



QUESTION WORKBOOK

Wave-particle duality

Quantum phenomena · Year 12

AQA 3.2.2.4 · CIE 22.3.1, 22.3.2, 22.3.3, 22.3.4 · OCR A 4.5.3(a), 4.5.3(b), 4.5.3(c)

19 questions · 55 marks

PRINT EDITION

SECTION A · Warm-up

- A1** State the two pieces of evidence showing that light and electrons each have both wave and particle properties. [2]

- A2** A particle has a momentum of $2.0 \times 10^{-24} \text{ kg m s}^{-1}$. Calculate its de Broglie wavelength ($h = 6.63 \times 10^{-34} \text{ J s}$). [2]

- A3** State the de Broglie equation and define each term. [2]

- A4** The electrons in an electron microscope have a de Broglie wavelength of $1.2 \times 10^{-10} \text{ m}$. Calculate their momentum ($h = 6.63 \times 10^{-34} \text{ J s}$). [2]

- A5** State the condition needed for a beam of particles to be diffracted appreciably by the atoms of a crystal. [1]

- A6** The momentum of a particle is doubled. State what happens to its de Broglie wavelength. [1]

SECTION B · Standard

- B1** An electron moves at $1.0 \times 10^6 \text{ m s}^{-1}$. Calculate its de Broglie wavelength ($m_e = 9.11 \times 10^{-31} \text{ kg}$). [3]

- B2** An electron is accelerated from rest through a potential difference of 100 V. Calculate (a) its speed and (b) its de Broglie wavelength ($e = 1.60 \times 10^{-19} \text{ C}$, $m_e = 9.11 \times 10^{-31} \text{ kg}$). [4]

- B3** An electron and a proton travel at the same speed of $1.0 \times 10^5 \text{ m s}^{-1}$. Calculate the de Broglie wavelength of each ($m_p = 1.67 \times 10^{-27} \text{ kg}$) and state which is larger. [3]

- B4** Explain what the diffraction of electrons by a thin crystal shows about the nature of electrons. [3]

- B5** In an experiment to show that whole atoms have wave properties, a beam of helium atoms is directed at a crystal whose atomic spacing is $1.0 \times 10^{-10} \text{ m}$. Calculate the speed at which a helium atom, of mass $6.6 \times 10^{-27} \text{ kg}$, has a de Broglie wavelength equal to this spacing ($h = 6.63 \times 10^{-34} \text{ J s}$). [3]

- B6** An electron travels at $3.3 \times 10^6 \text{ m s}^{-1}$. Determine the speed at which a proton would have the same de Broglie wavelength as this electron ($m_e = 9.11 \times 10^{-31} \text{ kg}$, $m_p = 1.67 \times 10^{-27} \text{ kg}$). [3]

- B7** In a molecular-beam experiment, molecules travelling at 500 m s^{-1} produce a diffraction pattern corresponding to a de Broglie wavelength of $2.8 \times 10^{-11} \text{ m}$. The beam is one of: helium (particle mass $6.6 \times 10^{-27} \text{ kg}$), nitrogen ($4.7 \times 10^{-26} \text{ kg}$) or oxygen ($5.3 \times 10^{-26} \text{ kg}$). Determine the mass of one molecule and deduce which gas the beam contains ($h = 6.63 \times 10^{-34} \text{ J s}$). [4]

SECTION C · Stretch

- C1** A cricket ball of mass 0.16 kg is bowled at 30 m s^{-1} . Calculate its de Broglie wavelength and explain why no diffraction of the ball is ever observed. [4]

- C2** Calculate the accelerating potential difference needed to give an electron a de Broglie wavelength of $1.0 \times 10^{-10} \text{ m}$ ($h = 6.63 \times 10^{-34} \text{ J s}$, $m_e = 9.11 \times 10^{-31} \text{ kg}$, $e = 1.60 \times 10^{-19} \text{ C}$). [4]

- C3** Explain how and why the electron diffraction pattern changes when the electrons are accelerated to a higher speed. [3]

- C4** A researcher wants to study a crystal whose atomic plane spacing is 2.0×10^{-10} m by diffraction. Two beams are available: electrons moving at 1.0×10^7 m s⁻¹, or neutrons moving at 2.0×10^3 m s⁻¹. Deduce which beam is better matched to the crystal ($h = 6.63 \times 10^{-34}$ J s, $m_e = 9.11 \times 10^{-31}$ kg, neutron mass = 1.67×10^{-27} kg). [4]

- C5** Show that the kinetic energy of a particle of mass m with de Broglie wavelength λ is given by $E_k = h^2/(2m\lambda^2)$. Go on to calculate the kinetic energy of an electron whose de Broglie wavelength is 5.0×10^{-10} m ($h = 6.63 \times 10^{-34}$ J s, $m_e = 9.11 \times 10^{-31}$ kg). [4]

- C6** The smallest detail a microscope can resolve is roughly the size of the wavelength it uses. Visible light has wavelengths around $5 \times 10^{-7} \text{ m}$; the electrons in an electron microscope have a de Broglie wavelength of about $1 \times 10^{-11} \text{ m}$. Explain why an electron microscope can resolve far finer detail than an optical microscope.

[3]
