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.

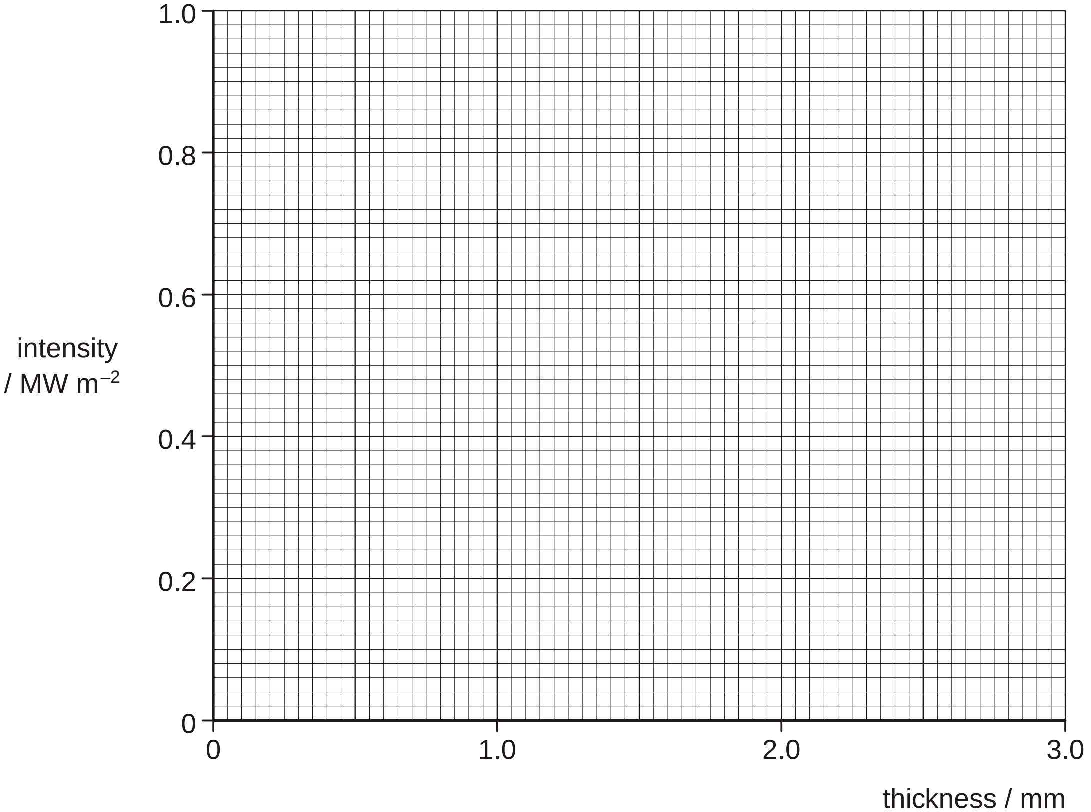

Fig. 2

[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.

....

....

[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.

....

....

[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 $7.5 \times 10^{17}\ s^{-1}$. 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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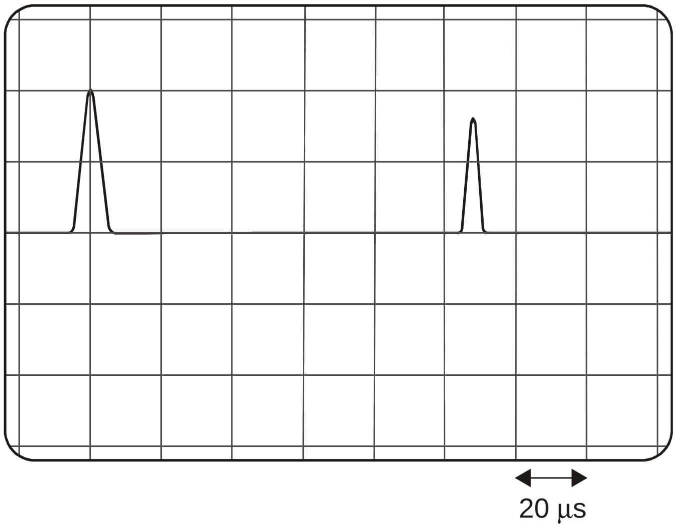
[3]

[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]

1. (a) 6 points plotted correctly (1)
remaining point plotted correctly (1)
sensible continuous smooth graph drawn (1) 3

(b) (i) 0.95 +/– 0.10 mm (1) 1

(ii) $I / I_o = e^{-x}$ (1)
$0.50 = e^{-0.0009}$ (1)
$\mu = 730$ (1)
m^{-1} (1) 4

[8]

2. (a) <u>Density</u> (of medium) B1
<u>Speed of ultrasound</u> (in medium) or any factors that affect the speed of ultrasound in the medium e.g. Young modulus B1

(b) (i) blood:
$f = (1.59 \times 10^{-6} - 1.63 \times 10^{-6})^2 / (1.59 \times 10^{-6} + 1.63 \times 10^{-6})^2$
$f = 1.54 \times 10^{-4}$ B1
muscle:
$f = 1.70 \times 10^{-6} - 1.63 \times 10^{-6})^2 / (1.70 \times 10^{-6} + 1.63 \times 10^{-6})^2$ B1
$f = 4.4 \times 10^{-4}$ B1
so the medium is muscle A1
(bald muscle scores zero)

(ii) $(s = u \times t)$
$s = 1.54 \times 10^3 \times 26.5 \times 10^{-6} = 0.0408$ m C1
depth = 0.0408 / 2 = 0.020 m A1

(iii) $\lambda = 1.54 \times 10^3 / 3.5 \times 10^6$ C1
$= 4.4 \times 10^{-4}$ m A1
(do not penalise the same power of ten error in (iii) as in (ii)

[10]

3. (a) Low energy X-rays are absorbed by the skin / undesirable as can cause damage /greater ionising B1

(b) $I = I_0 e^{-\mu x}$ $\quad \ln I = \ln I_0 - \mu x$ C1
$I_0 = 347 / e^{-250 \times 0.025}$ $\quad \ln I_0 = \ln 347 + 250 \times 0.025$ C1
$I_0 = 1.79 \times 10^5$ Wm^{-2} A1

(c) $P = I \times A$
$P = 347 \times \pi \times (0.010 \times 10^{-2})^2$ C1
$P = 1.09 \times 10^{-3}$ W A1

[6]

4. (a) Low energy X-rays are absorbed by the skin / undesirable as can cause damage / greater ionising (1) 1

(b) $I = I_0 e^{-\mu x}$ (1) $\ln I = \ln I_o - \mu\ x$

$I_o = \dfrac{347}{e^{-250\times0.025}}$ (1) $\ln I_o = \ln 347 + 250 \times 0.025$

$I_o = 1.79 \times 10^5\ Wm^{-2}$ (1) 3

(c) $P = I \times A$ (0)
$P = 347 \times \pi \times (0.10 \times 10^{-2})^2$ (1)
$P = 1.09 \times 10^{-3}$ W (1) 2

(d) (i) $P = 18 \times 100 / 0.15$ (1)
$P = 12000$ W (1) 2

(ii) $12000 / 7.5 \times 10^{17}$ (= 1.6×10^{-14} J = energy of each electron) (1)
$0.5\ m\ v^2 = 1.6 \times 10^{-14}$ (0)
$v = 1.9 \times 10^8\ ms^{-1}$ (1) 2

(iii) tube current = $7.5 \times 10^{17} \times 1.6 \times 10^{-19} = 0.12$ A (1)
$V \times I = 12000$ (1)
V =12000 / 0.12 = 100,000 V or 100 kV (1) 3

[13]

5. (a) (to a maximum of 7 marks) e.g.

- X-ray source + detectors round patient …
- … rotated around patient …/ the signal / X-ray passes through the same section of the body from different directions.
- … producing a (thin) slice / cross-section.
- Idea of absorption / less gets through / more is absorbed …
- by dense material / bone / material of high Z / High Z related to materials such as bone / Low Z to materials such as soft tissue
- attenuation is by the photo-electric effect
- the possibility of using a contrast medium.
- better than a simple X-ray at differentiating other organs.
- patient is moved a small distance and the process is repeated / process continues in a spiral.
- a computer (analyses the data) / identifies the position of organ/bone …
- … and forms a 3-D image. 7

(b)

- Patients are exposed to <u>ionising</u> radiation. (1)
- (Ionising radiation) could cause cancer / damage cells (1)

Plus a maximum of ONE from:-e.g. (1)

- It's expensive.
- Time consuming / uses valuable resources, etc.. 3

[10]

6. (i)

- 5.4 cm +/– 0.1 cm read from the graph (1)
- = $5.4 \times 20\ \mu s\ cm^{-1} \times 1.5 \times 10^3\ m\ s^{-1}$ (1)
- = 0.162 m (1)
- 0.162 / 2 = 0.081 m or 8.1 cm (1) 4

(ii)

- High reflection at the air-skin boundary / Little ultrasound enters the body / A very large peak right at the start … (1)
- … due to large <u>difference</u> in <u>acoustic impedance</u> / allow '…due to large <u>difference</u> in <u>density</u>'. (1)
- Very low <u>peaks</u> / no (subsequent) <u>peaks</u> (not just 'nothing') (1) 3

[7]

7. Any **six** from:
method does not use ionising radiation
hence no radiation hazard to patient or staff
gives better soft tissue contrast than CT scans
generates data from a 3D volume simultaneously
information can be displayed on a screen as a section in any direction
there are no moving mechanisms involved in MRI
There is no sensation, after effects at the field strengths used for routine diagnosis
Strong magnetic field could draw steel objects into the magnet
Metallic objects may become heated
Cardiac pacemakers may be affected by the magnetic fields
CT scanners better for viewing bony structures B1 × 6

[6]

8. alternating voltage or alternating E-field across crystal (1)
at resonant frequency (1) allow reference to resonance of crystal 2

[2]

9. **Formation of image to a max 3** e.g.

X-rays are detected by a film / scintillation counter etc., (1)
High 'Z' means high attenuation / low transmission
[Allow atomic mass / nucleon number] (1)
shadow on the film / reference to exposure after attenuation (1)
Reference to photoelectric effect / energy range around 1–100keV /
absorption $\propto Z^3$ (1)

Explanation of the use of a contrast medium to a max.4 e.g.

X-rays do not differentiate / show up soft tissues well …(1)
… as similar absorption / 'Z' is similar / 'Z' is low for these tissues. (1)
Contrast medium has high 'Z' / absorbs X-rays strongly.(1)
It is usually taken orally / as an enema / can be injected.(1)

Example of type of structure that can be imaged to a max.1 e.g.

digestive tract / throat / stomach.(1) to a max. 8

[8]