X-ray

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Introduction

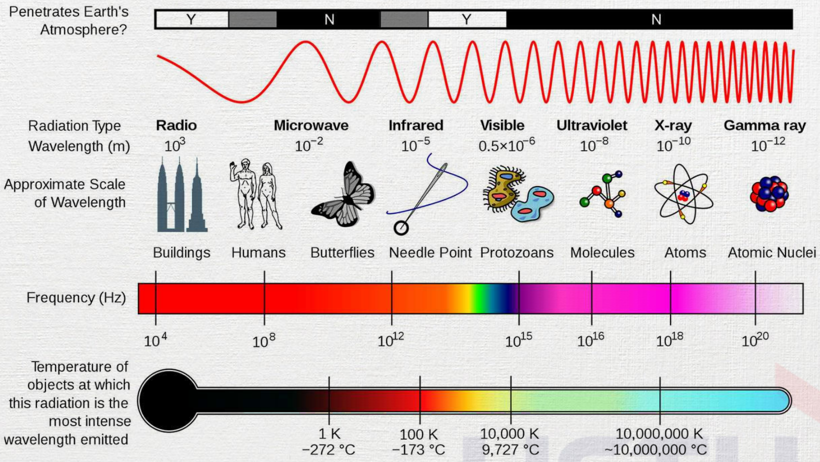
Medical Imaging

- Radiological technologies
    - **X-ray**
    - computed tomography (CT)
    - mammography
- Magnetic resonance imaging (MRI)
- Nuclear medicine imaging
    - single photon computed tomography (SPECT)
    - positron emission tomography (PET)
- Ultrasound (US)
- Other imaging techniques

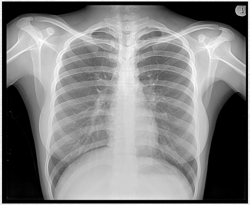
Introduction

The discovery of X rays in 1895 was the beginning of a revolutionary change in our understanding of the physical world.

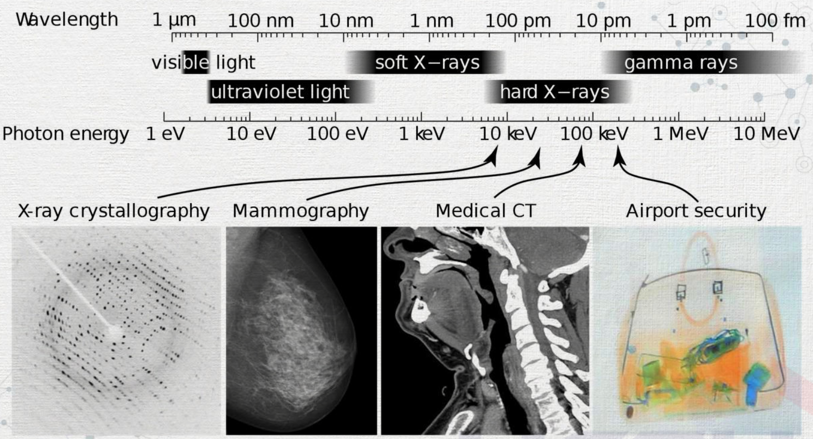
Introduction



Introduction



Introduction



Introduction

- Wilhelm Conrad Röntgen, 1895, German
- Electro-magnetic radiation
- Nobel prize in Physics in 1905

X-ray

- Electromagnetic radiation
- Wavelength
    - 10 picometers (10^{-12}m) to 10 nanometers (10^{-9}m)
    - Shorter than UV rays
    - Long than gamma rays
- 10 petahertz (30×10^{15} Hz) to 30 exahertz (30×10^{18} Hz)
- High-energy: 124 eV to 124 keV

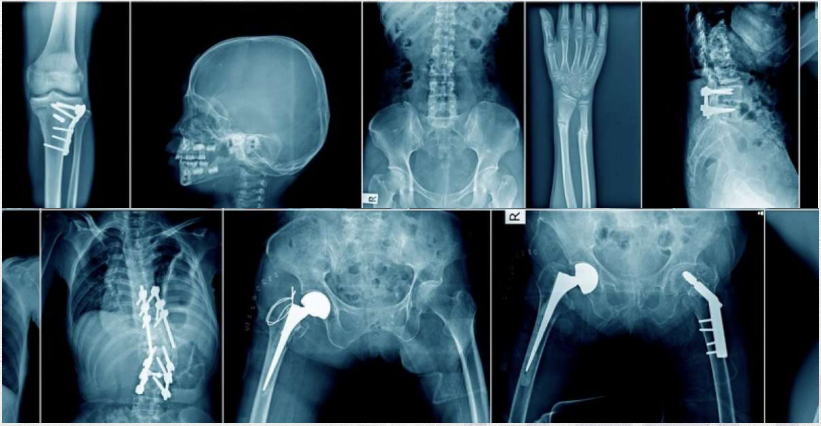
X-ray diagnostic

- One of the most important tools in modern medicine
- Approximately 120,000 x-ray systems are in operation (US)
- Estimated 240 million x-ray procedures each year
- Based on the tissue-differential contrast generated by x-ray and tissue interaction

X-ray Applications

- Various domain: industrial, **medical**, pure science research and X- ray crystallography etc...
- Detect defects in radio valves
- Detect cracks in structures
- Analyse the structures of alloys and other composite bodies by diffraction of X-rays
- Study structure of materials like rubber, cellulose, plastic, fibers...
- Destroy abnormal internal tissues

X-ray Applications in Medical



Tissue Contrast

Biological Tissue–X-Ray Interaction and Tissue Contrast

- Attenuation-Based Tissue Contrast
  - X-rays are ionizing and invisible electromagnetic radiation, much shorter wavelengths than light
  - Relationship between energy E (in keV) and wavelength γ (in Å) of an x-ray photon

$$\gamma = \frac{12.4}{E}$$

Biological Tissue–X-Ray Interaction and Tissue Contrast

- Attenuation-Based Tissue Contrast
  - X-ray exposure unit: Roentgen (R), $1R = 2.58 \times 10^{-4}$ coulomb/kg.
  - Interacts with atomic electrons of biological tissue
  - X-ray photons can be absorbed, scattered or transmitted by the tissue

Biological Tissue–X-Ray Interaction and Tissue Contrast

- Attenuation-Based Tissue Contrast
  - Absorption and scattering result in attenuation of the x-ray intensity I_0
  - The remaining x-ray is transmitted with an intensity I

$$I = I_0 e^{-\frac{\mu}{\rho}\rho t} = I_0 e^{-\mu t}$$

- where
  - μ/ρ: mass attenuation coefficient
  - ρ: mass density
  - μ: linear attenuation coefficient of the tissue
  - t: thickness of the tissue

Biological Tissue–X-Ray Interaction and Tissue Contrast

- Biological tissue's mass attenuation coefficient can be calculated as

$$(\frac{\mu}{\rho})_{tissue} = \sum_i w_i (\frac{\mu}{\rho})_i$$

- where
  - $(\frac{\mu}{\rho})_i$: mass attenuation coefficient for the i^{th} element
  - w_i: corresponding weight fraction

Biological Tissue-X-Ray Interaction and Tissue Contrast

X-Ray Photon, E (keV)	μ/ρ (m^2/kg)
10	0.5232
20	0.0795
30	0.0376
40	0.0268
50	0.0228
60	0.0207
70	0.0193
80	0.0183
90	0.0175
100	0.0169
110	0.0164
120	0.0159
130	0.0155
140	0.0152

Biological Tissue-X-Ray Interaction and Tissue Contrast

- Tissue attenuation contrast in x-ray imaging is determined by the subject contrast (SC):

$$SC = ln\frac{E_2}{E_1}$$

- where
  - E1 and E2 are the absorbed x-ray energy fluencies in the detector corresponding to the two tissue projection areas.

Biological Tissue–X-Ray Interaction and Tissue Contrast

- If μ_1 and μ_2 are the linear attenuation coefficients for the two tissues, each of thickness t, then the SC between these two tissues for a monoenergetic incident x-ray can be calculated

$$SC = ln\frac{-t\mu_2}{-t\mu_1} = (\mu_1 - \mu_2)t$$

Biological Tissue–X-Ray Interaction and Tissue Contrast

- X-ray attenuation and tissue contrast are dependent on the x-ray photon energy
- This is achieved by controlling the x-ray spectrum used for imaging
- X-rays are typically generated through the interaction of electromagnetic fields with charged particles such as electrons.

X-ray Imaging

Charged particles

- A charged particle in *uniform motion of any velocity* cannot produce an electromagnetic wave, even if the particle is surrounded by an electromagnetic field.
- Only charged particles undergoing **acceleration** or **deceleration** can emit x-ray radiation

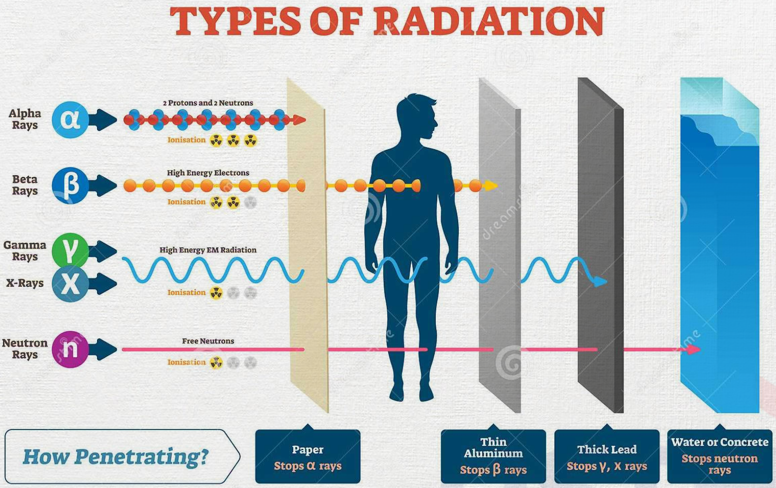
Mechanism

- X-rays are generally produced by bombarding a metal target with energetic electrons.
- Upon impact with the metal target, the incident electrons collide with the electrons and nuclei of the metal atoms
- The collisions slow down and deflect the incident electrons

Mechanism

- Rapidly increase the momentum of the incident electrons, producing large **acceleration** values.
- Deflected incident electrons emit x-rays.

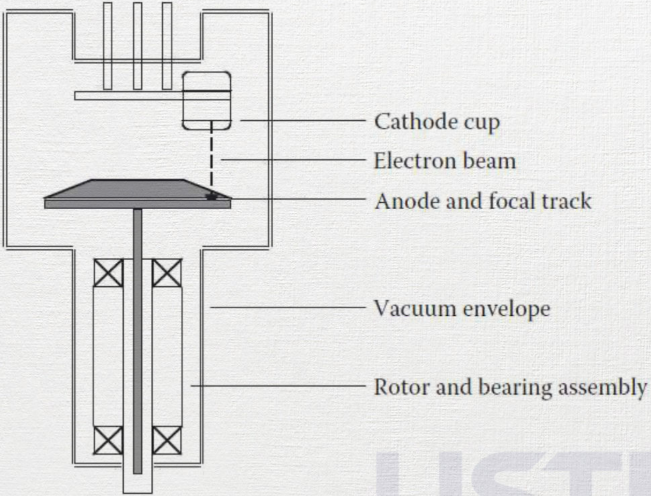
Alpha, Beta, Gamma



X-ray tube

- A device designed to generate x-rays.
  - a cathode emitting the electrons
  - a rotating anode disc acting as the metal target,
  - a glass or metal envelope providing structural support (vacuum)

X-ray tube


Cathode cup
Electron beam
Anode and focal track
Vacuum envelope
Rotor and bearing assembly

X-Ray Imaging

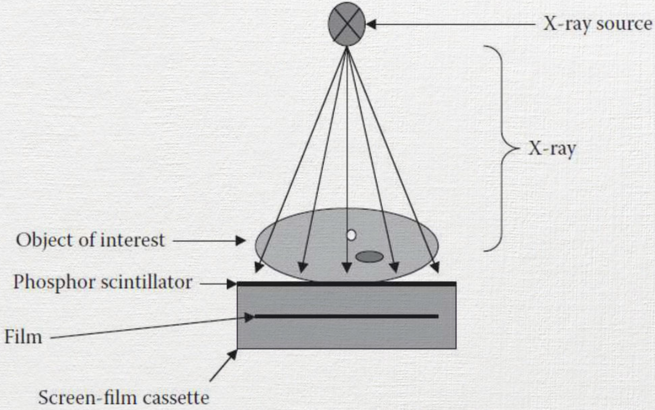
Conventional Radiography

- Projection radiography is the conventional technique performed in radiological imaging.
- It uses an x-ray beam to generate a 2D transmission image of the patient anatomy.
- The x-ray beam passes through the body of the patient during x-ray exposure and is recorded by a 2D detector.

X-Ray Imaging

- Within the body, the x-ray radiation experiences attenuation, through absorption and scattering, as well as diffraction.
- The x-ray beam is attenuated and diffracted in different amounts according to the anatomical structure and thickness of the body.

X-Ray Imaging



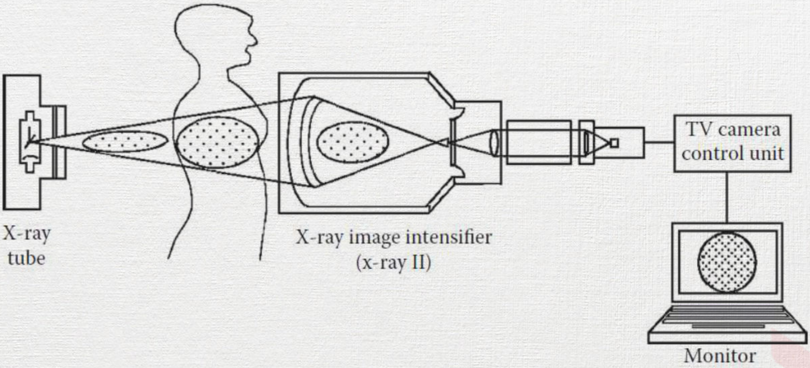
X-Ray Imaging

A projection radiograph is a 2D map of $I(x, y)$:

$$I(x, y) = I_0 e^{-\int I(x,y;s)ds}$$

- where
  - I_0 is the incident x-ray intensity
  - $I(x, y; s)$ is the detected intensity at position $(x, y; s)$
    - s is the distance along the ray direction from the focal spot to point (x, y)

X-Ray Imaging



Practice!

Practical work 3

- Segmentation of COVID19 X-ray images
  - Download COVID-QU-Ex dataset
  - Explore the dataset
  - Build ONE machine learning/deep learning model to perform **segmentation** of infection area in the input image.

Practical work 3

- Write a report (in LaTeX)
    - Name it « Report.3.tex »
    - Describe the dataset *in detail* that you have downloaded
    - Explain how you implement the model
    - Compare your results with other state of the art methods
    - Try experimenting with different hyperparameter values
- Push the report and your code (Notebook and .py script) to your forked repository