Introduction to NMR

Physical principles

Skejby Sept. 2003

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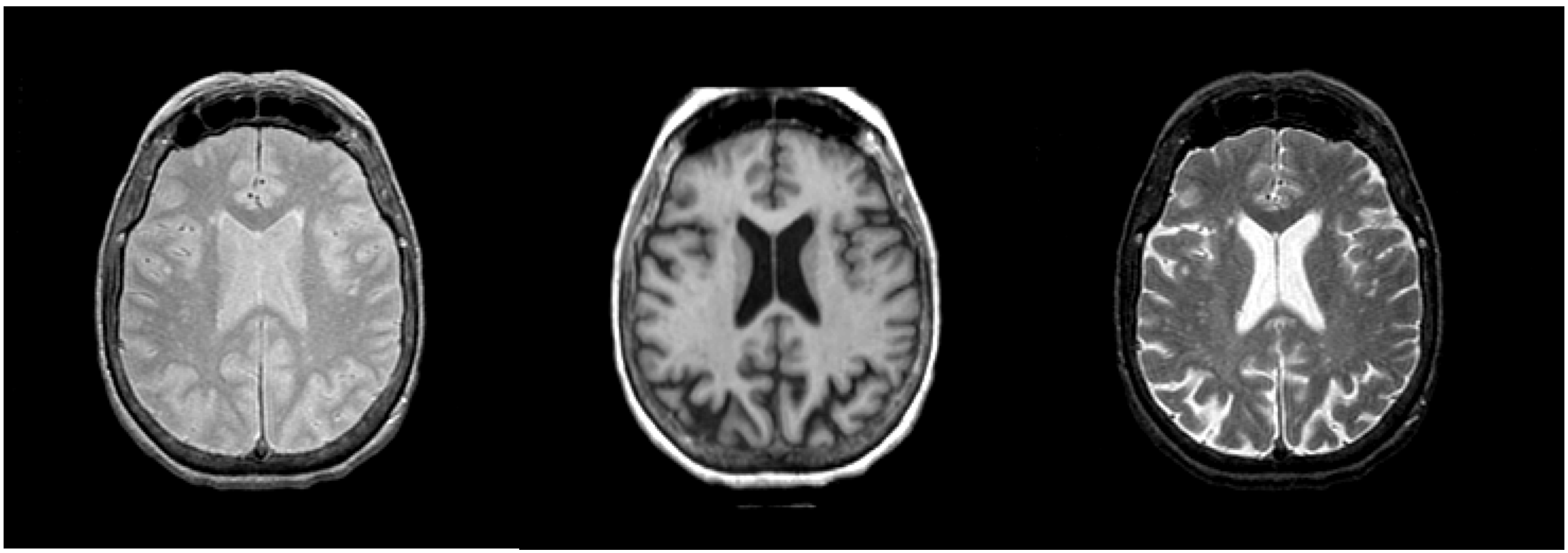
MRI of the human brain



Basic steps

Object —1)→ Data/Signal —2)→ Image

1) By means of magnetic fields and RF pulses

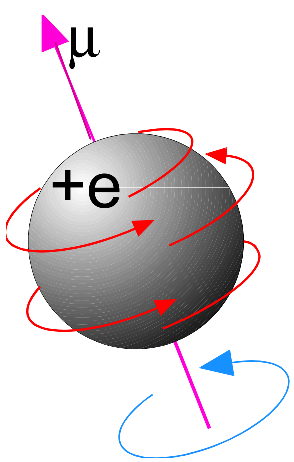
2) Data processing (Fourier transformation)

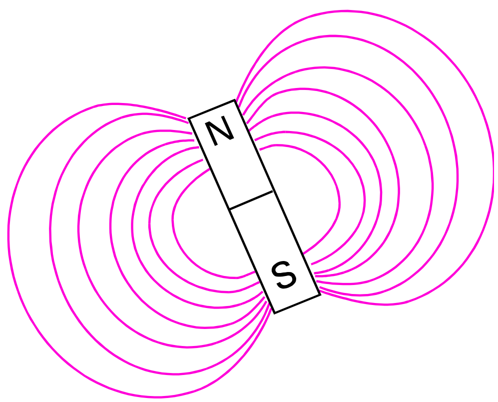
Outline

- Nuclear spins
- Spin dynamics in magnetic fields
- Spin interactions
- Spin excitation
- Spin RF radiation and detection

Spin and magnetic fields

Proton





Permanent Magnet (dipole)

A charged proton that spins will create a circulating current which in turn induces a magnetic field.

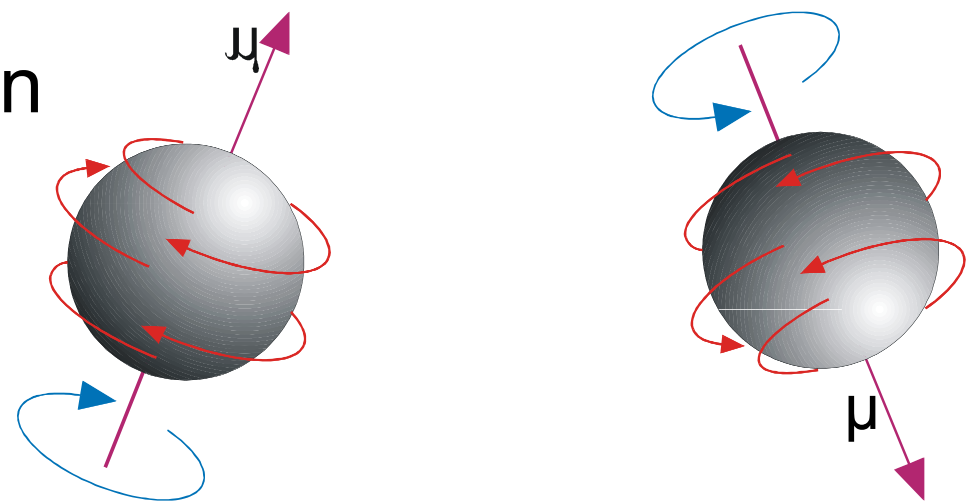
The dipole vector **μ** describes the strength and direction of magnetic field. C.g. permanent magnet.

Spin is a fundamental quantum mechanical property. All nuclei (and other particles) have spin:

S=0,1/2,1,3/2….. $h/2\pi$ (Planck'sconstant).

For S=I there are 2I+1 states, corresponding to the possible orientations of the spin.

Proton



Spin and magnetic field

The fundamental

γ (gamma) is the g
depends on the nu
$2{,}675 \cdot 10^{8}$ rad/s/T.

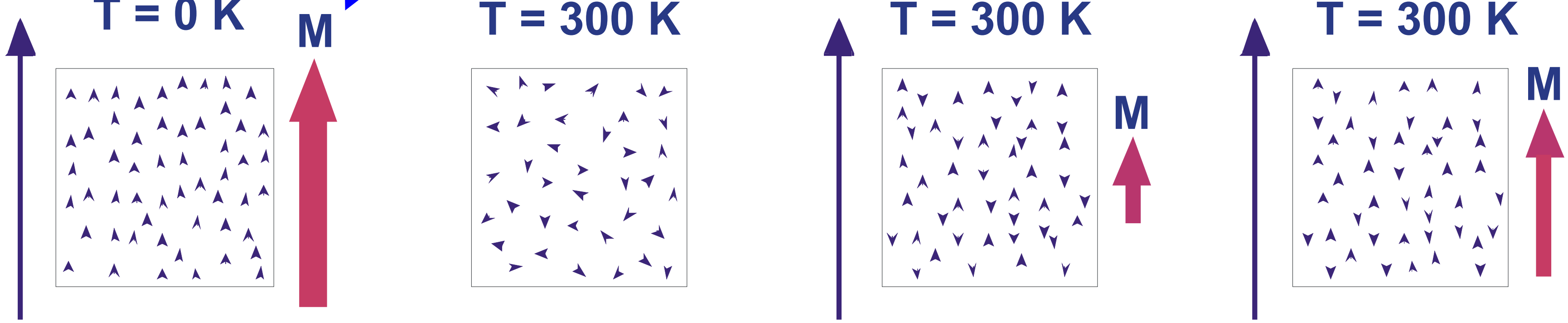
Only nuclei with non-zero spin have magnetic moments, and are thus NMR active.

T=Tesla. 1 Gauss=10000 Tesla. Earths magnetic field is roughly .5 Gauss. A clinical scanner has 1.5 Tesla, i.e. 30000 times the earths magnetic field.

Spins in external fields

A magnetic dipole ten… …ernal field (e.g. a compass … …eld). Thermal motion oppo…

M (magnetization) is the magnetic dipole moment per unit volume.



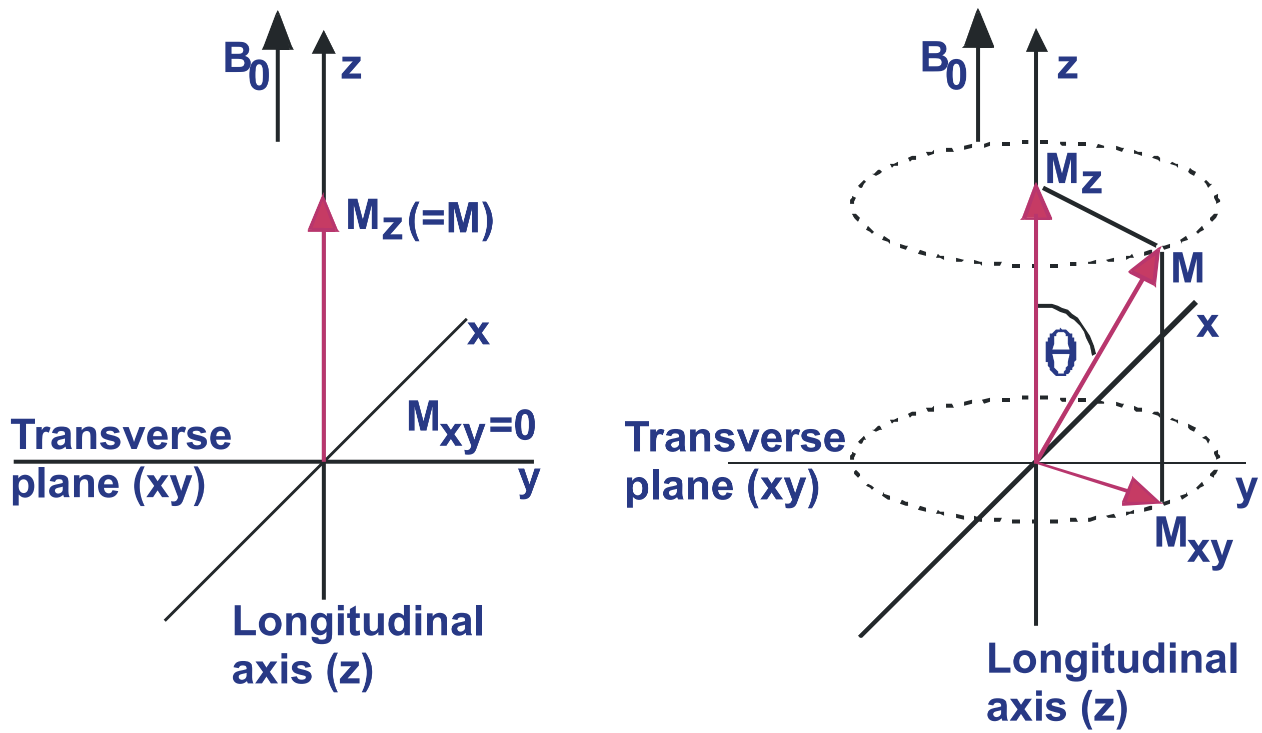
B = 0.1 tesla T = 0 K — Spins aligned 100%

B = 0 tesla T = 300 K — Spins aligned 0%

B = 0.1 tesla T = 300 K — Spins aligned 1 ppm

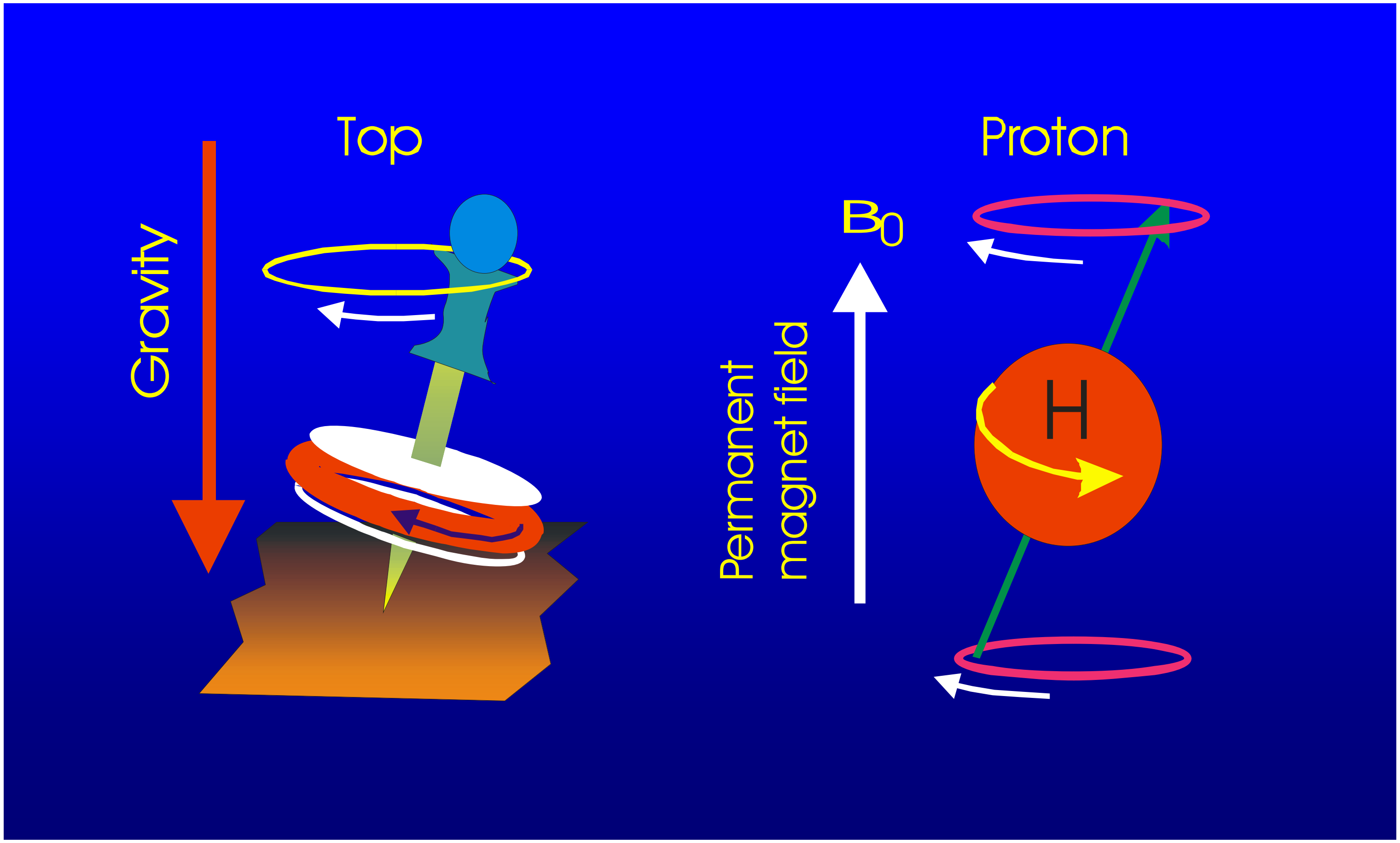
B = 0.5 tesla T = 300 K — Spins aligned 5 ppm

Magnetization



M is the sum of the individual spin magnetic moments.

Spin dynamics



Larmor frequency

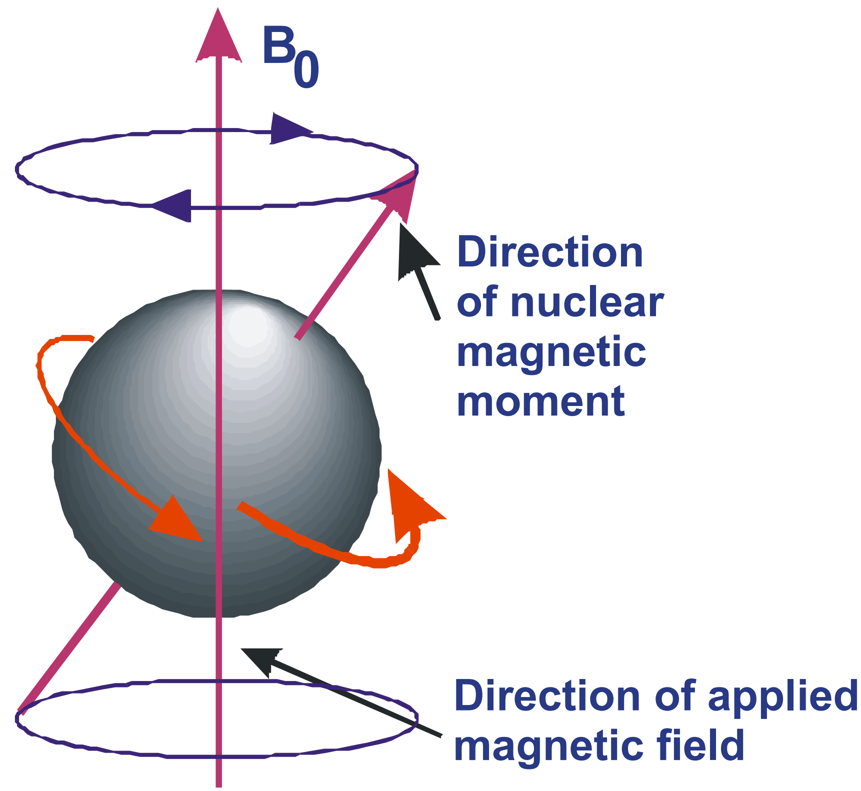
ω is the Larmor frequency:

$$\omega_0 = \gamma B_0$$

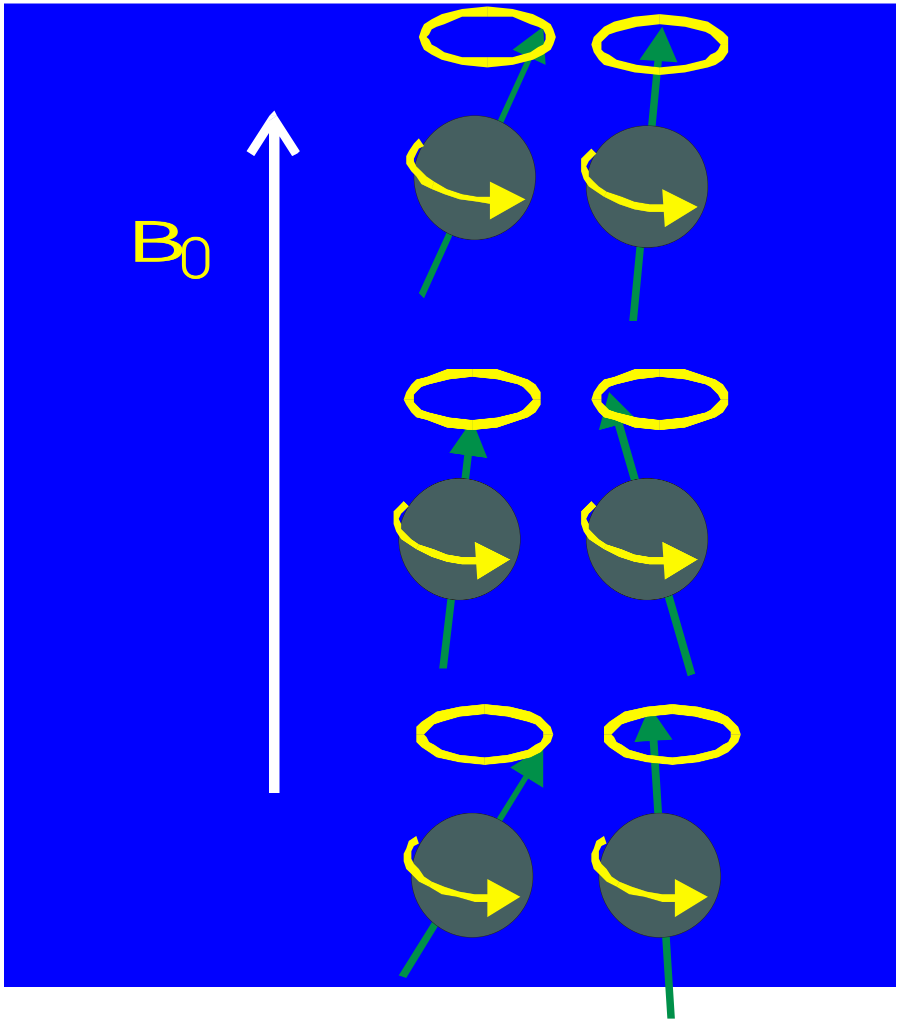
For protons in a clinical scanner, B_0=1.5T so

$$\omega_0 = 63.87\text{Mhz.}$$

Compare DRP1@88.1Mhz.



Magnetization



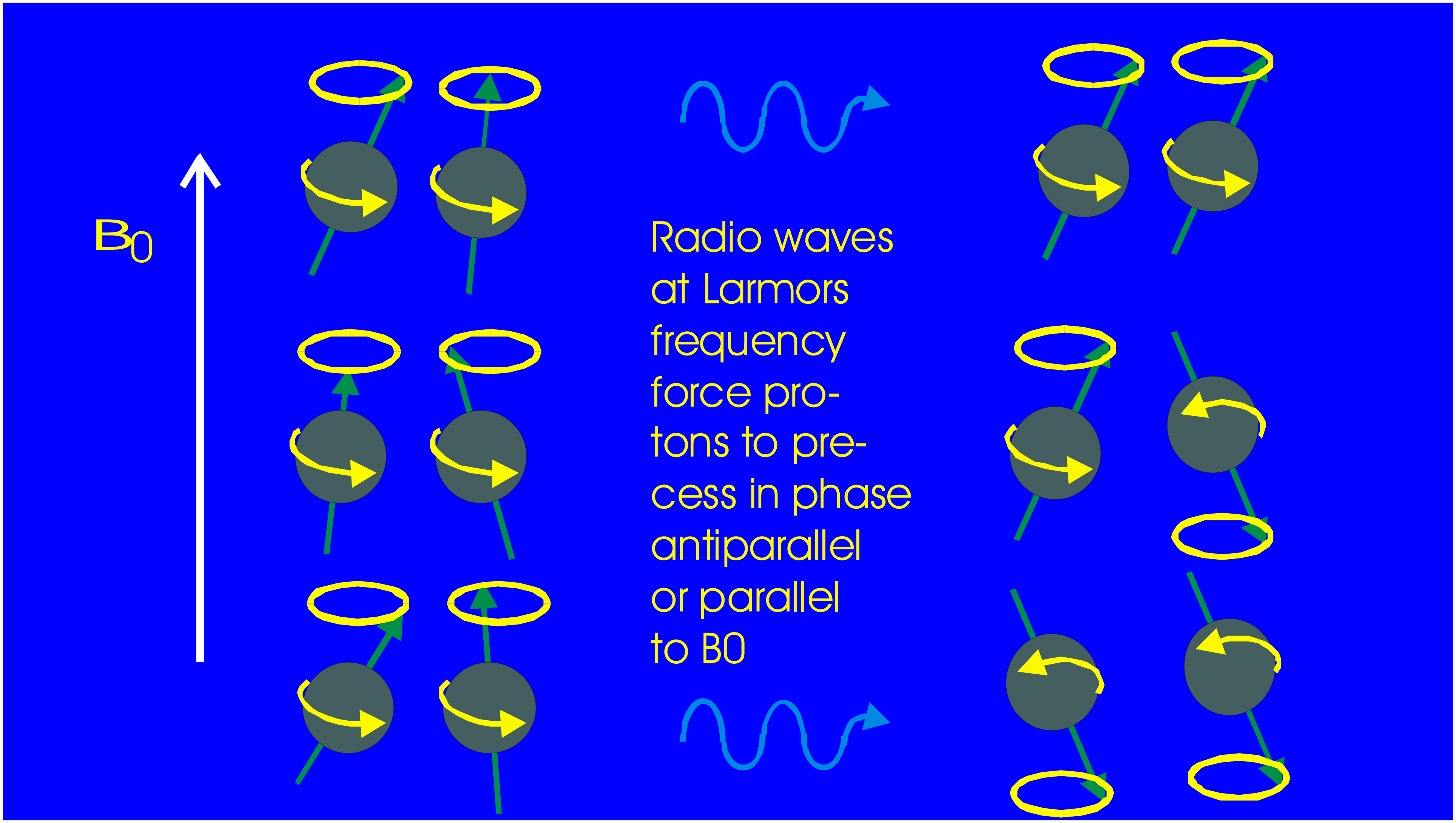
Magnetization M is:

$$M_z = M_0$$

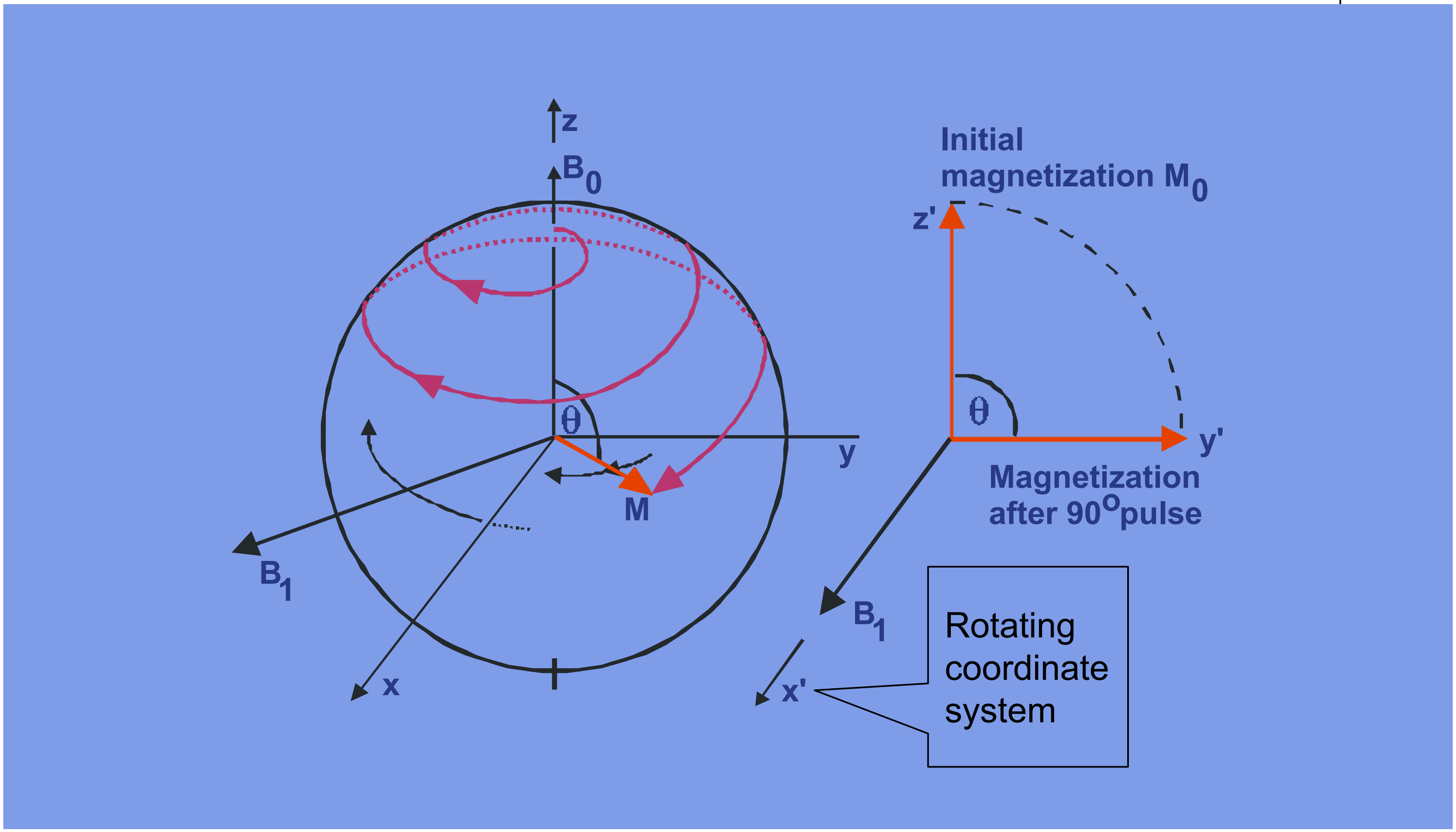
$$M_{xy} = 0$$

Transverse magnetization is zero because of random phases.

Radio-frequency pulses



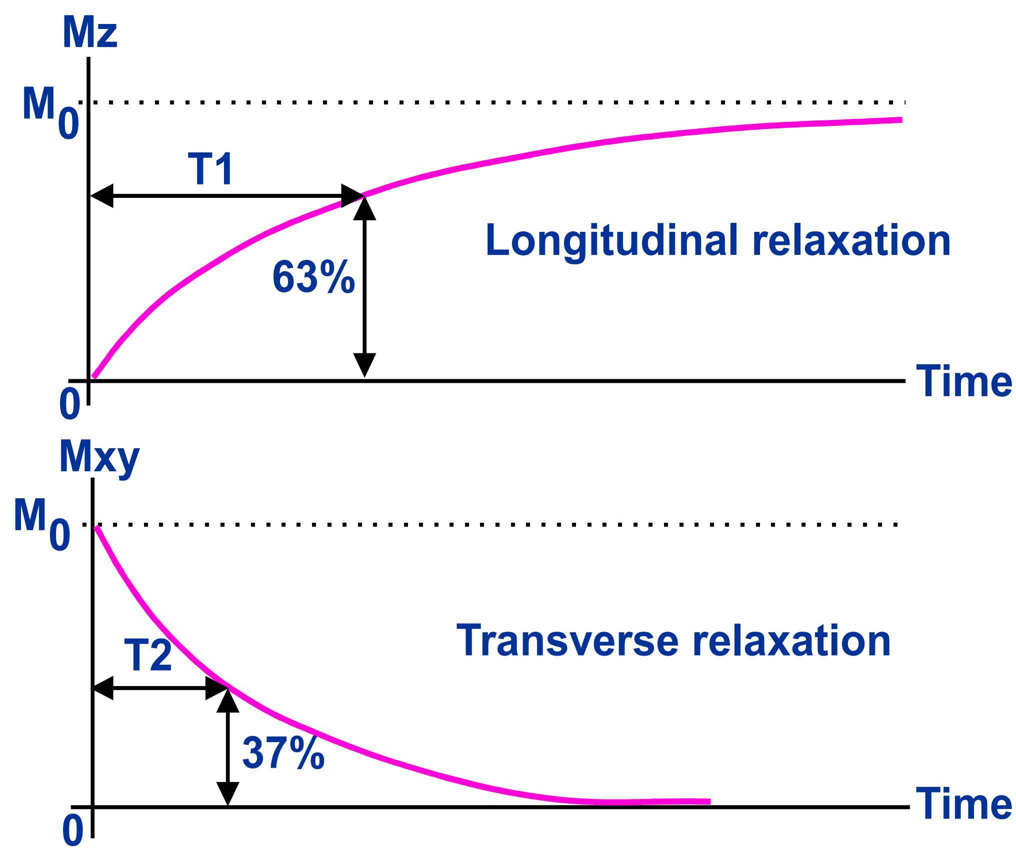
RF pulses and magnetization



Spin interactions

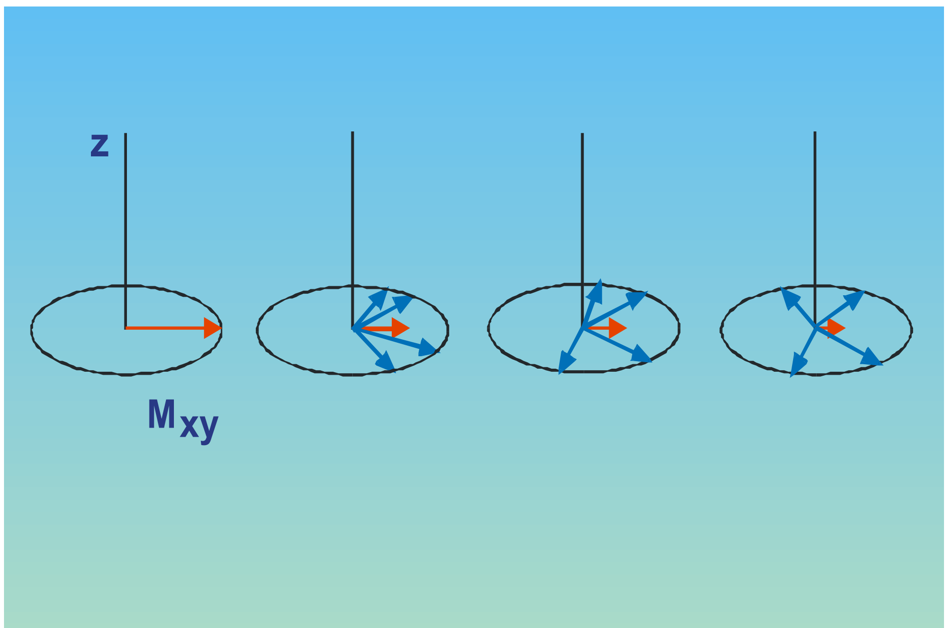
Instead of precessing forever in the transverse plane, the magnetization relaxes back to the equilibrium value.

T1 and T2 are characteristic relaxation constants.



T2 and T2*

T2 dephasing

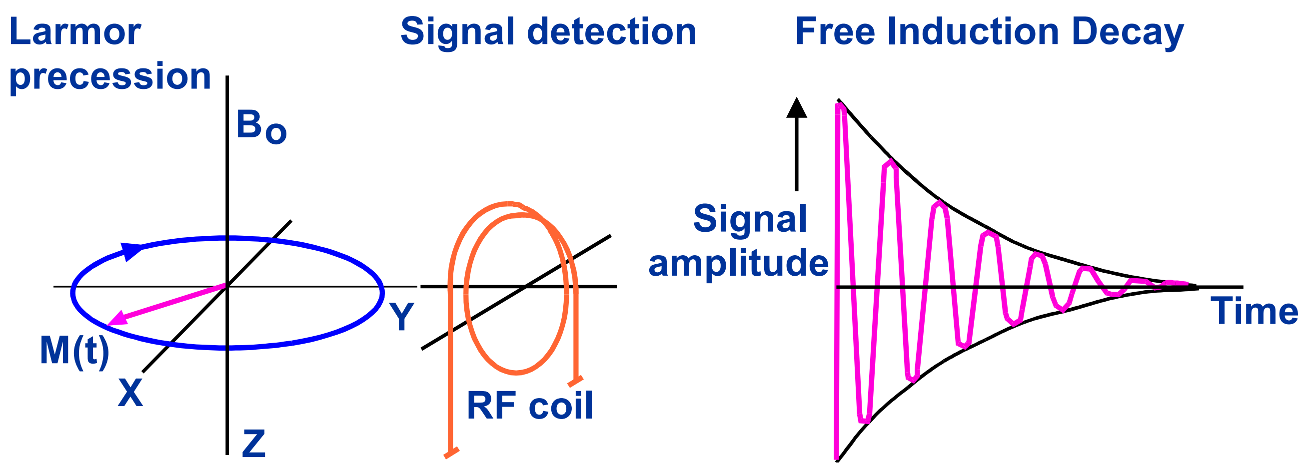


The dephasing in T2 relaxation results from differing local interactions, leading to locally varying Larmor frequencies. T2* is the same phenomenon, but is a result from magnetic field inhomogeneities.

Biological T1-T2 values

TISSUE	T1 at 1.5 T (ms)	T1 at 0.5 T (ms)	T2 (ms)
Skeletal muscle	870	600	47
Liver	490	323	43
Kidney	650	449	58
Spleen	780	554	62
Fat	260	215	84
Grey matter	920	656	101
White matter	790	539	92
Cerebrospinal fluid	>4000	>4000	>2000
Lung	830	600	79

Spin RF radiation and detection



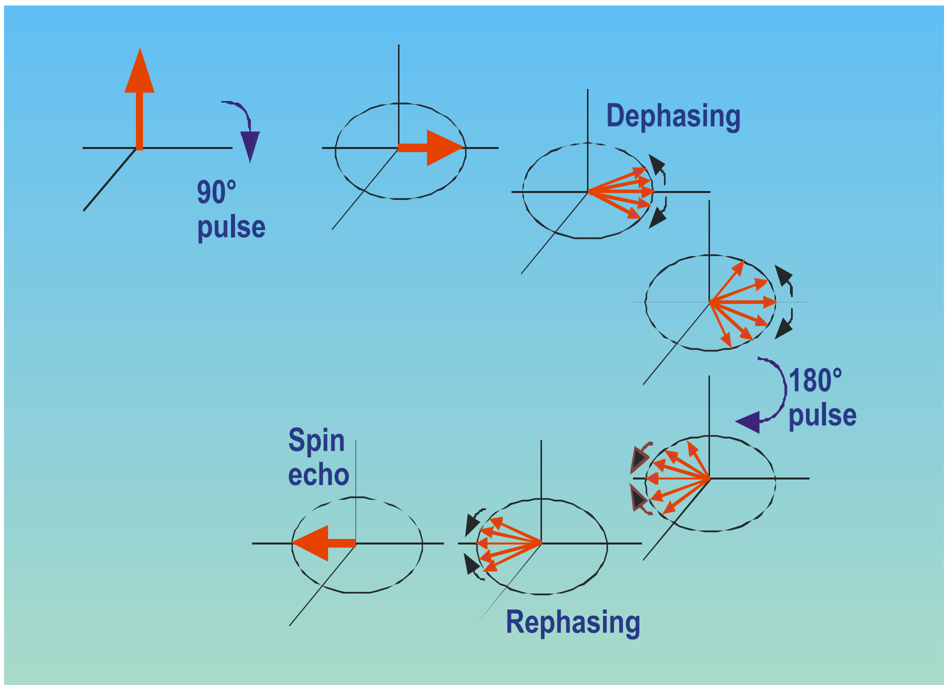
Law of induction: changing magnetic field induces electromotoric force. From M_{xy}

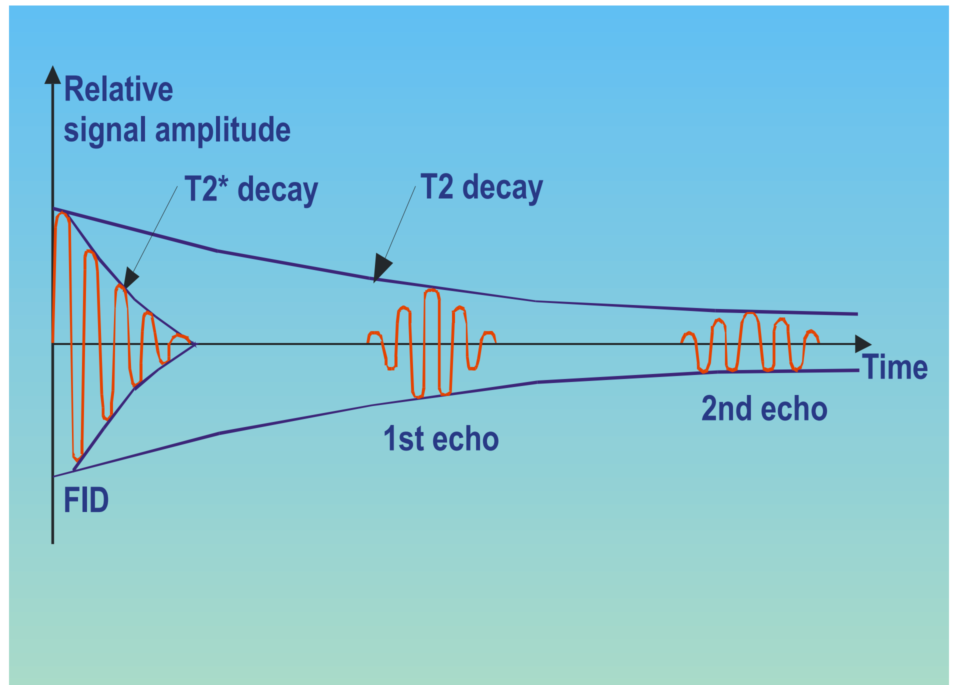
Detected by RF coil and measured as a time varying current. Decays according to T2*. What about T2?

Spin echo

Spin echo

- Or spin refocussing





[90]-TE/2-[180]-TE/2-ECHO

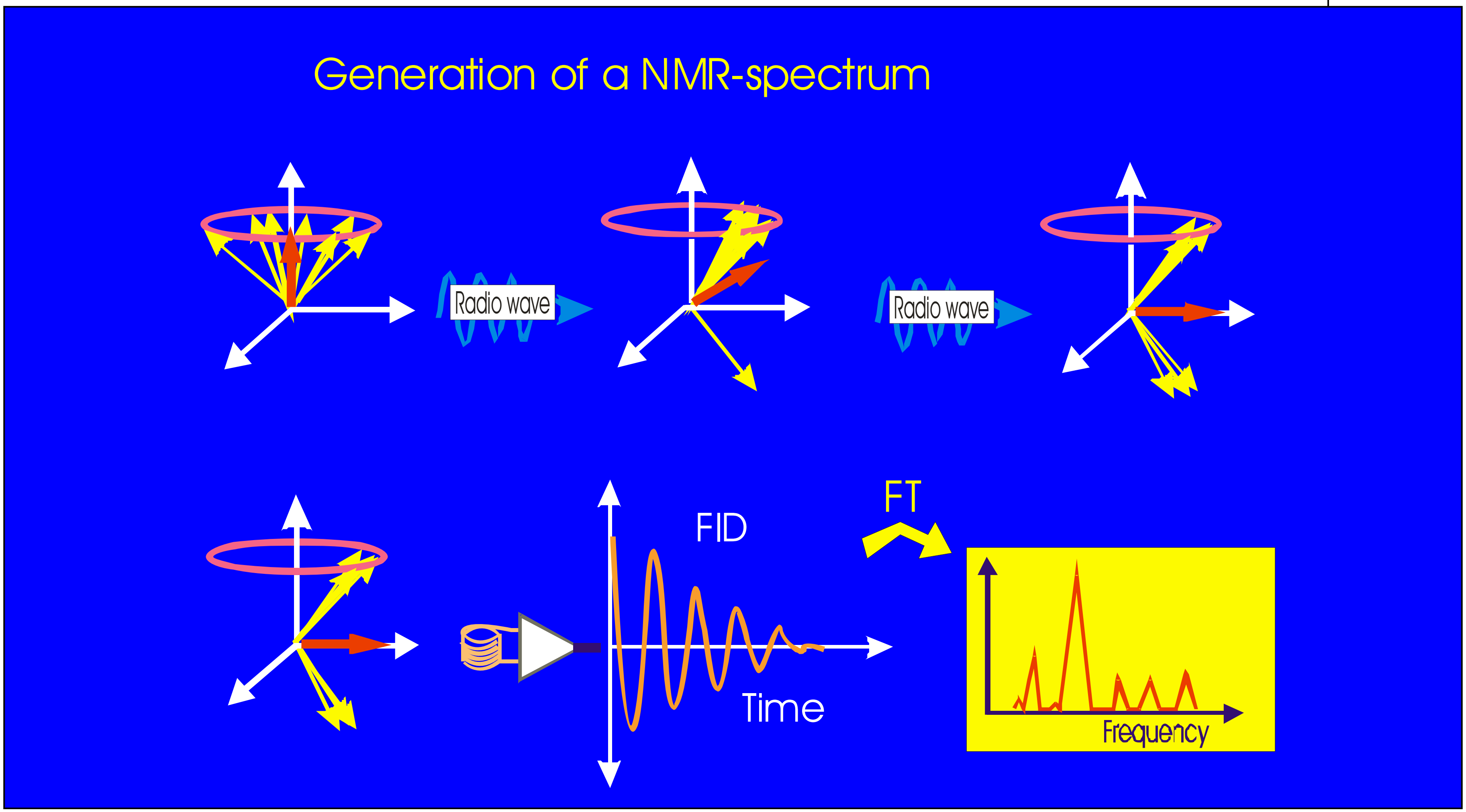
Pulse sequences and contrast

By using different pulse sequences, one can create contrast on the basis of e.g. T1, T2, T2* or spin density.

Spin echo:

$$S = \rho \cdot (1 - e^{-TR/T_1}) \cdot e^{-TE/T_2}$$

Overview


Generation of a NMR-spectrum
Radio wave
Radio wave
FT
FID
Time
Frequency