A-LEVEL PHYSICS • EXERCISE SHEET

22.3 Wave-particle duality

Name: ______________ Class: __________ Date: ____________ **Total: 17 marks**

Objective

Build the skills to answer exam questions on **wave–particle duality** and the de Broglie wavelength.

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**

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.

■ 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:

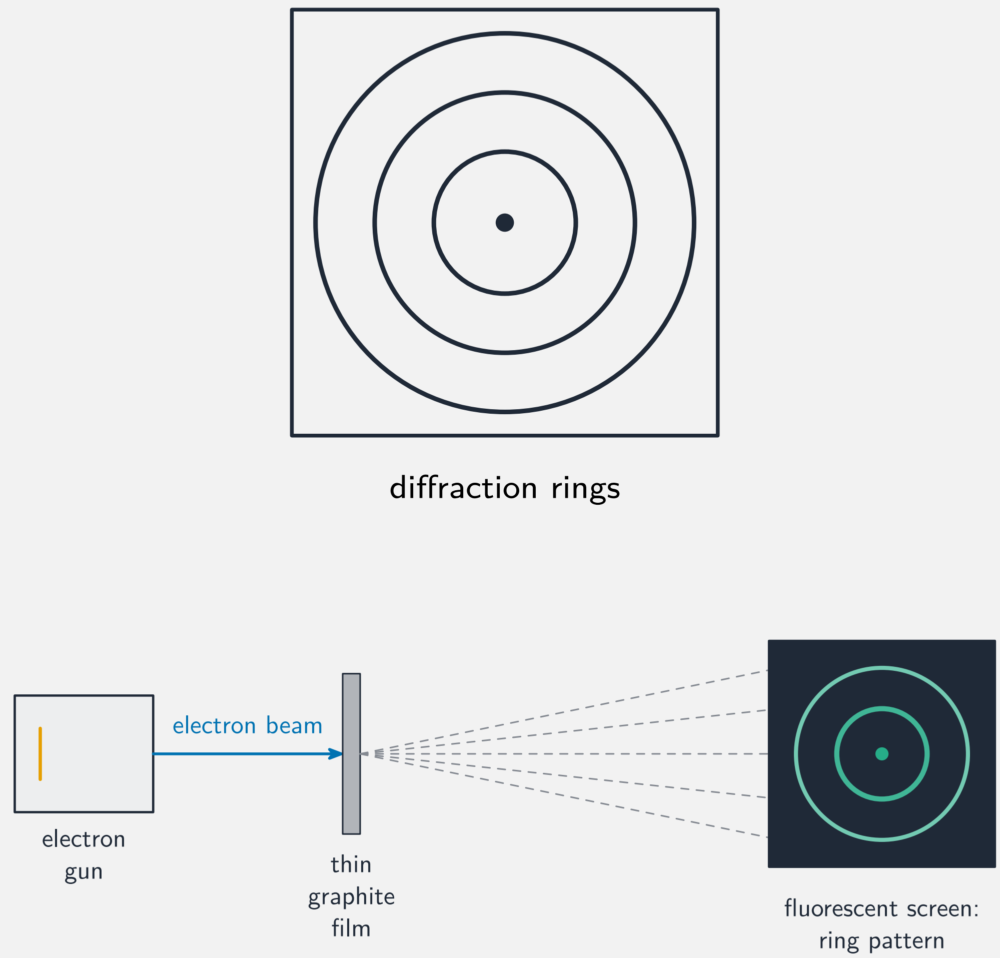
$$\lambda = \frac{h}{p} = \frac{h}{mv}.$$

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.

■ Electron diffraction

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



Electron diffraction shows wave behaviour

2 Practice

Now apply the methods above.

2.1 State **one** phenomenon that is evidence for the **particle** nature of light. [1]

2.2 State **one** phenomenon that is evidence for the **wave** nature of light. [1]

2.3 Write the **de Broglie** equation. [1]

2.4 State what **electron diffraction** demonstrates. [1]

3 Exam-style questions

3.1 The de Broglie wavelength of a particle is: [1]

- **A** hf
- **B** h/p
- **C** E/c
- **D** hc

3.2 Calculate the de Broglie wavelength of an electron with momentum 4.5×10^{-23} kg m s^{-1}. [2]

3.3 Describe the **evidence** that electron diffraction provides for the **wave nature** of particles. [3]

3.4 Explain what is meant by **wave–particle duality**. [2]

3.5 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.) [3]

4 Go further

You are now ready for the real exam questions on this subtopic. Open the **22.3 Wave–particle duality** past-paper sheet in the Library, or try these in **Practice mode**:

- 9702/44 J25 —Q9 (de Broglie wavelength from speed)
- 9702/41 J25 —Q8 (wave–particle duality)
- 9702/43 J25 —Q8 (electron diffraction)

Solutions

2.1 The **photoelectric effect**.

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

2.3 $\lambda = h/p$.

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

3.1 **B** —h/p.

3.2 $\lambda = h/p = (6.63 \times 10^{-34})/(4.5 \times 10^{-23}) = 1.5 \times 10^{-11}$ m.

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

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

3.5 $p = mv = (9.1 \times 10^{-31})(4.9 \times 10^{7}) = 4.5 \times 10^{-23}$ kg m s^{-1}; $\lambda = \dfrac{h}{p} = \dfrac{6.63 \times 10^{-34}}{4.5 \times 10^{-23}}$ $= 1.5 \times 10^{-11}$ m.