A-LEVEL PHYSICS • EXERCISE SHEET

22.1 Energy and momentum of a photon

Name: _____ Class: _____ Date: _____ **Total: 24 marks**

KEY WORDS photon 光子 • momentum 动量 • electronvolt 电子伏特 • wavelength 波长 • electron 电子

Objective

Build the skills to answer exam questions on the **photon** — its energy and momentum.

You must be able to:

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

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Photons

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

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

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

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

Worked example. $\lambda = 500$ nm: $E = \dfrac{hc}{\lambda} = \dfrac{(6.63 \times 10^{-34})(3.0 \times 10^{8})}{500 \times 10^{-9}} = 4.0 \times 10^{-19}$ J.

2 Practice

Now apply the methods above.

2.1 Write the formula for the **energy** of a photon. [1]

2.2 State the value of the **Planck constant**. [1]

2.3 Find the energy of a photon of frequency 5.0×10^{14} Hz. [2]

2.4 Convert your answer to **electronvolts**. [1]

3 Exam-style questions

3.1 The momentum of a photon of energy E is: [1]

- **A** hf
- **B** E/c
- **C** mc
- **D** h/c

3.2 Calculate the energy of a photon of wavelength 500 nm. [3]

3.3 Calculate the **momentum** of this photon. [2]

3.4 State what a **photon** is. [1]

3.5 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**. [2]

(b) The gamma photon carries an energy of 0.050 MeV. **Determine** its wavelength. [3]

(c) **Determine** the momentum of that photon. [2]

(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. [3]

(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. [2]

Solutions

2.1 $E = hf$ (or $E = hc/\lambda$).

2.2 $h = 6.63 \times 10^{-34}$ J s.

2.3 $E = hf = (6.63 \times 10^{-34})(5.0 \times 10^{14}) = 3.3 \times 10^{-19}$ J.

2.4 $E = (3.3 \times 10^{-19})/(1.6 \times 10^{-19}) = 2.1$ eV.

3.1 B — E/c.

3.2 $E = \dfrac{hc}{\lambda} = \dfrac{(6.63 \times 10^{-34})(3.0 \times 10^{8})}{500 \times 10^{-9}} = 4.0 \times 10^{-19}$ J.

3.3 $p = E/c = (4.0 \times 10^{-19})/(3.0 \times 10^{8}) = 1.3 \times 10^{-27}$ kg m s^{-1}.

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

3.5 (a) A photon is a **quantum (discrete packet) of electromagnetic radiation**, carrying energy $E = hf$.
(b) $E = 0.050 \times 1.60 \times 10^{-13} = 8.0 \times 10^{-15}$ J; $\lambda = \dfrac{hc}{E} = \dfrac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{8.0 \times 10^{-15}}$ $= 2.5 \times 10^{-11}$ m.
(c) $p = \dfrac{E}{c} = \dfrac{8.0 \times 10^{-15}}{3.00 \times 10^{8}} = 2.7 \times 10^{-23}$ N s. (Or $p = h/\lambda$, which gives the same number.)
(d) Momentum is conserved and the nucleus started at rest, so it must recoil with momentum **equal and opposite** to the photon's. $v = \dfrac{p}{m} = \dfrac{2.67 \times 10^{-23}}{234 \times 1.66 \times 10^{-27}} =$ 6.9×10^{-2} m s^{-1}.
(e) The nucleus has **discrete energy levels**: the photon energy is the difference between two definite levels, and a single wavelength means every nucleus in the sample makes the **same** transition.