Exercise walk-through

Energy and momentum of a photon ▪ 22.1

eXercise

You must be able to

- use $E = hf = \dfrac{hc}{\lambda}$ and the **electronvolt**
- use $p = E/c$ for the photon momentum

Method — Photons

A **photon** is a **quantum** (packet) of electromagnetic energy:

$$E = hf = \frac{hc}{\lambda}, \qquad p = \frac{E}{c},$$

with $h = 6.63 \times 10^{-34}$ J s. The **electronvolt**: 1 eV $= 1.6 \times 10^{-19}$ J.

Worked example. $\lambda = 500$ nm:

$$E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34})(3.0 \times 10^{8})}{500 \times 10^{-9}} = 4.0 \times 10^{-19} \text{ J}.$$

$$E = hf = \frac{hc}{\lambda}, \qquad p = \frac{E}{c}$$

Practice 2.1 ▪ 1 mark

Write the formula for the **energy** of a photon.

Solution 2.1

Method: Photons

Worked steps

$E = hf$ (or $E = hc/\lambda$) B1.

Practice 2.2 ▪ 1 mark

State the value of the **Planck constant**.

Solution 2.2

Worked steps

$h = 6.63 \times 10^{-34}$ J s B1.

Practice 2.3 ▪ 2 marks

Find the energy of a photon of frequency 5.0×10^{14} Hz.

Solution 2.3

Method: Photons

Worked steps

$E = hf = (6.63 \times 10^{-34})(5.0 \times 10^{14}) = 3.3 \times 10^{-19}$ J M1 A1.

Practice 2.4 ▪ 1 mark

Convert your answer to **electronvolts**.

Solution 2.4

Worked steps

$E = (3.3 \times 10^{-19})/(1.6 \times 10^{-19}) = 2.1$ eV B1.

Exam-style 3.1 ▪ 1 mark

The momentum of a photon of energy E is:

A hf

B E/c

C mc

D h/c

Solution 3.1

Method: Photons

A hf

B E/c ✓

C mc

D h/c

Worked steps

B — E/c.

Exam-style 3.2 ▪ 3 marks

Calculate the energy of a photon of wavelength 500 nm.

Solution 3.2

Method: Photons

Worked steps

$$E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34})(3.0 \times 10^{8})}{500 \times 10^{-9}} \quad \text{M1 M1} \quad = 4.0 \times 10^{-19}\ \text{J} \quad \text{A1}.$$

Exam-style 3.3 ▪ 2 marks

Calculate the **momentum** of this photon.

Solution 3.3

Method: Photons

Worked steps

$p = E/c = (4.0 \times 10^{-19})/(3.0 \times 10^{8}) = 1.3 \times 10^{-27}$ kg m s^{-1} **M1** **A1**.

Exam-style 3.4 ▪ 1 mark

State what a **photon** is.

Solution 3.4

Worked steps

A **quantum (packet) of electromagnetic energy** B1.

Exam-style 3.5 ▪ 2 marks

A nucleus of uranium-238 decays by emitting an α-particle and a single gamma photon. Take 1 u $= 1.66 \times 10^{-27}$ kg, $c = 3.00 \times 10^{8}$ m s^{-1}, $h = 6.63 \times 10^{-34}$ J s and 1 MeV $= 1.60 \times 10^{-13}$ J.

(a) **State** what is meant by a **photon**.

(b) The gamma photon carries an energy of 0.050 MeV. **Determine** its wavelength.

(c) **Determine** the momentum of that photon.

(d) The photon is emitted by a nucleus that was at rest. **Explain** why the nucleus recoils, and **determine** its recoil speed, given that its mass is 234 u.

(e) Gamma radiation from a sample of this nuclide has a **single** wavelength. **Suggest** what this tells you about the energy levels of the nucleus.

Solution 3.5

Method: Photons

Worked steps

(a) A photon is a **quantum (discrete packet) of electromagnetic radiation** B1, carrying energy $E = hf$ B1.

(b) $E = 0.050 \times 1.60 \times 10^{-13} = 8.0 \times 10^{-15}$ J M1;

$\lambda = \dfrac{hc}{E} = \dfrac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{8.0 \times 10^{-15}}$ M1 $= 2.5 \times 10^{-11}$ m A1.

(c) $p = \dfrac{E}{c} = \dfrac{8.0 \times 10^{-15}}{3.00 \times 10^{8}}$ M1 $= 2.7 \times 10^{-23}$ N s A1. (Or $p = h/\lambda$, which gives the same number.)

(d) Momentum is conserved and the nucleus started at rest, so it must recoil with

Solution 3.5

momentum **equal and opposite** to the photon's B1. $v = \frac{p}{m} = \frac{2.67 \times 10^{-23}}{234 \times 1.66 \times 10^{-27}}$ M1 $= 6.9 \times 10^{-2}$ m s^{-1} A1.

(e) The nucleus has **discrete energy levels** B1: the photon energy is the difference between two definite levels, and a single wavelength means every nucleus in the sample makes the **same** transition B1.