Memorial Sloan Kettering Cancer Center

X-rays: a short foray

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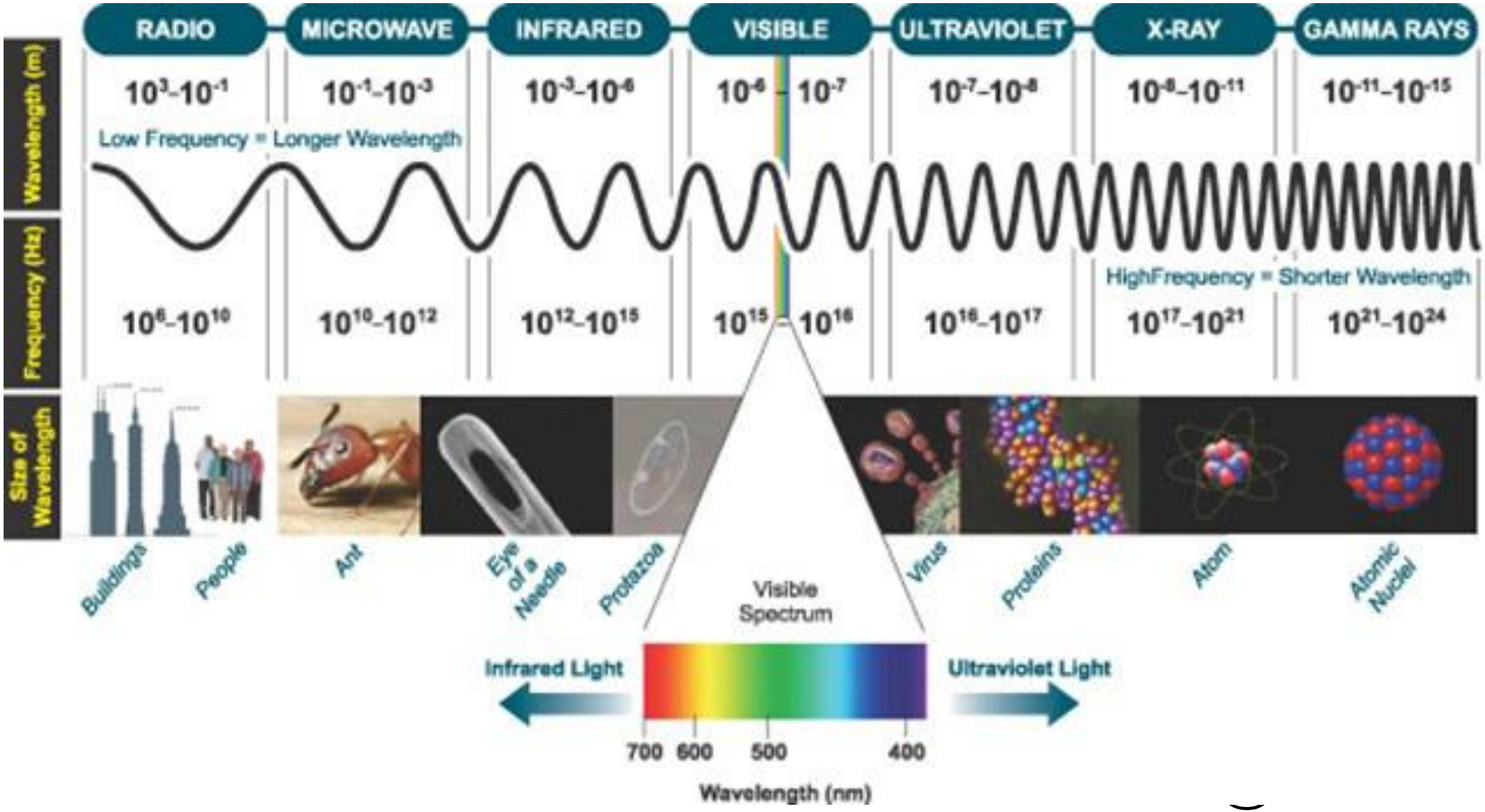
What are x-rays?



ring

How were x-rays discovered?

Wilhelm Conrad Röntgen: Nobel Prize in Physics, 1901

Accidently discovered x-rays by passing electric charges through vacuum tubes, creating an electron beam that elicited x-rays when they hit a glass lid of the tube.

Discovery took place on November 8, 1895

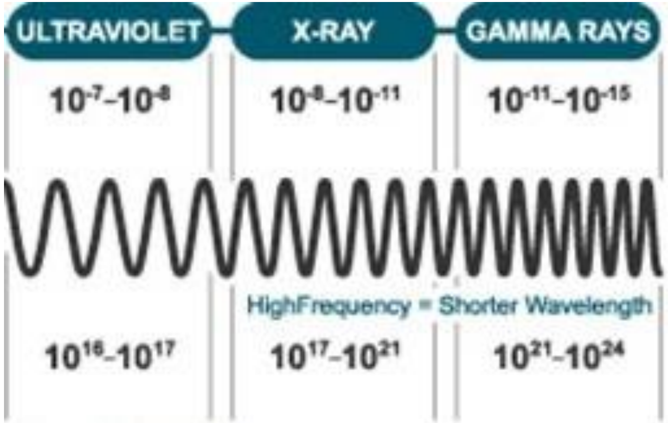
November 8 is World Radiography Day

Took a “picture” of his wife’s hand

Why was it called x-rays?

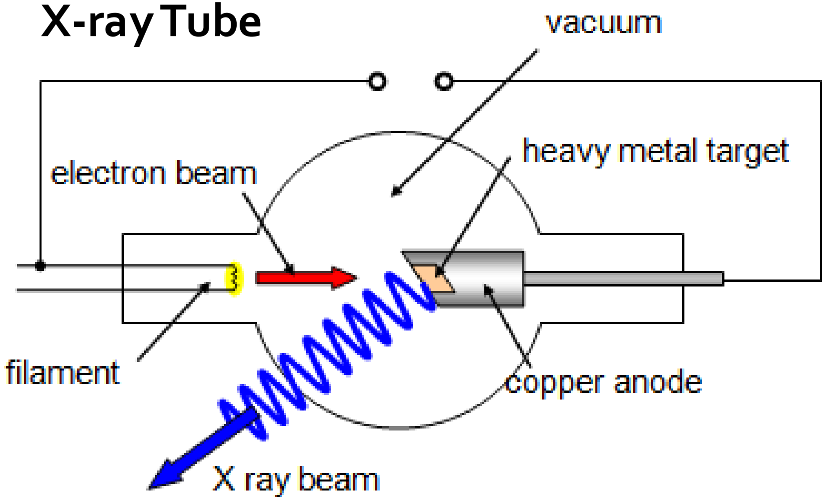
Why are x-rays so useful?

Briefly: x-ray interaction with human bone and tissue is at the sweet spot such that they readily penetrate soft tissues and are absorbed by hard matter like bone



- UV has limited penetration through tissue
- Gamma rays fly through all tissue
- X-rays strike the right balance

How are x-rays generated?

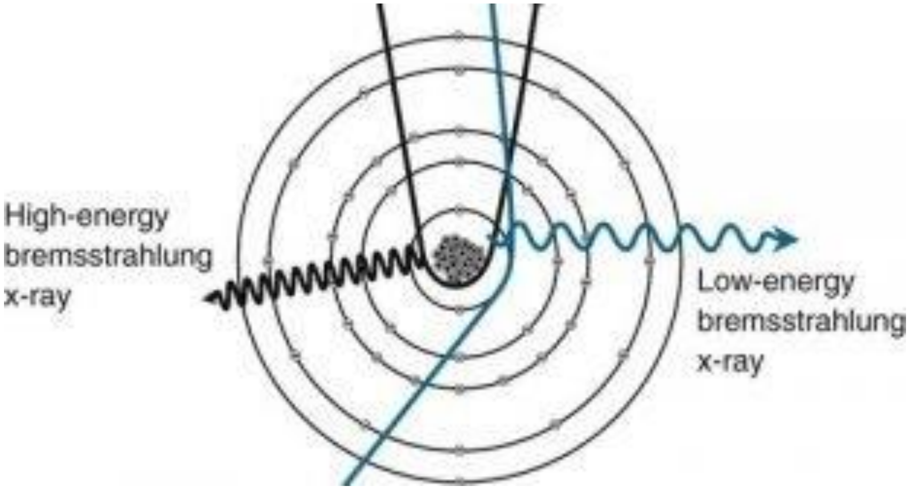


- Heat a filament of something like tungsten
- Connect to two electrodes to create an electric field
- Electrons start flying out
- Accelerate electrons towards a metal target
- Once the electrons hit, energy is released in the forms of x-rays
- The x-rays can then be guided to the destination of interest.

How are x-rays generated? A slightly deeper look

When electrons hit a target, there are roughly two models of how x-ray radiation is generated from that: **Bremsstrahlung radiation** and **characteristic radiation**

Bremsstrahlung radiation



- As electrons pass near a nucleus (positive charge) they change direction and emit x-ray radiation
- Energy lost by electrons and emitted as a photon depends on electron proximity to the nucleus and the starting electron energy (E-field between electrodes)
- Do these emitted x-rays have one frequency or a range of frequencies?

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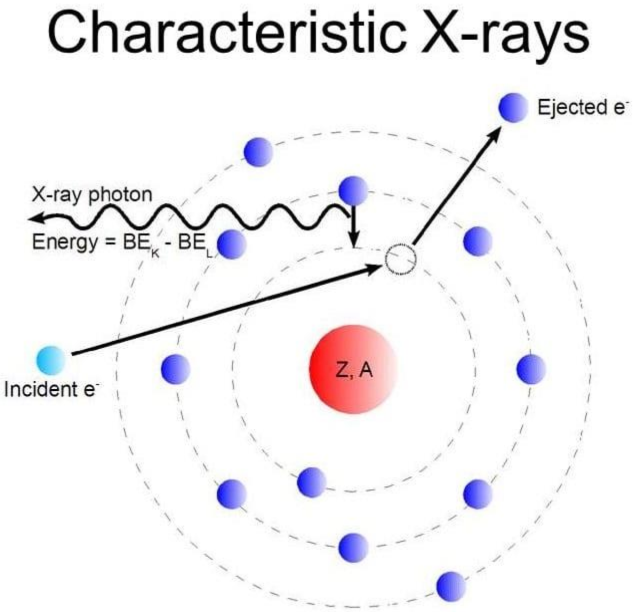
Characteristic radiation



- An incoming electron can knock out an existing electron in one of the "shells" of the electron cloud in the target
- An electron from another shell can fill the vacancy thus releasing energy
- Do these emitted x-rays have specific single frequencies or a range of frequencies?

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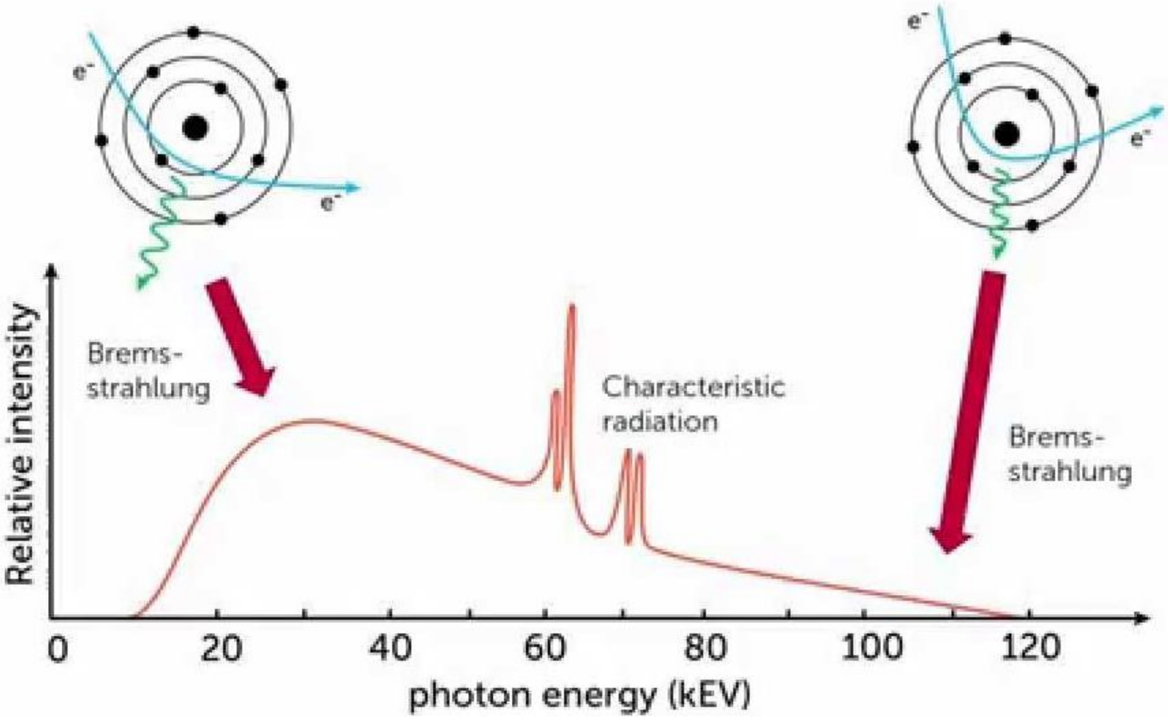

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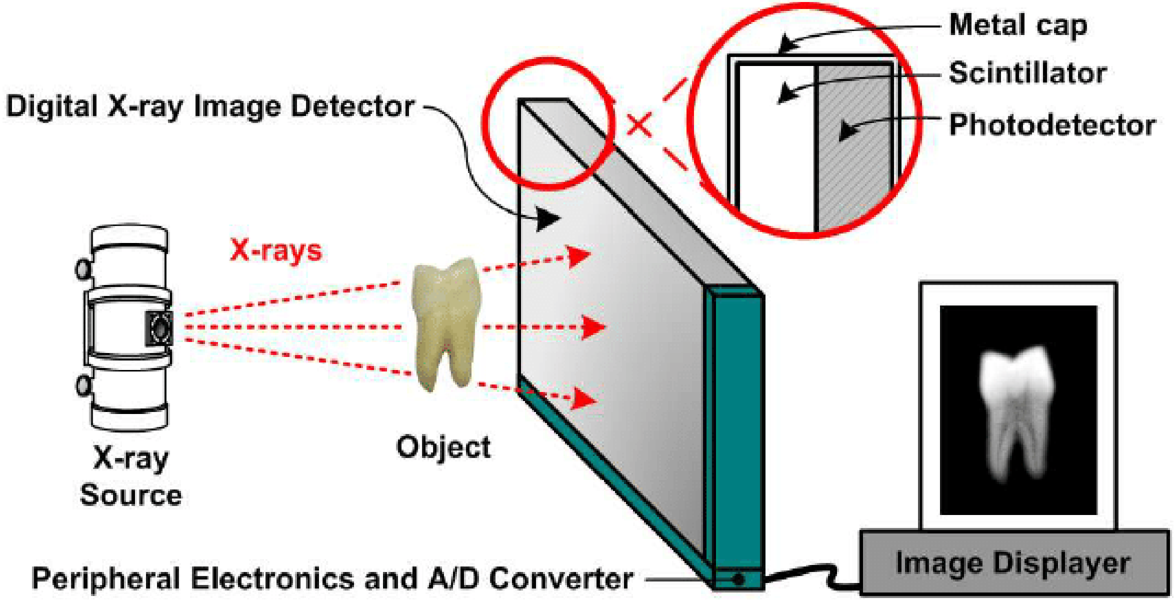
How do we detect x-rays



- Scintillator converts x-ray radiation into visible photons
- Photodetector converts (and sometimes amplifies) light signal into electric signal to produce an image

Jung, Phill & Lee, Chi & Bae, Kong & Lee, Jae & Lee, Sang & Lim, Chang & Yun, Seungman & Kim, Ho Kyung & Ko, Jong. (2010). Microdome-gooved Gd(2)O(2)S:Tb scintillator for flexible and high resolution digital radiography. Optics express. 18. 14850-8. 10.1364/OE.18.014850.

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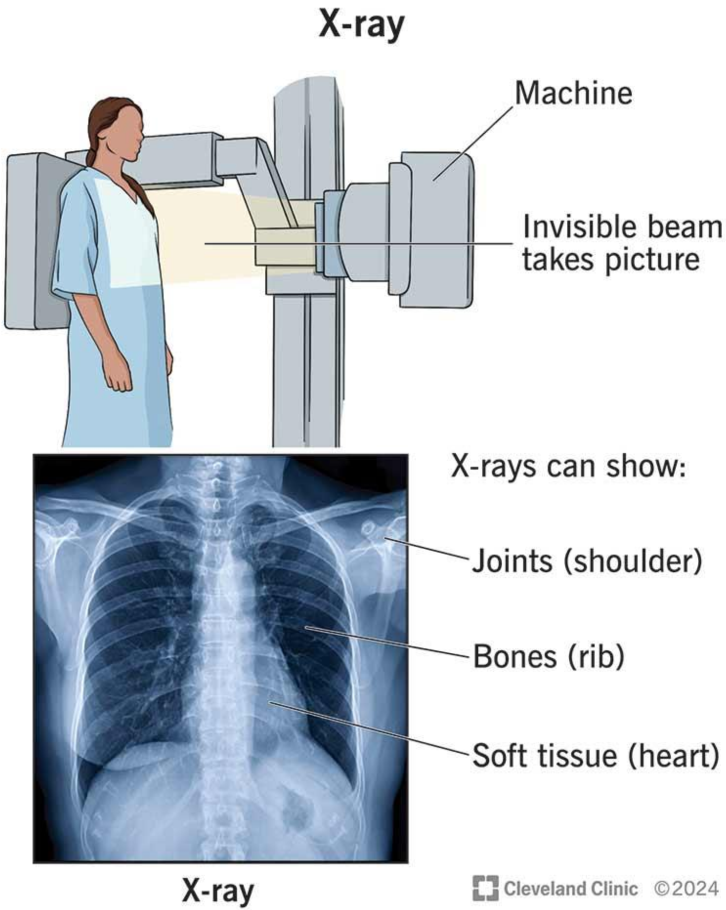
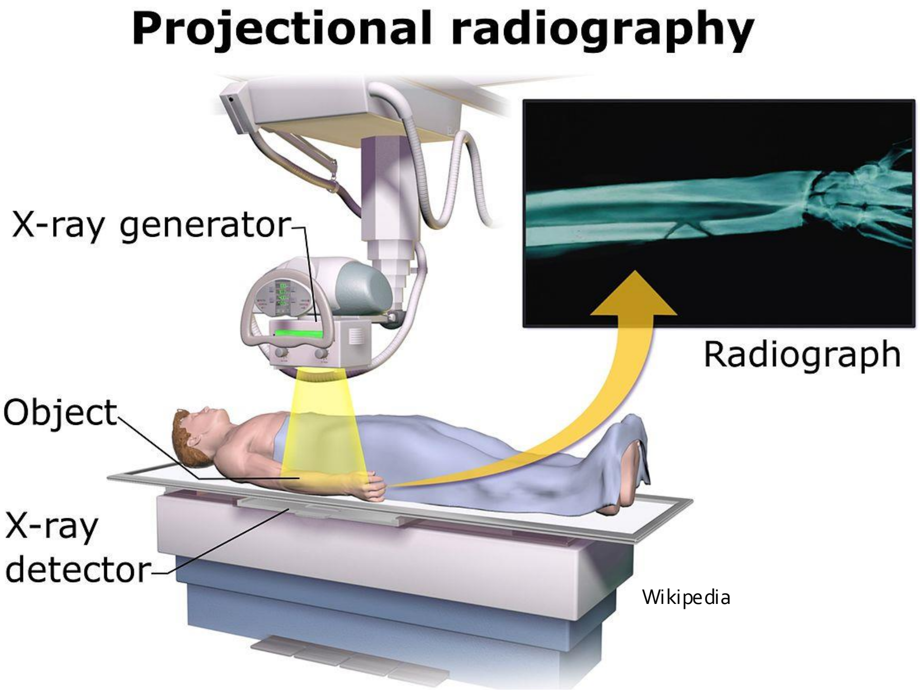
What does x-ray imaging look like?





Wikipedia

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X-Ray example

So far, which mode of optical imaging is this kind of projection radiography closest to?

(a) Brightfield reflection mode
(b) Brightfield transmission mode
(c) Darkfield imaging
(d) Phase imaging

Should places of higher transmission be bright or dark?

If x-ray imaging is like transmission...

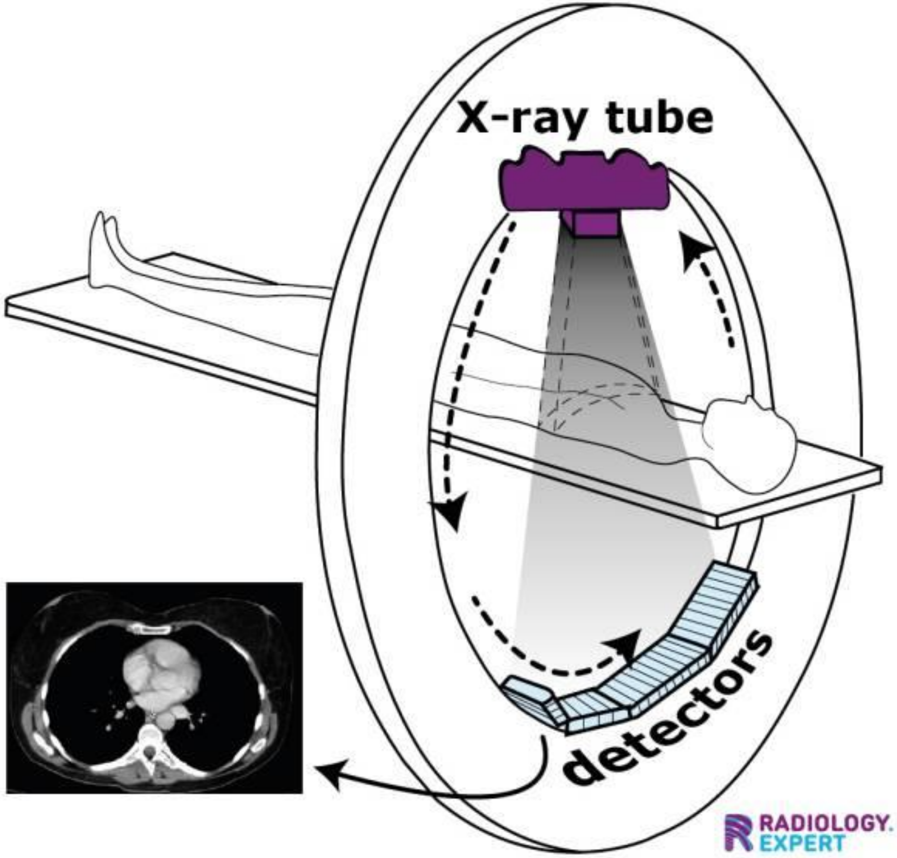
Is contrast here based on properties of the material or biological function?

What creates contrast in x-rays is **radiodensity**. It is a measure of how much x-rays are absorbed. It depends on:

- Mass density
- Mass number

Can anyone spot a fracture here?

CT: going from 2D to 3D



As with SPECT, tomography means we are acquiring many 2D images and reconstruct a 3D image from them

https://www.radiology.expert/en/modules/xrayct-technique/types-of-ct-techniques/

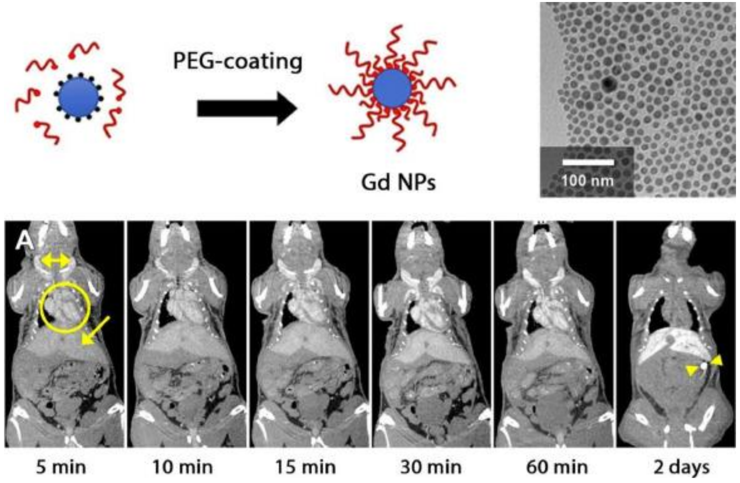
X-Ray contrast agents

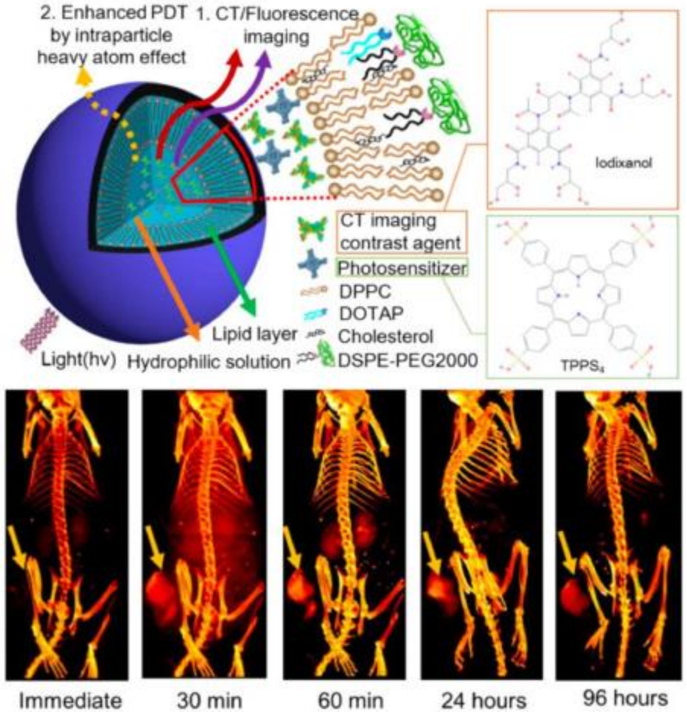
How would you design a contrast agent for x-ray tomography? What are some basic principles you'd want to implement?

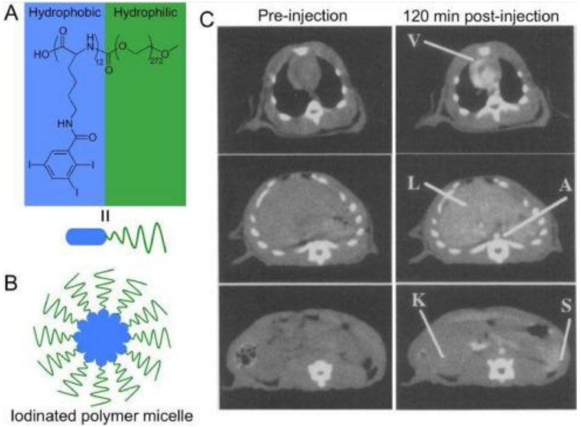
Since x-ray contrast is based on radiodensity, would like a contrast agent that either increases or decreases radiodensity.

- Decreasing radiodensity is difficult
- Contrast agent largely increase radiodensity
- Introduce a nucleus that has a large atomic numbers
  - Large atomic number means large number of electrons too / big electron clouds
  - More chance of interaction / absorption of x-rays
- Iodine and barium sulfate are some of the most common contrast agents
- Metal nano-particles sometimes as well

Example x-ray contrast







CT and X-ray contrast agents: Current clinical challenges and the future of contrast

C. Owens, Nicolas Anton, Mohamed F. Attia

Cancer Applications

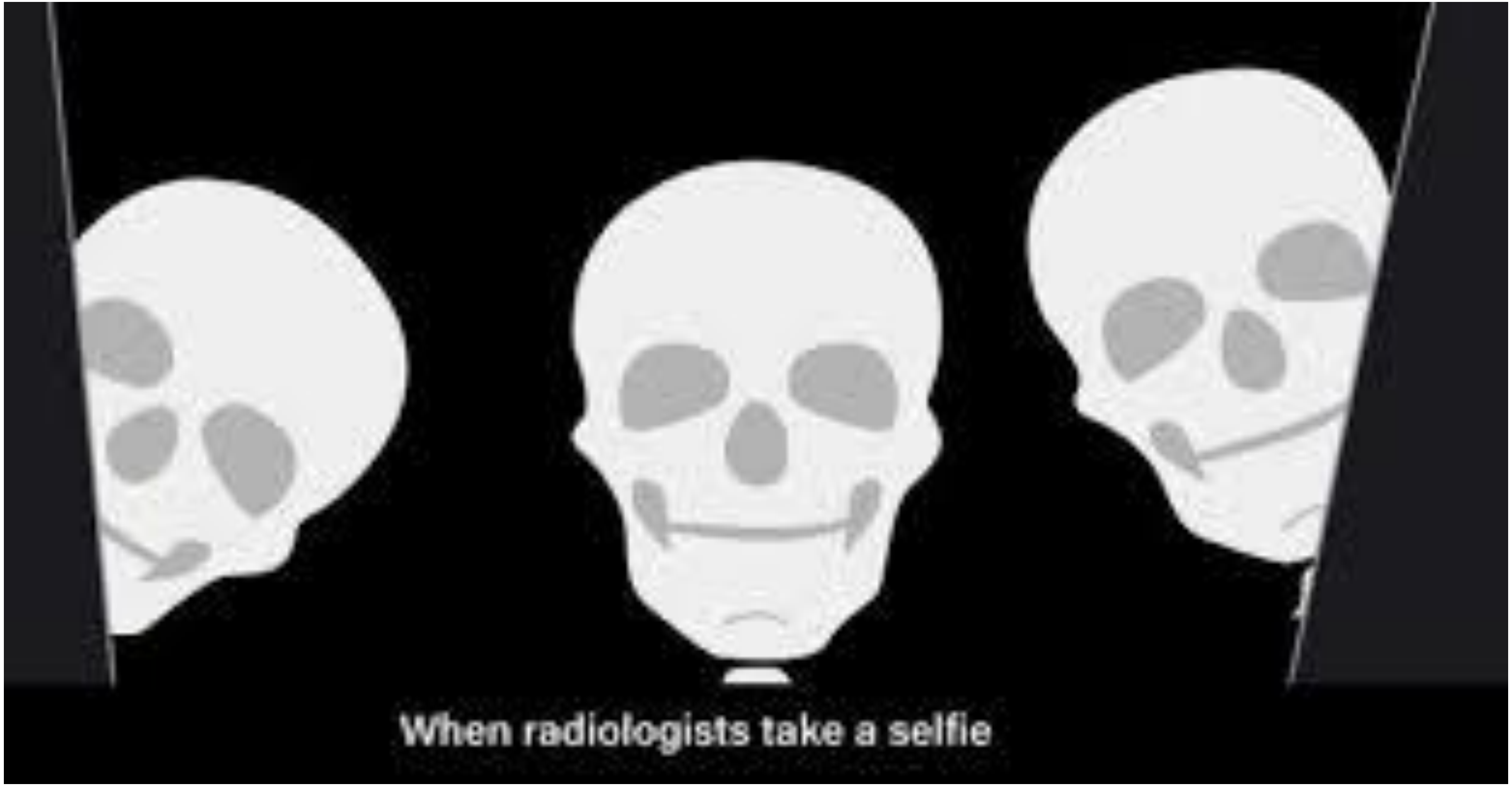
- Detecting and evaluating tumors based on different radiodensity
  - Mammography
  - Lung cancer
  - Bone metastases
- Cancer staging with CT – assessing where cancer spread in the body
- In some cases, it's particularly suited for contrast agents in tumors with enhanced vasculature.
- Guidance for radiation therapy (a version of fluoroscopy)
  - ➢ Fluoroscopy is a continuous x-ray scanning to provide real-time anatomic information
- In combination with PET, SPECT and MRI to coregister
- Treatment response

Non-cancer Applications

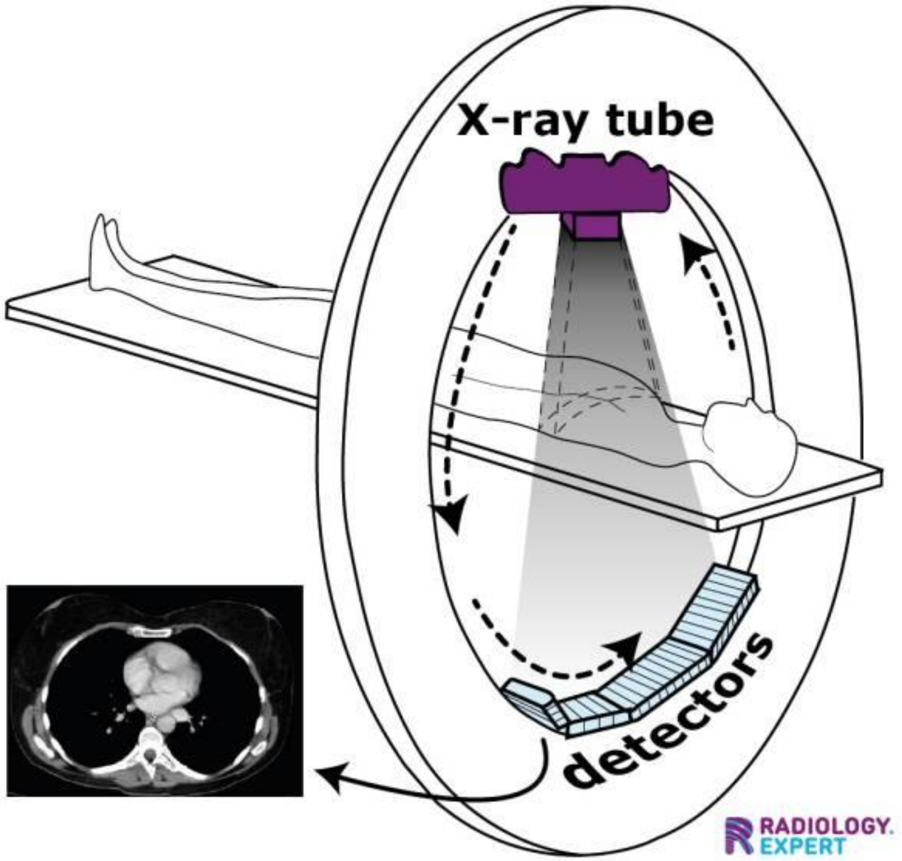
- Detecting bone fractures
- Dental applications
- Imaging obstructions in different organs: heart, lung, kidney
- Fluoroscopy for different procedures
- In combination with PET, SPECT and MRI
- Can be used for treatment of benign tissues as well (joint pain etc)

Safety concerns

- Even though x-rays are lower energy than gamma photons, possibility of damage still exists
- Concern that exposure to x-rays can have a cumulative effect
- Overall, rather safe, but not advisable to get x-rays very often.
- Special PPE like lead shields etc
- Dosimeters to monitor exposure to clinicians and researchers
- Limit when possible

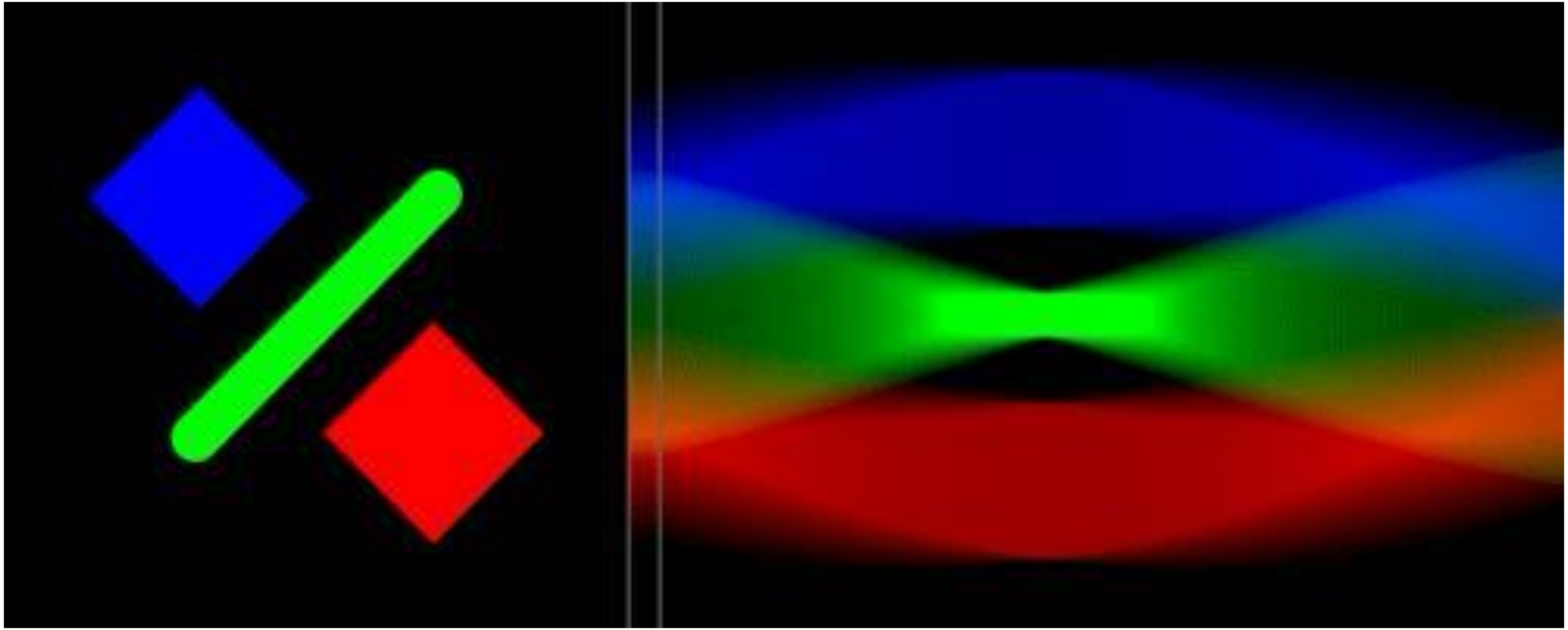

When radiologists take a selfie

CT: going from 2D to 3D



- Radon transform is a mathematical function that will turn a set of 1D projects from different angles into a 2D image (and vice-versa)
- Generalized will do so in 3D as well

Radon transform intuition



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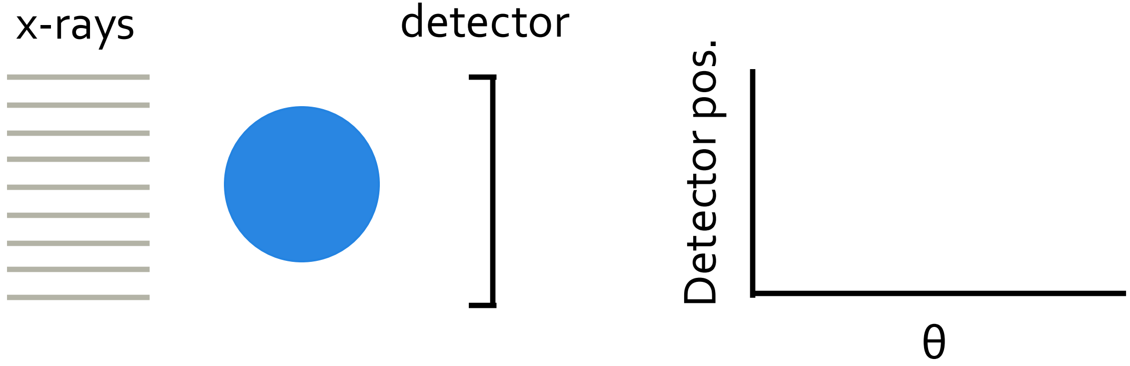
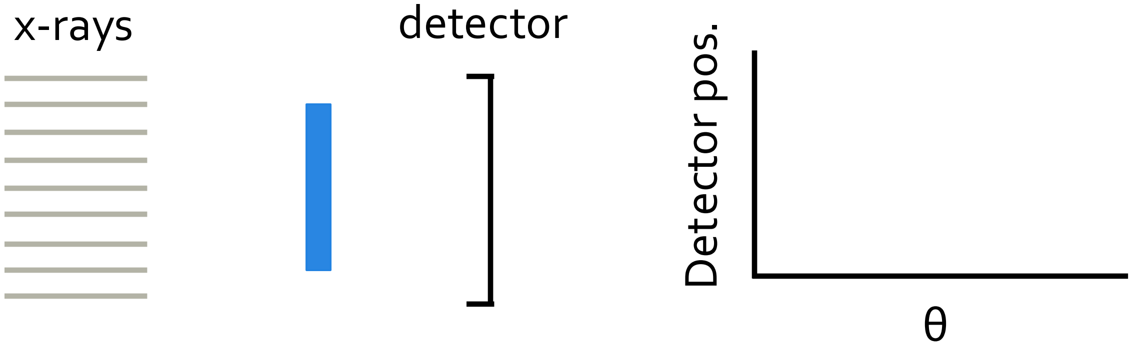
Exercise: 2 groups at the white board

Group 1: Draw the sinogram of a circle



Group 2: Draw the sinogram of a rod



Exercise 2:

Individually and in pairs explore the notebook / google colab to reconstruct images from sinograms and vice versa

1. Verify the sinograms of a ball and a rod
2. Transform back into the image
3. Optional exercises with modifications
4. Check out the sinogram of a chest x-ray and transform back into an image
5. Explore what happens when you acquire fewer angles or block out certain angles