Week 16

A-Level Physics

Homework bundle for this week

本周作业合集

exercises.lol

Contents 目录

A-Level Physics Name: ______________ Score: ______

1. When two waves overlap at a point, the resultant displacement is:
   - ☐ the sum of their separate displacements
   - ☐ always the larger displacement
   - ☐ always zero
   - ☐ the average of the two
2. Diffraction is the ______ of a wave as it passes through a gap.
   - ☐ spreading
   - ☐ speeding up
   - ☐ reflection
   - ☐ disappearing
3. Two coherent sources have:
   - ☐ a constant phase difference
   - ☐ the same amplitude only
   - ☐ randomly changing phases
   - ☐ different frequencies
4. A diffraction grating is made of:
   - ☐ many equally spaced slits
   - ☐ exactly two slits
   - ☐ a single slit
   - ☐ a curved mirror
5. Two equal waves meeting in phase give four times the intensity of one wave alone.

   ☐ True ☐ False
6. All waves can diffract.

   ☐ True ☐ False
7. Two separate lamps make a steady, visible interference pattern.

   ☐ True ☐ False

8. Light hits a grating of slit spacing 2.0 μm. The first-order ($n = 1$) maximum is where $\sin\theta = 0.30$. Find the wavelength, in nm.

   ________________ nm

9. A point on a stationary wave that is always at zero displacement is called a ______.

   ____

10. A wave spreads out the most when the gap is:

    ☐ about the same size as the wavelength

    ☐ much wider than the wavelength

    ☐ made of metal

    ☐ perfectly square

A-Level Physics

1. **the sum of their separate displacements**

   That is the principle of superposition — displacements add (as vectors) at each point.

2. **spreading**

   Diffraction is the spreading (bending) of a wave at a gap or obstacle.

3. **a constant phase difference**

   Coherence means a constant phase difference (and so the same frequency) — needed for a steady pattern.

4. **many equally spaced slits**

   Hundreds or thousands of equally spaced slits, each acting as a coherent source.

5. **True**

   The amplitude doubles to $2A$, and $I \propto A^2$, so $I \propto (2A)^2 = 4A^2$.

6. **True**

   Yes — water, sound, light and microwaves all spread at a gap or edge.

7. **False**

   No — their phase difference changes randomly, so any pattern flickers too fast to see.

8. **600 nm**

   $\lambda = \dfrac{d\sin\theta}{n} = \dfrac{2.0 \times 10^{-6} \times 0.30}{1} = 6.0 \times 10^{-7}\ \text{m} = 600\ \text{nm}.$

9. **node**

   At a node the two waves always cancel. Halfway between nodes is an antinode (biggest swing).

10. **about the same size as the wavelength**

    When the gap ≈ the wavelength, the wave fans out strongly; a much wider gap lets it pass nearly straight.

A-LEVEL PHYSICS • EXERCISE SHEET

8.1 Stationary waves

Name: ______________ Class: __________ Date: ____________ **Total: 18 marks**

KEY WORDS wave 波 • stationary wave 驻波 • node 波节 • antinode 波腹 • wavelength 波长

Objective

Build the skills to answer exam questions on **stationary waves 驻波** — superposition, nodes and antinodes, and the **reflection** experiments that form them.

You must be able to:

- use the **principle of superposition** (constructive/destructive)
- explain how a **stationary wave** forms — including by **reflection** off a surface
- identify **nodes** and **antinodes** and find **wavelength** from node spacing
- use $v = f\lambda$ (and $c = f\lambda$ for microwaves) and name the spectrum region

1 Worked examples

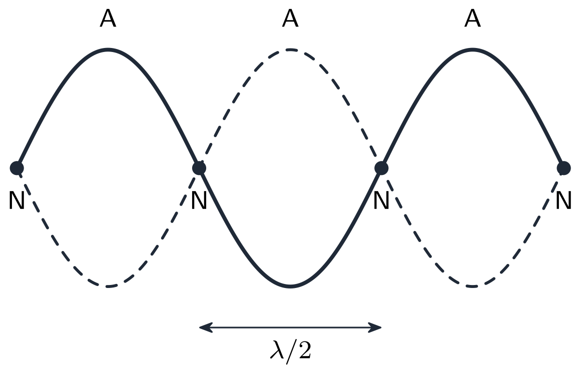
Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Superposition

Where waves overlap, the displacement is the **sum** of the separate displacements. In phase → **constructive** (amplitude $A_1 + A_2$); exactly out of phase → **destructive** ($|A_1 - A_2|$). Since $I \propto A^2$, two equal waves in phase give **four times** the intensity.

■ Stationary waves

Two identical waves travelling in **opposite directions** overlap to make a **stationary wave**:

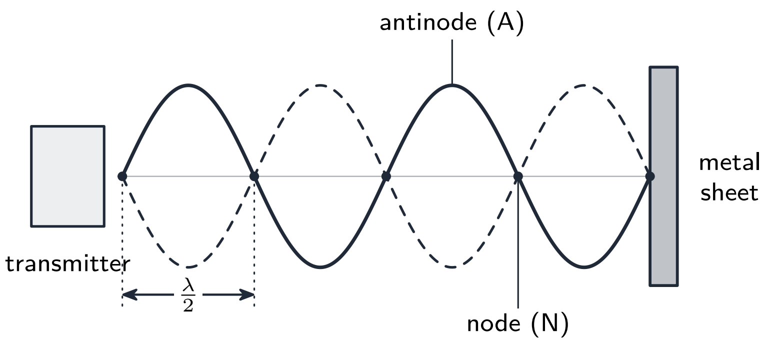


- **node (N):** always zero displacement; **antinode (A):** maximum amplitude.
- node-to-node $= \lambda/2$; node to next antinode $= \lambda/4$.

A stationary wave does **not** transfer energy along its length, and the nodes stay fixed. Find λ from node spacing, then $v = f\lambda$.

■ Stationary waves by reflection

In the exam, the second wave is very often the **reflection** of the first. A common set-up: a **microwave** transmitter faces a **metal sheet**. The waves travel to the sheet, **reflect**, and the reflected waves travel back and **superpose** with the incoming waves — forming a stationary wave, with a **node at the sheet**:



To explain the formation (a frequent "explain" question), say: the incident wave **reflects** off the sheet; the reflected wave travels back in the **opposite direction**; the two waves have the same frequency and **superpose**; at **nodes** they are always out of phase and cancel, at **antinodes** they reinforce.

Worked example. A detector is moved between transmitter and sheet; adjacent points of minimum signal (nodes) are 25 mm apart. Then $\lambda/2 = 25$ mm, so $\lambda = 50$ mm $= 0.050$ m. As these are microwaves (an EM wave), $f = \dfrac{c}{\lambda} = \dfrac{3.0 \times 10^8}{0.050} = 6.0 \times 10^9$ Hz — in the **microwave** region of the spectrum.

2 Practice

Now apply the methods above.

2.1 State the **principle of superposition**. [1]

2.2 State the distance between **two adjacent nodes**. [1]

2.3 Two waves each of amplitude A meet **in phase**. State the resultant **amplitude** and the **intensity** compared with one wave. [2]

2.4 State **one** difference between a stationary wave and a progressive wave. [1]

2.5 In a microwave stationary wave, adjacent nodes are 16 mm apart. State the **wavelength**. [1]

3 Exam-style questions

3.1 The distance between a node and the **next antinode** is: [1]

- **A** λ
- **B** $\lambda/2$
- **C** $\lambda/4$
- **D** 2λ

3.2 A stationary wave on a string has adjacent nodes 0.30 m apart. The frequency is 250 Hz. Find (a) the wavelength, (b) the wave speed. [3]

3.3 A microwave transmitter faces a metal sheet. The reflected microwaves superpose with the incoming microwaves to form a stationary wave.

(a) Explain how the stationary wave is formed, referring to **nodes** and **antinodes**. [3]

(b) A detector finds that adjacent nodes are 25 mm apart. Calculate the **frequency** of the microwaves, and name the region of the electromagnetic spectrum they belong to. ($c = 3.0 \times 10^8$ m s^{-1}.) [3]

3.4 State **two** differences between a **node** and an **antinode**. [2]

Solutions

2.1 When waves overlap, the resultant displacement is the **(vector) sum** of the individual displacements.

2.2 $\lambda/2$.

2.3 Amplitude $= 2A$; intensity $= 4\times$ that of one wave (since $I \propto A^2$).

2.4 Any one: a stationary wave does **not transfer energy** along its length; its amplitude **varies** (zero at nodes, max at antinodes) whereas a progressive wave has the same amplitude everywhere; the nodes are fixed.

2.5 $\lambda = 2 \times 16 = 32$ mm.

3.1 **C** — $\lambda/4$.

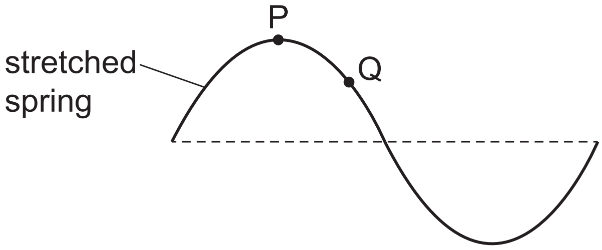
3.2 (a) node spacing $= \lambda/2 = 0.30$ m, so $\lambda = 0.60$ m. (b) $v = f\lambda = 250 \times 0.60 = 150$ m s^{-1}.

3.3 (a) The incident microwaves **reflect** off the sheet and travel back the **opposite way**; the incident and reflected waves have the same frequency and **superpose**; where they are always out of phase they cancel (**nodes**), where they reinforce there is maximum amplitude (**antinodes**).

3.3 (b) $\lambda = 2 \times 25 = 50$ mm $= 0.050$ m; $f = \dfrac{c}{\lambda} = \dfrac{3.0 \times 10^8}{0.050} = 6.0 \times 10^9$ Hz; region: **microwaves**.

3.4 Any two: a node has **zero** displacement, an antinode has **maximum** amplitude; a node never moves, an antinode oscillates most; adjacent points either side of a node are in **antiphase**.

29 The diagram shows a stationary wave on a stretched spring at an instant in time.



Two particles on the spring, P and Q, are shown.

Which statement about the vibrations of P and Q is correct?

A They have different frequencies.

B They have the same amplitudes.

C They have different periods.

D They are always in phase.

A-Level Physics: **w25 12**

30 Two progressive sound waves move in opposite directions and superpose to form a stationary wave.

Which statement describes an antinode of this stationary wave?

A a position where the phase difference between the two waves is always 0°

B a position where the phase difference between the two waves is always 180°

C a position where the stationary wave has maximum amplitude

D a position where the stationary wave has minimum amplitude

A-Level Physics: **w25 14**

29 A wire is fixed at both ends and is vibrated by a source of frequency *f*. A stationary wave is formed on the wire with a total of two antinodes.

The frequency of the source is increased to 3*f* and a new stationary wave is formed.

What is the total number of antinodes on the new wave?

A 4 **B** 5 **C** 6 **D** 9

4 **(a)** State the principle of superposition.

....

....

.... [2]

(b) An electromagnetic wave of wavelength 0.026 m in free space is incident normally on an aluminium sheet, as shown in Fig. 4.1.

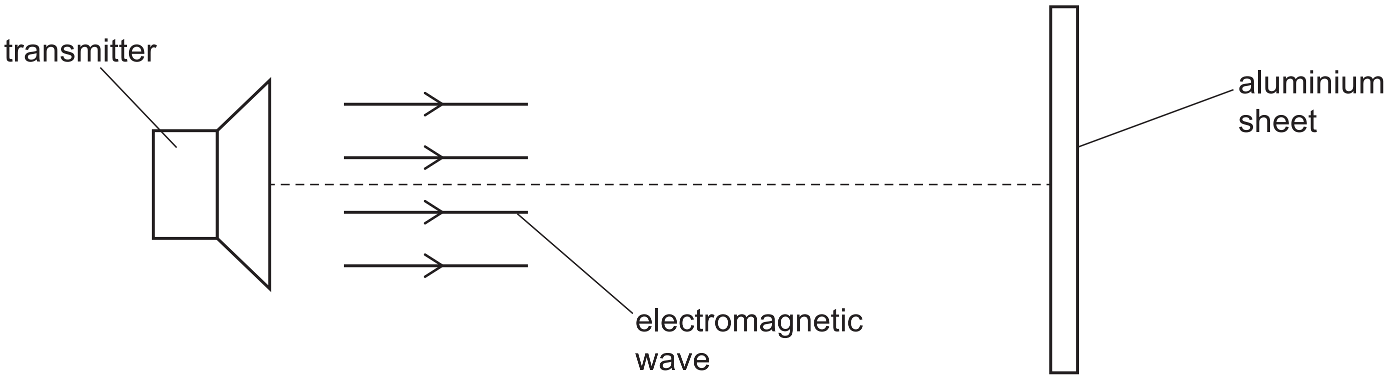


Fig. 4.1

The wave reflects at the aluminium sheet and a stationary wave is formed in the region between the transmitter and the sheet.

(i) Explain how the stationary wave, including its nodes and antinodes, is formed.

....

....

....

....

.... [3]

(ii) Calculate the frequency of the electromagnetic wave.

frequency = ... Hz [2]

(iii) State the principal region of the electromagnetic spectrum to which the wave belongs.

.... [1]

(iv) Determine the distance between a node and an adjacent antinode.

distance = ... m [1]

[Total: 9]

29 One wave has an amplitude of $2A$. A second wave has an amplitude of $\frac{A}{2}$. The waves are otherwise identical.

The two waves travel in opposite directions and overlap.

What is the ratio $\dfrac{\text{maximum amplitude of combined wave}}{\text{minimum amplitude of combined wave}}$?

A $\frac{3}{2}$ **B** $\frac{5}{3}$ **C** $\frac{5}{2}$ **D** 4

31 A hollow tube is closed at one end and open at the other.

A stationary sound wave of the lowest possible frequency, 820 Hz, is produced in the tube.

The speed of sound in air is $330\,\text{m}\,\text{s}^{-1}$.

What is the length of the tube?

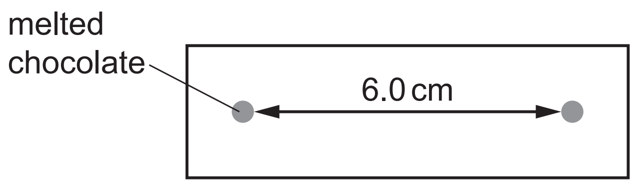
A 10 cm **B** 20 cm **C** 40 cm **D** 160 cm

24 A teacher removes the turntable from a microwave oven and places a bar of chocolate in the oven. She then switches the oven on for a short time.

A stationary wave is formed in the oven.

When the chocolate is removed, the teacher observes that there are two small sections of melted chocolate 6.0 cm apart with unmelted chocolate in between.

Each section of melted chocolate is located at an antinode.



Assume that the speed of the microwaves is $3.0 \times 10^{8}\,\mathrm{m\,s^{-1}}$.

What is the frequency of the microwaves emitted by the oven?

A 25 MHz **B** 50 MHz **C** 2.5 GHz **D** 5.0 GHz

30 Two waves meet.

What is **not** a necessary condition for the waves to produce a stationary wave?

A They must be of the same type.

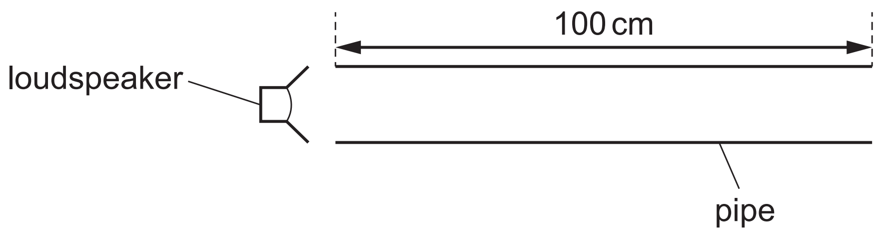
B They must have the same period.

C They must have the same wavelength.

D They must travel in the same direction.

A-Level Physics: **s25 14**

25 A pipe of length 100 cm is open at both ends. A loudspeaker situated at one end of the pipe can emit sound of different wavelengths.



Which wavelength can produce a stationary wave in the pipe?

A 50 cm **B** 75 cm **C** 150 cm **D** 300 cm

4 A device containing a microwave emitter and receiver is placed in front of a large metal sheet in a vacuum as shown in Fig. 4.1.

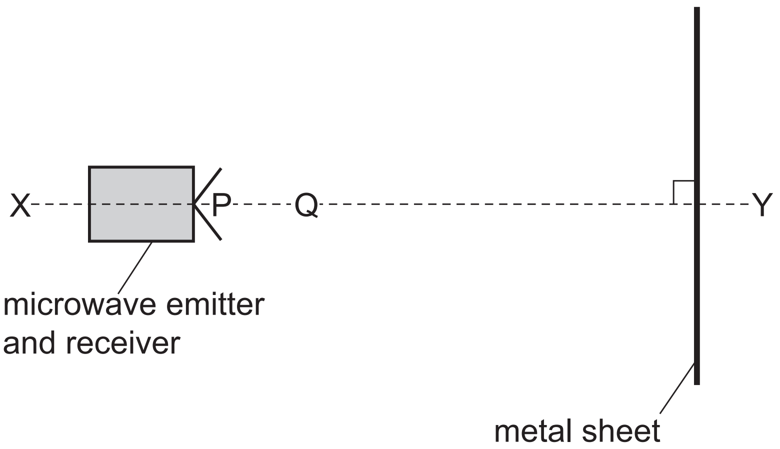


Fig. 4.1 (not to scale)

The line XY is perpendicular to the metal sheet. The device emits microwaves of frequency 6.3 GHz.

(a) When the device is at position P, a stationary wave is formed between the device and the sheet.

Explain how the stationary wave, including the nodes and the antinodes, is formed.

....

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....

....

.... [4]

(b) **(i)** Calculate the wavelength of the microwaves.

wavelength = ... m [2]

(ii) At point P the receiver detects a maximum amplitude of the stationary wave.

The device is moved slowly from point P along the line XY and the receiver detects a series of minimum and maximum amplitudes. The first time a minimum amplitude is detected by the receiver is when the device is at point Q.

Determine the distance between P and Q.

distance = ... m [1]

(iii) The intensity of the microwaves emitted by the device is increased. The frequency of the microwaves is unchanged. The device is moved slowly along the line XY from point Q until the next maximum amplitude is detected at point R.

State and explain whether the distance QR is greater than, less than or the same as distance PQ.

....

....

.... [1]

[Total: 8]

8.2 Diffraction

Name: ______________ Class: __________ Date: ____________ **Total: 23 marks**

KEY WORDS diffraction 衍射 • wavelength 波长 • obstacle 障碍物 • wave 波

Objective

Build the skills to answer exam questions on **diffraction 衍射** — what it is and how it depends on the gap width.

You must be able to:

- explain **diffraction** and where it occurs
- describe how the **gap width** relative to the **wavelength** changes the spreading

1 Worked examples

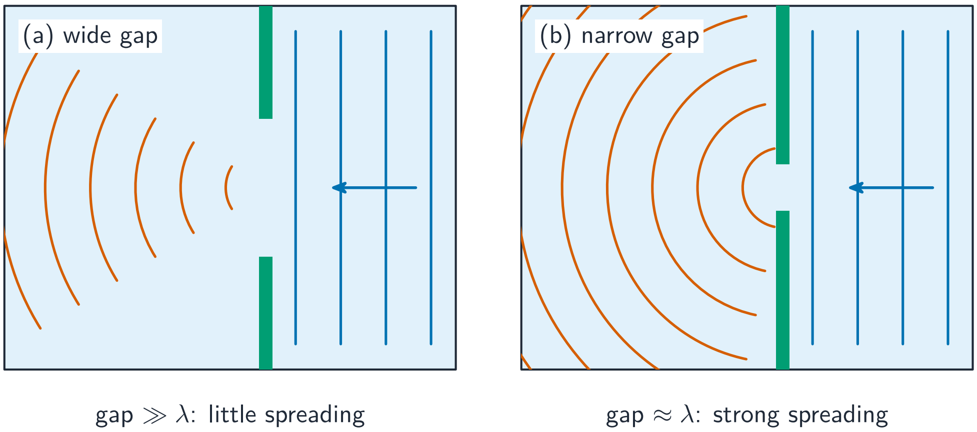
Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Diffraction

Diffraction is the **spreading** of a wave as it passes through a gap or around an obstacle. **All** waves diffract. The spreading depends on the **gap width compared with the wavelength**:

(a) wide gap

(b) narrow gap



Diffraction of waves through a gap

- gap **much wider** than $\lambda \to$ little spreading;
- gap **about** $\lambda \to$ strong spreading.

This is why you can **hear** around a corner (sound $\lambda \approx 1$ m, near a doorway's width) but cannot **see** around it (light $\lambda \approx 500$ nm, far smaller). The wavelength and speed are **unchanged** by diffraction.

2 Practice

Now apply the methods above.

2.1 Define **diffraction**. [1]

2.2 State what happens to the amount of diffraction as a gap is made **narrower** (towards the size of λ). [1]

2.3 State why you can **hear** but not **see** around a corner. [2]

2.4 State which kinds of wave can **diffract**. [1]

3 Exam-style questions

3.1 Noticeable diffraction occurs when the gap width is: [1]

- **A** much larger than the wavelength
- **B** about the same as the wavelength
- **C** exactly zero
- **D** a thousand times the wavelength

3.2 Explain, using diffraction, why **sound** passes through a doorway and spreads into the room, but **light** does not noticeably spread. [3]

3.3 Describe a **ripple-tank** experiment to show that diffraction depends on the gap width. [3]

3.4 State the effect of diffraction on the **wavelength** and **speed** of the wave. [1]

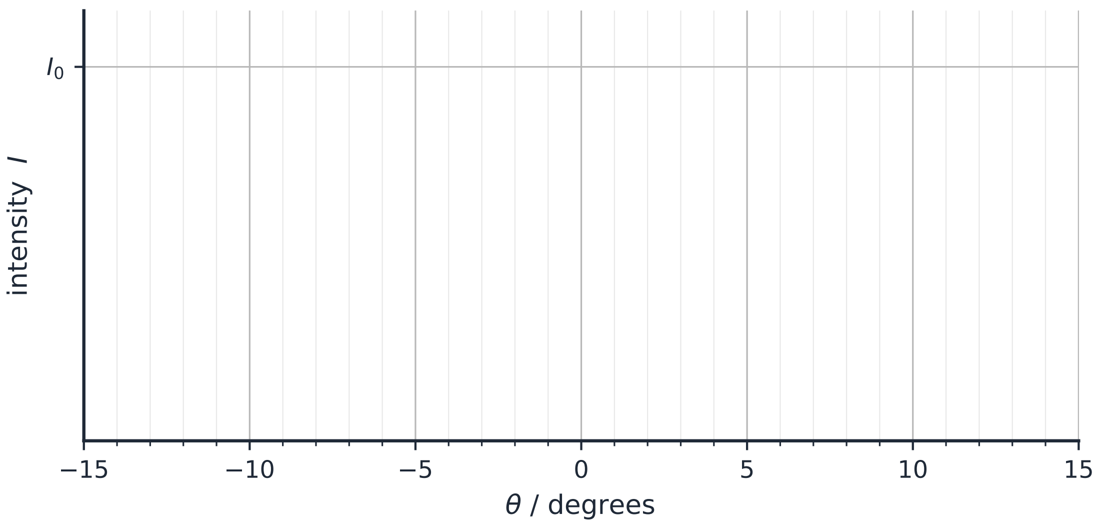
3.5 A parallel beam of light of wavelength 540 nm falls normally on a diffraction grating whose lines are 5.0×10^{-6} m apart. The grating sits at the centre of a circular screen, and the central bright fringe forms at $\theta = 0$ with intensity I_0.

(a) **State** what is meant by the **diffraction** of a wave. [2]

(b) **Show that** the first-order bright fringe forms at $\theta = 6.2°$. [2]

(c) **Determine** the angle at which the **second-order** fringe forms. [1]

(d) On the axes below, **sketch** how the intensity I varies with θ between $-15°$ and $+15°$. [3]



(e) A polarising filter is now placed in the beam **before** the grating. **Suggest** how the pattern on the screen changes. [2]

Solutions

2.1 The **spreading** of a wave as it passes through a gap or around an obstacle.

2.2 The diffraction (spreading) **increases**.

2.3 Sound has a wavelength **close to** the doorway/gap size, so it diffracts a lot; light's wavelength is **far smaller** than the gap, so it diffracts negligibly.

2.4 **All** waves (water, sound, light, microwaves, …).

3.1 **B** — about the same as the wavelength.

3.2 Sound's wavelength is **similar** to the doorway width, so it diffracts strongly and spreads into the room; light's wavelength is **much smaller** than the doorway, so its diffraction is negligible.

3.3 Send straight water waves at a barrier with a gap; observe how much they spread after the gap; make the gap narrower and see the waves spread **more** (compare wide vs narrow gap).

3.4 Both the **wavelength** and the **speed** are **unchanged**.

3.5 (a) A wave passing through a **gap** (or round an edge) **spreads out** into the region beyond it.
(b) $n\lambda = d\sin\theta$ with $n = 1$, so $\sin\theta = \dfrac{540 \times 10^{-9}}{5.0 \times 10^{-6}} = 0.108$ and $\theta = 6.2°$.
(c) $\sin\theta = \dfrac{2 \times 540 \times 10^{-9}}{5.0 \times 10^{-6}} = 0.216$, so $\theta = 12°$. (Note it is **not** exactly twice 6.2°, though it is close at small angles.)
(d) Maxima at $\theta = 0$, $\pm 6.2°$ and $\pm 12°$; intensity **zero** between them, so the pattern is a set of separated peaks, not a continuous curve; the central peak has intensity I_0 and the outer peaks are equal to or lower than it.
(e) The maxima stay at the **same angles** — the filter changes neither the wavelength nor the grating — but every peak is **less intense**, because the filter removes the component of the light polarised at right angles to its transmission axis; for unpolarised light the intensity roughly halves.

28 A light wave passes through a single slit and a diffraction pattern forms.

What happens to the frequency and the speed of the wave when it is diffracted?

	frequency	speed
A	decreases	increases
B	increases	decreases
C	no change	decreases
D	no change	no change

A-Level Physics: **w25 14**

26 For a progressive transverse wave, what describes the term diffraction?

A the change in observed frequency of a wave due to a movement of the wave source

B the spreading of a wave as it passes through a gap or around an obstacle

C when oscillations of a wave are confined to one plane

D the resultant displacement of two waves is equal to the sum of the displacements of the individual waves when the waves meet

4 **(a)** State what is meant by diffraction of a wave.

....

....

.... [2]

(b) A beam of vertically polarised light of wavelength 540 nm is incident normally on a diffraction grating, as shown in Fig. 4.1.

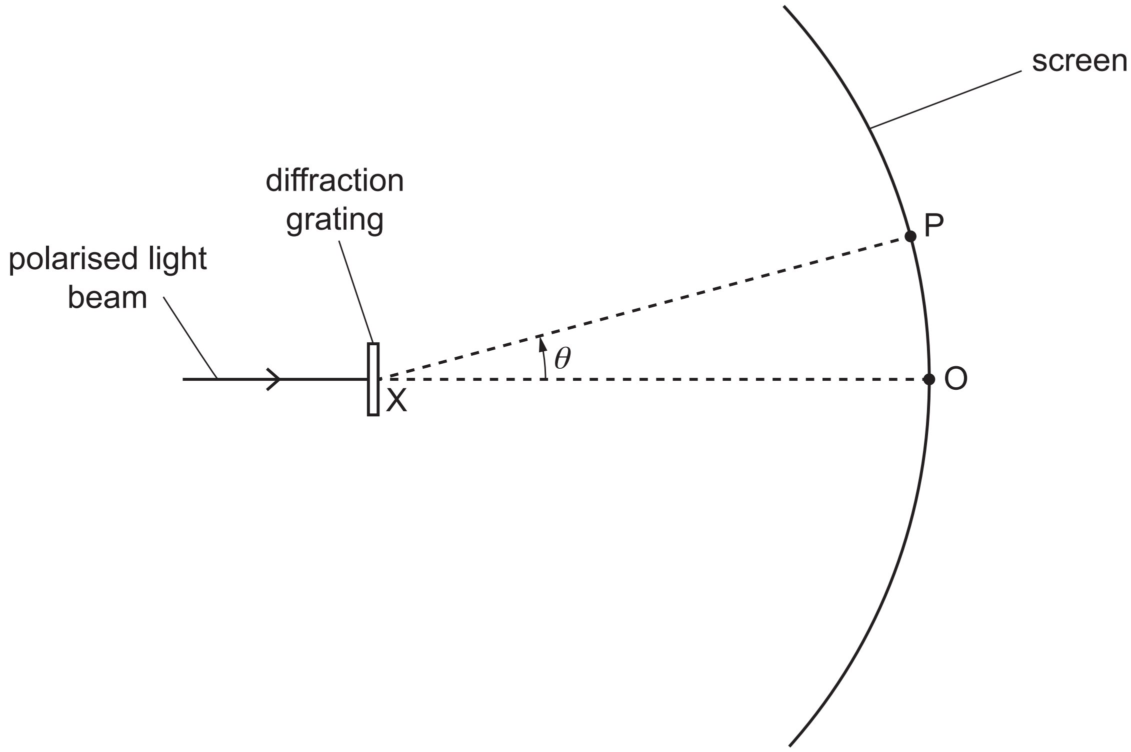


Fig. 4.1 (not to scale)

The diffraction grating has a line spacing of 5.0×10^{-6} m.

The light transmitted by the diffraction grating illuminates a circular screen. The diffraction grating is at the centre X of the circle.

The central bright fringe is formed at point O on the screen and has intensity I_0.

P is a point on the screen where the line XP is at a variable angle θ to the line XO. The intensity I of light on the screen at P varies with θ.

(i) Show that the angle θ at which the first-order bright fringe is formed is 6.2°.

[2]

(ii) Determine the value of θ at which the second-order bright fringe is formed.

θ = ...° [1]

(iii) On Fig. 4.2, sketch the variation of the intensity I with θ for values of θ from –15° to +15°.

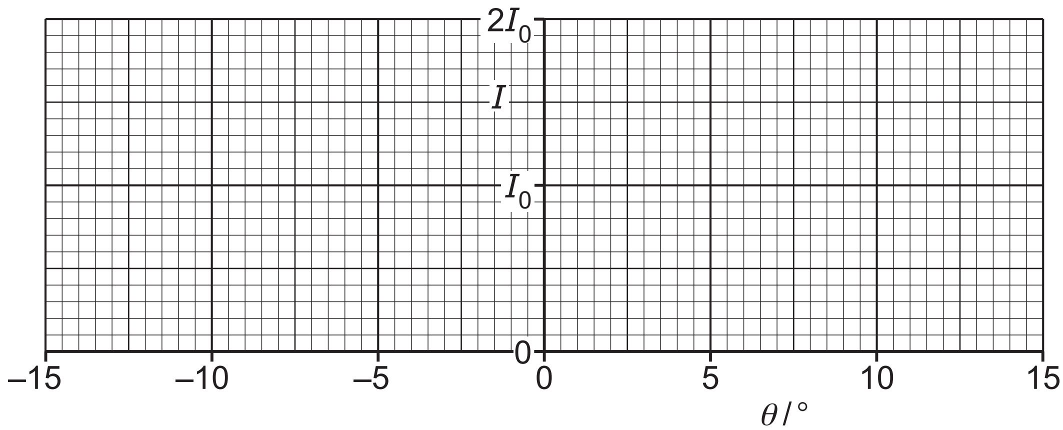


Fig. 4.2

[3]

(c) A polarising filter is placed in the path of the light beam that is incident on the diffraction grating in Fig. 4.1. The transmission axis of the filter is at 45° to the vertical.

Suggest how the variation of intensity with θ for the light on the screen compares with the answer in **(b)(iii)**.

....

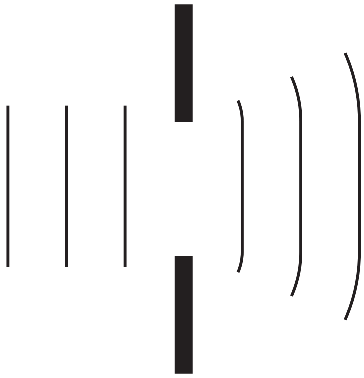
....

.... [2]

[Total: 10]

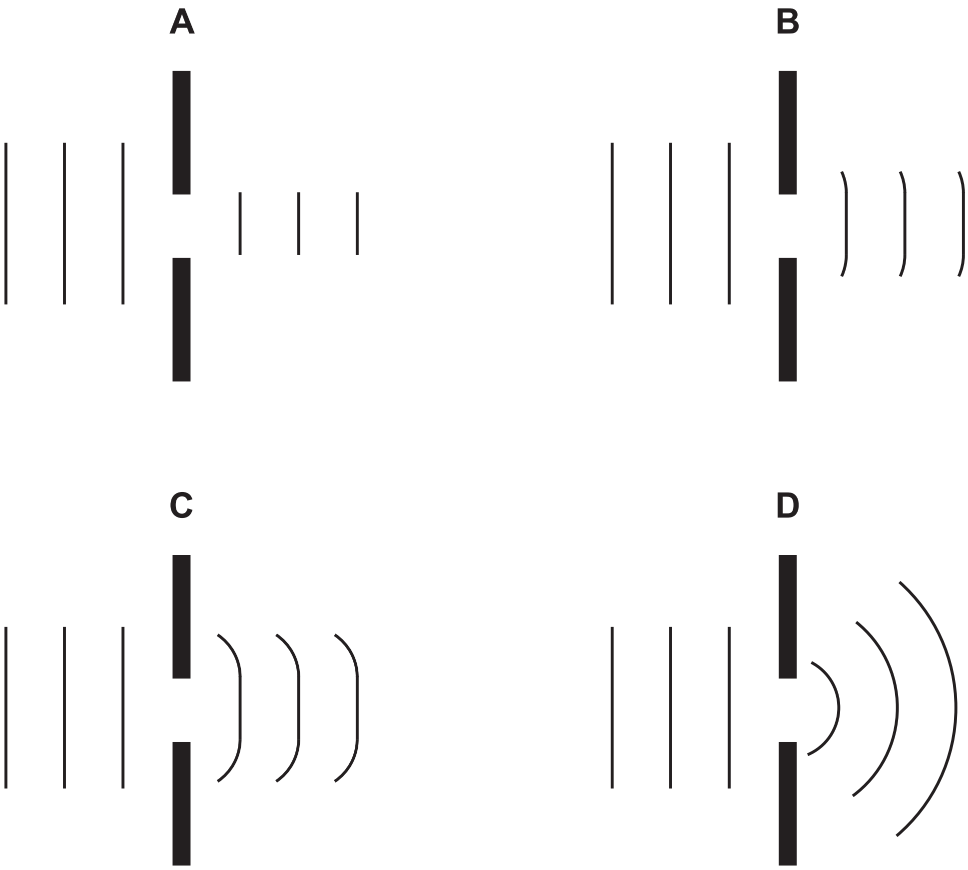
30 A ripple tank contains water at a constant depth.

A water wave of constant frequency travels towards a gap in a barrier placed in the ripple tank.

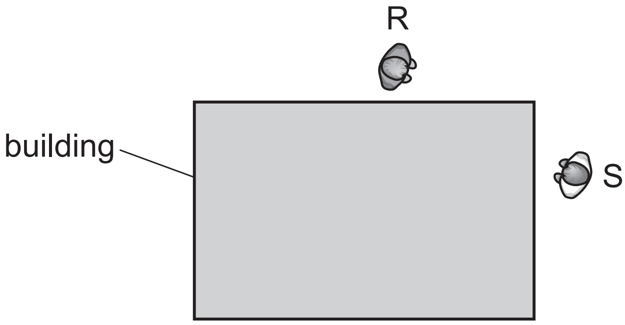


The gap is made smaller.

Which diagram represents the wave before and after the barrier?



26 A student makes a sound at point R near a building. A second student, standing at point S around the corner of the building, hears the sound. The building is a solid structure and there are no other structures nearby.



Which effect best explains how the student at point S is able to hear the student at point R?

A diffraction

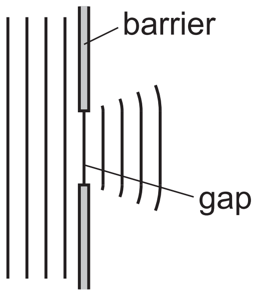
B interference

C polarisation

D reflection

A-Level Physics: **m25 12**

28 The diagram shows a water wave in a shallow tank. The wave is diffracted through a gap in a barrier and spreads. The wavelength of the wave is much smaller than the width of the gap.



The wavelength of the wave and the width of the gap are both changed by a small amount.

Which combination of changes **must** increase the amount of spreading due to diffraction?

	wavelength	width of gap
A	decreases	decreases
B	decreases	increases
C	increases	decreases
D	increases	increases

8.3 Interference

Name: ______________ Class: __________ Date: ____________ **Total: 17 marks**

KEY WORDS fringe 条纹 • interference 干涉 • double-slit 双缝 • fringe spacing 条纹间距 • coherence 相干

Objective

Build the skills to answer exam questions on **interference 干涉** — coherence, path difference, and the **double-slit** experiment.

You must be able to:

- explain **interference** and **coherence 相干**, and how fringes form
- use **path difference** for constructive/destructive interference
- use $\lambda = \dfrac{ax}{D}$, finding x by measuring across **several** fringes
- go on to the **frequency** with $c = f\lambda$

1 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.

■ Interference and coherence

Interference is the superposition of two **coherent** waves giving a steady pattern. **Coherent** = a **constant phase difference** (so the same frequency). Two separate lamps are **not** coherent — their phase changes randomly.

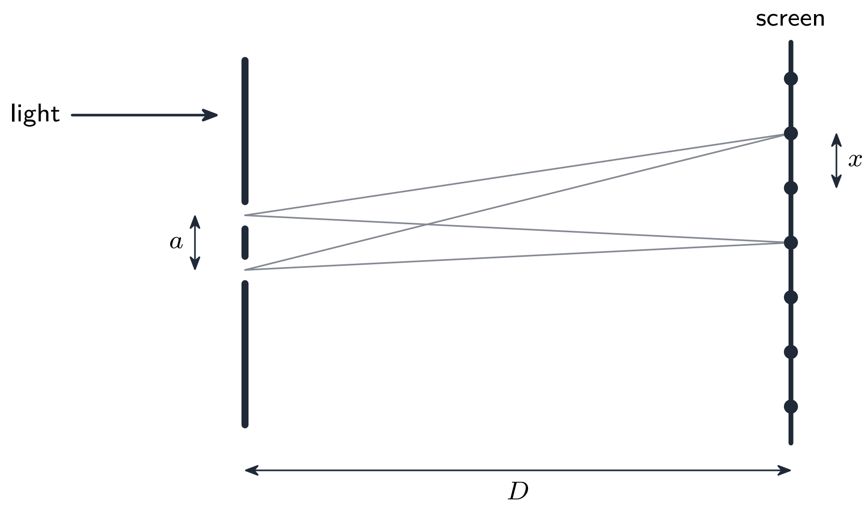
■ Path difference

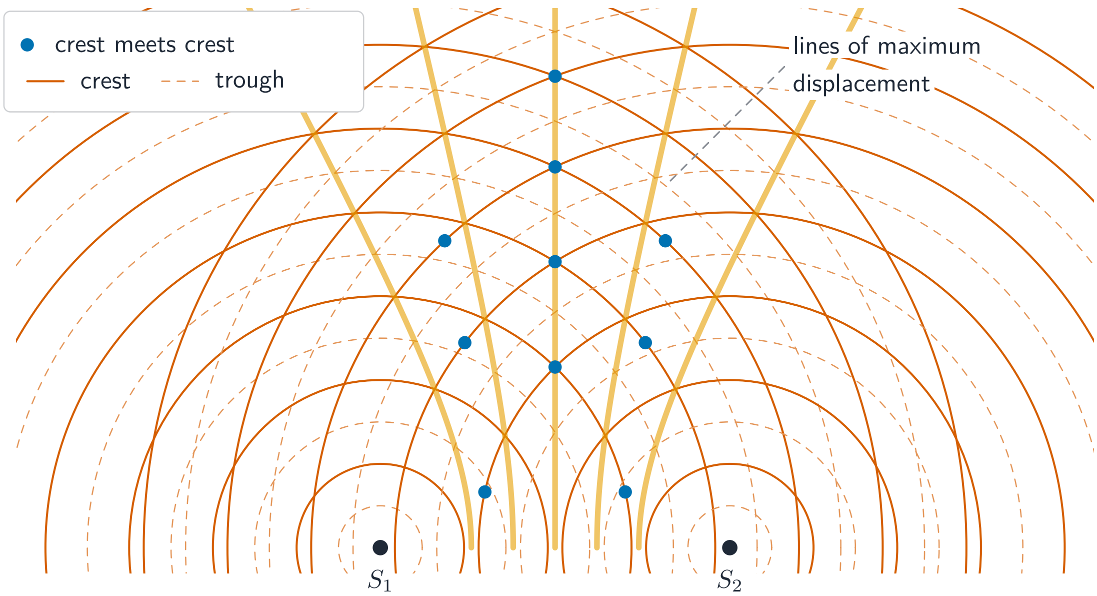
At a point, the result depends on the **path difference** Δx from the two sources:

- constructive (bright): $\Delta x = n\lambda$; destructive (dark): $\Delta x = (n + \frac{1}{2})\lambda$.

So bright fringes appear where the waves arrive **in phase**, dark fringes where they arrive **exactly out of phase**.

■ Young's double slit





Two-source interference of waves

$$\lambda = \frac{ax}{D}, \qquad x = \frac{\lambda D}{a},$$

where a = slit separation, D = slit-to-screen distance, x = fringe spacing. A single slit before the double slit makes the two slits coherent.

■ Measuring x accurately

The fringes are close together, so you **never** measure one gap. Measure across **several** fringes and divide:

Worked example. 9 bright fringes span 18 mm. That is **8 gaps**, so $x = \frac{18}{8} = 2.25$ mm. With $a = 0.40$ mm and $D = 1.5$ m: $\lambda = \frac{ax}{D} =$

$$\frac{(0.40 \times 10^{-3})(2.25 \times 10^{-3})}{1.5} = 6.0 \times 10^{-7} \text{ m.}$$

■ **Frequency from wavelength**

Light is an EM wave, so $f = \frac{c}{\lambda}$. For the example above, $f = \frac{3.0 \times 10^{8}}{6.0 \times 10^{-7}} = 5.0 \times 10^{14}$ Hz.

2 Practice

Now apply the methods above.

2.1 Define **interference**. [1]

2.2 State what it means for two sources to be **coherent**. [1]

2.3 State the **path difference** for constructive and for destructive interference. [2]

2.4 State why **two separate lamps** do not give a steady interference pattern. [1]

2.5 In a double-slit pattern, 11 bright fringes span 20 mm. State the **fringe spacing** x. [1]

3 Exam-style questions

3.1 For **destructive** interference, the path difference is: [1]

- **A** $n\lambda$
- **B** $(n + \frac{1}{2})\lambda$
- **C** $\lambda/4$
- **D** zero only

3.2 A laser shines on a double slit. The slits are 0.40 mm apart and the screen is 1.5 m away. On the screen, 9 bright fringes span 18 mm.

(a) Calculate the **fringe spacing** x. [1]

(b) Calculate the **wavelength** of the laser light. [2]

(c) Hence calculate the **frequency** of the light. ($c = 3.0 \times 10^8$ m s^{-1}.) [2]

3.3 Explain how the pattern of **bright and dark fringes** is formed in the double-slit experiment, using the idea of **path difference**. [3]

3.4 State what happens to the **fringe spacing** if (a) the slit separation a is **increased**, (b) the screen distance D is **increased**. [2]

Solutions

2.1 The superposition of two **coherent** waves to give a **steady pattern** of constructive (high) and destructive (low) amplitude.

2.2 They have a **constant phase difference** (and the same frequency).

2.3 Constructive: $\Delta x = n\lambda$; destructive: $\Delta x = (n + \frac{1}{2})\lambda$.

2.4 Their phases change **randomly** (they are not coherent), so any pattern flickers and averages out.

2.5 11 fringes = 10 gaps, so $x = 20/10 = 2.0$ mm.

3.1 **B** — $(n + \frac{1}{2})\lambda$.

3.2 (a) 9 fringes = 8 gaps; $x = 18/8 = 2.25$ mm.

3.2 (b) $\lambda = \dfrac{ax}{D} = \dfrac{(0.40 \times 10^{-3})(2.25 \times 10^{-3})}{1.5} = 6.0 \times 10^{-7}$ m.

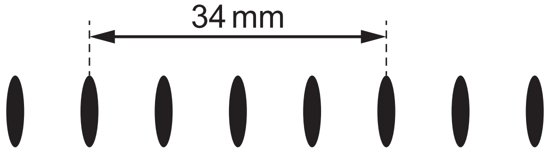
3.2 (c) $f = \dfrac{c}{\lambda} = \dfrac{3.0 \times 10^{8}}{6.0 \times 10^{-7}} = 5.0 \times 10^{14}$ Hz.

3.3 Light from the two slits is **coherent** and overlaps on the screen; where the **path difference** is a whole number of wavelengths the waves arrive **in phase** and reinforce → a **bright** fringe; where it is an odd number of half-wavelengths they arrive **out of phase** and cancel → a **dark** fringe.

3.4 (a) fringe spacing **decreases** ($x = \lambda D/a$, so $x \propto 1/a$); (b) fringe spacing **increases** ($x \propto D$).

28 A student carries out a double-slit experiment using a laser emitting red light of wavelength of 680 nm. The light is incident normally on a double slit.

The diagram shows part of the pattern of bright fringes visible on a screen at a distance of 2.4 m from the slits. The distance across five bright fringes is measured as 34 mm.

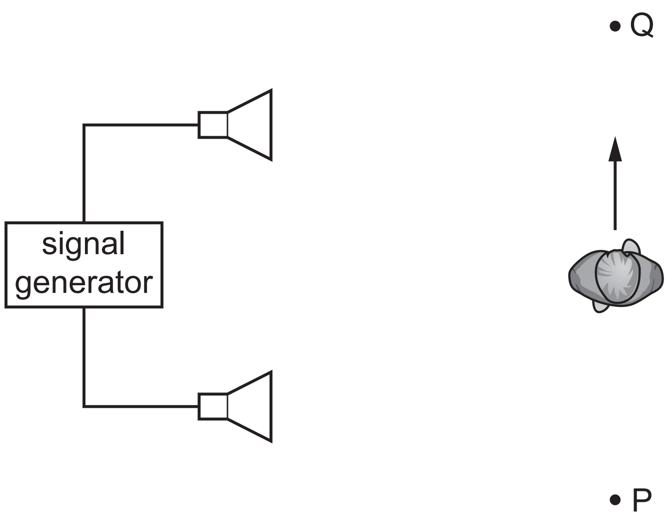


What is the slit separation?

A 8.5×10^{-3} m **B** 2.4×10^{-4} m **C** 1.9×10^{-4} m **D** 4.8×10^{-5} m

A-Level Physics: **w25 12**

31 A student connects two loudspeakers to a signal generator.



As the student walks from P to Q, he notices that the loudness of the sound rises and falls repeatedly.

What causes the loudness of the sound to vary?

A diffraction of the sound waves

B Doppler shift of the sound waves

C interference of the sound waves

D reflection of the sound waves

31 Two light sources are used to produce an interference pattern.

Interference fringes appear when the two sources emit waves that are coherent.

What is meant by coherent waves?

A The two waves are emitted with the same frequency.

B The two waves are emitted with constant phase difference.

C The two waves are emitted with the same intensity.

D The two waves are emitted with zero phase difference.

4 A laser emits visible light of a single frequency in a vacuum. The light is incident normally on a double slit and then forms a pattern of bright and dark fringes on a screen, as shown in Fig. 4.1.

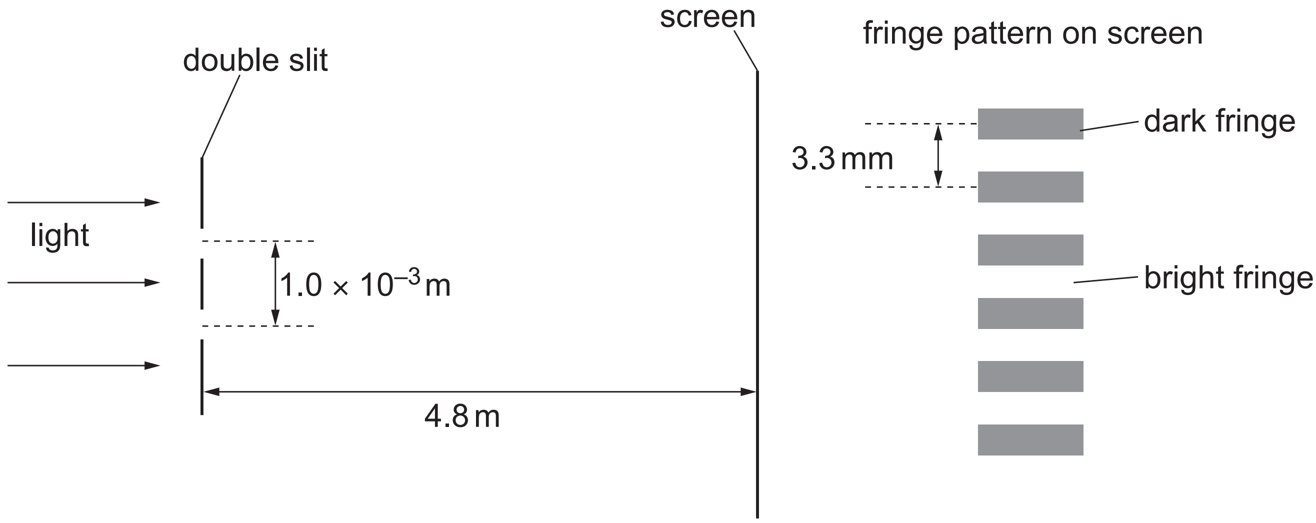


Fig. 4.1 (not to scale)

The separation of the slits is 1.0×10^{-3} m. The distance from the slits to the screen is 4.8 m. The distance between the centres of adjacent dark fringes on the screen is 3.3 mm.

(a) Explain how the pattern of bright and dark fringes is formed.

....

....

....

....

.... [3]

(b) Calculate the frequency of the light emitted by the laser.

frequency = ... Hz [4]

(c) The double slit is removed. A second laser is placed beside the first laser. The second laser produces visible light of a different frequency from that of the first laser. The beams of light from the two lasers overlap on the screen.

Explain why a steady pattern of bright and dark fringes is **not** formed on the screen.

....

.... [1]

[Total: 8]

A-Level Physics: **s25 12**

31 Light of a single wavelength is incident normally on a double slit. Interference fringes are observed on a screen.

The distance from the double slit to the screen is 0.60 m and the fringe separation is 1.8 mm.

The distance from the double slit to the screen increases by 0.90 m.

What is the new fringe separation?

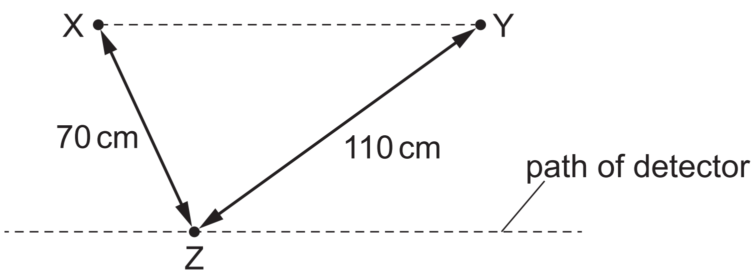
A 1.2 mm **B** 2.7 mm **C** 4.5 mm **D** 5.4 mm

A-Level Physics: **s25 13**

28 Electromagnetic waves of equal wavelengths are emitted from two sources, X and Y. The waves are emitted from X and Y with a phase difference of 180°.

A detector moves along a path that is parallel to the line XY and detects a pattern of intensity maxima and minima.

The diagram shows the arrangement of the sources and the path of the detector.



An intensity maximum is detected at point Z. Length XZ is 70 cm and length YZ is 110 cm.

What is a possible wavelength of the waves?

A 10 cm **B** 16 cm **C** 20 cm **D** 40 cm

27 Red light of a single wavelength from a laser is incident on a double slit.

A pattern of interference fringes is observed on a flat screen that is placed parallel to the double slit.

Which change increases the separation of the interference fringes on the screen?

A Decrease the distance from the double slit to the screen.

B Decrease the separation of the slits.

C Replace the red light with blue light.

D Replace the red light with green light.

4 **(a)** State the principle of superposition.

....

....

.... [2]

(b) Light of wavelength 7.2×10^{-7} m is incident normally on a double slit, as shown in Fig. 4.1.

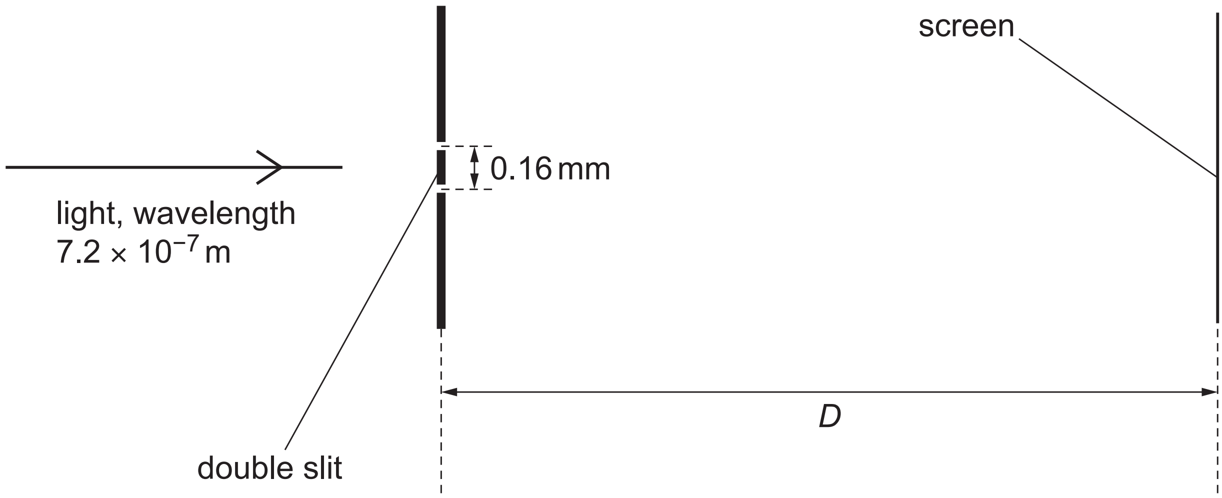


Fig. 4.1 (not to scale)

A screen is at a distance D from the double slit. The double slit and the screen are parallel.

The separation of the slits in the double-slit arrangement is 0.16 mm. The resulting interference pattern on the screen contains nine dark fringes, as shown in Fig. 4.2.

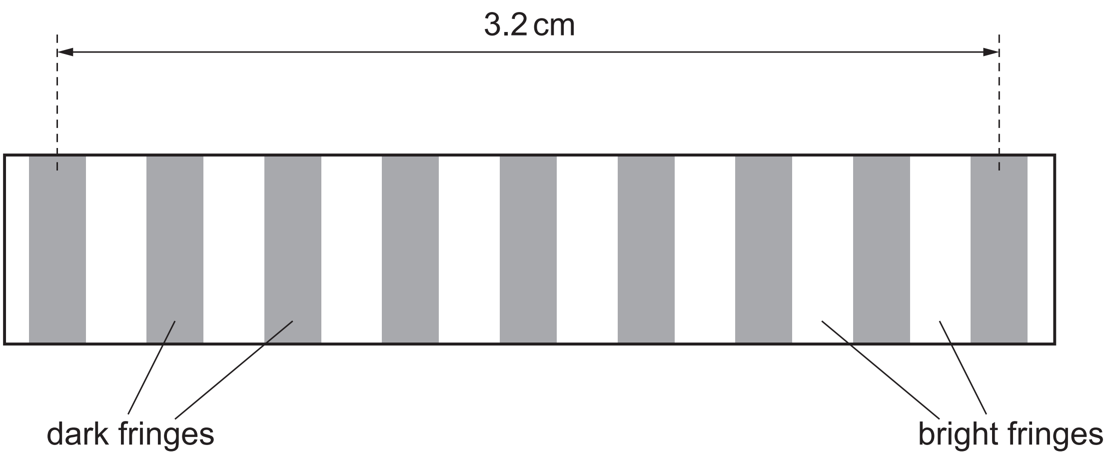


Fig. 4.2 (not to scale)

The distance between the centres of the first and ninth dark fringes is 3.2 cm.

(i) Calculate D.

D = ... m [3]

(ii) The slit separation is now gradually decreased from 0.16 mm to 0.04 mm. The distance between the centres of adjacent dark fringes is x.

On Fig. 4.3, sketch the variation of x with slit separation.

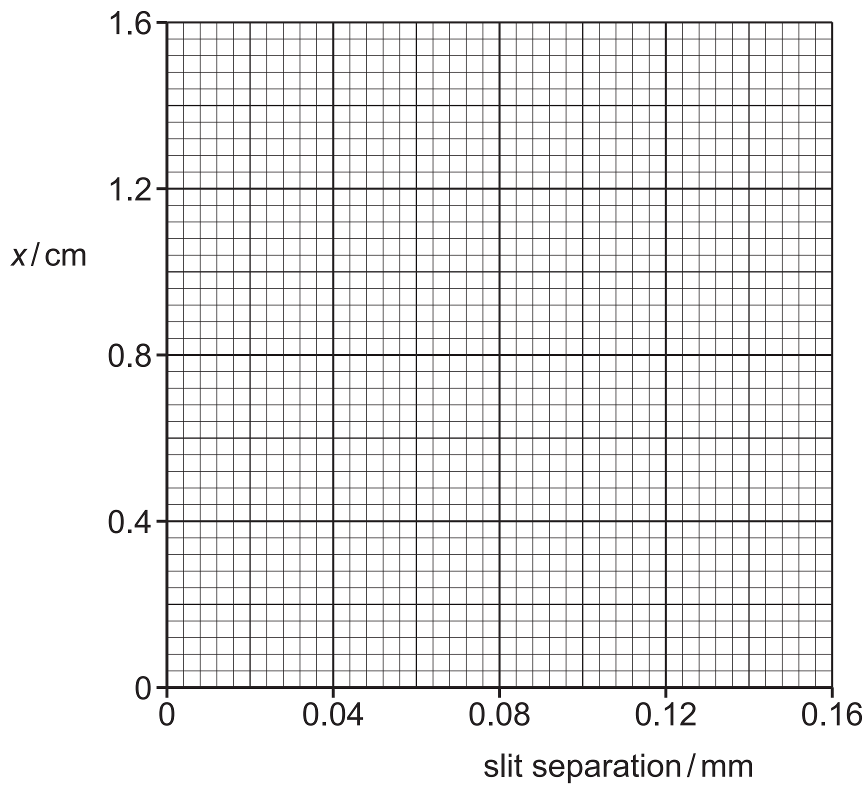


Fig. 4.3

[3]

[Total: 8]

27 Light waves are emitted from two sources.

What is a necessary condition for observable interference fringes to be produced?

A The waves must be polarised.

B The waves must **not** be polarised.

C The waves must be coherent.

D The waves must have equal amplitudes.

6 Two coherent sources X and Y of microwaves of frequency 2.5×10^{10} Hz are a distance of 0.18 m apart in a vacuum, as shown in Fig. 6.1.

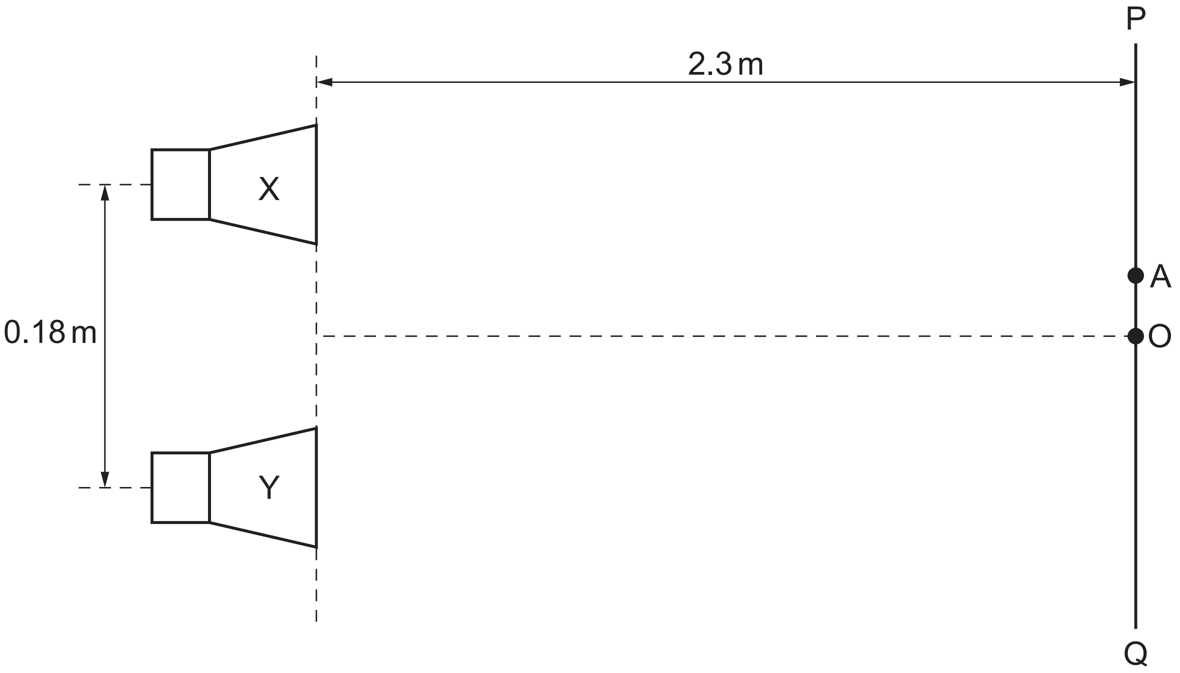


Fig. 6.1 (not to scale)

There is a phase difference of 90° between the waves emitted at the two sources.

A microwave detector moves along the line PQ, which is parallel to the line joining the two sources and 2.3 m away from it.

Point O is on the line PQ at a position that is equidistant from the two sources.
Point A is the position on line PQ where the intensity of the microwaves is the greatest.

(a) **(i)** Explain why the position of greatest intensity is **not** at point O.

....

....

....

.... [2]

(ii) On Fig. 6.1, draw a cross (×) to show the position of the point on line PQ where the intensity minimum that is the closest to point O occurs. Label this point B. [2]

(b) **(i)** Show that the wavelength of the microwaves is 0.012 m.

[2]

(ii) For point A on line PQ, determine the difference in the distances Δx travelled by the microwaves from X and the microwaves from Y.

Δx = ... m [1]

(iii) Use the formula for the double-slit interference of light to calculate the distance between adjacent intensity maxima on line PQ.

distance = ... m [2]

[Total: 9]

A-LEVEL PHYSICS • EXERCISE SHEET

8.4 The diffraction grating

Name: ____________ Class: ________ Date: __________ **Total: 18 marks**

KEY WORDS diffraction grating 衍射光栅 • wavelength 波长 • diffraction 衍射 • normal 法线 • order 级次

Objective

Build the skills to answer exam questions on the **diffraction grating 衍射光栅**.

You must be able to:

- use $d\sin\theta = n\lambda$ in **both** directions (find an angle; find the grating)
- find the slit spacing from **lines per mm** and the **highest order**
- describe using a grating to measure **wavelength**

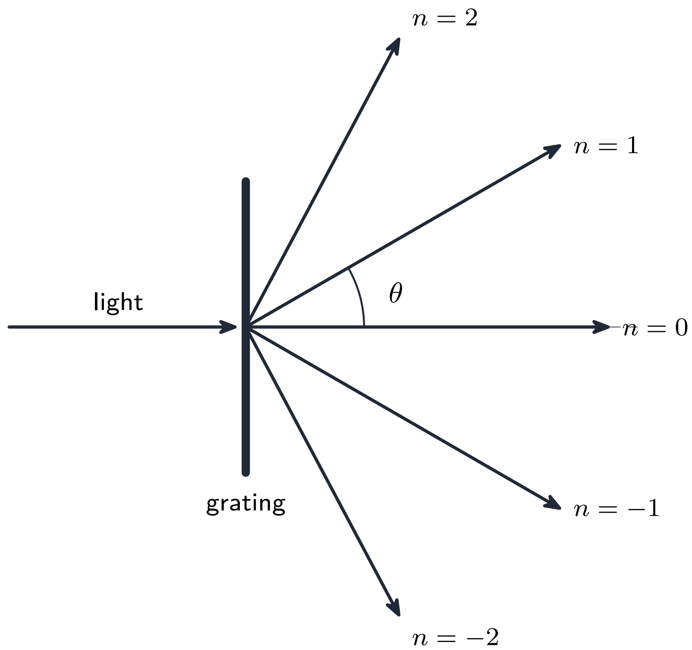
1 Worked examples

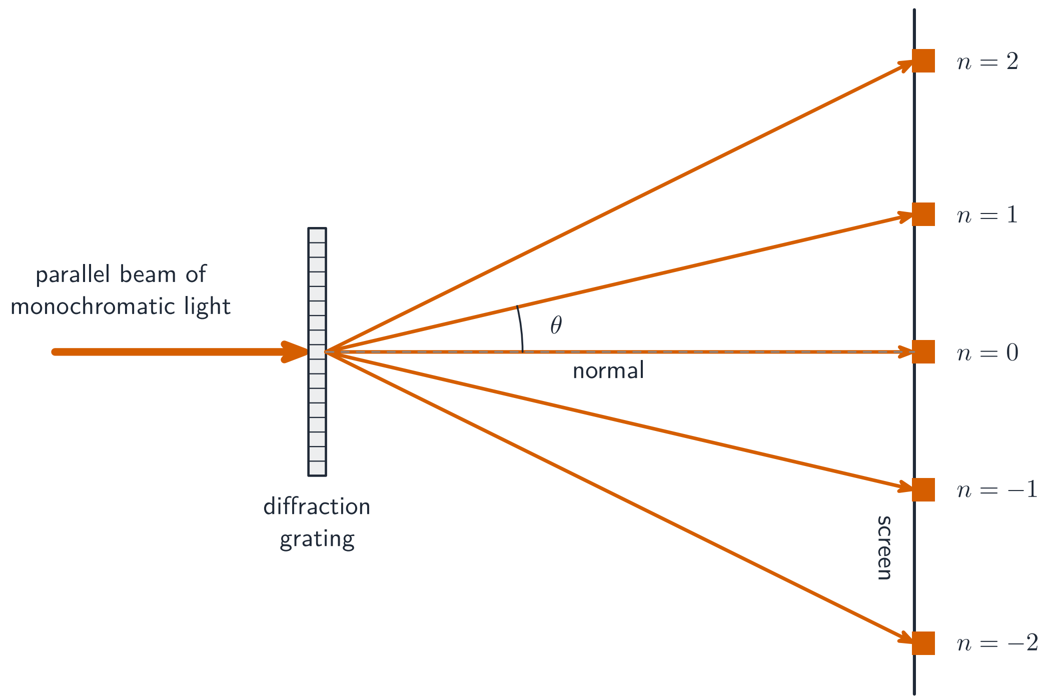
Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ The grating equation

A grating has many equally spaced slits, slit spacing d. Bright maxima (orders n) appear where

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





A diffraction grating spreads the orders

Worked example (find the angle). 500 lines/mm, $\lambda = 600$ nm: $d = \dfrac{1}{500}$ mm $= 2.0 \times 10^{-6}$ m; $\sin\theta = \dfrac{n\lambda}{d} = \dfrac{600 \times 10^{-9}}{2.0 \times 10^{-6}} = 0.30$, so $\theta \approx 17°$.

■ **Working backwards — find the grating**

Exam questions often **give** an order's angle and ask for the grating. Rearrange to $d = \dfrac{n\lambda}{\sin\theta}$, then **lines per mm** $= \dfrac{1}{d\text{ (in mm)}}$.

Worked example. The **second-order** ($n = 2$) maximum for $\lambda = 730$ nm is at $\theta = 35°$. Then $d = \dfrac{2 \times 730 \times 10^{-9}}{\sin 35°} = \dfrac{1.46 \times 10^{-6}}{0.574} = 2.55 \times 10^{-6}$ m. In mm, $d = 2.55 \times 10^{-3}$ mm, so **lines per mm** $= \dfrac{1}{2.55 \times 10^{-3}} \approx 390$.

■ **Slit spacing and highest order**

N lines per mm $\to d = 10^{-3}/N$ m. Since $\sin\theta \leq 1$, the **highest order** is $n_{\text{max}} = \lfloor d/\lambda \rfloor$.

■ **Finding wavelength**

Shine parallel light normally on the grating, measure θ_1 for the first order, then $\lambda = d\sin\theta_1$. A grating gives **sharper** maxima than a double slit (many slits add).

2 Practice

Now apply the methods above.

2.1 State what d represents in $d\sin\theta = n\lambda$. [1]

2.2 A grating has 500 lines per mm. Find the slit spacing d in metres. [2]

2.3 State **one** reason a grating gives **sharper** maxima than a double slit. [1]

2.4 Write the formula for the **highest order** observable. [1]

3 Exam-style questions

3.1 A grating with 500 lines per mm is illuminated normally by light of wavelength 600 nm. Calculate the angle of the **first-order** maximum. [3]

3.2 For the same grating and wavelength, calculate the **highest order** that can be seen. [2]

3.3 A grating has 600 lines per mm. Light of wavelength 590 nm is incident normally on it. **Determine** the highest order of maximum that can be observed, and **explain** what limits it. [4]

3.4 Describe how a diffraction grating can be used to **measure the wavelength** of light. [3]

3.5 A grating with **more** lines per mm (smaller d) is used. The diffraction angles become: [1]

- **A** smaller
- **B** larger
- **C** unchanged
- **D** zero

Solutions

2.1 The **slit spacing** — the (centre-to-centre) distance between adjacent slits.

2.2 $d = \dfrac{1}{500}$ mm $= \dfrac{10^{-3}}{500} = 2.0 \times 10^{-6}$ m.

2.3 Many slits contribute, so the maxima are **sharper/brighter** and other directions are more completely cancelled.

2.4 $n_{\max} = \lfloor d/\lambda \rfloor$ (the largest integer with $\sin\theta \leq 1$).

3.1 $d = 2.0 \times 10^{-6}$ m; $\sin\theta = \dfrac{(1)(600 \times 10^{-9})}{2.0 \times 10^{-6}} = 0.30$; $\theta = 17°$.

3.2 $d/\lambda = \dfrac{2.0 \times 10^{-6}}{600 \times 10^{-9}} = 3.33$; highest order $n = 3$ ($n = 4$ needs $\sin\theta > 1$).

3.3 $d = \dfrac{1 \text{ mm}}{600} = 1.67 \times 10^{-6}$ m; the largest possible diffraction angle is 90°, where $\sin\theta = 1$, so $n_{\max} = \dfrac{d}{\lambda} = \dfrac{1.67 \times 10^{-6}}{590 \times 10^{-9}} = 2.8$. An order must be a whole number, so the highest observed is the **2nd order** — n cannot be rounded up, because $\sin\theta$ can never exceed 1.

3.4 Shine **parallel monochromatic** light normally on the grating; measure the **angle** θ of a known order n from the straight-through direction; calculate $\lambda = \dfrac{d\sin\theta}{n}$.

3.5 **B** — larger (smaller d gives larger $\sin\theta$ for each order).

30 Green laser light passes through a diffraction grating and forms an interference pattern.

The diffraction grating contains 400 lines per mm.

The wavelength of the laser light is 550 nm.

What is the highest order diffraction maximum produced by the grating?

A 4 **B** 5 **C** 8 **D** 9

A-Level Physics: **w25 12**

29 The equation $n\lambda = d\sin\theta$ can be used with a diffraction grating to find the wavelength of visible light.

Which quantity is **not** correct for use in this equation?

	symbol	quantity
A	d	distance from grating to screen
B	λ	wavelength of light
C	n	order of intensity maximum
D	θ	diffraction angle of intensity maximum

A-Level Physics: **w25 14**

30 A parallel beam of red light of wavelength 700 nm is incident normally on a diffraction grating that has 400 lines per millimetre.

What is the total number of intensity maxima from the grating?

A 6 **B** 7 **C** 8 **D** 9

A-Level Physics: **s25 11**

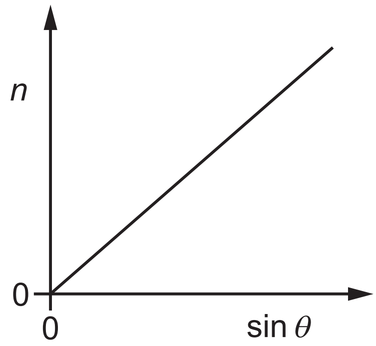
30 Light of wavelength 680 nm is incident normally on a diffraction grating with 450 lines mm^{-1}.

What is the angle of diffraction of the second-order maximum in the diffraction pattern that is produced?

A 1.8° **B** 3.5° **C** 18° **D** 38°

29 A student uses a diffraction grating to determine the wavelength of visible light from a source.

The diffraction grating has 300 lines per mm. The student measures the angle θ of each order n of the intensity maxima. A graph of n against $\sin\theta$ is plotted. The line of best fit for the plotted points is shown and has gradient G.



Which expression represents the wavelength, in m, of the visible light in terms of G?

A $3 \times 10^{5}\,G$ **B** $3.3 \times 10^{-6}\,G$ **C** $\dfrac{3.3 \times 10^{-6}}{G}$ **D** $\dfrac{300}{G}$

A-Level Physics: **s25 14**

28 An electromagnetic wave is incident normally on a diffraction grating.

A second-order maximum is produced at an angle of 30° to the direction of the incident light.

The grating has 5000 lines per cm.

What is the wavelength of the wave?

A 2.5×10^{-7} m **B** 5.0×10^{-7} m **C** 1.0×10^{-6} m **D** 5.0×10^{-5} m

6 **(a)** State what is meant by diffraction.

....

.... [1]

(b) Light of wavelength 720 nm in a vacuum is incident normally on a diffraction grating as shown in Fig. 6.1.

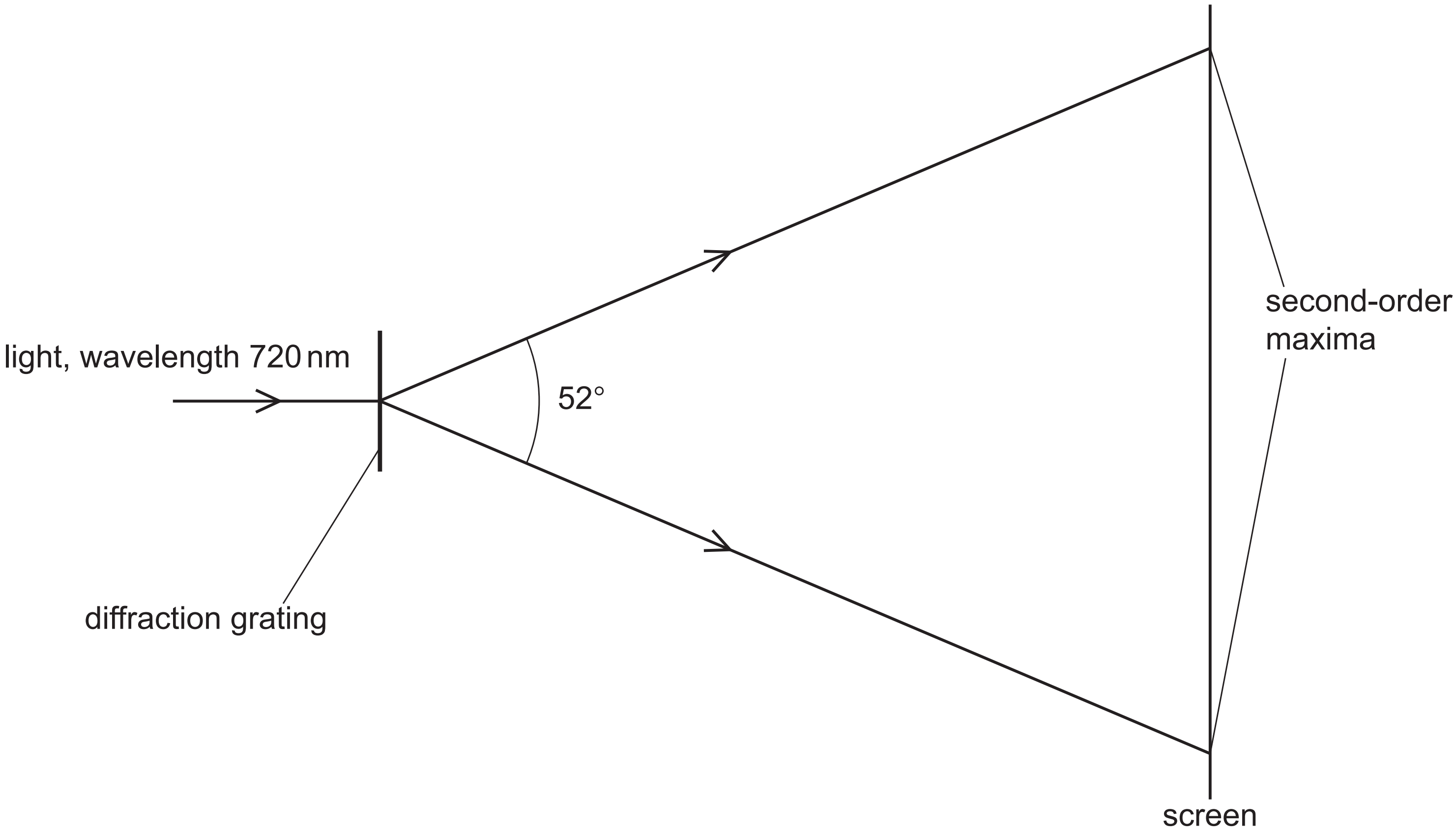


Fig. 6.1 (not to scale)

A screen is parallel to the grating. An interference pattern is seen on the screen and the angle between the **second**-order maxima is 52°.

(i) Calculate the frequency of the light.

frequency = ... Hz [2]

(ii) Calculate the number of lines per unit length in the diffraction grating.

number per unit length = ... m^{-1} [3]

(iii) The light in Fig. 6.1 is now replaced with light of a different wavelength λ. It is observed that the third-order maxima of this light are at the same positions as the second-order maxima of the light in Fig. 6.1.

Calculate, in nm, the wavelength λ.

λ = ... nm [2]

[Total: 8]

29 Light of wavelength 567 nm is incident normally on a diffraction grating. The grating has 400 lines per mm. A number of diffraction maxima are observed on the far side of the grating.

What is the angle between the second-order maximum and the third-order maximum?

A 13.1° **B** 13.9° **C** 15.9° **D** 27.0°