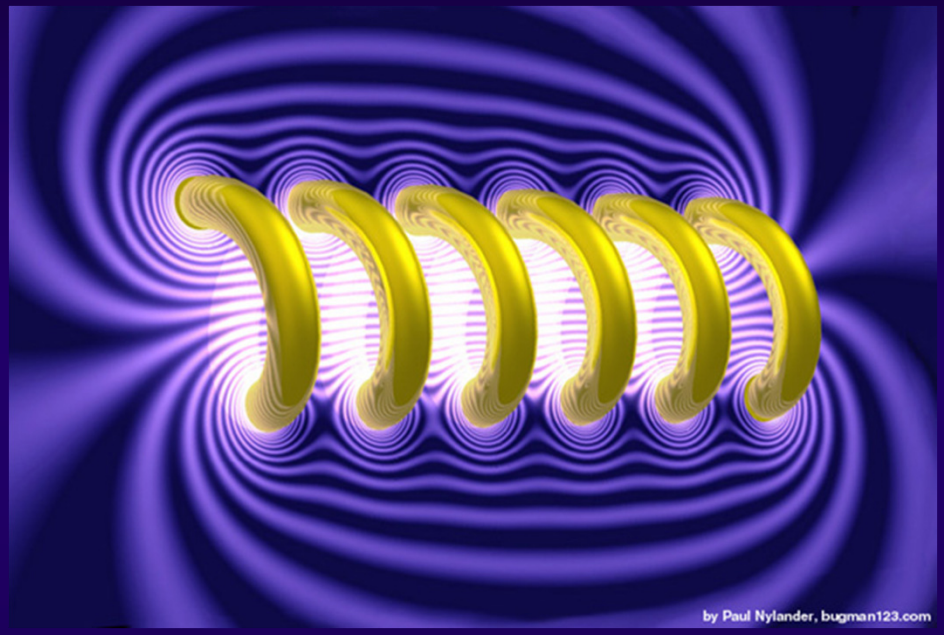
Magnetic Resonance Imaging

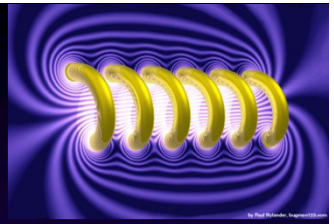


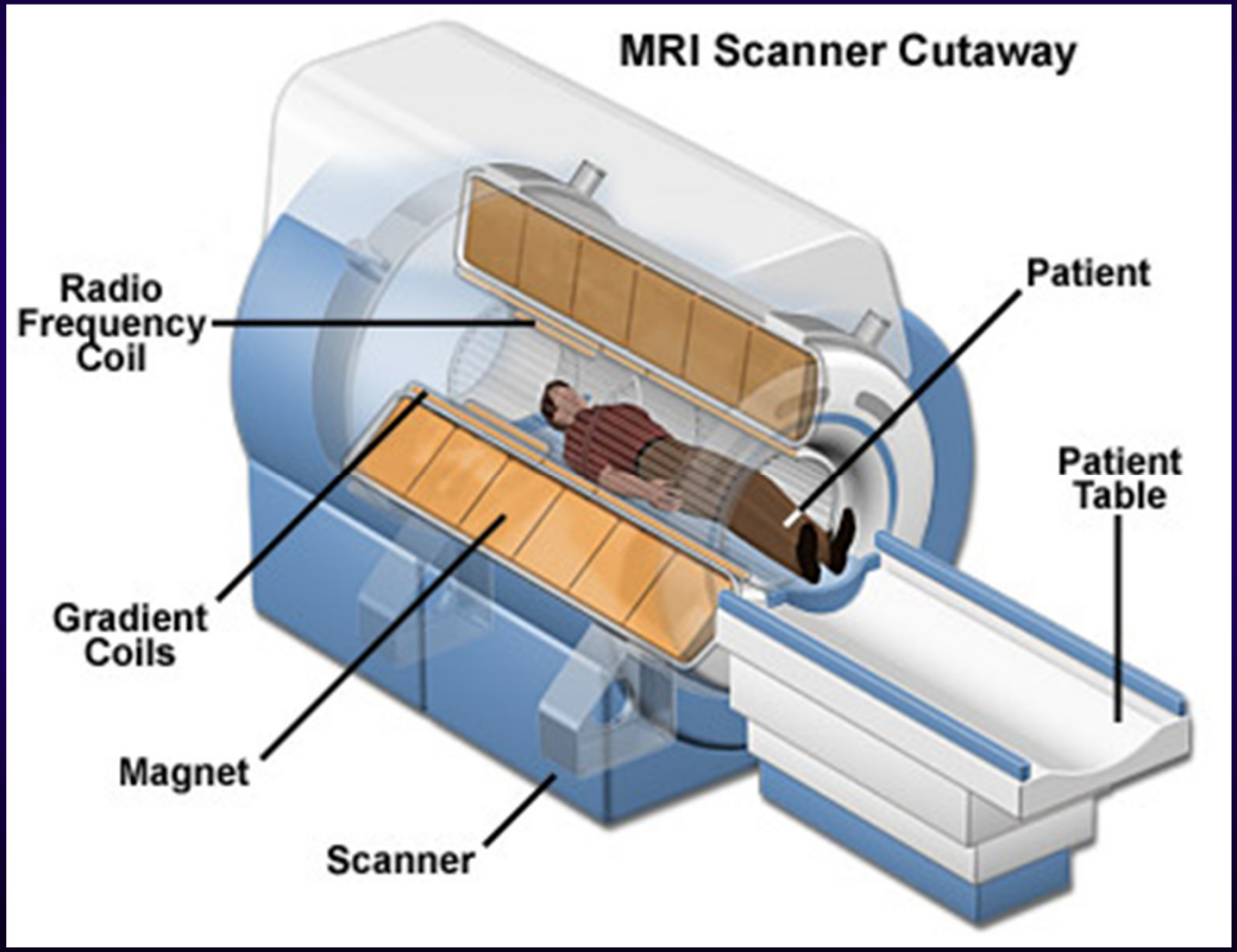
BME 4401 Medical Imaging

Instructor: Dr. Anuradha Godavarty

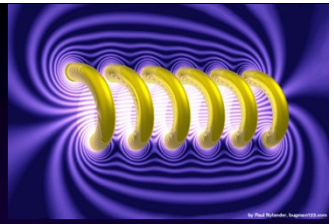
Lecturer: Dr. Sarah Erickson

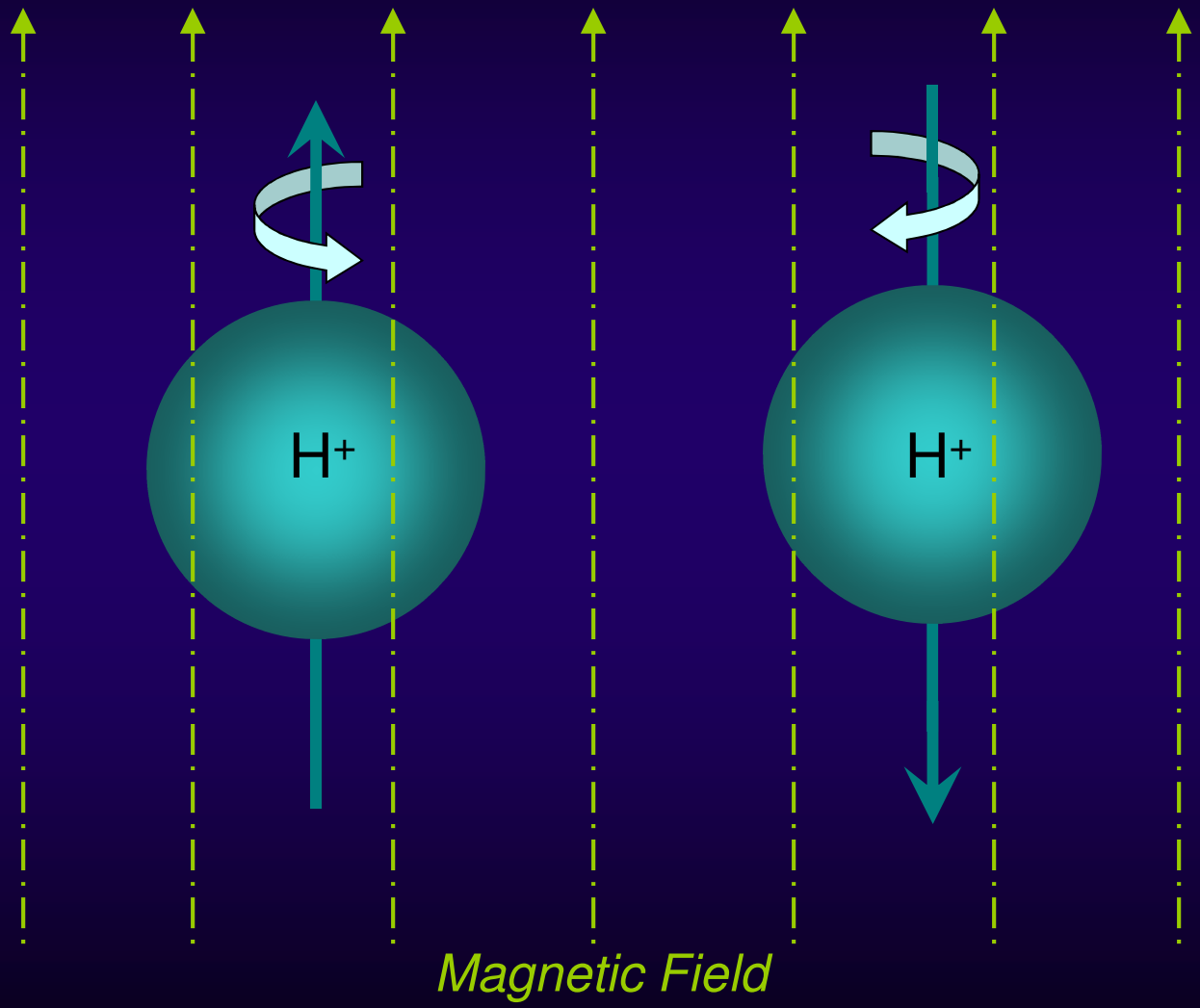
MRI Instrumentation



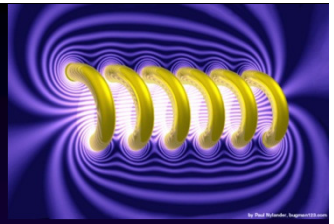


Magnetic Moment and Precession





Analogy: Spinning Top

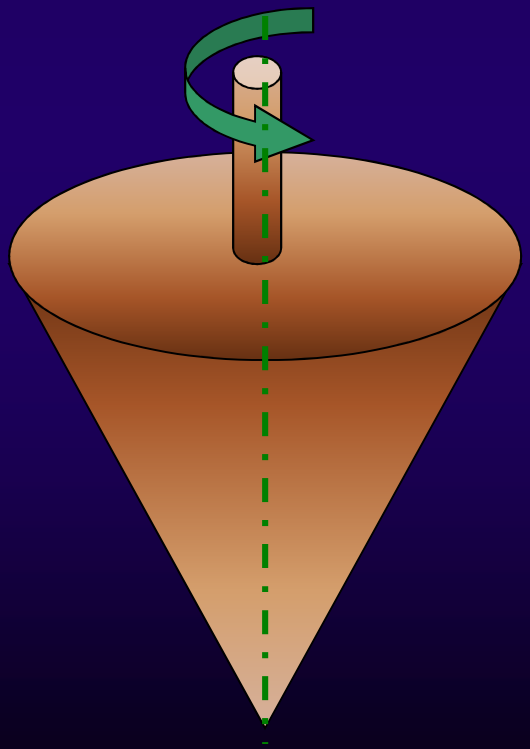


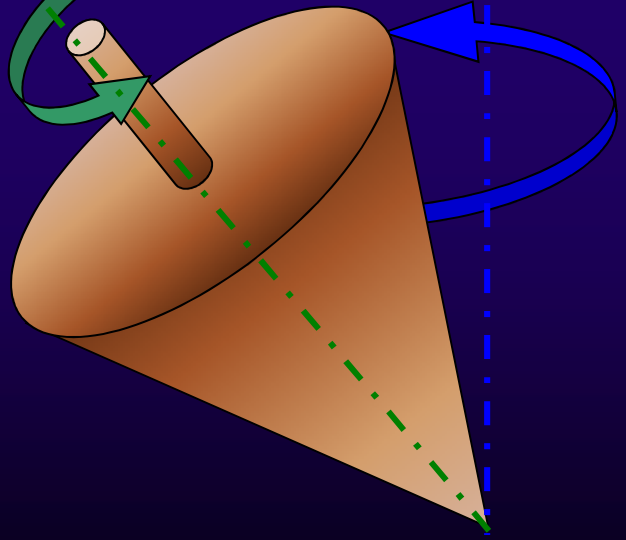
$\Delta\theta$ = Nutation

Rotation

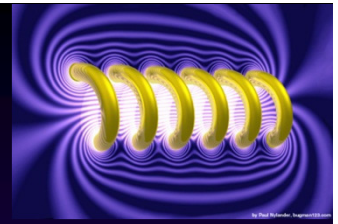
θ

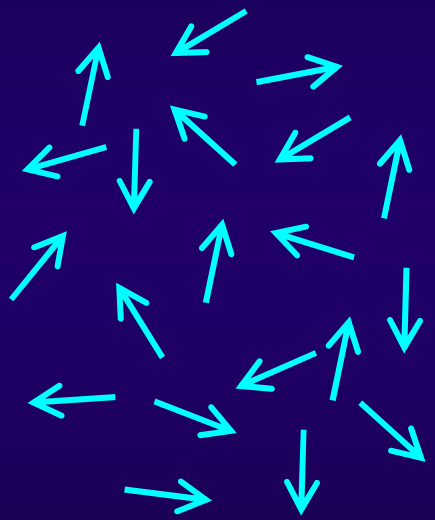
Precession



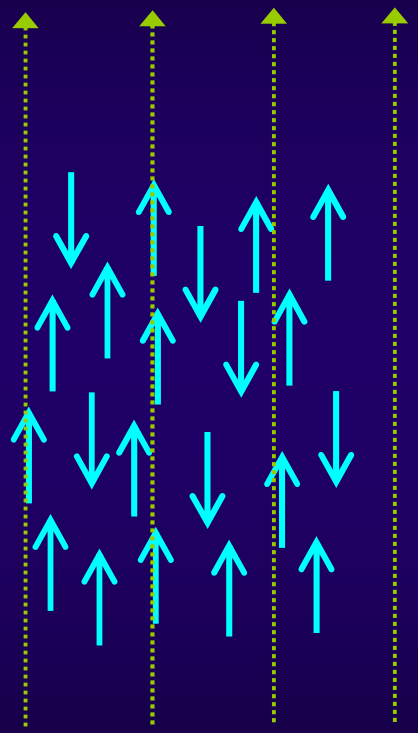


Alignment and Nutation

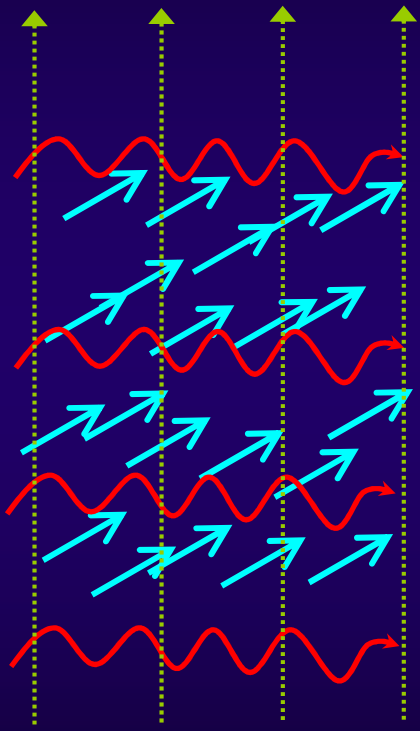




Random Initial State

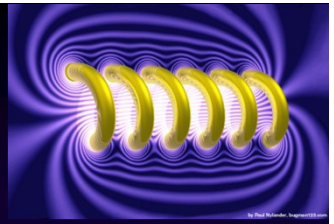


B-Field



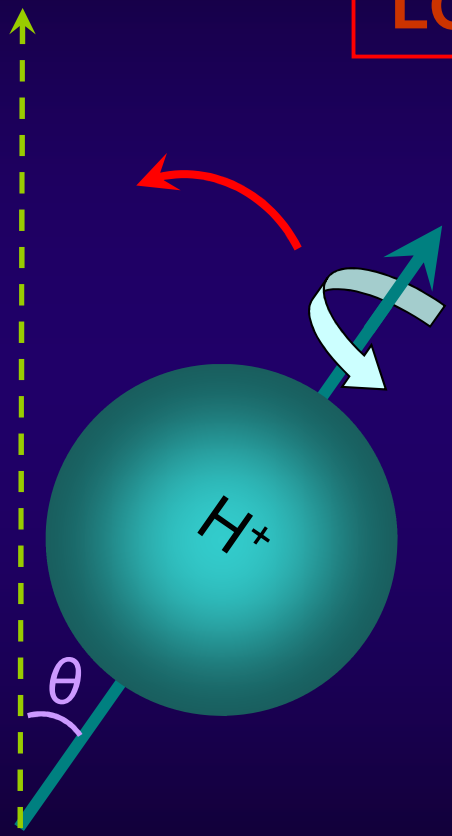
RF Signal

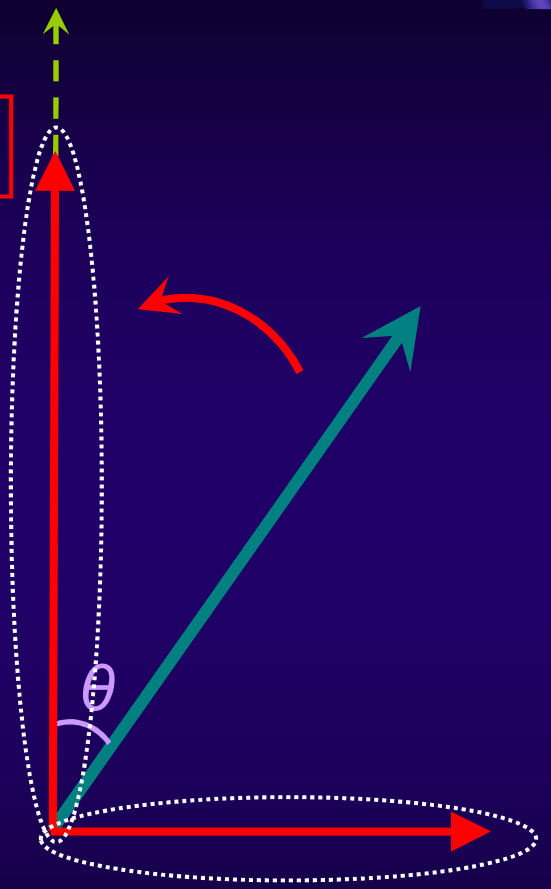
Relaxation



LONGITUDINAL

(T1)



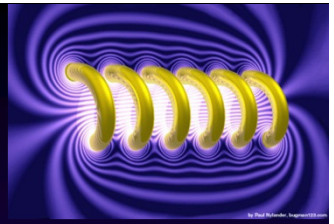


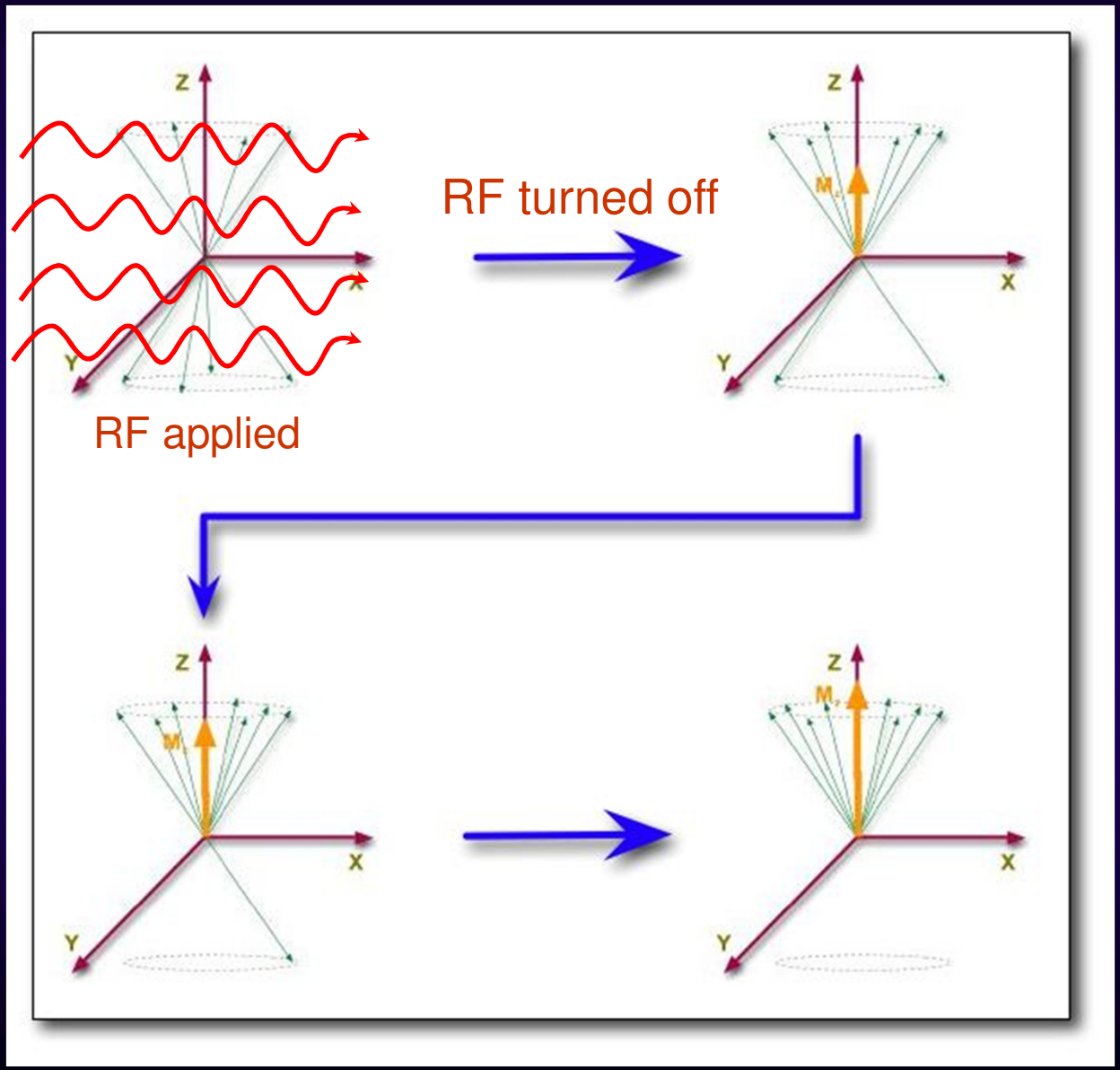
TRANSVERSE

(T2)

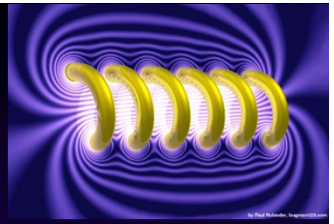
T1 > T2

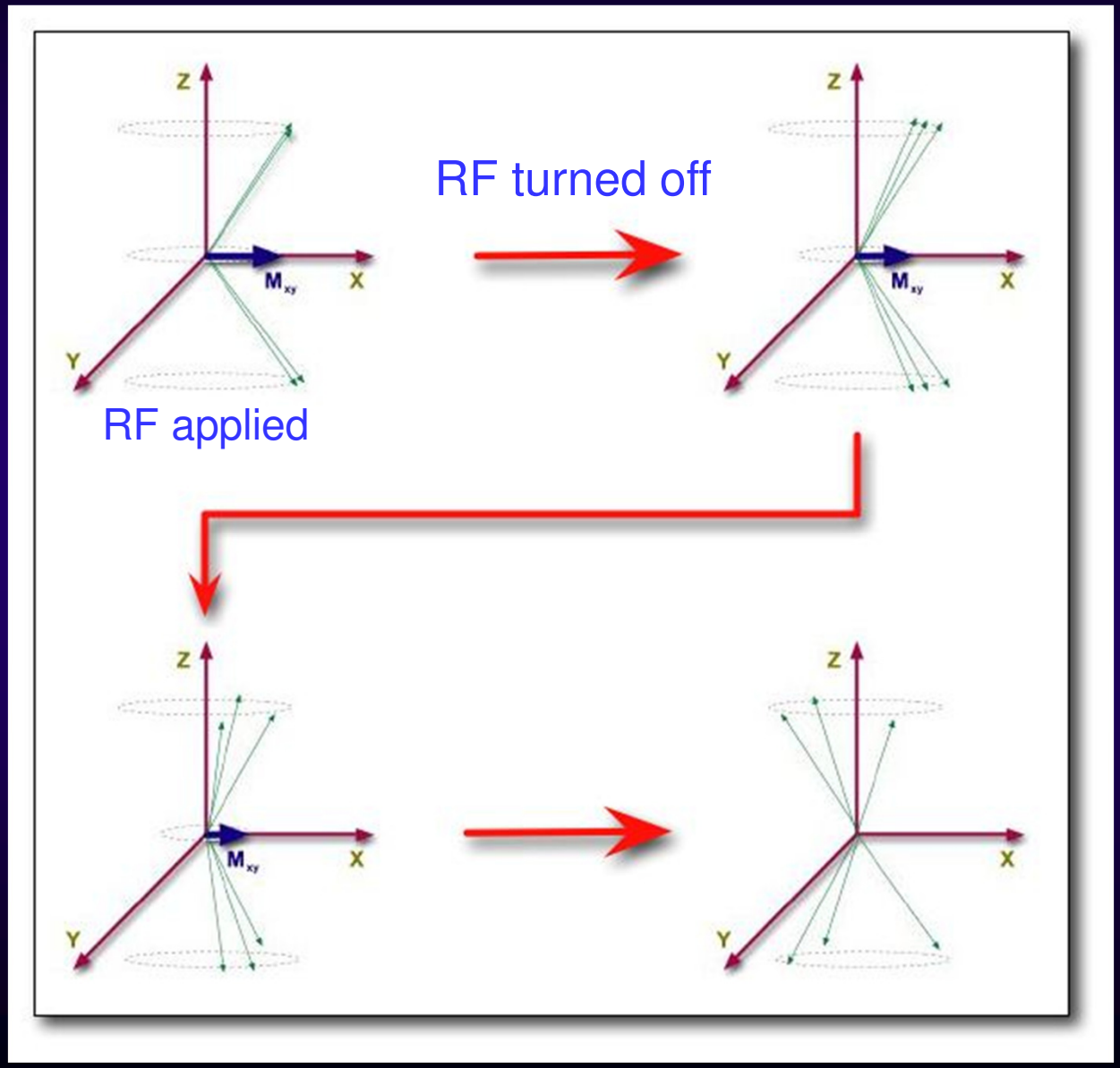
Longitudinal Relaxation



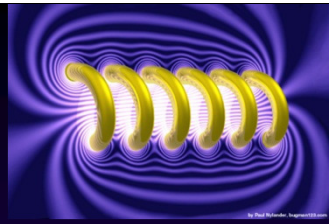


Transverse Relaxation



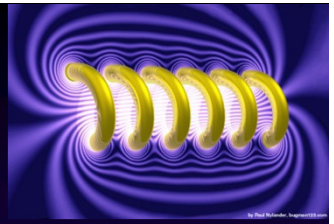


Brain Tissue Relaxation Times



ORGAN	T1(ms)	T2 (ms)
Thalamus	703 +/- 33	75 +/- 4
Cortical gray matter	871 +/- 73	87 +/- 2
Superficial white matter	515 +/- 27	74 +/- 5
Cerebrospinal fluid	1900 +/- 353	250 +/- 3

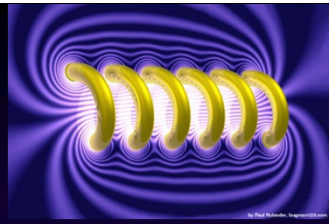
T1 and T2 Values @ 1.5 Tesla

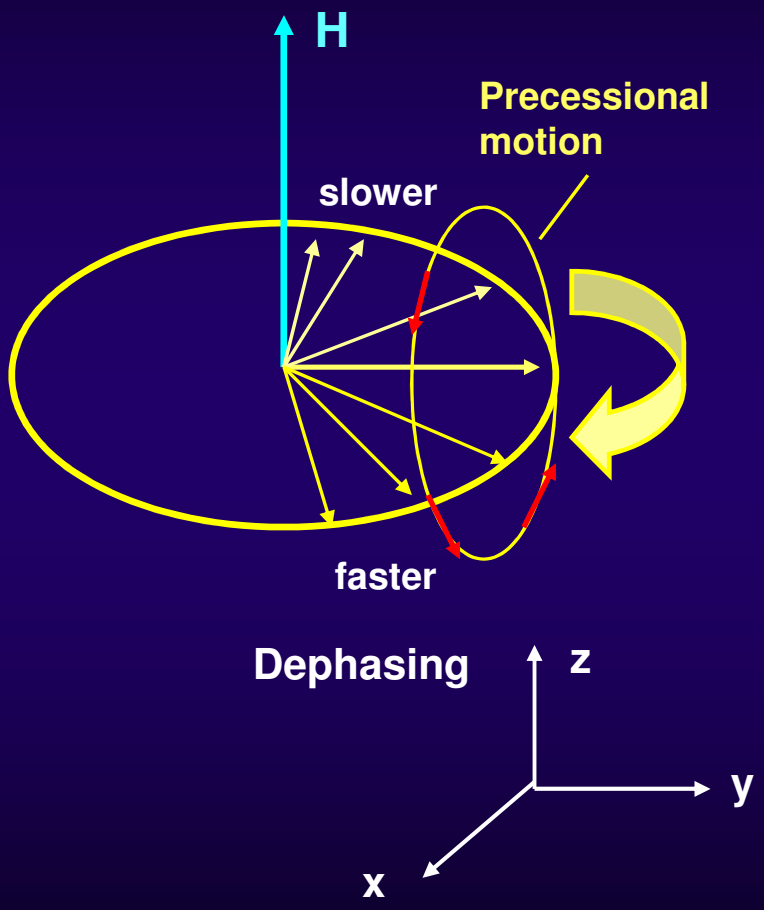


Tissue	T1 (ms)	T2 (ms)
Muscle	870	47
Liver	490	43
Kidney	650	58
Grey Matter	920	100
White Matter	790	92
Lung	830	80
CSF	2,400	160

T1 > T2

Spin Echo Technique





Used to compensate for dephasing in T2 relaxation.

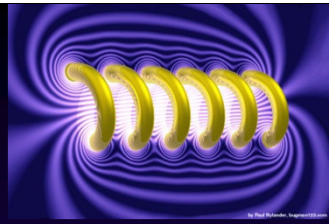
Caused by inhomogeneities in B-field and spin-spin interactions.

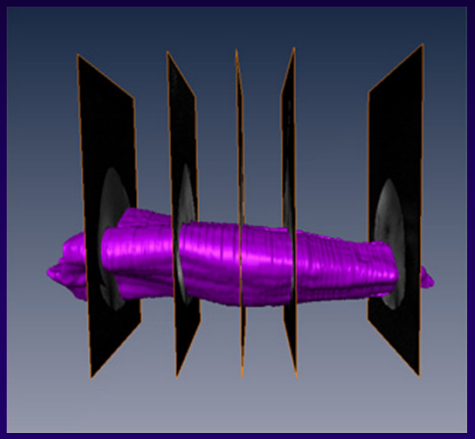
Dephasing results in differences in Larmor frequency and loss of signal.

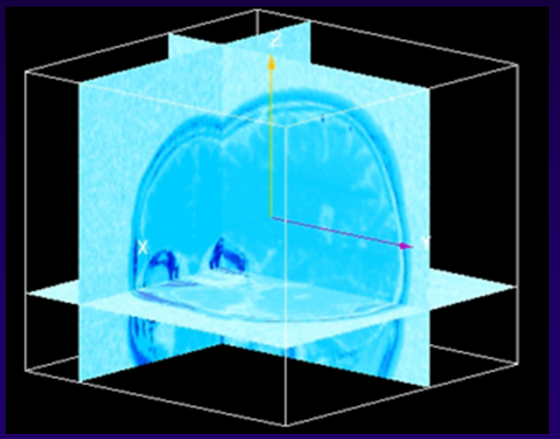
Spin-echo technique improves the signal by reducing loss.

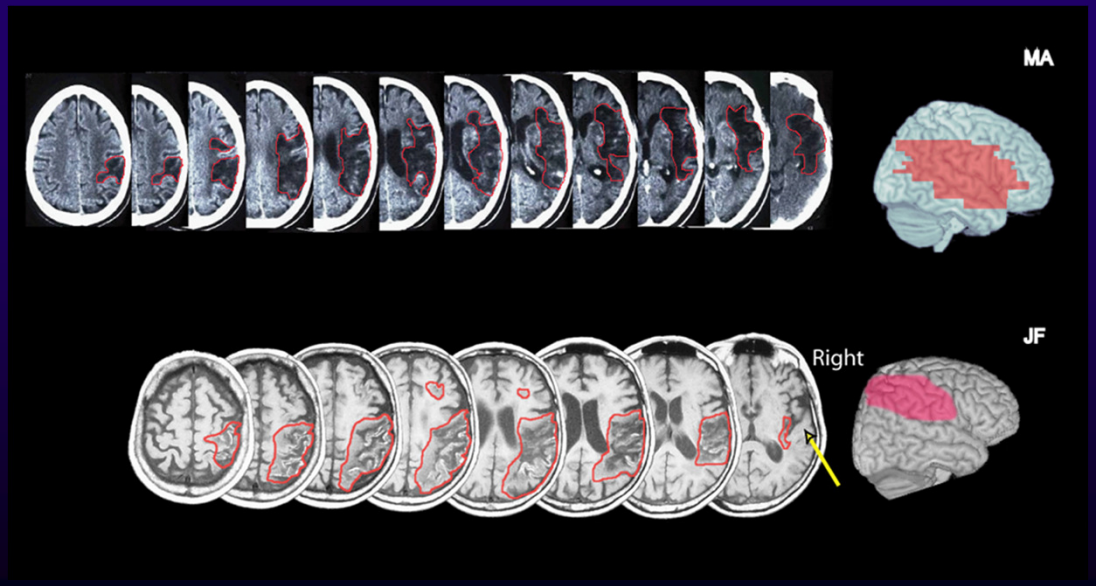
http://www.youtube.com/watch?v=FxyiH2TjQvI

MRI Slices

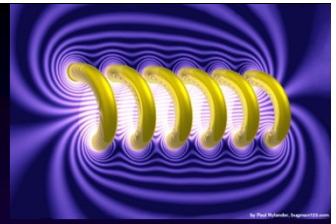


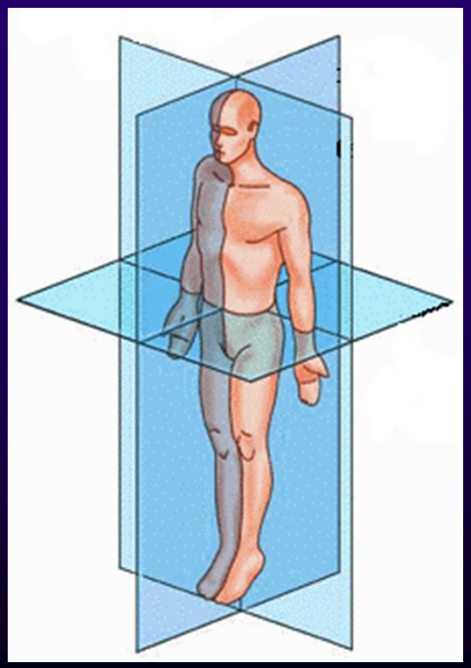


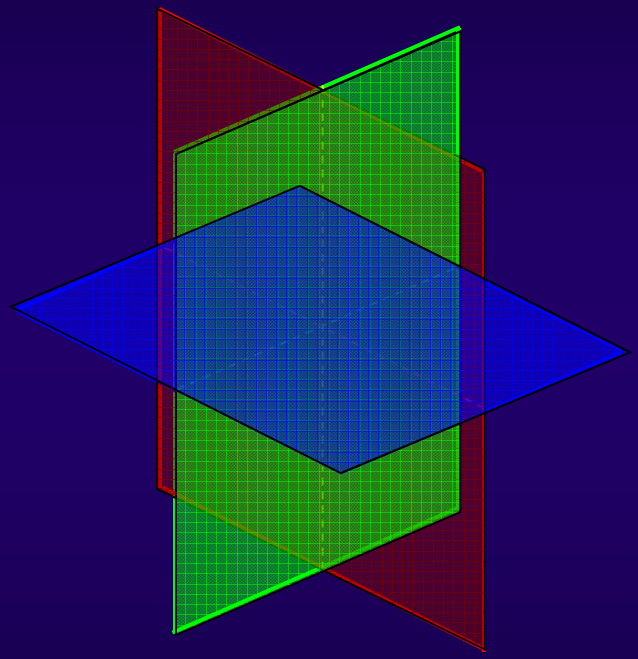




Imaging Sections





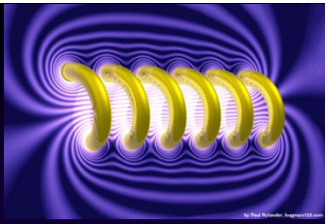


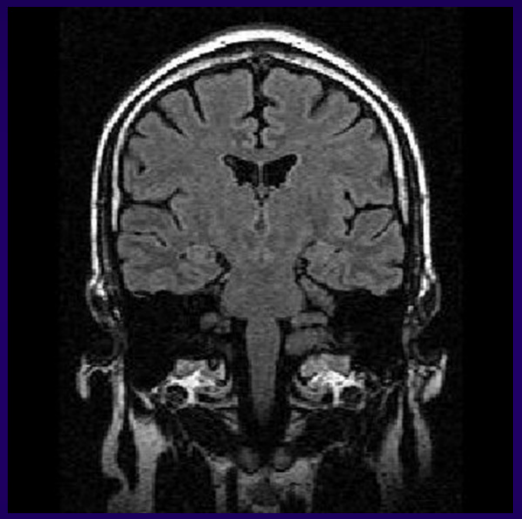
Gz: transversal slice

Gy: coronal slice

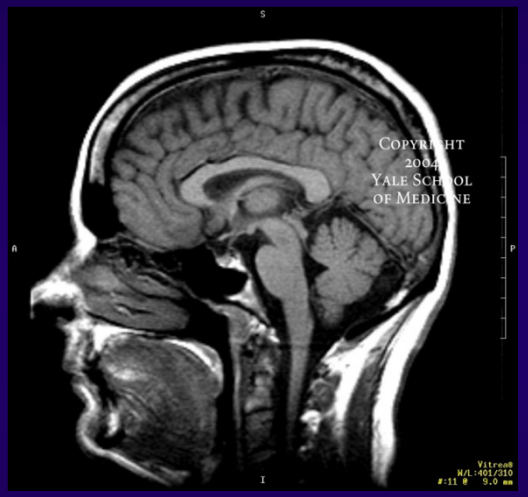
Gx: sagittal slice

MRI Brain Image Sections

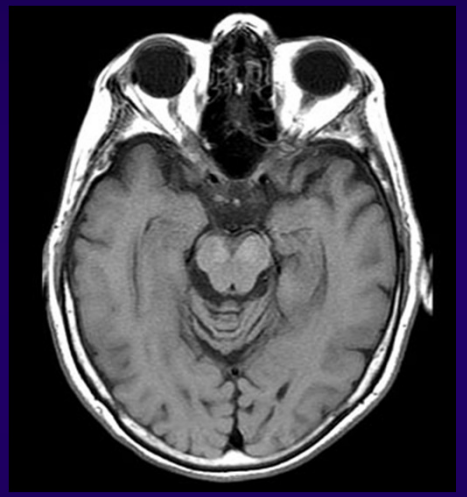




Coronal



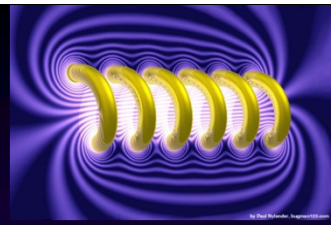
Sagittal

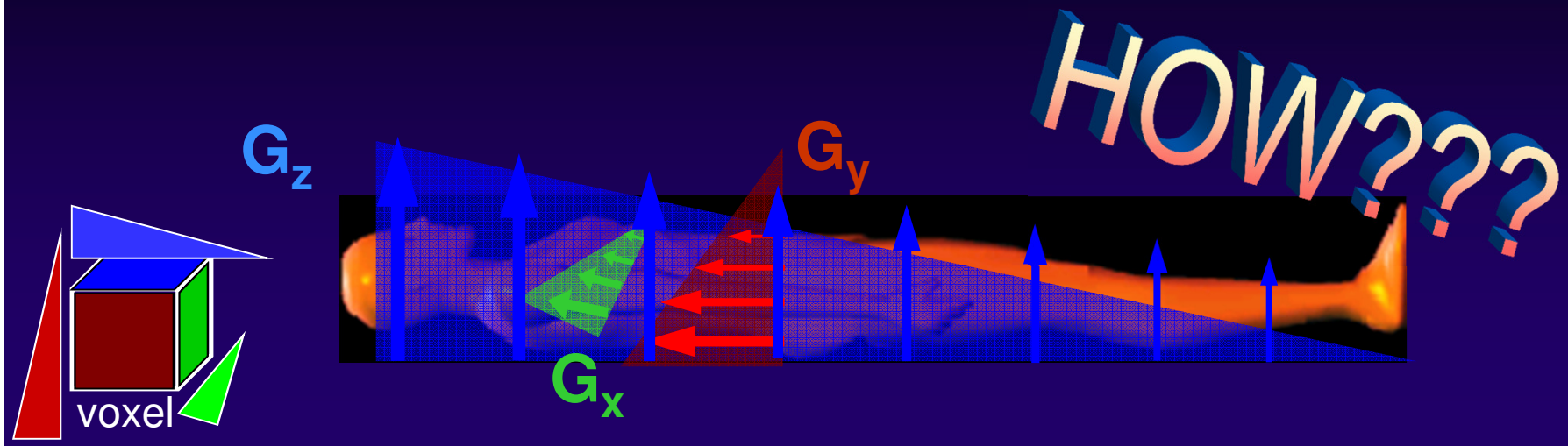


Transversal

(axial)

Spatial Encoding of MR Signals

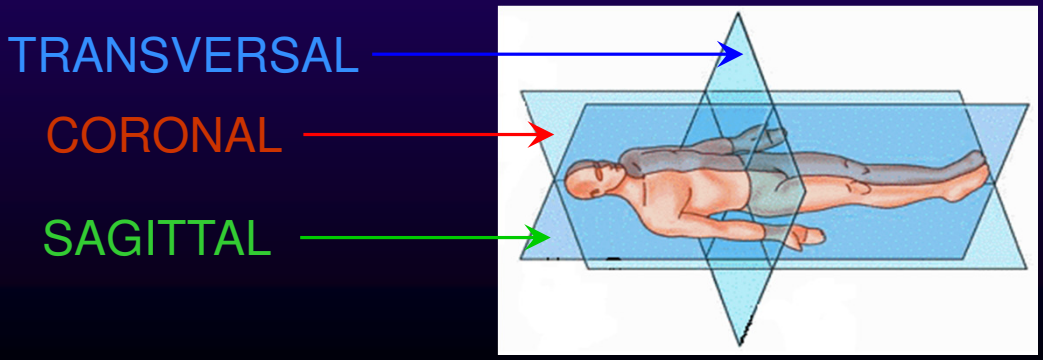




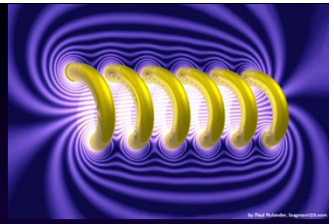
Gz: *Cranial-caudal gradient defines a transversal slice*

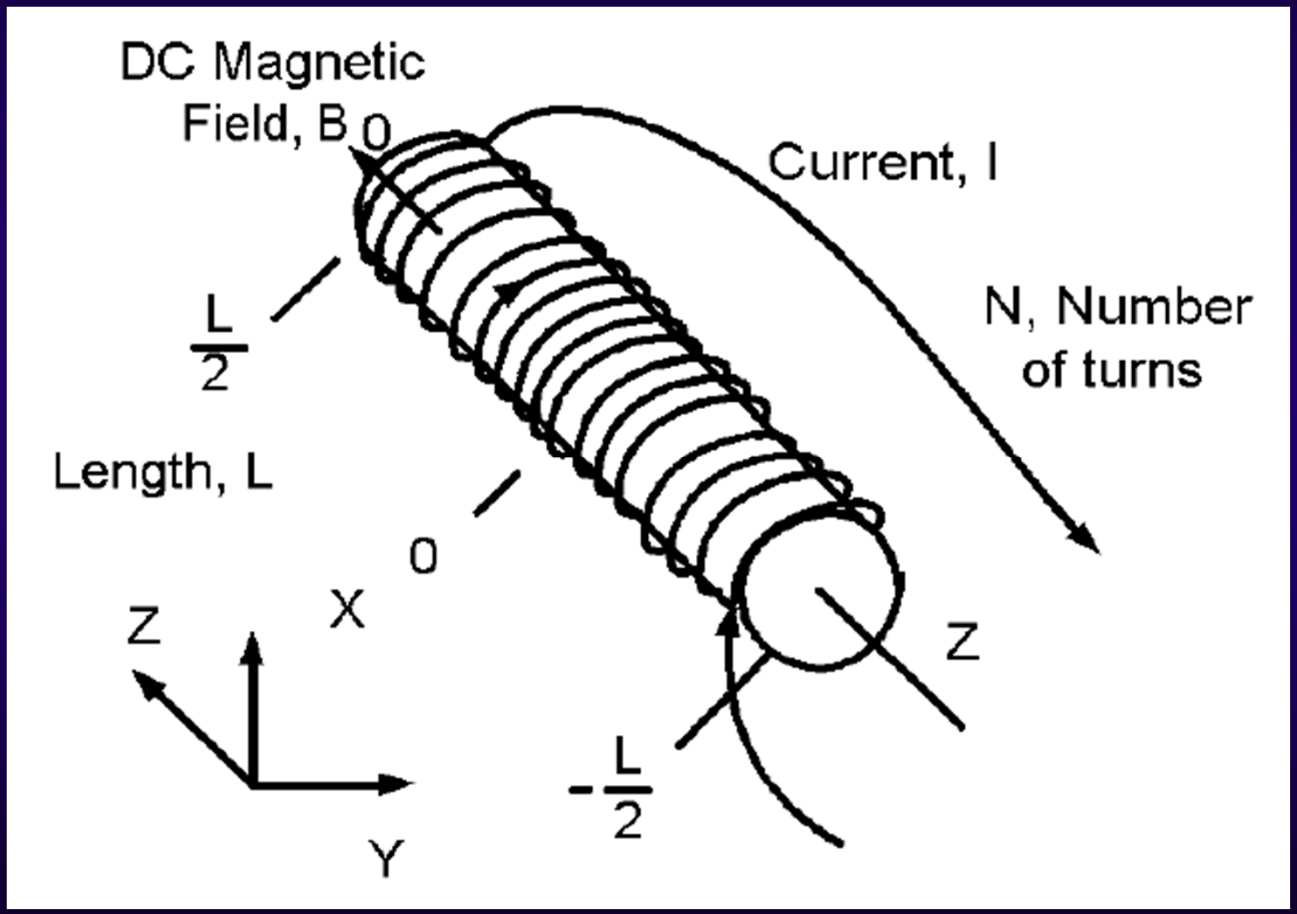
Gy: *Dorsal-ventral gradient defines a coronal slice*

Gx: *Left-right gradient defines a sagittal slice*

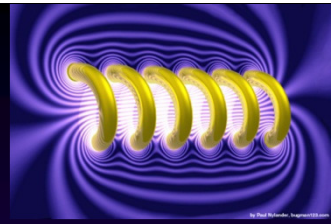


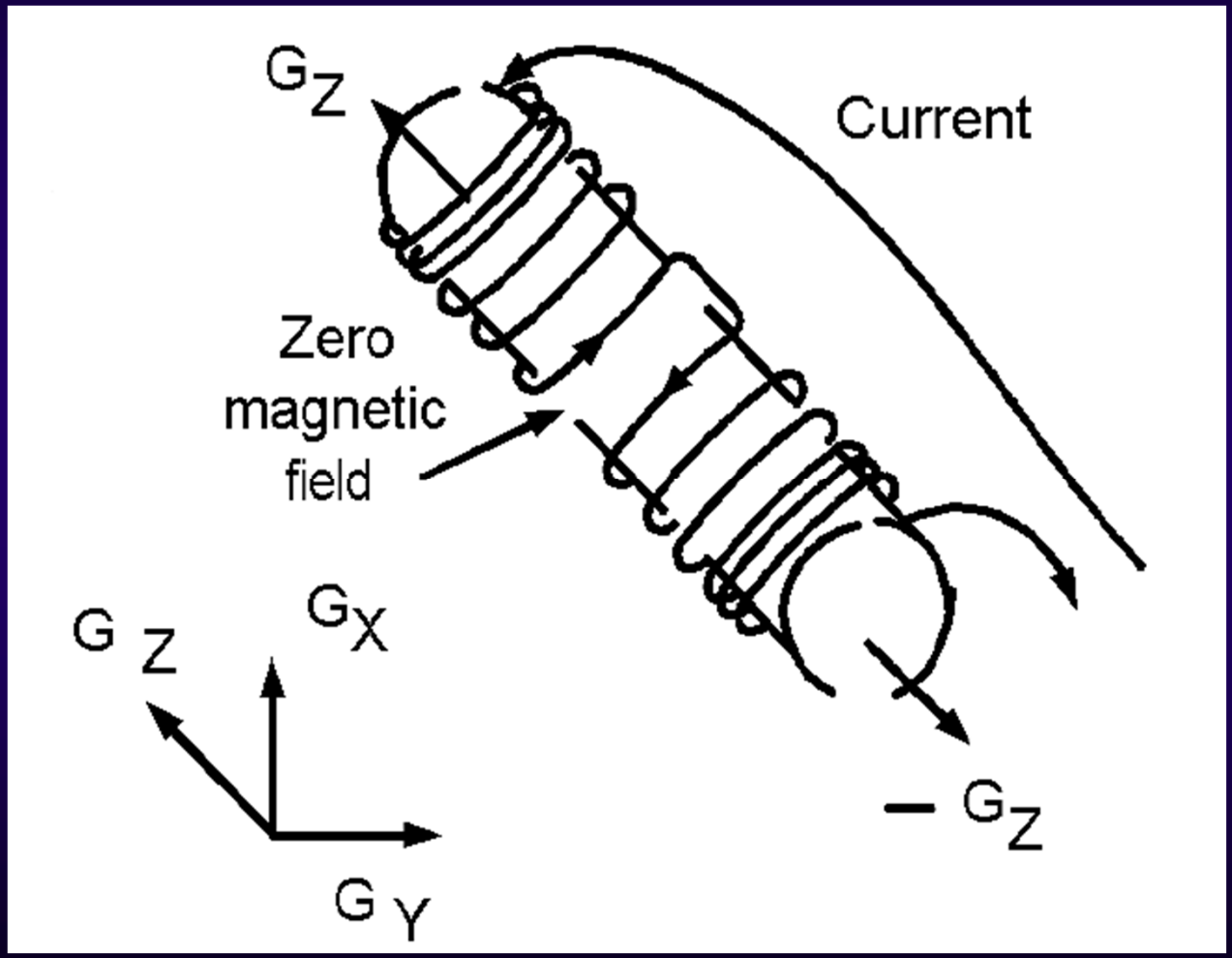
DC Magnetic Field Coil



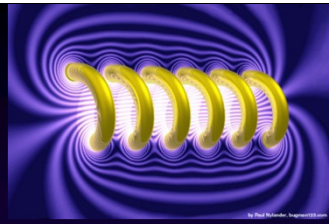


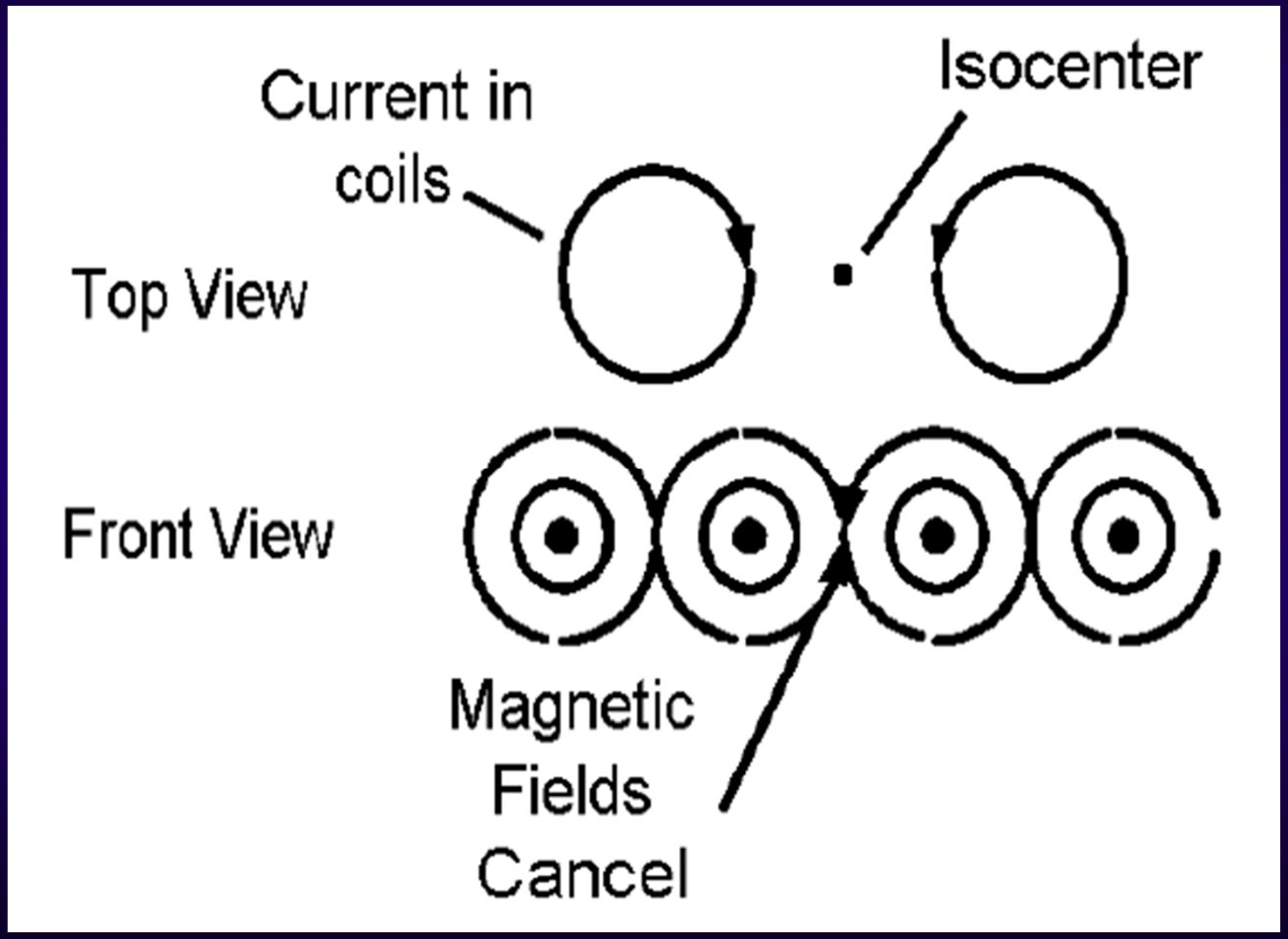
Z-Direction Magnetic Field Gradient



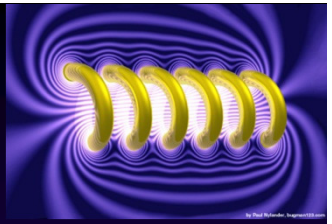


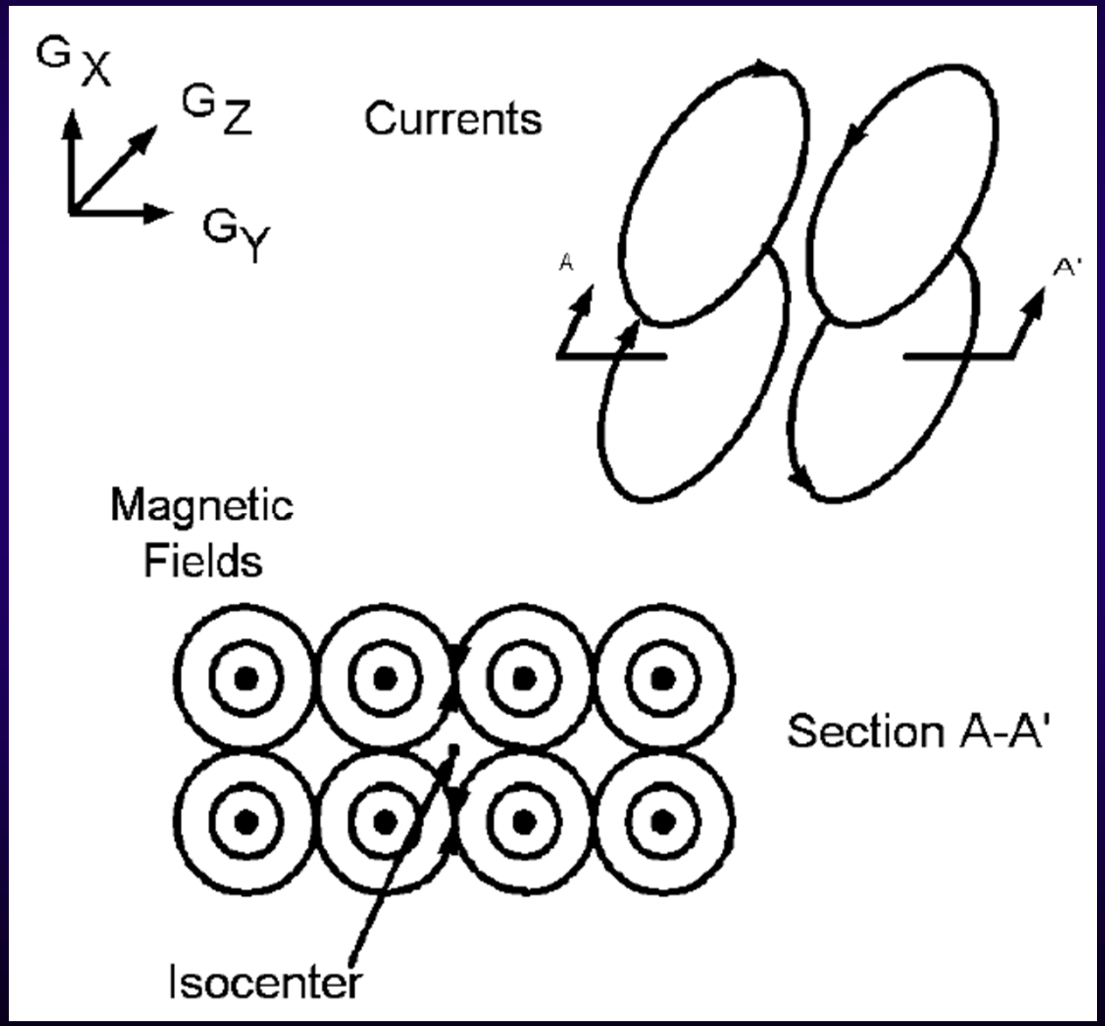
X-Y Direction Magnetic Field Gradient



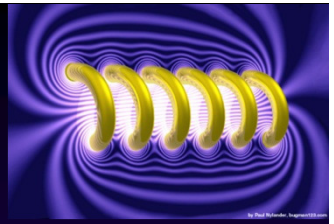


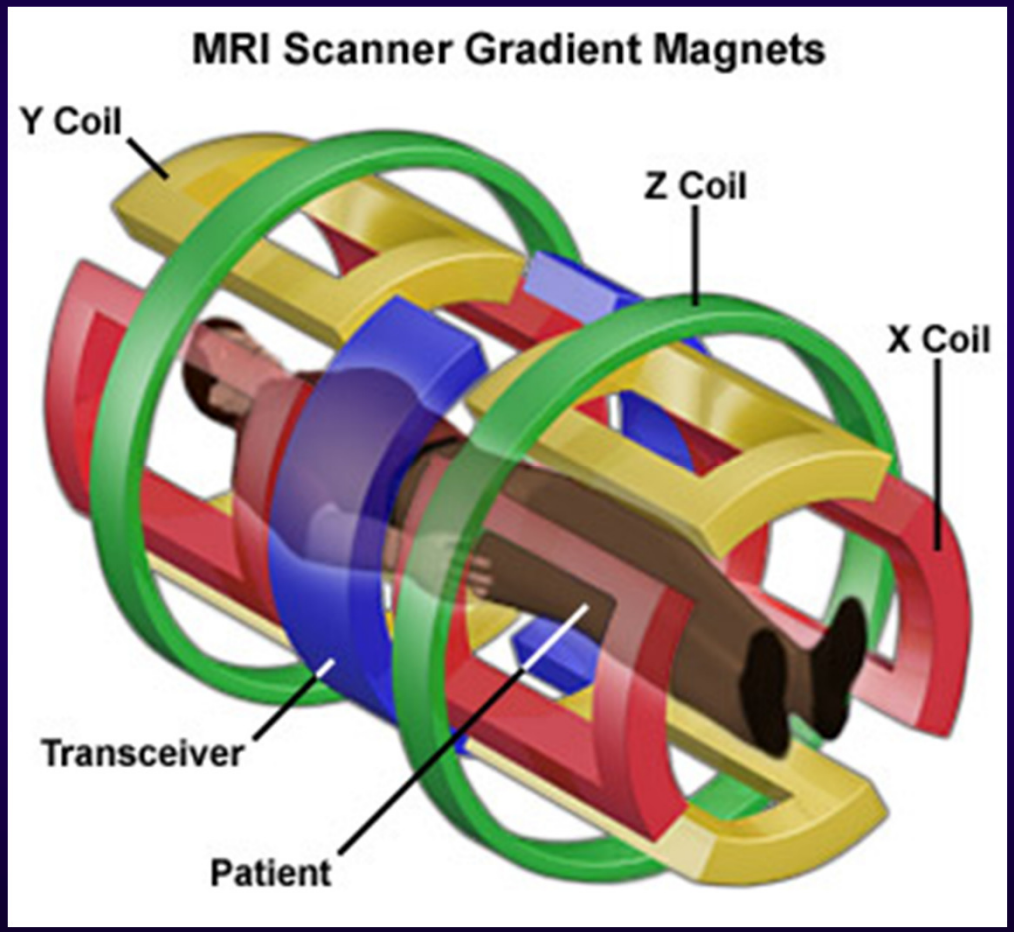
X-Y Direction Magnetic Field Gradient



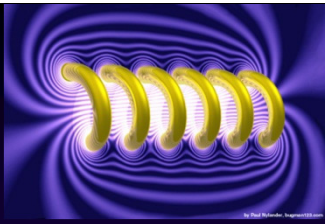


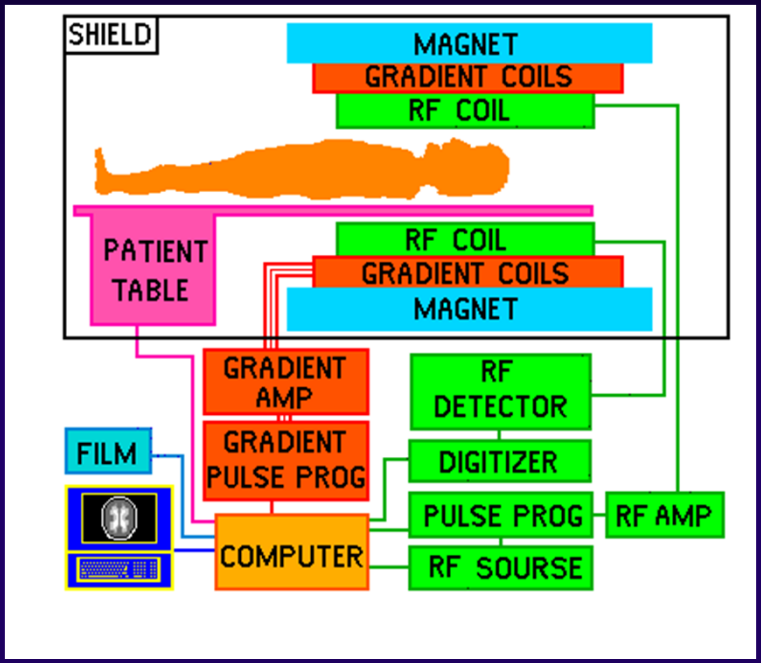
MRI Instrumentation

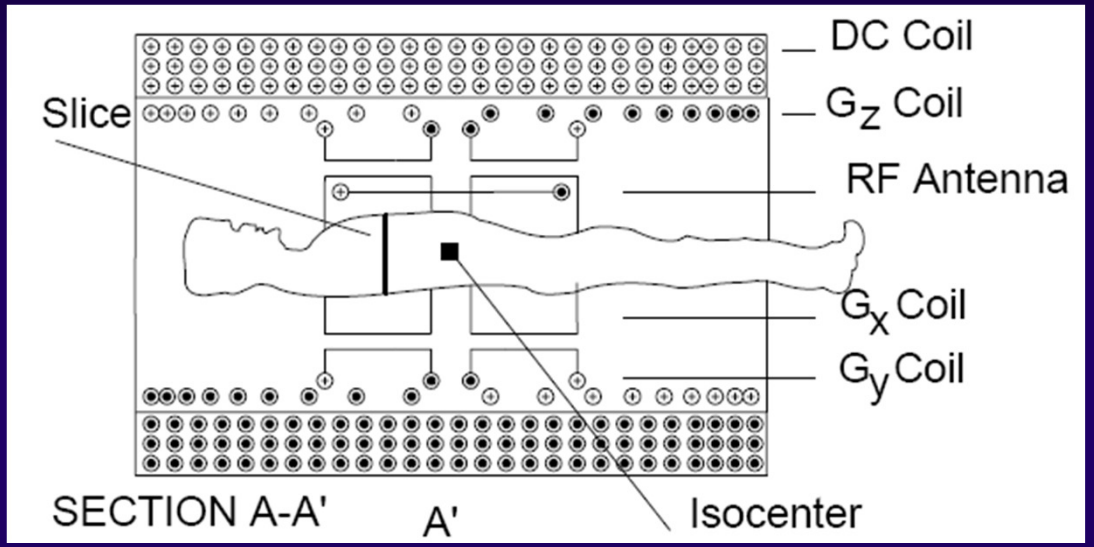




MRI Instrumentation





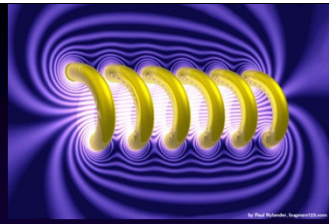


DC Coil produces constant magnetic field B_z.

G coils produce variation in B along x,y,z axes (Larmor eq).

RF coil generates radiofrequency causing atoms to nutate.

MRI Instrumentation



Types of Magnets:

(1) Superconducting electromagnets

- most commonly used
- produce strong, homogeneous magnetic fields
- expensive and require regular maintenance

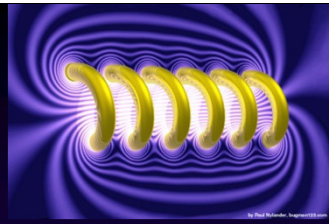
(2) Resistive electromagnets

- cheaper, easier to maintain
- less powerful, require a cooling system

(3) Permanent (fixed)

- inexpensive, easy to maintain
- heavy, weak intensity

MRI Instrumentation



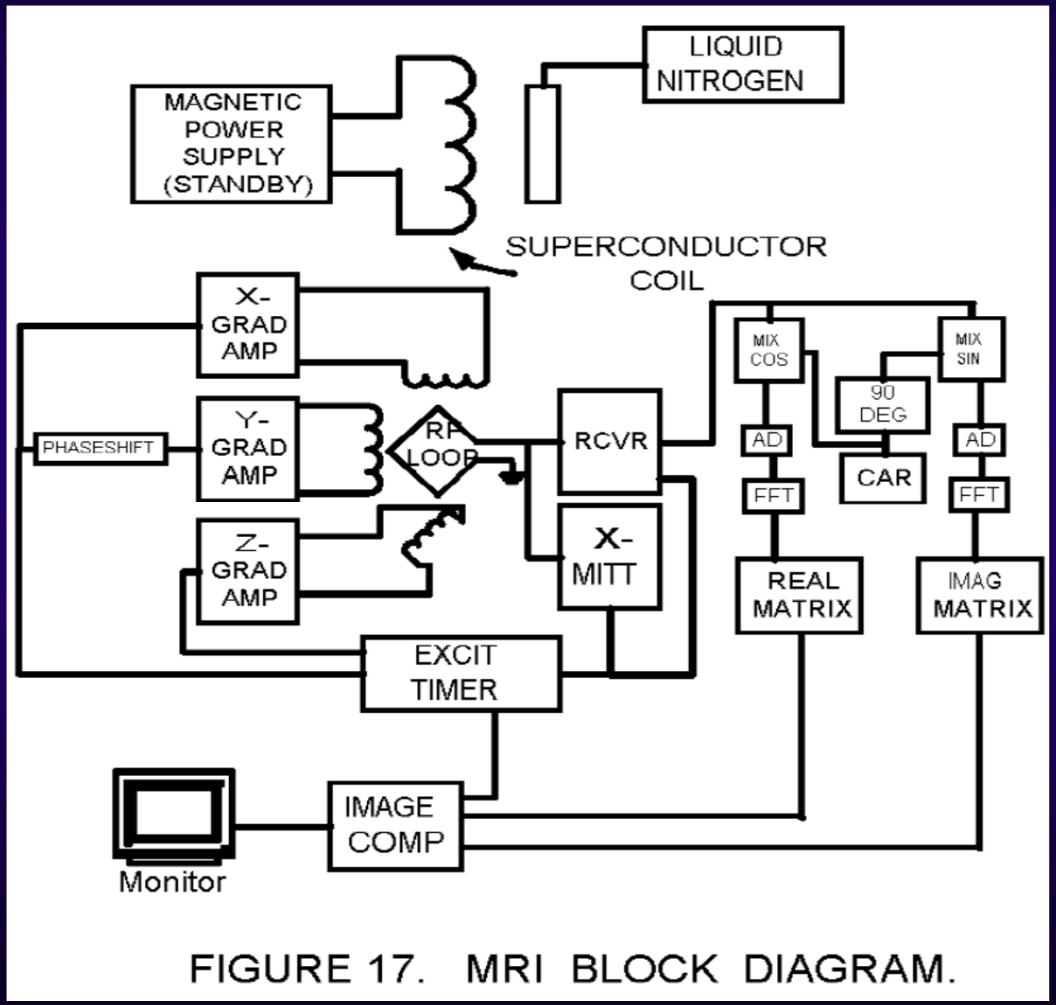


FIGURE 17. MRI BLOCK DIAGRAM.

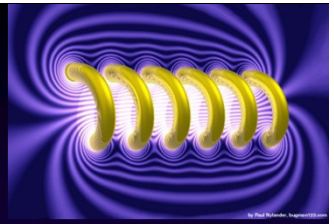
RF loop antenna is energized by transmitter.

Gradient amplifiers drive currents into G coils.

When RF is turned off, signal is picked up by receiver.

FID signal is processed and used to generate an image.

Signals Controlled by MRI Electronics



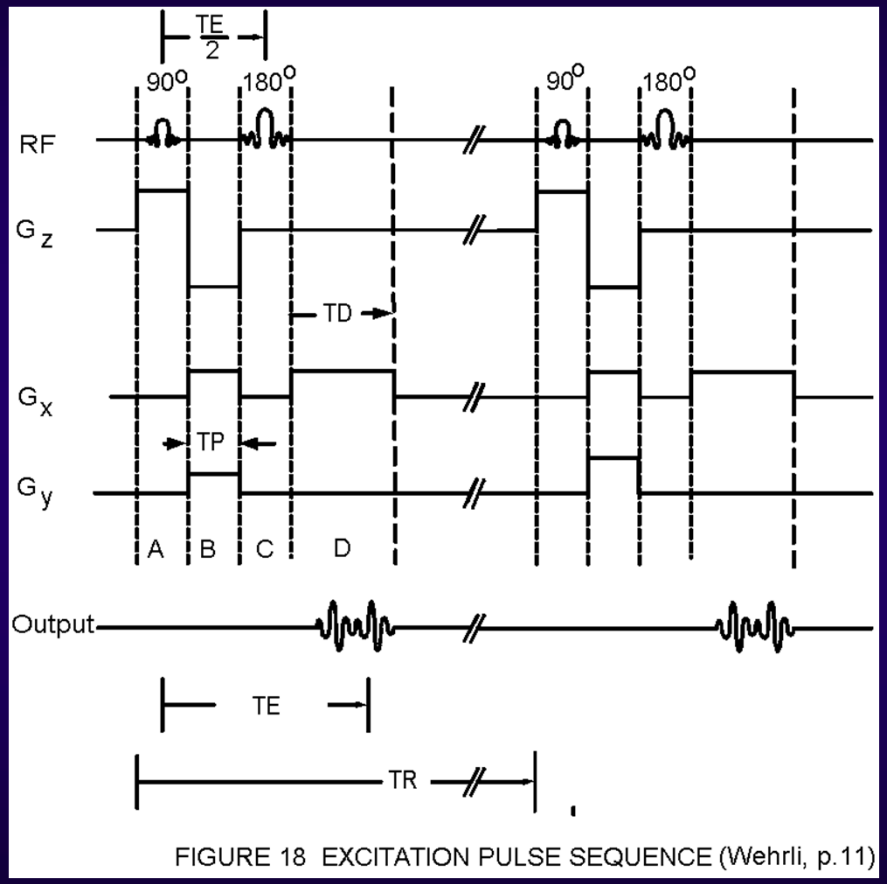


FIGURE 18 EXCITATION PULSE SEQUENCE (Wehrli, p.11)

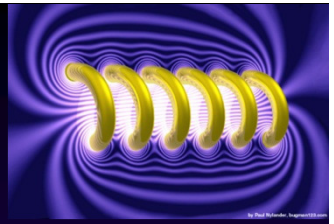
Time-period A

90° RF pulse & Gz-direction magnetic field select one slice

Voxels precess according to Larmor equation and gyromagnetic ratio

Difference in phase must be compensated.

Signals Controlled by MRI Electronics



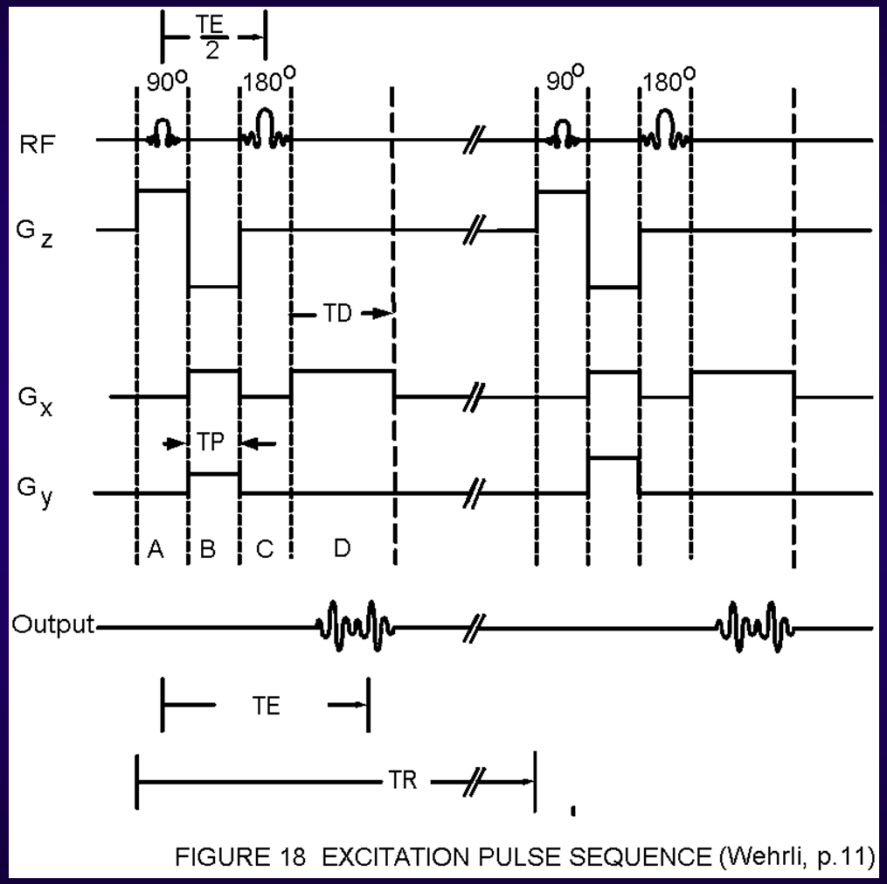


FIGURE 18 EXCITATION PULSE SEQUENCE (Wehrli, p.11)

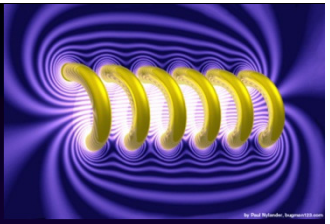
Time-period B

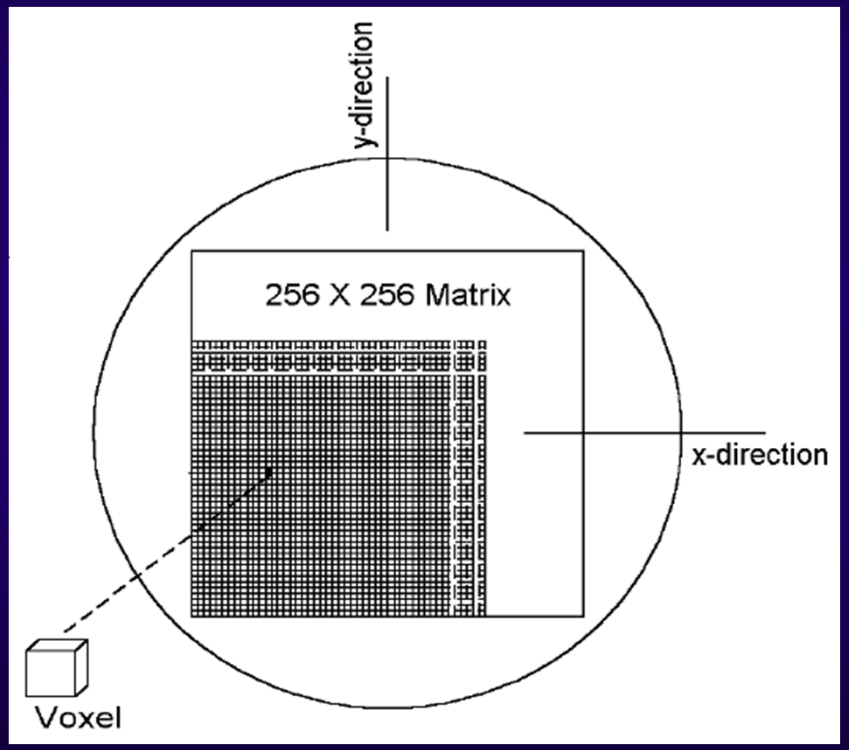
Second pulse in opposite direction along z-gradient

All slices will have same phase

Gx and Gy gradients energized

Generation of Slice Matrix





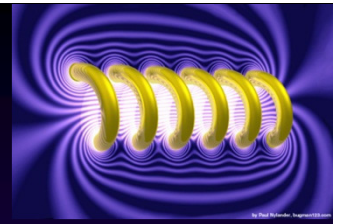
Time-period B

Magnetic fields across the slice vary linearly in x and y directions

Voxels acquire different frequencies determined by Larmor equation

By end of time period B voxels acquire different phases

Signals Controlled by MRI Electronics



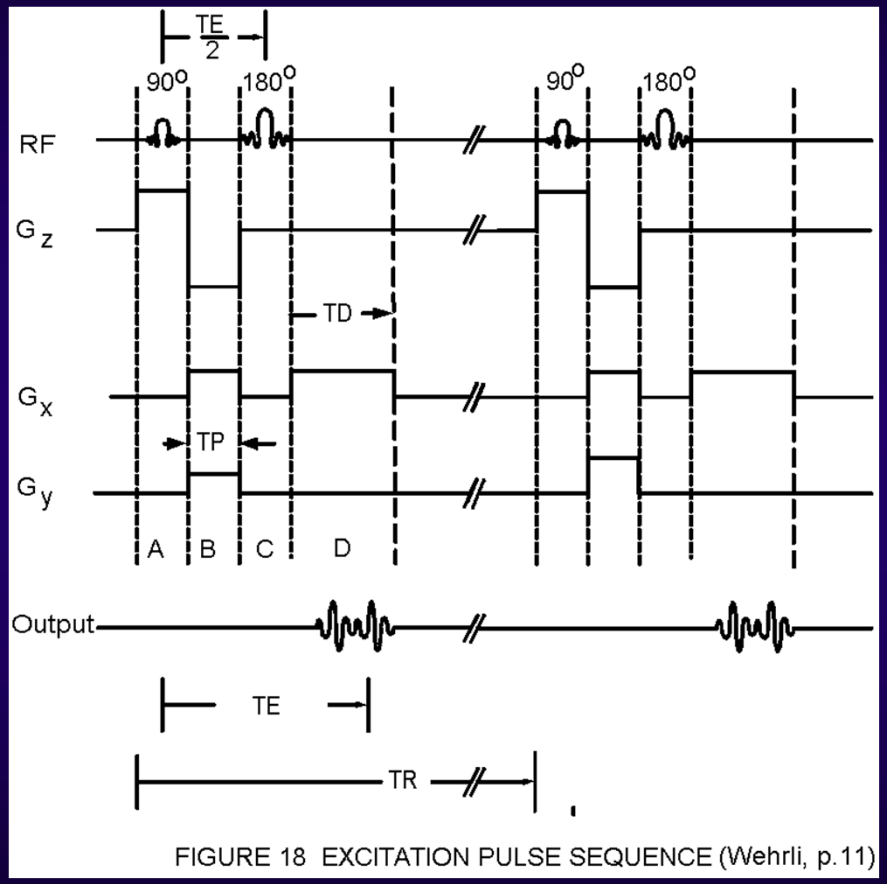


FIGURE 18 EXCITATION PULSE SEQUENCE (Wehrli, p.11)

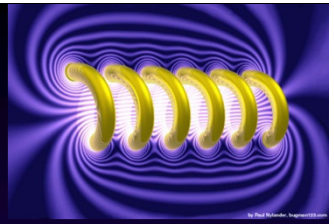
Time-period C

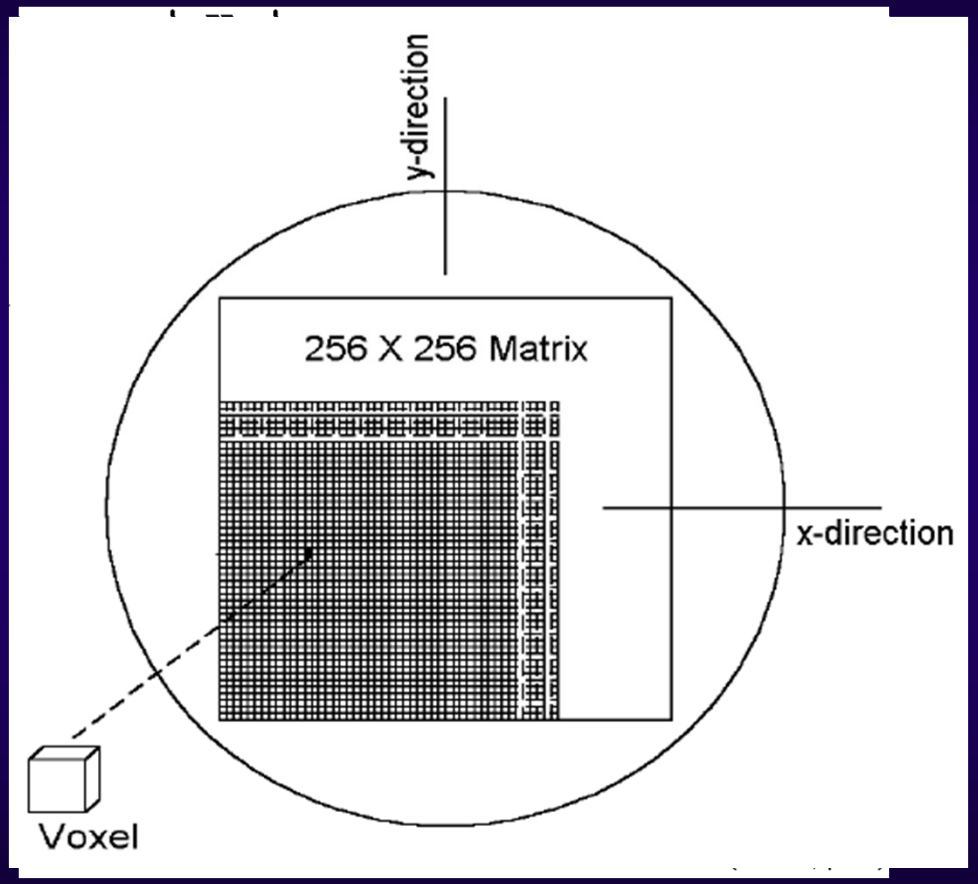
Magnetic field gradients are shut down (only B_0 remains)

Second pulse at 180° (spin echo)

Cancellation of dephasing by reversing phase

Signals Controlled by MRI Electronics





Time-period D

Gradient Gx is applied

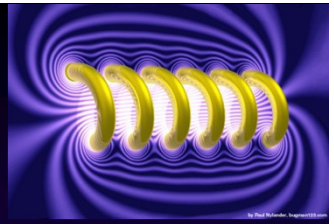
Phases vary linearly in x, remain constant in y

Receiver is turned on

Antenna coil picks up summation of all radiations in the line

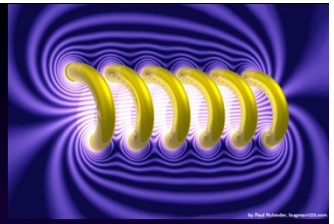
One-dimensional FT of the one-line scan (x-dim) is stored

MRI Safety



MRI produces strong magnetic fields!

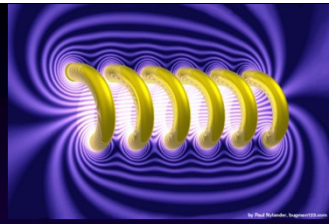
MRI Safety Concerns

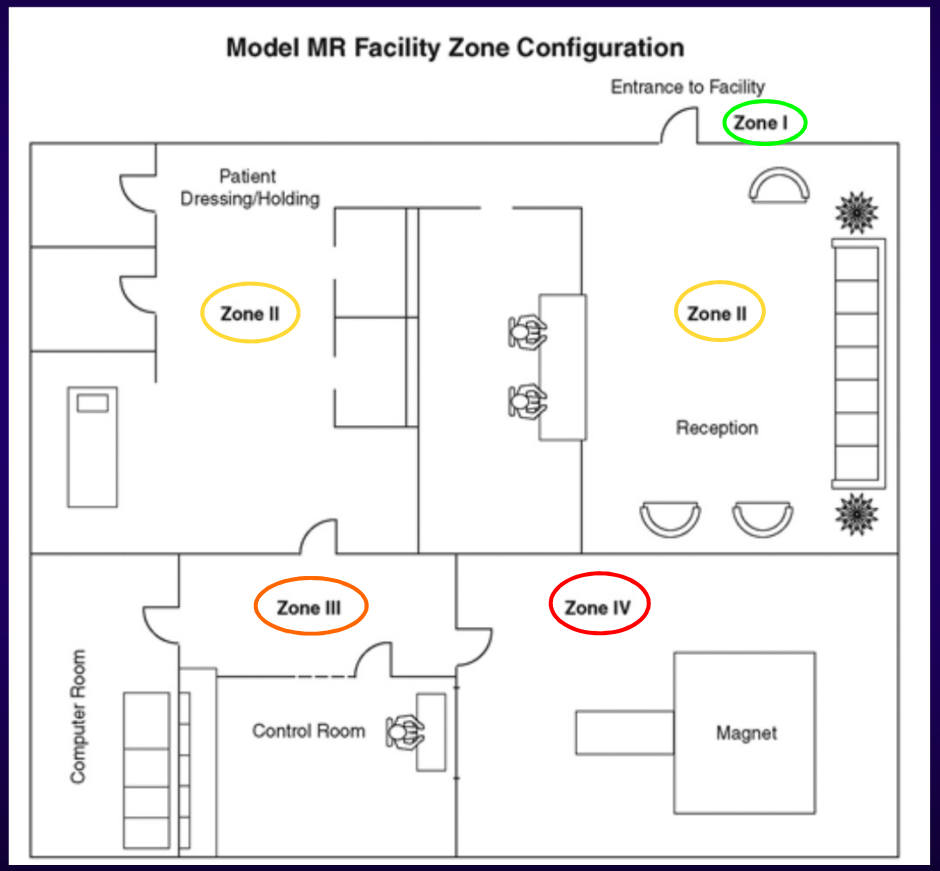


Exposure of patients, volunteers for experiments and workers

- static magnetic fields
  - *Clinic: 1.5-3 Tesla*
  - *Research: 7-8 Tesla*
- time-varying magnetic fields
- radiofrequency electromagnetic fields
- special environment (narrow tunnel)

MRI Safety Concerns





Zone I: Free access

Zone II: Supervised access

Zone III: Restricted access

Zone IV: Strictly controlled

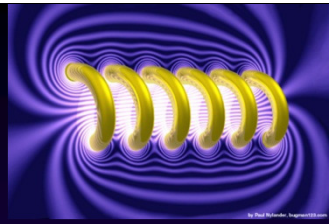
All portable objects in Zone IV must be labeled:

MR safe

MR conditional

Not MR safe

MRI Patient Safety



Patients must be examined/interviewed for the presence of ferromagnetic objects such as surgical clips, shrapnel, prostheses, etc.

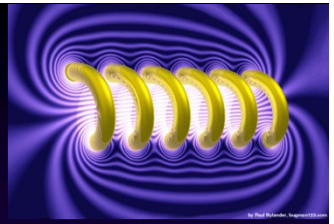
3 Issues of Concern:

(1) torque or force on the object in the patient

(2) heating of the material

(3) distortion of the image

MRI Safety: Pacemakers



Studies show safe MRI with pacemakers at low magnetic fields: 0.5-1.5 Tesla:

http://radiology.rsna.org/content/215/3/869.full.pdf+html

http://www.imrser.org/PDF/JACC.PACEMAKERS.MRI.pdf

Research to develop MRI-safe pacemakers:

Medtronic

http://wwwp.medtronic.com/Newsroom/NewsReleaseDetails.do?itemId=1220188242171&lang=en_US

http://www.hospitalradiologyeurope.com/default.asp?article.id=7988&page=article.display&title=FDAgivesMedtronicapprovaltostartpacemakerMRItrials