1. (a) High-energy X-rays are used in the treatment of a cancer tumour inside a patient's body. The patient is given a series of scans before the treatment is started.

Discuss how these scans are used to help provide the best and safest treatment for the patient when using the high-energy X-rays.

____

____

____

____

____

____

____

____

____

____

____

(3)

(b) Lead is commonly used as shielding when using X-rays due to its small half-value thickness.

Which statement gives the correct meaning of half-value thickness?
Tick (✓) the correct answer.

The thickness of material needed to reduce the energy of an X-ray photon by half.	☐
The thickness of material needed to reduce the wavelength of the photons in the X-ray beam by half.	☐
The thickness of material needed to reduce the intensity of the X-ray beam by half.	☐
Half the thickness of material needed to stop the X-ray beam.	☐

(1)

(c) The half-value thickness of lead for 500 keV X-rays is 4.2×10^{-3} m

Calculate the mass attenuation coefficient of lead for 500 keV X-rays.

State an appropriate unit for your answer.

density of lead = 1.1×10^{4} kg m^{-3}

mass attenuation coefficient = ____________________ unit ___________

(4)

(Total 8 marks)

2. In the past, doctors could only use a simple X-ray image to assess head injuries.

A CT scan is now a preferred technique.

Discuss why the CT scan has replaced the simple X-ray image to assess head injuries, but a simple X-ray procedure is suitable for assessing other injuries.

In your answer, you should:

- describe the basic principles of a CT scanner
- discuss the advantage of the CT scan over a simple X-ray image for head injuries
- explain why a simple X-ray procedure is more suitable for assessing other injuries.

____

____

____

____

____

____

____

____

____

____

____

____

(Total 6 marks)

3. X-ray photons can be used to treat cancerous tumours in radiotherapy.
Some photons are absorbed by healthy tissue before they reach the tumour.

Photons with a range of energies are generated in an X-ray machine.

Table 1 shows the linear attenuation coefficient of brain tissue for photons of energy 100 keV and 500 keV.

Table 1

Energy / keV	**Linear attenuation coefficient of brain tissue / cm^{-1}**
100	0.15
500	0.087

(a) Deduce whether photons of energy 100 keV or 500 keV are better for treating a brain tumour at a depth of 11 cm.

(4)

(b) Metal filters are used in X-ray machines to limit the damage to healthy tissues. **Table 2** gives data for possible filter materials.

Table 2

Energy / keV	**Linear attenuation coefficient / cm^{-1}**	
	Aluminium	**Copper**
100	0.44	3.8
500	0.23	0.73

Discuss whether it would be better to use aluminium or copper to filter the X-rays in part (a).
No calculations are required.

(c) State and explain **one** other method used to limit exposure of healthy cells during X-ray radiotherapy.

Method ____

Explanation ____

____

____

____

(2)

(Total 8 marks)

4. In an X-ray machine, X-rays are emitted from an emission spot on a tungsten target.

Figure 1

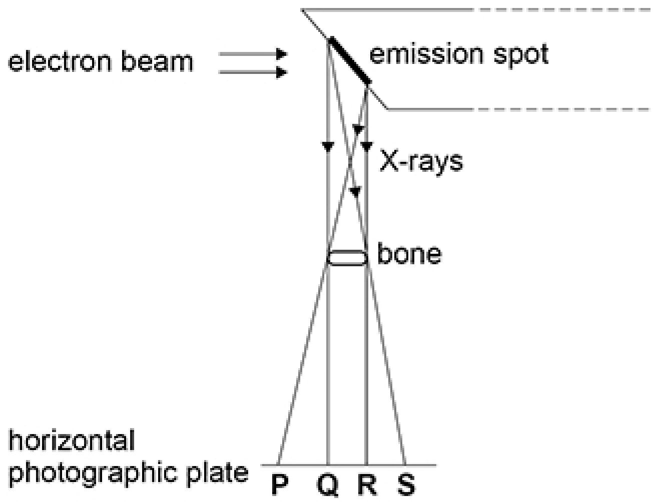
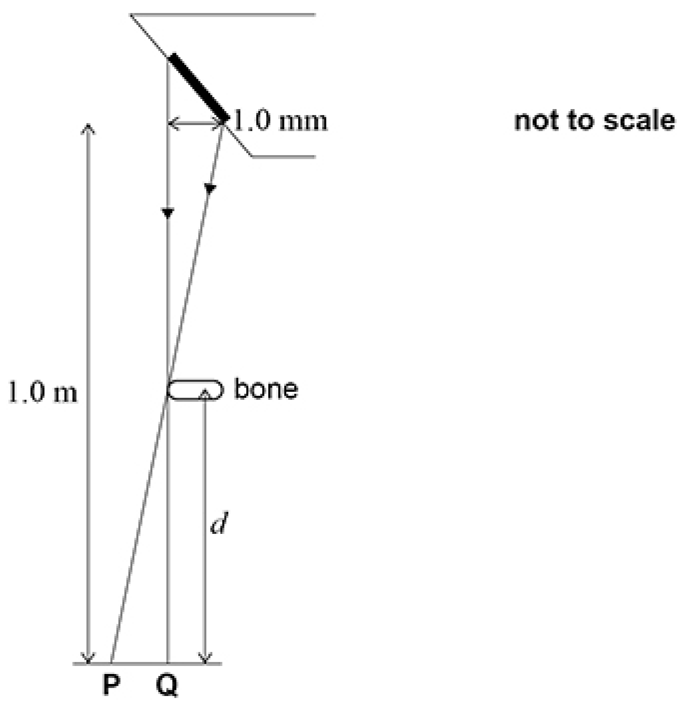


Figure 1 shows how a total shadow is produced in the region **QR** where no X-rays from any part of the emission spot can reach the photographic plate. Partial shadows are formed in regions **PQ** and **RS** where X-rays from only part of the emission spot can reach the plate.

Figure 2 shows detail of the formation of edges of the partial shadow **PQ**.
The bottom of the emission spot is 1.0 m vertically above the plate.
The horizontal distance across the beam is 1.0 mm at the bottom of the emission spot.

Figure 2



(a) To produce a sharp image of a bone, the partial shadow in region **PQ** must be no more than 0.10 mm wide.

Calculate the maximum distance d between a bone and the plate.

d = _______________ m

(2)

(b) Discuss whether an X-ray image of a chest or an X-ray image of a hand is likely to be sharper when exposed to the same X-ray source.

____

____

____

____

____

____

(2)

(Total 4 marks)

5. (a) A patient with a suspected broken arm is going to have an X-ray image taken.

Explain the risk to the patient of exposure to X-rays.

Go on to discuss **three** ways by which the design and use of the X-ray equipment minimises this risk.

(6)

(b) The blood vessel called the aorta passes through the abdomen. A second patient with a suspected fault in the wall of the aorta can be given an ultrasound scan or an X-ray of the abdomen.

Suggest, with reasons, which is the better procedure for investigating this suspected fault.

(2)

(c) When ultrasound travels across a boundary from blood to the wall of the aorta there is a decrease in acoustic impedance across the boundary. This results in 0.0625% of the intensity of the incident ultrasound being reflected at the boundary.

Calculate the acoustic impedance of the aorta wall tissue.

acoustic impedance of blood = 1.64×10^6 kg m^{-2} s^{-1}

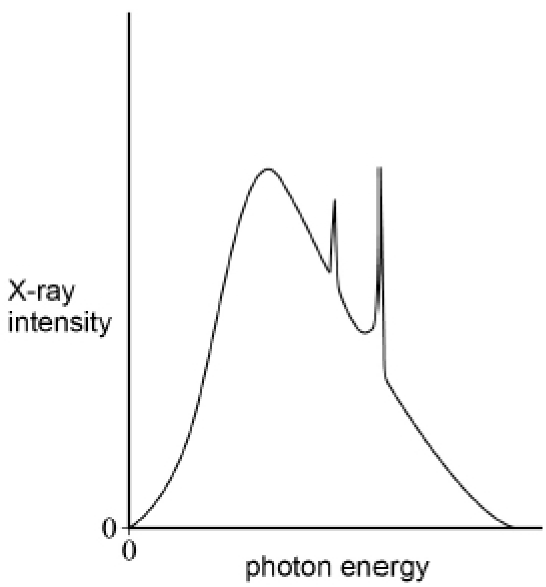
acoustic impedance of aorta wall tissue = ____________________ kg m^{-2} s^{-1}

(4)

(Total 12 marks)

6. **Figure 1** shows the X-ray spectrum produced in a medical X-ray machine at a particular anode potential difference (pd).

Figure 1



(a) In an X-ray tube, electrons collide with a tungsten target.

Explain how the continuous spectrum and the characteristic spectra are produced by these electron collisions.

Continuous spectrum ____

____

____

____

____

____

____

Characteristic spectra ____

____

____

____

____

____

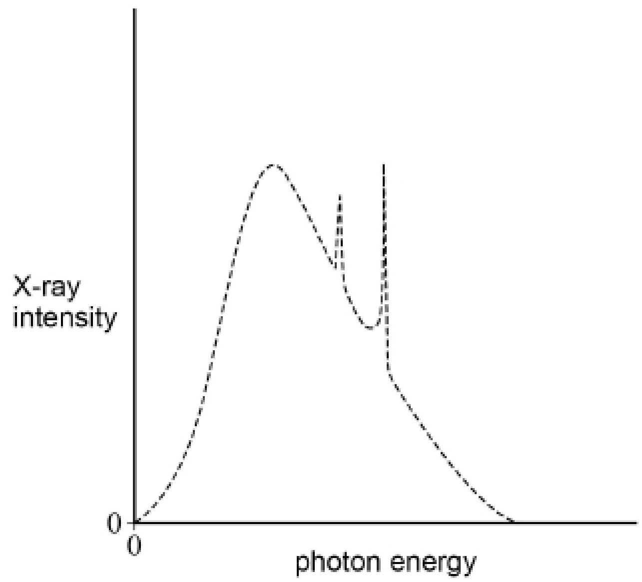
____

(4)

(b) The dashed line on **Figure 2** shows the X-ray spectrum for the initial anode pd.

Sketch on **Figure 2** the X-ray spectrum produced when the anode pd is increased.

Figure 2



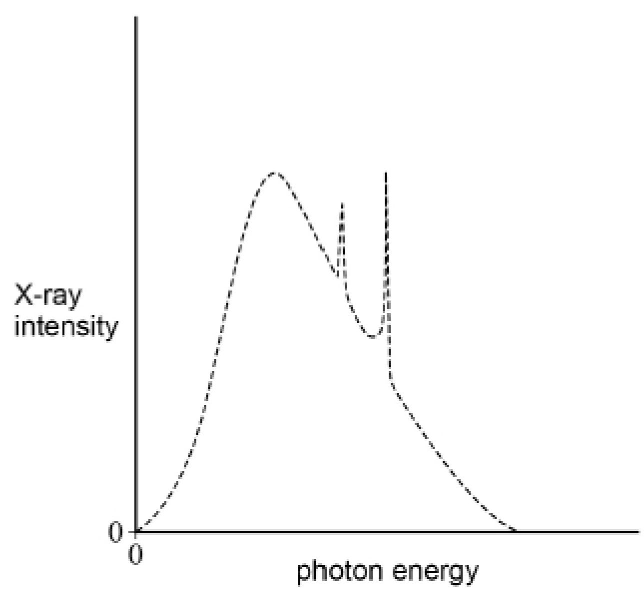
(2)

(c) In the medical X-ray machine, the X-rays produced with the initial anode pd are now passed through an aluminium filter.

The dashed line on **Figure 3** shows the X-ray spectrum for the initial anode pd.

Sketch on **Figure 3** the X-ray spectrum of the X-rays that emerge from the filter.

Figure 3



(1)

(Total 7 marks)