

Exercise walk-through

7.5

Polarisation

A-Level Physics

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

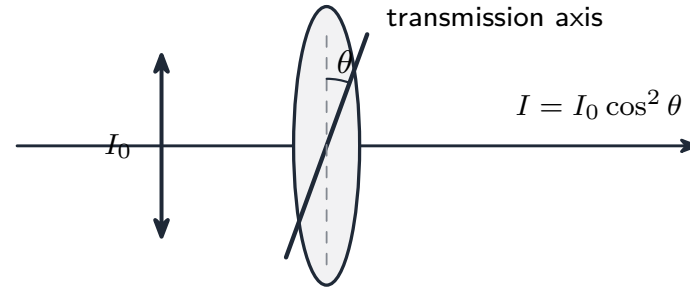
Study these first. Each one shows the method for a question type used later – follow the steps and you can do the Practice and Exam-style questions yourself.

■ 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:



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

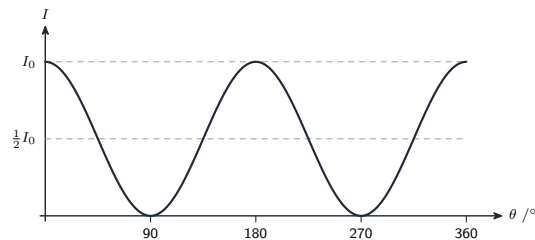
- $\theta = 0^\circ$: $I = I_0$ (all passes); $\theta = 90^\circ$: $I = 0$ (blocked); $\theta = 45^\circ$: $I = \frac{1}{2}I_0$; $\theta = 60^\circ$: $I = \frac{1}{4}I_0$.

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

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**.

■ 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 $90^\circ - \phi$. Malus's law gives $I = I_0 \cos^2(90^\circ - \phi) = I_0 \sin^2 \phi$. Here I_0 is the intensity of the already polarised light reaching this filter, not the intensity before an earlier polariser.

Exercises 2.1-2.2

2.1 State what **polarisation** means.

[1]

polarisation

2.2 State why **sound** cannot be polarised.

[1]

sound

polarisation

Exercises 2.1·2.2

2.1 State what **polarisation** means.

[1]

polarisation

2.1

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

2.2 State why **sound** cannot be polarised.

[1]

sound

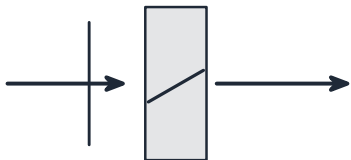
polarisation

2.2

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

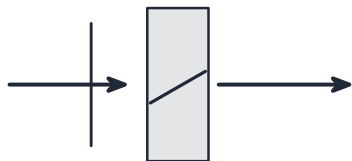
Exercise 2.3

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



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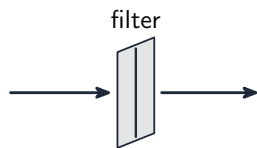
60°

2.3

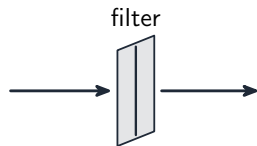
- Malus: $I = I_0 \cos^2 \theta$
- $\frac{I}{I_0} = \cos^2 60^\circ = 0.25$, so the intensity is **one quarter**

Exercises 2.4·2.5

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]

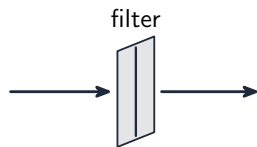


$$I = 0.25 I_0$$

$$A_0$$

Exercises 2.4-2.5

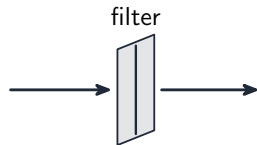
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2.4

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

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



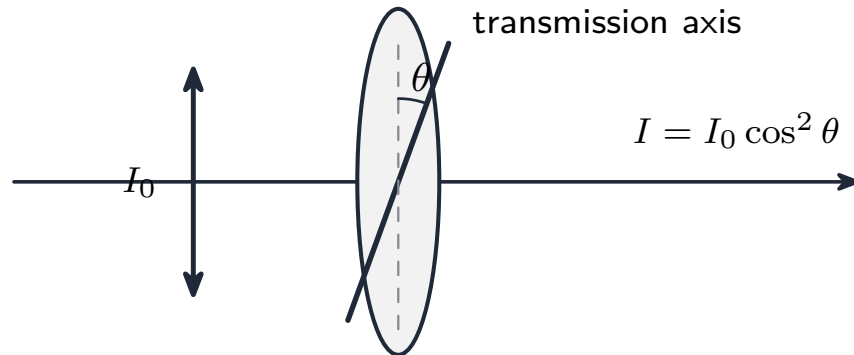
$$I = 0.25 I_0$$
$$A_0$$

2.5

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

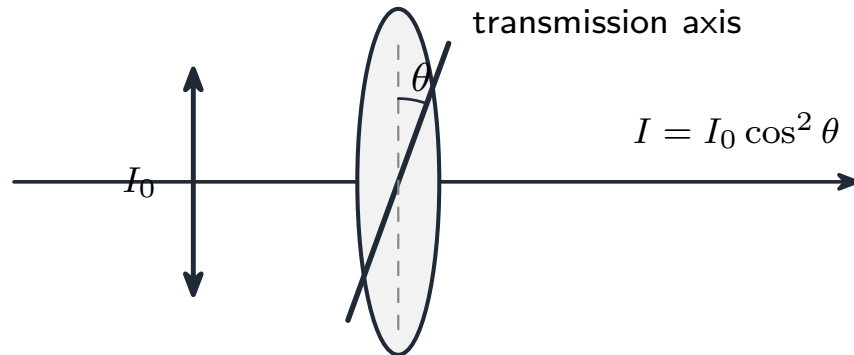
Exercise 2.6

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]



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2.6

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

Exercise 3.1

3.1 Which of these **can** be polarised?

[1]

☐

A sound waves

B all electromagnetic waves

C longitudinal waves

D all of these

polarisation

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[1]

☐

A sound waves

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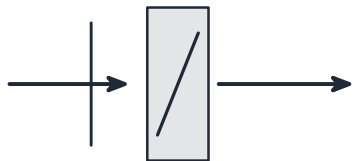
polarisation

3.1 B

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

Exercise 3.2

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]

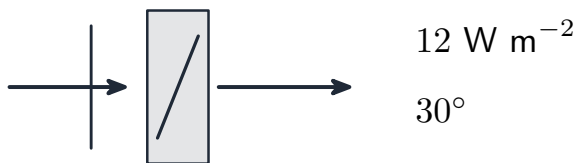


12 W m^{-2}

30°

Exercise 3.2

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3.2

- Malus's law

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

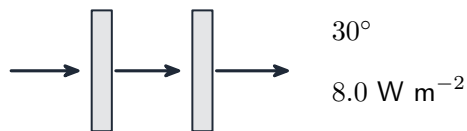
Exercise 3.3

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]



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3.3

- first filter

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

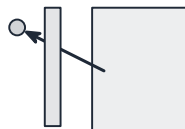
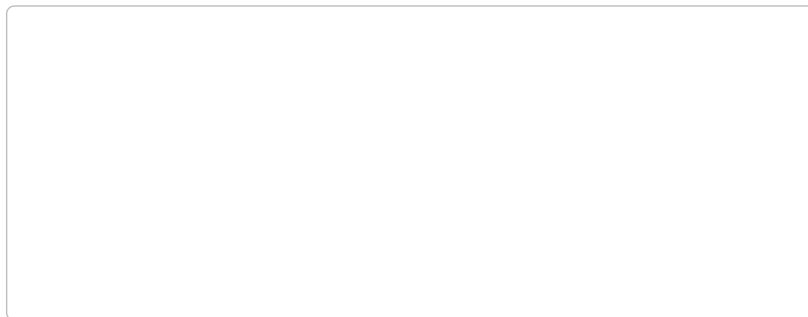
- second filter, a further 30°

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

Exercise 3.4 (a)

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.

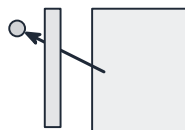
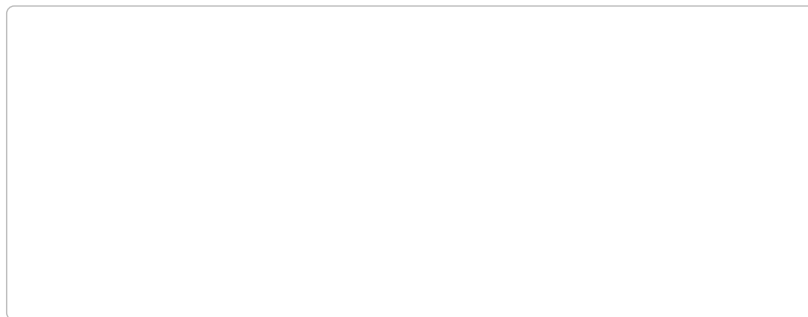
(a) On the axes, sketch how the transmitted intensity I varies with the rotation angle ϕ . [2]

 I_0 360° 

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

 I_0 360° 

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

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

Exercise 3.4 (b)

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.

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

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

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

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

Exercise 3.4 (c)

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.

(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]

Exercise 3.4 (c)

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(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]

(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

Exercise 3.5

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

transverse

longitudinal

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transverse

longitudinal

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**