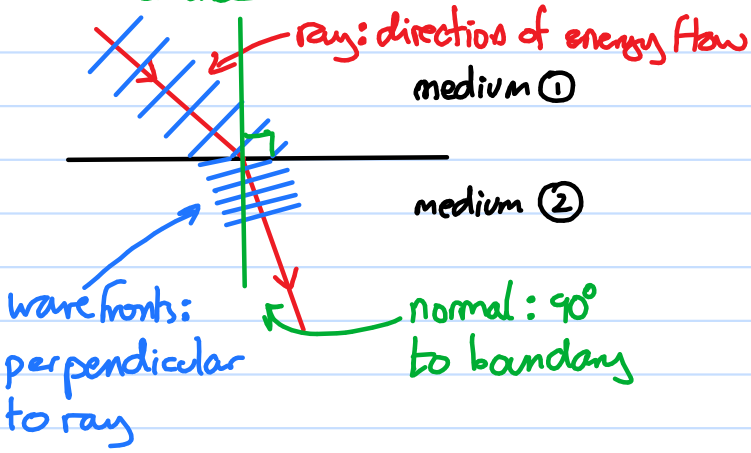
Refraction of light

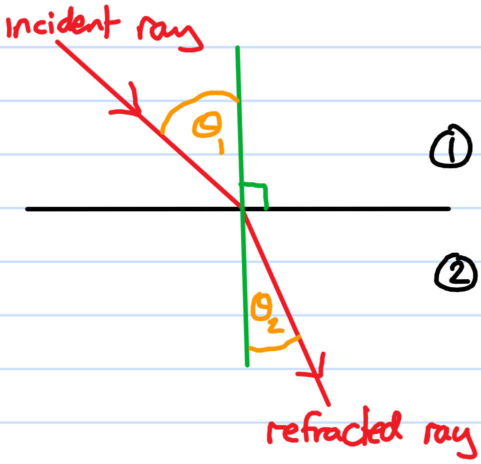
Three things light does when incident on a media boundary

hits boundary — media; stuff — boundary

1. transmission   2. reflection   3. absorption

no refraction if angle of incidence $= 0°$





θ_1 = angle of incidence in this case
θ_2 = angle of refraction " " "

$\theta_1 = i = \theta_i$ $\theta_2 = r = \theta_r = \theta_t$

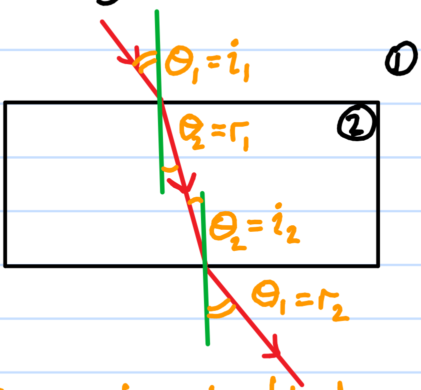
The point is: BE CAREFUL WITH NOTATION

refractive index → $\cancel{n = \dfrac{\sin i}{\sin r}}$

UH OH! Only works for light leaving a vacuum

$n_m = \dfrac{c_0}{c_m}$ ← c_0: speed of light in vacuo; c_m: speed of light in medium ✓

Geometry:

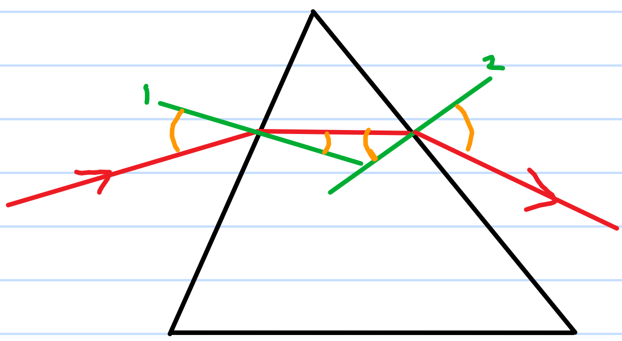


$n_2 > n_1$

$n_2 = \dfrac{\sin i_1}{\sin r_1}$ if $n_1 = 1$

$n_2 = \dfrac{\sin r_2}{\sin i_2}$ if $n_1 = 1$

For rectangular blocks
$i_1 = r_2$ $r_1 = i_2$



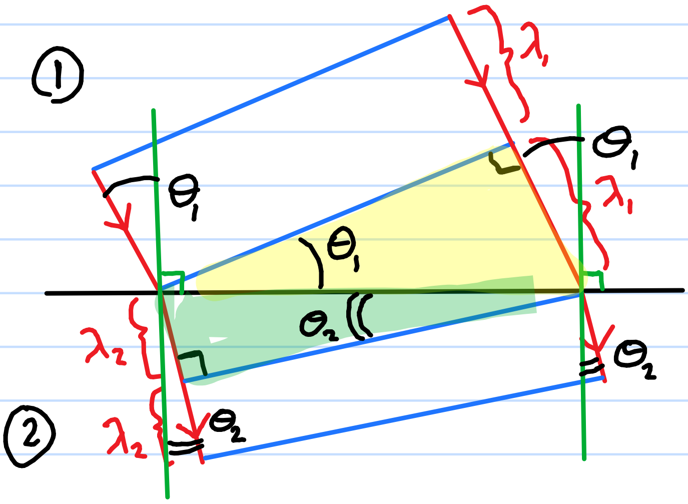
More about refraction

Snell's law : $n = \frac{\sin i}{\sin r}$ (weak equation)

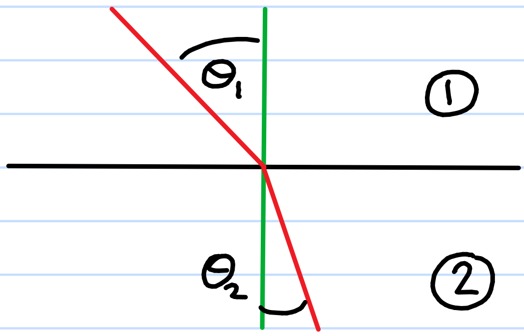
$n_m = \frac{c_0}{c_m}$ ← speed of light in vacuo / ← speed of light in medium

↑ refractive index

Only works for light leaving a vacuum and entering medium



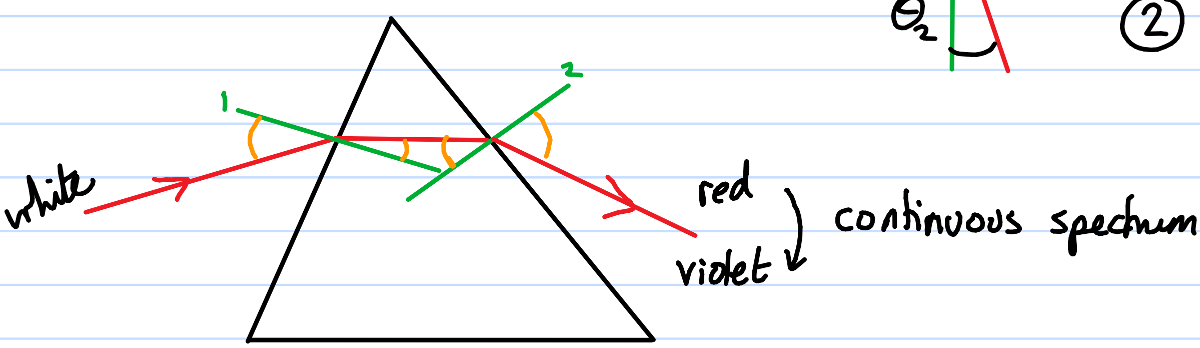
- Hypotenuse of yellow triangle (1) is equal to hypotenuse of green triangle (2)
- $\sin\theta_1 = \frac{\lambda_1}{hyp}$ • $\sin\theta_2 = \frac{\lambda_2}{hyp}$
- $\frac{1}{\lambda_1}\sin\theta_1 = \frac{1}{hyp}$ • $\frac{1}{\lambda_2}\sin\theta_2 = \frac{1}{hyp}$
- $\frac{1}{\lambda_1}\sin\theta_1 = \frac{1}{\lambda_2}\sin\theta_2$
- $f_1 = f_2 = f$
- $\times \frac{c_0}{f}$
- $\frac{c_0}{f\lambda_1}\sin\theta_1 = \frac{c_0}{f\lambda_2}\sin\theta_2$
- $c_1 = f\lambda_1 \quad c_2 = f\lambda_2$
- $\frac{c_0}{c_1}\sin\theta_1 = \frac{c_0}{c_2}\sin\theta_2$
- $\boxed{n_1 \sin\theta_1 = n_2 \sin\theta_2}$



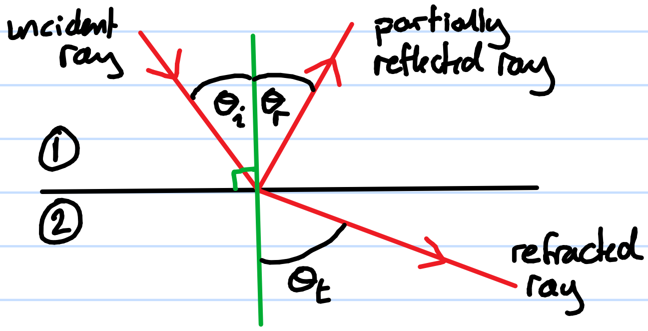
$n_{vacuum} = 1$
$n_{air} = 1.0003$
$n_{water} = 1.3$
$n_{glass} = 1.5$
$n_{diamond} = 2.2$

White light can be split (dispersion) by a prism into continuous spectrum because n depends slightly on λ
red is faster than violet in glass $n(\text{red}) < n(\text{violet})$

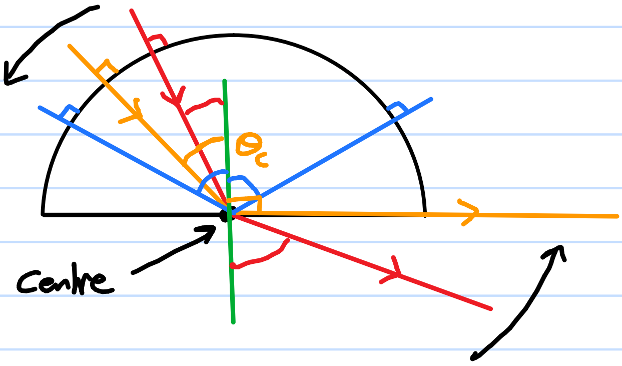
Dispersion



Total internal reflection



- if $\theta_t \leqslant 90°$, we have partial internal reflection
- (the light is "internally reflected" because it stays in the more optically dense medium)



Law of reflection : $\theta_i = \theta_r$

Snell's law : $n_1 \sin\theta_1 = n_2 \sin\theta_2$

As θ_i increases, θ_r increases AND θ_t increase

- $n_1 > n_2$ light coming from higher optical density (refractive index)
- $\sin\theta_i \propto \sin\theta_t$
- θ_t cannot exceed $90°$
- $n_1 \sin\theta_i = n_2 \sin 90°$ (Maximum θ_t)
- $\theta_i = \arcsin\left(\frac{n_2}{n_1}\right)$

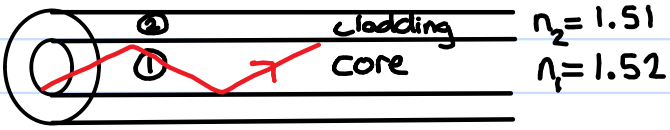
$\boxed{\sin^{-1} x = \arcsin x}$

$\sin^2 x = (\sin x)^2$

- $\theta_i = \theta_c$ the critical angle : the maximum angle of incidence that causes refraction
- if $n_1 > n_2$ (internal) and $\theta_i > \theta_c$ then we have TOTAL INTERNAL REFLECTION

Uses

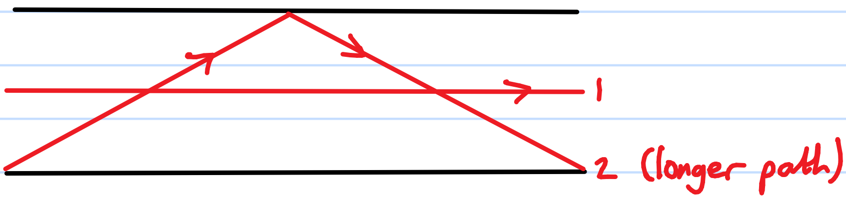
- Endoscopy

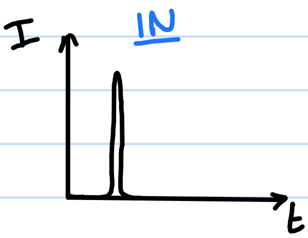


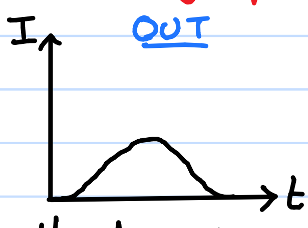
See inside body using a bundle of optical fibres

$$\theta_c = \arcsin\left(\frac{n_2}{n_1}\right) = \arcsin\left(\frac{1.51}{1.52}\right) = 83.4°$$

- Data transmission



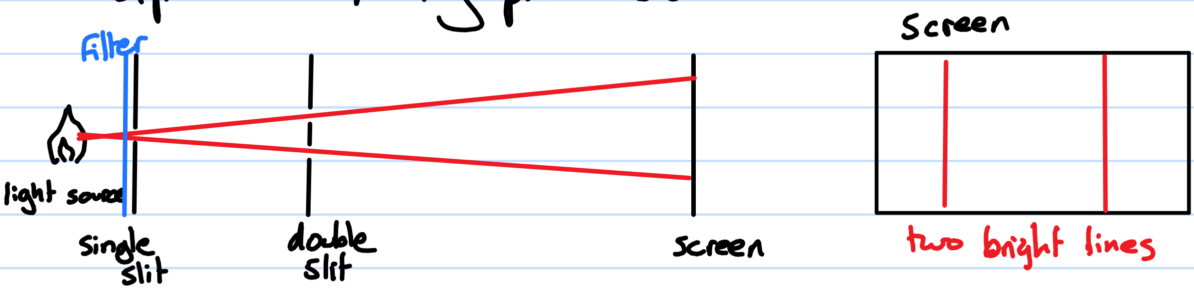




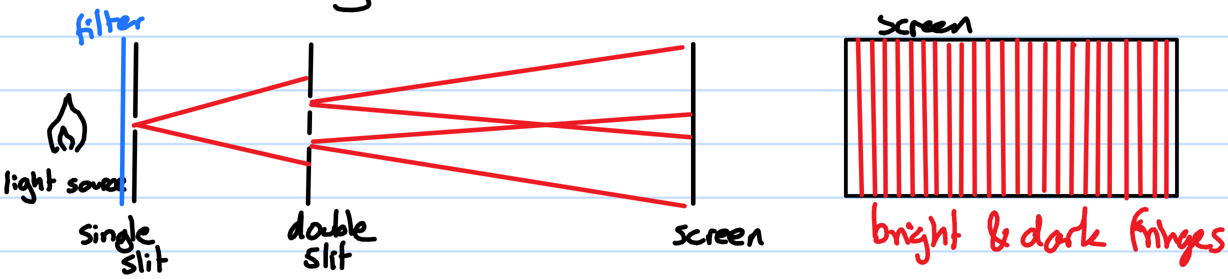
- multipath dispersion

Double slit interference

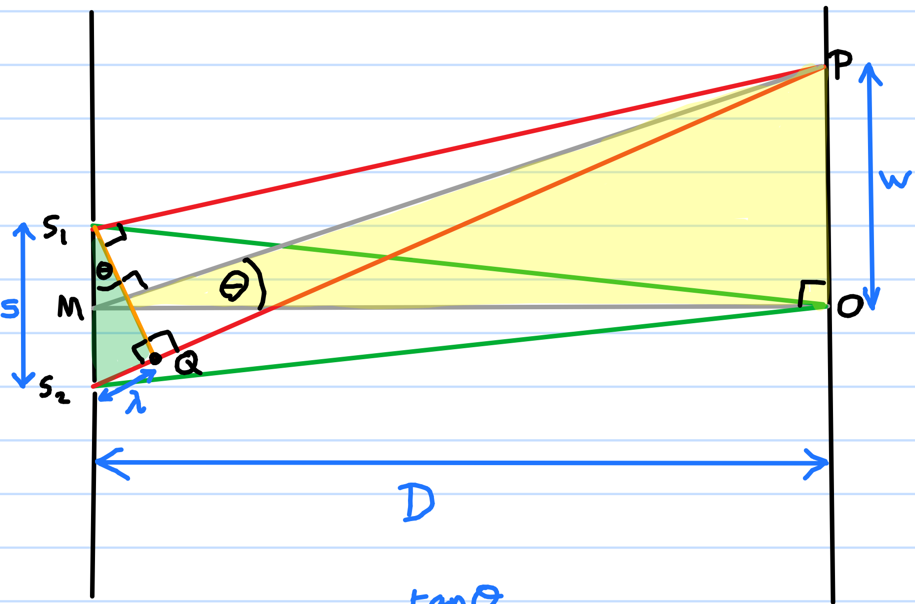
Corpuscular theory predicts:



Thomas Young observed:

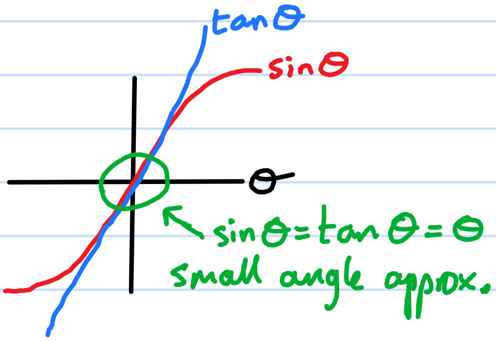


Derivation of two-slit fringe equation:



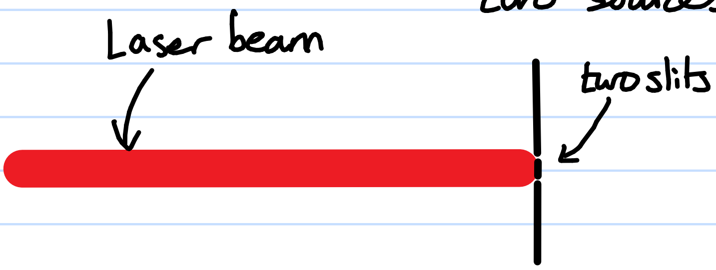
- $S_1O = S_2O \quad \therefore \Delta x = 0$
- $\Delta\phi = 2\pi\frac{\Delta x}{\lambda} \quad \therefore \Delta\phi = 0$ so in phase
- constructively interfere, bright fringe
- If bright fringe at P and no other bright fringes between O and P
- $\Delta\phi = 2\pi$ between S_1P and S_2P
- So $\Delta x = \lambda$
- $\theta_M = \theta_{S_1}$
- Green triangle nearly similar to yellow triangle
- Yellow triangle: $\tan\theta = \frac{W}{D}$
- Green triangle: $\sin\theta = \frac{\lambda}{s}$
  ONLY TRUE IF θ IS SMALL
- Small angle approx. $\sin\theta = \tan\theta$
- $\frac{W}{D} = \frac{\lambda}{s}$ $\quad \boxed{W = \frac{\lambda D}{s}}$

Only valid if $D \gg \lambda$



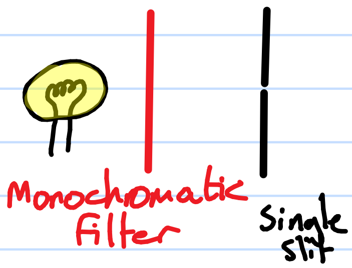
More about interference

Coherent sources: two sources with constant phase difference $\Delta\Phi$.
two sources with same frequency



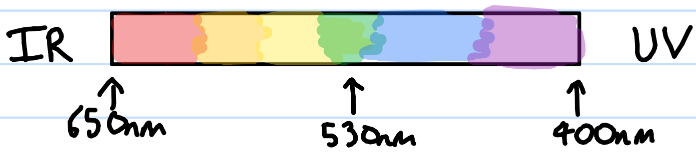
- Lasers produce coherent beam
- Lenses can be used to diverge beam, make it wider so both slits illuminated

OR



For white light:

$w = \frac{\lambda D}{s}$ for different λ, we get different w

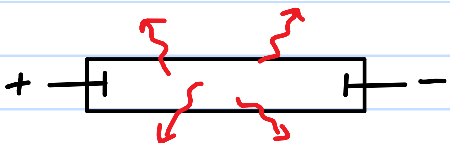


Two slit interference for white light:

$\lambda_{violet} < \lambda_{red} \therefore w_{violet} < w_{red}$

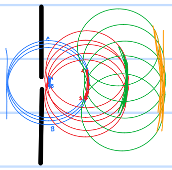
Other light sources:

- Giessler tube/gas discharge lamp



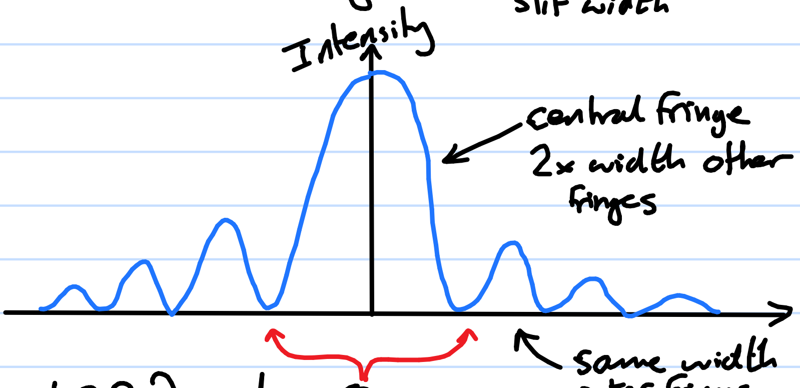
- The Sun + filter
- Fire/candle

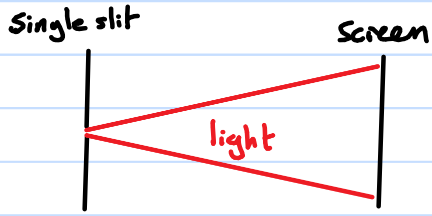
Diffraction "The spreading out of a wave"



Huygen's wave principle: Each point on a wavefront is a source of a new wavelet and the superposition of those wavelets produces the next wavefront

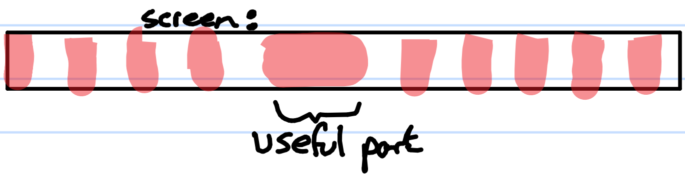
- Diffraction angle $\propto \frac{\text{wavelength}}{\text{slit width}}$



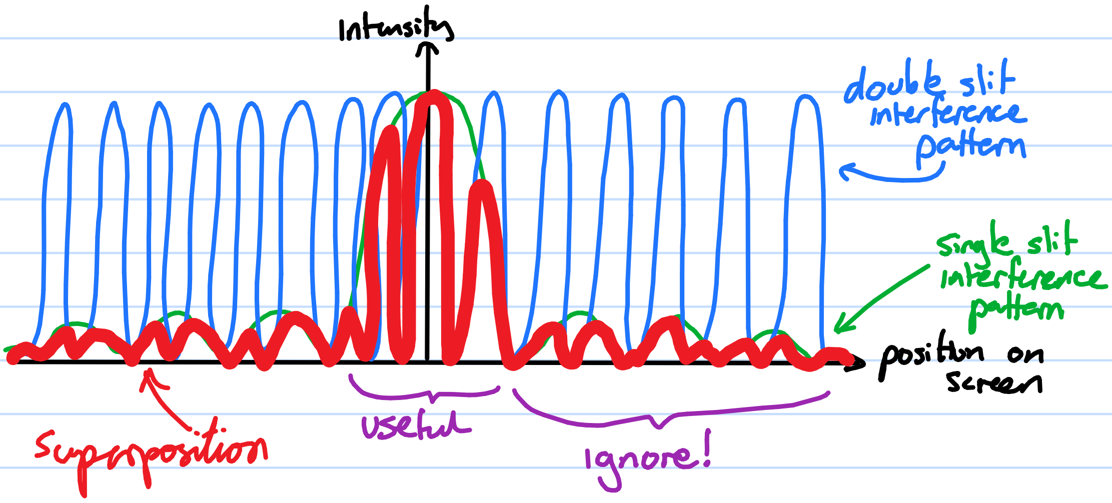


$1.22\lambda = d \sin\theta$

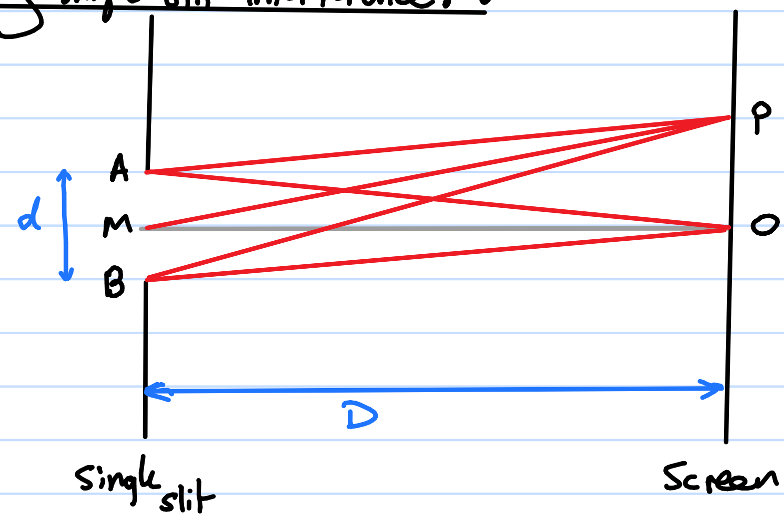
width of single slit



Double slits of finite width:



Why single slit interference?:



Single slit is an infinite number of infinitesimally spaced sources

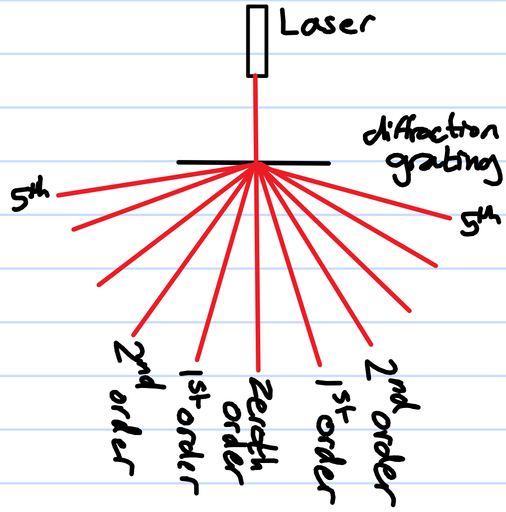
The diffraction grating

Lots of slits that are close together

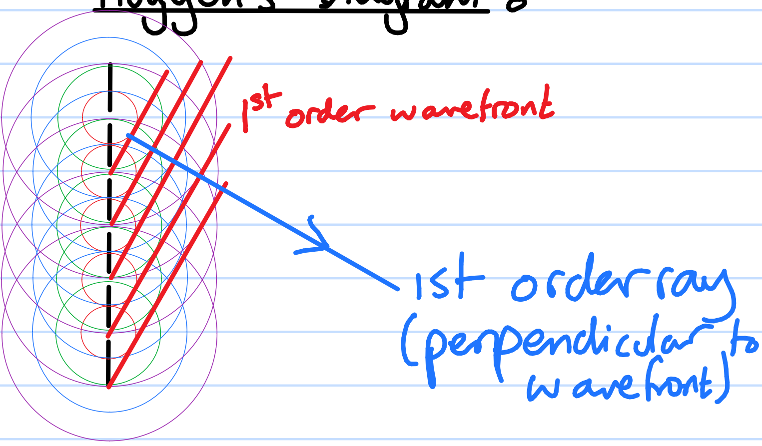
300 Slits mm^{-1} $\Rightarrow$ $\frac{1}{300}$ mm between each slit

600 slits mm^{-1} $\Rightarrow$ $\frac{1}{600}$ mm between each slit

$(2n_{max}+1)$ spots on a screen



Huygen's diagram:



Derive equation:

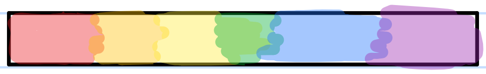
For each adjacent slit we add integer number of wavelengths path difference

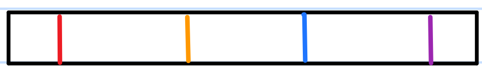
$\sin\theta = \frac{n\lambda}{d}$ $\quad$ $n\lambda = d\sin\theta$

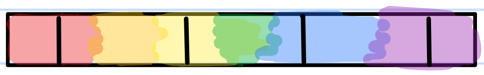
$60' = 1^\circ$	($60' = 60$ arcminutes)
$60'' = 1'$	($60'' = 60$ arc seconds)

Types of spectrum:

- Continuous spectrum (filament lamp)
- Line emission spectrum (gas discharge lamp)
- Line absorption spectrum (white light passed through a glowing gas has colours removed)

IR  UV

IR  UV

IR  UV

Calculating maximum order:

$\theta = 90^\circ$ $\quad$ $n\lambda = d\sin\theta$

$n = \frac{d}{\lambda}$ highest integer!