

MAGNETIC RESONANCE IMAGING

Physics

"Nuclear Magnetic Resonance"
discovered independently by Bloch & Purcell

"Classical Descriptions" (full desc. requires QM)

atoms w/ odd # protons and/or neutrons

Spin angular momentum

$$\vec{S} = \hbar \vec{I}$$

\uparrow ← spin quantum number
 $\frac{\text{Planck's const}}{2\pi}$



magnetic dipole moment $\vec{\mu} = \gamma \vec{S}$

← gyromagnetic ratio

charged spinning sphere = $\gamma \hbar \vec{I}$

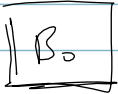


Atoms? ^1H , ^{31}P , ^{23}Na , ^{13}C
most abundant "Spins"

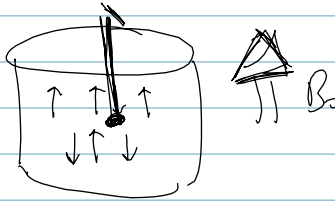
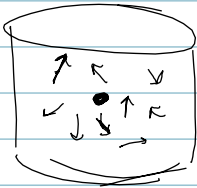
Magnetic Fields



- B_0 - static, v. strong
- B_1 - radio frequency
- $G_{x,y,z}$ - spatial encoding



Polarization: achieves macroscopic magnetization



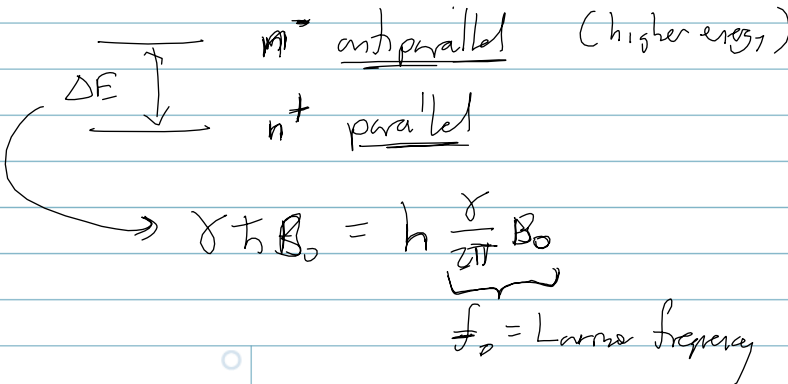
$$\begin{aligned} \text{energy } \vec{\mu} \text{ in } \vec{B}_0 &= -\vec{\mu} \cdot \vec{B} = -\mu_z B_0 \\ &= \pm \frac{\gamma \hbar B_0}{2} \end{aligned}$$

$$= -\gamma \hbar I B_0$$

↑

$$I = \pm \frac{1}{2}$$

two energy states



Boltzmann distribution \swarrow energy diff

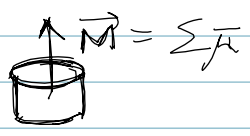
$$\frac{n^-}{n^+} = e^{-\frac{\Delta E}{kT}}$$

\nwarrow absolute temperature
 \swarrow Boltzmann const

@ ^1H , Room Temp, 1.5 T

$$\frac{n^-}{n^+} \approx 0.999993$$

"weak" polarization
basis for almost all
MRI.



Establishes Resonance Condition

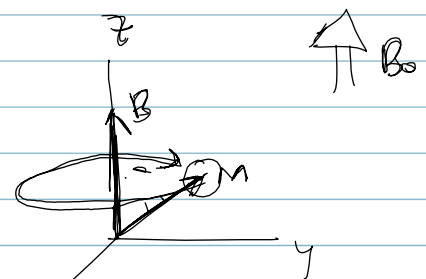
@ equilibrium $\vec{M} \parallel \vec{B}_0$

If $\vec{M} \not\parallel \vec{B}_0$ there is an induced torque

$$\frac{d\vec{M}}{dt} = \vec{M} \times \gamma \vec{B}$$

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⊙ out of the board
 $\vec{M} \times \vec{B}$
 ⊙ is preserved

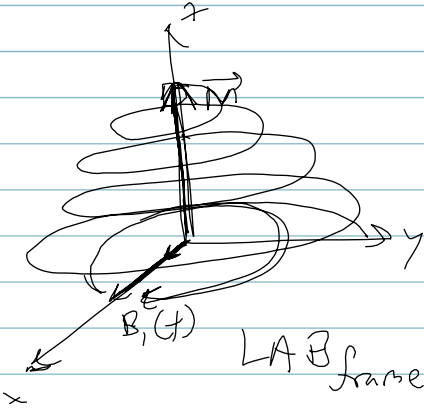


frequency is $\gamma |\vec{B}| = f_0$

$$\frac{\gamma}{2\pi} = 42.58 \text{ MHz/T}$$

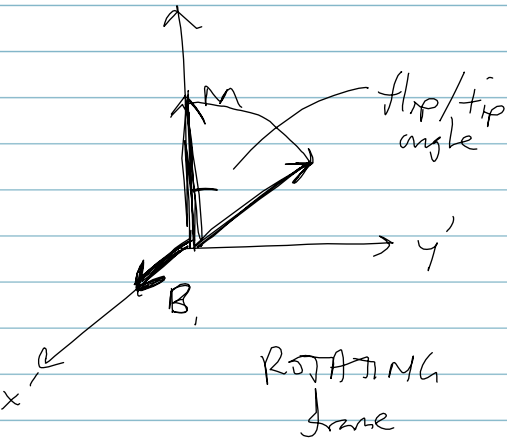
B_0 provides polarization & resonance conditions

$|B_1|$ radiofrequency $\times B_0$ to excite nuclei to states



apply rotates $B_1(t)$ in the transverse plane at f_0

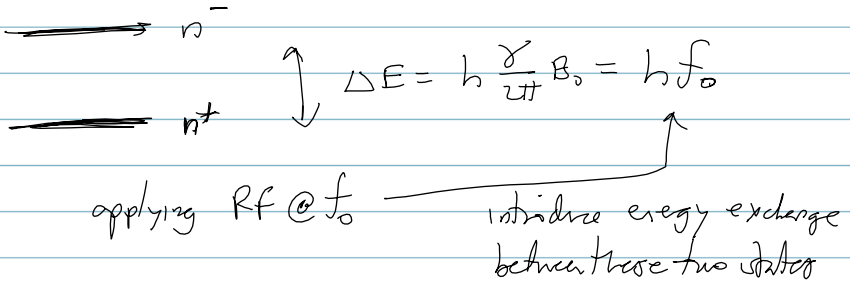
perturb nuclei



x', y' rotates @ f_0

$$\frac{d\vec{M}_{rot}}{dt} = \vec{M}_{rot} \times \gamma(\vec{B}_{eff})$$

another look:



yet another look:

