ELECTROMAGNETIC WAVES & THE EMWS SPECTRUM & *COMPUTED TOMOGRAPHY*

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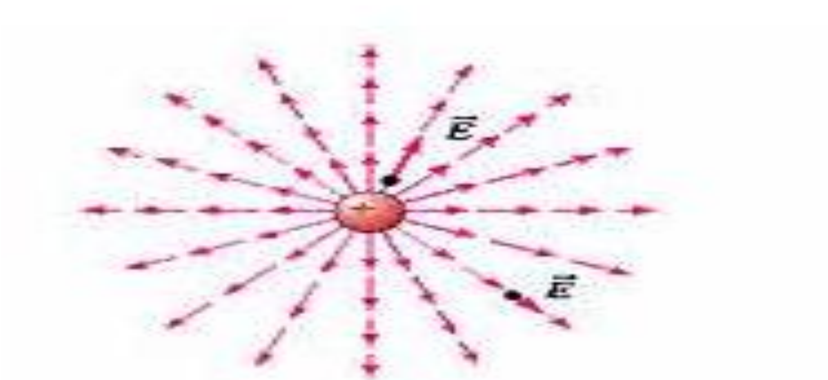
Learning Objectives

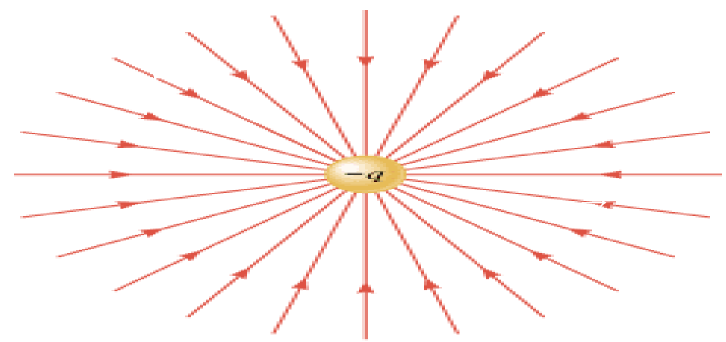
- To describe
  - basically Electric Field, Magnetic Field and Electromagnetic waves
  - characteristics of EM waves
- To list types of EM waves on the EM spectrum
- To explain
  - relation between wavelength, energy and frequency
  - where we can use different types of EM waves
- What else in medicine?

Electric Field

- Electric field is defined as the electric force per unit charge.
- The electric field is radially outside from a positive charge and radially in toward a negative point charge.
- It is a vector quantity and its unit is N/C or V/m.



Electric field lines of a positive point charge

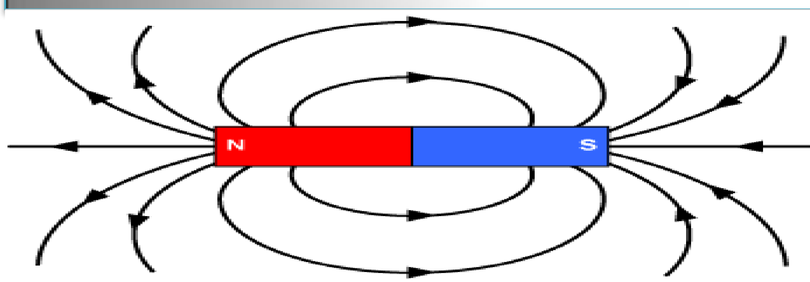


Electric field lines of a negative point charge

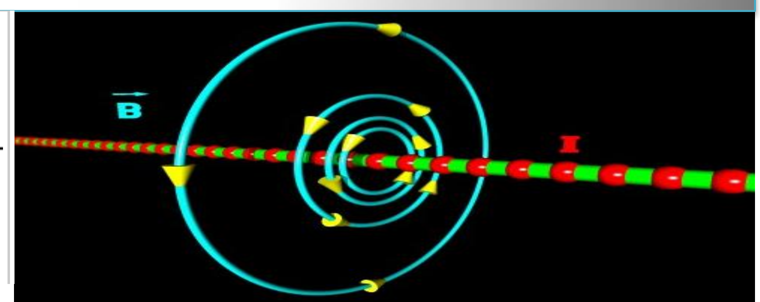
Magnetic Field

- A magnetic field is a field of force produced by a magnetic object or particle, or by a changing electric field.
- The SI unit for magnetic field is the Tesla.
- There is strong relationship between magnetic and electric fields.

Magnetic field sources



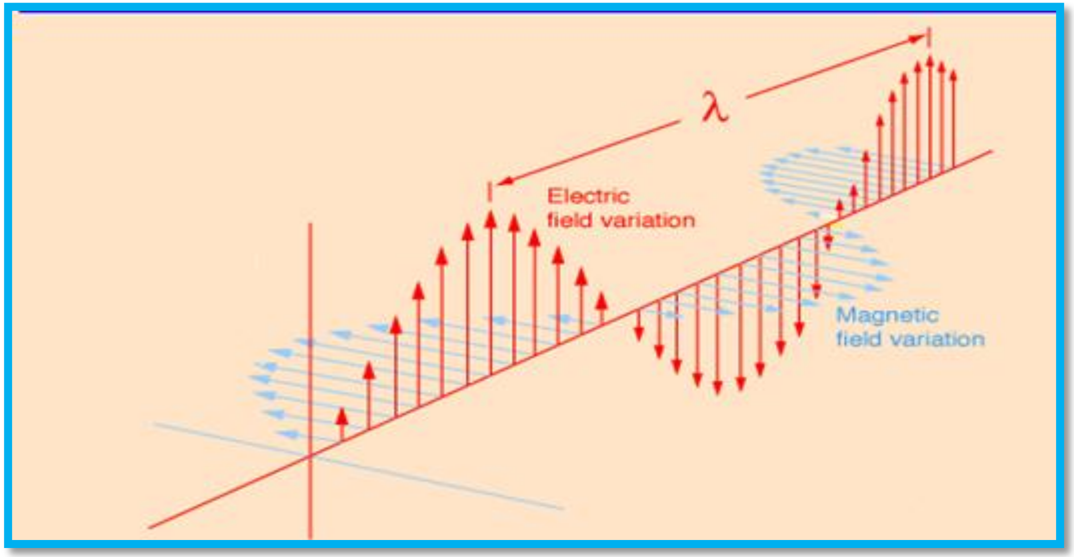
A bar magnet with magnetic field lines around it



Current in wire

Electromagnetic (EM) Waves

- EM waves are formed when there is a continuous process of an electric field developing a magnetic field and vice versa.
- An EM wave has both, electric as well as magnetic components.
- Magnetic field variation is perpendicular to electric field.

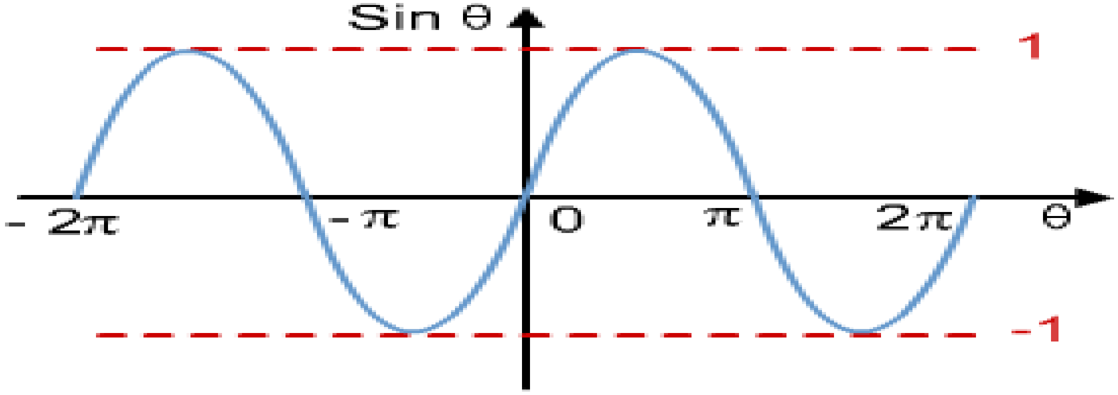


Characteristics of EM Waves

EM waves

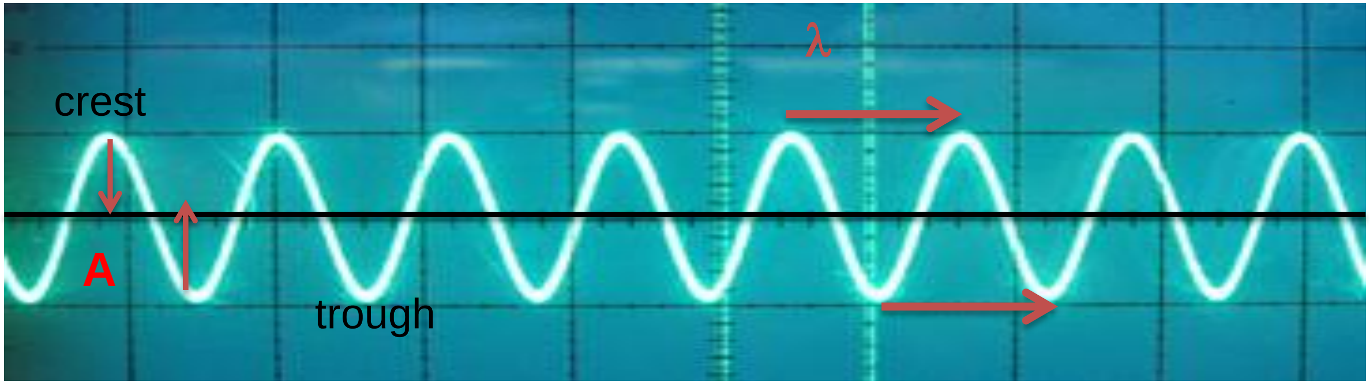
- are transverse waves.
- spread in space.
- move at the speed of light.

Electric and magnetic fields change in a sinusoidal shape



•Transverse : If the displacement of medium is perpendicular to the direction of travel of wave.
•Longitudinal : if the displacement of medium is parallel to the direction of travel of wave

Electromagnetic radiation is characterized by a broad range of wavelengths and frequencies, each associated with a specific amplitude (or intensity) and quantity of energy.



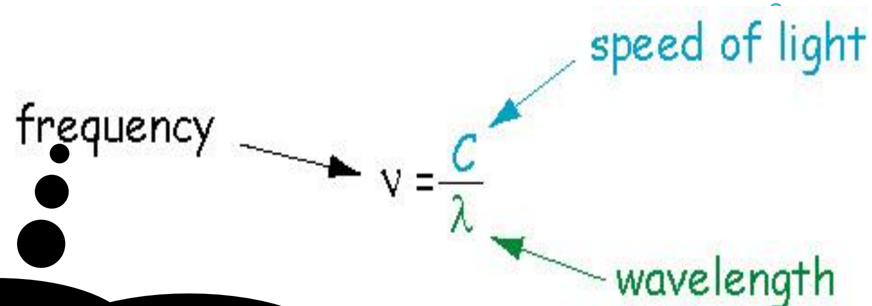
Amplitude is the distance from the midpoint to the crest of wave.

Wavelength is the distance from the top of one crest to the top of next one **(nm)**.

Frequency is the number of crests that pass a given point per unit time **(s^{-1} - Hz)**.

EMWs all travel the same speed – what we call "The speed of light" BUT have different properties.

EMWs propagate at the speed of light



EMWs have different frequencies

EMWs have different wavelengths

λ: Wavelength

h: Planck's constant

6.626068×10^{-34} J.s

1 eV=1.6×10^{-19} J

4.14×10^{-15} eV.s

c: Speed of light

speed of light=wavelength.frequency

c=~300 Km/s

$$E = hf = hc/\lambda$$

❖ **EM waves can transfer different energy values.**

Units for Electromagnetic Waves

Wavelength (l)	Frequency (f)	Wavenumber (n)
• cm (10^{-2} m) • mm (10^{-3}m) • Micron or micrometer, μm (10^{-6} m) • Angstrom, Å (10^{-10} m astronomy) • Nanometer, nm (10^{-9}m)	• Hz • MHz (10^3 Hz) • GHz (10^6 Hz)	• $1/\lambda$ • $(2\pi/\lambda)$ • cm^{-1}

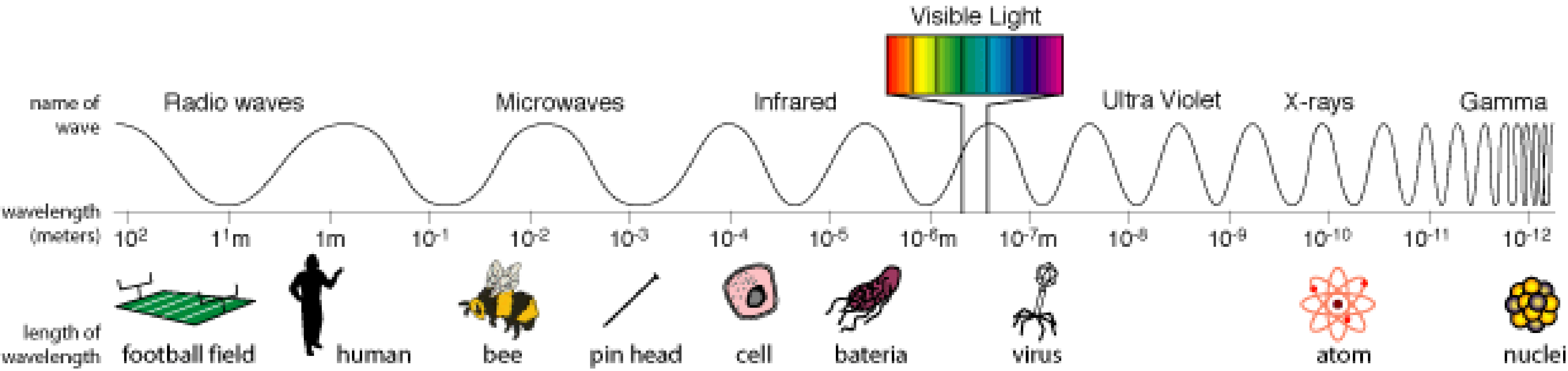
To sum up

EMWs

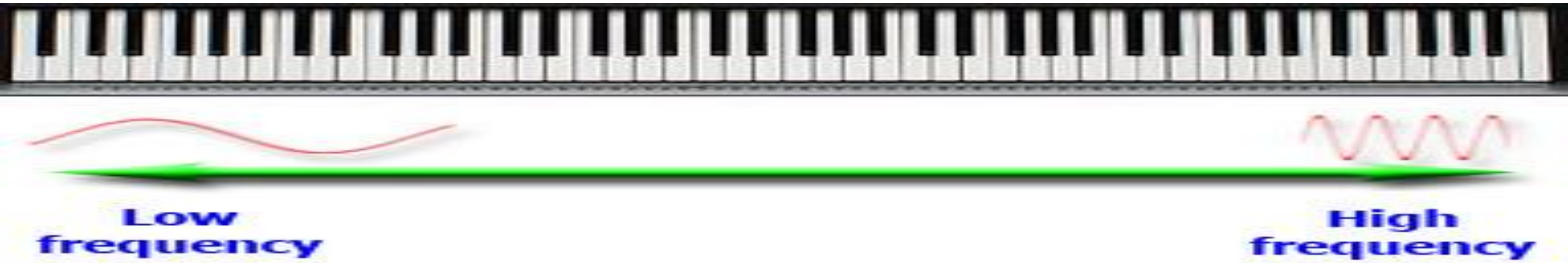
- are transverse waves.
- have some electrical and magnetic properties.
- don’t need matter to transfer energy.
- don’t need medium to spread, like sound and water waves.
- can travel in a vacuum (in space)
- all travel 3.10^8 m/s in a vacuum
- travel as vibrations in electric and magnetic fields.

- There is a ratio between the amplitudes of electric and magnetic fields
- Electric and magnetic fields change in a sinusoidal shape

• **[The EM spectrum](#)** is the classification of EM waves according to frequency (wavelength, transfered energy)



Increasing Energy



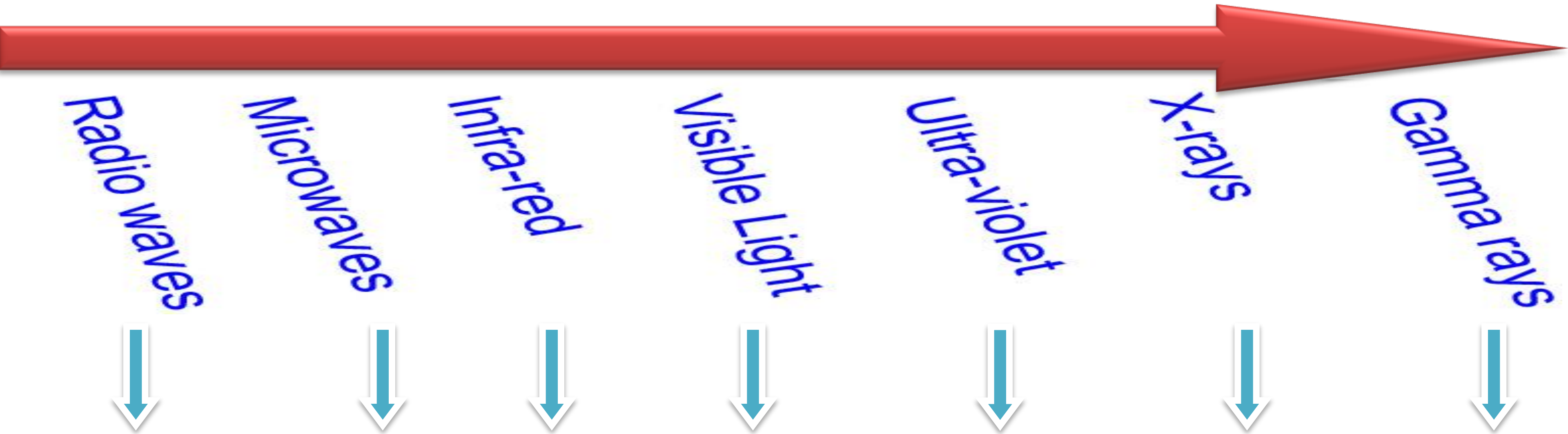
like the notes on a piano keyboard,

The 'low notes' have a low frequency and a long wavelength. :: Base sound

The 'high notes' have a high frequency and a short wavelength :: whistle sound

Long wavelength
Low frequency

Short wavelength
High frequency

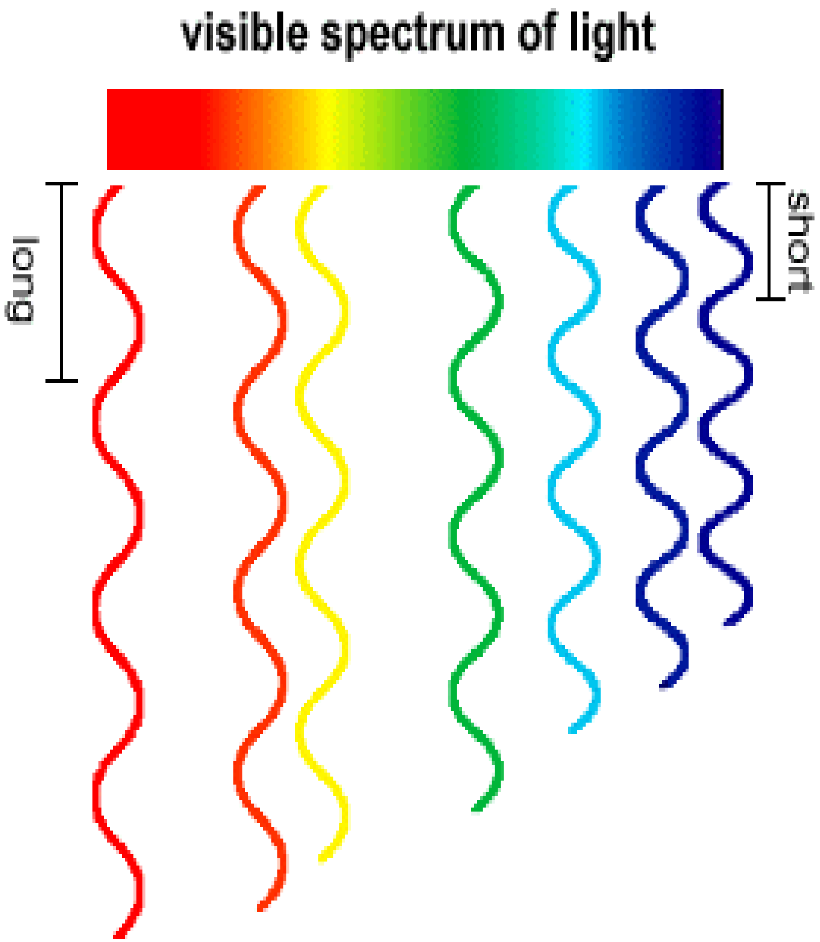


Rabbits Move In Very Unusual eXpensive Gardens

❖The EM waves which have higher frequency transfer higher energy.

❖The EM waves which have higher frequency is generally more danger.

• VISIBLE SPECTRUM



The Visible Light Spectrum

Color	Wavelength (nm)
Red	625 - 740
Orange	590 - 625
Yellow	565 - 590
Green	520 - 565
Cyan	500 - 520
Blue	435 - 500
Violet	380 - 435

DANGERS

Radio waves Large doses of radio waves cause cancer, leukaemia.

Micro waves Prolonged exposure to microwaves cause cataracts in eyes.

Microwaves from mobile phones can affect parts of your brain

Infra Red (IR) Too much Infra-Red radiation causes overheating.

Visible Light (VL) Too much light can damage the retina.

Ultra Violet (UV) Large doses of UV can damage the retina, sunburn and even skin cancer.

X-Rays can cause cell damage and cancers

Gamma-Rays (γ-Rays) can cause cell damage, a variety of cancers, mutations in growing tissues.

What Else In Medicine?

IR

- Pulse oximetry
- NIRS (Near Infrared Spectroscopy)
- Thermography

VL

- Endoscopy
- Scanning laser ophthalmoscope
- PDT (Photodynamic therapy)
- Blue (Blue light treatment of jaundice in babies)

X-Rays

- Radiography
- CT

X-Rays+ γ-Rays

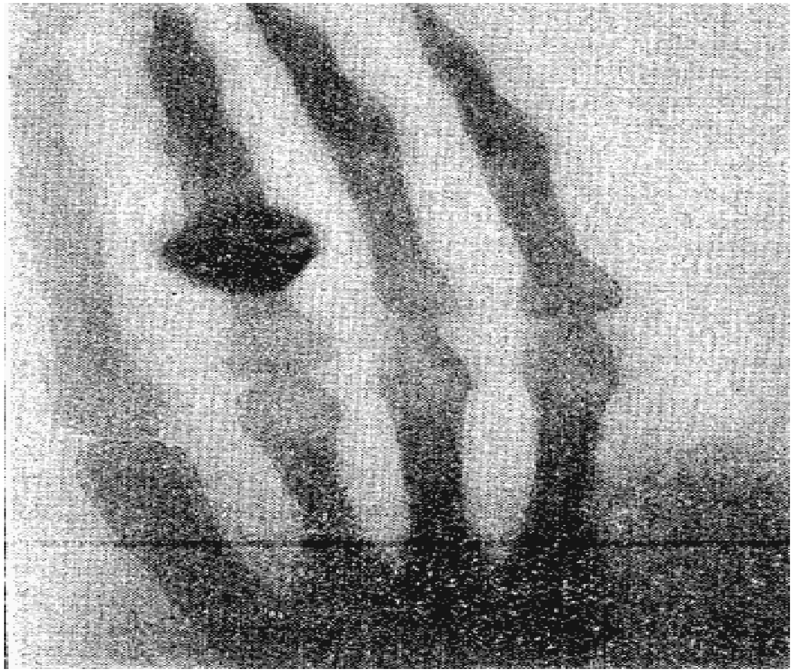
- Radiotherapy

X-Rays

- high energy waves
- have great power for penetration.
- are used extensively in medical applications
- pass easily through soft tissues, but not so easily through bones
- can be used to scan soft areas such as the brain
- lower energy X-Rays don't pass easily through tissues.

X-Ray Radiography

It is the use of X-rays to view a cross sectional area of a non uniformly composed material such as the human body.

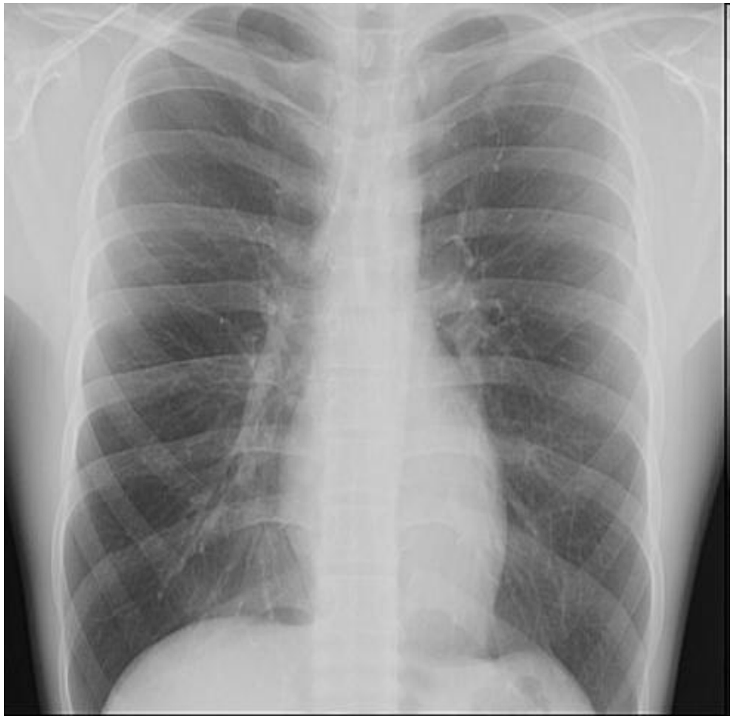


The first clinical x-ray by Wilhelm Roentgen in 1895

X-rays pass through patient and detected by film or sensor.

It shows X-ray attenuation of a body part.

Typically white means high attenuation, black means low attenuation.



Computed Tomography (CT)

History

- CT was invented in **1972** by British engineer Godfrey **Hounsfield** of EMI Laboratories.

- Hounsfield and Cormack were later awarded the Nobel Peace Prize for their contributions to medicine and science.

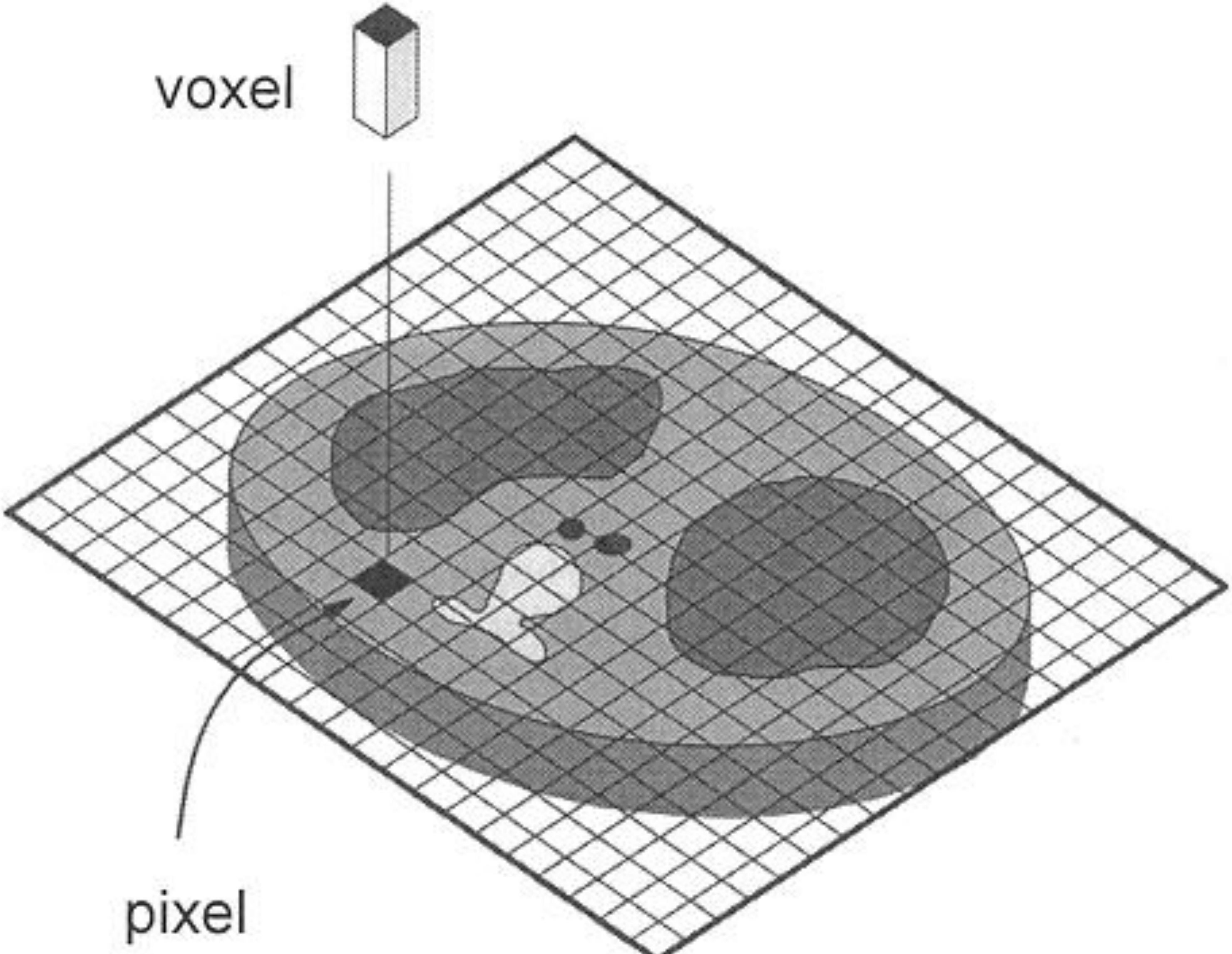
- The first clinical CT scanners were installed between 1974 and 1976

In order to obtain a CT section

- X-ray is passed through from each direction of cross-sectional plane.
- The measurements are processed with computers.
- Numerical parameters are converted gray-scale

• *Tomographic Image*

- The tomographic image is a picture of a slab of the patient's anatomy.
- The 2D CT image corresponds to a 3D section of the patient.
- 3th dimension : thickness (very thin "1 to 10 mm" and uniform)
- The 2D array of pixels (picture element) in the CT image corresponds to an equal number of 3D voxels (volume elements) in the patient
- Each pixel on the CT image displays the average x-ray attenuation properties of the tissue in the corresponding voxel


voxel
pixel

Definitions

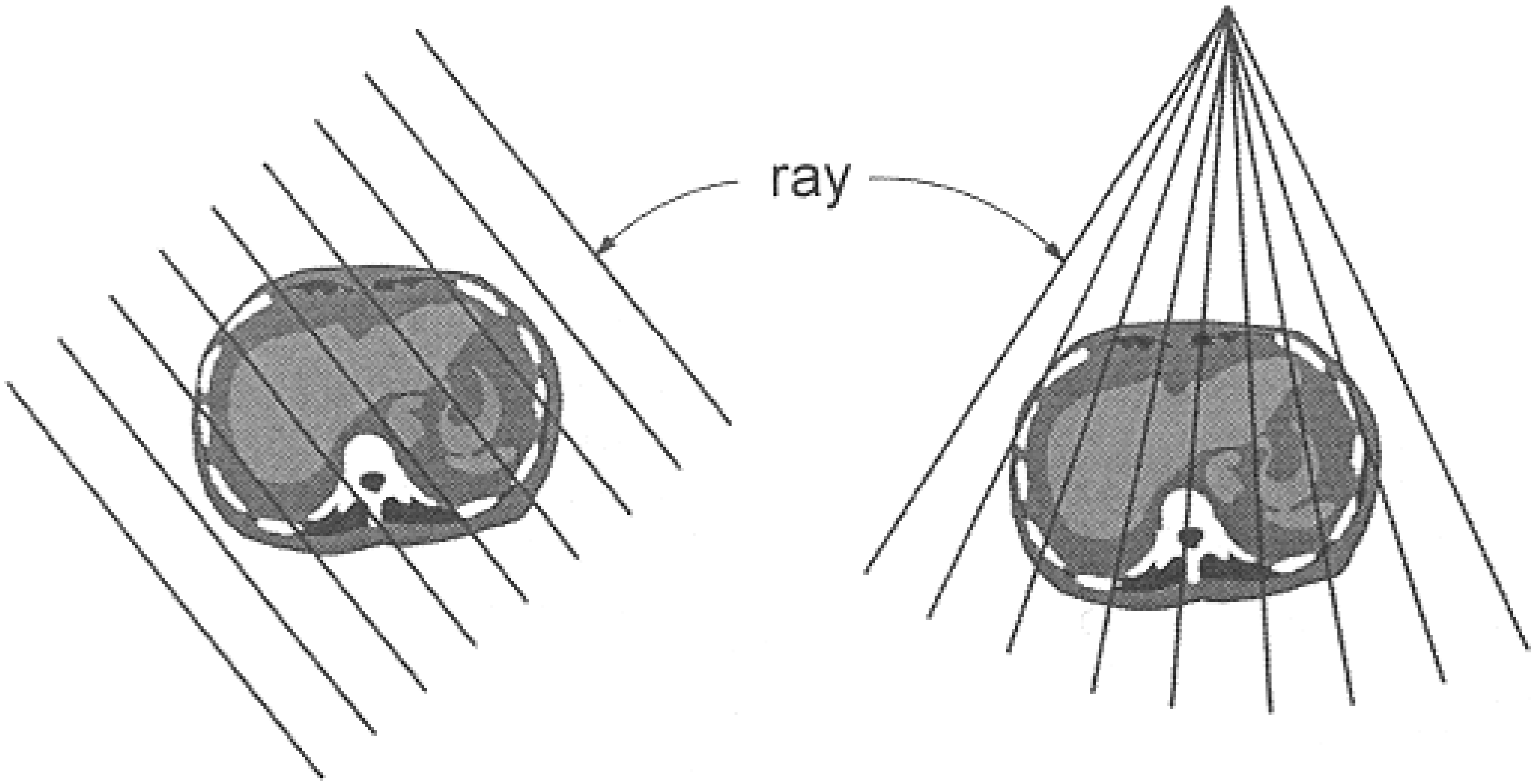
Ray: Single transmission X-ray measurement through the patient made by a single detector at a given moment in time is called a *ray*

Projection: A series of rays that pass through the patient at the same orientation is called a *projection* or *view*

Two projection geometries have been used in CT imaging:

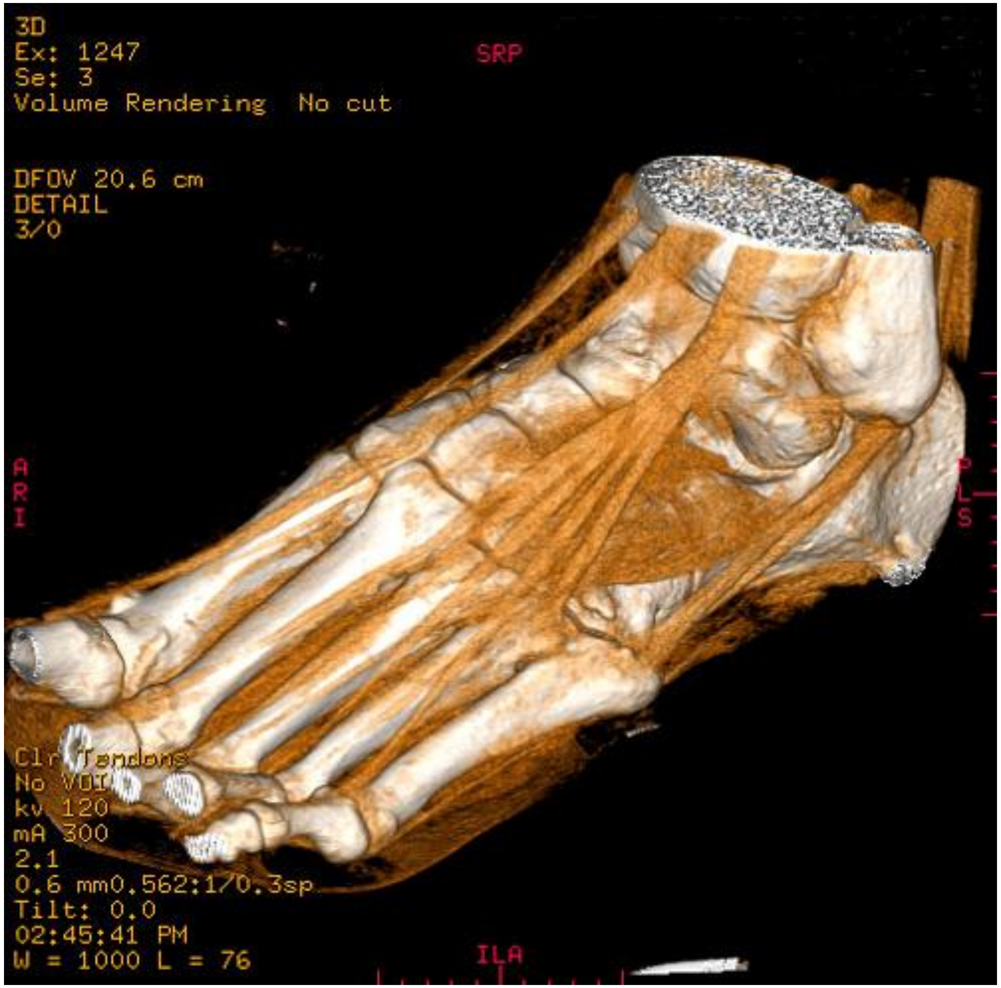
Parallel beam geometry with all rays in a projection parallel to one another

***Fan beam geometry*,** in which the rays at a given projection angle diverge



parallel beam projection   fan beam projection

CT



- CT takes images that are slices through the body.
- A CT image is a pixel-by-pixel map of X-ray beam attenuation (essentially density).
- A bright pixel in image = a "hyperattenuating" or "hyperdense" tissue voxel
- Voxel: smallest volume unit (3D version of pixel).

They can be reconstructed to make a 3D image of the body.

The Advantages of CT

- is an X-ray method
- displays the body in sections
- **No superposition**
- **More detailed images**

What do we do with these images?

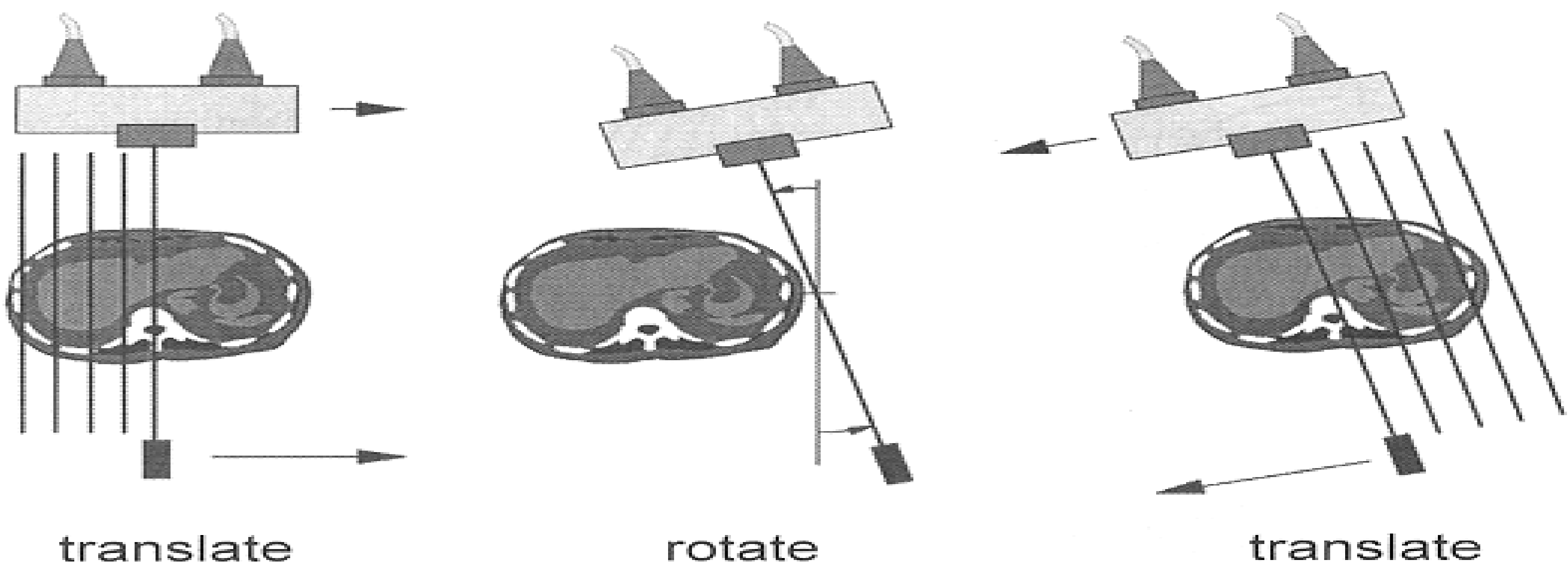
- We can see tissues, pathologies etc.
- We measure volume, area and length of them
- With very fast CT devices we can see their movement (for example movements of heart to evaluate its functions etc.) in some cases.

Main Idea

" If an unlimited number of images from all directions can be achieved for an object, its sectional image can be obtained." (1917- Radon)

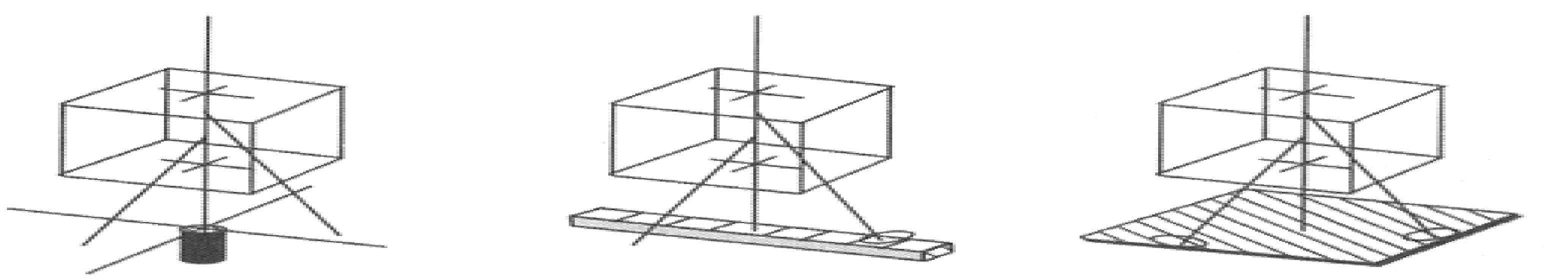
1st generation:
rotate/translate, pencil beam

- Parallel ray geometry
- Only 2 x-ray detectors used (two different slices)
- Rotated slightly between translations to acquire 180^o projections at 1-degree intervals



2nd generation:
rotate/translate, narrow fan beam

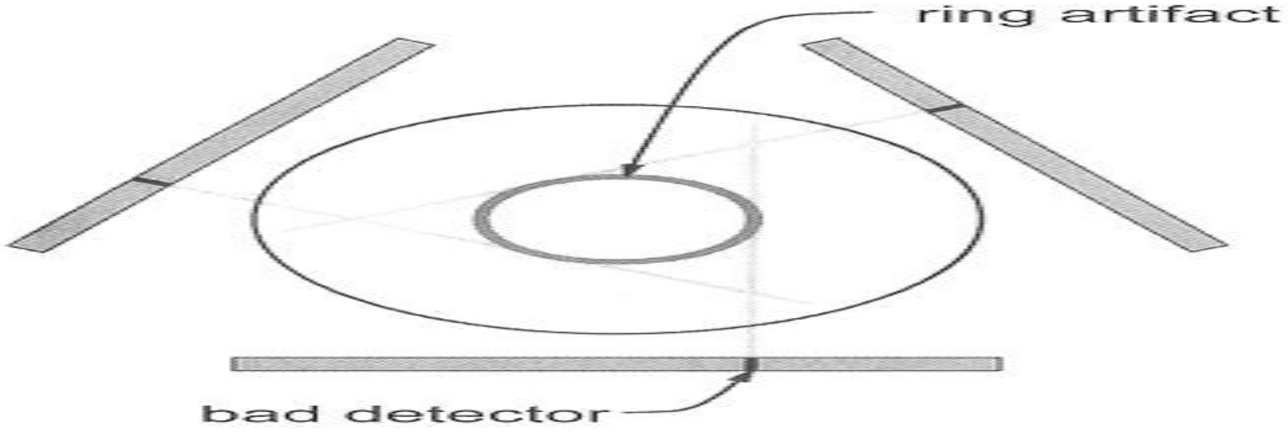
- Incorporated linear array of 30 detectors
- More data acquired to improve image quality
- Shortest scan time was 18 seconds/slice
- Narrow fan beam allows more scattered radiation to be detected



Pencil Beam Geometry | Fan Beam Geometry | Open Beam Geometry

3rd generation:
rotate/rotate, wide fan beam

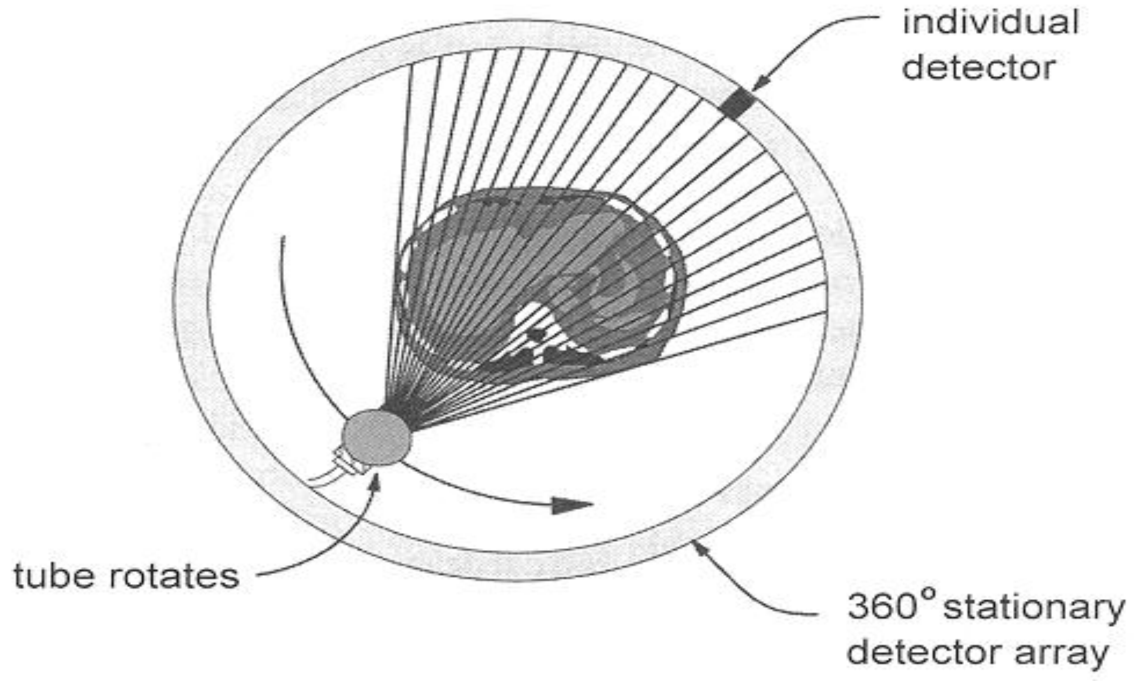
- Number of detectors increased substantially (to more than 800 detectors)
- Angle of fan beam increased to cover entire patient
- It eliminated the need for translational motion
- Mechanically joined x-ray tube and detector array rotate together
- Newer systems have scan times of ½ second



4th generation: rotate/stationary

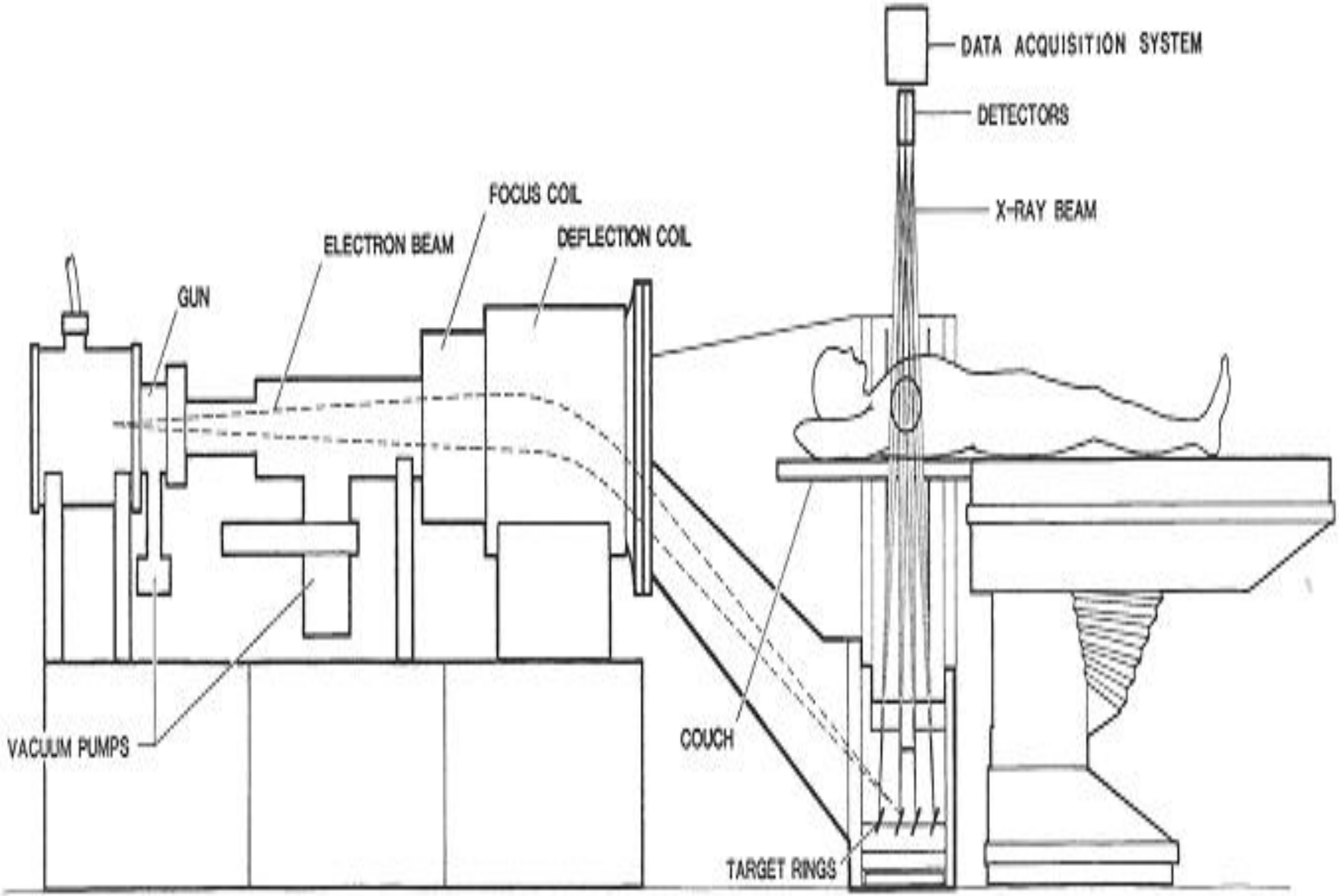
Designed to overcome the problem of ring artifacts

Stationary ring of about 4,800 detectors



5^{th} generation:
stationary/stationary

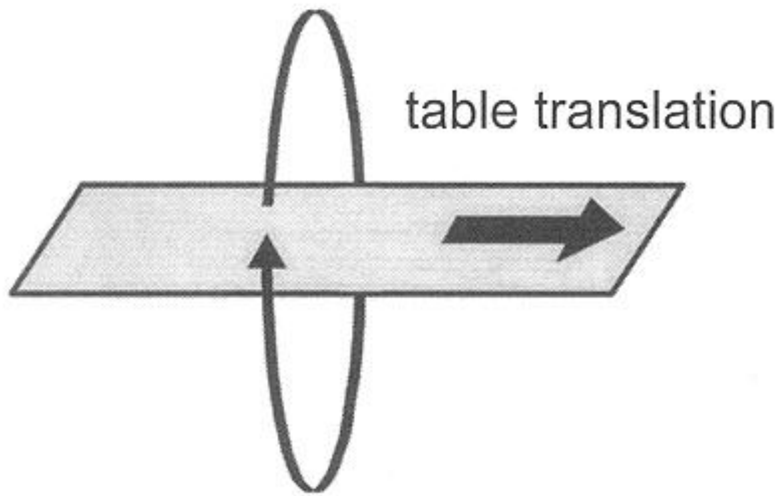
- Developed specifically for cardiac tomographic imaging
- No conventional x-ray tube; large arc of tungsten encircles patient and lies directly opposite to the detector ring
- Electron beam steered around the patient to strike the annular tungsten target
- Capable of 50-msec scan times; can produce fast-frame-rate
- CT movies of the beating heart



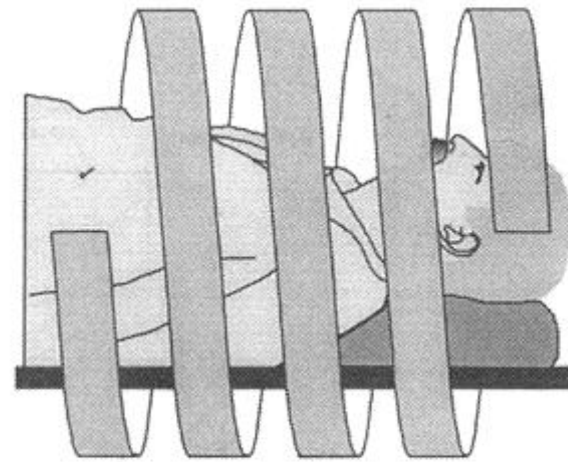
DATA ACQUISITION SYSTEM
DETECTORS
X-RAY BEAM
FOCUS COIL
DEFLECTION COIL
ELECTRON BEAM
GUN
VACUUM PUMPS
COUCH
TARGET RINGS

6th generation: helical

- Helical CT scanners acquire data while the table is moving
- By avoiding the time required to translate the patient table, the total scan time required to image the patient can be much shorter
- In some instances the entire scan be done within a single breath-hold of the patient



x-ray tube rotation



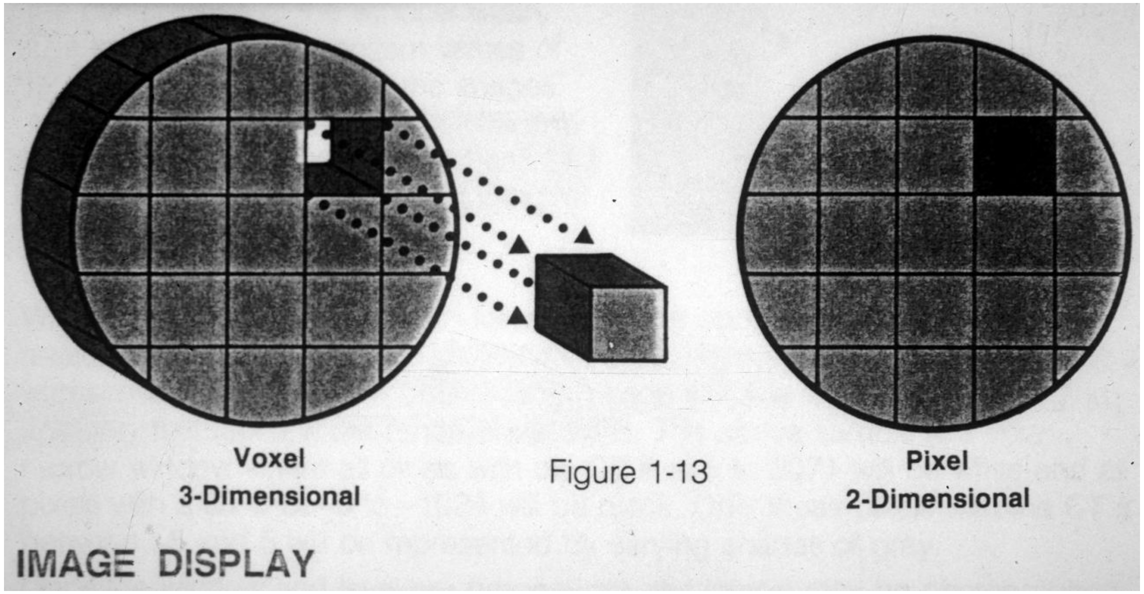
helical x-ray tube
path around patient

7th generation:
multiple detector array

When using multiple detector arrays, the collimator spacing is wider and more of the x-rays that are produced by the tube are used in producing image data. Opening up the collimator in a single array scanner increases the slice thickness, reducing spatial resolution in the slice thickness dimension.

How it works

The information acquired by CT is stored on computer as digital raw data and an image can be displayed on a video monitor or printed on to X-ray film. The image is made up of a matrix of thousands of tiny squares or pixels (65000 pixels in a conventional image).

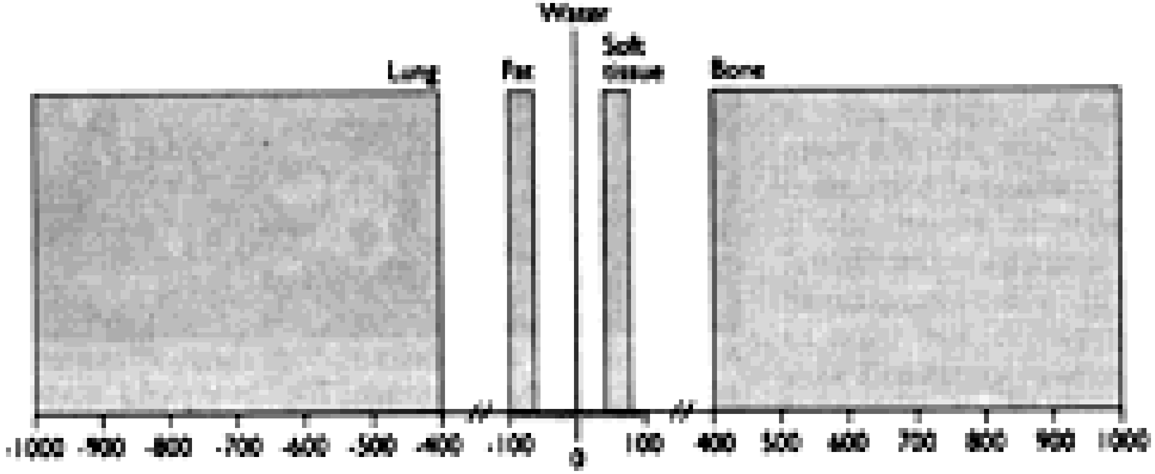


Each pixel has a CT number attributed to Hounsfield.

The computed tomography number is a measure of how much of the initial x ray beam is absorbed by the tissues at each point in the body.

This varies according to the density of the tissues. The denser the tissue is the higher the computed tomography number, ranging from -1000 HU (air) to + 1000 (bone).

This is a 2000 unit range .<u>But it is converted to 32 shades of gray in the film.</u>

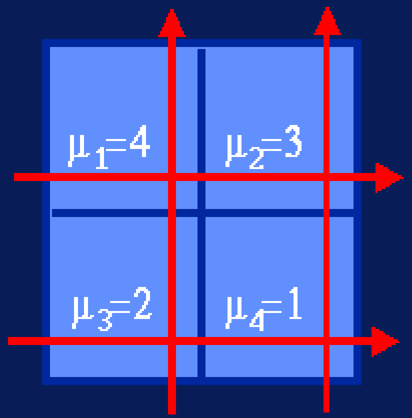


How is an image reconstructed

Mathematical principles of CT were first developed in 1917 by Radon

He proved that an image of an unknown object could be produced if one had an infinite number of projections through the object

Reconstruction Idea



$$\begin{cases} \mu_1 + \mu_2 = 7 \\ \mu_3 + \mu_4 = 3 \\ \mu_1 + \mu_3 = 6 \\ \mu_2 + \mu_4 = 4 \end{cases}$$

Resolution

There are four characteristics that determine the resolution

1- spatial resolution

2- contrast resolution

3- linearity

4- noise of the system

1. **Spatial resolution** (resolution of smaller objects) depends on

- difference in CT number
- pixel size (and number). As pixel size large resolution will be low and pixel number high resolution high
- detector size and collimation of beam

2. Low Contrast resolution (ability to distinguish objects having low contrast without regard for size and shape) depends on size and uniformity of the object and the CT scanner. Contrast enhancing materials can be used.

3- Linearity: is the calibration of the system with known substances of known CT numbers. CT versus linear attenuation coefficient must be linear.

4- System Noise: The values for a pixel may vary about a mean value. This will afect low contrast resolution. System noise depends on

- voltage
- pixel size (as pixel size is small less system noise formed)
- slice thickness (as slice thickness small less noise)
- patient dose

Time to think

1. What is the relationship between frequency and wavelength ?
2. What is meant by ‘spectrum’?
3. Which color is more energetic, red or yellow?
4. Which type of wave travels faster, gamma or radio?
5. Can you actually see x-rays?

1. Frequency and wavelength are properties of waves and since speed is constant for em waves, as frequency increases, wavelength decreases.

2. Spectrum is a continuum of all electromagnetic waves

3. Yellow is higher energy than red because it has a shorter wavelength and higher frequency.

4. Both travel at the same speed, 300,000 km/s (all em waves travel at the same speed)

5. X-rays can not be seen, only the waves in the visible light portion are visible.