24. Medical Physics

24.1 Production and use of ultrasound

Paper 4

Question Paper

1 **(a)** Describe how reflected ultrasound pulses may be used to obtain diagnostic information about internal structures.

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..... [2]

(b) **(i)** Define specific acoustic impedance of a medium.

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..... [2]

(ii) Table 10.1 shows some data for water and for glass.

Table 10.1

	density / kg m^{-3}	speed of sound / m s^{-1}
water	1000	1420
glass	2500	4560

Determine the intensity reflection coefficient for ultrasound that is incident on a water–glass boundary.

intensity reflection coefficient = ... [3]

2 **(a)** Table 8.1 shows some data relating to the properties of air, gel and body tissue. The data are given to three significant figures.

Table 8.1

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

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

[1]

(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) Use the information in **(a)** to calculate the intensity reflection coefficient for:

(i) an air–tissue boundary

intensity reflection coefficient = ... [2]

(ii) a gel–tissue boundary.

intensity reflection coefficient = ... [1]

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

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..... [2]

3 Ultrasound and X-rays are both types of wave that are used in medical diagnosis to form images of internal body structures.

(a) Complete Table 10.1 to state, for each type of wave:

- the method of production of the wave
- whether the wave that is detected and used to form the image is the wave that has been absorbed, reflected or transmitted by the internal body structure.

Table 10.1

	ultrasound	X-rays
method of production	....	....
detected wave (absorbed, reflected or transmitted)	.....	.....

[4]

4 **(b)** The alternating voltage in **(a)** is now applied to a piezoelectric crystal in air.

(i) Explain what happens to the air surrounding the crystal.

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..... [3]

(ii) A second piezoelectric crystal is placed in the air near to the first crystal.

Explain the effect of the surrounding air in **(b)(i)** on the second crystal.

..... [1]

5 Outline the **use** of ultrasound to obtain diagnostic information about internal body structures.

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..... [5]

6 **(a)** A piezoelectric transducer containing a quartz crystal is used to obtain diagnostic information about internal structures.

Describe the function of the quartz crystal.

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..... [3]

(b) **(i)** Define *specific acoustic impedance*.

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..... [2]

(ii) Describe, qualitatively, how the specific acoustic impedances of two materials affect the intensity reflection coefficient at a boundary between the materials.

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..... [2]

7 **(a)** **(i)** By reference to an ultrasound wave, explain what is meant by *specific acoustic impedance*.

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..... [2]

(ii) An ultrasound wave is incident normally on the boundary between two media. The media have specific acoustic impedances Z_1 and Z_2.

State how the ratio

$$\frac{\text{intensity of ultrasound reflected from boundary}}{\text{intensity of ultrasound incident on boundary}}$$

depends on the relative magnitudes of Z_1 and Z_2.

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..... [2]

(b) **(i)** State what is meant by the *attenuation* of an ultrasound wave.

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..... [1]

(ii) A parallel beam of ultrasound is passing through a medium.
The incident intensity I_0 is reduced to $0.35\,I_0$ on passing through a thickness of 0.046 m of the medium.

Calculate the linear attenuation coefficient μ of the ultrasound beam in the medium.

μ = ... m^{-1} [2]

8 **(a)** Explain the principles of the **detection** of ultrasound waves for medical diagnosis.

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(b) By reference to specific acoustic impedance, explain why there is very little transmission of ultrasound waves from air into skin.

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9 **(a)** Explain the principles of the **generation** of ultrasound waves for use in medical diagnosis.

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..... [4]

(b) The linear attenuation (absorption) coefficient for a parallel beam of ultrasound waves in air is $1.2\,\text{cm}^{-1}$.

The parallel beam passes through a layer of air of thickness 3.5 cm.

Calculate the ratio, in dB,

$$\frac{\text{intensity of beam after passing through the layer of air}}{\text{intensity of beam entering the layer of air}}.$$

ratio = ... dB [4]

10 (a) State what is meant by the *specific acoustic impedance* of a medium.

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.....[2]

(b) A parallel beam of ultrasound of intensity I_0 is incident on the boundary between two media A and B, as illustrated in Fig. 4.1.

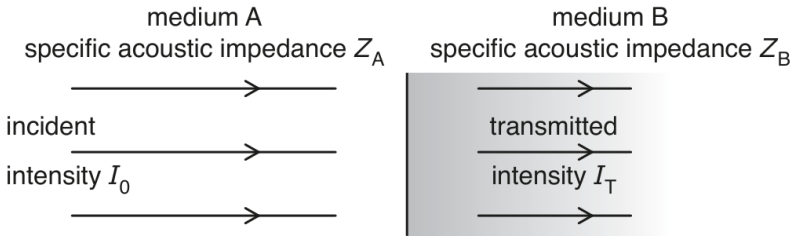


Fig. 4.1

The two media A and B have specific acoustic impedances Z_A and Z_B respectively. The intensity of the beam transmitted through the boundary is I_T.

State how the ratio

$$\frac{\text{intensity } I_T \text{ of transmitted beam}}{\text{intensity } I_0 \text{ of incident beam}}$$

depends on the relative magnitudes of Z_A and Z_B.

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.....[2]

(c) The linear absorption (attenuation) coefficient μ of medium B is $23\,m^{-1}$.

Calculate the thickness of medium B required to reduce the intensity of the ultrasound beam to 34% of its initial intensity in medium B.

thickness = ... m [3]

11 (a) (i) State what is meant by the *specific acoustic impedance* of a medium.

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..... [2]

(ii) The density of a sample of bone is $1.8\,g\,cm^{-3}$ and the speed of ultrasound in the bone is $4.1 \times 10^{3}\,m\,s^{-1}$.

Calculate the specific acoustic impedance Z_B of the sample of bone.

Z_B = ... $kg\,m^{-2}\,s^{-1}$ [1]

(b) A parallel beam of ultrasound passes normally through a layer of fat and of muscle, as illustrated in Fig. 5.1.

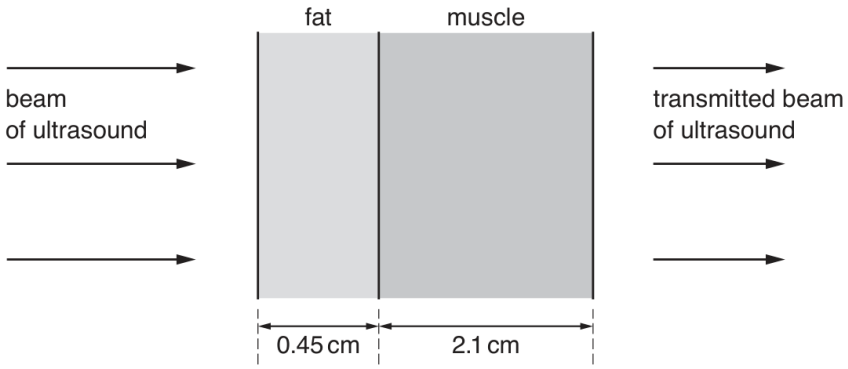


Fig. 5.1 (not to scale)

The fat has thickness 0.45 cm and the muscle has thickness 2.1 cm.

Data for fat and for muscle are given in Fig. 5.2.

	specific acoustic impedance $Z/10^6\,\text{kg m}^{-2}\,\text{s}^{-1}$	linear attenuation (absorption) coefficient μ/cm^{-1}
fat	1.3	0.24
muscle	1.7	0.23

Fig. 5.2

The intensity reflection coefficient α at a boundary between two media of specific acoustic impedances Z_1 and Z_2 is given by the expression

$$\alpha = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}.$$

Calculate the fraction of the intensity of the ultrasound that is **transmitted** through the boundary between the fat and the muscle.

fraction transmitted = ... [1]

(c) **(i)** State what is meant by *attenuation* of an ultrasound wave.

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..... [2]

(ii) Data for linear attenuation coefficients are given in Fig. 5.2.

Determine the ratio

$$\frac{\text{intensity of ultrasound transmitted through the medium}}{\text{intensity of ultrasound entering the medium}}$$

for:

1. the layer of fat of thickness 0.45 cm

ratio = ...

2. the layer of muscle of thickness 2.1 cm.

ratio = ...
[3]

(d) Use your answers in **(b)** and **(c)(ii)** to determine the fraction of the intensity entering the layer of fat that is transmitted through the layer of muscle.

fraction transmitted = ... [1]

12 Piezo-electric transducers are used for the generation of ultrasonic waves.

(a) State one other use, apart from in ultrasound, of piezo-electric transducers.

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.....[1]

(b) Explain the main principles behind the **use** of ultrasound to obtain diagnostic information about internal body structures.

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13 (a) Explain the main principles behind the **use** of ultrasound to obtain diagnostic information about internal body structures.

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.....[6]

(b) (i) Define *specific acoustic impedance*.

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.....[2]

(ii) The fraction of the incident intensity of an ultrasound beam that is reflected at a boundary between two media depends on the specific acoustic impedances Z_1 and Z_2 of the media.

Discuss qualitatively how the relative magnitudes of the two specific acoustic impedances affect the reflected intensity.

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.....[2]