Topic 4.3
Wave characteristics
Kahoot!
Subject guide

Understandings:
- Wavefronts and rays
- Amplitude and intensity
- Superposition
- Polarization

Applications and skills:
- Sketching and interpreting diagrams involving wavefronts and rays
- Solving problems involving amplitude, intensity and the inverse square law
- Sketching and interpreting the superposition of pulses and waves
- Describing methods of polarization
- Sketching and interpreting diagrams illustrating polarized, reflected and transmitted beams
- Solving problems involving Malus’s law

Guidance:
- Students will be expected to calculate the resultant of two waves or pulses both graphically and algebraically
- Methods of polarization will be restricted to the use of polarizing filters and reflection from a non-metallic plane surface

Data booklet reference:
- \( I \propto A^2 \)
- \( I \propto x^{-2} \)
- \( I = I_0 \cos^2 \theta \)
Polarization

Circular polarization

Plane polarization
Malu’s law  \[ I = I_0 \cos^2 \theta \]

Polarization of Light

Unpolarized light

Polarizer

Analyzer

\( I_0 \)

\( I_0 / 2 \)

\( I_0 / 2 \times \cos^2(\theta) \)
1 Unpolarized light is incident on a polarizer which in turn, transmits polarized light to a second polarizer. If the original light has an intensity of $I_0$ and the intensity emerging from the second polarizer is $0.397 \ I_0$, find the angle that the second polarizer’s axes make with the first.

2 Unpolarized light is incident on a polarizer which in turn, transmits polarized light to a second polarizer. If the second polarizer’s axes are at $57.0^\circ$ with respect to the first polarizer and the intensity emerging from the second polarizer is $3.00 \ Wm^{-2}$, find the original intensity of the unpolarized light.
Using filters

Go to: www.ophysics.com/l3.html

1. Choose “show one slit”
What happens when the angles between the transmission axes are
a) Parallel?
b) Perpendicular?
c) Somewhere in between?

2. Choose “show two slits”

Let the angle between the polarizer (first) and analyzer (last) be 90°.
What happens when you middle filter is at an angle of 45° to both filters?

a) If the original intensity is $I_0$. Find the intensity of the transmitted ray.

b) If the original amplitude is $A_0$. Find the amplitude of the transmitted ray.
Demonstration using the overhead projector
Task: Rewrite Malu’s law in terms of the amplitudes

Hint: substitute $I = kA^2$
9. Unpolarized light of intensity $I_0$ is incident on a polarizer. The transmitted light is then incident on a second polarizer. The axis of the second polarizer makes an angle of $60^\circ$ to the axis of the first polarizer.

The cosine of $60^\circ$ is $\frac{1}{2}$. The intensity of the light transmitted through the second polarizer is

A. $I_0$,  
B. $\frac{I_0}{2}$,  
C. $\frac{I_0}{4}$,  
D. $\frac{I_0}{8}$. 

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A. $I_0$.  B. $\frac{I_0}{2}$.  C. $\frac{I_0}{4}$.  D. $\frac{I_0}{8}$.
10. Two polarizing sheets have planes of polarization that are initially parallel.

The incoming light on sheet 1 is unpolarized. The intensity of the light transmitted is \( I \). To reduce the intensity to \( \frac{I}{2} \), which sheet must be rotated and through what angle?

<table>
<thead>
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<th>Sheet to be rotated</th>
<th>Rotation angle</th>
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<tbody>
<tr>
<td>A. 1 only</td>
<td>( \theta = \cos^{-1}\left( \frac{1}{\sqrt{2}} \right) )</td>
</tr>
<tr>
<td>B. 2 only</td>
<td>( \theta = \cos^{-1}\left( \frac{1}{2} \right) )</td>
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<tr>
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10. Two polarizing sheets have planes of polarization that are initially parallel.

The incoming light on sheet 1 is unpolarized. The intensity of the light transmitted is $I$. To reduce the intensity to $\frac{I}{2}$, which sheet must be rotated and through what angle?

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3. This question is about polarized light.

(a) Distinguish between polarized and unpolarized light.

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3. (a) In unpolarized light the **electric field vector** may vibrate in any plane (normal to the direction of propagation); in polarized light the vector/electric field vibrates in one plane only;

*To award [2 max] reference must be made to “electric field vector” at least once. Award [2 max] for any relevant correctly labelled diagram.*
A beam of plane polarized light of intensity $I_0$ is incident on an analyser. The direction of the beam is at right angles to the plane of the analyser.

The angle between the transmission axis of the analyser and the plane of polarization of the light is $\theta$. In the position shown the transmission axis of the analyser is parallel to the plane of polarization of the light ($\theta = 0$).

On the axes, sketch a graph to show how the intensity $I$ of the transmitted light varies with $\theta$ as the analyser is rotated through $180^\circ$.

(b) $\cos^2 \theta$ graph; (judge shape by eye) max $I_0$ at $0^\circ$ and $180^\circ$ and zero at $90^\circ$;
A beam of unpolarized light of intensity $I_0$ is incident on a polarizer. The polarization axis of the polarizer is initially vertical as shown.

The polarizer is then rotated by 180° in the direction shown. Sketch a graph to show the variation with the rotation angle $\theta$, of the transmitted light intensity $I$, as $\theta$ varies from 0° to 180°. Label your sketch-graph with the letter U.
b) The beam in a) is now replaced with a polarized beam of light of the same intensity. The plane of polarization of the light is initially parallel to the polarization axis of the polarizer.

The polarizer is then rotated by $180^\circ$ in the direction shown. On the same axes in a), sketch a graph to show the variation with the rotation angle $\theta$, of the transmitted light intensity $I$, as $\theta$ varies from $0^\circ$ to $180^\circ$. 
Polarization from reflection

- If Angle between refracted and reflected ray = 90°
- Then the reflected ray is plane polarized
- The incident angle is called “Brewster’s angle”
Polarization from reflection

Go to:  http://www.cabrillo.edu/~jmccullough/Applets/optics.html

Or just search for this and choose the first result
Small oscillations perpendicular to surface

No oscillations perpendicular to surface

Not 90°

Side view

90°
Polarization from water

I’ll show you a 22 second video clip.

1) Discuss with your team what do you see happening
2) Provide an explanation for it

Video
Without sunglasses  

With sunglasses
Unpolarized light of intensity $I_0$ is incident on a polarizer. The transmitted light is then incident on a second polarizer. The axis of a polarizer makes an angle of 60° to the axis of the first polarizer.

The cosine of 60° is $\frac{1}{2}$. The intensity of the light transmitted through the second polarizer is:

a) $I_0$  
b) $I_0/2$  
c) $I_0/4$  
d) $I_0/8$
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The cosine of 60° is $\frac{1}{2}$. The intensity of the light transmitted through the second polarizer is:

a) $I_0$  
 b) $I_0/2$  
 c) $I_0/4$  
 d) $I_0/8$
Unpolarized light is incident on the surface of a transparent medium. The reflected light is completely plane polarized. The refracted light will be

A. unpolarized.
B. partially plane polarized.
C. completely plane polarized at right angles to the reflected light.
D. completely plane polarized parallel to the reflected light.
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Markscheme
B
Unpolarized light is incident on a polarizer. The light transmitted by the first polarizer is then incident on a second polarizer. The polarizing axis of the second polarizer is at 60° to that of the first polarizer.

The intensity emerging from the second polarizer is $I_f$.

Which of the following correctly gives the intensity incident on the first polarizer?

A. $\frac{I_f}{8}$
B. $\frac{I_f}{4}$
C. $4I_f$
D. $8I_f$
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Markscheme
D
Two polarizing filters are set up so the transmitted light is at a maximum intensity.

Through which angle should polarizer 2 be rotated so that no light is transmitted?

A. 45°
B. 60°
C. 90°
D. 180°
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**Markscheme**
C
Unpolarized light of intensity \( I_0 \) is transmitted through a polarizer which has a transmission axis at an angle \( \theta \) to the vertical. The light is then incident on a second polarizer with a transmission axis at an angle \( \phi \) to the transmission axis of the first polarizer, as shown below.

The intensity of the light that emerges from the second polarizer is \( I \). What is the ratio \( \frac{I}{I_0} \)?

A. 0.25
B. 0.5 \( \cos^2 (\theta + \phi) \)
C. 0.5 \( \cos^2 \phi \)
D. \( \cos^2 \theta \cos^2 \phi \)
Unpolarized light of intensity $I_0$ is transmitted through a polarizer which has a transmission axis at an angle $\theta$ to the vertical. The light is then incident on a second polarizer with a transmission axis at an angle $\phi$ to the transmission axis of the first polarizer, as shown below.

The intensity of the light that emerges from the second polarizer is $I$. What is the ratio $\frac{I}{I_0}$?

A. 0.25  
B. $0.5 \cos^2 (\theta + \phi)$  
C. $0.5 \cos^2 \phi$  
D. $\cos^2 \theta \cos^2 \phi$

**Markscheme**

C
Unpolarized light of intensity $I_0$ is incident on a polarizer with a vertical transmission axis. The transmitted light is incident on a sheet of material $X$. After transmission through $X$ the intensity of the light is $\frac{I_0}{2}$.

It is suggested that $X$ could be

I. a polarizer with vertical transmission axis

II. a polarizer with horizontal transmission axis

III. non polarizing glass.

Which of the above suggestions is/are correct?

A. I and III only
B. I only
C. II only
D. II and III only
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Which of the above suggestions is/are correct?

A. I and III only
B. I only
C. II only
D. II and III only

Markscheme

A
Unpolarized light of intensity $I_0$ is incident on a polarizer that has a vertical transmission axis.

The polarizer is rotated by an angle $\theta$ about the direction of the incident light. The intensity of the transmitted light is $I$. Which graph correctly shows the variation with the angle $\theta$ of the ratio $\frac{I}{I_0}$?
Unpolarized light of intensity $I_0$ is incident on a polarizer that has a vertical transmission axis.

The polarizer is rotated by an angle $\theta$ about the direction of the incident light. The intensity of the transmitted light is $I$. Which graph correctly shows the variation with the angle $\theta$ of the ratio $\frac{I}{I_0}$?

A. $\frac{I}{I_0}$

B. $\frac{I}{I_0}$

C. $\frac{I}{I_0}$

D. $I$
Do now

• Complete your notes on plane polarized waves.
• When done work on the problems listed on the homepage