Unit 21 · Photons

ANSWER KEY · FOR TEACHERS

Full marks 34

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

1 Key words

K · 4

i. ✓ **True**
ii. ✗ **False**: It gives more photoelectrons each second; their greatest kinetic energy stays the same.
iii. ✓ **True**
iv. ✓ **True**
v. ✗ **False**: It depends on the frequency of the light (and the metal), not its intensity.
vi. ✗ **False**: They come out at once, however dim the light.
vii. ✓ **True**
viii. ✗ **False**: The electrons are freed inside the silicon (the photovoltaic effect); none leaves the surface.

Each carries 0.5 mark.

2 Label the diagram

K · 2

1. vacuum
2. photoelectrons
3. μA
4. variable supply

Each carries 0.5 mark.

3 Multiple choice

i. **b.** 2.5 eV — A · 1

$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{500 \times 10^{-9}} = 3.98 \times 10^{-19}$ J, and $\div 1.6 \times 10^{-19}$ gives 2.5 eV.

ii. **c.** 620 nm — A · 1

$\lambda_0 = \frac{hc}{\varphi} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{2.0 \times 1.6 \times 10^{-19}} = 6.2 \times 10^{-7}$ m = 620 nm. Light of longer wavelength frees no electrons.

iii. **d.** 0.8 V — A · 1

$E_{k,\max} = hf - \varphi = 3.0 - 2.2 = 0.8$ eV, so the stopping potential is 0.8 V.

iv. **a.** 1.1×10^{-27} kg m/s — A · 1

$p = h/\lambda = 6.63 \times 10^{-34} \div 600 \times 10^{-9} = 1.1 \times 10^{-27}$ kg m/s. A photon has no rest mass but it does carry momentum.

v. **a.** are parallel, with slope h, but cross the frequency axis at different places — U · 1

$E_{k,\max} = hf - \varphi$: every line has slope h, and each meets the frequency axis at its own threshold frequency $f_0 = \varphi/h$.

4 Short answers

a. MARKING SCHEME — U · 2

✓ Wave theory: enough intensity (or time) at any frequency should free electrons.
✓ Observed: no emission below f_0 at any intensity; explained by one photon of energy hf per electron.

b. MARKING SCHEME — U · 2

✓ Energy comes in whole photons of hf, each given to one electron at once.
✓ Dim light means fewer photons (fewer electrons), not a delay.

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c. MARKING SCHEME U · 2

✓ A more positive collector gathers more of the emitted electrons.

✓ When it gathers them all the current saturates (set by the number emitted each second).

5 Long answer

ANSWER U · 4

$hf = \varphi + E_{k,\max}$, and the stopping potential V_s just stops the fastest electrons: $eV_s = E_{k,\max}$. So $eV_s = hf - \varphi$ and $V_s = \frac{h}{e}f - \frac{\varphi}{e}$, a straight line. Its slope is h/e, the same for every metal, and it meets the frequency axis where $V_s = 0$, at the threshold frequency $f_0 = \varphi/h$. Millikan measured V_s at many frequencies for clean metal surfaces, found a straight line, and from its slope found h (multiplying by the known e), which agreed with Planck's value; the intercept gave the work function.

MARKING SCHEME

✓ $eV_s = hf - \varphi$.

✓ $V_s = (h/e)f - \varphi/e$, a straight line.

✓ Slope h/e; intercept on the frequency axis $f_0 = \varphi/h$.

✓ Millikan's line gave h (and φ).

6 Numerical problems

a. ANSWER A · 4

i. $E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{420 \times 10^{-9}} = 4.74 \times 10^{-19}$ J = **2.96 eV**.

ii. $E_{k,\max} = 2.96 - 2.25 =$ **0.71 eV** (1.14×10^{-19} J).

iii. $V_s =$ **0.71 V**.

iv. $v = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2 \times 1.14 \times 10^{-19}}{9.1 \times 10^{-31}}} =$ **5.0×10^5 m/s**.

MARKING SCHEME

✓ Photon energy 2.96 eV.

✓ $E_{k,\max} = 0.71$ eV.

✓ $V_s = 0.71$ V.

✓ v = 5.0×10^5 m/s.

b. ANSWER A · 3

Each photon: $E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{650 \times 10^{-9}} = 3.06 \times 10^{-19}$ J.

$n = \frac{P}{E} = \frac{3.0 \times 10^{-3}}{3.06 \times 10^{-19}} =$ **9.8×10^{15} photons a second**.

MARKING SCHEME

✓ E = hc/λ = 3.06×10^{-19} J.

✓ n = P/E.

✓ About 9.8×10^{15} a second.

c. ANSWER A · 3

$eV_s = hf - \varphi$ at both: subtracting, $e(1.23 - 0.40) = h(8.0 - 6.0) \times 10^{14}$, so $h = \frac{1.6 \times 10^{-19} \times 0.83}{2.0 \times 10^{14}} =$ **6.6 $\times 10^{-34}$ J s**.

$\varphi = hf - eV_s = 6.63 \times 10^{-34} \times 6.0 \times 10^{14} - 1.6 \times 10^{-19} \times 0.40 =$ **3.3×10^{-19} J** (2.1 eV).

MARKING SCHEME

✓ Two equations $eV_s = hf - \varphi$, subtracted.

✓ h = 6.6×10^{-34} J s.

✓ $\varphi = 3.3 \times 10^{-19}$ J (2.1 eV).

7 Think

ANSWER

In the photoelectric effect one photon gives all its energy to one electron. An electron that takes in a 1.2 eV photon still lacks 0.7 eV, and the energy is lost (as heat) before a second photon could reach the

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same electron. A hundred times brighter means a hundred times as many photons, but each still has only 1.2 eV, so still **no** electrons come out (the metal only warms up).

MARKING SCHEME

- ✓ One photon gives its energy to one electron.
- ✓ 1.2 eV is less than the work function, so no electron escapes.
- ✓ Brighter light: more photons of the same energy, still no emission.

8 Activity: Light, a solar cell and a meter

(not marked)

WHAT STUDENTS SHOULD FIND

The reading rises the brighter the light and falls as the torch moves back; under black paper it drops to zero. Filters cut it. It is **not** photoelectric emission: no electron leaves the panel's surface. It is the photovoltaic effect, photons freeing electrons inside the silicon, but it rests on the same idea, one photon freeing one electron, so more light (more photons) gives more current.

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	6	11	14	3	**34**

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