CAMBRIDGE INTERNATIONAL A LEVEL • PHYSICS 9702

Topical Questions

Unit 24: Medical Physics

Past Papers 2021 – 2025

QUESTION PAPER 26 Questions

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Question 1

(a) State, for an X-ray image, what is meant by:

(i) *sharpness*

.....

..... [1]

(ii) *contrast*.

.....

..... [1]

(b) A parallel X-ray beam passes through a thickness of 2.3 cm of soft body tissue. The intensity of the emerging beam is 12% of the intensity of the incident beam.

Calculate the linear attenuation (absorption) coefficient μ of the soft body tissue. Give a unit with your answer.

μ = ... unit ..... [3]

(c) In medical diagnosis, X-rays may be used to produce a single X-ray image or may be used in computed tomography (CT scanning).

Suggest an advantage and a disadvantage of CT scanning compared with single X-ray imaging for diagnosis.

advantage: .....

.....

disadvantage: .....

.....

[2]

[Total: 7]

Question 2

(a) Define radioactive *decay constant*.

.....

.....

..... [2]

(b) A sample of radioactive iodine-131 ($^{131}_{53}\text{I}$) of mass 5.87×10^{-10} kg has an activity of 2.92×10^{9} Bq.

Determine the decay constant of iodine-131.

decay constant = ... s^{-1} [3]

(c) Suggest **two** reasons why a detector placed near to the sample in **(b)** would record a count rate much less than 2.92×10^{9} counts per second.

1. .....

.....

2. .....

.....

[2]

[Total: 7]

Question 3

(a) A piezoelectric transducer containing a quartz crystal is used to obtain diagnostic information about internal structures.

Describe the function of the quartz crystal.

.....

.....

.....

..... [3]

(b) **(i)** Define *specific acoustic impedance*.

.....

.....

..... [2]

(ii) Describe, qualitatively, how the specific acoustic impedances of two materials affect the intensity reflection coefficient at a boundary between the materials.

.....

.....

.....

..... [2]

[Total: 7]

Question 4

(a) State how, in a modern X-ray tube, the intensity of the X-ray beam and its hardness are controlled.

intensity: .....

.....

hardness: .....

.....

[2]

(b) A model of a limb consists of soft tissue and bone, as illustrated in Fig. 11.1.

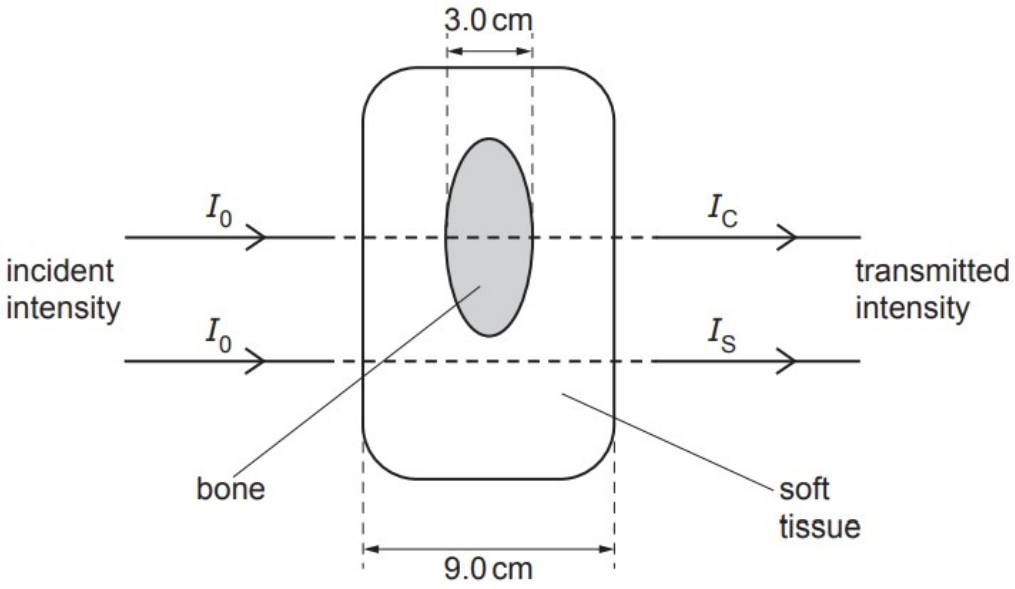


Fig. 11.1

The soft tissue has a thickness of 9.0 cm. The bone within the soft tissue has a thickness of 3.0 cm.

Data for the linear attenuation (absorption) coefficient μ of X-rays in soft tissue and in bone are shown in Table 11.1.

Table 11.1

	μ/cm^{-1}
soft tissue	0.92
bone	2.9

A parallel beam of X-rays of intensity I_0 is incident normally on the model.

Calculate, in terms of I_0:

(i) the transmitted intensity I_S through soft tissue alone

I_S = ... I_0 [2]

(ii) the transmitted intensity I_C through soft tissue and bone.

I_C = ... I_0 [2]

(c) By reference to your answers in **(b)**, suggest, with a reason, whether good contrast on an X-ray image would be obtained.

.....

..... [1]

[Total: 7]

Question 5

(a) State the purpose of computed tomography (CT scanning).

.....

..... [1]

(b) Outline the principles of CT scanning.

.....

.....

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.....

.....

.....

.....

.....

.....

..... [5]

[Total: 6]

Question 6

(a) Electrons are accelerated through a potential difference of 15 kV. The electrons collide with a metal target and a spectrum of X-rays is produced.

(i) Explain why a continuous spectrum of energies of X-ray photons is produced.

.....

.....

.....

.....

..... [3]

(ii) Calculate the wavelength of the highest energy X-ray photon produced.

wavelength = ... m [3]

(b) A beam of X-rays has an initial intensity I_o. The beam is directed into some body tissue. After passing through a thickness x of tissue the intensity is I. The graph in Fig. 11.1 shows the variation with x of ln (I/I_o).

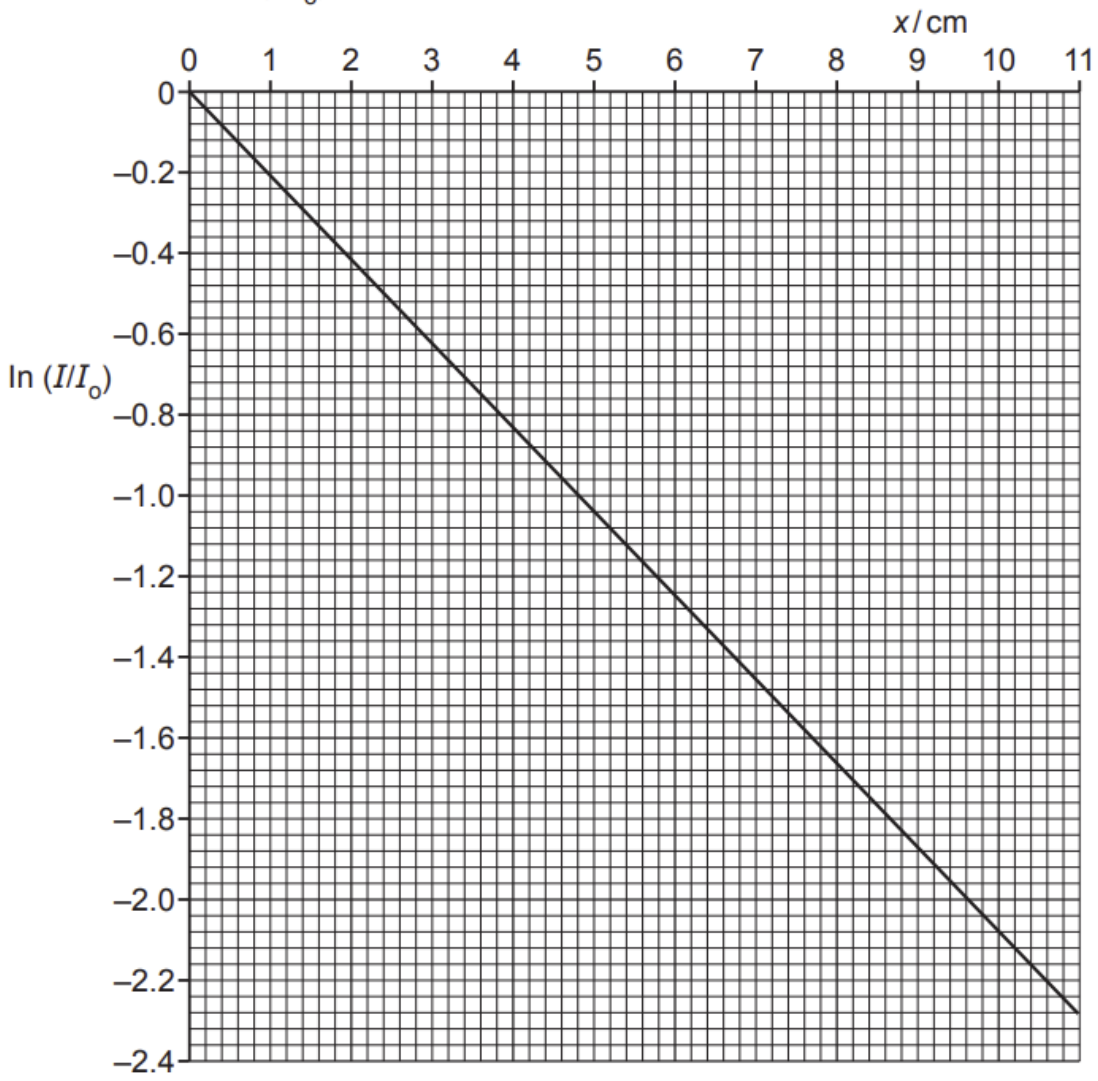


Fig. 11.1

(i) Determine the linear attenuation (absorption) coefficient μ for this beam of X-rays in the tissue.

μ = ... cm^{-1} [2]

(ii) Determine the thickness of tissue that the X-ray beam must pass through so that the intensity of the beam is reduced to 5.0% of its initial value.

thickness = ... cm [2]

[Total: 10]

Question 7

In an X-ray tube, electrons are accelerated through a potential difference of 75 kV. The electrons then strike a tungsten target of effective mass 15 g.

The electron energy is converted into the energy of X-ray photons with an efficiency of 5.0%. The rest of the energy is converted into thermal energy.

(a) The X-ray tube produces an image using a current of 0.40 A for a time of 20 ms.

The specific heat capacity of tungsten is 130 $J\,kg^{-1}\,K^{-1}$.

Determine the temperature rise ΔT of the tungsten target.

ΔT = ... K [3]

(b) The linear attenuation coefficient of the X-ray photons in muscle is 0.22 cm^{-1}.

Calculate the thickness t of muscle that will absorb 80% of the incident X-ray intensity.

t = ... cm [2]

(c) Table 10.1 shows the linear attenuation coefficient μ for the X-ray photons in different tissues.

Table 10.1

	μ/cm^{-1}
bone	3.0
blood	0.23
muscle	0.22

Two X-ray images are taken, one of equal thicknesses of bone and muscle and another of equal thicknesses of blood and muscle.

Explain why one of these images has good contrast, but the other does not.

.....

.....

.....

..... [2]

[Total: 7]

Question 8

Positron emission tomography (PET scanning) obtains diagnostic information from a person. The information is used to form an image.

(a) PET scanning uses a tracer.

Explain what is meant by a tracer.

.....

..... [1]

(b) PET scanning involves annihilation.

(i) Explain what is meant by annihilation.

.....

..... [1]

(ii) State the names of the particles involved in the annihilation process.

..... [1]

(c) **(i)** Calculate the total energy released in one annihilation event in **(b)**.

energy = ... J [1]

(ii) Calculate the wavelength of each gamma photon released.

wavelength = ... m [2]

(d) Explain how the gamma photons are used to produce an image.

.....

.....

.....

.....

.....

..... [3]

[Total: 9]

Question 9

(a) **(i)** Explain how X-rays are produced for use in medical diagnosis.

.....

.....

.....

..... [3]

(ii) State why X-ray images are taken of multiple sections of the body during computed tomography (CT) scanning.

.....

..... [1]

(b) An X-ray image is taken of the structure shown in Fig. 9.1.

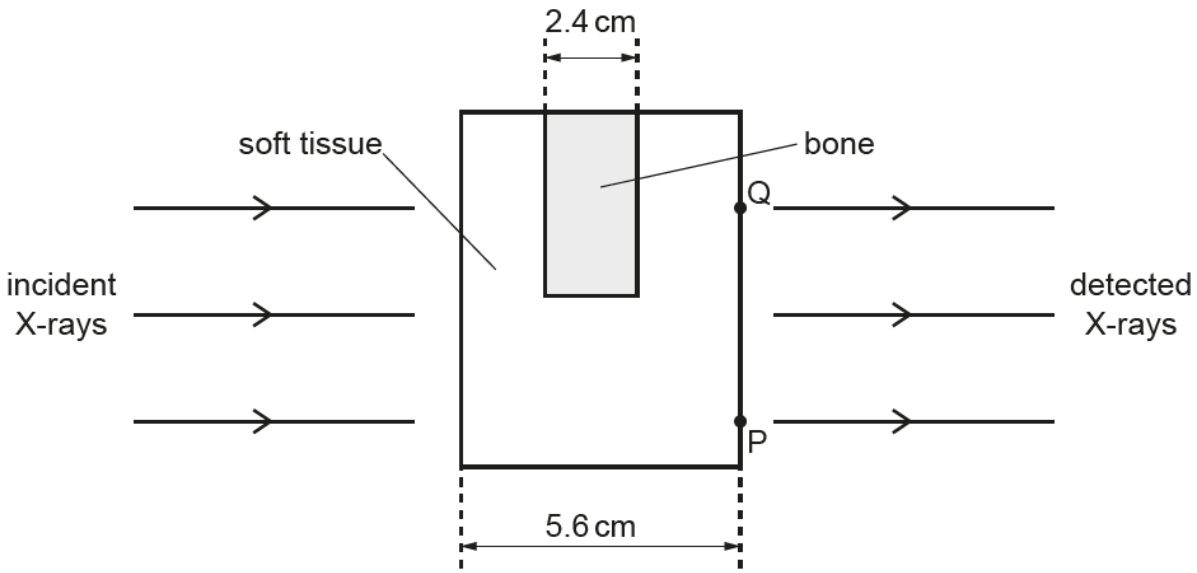


Fig. 9.1

The linear attenuation coefficient of bone is $3.4\,cm^{-1}$.
The linear attenuation coefficient of soft tissue is $0.89\,cm^{-1}$.

The incident X-rays are parallel and have a uniform intensity I_0 across the structure.

Determine, in terms of I_0, the intensity of the detected X-rays from:

(i) point P

detected intensity = ... I_0 [2]

(ii) point Q.

detected intensity = ... I_0 [2]

(c) Explain, with reference to your answers in **(b)**, whether the X-ray image of the structure in Fig. 9.1 has good contrast.

.....

.....

..... [1]

[Total: 9]

Question 10

(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 $t = 40\,\mu s$. Assume that $P = 0$ when $t = 0$.

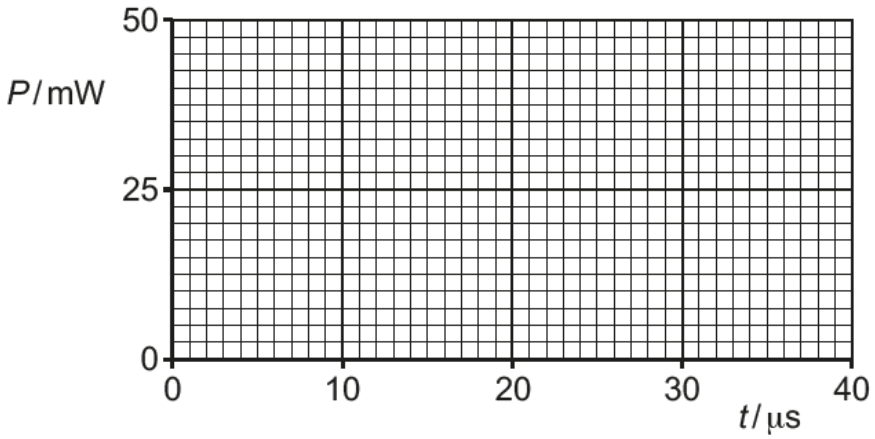


Fig. 7.1

[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]

[Total: 10]

Question 11

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]

[Total: 9]

Question 12

(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 1.68×10^6 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]

[Total: 8]

Question 13

(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]

[Total: 9]

Question 14

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]

[Total: 8]

Question 15

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

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

(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.

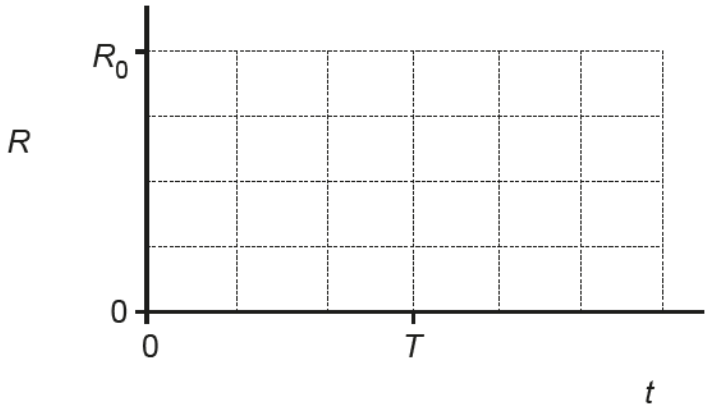


Fig. 9.1

[2]

[Total: 12]

Question 16

(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.

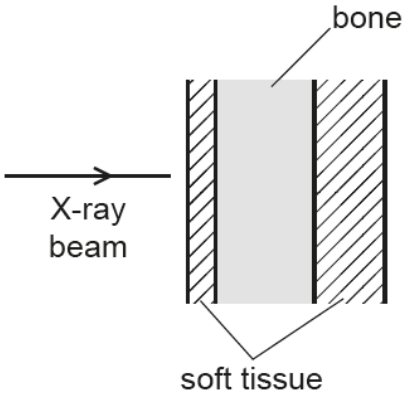


Fig. 9.1

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]

[Total: 13]

Question 17

(a) State what is meant by a photon.

.....

.....

..... [2]

(b) Fig. 8.1 shows a tube in which X-rays are produced at a metal target.

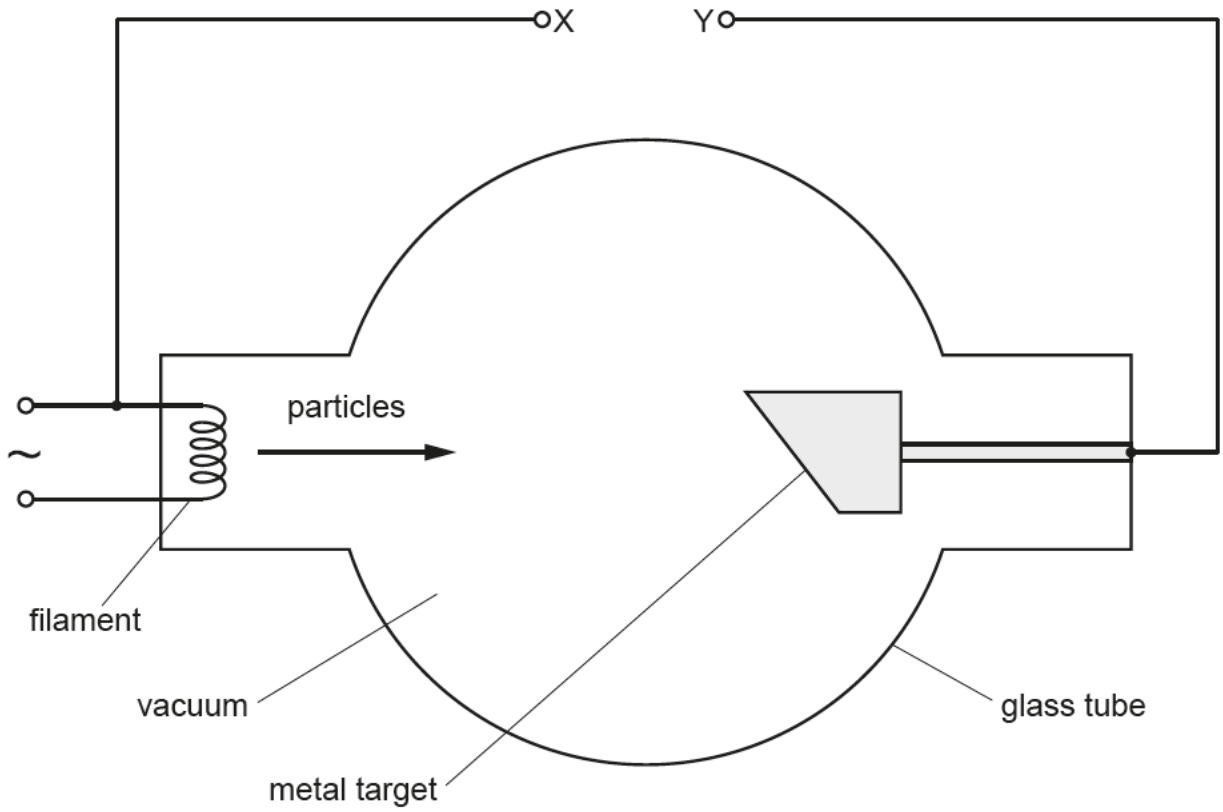


Fig. 8.1

Particles are accelerated from the filament to the target by a constant high voltage applied across the terminals X and Y.

(i) State the name of the particles.

..... [1]

(ii) On Fig. 8.1, use + and – signs to label terminals X and Y to indicate the polarity of the high voltage. [1]

(c) For an accelerating voltage of 32 kV in Fig. 8.1, determine:

(i) the maximum energy, in MeV, of an X-ray photon produced at the target

maximum photon energy = ... MeV [1]

(ii) the maximum momentum of an X-ray photon produced at the target

maximum photon momentum = ... Ns [2]

(iii) the minimum wavelength of X-rays produced at the target.

minimum wavelength = ... m [3]

(d) Explain why X-rays can be used to produce images of internal body structures that have good contrast.

.....

.....

.....

.....

..... [3]

[Total: 13]

Question 18

(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]

[Total: 7]

Question 19

A small sample of fluorine-18 injected into the body acts as a tracer for use in medical imaging.

(i) Describe how the interaction of a β^+ particle with an electron in the body enables the formation of an image.

.....

.....

.....

.....

..... [3]

(ii) Suggest why 110 minutes is a suitable half-life for a nuclide used as a tracer in medical diagnosis.

.....

.....

..... [2]

[Total: 10]

Question 20

Positron emission tomography (PET scanning) uses a radioactive tracer.

(i) State what happens to the positrons emitted by the tracer.

.....

..... [1]

(ii) Explain why a tracer with a half-life of approximately 2 hours is a suitable tracer to use.

.....

..... [1]

Question 21

(a) State what is meant by the de Broglie wavelength.

.....

..... [1]

(b) Calculate the de Broglie wavelength of an electron moving at a speed of $4.9 \times 10^7\,\text{m s}^{-1}$.

wavelength = ... m [2]

(c) State **one** similarity and **one** difference between an electron and a positron.

similarity: .....

.....

difference: .....

.....

[2]

(d) An electron moving at a speed of $4.9 \times 10^7\,\text{m s}^{-1}$ collides with a positron that is travelling at the same speed in the opposite direction. As a result of the collision, two gamma-ray photons are produced.

(i) State the name of this type of reaction.

..... [1]

(ii) State what happens to the electron and to the positron.

.....

.....

..... [2]

(iii) Explain why two gamma-ray photons are produced, rather than just one.

.....

..... [1]

(iv) Show that the kinetic energy of the electron before the collision is 1.1×10^{-15} J.

[1]

(v) Use the information in **(d)(iv)** to determine, to three significant figures, the wavelength associated with the gamma radiation emitted in the collision.

wavelength = ... m [3]

[Total: 13]

Question 22

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

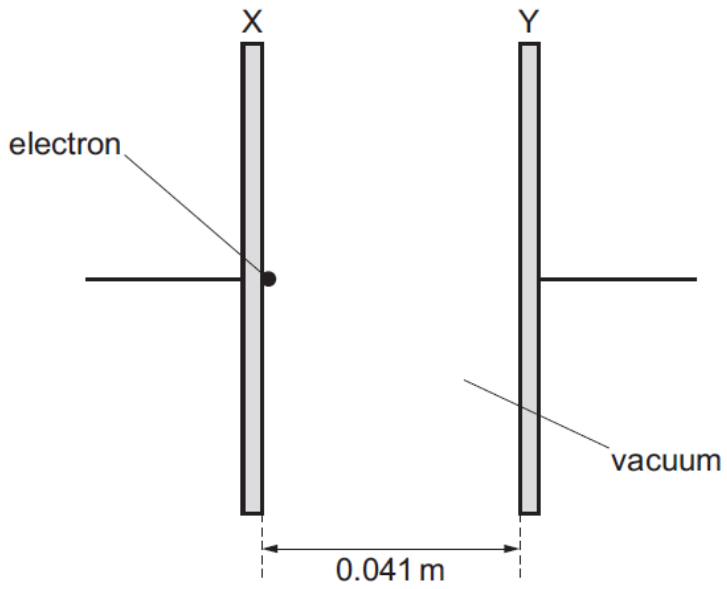


Fig. 6.1

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]

[Total: 11]

Question 23

(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.

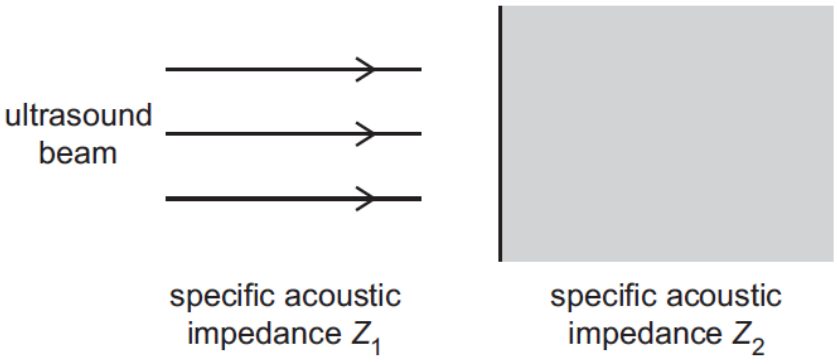


Fig. 10.1

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]

[Total: 9]

Question 24

(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]

[Total: 8]

Question 25

(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.

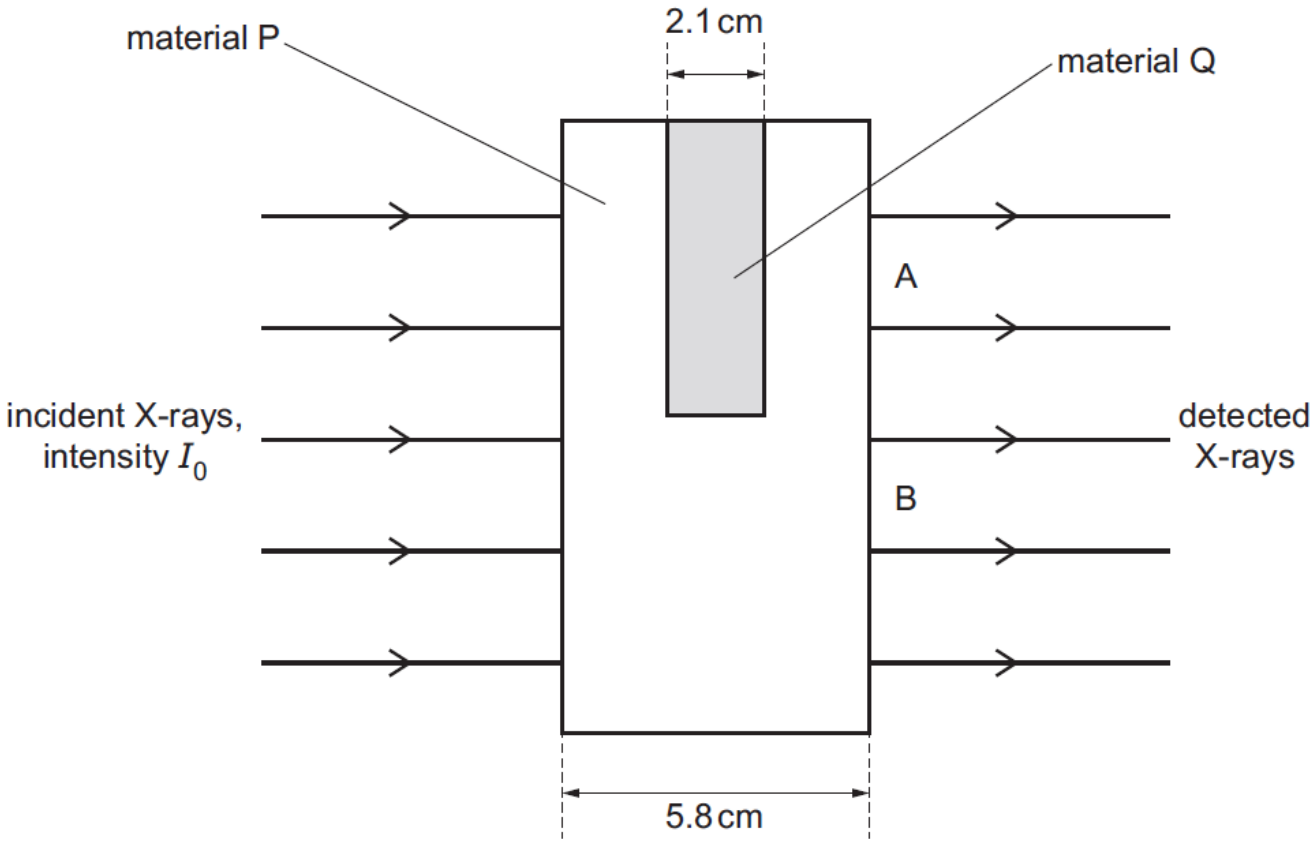


Fig. 10.1

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]

[Total: 9]

Question 26

Oxygen-15 ($^{15}_{8}O$) 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

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

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]

[Total: 15]

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