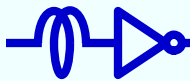
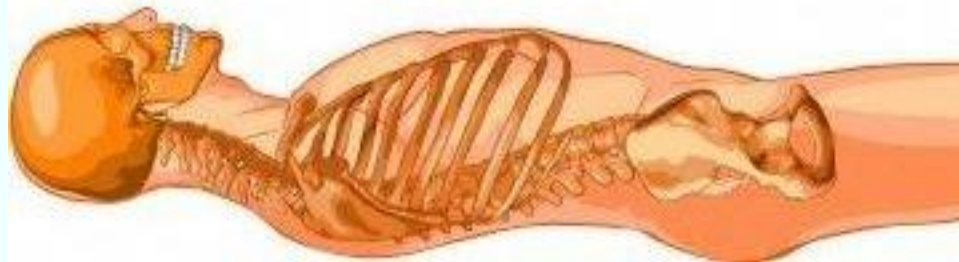




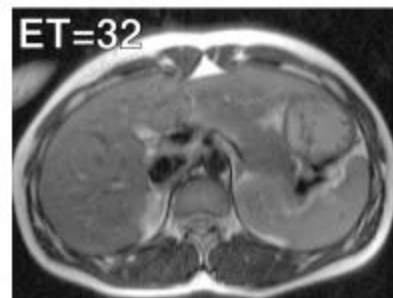
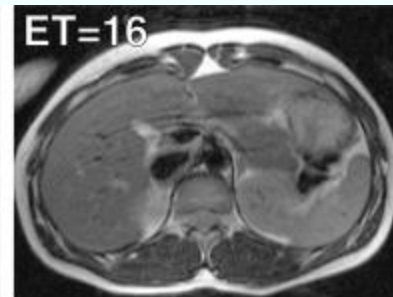
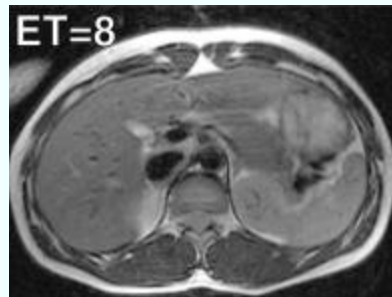
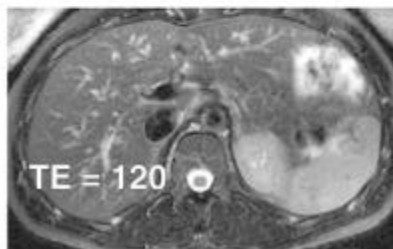
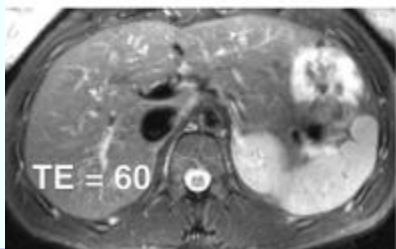
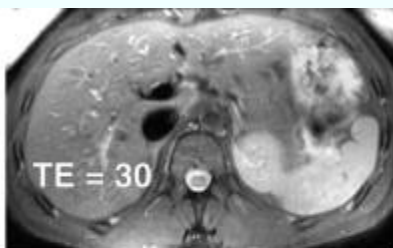
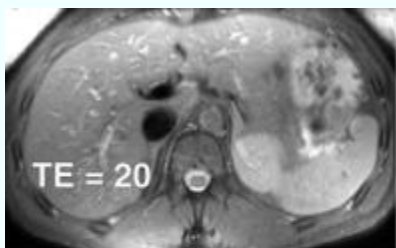
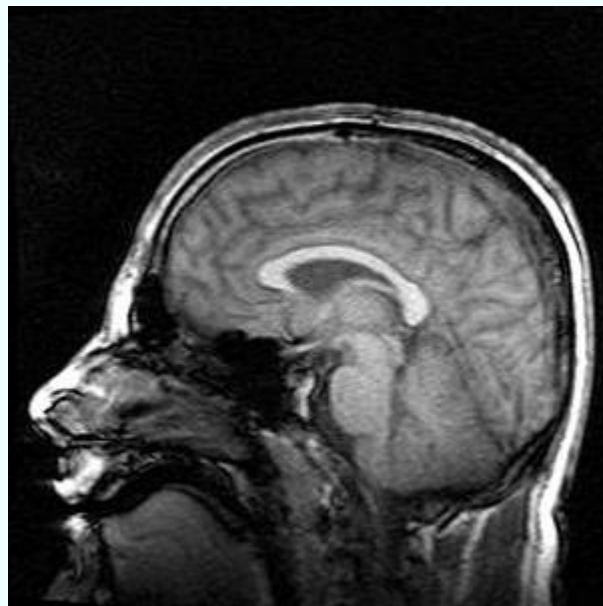
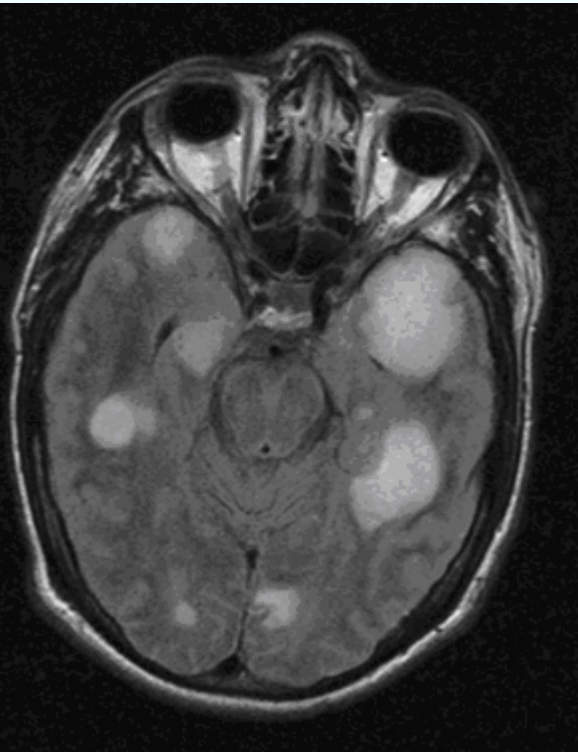
# MRI

Magnetic Resonance Imaging



*Inductive Logic*

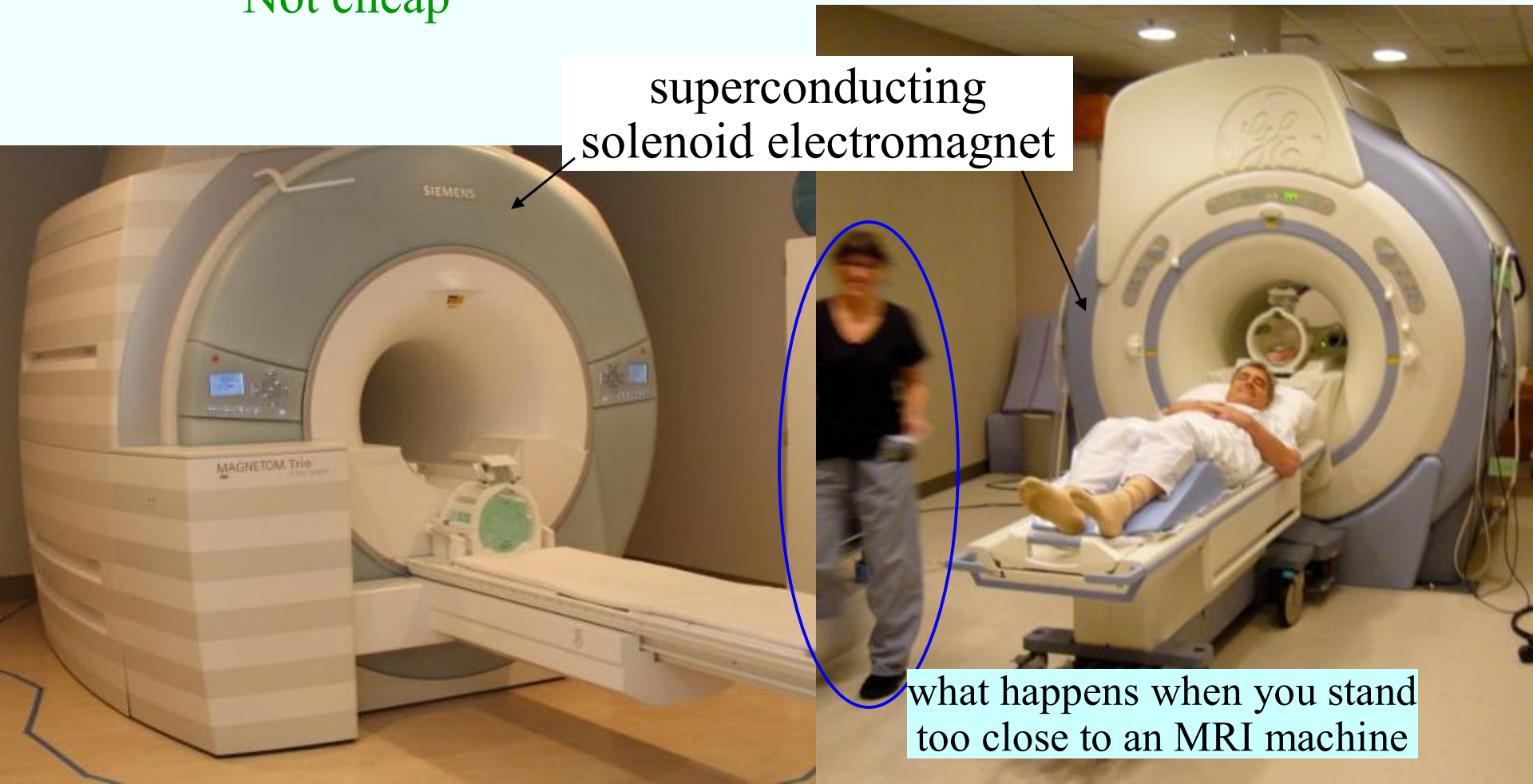
# Slice, without cutting



# How do we do it?

- With an MRI machine

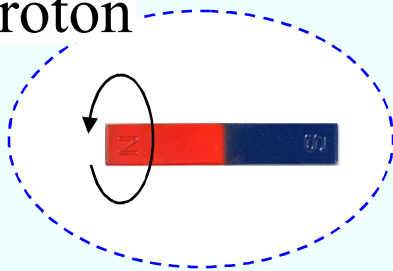
- Electromagnet cooled with liquid He (at 4 K)
- Surrounded by a liquid N<sub>2</sub> jacket (at 77 K)
- Not cheap



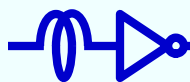
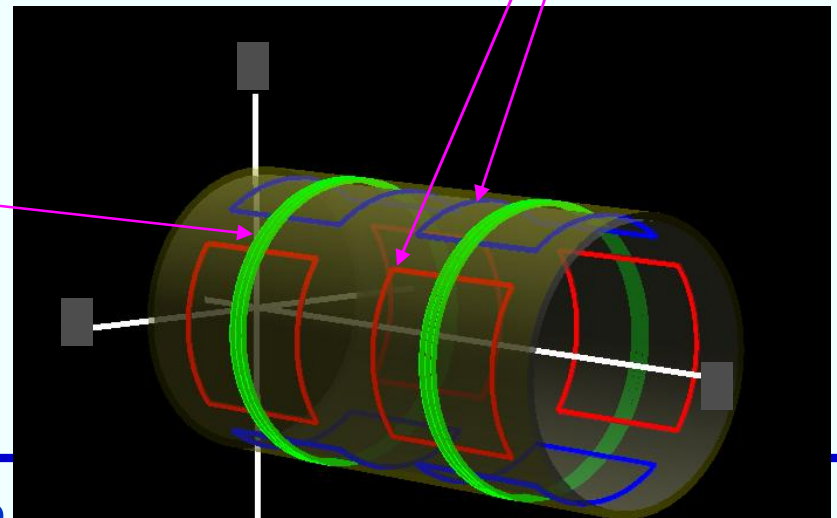
# What's the big idea?

- Protons (H nuclei) are spinning bar magnets
  - Machine makes *your protons* into a magnet
- Spinning magnets precess in a magnetic field
  - Just like a spinning gyroscope in the gravitational field
- Precession makes your magnetic field go 'round
- Changing magnetic field *induces* currents in wires
- We measure those currents
  - Which measures the strength of the proton B-field

proton

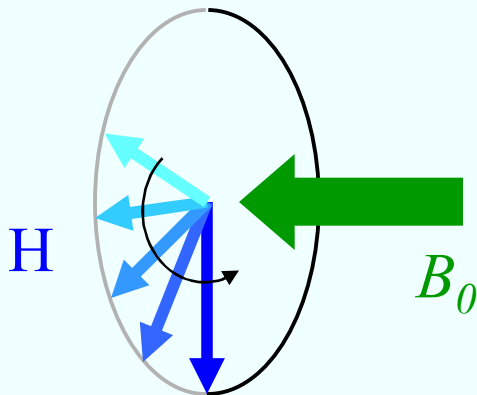


main  
coils



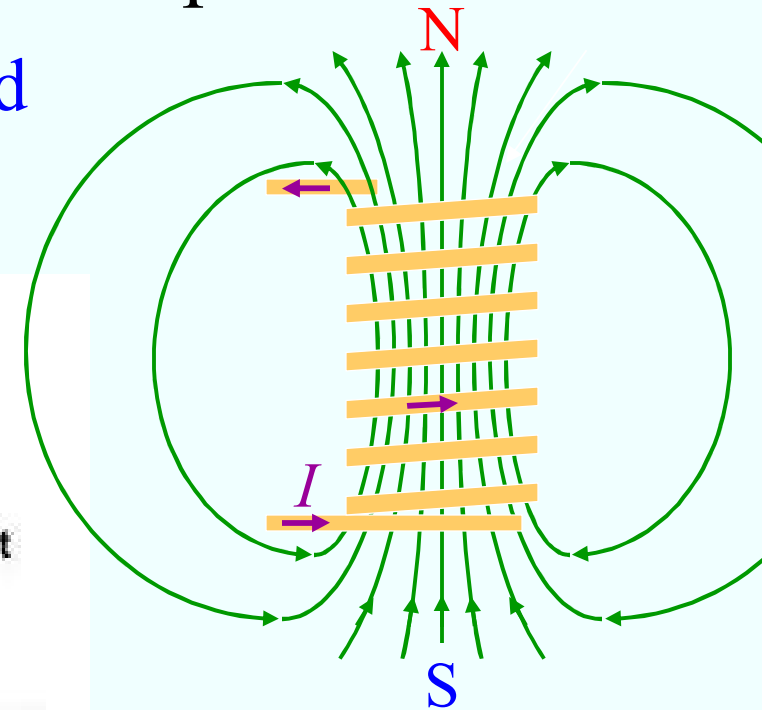
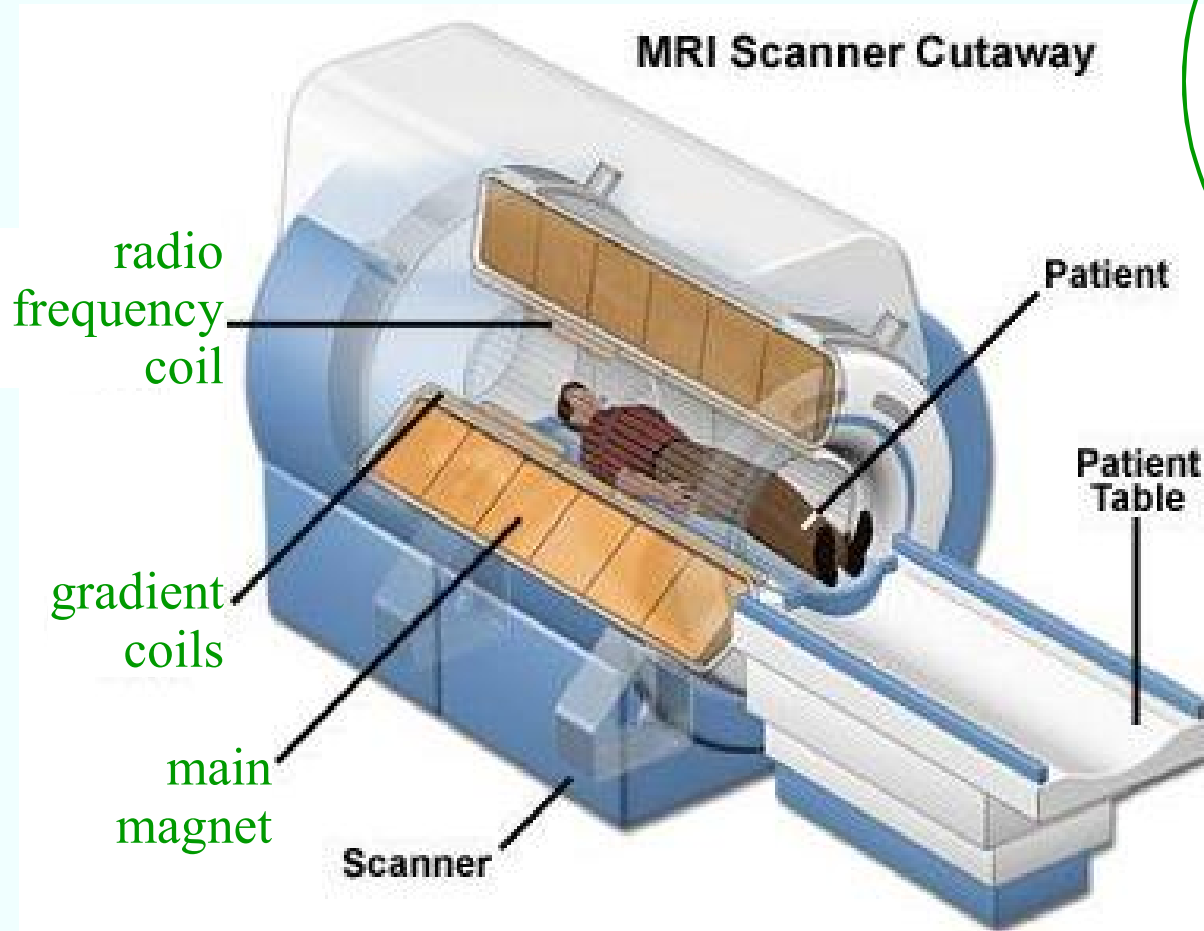
# Why hydrogen (protons)? (or “Who’s been precessing in *my* bed?”)

- Protons (H nuclei) are spinning bar magnets
  - So are all other nuclei
    - Others move (precess) too slowly: hard to use
    - However, some specialized, laboratory MRI use other nuclei
  - So are electrons
    - They move (precess) too fast: hard to use
  - Hydrogen precesses “just right”
    - 64 to 128 MHz at 1.5 - 3 T



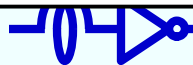
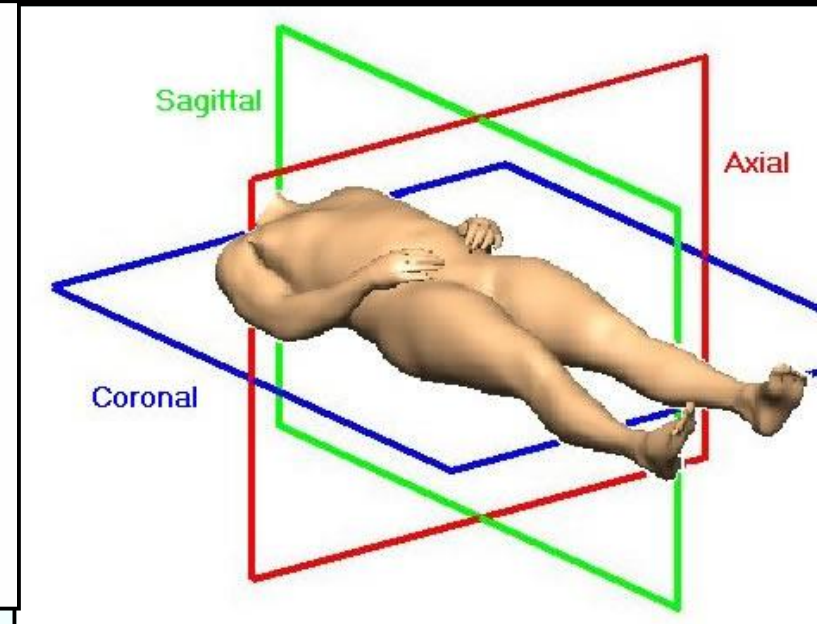
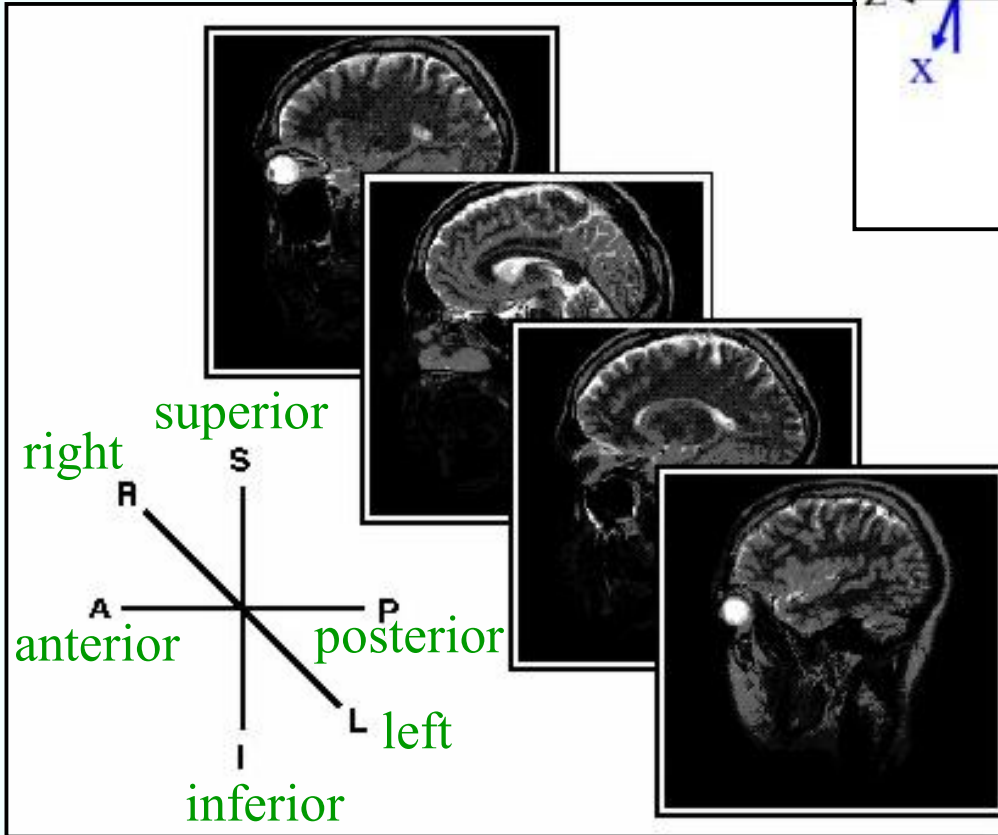
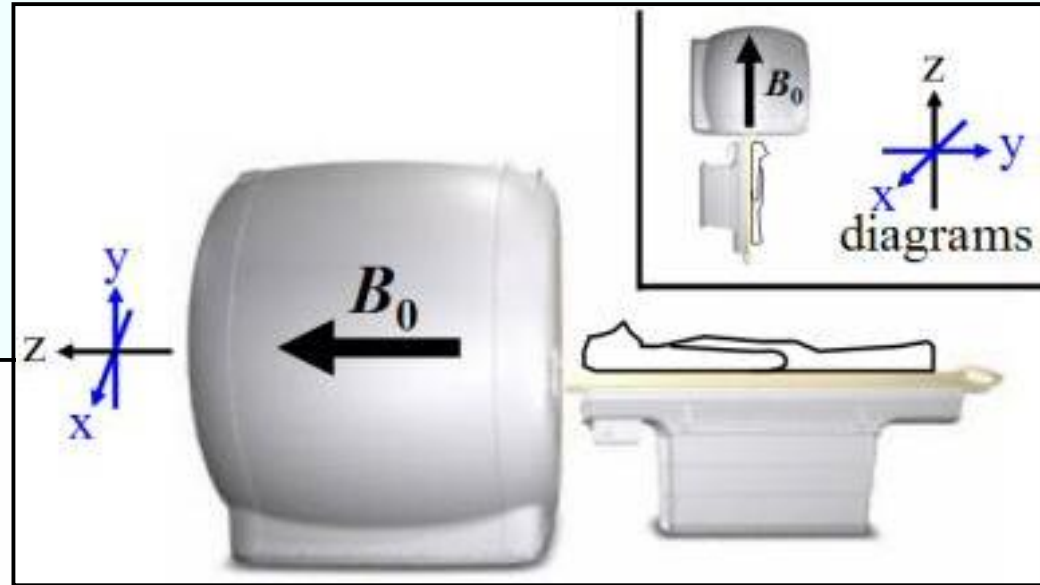
# Schematic view of MRI with patient

- Main coil is an air-core solenoid



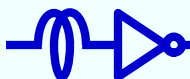
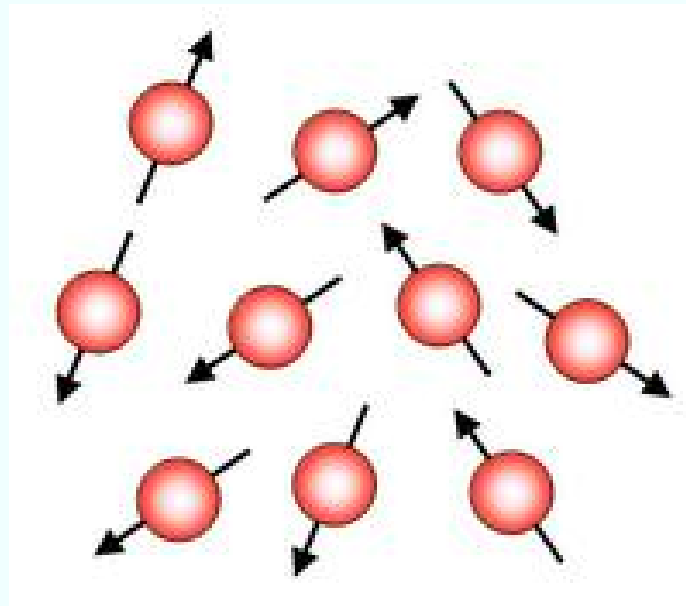
# MRI axes

- Doctors use lots of different words
  - Even more than here
- We use  $x, y, z$



# Your body outside a B-field

- Hydrogen nuclei (protons) point randomly
- No net magnetic field





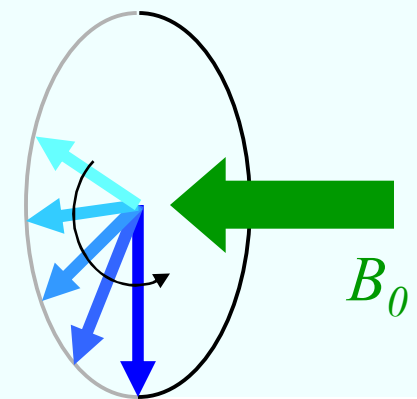
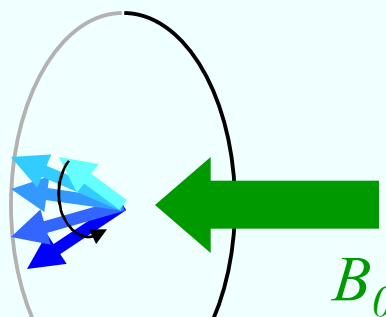
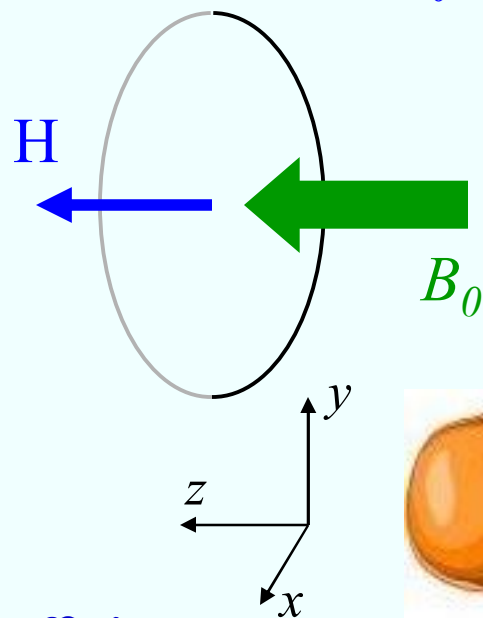
# Hydrogen in a strong magnetic field

- 1.5 to 3 T (tesla)
  - Stronger fields for specialized applications
- To knock over the H, we “kick” it
  - With a rotating magnetic field
  - Synchronized to its precession frequency (**resonance**)

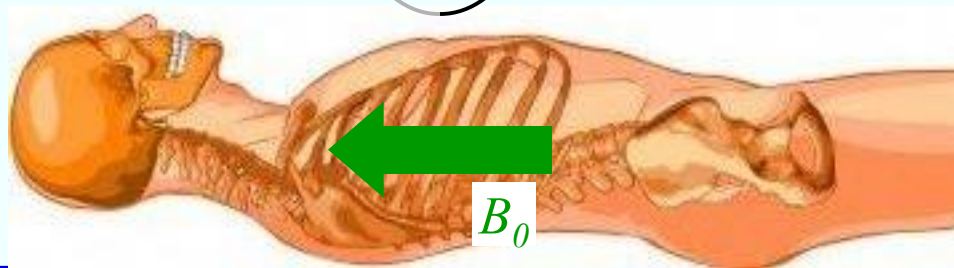
Equilibrium: H-magnets align with  $B_0$

Resonant RF pulse pushes H-magnets off-axis

H-magnets pushed into  $x$ - $y$  plane

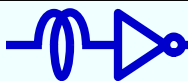
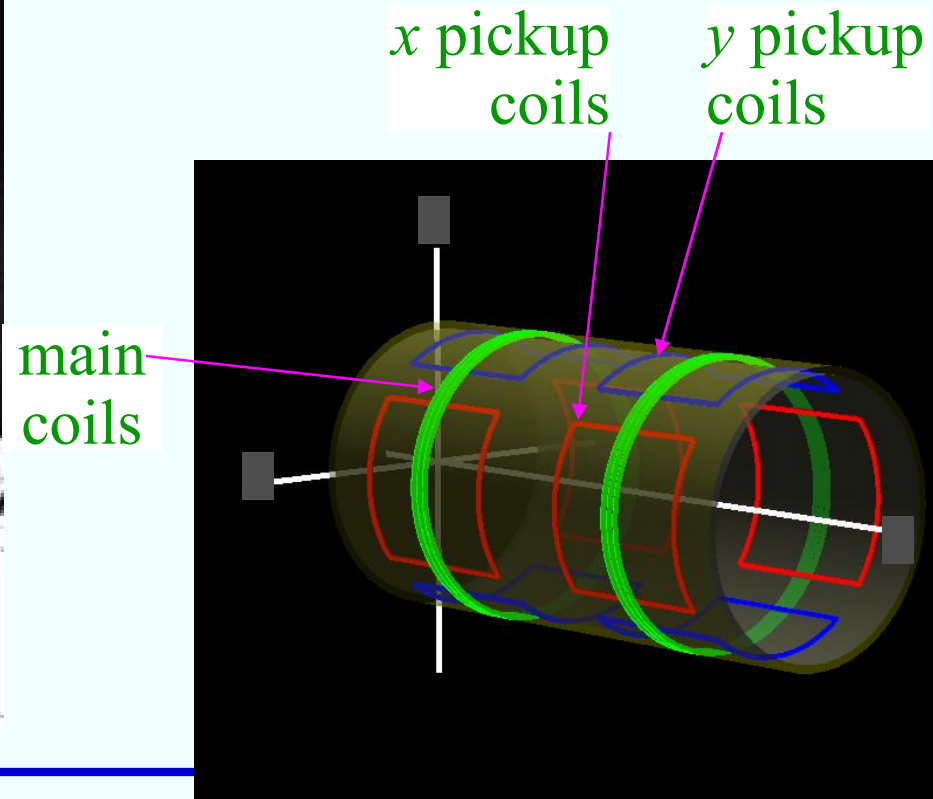
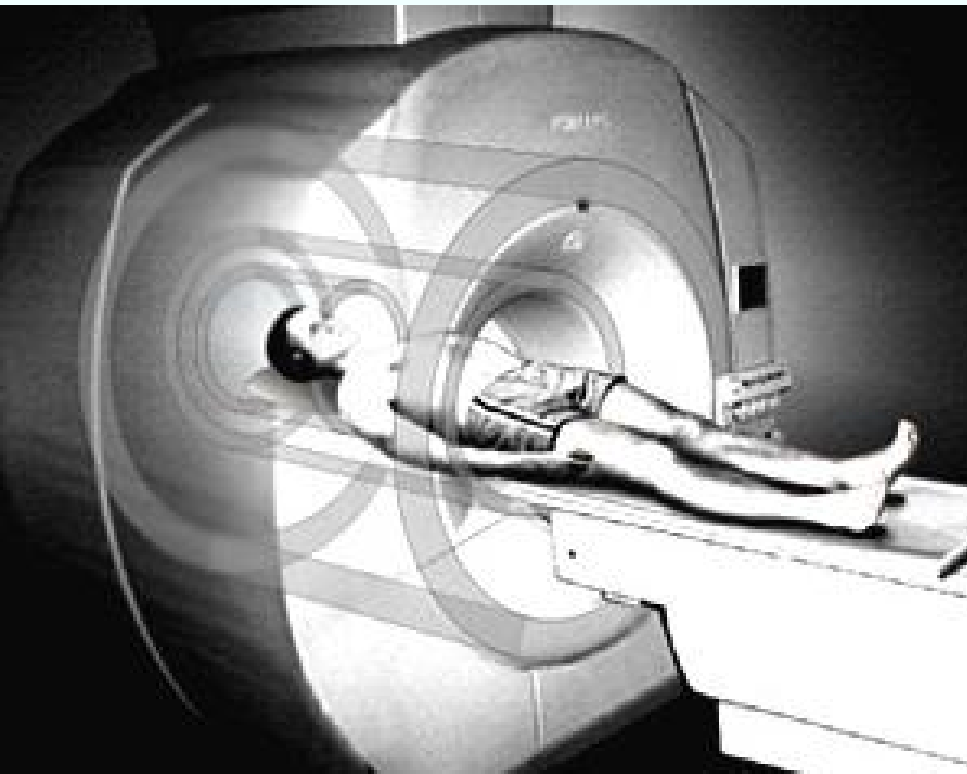


precessing in  $x$ - $y$  plane



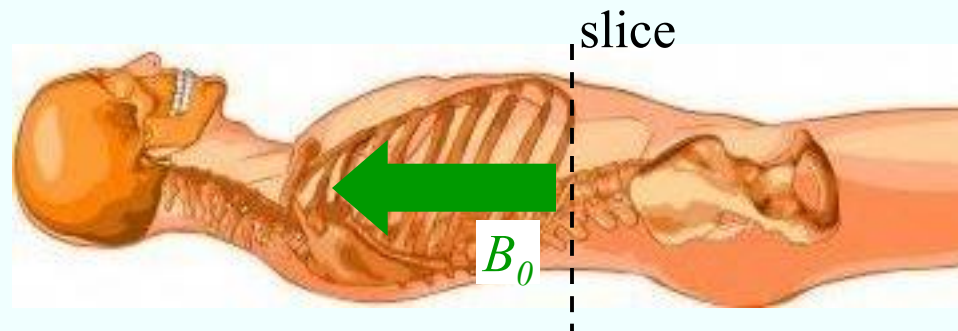
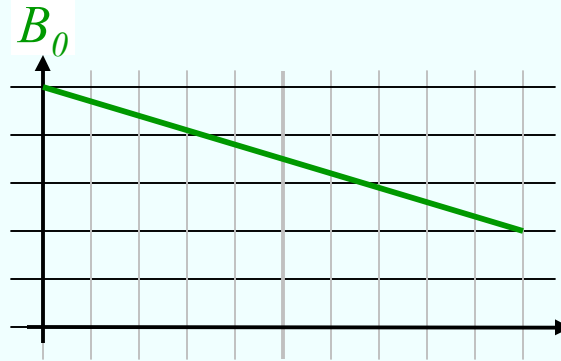
# I sing the body magnetic

- The precessing protons in your body make a rotating magnetic field
  - Only about 1 proton in a million actually lines up
- Which induce voltages in the pick up coils



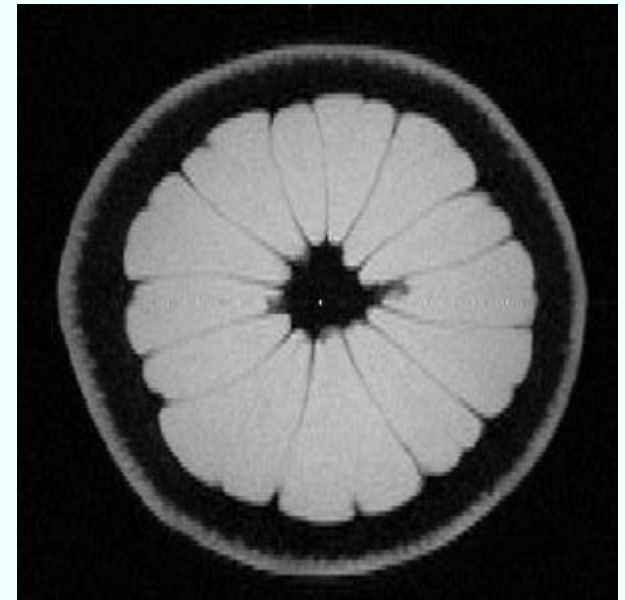
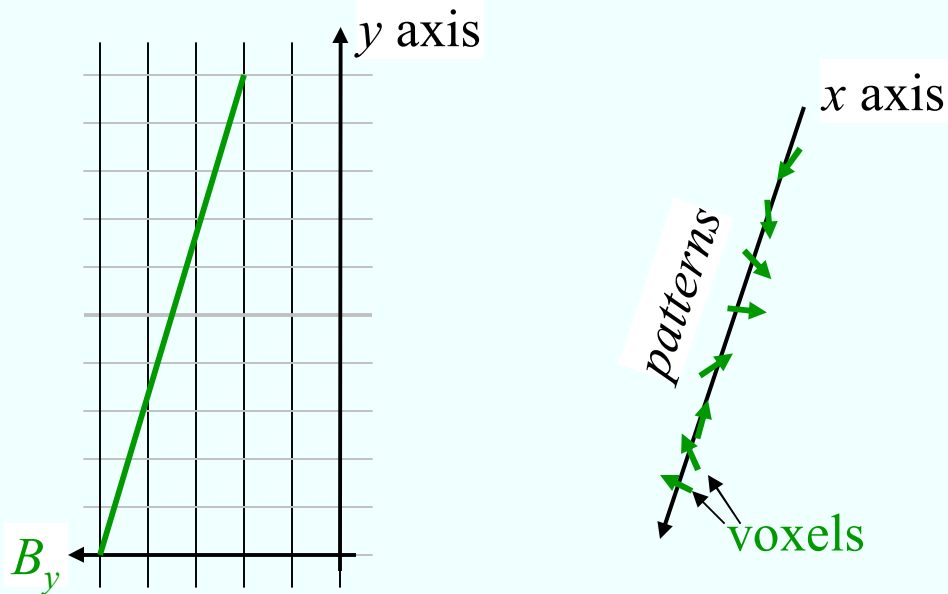
# Spatial localization (resolution)

- Change the main B-field slightly with distance
  - I.e., create a “magnetic gradient”
  - Different “slices” resonate at different frequencies
  - We choose the slice by choosing the frequency



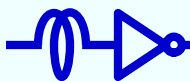
# Y and X localization

- Y localization: another (but smaller) gradient
- X localization: **Phase encoding**
  - We kick the  $x$  voxels into a series of specific patterns
  - Requires 256 pattern readings for 256-voxel  $x$ -resolution
    - 256 equations and 256 unknowns
    - But Fourier transform simplifies this



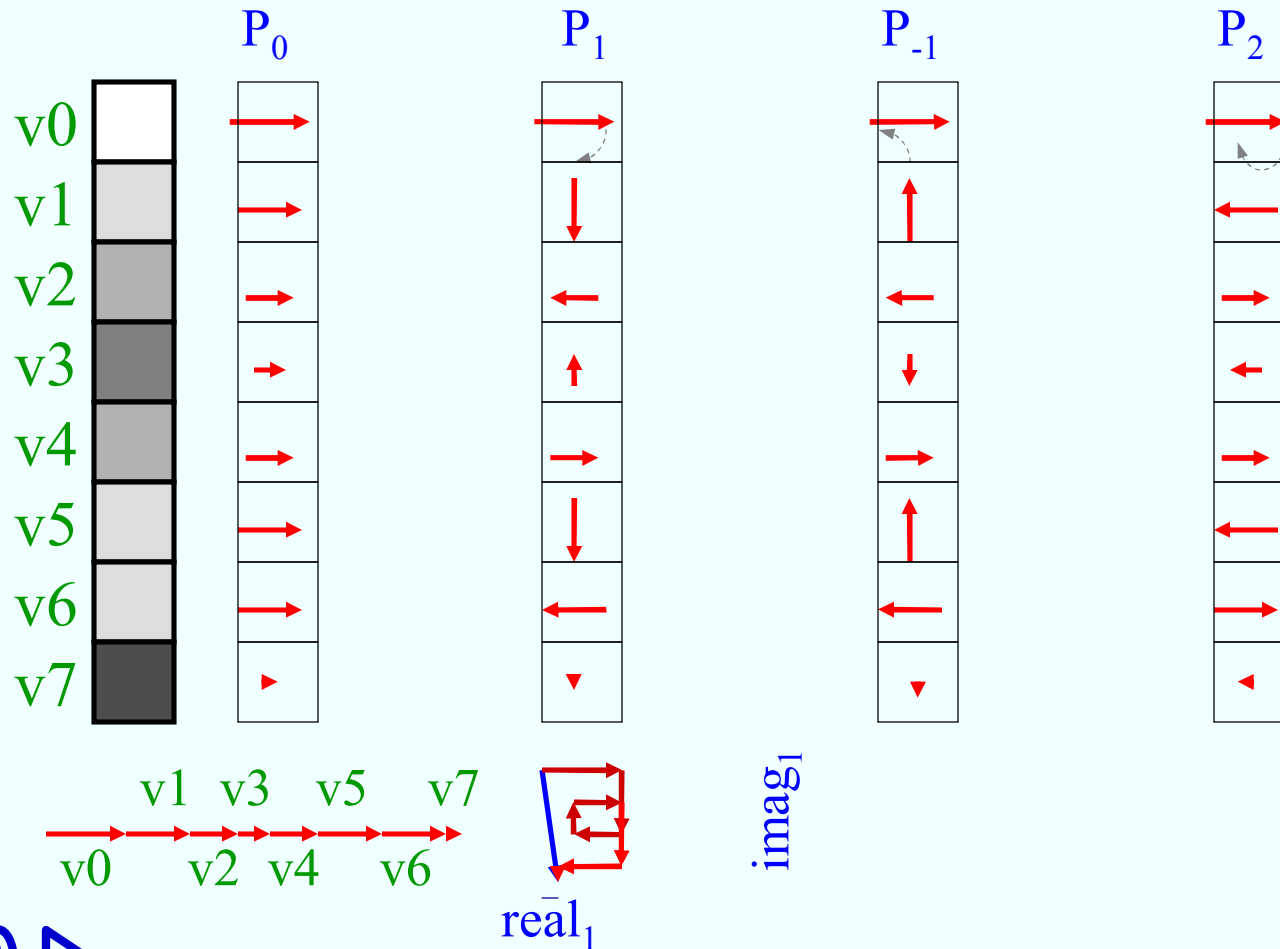
# Open MRI

- Reduced claustrophobia



# Phase Encoding (under construction)

- One set of rotations for each voxel
  - Yields 8 equations for 8 unknowns



# Phase Encoding

- One set of rotations for each voxel
  - Yields 8 equations for 8 unknowns

