

PRINCIPLES OF MAGNETIC RESONANCE IMAGING

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11/15/06

Magnetic Resonance Imaging MRI

A painless non-invasive diagnostic technique to examine the inside of the body.

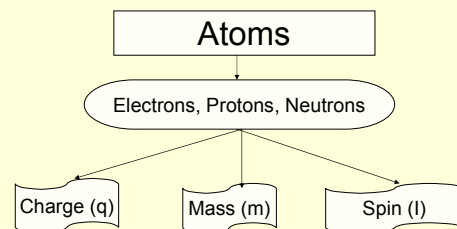
MRI machine



Typical MRI picture of Brain



WHY and **HOW** does the human body respond to the magnetic field?



Intrinsic properties

Intrinsic properties!!

- Charges exist in nature in multiples of electronic charge.
- Electron has a negative charge, proton has positive charge and neutron has no charge
- Spin comes in multiples of $1/2$.
- *Individual* electrons, protons, and neutrons each possess a spin = $1/2$.

Human body...

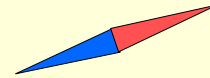
- Human body consists of large quantities of water and fat.
- Hydrogen is present in water molecules of the body.
- The nucleus of hydrogen contains one proton. Since the spin of proton is $1/2$, the **nucleus of hydrogen atom has a spin of $1/2$** .

So.....

The spin of this proton makes the proton to behave like a tiny magnet with a north and south pole.

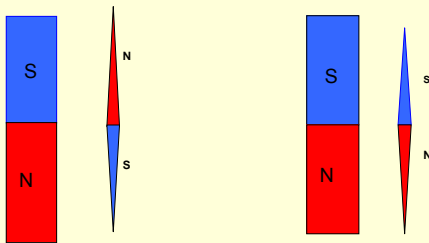
Proton is 

Apply a magnetic field...



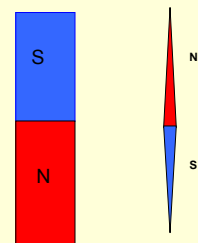
This tiny magnet gets affected by the externally applied magnetic field. When a magnetic field is applied, this spin aligns in the direction of the magnetic field.

Two possibilities!!!!



Activity....

- Take a magnet
- Keep a compass next to it.
- Note which direction the compass points to.
- Turn the magnet and repeat.

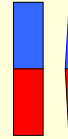


Result...

- The compass has a natural tendency to align with the north pole towards the south pole and vice versa. Let us call this a **parallel alignment**.
- How do we make the N-N and S-S arrangement?

Turn the spin around....

- To do this we need to do work *i.e.*, supply energy to the compass. Then.....



Anti parallel

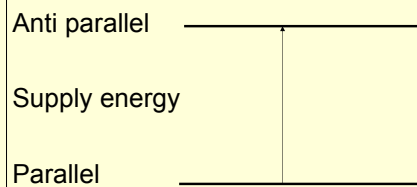
In other words.....

Natural parallelLow energy state

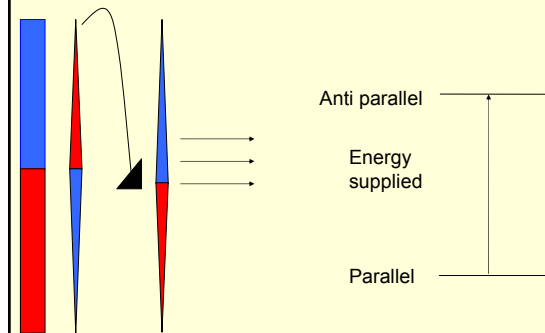
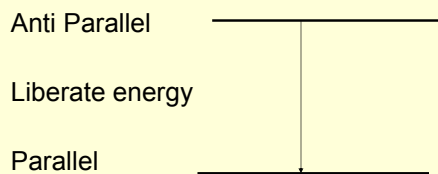
Forced anti parallel..... High energy state

Turning the magnetic moment by giving energy is equivalent to moving from low energy state to high energy state

Pictorially



Equally well.....



Energy / frequency

The energy, E , of a photon is related to its frequency, ν , by Planck's constant ($h = 6.626 \times 10^{-34}$ J s).

$$E = h\nu$$

Energy and nature of atom

The energy (frequency) depends on the gyromagnetic ratio γ of the particle.

$$E = \hbar\gamma B$$

For proton $\gamma = 42,38$ MHz/T

Absorption conditions

When placed in a magnetic field of strength B , a particle with a spin can absorb energy provided the energy supplied is equal to the energy level difference.

Translated ...

- $E = h\nu$
- The energy (frequency) depends on the gyromagnetic ratio γ of the particle.

$$E = \hbar\gamma B$$

For absorption the energies must be equal.

$$\nu = \gamma B / 2\pi$$

Some numbers....

If the magnetic field strength = 1 T

The frequency = 6.77 MHz

This energy for absorption is supplied by a RF source having the required frequency. Since we provide energy equal to the difference in energy levels, we have the phenomenon of **resonance**. The corresponding frequency is called the resonance or **Larmor** Frequency.

Points to remember!!

$$E = h\nu = \hbar\gamma B$$

- The energy (frequency) depends on the nature of the atom.
- The energy (frequency) depends on the magnetic field.

Collection of spins

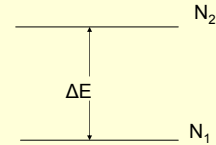
When we are looking at magnetic imaging picture of human body, we do not have one proton but a large number of protons *i.e.*, large number of spins.

HOW DOES THIS COLLECTION OF SPINS BEHAVE IN A MAGNETIC FIELD?

Maxwell Boltzmann distribution

In the presence of magnetic field, the spins distribute between the energy level according to Maxwell distribution.

$$\frac{N_1}{N_2} = e^{\frac{-\Delta E}{kT}}$$



For system of protons...

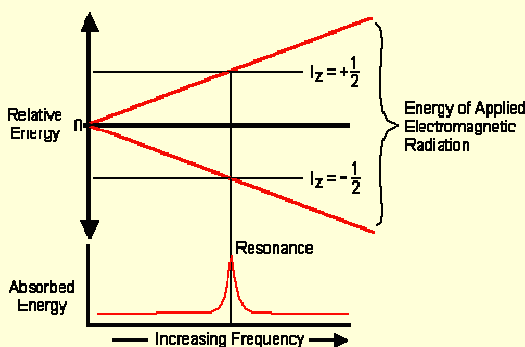
For protons in a magnetic field of 1T, the frequency is 42.58 MHz,

$$N_1/N_2 \approx 1$$

Both energy levels are almost equally populated at 300 K. (But remember N_1 is large).

Summary

When a system of protons are placed in a magnetic field and energy is supplied there is net absorption.



During the experiment, electromagnetic radiation is applied to the sample with an energy exactly equivalent to the energy separation of two adjacent spin states. Some of the energy is absorbed and the alignment of one nucleus' magnetic field reorients from a lower energy to a higher energy alignment (spin transition). By sweeping the frequency, and hence the energy, of the applied electromagnetic radiation, a plot of frequency versus energy absorption can be generated. This is the NMR spectrum.