

24.2.1 Intensity against hardness, at- tenuation through layers, and sharp- ness against contrast

Name: _____ Class: _____ Date: _____ **Total: 35 marks**

KEY WORDS contrast 对比度 • x-ray tube X 射线管 • contrast medium 造影剂 • target 靶
• electron 电子

Objective

Build the skills to answer the **X-ray imaging** questions that sheet 24.2 does not reach. That sheet produces X-rays, uses $\lambda_{\min} = hc/(eV)$ and $I = I_0 e^{-\mu x}$, defines contrast and describes a CT scan. Three things the topic is really assessed on are absent from it: how the tube's two controls set the **intensity** and the **hardness** 硬度 separately, what makes an image **sharp** as opposed to high in **contrast** 对比度, and the **half-value thickness** 半值厚度.

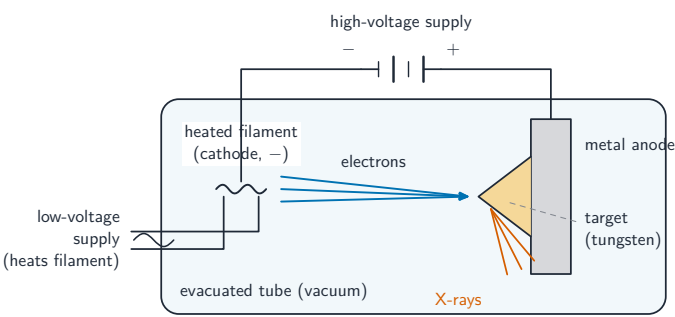
You must be able to:

- explain how X-rays are produced by electron bombardment, and calculate the minimum wavelength from the accelerating p.d.
- state which control sets the **intensity** of the beam and which sets its **hardness**, and why
- use $I = I_0 e^{-\mu x}$, including through **layers** of different materials, and use the half-value thickness
- distinguish **sharpness** from **contrast**, and state what improves each

1 Worked examples

Study these first. Each one shows a **method** that a question later on this sheet needs.

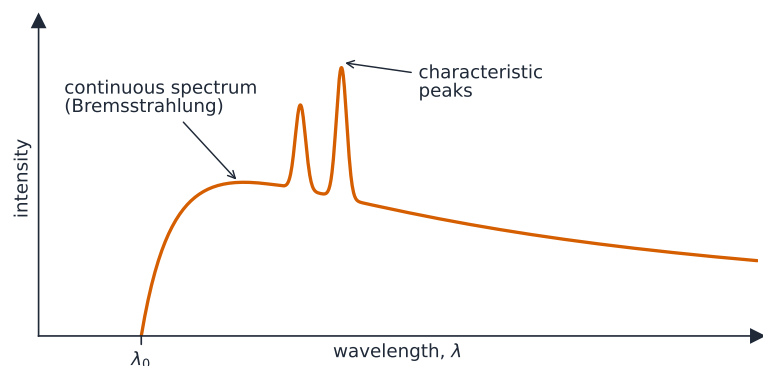
- The tube has two controls, and they do different jobs



Electrons are released from a **heated filament**, accelerated through a large **p.d.**, and stopped suddenly by a metal **target**. Most of their kinetic energy becomes heat, which is why the target is cooled; a small fraction becomes X-ray photons.

Control	Sets	Why
filament current	the intensity	a hotter filament emits more electrons per second , so more photons per second
accelerating p.d.	the hardness (penetrating power)	a larger p.d. gives each electron more energy, so higher-energy, shorter-wavelength photons

- Swapping these two round is the commonest error in the topic. The p.d. does **not** set the intensity, and the filament current does **not** set the hardness.
- A metal **filter** is placed in the beam to absorb the softest X-rays, which would be absorbed in the patient's skin without ever reaching the detector, adding dose but no information.



X-ray: continuous bremsstrahlung + characteristic peaks

The spectrum stops abruptly at a **minimum wavelength**, which is the case where an electron gives up **all** its kinetic energy in a single collision:

$$eV = \frac{hc}{\lambda_{\min}} \Rightarrow \lambda_{\min} = \frac{hc}{eV}$$

Worked example. Find $\lambda_{\min}$ for a tube at 50 kV.

$$\lambda_{\min} = \frac{(6.63 \times 10^{-34})(3.00 \times 10^8)}{(1.60 \times 10^{-19})(50 \times 10^3)} = \mathbf{2.5 \times 10^{-11} \text{ m}}$$

- $\lambda_{\min}$ depends **only** on the p.d., not on the target material or the current. Doubling the p.d. halves it.

■ Attenuation, layers, and the half-value thickness

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

Worked example. A beam passes through 2.8 cm of a material with $\mu = 1.4 \text{ cm}^{-1}$. What fraction is absorbed?

$$\frac{I}{I_0} = e^{-1.4 \times 2.8} = e^{-3.92} = 0.020$$

So 2.0% is transmitted and **98%** is absorbed.

- Read the question twice: "absorbed" is $1 - I/I_0$, not I/I_0 .
- Keep μ and x in the **same** units. A μ in cm^{-1} needs x in cm.

Through layers, the exponents **add**, because each layer attenuates what the previous one passed on:

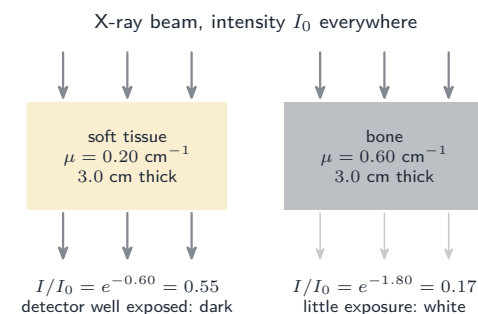
$$\frac{I}{I_0} = e^{-(\mu_1 x_1 + \mu_2 x_2)}$$

The **half-value thickness** is the thickness that halves the intensity:

$$x_{1/2} = \frac{\ln 2}{\mu}$$

Here $x_{1/2} = 0.693/1.4 = 0.50 \text{ cm}$, so 2.8 cm is 5.6 half-value thicknesses and $(1/2)^{5.6} = 0.020$ – the same answer, and a useful check.

■ Sharpness and contrast are different things



contrast comes from the difference in μ : the two exposures differ by a factor of 3

- **Contrast** is the difference in **degree of blackening** between neighbouring regions. It comes from a difference in μ – bone attenuates far more than soft tissue, so it shows white against grey. Contrast is improved by choosing a p.d. that maximises the difference in attenuation, or by using a **contrast medium** such as barium, whose large μ makes a soft-tissue organ visible at all.
- **Sharpness** is how well **defined the edges** are. It is improved by a **small** X-ray source (a small spot on the target), a **stationary** patient, and the detector **close** to the patient.
- **The two are independent.** An image can be sharp with poor contrast, or high in contrast but blurred. A question naming one is not asking about the other.

2 Practice

Now use the methods above.

2.1 State which control of an X-ray tube sets the **intensity** of the beam, and which sets its **hardness**. [2]

2.2 Calculate the minimum wavelength of the X-rays from a tube operating at 80 kV. [3]

2.3 State what is meant by the **half-value thickness**, and write it in terms of μ . [2]

2.4 State the difference between the **sharpness** and the **contrast** of an X-ray image. [2]

2.5 State why a metal filter is placed in the beam leaving an X-ray tube. [2]

3 Exam-style questions

3.1 An X-ray beam passes through 2.8 cm of tissue for which $\mu = 1.4 \text{ cm}^{-1}$.

(a) Calculate the percentage of the incident intensity that is **absorbed**. [3]

(b) Calculate the half-value thickness of this tissue, and use it to check your answer to (a). [3]

3.2 A beam passes through 1.5 cm of bone ($\mu = 2.9 \text{ cm}^{-1}$) and then 4.0 cm of soft tissue ($\mu = 0.20 \text{ cm}^{-1}$).

Calculate the fraction of the incident intensity that emerges. [4]

3.3 Explain why bone appears white and soft tissue grey on an X-ray image, and state what is meant by the **contrast** of the image. [3]

3.4 State **two** changes to the apparatus that would improve the **sharpness** of an X-ray image, and explain why each works. [4]

3.5 Computed tomography (CT) scanning produces a 3D image of an **internal** structure: **multiple** X-ray images of the same section are taken from different angles and combined to **obtain** a 2D image of that section, and the process is repeated along an axis so that the 2D images of many sections can be combined.

(a) State **two** advantages of a CT image over a single X-ray image of the same body part. [2]

(b) State **one** disadvantage, and explain it. [2]

3.6 A radiographer increases the accelerating p.d. of an X-ray tube.

State the effect on the minimum wavelength, on the penetrating power of the beam, and on the intensity. [3]
