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Introduction to MRI

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Contents

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- Image contrast
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- Image formation
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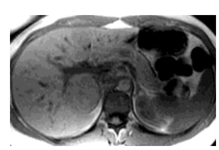

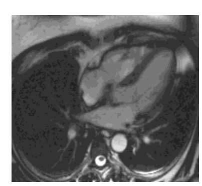

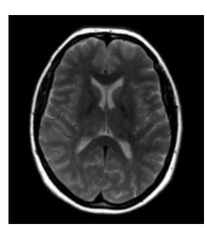

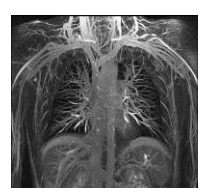

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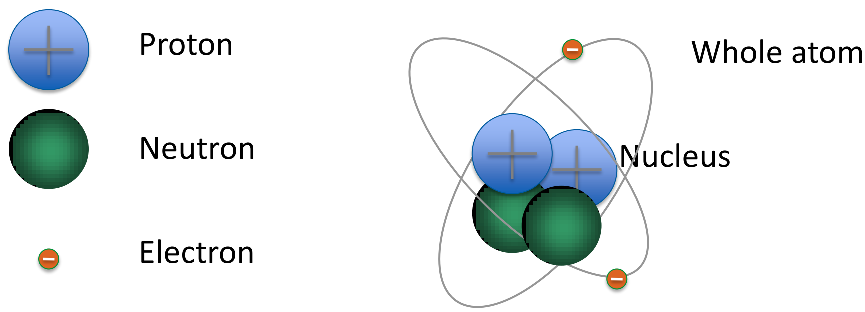
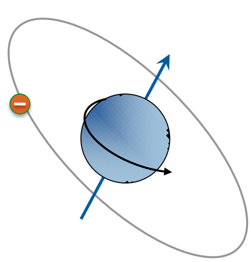
Atoms



Hydrogen atom



- nucleus of hydrogen is a single proton
- The proton is a charged particle which spins.
- This gives it a small magnetic moment **μ.**

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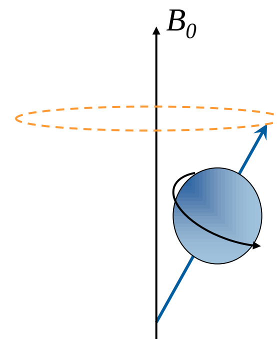
Precession - Larmor frequency

Proton spins precess (wobble) about external magnetic field B_0.



Frequency $\propto$ Field

$$f_0 = \gamma B_0$$

frequency (MHz) = 42 x field (T)

Gyro-magnetic ratio, "Gamma is 42"

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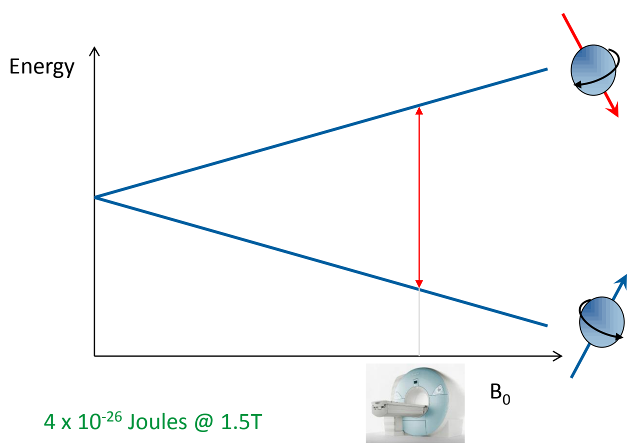
Energy, B_0 & frequency



$\Delta E = h f$

$f = \gamma B_0$

4×10^{-26} Joules @ 1.5T

(0.00000000000000000000000004 J)

(Mars bar is 1,095,000 J)

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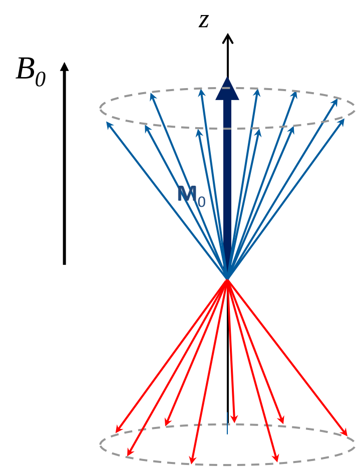
Macroscopic magnetisation vector

Consider the behaviour of lots of protons

Vectors

Macroscopic magnetisation M_0

- ≈20 μT for a head @ 1.5T



Apply RF at resonant frequency

- B_1 = RF pulse

M precesses about B_1

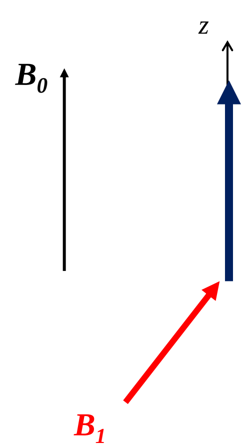
Flip angle

$\alpha = \gamma B_1 t$

For $\alpha = 90^\circ$

$M_z \rightarrow 0$

$M_{xy} = M_0$



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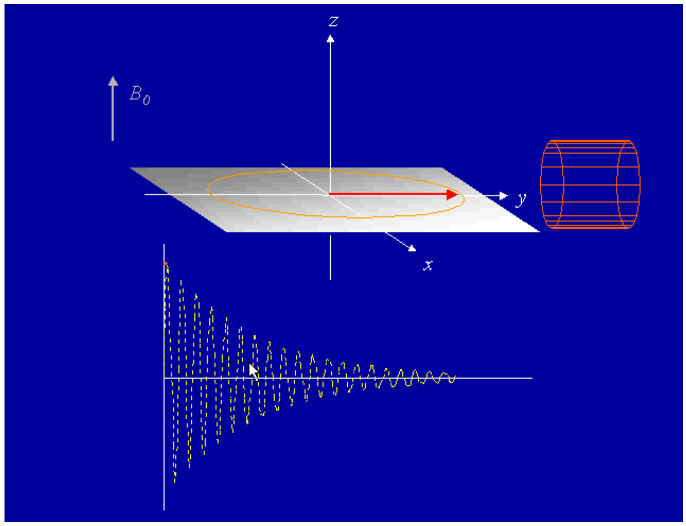
Detect signal: induction



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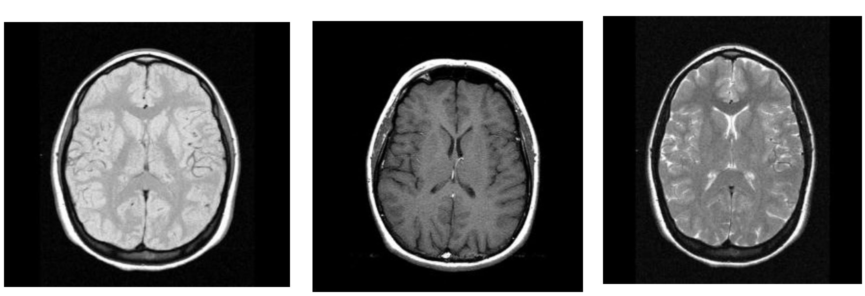
What are we scanning?

- Water! H_20
- Fat! $CH_3(CH_2)_nCOOH$

Frequency difference = 220 Hz @ 1.5T



PD T_1 T_2

Why does water look so different?

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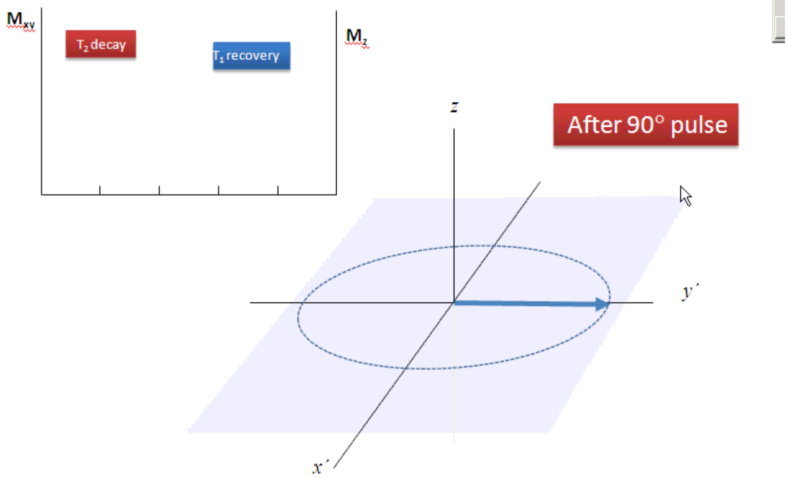
T1 and T2 relaxation



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Dephasing T2*

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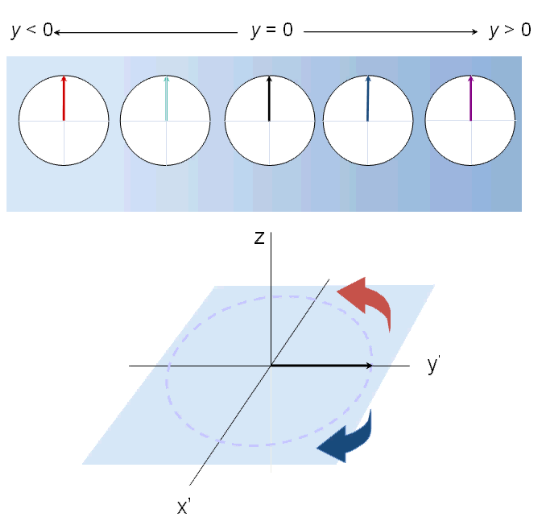

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Spin echo

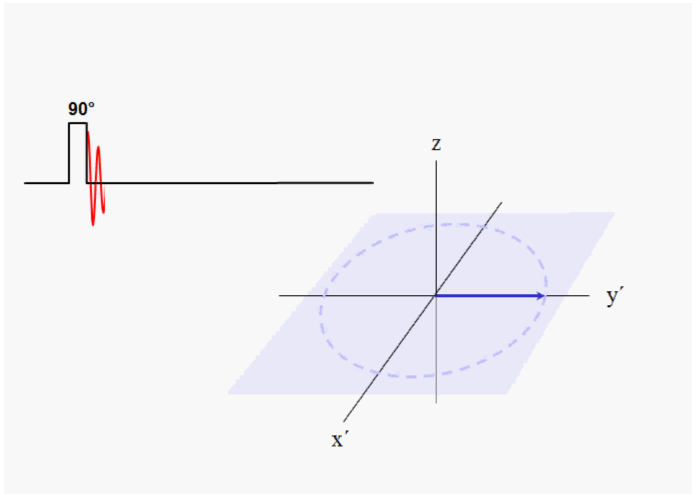

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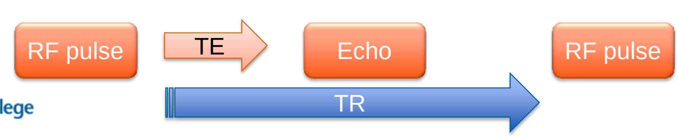
Image contrast

- MR signal is made as an echo after we put RF energy in: This is called **Excitation**
- The time between the RF pulse and the echo is **TE**
- The time between the RF excitations is **TR**



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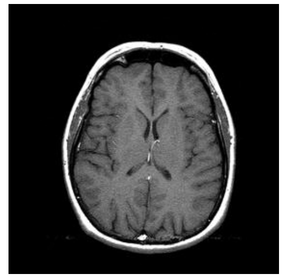
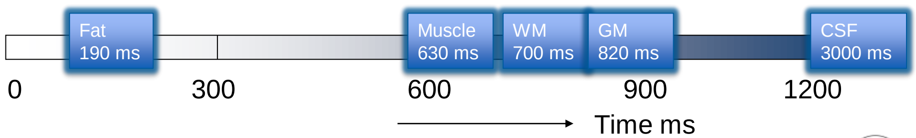
T1

T1 is a measure of how long the RF energy stays in tissues

For fluids, this is a relatively long time 100s of milli-seconds)

Increased water content from oedema or increased vascularisation often means that T1 is longer for diseased tissues.



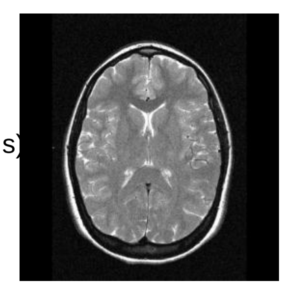


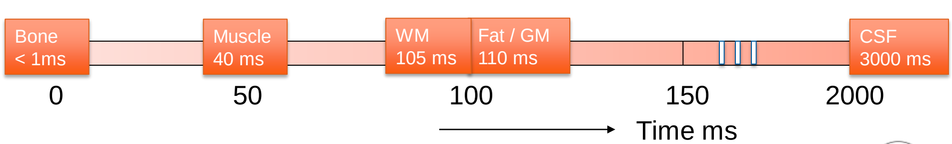
T2

T2 is a measure of how long the signal remains (how long the echo reverberates)

Solid tissues have very short T2 (< 1ms)
"Watery" tissues have longer T2 (100s of ms)

Increased water content from oedema or increased vascularisation often means that T2 is longer for diseased tissues.

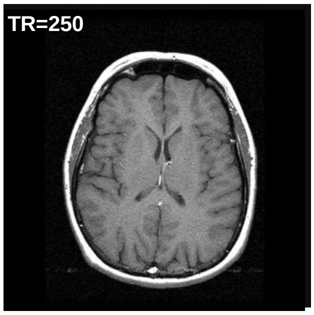


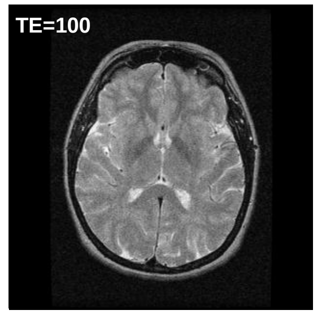


Controlling the "weighting"

TR controls the T1 weighting

TE controls the T2 weighting





TR (msec)

TE (msec)

Spin echo contrast summary

- Spin echo (SE) is the "standard way"
- Most reliable image quality
- Has long TR
- Longer scan times
- Fast/turbo SE speeds it up

Spin echo	TE	
TR	<40 ms	>75 ms
< 700 ms	T1w	
>1500 ms	PDw	T2w

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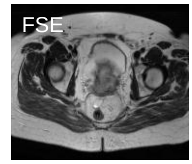
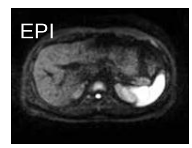
Fast / turbo spin echo

Like Spin echo – but faster



Single shot fast/turbo spin echo - fast

Echo planar imaging (EPI) - fastest



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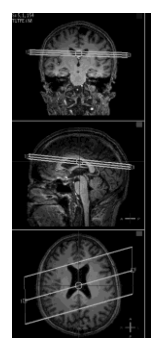
Gradient echo

- Gradient echo (GE) is faster than SE
- Good for contrast-enhanced, dynamic scans, angio, localisers
- Has very short TR
- A new sequence parameter: flip angle α
- T2* (like T2 but affected by scanner)



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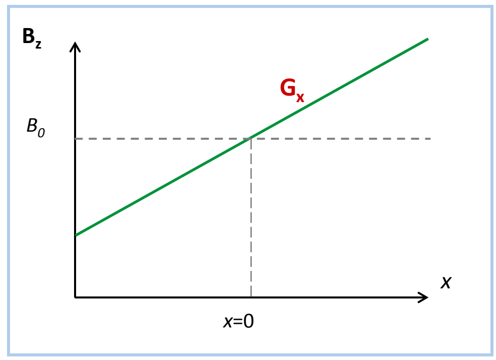
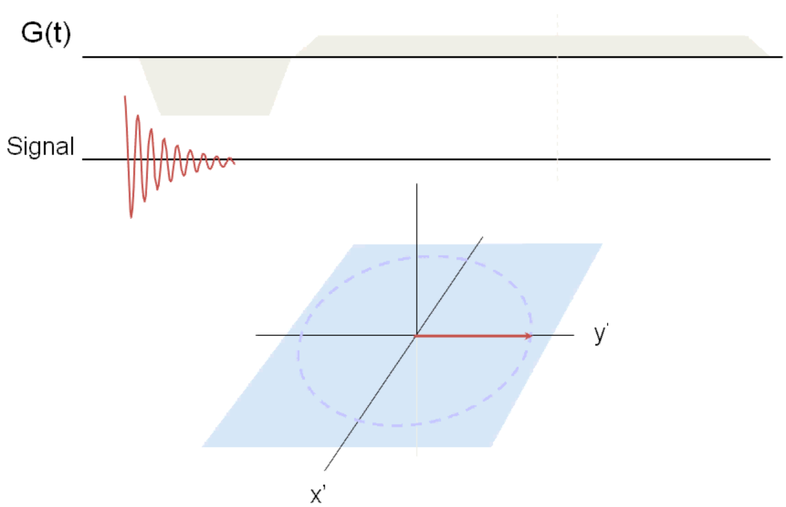
Gradients

A gradient is a linear variation in B_z field with position

(mT/m)



Forming a gradient echo



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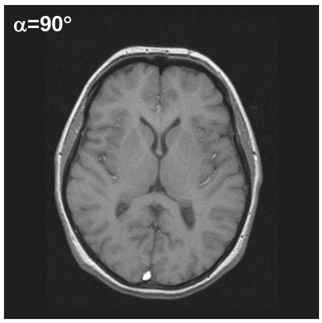
Controlling T1 contrast in GE

α controls the T1 weighting



α (°)

Gradient echo	TE	
Flip angle	<15 ms	>20 ms
< 15°	PDw	T2*
> 25°	T1w	T2/T1

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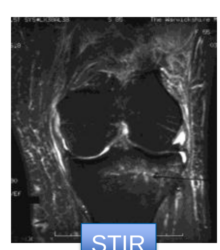
Removal of fat

- Fat sat
  - Chemical saturation, uses frequency difference
- Water selection
  - Uses phase differences
- In-phase / out-of-phase
  - Phase cancellation
- STIR, SPIR, SPAIR
  - Inversion recovery sequence
  - Relaxation time of fat



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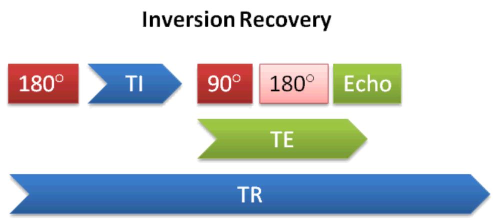
Inversion recovery



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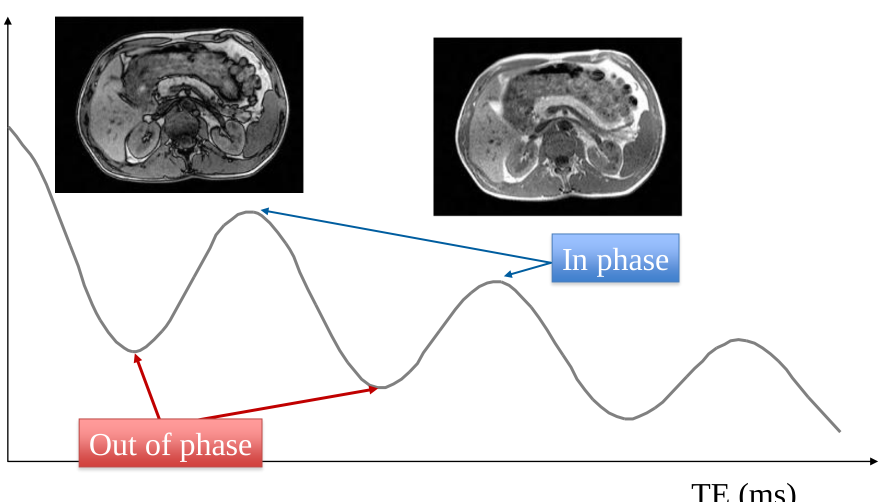
Phase cancellation artefact



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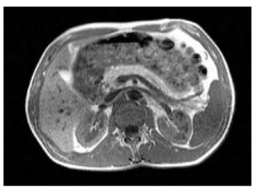
Water-fat images: Dixon Method

Acquire IP and OOP images

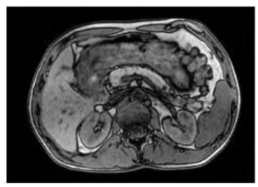
IP= Water+ Fat

OOP = Water- Fat



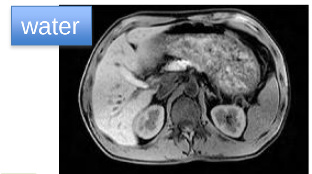
In phase

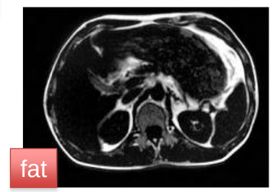
\+ / −



Out of phase

=





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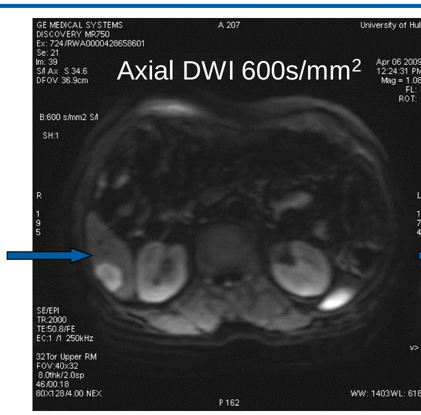
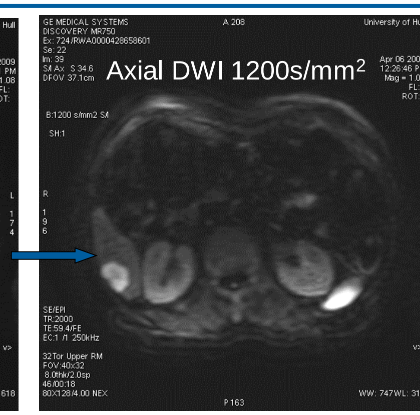
Diffusion-weighted imaging





Tumour in the liver more clearly shown on b-value 1200 s/mm^2

"b value" controls the diffusion contrast

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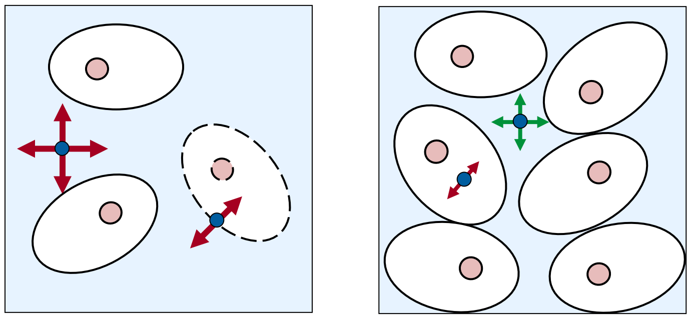
Intracellular and extracellular

Free diffusion　　　　Restricted diffusion

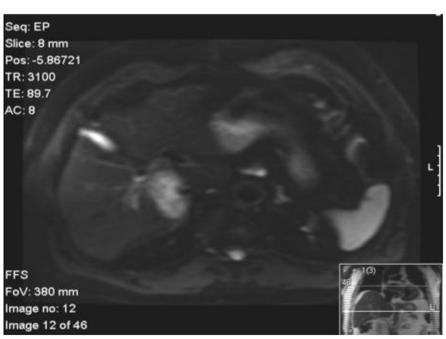


Low cellularity
Defective membrane

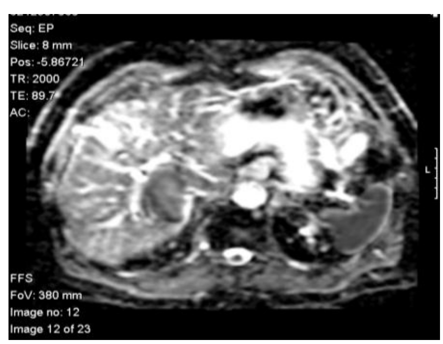
High cellularity

ADC measurement

$$\text{ADC image} = \frac{1}{\Delta b} \ln\left(\frac{\text{Large b image}}{\text{Small b image}}\right)$$



Diffusion image
b= 500



ADC image

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Apparent Diffusion Coefficient

Tissue	ADC x 10^3 mm^2/s
Water	2.0
WM/GM	0.7/ 0. 9
Liver	1.8
Liver benign Cysts/hemangioma	2. 5
Liver Metastases/HCC	1.1
Kidney Cortex/medula	2.4/ 2.2
Prostate Peri/central	1.9/1.5

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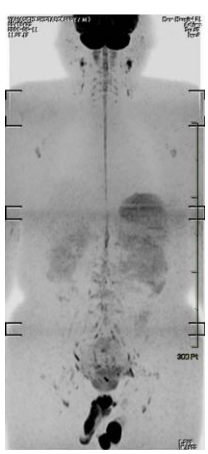
Whole body diffusion



Use DW-EPI
STIR
Free breathing
High b (1000)
Parallel imaging
Multiple averages
Multiple stations
MIP / contrast reversal

Takahara, T., et al., Diffusion weighted whole body imaging with background body signal suppression (DWIBS): technical improvement using free breathing, STIR and high resolution 3D display. *Radiation Medicine*, 2004. 22(4): p. 275-82

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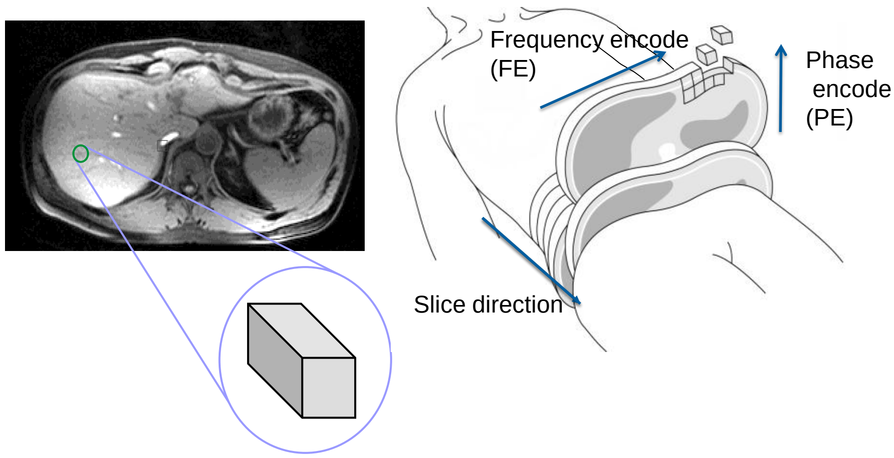
Image formation



Matrix is the number of pixels in each direction

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Position-dependent frequency

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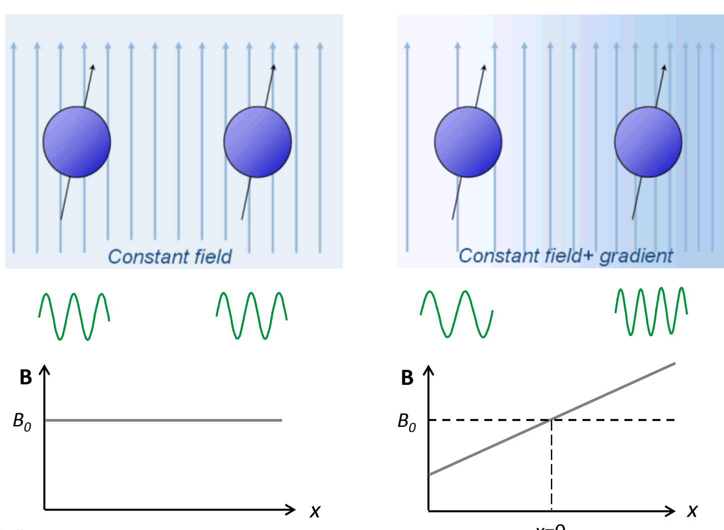

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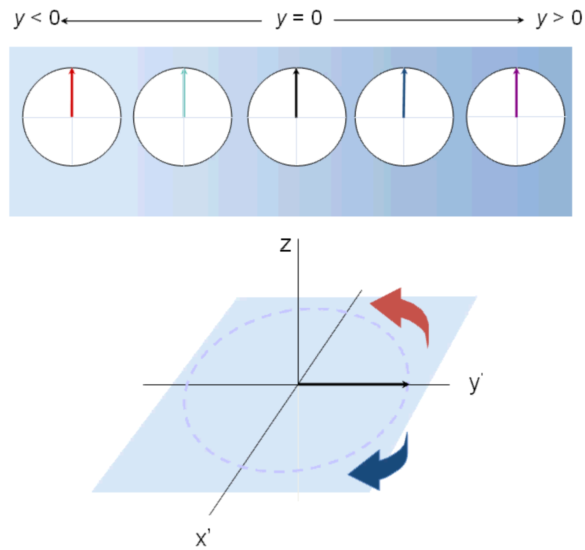
Gradients alter signal phase



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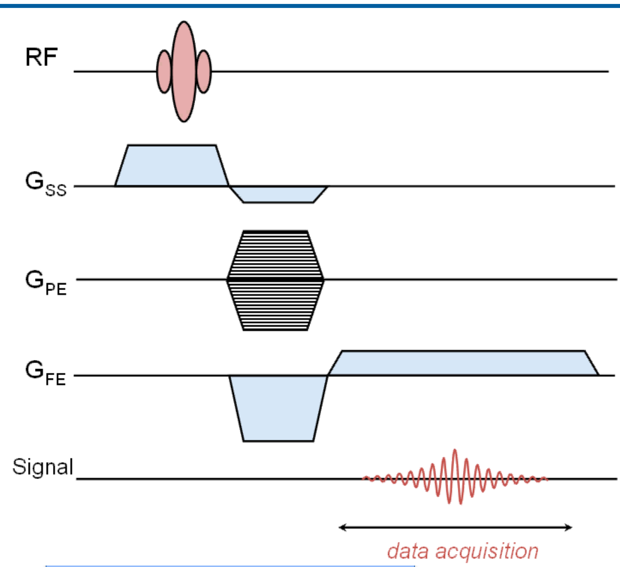
Imaging pulse sequence



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Scan time = NSA x N_{PE} x TR

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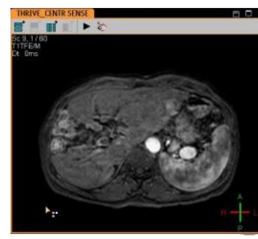
3D scanning

- Very rapid TR gradient echo acquisition, low α
- Preparation pre-pulse (e.g. Inversion)
- T1 contrast

3DFGRE 3d TFE MP-RAGE

- With interpolation (for breath-hold scans)

LAVA THRIVE VIBE



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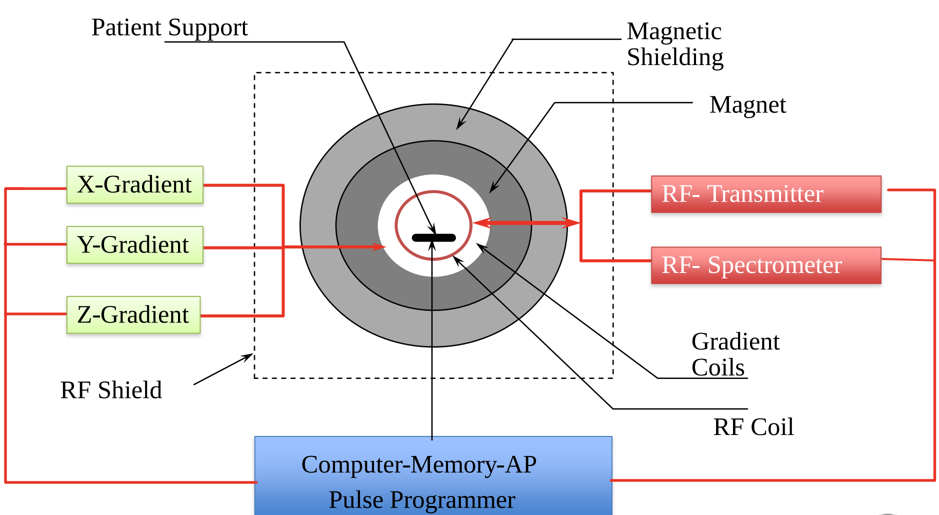
MRI system overview



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Superconducting Magnets

- Windings cooled to close to absolute zero
- Liquid Helium:
  - 269ºC *boiling* point
- Contained in cryostat
- In superconducting state windings have no electrical resistance
- Current persists permanently
- Very stable. Uniform and strong fields
- Energy expended in cooling

1.5T Oxford magnet

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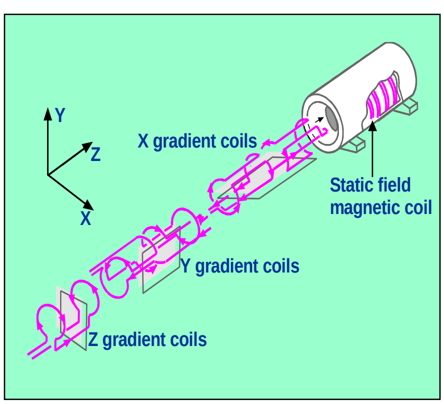
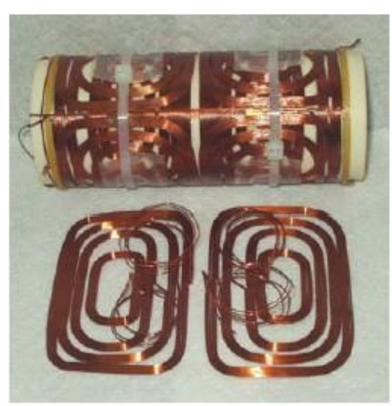
Gradient coils





$G_x = dB_z/dx$; $G_y = dB_z/dy$; $G_z = dB_z/dz$

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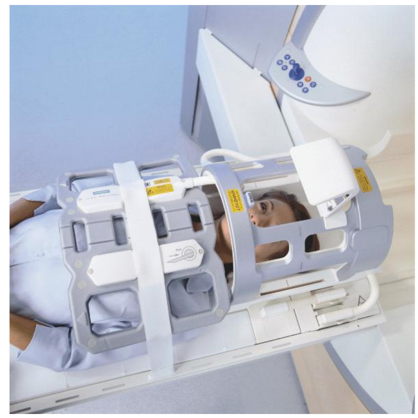
Array coils

- Improve SNR
  - Lower NEX
  - Higher Resolution
  - Shorten scan time
  - Better breath-hold
- Greater coverage
- Less need to move patient



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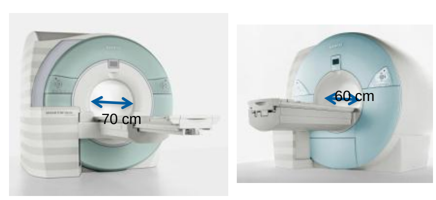
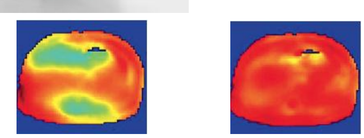
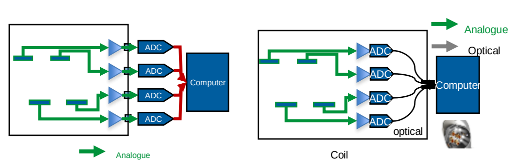
New technical developments

- High field
  More SNR
- Wide bore magnets
  Better for patients
- Parallel imaging
  Faster scans
- Parallel transmit
  More uniform excitation at high B_0
- Direct digital receive
  Better SNR





Birdcage coil | Parallel Tx



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Safety: EMF exposures in MRI

The fringe field of the magnet – *dB/dr*

- Static magnetic field in magnet B_0
- Gradients - time-varying fields $G_{x,y,z}$
- RF time-varying magnetic field B_1

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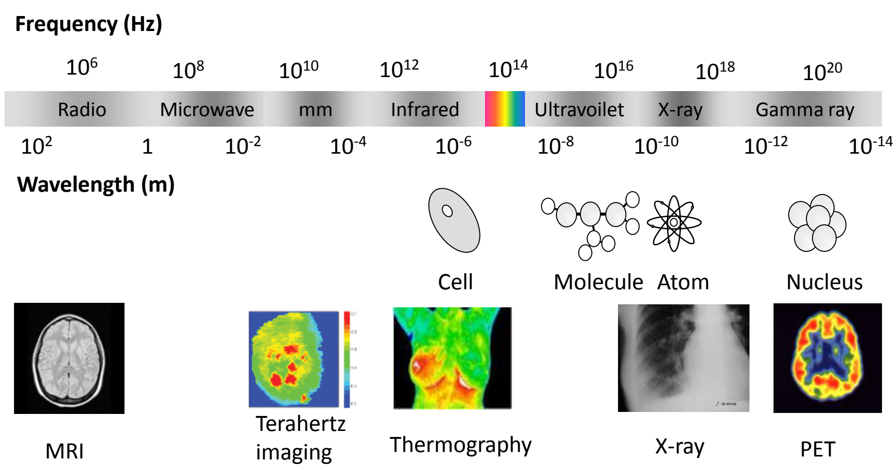
Electro-magnetic spectrum



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Force fields I

Translational force

- magnetic susceptibility χ
- Volume V
- field B
- fringe field gradient *dB/dr*

$$F \propto \chi VB \cdot \frac{dB}{dr}$$

Needs the field to *vary* over distance
Strongest near bore entrance

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Force fields II

Torque (twisting force)

- Objects twisted even in uniform fields
- Depends on B^2
- Affects implanted objects

$$T \propto \chi^2 VB^2$$

Strongest within the bore of the magnet

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Active implants - risks

- Dislocation
- Malfunction
  - Programming changes
- Loss of therapy
  - Inhibition
  - Unwanted stimulation
- Loss of data
- Damage to device
- Vibration
- Induced voltages
- Heating in lead wires
- Image artefacts

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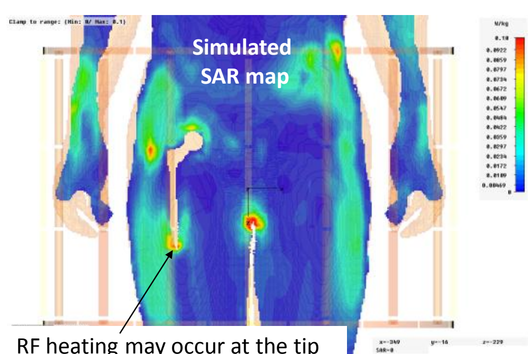
Passive implants - risks

Dislocation – extremely unlikely with modern implants

RF heating

CoCrMo ASTM F75



RF heating may occur at the tip of the shaft, but is often less than elsewhere

Powell et al 2012

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Bio-effects

- Vertigo
- Taste sensations

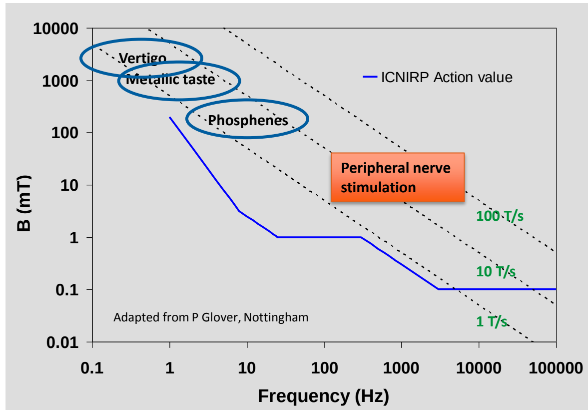
Associated with head movement in static field

- Peripheral nerve stimulation

From time-varying-gradients

- Tissue heating from RF

SAR = specific absorption rate (W/kg)



To date we know of no long term effects

Peripheral nerve stimulation is not harmful

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MHRA advice: Pregnancy

Patients

- Clinical decision
- Acoustic noise – use quieter gradients where possible
- Keep within lower limits
- Consent required

Staff

- Don't stay in room during scanning
- MHRA /SoR advice – carry on except in room during scan

Public

- MHRA: Whole term - less than 3mT

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Summary

- MRI detects the hydrogen nucleus using static and RF magnetic fields
- Magnetic field gradient pulses localise the signal to produce the image
- Image contrast depends upon T1 and T2 relaxation times and molecular diffusion
- Magnets are 1.5-3T; technology is developing
- Minor acute bio-effects, but the MR environment is hazardous for ferromagnetic objects and active implants.

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