Introduction to Magnetic Resonance Imaging

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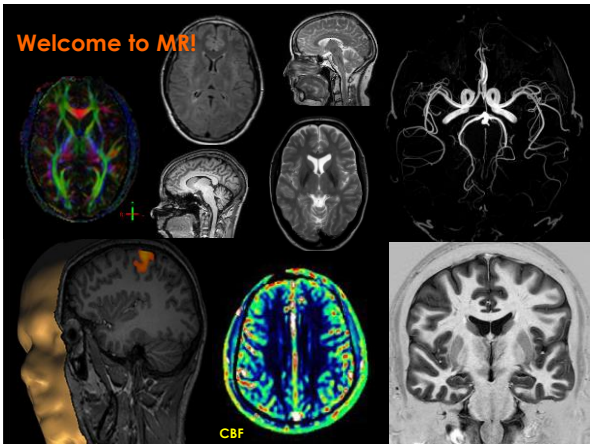
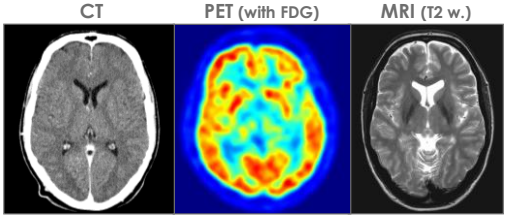
Basic Kinetic Modeling in Molecular Imaging



Common medical imaging modalities

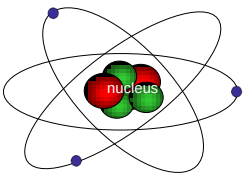
	CT	PET (with FDG)	MRI (T2 w.)
Images			
Physics	Attenuation of x-rays	Positron emission from radioactive tracer	Magnetic resonance with radio waves

Introduction to Magnetic Resonance Imaging

MR Physics:
- Nuclear spins
- Magnetic resonance
- Precession
- Radio waves
- Signal detection
- Spatial encoding
- Relaxation times

MR Image types:
- T2 weighted
- T1 weighted
- Sequence parameters
- FLAIR

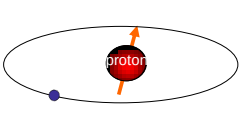
Atoms, nuclei, spin



The **spin** of a nucleus depends on the number of neutrons and protons.

Nuclear spin and magnetism

Nuclei with **spin** ≠ 0 have magnetic properties.



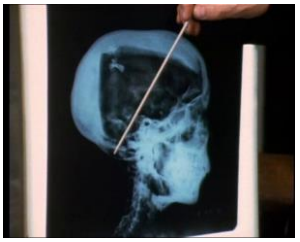
A proton has spin = ½.

Nuclei with spin

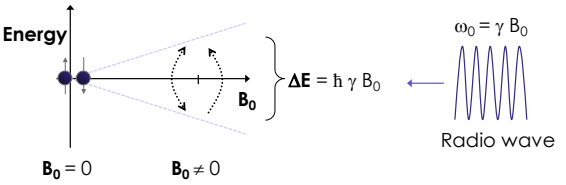
atom	abundance
^{1}H	63 %
^{13}C	0.10 %
^{23}Na	0.041 %
^{31}P	0.24 %

Nuclei with spin ≠ 0 in biological tissue.

MRI of Tut-ankh-amon?



Magnetic resonance, quantum physics



Nobel prize Rabi (1944) and Bloch/Purcell (1952)

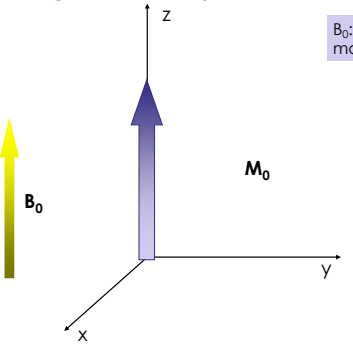
MR scanner, static magnetic field

Magnetic field = 3 T

Magnet fields are measured in Tesla (T).

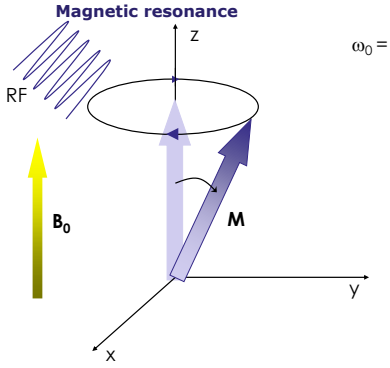
Commonly used static magnetic fields on clinical scanners: 0.2 T, 0.5 T, 1.0 T, 1.5 T, 3.0 T

Magnetization in equilibrium



B_0: static magnetic field

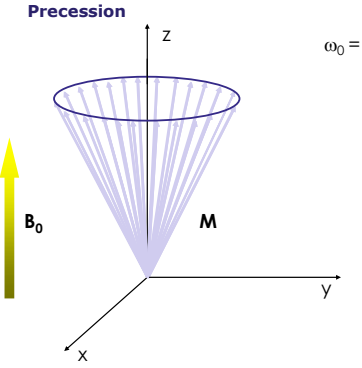
Magnetic resonance



$\omega_0 = \gamma B_0$

B_0 (T)	ω_0 (MHz)
0.2	9
0.5	21
1.0	43
1.5	64
3.0	128

Precession



$\omega_0 = \gamma B_0$

B_0 (T)	ω_0 (MHz)
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1.5	64
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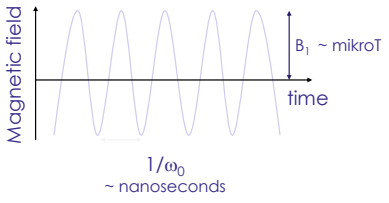
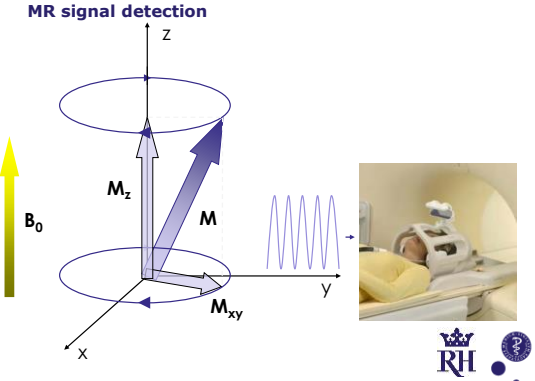
Radio waves



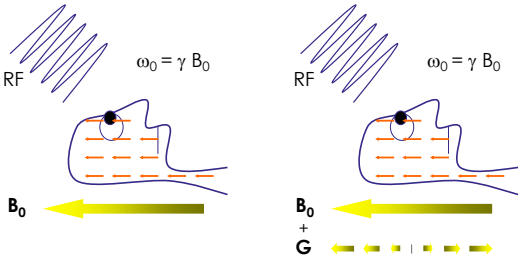
RF: a radiowave is a time dependent electric and magnetic field

MR signal detection

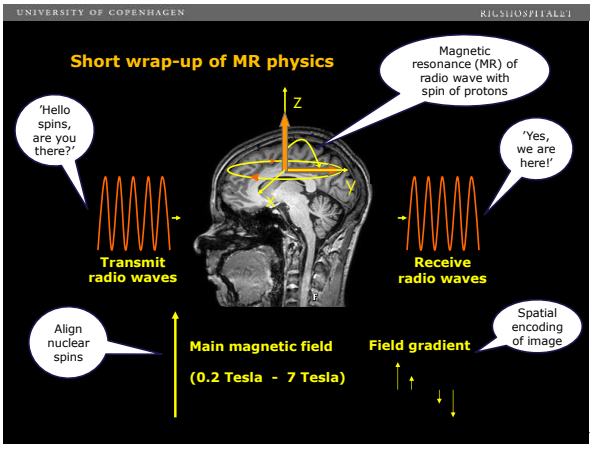


Slice selection with magnetic field gradient

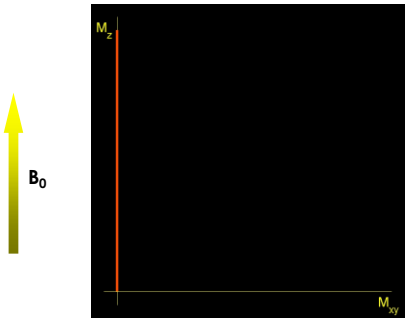
- Spatial encoding of MR images uses magnetic field gradients.
- Gradients can be used for slice selection, frequency- and phase-encoding.



Short wrap-up of MR physics



Relaxation af M



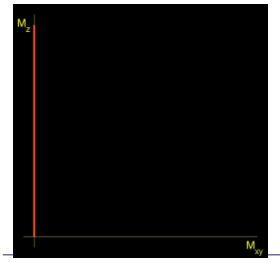
Gray matter

Times T1 and T2

T1: decay time for M_z

T2 : decay time for M_{xy}

Gray matter: T1 = 950 ms, T2 = 100 ms (1.5 T)



$M_{xy} = M_0 \cdot \exp(-t/T2)$

$M_z = M_0 \cdot (1-\exp(-t/T1))$

Times T1 and T2

T1 and T2 depend on the microstructure of tissue:

- T1≥T2 for basic physics reasons
- In fluids will T1 and T2 depend on viscosity (T1 is smaller for less viscous fluids).
- T1 and T2 depend on the amount of water in tissue.
- T1 and/or T2 are affected by iron, deoxy-hemoglobin, MR contrast agent, …
- T1 are T2 are reduced in fat and WM (myelin).
- T1 and T2 depend on the magnetic field (T2 more than T1).

- Gives T1 and T2 image contrast!

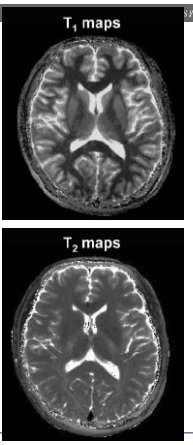
T1 and T2, measured

	T_1 (ms)	T_2 (ms)
CSF	4500	2200
blood	1200	100-200
GM	950	100
WM	600	80
fat	250	60
muscle	900	50

Haacke et al. (1.5 T)

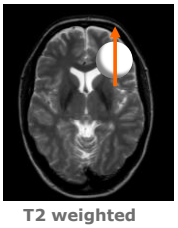
Synovial fluid	2900	1200
Cartilage	1100	40

Gold et al. (1.5 T, knee)



Lu et al. (3 T)

MR signal loss



T2 weighted image

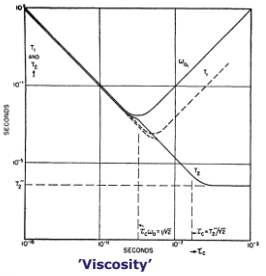
Slow signal loss:
Mobile nuclei, in particular fluids

Fast signal loss:
Tissue with large immobile molecules, solids

Time scale:
~ 0.1 – 2 seconds

Theory of MR in fluids

T1, T2



'Viscosity'

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Relaxation Effects in Nuclear Magnetic Resonance Absorption*

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Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts
(Received December 29, 1947)

Introduction to Magnetic Resonance Imaging

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- Radio waves
- Signal detection
- Spatial encoding
- Relaxation times

MR Image types:
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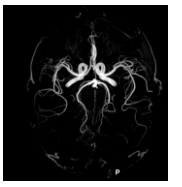
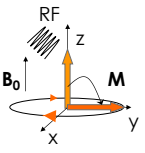
- T1 weighted
- Sequence parameters
- FLAIR

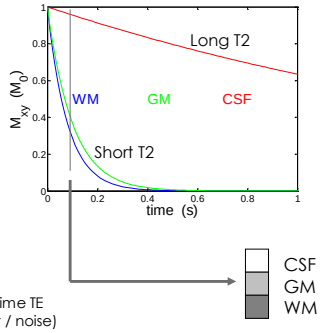
Sources of MR image contrast

- Water content of tissue
- T1 and T2 of tissue
- Diffusion (Brownian motion of water)
- Flow (blood, CSF)
- Contrast agents (Gd)
- Paramagnetic compunds (…)
- …



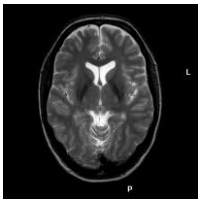
T2 weighting



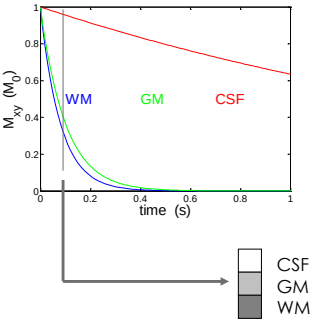


M_{xy} read out after echo time TE
(maximization of contrast / noise)

T2 weighting



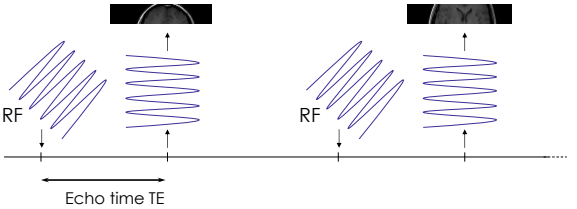
T2 weighted, fat suppr.
TR = 3000 ms, TE = 100 ms



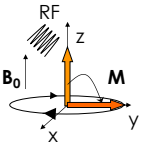
M_{xy} read out after echo time TE

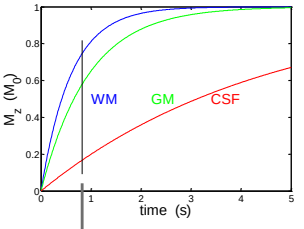
TR and TE

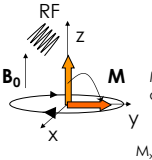
In standard MR sequences, one line of the image is read out after a RF excitation



T1 weighting



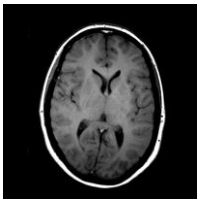




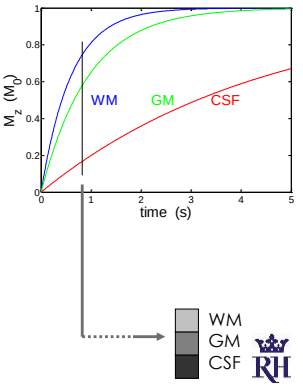
M is flipped again after a repetition time TR

M_{xy} read out after echo time TE

T1 weighting

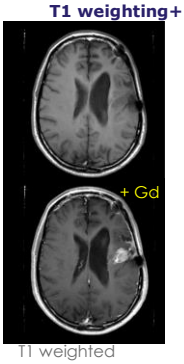


T1 weighted
TR = 500 ms, TE = 10 ms



WM
GM
CSF

T1 weighting+ Gd



T1 weighted
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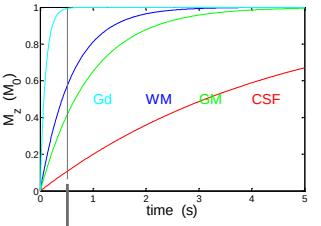
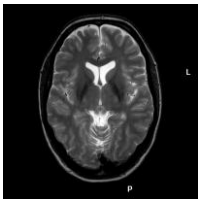


Gd uptake
WM
GM
CSF

Sequence parameters



T2 weighted, fat suppr.
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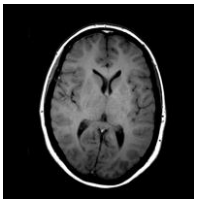
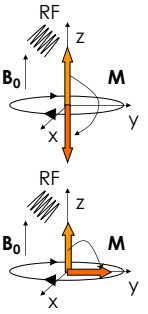
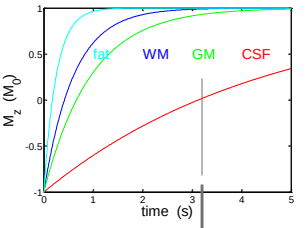


T1 weighted
TR = 500 ms, TE = 10 ms

TE \ TR	short	long
short	T1 w	proton density
long	-	T2 w

IR - FLAIR

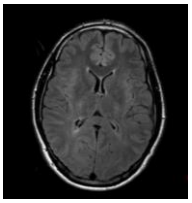




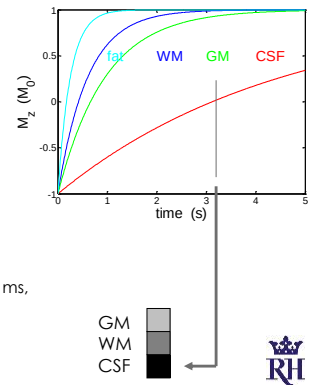
M is flipped again after a Inversion time TI

CSF is 'nulled'

IR - FLAIR



FLAIR, T2 weigthed
TR = 11000 ms, TE = 125 ms,
TI = 2800 ms



GM
WM
CSF

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