8.3 Interference, coherence and the double slit

Name: _____ Class: _____ Date: _____ **Total: 28 marks**

KEY WORDS interference • coherent • path difference • fringe • double slit

Objective

Answer exam questions on **interference**: coherence, path difference, the two-source experiments with water, sound, microwaves and light, the conditions for visible fringes, and **Young's double slit** with $\lambda = \frac{ax}{D}$. Syllabus 8.3, learning outcomes 1 to 4.

You must be able to:

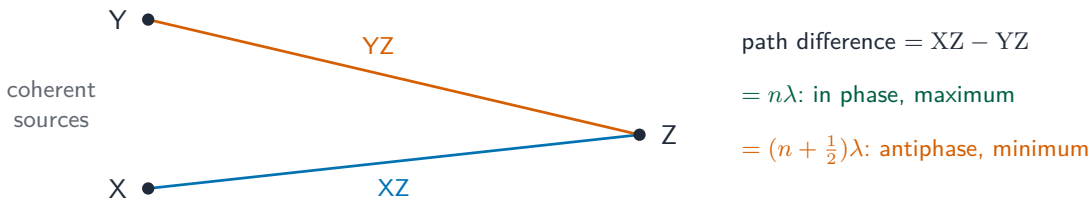
- define interference and coherence
- decide from the path difference whether two waves meet in phase or in antiphase
- describe two-source interference with water waves, sound, microwaves and light, and state the conditions for observable fringes
- use $\lambda = \frac{ax}{D}$, and say how the fringes change when a, D or λ changes

1 Key knowledge and worked examples

■ **Key knowledge: interference and coherence**

Term	Meaning
interference	the superposition of waves from two (or more) **coherent** sources, giving regions of greater and smaller amplitude
coherent	having a **constant phase difference** (and so the same frequency)
path difference	the difference in the distances from the two sources to a point

Sources in phase; path difference	Waves meet	Result
$0,\ \lambda,\ 2\lambda,\ \cdots = n\lambda$	in phase	**constructive**: a maximum (bright fringe, loud, strong signal)
$\frac{1}{2}\lambda,\ \frac{3}{2}\lambda,\ \cdots = (n+\frac{1}{2})\lambda$	in antiphase	**destructive**: a minimum (dark fringe, quiet)



The path difference decides what happens at Z

Conditions for observable fringes: the sources are **coherent**; the waves have similar amplitudes, so the minima are dark; for light, the slit separation is small (about 1 mm or less) and the screen is far away, so the fringes are wide enough to see.

■ Key knowledge: source phase and path phase

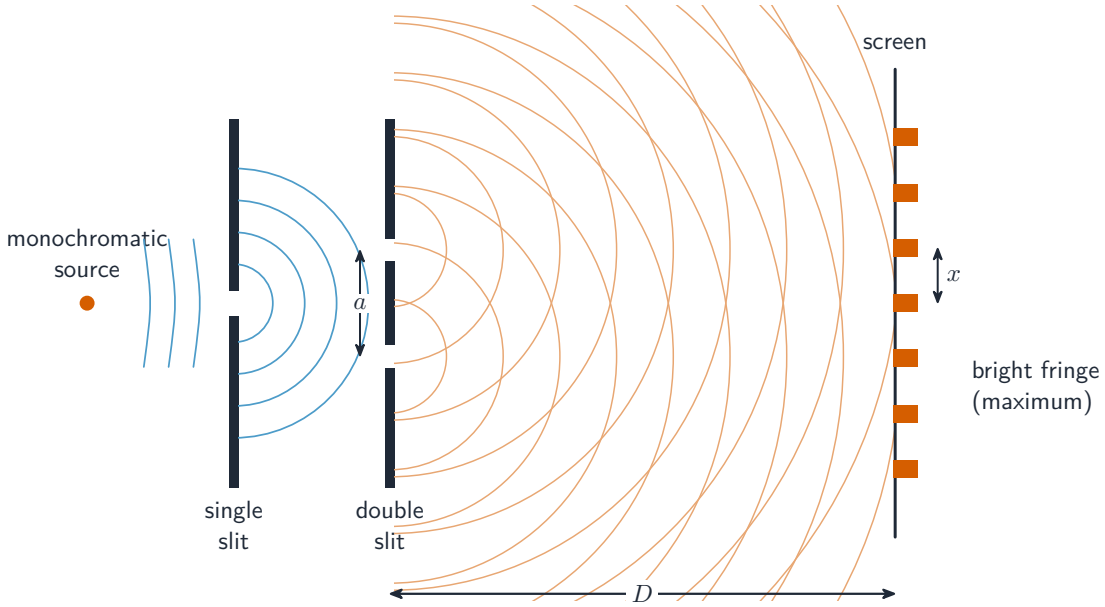
Coherent sources have a **fixed** phase difference; they need not emit in phase. The phase difference at an observation point combines the initial source phase with the phase change due to the path difference. Use a consistent sign convention and reduce the result modulo 360°.

For a lagging second source, $\delta_{\text{arrival}} = \delta_{\text{source}} + 360°(r_2 - r_1)/\lambda$. A multiple of 360° gives a maximum; 180° modulo 360° gives a minimum (zero only for equal amplitudes).

Worked example. Sources emit 180° apart. An extra path of $\lambda/2$ adds 180°, giving 360° at arrival: a **maximum**, not a minimum. In a wavefront diagram, a crossing of two crests is a maximum; a crest meeting a trough is a minimum.

■ Key knowledge: the experiments

Waves	Two coherent sources	What is observed
water	two dippers on one vibrating bar in a ripple tank	lines of still water between lines of large ripples
sound	two loudspeakers driven by **one** signal generator	loud and quiet regions as you walk across
microwaves	one transmitter and a metal sheet with two slits	maxima and minima on a detector moved sideways
light	a laser (or a single slit before the double slit) lighting two narrow slits	bright and dark fringes on a screen



Young's double slit: the single slit makes the two slits coherent sources

$$\lambda = \frac{ax}{D} \qquad a = \text{slit separation},\ x = \text{fringe separation},\ D = \text{slits to screen}$$

- measure **several** fringe spacings and divide, for a smaller percentage uncertainty in x
- $x = \dfrac{\lambda D}{a}$: a larger D or λ spreads the fringes; a larger a packs them closer; blue light gives narrower fringes than red

■ Worked example: path difference

Two dippers in phase make waves of wavelength 3.0 cm. Point P is 12.0 cm from one dipper and 16.5 cm from the other.

1. **Path difference** – $16.5 - 12.0 = 4.5$ cm.
2. **In wavelengths** – $\frac{4.5}{3.0} = 1.5$: an odd number of half wavelengths, so the waves arrive in antiphase.
3. **Result** – destructive interference: the water at P hardly moves.

■ Worked example: Young's double slit

Laser light passes two slits 0.50 mm apart onto a screen 2.40 m away. Ten fringe spacings measure 29 mm.

1. **Fringe separation** – $x = \frac{29 \text{ mm}}{10} = 2.9 \times 10^{-3}$ m.
2. **Wavelength** – double-slit equation, $\lambda = \frac{ax}{D} = \frac{0.50 \times 10^{-3} \times 2.9 \times 10^{-3}}{2.40} = 6.0 \times 10^{-7}$ m.
3. **Frequency** – $f = \frac{c}{\lambda} = \frac{3.0 \times 10^{8}}{6.0 \times 10^{-7}} = 5.0 \times 10^{14}$ Hz.

■ Worked example: two loudspeakers

Two loudspeakers 1.5 m apart are driven by one signal generator at 680 Hz. The speed of sound is 340 $\frac{\text{m}}{\text{s}}$. A student walks along a line 5.0 m in front of them.

1. **Wavelength** – $\lambda = \frac{v}{f} = \frac{340}{680} = 0.50$ m.
2. **Spacing of the loud regions** – the same geometry as the double slit: $x = \frac{\lambda D}{a} = \frac{0.50 \times 5.0}{1.5} = 1.7$ m.
3. **Why one generator** – it keeps the two sources coherent, with a constant phase difference.

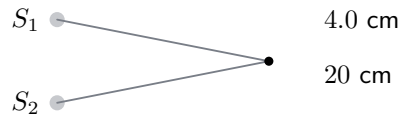
2 Practice

Now apply the methods above.

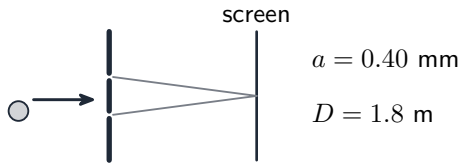
2.1 Define **coherence**. [1]

coherence

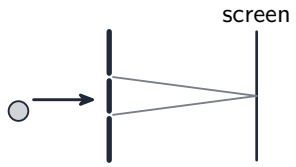
2.2 Two sources in phase emit waves of wavelength 4.0 cm. A point is 20 cm from one source and 26 cm from the other. State and explain whether there is a maximum or a minimum at the point. [2]



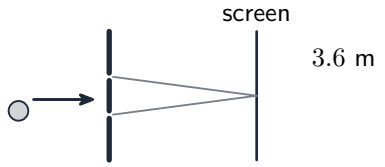
2.3 In a double-slit experiment, $a = 0.40$ mm, $D = 1.8$ m and the fringe separation is 2.7 mm. Calculate the wavelength of the light. [2]



2.4 State **two** conditions needed for two-source interference fringes to be observed. [2]



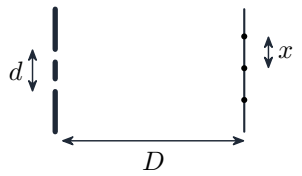
2.5 The screen in **2.3** is moved to 3.6 m from the slits. State the new fringe separation. [1]



3 Exam-style questions

3.1 Which change makes the fringes in a double-slit experiment with light **further apart**? [1]

- [ ] **A** using slits that are further apart
- [ ] **B** moving the screen closer to the slits
- [ ] **C** using blue light instead of red light
- [ ] **D** moving the screen further from the slits



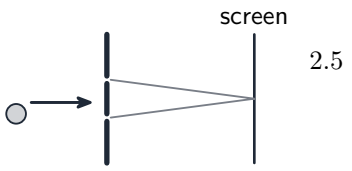
3.2 Two coherent sources emit waves in phase. At a point, the path difference is 2.5 wavelengths. What happens at the point? [1]

☐ **A** constructive interference, because the path difference is more than two wavelengths

B destructive interference, because the waves arrive in antiphase

C constructive interference, because the waves arrive in phase

D no interference, because the path difference is not a whole number of wavelengths

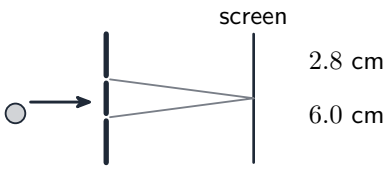


3.3 Microwaves of wavelength 2.8 cm from one transmitter pass through two slits 6.0 cm apart in a metal sheet. A detector is moved along a line 0.80 m beyond the sheet, parallel to it.

(a) **Explain** why the two slits act as coherent sources. [2]

(b) State what the detector records as it moves along the line. [1]

(c) Calculate the distance between neighbouring positions of maximum signal. [2]

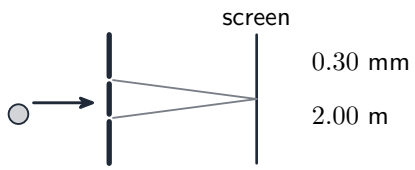


(d) At a point the path difference is 4.2 cm. State and explain the signal there. [2]

3.4 A student uses a laser and a double slit to measure the wavelength of the laser light. The slit separation is 0.30 mm and the screen is 2.00 m from the slits.

(a) **Define** interference. [1]

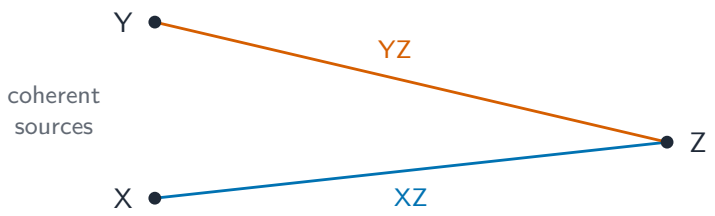
(b) The student measures the distance across 8 fringe spacings as 34 mm. **Determine** the wavelength. [3]



(c) **Explain** why the student measures across several fringes rather than one. [1]

(d) The slit separation is changed to 0.60 mm. State and explain the effect on the fringes. [2]

3.5 Two equal-amplitude coherent sources emit 180° apart. Their paths to P differ by 1.5 wavelengths. Find the arrival phase difference modulo 360° and state whether P is a maximum or minimum. What happens when the path difference becomes one wavelength? [4]



path difference $= \mathrm{XZ} - \mathrm{YZ}$

$= n\lambda$: in phase, maximum

$= (n + \frac{1}{2})\lambda$: antiphase, minimum