MRI
‘’ Magnetic Resonance Imaging ’’

NEU Faculty Of Medicine
Assist. Prof. Aslı AYKAÇ, PhD

Bloch and Purcell independently discovered NMR in 1946. They were awarded the *Nobel Prize* for their achievements in 1952.

Edward Purcell
(1912-1997)

Felix Bloch
(1905-1983)

- Nuclear Magnetic Resonance (NMR) is a non-invasive means of
    - obtaining clinical images
    - studying tissue metabolism in vivo

- The process of detecting metabolites by NMR is known as Magnetic Resonance Spectroscopy (MRS or just NMR).
- The process of acquiring 2D and 3D images by NMR, known as Magnetic Resonance Imaging (MRI).
- Radio frequency (RF),electromagnetic (EM) waves and strong magnetic fields are used for MRI.

- Proton nuclear magnetic resonance (NMR) detects the presence of hydrogens (protons)
  - by subjecting to a large magnetic field to polarize the nuclear spins
- then exciting the spins
  - with properly tuned radio frequency (RF) radiation,
- and then detecting weak radio frequency radiation from them as they ‘’relax’’ from this magnetic interaction.

The frequency of this proton "signal" is proportional to the magnetic field to which they are subjected during this relaxation process.

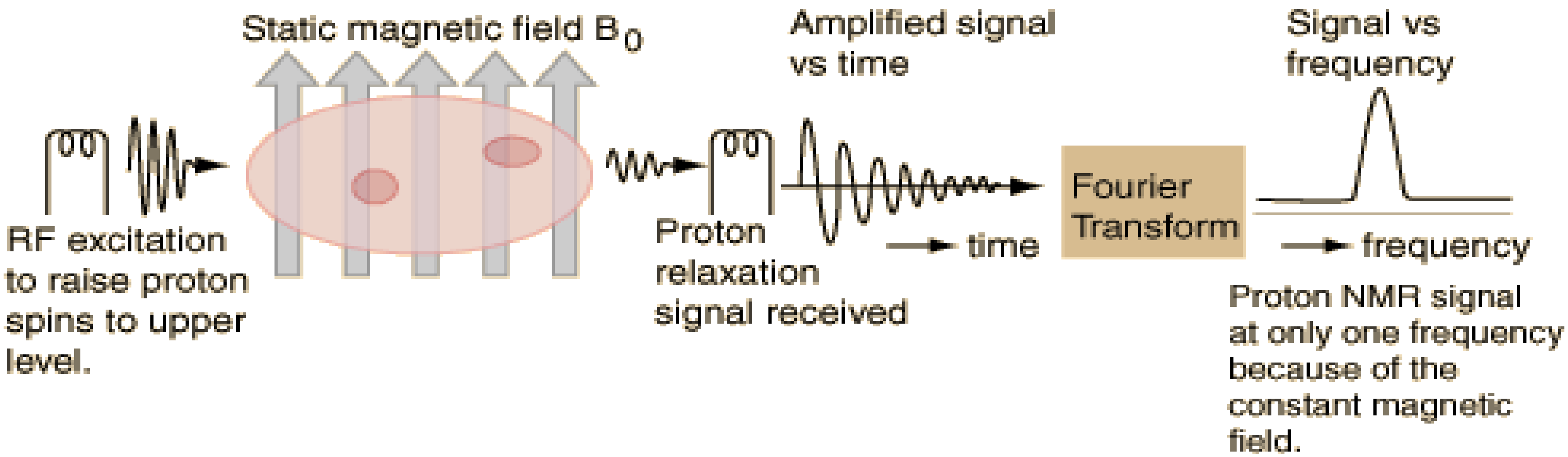
- An image of a cross-section of tissue can be made by producing a well-calibrated magnetic field gradient across the tissue.
- Since the proton signal frequency is proportional to that magnetic field, a given proton signal frequency can be assigned to a location in the tissue.
- This provides the information to map the tissue in terms of the protons present there.

- Since the proton density varies with the type of tissue, a certain amount of contrast is achieved to image the organs and other tissue variations in the subject tissue.

- Since the MRI uses proton NMR, it images the concentration of protons. Many of those protons are the protons in water.
- MRI is particularly well suited for the imaging of soft tissue, like the brain, eyes, and other soft tissue structures in the head.

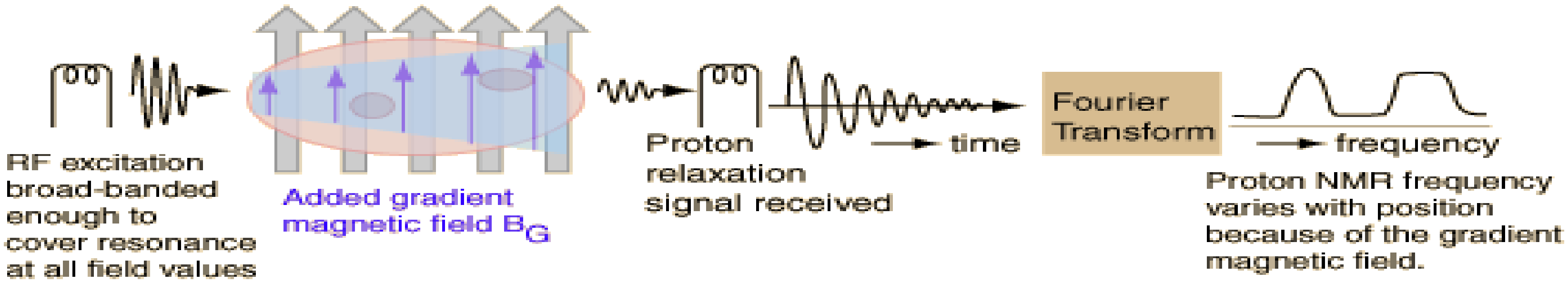
- The bone of the skull doesn't have many protons, so it shows up dark. Also the sinus cavities image as a dark region.

- Bushong's assessment
  - is that about 80% of the body‘ s atoms are hydrogen atoms.
- Most parts of the body have an abundance of sources for the hydrogen NMR signals which make up the MRI.



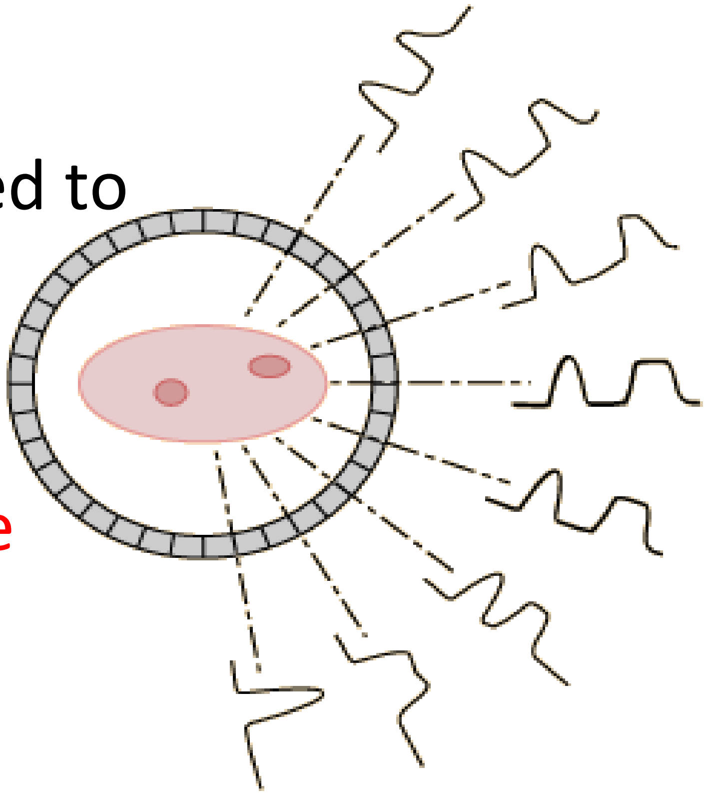
- The hydrogen spin frequency
  - is same for all parts of the sample.
- Once excited by the RF signal, the hydrogens will
  - tend to return to their lower state in a process called "relaxation"
  - re-emit RF radiation at their Larmor frequency.
- This signal is
  - detected as a function of time
  - converted to signal strength as a function of frequency by means of a Fourier transformation (FT).

- Since the protons are subjected to the same magnetic field, they will produce the same frequency of radiation and the FT of the detected signal will have only one peak.
- This one peak demonstrates the presence of hydrogen atoms, but gives no information to locate them in the sample.



- With an increasing magnetic field as you move to the right across the sample, the frequency of the emitted signal increases from left to right.
- When excited by an RF, the emitted signal contains different frequencies for the two proton concentration areas.
- These frequencies can be separated by means of the FT and the example gives two different regions of frequency for the two sample areas.
- This is the beginning of the process of locating the hydrogen atoms. It only locates them along the horizontal direction.

- When a rotating field gradient is used, linear positioning information is collected along a number of different directions.
- That information can be combined to produce a 2-D map of the proton densities.
- The proton NMR signals are quite sensitive to differences in proton content that are characteristic of different kinds of tissue.



- Even though the spatial resolution of MRI is not as great as a conventional x-ray film, its contrast resolution is much better for tissue.
- Rapid scanning and computer reconstruction give well-resolved images of organs.

- MRI is a way of getting pictures of various parts of your body *without* the use of X-rays, unlike regular X-rays pictures and CT.
- A MRI scanner consists of a large and very strong magnet in which the patient lies.

- A radio wave antenna is used to send signals to the body and then receive signals back.
- These returning signals are converted into pictures by a computer attached to the scanner.
- Pictures of almost any part of your body can be obtained at almost any particular angle.

MRI scanners are good at looking at the non-bony parts or "soft tissues" of the body.

- In particular, the brain, spinal cord and nerves are seen much more clearly with MRI than with regular x-rays and CT.
- Also, muscles, ligaments and tendons are seen quite well so that MRI scans are commonly used to look at knees and shoulders following injuries.
- A MRI scanner uses no x-rays or other radiation. A disadvantage of MRI is it’s higher cost compared to a regular x-ray or CT.
- Also, CT is frequently better at looking at the bones that MRI.

MR imaging of the body is performed to evaluate:

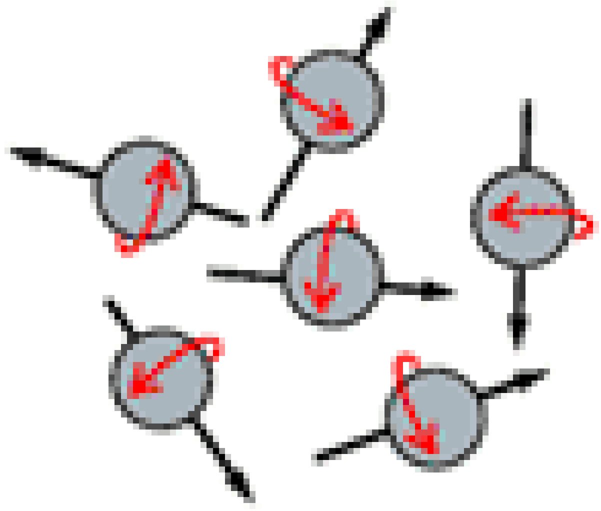
- organs of the chest and abdomen—including the heart, liver, biliary tract, kidneys, spleen, bowel, pancreas and adrenal glands.
    - » certain types of heart problems.
    - » diseases of the liver, such as cirrhosis and tumors, and that of other abdominal organs, including the bile ducts, gallbladder, and pancreatic ducts.

- blood vessels (MR Angiography).
    - blockages, enlargements or anatomical variants of blood vessels, including the aorta, renal arteries, and arteries in the legs.

- pelvic organs including the reproductive organs in the male (prostate and testicles) and the female (uterus, cervix and ovaries).
    - » tumors and other abnormalities of the reproductive organs (e.g., uterus, ovaries, testicles, prostate).
    - » causes of pelvic pain in women, such as fibroids, endometriosis and adenomyosis.
    - » suspected uterine congenital abnormalities in women undergoing evaluation for infertility.
- breasts cancer and implants.

Effect of magnetic field on proton and MRI

In unperturbed tissue, protons (***protons = H^+ atoms of H_2O molecule***) spin around their axes, with random direction magnetic fields.

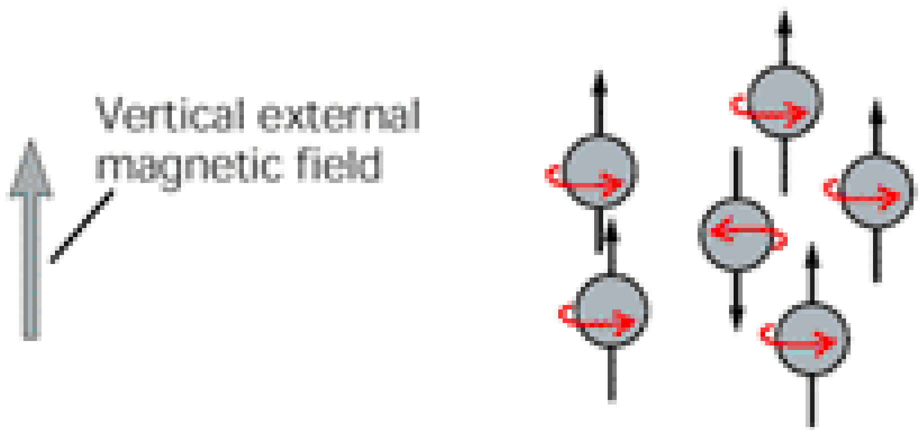


Effect of magnetic field on proton and MRI

When a **vertical** magnetic field is applied, the protons aline with the vertical magnetic field.

Sum of horizontal magnetic fields ≅ **zero**.

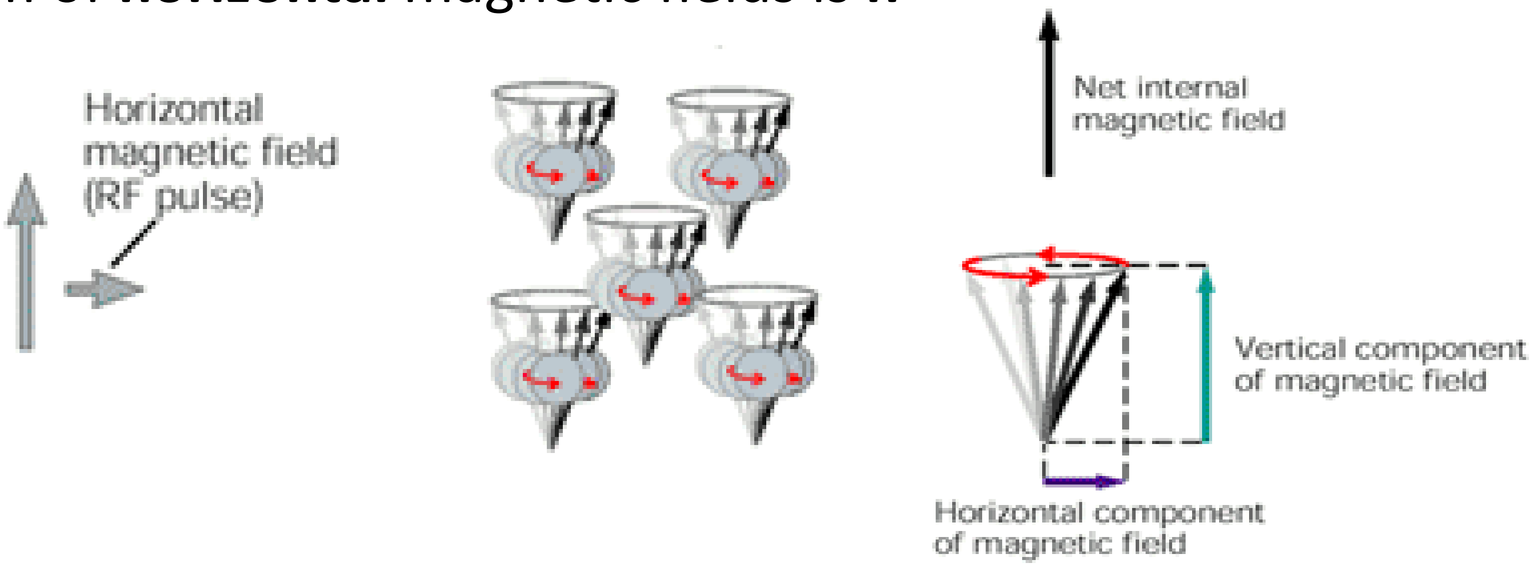
Sum of vertical magnetic fields are **not zero**.

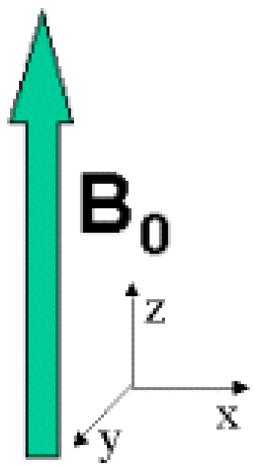


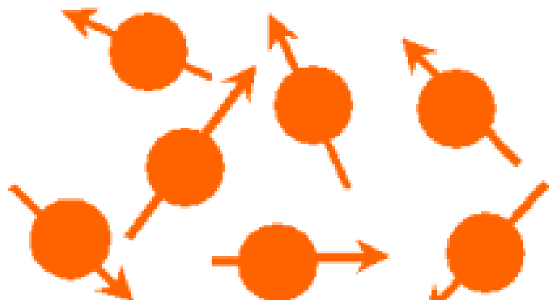
Effect of magnetic field on proton and MRI

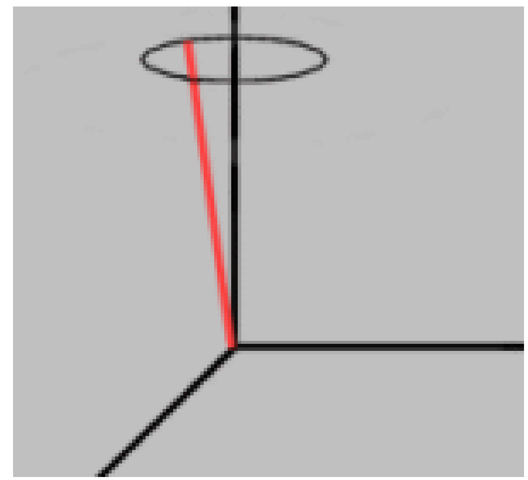
In addition to the **vertical** magnetic field, when a radio frequency pulse applied in **horizontal** direction, the protons wobble around their vertical axes.

Sum of **horizontal** magnetic fields is **not zero**.




B_0
z
x
y





Which type of magnets are used for MRI?

1. **<u>Permanent (Vertical) :</u>** These magnets are constructed of two magnets (one at each pole).

- No electricity are needed to maintain the magnetic field
- Their more open design may help alleviate some patient anxiety
- Relatively low cost

2. Resistive (Horizontal):

- These magnets are constructed from a coil of wire.
- The more turns to the coil, and the more current in the coil, the higher the magnetic field.
- The ability to “turn off” the magnetic field
- Relatively small fringe field.

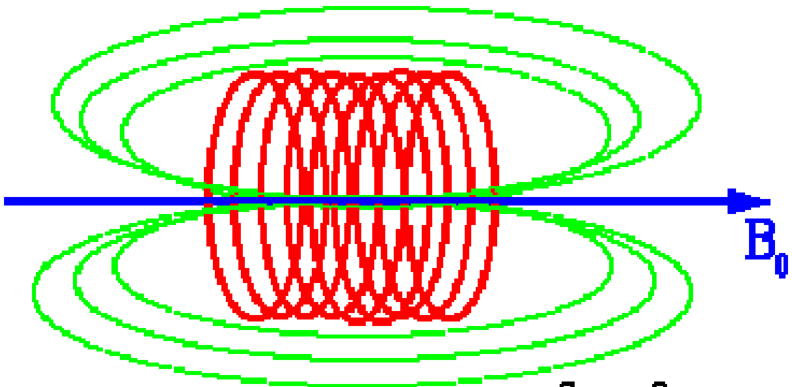
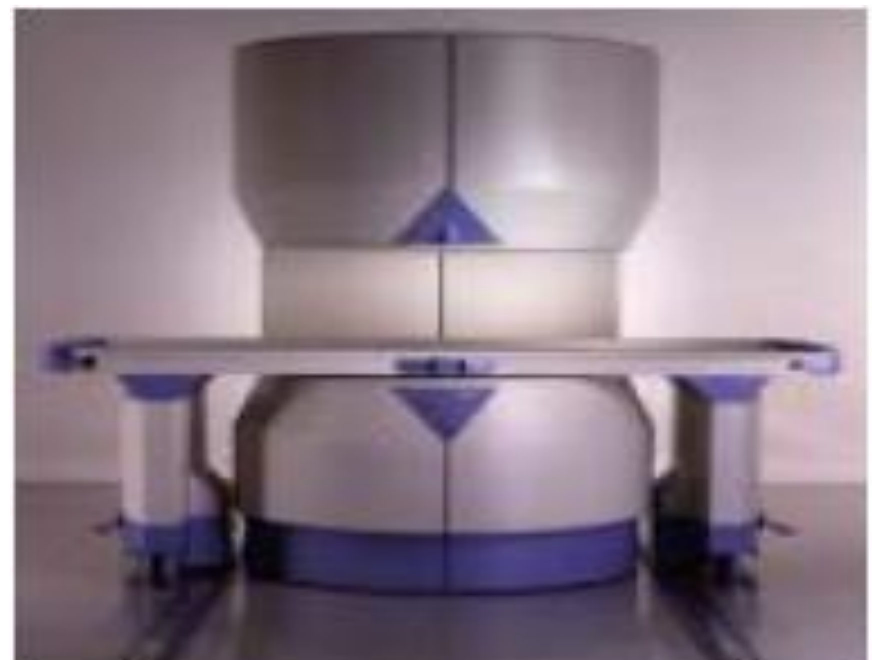


figure 2



3- Superconductive:

- They are made from coils of wire.
- Produce a horizontal field.
- They use liquid helium to keep the magnet wire at 4 ^{o}K where there is no resistance.
- The current flows through the wire without having to be connected to an external power source.

- The main advantage

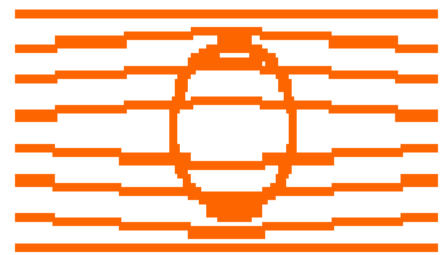
  To produce magnetic field strengths between 3 Tesla (for clinical image) and 10 Tesla or more (small bore spectroscopy magnets).

Magnetic Properties of Matter

The three types of magnetic properties are:

1- diamagnetic:

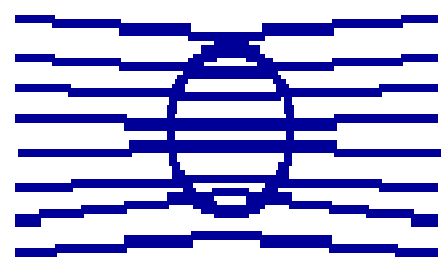
When they are placed in a external MF; negative interaction, they are slightly repelled by the MF.



Diamagnetic

2- paramagnetic:

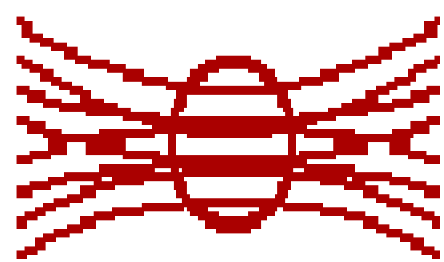
Positive interaction, they are slightly attracted by the MF.



Paramagnetic

3- ferromagnetic:

They exhibit an extremely strong attraction to the magnetic field. These substances (such as iron) retain magnetic properties when removed from the magnetic field.



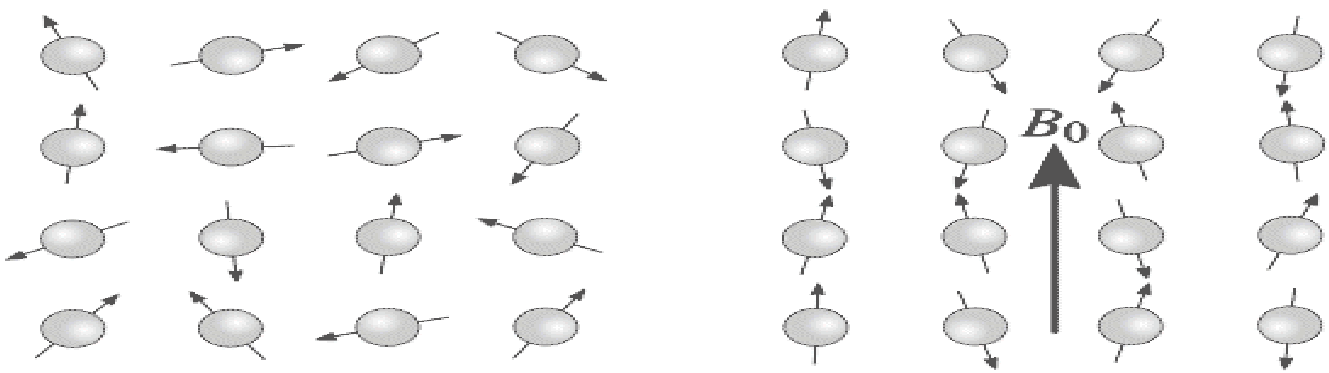
Ferromagnetic

Hydrogen

- The strength of the magnetic moment is a property of the type of nucleus.
- Hydrogen nuclei ($_1H$) has only 1 proton
- Hydrogen nuclei ($_1H$), possess the strongest magnetic moment and are in high abundance in biological material.
- Consequently hydrogen imaging is the most widely used in MRI.

Consider a collection of $_1$H nuclei (spinning protons)

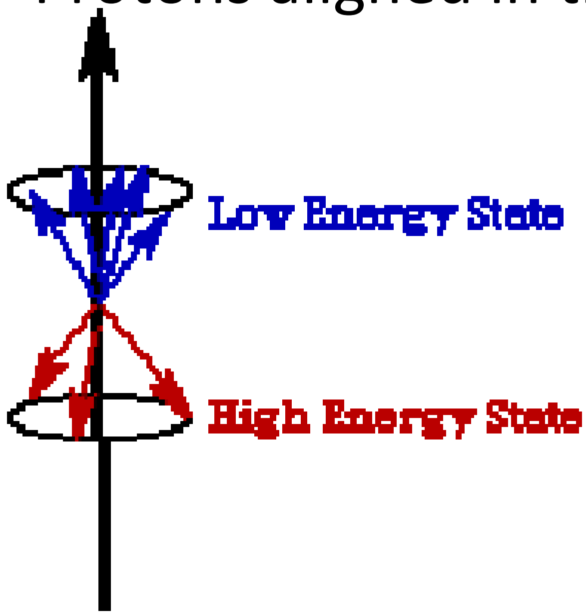
- In the absence of an externally applied magnetic field, the magnetic moments have random orientations.
- If an externally supplied magnetic field B_0 is imposed, the magnetic moments have a tendency to aline with the external field
- The magnetic moments or spins are constrained to adopt one of two orientations with respect to B_0, denoted parallel and anti-parallel.

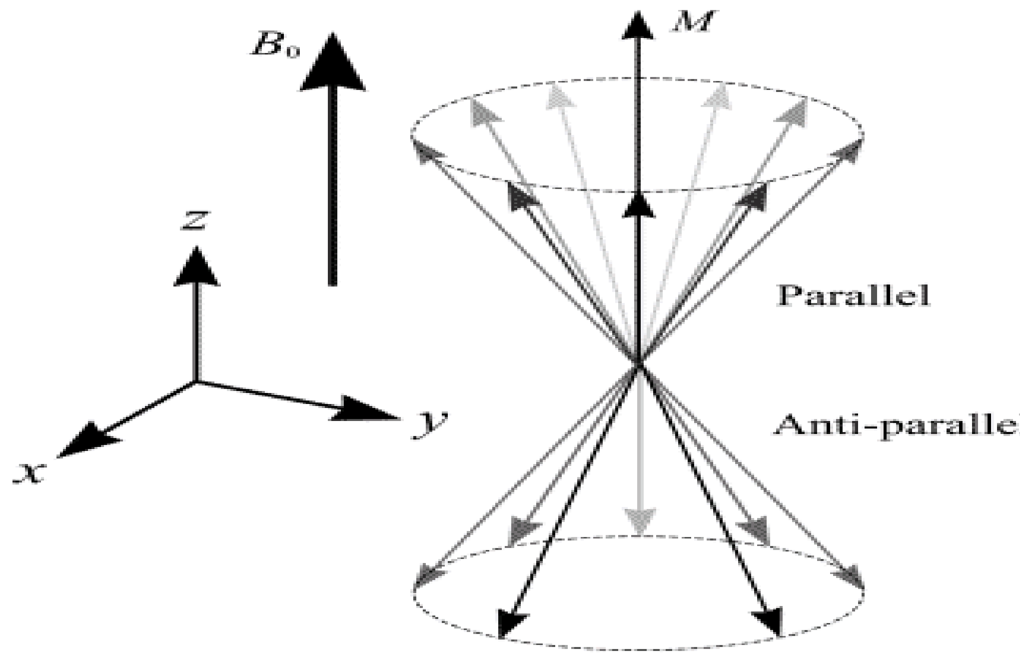


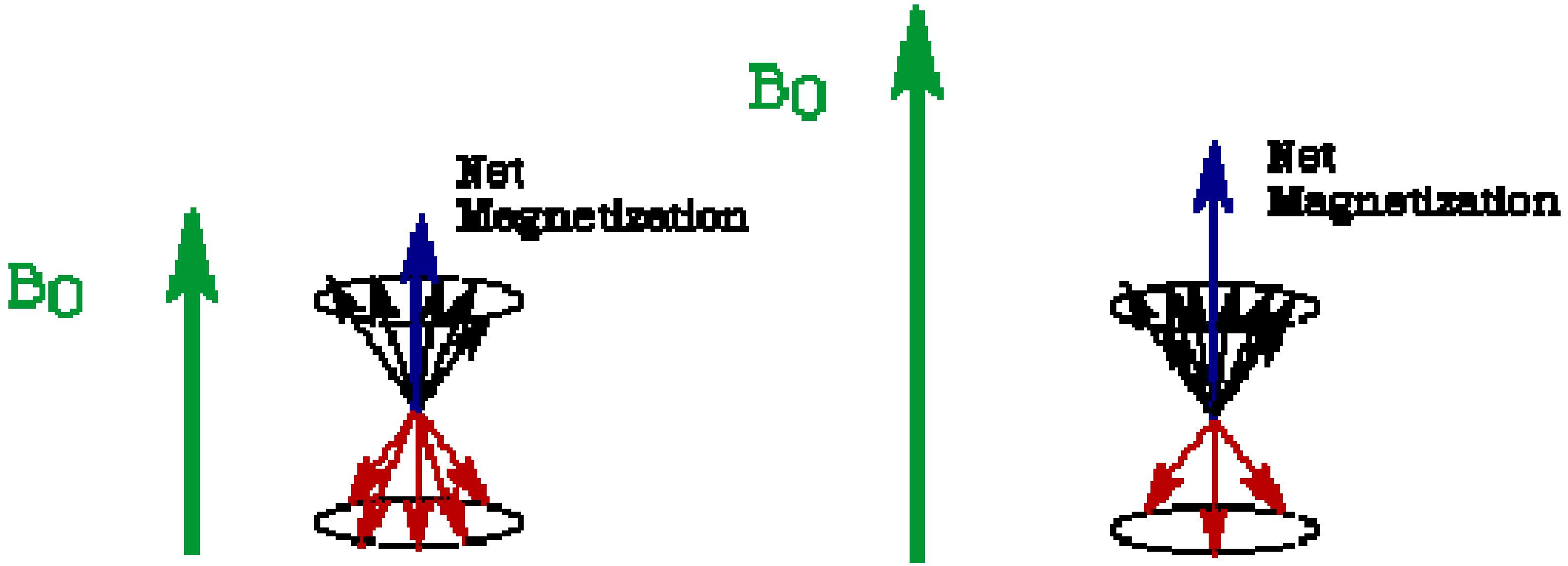
B_0:(external magnetic field)

For a collection of 1H nuclei:

- Some protons aline antiparallel and a slight majority alines parallel.
- Protons aligned in the parallel: Low energy state
- Protons aligned in the anti-parallel: High Energy state







- Net magnetization is parallel to external magnetic field.
- Net magnetization (in tissue) = Longitudinal magnetization
- The larger external magnetic field forms larger longitudinal net magnetization in tissue.

Relaxation

- Following termination of an RF pulse M will return to its equilibrium state (the direction of the z-axis) and the absorbed energy given to the surrounding.
- The process of giving off RF energy occurs as the spins go from a high energy state to a low energy state, realigning *with* $\mathbf{B_o}$ **as before**.

RF energy is given in two ways:

- **T1 relaxation** (spin-lattice relaxation)
- **T2 relaxation** (spin-spin relaxation)

MRI imaging depends on the measurement of these relaxations and the **spin density**.

T1 relaxation:

The absorbed energy by the protons is released back into the surrounding lattice.

T2 relaxation:

The temporary and random interaction between two excited spins that causes an overall loss of signal also known as transverse relaxation.

- **Both of these parameters differ according to type and density of the tissue.**

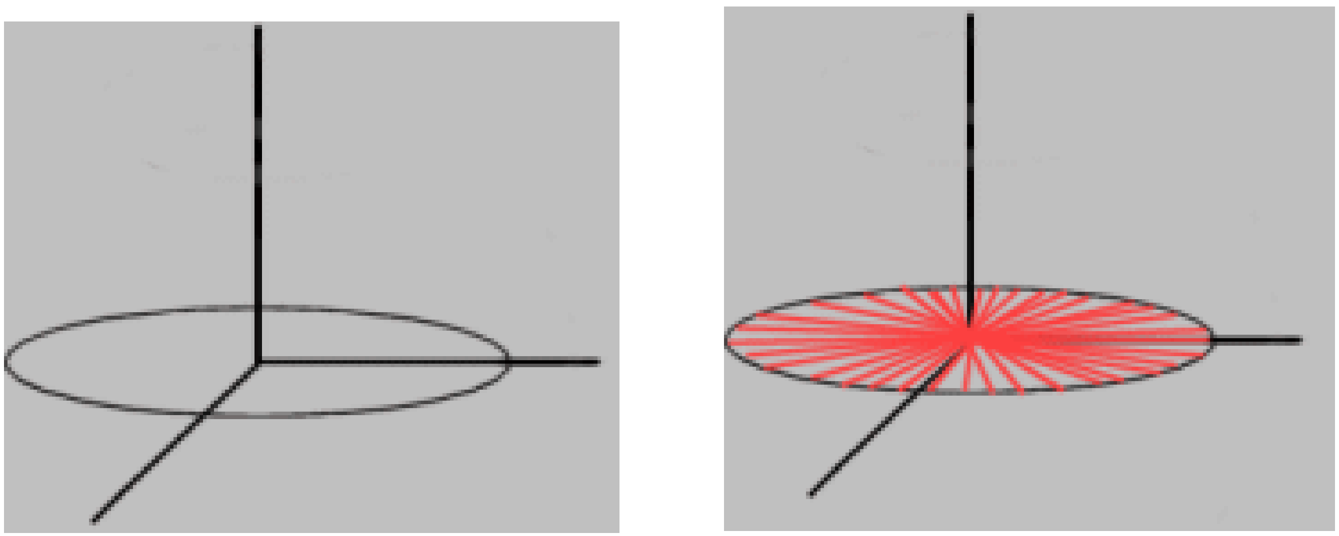
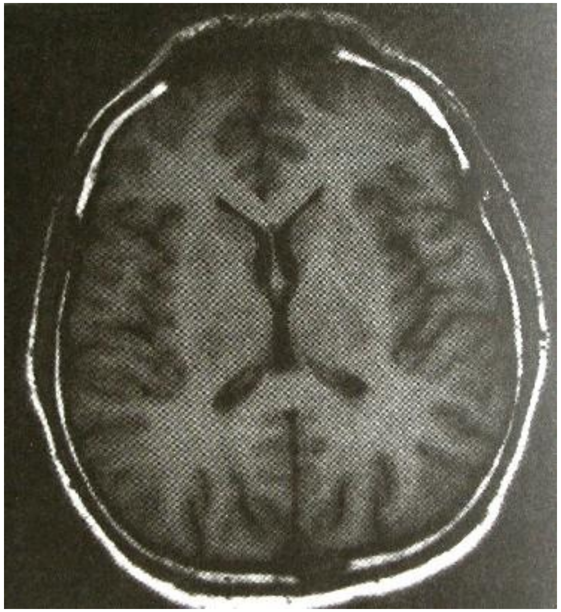


Figure: *(left) Having been tipped into the transverse plane, the net magnetisation begins to dephase (T_2^*).*
(right) Once fully dephased the spins return to equilibrium (T_1).

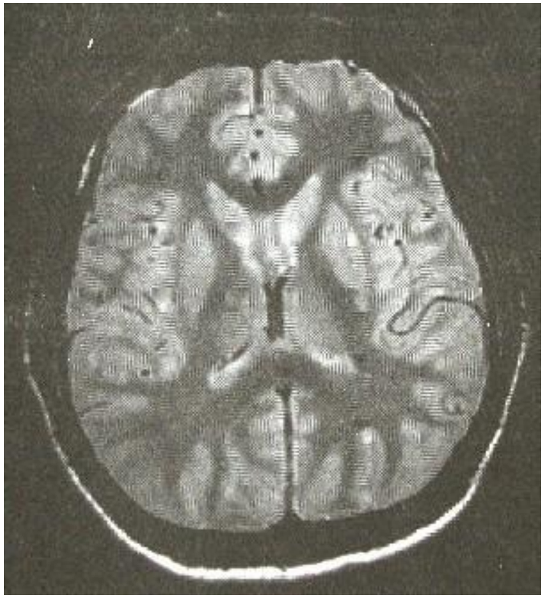
There are 3 different and independent parameters that affect the image in MRI

- T1 relaxation (T1 weighted)
- T2 relaxation (T2 wieghted)
- Spin density (Proton wieghted)

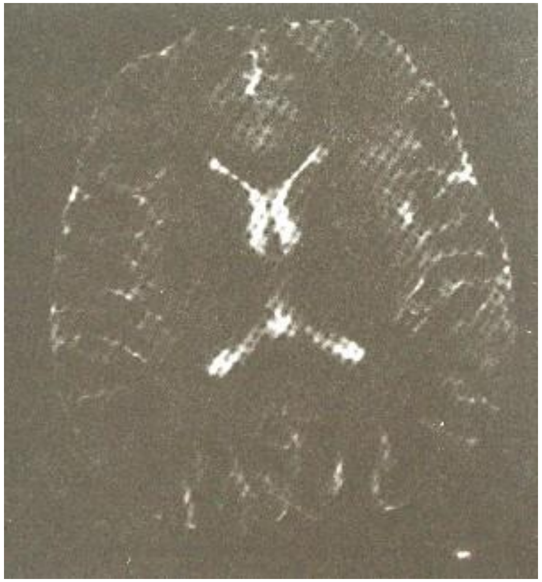
MRI can be made according to T2 ,T1 or spin density



T1 weighted



Proton weighted



T2 weighted

- if a long TE is used, inherent differences in T_2 times of tissues will become apparent.
- Tissues with a long T_2 (e.g. water) will take longer to decay and their signal will be greater (or appear brighter in the image) than the signal from tissue with a short T_2 (fat).

- T_2-weighting requires long echo time (TE), long repetition time (TR)
- T_1-weighting requires short TE, short TR
- PD-weighting requires short TE, long TR

Advantages of MRI

- Best low contrast resolution

(due to three independent parameters, compared to CT which has dependend only on one parameter : X-ray attenuation)

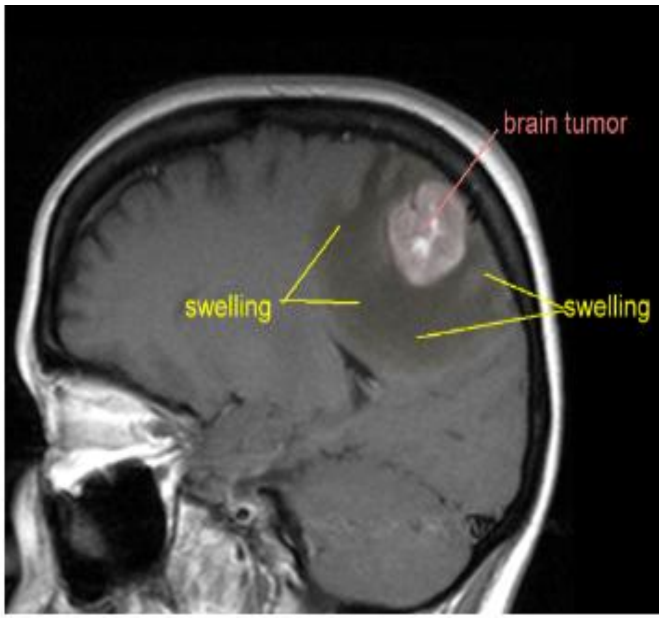
- No bone or air artifact
- No ionizing radiation
- Totally non-invasive

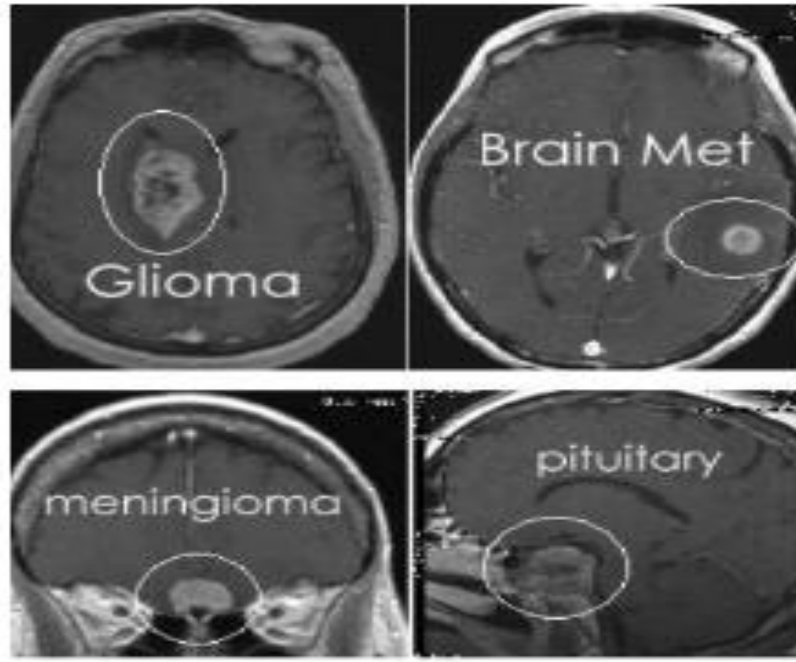
- What was send to patient during MRI?

- What does MRI measure?

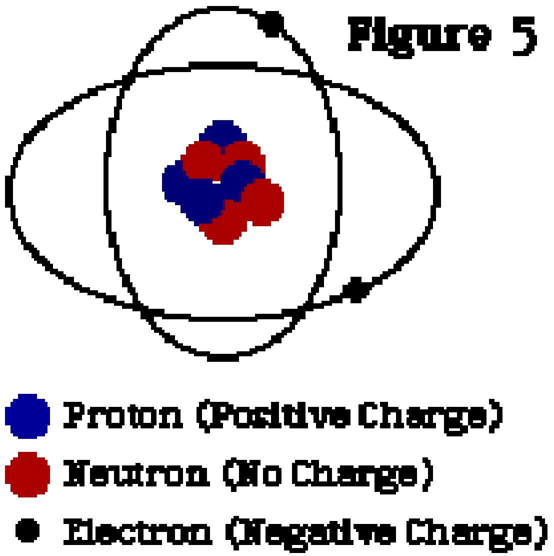
- Strong Magnetic fields + radio frequency (RF) Electromagnetic (EM) waves

- T1 & T2 relaxation coefficients and proton (of water) density of tissues etc.


brain tumor
swelling
swelling


Glioma
Brain Met
meningioma
pituitary

Atomic Structure



- Both the neutrons and protons spin about their axis
- The spinning produces angular momentum.
- If an atom has an even number of both protons and neutrons, angular momentum is zero.

- The nuclei exhibit magnetic properties.
- A proton has mass, a positive charge, and spins,
- It produces a small magnetic field much like a bar magnet.
- Magnetic field of the proton is referred to as the magnetic moment (vector quantitiy)
- Magnetic moment is oriented in the same direction as the angular momentum.