

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

A-level PHYSICS

Paper 3

Section B Medical physics

Thursday 29 June 2017

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	
TOTAL	



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

Section B

Answer **all** questions in this section.

0 1

A person suffers from hypermetropia (long sight).
Use of a spectacle lens of power +2.0D 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]

The eye lens cannot be made powerful enough (it cannot be made fat / convex enough) to bend the rays enough, or the eyeball is too short.

So the rays cannot be brought to a focus on the retina; they would be focused behind the retina.

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]

$$1/u + 1/v = 1/f = P, \text{ with } u = 24 \text{ cm} = 0.24 \text{ m and } P = +2.0 \text{ D}$$

$$1/0.24 + 1/v = 2.0$$

$$1/v = 2.0 - 4.17 = -2.17 \text{ m}^{-1}$$

$$v = -0.46 \text{ m} = -46 \text{ cm (virtual image, same side as the object)}$$

image distance = -46 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

☒

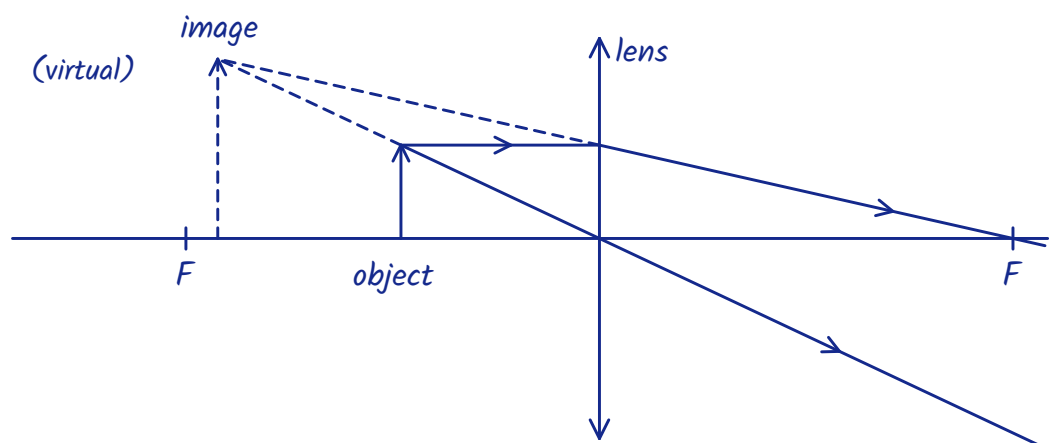
0 1 . 4

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]



Turn over for the next question

9

Turn over ►



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]

X-rays are ionising radiation: the high energy photons can ionise atoms in the patient's cells. This can damage DNA and cause mutations, which could lead to cancer, so the patient's exposure (dose) must be kept as low as possible.

1. Lead diaphragm plates (collimator) define the beam so that only the area to be investigated, the arm, is exposed to the X-rays. This limits the exposure of the rest of the body to ionising photons.

2. An aluminium filter is placed in the path of the beam. It absorbs a large percentage of the low energy photons, which are not needed for the image because they would be absorbed by the body and not reach the detector. This reduces the number of ionising photons absorbed by the patient.

3. The anode (tube) voltage is selected to produce the best energy photons for imaging bone, which limits the photons to those needed to produce a suitable image.

Also, when using film, intensifying screens are used so that a shorter exposure time is needed, and a grid between the patient and the image receptor stops scattered X-rays blurring the image, so the X-ray does not need to be repeated, avoiding further exposure.



[illegible]

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.

[2 marks]

Also, ultrasound gives a better definition image of the boundary between soft tissue (the aorta wall) and blood, whereas X-rays give poor contrast between soft tissues and blood.

Turn over ►



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]

$$I_r/I_i = ((Z_2 - Z_1)/(Z_2 + Z_1))^2, \quad 0.0625\% = 6.25 \times 10^{-4}$$

$$6.25 \times 10^{-4} = ((Z - 1.64 \times 10^6)/(Z + 1.64 \times 10^6))^2$$

Z decreases, so $Z < 1.64 \times 10^6$ and the negative root is needed:

$$(Z - 1.64 \times 10^6)/(Z + 1.64 \times 10^6) = -2.5 \times 10^{-2}$$

$$Z - 1.64 \times 10^6 = -0.025Z - 4.1 \times 10^4$$

$$1.025 Z = 1.64 \times 10^6 - 4.1 \times 10^4 = 1.599 \times 10^6$$

$$Z = 1.599 \times 10^6 / 1.025 = 1.56 \times 10^6 \text{ kg m}^{-2} \text{ s}^{-1}$$

$$\text{acoustic impedance of aorta wall tissue} = \underline{1.56 \times 10^6} \text{ kg m}^{-2} \text{ s}^{-1}$$

12



Turn over for the next question

**DO NOT WRITE ON THIS PAGE
ANSWER IN THE SPACES PROVIDED**

Turn over ►



03

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.

03.1

State what is meant by a radioisotope.

[1 mark]

*A material containing nuclei which are unstable, so they will decay
and emit ionising radiation.*

03.2

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]

$$1/T_E = 1/T_P + 1/T_B$$

$$1/T_E = 1/110 + 1/185 = 0.009091 + 0.005405 = 0.014496 \text{ min}^{-1}$$

$$T_E = 1/0.014496 = 68.98 \text{ min} = 69 \text{ min (about 70 minutes)}$$



0	3	.	3
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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]

A suitable time would be about 30 to 60 minutes (between 10 and 70 minutes), which is less than the effective half-life of about 70 minutes, so enough activity remains for the scan.

This allows time for the blood to carry the isotope around the body, and allows time for the isotope to be taken in (absorbed) by the body part (organ / tissue) to be investigated.

0	3	.	4
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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]

The positron collides with an electron and they annihilate.

All the mass of the positron and electron is converted to energy in the form of two gamma photons, which travel in opposite directions to conserve momentum.

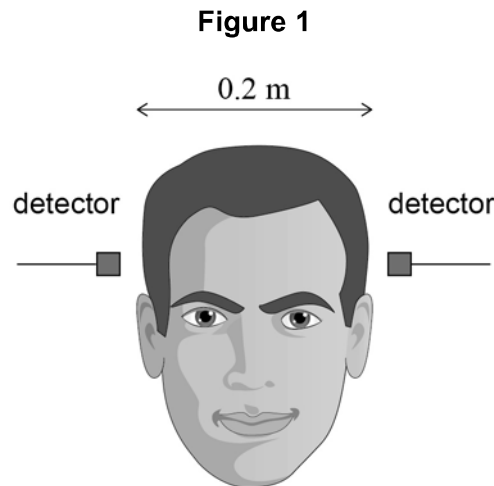
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0 3 . 5

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]

Using $3 \times 10^8 \text{ m s}^{-1}$ for the speed of the gamma photons and 0.2 m

for the width of the head, the time to travel across the head is $t =$

$$0.2 / 3 \times 10^8 = 6.7 \times 10^{-10} \text{ s}.$$

If the photons are produced at the centre of the head, both travel

equal distances, so $\Delta t = 0 \text{ s}$ (minimum).

If they are produced at the edge of the head, one photon travels 0.2

m further than the other, so $\Delta t = 6.7 \times 10^{-10} \text{ s}$ (maximum).

So the scanner must measure Δt from 0 to about $6.7 \times 10^{-10} \text{ s}$, and

must resolve much shorter intervals to locate the position.

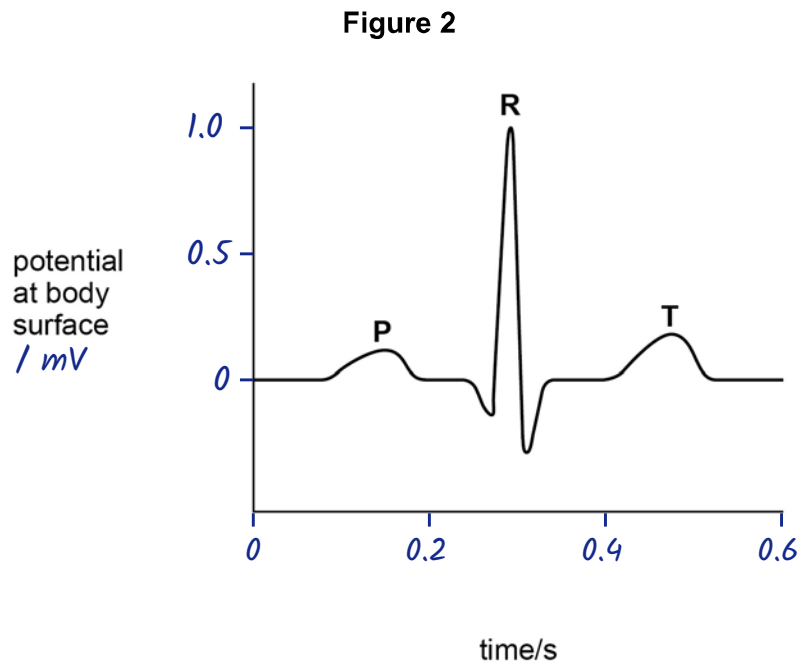


0 4 . 1

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

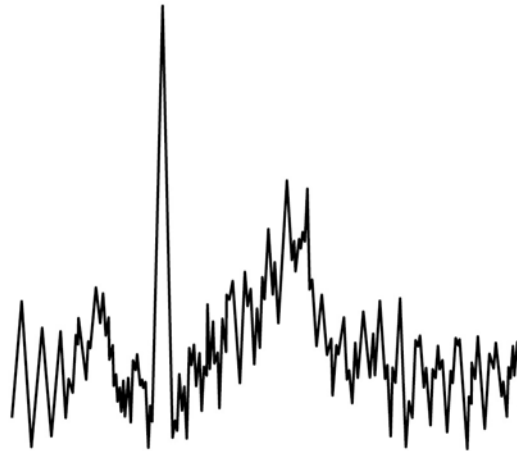
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0 4 . 2

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]

The electrodes may not be non-reactive (or the skin was not cleaned / no conducting gel), giving poor, varying contact and a noisy signal.

The electrodes may not be securely taped in place, or the patient was not relaxed / did not remain still, so muscle movement added extra potentials.

The amplifier may not be low noise, or may have damaged (unshielded) leads, giving interference from other AC sources such as the mains supply.

5

END OF QUESTIONS

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