Master of Science in Cognitive Neuroscience & Neuroimaging

Magnetic Resonance Imaging
Part 1

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- MRI in 5mn
- spin & magnetic resonance
- B_0 & magnets
- magnet safety

overview

- Unique Selling Proposition

  non-ionizing radiation (non-invasive)

  good spatial 3D resolution

  superior soft-tissue contrast in vivo

  extremely versatile (structure, function, blood flow, etc.)

- Timeline

Bloch & Purcell (1946)	magnetic resonance phenomenon (interaction atom/radio waves)
Lauterbur (1971)	MRI in a test tube sample (back projection approach)
Mansfield (1973)	k-space approach

EPI (1977), fMRI (1992), DTI (1985)

why & when

- Synopsis of MRI
  1. subject placed inside intense homogeneous magnetic field: protons align
  2. transmit radio waves: protons get excited
  3. turn off radio waves: protons relax
  4. measure radio waves emitted by protons
  5. modify field and repeat step 2

- Main factors of MRI

  quantum properties of nuclear spin

  radio-frequency excitation, tissue relaxation

  magnetic field strength and gradient

  MR sequence (timing of gradient & RF pulses, signal detection)

what

J. Hornak website

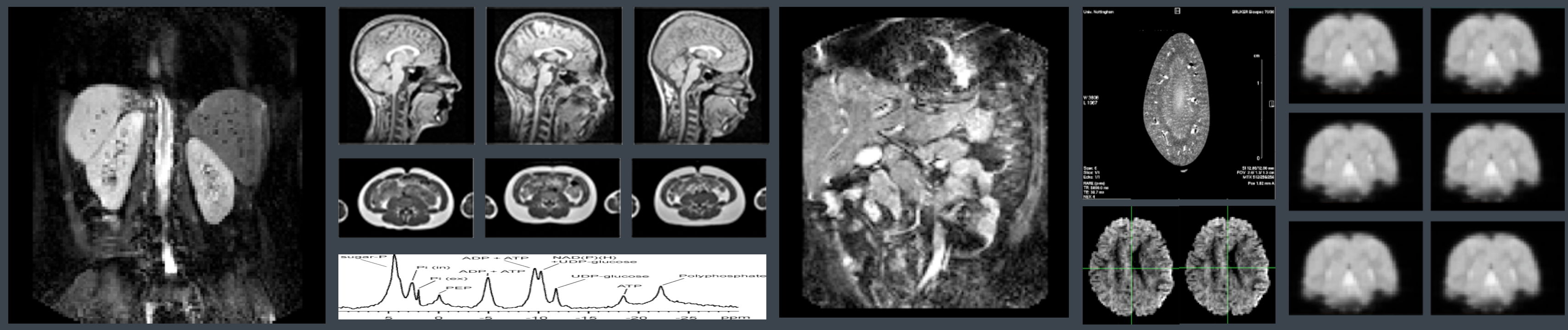
http://www.cis.rit.edu/htbooks/mri/inside.htm

Article

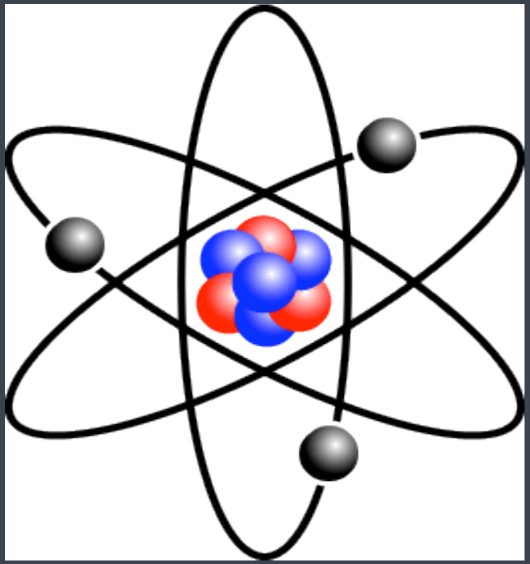
R.A. Pooley, “Fundamental Physics of MR Image”, RadioGraphics 2005

Book

M.A. Bernstein, “Handbook of MRI Pulse Sequences”, Academic Press, 2004



- building block of matter



- nucleus (protons + neutrons) and cloud of orbiting electrons

  electrons responsible for chemical reactions

- atom: 10^{-10}m, nucleus: 10^{-14}m

  ⇐ mostly empty

- electrical charges:

  proton: +, electron: -, neutron: no charge

  atoms are neutral ⇐ n^b protons = n^b electrons

the atom

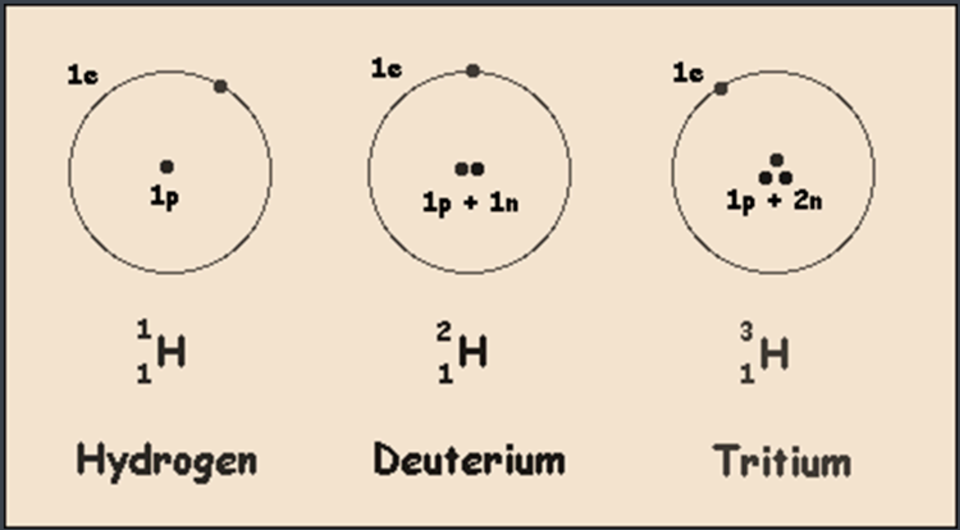
- some notations

  atomic number Z: number of protons

  mass number A: number of nucleons (protons + neutrons)

$$ {}^{A}_{Z}X $$

- isotope ≡ same Z, different A
  - almost identical chemical properties
  - vastly different nuclear properties



isotopes

- spin ≡ fundamental property of nature

  multiples of ½, + or –

  unpaired protons, neutrons, electrons have spin ½

  particles with opposite sign spins can pair up: resulting spin is zero (e.g. He)

- nuclei with spin
  - nucleons fill orbitals (like electrons)

    2, 8, 20, 28, 50, 82, and 126 nucleons
  - filled orbitals have zero spin

⇐ NMR interested in sufficiently abundant isotopes with non zero spin

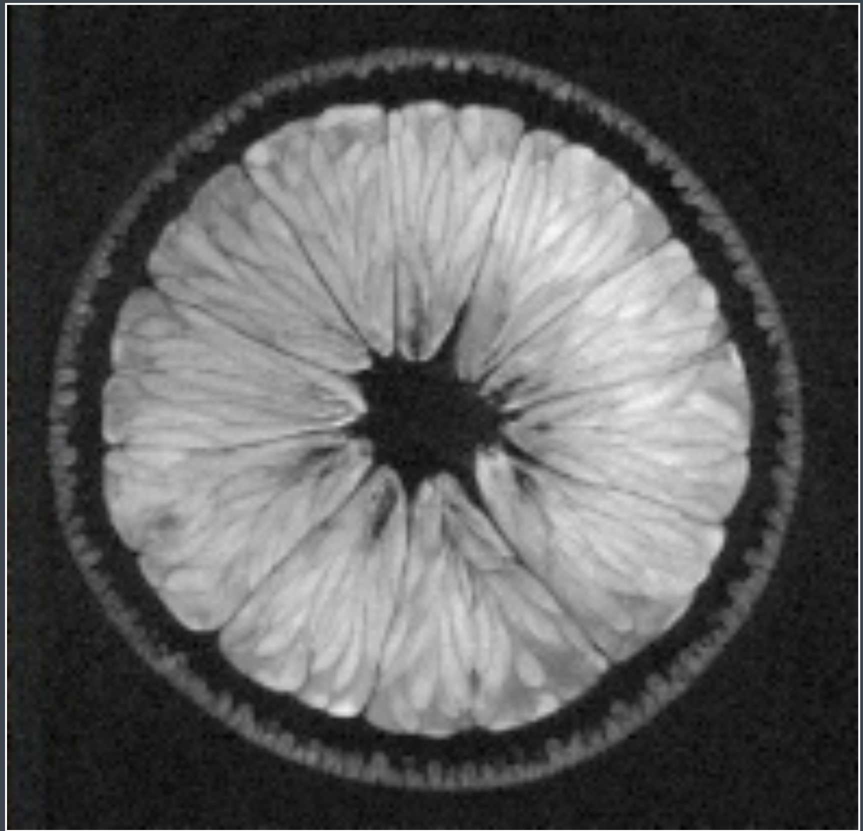
odd number of proton and/or neutron

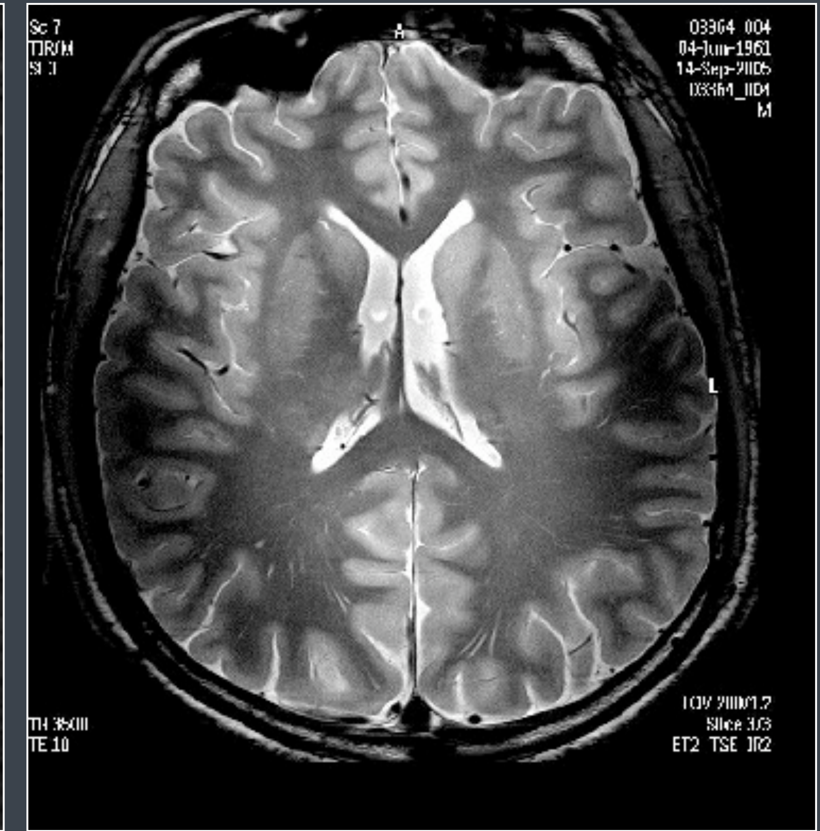
spin

Nuclei	Unpaired protons	Unpaired neutrons	Net spins	γ(MHz/T)
^{1}H	1	0	1/2	42.58
^{2}H	1	1	1	6.54
^{31}P	1	0	1/2	17.25
^{23}Na	1	2	3/2	11.27
^{14}N	1	1	1	3.08
^{13}C	0	1	1/2	10.71
^{19}F	1	0	1/2	40.08

isotopes of interest

^1H, very abundant





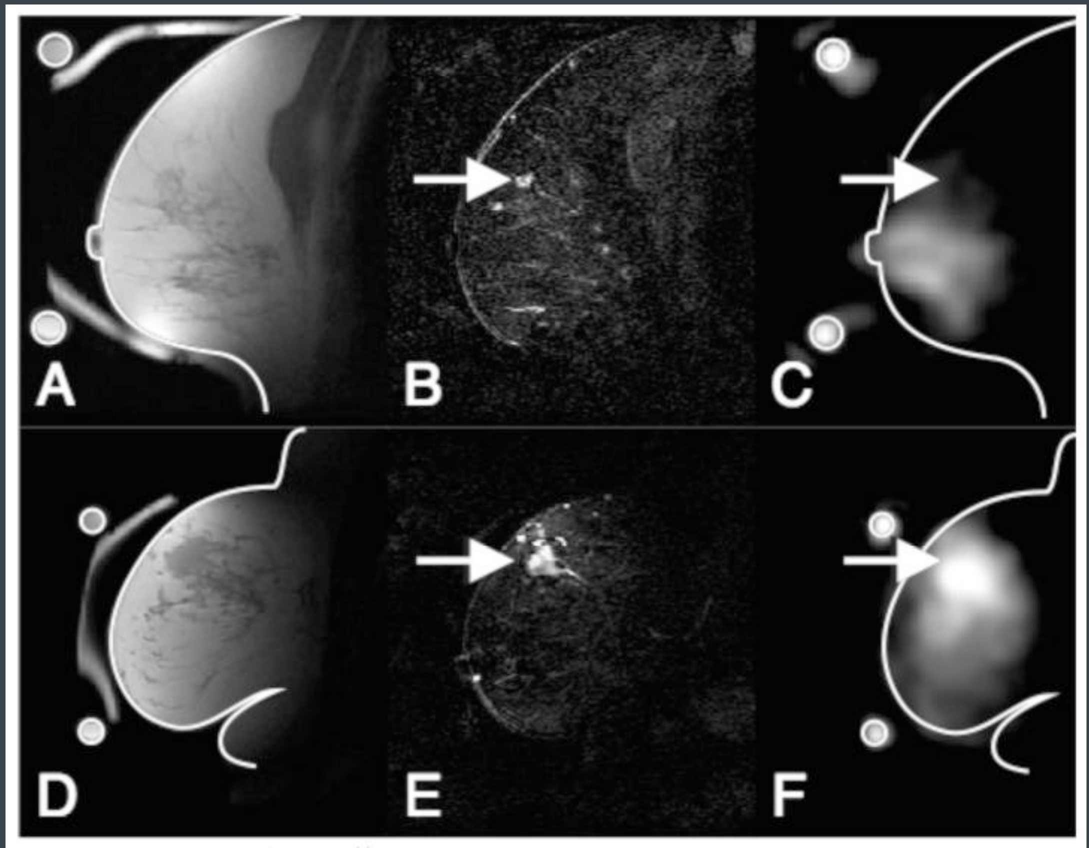
images acquired on SPMMRC 7T scanner

sample images

^{23}Na, physiology, cellular metabolism

^{23}Na MRI: From Research to Clinical Use

R. Ouwerkerk and R.H. Morgan, J Am Coll Radiol. 2007



benign lesion

malignant lesion

^{1}H Gd difference ^{23}Na

sample images

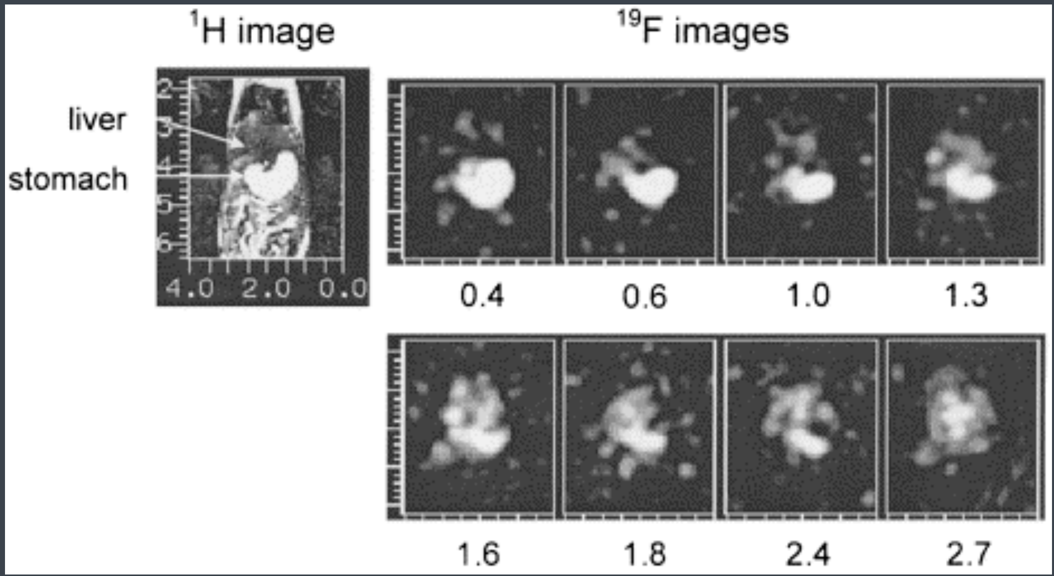
- ^{19}F, used a tracer

e.g.: perfluorooctanoic acid

^{19}F Magnetic resonance imaging of perfluorooctanoic acid encapsulated in liposome for biodistribution measurement

A. Kimura, M. Narazakib, Y. Kanazawab and H. Fujiwaraa

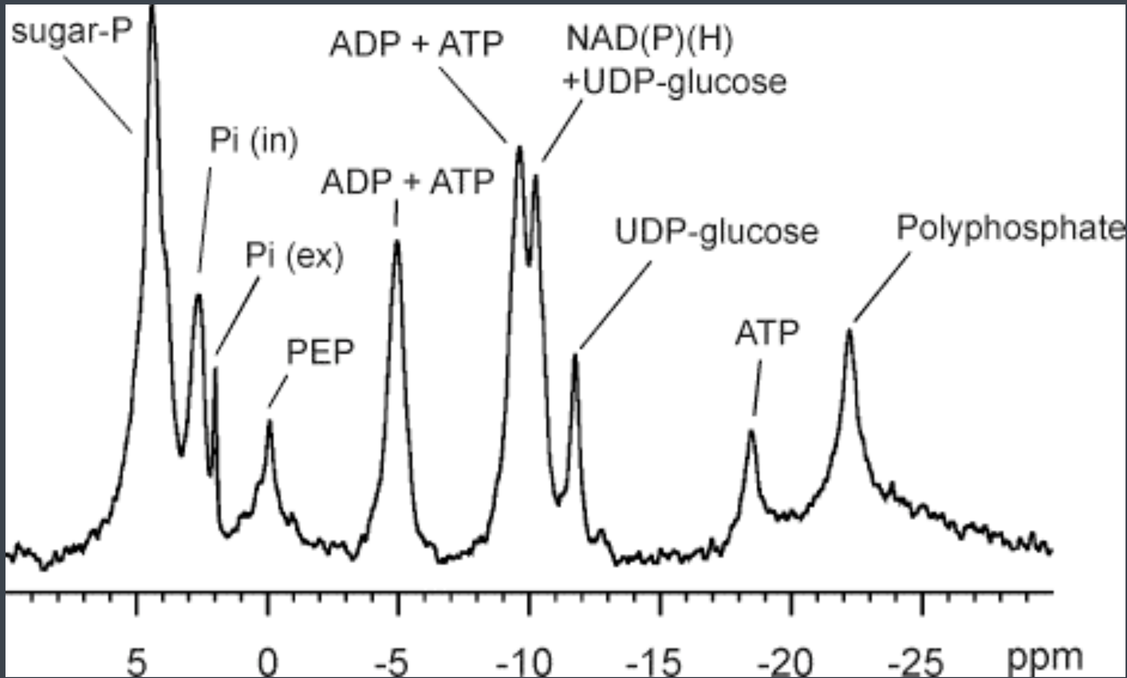
Magnetic Resonance Imaging, 2004



in vivo images of PFOA administered mouse

sample images

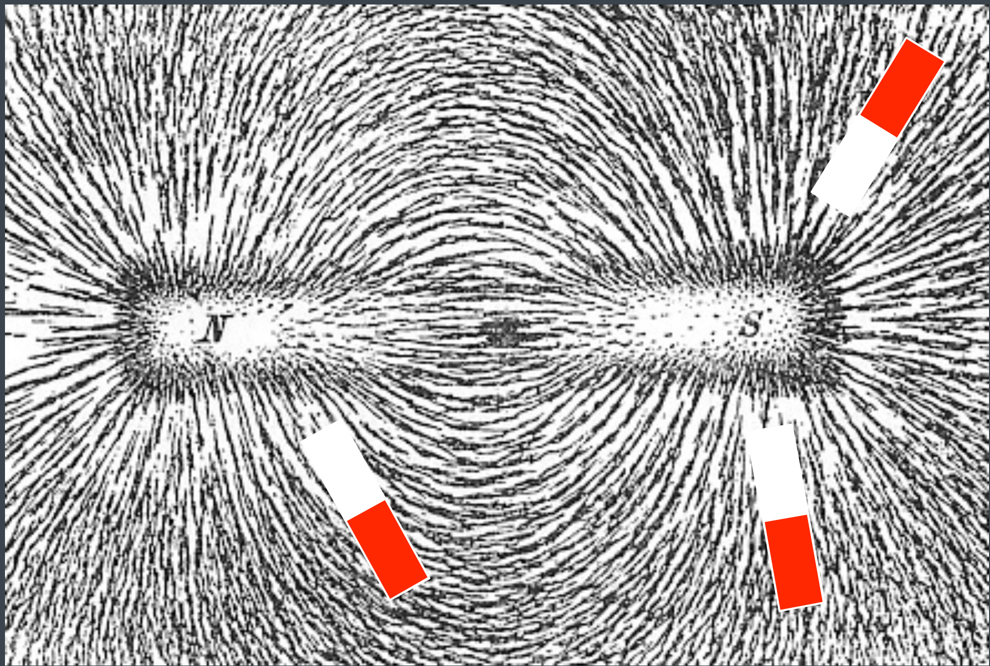
- ^{31}P, energy metabolism

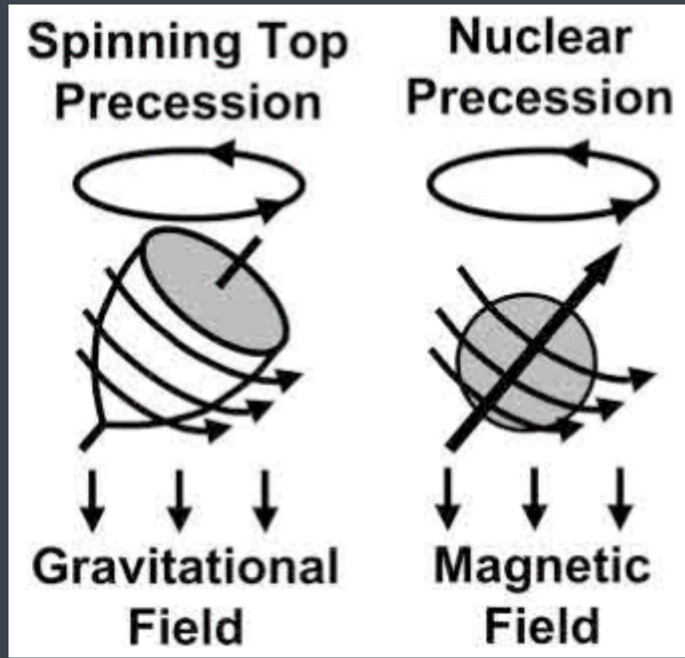


sample images

nuclear spin + electric charge ⇐ magnetic moment

protons ≡ moving magnets





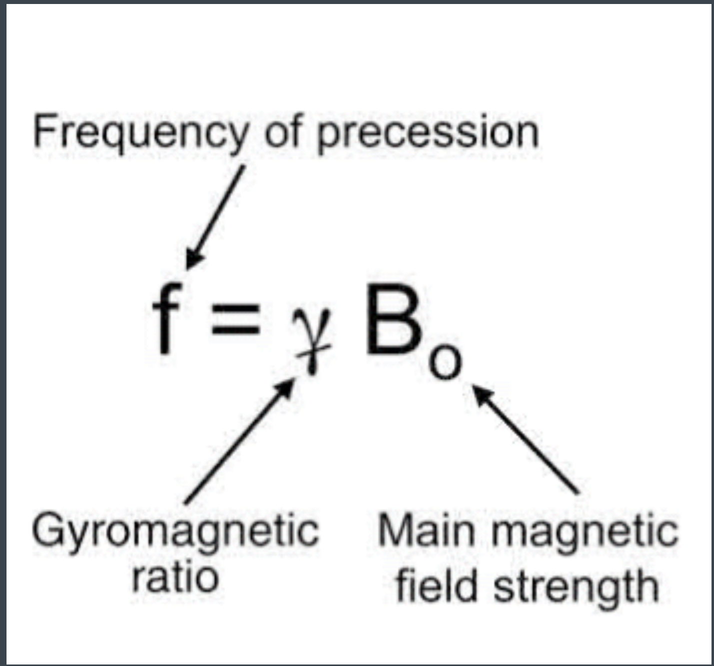
non spinning magnets align with magnetic field

spinning magnets precess in field

magnetic moment

nuclear spin + electric charge ⇐ magnetic moment

protons ≡ moving magnets



$$f = \gamma B_o$$

Larmor equation

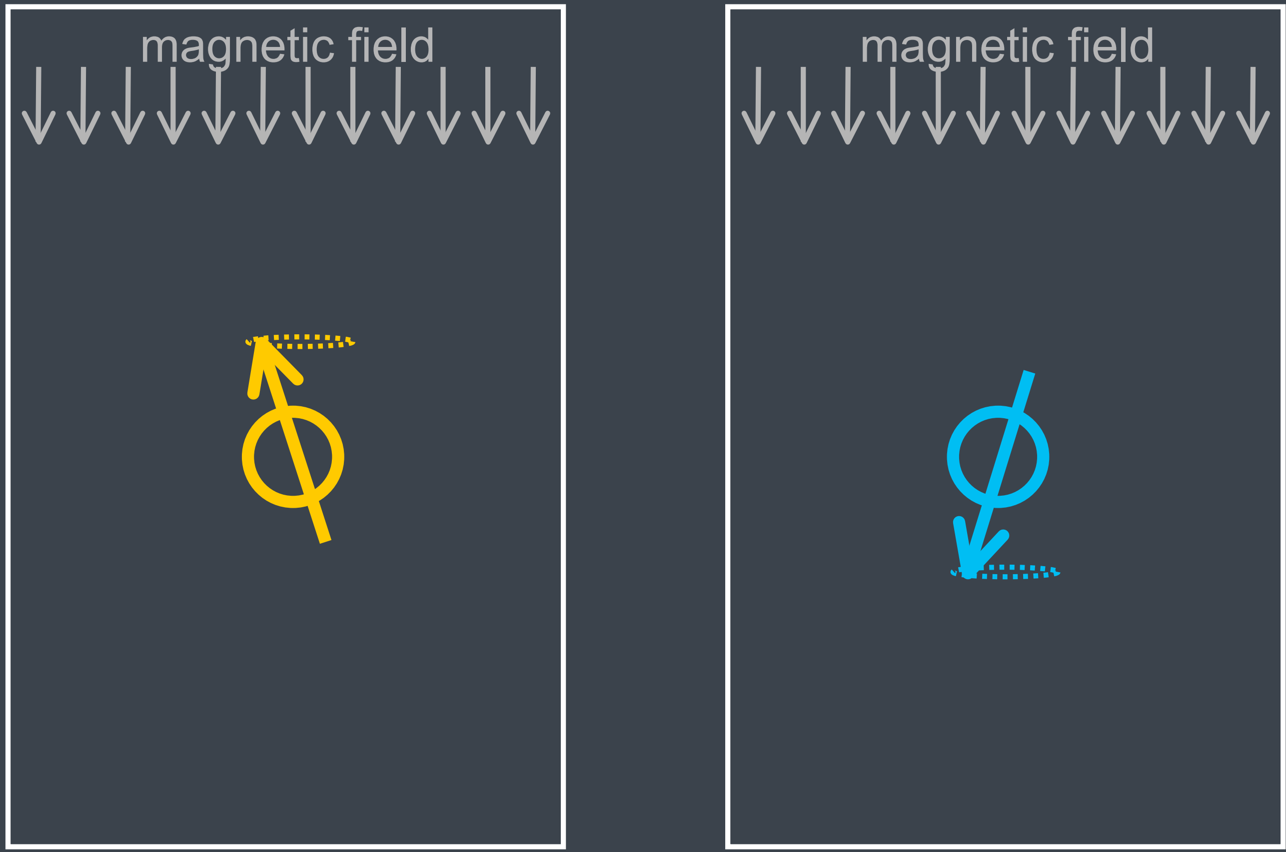
two energy configurations for gymnast in gravitational field

high energy state

low energy state

energy level & transition

two energy configurations for proton in magnetic field (Zeeman effect)

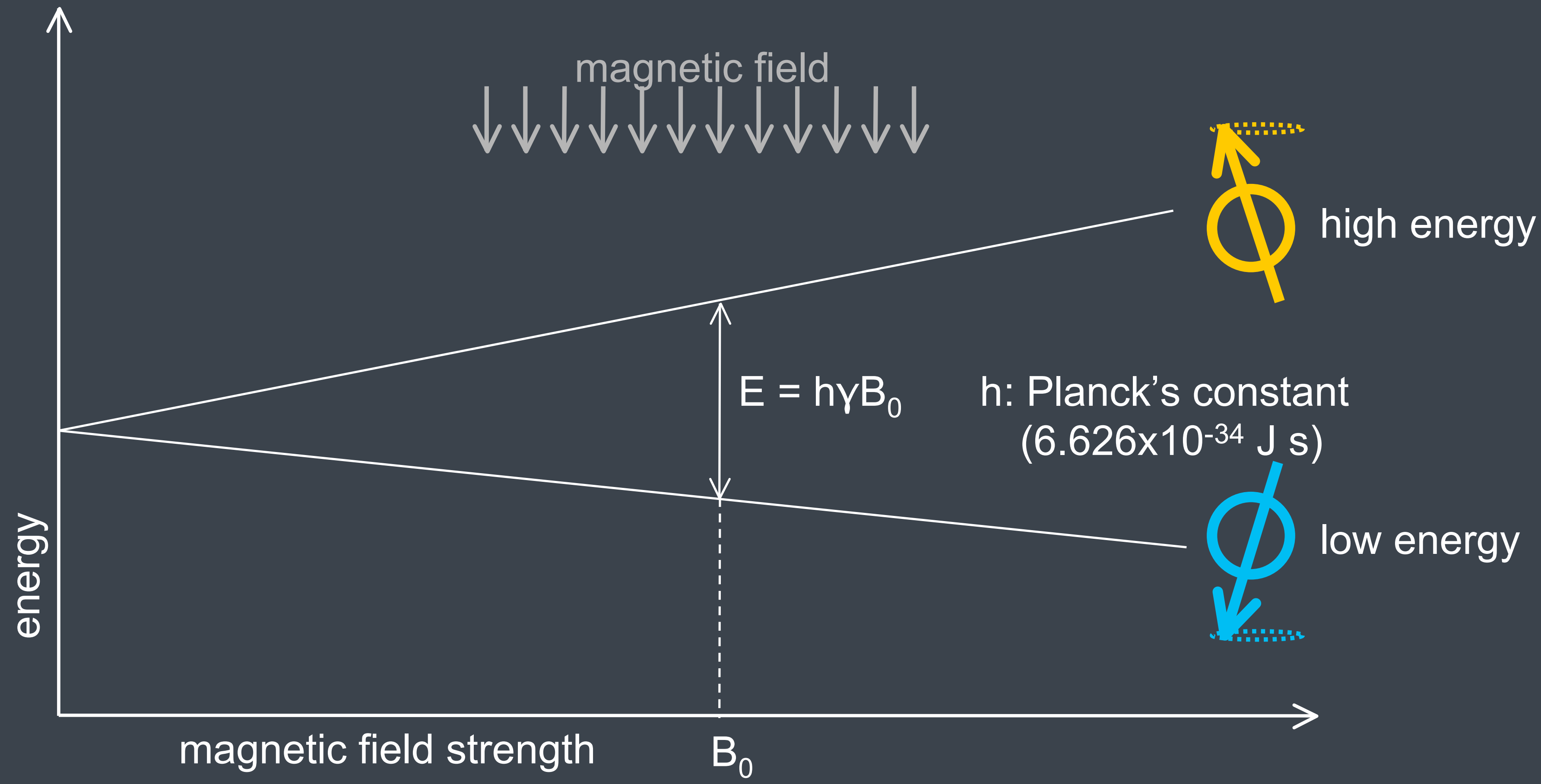


high energy state

low energy state

energy level & transition

transition between level by absorption of photon



energy level diagram

- Zeeman effect is tiny

  very small energy difference between states

  ⇐ MRI considers net magnetization

- Boltzmann statistics

  N^+: number of spins at lower energy level

  N^-: number of spins at higher energy level

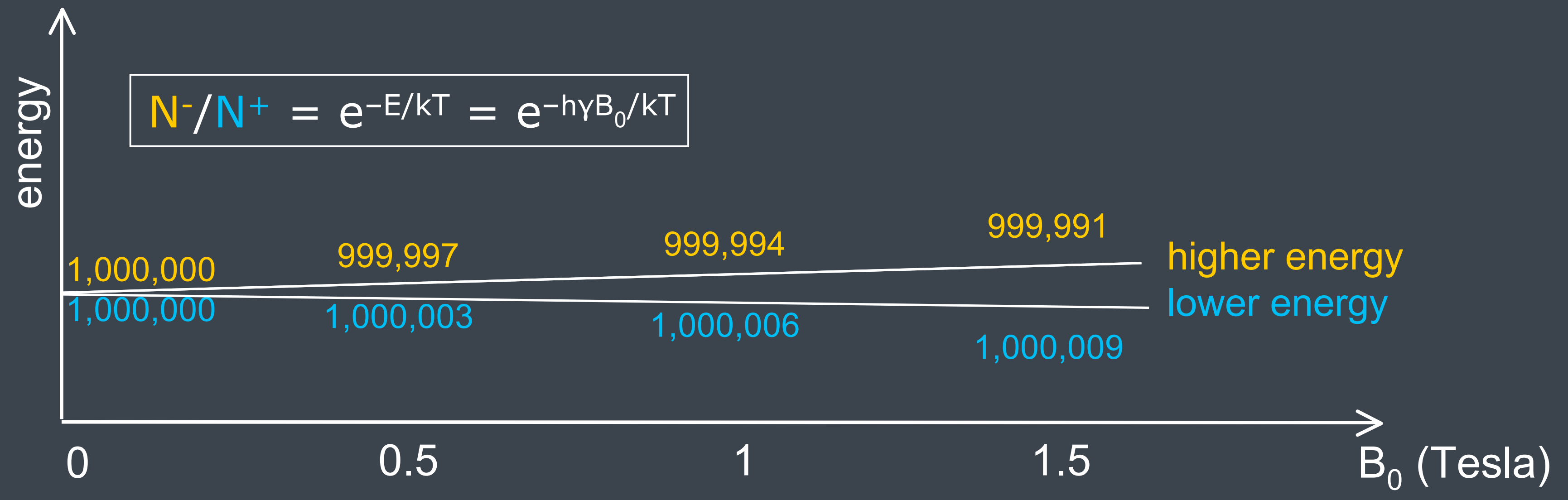
$$N^-/N^+ = e^{-E/kT} = e^{-h\gamma B_0/kT}$$

k: Boltzmann constant (1.3805x10-23 J/Kelvin)

T: temperature (in Kelvin)

⇐ MR signal proportional to population difference between states

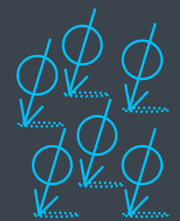
Boltzmann statistics



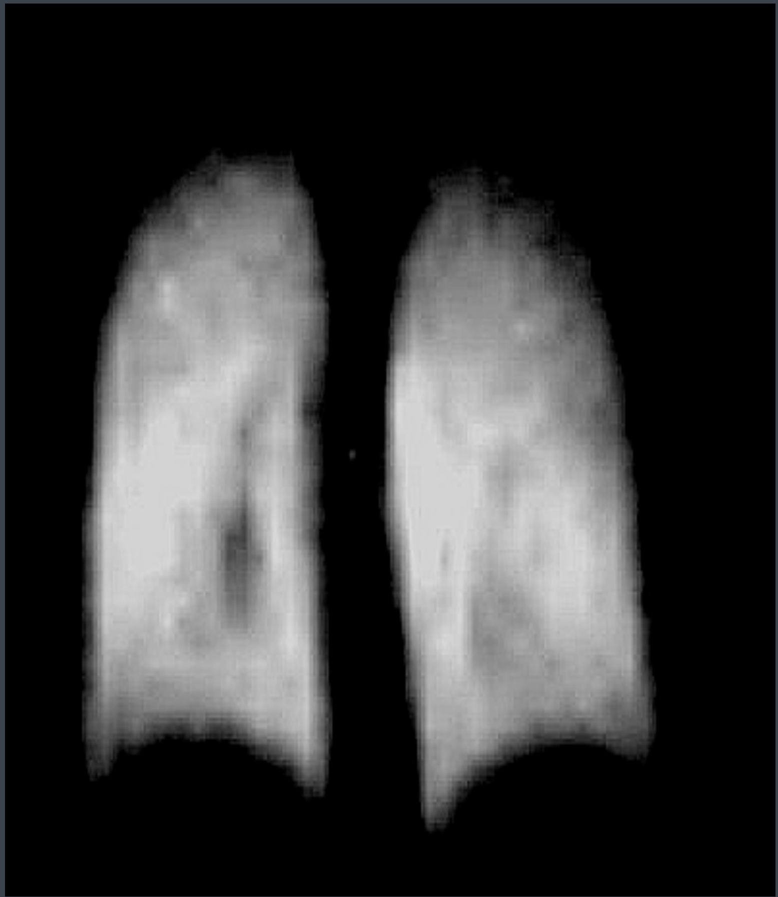
- B_0=1T, T=310K: 3ppm aligned
- T ⌊: N^-/N^+ ⌊
- B_0=0T, T=310K: $N^-/N^+=1$
- T=0K: $N^-/N^+=0$

0% spin aligned
no net magnetization

100% spin aligned



field strength, temperature & spin state

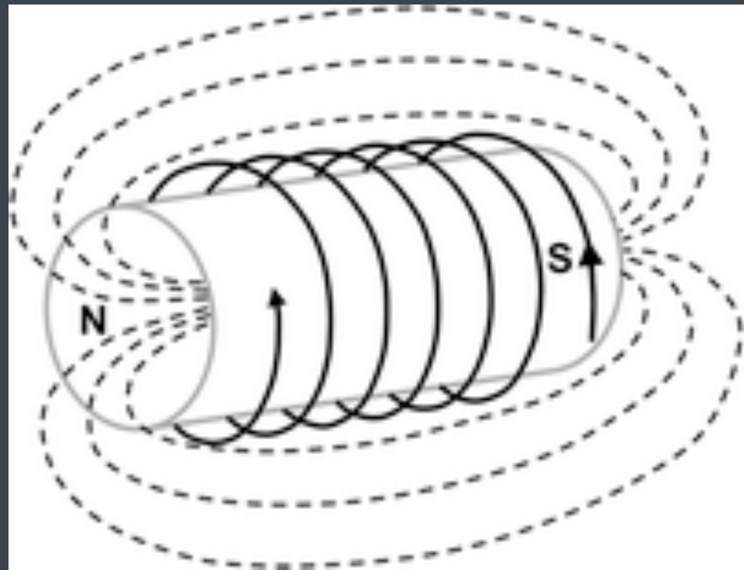


Lung imaging of ^{3}He at 0.15T

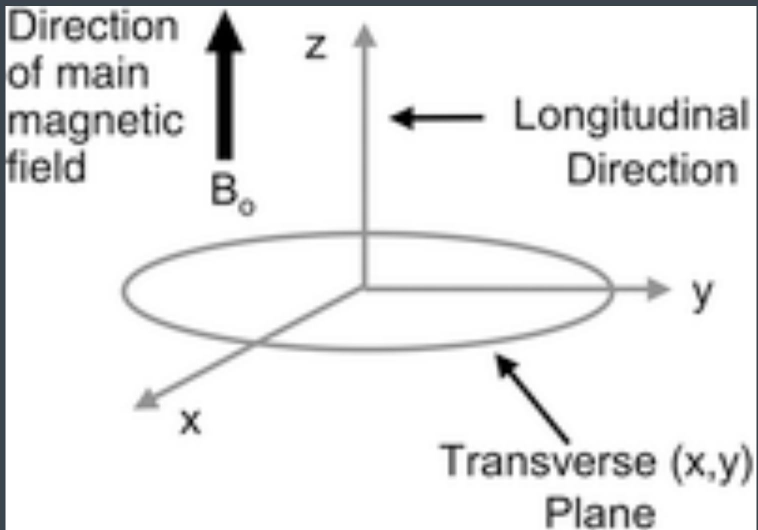
hyperpolarization

B_0 ≡ static field associated with NMR

– created by superconducting magnets
– order of 1T (10^4 Earth's field)

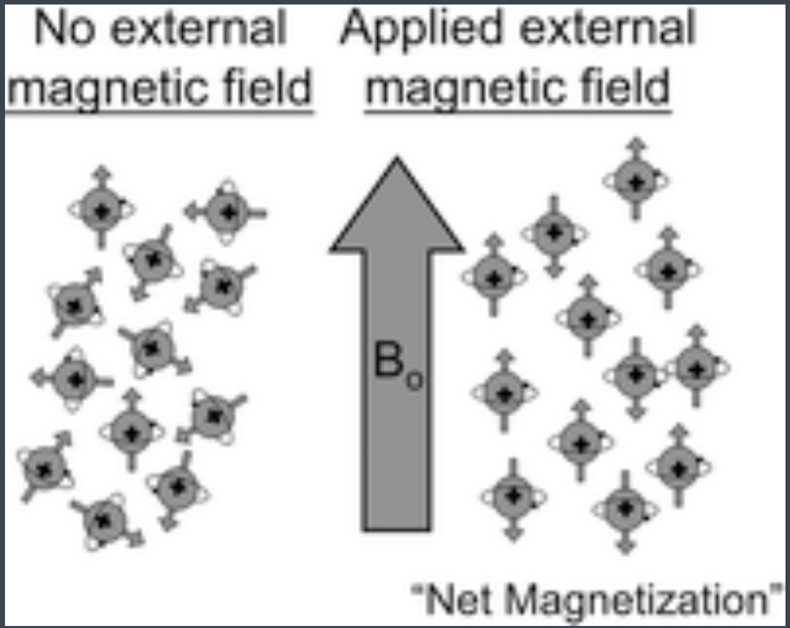


⇐ coordinate system



B_0 field

- In B_0 , spins align ⇐ bulk magnetisation

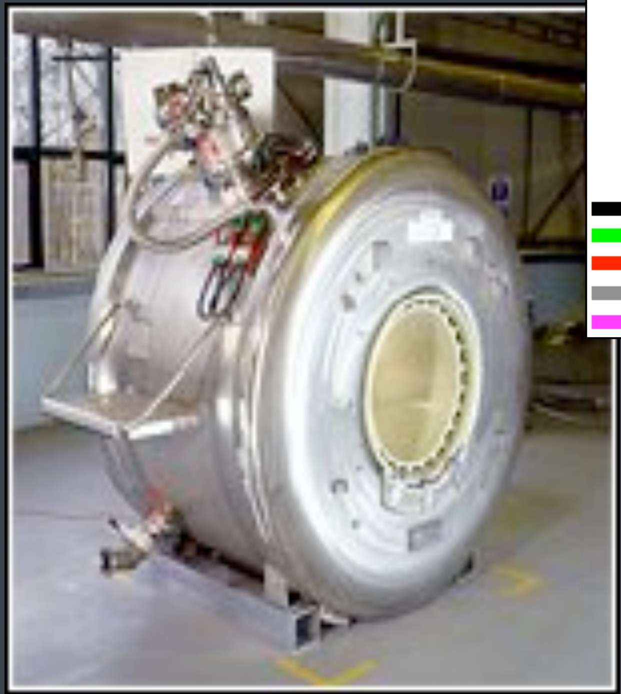


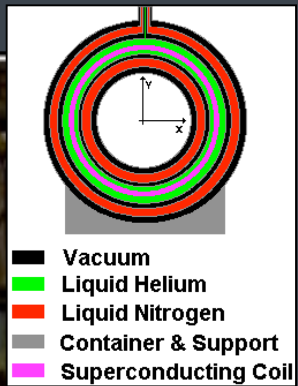
- spins precess at 54° to the z axis with random phase
- net bulk magnetisation parallel to B_0

B_0 field

3T Philips Achieva @ SPMMRC

- 60,000 x Earth's field
- superconducting wires
- contains 1000 litres of liquid He





superconducting magnets

now

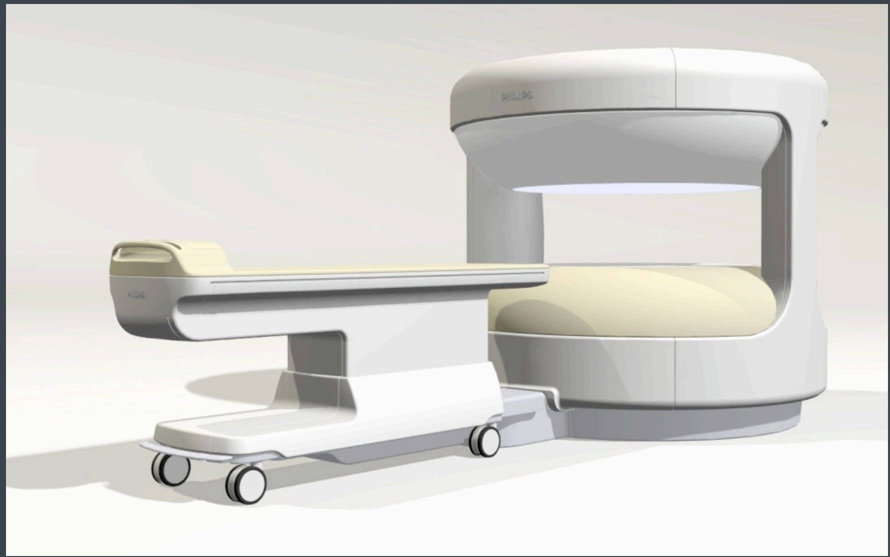
location	1990's	2000's
district general hospitals	0.5T	1.5T
medical schools	1.5T	3T
large research institutes	3T	7T

and up to 17T in animals!

(near) future

- 11.7T planned at Neurospin (CEA, France) (900mm warm bore)

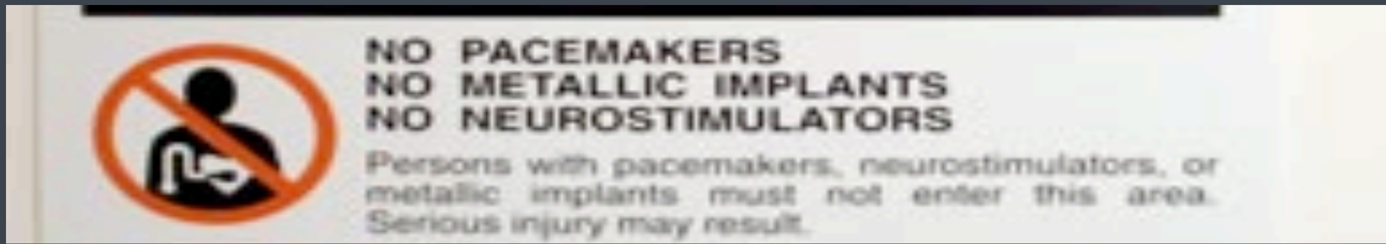
magnetic strength trends



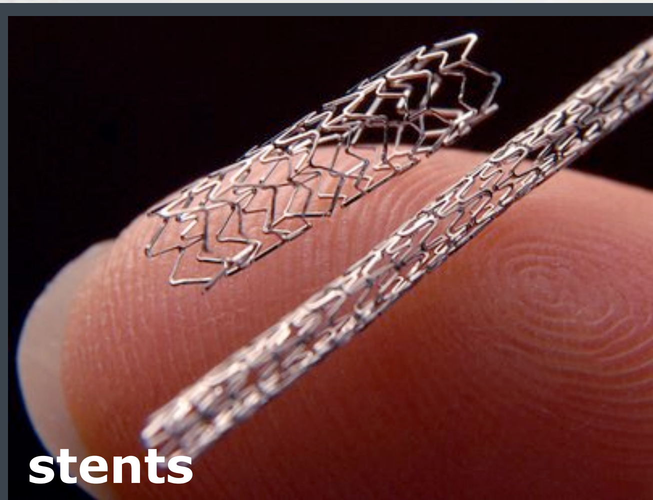
magnet designs

Magnetic force is powerful, permanent, increases rapidly in proximity of scanner

DANGER




pacemakers


stents

DANGER


DIZZINESS

- Classify staff and train appropriately
- Zone spaces to prevent accidental access

  visually indicate 5 G line for each magnet

- MR incompatible implants and projectiles

  make no assumptions

  ⇐ devices that are safe at 1.5T may not be at 3T

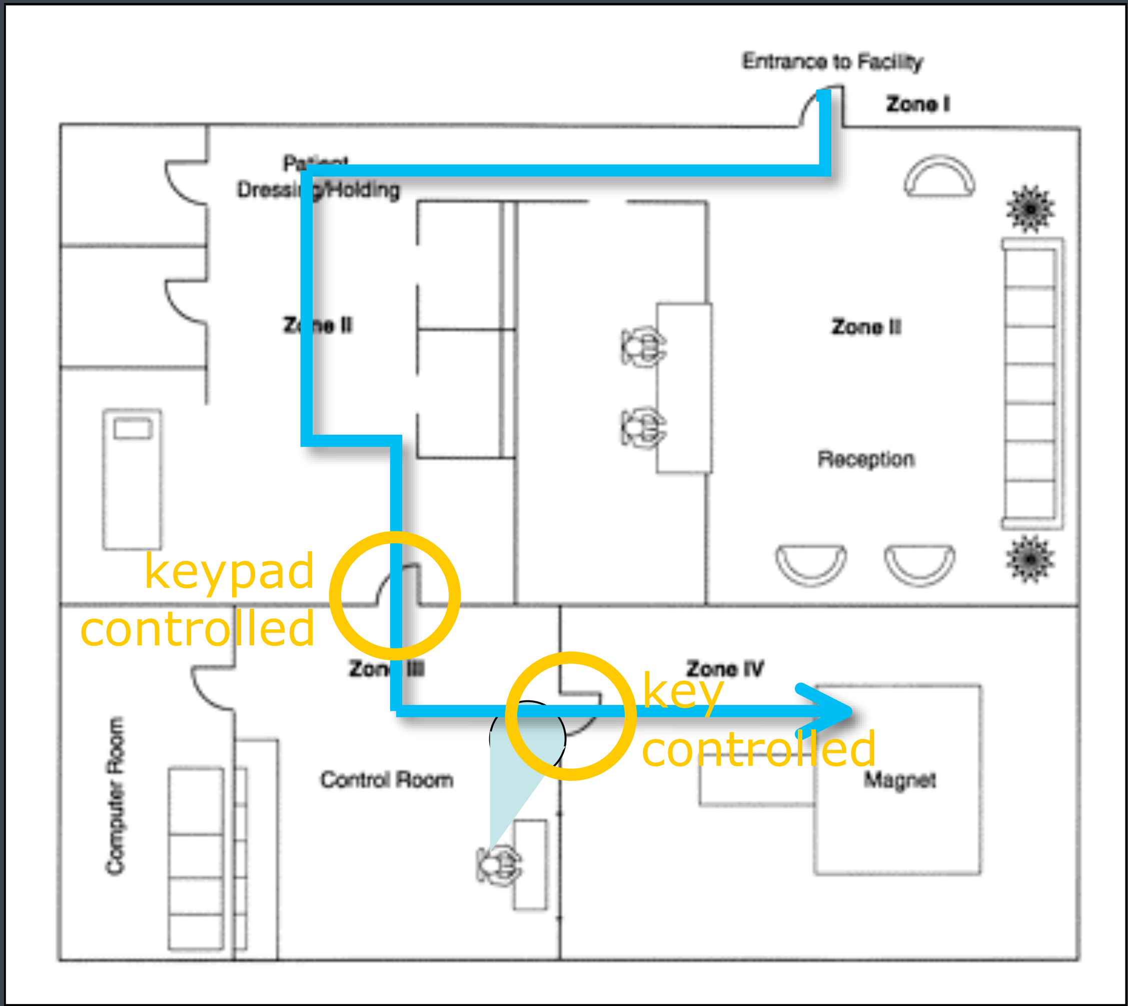
  screen, screen and screen again

  - in writing
  - at dressing room, verbally
  - screen again on entrance to magnet hall verbally

site management best practice

Limiting access

ACR white paper, 2002



site management best practice