inkPhysics

ANSWER BOOK

The photoelectric effect

Quantum phenomena · Year 12

AQA 3.2.2.1 · CIE 22.1.1, 22.1.2, 22.1.3, 22.1.4, 22.1.5, 22.2.1, 22.2.2, 22.2.3, 22.2.4, 22.2.5
OCR A 4.5.1(a), 4.5.1(b), 4.5.1(c), 4.5.1(d), 4.5.1(e)(i), 4.5.2(a)(i), 4.5.2(b), 4.5.2(c), 4.5.2(d), 4.5.2(e), 4.5.2(f)

19 questions · 58 marks

NAVY EDITION

SECTION A · Warm-up

A1 There is a threshold frequency below which no electrons are emitted whatever the intensity (1). The maximum kinetic energy of the emitted electrons depends on the frequency of the light, not on its intensity (1). (Also accept: emission is instantaneous even in very dim light.) [2]

A2 $E = hf = 6.63 \times 10^{-34} \times 5.0 \times 10^{14}$ (1)
$E = 3.31 \times 10^{-19}$ J (1) [2]

A3 The work function is the minimum energy needed (1) to release an electron from the surface of the metal (1). [2]

A4 Photon energy $E = hf = 6.63 \times 10^{-34} \times 9.0 \times 10^{14} = 5.97 \times 10^{-19}$ J (1). This is less than the work function, and at ordinary intensities an electron absorbs only one photon, so no photon supplies enough energy to release an electron; greater intensity means more photons, not more energetic ones (1). [2]

A5 The Planck constant h (1). [1]

A6 The number emitted per second doubles (1), because the number of photons arriving per second doubles and each emission needs one photon (1). [2]

SECTION B · Standard

B1 At the threshold, $hf_0 = \varphi$, so $f_0 = \varphi/h$ (1)
$= (3.2 \times 10^{-19})/(6.63 \times 10^{-34})$ (1)
$f_0 = 4.83 \times 10^{14}$ Hz (1) [3]

B2 (a) $E_{k(max)} = hf - \varphi$ (1)
$= 6.63 \times 10^{-34} \times 8.0 \times 10^{14} - 3.0 \times 10^{-19} = 2.30 \times 10^{-19}$ J (1)
(b) $v = \sqrt{(2E_k/m)}$ (1)
$v = 7.11 \times 10^{5}$ m s^{-1} (1) [4]

B3 $E = (3.31 \times 10^{-19})/(1.60 \times 10^{-19})$ (1)
$E = 2.07$ eV (1) [2]

B4 At the stopping potential the most energetic electrons are just turned back, so $eV_s = E_{k(max)}$ (1)
$V_s = E_{k(max)}/e = (2.30 \times 10^{-19})/(1.60 \times 10^{-19})$ (1)
$V_s = 1.44$ V (1) [3]

B5 The intercept on the frequency axis is the threshold frequency, so $\varphi = hf_0$ (1). $\varphi = 6.63 \times 10^{-34} \times 4.6 \times 10^{14} = 3.05 \times 10^{-19}$ J (1) = 1.9 eV (1). [3]

B6 At the stopping potential $eV_s = E_{k(max)}$, so $\varphi = hf - eV_s$ (1). $\varphi = 6.63 \times 10^{-34} \times 7.5 \times 10^{14} - 1.60 \times 10^{-19} \times 0.60 = 4.01 \times 10^{-19}$ J (1) = 2.5 eV (1). [3]

B7 Photon energy $E = hc/\lambda = (6.63 \times 10^{-34} \times 3.0 \times 10^{8})/(500 \times 10^{-9}) = 3.98 \times 10^{-19}$ J = 2.49 eV (1). $E_{k(max)} = E - \varphi = 2.49 - 1.9 = 0.59$ eV (1) = 9.4×10^{-20} J (1). [3]

SECTION C · Stretch

C1 [4]

$\varphi = 2.0 \times 1.60 \times 10^{-19} = 3.20 \times 10^{-19}$ J (1)

$\lambda_0 = hc/\varphi$ (1)

$= (6.63 \times 10^{-34} \times 3.0 \times 10^{8})/(3.20 \times 10^{-19})$ (1)

$\lambda_0 = 622$ nm (1)

C2 [4]

Photon energy $E = hc/\lambda = (6.63 \times 10^{-34} \times 3.0 \times 10^{8})/(400 \times 10^{-9})$ (1)

$E = 4.97 \times 10^{-19}$ J (1)

(a) $E_{k(max)} = E - \varphi = 4.97 \times 10^{-19} - 3.20 \times 10^{-19} = 1.77 \times 10^{-19}$ J (1)

(b) $V_s = E_{k(max)}/e = 1.11$ V (1)

C3 Each electron is emitted by absorbing a single photon, and a photon's energy depends only on frequency ($E = hf$) (1). Increasing intensity delivers more photons per second, so more electrons are emitted (1), but each still carries the same energy, so the maximum kinetic energy is unchanged (1). [3]

C4 The least energetic visible photon is at 700 nm: $E = hc/\lambda = 2.84 \times 10^{-19}$ J = 1.8 eV (1). To respond across the whole range, the work function must not exceed this photon energy (1). Y emits only for wavelengths below $hc/\varphi = 565$ nm, and Z only for ultraviolet, so neither covers the range (1). Coating X (1.4 eV < 1.8 eV) emits for all visible wavelengths, so the student should choose X (1). [4]

C5 Photon energy $E = hc/\lambda = (6.63 \times 10^{-34} \times 3.0 \times 10^{8})/(365 \times 10^{-9}) = 5.45 \times 10^{-19}$ J (1). Photons per second = $P/E = (2.4 \times 10^{-3})/(5.45 \times 10^{-19}) = 4.4 \times 10^{15}$ s^{-1} (1). Electrons per second = $4.4 \times 10^{15}/120 = 3.7 \times 10^{13}$ s^{-1} (1). Current I = electrons per second × e (1) = 5.9×10^{-6} A, about 5.9 μA (1). [5]

C6 An ultraviolet photon has energy hf greater than the work function of zinc (1), so each photon absorbed at the surface releases one electron from the plate (1). The plate gradually loses its negative charge, so the leaf falls (1). A visible photon has energy less than 6.9×10^{-19} J: its frequency is below the threshold frequency (1). At the intensities of an ordinary lamp an electron absorbs only one photon, so no electron gains enough energy to escape and energy cannot accumulate over time (1). Increasing the intensity increases the number of photons, not the energy of each, so no electrons are released and the leaf stays up (1). (Multiphoton absorption below the threshold is possible under an intense pulsed laser, but not with any ordinary light source.) [6]