7.5 Polarisation

Name: _____ Class: _____ Date: _____ **Total: 22 marks**

KEY WORDS polarising filter • polarisation • transverse • plane-polarised • wave

Objective

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

You must be able to:

- explain that only **transverse** 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** using $I \propto A^2$

1 Key knowledge and worked examples

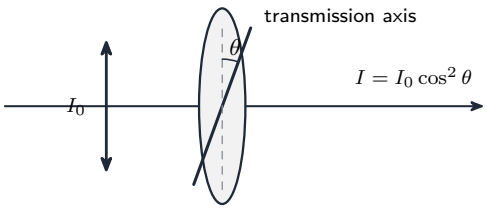
Study these first. Each one shows the method for a question type used later – follow the steps and you can do the Practice and Exam-style questions yourself.

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** 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** is at angle θ to the plane of polarisation. The transmitted intensity is:



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

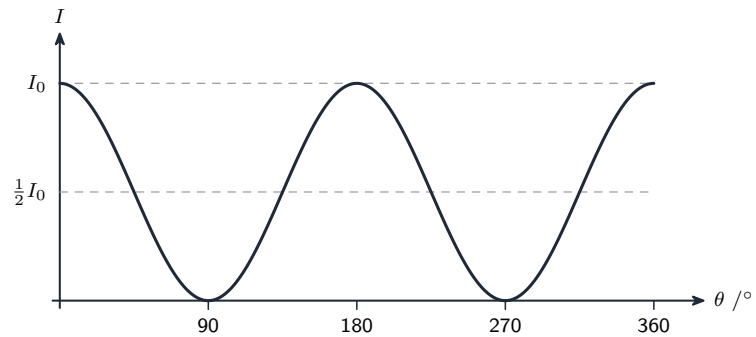
- $\theta = 0°$: $I = I_0$ (all passes); $\theta = 90°$: $I = 0$ (blocked); $\theta = 45°$: $I = \frac{1}{2}I_0$; $\theta = 60°$: $I = \frac{1}{4}I_0$.

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

■ **Key knowledge: a polariser initially perpendicular**

If a transmission axis starts perpendicular to already polarised light and rotates by ϕ, its angle to the incident polarisation is $90° - \phi$. Malus's law gives $I = I_0 \cos^2(90° - \phi) = I_0 \sin^2 \phi$. Here I_0 is the intensity of the already polarised light reaching this filter, not the intensity before an earlier polariser.

2 Practice

Now apply the methods above.

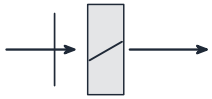
2.1 State what **polarisation** means. [1]

polarisation

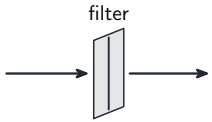
2.2 State why **sound** cannot be polarised. [1]

sound polarisation

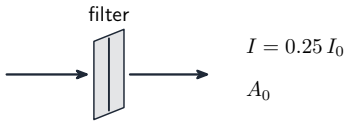
2.3 Plane-polarised light meets a filter whose axis is at 60° to its plane. State the **fraction** of intensity transmitted. [1]



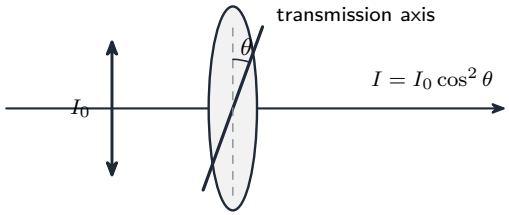
2.4 A filter transmits **half** the incident intensity. State the angle θ between its axis and the plane of polarisation. [1]



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



2.6 Already polarised light of intensity 80 W/m^2 reaches an analyser whose axis initially blocks it. The analyser rotates by 30°. Calculate the transmitted intensity. [2]



3 Exam-style questions

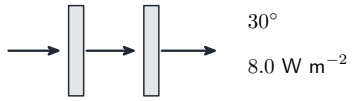
3.1 Which of these **can** be polarised? [1]

polarisation

- **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]

transverse longitudinal

Solutions

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

2.1

- restricting the oscillations of a transverse wave to **one plane**

2.2

- sound is **longitudinal** – oscillation is along the direction of travel, so there is no other plane to restrict it to

2.3

- Malus: $I = I_0 \cos^2 \theta$
- $\dfrac{I}{I_0} = \cos^2 60° = 0.25$, so the intensity is **one quarter**

2.4

- $\cos^2 \theta = 0.5 \Rightarrow \cos \theta = \sqrt{0.5} \Rightarrow \theta = \mathbf{45}°$

2.5

- intensity $\propto A^2$, so $A = A_0\sqrt{0.25} = 0.50\, A_0$ – **half** the amplitude

2.6

$I = I_0 \sin^2 \phi$, hence $I = 80 \sin^2 30° = 20$ W m^{-2}.

3.1 B

- all **electromagnetic** waves are transverse, so they can be polarised

3.2

- Malus's law

$$I = I_0 \cos^2 \theta = (12 \text{ W m}^{-2}) \cos^2 30° = 12 \times 0.75 = \mathbf{9.0} \text{ W m}^{\mathbf{-2}}$$

3.3

- first filter

$$I_1 = I_0 \cos^2 \theta = (8.0 \text{ W m}^{-2}) \cos^2 30° = 8.0 \times 0.75 = 6.0 \text{ W m}^{-2}$$

- second filter, a further 30°

$$I_2 = I_1 \cos^2 30° = 6.0 \times 0.75 = \mathbf{4.5} \text{ W m}^{\mathbf{-2}}$$

3.4

(a) a $\cos^2$ curve: **starts at the maximum** I_0 (axes parallel)

- zero at $\phi = 90°$ and 270°; back to I_0 at 180° and 360°

(b) $I = I_0 \cos^2 \phi = 0.5\, I_0 \Rightarrow \cos^2 \phi = 0.5$

- $\cos \phi = 0.707 \Rightarrow \phi = \mathbf{45}°$

(c) intensity $\propto A^2$, so $A = A_0\sqrt{0.5} = \mathbf{0.71\, A_0}$

- glare from glass is polarised in one plane, so turning towards 90° to that plane cuts the reflected light, while unpolarised light from inside is only halved

3.5

- polarisation restricts the oscillation to **one plane**
- that is only possible if the oscillation is **perpendicular** to the travel direction – i.e. the wave is **transverse**