A-LEVEL PHYSICS • EXERCISE SHEET

24.2 Production and use of X-rays

Name: ____________ Class: ________ Date: __________ **Total: 25 marks**

KEY WORDS contrast 对比度 • x-ray tube X 射线管 • electron 电子 • target 靶 • cathode 阴极

Objective

Build the skills to answer exam questions on **X-rays** in medicine.

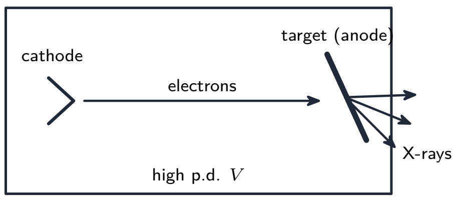
You must be able to:

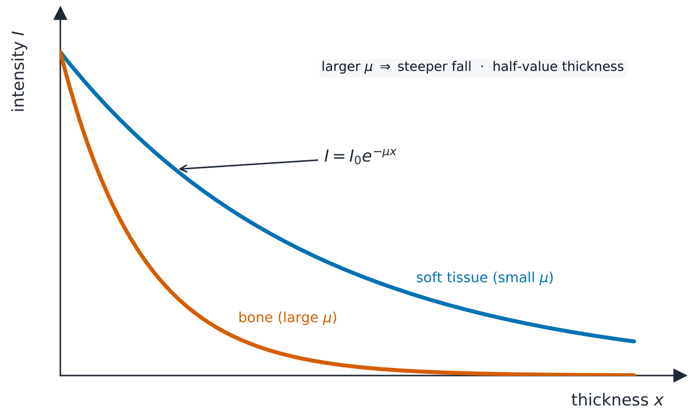
- explain X-ray production and find the **minimum wavelength**
- use the attenuation $I = I_0 e^{-\mu x}$ and **contrast**
- describe **CT scanning**

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Production





X-ray attenuation through tissue

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:

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

■ 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.

2 Practice

Now apply the methods above.

2.1 Describe how **X-rays** are produced in an X-ray tube. [2]

2.2 Write the equation for the **minimum wavelength** of X-rays. [1]

2.3 Write the equation for the **attenuation** of X-rays. [1]

2.4 State what is meant by **contrast** in an X-ray image. [1]

3 Exam-style questions

3.1 The **minimum wavelength** of the X-rays from a tube depends on: [1]

- **A** the target metal
- **B** the accelerating p.d.
- **C** the tube current
- **D** the tube length

3.2 An X-ray tube uses an accelerating p.d. of 50 kV. Calculate the **minimum wavelength** of the X-rays. [3]

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

3.4 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. [3]

(b) **Explain** why the spectrum has a sharp **minimum** wavelength. [2]

(c) **Determine** that minimum wavelength. [3]

(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. [3]

(e) **Explain** why a contrast medium such as barium is given to a patient before imaging soft tissue. [2]

Solutions

Each answer shows the steps, then the **result**.

2.1

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

2.2

- $\lambda_{\text{min}} = hc/(eV)$

2.3

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

2.4

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

3.1 B

- λ_{min} is set by the **accelerating p.d.**

3.2

- $\lambda_{\text{min}} = hc/(eV)$

$$\lambda_{\text{min}} = \frac{(6.63 \times 10^{-34}\ \text{J s})(3.0 \times 10^{8}\ \text{m s}^{-1})}{(1.6 \times 10^{-19}\ \text{C})(50\,000\ \text{V})} = \mathbf{2.5 \times 10^{-11}}\ \text{m}$$

3.3

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

3.4

(a) **bremsstrahlung** (braking radiation), where an electron is decelerated by a target nucleus

- **characteristic** X-ray emission, where an inner-shell electron is knocked out and an outer electron falls in to replace it
- bremsstrahlung gives the **continuous** spectrum; the characteristic process gives the sharp spikes on top of it

(b) the most energetic photon possible is produced when an electron gives up **all** of its kinetic energy in a single interaction

- no photon can carry more energy than that, and a maximum energy means a **minimum** wavelength

(c) $eV = hc/\lambda_{\text{min}}$

$$\lambda_{\text{min}} = \frac{(6.63 \times 10^{-34}\ \text{J s})(3.00 \times 10^{8}\ \text{m s}^{-1})}{(1.60 \times 10^{-19}\ \text{C})(5800\ \text{V})} = \mathbf{2.1 \times 10^{-10}}\ \text{m}$$

(d) $I/I_0 = e^{-\mu x}$ with $\mu x = 1.4 \times 2.8 = 3.92$

$$I/I_0 = e^{-3.92} = 0.0198$$

- the fraction **absorbed** is $1 - 0.0198$, i.e. 98%

(e) soft tissues have very similar attenuation coefficients, so they absorb almost equally and the image shows little contrast between them

- 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