Week 48

A-Level Physics

Homework bundle for this week

本周作业合集

exercises.lol

Contents 目录

Topic 22 quiz 2

Exercise sheet 22.1 5

Past-paper questions 22.1 10

Exercise sheet 22.2 13

Past-paper questions 22.2 19

Exercise sheet 22.3 22

Past-paper questions 22.3 28

Exercise sheet 22.4 32

Past-paper questions 22.4 37

A-Level Physics Name: ____________________ Score: ________

1. The energy of a photon is:

☐ hf

☐ $\frac{h}{f}$

☐ hf^2

☐ $\frac{f}{h}$

2. Below the threshold frequency, shining a brighter light on the metal:

☐ still emits no electrons

☐ emits more electrons

☐ emits faster electrons

☐ melts the metal

3. Light shows its wave nature in interference, and its particle nature in:

☐ the photoelectric effect

☐ refraction

☐ reflection

☐ shadows

4. Electrons in an atom can only occupy certain ______ energy levels.

____

5. A photon has energy 3.2×10^{-19} J. What is this in eV? (1 eV $= 1.6 \times 10^{-19}$ J)

__________________ eV

6. The minimum energy needed to free an electron from the surface is the ______ function.

____

7. The de Broglie wavelength of a particle is:

☐ $\frac{h}{p}$

☐ hp

☐ $\frac{p}{h}$

☐ $\frac{h}{f}$

8. Atomic energy levels are written as negative, with 0 for a just-free electron.

☐ True ☐ False

9. Higher-frequency photons carry more energy.

☐ True ☐ False

10. A 5.0 eV photon hits a metal with work function 2.0 eV. What is the maximum KE of the photoelectron?

_________________ eV

A-Level Physics

1. hf

   $E = hf = \dfrac{hc}{\lambda}$ — proportional to frequency.

2. **still emits no electrons**

   Each photon is below Φ, so no single photon can free an electron — brightness cannot help.

3. **the photoelectric effect**

   The photoelectric effect needs photons (particles); interference and diffraction need waves.

4. **discrete**

   The levels are discrete (quantised) — an electron cannot have an energy in between them.

5. **2 eV**

   $\dfrac{3.2 \times 10^{-19}}{1.6 \times 10^{-19}} = 2.0$ eV.

6. **work**

   The work function $\Phi = hf_0$ — the least energy to release a surface electron.

7. $\dfrac{h}{p}$

   $\lambda = \dfrac{h}{p}$ — wavelength is Planck's constant over momentum.

8. **True**

   The most tightly bound (ground) state is the most negative; energy rises toward 0 as the electron is freed.

9. **True**

   $E = hf$, so energy rises with frequency — a γ-ray photon carries far more than a radio one.

10. **3 eV**

    Max KE $= hf - \Phi = 5.0 - 2.0 = 3.0$ eV.

22.1 Energy and momentum of a photon

Name: ______________ Class: __________ Date: ____________ **Total: 24 marks**

KEY WORDS photon 光子 • momentum 动量 • electronvolt 电子伏特 • wavelength 波长 • electron 电子

Objective

Build the skills to answer exam questions on the **photon** — its energy and momentum.

You must be able to:

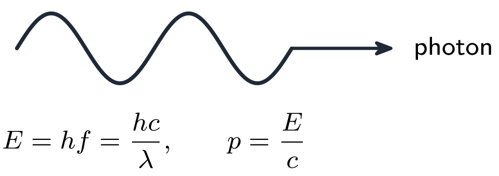
- use $E = hf = \dfrac{hc}{\lambda}$ and the **electronvolt**
- use $p = E/c$ for the photon momentum

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.

Photons

A **photon** is a **quantum** (packet) of electromagnetic energy:



$$E = hf = \frac{hc}{\lambda}, \qquad p = \frac{E}{c},$$

with $h = 6.63 \times 10^{-34}$ J s. The **electronvolt**: 1 eV $= 1.6 \times 10^{-19}$ J.

Worked example. $\lambda = 500$ nm: $E = \dfrac{hc}{\lambda} = \dfrac{(6.63 \times 10^{-34})(3.0 \times 10^{8})}{500 \times 10^{-9}} = 4.0 \times 10^{-19}$ J.

2 Practice

Now apply the methods above.

2.1 Write the formula for the **energy** of a photon. [1]

2.2 State the value of the **Planck constant**. [1]

2.3 Find the energy of a photon of frequency 5.0×10^{14} Hz. [2]

2.4 Convert your answer to **electronvolts**. [1]

3 Exam-style questions

3.1 The momentum of a photon of energy E is: [1]

- **A** hf
- **B** E/c
- **C** mc
- **D** h/c

3.2 Calculate the energy of a photon of wavelength 500 nm. [3]

3.3 Calculate the **momentum** of this photon. [2]

3.4 State what a **photon** is. [1]

3.5 A nucleus of uranium-238 decays by emitting an α-particle and a single gamma photon. Take 1 u = 1.66×10^{-27} kg, $c = 3.00 \times 10^{8}$ m s^{-1}, $h = 6.63 \times 10^{-34}$ J s and 1 MeV = 1.60×10^{-13} J.

(a) **State** what is meant by a **photon**. [2]

(b) The gamma photon carries an energy of 0.050 MeV. **Determine** its wavelength. [3]

(c) **Determine** the momentum of that photon. [2]

(d) The photon is emitted by a nucleus that was at rest. **Explain** why the nucleus recoils, and **determine** its recoil speed, given that its mass is 234 u. [3]

(e) Gamma radiation from a sample of this nuclide has a **single** wavelength. **Suggest** what this tells you about the energy levels of the nucleus. [2]

Solutions

2.1 $E = hf$ (or $E = hc/\lambda$).

2.2 $h = 6.63 \times 10^{-34}$ J s.

2.3 $E = hf = (6.63 \times 10^{-34})(5.0 \times 10^{14}) = 3.3 \times 10^{-19}$ J.

2.4 $E = (3.3 \times 10^{-19})/(1.6 \times 10^{-19}) = 2.1$ eV.

3.1 **B** — E/c.

3.2 $E = \dfrac{hc}{\lambda} = \dfrac{(6.63 \times 10^{-34})(3.0 \times 10^{8})}{500 \times 10^{-9}} = 4.0 \times 10^{-19}$ J.

3.3 $p = E/c = (4.0 \times 10^{-19})/(3.0 \times 10^{8}) = 1.3 \times 10^{-27}$ kg m s^{-1}.

3.4 A **quantum (packet) of electromagnetic energy**.

3.5 (a) A photon is a **quantum (discrete packet) of electromagnetic radiation**, carrying energy $E = hf$.
(b) $E = 0.050 \times 1.60 \times 10^{-13} = 8.0 \times 10^{-15}$ J; $\lambda = \dfrac{hc}{E} = \dfrac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{8.0 \times 10^{-15}}$ $= 2.5 \times 10^{-11}$ m.
(c) $p = \dfrac{E}{c} = \dfrac{8.0 \times 10^{-15}}{3.00 \times 10^{8}} = 2.7 \times 10^{-23}$ N s. (Or $p = h/\lambda$, which gives the same number.)
(d) Momentum is conserved and the nucleus started at rest, so it must recoil with momentum **equal and opposite** to the photon's. $v = \dfrac{p}{m} = \dfrac{2.67 \times 10^{-23}}{234 \times 1.66 \times 10^{-27}} =$ 6.9×10^{-2} m s^{-1}.
(e) The nucleus has **discrete energy levels**: the photon energy is the difference between two definite levels, and a single wavelength means every nucleus in the sample makes the **same** transition.

8 **(a)** State what is meant by a photon.

....

....

.... [2]

(b) A stationary nucleus of uranium-238 ($^{238}_{92}U$) undergoes alpha decay to produce a nucleus of thorium-234 ($^{234}_{90}Th$). The kinetic energy of the emitted alpha particle is 4.200 MeV. A gamma-ray photon is also emitted during the decay.

Assume that the rebound kinetic energy of the thorium nucleus is negligible.

Table 8.1 shows the masses of the nuclides involved in the decay reaction. The mass of the uranium-238 nuclide is missing.

Table 8.1

nuclide	nuclide mass / u
$^{4}_{2}\alpha$	4.000 407
$^{234}_{90}Th$	233.915 174
$^{238}_{92}U$	

The total energy released in the decay of the nucleus of uranium-238 is 4.274 MeV.

(i) Calculate the mass, in u, of the uranium-238 nuclide. Give your answer to five decimal places.

mass = ... u [3]

(ii) Determine a value for the wavelength of the gamma radiation emitted during the decay of the uranium-238 nucleus.

wavelength = ... m [3]

(iii) In practice, the rebound kinetic energy of the thorium nucleus is **not** negligible.

Explain, without further calculation, how your answer in **(b)(ii)** compares with the true wavelength of gamma radiation emitted during the decay of the uranium-238 nucleus.

....

....

.... [1]

(c) Gamma radiation emitted during the decay of a sample of uranium-238 has a single wavelength.

Nuclei of cobalt-60 ($^{60}_{27}Co$) decay by beta emission, and also emit gamma radiation in the process.

Suggest why there is **not** a single wavelength for the gamma radiation emitted during the decay of a sample of cobalt-60.

....

....

.... [2]

[Total: 11]

8 **(a)** State what is meant by a photon.

....

....

.... [2]

(b) A laser emits red light of a single wavelength. The light is produced when electrons move from a higher energy level to a lower energy level. The difference in energy between the two levels is 1.96 eV.

(i) Calculate the wavelength of the light.

wavelength = ... m [3]

(ii) The power of the beam emitted by the laser is 1.0×10^{-2} W.

Calculate the number of photons emitted per unit time by the laser.

number per unit time = ... s^{-1} [1]

(iii) The photons are incident normally on a surface. Half of the number of photons are absorbed by the surface, and half are reflected.

Determine the average force exerted by the beam of photons on the surface.

average force = ... N [4]

[Total: 10]

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

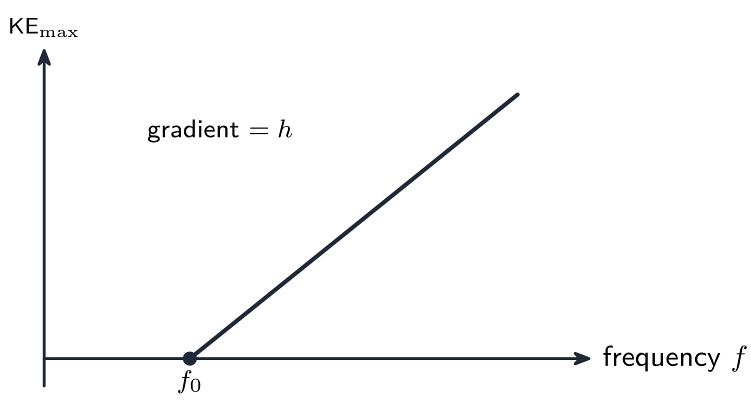
1 Worked examples

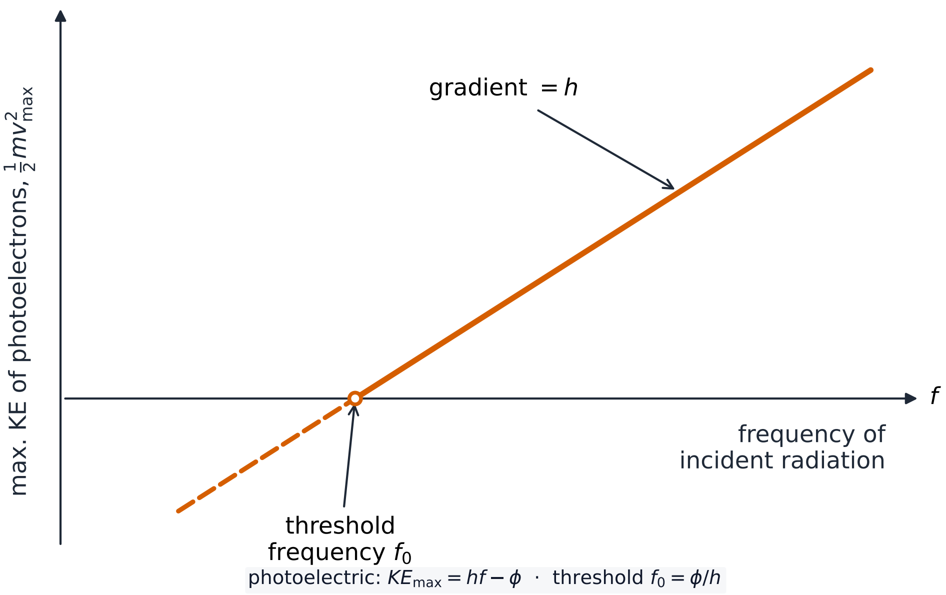
Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

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:

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





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

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 $\mathrm{KE}_{\max} = hf - \Phi = 3.5 - 2.0 = 1.5$ 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) $E_{\mathrm{K,max}} = hf - \phi = 3.03 - 2.3 = 0.73$ eV $= 1.17 \times 10^{-19}$ J; $v = \sqrt{\dfrac{2E_{\mathrm{K}}}{m}} = \sqrt{\dfrac{2 \times 1.17 \times 10^{-19}}{9.11 \times 10^{-31}}} = 5.1 \times 10^5$ 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.

9 **(a)** State what is meant by the photoelectric effect.

....

....

.... [2]

(b) The photoelectric effect is investigated using two clean metal plates. One plate is made from metal X and the other is made from metal Y.

Metal X has work function energy Φ. Metal Y has work function energy 2Φ.
Metal X has threshold frequency F.

State expressions, in terms of either or both of Φ and F, for

(i) the threshold frequency of metal Y

threshold frequency = ... [1]

(ii) the Planck constant.

Planck constant = ... [1]

(c) The maximum kinetic energy E_K of photoelectrons is determined for each of the plates in **(b)** for different frequencies f of incident radiation.

On Fig. 9.1, sketch the variation of E_K with f for each plate. Label your lines X and Y to identify which line relates to which plate.

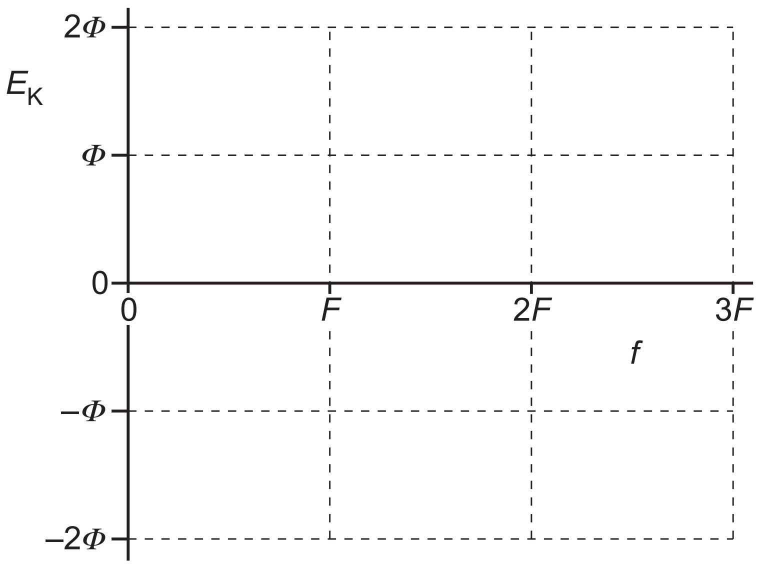


Fig. 9.1

[4]

[Total: 8]

9 **(a)** State what is meant by the photoelectric effect.

....

....

.... [2]

(b) The photoelectric effect is investigated in two stages using the circuit shown in Fig. 9.1.

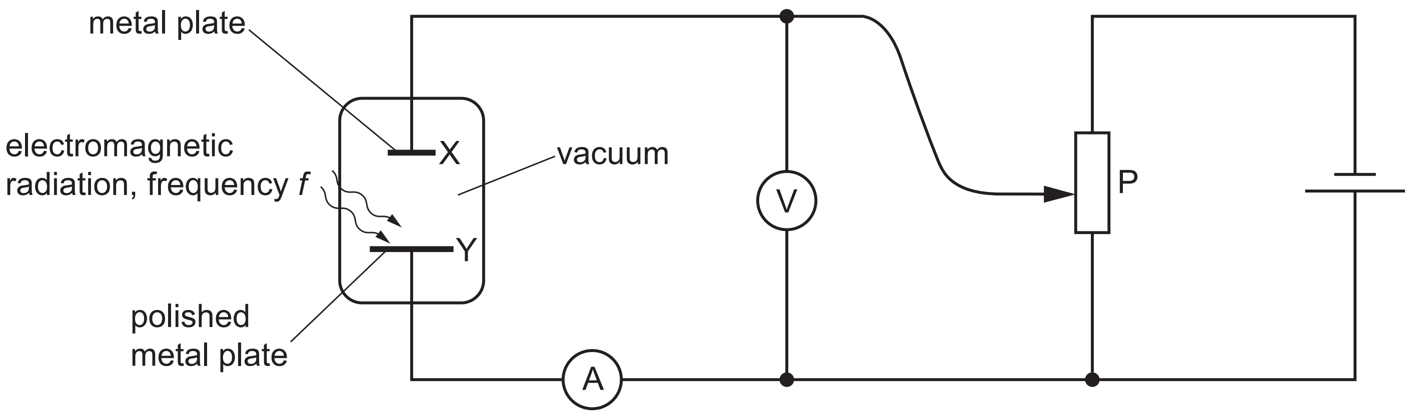


Fig. 9.1

The polished metal plate Y is illuminated with electromagnetic radiation of frequency f and constant power.

In stage 1 of the investigation, frequency f is set to a constant value of 2.5×10^{15} Hz. The current I in the ammeter is varied by adjusting the potentiometer P. Fig. 9.2 shows the variation of I with the voltmeter reading V. There is a value V_S of V at which the current just falls to zero.

In stage 2 of the investigation, stage 1 is repeated for different values of frequency. As frequency f is varied, the voltmeter reading V_S at which the current just falls to zero is measured. Fig. 9.3 shows the variation of V_S with f.

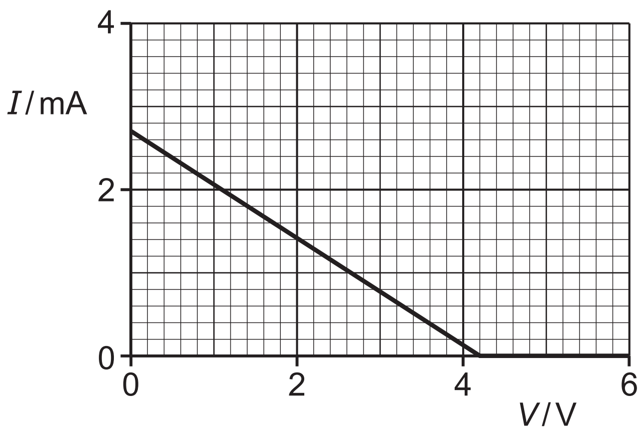


Fig. 9.2

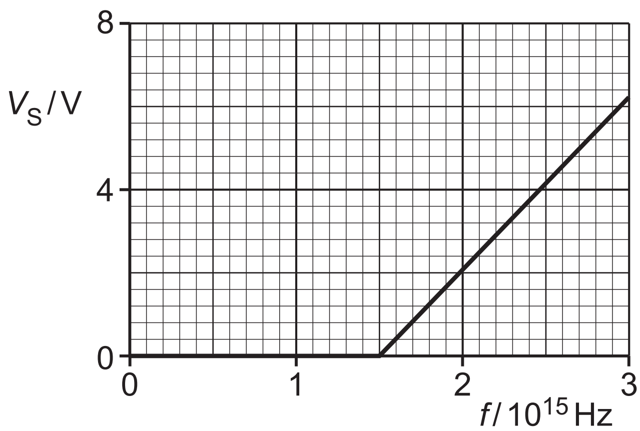


Fig. 9.3

(i) Explain, with reference to photons, why V_S depends on the frequency of the incident electromagnetic radiation.

....

....

....

....

....

.... [3]

(ii) State **three** quantitative conclusions that can be drawn from the results in Fig. 9.2 and Fig. 9.3. Use the space for any working.

1 ....

....

2 ....

....

3 ....

....

[3]

[Total: 8]

A-LEVEL PHYSICS • EXERCISE SHEET

22.3 Wave-particle duality

Name: ______________ Class: __________ Date: ____________ **Total: 27 marks**

KEY WORDS de broglie wavelength 德布罗意波长 • wave–particle duality 波粒二象性 • diffraction 衍射 • electron diffraction 电子衍射 • interference 干涉

Objective

Build the skills to answer exam questions on **wave–particle duality** and the de Broglie wavelength.

You must be able to:

- state the evidence for the **wave** and **particle** natures
- use the **de Broglie wavelength** $\lambda = h/p$
- describe **electron diffraction**

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.

Wave–particle duality

- **particle** nature of light: the **photoelectric effect**;
- **wave** nature of light: **interference** and **diffraction**.

So light has both — **wave–particle duality**. De Broglie said moving **particles** also have a wavelength:

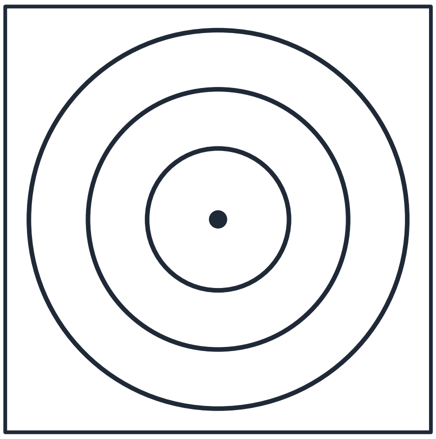
$$\lambda = \frac{h}{p} = \frac{h}{mv}.$$

Usually you are given the **speed**: find the momentum $p = mv$ first, then $\lambda = h/p$.

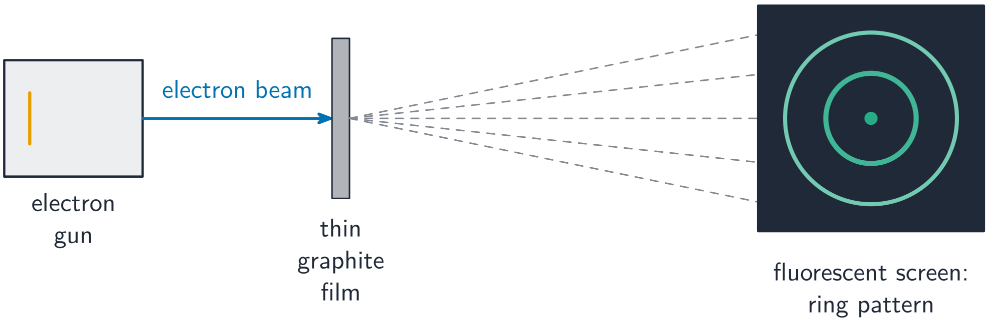
Worked example. An electron ($m = 9.1 \times 10^{-31}$ kg) moves at 4.9×10^{7} m s^{-1}: $p = mv = 4.5 \times 10^{-23}$ kg m s^{-1}, so $\lambda = \dfrac{h}{p} = \dfrac{6.63 \times 10^{-34}}{4.5 \times 10^{-23}} = 1.5 \times 10^{-11}$ m.

■ Electron diffraction

Electrons fired at a thin crystal produce **diffraction rings** — only waves diffract, so this shows the **wave nature of particles**:



diffraction rings



Electron diffraction shows wave behaviour

2 Practice

Now apply the methods above.

2.1 State **one** phenomenon that is evidence for the **particle** nature of light. [1]

2.2 State **one** phenomenon that is evidence for the **wave** nature of light. [1]

2.3 Write the **de Broglie** equation. [1]

2.4 State what **electron diffraction** demonstrates. [1]

3 Exam-style questions

3.1 The de Broglie wavelength of a particle is: [1]

- **A** hf
- **B** h/p
- **C** E/c
- **D** hc

3.2 Calculate the de Broglie wavelength of an electron with momentum 4.5×10^{-23} kg m s^{-1}. [2]

3.3 Describe the **evidence** that electron diffraction provides for the **wave nature** of particles. [3]

3.4 Explain what is meant by **wave–particle duality**. [2]

3.5 Calculate the de Broglie wavelength of an electron moving at 4.9×10^7 m s^{-1}. ($m_e = 9.1 \times 10^{-31}$ kg.) [3]

3.6 In an electron diffraction tube, electrons are accelerated through a potential difference of 4.8 kV and strike a thin graphite film. Take $h = 6.63 \times 10^{-34}$ J s, $e = 1.60 \times 10^{-19}$ C and the electron mass as 9.11×10^{-31} kg.

(a) **State** what is meant by the **de Broglie wavelength** of a particle. [2]

(b) **Determine** the speed of an electron after acceleration. [3]

(c) **Determine** its de Broglie wavelength. [2]

(d) **Explain** why a diffraction pattern is seen on the screen, and what it demonstrates about electrons. [3]

(e) The accelerating p.d. is **increased**. **State and explain** what happens to the spacing of the rings in the pattern. [2]

Solutions

2.1 The **photoelectric effect**.

2.2 Interference (e.g. double-slit) or **diffraction**.

2.3 $\lambda = h/p$.

2.4 That **particles** (electrons) have a **wave nature**.

3.1 B — h/p.

3.2 $\lambda = h/p = (6.63 \times 10^{-34})/(4.5 \times 10^{-23}) = 1.5 \times 10^{-11}$ m.

3.3 Electrons fired at a crystal produce a pattern of **rings/maxima** on a screen; this is a **diffraction** pattern, and **only waves diffract**; so the electrons must have a **wave nature** (matching $\lambda = h/p$).

3.4 Matter and radiation show **both** wave-like behaviour (interference/diffraction) **and** particle-like behaviour (photons/photoelectric effect).

3.5 $p = mv = (9.1 \times 10^{-31})(4.9 \times 10^{7}) = 4.5 \times 10^{-23}$ kg m s^{-1}; $\lambda = \dfrac{h}{p} = \dfrac{6.63 \times 10^{-34}}{4.5 \times 10^{-23}}$ $= 1.5 \times 10^{-11}$ m.

3.6 (a) The wavelength associated with a **moving particle**, given by $\lambda = \dfrac{h}{p}$, where p is its momentum.
(b) The work done by the accelerating p.d. becomes kinetic energy: $eV = \frac{1}{2}mv^2$; $v = \sqrt{\dfrac{2eV}{m}} = \sqrt{\dfrac{2 \times 1.60 \times 10^{-19} \times 4800}{9.11 \times 10^{-31}}} = 4.1 \times 10^{7}$ m s^{-1}.
(c) $\lambda = \dfrac{h}{mv} = \dfrac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 4.11 \times 10^{7}} = 1.8 \times 10^{-11}$ m.
(d) The spacing between the graphite atoms is of the same order as this wavelength, so the electrons are **diffracted** by the atomic planes and the diffracted waves **interfere** to give rings. Diffraction and interference are wave behaviours, so this shows that particles have a **wave nature**.
(e) A larger p.d. gives the electrons more momentum, so $\lambda = h/p$ is **smaller**; less diffraction means the rings move **closer together**.

8 **(a)** State what is meant by the de Broglie wavelength.

....

.... [1]

(b) Calculate the de Broglie wavelength of an electron moving at a speed of $4.9 \times 10^7\,\mathrm{m\,s^{-1}}$.

wavelength = ... m [2]

(c) State **one** similarity and **one** difference between an electron and a positron.

similarity: ....

....

difference: ....

....
[2]

(d) An electron moving at a speed of $4.9 \times 10^7\,\mathrm{m\,s^{-1}}$ collides with a positron that is travelling at the same speed in the opposite direction. As a result of the collision, two gamma-ray photons are produced.

(i) State the name of this type of reaction.

.... [1]

(ii) State what happens to the electron and to the positron.

....

....

.... [2]

(iii) Explain why two gamma-ray photons are produced, rather than just one.

....

.... [1]

(iv) Show that the kinetic energy of the electron before the collision is 1.1×10^{-15} J.

[1]

(v) Use the information in **(d)(iv)** to determine, to three significant figures, the wavelength associated with the gamma radiation emitted in the collision.

wavelength = ... m [3]

[Total: 13]

9 **(a)** **(i)** Describe what is meant by wave–particle duality.

....

....

.... [2]

(ii) State the relationship between the de Broglie wavelength λ of a particle and its momentum p. State the meaning of any other symbols that you use.

....

.... [2]

(b) A narrow beam of electrons, all with the same speed, is incident normally on a carbon film. The electrons then move on to a fluorescent screen, as illustrated in Fig. 9.1.

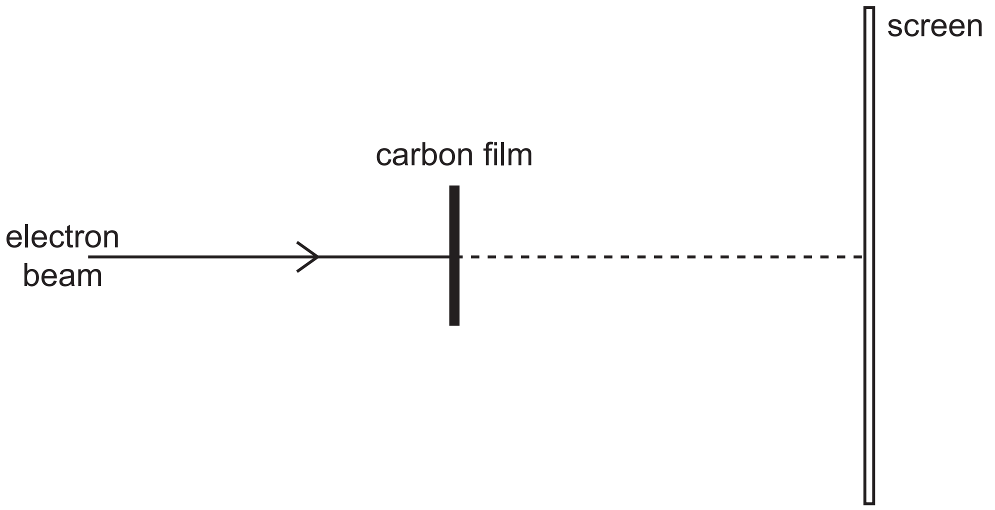


Fig. 9.1

The apparatus is in a vacuum.
The pattern produced on the screen is shown in Fig. 9.2.

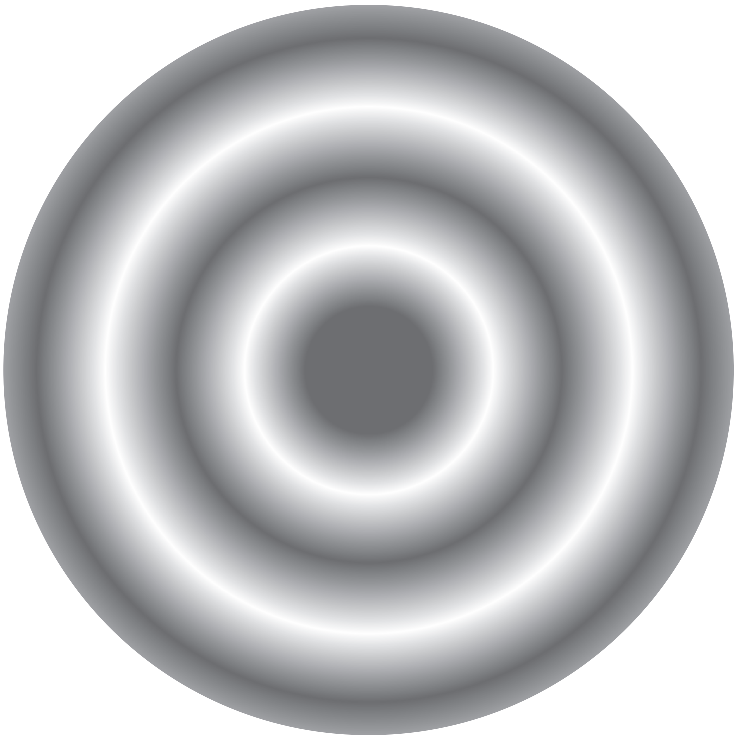


Fig. 9.2 (not to scale)

(i) Explain why the pattern in Fig. 9.2 provides experimental evidence to indicate a wave nature for the electrons.

....

....

.... [2]

(ii) The speed of the electrons is increased.

Suggest, with a reason, how this change affects the pattern observed on the screen.

....

....

.... [2]

[Total: 8]

22.4 Energy levels in atoms and line spectra

Name: ____________ Class: ________ Date: __________ **Total: 25 marks**

KEY WORDS emission spectrum 发射光谱 • energy level 能级 • discrete 分立 • absorption spectrum 吸收光谱 • electron 电子

Objective

Build the skills to answer exam questions on **energy levels** and line spectra.

You must be able to:

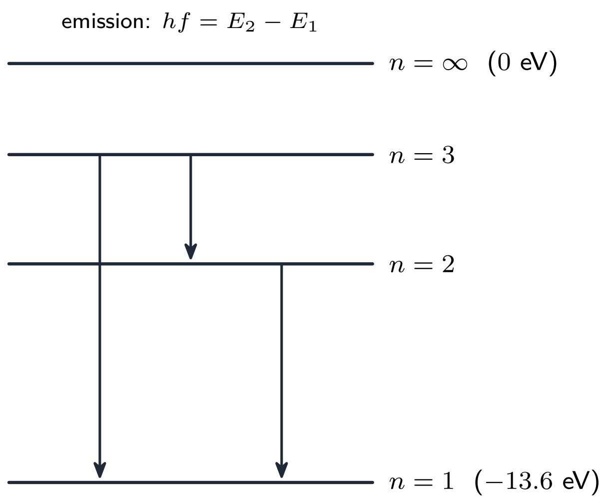
- explain **discrete energy levels** and line spectra
- use $hf = E_2 - E_1$

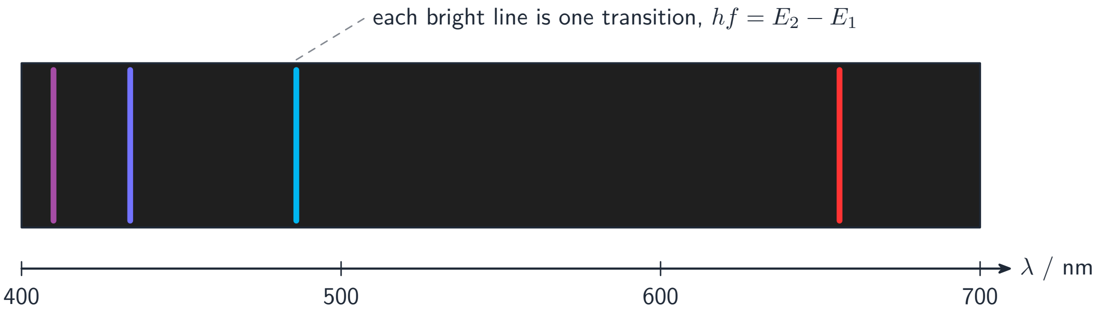
1 Worked examples

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.

■ Energy levels

An atom's electrons can only sit at **discrete** energy levels (written **negative**, with 0 for a free electron):





Line spectra from atomic energy levels

When an electron **drops** from E_2 to a lower E_1, it emits a photon:

$$hf = E_2 - E_1.$$

Because the levels are **discrete**, only certain photon energies (wavelengths) appear — an **emission spectrum** is a set of **bright lines** on a dark background (a fingerprint of the element). An **absorption spectrum** is dark lines on a bright background.

2 Practice

Now apply the methods above.

2.1 State what is meant by **discrete** energy levels. [1]

2.2 Write the equation linking photon frequency to two energy levels. [1]

2.3 State why the energy levels are written as **negative** values. [1]

2.4 State what an **emission spectrum** looks like. [1]

3 Exam-style questions

3.1 An **emission** line spectrum consists of: [1]

- **A** a continuous range of colours
- **B** dark lines on a bright background
- **C** bright lines on a dark background
- **D** a single colour only

3.2 An electron drops from an energy level of -3.4 eV to -13.6 eV. Calculate the **energy** of the emitted photon, in eV and in joules. [3]

3.3 Calculate the **wavelength** of the photon emitted in question 3.2. [3]

3.4 Explain why only **certain** wavelengths appear in an emission spectrum. [2]

3.5 The lowest four energy levels of a hydrogen atom are at -13.6 eV, -3.40 eV, -1.51 eV and -0.85 eV. Take $h = 6.63 \times 10^{-34}$ J s, $c = 3.00 \times 10^{8}$ m s^{-1} and 1 eV $= 1.60 \times 10^{-19}$ J.

(a) Use the **photon model** to explain how the existence of sharp **spectral lines** shows that the atom has discrete energy levels. [3]

(b) **Calculate** the energy of the ground state in **joules**. [1]

(c) **Show that** the energy difference between the $n = 1$ and $n = 2$ levels is 10.2 eV. [1]

(d) **Complete** the table for transitions **down to the ground state**. [3]

transition	**energy difference / eV**	**wavelength of photon / nm**
$n = 2 \rightarrow n = 1$	10.2	______
$n = 3 \rightarrow n = 1$	______	______
$n = 4 \rightarrow n = 1$	______	______

(e) **State and explain** whether these three photons are visible to the eye. [2]

(f) **Explain** why the energies of the levels are given as **negative** numbers. [2]

Solutions

2.1 The electron can only have **certain fixed energies** — never values in between.

2.2 $hf = E_2 - E_1$.

2.3 Energy is measured from 0 for a **free** electron, and a bound electron has **less** energy than that — so it is negative.

2.4 A series of **sharp bright lines** on a dark background.

3.1 **C** — bright lines on a dark background.

3.2 $\Delta E = -3.4 - (-13.6) = 10.2$ eV; in joules $= 10.2 \times 1.6 \times 10^{-19} = 1.6 \times 10^{-18}$ J.

3.3 $\lambda = \dfrac{hc}{E} = \dfrac{(6.63 \times 10^{-34})(3.0 \times 10^{8})}{1.6 \times 10^{-18}} = 1.2 \times 10^{-7}$ m.

3.4 The energy levels are **discrete**, so the differences $E_2 - E_1$ — and hence the photon energies/wavelengths — can only take **certain values**.

3.5 (a) An atom emits a photon when an electron falls from a higher level to a lower one, and the photon energy equals the **difference** between the two levels. Since $E = hf$, one energy difference gives one frequency and so one sharp line. A continuous range of energies would give a continuous spectrum, so sharp lines show only **certain** energies are allowed, i.e. the levels are discrete.
(b) $-13.6 \times 1.60 \times 10^{-19} = -2.18 \times 10^{-18}$ J.
(c) $-3.40 - (-13.6) = 10.2$ eV.
(d) Differences: 10.2, 12.09 and 12.75 eV. Wavelengths from $\lambda = \dfrac{hc}{E}$: 122 nm, 103 nm and 97 nm.
(e) **No** — all three lie near 100 nm, in the **ultraviolet**, well below the roughly 400–700 nm visible range.
(f) The zero of energy is taken as the electron being **free**, at infinity and at rest; a bound electron has less energy than that, so energy must be **supplied** to free it and its energy is written as negative.

8 Fig. 8.1 shows the three lowest-frequency lines in the part of the emission spectrum for hydrogen that relates to electron transitions to the ground state (level n = 1).

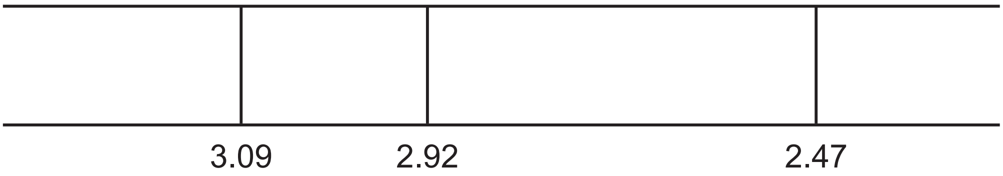


Fig. 8.1 (not to scale)

The numbers represent the frequencies, in 10^{15} Hz, associated with the spectral lines.

(a) Use the photon model of electromagnetic radiation to explain how the existence of spectral lines in the emission spectrum provides evidence for discrete electron energy levels in the hydrogen atom.

....

....

....

....

.... [3]

(b) The energy of the ground state (level n = 1) in a hydrogen atom is –13.6 eV.

(i) Calculate the energy, in J, of the ground state.

energy = ... J [1]

(ii) Show that the energy difference between levels n = 1 and n = 2 is 10.2 eV.

[2]

(iii) Complete Table 8.1 to show the energy differences from the ground state, and the energies of the levels up to n = 4, in the hydrogen atom. Use the space for any working.

Table 8.1

level	(energy difference from n = 1) / eV	energy / eV
n = 4		
n = 3		
n = 2	10.2	
n = 1	0.0	–13.6

[4]

[Total: 10]