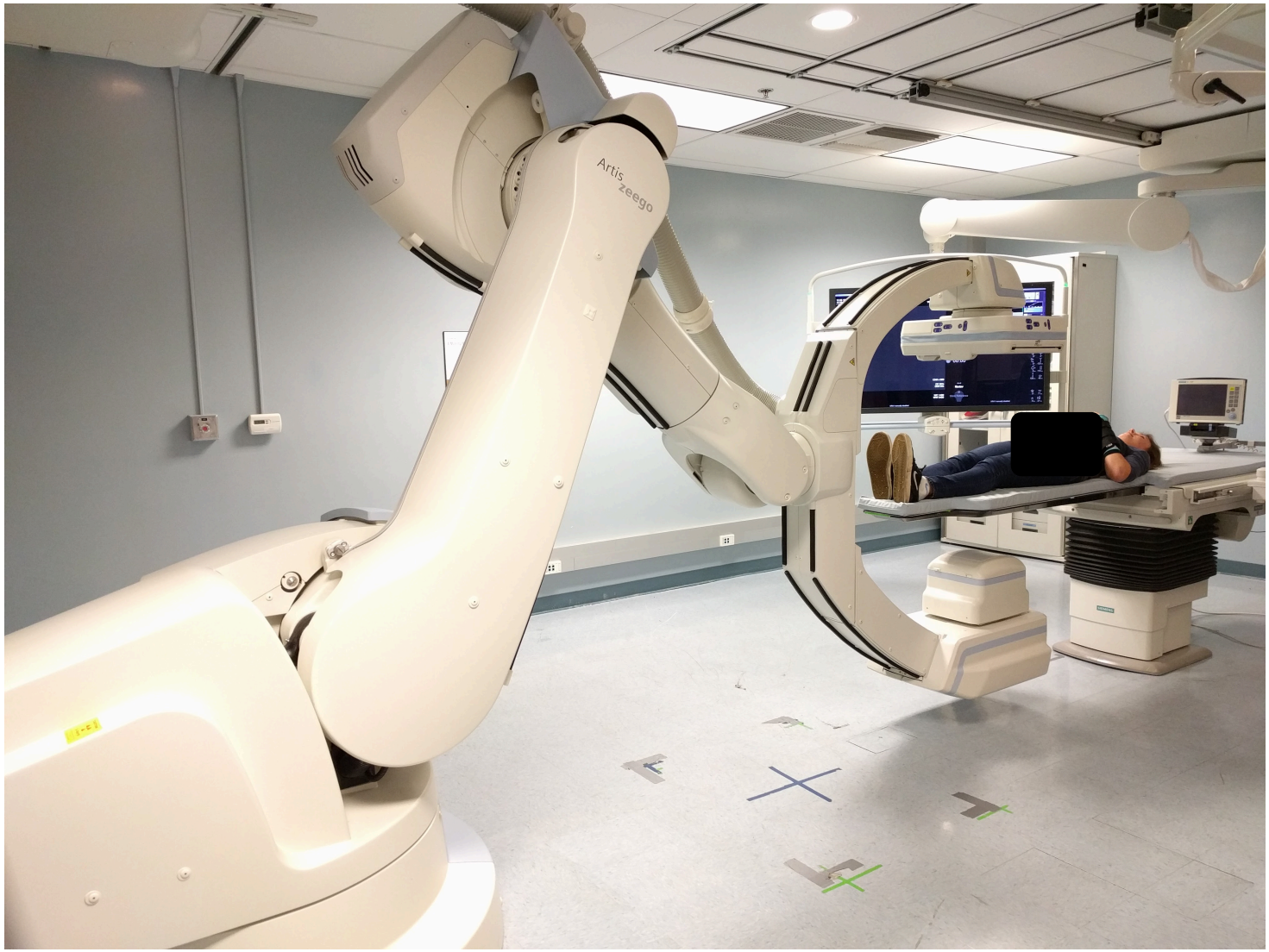
Introduction to X-ray-based Imaging

Serena Bonaretti, PhD
serena.bonaretti@stanford.edu

Acknowledgments

- Stanford
  - Kerstin Müller
  - Rebecca Fahrig
  - Norbert Pelc
- University of Erlangen-Nuremberg
  - Andreas Maier
- Siemens Medical Solutions
  - Teri Moore
  - Sanjit Datta
- Financial Support
  - National Institute of Health
  - Siemens Healthcare GmbH

Zeego Lab – S088



Cone-Beam Computed Tomography (CBCT)

C-arm Computed Tomography (C-arm CT)

Machine and Images

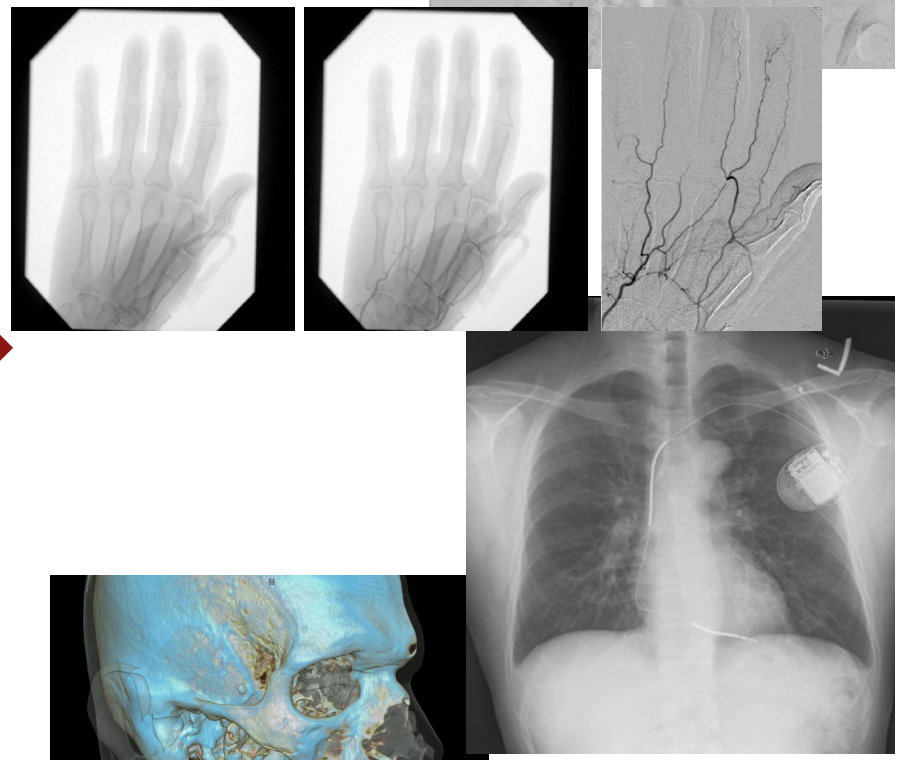
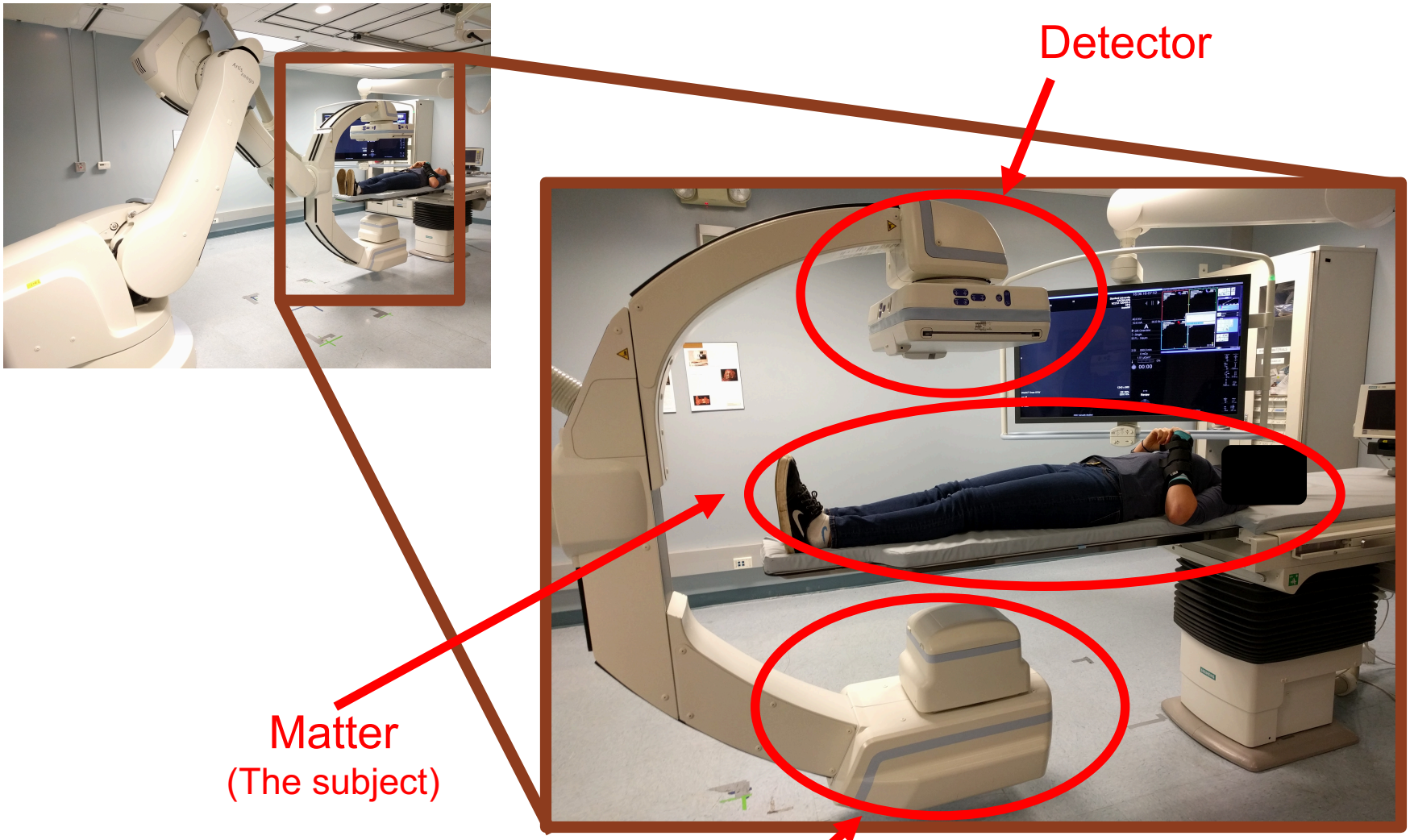


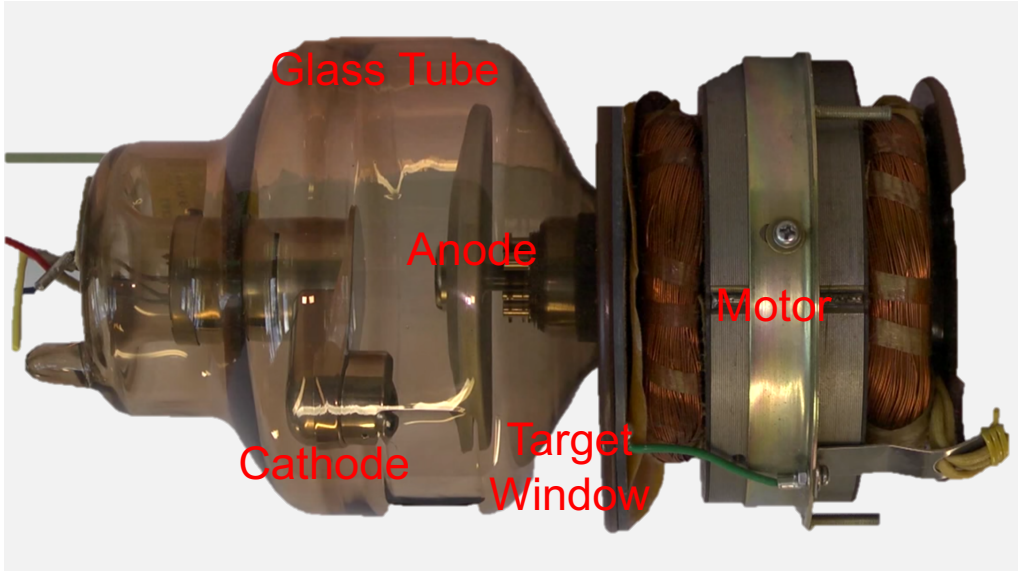
Image source: Siemens Healthcare, Erlangen, Germany and N. Kothary

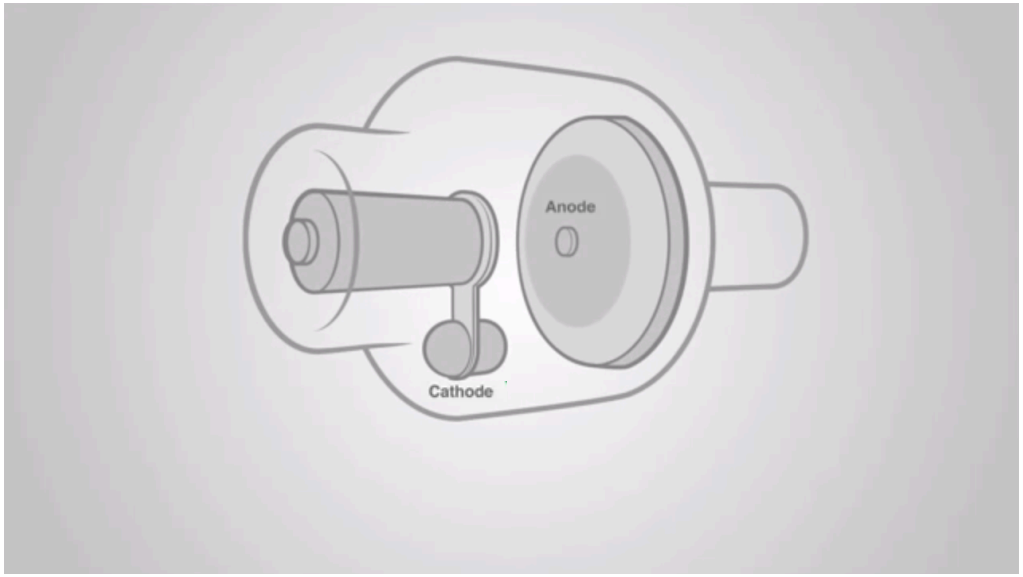
The imaging system: X-ray Tube, Detector and Subject



The X-ray Tube

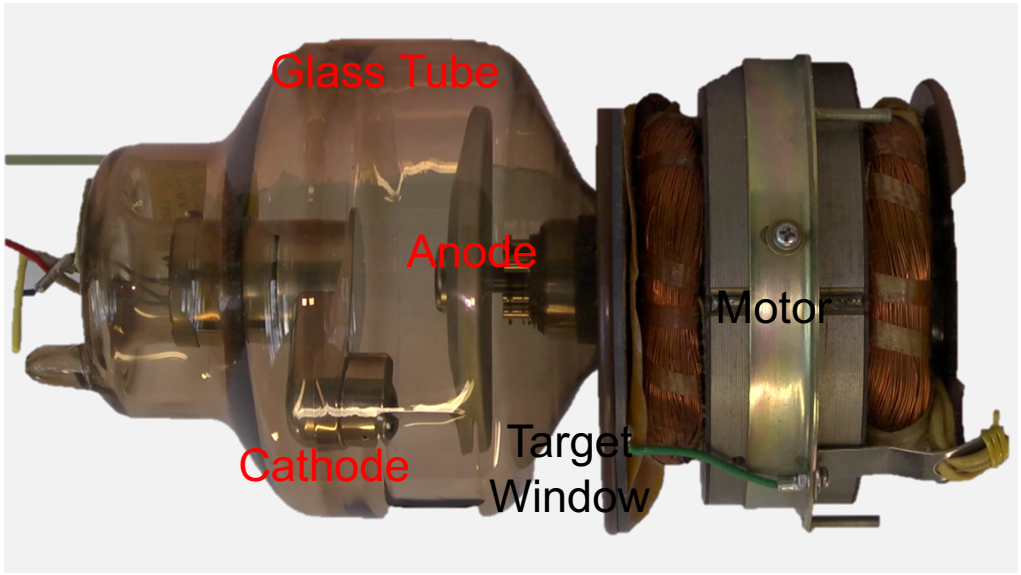
X-ray Tube

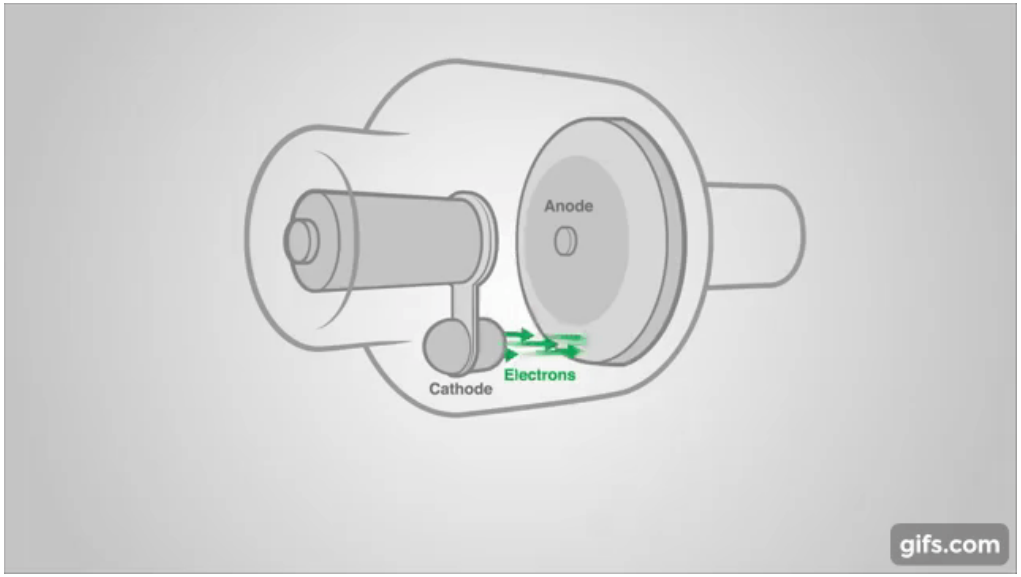




https://www.youtube.com/watch?v=3_bZCA7tlFQ

X-ray Tube

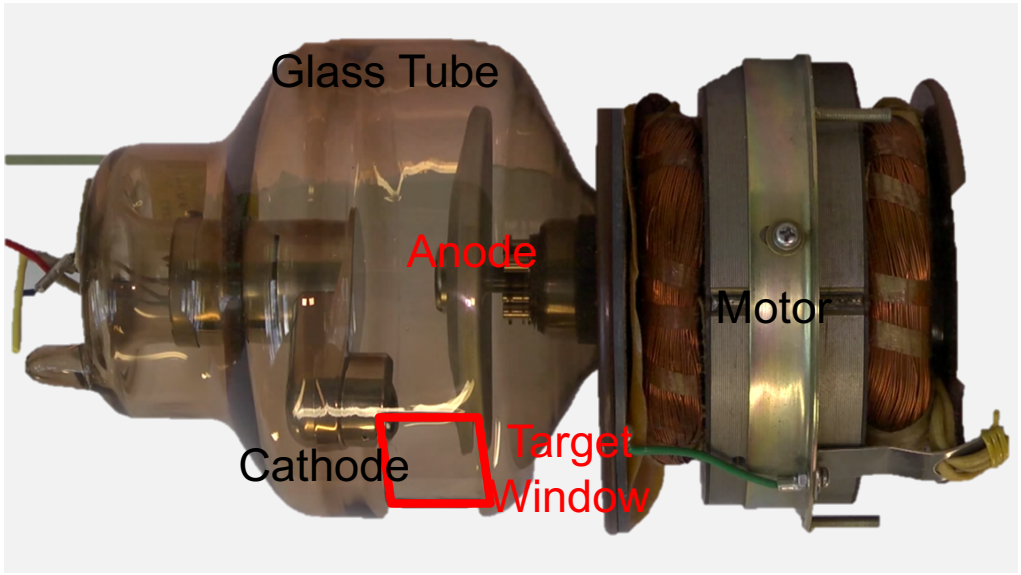


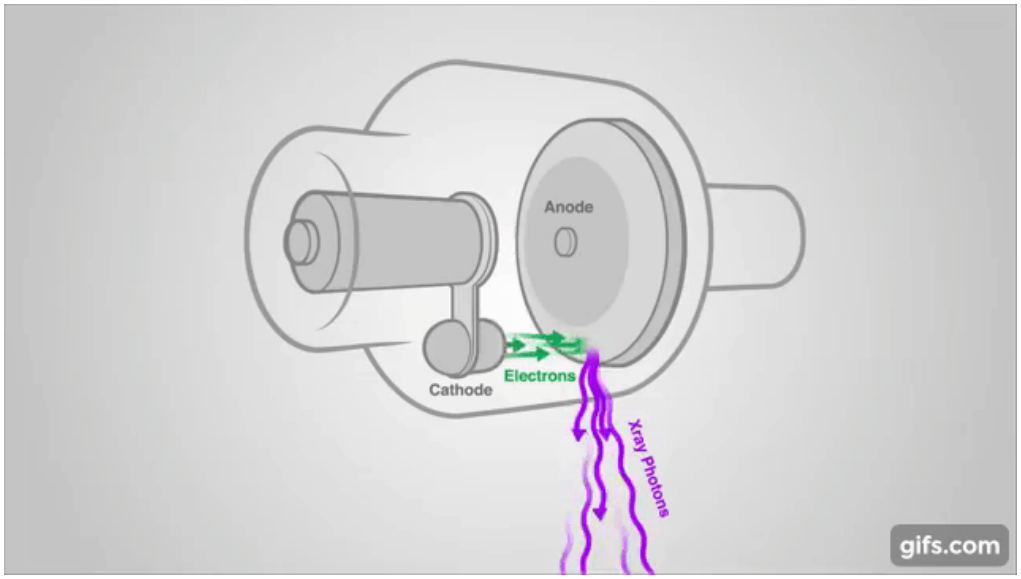


https://www.youtube.com/watch?v=3_bZCA7tlFQ

- Accelerating voltage:
  - 20-150 kVp
- Electron current:
  - 0.1-1.0A
- Vacuum in glass tube to avoid collision with air particles

X-ray Tube

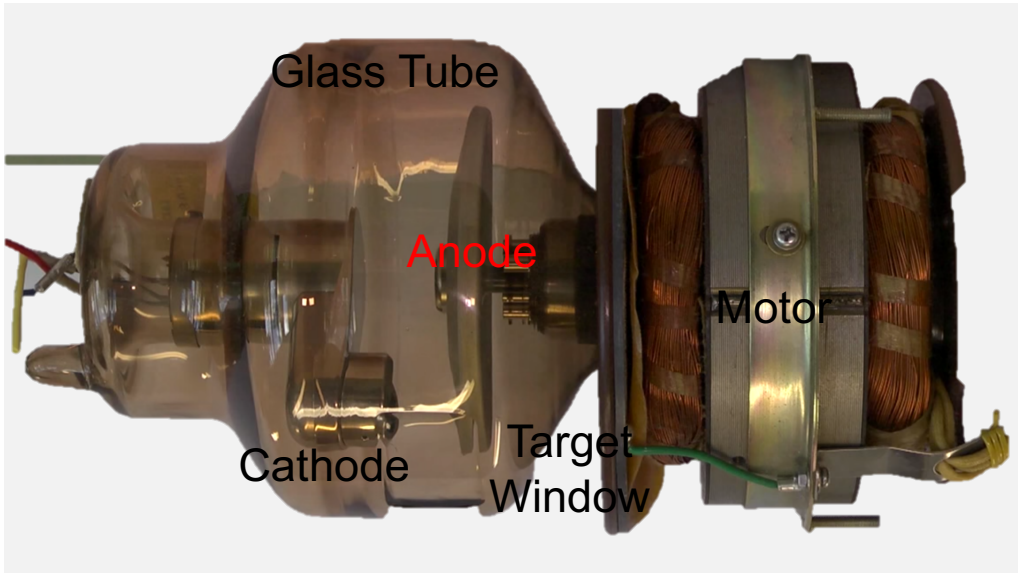


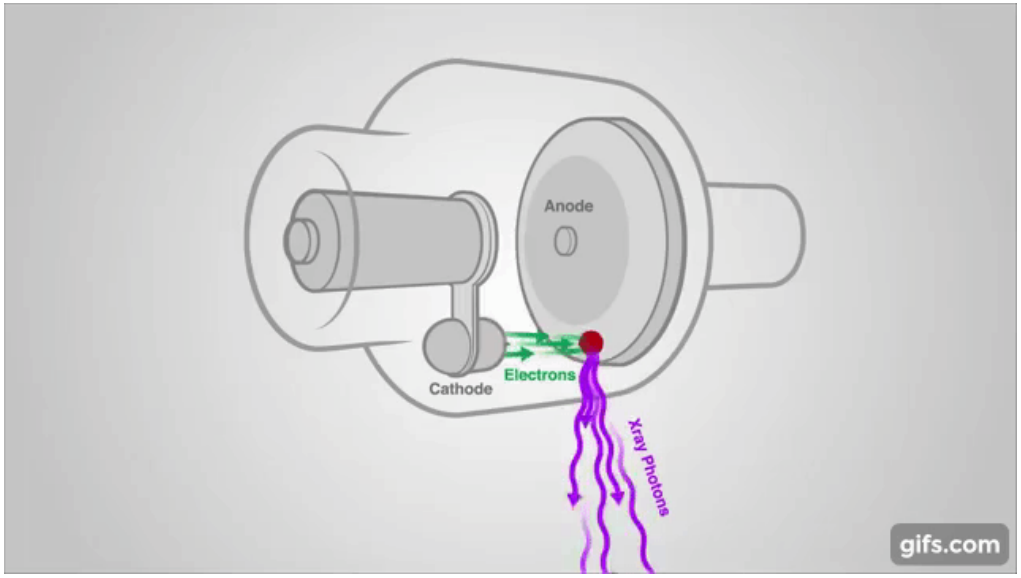


https://www.youtube.com/watch?v=3_bZCA7tlFQ

- The angle of the anode directs X-rays towards target window
- 1% of e^- energy becomes X-rays

X-ray Tube

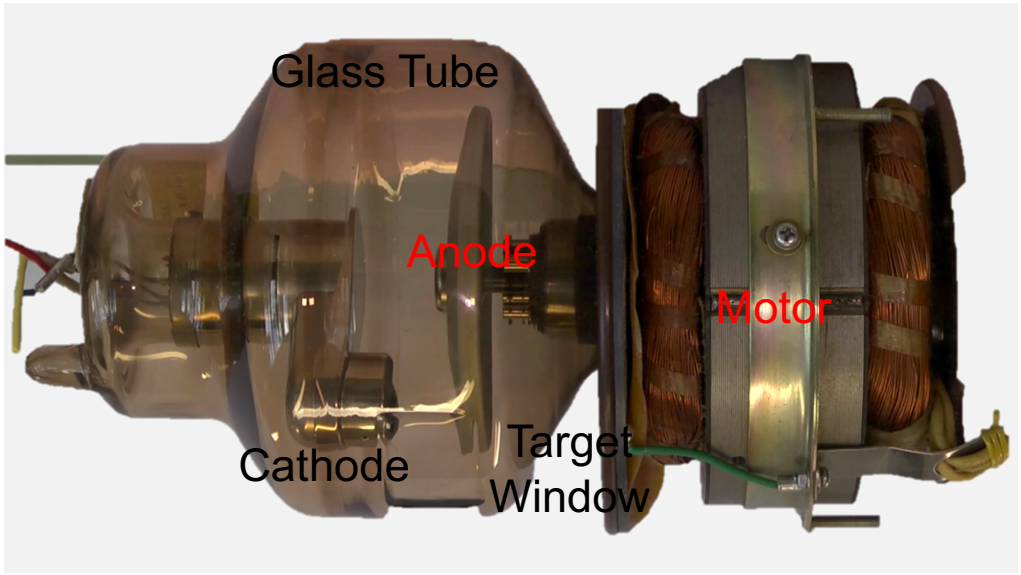


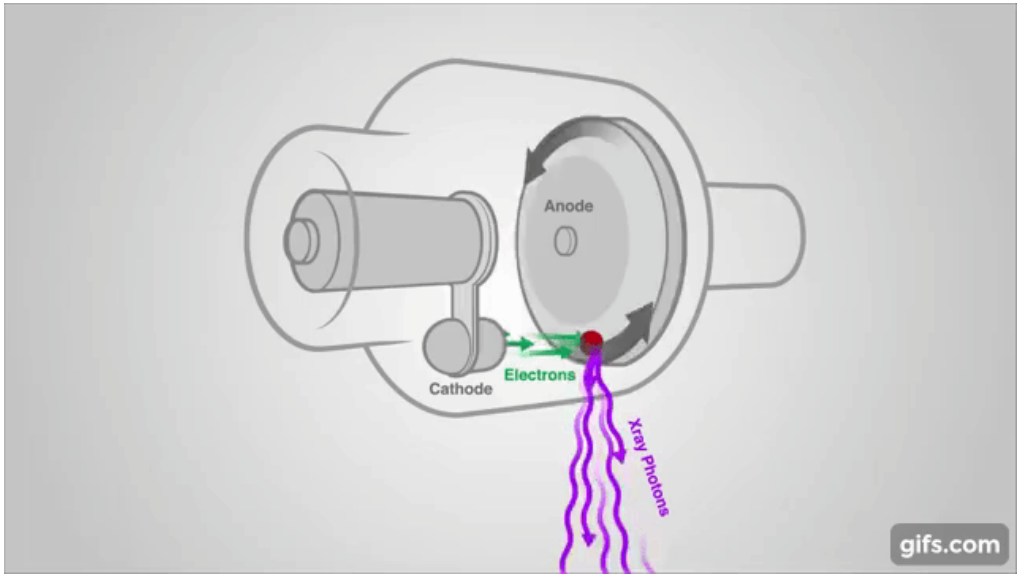


https://www.youtube.com/watch?v=3_bZCA7tlFQ

- 99% of e^- energy is converted to heat

X-ray Tube

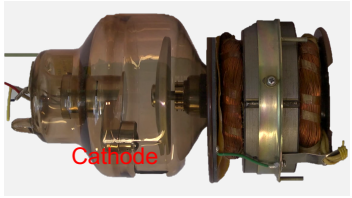


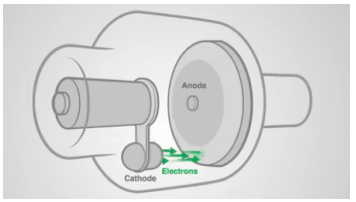


https://www.youtube.com/watch?v=3_bZCA7tlFQ

- The motor rotates the anode to change hit spot

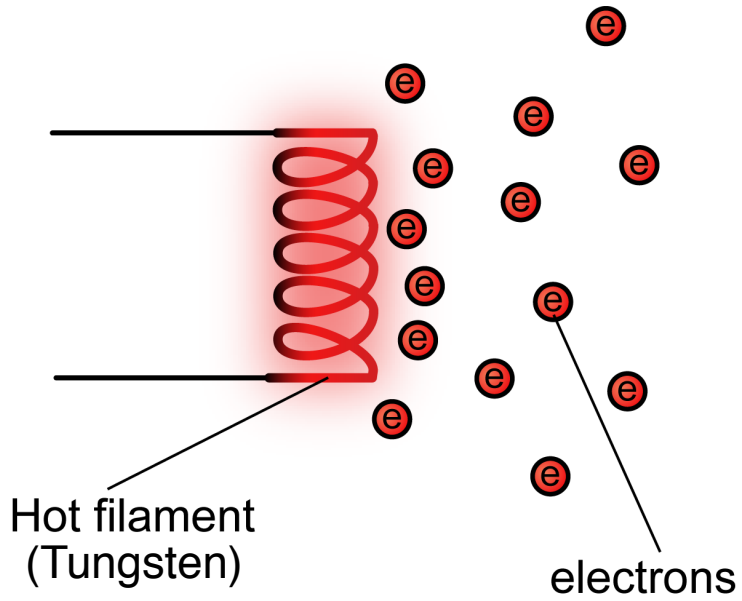
What happens at the cathode?





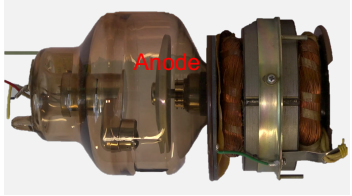
- e^- production!

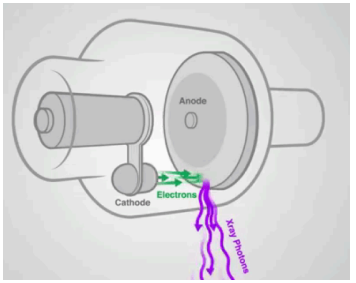
- How? Thermionic emission:



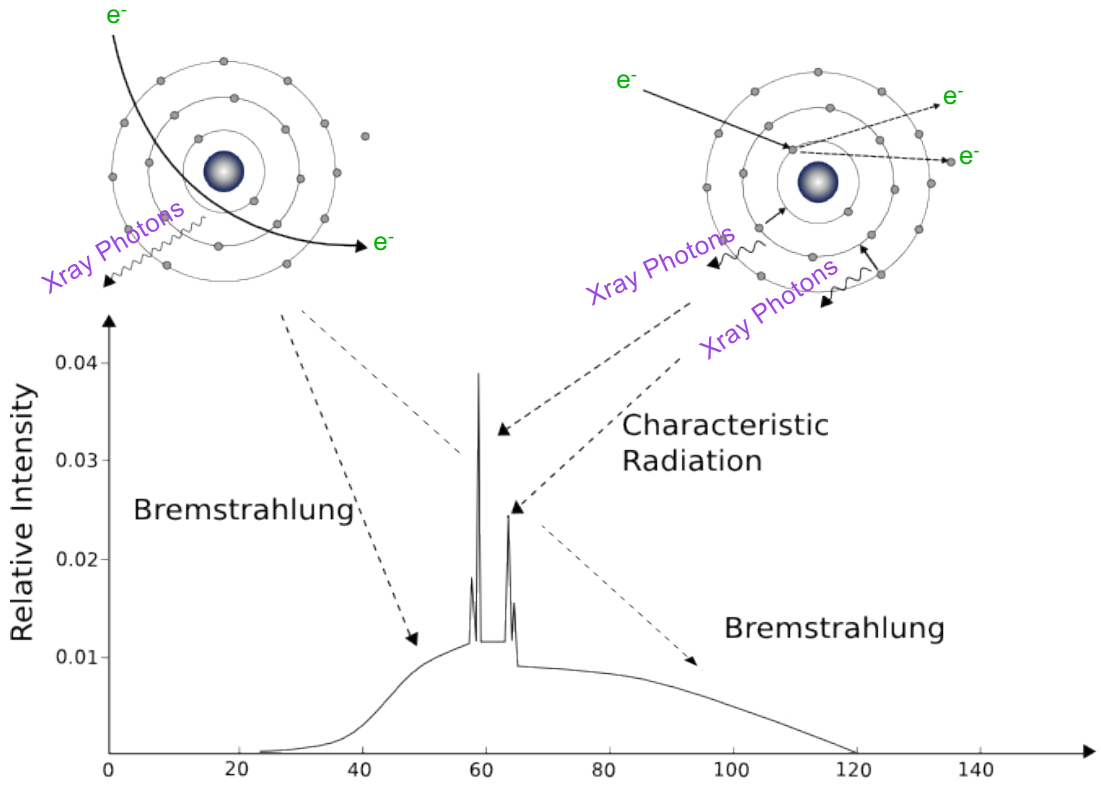
http://spmphysics.onlinetuition.com.my/2013/06/thermionic-emission.html

What happens at the anode?



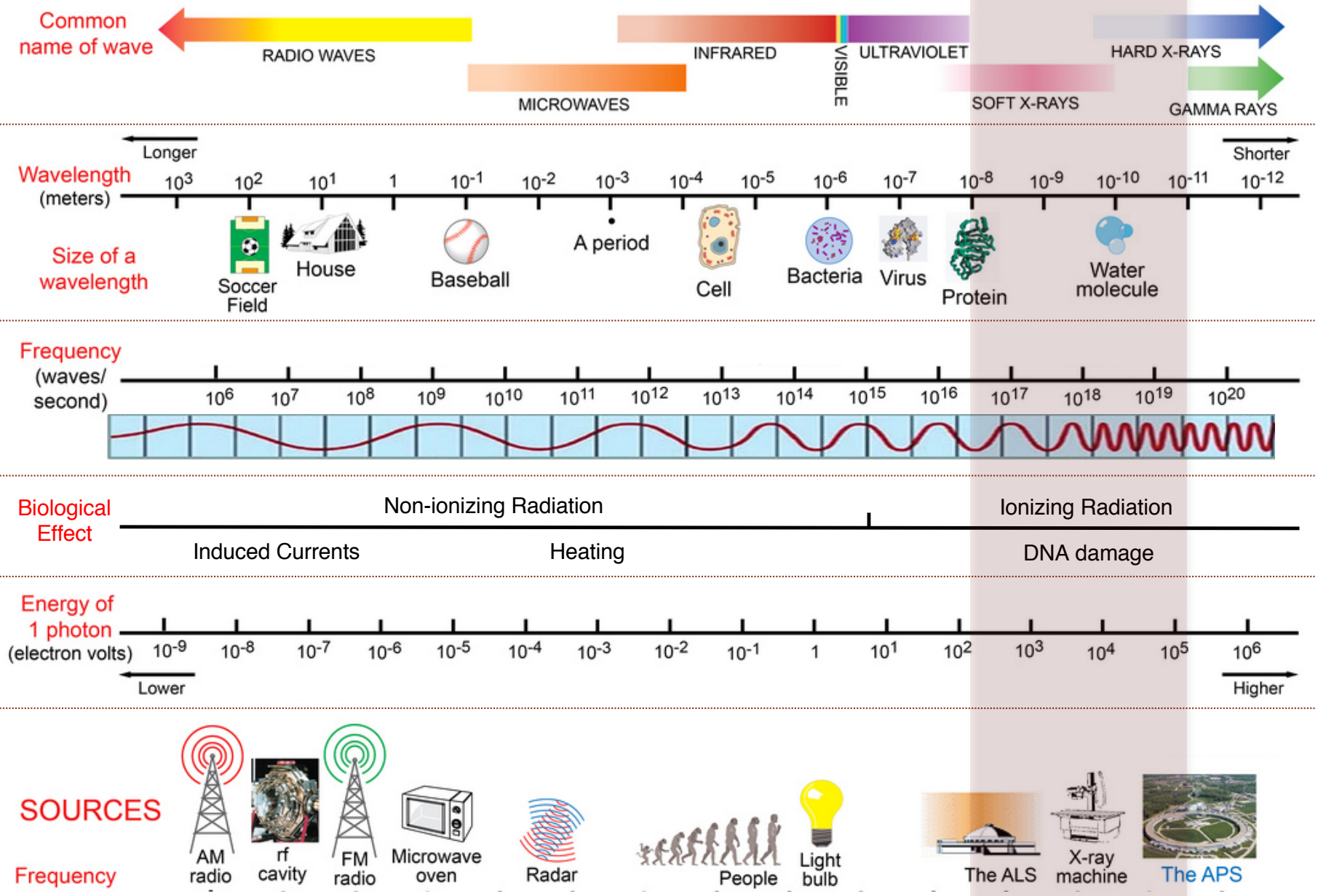


- X-ray production!
- How?



Characteristics of X-rays

ELECTROMAGNETIC SPECTRUM



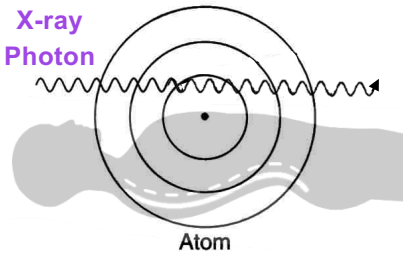
Adapted from https:https://c1.staticflickr.com/7/6142/5940581568_1db150f055_b.jpg

Interaction with Matter

(The Subject)

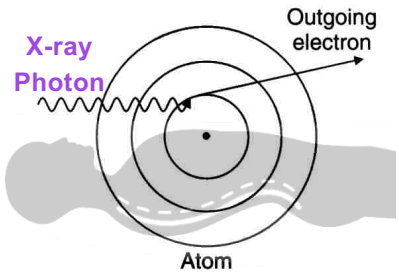
X-ray interaction with matter

1. TRANSMITTED PHOTONS



- Photon does not interact with matter and goes to detector

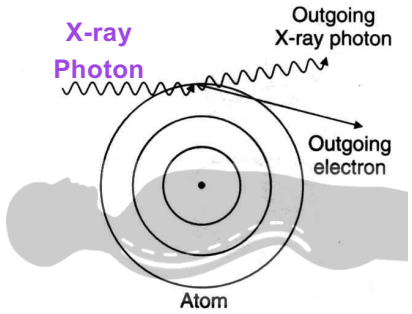
2. PHOTOELECTRIC ABSORPTION



- Photon absorbed in body
- Electron scatters again until it looses all its energy

  → free radicals → DNA damage

3. COMPTON SCATTERING

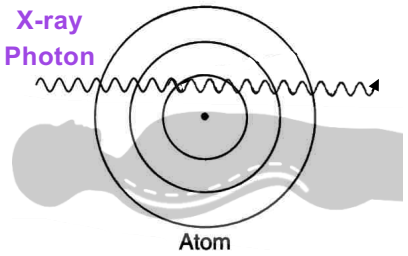


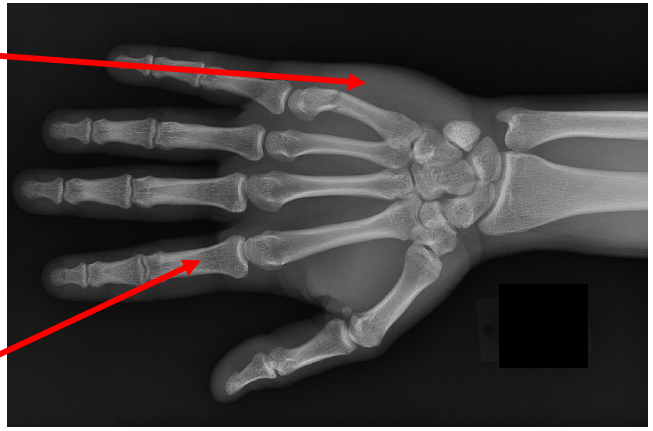
- Photon goes to detector (noise) or around (radiations for operators)
- Electron scatters again until it looses energy

  → free radicals → DNA damage

X-ray attenuation

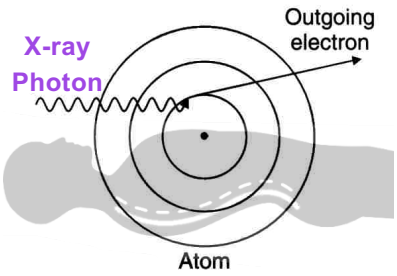
1. TRANSMITTED PHOTONS





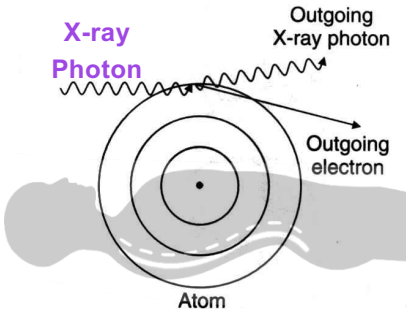
2. PHOTOELECTRIC ABSORPTION

[CONTRAST]



3. COMPTON SCATTERING

[NOISE]



+

ATTENUATION

Total reduction in number of X-rays in beam after passing through tissue

$$I = \int_0^{E_{max}} I_0(E) \cdot e^{-\int \mu \cdot dx} dE$$

[LAMBERT BEER'S LAW]

The Detector

Analog and digital detectors

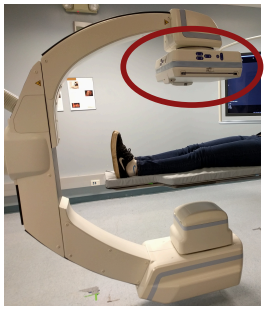
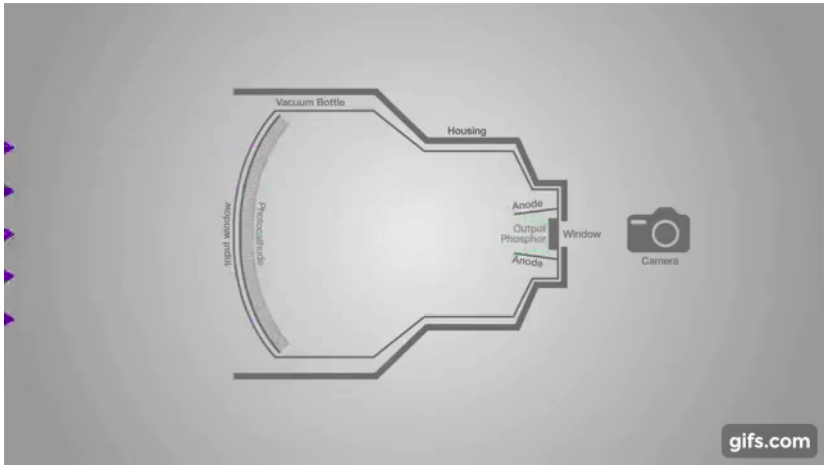


IMAGE INTENSIFIER



https://www.youtube.com/watch?v=BQ0PZGnC334

Analog and digital detectors

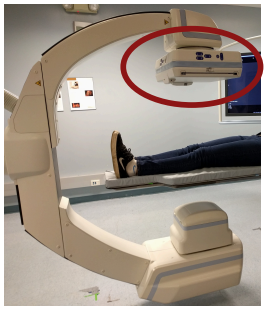
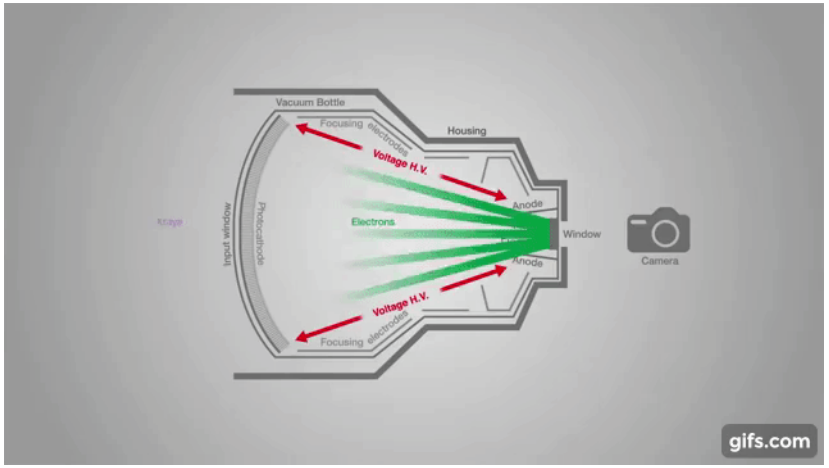


IMAGE INTENSIFIER



https://www.youtube.com/watch?v=BQ0PZGnC334

Analog and digital detectors

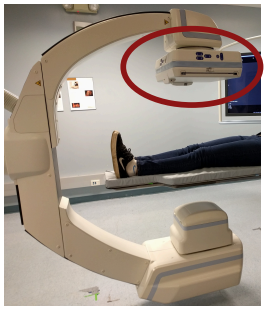
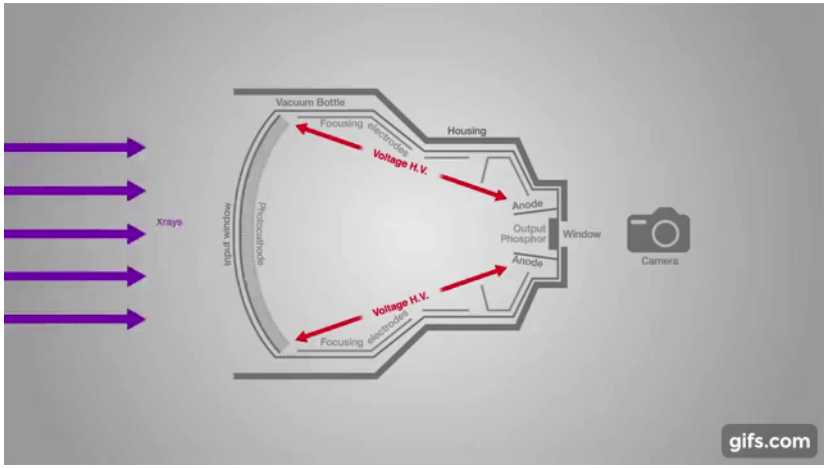


IMAGE INTENSIFIER



https://www.youtube.com/watch?v=BQ0PZGnC334

Analog and digital detectors

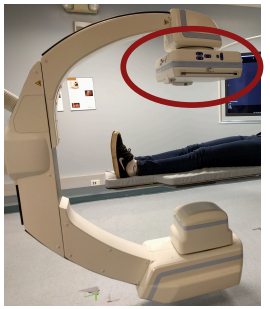
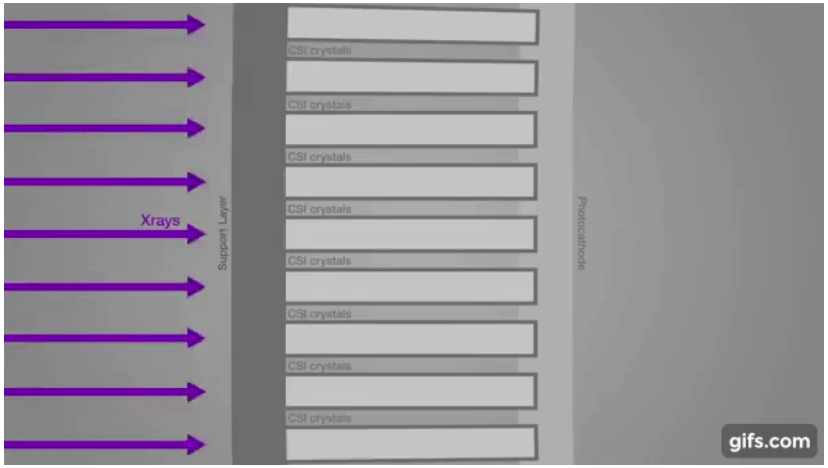


IMAGE INTENSIFIER



https://www.youtube.com/watch?v=BQ0PZGnC334

Analog and digital detectors

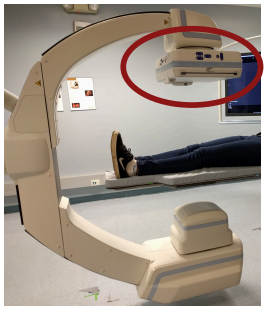
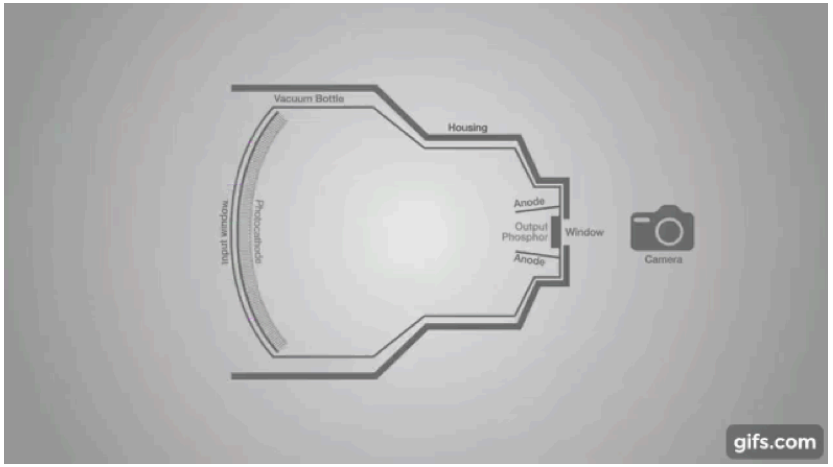


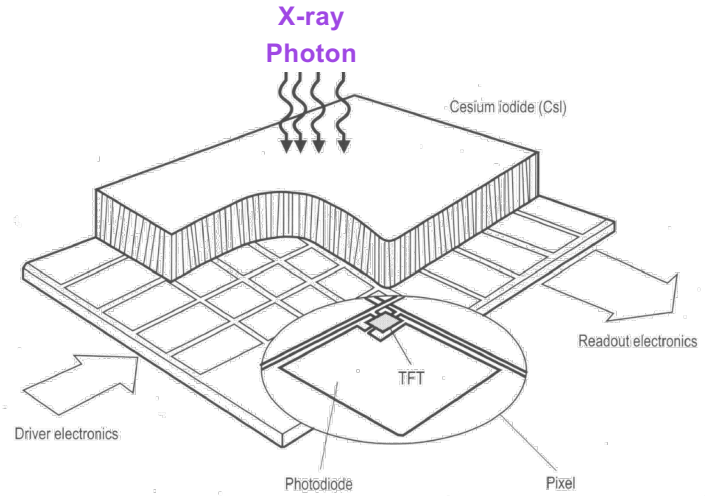
IMAGE INTENSIFIER



https://www.youtube.com/watch?v=BQ0PZGnC334

- X-rays → Light → Electrons → Light → Image
- Introduced in the 1940s

FLAT PANEL DETECTOR



- X-rays → Light → Electrons → Image
- Introduced in the 1990s
- Images are digitalized and thus easily viewed, shared, stored

The Image

2D and 3D images (Zeego system)

- 2D images are directly digitalized from the Flat Panel Detector
  - Matrix size: 1920x1920 / Pixel size: 150x150µm

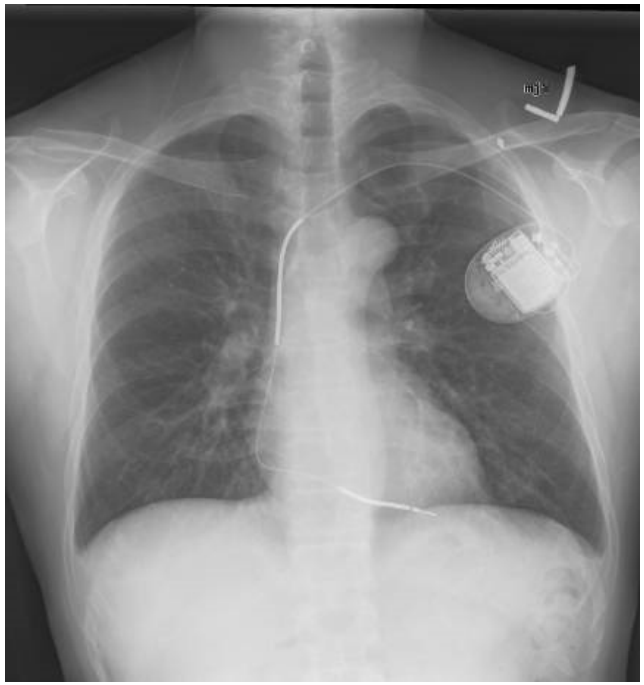
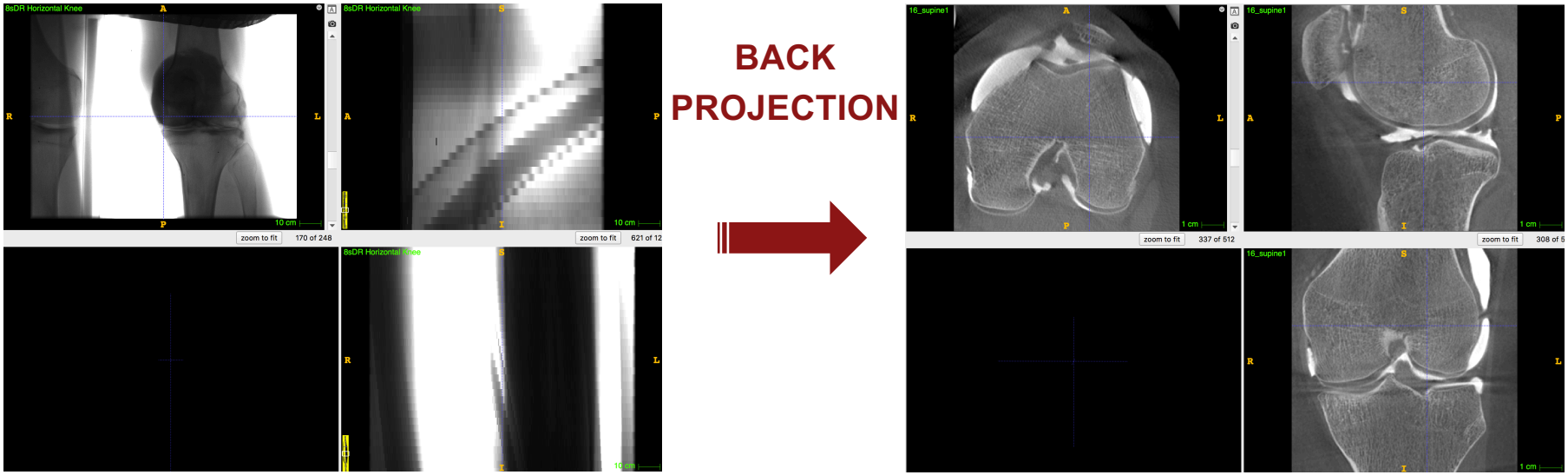


Image source: Siemens Healthcare, Erlangen, Germany and N. Kothary

2D and 3D images (Zeego system)

- 2D images are directly digitalized from the Flat Panel Detector
  - Matrix size: 1920x1920 / Pixel size: 150x150µm

- 3D images are a sequence of 2D image acquired over 200˚
  → We need to reconstruct the volume
    - Matrix size: 512x512x512 / Pixel size: 200x200µm



[Back Projection works like Sudoku or Crosswords!
Example here: https://www.youtube.com/watch?v=GGR6NTAvPao]

X-ray Applications

2D X-ray applications

RADIOGRAPHY

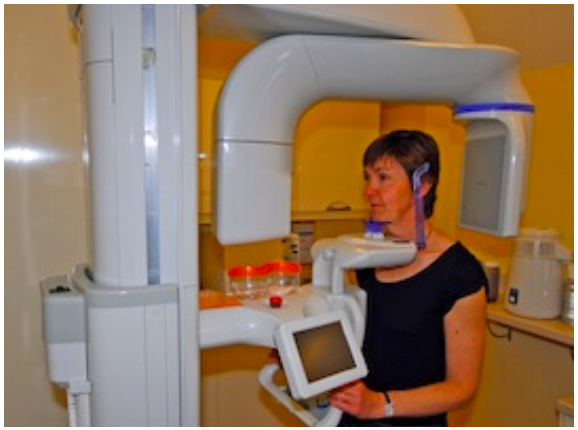
FLUOROSCOPY

Image source: Siemens Healthcare, Erlangen, Germany and N. Kothary

3D X-ray applications

COMPUTED TOMOGRAPHY

CONE BEAM CT



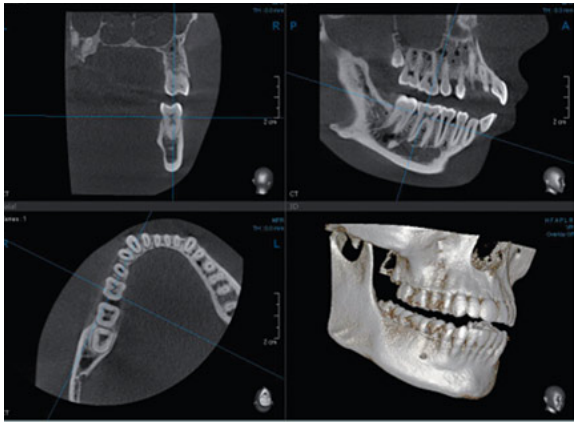


Image source: Siemens Healthcare, Erlangen, Germany and N. Kothary

Radiology Safety

Principle and Practice

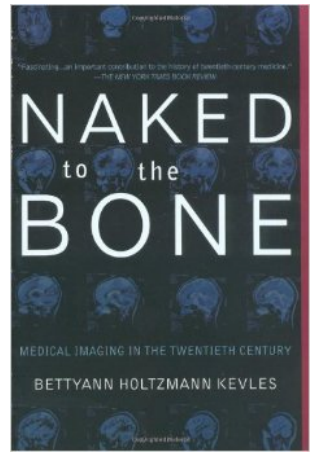
- ALARA (As Low As Reasonably Achievable) principle
  - To ensure that radiation dose to workers, members of the public, and to the environment is as low as reasonably achievable
  - Distance: inverse square law
  - Time: reduce time exposure to X-ray
  - Shielding: use lead apron, movable led walls, plexiglass

PAY ATTENTION TO SAFETY SIGNS

WEAR LEAD APRON

WEAR DOSIMETER BADGE

Did you know?
(Curious historical facts about X-rays)



Did you know?

- 1895: Wilhelm Conrad Röntgen discovers X-rays

Did you know?

- Beyond being used for medical applications, X-rays triggered unprecedented euphoria

MAGIC THEATER

Affiche de spectacle au Théâtre Robert-Houdin
(source : revue *Contrastes* de Guerbet, 1995)

http://adammunich.com/a-brief-history-of-the-x-ray/

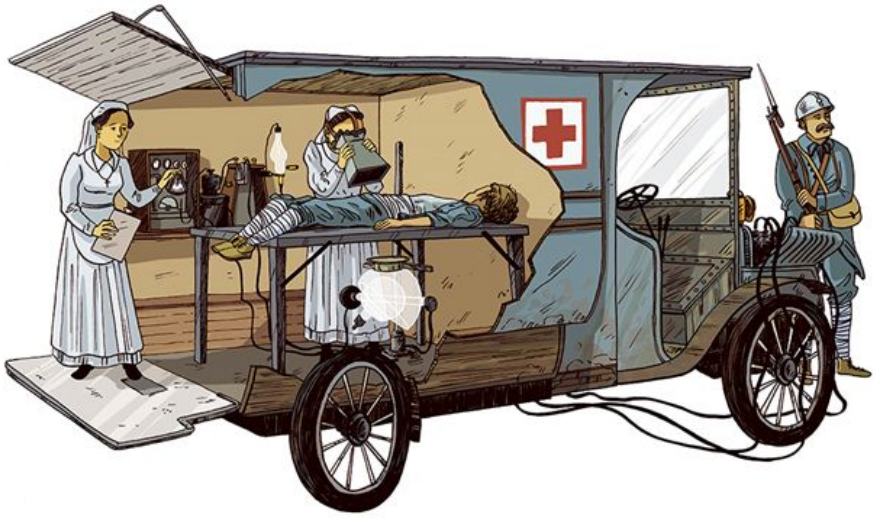
COIN OPERATED X-RAY MACHINES

http://www.underthepier.com/17_novelty_machines.htm

Did you know?

- 1914-1918 (World War I): Marie Curie created mobile X-ray vehicles to assist battlefield surgeons

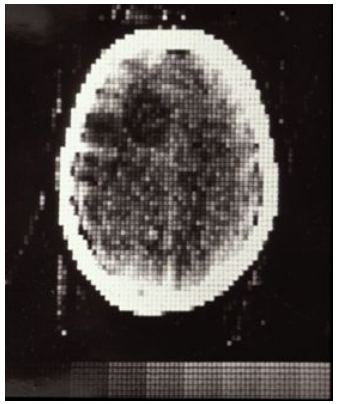
https://en.wikipedia.org/wiki/Marie_Curie#World_War_I



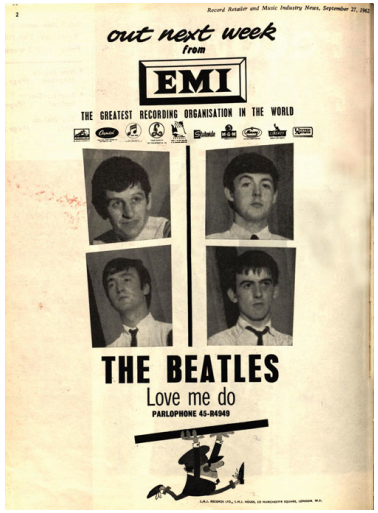
http://www.carestream.com/blog/2014/11/13/radiology-first-world-war/

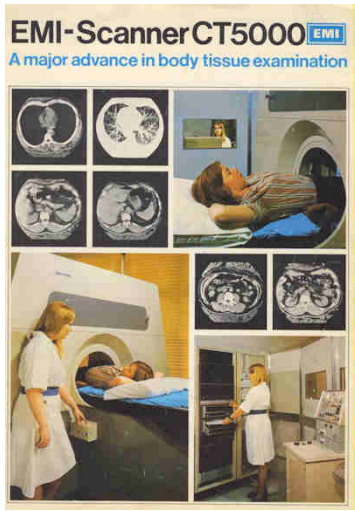
Did you know?

- 1979: Godfrey Newbold Hounsfield invented Computed Tomography



- CT scanner was “the greatest legacy” of the Beatles: the massive profits from their record sales enabled EMI to fund scientific research





See you at the Zeego Lab!