MP 710 – Lecture 3
Sept. 2017

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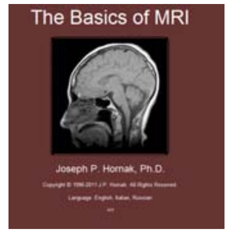
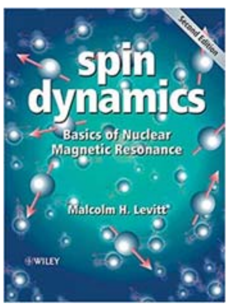
MRI – Selected Online Resources



http://www.cis.rit.edu/htbooks/mri/

https://www.mriquestions.com/index.html

MR Signal – Quantum Mechanics



Is Quantum Mechanics Necessary for Understanding Magnetic Resonance?

LARS G. HANSON

Nuclei with spin – relevant to MR

The shell model for the nucleus tells us that nucleons, just like electrons, fill orbitals. When the number of protons or neutrons equals 2, 8, 20, 28, 50, 82, and 126, orbitals are filled. Because nucleons have spin, just like electrons do, their spin can pair up when the orbitals are being filled and cancel out. Almost every element in the periodic table has an isotope with a non zero nuclear spin. NMR can only be performed on isotopes whose natural abundance is high enough to be detected, however some of the nuclei which are of interest in MRI are listed below.

Nuclei	Unpaired Protons	Unpaired Neutrons	Net Spin	γ (MHz/T)
^{1}H	1	0	1/2	42.58
^{2}H	1	1	1	6.54
^{31}P	1	0	1/2	17.25
^{23}Na	1	2	3/2	11.27
^{14}N	1	1	1	3.08
^{13}C	0	1	1/2	10.71
^{19}F	1	0	1/2	40.08

Source: http://www.cis.rit.edu/htbooks/mri/

31P, 13C, 14N, spectroscopy
13C hyperpolarized gas
23 Na – sodium imaging – 90% extracellular

Abundance

Natural abundance of an isotope is the fraction of nuclei having a given number of protons and neutrons, or atomic weight

Element	Symbol	Natural Abundance
Hydrogen	^{1}H	99.985
	^{2}H	0.015
Carbon	^{13}C	1.11
Nitrogen	^{14}N	99.63
	^{15}N	0.37
Sodium	^{23}Na	100
Phosphorus	^{31}P	100
Potassium	^{39}K	93.1
Calcium	^{43}Ca	0.145

Source: http://www.cis.rit.edu/htbooks/mri/

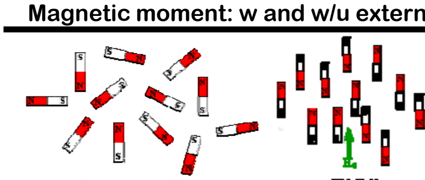
Biological abundance - fraction of one type of atom in the human body

Element	Biological Abundance*
Hydrogen (H)	0.63
Sodium (Na)	0.00041
Phosphorus (P)	0.0024
Carbon (C)	0.094
Oxygen (O)	0.26
Calcium (Ca)	0.0022
Nitrogen (N)	0.015

* Calculated from R.

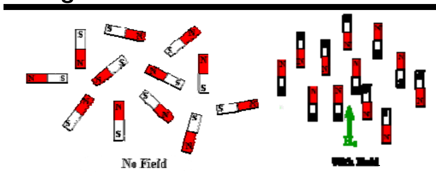
Source: http://www.cis.rit.edu/htbooks/mri/

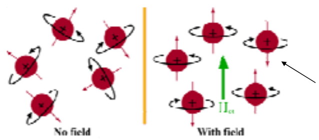
Magnetic moment: w and w/u external field



Source: http://www.mhhe.com/physsci/chemistry/carey/student/olc/ch13nmr.html

Magnetic moment: w and w/u external field

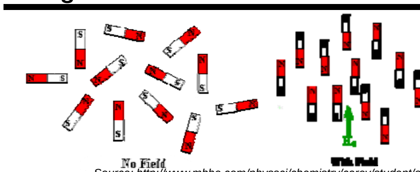




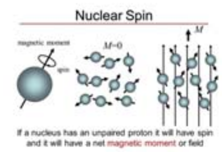
Not really!

Source: http://www.mhhe.com/physsci/chemistry/carey/student/olc/ch13nmr.html

Magnetic moment: w and w/u external field



Source: http://www.mhhe.com/physsci/chemistry/carey/student/olc/ch13nmr.html



Source: https://www.quora.com/How-are-atomic-nuclei-and-magnets-similar

Magnetic Moment in external field

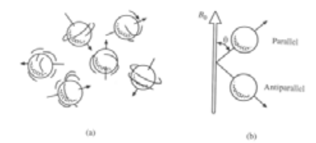
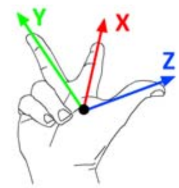
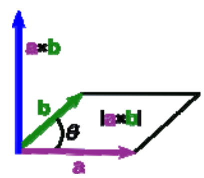


Figure 3.2 Nuclear magnetic moment vectors (a) pointing in random directions and (b) aligned in the direction of an external magnetic field.

Right Hand Rule – Cross Product





R. Hewitt - Original publication: ManufacturingET.org Immediate source: http://www.manufacturinget.org/wp-content/uploads/2011/12/righthandrule.png

Magnetic force on a moving charged particle[edit]
The direction of the cross product may be found by application of the right hand rule as follows: Using your right hand,
Point your index finger in the direction of the first vector A.
Point your middle finger in the direction of the second vector B.
Your thumb will point in the direction of the cross product C.

From http://en.wikipedia.org/wiki/Right-hand_rule

Precession

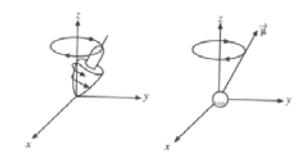


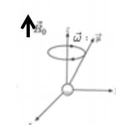
Figure 3.3 Precession of a nuclear spin about an external magnetic field is similar to the wobbling of a spinning top in a gravitational field.

Source:
https://en.wikibooks.org/wiki/Basic_Physics_of_Nuclear_Medicine/MRI_%26_Nuclear_Medicine

'Left Hand Rule'

Right Hand:
Prediction of direction of field (*B*), given that the current *I* flows in the direction of the thumb

From http://en.wikipedia.org/wiki/Right-hand_rule

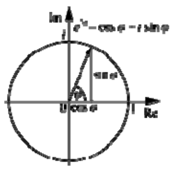


$$\vec{\omega} = -\gamma \vec{B}_0 = -\omega_0 \vec{k}$$

which is known as the Larmor frequency. Second, precession of $\vec{\mu}$ about $\vec{B}_0$ is clockwise if observed against the direction of the magnetic field. In practice, it is easy to determine the precession direction using $\boxed{\text{the left-hand rule}}$. That is, if the left thumb points in the direction of $\vec{B}_0$, nuclear precession follows the direction of other fingers.

In addition to Eq. (3.16), nuclear precession can be described by an angular velocity vector defined as

Euler’s Formula



$$e^{ix} = \cos x + i \sin x$$

Energy level diagram

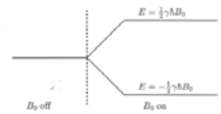
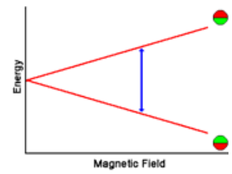


Figure 3.4 Zeeman splitting for a spin-$\frac{1}{2}$ system.



^{1}H MR Spectrum

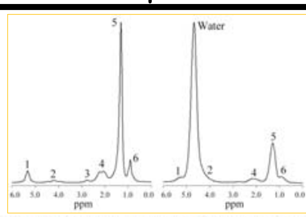
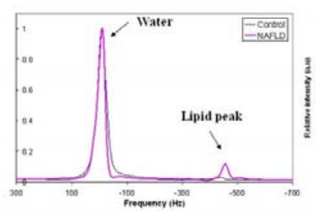


Figure 1. ^{1}H MR spectra (STEAM, TE 20 msec) from an animal fat phantom (left) and in vivo from a human liver (right). The peak assignments are shown in Table 1. In human liver it is not possible to accurately delineate peaks 1 and 2 due to their proximity to the water peak, which is absent in the phantom; also, peak 3 (2.75 ppm) is generally not seen in vivo.

Original Research

Effect of PRESS and STEAM Sequences on Magnetic Resonance Spectroscopic Liver Fat Quantification

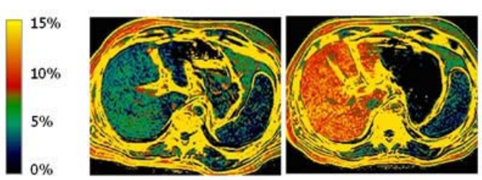
Hydrogen spectrum



Typical proton spectra acquired from the liver (2 minutes) depicting liver water and fat content for a control subject (0.9% lipid) and a NAFLD patient (6.6% lipid).

Source: Newcastle Magnetic Resonance Centre:
http://www.ncl.ac.uk/magres/research/liver/

Fat map



Liver fat maps showing individuals with 4% fat conent and (right) with 9% fat content.

Source: Newcastle Magnetic Resonance Centre:
http://www.ncl.ac.uk/magres/research/liver/

Net magnetization in static field

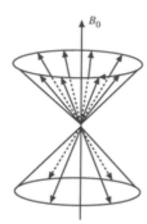


Figure 3.5 Distribution of nuclear magnetic moments observed at an arbitrary time instant. The excess of vectors pointing along the external field is greatly exaggerated.

No net magnetization in xy
random phase
Net magnetization in z

RF system – single TR coil

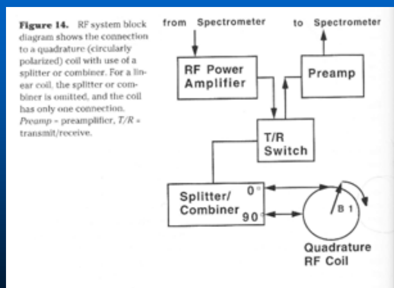


Figure 14. RF system block diagram shows the connection to a quadrature (circularly polarized) coil with use of a splitter or combiner. For a linear coil, the splitter or combiner is omitted, and the coil has only one connection. *Preamp* = preamplifier, *T/R* = transmit/receive.

from McFall, 1997

RF system – separate TR coils

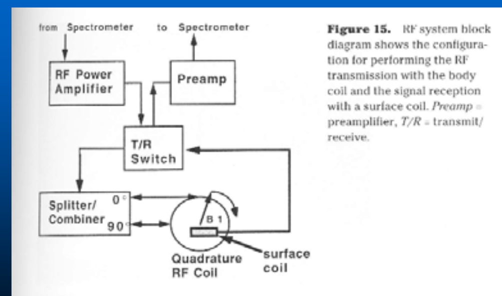


Figure 15. RF system block diagram shows the configuration for performing the RF transmission with the body coil and the signal reception with a surface coil. *Preamp* = preamplifier, *T/R* = transmit/receive.

from McFall, 1997

Birdcage Coil

MR Signal Detection

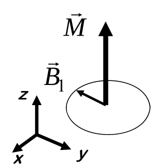
***M*: Magnetization**

$$\vec{M} = M_0 \vec{e}_z$$

f_0: Larmor Frequency

$$f_0 = \frac{\gamma}{2\pi} B_0$$

= 63.86 MHz

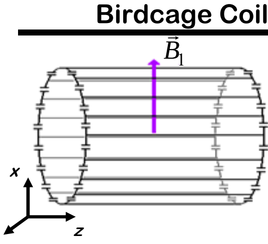


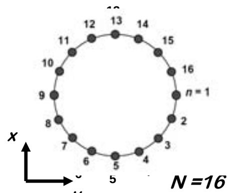
B_1 = Transverse Field

$$B_1(t) = \hat{B}_1 \sin(2\pi f_0 t)$$

$\hat{B}_1$ **= 20 μT = 0.2 G**

Birdcage Coil – RF Excitation





$$J_n = J_s(t) \sin(2\pi(n-1)/N)$$

$$J_s(t) = \hat{J}_s \cos(2\pi f_0 t)$$

Linear birdcage volume coil

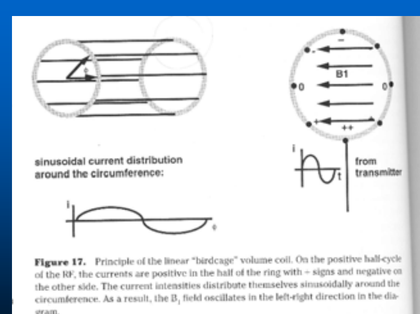
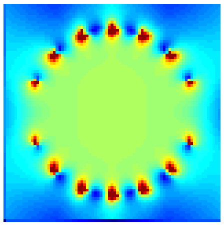


Figure 17. Principle of the linear "birdcage" volume coil. On the positive half-cycle of the RF, the currents are positive in the half of the ring with + signs and negative on the other side. The current intensities distribute themselves sinusoidally around the circumference. As a result, the B_1 field oscillates in the left-right direction in the diagram.

Linear Polarized Field

$\hat{H}$



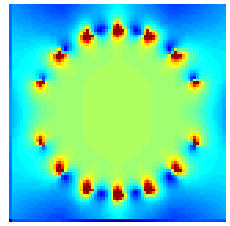
Scale: 0-40 A/m

$$J_n = J_s(t)\sin(2\pi(n-1)/N)$$
$$J_s(t) = \hat{J}_s\cos(2\pi f_0 t)$$

$$\vec{H}(t) = \hat{H}\cos(2\pi f_0 t)\vec{e}_x$$
$$H(t) = \frac{\hat{H}}{2}\left(e^{j2\pi f_0 t} + e^{-j2\pi f_0 t}\right)$$

Linear Polarized Field

$\hat{H}$



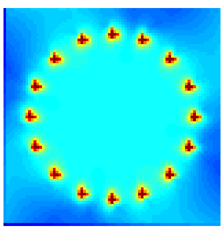
Scale: 0-40 A/m

Alternative names for B [T]
•Magnetic flux density •Magnetic induction •Magnetic field
Alternative names for H [A/m]
•Magnetic field strength •Magnetic field intensity •Magnetic field •Magnetizing field *Depends on material*

$$\vec{H}(t) = \hat{H}\cos(2\pi f_0 t)\vec{e}_x$$
$$H(t) = \frac{\hat{H}}{2}\left(e^{j2\pi f_0 t} + e^{-j2\pi f_0 t}\right)$$

Circular Polarized Field

$\hat{H}$



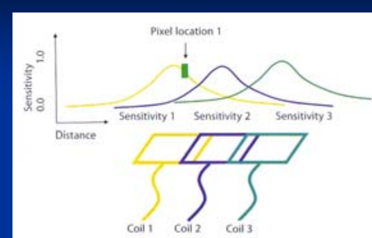
Scale: 0-40 A/m

$$J_n = J_{A,n} + J_{B,n}$$
$$J_{A,s}(t) = \hat{J}_s\cos(2\pi f_0 t)$$
$$J_{B,s}(t) = \hat{J}_s\sin(2\pi f_0 t)$$

$$\vec{H}_x(t) = \hat{H}\cos(2\pi f_0 t)\vec{e}_x$$
$$\vec{H}_y(t) = \hat{H}\sin(2\pi f_0 t)\vec{e}_y$$
$$H(t) = \hat{H}e^{j2\pi f_0 t}$$

Alexey Samsonov, PhD, UW Madison

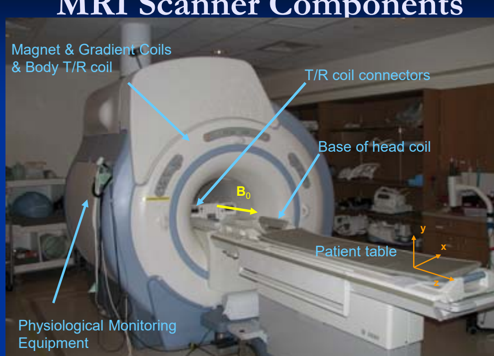
Multichannel Reception



- Receive channels a.k.a. receivers, coil elements
- Elements sensitive to signal from limited regions
  - depth of penetration is on the order of the coil diameter

Parallel Imaging in Clinical MR Applications, Springer, 2007

MRI Scanner Components



MR Coils

MR Coils

MR Coils

MR Coils

Total Digital Imaging (TDI)

The SIGNA™ Architect offers startling advances in imaging and a total imaging win with TDI.

GE's **Direct Digital Interface (DDI)** employs an independent analog-to-digital converter to digitize inputs from each of 128 RF channels, eliminating unnecessary noise enhancement.

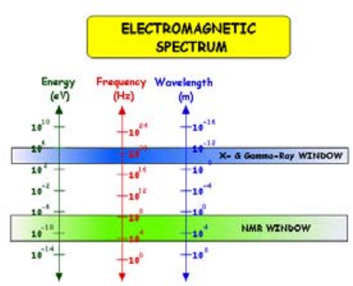
Digital Micro Switching (DMS) technology represents a revolutionary advance in RF coil design by replacing analog blocking circuits with intelligent Micro Electro-Mechanical Switches (MEMS).

The SIGNA™ Architect comes prepared for **Digital Surround Technology (DST)**. DST combines signals from every coil element. The exceptional SNR and sensitivity of the high-density surface coils are combined with the superior homogeneity and deeper signal penetration of the integrated RF body coil.

http://www3.gehealthcare.com/en/products/categories/magnetic_resonance_imaging/3-0t/signa_architect

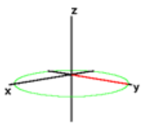
GE - Air Coils

NMR Window in EM spectrum



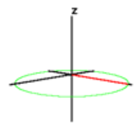
Source:
https://en.wikibooks.org/wiki/Basic_Physics_of_Nuclear_Medicine/MRI_%26_Nuclear_Medicine

Rotating frame of reference



Rotating frame

Faster than rot frame



slower than rot frame

Spin packet