

Mark schemes

1

- (a) A glass tube **(1)**
(sealed), evacuated, allows electrons to travel unimpeded **(1)**
- B rotating anode [or target] **(1)**
rotation of anode [or target] to spread heated area **(1)**
target which emits X-rays when hit by (energetic) electrons **(1)**
- C filament [or cathode] **(1)**
heat source to release electrons from surface of cathode by thermionic emission **(1)**
- D lead housing **(1)**
prevent X-rays from escaping in unwanted directions **(1)**
- (b) path of electrons shown from filament (C) to anode (B) **(1)**
path of X-rays shown starting at anode (B)
and emerging through window in lead housing (D) **(1)**

max 8

2
[10]

2

- (a) specific to anode element/target atoms/material **(1)**
energy level transition **(1)**
- (b) new curve to show:
entire curve has more intensity **(1)**
stops at 90 kV **(1)**
spikes in same position **(1)**
- (c) % into heat = $(100 - 0.70) = 99.3$ **(1)**

2

3

$$\text{rate of heat produced} = \frac{99.3}{100} \times 80 \times 10^3 \times 120 \times 10^{-3} \text{ (1)}$$

$$= 9.5 \text{ kW (1) (9.53 kW)}$$

3

[8]

3

- (a) electrons strike anode and ionise/excite the target **atoms** ✓
excited/higher electrons fall to **inner** energy level ✓
fixed energy gaps produce fixed energy photons ✓

3

- (b) convert X-ray (photons) to light (photons) ✓✓

light photons expose film in correct place due to closeness of the screens to the film ✓✓

reduces radiation dose to the patient/the exposure time is shorter ✓✓

3

[6]

4

- (a) (i) $1.60 \times 10^{-19} \times 72.5 \times 10^3 = 1.16 \times 10^{-14} \text{ (J)}$

Sig Fig mark for 3sf

2

- (ii) $\lambda = (6.63 \times 10^{-34} \times 3.00 \times 10^8) / 1.16 \times 10^{-14}$

$$= 1.71 \times 10^{-11} \text{ (m)}$$

2

- (b) Narrow beam of X-rays

X ray generator rotated (in circular path) around patient

Detectors arranged around outside of the path

Detector opposite generator registers transmitted intensity

Detectors connected to computer which (over time) produces cross sectional image

Any **three** relevant points.

3

[7]

5

- (i) thickness needed to reduce intensity by half **(1)**
for X-rays of specific energy **(1)**

(ii) $\mu = \frac{\ln 2}{x}$ **(1)**

$= 58 \text{ m}^{-1}$ **(1)** (57.8 m^{-1})

- (iii) (use of $I = I_0 e^{-\mu x}$ gives) $0.05 = e^{-57.8x}$ **(1)**

$x = 0.052 \text{ m}$ (or 52 mm) **(1)** (51.8 mm)

(allow C.E. for value of μ from (ii))

[6]**6**

- (a) 1: vacuum / evacuated (tube) **(1)**
2: lead (lined shield) **(1)**
3: electrons (beam) **(1)**

3

- (b) (i) heat is spread over a greater volume / area / section **(1)**
thus allows more energetic X-rays to be produced
[or allows X-rays to be generated for longer] **(1)**

- (ii) (bevelled edge) gives larger target area **(1)**
but small source area (to produce sharp image) **(1)**

max 3

- (c) (i) the fraction of X-rays removed per unit thickness of the material **(1)**
(ii) the thickness of the material which will reduce the intensity
to half its original level **(1)**
for a specified energy of the X-rays (in either (i) or (ii)) **(1)**

2

- (d) (use of $\mu = \frac{\ln 2}{t_{1/2}}$ gives) $\mu = \frac{\ln 2}{3.2} = 0.22 \text{ mm}^{-1}$ **(1)** (0.217 mm^{-1})

(use of $I = I_0 e^{-\mu x}$ gives) $I = 6.0 \times e^{-0.217 \times 2}$ **(1)**

(allow C.E. for value of μ)

$= 3.9 \text{ W m}^{-2}$ **(1)**

3

[11]

7

(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) $\ln 2 / 15 = 0.046$

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

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1

[10]

8

(a) (i) method 1: increasing pd across the tube **(1)**

method 2: increasing tube current or increasing filament temperature **(1)**

(ii) method 1: will increase the maximum photon energy **(1)**

method 2: will not change the maximum photon energy **(1)**

max 3

- (b) reduces intensity of low energy photons **(1)**
 hardly changes intensity of high energy photons **(1)**
 need high energy for picture
 [or low energy no good for picture] **(1)**
 reducing low energy reduces dose received by patient **(1)**

max 3

[6]

9

- (a) for clear image need large difference in densities between
 part being investigated and parts around it **(1)**
 when this is not natural, add material to part under investigation **(1)**
 which has high density to provide good attenuation of X-rays **(1)**
 barium meal use barium sulphate **(1)**

max 3

- (b) $\mu (= \rho\mu_m) = 2700 - 0.012 = 32.4$ **(1)**

(use of $I = I_0 e^{-\mu x}$ gives) $1.2 \times 10^{-2} = 3.2 \times 10^{-2} \times e^{-32.4x}$ **(1)**

(allow C.E. for value of μ)

$x = 0.03(0)$ m **(1)**

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[6]

10

- (a) (i) Provide aperture through which X-rays may pass, stopping others ✓
Alternatives: provides collimation; produces narrow beam of X-rays;
protects areas of the body not being scanned
- (ii) Filters out (most) low energy photons (but allows high energy photons to pass through) ✓
Allow 'soft' or underpower' for low energy
Allow only high energy photons pass through

1

1

(b) $I / I_0 = 0.917 \checkmark$

$$\ln(0.917) = -\mu \times 2.7 \times 10^{-3} \checkmark$$

$$\mu = 32.1 \checkmark$$

$$\mu_m = \mu / 2700 = 0.012 \checkmark$$

$$\text{m}^2 \text{kg}^{-1} \checkmark$$

If 0.083 or 91.7 used, final 3 calc marks can be given

If 0.83 or 8.3 or 9.17 used, final 2 calc marks can be given

Unit mark is independent mark

5

[7]

Examiner reports

1 Those candidates who recognised the diagram and understood the basic principles were able to score high marks quickly in this question. A number of common misconceptions were seen. There is a belief that electrons are reflected from the angled surface of the anode and are mysteriously 'converted' into X-rays at some point during the reflection process. Some candidates believe that X-rays are directed, focussed or reflected in the direction of the window in the lead case. Not many candidates could explain that the tube needs to be evacuated to allow electrons unimpeded passage to the anode. Neither could candidates explain that the anode rotates to spread the electron impacts over a larger surface area, thus preventing damage to the surface of the target area.

2 Very few candidates gained full marks for this question. In part (a), most candidates failed to state that the photon energies were specific to the target material. There were better answers to part (b), but many candidates tried to keep the areas under the graphs the same, which made them lose the mark for the 90 keV curve having greater intensity than the original curve. The new curve should have finished midway between the 80 and 100 keV marks, but this was too much for quite a few candidates. This was a careless error which could, and should, have been avoided.

For what was a relatively simple calculation in part (c), the answers were poor. Most candidates managed to obtain the input power, but then went on to work out 0.7% (or 70%, or 0.7) and gave that answer as the heat produced. Examiners would have hoped that an answer of 67W would have struck the candidates as being far too low for an X-ray tube. Many otherwise good answers were spoilt by the careless use of significant figures in the final answer.

3 Part (a) highlighted the inability of many candidates to state their answers clearly and so marks were often lost by omission; omission to state the atoms of the target anode were excited or ionised, rather than just the target; omission to mention the inner electron shell is involved in this process if X-rays are produced; omission to relate the specific energy of the X-ray photon to the specific difference in energy due to the specific levels of the excited/de-excited atom.

Part (b) produced some good answers, but there was quite a lot of confusion between the intensifying cassette and the intensifier tube; some candidates had X-rays producing light photons then electrons drawn to an anode and a second fluorescent layer which they thought might be the rear intensifying screen. The point that the screens being in close contact with the film mean that the film is exposed by the light in the same place as it would have been exposed by the X-ray was missed by nearly all candidates.

4 This question was related to X-ray production and use. Part (a) (i) and (ii) were related to A/S work and although there were good answers which showed a clear understanding of the principle needed in part (i), there were far more answers which had students trying to use the general equation for kinetic energy with random values being substituted for the electron's speed. A wrong answer in (i) was carried forward to (ii) where students were able to gain both marks on offer. There were better answers in part (ii), but random equations such as that for the deBroglie wavelength were often seen. Part (b) was to do with a simple description of a CT scan. Good answers were seen where students were able to express clearly and concisely the main points of the scan. However, too many students again failed to score high marks by either contradicting themselves or by being too vague in what they were writing. Answers such as 'the CT scanner rotates' rather than the X-ray source rotates. From some answers it seemed that students hadn't covered this topic, and instead of describing the CT scan, they thought they would make up for it by describing how X-rays are produced, or how images are obtained by fluoroscopy.

5 In part (i) many candidates stated that it was the reduction of intensity to half the original value that gave the half-value thickness, but only one candidate was able to complete the definition by relating this to a specific energy of an X-ray beam. Only half the candidates were able to quote the correct equation in part (ii), and again, many candidates lost a mark by failing to give a correct unit with their answer. It was evident that in part (iii) candidates failed to understand what the intensity of the beam meant. Very often they would start by suggesting that the initial intensity was 90 keV and the final intensity 4.5 keV. Such a basic error in Physics ensured that no further marks were awarded.

6 Part (a) was, in general, well done, the most common error being the labelling of the surround of the X-ray tube as concrete rather than lead. Part (b), on the other hand, was poorly answered with explanations in part (i) merely stating, for example, 'to stop the anode from overheating'. Such answers were not awarded the allocated mark. The use of the bevelled edge in part (ii) was also poorly understood. The most common answer was 'to reflect the X-rays out of the window'. Other candidates suggested that 'it focused the X-ray beam' or 'that it created a narrow beam of X-rays'.

In part (c) there were very few correct definitions of the attenuation coefficient, most of them coming from a handful of centres. Definitions of the half-value thickness were much better, but some candidates lost the mark by relating their answer to reducing energy rather than to intensity. Very few candidates related either the linear attenuation coefficient or the half-value thickness as being specific to a mono-energetic X-ray beam and consequently the usual mark for part (c) was one.

Part (d) was done well by those candidates who knew the relationship between the attenuation coefficient and the half-value thickness, whilst others worked from first principles and obtained the correct answer. However, many candidates failed to even start the calculation.

7

- (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.

8

This question was, in general, answered well, but many candidates wrote a great deal, especially in part (b) and gained no marks. In part (a) many wrong ideas were encountered, especially in part (i). These including “focussing the beam more”, “increasing the distance between the beam and the patient” and “increasing the angle of the bevelled edge”. In nearly all cases it was found that if a candidate was able to give a correct method in part (i) then the correct effect was given in part (ii).

Although many candidates failed on part (b), full marks were gained sometimes. The main error was a failure to use correct terminology. Several candidates referred to X-ray intensity when they meant X-ray photon energy. Other candidates wrongly based their answer on the use of the grid in front of the detector to stop scattered X-rays.

9

Although a number of candidates gained full marks, this question proved to be difficult for some. Answers to part (a) often lacked the clarity needed to be awarded the allocated marks and usually candidates were only awarded one or two marks of the possible three. A number of candidates did not really understand what was required by the question and tried to answer in terms of an image intensifier or intensifying screens. Some candidates even discussed the use of a grid to enhance the picture by reducing scattered x-rays reaching the film.

It was very pleasing to find that the calculation in part (b) was carried out correctly in a number of cases. Some candidates failed to rearrange the exponential equation correctly but they appeared to be fewer in number than in previous years.

- (a)
 - (i) Many candidates were able to describe the use of the lead sheets correctly, but others lost marks as the answers were too vague such as 'to reduce the intensities of the X-ray' or 'to reduce the exposure to the patient', both of which can be done in several other ways.
 - (ii) Again many candidates were able to give the correct answer, but the same answers as stated above were too often given and again they scored no marks. This part also gave rise to the common answer 'to stop beta radiation'.
- (b) There were many correct answers to this calculation, candidates working their way carefully through the steps required. If a candidate failed to realise that the question stated 'reduced by', but worked using 'reduced to' 8.3%, they were only penalised by losing the first mark. Other arithmetic errors generally resulted in the loss of two marks. The final mark was an independent mark for the correct unit and this was not answered well with few candidates gaining this mark.