Medical Imaging Systems

- Radiography
- Tomography
- **Magnetic Resonance Imaging (MRI)**
- Nuclear Medicine
- Ultrasound
- Electrical Impedance Tomography
- Breast Thermography
- Others (**Elastography, Spectroscopy, Ophthalmology**)

Magnetic Resonance Imaging (MRI)

- **A medical imaging** technique used in **radiology** to visualize detailed internal structure and limited function of the body.

- Invented by **Dr. Raymond V. Damadian** :
  2007 National Inventor of the Year Top Inventor Award for the MRI.

- Nobel Prize for discoveries using the MRI :
  Paul Lauterbur and Sir **Peter Mansfield** in 2003.

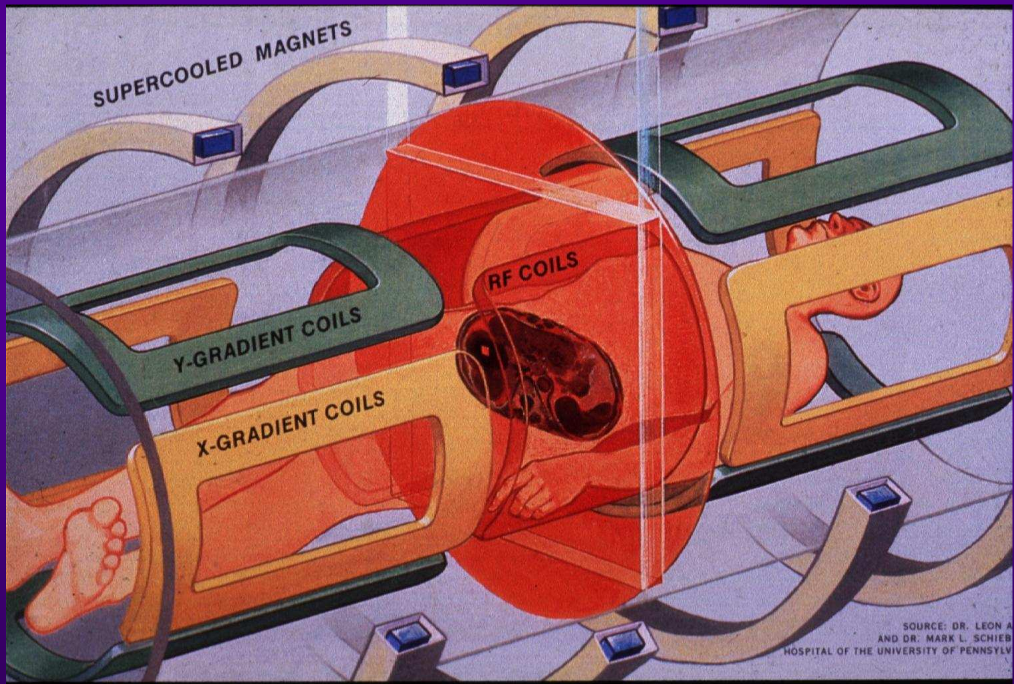
MRI

- MRI provides much greater **contrast** between the different soft tissues of the body than **computed tomography** (CT) .

Magnetic resonance imaging

(*MR tomography*)

exellent soft tissue contrast



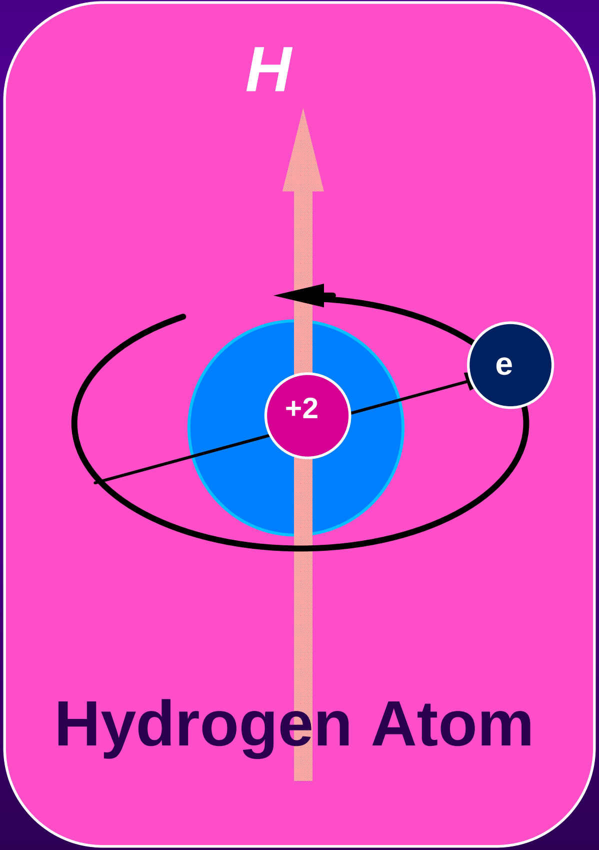
Spatial and temporal variation of magnetic fields and radiofrequency pulses

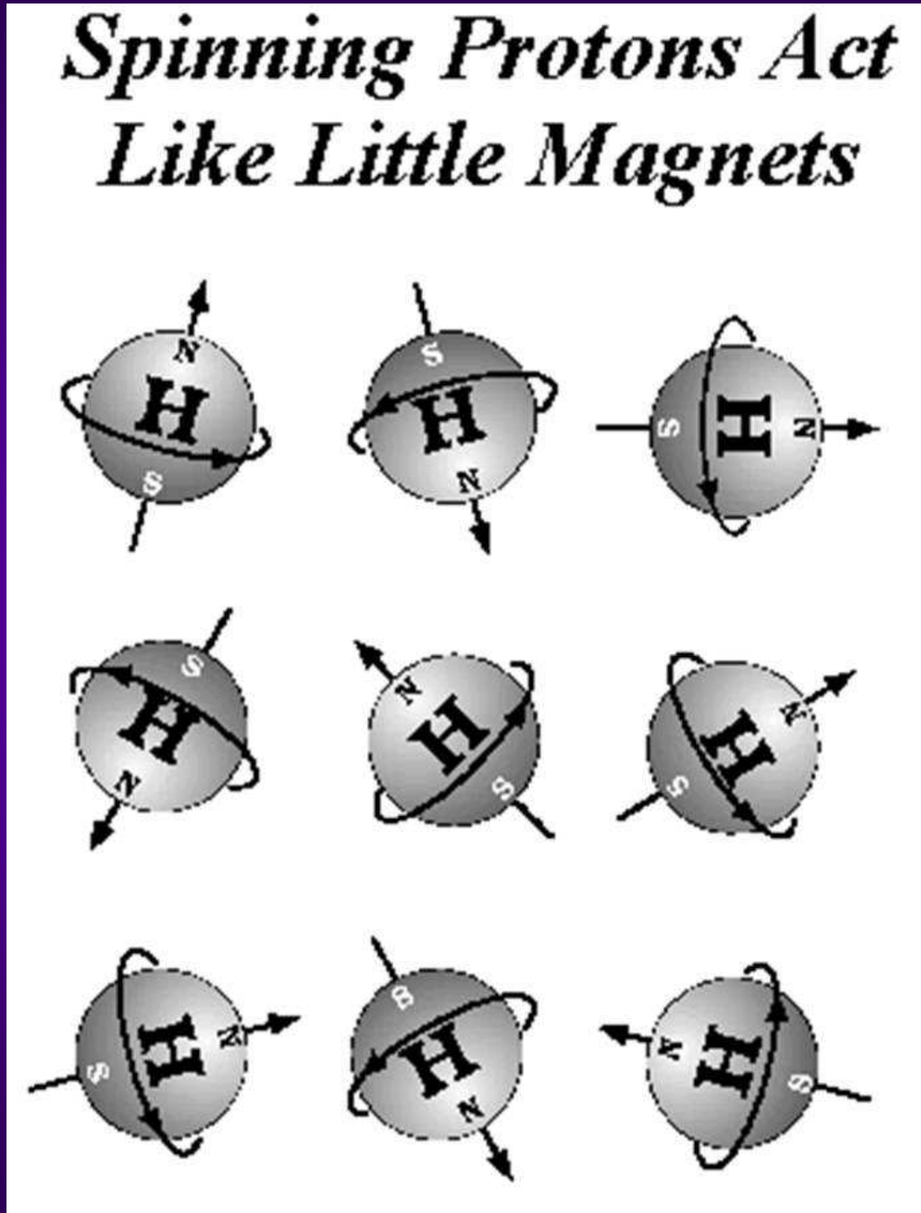
Sagittal mid-line brain section

Principle of the MRI

- Exploits the existence of **induced nuclear** magnetism in the patient.

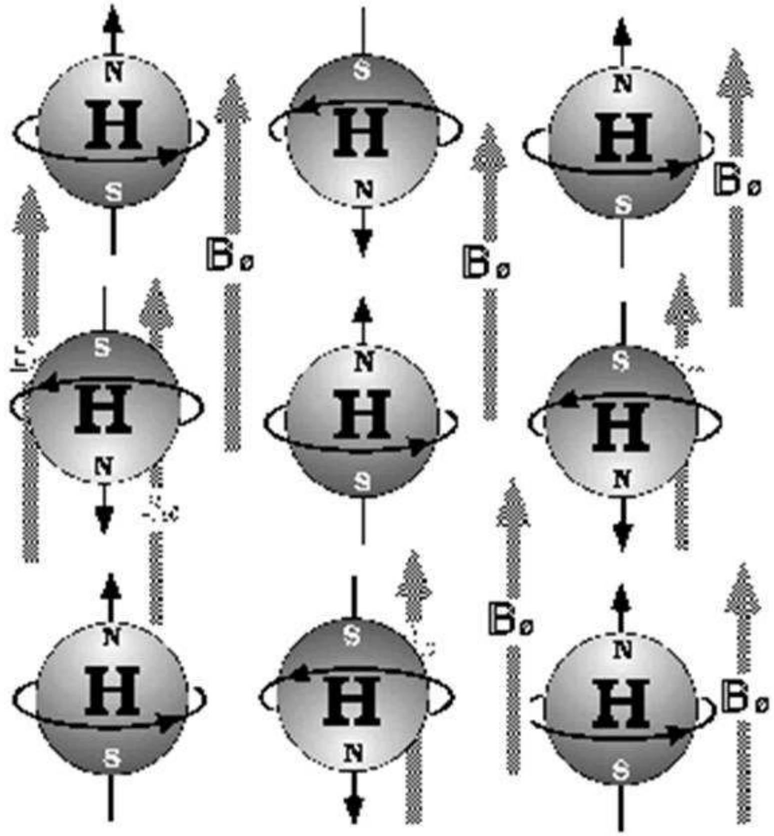
- **Magnets with an odd number of protons or neutrons possess a weak but observable nuclear magnetic moment.**





Ref: www.simplyphysics.com

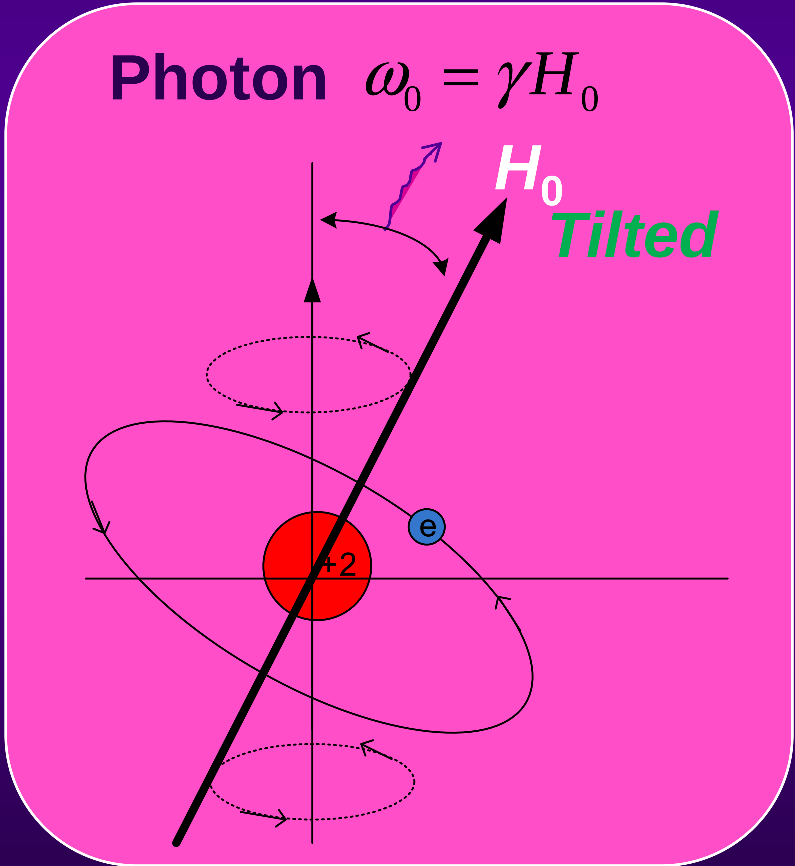
They Align With An External Magnetic Field (Bø)



- **The nuclear moments are normally randomly oriented,**

- **but they align when placed in a strong magnetic field (typically 0.2-1.5 T).**

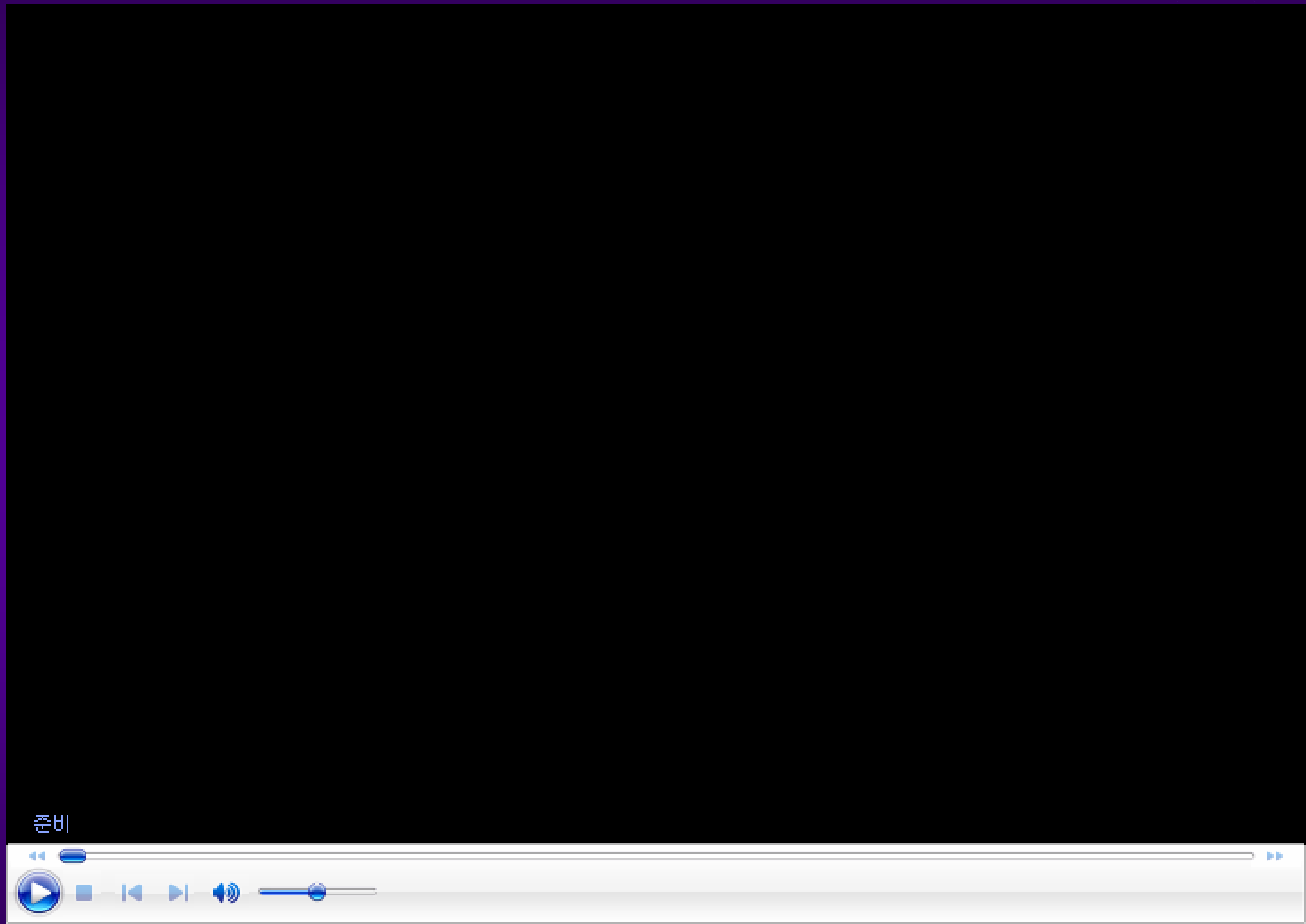
MRI Signal Source



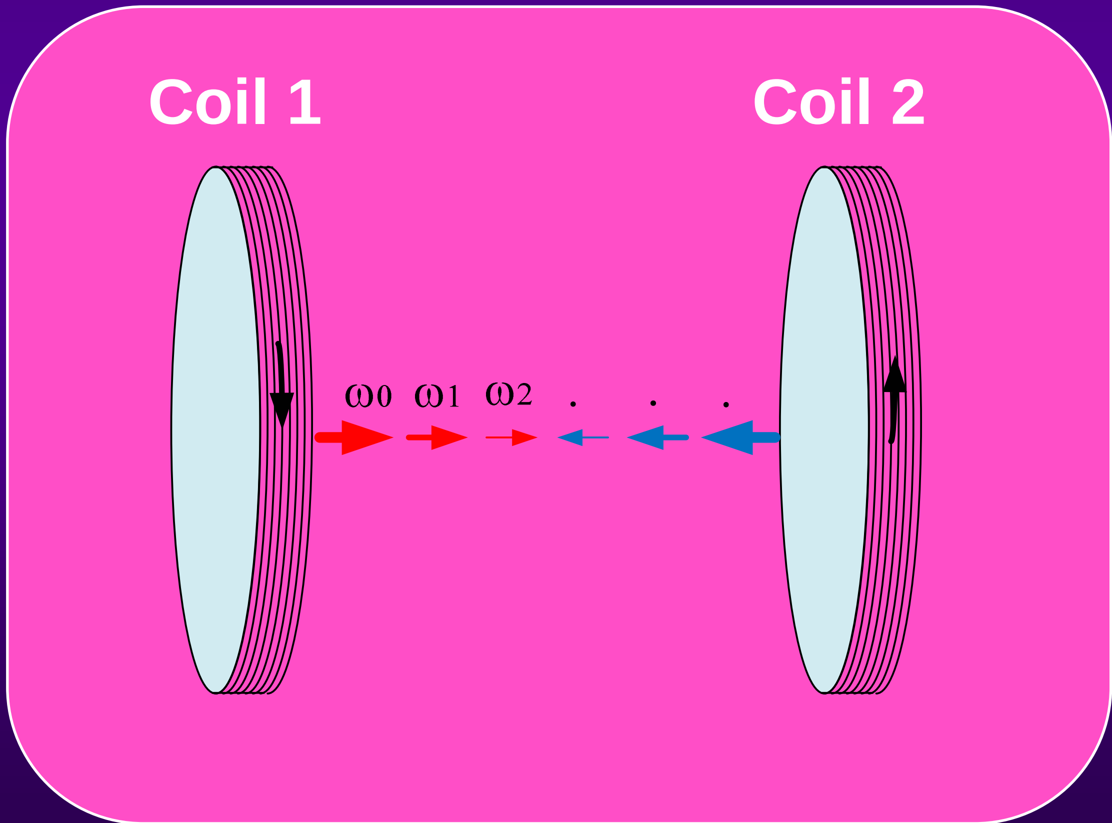
$$\omega_0 = \gamma H_0$$

When a nuclear magnet is tilted away from the external magnetic field it rotates (precesses) at the Larmour frequency.
For hydrogen, the Larmour frequency is 42.6 MHz per Tesla.

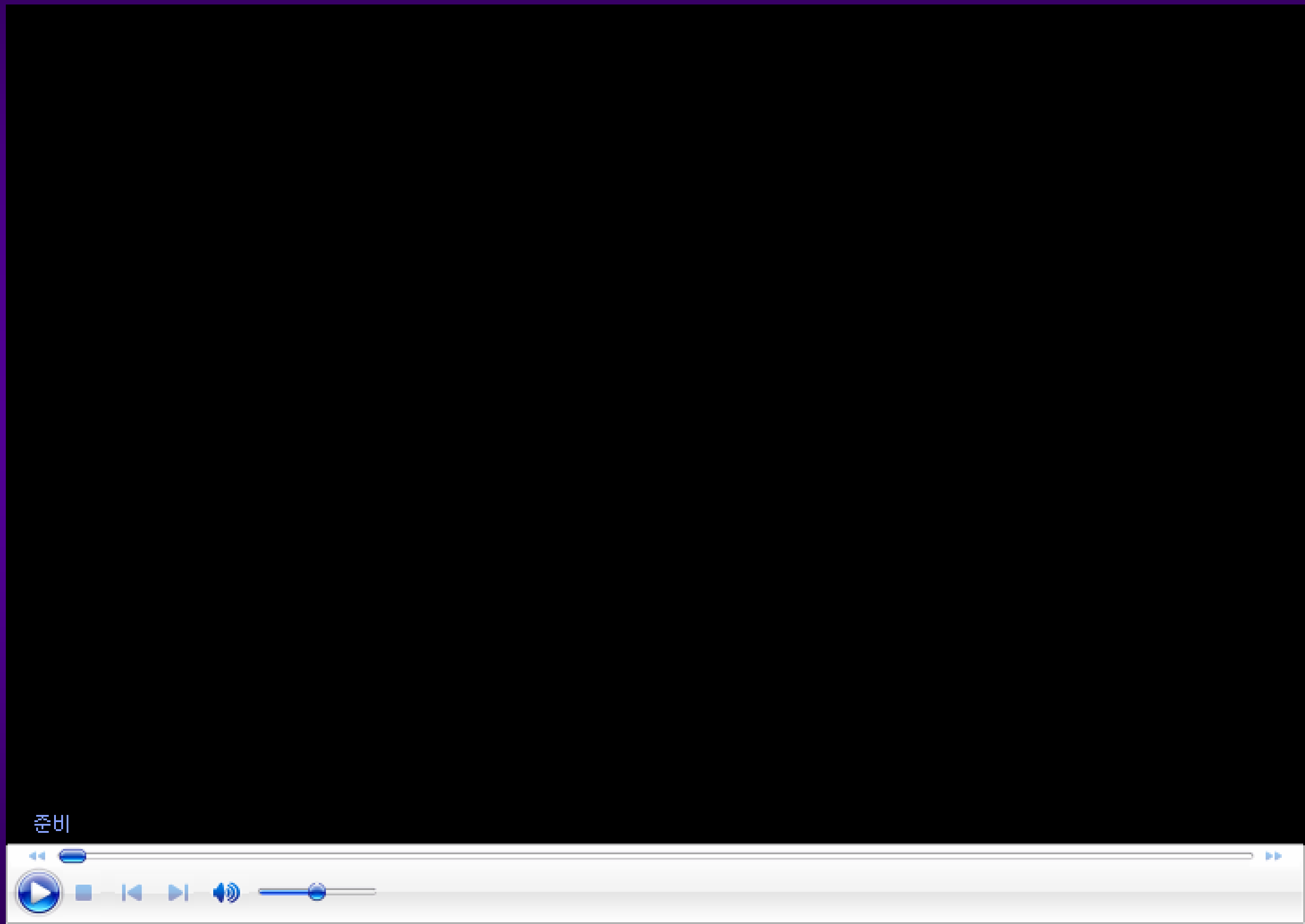
MRI _ proton Precession

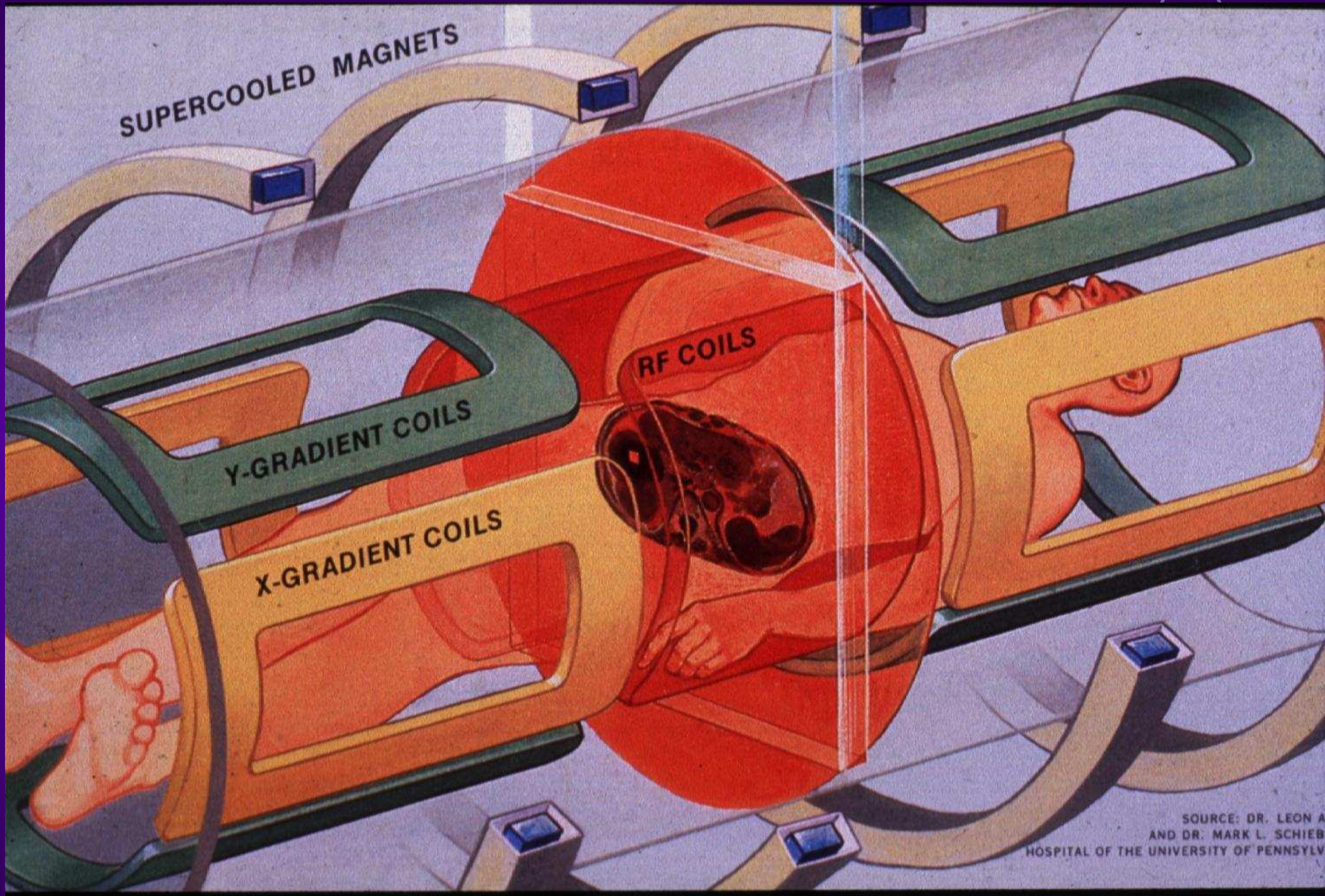


- Frequency depends on the strength of magnetization
- Applying the **slope of the magnetization** enables to be localized.



Gradient Coils in MRI





SUPERCOOLED MAGNETS
RF COILS
Y-GRADIENT COILS
X-GRADIENT COILS
SOURCE: DR. LEON A
AND DR. MARK L. SCHIEB
HOSPITAL OF THE UNIVERSITY OF PENNSYLV

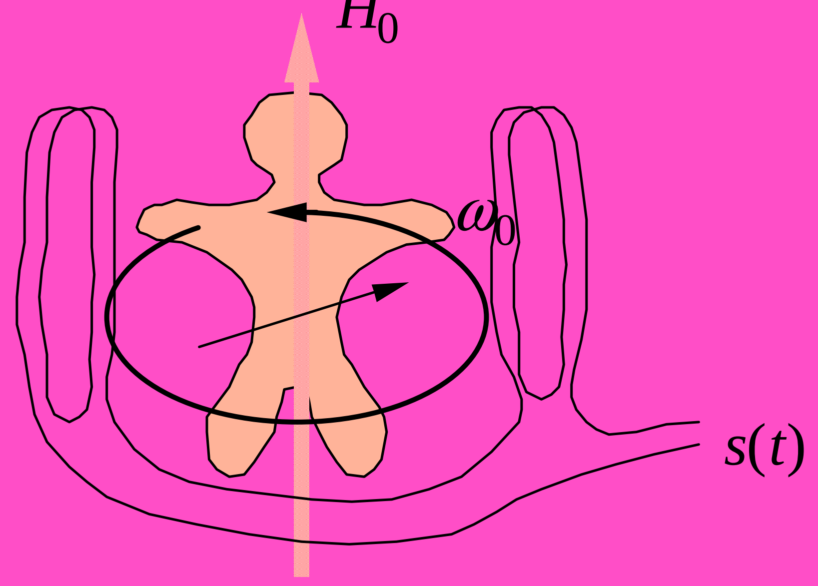
- **The key innovation for MRI is to impose spatial variation on the magnetic field to distinguish spins by their location.**

- **Applying a magnetic field gradient causes each region of the volume to oscillate at a distinct frequency.**

Detected Signal in MRI

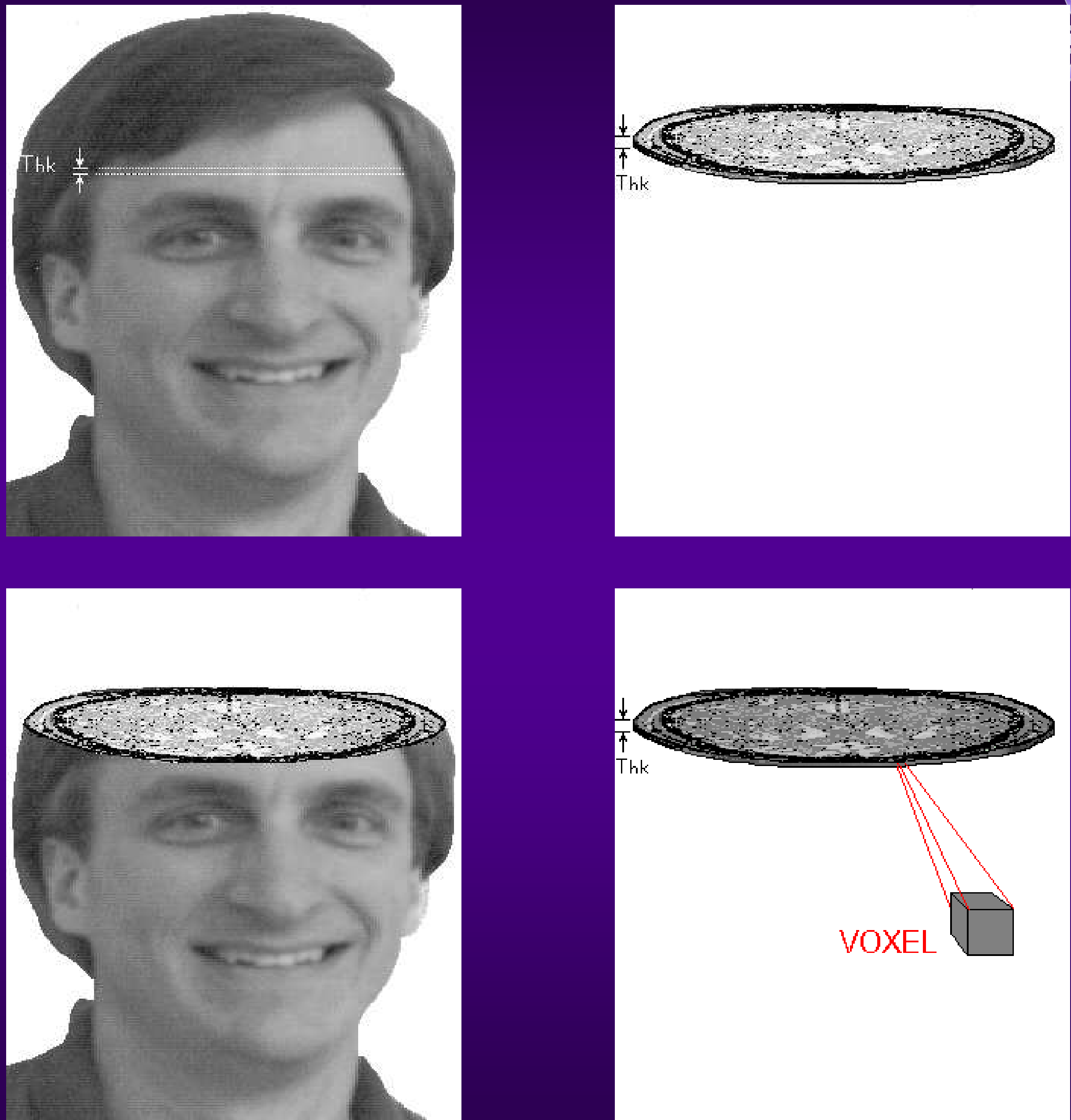
Induced voltage in external coils:

proportional to the size of magnetic moment and to the frequency.

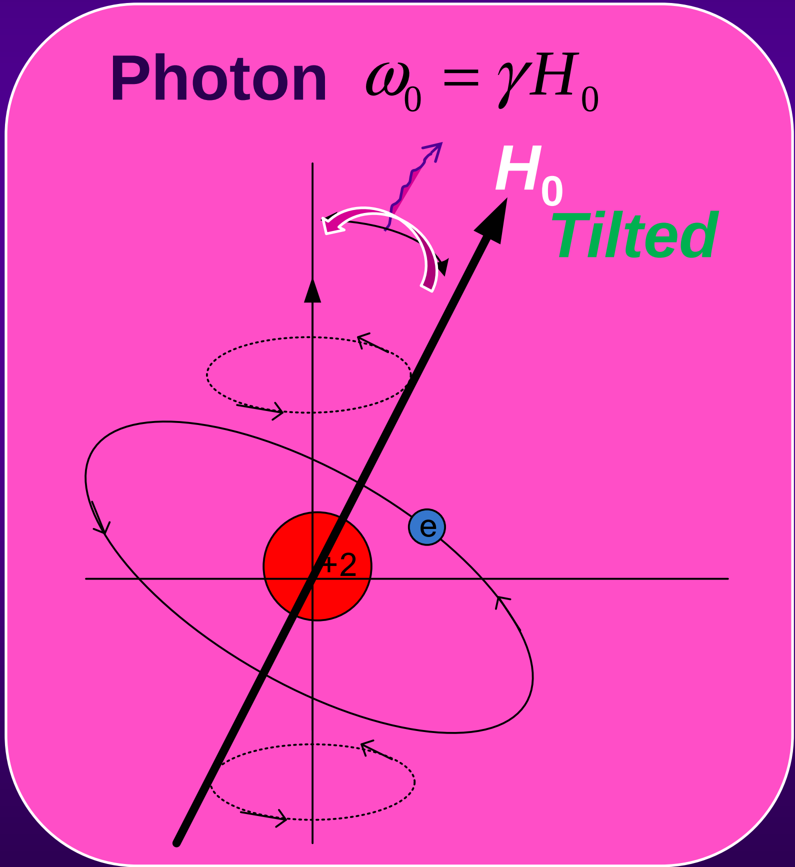


MRI Image Formation

- **Signals collected with multiple gradients are processed by computer to produce an image, typically of a section through the body.**


Thk
Thk
Thk
VOXEL

MRI Radio Frequency Signal Generation



$$\omega_0 = \gamma H_0$$

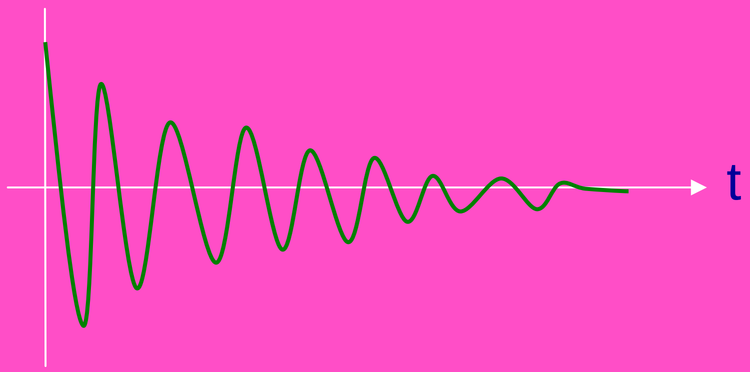
When external magnetic field is stopped, RF signal with the Larmour frequency is generated and detected by the external RF coil.

The primary imaging mechanisms exploit relaxation times T_1 and T_2.

Spin-lattice relaxation time T_1 : The time to recover 63% of the final z component, depending on tissue.

Spin-Spin decaying time T_2 : The time to decay of 37% of its original magnetization of x and y components, depending on tissue.

Transverse Magnetization Component



$$M(t) = M_0 e^{-t/T_2} e^{-i\varpi_0 t}$$

This is a decaying sinusoid.

◆**The time of 37% decay of x-y signal component tells what kind of tissue it is.**

MR: Relaxation : Some sample tissue time constants T2

T_2 of some normal tissue types

Tissue	T_2 (ms)
gray matter	100
white matter	92
muscle	47
fat	85
kidney	58
liver	43

Table: Nishimura, Table 4.2

MR Relaxation :

Longitudinal recovery time constant T1

$$M_z(t) = M_z^0 e^{-t/T_1} + M_0(1 - e^{-t/T_1})$$

MR: Relaxation: Some sample tissue time constants - T_1

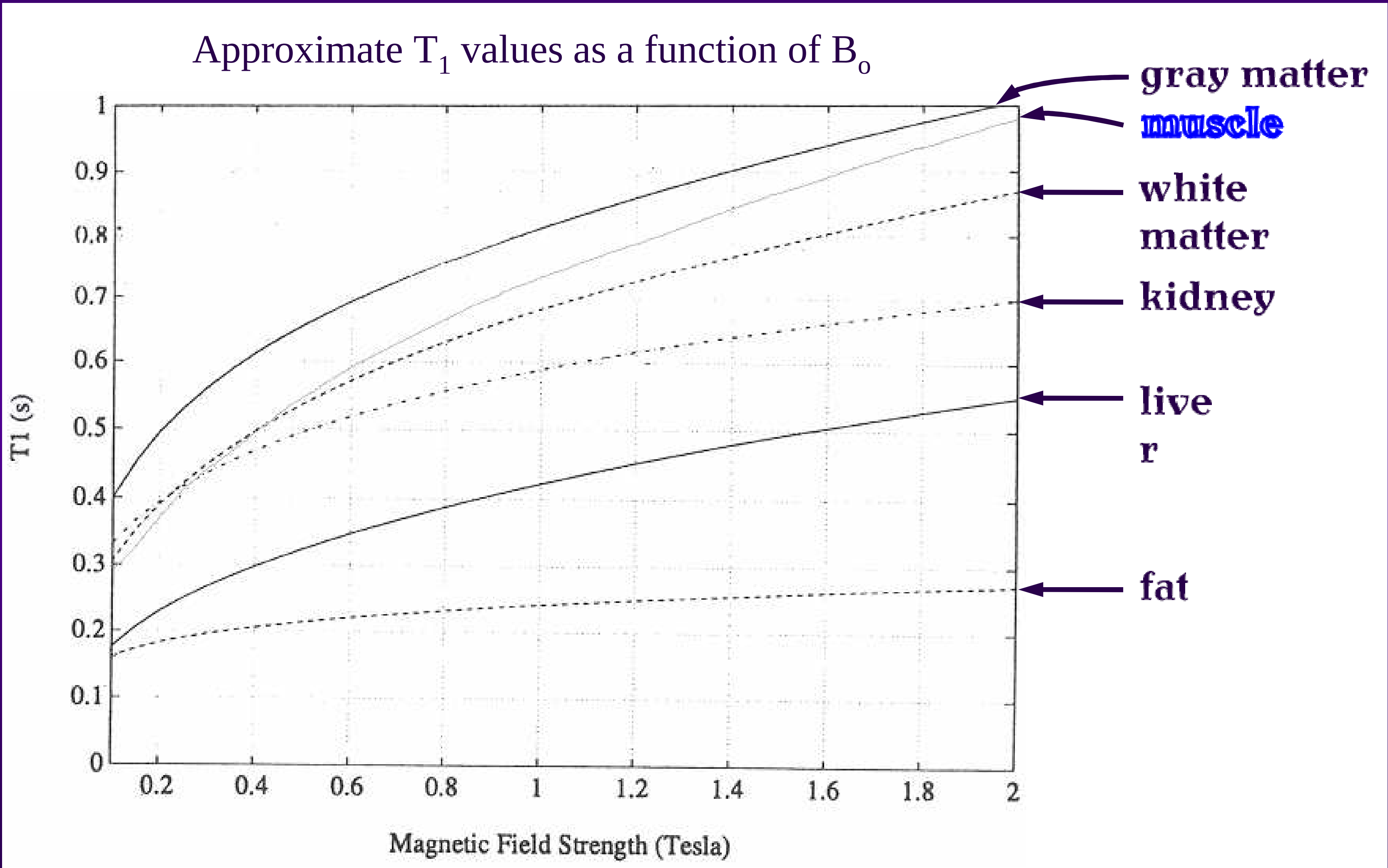


Image is formed with the factors as following

- Difference of measured T1 and T2 Values
- Density of Hydrogen Atoms
- ETC

Features

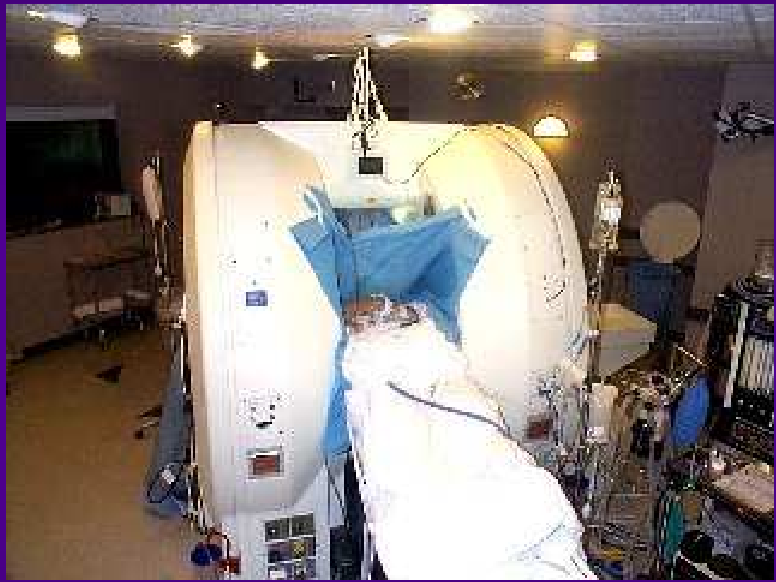
- MR images provide excellent contrast between various forms of soft tissues.

- MRI scanning appears to be perfectly safe and can be repeated as often as necessary without danger.

- **Typical imaging takes from 1 to 10 minutes but new fast imaging techniques acquire images in less than 50 msec.**

- **Slower and more expensive than X-ray**

MRI by Picker



Open MRI units

Example of MRI Images

Spinal cord

Brain section

Functional MRI

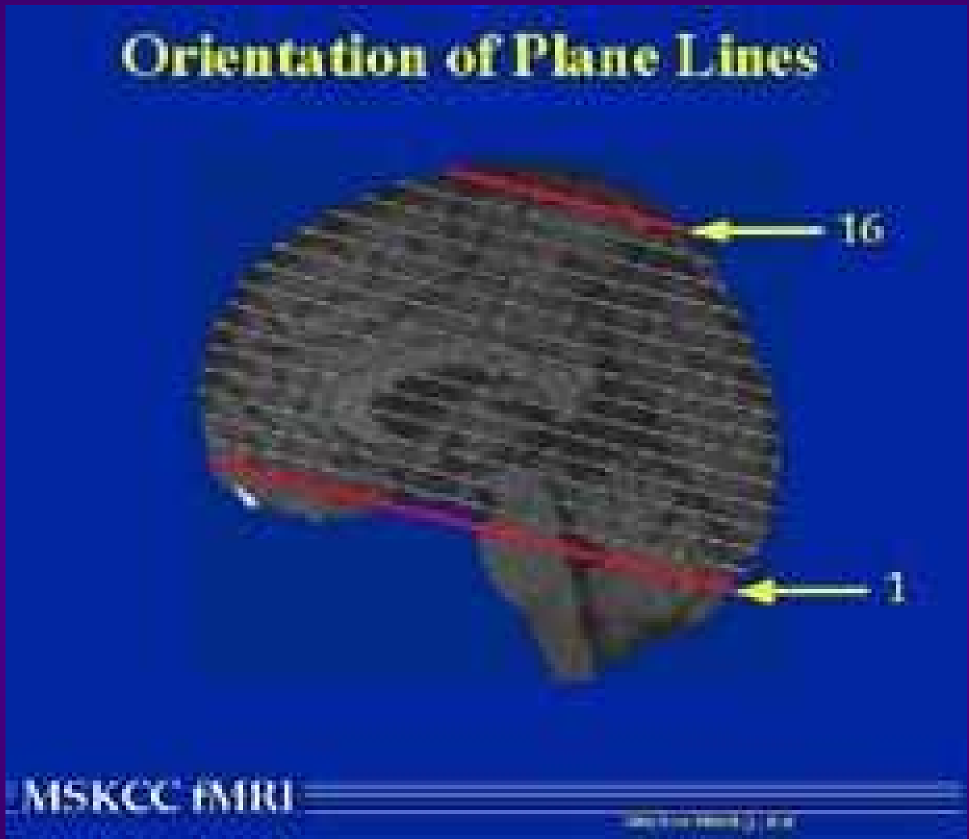
- ***f*** **MRI is a technique that measures the <u>hemodynamic response</u> (change in blood flow) related to <u>neural</u> activity in the <u>brain</u> or <u>spinal cord</u>.**

- **Changes in neuronal activity are accompanied by changes in cerebral blood flow (CBF), blood volume (CBV), blood oxygenation and metabolism.**

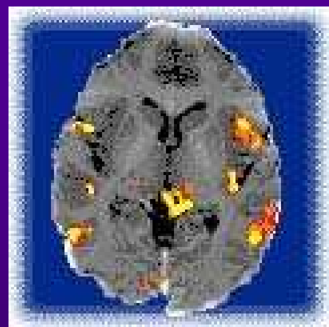
- **Changes in blood flow is measured also with injection of contrast agents (i.e. gadolinium-DTPA).**

Contrast enhancing agent: iron oxide

Example of fMRI



Plane 3

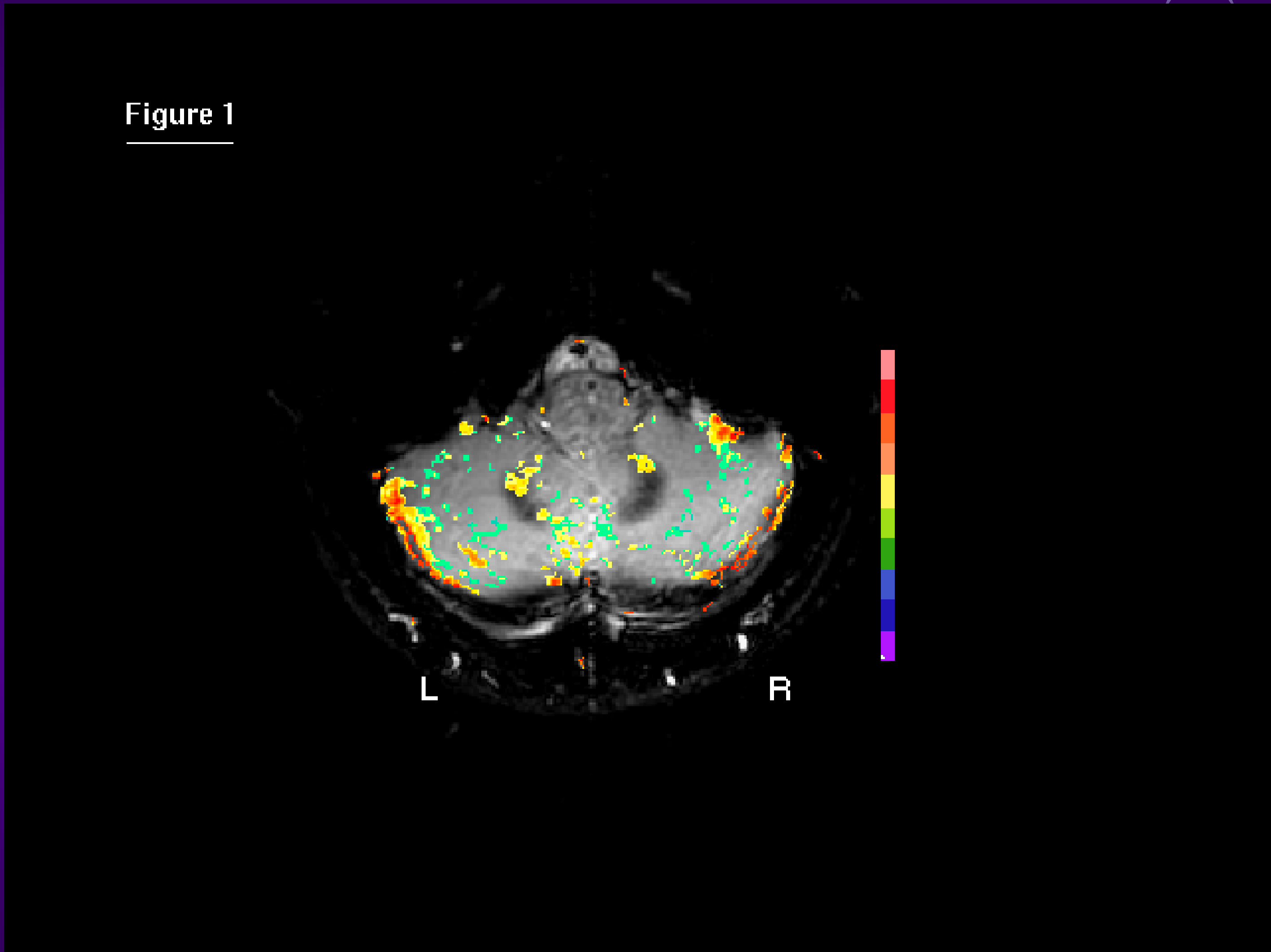


Plane 6

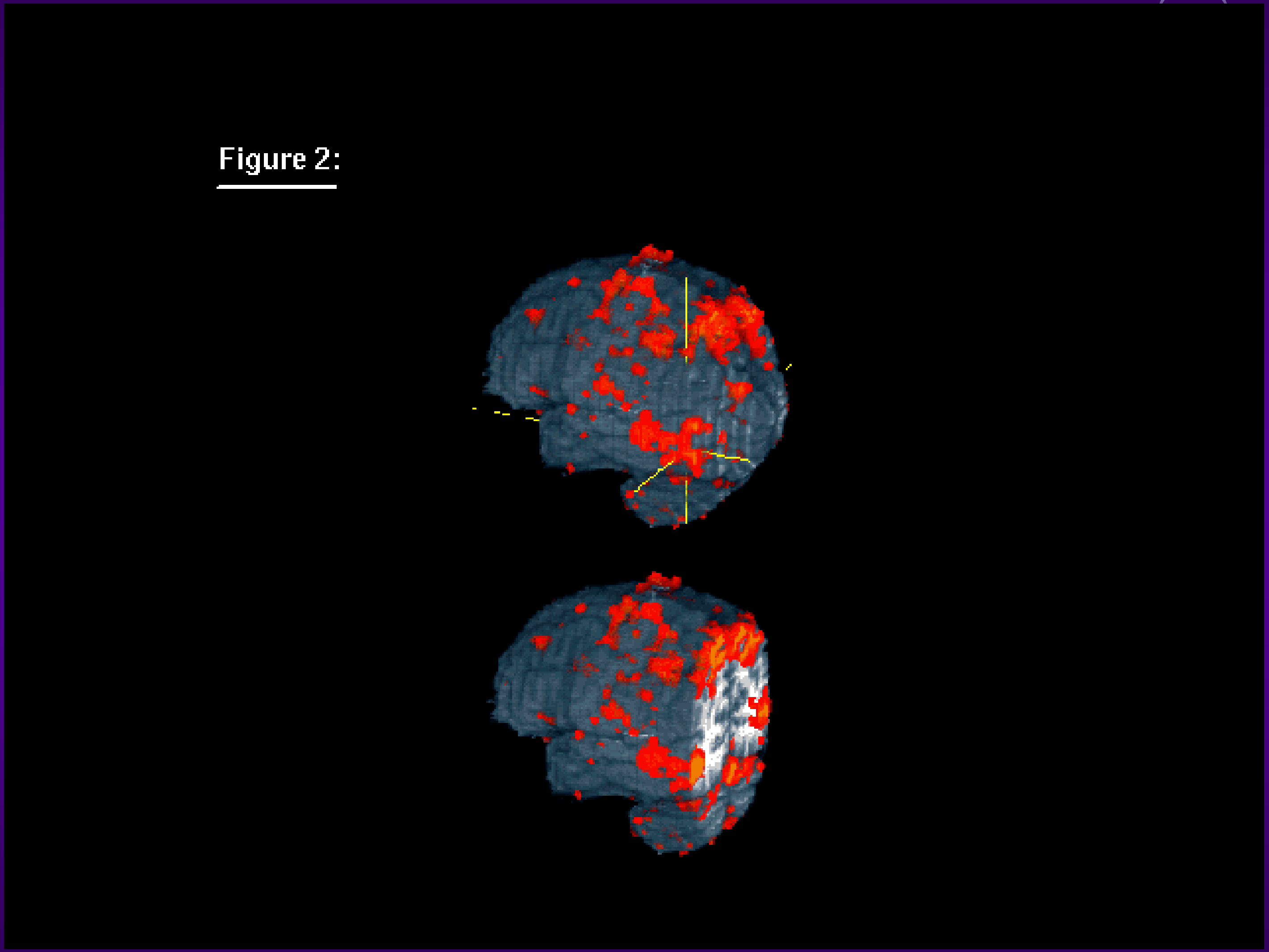
Two of sixteen planes through brain of subject participating in an image-naming experiment.

- Plane 3 shows functional activity in the visual cortex (bottom)

- Plane 5 shows activity in the speech area (image right).



A functional map (in color) in the cerebellum during performance of a cognitive peg- board puzzle task.



Whole brain functional imaging study during a visuo-motor error detection and correction task. Activation (in color) is observed at various brain areas.