

1. Fig. 1 shows data for the intensity of a parallel beam of X-rays after penetration through varying thicknesses of a material.

| intensity / MW m^{-2} | thickness / mm |
|--------------------------------|----------------|
| 0.91 | 0.40 |
| 0.69 | 0.80 |
| 0.52 | 1.20 |
| 0.40 | 1.60 |
| 0.30 | 2.00 |
| 0.23 | 2.40 |
| 0.17 | 2.80 |

Fig. 1

- (a) On Fig. 2 plot a graph of transmitted X-ray intensity against thickness of absorber.

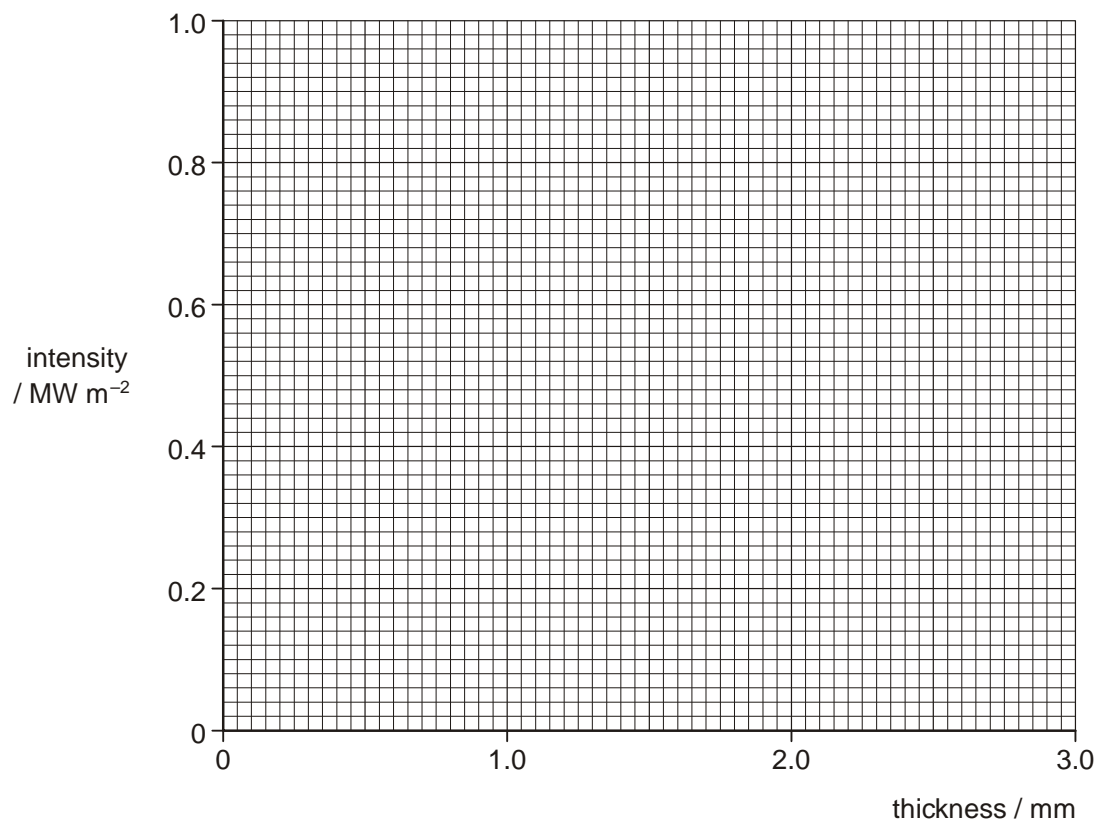


Fig. 2

- (b) (i) Find the thickness that reduces the intensity of the incident beam by one half.

thickness = mm

[1]

- (ii) Use your answer to (b)(i) to calculate the linear attenuation coefficient μ . Give the unit for your answer.

$\mu = \dots\dots\dots$ unit $\dots\dots\dots$

[4]

[Total 8 marks]

2. The quality of ultrasound images is increasing at a phenomenal pace, thanks to advances in computerised imaging techniques. The computer technology is sophisticated enough to monitor and display tiny ultrasound signals from a patient.

The ratio of reflected intensity to incident intensity for ultrasound reflected at a boundary is related to the acoustic impedance Z_1 of the medium on one side of the boundary and the acoustic impedance Z_2 of the medium on the other side of the boundary by the following equation.

$$\frac{\text{reflected intensity}}{\text{incident intensity}} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$$

- (a) State **two** factors that determine the value of the acoustic impedance.

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[2]

- (b) An ultrasound investigation was used to identify a small volume of substance in a patient. It is suspected that this substance is either blood or muscle.

During the ultrasound investigation, an ultrasound pulse of frequency of 3.5×10^6 Hz passed through soft tissue and then into the small volume of unidentified substance. A pulse of ultrasound reflected from the front surface of the volume was detected $26.5 \mu\text{s}$ later. The ratio of the reflected intensity to the incident intensity, for the ultrasound pulse reflected at this boundary was found to be 4.42×10^{-4} . The table below shows data for the acoustic impedances of various materials found in a human body.

| medium | acoustic impedance $Z / \text{kg m}^{-2} \text{ s}^{-1}$ |
|--------------|--|
| air | 4.29×10^2 |
| blood | 1.59×10^6 |
| water | 1.50×10^6 |
| brain tissue | 1.58×10^6 |
| soft tissue | 1.63×10^6 |
| bone | 7.78×10^6 |
| muscle | 1.70×10^6 |

- (i) Use appropriate data from the table above to identify the unknown medium. You must show your reasoning.

medium =

[4]

- (ii) Calculate the depth at which the ultrasound pulse was reflected if the speed of ultrasound in soft tissue is 1.54 km s^{-1} .

depth = cm

[2]

(iii) Calculate the wavelength of the ultrasound in the soft tissue.

wavelength =m

[2]

[Total 10 marks]

3. An average person in the UK will have at least 30 X-ray photographs taken in their lifetime.

In order to take an X-ray photograph, the X-ray beam is passed through an aluminium filter to safely remove low energy X-ray photons before reaching the patient.

(a) Suggest why it is necessary to remove these low energy X-rays.

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[1]

- (b) The average linear attenuation coefficient for X-rays that penetrate the aluminium is 250 m^{-1} .
The intensity of an X-ray beam after travelling through 2.5 cm of aluminium is 347 W m^{-2} .

Show that the intensity incident on the aluminium is about $2 \times 10^5 \text{ W m}^{-2}$.

[3]

- (c) The X-ray beam at the filter has a circular cross-section of diameter 0.20 cm. Calculate the power of the X-ray beam from the aluminium filter. Assume that the beam penetrates the aluminium filter as a parallel beam.

power = W

[2]

[Total 6 marks]

4. In order to take an X-ray photograph, the X-ray beam is passed through an aluminium filter to remove low energy X-ray photons before reaching the patient.

(a) Suggest why it is necessary to remove these low-energy X-rays.

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[1]

(b) The average linear attenuation coefficient for X-rays that penetrate the aluminium is 250 m^{-1} . The intensity of an X-ray beam after travelling through 2.5 cm of aluminium is 347 W m^{-2} .

Show that the intensity incident on the aluminium is about $2 \times 10^5 \text{ W m}^{-2}$.

[3]

- (c) The X-ray beam at the filter has a circular cross-section of diameter 0.20 cm. Calculate the power of the X-ray beam emerging from the aluminium filter. Assume that the beam penetrates the aluminium filter as a parallel beam.

power = W

[2]

- (d) The total power of X-rays generated by an X-ray tube is 18W. The efficiency of conversion of kinetic energy of the electrons into X-ray photon energy is 0.15%.
 - (i) Calculate the power of the electron beam.

power = W

[2]

- (ii) Calculate the velocity of the electrons if the rate of arrival of electrons is $7.5 \times 10^{17} \text{ s}^{-1}$. Relativistic effects may be ignored.

velocity = m s^{-1}

[2]

- (iii) Calculate the p.d. across the X-ray tube required to give the electrons the velocity calculated in **(ii)**.

p.d.= V

[3]

[Total 13 marks]

5. Full-body CT scans produce detailed 3-D information about a patient and can identify cancers at an early stage in their development.

(a) Describe how a CT scan image is produced, referring to the physics principles involved.

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[7]

(b) State and explain **two** reasons why full-body CT scans are not offered for regular checking of healthy patients.

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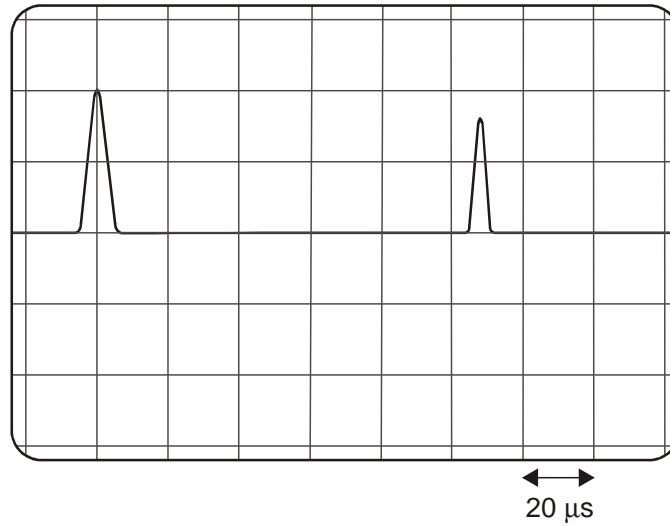
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[3]

[Total 10 marks]

6. The diagram below shows a trace on a cathode-ray oscilloscope (CRO) of an ultrasound reflection from the front edge and rear edge of a foetal head.



The CRO timebase is set to $20 \mu\text{s cm}^{-1}$. The speed of ultrasound in the foetal head is $1.5 \times 10^3 \text{ m s}^{-1}$.

- (i) Calculate the size of the foetal head.

size = cm

[4]

(ii) State and explain what would be seen on the CRO screen if gel had **not** been applied between the ultrasound transducer and the skin of the mother.

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[Total 7 marks]

7. Discuss briefly the advantages and disadvantages of scanning using MRI techniques.

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[Total 6 marks]

- 8. Explain how ultrasound is produced using a piezoelectric crystal such as quartz.

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[Total 2 marks]

- 9. Describe the use of a contrast medium, such as barium, in the imaging of internal body structures. Your answer should include
 - how an image of an internal body structure is produced from an X-ray beam
 - an explanation of the use of a contrast medium
 - examples of the types of structure that can be imaged by this process.

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[Total 8 marks]