EVROPSKÁ UNIE
Evropské strukturální a investiční fondy
Operační program Výzkum, vývoj a vzdělávání

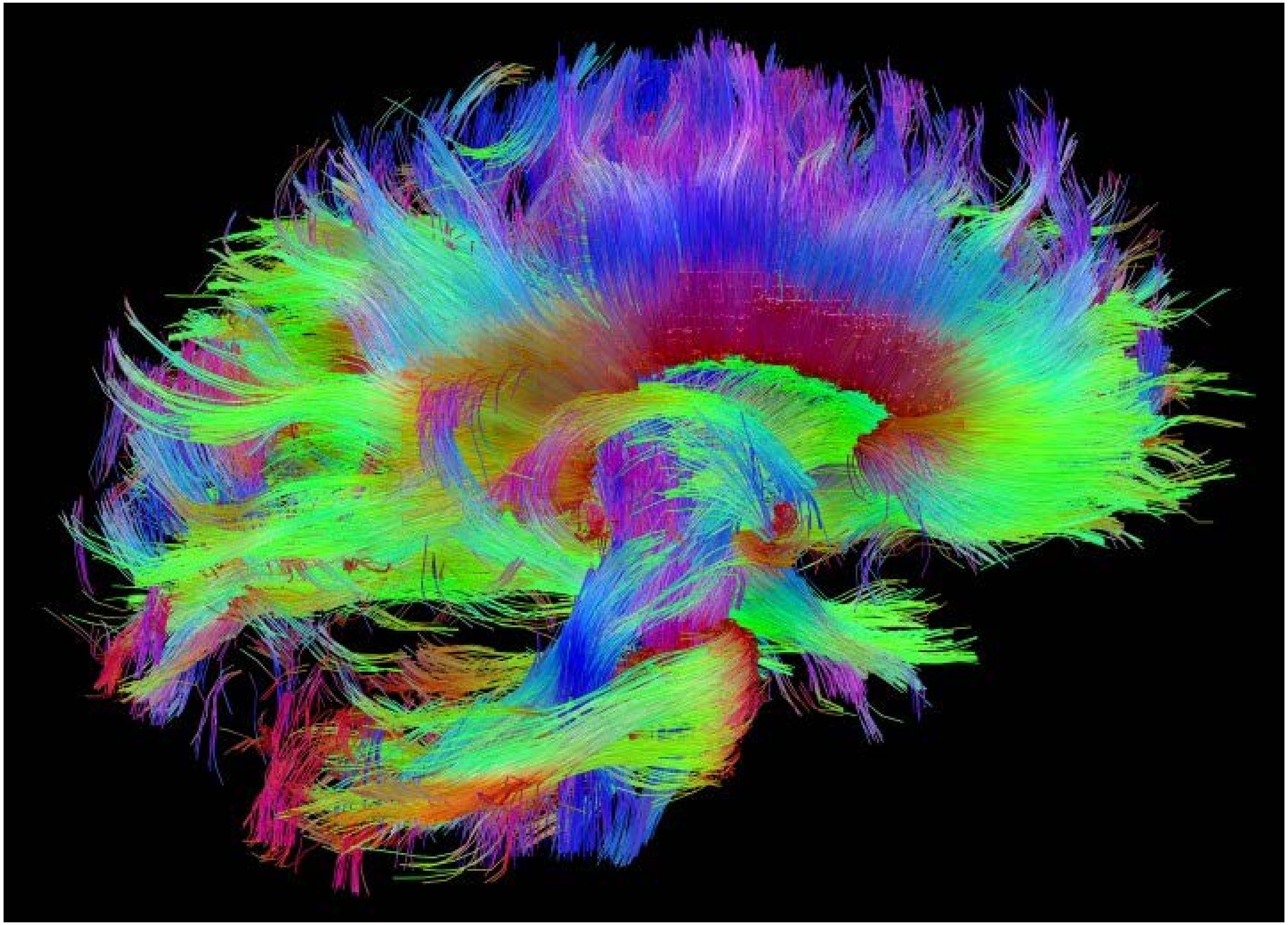
MINISTERSTVO ŠKOLSTVÍ
MLÁDEŽE A TĚLOVÝCHOVY

(Jaderná) Magnetická Rezonance

Diffusion Tensor Imaging - DTI

Zdroj: https://predmety.fbmi.cvut.cz/cs/doktorske-bme

Human Connectome Project



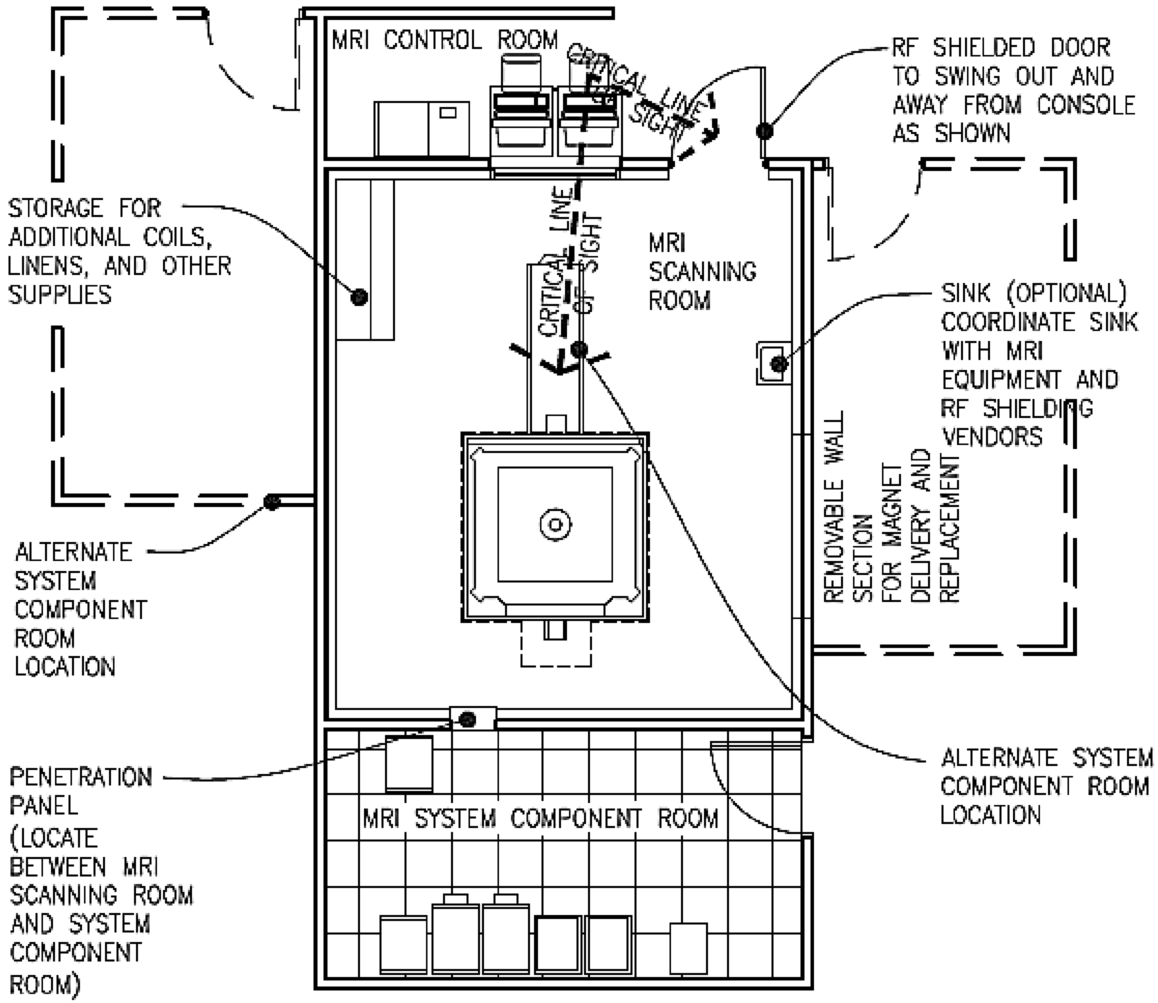
http://www.humanconnectomeproject.org/

MRI přístroj – 7 T

System weight (in operation) **<25 tons**

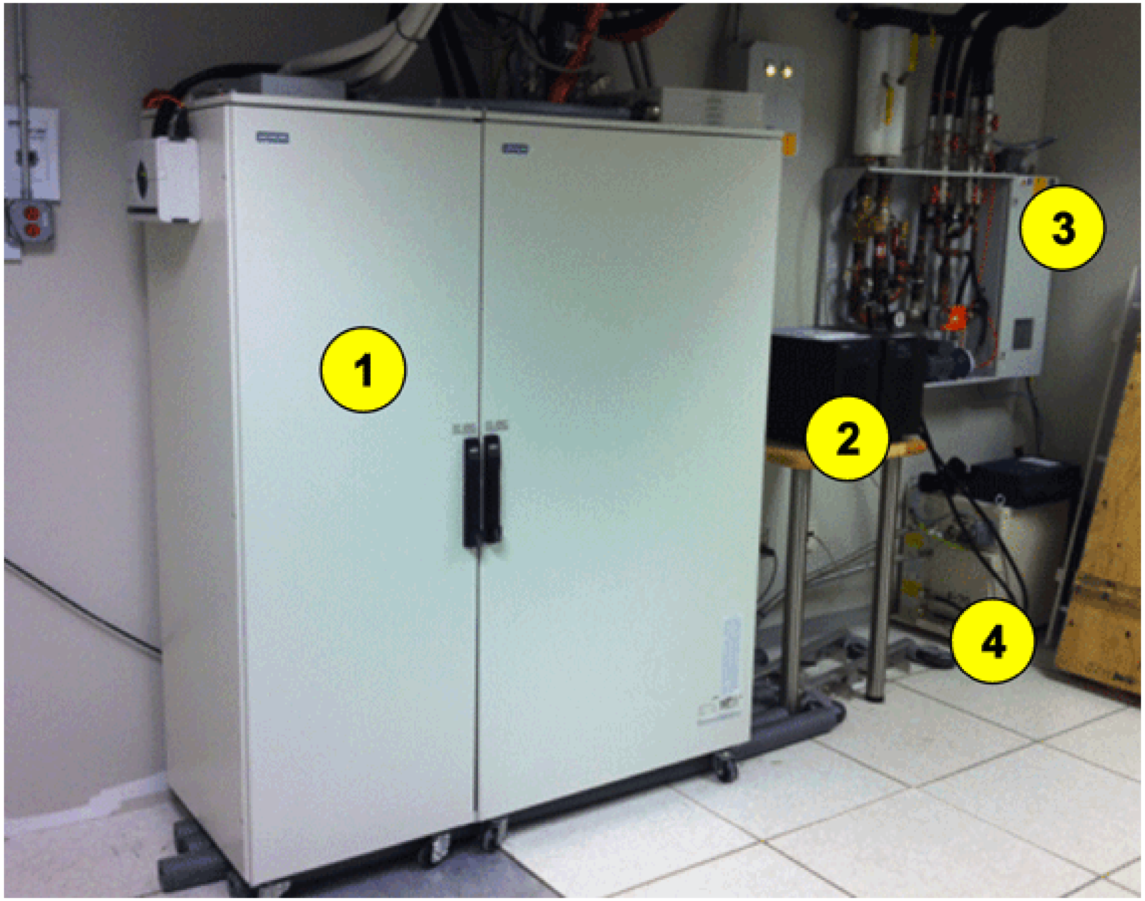
https://www.siemens-healthineers.com/magnetic-resonance-imaging/7t-mri-scanner/magnetom-terra

MRI přístroj – instalace



http://mriquestions.com/mr-system-layout.html

MRI přístroj – instalace

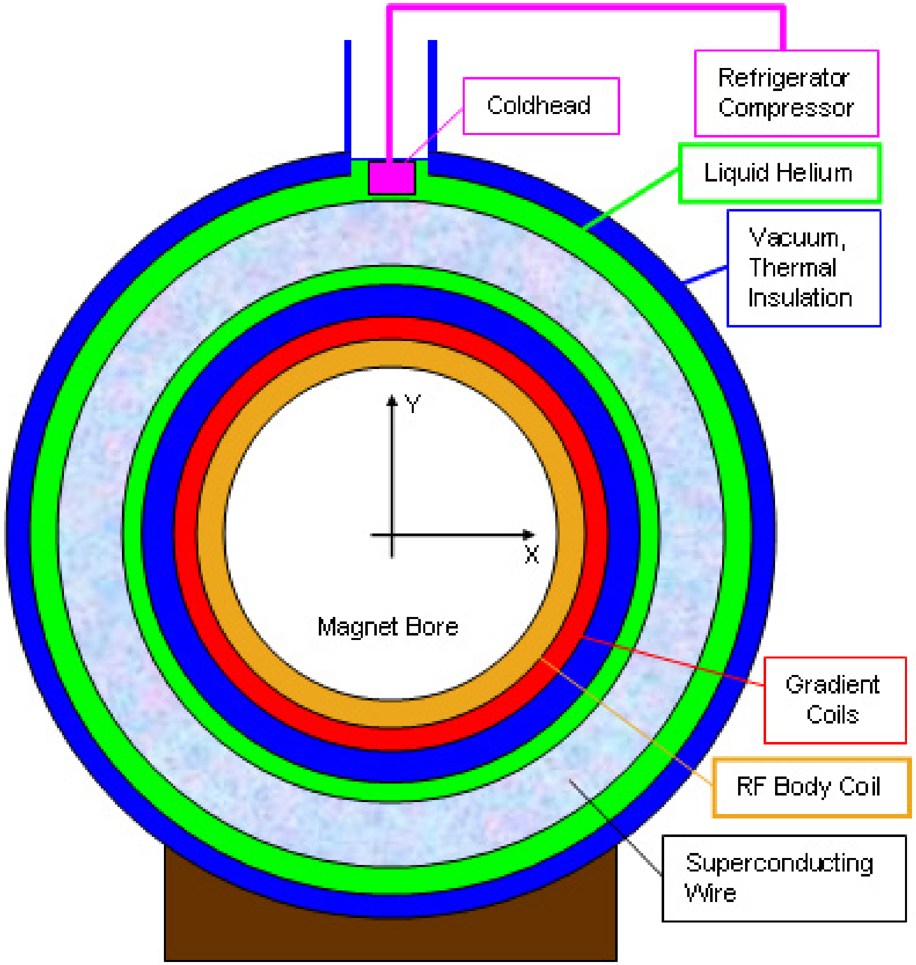


Cca 80 kVA (MRI)
v.
20 kVA (RD el. vyt.)

1) Gradient and radiofrequency cabinet; 2) universal power supply; 3) water pump/chiller; and 4) helium pump.

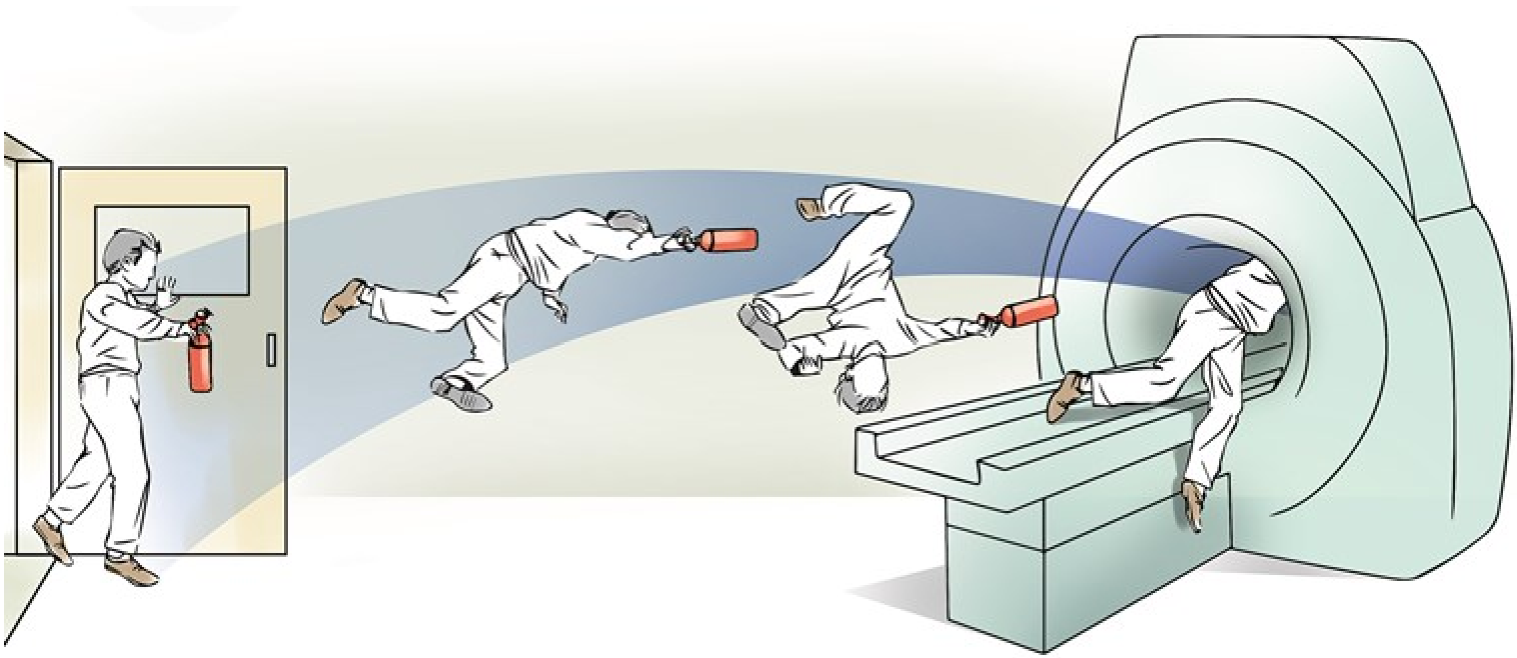
http://mriquestions.com/mr-system-layout.html

MRI přístroj - chlazení



https://www.cis.rit.edu/htbooks/mri/chap-9/i2-3.htm

MRI přístroj – kovové materiály



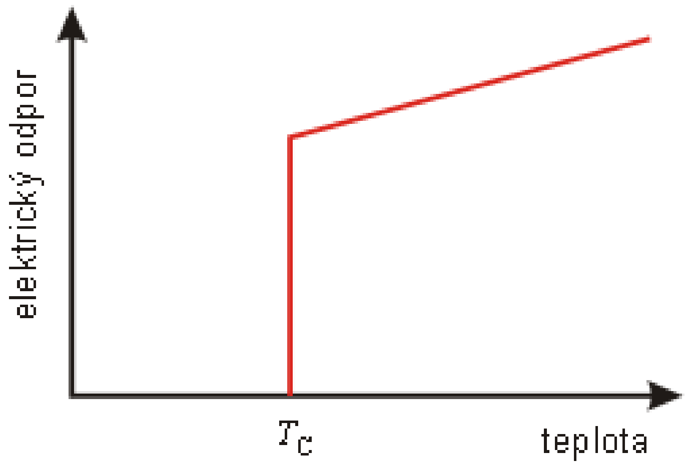
Červené tlačítko – Magnet quench: A quench refers to the sudden loss of superconductivity when its temperature is raised - https://www.youtube.com/watch?v=9SOUJP5dFEg

https://indianexpress.com/article/explained/story-of-an-extraordinary-death-how-mri-machines-work-and-can-in-rare-cases-kill-5051494/

Základy fyziky

Základy fyziky – supravodivost

Supravodivost je jev kvantové mechaniky, při němž materiál ochlazený pod svou kritickou teplotu (TC) vede elektrický proud bez odporu, takže se žádná energie neztrácí přeměnou na Jouleovo teplo.

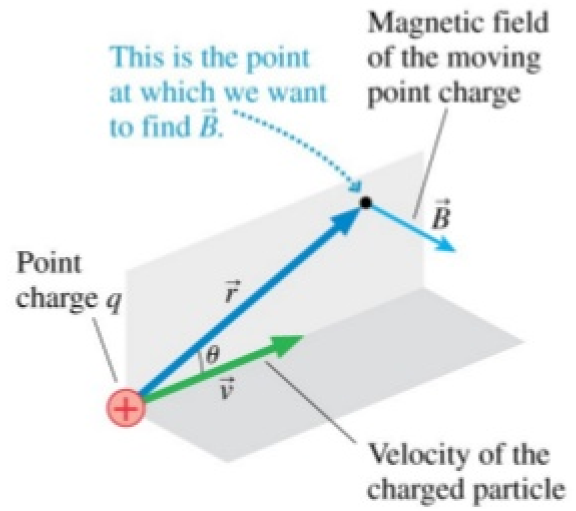


https://www.aldebaran.cz/bulletin/2004_36_hts.php

Základy fyziky – Biot Savartův zákon

The source of the magnetic field: Moving charges

- The current in the wire consists of moving charges
- A moving charge alters the space to produce a magnetic field.
- A stationary charge will not produce a magnetic field



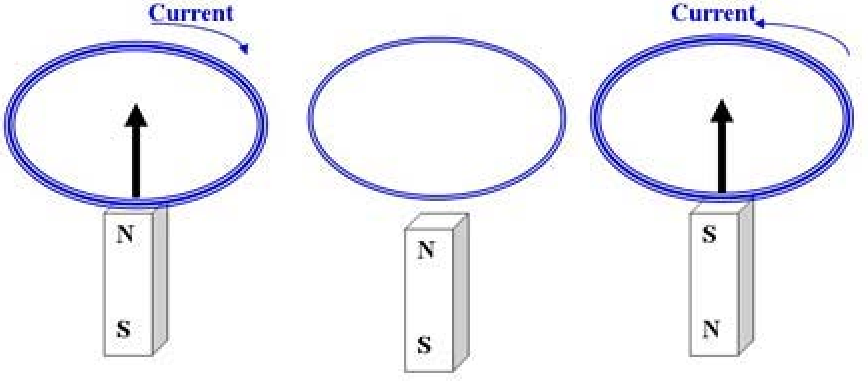
Ampérovo pravidlo pravé ruky

https://www.slideshare.net/abhinaypotlabathini/magnetic-39152188

Základy fyziky – Faradayův zákon elektromagnetické indukce

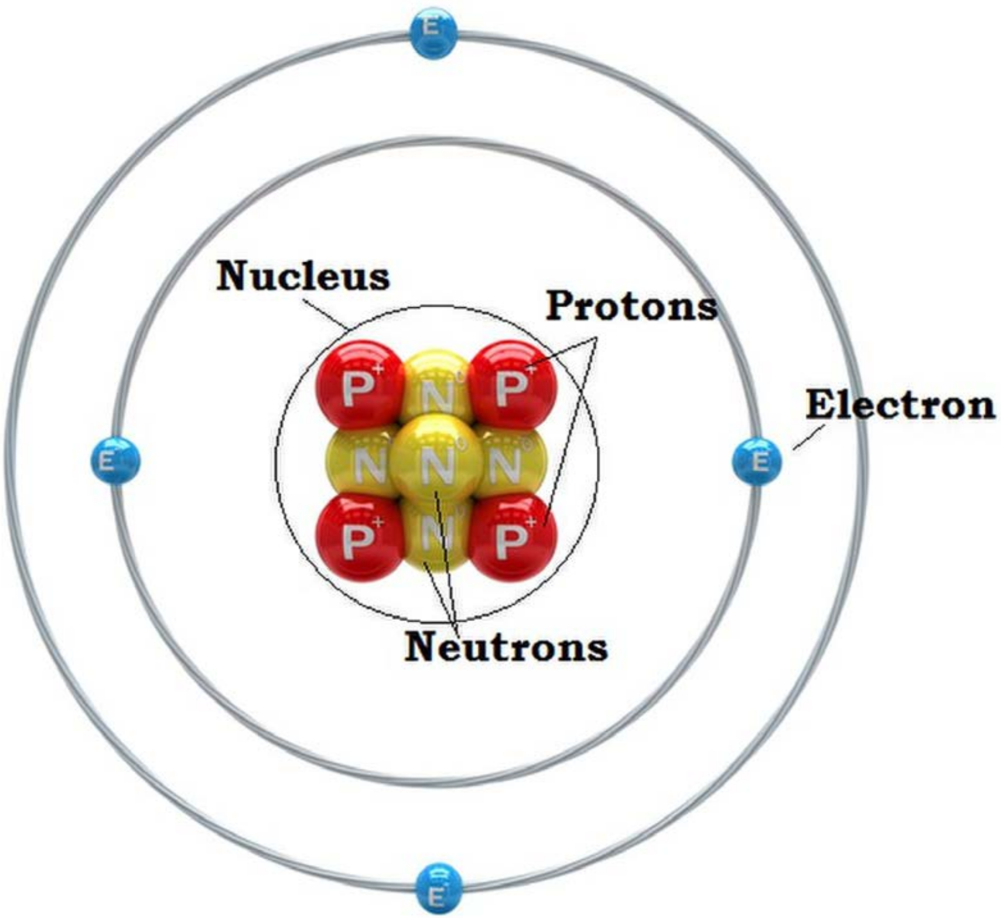
Indukované elektromotorické napětí U_i je rovno záporně vzaté časové změně magnetického indukčního toku:

$$U_i = -\frac{\Delta\Phi}{\Delta t}$$



https://www.sciencebuddies.org/science-fair-projects/project-ideas/Elec_p079/electricity-electronics/manipulating-magnets-to-improve-generator-output#background

Základy fyziky – struktura atomu



Náboj:

1.6×10^{-19} C

-1.6×10^{-19} C

Hmotnost:

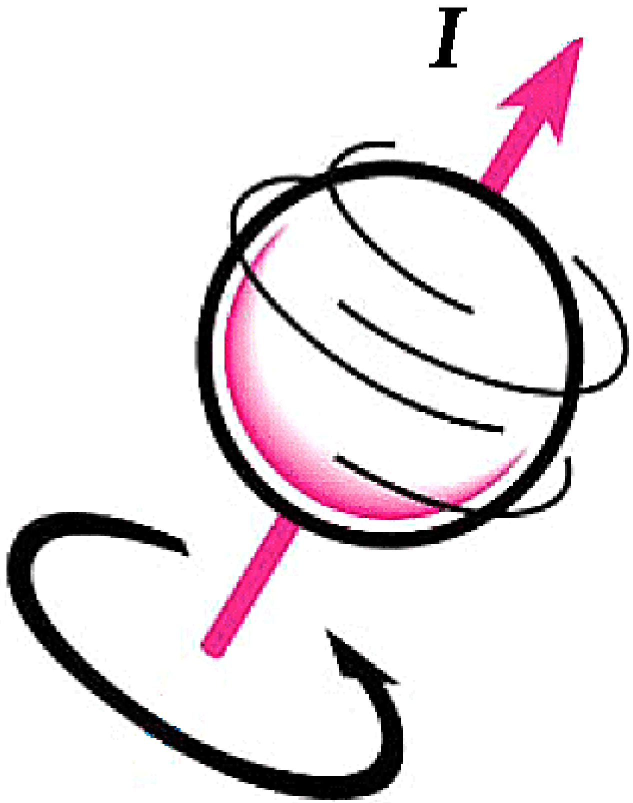
1.6749×10^{-27} kg

1.673×10^{-27} kg

9.109×10^{-31} kg

https://www.livescience.com/37206-atom-definition.html

Fyzika částic - spin

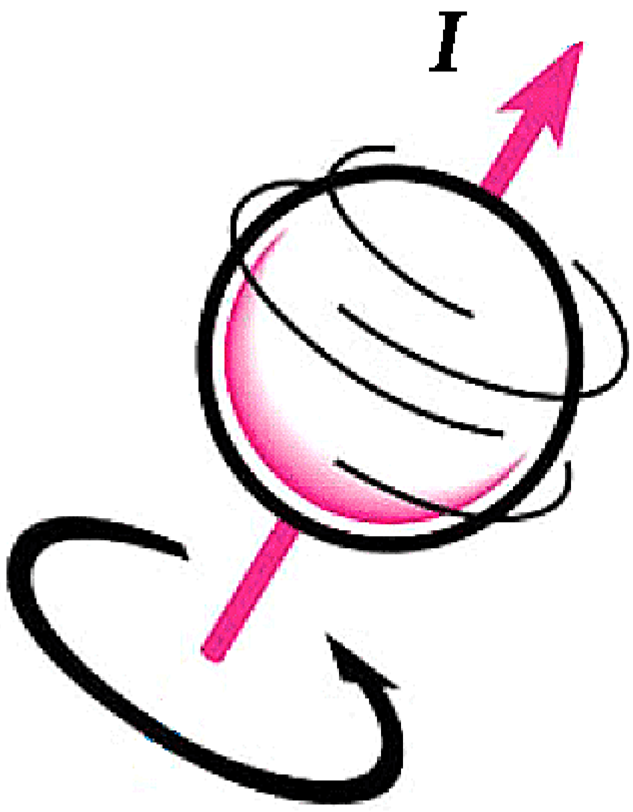


Atomic and subatomic particles posses a corresponding property known as ***spin*** or ***spin angular momentum.*** Protons, neutrons, whole nuclei, and electrons all possess *spin* and are often represented as tiny spinning balls.

https://courses.engr.illinois.edu/ece480/fa2018/virtual_lab_generation.html

Princip Magnetické rezonance

Fyzika částic - spin



- **Proton and neutron** spins are known as nuclear spins.
- An unpaired component has a spin of ½ and two particles with opposite spin cancel one another.
- **In NMR it is the unpaired nuclear spins that produce a signal in a magnetic field.**

https://courses.engr.illinois.edu/ece480/fa2018/virtual_lab_generation.html

Common Nuclei with NMR properties

- Criteria:

  Must have ODD number of protons or ODD number of neutrons.

Reason?

It is impossible to arrange these nuclei so that a zero net angular momentum is achieved. Thus, these nuclei will display a magnetic moment and angular momentum necessary for NMR.

Examples:

^{1}**H**, ^{13}C, ^{19}F, ^{23}N, and ^{31}P with gyromagnetic ratio of **42.58**, 10.71, 40.08, 11.27 and 17.25 **MHz/T**.

Atomy a výsledný spin

Number of protons	Number of neutrons	Spin quantum number	Examples
Even	Even	0	^{12}C, ^{16}O, ^{32}S
Odd	Even	1/2	^{1}H, ^{19}F, ^{31}P
"	"	3/2	^{11}B, ^{35}Cl, ^{79}Br
Even	Odd	1/2	^{13}C
"	"	3/2	^{127}I
"	"	5/2	^{17}O
Odd	Odd	1	^{2}H, ^{14}N

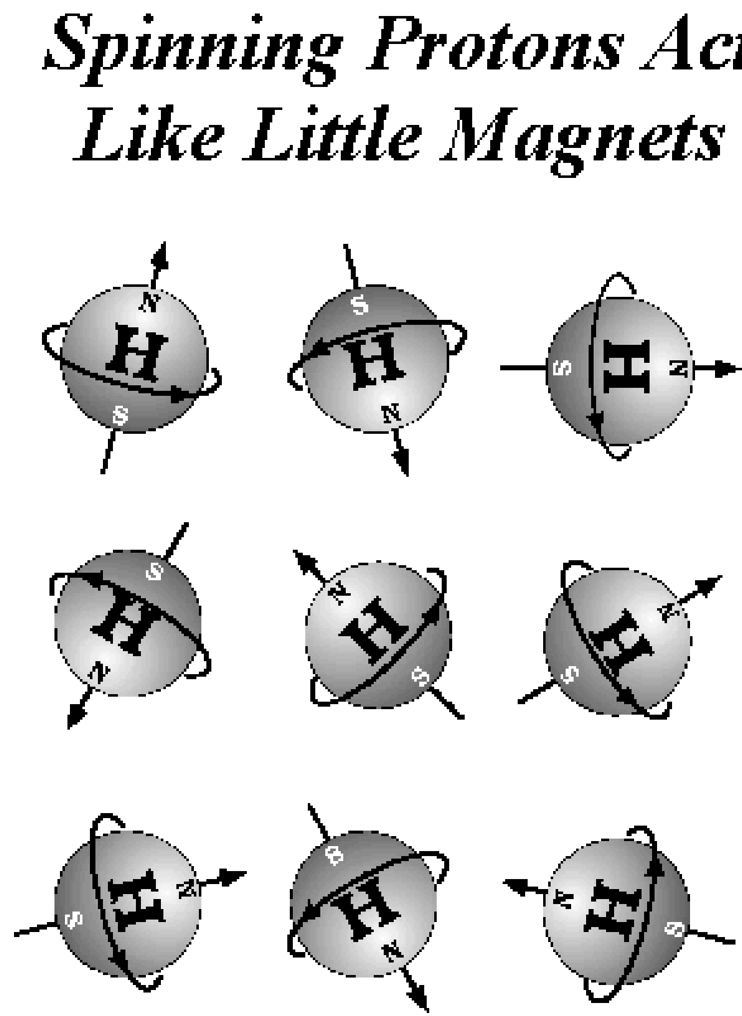
Hydrogen

- Human body is mainly composed of fat and water, which makes the human body composed of about 63% hydrogen.

Example – 2 dcl water

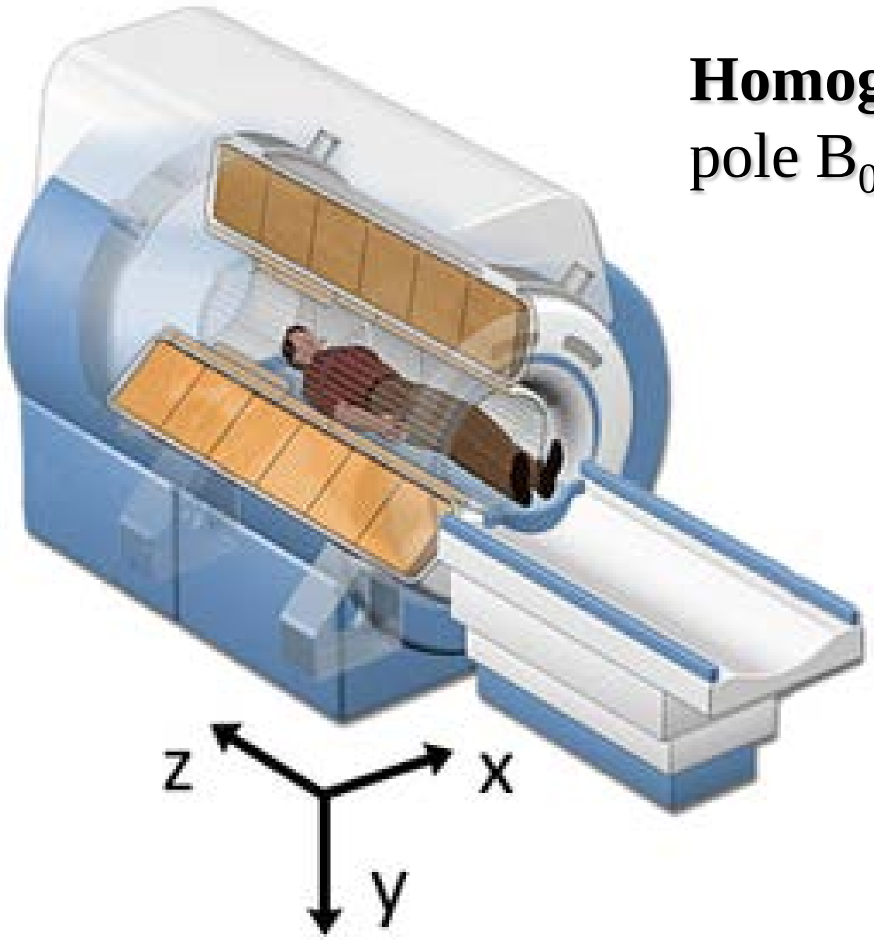
- Why Are Protons Important to MRI?
  - positively charged
  - spin about a central axis
  - a moving (spinning) charge creates a magnetic field.
  - the straight arrow (vector) indicates the direction of the magnetic field.

Protons of Hydrogen



Magnetické pole BO

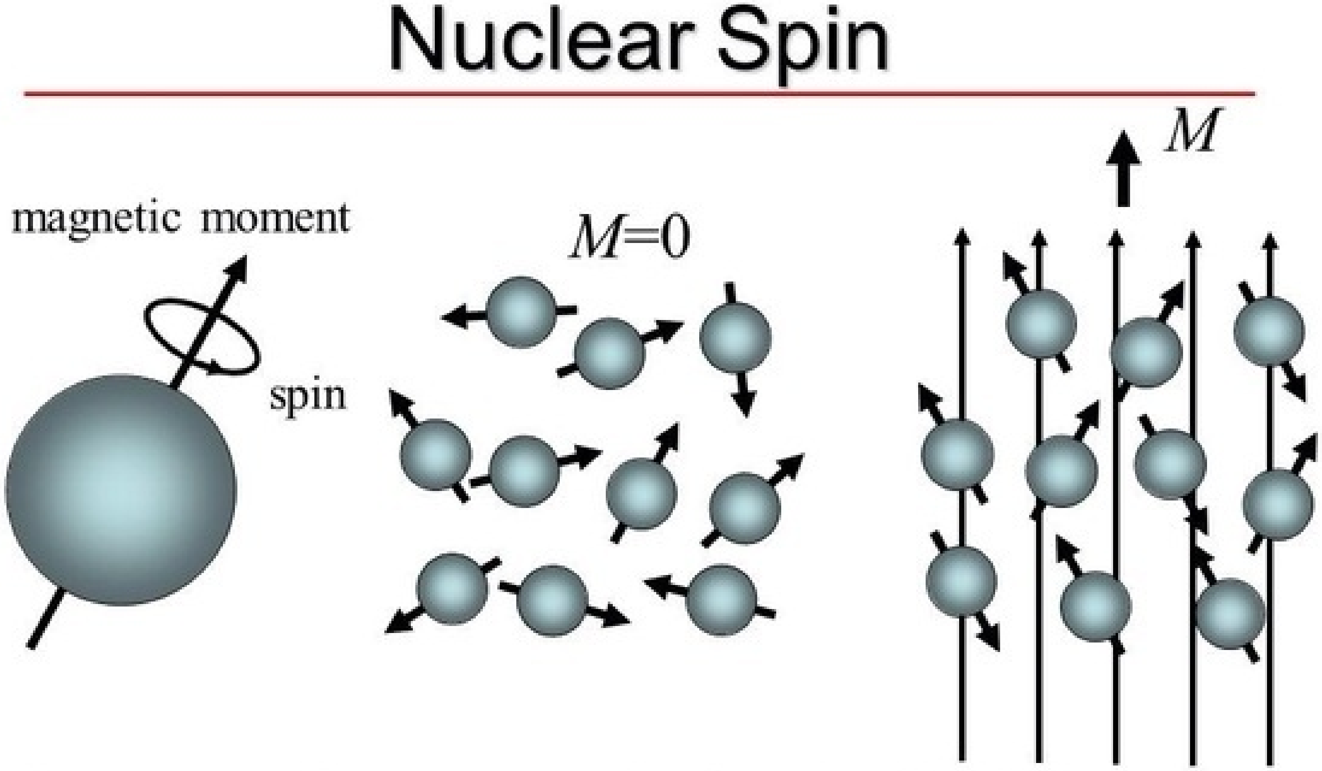
MRI - coordinates



Homogenní magnetické pole B_0 ve směru osy z.

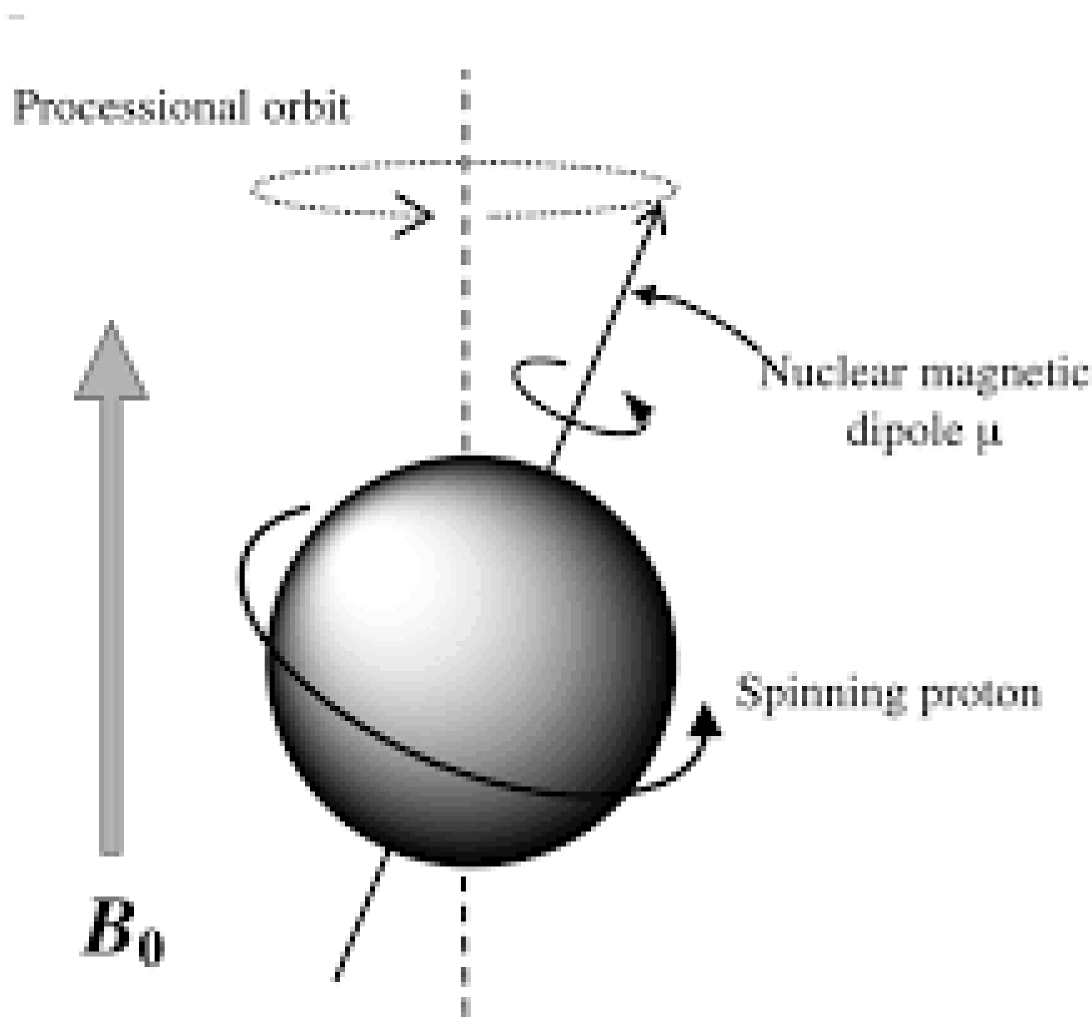
Homogenita mag. pole

Protons of Hydrogen in B_0



If a nucleus has an unpaired proton it will have spin and it will have a net magnetic moment or field

Precesní pohyb



Larmor Equation

- Frequency (rate) of precession is proportional to the strength of magnetic field

$$\omega = \gamma * B$$

Larmor Frequency

$$\omega = \gamma * B$$

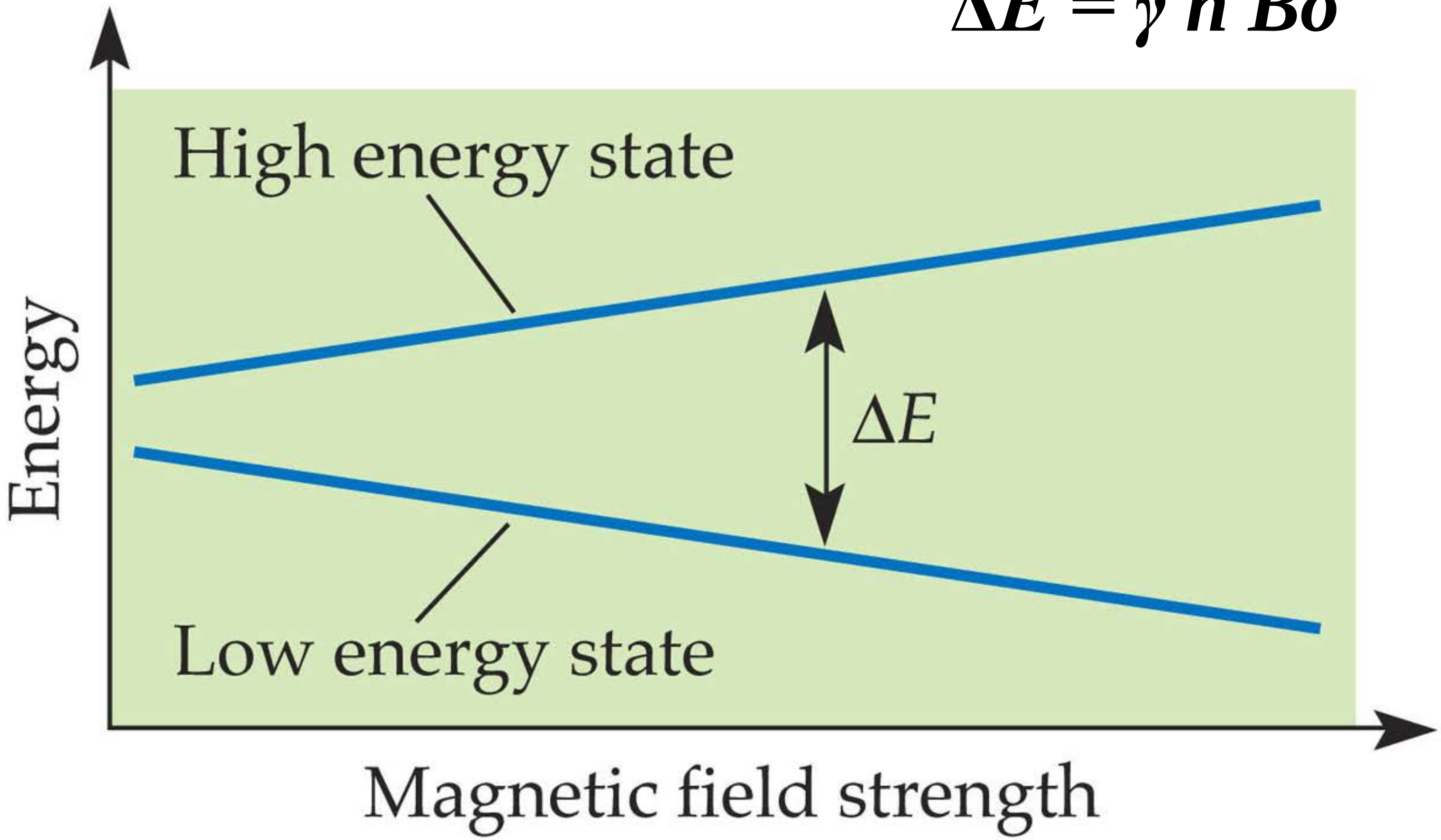
$\omega = 63MHz$ If B = 1.5T

$\omega = 2 * 63MHz$ If B = 3.0T

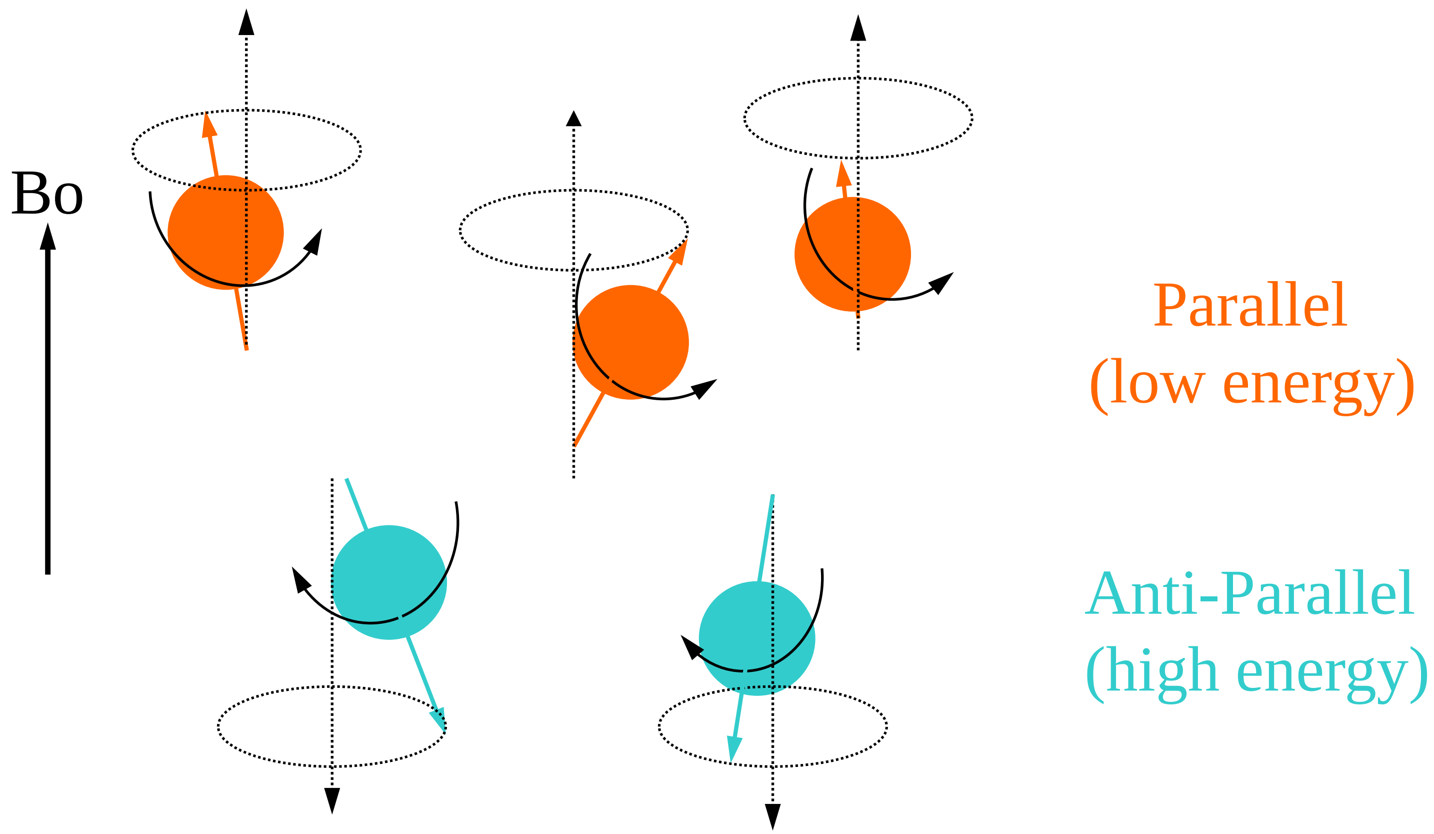
$= 126MHz$

Zeeman Effect

$$\Delta E = \gamma\, h\, Bo$$

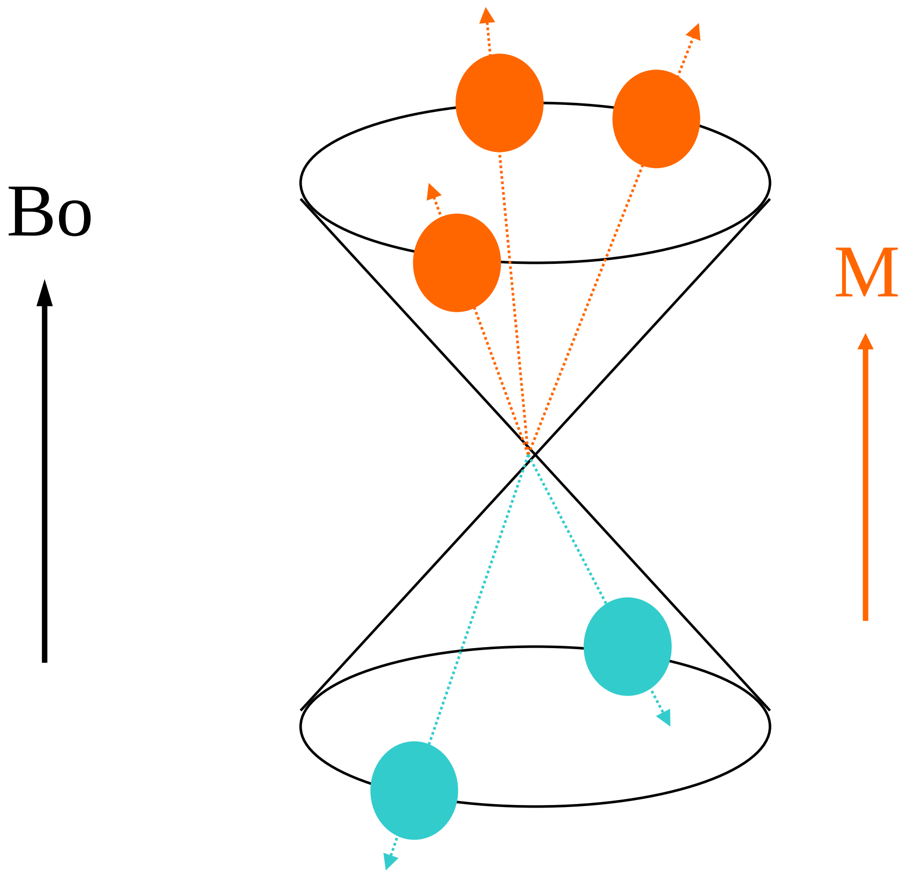


Protons in Magnetic Field $\mathbf{B_0}$



Spinning protons in a magnetic field will assume two states.
If the temperature is 0° K, all spins will occupy the lower energy state.

Net Magnetization

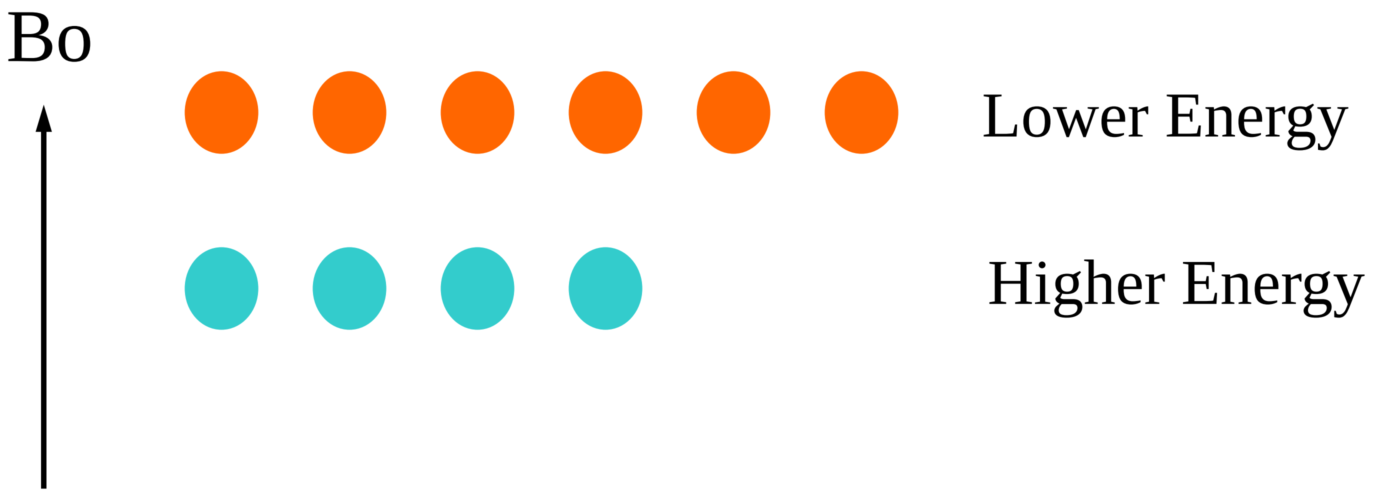


$$M = c\frac{B_o}{T}$$

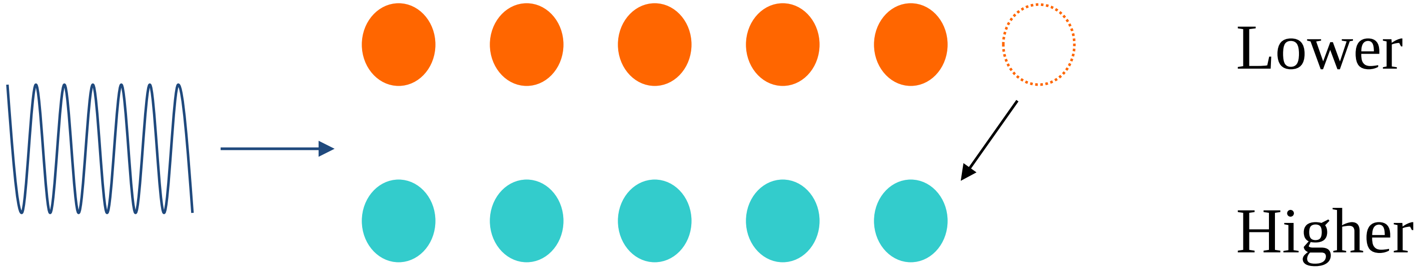
The Boltzman equation describes the population ratio of the two energy states:

$$N^-/N^+ = e^{-\Delta E/kT}$$

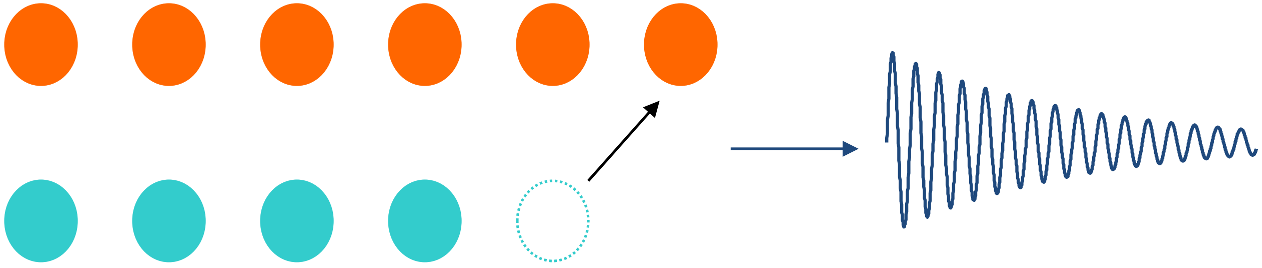
Spin System Before Irradiation



The Effect of Irradiation to the Spin System

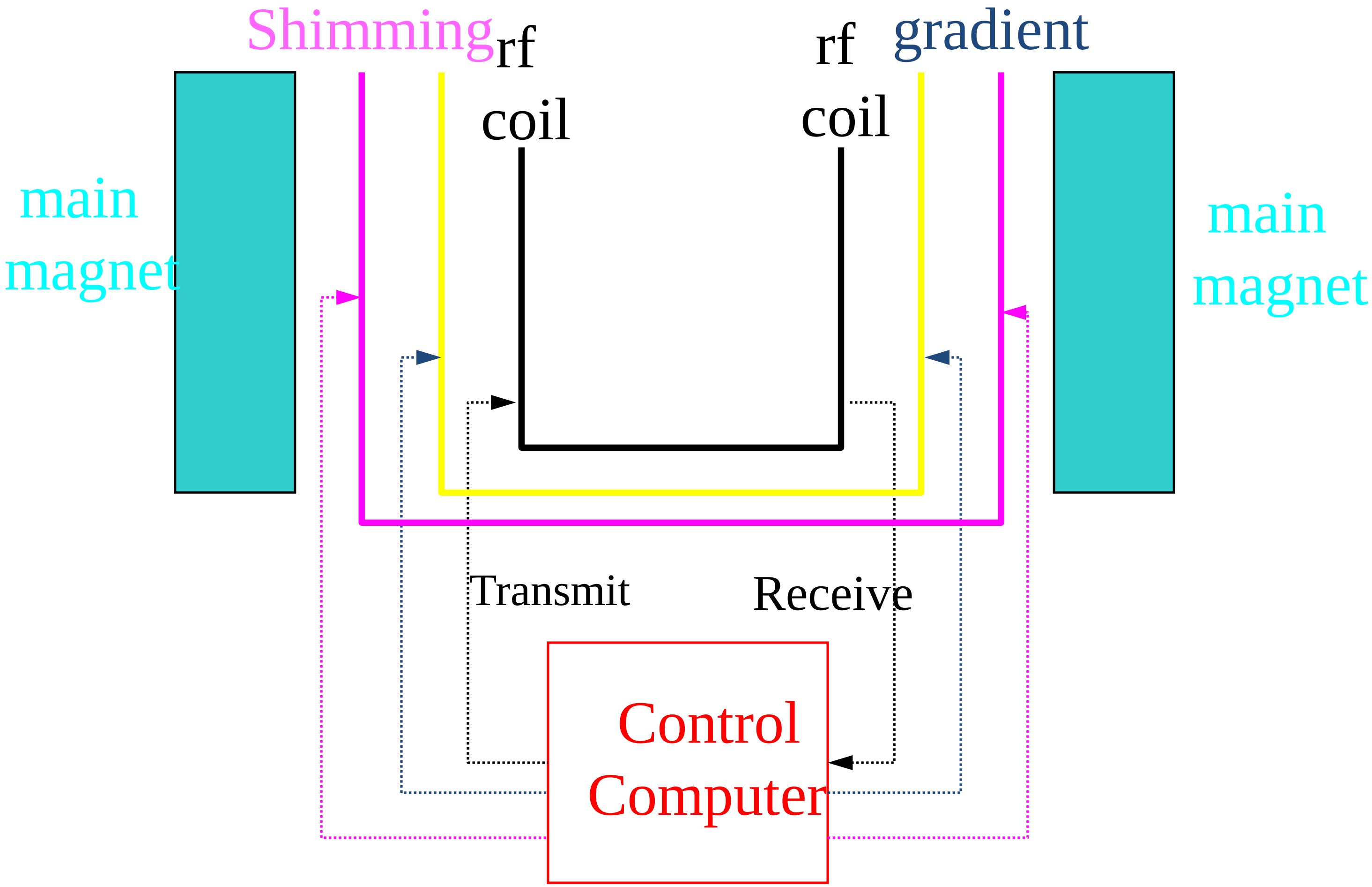


Spin System After Irradiation

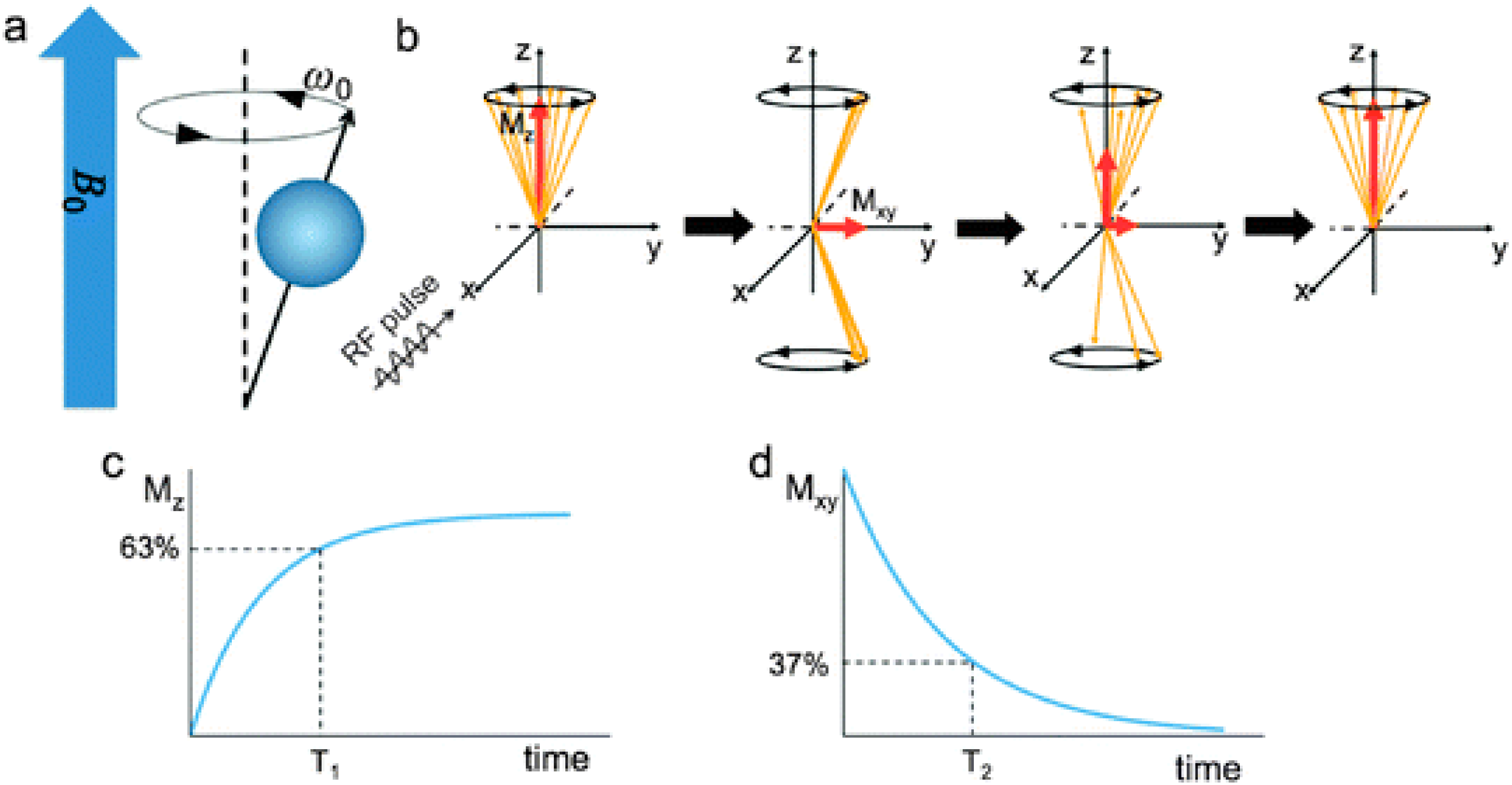


RF a gradientní cívky

Components of MRI



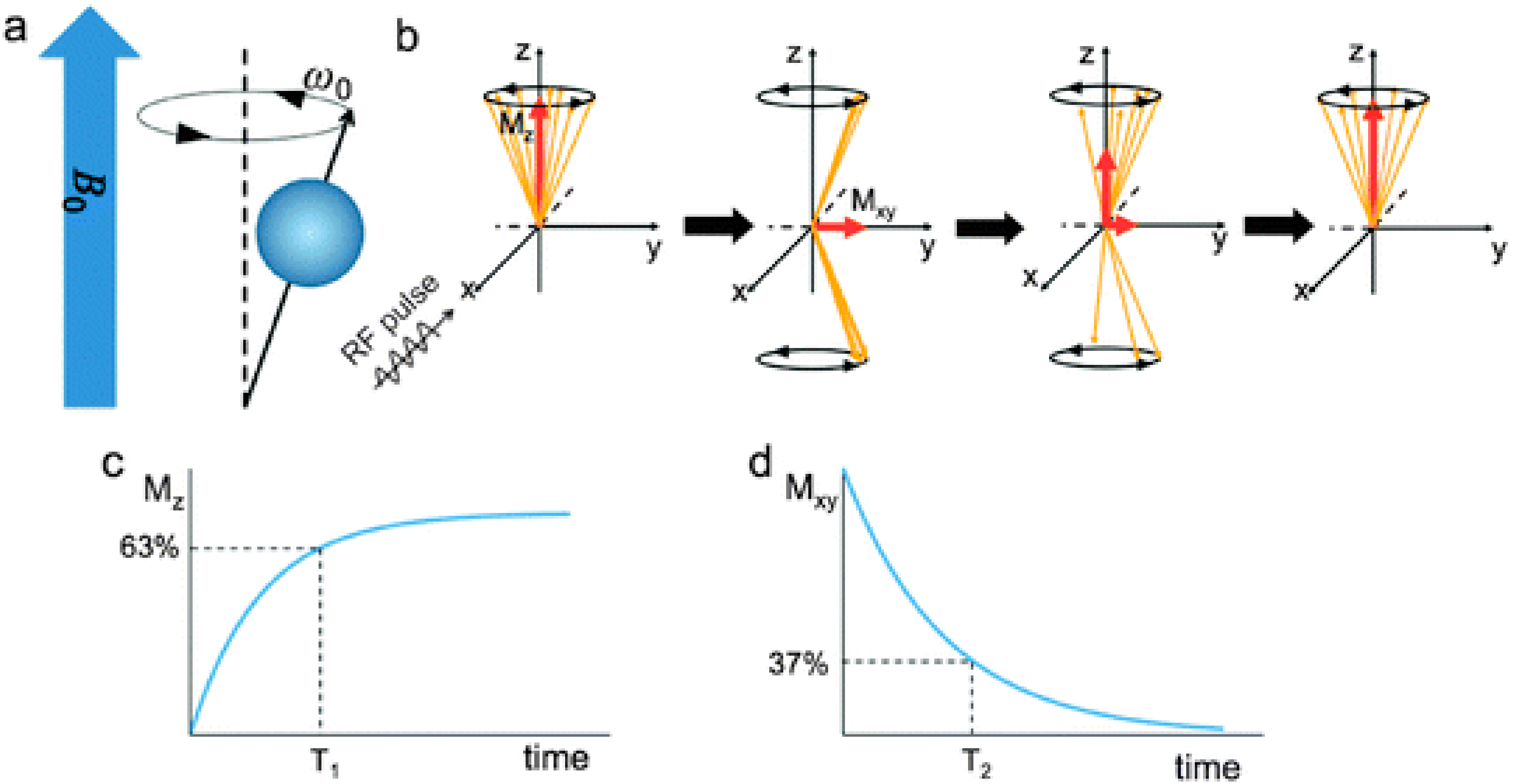
Radio-frequency pulse 90˚ – RF90



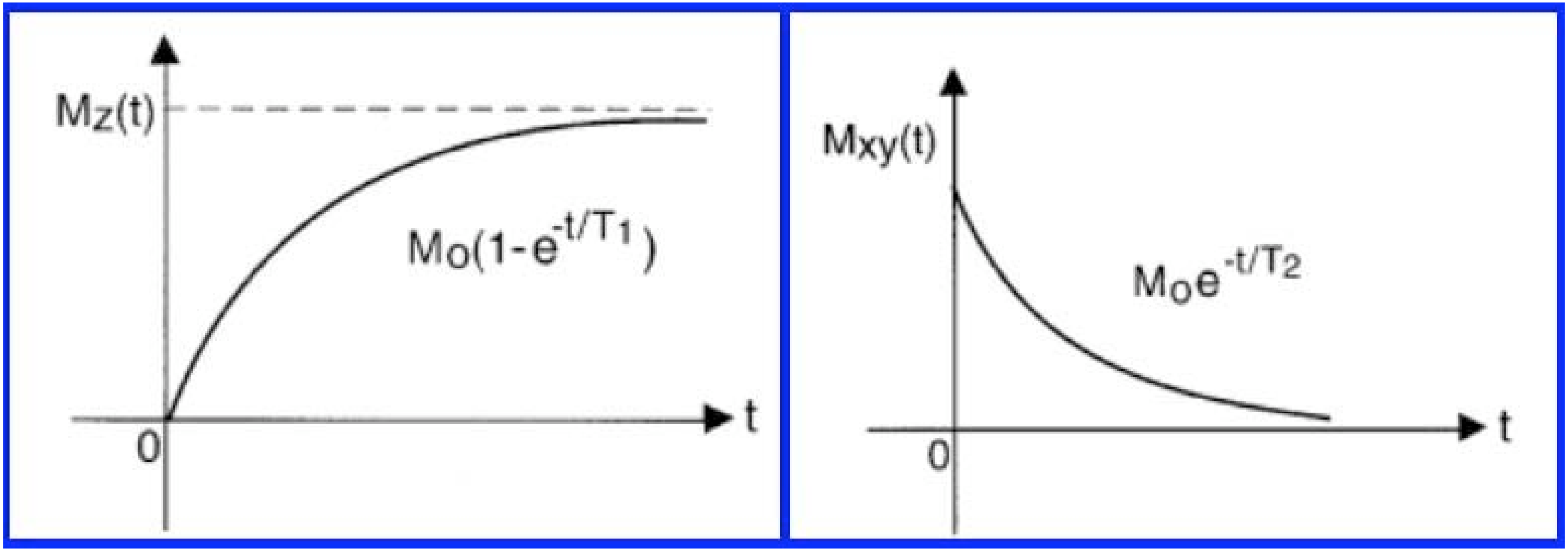
Types of Relaxation

- *Longitudinal* – precessing protons are pulled back into alignment with main magnetic field of the scanner (B_o) reducing size of the magnetic moment vector in the x-y plane
- *Transverse* – precessing protons become out of phase leading to a drop in the net magnetic moment vector (M_o)
- Transverse relaxation occurs much faster than Longitudinal relaxation
- *Tissue contrast is determined by differences in these two types of relaxation*

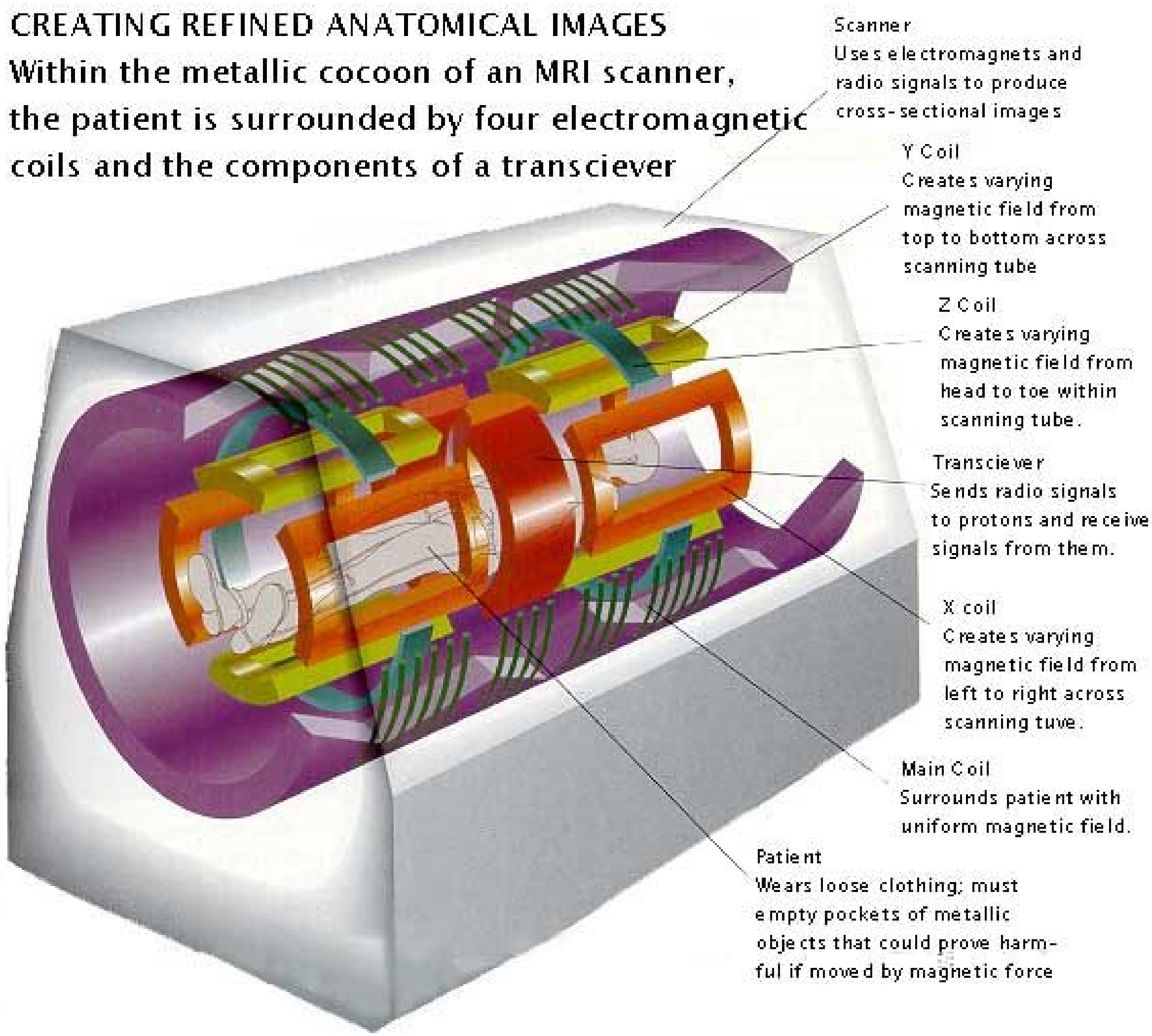
Relaxations



Magnetization – PD, T1, T2

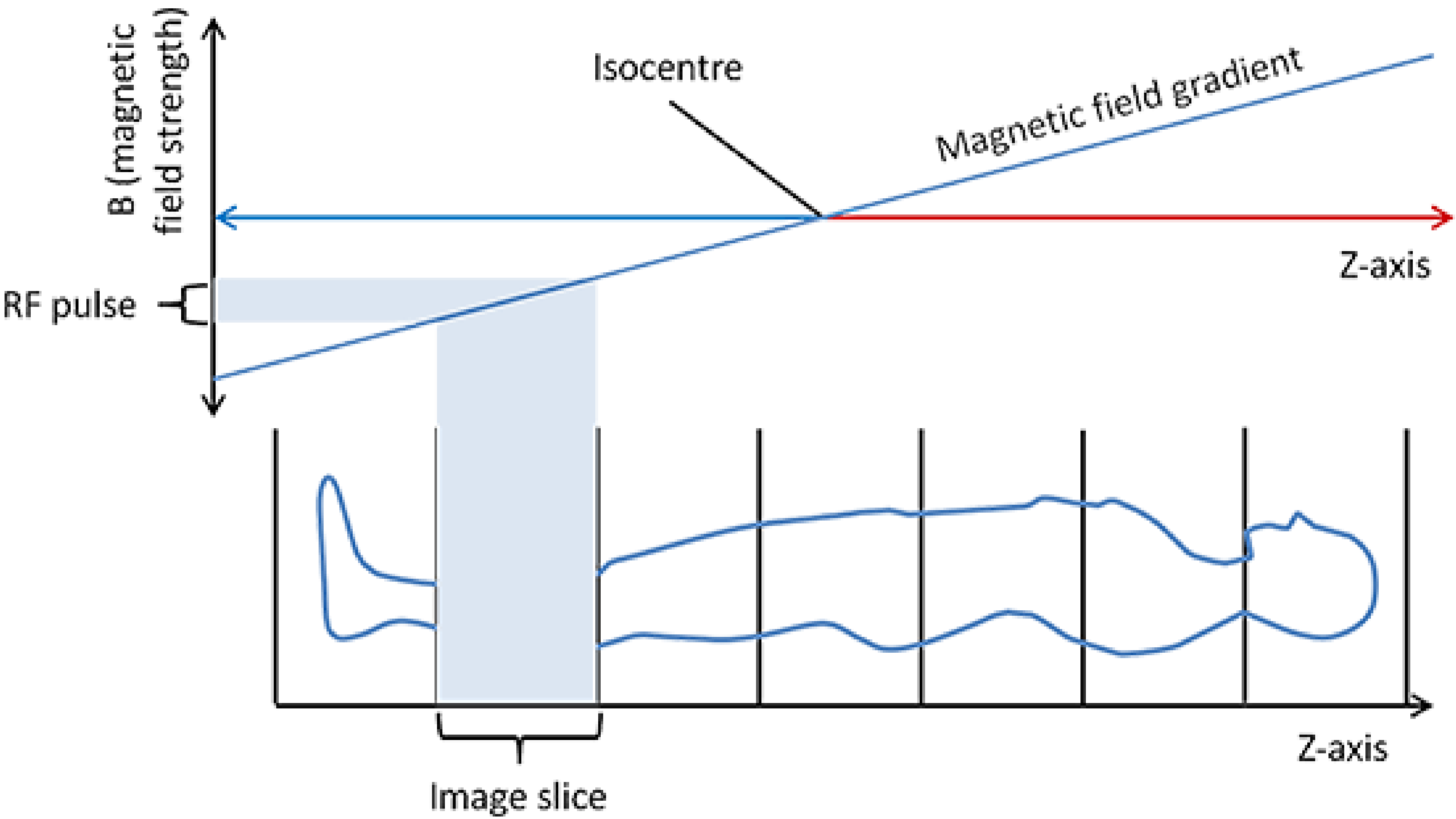


Gradient coils



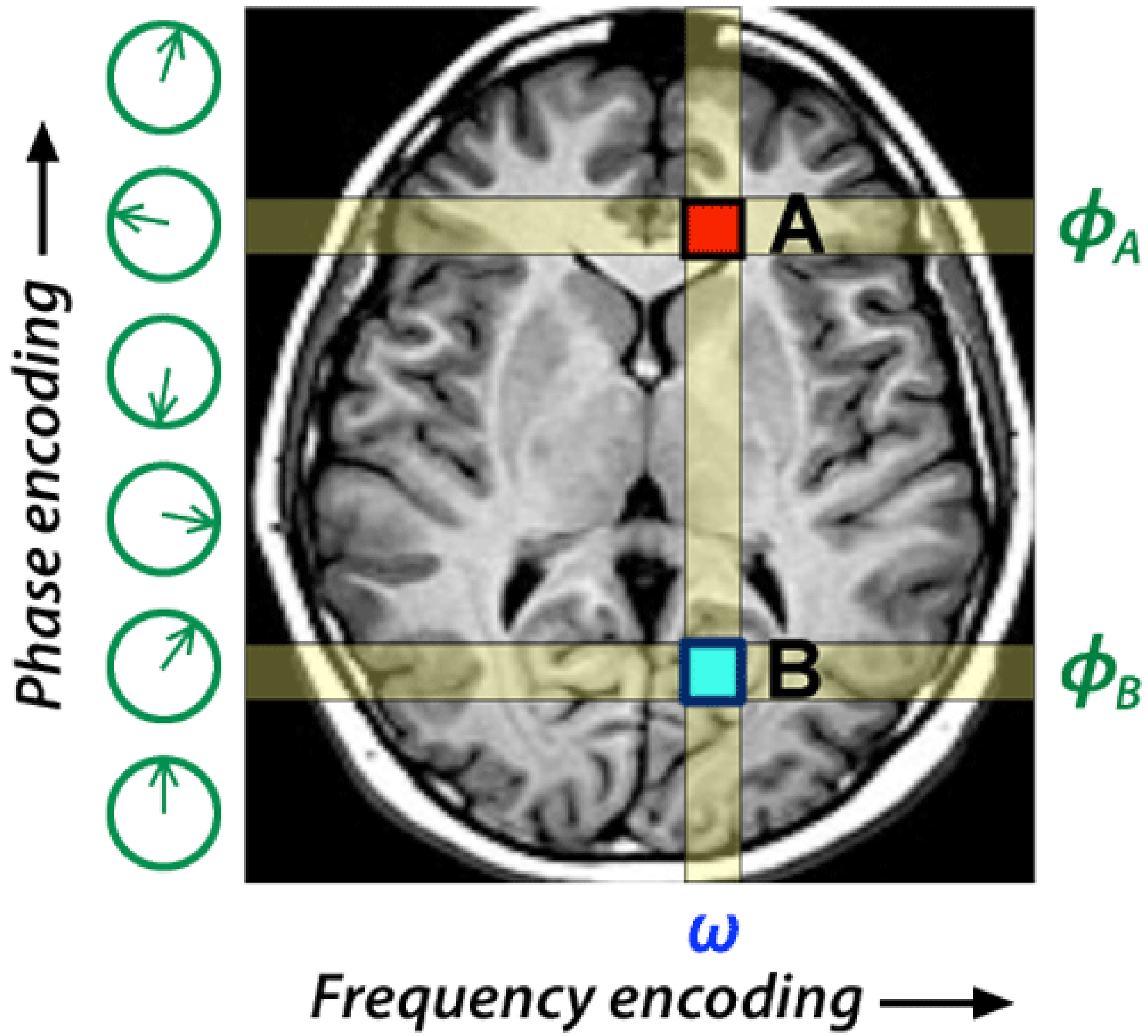
https://cz.pinterest.com/pin/146648531586128760/

Výběr řezu



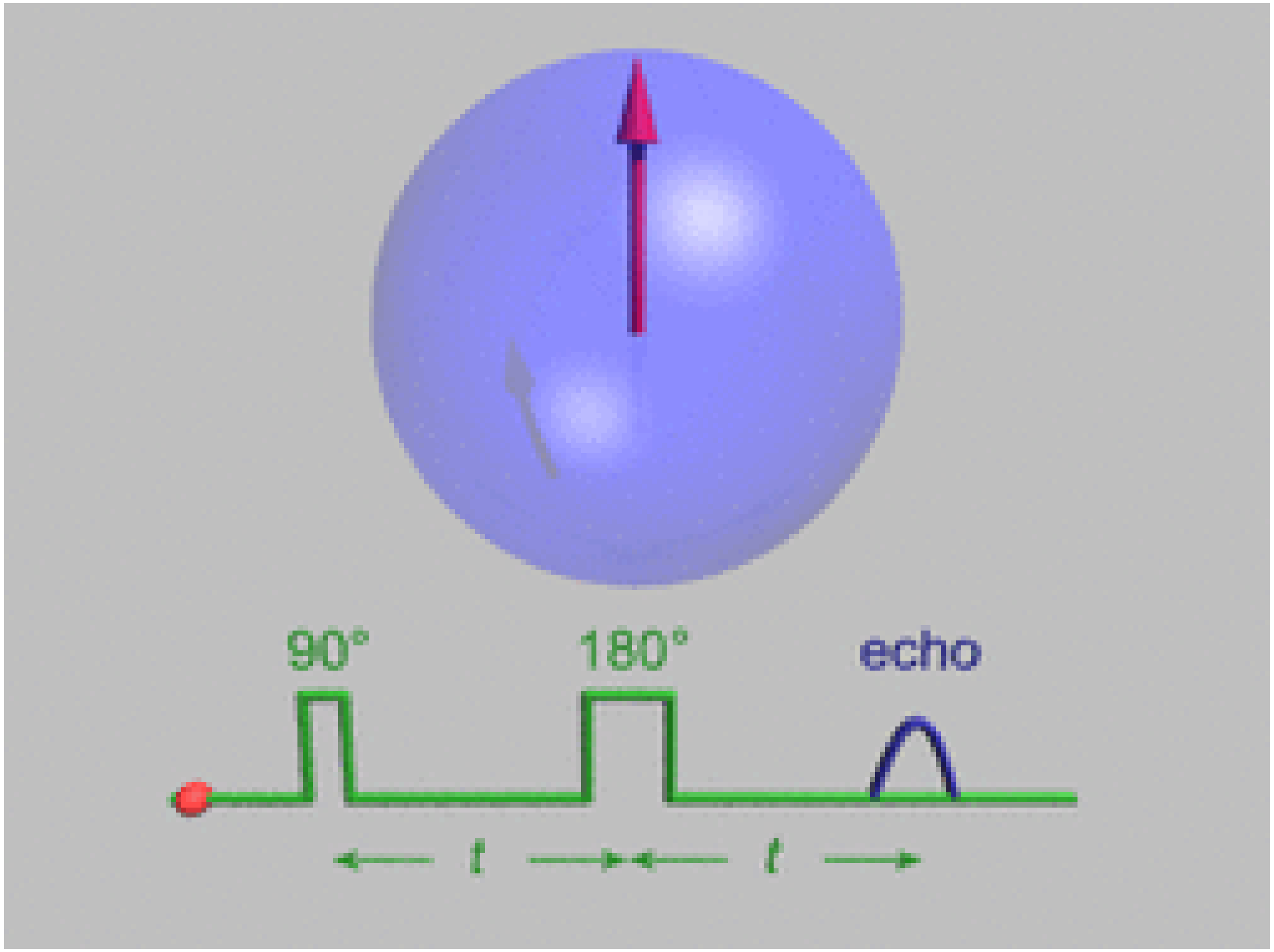
https://www.radiologycafe.com/radiology-trainees/frcr-physics-notes/slice-selection

Prostorové kódování



http://mriquestions.com/single-pe-step.html

Spin echo sekvence

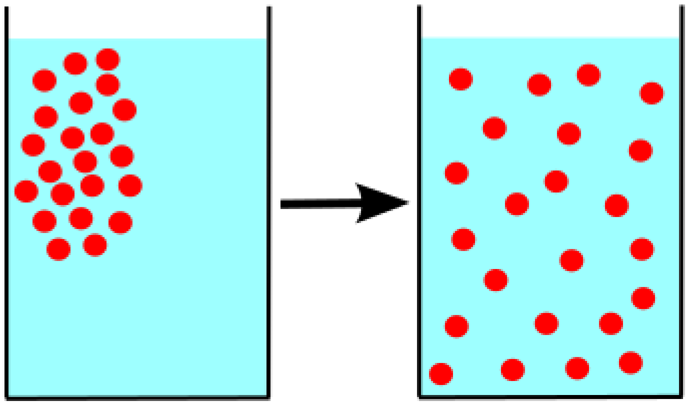


http://mriquestions.com/se-vs-multi-se-vs-fse.html

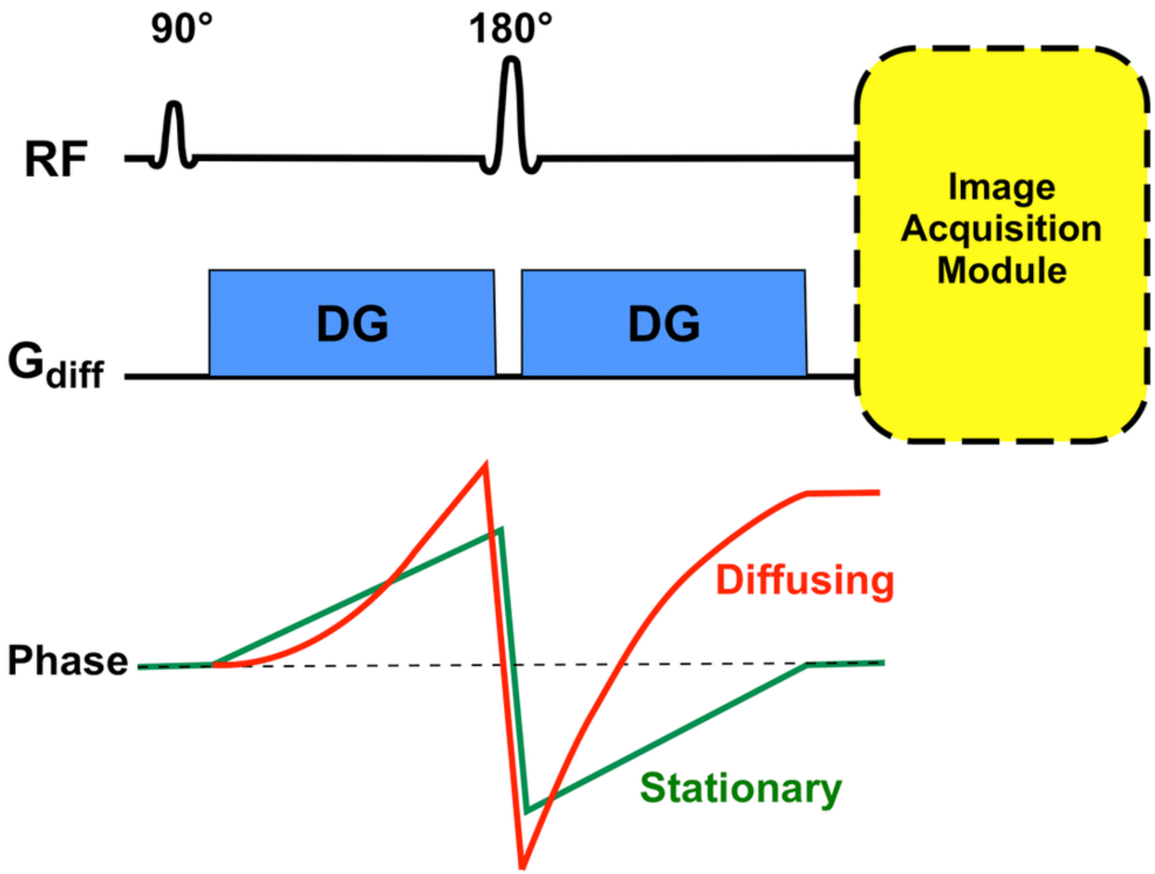
Fyzika pro DWI

Difuze

Látky přecházejí samovolně (náhodným pohybem) z prostředí, kde je jejich koncentrace vyšší směrem tam, kde byla dosud jejich koncentrace nižší. Nedifunduje jen jedna látka do druhé. Proces je pro látku a rozpouštědlo vzájemný.



Diffusion Weight Imaging



Stationary spins are not affected by the paired gradients, but diffusing spins are dephased.

https://www.imagilys.com/diffusion-tensor-imaging-dti/

Fyzika pro DTI

Fyzika pro DTI

Izotropní prostředí

- kámen vhozený do vody:

  na vodní hladině vznikají kruhové vlny

  kruhový tvar svědčí o stejné rychlosti vlnění ve všech směrech

  prostředí má ve všech směrech stejné vlastnosti

  izotropní prostředí

  za dobu t se vytvoří na vodní hladině kružnice o poloměru r

  $r = v.t$

  všechny body na této kružnici mají stejnou fázi

  podobně se šíří i mechanické vlnění včetně zvuku

- rychlost světla nezávisí na směru šíření (sklo)

Fyzika pro DTI

Anizotropní prostředí

- opticky anizotropní prostředí - rychlost světla závisí na směru šíření (krystal křemene)
- **Anizotropie** je vlastnost, kterou se označuje závislost určité veličiny na volbě směru.
- Biological tissues are highly anisotropic, meaning that their diffusion rates are *not* the same in every direction.

Fyzika pro DTI

Skalár se skládá z čísla a fyzikální jednotky.

Mezi skaláry patří např. termodynamická teplota (100 K), délka (10 m), objem (2 m^3), ale i hmotnost (3 kg) atd.

Vektory jsou fyzikální veličiny, které jsou kromě velikosti určeny také směrem.

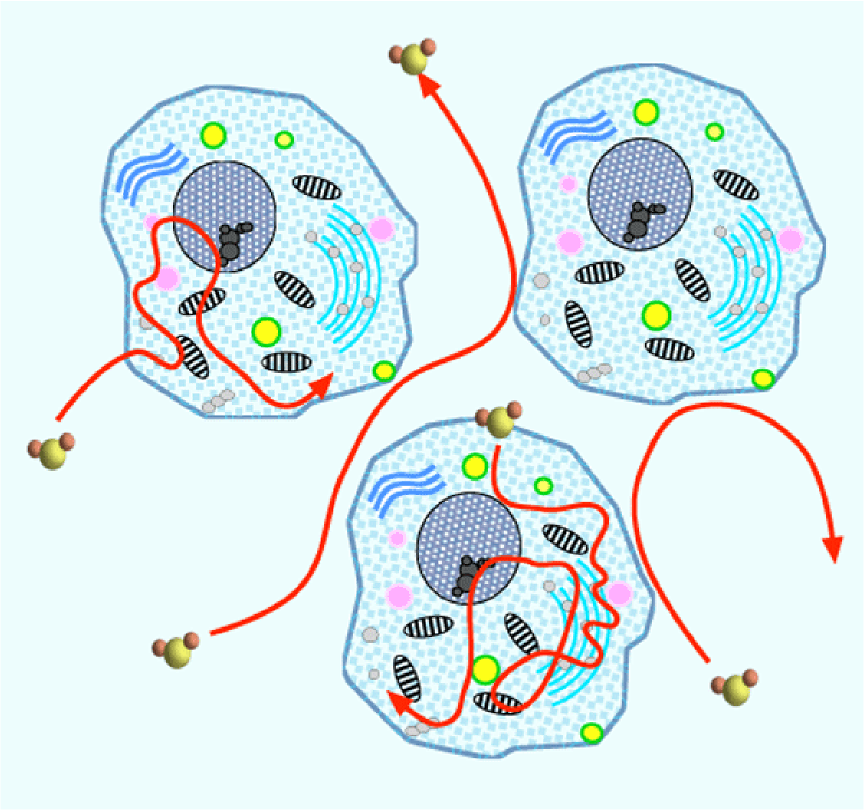
Většinou označujeme vektor šipkou nad příslušným písmenem. Mezi vektorové veličiny patří např. okamžitá rychlost *v*, síla *F atd*.

Fyzika pro DTI

Tenzor

Patří mezi fyzikální veličiny, které mají složitější strukturu než vektory. **Obecně není názorná interpretace tenzorů možná**, ale je možné si ji u kázat alespoň na několika konkrétních příkladech. Mezi tenzorové veličiny patří např. tenzor napětí nebo tenzor deformace.

Difuze molekul vody



Diffusion of water molecules (red arrows) is hindered in the intracellular compartment due to the presence of macromolecules, increased viscosity, and multiple membranes. Only mild restriction of diffusion (due principally to tortuosity) occurs in the extracellular space.

http://mriquestions.com/what-is-diffusion.html#

Diffusion tensor

Biological tissues are highly anisotropic, meaning that their diffusion rates are *not* the same in every direction.

Diffusion Tensor

$$\mathcal{D} = \begin{bmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{yx} & D_{yy} & D_{yz} \\ D_{zx} & D_{zy} & D_{zz} \end{bmatrix}$$

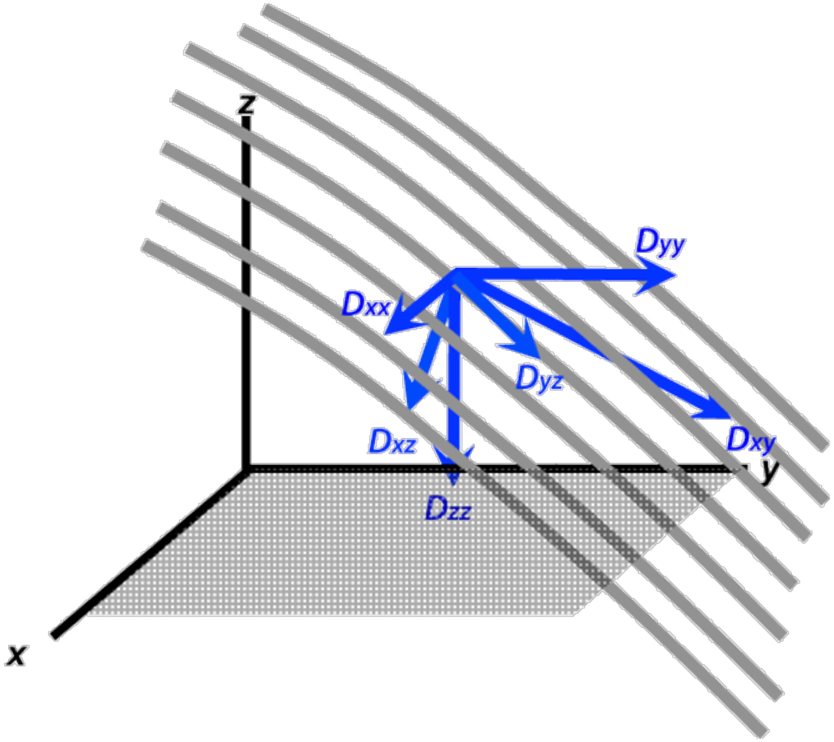
$$\mathcal{D}_{isotropic} = \begin{bmatrix} D & 0 & 0 \\ 0 & D & 0 \\ 0 & 0 & D \end{bmatrix}$$

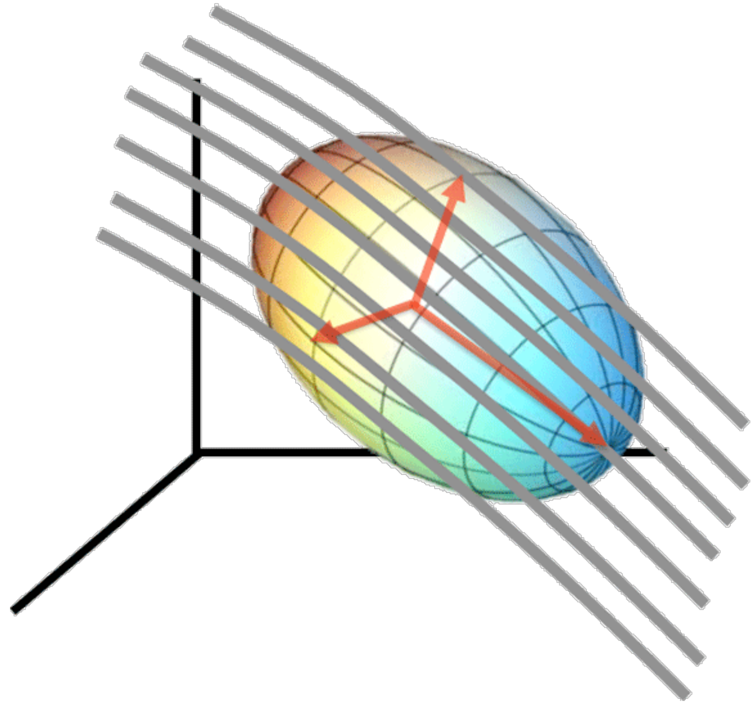
The values we calculate for each tensor component (such as *Dxx* or *Dxy*), however, are not unique, being dependent on the (*x*-*y*-*z*) frame of reference chosen for measurement. Had we selected a different coordinate system (*x'*-*y'*-*z'*) not aligned with the patient but at some arbitrary angle, the calculated values (*Dx'x'* or *Dx'y'*) would have been completely different.

http://mriquestions.com/diffusion-tensor.html

Diffusion tensor

Fortunately an ideal frame of reference for viewing the diffusion tensor exists and can be determined using measurements obtained from *any* frame of reference. This optimal coordinate system is based upon the ***diffusion ellipsoid***, whose main axis is parallel to the principal diffusion direction within a voxel. This principal axis often corresponds to anatomic features such as white matter tracts or fascial planes.

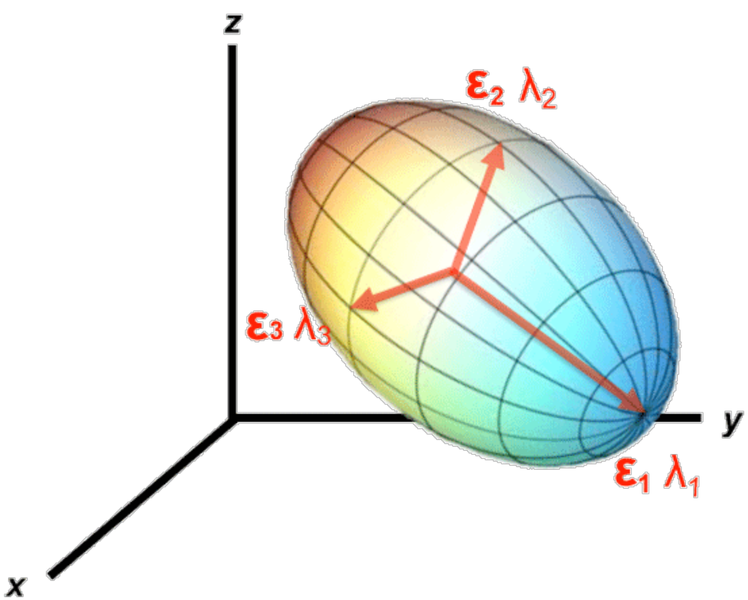


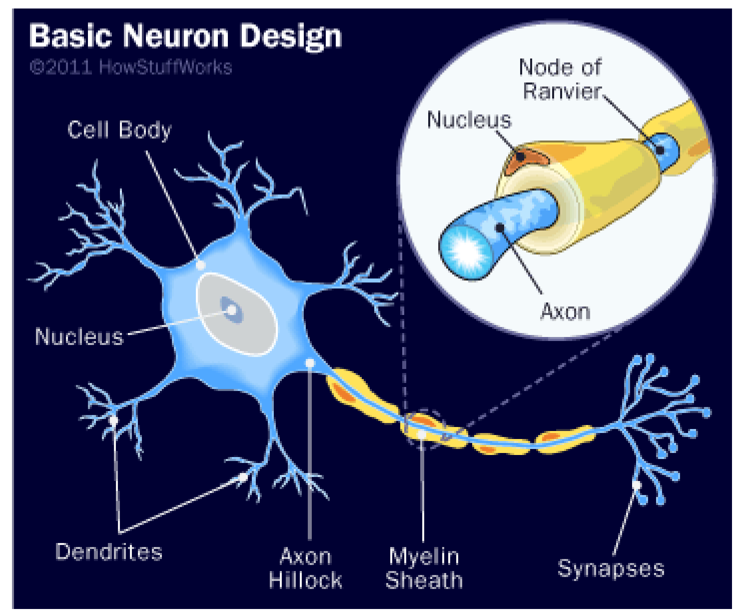


http://mriquestions.com/diffusion-tensor.html

Diffusion tensor

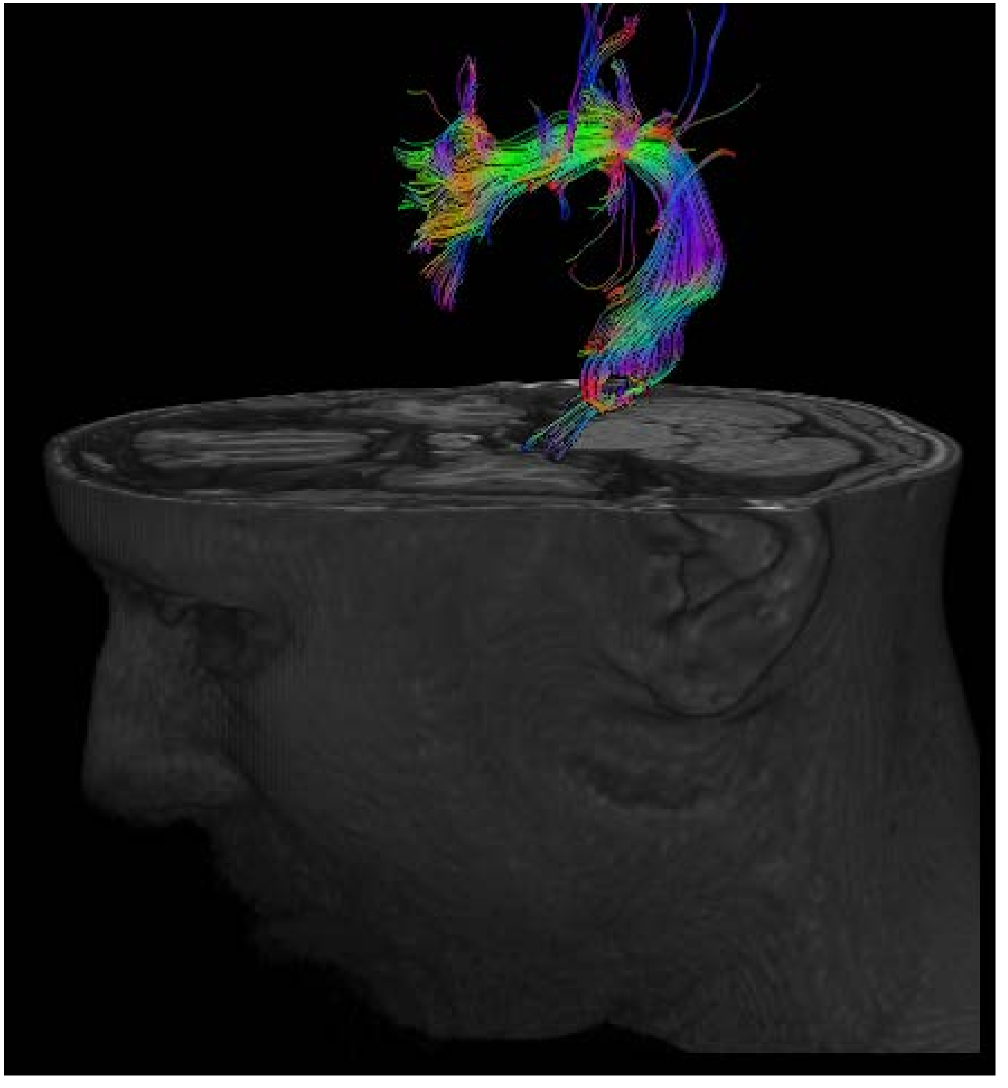
The major and minor axes of the diffusion ellipsoid are defined by thee orthogonal unit vectors (***ε1***, ***ε2***, and ***ε3***) known as ***eigenvectors***. The length of each eigenvector (***εi***) is multiplied by a factor *λi*, called the ***eigenvalue***. The eigenvalues of the ellipsoid are proportional to Einstein's root mean squared diffusion displacement in each direction. By convention, eigenvalues are labeled in descending order of magnitude (*λ1 ≥ λ2 ≥ λ3*).





http://mriquestions.com/diffusion-tensor.html, https://science.howstuffworks.com/life/inside-the-mind/human-brain/brain1.htm

Fiber Tracking (tractography)

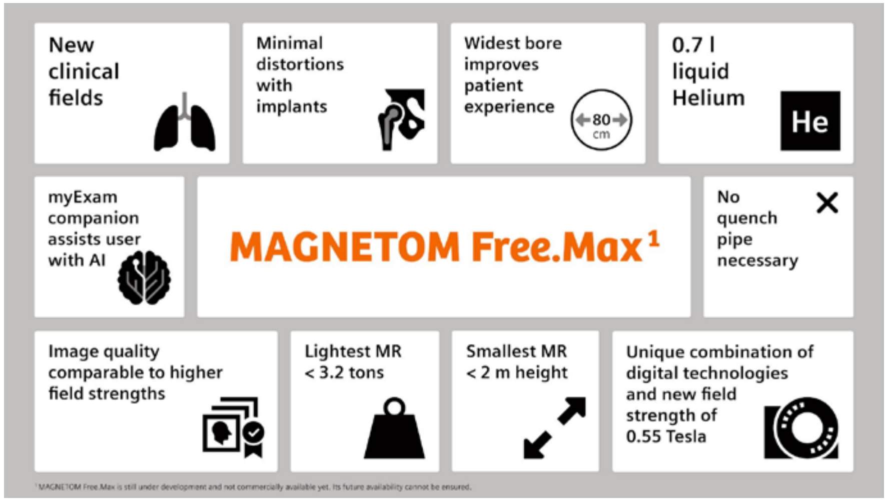


https://www.imagilys.com/diffusion-tensor-imaging-dti/

Novell trends in MRI

- Canon
- GE
- Philips
- Siemens

Helium free



GE Healthcare

PRESS RELEASE

Setting Helium Free: Revolutionary MRI Tech from GE Healthcare

Freelium, a magnet technology, designed to use 20 liters of liquid helium instead of 2,000 liters

CHICAGO - November 29, 2016 – Helium, a critical component in magnetic resonance imaging (MRI) systems, has gone through two potential shortage crises, impacting hospitals and patients around the globe. But the helium supply is finite and demand has been rising over the past decades. At #RSNA16, GE Healthcare (NYSE: GE) proudly unveils Freelium*, a magnet technology designed to use one percent of liquid helium compared to conventional MRI magnets. Instead of the average 2,000 liters of precious liquid helium, Freelium is designed to use only about 20 liters.

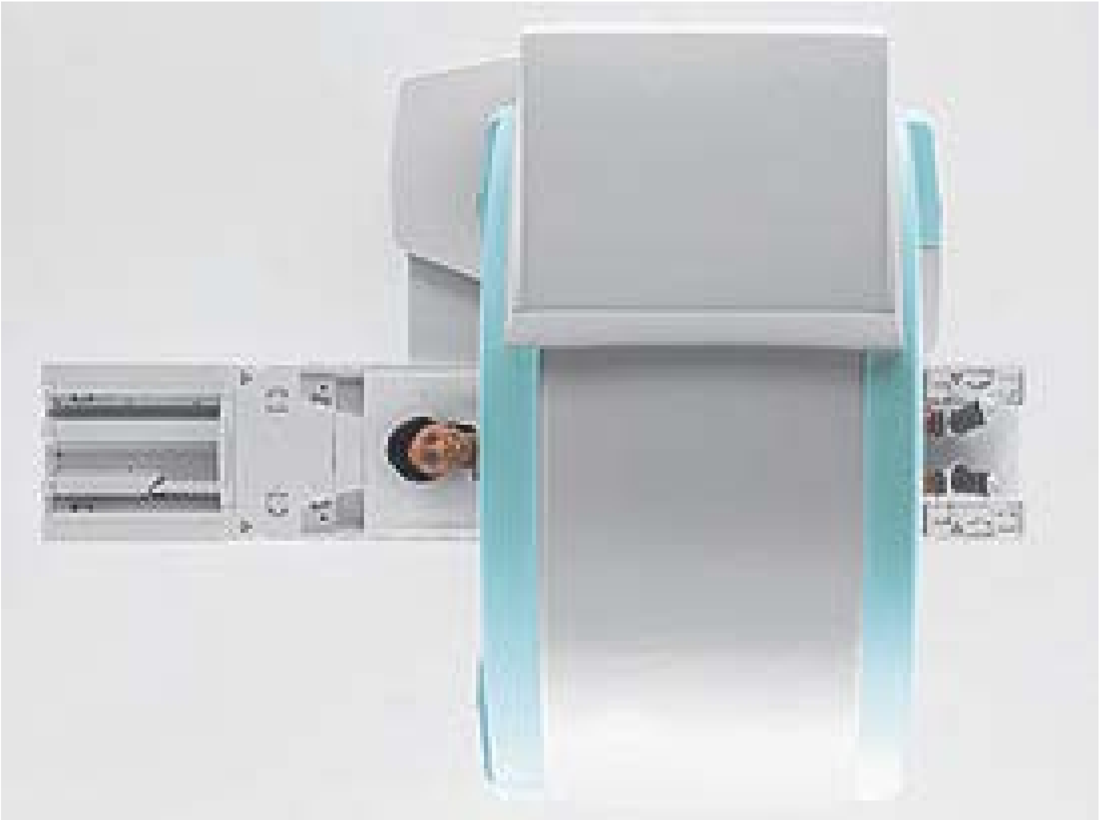
Ingenia Ambition 1.5T X

Excel in your daily MR services, helium-free

Najít podobné výrobky ›

Based on its new, revolutionary fully sealed BlueSeal magnet, Ingenia Ambition X lets you experience more productive[1] helium-free MR operations. The Ingenia Ambition X delivers superb image quality even for challenging patients, and performs MRI exams up to 50% faster[2] with Compressed SENSE accelerations for all anatomies, in both 2D- and 3D scanning. Fast overall exam-time is achieved by simplifying patient handling at the bore with the touchless guided patient setup. Furthermore, the Ingenia Ambition offers an immersive audio-visual experience to help calm patients and guide them through MR exams.

Patient's comfort



unique **over-sized bore opening** and **short magnet design** delivers the most comfortable patient experience available along with exceptional imaging results – ***Claustrophobia v. magnetic field homogeneity.***

https://www.arnothealth.org/services/mri

Strong magnetic field – B_0 + grad.

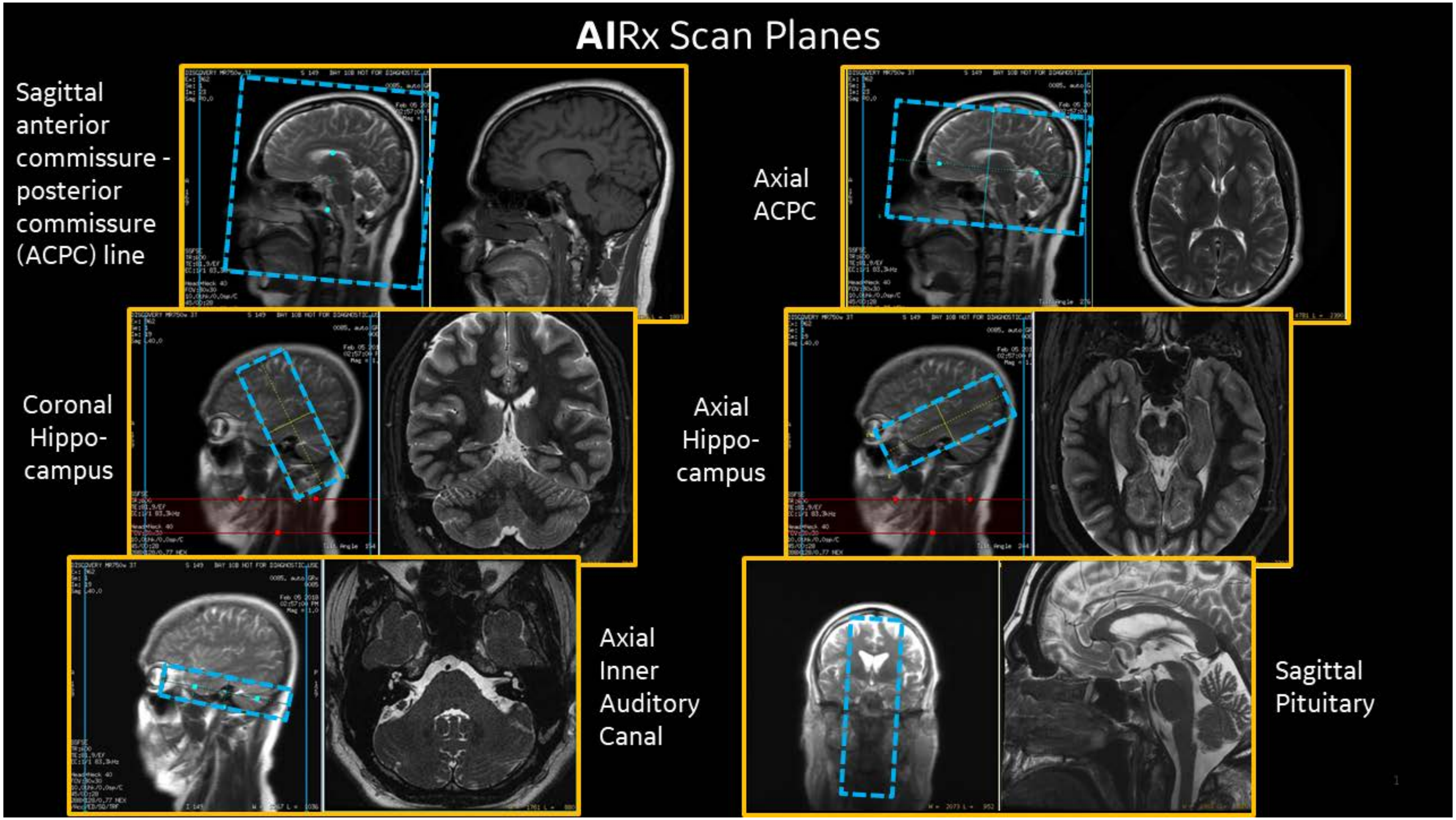
System weight (in operation) **<25 tons**

https://www.siemens-healthineers.com/magnetic-resonance-imaging/7t-mri-scanner/magnetom-terra/technical-details

Flexible coils

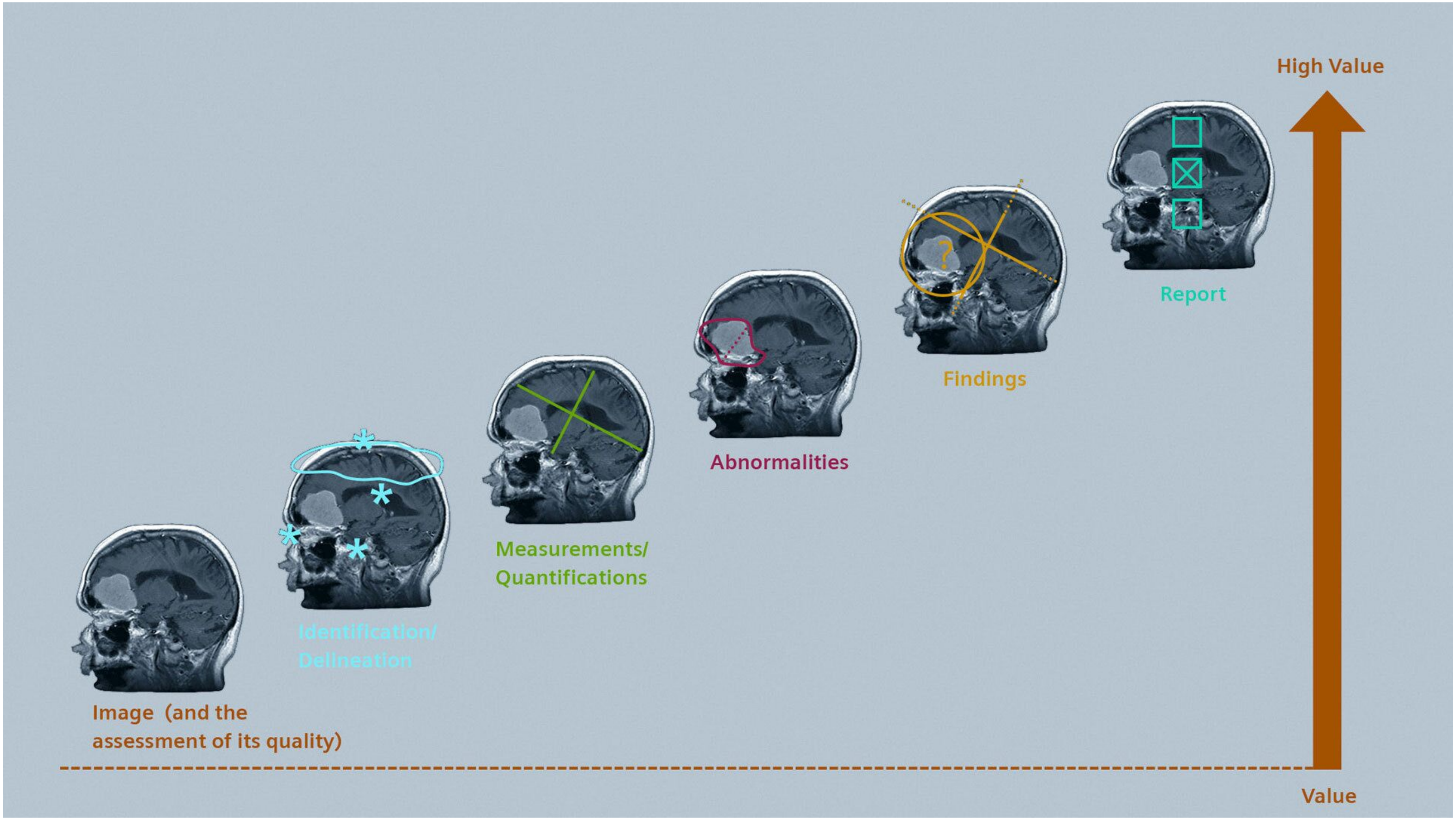
https://magneticsmag.com/ges-flexible-coils-receiving-favorable-user-reviews-in-mri-procedures/

Artificial intelligence in MRI



http://newsroom.gehealthcare.com/this-ai-tech-is-changing-mr-neuro-imaging/

Artificial intelligence in MRI



https://www.siemens-healthineers.com/magnetic-resonance-imaging/news/artificial-intelligence-for-mri.html

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