inkPhysics

ANSWER BOOK

# 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 EDITION

## SECTION A · Warm-up

**A1** Electron diffraction shows that electrons (particles) behave as waves (1); the photoelectric effect shows that light (a wave) behaves as particles (photons) (1). [2]

**A2** $\lambda = h/p = (6.63 \times 10^{-34})/(2.0 \times 10^{-24})$ (1)
$\lambda = 3.32 \times 10^{-10}$ m (1) [2]

**A3** $\lambda = h/mv$ ($= h/p$) (1), where $\lambda$ is the de Broglie wavelength, h the Planck constant, m the mass, v the speed and p the momentum (1). [2]

**A4** $p = h/\lambda = (6.63 \times 10^{-34})/(1.2 \times 10^{-10})$ (1) $= 5.52 \times 10^{-24}$ kg m s$^{-1}$ (1). [2]

**A5** The de Broglie wavelength must be comparable to the atomic spacing (1). [1]

**A6** It halves, since $\lambda = h/p$ (1). [1]

## SECTION B · Standard

**B1** $\lambda = h/mv$ (1)
$= (6.63 \times 10^{-34})/(9.11 \times 10^{-31} \times 1.0 \times 10^{6})$ (1)
$\lambda = 7.28 \times 10^{-10}$ m (1) [3]

**B2** $E_k = eV = 1.60 \times 10^{-17}$ J (1) [4]
(a) $v = \sqrt{(2E_k/m)}$ (1)
$v = 5.93 \times 10^{6}$ m s$^{-1}$ (1)
(b) $\lambda = h/mv = 1.23 \times 10^{-10}$ m (1)

**B3** Electron: $\lambda = h/mv = 7.28 \times 10^{-9}$ m (1) [3]
Proton: $\lambda = 3.97 \times 10^{-12}$ m (1)
The electron's wavelength is larger, because it has the smaller mass (1)

**B4** Diffraction is a wave property, produced when a wave passes through gaps comparable to its wavelength (1) (here the atomic spacing). Electrons producing a diffraction pattern therefore behave as waves (1), evidence for wave–particle duality (1). [3]

**B5** $\lambda = h/mv$, so $v = h/m\lambda$ (1) $= (6.63 \times 10^{-34})/(6.6 \times 10^{-27} \times 1.0 \times 10^{-10})$ (1) $= 1.00 \times 10^{3}$ m s$^{-1}$, about 1.0 km s$^{-1}$ (1). [3]

 

**B6** Equal wavelengths mean equal momenta: $m_e v_e = m_p v_p$ (1). $v_p = (9.11 \times 10^{-31} \times 3.3 \times 10^{6})/(1.67 \times 10^{-27})$ (1) $= 1.80 \times 10^{3}$ m s$^{-1}$ (1). [3]

**B7** $\lambda = h/mv$, so $m = h/(\lambda v)$ (1) $= (6.63 \times 10^{-34})/(2.8 \times 10^{-11} \times 500)$ (1) $= 4.7 \times 10^{-26}$ kg (1). This matches nitrogen, so the beam is nitrogen (1). [4]

## SECTION C · Stretch

**C1** $\lambda = h/mv = (6.63 \times 10^{-34})/(0.16 \times 30)$ (1) [4]
$\lambda = 1.38 \times 10^{-34}$ m (1)
This is many orders of magnitude smaller than any gap the ball could pass through (1) so any diffraction is far too small to detect (1)

**C2** $p = h/\lambda = (6.63 \times 10^{-34})/(1.0 \times 10^{-10})$ (1) [4]
$p = 6.63 \times 10^{-24}$ kg m s$^{-1}$ (1)
$E_k = p^2/2m = 2.41 \times 10^{-17}$ J (1)
$V = E_k/e = 151$ V (1)

**C3** A higher speed means greater momentum, so from $\lambda = h/mv$ the de Broglie wavelength is shorter (1). With a shorter wavelength the electrons diffract less (1), so the rings of the pattern move closer together (the pattern shrinks) (1). [3]

**C4** Electrons: $\lambda = h/mv = 7.28 \times 10^{-11}$ m (1). Neutrons: $\lambda = 1.99 \times 10^{-10}$ m (1). Diffraction is strongest when $\lambda$ is comparable to the spacing (1). The neutron wavelength is almost exactly $2.0 \times 10^{-10}$ m, while the electron wavelength is nearly three times smaller, so the neutron beam is the better match (1). [4]

**C5** $p = h/\lambda$ (1). $E_k = p^2/2m$, so $E_k = h^2/(2m\lambda^2)$ (1). $E_k = (6.63 \times 10^{-34})^2/(2 \times 9.11 \times 10^{-31} \times (5.0 \times 10^{-10})^2)$ (1) $= 9.65 \times 10^{-19}$ J, about 6.0 eV (1). [4]

**C6** Resolution is limited by diffraction, which blurs any detail smaller than about one wavelength (1). The electron de Broglie wavelength, about $10^{-11}$ m, is tens of thousands of times shorter than that of visible light (1), so diffraction only limits the electron microscope at a far smaller scale and it can resolve much finer detail (1). [3]