

Please write clearly in block capitals.

Centre number

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Candidate number

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Surname

StemUp Model Solution

Forename(s)

Candidate signature

I declare this is my own work.

A-level PHYSICS

Paper 3

Section B Medical physics

Materials

For this paper you must have:

- a pencil and a ruler
- a scientific calculator
- a Data and Formulae Booklet
- a protractor.

Instructions

- Use **black ink** or **black ball-point pen**.
- **Fill** in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- If you need extra space for your answer(s), use the lined pages at the end of this book. Write the question number against your answer(s).
- Do **all** rough work in this book. Cross through any work you do not want to be marked.
- Show **all** your working.

Information

- The marks for questions are shown in brackets.
- The maximum mark for this paper is 35.
- You are expected to use a scientific calculator where appropriate.
- A Data and Formulae Booklet is provided as a loose insert.

Time allowed: The total time for both sections of this paper is 2 hours. You are advised to spend approximately 50 minutes on this section.

For Examiner's Use	
Question	Mark
1	
2	
3	
4	
5	
TOTAL	



J U N 2 2 7 4 0 8 3 B B 0 1

Section B

Answer **all** questions in this section.

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]

$$P = 1/u + 1/v$$

$$4.0 = 1/0.75 + 1/v$$

$$1/v = 4.0 - 1.33 = 2.67 \text{ m}^{-1}$$

$$v = (4.0 - 1/0.75)^{-1} = 0.375 \text{ m}$$

$$\text{magnification } m = v / u = 0.375 / 0.75$$

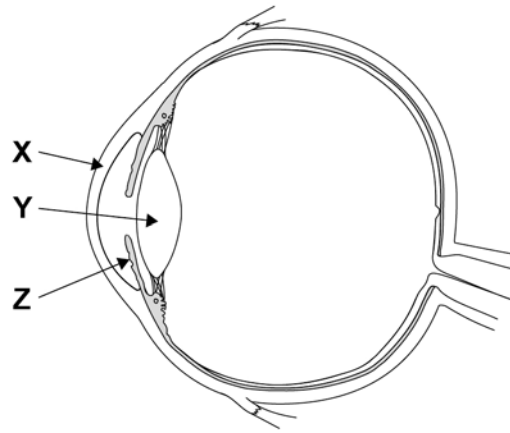
$$m = 0.50$$

magnification = 0.50

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 cornea

Primary optical function of X It refracts light (it is the primary refractor, providing most of the eye's power) to form an image on the retina.

Name of Y lens

Primary optical function of Y Accommodation: it changes shape to vary the focal length (power) of the eye, so objects at different distances are focused on the retina.

Name of Z iris

Primary optical function of Z It controls the amount of light entering the eye by changing the size of the pupil.



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0 2 . 1

An X-ray image is to be made of a broken bone.
The image can be formed on

- photographic film
- a flat panel (FTP) detector or
- an intensifying screen using fluoroscopic image intensification.

State and explain which one of these detection methods should be used in this situation.

Go on to discuss why the other two methods are less suitable.

[4 marks]

A flat panel (FTP) detector should be used.

The bone is not moving, so a real-time moving (fluoroscopic) image is not required; a single still image is enough.

The flat panel detector is more sensitive than film, so a lower dose of X-rays can be used. It is also faster than film, since the image does not have to be developed, and the digital image is easy to store, share and transfer.

Film is less suitable because it is less sensitive and slower, as it must be developed. An image intensifier is less suitable because it gives a moving real-time image, which is not needed here, and unlike the FTP it does not save a picture.

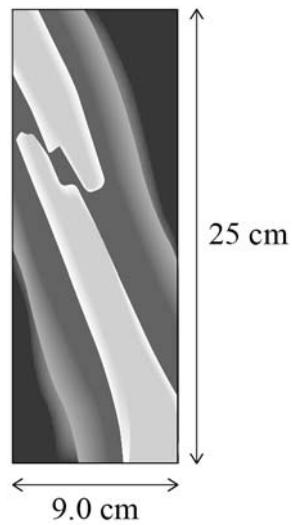
Question 2 continues on the next page

Turn over ►



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}



0 2 . 2

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

[5 marks]

Take the thickness of bone as its mean diameter: $x = 0.040 \text{ m}$

transmitted: $I = I_0 e^{-\mu x} = 0.013 \times e^{-58.3 \times 0.040}$

$I = 0.00126 \text{ W m}^{-2}$

absorbed intensity = $0.013 - 0.00126 = 0.0117 \text{ W m}^{-2}$

length of bone $\approx$ diagonal of image = $\sqrt{(0.25^2 + 0.090^2)} = 0.266 \text{ m}$

area of bone = $0.266 \times 0.040 = 0.0106 \text{ m}^2$

power absorbed $P = IA = 0.0117 \times 0.0106 = 1.24 \times 10^{-4} \text{ W}$

energy $E = Pt = 1.24 \times 10^{-4} \times 0.80 = 9.9 \times 10^{-5} \text{ J}$

$\approx 1.0 \times 10^{-4} \text{ J}$

energy absorbed = 1.0×10^{-4} J

0 2 . 3

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

[2 marks]

1 *The bone is assumed to be a rectangular block (cuboid) of constant thickness 0.040 m , but it is roughly cylindrical, so it is thinner near its edges and absorbs less there.*

2 *It assumes none of the X-rays are absorbed by the soft tissue before reaching the bone, but some are, so less than 0.013 W m^{-2} reaches the bone. Some X-rays are also scattered rather than absorbed.*

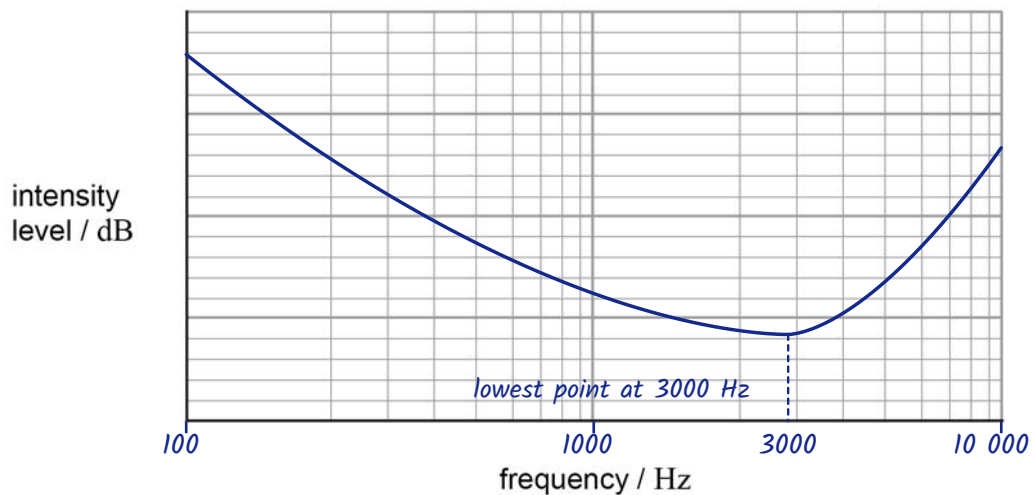


0 3 . 1

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



0 3 . 2

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

[2 marks]

Sounds of different frequencies are played to the person through earphones, one at a time, and each is compared with a 1 kHz reference signal of fixed intensity level.

The volume (intensity) of each test frequency is changed until it sounds the same loudness as the reference signal, and its intensity level is recorded.



0 3 . 3

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

[2 marks]

$$\text{intensity level} = 10 \log (I / I_0)$$

$$30 = 10 \log (I / 1.0 \times 10^{-12})$$

$$I = 1.0 \times 10^{-12} \times 10^{30/10} = 1.0 \times 10^{-12} \times 10^3$$

$$\text{intensity} = \underline{1.0 \times 10^{-9}} \text{ W m}^{-2}$$

7

Turn over for the next question**Turn over ►**

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]

Image quality: calcium kidney stones contain no water, so they contain very few hydrogen nuclei and give almost no signal in an MR scan. So the MR scan would give a poor image of the stones (they appear dark, like bone), even though it gives a high resolution image of soft tissue.

A CT scan gives a high resolution image of the kidney stones, because the calcium in the stones has a high attenuation coefficient for X-rays (like bone), so there is good contrast with the surrounding soft tissue and their size and position are shown precisely.

An ultrasound scan gives a lower resolution image than CT, but the stones reflect ultrasound strongly (large difference in acoustic impedance, like bone), so they still show up clearly enough to be detected and located.

Other factors: CT uses X-rays, which are ionising, so they can damage or kill cells and increase the risk of cancer, and the dose from a CT scan is relatively high. Ultrasound and MR scans use no ionising radiation and cause no known harm. CT and MR scanners are much more expensive than ultrasound. In an MR scanner the patient must



stay still for a long time in a narrow tube, which can cause claustrophobia. Ultrasound is the fastest, gives a real-time image and the patient does not have to remain still.

Recommendation: I would recommend an ultrasound scan. Its image quality is good enough to detect and locate calcium kidney stones, and it is cheaper, quicker and safe because there is no ionising radiation, so it can be repeated to monitor the stones and is suitable for pregnant women and children.

A CT scan gives the best quality image of the stones, so it would only be used if a more detailed image were needed (for example before surgery), as it carries the risk of ionising radiation. An MR scan is the least suitable, as it gives a poor image of stones that contain no water.

Turn over for the next question

Turn over ►



0	5	.	1
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State the purpose of the magnetic field in a magnetic resonance scanner.

[1 mark]

To align the spins (magnetic moments) of the protons (hydrogen nuclei) in the body, so that they precess around the direction of the magnetic field.

0	5	.	2
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Describe the role of the radio frequency pulses in a magnetic resonance scanner.

[2 marks]

The radio frequency pulses are absorbed by the protons, exciting them and flipping their spins out of alignment with the magnetic field (into antialignment).

When each pulse stops, the protons relax back into alignment and emit radio frequency signals, which are detected and used to form the image.

3

END OF QUESTIONS



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