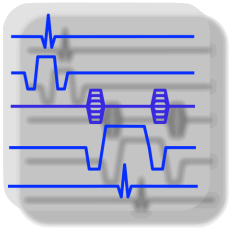


Principles of MRI

EE225E / BIO265

Lecture 08

Instructor: Miki Lustig
UC Berkeley, EECS

Spin, Magnetic Moment and Magnetization

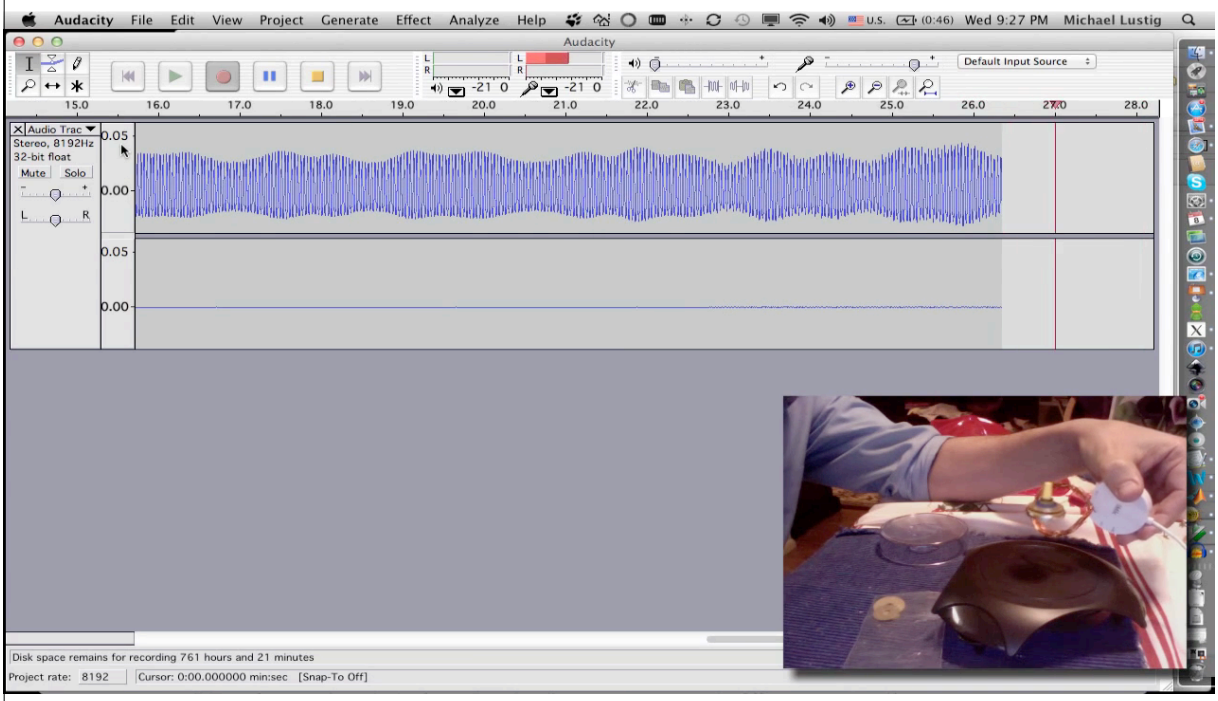
- Nuclei with Odd # protons/Neutrons posses spin angular momentum

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

- Associated with S is a magnetic moment

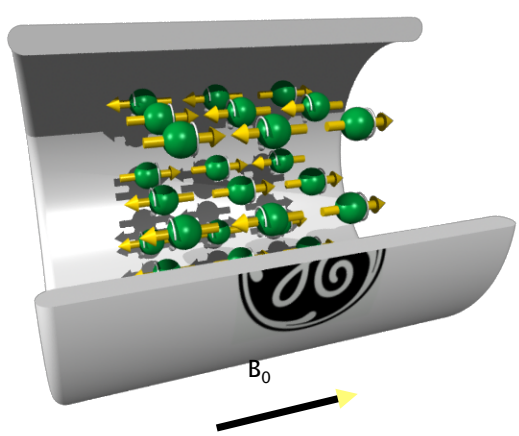
$$\mu = \gamma \hat{S} = \gamma \hbar \hat{I}$$

Demonstration of Magnetic Resonance



Spin, Magnetic Moment and Magnetization

- In a strong magnetic field B0, spins align with B0 giving a net magnetization
- Magnetic Moment is produced
- $$M = \sum \mu$$



*Graphic rendering Bill Overall

$$E = -\mu \cdot B = -\mu_z B_0 = -\gamma S_z B_0$$

potential ENERGY

No xverse component

S_z IS QUANTIZED to $\hbar I_z \Rightarrow I_z = \pm \frac{1}{2}$

(1) $-\gamma \hbar B_0 \frac{1}{2}$

(2) $-\gamma \hbar B_0 \left(-\frac{1}{2}\right)$

$$\Delta E = \frac{\gamma}{2\pi} h B_0$$

Zeeman SPLITTING

NO FIELD SINGLET STATE

TWO POPULATIONS n_+ ||

n_- anti ||

JUMP BETWEEN STATES DUE TO THERMAL ENERGY

$$\frac{n_-}{n_+} = e^{-\frac{\Delta E}{kT}} \approx 0.999993$$

BOLTZMAN DISTRIBUTION

CAN BE SHOWN:

$$M_0 = \frac{N \gamma^2 \hbar^2 I_z (I_z+1) B_0}{3kT}$$

(1) LINEAR WITH FIELD

(2) QUADRATIC WITH γ

(3) LINEAR WITH # PROTONS

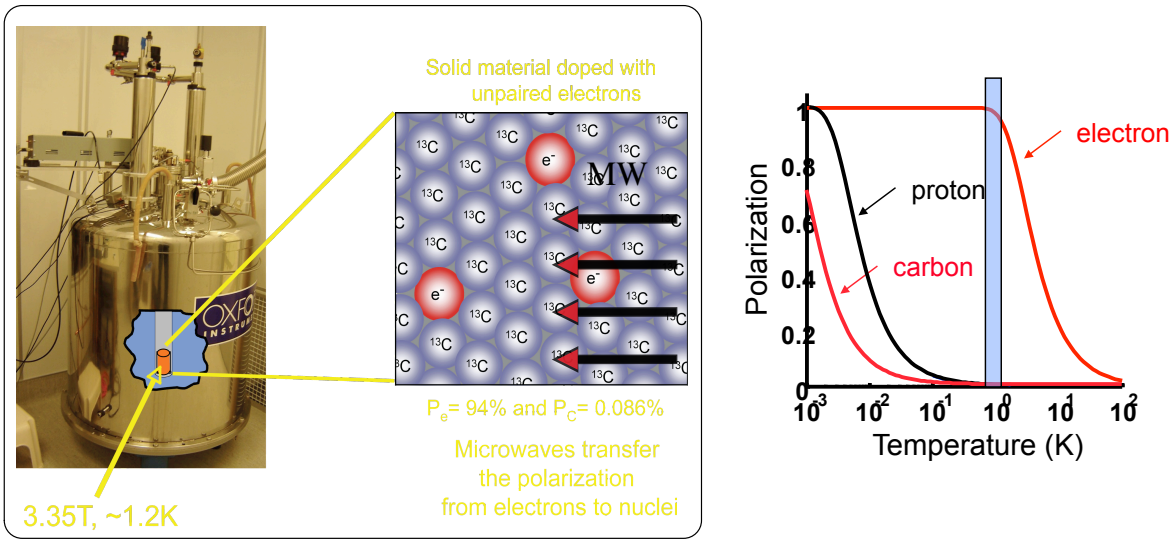
Increase in signal-to-noise ratio of >10,000 times in liquid-state NMR

Jan H. Ardenkjær-Larsen*, Björn Fridlund, Andreas Gram, Georg Hansson, Lennart Hansson, Mathilde H. Lerche, Rolf Servin, Mikkel Thaning, and Klaes Golman

Amersham Health Research and Development AB, Medeon, SE-205 12 Malmö, Sweden

Communicated by Albert W. Overhauser, Purdue University, West Lafayette, IN, June 20, 2003 (received for review April 16, 2003)

PNAS **September 2, 2003** vol. 100 no. 18 **10158–10163**



Slide: Simon Hu, UCSF

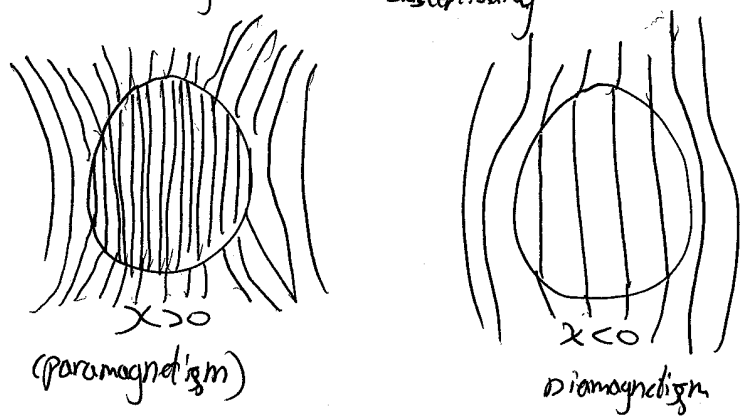
MAGNETISM

MOST OBJECTS DISPLAY INDUCED MAGNETISM

APPLY FIELD ⇒ MAGNETIC MOMENT

$$M_{induced} = \mu_0^{-1} V \chi B$$

magnetic permiability — volume — magnetic susceptibility — magnetic field.



WHERE DOES IT COME FROM?

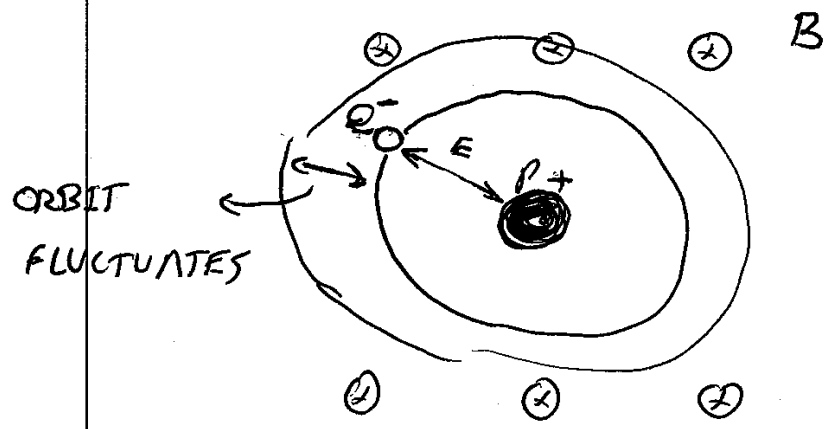
(i) circulation of ELECTRIC CURRENTS

(ii) MAGNETIC MOMENT OF e^-

(iii) MAGNETIC MOMENT OF NEUCLEI

(i) + (ii) >>> (iii)

(i) EXPLAINED BY CLASSICAL PHYSICS



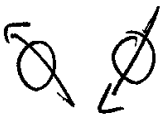
CONTRIBUTES TO DIAMAGNETISM.

(ii)+(iii) INTRINSIC MAGNETISM

$$\hat{\mu} = \gamma \hat{S}$$

$$|\gamma_e| \gg |\gamma_p|$$

EFFECT (ii) CANCELS IN MOST MATERIALS DUE TO PAIRED ELECTRONS



EFFECT ($\hat{I}$) IS HUGE!!!

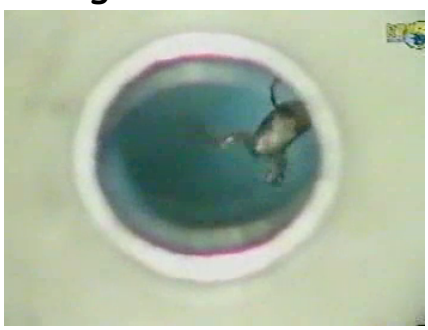
MACROSCOPICALLY, JUST CHANGES BULK MAGNETIC ~~MOMENT OF~~ FIELD

$\chi_{water} \simeq -9 \cdot 10^{-6}$ $\qquad$ $\chi_{proton} \approx 4 \cdot 10^{-9}$

$\Downarrow$

No Precession $\qquad$ Precession!

Diamagnetic Levitation example:



CHEMICAL SHIFT

$\hookrightarrow$ BUT ($\hat{I}$) HAS MICROSCOPIC EFFECT

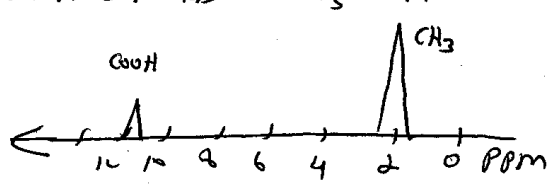
$$B_{eff} = B_0 - B_0 \chi = B_0 (1 - \chi)$$

$$\omega_{eff} = \omega_0 (1 - \chi)$$

$$\delta \rightarrow \text{CHEMICAL SHIFT} = \frac{\omega_s - \omega_{reference}}{\omega_{reference}} \times 10^6$$

FOR EXAMPLE:

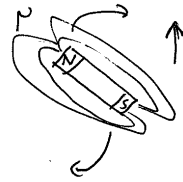
ACETIC ACID CH_3COOH



DIRECTION IS $\leftarrow$ HISTORICAL

OXIGEN ATTRACTS ELECTRONS

PRECESSION



$\uparrow B$ (1) TORQUE $= \mu \times B$

(2) TORQUE $= \frac{\partial S}{\partial t}$ change of angular momentum.

$$\gamma \times \frac{dS}{dt} = \mu \times B \;\; \times\gamma \Rightarrow \frac{d\mu}{dt} = \mu \times \gamma B$$

unit volume $\leftarrow$ $$\frac{dM}{dt} = M \times \gamma B$$

or

$$\frac{dM}{dt} = -\gamma B \times M$$

SOLUTION IS PRECESSION @ $f = \frac{\gamma}{2\pi} B$, $\omega = \gamma B$

$$\frac{dM}{dt} = M \times \gamma B$$

spatial distribution

we have control!