Topic 22.2 — The Photoelectric Effect

Cambridge International AS & A Level Physics 9702 — Simulation Worksheet — **Mark Scheme**

Constants: $h = 6.63 \times 10^{-34}$ J s $c = 3.00 \times 10^{8}$ m s^{-1} $e = 1.60 \times 10^{-19}$ C $m_e = 9.11 \times 10^{-31}$ kg

General guidance: Award marks as shown. Accept any physically correct equivalent answer. Sections A–D are simulation-based; accept values within ±5% of expected readings. Mark numericals consequentially where a student applies their own measured value correctly.

Section A — Threshold Wavelength

1. Expected values for threshold wavelength table (accept ±10 nm):

Metal	λ_0 / nm	Φ / J	Φ / eV
Caesium (Cs)	590	3.36×10^{-19}	2.10
Potassium (K)	539	3.69×10^{-19}	2.30
Zinc (Zn)	288	6.90×10^{-19}	4.30
Copper (Cu)	267	7.44×10^{-19}	4.65
Gold (Au)	243	8.16×10^{-19}	5.10
Platinum (Pt)	219	9.06×10^{-19}	5.65

Example (Cs): $\Phi = hc/\lambda_0 = (6.63 \times 10^{-34} \times 3.00 \times 10^{8})/(590 \times 10^{-9}) = 3.37 \times 10^{-19}$ J $= 2.11$ eV. Award marks for correct method with values consistent with the student's λ_0.

2. [2]

Caesium and Potassium only. [1]
Their threshold wavelengths (590 nm and 539 nm) lie within the visible range (400–700 nm), so visible photons have sufficient energy to exceed the work function. [1]

Zn, Cu, Au and Pt all have λ_0 in the UV; visible photons cannot eject electrons from them.

3. [2]

Example for Cs, $\lambda_0 = 590$ nm:

$$\Phi = \frac{hc}{\lambda_0} = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{590 \times 10^{-9}} = 3.37 \times 10^{-19} \text{ J}$$

Correct substitution into $\Phi = hc/\lambda_0$. [1] Correct conversion: $3.37 \times 10^{-19}/1.60 \times 10^{-19} = 2.11$ eV. [1]

Section B — Effect of Wavelength

4.

(a) [2]
Photon energy $E = hc/\lambda$ increases as wavelength decreases. [1]
Shorter wavelength means higher frequency and greater energy per photon, consistent with $E \propto 1/\lambda$. [1]

(b) [2]
$E_{k\,\max} = hc/\lambda - \Phi$ increases as λ decreases. [1]
Photon energy increases while the work function remains constant, so more energy is available as kinetic energy. [1]

(c) [3]
The ammeter reading decreases as wavelength decreases. [1]
At constant intensity the total energy arriving per second is fixed; as each photon carries more energy ($E = hc/\lambda$), fewer photons arrive per second. [1]
Fewer photons means fewer photoelectrons emitted per second, so the current decreases. [1]

5. [3]
Electron emission stops immediately / abruptly when $\lambda > \lambda_0$. [1]
Each photon must supply energy $hc/\lambda \geq \Phi$ to liberate one electron. [1]
Energy is transferred in discrete quanta — if a single photon has insufficient energy, no accumulation across photons can release the electron, so there is no gradual decrease. [1]

6. [2]
Photons are shown as localised, finite wave packets — they occupy a limited region of space. [1]
This suggests light delivers energy in discrete, concentrated bursts rather than as a continuous wave, consistent with the photon model. [1]

Section C — Effect of Intensity

7. [3]
The ammeter reading increases as intensity increases. [1]
Greater intensity means more photons arrive at the cathode per second. [1]
Each photon releases one photoelectron, so more electrons reach the anode per second, giving a larger current. [1]

8. [3]
$E_{k\,\max}$ does not change as intensity varies. [1]
Intensity controls the number of photons arriving per second, not the energy of each photon. [1]
Each photon still carries hc/λ, so $E_{k\,\max} = hc/\lambda - \Phi$ is unchanged. [1]

9. [3]

The threshold wavelength for Platinum is approximately 219 nm, which is less than 225 nm. [1]
At 225 nm the photon energy is below Φ_{Pt}, so no electrons are emitted regardless of intensity. [1]
Increasing intensity increases the photon rate but each photon still has insufficient energy to liberate an electron; the claim is incorrect. [1]

Mark consequentially if the student's table gives $\lambda_0 > 225$ nm for Pt — their conclusion should then be that emission does occur.

Section D — Stopping Voltage

10.

Expected: $E_{k\,\max} = hc/\lambda - \Phi = 6.22 - 4.30 = 1.92$ eV, so $V_s \approx 1.92$ V. Accept simulation reading in the range 1.8–2.0 V.

11. [3]

$$\frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{200 \times 10^{-9}} = 9.95 \times 10^{-19}\ \mathrm{J} = 6.22\ \mathrm{eV}$$

Correct photon energy calculation. [1]

$$E_{k\,\max} = 6.22 - 4.30 = 1.92\ \mathrm{eV} \quad \Rightarrow \quad V_s = 1.92\ \mathrm{V}$$

Correct subtraction of work function. [1] V_s consistent with simulation reading. [1]

12. [2]

The current increases. [1]
Reducing the stopping voltage below V_s means fewer electrons are decelerated to a halt; more electrons reach the anode per second, so the current rises. [1]

13.

(a) [2]

The stopping voltage will be **larger** for Caesium. [1]
Cs has a smaller work function (2.10 eV vs 4.30 eV for Zn), so $E_{k\,\max} = hc/\lambda - \Phi$ is larger, requiring a higher voltage to stop the fastest electrons. [1]

(b) [1]

Expected: $V_s = 6.22 - 2.10 = \mathbf{4.12}$ V for Cs (compared to 1.92 V for Zn). [1]
Accept simulation reading in the range 4.0–4.3 V.

Section E — Examination-Style Questions

14.

(a) [2]

$$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{350 \times 10^{-9}} = 5.68 \times 10^{-19}\ \text{J}$$

Correct formula. [1] Correct answer 5.68×10^{-19} J. [1]

(b) [2]

$$E_{k\,\max} = \frac{5.68 \times 10^{-19}}{1.60 \times 10^{-19}} - 2.10 = 3.55 - 2.10 = \mathbf{1.45}\ \text{eV}$$

Correct conversion and subtraction of Φ. [1] Answer 1.45 eV. [1]

(c) [2]

$$eV_s = E_{k\,\max} \quad \Rightarrow \quad V_s = \mathbf{1.45}\ \text{V}$$

Correct use of $eV_s = E_{k\,\max}$. [1] Answer 1.45 V. [1]

(d) [2]

The stopping voltage increases. [1]
Shorter wavelength means higher photon energy, so $E_{k\,\max} = hc/\lambda - \Phi$ is larger and a higher V_s is needed to stop the fastest electrons. [1]

15. [4]

(i) $E_{k\,\max}$ is **unchanged**. [1] Wavelength (and hence photon energy hc/λ) is constant and Φ is fixed, so $E_{k\,\max} = hc/\lambda - \Phi$ does not change. [1]

(ii) Rate of emission **increases**. [1] Greater intensity means more photons per second; each photon with $hc/\lambda \geq \Phi$ releases one electron, so more electrons are emitted per second. [1]

16. [4]

Stopping voltage read from simulation. [1]
Accept V_s in range 3.0–3.4 V.

Correct rearrangement of $eV_s = hc/\lambda - \Phi$ to give $h = (eV_s + \Phi e)\lambda/c$. [1]
Correct substitution of their V_s, $\lambda = 150 \times 10^{-9}$ m, $\Phi = 5.10$ eV and $e = 1.60 \times 10^{-19}$ C. [1]
Answer in range 6.4–6.8 $\times 10^{-34}$ J s. [1]

Example using $V_s = 3.19$ V:

$$h = \frac{(1.60 \times 10^{-19} \times 3.19 + 5.10 \times 1.60 \times 10^{-19}) \times 150 \times 10^{-9}}{3.00 \times 10^{8}} = 6.63 \times 10^{-34}\ \text{J s}$$

Mark consequentially if the student uses a slightly different V_s from the simulation, provided the method is correct.