereviciae during the fermentation of glucose







- Monitoring over 35h

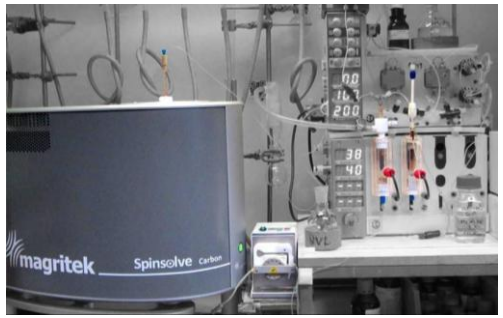
Benchtop NMR applications

Synthesis

Pharma

Macromolecules

Education



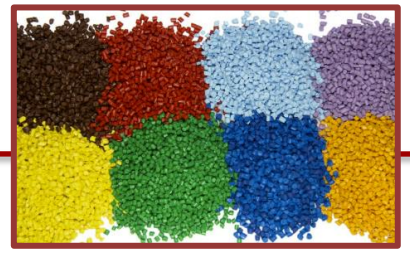
Flow chemistry

Batteries

Food & Agriculture

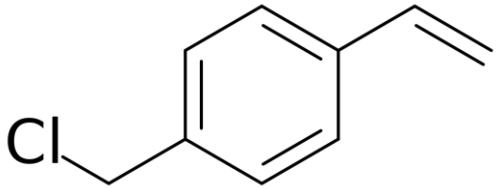
Forensics

Analytics



Quality check of a monomer solution

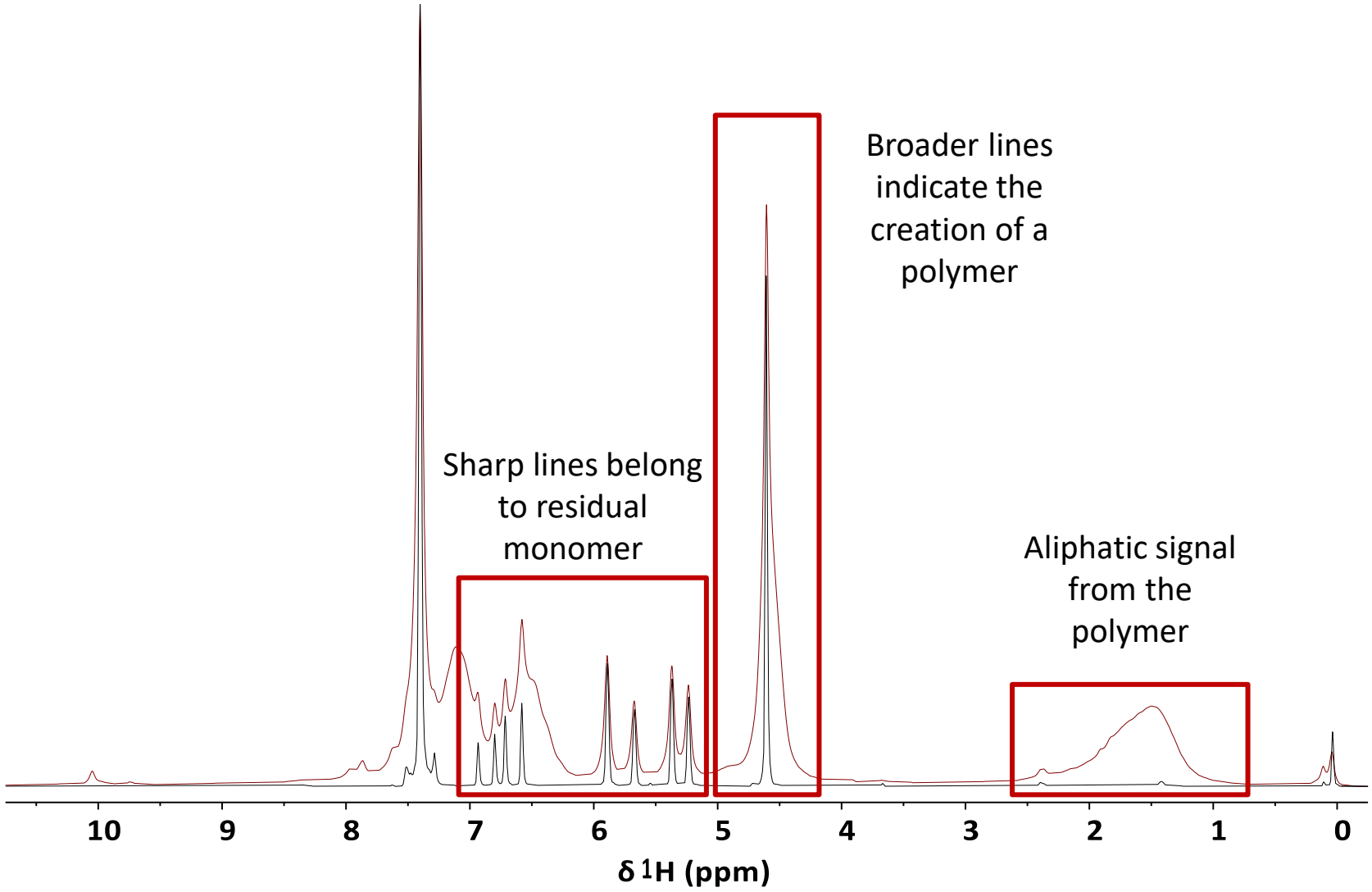
1D ^{1}H /Repetition time: 10 s/Number of scans: 1/**Measurement time: 10 s**

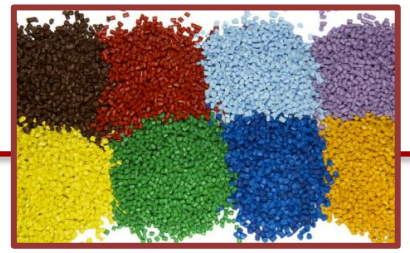


4-vinylbenzyl chloride

Fresh sample

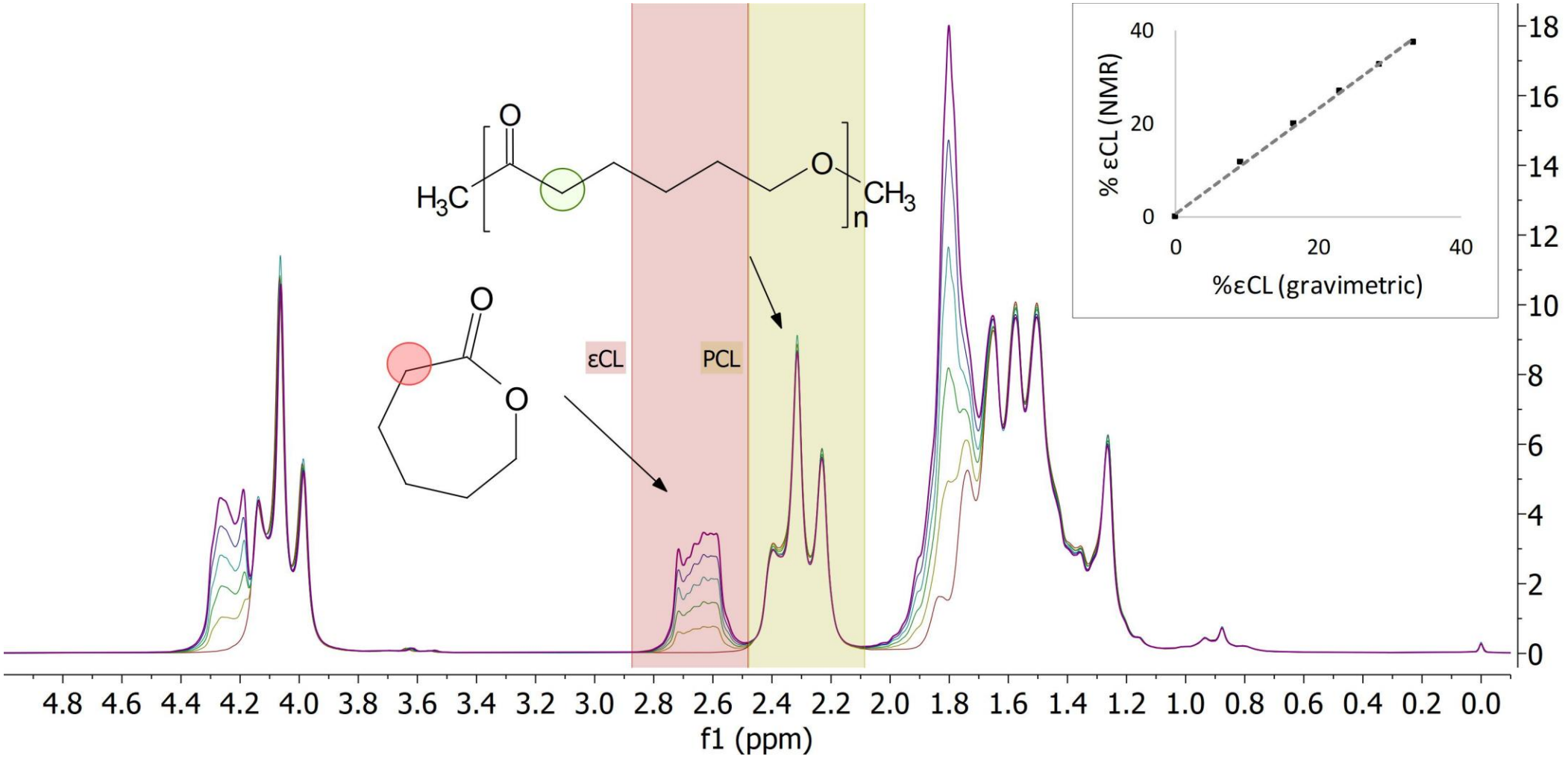
Sample after a few months without storage care (room temperature)

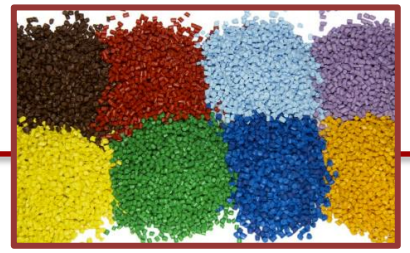




Conversion during the polymerization

Signals of polymer and monomers should be separated in the spectra



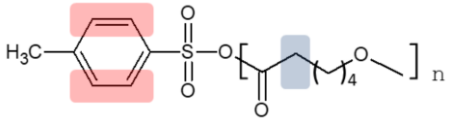


Polymer end-group analysis

$$M_n = DP \times M_{repeating\ unit} \qquad DP = \frac{\text{Integral of the repeating unit}}{\text{number of protons of the repeating unit}} \times \frac{\text{number of protons of the end group}}{\text{integration of the end group}}$$

Polycaprolactone

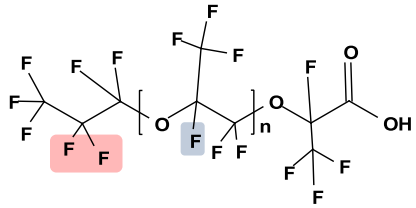
1D ^{1}H/Repetition time: 10 s/Number of scans: 16/**Measurement time: 3 min**



DP = 36.4
M = 4100 g/mol

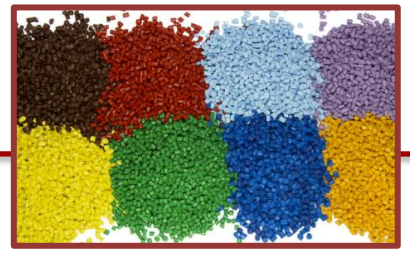
Perfluoropolyether

1D ^{19}F/Repetition time: 3 s/Number of scans: 8/**Measurement time: 30 s**



DP = 42.5
M = 7400 g/mol

Free resources available online: https://magritek.com/applications/polymers/



Copolymer ratio

$$\frac{DP_1}{DP_2} = \frac{Integral\ of\ the\ repeating\ unit\ 1}{number\ of\ ^1H\ of\ the\ repeating\ unit\ 1} \ x \ \frac{number\ of\ ^1H\ of\ the\ repeating\ unit\ 2}{Integral\ of\ the\ repeating\ unit\ 2}$$

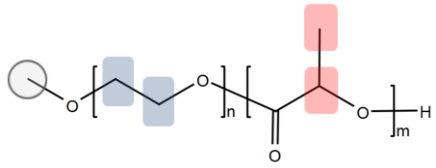
Poloxamer

1D ^{1}H/Repetition time: 10 s/Number of scans: 16/**Measurement time: 3 min**

DP_{PEO} / DP_{PPO} = 5.7

Poly(ethylene glycol)-*b*-poly(lactic acid)

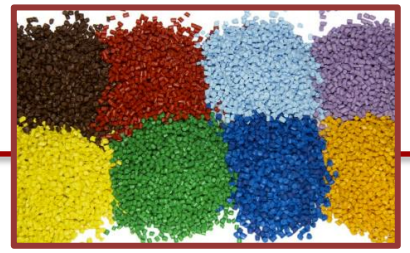
1D ^{1}H/Repetition time: 10 s/Number of scans: 16/**Measurement time: 3 min**



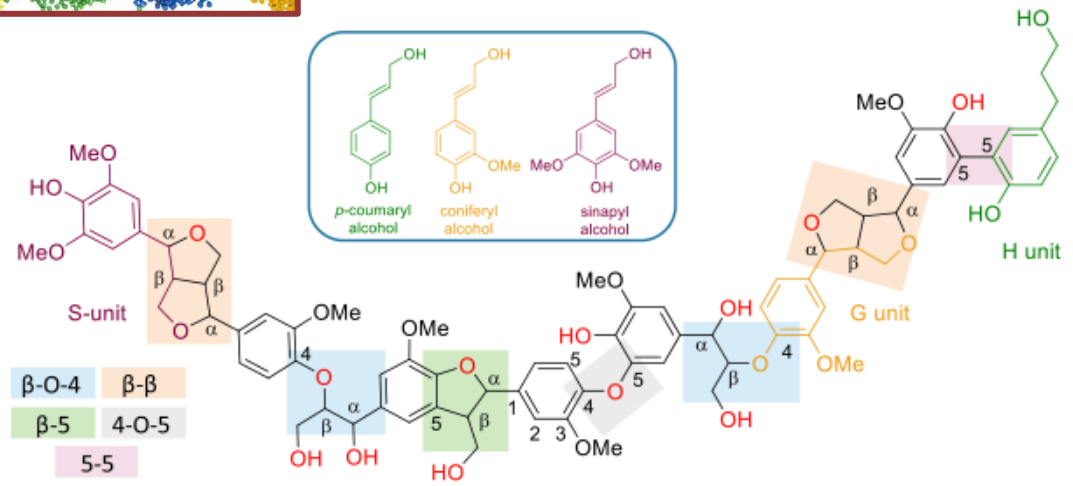
DP_{PLA} / DP_{PEG} = 3.2
Mw_{PLA} = 7650 g/mol
Mw_{PEG} = 7990 g/mol
Mw_{total} = 15640 g/mol

Free resources available online: https://magritek.com/applications/polymers/

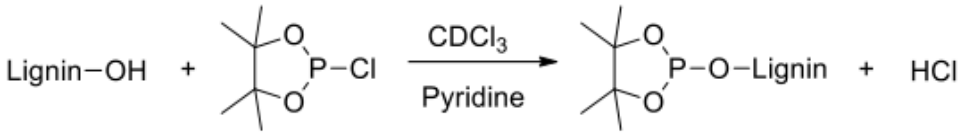
Polymers



Quantification of lignin -OH groups

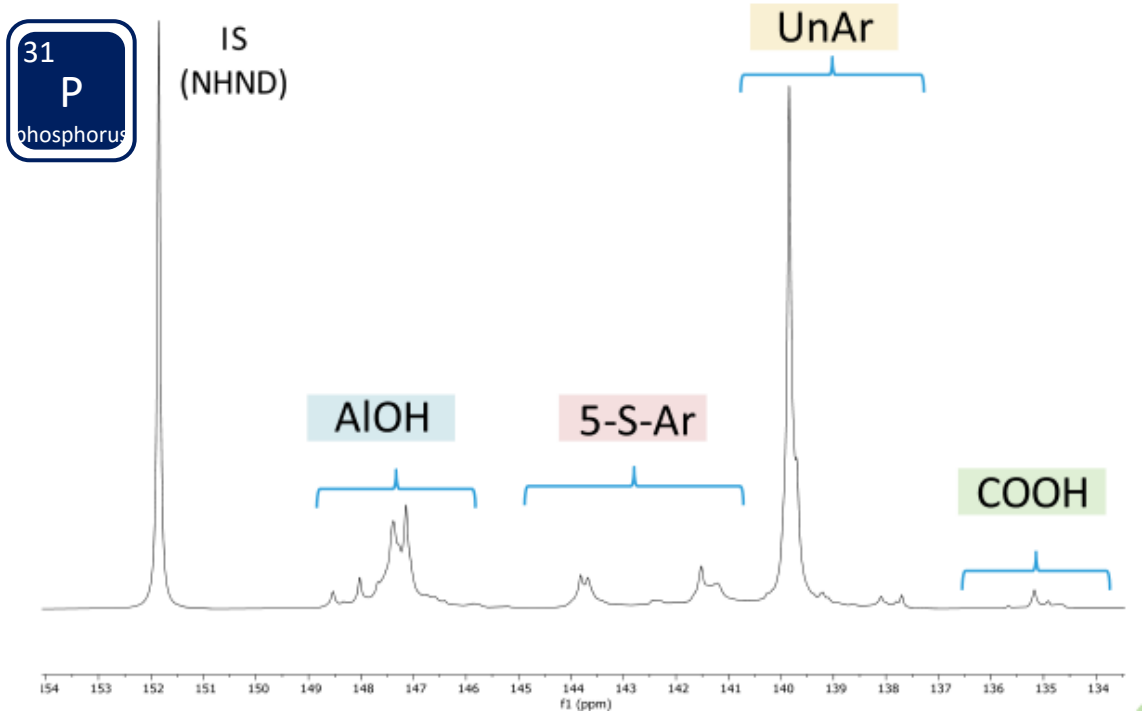


Representative structure of lignin with the most common bonds



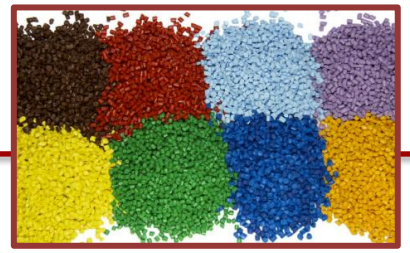
Derivatization of -OH group to introduce a phosphorous group

Spinsolve 80

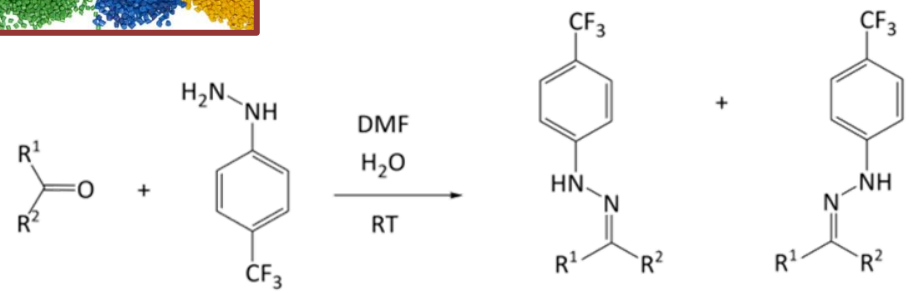


- Determination of lignin -OH groups
- Results in accordance with High-Field NMR

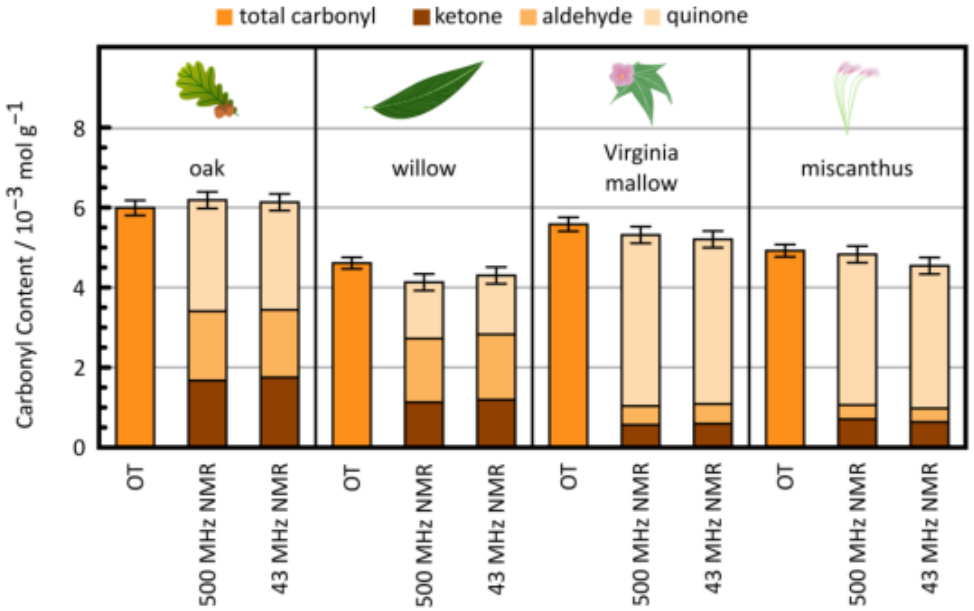
J. Gracia-Vitoria , M. Rubens , E. Feghali , Peter Adriaensens , K. Vanbroekhoven, R. Vendamme, Industrial Crops & Products 176 (2022) 114405 - https://www.sciencedirect.com/science/article/abs/pii/S0926669021011705



Quantification of pyrolysis oils carbonyl groups

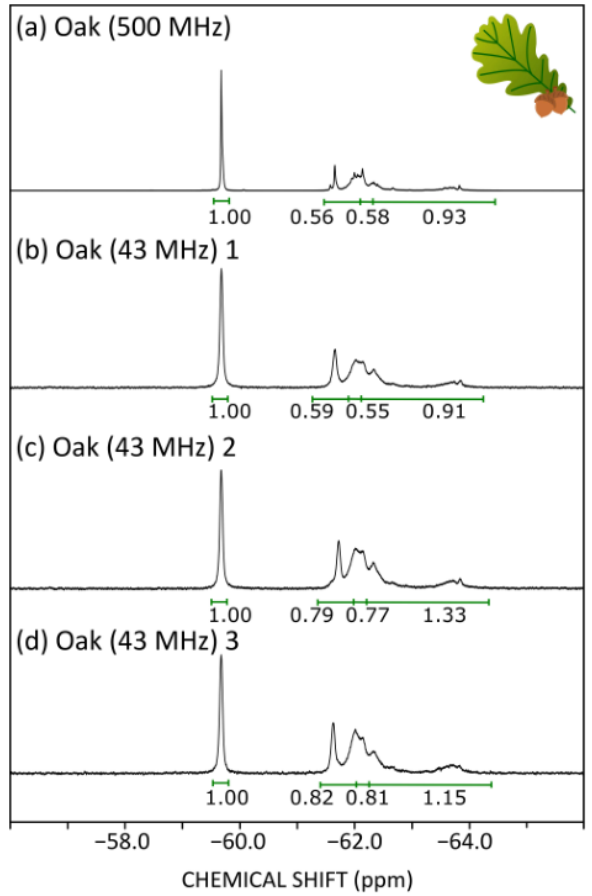


Derivatization of -C=O group to introduce a fluorinated group



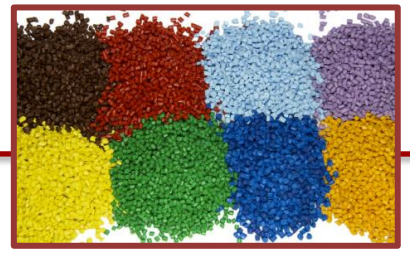
Spinsolve 43

19 F fluorine



- Quantification of carbonyl groups
- Results in accordance with High-Field NMR & titration

Bridget Tang, Katie Chong, Arthur J. Ragauskas, and Robert Evans, ChemSusChem **2023**, 16, doi.org/10.1002/cssc.202300625

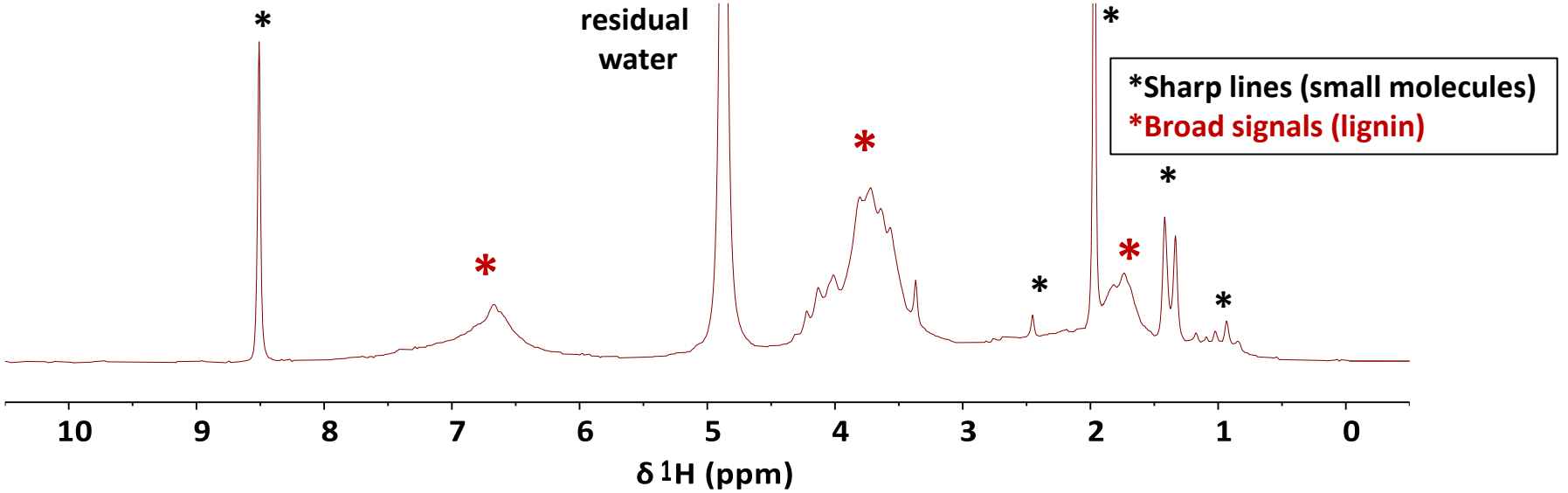


Black liquor analysis

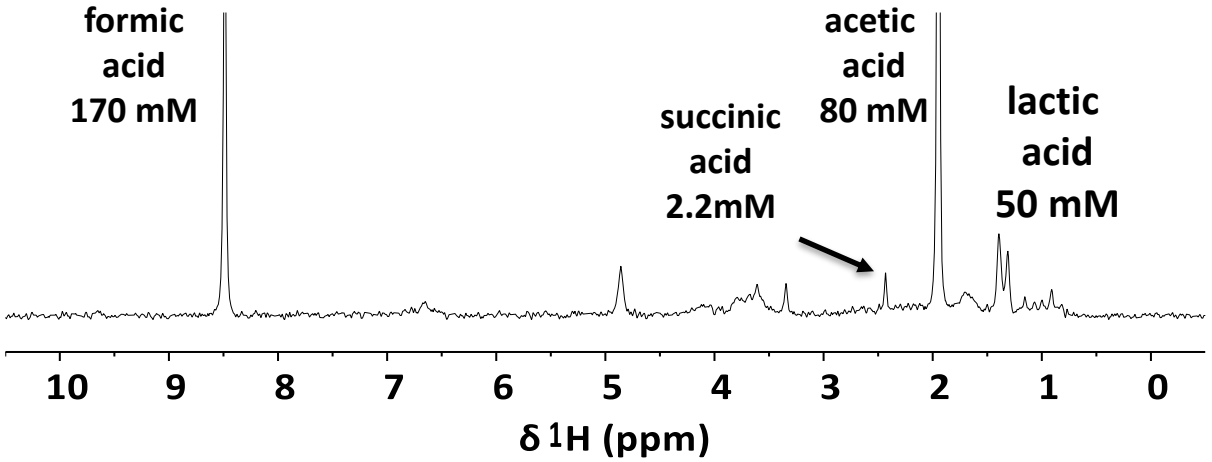
Spinsolve 80

^{1}H WET (solvent suppression)

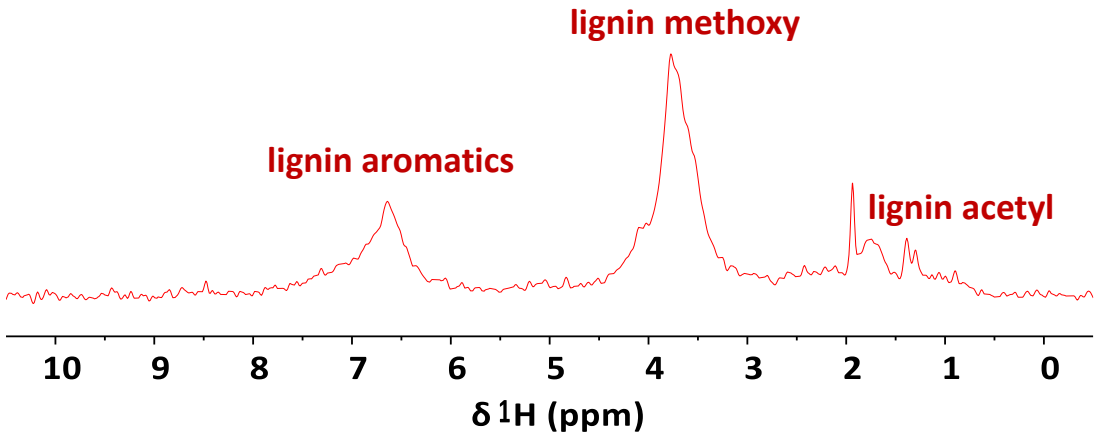
- Black liquor is a waste of the kraft paper industry

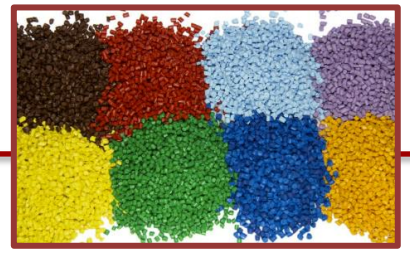


WET with T2 filter (small molecules only)

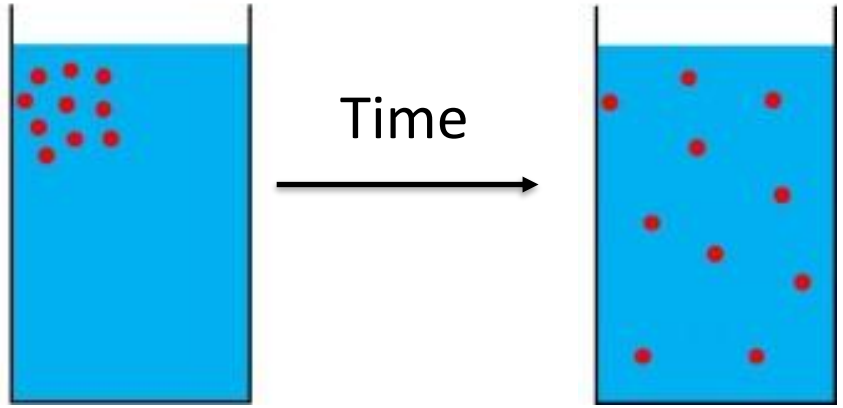


^{1}H with diffusion filter (large molecules only)





Diffusion of (macro)molecules



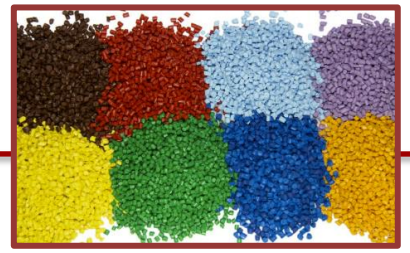
Diffusion - Brownian motion

- In solution, every (macro)molecule diffuse
- Speed of diffusion depend on different parameters, and the Stokes-Einstein equation give the value of the diffusion coefficient

$$D = \frac{kT}{6\pi\eta R_H}$$

Can be determined by NMR with a pulse field gradient method

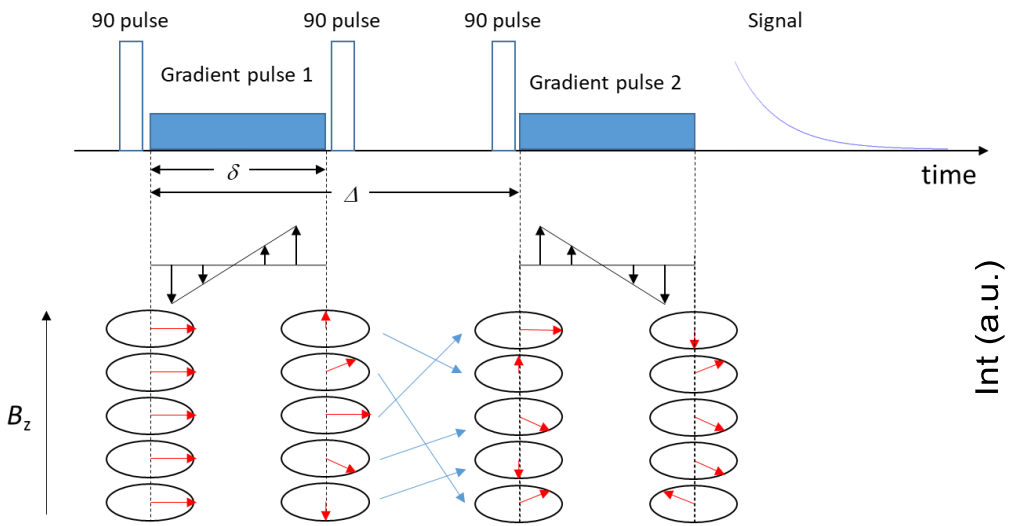
https://magritek.com/2016/07/10/gradients-in-nmr-spectroscopy-part-4-a-short-intermezzo-on-diffusion/

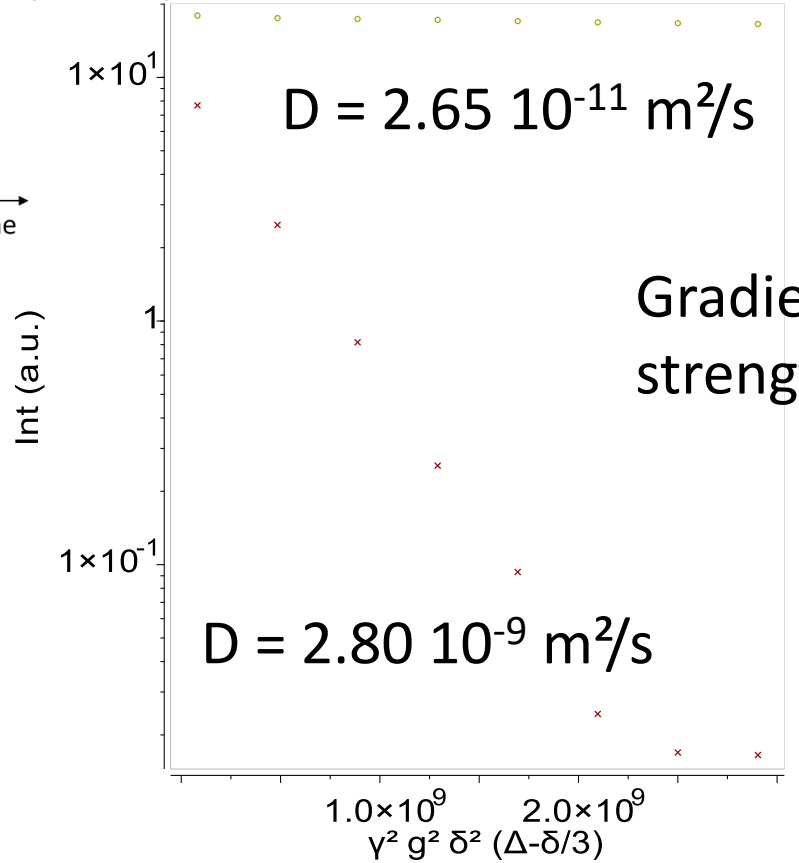


NMR method – pulse sequence

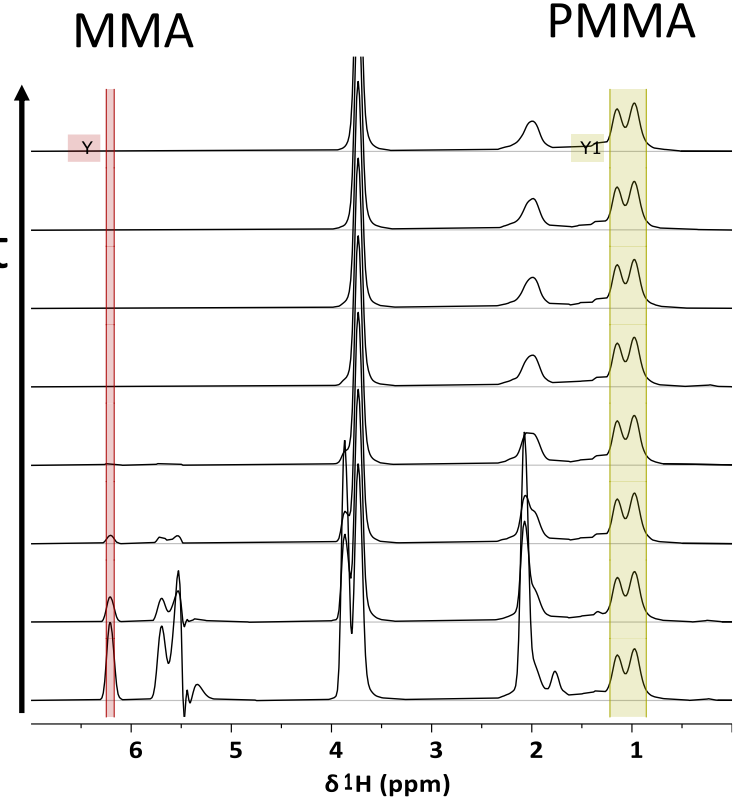
Sample: PMMA + MMA in CH_2Cl_2

Pulse sequence: Pulsed Gradient Stimulated Echo (PGSTE)





Gradient strength



Stejskal and Tanner equation

$$ln\left(\frac{S}{S_0}\right) = -D.\gamma^2.g^2.\delta^2.\left(\Delta - \frac{\delta}{3}\right)$$

Stejskal, E.O., and Tanner, J.E., *Chem. Phys*. **42**, 288 (1965).

How to connect D to MW?

Method – MW from diffusion coefficient

Stokes-Einstein equation

$$D = \frac{kT}{6\pi\eta R_H}$$

D: the diffusion coefficient
K: the Boltzmann constant
T: the absolute temperature
η: the solvent viscosity
R_H: the hydrodynamic radius

Rouse-Zimm model

$$R_H \sim bM^{\nu}$$

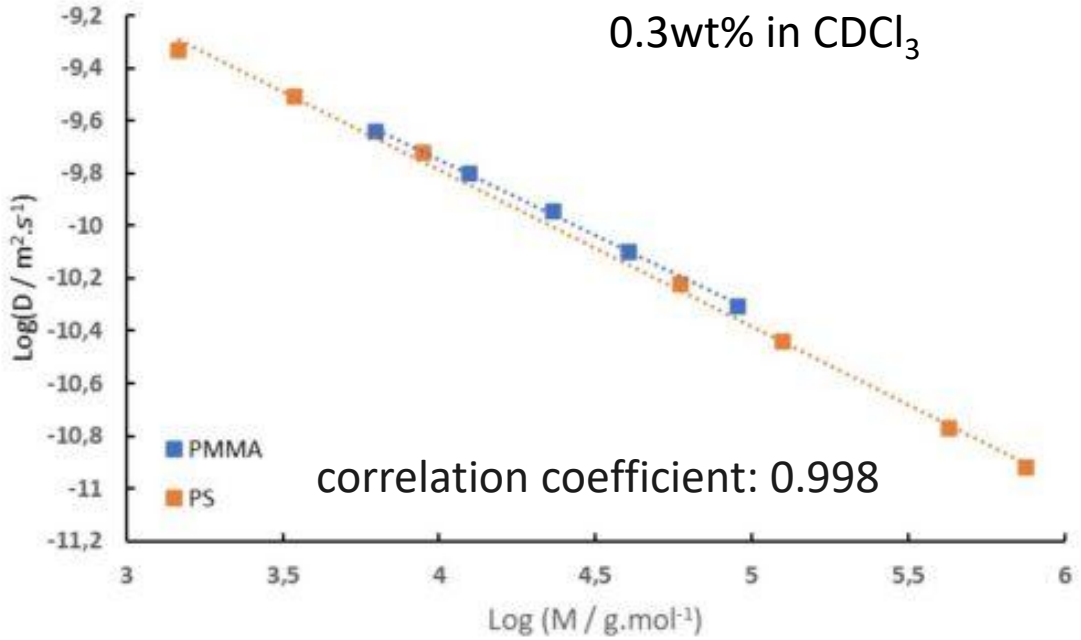
rewriting of the Stokes-Einstein equation (if T and η are constant)

$$D = b'M^{-\nu}$$

$$log(D) = log(b') - \nu\, log(M)$$

MW Determination of PS and PMMA via PFG

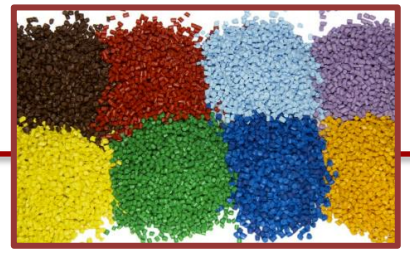
PS		PMMA	
MW (g/mol)	D (m²/s)	MW (g/mol)	D (m²/s)
1470	$4{,}64\ 10^{-10}$	6270	$2{,}29\ 10^{-10}$
3460	$3{,}12\ 10^{-10}$	12500	$1{,}58\ 10^{-10}$
8900	$1{,}89\ 10^{-10}$	23200	$1{,}13\ 10^{-10}$
58900	$6{,}02\ 10^{-11}$	40300	$7{,}96\ 10^{-11}$
125000	$3{,}63\ 10^{-11}$	90600	$4{,}92\ 10^{-11}$
426000	$1{,}69\ 10^{-11}$		
753000	$1{,}20\ 10^{-11}$		



δ = 10 ms; Δ = 300 ms; G = 50%; meas. time < 10 min

✓ **MW as high as 750 kg/mol**
✓ **D as low as 1.2 10^{-11} m²/s**
✓ **Far from the limit of the benchtop NMR**
✓ **Fast, less than 10 min**

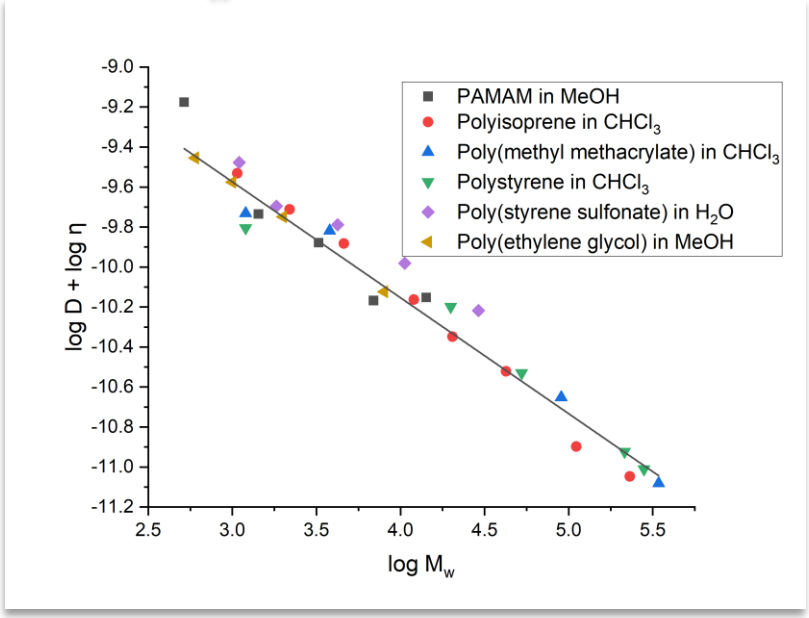
Fit the literature (determined on high field NMR) with the same concentration



Online polymer mass detector through diffusion NMR

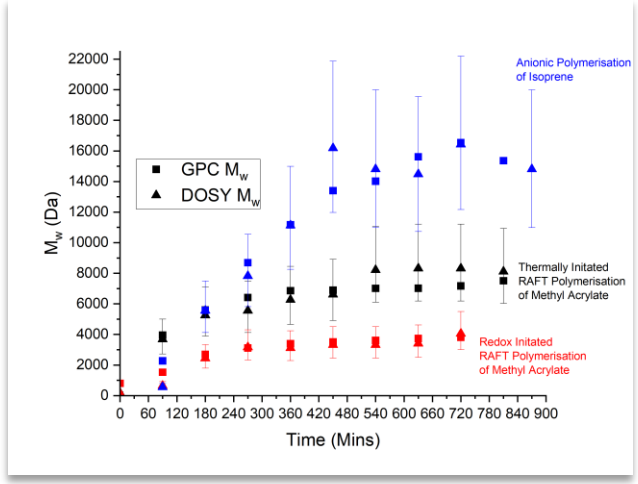
Calibrate

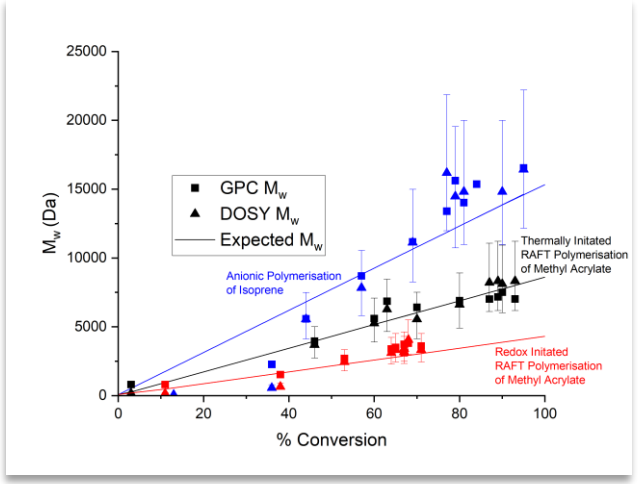
$$M_w = 10^{\frac{(logD+log\eta)+7.74}{-0.597}}$$



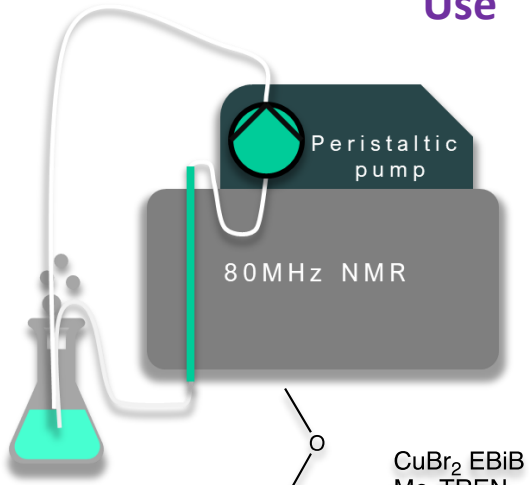
- Using a range of different polymer standards in different solvents and correcting for the solvent viscosity

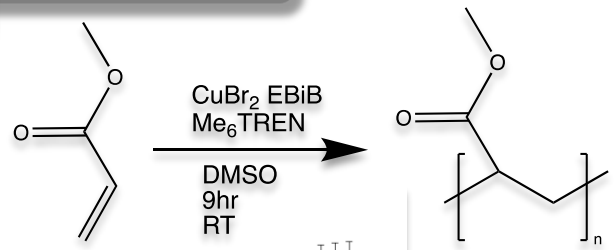
Compare with SEC-GPC

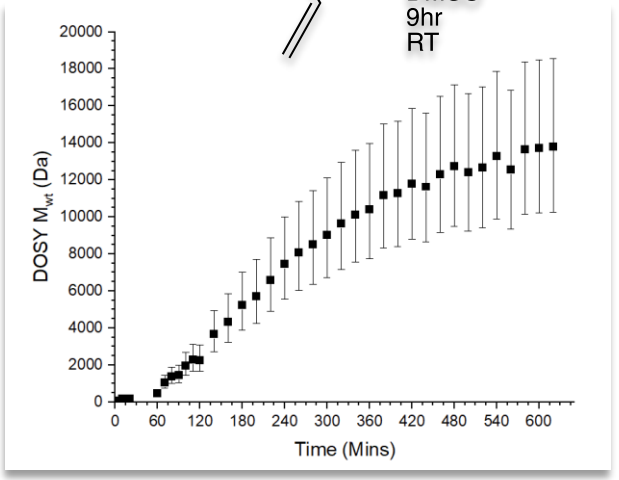




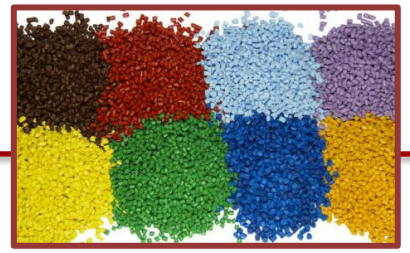
Use







MaDDOSY (Mass Determination Diffusion Ordered Spectroscopy) using an 80 MHz Bench Top NMR for the Rapid Determination of Polymer, Macromolecular Molecular Weight;
O. Tooley, W. Pointer, R. Radmall, M. Hall, V. Beyer, K. Stakem, T. Swift, J. Town, T. Junkers, P. Wilson, D. Lester, D. Haddleton, (2024) DOI: 10.1002/marc.202300692



D to M_{wt} calculator

Group Members ▶ Owen Tooley ▶ DOSY Molecular Weight Calculator

DOSY Molecular Weight Calculator

Calculate M_{wt} from DOSY

Please Consider Citing: https://doi.org/10.1002/marc.202300692

Diffusion Constant ($m^2 s^{-1}$):

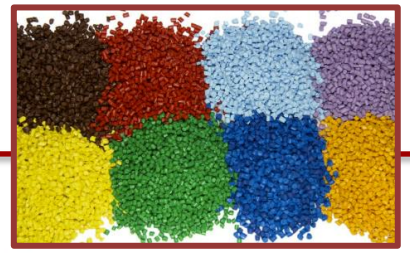
Solvent Bulk Viscosity (mPa.s):

Number of Scans:

Calculate

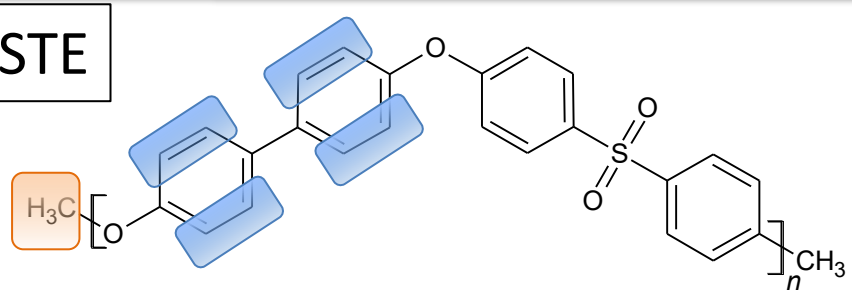
https://warwick.ac.uk/fac/sci/chemistry/research/haddleton/haddletongroup/meetthegroup/currentmembers/owentooley/dosymwtcalculator/

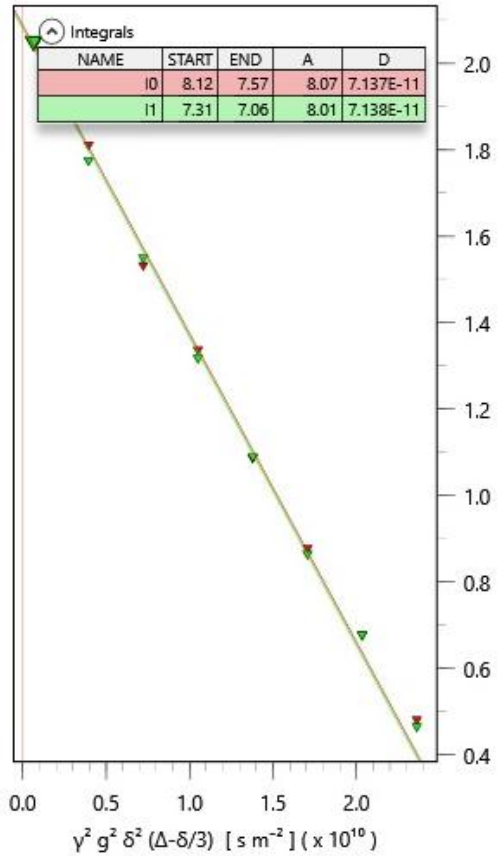
Polymers



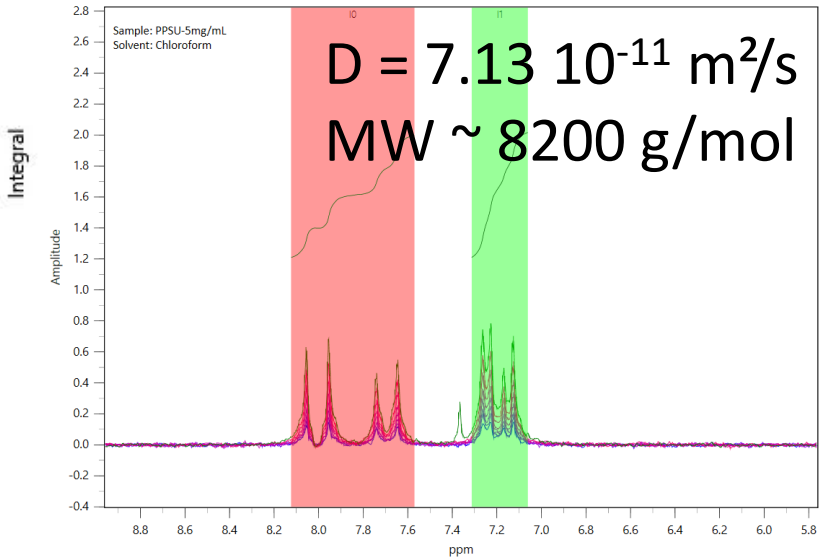
PPSU MW - end-group analysis vs PFG

PGSTE



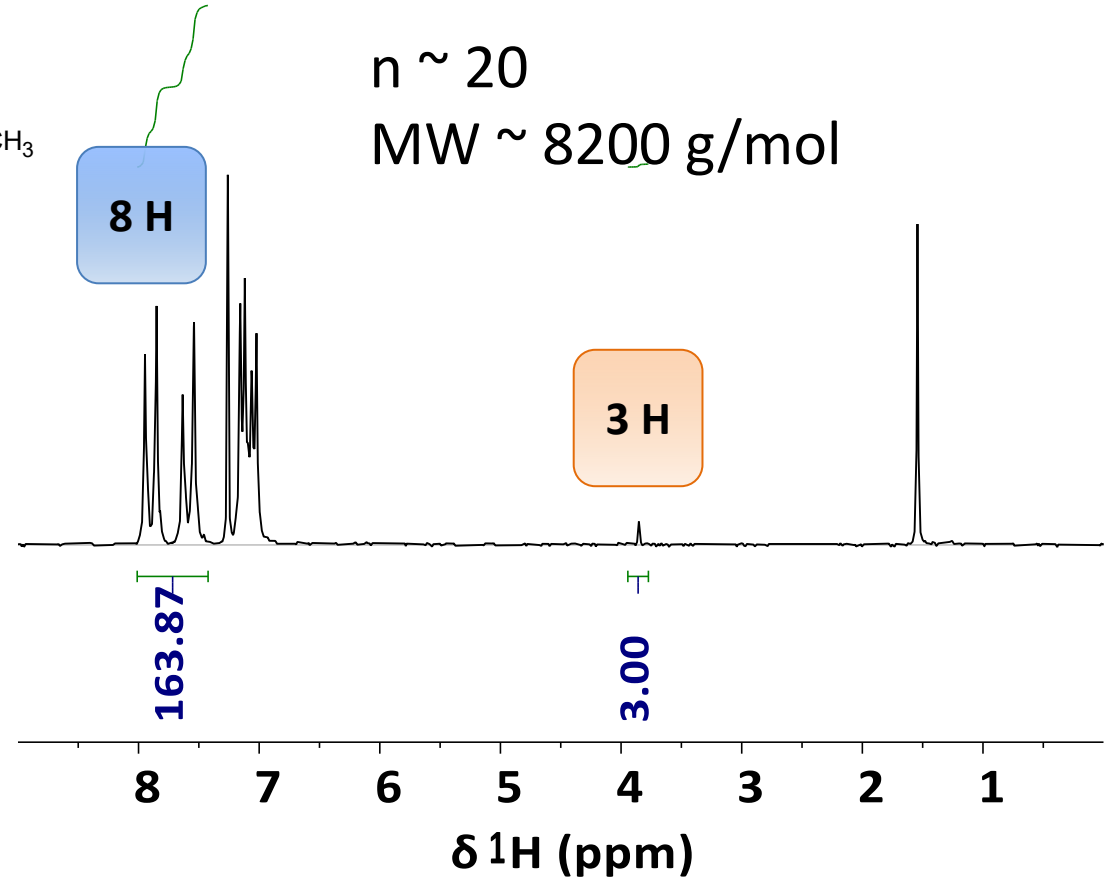


δ=5 ms; Δ=30 ms; G=75%



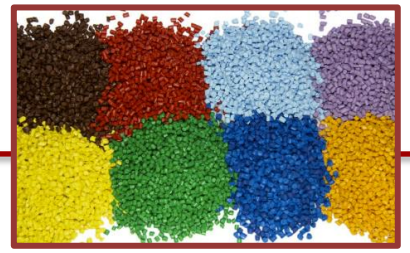
1D 1H - End-group analysis

n ~ 20
MW ~ 8200 g/mol

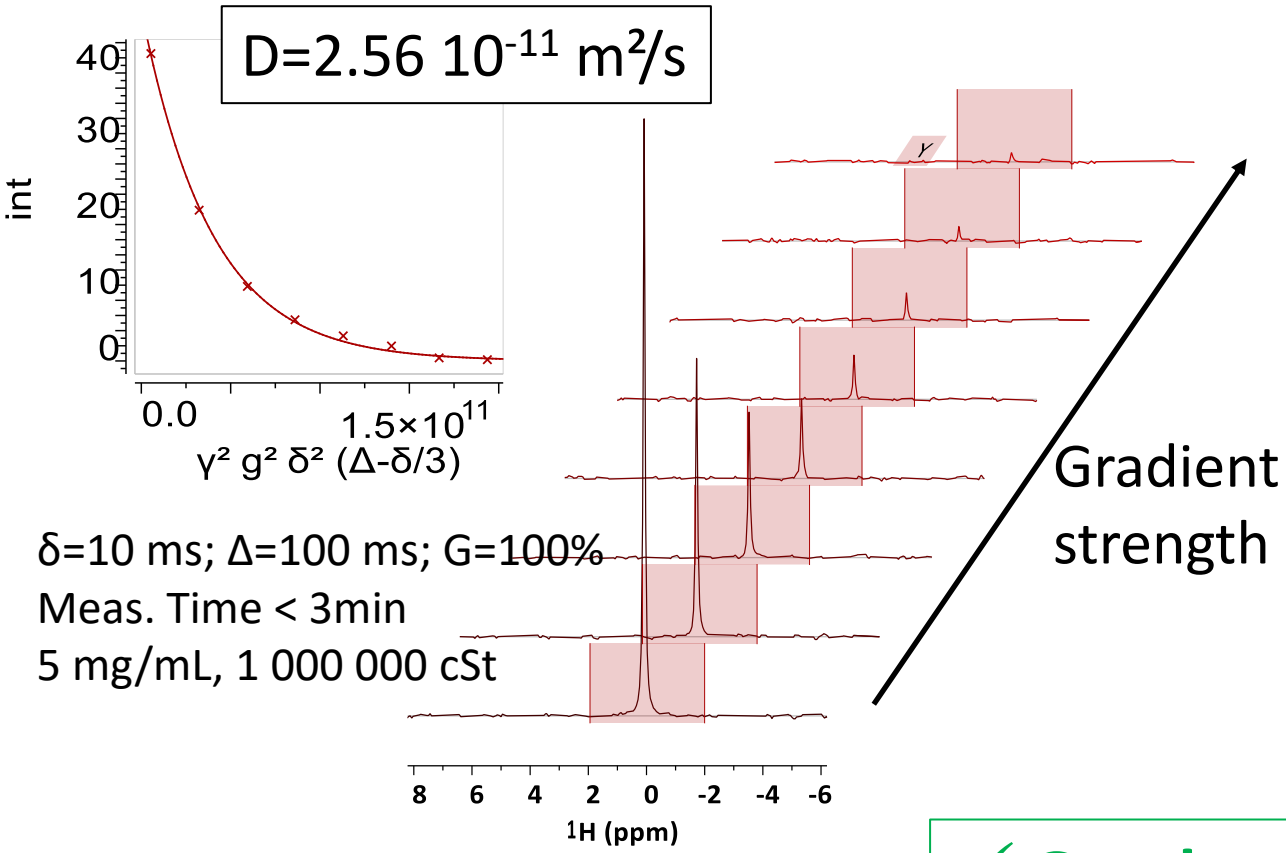


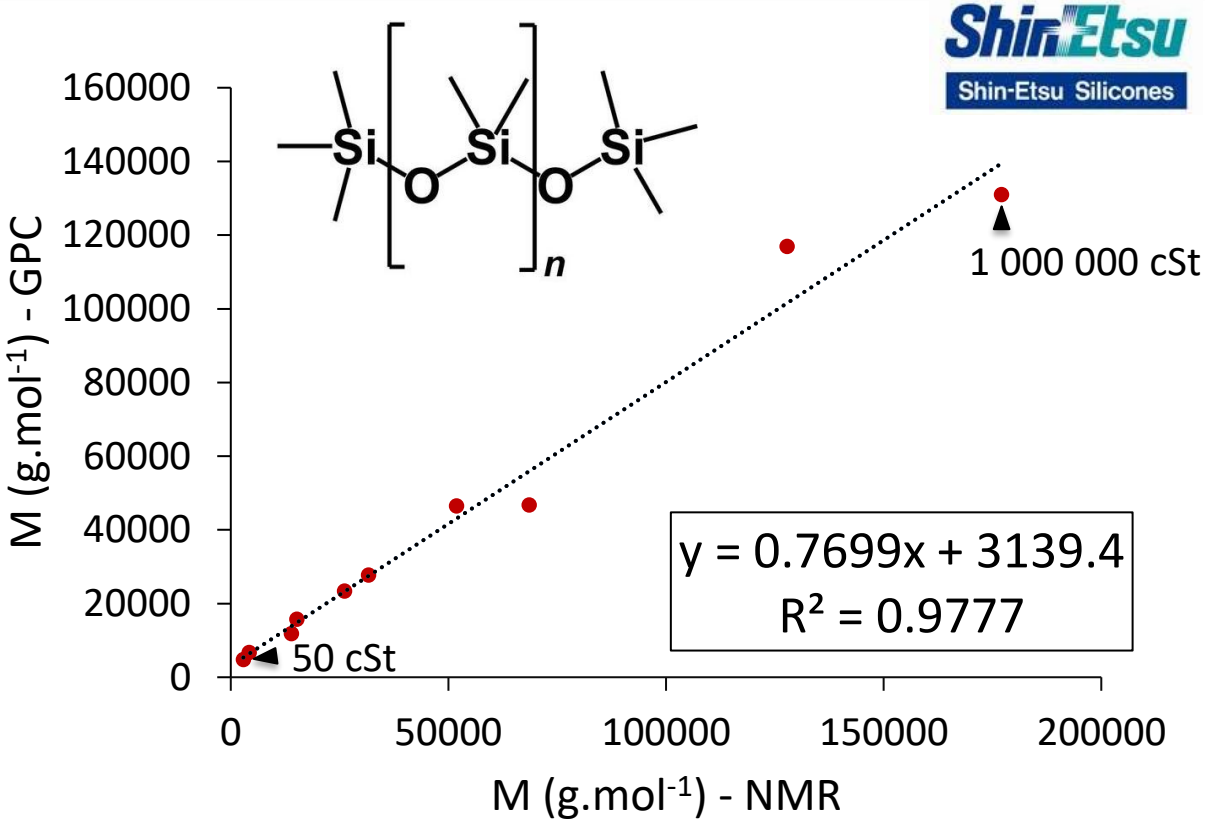
✓ Both method give the same MW
✓ Far from the limit of the benchtop NMR

https://magritek.com/wp-content/uploads/2025/01/App-Note-Polymer-MW-Calculation.pdf



PDMS MW - GPC vs PFG analysis





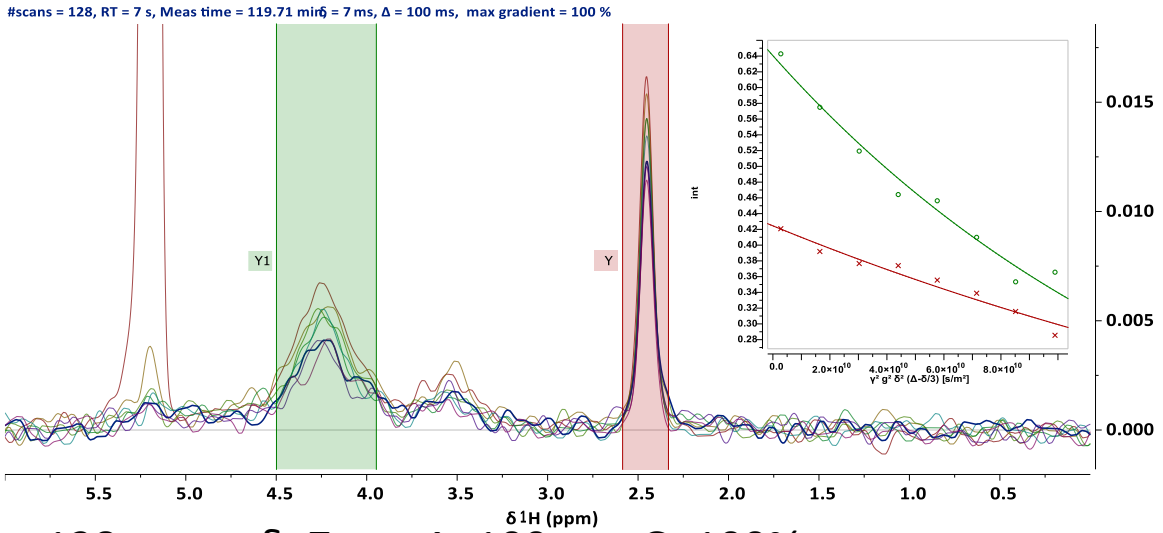
https://magritek.com/wp-content/uploads/2025/12/AppNote_Mw-determination-of-PDMS-by-diffusion_final-1.pdf

✓ Good correlation between GPC and NMR values

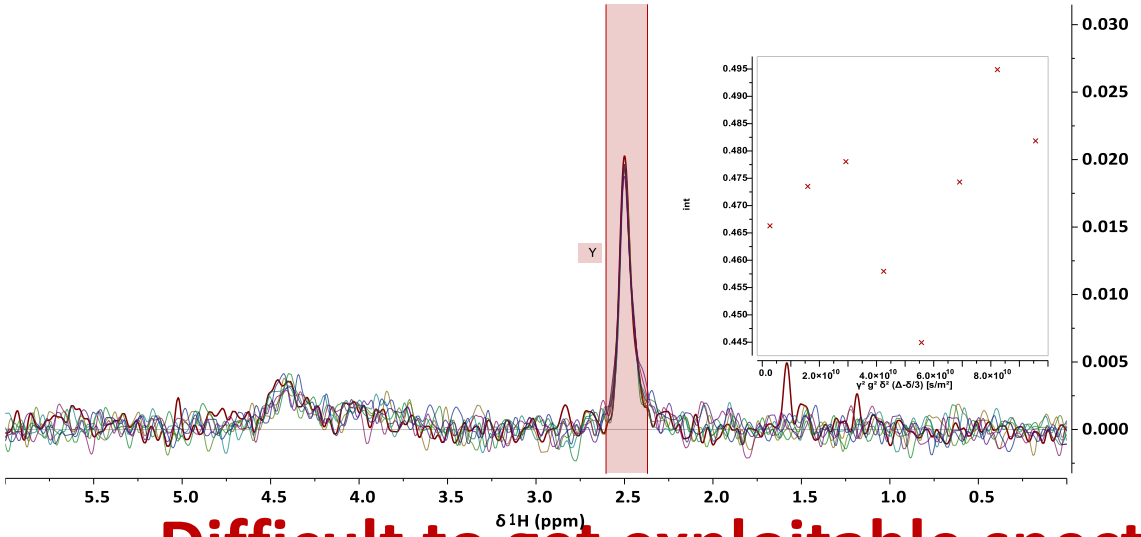
✓ Fast, 3 min measurement time

✓ Sustainable alternative, only 0.5 mL of Solvent

Natural polymer: chitosan



128 scans; δ=7 ms; Δ=100 ms; G=100%



MW = 105 kg/mol; C = 10 mg/mL in D_2O with 2% formic acid

$D = 3.50\ 10^{-12}\ m^2/s$

Higher MW of chitosan solution!

Difficult to get exploitable spectra to extract the diffusion coefficient

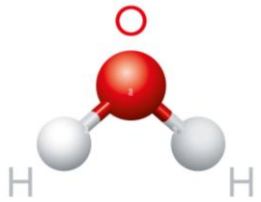
PFG at 60 °C

Advantages of higher T measurements:

- Solvent is less viscous

Bulk viscosity of H_2O		
	25 °C	0.89 mPa s
	60 °C	0.47 mPa s

- Brownian motion of a (macro)molecule in solution increase

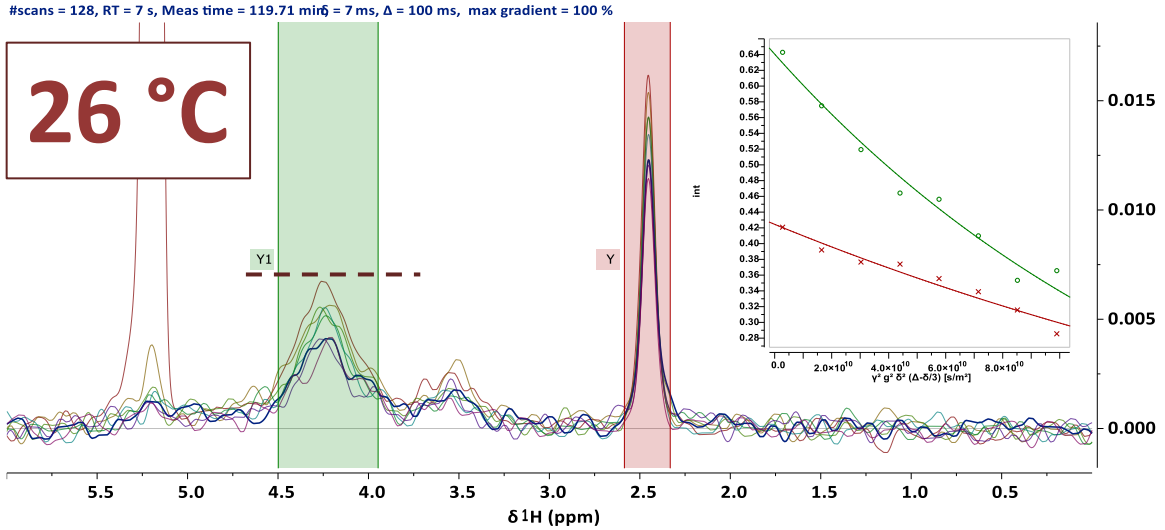


Diffusion coef. of water		
	25 °C	2.30 10^{-9} m²/s
	60 °C	4.70 10^{-9} m²/s

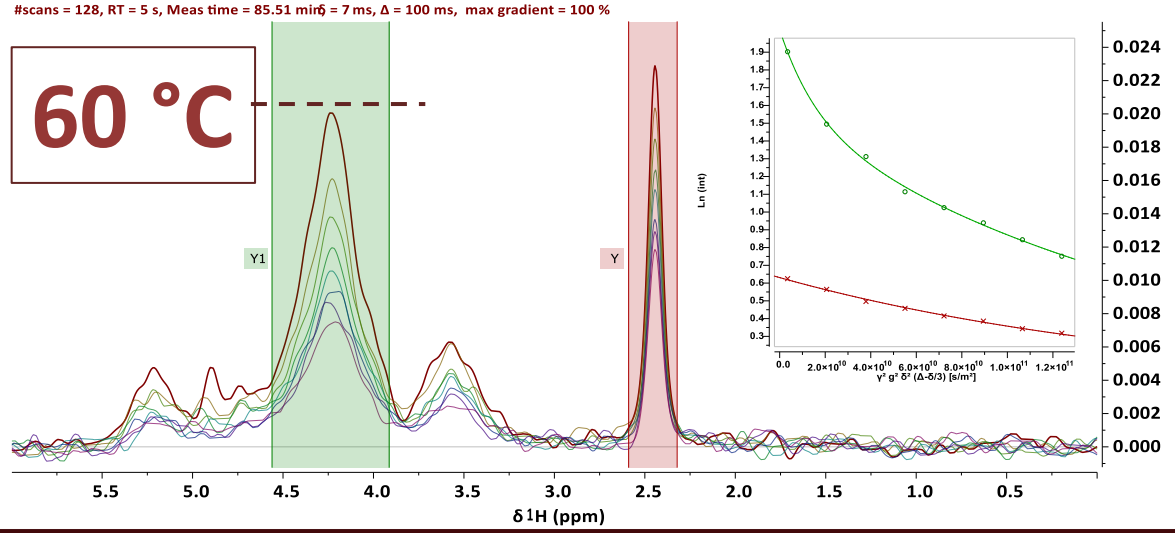
- Higher value of T_2 -> less signal loss due to T_2 effect

PFG of chitosan: 26 vs 60 °C

MW = 105 kg/mol; C = 10 mg/mL in D_2O with 2% formic acid



D = 3.50 10^{-12} m²/s

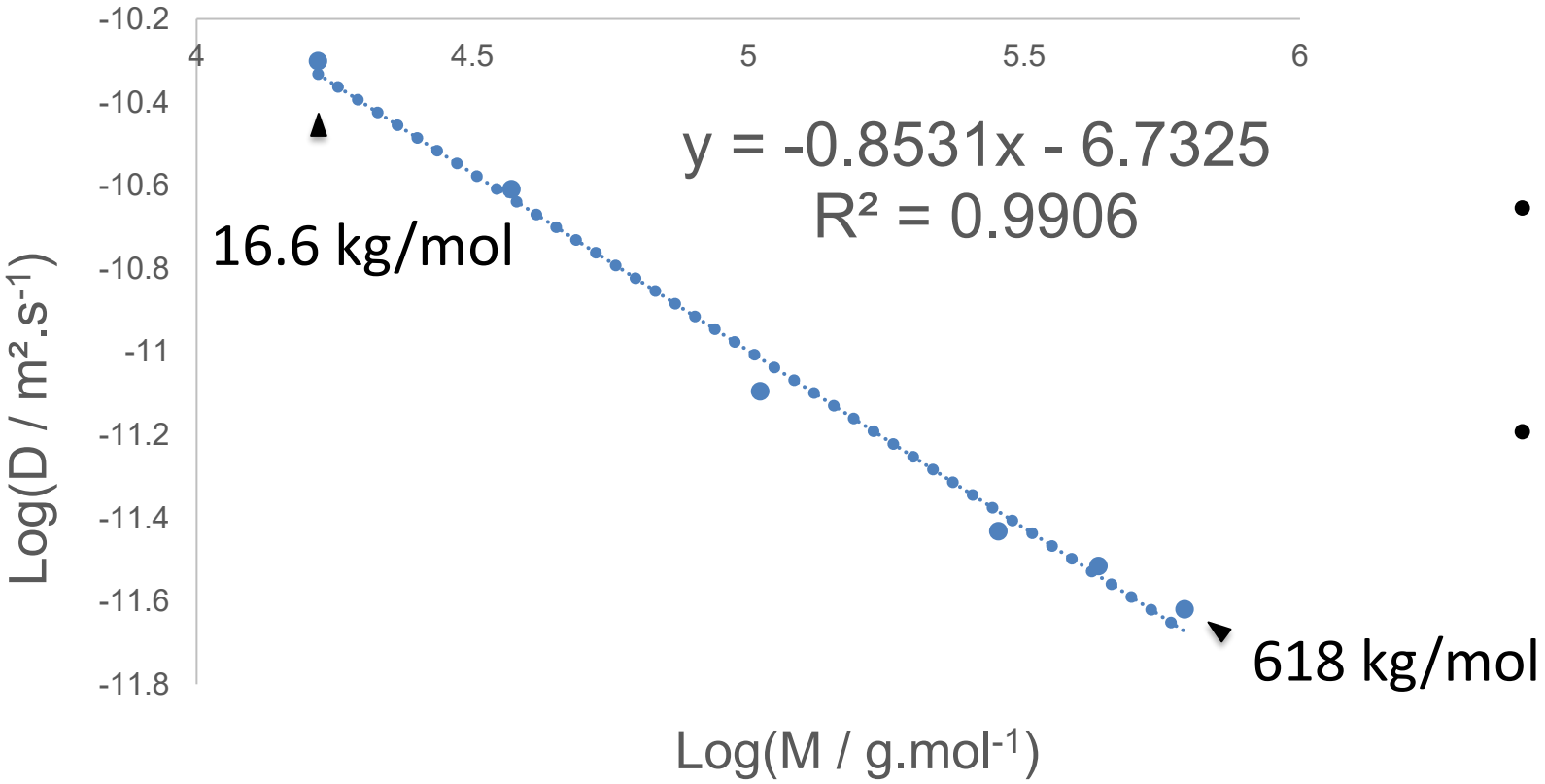


D = 5.70 10^{-12} m²/s

✓ Gained in signal intensity

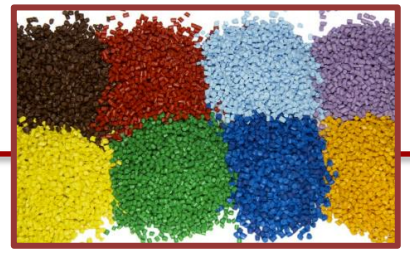
✓ Difference by a factor of 2 in the diffusion coefficient

Chitosan: PFG calibration curve

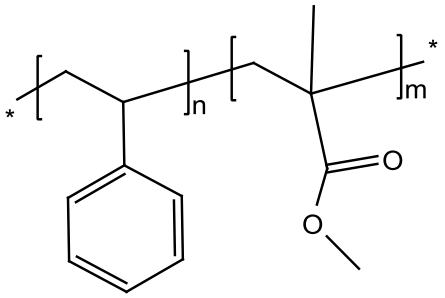


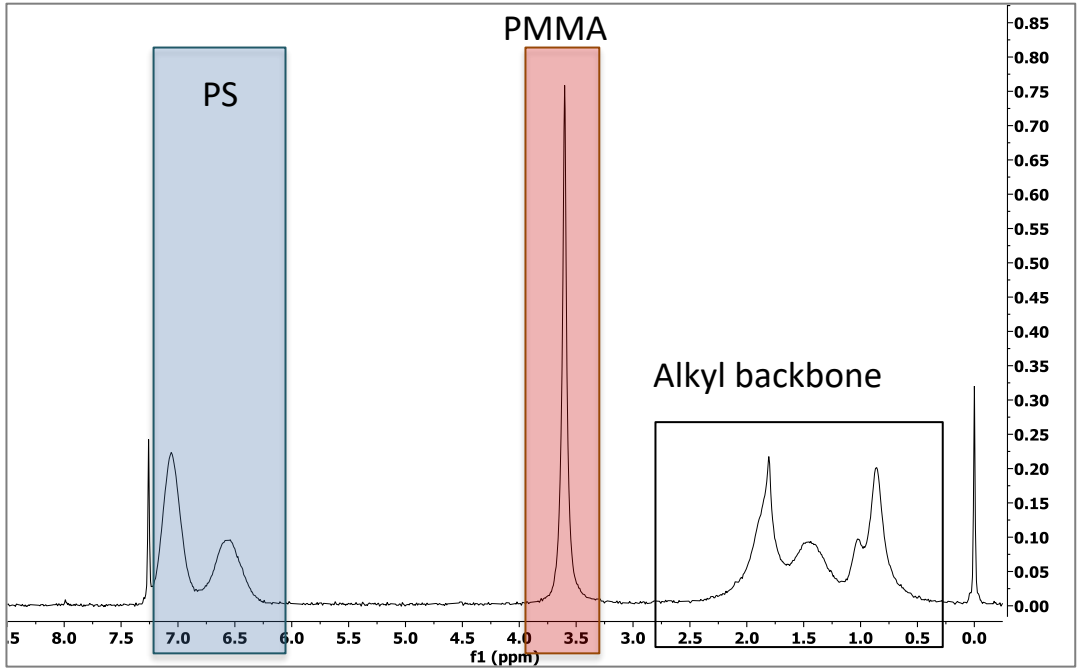
- Diffusion coefficient measured at 60 °C
- Average of 3 measurements

✓ **Possibility to build a calibration curve with chitosan standard**



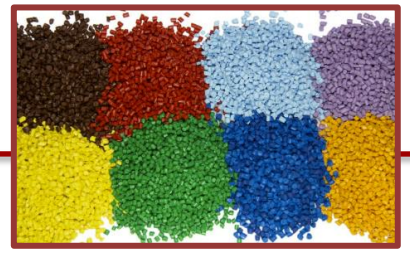
Quality of the copolymer/copolymerization



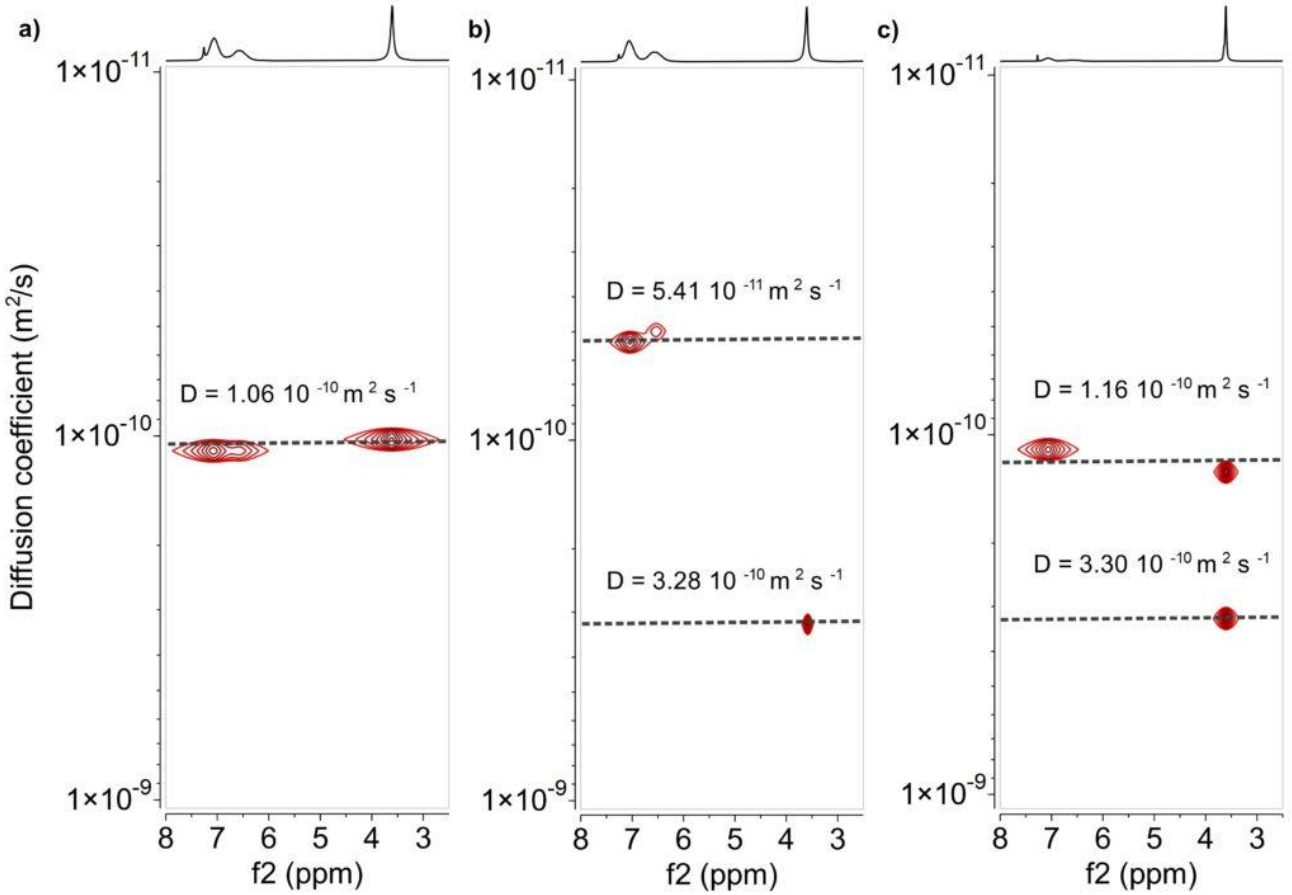


What do you have in your solution that 1D 1H does not reveal but DOSY does?

Only PS-*b*-PMMA Block copolymer?
PS homopolymer and PMMA homopolymer?
PS-*b*-PMMA Block copolymer and PMMA homopolymer?
…



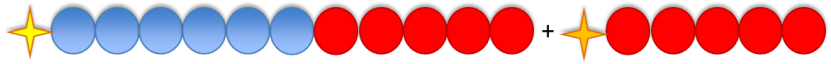
Quality check by diffusion measurements



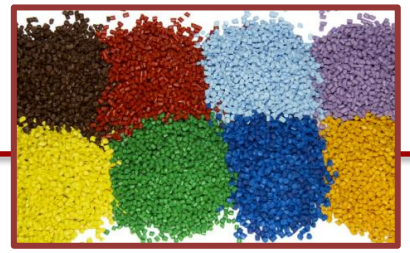
a)

b)

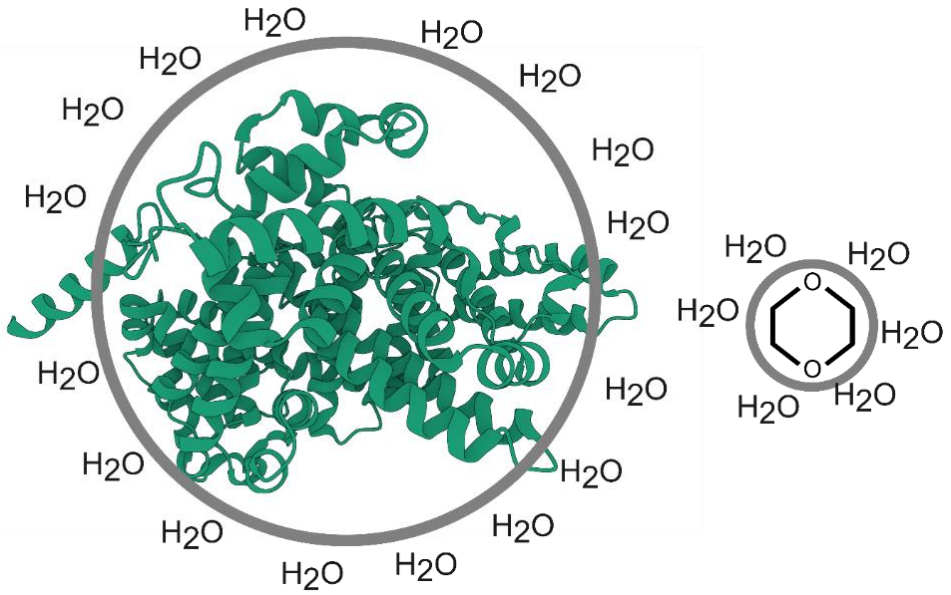
c)



https://magritek.com/2020/12/02/distinguishing-copolymers-and-polymer-blends-by-diffusion-ordered-spectroscopy-dosy/



Protein Radius of Hydration by Diffusion NMR



$$ln(I/I_0) = \gamma^2\delta^2 g^2[\Delta - \delta/3]D. [1]$$

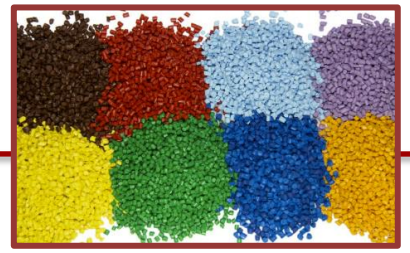
$$D = \frac{k_B T}{6\pi\eta R_H}$$

$$D_{standard}\ R_{H\ standard} = \frac{k_B T}{6\pi\eta} = D_{unknown}\ R_{H\ unknown}$$

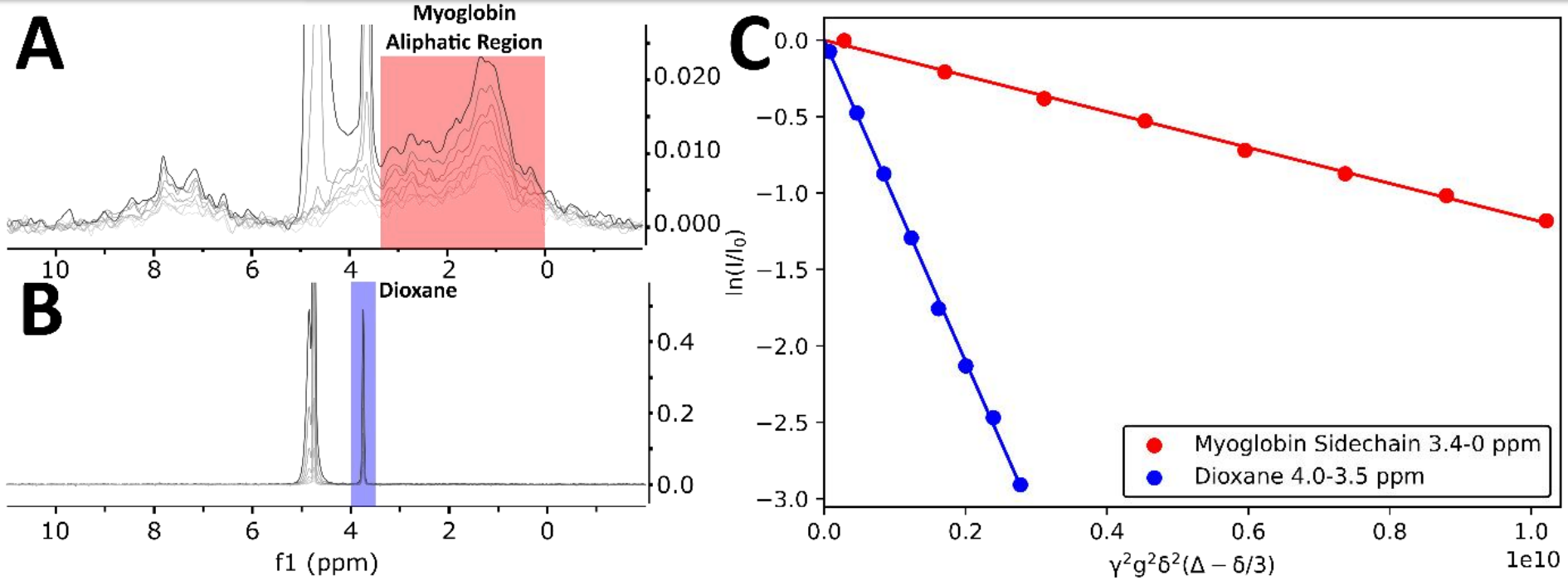
$$R_H = R_{H\ dioxane}\frac{D_{dioxane}}{D_{sample}}$$

Ínternal diffusion standard (dioxane) and protein -> same bulk solution properties

https://magritek.com/wp-content/uploads/2025/02/App-Note-Protein-Radius-of-Hydration.pdf



Protein Radius of Hydration by Diffusion NMR



Protein	Dioxane Diffusion	Protein Diffusion	R_H *	Literature R_H
Bovine Serum Albumin	$9.86 \times 10^{-10} m^2/s$	$6.12 \times 10^{-11} m^2/s$	35 ± 1 Å	37.4 Å [5]
Equine Heart Myoglobin	$1.05 \times 10^{-9} m^2/s$	$1.17 \times 10^{-10} m^2/s$	19.4 ± 0.2 Å	20.4 Å [8]

https://magritek.com/wp-content/uploads/2025/02/App-Note-Protein-Radius-of-Hydration.pdf

Benchtop NMR applications





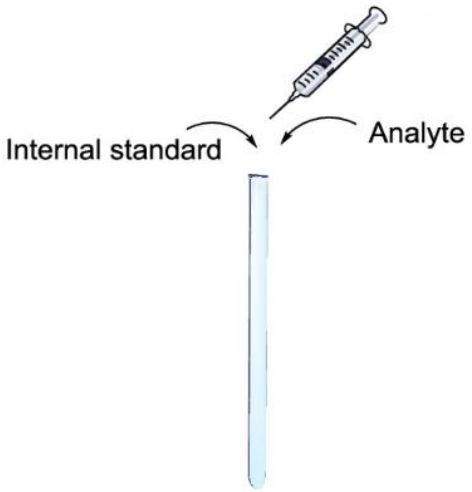
Synthesis	Pharma	Macromolecules	Education	Flow chemistry




Batteries	Food & Agriculture	Forensics	Analytics

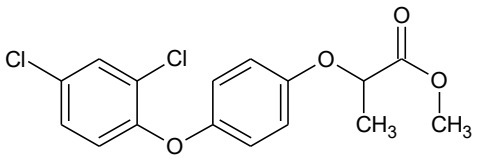
Absolute quantification (assay) with internal standard

- NMR is typically used to measure product assay with the use of an internal standard



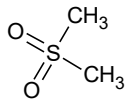
- Access to the assay (not purity) of the compound

Diclofop-methyl

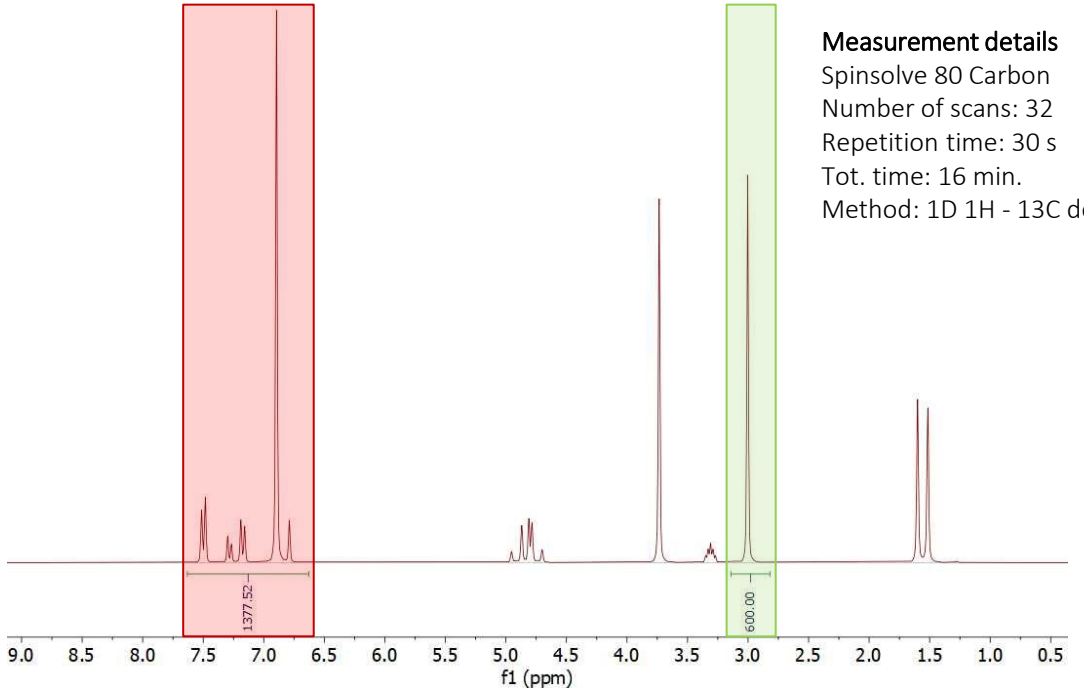


Molecular Formula: $C_{16}H_{14}Cl_2O_4$
Formula Weight: 341.18

Dimethyl sulfone



Molecular Formula: $C_2H_6O_2S$
Formula Weight: 94.13284



Measurement details
Spinsolve 80 Carbon
Number of scans: 32
Repetition time: 30 s
Tot. time: 16 min.
Method: 1D 1H - 13C dec.

HPC Standards GmbH

The HPC Standards GmbH is a Manufacturer and distributor of high-purity analytical standards for residue analysis.

Sample preparation details

Diclofop-methyl:	34.9 mg
Internal std (Dimethyl sulfone):	4.9 mg
Solvent (MeOH-d4):	1 mL
Sample volume:	500 µL

Concentrations:

Diclofop-methyl	100 mM
DMS	50 mM

$$Assay_{Prod}[\%] = \frac{Assay_{Std}}{100}\frac{W_{Std}}{M_{Std}}\frac{M_{Prod}}{W_{Prod}}\frac{Int_{Prod}}{Int_{Std}}\frac{N_{Std}}{N_{Prod}}$$

$$Assay_{Prod}[\%] = 99.7\ \%$$

https://magritek.com/2020/12/04/quantitative-nmr-with-internal-standard-on-a-spinsolve-benchtop-nmr-spectrometer/

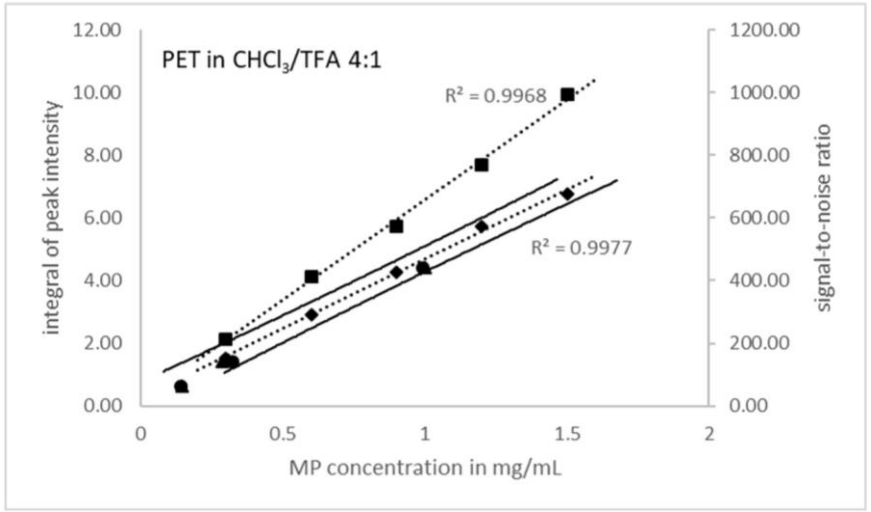
Microplastics quantification

RESEARCH ARTICLE | Open Access

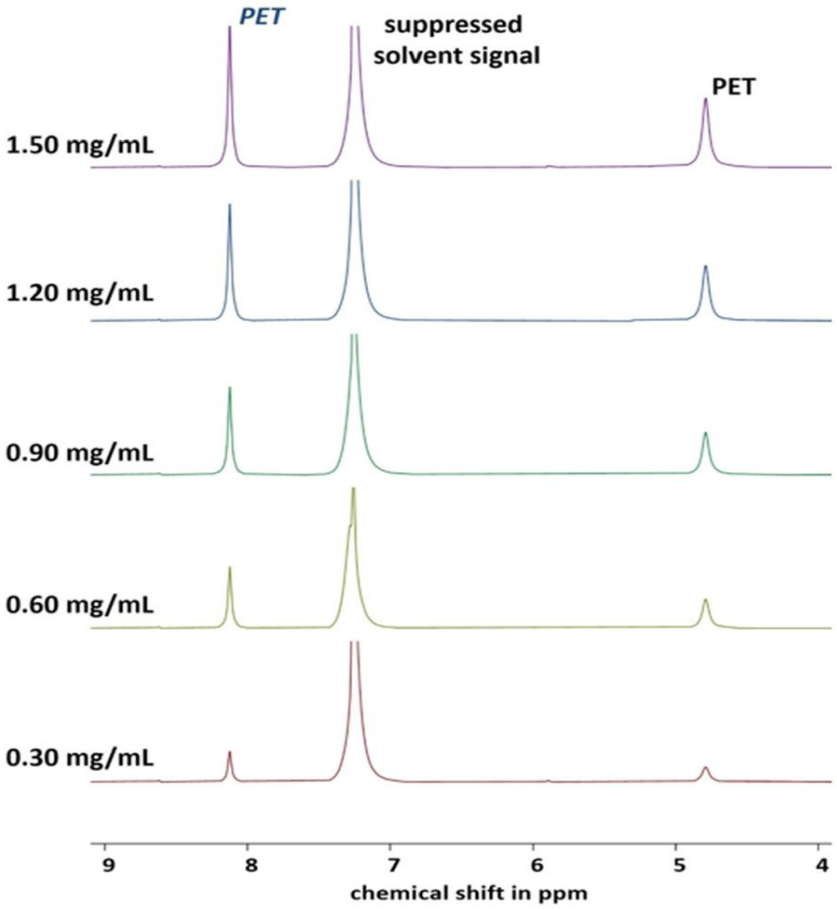
Applicable and cost-efficient microplastic analysis by quantitative ^{1}H-NMR spectroscopy using benchtop NMR and NoD methods

Nadine Peez, Torsten Rinesch, Jürgen Kolz, Wolfgang Imhof

First published: 20 August 2021 | https://doi.org/10.1002/mrc.5210



- External qNMR method



^{1}H-NMR stack plot of 5 different concentrations (0.25–1.5 mg/ml)

Nadine Peez, Torsten Rinesch, Jürgen Kolz and Wolfgang Imhof; *Magnetic Resonance in Chemistry*; (2021); DOI: 10.1002/mrc.5210

Microplastics quantification

	LOD
PET	4 µg/ml (29.87 min)
PVC	19 µg/ml (136.52 min)
PS	21 µg/ml (34.13 min)
	LOQ
PET	12 µg/ml (29.87 min)
PVC	57 µg/ml (136.52 min)
PS	64 µg/ml (34.13 min)

- Routine analysis of environmental samples
- No cleaning step between samples
- Competitive against thermoanalytical methods like Thermal Extraction - Desorption Gas Chromatography Mass Spectrometry (TED-GC-MS), pyrolysis-GCMS, and Thermogravimetry Gas Chromatography Mass Spectrometry (TGA-GC-MS)) and even
- Faster than spectroscopic methods (FTIR and Raman), which take up to 1 day

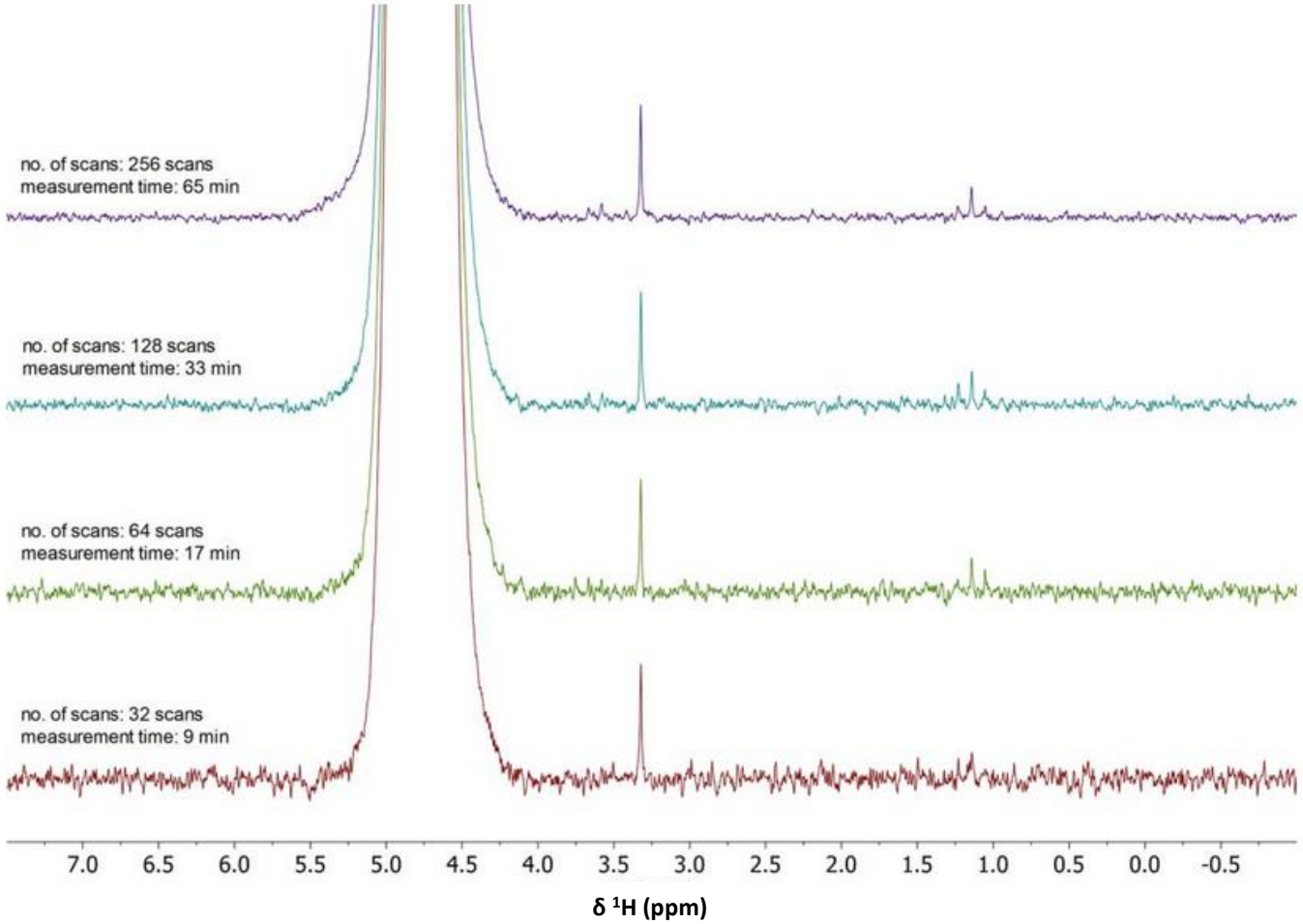
Nadine Peez, Torsten Rinesch, Jürgen Kolz and Wolfgang Imhof; *Magnetic Resonance in Chemistry*; (2021); DOI: 10.1002/mrc.5210

Solvent traces quantification

- 1D ^{1}H (PRESAT)
- 10 ppm MeOH/EtOH in H_2O
- Spinsolve 80 ULTRA

$$c(\mathrm{LOD}, MeOH) = \frac{3}{4.29749} = 0.70\ ppm = 22\ \mu M$$

$$c(\mathrm{LOD}, EtOH) = \frac{3}{1.32488} = 2.26\ ppm = 50\ \mu M$$



Free resources available online: https://magritek.com/2020/11/23/1h-nmr-presat-stack-plot-of-10-ppm-meoh-etoh-in-h2o/

Residual solvent quantification in API sample

Quantitative T2-filter NMR protocol for residual solvent trace quantification (in the ppm order of magnitude)

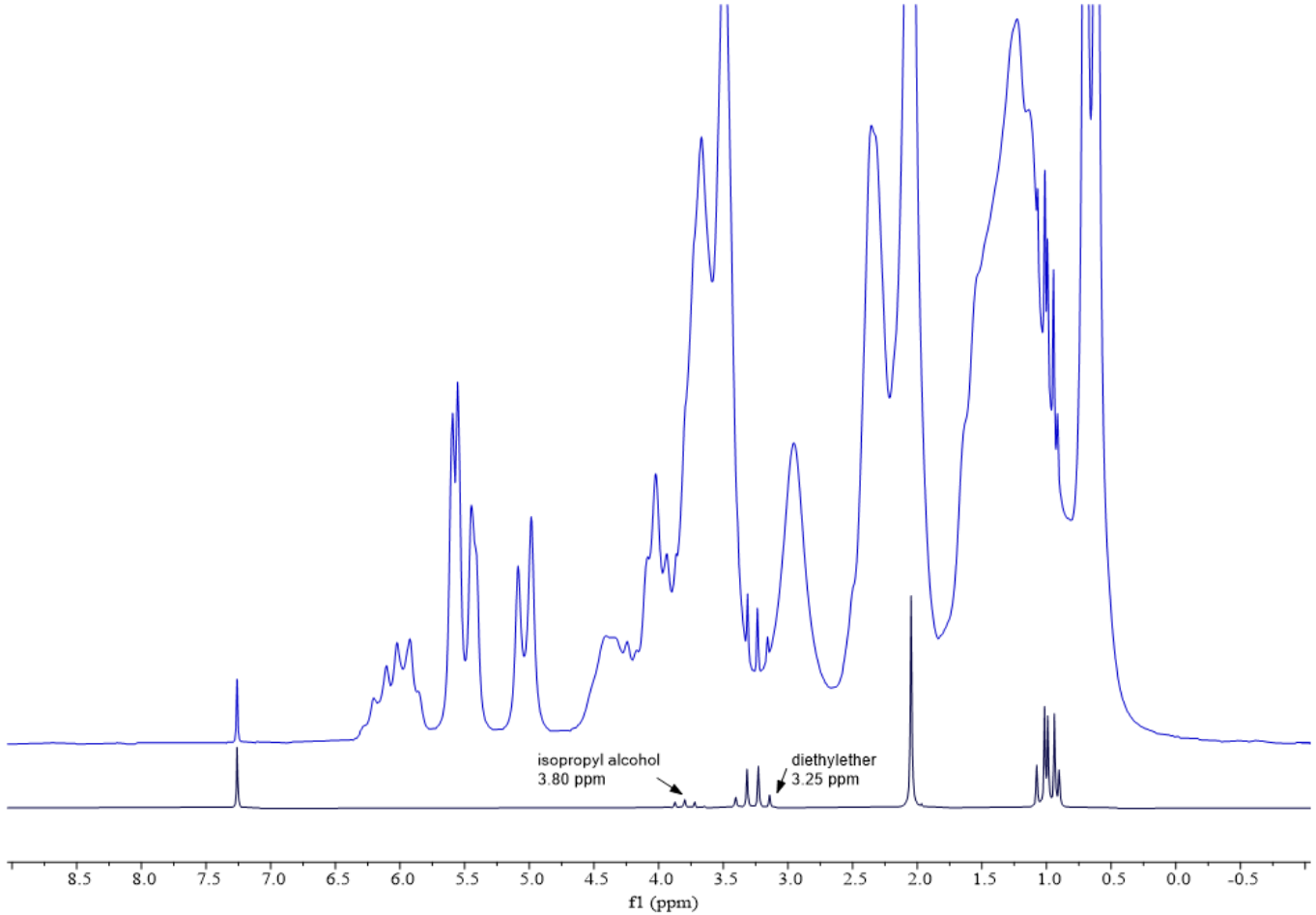


Figure 1: Stacked spectra of the API scaffold without (blue) and with (black) the relaxation filter applied before the NMR protocol.

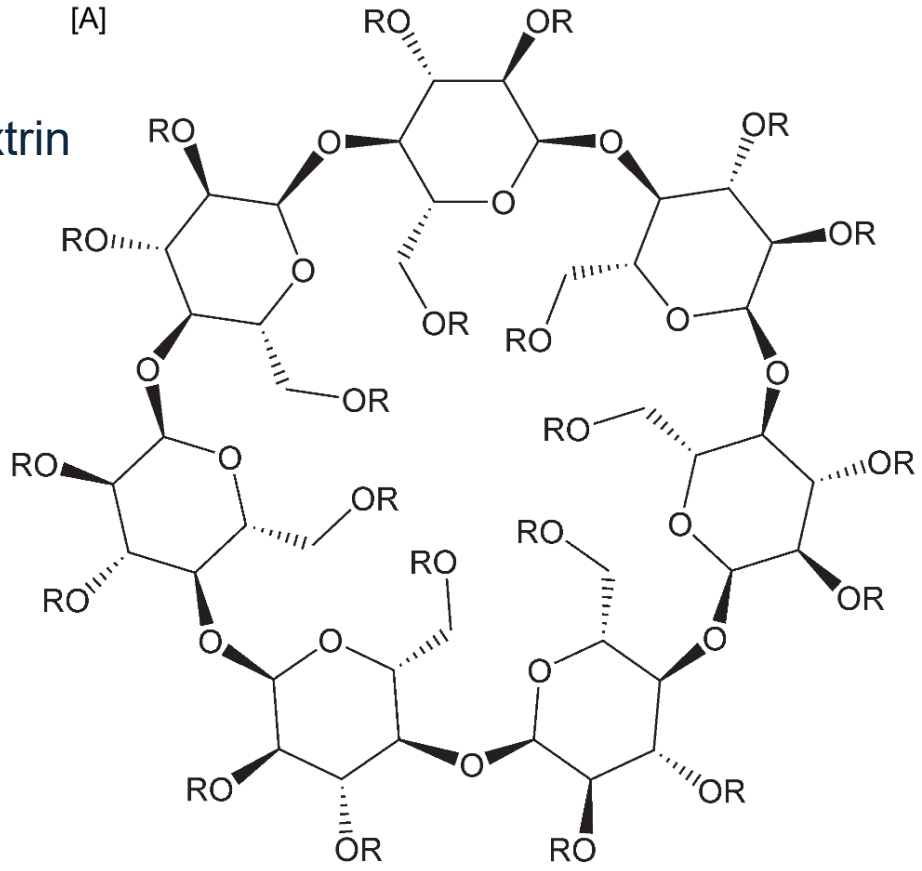
Free resources available online: https://magritek.com/2023/12/08/quantifying-residual-solvents-in-active-pharmaceutical-ingredients/

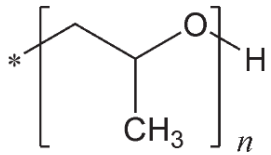
Pharma

Cyclodextrin Drug Inclusion

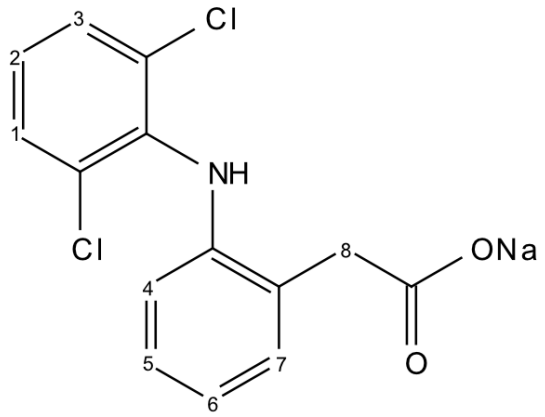
2-hydroxylpropyl-β-cyclodextrin

[A]

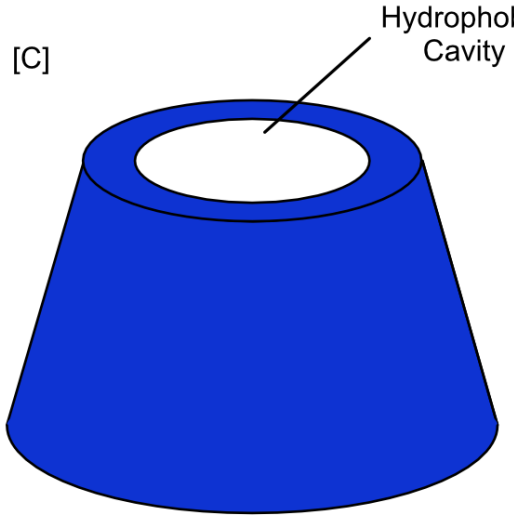


R =  or -H

sodium diclofenac



[C]



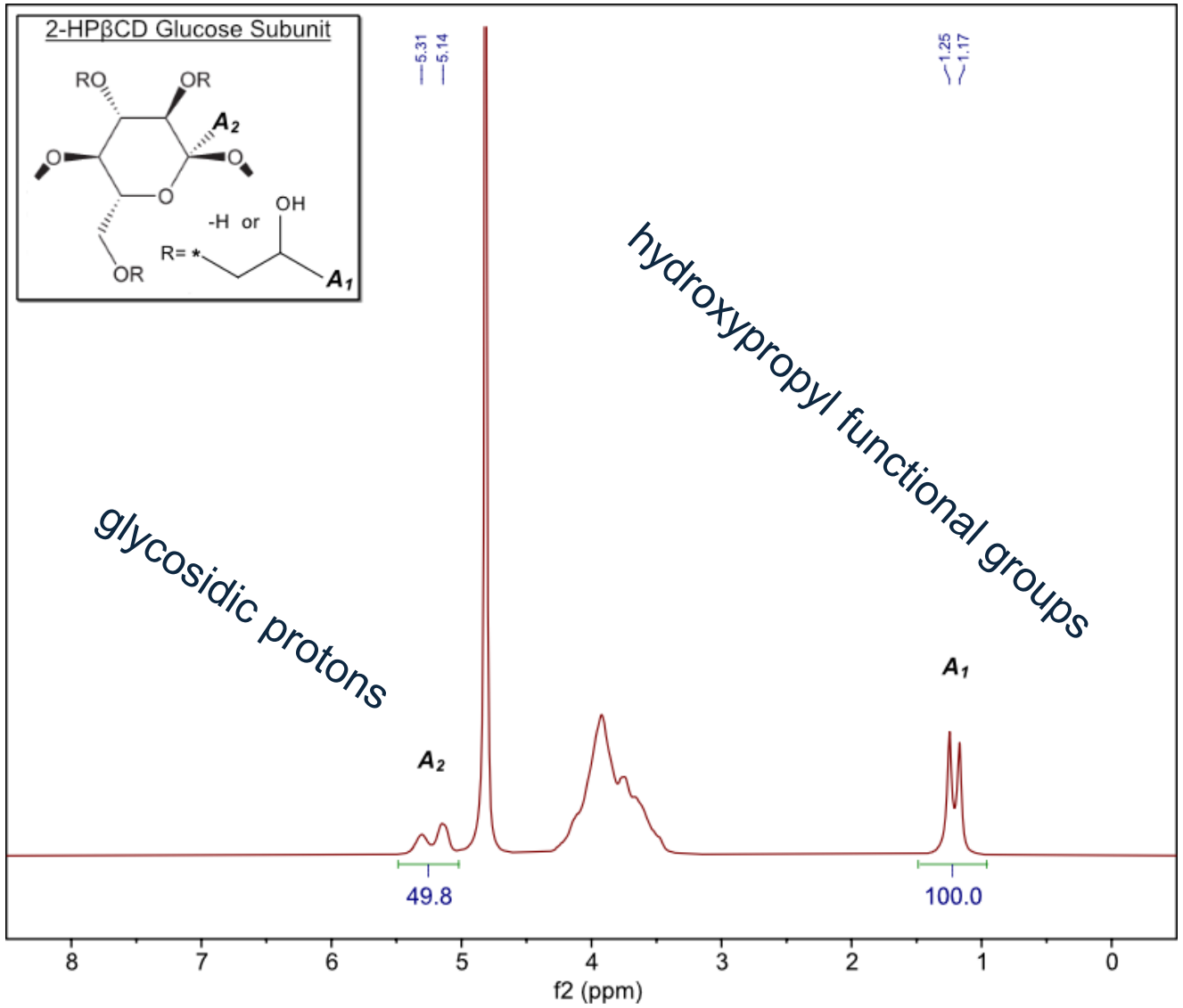
Challenge: rapid and reliable confirmation of inclusion complex formation and geometry during early-stage screening.

Pharma

Molar Substitution Determination of 2-HP-B-CD

$$MS = \frac{A_1}{3 \times A_2}$$

MS = 0.67
Labeling: MS=0.7

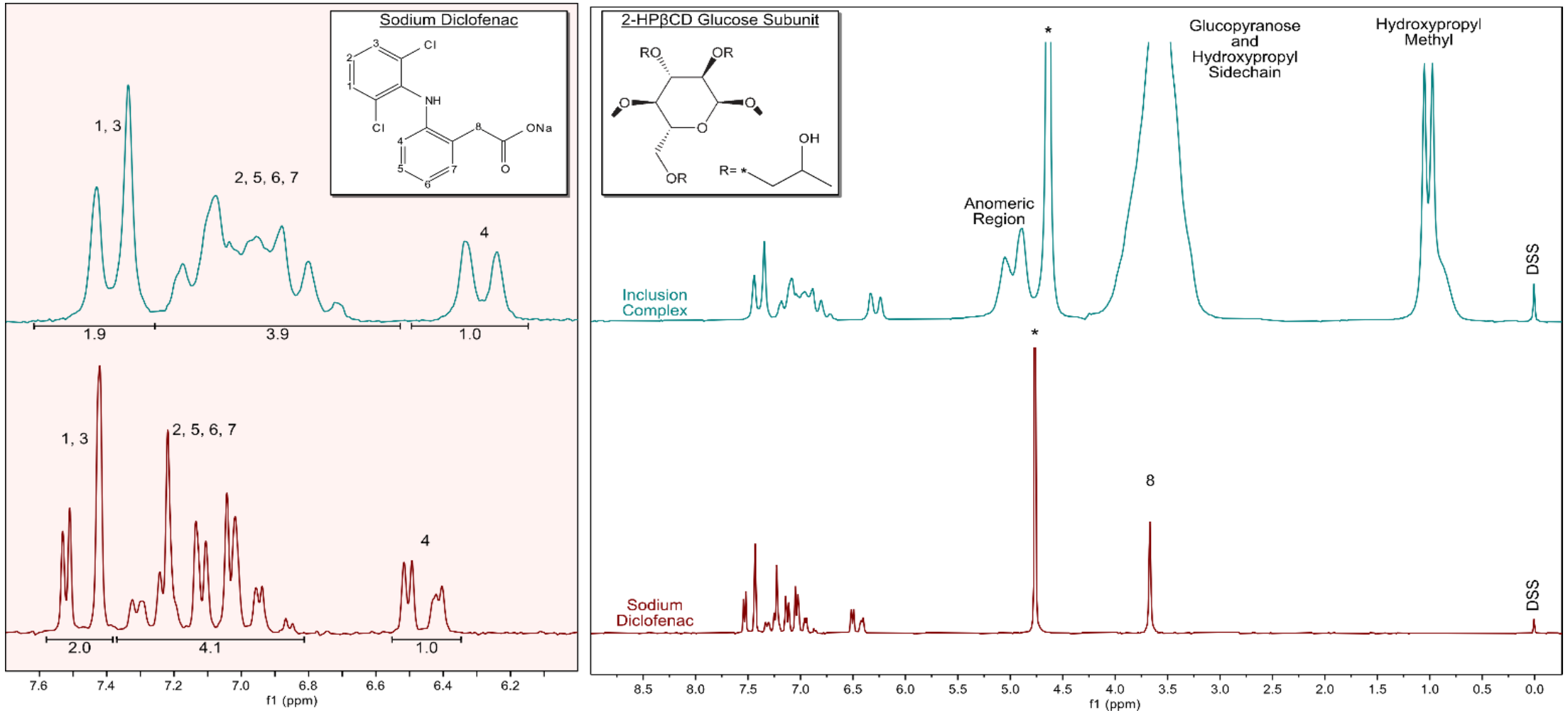


Pharma

1D 1H Spectroscopy as an Inclusion Screening Tool

magritek
www.magritek.com

75 mg of sodium diclofenac was added to 1 mL of D_2O, heated to 60 °C, and stirred while 160 mg of 2-HPβCD in 2 mL of D_2O was added dropwise over 5 minutes

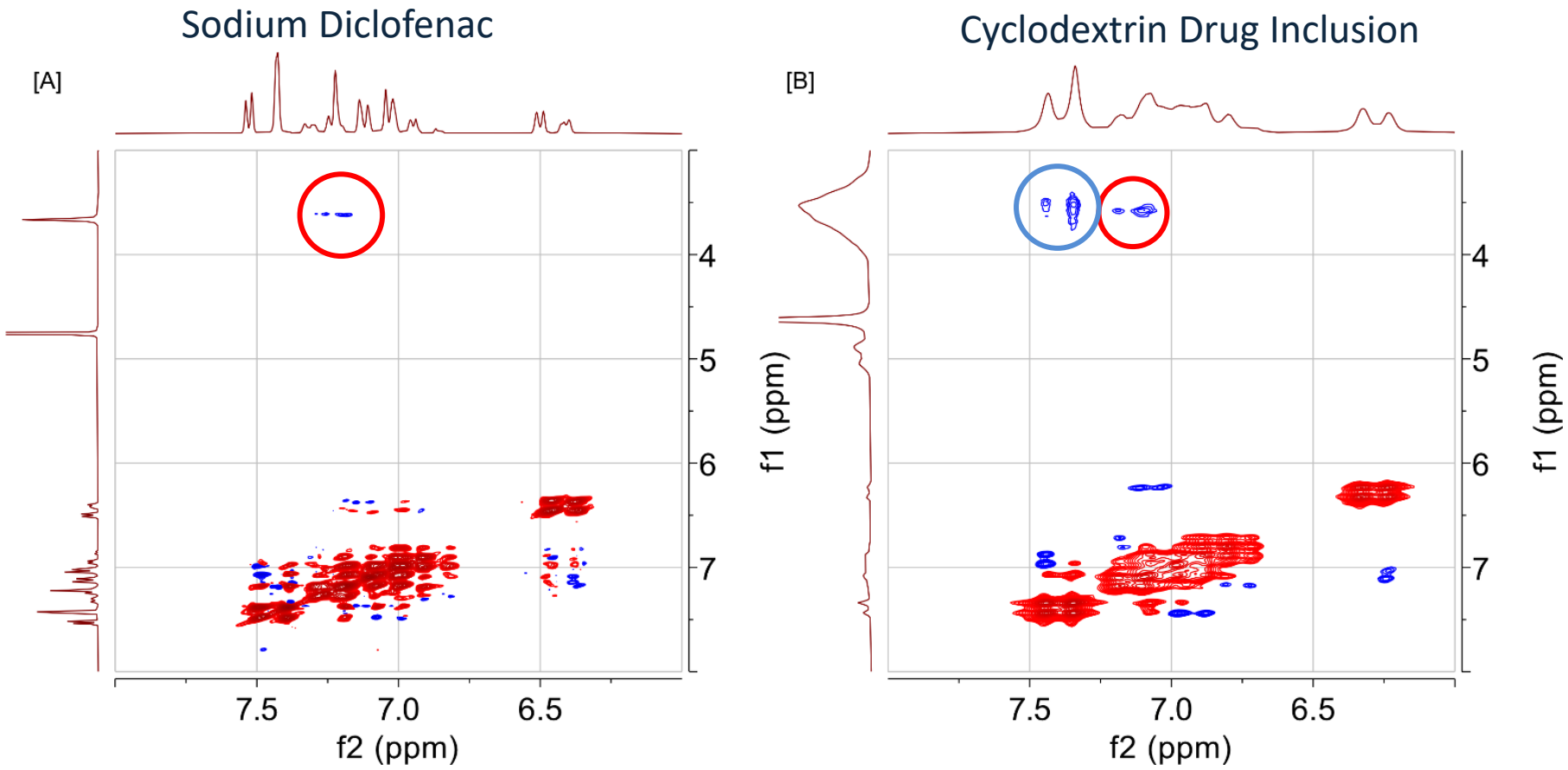


Pharma

Through-space 2D NMR technique : ROESY

Red circle: intramolecular coupling between the methylene protons (3.7 ppm) and aromatic protons (7.3 ppm)

Blue circle: coupling between the 2-HPβCD cavity protons (3.6 ppm) and the sodium diclofenac H-1 and H-3 protons (7.4 ppm)



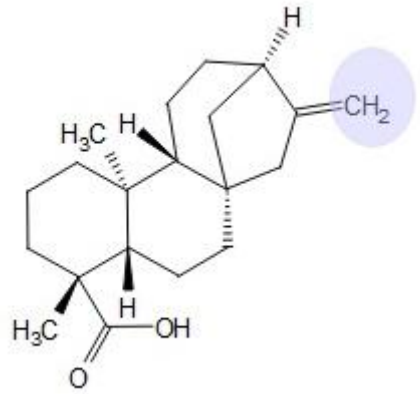
- ✓ Rapidly assessing drug product inclusion complexes
- ✓ Further work to quantify binding interactions (e.g., via NMR titration)
- ✓ Directly in the formulation laboratory, on the bench

Pharma

Quantitation by $^{1}H,^{13}C$ HSQC of Kaurenoic Acid in Copaiba Extracts

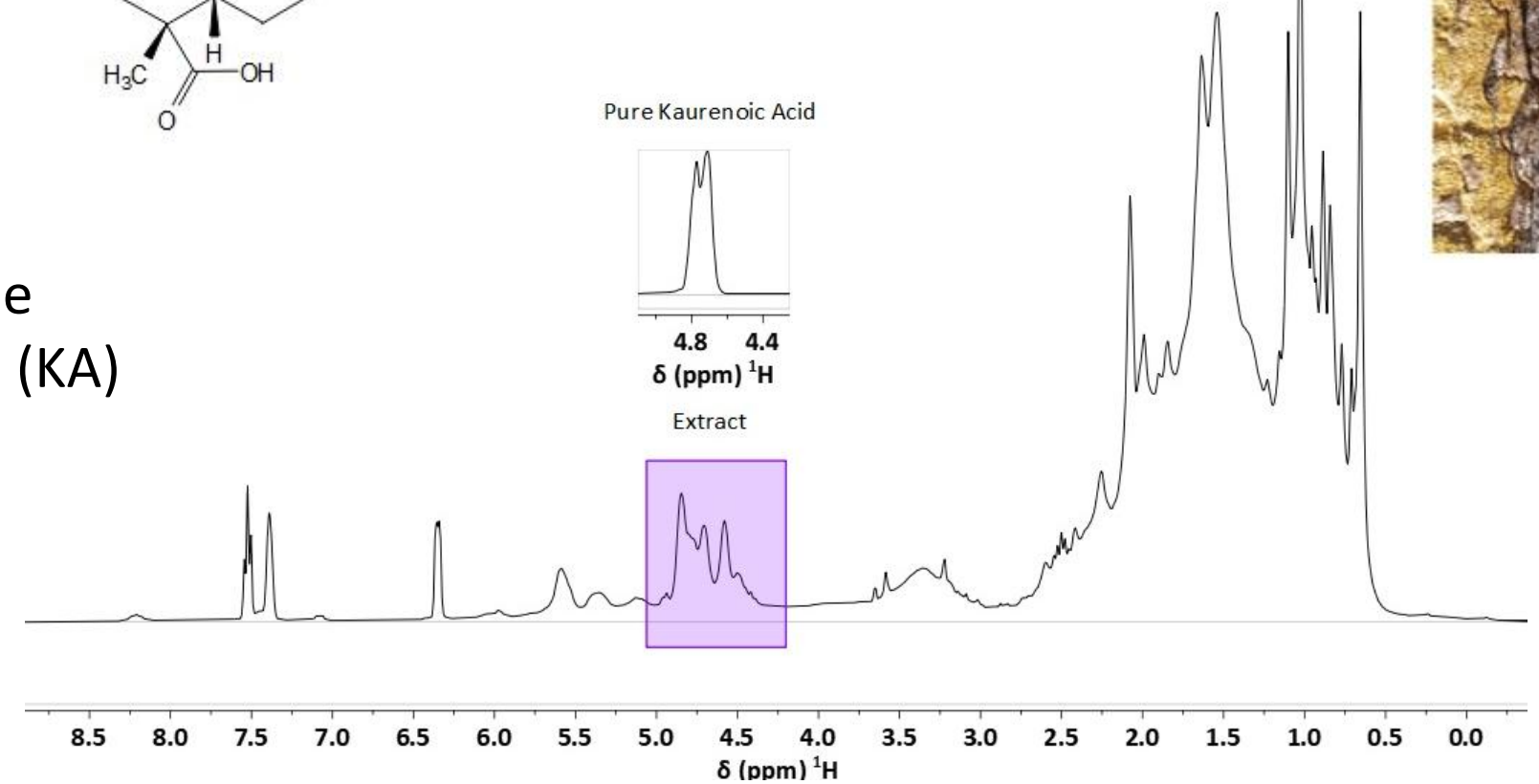
1D ^{1}H

Spinsolve 80 ULTRA



kaurenoic acid: diterpene with antibacterial activity, extracted from Copaiba

Goal: determination of the amount of kaurenoic acid (KA) in the Copaiba extract (define the quality)

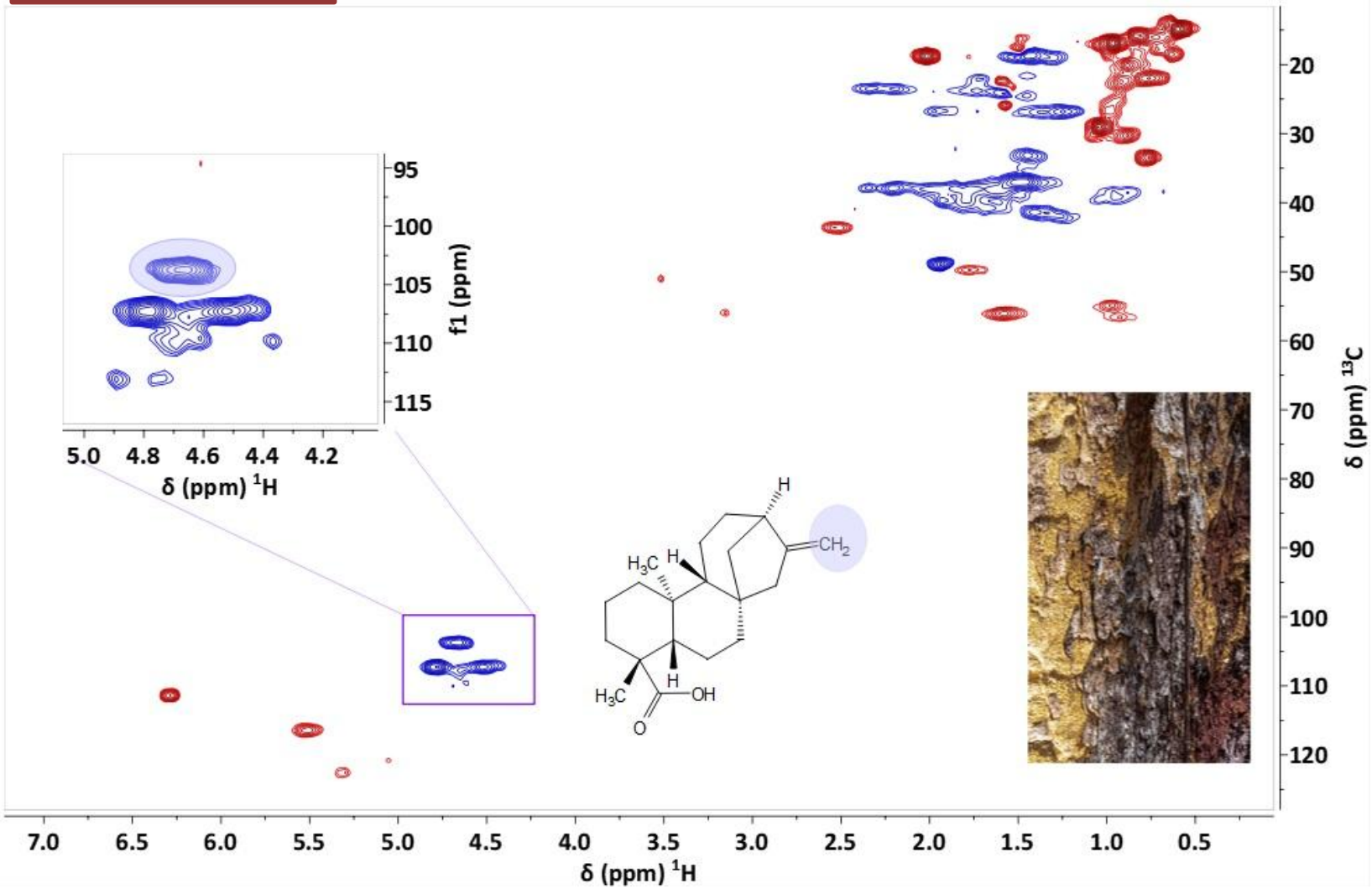


Free resources available online: https://magritek.com/wp-content/uploads/2025/04/App-Note-Quantitation-bei-HSQC-kaurenoic-acid.pdf

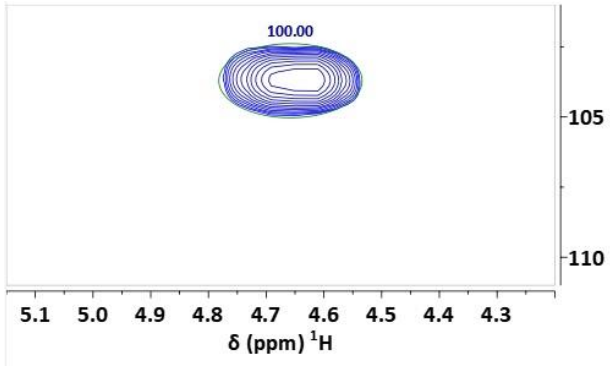
Quantitation by $^{1}H,^{13}C$ HSQC of Kaurenoic Acid in Copaiba Extracts

2D ^{1}H, ^{13}C HSQC-ME

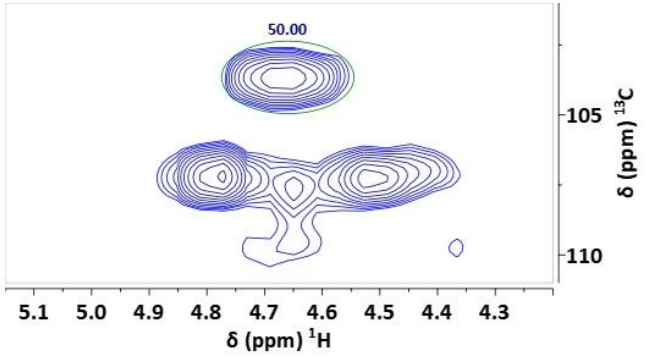
Spinsolve 80 ULTRA



KA External standard



Extract



This sample contains 9.2% KA

Free resources available online: https://magritek.com/wp-content/uploads/2025/04/App-Note-Quantitation-bei-HSQC-kaurenoic-acid.pdf

Quantification of hydrocarbon mixtures

n-pentane

n-hexane

1-hexene

isooctane

OH

2-propanol

cyclohexane

cyclooctane

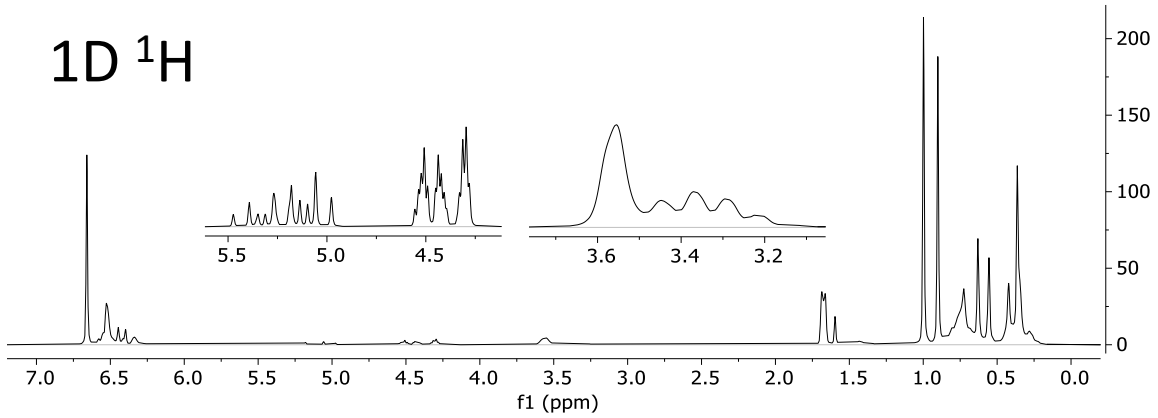
benzene

toluene

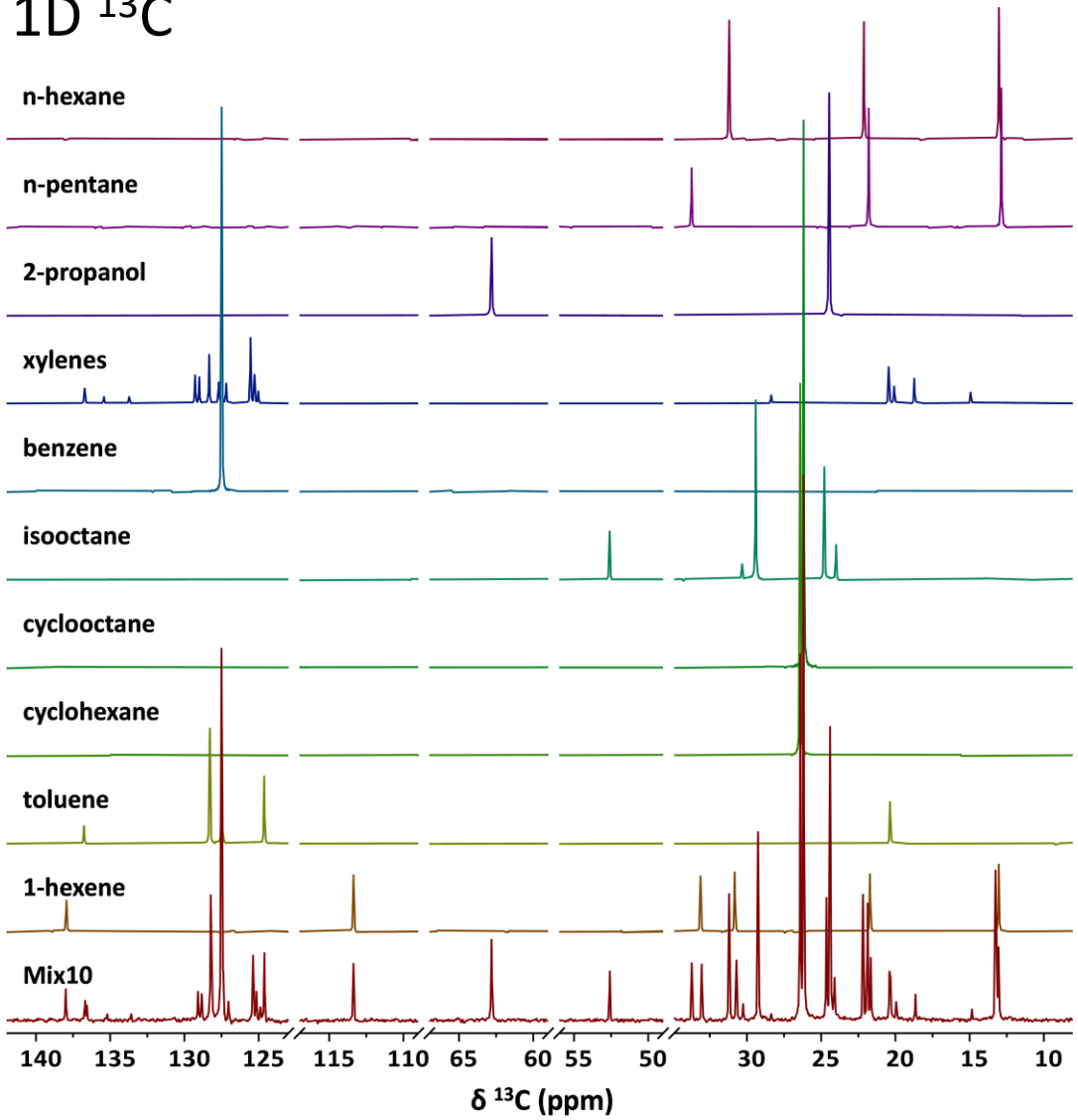
xylenes

(ortho-, meta-, para-xylene and ethylbenzene mixture)

1D ^{1}H



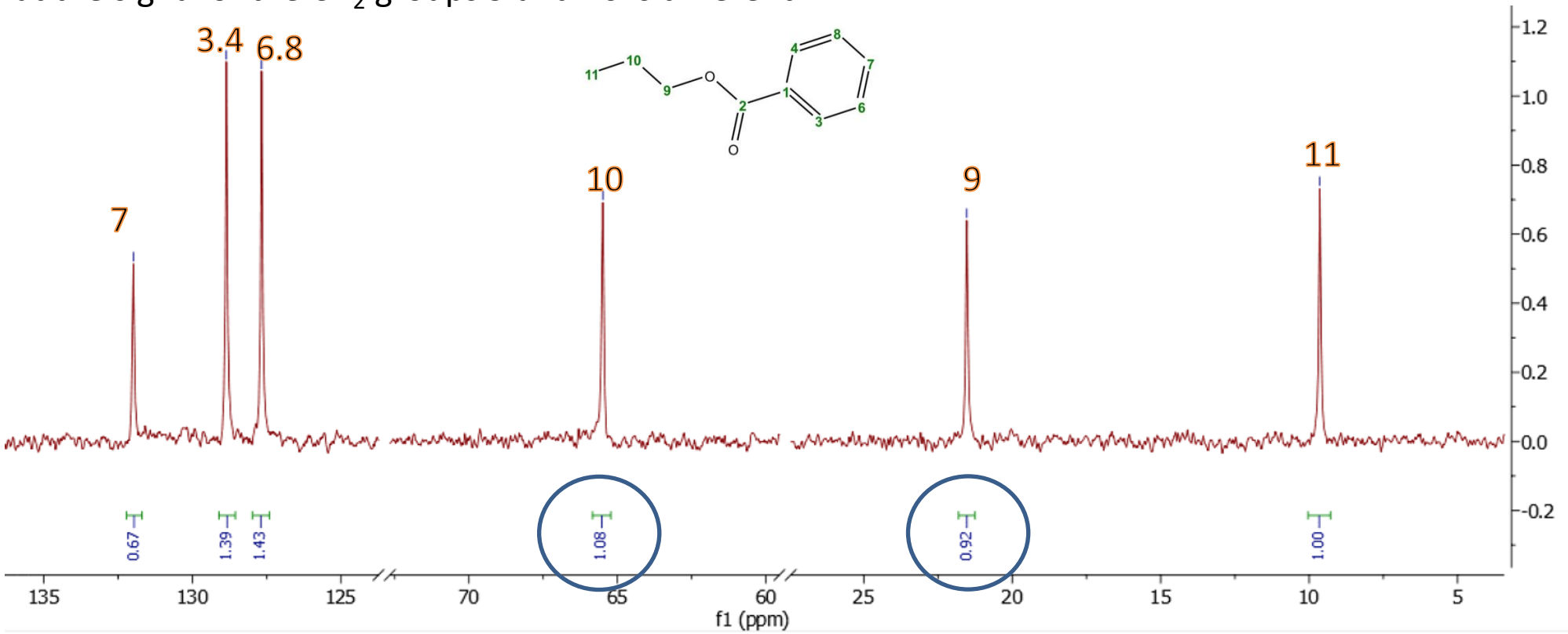
1D ^{13}C



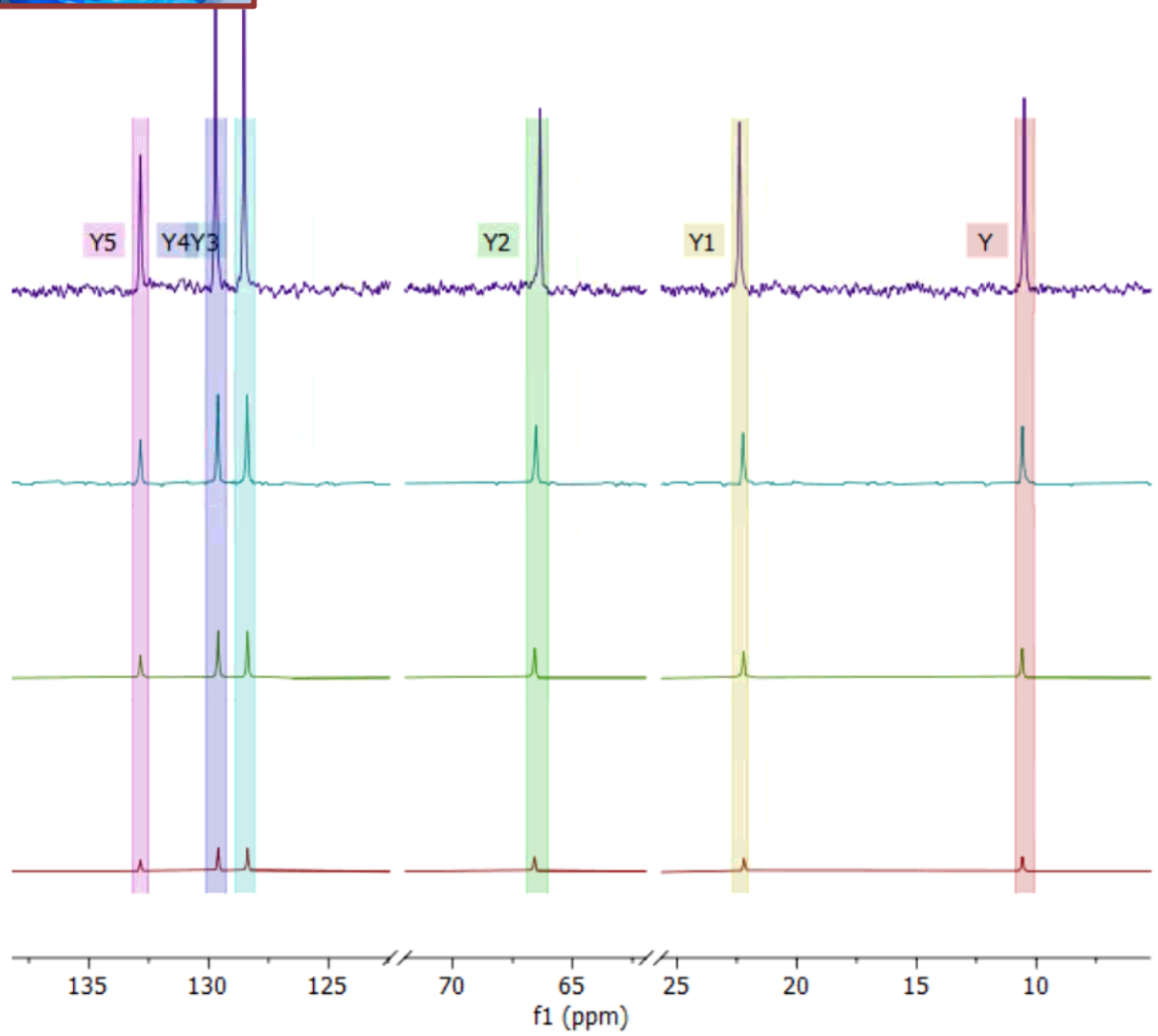
https://magritek.com/wp-content/uploads/2022/02/App-Note-Quantification-of-single-components-in-complex-mixture-by-13C-NMR-1.pdf

Quantification with 13C NMR

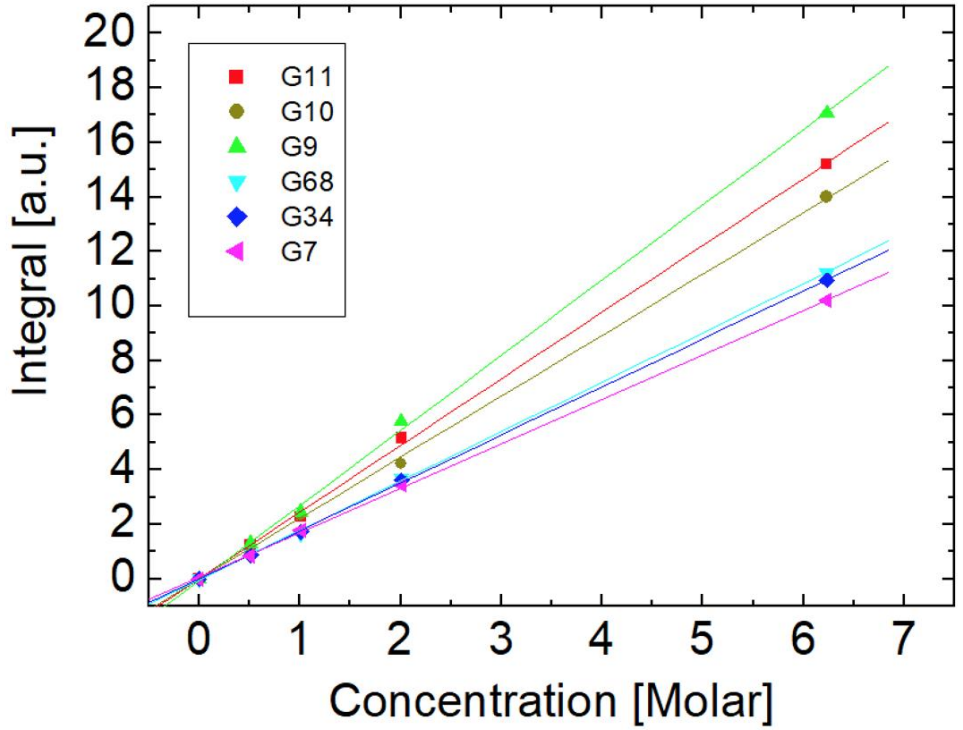
- ^{13}C can be run under so-called quantitative conditions but measurement times will be long
- In ^{13}C NMR methods like polarization transfer from ^{1}H to ^{13}C decouple ^{1}H from ^{13}C during the acquisition of the ^{13}C signal
- The integral of the carbon signals of each chemical group IS NOT proportional to the number of carbons
- This is due to the fact that the efficiency of the polarization transfer depends on the number of ^{1}H coupled to the ^{13}C
- **Notice** that the signal of the CH_2 groups 9 and 10 is different



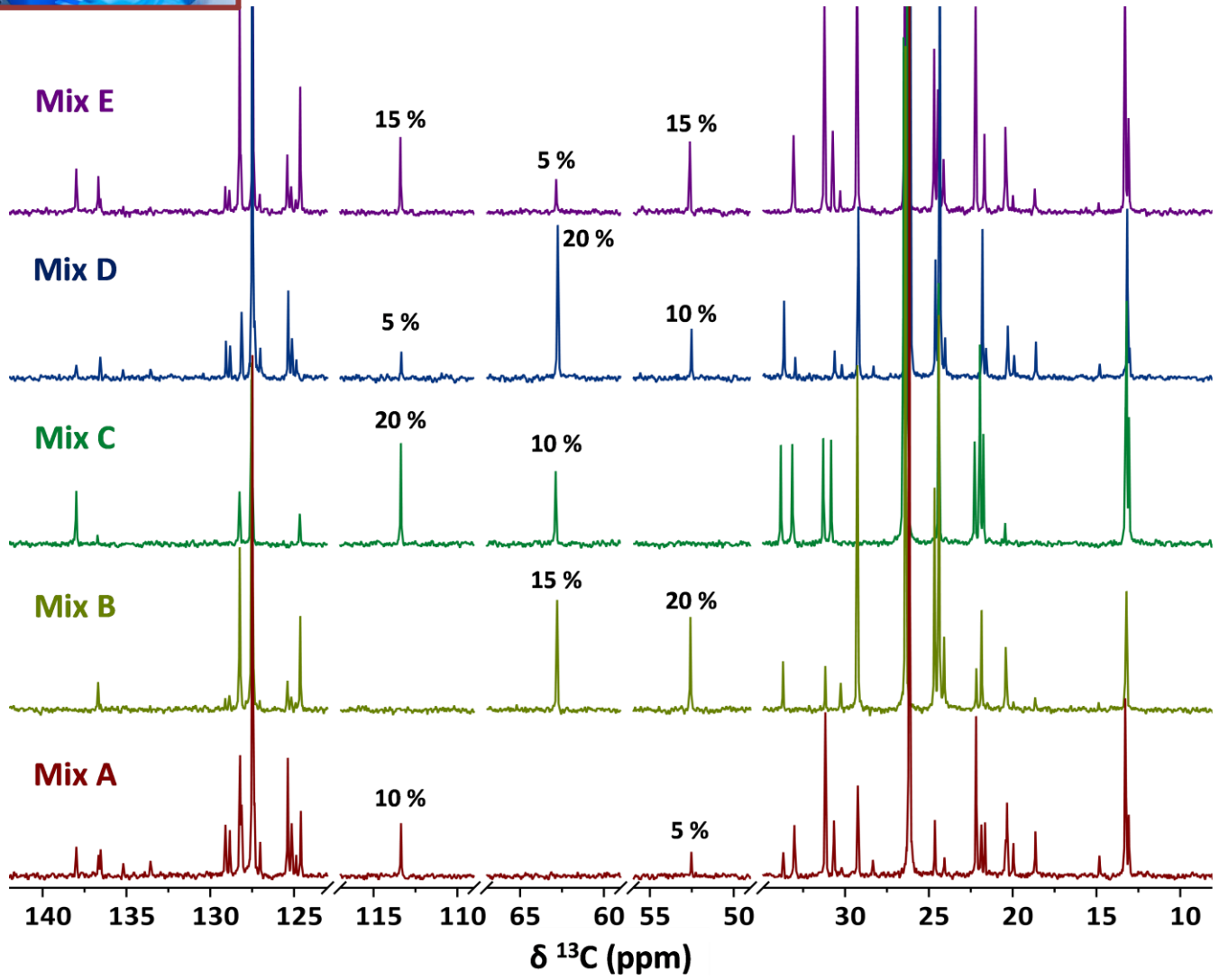
The signal of each group is still proportional to the concentration



- Each carbon has a different calibration
- Even similar chemical groups like the CH2s 9 and 10 cannot be compared
- BUT all are linear with concentration



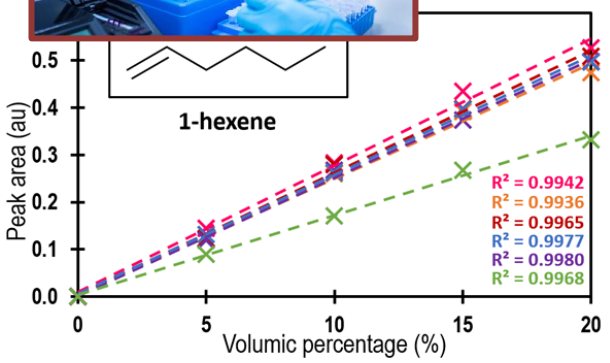
Calibration mixtures

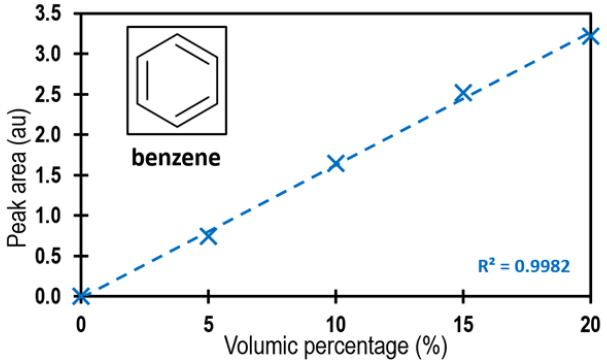


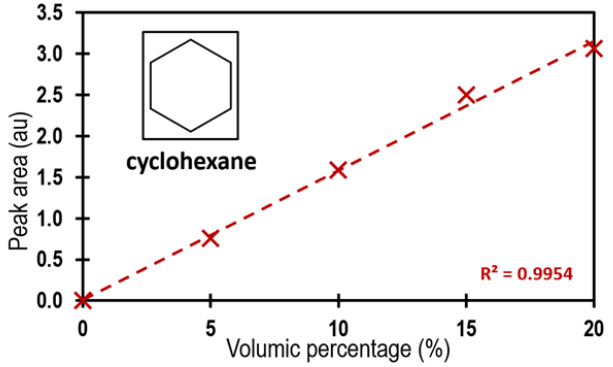
- 5 calibration mixtures were prepared and used as external standards
- The concentration of each component was varied between samples so that for each component the whole calibration range was covered
- Spectra were acquired with NOE and decoupling
- Repetiton time = 4 s; scans = 1024

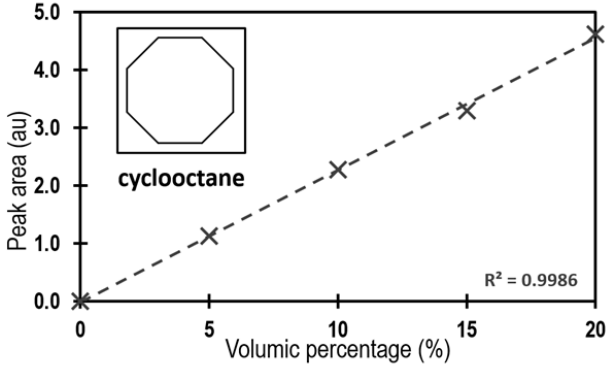
	Mix A	Mix B	Mix C	Mix D	Mix E
cyclooctane	20	0	15	10	5
n-pentane	5	10	20	15	0
n-hexane	15	5	10	0	20
cyclohexane	0	20	15	5	10
isooctane	5	20	0	10	15
2-propanol	0	15	10	20	5
1-hexene	10	0	20	5	15
toluene	10	15	5	0	20
xylenes	20	5	0	15	10
benzene	15	10	5	20	0

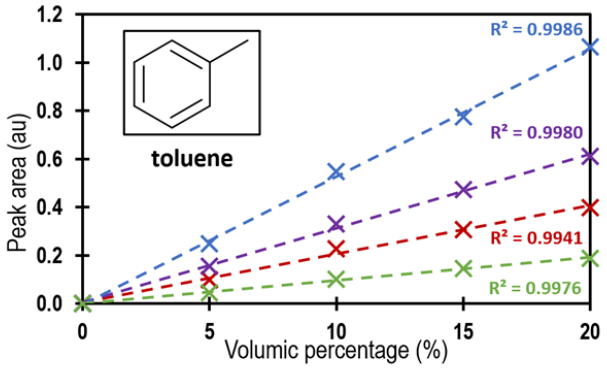
Calibration graphs

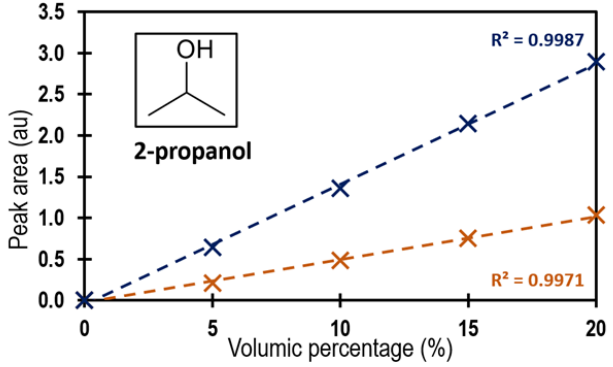


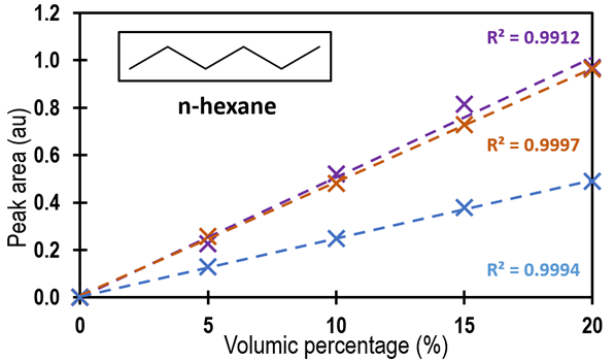


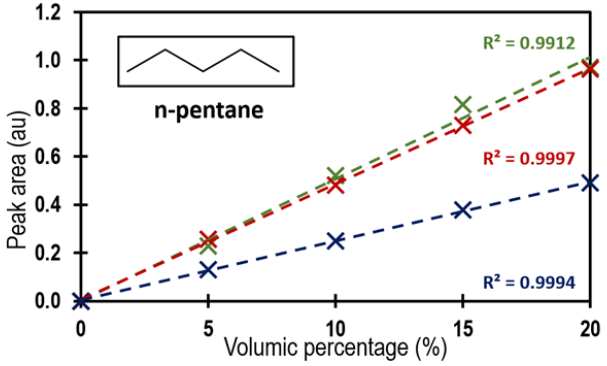


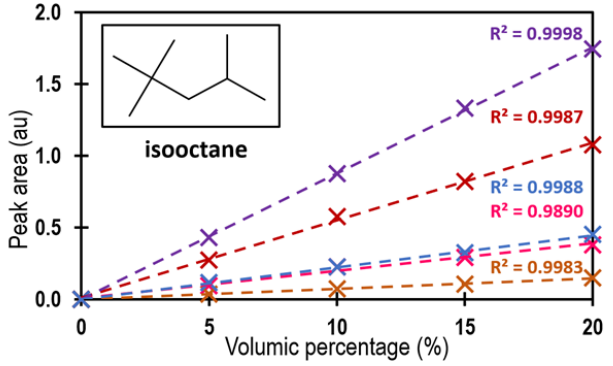


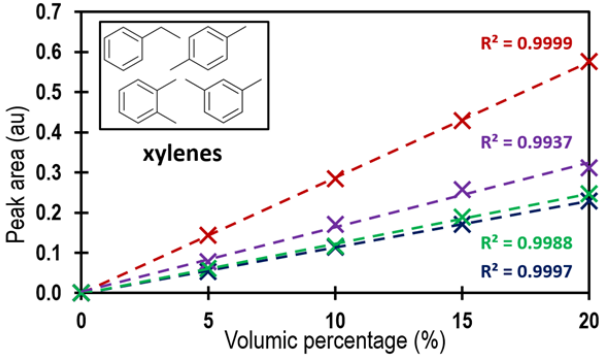






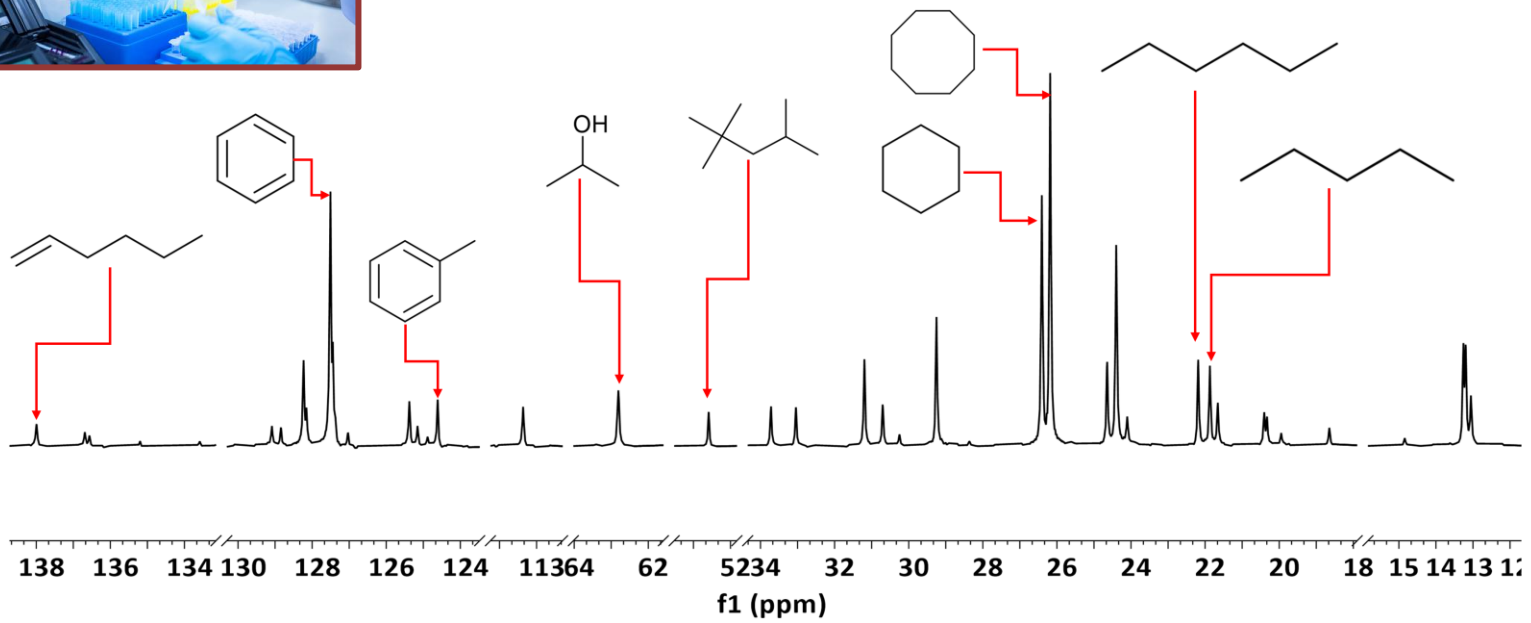


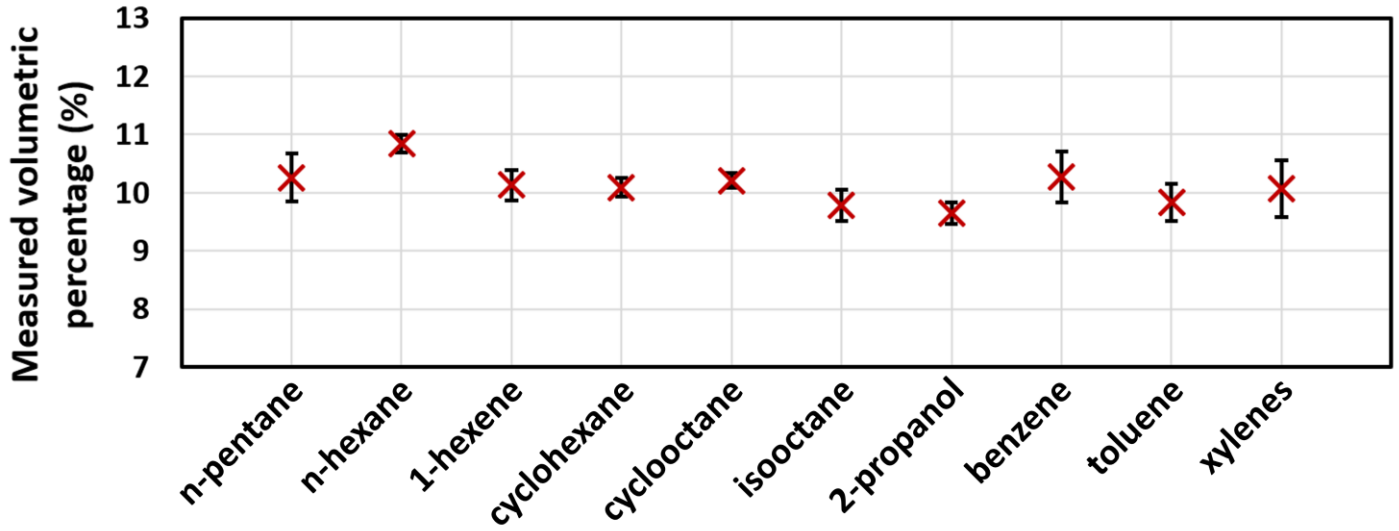




- Each component shows at least one peak that can be used for quantifications
- For all components a linear behavior is observed

Validation





- Mixture with 10 % of each component
- Spectrum was acquired with 1024 scans and repetition time of 4 seconds
- Standard deviation < 0.5% for all components

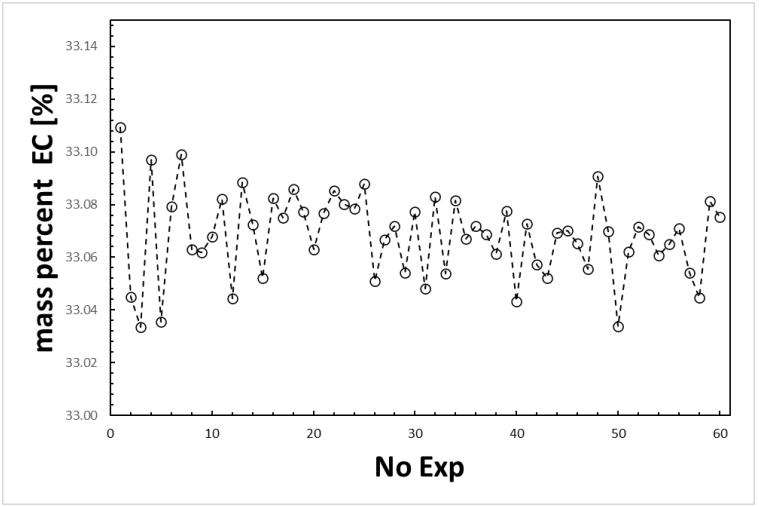
	v/v (% Vol)	std (% Vol)
n-pentane	10.26	0.41
n-hexane	10.85	0.14
1-hexene	10.13	0.26
cyclohexane	10.09	0.15
cyclooctane	10.21	0.12
isooctane	9.79	0.27
2-propanol	9.65	0.18
benzene	10.28	0.43
toluene	9.84	0.32
xylenes	10.06	0.49

Benchtop NMR applications

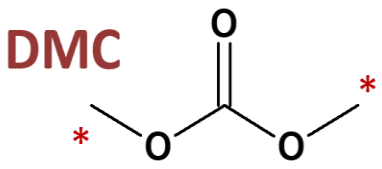
Synthesis	Pharma	Macromolecules	Education	Flow chemistry

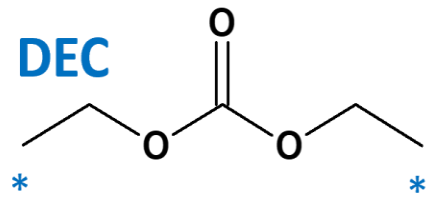
Batteries	Food & Agriculture	Forensics	Analytics

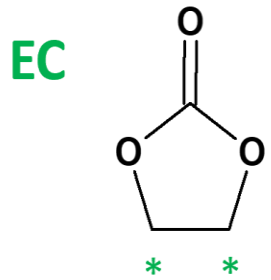
Quantification of electrolyte components



60 consecutive measurements



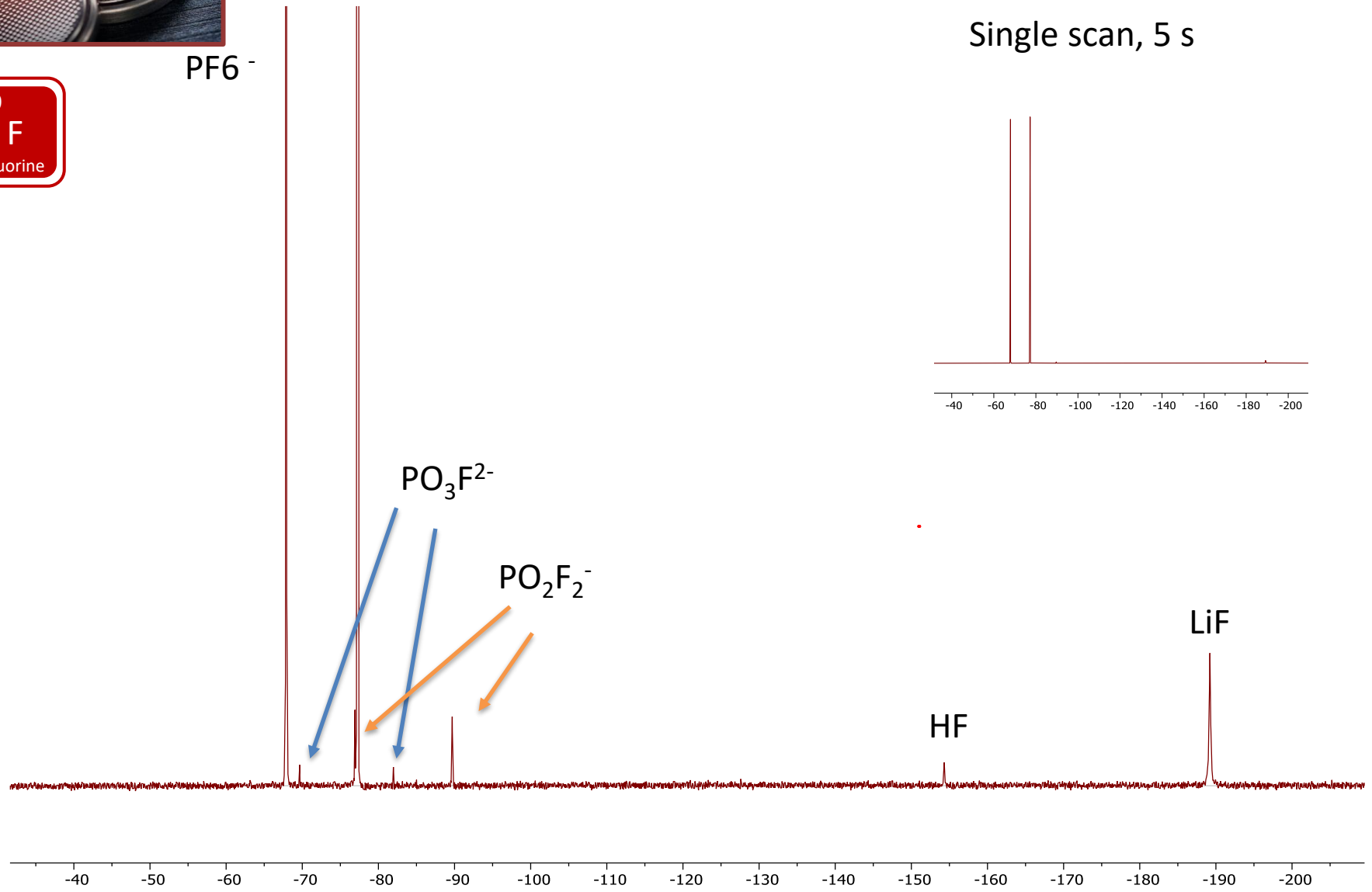




Substance	wt% gravi.	wt% NMR
DMC	33.05	33.07 ± 0.02
DEC	42.91	42.95 ± 0.02
EC	24.04	23.99 ± 0.02

Monitoring the degradation/oxidation of PF_6^-

19 F fluorine



Single scan, 5 s

Initial hydrolysis of $LiPF_6$:

$$LiPF_6 \rightleftharpoons LiF + PF_5$$

$$PF_5 + H_2O \longrightarrow 2HF + POF_3$$

$$POF_3 + H_2O \rightleftharpoons PO_2F_2^- + HF + H^+$$

$$PO_2F_2 + H_2O \rightleftharpoons PO_3F^{2-} + HF + H^+$$

Batteries

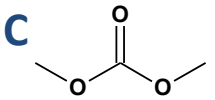
Monitoring the degradation/oxidation of PF_6^-

- **Addition of a few drops of H_2O to accelerate the degradation of $LiPF_6$**

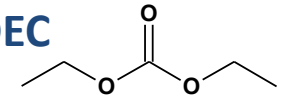
→ **Formation of other species following the expected pathway**

$LiPF_6 + H_2O \text{ -----> } LiF + POF_3 + 2\,HF$

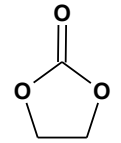
DMC

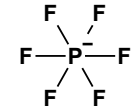


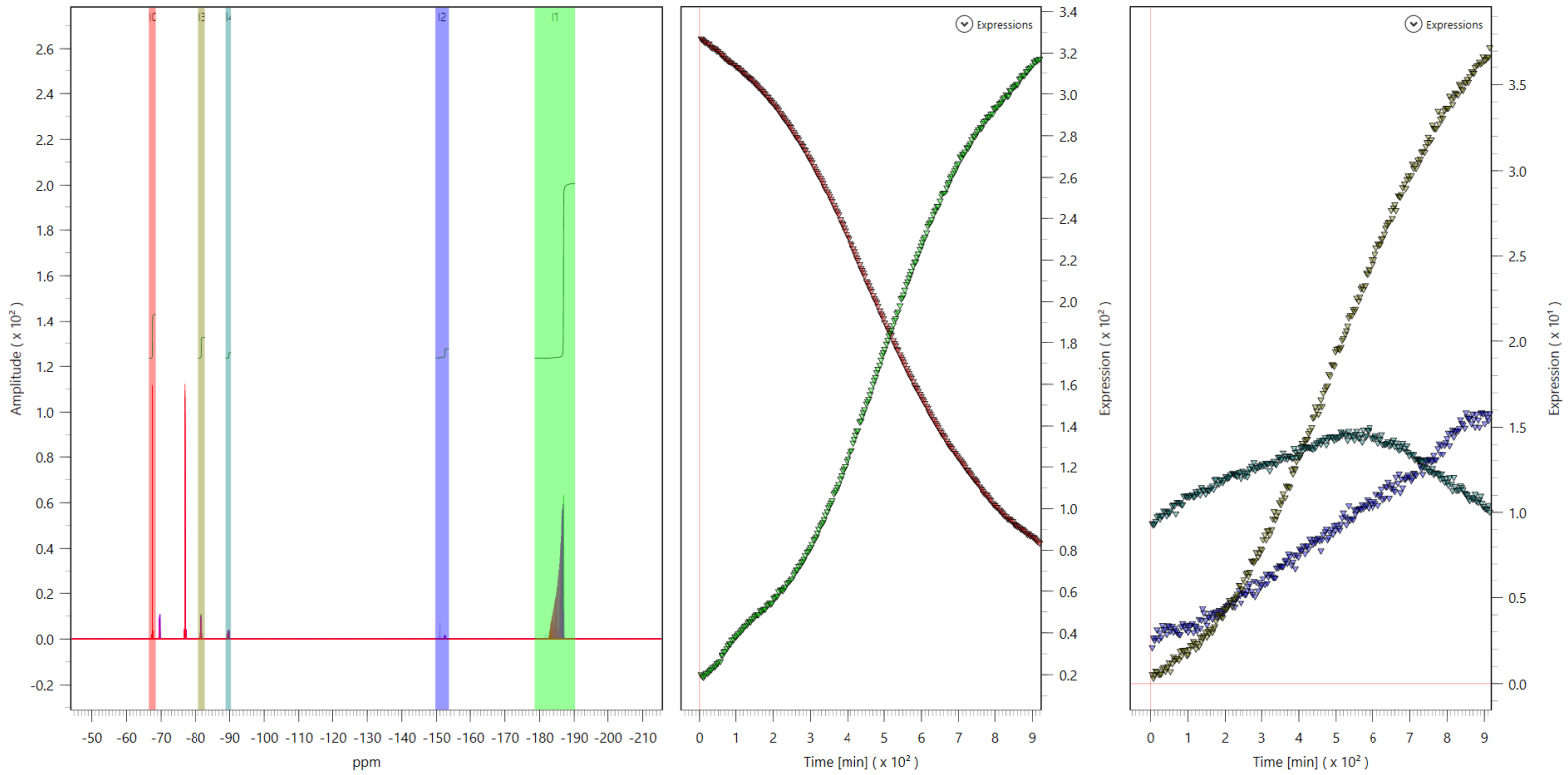
DEC



EC







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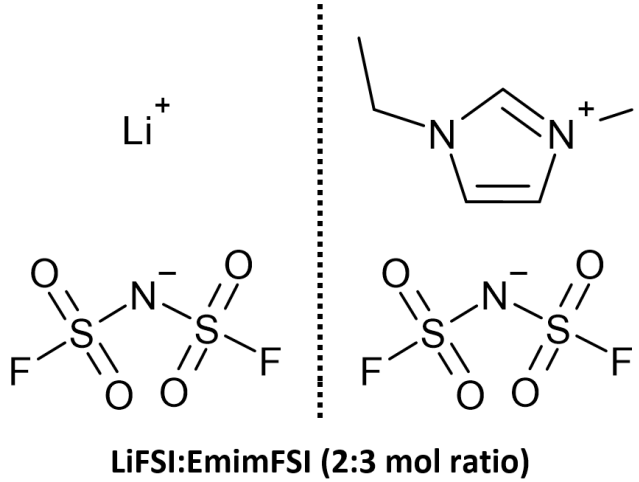
$POF_3 + H_2O \rightleftharpoons PO_2F_2^- + HF + H^+$

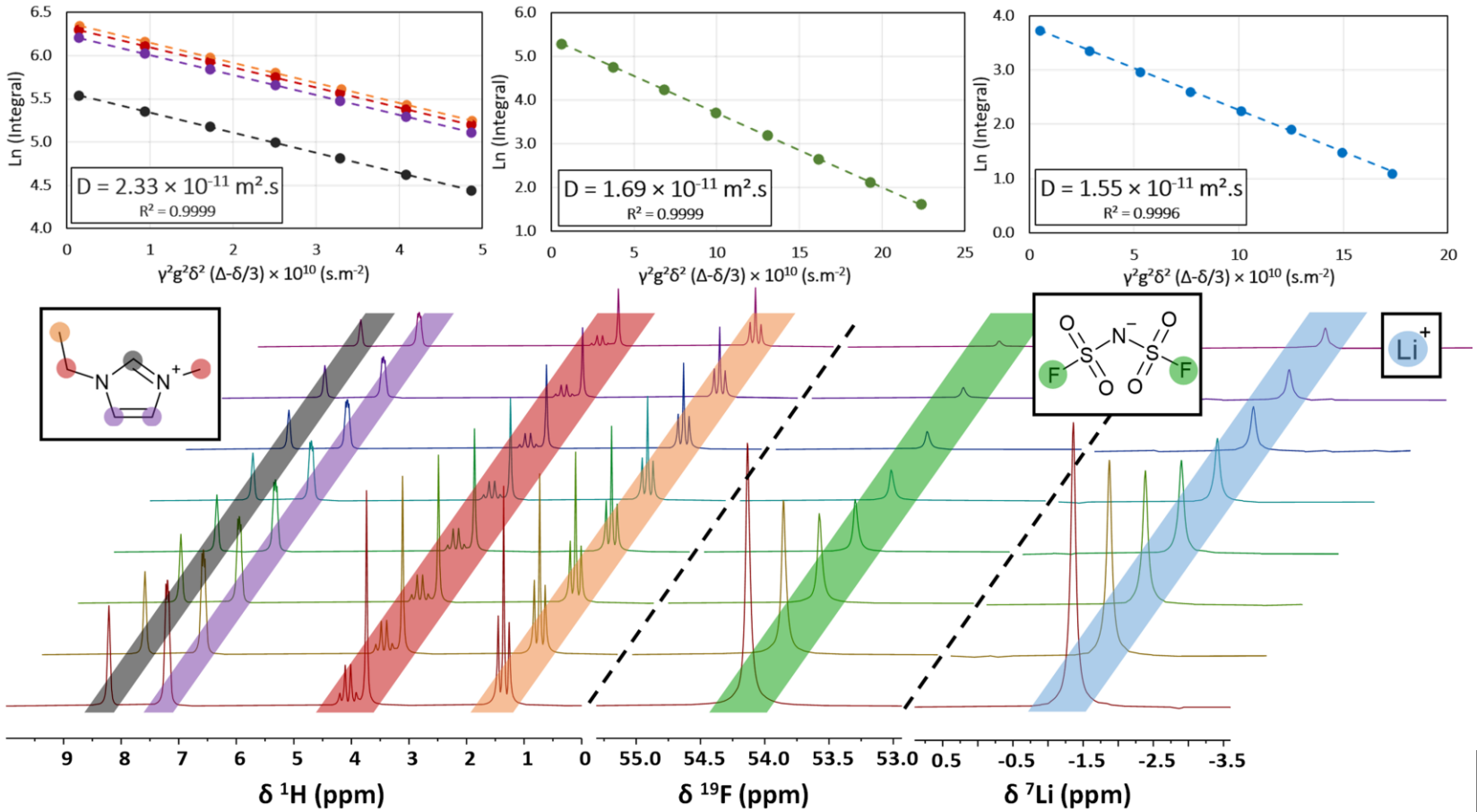
$PO_2F_2 + H_2O \rightleftharpoons PO_3F^{2-} + HF + H^+$

Batteries

Ion diffusion in electrolytes



LiFSI:EmimFSI (2:3 mol ratio)

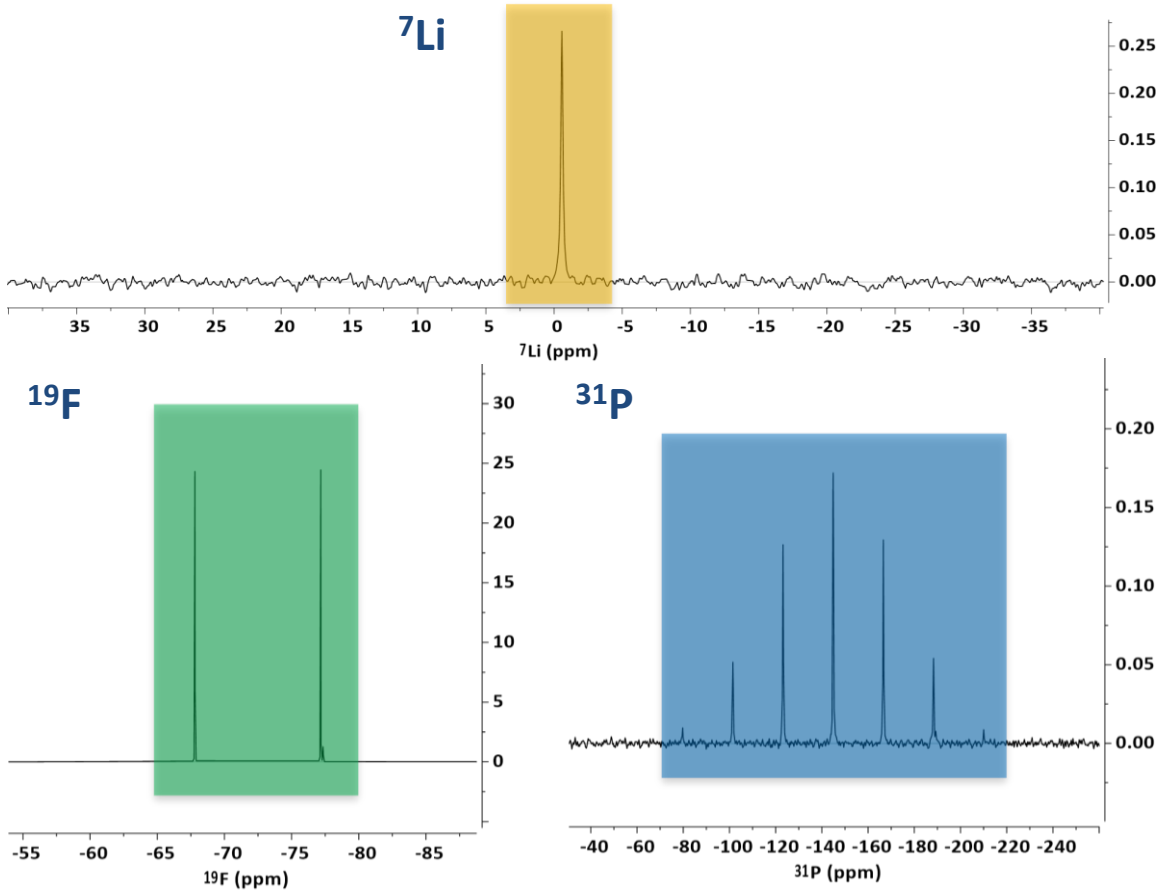


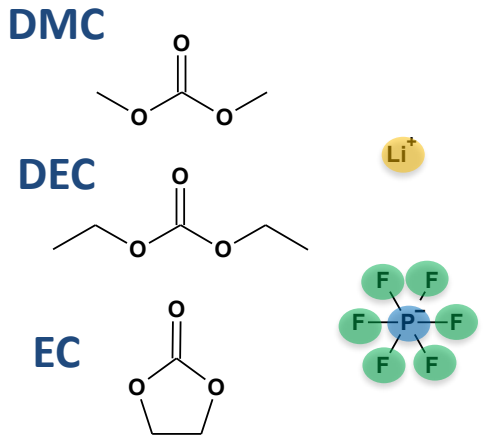
- Li-based Ionic liquid electrolyte
- Transport properties of battery components

Free online resource: https://magritek.com/2020/09/21/study-of-transport-processes-in-li-ion-electrolytes-by-multi-nuclear-diffusion-nmr/

Batteries

Ion properties of electrolytes





- Calculation of Ion properties of electrolytes:

1) Ion conductivity σ

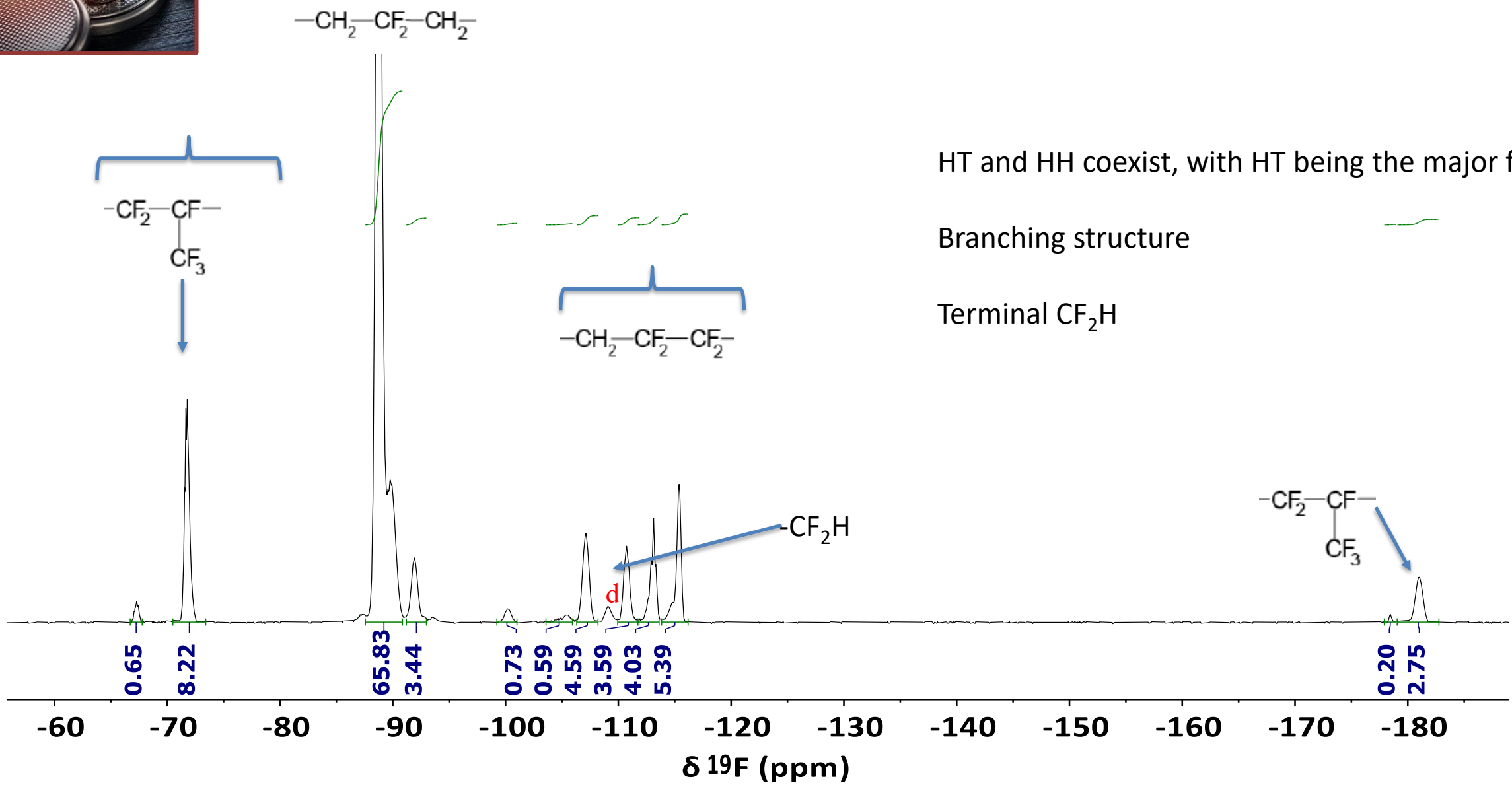
$$\sigma = \frac{F^2 c(D_+ + D_-)}{RT}$$

2) Transference/transport number

$$t_+ = \frac{D_+}{D_+ + D_-} \text{ and } t_- = \frac{D_-}{D_+ + D_-}$$

D+ (Li^+) [m^2/s]	D- (PF_6^-) [m^2/s]	Conductivity σ [S/m]	Transference t+	Transference t-
$3.89\ 10^{-10}$	$5.23\ 10^{-10}$	1.261	0.427	0.573

PVDF characterization



HT and HH coexist, with HT being the major form

Branching structure

Terminal CF_2H

Conclusion

NMR spectroscopy

- Negligible-cost consumable
- No maintenance/long lifespan (>10y)
- Low solvent volume (< 0.5 mL)
- Universal liquid detector (No-D)
- Immediate/real-time analysis
- Flow compatible
- Quantitative
- Non-destructive

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Standard Laboratory Setup

Reaction Monitoring Setup