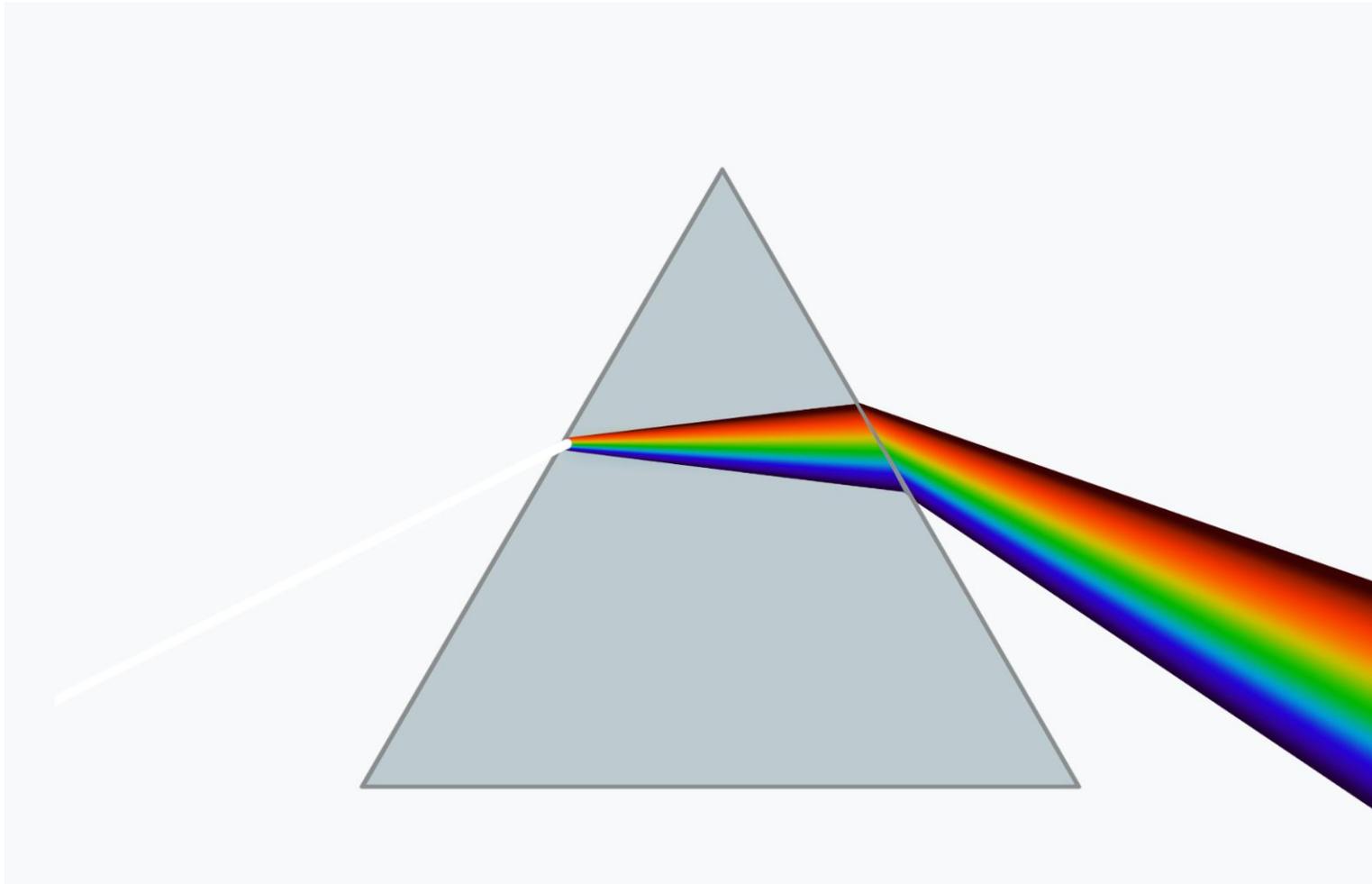


Waves



Material Covered

Properties of Waves

1. Reflection, Refraction and Diffraction.
2. Total Internal Reflection and the Critical Angle.
3. Polarisation

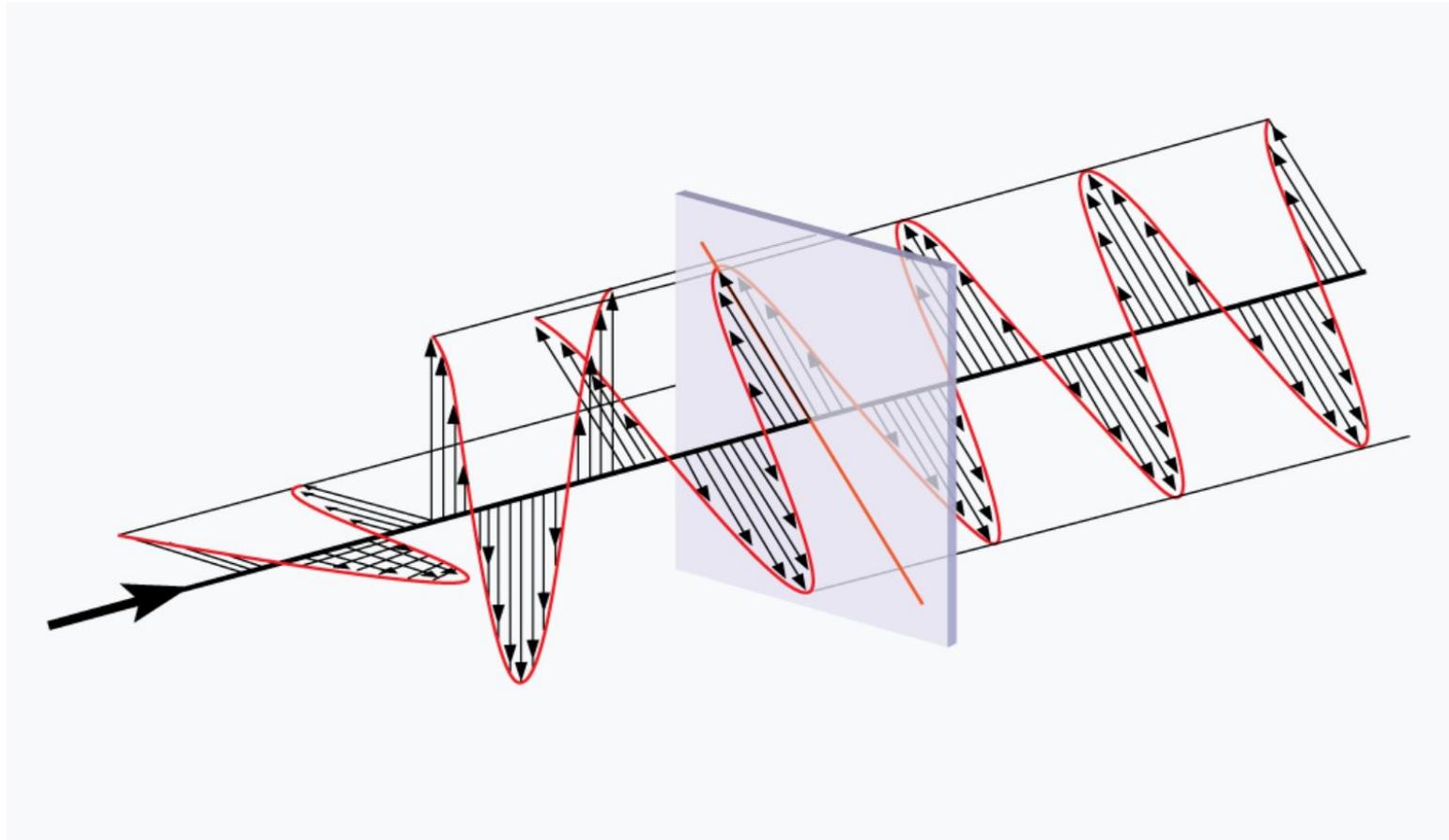
Superposition and Interference

1. Superposition.
2. Interference Patterns.

Standing Waves

1. Progressive Waves and Standing Waves.
2. Harmonics.

Properties of Waves



Specification Points - AQA

3.3.1.1 Progressive waves

Content

Oscillation of the particles of the medium;

amplitude, frequency, wavelength, speed, phase, phase difference, $c = f\lambda$ $f = \frac{1}{T}$

Phase difference may be measured as angles (radians and degrees) or as fractions of a cycle.

3.3.1.2 Longitudinal and transverse waves

Content

Nature of longitudinal and transverse waves.

Examples to include: sound, electromagnetic waves, and waves on a string.

Students will be expected to know the direction of displacement of particles/fields relative to the direction of energy propagation and that all electromagnetic waves travel at the same speed in a vacuum.

Polarisation as evidence for the nature of transverse waves.

Applications of polarisers to include Polaroid material and the alignment of aerials for transmission and reception.

Malus's law will not be expected.

3.3.2.3 Refraction at a plane surface

Content

Refractive index of a substance, $n = \frac{c}{c_s}$

Students should recall that the refractive index of air is approximately 1.

Snell's law of refraction for a boundary $n_1 \sin \theta_1 = n_2 \sin \theta_2$

Total internal reflection $\sin \theta_c = \frac{n_2}{n_1}$

Simple treatment of fibre optics including the function of the cladding.

Optical fibres will be limited to step index only.

Material and modal dispersion.

Students are expected to understand the principles and consequences of pulse broadening and absorption.

Specification Points - OCR A

4.4.1 Wave motion

Learning outcomes	Additional guidance
<i>Learners should be able to demonstrate and apply their knowledge and understanding of:</i>	
(a) progressive waves; longitudinal and transverse waves	HSW8
(b) (i) displacement, amplitude, wavelength, period, phase difference, frequency and speed of a wave	HSW8
(ii) techniques and procedures used to use an oscilloscope to determine frequency	PAG5
(c) the equation $f = \frac{1}{T}$	
(d) the wave equation $v = f\lambda$	
(e) graphical representations of transverse and longitudinal waves	HSW5
(f) (i) reflection, refraction, polarisation and diffraction of all waves	Learners will be expected to know that diffraction effects become significant when the wavelength is comparable to the gap width.
(ii) techniques and procedures used to demonstrate wave effects using a ripple tank	HSW1, 4.

4.4.2 Electromagnetic waves

Learning outcomes	Additional guidance
(d) (i) refraction of light; refractive index; $n = \frac{c}{v}$; $n \sin \theta = \text{constant}$ at a boundary where θ is the angle to the normal	
(ii) techniques and procedures used to investigate refraction and total internal reflection of light using ray boxes, including transparent rectangular and semi-circular blocks	PAG6
(e) critical angle; $\sin C = \frac{1}{n}$; total internal reflection for light.	

Specification Points - OCR B

3.1.1 Imaging and signalling

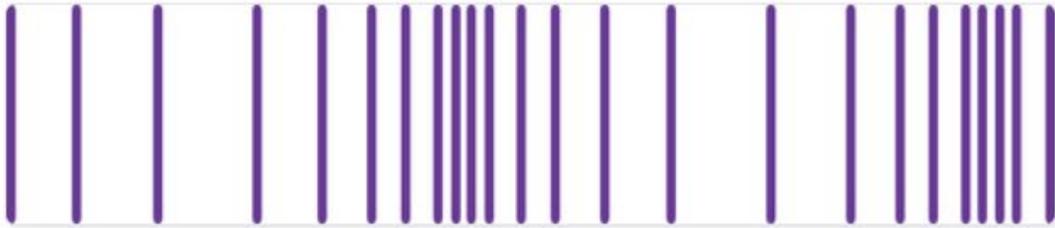
Learning outcomes	Additional guidance								
<p>(a) <i>Describe and explain:</i></p> <p>(iv) evidence of the polarisation of electromagnetic waves.</p> <p>(c) <i>Make calculations and estimates involving:</i></p> <p>(v) $v = f\lambda$ including the use of $f = 1/T$</p>	<p>4.1 Waves and quantum behaviour</p> <table border="1"> <thead> <tr> <th>Learning outcomes</th> <th>Additional guidance</th> </tr> </thead> <tbody> <tr> <td> <p>(a) <i>Describe and explain:</i></p> <p>(iii) refraction of light at a plane boundary in terms of the changes in the speed of light and explanation in terms of the wave model of light</p> <p>(iv) diffraction of waves passing through a narrow aperture</p> </td> <td> <p>MO.2</p> <p>HSW6</p> </td> </tr> <tr> <td> <p>(b) <i>Make appropriate use of:</i></p> <p>(i) the terms: phase, phasor, amplitude, probability, interference, diffraction, superposition, coherence, path difference, intensity, electronvolt, refractive index, work function, threshold frequency.</p> </td> <td></td> </tr> <tr> <td> <p>(d) <i>Demonstrate and apply knowledge and understanding of the following practical activities (HSW4):</i></p> <p>(ii) determining refractive index for a transparent block</p> </td> <td> <p>links to 4.1c(ii) PAG6</p> </td> </tr> </tbody> </table>	Learning outcomes	Additional guidance	<p>(a) <i>Describe and explain:</i></p> <p>(iii) refraction of light at a plane boundary in terms of the changes in the speed of light and explanation in terms of the wave model of light</p> <p>(iv) diffraction of waves passing through a narrow aperture</p>	<p>MO.2</p> <p>HSW6</p>	<p>(b) <i>Make appropriate use of:</i></p> <p>(i) the terms: phase, phasor, amplitude, probability, interference, diffraction, superposition, coherence, path difference, intensity, electronvolt, refractive index, work function, threshold frequency.</p>		<p>(d) <i>Demonstrate and apply knowledge and understanding of the following practical activities (HSW4):</i></p> <p>(ii) determining refractive index for a transparent block</p>	<p>links to 4.1c(ii) PAG6</p>
Learning outcomes	Additional guidance								
<p>(a) <i>Describe and explain:</i></p> <p>(iii) refraction of light at a plane boundary in terms of the changes in the speed of light and explanation in terms of the wave model of light</p> <p>(iv) diffraction of waves passing through a narrow aperture</p>	<p>MO.2</p> <p>HSW6</p>								
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<p>(d) <i>Demonstrate and apply knowledge and understanding of the following practical activities (HSW4):</i></p> <p>(ii) determining refractive index for a transparent block</p>	<p>links to 4.1c(ii) PAG6</p>								

Specification Points - Edexcel

59.	understand the terms <i>amplitude</i> , <i>frequency</i> , <i>period</i> , <i>speed</i> and <i>wavelength</i>
60.	be able to use the wave equation $v = f\lambda$
61.	be able to describe longitudinal waves in terms of pressure variation and the displacement of molecules
62.	be able to describe transverse waves
63.	be able to draw and interpret graphs representing transverse and longitudinal waves including standing/stationary waves
71.	know and understand that at the interface between medium 1 and medium 2 $n_1 \sin \theta_1 = n_2 \sin \theta_2$ where refractive index is $n = \frac{c}{v}$
72.	be able to calculate <i>critical angle</i> using $\sin C = \frac{1}{n}$
73.	be able to predict whether total internal reflection will occur at an interface
74.	understand how to measure the refractive index of a solid material
82.	understand what is meant by <i>plane polarisation</i>
83.	understand what is meant by <i>diffraction</i> and use Huygens' construction to explain what happens to a wave when it meets a slit or an obstacle

Properties of Waves

- Waves are periodic **longitudinal** or **transverse** oscillations.



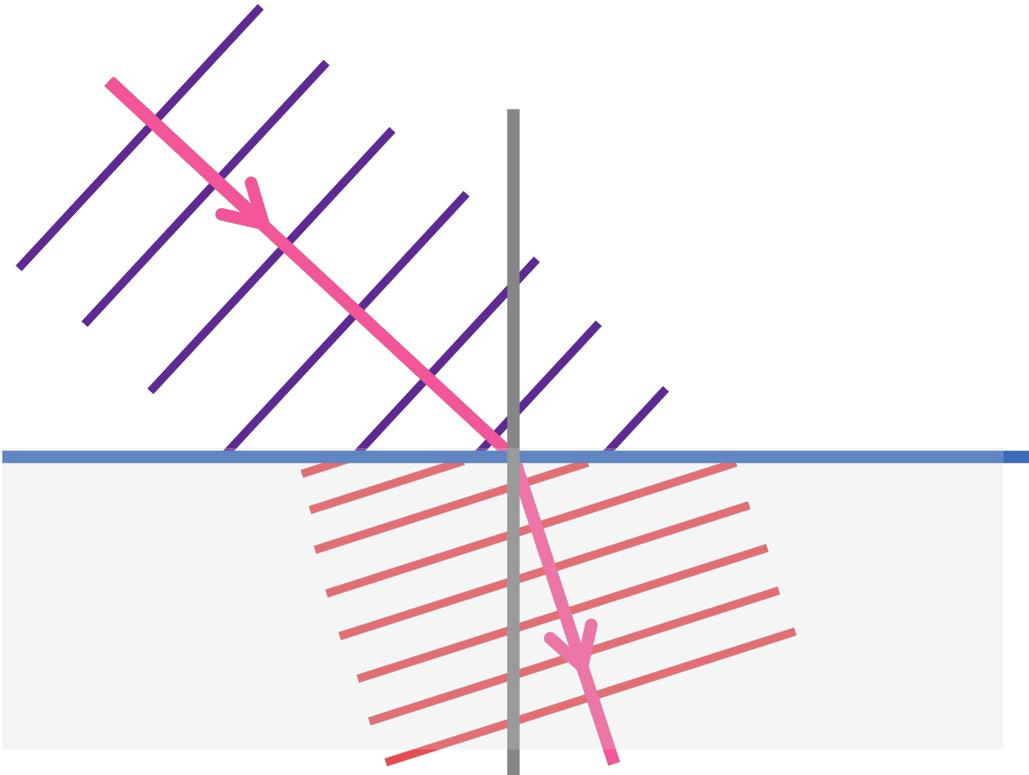
- Most waves **propagate** through a **medium** at a **speed** (v) equal to the **product** of their **frequency** (f) and **wavelength** (λ).

$$v = f \times \lambda$$

- **Light** (electromagnetic waves) travel through a **vacuum** at $v = c$.

Reflection, Refraction and Diffraction

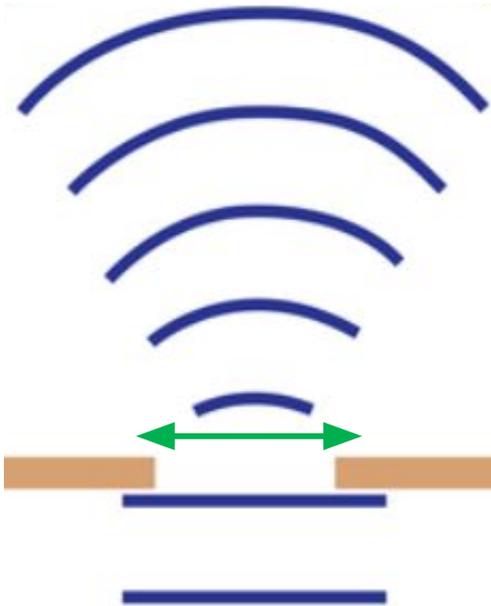
- **Refraction** – The **change in direction** of a **wave** when it enters a **new medium** where it **travels at a different speed**.



$$\frac{\sin i}{\sin r} = \frac{n_r}{n_i} = \frac{v_1}{v_2}$$

Reflection, Refraction and Diffraction

- **Diffraction** – Spreading out of a wave as it passes through a **gap** or around an edge.



Maximum displacement when

$$\lambda \sim L$$

Exemplar Calculation Exam Question

Context: Refraction. May require **Snell's Law.**

Key numerical values of variables which may be **required** for the **calculation.**

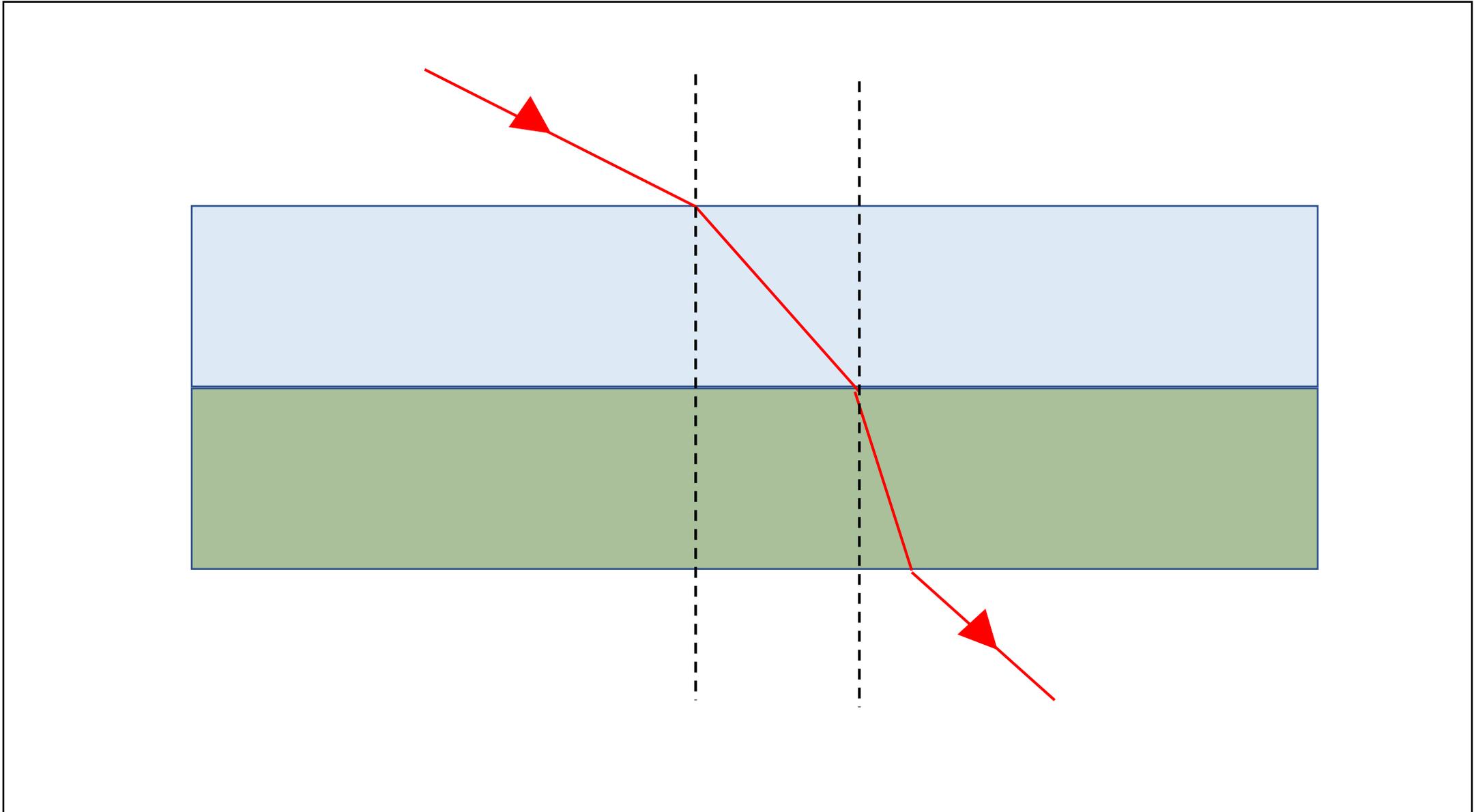
- 1) Light travelling through air is incident on a layer of glass at an angle of $i = 45^\circ$. The refractive index of glass is $n = 1.5$. The refracted light then enters a layer of Perspex with refractive index $n = 2$. Calculate the direction the light travels through the Perspex as the angle it makes with its normal. You may assume that the Perspex and the glass are flat and parallel to each other.

Answer should be an angle with **units** of **degrees** ($^\circ$).

[3 marks]

Calculation Question: Mathematical question – we need to show our working.

Indicates that there will be about **3 steps** to our **calculation**. Any less and we may have missed something.



Exemplar Calculation Question Answer

Write out Snell's Law $\frac{n_2}{n_1} = \frac{\sin i}{\sin r}$

Plug in the values from the question and rearrange to solve for the unknown.

$$\frac{1.5}{1} = \frac{\sin 45^\circ}{\sin r_1} \Rightarrow \sin r_1 = \frac{\sin 45^\circ}{1.5} \Rightarrow r_1 = 28.12^\circ \quad [1 \text{ Mark}]$$

$$i_2 = r_1 = 28.13^\circ \quad [1 \text{ Mark}]$$

Exemplar Calculation Question Answer

$$\frac{n_2}{n_1} = \frac{\sin i}{\sin r}$$

$$\frac{2}{1.5} = \frac{\sin 28.12^\circ}{\sin r_2} \Rightarrow \sin r_2 = \frac{1.5 \times \sin 28.12^\circ}{2}$$

Solve for answer. Remember the units. Give answer to 3 s.f
(as no clear precision in question).

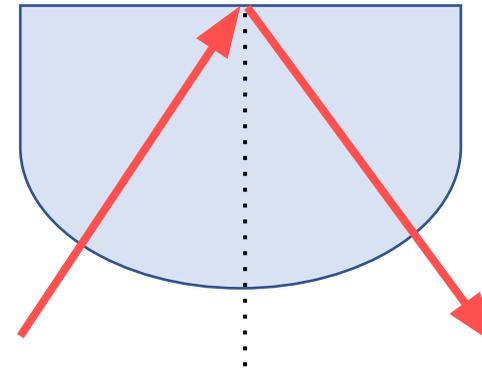
$$\Rightarrow r_2 = 20.7^\circ$$

[1 Mark]

Total Internal Reflection

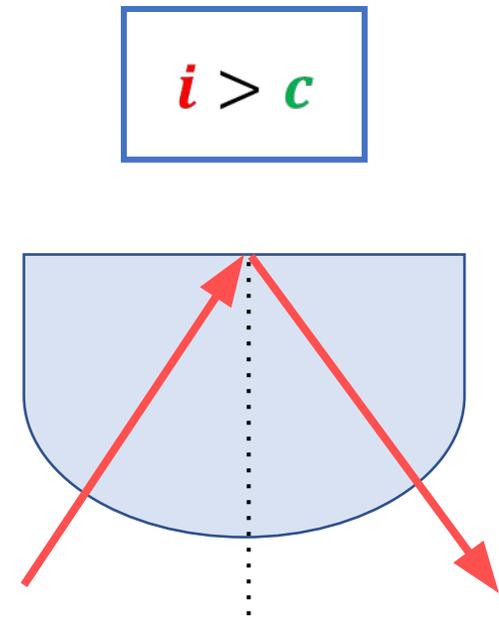
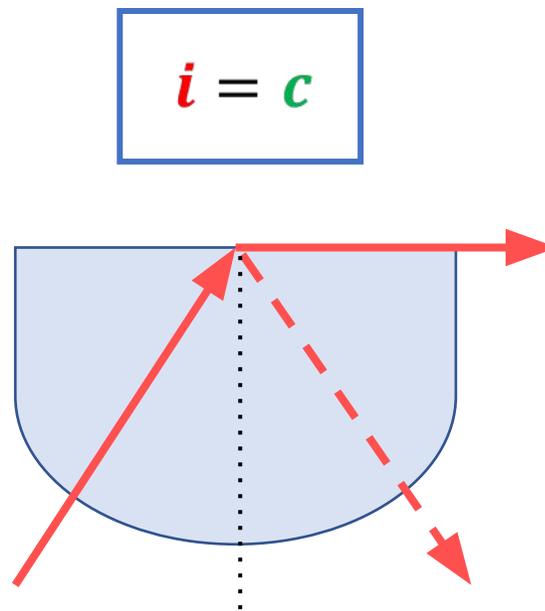
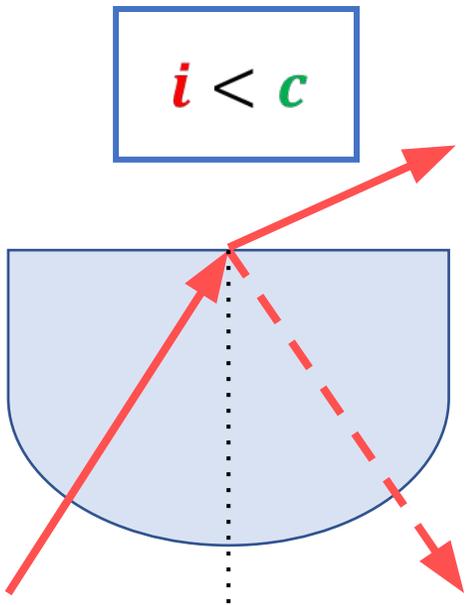
Total internal reflection occurs when a **wave** travelling in a **medium** of **refractive index** n_1 approaches a **medium** of smaller **refractive index** (n_2) at $i \geq$ **critical angle** (c) and is not **transmitted**.

$$\sin c = \frac{n_2}{n_1}$$



- **Total internal reflection** is used in **fibre optic cables** and **endoscopes** to transfer **information** using **light**.

- At $i = c$ the **wave** travels along the **interface** of the two **media**.
- **Partial internal reflection** occurs at an **interface** when $i \leq c$.
- **Total internal reflection** occurs at an **interface** when $i > c$.



Exemplar Calculation Exam Question

Context: Total internal reflection. May require **critical angle equation**.

**Key
values.**

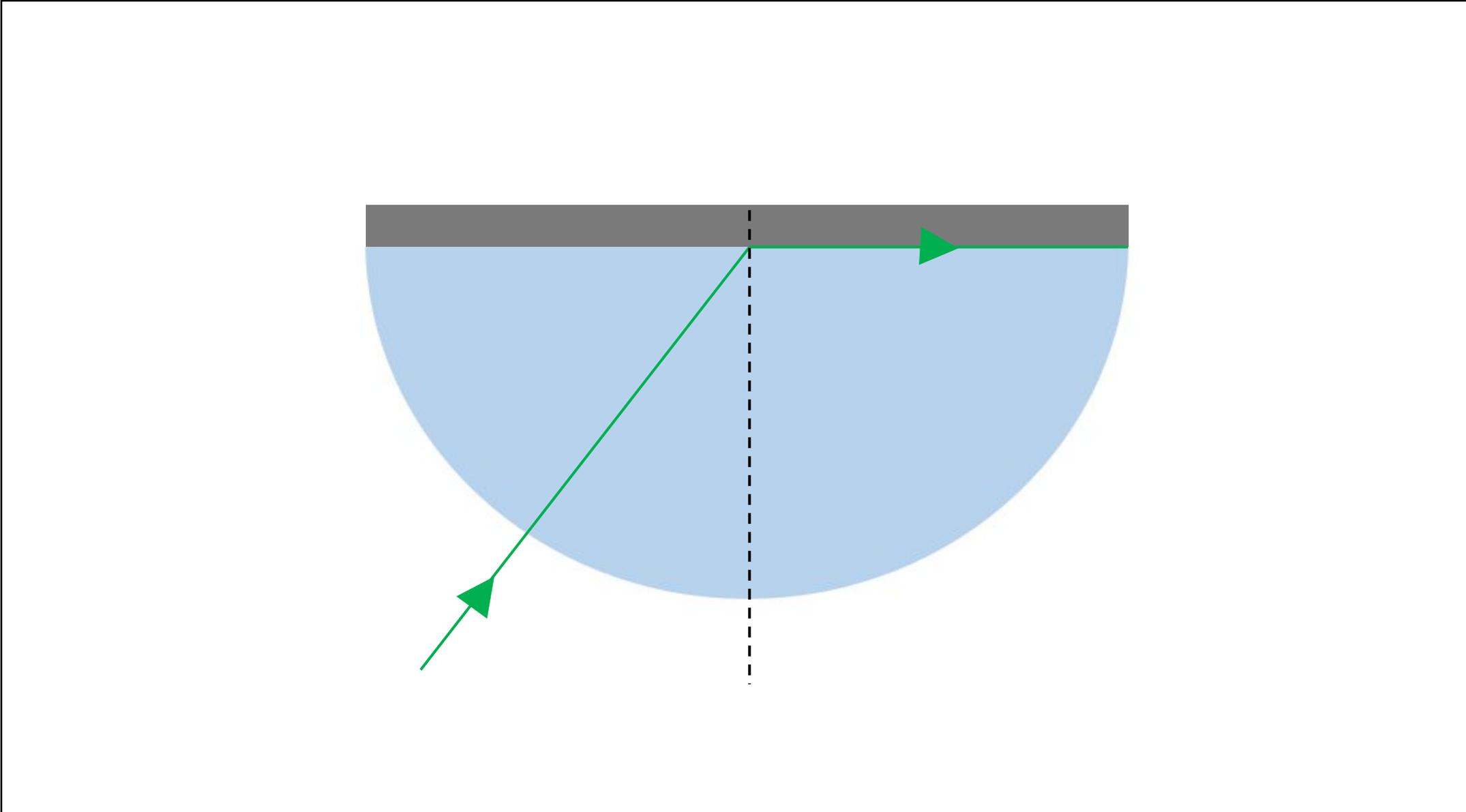
- 1) Monochromatic green light enters a glass prism of refractive index $n = 1.5$ at an angle of 48° to the normal as shown in the following diagram. The back surface of the prism is coated in a layer of liquid. Total internal reflection occurs and the light travels along the interface between the glass and the liquid. Determine the refractive index of the liquid.

Calculation question: Show working.

[2 marks]

Answer will be a **unitless number**.

At least **2 steps** to calculation.



Exemplar Calculation Question Answer

Use critical angle formula to calculate index

Given that light is travelling at critical value, so can use

$$\sin c = \frac{n_2}{n_1}$$

[1 Mark]

$$n_2 = n_1 \sin c$$

$$n_2 = 1.5 \sin 48$$

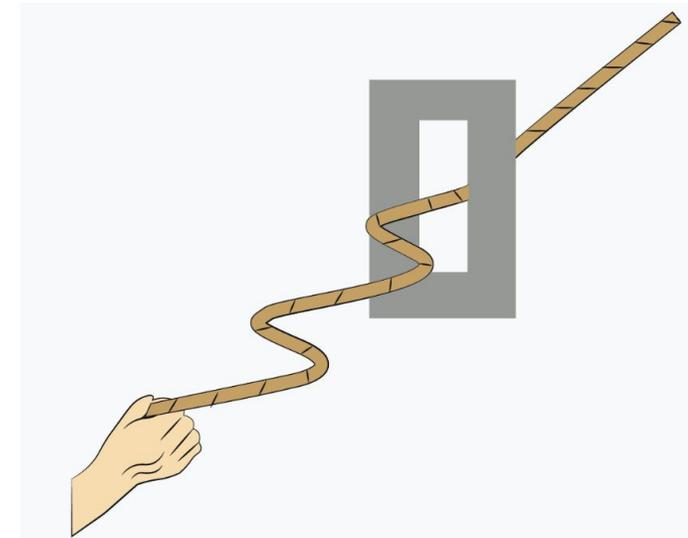
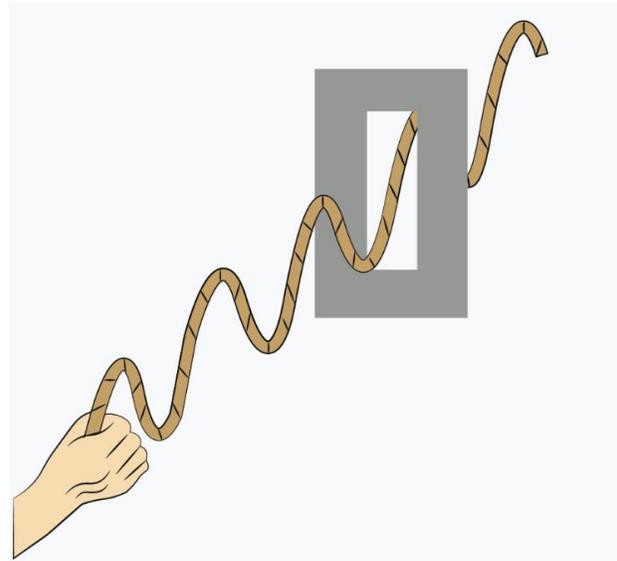
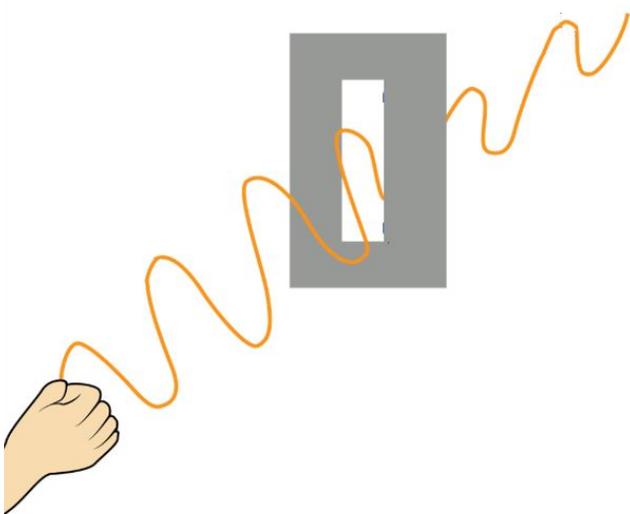
$$n_2 = 1.1$$

[1 Mark]

Polarisation

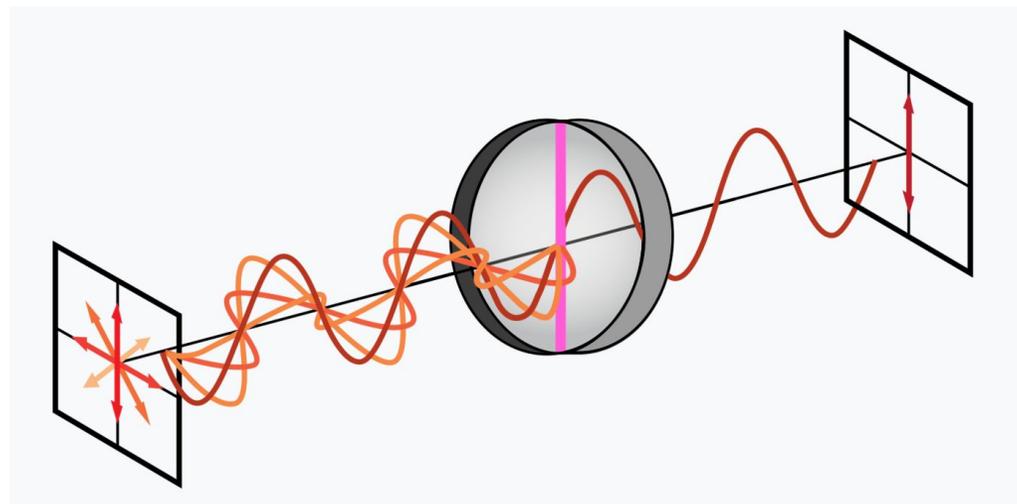
Transverse waves can be **plane-polarised**. **Plane-polarised waves** have **oscillations** which occur in **one plane** only.

- **Plane-polarised waves** which are **aligned** with a **polarising filter** pass **unaffected**.
- **Plane-polarised waves** with a **component parallel** to the **filter** pass with **reduced intensity**.



Polarising Light

- **Light** from **sources** like the **sun** or a **lightbulb** are **unpolarised**, meaning they are made up of many different **plane-polarisations**.
- **Unpolarised light waves** can be **converted** to **plane-polarised light** by a **polarising filter**.
- The **light waves** are **polarised** in the **plane** lying **parallel** to **direction** of the **polarising filter**.



Exemplar Explanation Exam Question

Theory from question.

Context: Polarising filters with respect to **light**.

Description
for our
diagram.

- 1) Polarising sunglasses act as a polarising filter, blocking all polarisations of light from the sun except those in a single plane. Consider holding two lenses of these sunglasses up to an unpolarised light source with one positioned along the line of sight behind the other. Describe with the aid of a diagram what you will see as you rotate one of the lenses.

[4 marks]

Explanation Question: Bullet-point
format. We need to **sketch** a **diagram** to
support our answer.

Indicates that we will need to mention about **4**
points. **1 mark** will likely be for our **diagram**.



Case 1: When lenses are aligned with polarising direction parallel, the light is transmitted as plane polarised light.

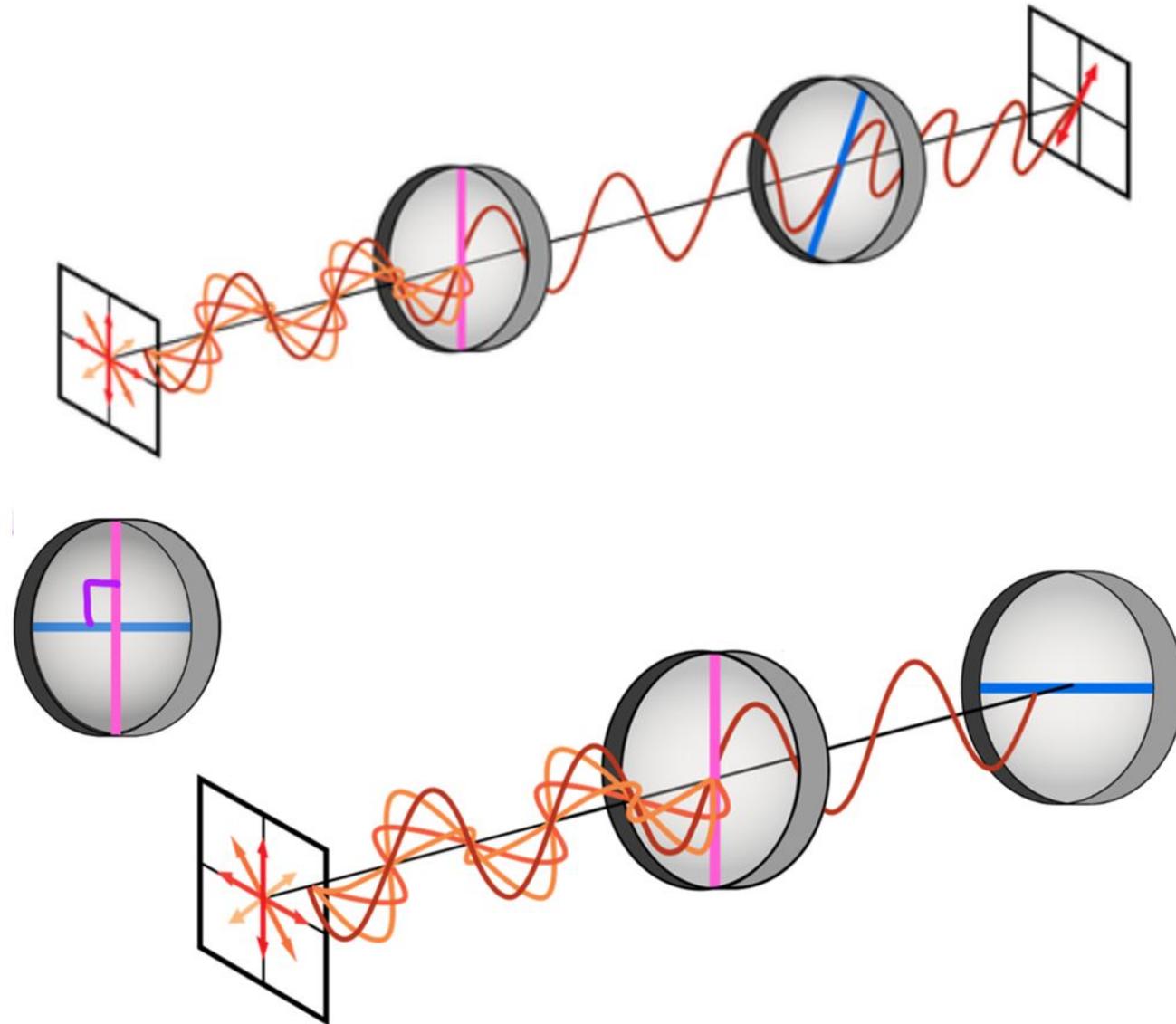
[1 Mark]

Case 2: As the back lens is rotated the intensity of the transmitted light is reduced, causing the lens to become darker.

[1 Mark]

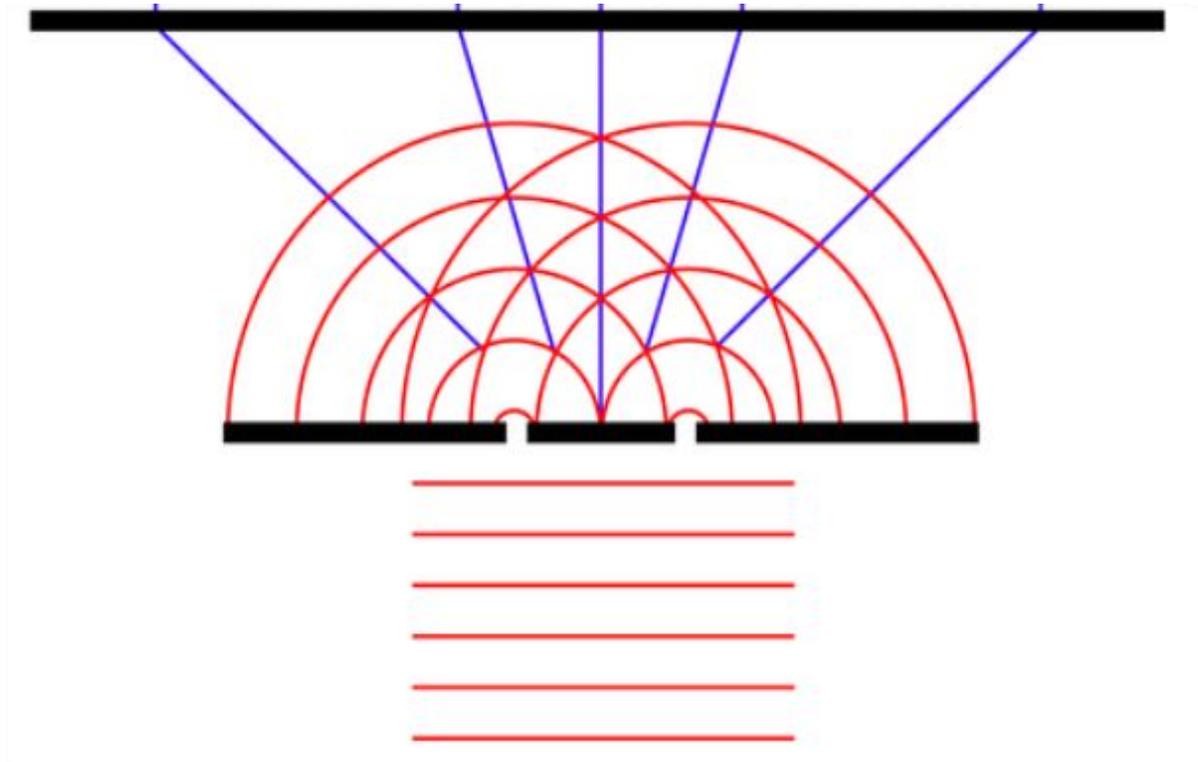
Case 3: When the polarising direction of the lenses is perpendicular no light is transmitted (lens appears completely dark).

[1 Mark]



[1 Mark]

Superposition and Interference



Specification Points - AQA

3.3.2.1 Interference

Content	Opportunities for skills development
<p>Path difference. Coherence.</p> <p>Interference and diffraction using a laser as a source of monochromatic light.</p> <p>Young's double-slit experiment: the use of two coherent sources or the use of a single source with double slits to produce an interference pattern.</p> <p>Fringe spacing, $w = \frac{\lambda D}{s}$</p> <p>Production of interference pattern using white light.</p> <p>Students are expected to show awareness of safety issues associated with using lasers.</p> <p>Students will not be required to describe how a laser works.</p> <p>Students will be expected to describe and explain interference produced with sound and electromagnetic waves.</p> <p>Appreciation of how knowledge and understanding of nature of electromagnetic radiation has changed over time.</p>	<p>AT i</p> <p>Investigation of two-source interference with sound, light and microwave radiation.</p>
<p>Required practical 2: Investigation of interference effects to include the Young's slit experiment and interference by a diffraction grating.</p>	

3.3.2.2 Diffraction

Content
<p>Appearance of the diffraction pattern from a single slit using monochromatic and white light.</p> <p>Qualitative treatment of the variation of the width of the central diffraction maximum with wavelength and slit width. The graph of intensity against angular separation is not required.</p> <p>Plane transmission diffraction grating at normal incidence.</p> <p>Derivation of $d \sin \theta = n \lambda$</p> <p>Use of the spectrometer will not be tested.</p> <p>Applications of diffraction gratings.</p>

Specification Points - OCR A

4.4.3 Superposition

Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

- (a) (i) the principle of superposition of waves
- (ii) techniques and procedures used for superposition experiments using sound, light and microwaves
- (b) graphical methods to illustrate the principle of superposition
- (c) interference, coherence, path difference and phase difference
- (d) constructive interference and destructive interference in terms of path difference and phase difference
- (e) two-source interference with sound and microwaves

(f) Young double-slit experiment using visible light

(g) (i) $\lambda = \frac{ax}{D}$ for all waves where $a \ll D$

(ii) techniques and procedures used to determine the wavelength of light using (1) a double-slit, and (2) a diffraction grating.

Learners should understand that this experiment gave a classical confirmation of the wave-nature of light. HSW7 Internet research on the ideas of Newton and Huygens about the nature of light.

M4.6

PAG5

$d \sin\theta = n\lambda$ and diffraction gratings will only be assessed at A level

Specification Points - OCR B

4.1 Waves and quantum behaviour

Learning outcomes	Additional guidance
<p>(a) <i>Describe and explain:</i></p> <p>(ii) interference of waves from two slits</p> <p>(v) diffraction by a grating</p>	
<p>(b) <i>Make appropriate use of:</i></p> <p>(i) the terms: phase, phasor, amplitude, probability, interference, diffraction, superposition, coherence, path difference, intensity, electronvolt, refractive index, work function, threshold frequency.</p>	<p>(c) <i>Make calculations and estimates involving:</i></p> <p>(iii) path differences for double slits and diffraction grating, for constructive interference $n\lambda = d \sin \theta$ (both limited to the case of a distant screen)</p> <p>(d) <i>Demonstrate and apply knowledge and understanding of the following practical activities (HSW4):</i></p> <p>(iv) determining the wavelength of light with a double-slit and diffraction grating</p>
	<p>angles may be given in degrees or radians, the use of the small angle approximation is expected. M0.6, M4.6, M4.7</p> <p>links to 4.1a(ii), a(v), c(iii) PAG5</p>

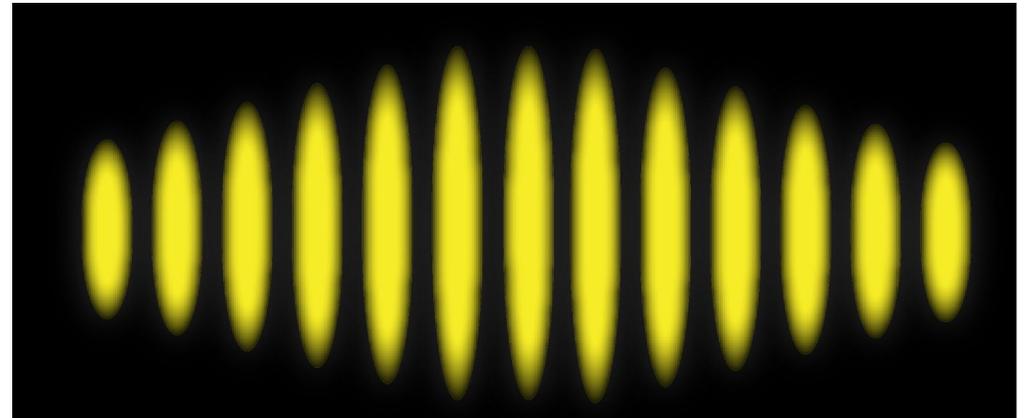
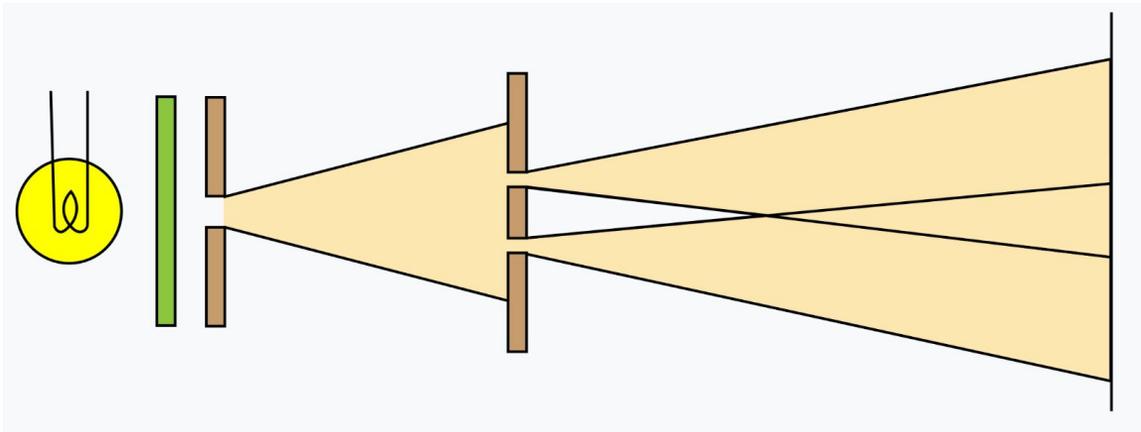
Specification Points - Edexcel

65.	know and understand what is meant by <i>wavefront</i> , <i>coherence</i> , <i>path difference</i> , <i>superposition</i> , <i>interference</i> and <i>phase</i>
66.	be able to use the relationship between <i>phase difference</i> and <i>path difference</i>
83.	understand what is meant by <i>diffraction</i> and use Huygens' construction to explain what happens to a wave when it meets a slit or an obstacle
84.	be able to use $n\lambda = d\sin\theta$ for a diffraction grating
85.	CORE PRACTICAL 8: Determine the wavelength of light from a laser or other light source using a diffraction grating.

Superposition

- **Principle of Superposition** – When 2 waves meet the **resultant displacement** is equal to the **sum** of the **individual displacements** of the waves.
- **Interference** – **Superposition** of waves to form a **resultant wave**.

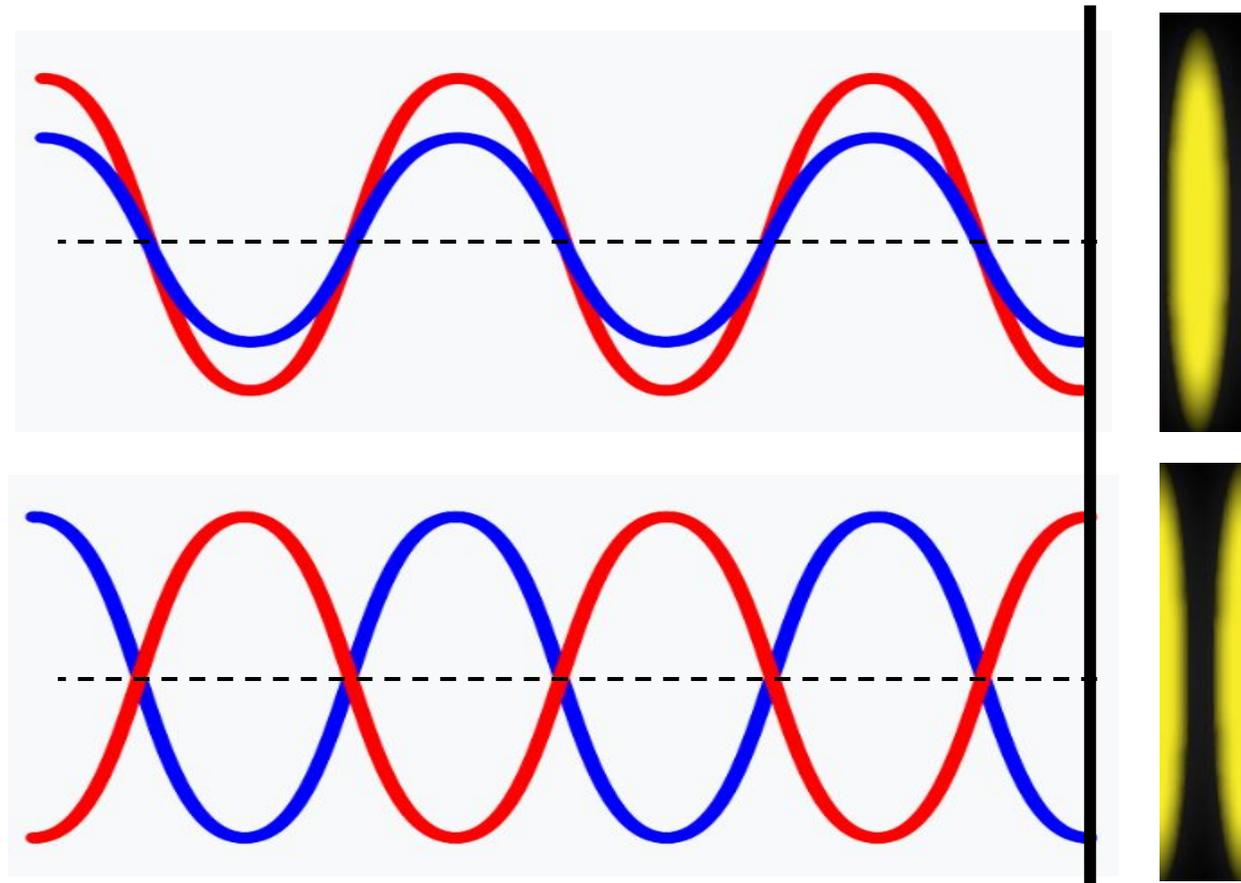
Diffraction through a **double slit** acts as dual **coherent** wave sources. This forms an interesting **fringe pattern** on the **screen** due to **interference**.



Superposition

To explain this **fringe pattern** we must consider the **phase difference** of the **waves** arriving at the **screen**.

- When waves arrive **in phase**, **constructive interference** occurs, giving the **bright spots** on the **pattern**.
- When **waves** arrive **out of phase** **destructive interference** occurs, giving the **dark spots** on the **pattern**.



Exemplar Statement Exam Question

Statement Question: Simple self-contained sentence required for each mark.

- 1) Define the terms *coherence* and *phase* in reference to waves.
[2 marks]

These **terms** must appear **explicitly** in our answer.

Context: Waves.

1 mark for each **definition**.

Coherence – Fixed phase difference between two waves of the same wavelength.

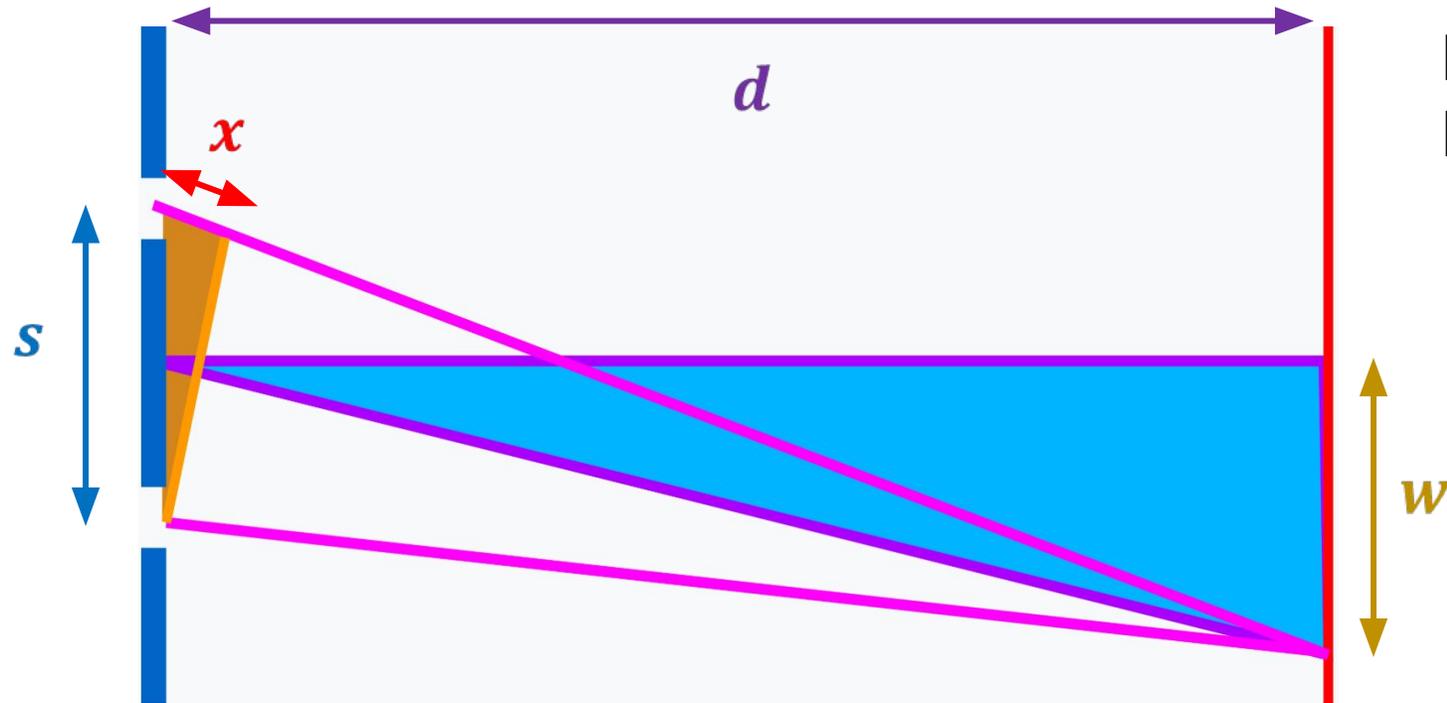
[1 Mark]

Phase – Angular measure of a point on a wave through its wave cycle.

[1 Mark]

Interference Patterns

Derivation of Pattern Spacing for Double Slit



$$\frac{x}{s} = \frac{w}{d}$$

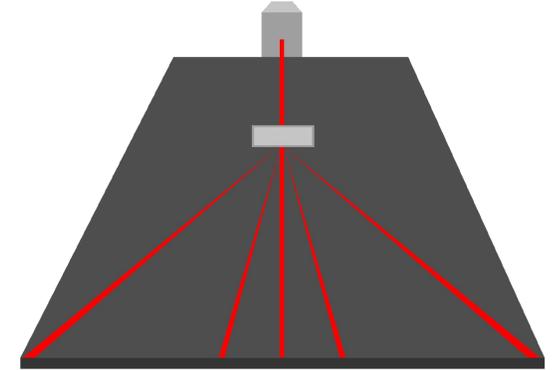
$$\frac{n\lambda}{s} = \frac{nw}{d}$$

2 Slits:

$$w = \frac{\lambda d}{s}$$

Interference Patterns

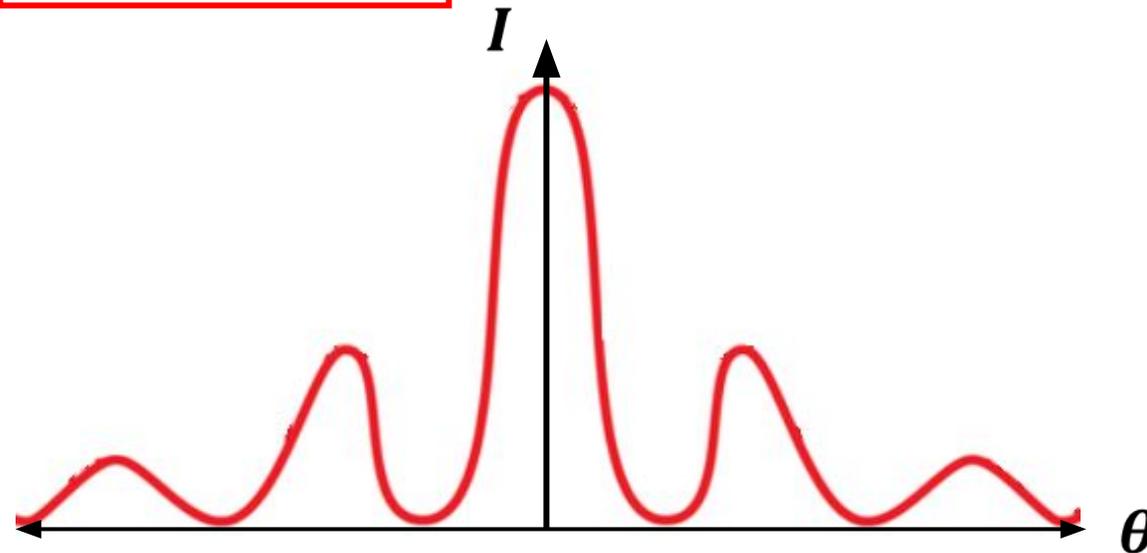
Diffraction and interference through a **grating** formed of **many slits** produces a similar **diffraction pattern** to the **double slit**.



Diffraction Grating:

$$d \sin \theta = n\lambda$$

Plotting intensity of waves (I) against **angle** (θ) gives the following **graph**:



Exemplar Explanation Exam Question

Context: Interference.

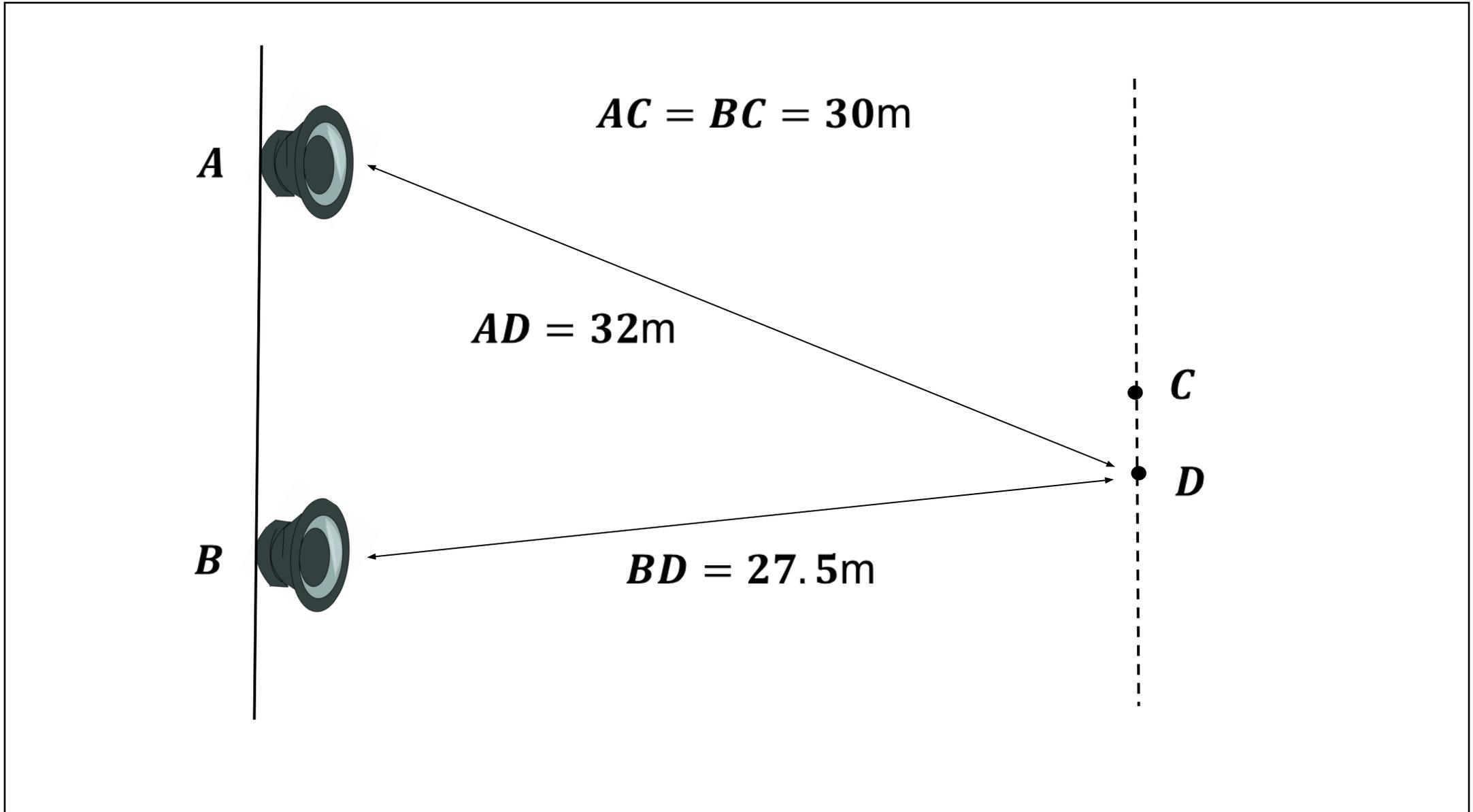
- 1) Two loudspeakers produce coherent sound waves of frequency **110 Hz**. They are positioned at ***A*** and ***B***, as shown in the following diagram. The speed of sound in air is **330 ms^{-1}** . An observer begins at point ***C*** which is **30 m** from both ***A*** and ***B***. State and explain what an observer moving from point ***C*** to point ***D*** would hear.

5 points expected.

Explanation Question:
Bullet-points.

Data implies may require some
quantitative reasoning.

[5 marks]



$$v = f\lambda \quad \Rightarrow \quad \lambda = \frac{v}{f} = \frac{330}{110} = 3 \text{ m} \quad \text{[1 Mark]}$$

- Constructive interference occurs when path difference is $n\lambda$ (where n is an integer).
- Destructive interference occurs when path difference is $\left(n + \frac{1}{2}\right)\lambda$.

[1 Mark]

C: Path Difference = 0 \Rightarrow Constructive Interference.

D: Path Difference = $32 - 28.5 = 4.5 \text{ m} = \left(1 + \frac{1}{2}\right)\lambda$

\Rightarrow Destructive Interference.

[1 Mark]

- Sound is loudest at **C** (maximum) and quietest at **D** (minimum).
- Between **C** and **D** there is an additional maximum (corresponding to path difference of **3 m**) and an additional minimum (corresponding to path difference of **1.5 m**).

[1 Mark]

- Therefore sound starts loud at **C**, gets quieter to minimum, gets louder again to maximum, then gets quiet again to minimum at **D**.

[1 Mark]

Standing Waves



Specification Points - AQA

3.3.1.3 Principle of superposition of waves and formation of stationary waves

Content	Opportunities for skills development
<p>Stationary waves.</p> <p>Nodes and antinodes on strings.</p> <p>$f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$ for first harmonic.</p> <p>The formation of stationary waves by two waves of the same frequency travelling in opposite directions.</p> <p>A graphical explanation of formation of stationary waves will be expected.</p> <p>Stationary waves formed on a string and those produced with microwaves and sound waves should be considered.</p> <p>Stationary waves on strings will be described in terms of harmonics. The terms fundamental (for first harmonic) and overtone will not be used.</p>	<p>MS 4.7 / PS 1.2, 2.1 / AT i</p> <p>Students can investigate the factors that determine the frequency of stationary wave patterns of a stretched string.</p>

Specification Points - OCR A

4.4.4 Stationary waves

Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

- (a) stationary (standing) waves using microwaves, stretched strings and air columns
- (b) graphical representations of a stationary wave
- (c) similarities and the differences between stationary and progressive waves
- (d) nodes and antinodes
- (e)
 - (i) stationary wave patterns for a stretched string and air columns in closed and open tubes
 - (ii) techniques and procedures used to determine the speed of sound in air by formation of stationary waves in a resonance tube
- (f) the idea that the separation between adjacent nodes (or antinodes) is equal to $\lambda/2$, where λ is the wavelength of the progressive wave
- (g) fundamental mode of vibration (1st harmonic); harmonics.

Specification Points - OCR B

4.1 Waves and quantum behaviour

Learning outcomes	Additional guidance
(a) <i>Describe and explain:</i>	
(i) production of standing waves by waves travelling in opposite directions	Including graphical treatment HSW1, 2
(b) <i>Make appropriate use of:</i>	
(i) the terms: phase, phasor, amplitude, probability, interference, diffraction, superposition, coherence, path difference, intensity, electronvolt, refractive index, work function, threshold frequency.	
(c) <i>Make calculations and estimates involving:</i>	
(i) wavelength of standing waves	end corrections not required

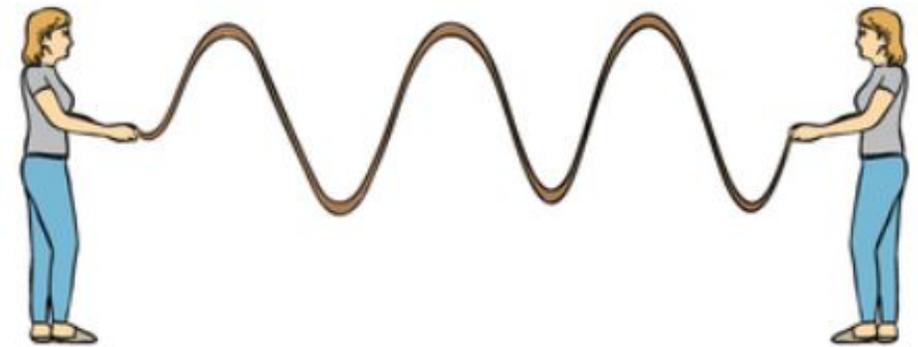
Specification Points - Edexcel

67. know what is meant by a *standing/stationary* wave and understand how such a wave is formed, know how to identify nodes and antinodes

Progressive and Standing Waves

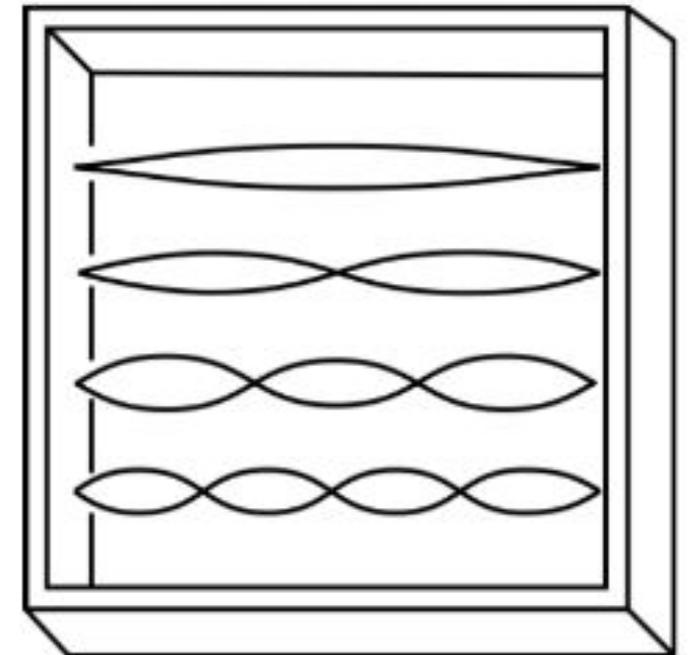
Waves can be **progressive** or **stationary (standing waves)**.

- **Progressive waves** transfer **energy** or **information** in the direction of the wave (they **propagate**).
- **Standing waves** have no net **energy transfer** and have points with **zero amplitude** (called **nodes**).



Formation of Standing Waves

- **Standing waves** are formed by **constructive** and **destructive** interference.
- They are a **superposition** of an **incident** and **reflected wave**. These waves must:
 1. Have the same **frequency** and **velocity**.
 2. Be travelling in **opposite directions**.
- This results in a **waveform** with fixed **nodes** (points of **zero displacement**) and **antinodes** (points of **maximum displacement**).



Exemplar Explanation Exam Question

Explanation Question: Bullet-point format.

Context: Sound waves.

- 1) Microwaves are analysed by reflecting them off a perpendicular surface a certain distance away.
Explain how this process can form a standing wave

[3

marks]

Our answer should **describe** the **phenomenon** of **standing waves** in the **context** given.

3 marks means at least 3 points are required.

-
- Reflection causes microwave to travel back on itself, with same frequency and wavelength
-

[1 Mark]

-
- Microwave will then superpose upon itself.
-

[1 Mark]

-
- If surface is correct distance away, both waves will have points of constant phase and antiphase and will form a stationary wave
-

[1 Mark]

Harmonics

Only **frequencies of harmonics** are allowed for **standing waves**. These are known as the different **modes of vibration**.

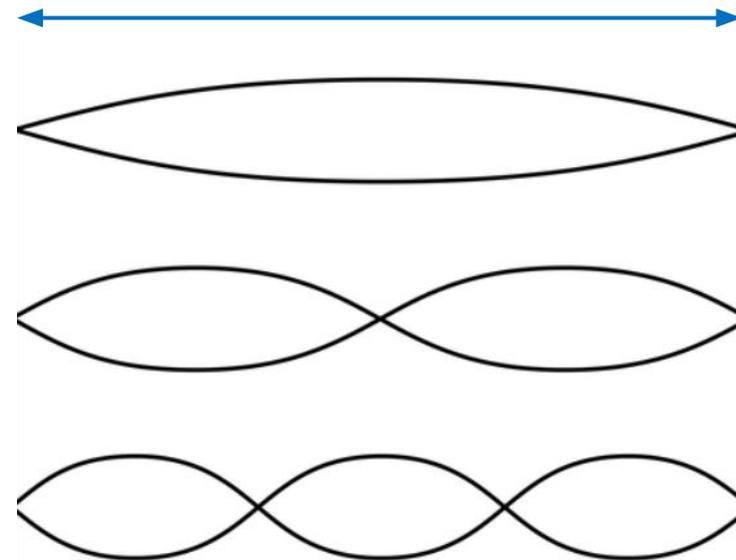
$$f = n \times f_0$$

Fixed Ends
(Guitar String):

f

L

λ



- The **fundamental** or **first harmonic** is the **mode** with the **lowest** possible **frequency** and **smallest** number of **nodes**.

Exemplar Plot/Sketch Exam Question

Context: Harmonics. Recall the modes of vibration for a string fixed at both ends.

Extend our knowledge to the fourth harmonic.

- 1) The diagram below shows a taut guitar string fixed at either end. Plucking the string can form standing waves on the wire. Sketch the fourth harmonic of a standing wave on the diagram and label the positions of the nodes.

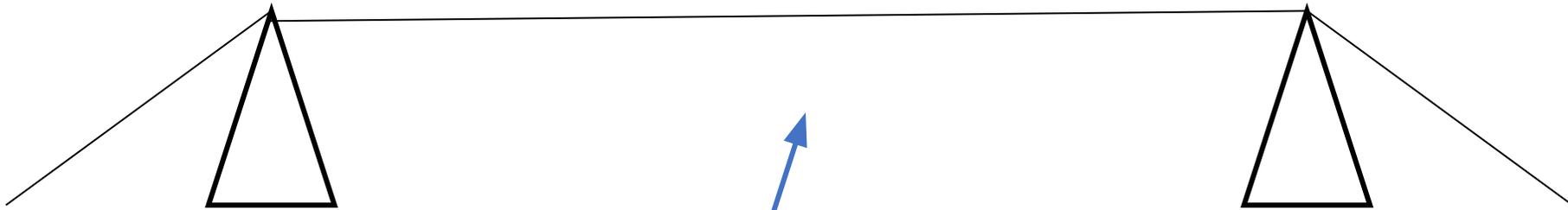
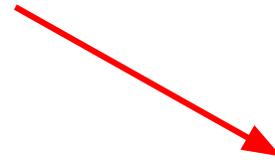
[2 marks]

Plot/Sketch Question: Make **diagram** neat and easy for the examiner to **interpret**.

1 mark for correct **sketch** and **1 mark** for correct **labels**. Remember both!

Exemplar Plot/Sketch Question Answer

Correct sketch. [1 Mark]



Correct labels. [1 Mark]



MINI MOCK PAPER



- 1) Explain what is meant by a polarised wave and then describe the difference between longitudinal and transverse waves with respect to polarisation.
[3 marks]

- A polarised wave has all of its oscillations occur in
a single plane.

[1 Mark]

- Transverse waves can be polarised as their
oscillations can occur in any number of planes
perpendicular to the direction of travel.

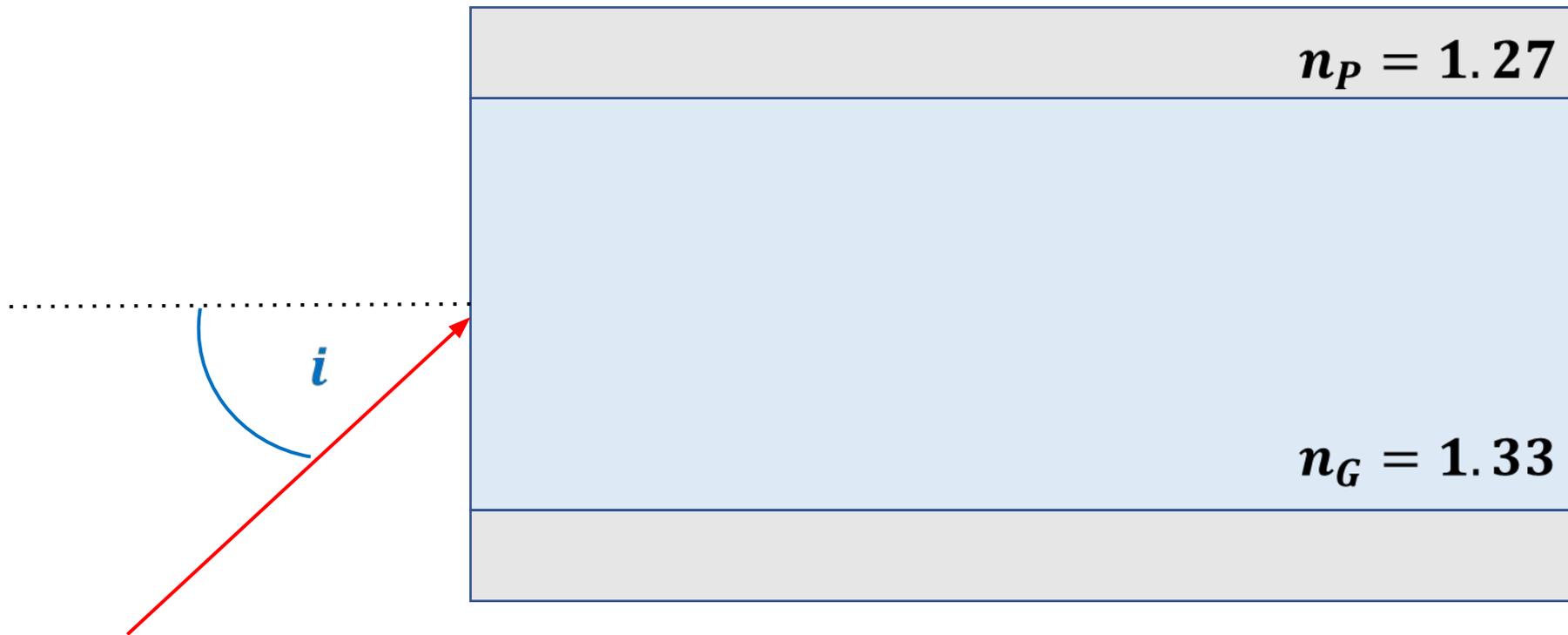
[1 Mark]

- Longitudinal waves cannot be polarised as they
oscillate in one direction only - the direction of
travel.

[1 Mark]

2) A ray of visible light travelling through air enters an optical fibre at an angle of incidence i to the normal. The optical fibre consists of a central glass tube of refractive index $n_G = 1.33$ encased by a plastic tube of refractive index $n_P = 1.27$ as shown in the following diagram. Calculate the maximum value of i for which the ray of light will undergo total internal reflection on reaching the glass-plastic boundary.

[4 marks]



Exam Question Answer

Determine condition for maximum angle of incidence

Maximum angle of incidence into the fibre will cause the ray to hit the glass/plastic boundary at its critical angle

[1 Mark]

Determine critical angle C

$$\sin C = \frac{n_P}{n_G}$$

$$C = \sin^{-1} \left(\frac{n_P}{n_G} \right) = \sin^{-1} \left(\frac{1.27}{1.33} \right)$$

$$C = 72.724 \dots^\circ$$

[1 Mark]

Exam Question Answer

Determine relation between angles r and c

Ray and normals form a right angle triangle

$$r = 90 - C = 90 - 72.724 \dots = 17.2756 \dots^\circ \quad [1 \text{ Mark}]$$

Use Snell's Law to determine angle of incidence

$$n_a \sin i = n_G \sin r$$

$$i = \sin^{-1} \left(\frac{n_G \sin r}{n_a} \right) = \sin^{-1} \left(\frac{1.33 \sin 17.2756 \dots^\circ}{1} \right)$$

$$i = 23.2640 \dots^\circ = 23.3^\circ \text{ (to 3 s.f.)} \quad [1 \text{ Mark}]$$

- 3) Draw a labelled diagram to show the difference between plane water waves, in a ripple tank, diffracting through a rectangular slit roughly the same width as their wavelength, and through a slit with a width ten times greater than their wavelength

[3 marks]

[3 marks]