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 $hf = \Phi + \frac{1}{2}mv^2_{\text{max}}$
- explain why max KE is independent of intensity but the current is not

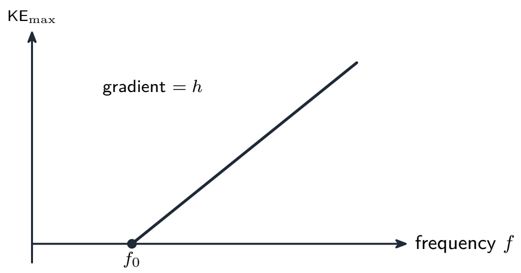
1 Worked examples

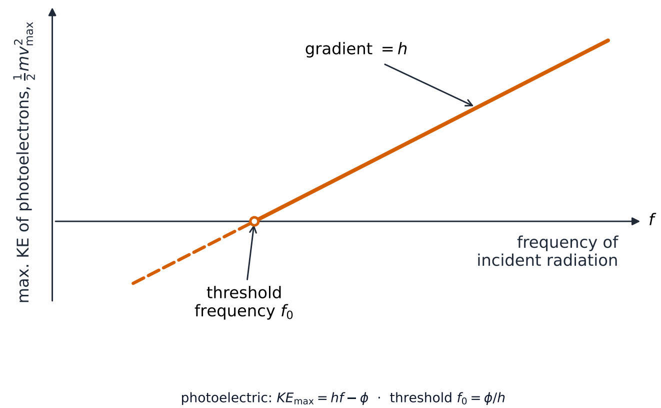
Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

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:

$$hf = \Phi + \tfrac{1}{2}mv^2_{\text{max}}.$$





Maximum KE against frequency in the photoelectric effect

Reading the KE–frequency graph

Rearranging gives $\text{KE}_{\text{max}} = hf - \Phi$, 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 $\text{KE}_{\text{max}} = 0$);
- 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

Each answer shows the steps, then the **result**.

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

- below threshold, **no electrons** are emitted

3.2

- $\text{KE}_{\text{max}} = hf - \Phi$

$$\text{KE}_{\text{max}} = 3.5\text{ eV} - 2.0\text{ eV} = \mathbf{1.5}\text{ eV}$$

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

- $f_0 = \Phi/h$

$$f_0 = \frac{3.2 \times 10^{-19}\text{ J}}{6.63 \times 10^{-34}\text{ J s}} = \mathbf{4.8} \times \mathbf{10^{14}}\text{ Hz}$$

3.5

(a) the **Planck constant** h

(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) $E = hc/\lambda$

$$E = \frac{(6.63 \times 10^{-34}\text{ J s})(3.00 \times 10^{8}\text{ m s}^{-1})}{410 \times 10^{-9}\text{ m}} = 4.85 \times 10^{-19}\text{ J}$$

$$\frac{4.85 \times 10^{-19}\ \text{J}}{1.60 \times 10^{-19}\ \text{J eV}^{-1}} = \mathbf{3.0}\ \text{eV}$$

(c) $E_{\text{K,max}} = hf - \phi = 3.03\ \text{eV} - 2.3\ \text{eV} = 0.73\ \text{eV} = 1.17 \times 10^{-19}\ \text{J}$

$$v = \sqrt{\frac{2E_\text{K}}{m}} = \sqrt{\frac{2 \times 1.17 \times 10^{-19}\ \text{J}}{9.11 \times 10^{-31}\ \text{kg}}} = \mathbf{5.1} \times \mathbf{10^5}\ \text{m s}^{-1}$$

(d) at the threshold all the photon energy goes into escaping: $\lambda_0 = hc/\phi$

$$\lambda_0 = \frac{(6.63 \times 10^{-34}\ \text{J s})(3.00 \times 10^8\ \text{m s}^{-1})}{(2.3)(1.60 \times 10^{-19}\ \text{J})} = 5.4 \times 10^{-7}\ \text{m} = \mathbf{540}\ \text{nm}$$

(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