Past-paper walk-through

Production and use of ultrasound ▪ 24.1

eXercise

Questions in this set

- 9702/41 N25 Q10 ▪ 8 marks
- 9702/44 J25 Q10 ▪ 9 marks
- 9702/43 J23 Q8 ▪ 8 marks
- 9702/42 M23 Q9 ▪ 9 marks

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 10

9702/41 N25 ▪ Q10 ▪ 8 marks

(a) Define specific acoustic impedance. **[2]**

(b) Explain how ultrasound waves are detected by a piezoelectric crystal. **[2]**

(c)(i) Calculate the intensity reflection coefficient for ultrasound incident on a water–steel boundary. **[2]**

(c)(ii) Explain, without calculation, what is likely to happen when ultrasound is incident on a body tissue–water boundary. **[2]**

Question 10

material	Z / kg m^{-2} s^{-1}
body tissue	1.38×10^{6}
water	1.48×10^{6}
steel	4.04×10^{7}

Solution 10

(a)

Mark scheme

- product of density and speed **M1**
- speed of sound in medium (and density of the medium) **A1**

Solution 10

(b)

Mark scheme

- ultrasound waves cause crystal to vibrate **B1**
- vibrations (of crystal) cause induced e.m.f. (across crystal) **B1**

Solution 10

(c)(i) Worked steps

- Intensity reflection coefficient: $\frac{I_R}{I_0} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$.
- $= \frac{(40.4 - 1.48)^2}{(40.4 + 1.48)^2}$
- $= 0.86$

Solution 10

The impedances may be left in units of 10^6 throughout, because the formula is a ratio — the powers of ten cancel. And a coefficient of 0.86 says 86% of the intensity comes straight back, which is exactly why a gel is used to couple a probe to skin.

Mark scheme

- intensity reflection coefficient $= (40.4 - 1.48)2 \ / \ (40.4 + 1.48)2$ **C1**
- $= 0.86$ **A1**

Solution 10

(c)(ii)

Mark scheme

- Z values are very similar **B1**
- (almost) all the ultrasound will be transmitted or
- (almost) none of the ultrasound will be reflected **B1**

Question 10

9702/44 J25 ▪ Q10 ▪ 9 marks

10 **(a)** Describe how the piezoelectric crystal in a transducer generates ultrasound waves for use in medical diagnosis.

Question 10

(b) A parallel ultrasound beam is incident on the boundary between two media, as illustrated in Fig. 10.1.

Question 10

specific acoustic impedance Z_1

specific acoustic impedance Z_2

Fig. 10.1

The media have specific acoustic impedances Z_1 and Z_2.

At the boundary, a fraction α of the incident intensity of the ultrasound beam is reflected. The remainder is transmitted.

(i) State what is meant by specific acoustic impedance.

Question 10

(ii) Describe how α depends on the relative values of Z_1 and Z_2.

Question 10

(c) A parallel ultrasound beam of intensity I_0 enters a region of soft tissue. After passing a distance of 2.1 cm through this tissue, the intensity of the ultrasound is $0.62\,I_0$.

Calculate the linear attenuation coefficient μ of ultrasound in the soft tissue. Give a unit with your answer.

Question 10

[Total: 9]

Solution 10

(a)

Mark scheme

- alternating p.d. (applied to crystal) makes crystal vibrate
- when frequency of applied p.d. equals natural frequency of crystal, crystal resonates
- natural frequency of crystal is in ultrasound range

Solution 10

(b)(i)

Mark scheme

- product of density and speed
- speed is speed of ultrasound in medium (and density of medium)

(b)(ii)

Mark scheme

- (α is close to) 0 when Z1 and Z2 are equal
- (α is close to) 1 when Z1 and Z2 are very different

Solution 10

(c) Worked steps

Attenuation through a thickness of tissue is exponential, so take logs.

- $I = I_0 e^{-\mu x}$, so $\ln\left(\frac{I}{I_0}\right) = -\mu x$.
- $\ln 0.62 = -\mu \times 2.1$, and $\ln 0.62 = -0.478$.
- $\mu = \frac{0.478}{2.1} = 0.23\ \text{cm}^{-1}$

Solution 10

The unit comes from the thickness: centimetres in, so per centimetre out. Take the **natural** log, not $\log_{10}$ — using base 10 gives 0.10 and is the standard error here.

Solution 10

μ is a property of the tissue at that frequency, so a larger value means a more strongly absorbing tissue: bone attenuates far more than soft tissue, which is why ultrasound images poorly through it.

Mark scheme

- $I = I0 \exp(-\mu x)$
- $\ln (I / I0) = - \mu x$
- $\ln 0.62 = - \mu \times 2.1$
- $\mu = 0.23$ cm–1
- 9702/44
- May/June 2025

Question 8

9702/43 J23 ▪ Q8 ▪ 8 marks

(a)(i) Show that the specific acoustic impedance of gel is 1.68×10^6 kg m^{-2} s^{-1}. **[1]**

(a)(ii) Complete Table 8.1 by calculating the missing values to three significant figures. Use the space below for any working that you need. **[2]**

(b)(i) an air–tissue boundary **[2]**

(b)(ii) a gel–tissue boundary. **[1]**

(c) Use your answers in (b) to explain why gel is applied to the skin during ultrasound scanning. **[2]**

Question 8

material	density / $kg\,m^{-3}$	speed of sound / $m\,s^{-1}$	specific acoustic impedance / $kg\,m^{-2}\,s^{-1}$
air		340	440
gel	1200	1400	
tissue	1090		1.68×10^{6}

Solution 8

(a)(i) Worked steps

Know. The specific acoustic impedance of a material is its density multiplied by the speed of sound in it. It measures how hard the material is to set vibrating.
Equation. $Z = \rho c$.
Substitute. $Z = 1200 \times 1400$.
Answer. $Z = 1.68 \times 10^6$ kg m^{-2} s^{-1}, as required.

Solution 8

Check. The unit follows from the equation: kg $m^{-3} \times$ m s^{-1} gives kg m^{-2} s^{-1}. It is worth writing out once, because a later part of this question asks for it.

Mark scheme

- specific acoustic impedance $= 1200 \times 1400 = 1.68 \times 10^6$ kg m^{-2} s^{-1}

Solution 8

(a)(ii) Worked steps

Know. The same relation $Z = \rho c$ fills either gap, depending on which two of the three quantities the table already gives.

Density of air. $\rho = \dfrac{Z}{c} = \dfrac{440}{340} = 1.29$ kg m^{-3}.

Speed in tissue. $c = \dfrac{Z}{\rho} = \dfrac{1.68 \times 10^6}{1090} = 1540$ m s^{-1}.

Solution 8

Check. Three significant figures are asked for, so 1.29 and 1540, not 1.3 and 1541.3. Both values are also worth a moment's thought: air is about a thousand times less dense than tissue, and sound travels about four times faster in tissue than in air.

Mark scheme

- density of air shown in table as 1.29
- speed of sound in tissue shown in table as 1540

Solution 8

(b)(i) Worked steps

Know. The fraction of the intensity reflected at a boundary depends on how different the two impedances are.

Equation. $\dfrac{I_R}{I_0} = \dfrac{(Z_1 - Z_2)^2}{(Z_1 + Z_2)^2}$.

Substitute. $\dfrac{(1\,680\,000 - 440)^2}{(1\,680\,000 + 440)^2}$.

Answer. 0.999.

Solution 8

Check. Almost **all** the ultrasound bounces off an air-tissue boundary, which is exactly why a scan through a layer of air shows nothing at all. Squaring both the top and the bottom matters: forgetting the squares gives 0.9995, which looks similar but is not the coefficient asked for.

Mark scheme

- intensity reflection coefficient $= (Z_1 - Z_2)^2/(Z_1 + Z_2)^2$
- $= (1680000 - 440)^2/(1680000 + 440)^2$
- $= 0.999$

Solution 8

(b)(ii) Worked steps

Know. The same equation, but here the two impedances are identical, because the gel was designed that way.

Substitute. $\dfrac{(1\,680\,000 - 1\,680\,000)^2}{(1\,680\,000 + 1\,680\,000)^2}$.

Answer. 0.

Solution 8

Check. Nothing is reflected, so all of the ultrasound crosses into the tissue. Put the two answers side by side and the reason for the gel is complete: it replaces a boundary that reflects 99.9% with one that reflects none.

Mark scheme

- intensity reflection coefficient $= (Z_1 - Z_2)^2/(Z_1 + Z_2)^2$
- $= (1680000 - 1680000)^2/(1680000 + 1680000)^2$
- $= 0$

Solution 8

(c)

Mark scheme

- without gel, (almost) all of the (incident) ultrasound is reflected (from skin)
- with gel, (almost) all of the (incident) ultrasound is transmitted (into the body)

Question 9

9702/42 M23 ▪ Q9 ▪ 9 marks

Ultrasound is used to produce diagnostic information about internal body structures.

(a) Explain how ultrasound waves are detected. **[3]**

(b)(i) V_0 **[1]**

(b)(ii) ω. **[1]**

(c)(i) Determine the unit for the specific acoustic impedance values shown in Table 9.1. **[1]**

(c)(ii) Calculate the density of soft tissue. **[1]**

(c)(iii) Use data from Table 9.1 to explain why ultrasound cannot be used to produce an image inside an air-filled cavity such as the lungs. **[2]**

Question 9

	density / $kg\,m^{-3}$	speed of ultrasound / $m\,s^{-1}$	specific acoustic impedance / ....
air	1.30	330	4.3×10^2
soft tissue		1600	1.7×10^6

Solution 9

(a)

Mark scheme

- piezo-electric crystal
- (ultrasound) wave causes shape change / vibrations (of crystal)
- shape change / vibrations causes e.m.f. (which is detected)

Solution 9

(b)(i)

Mark scheme

- 93V

(b)(ii)

Mark scheme

- 2.7×10^7 rad s^{-1}

Solution 9

(c)(i)

Worked steps

Know. Read the unit off the defining equation rather than trying to remember it.
Equation. $Z = \rho c$, and density is in kg m^{-3} while speed is in m s^{-1}.
Combine. kg m^{-3} $\times$ m s^{-1} $=$ kg m^{-2} s^{-1}.
Answer. kg m^{-2} s^{-1}.
Check. Deriving a unit from its equation works for any quantity in this course and is far safer than recalling it. Note that the units do **not** simplify to anything with a name, so leave the answer in this form.

Mark scheme

- kg m^{-2} s^{-1}

Solution 9

(c)(ii) Worked steps

Know. The table gives the impedance and the speed of sound, so rearranging $Z = \rho c$ gives the density.

Equation. $\rho = \dfrac{Z}{c}$.

Substitute. $\rho = \dfrac{1.7 \times 10^6}{1600}$.

Answer. $\rho = 1100 \text{ kg m}^{-3}$.

Solution 9

Check. Soft tissue should come out close to the density of water, 1000 kg m^{-3}, and it does. That is a useful sanity check throughout this topic, because the body is mostly water.

Mark scheme

- $\rho = Z/c = 1.7 \times 10^6/1600$
- $= 1100$ kg m^{-3}

Solution 9

(c)(iii)

Mark scheme

- intensity reflection coefficient ≈ 1 or Z_1 and Z_2 are very different
- almost no / no ultrasound transmitted (into air filled cavity)