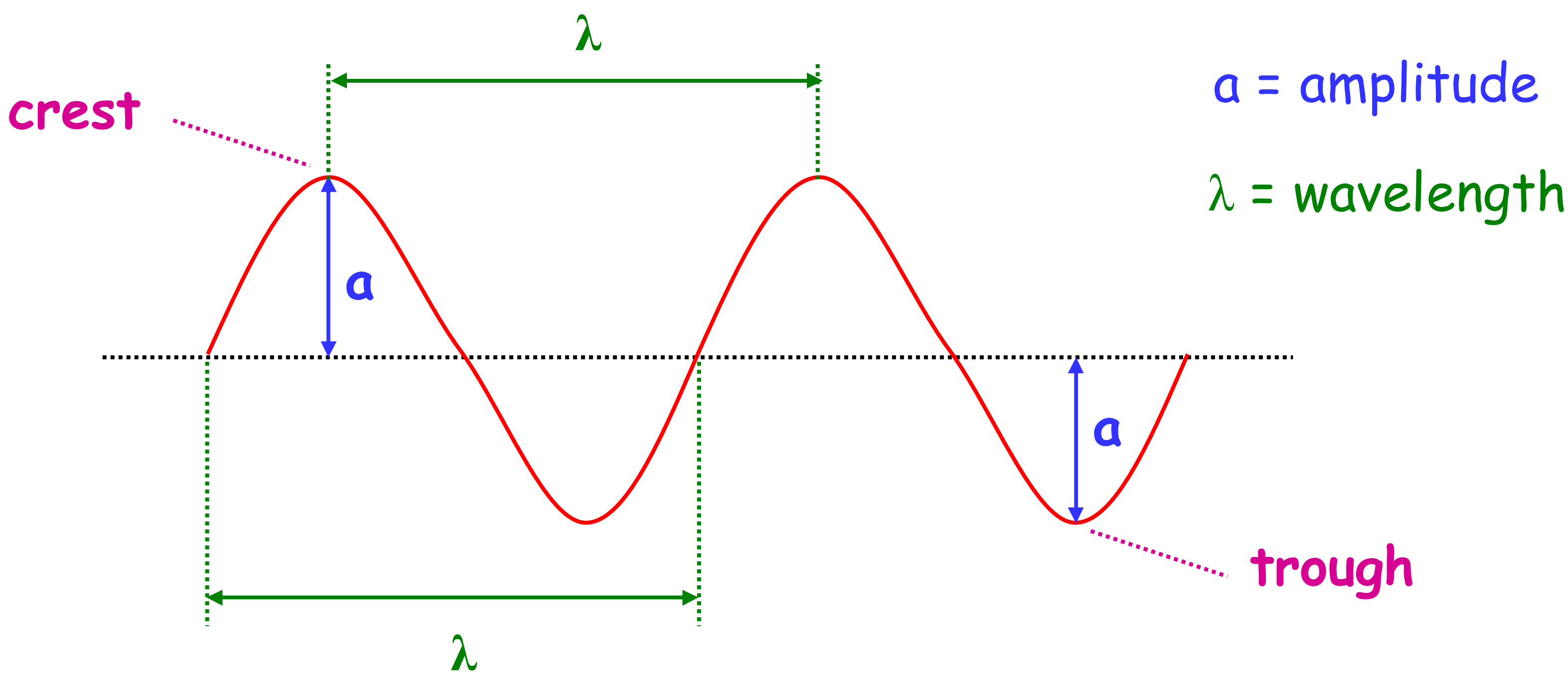
# Higher Physics – Unit 3

## 3.1 - Waves

# Wave Theory

All waves transmit **energy**.

The energy of a wave depends on its **amplitude**.



**Frequency** of a wave: the **number of waves** per **second**.

**Period** of a wave: **time** taken for **one complete wave** to pass a point/be **transmitted**.

frequency (Hz)

$$\boxed{f = \frac{1}{T}}$$

period (s)

frequency of wave = frequency of source

Wave **speed**: is the **distance travelled** in **one second**.

**Wavelength**: is the minimum **distance** in which a **wave repeats**.

speed ($ms^{-1}$)

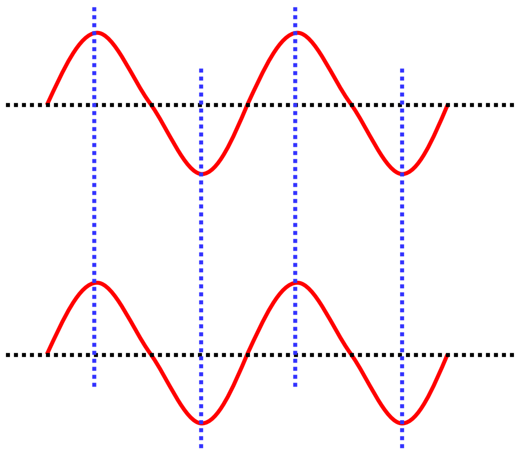
$$\boxed{v = f \times \lambda}$$

wavelength (m)

frequency (Hz)

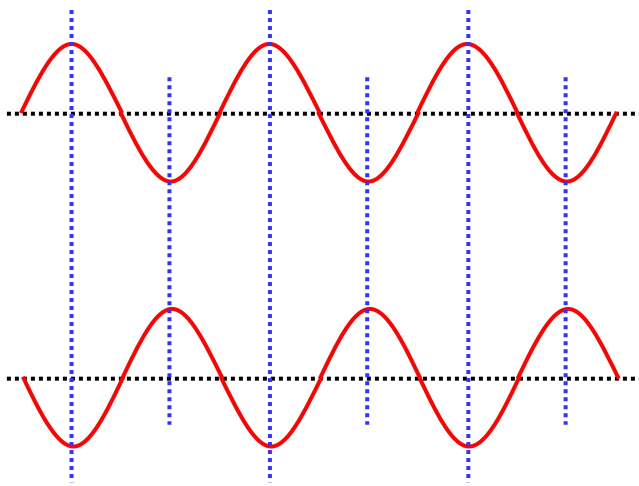
## In Phase

Two waves are **in phase** when the same part of both waves arrive at the same point in space (peak/trough) at the same time.



## Out of Phase

Two waves are **exactly out of phase** when opposite parts of both waves arrive at the same point in space (peak and trough) at the same time.



## Coherence

Two **waves are coherent** if they are:

- the **same frequency** ( $\therefore$ same wavelength)
- the **same speed**
- **in phase**.

# Wave Behaviour

All waves display characteristic behaviour.

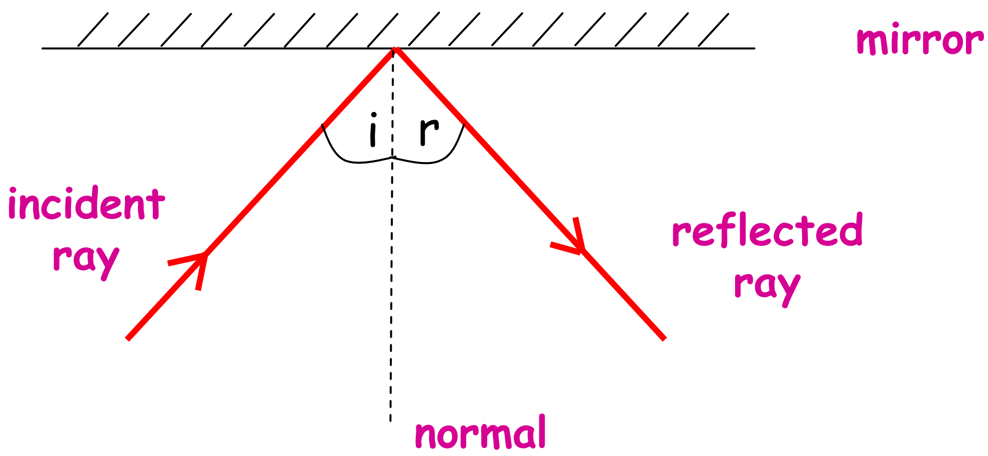
They all show:

- **reflection**
- **refraction**
- **diffraction**
- **interference**.

## Reflection

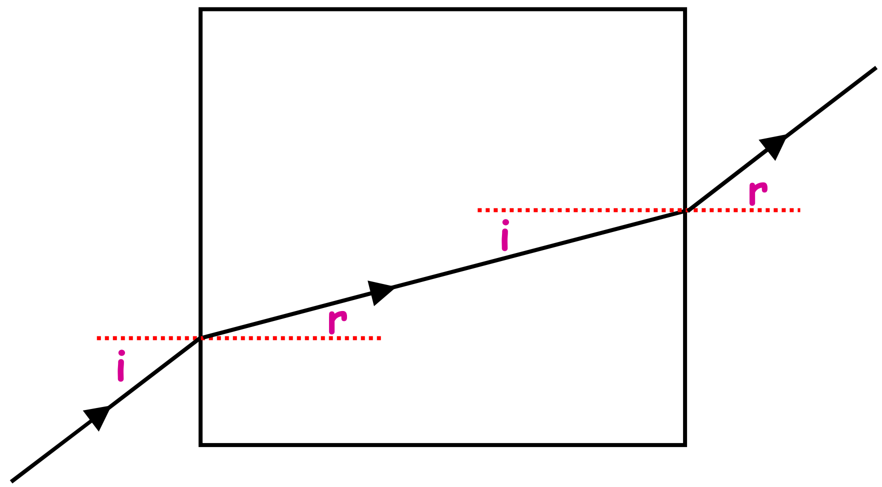
The **law of reflection** states:

**angle of incidence = angle of reflection**



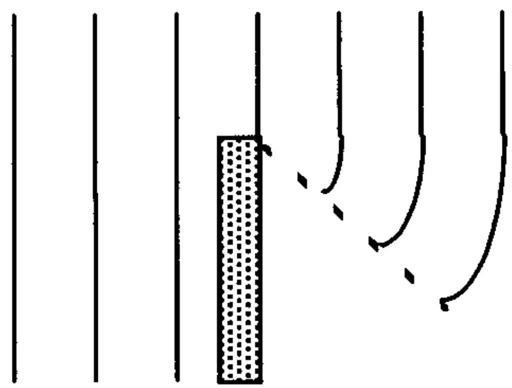
## Refraction

Waves **change speed and direction** when passing from one medium to another.

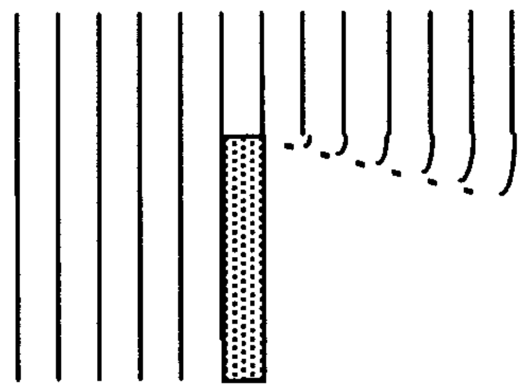


# Diffraction

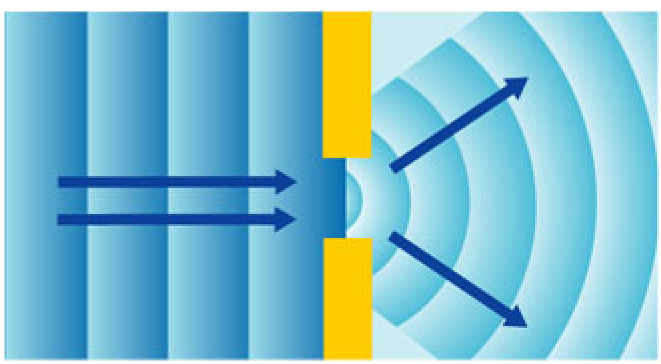
Waves bend round corners.



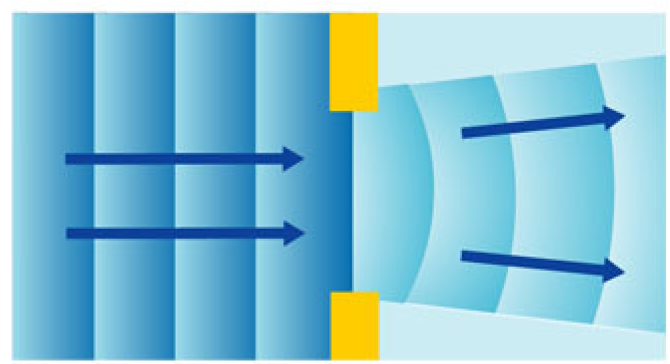
long wavelength



short wavelength



narrow gap



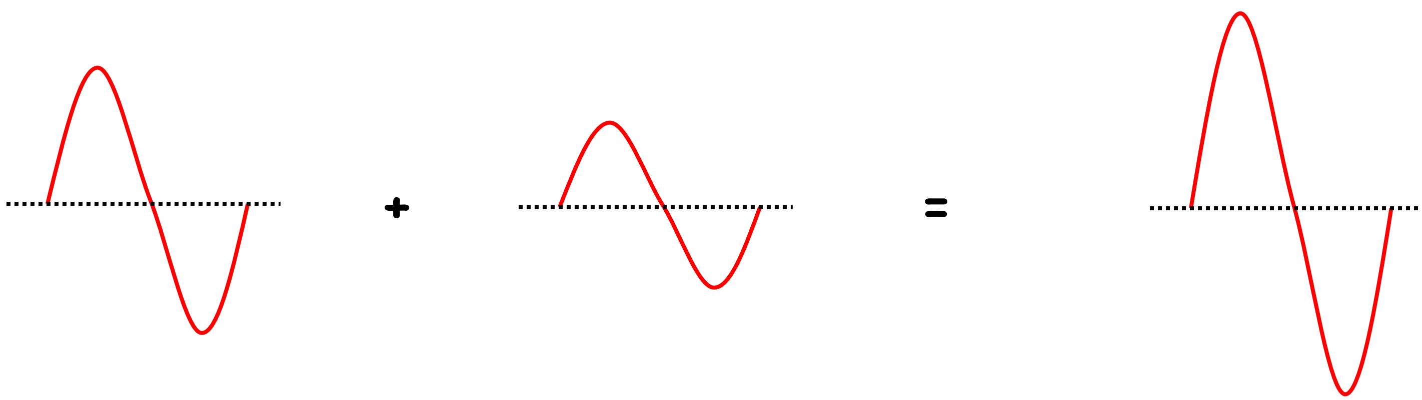
large gap

## Interference

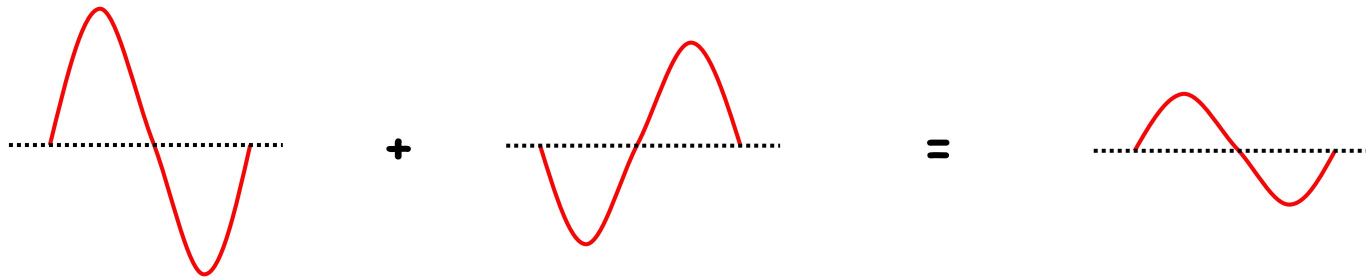
**Interference** occurs when two or more **waves** are **superimposed**.

The total effect is the **sum** of the **waves**.

**constructive interference (in phase)**



## destructive interference (exactly out of phase)



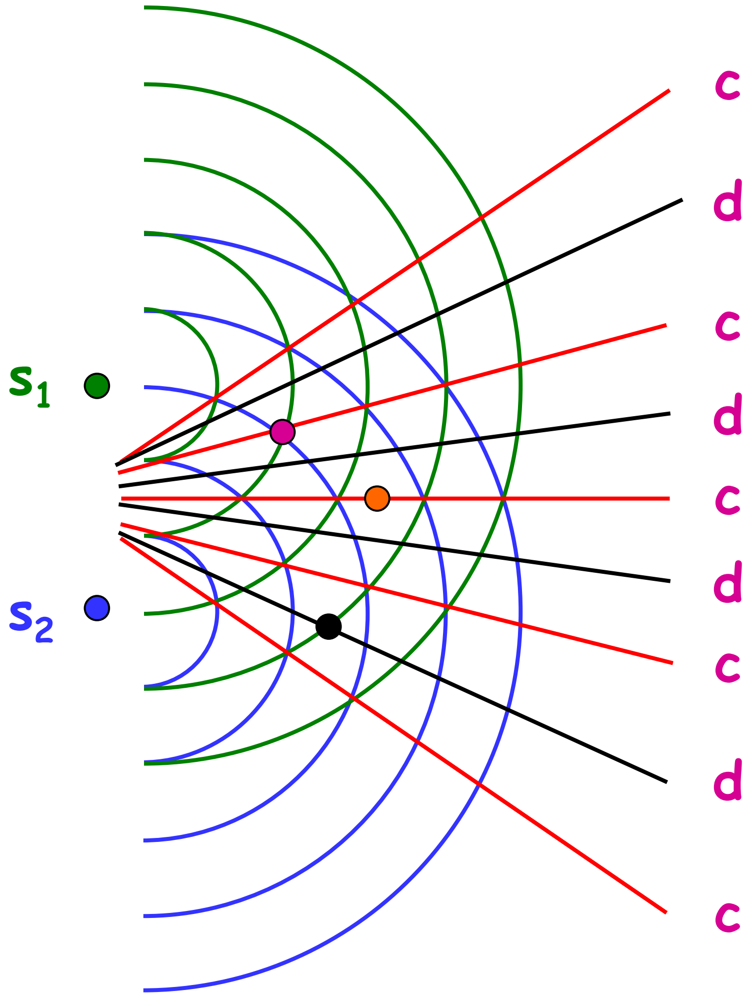

**Interference is the test for a wave.**

In order to prove that any form of energy travels as a wave, an **interference pattern** must be shown.

# Interference Patterns

To show that a form of **energy travels** as a **wave**, an **interference pattern** must be shown.

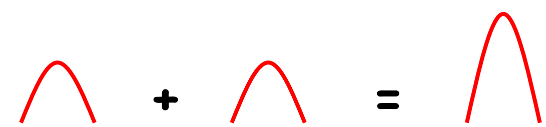
Thomas Young did this in 1801 for light, proving that light is a wave motion.



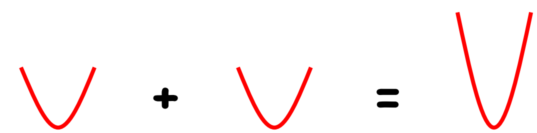

crest lines from $s_1$

crest lines from $s_2$

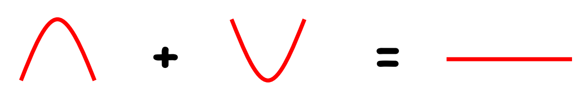
two crests meet
constructive interference



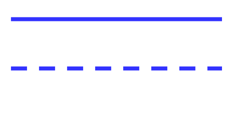

two troughs meet
constructive interference




crest and trough meet
destructive interference




Troughs are not drawn, but they would be between two crests:



All the points of constructive interference join up to form a series of lines.

Similarly, all the points of destructive interference join up to form a series of lines.

The **two sources** of wave must have the **same frequency** and be **in phase**.

In practice this is difficult to achieve, so often a **single source** is used and split using a **double slit**.

# P&N Tutorial Booklets

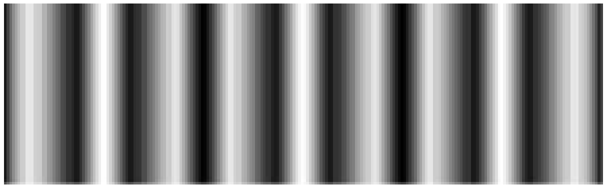
Q3.1 - 3.8

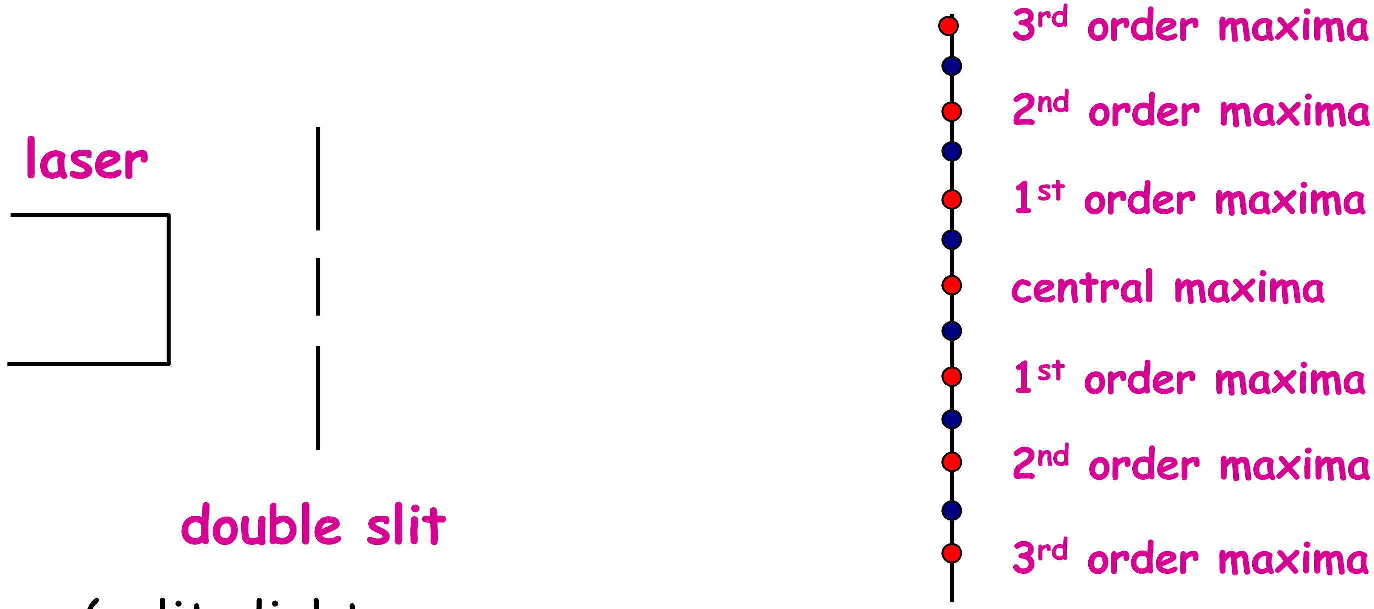
# Young's Slits Experiments

Thomas Young passed light from one source through a double slit in 1801.

He was trying to resolve the argument of whether light was a wave or made of particles.

He observed a series of equally spaced bright and dark fringes.






(splits light source into two)

> The **fringes** are more **widely spread** when the **slits** are **closer** together.

● maxima

● minima

**Bright** spots are called **maxima**(waves must be arriving **in phase** and **constructive interference** occurs).

**Dark** regions are called **minima** (waves arriving exactly **out of phase** and **destructive interference** occurs).

**Monochromatic light** is light consisting of one only **one colour** and **wavelength**.

**White light** is made up of **many colours** each with **different wavelengths**.

Passing white light through a double slit produces light and dark fringes.

The edges of light fringes have coloured edges (visible spectrum).

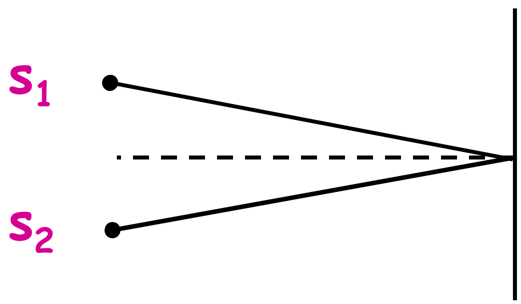
## Path Difference for Maxima

| Fringe | Path Difference |
|---|---|
| central maxima | 0 |
| 1st maxima | $\lambda$ |
| 2nd maxima | $2\lambda$ |
| 3rd maxima | $3\lambda$ |
| nth maxima | $n\lambda$ |

where $n$ = fringe number

$$\boxed{\text{path difference} = n\lambda}$$

## Central Maxima




Waves from $s_1$ and $s_2$ are travelling the **same distance**, so there is **no path difference** for the **central maxima**.

**Waves** must be arriving **in phase**.

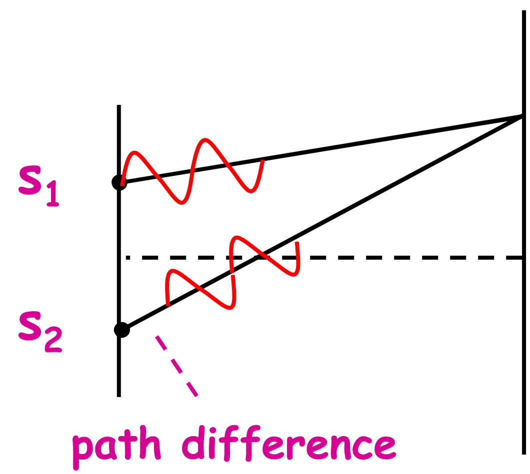
Physics Animations - Path Difference

(Waves -> Path Difference)

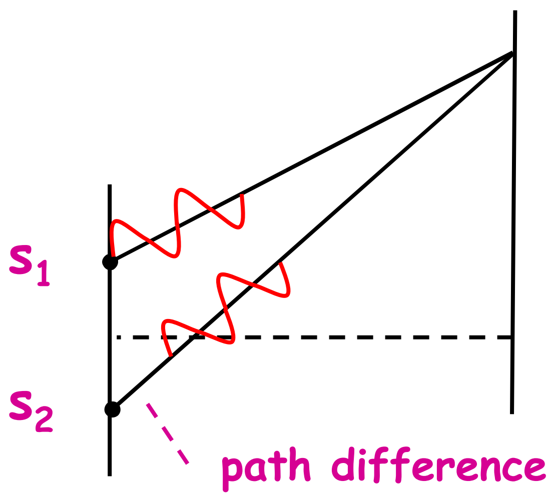
## First Order Maxima

At the **first order maxima**, **waves** must arrive **in phase**.

The **path difference** must be **one** complete **wavelength**.



## Second Order Maxima




At the **second order maxima**, **waves** must arrive **in phase**.

The **path difference** must be **two** complete **wavelengths**.

## Path Difference for Minima

| Fringe | Path Difference |
|---|---|
| 1st minima | $\frac{1}{2}\lambda$ |
| 2nd minima | $1\frac{1}{2}\lambda$ |
| 3rd minima | $2\frac{1}{2}\lambda$ |
| nth minima | $(n - \frac{1}{2})\lambda$ |

where n = fringe number

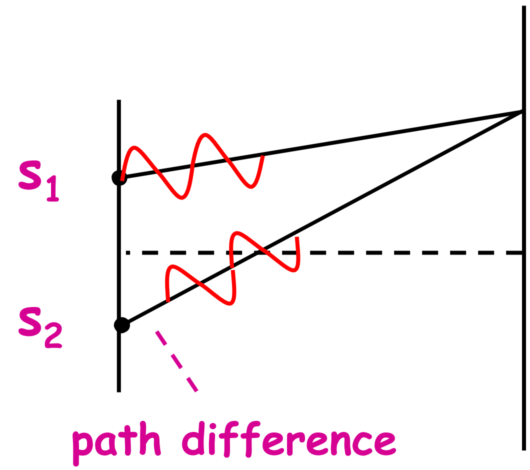
$$\text{path difference} = \left(n - \frac{1}{2}\right)\lambda$$

*** DIFFERENT from SQA data book ***

## First Order Minima

At the **first order minima**, **waves** must arrive **exactly out of phase**.

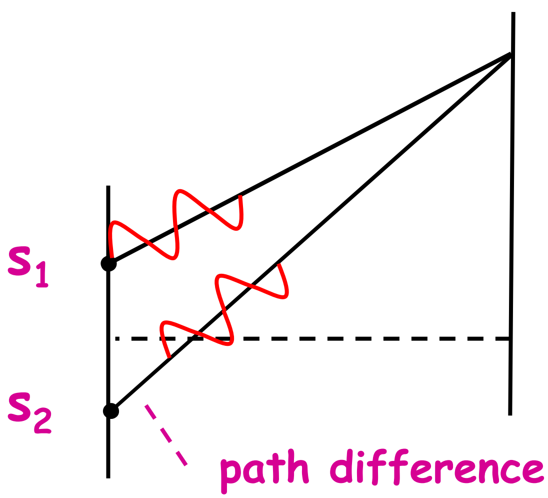
The **path difference** must be $\frac{1}{2}$ a **wavelength**.




Physics Animations - Path Difference

(Waves -> Path Difference)

## Second Order Minima

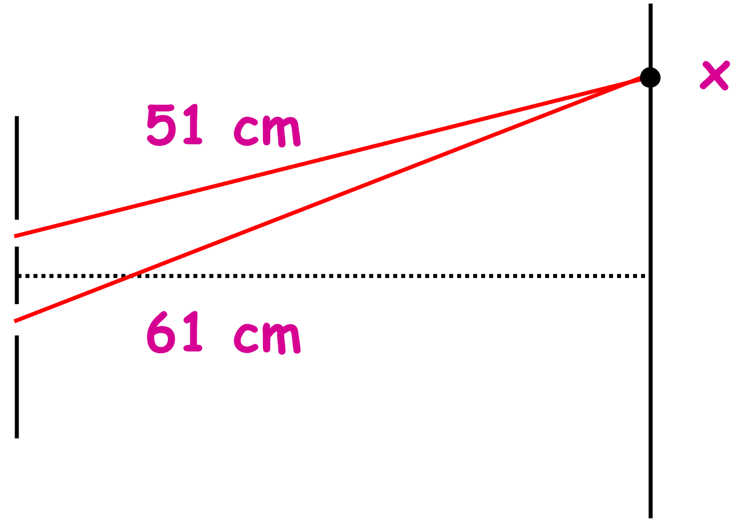



At the **second order minima**, **waves** must arrive **exactly out of phase**.

The **path difference** must be $1\frac{1}{2}$ **wavelengths**.

## Example 1

Find the wavelength of the signals used in the following experiment, where **x** represents the 3rd minima.




## Minima

$$\text{path difference} = \left(n - \frac{1}{2}\right)\lambda$$

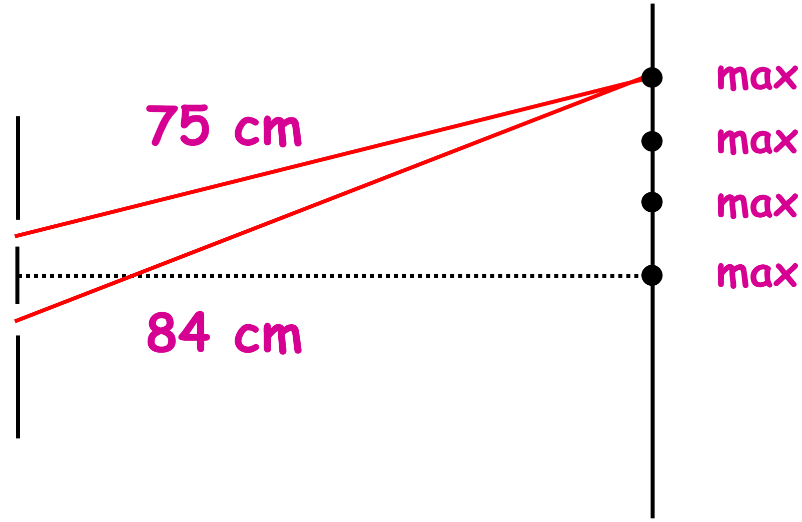
$$61 - 51 = \left(3 - \frac{1}{2}\right)\lambda$$

$$10 = 2\frac{1}{2}\lambda$$

$$\underline{\underline{\lambda = 4\ \text{cm}}}$$

## Example 2

Find the wavelength of microwaves used in the experiment shown.




## Maxima

$$\text{path difference} = n\lambda$$

n = 3 (since central maxima is n = 0)

$$84 - 75 = 3\lambda$$

$$9 = 3\lambda$$

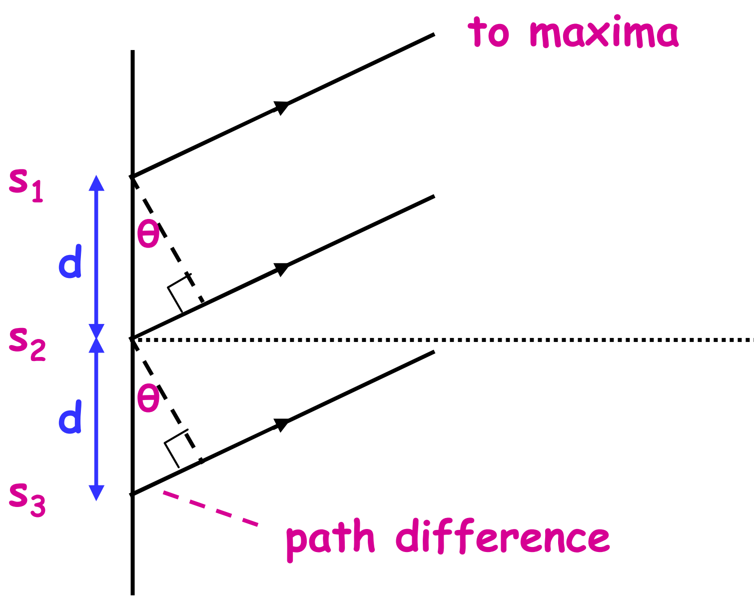
$$\lambda = 3\ \text{cm}$$

# P&N Tutorial Booklets

Q3.9 - 3.13

# Diffraction Grating

A **diffraction grating** is a slide with **multiple slits** equally spaced. (typically 400-800 per mm).




**For Maxima**

$$\text{path difference} = n\lambda$$

$$\sin\theta = \frac{\text{path difference}}{d}$$

$$\sin\theta = \frac{n\lambda}{d}$$

$$\boxed{n\lambda = d\sin\theta}$$

## Example 1

Calculate the wavelength of light passed through a diffraction grating, when the first order maxima is produced at an angle of 21°.

The grating has 600 lines per mm.

$$\theta = 21°$$

$$d = \frac{1\times10^{-3}}{600}$$

$$= 1.67\times10^{-6}\,\text{m}$$

$$n = 1$$

$$\lambda = ?$$

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

$$1\times\lambda = (1.67\times10^{-6})\times\sin 21$$

$$\lambda = (1.67\times10^{-6})\times\sin 21$$

$$\lambda = 5.97\times10^{-7}\ \text{m}$$

$$\lambda = 597\ \text{nm}$$

**Example 2**

Light of wavelength 700 nm is shone through a diffraction grating that has 1200 slits per millimetre.

Calculate the angle between the central and first order maxima.

$$\lambda = 700 \text{ nm}$$
$$= 700 \times 10^{-9} \text{ m}$$

$$d = \frac{1 \times 10^{-3}}{1200}$$
$$= 8.33 \times 10^{-7} \text{ m}$$

$$n = 1$$

$$\theta = ?$$

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

$$1 \times \left(700 \times 10^{-9}\right) = \left(8.33 \times 10^{-7}\right) \times \sin\theta$$

$$\sin\theta = \frac{700 \times 10^{-9}}{8.33 \times 10^{-7}}$$

$$\sin\theta = 0.84$$

$$\theta = \sin^{-1}(0.84)$$

$$\theta = 57.1^\circ$$

# P&N Tutorial Booklets

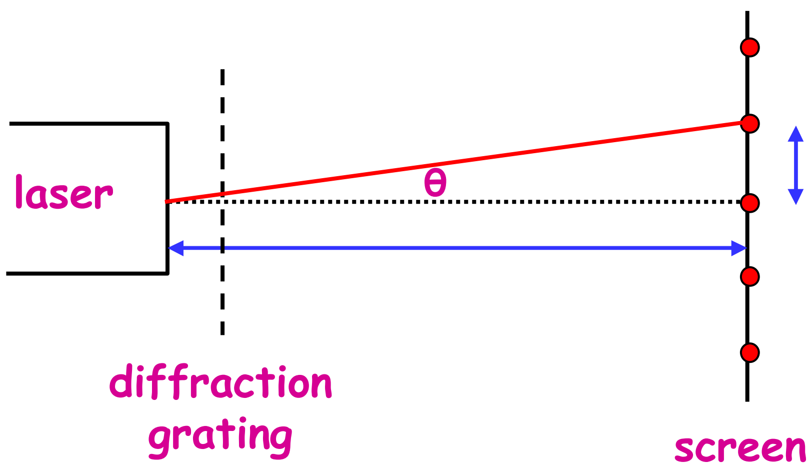
Q3.14 – 3.19

# Measuring Wavelength

**Aim**

To show the wavelength of light from a laser is 632.8 nm.

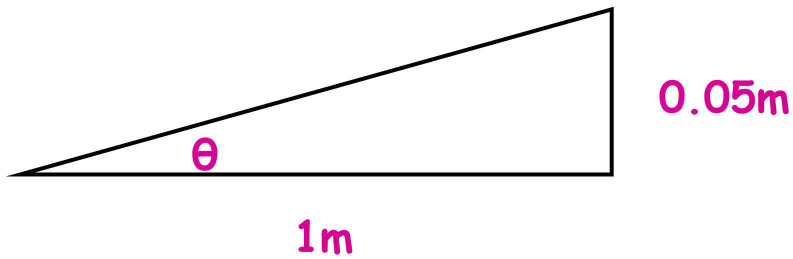
**Diagram**



## Method

- Measure distance from laser to screen using a ________________.
- Measure distance between central and first order maxima.
  using __________________.
- Using trigonometry, calculate angle at which constructive interference occurs.
- Slit separation is calculated by: $$d = \frac{\text{distance}}{\text{no. of slits}}$$
- For first order maxima, n = 1.

## Results




$$\tan\theta = \frac{opp}{adj}$$

$$\tan\theta = \frac{0.05}{1}$$

$$\theta = \tan^{-1}(0.05)$$

$$\theta = 2.8°$$

$$\theta = 2.8°$$

$$d =$$

$$n = 1$$

$$\lambda = ?$$

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

# Effect of Colour on Gratings

Monochromatic light beams consist of one single frequency of light.

Here are some wavelengths of monochromatic light:

| Colour | Wavelength (nm) |
|---|---|
| red | 700 |
| green | 550 |
| blue | 500 |
| violet | 400 |

need to know these values but

** NOT GIVEN IN EXAM **

**TASK**

Calculate the angle between the central and first order maxima for the four colours of light passing through a diffraction grating with 700 lines per mm.

**Red**

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

$$1\times(700\times10^{-9}) = (1.43\times10^{-6})\times\sin\theta$$

$$\sin\theta = \frac{700\times10^{-9}}{1.43\times10^{-6}}$$

$$\sin\theta = 0.49$$

$$\theta = \sin^{-1}(0.49)$$

$$\theta = 29.3°$$

**Green**

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

$$1\times(550\times10^{-9}) = (1.43\times10^{-6})\times\sin\theta$$

$$\sin\theta = \frac{550\times10^{-9}}{1.43\times10^{-6}}$$

$$\sin\theta = 0.38$$

$$\theta = \sin^{-1}(0.38)$$

$$\theta = 22.6°$$

## Blue

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

$$1\times(500\times10^{-9}) = (1.43\times10^{-6})\times\sin\theta$$

$$\sin\theta = \frac{500\times10^{-9}}{1.43\times10^{-6}}$$

$$\sin\theta = 0.35$$

$$\theta = \sin^{-1}(0.35)$$

$$\theta = 20.5^\circ$$

## Violet

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

$$1\times(400\times10^{-9}) = (1.43\times10^{-6})\times\sin\theta$$

$$\sin\theta = \frac{400\times10^{-9}}{1.43\times10^{-6}}$$

$$\sin\theta = 0.28$$

$$\theta = \sin^{-1}(0.28)$$

$$\theta = 16.2^\circ$$

## Conclusion

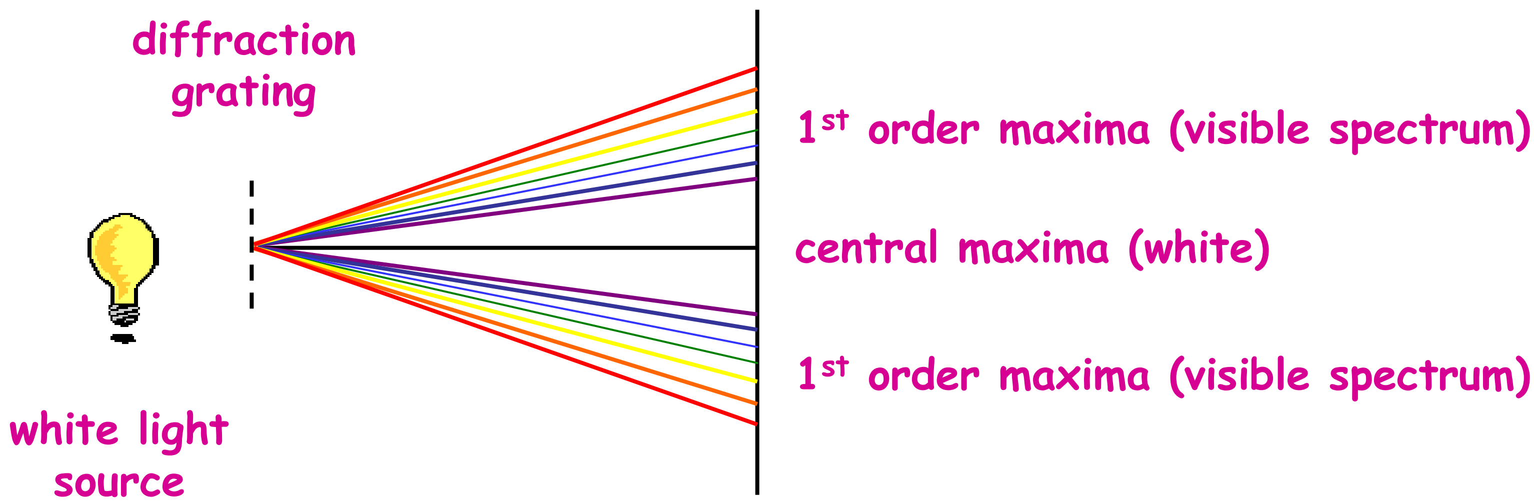
The longer the wavelength the ___**greater**___ the maxima separation.

The shorter the wavelength the ___**smaller**___ the maxima separation.

# White Light Spectra

**<u>Diffraction Grating</u>**

When a white light source is used to produce an interference pattern with a diffraction grating, the following is seen:



**Dispersion** is caused by **interference**.

The **central maxima** is **white light**.

All other **maxima** are seen in the form of the **visible spectrum**.

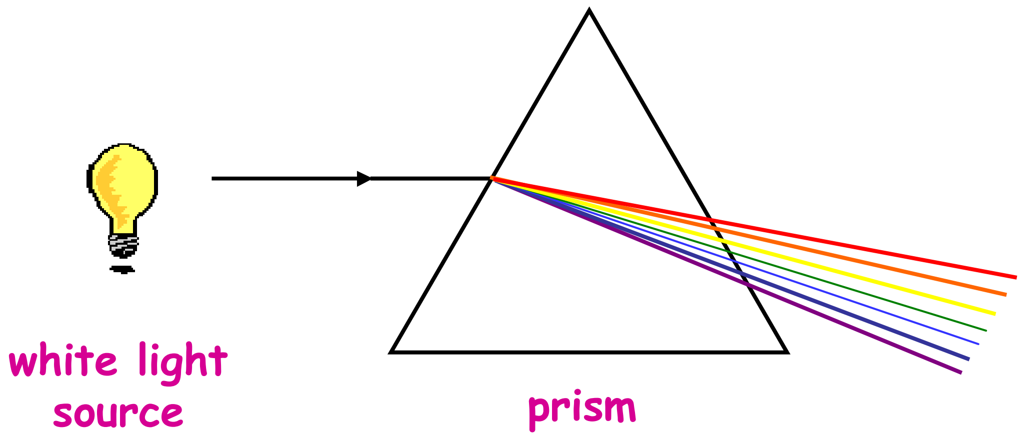
**Red** light makes the **greatest angle** with the original ray of white light because it has the **longest wavelength**.

The **longer** the **wavelength** the **greater** the maxima **separation**.

**More** than **one spectra** is produced.

# Prism

When light is dispersed using a prism, the following is seen:




**Dispersion** is caused by **refraction**.

**Violet** light makes the **greatest angle** with the original ray of white light because it has the **highest frequency**.

The **higher** the **frequency**, the **greater refraction** that takes place.

Only **one spectrum** is produced.

# P&N Tutorial Booklets

Q3.20 - 3.21