AQA A-LEVEL PHYSICS · 7408

PHYSICS



EXAM QUESTION PACK

3.10.3 TO 3.10.6 BIOLOGICAL MEASUREMENT AND IMAGING

SCORE	PERCENTAGE
/121	%

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Q1.

(a) 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.

Bundle 1 _____

_____

_____

_____

_____

Bundle 2 _____

_____

_____

_____

_____

(4)

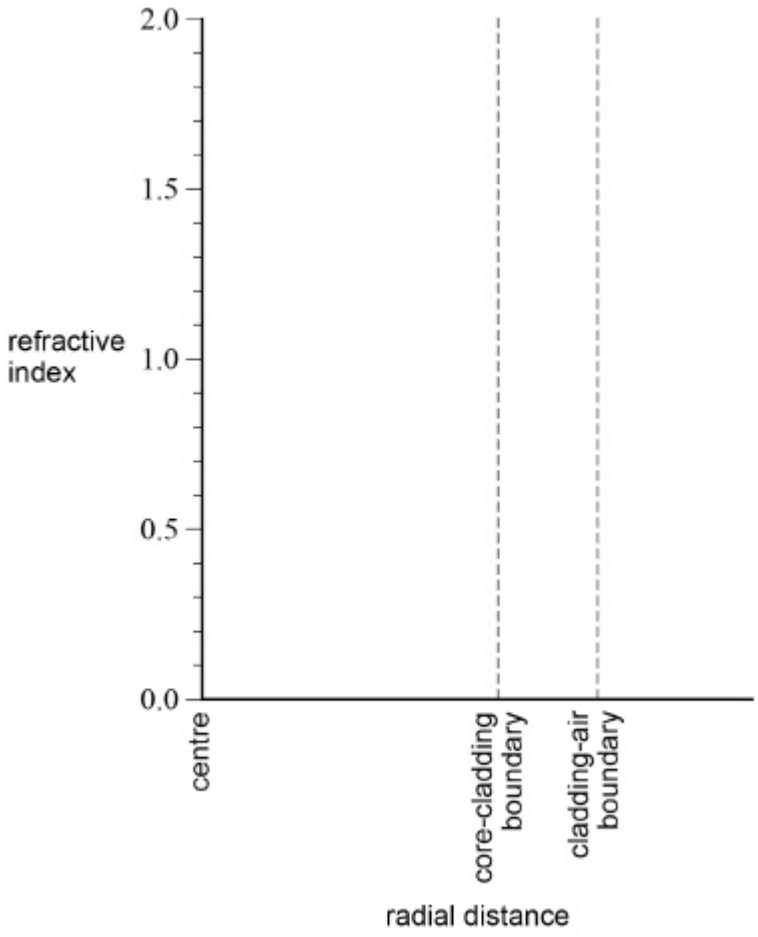
(b) A single optical fibre is placed in air. The optical fibre has a core surrounded by cladding. The critical angle is 75° at the core-cladding boundary.

Complete the graph 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

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(2)
(Total 6 marks)

Q2.

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.

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(Total 6 marks)

Q3.

(a) 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)

(b) 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.

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.	☐

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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. ☐

(1)

(c) 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}

mass attenuation coefficient = _____ unit _____

(4)

(Total 8 marks)

Q4.

(a) 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.

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_____

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(6)

(b) 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.

_____

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(2)

(c) 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.

acoustic impedance of blood = 1.64×10^{6} kg m^{-2} s^{-1}

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

(4)

(Total 12 marks)

Q5.

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

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table and is moved into the PET scanner. The scanner has many detectors positioned in a vertical circular pattern around the patient.

(a) State what is meant by a radioisotope.

(1)

(b) 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)

(c) 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)

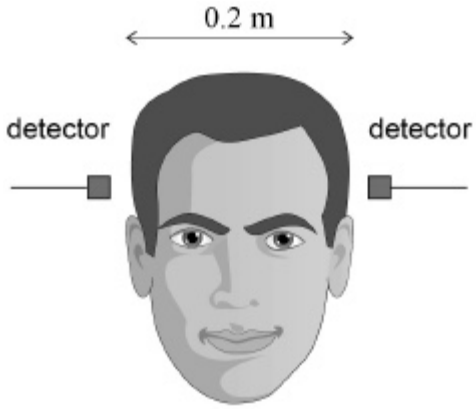
(d) The decay of the radionuclide results in the emission of a positron. Two of the detectors, directly opposite to each other, are triggered as they each receive a gamma photon.

Explain the process in which the gamma photons are created.

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(2)

(e) The diagram 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 the diagram, 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 3×10^8 m s^{-1}.

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_____

_____

_____

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_____

(2)
(Total 9 marks)

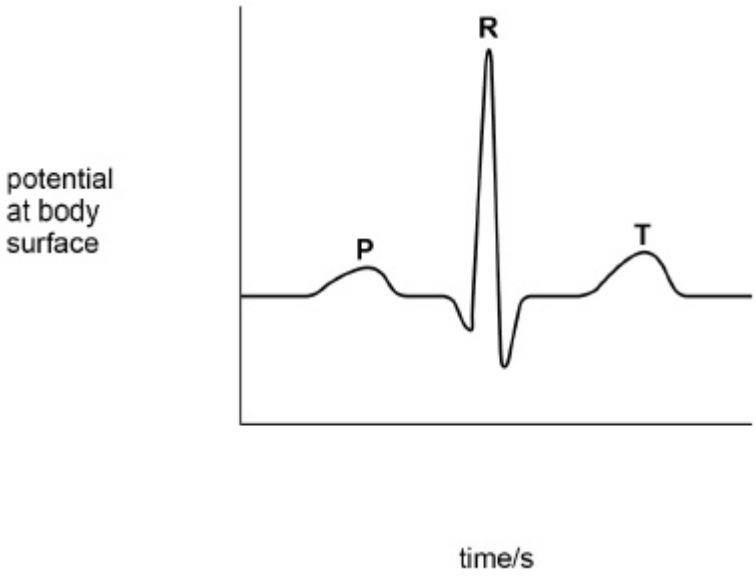
Q6.

(a) **Figure 1** shows an ECG trace for a healthy person.

Complete **Figure 1** by adding a suitable unit and scale to the potential axis, and a suitable scale to the time axis.

Figure 1

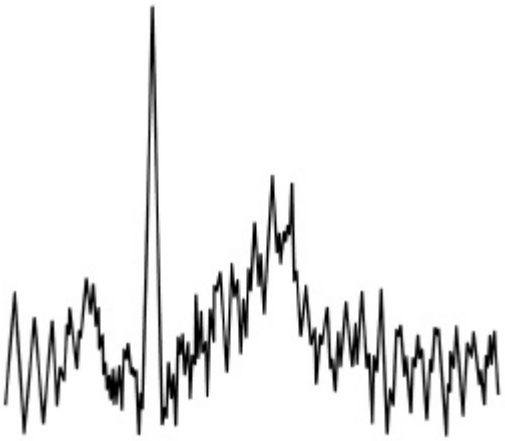
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(2)

(b) **Figure 2** shows a faulty ECG trace which was obtained for another healthy person.

Figure 2



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

(3)

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(Total 5 marks)

Q7.

(a) Discuss the design of the anode of a modern X−ray tube.

In your answer you should consider features that:

- limit the anode temperature reached when the tube is operating
- allow a sharp image to be produced.

(6)

(b) In an X−ray tube, electrons are accelerated from rest through a pd of 82.5 kV before
they reach the anode.

Calculate the kinetic energy of an electron as it reaches the anode.
Give your answer to an appropriate number of significant figures.

kinetic energy = _____ J

(2)

(c) An electron transfers 75 keV of energy to produce a single X−ray photon.

Calculate the wavelength of this photon.

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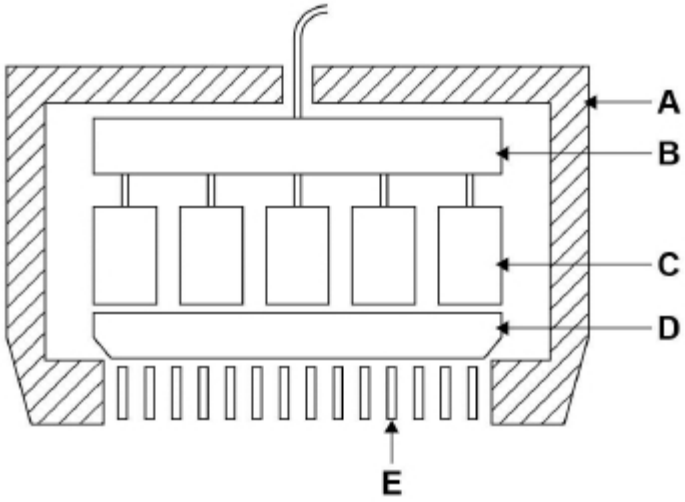
wavelength = _____ m

(3)

(Total 11 marks)

Q8.

(a) The diagram below shows the main components of a gamma camera.



Explain briefly the operation of the camera referring to the parts labelled A to E.

_____

_____

_____

_____

_____

_____

_____

_____

(4)

(b) Describe how the image obtained using the gamma camera differs from that obtained using diagnostic X−rays and why this difference can be an advantage in medical diagnosis.

_____

_____

_____

_____

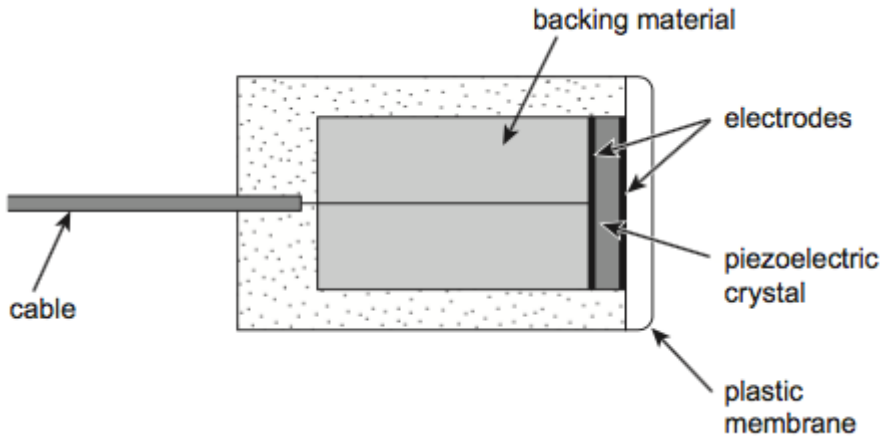
(2)

(Total 6 marks)

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Q11.

The diagram shows a cross-section through an ultrasound transducer.



(a) Explain how the transducer produces a pulse of ultrasound.

(3)

(b) Why does the ultrasound pulse produced need to be short?
Place a tick (✓) in the right-hand column to show the correct answer.

	✓ if correct
To reduce pulse spreading	
To stop the probe overheating	
To allow the probe to act as a receiver	

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To reduce damage to cells in the patient	

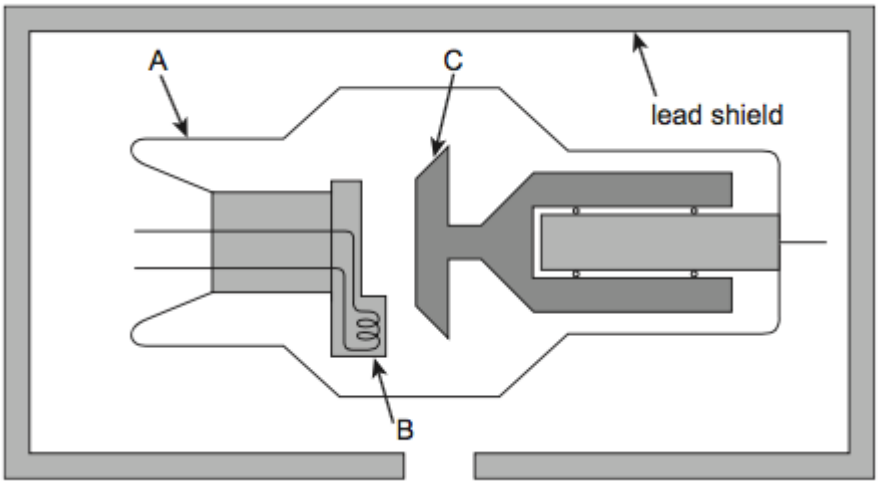
(1)

(c) A coupling gel is needed when performing an ultrasound scan.
Explain how and why a coupling gel is used.

(3)
(Total 7 marks)

Q12.

The diagram shows a simplified modern X-ray tube with a rotating anode.



(a) Explain the design and operation of the X-ray tube and the purposes of the components labelled on the diagram.

In your answer you should include:

- reference to the components labelled A, B, C and the lead shield
- an explanation of the physical processes by which X-rays are produced.

The quality of your written communication will be assessed in your answer.

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(6)

(b) The X-ray tube produces photons of energy 50 keV. The half-value thickness of bone for photons of this energy is 15 mm.

(i) Explain what is meant by half-value thickness.

(1)

(ii) Show that for 50 keV X-ray photons, the attenuation coefficient of bone μ is 0.046 mm^{-1}.

(1)

(iii) A beam of 50 keV X-ray photons is incident on a bone of thickness 12 mm. Calculate the percentage of the incident photons that leave the far side of the bone.

percentage of incident photons = _____ %

(2)

(Total 10 marks)

Q13.

An ECG trace is to be obtained for a healthy patient. Describe the procedure involved to

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ensure that a good trace is obtained. Your answer should include reference to:

- connections to the body
- how unwanted signals are avoided
- some properties of the amplifier used.

The quality of your written communication will be assessed in your answer.

(Total 6 marks)

Q14.

(a) An endoscope uses **coherent** and **non−coherent** fibre bundles.

(i) State the use of the **coherent** bundle and describe its arrangement of fibres.

(2)

(ii) State the use of the **non−coherent** bundle and describe its arrangement of fibres.

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(2)

(b) Each fibre has a core surrounded by cladding.
Calculate the critical angle at the core−cladding interface.

refractive index of core = 1.52
refractive index of cladding = 1.49

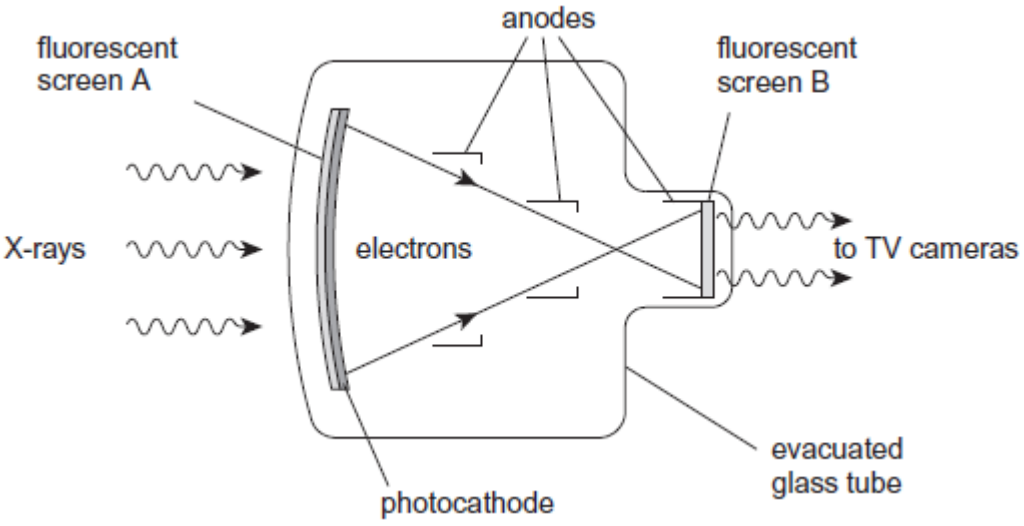
critical angle = _____ degree

(1)

(Total 5 marks)

Q15.

(a) The diagram below shows a fluoroscopic image intensifier.



State the purpose of each of the following components of the intensifier.

(i) fluorescent screen A,

_____

_____

(1)

(ii) photocathode,

_____

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_____

(1)

(iii) anodes,

_____

_____

_____

_____

(2)

(iv) fluorescent screen B.

_____

_____

(1)

(b) A patient is asked to swallow a suspension of barium sulfate before X−ray images are to be obtained. This is known as a barium meal technique.
Explain why the patient needs to swallow the barium sulfate.

_____

_____

_____

_____

_____

_____

(2)

(Total 7 marks)

Q16.

(a) When ultrasound is incident at an interface between two different media some energy is transmitted and some is reflected. The ratio of the reflected energy intensity I_r to the incident energy intensity I_i depends on the relative acoustic impedances of the two substances.

Acoustic impedance Z is a property of the substance and is given by $Z = \rho v$

where ρ is the density of the substance and v is the velocity of the ultrasound wave.
The ratio is given by

$$\frac{I_r}{I_i} = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2$$

Z_1 is the acoustic impedance of the substance into which the wave is reflected.
Z_2 is the acoustic impedance of the substance into which the wave is transmitted.

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The table below shows the density and velocity of waves in two different substances.

Substance	Density / kg m^{-3}	Velocity / m s^{-1}
1	1050	1540
2	925	1450

(i) Calculate the percentage of incident energy that is reflected when ultrasound is incident on a surface while travelling from substance 1 into substance 2.

percentage reflected _____ %

(3)

(ii) An ultrasound wave of frequency 2.00 MHz travels in substance 1.

Calculate the wavelength of the ultrasound in metres.

wavelength _____ m

(2)

(b) Describe how ultrasound is used to produce an image of different tissues within the body.

Your answer should include:
- an explanation of how the image is produced
- an explanation of how the differences in acoustic impedance of body tissues affect the quality of the image produced.

The quality of your written communication will be assessed in your answer.

_____

_____

_____

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(6)

(c) The resolution of an image is an important factor in the design of ultrasound equipment.

State what is meant by **resolution** and explain why the wavelength of the ultrasound determines the resolution of the image.

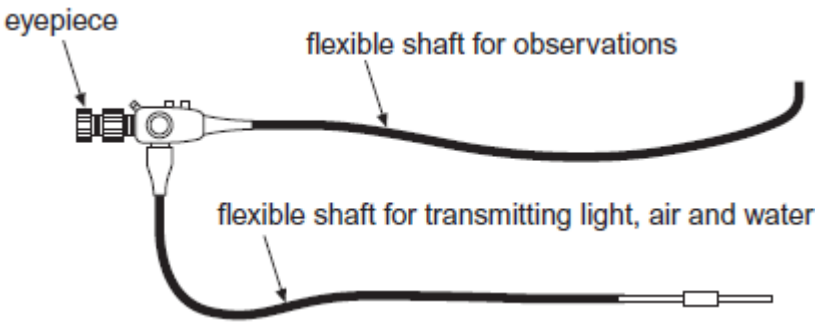
(2)

(Total 13 marks)

Q17.

Figure 1 shows an endoscope. Some of the optical fibres in the endoscope are arranged in coherent bundles and others are in incoherent bundles. The eyepiece of the endoscope may be replaced with a digital camera.

Figure 1



(a) Explain the difference between **coherent bundles** and **incoherent bundles** of optical fibres and explain which are appropriate for the different parts of the endoscope.

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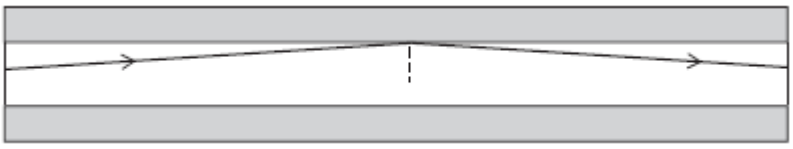
(3)

(b) Explain how a digital camera can store the image produced by the endoscope.

(3)

(c) **Figure 2** shows a ray of light travelling through an individual fibre consisting of cladding and a core. One part has a refractive index of 1.485 and the other has a refractive index of 1.511.

Figure 2



(i) State which part of the fibre has the higher refractive index **and** explain why.

(1)

(ii) Calculate the critical angle for this fibre.

critical angle _____ degrees

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(1)

(iii) The endoscope image quality may be reduced by crosstalk.

Explain what is meant by **crosstalk** and how it limits the usefulness of the endoscope.

_____

_____

_____

_____

(2)
(Total 10 marks)

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