1 Outline briefly the main principles of the use of magnetic resonance to obtain information about internal body structures.

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2 (a) Explain the main principles behind the **use** of ultrasound to obtain diagnostic information about internal body structures.

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(b) Data for the acoustic impedances and absorption (attenuation) coefficients of muscle and bone are given in Fig. 11.1.

	acoustic impedance / $kg\,m^{-2}\,s^{-1}$	absorption coefficient / m^{-1}
muscle	1.7×10^6	23
bone	6.3×10^6	130

Fig. 11.1

The intensity reflection coefficient is given by the expression

$$\frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}.$$

The attenuation of ultrasound in muscle follows a similar relation to the attenuation of X-rays in matter.

A parallel beam of ultrasound of intensity I enters the surface of a layer of muscle of thickness 4.1 cm as shown in Fig. 11.2.

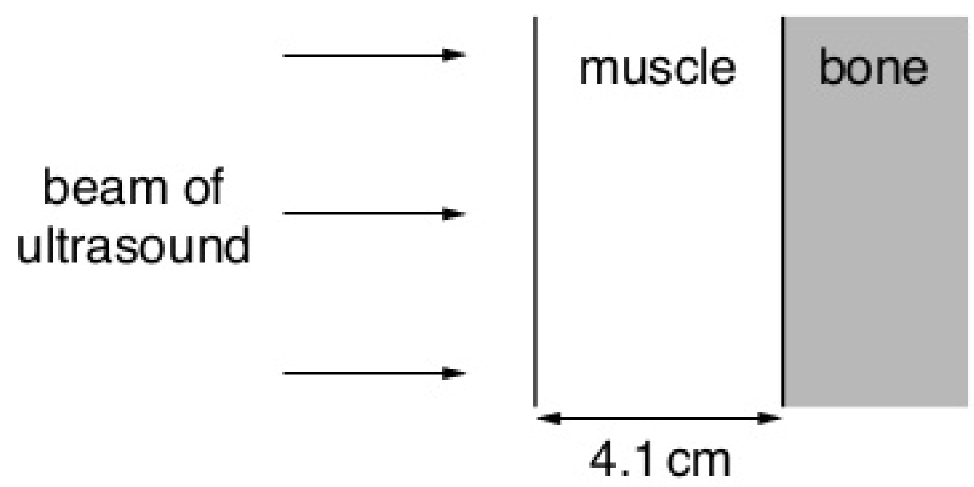

Fig. 11.2

The ultrasound is reflected at a muscle-bone boundary and returns to the surface of the muscle.

Calculate

(i) the intensity reflection coefficient at the muscle-bone boundary,

coefficient = ... [2]

(ii) the fraction of the incident intensity that is transmitted from the surface of the muscle to the surface of the bone,

fraction = ... [2]

(iii) the intensity, in terms of I, that is received back at the surface of the muscle.

intensity = ... I [2]

For Examiner's Use

3 **(a)** State what is meant by *acoustic impedance*.

....

.... [1]

(b) Explain why acoustic impedance is important when considering reflection of ultrasound at the boundary between two media.

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.... [2]

(c) Explain the principles behind the use of ultrasound to obtain diagnostic information about structures within the body.

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For Examiner's Use

4 (a) Distinguish between the images produced by CT scanning and X-ray imaging.

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(b) By reference to the principles of CT scanning, suggest why CT scanning could not be developed before powerful computers were available.

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For Examiner's Use

5 Outline briefly the main principles of the use of magnetic resonance to obtain diagnostic information about internal body structures.

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6 (a) A typical spectrum of the X-ray radiation produced by electron bombardment of a metal target is illustrated in Fig. 10.1.

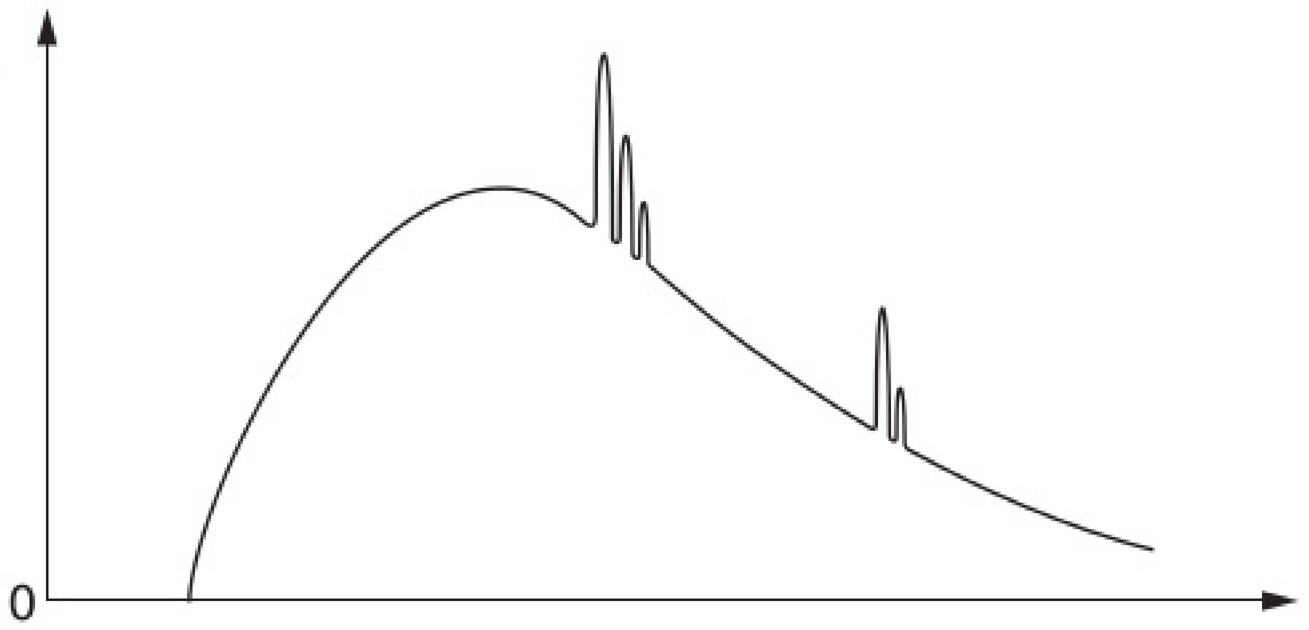

Fig. 10.1

Explain why

(i) a continuous spectrum of wavelengths is produced,

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.... [3]

(ii) the spectrum has a sharp cut-off at short wavelengths.

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.... [1]

For Examiner's Use

(b) The variation with photon energy *E* of the linear absorption coefficient μ of X-rays in soft tissue is illustrated in Fig. 10.2.

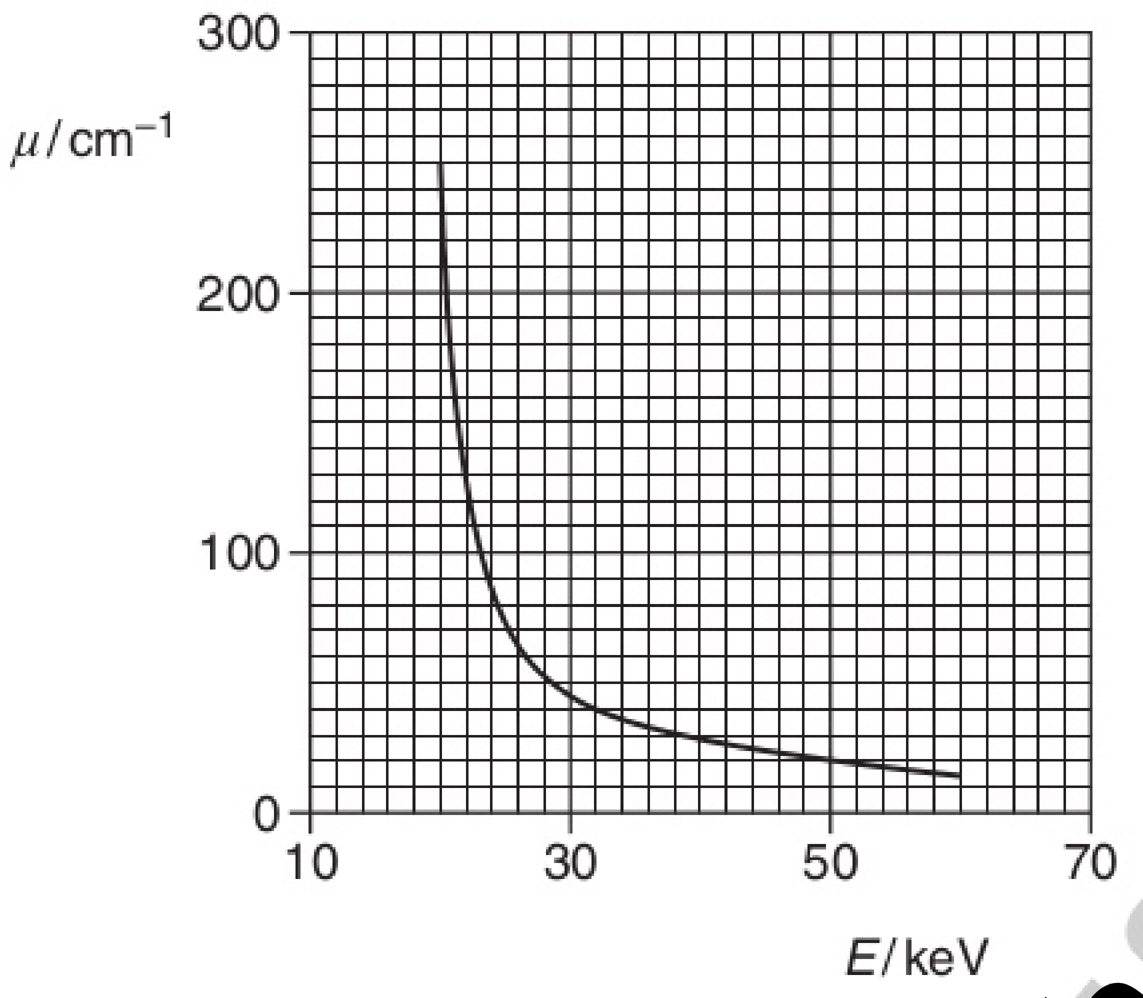

Fig. 10.2

(i) Explain what is meant by *linear absorption coefficient*

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.... [3]

(ii) For one particular application of X-ray imaging, electrons in the X-ray tube are accelerated through a potential difference of 50 kV.

Use Fig. 10.2 to explain why it is advantageous to filter out low-energy photons from the X-ray beam.

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.... [3]

7 Explain the main principles behind the **generation** of ultrasound to obtain diagnostic information about internal body structures.

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For Examiner's Use

For Examiner's Use

8 (a) Briefly explain the principles of CT scanning.

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.... [6]

(b) A simple section through a body consists of four voxels, as illustrated in Fig. 10.1.

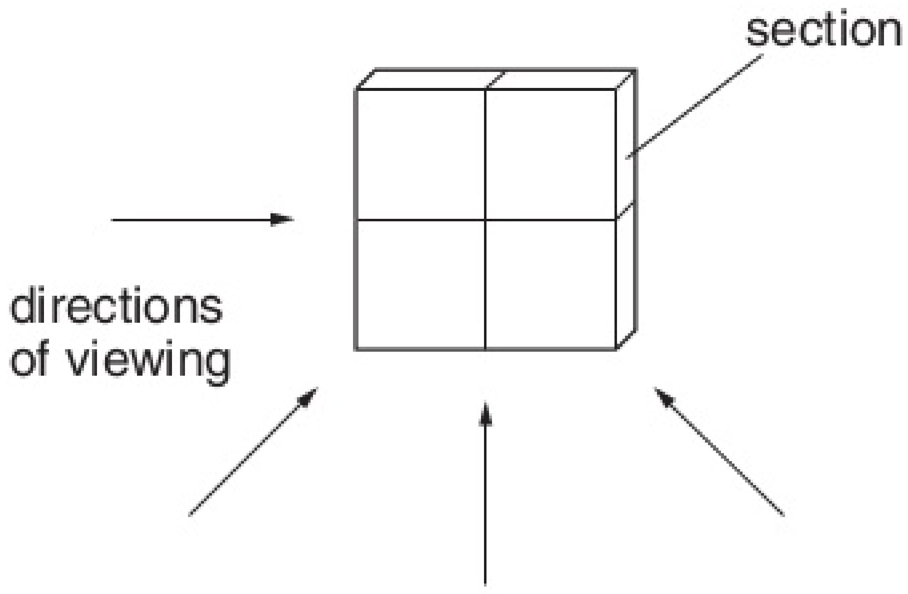

Fig. 10.1

An X-ray image of the section is obtained by viewing along each of the directions shown in Fig. 10.1.
The detector readings for each direction of viewing are summed to give the pattern of readings shown in Fig. 10.2.

25	22
34	31

Fig. 10.2

For any one direction, the total of the detector readings is 16.

(i) For the pattern of readings of Fig. 10.2, state the magnitude of the background reading.

background reading = ... [1]

(ii) On Fig. 10.1, mark the pattern of pixels for the four-voxel section. [2]

For Examiner's Use

10 (a) (i) State what is meant by the *acoustic impedance* of a medium.

....

.... [1]

(ii) Data for some media are given in Fig. 10.1.

medium	speed of ultrasound / $m s^{-1}$	acoustic impedance / $kg m^{-2} s^{-1}$
air	330	4.3×10^2
gel	1500	1.5×10^6
soft tissue	1600	1.6×10^6
bone	4100	7.0×10^6

Fig. 10.1

Use data from Fig. 10.1 to calculate a value for the density of bone.

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

(b) A parallel beam of ultrasound has intensity I. It is incident at right-angles to a boundary between two media, as shown in Fig. 10.2.

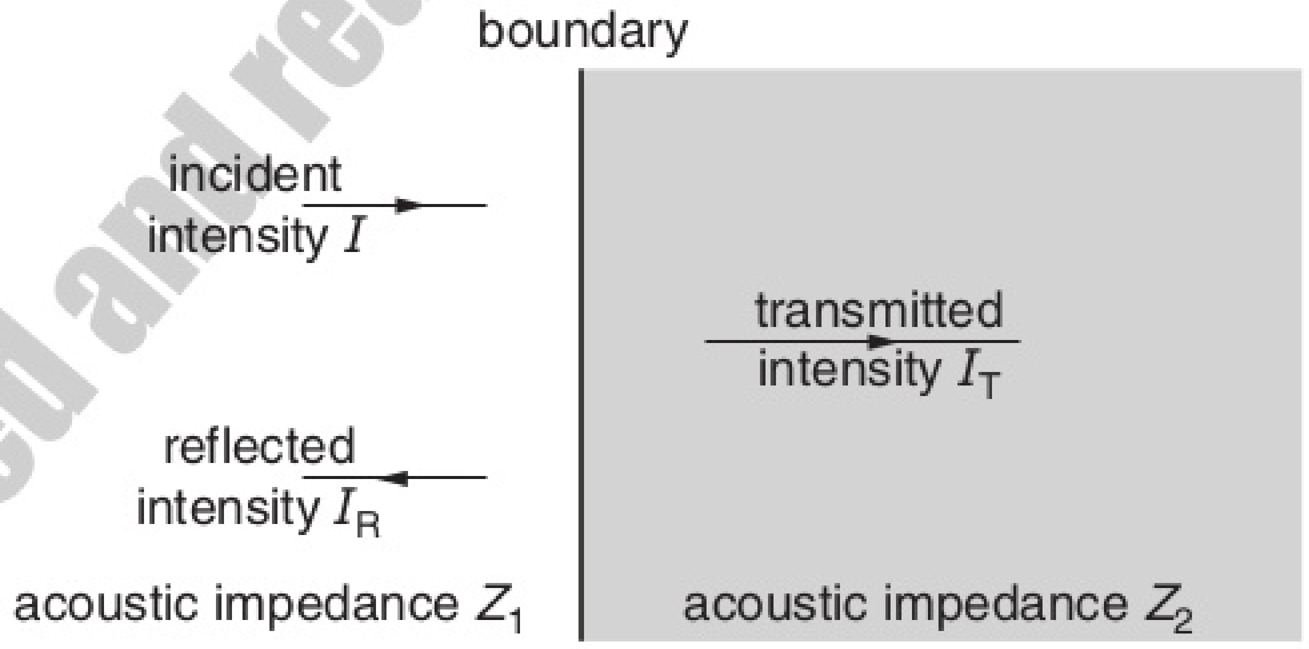

Fig. 10.2

The media have acoustic impedances of Z_1 and Z_2. The transmitted intensity of the ultrasound beam is I_T and the reflected intensity is I_R.

(i) State the relation between I, I_T and I_R.

.... [1]

For Examiner's Use

(ii) The reflection coefficient α is given by the expression

$$\alpha = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}.$$

Use data from Fig. 10.1 to determine the reflection coefficient α for a boundary between

1. gel and soft tissue,

α = ... [2]

2. air and soft tissue.

α = ... [1]

(c) By reference to your answers in **(b)(ii)**, explain the use of a gel on the surface of skin during ultrasound diagnosis.

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.... [3]

For Examiner's Use

9 **(a)** **(i)** State, with reference to X-ray images, what is meant by *sharpness*.

....

.... [1]

(ii) Describe briefly two factors that affect the sharpness of an X-ray image.

1. ....

....

2. ....

....
[3]

(b) An X-ray image is taken of the skull of a patient. Another patient has a CT scan of his head.
By reference to the formation of the image in each case, suggest why the exposure to radiation differs between the two imaging techniques.

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.... [4]

11 The linear attenuation (absorption) coefficient μ for X-ray radiation in bone, fat and muscle is given in Fig. 11.1.

	μ / cm^{-1}
bone	2.9
fat	0.90
muscle	0.95

Fig. 11.1

(a) A parallel X-ray beam of intensity I_0 is incident either on some bone or on some muscle.
The emergent beam has intensity I.

Calculate the ratio $\frac{I}{I_0}$ for a thickness of

(i) 1.5 cm of bone,

ratio = ... [2]

(ii) 4.6 cm of muscle.

ratio = ... [1]

(b) Suggest why, on an X-ray plate, the contrast between bone and muscle is much greater than that between fat and muscle.

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....[3]

For Examiner's Use

10 **(a)** State what is meant by the *acoustic impedance Z* of a medium.

....

....[1]

(b) Two media have acoustic impedances Z_1 and Z_2.
The intensity reflection coefficient α for the boundary between the two media is given by

$$\alpha = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}.$$

Describe the effect on the transmission of ultrasound through a boundary where there is a large difference between the acoustic impedances of the two media.

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....[3]

(c) Data for the acoustic impedance Z and the absorption coefficient μ for fat and for muscle are shown in Fig. 10.1.

	Z / kg m^{-2} s^{-1}	μ / m^{-1}
fat	1.3×10^6	48
muscle	1.7×10^6	23

Fig. 10.1

The thickness x of the layer of fat on an animal, as illustrated in Fig. 10.2, is to be investigated using ultrasound.

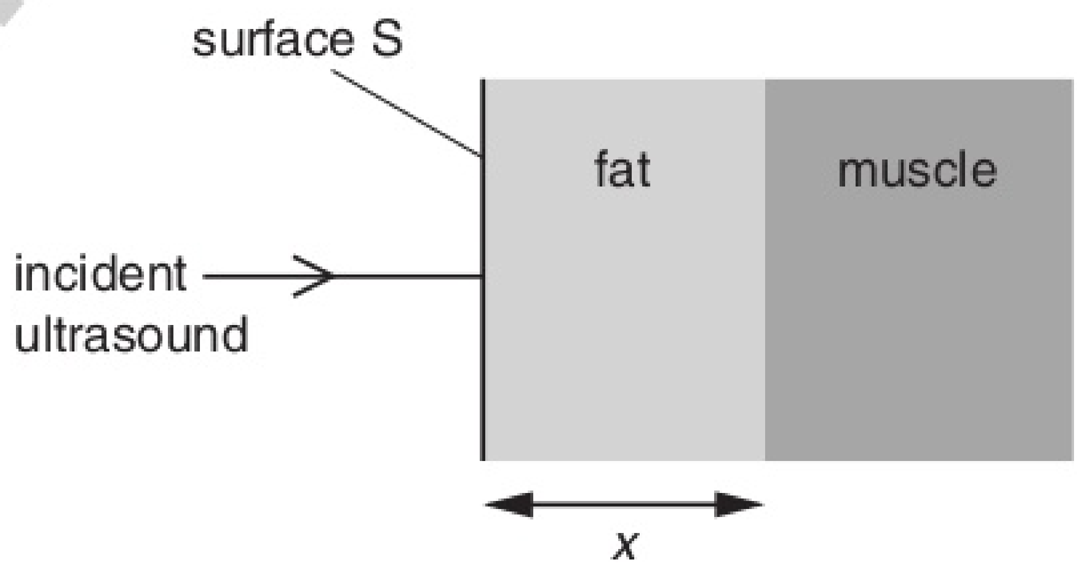

Fig. 10.2

For Examiner's Use

The intensity of the parallel ultrasound beam entering the surface S of the layer of fat is I.
The beam is reflected from the boundary between fat and muscle.
The intensity of the reflected ultrasound detected at the surface S of the fat is 0.012 I.
Calculate

(i) the intensity reflection coefficient at the boundary between the fat and the muscle,

coefficient = ...[2]

(ii) the thickness x of the layer of fat.

x = ... cm [3]

10 Explain briefly the main principles of the use of magnetic resonance to obtain diagnostic information about internal body structures.

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.... [8]

For Examiner's Use

10 (a) Cable television uses optic fibres for the transmission of signals.
Suggest four advantages of optic fibres over coaxial cables for the transmission of data.

1. ....

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2. ....

....

3. ....

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4. ....

.... [4]

(b) Electromagnetic radiation of wavelength 1310 nm is frequently used for optic fibre communication, rather than visible light.

(i) State the region of the electromagnetic spectrum in which radiation of wavelength 1310 nm is found.

.... [1]

(ii) Suggest why this radiation is used, rather than visible light.

....

.... [1]

(c) An optic fibre has an attenuation per unit length of 0.2 dB km^{-1}.
A signal is transmitted along the optic fibre of length 30 km to a receiver. The noise power at the receiver is 9.3 μW.
The minimum acceptable signal-to-noise ratio at the receiver is 26 dB.

Calculate

(i) the minimum signal power at the receiver,

power = ... W [2]

(ii) the minimum input signal power to the optic fibre.

power = ...W [2]

For Examiner's Use

10 (a) Cable television uses optic fibres for the transmission of signals.
Suggest four advantages of optic fibres over coaxial cables for the transmission of data.

1. ....

....

2. ....

....

3. ....

....

4. ....

.... [4]

(b) Electromagnetic radiation of wavelength 1310 nm is frequently used for optic fibre communication, rather than visible light.

(i) State the region of the electromagnetic spectrum in which radiation of wavelength 1310 nm is found.

.... [1]

(ii) Suggest why this radiation is used, rather than visible light.

....

.... [1]

For Examiner's Use

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The minimum acceptable signal-to-noise ratio at the receiver is 26 dB.

Calculate

(i) the minimum signal power at the receiver,

power = ... W [2]

(ii) the minimum input signal power to the optic fibre.

power = ...W [2]

For Examiner's Use

10 Explain the principles of the generation and detection of ultrasound waves.

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.... [6]

11 **(a)** Distinguish between *sharpness* and *contrast* in X-ray imaging.

sharpness: ....

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contrast: ....

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[2]

(b) A student investigates the absorption of X-ray radiation in a model arm. A cross-section of the model arm is shown in Fig. 11.1.

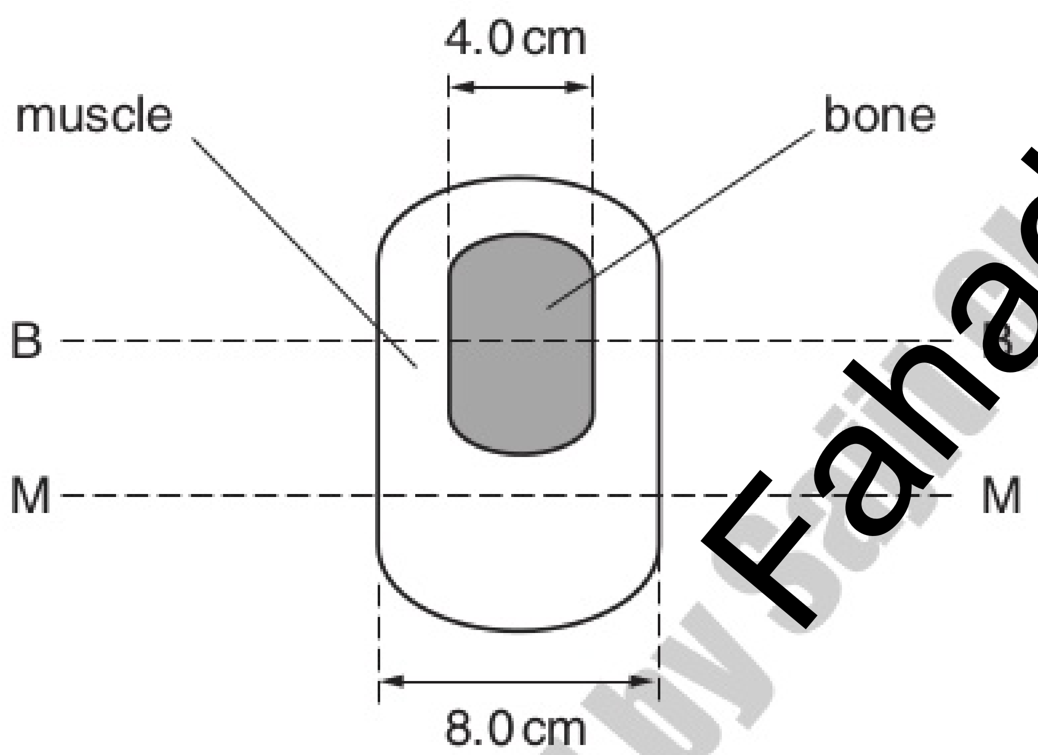

Fig. 11.1

Parallel X-ray beams are directed along the line MM and along the line BB.
The linear absorption coefficients of the muscle and of the bone are $0.20\,\text{cm}^{-1}$ and $12\,\text{cm}^{-1}$ respectively.

Calculate the ratio

$$\frac{\text{intensity of emergent X-ray beam from model}}{\text{intensity of incident X-ray beam on model}}$$

for a parallel X-ray beam directed along the line

(i) MM,

ratio = ... [2]

(ii) BB.

For Examiner's Use

ratio = ... [3]

(c) State whether your answers in (b) would indicate that the X-ray image

(i) is sharp,

.... [1]

(ii) has good contrast.

.... [1]

For Examiner's Use

11 High-speed electrons are incident on a metal target. The spectrum of the emitted X-ray radiation is shown in Fig. 11.1.

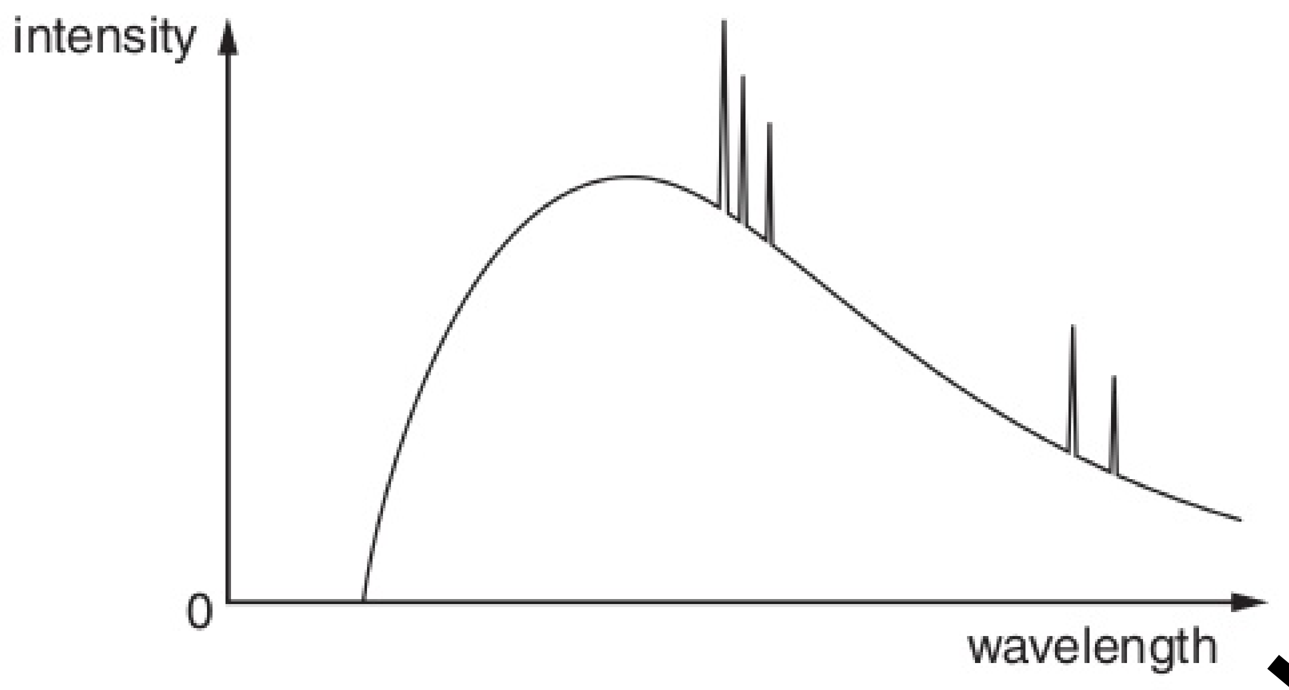

Fig. 11.1

(a) Explain why

(i) there is a continuous distribution of wavelengths,

....

....

.... [2]

(ii) there is a sharp cut-off at short wavelength.

....

....

.... [2]

(b) State

(i) what is meant by the *hardness* of an X-ray beam,

....

....

.... [2]

(ii) how hardness is controlled.

....

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.... [2]

(c) (i) Suggest why, when producing an X-ray image, long-wavelength X-ray radiation poses a greater hazard to health than short-wavelength radiation.

....

.... [1]

(ii) Suggest how this hazard is minimised.

....

.... [1]

12 A person is to be investigated using a magnetic resonance (MR) scanner.

(a) This technique involves the use of two superimposed magnetic fields.
Describe the functions of these two magnetic fields.

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.... [4]

(b) The frequency *f* of the electromagnetic waves emitted by protons on relaxation in an MR scanner is given by the equation

$$f = 2cB$$

where *B* is the total magnetic flux density and *c* is a constant equal to $1.34 \times 10^{8}\,\text{s}^{-1}\,\text{T}^{-1}$.
The magnetic flux density changes by 2.0×10^{-4} T for each 1.0 cm thickness of tissue in a section.
The scanner is adjusted so that the thickness of each section is 3.0 mm.

Calculate, for corresponding points in neighbouring sections,

(i) the difference in magnetic flux density,

difference in flux density = ... T [1]

(ii) the change in emitted frequency.

frequency change = ... Hz [2]

10 **(a)** An aluminium block is placed near to a small source of X-ray radiation, as shown in Fig. 10.1.

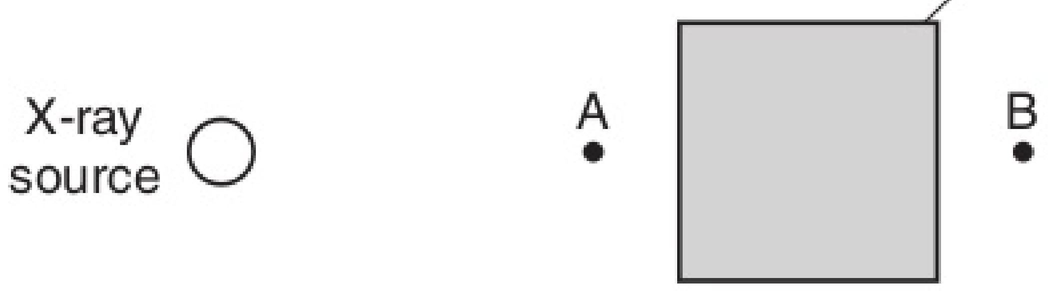

Fig. 10.1

X-rays from the source are detected at point A and at point B.

State two reasons why the intensity of the X-ray beam at point B is not as great as the intensity at point A.

1. ....

....

2. ....

.... [2]

(b) A cross-section through a model of a finger is shown in Fig. 10.2.

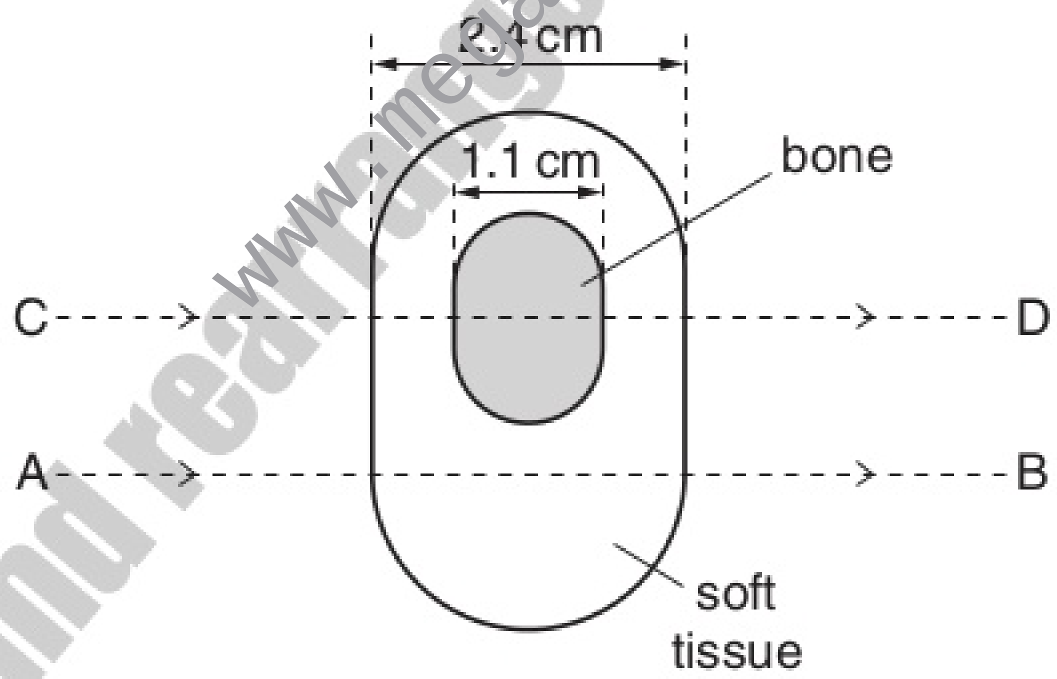

Fig. 10.2

The thickness of the model is 2.4 cm and that of the bone in the model is 1.1 cm. Parallel beams of X-rays are incident on the model in the directions AB and CD, as shown in Fig. 10.2.

Data for the linear attenuation (absorption) coefficient μ for the bone and the soft tissue in the model are given in Fig. 10.3.

	μ / cm^{-1}
bone	3.0
soft tissue	0.27

Fig. 10.3

Calculate the ratio

$$\frac{\text{intensity of X-ray beam incident on the model}}{\text{intensity of X-ray beam emergent from the model}}$$

for

(i) the beam AB,

ratio = ... [2]

(ii) the beam CD.

ratio = ... [2]

(c) Use your answers in **(b)** to suggest why, for this model, an X-ray image with good contrast may be obtained.

....

.... [1]

For Examiner's Use

11 High-speed electrons are incident on a metal target. The spectrum of the emitted X-ray radiation is shown in Fig. 11.1.

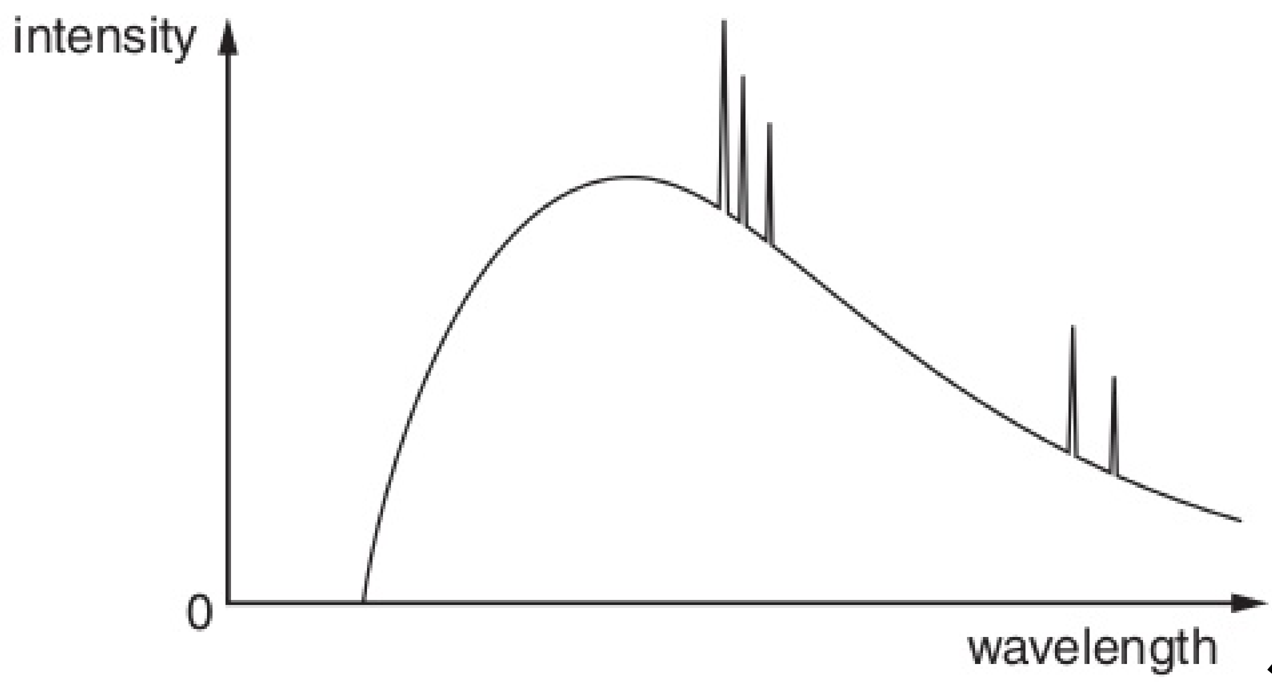

Fig. 11.1

(a) Explain why

(i) there is a continuous distribution of wavelengths,

....

....

.... [2]

(ii) there is a sharp cut-off at short wavelength.

....

....

.... [2]

(b) State

(i) what is meant by the *hardness* of an X-ray beam,

....

....

.... [2]

(ii) how hardness is controlled.

....

....

.... [2]

For Examiner's Use

(c) (i) Suggest why, when producing an X-ray image, long-wavelength X-ray radiation poses a greater hazard to health than short-wavelength radiation.

....

.... [1]

(ii) Suggest how this hazard is minimised.

....

.... [1]

12 A person is to be investigated using a magnetic resonance (MR) scanner.

(a) This technique involves the use of two superimposed magnetic fields.
Describe the functions of these two magnetic fields.

....

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....

....

.... [4]

(b) The frequency *f* of the electromagnetic waves emitted by protons on relaxation in an MR scanner is given by the equation

$$f = 2cB$$

where *B* is the total magnetic flux density and *c* is a constant equal to $1.34 \times 10^{8}\,s^{-1}\,T^{-1}$.
The magnetic flux density changes by 2.0×10^{-4} T for each 1.0 cm thickness of tissue in a section.
The scanner is adjusted so that the thickness of each section is 3.0 mm.

Calculate, for corresponding points in neighbouring sections,

(i) the difference in magnetic flux density,

difference in flux density = ... T [1]

(ii) the change in emitted frequency.

frequency change = ... Hz [2]

For Examiner's Use

10 Outline the principles of CT scanning.

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10 A simple model of one section of a CT scan is shown in Fig. 10.1.

A	*B*
D	*C*

Fig. 10.1

The model consists of four voxels with pixel numbers *A*, *B*, *C* and *D*.

In this model, the voxels are viewed in turn along four different directions D_1, D_2, D_3 and D_4 as shown in Fig. 10.2.

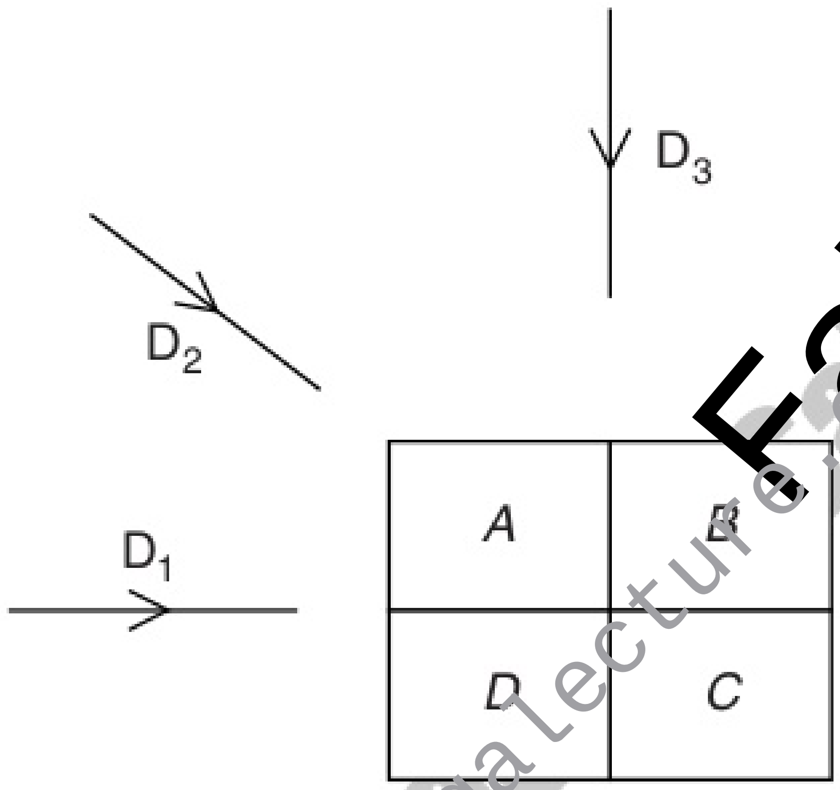

Fig. 10.2

The pixel readings in each of the four directions are noted.
The total pixel reading for any one direction is 19.
The pixel readings for all of the directions are summed to give the pattern of readings shown in Fig. 10.3.

25	34
28	46

Fig. 10.3

(a) State the background reading in this model.

background reading = ... [1]

For Examiner's Use

(b) Determine each of the pixel readings.

A = …………	B = …………
D = …………	C = …………

[4]

(c) Use your answers in **(b)** to determine the pixel readings along

(i) the direction D_3,

....[1]

(ii) the direction D_4.

....[2]