A-LEVEL PHYSICS • EXERCISE SHEET

22.3 Wave-particle duality

Name: ____________ Class: ________ Date: __________ **Total: 27 marks**

KEY WORDS de broglie wavelength 德布罗意波长 • wave–particle duality 波粒二象性 • diffraction 衍射 • electron diffraction 电子衍射 • interference 干涉

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:

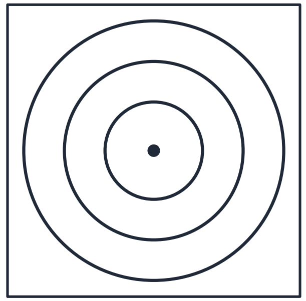
$$\lambda = \frac{h}{p} = \frac{h}{mv}.$$

Usually you are given the **speed**: find the momentum $p = mv$ first, then $\lambda = h/p$.

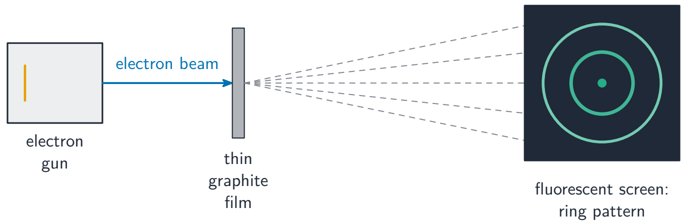
Worked example. An electron ($m = 9.1 \times 10^{-31}$ kg) moves at 4.9×10^{7} m s^{-1}: $p = mv = 4.5 \times 10^{-23}$ kg m s^{-1}, so $\lambda = \dfrac{h}{p} = \dfrac{6.63 \times 10^{-34}}{4.5 \times 10^{-23}} = 1.5 \times 10^{-11}$ m.

Electron diffraction

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



diffraction rings



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]

3.6 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. [2]

(b) **Determine** the speed of an electron after acceleration. [3]

(c) **Determine** its de Broglie wavelength. [2]

(d) **Explain** why a diffraction pattern is seen on the screen, and what it demonstrates about electrons. [3]

(e) The accelerating p.d. is **increased**. **State and explain** what happens to the spacing of the rings in the pattern. [2]

Solutions

Each answer shows the steps, then the **result**.

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

- de Broglie: $\lambda = h/p$

3.2

- $\lambda = h/p$

$$\lambda = \frac{6.63 \times 10^{-34}\ \text{J s}}{4.5 \times 10^{-23}\ \text{kg m s}^{-1}} = \mathbf{1.5 \times 10^{-11}}\ \text{m}$$

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

- $p = mv$

$$p = (9.1 \times 10^{-31}\ \text{kg})(4.9 \times 10^{7}\ \text{m s}^{-1}) = 4.5 \times 10^{-23}\ \text{kg m s}^{-1}$$

- $\lambda = h/p$

$$\lambda = \frac{6.63 \times 10^{-34}\ \text{J s}}{4.5 \times 10^{-23}\ \text{kg m s}^{-1}} = \mathbf{1.5 \times 10^{-11}}\ \text{m}$$

3.6

(a) the wavelength associated with a **moving particle**

- $\lambda = h/p$, where p is its momentum

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

$$v = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2 \times (1.60 \times 10^{-19}\ \text{C})(4800\ \text{V})}{9.11 \times 10^{-31}\ \text{kg}}} = \mathbf{4.1 \times 10^{7}}\ \text{m s}^{-1}$$

(c) $\lambda = h/(mv)$

$$\lambda = \frac{6.63 \times 10^{-34}\ \text{J s}}{(9.11 \times 10^{-31}\ \text{kg})(4.11 \times 10^{7}\ \text{m s}^{-1})} = \mathbf{1.8 \times 10^{-11}}\ \text{m}$$

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

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

(e) a larger p.d. gives the electrons more momentum, so $\lambda = h/p$ is **smaller**

- less diffraction means the rings move **closer together**