

Solutions

Original-task marking: M1 method, A1 accuracy, B1 reasoning.

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

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

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 $\frac{1}{2}mv^2 = eV$: $v = \sqrt{2eV/m} = \sqrt{(2 \times 1.6 \times 10^{-19} \times 54)/(9.1 \times 10^{-31})} = \sqrt{1.9 \times 10^{13}} = 4.4 \times 10^6$ 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.

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 $f_0 = \Phi/h = (2.5 \times 1.6 \times 10^{-19})/(6.6 \times 10^{-34}) = 6.1 \times 10^{14}$ 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.