

E.2 Quantum physics

Practice Worksheet – name: _____ date: _____

FORMULAS FOR THIS TOPIC

PHOTOELECTRIC EQUATION $E_{\max} = hf - \Phi$ PHOTON ENERGY $E = hf = \frac{hc}{\lambda}$ DE BROGLIE WAVELENGTH $\lambda = \frac{h}{p} = \frac{h}{mv}$ COMPTON SCATTERING $\lambda' - \lambda = \frac{h}{m_e c} (1 - \cos \theta)$

SECTION A — MULTIPLE CHOICE

A1. Doubling the intensity of light above the threshold frequency shining on a metal surface:

- A Doubles the maximum kinetic energy of the photoelectrons
- B Doubles the number of photoelectrons emitted per second
- C Halves the work function
- D Doubles the stopping potential

A2. Light of photon energy 3.0 eV strikes a metal of work function 2.0 eV. The stopping potential is:

- A 5.0 V
- B 3.0 V
- C 2.0 V
- D 1.0 V

A3. An electron and a proton have the same de Broglie wavelength. They must have the same:

- A Speed
- B Kinetic energy
- C Momentum
- D Mass

SECTION B — SHORT ANSWER

B1. State two observations of the photoelectric effect that cannot be explained by the wave model of light, and explain how the photon model accounts for each. [4 marks]

B2. Calculate the de Broglie wavelength of an electron accelerated through 150 V. [3 marks]

B3. In Compton scattering, explain why the scattered photon has a longer wavelength, and state the angle at which the shift is greatest. [3 marks]

ANSWER KEY

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Section A

A1: Doubles the number of photoelectrons emitted per second — Intensity means more photons per second, hence more electrons per second — but each photon still carries hf , so $E_{max} = hf - \Phi$ (and the stopping potential) is unchanged. This is precisely what the wave model cannot explain.

A2: $1.0 \text{ V} - E_{max} = 3.0 - 2.0 = 1.0 \text{ eV}$, and the stopping potential in volts equals the maximum kinetic energy in electronvolts: $V_s = 1.0 \text{ V}$.

A3: Momentum — $\lambda = h/p$ depends only on momentum. Equal wavelengths mean equal momenta — the lighter electron must be moving much faster, and (at these non-relativistic speeds) carries far more kinetic energy.

Section B

B1: (1) A threshold frequency exists: below it no electrons are emitted regardless of intensity. Photon model: one photon delivers all its energy to one electron; if $hf < \Phi$, no single photon can free an electron. (2) Emission is instantaneous even in dim light: energy arrives in concentrated packets rather than accumulating gradually over the surface. (Also acceptable: E_{max} depends on frequency, not intensity.)

B2: $E_k = eV = 150 \text{ eV} = 2.4 \times 10^{-17} \text{ J}$. Momentum: $p = \sqrt{2mE_k} = \sqrt{2(9.11 \times 10^{-31})(2.4 \times 10^{-17})} \approx 6.6 \times 10^{-24} \text{ kg m s}^{-1}$. Then $\lambda = h/p \approx 1.0 \times 10^{-10} \text{ m}$ — atomic spacing, which is why crystals diffract electrons.

B3: The photon transfers some of its energy and momentum to the recoiling electron in an elastic collision. Less energy means, via $E = hc/\lambda$, a longer wavelength. The shift $\Delta\lambda = \frac{h}{m_e c}(1 - \cos\theta)$ is maximal at $\theta = 180^\circ$ (backscattering), where it equals twice the Compton wavelength.