Medical Imaging 1 : X-Rays

Specification Objectives

Lesson 1

1. basic structure of an X-ray tube; components – heater (cathode), anode, target metal and high voltage supply
2. production of X-ray photons from an X-ray tube; x-ray spectra

Lesson 2

3. attenuation of X-rays; $I = I_0 e^{-\mu x}$ where μ is the attenuation (absorption) coefficient
4. X-ray imaging with contrast media; barium and iodine

Lesson 3

5. computerised axial tomography (CAT) scanning; components – rotating X-tube producing a thin fan-shaped X-ray beam, ring of detectors, computer software and display
6. advantages of a CAT scan over an X-ray image.

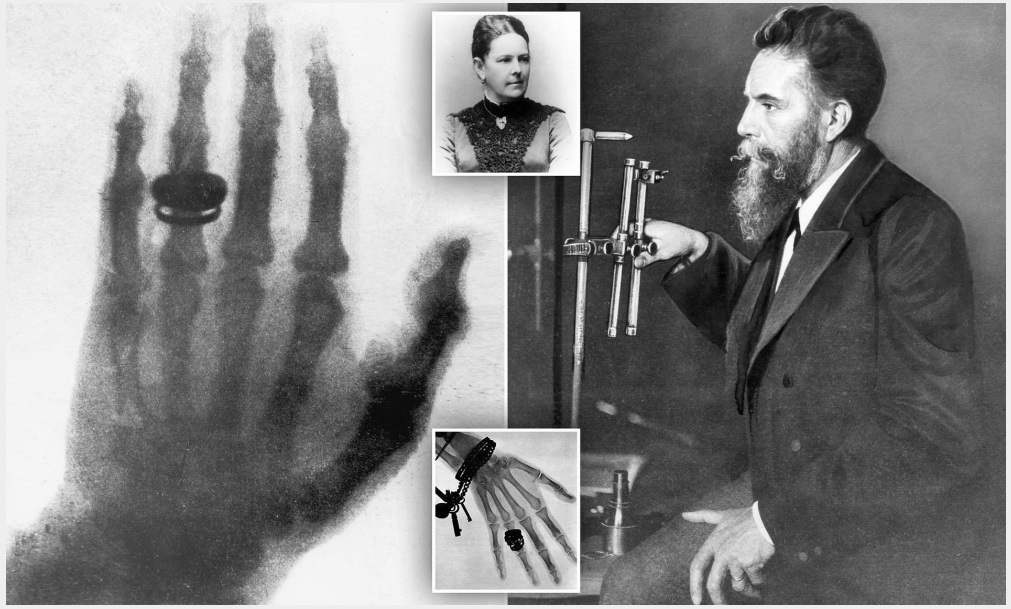
Lesson 1: Using X-rays

Learning Outcomes

- list the basic components of an x-ray tube
- describe and draw the basic structure of an x-ray tube
- calculate the minimum wavelength for an x-ray photon given the anode potential
- compare 'bremssstrahlung' and 'characteristic' x-rays
- sketch a graph of an x-ray spectrum including the effect of changing the anode potential

Introduction: properties of X-Rays

- Wilhelm Roentgen discovered X-Rays by accident in 1895.
- What are some properties of X-Rays?
- What are 'soft' X-Rays?



Key Question

Basic structure of an X-ray tube

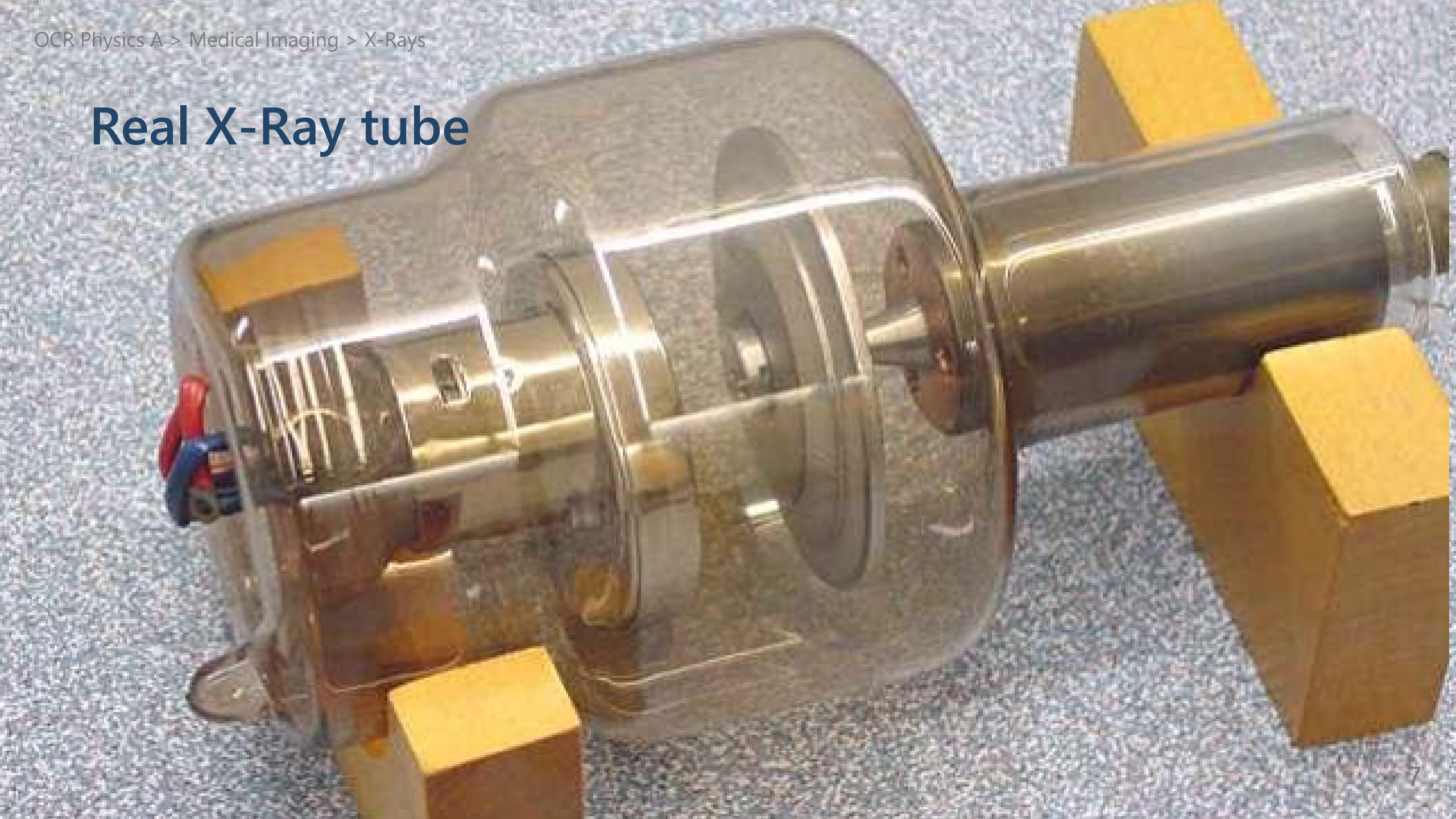
Draw a diagram to include heater (cathode), anode, target metal and high voltage supply.

Key Question

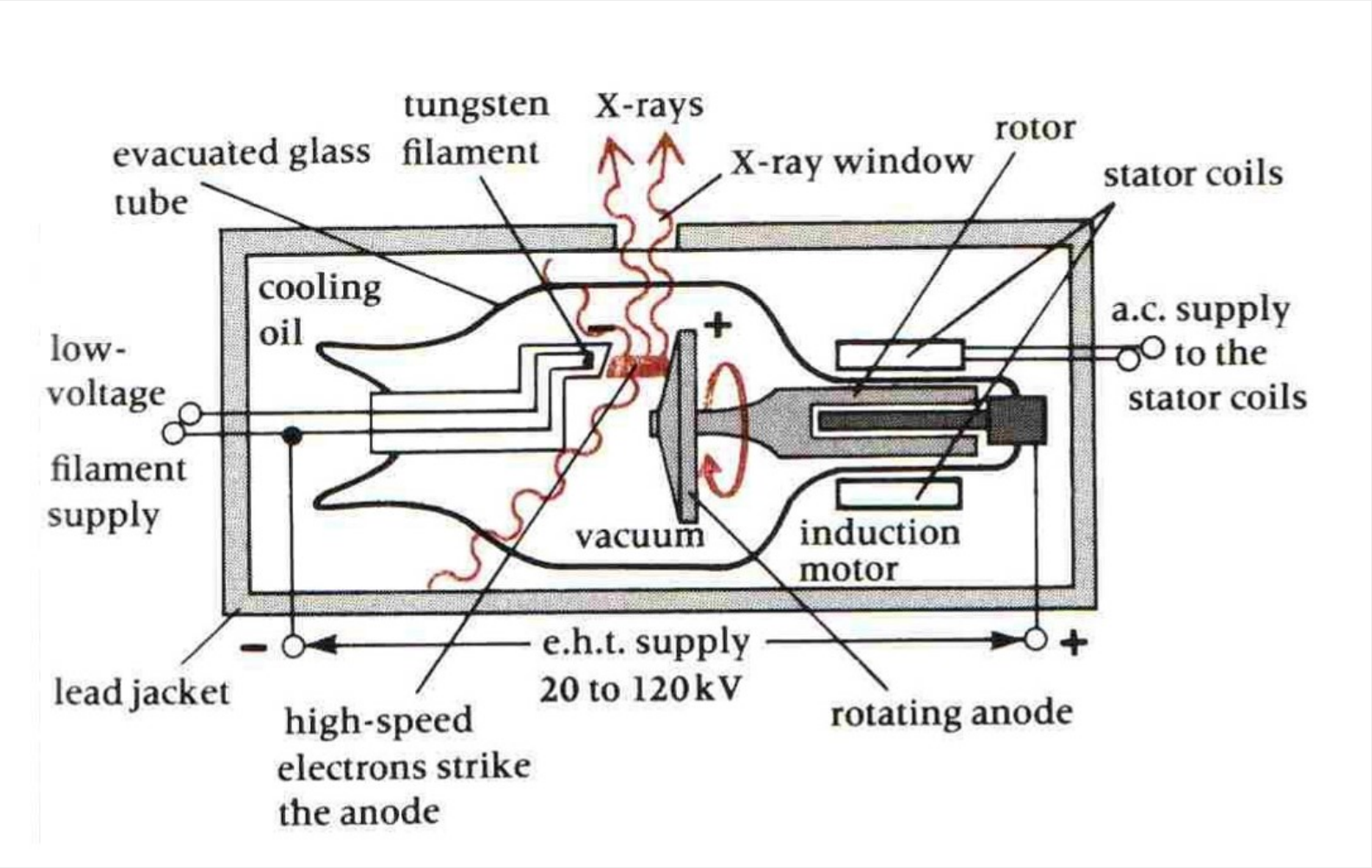
Anode potential and wavelength

Calculate the minimum x-ray photon wavelength if the anode potential is (a) 20 kV (b) 100 kV.

Real X-Ray tube



Real X-Ray Tube: Schematic



Key Question

The production of X-Rays generates a large quantity of heat. Explain how an X-Ray tube's design can prevent damage to the tube.

X-Ray Spectra

- Bremsstrahlung ('braking radiation')
- Characteristic x-rays

Key Question

Sketch a graph of relative intensity vs. wavelength for X-Ray spectra. Show the effect of increasing anode potential.

27.1 Summary Questions

Lesson 2: Attenuation of X-Rays

Learning Outcomes

- state the meaning of 'attenuation'
- list and compare the attenuation mechanisms of X-rays
- use the equation $I = I_0 e^{-\mu x}$ where μ is the attenuation (absorption) coefficient
- derive and use the 'half-value' formula $\ln 2 = \mu x_{\frac{1}{2}}$;
- explain the need for contrast media to improve x-ray images e.g. barium and iodine

Intensity

> The power per unit area of a beam of radiation.

Measured in Wm^{-2}.

Attenuation

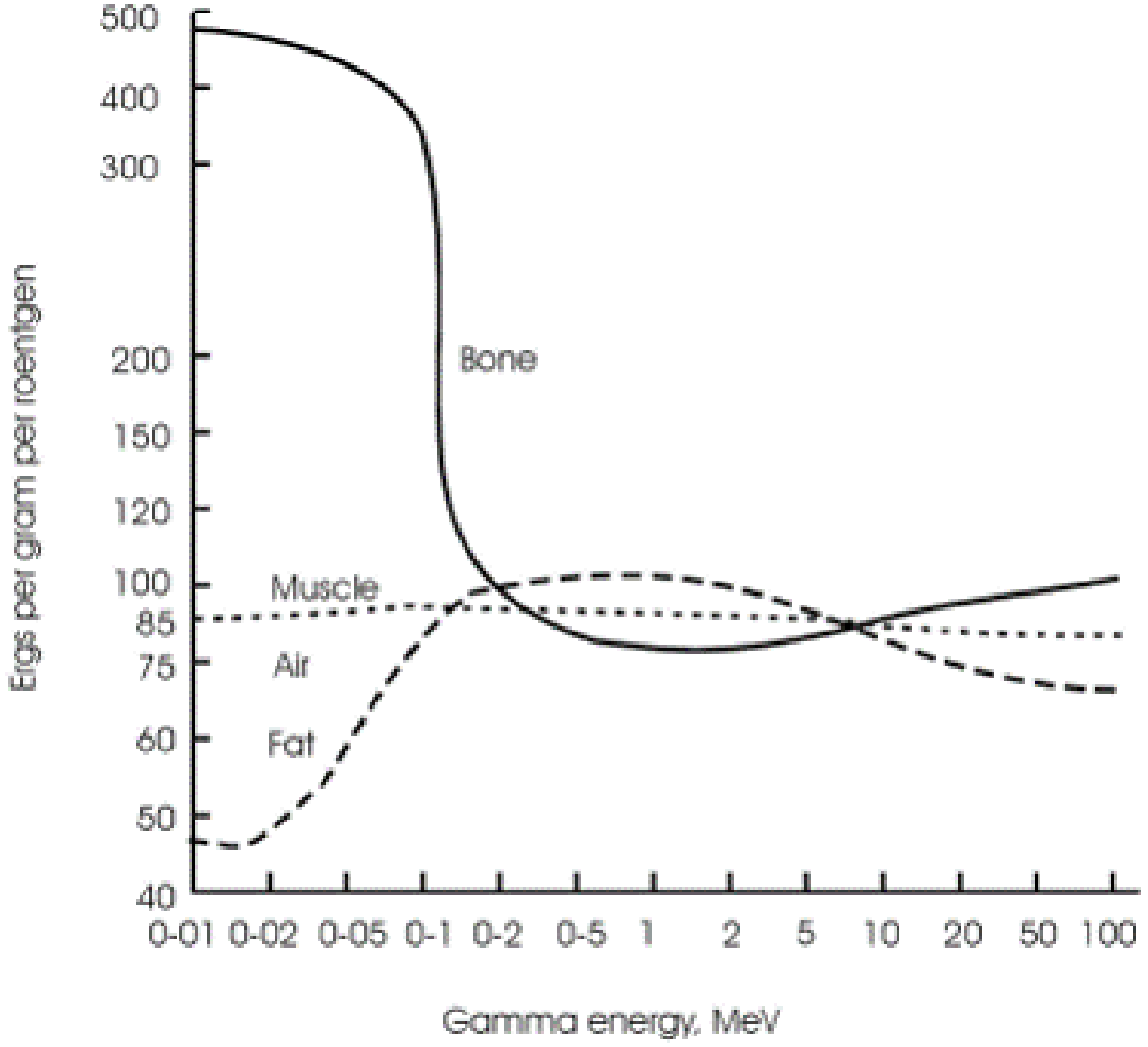
> A gradual decrease in the **intensity** of the X-Ray beam as it travels through a medium.

Dependent on:

- anode potential (because of different **attenuation mechanisms**)
- medium

Absorption of X-Rays

What energy range is used for diagnosis of the skeletal system?



Energy absorption per roentgen of various tissues.
(From O. Glasser, *Medical Physics*, Vol. II)

Modelling attenuation

- A simple model of attenuation assumes probability of absorption per unit depth of penetration is constant.
- This leads to $I = I_0 e^{-\mu x}$
- However μ is not constant across different energy ranges

Worked example using $I = I_0 e^{-\mu x}$

- The attenuation coefficient for lead at 100 kV anode potential is $0.27\ \mathrm{mm}^{-1}$.
- Calculate the distance required for the intensity to fall to 10% of the initial value.

Half-value

Half-value $x_{\frac{1}{2}}$ defined as the attenuation distance required for the radiation to fall to one-half of it's initial value.

Worked example

Show that $\ln 2 = \mu x_{\frac{1}{2}}$.

X-ray Attenuation Mechanisms

There are four mechanisms.

1. simple scatter
2. photoelectric effect
3. Compton effect
4. pair production

X-Ray Attenuation Mechanisms

1. Simple scatter

- photon energy 1-20 keV (too low for hospital X-Ray)
- direction of photon **changed**
- energy of photon **unchanged**

X-Ray Attenuation Mechanisms

2. Photoelectric effect

- photon energy < 100 keV
- x-ray photon **completely** absorbed
- electron emitted
- **predominant interaction mechanism** for **X-Ray imaging** ('soft' X-Rays)

X-Ray Attenuation Mechanisms

3. Compton scattering

- photon energy 0.5 - 5 MeV
- dominant effect in high energy ('hard') X-Rays used in **radiotherapy**
- **elastic scattering** of X-Rays by orbital electrons

X-Ray Attenuation Mechanisms

4. Pair production

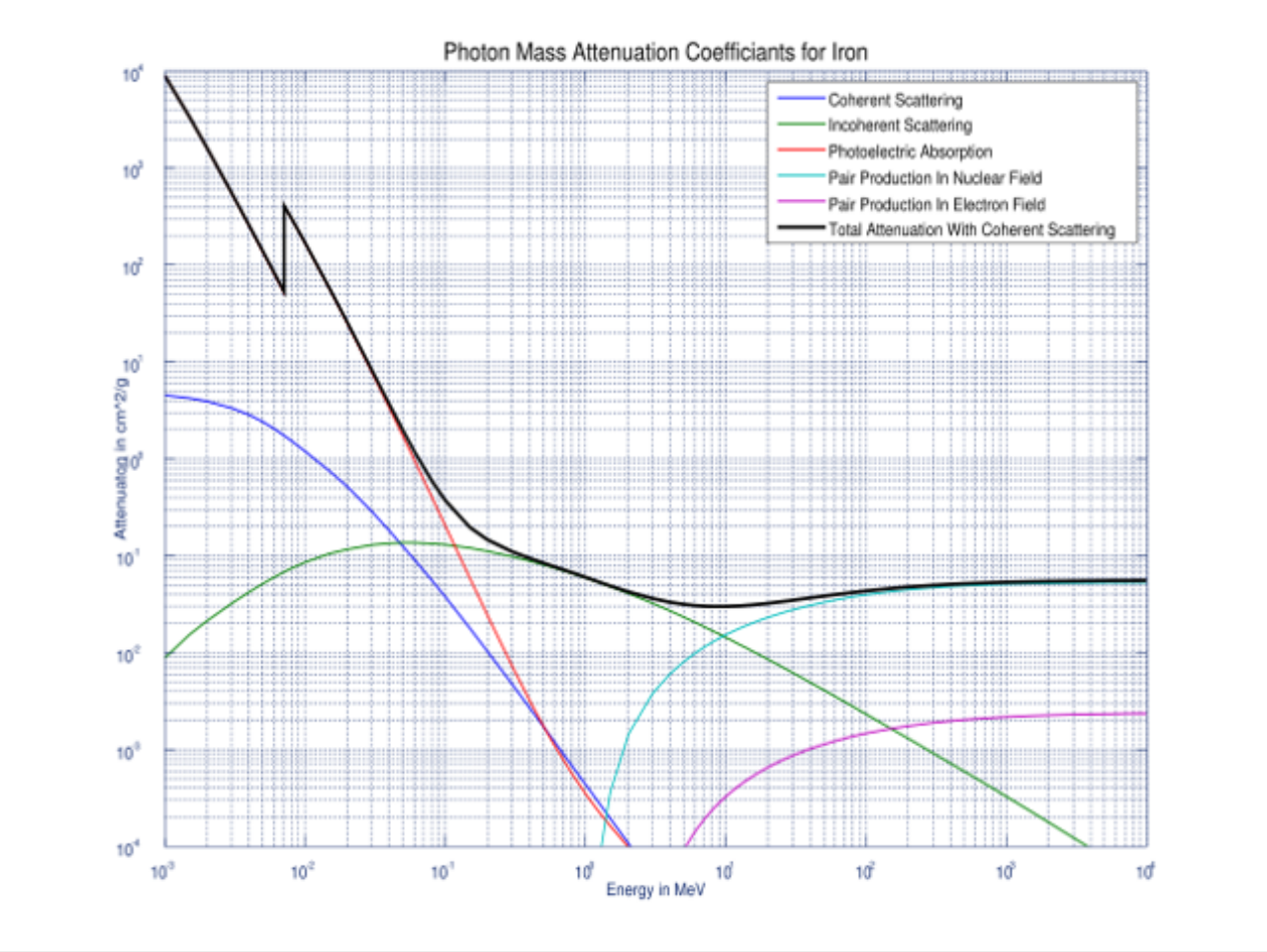
- photon energy > 1.02 MeV
- X-Ray photon forms **electron-positron** pair

Contrast media

- Used to enable imaging of **soft tissue** e.g. digestive tract, heart
- most of absorption due to **photoelectric effect**
- absorption related to Z^3, where Z is **atomic number** of material

Appendix

Attenuation coefficient variation with photon energy



Appendix

Half-values of lead and concrete

Anode potential / kV	lead	concrete
50	0.06	4.32
100	0.27	15.10
150	0.30	22.32
200	0.52	25.00
250	0.88	28.00

Values in mm^{-1}

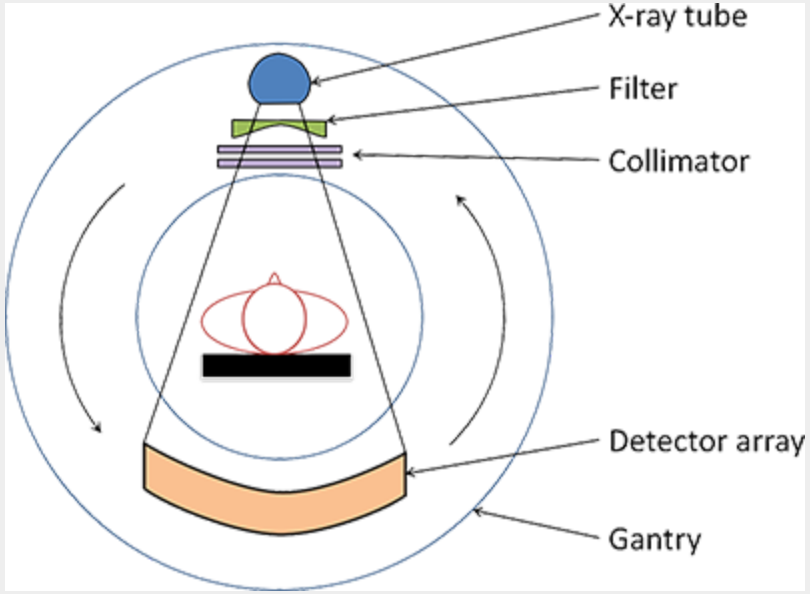
Lesson 2: Summary Questions (27.2)

Lesson 3: CAT scans

Learning Outcomes

- describe the basic components of a CAT scanner - explain how the components of a CAT scan are used to generate a 3D image
- list the advantages of a CAT scan over an X-ray image

Basic components of a CAT scan



Key Question

How are the components of a CAT scan used to generate a 3D image?

Key Question

Compare the advantages/disadvantages of using a CAT (CT) scan over a normal X-Ray.

Lesson 3: Summary Questions (27.3)