Biological measurement and imaging

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 ____

____

____

____

____

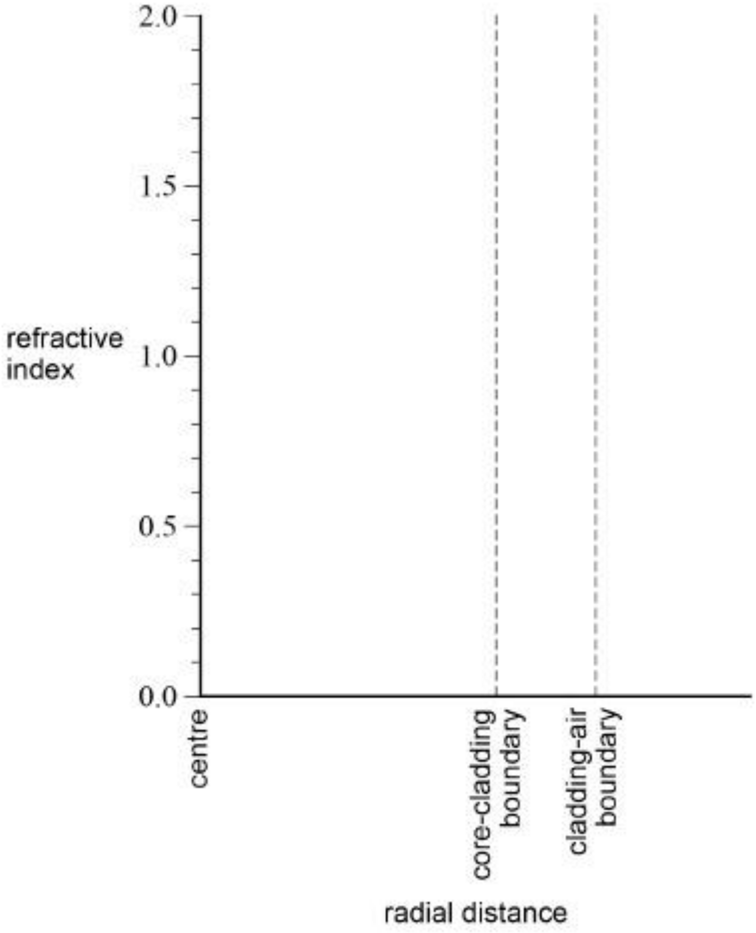
(4)

(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



(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.

____

____

____

____

____

____

(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.	☐

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.

___

___

___

___

___

___

___

___

___

(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.

(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 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.

____

____

____

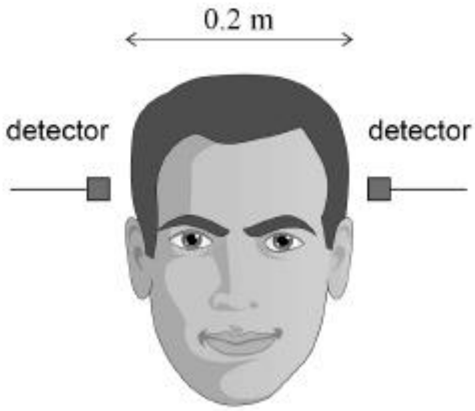
____

____

____

(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}.

____

____

____

____

____

____

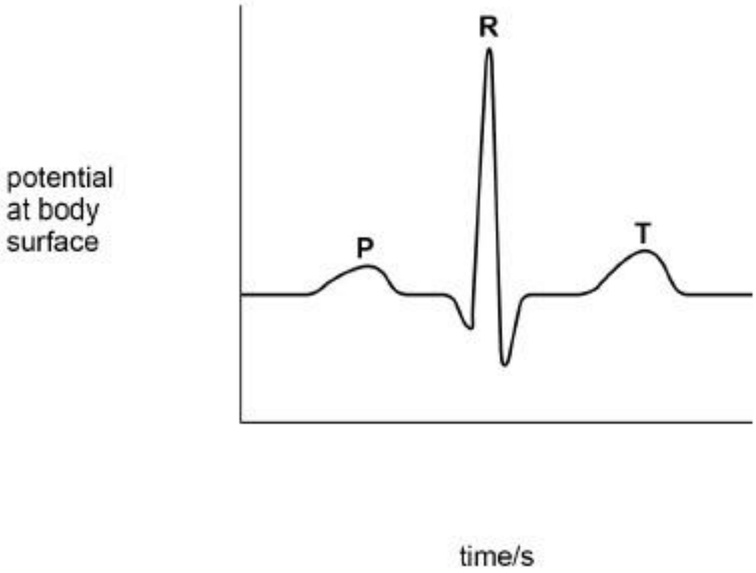
(2)
(Total 9 marks)

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.

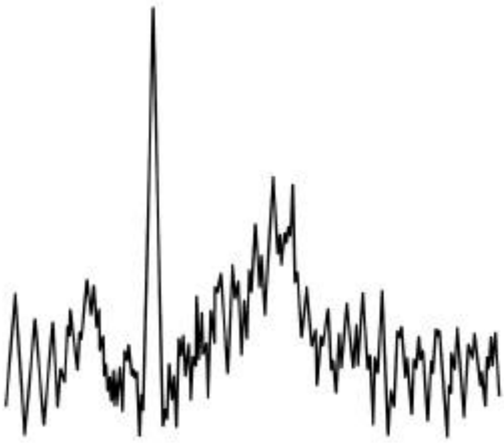
Figure 1



(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)

(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.

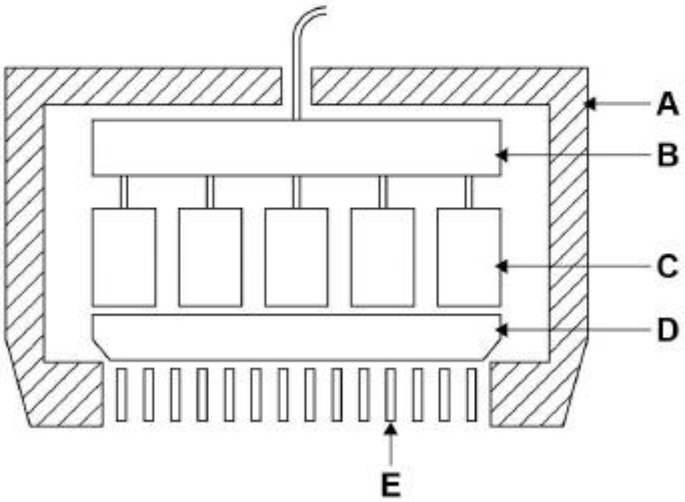
wavelength = __________ m

(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.

____

____

____

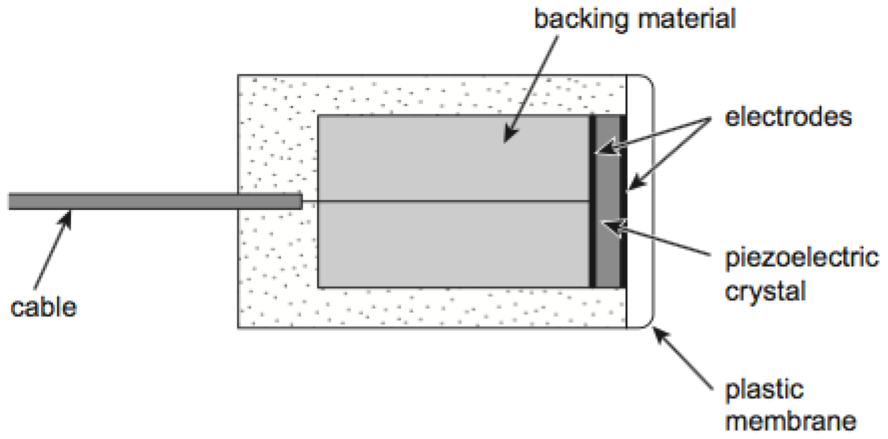
____

(2)

(Total 6 marks)

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	
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.

___

___

___

___

___

___

___

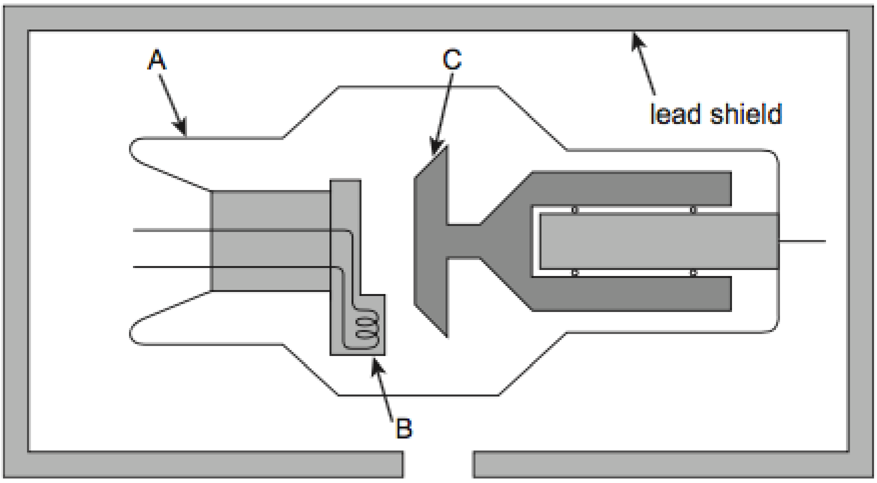
___

___

(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.

___

___

(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 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.

(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

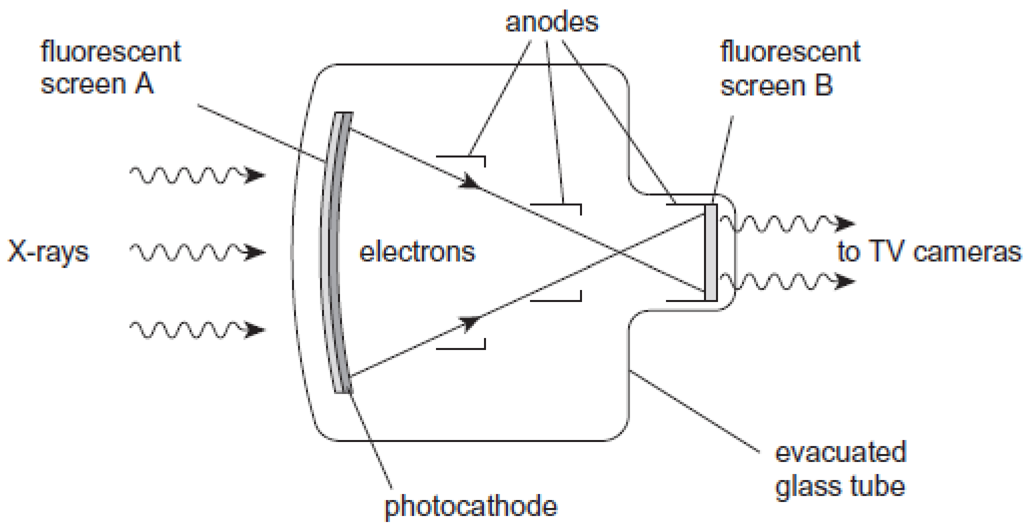
critical angle = ____________________ degree

(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,

____

____

(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.

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

Substance	**Density / kg**	**Velocity / m s^{-1}**

	m^{-3}	
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.

____

____

____

____

____

(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.

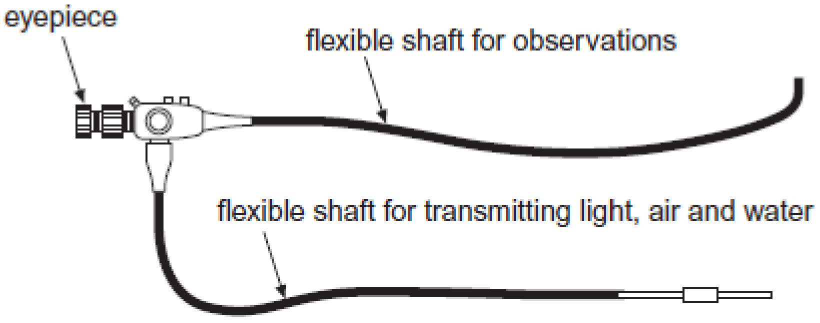
(2)

(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.

(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

(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)

Mark schemes

Q1.

(a) Coherent bundle – fixed arrangement of fibres at each end ✓

Used to transmit image (from inside the body to the viewer) ✓

Non-coherent bundle – random arrangement of fibres ✓

Used to transmit light into the body / to illuminate (area under investigation) ✓

Name of bundle plus either point for first mark.

If no marks awarded, give 1 mark if both bundles have been named.

4

(b) Core at 1.6; cladding 1.55 ie half way between their core and 1.5 ✓

Series of clear horizontal steps with air at 1.0 ✓

Although they are told to do a calculation, give the mark on the diagram for 1.55 even if no calc shown.

If no marks awarded for drawing, then give 1 mark for correct calculation.

2

[6]

Q2.

Points to consider:

For the basic principles of the CT scan

- Patient lies in centre of ring
- X-ray tube is mounted on one side of the ring with array of detectors mounted on the other side of the ring opposite the X-ray tube.
- Narrow beam of X-rays in a short pulse sent through the head 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 and pulses of X-rays are sent through the patient's head from different directions.
- The signals from the detectors are then added together and a 2D image of that slice of the head is produced by the computer.

For advantages of CT for head injuries

- Better defined image of tissue boundaries inside skull
- Possible to identify bleeding inside skull

For simple X-rays

- Cheaper and easier for patient
- Allows simple fractures to be identified
- Less harmful as patient dose is less than that of CT scan

6 marks will clearly explain the basic principles of the CT scan. They will explain using this scan to assess head injuries. They will give good reasons for the use of basic X-rays in certain situations.

5 marks will clearly explain some of the basic principles of *the CT scan. They will give some explanation for using this scan to assess head injuries. They will give good reasons for the use of basic X-rays in certain situations.*

4 marks will explain some of the basic principles of the CT scan. They will give some explanation for using this scan to assess head injuries. They will give some explanation for the use of basic X-rays in certain situations.

3 marks will address at least two of the bullet points

2 marks will address at least one of the bullet points

1 mark will have any sensible comment

0 marks has no relevant Physics.

[6]

Q3.

(a) There will be many answers possible and examiners must use their professional judgement. These answers may include:

- Using scan before treatment to locate the precise position / size of the tumour
- Using X-rays of the correct energy for the depth/size of the tumour
- Using a computer to position X-ray relative to patient / target the tumour
- Minimising time of use
- Irradiating tumour from different directions
- Less damage caused to healthy cells

✓ ✓ ✓ for three relevant answers

3

(b) The thickness of material needed to reduce the intensity of the X-ray beam by half ✓

1

(c) $\mu = \ln 2$ / half thickness ✓

$\mu = 165$ ✓

$\mu_m = \mu / \rho = 1.5 \times 10^{-2}$ ✓ unit $m^2\ kg^{-1}$ ✓

Unit mark is independent of the numerical answer or indeed a lack of any numerical working.

3rd mark is ecf.

4

[8]

Q4.

(a) Points to consider:

The risk comes as X-rays are ionising radiation: the photons could ionise cells causing mutations / cancer.

Use of lead diaphragm plates to define beam so that only the area to be investigated is exposed to the X-rays – limits exposure to ionising photons.

Use of aluminium filter in path of beam to remove a large percentage of the low energy photons which are not needed for the image to be produced – reduces ionising photons which could be absorbed by the body.

(Anode voltage) selected to produce best energy photons for imaging – limits the photons required to produce a suitable image.

When using film, use of intensifying screens – give exposure in shorter time limits exposure.

Use of grid between the patient and image receptor to stop scattered X-rays blurring the image – thus stopping the need for further X-ray and further exposure.

6 marks will clearly explain the risk involved. They will then mention three ways of minimising the exposure and discuss these.

5 marks will clearly explain the risk involved. They will then mention three ways of minimising the exposure and discuss 2 of these.

4 marks will mention the risk involved. They will mention at least two ways of minimising the exposure and may discuss both or discuss one of these together with explaining the risk involved.

3 marks will mention the risk involved. They will mention at least two ways of minimising the exposure and may discuss one of these or explain the risk involved

2 marks will mention the risk and may state one way of limiting exposure or state and discuss either.

1 mark will have any sensible comment.

0 marks has no relevant Physics.

6

(b) Ultrasound is non-ionising / has no known adverse effects ✓

Ultrasound can be used for better definition image between tissue and blood ✓

Allow credit for converse arguments re. not X-rays

2

(c) correct sub of numbers in the equation

$$6.25 \times 10^{-4} = \left(\frac{Z - 1.64 \times 10^6}{Z + 1.64 \times 10^6} \right)^2$$ ✓

As Z decreases, the negative root is needed

$$-2.5 \times 10^{-2} = \left(\frac{Z - 1.64 \times 10^6}{Z + 1.64 \times 10^6} \right)$$ ✓

rearrange equation

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

correct answer

1.56×10^6 (kg m^{-2} s^{-1}) ✓

Candidates who ignore the negative root can get three marks max for arranging the equation correctly and getting 1.72 by using the positive root.

Basic rule -1 for each error.

Last two marks for working can be given for wrong values above that point.

4

[12]

Q5.

(a) Material with nuclei which are unstable / will decay / emits ionising / radiation. ✓

At least two of the descriptors

1

(b) Calc with answer showing T_E = 68.98 or 69 ✓

$$\frac{1}{T_E} = \frac{1}{110} + \frac{1}{185}$$

1

(c) Mention of time between 10 to 70 minutes with reference to effective half life / time for a scan ✓

and to allow the **blood** to carry the isotope around the body ✓

and to allow the isotope to be taken in by the body part to be investigated ✓

3

(d) Positron (collides with an) electron and results in annihilation ✓

All the mass of positron and electron is converted to energy in gamma photons ✓

Must be two photons travelling in opposite directions to conserve momentum ✓

MAX 2

(e) Use of 0.18 to 0.2 m and 3×10^8 m/s for speed of em waves through the head to get a time between 0.6 and 0.7×10^{-9} s for time to travel across head ✓

then explanation of difference in trig times from a minimum of 0 s at centre of head to a maximum of their calculated answer at edge of head. ✓

2

[9]

Q6.

(a) potential axis: unit mV and suitable labelling of 0 and 1 for scale ✓

time axis suitable use of numbers from 0 to 0.6 / 1 ✓

2

(b) Possible answers to include:

electrodes are not non-reactive ✓

electrodes are not securely taped in place ✓

the patient is not relaxed or does not remain still ✓

the amplifier is not low noise ✓

the amplifier has damaged shielded leads / interference from other AC sources ✓

Any 3 points with reason and some extension to explain.
Be aware of the section 3.1 in the instructions to examiners.
If more than 3 answers given remember
'right + wrong = wrong'

3

[5]

Q7.

(a) **The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of *the Mark Scheme Instructions* document should be used to assist marking this question.**

L3 5-6 marks	Both bullet points of the question are addressed in good detail. The answer includes at least 8 answer points from the list below.	The student presents relevant information coherently, employing structure, style and sp&g to render meaning clear. The text is legible.
L2 3-4 marks	The answer includes some discussion of both bullet points. The answer includes at least 5-7 answer points from the list below.	The student presents relevant information and in a way which assists the communication of meaning. The text is legible. Sp&g are sufficiently accurate not to obscure meaning.
L1 1-2 marks	The answer addresses one bullet point in some detail but the other may be neglected. There may be consideration of up to 4 answer points from the list below.	The student presents some relevant information in a simple form. The text is usually legible. Sp&g allow meaning to be derived although errors are sometimes obstructive.

0 marks	Little or no discussion of relevant content.	The student's presentation, spelling, punctuation and grammar seriously obstruct understanding.

The following statements could be present

Reference to temperature:

- *anode rotates*
- *spread heat load*
- *allows higher intensity*
- *allows longer use of tube*
- *larger mass*
- *mean temperature less for given heat energy transfer*
- *cooling arrangements provided*
- *good conductor*
- *high specific heat capacity.*

Reference to sharpness:

- *angled anode*
- *produces larger focal target area*
- *reduction of effective area of focal spot for x-ray emission.*

6

(b) ke = $1.6 \times 10^{-19} \times 82.5 \times 10^{3} = 1.32 \times 10^{-14}$ J ✓

Independent mark for 3 sig figs ✓

2

(c) energy = $1.6 \times 10^{-19} \times 75 \times 10^{3}$ ✓

$$\lambda = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{1.6 \times 10^{-19} \times 75 \times 10^{3}}$$ ✓

$\lambda = 1.7 \times 10^{-11}$ m ✓

3

[11]

Q8.

(a) Gamma photon travels through collimator grid, E, ensuring that the point of emission of the gamma photon is directly below the point where the photon interacts with the scintillation crystal, D. ✓

Gamma photon is converted to many light photons in scintillation event in crystal. ✓

The light photons produced travel to photomultiplier tubes, C, where signal is produced and amplified. ✓

The amplified signals are passed to processing unit, B, which compares the strengths of the signals, deduces the position of the scintillation and displays this on a screen. ✓

The lead shield, A, protects the crystal and photomultipliers from random background signals. ✓

Any 4 relevant points.

Allow marks to be awarded for clear labelled diagram.

MAX 4

(b) Image in diagnostic X-ray is a shadow photograph. ✓

Image produced by gamma camera is image of actual emission points which can be used to monitor rapidly changing situations. ✓

2

[6]

Q11.

(a) Alternating pd applied across the electrodes / crystal
Causes crystal to expand and contract
Produces (ultrasonic) vibrations at front of membrane
Backing material damps vibration of the crystal when pd is removed

Max 3

Any reverse argument converting ultrasound to signal gains zero

3

(b) To allow probe to act as a receiver

Auto marked

1

(c) Needed between probe and skin
If air present, large difference in acoustic impedance so little transmitted / Gel excludes air and has acoustic impedance close to that of skin
Gel maximises transmission

Use of minimising / maximising pulses / waves penalises 1 mark from last 2 marks

Accept minimises reflection

1
1
1

[7]

Q12.

(a) Points to be considered:
A – glass envelope. This is needed to allow low pressure within the tube
B – heated cathode. Heated to provide thermionic emission of electrons from the surface
C – anode. Used to accelerate electrons across the gap between cathode and anode.
lead shielding - Prevents much of the emission in unwanted directions.
The anode rotates to allow heat to be dissipated over greater area and thus allows longer use without over-heating. The anode is bevelled to allow a larger 'target' area for the electrons, whilst also producing a smaller 'source' area for the photons in the required direction.
Low pressure is required in the tube to allow the electrons to be accelerated across the gap without colliding with gas atoms and losing energy in the collision.
Electrons colliding with anode material excite / ionise the atoms and as the atoms de-excite X-ray photons of specific energies are produced.

Electrons can also be decelerated as they pass through the anode. The energy of the X-ray photon is equal to the energy lost by the decelerated electron. This can be any value from the max energy of the electron to zero. This produces a continuous background spectrum of X-ray photon energies.
Good candidates will name and state the use of the labelled components and will expand on a property of the anode and suggest why some X-rays are produced.
Middle candidates will name and state the use of 3 or all of the labelled components. They may try to expand on the anode properties or the method of X-ray production.
Poor candidates may be able to name some labelled components, but will fail to apply the ideas.

6

(b) (i) Thickness of material needed to reduce (beam) intensity by half

Accept (beam) power NOT energy

1

(ii) ln2 / 15 = 0.046

Use of 50 and 25 is EOP

1

(iii) $\% \, I^T / I_0 = e^{-(0.046 \times 12)} \times 100$
= 58 %

If 0.0462 is used, the answer 57.4 or 57 is correct

1
1

[10]

Q13.

High Level (Good to excellent): 5 or 6 marks
The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.
The student accurately describes measures to ensure good contact between the electrodes and the skin including the use of conducting gel. The student will mention the need for more than one electrode and the need for the patient to remain relaxed and still. They will need at least two properties of the amplifier.

Intermediate Level (Modest to adequate): 3 or 4 marks
The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate. The student will include most measures to ensure good contact between electrodes and the skin. They should give a property of the amplifier and may mention the need for the patient to remain relaxed and still.

Low Level (Poor to limited): 1 or 2 marks
The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate. The student will mention electrodes connected to the skin and might make some other sensible comments on the arrangement.

Points which might be considered include:

Attach more than one electrode

To reduce contact resistance

- *sandpaper skin to remove hairs and some dead* *skin*

- *apply conducting gel between electrode and skin*
- *securely attach electrode and stick / tape in place*

To remove unwanted signals

- *electrodes should be non-reactive*
- *patient to remain relaxed and still*
- *shielded leads / reducing interference from ac sources*

Properties of amplifier

- *large input impedance*
- *high gain*
- *low noise or differential amp*

[6]

Q14.

(a) (i) Coherent − used to transfer / transmit image (out of body) 1

Coherent − same fibre arrangements **at both ends of bundle**

Allow same relative position

Do not allow symmetrical

1

(ii) Non-coherent − used to transfer light into body (to illuminate) 1

Non-coherent − random fibre arrangement along bundle

Do not allow not symmetrical

1

(b) $\sin \theta_c = 1.49 / 1.52$

$\theta_c = 79$ (degree)

1

[5]

Q15.

(a) (i) Fluorescent screen A − converts X-ray (photon) to light (photons) / lower energy photon(s)

1

(ii) Photocathode − uses (energy of) each light photon to release an electron from surface of cathode

Do not allow converts light / photon into electron

1

(iii) Anodes − accelerate (released) electrons

focuses electron beams

Mention of negative anode disqualifies first mark awarded

Do not accept direct towards the screen as focussing

2

(iv) Fluorescent screen B − converts energy of electron(s) into (many) light (photons)

Do not allow converts electrons into light / photons

1

(b) Without Barium poor contrast between area to be investigated and surrounding tissue

This will get first mark

1

Barium meal proves high proton number / high density / high attenuation material at site to be investigated which provides much better contrast

This will gain the second mark

1

Barium meal proves high proton number / high density / high attenuation material at site to be investigated which provides much better contrast between area to be investigated and surrounding tissue

But this will get both marks

[7]

Q16.

(a) (i) Z values calculated correctly 1.617×10^6 and 1.341×10^6

Allow substitutions in equation

C1

Substitute their values in formula for I_r / I_i

C1

0.87%

A1

3

(ii) Uses $v=f\lambda$ in any form condone incorrect power of 10

C1

7.7×10^{-4} (m)

A1

2

(b) The marking scheme for this question includes an overall assessment for the quality of written communication (QWC). There are no discrete marks for the assessment of QWC but the candidate's QWC in this answer will be one of the criteria used to assign a level and award the marks for this question.

Descriptor − an answer will be expected to meet most of the criteria in the level descriptor.

Level 3 − good:

claims supported by an appropriate range of evidence

good use of information or ideas about physics, going beyond those given in the question

argument well structured with minimal repetition or irrelevant points

accurate and clear expression of ideas with only minor errors of grammar,

punctuation and spelling.
Level 2 − modest:
claims partly supported by evidence
good use of information or ideas about physics given in the question but limited beyond this
the argument shows some attempt at structure
the ideas are expressed with reasonable clarity but with a few errors of grammar, punctuation and spelling.
Level 1 − limited:
valid points but not clearly linked to an argument structure
limited use of information about physics
unstructured
errors in spelling, punctuation and grammar or lack of fluency.
Level 0:
incorrect, inappropriate or no response.

5 / 6 Expect a coherent account incorporating at least 4 from each section
3 / 4 Account may cover the first part well and give a more superficial account of the second giving one or two points. Or two or three points from each section.The structure may not make it easy to follow
1 / 2 Provides superficial response for one of the topics and may be brief and poorly expressed

5−6 *Answer addresses both bullets. The first should be very clear and have no significant omissions. The second may be less well done but the effect of different acoustic impedances at the boundaries should be there should be covered clearly*

3−4 *Both aspects are likely to be addressed but there will be less coherence in the response and significant points may be omitted*

1−2 *There is likely to be a superficial qualitative response probably more inclined toward the first bullet point*

Examples of creditworthy statements*:*

1 Transducer swept across surface of skin

2 Emits pulsed ultrasound signal

3 Reflected at boundaries where acoustic impedance changes

4 Time for pulse to return is measured

5 Depth of boundary calculated / position of boundary is plotted

6 Equation relating to establishing depth

1 Acoustic impedance is resistance to passage of sound through the medium

2 Causes attenuation of ultrasound

3 Causes reflection of sound at a boundary

4 Is needed in order to produce image

5 Reduced by use of gel on skin

6

(c) Ability to distinguish between objects that are close together.
Smallest angle that objects can subtend the observer and be seen as separate
OWTTE

Not clarity or number of pixels

B1

Idea that the smallest structure visible on image is comparable with wavelength
Mention of diffraction

B1
2L

[13]

Q17.

(a) Idea that fibres in a coherent bundle maintain the same relative position to each other

B1

In incoherent bundles the fibres may be in different / random positions (at each end)

B1

Coherent bundle needs to be used for the observation image. Incoherent bundle may be used for the light transmission

B1
3

(b) Mentions charge coupled device / CCD

B1

Capacitor / photosite / photodiode charges / stores charge as light falls on it

B1

(Photons arriving cause) electrons to be excited / emitted

B1

Charge depends on light intensity

B1

Lots of photosites / concept of pixels

B1

ANY 3

Max 3

(c) (i) Core

M0

So that total internal reflection can occur

A1
1

(ii) 79(.4)(°)

B1
1

(iii) Ray leaving one fibre and entering adjacent fibre

B1

Reduces resolution / image will be blurred / less clear /
limits angle through which fibre may be bent

B1
2

[10]

Q1.

Part (a) was descriptive. Although the vast majority of students were able to name the two fibre bundles correctly, few were able then to explain their use well enough to gain full marks (16.2% gained all four available marks). The question required the students to name the bundle and link the fibre arrangement to the use of the bundle. Answers for the use of the coherent bundle such as “used to obtain an image”, “to form an image”, “see inside the body” and “it can image the inside of the body” were not awarded a mark. In a similar way, the answer for the use of the non-coherent bundle “used to transmit light” was not awarded a mark as both bundles transmit light.

Part (b) required a simple drawing showing how the refractive index varied from the core into air. It was a requirement to do a calculation to work out the refractive index of the cladding – good students did this well. When the calculation was not shown, the marks could still be awarded for accurately drawn lines on the diagram. All types of lines were seen from curves to slopes, but better students were able to draw the series of steps as required.

Q2.

This question required the students to discuss the basic principles of a CT scanner, to explain why a CT scan was advantageous for assessing head injuries and to explain why a simple X-ray procedure was more suitable for assessing other injuries. Their answers highlighted the lack of clarity in many students’ written work. Many failed to address the advantages of the CT scan for assessing head injuries and thus limited the mark available. A noticeable number seemed to have little or no idea of what a CT scan is and either wrote about an MR scan, or about injecting radioisotopes and detecting the emitted radiation using gamma cameras. The mean mark on this question was 2.55 out of 6, with only 1.1% of students scoring all six marks available.

Q3.

Part (a) required students to discuss why initial scans are important in deciding the best treatment of a patient with a tumour. This was a very open question, with many relevant points being allowed to gain credit. Over half of students did score all three marks, however many students were unable to write clear statements, often writing two opposite statements which cancelled each other.

Part (b) was a simple multiple choice question on the meaning of half-value thickness which the majority of students (76.2%) answered correctly.

Many students were able to do the calculation in part (c) (59.4% gained at least three marks). However, only a small number of students were able to state the correct unit for the mass attenuation coefficient.

Q4.

This question was on the dangers of X-rays and the use of ultrasound.

Part (a) was an open text response part which considered the danger of X-rays and how the danger was managed for a simple X-ray of a suspected broken arm. Most students were aware of the danger and were able to explain the possible result of cell damage and the formation of cancerous tumours. However, the discussion of three methods for limiting the danger often lacked relevance and explanation.

Irrelevant answers often seen included use of fluoroscopic imaging with a barium meal, and details of the rotating anode which allowed the anode to emit X-rays in only one direction. There were many who stated that the patient needed to be covered by lead sheets. Where students had an understanding of the situation, some good answers were seen, but these were few in number.

Part (b) asked students to explain whether X-rays or ultrasound would be best to investigate a suspected fault in the aorta as it passed through the abdomen. Some students failed to read the question and wrote about imaging the heart, stating that ultrasound could not be used as it would have to pass through the ribs. When students were discussing the correct situation, many failed to gain the mark for stating that ultrasound gave better definition between different tissues and blood. Having pointed to the dangers of X-rays in the first part of the question, it was noticeable that many students failed to state that another reason for using ultrasound was the fact that it produced no known adverse effects on the patient.

The last part, (c), was a calculation of acoustic impedance. The information given in the question required the student to use the negative value of a square-root in order to complete the calculation. This was rarely seen. Students who used the positive root and then completed the calculation correctly were given 3 out of the 4 marks available. Other errors were seen, examples of which were not converting the percentage to the correct number, not rooting the value and calculating the wrong acoustic impedance, Z_1 rather than Z_2.

Q5.

This question was on a new part of the specification, PET scans.

In part (a), a common answer was ‘a radioactive isotope’, which gave no additional information and could not be given the mark.

Part (b) was well answered by many students. A common incorrect response was the complete line which started with $\frac{1}{T}$, and then continued with a series of equal signs to 68.9 with no indication that this was in fact T.

Part (c) asked for some discussion as to the suitable time the patient may be left to relax. As the question stated that the isotope was injected into the blood, credit was focused on clear reference to the isotope being carried around the body in the blood stream.

Very few students suggested that time may then be needed for the part of the body being investigated to take in the isotope. The most commonly awarded mark was for some sensible link between the time to relax and the effective half-life. This question revealed some fairly common misconceptions about the term *half-life*.

Many stated or implied that a scan could not be performed after one half-life had passed, whilst others suggested that no decay would occur until this point. Some students used technetium-99 as the isotope, quoting a half-life of 6 hours, when they were told previously that the half-life of the isotope being used was 110 minutes.

Part (d) on the process on annihilation was well answered with many students getting both marks.

Part (e) on the time delay between photon detection provided many good answers. The maximum delay was worked out as 6.7×10^{-10}s by most students, but some students were not able to suggest that the minimum time delay was in fact 0 for gamma photons produced in the centre of the head.

Q6.

This question was based on ECG traces.

Part (a) proved difficult. The labelling of the potential axis caused most problems with many students failing to put the 0 for the scale in the correct place. However, the scale on the time axis also caused problems. A common mistake was to place a number at the end of an axis without another number on the axis to provide a point of reference. For example, the sole number 0.8 at the right of the time axis did not gain credit.

Part (b) required students to look at the noise on the trace and suggest reasons for that noise. Answers such as “the skin had not been cleaned”, or “dead skin and hair had not been removed”, were treated as neutral answers, but with the inclusion of “resulting in the electrodes not being securely connected” the correct point was made and a mark awarded. Another answer which was felt to be too vague for the award of a mark was “the electrodes weren’t properly attached”.

Q11.

(a) Similar questions have been asked many times before, but the students still fail to produce clearly worded answers. The main errors included; stating a voltage is applied rather than an alternating voltage; current is applied to the electrodes; the crystal expands and relaxes rather than expands and contracts; failure to explain that pd is removed and backing material stops oscillation of the crystal to provide short pulse.

(b) Over 85% of students chose the correct response on this question.

(c) Many students scored 1 or 2 marks on this question, but few gained 3 marks. Answers which suggested that more or fewer waves or pulses were able to enter the patient rather than talking about the intensity of the pulse were penalised 1 mark. Another common error was suggesting that the gel reduced the difference in acoustic impedance between the air and skin, suggesting that air was still present.

Q12.

(a) The long descriptive question was on the basic working of an X-ray tube. Students were expected to name the evacuated glass tube, the heated cathode and the rotating anode. They were then expected to explain the basic use of these components and the labelled lead shield as well as how X-rays were produced. The average mark for the question was higher than in previous years showing that the students were able to give some basic ideas, but many students failed to gain the higher marks due to poor wording of answers. Common weaker answers included; the high energy of the electrons coming from the heating of the cathode; confusion between where the electrons were and where the X-rays were; the labelled component A was an aluminium filter.

(b) (i) Weaker answers were common where the students stated that the photons or X-rays lost half of their energy.

(ii) Many students were able to show how to gain the value given for the attenuation coefficient. If, however, students suggested that the 50keV reduced to 25 keV, this was regarded as an error of physics and a mark of zero was awarded.

(iii) Many students found this a straight forward question. In order that students were not penalised twice, the use of the 50 keV as part of the calculation was allowed which meant that more of the students were able to gain both marks for this part.

Q13.

This QWC question was on the procedure involved in obtaining an ECG trace. The answers to this question were slightly better than answers to previous QWC questions. The more able students seemed to use the bullet points to order their answers and thus gained good marks. There were a noticeable number of answers which suggested that the gel between the electrode and the skin should have an acoustic impedance similar to that of skin, as would be needed for an ultra-sound scan! The section which was most poorly explained was that on 'how unwanted signals are avoided'. The special rooms described by some were fiction at its best along with the lead boxes which were placed over all mains equipment. The picture of a patient lying on a bed to remain still and calm, but with his leg hanging over the edge of the bed to ensure it touched the ground, was one described by several students. When talking about the amplifier, several vague answers which failed to give a clear understanding of what was needed included 'it needs to amplify the signal' and 'it needs to sort out noise'.

Q14.

This question on the fibre bundles used in an endoscope produced many good answers.

(a) (i) Whether some students had learnt their answers in a particular order might give a clue as to why several described the non-coherent answer here and the coherent answer in (a)(ii). Credit could not be given for this. From the students who tried to talk about the coherent bundle, some said that the bundle had the same relative position at both ends rather than referring to the fibres within the bundle while others suggested that the coherent bundle forms the image, both of which failed to gain marks.

(ii) When talking about the non-coherent bundle, a noticeable number of students gave the bald answer 'it is used to carry light⅂ which failed to gain the mark as coherent bundles also carry light. Some students lost the mark by adding to their answer such as 'used to take light into the body for illumination and also water for washing out the area⅂.

(b) This proved to be the easiest mark on the paper as was expected. Nearly all the students who got it wrong, gave the answer 1.3 having failed to realise that their calculator was set to radian.

Q15.

This was a question which tested the students' understanding of the workings of the image intensifier. It was obvious that some students had no real knowledge of the parts involved, with X-rays present at all stages. In all stages, many marks were lost due to answers which lacked an important detail.

(a) (i) The answer required for the purpose of the fluorescent screen, A, needed an indication that the X-ray hits the screen and light leaves the screen. Answers which referred to 'X-rays hitting and photons leaving' failed to get the mark as the important missing fact was 'light' photons leaving.

(ii) The answer required for the photocathode needed an indication that photons incident on the surface released electrons from the surface. Many students lost this mark for stating that ‘photons are changed / turned into electrons’.

(iii) The answers required for the anodes were to accelerate the electrons and to focus the electron beams. The mark for the first part of the answer was gained by the majority of students who talked of the electrons being accelerated / gaining speed / gaining kinetic energy, but the answer given by some of ‘the electron gains energy’ was not given the mark as it was missing ‘kinetic’. The second mark was lost by the majority of students who talked about the electrons being deflected rather than the beams being focused.

(iv) The answer required for the fluorescent screen, B, needed a clear statement that the **energy** of the electrons was used to produce light photons emitted from the screen. The majority of students failed to gain the mark by simply stating ‘electrons are converted to light’. Some students lost this mark by suggesting that the electrons energy was converted into a new X-ray photon.

(b) This answer, as with previous answers, required the explanation of what was happening to gain the marks. Too often students were unable to clearly state why the barium sulfate was needed and why it produced the required change in image contrast. Vague answers included ‘to allow problems with the digestive system to be seen’ and ‘to see if the barium sulfate gets stuck in the body’. A number of students thought that the barium sulfate was a tracer emitting gamma radiation. The final mistaken answer must be a one answer fits all, ‘it shows up well in the digestive system as it has a large difference in acoustic impedance to its surroundings’.

Q16.

(a) (i) Well done, but some failed to square.

(ii) Most answered correctly.

(b) Many good accounts of how the image is produced were seen and some excellent accounts of the importance of acoustic impedance were offered. However, to gain high marks, **both** bullet points need to be addressed in some detail, and this was not often seen.

(c) Vague statements about the clarity of the image were not accepted for the meaning of resolution, but most candidates were aware of the importance of wavelength.

Q17.

(a) Most answer were clearly expressed and gained full marks.

(b) Again this was well understood by most candidates.

(c) (i) Most candidates gave cladding as the medium with the higher index.

(ii) Almost universally correct.

(iii) Generally good knowledge of this, but more than “reduced quality” of image was expected.