Exercise walk-through

Production and use of X-rays ▪ 24.2

eXercise

You must be able to

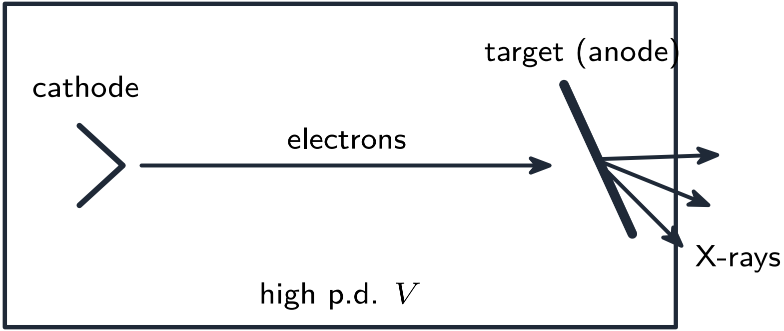
- explain X-ray production and find the **minimum wavelength**
- use the attenuation $I = I_0 e^{-\mu x}$ and **contrast**
- describe **CT scanning**

Method — Production

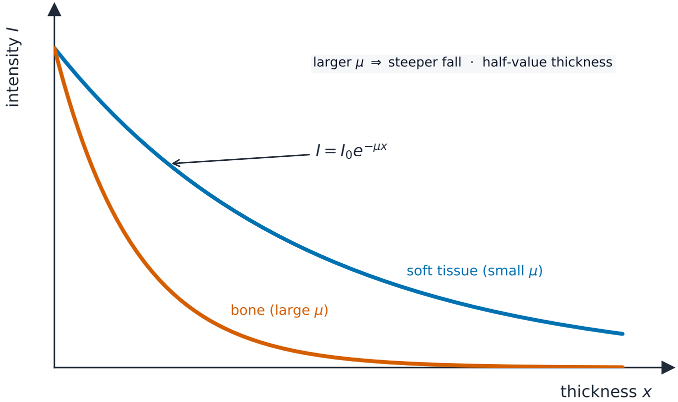
Electrons from a heated **cathode** are accelerated by a high p.d. V onto a metal **target**. The most energetic photon has the full electron KE:

$$hf_{\max} = eV, \qquad \lambda_{\min} = \frac{hc}{eV}.$$

Method — Production



Method — Production



X-ray attenuation through tissue

Method — Imaging

X-rays are **attenuated** as $I = I_0 e^{-\mu x}$; bone (high μ) absorbs more than soft tissue, giving **contrast**. **CT scanning** combines many X-ray images from different angles into a 2D slice, then stacks slices into a **3D** image.

Practice 2.1 ▪ 2 marks

Describe how **X-rays** are produced in an X-ray tube.

Solution 2.1

Method: Production

Worked steps

A heated **cathode** emits electrons (thermionic emission) B1; a high p.d. accelerates them onto a metal **target**, where they decelerate and emit X-rays B1.

Practice 2.2 ▪ 1 mark

Write the equation for the **minimum wavelength** of X-rays.

Solution 2.2

Worked steps

$$\lambda_{\min} = \frac{hc}{eV} \quad \boxed{\textbf{B1}}.$$

Practice 2.3 ▪ 1 mark

Write the equation for the **attenuation** of X-rays.

Solution 2.3

Method: Production

Worked steps

$I = I_0 e^{-\mu x}$ **B1**.

Practice 2.4 ▪ 1 mark

State what is meant by **contrast** in an X-ray image.

Solution 2.4

Method: Imaging

Worked steps

The **difference in brightness** between structures (e.g. bone vs soft tissue) caused by their different absorption of X-rays B1.

Exam-style 3.1 ▪ 1 mark

The **minimum wavelength** of the X-rays from a tube depends on:

A the target metal

B the accelerating p.d.

C the tube current

D the tube length

Solution 3.1

Method: Production

A the target metal

B the accelerating p.d. ✓

C the tube current

D the tube length

Worked steps

B — the accelerating p.d.

Exam-style 3.2 ▪ 3 marks

An X-ray tube uses an accelerating p.d. of 50 kV. Calculate the **minimum wavelength** of the X-rays.

Solution 3.2

Method: Production

Worked steps

$$\lambda_{\min} = \frac{hc}{eV} = \frac{(6.63 \times 10^{-34})(3.0 \times 10^{8})}{(1.6 \times 10^{-19})(50\,000)} \quad \text{M1}\ \text{M1} \quad = 2.5 \times 10^{-11}\ \text{m} \quad \text{A1}.$$

Exam-style 3.3 ▪ 3 marks

Describe how a **CT scan** produces a 3D image of the body.

Solution 3.3

Worked steps

Take many X-ray images of one **slice** from **different angles** and combine them into a 2D image of that slice B1; repeat for many slices **along the body** B1; stack the slices to build a **3D** image B1.

Exam-style 3.4 ▪ 3 marks

An X-ray tube accelerates electrons through a potential difference of 5.80 kV onto a metal target. Take $h = 6.63 \times 10^{-34}$ J s, $c = 3.00 \times 10^{8}$ m s^{-1} and $e = 1.60 \times 10^{-19}$ C.

(a) **Name** the two processes by which X-rays are produced at the target, and **state** which gives the continuous part of the spectrum.

(b) **Explain** why the spectrum has a sharp **minimum** wavelength.

(c) **Determine** that minimum wavelength.

(d) The X-rays pass through a medium of attenuation coefficient 1.4 cm^{-1}. **Determine** the percentage of the X-ray energy **absorbed** by a thickness of 2.8 cm.

(e) **Explain** why a contrast medium such as barium is given to a patient before imaging soft tissue.

Solution 3.4

Method: Production

Worked steps

(a) **Bremsstrahlung** (braking radiation), where an electron is decelerated by a target nucleus **B1**, and **characteristic** X-ray emission, where an inner-shell electron is knocked out and an outer electron falls in to replace it **B1**. Bremsstrahlung gives the **continuous** spectrum; the characteristic process gives the sharp spikes on top of it **B1**.

(b) The most energetic photon possible is produced when an electron gives up **all** of its kinetic energy in a single interaction **B1**; no photon can carry more energy than that, and a maximum energy means a **minimum** wavelength **B1**.

Solution 3.4

(c) $eV = \dfrac{hc}{\lambda_{\text{min}}}$ **M1**, so $\lambda_{\text{min}} = \dfrac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{(1.60 \times 10^{-19})(5800)}$ **M1** $= 2.1 \times 10^{-10}$ m **A1**.

(d) $\dfrac{I}{I_0} = e^{-\mu x}$ with $\mu x = 1.4 \times 2.8 = 3.92$ **M1**; $\dfrac{I}{I_0} = e^{-3.92} = 0.0198$ **M1**, so the fraction **absorbed** is $1 - 0.0198$, i.e. 98% **A1**. (Answering 2% gives the transmitted share instead.)

(e) Soft tissues have very similar attenuation coefficients, so they absorb almost equally and the image shows little contrast between them **B1**. Barium has a much higher atomic number and absorbs far more strongly, so an organ filled with it stands out sharply against the tissue around it **B1**.