

Exercise walk-through

Energy and momentum of a photon ■ 22.1

eXercise

You must be able to

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

Method — Photons

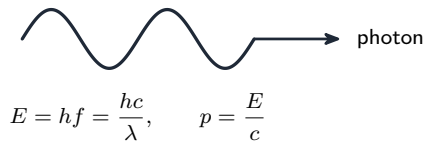
A **photon** is a **quantum** (packet) of electromagnetic energy:

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

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

Worked example. $\lambda = 500 \text{ nm}$:

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



Practice 2.1 ■ 1 mark

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

Solution 2.1

Method: Photons

Worked steps

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

Practice 2.2 ■ 1 mark

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

Solution 2.2

Worked steps

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

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

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

Practice 2.4 ■ 1 mark

Convert your answer to **electronvolts**.

Solution 2.4

Worked steps

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

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

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

Exam-style 3.3 ■ 2 marks

Calculate the **momentum** of this photon.

Solution 3.3

Method: Photons

Worked steps

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

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 $1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$, $c = 3.00 \times 10^8 \text{ m s}^{-1}$, $h = 6.63 \times 10^{-34} \text{ J s}$ and $1 \text{ MeV} = 1.60 \times 10^{-13} \text{ J}$.

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

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

(c) $p = \frac{E}{c} = \frac{8.0 \times 10^{-15}}{3.00 \times 10^8} \text{ **(M1)** } = 2.7 \times 10^{-23} \text{ N s **(A1)** }.$ (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 $= 6.9 \times 10^{-2} \text{ m s}^{-1}$ **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**.