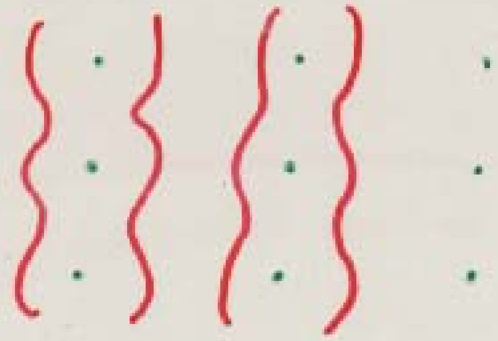
Polarization continued - Birefringence (● Thurs lab)

Some crystals transmit EM waves at different speeds depending on orientation of $\vec{E}$

e.g.

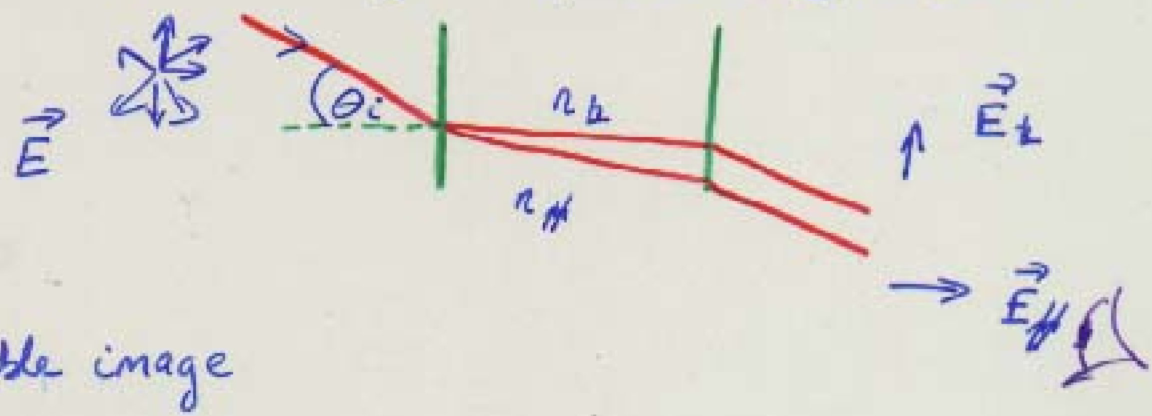


electron clouds have different restoring force in $\updownarrow$ and $\leftrightarrow$ directions

$\Rightarrow$ two refractive indices $n_\perp$ and $n_\parallel$

e.g. calcite, also Scotch tape, cellophane wrap

Result: un-polarized light refracted along 2 paths



$\Rightarrow$ double image

Applications: Stress can align ("stretch") molecules in plastics, glass $\rightarrow$ birefringence.

View through crossed polaroid filters

$\rightarrow$ photoelastic stress imaging.

Interference

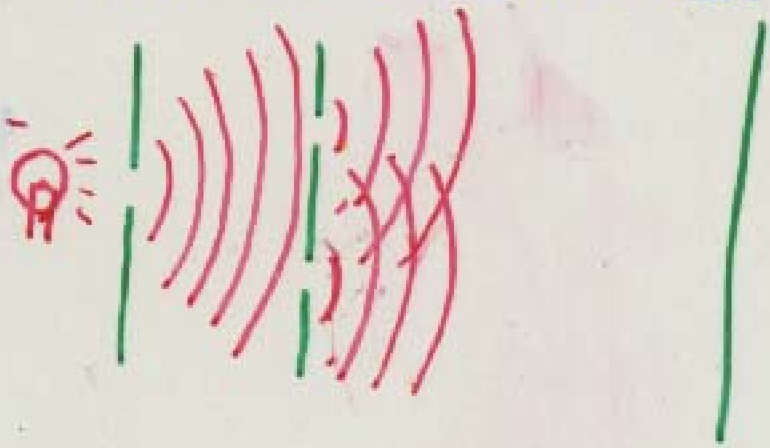
Two EM waves can add constructively: 

or destructively 

As long as sources are <u>coherent</u> (same offset in phase over time), interference pattern is stationary (i.e. can be observed)

Young's Experiment

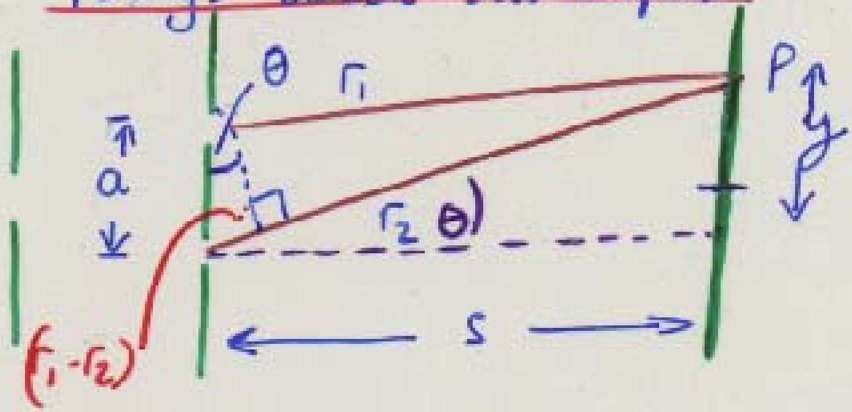
Single source illuminates 2 slits – easy way to make two coherent sources

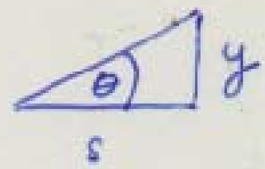


⇒ interference pattern on screen

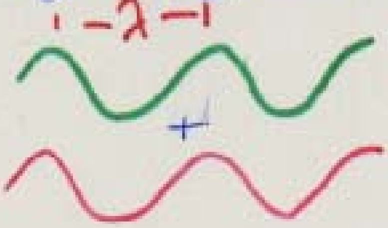
(bright fringe : constructive
dark : destructive)

Young's Double-Slit Expt.





Bright fringe (constructive) when path length **difference**



$$(r_1 - r_2) = m\lambda \quad m = 0, \pm 1, \pm 2 \ldots$$

For a point P at angle θ from mid-point of slits

$$(r_1 - r_2) = a \sin\theta \quad \begin{cases} = m\lambda & \text{(bright fringe)} \\ = (m + 1/2)\lambda & \text{(dark fringe)} \end{cases}$$

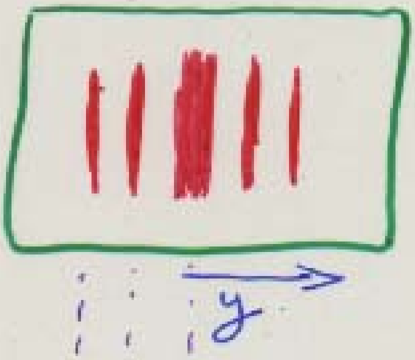
$\therefore$ for bright fringe, $\sin\theta = \dfrac{m\lambda}{a}$.

If screen is at distance s from slits, displacement of P from centerline is $y = s\tan\theta \approx s\sin\theta$ for small θ.

$\therefore$ Bright fringes found at $y_m = \dfrac{s\,m\lambda}{a}$: $m = \pm 0, \pm 1, \pm 2 \ldots$

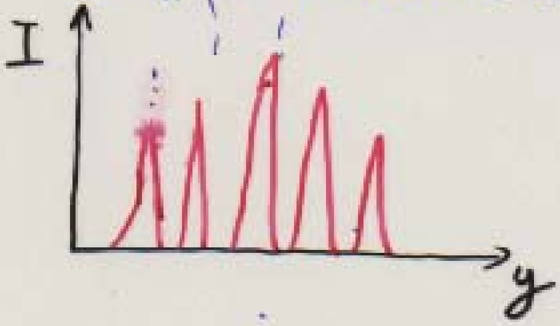
separated by dark fringes at $y_m = \dfrac{s\,(m + 1/2)\lambda}{a}$

Fringe spacing $(\Delta m = 1) \Rightarrow \Delta y = \dfrac{s\lambda}{a}$.



Resulting finge pattern for monochromatic light

Can plot irradiance as function of position:



e.g. (Hecht ex 25.4) : double-slit with $a = 0.2$ mm,

$\lambda = 632.8$ nm (He/Ne laser)

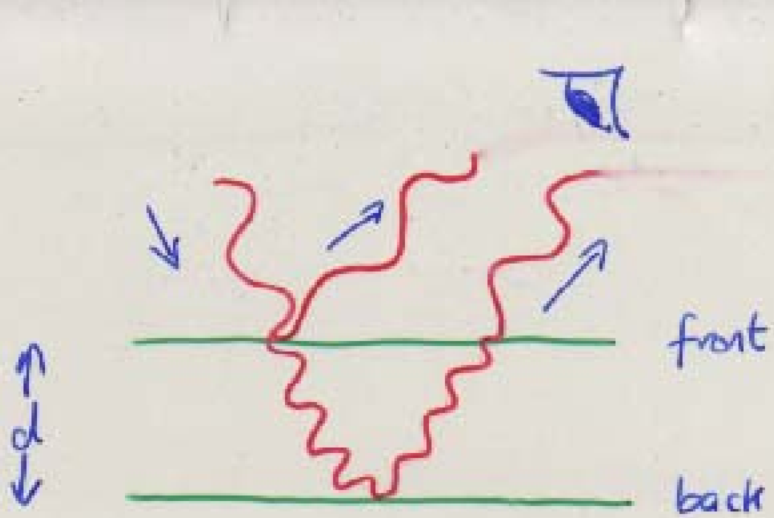
$\Rightarrow$ first <u>minimum</u> (dark finge) where $\sin\theta = \dfrac{(m+\frac{1}{2})\lambda}{a}$; $m = 0$

$\Rightarrow \theta_1 = \pm \frac{1}{2}\lambda/a = \pm 1.58 \times 10^{-3}$ rad.

If screen is 2m away ($s = 2$m), then this finge is formed at $y_1 = s\tan\theta_1 \approx s\sin\theta_1 = s.\theta.$ for small angles

$\Rightarrow y = 2\text{m} \times 1.58 \times 10^{-3}\,\text{rad} = \underline{\pm 3.2\,\text{mm}}.$

Thin Film Interference



When light with λ reflects off a thin film,

$\Rightarrow$ interference between front and back-side reflections.

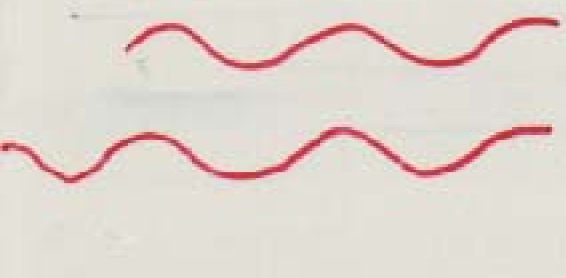
Beam from back surface travels an extra

path length $\approx 2d$ (for $\theta = 0^\circ$, normal incidence)

Wavelength in film $\lambda_f = \lambda_0 / n_f$

$\Rightarrow$ wavelength shift $\Delta N = \dfrac{2d}{\lambda_f} = \dfrac{2dn_f}{\lambda_0}$

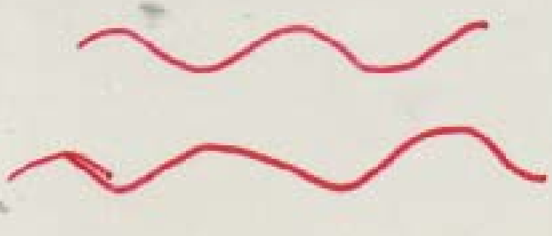
$\therefore$ Phase shift (at 2π per wavelength) $\Delta\varphi = 2\pi\Delta N = \dfrac{4\pi d n_f}{\lambda_0}$



: constructive $\Delta N = m\lambda$

$\Delta\varphi = 2\pi m$

$m = 0, \pm 1, \pm 2 \ldots\ldots$



: destructive $\Delta N = (m + 1/2)\lambda$

$\Delta\varphi = (2m+1)\pi$

Anti-reflection coatings

If front + back-reflected light interferes destructively
$\Rightarrow$ reflected light "cancelled" out

Then $\Delta\phi = \frac{4\pi d n_f}{\lambda_0} = (2m+1)\pi \quad m = 0, 1, 2, \ldots$

$= \pi, 3\pi, 5\pi, \ldots$

coating thickness $d = \underbrace{\frac{\lambda_0}{4n_f}}\cdot(2m+1)$

$= \frac{\lambda_f}{4}(2m+1)$

So min. thickness $(m=0, \Delta\phi = \pi) \Rightarrow d_{min} = \frac{\lambda_f}{4}$

results in ½-wavelength shift in phase

e.g. For MgF_2 coating $(n = 1.38)$, yellow light (550 nm)

film thickness on glass lens should be

$d = \frac{\lambda_0}{4n_f}(2m+1) = \frac{550}{4 \times 1.38}(2m+1) = 99.6\,nm \times (2m+1)$

$m = 0, +1, +2, \ldots$

$= 99.6\,nm$ or $298.8\,nm$ or $498.0\,nm$

Note: thickness only works for specific λ (choose mid-range visible)

Also: do not touch! Losing ~ 50nm of thickness destroys the effect!