MRI practical course 1

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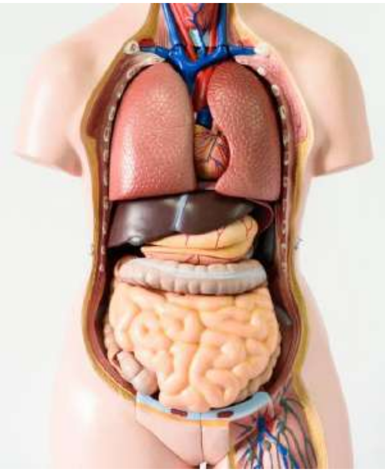
Introduction

Medical imaging

Medical imaging: basic concepts

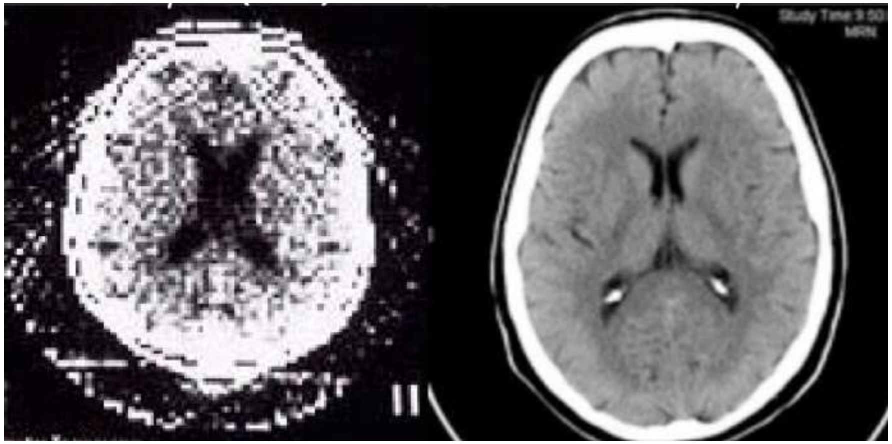
Energy source:
magnetic field,
Xray,
high energy
particles



Energy detection:
coils,
detectors…

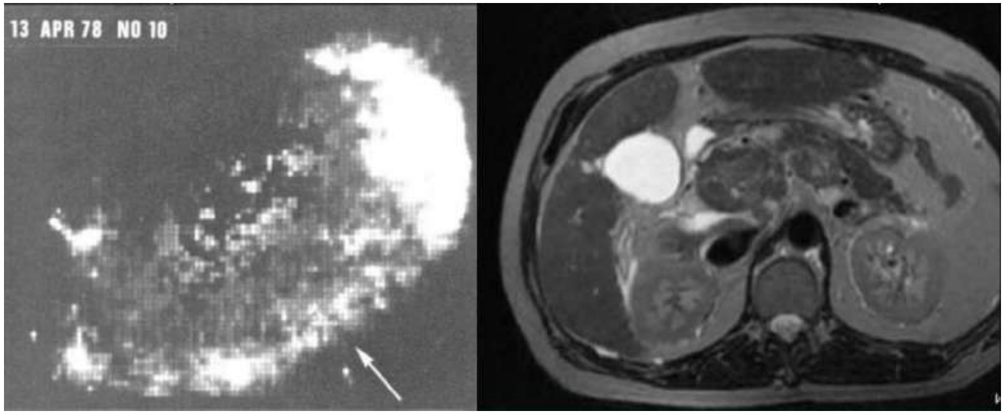
Imaging System
(Electronics, control, computing, algorithms, visualization....) e.g.,
Engineering!

Medical imaging: technology advances



early CT (1975)

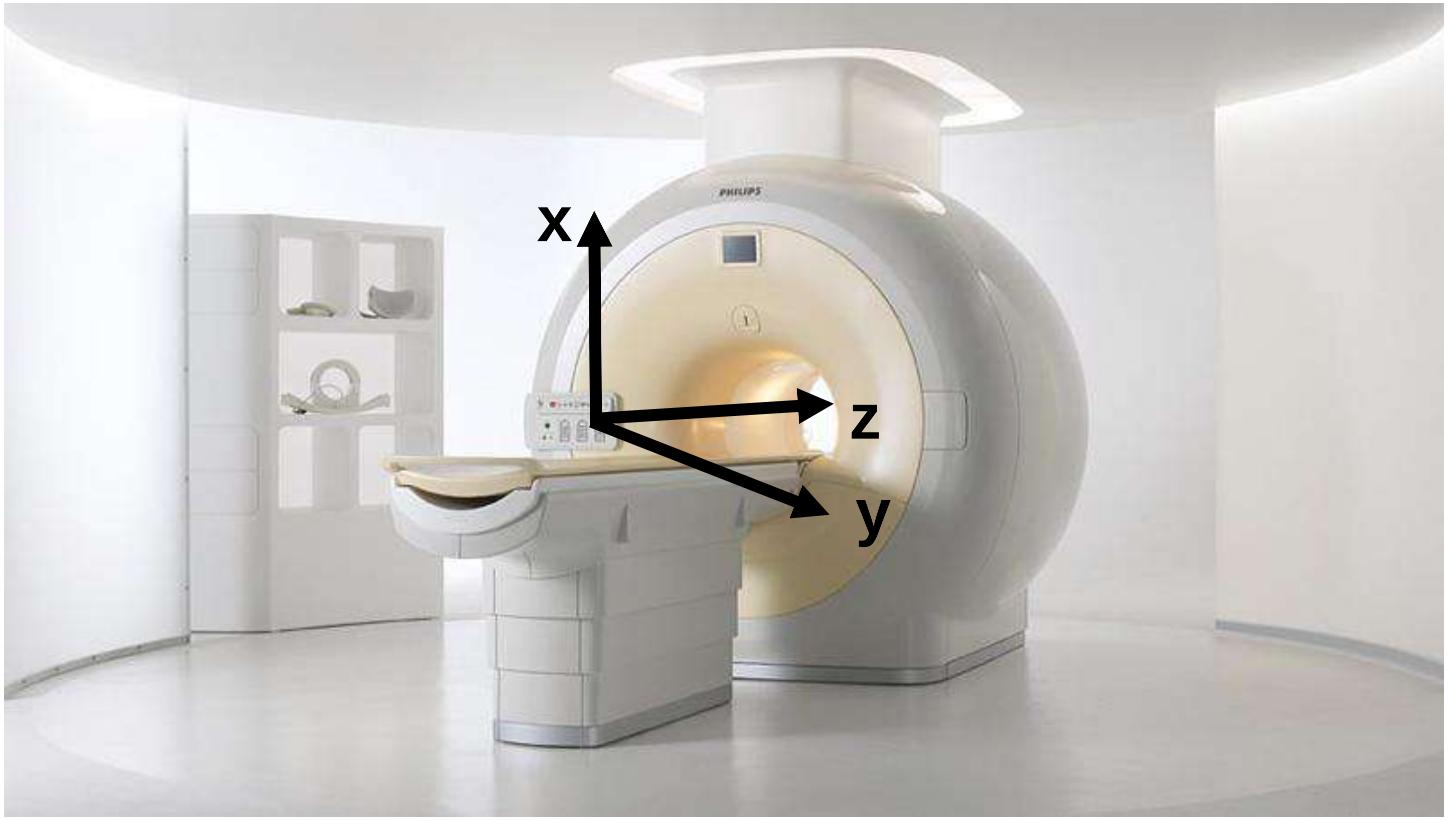
today



early MRI (1978)

today

MRI : Setup



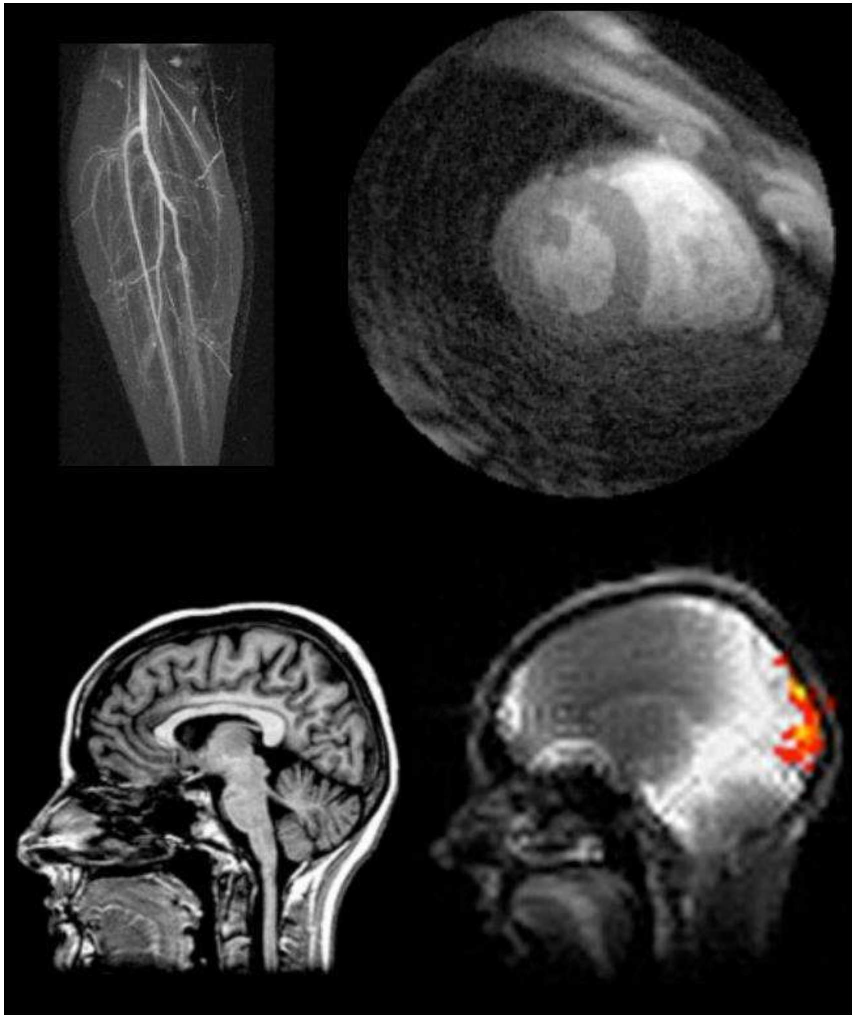
- 3 different magnetic fields, today B_0, B_1, (but no G)

MR imaging

- Magnetic resonance imaging has revolutionized medicine

- Directly visualizes soft tissues in 3D

- Wide range of contrast mechanisms
  - Tissue character (solid, soft, liquid, fat, ...)
  - Diffusion
  - Temperature
  - Flow, velocity
  - Oxygen Saturation



MRI: how does it work

- Magnetic Polarization ~ B_0

-- Very strong uniform magnet

- Excitation ~ B_1

-- Very powerful RF transmitter

- Acquisition ~ G

-- Location is encoded by gradient magnetic fields

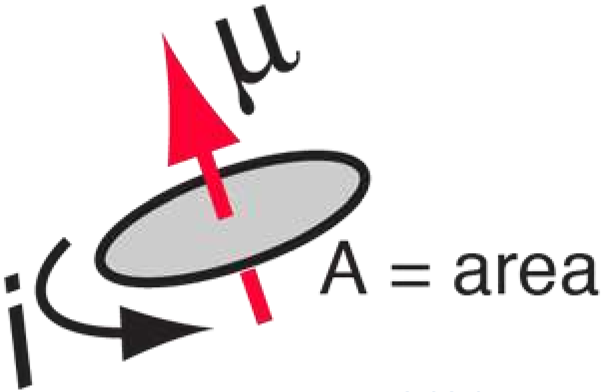
-- Very powerful audio amps

The B_0 and B_1 field

Why do we need the B0-field?

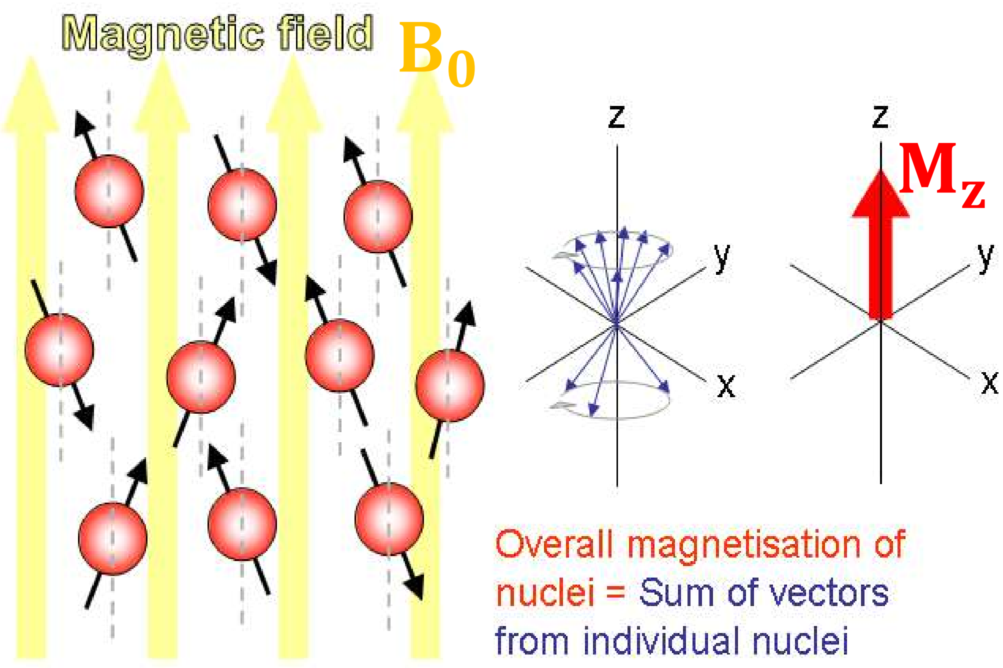
- Polarization

- Protons have a magnetic moment
- Protons have spins
- Like "tiny" rotating magnets
- Body has a lot of protons
- In a strong magnetic field B0, spins align with B0 giving a net magnetization

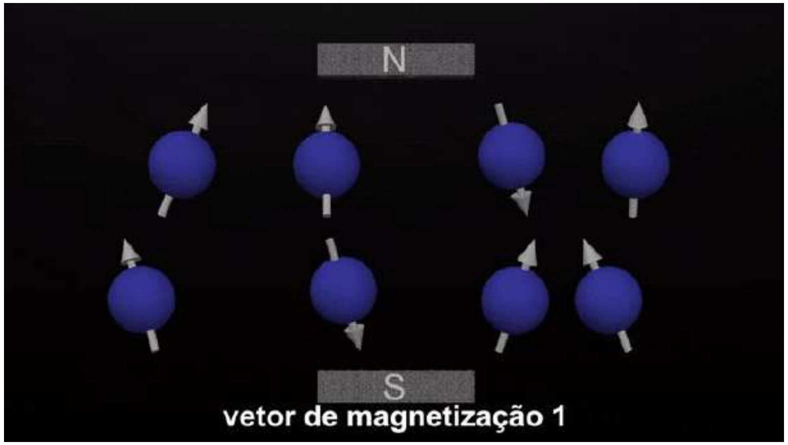


Why do we need the B0-field?

- Nuclear magnetic moments



Overall magnetisation of nuclei = Sum of vectors from individual nuclei

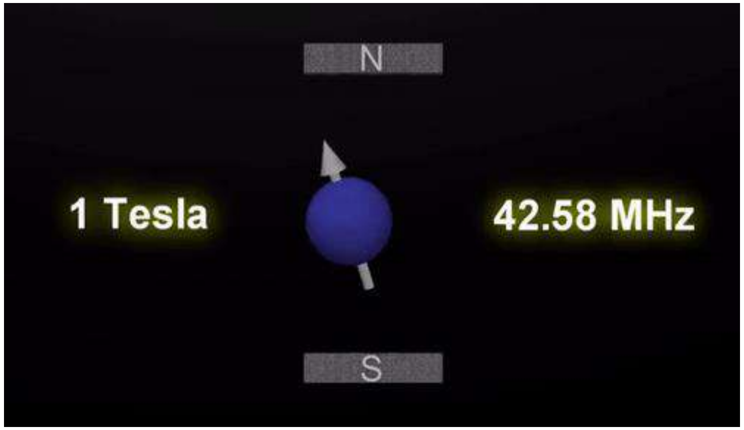


http://physiology-physics.blogspot.de/2010/06/understanding-basic-principles-of.html

B0-field scale

- Very strong constant magnet field

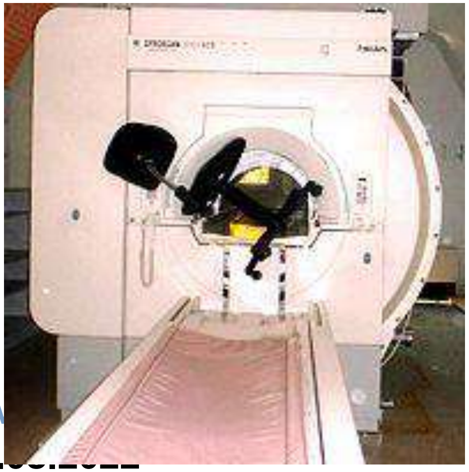
Field strength / T	Example
0.00005	Earth’s magentic field in Germany
0.1	Typical horseshoe magnet
1.6	Strongest permanent magnet
3	Typical clinical MRI
9.4	Strongest clinical MRI
23.5	Strongest MRI (NMR)



B0-field generation

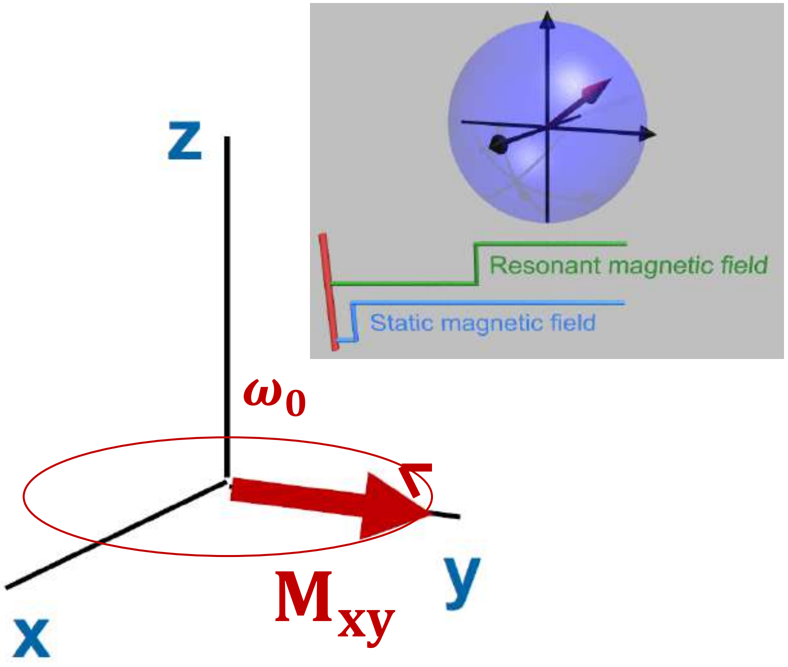
- Generation with superconducting coils
- Superconducting material: very low temperature
  - (~ -269 °C) → electrical resistivity is 0
- Very high currents possible → very high magnetic fields
- Low temperatures → liquid helium (pump)

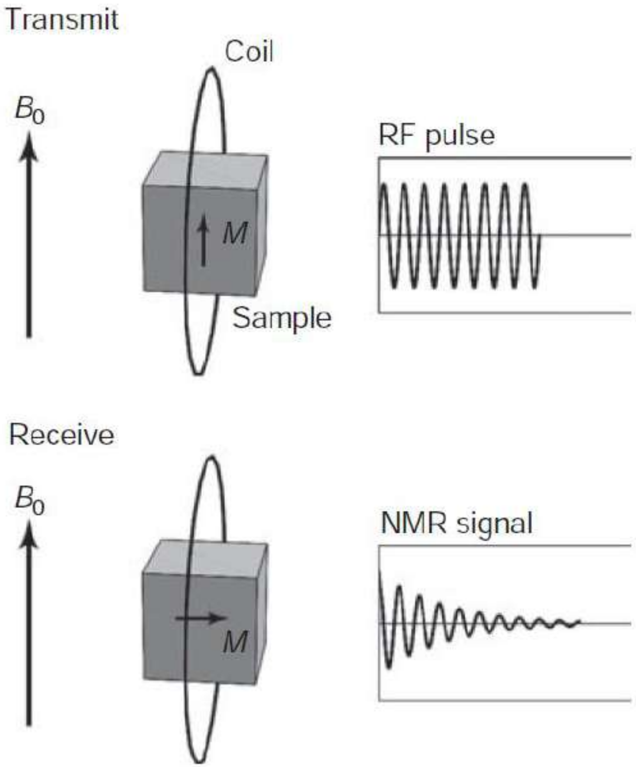

B0-field



Why do we need the B1-field???

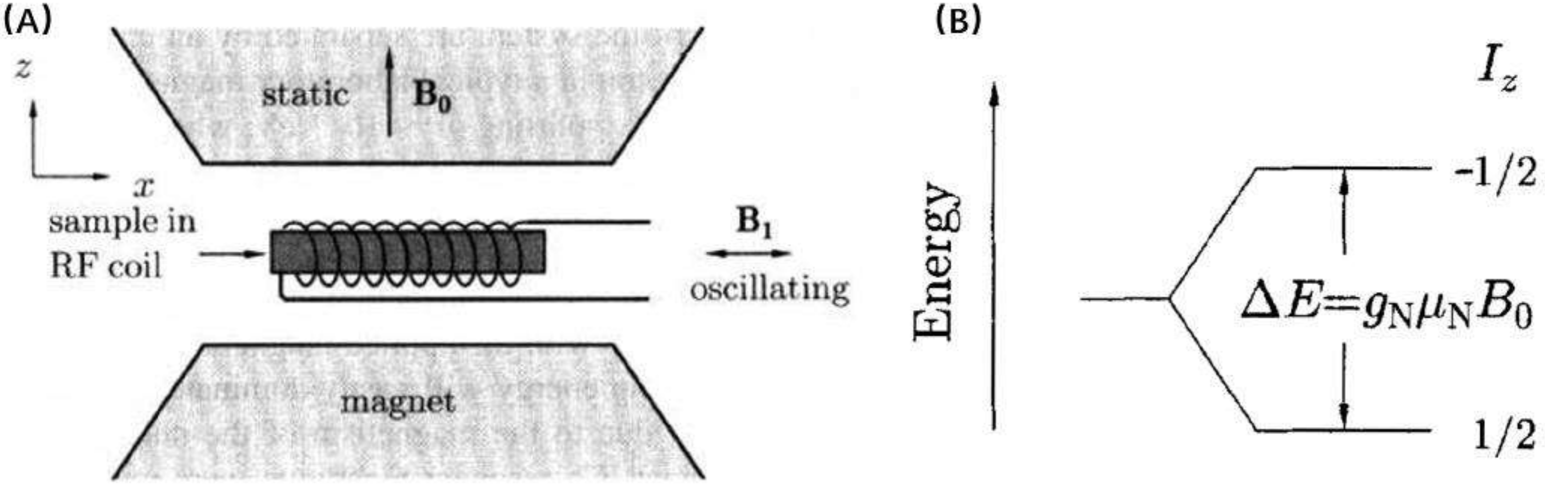
- Flip magnetization into xy-plane, alternating magnetic field → NMR signal

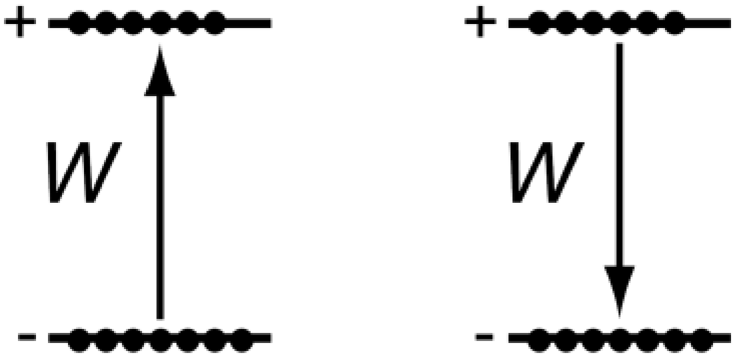




Buxton: Introduction to fMRI. Cambridge University Press, 2009

Deviated from the classical picture

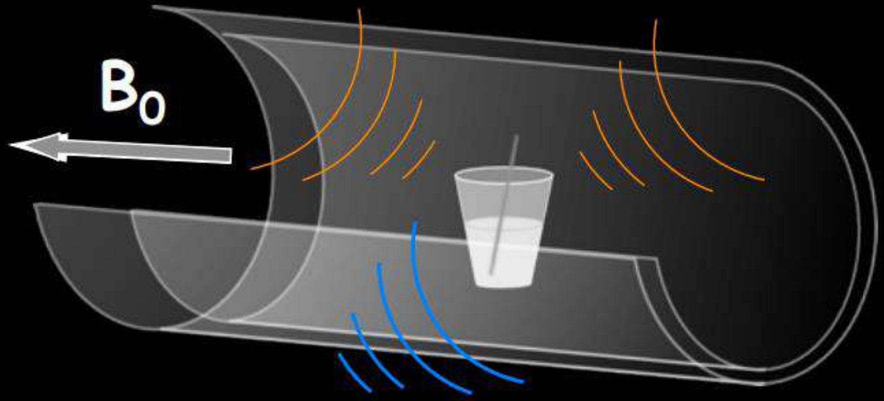


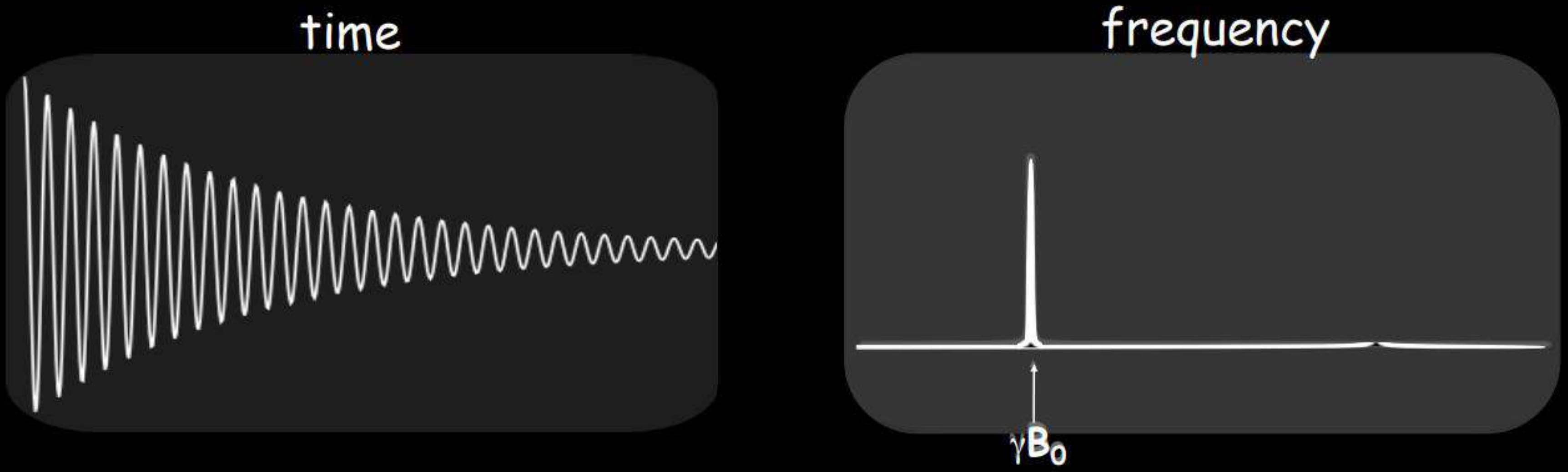


Measuring with dedicated coils

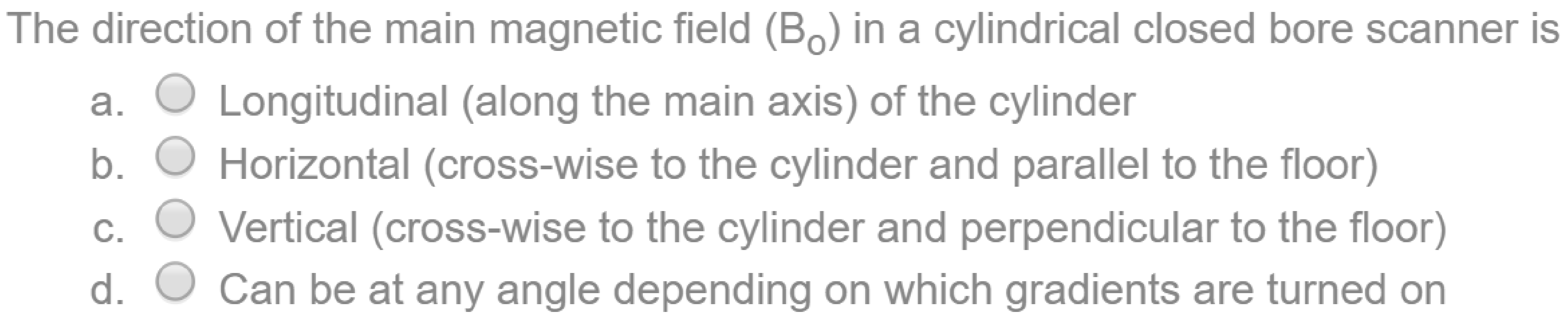
NMR signal

- Signal from ^{1}H (mostly water)
- Magnetic field ⇒ Magnetization
- Radio frequency ⇒ Excitation
- Frequency ∝ Magnetic field



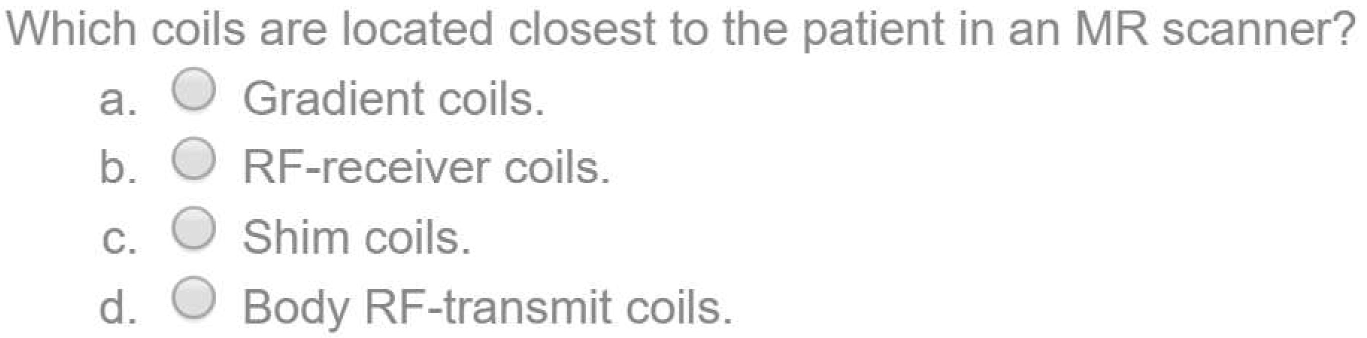


Refresh your mind



The direction of the main magnetic field (B_0) in a cylindrical closed bore scanner is

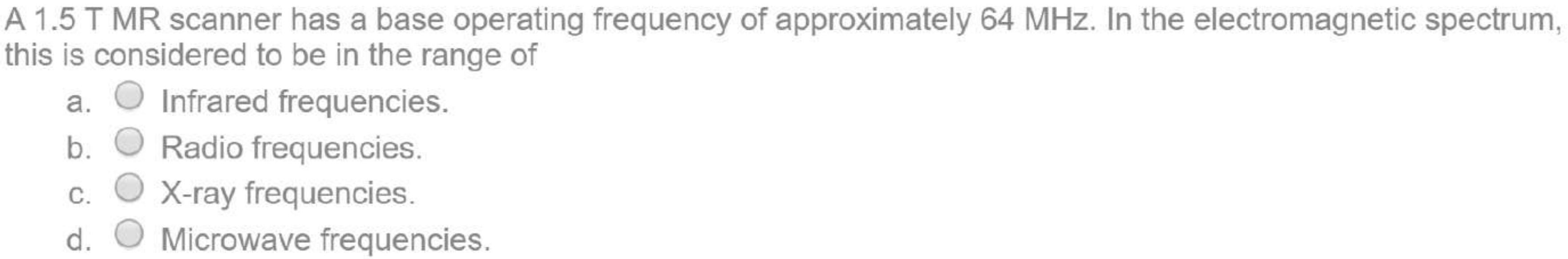
a. ○ Longitudinal (along the main axis) of the cylinder
b. ○ Horizontal (cross-wise to the cylinder and parallel to the floor)
c. ○ Vertical (cross-wise to the cylinder and perpendicular to the floor)
d. ○ Can be at any angle depending on which gradients are turned on



Which coils are located closest to the patient in an MR scanner?

a. ○ Gradient coils.
b. ○ RF-receiver coils.
c. ○ Shim coils.
d. ○ Body RF-transmit coils.

Refresh your mind



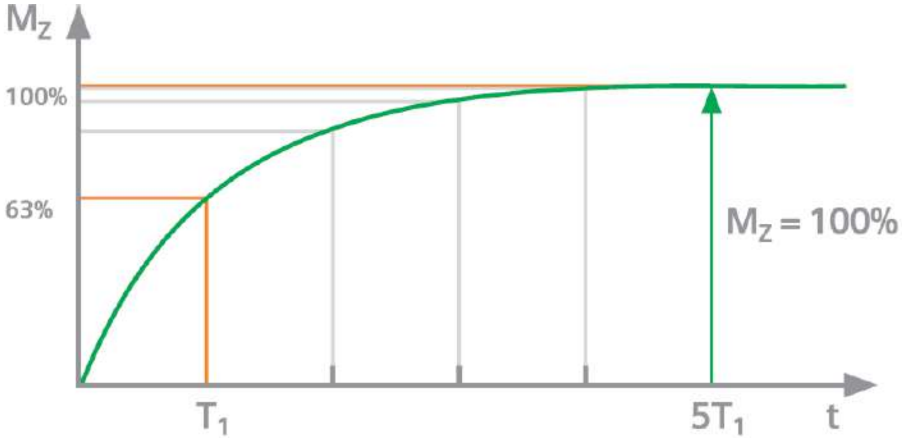
A 1.5 T MR scanner has a base operating frequency of approximately 64 MHz. In the electromagnetic spectrum, this is considered to be in the range of

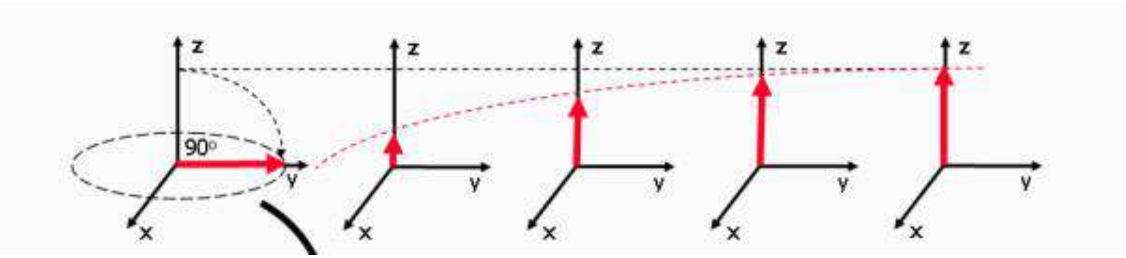
a. ○ Infrared frequencies.
b. ○ Radio frequencies.
c. ○ X-ray frequencies.
d. ○ Microwave frequencies.

Relaxations

Relaxing back to equilibrium (spin-lattice-relaxation, T1)

- After a flip, M relaxes back to equilibrium
  - $M_z(t) = M_0 \cdot \left(1 - \exp\left(-\frac{t}{T_1}\right)\right) + M_z(0) \cdot \exp\left(-\frac{t}{T_1}\right)$

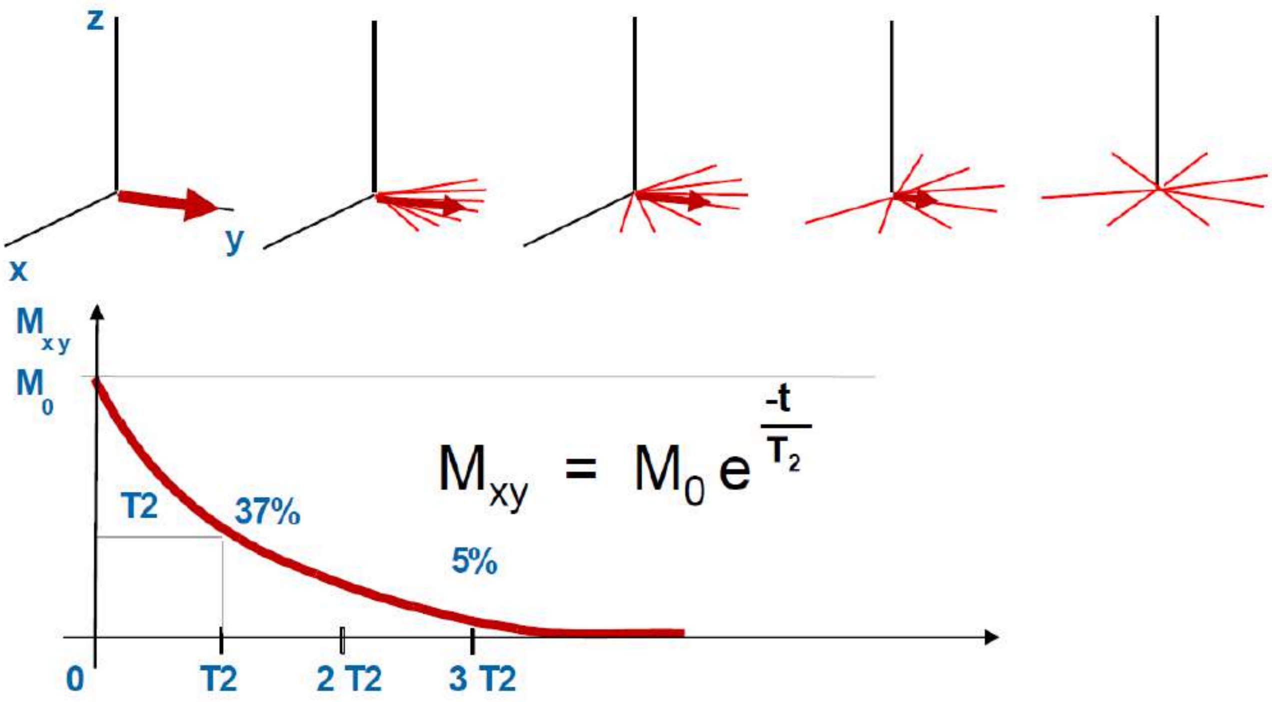




Siemens Medical: Magnets, Spins, and Resonances (2003)

More relaxation: Spin-spin relaxation (T2)

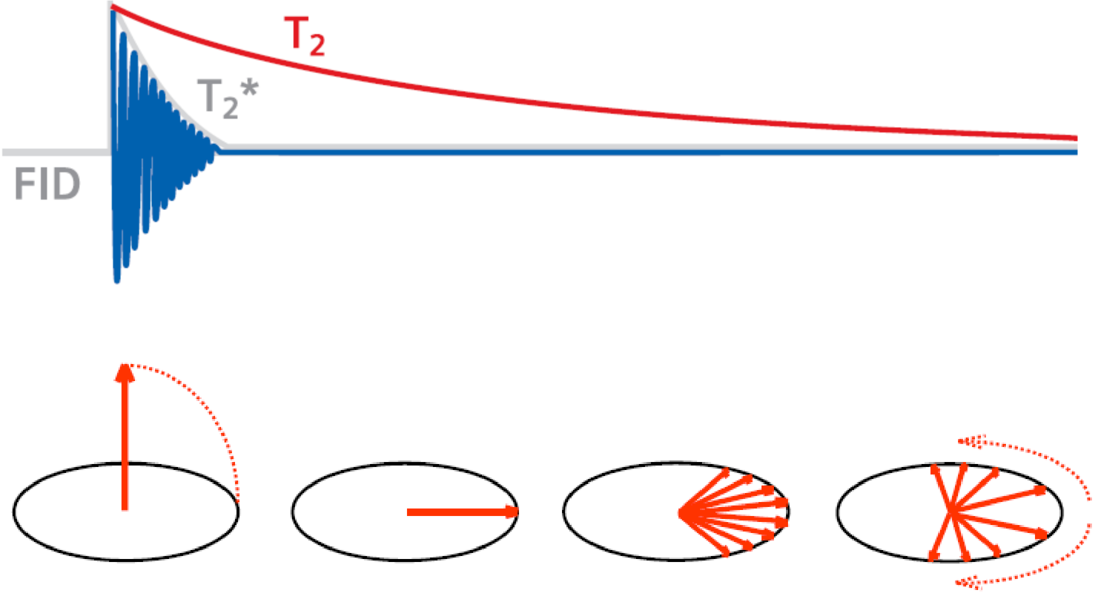
- Spins lose phase-coherence
- Effect of the material of the sample itself



$$M_{xy} = M_0 e^{\frac{-t}{T_2}}$$

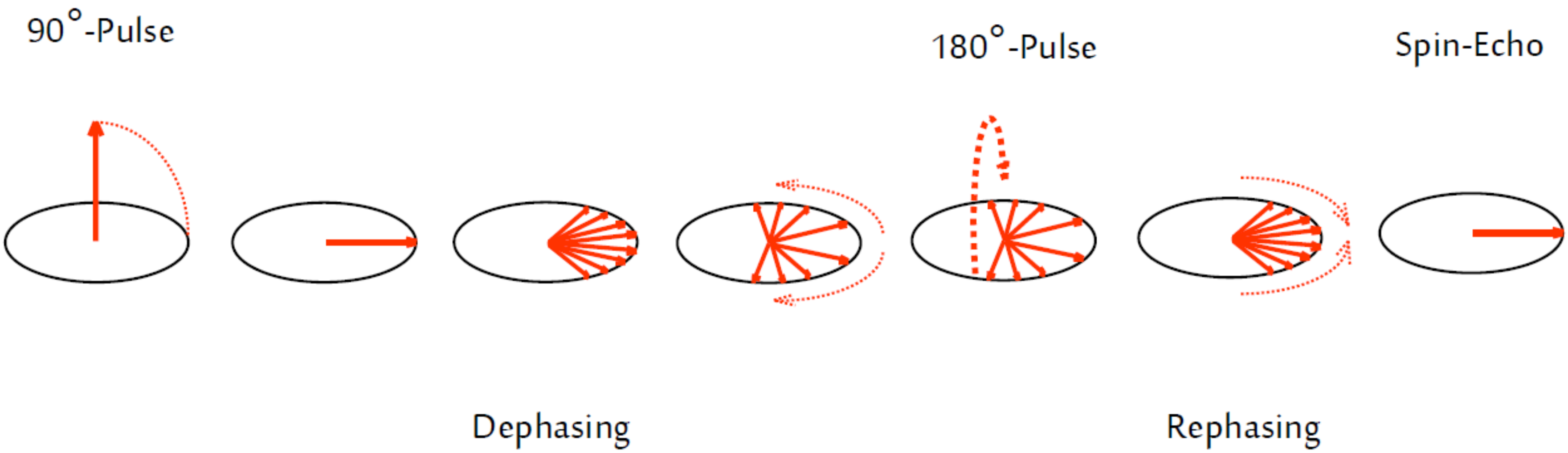
What‘s the T2* relaxation?

- Effect of B_0-inhomogeneities: $B(\vec{r}) = B_0 + \Delta B_0(\vec{r})$
  - $\omega_0(\vec{r})$ is spatially dependant
  - In a voxel: some magnetization vectors rotate faster than others
  - Additional decay of M_{xy}: $\frac{1}{T_2^*} = \frac{1}{T_2} + \gamma \cdot \Delta B_0$

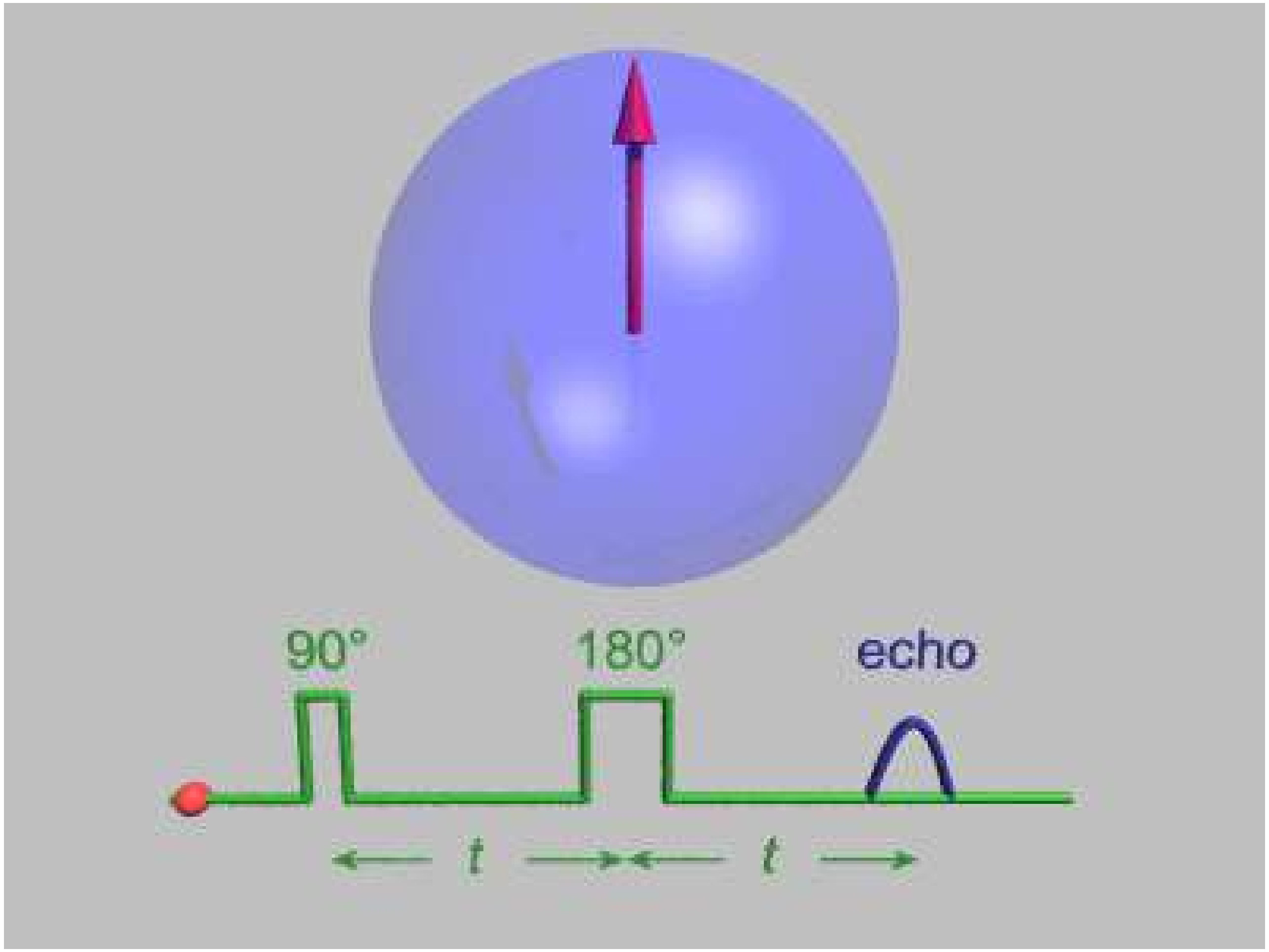


Refocusing signals

- 180° pulse can refocus M_{xy}, because B_0-inhomogeneities are time-independent



- Spin Echo used e.g. in SE, TSE, RARE (Bruker)


90°
180°
echo
t
t

Summary: most important

- In equilibrium: M is in z-direction
- RF-pulses: Flip the magnetization
- Measured signal is M_{xy}!
- There is relaxation... Two mechanisms

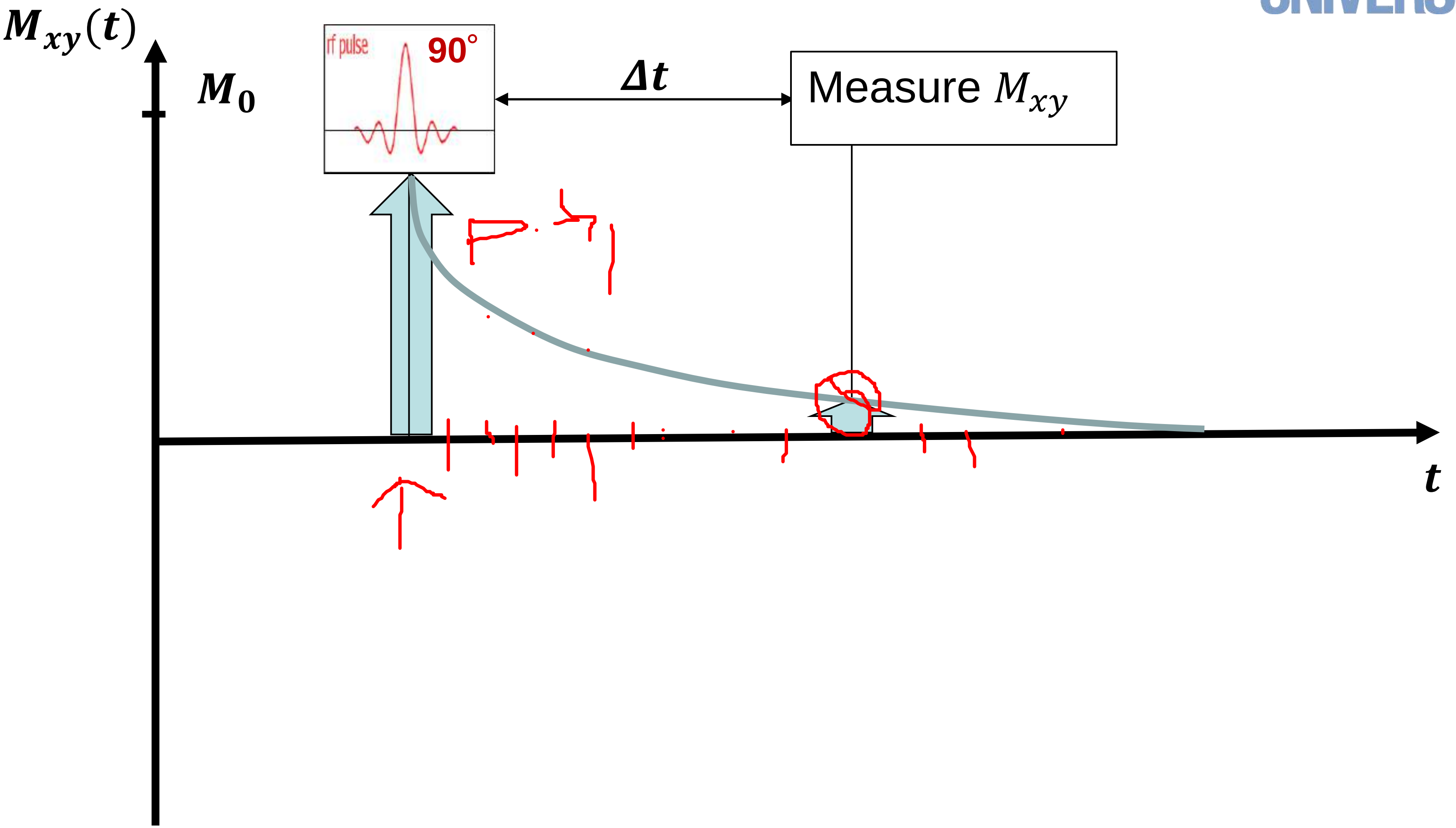
Exercise 1:
Basic sequences

Basic sequence objects

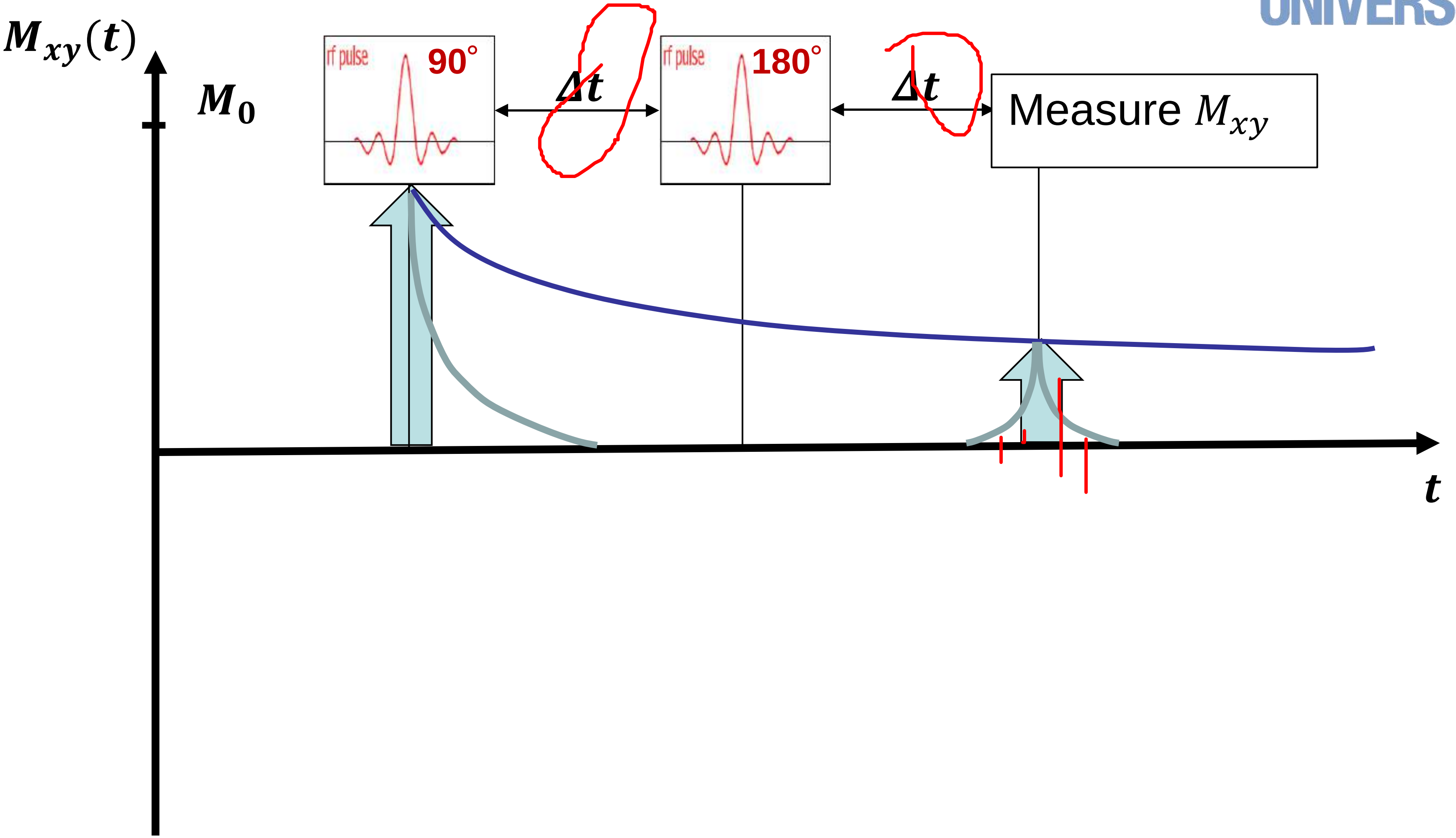
- RF pulses (90° , 180°)
- Acquisition timepoints
- Time delays

TASK: Develop 3 sequences to measure T_1, T_2, T_2* in groups, sketch signals

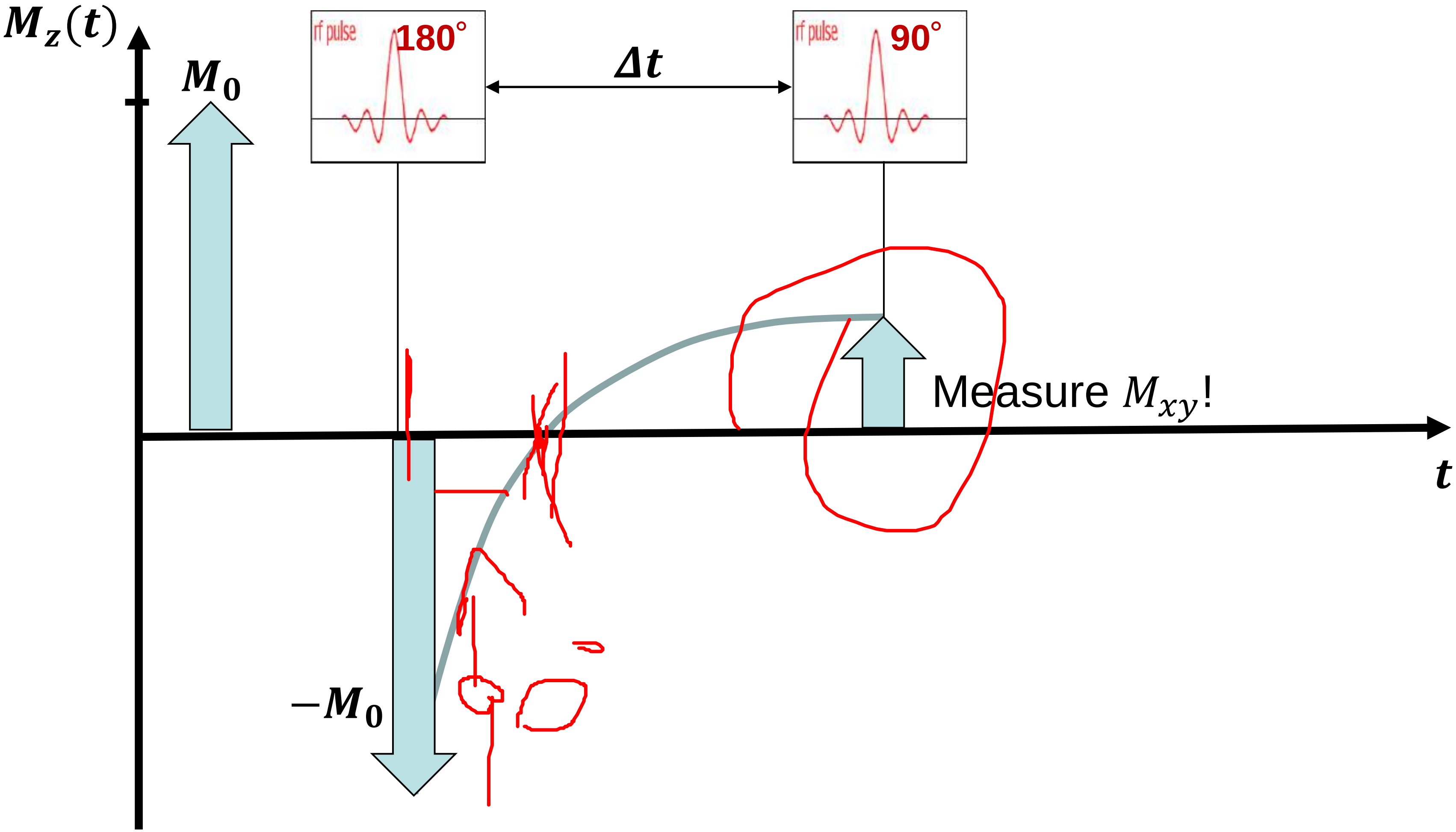
T2* sequence



T2 sequence



T1 sequence



Exercise 2:
T1, T2, T2* determination

- Formulas:

$$M_z(t) = M_0 \cdot \left(1 - 2 \cdot \exp\left(-\frac{t}{T_1}\right)\right)$$

$$M_{xy}(t) = M_0 \cdot \exp\left(-\frac{t}{T_2^*}\right)$$

$$M_{xy}(t) = M_0 \cdot \exp\left(-\frac{t}{T_2}\right)$$

- Values:

t [ms]	M(t)	ln(M)
10	266	5,58
30	210	5,35
50	165	5,11
100	91	4,51
150	50	3,91
200	28	3,33

t [ms]	M(t)	ln(M)
10	182	5,20
20	110	4,70
30	67	4,20
40	41	3,71
50	25	3,22
60	15	2,71

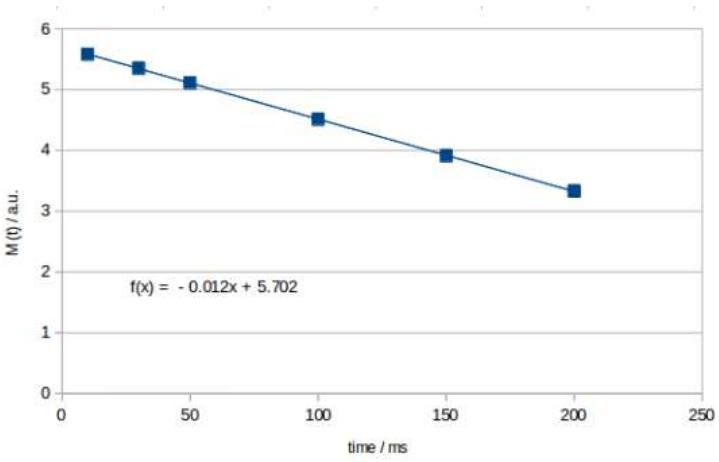
t [ms]	M(t)
10	-277
50	-195
100	-108
150	-37
200	22
250	71
300	111

Solution

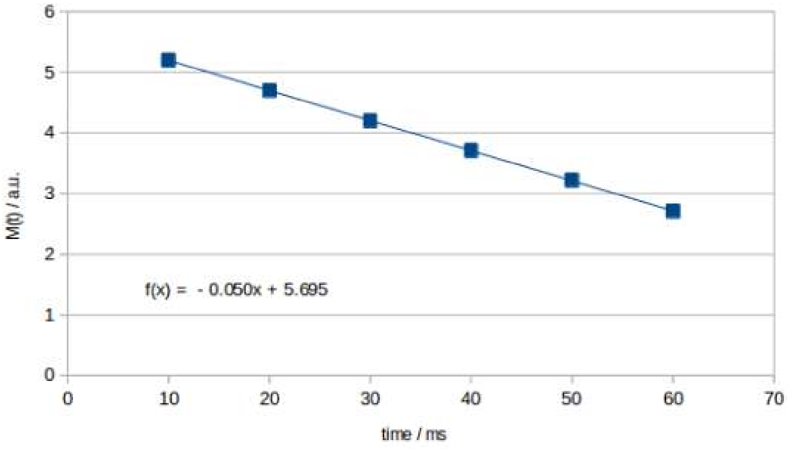
$$M_{xy}(t) = M_0 \cdot \exp\left(-\frac{t}{T_2^*}\right)$$

$$=> \ln(M_{xy}(t)) = \ln(M_0 \cdot \exp\left(-\frac{t}{T_2^*}\right))$$

$$=> \ln(M_{xy}(t)) = \ln(M_0) - \frac{t}{T_2^*}$$

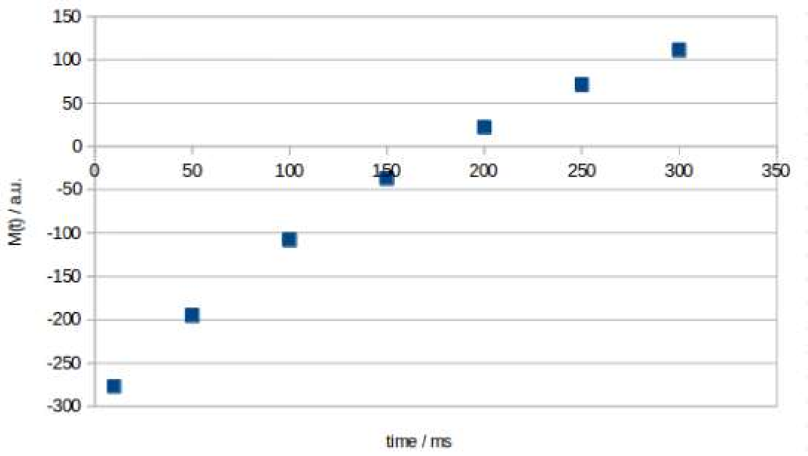


$$T_2 = \ 83\ ms$$



$$T_2^* = \ 20\ ms$$

Solution

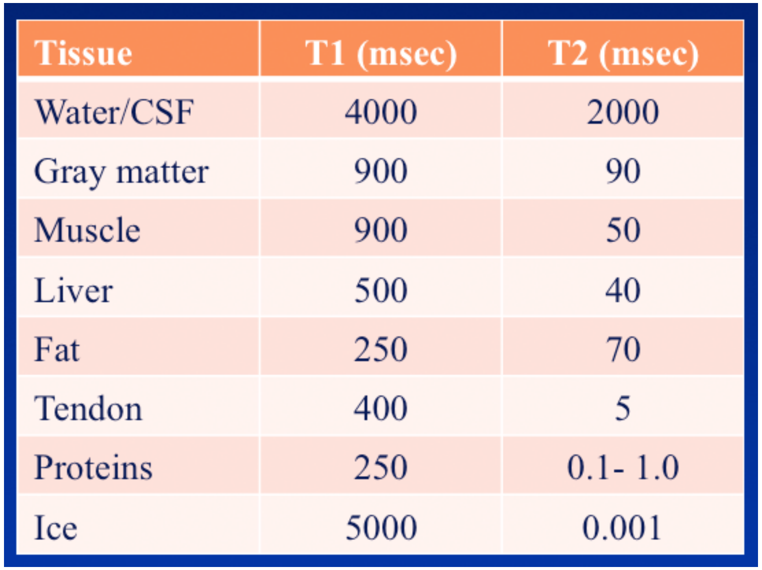


0

$$M_z(t) = M_0 \cdot \left(1 - 2 \cdot \exp\left(-\frac{t}{T_1}\right)\right)$$

$$\Rightarrow T_1 = - \frac{t}{\ln(1/2)}$$

$$T_1 = 250\ ms$$



Tissue	T1 (msec)	T2 (msec)
Water/CSF	4000	2000
Gray matter	900	90
Muscle	900	50
Liver	500	40
Fat	250	70
Tendon	400	5
Proteins	250	0.1- 1.0
Ice	5000	0.001

Vielen Dank für Ihre Aufmerksamkeit!

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MRI – Practical Course 1

Task 1:

Task 1: Basic sequence objects

You dispose of an MRI scanner and you have an unknown tissue sample. You would like to measure its different relaxation times (T1, T2, T2*) to get an idea about the material properties. This means, you need to measure the corresponding signal decay and recovery curves.

You have the following “building blocks” to compose the three MRI sequences:

- RF pulses (90° , 180°)
- Acquisition timepoints
- Time delays

1. Please start with building the T2* sequence.
2. Next one: T2 sequence. Hint: you need to get rid of the B0-inhomogeneities.
3. Please build the sequence for the quantitative T1 measurement.

Task 2:

A T1, T2 and T2* decay were measured. Below you find the corresponding formulas and signal intensities.

(1) Determine which table of values belongs to which formula.
(2) Determine T1, T2 and T2* of the measured material.
(3) Which kind of tissue/material may have been investigated?
(4) Why is T2* always shorter than T2?

- Formulas:

$$M_z(t) = M_0 \cdot \left(1 - 2 \cdot \exp\left(-\frac{t}{T_1}\right)\right)$$

$$M_{xy}(t) = M_0 \cdot \exp\left(-\frac{t}{T_2^*}\right)$$

$$M_{xy}(t) = M_0 \cdot \exp\left(-\frac{t}{T_2}\right)$$

- Values:

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Questions?

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