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.

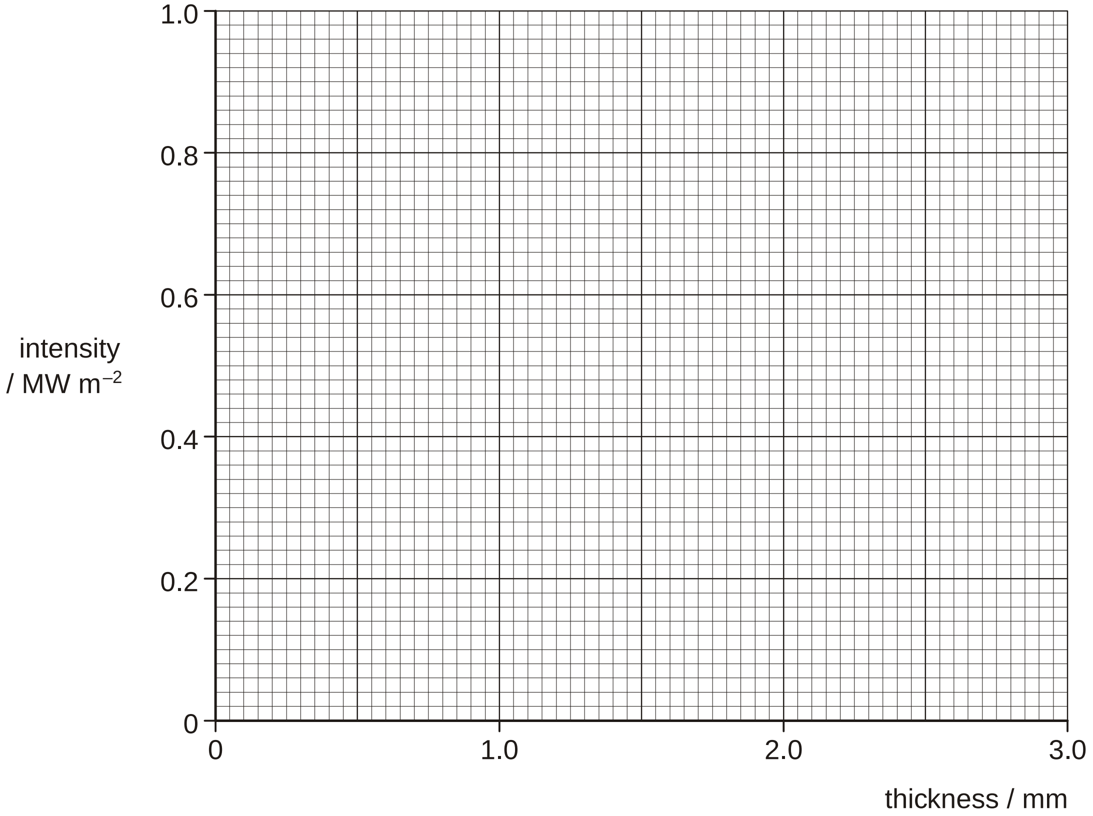

Fig. 2

[3]

(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.

μ = …………….. unit ………

[4]

[Total 8 marks]

2. The quality of ultrasound images in 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 μs 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*/ kg m^{-2} 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 2×10^5 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.

....

....

[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 2×10^5 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 7.5×10^{17} 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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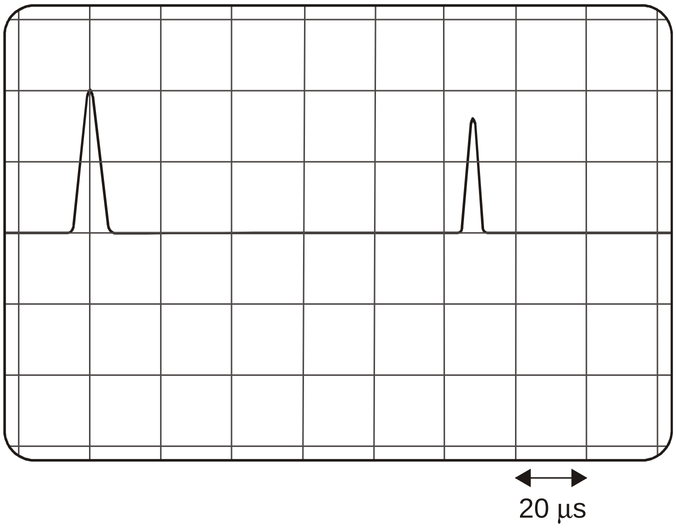
[3]

[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 μs cm^{-1}. The speed of ultrasound in the foetal head is 1.5×10^3 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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[3]

[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]