جامعة الانبار
كلية العلوم التطبيقية – هيت
قسم الفيزياء الحياتية

الاجهزة الطبية

Magnetic Resonance Imaging (MRI)

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Magnetic Resonance Imaging

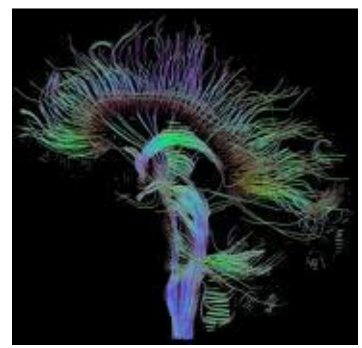
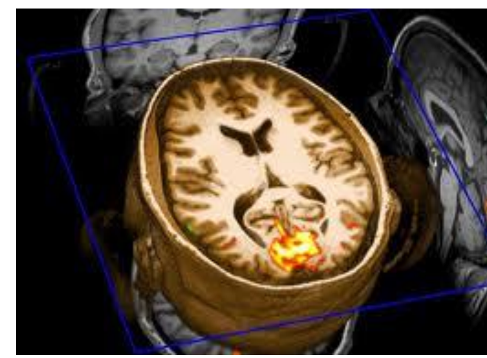
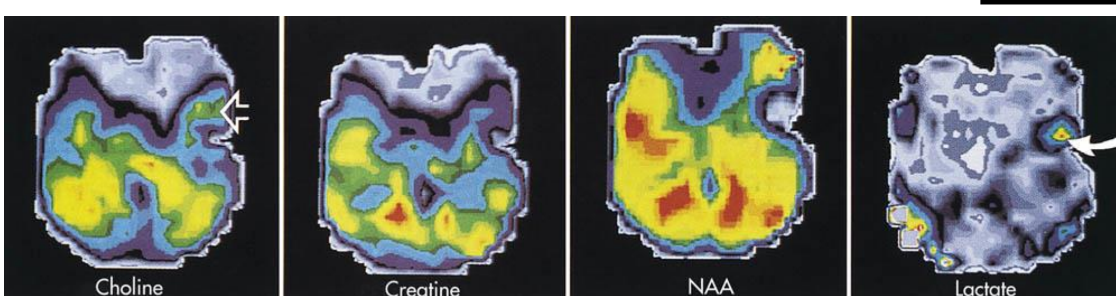
Normal MRI

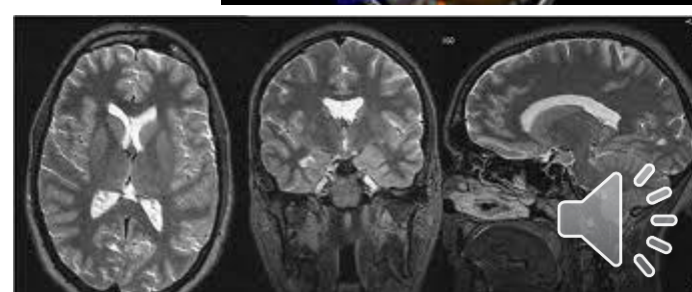
Open MRI

Magnetic Resonance Imaging functions

- Anatomy تشريح
- Physiology (function) فسلجة
- Angiography تصوير الاوعية
- Diffusion الانتشار
- Perfusion النضح
- Spectroscopy التحليل الطيفي



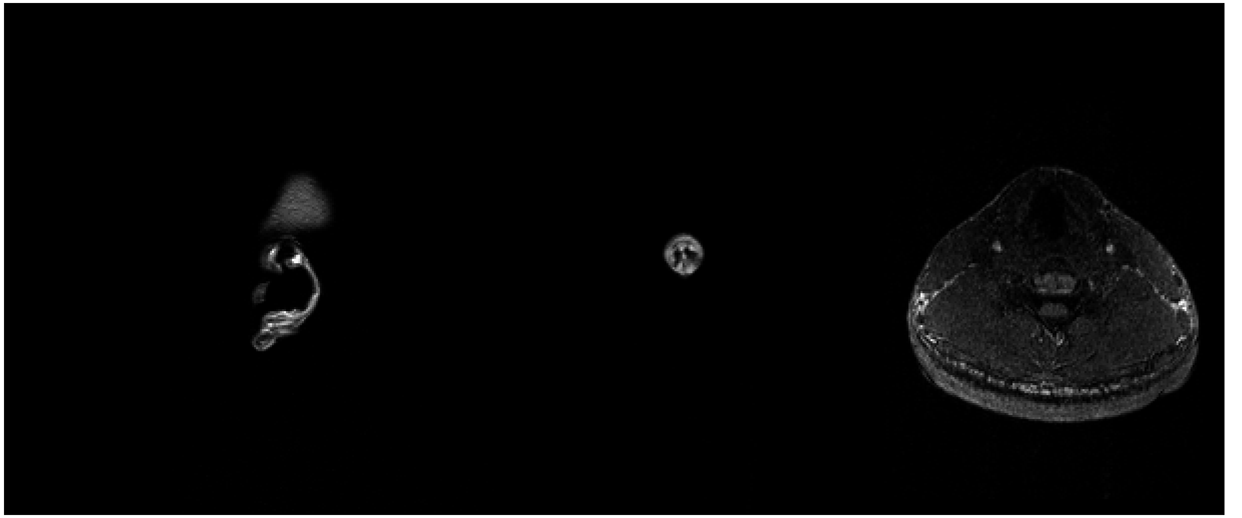


History

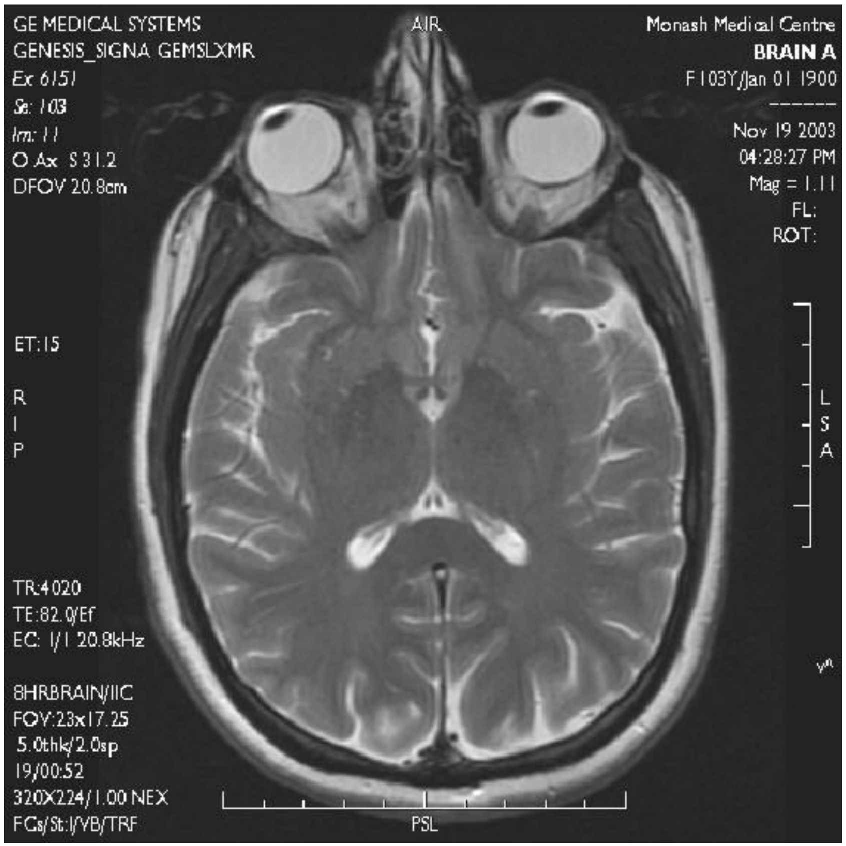
- The first MR image was published in 1973
- The first studies performed on humans were published in 1977 created by Dr. Raymond V. Damadian, Dr. Larry Minkoff and Dr. Michael Goldsmith
- In 2003, The 2003 Nobel Prize in Physiology or Medicine was awarded to Paul C Lauterbur and Peter Mansfield
    - Made new MR imaging techniques
    - Faster and more efficient

What is MRI?

- Produces very clear, detailed pictures of the organs and structures in the body with two or three dimensions.
- It is a form of medical imaging that uses no Ionizing radiation
- MRI makes use of the property of Nuclear magnetic resonance (NMR) to image nuclei of atoms inside the body.



Common Uses



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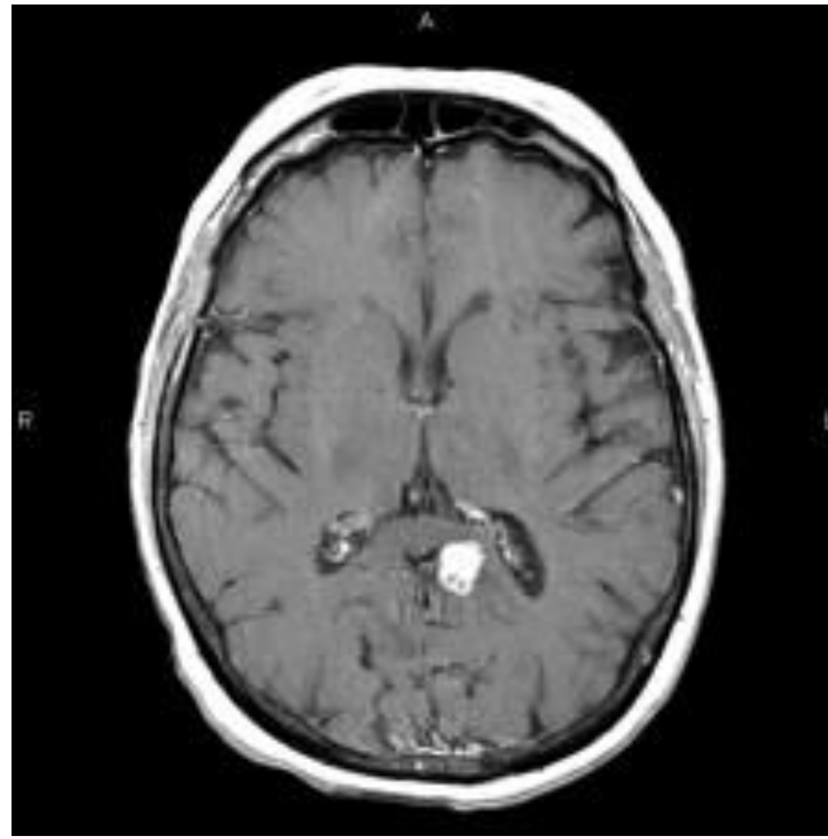

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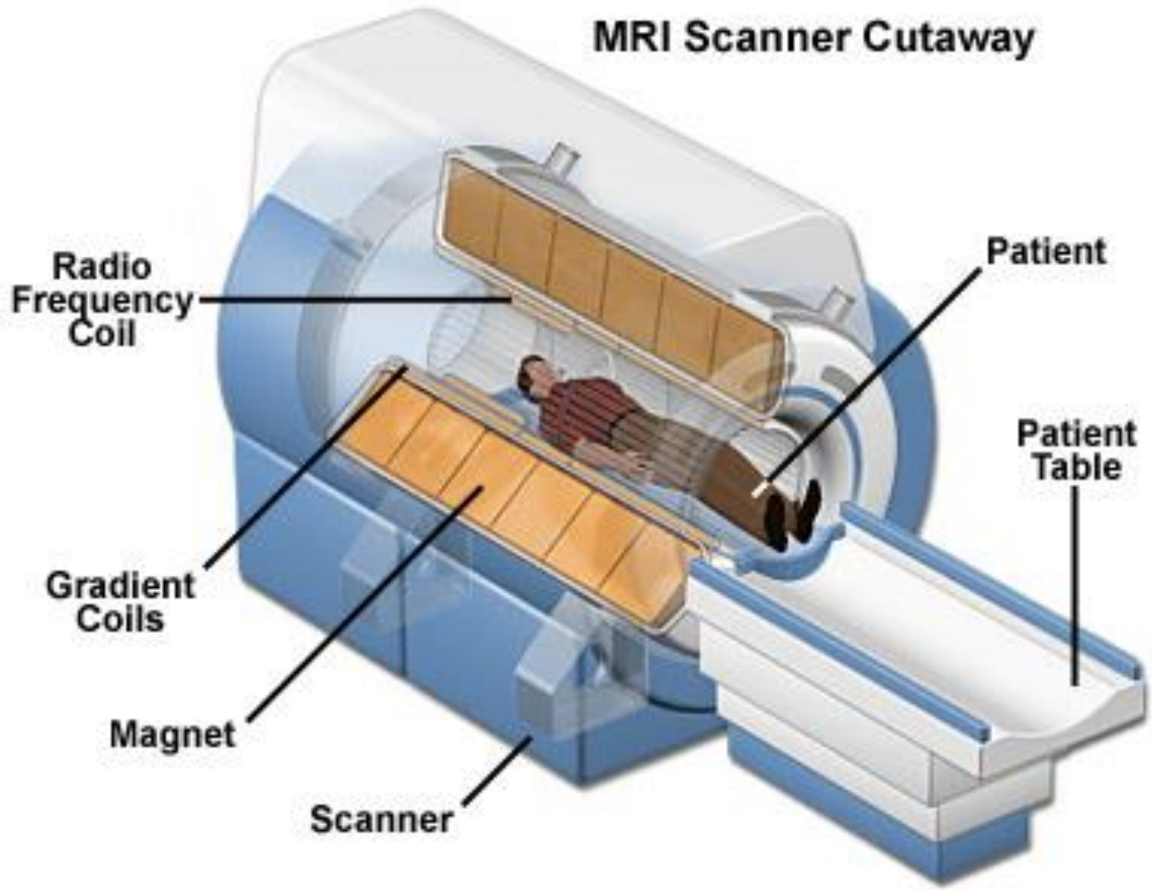
MRI Common Uses

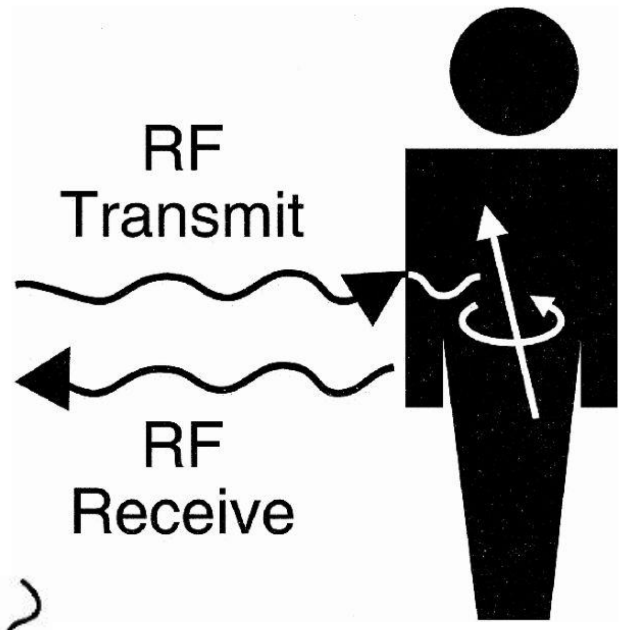
- Physicians use the MR examination to help diagnose or monitor treatment for conditions such as:
  1. Tumors اورام and other cancer سرطانrelated abnormalitiesشذوذ .
  2. Certain types of heart قلب problems.
  3. Blockages انسداد or enlargements تضخم of blood vessels
  4. Diseases of the liver الكبد , such as cirrhosis تليف, and that of other abdominal البطنية organs.
  5. Diseases of the small intestine الامعاء , colon القولون , and rectum المستقيم

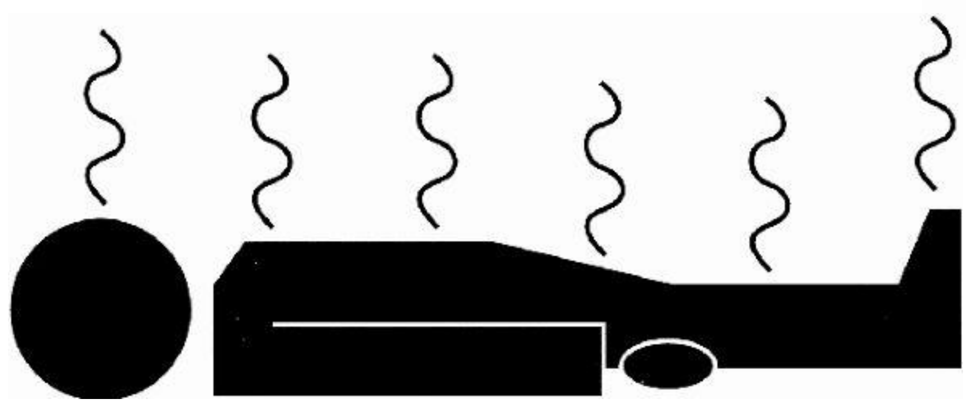
How does it work?



Steps to Perform MR Imaging

- **M**: Magnetic Field
  - Patient is placed inside magnet
- **R**: Radio-Frequency (RF) Pulse
  - RF pulse is applied
- **R**: Relaxation
  - After RF application, signal is collected from relaxation





General Steps work?

1. An MRI machine uses a powerful magnetic field to align the magnetization of some atoms in the body

2. Radio frequency fields systematically alter the alignment of this magnetization

3. This causes the nuclei to produce a rotating magnetic field detectable by the scanner.

4. The detected field information is recorded to construct an image of the body.

What kinds of nuclei can be used for NMR?

- Nucleus needs to have 2 properties:
  - Spin
  - charge

- Pairs of spins tend to cancel their magnetic field, so only atoms with an odd number of protons or neutrons have spin
  - **Good MR nuclei are ^{1}H, ^{13}C, ^{19}F, ^{23}Na, ^{31}P**

Hydrogen atoms are best for MRI

- Biological tissues are predominantly ^{12}C, ^{16}O, ^{1}H, and ^{14}N
- Hydrogen atom is the only major species that is MR sensitive
- Hydrogen is the most abundant atom in the body
- The majority of hydrogen is in water (H_2O)
- Essentially all MRI is hydrogen (proton) imaging

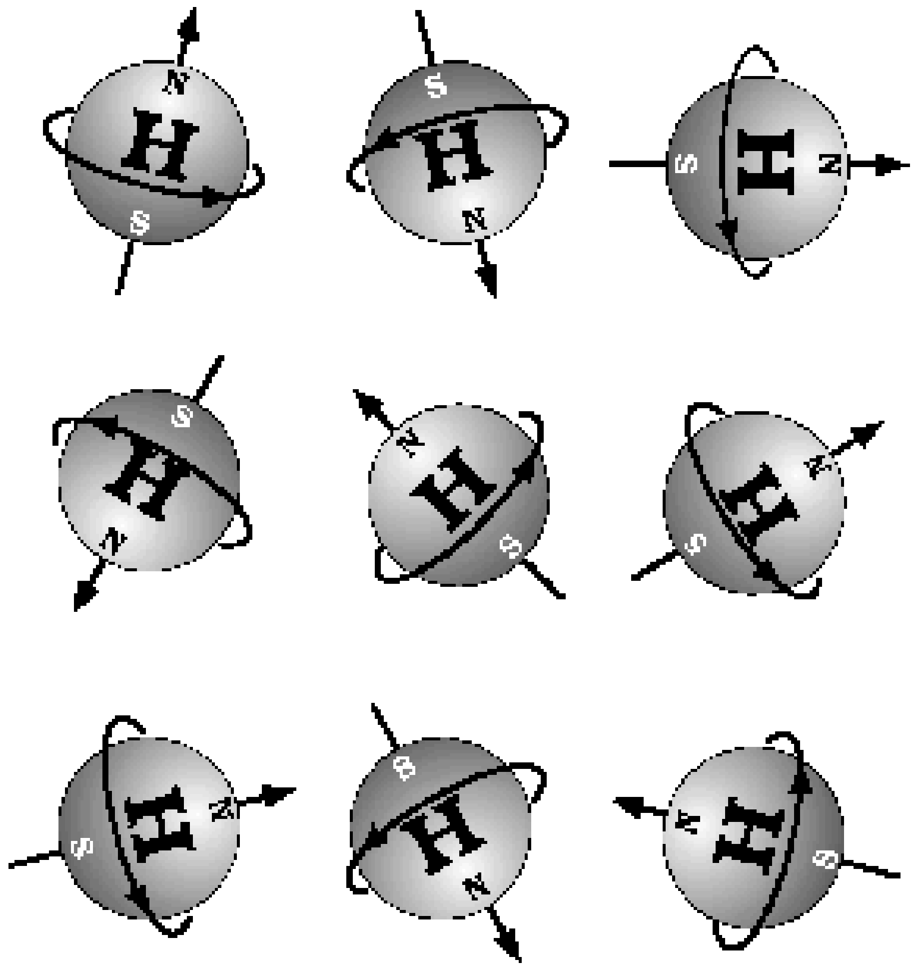
Nuclear Magnetic Resonance Visible Nuclei

Nucleus	Natural Abundance (%)	Relative Sensitivity
^{1}H	99.98	100.0
^{2}D	0.016	.00015
^{13}C	1.11	.016
^{14}N	99.60	.1
^{19}N	0.36	.00037
^{23}F	100	83.0
^{31}Na	100	9.3
^{31}P	100	6.6
^{35}Cl	75.4	.35
^{39}K	9.1	.046

How do protons interact with a magnetic field?

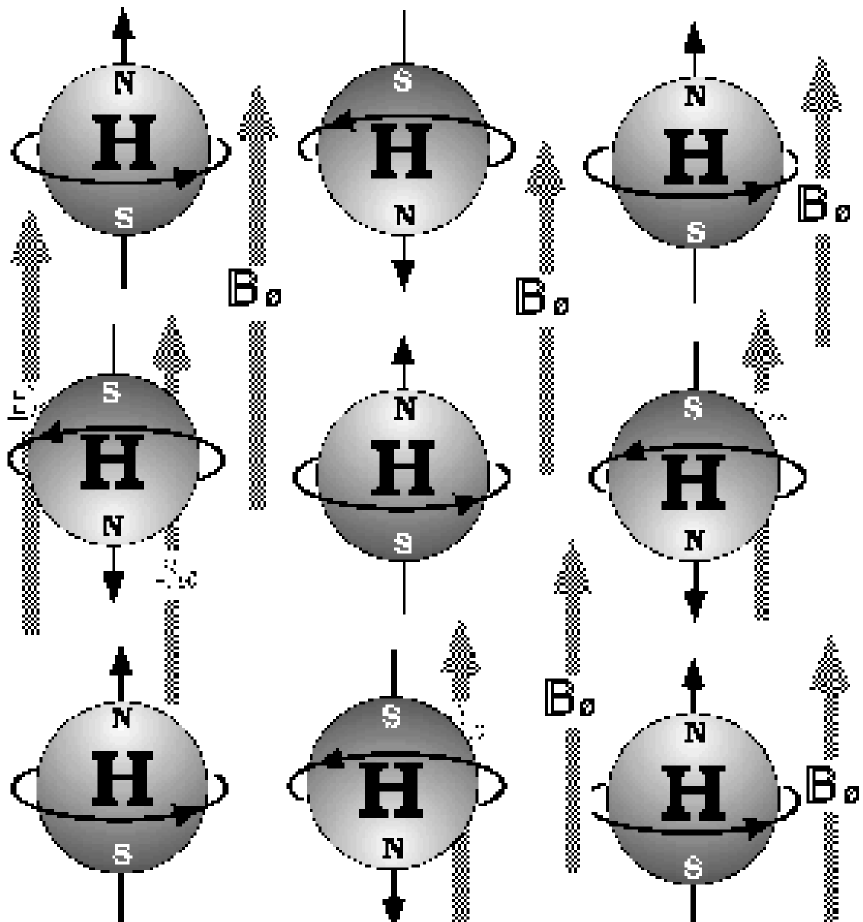
- Moving (spinning) charged particle generates its own little magnetic field
- Such particles will tend to line up with external magnetic field lines (think of iron filings around a magnet)

Spinning Protons Act Like Little Magnets



Net magnetic field= 0

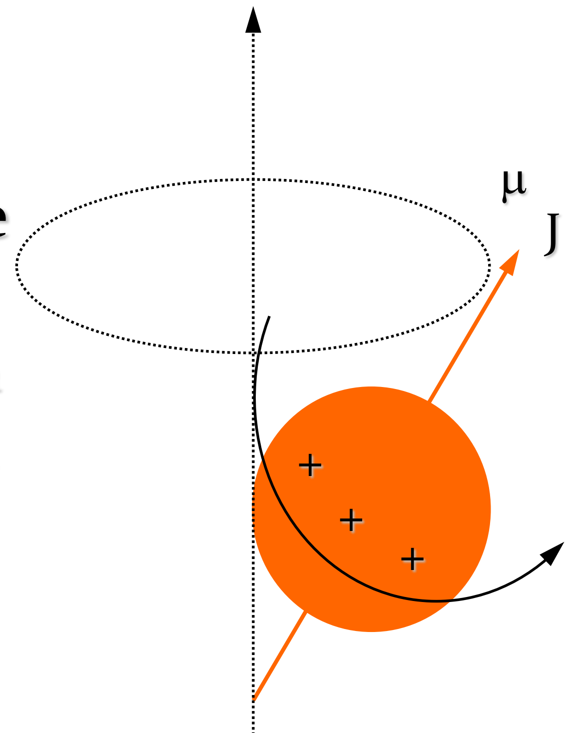
They Align With An External Magnetic Field (Bø)



Net magnetic field is exists

A Single Proton Precession

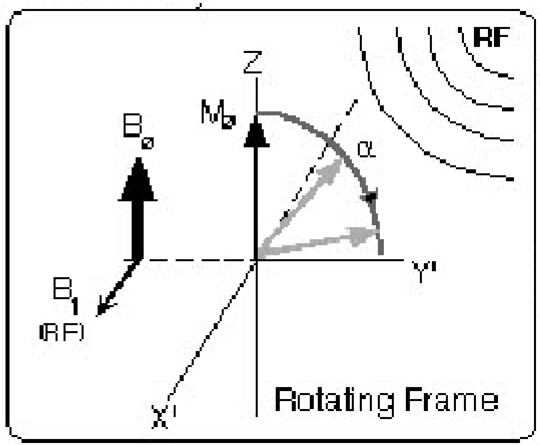
There is electric charge on the surface of the proton, thus creating a small current loop and generating magnetic moment μ.



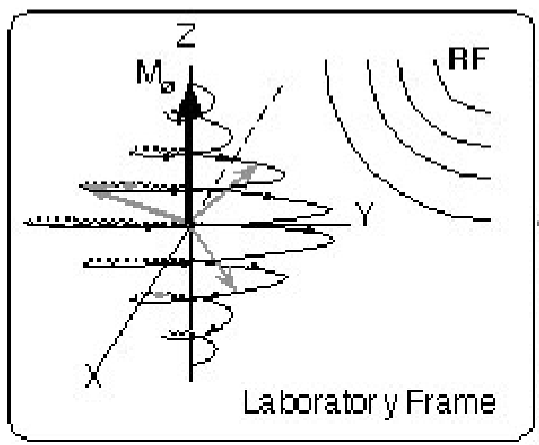
The proton also has mass which generates an angular momentum J when it is spinning.

Thus proton “magnet” differs from the magnetic bar in that it also possesses angular momentum caused by spinning.

Apply an RF Pulse on Resonance



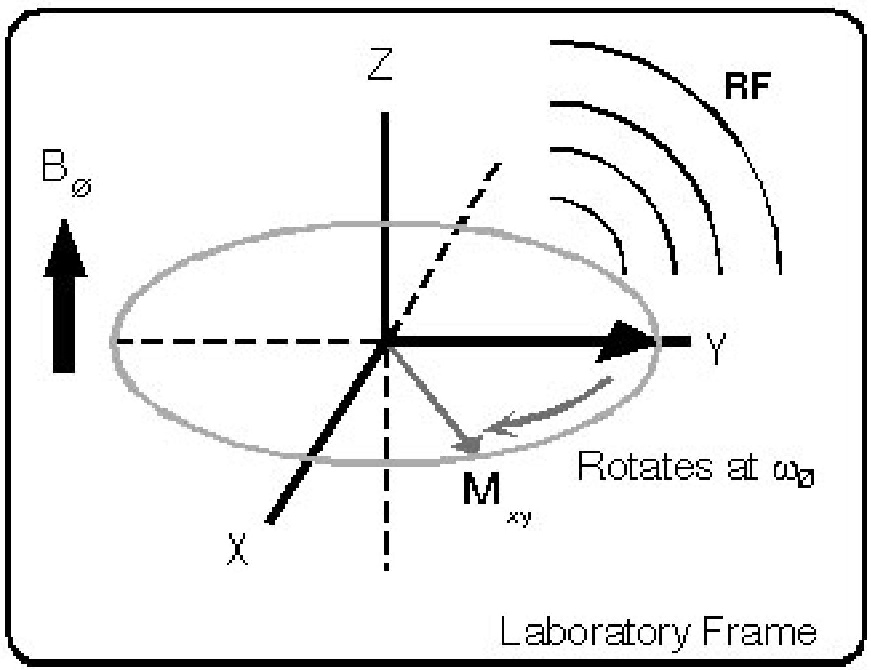
Proton spins tip in theB0 field.



Tilted spins rotate around the B0 axis.

Turn Off the Transmitter What Happens?

- RF energy is retransmitted
- This is the "NMR" signal
- At the resonance frequency
- Signal proportional to Proton Density



The energy difference between the two alignment states depends on the nucleus

$$\Delta E = 2\,\mu_z\,B_o$$

$$\Delta E = h\,\nu$$

$$\nu = \gamma/2\pi\;B_o$$

known as Larmor frequency

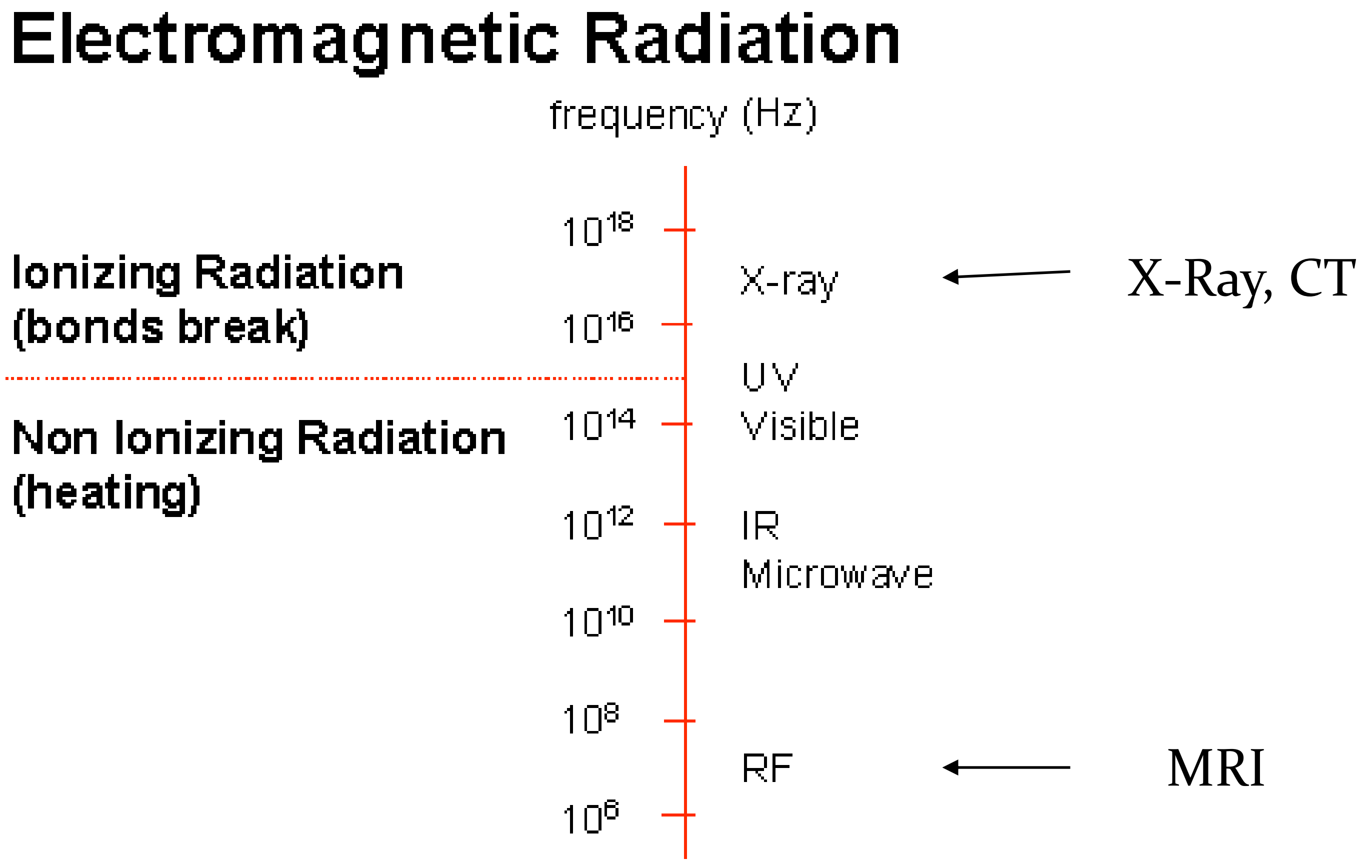
$\gamma/2\pi$ = 42.57 MHz / Tesla for proton

Resonance frequencies of common nuclei

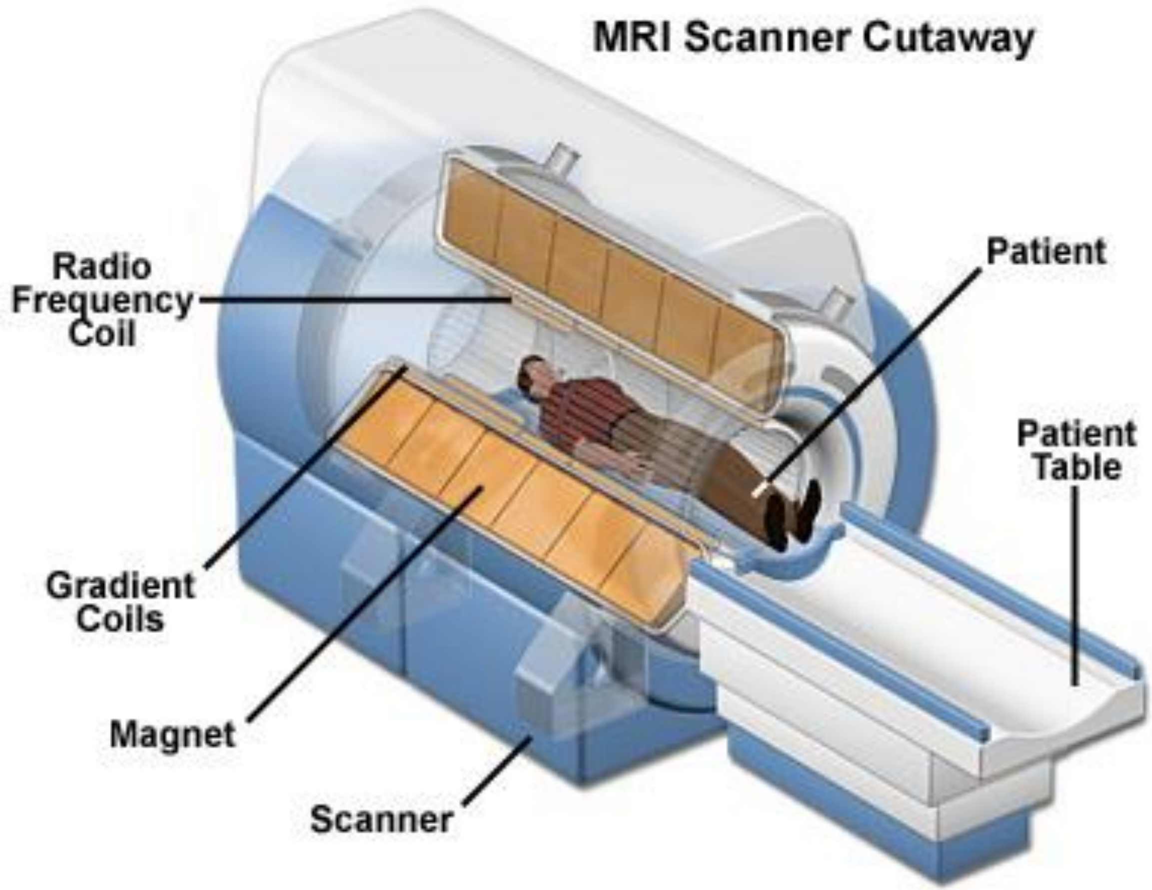
Nucleus	Resonance Frequency (1.5Tesla) MHz
^{1}H	63.86
^{2}D	9.81
^{13}C	16.05
^{14}N	4.62
^{19}N	6.57
^{23}F	60.07
^{31}Na	16.89
^{31}P	25.86
^{35}Cl	6.27
^{39}K	2.97

Note: Resonance at 1.5T = Larmor frequency X 1.5

Electromagnetic Radiation Energy



Functioning of MRI device Parts



MRI uses a combination of Magnetic and Electromagnetic Fields

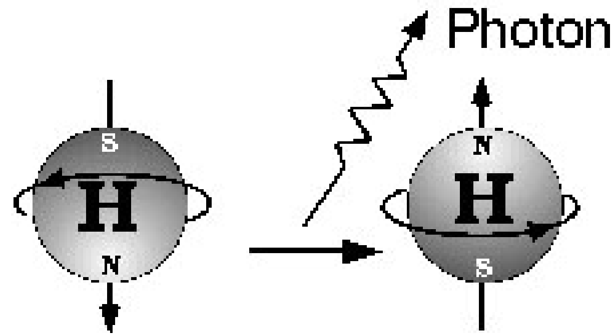
- MR measures the net magnetization of atomic nuclei in the presence of magnetic fields
- Magnetization can be manipulated by changing the magnetic field environment (static, gradient, and RF fields)
- Static magnetic fields don't change (< 0.1 ppm / hr):

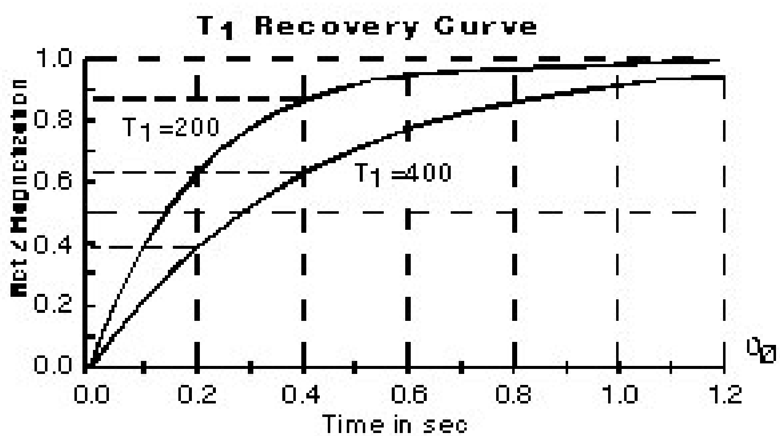
  The main field is static and (nearly) homogeneous
- RF (radio frequency) fields are electromagnetic fields that oscillate at radio frequencies (tens of millions of times per second)
- Gradient magnetic fields change gradually over space and can change quickly over time (thousands of times per second)

Recording the MR signal

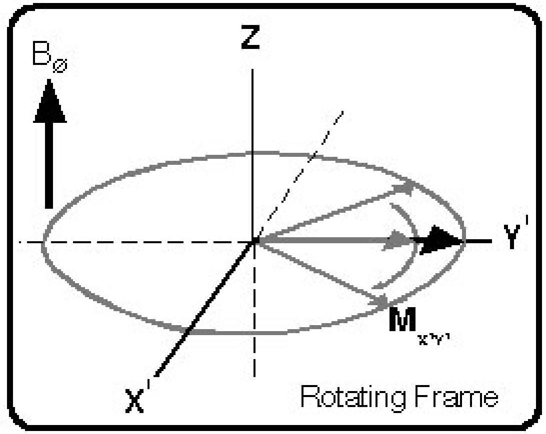
- Need a receive coil tuned to the same RF frequency as the exciter coil.

T_1 Relaxation

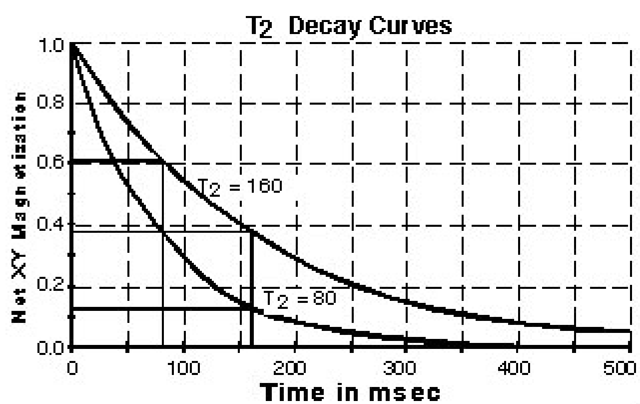




T_2 Relaxation



Loss of Phase



NMR signal decays in time

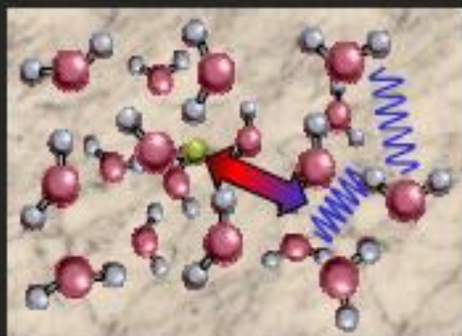
- T1 relaxation – Flipped nuclei realign with the magnetic field.
- T2 relaxation – Flipped nuclei start off all spinning together, but quickly become incoherent (out of phase).
- T2* relaxation – Disturbances in magnetic field increase the rate of spin coherence T2 relaxation.
- The total NMR signal is a combination of the total number of nuclei (proton density), reduced by the T1, T2, and T2* relaxation components

T2* decay

- Spin coherence is also sensitive to the fact that the magnetic field is not completely uniform
- Inhomogeneities in the field cause some protons to spin at slightly different frequencies so they lose coherence faster
- Factors that change local magnetic field (susceptibility) can change T2* decay

Nuclear Magnetic Resonance Imaging: Two important relaxation mechanisms

Spin-lattice relaxation — T1



Restoration of longitudinal magnetization

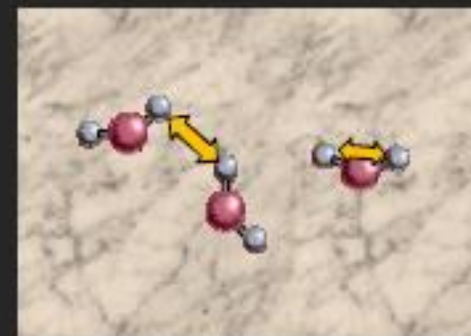
Energy transfered to lattice (phonons)

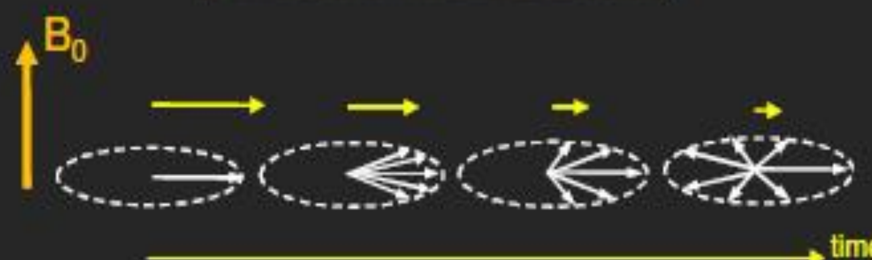
Entropy increases

Repopulation of spins between spin energy levels

Interactions with magnetic field fluctuations at Larmor frequency

Spin-spin relaxation — T2





Dephasing of transverse magnetization

Energy transferred between spins

No entropy change of total spin system

No repopulation of spins between spin energy levels

Interactions with magnetic field fluctuations at low frequency

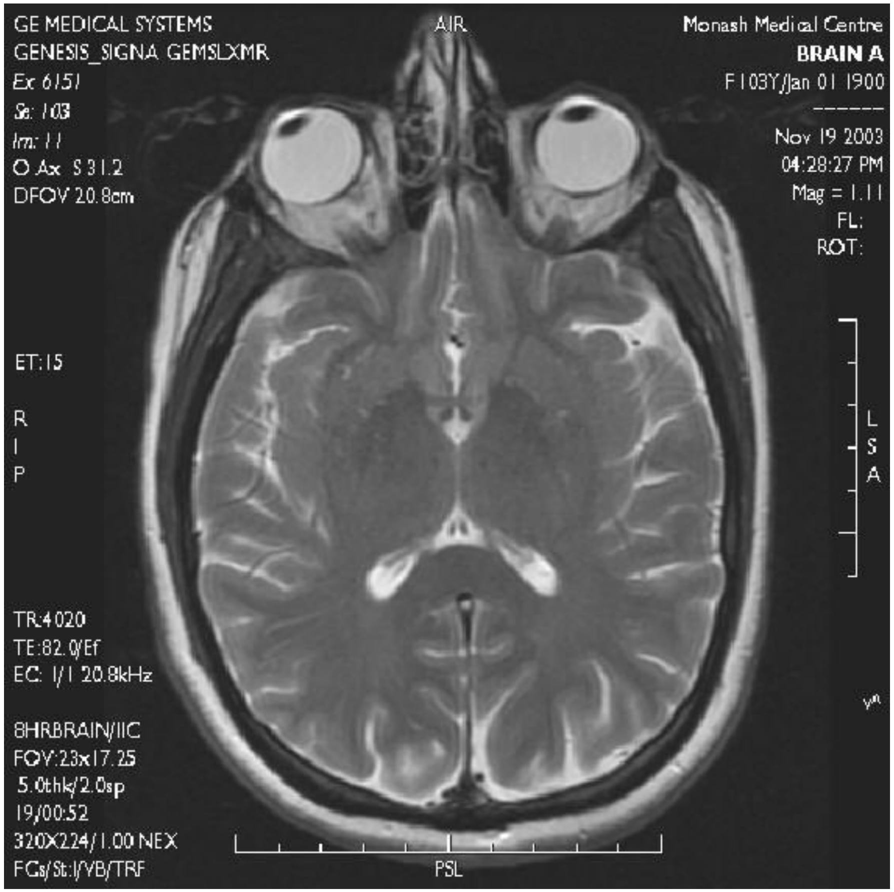
Image Construction?

- Images are constructed when protons in different tissues return to equilibrium state at different rates.
- Five variables effect these rates
    1. Spin Density: Concentration of nuclei in tissue processing in a given region under a magnetic field.
    2. T_1: Longitudinal طولي relaxation time
    3. T_2: Transverse عرضي relaxation time
    4. Flow: Shows blood flow, CSF flow
    5. Spectral Shifts: Angle/zoom the picture is taken from.

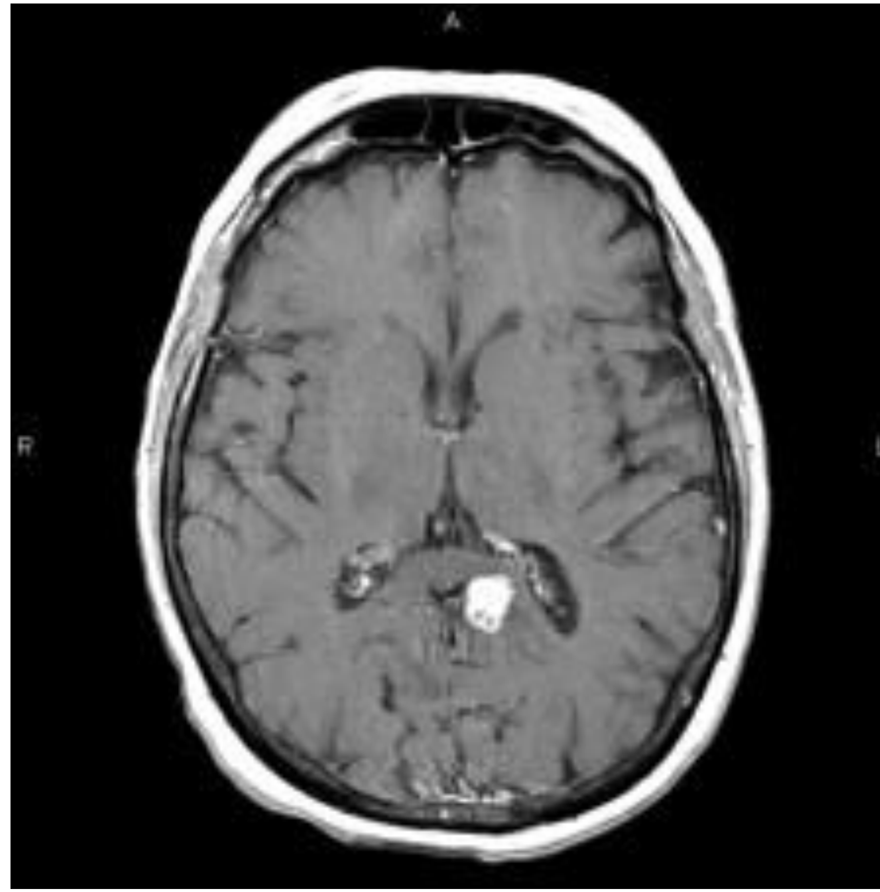
MRI Scans Properties for T1 and T2

- T_1-weighted: Differentiate fat from water
  - Water is Darker, fat is brighter
  - Provide good gray matter/white matter contrast in brain.
- T_2-weighted: Differentiate fat from water
  - Fat shows darker, and water lighter.
  - Good for imaging edema
    - Abnormal accumulation of fluid beneath the skin or in one or more cavities of the body

Basic MRI Scans

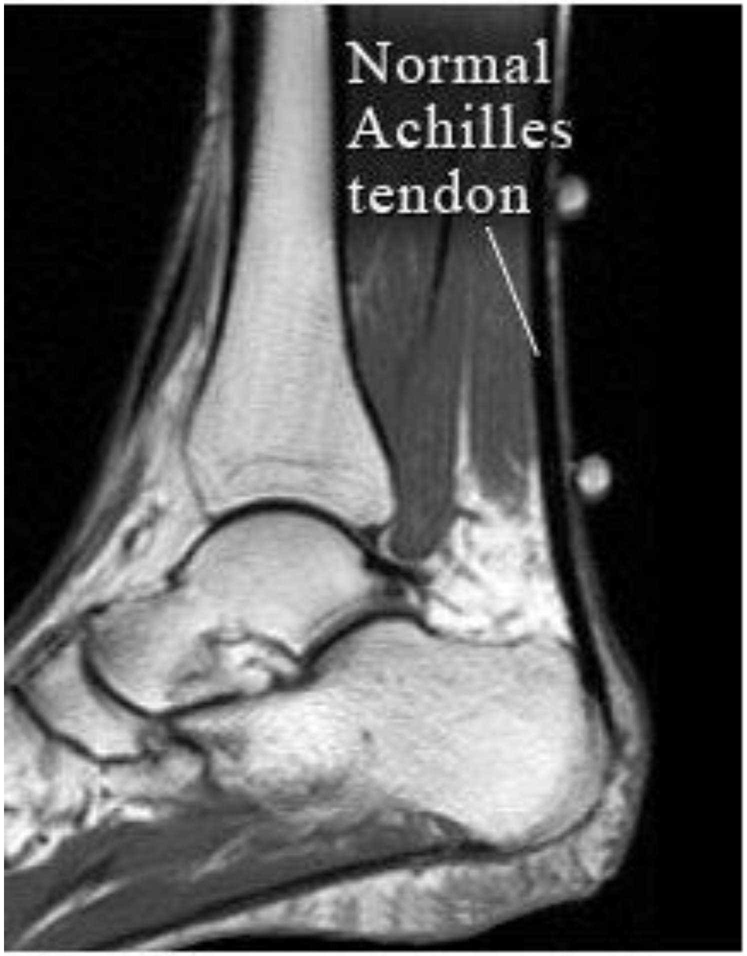


T_2-weighted



T_1-weighted

Basic MRI Scans



T1

T2

Synopsis of MRI

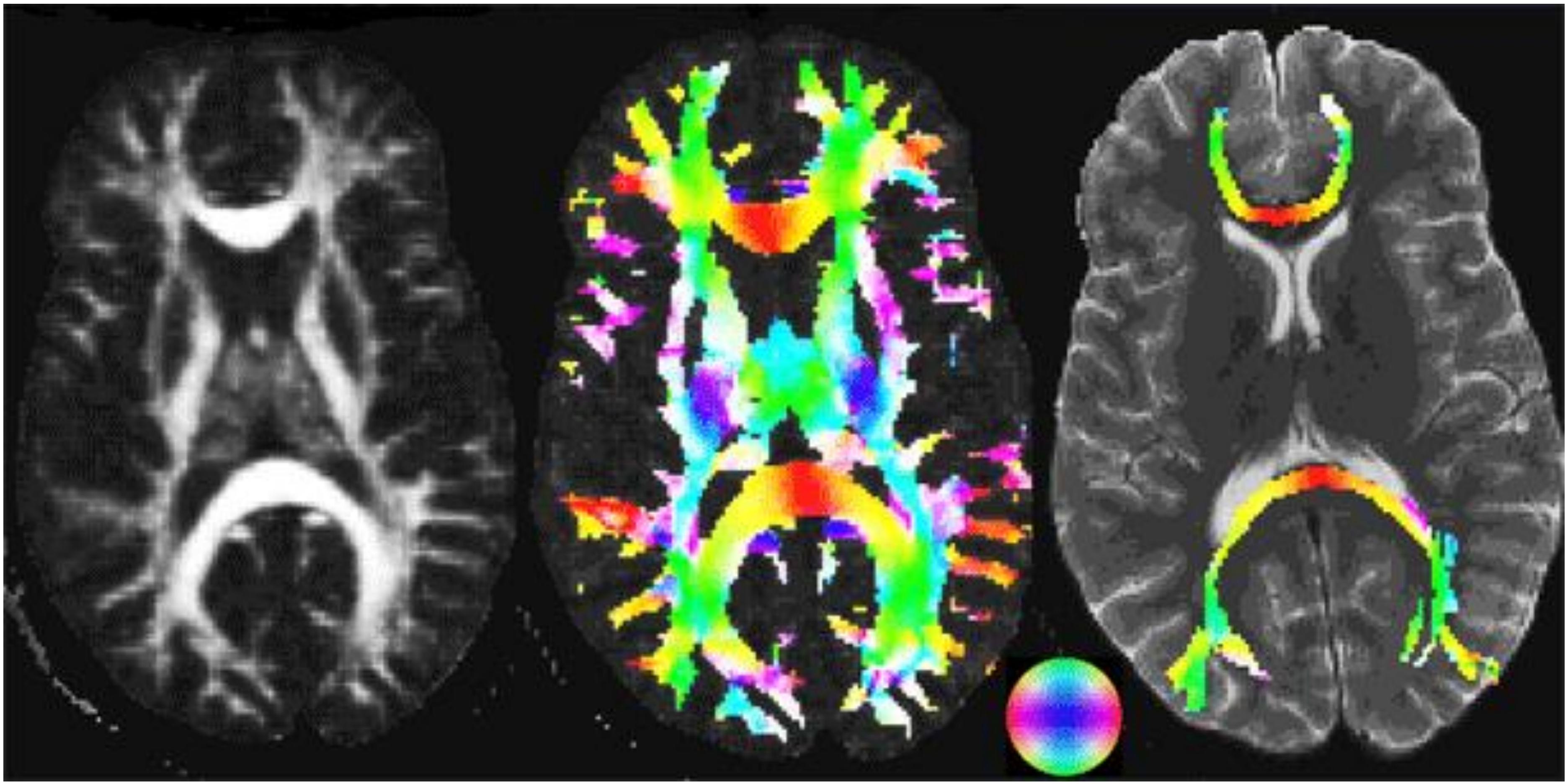
1) Put subject in big magnetic field
2) Transmit radio waves into subject [2~10 ms]
3) Turn off radio wave transmitter
4) Receive radio waves re-transmitted by subject
5) Convert measured RF data to image

Specialized MRI Scans

Diffusion MRI

- Measures diffusion of water through biological tissues.
  - Diffusion may be anisotropic متباين(unequal physical properties along different axes)
- Diffusion Tensor Imaging (DTI)
  - Examine areas of neural degeneration and demyelination ازاله النخاعين in diseases such as Multiple Sclerosis (MS)التصلب المتعدد

Diffusion MRI



Specialized MRI Scans

Magnetic Resonance Angiography (MRA)

- Generates pictures of arteries.
  - Evaluates the arteries of the neck and brain, the thoracic and abdominal aorta, the renal arteries, and the legs
- Uses Gadolinium injection as paramagnetic contrast agent
- Magnetic Resonance Venography (MRV) is a similar procedure that is used to image veins.

Magnetic Resonance Angiography

Safety Risks

- MRI's create up to 120dB
  - Equivalent to jet engine at take off.

Setbacks:

1. Pacemakers, Vagus Nerve Stimulators, implantable defibrillators, insulin pumps, deep brain stimulatorsأجهزة

ضبط نبضات القلب،المنبهات العصبية المبهم،أجهزة تنظيم ضربات القلب

المزروعة، مضخات الأنسولين،منبهات الدماغ العميقة

2. Any electronic or magnetized foreign bodies (surgical prosthesis)

Peripheral Nerve Stimulation (PNS)

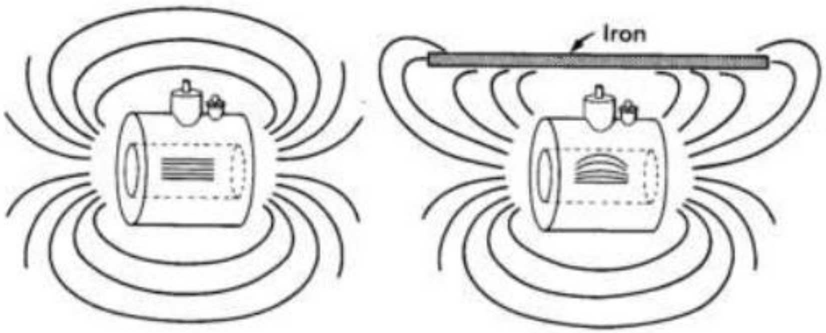
- Rapid switching on and off of the magnetic field gradients is capable of causing nerve stimulation

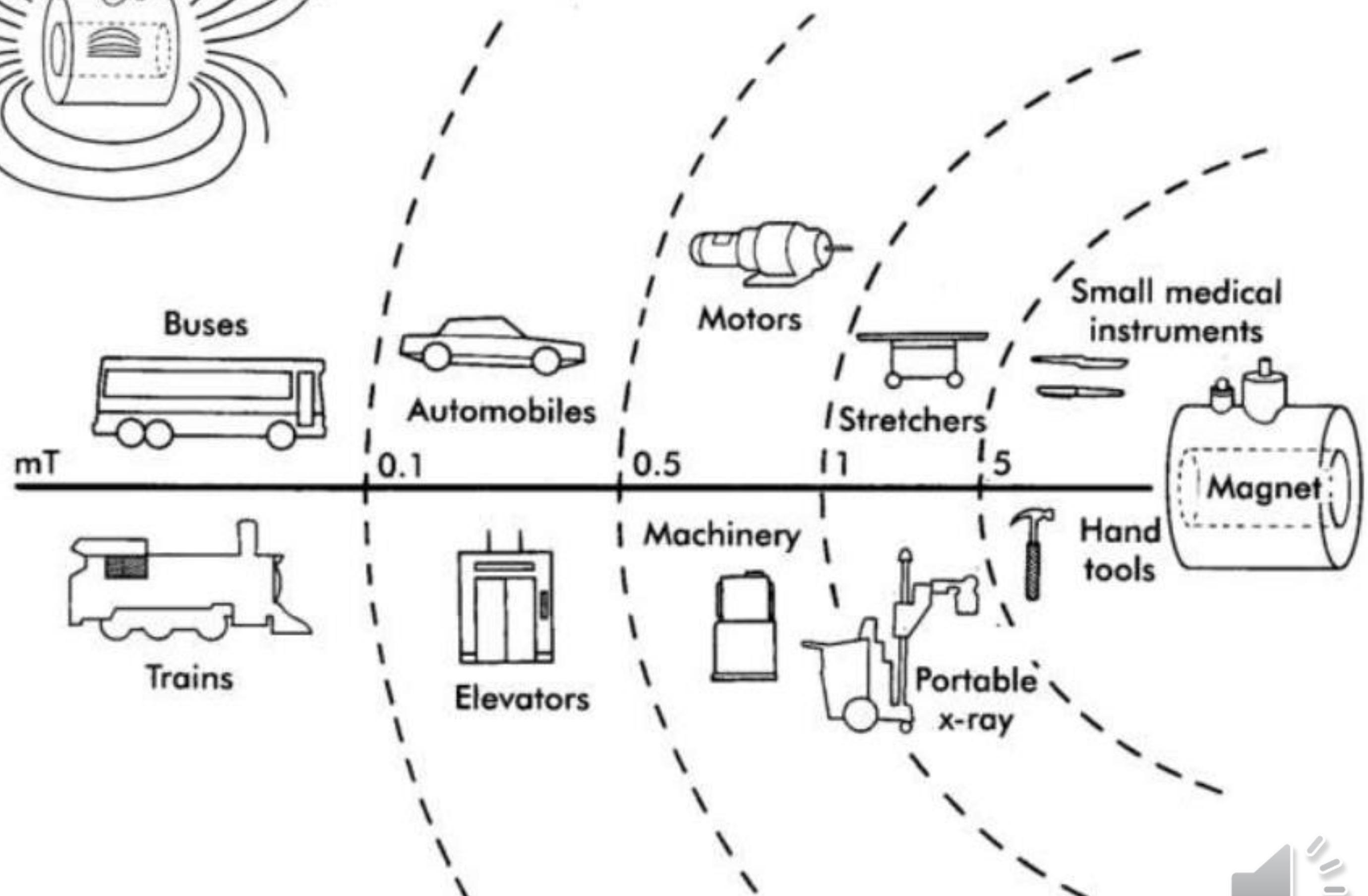
During Procedure

1. People hold the part of their body being scanned motionless for 30-60 minutes.

2. Procedure is done in multiple parts.
   - Takes time to switch between different scans and fields of view.

Effects of the Environment on MRI





Future?

- More detailed images
  - All MRIs use color?
- Better pictures of bone structures
  - Shift from x-rays and CT scans to MRI
- New Scanning sequences