Exercise walk-through

Wave-particle duality ▪ 22.3

eXercise

You must be able to

- state the evidence for the **wave** and **particle** natures
- use the **de Broglie wavelength** $\lambda = h/p$
- describe **electron diffraction**

Method — Wave–particle duality

- **particle** nature of light: the **photoelectric effect**;
- **wave** nature of light: **interference** and **diffraction**.

So light has both — **wave–particle duality**. De Broglie said moving **particles** also have a wavelength:

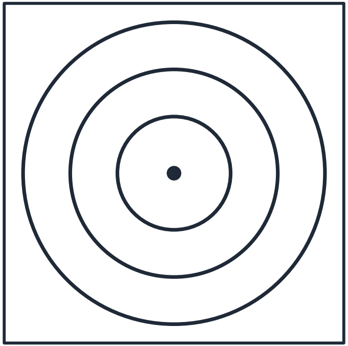
$$\lambda = \frac{h}{p} = \frac{h}{mv}.$$

Usually you are given the **speed**: find the momentum $p = mv$ first, then $\lambda = h/p$.
Worked example. An electron ($m = 9.1 \times 10^{-31}$ kg) moves at 4.9×10^{7} m s^{-1}:
$p = mv = 4.5 \times 10^{-23}$ kg m s^{-1}, so $\lambda = \dfrac{h}{p} = \dfrac{6.63 \times 10^{-34}}{4.5 \times 10^{-23}} = 1.5 \times 10^{-11}$ m.

Method — Electron diffraction

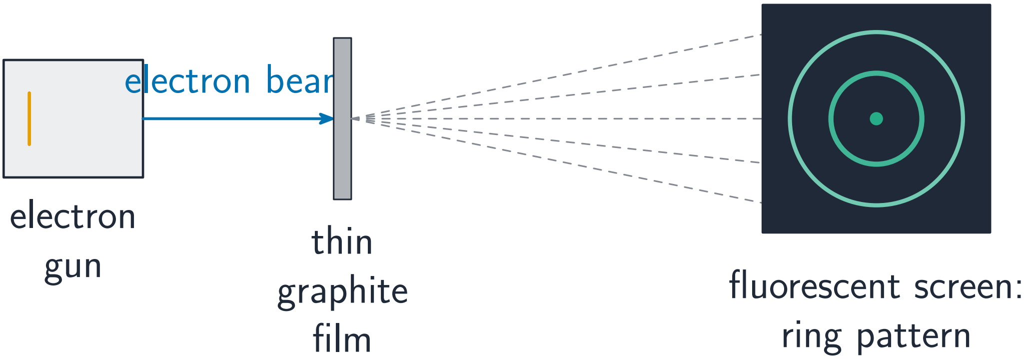
Electrons fired at a thin crystal produce **diffraction rings** — only waves diffract, so this shows the **wave nature of particles**:

Method — Electron diffraction



diffraction rings

Method — Electron diffraction



Electron diffraction shows wave behaviour

Practice 2.1 ▪ 1 mark

State **one** phenomenon that is evidence for the **particle** nature of light.

Solution 2.1

Method: Wave–particle duality

Worked steps

The **photoelectric effect** B1.

Practice 2.2 ▪ 1 mark

State **one** phenomenon that is evidence for the **wave** nature of light.

Solution 2.2

Worked steps

Interference (e.g. double-slit) or **diffraction** B1.

Practice 2.3 ▪ 1 mark

Write the **de Broglie** equation.

Solution 2.3

Worked steps

$\lambda = h/p$ **B1**.

Practice 2.4 ▪ 1 mark

State what **electron diffraction** demonstrates.

Solution 2.4

Worked steps

That **particles** (electrons) have a **wave nature** B1.

Exam-style 3.1 ▪ 1 mark

The de Broglie wavelength of a particle is:

A hf

B h/p

C E/c

D hc

Solution 3.1

Method: Wave–particle duality

A hf

B h/p ✓

C E/c

D hc

Worked steps

B — h/p.

Exam-style 3.2 ▪ 2 marks

Calculate the de Broglie wavelength of an electron with momentum 4.5×10^{-23} kg m s^{-1}.

Solution 3.2

Method: Wave–particle duality

Worked steps

$\lambda = h/p = (6.63 \times 10^{-34})/(4.5 \times 10^{-23}) = 1.5 \times 10^{-11}$ m **M1** **A1**.

Exam-style 3.3 ▪ 3 marks

Describe the **evidence** that electron diffraction provides for the **wave nature** of particles.

Solution 3.3

Method: Electron diffraction

Worked steps

Electrons fired at a crystal produce a pattern of **rings/maxima** on a screen B1; this is a **diffraction** pattern, and **only waves diffract** B1; so the electrons must have a **wave nature** (matching $\lambda = h/p$) B1.

Exam-style 3.4 ▪ 2 marks

Explain what is meant by **wave–particle duality**.

Solution 3.4

Method: Wave–particle duality

Worked steps

Matter and radiation show **both** wave-like behaviour (interference/diffraction) **and** particle-like behaviour (photons/photoelectric effect) **B1** **B1**.

Exam-style 3.5 ▪ 3 marks

Calculate the de Broglie wavelength of an electron moving at 4.9×10^7 m s^{-1}.
($m_e = 9.1 \times 10^{-31}$ kg.)

Solution 3.5

Method: Wave–particle duality

Worked steps

$p = mv = (9.1 \times 10^{-31})(4.9 \times 10^{7}) = 4.5 \times 10^{-23}$ kg m s^{-1} **M1**; $\lambda = \dfrac{h}{p} = \dfrac{6.63 \times 10^{-34}}{4.5 \times 10^{-23}}$ **M1** $= 1.5 \times 10^{-11}$ m **A1**.

Exam-style 3.6 ▪ 2 marks

In an electron diffraction tube, electrons are accelerated through a potential difference of 4.8 kV and strike a thin graphite film. Take $h = 6.63 \times 10^{-34}$ J s, $e = 1.60 \times 10^{-19}$ C and the electron mass as 9.11×10^{-31} kg.

(a) **State** what is meant by the **de Broglie wavelength** of a particle.

(b) **Determine** the speed of an electron after acceleration.

(c) **Determine** its de Broglie wavelength.

(d) **Explain** why a diffraction pattern is seen on the screen, and what it demonstrates about electrons.

(e) The accelerating p.d. is **increased**. **State and explain** what happens to the spacing of the rings in the pattern.

Solution 3.6

Method: Wave–particle duality

Worked steps

(a) The wavelength associated with a **moving particle** B1, given by $\lambda = \frac{h}{p}$, where p is its momentum B1.

(b) The work done by the accelerating p.d. becomes kinetic energy: $eV = \frac{1}{2}mv^2$ M1;

$v = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2 \times 1.60 \times 10^{-19} \times 4800}{9.11 \times 10^{-31}}}$ M1 $= 4.1 \times 10^{7}$ m s^{-1} A1.

(c) $\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 4.11 \times 10^{7}}$ M1 $= 1.8 \times 10^{-11}$ m A1.

(d) The spacing between the graphite atoms is of the same order as this wavelength

Solution 3.6

B1, so the electrons are **diffracted** by the atomic planes and the diffracted waves **interfere** to give rings B1. Diffraction and interference are wave behaviours, so this shows that particles have a **wave nature** B1.

(e) A larger p.d. gives the electrons more momentum, so $\lambda = h/p$ is **smaller** B1; less diffraction means the rings move **closer together** B1.