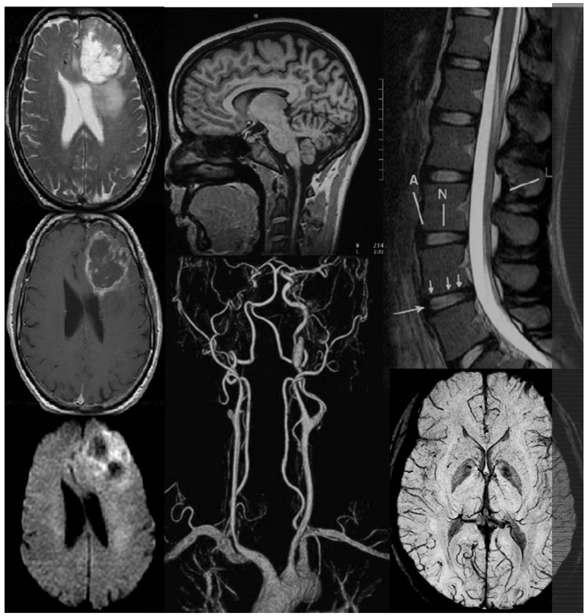

磁振影像學MRI
基本原理與設備

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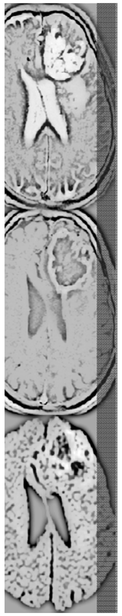
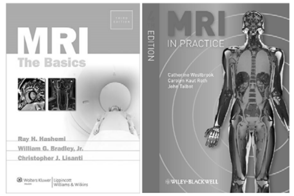
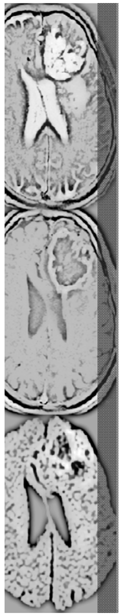


本週課程內容 http://cflu.lab.nycu.edu

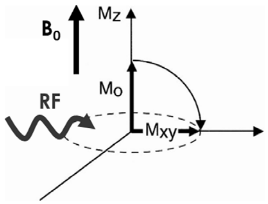
- 磁振原理
- 磁振造影設備

- **MRI The Basics (3rd edition)**
  - Chapter 2: Basic Principles of MRI
- **MRI in Practice, (4th edition)**
  - Chapter 1: Basic Principles
  - Chapter 9: Instrumentation and equipment

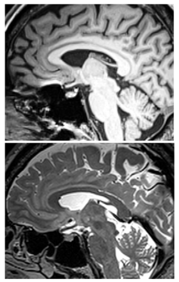




Procedure of MRI



- 1. Alignment (magnetization) B_0
- 2. Precession $\omega_0 = \gamma B_0$
- 3. Resonance (given B_1 by RF with ω_2) $\omega_1 = \gamma B_1$, $B_1 \perp B_0$
  - The most effective resonance is produced when $\omega_0 = \omega_2$
- 4. MR signal (EMF, electromotive force)
- 5. Imaging (Pulse sequencing)
  - Image Contrast: Relaxation time
  - Spatial localization: Spatial Encoding

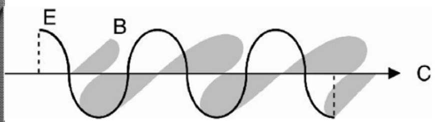


磁振原理

MR Principles

Electromagnetic Waves

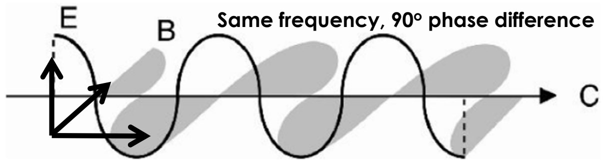
- All travel at the speed of light c = 3 x 10^8 m/sec
- Maxwell's wave theory:
  - an electric field E
  - A magnetic field B



	Frequency (Hz)	Energy (eV)	Wavelength (m)
Gamma rays and X-rays	10^{24}	10^{10}	10^{-16}
	10^{23}	10^{9}	10^{-15}
	10^{22}	10^{8}	10^{-14}
	10^{21}	10^{7}	10^{-13}
	10^{20}	10^{6} (1 MeV)	10^{-12} (1 pm)
	10^{19}	10^{5}	10^{-11}
	10^{18}	10^{4}	10^{-10}
Ultraviolet	10^{17}	10^{3} (1 keV)	10^{-9} (1 nm)
	10^{16}	10^{2}	10^{-8}
Visible light	10^{15}	10^{1}	10^{-7}
Infrared	10^{14}	10^{0} (1 eV)	10^{-6} (1 μ)
	10^{13}	10^{-1}	10^{-5}
Microwaves	10^{12} (1 GHz)	10^{-2}	10^{-4}
	10^{11}	10^{-3}	10^{-3} (1 mm)
	10^{10}	10^{-4}	10^{-2} (1 cm)
	10^{9}	10^{-5}	10^{-1}
MRI	10^{8} (100 MHz)	10^{-6}	10^{0} (1 m)
	10^{7}	10^{-7}	10^{1}

Electromagnetic Waves

- The angular frequency **ω=2π*f***, *f* is linear frequency
- We are interested in the magnetic field rather than the electric field
  - Electric field generates heat



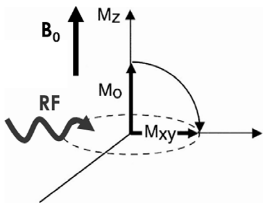
Changes in the E generates the B, and vice versa.

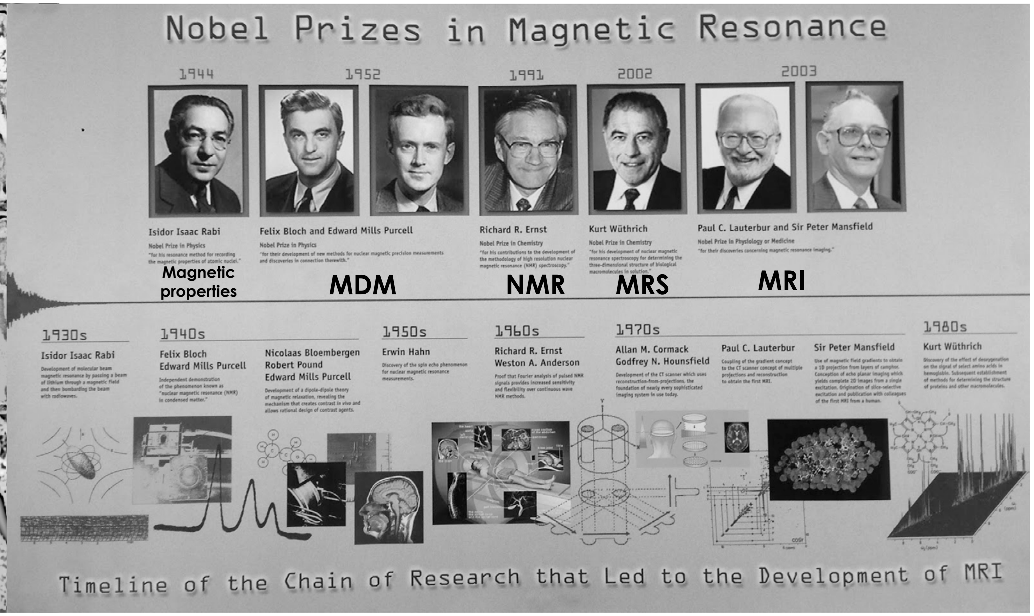
Radio frequency (RF) pulse

- The electromagnetic pulse used in MRI to get a signal is called an RF pulse.

	Frequency (Hz = Hertz)	Energy (eV = electron volts)	Wave Length (m = meters)
X-ray	1.7-3.6 × 10^{18} Hz	30-150 KeV	80-400 pm
Visible light (violet)	7.5 × 10^{14} Hz	3.1 eV	400 nm
Visible light (red)	4.3 × 10^{14} Hz	1.8 eV	700 nm
MRI	3-100 MHz	20-200 meV	6-60 m

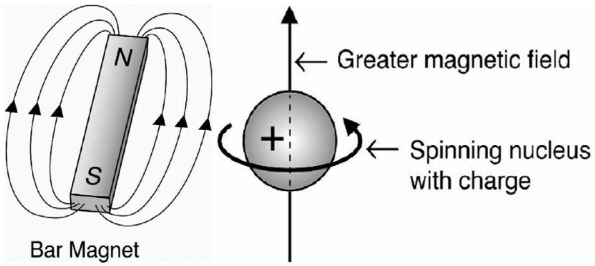
AM radio frequency	0.54-1.6 MHz (540-1600 kHz)
TV (Channel 2)	Slightly over 64 MHz
FM radio frequency	88.8-108.8 MHz
RF used in MRI	3-100 MHz





Spins and electromagnetic field

- **Felix Bloch** (Standard University, Nobel prize in physics, 1952)
  - Any spinning charged particle (such as the **hydrogen nucleus**) creates an electromagnetic field.



Magnetic dipole moment (MDM)

1905.10.23~1983.09.10

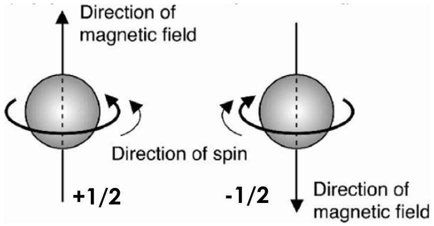
Quantum theory: Energy levels

- The hydrogen nucleus (a proton) has a **spin quantum number (S)**

  $S(^1H)=1/2$

- The number of energy states of a nucleus

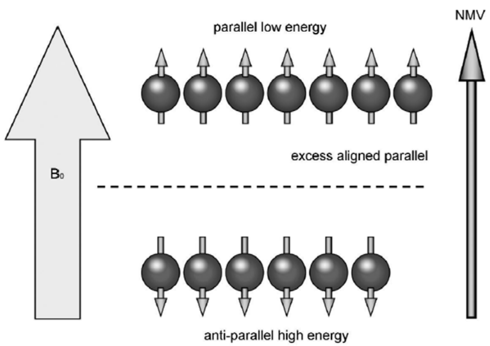
  # of energy states = 2S+1 (for ^1H = 2)



$S(^{23}Na)=3/2$
# of energy states = 2 (3/2) +1 = 4
(-3/2, -1/2, 1/2, 3/2)

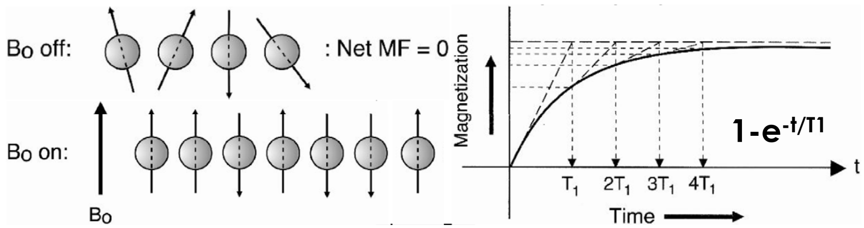
Net Magnetic Vector (NMV)

- With B_0, protons line up and approximately half spin-up (parallel, low energy) and half spin-down (anti-parallel, high energy).
- About one in a million more protons point in the direction of B_0.
- ppm (parts per million)



Alignment & T1 Relaxation time

- At time t = 0, proton spins are distributed randomly and net magnetic field is zero.
- Immediately after B_0 is presented, magnetization increases over time.



Spin and Precession

- Wheel rolling: spin
- Gravity: B_0

- Spiral precession

Magritek videos on youtube (6:33)!!

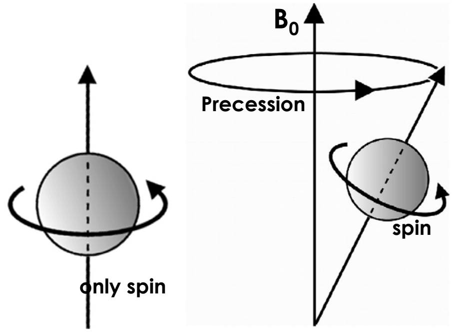
Precession

- With B_0, the proton not only spins about its own axis, but also precesses about the axis of the B_0.
- Each proton spins much faster about its own axis than it rotates around the axis of the B_0.
- **Larmor equation (frequency)**

  $\omega = \gamma B_0$

  γ is gyromagnetic ratio (MHz/T)

For B_0 from 1.5T → 3T
ω = 42.6 x 1.5T = 63.9 MHz
= 42.6 x 3.0T = 127.8 MHz
The RF range for MRI !!



Magnetic dipole moment (MDM)

- An MDM is found in any nucleus with **an odd number of protons, neutrons, or both**.
- MDM is the signal source of MRI.

		Spin Quantum Number (S)	Gyromagnetic Ratio (MHz/T)
1P0N	^{1}H	1/2	42.6
9P10N	^{19}F	1/2	40.0
11P12N	^{23}Na	3/2	11.3
6P7N	^{13}C	1/2	10.7
8P9N	$^{17}0$	5/2	5.8

S ≠ 0, can be MR signal source

Hydrogen Nucleus (^{1}H)

- We use hydrogen for imaging because of…
  - its abundance (about 60~70% of body is water)
  - Hydrogen protons (^{1}H) in water (H_2O) and fat ($-CH_2-$)
  - its high MR sensitivity (high gyromagnetic ratio, γ = 42.58 MHz/T)

		Spin Quantum Number (S)	Gyromagnetic Ratio (MHz/T)
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11P12N	^{23}Na	3/2	11.3
6P7N	^{13}C	1/2	10.7
8P9N	$^{17}0$	5/2	5.8

Magnetic Susceptibility, χ

- χ is the measure of magnetizability of a substance.
- The χ is defined as the ratio of the induced magnetic field (M) to the applied magnetic field H:

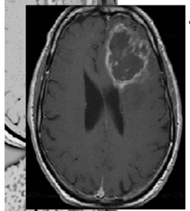
$$M = \chi H \ \text{ or } \ \chi = M/H.$$

- The *magnetic induction field* or *magnetic flux density*, B, is the net magnetic field effect caused by an external magnetic field H:

$$B = \mu H = (1+\chi)H = H + M.$$

μ represents the *magnetic permeability*.

Magnetic Substances



- **Diamagnetic**
  - No unpaired orbital electrons
  - Under an external B_0, a weak M is induced in the opposite direction to B_0 ($\chi<0$ and $\mu<1$).
  - Most tissues in body are diamagnetic.
- **Paramagnetic**
  - Unpaired orbital electrons
  - M is in the same direction as B_0 ($\chi>0$ and $\mu>1$).
  - Become demagnetized once the B_0 has been turned off.
  - Dipole-dipole (proton-proton and proton-electron) interactions cause T1 shortening (bright signal on T1-weighted images)
  - gadolinium (Gd) chelates – contrast agent
- **Superparamagnetic**
  - breakdown products of hemoglobin: deoxyhemoglobin, methemoglobin, hemosiderin

Magnetic Substances

- **Ferromagnetic**
  - Become permanently magnetized even after the magnetic field has been turned off ($\chi>>0$ and $\mu>>1$).
  - Iron (Fe), cobalt (Co), and nickel (Ni)
  - Aneurysm clips and shrapnel

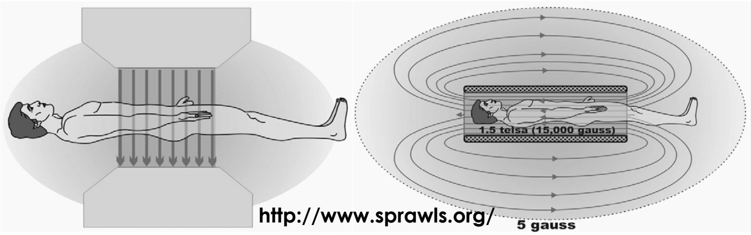
potential projectiles! Safety issue!

磁振造影設備

MRI Instrument

External B_0 Magnetic Field

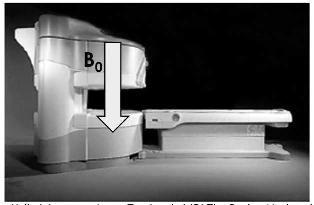
- On the order of 1 Tesla (1T) = 10000 Gauss (0.5 Gauss for earth's magnetic field in average)
- Required magnetic uniformity is less than 5 ppm (parts per million), which can be achieved by shimming and shielding.

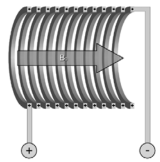


Types of Magnets

alnico alloy: 鋁aluminum(Al)、鎳nickel(Ni)、鈷cobalt(Co)合金

- Permanent magnets (for open MRI scanners), always stay on
- Resistive magnets (for low field MRI), can be turned on/off
- Superconducting magnets (the most common today)
  - operate near absolute zero temperature
  - generate a high B_0 without generating significant heat
  - require cryogens (interior 4^oK liquid helium; outer 77^oK liquid nitrogen), very expensive !!
  - Niobium-titanium alloy (鈮鈦合金)

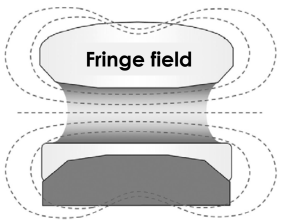


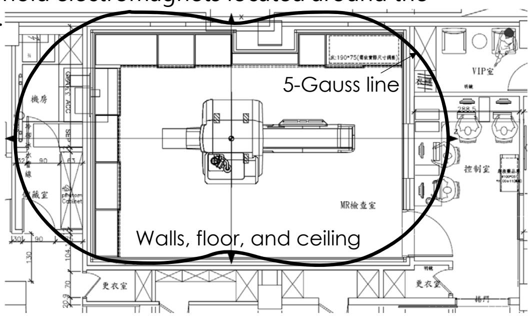


(屏蔽)
Shielding

1) Prevent extraneous electromagnetic waves from contaminating/distorting the MR signal
2) Reduce electromagnetic field generated by the MR scanner

- **Passive (magnetic) shielding**: scanner room with galvanized steel plates
  - RF shielding is accomplished by lining the scan room walls with copper.
- **Active shielding**: additional solenoid electromagnets located around the outside of the main magnet coil.
- **5 Gauss line** – safety zone



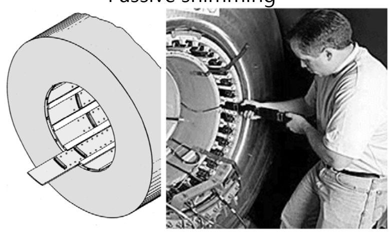


(補塾)
Shimming

Generally **passive shimming** is used to get the magnetic field to a particular level of homogeneity and then **active shimming** is used to optimize for each patient examination.

- Passive shimming
  - involving the use of ferromagnetic materials, typically iron or steel, placed in a regular pattern at specific locations along the inner bore of the magnet.
- Active shimming
  - performed by an electro-magnetic coil and can be used to shim the system for each patient or even each sequence within a protocol.

Passive shimming



12-24 sliding trays arranged symmetrically with metallic shims
http://mriquestions.com/passive-shimming.html

Coils

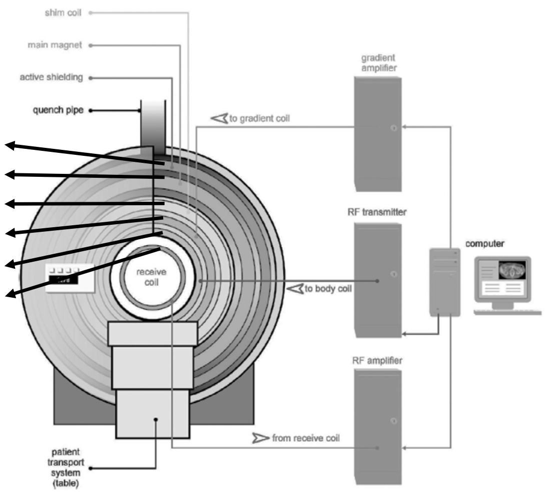
- Gradient coils
  - Shim coil – increase B_0 homogeneities
  - Imaging gradient coil – intentional perturbation for spatial encoding
- Transmit and/or receive RF coils
  - Linear phase or quadrature (receive or transmit)
  - Surface or volume (Helmholtz or solenoid)
  - Single or phased-array

RF Coils

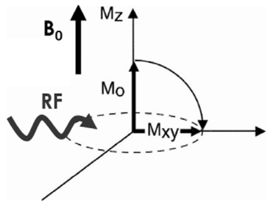
- A transmitter coil transmits an RF pulse
- A receiver coil receives an RF pulse
- Types of coils
  - Body coils: both transmitters and receivers, a part of magnet
  - Head coils: both transmitters and receivers, a helmet-like device
  - Surface coils: just receivers, imaging joints
- Quadrature-phased array coils
  - Multiple elements of coils, larger FOV and better SNR

Setup

- Outer → inner
  - Active shielding
  - Main magnet
  - Shim coil
  - Gradient coil
  - Body coil
  - Receive coil



Procedure of MRI



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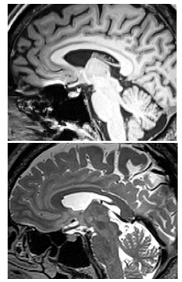

THE END

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