**Q1.**

7 **(a)** Briefly explain the principles of the production of an X-ray beam.

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..... [5]

**(b)** State how, in an X-ray tube,

**(i)** the intensity of the X-ray beam may be increased,

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**(ii)** the X-ray beam may be made more penetrating,

.....

**(iii)** the unwanted 'soft' X-rays may be removed from the beam.

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[3]

**(c)** The intensity of a parallel X-ray beam is reduced to one half of its initial intensity when it passes through bone of thickness 0.40 cm. Calculate the thickness of bone necessary to reduce the beam intensity to one tenth of its initial value.

thickness = ..... cm [3]

**Q2.**

8 Suggest why, when using a laser as a scalpel,

(a) the laser beam is focused using a short focal length convex lens,

.....

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..... [2]

(b) less bleeding is caused than when using a knife.

.....

.....

..... [2]

**Q3.**

9 (a) Explain what is meant by the *sensitivity* of the ear.

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..... [2]

(b) A person stands in a room where the intensity of the background noise due to a party is $4.5 \times 10^{-5}$ W m$^{-2}$. The smallest change in intensity level of sound that can be detected by the person is 3.0 dB.

Calculate the change in intensity of sound necessary for the person to hear someone else speak above the background noise.

change = ..... W m$^{-2}$ [3]

**Q4.**

9 **(a)** Explain the principles behind the use of X-rays for imaging internal body structures.

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..... [4]

**(b)** Describe how the image produced during CT scanning differs from that produced by X-ray imaging.

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**Q5.**

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

For Examin Use

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.....[8]

**Q6.**

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

*For Examiner's Use*

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..... [4]

**(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 | $1.7 \times 10^6$ | 23 |
| bone | $6.3 \times 10^6$ | 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.

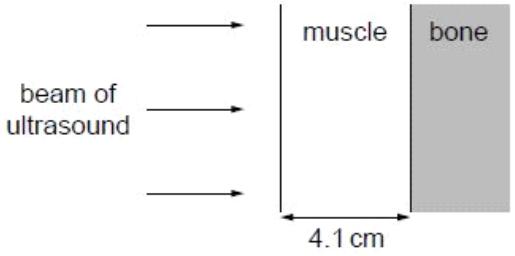


**Fig. 11.2**

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]

**Q7.**

10 **(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.

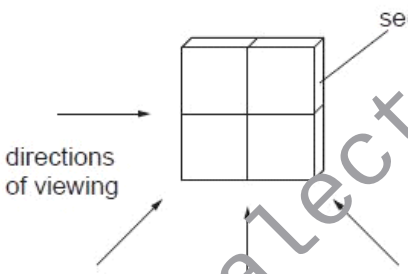


**Fig. 10.1**

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]

**Q8.**

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

*For Examin Use*

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**Q9.**

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

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.....[1]

**(b)** Two media have acoustic impedances $Z_1$ and $Z_2$.
The intensity reflection coefficient $\alpha$ 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.

.....

.....

.....

.....[3]

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

| | $Z$/kg m$^{-2}$ s$^{-1}$ | $\mu$/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.

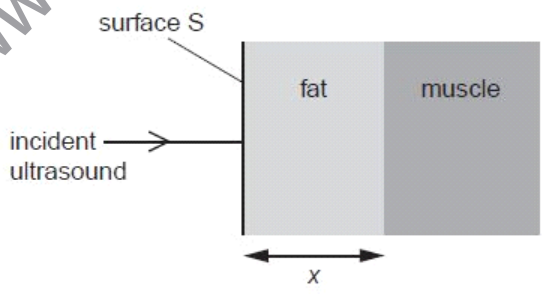


**Fig. 10.2**

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

For Examin Use

**(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]

**Q10.**

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

For Examiner Use

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..... [8]

## Q11.

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

For Examiner Use

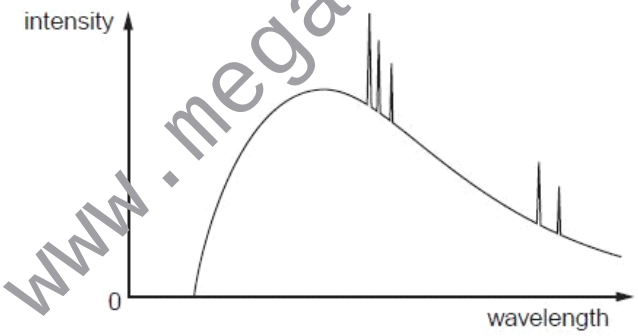


**Fig. 11.1**

**(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]

**(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]

**Q12.**

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

For Examiner Use

**(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 $2.0 \times 10^{-4}$ 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,

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]

**Q13.**

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

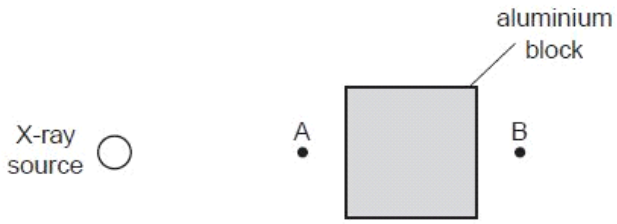


**Fig. 10.1**

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.

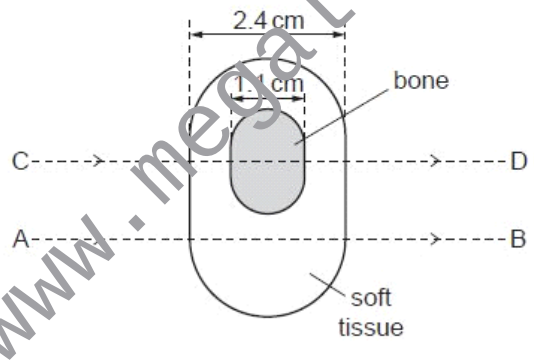


**Fig. 10.2**

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 $\mu$ for the bone and the soft tissue in the model are given in Fig. 10.3.

For Examin Use

| | $\mu$ / 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]

## Q14.

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

*For Examiner Use*

sharpness: .....

.....

contrast: .....

.....

[2]

**(b)** State two causes of loss of sharpness of an X-ray image.

1. .....

.....

2. .....

.....

[2]

**(c)** Data for the linear attenuation (absorption) coefficient $\mu$ of X-ray photons are given in Fig. 10.1.

| | $\mu$/cm$^{-1}$ |
|---|---|
| bone | 2.85 |
| muscle | 0.95 |

**Fig. 10.1**

A parallel beam of X-rays is incident, separately, on a thickness of 3.5 cm of bone and on a muscle of thickness 8.0 cm.

**(i)** Calculate the ratio

$$\frac{\text{intensity of X-ray beam transmitted through bone}}{\text{intensity of X-ray beam transmitted through muscle}}$$

ratio = ..... [3]

**(ii)** Use your answer in **(i)** to suggest whether an X-ray image of the bone and muscle would show good or poor contrast.

.....

.....

.....[2]

**Q15.**

10 **(a)** By reference to ultrasound waves, state what is meant by *acoustic impedance*.

For Examine Use

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..... [2]

**(b)** An ultrasound wave is incident on the boundary between two media. The acoustic impedances of the two media are $Z_1$ and $Z_2$, as illustrated in Fig. 10.1.

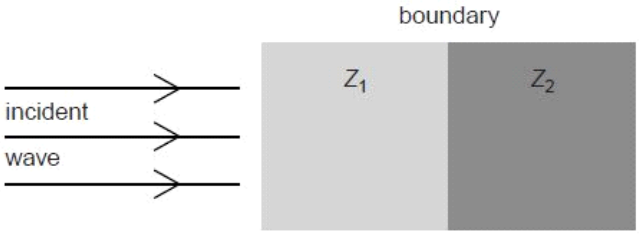


**Fig. 10.1**

Explain the importance of the difference between $Z_1$ and $Z_2$ for the transmission of ultrasound across the boundary.

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.....

..... [3]

**(c)** Ultrasound frequencies as high as 10 MHz are used in medical diagnosis.
State and explain one advantage of the use of high-frequency ultrasound compared with lower-frequency ultrasound.

.....

.....

..... [2]



**Q16.**

11 **(a)** Explain how the hardness of an X-ray beam is controlled by the accelerating voltage in the X-ray tube.

*For Examiner's Use*

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.....

..... [2]

**(b)** The attenuation of a parallel beam of X-ray radiation is given by the expression

$$\frac{I}{I_0} = e^{-\mu x}$$

where $\mu$ is the linear attenuation (absorption) coefficient and $x$ is the thickness of the material through which the beam passes.

**(i)** State

**1.** what is meant by *attenuation*,

.....

..... [1]

**2.** why the expression applies only to a parallel beam.

.....

.....

..... [2]

**(ii)** The linear attenuation coefficients for X-rays in bone and in soft tissue are $2.9\,cm^{-1}$ and $0.95\,cm^{-1}$ respectively.

Calculate, for a parallel X-ray beam, the ratio

$$\frac{\text{fraction } \frac{I}{I_0} \text{ of intensity transmitted through bone of thickness } 2.5\,cm}{\text{fraction } \frac{I}{I_0} \text{ of intensity transmitted through soft tissue of thickness } 6.0\,cm}.$$

ratio = ..... [2]

**Q17.**

9 **(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.

.....

.....

.....[2]

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

.....

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.....[5]

**Q18.**

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

For Examiner Use

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.....[3]

**(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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.....[5]

**Q19.**

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

For Examiner's Use

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.....[6]

**Q20.**

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

For Examiner Use

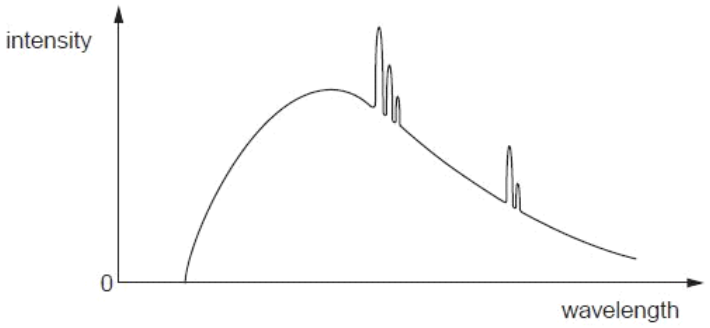


**Fig. 10.1**

Explain why

**(i)** a continuous spectrum of wavelengths is produced,

.....

.....

.....

..... [3]

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

.....

..... [1]

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

For Examiner's Use

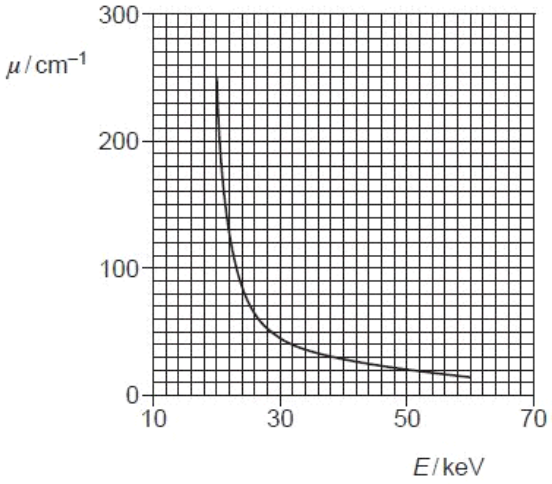


**Fig. 10.2**

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

.....

.....

.....

..... [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.

.....

.....

.....

..... [3]

**Q21.**

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

For Examiner's Use

.....

.....[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 | $4.3 \times 10^2$ |
| gel | 1500 | $1.5 \times 10^6$ |
| soft tissue | 1600 | $1.6 \times 10^6$ |
| bone | 4100 | $7.0 \times 10^6$ |

**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.

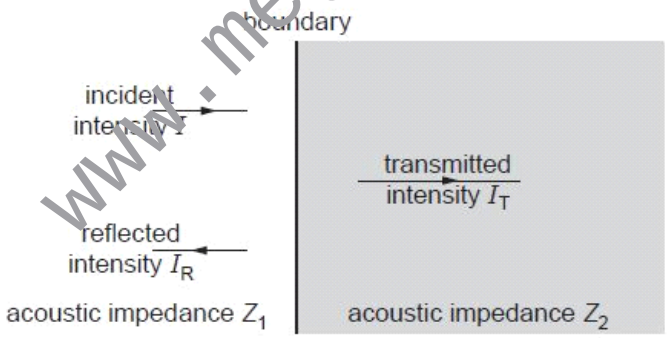


**Fig. 10.2**

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]

**(ii)** The reflection coefficient $\alpha$ 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 $\alpha$ for a boundary between

**1.** gel and soft tissue,

$\alpha$ = .....[2]

**2.** air and soft tissue.

$\alpha$ = .....[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]

**Q22.**

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.

.....

.....

.....

.....

.....[4]

**Q23.**

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

For Examiner's Use

| | $\mu$ / 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.

.....

.....

.....

.....[3]

**Q24.**

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

For Examiner's Use

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..... [6]

**Q25.**

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

For Examiner's Use

sharpness: .....

.....

contrast: .....

..... [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.

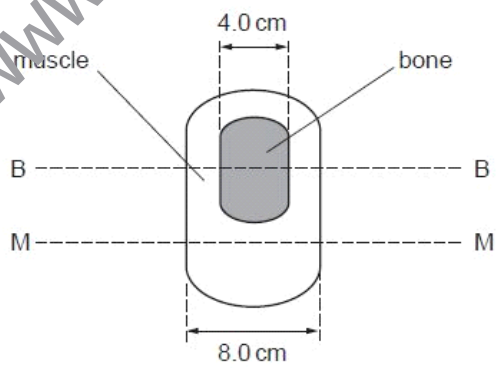


**Fig. 11.1**

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 $0.20\,cm^{-1}$ and $12\,cm^{-1}$ 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]

**Q26.**

**10** Outline the principles of CT scanning.

For Examiner's Use

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..... [6]

## Q27.

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

For Examiner's Use

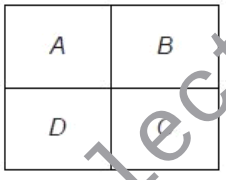


**Fig. 10.1**

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.

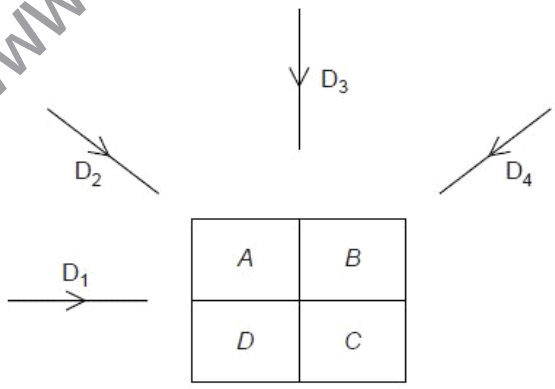


**Fig. 10.2**

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]

**(b)** Determine each of the pixel readings.

*For Examiner's Use*

| | |
|---|---|
| *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]

**Q28.**

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

*For Examiner's Use*

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.....[6]

**(b)** State and explain one advantage of the use of high frequency ultrasound as compared with low frequency ultrasound for medical diagnosis.

.....

.....

.....[2]

**(c)** The absorption (attenuation) coefficient for ultrasound in muscle is $23\,m^{-1}$.
A parallel beam of ultrasound is passed through a muscle of thickness 6.4 cm.

**(i)** Calculate the ratio

$$\frac{\text{intensity of transmitted beam}}{\text{intensity of incident beam}}.$$

ratio = .....[3]

**(ii)** An ultrasound transmitter emits a pulse.
Suggest why, when the signal from the pulse is processed, any signal received later at the detector is usually amplified more than that received at an earlier time.

*For Examiner's Use*

.....

.....

.....[2]

## Q29.

**10** Magnetic resonance imaging (MRI) requires the use of a non-uniform magnetic field superimposed on a large uniform magnetic field.

*For Examiner's Use*

State and explain the purpose of

**(a)** the large uniform magnetic field,

.....

.....

.....

.....

.....[3]

**(b)** the non-uniform magnetic field.

.....

.....

.....

.....

.....[3]

## Q30.

12 (a) Outline briefly the principles of CT scanning.

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..... [5]

(b) In a model for CT scanning, a section is divided into four voxels. The pixel numbers *P*, *Q*, *R* and *S* of the voxels are shown in Fig. 12.1.

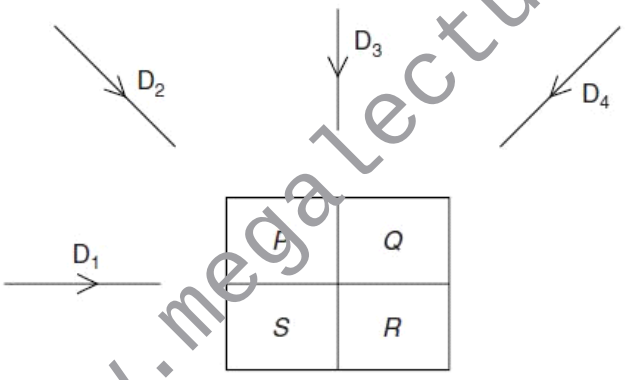


**Fig. 12.1**

The section is viewed from the four directions $D_1$, $D_2$, $D_3$ and $D_4$.
The detector readings for each direction are noted.

The detector readings are summed as shown in Fig. 12.2.

| | |
|---|---|
| 49 | 61 |
| 73 | 55 |

**Fig. 12.2**

The background reading is 34.

Determine the pixel numbers *P*, *Q*, *R* and *S* as shown in Fig. 12.3.

| | |
|---|---|
| *P* | *Q* |
| *S* | *R* |

**Fig. 12.3**

*P* = ..... *Q* = .....

*S* = ..... *R* = .....

[4]

## Q31.

11 (a) Distinguish between an X-ray image of a body structure and a CT scan.

X-ray image: .....

.....

.....

.....

.....

CT scan: .....

.....

.....

.....

.....

[5]

**(b)** Data for the linear absorption (attenuation) coefficient $\mu$ of X-ray radiation of energy 80 keV are given in Fig. 11.1.

| metal | $\mu$ / mm$^{-1}$ |
|---|---|
| aluminium | 0.46 |
| copper | 0.69 |

**Fig. 11.1**

A parallel X-ray beam is incident on a copper filter, as shown in Fig. 11.2.

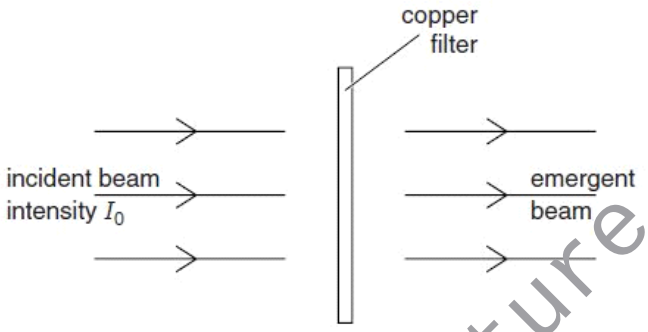


**Fig. 11.2**

The intensity of the incident beam is $I_0$.

(i) Calculate the thickness of copper required to reduce the intensity of the emergent beam to $0.25 I_0$.

thickness = ..... mm [2]

(ii) An aluminium filter of thickness 2.4 mm is now placed in the X-ray beam, together with the copper filter in **(i)**.

Calculate the fraction of the incident intensity that emerges after passing through the two filters.

fraction = ..... [2]

(iii) Express your answer in **(ii)** as a gain in decibels (dB).

gain = ..... dB [3]

**Q32.**

11 The use of X-rays in medical diagnosis gives rise to an increased exposure of the patient to radiation.

Explain why

(a) an aluminium filter may be placed in the X-ray beam when producing an X-ray image of a patient,

.....

.....

.....

.....

..... [3]

(b) the radiation dose received by a patient is different for a CT scan from that for a simple X-ray image.

.....

.....

.....

.....

.....

..... [4]

**Q33.**

11 (a) By reference to ultrasound waves, state what is meant by the *specific acoustic impedance* of a medium.

.....

.....

..... [2]

(b) A parallel beam of ultrasound of intensity $I$ is incident normally on a muscle of thickness 3.4 cm, as shown in Fig. 11.1.

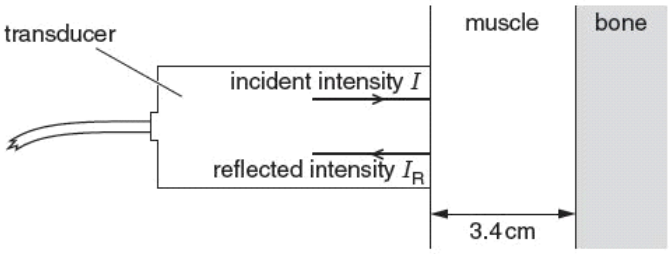


Fig. 11.1

The ultrasound wave is reflected at a muscle-bone boundary. The intensity of the ultrasound received back at the transducer is $I_R$.

Some data for bone and muscle are given in Fig. 11.2.

| | specific acoustic impedance / kg m$^{-2}$ s$^{-1}$ | linear absorption coefficient / m$^{-1}$ |
|---|---|---|
| bone | $6.4 \times 10^6$ | 130 |
| muscle | $1.7 \times 10^6$ | 23 |

Fig. 11.2

(i) The intensity reflection coefficient $\alpha$ for two media having specific acoustic impedances $Z_1$ and $Z_2$ is given by

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

Calculate the fraction of the ultrasound intensity that is reflected at the muscle-bone boundary.

fraction = ..... [2]

(ii) Calculate the fraction of the ultrasound intensity that is transmitted through a thickness of 3.4 cm of muscle.

fraction = ..... [3]

(iii) Use your answers in (i) and (ii) to determine the ratio $\frac{I_R}{I}$.

ratio = ..... [2]