

Photon energy, work function and matter waves

Physics grades 11-12 (A Level · IB · Class 11-12) · Worksheet answers

Each answer shows the formula, the substitution and the result with its unit. Keep track of whether energies are in joules or electronvolts, and convert before subtracting. Small rounding differences in the last digit are acceptable.

Level: Physics grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** IB E.2

Problem 1 Energy from frequency

- $E = hf = 6.63 \times 10^{-34} \times 6.0 \times 10^{14} = \mathbf{3.98 \times 10^{-19} \text{ J}}$.
- $3.98 \times 10^{-19} / 1.60 \times 10^{-19} = \mathbf{2.49 \text{ eV}}$.

Problem 2 Laser pointer photon

$$E = hc/\lambda = 6.63 \times 10^{-34} \times 3.00 \times 10^8 / 650 \times 10^{-9} = \mathbf{3.06 \times 10^{-19} \text{ J} = 1.91 \text{ eV}}$$

Problem 3 Frequency of ultraviolet

$$f = c/\lambda = 3.00 \times 10^8 / 250 \times 10^{-9} = \mathbf{1.2 \times 10^{15} \text{ Hz}}$$

Problem 4 Caesium threshold

- $\phi = 2.1 \times 1.60 \times 10^{-19} = \mathbf{3.36 \times 10^{-19} \text{ J}}$.
- $f_0 = \phi/h = 3.36 \times 10^{-19} / 6.63 \times 10^{-34} = \mathbf{5.07 \times 10^{14} \text{ Hz}}$.

Problem 5 Photon sharing its energy

- $K_{\max} = hf - \phi = 3.2 - 2.4 = \mathbf{0.8 \text{ eV}}$.
- $0.8 \times 1.60 \times 10^{-19} = \mathbf{1.3 \times 10^{-19} \text{ J}}$.

Problem 6 Bright red light

Each electron absorbs **one photon** and needs at least the work function. Red photons have less energy than ϕ , so none can free an electron, however many arrive. Each ultraviolet photon has enough energy, so even a weak beam releases electrons.

Problem 7 Stopping potential

$$\text{eVs} = K_{\max}, \text{ so } V_s = 2.4 \times 10^{-19} / 1.60 \times 10^{-19} = \mathbf{1.5 \text{ V}}$$

Problem 8 Green laser photons

1. $E = hc/\lambda = 1.99 \times 10^{-25} / 532 \times 10^{-9} = \mathbf{3.74 \times 10^{-19} \text{ J}}$.
2. $N = P/E = 5.0 \times 10^{-3} / 3.74 \times 10^{-19} = \mathbf{1.3 \times 10^{16} \text{ photons/s}}$.

Problem 9 Potassium test

1. 500 nm: 2.49 eV. 600 nm: 2.07 eV.
2. Only **500 nm**, since 2.49 eV is greater than 2.3 eV, and $K_{\max} = 2.49 - 2.3 = \mathbf{0.19 \text{ eV}}$. At 600 nm the photon energy is below ϕ , so nothing is emitted.

Problem 10 Reading a $K_{\max}$ graph

1. The line meets the axis at $f_0 = \mathbf{5.5 \times 10^{14} \text{ Hz}}$.
2. Gradient = $1.87 / (4.5 \times 10^{14}) = \mathbf{4.2 \times 10^{-15} \text{ eV s}}$.
3. $\phi = \text{gradient} \times f_0 = 4.16 \times 10^{-15} \times 5.5 \times 10^{14} = \mathbf{2.29 \text{ eV}}$. As a check, gradient $\times e = 6.6 \times 10^{-34} \text{ J s}$, which agrees with Planck's constant.

Problem 11 Doubling the brightness

1. The photocurrent **doubles**.
2. $K_{\max}$ is **unchanged**.
3. Doubling the intensity doubles the number of photons per second, so twice as many electrons leave. Each photon still has energy hf , so each electron still has the same maximum kinetic energy.

Problem 12 Finding the work function

1. $E = hc/\lambda = 6.63 \times 10^{-19} \text{ J} = \mathbf{4.14 \text{ eV}}$.
2. $K_{\max} = 1.74 \text{ eV}$, so $\phi = 4.14 - 1.74 = \mathbf{2.40 \text{ eV}}$.
3. $\lambda_0 = hc/\phi = 1.99 \times 10^{-25} / (2.40 \times 1.60 \times 10^{-19}) = \mathbf{517 \text{ nm}}$.

Problem 13 Wavelength of an electron

1. $\lambda = h/(mv) = 6.63 \times 10^{-34} / (9.11 \times 10^{-31} \times 2.0 \times 10^6) = \mathbf{3.6 \times 10^{-10} \text{ m}}$ (0.36 nm).
2. It is of the same order as atomic spacings, so crystals diffract such electrons.

Problem 14 Cricket ball wavelength

1. $\lambda = h/(mv) = 6.63 \times 10^{-34} / (0.16 \times 38) = \mathbf{1.1 \times 10^{-34} \text{ m}}$.
2. This is about 10^{19} times smaller than a nucleus, so no gap or obstacle is small enough to show diffraction.

Problem 15 Current-voltage graph

1. Current falls to zero at -1.2 V, so the stopping potential is **1.2 V** and $K_{\max} = 1.2$ eV.
2. The bright beam gives **twice the saturation current** ($6 \mu\text{A}$ against $3 \mu\text{A}$).
3. Both beams have the same frequency, so each photon has the same energy and $K_{\max}$ is the same.

Problem 16 Photon against electron

1. $E = hc/\lambda = 1.99 \times 10^{-25} / 1.0 \times 10^{-10} = 1.99 \times 10^{-15} \text{ J} = 12.4 \text{ keV}$.
2. $p = h/\lambda = 6.63 \times 10^{-24} \text{ kg m/s}$. $K = p^2/2m = 2.41 \times 10^{-17} \text{ J} = 151 \text{ eV}$.
3. The electron has the same wavelength (the same resolution) but only about 151 eV, so it is far less damaging to a delicate sample than a 12 keV X-ray photon.

Problem 17 Electron diffraction

1. $eV = p^2/2m$, so $p = \sqrt{2meV} = \sqrt{2 \times 9.11 \times 10^{-31} \times 1.60 \times 10^{-19} \times 150} = 6.61 \times 10^{-24} \text{ kg m/s}$.
2. $\lambda = h/p = 6.63 \times 10^{-34} / 6.61 \times 10^{-24} = 0.100 \text{ nm}$.
3. $\sin \theta = \lambda/d = 0.100 / 0.215 = 0.466$, so $\theta = 27.8^\circ$.

Problem 18 Two wavelengths

1. 400 nm: $E = 3.108 \text{ eV}$, $K_{\max} = 0.21 \text{ eV}$, $V_s = 0.21 \text{ V}$. 300 nm: $E = 4.144 \text{ eV}$, $K_{\max} = 1.24 \text{ eV}$, $V_s = 1.24 \text{ V}$.
2. $v = \sqrt{2K/m} = \sqrt{2 \times 1.244 \times 1.60 \times 10^{-19} / 9.11 \times 10^{-31}} = 6.6 \times 10^5 \text{ m/s}$.
3. $\lambda_0 = hc/\phi = 1.99 \times 10^{-25} / (2.9 \times 1.60 \times 10^{-19}) = 429 \text{ nm}$.

Problem 19 Photocell current

1. $E = hc/\lambda = 4.97 \times 10^{-19} \text{ J}$, so $N = 2.0 \times 10^{-3} / 4.97 \times 10^{-19} = 4.02 \times 10^{15} \text{ s}^{-1}$.
2. Electrons per second = $0.010 \times 4.02 \times 10^{15} = 4.02 \times 10^{13} \text{ s}^{-1}$.
3. $I = (\text{electrons per second}) \times e = 4.02 \times 10^{13} \times 1.60 \times 10^{-19} = 6.4 \times 10^{-6} \text{ A}$ ($6.4 \mu\text{A}$).

Problem 20 Spot the errors

1. The denominator is $9.11 \times 10^{-31} \times 3.0 \times 10^6 = 2.73 \times 10^{-24}$, so $\lambda = 2.4 \times 10^{-10} \text{ m}$ (0.24 nm), ten times smaller than the student's value.
2. Doubling the intensity doubles the **photocurrent**; $K_{\max}$ depends on frequency only and is unchanged.
3. $10^{-34} \div 10^{-24}$ is about 10^{-10} m , so a result near 10^{-9} m would be suspect.