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AQA A LEVEL PHYSICS (7408): QUESTIONS BY TOPIC

Medical physics (3.10)

A Level Physics (7408) · Section 3.10

41 questions · 315 marks · Mark schemes included

AQA A Level Physics (7408), June 2017 – June 2025

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HOW TO USE THIS BOOKLET

Questions are grouped by specification sub-topic and run from the lowest mark tariff to the highest within each one.

Click any row below to jump straight to that sub-topic or 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.

QUESTION	SOURCE	MARKS	PAGE
3.10.1 PHYSICS OF THE EYE		9 Qs · 73 marks	4
1. Q1	7408/3 Section B: Medical physics June 2024	4	5
2. Q2	7408/3 Section B: Medical physics June 2018	7	6
3. Q5	7408/3 Section B: Medical physics November 2021	7	7
4. Q1	7408/3 Section B: Medical physics June 2022	8	8
5. Q1	7408/3 Section B: Medical physics June 2017	9	10
6. Q1	7408/3 Section B: Medical physics November 2020	9	12
7. Q1	7408/3 Section B: Medical physics June 2025	9	14
8. Q1	7408/3 Section B: Medical physics June 2019	10	16
9. Q2	7408/3 Section B: Medical physics June 2023	10	18
3.10.2 PHYSICS OF THE EAR		8 Qs · 51 marks	21
10. Q3	7408/3 Section B: Medical physics June 2023	4	22
11. Q2	7408/3 Section B: Medical physics November 2020	5	23
12. Q3	7408/3 Section B: Medical physics November 2021	5	24
13. Q2	7408/3 Section B: Medical physics June 2024	6	25
14. Q3	7408/3 Section B: Medical physics June 2022	7	26
15. Q3	7408/3 Section B: Medical physics June 2025	7	27
16. Q4	7408/3 Section B: Medical physics June 2018	8	28
17. Q2	7408/3 Section B: Medical physics June 2019	9	29
3.10.3 BIOLOGICAL MEASUREMENT (ECG)		1 Qs · 5 marks	31
18. Q4	7408/3 Section B: Medical physics June 2017	5	32
3.10.4 NON-IONISING IMAGING: ULTRASOUND, ENDOSCOPY AND MR		9 Qs · 67 marks	34
19. Q5	7408/3 Section B: Medical physics June 2022	3	35
20. Q2	7408/3 Section B: Medical physics November 2021	4	36
21. Q5	7408/3 Section B: Medical physics June 2024	5	37
22. Q1	7408/3 Section B: Medical physics June 2018	6	38
23. Q4	7408/3 Section B: Medical physics June 2022	6	39
24. Q4	7408/3 Section B: Medical physics June 2019	9	40
25. Q3	7408/3 Section B: Medical physics June 2024	10	42
26. Q4	7408/3 Section B: Medical physics June 2023	11	43
27. Q4	7408/3 Section B: Medical physics November 2020	13	46
3.10.5 X-RAY IMAGING AND CT		9 Qs · 72 marks	49
28. Q4	7408/3 Section B: Medical physics November 2021	4	50



QUESTION	SOURCE	MARKS	PAGE
29. Q3	7408/3 Section B: Medical physics June 2018	6	52
30. Q3	7408/3 Section B: Medical physics June 2019	7	53
31. Q5	7408/3 Section B: Medical physics June 2018	8	55
32. Q3	7408/3 Section B: Medical physics November 2020	8	57
33. Q5	7408/3 Section B: Medical physics June 2023	8	59
34. Q4	7408/3 Section B: Medical physics June 2025	8	60
35. Q2	7408/3 Section B: Medical physics June 2022	11	62
36. Q2	7408/3 Section B: Medical physics June 2017	12	65
3.10.6 RADIONUCLIDE IMAGING AND THERAPY		5 Qs · 47 marks	67
37. Q1	7408/3 Section B: Medical physics June 2023	2	68
38. Q3	7408/3 Section B: Medical physics June 2017	9	69
39. Q4	7408/3 Section B: Medical physics June 2024	10	72
40. Q2	7408/3 Section B: Medical physics June 2025	11	74
41. Q1	7408/3 Section B: Medical physics November 2021	15	77



QUESTIONS

41 questions · 315 marks · 6 sub-topics



SUB-TOPIC 3.10.1

PHYSICS OF THE EYE

Sub-topic 3.10.1 · 9 questions · 73 marks · lowest tariff first



01.1

A human eye has a far point of 6.0 m.

State the name of this defect of vision.

[1 mark]

01.2

Calculate the power of the correcting lens required for this eye.

[2 marks]

power = _____ D

01.3

An eye with astigmatism requires the following prescription:

−4.00 −0.75 ×30

Which row identifies the meaning of each number?

Tick (✓) **one** box.

[1 mark]

−4.00	−0.75	×30	
axis	cylinder	spherical	
cylinder	axis	spherical	
spherical	cylinder	axis	
cylinder	spherical	axis	

0 2 . 1

The fovea in a typical human eye consists of cones which have an average diameter of 1.5×10^{-6} m

An eye looks directly at two point sources of light which are 12 mm apart at a distance of 61 m from the centre of the eye lens. The fovea is at the centre of the retina a distance of 21 mm behind the centre of the eye lens.

Deduce whether the eye would be able to resolve the two images formed at the fovea. **[4 marks]**

0 2 . 2

Three types of cone are present at the fovea.

On **Figure 2** sketch and clearly label **three** curves to show how the relative light absorption of each type of cone varies with wavelength.

[3 marks]

Figure 2



0 5 . 1

Which would be a correct lens prescription for a person with hypermetropia and astigmatism?

Tick (✓) **one** box.

[1 mark]

−2.00 +0.50 75

☐

+2.00 −0.50 75

☐

−2.00 +0.50 255

☐

+2.00 −0.50 255

☐
0 5 . 2

A student views an object **O** and cannot see it clearly unaided.

The student is diagnosed with myopia and is prescribed a suitable correcting lens. Using the correcting lens, an intermediate image is formed that can be viewed clearly by the student.

The student states that she can see **O** more clearly because the intermediate image is enlarged.

Discuss the validity of the student's statement.

In your answer you should:

- describe how myopia affects vision
- draw a labelled ray diagram of the correcting lens, showing how the intermediate image of **O** is formed
- explain how the correcting lens enables the student to see clearly.

[6 marks]

Space for diagram

END OF QUESTIONS



0 1

An eye condition is corrected using a +4.0D lens.

0 1 . 1

Which eye condition could be corrected by using this lens?

Tick (✓) **one** box.**[1 mark]**

astigmatism

☐

hypermetropia

☐

myopia

☐**0 1 . 2**

Calculate the magnification produced by the +4.0D lens when viewing an object 75 cm from this lens.

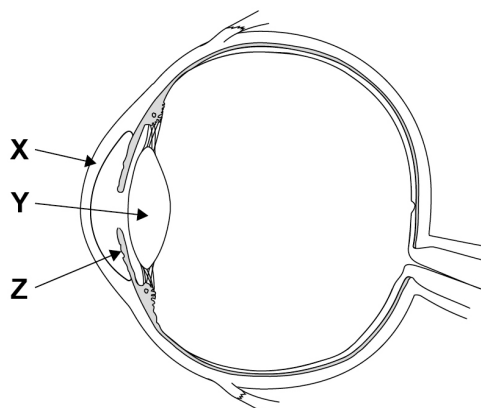
[3 marks]

magnification = _____



0 1 . 3 Figure 1 shows a diagram of an eye.

Figure 1



State the name and primary optical function of **X**, **Y** and **Z**.

[4 marks]

Name of **X** _____

Primary optical function of **X** _____

Name of **Y** _____

Primary optical function of **Y** _____

Name of **Z** _____

Primary optical function of **Z** _____

0	1
---	---

A person suffers from hypermetropia (long sight).
Use of a spectacle lens of power $+2.0\text{D}$ allows the person to just see clearly an object placed 24 cm away from the eye.

0	1	.	1
---	---	---	---

Explain why the unaided defective eye cannot form a clearly focused image of the object placed 24 cm from the eye.

[2 marks]

0	1	.	2
---	---	---	---

An object is placed 24 cm from the spectacle lens.

Calculate the distance of the image formed from the spectacle lens.
Give your answer to a suitable number of significant figures.

[3 marks]

image distance = _____ cm



0 1 . 3

What is the name for the position where the image is formed by the spectacle lens?

Tick (✓) the correct answer.

[1 mark]

The eye's aided far point

☐

The eye's aided near point

☐

The eye's unaided far point

☐

The eye's unaided near point

☐**0 1 . 4**

Draw a ray diagram to show how this spectacle lens forms an image of the object placed 24 cm from the spectacle lens.

On your diagram clearly label the object, image and a principal focus of the lens.

Your diagram does not have to be drawn to scale.

[3 marks]

0	1	.	1
---	---	---	---

State and explain **two** differences between the perceived image of a brightly coloured object in bright light and the perceived image of the same object when viewed in very dark conditions.

In your answer you should refer to the visual receptors in the eye.

[5 marks]

Difference 1 _____

Difference 2 _____



According to some legends, in the 17th century a pirate with two healthy eyes covered one eye with a patch to keep the eye in the dark. The patch was removed when going from bright conditions outside to the very dark conditions below decks in an enemy ship.

It was necessary for the pirate to put the patch on about 45 minutes before going into the very dark conditions inside the ship.

0 1 . 2

What is the name of the process which occurs when the pirate's eye is covered by the patch?

Tick (✓) **one** box.

[1 mark]

aberration

☐

accommodation

☐

adaptation

☐

adjustment

☐

0 1 . 3

Discuss why it was necessary to wear the eye patch for 45 minutes before entering the ship.

[3 marks]



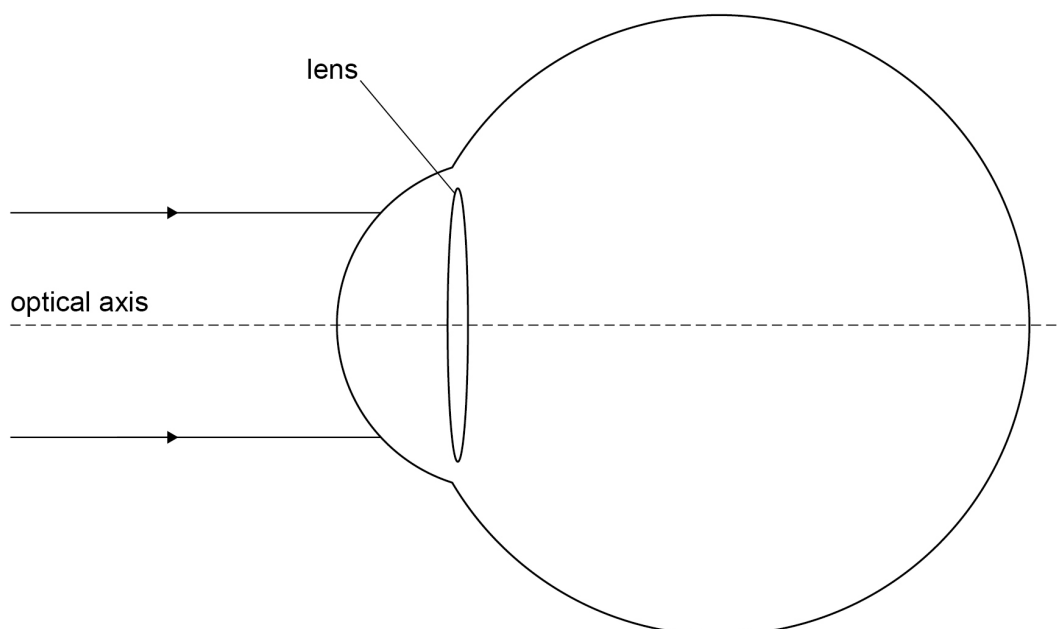
0 1 . 1

Figure 1 shows a simplified diagram of an eye that has no sight defects. The eye is viewing a distant point object.

Complete, on **Figure 1**, the paths of the two rays to the back of the eye.

[2 marks]

Figure 1



0 1 . 2

Accommodation is the ability of the eye to change its optical power.

Which part of the eye enables accommodation?

Tick (✓) **one** box.

[1 mark]

cornea

☐

iris

☐

lens

☐

Question 1 continues on the next page

The accommodation amplitude A , in dioptres, is given by

$$A = \frac{1}{d_1} - \frac{1}{d_2}$$

where

d_1 is the distance, in m, from the eye to its near point

d_2 is the distance, in m, from the eye to its far point.

Figure 2 shows how the value of A varies with age for a typical person.

Figure 2

0 1 . 3

An eye of a typical 30-year-old person has a far point at infinity.

The focal length of the eye when viewing an object at its far point is 23 mm.

Calculate the focal length of the eye when viewing an object at its near point.

[4 marks]

focal length = _____ mm

0 1 . 4

For a typical person, the far point remains at infinity as the person's age increases. Some studies suggest that hypermetropia increases with age.

Explain how **Figure 2** supports this suggestion.

[2 marks]



0 1

Car drivers must be able to

- read a speedometer from a distance of 50 cm
- read a number plate from a distance of 20.5 m.

A driver has an unaided far point of 55 cm and an unaided near point of 25 cm.

0 1 . 1

Identify the driver's eye defect.

Tick (✓) **one** box.

[1 mark]

Astigmatism	
Hypermetropia	
Myopia	

0 1 . 2

Figure 1 shows the position of a number plate at a distance of 20.5 m in front of the driver's unaided eye.

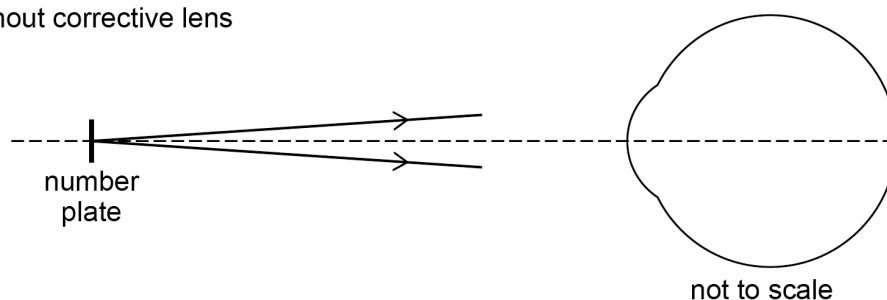
Figure 2 shows the same situation and the position of a corrective lens.

Complete both ray diagrams to show how and where the image of the number plate is formed in each case.

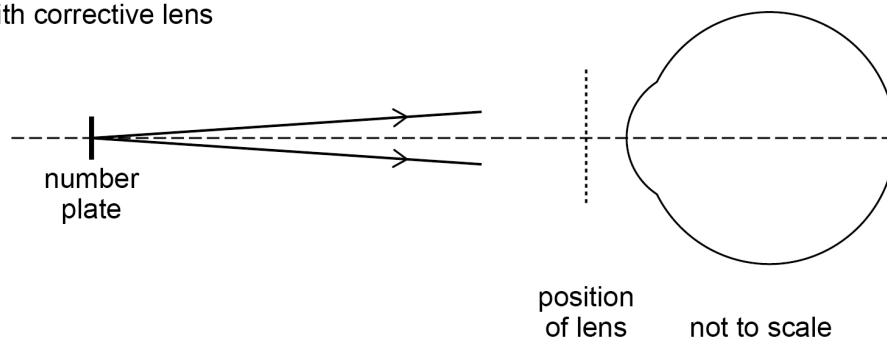
Add a suitable lens to **Figure 2**.

[4 marks]**Figure 1**

Without corrective lens

**Figure 2**

With corrective lens



Question 1 continues on the next page

0 1 . 3

An optician considers the use of **three** different lenses, **A**, **B** and **C**, for use by the driver when driving.

Power of **A** = -2.18D

Power of **B** = -1.77D

Power of **C** = $+1.95\text{D}$

Deduce which lens is suitable.

Support your answer with calculations.

[5 marks]

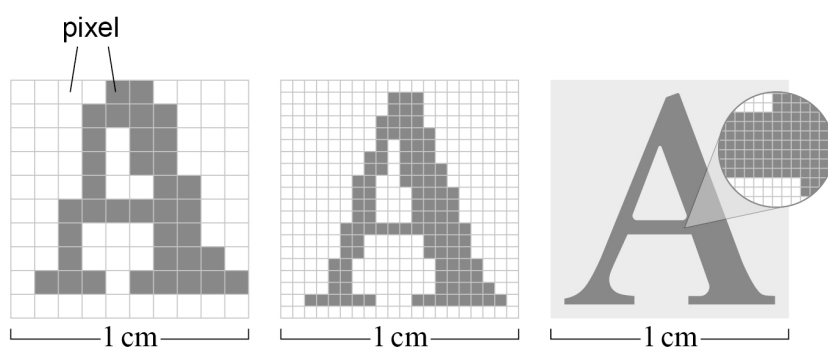
0 2

Electrophoretic screens are used in handheld electronic devices.

The screen contains individual squares known as pixels. Pixels can be changed independently from light to dark to create the shapes of letters and numbers. An external light source is needed in order to read the screen.

Figure 1 shows a letter formed by three electrophoretic screens that have different pixel line densities. Pixel line density is the number of pixels along a 1.0 cm length of the screen.

Figure 1

**0 2 . 1**

A particular screen is designed so that two dark pixels separated by one light pixel cannot be resolved as separate images by the eye when viewed from a distance of 0.50 m.

Determine, in pixels per cm, the minimum pixel line density required for this screen.

typical diameter of cones in a human eye at the fovea = $1.5 \mu\text{m}$

typical length of the human eye = 21 mm

[3 marks]

pixels per cm = _____

Question 2 continues on the next page

0 2 . 2

On a different electrophoretic screen, two dark pixels separated by one light pixel can just be resolved at a particular distance when the external light source is bright.

Explain why these pixels cannot be resolved at the same distance when the intensity of the external light source is reduced.

[3 marks]

Figure 2 shows the spectral response of the three different types of cone in a human eye.

Figure 2



0 2 . 3 The eye is illuminated by light of wavelength 603 nm.

Show that the response of a red-sensitive cone is approximately double the response of a green-sensitive cone.

[1 mark]

0 2 . 4 Other types of screen use blue, green and red pixels to produce coloured images.

Table 1 shows the wavelength of the light emitted by each pixel when it is turned on.

Table 1

Pixel	Wavelength / nm
blue	450
green	520
red	650

On one screen, the blue pixels are turned off.

When the green pixels and the red pixels are turned on, they emit light with the same intensity. A human eye that has the spectral response shown in **Figure 2** responds to this light.

Determine, in nm, the **single** wavelength of light that will produce the same response in the same human eye as the light emitted from the green and red pixels.

[3 marks]

wavelength = _____ nm



SUB-TOPIC 3.10.2

PHYSICS OF THE EAR

Sub-topic 3.10.2 · 8 questions · 51 marks · lowest tariff first



0 3 . 1 Define sound intensity.

[1 mark]

0 3 . 2 The intensity level, in dB, of a sound is I .

What is the intensity level of a sound with double the intensity?

Tick (✓) **one** box.

[1 mark]

$I + 2$	☐
$I + 3$	☐
$I + 7$	☐
$2I$	☐
$3I$	☐
I^2	☐

0 3 . 3 The amplitude of the pressure wave at the oval window of an ear is 20 times greater than at the tympanic membrane.

Calculate the ratio $\frac{\text{force on oval window}}{\text{force on tympanic membrane}}$.

$$\text{area of oval window} = 5.9 \times 10^{-6} \text{ m}^2$$

$$\text{area of tympanic membrane} = 7.2 \times 10^{-5} \text{ m}^2$$

[2 marks]

ratio = _____



0 2

A sound wave produces a maximum increase in pressure on an ear of $2.5 \times 10^{-3} \text{ N m}^{-2}$.

This causes a maximum increase in pressure in the fluid of the inner ear of $5.0 \times 10^{-2} \text{ N m}^{-2}$.

0 2 . 1

Explain how the ossicles contribute to this increase in pressure in the fluid of the inner ear.

[2 marks]

0 2 . 2

The ear's tympanic membrane can be assumed to be a circle of diameter 1.0 cm.

Calculate the area, in m^2 , of the oval window.

[3 marks]

area = _____ m^2



03.1 A point source of sound has a power of 17 W.

Calculate, in dB, the intensity level at a distance of 12 m from the source.

[3 marks]

intensity level = _____ dB

03.2 The frequency of a sound is increased from 3.0 kHz to 8.0 kHz with no change in intensity.

One change in the sound perceived by a person with normal hearing is an increase in pitch.

Explain **one** other change to the sound perceived by the person as the frequency is increased from 3.0 kHz.

[2 marks]



0 2 . 1

A stadium is full of spectators. The peak sound-intensity level at the centre of the stadium is 110 dB.

On another occasion the number of spectators in the stadium is reduced by 60%.

Estimate the peak sound-intensity level at the centre of the stadium.

You should assume that on both occasions:

- the sound intensity produced by each spectator is the same
- the spectators are distributed evenly around the stadium.

[4 marks]

peak sound-intensity level = _____ dB

0 2 . 2

Describe the changes to a person's hearing that may result from **prolonged** exposure to sound at 110 dB.

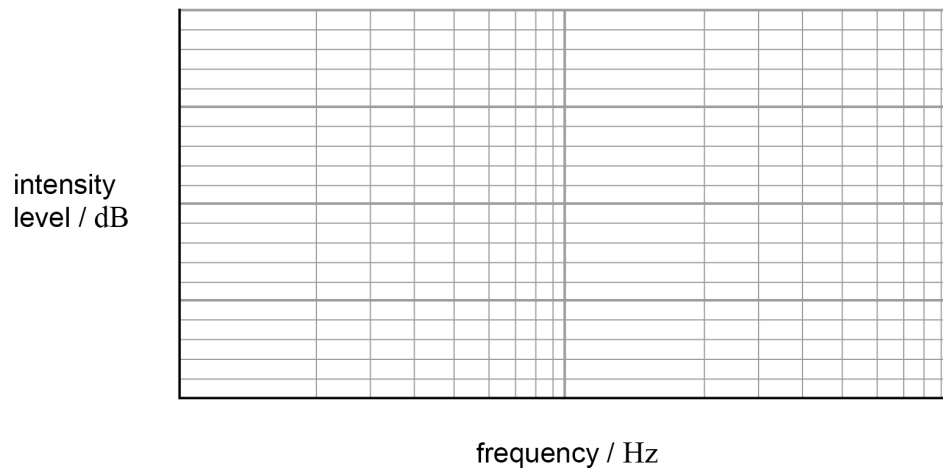
[2 marks]

03.1

Sketch an equal loudness curve on **Figure 3** showing the normal response of a healthy ear.
Annotate the **frequency** axis with an appropriate scale.

[3 marks]

Figure 3



03.2

Describe the procedure used to gather the data for an equal loudness curve.

[2 marks]

03.3

Calculate the intensity of a sound that produces an intensity level of 30 dB.

[2 marks]

intensity = _____ W m^{-2}



03.1

State what is meant by the threshold of hearing for a person with good hearing.

[2 marks]

In a hearing test, a person is found to have good hearing.

Figure 4 shows the equal loudness curve produced in the test.**Figure 4**

03.2

The eardrum of the person being tested has a cross-sectional area of 60 mm^2 .

Calculate the power that is incident on the eardrum when the frequency is 50 Hz.

[3 marks]

power = _____ W

03.3

Sketch, on **Figure 4**, an equal loudness curve that passes through 100 dB at 1 kHz.

[2 marks]

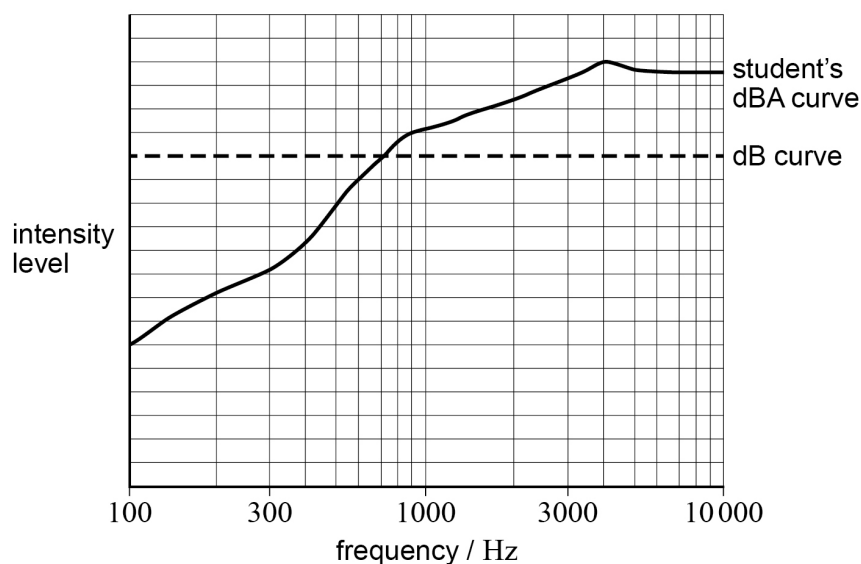


0 4 . 1

A source of constant output power is used to generate a sound which is measured using a sound meter.

The dashed line in **Figure 3** shows the intensity level curve over a range of frequencies with the meter set to the dB setting.

Figure 3



A student sketches a curve, over the same frequency range, which he thinks would be obtained when the meter is changed to the dBA setting. The curve drawn by the student is shown as the solid line in **Figure 3**.

Discuss whether the dBA curve drawn is correct.

[4 marks]

0 4 . 2

Mesh barriers are set up to keep pedestrians at a safe distance from a noisy drill. The maximum noise level which pedestrians should be subjected to is 110 dB. The drill emits sound with a power of 7.8 W and acts as a point source. The mesh barriers are set up a distance of 2.0 m from the drill.

Discuss whether this will keep pedestrians at a safe distance from the sound source.

[4 marks]

0 2

Three customers, **P**, **Q** and **R**, are sitting in a café listening to music from a loudspeaker.

Customer **P** is 11 m from the loudspeaker. At the position of customer **P**, the sound intensity is $3.4 \times 10^{-8} \text{ W m}^{-2}$.

0 2 · 1

Customer **P** moves to a distance of 7.0 m from the loudspeaker.

Calculate the sound intensity at the new position of customer **P**.
Assume that the loudspeaker is a point source.

[2 marks]

sound intensity = _____ W m^{-2}

0 2 · 2

The sound intensity level is 65 dB at the position of customer **Q** and 42 dB at the position of customer **R**.

Calculate the ratio $\frac{\text{sound intensity at the position of Q}}{\text{sound intensity at the position of R}}$.

[2 marks]

ratio = _____



0 2 . 3 Customer **Q** perceives the loudness of the sound differently to customer **R**.

Discuss whether the use of intensity level or intensity is more appropriate to compare the perceived loudness.

[2 marks]

0 2 . 4 Customers **P**, **Q** and **R** move to the same distance from the loudspeaker.

Customer **P** is 80 years old and has hearing loss due to her age.

Customer **Q** is 35 years old and has hearing loss due to working in an extremely noisy environment.

Customer **R** is 35 years old and has no hearing loss.

The hearing defects of **P** and **Q** affect their perception of the music being played.

Describe how their perceptions are different from that of **R**.

[3 marks]



SUB-TOPIC 3.10.3

BIOLOGICAL MEASUREMENT (ECG)

Sub-topic 3.10.3 · 1 question · 5 marks · lowest tariff first

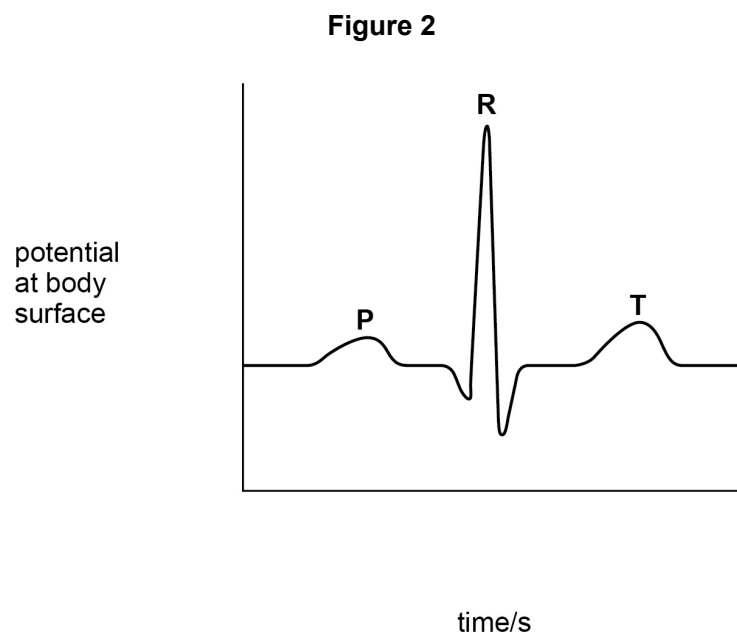


0	4	.	1
---	---	---	---

Figure 2 shows an ECG trace for a healthy person.

Complete **Figure 2** by adding a suitable unit and scale to the potential axis, and a suitable scale to the time axis.

[2 marks]

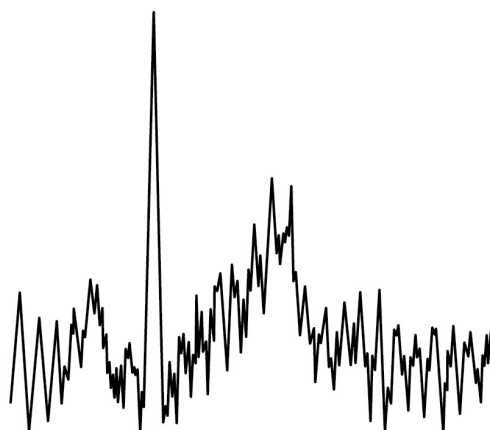


Question 4 continues on the next page

0	4	.	2
---	---	---	---

Figure 3 shows a faulty ECG trace which was obtained for another healthy person.

Figure 3



Discuss **three** possible reasons why this faulty trace was obtained.

[3 marks]

END OF QUESTIONS

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SUB-TOPIC 3.10.4

NON-IONISING IMAGING: ULTRASOUND, ENDOSCOPY AND MR

Sub-topic 3.10.4 · 9 questions · 67 marks · lowest tariff first



0 5 . 1

State the purpose of the magnetic field in a magnetic resonance scanner.

[1 mark]

0 5 . 2

Describe the role of the radio frequency pulses in a magnetic resonance scanner.

[2 marks]

END OF QUESTIONS

0 2

Figure 2 shows scanned images of three different human heads. Each image used **one** of the following scanning techniques:

- magnetic resonance (MR)
- CT
- ultrasound
- PET.

Figure 2



Identify the scanning technique used for each image.

Go on to explain how the features of each image enabled you to identify the type of scan.

[4 marks]

A: Scanning technique _____

Explanation _____

B: Scanning technique _____

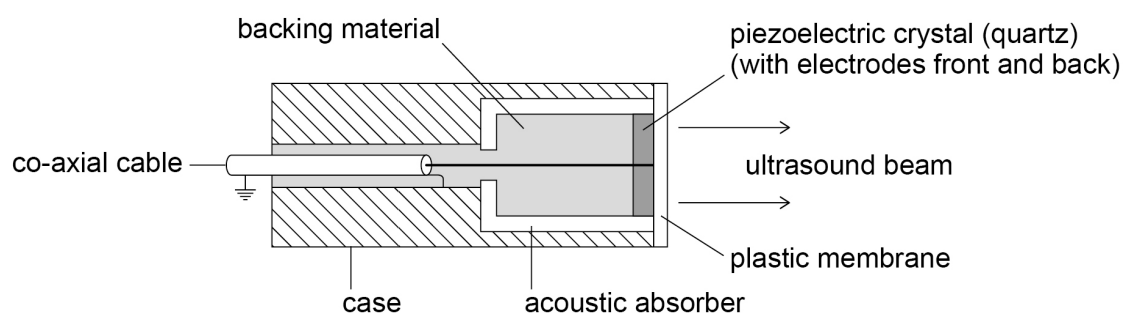
Explanation _____

C: Scanning technique _____

Explanation _____

0 5 . 1 Figure 2 shows a transducer used in a medical ultrasound scanner.

Figure 2



Explain why a backing material is used.

[2 marks]

0 5 . 2 A beam of ultrasound is transmitted from muscle into bone.

Calculate the percentage of the incident intensity that is transmitted.

acoustic impedance of bone = $5.3 \times 10^6 \text{ kg m}^{-2} \text{ s}^{-1}$

density of muscle = 1100 kg m^{-3}

speed of ultrasound in muscle = 1600 m s^{-1}

[3 marks]

percentage = _____ %

END OF QUESTIONS

0 1 . 1

An endoscope is used to view an area inside the body. The endoscope contains two bundles of optical fibres.

Name each bundle and explain its use in the process.

[4 marks]

Bundle 1 _____

Bundle 2 _____

0 1 . 2

A single optical fibre is placed in air. The optical fibre has a core surrounded by cladding. The critical angle is 75° at the core-cladding boundary.

Complete **Figure 1** to show how the refractive index varies with radial distance from the centre of the core to the air surrounding the fibre.

Your answer should be supported by a suitable calculation.

refractive index of core = 1.6

[2 marks]

Figure 1



0	4
---	---

A patient has calcium kidney stones.

Three types of scan are available to investigate the condition:

- a magnetic resonance (MR) scan
- a CT scan
- an ultrasound scan.

Calcium kidney stones contain no water and appear similar to bone in each of the scans.

Discuss the advantages and disadvantages of each option.

In your answer you should

- refer to the relevant quality of the image obtained from each scan
- identify other factors that should be considered
- justify the type of scan you would recommend.

[6 marks]

0 4

Ultrasound is commonly used in medical procedures.

0 4 · 1

An ultrasound A-scan is used to find the length l of an eye as shown in **Figure 6**. **Figure 7** shows the simplified A-scan for the eye. A short pulse of ultrasound is transmitted at time $t = 0$

The average speed of ultrasound in the eye = 1560 m s^{-1} .

Figure 6

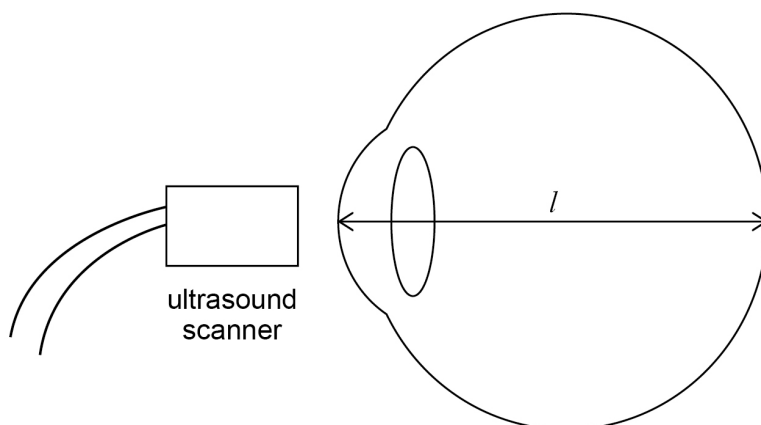
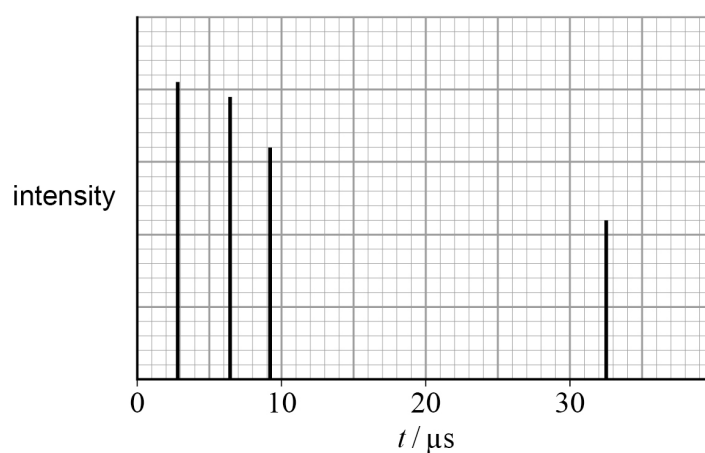


Figure 7



Calculate l .

[3 marks]

$l =$ _____ m

0 3 . 1

Name the two types of optical fibre bundle used in an endoscope.

Go on to discuss whether the optical fibres in either of these bundles require cladding.

[4 marks]

0 3 . 2

Modal and material dispersion can cause problems in fibre-optic communications.

Discuss why the methods used to reduce modal and material dispersion are not required in an endoscope.

In your answer you should:

- describe the methods used to reduce dispersion in an optical fibre used for communication
- explain why the methods are not required in an endoscope
- explain how using these methods in an endoscope would affect its function.

[6 marks]

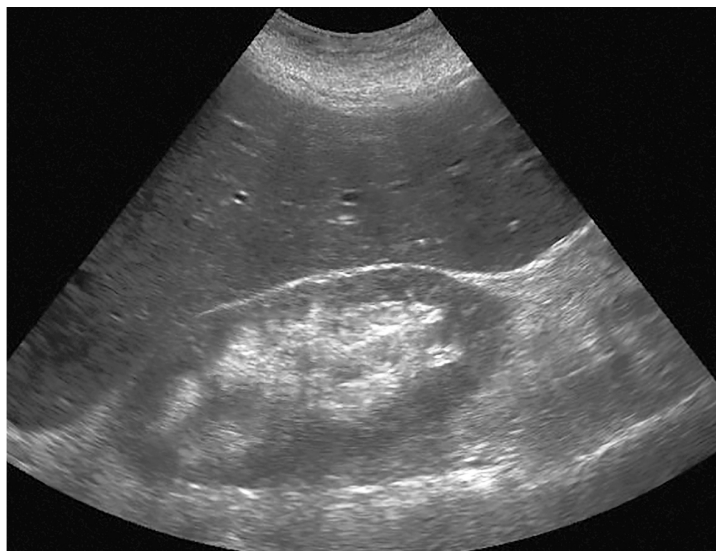
0 4

Different ultrasound techniques are used to investigate the health of a patient's kidneys.

0 4 . 1

Figure 3 shows the results of an ultrasound scan of a kidney using one technique.

Figure 3



Identify the type of ultrasound scan used to produce **Figure 3**.

Explain your answer.

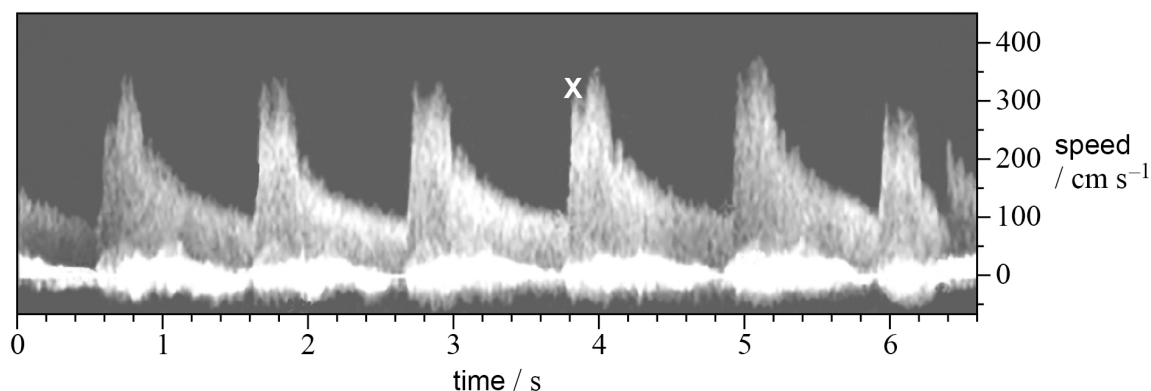
[1 mark]

Question 4 continues on the next page

Another ultrasound technique is used to measure the speed of blood flow in one of the kidney's blood vessels.

Figure 4 shows an image formed using this technique. It shows how the speed of flow through the blood vessel varies with time. Point **X** shows this speed at one instant of time.

Figure 4



0 4 . 2 Determine the patient's heart rate in beats per minute.

[3 marks]

heart rate = _____ beats per minute

0 4 . 3 An ECG was made for the patient in Question **04.2**.

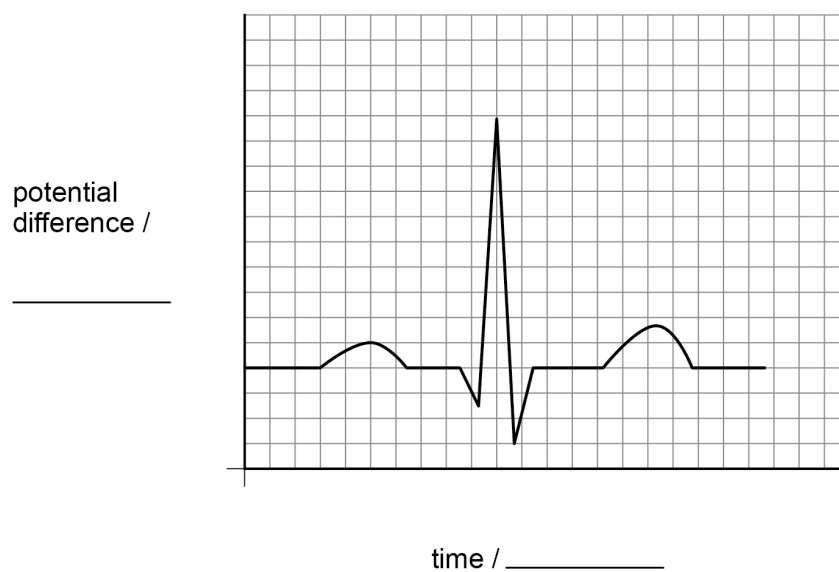
Figure 5 shows one heartbeat from the ECG.

Annotate **Figure 5** to show:

- units on both axes
- scales on both axes
- point **Y** that corresponds to point **X** on **Figure 4**.

[4 marks]

Figure 5



Question 4 continues on the next page

0 4 . 4 A backing gel is used between an ECG pad and the skin of the patient. The gel is sticky. This property ensures that the pad is securely attached to the skin.

Explain:

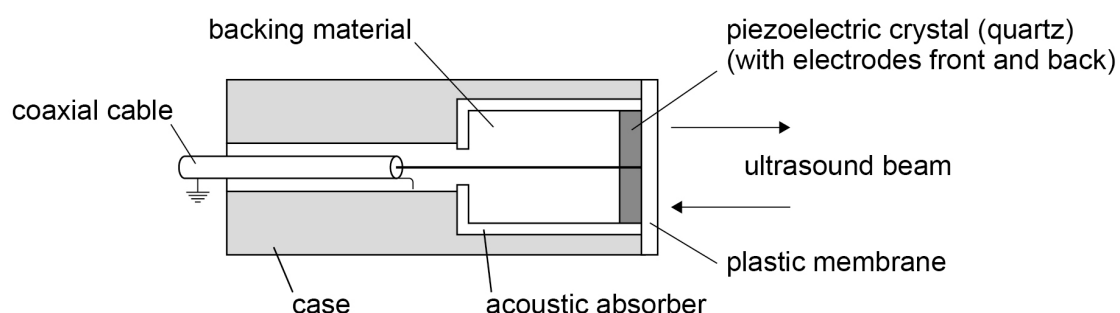
- one other reason why the backing gel is needed
- one other property of the backing gel
- how the skin is prepared for the pad to be applied.

[3 marks]

0 4

Figure 1 shows an ultrasound transducer used to perform medical scans.

Figure 1



0 4 . 1

Explain how the transducer in **Figure 1** operates in medical diagnosis.

In your answer you should explain how

- an ultrasound pulse is produced by the transducer
- the reflected ultrasound pulse is detected by the transducer
- the transducer can both transmit a pulse and receive the reflected pulse.

[6 marks]

0 4 . 2

Ultrasound of frequency 1.0 MHz is used to scan a person's liver.

Estimate the resolution of the scan.

$$\text{speed of sound in liver tissue} = 1600 \text{ m s}^{-1}$$

[1 mark]

resolution = _____ mm

Question 4 continues on the next page

0	4	.	3
---	---	---	---

Ultrasound travels from a transducer through the chest wall to an air pocket inside the lung. From the air pocket, the ultrasound is then incident on lung tissue.

Calculate the percentage of the incident ultrasound intensity that is transmitted into the lung tissue.

$$\text{speed of sound in lung tissue} = 1580 \text{ m s}^{-1}$$

$$\text{density of lung tissue} = 1075 \text{ kg m}^{-3}$$

$$\text{speed of sound in air} = 330 \text{ m s}^{-1}$$

$$\text{density of air} = 1.3 \text{ kg m}^{-3}$$

[4 marks]

percentage = _____ %



0	4	.	4
---	---	---	---

Discuss whether an ultrasound scan would be suitable to investigate a tumour inside a lung.

[2 marks]

END OF QUESTIONS



SUB-TOPIC 3.10.5

X-RAY IMAGING AND CT

Sub-topic 3.10.5 · 9 questions · 72 marks · lowest tariff first



0 4

In an X-ray machine, X-rays are emitted from an emission spot on a tungsten target.

Figure 3

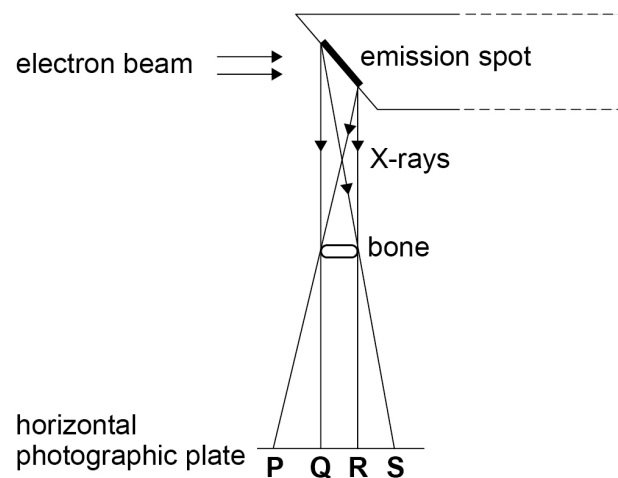


Figure 3 shows how a total shadow is produced in the region **QR** where no X-rays from any part of the emission spot can reach the photographic plate. Partial shadows are formed in regions **PQ** and **RS** where X-rays from only part of the emission spot can reach the plate.

Figure 4 shows detail of the formation of edges of the partial shadow **PQ**. The bottom of the emission spot is 1.0 m vertically above the plate. The horizontal distance across the beam is 1.0 mm at the bottom of the emission spot.

Figure 4

0 4 . 1

To produce a sharp image of a bone, the partial shadow in region **PQ** must be no more than 0.10 mm wide.

Calculate the maximum distance d between a bone and the plate.

[2 marks] $d =$ _____ m**0 4 . 2**

Discuss whether an X-ray image of a chest or an X-ray image of a hand is likely to be sharper when exposed to the same X-ray source.

[2 marks]

0	3
---	---

In the past, doctors could only use a simple X-ray image to assess head injuries. A CT scan is now a preferred technique.

Discuss why the CT scan has replaced the simple X-ray image to assess head injuries, but a simple X-ray procedure is suitable for assessing other injuries.

In your answer, you should:

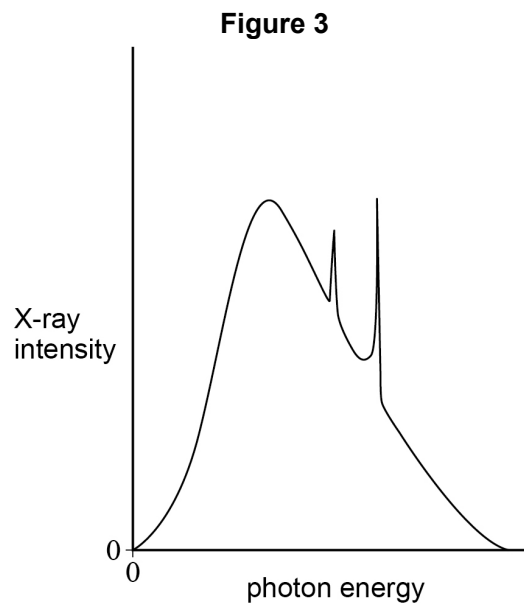
- describe the basic principles of a CT scanner
- discuss the advantage of the CT scan over a simple X-ray image for head injuries
- explain why a simple X-ray procedure is more suitable for assessing other injuries.

[6 marks]



0 3

Figure 3 shows the X-ray spectrum produced in a medical X-ray machine at a particular anode potential difference (pd).



0 3 . 1

In an X-ray tube, electrons collide with a tungsten target.

Explain how the continuous spectrum and the characteristic spectra are produced by these electron collisions.

[4 marks]

Continuous spectrum _____

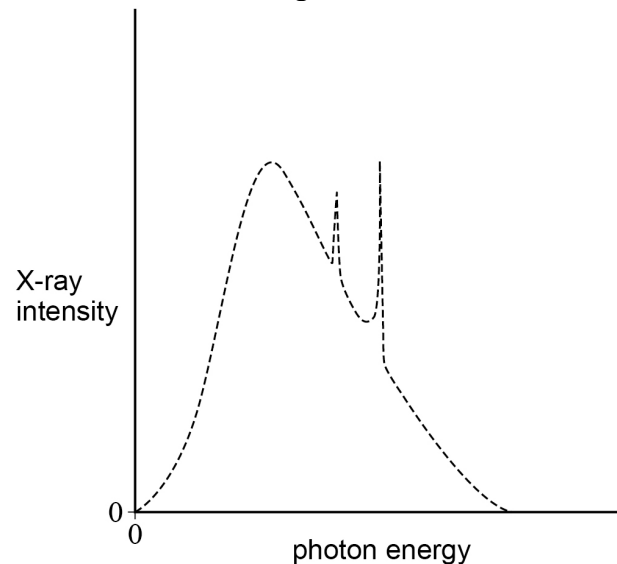
Characteristic spectra _____

0 3 . 2 The dashed line on **Figure 4** shows the X-ray spectrum for the initial anode pd.

Sketch on **Figure 4** the X-ray spectrum produced when the anode pd is increased.

[2 marks]

Figure 4



0 3 . 3 In the medical X-ray machine, the X-rays produced with the initial anode pd are now passed through an aluminium filter. The dashed line on **Figure 5** shows the X-ray spectrum for the initial anode pd.

Sketch on **Figure 5** the X-ray spectrum of the X-rays that emerge from the filter.

[1 mark]

Figure 5

0 5 . 1

High-energy X-rays are used in the treatment of a cancer tumour inside a patient's body. The patient is given a series of scans before the treatment is started.

Discuss how these scans are used to help provide the best and safest treatment for the patient when using the high-energy X-rays.

[3 marks]

0 5 . 2

Lead is commonly used as shielding when using X-rays due to its small half-value thickness.

Which statement gives the correct meaning of half-value thickness?
Tick (✓) the correct answer.

[1 mark]

The thickness of material needed to reduce the energy of an X-ray photon by half.

☐

The thickness of material needed to reduce the wavelength of the photons in the X-ray beam by half.

☐

The thickness of material needed to reduce the intensity of the X-ray beam by half.

☐

Half the thickness of material needed to stop the X-ray beam.

☐

0 5 . 3 The half-value thickness of lead for 500 keV X-rays is 4.2×10^{-3} m

Calculate the mass attenuation coefficient of lead for 500 keV X-rays.

State an appropriate unit for your answer.

density of lead = 1.1×10^4 kg m⁻³

[4 marks]

mass attenuation coefficient = _____ unit _____

END OF QUESTIONS



0 3

X-ray photons can be used to treat cancerous tumours in radiotherapy. Some photons are absorbed by healthy tissue before they reach the tumour.

Photons with a range of energies are generated in an X-ray machine.

Table 1 shows the linear attenuation coefficient of brain tissue for photons of energy 100 keV and 500 keV.

Table 1

Energy / keV	Linear attenuation coefficient of brain tissue / cm^{-1}
100	0.15
500	0.087

0 3 . 1

Deduce whether photons of energy 100 keV or 500 keV are better for treating a brain tumour at a depth of 11 cm.

[4 marks]

0 3 . 2

Metal filters are used in X-ray machines to limit the damage to healthy tissues. **Table 2** gives data for possible filter materials.

Table 2

Energy / keV	Linear attenuation coefficient / cm^{-1}	
	Aluminium	Copper
100	0.44	3.8
500	0.23	0.73

Discuss whether it would be better to use aluminium or copper to filter the X-rays in Question **03.1**.

No calculations are required.

[2 marks]

0 3 . 3

State and explain **one** other method used to limit exposure of healthy cells during X-ray radiotherapy.

[2 marks]

Method _____

Explanation _____

0 5 . 1

Figure 6 shows an X-ray image of a chest on photographic film.

Figure 7 shows a diagram of a horizontal cross-section of the chest along the dashed line in **Figure 6**.

Figure 6

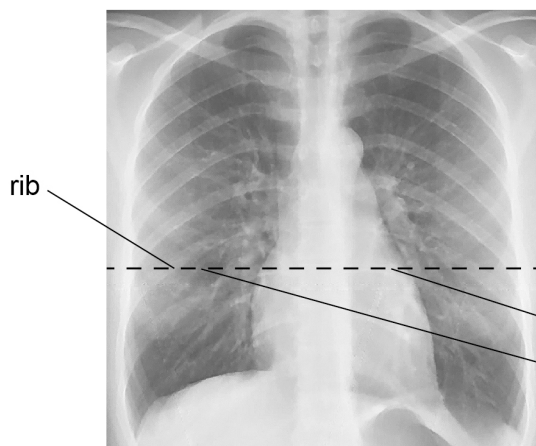
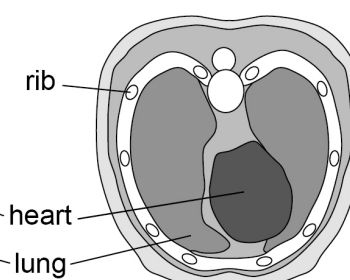


Figure 7



Discuss the half-value thicknesses of the labelled body parts relative to each other.

In your answer you should:

- explain how the intensity of the X-rays affects the brightness of the image
- explain how the thickness of the labelled parts affects the intensity of the X-rays
- compare the relative half-value thicknesses of the labelled body parts.

[6 marks]

0 5 . 2

The stomach is not clearly visible in **Figure 6**.

Explain the method used to improve the image of the stomach on X-ray photographic film.

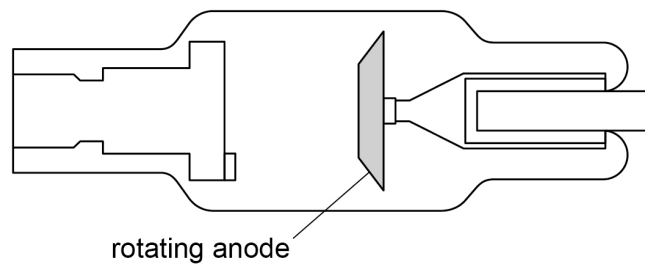
[2 marks]

END OF QUESTIONS

0 4

Figure 5 shows a rotating-anode X-ray tube used to produce an image of a bone.

Figure 5



0 4 . 1

X-rays originate from a region on the rotating anode known as the focal spot.

Explain:

- one advantage of using a small focal spot
- why the focal spot should not be too small.

[2 marks]

0 4 . 2

State and explain **three** methods used to limit exposure of the patient's healthy cells to X-rays during a diagnostic procedure.

[3 marks]

1 _____

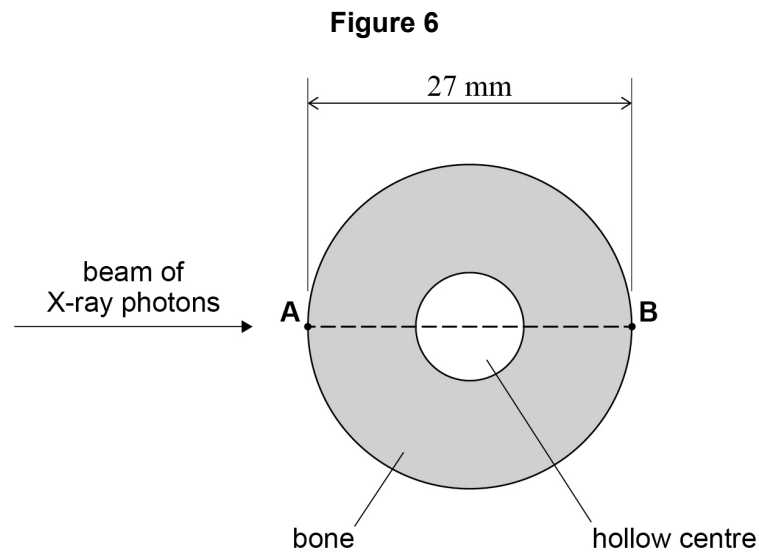
2 _____

3 _____

Question 4 continues on the next page

0 4 . 3

Figure 6 shows a scale diagram of a cross-section through a human bone called a femur.



A dashed line has been drawn from point **A** to point **B** through the centre of the femur. Along **AB** the femur has a circular cross-section with an external diameter of 27 mm. The femur has a hollow centre.

A beam of X-ray photons is incident on the femur at **A** in the direction **AB**. For these photons, the half-value thickness of bone is 15 mm.

Determine, using the scale diagram in **Figure 6**, the percentage of the X-ray photons incident on **A** that emerge at **B**.

[3 marks]

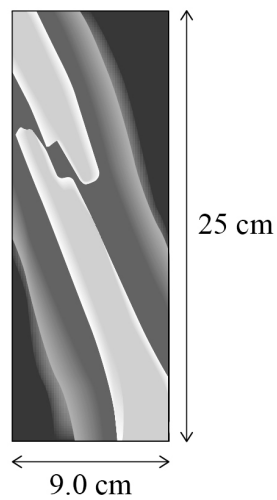
percentage = _____ %

END OF QUESTIONS



Figure 2 shows an X-ray of a broken bone.

Figure 2



mean diameter of bone = 0.040 m

intensity of incident X-rays = 0.013 W m^{-2}

exposure time of X-ray = 0.80 s

linear attenuation coefficient of bone = 58.3 m^{-1}

02.2

Calculate an estimate for the X-ray energy that is absorbed by the bone.

[5 marks]

energy absorbed = _____ J

02.3State **two** reasons why the estimate of energy absorption in Question **02.2** may be greater than the actual value.**[2 marks]**

1 _____

2 _____



0	2	.	1
---	---	---	---

A patient with a suspected broken arm is going to have an X-ray image taken.

Explain the risk to the patient of exposure to X-rays.

Go on to discuss **three** ways by which the design and use of the X-ray equipment minimises this risk.

[6 marks]

0	2	.	2
---	---	---	---

The blood vessel called the aorta passes through the abdomen. A second patient with a suspected fault in the wall of the aorta can be given an ultrasound scan or an X-ray of the abdomen.

Suggest, with reasons, which is the better procedure for investigating this suspected fault.

[2 marks]

Question 2 continues on the next page



0	2	.	3
---	---	---	---

When ultrasound travels across a boundary from blood to the wall of the aorta there is a decrease in acoustic impedance across the boundary. This results in 0.0625% of the intensity of the incident ultrasound being reflected at the boundary.

Calculate the acoustic impedance of the aorta wall tissue.

$$\text{acoustic impedance of blood} = 1.64 \times 10^6 \text{ kg m}^{-2} \text{ s}^{-1}$$

[4 marks]

acoustic impedance of aorta wall tissue = _____ $\text{kg m}^{-2} \text{ s}^{-1}$



SUB-TOPIC 3.10.6

RADIONUCLIDE IMAGING AND THERAPY

Sub-topic 3.10.6 · 5 questions · 47 marks · lowest tariff first



0	1
---	---

Brachytherapy is used to treat small tumours. In this technique a sealed radioactive source is placed inside a patient's body next to the tumour.

Explain **one** advantage of using beta radiation rather than gamma radiation in brachytherapy.

[2 marks]



0	3
---	---

A patient is going to have a PET scan. A small amount of radioisotope is injected into the patient's bloodstream and the patient is left to relax. The patient then lies on a horizontal table and is moved into the PET scanner. The scanner has many detectors positioned in a vertical circular pattern around the patient.

0	3	.	1
---	---	---	---

State what is meant by a radioisotope.

[1 mark]

0	3	.	2
---	---	---	---

The radionuclide used in the PET scan has a physical half-life of 110 minutes. The radionuclide is excreted from the body with a biological half-life of 185 minutes.

Show that the effective half-life of the radionuclide in the body is about 70 minutes.

[1 mark]



0	3	.	3
---	---	---	---

Discuss what might be a suitable length of time for the patient to relax between injecting the radionuclide and moving the patient into the PET scanner.

[3 marks]

0	3	.	4
---	---	---	---

The decay of the radionuclide results in the emission of a positron. Two of the detectors, directly opposite to each other, are triggered as they each receive a gamma photon.

Explain the process in which the gamma photons are created.

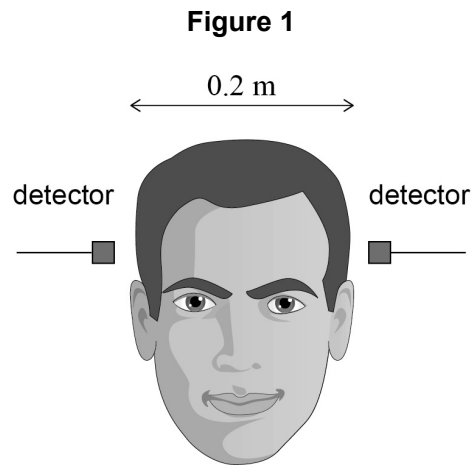
[2 marks]

Question 3 continues on the next page



0 3 . 5

Figure 1 shows the head of a patient that is 0.2 m across, placed centrally between two of the many detectors in a PET scanner.



To determine the position where the gamma photons are produced between the detectors, the scanner measures the short interval of time Δt between the triggering of the first detector and the triggering of the second detector.

Discuss, for the detector positions shown in **Figure 1**, the range of the values of Δt that the scanner must measure to perform a PET scan on the head.

Assume that the speed of the gamma photons in the head is $3 \times 10^8 \text{ m s}^{-1}$.

[2 marks]

0 4

Fluorine-18 has a biological half-life of 6.0 hours.

0 4**1**

Explain what is meant by this statement.

[2 marks]

In a PET scan, fluorine-18 is used as a tracer and is injected into the person being scanned.

0 4**2**

The physical half-life of fluorine-18 is 110 minutes.

Calculate the percentage of fluorine-18 that remains in the person 4.0 hours after it is injected.

[3 marks]

percentage = _____ %

0 4**3**

Name the particles emitted when a fluorine-18 nucleus decays.

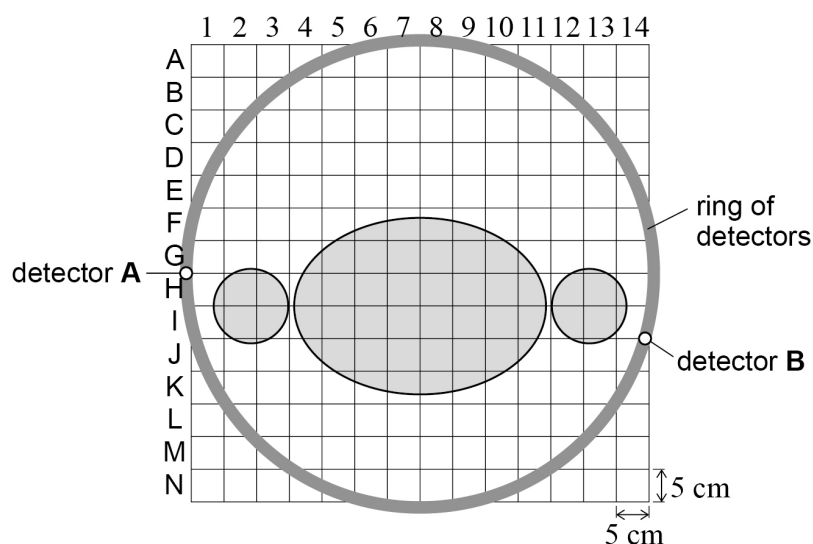
[1 mark]

0 4 . 4

Figure 1 shows the cross-section of a body inside a ring of detectors during a PET scan.

The side of each square represents 5 cm.

Figure 1



One of the products from the fluorine-18 decay goes on to produce two new particles. These particles travel in opposite directions in the plane shown in **Figure 1**. The particles are then detected by the detectors labelled **A** and **B**. Detector **A** detects a particle 0.79 ns before detector **B**.

Determine the square in **Figure 1** in which the particles were produced. You should identify the square with a letter and a number, eg B5.

[4 marks]

square = _____

0 2

Technetium- $^{99\text{m}}\text{Tc}$ is produced from the decay of molybdenum-99 (^{99}Mo). In hospitals, $^{99\text{m}}\text{Tc}$ is extracted from a molybdenum-technetium generator.

^{99}Mo is put into the generator at time $t = 0$

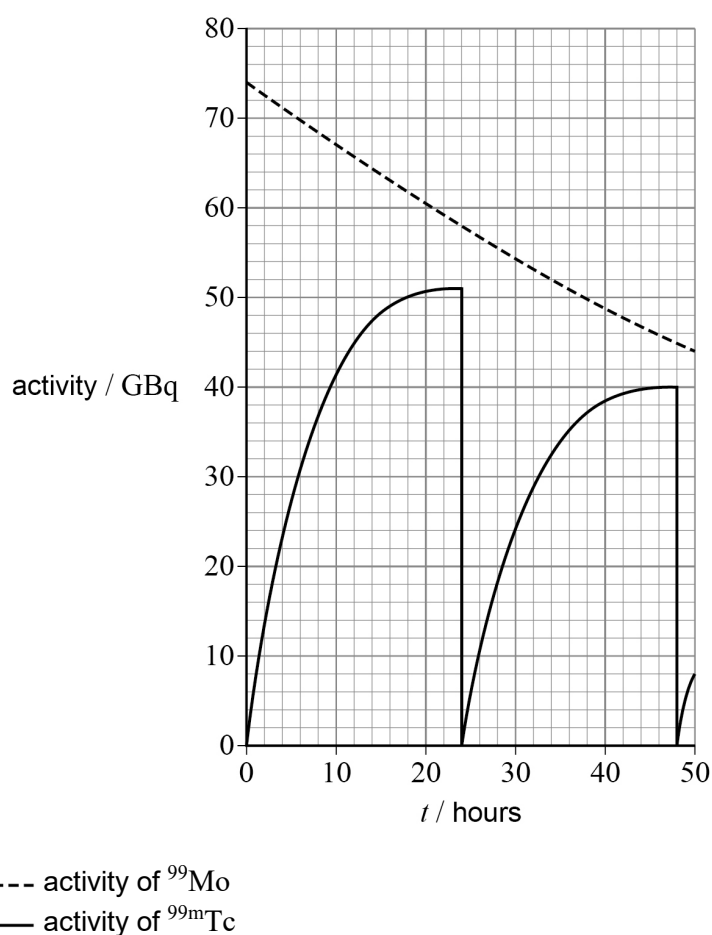
As ^{99}Mo decays, the amount of $^{99\text{m}}\text{Tc}$ increases to a maximum at $t = 24$ hours.

$^{99\text{m}}\text{Tc}$ is extracted from the generator at regular intervals.

At each extraction, the activity of $^{99\text{m}}\text{Tc}$ in the generator falls to zero and then increases again.

Figure 3 shows how the activities of ^{99}Mo and $^{99\text{m}}\text{Tc}$ in the generator vary with t when extractions are made at $t = 24$ hours and $t = 48$ hours.

Figure 3



0 2 . 1 Show that about 6×10^{15} nuclei of ^{99}Mo decay between $t = 0$ and $t = 24$ hours.

decay constant for $^{99}\text{Mo} = 2.8 \times 10^{-6} \text{ s}^{-1}$

[2 marks]

0 2 . 2 90% of the ^{99}Mo nuclei decay to form $^{99\text{m}}\text{Tc}$ nuclei. The other 10% decay to form different nuclei.

Estimate the number of $^{99\text{m}}\text{Tc}$ nuclei that are extracted from the generator at $t = 24$ hours.

[3 marks]

number = _____

Question 2 continues on the next page



0 2 3

Information about heart function can be obtained from a multi-gated acquisition (MUGA) scan or from a transthoracic echocardiogram (TTE) scan. Heart specialists use these scans to diagnose a range of heart conditions.

In a MUGA scan, a patient is injected with a compound containing $^{99\text{m}}\text{Tc}$ which binds to red blood cells.

Using images of the red blood cells, a precise reading can be made of blood flow rate through the heart.

A TTE is an ultrasound scan of the heart.

Images of the heart are seen on a monitor as a transducer is moved across the surface of the patient's chest.

Compare the MUGA method of investigating heart function with the TTE method of investigating heart function.

In your answer you should:

- outline how an image of the red blood cells is obtained during a MUGA scan
- explain the advantages that a MUGA scan and a TTE scan have in common
- compare the strengths and weaknesses of a MUGA scan and a TTE scan.

[6 marks]

0 1

A hospital uses the radioactive isotope technetium-99m as a tracer. Technetium-99m is produced using a Molybdenum-Technetium generator on site at the hospital.

0 1 . 1

Explain why the value of the half-life of technetium-99m:

- makes it suitable for use as a tracer
- means that it must be produced in a generator on site.

[4 marks]

0 1 . 2

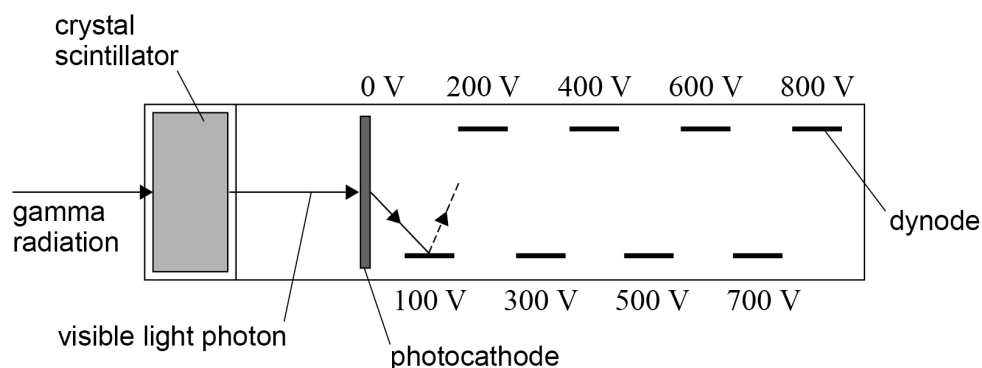
Technetium-99m emits **only** gamma rays.

Explain why this makes technetium-99m suitable for use as a tracer.

[4 marks]

0 1 . 3

A gamma camera can be used to form images when using a tracer. **Figure 1** shows a photomultiplier tube from a gamma camera.

Figure 1

At the crystal scintillator, each photon of gamma radiation leads to the emission of one visible light photon.

Describe how the current produced by the photocathode is amplified in the photomultiplier tube.

[3 marks]

Question 1 continues on the next page

0 1 . 4 Iodine-131 is a medical tracer that can be detected using a gamma camera.

Iodine-131 has a physical half-life of 8.0 days.

A patient is injected with iodine-131 that has an initial activity of 3.2 GBq. For this patient, the biological half-life is 66 days. For safety reasons, the patient cannot be discharged from hospital until the activity due to the iodine in the patient's body drops to 1.1 GBq.

Determine whether the patient can be safely released from hospital after 10 days.

[4 marks]

MARK SCHEMES

official mark schemes



01.1	myopia ✓	Allow short sightedness	1	AO2
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Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	Max one from ✓ - Evidence of with $u = \infty$ and $v = -6$ ✓_a - Correct use of a power equation ✓_b $P \left(= \frac{1}{f} \right) = -0.17 \text{ (D)} \checkmark$	✓_b $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ with: $u = \infty, v = (-)6$ $u = \infty, v = 0.02$ $u = 6, v = 0.02$ Where $u = \infty$, condone missing $\frac{1}{u}$ Allow $\frac{1}{(-)6} + \left(\frac{1}{\infty} \right)$ if u and v not defined Correct answer ✓✓ Max 1 mark for correct answer where clear statement that $v = \infty$ and $u = -6$ ECF for hypermetropia/ long sightedness on 01.1 $\frac{1}{f} = \frac{1}{0.25} + \frac{1}{(-)6} \checkmark$ $= 3.83 \checkmark \text{ (D)}$	2	AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	spherical cylinder axis ✓		1	AO1
Total			4	

Question	Answers	Additional comments/Guidelines	Mark	AO
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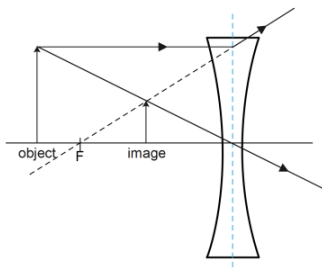


02.1	4.1 / 1.5 = 2.75 ✓ Eye can resolve the images as they are more than 2 cell diameters apart / a distance greater than 3×10^{-6} m apart / separated by at least 1 unstimulated cell. ✓	Marks 3 and 4 are ECF	4
02.2	three curves labelled blue, green, red from left to right ✓ roughly at correct height green, red above 2/3 green, and blue less than 1/3 green ✓ blue 375 to 500, green 425 to 675, red 475 to 725 ; all + or –30 ✓		3
Total			7

Question	Answers	Additional Comments/Guidelines	Mark
	Points to consider: For the basic principles of the CT scan • Patient lies in centre of ring • X-ray tube is mounted on one side of the ring with array of detectors mounted on the other side of the ring opposite the X-ray tube. • Narrow beam of X-rays in a short pulse sent through the head and the signals from the array of detectors are fed into a computer. • The X-ray tube and detectors are rotated about the patient's head and pulses of X-rays are sent through the patient's head from different directions	6 marks will clearly explain the basic principles of the CT scan. They will explain using this scan to assess head injuries. They will give good reasons for the use of basic X-rays in certain situations. 5 marks will clearly explain some of the basic principles of the CT scan. They will give some explanation for using this scan to assess head injuries. They will give good reasons for the use of basic X-rays in certain situations. 4 marks will explain some of the basic principles of	

05.1	+2.00	−0.50	75			1	AO2
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Question	Answers	Additional comments/Guidelines	Mark	AO																
05.2	The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the ‘Mark Scheme Instructions’ document should be used to assist in marking this question.		1 3 2	AO1 AO2 AO3																
	<table><tr><th>Mark</th><th>Criteria</th></tr><tr><td>6</td><td>All 3 areas covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.</td></tr><tr><td>5</td><td>All 3 areas covered at least 2 in detail. Whilst there will be gaps, there should only be an occasional error.</td></tr><tr><td>4</td><td>Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be several gaps, there should only be an occasional error.</td></tr><tr><td>3</td><td>One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.</td></tr><tr><td>2</td><td>Only one area discussed, or makes a partial attempt at two areas.</td></tr><tr><td>1</td><td>None of the three areas covered without significant error.</td></tr><tr><td>0</td><td>No relevant analysis.</td></tr></table>				Mark	Criteria	6	All 3 areas covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.	5	All 3 areas covered at least 2 in detail. Whilst there will be gaps, there should only be an occasional error.	4	Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be several gaps, there should only be an occasional error.	3	One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.	2	Only one area discussed, or makes a partial attempt at two areas.	1	None of the three areas covered without significant error.	0	No relevant analysis.
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	1	None of the three areas covered without significant error.																		
	0	No relevant analysis.																		
Ray diagram 																				
• Concave lens • Principal axis shown • Focal length labelled / principal focus labelled • Rays bend outward at lens • Object beyond focal length • Image inside focal length • Virtual image smaller than object • Object and image labelled																				
Description of myopia • Far point of eye closer than infinity • Can't focus on objects further than far point • Image formed in front of retina • Can focus near objects but not those far away																				
Explanation for lens correcting vision • Student is incorrect due to magnification factor < 1 / smaller image than object • Use of concave lens • Image is formed on retina • Creates image closer than the eye's unaided far point (and further than eye's unaided near point)																				

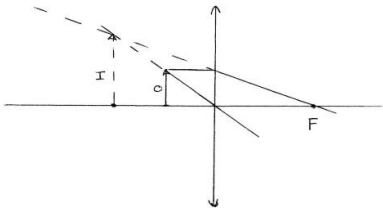
01.1	hypermetropia ✓		1	AO2
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Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	Use of $P = \frac{1}{u} + \frac{1}{v}$ correctly. Must see correct substitution for u or calculation for v, $v = \left(4 - \frac{1}{0.75}\right)^{-1}$ _{1✓} ($= 0.375 \text{ m}$) Correct substitution in $m = \frac{v}{u}$ _{2✓} ($= \frac{0.375}{0.75}$) 0.50 _{3✓}	Correct substitution may be inferred from using the answer as the top line in $m = \frac{v}{u}$ Allow PoT for _{1✓} and _{2✓} Allow ecf for _{2✓} (allow ecf for mixing up u and v for this mark, expect to see an answer of 2 for magnification) No ecf or PoT for _{3✓} Condone 1SF MAX 2 if incorrect negative sign seen.	3	3 x AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	X – cornea, Y – lens, Z – iris ✓ X / cornea form image (on retina) / (primary) refractor / (most of) refraction takes place ✓ Y / lens Accommodation / varies the focal length / power (of eye) ✓ Z / iris Control the amount of light entering the eye ✓	First mark is for correctly naming all three parts Other marks can be gained for attaching the correct description to either the label or the name (if parts not correctly identified) Treat non optical functions as neutral. Do NOT allow “to direct the light” for refraction Condone “change shape to view / focus on objects at different distances” for Y Condone intensity if linked to retina or back of the eye.	4	4 x AO1
Total			8	

Question	Answers	Additional comments/Guidelines	Mark	AO
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01.1	Eye lens cannot be made powerful enough / rays cannot be bent enough / eyeball is too short ✓ cannot be brought to a focus on the retina / fovea / back of the eyeball ✓	Accept not strong / fat/convex enough Do not accept fat enough – neutral answer Accept rays would be / are focused behind the retina	2
01.2	$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$ $\frac{1}{0.24} + \frac{1}{v} = 2$ ✓ $v = (-) 46 \text{ (cm)}$ ✓ ans to 2 sig figs ✓	Use of 2 and 1/24 is AE Answer 0.46 gets 1 working mark	3
01.3	D the eye's unaided near point.		1
01.4	first correct ray ✓ completed ray diagram with two rays and 'image' drawn ✓ labelled object, image and at least 1 principal focus. ✓ 	First two marks are for a diagram showing a virtual image Third mark is for any diagram. Do not allow f for F unless other labelling is present.	3
Total			9

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Question	Answers	Additional Comments/Guidelines	Mark
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01.1	Bright light uses only cones and very dim light uses only rods ✓ Comparison between high resolution in bright light and low resolution in low light ✓ Because cones have a nerve each, rods share nerves ✓ Comparison between coloured image in bright light and black and white image in low light ✓ Cones see in colour, rods see in black and white ✓	The first mark may be in either answer and is independent. Ignore clearer, more focused. If no comparison is given award one mark max for one valid statement about resolution and one about colour, eg bright light is in colour and high resolution. The explanation must match the description to gain credit.	5	2× AO1.1a 3× AO1.1b
01.2	Adaptation ✓		1	AO1.1a
01.3	Takes time for rods to adapt to the dark ✓ Time for rods to regenerate <u>rhodopsin/visual purple/</u> reverse the effects of <u>bleaching</u> the rods ✓ It allows the pirate's eye to see immediately in low light levels / the pirate's eye is already dark-adapted ✓	Rods must be mentioned in answer for 3 marks. First marking point is for time taken, ignore wrong term for process.	3	AO3.1b
Total			9	

Question	Answers	Additional comments/Guidelines	Mark	AO
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01.1	Both rays refracted towards optical axis at cornea ₁ ✓ Rays refracted towards optical axis at lens and meets at the intersection of optical axis with back of eye and rays are continuous between lens and back of eye ₂ ✓	Condone non-straight line for MP1 or MP2 but not both.	2	AO1
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Question	Answers	Additional comments/Guidance	Mark	AO
01.2	lens ✓	tick in 3rd box only; CAO	1	AO1

Question	Answers	Additional comments/Guidance	Mark	AO
01.3	(A =) 8.8 (dioptries) ₁✓ Correctly calculates d_1 from formula using their A ₂✓ use of the lens formula ₃✓ focal length correct ₄✓	for ₁✓ CAO Allow evidence of 8.8 on Figure 2 for ₂✓ expect to see $d_1 = 114 \text{ (mm)}$ allow 2 sf 110 (mm) must see appropriate working., e.g. allow $d_1 = \frac{1}{8.8}$ Or $d_1 = \frac{5}{44}$ Or $(A=) 8.8 = \frac{1}{d_1}$ for ₃✓ allow one POT error EITHER Find v with object at far point, e.g. $\frac{1}{23} = \left(\frac{1}{\infty}\right) + \frac{1}{v}$ condone $\frac{1}{f} = \left(\frac{1}{\infty}\right) + \frac{1}{23}$ expect to see $v = 23 \text{ (mm)}$ OR Find focal length with object at near point, e.g. $\frac{1}{f} = \frac{1}{\text{their } u} + \frac{1}{\text{their } v}$ expect to their $u = \text{their } d_1$ Condone: u, v mix up - allow either their u or their v but not both penalise incorrect signs in ₃✓ for ₄✓ allow 19(.1) for $d_1 = 114 \text{ mm}$ and 19(.0) for $d_1 = 110 \text{ mm}$ Must see correct working in MP3 to support this answer.	4	2 × AO2 2 × AO3



Question	Answers	Additional comments/Guidance	Mark	AO
01.4	explains hypermetropia Or Interprets Figure 2 in terms of d_1 OR A and d_2 $_1✓$ Describes the relationship between A and d_1 therefore identifying how Figure 2 suggests hypermetropia increases with age $_2✓$	for $_1✓$ accept - cannot focus on nearby objects - light from nearby objects focused behind retina - near point further away / near point increases - idea that d_1 increases A decreases and d_2 does not change Treat each bullet point as independent. 'long-sighted' is neutral for $_2✓$ (Figure 2 shows) A decreases (with age) because d_1 increases OR (Figure 2 shows) A decreases (with age) because $\frac{1}{d_1}$ decreases. any suggestion that d_2 changes loses $_2✓$ For $_{12}✓$, allow A referred to as 'accommodation amplitude' but must refer to either d_1 or $\frac{1}{d_1}$ for $_2✓$	2	1 × AO1 1 × AO3

Total			9
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Question	Answers	Additional comments/Guidance	Mark	AO
		5.1 × 10 ⁸ 5.2 × 10 ⁸ 4.1 × 10 ⁸	1	1.1.1



01.1	Myopia		1
01.2	Rays bends inward at cornea on both diagrams ✓ Figure 1 image in front of retina ✓ Figure 2 image on retina ✓ Concave lens drawn, which bends rays outward ✓	Max 3, if light rays are not drawn with a ruler	

01.3	rejection of C / +1.95 D since it is the wrong shape / wrong sign / convex / corrects wrong defect ✓₁ Any valid substitution demonstrating $P = \frac{1}{f}$ and evidence of the correct usage of u and v ✓₂ 1st valid calculation of either virtual image location or aided near / far point for A, B or C or calculation of lens needed to correct far point or calculation of lens needed to see number plate ✓₃ 2nd valid calculations of either virtual image location or aided near / far point for A, B ✓₄ Lens B / -1.77 D because it is the only lens where both number plate and speedometer can be seen (lens A cannot focus on speedometer) ✓₅	✓₁ must have a valid reason ✓₂ f may be calculated and substituted or P used as $\frac{1}{f}$ in equation. Ignore use of $\frac{1}{x'}$, correct use of u, v must be seen For virtual image location v must be subject For aided near/far point u must be subject Ignore PoT and sign errors ✓₃ and ✓₄ Mark 3 (options) Lens to correct far point $P = -1.82$ D or $f = -0.55$ m Lens to see number plate $P = -1.77$ D or $f = -0.57$ m Lens C speedometer $v = -20$ m Lens C number plate $v = 53$ cm (=0.53 m) Mark 3 or Mark 4 (options) Lens A speedometer $v = -24$ cm Lens A number plate $v = -45$ cm Lens B speedometer $v = -27$ cm Lens B number plate $v = -55$ cm Lens A aided far point $u = \infty$ (-2.76m) Lens A aided near point $u = 55$ cm Lens B aided far point $u = 2080$ cm (= 20.8 m) Lens B aided near point $u = 45$ cm ✓₅ must be supported by calculations for B showing both number plate and speedometer can be seen Identification of the lens with no supporting evidence scores 0.	1 1 1 1
Total			10

Question	Answers	Additional Comments/Guidelines	Mark
	$I \propto \frac{1}{A} = \frac{1}{r^2}$ or $P = IA = 3.4 \times 10^{-8} \times 4\pi 11^2 \checkmark (= 5.17 \times 10^{-5} \text{ W})$	M1 Working mark Evidence of either a proportion calculation or calculation of power from intensity	1



02.1	Use of ratio or tan used consistently ✓ $d = 7.14 \times 10^{-5} \text{ m}$ or $3.57 \times 10^{-5} \text{ m}$ OR image size 4.2×10^{-4} OR their number of pixels = $\frac{0.01}{\text{their } d}$ OR number of cones = $\frac{\text{their image size}}{(2 \times) 1.5 \times 10^{-6}}$ ✓ 140 (pixels per cm) ✓	Condone POT error in MP1 and MP2 For MP3 allow 280 pixels per cm only when d represents the distance from the centre of one dark pixel to the centre of the next dark pixel. Expect to see $\frac{2 \times 1.5 \times 10^{-6}}{21 \times 10^{-3}} = \frac{d}{0.5}$ $d = 7.14 \times 10^{-5} \text{ m}$ Answer = $\frac{0.01}{7.14 \times 10^{-5}} = 140 \text{ (pixels per cm)}$	3	$3 \times \text{AO3}$
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Question	Answers	Additional comments/Guidelines	Mark	AO
02.2	Viewed by rods not cones ✓ Multiple rods share a nerve ✓ Idea that there must be one unstimulated receptor between stimulated ones OR separation on retina needs to be larger for resolution OR Idea that it will be impossible to determine which rod was activated (with MP2) ✓	Max 2 if suggests rods are larger Allow 'only rods'; do not allow 'fewer cones' Ignore references to the spacing of rods For MP3 allow idea that the light receptors have an increased effective diameter Alternative for 1 mark: Correct reference to change in pupil size (increase in dark) and less diffraction OR correct reference to pupil size and eye's ability to focus is further reduced ✓	3	3 × AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
02.3	$0.875/0.500 = 1.75 (\geq 2 \text{ sf})$ OR 0.500×2 compared to 0.875 OR $0.875 \div 2$ compared to 0.500✓	Allow 0.850-0.900 for red; 0.450-0.525 for green (gives range 1.62- 2.00)	1	1 × AO2
02.4	Green (520): Green cone 0.80 OR Red cone 0.15 OR Red (650): Red cone 0.25 ✓ ₁ Green = 0.80 and Red = 0.15 + 0.25 = 0.40 OR Green = 2 × Red ✓ ₂ Leading to wavelength = 546 ✓ ₃ nm	If average red cone value can award ✓ ₁ and ✓ ₃ e.g. 0.20 Red, Green = 4 × Red, leading to answer in range 520 to 530 nm If no recognition that green LED contributes to red cone value can award ✓ ₁ and ✓ ₃ e.g. Green = 3.2 x Red, leading to answer in range 530 to 540 nm allow 540 to 550 nm. Bald answer receives zero marks.	3	3 × AO3
Total			10	

Question

Answers

Additional comments/Guidelines

Mark

AO



03.1	Power (of sound) per unit area OR Energy (of source) per unit area per second ✓	allow 'per m ² ' for 'per unit area'	1	1 × AO1
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Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	$I + 3$		1	1 × AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
03.3	Division of areas seen OR correct use of factor of 20 ($20 \times 5.9 \times 10^{-6}$) ✓ 1.6 ✓	Use of incorrect relationship between pressure, force and area receives zero marks. Expect to see $\frac{20 \times 5.9 \times 10^{-6}}{7.2 \times 10^{-5}}$ Condone 1.6: 1 for MP2	2	2 × AO2
Total			4	

Question	Answers	Additional comments/Guidelines	Mark	AO
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02.1	Ossicles act like levers ✓ To increase the force ✓		2	AO1.1a
02.2	Area of ear drum = $\frac{\pi d^2}{4} = \frac{\pi 0.01^2}{4} \checkmark_1 = 7.85 \times 10^{-5} \text{ (m}^2\text{)}$ Increase in pressure due to window size = $\frac{5.0 \times 10^{-2}}{2.5 \times 10^{-3} \times 1.5} = 13.3$ (or $1/13.3 = 0.075$) $\checkmark_2$ Area of oval window = $\frac{7.85 \times 10^{-5}}{13.3} = 5.9 \times 10^{-6} \text{ (m}^2\text{)} \checkmark_3$	ignore PoT for $\checkmark_1$ if mix up r and d ecf for $\checkmark_2$ and $\checkmark_3$ dividing gain or area by 1.5 or multiplying force by 1.5 gains $\checkmark_2$ (allow a factor between 1.5 to 5) correct PoT needed for $\checkmark_3$ (process mark for calculating area, answer may differ from that shown when a different factor for the effect of ossicles are used) ignoring 1.5 from ossicles and calculating $A = 3.9 \times 10^{-6} \text{ (m}^2\text{)}$ scores $\checkmark_1$ and $\checkmark_3$ Alternative method for $\checkmark_2$ and $\checkmark_3$ Force on ear drum = $PA = 2.5 \times 10^{-3} \times 7.85 \times 10^{-5} = 1.96 \times 10^{-7} \text{ N}$ Force on oval window $= 1.96 \times 10^{-7} \times 1.5 \checkmark_2$ Area of oval window = $\frac{F}{P} = \frac{2.94 \times 10^{-7}}{5.0 \times 10^{-2}} = 5.9 \times 10^{-6} \checkmark_3 \text{ (m}^2\text{)}$	3	AO2.1b
Total			5	

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Question	Answers	Additional comments/Guidelines	Mark	AO
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03.1	Calculation of area $A (= 4\pi r^2) = 4\pi 12^2 (= 1810) \checkmark_1 (\text{m}^2)$ Calculation of intensity $I = \frac{P}{A} = \frac{17}{1810} (= 9.49 \times 10^{-3}) \checkmark_2 (\text{W m}^{-2})$ Calculation of intensity level $I = 10 \log \frac{9.49 \times 10^{-3}}{10^{-12}} = 100 \checkmark_3$	ecf for $\checkmark_2$ if area calculation attempted ecf for $\checkmark_3$ even if no area calculation attempted	3	AO2
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Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	The sound would be quieter ✓ ear is most sensitive at 3 kHz ✓		2	AO2
Total			5	

Question	Answers	Additional comments/Guidelines	Mark	AO
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02.1	Max 3 from ✓✓✓ Use of $I = I_0 10^{\frac{IL}{10}}$ to find intensity ✓_a Intensity reduction factor of 0.40 ✓_b Multiply the intensity by 0.40 or 0.60 ✓_c Use of $IL = 10 \log \left(\frac{I}{I_0} \right)$ to find intensity level ✓_d 106 (dB) ✓	✓_a $I \left(= I_0 10^{\frac{IL}{10}} \right) = 10^{-12} 10^{\frac{110}{10}} (= 0.10 \text{ W m}^{-2})$ ✓_b condone reduction of intensity level ✓_c $I = 0.10 \times 0.40 (= 0.040 \text{ W m}^{-2})$ ✓_d $IL = \left(10 \log \left(\frac{I}{I_0} \right) = 10 \log \left(\frac{0.040}{10^{-12}} \right) \right) = 106 \text{ (dB)}$ ✓_d substitution for I must be an intensity, not an intensity level 1 mark for answer of 108 (dB) with no supporting working Alternative method Max 3 from ✓✓✓ Reduction factor of 0.40 seen ✓_a Use of their reducing factor in ΔIL equation ✓_b eg $\Delta IL = 10 \log \left(\frac{I_2}{I_1} \right) = 10 \log (0.40)$ Value of ΔIL consistent with their reduction factor eg $\Delta IL = (-) 3.98$ ✓_c Subtraction of their ΔIL from 110 eg new $IL = 110 - 3.98$ ✓_d 106 (dB) ✓	4	AO3.1
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Question	Answers	Additional comments/Guidelines	Mark	AO
02.2	Idea of reduction in sensitivity at all frequencies ✓ ₁ Most loss occurs at 4 kHz ✓ ₂	✓ ₁ for idea of reduction in sensitivity accept: hearing loss/ perceives sounds to be quieter/ drop in perceived loudness/ higher intensity required for same loudness ✓ ₂ accept a range of ± 1 kHz provided that 4 kHz lies in the range ✓ ₂ Do not award for any suggestion that this is due to the loud noise being at 4 kHz If no other mark given award 1 mark for suggestion that person will suffer from tinnitus	2	AO1
Total			6	

Question	Answers	Additional comments/Guidelines	Mark	AO
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03.1	Frequency axis correctly labelled from 100, 1000, 10 000, including the location of 3000 Hz, if marked ✓ Graph line showing a U shape ✓ Lowest point of graph at 3000 Hz ✓	Allow 1000, 10 000 and 100 000 if line $\leq 20\,000$ 3 rd mark depends on a valid scale or clear marking of 3000 Hz at the lowest point.	3	3 x AO1
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Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	(different) frequencies are played (through earphones) and compared to a 1kHz reference signal ✓ Volume is changed until it sounds the same loudness as the reference signal ✓		2	2 x AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
03.3	Correct substitution or correct rearrangement for I ✓ $I \left(= I_0 10^{\frac{\text{intensity level}}{10}} \right) = 1 \times 10^{-12} \times 10^{\frac{30}{10}} = 1.0 \times 10^{-9} \text{ ✓ (W m}^{-2}\text{)}$	e.g. $30 = 10 \log \frac{I}{10^{-12}}$	2	2 x AO2
Total			7	

Question	Answers	Additional comments/Guidelines	Mark	AO
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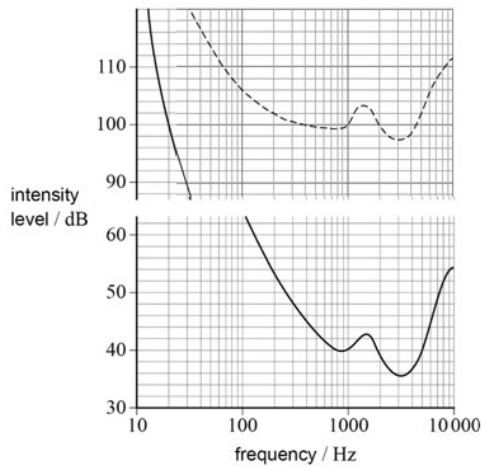


03.1	the minimum intensity that (a normal) ear can hear ₁✓ at 1 kHz ₂✓	word definition required: data sheet value is neutral allow 'power per m²' for 'intensity' Do not accept 'minimum sound intensity level'	2	AO1
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Question	Answers	Additional comments/Guidance	Mark	AO
03.2	Max two from ✓✓ • use of Figure 4 to read intensity level at 50 Hz (1) • use of intensity level formula (2) • power = their intensity × area (3) (power =) 3.8×10^{-9} (W) ✓	For (1) expect 78 ± 1 (dB) Allow evidence of 78 ± 1 (dB) on Figure 4 Where only set equal to intensity withhold bp1 but can still score where 78 is seen as read-off in Figure 4. for (2) use of means their intensity level = $10 \times \log \frac{I}{1.0 \times 10^{-12}}$ (any subject) OR I evaluated using their intensity, correct to 2 sf; for 78 dB expect $I = 6.3 \times 10^{-5}$ (W m⁻²) For (3) Condone power of ten error in area. Do not accept 78 ± 1 (dB) or 50 (Hz) for their intensity Accept an answer that rounds to 3.8×10^{-9} (W) Condone an answer given to 1 significant figure where supporting working to greater sf seen.	3	AO2



Question	Answers	Additional comments/Guidance	Mark	AO
03.3	for $f < 1$ kHz curve of decreasing gradient, (flattening out) to pass through 1 kHz, 100 dB $_1✓$ For $f > 1$ kHz one dip below 100 dB at about 3 kHz followed by an increase (towards a maximum turning point) $_2✓$	sketch of one continuous line: for $_1✓$ line should meet top of grid without meeting existing curve condone a curve with a shallow minimum for $f < 1$ kHz (as shown below) with an intensity level $>$ intensity level at 3 kHz for $_2✓$ where the line meets the right-hand edge of the grid, the intensity level must be greater than 100 db. Accept a single dip where the minimum occurs at frequencies in range greater than 2kHz and less than 4 kHz. don't insist on a peak between 1 kHz and 2 kHz 	2	AO2
Total			7	

Question	Answers	Additional comments/Guidance	Mark	AO
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04.1	mention of 3 kHz being the frequency of maximum sensitivity of the ear ✓ both scales should have same reading at 1 kHz which they don't / it is wrong that the curves cross at about 750 Hz ✓ dBA curve should have maximum value at 3 kHz which it doesn't / wrong as max sensitivity of dBA scale is shown at 4 kHz ✓		4
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04.2	Initial use of 110 dB in correct equation – $110 = 10 \log (I / I_0)$ leading to correct calculation of intensity = $0.10 \text{ (W m}^{-2}\text{)}$ ✓ Use of equation the calculated intensity = $7.8 / 4\pi r^2$ ✓ Leads to distance = 2.5 m ✓ Thus 2 m is slightly too close to the drill as it is less than 2.5m ✓	The 4 marks are basically 1. The correct manipulation of the equation relating intensity and power 2. The correct answer from this 3. The correct use of the decibel equation 4. A suitable statement relating numbers These marks can come in any order depending on how they attack the problem. They may do 3 before 1 and 2, as in my original mark scheme, but many are doing 1 and 2 before 3. If 1 is wrong then this is EOP and thus 2 cannot be awarded, but 3 and 4 are ECF and are still available. Be aware that by using the initial power and distance quoted in the question, the final answer for the intensity level is 112 dB. Some candidates may then say that to 2sf, this is 110 dB which is that quoted as the safe level. This argument must be given the credit which it deserves. Remember that ECF is available from 2 to 3, or from 3 to 1 and 2. The final mark is for a sensible comment based on their final answer with some numeric comparison.	4
Total			8

Question	Answers	Additional Comments/Guidelines	Mark
	There will be many answers possible and examiners must use their professional judgement. These answers may include: • Using scan before treatment to locate the precise position / size of the tumour • Using X-rays of the correct energy for the depth/size of the tumour		



02.1	Either $(I = \frac{3.4 \times 10^{-8} \times 11^2}{7^2}$ or $I = \frac{P}{A} = \frac{5.17 \times 10^{-5}}{4\pi 7^2})$ $= 8.4 \times 10^{-8} \text{ W m}^{-2} \checkmark$	Use of $I \propto \frac{1}{r^2}$ with the wrong factor for r still scores M1 (but not M2) M1 cannot be awarded if πr^2 is used for the area but M2 can still be awarded.	1
02.2	One from $I_1 = I_0 10^{\frac{IL}{10}} = 10^{-12} \times 10^{4.2} = 1.58 \times 10^{-8} \text{ W m}^{-2}$ or $I_2 = I_0 10^{\frac{IL}{10}} = 10^{-12} \times 10^{6.5} = 3.16 \times 10^{-6} \text{ W m}^{-2}$ or $\frac{I_2}{I_1} = 10^{6.5-4.2}$ or $\frac{I_2}{I_1} = \frac{10^{6.5}}{10^{4.2}} \checkmark$ $\frac{I_2}{I_1} \left(= \frac{3.16 \times 10^{-6}}{1.58 \times 10^{-8}} \text{ or } 10^{6.5-4.2} \right) = 200 \checkmark$	Correct values for I_1 or I_2 or a correct rearranged substitution can gain M1 Ignore any units given Accept anything from a correct calculation that rounds to 200 to 2SF	1 1
02.3	<u>Intensity level</u> must be stated uses a logarithmic scale $\checkmark$ which matches the response of the human ear $\checkmark$	Do not allow matches the frequency response of the human ear for the second mark. Mark 2 is dependent on mark 1	1 1

02.4	P and Q would hear (all frequencies) at lower volume/quieter than R . ✓	If no other marks are given allow 1 mark for	1
	P would experience most hearing loss at high frequencies (compared to R) ✓	P hears at a lower volume/quieter than R and Q 's hearing loss is frequency dependent ✓	1
	Q would experience most hearing loss at/around 4 kHz (compared to R) ✓		1
Total			9



Question	Answers	Additional Comments/Guidelines	Mark
	Smooth curve/continuous spectrum is due to the deceleration of the electrons / transfer their kinetic energy to X-ray photons ✓ ₁	Bremsstrahlung is not expected but is allowed for smooth curve or continuous spectrum.	1
	Maximum energy limited by kinetic energy / accelerating voltage of electrons. ✓ ₂	Condone acceleration for deceleration in ✓ ₁ and ✓ ₃	1
	Electrons are decelerated by different amounts so a continuous spectra is emitted. ✓ ₃	If candidates are missing inner and outer but would otherwise gain ✓ ₄ and ✓ ₅ award one mark ✓ ₄₅	1



04.1	potential axis: unit mV and suitable labelling of 0 and 1 for scale ✓ time axis suitable use of numbers from 0 to 0.6 / 1 ✓		2
04.2	Possible answers to include: electrodes are not non-reactive ✓ electrodes are not securely taped in place ✓ the patient is not relaxed or does not remain still ✓ the amplifier is not low noise ✓ the amplifier has damaged shielded leads / interference from other AC sources ✓	Any 3 points with reason and some extension to explain. Be aware of the section 3.1 in the instructions to examiners. If more than 3 answers given remember 'right + wrong = wrong'	3
Total			5

05.1	Align spins of protons / hydrogen nuclei ✓	Do NOT allow hydrogen atoms Allow causes protons / hydrogen nuclei to precess around magnetic field / in one direction Do NOT allow causes protons to spin	1	AO1
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Question	Answers	Additional comments/Guidelines	Mark	AO
05.2	(radio frequency photons) excite protons ✓ Flip the (spin of) protons ✓ (When pulse stopped) protons emit radio frequency signals when they relax ✓	MAX 2 Condone RF Condone atoms for protons Condone move or make into antialignment with magnetic field for MP2	2	2 x AO1
Total			3	

02	Correct identification of all three A: CT scanner, B: MR scanner, C: Ultrasound scanner ✓ A: good picture of bone / bright picture of bone / lacking detail on soft tissue (eg eyes, brain) ✓ B: highest resolution / good (detailed/bright) image of soft tissue (eg eyes, brain) / dim picture of bone ✓ C: low resolution / image shows external boundaries (eg uterus) / lack of detail inside skull ✓	Allow CAT for CT and MRI for MR	4	AO3
Total			4	

Question	Answers	Additional comments/Guidelines	Mark	AO
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05.1	To damp the vibrations (of the piezoelectric crystal) (after the pulse has been transmitted) ✓ To allow the crystal to serve as receiver (as well as transmitter)/ so reflected and transmitted pulses remain separate (at the transducer)/ so pulses can be short ✓		2	AO1
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Question	Answers	Additional comments/Guidelines	Mark	AO
05.2	Max 2 from ✓✓ (Muscle $Z = \rho c = 1100 \times 1600$ OR 1.76×10^6 ($\text{kg s}^{-1} \text{m}^{-2}$) ✓_a Use of $\left(\frac{I_r}{I_i} = \left(\frac{Z_2 - \text{their } Z_1}{Z_2 + \text{their } Z_1}\right)^2\right)$ to find reflected ratio OR 0.25 ✓_b Conversion of their ratio to % and subtraction from 100 ✓_c 75 (%) ✓	✓_b Accept Z_1 and Z_2 in either order Expect $\left(\frac{5.3 \times 10^6 - 1.76 \times 10^6}{5.3 \times 10^6 + 1.76 \times 10^6}\right)^2$ do not accept use of ρ or c as Z Calc value 74.85815631	3	AO2
Total			5	

01.1	Non-coherent bundle – random arrangement of fibres ✓ Used to transmit light into the body / to illuminate (area under investigation) ✓	... have been named.	4
01.2	Core at 1.6; cladding 1.55 ie half way between their core and 1.5 ✓ series of clear horizontal steps with air at 1.0 ✓	Although they are told to do a calculation, give the mark on the diagram for 1.55 even if no calc shown If no marks awarded for drawing, then give 1 mark for correct calculation.	2
Total			6

6

Question	Answers	Additional Comments/Guidelines	Mark
	$d / 21 \times 10^{-3} = 12 \times 10^{-3} / 61$ ✓ $d = 4.1 \times 10^{-6} \text{ m}$ ✓ $4.1 / 1.5 = 2.75$ ✓		



04	The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question.		Points to consider: Relevant quality - MR scanner – low quality image of calcium / kidney stones (allow cannot see) - CT scanner – high resolution image of kidney stone - Ultrasound – low resolution image of kidney stone (Allow CT scanner and Ultrasound produce good images of kidney stone but not for 6 marks) Allow references to bone instead of kidney stone Other factors (CT scanner / MRI is more expensive than ultrasound) - Ultrasound / MRI causes no harm - CT scanner emits ionising radiation - Ionising radiation damages cells - Do not have to remain still for ultrasound - Ultrasound is fastest / real time - MRI can cause claustrophobia Ignore references to metal / pace maker in the body for MRI Ignore references to 3D images Justified choice - Ultrasound - Quality is good enough, (cheaper) and safe - CT - Best quality image of kidney stones (except for pregnant women and children)	6	5 × AO3 1 × AO2
	Mark	Criteria			
	6	Ultrasound or CT identified and justified, quality comments on all 3, at least 3 other factors. Must refer to resolution / detail for 6 marks.			
	5	Ultrasound or CT identified and justified, quality comments on all 3, at least 2 other factor Must differentiate between the quality of CT and ultrasound for kidney stones.			
	4	Ultrasound or CT scanner identified. Quality comments on all 3 or 2 quality comments and 1 other factor.			
	3	Ultrasound or CT scanner identified. 2 comments including at least 1 quality comment Or MR scanner identified and stated as highest resolution, with 2 quality comments and 2 others factors.			
	2	Any choice, with a relevant supporting argument (allow MR scanner as highest resolution provided one other relevant factor is provided). Or At least 3 valid comments with no choice made			
	1	Any valid comments (ignore MR scanner as highest resolution).			
	0	No relevant comments.			

04.1	$s = vt = 1560 \times 29.5 \times 10^{-6} \checkmark (= 46 \times 10^{-3} \text{ m})$ Eyeball length = $\frac{46 \times 10^{-3}}{2} = 23 \times 10^{-3} \checkmark \text{ m}$	ecf for 2 nd and 3 rd mark if wrong reflections used. 3 rd mark is for dividing by 2 and is independent	1
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04.2	The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question.		6
	Mark	Criteria	
	6	Select the B-scan, Cover all 3 areas in detail, referring to both scans in at least 2 areas, without error. It must relate to amniocentesis.	
	5	Select the B-scan, Cover all 3 areas, referring to both scans in at least 2 areas. May contain minor errors. It must relate to amniocentesis.	
	4	choose the B-scan Cover at least 2 areas, referring to both scans Or cover all 3 areas referring to one scan	
	3	Cover at least 2 areas referring to one scan Or Cover 1 area referring to both scans in detail It may or may not choose the B-scan.	
	2	Cover 1 area referring to both scans It may or may not choose the B-scan	
	1	Cover 1 area referring to one scan. It may or may not choose the B-scan	
	0	No relevant comments	
Difference between the A-scan and B-scan - Multiple sensors in B-scan as opposed to one sensor in A-scan - A scan intensity determines amplitude - B scan intensity determines brightness Advantages/Disadvantages A-scan - An A-scan only produces a graph - Good for accurately determining distances (where a limited number of surfaces lie along a straight line) - With complex structures it is difficult to identify which surface produces which echo - The structures may not lie along one line B-scan - B-scan produces a picture - A 2D cross section is obtained rather than a single line - Allows the structures to be identified more easily - Allows features that are not along one line to be identified - Harder to accurately determine distances along a straight line Suitability Why a B-scan is suitable - Multiple features of needle, foetus, uterus and placenta require an image to identify Why an A-scan is not suitable - Multiple features of needle, foetus, uterus and placenta - are complex structures - which do not lie along a straight line - cannot be easily identified on a graph			

Total			9
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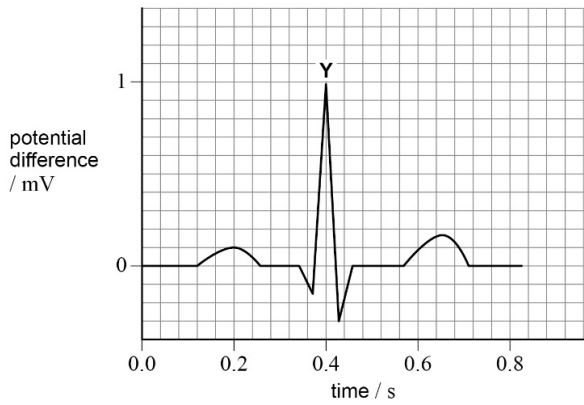
03.1	Name coherent and non-coherent bundle ✓₁ Coherent bundle transmits images OR non-coherent bundle transmits light for illumination/ into the body ✓₂ Bundle that transmits light for illumination requires no cladding ✓₃ Cladding is required in bundle that transmits images so that light does not pass from one fibre to another (which would destroy the image) ✓₄	✓₁ Accept 'incoherent' ✓₂ 'transmits light' insufficient for function of non-coherent bundle ✓₃ and ✓₄ are for linking the function to the requirement for cladding and can be awarded if names are missing, incorrect or mixed up so long as function clear. ✓_{3 4} 1 mark for stating coherent need cladding and non-coherent do not	4	2×AO1 2×AO3
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Question	Answers	Additional comments/Guidelines	Mark	AO
03.2	The mark scheme gives some guidance as to what statements are expected to be seen in a 1- or 2-mark (L1), 3- or 4-mark (L2) and 5- or 6-mark (L3) answer. Guidance provided in section 3.10 of the ‘Mark Scheme Instructions’ document should be used to assist in marking this question.	In each area, a partial response covers one bullet point, a detailed response requires two.	6	2×AO1 2×AO2 2×AO3
		Methods used to reduce dispersion - Mentions either mono-mode fibre (mod), monochromatic light (mat), small difference in refractive indices of core and cladding (mod) or repeaters (both) - Mentions two methods with at least one linked to correct type of dispersion (name or description)		
		Why the methods are not required - Short distance of the endoscope - Reason given for why this results in insignificant dispersion - No pulse broadening due to analogue signal - Idea that function of non-coherent bundle is unaffected by dispersion - Comparison of (lower) data transfer rate for endoscope compared to high speed data transfer for communications. Means dispersion is not noticeable		
		How the methods affect the function - Refractive index of core close to refractive index of cladding – lots of light escapes. Reduces intensity of image (which makes it harder to see) - Mono-mode fibre reduces amount of light transmitted. Reduces intensity of image - Monochromatic light – image is monochrome (which makes diagnosis harder) - Narrower fibres therefore more fibres can fit in the bundle therefore better resolution - Discussion of impact of any one of these changes on diagnosis/ treatments - Repeaters would make the endoscope too wide to go inside patient.		
Total			10	

Question	Answers	Additional comments/Guidelines	Mark	AO
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04.1	B scan because it is an image (rather than a graph) ✓	Allow 'brightness scan' for B scan	1	1 × AO1
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Question	Answers	Additional comments/Guidelines	Mark	AO
04.2	Determines accurate time for a whole number of heartbeats OR $\frac{\text{their number of beats}}{\text{their time}}$ OR $\frac{\text{their time}}{\text{their number of beats}}$ OR converts their bps to bpm ✓ Evidence of T taken from 3, 4 or 5 heartbeats OR repeat and mean for at least three measurements ✓ Leading to answers that round to 56 or 57 bpm ✓	Accept correct use of frequency for MP2	3	1 × AO2 1 × AO3 1 × AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
04.3	mV on y-axis and s on x-axis ✓ values of y-axis with at least 2 values labelled, consistent with 0 at start of line and 1 at peak ✓ values on x-axis with end point between 0.55 and 1.0 s. At least three evenly spaced values seen including 0 ✓ position of Y indicated to be within one square of the highest peak ✓	 potential difference / mV time / s Allow for alternative correct units and values eg 0.001 V, time of 400–750 ms For MP3 ticks on x-axis required; do not accept awkward scales	4	3 × AO1 1 × AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
04.4	Why backing is needed: Idea that gels improves electrical contact ✓ Property of backing: gel should have low (electrical) resistance or non-irritating to skin or shouldn't react to chemicals produced by skin ✓ How skin is prepared: skin is shaved / rubbed with abrasive paper/ hair removed ✓	For MP2 do not allow reference to or implication of acoustic resistance / impedance MP3 - allow skin is dried or cleaned	3	2 × AO1 1 × AO2
Total			11	

Question	Answers	Additional comments/Guidelines	Mark	AO
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04.1

The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question.

Mark	Criteria
6	All 3 areas covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.
5	All 3 areas covered at least 2 in detail. Whilst there will be gaps, there should only be an occasional error.
4	Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be several gaps, there should only be an occasional error.
3	One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.
2	Only one area discussed, or makes a partial attempt at two areas.
1	None of the three areas covered without significant error.
0	No relevant analysis.

Points to consider

How an ultrasound pulse is produced:

- alternating potential difference applied across the crystal
- causes crystal to expand and contract
- creating pressure waves in the crystal / plastic membrane
- frequency of alternating pd equal to that of crystal / resonant frequency of crystal
- which is above 20 kHz.

How the ultrasound reflection is detected:

- pressure wave in the crystal
- causes crystal to expand and contract
- which produces a potential difference across the crystal.

The same transducer acts as receiver as well as transmitter:

- short application of ac to produce short pulse
- use of backing material to damp and stop vibration of crystal
- crystal must stop vibrating before reflection reaches it.

6

2×
AO1.1a4×
AO2.1b

Question	Answers	Additional comments/Guidelines	Mark	AO
04.2	$\lambda = \frac{c}{f} = \frac{1600}{1.0 \times 10^6} = 0.0016$ Resolution = 1.6 mm ✓	Allow 1 sf answer of 2 mm	1	AO2.1b
04.3	$Z_1 = \rho c = 1.3 \times 330 (= 429)$ or $Z_2 = \rho c = 1075 \times 1580 (= 1.70 \times 10^6)$ ✓ $\left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2 = \left(\frac{1.70 \times 10^6 - 4.29 \times 10^2}{1.70 \times 10^6 + 4.29 \times 10^2}\right)^2 \checkmark = 0.999 \checkmark$ $100 - 99.9 = 0.1\%$ ✓	Allow ecf Allow 1 sf	4	AO2.1b
04.4	Not suitable as all/most/99.9% of the ultrasound would be reflected ✓ when going from the air inside the lungs to the lung tissue ✓	Allow correct argument based around transmission MP2 is for the direction where most is reflected.	2	AO3.1a
Total			13	

04.1	$\frac{1-d}{10^{-3}} = \frac{d}{0.1 \times 10^{-3}} \checkmark$ $d = \frac{0.1 \times 10^{-3}}{1.1 \times 10^{-3}} = 9.1 \times 10^{-2} \checkmark \text{ (m)}$	Allow alternative methods Condone 1 SF	2	AO2
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Question	Answers	Additional comments/Guidelines	Mark	AO
04.2	(Hand) Chest is thicker so parts will be further away from plate (increasing fuzziness) ✓ Chest is thicker and not uniformly thick (each part producing a shadow producing an unsharp image) / front and back can't both be focussed at the same time ✓ Can keep hand still but not heart so heart will be blurred ✓	Max 2 Condone can't stop breathing	2	AO3
Total			4	

Question	Answers	Additional comments/Guidelines	Mark	AO
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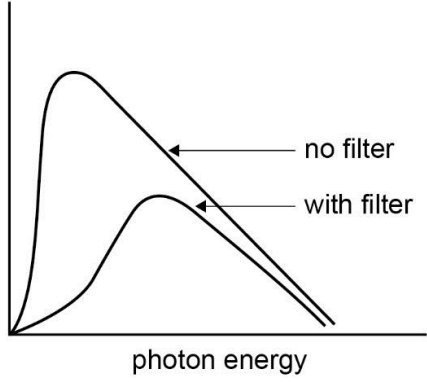
03	from different directions. - The signals from the detectors are then added together and a 2D image of that slice of the head is produced by the computer. For advantages of CT for head injuries - Better defined image of tissue boundaries inside skull - Possible to identify bleeding inside skull For simple X-rays - Cheaper and easier for patient - Allows simple fractures to be identified - Less harmful as patient dose is less than that of CT scan	the CT scan. They will give some explanation for using this scan to assess head injuries. They will give some explanation for the use of basic X-rays in certain situations. 3 marks will address at least two of the bullet points 2 marks will address at least one of the bullet points 1 mark will have any sensible comment 0 marks has no relevant Physics.	6
Total			6

8

Question	Answers	Additional Comments/Guidelines	Mark
	Mention of ear's sensitivity starting low, increasing to maximum and then falling again resulting in convex nature of their curve which is wrong as does not fall after 5 kHz / should fall at higher frequencies and not plateau ✓ Mention of 1 kHz being the reference frequency for both scales / mention of 3 kHz being the frequency of maximum sensitivity of the		



03.1	Spikes/discrete/characteristic spectra due to electrons knocking <u>inner electrons</u> from atoms. ✓₄ <u>Outer electrons</u> drop down to fill the gaps left behind. ✓₅ Emitting X-ray photons (with the energy lost) by the electrons moving downwards (producing specific energies only/discrete spectrum) ✓₆ (Max 4)		
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03.2	Peak and final point moves to the right ✓ Intensity larger at all points (except 0,0) and location of spikes remain the same ✓		1 1
03.3	Peak moves to the right, start at 0,0 end at or before end of existing curve, curve at or below at all points ✓ 	Ignore spikes even if incorrectly placed (penalised in question 03.2) Be tolerant of shape if marking criteria are met.	1
Total			7

Question	Answers	Additional Comments/Guidelines	Mark
	$t = (32.5 - 3.0) \times 10^{-6} (= 29.5 \times 10^{-6} \text{ s}) \checkmark$ $s = vt = 1560 \times 29.5 \times 10^{-6} \checkmark (= 46 \times 10^{-3} \text{ m})$	1 st mark is for correctly using the timing from the first and last reflection. 2 nd for 2nd and 3 rd mark if forward reflections used	1 1



05.1	- Using X-rays of the correct energy for the depth/size of the tumour - Using a computer to position X-ray relative to patient / target the tumour - Minimising time of use - Irradiating tumour from different directions - Less damage caused to healthy cells ✓ ✓ ✓ for three relevant answers		3
05.2	The thickness of material needed to reduce the intensity of the X-ray beam by half ✓		1
05.3	$\mu = \ln 2 / \text{half thickness}$ ✓ $\mu = 165$ ✓ $\mu_m = \mu / \rho = 1.5 \times 10^{-2}$ ✓ unit $\text{m}^2 \text{kg}^{-1}$ ✓	Unit mark is independent of the numerical answer or indeed a lack of any numerical working. 3 rd mark is ecf	4
Total			8

03.1	Attempt to use $I = I_0 e^{-\mu x}$ ✓₁ Two correct answers 100 keV $\left(\frac{I}{I_0} = e^{-\mu x} = e^{-0.15 \times 11} = \right) 0.19$ 500 keV $\left(\frac{I}{I_0} = e^{-\mu x} = e^{-0.087 \times 11} = \right) 0.38$ ✓₂ More of the 500 keV radiation reaches the tumour so is to be preferred or less radiation is absorbed by brain ✓₃ Less damage to surrounding tissue. ✓₄	Alternative approach for first two marks Use of $x_{1/2} = \frac{\ln 2}{\mu}$ ✓₁ 100 keV $\left(x_{1/2} = \frac{\ln 2}{\mu} = \frac{\ln 2}{0.15} = \right) 4.6 \text{ cm}$ 500 keV $\left(x_{1/2} = \frac{\ln 2}{\mu} = \frac{\ln 2}{0.087} = \right) 8.0 \text{ cm}$ ✓₂ If use 100/500 keV for I_0 do not award ✓₁ or ✓₂	4	1× AO3.1a 3× AO3.1b
03.2	Copper better at removing 100 keV (damage cells)✓ Remove a larger <u>percentage</u> or <u>fraction</u> of the 100 keV radiation than the 500 keV ✓	Allow ecf argument if 03.1 specifies 100 keV should be preferred. 2nd marking point implies first (with metal identified)	2	AO3.1a

Question	Answers	Additional comments/Guidelines	Mark	AO
03.3	Any one from: Method: Use of scans to locate the tumour ✓ Reason: Allows accurate targeting of the beam ✓ Method: Multiple beam or rotating beam ✓ Reason: X-rays are spread out so each part receives a lower dose ✓ Method: (Fine) collimated beam ✓ Reason: X-rays don't spread beyond the size of the tumour / filter ✓ Method: lead shielding ✓ Reason: to block X-rays from healthy tissues ✓	Reason mark depends on method mark and must match. Do NOT credit techniques that are only applicable to X-ray imaging.	2	1× AO1.a 1× AO1.b
Total			8	

Question	Answers	Additional comments/Guidelines	Mark	AO
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05.1

The mark scheme gives some guidance as to what statements are expected to be seen in a 1- or 2-mark (L1), 3- or 4-mark (L2) and 5- or 6-mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question.

Mark	Criteria
6	All three areas covered with at least two aspects covered in some detail. There should be at least one statement from the conclusions. Can be awarded even if there is an error and/or parts of one aspect missing.
5	A fair attempt to analyse all three areas, with two areas discussed successfully and one are partially.
4	Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be several gaps, there should only be an occasional error.
3	One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.
2	Only one area discussed, or makes a partial attempt at two areas.
1	None of the three areas covered without significant error.
0	No relevant comments

Ignore references to body parts other than ribs, heart, lung.

Statements can be in terms of transmission or absorption.

Area 1: Brightness

Film is darkened by X-rays.

More X-rays darker film / lighter areas have fewer X-rays.

Brightness:

Heart > ribs >> lungs

Lungs allows the most X-rays to be transmitted and are darkest.

Heart allows the fewest X-rays to be transmitted and is lightest.

Rib allows more X-rays than the heart but fewer than lungs to be transmitted and is medium brightness.

Area 2: Thickness

Thicker tissue decreases the amount of X-rays transmitted.

Reference to exponential decrease in X-rays transmitted with thickness.

Rib << heart < lungs

Rib - very thin, so transmits more X-rays than heart.

Heart - much thicker than rib transmits less X-rays.

Lung - very thick (but transmit most X-rays).

6

2 × AO1

4 × AO3

		Area 3: Half-value thickness Half-value thickness is the thickness needed to reduce intensity by half. Larger $x_{1/2}$ increases the amount of X-rays transmitted for the same thickness. Half value thickness: Lungs >> heart > ribs Rib has smallest $x_{1/2}$ (most dense) Heart has medium $x_{1/2}$ (medium density) Lung has largest $x_{1/2}$ (least dense) Conclusions Ideas that: Heart brightest as it has medium $x_{1/2}$ but is thick Rib almost as bright as heart as it has smallest $x_{1/2}$ but is much thinner. Lung darkest as although thicker, it has highest $x_{1/2}$		
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Question	Answers	Additional comments/Guidelines	Mark	AO
05.2	Idea of ingestion of barium meal/ contrast medium ✓ To improve contrast of image / to increase the number of X-rays absorbed (by contents of stomach) / barium is a good absorber of X-rays/ barium has high attenuation (coefficient) ✓	Do not allow any response suggesting ingestion of a radioisotope Do not award MP2 without MP1 being given. MP2: ignore 'has higher atomic number' Do not allow reference to increased reflection.	2	2 × AO2
Total			8	

04.1	(small size of focal spot) to increase sharpness of image $_1\checkmark$	for $_1\checkmark$ allow 'to reduce (size of) penumbra' / 'reduce region of geometric unsharpness' Condone: • improve (spatial) resolution • see finer detail • reduce blurring at edges (of image) Neutral statements include • more precise beam / more accurate beam • clearer image / better image • better focused for $_2\checkmark$ allow: • to limit temperature increase (of anode) • to prevent it heating up too quickly	2	AO1
	Idea of (must not be too small otherwise) danger of overheating (the anode) $_2\checkmark$			

Question	Answers	Additional comments/Guidance	Mark	AO																																							
04.2	one correct method and one aspect of a relevant explanation 1✓ second correct method and one aspect of relevant explanation 2✓ third correct method and one aspect of relevant explanation 3✓	Where no other mark is scored allow Max 1 for two correct methods	3	AO1																																							
		<table><tr><th>Method</th><th>Explanation (how it works)</th><th>Explanation for limit exposure (why it is necessary)</th></tr><tr><td colspan="3">For reducing target area</td></tr><tr><td>'window' defining target area / tube surrounded in lead (casing) / collimator / set aperture of diaphragm</td><td>Highly attenuating material that reduces x-ray propagation in undesired direction thereby producing a directed beam</td><td>Less exposure to surrounding tissue / body</td></tr><tr><td>use of a lead apron on patient (to shield area not being imaged)</td><td>Highly attenuating material reduces x-rays</td><td>Exposure to rest of body is reduced</td></tr><tr><td>reduce distance between source and patient</td><td>To reduce the divergence in beam</td><td>Less exposure for rest of body / healthy cells</td></tr><tr><td>keep the patient still</td><td>Only intended target is exposed to X-rays</td><td>Less exposure (for healthy cells) in other parts of body</td></tr><tr><td colspan="3">For reducing X-ray intensity</td></tr><tr><td>use of an (aluminium) filter / beam hardening</td><td>% of less energetic X-rays is reduced by filter</td><td>Idea of (unnecessary) exposure to 'softer' x-rays is reduced</td></tr><tr><td>use of intensifying screen / contrast medium / flat panel detector / FTP detector</td><td>To ensure adequate image quality (from a lower intensity beam)</td><td>Exposure (time) for (healthy cells) is minimised</td></tr><tr><td colspan="3">For avoiding repeats</td></tr><tr><td>correct tube voltage</td><td>to obtain best / appropriate X-ray (energy)</td><td>Image quality maximised without need to repeat so minimising exposure (for healthy cells)</td></tr><tr><td>keep the patient still</td><td>Reduces blurring in image.</td><td>The x-ray doesn't need to be retaken therefore minimising exposure (for healthy cells)</td></tr><tr><td>reduce distance between source and patient</td><td>To reduce the divergence in beam</td><td>Image quality maximised without need to repeat so minimising exposure</td></tr></table>			Method	Explanation (how it works)	Explanation for limit exposure (why it is necessary)	For reducing target area			'window' defining target area / tube surrounded in lead (casing) / collimator / set aperture of diaphragm	Highly attenuating material that reduces x-ray propagation in undesired direction thereby producing a directed beam	Less exposure to surrounding tissue / body	use of a lead apron on patient (to shield area not being imaged)	Highly attenuating material reduces x-rays	Exposure to rest of body is reduced	reduce distance between source and patient	To reduce the divergence in beam	Less exposure for rest of body / healthy cells	keep the patient still	Only intended target is exposed to X-rays	Less exposure (for healthy cells) in other parts of body	For reducing X-ray intensity			use of an (aluminium) filter / beam hardening	% of less energetic X-rays is reduced by filter	Idea of (unnecessary) exposure to 'softer' x-rays is reduced	use of intensifying screen / contrast medium / flat panel detector / FTP detector	To ensure adequate image quality (from a lower intensity beam)	Exposure (time) for (healthy cells) is minimised	For avoiding repeats			correct tube voltage	to obtain best / appropriate X-ray (energy)	Image quality maximised without need to repeat so minimising exposure (for healthy cells)	keep the patient still	Reduces blurring in image.	The x-ray doesn't need to be retaken therefore minimising exposure (for healthy cells)	reduce distance between source and patient	To reduce the divergence in beam	Image quality maximised without need to repeat so minimising exposure
		Method			Explanation (how it works)	Explanation for limit exposure (why it is necessary)																																					
		For reducing target area																																									
		'window' defining target area / tube surrounded in lead (casing) / collimator / set aperture of diaphragm			Highly attenuating material that reduces x-ray propagation in undesired direction thereby producing a directed beam	Less exposure to surrounding tissue / body																																					
		use of a lead apron on patient (to shield area not being imaged)			Highly attenuating material reduces x-rays	Exposure to rest of body is reduced																																					
		reduce distance between source and patient			To reduce the divergence in beam	Less exposure for rest of body / healthy cells																																					
		keep the patient still			Only intended target is exposed to X-rays	Less exposure (for healthy cells) in other parts of body																																					
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		use of an (aluminium) filter / beam hardening			% of less energetic X-rays is reduced by filter	Idea of (unnecessary) exposure to 'softer' x-rays is reduced																																					
		use of intensifying screen / contrast medium / flat panel detector / FTP detector			To ensure adequate image quality (from a lower intensity beam)	Exposure (time) for (healthy cells) is minimised																																					
		For avoiding repeats																																									
		correct tube voltage			to obtain best / appropriate X-ray (energy)	Image quality maximised without need to repeat so minimising exposure (for healthy cells)																																					
		keep the patient still			Reduces blurring in image.	The x-ray doesn't need to be retaken therefore minimising exposure (for healthy cells)																																					
		reduce distance between source and patient			To reduce the divergence in beam	Image quality maximised without need to repeat so minimising exposure																																					

Question	Answers	Additional comments/Guidance	Mark	AO
04.3	Max Two from ✓✓ $\mu = 4.6(2) \times 10^{-2} (\text{mm}^{-1})$ (1) - calculates thickness x (2) - Use of $\frac{I}{I_0} = e^{-\mu x}$ with their μ and their thickness x OR calculates $\left(\frac{1}{2}\right)^{\frac{\text{their thickness } x}{15}}$ (3) (percentage=) 44 (%) ✓	for (1) and (2) allow working in m or cm $\mu = 46.2 (\text{m}^{-1})$ $\mu = 0.462 (\text{cm}^{-1})$ for (1) accept $\mu = \frac{\ln 2}{15}$ or equivalent in m or cm for (2) thickness x in range 17 mm to 19 mm Expect to see a calculation based on scale diagram In (3), their x must be a distance, condone power of ten errors An answer for solid bone = 29% (28.7%) is worth 2 marks. accept an answer in range 41% to 46% reject decimal answer reject answer rounded to one significant figure	3	1 × AO2 2 × AO3
Total			8	



02.1	Flat panel detector ✓ If flat panel detector, max 3 from: Not moving, so fluoroscopic image intensity not required ✓ Saves a picture unlike an intensifying screen ✓ FTP digital image is easier to share or transfer unlike film ✓ Flat panel detector is more sensitive (than film) ✓ Faster than film / film is slower / doesn't have to be developed like film ✓ To minimise dose of X-rays to be used ✓ If film selected Not moving, so film is preferred to intensifying screen ✓ Saves a picture unlike an intensifying screen ✓ Minimise dose of X-rays to be used (compared to moving image with intensifying screen) ✓ If image intensifier selected Intensifying screen is more sensitive (than film) ✓ Does not need to be developed like film / real time image ✓	Ignore references to resolution / image quality Treat cost / portability as neutral Do NOT accept minimise dose compare to flat panel detector Condone increases contrast (at low intensity) as an alternative to increase sensitivity If no selection is made max 2 for correct comments.	4	4 x AO3
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Question	Answers	Additional comments/Guidelines	Mark	AO
02.2	First mark is for calculating intensity (or power or energy if calculation done in a different order) transmitted through bone (allow thickness < 4 cm if justified as mean eg $r\sqrt{\pi}$ accept $r = 0.02 < \text{thickness} \leq d = 0.04$) must include a factor $e^{-\mu x}$ ✓ Second mark is for calculating intensity absorbed by bone (or power or energy if calculation done in a different order) ✓ Third mark is for calculating the area of the bone ✓ Fourth mark is for converting an intensity into a power (allow ecf for incorrect intensity, including I_0, or area) ✓ Fifth mark is for converting a power into an energy (allow ecf for incorrect energy) ✓	Expected answer $I = I_0 e^{-\mu x} = 0.013 \times e^{-58.3 \times 0.04}$ ✓ (= 0.00126) Absorbed intensity = $I_0 - I = 0.013 - 0.00126$ ✓ (= 0.0117) Area of bone = $\sqrt{0.25^2 + 0.09^2} \times 0.04$ ✓ (= 0.0106 m²) $P = IA = 0.0117 \times 0.0106$ ✓ (= 0.000124) $E = Pt = 0.000124 \times 0.8 = 1.0 \times 10^{-4}$ ✓ (J) (allow 9.9×10^{-5} or 1.1×10^{-4}) Condone rounding of answers/values as estimate asked for. Award max 4 if PoT error in final answer.	5	4 × AO2 1 × AO3
Question	Answers	Additional comments/Guidelines	Mark	AO
02.3	Assuming bone has constant thickness / bone is rectangular/cuboid ✓ Assuming none of the X-rays are absorbed by tissue before it reaches the bone ✓	Allow any other sensible assumption that leads to a larger value For the first mark it must be clear that the distance referred to is x in the equation $I = I_0 e^{-\mu x}$ and not the mean diameter used to calculate the cross sectional areas. First mark can also be gained from an attempt to use an average value for x in 02.2 Allow some X-rays are scattered (rather than being absorbed) ✓ Treat references to X-rays reflecting as neutral	2	2 × AO3
Total			11	

Question	Answers	Additional comments/Guidelines	Mark	AO
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02.1	Points to consider: The risk comes as X-rays are ionising radiation: the photons could ionise cells causing mutations/cancer Use of lead diaphragm plates to define beam so that only the area to be investigated is exposed to the X-rays – limits exposure to ionising photons Use of aluminium filter in path of beam to remove a large percentage of the low energy photons which are not needed for the image to be produced – reduces ionising photons which could be absorbed by the body. (Anode voltage) selected to produce best energy photons for imaging – limits the photons required to produce a suitable image When using film, use of intensifying screens - give exposure in shorter time limits exposure Use of grid between the patient and image receptor to stop scattered X-rays blurring the image - thus stopping the need for further X-ray and further exposure.	6 marks will clearly explain the risk involved. They will then mention three ways of minimising the exposure and discuss these. 5 marks will clearly explain the risk involved. They will then mention three ways of minimising the exposure and discuss 2 of these. 4 marks will mention the risk involved. They will mention at least two ways of minimising the exposure and may discuss both or discuss one of these together with explaining the risk involved 3 marks will mention the risk involved. They will mention at least two ways of minimising the exposure and may discuss one of these or explain the risk involved 2 marks will mention the risk and may state one way of limiting exposure or state and discuss either 1 mark will have any sensible comment 0 marks has no relevant Physics.	6
02.2	Ultrasound is non-ionising / has no known adverse effects ✓ Ultrasound can be used for better definition image between tissue and blood ✓	Allow credit for converse arguments re. not X-rays	2

Question	Answers	Additional Comments/Guidelines	Mark
02.3	correct sub of numbers in the equation $6.25 \times 10^{-4} = \left(\frac{Z-1.64 \times 10^6}{Z+1.64 \times 10^6} \right)^2 \quad \checkmark$ As Z decreases, the negative root is needed $-2.5 \times 10^{-2} = \left(\frac{Z-1.64 \times 10^6}{Z+1.64 \times 10^6} \right) \quad \checkmark$ rearrange equation $1.025 Z = 1.64 \times 10^6 - 4.1 \times 10^4 \quad \checkmark$ correct answer $1.56 \times 10^6 \quad (\text{kg m}^{-2} \text{ s}^{-1}) \quad \checkmark$	Candidates who ignore the negative root can get three marks max for arranging the equation correctly and getting 1.72 by using the positive root. Basic rule -1 for each error Last two marks for working can be given for wrong values above that point.	4
Total			12

Question	Answers	Additional Comments/Guidelines	Mark
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01	beta is more ionising/less penetrating than gamma 1✓ One from✓ - will produce localised ionisation of the tumour without reaching neighbouring healthy tissue (whereas the gamma will produce more extended ionisation) - lower activity source can be used as more ionisation of the tumour per emission (whereas a more active gamma source will be required to produce the same level of ionisation in the tumour) - the tumour is small so the ionisation will occur only in the tumour - will cause less damage to healthy tissue (due to low penetration of beta) - Will be more effective (at treating the tumour as) it will ionise/damage it to a greater extent than gamma	For two marks there must be a comparison implied and MP1 and MP2 must correlate For two marks mention of ionisation must be seen Accept 'damage' for 'ionise' in MP2 provided 'ionise' seen in MP1 For MP2 Condone: gamma could escape the body and pose a risk to others (beta cannot)	2	2 × AO1
Total			2	

Question	Answers	Additional comments/Guidelines	Mark	AO
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03.1	Material with nuclei which are unstable / will decay / emits ionising / radiation. ✓	At least two of the descriptors	1
03.2	Calc with answer showing $T_E = 68.98$ or 69 ✓ $\frac{1}{T_E} = \frac{1}{110} + \frac{1}{185}$		1
03.3	Mention of time between 10 to 70 minutes with reference to effective half life / time for a scan ✓ and to allow the blood to carry the isotope around the body ✓ and to allow the isotope to be taken in by the body part to be investigated ✓		3
03.4	Positron (collides with an) electron and results in annihilation ✓ All the mass of positron and electron is converted to energy in gamma photons ✓ Must be two photons travelling in opposite directions to conserve momentum ✓		Max 2
03.5	Use of 0.18 to 0.2 m and 3×10^8 m/s for speed of em waves through the head to get a time between 0.6 and 0.7×10^{-9} s for time to travel across head. ✓ then explanation of difference in trig times from a minimum of 0 s at centre of head to a maximum of their calculated		2



	answer at edge of head.✓		
Total			9

Question	Answers	Additional Comments/Guidelines	Mark
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04.1	the time taken to halve the amount of fluorine-18/ number of particles is 6 hours ✓₁ by excretion of fluorine-18 from the body (by biological means)✓₂	✓₁ Condone 'mass' as alternative to 'amount'. Condone 'activity' ✓₂ must include the idea that the fluorine is removed from the body Do not allow decay in MP1 or in MP2	2	AO1
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Question	Answers	Additional comments/Guidelines	Mark	AO
04.2	Max 2 from ✓✓ Correct use of $\left(\frac{1}{T_E}\right) = \frac{1}{T_P} + \frac{1}{T_B}$ to find T_E ✓_a Use of their $T_E = \frac{\ln 2}{\lambda}$ to find their λ ✓_b Use of $N = N_0 e^{-\text{their } \lambda \times t}$ to find their % remaining with consistent units ✓_c 14 (%) ✓	✓_a Expect: $\frac{1}{T_E} = \frac{1}{110} + \frac{1}{6 \times 60} \therefore T_E = 84 \text{ mins (1.4 hours, 5055 s)}$ ✓_b $\lambda = \frac{\ln 2}{84} = 8.3 \times 10^{-3} \text{ mins}^{-1} \text{ (0.50 hours}^{-1}, 1.4 \times 10^{-4} \text{ s}^{-1})$ ✓_b Condone use of T_B or T_P ✓_c $\frac{N}{N_0} = e^{-\lambda t} = e^{-8.3 \times 10^{-3} \times 4.0 \times 60} = 0.14$ Or $N = N_0 e^{-\lambda t} = 100 e^{-8.3 \times 10^{-3} \times 4.0 \times 60} = 14\%$ Calculator value = 13.88419224 Alternative Method Calculation of effective half-life ✓_a Uses their T_E to find number of half-lives in 4.0 hours with consistent units (e.g. $4.0 / 1.4 = 2.85$) ✓_b ✓_b Condone use of T_B or T_P Calculation of percentage remaining $\frac{1}{2^{\text{their number of half-lives}}} \times 100$ OR $0.5^{\text{their number of half-lives}} \times 100$ ✓_c	3	AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
04.3	Beta plus/positron and (electron) neutrino ✓	Ignore (incorrect) symbols. Reference to emission of anti-neutrino, gamma, protons, neutrons or daughter nucleus scores zero.	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
04.4	Use of $3 \times 10^8 \text{ m s}^{-1}$ (as speed of photons) ✓₁ Use of Pythagoras to determine AB or half AB OR appropriate use of scale ✓₂ Extra distance to travel to B = $(3 \times 10^8 \times 0.79 \times 10^{-9}) = 23.7 \times 10^{-2} \text{ (m)}$ OR calculates time for light to travel from A to B (2.36 ns) ✓₃ H5 from some correct working ✓₄	✓₂ Ignore POT. ✓₂ $AB = \sqrt{10^2 + 70^2} (= 70.7 \text{ cm})$ Allow calculation in cm or number of squares (AB = 14.1 squares) ✓₂ Appropriate use of scale e.g. $23.7 \div 5 = 4.7$ squares ✓₃ Allow use of half the time to work out distance from centre ✓₄ Allow credit for any method which uniquely identifies square H5 (Any grid reference takes precedence.) If no use of $3 \times 10^8 \text{ m s}^{-1}$ then a mark can be awarded for any square along the line AB that is closer to A (H1 – H7)	4	1×AO1 2×AO3 1×AO3
Total			10	

Question	Answers	Additional comments/Guidelines	Mark	AO
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02.1	Max one from ✓ - Reads off activities of $74(\times 10^9)$ and $58(\times 10^9)$ from the graph (and calculates the difference) (1) - Use of $A = -\lambda N$ to find number of nuclei at $t=0$ / $t=24$ / difference between $t=0$ and $t=24$ (2) - Use of $N = N_0 e^{-\lambda t}$ (3) - Use of $(\Delta)N = N_0 (1 - e^{-\lambda t})$ (4) - determines area under ^{99}Mo graph between $t = 0$ and $t = 24$ hours. (5) 5.7×10^{15} ✓	Expect to see $74(\times 10^9) - 58(\times 10^9) (= 16 \times 10^9)$ Condone consistent power of ten errors where attempt to find difference is seen Condone one other error in read offs where their difference is calculated. Expect to see one of $(N =) \frac{74 \times 10^9}{2.8 \times 10^{-6}} (= 2.64 \times 10^{16})$ (a) $(N =) \frac{58 \times 10^9}{2.8 \times 10^{-6}} (= 2.07 \times 10^{16})$ (b) $(N =) \frac{16 \times 10^9}{2.8 \times 10^{-6}}$ (c) $74(\times 10^9) - 58(\times 10^9) = 2.8(\times 10^{-6}) \times N$ (d) $16(\times 10^9) = 2.8(\times 10^{-6}) \times N$ (e) - Finding difference of 2.64×10^{16} and 2.07×10^{16} seen (f) - Condone one error in $\frac{\text{difference in activity}}{2.8 \times 10^{-6}}$ (g) condone power of ten errors in (d) and (e) and (f) For Use of in (3) is by substitution of N (or N_0) and $t = 24 (\times 60^2)$, condone $N(1.82 \times 10^{16})$ from $A = 51 \text{ GBq}$. For (3) $N_0 = 2.64(\times 10^{16}) / N = 2.07(\times 10^{16})$ $t = 24 (\times 60^2)$ For (4) $N_0 = 2.64(\times 10^{16})$ $t = 24 (\times 60^2)$ allow area of a trapezium: expect base 24×3600 and parallel sides 74×10^9 and 58×10^9 allow counting squares: expect 325 to 400 small squares (13 to 16 large squares) x by area of one square for MP2 accept > 2 sf, rounding to 5.7×10^{15} Must see MP1 to award MP2	2	AO2
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Question	Answers	Additional comments/Guidance	Mark	AO
02.2	Method 1: calculates number of ^{99m}Tc (that have decayed between $t = 0$ and $t = 24$) $_1\checkmark$ use of $(0.9 \times)$ their 02.1 – their number of ^{99m}Tc (that have decayed between $t = 0$ and $t = 24$) $_2\checkmark$ number of ^{99m}Tc extracted in range 1.4 to 2.4×10^{15} $_3\checkmark$ Method 2: use of recognisable half-life to determine the decay constant for ^{99m}Tc $_1\checkmark$ use of activity at $t = 24$ hours and a decay constant to determine number of ^{99m}Tc extracted $_2\checkmark$ number of ^{99m}Tc extracted in range 1.50 to 1.63×10^{15} $_3\checkmark$	for $_1\checkmark$ number in range 3.0 to 3.7×10^{15} For $_2\checkmark$ allow use of $(0.9 \times) 6 \times 10^{15}$ – their number of ^{99m}Tc for $_3\checkmark$ must see use of 0.9 in a valid difference calculation for $_1\checkmark$ evidence for half-life of $6(.0)$ hours seen in working; expect $\lambda = 3.2 \times 10^{-5} (\text{s}^{-1})$ based on half-life $= 2.2 \times 10^4 \text{ s}$ allow substitution of half-life in hours, eg $\lambda = \frac{\ln 2}{6(.0)}$ for $_2\checkmark$ substitution of A in range $50(\times 10^9)$ to $52(.2) (\times 10^9)$, eg $N = \frac{51(\times 10^9)}{\text{their } \lambda}$ allow PoT on activity in MP2 for $_3\checkmark$ allow 2 sf in range 1.5 to 1.6×10^{15} Where no other mark is scored, Max 1 for: attempt to find area (under ^{99m}Tc curve) • 215 to 255 small squares (or 8 to 10 large) • allow area of triangle and trapezium • finds area of one small square $= 1.4 \times 10^{13}$	3	$1 \times \text{AO2}$ $2 \times \text{AO3}$



Question	Answers		Additional comments/Guidance	Mark	AO
02.3	Mark	Criteria	In each area, a partial response covers one bullet point while a detailed response covers at least two. Area 1: How images obtained (MUGA scan) ^{99m}Tc is used as a tracer OR ^{99m}Tc is a gamma-emitter (do not award if annihilation mentioned) - the imaging device is a gamma camera (mentioning a detector / scanner insufficient) - details of gamma camera (collimator, photomultiplier, dynodes) treat as neutral: ^{99m}Tc quickly removed from body (in about 24 hours) / has a short (effective) half-life Area 2: Common advantages - both are non-invasive - both generate (2D) images that provide an animated view of the functioning heart or wtte - no need to anaesthetise patient - both are outpatient procedures - patients do not have to remain still / allow 'both may be used during stress testing' 'can be used if patient has pacemaker' is neutral Area 3: Strength and weakness - MUGA provides (both) quantitative (and qualitative) information / MUGA is more accurate / TTE provides only qualitative information / MUGA image intensity is related to number of red blood cells in region - Interpretation of TTE images may be subjective / not reproducible - TTE lower cost / allow 'takes less time' allow reverse argument - TTE uses non-ionising radiation / no side effects / MUGA uses ionising radiation. 'MUGA produces higher resolution images' is neutral	6	2 × AO2 4 × AO3
	6	All three areas covered in some detail. 6 marks can be awarded even if there is an error and/or parts of one aspect missing.			
	5	All three areas covered, at least two in detail. Whilst there will be gaps, there should only be an occasional error.			
	4	Two areas successfully discussed, or one discussed and two others covered partially. Whilst there will be several gaps, there should only be an occasional error.			
	3	One area discussed and one discussed partially, or all three covered partially. There are likely to be several errors and omissions in the discussion.			
	2	Only one area discussed or makes a partial attempt at two areas.			
	1	Only one area covered and that partially.			
	0	No relevant comments			

Total			11
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13				
Question	Answers	Additional comments/Guidance	Mark	AO



01.1	Half-life of 6 hours ✓ Long enough to allow scan to take place ✓ Short enough not to expose the patient to excessive radiation / patient is not left with an active source for too long ✓ Too short to keep stored / transport with enough activity / enough undecayed nuclei to be useful ✓	Condone several hours Do NOT allow couple / few hours	4	AO1
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Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	Other radiation causes damage to tissue without being detectable ✓ Pass through the body (tissue) so that it can be detected (outside) ✓ Least ionising so that it causes least damage to tissue ✓ Energy / frequency of gamma is similar to medical X-rays so that an X-ray camera can be used for detection ✓	Reference to least ionising without reason not enough	4	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	Photocathode emits an electron ✓ Electrons accelerated to (positive) dynodes ✓ Each electron collides with dynode to releases more (4) electrons✓	Do NOT allow suggestion that 1 photon leads to the release of more than 1 electron at photocathode	3	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.4	Calculation of effective half life or justification for ignoring biological half-life ✓ Calculation of decay constant ✓ Substitution or rearrangement of $A = A_0 e^{-\lambda t}$ ✓ Conclusion consistent with calculation based on effective half-life ✓	Ecf available for incorrect calculation of effective half-life or use of one of the half-lives and for decay constant. eg $T_E = (8.0^{-1} + 66^{-1})^{-1} = 7.1$ $\lambda = \frac{\ln 2}{7.1} = 0.097 \text{ days}^{-1} (1.12 \times 10^{-6} \text{ s}^{-1})$ $t = -\frac{\ln(\frac{1100}{3200})}{0.097} = 11 \text{ days } (9.50 \times 10^5 \text{ s})$ or $A = 3.2e^{-0.097 \times 10} = 1.2 \text{ GBq}$ Ignoring biological half life gives $\lambda = \frac{\ln 2}{7.1} = 0.0867 \text{ days}^{-1} (1.00 \times 10^{-6} \text{ s}^{-1})$ $t = -\frac{\ln(\frac{1100}{3200})}{0.0867} = 12 \text{ days } (1.04 \times 10^6 \text{ s})$ or $A = 3.2e^{-0.0867 \times 10} = 1.3 \text{ GBq}$ Condone conclusion based on physical half-life	4	AO3
Total			15	

Question	Answers	Additional comments/Guidelines	Mark	AO
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