Unit 21 · Photons

HARDER PRACTICE QUESTIONS · ANSWER KEY

Full marks 32

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Spot the error

ANSWER U · 3

She subtracted a work function in **electron volts** from a photon energy in **joules**. In joules, $\varphi = 2.0 \times 1.6 \times 10^{-19} = 3.2 \times 10^{-19}$ J, and hf $= 4.97 \times 10^{-19}$ J, so $E_k = \mathbf{1.8 \times 10^{-19}\ J}$ (1.1 eV): electrons do come out.

MARKING SCHEME

- ✓ The error: units mixed (eV and J).
- ✓ $\varphi = 3.2 \times 10^{-19}$ J and hf $= 4.97 \times 10^{-19}$ J.
- ✓ $E_k = 1.8 \times 10^{-19}$ J; electrons are emitted.

2 Read the data

ANSWER HA · 4

(The readings are made up, for a metal of work function 2.06 eV.)

i. Slope $= (1.67 - 0.22) \div (9.0 - 5.5) \times 10^{14} = \mathbf{4.14 \times 10^{-15}\ V\ s}$.

ii. h = e × slope $= 1.6 \times 10^{-19} \times 4.14 \times 10^{-15} = \mathbf{6.6 \times 10^{-34}\ J\ s}$.

iii. Going back $0.22 \div 4.14 \times 10^{-15} = 0.53 \times 10^{14}$ Hz from 5.5×10^{14} Hz: $f_0 \approx \mathbf{5.0 \times 10^{14}\ Hz}$; $\varphi = \mathrm{hf}_0 \approx \mathbf{3.3 \times 10^{-19}\ J}$ (2.1 eV).

iv. It is below the threshold, so **no** electrons come out, however bright it is.

MARKING SCHEME

- ✓ Slope 4.14×10^{-15} V s.
- ✓ h $= 6.6 \times 10^{-34}$ J s.
- ✓ $f_0 \approx 5.0 \times 10^{14}$ Hz and $\varphi \approx 2.1$ eV.
- ✓ No emission at 4.5×10^{14} Hz.

3 Predict, then explain

MARKING SCHEME U · 3

- ✓ Greatest kinetic energy rises (hf larger).
- ✓ Saturation current falls.
- ✓ Same power in bigger packets means fewer photons each second.

4 Show that

MARKING SCHEME A · 3

- ✓ $\lambda_0 = hc/\varphi$ with $\varphi = \varphi(\mathrm{eV}) \times \mathrm{e}$.
- ✓ hc/e $= 1.24 \times 10^{-6}$ V m, so $1240/\varphi$ in nm.
- ✓ 400 nm.

5 Estimate it

ANSWER A · 3

Each photon $\approx 2 \times 1.6 \times 10^{-19} = 3.2 \times 10^{-19}$ J, so n $\approx 1000 \div 3.2 \times 10^{-19} \approx \mathbf{3 \times 10^{21}\ photons\ a\ second}$. With so many, each carrying so little, the flow seems smooth, just as a river seems smooth though it is made of molecules.

MARKING SCHEME

- ✓ Photon energy 3.2×10^{-19} J.
- ✓ About 3×10^{21} a second.
- ✓ So many tiny packets that the light seems continuous.

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6 Which explanation fits?

MARKING SCHEME U · 2

✓ B, photons.

✓ A wave would need time to build up energy in dim light; a photon acts at once.

7 Correct the misconceptions

ANSWER U · 3

1. Light below the threshold frequency frees **no** electrons, however bright.
2. They leave with a **range** of kinetic energies, up to a greatest value $hf - \varphi$ (those from deeper inside lose some energy on the way out).
3. The work function **differs** from metal to metal (cesium about 1.9 eV, copper about 4.5 eV).

MARKING SCHEME

✓ No emission below the threshold frequency.

✓ A range of energies up to hf $- \varphi$.

✓ Each metal has its own work function.

8 Work backwards

ANSWER A · 3

$E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 9.1 \times 10^{-31} \times (6.0 \times 10^5)^2 = 1.64 \times 10^{-19}$ J; $hf = \frac{hc}{\lambda} = 5.23 \times 10^{-19}$ J. $\varphi = 5.23 - 1.64 = 3.6 \times 10^{-19}$ J = **2.2 eV**.

MARKING SCHEME

✓ $E_k = 1.64 \times 10^{-19}$ J.

✓ hf $= 5.23 \times 10^{-19}$ J.

✓ $\varphi = 3.6 \times 10^{-19}$ J = 2.2 eV.

9 Design it

ANSWER A · 4

i. Blue: 1240 ÷ 450 ≈ **2.76 eV**; red: 1240 ÷ 650 ≈ **1.91 eV**.

ii. **Lithium**: 2.76 eV is more than 2.5 eV, so blue frees electrons, but 1.91 eV is less, so red doesn't. Cesium (1.9 eV) would respond to the red too; copper (4.5 eV) to neither.

iii. 2.76 − 2.5 ≈ **0.26 V**.

MARKING SCHEME

✓ 2.76 eV and 1.91 eV.

✓ Lithium chosen.

✓ Cesium responds to red too; copper to neither.

✓ $V_s \approx 0.26$ V.

10 What if?

ANSWER HA · 2

The stopping potential **falls**: each photon has less energy, so $hf - \varphi$ is smaller. The saturation current **rises**: twice the power in slightly smaller photons means more than twice as many photons each second, so more electrons.

MARKING SCHEME

✓ Stopping potential falls (smaller hf).

✓ Saturation current rises (more photons each second).

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11 Make your own

ANSWER HA · 2

For example: “Light of wavelength 310 nm falls on a metal of work function 2.5 eV. Find the stopping potential.” hf = 1240 ÷ 310 = 4.0 eV, so $V_s = 4.0 - 2.5 = 1.5$ V. Any numbers with hf $- \varphi = 1.5$ eV are right.

MARKING SCHEME

- ✓ A sensible problem.
- ✓ Solved correctly to 1.5 V with $eV_s = hf - \varphi$.

See it at Science Playground

Exhibits and plants at the center, Bhaktapur, that go with this unit. Book a class visit at science-playground.com/booking.

- **Glowing Wire Sculptures** (exhibit): Ultraviolet makes the coating glow with visible light: each UV photon, E = hf, carries more energy than each visible photon the coating gives back.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	0	11	13	8	**32**

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