Introduction to Magnetic Resonance Imaging

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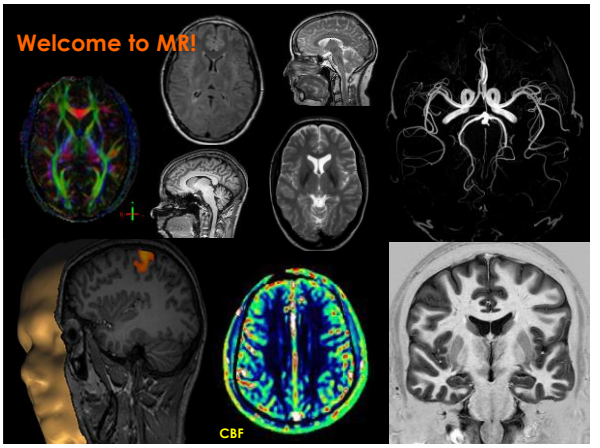
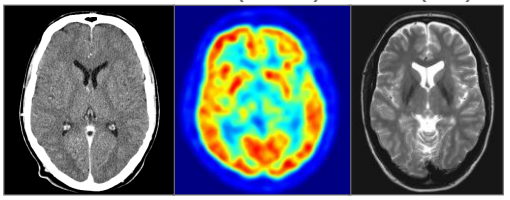
Rigshospitalet

Basic Kinetic Modeling in Molecular Imaging



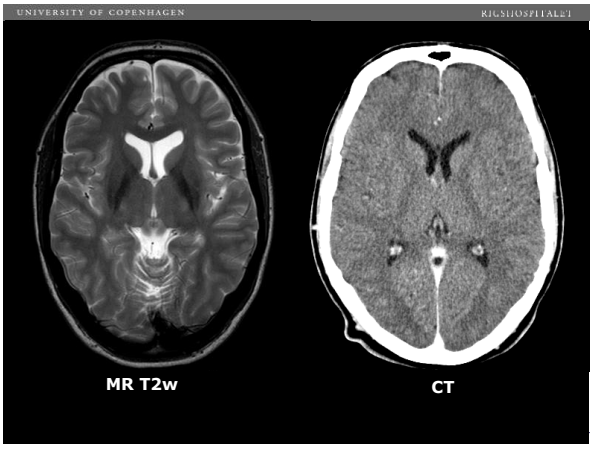
Common medical imaging modalities

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

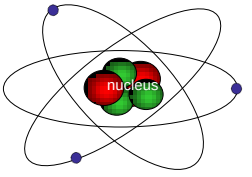
Introduction to Magnetic Resonance Imaging

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

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



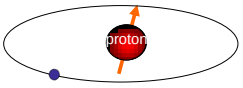
Atoms, nuclei, spin



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

Nuclear spin and magnetism

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



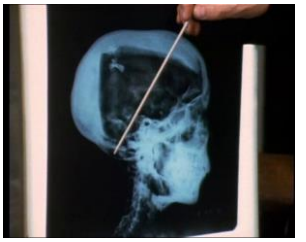
A proton has spin = ½.

Nuclei with spin

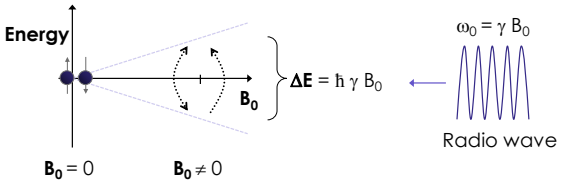
atom	abundance
^{1}H	63 %
^{13}C	0.10 %
^{23}Na	0.041 %
^{31}P	0.24 %

Nuclei with spin ≠ 0 in biological tissue.

MRI of Tut-ankh-amon?



Magnetic resonance, quantum physics



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

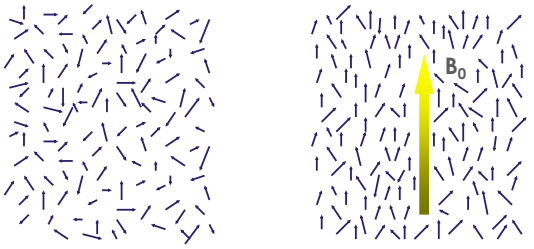
MR scanner, static magnetic field

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

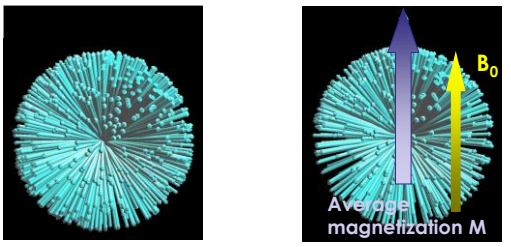
Effect of magnetic field on nuclear spins



Nuclear spins **outside** field

Nuclear spins **in** field

Effect of magnetic field on magnetization

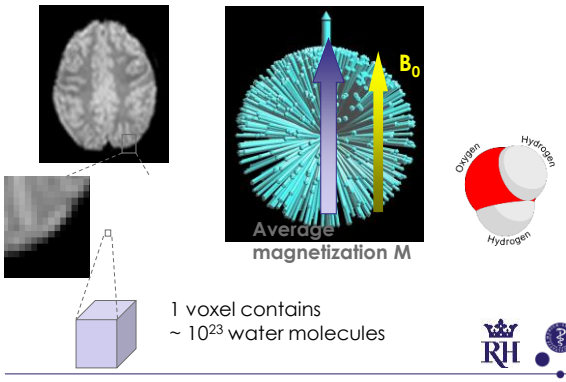


Nuclear spins **outside** field

Nuclear spins **in** field

From Lars G. Hanson, Concepts in Magnetic Resonance Part A, 32A (5), 2008

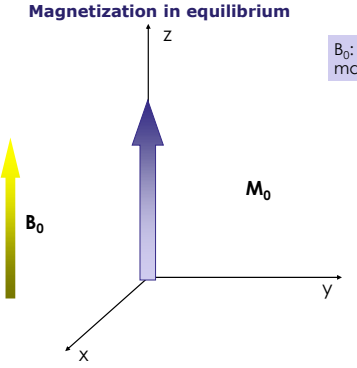
Magnetization of water in biological tissue



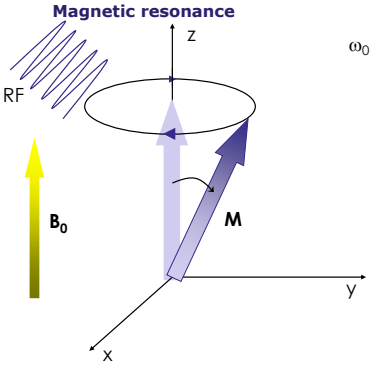
1 voxel contains
~ 10^{23} water molecules

Magnetization in equilibrium

B_0: static magnetic field



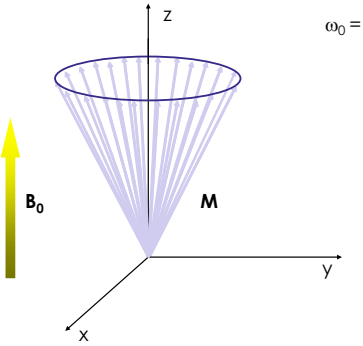
Magnetic resonance



$\omega_0 = \gamma B_0$

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

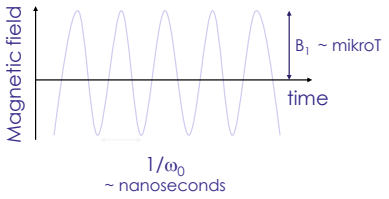
Precession



$\omega_0 = \gamma B_0$

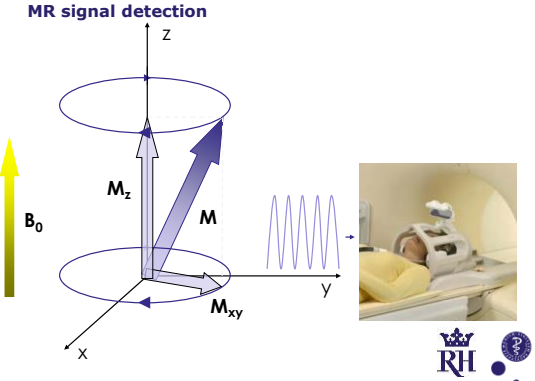
B_0 (T)	ω_0 (MHz)
0.2	9
0.5	21
1.0	43
1.5	64
3.0	128

Radio waves



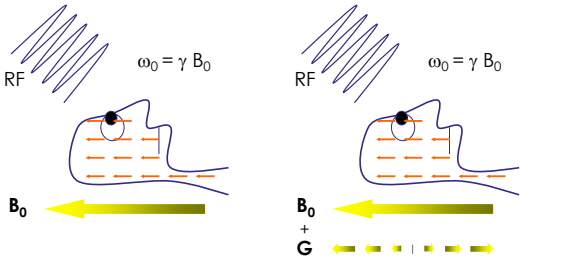
RF: a radiowave is a time dependent electric and magnetic field

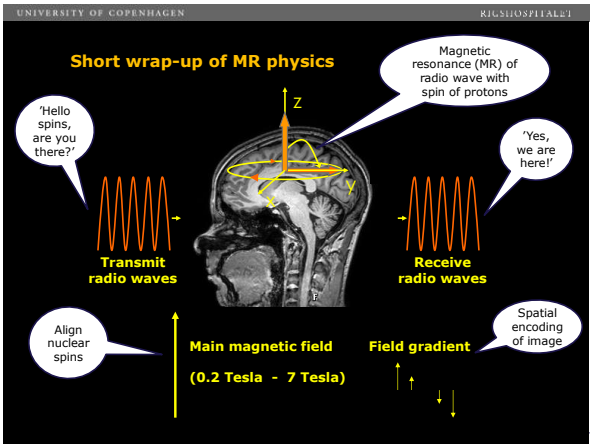
MR signal detection



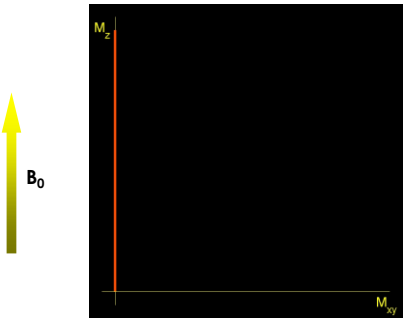
Slice selection with magnetic field gradient

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





Relaxation af M



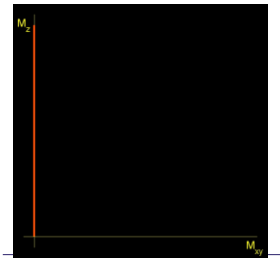
Gray matter

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!

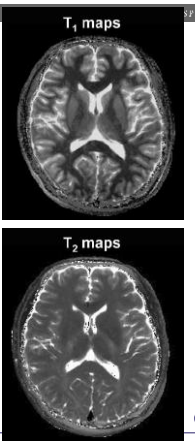
T1 and T2, measured

	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)

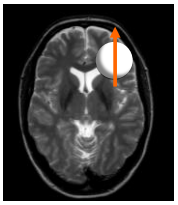
Synovial fluid	2900	1200
Cartilage	1100	40

Gold et al. (1.5 T, knee)



Lu et al. (3 T)

MR signal loss



T2 weighted image

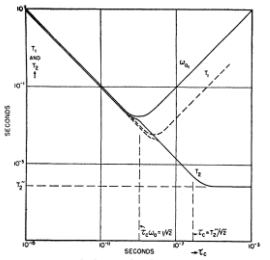
Slow signal loss:
Mobile nuclei, in particular fluids

Fast signal loss:
Tissue with large immobile molecules, solids

Time scale:
~ 0.1 – 2 seconds

Theory of MR in fluids

T1, T2



'Viscosity'

PHYSICAL REVIEW VOLUME 73, NUMBER 7 APRIL 1, 1948

Relaxation Effects in Nuclear Magnetic Resonance Absorption*

N. Bloembergen,** E. M. Purcell, and R. V. Pound,***
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts
(Received December 20, 1947)

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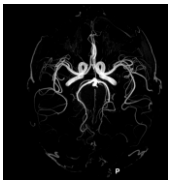
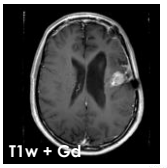
- T1 weighted
- Sequence parameters
- FLAIR
- Diffusion

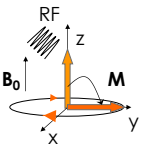
Sources of MR image contrast

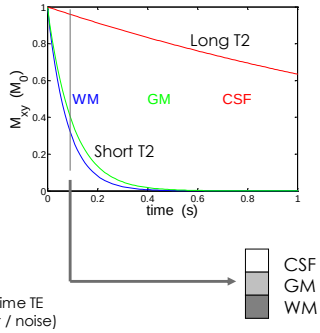
- Water content of tissue
- T1 and T2 of tissue
- Diffusion (Brownian motion of water)
- Flow (blood, CSF)
- Contrast agents (Gd)
- Paramagnetic compunds (…)
- …





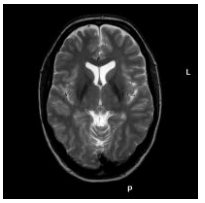
T2 weighting



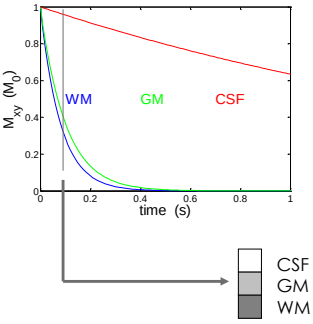


M_{xy} read out after echo time TE
(maximization of contrast / noise)

T2 weighting



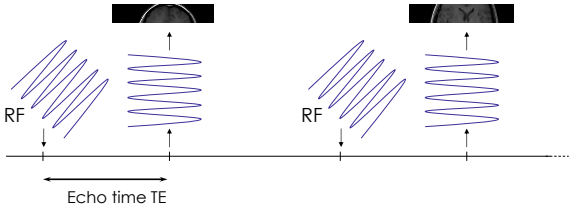
T2 weighted, fat suppr.
TR = 3000 ms, TE = 100 ms



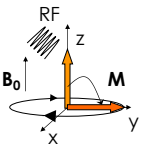
M_{xy} read out after echo time TE

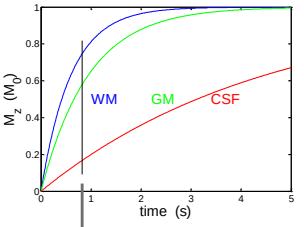
TR and TE

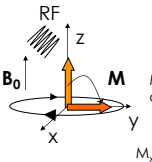
In standard MR sequences, one line of the image is read out after a RF excitation



T1 weighting



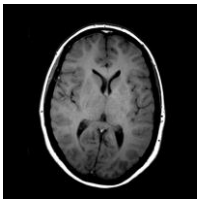




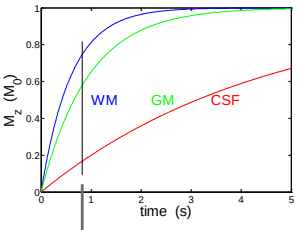
M is flipped again after a repetition time TR

M_{xy} read out after echo time TE

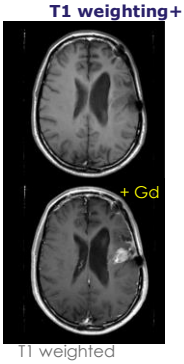
T1 weighting



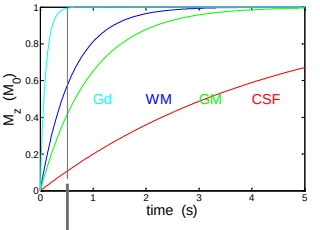
T1 weighted
TR = 500 ms, TE = 10 ms

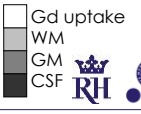


T1 weighting+ Gd

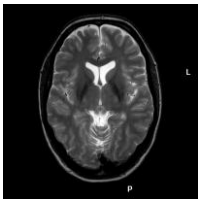


T1 weighted
TR = 500 ms, TE = 10 ms

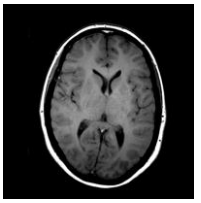




Sequence parameters



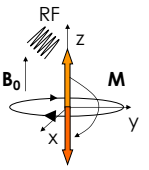
T2 weighted, fat suppr.
TR = 3000 ms, TE = 100 ms

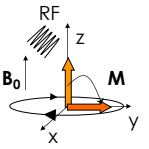


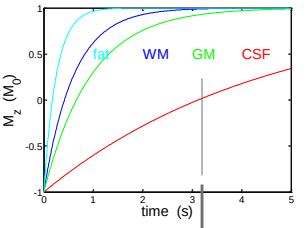
T1 weighted
TR = 500 ms, TE = 10 ms

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

IR - FLAIR



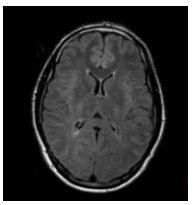




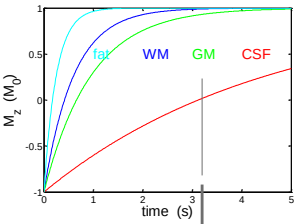
M is flipped again after a Inversion time TI

CSF is 'nulled'

IR - FLAIR

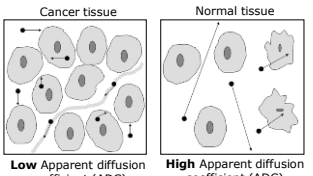


FLAIR, T2 weigthed
TR = 11000 ms, TE = 125 ms,
TI = 2800 ms



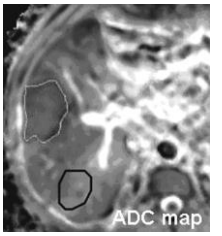
GM
WM
CSF

MR Diffusion Weighted Imaging



Low Apparent diffusion coefficient (ADC)

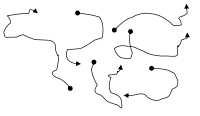
High Apparent diffusion coefficient (ADC)



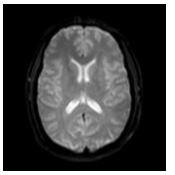
Koh, Collins, AJR (2007)

Diffusion weighted imaging

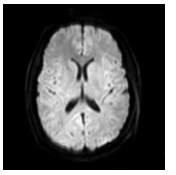
- T2 weighted sequence with additional diffusion weighting
- Diffusion weighting: sensitization to the Brownian motion of water molecules
- Large diffusion: less signal
  Small diffusion: more signal



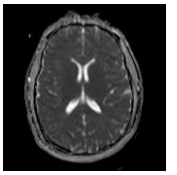
Diffusion weighted imaging



b=0 (no diffusion weighting)



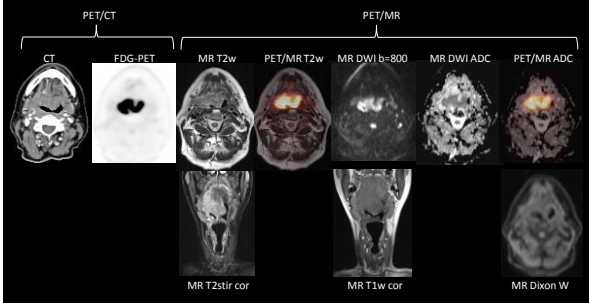
b=1000 (large diffusion weighting)



ADC (apparent diffusion coefficient)

$ADC = -1/b \cdot \ln(Image_b/Image_0)$

PET/MR with DWI versus PET/CT in head/neck



/J. Löfgren, data from study by J. Rasmussen, B.M. Fischer et al.

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Introduction to Magnetic Resonance Imaging

MR Physics:

- Nuclear spins
- Magnetization
- Magnetic resonance
- Precession
- Radio waves
- Signal detection
- Spatial encoding
- Relaxation times

MR Image types:

- T2 weighted
- T1 weighted
- Sequence parameters
- FLAIR
- Diffusion