Exercise walk-through

Photoelectric effect ▪ 22.2

eXercise

You must be able to

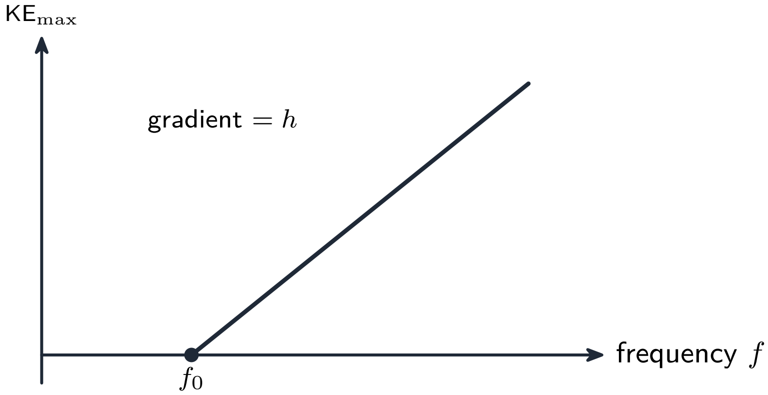
- use **threshold frequency** and **work function**
- use $hf = \Phi + \frac{1}{2}mv_{\mathrm{max}}^2$
- explain why max KE is independent of intensity but the current is not

Method — Photoelectric effect

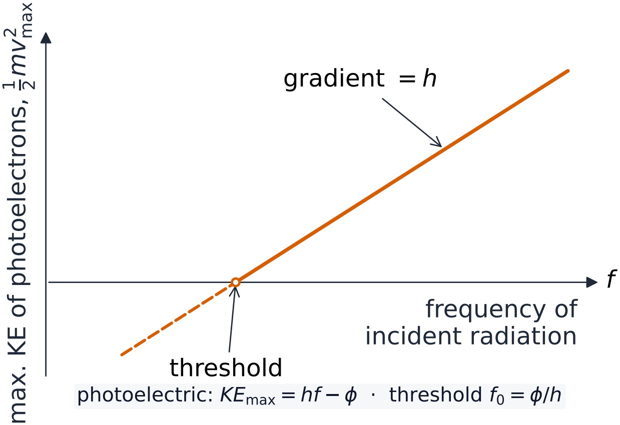
Light above a **threshold frequency** f_0 frees electrons from a metal. The **work function** $\Phi = hf_0$ is the least energy to free an electron:

$$hf = \Phi + \frac{1}{2}mv_{\max}^2.$$

Method — Photoelectric effect



Method — Photoelectric effect



Maximum KE against frequency in the photoelectric effect

Method — Reading the KE–frequency graph

Rearranging gives $\text{KE}_{\max} = hf - \Phi$, the equation of a straight line:

- **gradient** $= h$ (the Planck constant — the **same for every metal**);
- the line meets the f-axis at the **threshold frequency** f_0 (where $\text{KE}_{\max} = 0$);
- extending it back, the y-**intercept** is $-\Phi$.

So two different metals give **parallel** lines (same gradient h); the one with the **larger** work function has the **larger** f_0 (its line is further to the right).

- **max KE** depends only on **frequency** (one photon $\rightarrow$ one electron), not intensity;
- the **current** (number of electrons per second) depends on **intensity**.

Practice 2.1 ▪ 1 mark

Define **threshold frequency**.

Solution 2.1

Method: Reading the KE–frequency graph

Worked steps

The **lowest frequency** of radiation that will release electrons from the metal B1.

Practice 2.2 ▪ 1 mark

Define the **work function** of a metal.

Solution 2.2

Method: Reading the KE–frequency graph

Worked steps

The **minimum energy** needed to free an electron from the surface **B1**.

Practice 2.3 ▪ 1 mark

Write the **photoelectric equation**.

Solution 2.3

Method: Reading the KE–frequency graph

Worked steps

$hf = \Phi + \frac{1}{2}mv_{\max}^2$ **B1**.

Practice 2.4 ▪ 1 mark

State why **no** electrons are emitted below the threshold frequency.

Solution 2.4

Worked steps

Each photon has energy $hf < \Phi$, so it **cannot supply** enough energy to free an electron (and energy is one-photon-per-electron) **B1**.

Exam-style 3.1 ▪ 1 mark

Below the threshold frequency, increasing the **intensity** of the light:

A emits more electrons

B emits faster electrons

C emits no electrons

D lowers the threshold frequency

Solution 3.1

A emits more electrons

B emits faster electrons

C emits no electrons ✓

D lowers the threshold frequency

Worked steps

C — no electrons.

Exam-style 3.2 ▪ 2 marks

A metal has a work function of 2.0 eV. Photons of energy 3.5 eV strike it. Find the **maximum kinetic energy** of the photoelectrons.

Solution 3.2

Method: Photoelectric effect

Worked steps

$\mathrm{KE}_{\mathrm{max}} = hf - \Phi = 3.5 - 2.0 = 1.5$ eV **M1** **A1**.

Exam-style 3.3 ▪ 3 marks

Explain why the **maximum KE** of the photoelectrons is independent of intensity, while the **current** is proportional to intensity.

Solution 3.3

Method: Reading the KE–frequency graph

Worked steps

Each electron absorbs **one photon**, so its max KE depends only on the **photon energy (*hf*)**, set by frequency B1; higher intensity means **more photons per second** B1, so more electrons per second — a larger current, but the same energy per electron B1.

Exam-style 3.4 ▪ 2 marks

A metal has a work function of 3.2×10^{-19} J. Calculate its **threshold frequency**.

Solution 3.4

Method: Reading the KE–frequency graph

Worked steps

$f_0 = \Phi/h = (3.2 \times 10^{-19})/(6.63 \times 10^{-34})$ **M1** $= 4.8 \times 10^{14}$ Hz **A1**.

Exam-style 3.5 ▪ 1 mark

In a photoelectric experiment, the maximum kinetic energy $\mathrm{KE}_{\mathrm{max}}$ of the photoelectrons is plotted against the frequency *f* of the incident light, giving a straight line.

(a) The line has gradient 6.6×10^{-34} J s. State the quantity this gradient represents.

(b) The experiment is repeated with a metal of **larger** work function. On the same axes, describe how the new line compares with the first.

Solution 3.5

Method: Photoelectric effect

Worked steps

(b) A line with the **same gradient** (parallel to the first), but shifted to the **right** — a **higher threshold frequency** f_0 (and a more negative y-intercept $-\Phi$) **B1** **B1**.

Exam-style 3.6 ▪ 1 mark

Light of wavelength 410 nm falls on a clean metal surface in a vacuum photocell. The work function of the metal is 2.3 eV. Take $h = 6.63 \times 10^{-34}$ J s, $c = 3.00 \times 10^{8}$ m s^{-1}, $e = 1.60 \times 10^{-19}$ C and the electron mass as 9.11×10^{-31} kg.

(a) **State** what is meant by the **work function** of a metal.

(b) **Determine** the energy of one photon, in joules and in electronvolts.

(c) **Determine** the maximum kinetic energy of an emitted electron, and its maximum speed.

(d) **Determine** the threshold wavelength for this metal.

(e) The **intensity** of the light is doubled, at the same wavelength. **State and explain** the effect on (i) the maximum kinetic energy of the emitted electrons and (ii) the rate at which electrons are emitted.

(f) **Explain** why the existence of a threshold wavelength cannot be explained by a **wave** model of light.

Solution 3.6

Worked steps

(a) The **minimum energy** needed to remove an electron from the surface of the metal **B1**.

(b) $E = \dfrac{hc}{\lambda} = \dfrac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{410 \times 10^{-9}}$ **M1** $= 4.85 \times 10^{-19}$ J **A1**; dividing by 1.60×10^{-19} gives 3.0 eV **A1**.

(c) $E_{\mathsf{K,max}} = hf - \phi = 3.03 - 2.3 = 0.73$ eV $= 1.17 \times 10^{-19}$ J **M1** **A1**;
$v = \sqrt{\dfrac{2E_{\mathsf{K}}}{m}} = \sqrt{\dfrac{2 \times 1.17 \times 10^{-19}}{9.11 \times 10^{-31}}} = 5.1 \times 10^{5}$ m s^{-1} **A1**.

(d) At the threshold all the photon energy goes into escaping:
$\lambda_0 = \dfrac{hc}{\phi} = \dfrac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{2.3 \times 1.60 \times 10^{-19}}$ **M1** $= 5.4 \times 10^{-7}$ m, i.e. 540 nm **A1**.

Solution 3.6

Worked steps

(e) (i) **No change** B1 — the maximum kinetic energy depends only on the photon energy, i.e. on the wavelength, and one electron absorbs one photon B1. (ii) The rate **doubles**, because twice as many photons arrive each second and each can free one electron B1.

(f) A wave model says energy arrives continuously and spreads over the surface, so any wavelength should eventually free an electron if you wait long enough or make the light bright enough B1. In fact **no** electrons are emitted below the threshold however intense the light, which only makes sense if the energy arrives in whole photons of energy hf B1.