MOLECULAR DIFFUSION AND DIFFUSION NMR SPECTROSCOPY

Dissolved molecules can translate (diffuse) through mobile solutions.

Diffusion Coefficient (*D*) may be related to molecular size through the Stokes-Einstein equation.

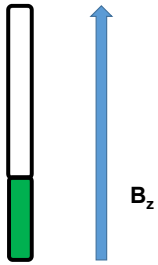
$$D = \frac{k_B T}{6\pi\eta r s}$$

η = viscosity of the solution
r_s = hydrodynamic radius of the sample molecule

DIFFUSION-ORDERED SPECTROSCOPY (DOSY)

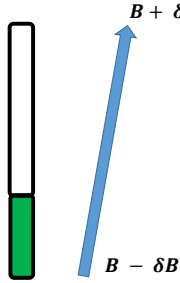
We can study diffusion with NMR spectroscopy…called DOSY.
The approach is broadly analogous to that used in MRI (Magnetic Resonance Imaging)…SPACIAL ENCODING.

Need to be able to label molecules according to their position and track them as they diffuse…PULSED FIELD GRADIENTS

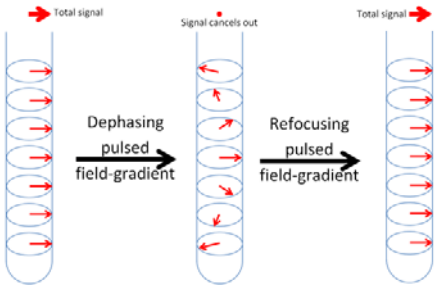


Classical NMR picture of constant, homogeneous magnetic field in the Cartesian z-axis…called B_o

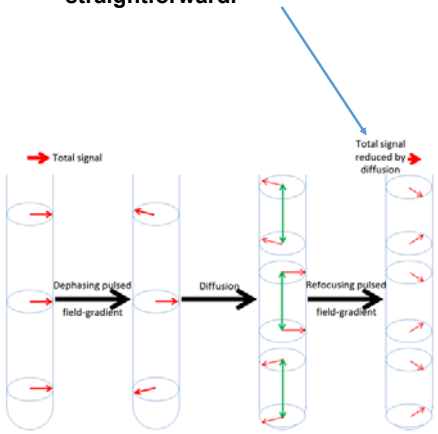
What would happen if, instead of applying a constant field, we applied a GRADIENT field?
Transition frequencies will be slightly higher at the top of the tube.
We have LABELLED the spins according to position!



$$\nu = \frac{g\beta_N B_o}{h}$$



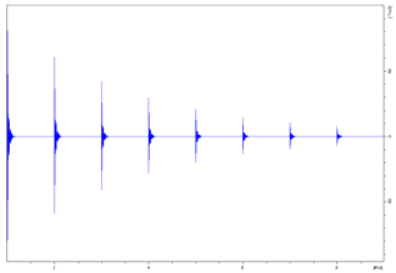
Diffusion coefficient encoded in this observation, but extracting it has not been straightforward.



HOW DOES DOSY WORK?

Pseudo-2D experiment.

Acquire a series of FIDS, varying (increasing) only the amplitude of the gradient field each time…produces a set with decreasing signal intensity.



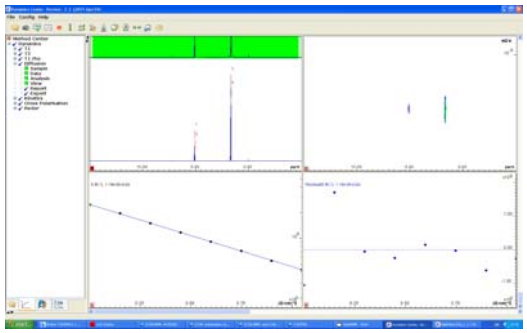
Why pseudo-2D experiment?
Genuine 2D is a function of two time (frequency) domains, $\mathrm{f(t1, t2)}$.
DOSY is a function of time (frequency) and gradient amplitude (diffusion).
Can FT the time dimension…but
What about the other one?!
Fit using additional processing

Processing software available.

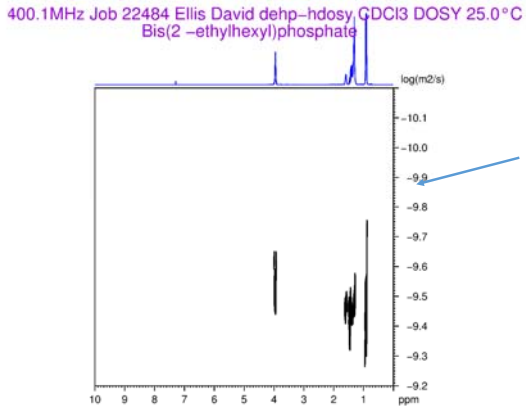
DOSY Toolbox (now imbedded within GNAT…General NMR Analysis Toolbox at https://nmr.chemistry.manchester.ac.uk/?q=node/430.

Bruker 'Dynamics Centre'.

Older versions of TopSpin, need to FT the data and then export to Dynamics Centre. New versions coupled to DC and opens from within TopSpin.



Can use the fitting protocol to generate a '2D spectrum'.



Note that this axis IS NOT a frequency axis, it is the DIFFUSION axis

APPLICATIONS

Lots but we only have time to consider a few.

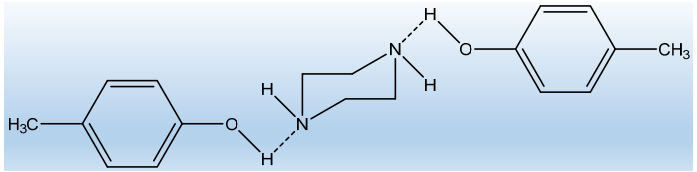
- 1. Hydrogen Bonding.
- 2. Ion Pairing.
- 3. Aggregation.
- 4. Separation of Mixtures.

- Hydrogen Bonding.

p-Cresol and piperazine form a hydrogen-bonded assembly…in the solid state, we can confirm this by X-ray crystallography.

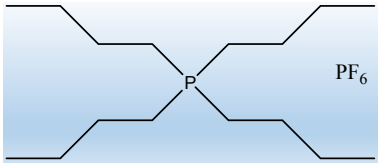
In solution, we can run DOSY experiments on the two pure components separately, and then on the mixture…all in $CDCl_3$, and look at the values of *D* that we obtain.

	D - Pure component (10^{-10} m^2/s)	*D* - Mixture (10^{-10} m^2/s)
P-Cresol	16.7	9.71
Piperazine	25.3	9.91



Reduced value of *D* for the mixture reflects the presence of the hydrogen-bonded aggregate.

➢ **Ion Pairing.**

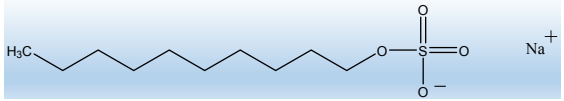


One interpretation…the compound behaves as a tight ion-pair in $CDCl_3$ but NOT in DMSO.
Note that DOSY is possible with heteronuclei (^{31}P, ^{19}F) not restricted to ^{1}H.

Nature of analysis	*D* (10^{-10} m^2/s) in $CDCl_3$	*D* (10^{-10} m^2/s) in DMSO
^{31}P cation	3.8	1.7
^{31}P anion	3.8	3.6
^{19}F anion	3.7	3.6

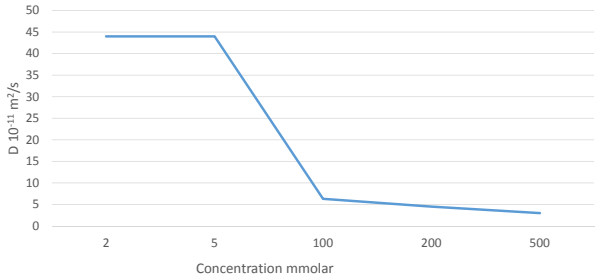
➢ **Aggregation.**

Dissolve SDS (sodium dodecylsulphate) in D_2O…carry out DOSY at different concentrations…what do we observe?



Can determine the Critical Micelle Concentration (CMC) by DOSY

Formation of micelles at high concentrations – molecular aggregates which diffuse slowly.
Micelles are formed by AMPIPHILIC molecules (display hydrophobic and hydrophilic character)



➢ **'Separation' of Mixtures.**

We have prepared a polymer (polylactic acid) from lactide and we have them both in a crude reaction mix…they have very different molecular weights…we should be able to 'separate' them in a DOSY experiment.