THE UNIVERSITY of TEXAS
HEALTH SCIENCE CENTER AT HOUSTON
SCHOOL of HEALTH INFORMATION SCIENCES

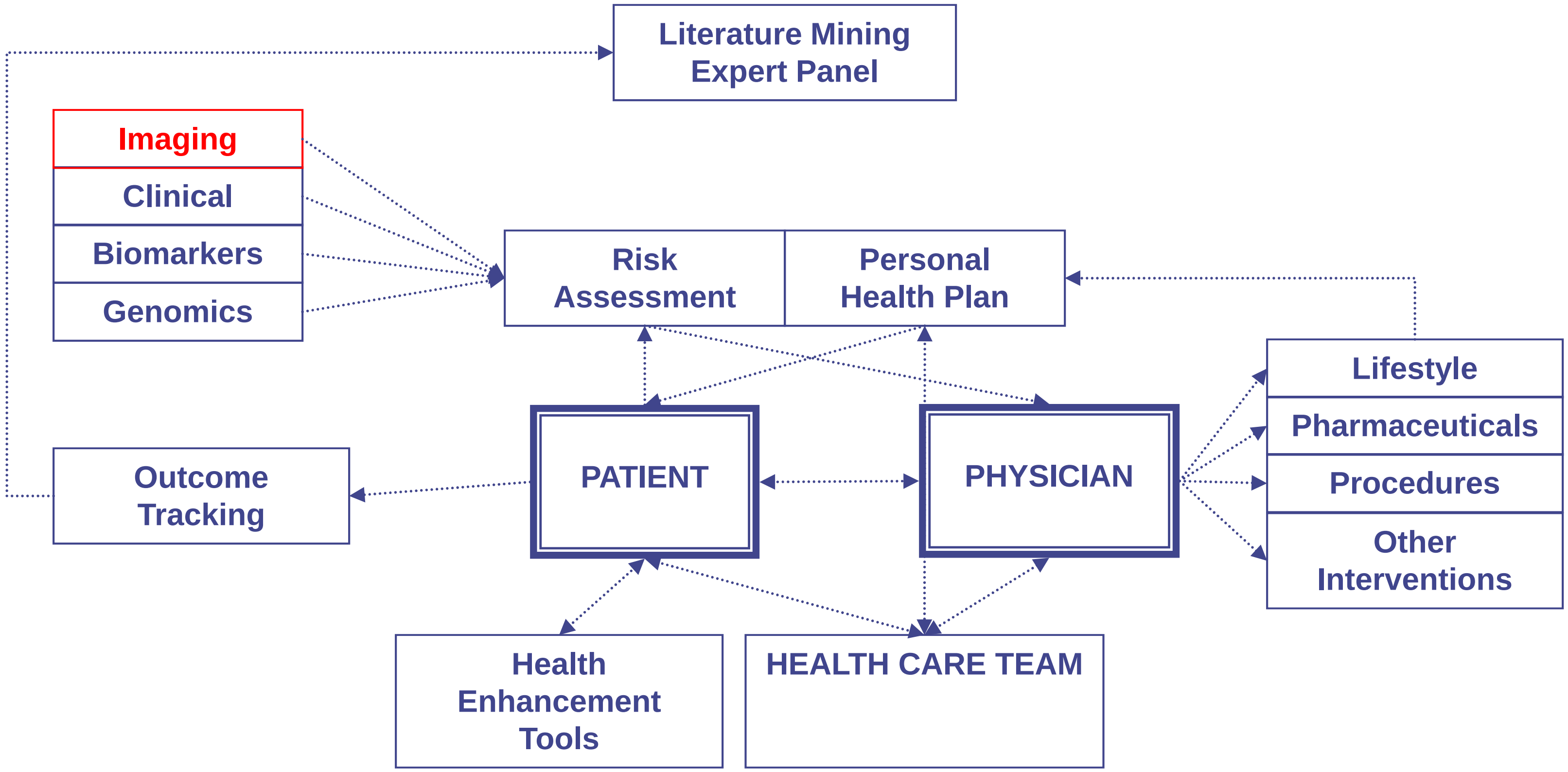
Medical Imaging

For students of HI 5323
"Image Processing"

Willy Wriggers, Ph.D.
School of Health Information Sciences

http://biomachina.org/courses/processing/11.html

Prospective Health Care



Snyderman R, Williams RS. Prospective medicine: The next health care transformation. Acad Med 2003;78(11):1079-1084

Objectives

Understand basic principles

- Ultrasound Imaging
- Conventional X-ray Imaging
    - Fluoroscopy
    - Computed Radiography
    - Computed Tomography (CT)
- Nuclear Medicine (Radioisotope) Imaging
    - Single Photon Emission (SPECT)
    - Positron Emission (PET)
- Magnetic Resonance Imaging (MRI)

Appreciate their difference

Imaging Modalities

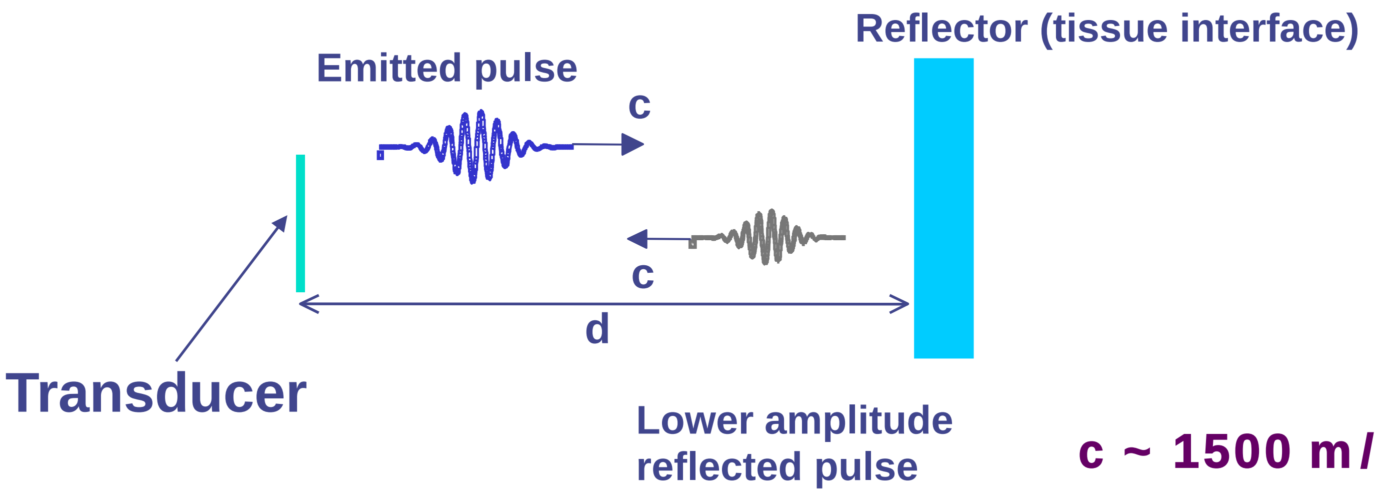
Ultrasound Imaging
Represents a mapping of changes in acoustic impedances.

X-ray Imaging
Represents a mapping of X-ray attenuation coefficients.

Radioisotope Imaging
Represents the internal functional distribution of an administered radiopharmaceutical.

Magnetic Resonance Imaging
Represents a mapping of proton density weighted with nuclear relaxation times associated with different molecular environments.

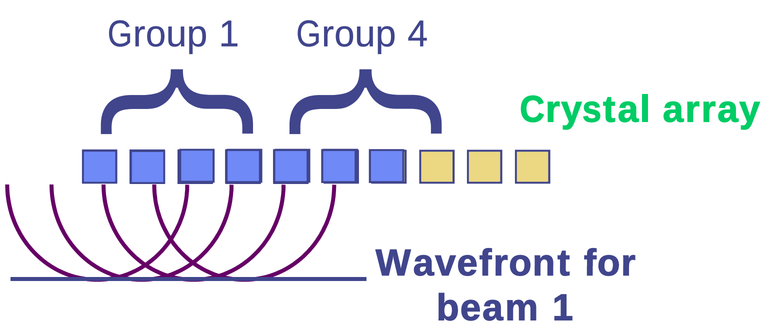
Ultrasound Imaging



c ~ 1500 m/s

- Ultrasound reflection times calculate position.
- Position calculated using equation $d = ct/2$
- Size of reflected pulse detected gives acoustic impedance & brightness.

Ultrasound Imaging



Array of PIEZOELECTRIC crystals ~ 200.

Fired sequentially to scan beam over 2D FOV.

After pulse-echo for Group 1 move to Group 2 …

Pulse rate ~ 3000 per second.

Frequency of each pulse ~ 2 up to 15 MHz.

High frequency	-	**Less penetration.**
	-	**Higher spatial resolution.**
Linear array	-	**Good images for superficial structures.**
Curved array	-	**Wider field of view (FOV) at depth.**

Ultrasound Scanner and Probes

Obstetric Scan

Sector Arrays

Linear Arrays

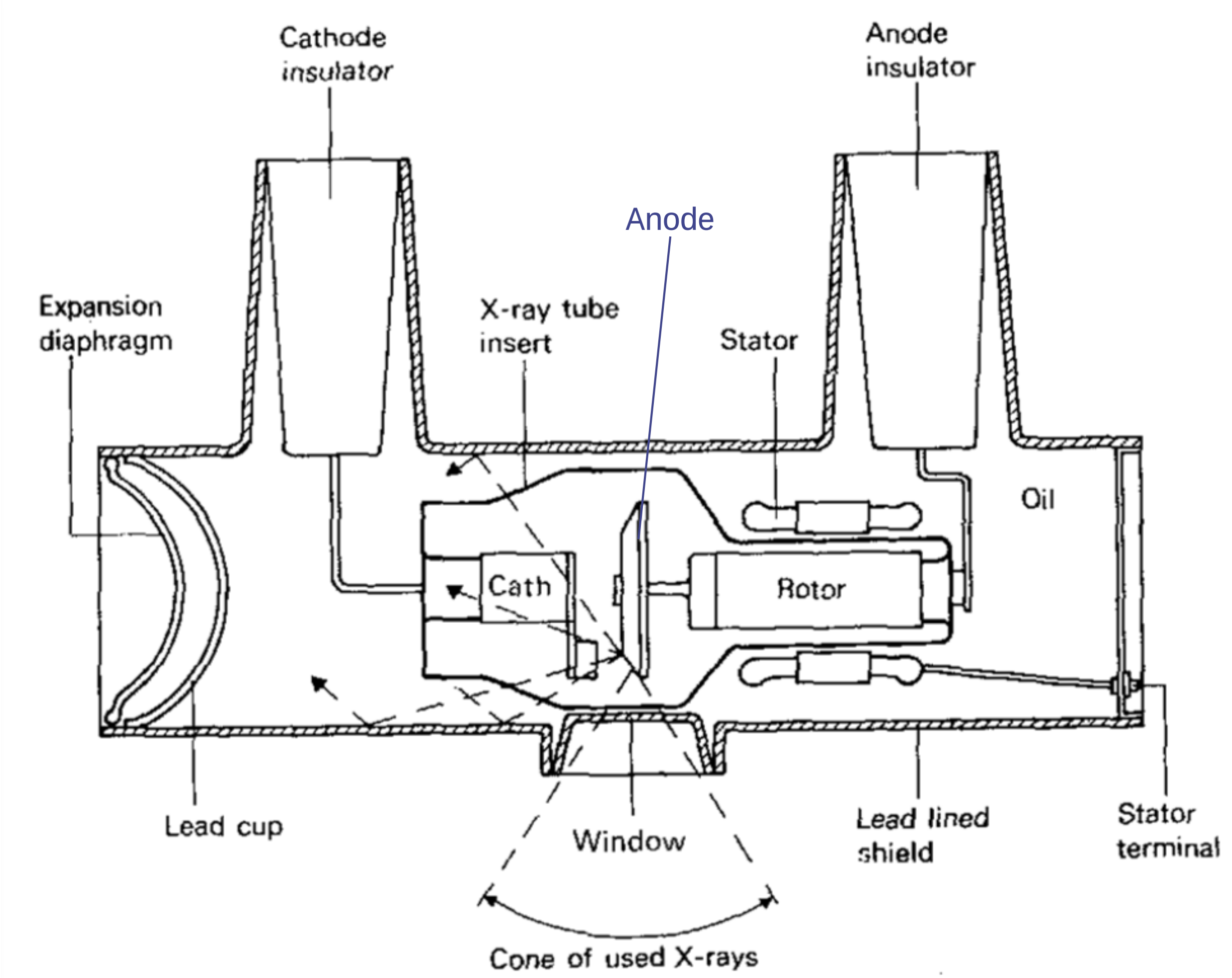
Ultrasound Image of 19 Week Old Fetus

Conventional X-ray Imaging

X-ray Production

Electrons from cathode filament are accelerated towards and impact the rotating anode.

Rapid deceleration produces heat (~ 98%) and x-rays (~2%)



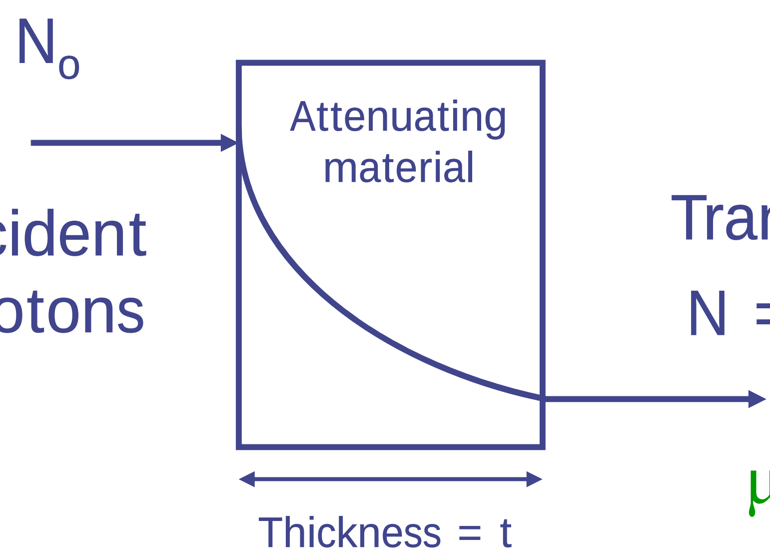
Conventional X-ray Imaging

Anatomy removes photons from the beam.

Information coded as a variation in the number of photons in emerging beam.

Interaction of diagnostic x-ray photons with tissue – PHOTOELECTRIC EFFECT.

Attenuation = absorption and scatter. Approximately EXPONENTIAL.



Incident photons

Transmitted photons

$$N = N_o \exp(-\mu t)$$

μ = Linear Attenuation Coefficient

Conventional X-ray Imaging

Linear Attenuation Coefficient	=	Mass attenuation Coefficient	x	physical density

$$\mu = \mu_m \times \rho$$

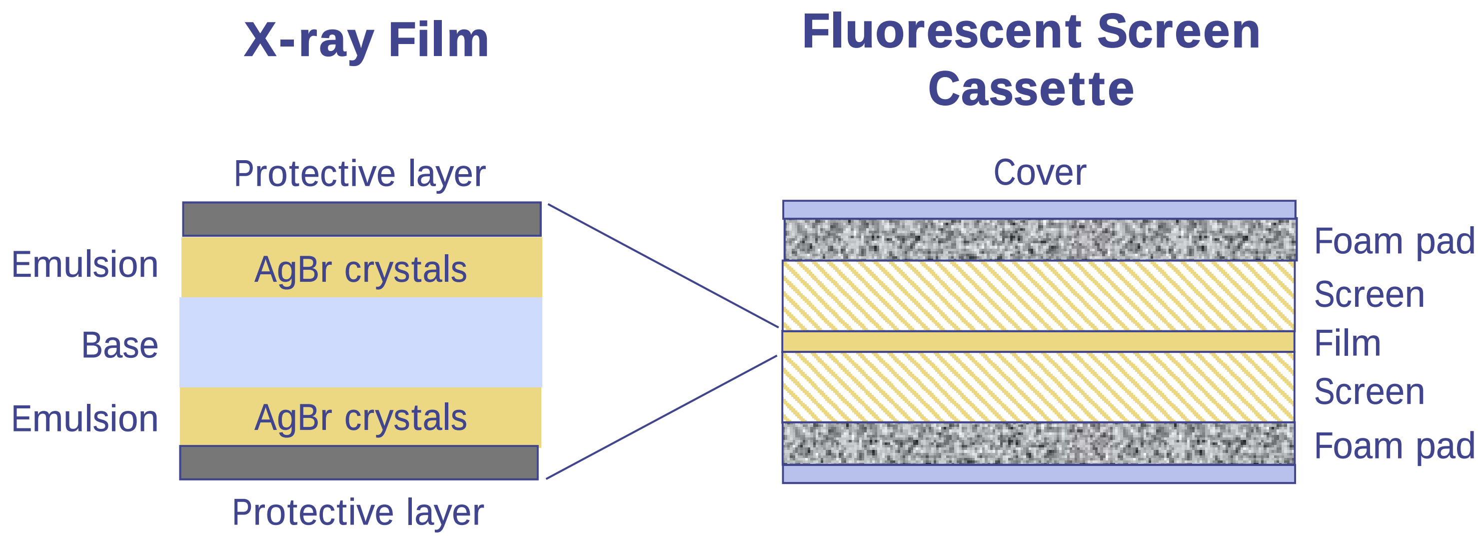
μ_m for Photoelectric effect $\propto$ (atomic number)^3

Tissue	Z_{eff}	Density (gm/cm^3)
Bone	11.6	1.75
Fat	6.3	0.92
Muscle	7.4	1.00

The difference between Z_{eff} for bone & soft tissue leads to image contrast.

BUT a lot of soft tissue anatomy is <u>NOT</u> visualised.

Film-Screen Cassettes



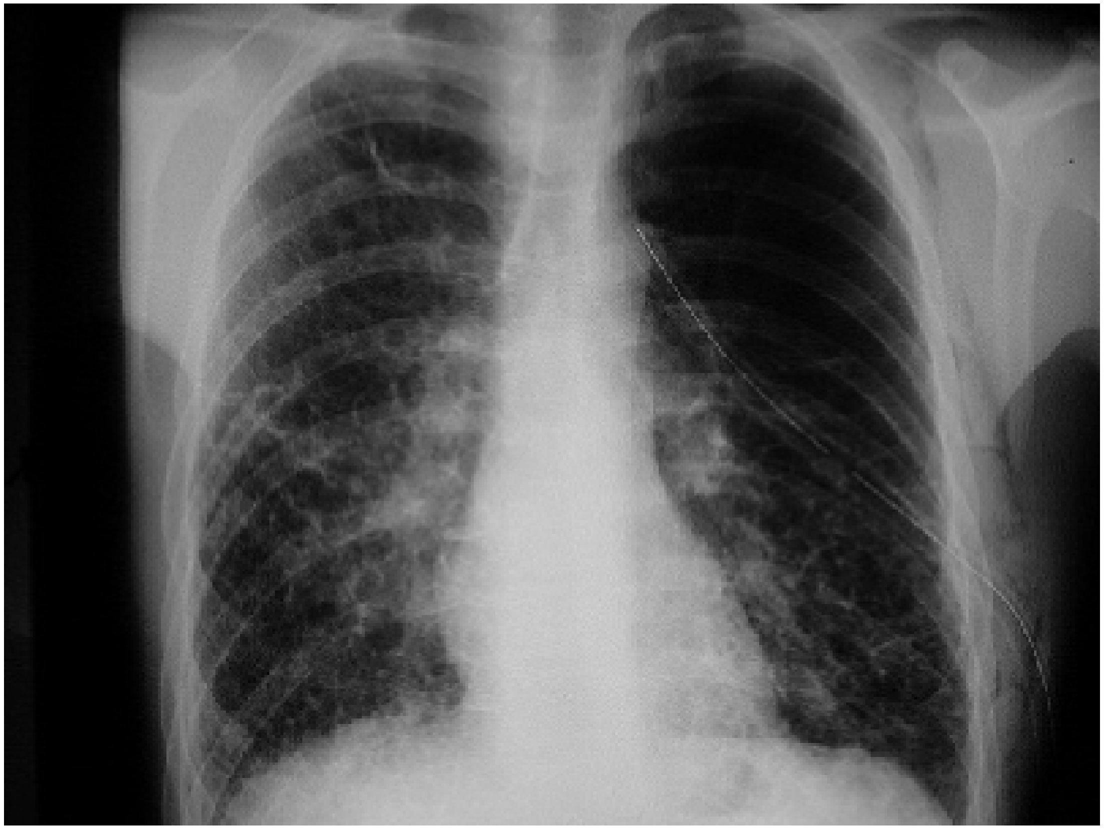
Using fluorescent screens improves film blackening – despite visible photon only ~ 2-3eV

20-40 times more x-ray photons absorbed in screen than in film alone.
400-1000 visible photons released per x-ray absorption in screen.

The more photons absorbed in film – greater film blackening.

Overcouch X-ray Tube and Table

Chest X-ray

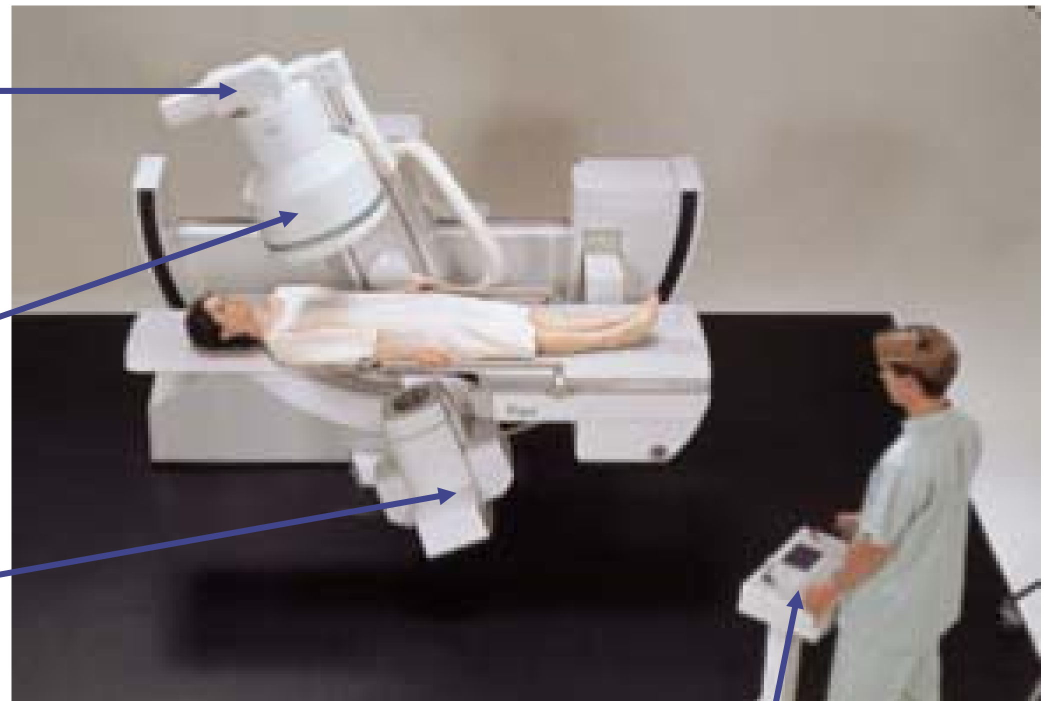


Conventional X-ray Image of a Hand

Normal

Arthritic

Fluoroscopy



Allows dynamic imaging of blood vessels (angiography) and ‘interventional’ procedures

Digital Radiography

No film !!

Advantages

Wide exposure latitude.

Potentially to improve soft tissue contrast.

Faster and less messy than wet processing.

Electronic image analysis and post-processing.

Digital Radiography

No film !!

Two main types in clinical usage:

Flat Panels

Arrays of semiconductor detectors permanently built into patient table.

Computed Radiography

Rigid reusable plate made from Eu-activated barium fluorohalide in a cassette.

Photo Stimulated Luminescence (PSL).

Image capture – expose plate to x-rays causes electrons to be excited into traps.

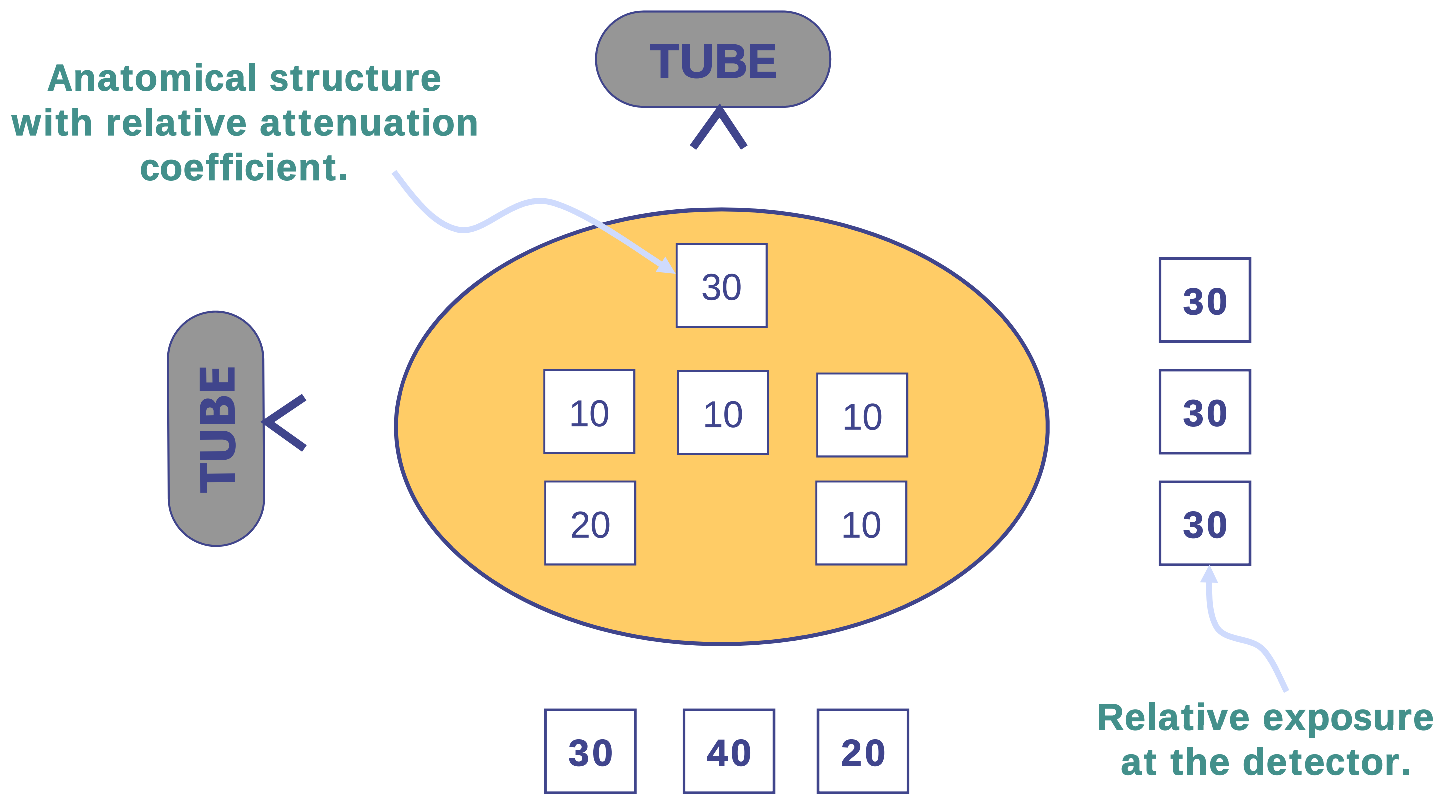
Reading – laser beam ‘knocks’ electrons out of traps. Visible photons produced detected by PMT.

Number of visible photons $\propto$ x-ray energy stored in the plate.

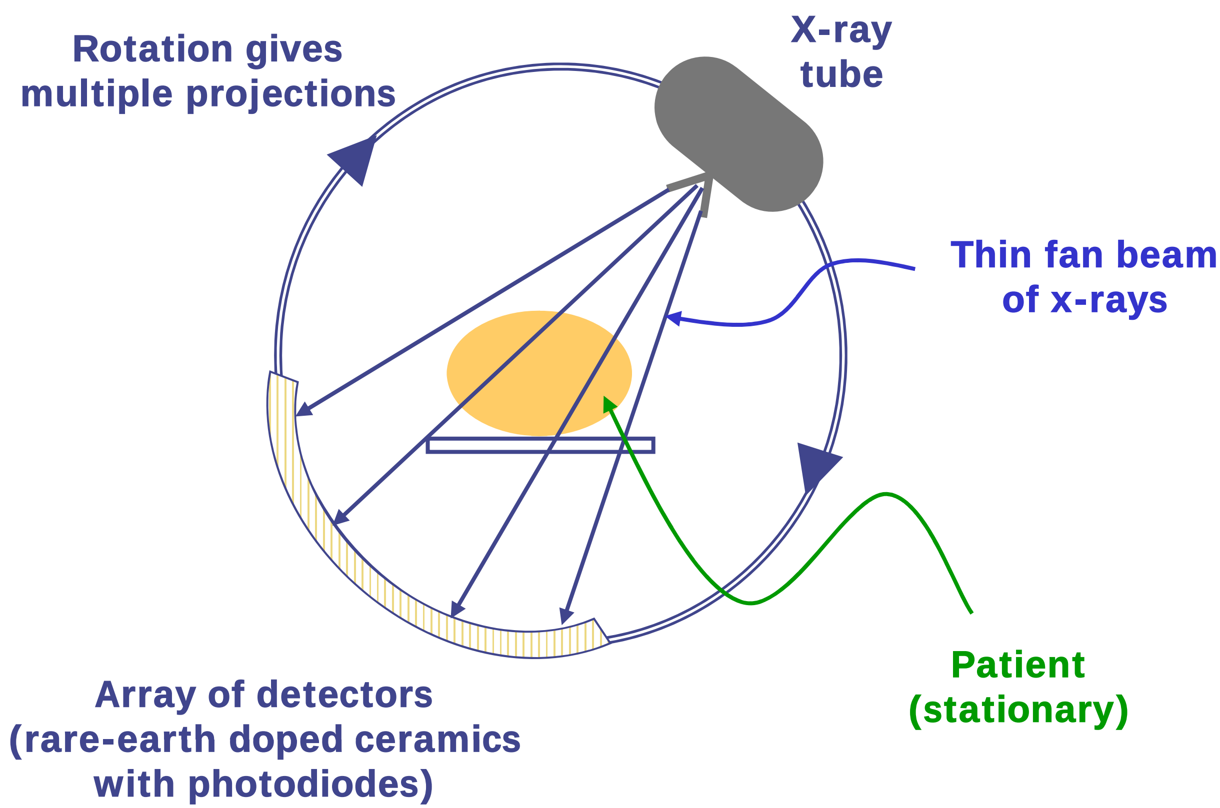
Computed Tomography (CT)

- Conventional radiography suffers from the collapsing of 3D structures into 2D images.
- CT, although having lower spatial resolution, produces excellent anatomical images of a 'SLICE'.
- CT uses high radiation dose to give extremely good low contrast resolution (~10 times that of conventional for 2mm object).
- Enables detection of small changes in (μ) tissue type.

Computed Tomography (CT)

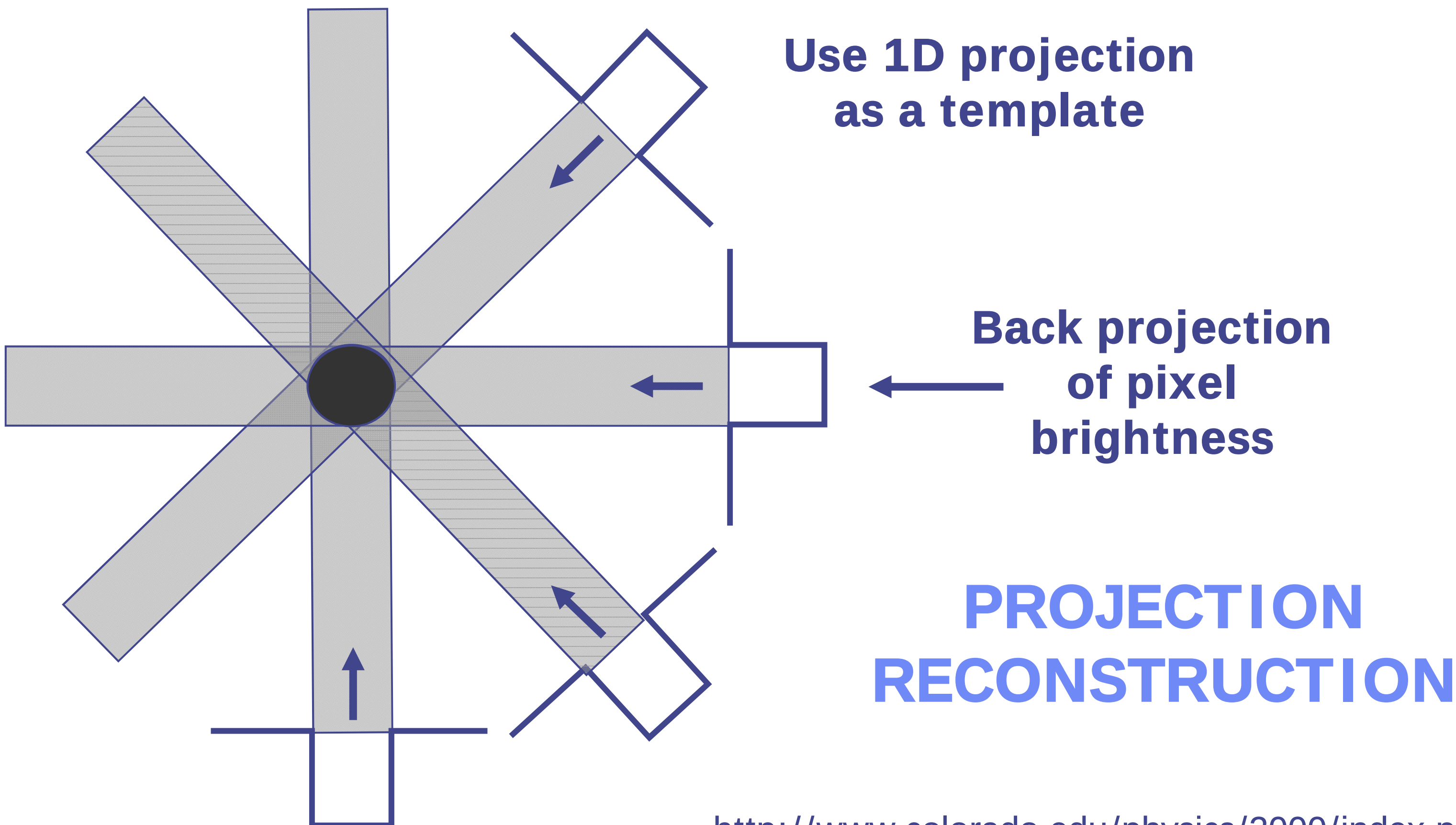


Computed Tomography (CT)



Computed Tomography (CT)

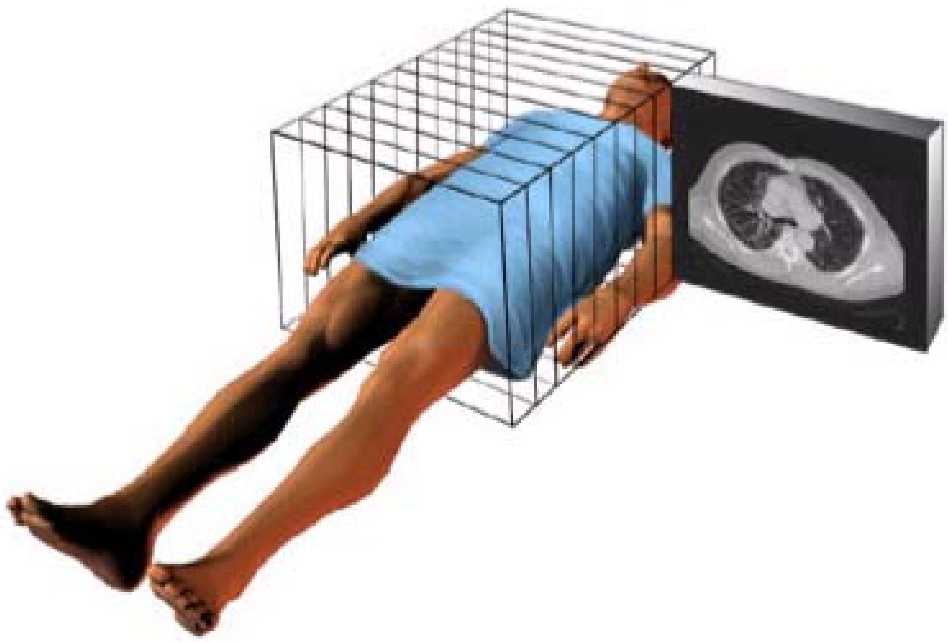
Back Projection



http://www.colorado.edu/physics/2000/index.pl

CT Scanner

CT Image of Heart & Lung

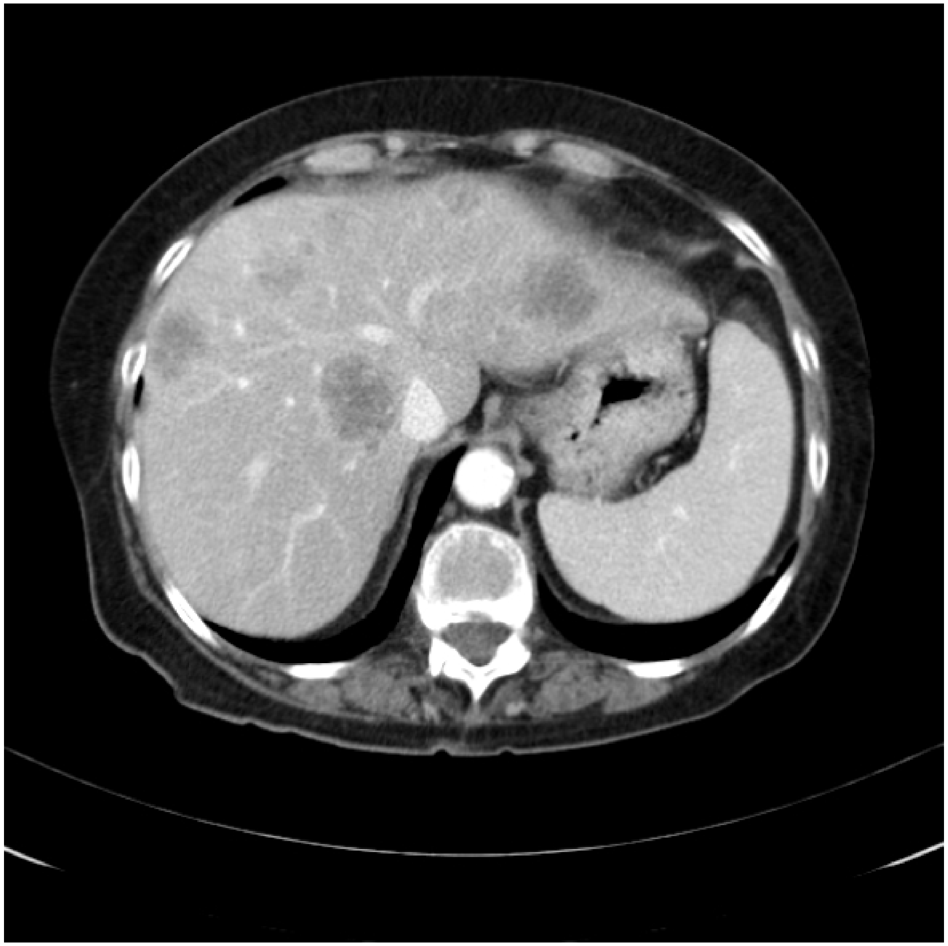


-By Mayo Clinic staff © 1998-2004 Mayo Foundation for Medical Education and Research (MFMER).

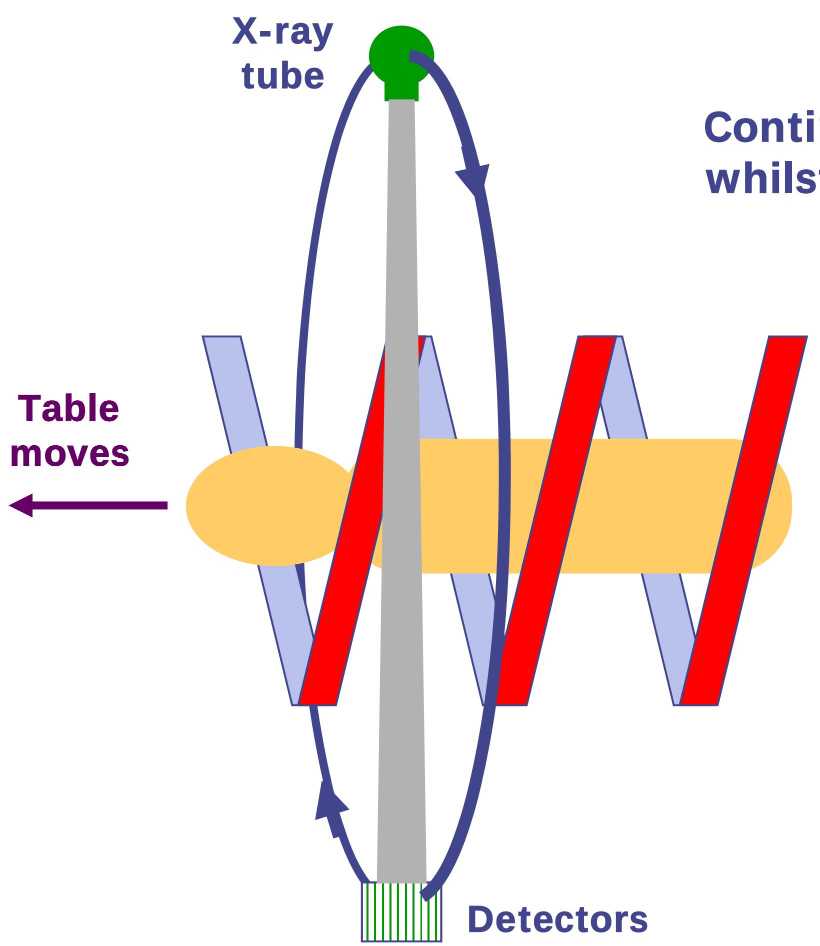
CT Image of Abdomen

Axial image looking up from the feet.

Liver metastasis from colon carcinoma



Helical CT



Continuous rotation of tube (slip rings) whilst patient moves through aperture.

Each projection angle corresponds to a slightly different **SLICE** of the patient.

To reconstruct any particular **'SLICE'** must **INTERPOLATE** projections from neighbouring positions.

Much faster scanning.

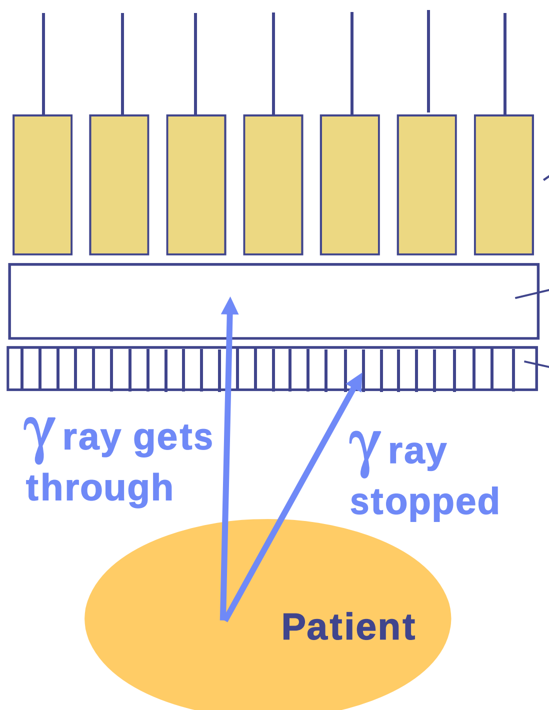
Radioisotope Imaging

- Gamma (γ) emitting radioisotope administered to patient and a **GAMMA CAMERA** detects the spatial distribution of radiation coming out of the patient.
- Over 90% of routine scans done with Technetium-99m (^{99m}Tc) e.g. kidney function in dynamic mode – **FUNCTIONAL** imaging.
- ^{99m}Tc emits almost entirely monoenergetic γ – rays at 140keV with T½ = 6 hours.
- Produced in a Molybdenum (Mo) generator or '**COW**'.

$$^{99}Mo_{42} \xrightarrow[\text{67 hours}]{\beta\text{- decay}} {}^{99m}Tc_{43} \xrightarrow[\text{6 hours}]{\gamma\text{ decay}} {}^{99}Tc_{43} \xrightarrow[\text{200k years}]{\beta\text{- decay}}$$

- Mo stuck to alumina in tube. Saline runs through and 'elutes' the Tc.
- $^{99}Mo_{42}$ produced by neutron bombardment in a **NUCLEAR REACTOR**.
- Compounds labelled with Tc in a **RADIOPHARMACY**.

Gamma Camera



Array of PMTs connected to amplifiers, positional logic circuits etc.

NaI (Tl) scintillation crystal.

Collimator – Pb with holes in it.
Encodes spatial information.

The γ rays that get through cause a photoelectric ionisation in the NaI crystal.

The secondary electron from this event Produces visible photons via SCINTILLATION.

Radioisotope Imaging

Image Reconstruction.

Position Logic Circuits.

Each PMT has its output weighted depending on its X and Y position.

X and Y of the photoelectric event found by weighted sum from all PMTs.

Pulse Height Analyser.

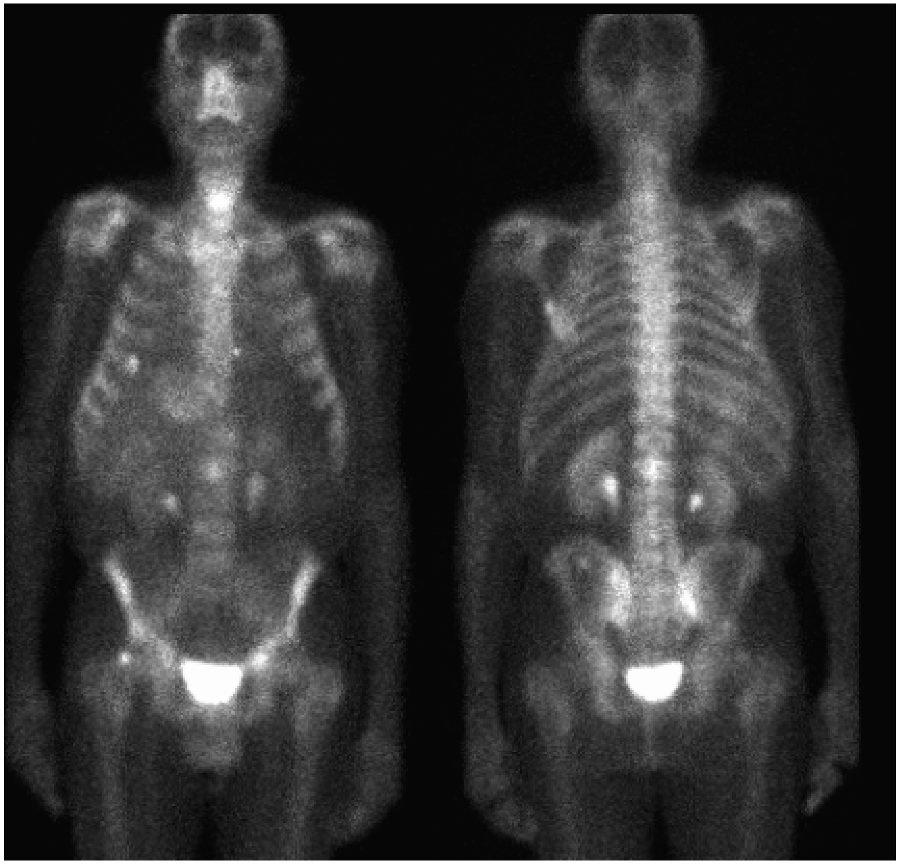
Discriminates against lower energy scattered gamma ray photons

Gamma Camera

Gamma camera head

Rotation available for SPECT

Gamma Camera Scan



Liver metastasis from prostate carcinoma.

IV administration of Tc99m .

Accumulates in areas of increased blood flow due to active bone metabolism, oedema of inflammation or the angiogenesis associated with tumours.

Single Photon Emission Computed Tomography
(SPECT)

Gamma camera rotates around the patient (in typically 3^o steps) acquiring projections.

Images reconstructed in a similar way to CT.

Spatial resolution ~ 6mm – much poorer than CT.

BUT can give 3D functional image.

Positron Emission Tomography (PET)

β+ Decay

Proton-rich radioisotopes e.g. ^{15}O, ^{11}C, ^{18}F.

Produced by proton bombardment in a particle accelerator called a CYCLOTRON.

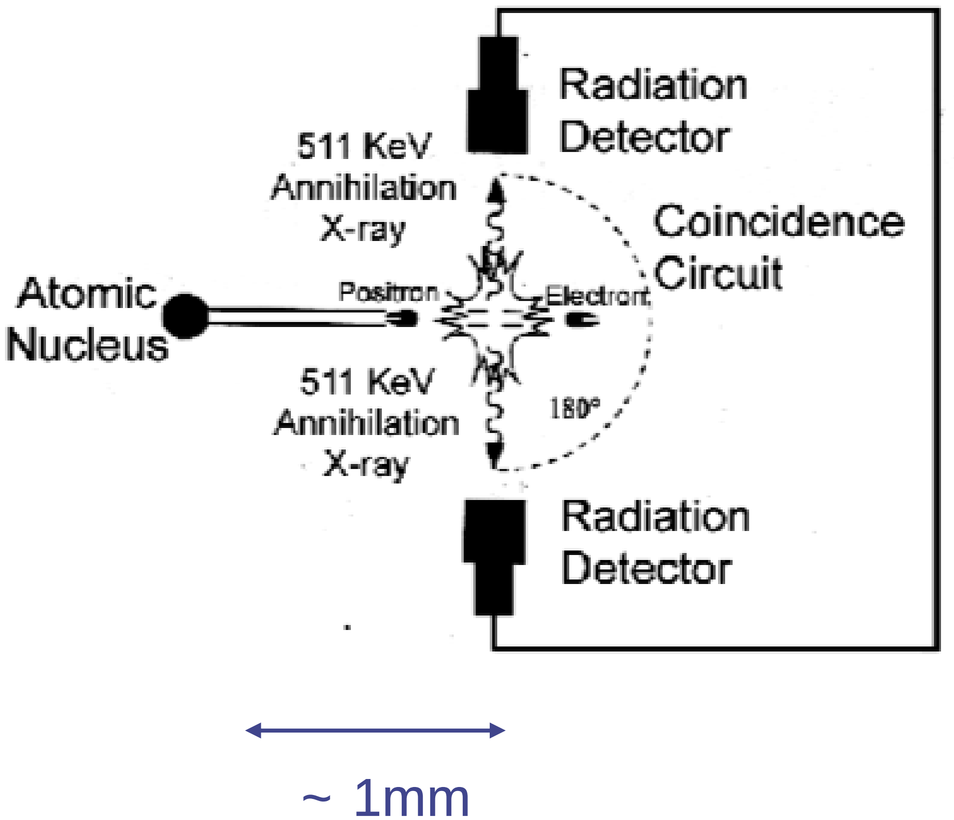
Decay by: $p \rightarrow n \; e^+ \; \nu$

e^+ = positron. This is ANTI-MATTER.

^{18}F – ½ life ~ 110 minutes.
^{11}C – ½ life ~ 20 minutes.
^{15}O – ½ life ~ 2 minutes!!

$\Rightarrow$ Get that cyclotron near the scanner!!

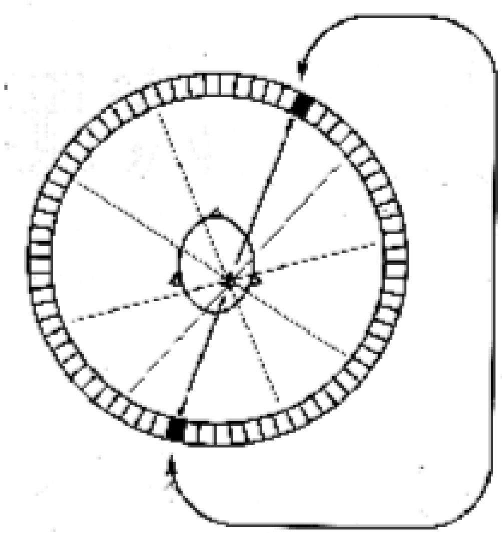
Positron Emission Tomography (PET)



Rings of dense & segmented scintillation crystals (BGO) coupled to PMT's surround patient.

2 x 511 keV photons emitted back-to-back at annihilation.

Positron Emission Tomography (PET)



Determining LINE OF RESPONSE (LOR) :

★ **POSITION detecting of crystal.**

★ **CO-INCIDENCE circuits determine if detector directly opposite detected same event (within ~ 2ns).**

★ **ENERGY of photon determined.**

Eliminates stray or scattered γ rays.

Image ⇒ projection reconstruction along multiple LORs (like in CT).

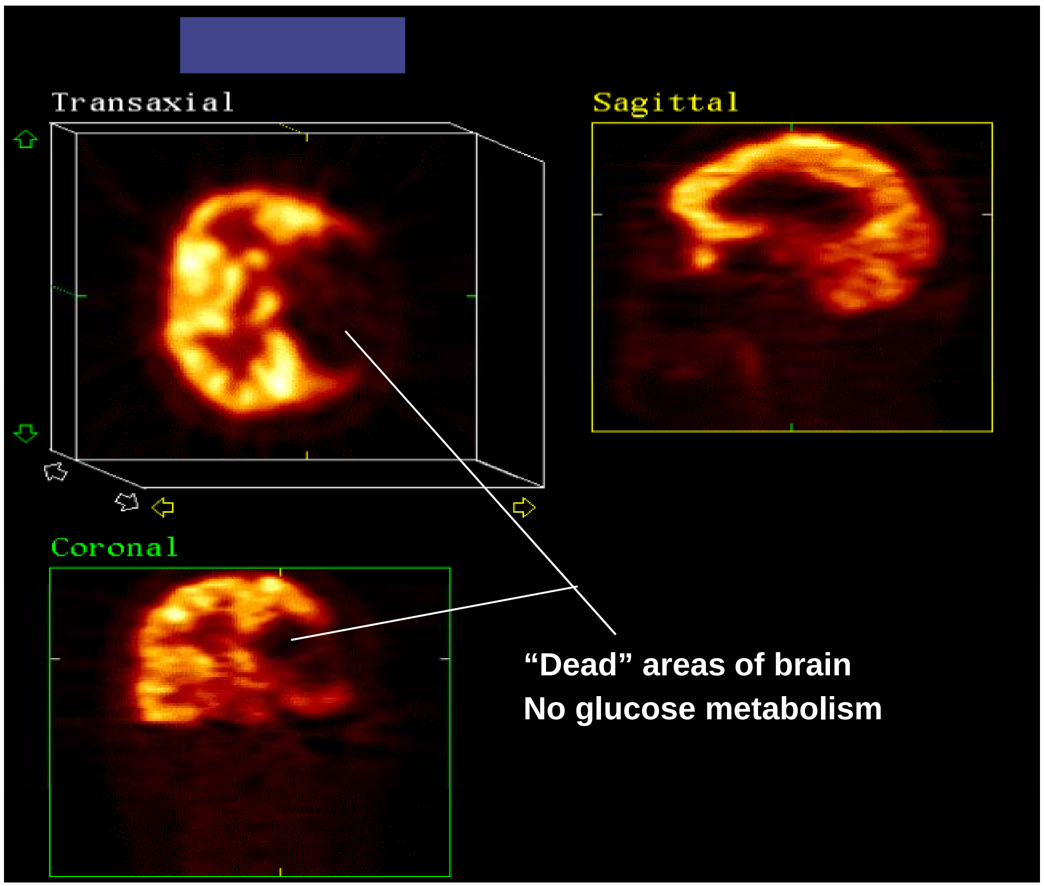
PET Scanner Installation

Cyclotron

Radiopharmacy

Scanner

Image of Human Brain - Stroke

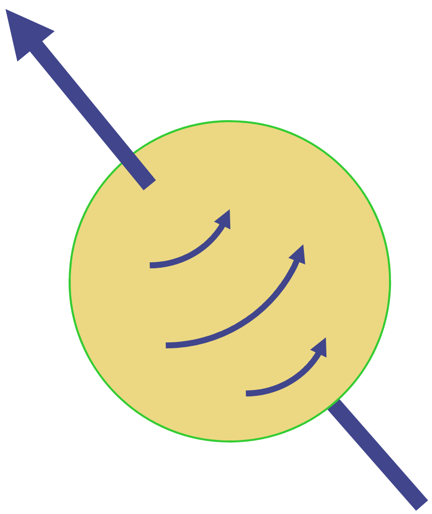


Glucose molecule labelled with Fluorine-18.

Intravenous administration.

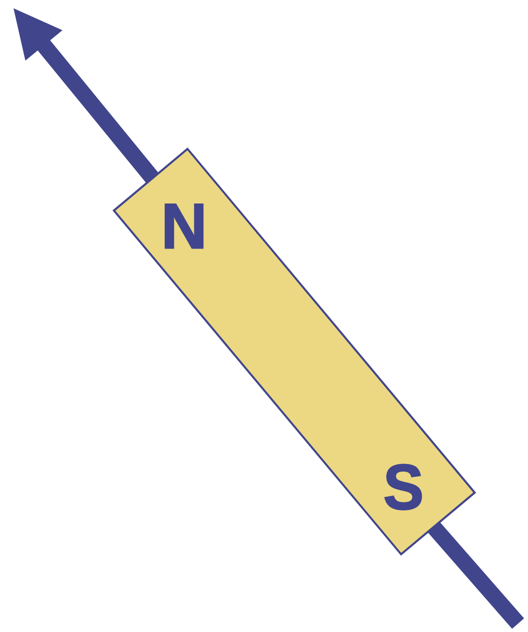
Magnetic Resonance Imaging (MRI)

Nuclear Magnetic Moment



Nucleus with SPIN
e.g. proton

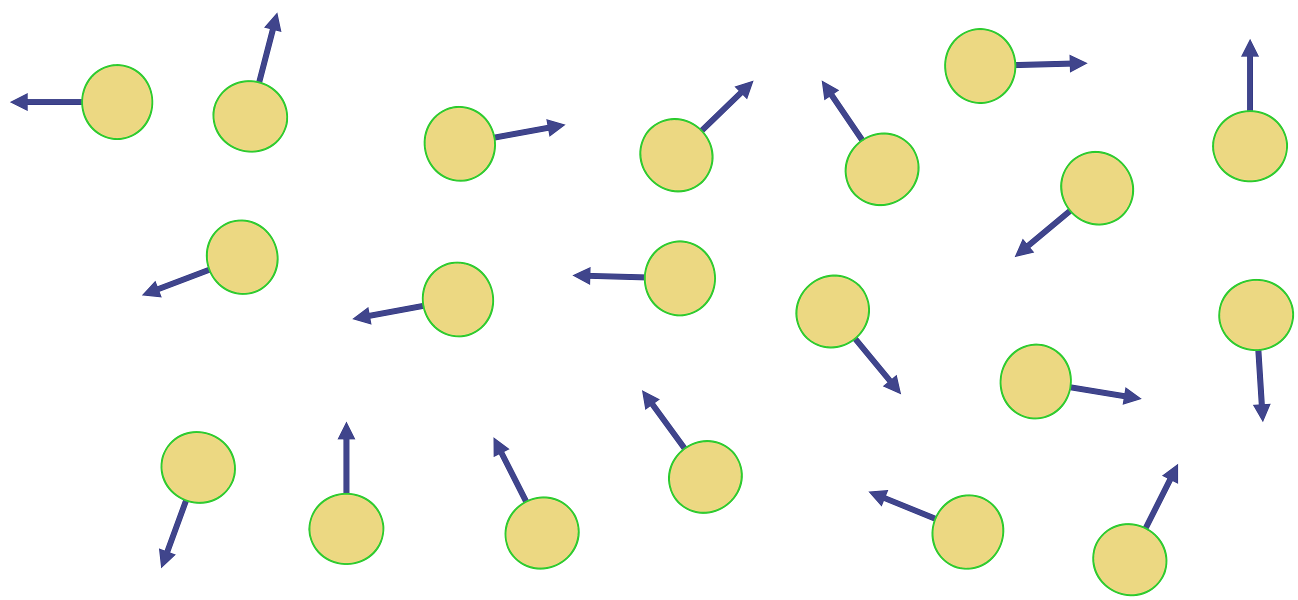
Magnetic Moment



Bar magnet

Magnetic Resonance Imaging (MRI)

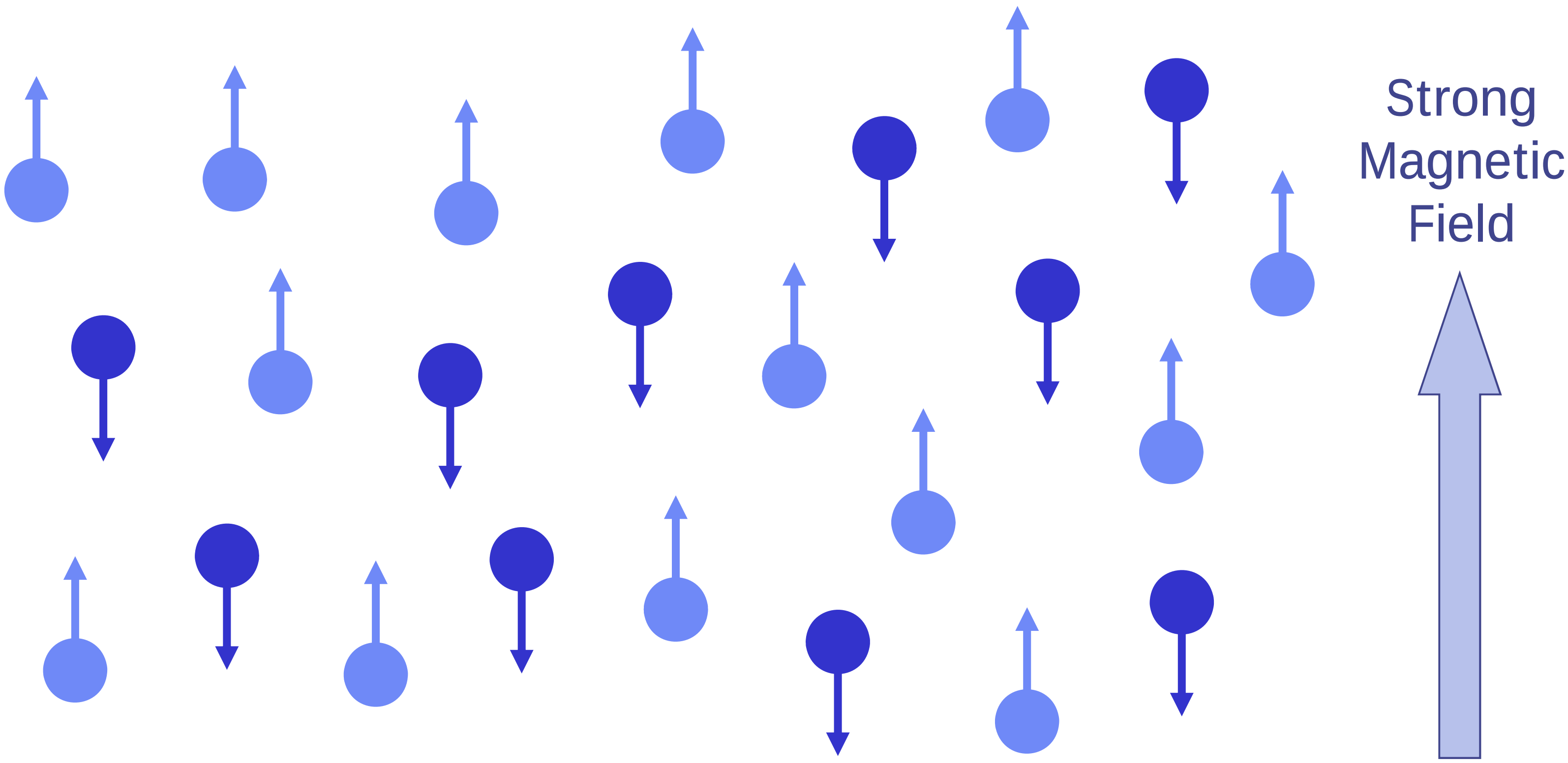
Zero External Magnetic Field



Point in random directions.

Magnetic Resonance Imaging (MRI)

In Strong External Magnetic Field



Some line up. Some line down. Just the majority line up.
Out of 1 million ~ 500,002 UP – 499,998 DOWN.

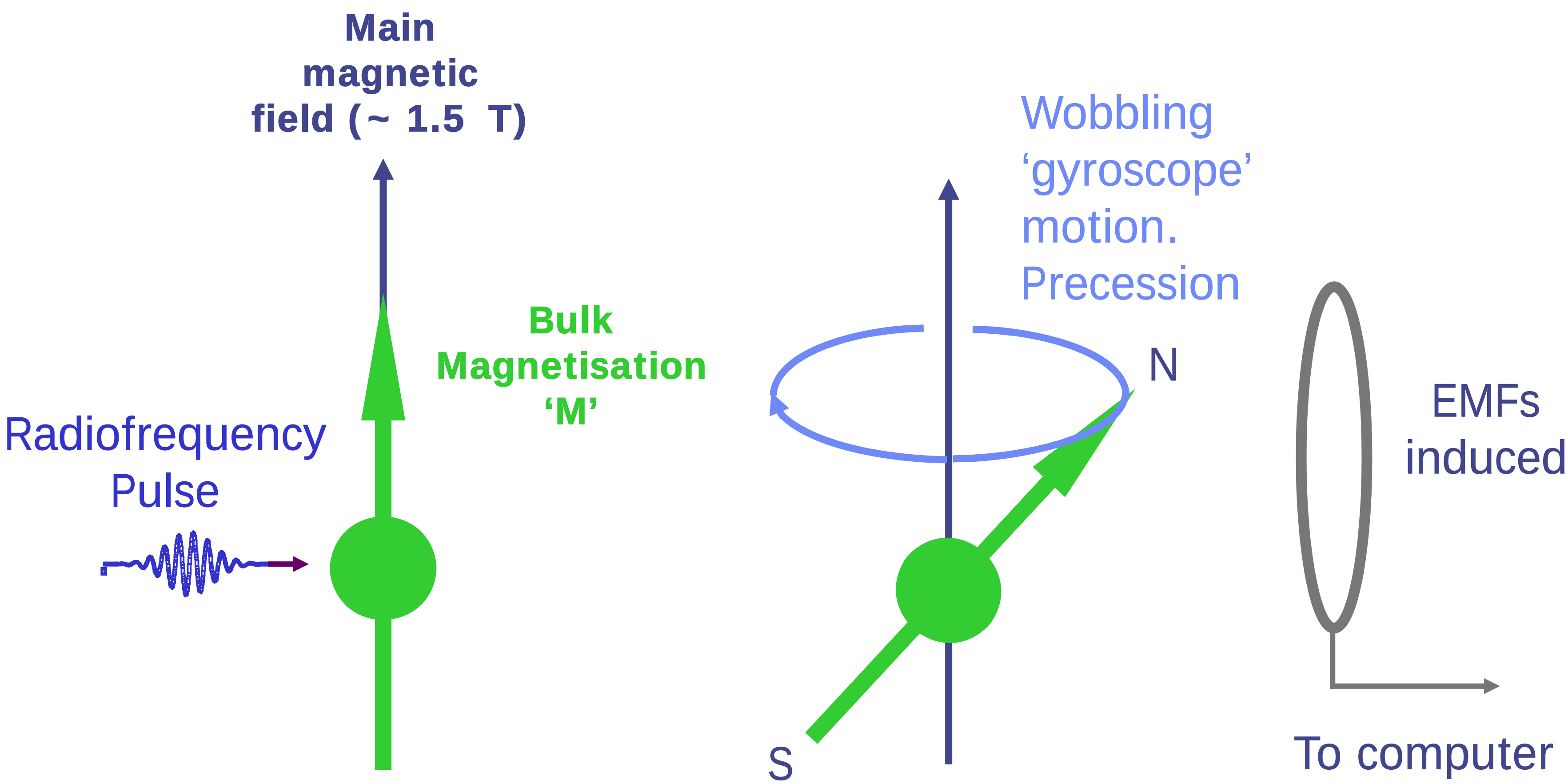
Magnetic Resonance Imaging (MRI)

Hydrogen Nucleus

- **The proton.**
- **Biggest nuclear magnetic moment of any stable nucleus.**
- **Most abundant nucleus in the human body.**
- **Water and lipid (fat).**
- **MRI gives a distribution of water and fat in the patient.**

Magnetic Resonance Imaging (MRI)

Flipping Spins



Magnetic Resonance Imaging (MRI)

Larmor Frequency

Rate of ‘wobbling’ depends on big magnetic field strength.

$$F = \gamma B$$

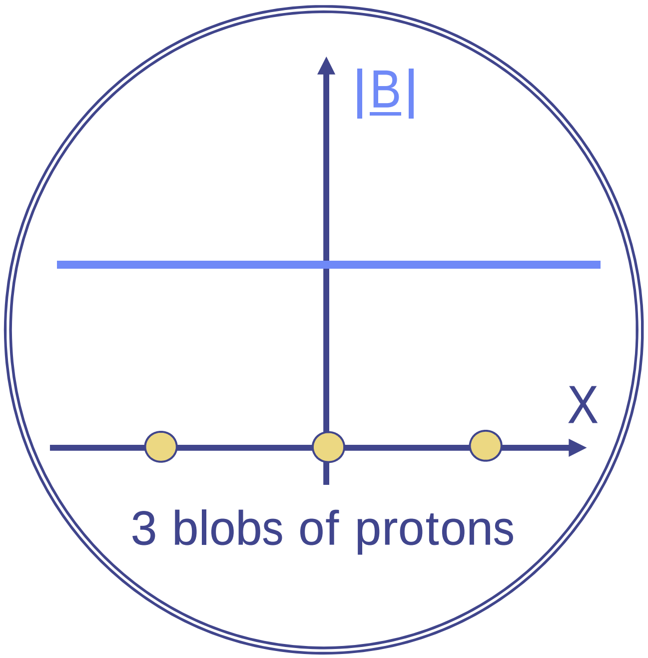
γ = gyromagnetic ratio
(42.57 MHz per Tesla for protons)

1 Tesla ≈ 10,000 x Earth’s magnetic field.

Magnetic Resonance Imaging (MRI)

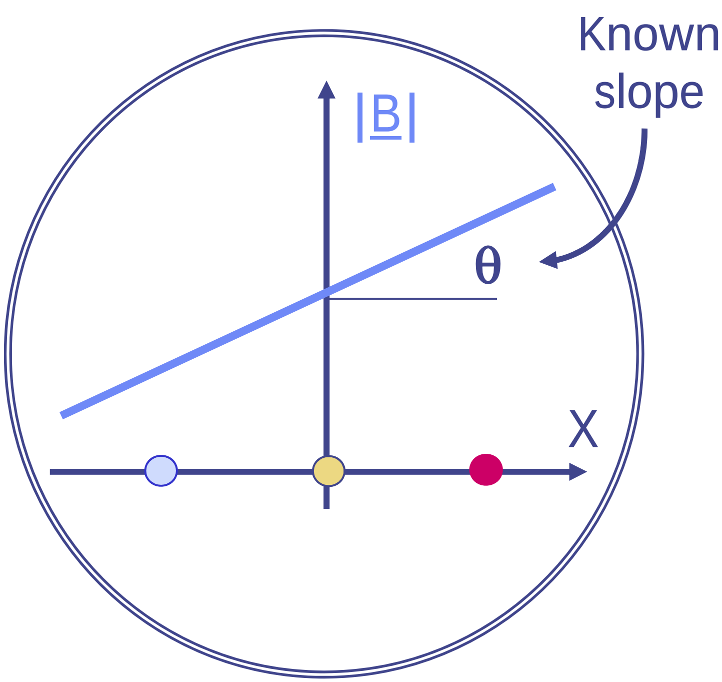
Frequency Encoding of Spatial Dimensions

No gradient



All 3 ‘see’ the same B
& wobble at same rate

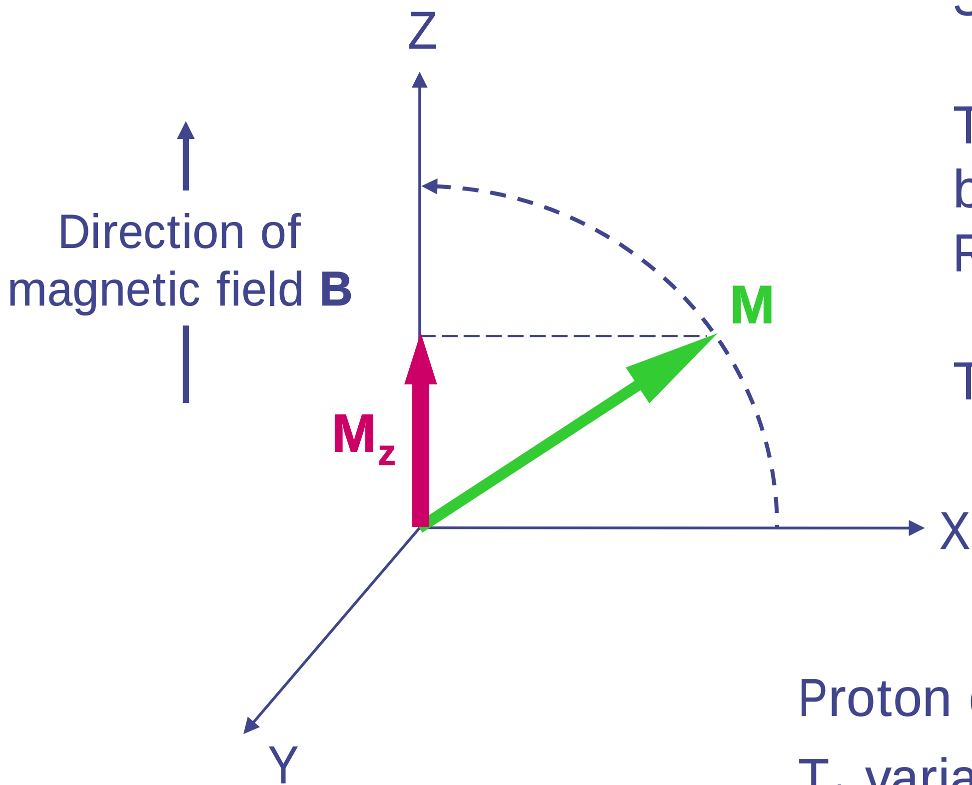
With gradient



Each ‘see’ a different B
& wobble at 3 different rates

Magnetic Resonance Imaging (MRI)

Nuclear Relaxation and Image Contrast



Spin-Lattice (or T_1) Relaxation.

Tipping back up of the
bulk magnetisation (**M**).
Re-aligns with **B**.

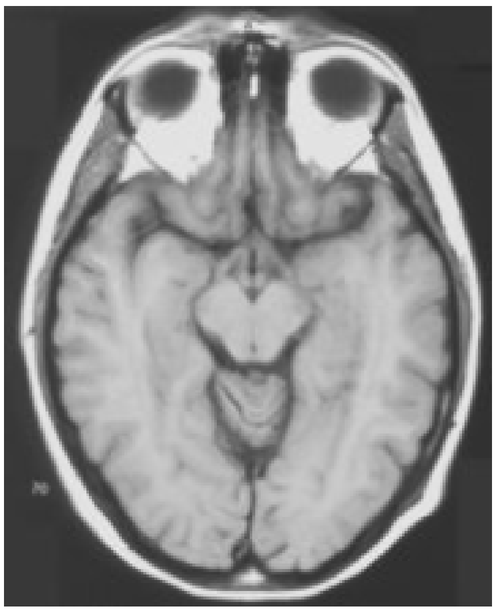
T_1 ~ 1 second for tissues.

Proton density variations < 10%

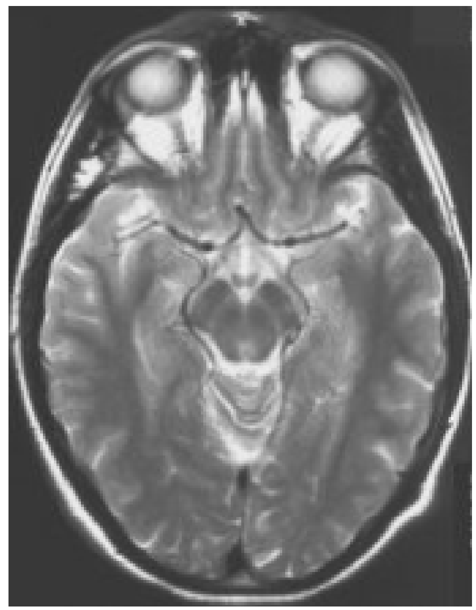
T_1 variations can be ~ 700%

Magnetic Resonance Imaging (MRI)

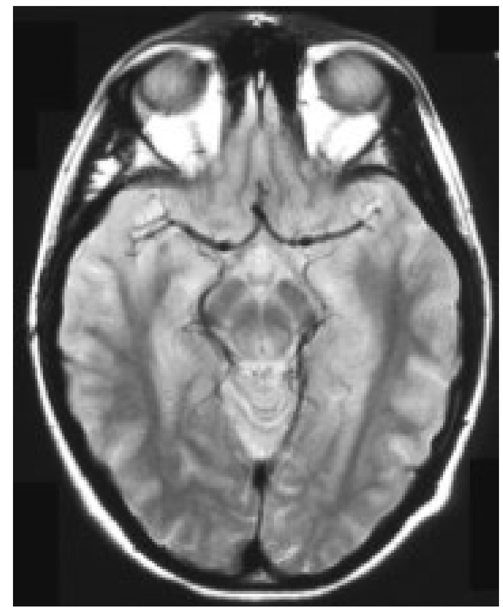
Axial Brain Images



T_1-weighted



T_2-weighted



Proton density weighted

MRI Scanner

- ★ Big superconducting magnet (~ 1.5 tesla).
- ★ Gradient coils.
- ★ Radiofrequency coils.

Costs

Ultrasound	**Conventional X-ray**
$30-80k	$50-150k

CT/Gamma	**MRI**	**PET**
$150-500k	$2-3M	~$7M

Safety

Modality	Radiation Type	Comments
X-ray imaging Radioisotope scanning	Ionising Radiation	Long history of effects. Stochastic damage.
Ultrasound Imaging MRI	Non-ionising Radiation	Less harmful effects. Better for the fetus.

Summary

What are they good at (or not)?

Imaging Technique	Advantage	Disadvantage
Ultrasound	Good soft tissue contrast. Quick and cheap.	Mainly anatomical. Only ‘reasonable’ spatial resolution. ‘Planar’.
X-ray	Bone-soft tissue interfaces. High spatial resolution. Quick(ish) and cheap.	Poor soft tissue contrast. Planar – except CT.
Nuclear Medicine	Functional rather than anatomical. Can be 3-dimensional. PET – very sensitive metabolic tool.	Functional rather than anatomical. Poor spatial resolution. PET very expensive. Long scan times.
Magnetic Resonance	Outstanding soft tissue contrast. Ability for functional imaging and spectroscopy. 3 (or 4) dimensional.	Only ‘reasonable’ spatial resolution. Long(ish) scan times.

Figure and Text Credits

Text and figures for this lecture were adapted in part from the following sources:

http://www.acphysci.com/docs/04%20editabstracts.pdf
Highlights from Academic Medicine. Academic Physician & Scientist, January 04.

http://www.mayoclinic.com/invoke.cfm?id=FL00065
MayoClinic.com

http://www.liv.ac.uk/~iop/PTC/TechMedicImag.ppt
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Resources

Medical Assistant Degree
http://www.medicalassistantdegree.com/resources/medical-imaging-resources/

Diagnostic Imaging. Medline Plus.
www.nlm.nih.gov/medlineplus/diagnosticimaging.html

Radiological Society of North America, Inc.
http://www.radiologyinfo.org/en/info.cfm?pg=gennuclear

W.E. Erkonen, *Radiology 101. The Basic and Fundamentals of Imaging*.
Lippincott Williams & Wilkins, Philadelphia, PA, 1998.