A-LEVEL PHYSICS • EXERCISE SHEET

7.5 Polarisation

Name: ______________ Class: __________ Date: ____________ **Total: 20 marks**

KEY WORDS polarising filter 偏振片 • polarisation 偏振 • transverse 横波 • plane-polarised 平面偏振 • wave 波

Objective

Build the skills to answer exam questions on **polarisation 偏振** and **Malus's law**.

You must be able to:

- explain that only **transverse 横波** waves can be polarised
- use **Malus's law** $I = I_0 \cos^2\theta$, and work **backwards** to find the angle
- sketch how the transmitted intensity varies as a filter is **rotated**
- link transmitted **intensity** to **amplitude** 振幅 using $I \propto A^2$

1 Worked examples

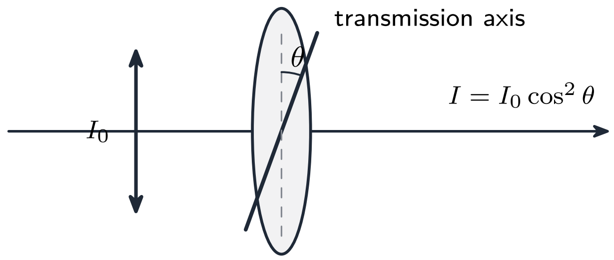
Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Polarisation

Polarisation makes a transverse wave oscillate in **one plane** only. Only **transverse** waves can be polarised (their oscillation is perpendicular to the travel direction, so different planes exist). **Longitudinal** 纵波 waves such as sound **cannot** — so polarisation is a **test for a transverse wave**.

■ Malus's law

Plane-polarised light of intensity I_0 meets a filter whose **transmission axis** 透射轴 is at angle θ to the plane of polarisation. The transmitted intensity is:



$$I = I_0 \cos^2 \theta.$$

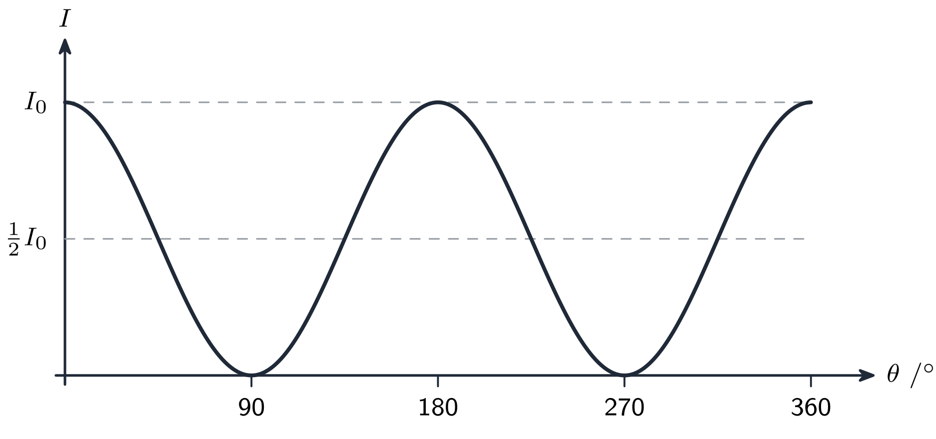
- $\theta = 0°$: $I = I_0$ (all passes); $\theta = 90°$: $I = 0$ (blocked); $\theta = 45°$: $I = \frac{1}{2} I_0$; $\theta = 60°$: $I = \frac{1}{4} I_0$.

Worked example (forward). $I_0 = 12$ W m^{-2}, $\theta = 30°$: $I = 12\cos^2 30° = 12 \times 0.75 = 9.0$ W m^{-2}.

Worked example (backwards). For what θ is the intensity **halved**? Set $\cos^2\theta = 0.5$, so $\cos\theta = \sqrt{0.5}$ and $\theta = 45°$.

■ Rotating the filter

If the angle θ between the axis and the polarisation is changed (by **rotating** the filter), the transmitted intensity traces a $\cos^2$ curve — maximum I_0 at $0°, 180°, 360°$ and zero at $90°, 270°$:



The "starts perpendicular" case. If the axis **begins perpendicular** to the polarisation and is then rotated by an angle ϕ, the angle in the formula is $\theta = 90° - \phi$. So $I = I_0 \cos^2(90° - \phi) = I_0 \sin^2\phi$: the intensity **starts at zero**, rises to I_0 after $\phi = 90°$, and so on.

■ **Intensity and amplitude**

Intensity is proportional to amplitude squared, $I \propto A^2$, so for a wave through a filter:

$$\frac{A}{A_0} = \sqrt{\frac{I}{I_0}}.$$

Worked example. If a filter transmits $I = 0.25\,I_0$, the amplitude is $A = A_0\sqrt{0.25} = 0.50\,A_0$ — the amplitude falls to **half**, even though the intensity falls to a **quarter**.

■ **Two filters in series**

Apply Malus's law **once per filter**; the second angle is measured from the **first** filter's axis. Two **crossed** filters (90° apart) transmit **nothing**.

2 Practice

Now apply the methods above.

2.1 State what **polarisation** means. [1]

2.2 State why **sound** cannot be polarised. [1]

2.3 Plane-polarised light meets a filter whose axis is at 60° to its plane. State the **fraction** of intensity transmitted. [1]

2.4 A filter transmits **half** the incident intensity. State the angle θ between its axis and the plane of polarisation. [1]

2.5 A filter transmits $I = 0.25\,I_0$. State the transmitted amplitude as a fraction of A_0. [1]

3 Exam-style questions

3.1 Which of these **can** be polarised? [1]

- **A** sound waves
- **B** all electromagnetic waves
- **C** longitudinal waves
- **D** all of these

3.2 Plane-polarised light of intensity 12 W m^{-2} meets a filter whose axis is at 30° to the plane of polarisation. Calculate the transmitted intensity. [2]

3.3 Plane-polarised light passes through **two** filters. The first axis is at 30° to the plane of polarisation; the second is a further 30° beyond the first. The light reaching the first filter has intensity 8.0 W m^{-2}. Calculate the intensity emerging from the **second** filter. [3]

3.4 A photographer looks at a shop window through a polarising filter. The light reflected from the glass is plane-polarised, of intensity I_0, and the filter's transmission axis starts **parallel** to the plane of polarisation. The filter is then rotated through 360° about the viewing direction.

(a) On the axes, sketch how the transmitted intensity I varies with the rotation angle ϕ. [2]

(b) Determine the smallest rotation ϕ that **halves** the transmitted intensity. [2]

(c) At that angle, find the transmitted **amplitude** as a fraction of the incident amplitude A_0, and explain why the photographer rotates the filter to cut the glare. [3]

3.5 Explain why the ability to **polarise** a wave shows that the wave is **transverse**. [2]

Solutions

2.1 Restricting the oscillations of a transverse wave to **one plane**.

2.2 Sound is **longitudinal** — its oscillation is along the direction of travel, so there is no other plane to restrict it to.

2.3 $\cos^2 60° = 0.25$, i.e. **one quarter**.

2.4 $\cos^2\theta = 0.5 \Rightarrow \cos\theta = \sqrt{0.5} \Rightarrow \theta = 45°$.

2.5 $A = A_0\sqrt{0.25} = 0.50\,A_0$ — **half** the amplitude.

3.1 **B** — all electromagnetic waves (they are transverse).

3.2 $I = I_0\cos^2\theta = 12 \times \cos^2 30° = 12 \times 0.75 = 9.0\ \mathrm{W\ m^{-2}}$.

3.3 First filter: $I_1 = 8.0\cos^2 30° = 8.0 \times 0.75 = 6.0\ \mathrm{W\ m^{-2}}$. Second filter (a further 30°): $I_2 = I_1\cos^2 30° = 6.0 \times 0.75 = 4.5\ \mathrm{W\ m^{-2}}$.

3.4 (a) A $\cos^2$-shaped curve: **starts at the maximum** I_0 (axis parallel), falls to zero at $\phi = 90°$, back to I_0 at 180°, zero at 270°, I_0 at 360°.

3.4 (b) $I = I_0\cos^2\phi = 0.5\,I_0$ gives $\cos^2\phi = 0.5$, so $\cos\phi = 0.707$ and $\phi = 45°$.

3.4 (c) Intensity $\propto$ amplitude^2, so $A = A_0\sqrt{0.5} = 0.71\,A_0$. Glare from the glass is polarised in one plane, so turning the axis towards 90° to that plane cuts the reflected light while the unpolarised light from inside the shop is only halved.

3.5 Polarisation restricts the oscillation to **one plane**; this is only possible if the oscillation is **perpendicular** to the direction of travel — i.e. the wave is transverse (a longitudinal wave oscillates along the travel direction, so it has only one possible plane).