

Photons, work functions and matter waves

AP Physics 2 (algebra-based) · Worksheet answers

Each answer shows the relationship, the substitution and the result with its unit. Use $hc = 1240 \text{ eV}\cdot\text{nm}$ and $1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$. Check whether you reasoned with the energy of one photon, not the energy of the whole beam.

Level: AP Physics 2 (algebra-based) · **Curriculum:** AP P2 Unit 15

Problem 1 Photon energy from frequency

- $E = hf = 6.63 \times 10^{-34} \times 5.0 \times 10^{14} = \mathbf{3.3 \times 10^{-19} \text{ J}}$.
- $3.3 \times 10^{-19} / 1.60 \times 10^{-19} = \mathbf{2.07 \text{ eV}}$.

Problem 2 Converting energy units

- $3.20 \times 1.60 \times 10^{-19} = \mathbf{5.12 \times 10^{-19} \text{ J}}$.
- $2.0 \times 10^{-19} / 1.60 \times 10^{-19} = \mathbf{1.25 \text{ eV}}$.

Problem 3 Energy from wavelength

- $E = 1240 / 620 = \mathbf{2.00 \text{ eV}}$.
- Energy is inversely proportional to wavelength, so 310 nm photons have **twice the energy**, 4.00 eV.

Problem 4 Bright light below the threshold

- Each red photon has less energy than the work function of zinc. An electron absorbs one photon at a time, so no electron receives enough energy, and extra photons cannot add up.
- Each ultraviolet photon has more energy than the work function, so a single photon can free an electron, even if there are few photons. **Frequency, not brightness, decides whether emission occurs.**

Problem 5 Threshold of a metal

- $\lambda_0 = hc / \phi = 1240 / 2.10 = \mathbf{590 \text{ nm}}$.
- $f_0 = c / \lambda_0 = 3.00 \times 10^8 / 5.90 \times 10^{-7} = \mathbf{5.1 \times 10^{14} \text{ Hz}}$.

Problem 6 Maximum kinetic energy

- $E = 1240 / 350 = \mathbf{3.54 \text{ eV}}$.
- $K_{\text{max}} = 3.54 - 2.30 = \mathbf{1.24 \text{ eV}}$.
- $V_s = K_{\text{max}} / e = \mathbf{1.24 \text{ V}}$.

Problem 7 Wavelength of a cricket ball

1. $p = mv = 0.16 \times 30 = \mathbf{4.8 \text{ kg}\cdot\text{m/s}}$.
2. $\lambda = h / p = 6.63 \times 10^{-34} / 4.8 = \mathbf{1.4 \times 10^{-34} \text{ m}}$.
3. This is far smaller than any object or gap, so no diffraction or interference is possible.

Problem 8 Reading a K max graph

1. The line meets the axis at $\mathbf{4.0 \times 10^{14} \text{ Hz}}$.
2. Gradient = $(1.66 - 0) / (8.0 - 4.0) \times 10^{14} = \mathbf{4.15 \times 10^{-15} \text{ eV}\cdot\text{s}}$.
3. $4.15 \times 10^{-15} \times 1.60 \times 10^{-19} = 6.64 \times 10^{-34} \text{ J}\cdot\text{s}$, matching $h = \mathbf{6.63 \times 10^{-34} \text{ J}\cdot\text{s}}$.
4. $\phi = h f_0 = 4.14 \times 10^{-15} \times 4.0 \times 10^{14} = \mathbf{1.66 \text{ eV}}$.

Problem 9 Photons per second

1. $E = hc / \lambda = 6.63 \times 10^{-34} \times 3.00 \times 10^8 / 5.32 \times 10^{-7} = \mathbf{3.74 \times 10^{-19} \text{ J}}$.
2. $N = P / E = 5.0 \times 10^{-3} / 3.74 \times 10^{-19} = \mathbf{1.3 \times 10^{16} \text{ photons per second}}$.

Problem 10 Momentum of an electron wave

1. $p = h / \lambda = 6.63 \times 10^{-34} / 2.0 \times 10^{-10} = \mathbf{3.32 \times 10^{-24} \text{ kg}\cdot\text{m/s}}$.
2. $v = p / m = 3.32 \times 10^{-24} / 9.11 \times 10^{-31} = \mathbf{3.64 \times 10^6 \text{ m/s}}$.
3. $K = p^2 / 2m = 6.03 \times 10^{-18} \text{ J} = \mathbf{37.7 \text{ eV}}$.

Problem 11 Predict the effect of changes

1. **Current doubles**; K max and V s are unchanged, because the number of photons doubles but each keeps the same energy.
2. K max and V s **increase** since each photon has more energy; the current may change slightly because fewer photons arrive per watt.
3. K max and V s **decrease** because ϕ is larger, and emission may stop if f falls below the new threshold.

Problem 12 Which light ejects electrons?

1. UV: $1240 / 250 = \mathbf{4.96 \text{ eV}}$. Red: $1240 / 700 = \mathbf{1.77 \text{ eV}}$.
2. Only **ultraviolet** works, since 1.77 eV is below 2.0 eV.
3. K max = $4.96 - 2.0 = \mathbf{2.96 \text{ eV}}$.

Problem 13 Stopping potential data

1. Energies: $1240/450 = 2.76$, $1240/400 = 3.10$, $1240/350 = 3.54$, $1240/300 = \mathbf{4.13 \text{ eV}}$.
2. E – eV s: 2.20, 2.20, 2.20, 2.20 eV.
3. The result is constant, so the work function is $\mathbf{2.20 \text{ eV}}$.

Problem 14 Spot the error

1. The student treats the beam energy as shared by all electrons. In the photon model an electron absorbs one photon, so what matters is the energy per photon, not the total energy.
2. **Brighter red light delivers more red photons, each with too little energy, so no electrons are ejected at any intensity.**

Problem 15 Sunscreen and bond breaking

1. $\lambda = 1240 / 3.8 = \mathbf{326 \text{ nm}}$.
2. 300 nm has 4.13 eV and **can** break the bond; 600 nm has 2.07 eV and **cannot**.

Problem 16 Unknown frequency from a stopping potential

1. $E = \phi + eV_s = 2.40 + 1.10 = \mathbf{3.50 \text{ eV}}$.
2. $f = E / h = 3.50 \times 1.60 \times 10^{-19} / 6.63 \times 10^{-34} = \mathbf{8.45 \times 10^{14} \text{ Hz}}$.
3. $\lambda = 1240 / 3.50 = \mathbf{354 \text{ nm}}$.

Problem 17 Electrons through a voltage

1. $K = 400 \times 1.60 \times 10^{-19} = \mathbf{6.4 \times 10^{-17} \text{ J}}$.
2. $p = \sqrt{2mK} = \sqrt{2 \times 9.11 \times 10^{-31} \times 6.4 \times 10^{-17}} = \mathbf{1.08 \times 10^{-23} \text{ kg}\cdot\text{m/s}}$.
3. $\lambda = h / p = 6.63 \times 10^{-34} / 1.08 \times 10^{-23} = \mathbf{6.1 \times 10^{-11} \text{ m}}$.
4. The wavelength is the same order of magnitude as the atom spacing, so the lattice acts as a diffraction grating.

Problem 18 Single electrons through slits

1. The spots form **bright and dark fringes** as in the double-slit pattern for light.
2. $\Delta y = \lambda L / d = 5.0 \times 10^{-11} \times 0.50 / 1.0 \times 10^{-6} = \mathbf{2.5 \times 10^{-5} \text{ m}}$.
3. Each electron arrives at one point like a particle, but the distribution of arrivals follows an interference pattern like a wave. Electrons show **both particle and wave behaviour**.

Problem 19 Photon against electron

1. $p = h / \lambda$ is the same for both: $6.63 \times 10^{-34} / 1.0 \times 10^{-10} = \mathbf{6.63 \times 10^{-24} \text{ kg}\cdot\text{m/s}}$.
2. $E = pc = 6.63 \times 10^{-24} \times 3.00 \times 10^8 = 1.99 \times 10^{-15} \text{ J} = \mathbf{12.4 \text{ keV}}$.
3. $K = p^2 / 2m = 2.41 \times 10^{-17} \text{ J} = \mathbf{151 \text{ eV}}$.
4. The photon has about 80 times more energy because it moves at c , while a massive electron needs far less kinetic energy for the same momentum.

Problem 20 Measure h with LEDs

1. Measure the voltage at which each LED just glows (use a dark tube) and plot V against $1/\lambda$ for several LEDs; the gradient is hc / e .

2. $1/\lambda$ is $1.587 \times 10^6 \text{ m}^{-1}$ and $2.128 \times 10^6 \text{ m}^{-1}$, so the gradient = $0.66 / 0.541 \times 10^6 = \mathbf{1.22 \times 10^{-6} \text{ V}\cdot\text{m}}$.

3. $h = \text{gradient} \times e / c = 1.22 \times 10^{-6} \times 1.60 \times 10^{-19} / 3.00 \times 10^8 = \mathbf{6.5 \times 10^{-34} \text{ J}\cdot\text{s}}$.