8 Oxygen-15 $\left({}^{15}_{8}\mathrm{O}\right)$ is radioactive and has a half-life of 2.04 minutes.

The decay of oxygen-15 produces positrons. For this reason, oxygen-15 is sometimes used as a tracer in positron emission tomography (PET scanning).

(a) State what is meant by a tracer.

....

....

.... [2]

(b) The equation for the decay of oxygen-15 is

$$ {}^{15}_{8}\mathrm{O} \rightarrow {}^{P}_{Q}\mathrm{X} + {}^{R}_{S}\beta^{+} + \mathrm{Z} $$

where X is the nucleus formed during the decay and Z is another particle.

(i) State the values of the integers P, Q, R and S.

P = ... R = ...

Q = ... S = ...

[2]

(ii) State the name of particle Z.

.... [1]

(c) **(i)** Define the activity of a sample.

....

.... [1]

(ii) Calculate the decay constant of oxygen-15. Give a unit with your answer.

decay constant = ... unit .... [2]

(iii) Determine the rate at which positrons are produced in a sample of oxygen-15 that has a mass of 2.85×10^{-6} kg.

rate = ... s^{-1} [4]

(d) The particles that are emitted from the body and detected outside it during PET scanning are not positrons but another type of particle.

(i) State the name of the particles that are detected.

.... [1]

(ii) Explain how these particles are formed inside the body.

....

....

....

.... [2]

10 **(a)** State what is meant by contrast in an X-ray image.

....

.... [1]

(b) X-rays of intensity I_0 are incident normally on a structure, as shown in Fig. 10.1.

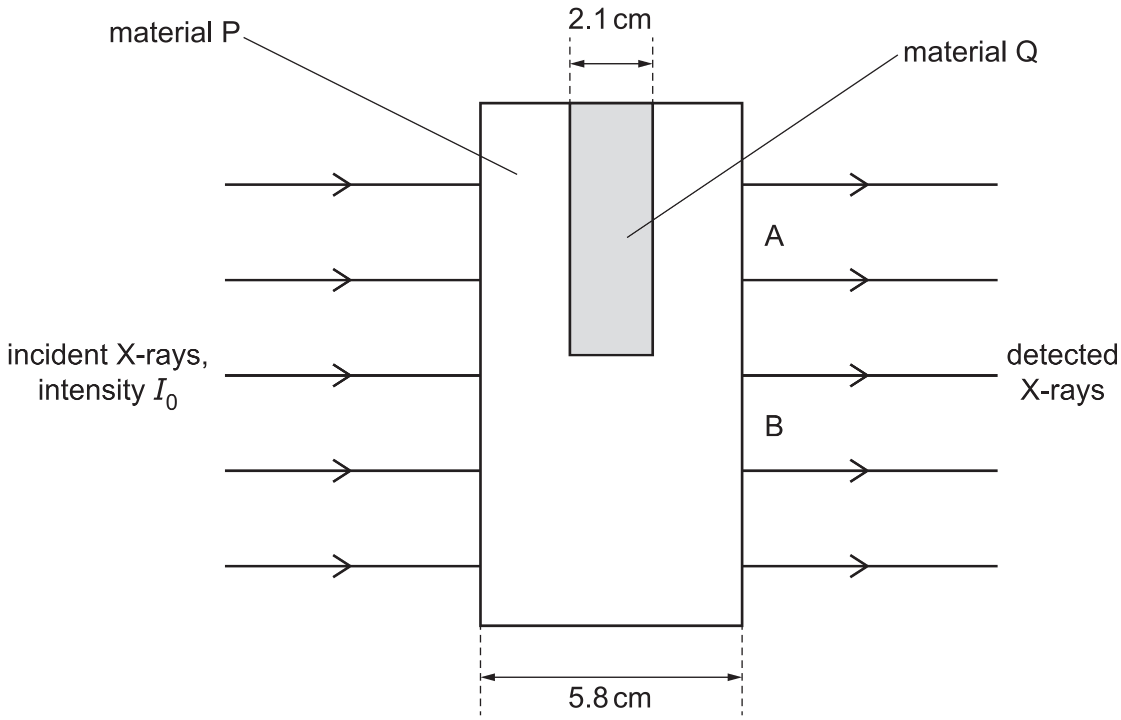

Fig. 10.1

Material P has a linear attenuation coefficient of 0.35 cm^{-1}.
The X-rays emerging from the structure in region A have an intensity of $0.053I_0$.

(i) Show that the intensity of the X-rays emerging in region B is $0.13I_0$.

[1]

(ii) Determine the linear attenuation coefficient μ of material Q.

μ = ... cm^{-1} [3]

(iii) Use the information in **(b)(i)** to suggest why the X-rays emerging from the structure form an image that has poor contrast.

....

....

.... [1]

(c) Explain how X-rays are used in computed tomography (CT) scanning to produce a three-dimensional image of an internal structure.

....

....

....

....

.... [3]

10 **(a)** Define specific acoustic impedance.

....

....

.... [2]

(b) Explain how ultrasound waves are detected by a piezoelectric crystal.

....

....

.... [2]

(c) Table 10.1 shows the specific acoustic impedance *Z* for body tissue, water and steel.

Table 10.1

material	Z / kg m^{-2} s^{-1}
body tissue	1.38×10^{6}
water	1.48×10^{6}
steel	4.04×10^{7}

(i) Calculate the intensity reflection coefficient for ultrasound incident on a water–steel boundary.

intensity reflection coefficient = ... [2]

(ii) Explain, without calculation, what is likely to happen when ultrasound is incident on a body tissue–water boundary.

....

....

.... [2]

10 **(a)** Describe how the piezoelectric crystal in a transducer generates ultrasound waves for use in medical diagnosis.

....

....

....

....

.... [3]

(b) A parallel ultrasound beam is incident on the boundary between two media, as illustrated in Fig. 10.1.

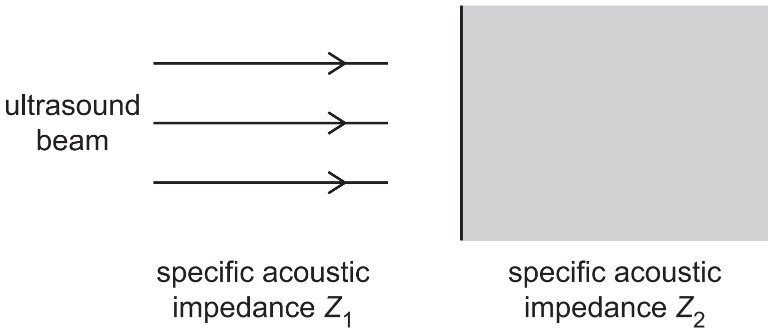

Fig. 10.1

The media have specific acoustic impedances Z_1 and Z_2.

At the boundary, a fraction α of the incident intensity of the ultrasound beam is reflected. The remainder is transmitted.

(i) State what is meant by specific acoustic impedance.

....

....

.... [2]

(ii) Describe how α depends on the relative values of Z_1 and Z_2.

....

....

....

.... [2]

(c) A parallel ultrasound beam of intensity I_0 enters a region of soft tissue. After passing a distance of 2.1 cm through this tissue, the intensity of the ultrasound is $0.62 I_0$.

Calculate the linear attenuation coefficient μ of ultrasound in the soft tissue. Give a unit with your answer.

μ = ... unit .... [2]

6 Two parallel metal plates X and Y are separated by a distance of 0.041 m, as shown in Fig. 6.1.

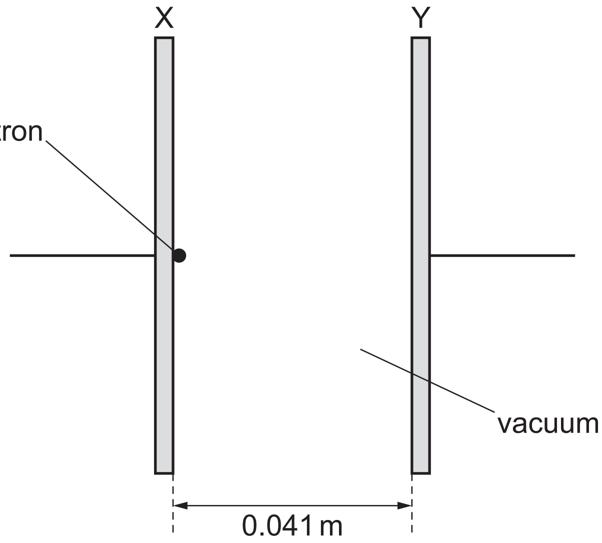

Fig. 6.1

There is a vacuum between the plates. An electron is at rest at the centre of plate X.

A potential difference (p.d.) of 58 kV is applied across the plates. This causes the electron to accelerate towards plate Y.

(a) On Fig. 6.1, use the symbols + and – to indicate which of plates X and Y is the positive plate and which is the negative plate. [1]

(b) **(i)** Calculate the electric field strength *E* between the plates. Give a unit with your answer.

E = ... unit .... [2]

(ii) Determine the acceleration of the electron.

acceleration = ... m s^{-2} [2]

(c) Many electrons are now accelerated from rest from plate X to plate Y in Fig. 6.1. When the electrons hit plate Y, the absorption of their kinetic energies results in the emission of electromagnetic waves.

(i) Show that the minimum wavelength of these electromagnetic waves is 21 pm.

[3]

(ii) State the region of the electromagnetic spectrum that contains these waves.

.... [1]

(iii) Explain how these electromagnetic waves may be used to form images of internal body structures.

....

....

....

.... [2]

4 A small crystal is made to vibrate with simple harmonic motion. The variation with time t of the displacement x of one surface of the crystal from its equilibrium position is shown in Fig. 4.1.

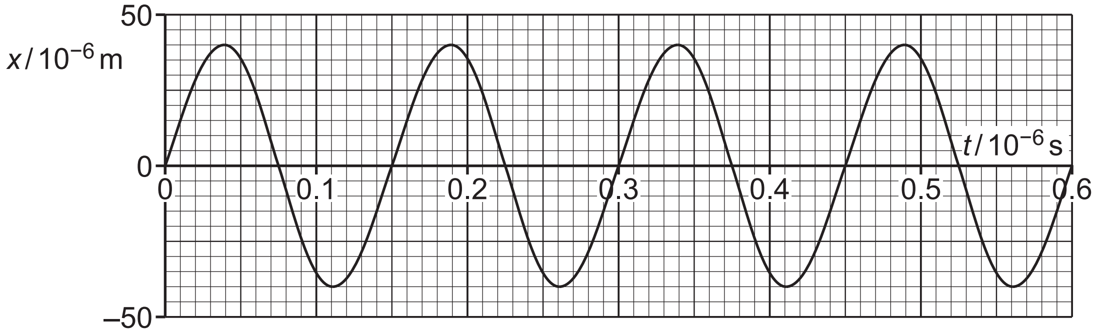

Fig. 4.1

(a) Show that the angular frequency of the vibration of the surface is $4.2 \times 10^{7}\,\text{rad}\,\text{s}^{-1}$.

[2]

(b) Determine the maximum acceleration a_0 of the vibration of the surface.

a_0 = ... $\text{m}\,\text{s}^{-2}$ [2]

(c) The crystal may be modelled as a single mass of 2.4×10^{-4} kg that vibrates as shown in Fig. 4.1.

Calculate the total energy E of the vibrations.

E = ... J [3]

(d) The crystal generates ultrasound waves that are used to obtain diagnostic information about internal structures.

(i) The crystal is made from piezoelectric material.

Explain how the crystal is made to vibrate.

....

....

....

.... [2]

(ii) A parallel beam of ultrasound waves is incident on a muscle-bone boundary. Data for muscle and bone are given in Table 4.1.

Table 4.1

material	density / $kg\,m^{-3}$	speed of sound / $m\,s^{-1}$
muscle	1100	1600
bone	1900	4100

Calculate the percentage of the intensity of the ultrasound beam that is transmitted at this boundary.

percentage transmitted = ... % [3]

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10 (a) Describe how reflected ultrasound pulses may be used to obtain diagnostic information about internal structures.

....

....

....

.... [2]

(b) (i) Define specific acoustic impedance of a medium.

....

....

.... [2]

(ii) Table 10.1 shows some data for water and for glass.

Table 10.1

	density / $kg\,m^{-3}$	speed of sound / $m\,s^{-1}$
water	1000	1420
glass	2500	4560

Determine the intensity reflection coefficient for ultrasound that is incident on a water–glass boundary.

intensity reflection coefficient = ... [3]

9 **(a)** Electrons in a vacuum are accelerated through a potential difference of 84 kV. The electrons then strike a metal target and X-rays are produced.

(i) Calculate the minimum wavelength of the X-rays that are produced.

wavelength = ... m [2]

(ii) The melting points of two metals are given in Table 9.1.

Table 9.1

metal	melting point / °C
copper	1090
tungsten	3420

Suggest why the metal target is made from tungsten rather than copper.

....

....

.... [2]

(b) An X-ray beam is incident normally on a sample of soft tissue and bone as shown in Fig. 9.1.

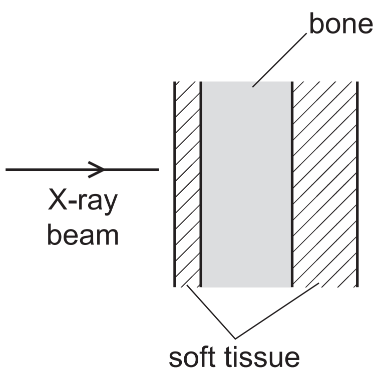

Fig. 9.1

Data for the two materials are given in Table 9.2.

Table 9.2

medium	linear attenuation coefficient μ / cm^{-1}	specific acoustic impedance Z / $10^6\,kg\,m^{-2}\,s^{-1}$
soft tissue	0.22	1.7
bone	3.0	7.8

The total thickness of soft tissue is x. The total thickness of bone is also x.

The incident intensity of the X-ray beam is I_0. The transmitted intensity of the X-ray beam is 13% of the incident intensity.

Determine x, in cm.

x = ... cm [3]

(c) **(i)** Define the specific acoustic impedance of a medium.

....

....

.... [2]

(ii) Use data from Table 9.2 to calculate the percentage of the intensity of ultrasound that is transmitted at a boundary between soft tissue and bone.

percentage transmitted = ... % [2]

(iii) The ultrasound is now incident on the sample of soft tissue and bone shown in Fig. 9.1.

Suggest **two** reasons why the transmitted intensity through the sample is less than the answer in **(c)(ii)**.

1 ....

....

2 ....

....
[2]

9 Fluorine-18 ($^{18}_{9}$F) is a radioactive nuclide that is used as a tracer in positron emission tomography (PET scanning). Fluorine-18 decays to a nuclide of oxygen (O) according to

$$^{18}_{9}\mathrm{F} \longrightarrow {}^{Q}_{P}\mathrm{X} + {}^{R}_{8}\mathrm{O}.$$

(a) **(i)** State what is meant by a tracer.

....

.... [1]

(ii) State the symbol of the particle that is represented by X and the values of P, Q and R.

X: .... P: ....

Q: .... R: ....

[2]

(b) **(i)** Explain how the radioactive decay of fluorine-18 results in the emission from the body of the gamma-ray photons that are detected during a PET scan.

....

....

....

.... [2]

(ii) Explain how the detection of the gamma-ray photons is used to produce an image of the tissue being examined.

....

....

....

.... [2]

(c) The half-life of fluorine-18 is T.
A patient is injected with amount of substance n of fluorine-18.

(i) Determine an expression for the initial value R_0 of the rate R of production of gamma-ray photons by the tracer, in terms of n, T and the Avogadro constant N_A.

R_0 = ... [3]

(ii) On Fig. 9.1, sketch the variation with time t of R.

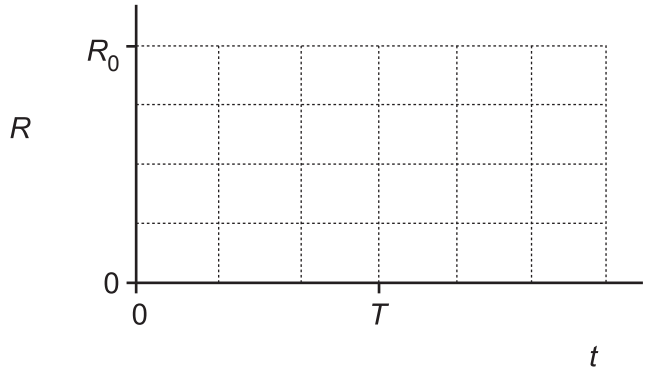

Fig. 9.1

[2]

10 Ultrasound and X-rays are both types of wave that are used in medical diagnosis to form images of internal body structures.

(a) Complete Table 10.1 to state, for each type of wave:

- the method of production of the wave
- whether the wave that is detected and used to form the image is the wave that has been absorbed, reflected or transmitted by the internal body structure.

Table 10.1

	ultrasound	X-rays
method of production	....	....
detected wave (absorbed, reflected or transmitted)	....	....

[4]

(b) (i) For one type of wave passing through tissue, the wave has 72% of its initial intensity after it has passed through 6.2 cm of the tissue.

Calculate the linear attenuation coefficient μ of the tissue for this wave.

μ = ... cm^{-1} [2]

(ii) Another wave of the same type as in **(b)(i)** passes through 9.3 cm of the same tissue.

Calculate the percentage of the initial intensity of the wave that is attenuated by the tissue.

percentage attenuated = ... % [2]

10 **(a)** X-rays for use in medical diagnosis are produced in an X-ray tube. In the X-ray tube, charged particles are accelerated towards a metal target by an applied potential difference (p.d.).

(i) State the name of the charged particles that are accelerated by the applied p.d.

.... [1]

(ii) Explain how X-rays are produced at the metal target.

....

....

....

.... [2]

(iii) Calculate the minimum wavelength of X-rays produced when the applied p.d. is 5.80 kV.

wavelength = ... m [3]

(b) X-rays pass through a medium that has an attenuation coefficient of 1.4 cm^{-1}.

Calculate the percentage of the X-ray energy that is **absorbed** by a 2.8 cm thickness of this medium.

percentage absorbed = ... % [3]

8 **(a)** Table 8.1 shows some data relating to the properties of air, gel and body tissue. The data are given to three significant figures.

Table 8.1

material	density / $kg\,m^{-3}$	speed of sound / $m\,s^{-1}$	specific acoustic impedance / $kg\,m^{-2}\,s^{-1}$
air		340	440
gel	1200	1400	
tissue	1090		1.68×10^6

(i) Show that the specific acoustic impedance of gel is $1.68 \times 10^6\,kg\,m^{-2}\,s^{-1}$.

[1]

(ii) Complete Table 8.1 by calculating the missing values to three significant figures. Use the space below for any working that you need.

[2]

(b) Use the information in **(a)** to calculate the intensity reflection coefficient for:

(i) an air–tissue boundary

intensity reflection coefficient = ... [2]

(ii) a gel–tissue boundary.

intensity reflection coefficient = ... [1]

(c) Use your answers in **(b)** to explain why gel is applied to the skin during ultrasound scanning.

....

....

.... [2]

9 Ultrasound is used to produce diagnostic information about internal body structures.

(a) Explain how ultrasound waves are detected.

....

....

....

.... [3]

(b) An alternating voltage V varies with time t according to

$$V = V_o \sin \omega t.$$

The voltage is applied to an ultrasound probe.

The root-mean-square (r.m.s.) voltage is 66 V. The frequency of the ultrasound generated by the probe is 4.3 MHz.

Determine the values of

(i) V_o

V_o = ... V [1]

(ii) ω.

ω = ...rad s^{-1} [1]

(c) Table 9.1 contains information about air and soft tissue.

Table 9.1

	density / kg m^{-3}	speed of ultrasound / m s^{-1}	specific acoustic impedance / ....
air	1.30	330	4.3×10^2
soft tissue		1600	1.7×10^6

(i) Determine the unit for the specific acoustic impedance values shown in Table 9.1. [1]

(ii) Calculate the density of soft tissue.

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

(iii) Use data from Table 9.1 to explain why ultrasound cannot be used to produce an image inside an air-filled cavity such as the lungs.

....

....

....

.... [2]

10 Positron emission tomography (PET scanning) involves the detection of gamma-radiation in order to identify the position of origin of positrons in the body.

(a) **(i)** Positrons are not naturally present in the body.

Explain how positrons come to be present in the body during PET scanning.

....

....

.... [2]

(ii) Explain how positrons cause the emission of gamma-radiation from the body during PET scanning.

....

....

....

.... [3]

(b) Show that the wavelength of the gamma-radiation that is detected during PET scanning is approximately 2.4 pm. Explain your reasoning.

[4]

7 **(a)** A sinusoidal alternating voltage has a root-mean-square (r.m.s.) potential difference (p.d.) of 4.2 V and a frequency of 50 kHz.

(i) The alternating voltage is applied across a resistor of resistance 760 Ω.

By considering the peak voltage, show that the maximum power dissipated by the resistor is 46 mW.

[2]

(ii) On Fig. 7.1, draw a smooth curve to show how the power P dissipated in the resistor varies with time t between t = 0 and t = 40 μs. Assume that P = 0 when t = 0.

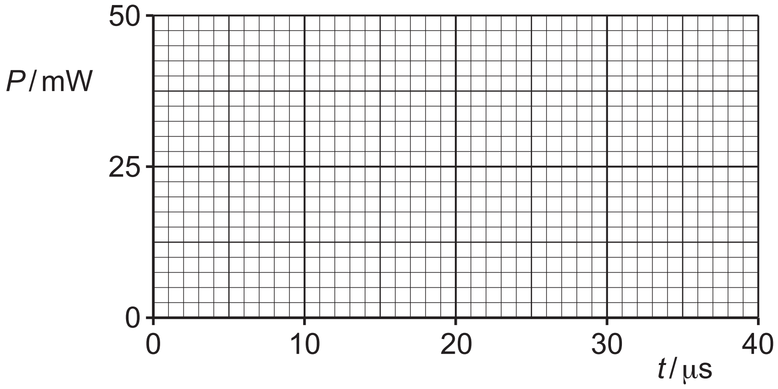

Fig. 7.1

[3]

(iii) Use your line in **(a)(ii)** to explain why the mean power dissipated in the resistor is 23 mW.

....

....

.... [1]

(b) The alternating voltage in **(a)** is now applied to a piezoelectric crystal in air.

(i) Explain what happens to the air surrounding the crystal.

....

....

....

.... [3]

(ii) A second piezoelectric crystal is placed in the air near to the first crystal.

Explain the effect of the surrounding air in **(b)(i)** on the second crystal.

.... [1]