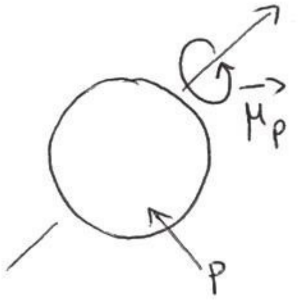
NUCLEAR MAGNETIC RESONANCE (NMR)

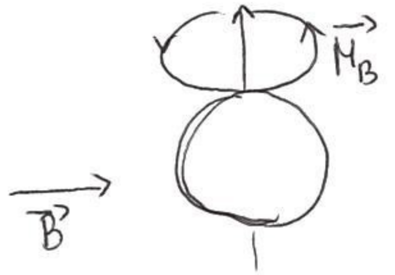
NMR is a method of physical observation in which nuclei in a strong constant magnetic field are perturbated by a weak oscillating magnetic field and respond by producing an e.m. signal with a frequency characteristic of the magnetic field at the nucleus.

The whole process is based on the magnetic dipole moment of a nucleus.

A proton can be modeled as a sphere that consists of infinitely many "current loops" that can add to for a nuclear magnetic dipole moment for the proton

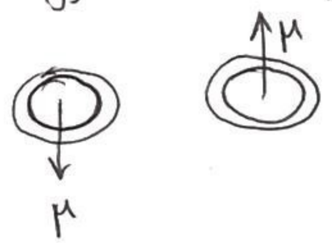


For a single proton $\vec{\mu}_p = 2{,}7928\ \mu_B$.
Whenever a magnetic dipole is placed into an external magnetic field it will fell a torque that will tend to align it with magnetic field.

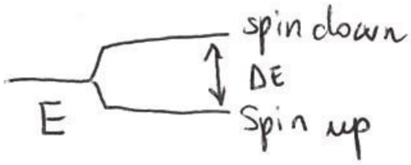


The magnetic dipole moment will try its best to align with the magnetic field lines but it will not line up exactly.
Instead it will procen around an axis and its frequency of preprocenion is comunly known as Larmor frequency.

If we take the simplest nucleus and we place it into an external $\vec{B}$ its energy level will split into two as a result of the two possible spins



One will align prallel to the $\vec{B}$ field and one anti-prolell.
In doing so, the energy for the spin up will DECREASE its energy by $-\mu_p B$, while the spin down will INcrease the energy by $+\mu_p B$



$$\Delta E = 2\mu_p B$$

and A radio frequency pulse hits the sample. If the frequency is "Just right", it will excite the nucleus from spin up to spin down. if this happens, the frequency is called "RESONANCE" (sudden increase of energy).

$$\Delta E = hf = 2\vec{\mu}_p \cdot \vec{B}_{TOT}$$

This equation gives us the amount of energy required by radio frequency photons to give the nuclei enough energy to TURN between states. The change of energy is known as chemical shift: different atoms have different chemical shifts ⇒ we can know the atoms that compounds one nucleus.

(e.g. in chemestry we can identify the type of compound)

in medicine: MRI (Magnetic Resonance Imaging - the world "nuclear" is omitted since the term tends to scare people)

Example on NMR

Suppose that we have a single hydrogen atom with no electrons. If it is placed into a magnetic field of 0,05 T. Determine the resonance frequency (chemical shift of the atom)

$\mu_p = 2,7928\ \mu_B$ $\qquad \mu_B = \frac{e\hbar}{2m_p} = \frac{eh}{4\pi m_p}$ $\qquad \Delta E = hf = 2\mu_p B$

$= 2\,(2,7928)\,\mu_B B$

$$f = 2{,}7928 \frac{(1{,}6 \cdot 10^{-19} C)(0{,}05 T)}{2\pi (1{,}67 \times 10^{-27} kg)} = 2{,}13 \times 10^{6} Hz$$

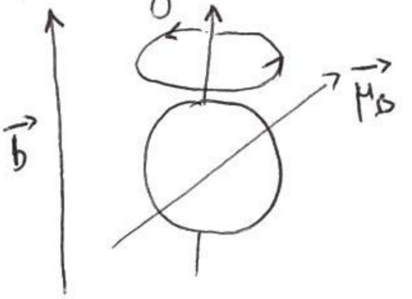
$A \cdot s \cdot \frac{kg}{C \cdot s} \cdot \frac{1}{kg}$, $C \cdot s = A \cdot s$, $= s^{-1}$

$f = f(B)$

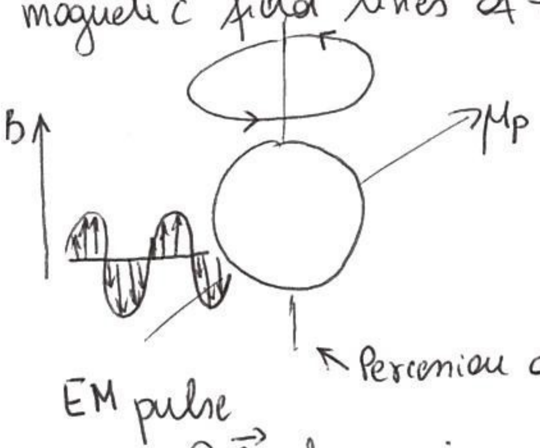
MAGNETIC RESONANCE IMAGING (MRI)

MRI is a tecnique that utilizes the nuclear magnetic resonance (NMR). When a p is placed into a magnetic field it feels a torque that will tend to orient the magnetic dipole moment along the same axis as the magnetic field lines.

The magnetic moment of p will process along the axis



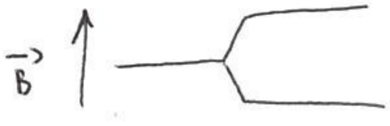
If we direct an e.m. wave of the right frequency the process of precession will flatten out since it will tend to align with the magnetic field lines of the wave.



⊙ $\vec{B}$ of em in one direction

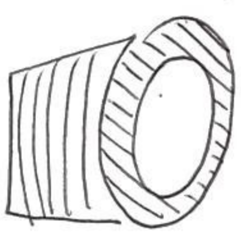
⊗ Flatten in inverse direction

By sending E.M. pulse, we give the spin-up protons enought energy to transition to spin down



Zeeman effect ≡ Splitting in energy

The human body consists mostly of water, which contains hydrogen atoms. H nuclei have the strongest NMR signals.
The MRI machine contains large magnetic coils that creates a large Magnetic field.
It also contains a second set of coils that create the e.m. pulse (R.F. pulse).
When the RF pulse is emitted the spin up transition to spin down.
When we turn off the $\vec{B}$ field the nuclei return back to ground state and release energy.
This energy that has varying intensity can be used to construct an image by a computer.
The higher the hydrogen density, the brighter it will appear on the screen. Density of H atom in a certain part of the body.



STATIC B field

$1 \div 5$ T

To understand from where the signal come from

→ 3^ magnetic field to create a gradient ~~[illegible]~~ is added

——— 1T

——— 2T

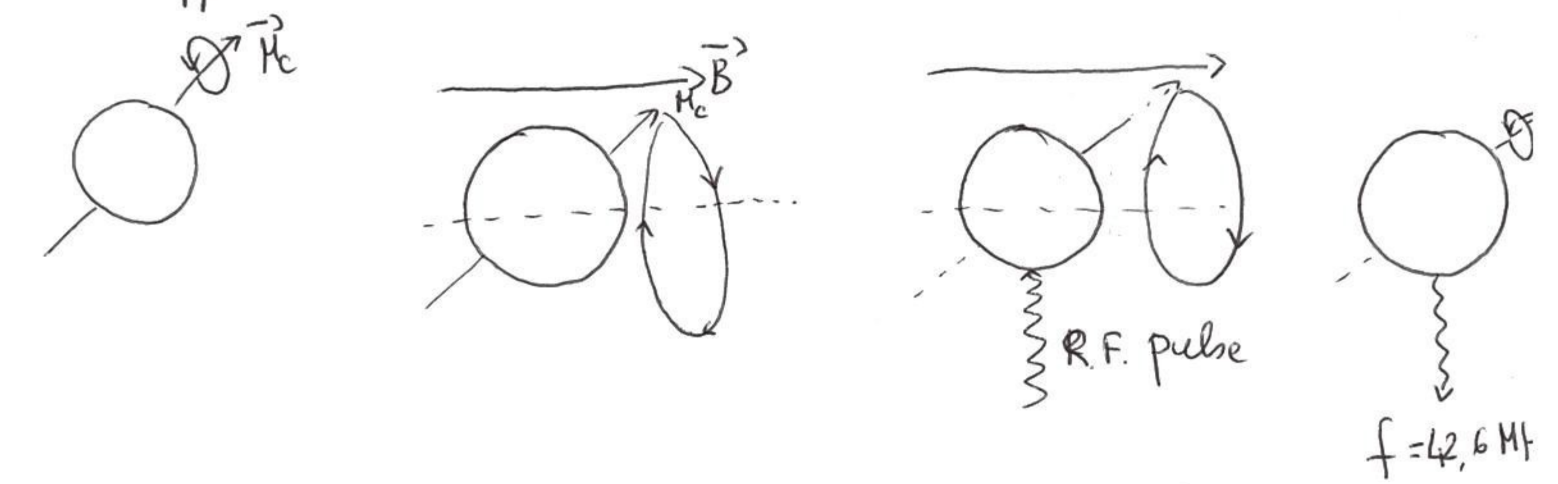
——— 3T

——— 4T

Since $E \propto B$, B determine the correct ν ⇒ the correct location of the point where the emission happens.

Exercise:
The carbon 13 isotope has a magnetic moment $\mu_C = 0{,}7023\, \mu_B$.
If you place it into a NMR machine, it determines a frequency change (chemical shift) of 42,6 MHz.
What is the strenght of the magnetic field created by the NMR machine?

What happens?



$$\Delta E = hf = 2\mu_c B$$

$$\vec{B} = \frac{hf}{2\mu_c} = \frac{hf}{2(0,7023)\mu_B} = \frac{hf}{2(0,7023)\frac{eh}{4\pi m_p}}$$

$$= \frac{2\pi f m_p}{(0,7023)e}$$

$$B = \frac{2\pi \cdot 4,6 \cdot 10^{6}\,Hz \cdot 1,67\times10^{-27}\,kg}{0,7023 \cdot 1,6 \cdot 10^{-19}\,C} \cong 4\,T$$

$$\frac{kg}{sC} = T$$

Due to the fact that the photon energy are small compared to other radiation the emitted after the NMR is rather small ⇒ it is not a ionizion radiation.