Field Gradients – Uses in NMR

BCMB/CHEM 8190
Pulsed Field Gradients – NMR Applications


Magnetization vectors precess at different rates depending on \( G(z) \) and \( \gamma \) for each volume element. They dephase - net \( M_x, M_y = 0 \).
Effects of Gradients can be Refocussed
Application: Water Suppression

Resonance not affected by 90 refocuses

Resonance affected by 90 dephases (H₂O)
1D $^1$H Water-Suppressed Spectrum

$Pf$-Rubredoxin in $^1$H$_2$O
Coherence Selection Using Pulse Field Gradients

- \( H(r) = -\sum_k \gamma_k [B_0 + B_z(r)] I_{kz} \) (in radians s\(^{-1}\) and neglecting chemical shifts)
- Effects on product operators for a z gradient:
  - \( I_{kz} \rightarrow -\gamma_k B_z(z) I_{kz} \tau \)  
  - \( I_{k+} \rightarrow -\gamma_k B_z(z) I_{kz} \tau \exp[i \gamma_k B_z(z) \tau] I_{k+} \)
  - \( I_{k-} \rightarrow -\gamma_k B_z(z) I_{kz} \tau \exp[-i \gamma_k B_z(z) \tau] I_{k-} \)
- For linear gradients \( B_z(z) = G_z z \)
- Observables are integrals over z – zero for \( I_{k+}, I_{k-} \)
Gradient Selected HSQC

\[ \sigma_{mn}(t2) = \text{Integral}_z \{ \sigma_{mn}(t1) \exp[i\gamma_N G_1 z] \exp[-i\gamma_H G_2 z] \} \]

\[ = \text{Integral}_z \{ \sigma_{mn}(t1) \exp[i(\gamma_N 2G_1 z - \gamma_H G_2 z)] \} \]

\[ \sigma_{mn}(t2) \text{ finite only if } \gamma_N 2G_1 = \gamma_H G_2 \]

All 1Q proton transverse magnetization eliminated
Translational Diffusion Constants for Macromolecules

- Determine aggregate size
- Determine protein-protein interactions
- Screen for bound ligands

\[<(X_1-X_0)^2> = nDt \quad \text{where} \quad D = \frac{kT}{6\pi \eta r}\]

- Key: if molecule moves, field is different, magnetization doesn’t refocus
Stejskal and Tanner Pulse Sequence for Diffusion Measurement

\[
\ln\left[\frac{S}{S_0}\right] = -\gamma^2 g^2 D \delta^2 (\Delta - \delta/3)
\]
Diffusion Measurement Continued

- Measurements are limited by natural $T_2$
- Improved sequence uses $z$ storage
  (Altieri, Hinton and Byrd, 1995)

![Graph showing the relationship between $\ln(S/S_0)$ and $g^2$ for large and small molecules.](image-url)
The Nobel Prize in Physiology or Medicine 2003

"for their discoveries concerning magnetic resonance imaging"

Paul C. Lauterbur  
Sir Peter Mansfield
Simple Imaging Strategy

- During gradient spins in each volume element have their own precession frequency
- Can get a 1D image of sample – used in gradient shimming
Simple 2D Image

- For 2D imaging use gradients in different directions (x, z) in different evolution periods (t1, t2)
Echo Planar Imaging – Speeding up Acquisitions

- t2 will have spatial image (needs to be reversed in even dw)
- t1 can sample a number of different properties
- t1 could have a gradient in another dimension – 2D map
- t1 could sample chemical shift dispersion - MRSI
Magnetic Resonance Spectroscopy Imaging (MRSI) 

Prostate Cancer 
B- Spectral Grid 
C- MRSI Array 

Swanson et al. 
Cancer Investigation 19, 510-523 (2001)
Vascular Architecture can be Imaged

Figure 1. Rat hindquarters using a contrast agent injected into the blood stream. 7T system. (Varian website)
Mn$^{2+}$ Enhanced MRI of Mouse Brain

- **Figure 1.** Typical horizontal (left), sagittal (center), and axial (right) cuts from a $T_1$-weighted spin-echo 3D-MEMRI of a mouse brain. Resolution is approximately 100 μ. 11.7T system. (Lee, Silva, Merkle, Koretsky, (2005) *Mag. Res. In Med.* **53**, 640-648.)
Visualizing Implanted Stem Cells

These cells are labeled with iron oxide nano-particles and cells have been injected into a mouse heart. Data are from a 7T MRI system.

(Kustermann et al. (2005) *NMRIn Biomedicine*, 18, 362-370)
MRS in Monitoring Disease Progression: a Mouse Model of Alzheimer’s Disease

Figure 1. Changes in brain metabolites as a function of age. 9.4T study on 18μL voxels. Myoinositol is also seen in APP-PS1 mice. (Marjanska,…, Ugurbil, Garwood, (2005) PNAS 102, 11906-11910.)