1. GENERAL RADIOLOGY

X-RAYS

Radiation symbols

International Radiation Symbol "The Trefoil"	X-ray Radiation Hazard	High Level Sealed Source Ionizing Radiation Symbol IAEA and SO — 2007
		

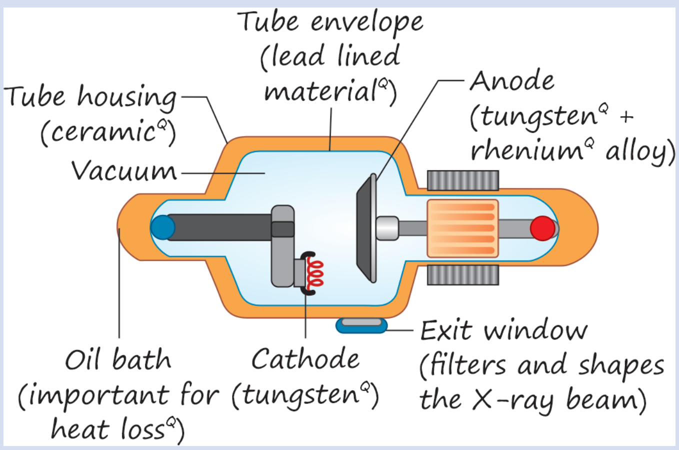
X-ray basics

Wilhelm Conrad Röntgen — Founding Father of Radiology

Discovered X-rays on 8th Nov 1895 Celebrated as *International Radiology Day*

1st X-ray Image Hand of *Mrs. Bertha Rontgen*

X-ray Tube — Structure



X-rays are a part of Electromagnetic spectrum[Q]

- Electromagnetic spectrum[Q]:
- All energy components are part of this spectrum.
- In increasing order of frequencies/energies this spectrum includes—radio waves (least frequency and energy),[Q] microwaves, infra-red, visible light, ultraviolet, X-rays and gamma rays (Maximum frequency and energy).[Q]
- All have same speed[Q]—speed of light—3×10^8 m/s
- All have same type of wave[Q]

X-ray specifics:

- Have relatively high frequency and high energy
- Wavelength = 0.01–10 nm
- Energy 100 eV – 100 keV

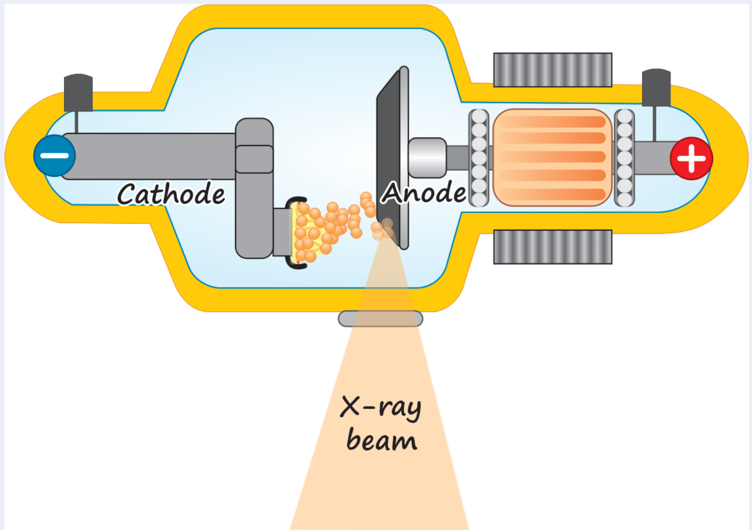
Tungsten:

- It is an important component of X-ray tube (Cathode filament)
- Symbol—W[Q]
- Atomic number—74[Q]
- Atomic mass number—184[Q]
- Classified as transitional metal[Q] in the periodic table

Contd...

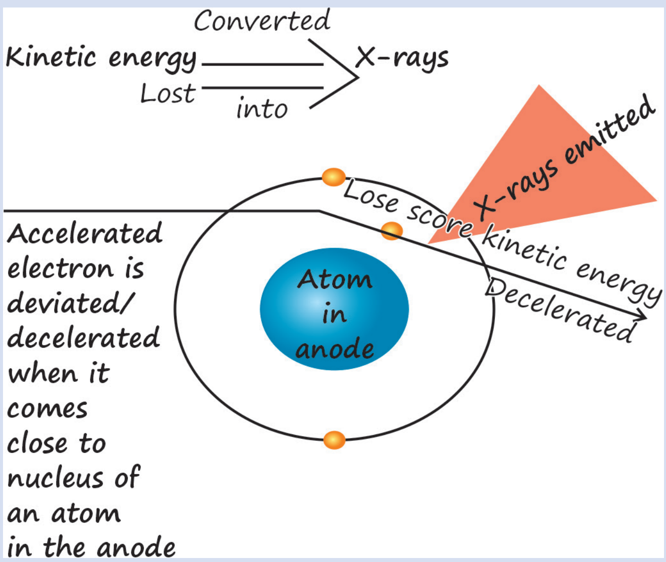
X-ray basics

- Electric current through cathode filament
- ↓ Cathode filament is heated
- ↓ Thermionic emission
- ↓ Cloud of electrons around cathode
- ↓ Electrons accelerated toward anode
- ↓ X-rays are produced



Mechanisms of X-ray Production

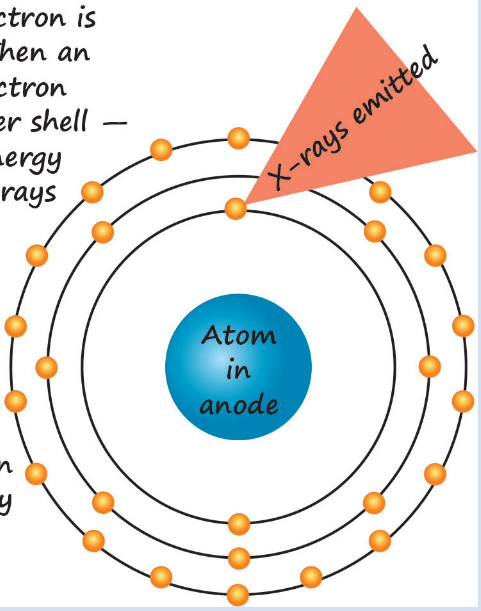
Continuous Spectrum—70–80%



Characteristic Spectrum—20–30%

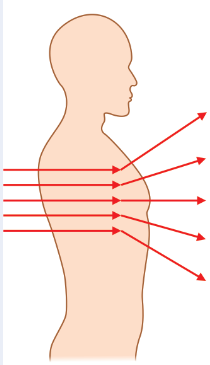
When electron hits inner shell electron — the inner shell electron is thrown out. Then an outer shell electron jumps to inner shell — losing some energy emitted as X-rays

Used in mammography



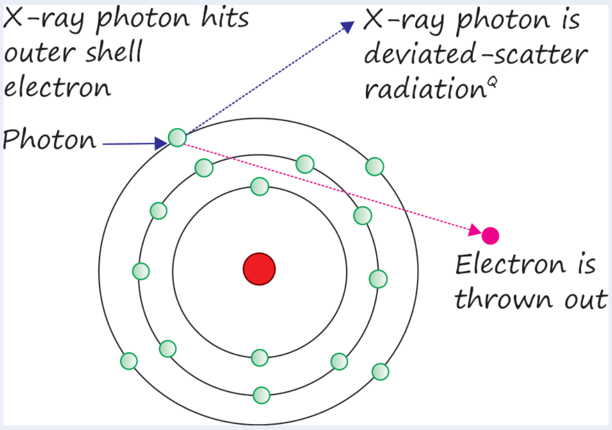
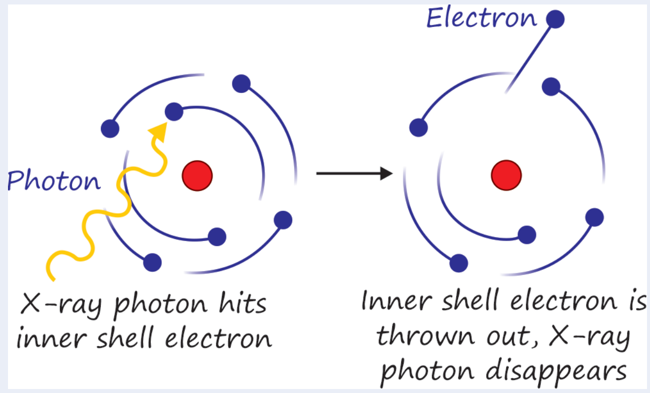
Interaction of X-rays with matter

Occurs Inside the patient body



1. Compton effect — Overall most common
2. Photoelectric effect — Also seen in diagnostic radiology
3. Coherent scattering
4. Photodisintegration
5. Pair production

(3–5) Not seen in diagnostic radiology

Compton effect—Interaction of X-ray photon with outer shell electron[Q]	Photo-Electric Effect—Interaction of X-ray photon with inner shell electron[Q]
	

• Most common interaction of X-rays with matter[Q]
• It is a mid-energy phenomenon[Q]
• Most important outcome is scatter radiation[Q]. It causes image distortion, blurring and decreased diagnostic quality of the radiographic image
• Hence, to minimize scatter radiation, we try to minimize compton effect[Q]
• Minimizing compton effect—Using high energy X-rays[Q]
	• Less common
	• It is a low-energy phenomenon[Q]
	• There is no scatter radiation[Q]—hence, image quality is better.
	• Because there is no scatter radiation, we try to maximize photoelectric effect[Q]
	• Maximizing photoelectric effect—
	  ▪ Using low energy X-rays[Q]
	  ▪ High atomic number target[Q]

Exposure Factors—Kilovoltage peak (kVp) and Milliampere second (mAs)

Kilovolt peak (kVp):	Milliampere second (mAs)[Q]

• Voltage applied across the cathode and anode in the X-ray tube.
• High kVp—results in higher penetrating power of X-rays[Q]
• kVp also affects radiographic contrast–
  ▪ Low kVp—high contrast[Q]—called short scale contrast[Q]
  ▪ High kVp—low contrast[Q]—called long scale contrast[Q]
	• Combination of:
	  ▪ mAmp[Q]—current passed through the cathode filament
	  ▪ Time[Q]—time of exposure
	• Determines the number of X-ray photons[Q] in the X-ray beam
	• Directly affects the contrast—increased mAs—increased contrast[Q]

RADIATION UNITS

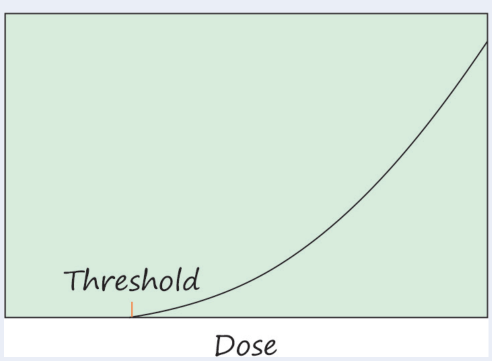
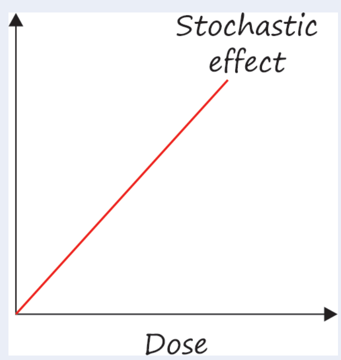
Radiation exposure	Absorbed dose
• Conventional unit—Rontgen[Q] • SI unit—Coulomb/Kg[Q]	• Conventional unit—Rad[Q] ▪ Rad—stands for radiation absorbed dose • SI unit—Gray[Q]
Absorbed dose equivalent	**Radioactivity**
• Conventional unit—REM[Q] ▪ Rem—stands for rontgen equivalent man • SI unit—Sievert[Q]	• Conventional unit–curie[Q] • SI unit–Becquerel[Q]

Acute radiation syndromes[Q]/Radiation sickness[Q]/Radiation toxicity[Q]	
Concept—Acute Radiation Syndromes (ARS)—Why do they occur in a particular order? **Law of Bergonié and Tribondeau[Q]: Basic Concept in Radiobiology** Whatever tissue/organ/region in the body has the maximum proportion of undifferentiated cells/cells in active mitosis will be more sensitive to radiation.	**Four stages of acute radiation syndromes** 1. Prodromal stage: Nausea vomiting-diarrhea stage—lasts from few minutes to hours 2. Latent phase: Lasts few hours to days 3. Manifest illness phase: Actual symptomatic stage—lasts from days to weeks 4. Recovery/Death stage: Lasts weeks to years

Acute hematological syndrome/ Bone marrow syndrome—1st clinical syndrome to occur Threshold dose: Around 1–2 Gray[Q]	**Gastrointestinal syndrome:** • 2nd organ system affected • Threshold dose is 6–10 Gray[Q] • Symptoms are malaise, severe diarrhea, electrolyte imbalance	**Cardiovascular[Q]/CNS syndrome[Q]:** Threshold dose is around 20 Gray[Q]

DETERMINISTIC AND STOCHASTIC EFFECTS OF RADIATION

Smart-Work strategy tip: Remembering the various properties of these effects can be difficult. Hence, let us study them in a comparative manner. Also try to remember their examples first so that using those examples we can remember the individual properties.

	Deterministic effects	Stochastic effects
Examples	• Acute radiation syndromes[Q] (discussed above) • Cataract[Q] • Skin changes[Q]—Erythema, ulceration • Sterility[Q] • Radiation myelitis • Fibrosis • Teratogenesis/Fetal death	• Radiation induced carcinogenesis[Q] • Genetic mutations[Q] • Chromosome aberrations[Q]
Onset	Acute[Q] and subacute[Q] effects	Chronic effects[Q]
Threshold dose	Yes[Q]	No threshold dose[Q]
Severity of effect	Directly proportional to dose[Q]	Not related to dose[Q]
Risk of occurrence	Nonlinear relationship with threshold[Q]	**Linear relationship with no threshold (LNT)**
		

RADIATION EXPOSURE, PROTECTION AND GUIDELINES

Radiation exposures in various modalities

Modality	Radiation exposure in mSv	
PET	25	CT/PET/ Radionuclide studies
CT abdomen	10	
CT thorax	8	
Dynamic cardiac scintigraphy	6	
Bone scan	4	
CT head[Q]	3.5	
Barium enema[Q]	7.2	Diagnostic procedures
Barium meal follow through	3	
Barium meal	2.6	
Barium swallow	1.5	
MCU[Q]	1.2	
Lumbar spine[Q]	1.0	Spot radiographs
Abdomen X-ray	0.7	
Hip joint	0.4	
Skull X-ray	0.06	
CXR PA view[Q]	0.02	
Limb X-rays[Q]/joint X-rays[Q]	<0.01	

Permissible radiation exposure—recent guidelines

Recommended dose limits in planned exposure situations:

Type of Dose	Occupational exposure	Public exposure
Effective dose	20 mSv per year[Q], averaged over defined 5-year periods (100 mSv in 5 years) Or provision that the effective dose should not be exceeded 50 mSv[Q] in any single year with the total dose at end of 5 years should be <100 mSv.	1 mSv in a year[Q] A higher per year exposure may be allowed in a single year, provided that the average over defined 5-year periods does not exceed 1 mSv per year[Q]
Annual equivalent dose in:		
Lens of eye	150 mSv[Q]	15 mSv[Q]
Skin	500 mSv[Q]	50 mSv[Q]
Hands and feet	500 mSv[Q]	–
Pragnant radiation workers	**After declaration of pregnancy – 1 mSv dose to the embryo/fetus should not be exceeded[Q].**	

The ICRP and AERB guidelines are exactly similar with just one difference:

AERB–allows maximum exposure to occupational workers in any one year to be a maximum of **30 mSv**, provided that the total dose at end of 5 years should be <100 mSv

PYQ ALERT

Thermoluminescent dosimeter (TLD) Badge[Q]—NEET 2020 pattern question

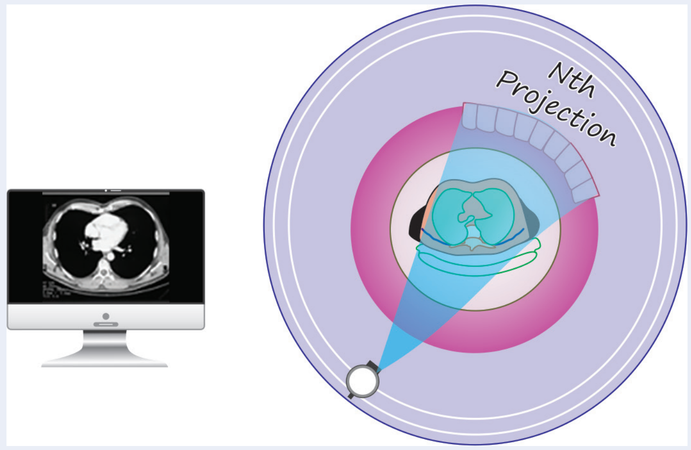
- Thermoluminescent dosimeter (TLD)[Q] is a passive radiation detection device that is used for personal dose monitoring or to measure patient dose.
- Composed of phosphor crystals[Q] [lithium fluoride (LiF)[Q], lithium borate ($Li_2B_4O_7$)[Q], beryllium oxide (BeO)[Q], and magnesium borate (MgB_4O_7)[Q]] that measure ionizing radiation primarily by trapping propagated gamma and neutron exposure.
- Incident energy is absorbed by some of the crystal's atoms thereby producing free electrons. Free electrons are trapped by the imperfect lattice structure of the crystal that is created due to doping impurities.
- The crystal is heated, the crystal vibrates to release the free electron back to its ground state. Trapped ionization is released as light, which is measured by photomultiplier tubes. This value is in ratio with the ionizing radiation captured by the phosphor, and represents the dosage administered to a person[Q], provided equipment was mounted properly.
- TLDs can measure doses between 0.01 mGy and 10 Gy[Q].

COMPUTED TOMOGRAPHY

Computed tomography is basically a fusion of two technologies:

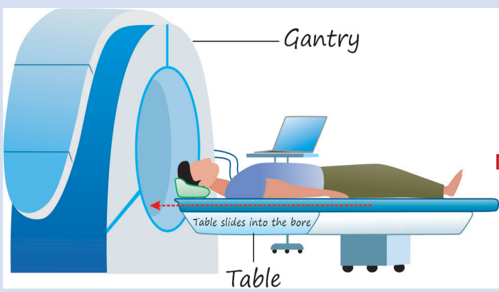
1. **Tomography**[Q]: X-ray-based imaging technique developed to acquire sectional images of the body.
2. **Computers**[Q]: Brought in to deal with the complex mathematical algorithms and iterations in the image reconstruction.

- **Father of CT technology**
- **Invented the 1st generation CT scanner/EMI scanner**
- **Hounsfield Unit Scale (HU scale/CT value scale)**
- **Awarded Nobel Prize jointly with Allan Cormack in 1979**

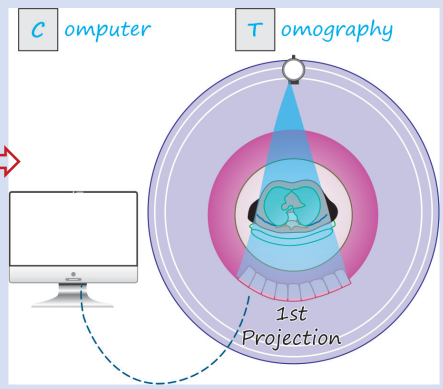


CT scan—basic principle: The internal structure of an object can be reconstructed from multiple projection of that object[Q].

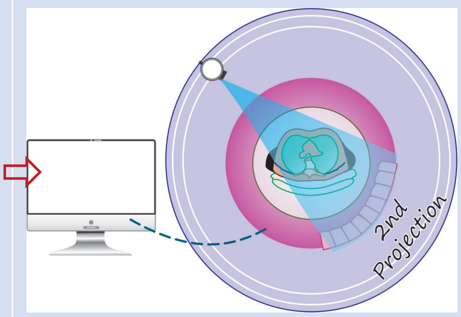
BASIC PRINCIPLE OF CT SCAN



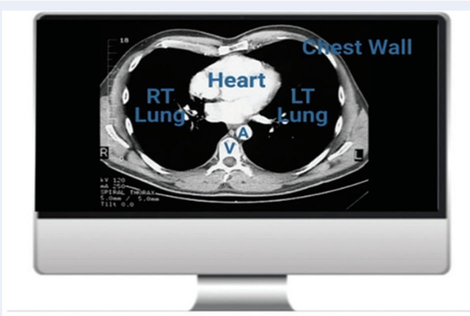
CT machine—has a gantry (tomographic unit) and tale (patient lies on this tale and it slides into the ore of the gantry)



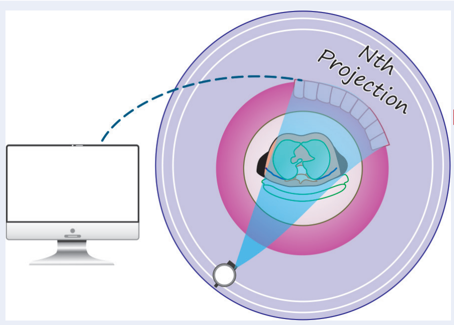
1st Projection data is obtained and transferred to computer



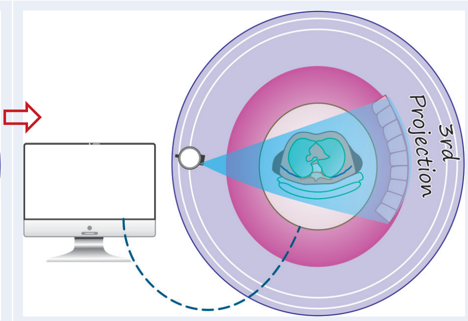
2nd Projection data is obtained (from a different angle) and transferred to computer



Computer reconstructs internal structure of body from all the projection data—using complex mathematical algorithms



Nth Projection is obtained—all from different angles around the patient and transferred to computer



3rd Projection data is obtained (from another different angles) and transferred to computer

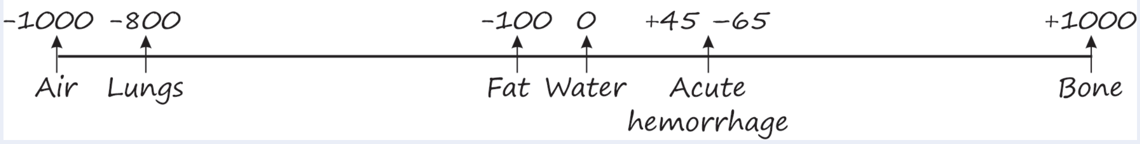
CT scan Miscellaneous

Hounsfield unit (HU) scale/CT value scale

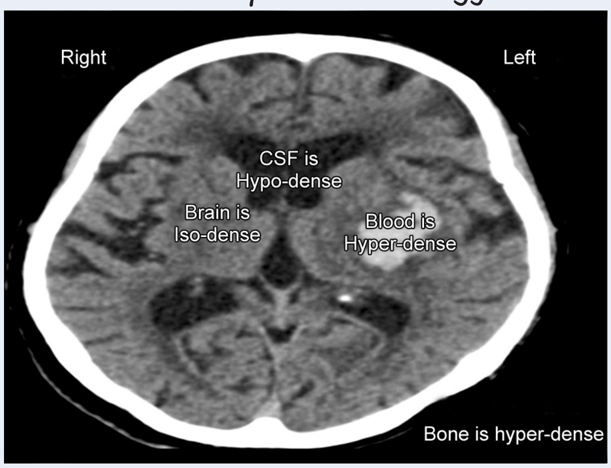
Each tissue in the body is allotted a numerical value – it is "HU/CT value"

$$\text{HU Value} = 1000 \times \frac{\mu_x - \mu_w}{\mu_w}$$

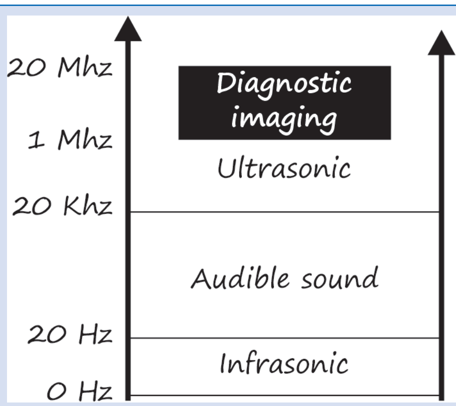
- μ_x = Linear attenuation coefficient of a tissue "x"
- μ_w = Linear attenuation coefficient of water
- Main determinant of linear attenuation coefficient of a tissue is its desnsity[Q]

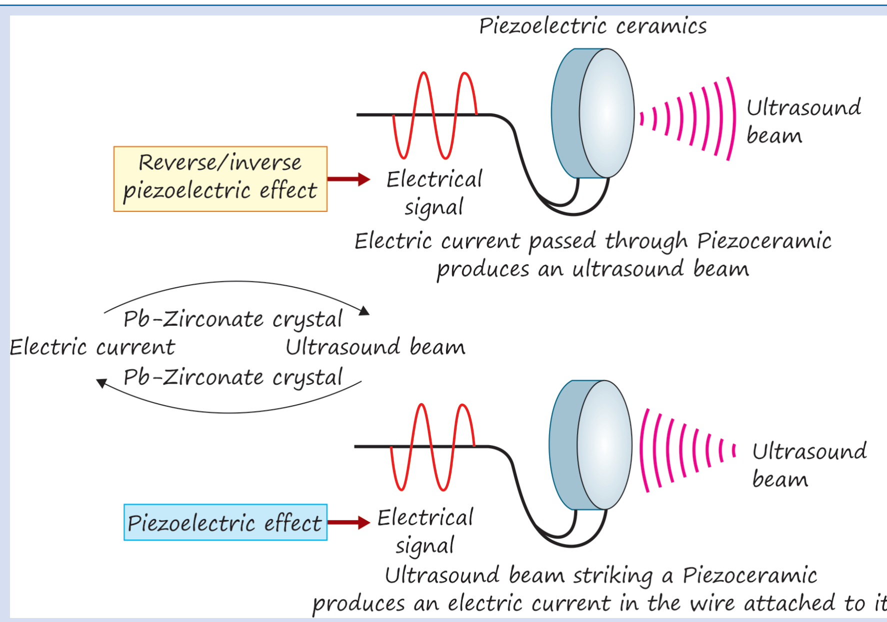


CT descriptive terminology



ULTRASOUND IMAGING





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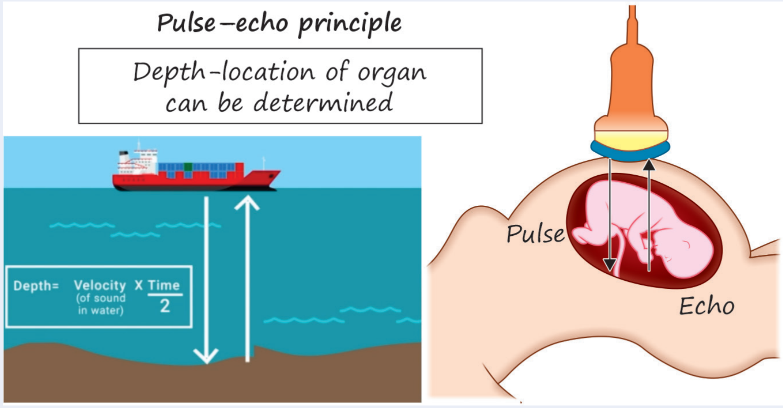
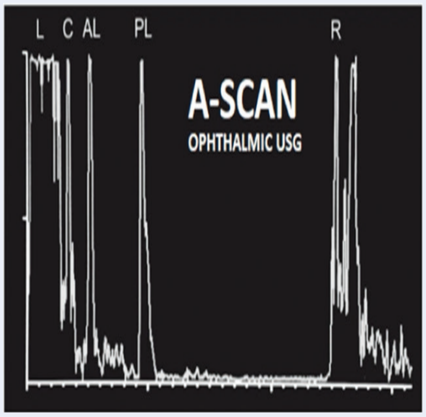
Pulse-echo principle

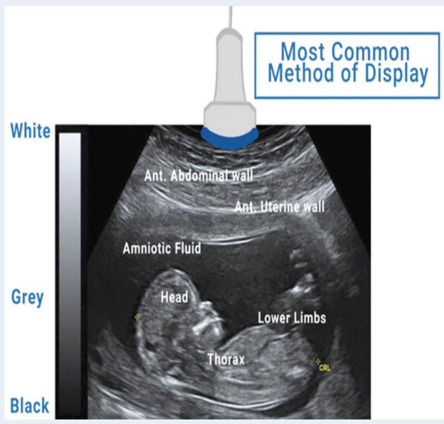


Sound emitted by probe (pulse)
↓
Hits an organ in the body and is reflected back (echo)
↓
Received by probe

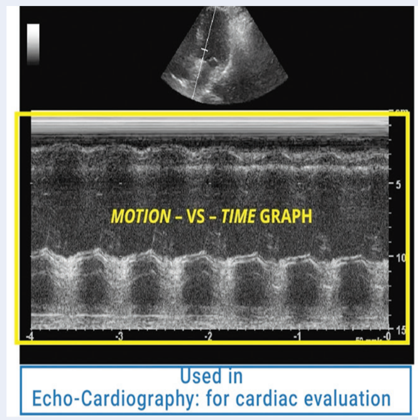
In methods of display of ultrasound



A-mode



B-mode



M-mode

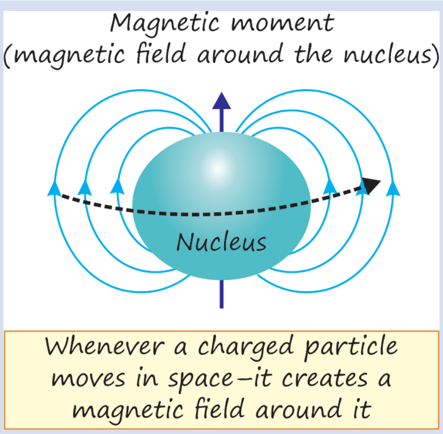
MRI BASICS

MRI Magnet—is a Superconducting Magnet[Q]

The magnetic field is generated by a current, which runs through a loop of wire. Surrounded with a coolant, such as liquid helium, to reduce the electric resistance of the wire. At 4 Kelvin (-269°C) electric wire loses its resistance. Thus producing a permanent magnetic field.

Basic Principle of MRI

"Human MRI is based on Gyromagnetic property[Q] of Hydrogen nucleus"



Gyromagnetic property:

- The nucleus of an atom rotates around itself.
- Because the nucleus is charged (+ve charge) this rotation creates a magnetic field around the nucleus.
- This creation of magnetic field (magnetic moment) around the nucleus created due to its rotation is called **Gyromagnetic property[Q].**

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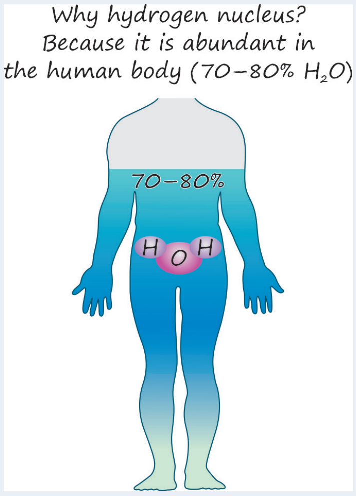
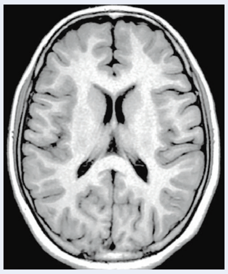
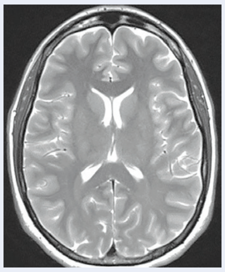
"Human MRI is based on Gyromagnetic property[Q] of Hydrogen nucleus"



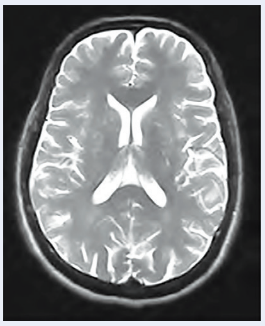
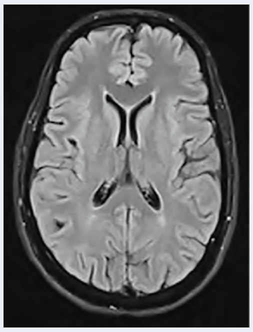
Why Hydrogen nucleus?

- Hydrogen has the highest Gyromagnetic ratio—suggests a strong gyromagnetic property.
- Hydrogen is very abundant in the human body (70–80% of body weight is formed by water)
- Hence, if we measure the signal arising from Hydrogen nuclei in the body—it will be a very strong signal—thus creating an excellent Image.

MRI Image Basics

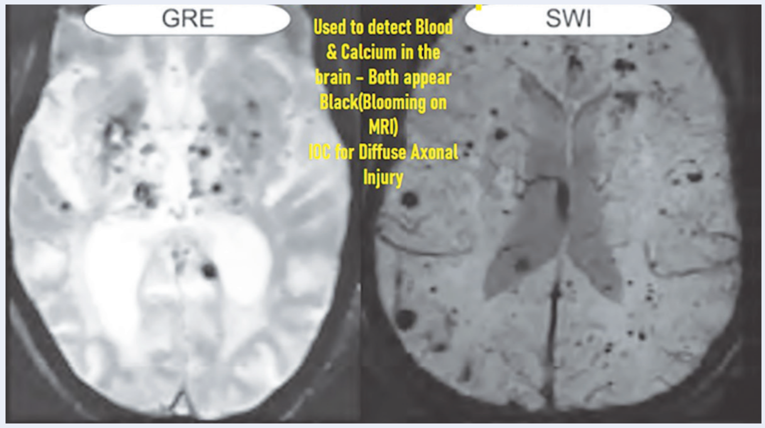
T1W	T2W H_2O is Bright on T2W images
	

CSF signal intensity	T1W	T2W
	CSF is Hypointense (Black)	CSF is Hyperintense (White)
Gray matter and white matter	Anatomical image – So white matter appears white, gray matter appears gray.	Appearance of gray and white matter is opposite to their names

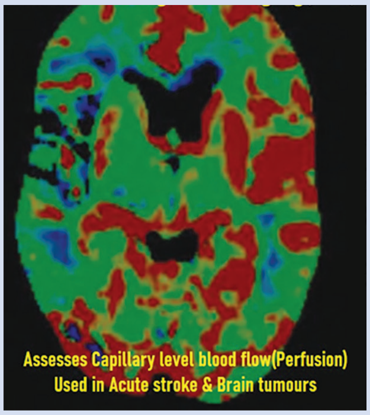
T2W	Fluid attenuated inversion recovery (FLAIR)
	
CSF/Water: Hyperintense Gray-White matter appearance (Opposite to their names) • Gray matter is hyperintense • White matter is hypointense	**CSF/Water**: Hypointense–Fluid signal is attenuated[Q]-hence the name: • Gray matter is hyperintense • White matter is hypointense
Better for depiction of pathology	Can detect even the smallest of lesions

MRI image gallery

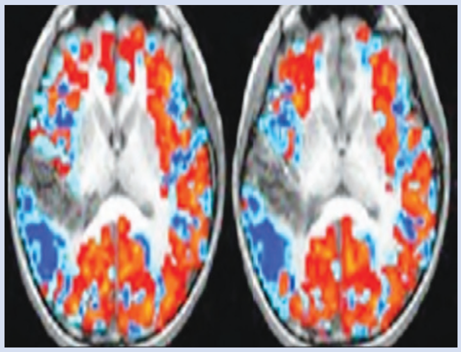
Short Tau inversion recovery (STIR)



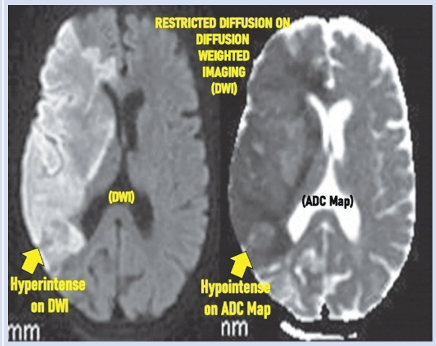
Blood sensitive sequences



Perfusion weighted imaging (PWI)

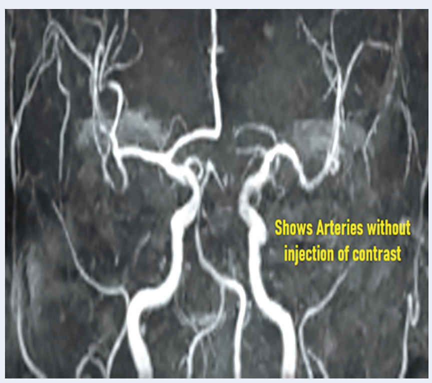


Functional MRI/Bold–Blood Oxygen Level Dependant Imaging Fat MRI acquisition–to detect functional centers of the brain

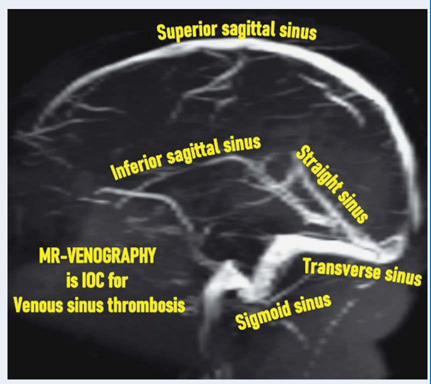


Diffusion weighted imaging (DWI)

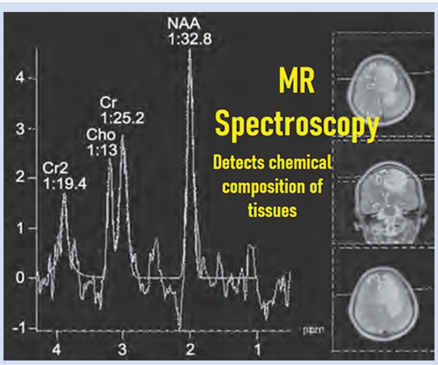
Proton density (PD) image

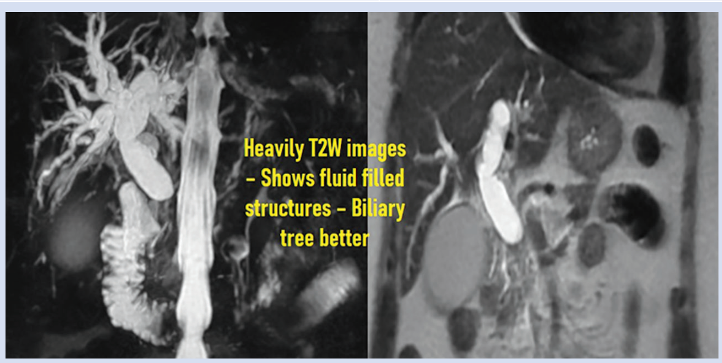


TOF–MRA: Time of flight MR angiography



MR–Venography





Magnetic Resonance Cholangio-Pancreaticography (MRC)