A-Level Physics

X-Ray Imaging

Mark Scheme

Time available: 69 minutes
Marks available: 55 marks

1. (a) Flat panel detector ✓

If flat panel detector, **max 3** from:

Not moving, so fluoroscopic image intensity not required ✓

Saves a picture unlike an intensifying screen ✓

Flat panel detector is more sensitive ✓

Faster than film / film is slower ✓

To minimise dose of X-rays to be used ✓

If film selected

Not moving, so film is preferred to intensifying screen ✓

Saves a picture unlike an intensifying screen ✓

To minimise dose of X-rays to be used ✓

If image intensifier selected

Intensifying screen is more sensitive than film ✓

Does not need to be developed like film ✓

To minimise lower dose of X-rays to be used ✓

4

(b) First mark is for calculating intensity (or power or energy if calculation done in a different order) transmitted through bone (allow thickness < 4 cm if justified as mean eg $r\sqrt{\pi}$ accept $r <$ thickness ≤ d) must include a factor $e^{-\mu x}$ ✓

Second mark is for calculating intensity absorbed by bone (or power or energy if calculation done in a different order) ✓

Third mark is for calculating the area of the bone ✓

Fourth mark is for converting an intensity into a power (allow ecf for incorrect intensity or area) ✓

Fifth mark is for converting a power into an energy (allow ecf for incorrect energy) ✓

Expected answer

$I = I_0 e^{-\mu x} = 0.013 \times e^{-58.3 \times 0.04}$ ✓ *(= 0.00126)*

Absorbed intensity $= I_0 - I = 0.013 - 0.00126$ ✓ *(= 0.0117)*

Area of bone $= \sqrt{0.25^2 + 0.09^2} \times 0.04$ ✓ *(= 0.0106 m²)*

$P = IA = 0.0117 \times 0.0106$ ✓ *(= 0.000124)*

$E = Pt = 0.000124 \times 0.8 = 1.0 \times 10^{-4}$ ✓ *(J)*

Condone rounding of answers/values as estimate asked for.

5

(c) Assuming bone has constant thickness / bone is rectangular/cuboid ✓

Assuming none of the X-rays are absorbed by tissue before it reaches the bone ✓

Allow any other sensible assumption that leads to a larger value

First mark can also be gained from an attempt to use an average value for diameter in ***(b)***

2

[11]

2. (a)

$\frac{1-d}{10^{-3}} = \frac{d}{0.1 \times 10^{-3}}$ ✓

$d = \frac{0.1 \times 10^{-3}}{1.1 \times 10^{-3}} = 9.1 \times 10^{-2}$ ✓ (m)

Allow alternative methods

Condone 1 SF

2

(b) (Hand)

Chest is thicker so parts will be further away from plate (increasing fuzziness) ✓

Chest is thicker and not uniformly thick (each part producing a shadow producing an unsharp image) / front and back can't both be focussed at the same time ✓

Can keep hand still but not heart so heart will be blurred ✓

Max 2

Condone can't stop breathing

2

[4]

3. (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]

4. (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

1
1

[10]

5. (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) ✓

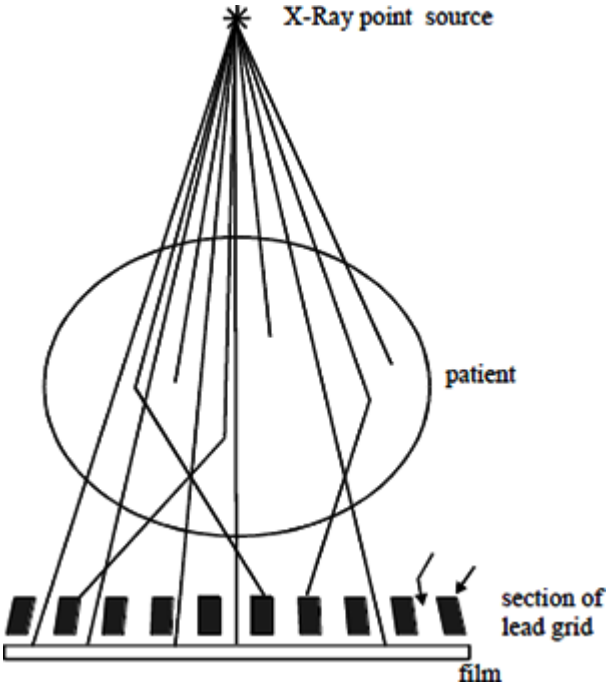
light photons expose film in correct place due to closeness of the screens to the film ✓

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

3

[6]

6. (a) (i) lead absorbs X-rays very well **(1)**



(ii) straight through tracks **(1)**
scattered tracks absorbed by lead **(1)**
some X-rays absorbed by patient **(1)**
clarity lost if scattered rays reach film, darkening image in random places **(1)**
lead grid allows through to film only those rays which are not scattered **(1)**
image intensity distribution represents accurately the body structure through which the radiation has passed **(1)**
grid moved systematically to prevent it forming image on film

(max 5)

(b) point source gives a <u>sharp</u> (shadow) <u>image</u>
[or point source produces <u>no penumbra</u> (grey fading at shadow edges) **(1)**

(1)

[6]

7.

(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)**

max 8

(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)**

2

[10]