

Please write clearly in block capitals.

Centre number

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Candidate number

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Surname

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Forename(s)

Candidate signature

A-level PHYSICS

Paper 3

Section B Medical physics

Thursday 14 June 2018

Morning

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.

Materials

For this paper you must have:

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

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.
- 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.

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



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

Section B

Answer **all** questions in this section.

0	1	.	1
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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 Coherent bundle: the fibres are in a fixed arrangement, with the same relative positions at each end.

It is used to transmit the image from inside the body back to the viewer (eyepiece or camera).

Bundle 2 Non-coherent bundle: the fibres are in a random arrangement.

It is used to transmit light into the body to illuminate the area under investigation.



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

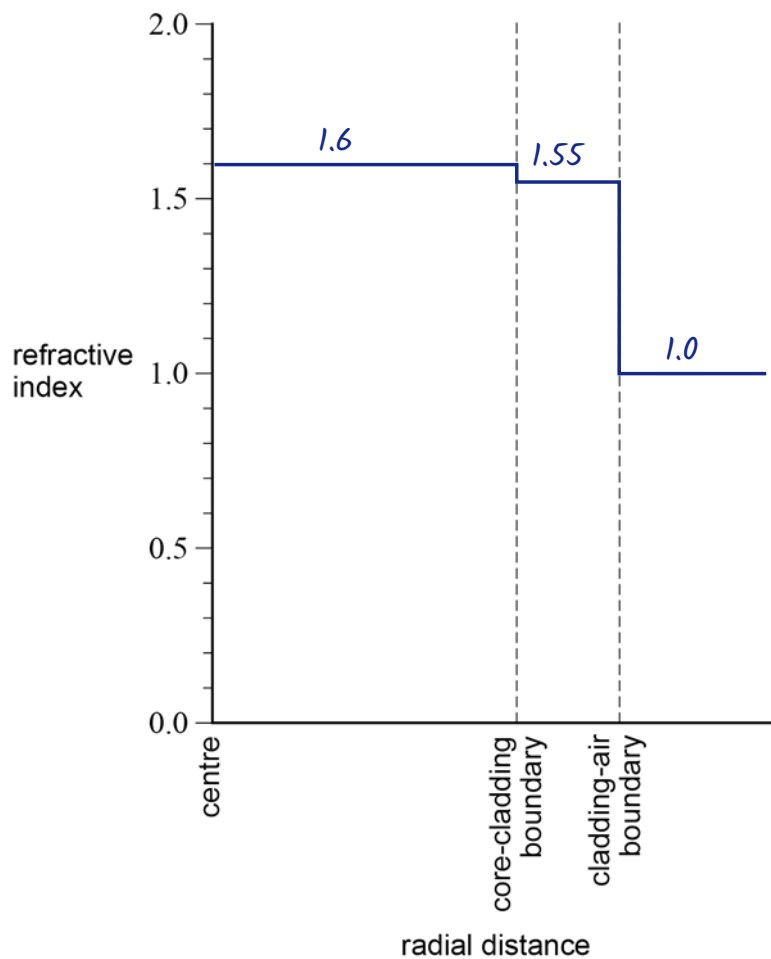
[2 marks]

$$\sin c = n_{\text{cladding}} / n_{\text{core}}$$

$$n_{\text{cladding}} = n_{\text{core}} \sin c = 1.6 \times \sin 75^\circ$$

$$n_{\text{cladding}} = 1.55 \quad (\text{air} = 1.0)$$

Figure 1



0 2 . 1

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

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]**

$$d / 21 \times 10^{-3} = 12 \times 10^{-3} / 61$$

$$d = 4.1 \times 10^{-6} \text{ m (separation of the images on the fovea)}$$

$$4.1 \times 10^{-6} / 1.5 \times 10^{-6} = 2.75 \text{ cone diameters}$$

The images are more than 2 cone diameters apart, so there is at least 1 unstimulated cone between them: the eye can resolve the two images.

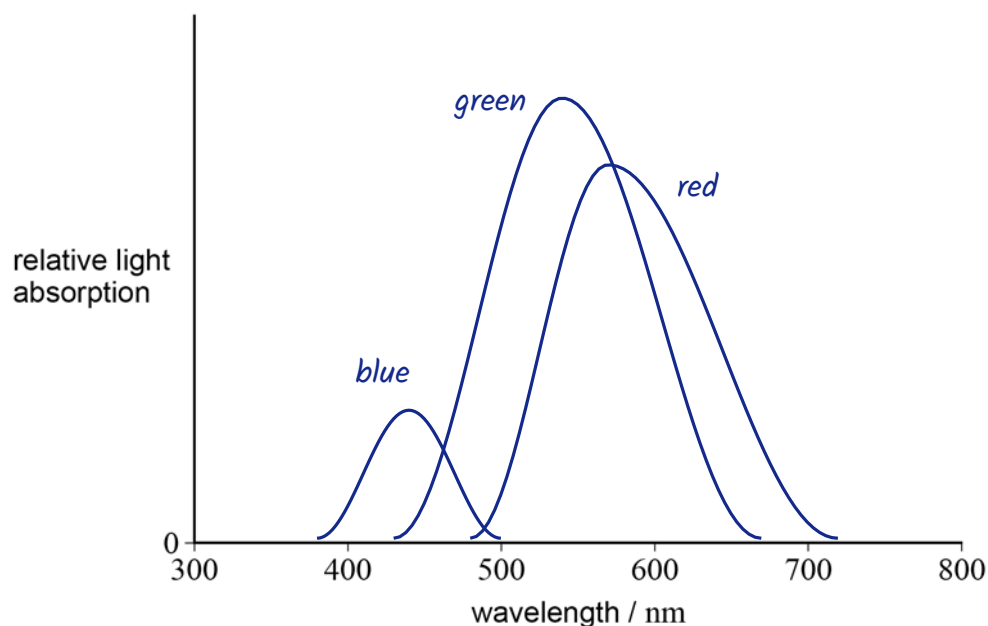
0 2 . 2

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



Turn over for the next question

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ANSWER IN THE SPACES PROVIDED**

Turn over ►



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]

Principles of a CT scanner: the patient lies in the centre of a ring. An X-ray tube is mounted on one side of the ring, with an array of detectors mounted on the opposite side of the ring.

A narrow beam of X-rays is sent through the head in short pulses, 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, so pulses of X-rays pass through the head from many different directions.

The computer adds the signals from all the directions together to produce a 2D image of that slice of the head. The patient is moved through the ring to build up a series of slices, giving a 3D image.

Advantages for head injuries: on a simple X-ray image the skull absorbs most of the X-rays and all the tissues overlap onto one 2D image, so soft tissue inside the skull shows up poorly.

A CT scan gives a much better defined image of the boundaries between the different soft tissues inside the skull, as it can distinguish small differences in attenuation. This makes it possible to identify bleeding (or swelling) inside the skull, which is the main danger after a head injury and cannot be seen on a simple X-ray.

Simple X-rays for other injuries: for injuries such as broken limbs, bone attenuates X-rays much more than the surrounding soft tissue, so a



simple X-ray image clearly shows simple fractures.

A simple X-ray is cheaper and quicker, more readily available and easier for the patient.

It is also less harmful, because the patient dose from a single simple X-ray is much less than from a CT scan (which uses many exposures), so the extra detail of CT is only worth the higher dose and cost where soft tissue must be seen, as in a head injury.

Turn over for the next question

Turn over ►

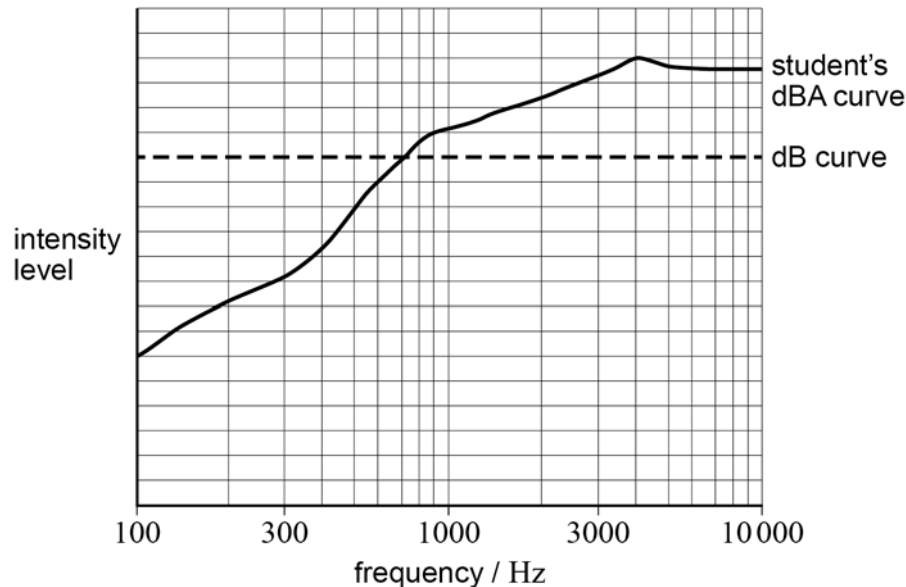


0 4 . 1

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]

The dBA curve drawn is not correct.

The ear's sensitivity starts low, increases to a maximum and then falls again at higher frequencies. The student's curve does not fall after about 5 kHz; it levels off (plateaus) when it should fall.

1 kHz is the reference frequency for both scales, so both curves should have the same reading at 1 kHz, but the student's curves cross at about 750 Hz.

The ear is most sensitive at about 3 kHz, so the dBA curve should have its maximum at 3 kHz, but the student's maximum is at about 4 kHz.



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]

$$110 = 10 \log (I / I_0), \quad I_0 = 1.0 \times 10^{-12} \text{ W m}^{-2}$$

$$I = 10^{11} \times 1.0 \times 10^{-12} = 0.10 \text{ W m}^{-2}$$

$$I = P / 4\pi r^2 \quad \text{so} \quad r^2 = 7.8 / (4\pi \times 0.10)$$

$$r = 2.5 \text{ m} \quad (\text{minimum safe distance})$$

$$\text{Check at 2.0 m: } I = 7.8 / (4\pi \times 2.0^2) = 0.155 \text{ W m}^{-2}, \text{ giving } 112 \text{ dB}$$

The intensity level at 2.0 m is about 112 dB, which is above the safe maximum of 110 dB.

The barriers would need to be at least 2.5 m from the drill. 2.0 m is less than 2.5 m, so the barriers are slightly too close to the drill and will not keep pedestrians at a safe distance.

8

Turn over for the next question

Turn over ►



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]

Scans (e.g. CT / MRI) are used before treatment to locate the precise position, size and depth of the tumour.

This allows X-rays of the correct energy to be chosen for the depth and size of the tumour.

A computer uses the scan data to position the X-ray beam relative to the patient so it targets the tumour accurately.

The tumour can be irradiated from several different directions, with the time of exposure kept to a minimum, so the tumour gets a high dose while less damage is caused to healthy cells.

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.

$$\text{density of lead} = 1.1 \times 10^4 \text{ kg m}^{-3}$$

[4 marks]

$$\mu = \ln 2 / \text{half-value thickness} = 0.693 / 4.2 \times 10^{-3}$$

$$\mu = 165 \text{ m}^{-1}$$

$$\mu_m = \mu / \rho = 165 / 1.1 \times 10^4$$

$$\mu_m = 1.5 \times 10^{-2} \text{ m}^2 \text{ kg}^{-1}$$

mass attenuation coefficient = 1.5×10^{-2} unit $\text{m}^2 \text{ kg}^{-1}$

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END OF QUESTIONS



There are no questions printed on this page

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