A-LEVEL PHYSICS • EXERCISE SHEET

22.2 Photoelectric effect

Name: ______________ Class: __________ Date: ____________ **Total: 29 marks**

KEY WORDS photoelectric effect 光电效应 • threshold frequency 极限频率 • work function 逸出功 • photoelectron 光电子 • frequency 频率

Objective

Build the skills to answer exam questions on the **photoelectric effect**.

You must be able to:

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

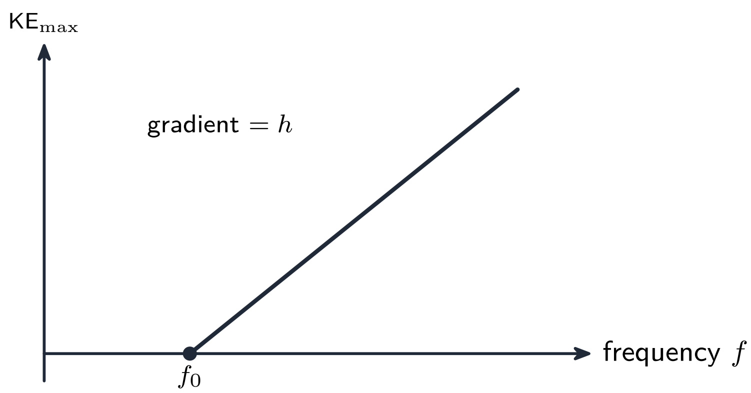
1 Worked examples

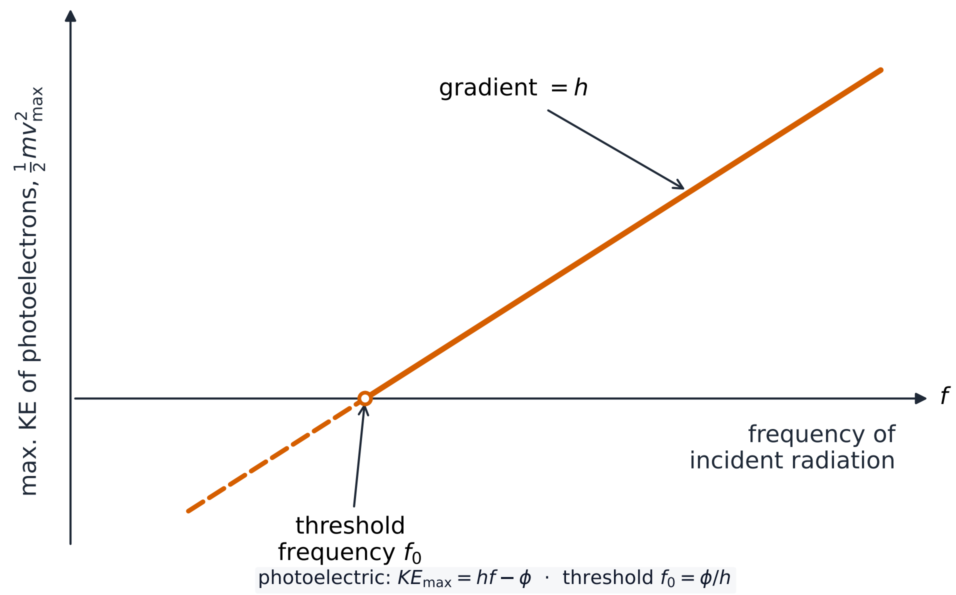
Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ 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:

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





Maximum KE against frequency in the photoelectric effect

Reading the KE–frequency graph

Rearranging gives $\mathrm{KE_{max}} = hf - \Phi$, 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 $\mathrm{KE_{max}} = 0$);
- 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 → one electron), not intensity;
- the **current** (number of electrons per second) depends on **intensity**.

2 Practice

Now apply the methods above.

2.1 Define **threshold frequency**. [1]

2.2 Define the **work function** of a metal. [1]

2.3 Write the **photoelectric equation**. [1]

2.4 State why **no** electrons are emitted below the threshold frequency. [1]

3 Exam-style questions

3.1 Below the threshold frequency, increasing the **intensity** of the light: [1]

- **A** emits more electrons
- **B** emits faster electrons
- **C** emits no electrons
- **D** lowers the threshold frequency

3.2 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. [2]

3.3 Explain why the **maximum KE** of the photoelectrons is independent of intensity, while the **current** is proportional to intensity. [3]

3.4 A metal has a work function of 3.2×10^{-19} J. Calculate its **threshold frequency**. [2]

3.5 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. [1]

(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. [2]

3.6 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. [1]

(b) **Determine** the energy of one photon, in joules and in electronvolts. [3]

(c) **Determine** the maximum kinetic energy of an emitted electron, and its maximum speed. [3]

(d) **Determine** the threshold wavelength for this metal. [2]

(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. [3]

(f) **Explain** why the existence of a threshold wavelength cannot be explained by a **wave** model of light. [2]

Solutions

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

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

2.3 $hf = \Phi + \frac{1}{2}mv_{\text{max}}^2$.

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

3.1 **C** — no electrons.

3.2 $\text{KE}_{\text{max}} = hf - \Phi = 3.5 - 2.0 = 1.5$ eV.

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

3.4 $f_0 = \Phi/h = (3.2 \times 10^{-19})/(6.63 \times 10^{-34}) = 4.8 \times 10^{14}$ Hz.

3.5 (a) The **Planck constant** h.

3.5 (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 $-\Phi$).

3.6 (a) The **minimum energy** needed to remove an electron from the surface of the metal.
(b) $E = \dfrac{hc}{\lambda} = \dfrac{6.63 \times 10^{-34} \times 3.00 \times 10^8}{410 \times 10^{-9}} = 4.85 \times 10^{-19}$ J; dividing by 1.60×10^{-19} gives 3.0 eV.
(c) $E_{\text{K,max}} = hf - \phi = 3.03 - 2.3 = 0.73$ eV $= 1.17 \times 10^{-19}$ J; $v = \sqrt{\dfrac{2E_{\text{K}}}{m}} = \sqrt{\dfrac{2 \times 1.17 \times 10^{-19}}{9.11 \times 10^{-31}}} = 5.1 \times 10^5$ m s^{-1}.
(d) At the threshold all the photon energy goes into escaping: $\lambda_0 = \dfrac{hc}{\phi} = \dfrac{6.63 \times 10^{-34} \times 3.00 \times 10^8}{2.3 \times 1.60 \times 10^{-19}}$ $= 5.4 \times 10^{-7}$ m, i.e. 540 nm.
(e) (i) **No change** — the maximum kinetic energy depends only on the photon energy, i.e. on the wavelength, and one electron absorbs one photon. (ii) The rate **doubles**, because twice as many photons arrive each second and each can free one electron.
(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. 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.