Topic 3.12: Properties of Photons

Revision Notes · AP Chemistry

UNIT 3 · PROPERTIES OF SUBSTANCES AND MIXTURES

On ExamFitter.com: Topic 3.12 Quiz · Topic 3.12 Worksheet · Unit 3: All Topics · AP Chemistry Home

One Photon, One Electron

Shine light on a clean metal surface in a vacuum and, under the right conditions, electrons are knocked straight out of the surface. This is the photoelectric effect, and it is the experiment that forced physics to treat light as particles.

The photon picture from Topic 3.11 does the explaining. Light arrives in photons, each carrying energy $E = h\nu$, with $h = 6.626 \times 10^{-34}$ J·s. Absorption is all or nothing: one photon hands its entire energy to one electron in a single event. Photons do not pool their energy, and an electron cannot save up energy from several photons.

The observations line up with that picture. Electrons appear the instant the light switches on, with no build-up time, but only when the frequency is high enough. Below a certain frequency nothing is ejected at all, however bright the light and however long it shines.

The Work Function and the Threshold

An electron in a metal is held by the attraction of the lattice around it. The minimum energy needed to remove one electron from the surface is the work function, Φ. It is a property of the metal alone: change the metal and Φ changes; change the light and it does not.

Work functions are small energies, so they are often quoted in electron volts as well as joules, with $1\ \text{eV} = 1.602 \times 10^{-19}$ J. Either unit works, provided the whole calculation stays in it.

A photon can free an electron only if it pays the full price: $h\nu \geq \Phi$. The frequency at which the photon energy exactly equals the work function is the threshold frequency, ν_0, defined by $\Phi = h\nu_0$,

© 2026 ExamFitter.com · Free AP Chemistry revision notes

so $\nu_0 = \Phi/h$. The matching threshold wavelength is $\lambda_0 = hc/\Phi$. Light must have frequency at least ν_0, equivalently wavelength λ_0 or shorter, to eject anything.

At exactly the threshold the electron escapes with nothing left over: its kinetic energy is zero. The threshold is a minimum on frequency and, turned around, a maximum on wavelength.

The Energy Ledger: KE = hν − Φ

Photon energy above the work function does not vanish. The electron spends Φ escaping and keeps the rest as kinetic energy:

$KE_{max} = h\nu - \Phi$

The label maximum matters. Φ is the minimum escape cost, paid by an electron sitting at the surface. Electrons struck deeper in the metal lose extra energy in collisions on the way out and emerge slower, so ejected electrons show a spread of kinetic energies running up to this maximum.

The equation also runs backwards. Measure KE_{max} for light of known photon energy and the work function falls out: $\Phi = h\nu - KE_{max}$. One subtraction, with the units kept consistent, is the whole method.

Read as a graph, the equation is a straight line. KE_{max} plotted against ν has slope h, crosses the frequency axis at ν_0, and would cross the energy axis at $-\Phi$. Measuring that slope is one of the classic experimental determinations of Planck's constant.

Intensity Counts Photons; Frequency Prices Them

Intensity is a headcount: the number of photons arriving per second. It says nothing about the energy of any one photon, which frequency alone fixes.

Above the threshold, raising the intensity raises the number of electrons ejected per second, because more photons means more one-to-one ejection events. The maximum kinetic energy does not move: each photon still carries hν and still pays the same Φ.

Raising the frequency at a fixed photon rate does the opposite job. The count of ejected electrons per second stays the same, but every photon arrives richer, so KE_{max} climbs. Frequency sets how hard each electron is hit; intensity sets how many are hit.

© 2026 ExamFitter.com · Free AP Chemistry revision notes

Worked Examples

Example 1: The threshold of a metal. A metal has work function $\Phi = 4.0 \times 10^{-19}$ J. Its threshold frequency is $\nu_0 = \Phi/h = (4.0 \times 10^{-19}) \div (6.626 \times 10^{-34}) = 6.0 \times 10^{14}$ Hz. Its threshold wavelength is $\lambda_0 = c/\nu_0 = (3.00 \times 10^{8}) \div (6.0 \times 10^{14}) = 4.97 \times 10^{-7}$ m, about 497 nm. Only light of 497 nm or shorter, the blue end of the visible range and beyond, can eject electrons from this metal; green light at 500 nm already falls short.

Example 2: Maximum kinetic energy in joules. Ultraviolet light of frequency 1.2×10^{15} Hz strikes the same metal. Each photon carries $E = h\nu = 6.626 \times 10^{-34} \times 1.2 \times 10^{15} = 7.95 \times 10^{-19}$ J. The ledger gives $KE_{max} = 7.95 \times 10^{-19} - 4.0 \times 10^{-19} = 3.95 \times 10^{-19}$ J, about 4.0×10^{-19} J.

Example 3: Working in electron volts. A second metal has $\Phi = 2.3$ eV, which is $2.3 \times 1.602 \times 10^{-19} = 3.68 \times 10^{-19}$ J. Violet light of wavelength 400 nm delivers photons of $E = hc/\lambda = (1.99 \times 10^{-25}) \div (4.00 \times 10^{-7}) = 4.97 \times 10^{-19}$ J, which is 3.10 eV. Working wholly in electron volts is faster: $KE_{max} = 3.10 - 2.3 = 0.80$ eV. The longest wavelength that can eject electrons from this metal is $\lambda_0 = hc/\Phi = (1.99 \times 10^{-25}) \div (3.68 \times 10^{-19}) = 5.39 \times 10^{-7}$ m, about 540 nm.

Example 4: From one photon to a mole of photons. One photon of 600 nm light carries $E = hc/\lambda = (1.99 \times 10^{-25}) \div (6.00 \times 10^{-7}) = 3.31 \times 10^{-19}$ J. One mole of these photons carries $3.31 \times 10^{-19} \times 6.022 \times 10^{23} = 2.0 \times 10^{5}$ J, about 2.0×10^{2} kJ/mol, the same scale as chemical bond energies. The total is large, but ejection is still decided photon by photon: it is the single photon's energy that must clear Φ.

Traps That Cost Marks in Topic 3.12

Waiting for dim light to build up. A wave model delivers energy continuously, so dim below-threshold light should eventually free electrons. It never does, because each photon is judged alone and a photon below Φ fails no matter how many arrive before or after it.

Doubling the frequency doubles the kinetic energy. It doubles $h\nu$, not $h\nu - \Phi$. The work function is subtracted both times, so KE_{max} grows by h times the original frequency, which is less than a doubling.

© 2026 ExamFitter.com · Free AP Chemistry revision notes

Brighter light means faster electrons. Brightness is a photon count. Above threshold it buys more electrons per second at exactly the same maximum kinetic energy.

The work function depends on the light used. Φ belongs to the metal. The same beam meets a different work function on every metal, which is why one metal ejects under light that leaves another untouched.

Red photons travel more slowly than blue ones. All photons travel at c in a vacuum. Red photons are poorer, not slower: their lower frequency means less energy each.

Subtracting electron volts from joules. KE = hν − Φ works only inside one unit system. Convert with 1 eV = 1.602×10^{-19} J first, or run the whole calculation in electron volts.

Every ejected electron has KE = hν − Φ. That is the maximum, earned only by an electron that loses nothing beyond Φ. Most electrons lose extra energy on the way out and emerge slower.

Key Relationships to Remember

- $E = h\nu = hc/\lambda$, with $h = 6.626 \times 10^{-34}$ J·s and $c = 3.00 \times 10^{8}$ m/s: one photon gives all of its energy to one electron, and photons never pool energy
- Work function Φ: the minimum energy needed to remove an electron from a metal surface, a property of the metal alone, in joules or electron volts (1 eV = 1.602×10^{-19} J)
- Threshold: $\Phi = h\nu_0$, so $\nu_0 = \Phi/h$ and $\lambda_0 = hc/\Phi$; ejection needs $\nu \geq \nu_0$, equivalently $\lambda \leq \lambda_0$, and at the threshold itself KE_max = 0
- KE_max = hν − Φ = $h(\nu - \nu_0)$; rearranged, Φ = hν − KE_max; most ejected electrons have less than the maximum
- A plot of KE_max against ν is a straight line: slope h, frequency-axis intercept ν_0, energy-axis intercept −Φ
- Intensity is a photon count per second: above threshold it sets how many electrons are ejected per second and never their kinetic energy; frequency sets the kinetic energy and, at fixed photon rate, never the count
- Energy per mole of photons = energy per photon × 6.022×10^{23} mol^{-1}

Continue Revising

Topic 3.12 Quiz: Properties of Photons

Topic 3.12 Worksheet

Unit 3: All Topics

© 2026 ExamFitter.com · Free AP Chemistry revision notes