

Exercise walk-through

21.2

Quantum physics (full E.2, HL)

International Baccalaureate · IB Diploma · Physics · HL

Quantum · 2.1

Reasoning

A photon has energy proportional to frequency. The work function is the minimum energy needed to release an electron from a surface. Above threshold, excess photon energy can become electron kinetic energy. photon: A quantum of electromagnetic radiation; work function: Minimum surface energy needed to release an electron.

Quantum · 3.1

Reasoning

Use photon energy = Planck constant $\times$ frequency. Maximum kinetic energy = photon energy - work function. Increasing intensity at fixed frequency increases photon arrival rate, not individual photon energy. Read axes carefully on a stopping-potential or kinetic-energy graph. Identify threshold frequency from the zero-energy intercept. State the metal and experimental conditions because work function is material-specific.

Threshold cannot be overcome by intensity

- 1 Set the model** A metal has work function 2.3 eV . Incident photons have energy 2.9 eV .
- 2 Calculate** Maximum kinetic energy $= 2.9 - 2.3 = 0.6 \text{ eV}$. Below $f_0 = \Phi/h$, the elementary single-photon model predicts no emission.

Decision

Greater intensity at fixed frequency increases photon arrival rate, not photon energy.
Matter waves obey $\lambda = h/p$.

Exercises 2.1-2.3

2.1 State the photoelectric equation, defining each symbol. [2]

2.2 Give two observations of the photoelectric effect that the classical wave theory of light cannot explain. [2]

2.3 State the de Broglie hypothesis. [1]

Exercises 2.1·2.3

2.1 State the photoelectric equation, defining each symbol. [2]

2.1 $E_{max} = hf - \Phi$: maximum photoelectron kinetic energy equals photon energy minus the metal's work function – the minimum energy to release an electron.

2.2 Give two observations of the photoelectric effect that the classical wave theory of light cannot explain. [2]

2.2 Any two of: emission is instantaneous even in dim light; no emission below a threshold frequency regardless of intensity; maximum electron energy depends on frequency, not intensity.

2.3 State the de Broglie hypothesis. [1]

2.3 A particle of momentum p has a wavelength $\lambda = h/p$ – matter behaves as a wave.

Exercises 2.4·3.2

2.4 In Compton scattering, state what happens to the wavelength of a photon scattered off an electron at 180° . [1]

3.1 Light of frequency 6.0×10^{14} Hz strikes a metal of work function 1.9 eV. Calculate the photon energy in eV and the maximum kinetic energy of the photoelectrons. [4]

3.2 An electron beam accelerated through 54 V shows a diffraction maximum from a nickel crystal. Calculate the electron speed from $\frac{1}{2}mv^2 = eV$ and its de Broglie wavelength, and compare with an atomic spacing of about 0.2 nm. [5]

Exercises 2.4.3.2

2.4 In Compton scattering, state what happens to the wavelength of a photon scattered off an electron at 180° . [1]

2.4 The wavelength increases by the maximum shift $2h/m_e c \approx 4.9 \times 10^{-12}$ m.

3.1 Light of frequency 6.0×10^{14} Hz strikes a metal of work function 1.9 eV. Calculate the photon energy in eV and the maximum kinetic energy of the photoelectrons. [4]

3.1 $E = hf = (6.6 \times 10^{-34} \times 6.0 \times 10^{14}) = 4.0 \times 10^{-19}$ J = 2.5 eV; $E_{max} = 2.5 - 1.9 = 0.6$ eV.

3.2 An electron beam accelerated through 54 V shows a diffraction maximum from a nickel crystal. Calculate the electron speed from $\frac{1}{2}mv^2 = eV$ and its de Broglie wavelength, and compare with an atomic spacing of about 0.2 nm. [5]

3.2 $\frac{1}{2}mv^2 = eV$: $v = \sqrt{2eV/m} = \sqrt{(2 \times 1.6 \times 10^{-19} \times 54)/(9.1 \times 10^{-31})} = \sqrt{1.9 \times 10^{13}} = 4.4 \times 10^6$ m/s; $\lambda = h/mv = (6.6 \times 10^{-34})/(9.1 \times 10^{-31} \times 4.4 \times 10^6) = 1.7 \times 10^{-10}$ m = 0.17 nm; comparable with the 0.2 nm atomic spacing, so diffraction is strong – the pattern appears where the spacing and wavelength match.

Exercises 3.3-3.4

3.3 Explain why Compton scattering is described as evidence for the particle nature of light, and why the shift depends on the scattering angle. [3]

3.4 A metal has work function 2.5 eV. Calculate its threshold frequency, and state what is observed when light of twice that frequency illuminates it. [3]

Exercises 3.3-3.4

3.3 Explain why Compton scattering is described as evidence for the particle nature of light, and why the shift depends on the scattering angle. [3]

3.3 The wavelength shift means each photon lost energy in a collision with a single electron – a particle–particle interaction transferring energy and momentum; a wave would spread its energy continuously, giving no discrete shift; at larger scattering angles the photon transfers more momentum to the electron, losing more energy – hence a larger $\Delta\lambda = (h/m_e c)(1 - \cos \theta)$.

3.4 A metal has work function 2.5 eV. Calculate its threshold frequency, and state what is observed when light of twice that frequency illuminates it. [3]

3.4 $f_0 = \Phi/h = (2.5 \times 1.6 \times 10^{-19})/(6.6 \times 10^{-34}) = 6.1 \times 10^{14}$ Hz; at $2f_0$ photons carry $2\Phi = 5.0$ eV, so photoelectrons are emitted instantly with maximum kinetic energy $5.0 - 2.5 = 2.5$ eV.