KAPITAŁ LUDZKI
NARODOWA STRATEGIA SPÓJNOŚCI

UNIA EUROPEJSKA
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# „Medical Imaging”

**Prezentacja multimedialna współfinansowana przez Unię Europejską w ramach Europejskiego Funduszu Społecznego w projekcie pt.**

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# Magnetic properties of atom nucleus

## Lecture overview:

Interaction of nucleus with a static magnetic field

Rotation and precession

Radio frequency wave -> nutation

Induction of Magnetic Resonance signal

Relaxation times T1 and T2

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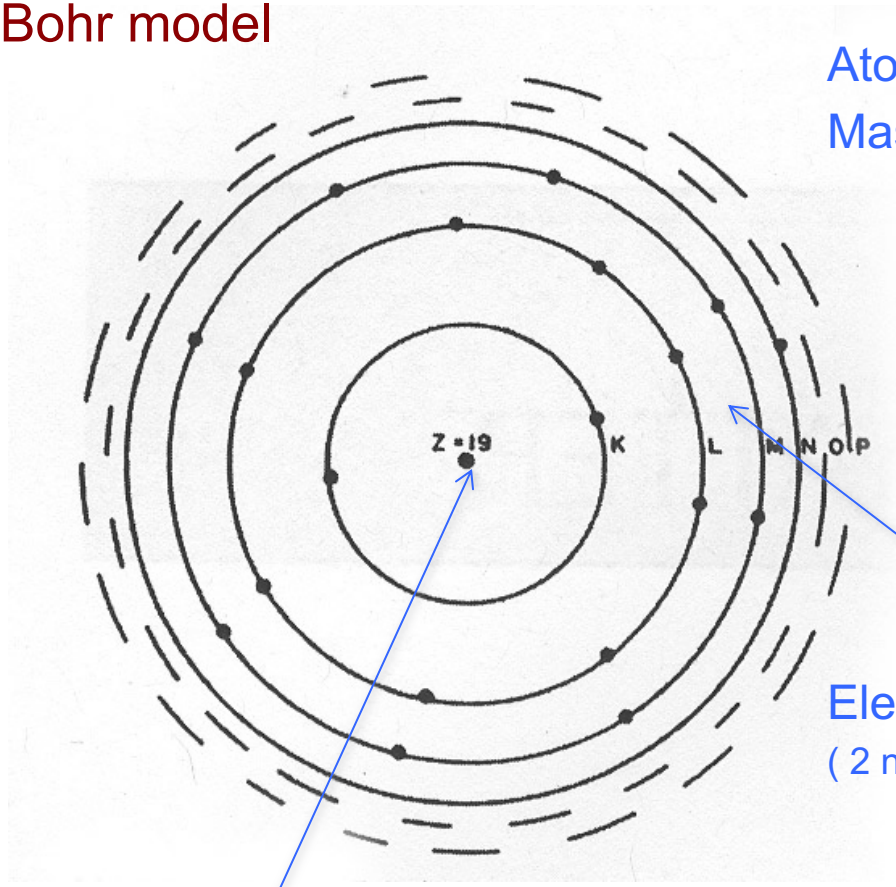
# Structure of the atom

## Bohr model



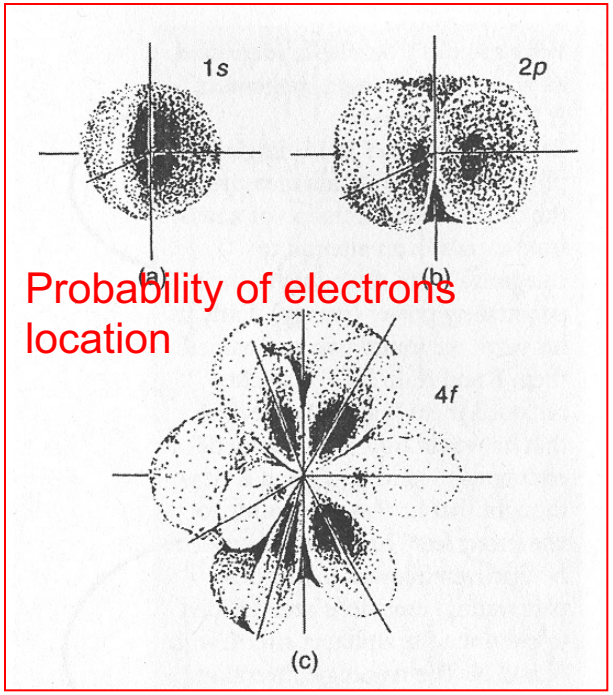

Atomic number Z : # protons = # electrons

Mass number A : # protons + # neutrons

Electrons

( $2n^2$, n - orbit no.)

Nucleus (protons, neutrons)



# Properties of the nuclei

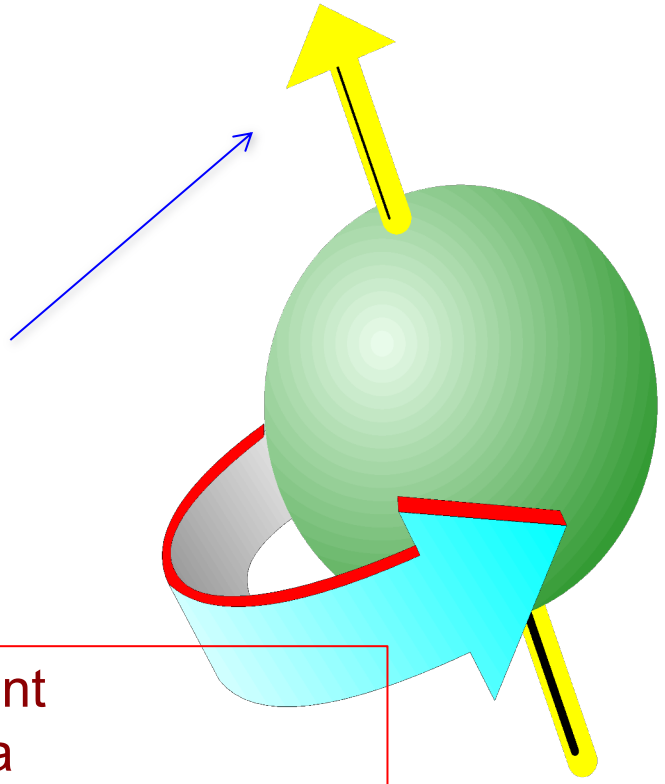
Hydrogen nuclei, 1 proton

classical mechanics:

proton – positively charged particle, circulates (spins) producing magnetic field.

This “small magnet” has its **magnetic moment.**

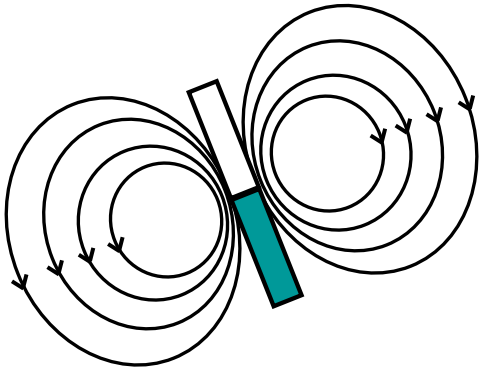
Rotating proton ⇔ spin



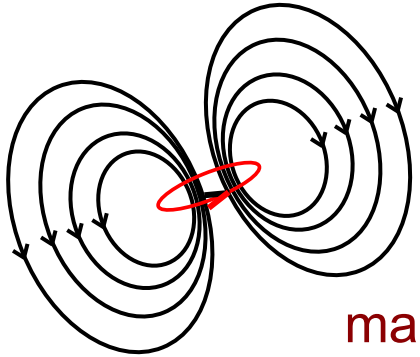
Other nuclei having a magnetic moment (# protons ≠ # neutrons): $^{15}N$, $^{31}P$, $^{23}Na$

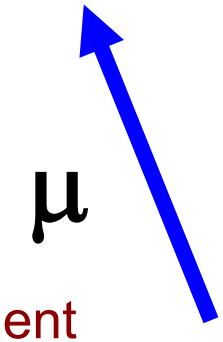
$^{12}C$ i $^{16}O$ do not have a magnetic moment

# Dipolar fields



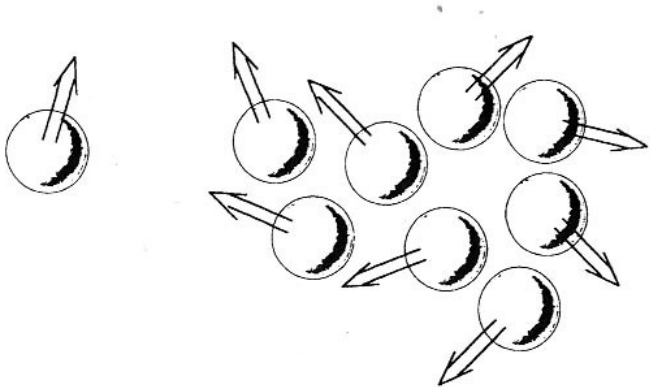
Earth's field, bar magnet or current loop



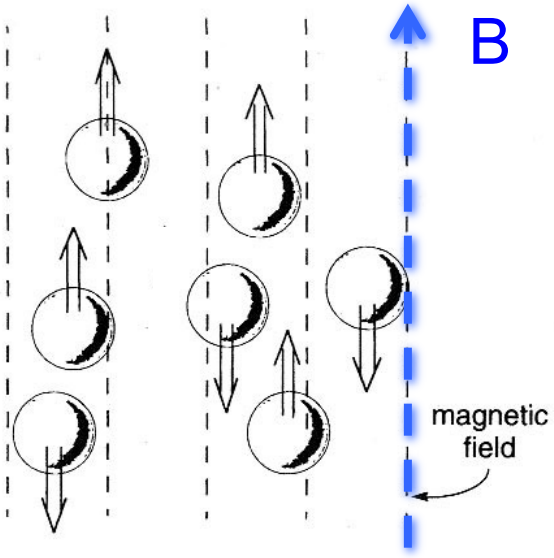



magnetic moment

# Protons in a magnetic field



In a typical material, magnetic moments are oriented randomly




In a presence of the magnetic field, magnetic moments align themselves along the direction of the field

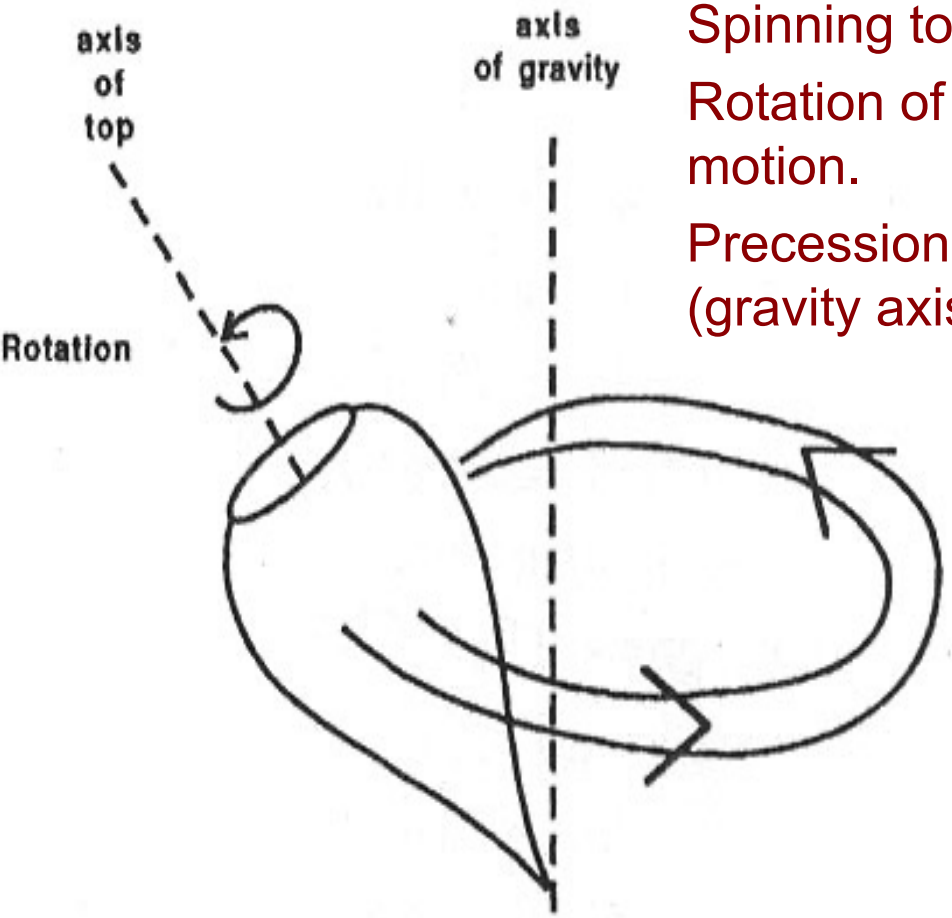
# Spins in magnetic field

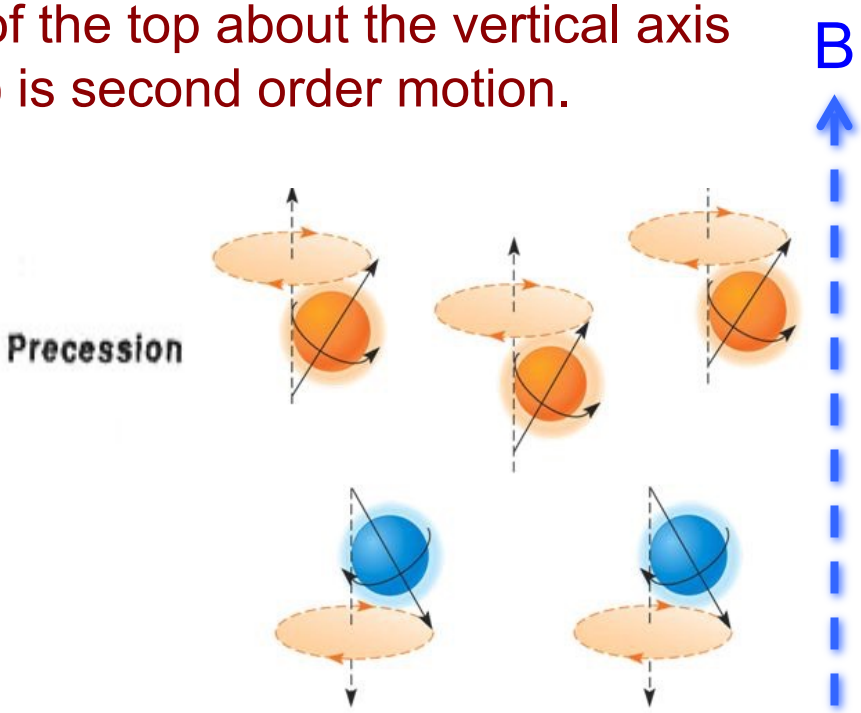
Magnetic moments also precesses about the field.

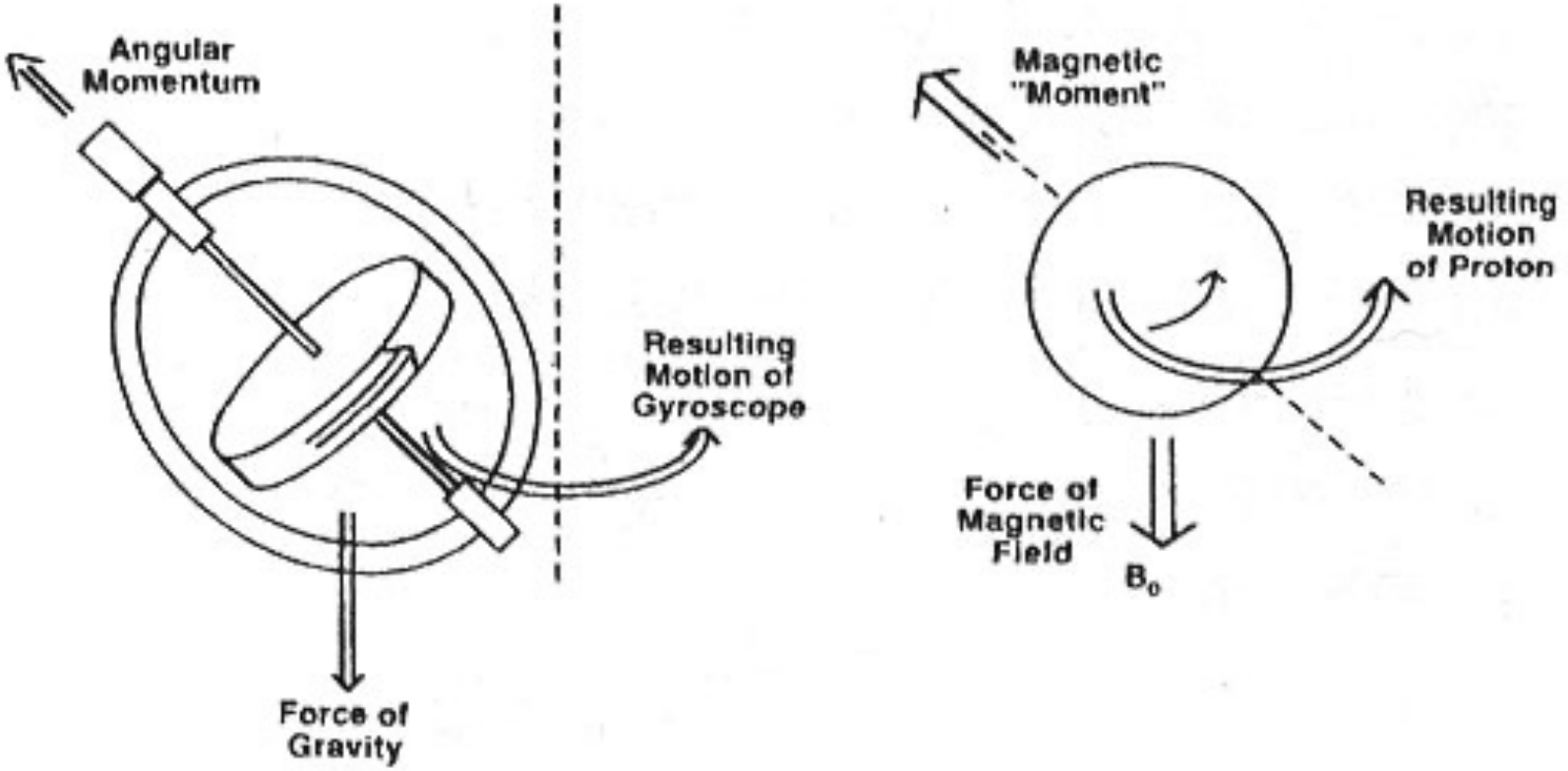
Spinning top like behavior:

Rotation of the top about its own axis is first order motion.

Precession of the top about the vertical axis (gravity axis) is second order motion.






Precession results from the interaction of forces with a rotating object. Angular momentum and gravity interact to cause precession of a gyroscope; magnetic moment and magnetic field result in a precession of a proton.

# The Larmor frequency

The relationship between field induction B [T] and a precession frequency f [Hz] is:

$$f = \gamma B$$

$\gamma$ is a gyromagnetic ratio

$\gamma$ (H) = 42.58 MHz/T, thus for typical B=1.5T in MR scanners, f≈64 MHz

**The precession frequency is called Larmor frequency**

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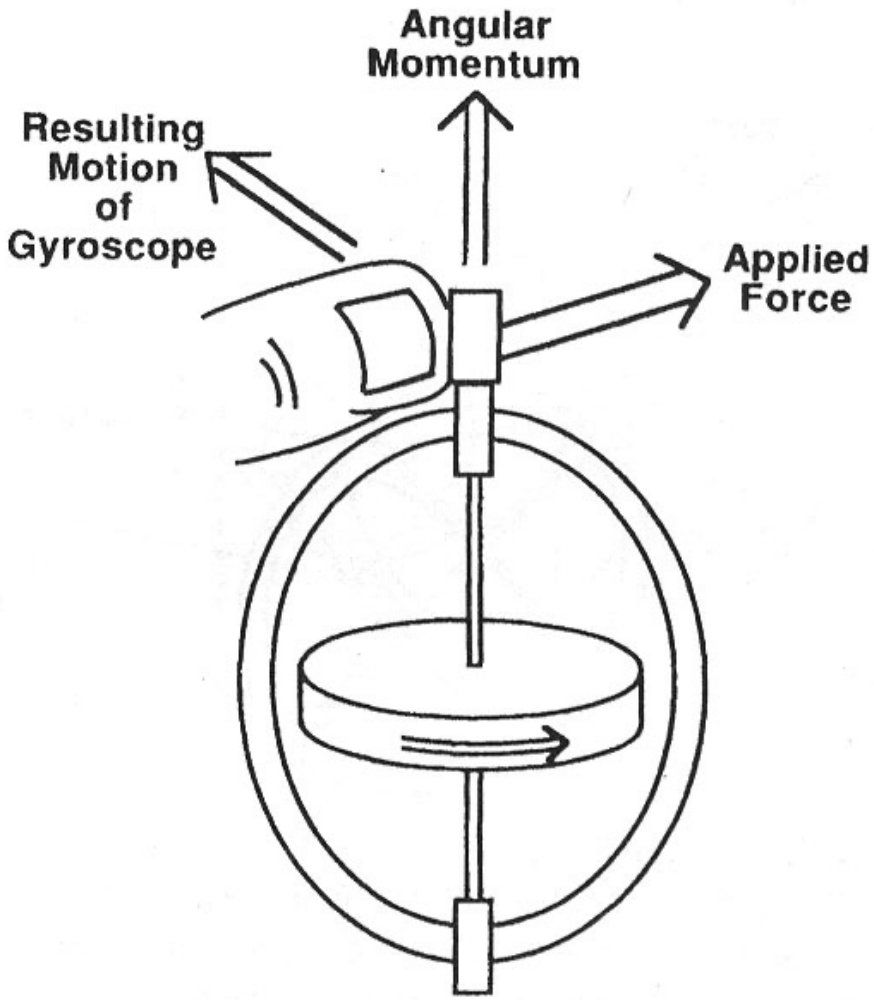
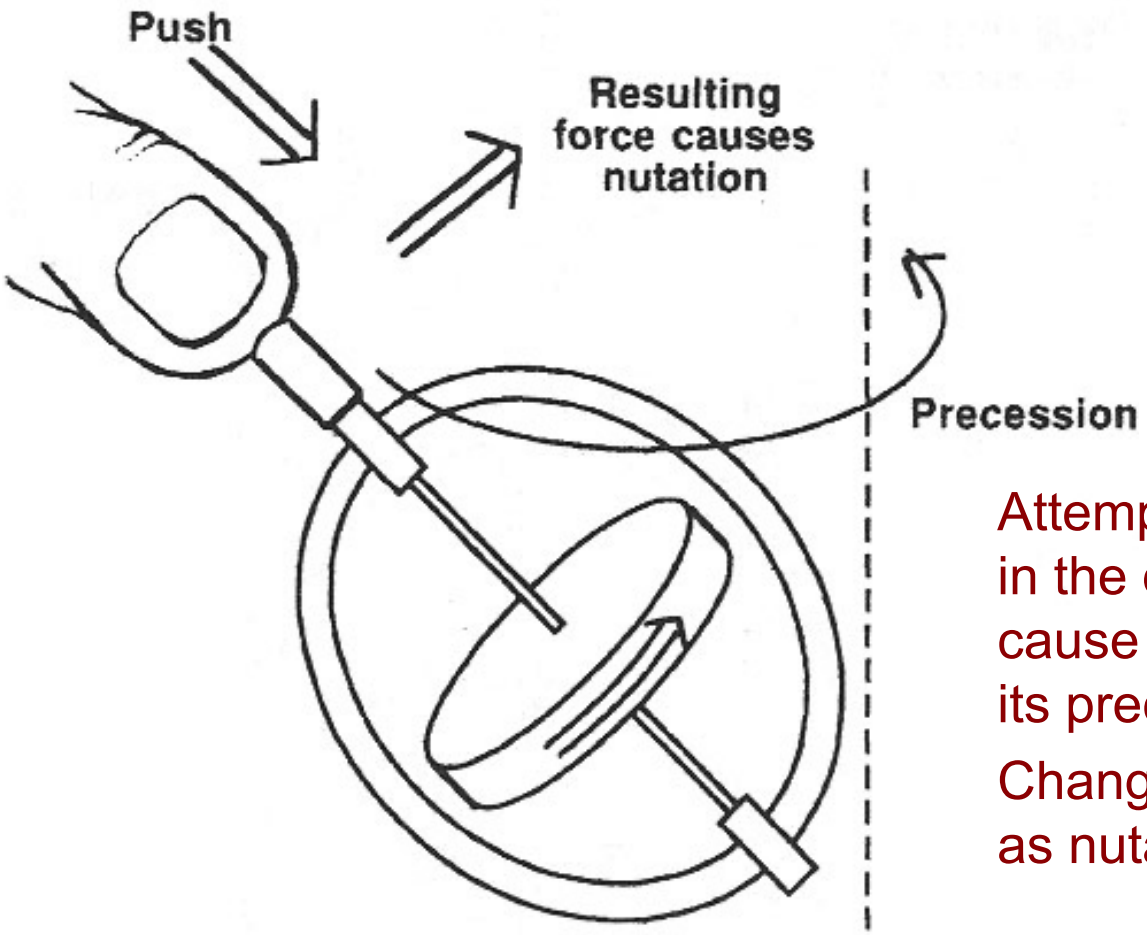
# External force and spins



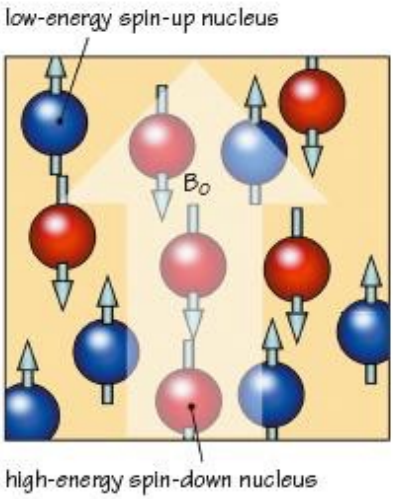

When force is applied to an object having an angular momentum, the resulting motion is at right angles to the force.

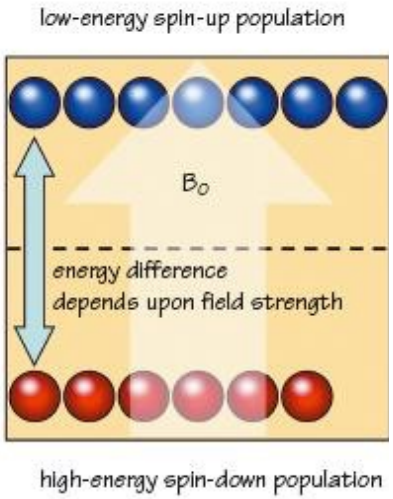


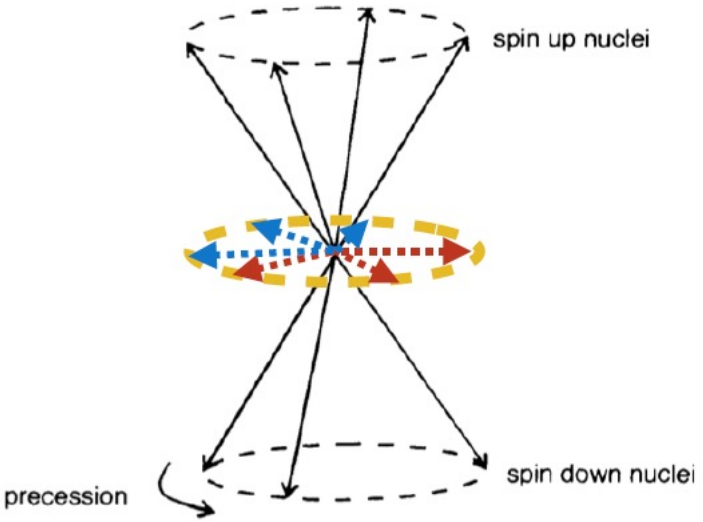

Attempting to push a gyroscope in the direction of precession cause the gyroscope to change its precession angle.

Change of this angle is referred as nutation (third order motion).

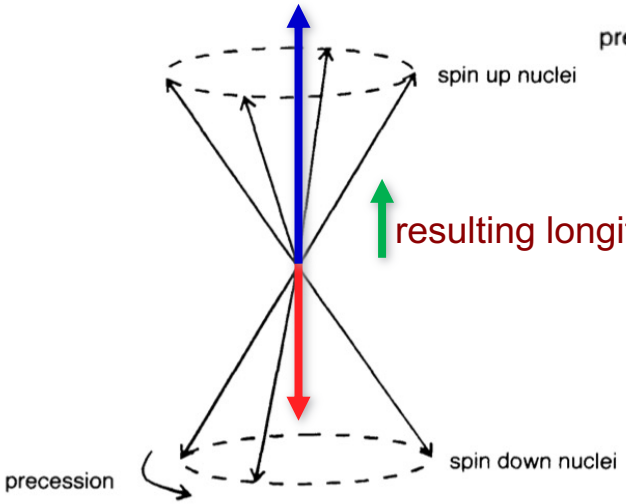
# Magnetic field distribution for all protons



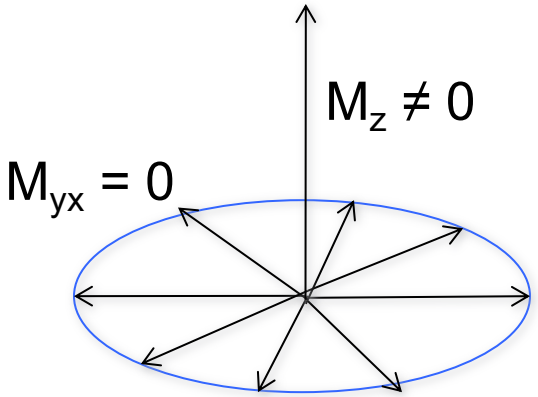

transverse magnetization= 0

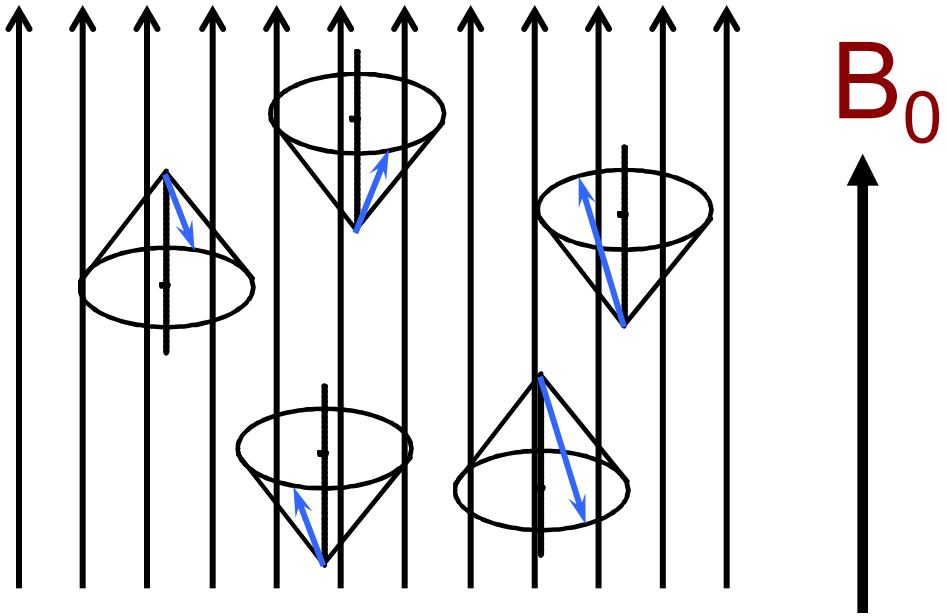



resulting longitudinal magnetization

# Magnetization in static field

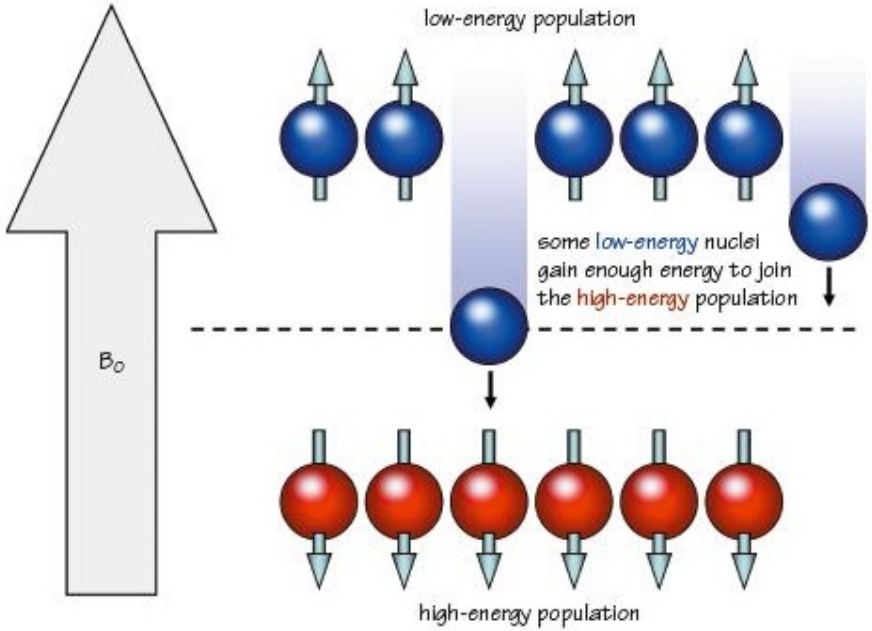
Static $B_0$ field, thermal equilibrium: more spin up than spin down, random phases



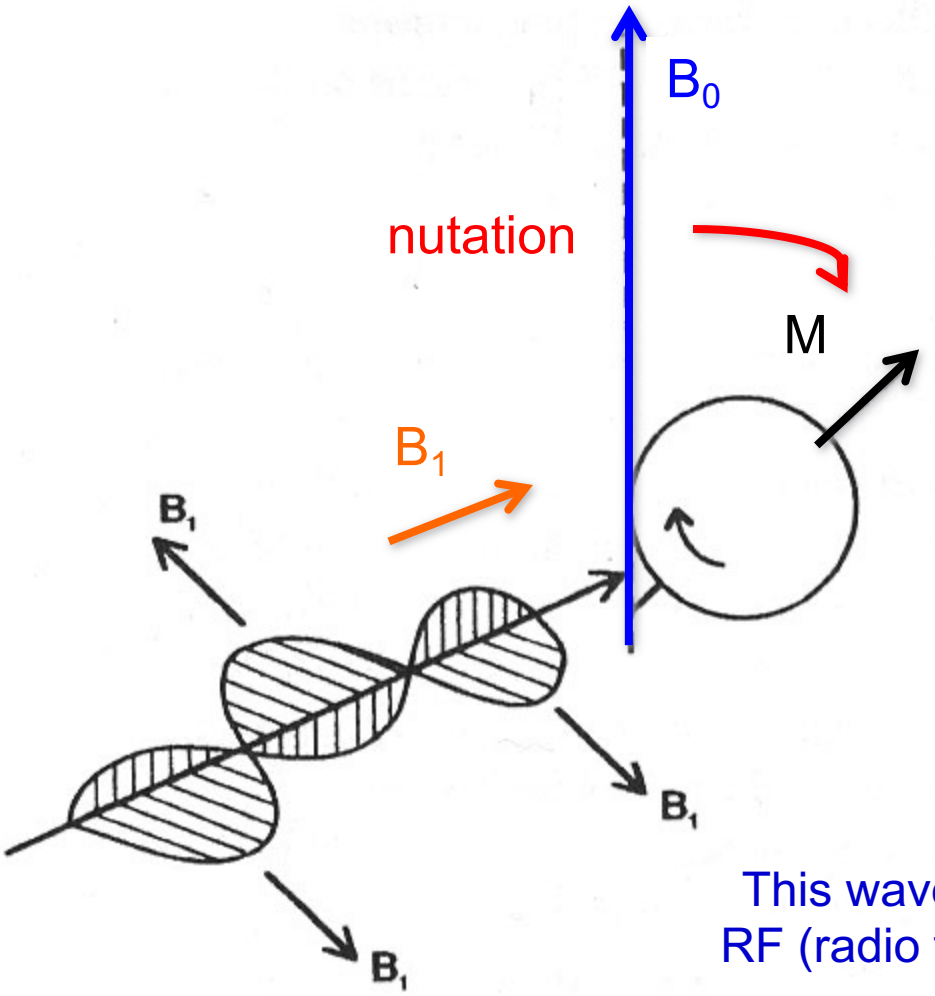

Resulting magnetization **$M \neq 0$ and // $B_0$**

# The effect of an additional electromagnetic pulse




The application of an RF (alternating magnetic field) pulse at the Larmor frequency will cause the phenomenon of **resonance** -> the pulse energy will be absorbed by the atomic nuclei, causing some of them to change the orientation of the magnetic moments to anti-parallel

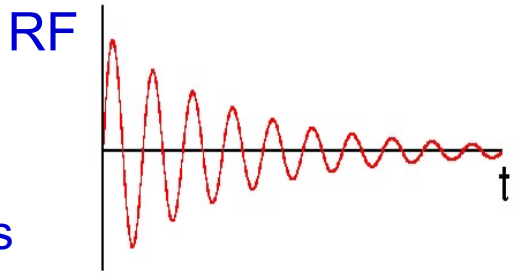
# Effect of additional field $B_1$ perpendicular to $B_0$




To introduce a variable B1 magnetic field, the electromagnetic wave should be applied.

If the frequency of the RF wave is equal to Larmor frequency, then the spin is in magnetic resonance.

The $B_1$, perpendicular to static $B_0$ causes the spin nutation (increasing the angle between magnetization vector and z axis)

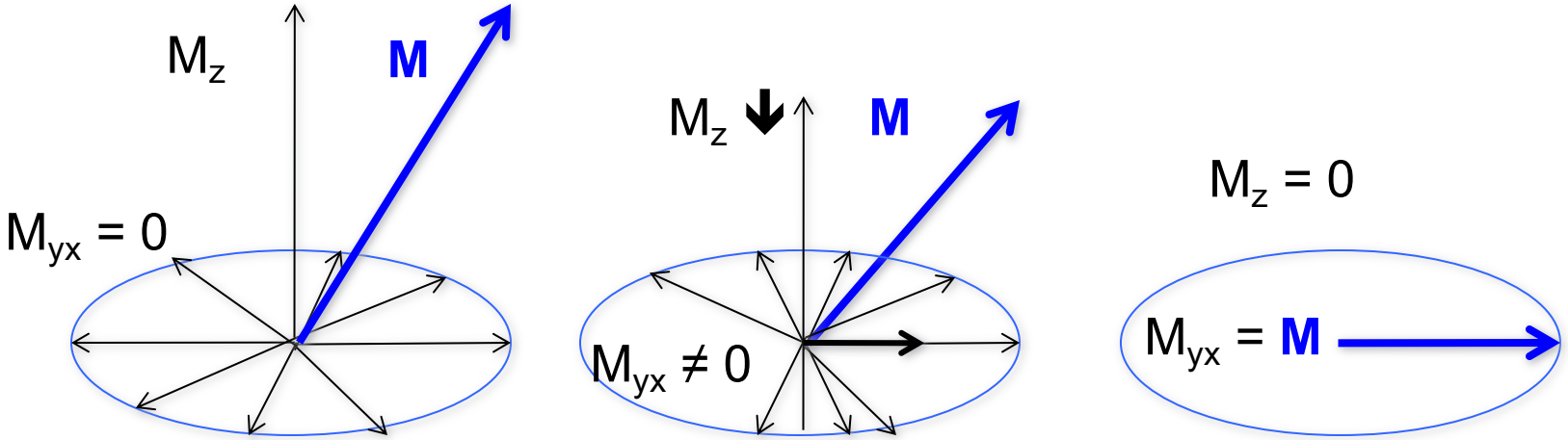



This wave corresponds to RF (radio frequency) waves

# Effects of $B_1$ field

Variable $B_1$ causes the following effects:

- parallel orientation of all spins -> $M_z$ decays
- phasing of spins -> $M_{xy}$ appears and increases



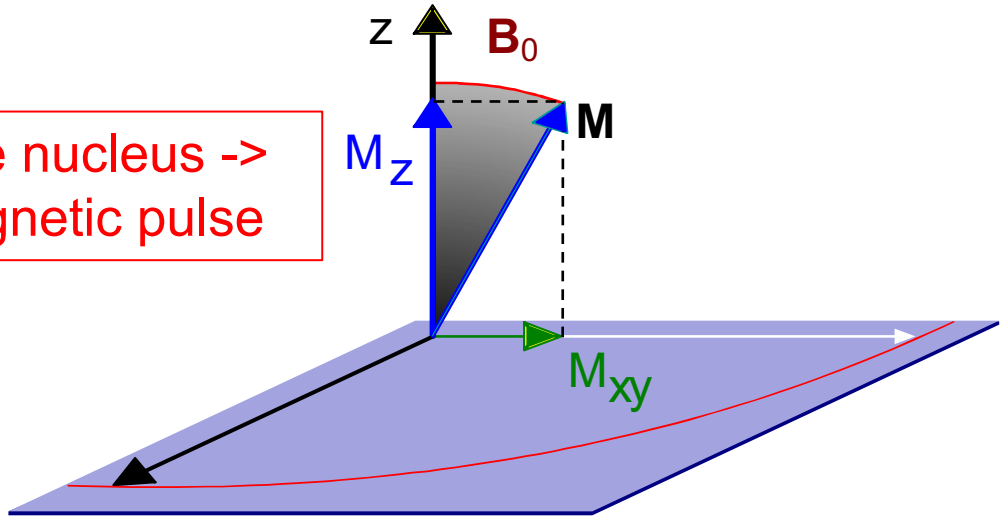

$t_0$, $B_1$ is on $t_1 > t_0$ $t_2 > t_1$

# Relaxation

When B1 disappears, **M** returns the equilibrium state:

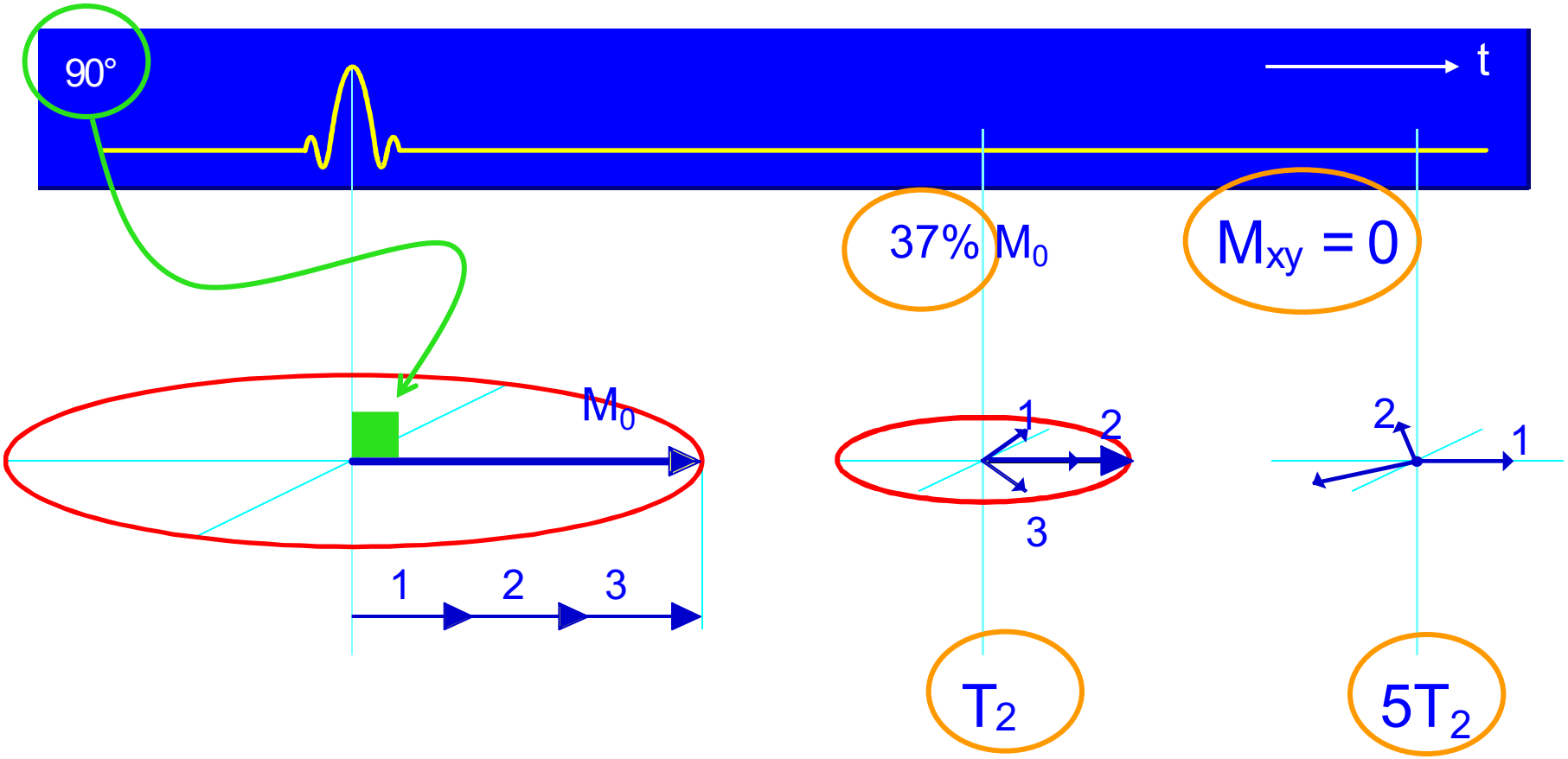
- longitudinal $M_z$ recovers
- transverse $M_{xy}$ decays
- there are two different relaxation effects governed by different time constants, $T_1$ and $T_2$

energy is given off by the nucleus -> generation of electromagnetic pulse



# Spin – spin (Transverse) relaxation – $T_2$

Loss of coherence: reorientation and dephasing
(spin-spin interactions - collisions, local $B_0$ inhomogeneities)

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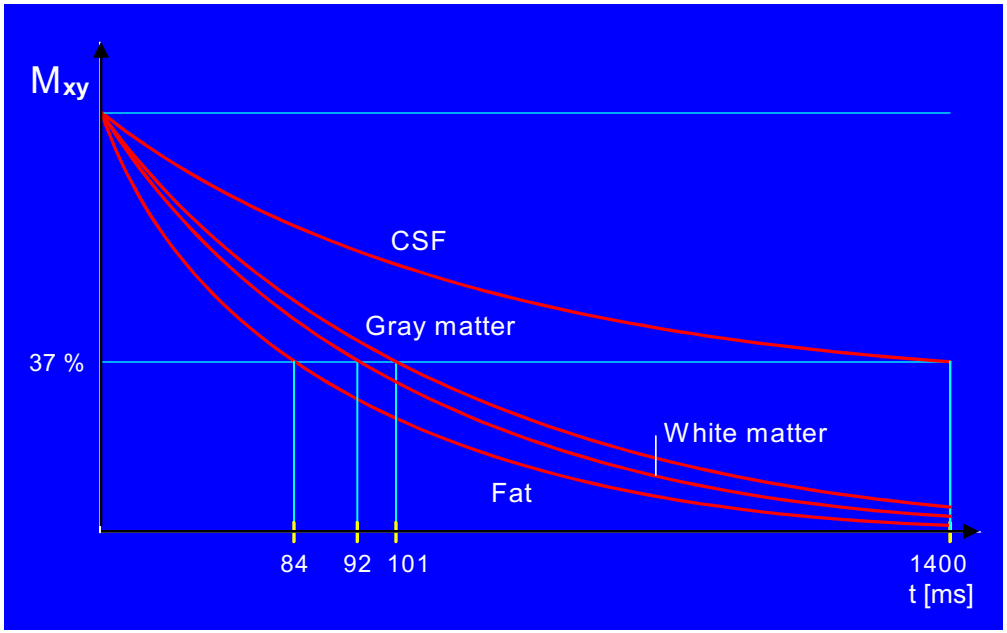
# Spin – spin (transverse) relaxation – $T_2$

## Quantitatively: exponential decay with time constant $T_2$

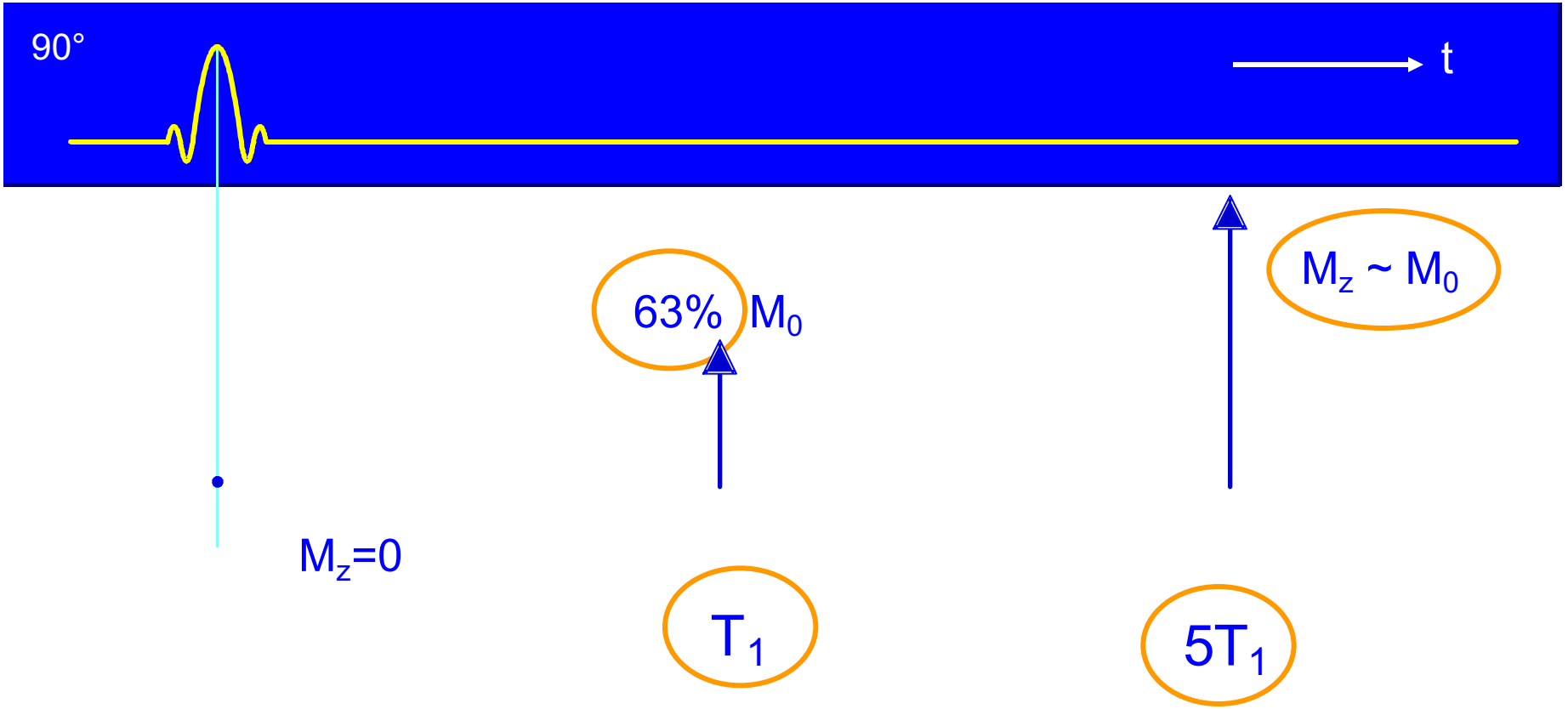



$T_2$ constants [ms] at $B_0$=1 T

| | |
|---|---|
| Fat | 84 |
| Muscle | 45 |
| White matter | 92 |
| Grey matter | 101 |
| CSF | 1400 |

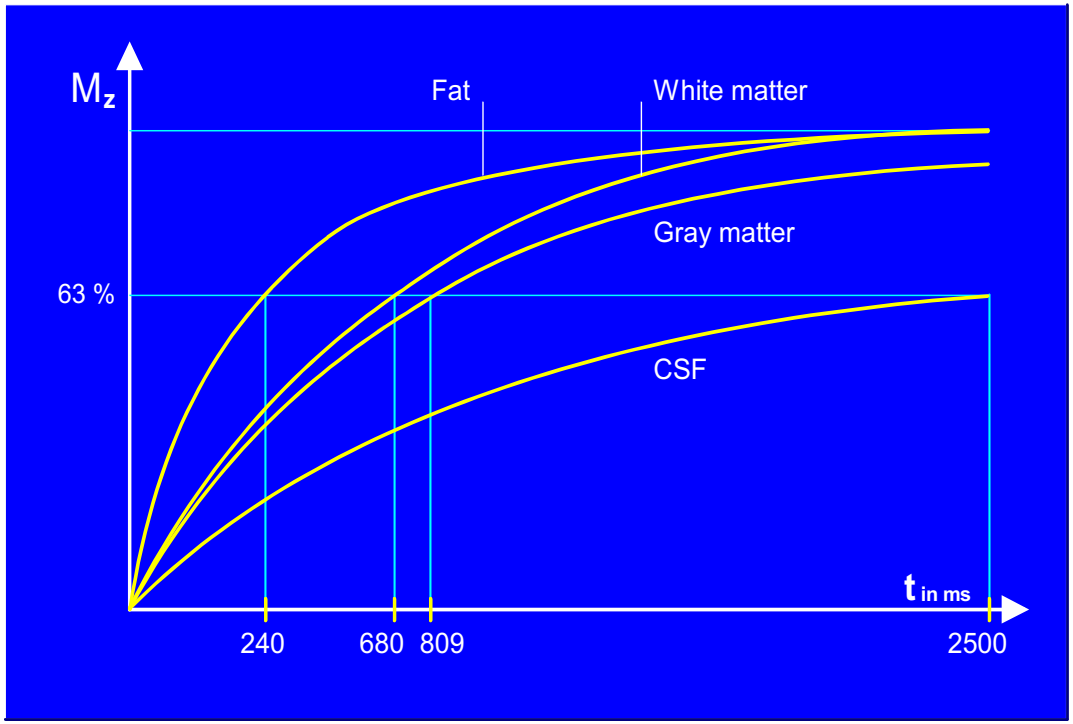
# Spin – lattice (longitudinal) relaxation – $T_1$

Interaction with spin surroundings -> net release of energy -> protons return to the lower energy state of alignment



# Spin – lattice (longitudinal) relaxation – $T_1$

## Quantitatively: exponential increase with time constant $T_1$

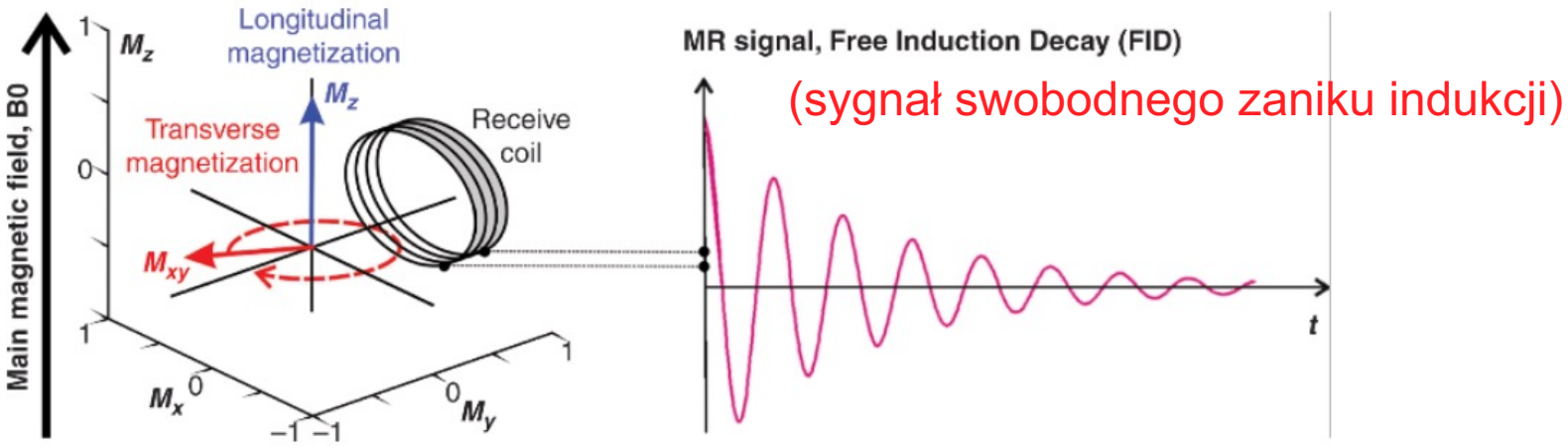



$T_1$ constants [ms] at 1 T

| | |
|---|---|
| Fat | 240 |
| Muscle | 730 |
| White matter | 680 |
| Grey matter | 809 |
| CSF | 2500 |

$T_1 > T_2$

# Source of the MR signal




The changing magnetic field induces a current in the loop of the conductive wire – receive coil (Faraday's law = electromagnetic induction principle). A proton has a magnetic moment and therefore acts like a small magnet. Precesing protons whose magnetic fields intersect the plane of the coil induce an electric current. This current is the FID "signal" of the magnetic resonance induced in the receiver coil - it comes only from the transverse magnetization vector (!?!)

# References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