Introduction to NMR

Physical principles
Skejby Sept. 2003
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MRI of the human brain
Basic steps

1) By means of magnetic fields and RF pulses
2) Data processing (Fourier transformation)
Outline

- Nuclear spins
- Spin dynamics in magnetic fields
- Spin interactions
- Spin excitation
- Spin RF radiation and detection
A charged proton that spins will create a circulating current which in turn induces a magnetic field. The dipole vector $\mu$ describes the strength and direction of magnetic field. C.g. permanent magnet.
Spin is a fundamental quantum mechanical property. All nuclei (and other particles) have spin:

\[ S = 0, \frac{1}{2}, 1, \frac{3}{2}, \ldots \frac{h}{2\pi} \text{ (Planck's constant)} \]

For \( S = l \) there are \( 2l+1 \) states, corresponding to the possible orientations of the spin.

Proton
Spin and magnetic field

The fundamental relationship is

\[ \mu = \gamma S \]

\( \gamma \) (gamma) is the gyromagnetic ratio. It depends on the nucleus. For the proton it is \( 2.675 \times 10^8 \) rad/s/T.

Only nuclei with non-zero spin have magnetic moments, and are thus NMR active.

\[ T = \text{Tesla. } 1 \text{ Gauss} = 10000 \text{ Tesla. Earths magnetic field is roughly } 0.5 \text{ Gauss.} \]

A clinical scanner has 1.5 Tesla, i.e. 30000 times the earths magnetic field.
A magnetic dipole tends to align along an external field (e.g. a compass in the earth's magnetic field). Thermal motion opposes this.

\[ M \text{ (magnetization)} \] is the magnetic dipole moment per unit volume.

- \( B = 0.1 \text{ tesla} \), \( T = 0 \text{ K} \): Spins aligned 100%
- \( B = 0 \text{ tesla} \), \( T = 300 \text{ K} \): Spins aligned 0%
- \( B = 0.1 \text{ tesla} \), \( T = 300 \text{ K} \): Spins aligned 1 ppm
- \( B = 0.5 \text{ tesla} \), \( T = 300 \text{ K} \): Spins aligned 5 ppm
Magnetization

M is the sum of the individual spin magnetic moments.
Spin dynamics

Gravity

Top

Permanent magnet field

$B_0$

Proton

H
Larmor frequency

\( \omega \) is the Larmor frequency:

\[ \omega_0 = \gamma B_0 \]

For protons in a clinical scanner, \( B_0 = 1.5 \text{T} \) so

\[ \omega_0 = 63.87 \text{Mhz.} \]

Compare

DRP1@88.1Mhz.
Magnetization

Magnetization $M$ is:

$$M_z = M_0$$

$$M_{xy} = 0$$

Transverse magnetization is zero because of random phases.
Radio-frequency pulses

Radio waves at Larmor frequency force protons to process in phase antiparallel or parallel to $B_0$.
RF pulses and magnetization

Initial magnetization $M_0$

Magnetization after 90° pulse

Rotating coordinate system
Spin interactions

Instead of precessing forever in the transverse plane, the magnetization relaxes back to the equilibrium value.

T1 and T2 are characteristic relaxation constants.
The dephasing in T2 relaxation results from differing local interactions, leading to locally varying Larmor frequencies. T2* is the same phenomenon, but is a result from magnetic field inhomogeneities.
## Biological T1-T2 values

<table>
<thead>
<tr>
<th>TISSUE</th>
<th>T1 at 1.5 T (ms)</th>
<th>T1 at 0.5 T (ms)</th>
<th>T2 (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skeletal muscle</td>
<td>870</td>
<td>600</td>
<td>47</td>
</tr>
<tr>
<td>Liver</td>
<td>490</td>
<td>323</td>
<td>43</td>
</tr>
<tr>
<td>Kidney</td>
<td>650</td>
<td>449</td>
<td>58</td>
</tr>
<tr>
<td>Spleen</td>
<td>780</td>
<td>554</td>
<td>62</td>
</tr>
<tr>
<td>Fat</td>
<td>260</td>
<td>215</td>
<td>84</td>
</tr>
<tr>
<td>Grey matter</td>
<td>920</td>
<td>656</td>
<td>101</td>
</tr>
<tr>
<td>White matter</td>
<td>790</td>
<td>539</td>
<td>92</td>
</tr>
<tr>
<td>Cerebrospinal fluid</td>
<td>&gt;4000</td>
<td>&gt;4000</td>
<td>&gt;2000</td>
</tr>
<tr>
<td>Lung</td>
<td>830</td>
<td>600</td>
<td>79</td>
</tr>
</tbody>
</table>
Law of induction: changing magnetic field induces electromotoric force. From $M_{xy}$

Detected by RF coil and measured as a time varying current. Decays according to $T_2^*$. What about $T_2$?

**Spin echo**
Spin echo

- Or spin refocussing

\[90^\circ\text{-}TE/2\text{-}[180^\circ\text{-}TE/2\text{-}ECHO}\]
Pulse sequences and contrast

By using different pulse sequences, one can create contrast on the basis of e.g. T1, T2, T2* or spin density.

Spin echo:

\[ S = \rho \cdot (1 - e^{-TR/T_1}) \cdot e^{-TE/T_2} \]
Overview

Generation of a NMR-spectrum

- Radio wave
- Radio wave
- FT

FID

Time

Frequency