Solutions

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

2.1

- the **filament current** sets the intensity: a hotter filament releases more electrons per second
- the **accelerating p.d.** sets the hardness: a larger p.d. gives each electron more energy and so produces higher-energy, more penetrating photons

2.2

- $\lambda_{\text{min}} = hc/(eV)$
- $= (6.63 \times 10^{-34})(3.00 \times 10^{8}) \div (1.60 \times 10^{-19} \times 80 \times 10^{3})$
- $= \mathbf{1.6 \times 10^{-11}}$ m

2.3

- the **thickness** of a material that reduces the intensity of the beam to **half** its incident value
- $x_{1/2} = \ln 2/\mu$, or $0.693/\mu$

2.4

- **sharpness** is how well **defined the edges** of structures are in the image
- **contrast** is the difference in **degree of blackening** between neighbouring regions, which comes from a difference in attenuation

2.5

- it absorbs the **softest** (lowest-energy, longest-wavelength) X-rays
- those would be absorbed in the patient's skin without reaching the detector, so they add to the radiation dose without contributing to the image

3.1

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

- $= 0.020$, so 2.0% is transmitted
- the percentage **absorbed** is $100 - 2.0 = \mathbf{98}$%
- quoting 2.0% answers the opposite question

(b) $x_{1/2} = \ln 2/\mu = 0.693/1.4 = \mathbf{0.50}$ cm

- 2.8 cm is $2.8/0.50 = 5.6$ half-value thicknesses, and $(1/2)^{5.6} = 0.020$, which agrees with (a)

3.2

- the exponents add, because each layer attenuates what the one before it transmitted
- bone: $\mu x = 2.9 \times 1.5 = 4.35$
- tissue: $\mu x = 0.20 \times 4.0 = 0.80$, giving a total of 5.15

- $I/I_0 = e^{-5.15} = \mathbf{5.8 \times 10^{-3}}$
- multiplying the two thicknesses, or averaging the two μ values, is the error this question is set to catch

3.3

- bone has a much **larger attenuation coefficient** than soft tissue, so far less of the beam passes through it
- less radiation reaches the detector behind bone, so that region is **less blackened** and appears white, while more passes through soft tissue and blackens the image there
- the **contrast** is the difference in degree of blackening between neighbouring regions of the image

3.4 any two, each with its reason:

- use a **smaller** X-ray source – a smaller spot on the target – so that the edge of a structure casts a narrower penumbra
- keep the **patient still**, since any movement during the exposure blurs every edge
- place the **detector close to the patient**, which reduces the geometric spreading of the beam between the structure and the image
- a **contrast medium** is not accepted here: it improves contrast, not sharpness

3.5

(a) any two: a CT image shows a **cross-section**, so structures are not superimposed on one another as they are in a single X-ray

- it has much better **contrast between soft tissues**, because each voxel's attenuation is computed from many views rather than from one; and the image can be rotated and viewed as a three-dimensional structure or as any chosen slice

(b) the **radiation dose** is much higher

- because many exposures are taken from many angles for each section, and the process is repeated for every section along the axis; the scan also takes longer and the equipment is far more expensive

3.6

- the minimum wavelength **decreases**, since $\lambda_{\text{min}} = hc/(eV)$ and V has increased
- the beam becomes **more penetrating**, because the photons have higher energy: it is harder
- the **intensity** also rises somewhat, because each electron delivers more energy, but the intensity is **controlled** by the filament current, not by the p.d.