1 **(a)** A patient has an X-ray scan taken in hospital. The high-energy X-ray photons interact with the atoms inside the body of the patient.

Explain what is meant by a *photon* and state **one** of its main properties.

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.... **[2]**

(b) An X-ray tube operates using a 150 kV supply. X-ray photons are produced inside the tube when a beam of high-speed electrons accelerated from the cathode collide with the metal anode. About 99% of the total kinetic energy of the electrons at the anode is converted into heat energy which heats the anode. The remaining energy is transformed into the energy of the X-ray photons.

The current in the electron beam between the cathode and the anode is 4.8 mA.

(i) Show that the number of electrons incident at the anode per second is $3.0 \times 10^{16}\,s^{-1}$.

[1]

(ii) The anode is made from metal of specific heat capacity $140\,J\,kg^{-1}\,K^{-1}$. It has a mass of 8.6 g. The X-ray tube is switched on. Calculate the initial rate of increase of temperature of the anode.

rate of temperature increase = ... $°C\,s^{-1}$ **[3]**

wavelength of the X-rays produced from the X-ray tube.

wavelength = ... m **[2]**

(c) An X-ray scan of the heart and its blood vessels shows very poor contrast. Describe and explain a technique that can be used to reveal these blood vessels in an X-ray scan.

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.... **[2]**

2 **(a)** Fig. 8.1 shows an image of a patient from a gamma camera scan.

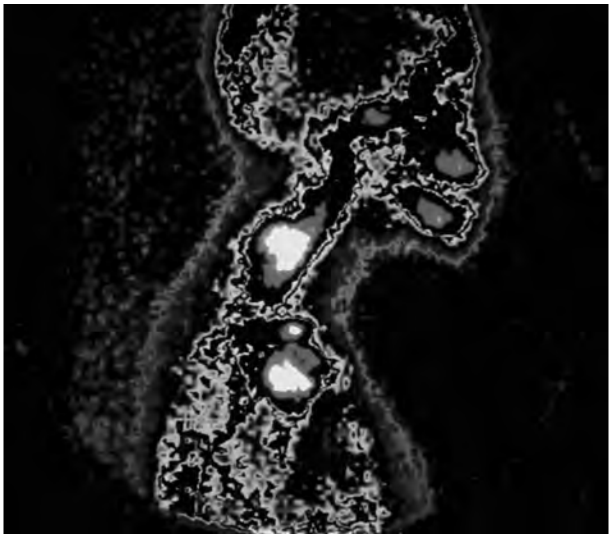

Fig. 8.1

The radioactive gamma-emitting tracer technetium-99m was injected into the patient before the scan. The image shows the distribution and intensity of gamma radiation emitted.

Discuss the advantages of using a gamma-emitting tracer in the patient rather than a beta-emitting tracer.

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.... **[2]**

(b) Many hospitals are equipped with computerised axial tomography (CAT) scanners.

Describe how the components of a CAT scanner are used to produce a three-dimensional image of a patient.

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.... **[5]**

3 (a) Explain what is meant by *Doppler effect*.

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.... **[1]**

(b) Describe how high-frequency ultrasound can be used to determine the speed of blood through the arteries of a patient.

In your answer you should make it clear how the speed is determined.

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.... **[3]**

(c) A patient is scanned using ultrasound of frequency 2.4 MHz. The speed of ultrasound in the blood is 1.57 km s^{-1}. The acoustic impedance of blood is 1.66×10^6 kg m^{-2} s^{-1}.
Calculate

(i) the density of blood

density = ... kg m^{-3} **[1]**

(ii) the wavelength of ultrasound in the blood.

wavelength = ... m **[1]**

(d) Fig. 9.1 shows a beam of ultrasound incident at right angles to the boundary between muscle and bone.

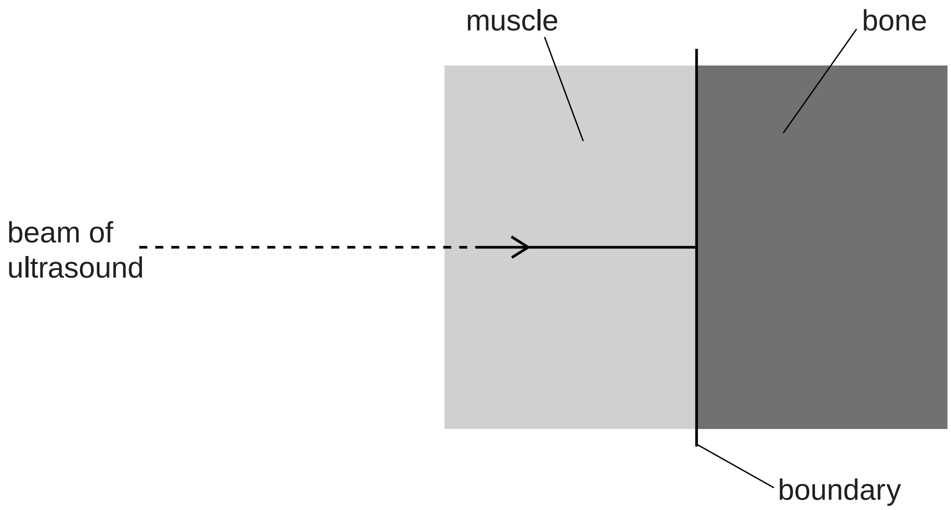

Fig. 9.1

The acoustic impedance of bone is 4 times that of muscle.

Calculate the percentage of ultrasound intensity transmitted into the bone.

intensity = ... % **[3]**

(e) During an ultrasound scan it is important that most of the ultrasound from the transducer is transmitted into the patient. Describe and explain how this is achieved.

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.... **[2]**

4 **(a)** X-rays are produced in an X-ray tube when fast moving electrons hit a metal target.

Fig. 7.1 shows a typical graph of intensity I against wavelength λ of X-rays emitted by an X-ray tube.

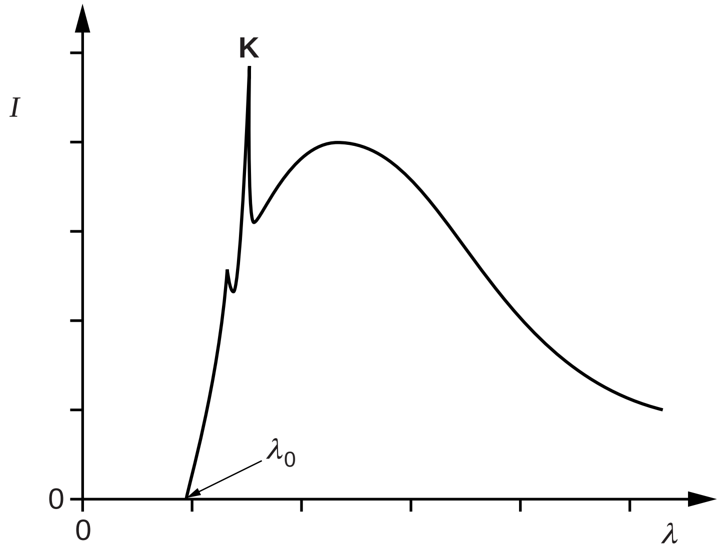

Fig. 7.1

High-speed electrons colliding with the atoms in the target metal can remove electrons from these atoms. The removal of such electrons creates 'gaps' in the lower energy levels of these atoms. These gaps are quickly filled by electrons in the higher energy levels making transitions to these lower energy levels. The electrons lose energy which is released as photons with particular wavelengths. These emission spectral lines are shown by the high intensity peaks such as **K** shown in Fig. 7.1.

Fig. 7.2 shows three of the energy levels, **A**, **B** and **C**, for the metal atoms of the target. The electron transition shown produces the peak **K**.

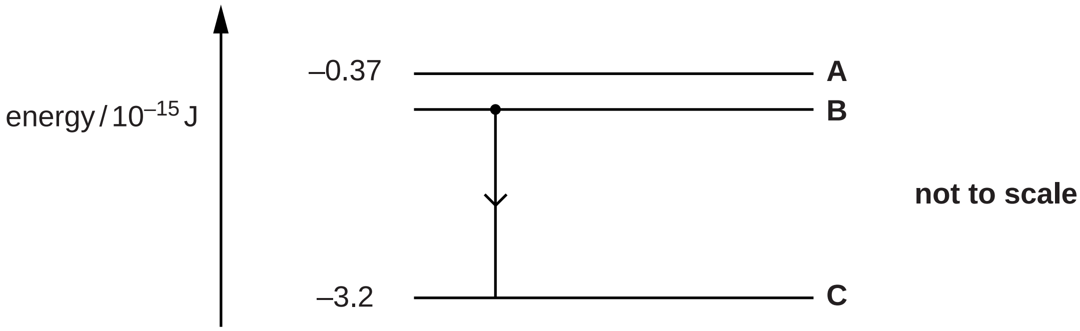

Fig. 7.2

(i) Explain what is meant by an *energy level* of an atom.

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.... **[1]**

(ii) The peak **K** occurs at a wavelength of 7.2×10^{-11} m. Calculate the value of the energy level **B**.

value of energy level = ... J **[3]**

(iii) In Fig. 7.1, the shortest wavelength λ_0 produced from an X-ray tube depends on the accelerating potential difference V. The maximum kinetic energy of a single accelerated electron is equal to the energy of a single X-ray photon of wavelength λ_0. Explain how λ_0 from the X-ray tube changes when the accelerating potential difference of the X-ray tube is **doubled**.

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.... **[2]**

(b) X-rays are used to scan the human body. A parallel beam of X-rays is incident on a muscle. The attenuation (absorption) coefficient μ for X-rays in muscle is $0.96\,\text{cm}^{-1}$.

(i) Calculate the fraction of X-ray intensity **absorbed** by 2.3 cm of muscle.

fraction = ... **[3]**

(ii) The attenuation coefficients for X-rays in bone and fat are $2.8\,\text{cm}^{-1}$ and $0.90\,\text{cm}^{-1}$ respectively. Two X-ray images are taken, one with bone and muscle and another with muscle and fat. State and explain which image will give better contrast.

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.... **[1]**

[Total: 10]

5 **(a)** Fig. 8.1 shows a B-scan image of an ultrasound scan of a 12 week foetus

Fig. 8.1

The outline of the head of the foetus can be seen in Fig. 8.1. Describe and explain the principles of a B-scan.

In your answer you should make clear how it is possible to distinguish the boundaries between different materials.

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(b) Fig. 8.2 shows an image of the brain using a positron emission tomography (PET) scanner.

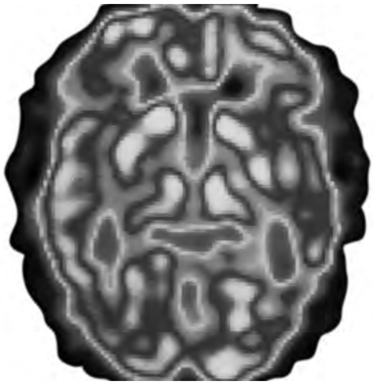

Fig. 8.2

The lighter regions in Fig. 8.2 show the active areas of the brain. Fluorine-18 is a common tracer injected into a patient before a PET scan.

Explain the basic principles of PET scanning, including how the image is formed.

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[Total: 7]