

7.5 Polarisation

Name: _____ Class: _____ Date: _____

Total: 18 marks

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

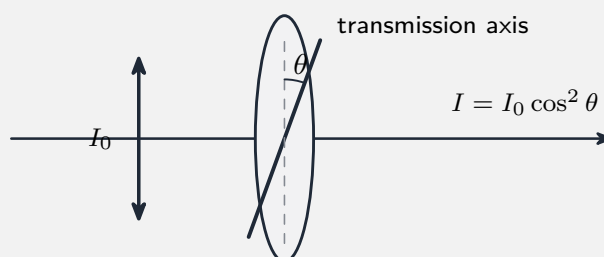
Study these first. Each one shows the method for a question type used later —follow the steps and you can do the Practice and Exam-style questions yourself.

■ 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:



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

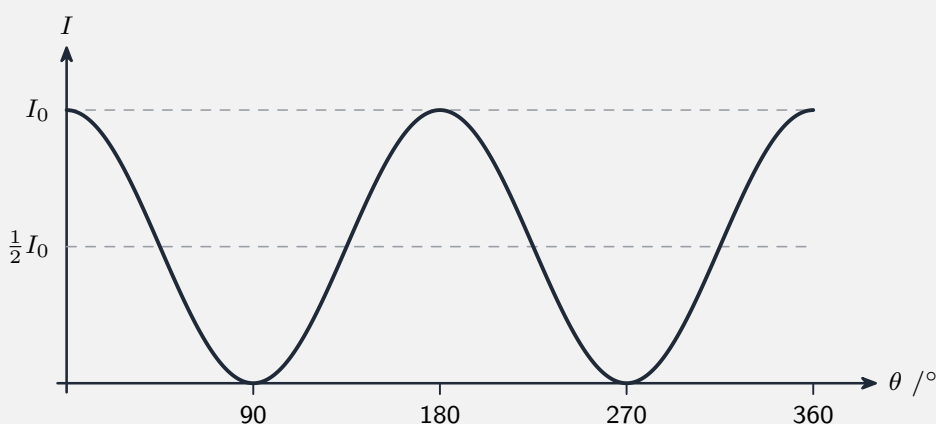
- $\theta = 0^\circ$: $I = I_0$ (all passes); $\theta = 90^\circ$: $I = 0$ (blocked); $\theta = 45^\circ$: $I = \frac{1}{2}I_0$; $\theta = 60^\circ$: $I = \frac{1}{4}I_0$.

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

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

■ 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 $0^\circ, 180^\circ, 360^\circ$ and zero at $90^\circ, 270^\circ$:



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 $\theta = 90^\circ - \phi$. So $I = I_0 \cos^2(90^\circ - \phi) = I_0 \sin^2 \phi$: the intensity **starts at zero**, rises to I_0 after $\phi = 90^\circ$, 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
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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 Plane-polarised light of intensity I_0 is incident normally on a polarising filter. The transmission axis is **initially perpendicular** to the plane of polarisation, and the filter is then rotated through 360° about the direction of travel.

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

(b) The filter is rotated by $\phi = 30^\circ$ from the start. Calculate the transmitted intensity in terms of I_0 . [2]

(c) Hence find the transmitted **amplitude** as a fraction of the incident amplitude A_0 . [2]

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

4 Go further

You are now ready for the real exam questions on this subtopic. Open the **7.5 Polarisation** past-paper sheet in the Library, or try these in **Practice mode**:

- 9702/23 J25 —Q5 (polarising filter rotated, intensity and amplitude)
- 9702/21 N25 —Q4 (polarisation and Malus's law)
- 9702/23 N25 —Q4 (polarisation, structured)
- 9702/11 J25 —Q28 (polarisation, multiple choice)
- 9702/12 J25 —Q27 (Malus's law, multiple choice)

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

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

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

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

3.4 (a) A $\sin^2$ -shaped curve: **starts at zero** (axis perpendicular), rises to a maximum I_0 at $\phi = 90^\circ$, back to zero at 180° , maximum I_0 at 270° , zero at 360° .

3.4 (b) Starting perpendicular, the angle in the formula is $\theta = 90^\circ - 30^\circ = 60^\circ$; $I = I_0 \cos^2 60^\circ = 0.25 I_0$.

3.4 (c) $A = A_0 \sqrt{I/I_0} = A_0 \sqrt{0.25} = 0.50 A_0$.

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).