inkPhysics

ANSWER BOOK

Quanta and wave-particle duality

Turning points · Year 13

AQA 3.12.2.4, 3.12.2.5, 3.12.2.6

10 questions · 28 marks

NAVY EDITION

SECTION A · Warm-up

A1 Classical wave theory predicts that a black body's radiated intensity should rise without limit at short wavelengths, toward the ultraviolet, in complete contradiction of the measured curve, which peaks and falls. [2]

A2 Energy is emitted and absorbed in quanta of size $E = hf$. High-frequency quanta are expensive, so the short-wavelength modes are starved of energy and the curve turns over as observed. [2]

A3 Any two of: the existence of a threshold frequency; emission is immediate, with no time to accumulate wave energy; increasing intensity raises the number of electrons but never their maximum kinetic energy. [2]

SECTION B · Standard

B1 $\lambda = h/\sqrt{(2meV)} = 6.63 \times 10^{-34}/\sqrt{(2 \times 9.11 \times 10^{-31} \times 1.60 \times 10^{-19} \times 150)} = 1.0 \times 10^{-10}$ m: the size of an atom. [3]

B2 $\lambda = h/\sqrt{(2meV)} = 1.7 \times 10^{-11}$ m: raising the pd shortens the wavelength, as $\lambda \propto 1/\sqrt{V}$. [3]

B3 $\lambda \propto 1/\sqrt{V}$, so the wavelength falls to a third of its value, and the diffraction rings shrink to a third of their radius: faster electrons, more momentum, shorter matter waves, tighter pattern. [3]

B4 Einstein took light itself to travel as quanta, photons of energy hf, one photon releasing one electron. Its success showed that electromagnetic radiation, so recently established as a wave, also behaves as particles: wave-particle duality for light. [3]

SECTION C · Stretch

C1 $V = h^2/(2me\lambda^2) = (6.63 \times 10^{-34})^2/(2 \times 9.11 \times 10^{-31} \times 1.60 \times 10^{-19} \times (5.0 \times 10^{-11})^2) = 603$ V: a few hundred volts suffices for atomic resolution. [4]

C2 An electron gun fires a beam down an evacuated column; magnetic coils act as lenses, condensing the beam through a very thin specimen and projecting the transmitted electrons onto a fluorescent screen. Denser regions scatter more electrons and appear darker, and the short de Broglie wavelength allows detail far beyond any light microscope. [3]

C3 A tip sharpened almost to a single atom is held about a nanometre above a conducting surface, close enough for electrons to tunnel across the gap. The tunnelling current falls extremely steeply with distance, so scanning the tip across the surface and monitoring the current maps its atoms. [3]