22485 Medical imaging systems

Magnetic Resonance Imaging I

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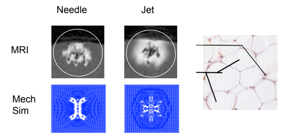
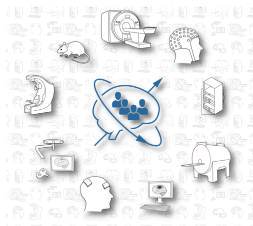
Module E2, Monday kl. 13.00 - 14.30 **in building 349, room 205**
and Thursday kl. 9.00 - 11.00, in building 349, room 205

My second home

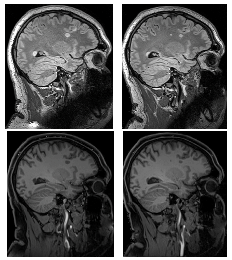
DANISH RESEARCH CENTRE FOR MAGNETIC RESONANCE



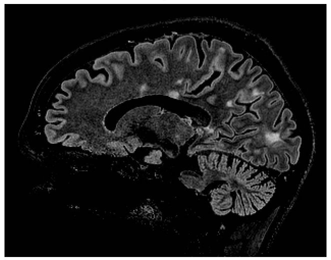
My first MRI project, DTU MSc Thesis 2007
Imaging injections in 'flæskesteg' (pork) samples



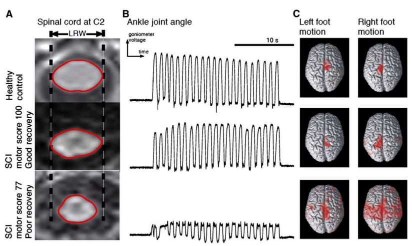
Multiple contrasts over time In Multiple Sclerosis

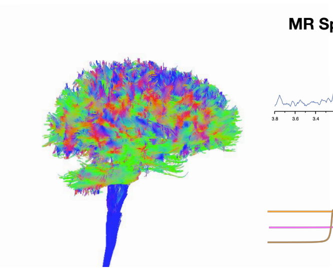


High resolution ultra high field 7T MRI in Multiple Sclerosis

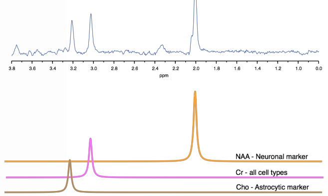


Structural spinal cord MRI combined with functional MRI during foot motion

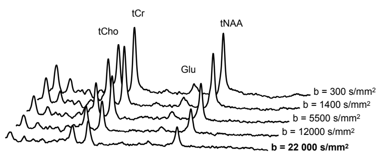




MR Spectroscopy detection of metabolites



Metabolite diffusion



All data, Lundell/DRCMR

Quiz-time!

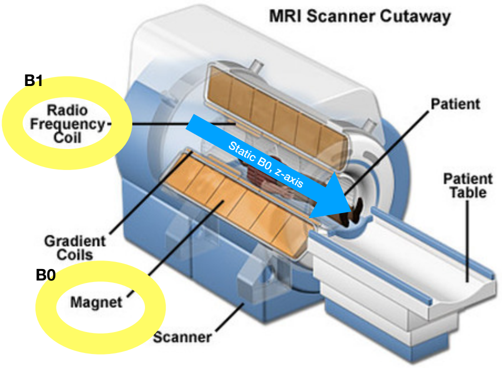
https://forms.office.com/e/XHLkdF5ktZ

The MRI system

Clinical 3T MRI system at DTU

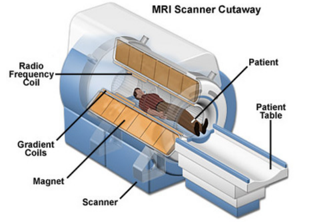
Ultra High Field Human 7T MRI at DRCMR Hvidovre Hospital

Ultra High Field Animal 7T MRI at DRCMR Hvidovre Hospital



Coyne, 2012

Overall MRI topics



Coyne, 2012

- **The basic hardware components of an MRI system**
- **Nuclear spins and precession**
- **RF-pulses (B1-field), magnetic resonance and relaxation**
- Signal preparation, sequences and contrast mechanisms
- Magnetic field gradients, slice selection and phase and frequency encoding
- The k-space and image reconstruction
- Image reconstruction (exercise)
- Advanced and emerging MRI methods and applications
- MRI safety

Safety around the MRI scanner!

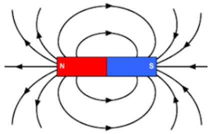
https://www.drcmr.dk/news-events/news/item/317-no-harm-done-but-close

MRI Teaching material

- Lecture notes by Lars G. Hanson (47 pages) available in English and Danish. (Link in course plan). Today: sections 1-11
- Chapter 12 and 13 in Prince and Links. Today: Ch 12
- Today we will use the CompassMR spin simulator https://www.drcmr.dk/CompassMR/ and later other simulators from the same resource
- Matlab exercise on November 27

Today’s Intended Learning Objectives

- Identify main hardware components of an MRI scanner and their role.
- Describe the basic properties of nuclear spins in a magnetic field (B0-field).
- Describe the interaction between a radio waves (RF, B1-field) and a magnetic moment.
- Distinguish between longitudinal and transverse relaxation processes and how it relates to the MR-signal.



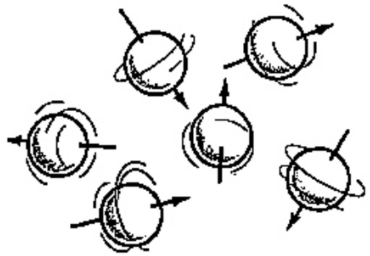
Nuclear spin

- Protons and neutrons have a property called spin providing a magnetic moment (like a compass needle) and is the key property used in MRI and NMR
- Even number of protons or neutrons in the nucleus pair up and annihilate the net magnetisation
- Nuclei with unpaired (uneven number) of protons and/or neutrons such as 1H, 13C, 19F and 31P
- The hydrogen (1H) nucleus (***often called proton***) provides the strongest naturally abundant MR signal in the human body and is highly abundant in all biological materials.

Exercise 1

- Go to https://www.drcmr.dk/CompassMR/ on laptop or phone
- Try the push button and describe what is happening.
- Try a low and a high magnetic field strength (B0-slider) and describe your observation.
- Activate the “coil” and set B0 to max.
- Describe the phenomena when adjusting the frequency and amplitude of the oscillating external field (B1).

Magnetic moment
+
Angular momentum (rotating mass)



Exercise 2

- Go to https://www.drcmr.dk/CompassMR/ on laptop or phone
- Enable "coil" and "spin" and give it a push. What is happening? Can you describe the motion?
- How could this be detected from the outside and how would it appear?

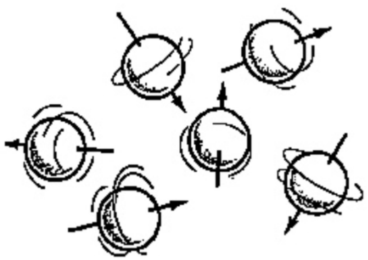
Signal from a precessing spin

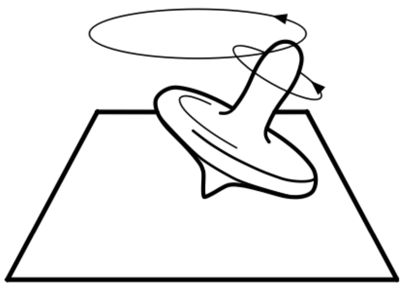
Precession

The Larmor equation

$$f = \gamma \cdot B_0$$

$$\gamma = 42 \text{ Hz/T}$$ **For protons**

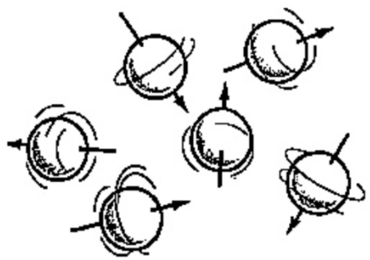




Precession

The Larmor equation

$$f = \gamma \cdot B_0$$



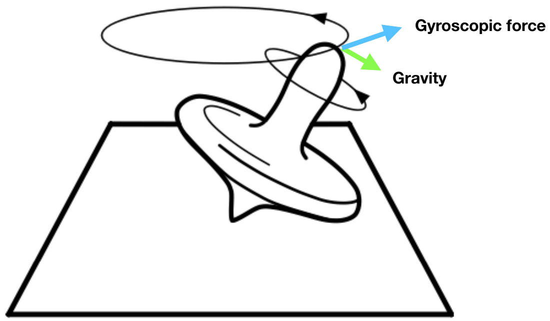
Gyromagnetic ratios for different nuclei

Nucleus	γ_n (10^6 rad·s^{-1}·T^{-1})	$\gamma_n/(2\pi)$ (MHz·T^{-1})
^1H	267.522 187 44(11)[15]	42.577 478 518(18)[16]
^1H (in H_2O)	267.515 3151(29)[17]	42.576 384 74(46)[18]
^2H	41.065	6.536
^3H	285.3508	45.415[19]
^3He	–203.789 4569(24)[20]	–32.434 099 42(38)[21]
^7Li	103.962	16.546
^{13}C	67.2828	10.7084
^{14}N	19.331	3.077
^{15}N	–27.116	–4.316
^{17}O	–36.264	–5.772
^{19}F	251.815	40.078
^{23}Na	70.761	11.262
^{27}Al	69.763	11.103
^{29}Si	–53.190	–8.465
^{31}P	108.291	17.235
^{57}Fe	8.681	1.382
^{63}Cu	71.118	11.319
^{67}Zn	16.767	2.669
^{129}Xe	–73.997	–11.777

Exercise 3

- Go to https://www.drcmr.dk/CompassMR/ on laptop or phone
- Enable “coil” and “spin”. (Tip: If you need to bring it back to rest at equilibrium unclick and click “spin” again.)
- Try to find a resonance, is something different?
- Can you see when and how the flip angle changes in relation to the oscillating B0 field?

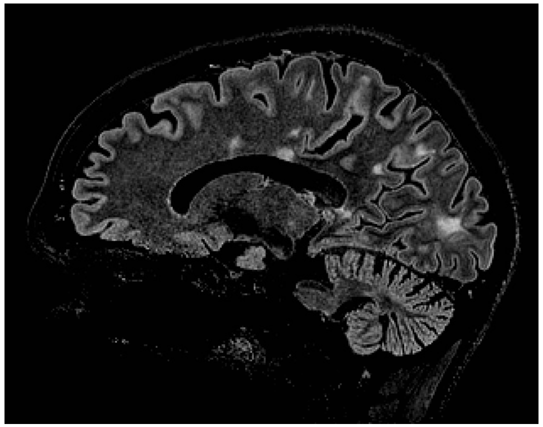
Gyroscopic forces



Exercise 4

- Go to https://www.drcmr.dk/CompassMR/ on laptop or phone.
- Enable “coil” and “spin”.
- Find a setting that turns the magnetisation exactly 180 deg (red end downwards) and leave it there!
- How could this view be realised in an MRI scanner?
- Rotating frame and a circularly polarised B1 field

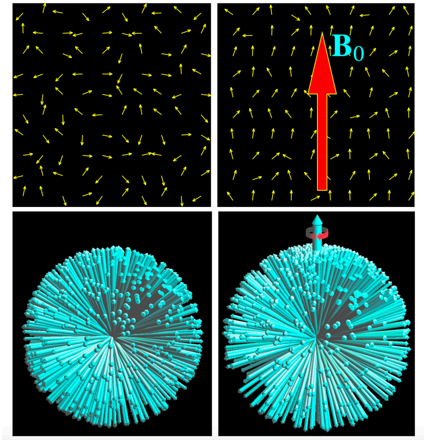
From one to many spins



The image intensity depend on the proton density and how relaxation effects are reflected in the image method (the sequence)

Polarisation of spins

- The polarisation of spins in a static magnetic field compete with thermal fluctuations (eq. 12.4 in Prince).
- At typical clinical field strengths the net ***polarisation correspond to the alignment of a few ppm*** of spins.
- The net polarisations interaction with the B1-field can in many ways be understood as the single spin in the MRCompass simulator.
- The collection of spins, however, interact and lead to additional ***relaxation*** effects.

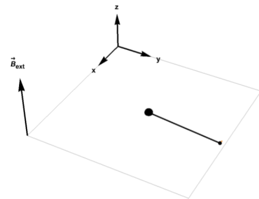


Longitudinal relaxation (T1)

- A precessing spin/magnetic moment M0 will interact with its surroundings and relax back to equilibrium with the time constant T1 (or rate R1=1/T1). For a 90 deg flip angle the magnetisation will grow back like:

$$M_z = M_0(1 - e^{-t/T1})$$

In e.g. brain tissue this process takes ~ 1 s and is called longitudinal relaxation.

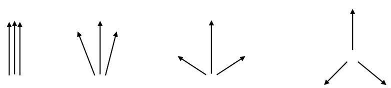


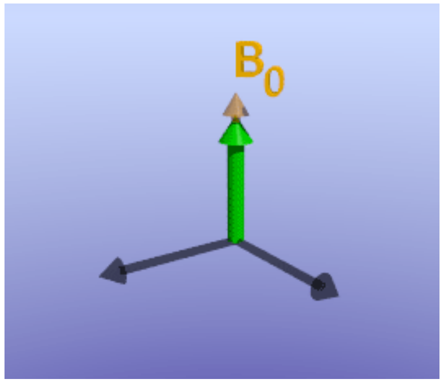
Relaxation (T2 (and T2*))

- The measured signal is the amplitude of the rotating projection in the xy-plane - the transverse plane perpendicular to the B0 field along the z-axis - and this amplitude decay with the constant T2* ("T2-star" or rate R2*=1/T2*).

$$M_{xy} = M_0 e^{-t/T2\star}$$

- T2* is shorter than T1 since collections of spins dephase over time.
- T2* include both irreversible dephasing from spin-spin interactions (called T2) and dephasing from field inhomogeneities at different locations (T2'). The latter can be restored with the "spin-echo" effect (next time). T2 and T2* are usually shorter than 100 ms.





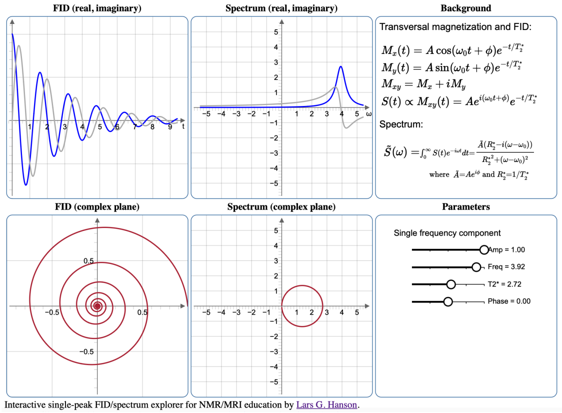
http://xrayphysics.com/sequences.html

The Bloch Equations

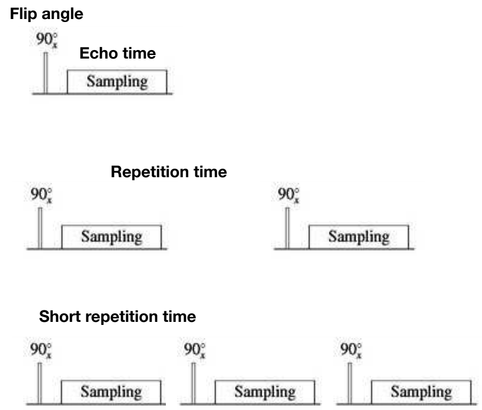
$$\frac{d\mathbf{M}}{dt} = \gamma \mathbf{M} \times \mathbf{B_0} - \mathbf{R}(\mathbf{M} - \mathbf{M_0})$$

Rate of change **Precession** **Relaxation**

Free induction decay



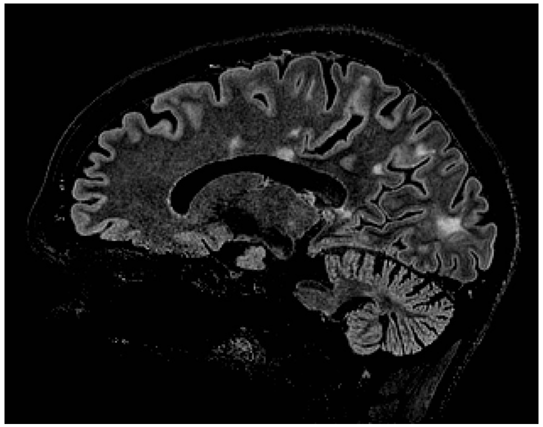
A simple sequence



The echo time determines T2* weighting

The repetition time determines T1 weighting

From signal to image



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Recommended reading for next time

- Today we covered contents in Lars G. Hansons lecture notes section 1-7 and Prince & Links Ch. 12.
- Next time we will recap and expand some of today's concepts and start discussing how different types of contrasts and images are formed (section 11 in the notes and Ch. 13.1-2).