

Exercise walk-through

22.2.1

Explaining photoelectric emission, and the stopping-potential experiment

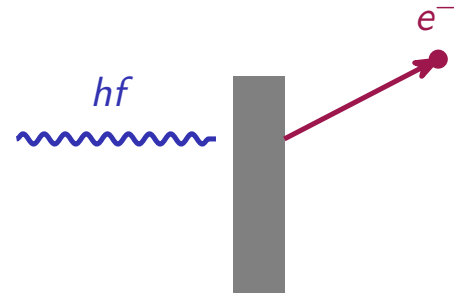
A-Level Physics

One photon frees one electron

EM radiation of high enough frequency hitting a metal emits **photoelectrons**.

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

Work function $\Phi = hf_0$ is the least energy to free an electron. Below the **threshold frequency** f_0 , **no** electrons come out, however bright.



Worked example – maximum KE

Work function 2.0 eV; photons of 3.5 eV

$$\begin{aligned}\frac{1}{2}mv_{\text{max}}^2 &= hf - \Phi = 3.5 - 2.0 \\ &= 1.5 \text{ eV}\end{aligned}$$

Maximum KE depends **linearly on frequency**,
not on brightness.

Convert Φ to joules before
subtracting if hf is in joules.
A negative answer means you
are below threshold.

Why the wave model fails

A wave model says brightness should set the KE, and any frequency should work given enough time. Experiment says otherwise:

no emission below f_0 , however bright

immediate emission at or above f_0 , even when dim

max KE depends on frequency, not brightness

the *number* of photoelectrons (the current) depends on brightness

Why max KE is fixed but current grows with brightness

A brighter beam of the **same frequency** has **more photons per second**, but each still carries hf .

So the maximum KE of any electron is $hf - \Phi$ (set by f only), while the rate of emission (the current) grows with the number of photons, i.e.

Brighter means more photons, not more energetic ones

A brighter beam of the **same frequency** has more photons per second, each still carrying hf . Doubling the brightness doubles the current but does **not** change the maximum KE.

Exercises 2.1·2.2

2.1 State what is meant by the **work function energy** of a metal.

[2]

2.2 Light is shone on a metal surface. Explain, in terms of photons, why no electrons are emitted when the frequency of the light is below the threshold frequency, however bright the light is.

[3]

Exercises 2.1·2.2

2.1 State what is meant by the **work function energy** of a metal.

[2]

2.1

- the **minimum** energy needed
- to remove an electron from the surface of the metal
- “the energy needed to free an electron” without “minimum” or “surface” earns one mark only

2.2 Light is shone on a metal surface. Explain, in terms of photons, why no electrons are emitted when the frequency of the light is below the threshold frequency, however bright the light is.

[3]

2.2

- one photon gives all of its energy to one electron, so a single photon must supply the whole work function energy by itself
- the energy of a photon is hf , which depends on the frequency alone
- below the threshold frequency $hf < \Phi$, so no single photon is enough; making the light brighter sends **more** photons, each one still too weak, so still no emission

Exercise 2.3 (a)

2.3 Monochromatic light of a frequency above the threshold frequency falls on a metal surface. The intensity of the light is doubled, with the frequency unchanged. State and explain the effect on

(a) the maximum kinetic energy of the emitted electrons,

[2]

Exercise 2.3 (a)

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(a) the maximum kinetic energy of the emitted electrons, [2]

(a)

- **unchanged**
- the electron's kinetic energy comes from one photon, and the photon energy hf has not changed: $\frac{1}{2}mv_{\max}^2 = hf - \Phi$

Exercise 2.3 (b)

2.3 Monochromatic light of a frequency above the threshold frequency falls on a metal surface. The intensity of the light is doubled, with the frequency unchanged. State and explain the effect on

(b) the photocurrent.

[2]

Exercise 2.3 (b)

2.3 Monochromatic light of a frequency above the threshold frequency falls on a metal surface. The intensity of the light is doubled, with the frequency unchanged. State and explain the effect on

(b) the photocurrent.

[2]

(b)

- **doubled**
- twice the intensity means twice as many photons arriving per second, so twice as many electrons released per second

Exercise 2.4

2.4 Photoelectric emission begins immediately, even when the light is extremely faint. State what a wave model of light predicts instead, and explain why the photon model predicts an immediate start. [3]

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2.4

- a wave model predicts a **delay**, because a faint wave would deliver energy slowly and the electron would have to absorb it over a long time before it had Φ
- in the photon model the energy arrives in whole packets, not as a trickle
- so the very first photon to arrive can free an electron at once, however few photons per second there are

Exercise 3.1

3.1 Monochromatic light causes photoelectric emission from a metal surface. The intensity of the light is doubled, with the frequency unchanged. Which row is correct? [1]

	maximum kinetic energy of the electrons	photocurrent
A	unchanged	unchanged
B	unchanged	doubled
C	doubled	unchanged
D	doubled	doubled

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C	doubled	unchanged
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3.1 B

- doubling the intensity doubles the number of photons per second, not the energy of each one
- so each electron is unchanged (ruling out **C** and **D**) but there are twice as many per second (ruling out **A**)

Exercise 3.2 (a)

3.2 Monochromatic light of frequency 7.5×10^{14} Hz falls on a metal surface of work function energy 2.1 eV.

(a) Show that the energy of a photon of this light is about 3.1 eV. [2]

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(a)

$$E = hf = 6.63 \times 10^{-34} \times 7.5 \times 10^{14} = 4.97 \times 10^{-19} \text{ J}$$

$$E = \frac{4.97 \times 10^{-19}}{1.60 \times 10^{-19}} = \mathbf{3.11} \text{ eV} \approx 3.1 \text{ eV}$$

Exercise 3.2 (b)

3.2 Monochromatic light of frequency 7.5×10^{14} Hz falls on a metal surface of work function energy 2.1 eV.

(b) Calculate the maximum kinetic energy of an emitted electron, in **joules**. [2]

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(b)

$$\frac{1}{2}mv_{\max}^2 = hf - \Phi = 3.11 - 2.1 = 1.01 \text{ eV}$$

$$= 1.01 \times 1.60 \times 10^{-19} = \mathbf{1.6 \times 10^{-19} \text{ J}}$$

Exercise 3.2 (c)

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(c) Determine the stopping potential for this surface with this light. [1]

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(c) Determine the stopping potential for this surface with this light. [1]

(c)

- $eV_s = \frac{1}{2}mv_{\text{max}}^2 = 1.01 \text{ eV}$, so $V_s = \mathbf{1.0 \text{ V}}$

Exercise 3.2 (d)

3.2 Monochromatic light of frequency 7.5×10^{14} Hz falls on a metal surface of work function energy 2.1 eV.

(d) The intensity of the light is halved, with the frequency unchanged. State and explain the effect on the stopping potential. [2]

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(d) The intensity of the light is halved, with the frequency unchanged. State and explain the effect on the stopping potential. [2]

(d)

- the stopping potential is **unchanged**
- $eV_s = hf - \Phi$ depends only on the frequency and the metal, and neither has changed; halving the intensity halves the current, not the energy of each electron

Exercise 3.3 (a)

3.3 A student shines light of several different frequencies on a metal surface, measures the stopping potential V_s for each, and plots eV_s against frequency f .

(a) Use the photoelectric equation to show that $eV_s = hf - \Phi$. [2]

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(a)

- the fastest electron is just stopped by the reverse p.d., so $eV_s = \frac{1}{2}mv_{\text{max}}^2$
- substituting into $hf = \Phi + \frac{1}{2}mv_{\text{max}}^2$ gives $eV_s = hf - \Phi$

Exercise 3.3 (b)

3.3 A student shines light of several different frequencies on a metal surface, measures the stopping potential V_s for each, and plots eV_s against frequency f .

(b) State what the **gradient** and the **intercept on the energy axis** of this graph represent. [2]

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(b)

- the **gradient** is the **Planck constant** h
- the intercept on the energy axis is $-\Phi$, so its magnitude is the **work function energy**

Exercise 3.3 (c)

3.3 A student shines light of several different frequencies on a metal surface, measures the stopping potential V_s for each, and plots eV_s against frequency f .

(c) The graph is a straight line of gradient $6.6 \times 10^{-34} \text{ J s}$ that crosses the frequency axis at $5.5 \times 10^{14} \text{ Hz}$. Calculate the work function energy of this metal, in eV. [3]

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(c)

- the line crosses the frequency axis where $eV_s = 0$, so there $hf_0 = \Phi$

$$\Phi = hf_0 = 6.6 \times 10^{-34} \times 5.5 \times 10^{14} = 3.63 \times 10^{-19} \text{ J}$$

$$\Phi = \frac{3.63 \times 10^{-19}}{1.60 \times 10^{-19}} = \mathbf{2.3 \text{ eV}}$$

Exercise 3.3 (d)

3.3 A student shines light of several different frequencies on a metal surface, measures the stopping potential V_s for each, and plots eV_s against frequency f .

(d) The experiment is repeated with a metal of **larger** work function energy. State **two** ways in which the new graph differs from the first. [2]

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(d) any **two** of:

- the gradient is the **same**, because the gradient is h and that is a constant of nature
- the line crosses the frequency axis at a **higher** threshold frequency, i.e. it is shifted to the right
- the intercept on the energy axis is **more negative**, since it is $-\Phi$
- the two lines are therefore parallel

Exercise 3.3 (e)

3.3 A student shines light of several different frequencies on a metal surface, measures the stopping potential V_s for each, and plots eV_s against frequency f .

(e) Explain why the line does **not** pass through the origin.

[1]

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(e)

- a photon of frequency f has to pay the work function energy Φ before any kinetic energy is left, so at $f = 0$ the line would sit at $-\Phi$, not at zero – there is no emission at all until f reaches f_0