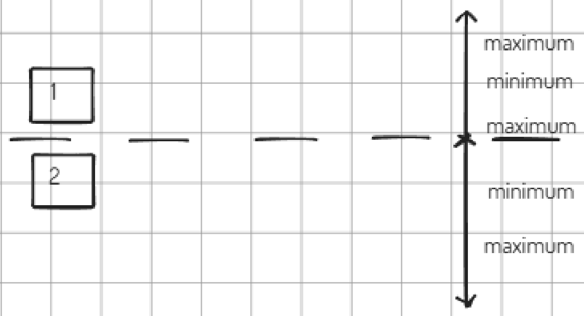
Interference

A stable pattern of interference will only occur if two waves are COHERENT.
COHERENT waves have the SAME wavelength and a CONSTANT phase relationship. 2 marker

A single sustained note from a signal generator is played through two identical speakers.
The sound as perceived from the observer will be louder and softer in different regions.



The PATH DIFFERENCE is the difference in distance travelled between the two waves in reaching the same point. Path difference is measured as a function of wavelength.

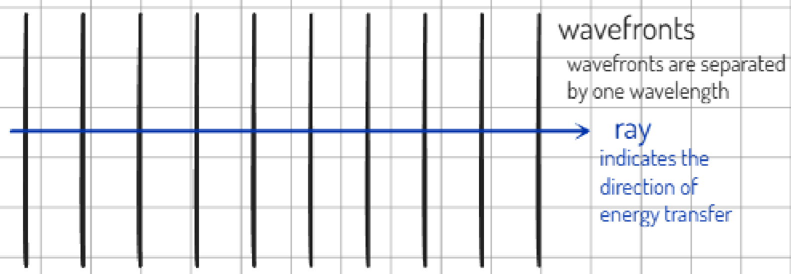
The waves leave the speakers in phase.

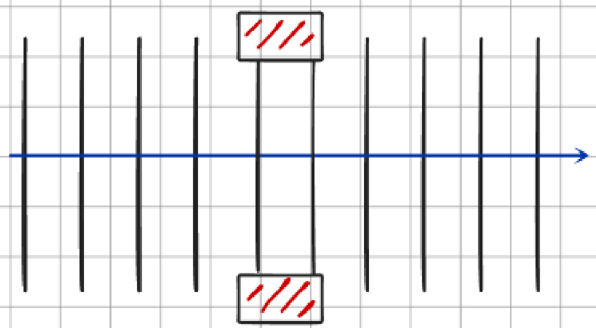
The waves will meet in phase if the path difference is equal to a whole number of wavelengths. [nλ] This will lead to CONSTRUCTIVE SUPERPOSITION giving a region of maximum displacement.

The waves will meet in antiphase when the path difference is equal to $\left(n + \frac{1}{2}\right)\lambda$
This will lead to DESTRUCTIVE SUPERPOSITION giving a region of minimum displacement.

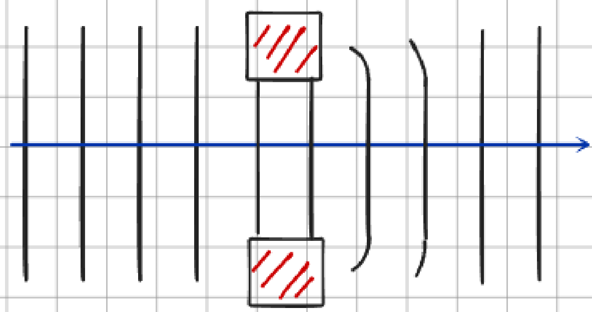
Diffraction

Diffraction is the spreading out of waves as they pass through an aperture. All waves diffract but it is much easier to observe if the wavelength is comparable to the size of the gap.

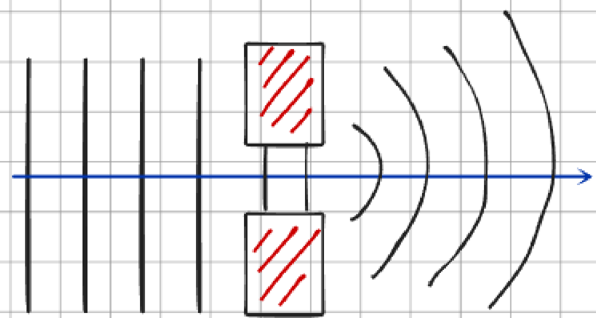




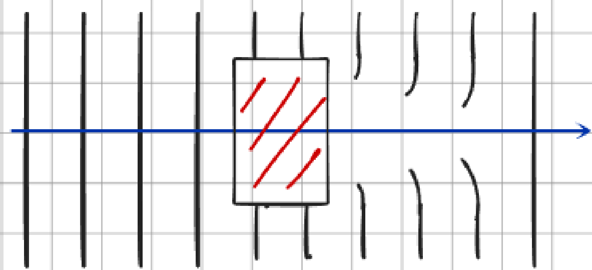
NO NOTICEABLE DIFFRACTION



SOME DIFFRACTION IF GAP IS MULTIPLE WAVELENGTHS WIDE



MAXIMUM DIFFRACTION IF THE GAP AND WAVELENGTH ARE SIMILAR

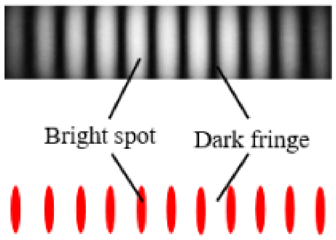


THE WIDER THE OBJECT, THE LONGER THE SHADOW

Young's Double Slit

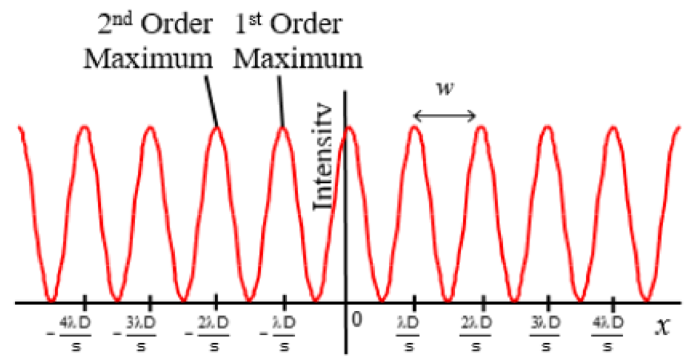
-Young's investigation involved a pair of narrow slits which he was using to investigate the properties of light.

When illuminated with a COHERENT, MONOCHROMATIC source, a diffraction pattern was observed.



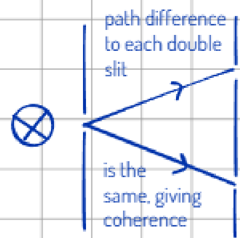
Young observed a series of bright and dark fringes formed on an illuminated screen.

(Note: for a theoretically ideal set of double slits, the aperture tends towards zero width)

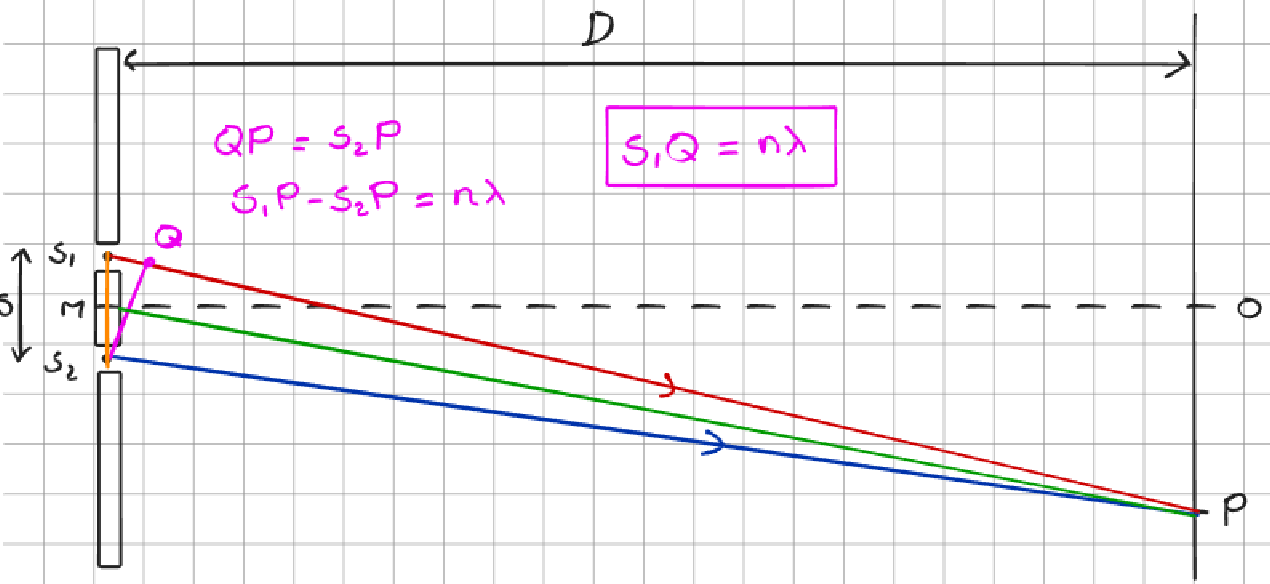


A coherent source can be manufacture using:

- A laser
  Lasers are coherent and monochromatic by nature
- Light from a bulb or the sun is INCOHERENT but can be made coherent by single slit diffraction.



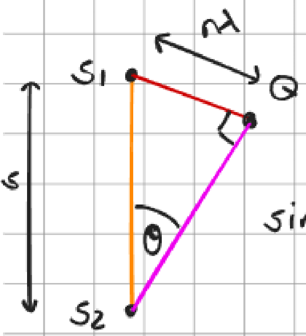
The separation of bright fringes



w is the fringe separation

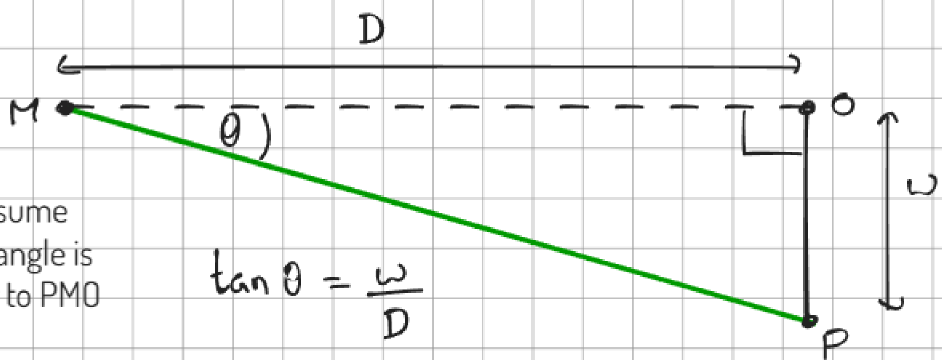
P is the position of the 1st order bright fringe

where s is the slit separation and M is central point between the fringes and O is the position of the 0th order bright fringe, D is the distance to the screen



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

lets assume this triangle is similar to PMO



$$\tan\theta = \frac{w}{D}$$

at small angles $\sin(\theta) = \tan(\theta) = \theta$

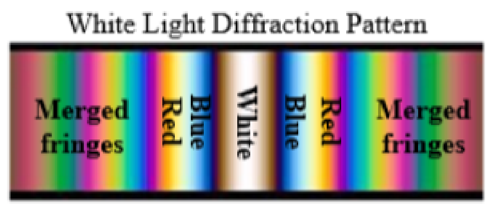
$$\theta = \frac{n\lambda}{s} \qquad \theta = \frac{w}{D} \qquad \frac{n\lambda}{s} = \frac{w}{D}$$

$$\lambda = \frac{ws}{D}$$

between adjacent fringes (n=1)

When WHITE LIGHT is incident on a diffraction grating, rather than monochromatic light, we see:

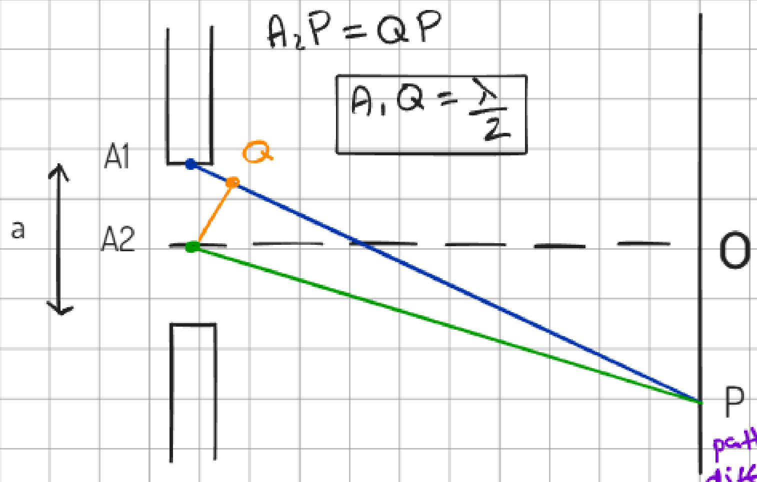
- The central maximum is WHITE since all wavelengths interfere constructively with a path difference of zero.
- The 1st order fringes separate into a visible spectrum, with longer wavelengths on the outer edge.
- Higher order fringes merge together.
- The peaks become less intense as order increases if bulb or candle light is used.



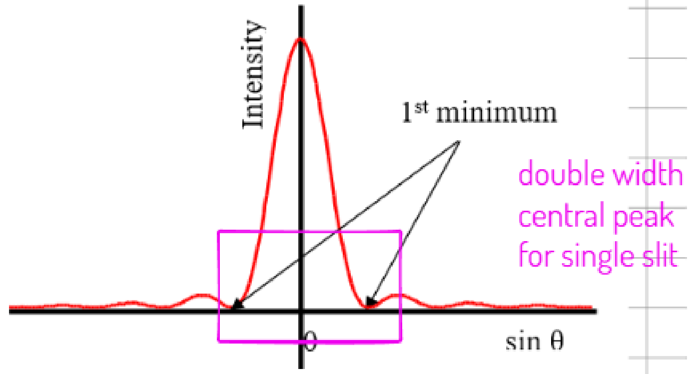
NOTE: The proof and graph drawn today are for the THEORETICAL interpretation of Youngs experiment and do not actually reflect the real results, more on this later.

Single Slit Diffraction

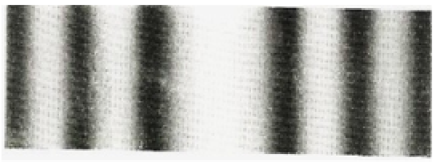
03/01/24



path difference $\frac{\lambda}{2}$

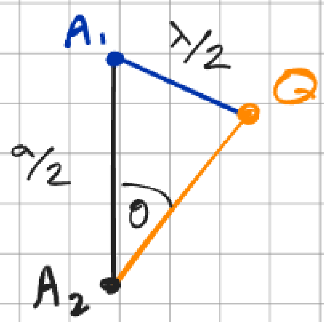


A graph of intensity against sin θ for a single slit



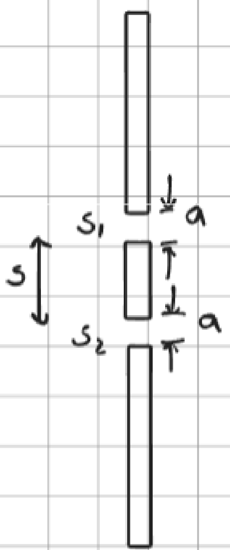
Treating A1 and A2 as secondary sources of wavelets (Huygens Theory)

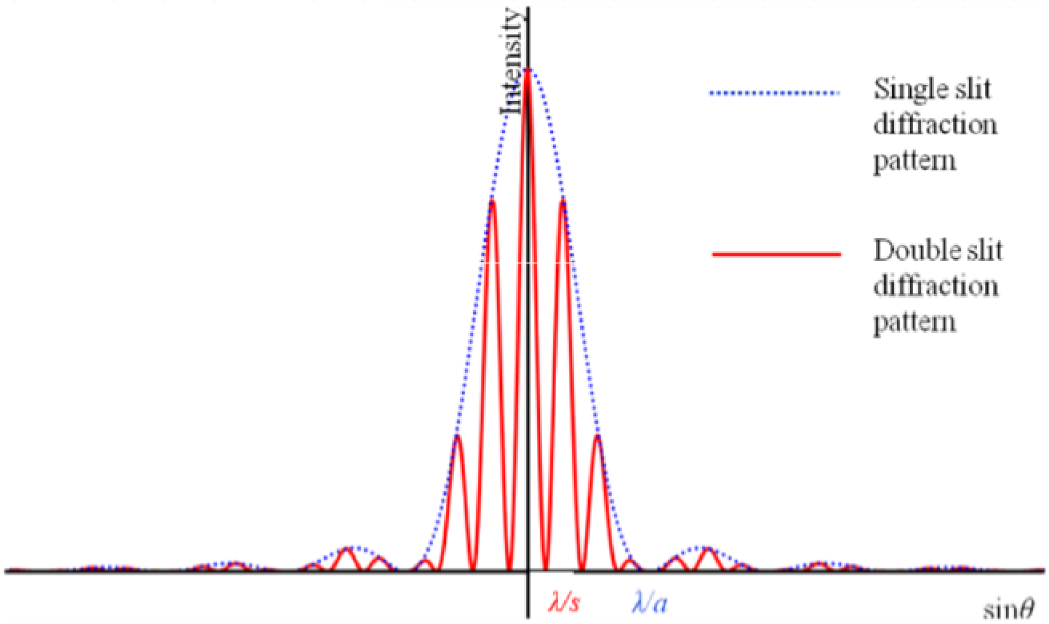
P is the location of the first minimum

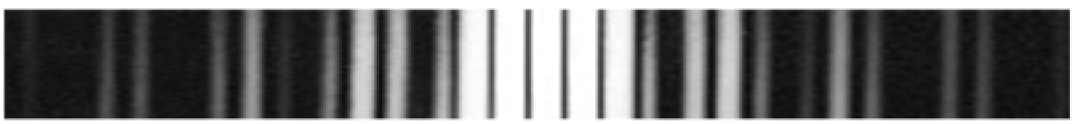


$$\sin\theta = \frac{(\lambda/2)}{(a/2)}$$

$$\sin\theta = \frac{\lambda}{a}$$ for the first minimum

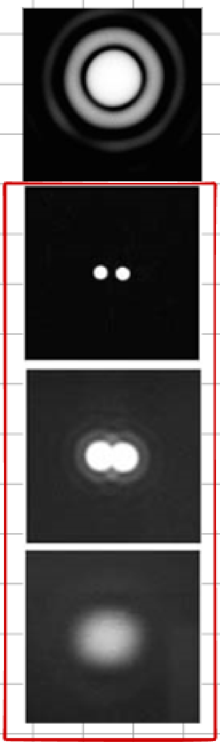






For a theoretically ideal double slit, the slits themselves will have negligible width and the diffraction pattern will shown bright spots of equal intensity.

For real double slits, each slit has a width (a) which produces a "single slit envelope" to encompass the double slit diffraction pattern. We say that the double slit interference pattern has been MODULATED by the the single slit pattern, so the intensity of the bright fringes varies and some can disappear entirely.



Resolution

When light passes through a circular aperture, it produces a pattern of DIFFRACTION RINGS. This is a result constructive and destructive interference based on the PATH DIFFERENCE between the waves arriving at a given point.

The position of the first minimum for a circular aperture is:

$$\sin\theta = 0.61\frac{\lambda}{R}$$

Where R is the radius of the opening and λ is the wavelength of the incident light.

So a smaller aperture gives a WIDER diffraction pattern.

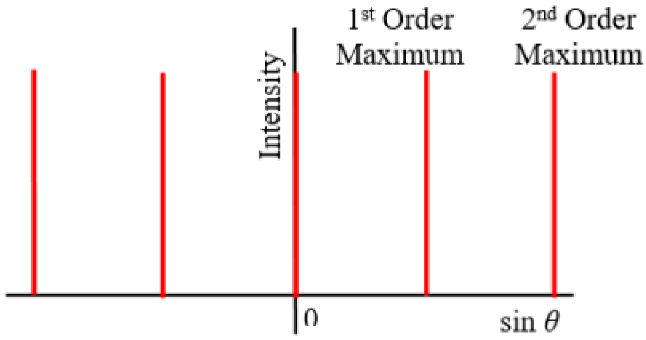
If the aperture is wide enough when observing two separate light sources, they will appear as distinct bright spots.
For a smaller aperture, the diffraction pattern becomes more apparent and the spots begin to merge.
If the aperture is too small, then we cannot resolve the individual sources as the patterns appear fully merged.

Diffraction Gratings

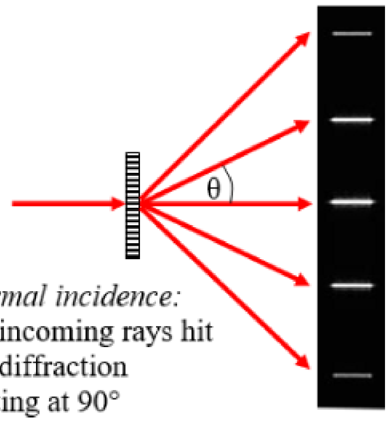
A diffraction grating is a large number of regularly spaced narrow slits. The distance between each of the slits is d. The number of slits (or lines) per unit length on the grating is N.

$$d = \frac{1}{N}$$

When a diffraction grating is illuminated with MONOCHROMATIC, COHERENT light, a series of bright SHARP LINES are produced.

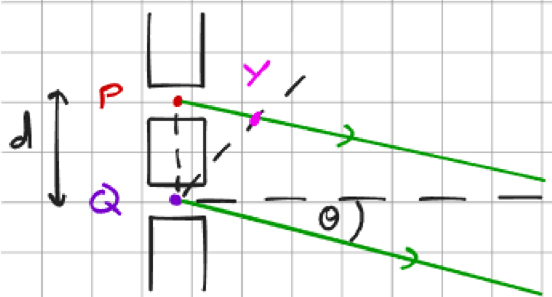


A graph of intensity against sin θ for a diffraction grating

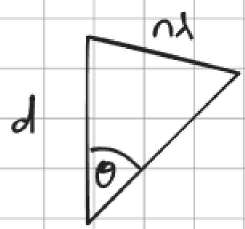


Normal incidence: the incoming rays hit the diffraction grating at 90°

Consider two adjacent slits in a grating:



To produce a bright fringe requires CONSTRUCTIVE INTERFERENCE. The path difference between PARALLEL RAYS from adjacent slits must be equal to an integer value of the wavelength.



n indicates the ORDER of the diffraction maximum, with the central maximum being the 0th order.

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

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

The number of orders

$$\theta_{max} = 90^\circ \qquad \sin(90) = 1$$

$$n_{max}\lambda \leq d \qquad \boxed{n_{max} \leq \frac{d}{\lambda}}$$

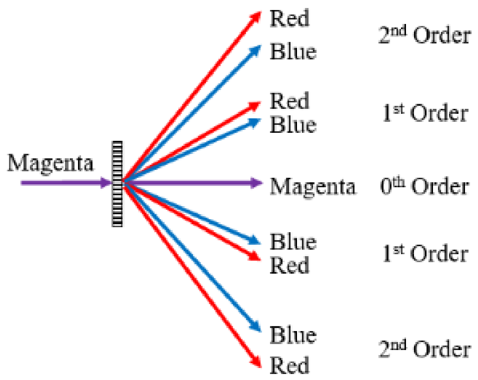
$$n_{max} = \text{integer}\left(\frac{d}{\lambda}\right)$$

ROUNDED DOWN!

Polychromatic light sources

When illuminated with multiple wavelengths, a diffraction grating produces a repeating pattern of sharps lines of varying colour corresponding with the different wavelengths.

The ZEROTH is NOT SEPARATED.

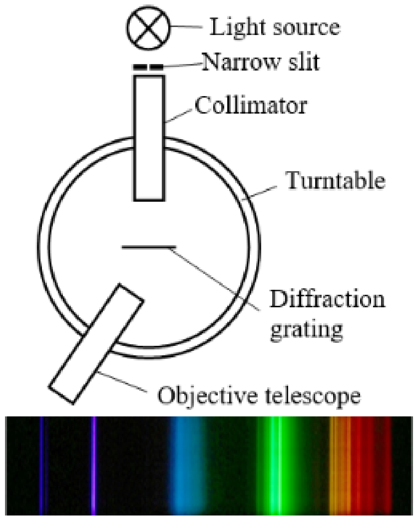


In higher orders, the shortest wavelengths will be diffracted through the smallest angle and appear first.

The degree of separation will increase with each order.

Spectrometers

Diffraction gratings are the basis of SPECTROMETERS.



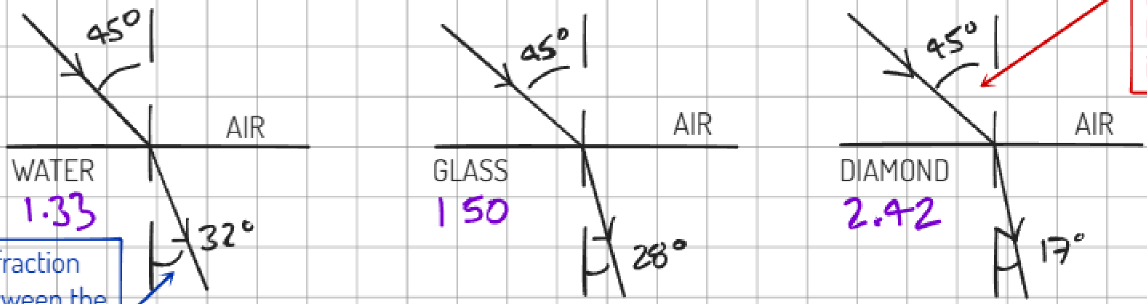
Line spectrum of a fluorescent lamp

They are used to produce a spectra of sharp lines which can be used to determine the wavelengths
of light emitted from a gaseous sample, resolving them into individual wavelengths.

Refraction at a Boundary

03/01/24

When a wave refracts there is a change in speed, leading to a change in wavelength. The frequency of the wave remains constant.



the angle of incidence is the angle between the normal and the incident ray

the angle of refraction is the angle between the normal and the refracted ray

The variation in angle depends on the REFRACTIVE INDICES of the media.

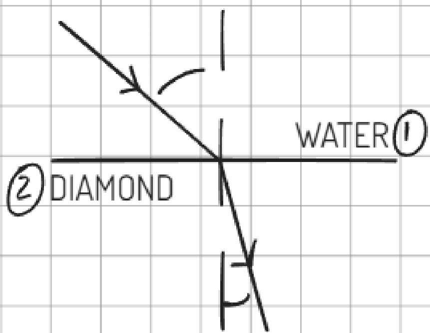
The normal line is the bearing from which all angles are measured.
It is drawn PERPENDICULAR to the material boundary.

The refractive index is the proportion by which the light is slowed.

$$n = \frac{c}{c_s}$$

(speed of light in a vacuum)

(speed of light in the medium)



$${}_1n_2 = \frac{c_1}{c_2}$$

relative refractive index

(speed of light in incident medium)

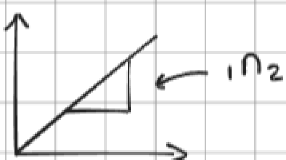
(speed of light in refracted medium)

$${}_1n_2 = \frac{2.42}{1.33} = 1.82$$

$$\frac{\left(c_1/c\right)}{\left(c_2/c\right)} = \frac{\left(1/n_1\right)}{\left(1/n_2\right)} = \frac{n_2}{n_1} = {}_1n_2$$

Willebroad von Snellius realised that

$\sin\theta_1$ vs $\sin\theta_2$



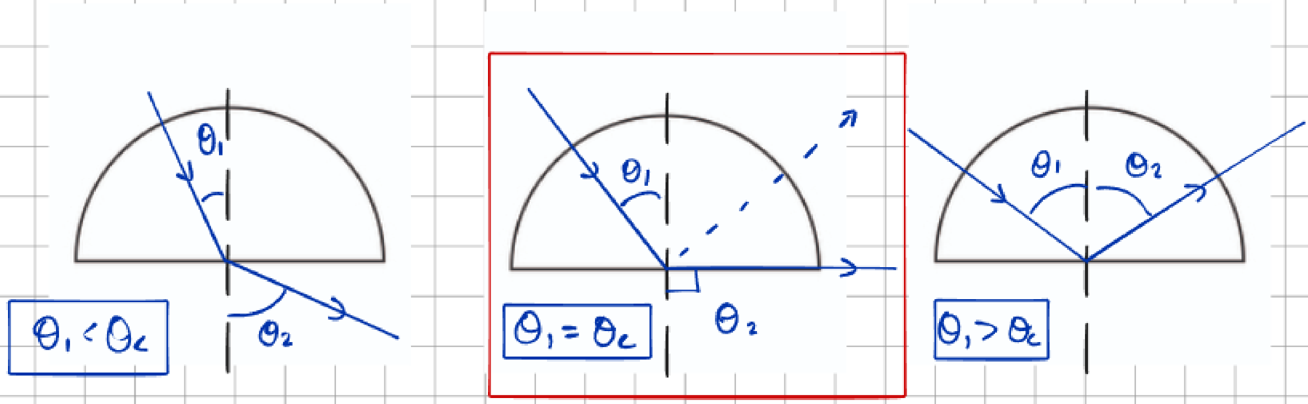
$$\frac{\sin\theta_1}{\sin\theta_2} = {}_1n_2$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$$

$$n_1\sin\theta_1 = n_2\sin\theta_2$$

Snell's Law

TOTAL INTERNAL REFLECTION



Below the critical angle the light will be refracted into the second medium as expected.

When θ2 is a right-angle, we say that θ1 is the CRITICAL ANGLE of that material.

$$n_1 \sin\theta_c = n_2 \sin(90)$$

$$\sin\theta_c = \frac{n_2}{n_1}$$

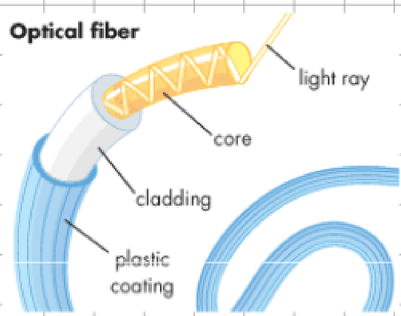
Above the critical angle the light will be TOTALLY INTERNALLY REFLECTED within the incident medium.

The conditions for TIR to occur are:

- The angle of incidence must be HIGHER than the CRITICAL ANGLE of the material.
- The wave must be travelling from a HIGHER REFRACTIVE INDEX to a LOWER REFRACTIVE INDEX.

OPTICAL FIBRES

Very thin flexibles tube of glass or plastic fibres.
High refractive index CORE surrounded by a lower refractive index CLADDING.
The cladding provides protection from scratches to the core and acts as secondary containment to prevent light escaping.



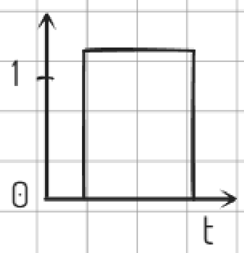
Light is shone down the end of the fibre and transmitted by TIR to the other end.
The fibre is NARROW to ensure that θ is higher than the CRITICAL ANGLE.

Optical fibres can:
- Carry significantly more data than copper wires as the frequency of light is significantly higher than that of AC current.
- There is no energy loss due to heating (as there would be in copper wire)
- There is no electrical interference between fibres. Plastic coating on the fibres prevent lights bleeding from one fibre to another.
- Plastic and glass are cheaper materials than copper to manufacture transmission lines.
- The speed of light is substantially higher than the drift velocity of electrons, so data transfer rate is much higher.

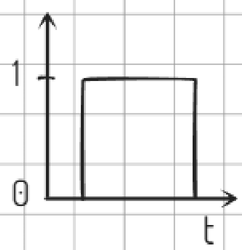
SIGNAL LOSS AND DISPERSION

Absorption

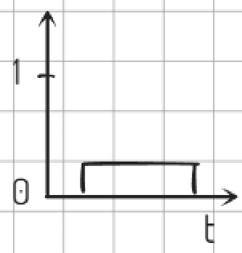
Some wavelengths are absorbed, leading to a reduction in signal intensity. Low absorption materials need to be used, and the transmitted signal is amplified to account for loss.



SENT



INTENDED



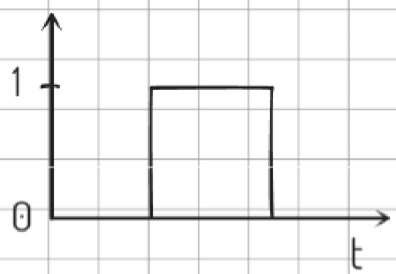
ABSORBED

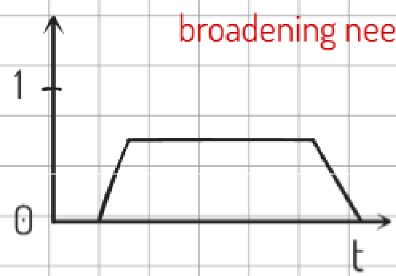
DISPERSION

MATERIAL DISPERSION

Refractive index varies with frequency. Different colours therefore travel at slightly different speeds. This can lead to pulse broadening.

This limits bandwidth as allowance for broadening need to be made.

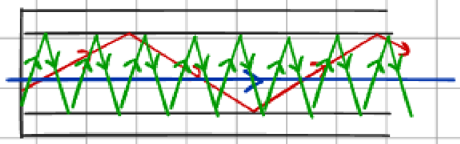




Use of monochromatic light can account for this.

MODAL DISPERSION

Occurs as rays take marginally different paths, again leading to pulse broadening.



Fibres must be VERY NARROW in order to limit the effects of modal dispersion.