Topics:
• Review of NMR basics
• Hardware Overview
• Prescan

Spins

Hydrogen Nucleus = Proton

• Mass
• Spin
• Charge

Angular Momentum
Magnetic Moment

Boltzmann Distribution

\[ E = \mu_z B_0 \]
\[ \Delta E = \gamma h B_0 \]
\[ E = -\mu_z B_0 \]

\[ \frac{down\_spins}{up\_spins} = e^{-\Delta E/kT} \]

Ratio = 0.99998 at 3T!

Corresponds to an excess of about 20 up spins per million
Equation of Motion for Magnetization Vector $\mathbf{M}$

**Bloch Equation:**

$$\frac{d\mathbf{M}}{dt} = \mathbf{M} \times \gamma \mathbf{B} - \frac{M_z \hat{i} + M_y \hat{j}}{T_2} - \frac{(M_z - M_0) \hat{k}}{T_1}$$

- **Precession**
- **Transverse Relaxation**
- **Longitudinal Relaxation**

**Solution:**

$$M_z(t) = M_0 + (M_z(0) - M_0)e^{-t/T_1}$$

$$M_{xy}(t) = M(0)e^{-j\omega_0 t}e^{-t/T_2}$$

$$\omega_0 = \gamma B$$

**Relaxation: Z-component**

$$M_z(t) = M_0 + (M_z(0) - M_0)e^{-t/T_1}$$

**Relaxation: Transverse Component**

$$\mathbf{M} = M_x + jM_y$$

$$\frac{d\mathbf{M}}{dt} = \frac{d}{dt}(M_x + iM_y)$$

$$= -j(\omega_0 + 1/T_2)\mathbf{M}$$

$$\mathbf{M}(t) = M(0)e^{-j\omega_0 t}e^{-t/T_2} \quad \omega_0 = \gamma B$$

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RF Excitation

Bloch equation says that magnetization will precess around the applied field.

$B_1$ radiofrequency field tuned to Larmor frequency and applied in transverse ($xy$) plane induces nutation (at Larmor frequency) of magnetization vector as it tips away from the $z$-axis.

- lab frame of reference

http://www-mrsrl.stanford.edu/~wro/defense/animations/

An NMR Experiment

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Basic 2D Imaging Pulse Sequence

\[ S(t) \propto \int M_T(\vec{r}) e^{i\vec{K}(t) \cdot \vec{r}} d\vec{r} \]

\[ \vec{K}(t) = \gamma \int \vec{G}(t) dt \]

Hardware Overview

Three fields:
- Main Field \((B_0)\)
  - Polarize Spins
- Gradient Fields \((G_{[XYZ]})\)
  - Map space into frequency
  - \(\frac{\partial B_z}{\partial [XYZ]}\)
- RF Fields \((B_1)\)
  - Change the latitude or zenith angle of (‘tips’) spins
Main Field ($B_0$)

How do we decide on $B_0$?

$$\Delta E = \gamma h B_0$$

$$M_0 \propto \Delta E$$

**: Bigger is better! … except …**

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3T Human @UCSD    7T Rodent @UCSD    7T Human @U.Minn.    9.4T Human @UIC

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Main Field ($B_0$)

Energy in a Magnetic Field:

$$E = \frac{1}{2\mu_0} \int B^2 dV$$

For $B=3T$ over $1m^3$:

$$E = \frac{1}{2(1.25 \times 10^{-6})} \cdot 9 = 3.6MJ$$

Heat of Vaporization of He = 2.5KJ/l

During a quench, $R$ goes from 0 to $\sim 100\Omega$,
$I\sim 100A$, so $P=I^2R\sim 1MW$

**: A quench can boil off $3.6MJ/2.5KJ/l=1400/l$ of Helium
in $3.6MJ/1MW \sim 3.6s$ !!!**

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Main Field ($B_0$)

Wavelength ($\lambda$) of RF:

In Vacuum:
5m @ 60MHz (1.5T)
1m @ 300MHz (7T)

In Brain:
12cm @ 300MHz (7T)$^1$

When $\lambda$ is not large compared to object, standing waves form. This is referred to as Dielectric Resonance. RF inhomogeneity during receive is fixed by scaling, but RF transmit inhomogeneity is much more difficult to address.

$^1$Vaughan et al, MRM 46 p24 2001

Gradient Fields

$$G_X = \frac{\partial B_Z}{\partial X} \quad G_Y = \frac{\partial B_Z}{\partial Y} \quad G_Z = \frac{\partial B_Z}{\partial Z}$$

How big do gradient fields need to be?
- Shortest soft tissue $T_2^*$ ~ 1ms
- For 0.2mm resolution in 1ms:
  $$G = \frac{K_{\text{max}}}{\gamma T} = \frac{(0.5/0.2\text{mm})}{(4257\text{Hz}/G)(1\text{ms})} = 5G/cm$$

- To fill $1m^3$ with 5G/cm gradients in 0.2ms requires:
  $$P = \frac{E}{T} = \frac{1/2\mu_0 \int B^2 dV}{T} = \frac{1/2\mu_0 (B_{\text{RMS}}(5G/cm))^2(1m^3)}{0.2\text{ms}} \approx 500KW \rightarrow \text{About 3 simultaneous Rolling Stones concerts}$$

- Modern gradient systems are also up against dB/dt limits for peripheral nerve stimulation (~50T/s)
- For diffusion or ultrashort $T_2^*$ imaging, more G would help a lot

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RF Fields

How big do RF fields need to be?

- Shortest soft tissue $T_2^* \sim 1\text{ ms}$
- To flip spins by 90° (0.25 rotations) in 0.2\text{ ms}:
  \[
  B_1 = \frac{0.25}{\gamma T} = \frac{0.25}{(4257\text{ Hz}/G)(0.2\text{ ms})} = 0.24G
  \]

- RF power absorption by the body is a complex function of frequency, conductivity, and geometry, but at 0.24G, approximately 200W/Kg are deposited in human tissue at 3T. Thus, for a 100Kg person, the RF system must supply 20KW of deposited power, or about 40KW of total power, assuming 50% losses to the coil, cabling, reflections, and radiation.

Prescan

Adjustments:
1. Center Frequency
2. Transmit Gain
3. Receive Gains
4. Shim