InkPhysics

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

NAVY SCREEN 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 2.0×10^{-24} kg m s^{-1}. Calculate its de Broglie wavelength ($h = 6.63 \times 10^{-34}$ 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 1.2×10^{-10} m. Calculate their momentum ($h = 6.63 \times 10^{-34}$ 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 1.0×10^{6} m s^{-1}. Calculate its de Broglie wavelength ($m_e = 9.11 \times 10^{-31}$ 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 ($e = 1.60 \times 10^{-19}$ C, $m_e = 9.11 \times 10^{-31}$ kg). [4]

B3 An electron and a proton travel at the same speed of 1.0×10^{5} m s^{-1}. Calculate the de Broglie wavelength of each ($m_p = 1.67 \times 10^{-27}$ 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 1.0×10^{-10} m. Calculate the speed at which a helium atom, of mass 6.6×10^{-27} kg, has a de Broglie wavelength equal to this spacing ($h = 6.63 \times 10^{-34}$ J s). [3]

B6 An electron travels at 3.3×10^{6} m s^{-1}. Determine the speed at which a proton would have the same de Broglie wavelength as this electron ($m_e = 9.11 \times 10^{-31}$ kg, $m_p = 1.67 \times 10^{-27}$ 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 2.8×10^{-11} m. The beam is one of: helium (particle mass 6.6×10^{-27} kg), nitrogen (4.7×10^{-26} kg) or oxygen (5.3×10^{-26} kg). Determine the mass of one molecule and deduce which gas the beam contains ($h = 6.63 \times 10^{-34}$ 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 1.0×10^{-10} m ($h = 6.63 \times 10^{-34}$ J s, $m_e = 9.11 \times 10^{-31}$ kg, $e = 1.60 \times 10^{-19}$ 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 5×10^{-7} m; the electrons in an electron microscope have a de Broglie wavelength of about 1×10^{-11} m. Explain why an electron microscope can resolve far finer detail than an optical microscope.

[3]