Past-paper walk-through

Production and use of X-rays ▪ 24.2

eXercise

Questions in this set

- 9702/43 J24 Q8 ▪ 13 marks
- 9702/43 N23 Q10 ▪ 8 marks
- 9702/42 J23 Q10 ▪ 9 marks

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 8

9702/43 J24 ▪ Q8 ▪ 13 marks

(a) State what is meant by a photon. **[2]**

(b)(i) State the name of the particles. **[1]**

(b)(ii) On Fig. 8.1, use + and – signs to label terminals X and Y to indicate the polarity of the high voltage. **[1]**

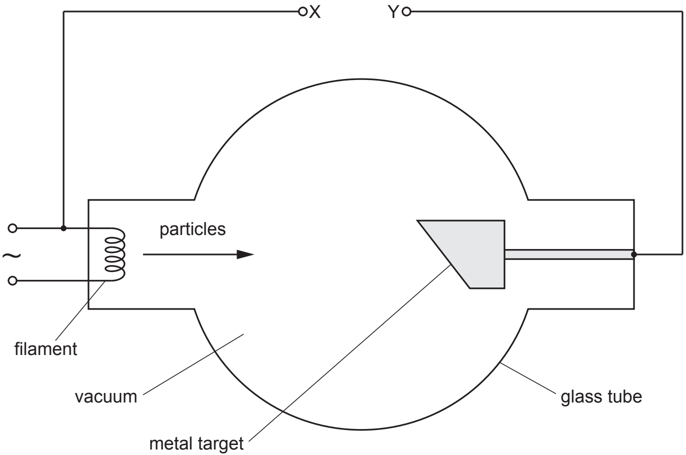
(c)(i) the maximum energy, in MeV, of an X-ray photon produced at the target **[1]**

(c)(ii) the maximum momentum of an X-ray photon produced at the target **[2]**

(c)(iii) the minimum wavelength of X-rays produced at the target. **[3]**

(d) Explain why X-rays can be used to produce images of internal body structures that have good contrast. **[3]**

Question 8



Solution 8

(a)

Mark scheme

- packet / quantum of energy
- of electromagnetic radiation

Solution 8

(b)(i)

Mark scheme

- electron(s)

(b)(ii)

Mark scheme

- X labelled $-$ and Y labelled $+$

Solution 8

(c)(i)

Mark scheme

- 0.032 MeV

(c)(ii)

Mark scheme

- momentum $= E/c$
- momentum $= (0.032 \times 1.60 \times 10^{-13})/(3.00 \times 10^{8})$
- $= 1.7 \times 10^{-23}$ N s

Solution 8

(c)(iii)

Mark scheme

- $E = hf$ and $\lambda = c/f$
- $\lambda = hc/E$
- $= (6.63 \times 10^{-34} \times 3.00 \times 10^{8})/(0.032 \times 1.60 \times 10^{-13})$
- $\lambda = 3.9 \times 10^{-11}$ m

Solution 8

(d)

Mark scheme

- discussion of bone and soft tissue
- discussion of different attenuation (coefficients)
- **or**
- discussion differences in penetration / transmission / absorption
- transmitted intensities (by bone and tissue) are very different (leading to good contrast images)

Question 10

9702/43 N23 ▪ Q10 ▪ 8 marks

Ultrasound and X-rays are both types of wave that are used in medical diagnosis to form images of internal body structures.

(a) Complete Table 10.1 to state, for each type of wave:

- the method of production of the wave
- whether the wave that is detected and used to form the image is the wave that has been absorbed, reflected or transmitted by the internal body structure.

Table 10.1

	ultrasound	X-rays
method of production		
detected wave (absorbed, reflected or transmitted)		

Question 10

[4]

Question 10

	ultrasound	X-rays
method of production	....	....
detected wave (absorbed, reflected or transmitted)	....	....

Question 10

9702/43 N23 ▪ Q10 ▪ 8 marks

Ultrasound and X-rays are both types of wave that are used in medical diagnosis to form images of internal body structures.

(b)(i) Calculate the linear attenuation coefficient μ of the tissue for this wave. **[2]**

(b)(ii) Another wave of the same type as in (b)(i) passes through 9.3 cm of the same tissue.

Calculate the percentage of the initial intensity of the wave that is attenuated by the tissue. **[2]**

Solution 10

(a) Mark scheme

- ultrasound production:
- vibrating quartz crystal **B1**
- X-ray production:
- electrons hitting metal target **B1**
- ultrasound detected wave:
- reflected **B1**
- X-ray detected wave:
- transmitted **B1**

Solution 10

(b)(i) Worked steps

Know. A parallel beam passing through matter is attenuated exponentially. The linear attenuation coefficient μ says how quickly.

Equation. $I = I_0 \exp(-\mu x)$, so $\ln\left(\dfrac{I}{I_0}\right) = -\mu x$.

Substitute. The beam keeps 72% of its intensity after 6.2 cm, so $\ln(0.72) = -\mu \times 6.2$.

Answer. $\mu = 0.053$ cm^{-1}.

Solution 10

Check. The answer is asked for in cm^{-1}, so keep the thickness in centimetres and do not convert to metres. $\ln(0.72)$ is negative, and so is $-\mu x$: the two minus signs cancel to leave a positive coefficient.

Mark scheme

- I = I0 exp (–μx) **C1**
- ln (0.72) = –6.2μ
- μ = 0.053 cm–1 **A1**

Solution 10

(b)(ii) Worked steps

Know. "Attenuated" means the fraction **removed**, not the fraction that gets through. Work out the transmitted fraction first, then subtract from one.

Equation. $\dfrac{I}{I_0} = \exp(-\mu x)$.

Substitute. $\dfrac{I}{I_0} = \exp(-9.3 \times 0.053) = 0.61$.

Subtract. Percentage attenuated $= 100 \times (1.00 - 0.61)$.

Answer. 39%.

Solution 10

Check. Answering 61% is the trap this question is built around: it is the percentage **transmitted**. Read the word in the answer line before writing the number. As a sanity check, a thicker slab than in part (b)(i) must remove more than the 28% removed there, and 39% is duly larger.

Mark scheme

- I / I0 = exp (–9.3 × 0.053)
- (= 0.61) C1
- percentage attenuated = 100 × (1.00 – 0.61)
- = 39% A1

Question 10

9702/42 J23 ▪ Q10 ▪ 9 marks

(a)(i) State the name of the charged particles that are accelerated by the applied p.d. **[1]**

(a)(ii) Explain how X-rays are produced at the metal target. **[2]**

(a)(iii) Calculate the minimum wavelength of X-rays produced when the applied p.d. is 5.80 kV. **[3]**

(b) X-rays pass through a medium that has an attenuation coefficient of 1.4 cm^{-1}. Calculate the percentage of the X-ray energy that is absorbed by a 2.8 cm thickness of this medium. **[3]**

Solution 10

(a)(i)

Mark scheme

- electrons

(a)(ii)

Mark scheme

- electrons are decelerated / stopped on impact with the target
- (kinetic) energy lost by electrons emitted as (X-ray) photons

Solution 10

(a)(iii) Worked steps

Know. The shortest wavelength is produced when an electron gives up **all** of its kinetic energy in a single collision. That kinetic energy is the work done on it by the accelerating p.d., eV.

Equation. $eV = \dfrac{hc}{\lambda_{\min}}$, so $\lambda_{\min} = \dfrac{hc}{eV}$.

Substitute. $\lambda_{\min} = \dfrac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{(1.60 \times 10^{-19})(5800)}$.

Solution 10

Answer. $\lambda_{\text{min}} = 2.14 \times 10^{-10}$ m.
Check. Convert the kilovolts to volts first. The answer is about 0.2 nm — X-ray wavelengths are of this order, comparable with the spacing between atoms in a crystal, which is why X-rays are diffracted by them.

Mark scheme

- $eV = hc/\lambda$
- $\lambda = (6.63 \times 10^{-34} \times 3.00 \times 10^{8})/(1.60 \times 10^{-19} \times 5800)$
- $= 2.14 \times 10^{-10}$ m

Solution 10

(b) Worked steps

Know. A parallel X-ray beam is attenuated exponentially: $I = I_0 e^{-\mu x}$, where μ is the attenuation coefficient.

Equation. The fraction **transmitted** is $\dfrac{I}{I_0} = e^{-\mu x}$; the fraction **absorbed** is what is left of 1.

Substitute. $\mu x = 1.4 \times 2.8 = 3.92$, so $\dfrac{I}{I_0} = e^{-3.92} = 0.0198$.

Answer. Percentage absorbed $= (1 - 0.0198) \times 100 = 98\%$.

Solution 10

Check. The units of μ and x must match — here both are in centimetres, so no conversion is needed and μx is a pure number. The question asks for what is **absorbed**, not transmitted; answering 2% is the trap.

Mark scheme

- $I = I_0 \exp(-\mu x)$
- $I_T/I_0 = \exp(-(1.4 \times 2.8))$
- $= 0.020$
- $\%$ absorbed $= (1.000 - 0.0198) \times 100$