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Centre number

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Surname

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Forename(s)

Candidate signature

I declare this is my own work.

# A-level PHYSICS

Paper 3

Section B Medical physics

Monday 17 June 2024

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
- 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.

For Examiner's Use

| Question     | Mark |
|--------------|------|
| 1            |      |
| 2            |      |
| 3            |      |
| 4            |      |
| 5            |      |
| <b>TOTAL</b> |      |



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## Section B

Answer **all** questions in this section.

0 1 . 1

A human eye has a far point of 6.0 m.

State the name of this defect of vision.

[1 mark]

*Myopia (short sight)*

0 1 . 2

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

[2 marks]

*Lens must form an image of an object at infinity at the far point:* *$u = \infty$ ,  $v = -6.0$  m (virtual image)*

*$P = 1/f = 1/u + 1/v = 1/\infty + 1/(-6.0) = 0 - 0.167$*

 *$P = -0.17$  D (diverging lens)*power = -0.17 D

0 1 . 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      |   |

4



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]

$$I = I_0 \times 10^{IL/10} = 1.0 \times 10^{-12} \times 10^{110/10} = 0.10 \text{ W m}^{-2}$$

*Number of spectators falls by 60%, so 40% remain and the total intensity is reduced by a factor of 0.40:*

$$\text{new } I = 0.40 \times 0.10 = 0.040 \text{ W m}^{-2}$$

$$IL = 10 \log(I / I_0) = 10 \log(0.040 / 1.0 \times 10^{-12})$$

$$IL = 10 \log(4.0 \times 10^{10}) = 106 \text{ dB}$$

peak sound-intensity level = 106 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]

*Permanent hearing loss: a reduction in sensitivity at all frequencies, so a higher intensity is needed for the same loudness (sounds seem quieter).*

*The greatest loss of sensitivity occurs at about 4 kHz (a dip in the equal loudness / audiogram curve around 4 kHz).*

Turn over ►



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]**

*The two types are the coherent bundle and the non-coherent*

*(incoherent) bundle.*

*The coherent bundle transmits the image back out of the body. The non-coherent bundle transmits light into the body to illuminate the area being viewed.*

*The non-coherent bundle does not need cladding: it only has to carry light for illumination, so it does not matter if light leaks from one fibre into a neighbouring fibre.*

*The fibres in the coherent bundle do need cladding, so that light does not pass from one fibre to another where the fibres touch. Each fibre carries light from one part of the image, so leakage between fibres would blur and destroy the image.*

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]**

*Methods used in communication: modal dispersion (pulse broadening because light rays take different paths of different lengths) is reduced by using a very narrow mono-mode (single mode) core, so light can only travel along one path, and by making the refractive index of the core only slightly greater than that of the cladding, so the critical angle is large and only rays close to the axis are guided. Material dispersion*



(different wavelengths travelling at different speeds in the glass) is reduced by using monochromatic light. Repeaters are also used to regenerate the pulses before they overlap.

Why they are not needed in an endoscope: the fibres in an endoscope are very short (about 1 to 2 m long) compared with communication links that are many km long. The difference in travel time between different paths or different wavelengths over such a short distance is tiny, so any dispersion is insignificant. The coherent bundle carries an analogue image, not a stream of digital pulses, so there is no pulse broadening or overlap of pulses to cause errors, and the data transfer rate is far lower than in high speed communications, so dispersion is not noticeable. The non-coherent bundle only carries light for illumination, so its function is not affected by dispersion at all.

Effect on the function of the endoscope: making the core refractive index close to that of the cladding would let a lot of light escape (the critical angle is larger), so the image would be much less bright and harder to see. Mono-mode fibres would accept and transmit much less light, again reducing the intensity of the image. Using monochromatic light would give a monochrome image with no true colours, so the doctor could not see the colour of tissue, making diagnosis harder.

Repeaters would make the endoscope far too wide to go inside the patient. (Narrower mono-mode fibres would allow more fibres in the bundle, giving better resolution, but the image would be too dim.)

Overall these changes would make diagnosis and treatment more difficult.



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]

*It is the time taken for the amount (number of nuclei) of fluorine-18 in the body to halve, which is 6.0 hours.*

*This is due to the fluorine-18 being removed (excreted) from the body by biological processes, not by radioactive decay.*

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]

$$1/T_E = 1/T_P + 1/T_B = 1/110 + 1/(6.0 \times 60) = 0.01187 \text{ min}^{-1}$$

$$T_E = 84.3 \text{ min}$$

$$\lambda = \ln 2 / T_E = 0.693 / 84.3 = 8.2 \times 10^{-3} \text{ min}^{-1}$$

$$\lambda t = 8.22 \times 10^{-3} \times 4.0 \times 60 = 1.97$$

$$N/N_0 = e^{-\lambda t} = e^{-1.97} = 0.139$$

$$\text{percentage remaining} = 0.139 \times 100 = 13.9\% \approx 14\%$$

percentage = 14 %

0 4 . 3

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

[1 mark]

*A positron ( $\beta^+$  particle) and an (electron) neutrino.*

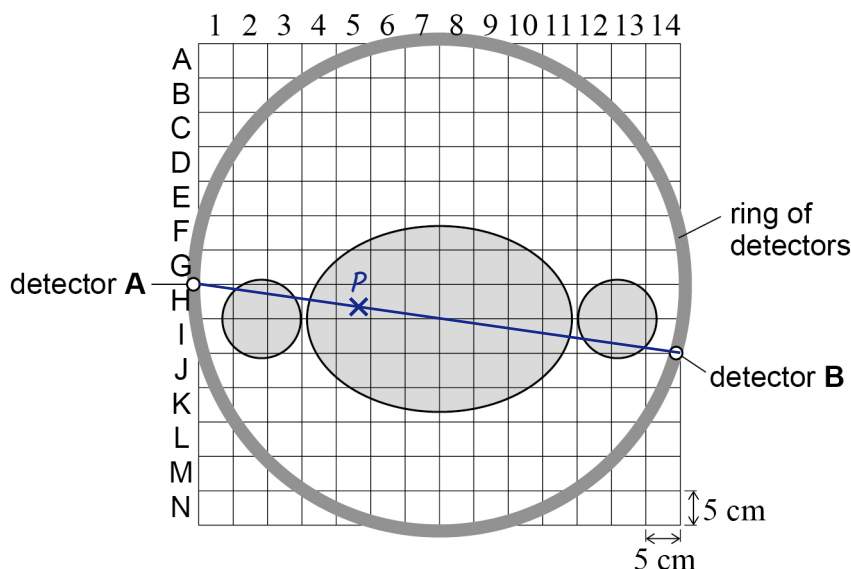


0 4 . 4

**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]**

*Particles (gamma photons) travel at  $c = 3.0 \times 10^8 \text{ m s}^{-1}$ .*

*$AB = \sqrt{(70^2 + 10^2)} = 70.7 \text{ cm}$  (14 squares across, 2 down)*

*Extra distance to B =  $ct = 3.0 \times 10^8 \times 0.79 \times 10^{-9} = 0.237 \text{ m} = 23.7 \text{ cm}$*

*So  $x + 23.7 = 70.7 - x$ , where  $x$  = distance from A*

*$x = (70.7 - 23.7) / 2 = 23.5 \text{ cm} = 4.7 \text{ squares along AB from A}$*

*4.7 squares along AB is 4.65 squares across and 0.66 squares down from A, which is in column 5, row H (marked P on Figure 1).*

square = HS

10

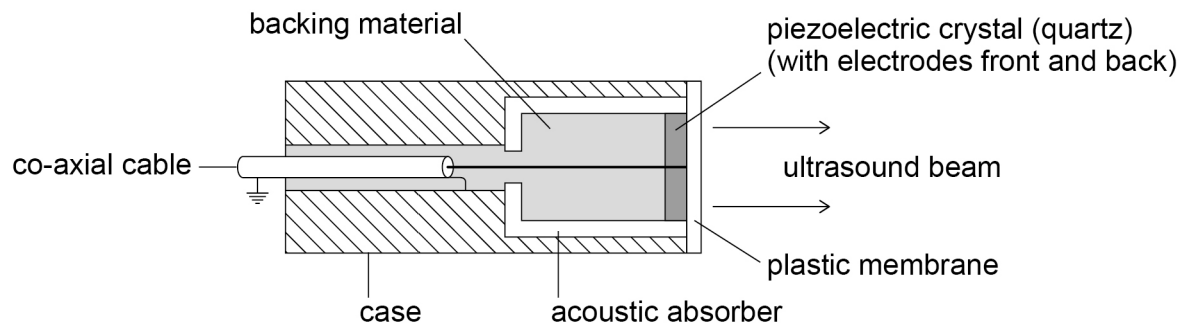
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0 5 . 1

**Figure 2** shows a transducer used in a medical ultrasound scanner.

**Figure 2**



Explain why a backing material is used.

**[2 marks]**

*The backing material damps the vibrations of the piezoelectric crystal*

*(stops it vibrating) after each pulse has been transmitted.*

*This makes the pulses short, so the crystal can then act as a receiver*

*for the reflected pulses and the transmitted and reflected pulses remain*

*separate.*



0 5 . 2

A beam of ultrasound is transmitted from muscle into bone.

Calculate the percentage of the incident intensity that is transmitted.

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

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

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

**[3 marks]**

$$Z_{\text{muscle}} = \rho c = 1100 \times 1600 = 1.76 \times 10^6 \text{ kg m}^{-2} \text{ s}^{-1}$$

$$I_r/I_i = ((Z_2 - Z_1) / (Z_2 + Z_1))^2$$

$$= ((5.3 \times 10^6 - 1.76 \times 10^6) / (5.3 \times 10^6 + 1.76 \times 10^6))^2$$

$$= (3.54 / 7.06)^2 = 0.251$$

$$\text{transmitted fraction} = 1 - 0.251 = 0.749$$

$$\text{percentage transmitted} = 74.9\% \approx 75\%$$

percentage = 75 %

5

**END OF QUESTIONS**

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