inkPhysics

ANSWER BOOK

X-rays and CT scanning

Medical physics · Year 13

AQA 3.10.5.1, 3.10.5.2, 3.10.5.3, 3.10.5.4 · CIE 24.2.1, 24.2.2, 24.2.3, 24.2.4
OCR A 6.5.1(a), 6.5.1(b), 6.5.1(c), 6.5.1(d), 6.5.1(e), 6.5.1(f), 6.5.1(g)

19 questions · 53 marks

NAVY EDITION

SECTION A · Warm-up

A1 Electrons are released from a heated cathode by thermionic emission (1) and accelerated through a large pd towards a metal target (1). When they decelerate rapidly in the target, part of their kinetic energy is radiated as X-ray photons; most of the rest becomes heat in the target (1). [3]

A2 $E_{max} = eV = 1.60 \times 10^{-19} \times 65\,000$ (1) [2]
$E_{max} = 1.04 \times 10^{-14}$ J; no photon can carry more energy than one electron brought across the tube (1)

A3 $I = I_0 e^{-\mu x}$ (1), where I_0 is the incident intensity, I the intensity after passing through thickness x of material, and μ the attenuation coefficient of that material (1). [2]

A4 So that the electrons do not collide with gas molecules on the way to the target, and arrive carrying the full energy eV gained from the accelerating pd (1). [1]

A5 Most electrons are not stopped in a single event but decelerate in several stages in the target (1). Each stage radiates a photon carrying only part of that electron's energy, so the spectrum fills in below eV (1). [2]

SECTION B · Standard

B1 $E_{max} = eV = 1.60 \times 10^{-14}$ J (1) [3]
$\lambda_{min} = hc/E_{max} = (6.63 \times 10^{-34} \times 3.00 \times 10^{8})/(1.60 \times 10^{-14})$ (1)
$\lambda_{min} = 1.24 \times 10^{-11}$ m $\approx 1.2 \times 10^{-11}$ m (1)

B2 $I/I_0 = e^{-\mu x}$ (1) [3]
$= e^{-0.21 \times 4.0}$ (1)
= 0.43, about 43% (1)

B3 Raising the voltage raises the maximum photon energy, making the beam more penetrating, or harder (1). Raising the current increases the number of electrons per second, so more photons are produced and the beam is more intense, with the photon energies unchanged (1). [2]

B4 $e^{-\mu x} = 0.5$ (1) [3]
$x = \ln 2/\mu = 0.693/0.60$ (1)
x = 1.2 cm (1)

B5 Contrast comes from differences in attenuation coefficient. Bone's μ is much larger than soft tissue's, so bone transmits far less intensity and throws a sharp shadow (1). Neighbouring soft tissues have similar μ and transmit almost equally, so they are nearly indistinguishable (1). A contrast medium such as a barium compound is a strong absorber swallowed into the organ, painting its outline into the image (1). [3]

B6 $e^{-\mu x} = 0.35$ (1). $\mu = \ln(1/0.35)/x = 1.05/2.5$ (1) $= 0.42\ \text{cm}^{-1}$ (1). [3]

B7 It needs far less exposure than film, so the patient receives a smaller dose (1). The digital image can be enhanced and shared immediately (1). [2]

B8 Pair production needs a photon of at least 1.02 MeV, twice the rest energy of an electron (1). A 90 kV tube produces photons of at most 90 keV, far below this threshold, so no pair production occurs (1). (Board note: naming the attenuation mechanisms is an OCR requirement; AQA asks for differential tissue absorption while excluding the details of the absorption processes, so treat this as extension for AQA.) [2]

SECTION C · Stretch

C1 [3]

$e^{-\mu x} = 0.1$ (1)

$x = \ln 10/\mu = 2.303/0.35$ (1)

$x = 6.6$ cm (1)

C2 The X-ray tube and detectors rotate around the patient, measuring attenuation along very many directions through one slice (1). A computer reconstructs the map of attenuation coefficient across the slice that is consistent with all the measurements, giving a cross-sectional image; stacked slices give three dimensions (1). Advantage: structures are not superimposed, and soft tissues can be distinguished (1). Disadvantage: many exposures give a much larger radiation dose than a single film (1). [4]

C3 [3]

$E_{max} = eV = 1.60 \times 10^{-19} \times 120\ 000 = 1.92 \times 10^{-14}$ J (1)

Electrons per second $= I/e = 2.0 \times 10^{-3}/(1.60 \times 10^{-19})$ (1)

$= 1.25 \times 10^{16}\ \text{s}^{-1}$ (1)

C4 It becomes heat in the target: only around one per cent of the electron energy is radiated as X-rays (1). The anode is made of tungsten, whose very high melting point tolerates the heating (1), and it is rotated so that the electron beam spreads its heating over a ring of material rather than boring into one spot (1). [3]

C5 Path missing the gut: $I/I_0 = e^{-0.20 \times 5.0} = 0.37$ (1). Path through the barium: $I/I_0 = e^{-(0.20 \times 4.0 + 3.0 \times 1.0)} = e^{-3.8} = 0.022$ (1). The transmitted intensities differ by a factor of about 16 (1). Rays crossing the gut arrive far weaker than their neighbours, so its outline stands out clearly: the barium meal does give useful contrast (1). [4]

C6 Simple scatter removes photons at the lowest photon energies (1). The photoelectric effect, in which a photon is absorbed and an electron ejected, is strongest at the lower diagnostic energies (1). Its strength climbs steeply with atomic number, so bone absorbs far more strongly than soft tissue: this is the source of bone contrast (1). Compton scattering, in which a photon scatters off an electron and loses part of its energy, dominates across most of the diagnostic range (1). Pair production needs photons above 1.02 MeV, so it is absent from diagnostic beams (1). (Board note: OCR asks for these mechanisms by name; AQA asks for differential tissue absorption while excluding the details of the absorption processes, so treat the mechanism list as extension for AQA.) [5]