Two point interference patterns

- **investigate and analyse theoretically and practically constructive and destructive interference from two sources with reference to coherent waves and path difference: nλ and $\left(n - \frac{1}{2}\right)$λ respectively.**
- **explain the results of Young's double slit experiment with reference to: – evidence for the wave-like nature of light.**

  – constructive and destructive interference of coherent waves in terms of path differences: nλ and $\left(n - \frac{1}{2}\right)$ respectively

  – effect of wavelength, distance of screen and slit separation on interference patterns: $\Delta x = \frac{\lambda L}{d}$

Paper	Multiple choice	Short Answer	Idea	Marks	%	Type
2022		12a	Central maximum and band formation	2	30%	Explanation
		12b	Wave model explanation	2	64%	Explanation
		12c	Band spacing	2	53%	Calculation
		12d	Effect of Δλ on pattern	2	42%	Explanation
2022 NHT		13a	c = fλ	2	NA	Calculation
		13b	Path difference	2	NA	Explanation
		13c	Path difference concept	2	NA	Explanation
		13d	Change in frequency effect	3	NA	Explanation
2021		13a	Young's DS, $\Delta x = \frac{n\lambda L}{d}$	2	51%	Calculation
		13b	Wave model explanation	2	57%	Explanation
2021 NHT	16		Double Slit, effect of Δλ	1	NA	Concept
		12a	Radio waves, PD = $\frac{1}{2}$ λ	2	NA	Calculation
		12b	Double Slit, wave model	3	NA	Explanation
2020		12a	Young's DS, fringe formation	2	45%	Explanation
		12b	Young's DS, $\Delta x = \frac{n\lambda L}{d}$	3	40%	Calculation
2019		14a	Double Slit PD, microwaves	2	35%	Calculation
		14b	Double Slit PD, $(n - \frac{1}{2})\lambda$	2	42%	Explanation
2019 NHT		13a	2 point interference, water	2	NA	Explanation
		13b	2 point interference, $\frac{\lambda L}{d}$	2	NA	Calculation

2018	12		Young's DS, $\Delta x = \frac{n\lambda L}{d}$	1	55%	Concept
		13b	Young's DS, central max	2	55%	Explanation
		13c	Young's DS, PD	2	50%	Calculation
2018 NHT		11b	2 point interference	2	NA	Calculation
2017		15b	Sound, 2 point interference	3	47%	Explanation
		15c	Sound, 2 point interference	3	23%	Explanation

Two point interference pattern questions can be grouped into the following ideas.

Wave model explanation	Worked example 1
$\Delta x = \frac{n\lambda L}{d}$, calculation	Worked example 2
Effect of $\Delta\lambda$, $\Delta x = \frac{n\lambda L}{d}$	Worked example 3
PD = 0	Worked example 4
PD = $\frac{1}{2}\lambda$, $(n - \frac{1}{2})\lambda$, light	Worked example 5
PD = $\frac{1}{2}\lambda$, $(n - \frac{1}{2})\lambda$, microwave	Worked example 6
$v = f\lambda$, $c = f\lambda$	Worked example 7

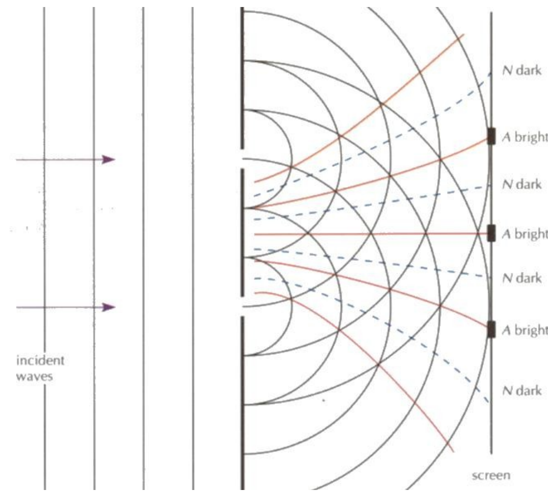
Wave model

In 1690 Huygens proposed the wave theory of light. This model suggests that light is transmitted as a wave between source and observer. The wave does not require a medium for transmission.

- Linear Propagation: The direction of energy transmission is perpendicular to the wave front. Two sets of waves pass through each other, apparently unaffected, as do two beams of light.
- Reflection: Can be explained in terms of waves.
- Inverse Square Law: A spherical wave starting from a point obeys the inverse square law.
- Diffraction and Interference effects can be explained with the wave model.

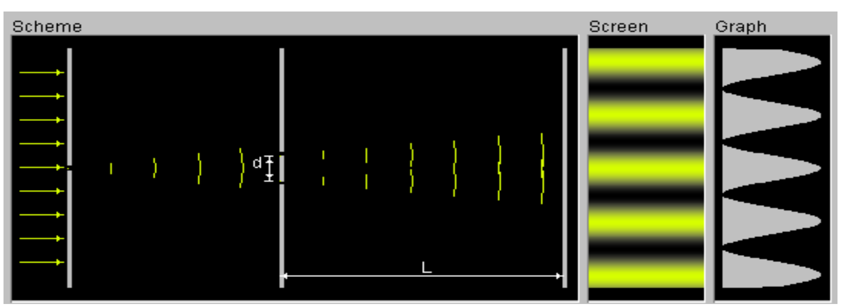
Young's Double Slit Experiment:

This experiment showed that light would produce an interference pattern, because it diffracted when passing through very small slits if the sources were close enough together. Young explained this result, using Huygens' Principle and assuming that each narrow slit acted as a source of secondary waves which spread out behind the slits and interfered with each other to form the bright and dark bands.



The interference pattern produced was from the two diffracted waves and has a pattern of nodes and antinodes just like sound or water. A series of light and dark lines were observed on the screen. Dark lines correspond to cancellation, or nodes, bright lines to antinodes.

Antinodes were where crests met crests and troughs met troughs and constructively interfered with each other to form the bright lines. Nodes were formed where crests met troughs and troughs met crests and the displacements cancelled each other out by destructive interference, producing lines of minimum intensity.

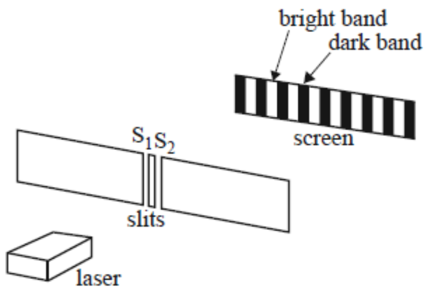


The pattern can be described algebraically as $\Delta x \approx \frac{n\lambda L}{d}$. Where Δx is the distance between the central maximum and the n^{th} local maximum, n is the nodal line, λ is the wavelength, L is the perpendicular distance from the slits to the screen, and 'd' is the distance between the two slits.

Young's double slit experiment can only be explained if we model light as a wave.

Worked example 1: Two point interference: Wave model explanation.

The apparatus for a Young's double-slit experiment is shown below.



2013 Question 22d, 3 marks

A student reads on a website that 'Young's experiment supports the particle model of light'.

Explain, with reasons, whether the statement is correct or incorrect.

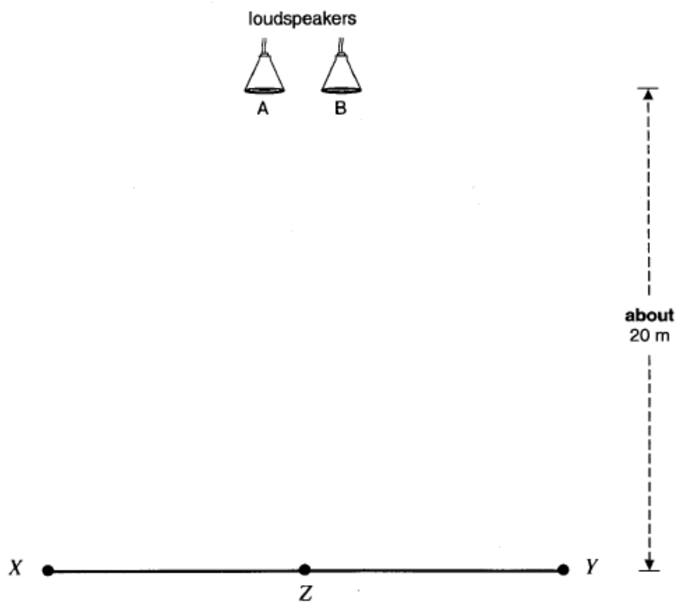
Solution	Current study design:
The statement is incorrect. Young's double slit experiment with light demonstrated interference, which was a wave effect. Young's experiment showed that the light from both slits interfered with each other and produced a pattern of light and dark lines. The interference was both constructive and destructive from the superposition of waves. The particle model predicted that two bands would appear on the screen behind the slits as sharp shadows, which are not observed. (60%)	**2022 Question 12a (30%)** **2022 Question 12b (64%)** **2021 Question 13b (57%)** **2021 NHT Question 12b** **2020 Question 12a (45%)** **2017 Question 15c (23%)**

Worked example 2: Two point interference: $\Delta x = \frac{n\lambda L}{d}$, calculation.

Two small loudspeakers are set up at one end of a school oval as shown below.

Both are connected to the same source and emit sound with the same amplitude, with a frequency of 1.7 kHz. The point Z is an equal distance from both loudspeakers.

The speed of sound is 340 m s^{-1}.



A student moves a distance of 1.5 m from Z towards Y, and notes that the sound intensity goes from a maximum at point Z through a minimum to another maximum at Y.

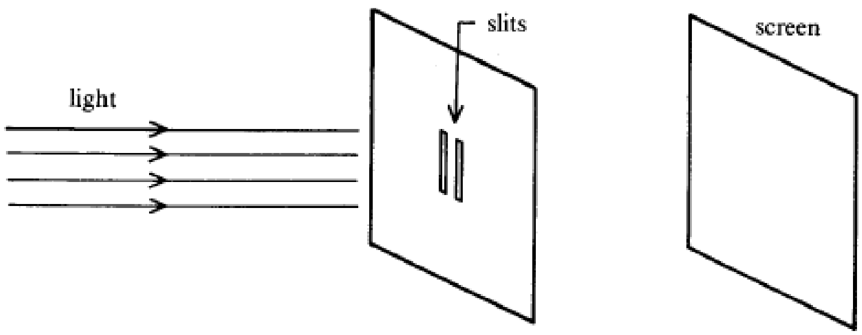
1996 Question 11, 2 marks

If the student is now exactly 20.4 m from speaker A, what is the distance to speaker B. Clearly show your working.

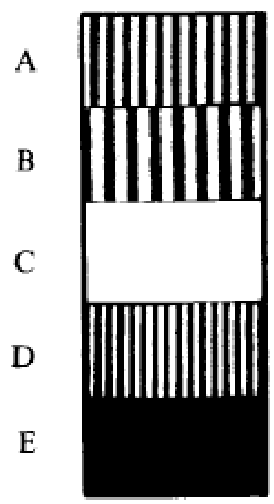
Solution	**Current study design:**
Use v = fλ ∴ $340 = 1.7 \times 10^3 \times \lambda$ ∴ λ = 0.2 m Since the student is at the first local maximum from the centre, the path difference must be λ. Speaker B is closer, ∴ the distance to B = 20.4 – 0.2 ∴ 20.2 m (ANS)	2022 Question 12c (53%) 2021 Question 13a (51%) 2020 Question 12b (40%) 2019 NHT Question 13b

Worked example 3: Two point interference: Effect of Δλ, $\Delta x = \frac{n\lambda L}{d}$.

Red light of a single wavelength is shone through two closely spaced narrow slits as shown below.



A series of bright and dark fringes is observed on the screen, and this is shown in diagram A below.



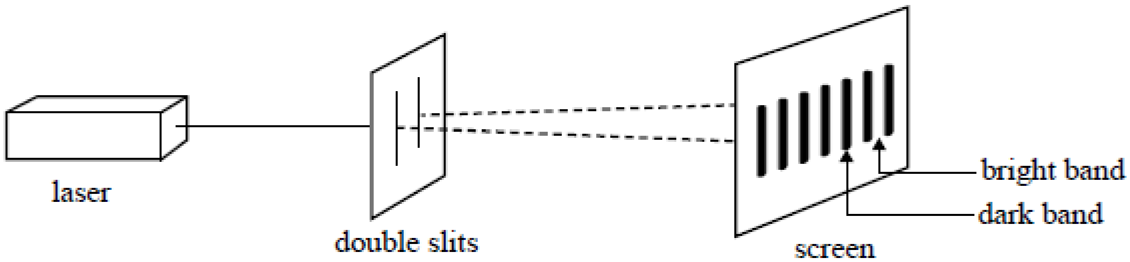
1983 Question 39, 1 mark

The red light source is replaced with a source of blue light of a single wavelength (of a shorter wavelength than red light). Which diagram above (**A - E**) best represents the pattern of light that is now seen on the screen?

Solution	**Current study design:**
Use $\Delta x \approx \frac{n\lambda L}{d}$, therefore as λ is decreased Δx will decrease, making the pattern less spread out. ∴ D (ANS), (71%)	2022 Question 12d (42%) 2021 NHT Question 16 2018 Question 12 (55%)

Worked example 4: Two point interference: PD = 0.

Two students, Karina and Kim, are investigating double-slit interference. They have a 633 nm wavelength laser and a slide with two narrow slits. They set up their experimental arrangement as shown below and see a pattern of alternating bright and dark bands on their screen.



Before they put the slide in place, they direct the laser beam onto the screen and mark the bright spot due to the laser on their screen. Kim believes that this point will be a dark band when the slide is put in place. Karina believes it will be a bright band.

2015 Question 17a, 3 marks

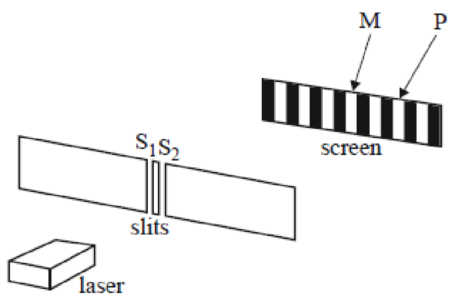
Is this point a bright band or a dark band? Give a reason for your choice.

Solution	**Current study design:**
The point is a bright band. At this central point the path difference from the two slits is zero. Therefore constructive interference occurs, resulting in a bright band. (60%)	2019 NHT Question 13a 2018 Question 13b (55%) 2017 Question 15b (47%)

Worked example 5: Two point interference: PD = $\frac{1}{2}\lambda$, $(n - \frac{1}{2})\lambda$, light.

A group of students carries out a two-slit interference experiment using light with a wavelength of 420 nm. The arrangement of the students' apparatus and the resulting interference pattern are shown below.

The point M on the screen is at the centre of the interference pattern. There is a bright band at point P on the screen. It is the second bright band to the right of M, as shown.



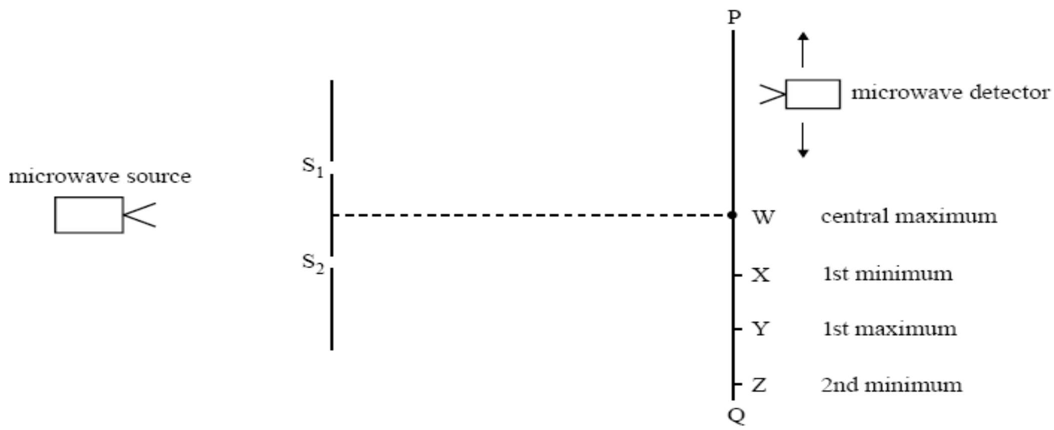
2014 Question 19a, 1 mark

Calculate the path difference $S_1P - S_2P$. (in mm)

Solution	**Current study design:**
The path difference to the second bright band is 2λ. ∴ 2 × 420 = 840 nm (ANS), (60%)	2021 NHT Question 12a 2018 Question 13c (50%)

Worked example 6: Two point interference: PD = $\frac{1}{2}$ λ, (n - $\frac{1}{2}$)λ, microwaves.

A group of students is studying Young's double slit experiment using microwaves (λ = 3.0 cm) instead of light. A microwave detector is moved along the line PQ, and the maxima and minima in microwave intensity are recorded. The experimental apparatus is shown below.



2008 Question 3, 2 marks

What is the path difference $S_1Z – S_2Z$ in cm?

Solution	**Current study design:**
Position Z is the second minimum, so the path difference is 1.5λ. So: PD = 1.5λ PD = 1.5 × 3.0 ∴ PD = 4.5 cm (ANS) (45%)	2022 NHT Question 13b 2022 NHT Question 13c 2022 NHT Question 13d 2019 Question 14a (35%) 2019 Question 14b (42%) 2018 NHT Question 11b

Worked example 7: Two point interference: v = fλ, c = fλ.

Two identical loudspeakers are emitting sound waves in phase.

A person stands at the point S, 3.00 m from one speaker and 3.25 m from the other.

The speed of sound in air is taken as 330 m s^{-1}.

1984 Question 46, 1 mark

What is the lowest frequency of sound for which destructive interference will occur at this point?

Solution	**Current study design:**
For destructive interference with the lowest frequency (longest wavelength), the path difference needs to be 0.5λ. ∴ 3.25 – 3.00 = 0.5λ ∴ λ = 0.5 m Use v = fλ ∴ 330 = f × λ ∴ 330 = f × 0.5 ∴ f = 660 Hz (ANS), (70%)	2022 NHT Question 13a