A-LEVEL PHYSICS • EXERCISE SHEET

24.1 Production and use of ultrasound

Name: ____________ Class: ________ Date: __________ **Total: 25 marks**

KEY WORDS ultrasound 超声波 • specific acoustic impedance 声阻抗 • transducer 换能器 • intensity reflection coefficient 强度反射系数 • piezo-electric 压电

Objective

Build the skills to answer exam questions on **ultrasound** in medicine.

You must be able to:

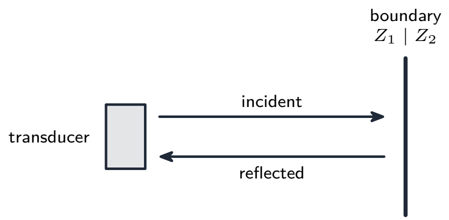
- explain the **piezo-electric** transducer (send and detect)
- use **acoustic impedance** $Z = \rho c$ and the **reflection coefficient**
- use the attenuation $I = I_0 e^{-\mu x}$

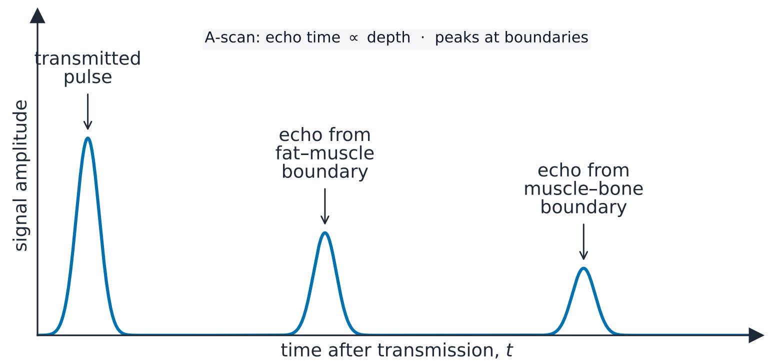
1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Transducer and pulse-echo

A **piezo-electric** crystal changes shape when a p.d. is applied (to **emit** ultrasound) and produces an e.m.f. when squeezed (to **detect** it) — so one transducer both sends and receives. A pulse partly **reflects** at a boundary between tissues:





An ultrasound A-scan trace

$$Z = \rho c, \qquad \frac{I_R}{I_0} = \frac{(Z_1 - Z_2)^2}{(Z_1 + Z_2)^2}, \qquad I = I_0 e^{-\mu x}.$$

A large impedance **mismatch** reflects strongly — which is why a **coupling gel** removes the air gap (air's Z is very different).

2 Practice

Now apply the methods above.

2.1 Describe the **piezo-electric effect**. [2]

2.2 Define the **specific acoustic impedance** of a medium. [1]

2.3 Explain how **one** transducer can both send and detect ultrasound. [2]

2.4 Write the equation for the **attenuation** of ultrasound. [1]

3 Exam-style questions

3.1 For a **strong** reflection at a tissue boundary, the two acoustic impedances must be: [1]

- **A** equal
- **B** very different
- **C** both zero
- **D** both very large

3.2 Calculate the intensity reflection coefficient for a boundary where $Z_1 = 1.6 \times 10^6$ and $Z_2 = 1.7 \times 10^6$ (SI units). [3]

3.3 Explain why a **coupling gel** is used between the transducer and the skin. [2]

3.4 Ultrasound of intensity I_0 passes through 5.0 cm of tissue with $\mu = 23\ \mathrm{m^{-1}}$. Calculate I/I_0. [2]

3.5 An ultrasound scanner sends a pulse into a patient. The specific acoustic impedance of soft tissue is $1.63 \times 10^6\ \mathrm{kg\ m^{-2}\ s^{-1}}$, of bone $6.40 \times 10^6\ \mathrm{kg\ m^{-2}\ s^{-1}}$ and of air $4.29 \times 10^2\ \mathrm{kg\ m^{-2}\ s^{-1}}$.

(a) **Define specific acoustic impedance**. [1]

(b) **Explain** how a piezoelectric crystal **detects** the reflected ultrasound. [2]

(c) **Determine** the intensity reflection coefficient at a soft tissue-bone boundary. [3]

(d) **Determine** the intensity reflection coefficient at a soft tissue-air boundary, and **explain** why a gel is smeared on the skin before a scan. [3]

(e) The pulse returns from a boundary 9.6 cm deep after 1.2×10^{-4} s. **Determine** the speed of ultrasound in the tissue. [2]

Solutions

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

2.1

- applying a p.d. across the crystal makes it **change shape**
- changing its shape makes it produce an **e.m.f.**

2.2

- $Z = \rho c$, the product of the medium's density and the speed of sound in it

2.3

- an alternating p.d. makes the crystal **vibrate**, emitting ultrasound
- a returning pulse makes it vibrate and produce an **e.m.f.**, which is detected

2.4

- $I = I_0 e^{-\mu x}$

3.1 B

- a large reflection when the two impedances are **very different**

3.2

- $I_R/I_0 = (Z_2 - Z_1)^2/(Z_2 + Z_1)^2$

$$\frac{I_R}{I_0} = \frac{(1.6 - 1.7)^2}{(1.6 + 1.7)^2} = \frac{(0.1)^2}{(3.3)^2} = \mathbf{9.2 \times 10^{-4}}$$

3.3

- without gel there is an **air gap**, whose acoustic impedance is very different from skin
- so almost all the ultrasound would be reflected; the gel removes the air gap so the ultrasound enters the body

3.4

- $I/I_0 = e^{-\mu x}$

$$\frac{I}{I_0} = e^{-(23\ \mathrm{m}^{-1})(0.050\ \mathrm{m})} = e^{-1.15} = \mathbf{0.32}$$

3.5

(a) the product of the **density** of the medium and the **speed of sound** in it, $Z = \rho c$

(b) the reflected wave's pressure variation makes the crystal **change shape**

- a piezoelectric crystal produces a **potential difference** across its faces when it is deformed, giving an electrical signal that varies with the received wave

(c) $I_R/I_0 = (Z_2 - Z_1)^2/(Z_2 + Z_1)^2$

$$\frac{I_R}{I_0} = \frac{(6.40 - 1.63)^2}{(6.40 + 1.63)^2} = \frac{22.8}{64.5} = \mathbf{0.35}$$

(d) with air

$$\frac{(1.63 \times 10^6 - 429)^2}{(1.63 \times 10^6 + 429)^2} \approx \mathbf{0.999}$$

- essentially **all** the ultrasound is reflected at a skin-air boundary; gel excludes the air layer and has an impedance close to that of skin, so the pulse actually enters the body

(e) the pulse travels **there and back**, a distance of 2×0.096 m $= 0.192$ m

$$c = \frac{0.192\ \mathrm{m}}{1.2 \times 10^{-4}\ \mathrm{s}} = \mathbf{1.6 \times 10^3}\ \mathrm{m\ s^{-1}}$$