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OCR A LEVEL PHYSICS A (H556): QUESTIONS BY TOPIC

Medical imaging (6.5)

A Level Physics A (H556) · Module 6: Particles and medical physics

29 questions · 154 marks · Mark schemes included

OCR A Level Physics A (H556), June 2017 – June 2025

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HOW TO USE THIS BOOKLET

Questions run from the lowest mark tariff to the highest, so similar questions sit together.

Click any row below to jump straight to that question.

On every question page, click ANSWER in the top-right corner to jump to its mark scheme.

Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

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QUESTIONS

29 questions · 154 marks · lowest tariff first



MULTIPLE-CHOICE QUESTIONS

12 questions in this booklet



- 14** There are four important attenuation mechanisms by which X-ray photons may interact when they pass through matter.

In which mechanism is the X-ray photon scattered with a longer wavelength?

- A** simple scattering
- B** Compton effect
- C** pair production
- D** photoelectric effect

Your answer

[1]



- 11 The acoustic impedance Z of a material in the shape of a cube can be determined using the equation

$$Z = \frac{Mc}{L^3}$$

where M is the mass of the material, L is the length of each side of the cube and c is the speed of ultrasound in the material.

The percentage uncertainty in L is 1.2% and the percentage uncertainty in c is 1.8%. The percentage uncertainty in M is negligible.

What is the percentage uncertainty in Z ?

- A 2.2%
- B 3.0%
- C 4.2%
- D 5.4%

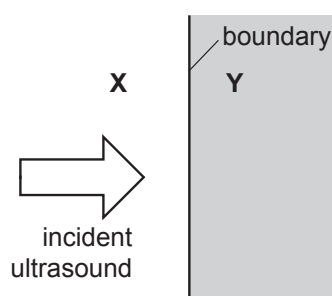
Your answer

[1]

12 The table shows some data on two tissues in a patient.

Tissue	Density	Acoustic impedance
X	ρ	$1.5Z$
Y	1.3ρ	Z

Ultrasound in tissue **X** is incident at the boundary between the tissues **X** and **Y**.



What is the percentage of the ultrasound intensity reflected at the boundary?

- A** 1.7 %
- B** 4.0 %
- C** 13 %
- D** 20 %

Your answer

[1]

15 A contrast material is used while taking an X-ray image of a patient.

Which statement is correct?

- A** Iodine is a contrast material.
- B** Technetium is a contrast material.
- C** A contrast material must have a short half-life.
- D** A contrast material is used for acoustic matching.

Your answer

[1]

SECTION B

Answer **all** the questions.



- 1 The Doppler effect is used to measure the speed of blood flow in arteries.

Which medical diagnostic method uses this technique?

- A barium scan
- B CAT scan
- C PET scan
- D ultrasound scan

Your answer

[1]



- 14 A beam of ultrasound is incident normally at a boundary between two tissues **F** and **G**.

The table below shows some data on the two tissues.

	Tissue F	Tissue G
Density of tissue	ρ	1.2ρ
Speed of ultrasound in tissue	c	$1.5c$

What percentage of the intensity of the ultrasound is reflected at the boundary?

- A** 0.83%
B 8.2%
C 9.1%
D 29%

Your answer

[1]



- 12 A small sample of muscle has volume 1.0 cm^3 and mass 1.10 g .
The speed of ultrasound in the muscle is 1600 m s^{-1} .

What is the acoustic impedance of the muscle?

- A $1.76 \times 10^3\text{ kg m}^{-2}\text{ s}^{-1}$
B $1.76 \times 10^4\text{ kg m}^{-2}\text{ s}^{-1}$
C $1.76 \times 10^6\text{ kg m}^{-2}\text{ s}^{-1}$
D $1.76 \times 10^{12}\text{ kg m}^{-2}\text{ s}^{-1}$

Your answer

[1]

6 Technetium-99m (Tc-99m) is a metastable isotope used in medical diagnosis.

Which ionising radiation does Tc-99m emit?

- A alpha
- B beta-minus
- C beta-plus
- D gamma

Your answer

[1]



3 Which one of these non-invasive medical scans does **not** expose the patient to ionising radiation?

- A CAT
- B PET
- C Ultrasound
- D X-ray

Your answer

[1]

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15 Which sequence shows the energies below in **increasing** order of magnitude?

- 1 The change in kinetic energy of an electron accelerated through a potential difference of 1 V.
- 2 The kinetic energy of a proton with a velocity of 1000 m s^{-1} .
- 3 The energy of an X-ray photon with a frequency of $3 \times 10^{17} \text{ Hz}$.

A 1 2 3

B 3 1 2

C 2 1 3

D 1 3 2

Your answer

[1]

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1 Which component of a gamma camera absorbs gamma rays and produces visible light?

- A collimator
- B computer
- C photomultiplier tube
- D scintillator

Your answer

[1]



15 Ultrasound scanning uses waves of a particular type and frequency.

Which row of the table is correct for these waves?

	Type	Frequency range
A	Longitudinal	Up to 20 kHz
B	Longitudinal	Above 20 kHz
C	Transverse	Up to 20 kHz
D	Transverse	Above 20 kHz

Your answer

[1]

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Turn over

Section B



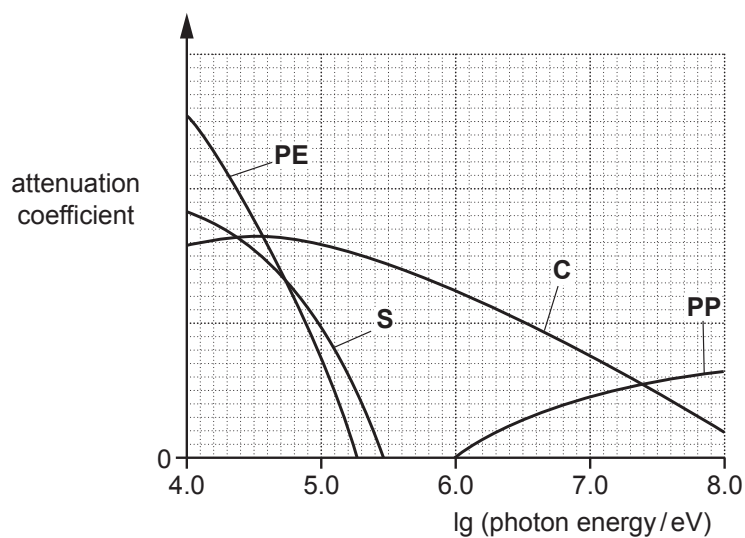
4-MARK QUESTIONS

2 questions in this booklet



25 X-ray photons interact with atoms.

The attenuation coefficient against $\lg(\text{photon energy})$ graphs for simple scattering (**S**), photoelectric effect (**PE**), Compton effect (**C**) and pair production (**PP**) are shown below.



- (a) For the X-ray tubes used in hospital, the X-ray photons have energy of about 10^5 eV.

State the attenuation mechanisms for these photons.

.....
 [1]

- (b) With the help of a calculation, explain the minimum photon energy shown on the graph for pair production.

.....

 [3]

- 22** The medical tracer fluorine-18 is used in positron emission tomography (PET).
Fluorine-18 is a beta-plus emitter with a short half-life.

Describe how the fluorine-18 nuclei are located in a patient using a PET scanner.

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..... [4]

5-MARK QUESTIONS

4 questions in this booklet



- 24 (a)** Explain how an ultrasound transducer can **emit** ultrasound.
You do **not** need to describe the design of the transducer.

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..... [2]

- (b)** Explain how the reflection of ultrasound at a boundary between two tissues depends on the physical properties of the tissues.

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..... [3]

16 This question is about the medical use of ultrasound.

- (a) In ultrasound scanning, explain what is meant by **impedance (acoustic) matching** and how it may be achieved.

.....
.....
..... [2]

- (b) There are several different types of ultrasound scanning techniques.

Explain how an A-scan could be used to measure the thickness of a patient's eye lens.
You may draw a diagram to help with your answer.

.....
.....
.....
.....
.....
..... [3]

24 The medical tracer technetium-99m is used in imaging organs such as the brain.

(a) Explain the advantages of using technetium-99m for this purpose.

.....
.....
..... **[2]**

(b) A gamma-camera uses powerful computers and sophisticated software to produce three-dimensional images of the patient's organ.

Name and describe the remaining three main components of the gamma camera.

.....
.....
.....
.....
.....
.....
..... **[3]**

23 A gamma camera has several important components including a collimator, scintillator and photomultiplier tubes.

(a) Suggest why the collimator needs to be long and narrow.

.....
..... [1]

(b) State the function of the scintillator.

.....
..... [1]

(c) In a single photomultiplier tube, a photon of light produces a $0.32\mu\text{A}$ pulse of current for a duration of 1.2 ns .

Calculate the number of electrons responsible for this pulse of current.

number of electrons = ... [2]

(d) State one diagnostic application of a gamma camera.

.....
..... [1]

Question 24 is on the next page

7-MARK QUESTIONS

1 question in this booklet



- 23 (a) Describe the basic structure of an X-ray tube and explain how X-ray photons are produced. You may draw a labelled diagram.

.....

.....

.....

.....

.....

..... [3]

- (b) A beam of X-rays is directed at tissues in a patient. The X-ray photons interact with the atoms of the tissues.

Simple scatter is one of the attenuation mechanisms.

Name and describe **two** other attenuation mechanisms.

1.

.....

.....

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2.

.....

.....

..... [4]

8-MARK QUESTIONS

1 question in this booklet



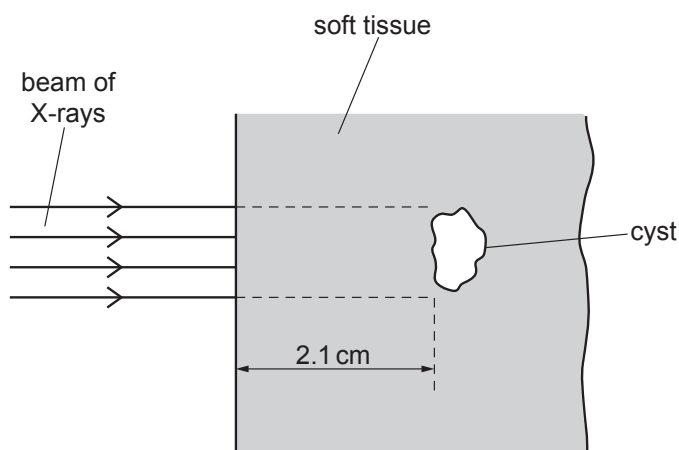
- 21 (a) A high-energy X-ray photon interacts with an electron of an atom through the **Compton effect**.

Describe this effect.

.....

 [2]

- (b) The diagram below shows a beam of X-rays incident normally on some soft tissue.



The attenuation (absorption) constant of the soft tissue is 0.85 cm^{-1} .

The intensity of the beam is $4.6 \times 10^3 \text{ W m}^{-2}$.

There is a small cyst 2.1 cm from the surface of the soft tissue. The cross-sectional area of the cyst normal to the beam is $3.4 \times 10^{-4} \text{ m}^2$.

The beam is switched on for 30 s.

Calculate the X-ray energy incident on the cyst in a period of 30 s.

energy = ... J [4]

- (c) The attenuation coefficients of the cyst and the soft tissues in (b) were similar. This prevented imaging the cyst using a two-dimensional X-ray image.

Name a different X-ray technique that could be used to image the cyst. Explain the advantage of this technique.

.....

.....

..... [2]

9-MARK QUESTIONS

3 questions in this booklet



24 (a) Describe, in terms of X-ray photons, the attenuation mechanism of Compton scattering.

.....

 [2]

(b) A parallel beam of X-rays is incident normally on a tissue as shown in **Fig. 24.1**.

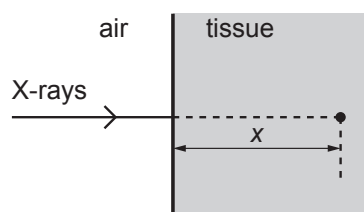


Fig. 24.1

The variation of the intensity I of the X-rays with depth x in the tissue is shown in **Fig. 24.2**.

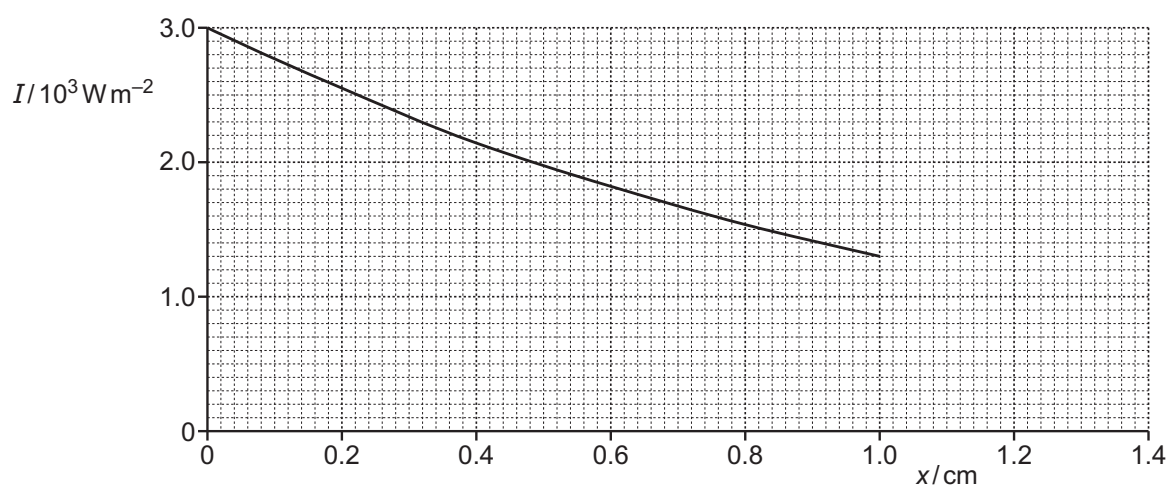


Fig. 24.2

The tissue has uniform structure between $x = 0$ and $x = 1.0 \text{ cm}$.

(i) Use the graph to determine the attenuation (absorption) coefficient μ in cm^{-1} of the tissue.

$\mu = \dots\dots\dots \text{cm}^{-1}$ [2]

- (ii) Use the graph to determine the exposure time t for the total radiant energy incident per cm^2 at a depth of 1.0 cm to be 2.6 J.

$t = \dots\dots\dots$ s [3]

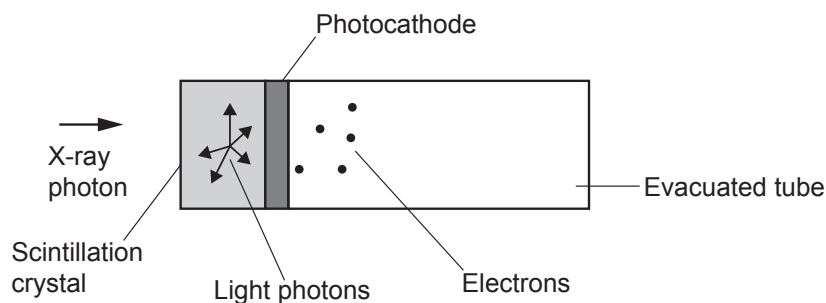
- (iii) Beyond $x = 1.0$ cm, the tissue has a larger attenuation coefficient than the value calculated in (i).

On **Fig. 24.2**, sketch the variation of I with x beyond $x = 1.0$ cm. [2]



- 19 The diagram shows part of an X-ray telescope which uses a crystal scintillation device to detect low energy X-rays from the stars.

X-rays hit the crystal and cause it to emit visible light photons. These travel to the photocathode in an evacuated tube. The photocathode uses the light photons to produce electrons.



Each X-ray photon detected by the telescope has an energy of 32 keV.

The light photons have a wavelength of 510 nm.

The efficiency of the crystal is 15%.

- (a) Show that each X-ray photon produces about 2000 light photons.

[3]

- (b) The photocathode has a work function of 2.3 eV.

- (i) Explain what is meant by the *work function*.

.....
 [1]

- (ii) Calculate the maximum kinetic energy of the electrons leaving the photocathode.

maximum kinetic energy = ...J [2]

- (iii) 12 X-ray photons are detected every minute.

Use your answer to (a) to calculate the current I leaving the photocathode. Assume that all the photons of light produce photoelectrons.

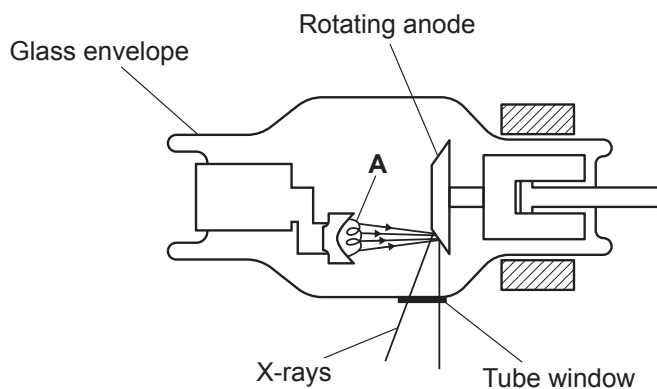
I = ... A [2]

- (iv) State one other assumption you have made to enable you to calculate the current I in (b)(iii).

.....
..... [1]

18 X-rays are used for diagnostic imaging in a hospital.

The diagram shows the structure of an X-ray tube.



(a) Name the component labelled **A** on the diagram.

..... [1]

(b) Suggest why the anode is made to rotate.

..... [1]

(c) X-rays are produced at characteristic wavelengths which depend on the material of the anode.

Describe how the electrons from component **A** are responsible for producing X-rays.

.....
.....
..... [2]

- (d) An electron strikes the anode. The kinetic energy of the electron changes from 150 keV to 60 keV.

Calculate the minimum wavelength, λ , of the X-ray photon emitted by the interaction of the electron with the anode.

$$\lambda = \dots\dots\dots \text{ m [3]}$$

- (e) A radiologist targets a uniform beam of X-rays at a tumour 4.6 cm below the skin of a patient. The beam is at right angles to the surface of the skin.

The intensity of the X-ray beam at the tumour is 30% of the incident intensity.

Calculate the attenuation coefficient, μ , of the tumour tissue in cm^{-1} .

$$\mu = \dots\dots\dots \text{ cm}^{-1} [2]$$

10-MARK QUESTIONS

1 question in this booklet



19

- (a)**
- Describe the difference between hadrons and leptons.

.....

.....

..... [2]

- (b)**
- An 'up' quark decays according to the equation below.

$$u \rightarrow d + {}^0_{+1}\text{e} + \nu$$

Give the name(s) of the lepton(s) in this equation.

..... [1]

- (c)**
- The above decay takes place within a nucleus of carbon-11. The half-life of this isotope of carbon is 1220 s.

A sample of carbon-11 has an activity of 800 Bq.

Calculate the activity, A , of this sample of carbon-11 after 5.0 minutes.

$A =$ Bq [3]

- (d)**
- The particle with symbol
- ${}^0_{+1}\text{e}$
- can annihilate with its anti-particle.

Describe a practical use of this process in medical imaging.

.....

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..... [4]

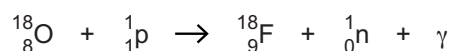


11-MARK QUESTIONS

3 questions in this booklet



- 25 (a) The nuclear reaction below shows how the isotope of fluorine-18 ($^{18}_9\text{F}$) is made from the isotope of oxygen-18 ($^{18}_8\text{O}$).



The oxygen-18 nucleus is **stationary** and the proton has kinetic energy of $0.25 \times 10^{-11} \text{ J}$. The binding energy of the $^{18}_8\text{O}$ nucleus is $2.24 \times 10^{-11} \text{ J}$ and the binding energy of the $^{18}_9\text{F}$ nucleus is $2.20 \times 10^{-11} \text{ J}$. The proton and the neutron have zero binding energy.

- (i) Explain why a high-speed proton is necessary to trigger the nuclear reaction shown above.

.....

 [2]

- (ii) Estimate the minimum wavelength λ of the gamma ray photon (γ).

$\lambda = \dots\dots\dots \text{ m}$ [3]

- (iii) Fluorine-18 is a positron emitter.
 Name a medical imaging technique that uses fluorine-18 and state one benefit of the technique.

.....

 [2]

(b) Describe how the components of a computerised axial tomography (CAT) scanner can produce high-quality images of the internal structures of a patient.

[4]

- 6 Fig. 6.1 shows a single photomultiplier tube and its internal components. The tube can detect gamma photons in high-energy physics experiments.

A single gamma photon incident on the scintillator crystal generates many photons of blue light. These visible light photons travel to the photocathode where they are converted into photoelectrons. The number of electrons is then multiplied in the photomultiplier tube with the help of electrodes called dynodes. A short pulse of electric current is produced at the output end of the photomultiplier tube.

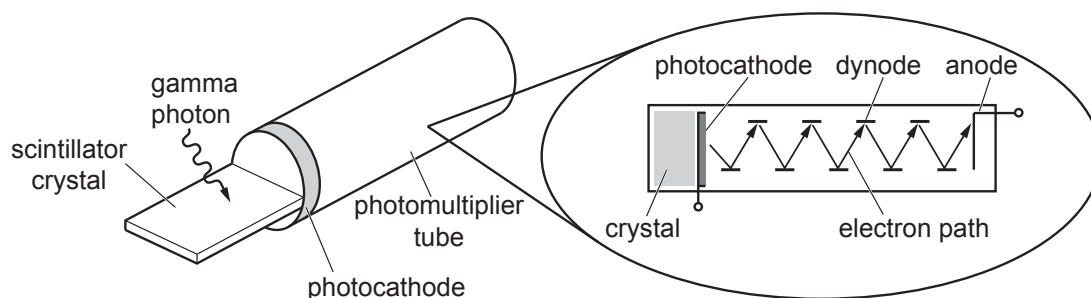


Fig. 6.1

- (a) Fig. 6.2 shows a section through the scintillator crystal in air.

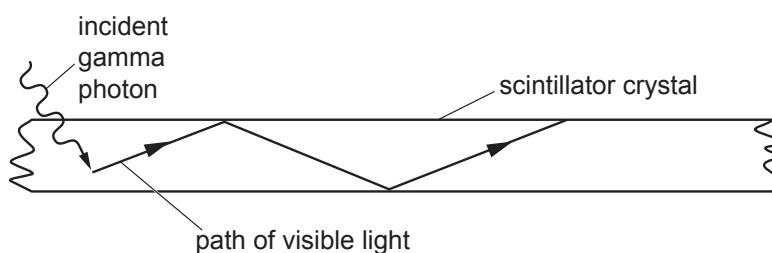


Fig. 6.2

- (i) The refractive index of the scintillator crystal for visible light is 1.69. The refractive index of air is 1.00. Calculate the critical angle C for this crystal.

$$C = \dots\dots\dots^\circ \quad [2]$$

- (ii) Explain why the visible light inside the scintillator crystal follows the path shown in Fig. 6.2.

.....

.....

.....

..... [2]

- (b) A high energy gamma photon passing through the scintillator crystal converts some of its energy into visible light photons of mean wavelength 450 nm.

Show that the energy of a single photon of wavelength 450 nm is less than 3 eV.

[3]

- (c) The photocathode is coated with potassium which has a work function of 2.3 eV. Each emitted photoelectron is accelerated by a potential difference of 100 V between the photocathode and a metal plate, called the first dynode.

- (i) Show that the maximum kinetic energy of an emitted electron at the photocathode is very small compared to its kinetic energy of 100 eV at the first dynode.

[1]

- (ii) 2000 photoelectrons are released from the photocathode. Each photoelectron has enough energy to release four electrons from the first dynode at the collision. These four electrons are then accelerated to the next dynode where the process is repeated. There are 9 dynodes in the photomultiplier tube. The total number of electrons collected at the anode for each photoelectron is 4^9 .

The pulse of electrons at the anode lasts for a time of 2.5×10^{-9} s.

Calculate the average current due to this pulse.

average current = ... A [3]



- 6 (a) Describe the **Doppler effect**.

.....
 [1]

- (b) Explain how ultrasound is used to measure the speed of blood flow in an artery.

.....

 [2]

- (c) In cosmology, the Doppler effect can be observed with light from distant galaxies. The Doppler effect can also be observed with sound waves.

Two students use sound waves to investigate the Doppler effect.

In an open space, one student swings a loudspeaker at constant speed in a horizontal circle of radius 0.60 m.

The other student stands a large distance away and holds a microphone. The microphone is connected to a data logger and computer.

Fig. 6.1 shows the situation, viewed from above.

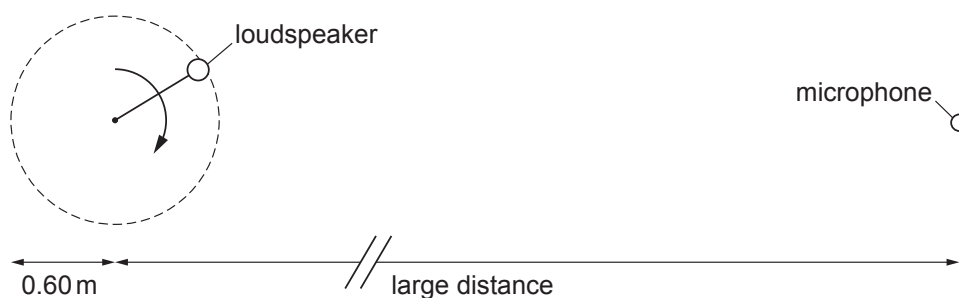


Fig. 6.1

The loudspeaker emits sound in all directions at a single frequency $f_0 = 1700$ Hz.

Fig. 6.2 shows the variation with time t of the frequency f received by the microphone.

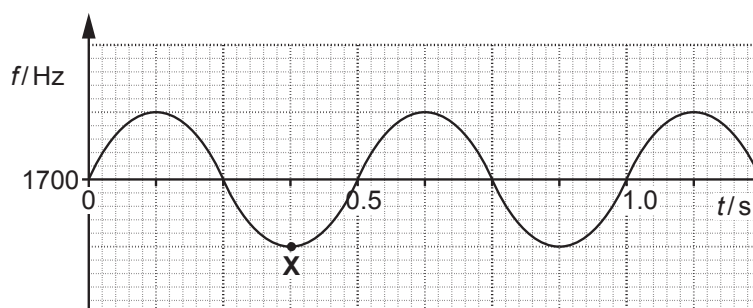


Fig. 6.2

- (i) Use Fig. 6.2 to show that the speed of the loudspeaker is 7.5 m s^{-1} .

[2]

- (ii) The speed of sound in this experiment is 330 m s^{-1} .

Calculate the maximum change in frequency Δf of the sound detected by the microphone.

$\Delta f = \dots\dots\dots \text{ Hz}$ [2]

- (iii) Hence complete the scale on the y-axis of Fig. 6.2. [1]

- (iv) Mark with an **X** on Fig. 6.1 the position of the loudspeaker which corresponds to the point **X** on Fig. 6.2. [1]

- (d) In their laboratory notes, one student writes about the **accuracy** of the measurements whereas the other writes about their **precision**.

Define these terms.

accuracy:

.....

precision:

..... [2]



13-MARK QUESTIONS

1 question in this booklet



17 Ultrasound B-scans can be used to image unborn babies.

(a) Explain what is meant by ultrasound.

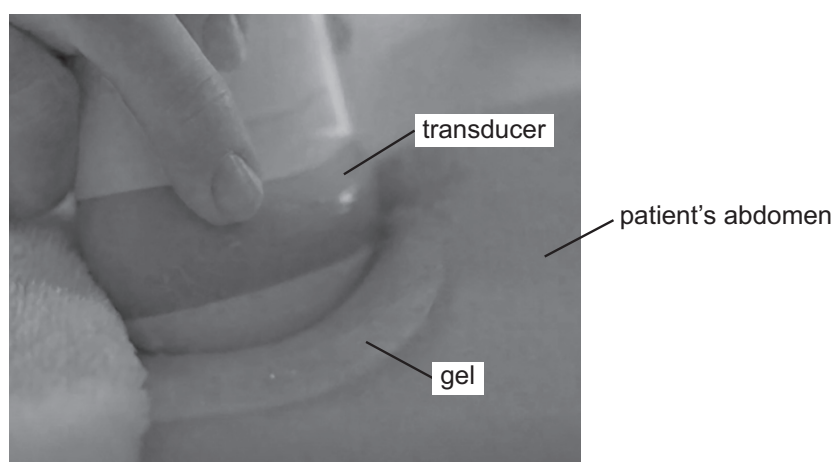
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..... [2]

(b)* Fig. 17.1 is a labelled photograph of an ultrasound examination of a patient.

Fig. 17.1



Explain how the transducer both produces and receives ultrasound waves.

Explain the purpose of the gel.

[6]

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Additional answer space if required

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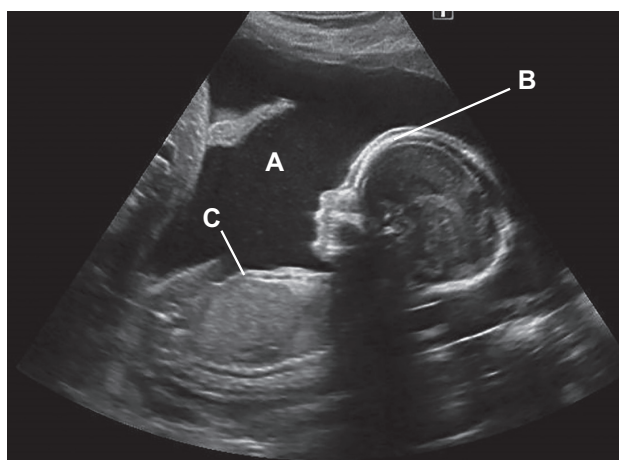
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Question 17 continues on page 14

- (c) Fig. 17.2 shows a B-scan of an unborn baby.

Fig. 17.2



- (i) Explain why no signal is received back from **A**.

.....
 [1]

- (ii) Explain why a greater signal is received back from **B** than **C**.

.....

 [2]

- (d) Doppler ultrasound can be used to measure the speed of blood flow through blood vessels.

The speed of ultrasound in blood is 1600 ms^{-1} .

A transducer emitting ultrasound of frequency 10.0000 MHz is placed at 50° to the blood vessel.

The reflected ultrasound has a frequency of 9.9987 MHz .

Calculate the speed v of the blood flow.

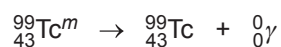
$v = \dots\dots\dots \text{ ms}^{-1}$ [2]

16-MARK QUESTIONS

1 question in this booklet



- 21** Technetium-99m ($^{99}_{43}\text{Tc}^m$) is a metastable radioisotope which can be used as a tracer in medical diagnosis. It is injected into the body and decays by gamma emission into technetium-99 according to the following chemical equation.



(a)

- (i)** Explain what is meant by a *tracer*.

.....
 **[1]**

- (ii)** $^{99}_{43}\text{Tc}^m$ only emits gamma radiation.

Give **two** advantages of using a tracer which only emits gamma radiation.

- 1

 2
 **[2]**

(b)

- (i)** A technetium-99m tracer with an activity of 900 MBq is injected into a body. The half-life of technetium-99m is 6.01 hours.

Calculate the number of technetium-99m nuclei initially present in the tracer.

number = ... **[3]**

- (ii)** Calculate the time in hours taken for the activity of the tracer to have fallen to 3.0% of its initial activity.

time = ... hours **[3]**

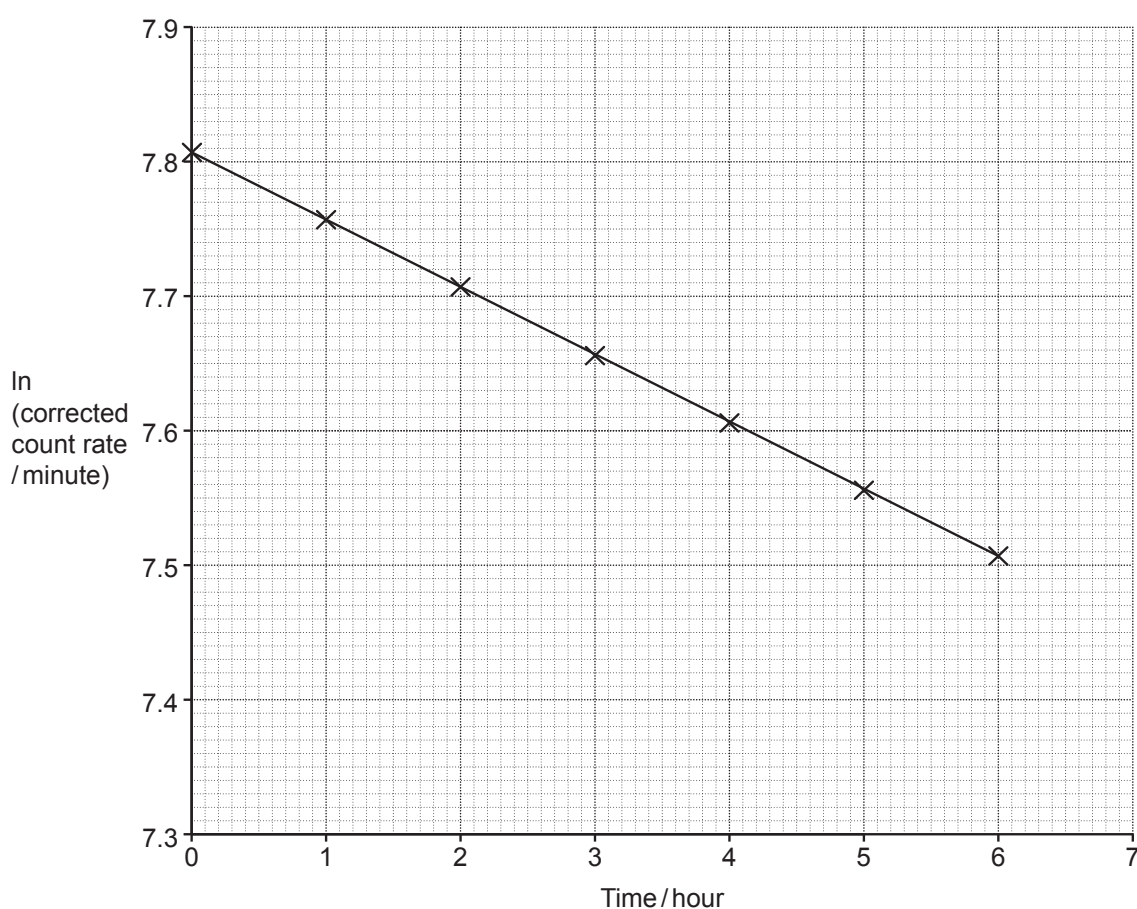
- (c) The daughter nucleus ($^{99}_{43}\text{Tc}$) decays by beta emission with a half-life of a little over 200 000 years. Approximately 50% of it is stored in the bones, and 50% is passed out of the body.

Suggest why the presence of this remaining $^{99}_{43}\text{Tc}$ in the body causes little additional risk to the patient.

.....

 [1]

- (d)* The half-life of a different radioisotope is to be determined using suitable apparatus. Each count represents one decay. The number of counts is measured for one minute every hour over a period of 6 hours. When the data has been collected, a graph of $\ln(\text{corrected count rate / minute})$ against time is plotted and shown below.



- Describe an appropriate method that could be used to obtain this data, naming any apparatus and safety precautions taken.
- Use the graph given above to determine the half-life of this radioisotope showing clear working.

[6]

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Additional space if required

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MARK SCHEMES

official OCR mark schemes



14	B	1	
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11	D		1	
----	---	--	---	--



12	B		1	
----	---	--	---	--



15	A	1	
	Total	15	

5

SECTION B

Question	Answer	Marks	Guidance
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1	D	1	
---	---	---	--



14	B	1	
----	---	---	--



12	C		1	
----	---	--	---	--



6	D	1	
---	---	---	--



3	C	1	
---	---	---	--



15	C	1	
	Total	15	

9

SECTION B

General rule: For substitution into an equation, allow any subject - unless stated otherwise in the guidance

Question	Answer	Mark	Guidance
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1	D	1	
---	---	---	--



15	B	1	
	Total	15	

9

SECTION B

General rule: For substitution into an equation, allow any subject - unless stated otherwise in the guidance

Question	Answer	Mark	Guidance
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25	(a)		All except pair production / PP	B1	Allow PE, S and C
	(b)		(energy =) $9.11 \times 10^{-31} \times (3.0 \times 10^8)^2$ (energy =) $2 \times 9.11 \times 10^{-31} \times (3.0 \times 10^8)^2 / 1.60 \times 10^{-19}$ $\lg 1.0(2) \times 10^6 = 6$ (as on graph) OR (energy =) 1.0×10^6 (eV) or $\lg 1.0 \times 10^6 = 6$ (from graph) (energy =) 1.6×10^{-13} J and evidence of mc^2 $2 \times 9.11 \times 10^{-31} \times (3.0 \times 10^8)^2 \approx 1.6 \times 10^{-13}$	B1 B1 B1 B1 B1 B1	Note this is 8.2×10^{-14} (J) Note this is $1.0(2) \times 10^6$ eV Note this can be shown in a variety of ways
			Total	4	



22			The positrons / beta-plus particles <u>annihilate</u> electrons (within the patient)	B1	
			Two gamma-photons are produced	B1	
			these (photons / rays) travel in opposite directions	B1	
			The difference in the arrival times at the detectors is used to locate the point of annihilation / nuclei	B1	
			Total	4	

24	(a)	Piezoelectric (effect) mentioned An alternating p.d. applied to the film / crystal produces vibrations / resonance (and this in turn produces ultrasound)	B1 B1	Allow 'applied p.d. changes the shape of a crystal / film' Allow alternating current / a.c. Allow expand and contract for vibrations (AW) Allow a named film / crystal
	(b)	density (of tissue) or speed (of ultrasound in tissue) or acoustic impedance mentioned Same Z, no reflection / different Z gives reflection $I_r/I_0 = [Z_1 - Z_2]^2/[Z_1 + Z_2]^2$ and intensity mentioned	B1 B1 B1	Not ρ or c or Z Allow same Z, total transmission / different Z gives some transmission Allow fraction of intensity reflected = $(Z_1 - Z_2)^2/(Z_1 + Z_2)^2$
		Total	5	

16	(a)	(special coupling) gel is used that has the same / 'matching' (acoustic) impedance as skin / body	B1	Allow Z Allow gel and impedance is the same / matching for two materials / mediums
		Reduced / less / zero <u>reflection</u> (at the skin)	B1	Allow more transmission
	(b)	(Pulses of) ultrasound sent into the eye	B1	Allow ultrasound reflected by any part of the eye Allow 'sound' / wave (since ultrasound is in the question) Ignore transducer placed close / next to eye
		Reflections from <u>front</u> and <u>back</u> of lens (and pulses displayed on oscilloscope)	B1	
		(Thickness of lens) determined from speed (of ultrasound) and time (difference)	B1	Allow thickness = $\frac{ct}{2}$ with c = speed (of ultrasound) and t = time (difference) Allow this mark even when the reflections are from incorrect boundaries
		Total	5	

24	(a)	Emits gamma (photons / radiation / waves / rays) Any one from: (Diagnosing the) function of organ Detecting tumour Small half-life (Gamma rays) can be detected outside body / passes through patient / least ionising Position of tracer located	B1 B1	Not injected into a patient / non-invasive Allow for half-life is a few hours
	(b)	Collimator: Allows gamma (photons) parallel to the axis of the tubes to pass through Scintillator: gamma (photons) produces (many) light (photons) Photomultiplier (tubes): light (photons) produces electrons / current / electrical pulse / p.d. / signal	B1 B1 B1	Ignore any other components named / described Allow photon / waves / rays Allow idea of tubes allowing the gamma (photons) to travel in the same direction Allow crystal (or named crystal) for scintillator Allow high-energy photons produce (many) low-energy photons
		Total	5	

23	(a)	Allows only those gamma rays / waves / photons travelling along axis (of the collimator) to get through (and reach scintillator)	B1	Allow less fuzzy / clear image Allow all the gamma rays / waves / photons are parallel / in the same direction (to each other) Allow <u>absorbs</u> those gamma rays / waves / photons not parallel (to the axis of collimator) Allow so the photons are travelling perpendicular to the scintillator Do not allow the gamma rays are travelling vertically, unless it is clear the collimator is also vertical
	(b)	Turn gamma (photons) into (many photons of) light	B1	Ignore reference to rays / waves Ignore reference to flash
	(c)	number of electrons = $\frac{0.32 \times 10^{-6} \times 1.2 \times 10^{-9}}{e}$ number of electrons = 2400	C1 A1	Ignore any POT error for C1 mark
	(d)	Any sensible <u>diagnostic</u> suggestion, e.g. <u>detection</u> of cancer / scans of (named) organ / scans of tissue / bone scans / observing functionality of (named) organ	B1	Not medical <u>treatment</u> e.g. radiotherapy Not body scan Ignore PET scanner Do not allow CAT scan
		Total	5	

23	(a)	(Evacuated tube with) cathode / heater / filament and target / metal / anode High voltage (supply) connected between cathode and anode (Accelerated) electrons hit the target / metal / anode and their KE is transformed into X-ray (photons)	B1 B1 B1	Ignore polarity of high voltage supply throughout Note the first two B1 marks can be scored on a labelled diagram Allow a specific value in the range 10 kV to 1 MV Note expecting 'high' or qualified by values in range above
	(b)	Any two from: Photoelectric (effect) Photon (is absorbed and an) electron removed (from the atom) Compton (scattering / effect) Photon scattered / deflection with longer wavelength / low frequency / low energy and electron removed (from the atom) Pair production Photon (absorbed) and produce electron-positron (pair)	M1 A1 M1 A1 M1 A1	Ignore if interaction between photons and electrons is not one-to-one Not X-ray wave etc; must refer to photon Not reflected Not X-ray wave etc; must refer to photon Not X-ray wave etc; must refer to photon
		Total	7	

21	(a)	Electron removed / ejected (from atom) <u>Photon</u> (scattered with) increased wavelength / lower frequency / lower energy	B1 B1	Needs a comparative statement
	(b)	(intensity $I = I_0 e^{-\mu x}$) $= 4.6 \times 10^3 \times e^{-0.85 \times 2.1}$ Either: (power =) $4.6 \times 10^3 \times e^{-0.85 \times 2.1} \times 3.4 \times 10^{-4}$ Or (energy per unit area =) $4.6 \times 10^3 \times e^{-0.85 \times 2.1} \times 30$ energy = $4.6 \times 10^3 \times e^{-0.85 \times 2.1} \times 3.4 \times 10^{-4} \times 30$ energy = 7.9 (J)	C1 C1 C1 A1	intensity = 772 (W m ⁻²) power = 0.262 (W) energy per unit area = 23160 J m ⁻² energy at surface = 47 (J) 2 marks
	(c)	CAT (CT) scan Any <u>one</u> from • A CAT scan will give 3D image • A CAT scan gives better contrast	M1 A1	Insufficient: more detail / clearer image
		Total	8	

24	(a)		Photon scattered with less energy / X-ray of lower frequency / X-ray of longer wavelength	B1	Allow X-ray for photon and vice versa Ignore wave
			Electron removed (from the atom)	B1	Not electron scattered or electron removed from surface
	(b)	(i)	Identification from graph of two intensities and corresponding separation between them (x). Correct substitution into $I = I_0 e^{-\mu x}$ and fully correct calculation leading to $\mu = 0.84 \text{ (cm}^{-1}\text{)}$	C1	Note check value of intensities to $\pm \frac{1}{2}$ small square. x missing implies $x = 1$. Graph misread lose all marks. May be seen from substitution into $I = I_0 e^{-\mu x}$. No POT error at this point
				A1	Note I_0 and I must be in correct position in equation, so that ($I < I_0$). If I and I_0 are reversed, μ will be negative. Penalise this mark for negative answer, or working that would lead to negative answer. Penalise POT error here. Allow small range of values around 0.84 for variations in graph readings.
		(ii)	$I = 1.3 \times 10^3$ / 1300 $(E = I \times A \times t) = 2.6 = 1300 \times 1.0 \times 10^{-4} \times t$ $t = 20 \text{ (s)}$	B1	Allow a value in the range $1.25 - 1.35 \times 10^3$. Allow ecf from incorrect reading of I at 1.0cm from (b)(i)
				C1	Allow use of value of I from B1 except use of 3000 POT error allowed on area if area clearly included in the calculation, or if A included in equation
				A1	Note: use of $I = 1.6 \times 10^3$ leading to $t = 16 \text{ (s)}$ with A included scores 2 marks
		(iii)	A curve starting at $x = 1.0\text{cm}$ with initially larger negative gradient at $x = 1.0 \text{ cm}$ Exponential curve	M1	Must not have a positive gradient for more than half a square vertically
				A1	Curve must not touch x-axis or be horizontal for more than 3 small squares
			Total	9	

19	(a)		Calculation in eV: $E_{\text{light photon}} = hc/\lambda = 6.63 \times 10^{-34} \times 3.0 \times 10^8 / 510 \times 10^{-9}$ $= 3.90 \times 10^{-19} \text{ (J)}$ $E_{\text{light photon}} = 3.9 \times 10^{-19} / 1.6 \times 10^{-19}$ $= 2.44 \text{ (eV)}$ Number of photons = $(E_{\text{x-ray photon}}/E_{\text{light photon}}) \times \text{efficiency}$ $= (32\,000 / 2.44) \times 0.15$ $= 1969$	C1 Calculation in J: $E_{\text{light photon}} = hc/\lambda = 6.63 \times 10^{-34} \times 3.0 \times 10^8 / 510 \times 10^{-9}$ $= 3.90 \times 10^{-19} \text{ (J)}$ C1 $E_{\text{x-ray photon}} = 32 \times 10^3 \times 1.6 \times 10^{-19}$ $= 5.12 \times 10^{-15} \text{ (J)}$ Number of photons = $(E_{\text{x-ray photon}}/E_{\text{light photon}}) \times \text{efficiency}$ $= (5.12 \times 10^{-15} / 3.90 \times 10^{-19}) \times 0.15$ C1 $= 1969$ A0 Answer to at least 3sf Allow use of 2.4eV for energy of light photon to give 2000 in either method
	(b)	(i)	(The work function is) the minimum energy required to release an electron (from the surface of a metal)	B1 Allow minimum work done for minimum energy Do not allow idea of energy needed to release multiple electrons Do not allow release of electron from atom Do not allow idea of ionisation energy
		(ii)	$\phi = 2.3 \times 1.6 \times 10^{-19} \text{ (= } 3.68 \times 10^{-19} \text{ J)}$ $KE_{\text{max}} = (3.90 - 3.68) \times 10^{-19} = 2.2 \times 10^{-20} \text{ (J)}$	C1 Or $\phi = 2.44 - 2.3 \text{ (= } 0.14 \text{ eV)}$ A1 $KE_{\text{max}} = 0.14 \times 1.6 \times 10^{-19} = 2.2 \times 10^{-20} \text{ (J)}$ Answer to at least 2sf Allow use of 2.4 eV to give $1.6 \times 10^{-20} \text{ (J)}$ ecf light photon energy from (a)

Question			Answer	Mark	Guidance
		(iii)	$I \left(= \frac{Q}{t} \right) = \frac{12 \times 1969 \times 1.6 \times 10^{-19}}{60}$ $= 6.3 \times 10^{-17} \text{ (A)}$	C1 A1	Allow full credit for use of 2000 Answer to at least 2sf (6.30) Allow use of $N = 2000$ to give $I = 6.4 \times 10^{-17} \text{ (A)}$ Allow ecf on N from (a)
		(iv)	One from: One to one interaction between (light) photon and electron That there are no secondary electrons That the current is continuous / X-rays arrive at a constant rate within the minute (or 1 every 5s) All the electrons leave the photocathode	B1	

18	(a)	Heater / cathode / filament	B1	ALLOW filament lamp IGNORE Thermionic
18	(b)	Cooling / preventing melting (of anode)	B1	NOT just 'so the same spot isn't hit all the time'
18	(c)	Electrons (in anode) are removed from (inner) energy level (by collision) (Outer) electron (in anode) falls to lower energy level (emitting characteristic X-ray photon)	B1 B1	Alternative answer: Electrons decelerate on collision with anode (X-rays / photons are produced) because of change in <u>kinetic</u> energy (of electrons)
18	(d)	Photon energy, $(E) = 90 \times 10^3 \times 1.6 \times 10^{-19}$ (= 1.44×10^{-14} J) $\lambda = hc/E = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.44 \times 10^{-14}}$ = 1.4×10^{-11} (m)	C1 C1 A1	ALLOW calculation of conversion of 150 keV (2.4×10^{-14}) or 60 keV (9.6×10^{-15}) for this mark only No conversion to J or conversion using wrong physics (e.g. division by 1.6×10^{-19}) to J is XP Use of $\lambda = h/p$ and $E = mc^2$ is XP Correct to at least 2 significant figures

Question		Answer	Mark	Guidance
18	(e)	$(I = I_0 e^{-\mu x} \text{ to give}) 0.3 = e^{-(\mu \times 4.6)}$	C1	ALLOW $3.3 = e^{(\mu \times 4.6)}$ Expect to see both 0.3 and 4.6 correctly substituted into equation
		$\mu (= -\ln(0.3) / 4.6) = 0.26 \text{ (cm}^{-1}\text{)}$	A1	Correct to at least 2 significant figures (0.262 cm ⁻¹) Negative final answer (- 0.26) loses second mark

19	(a)	Hadrons experience the strong force / hadrons are not fundamental particles / hadrons are made of quarks	B1	IGNORE references to mass IGNORE number of quarks
		Leptons do not experience strong force / leptons are fundamental / leptons are not made of quarks	B1	
19	(b)	Positron and (electron) neutrino	B1	Both required for the mark ALLOW anti-electron / beta-plus for positron IGNORE symbols
19	(c)	Decay constant = $\ln 2 / 1220 = (5.7 \times 10^{-4} \text{ s}^{-1})$	C1	Decay constant = $\ln 2 / 20.3 = (0.034 \text{ min}^{-1})$
		$A = 800 \times e^{-(5.7 \times 10^{-4} \times 300)}$	C1	ALLOW $A = 800 \times e^{(-0.034 \times 300)}$
		$A = (800 \times 0.84333) = 670 \text{ (Bq)}$	A1	Correct to at least 2 significant figures (675 Bq) Value using t in minutes with decay constant in s^{-1} gives 798 (Bq) is MAX 2
19	(d)	Positron emission tomography / PET (scan)	B1	IGNORE (gamma) waves and (gamma) radiation ALLOW γ for gamma
		Two <u>gamma</u> rays / <u>gamma</u> photons produced	B1	
		(Gamma rays) travel in opposite directions / 180°	B1	
		Arrival time(s) (at detector) used to locate position	B1	

Question		Answer	Mark	Guidance

Question	Answer	Mark	Guidance
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25	(a)	(i)	Proton is repelled (by nucleus) (High-speed) proton can get close to (oxygen) nucleus	B1 B1	Allow 'proton can experience the strong (nuclear) force' Not 'collide / hit nucleus'
		(ii)	$E = [0.25 - (2.24 - 2.20)] \times 10^{-11} \text{ (J)}$ or $0.21 \times 10^{-11} \text{ (J)}$ $\lambda = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^8}{0.21 \times 10^{-11}}$ (Any subject) $\lambda = 9.5 \times 10^{-14} \text{ (m)}$	C1 C1 A1	Allow 2 marks for 6.9×10^{-14} ; $E = 0.29 \times 10^{-11}$ used Allow 1 mark for a value correctly calculated based on any other incorrect value for E (e.g. $8(.0) \times 10^{-14}$ for $E = 0.25 \times 10^{-11}$ and $5(.0) \times 10^{-13}$ for $E = 0.04 \times 10^{-11}$)
		(iii)	Used in PET (scans) Any one from: Used to diagnose function of organ / brain / body Detection of cancer / tumour Non-invasive / no surgery / no infection 3D (image)	M1 A1	
	(b)		X-ray (tube) moves around the patient A thin (fan-shaped X-ray) beam is used (Images / scans of) cross-sections through the patient are taken Any one from: • A three-dimensional image is produced • (Soft) tissues can be identified	B1 B1 B1 B1	Allow 'X-rays passed through different angles.' Allow 'slice(s)' Allow 'good contrast image'
			Total	11	

Question	Answer	Mark	Comments
6	(a) (i)	$\sin C = 1/n = 1/1.69 (= 0.592)$ $C = 36^\circ$	C1 A1
	(ii)	<u>Total internal reflection</u> occurs because the <u>angle of incidence</u> (at the surface) is greater than the <u>critical angle/ 36°</u>	B1 B1 allow because $i > C$
	(b)	$E = (hc/\lambda =) 6.63 \times 10^{-34} \times 3.0 \times 10^8/450 \times 10^{-9}$ $E = 4.42 \times 10^{-19}$ (J) energy = 2.76 (eV)	C1 C1 A1 N.B. the answer here must be 2 SF or more
	(c) (i)	$2.76 - 2.3 = 0.46$ eV (so only 0.5% of energy/AW)	B1 allow $2.8 - 2.3 = 0.5$ eV and $3.0 - 2.3 = 0.7$ eV possible ecf from (b)
	(ii)	$n = 2000 \times 4^9 (= 5.24 \times 10^8)$ $Q = ne = 8.4 \times 10^{-11}$ (C) $I = 8.4 \times 10^{-11} / 2.5 \times 10^{-9}$ average current = 0.034 (A)	C1 C1 A1 allow ecf for wrong n allow 34 m(A); answer is 1.7×10^{-5} A if 2000 omitted (2/3)
		Total	11



6	(a)	Observed frequency is different to source frequency when source moves relative to observer.	B1	Allow synonyms for 'observed' e.g. perceived / detected / measured Allow any correct description of relative motion e.g. when source moves towards an observer (but not when source / observer moves) Allow the change in <u>observed</u> frequency / the <u>apparent</u> change or shift in frequency when source moves relative to observer Allow wavelength in place of frequency Answers must convey the difference between observed frequency and source frequency rather than a change in source frequency
	(b)	<u>Pulses</u> (of ultrasound waves) are aimed at / reflected from the (moving) blood (cells in the artery). - The probe / transducer is placed at an angle (usually 60°) (to the artery) - The (detected) frequency of <u>returning/reflected</u> waves is different to that of the emitted waves. (Knowing the speed of ultrasound in blood and) the <u>ratio</u> of the frequencies enables the speed (of blood flow) to be calculated/AW	B1 x 2	Max 2 marks from 4 marking points Allow ultrasound is emitted at an angle Allow there is a change in frequency when the wave is reflected Allow v found using formula $\Delta f = 2fv\cos\theta/c$ with c defined as velocity of (ultra)sound (in the medium) not light

H556/03			Mark Scheme		June 2019
Question			Answer	Marks	Guidance
	(c)	(i)	$T = 0.50$ (s) or $f = 2.0$ (Hz)	C1	
			$v = (2\pi r/T) = 2\pi \times 0.60/0.5$	M1	Allow $1.2\pi/0.5$ or 2.4π
			$v = 7.5$ (m s ⁻¹)	A0	$= 7.54$ (m s ⁻¹)
					<u>Alternative method:</u> $\omega = 4\pi$ or 12.6 (rad s ⁻¹) (C1) $v (= r \omega) = 0.60 \times 12.6$ or 2.4π (M1) $= 7.54$ (m s ⁻¹) (A0)
		(ii)	$\Delta f (\approx vf/c) = (7.5 \times 1700) / 330$	C1	Note that c represents the velocity of sound
			$\Delta f = 40$ (Hz) (or 39Hz)	A1	
		(iii)	y-axis labelled with correct scale	B1	Allow as a minimum one labelled point i.e. 1740 or 1660
					ECF(c)(ii) for incorrect Δf
		(iv)	X labelled at lowest point of circle on Fig. 6.1	B1	
	(d)		Accuracy is (a quality denoting) the closeness of the measured value to the true value	B1	Allow readings/results/data/values/measurements for <i>measured value</i> ; actual/real/allowed/correct for <i>true</i>
			Precision is (a quality denoting) the closeness of agreement between measured values (obtained by repeated measurements)	B1	Allow measurements are close together/are similar/have small range/have low spread/have low scatter/have good agreement/are all close to the average
			Total	11	



17	(a)		Longitudinal waves With a frequency greater than 20 kHz	B1 B1	 ALLOW 20 kHz and above
	(b*)	(i)	Level 3 (5–6 marks) Clear explanation of transducer and clear explanation of gel <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Clear explanation of transducer OR clear explanation of gel or Some explanation of transducer and some explanation of gel <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Limited explanation of transducer or gel <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks <i>No response or no response worthy of credit</i>	6 x B1	Use level of response annotations in RM Assessor Indicative scientific points may include: Transducer • High frequency alternating PD applied to the faces of the piezoelectric crystal. • Causes the piezoelectric crystal to stretch and compress / oscillate / resonate at high frequency. • Ultrasound waves sent in pulses • Between pulses, reflected ultrasound incident on the piezoelectric crystal causes the crystal to change shape / oscillate / resonate • An alternating PD is induced Gel • Acoustic impedance of air is different to body • Acoustic impedance of gel is similar to body • This allows greater transmission of the ultrasound waves into / out of the patient's body • There is less reflection of the ultrasound waves at the body boundary • Reference to $\frac{I_r}{I_0} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$

Question			Answer	Mark	Guidance
	(c)	(i)	There is no change in (acoustic) impedance	B1	ALLOW there is no change in the density (of the medium) ALLOW there is no boundary / there is nothing to reflect from NOT JUST there is nothing there IGNORE undefined symbols
		(ii)	<u>Acoustic</u> impedance of C is different from B Change in <u>acoustic</u> impedance at B is greater (than at C) (relative to their surrounding medium/A)	C1 A1	IGNORE explanations in terms of density Second point gains both marks ALLOW soft tissue/skin/belly for C ALLOW skull/bone/head for B
	(d)		$v = \Delta f c / 2 f \cos \theta$ $= \frac{(10.0000 \times 10^6 - 9.9987 \times 10^6) \times 1600}{2 \times 10.0000 \times 10^6 \times \cos 50}$ 0.16 (ms ⁻¹)	C1 A1	IGNORE cancelling powers of 10 Correct to at least 2 significant figures

21	(a)	(i)	Material (introduced into the body and) used so its position in the body can be detected / function of organ can be determined	B1	Allow “used to produce images” for “detected” Do not allow “trace” for “position detected” Ignore treatment
		(ii)	(Very) little ionisation (Most can) pass through the body tissue / can be detected outside / highly penetrating	B1 B1	Allow less ionising / least ionising Do not allow “zero ionisation” Allow other radiation would be absorbed within the body
	(b)	(i)	$\lambda = \frac{\ln 2}{T_{1/2}} = \frac{\ln 2}{6.01 \times 3600} (= 3.20 \times 10^{-5} \text{ s}^{-1})$ ($A = \lambda N$) $900 \times 10^6 = 3.20 \times 10^{-5} \times N$ $N = 2.8 \times 10^{13}$	C1 C1 A1	Correct to at least 2sf (2.81) Special case: Calculation of decay constant in hour^{-1} gives 0.115 leading to $N = 7.8 \times 10^9$ maximum 1 mark Calculation of decay constant in min^{-1} gives 1.9×10^{-3} leading to $N = 4.7 \times 10^{11}$ maximum 1 mark
		(ii)	(Correct use of $A = A_0 e^{-\lambda t}$) $0.03 = e^{-3.2 \times 10^{-5} t}$ $\ln(0.03) = -3.2 \times 10^{-5} t$ $t = 109\,500 \text{ s} = 30 \text{ hours}$	C1 C1 A1	Or use of λ as 0.115 hour^{-1} ecf for λ from (b)(i) $\ln(0.03) = -0.115 t$ Allow final answer that rounds to 30 or 31 hours

Question			Answer	Mark	Guidance
					Special case: if fall of 3% ($A = 0.97A_0$) calculated, leading to 0.26 hours then max 1
	(c)		Activity is low compared to background	B1	Allow activity is very low Allow decays very slowly / very little decay for low activity Allow rate of emission for activity Ignore references to long half life
	(d)		Level 3 (5–6 marks) Clear description and full correct calculation <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Clear description or full correct calculation OR Some description and some calculation <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Limited description or limited calculation <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i>	B1×6	Use level of response annotations in RM Assessor Indicative scientific points may include: Expect to see appropriate safety precaution for clear description Description: • Take background count • Over (at least) 3 minutes • Take count due to source • Over the same time • Measured using a stopwatch • Calculate the corrected count • Calculate the corrected count per minute • Use a Geiger-Muller tube and counter • Hold source at arms length when transferring • Keep in lead lined box at other times • Use tongs to hold source



Question			Answer	Mark	Guidance
			0 marks <i>No response or no response worthy of credit</i>		Calculation • $C = C_0 e^{-\lambda t}$ • $\ln C = \ln C_0 - \lambda t$ • e.g $7.51 = 7.81 - (\lambda \times 6)$ • λ around 0.05 hour^{-1} • $T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$ • $T_{\frac{1}{2}} = 13.9 \text{ hours}$ (allow any answer that round to 14 hours) • $T_{\frac{1}{2}} = 830 \text{ minutes}$ or $49\,900 \text{ seconds}$ (allow some tolerance for slight graph reading discrepancies) • Or by a graphical method

Question	Answer	Mark	Guidance
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