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ANSWER BOOK

Ultrasound imaging

Medical physics · Year 13

AQA 3.10.4.1, 3.10.4.2, 3.10.4.3 · CIE 24.1.1, 24.1.2, 24.1.3, 24.1.4, 24.1.5, 24.1.6
OCR A 6.5.3(a), 6.5.3(b), 6.5.3(c), 6.5.3(d), 6.5.3(e), 6.5.3(f), 6.5.3(g)

21 questions · 62 marks

NAVY EDITION

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SECTION A · Warm-up

A1 To generate: an alternating pd applied across the crystal makes it deform and vibrate at the driving frequency, launching an ultrasound pulse (1). To detect: a returning echo deforms the crystal, which produces a measurable pd across it (1). [2]

A2 $d = ct/2 = (1540 \times 90 \times 10^{-6})/2$, the factor of two accounting for the there-and-back journey (1)
$d = 6.9 \times 10^{-2}$ m ≈ 6.9 cm (1) [2]

A3 Acoustic impedance is the product of the density of a medium and the speed of sound in it: $Z = \rho c$ (1). Its unit is kg m^{-2} s^{-1} (1). [2]

A4 Use of $\lambda = c/f$ (1). $\lambda = 1540/(3.0 \times 10^6) = 5.1 \times 10^{-4}$ m = 0.51 mm (1). [2]

A5 Rearranging $Z = \rho c$ gives $c = Z/\rho = 7.8 \times 10^6/1900$ (1) = 4105 m s^{-1} ≈ 4.1×10^3 m s^{-1} (1). [2]

SECTION B · Standard

B1 $Z = \rho c = 1075 \times 1590$ (1) [2]
$Z = 1.71 \times 10^6$ kg m^{-2} s^{-1}, to the three significant figures the speed of sound carries (1)

B2 $t = 2d/c = 2 \times 0.035/1540$ (1) [3]
t = 45 µs (1)
If a new pulse left before the deepest echoes of the last one arrived, the scanner could not tell which pulse an echo belonged to, and depths would be assigned wrongly (1)

B3 An A-scan plots echo strength against time along a single line through the body, giving depths along that one direction (1). A B-scan sweeps the beam and turns each echo into a brightness point, building a two-dimensional image of the boundaries (1). [2]

B4 $I_r/I_0 = (Z_2 - Z_1)^2/(Z_2 + Z_1)^2$ (1) [3]
$= (0.07/3.33)^2$ (1)
$= 4.4 \times 10^{-4}$, about 0.04% (1)

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B5 Air's acoustic impedance is thousands of times smaller than tissue's (1), so at an air-skin boundary the impedance mismatch is enormous and nearly all the intensity reflects before entering the body (1). The gel displaces the air with a medium whose impedance is close to that of tissue, so the pulse is transmitted rather than reflected at the surface (1). [3]

B6 Listening time per pulse = 1/5000 = 200 μs (1). Evidence of use of $d = ct/2$ for the deepest echo (1). $d = (1540 \times 200 \times 10^{-6})/2 = 15.4$ cm ≈ 15 cm (1). [3]

B7 Only depths along a single line through the eye are needed, not a two-dimensional image (1). An A-scan gives exactly this: the echo times along one direction convert directly to the distances of the eye's surfaces (1). [2]

B8 Protons tipped out of line by the radio-frequency pulse relax back into line with the field, re-emitting a radio signal (1). The relaxation time depends on the tissue the protons sit in, so soft tissues that attenuate X-rays almost identically still return distinguishable signals, giving fine soft-tissue contrast (1). MR uses no ionising radiation, so this detail costs the patient no dose (1). (Board note: the relaxation-time step is extension for AQA, whose specification states that de-excitation relaxation times will not be examined.) [3]

SECTION C · Stretch

C1 $I_r/I_0 = ((1.63 \times 10^6 - 430)/(1.63 \times 10^6 + 430))^2$ (1) [3]
$= 0.9989 \approx 0.999$ (1)
Nearly everything reflects, which is exactly why an air gap makes imaging impossible and why the gel must exclude it (1)

C2 Front surface: $d = ct/2 = (1540 \times 52 \times 10^{-6})/2$ (1) [4]
$= 4.0$ cm (1)
Back surface: $d = (1540 \times 78 \times 10^{-6})/2 = 6.0$ cm (1)
Thickness = 2.0 cm ≈ 2.0 cm (1)

C3 Higher frequency means shorter wavelength, so finer detail can be resolved, which argues for high frequency (1). But attenuation in tissue increases with frequency, so a high-frequency pulse fades before reaching deep structures (1). The choice is a trade: high frequency for shallow, detailed work such as eye measurements, lower frequency for deep organs (1). [3]

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C4 Ultrasound is non-ionising, so it carries no radiation dose to the foetus (1), and it images in real time, showing movement (1). A limitation: it cannot image through bone or air-filled spaces, since the impedance mismatch reflects the pulse, so structures behind the skull or lungs are hidden (1). [3]

C5 Evidence of use of $I_r/I_0 = (Z_2 - Z_1)^2/(Z_2 + Z_1)^2$ at the gel-skin boundary (1). Gel P: $(0.13/3.13)^2 = 0.17\%$ reflected (1). Gel Q: $(0.53/2.73)^2 = 3.8\%$ reflected (1). Gel P should be chosen: its impedance is closer to skin's, so about 99.8% of the intensity enters the patient against about 96% for gel Q (1). [4]

C6 Echo time $t = 2d/c = 2 \times 0.030/1450 = 41.4\ \mu s$ (1). The scanner converts this time with 1540 m s^{-1}: displayed depth = $(1540 \times 41.4 \times 10^{-6})/2$ (1) = 3.19 cm (1). The displayed depth is 1.9 mm too deep (1). [4]

C7 An alternating pd applied across the piezoelectric crystal makes it vibrate and emit a short ultrasound pulse (1). Coupling gel excludes air between the probe and the skin, so the pulse is transmitted into the body instead of reflecting at the surface (1). At each boundary between tissues of different acoustic impedance, part of the pulse reflects back as an echo (1). The returning echoes deform the same crystal, generating pds that the scanner records (1). The depth of each boundary follows from $d = ct/2$, the factor of two because the pulse travels there and back (1). Each echo is displayed as a spot whose brightness follows the echo strength, and sweeping the beam across the body builds these spots into a two-dimensional image of the boundaries (1). [6]

C8 (a) Ultrasound: it is non-ionising, so there is no dose to the foetus, and it images in real time (1). (b) MR: relaxation times differ between soft tissues, so it gives the finest soft-tissue contrast, again with no ionising dose (1). (c) CT, because MR is ruled out: the device is MR Unsafe, so the scanner's strong magnetic field could disturb or damage it. (A modern MR Conditional pacemaker can be scanned under controlled protocols, which is why the safety labelling, not the pacemaker itself, decides.) (1) CT still resolves the brain's soft tissue well enough to diagnose, and it is fast, at the price of an X-ray dose (1). [4]

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