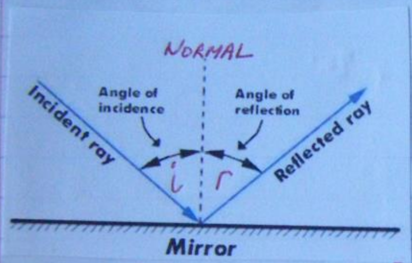
Waves – B McMULLEN

Four different types of wave effect:

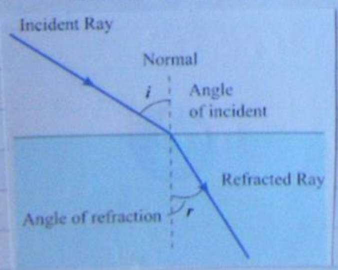
- Reflection
- Refraction
- Diffraction
- Interference

* Reflection



- angle of incidence (i) = angle of reflection (r)
- Rays of light are reversible.

* Refraction



Refraction is the change in the speed of light when moving from one medium to another.

- angle of incidence (i) > angle of refraction (r)

angle of light in air is greater than any other medium!!

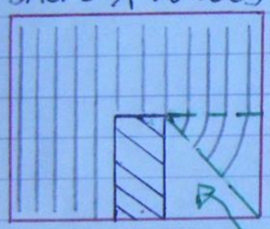
* Diffraction

- This is the bending effect of a wave around a barrier or an obstacle.

- Long wavelength waves bend much more easily (greater diffraction) than short wavelength waves.

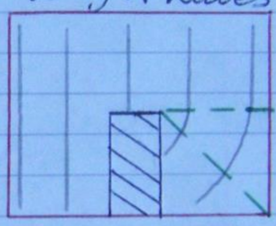
eg Water Waves.

Short λ waves



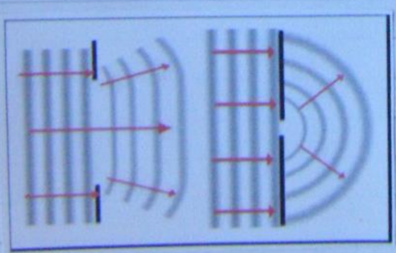
High frequency waves

Long λ waves



Low frequency waves.

No waves are detected in the shadow area.



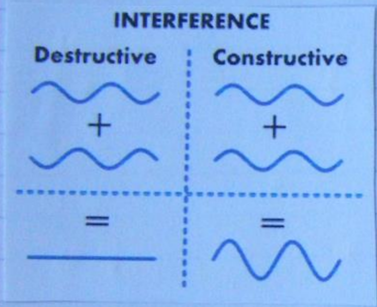
- If the gap is greater than the wavelength of the waves then the diffraction effect is clearly visible at the wave edges passing through.

- If the gap is approx the same as the waves wavelength then the waves diffract greatly when passing through the gap.

* Interference

The two main types of interference are:

- Constructive Interference
- Destructive Interference.



- When two waves of the same frequency meet in phase then constructive interference takes place.

The resultant wave has the same frequency but the amplitude of the wave increases.

- When two waves of the same frequency and amplitude meet 180° ($\frac{1}{2}\lambda$ or π rad) out of phase then destructive interference takes place.

The resultant wave in this particular case involves a total cancellation effect. ie No output waveform.

If the amplitude of the two waves were different then an output waveform would be observed with the resultant amplitude being lower.

ie $+3 + (-2) = 3 - 2 = \underline{\underline{+1}}$

Conclusion on Interference.

- Waves arrive at a point in phase where crest meets crest and trough meets trough in Constructive Interference.
- Waves arrive at a point 180° out of phase where crest meets trough and trough meets crest in Destructive Interference.

NATIONAL 5 RECAP!!

- Frequency

This is the number of waves that pass a point per second.

$$f = \frac{N}{t}$$

f – frequency (Hz); N – Number of Waves; t – Time (s)

The Period (T) is the time taken to complete one wave.

$f = \frac{N}{t}$ if $N = 1$ then $t = T$

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

f – frequency (Hz); T – Period (s)

Ex1

Q Calculate the frequency of an oscillator if it produces 7200 waves in two minutes.

A $f = ?$

$N = 7200$ waves

$t = 2$ minutes $= 120s$.

$$f = \frac{N}{t} = \frac{7200}{120} = 60Hz$$

Ex2

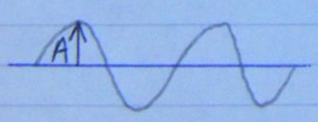
Q Calculate the period of the mains supply in the UK.

A $f = 50Hz$.

$$T = \frac{1}{f} = \frac{1}{50} = 0{\cdot}02s$$

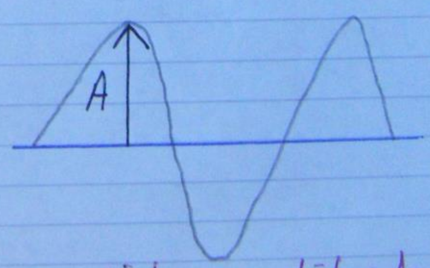
Amplitude of a wave

The amplitude is a measure of the energy in a wave.



Low amplitude

→ Low energy wave



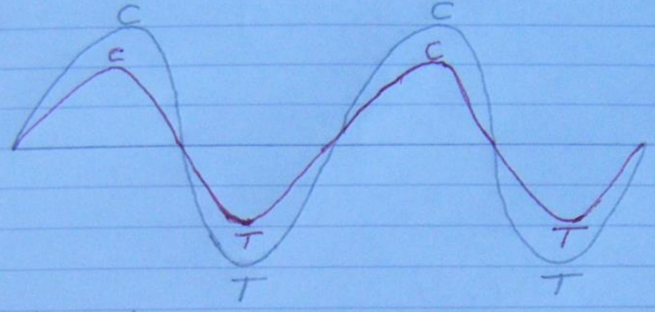
High amplitude

→ High energy wave.

Coherent Waves

This involves two sets of waves of the same frequency with a constant phase relationship between them.

eg

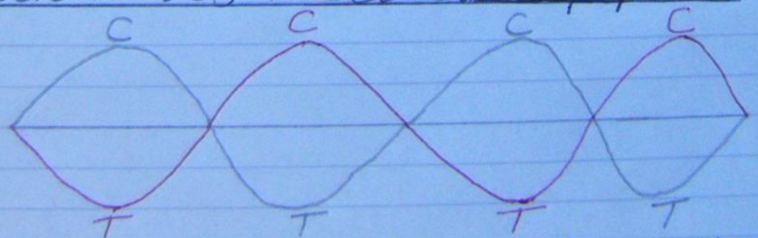


- Wave A
- Wave B

C - Crest   T - Trough

- These two waves are in-phase with one another.
- The only difference in these two waves is their amplitude ie Wave A > Wave B.

When waves meet out of phase

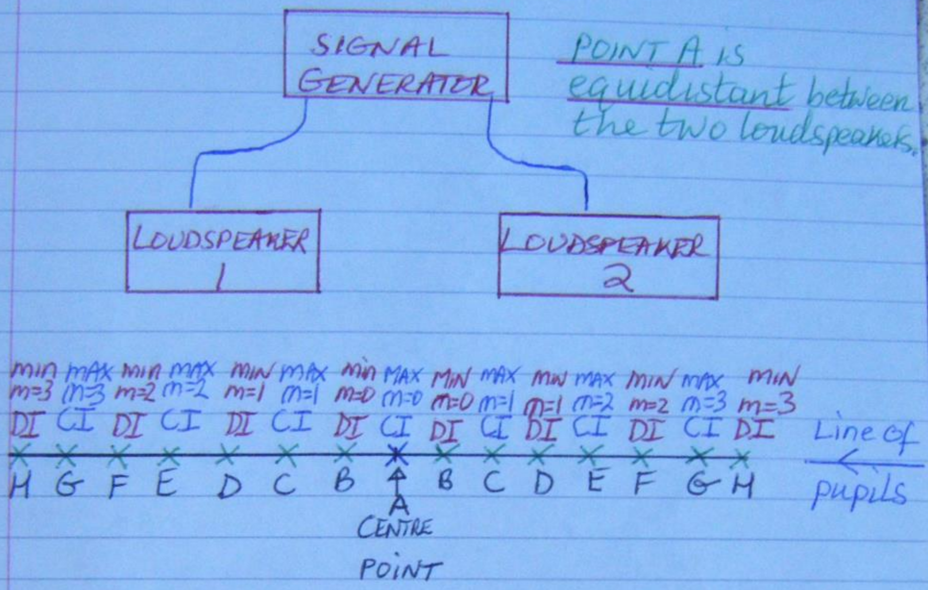


- Wave A
- Wave B

Waves A and B meet 180° out of phase (π rad or $\frac{1}{2}\lambda$)

*Period of a wave = 360° = λ = 2π rad *

Interference with sound waves



POINT A is equidistant between the two loudspeakers.

The pupils walk along the line covering their ear which is pointing to the wall. This will ensure that the pupils do not pick up reflected sound from the walls.

CI ⇒ • Constructive Interference
- Waves meet in phase
- Crest meets crest and trough meets trough
- This point is a maxima. (with light a bright fringe)

DI ⇒ • Destructive Interference
- Waves meet out of phase (180°)
- Crest meets trough and trough meets crest.
- This point is a minima (with light a dark fringe)

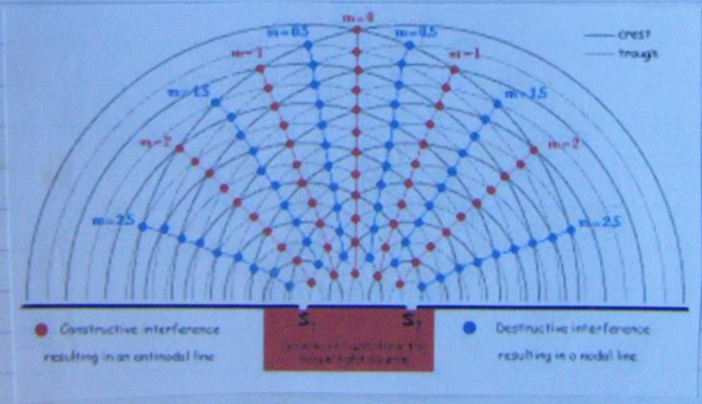
Conclusion

As the pupils walk along the line, the sound level continually varies from loud to quiet. (CI → DI → CI → DI etc).

Interference with water waves.

If two pebbles are dropped into the water at the beach a pattern of ripples will be observed coming from each stone.

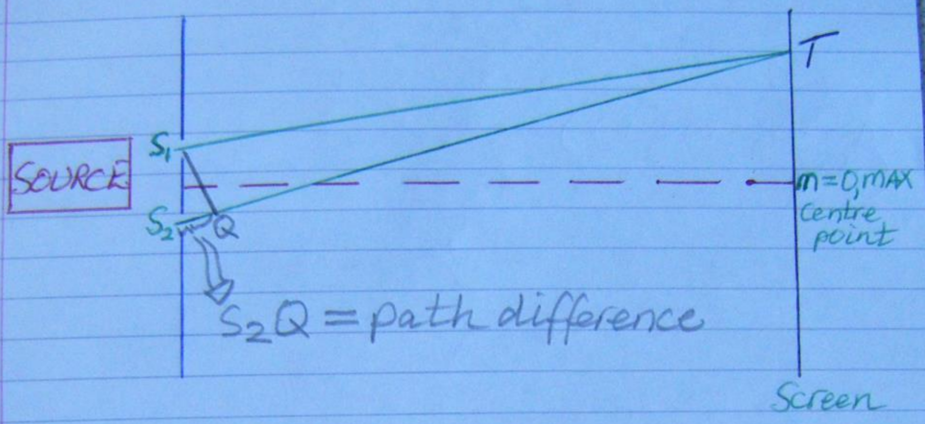
When these ripples overlap they will produce an interference pattern. This involves constructive and destructive interference.



The thicker line in each wave represents a crest and the thinner line represents a trough.

C → T → C → T → C → T etc.

Youngs Slits Experiment



S_1 and S_2 are slits.

$S_2T > S_1T$ ie $S_2T - S_1T = S_2Q$ ⇓ path difference.

* S_2Q, the path difference is the length by which S_2T is greater than S_1T. *

* The path difference will determine whether constructive Interference or destructive interference will take place at a particular part of the screen. *

* At the centre point we have the zero order maxima where $m = 0$. This is the reference point. *

Constructive Interference

$$\text{path difference} = m\lambda$$ ⇒ In DB!!

m → order of the maxima

λ → Wavelength of the source (m)

In older papers m is replaced by n.

ie When the path difference is a whole number of wavelengths of the source used then constructive interference takes place at that point.

ie $\lambda, 2\lambda, 3\lambda, 4\lambda$ etc

Destructive Interference

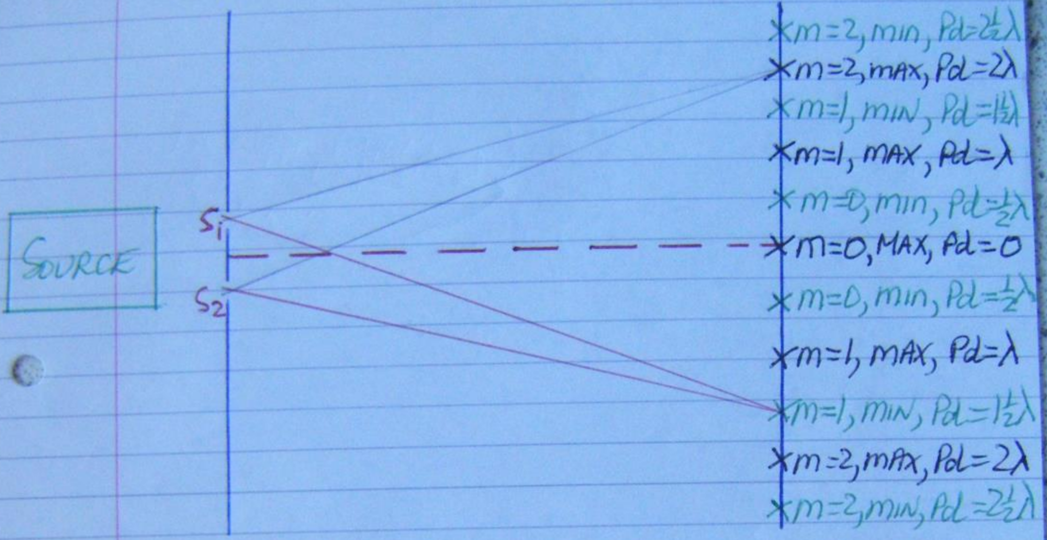
$$\text{path difference} = (m + \tfrac{1}{2})\lambda$$ ⇒ In DB!!

λ → Wavelength of the source.

ie When the path difference is an integral numbers of half wavelengths of the source used the destructive interference takes place at that point.

ie $\frac{1}{2}\lambda, 1\frac{1}{2}\lambda, 2\frac{1}{2}\lambda, 3\frac{1}{2}\lambda$ etc

Where does path difference fit in?



CI ⇒ MAXIMA ⇒ path difference $= m\lambda$

DI ⇒ MINIMA ⇒ path difference $= (m + \frac{1}{2})\lambda$

Key point!!

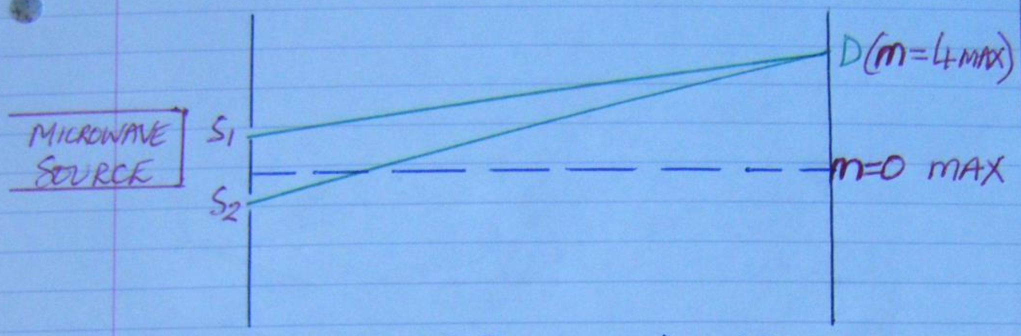
4^{th} maxima ⇒ $m = 4$ ∴ $Pd = 4\lambda$

7^{th} minima ⇒ $m = 6$ ∴ $pd = 6\frac{1}{2}\lambda$

10^{th} minima ⇒ $m = 9$ ∴ $pd = 9\frac{1}{2}\lambda$

6^{th} maxima ⇒ $m = 6$ ∴ $pd = 6\lambda$

Ex 3



$S_2D = 75cm$, $S_1D = 63cm$

Q Calculate or find:

a) path difference

b) Wavelength of the microwaves.

A a) path difference $= S_2D - S_1D$

$= 75 - 63$

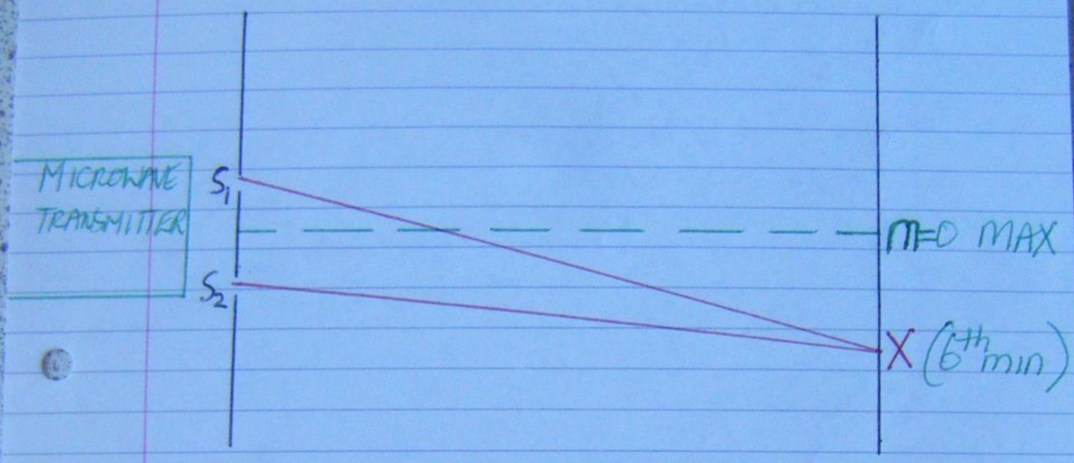
$= 12cm = \underline{\underline{0.12m}}$

b) path difference $= m\lambda$

$\Rightarrow \quad 0.12 = 4\lambda$

$\Rightarrow \quad \lambda = \frac{0.12}{4} = \underline{\underline{0.03m}}$

Ex4



The microwaves from the transmitter have a wavelength of 2·8cm.

Q Calculate or find:

a) The path difference at the 6th minimum.

b) The path difference at the 4th minimum.

A a) path difference $= (m + \frac{1}{2})\lambda \Rightarrow$ DI

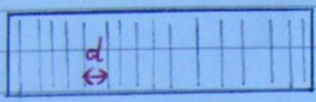
$\Rightarrow$ path difference $= (5 + \frac{1}{2}) \times 0{\cdot}028 = \underline{0{\cdot}154\text{m}}$

b) path difference $= (m + \frac{1}{2})\lambda \Rightarrow$ DI

$\Rightarrow$ path difference $= (3 + \frac{1}{2}) \times 0{\cdot}028 = \underline{0{\cdot}098\text{m}}$

Gratings (Formerly known as Diffraction gratings).

Gratings are used with light to produce interference patterns. This can be done with white light or monochromatic light.



Gratings with lines or slits

d = distance between the lines or slits (m).

Ex5

Calculate the distance between the lines or slits in the following gratings:

Q a) 400 lines mm^{-1} ← most common unit scenario!!!

b) 6000 lines cm^{-1}

c) 700,000 lines m^{-1}

A a) 400 lines → 1mm

$d = 1 \text{ line} \rightarrow \frac{1mm}{400} = 2.5 \times 10^{-3} mm$

$\therefore d = 2.5 \times 10^{-6} m$ $(1mm = 1 \times 10^{-3} m)$

b) 6000 lines → 1cm

$\therefore d = 1 \text{ line} = \frac{1\text{cm}}{6000} = 1.67 \times 10^{-4}\text{cm}$

$\Rightarrow d = 1.67 \times 10^{-6}\text{m}$ ($1\text{cm} = 1 \times 10^{-2}\text{m}$)

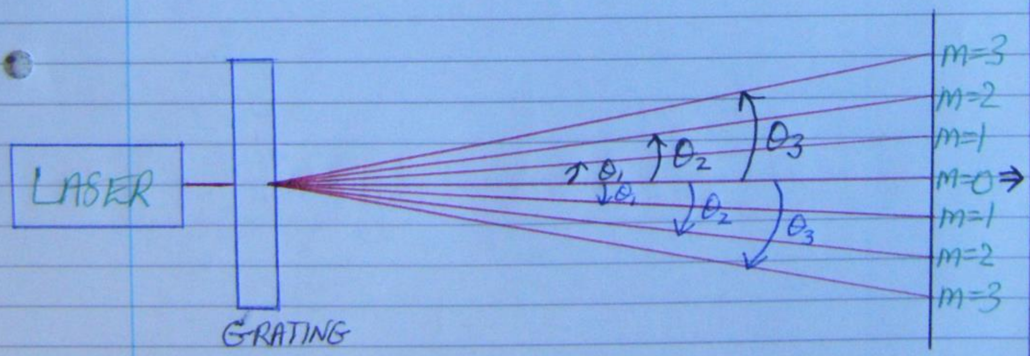
c) 700,000 lines → 1m

$\therefore d = 1 \text{ Line} = \frac{1\text{m}}{700{,}000} = 1.43 \times 10^{-6}\text{m}$

* These values for $d \approx \times 10^{-6}\text{m}$ *

Gratings with monochromatic light

Lasers are a good example of monochromatic light. ie light of one colour/wavelength/frequency.

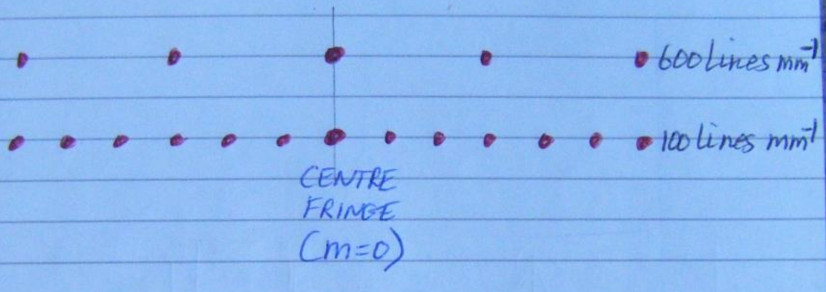


Each maxima on the screen involves bright fringes which is due to constructive Interference taking place. at that particular point on the screen.

$$d\sin\theta = m\lambda$$

- d → distance between the slits (m)
- θ → Angle from $m=0$ to the maxima being viewed. ($m=1$ or 2 or 3 etc).
- m → order of the maxima
- λ → wavelength of the source (m).

In the experiment in class the grating was changed from $600\,\text{lines mm}^{-1}$ to $100\,\text{lines mm}^{-1}$



Q. Why did the bright fringes come closer together when the $600\,\text{lines mm}^{-1}$ grating is replaced by the $100\,\text{lines mm}^{-1}$ grating?

A.
- $600\,\text{lines mm}^{-1} \rightarrow 100\,\text{lines mm}^{-1}$ $\therefore d\uparrow$
- From $d\sin\theta = m\lambda \Rightarrow d = \dfrac{m\lambda}{\sin\theta}$

$\therefore d \propto \dfrac{1}{\sin\theta}$

$\therefore$ As $d\uparrow$ then $\sin\theta$ and also $\theta\downarrow$

$\therefore$ The bright fringes are closer together.

Ex6

Light from a monochromatic light source strikes a grating of 600 lines mm^{-1}. If the second order maxima is found at an angle of 49.1°, then calculate or find:

Q a) Slit Separation (d).

b) The wavelength of the light source used.

A a) 600 lines → 1mm

$$\therefore d = 1\ \text{line} = \frac{1\,mm}{600} = 1.67 \times 10^{-3}\,mm$$

$$\Rightarrow d = 1.67 \times 10^{-6}\,m$$

b) $d = 1.67 \times 10^{-6}\,m$
$\theta = 49.1°$
$m = 2$
$\lambda = ?$

$$d \sin\theta = m\lambda$$

$$\Rightarrow 1.67 \times 10^{-6} \times \sin 49.1° = 2\lambda$$

$$\Rightarrow \lambda = \frac{1.67 \times 10^{-6} \times \sin 49.1°}{2} = 6.31 \times 10^{-7}\,m$$

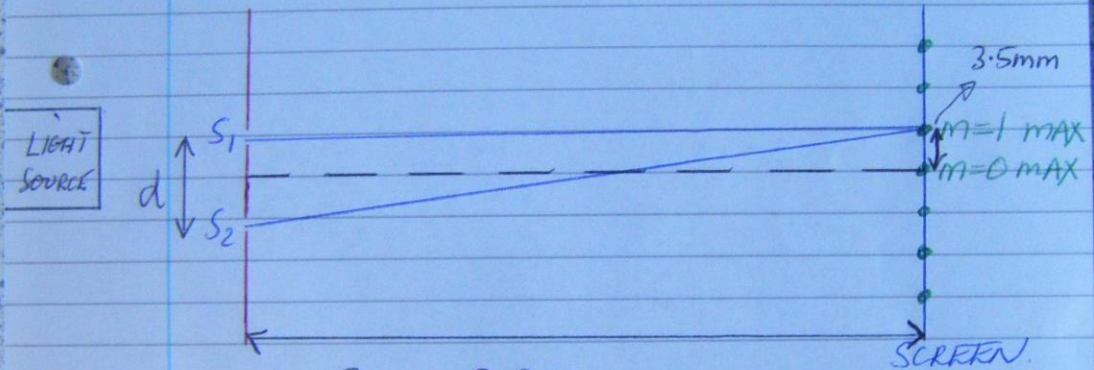
$\lambda = 6.31 \times 10^{-7}\,m = 631 \times 10^{-9}\,m = 631\,nm$.

$\lambda = 631\,nm \approx$ Orange (Red ≈ 700nm, Green ≈ 550nm, Violet ≈ 400nm)

Ex 7

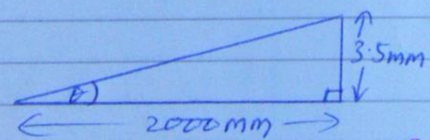
Light of wavelength $4 \cdot 3 \times 10^{-7}$ m falls onto a double slit and 2m away on a white screen an interference pattern is observed.

Q If the distance from the $m=0$ max and the first bright fringe at $m=1$ is 3·5mm, then calculate the slit separation d.



2m = 2000mm

A $d \sin\theta = m\lambda$



$d = ?$

$\theta = ?\ 0 \cdot 1^\circ$

$m = 1$

$\lambda = 4 \cdot 3 \times 10^{-7}$ m.

$\tan\theta = \frac{O}{A} = \frac{3 \cdot 5}{2000} = 1 \cdot 75 \times 10^{-3}$

$\Rightarrow \theta = \tan^{-1}(1 \cdot 75 \times 10^{-3}) = 0 \cdot 1^\circ$

$d = \frac{m\lambda}{\sin\theta} \Rightarrow d = \frac{1 \times 4 \cdot 3 \times 10^{-7}}{\sin(0 \cdot 1^\circ)} = 2 \cdot 46 \times 10^{-4}$ m

Ex8

Q A red light source is replaced by a green light source in the Young's slits experiment.

Explain how you could compare the maximas produced from these light sources on the screen.

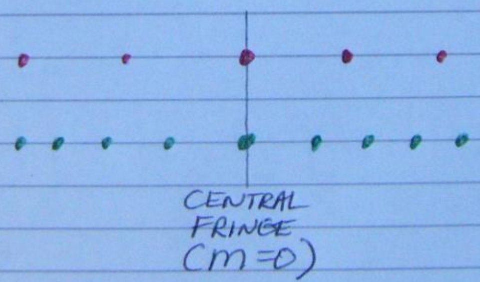
A Red → Green $\therefore \lambda$ will decrease.

$d \sin\theta = m\lambda$

$\therefore \sin\theta \propto \lambda$

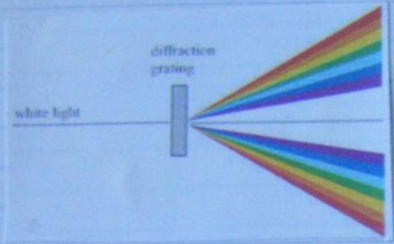
$\therefore$ As $\lambda \downarrow \therefore \sin\theta \downarrow \therefore \theta \downarrow$

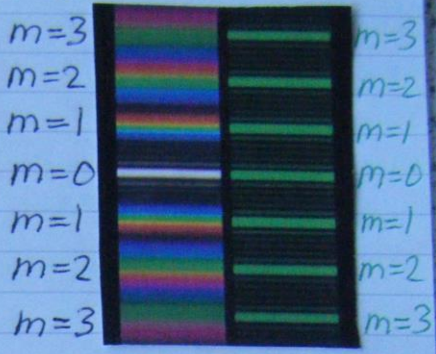
As θ decreases then the distance between the maximas with green light decreases.



The m=0 fringe for red and green light are at the same point.
However for each order of bright fringe after that the green fringes are closer than the red fringes.

White light with gratings





- Gratings produce spectra above and below the broad white band at m=0.

- In each order of spectra violet bends least and red bends most.

- A broad central white band is observed in the centre at m=0 maxima.

- If a green filter is used with white light then all of the other six colours are absorbed. This leaves green at the same point as it is found in each order of spectra.

- multiple orders of spectra are observed above and below the white central band.

* The path difference at the white central fringe is zero.

* All of the seven colours (ROYGBIV) are present to make up white.

Ex9

Q White light is passed through a grating of 4000 lines cm^{-1}. If the wavelength of red light is 680nm and the wavelength of violet light is 420nm, then calculate the angle between the red and the violet light for the second order spectrum.

A

Red	Violet
$d = ?$ $2.5 \times 10^{-6} m$	$d = ?$ $2.5 \times 10^{-6} m$
$\theta = ?$	$\theta = ?$
$m = 2$	$m = 2$
$\lambda = 680nm$	$\lambda = 420nm$

$d = ?$ 4000 lines $\rightarrow$ 1cm

$$\therefore d = 1 \text{ line} = \frac{1cm}{4000} = 2.5 \times 10^{-4} cm$$

$$\Rightarrow d = 2.5 \times 10^{-6} m$$

Red $d \sin\theta_R = m\lambda \Rightarrow \sin\theta_R = \frac{m\lambda}{d}$

$$\Rightarrow \sin\theta_R = \frac{2 \times 680 \times 10^{-9}}{2.5 \times 10^{-6}} = 0.544$$

$$\therefore \theta_R = \sin^{-1}(0.544)$$

$$\therefore \theta_R = 33.0^{\circ}$$

Violet

$d \sin\theta_V = m\lambda \Rightarrow \sin\theta_V = \frac{m\lambda}{d}$

$\Rightarrow \sin\theta_V = \frac{2 \times 420 \times 10^{-9}}{2.5 \times 10^{-6}} = 0.336$

$\Rightarrow \theta_V = \sin^{-1}(0.336) = \underline{19.6^\circ}$

$\therefore \Delta\theta = \theta_R - \theta_V = 33.0^\circ - 19.6^\circ = \underline{13.4^\circ}$

($\Delta\theta$ ↑ change in angle.)

Looking at relationships (Physics ones of course!!)

$d \sin\theta = m\lambda$

1) **d and m**

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

$\Rightarrow d \propto m$

2) **d and sinθ**

$d = \frac{m\lambda}{\sin\theta} \Rightarrow d \propto \frac{1}{\sin\theta}$

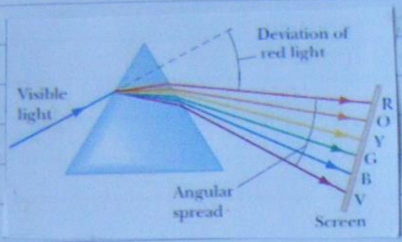
$\Rightarrow$ As $d\uparrow \therefore \theta\downarrow$ and vice-versa!!

3) **Sinθ and λ**

$\sin\theta = \frac{m\lambda}{d} \Rightarrow \sin\theta \propto \lambda$

$\Rightarrow$ As $\theta\uparrow \therefore \lambda\uparrow$ and vice-versa!!

Comparing spectra produced from Prisms and Gratings.



The graphics from spectra produced from gratings can be found on P20.

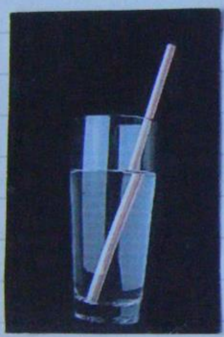
The spectra produced from a prism.

- Prism → One order of spectra.
- Gratings → multiple orders of spectra above and below the white central m=0 maxima.
- Prism → Spectra produced by the refraction of light.
- Gratings → Multiple orders of spectra produced from interference of light.
- Prism → Spectra produced is highly irradiant as it has only one order.
- Gratings → The multiple orders of spectra produced are less irradiant than that of a prism. (light energy spread over multiple spectra!!)

- Prism → Violet light bends most
- Gratings → Red light bends most in each order of spectra produced.

My brain hurts after all of this waves stuff!!

I need a glass of water!!



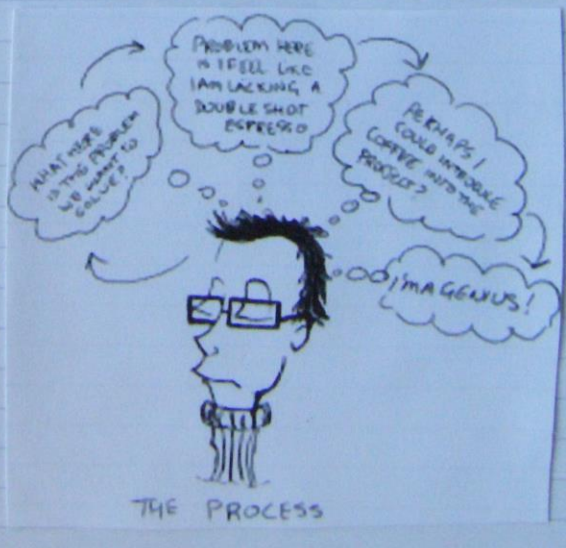
Refraction → shock horror!!

I still cannot get away from this waves theory!!

What about a coffee?

That's better!!

Now for a past paper question to finish off the topic.

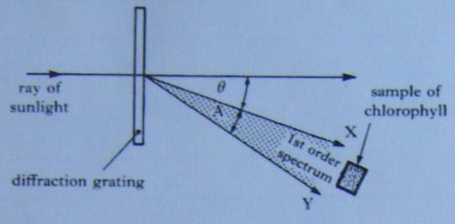


EX10 (1993 PAPER 2 Q8)

Q

A biologist is studying the effect of different colours of light on a sample of chlorophyll.

The biologist sets up the apparatus shown below, using a diffraction grating with $6 \cdot 0 \times 10^5$ lines per metre to produce a first order spectrum of sunlight.



(a) Explain briefly how a diffraction grating produces a continuous spectrum from the ray of sunlight. **2**

(b) (i) The wavelength of the light at the end X of the spectrum is 410 nm. Calculate the value of the angle θ.

(ii) The angle A, in the diagram above, is 9°. Calculate the wavelength at end Y of the spectrum. **5**

(c) The biologist now uses a triangular glass prism to produce a continuous spectrum from a ray of sunlight.

State **two** differences between this spectrum and the spectrum produced by the grating. **2**

(9)

A a) Sunlight is perceived as white light which is made of many colours of different wavelengths.
The diffraction grating diffracts the different wavelengths in the sunlight by different amounts. The longer wavelengths such as red diffract most and the smaller wavelengths such as violet diffract least.
At X → Violet light
At Y → Red light

b) i) $d = ?\ 1{\cdot}67 \times 10^{-6}\,m$
$\theta = ?$
$m = 1$
$\lambda = 410nm = 410 \times 10^{-9}\,m$

$6{\cdot}0 \times 10^5$ lines → 1m
$d = 1$ line → $\frac{1m}{6{\cdot}0 \times 10^5}$

$\Rightarrow d = 1{\cdot}67 \times 10^{-6}\,m$

$d\sin\theta = m\lambda$

$\Rightarrow \sin\theta = \frac{m\lambda}{d} = \frac{1\times 410\times 10^{-9}}{1.67\times 10^{-6}} = 0.246$

$\Rightarrow \theta = \sin^{-1}(0.246) = \underline{14.2^0}$

b) ii) $d = 1.67\times 10^{-6}\,m$
$\theta = 14.2^0 + 9^0 = 23.2^0$
$m = 1$
$\lambda = ?$

$d\sin\theta = m\lambda \Rightarrow \lambda = \frac{d\sin\theta}{m} = \frac{1.67\times 10^{-6}\times \sin 23.2^0}{1}$

$\Rightarrow \underline{\lambda = 6.58\times 10^{-7}\,m}$ $(658\times 10^{-9}\,m = 658\,nm)$

c) Any two of the four as discussed in detail on P23 and P24.

Prism	Grating
• One order of spectra	• multiple orders of spectra
• Refraction of light	• Interference of light
• Highly Irradiant Spectra	• Each Spectra is low in Irradiance
• Violet light bends most	• Red light bends most.