Introduction to NMR



A Practical Approach

By Daina Avizonis 10/2000

Why NMR?



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Atoms as small radio transmitters

• Certain atoms, when put in a magnet act as small radio transmitters. The strength of the magnetic field determines their "tuning" frequency. For example, a proton or hydrogen atom in a 14.1T field will tune or resonate at 600MHz.



Random spins(no magnetic field)



Aligned spins (inside a magnetic field)

Chemical Shift

- Each atom can have its own tuning or resonant frequency. The chemical environment of the atom of interest determines its resonant or tuning frequency.
- For example, a hydrogen atom connected to an oxygen atom will experience a different chemical environment which will give it a different resonant frequency from a hydrogen atom connected to a carbon atom.
- The chemical shift is defined as the difference between a reference frequency and the sample's resonance divided by the observe frequency (600MHz in previous example)

What makes an Atom NMR Active?



- This takes QUANTUM MECHANICS!
- If atomic number and atomic weight are both even, spin is 0 => NO NMR C12, O16, He4 (spin=0)
- If atomic number is odd and atomic weight is even, spin is an integer number (1,2,3,4...) =>NMR eg. H2, or N14 (quadrupolar)
- If atomic number and atomic weight are both odd, spin is (2n+1)/2 (n=0,1,2,3,...) => NMR possible eg. H1, N15, C13, P31, F19, Si29 (spin=1/2) or Na23 (spin=3/2) O17 (spin=-5/2) V51(7/2)

Vector Representation





Spins in a Magnetic Field

• By putting a sample in the magnet, a net "alignment is caused." The vector sum of the oriented spins gives a net macroscopic magnetization. Once the magnetization has been developed, we need to perturb it into the XY-plane to observe an NMR signal. This is done by a second radio frequency or B1 field.

Getting an NMR Signal The 90° Pulse



T_1 and T_2 Relaxation

- T₁ Spin Lattice or Longitudinal
- Exponential Recovery to Z
- Dipole-dipole/ Scalar interactions
- Chemical shift anisotropy
- Spin-rotation



- T₂ Spin-Spin or Transverse
- Exponential Decay
- Same mechanisms
- Field homogeneity (T_2^*)



More Relationships

Sampling Rate – determines resolution

sampling rate = 2^* (sweep width)

Sweep width is the frequency window for observing signals

VNMR defines the sampling rate by the parameter "sw"

Example:

On a 300MHz system a 15ppm of a 1H window corresponds to a 4500Hz sweep width (15*300)

so we take 2*4500=9000 samples/sec

250ppm of a C13 window on a 400:

250ppm=25000Hz (C13 is 100MHz on a 400MHz system) Thus we sample at a rate of 50,000 samples/second

Sampling and Resolution

The number of samples or points one collects depends on the desired resolution and on the decay of the NMR signal (there is nothing gained by sampling noise!).

The resolution of the spectrum is the smallest difference in frequency which can be resolved. It is the inverse of the acquisition time, if and only if there is signal present for the entire acquisition time.

Examples:

If the acquisition time (at) is 2s. Then the spectrum will have 0.5Hz resolution If you want 0.3Hz resolution then you need an acquisition time of 3.3s.

Remember that Sampling rate is determined by the range of frequencies to be observed (sw) The total number of samples (np) is simply the product of the sampling rate (2*sw) and the sampling time (at). np=(2*sw)*at

Signal To Noise

- After a pulse, the magnetization must return to equilibrium (along Z) before the next pulse or scan can be executed.
- There is more signal from each scan when you are closer to a 90° pulse. But the closer or greater the tip angle, the longer you have to wait between scans.
- Think about trade offs
- Signal to noise is a square root function. In other words the signal to noise increases as the square root of the number of scans.



Fourier Transform

A Complex mathematical translation of collected data (phase/time) into frequency information.

FT is mathematically complex

Real-absorptive

Imaginary – dispersive

Each contains np/2 points

The number of points in the (real) spectrum is np/2 which are distributed uniformly over the sweep width. The frequency difference between adjacent points is sw/(np/2) or 2*(sw/np). This is the the minimum splitting that can be resolved.



More FT and Weighting Functions



Back to Chemical Shift

- Chemical shift in ppm =(Freq-ref.-freq)/ref-freq* 10⁶
- The Chemical (electrical and nuclear) environment determines the chemical shift.
- For example:
- On a very low field system CHBr₃, CH₂Br₂, CH₃Br and TMS all have different "tones" or resonance frequencies. On a 2.11T System Trimethylsilane, TMS, our proton reference resonates at 90,000,000Hz (90MHz) where as, CH₃Br resonates at 90,000,237Hz, CH₂Br₂ at 90,000,441Hz and CHBr₃at 90,000614Hz
- The CHBr₃ resonance is said to be the most "deshielded and it resonates 'down field' where as TMS, the reference is said to be shielded and it resonates 'up field'

We calculate the chemical shifts of the bormo-molecules with the above formula:

 $CHBr_{3}\,$ resonates at about 6.82ppm (90000614-90000000)/90000000*10^6), $CH_{2}Br_{2}\,$ at 4.90ppm and $CH_{3}Br\,$ at 2.63ppm

Scalar Coupling – Spin ¹/₂

- Each proton or hydrogen atom can be thought of as a tiny magnet. Alone, its spin may align with the magnetic field. Rarely do we ever have single protons in a field. They are normally part of a molecule or combination of atoms held together by chemical bonds. These "mini-magnets" can interact through chemical bonds. This results in perturbations of each atom's energy state.
- One can also think of the protons in a molecule as separate radio stations that interfere with each other. When you are tuned to station A, you can still here some of station B.

Scalar Coupling Continued







M=2nI+1 M is the multiplicity and I is the spin (1/2) n is the number of equivalent neighboring nucleii 121 1331 14641

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M=n+1

What can j-coupling do for me?

- Ability to identify the type of carbon
- Provides information of what is connected to what
- Provides structural information torsion angles in a molecule





Other Important NMR Properties

- Through Space interactions NOE
- Can have NOE between different nuclei such as Carbon and Hydrogen or Hydrogen to hydrogen.
- Used to increase signal intensity
- Used to determine 3-D structure



NMR Tutorials on the World Wide Web.

- <u>http://www.chem.uni-potsdam.de/1hbuch/english/index.html</u>
- <u>http://www.chem.uni-potsdam.de/tools/index.html</u>
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- <u>http://web.chem.queensu.ca/FACILITIES/NMR/nmr/webcourse/index1.htm</u>
- <u>http://www.cis.rit.edu/htbooks/nmr/</u>
- <u>http://www.shu.ac.uk/schools/sci/chem/tutorials/molspec/nmr1.htm</u>
- <u>http://www.chembio.uoguelph.ca/driguana/NMR/TOC.HTM</u>