Chapter 24 – Wave Optics

- Interference – Light that can take multiple paths from a coherent source and reach the same point will undergo INTERFERENCE

- TWO types of interference:
    - Constructive – path difference is equal to an integer number of wavelengths (0,1,2,…)
    - Destructive – path difference is equal to a half-integer #of wavelengths (0.5, 1.5, …)

- Interference is caused by delta, which we define as the path difference

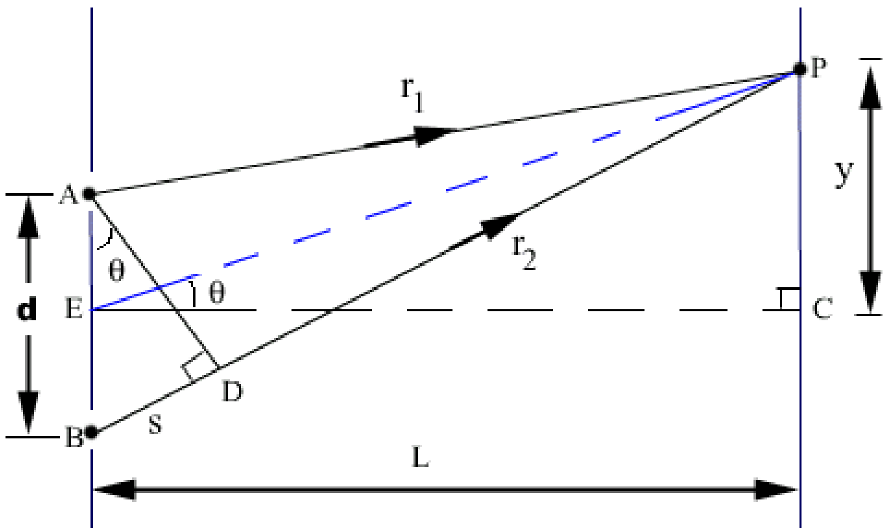
$$\delta = path\ difference$$

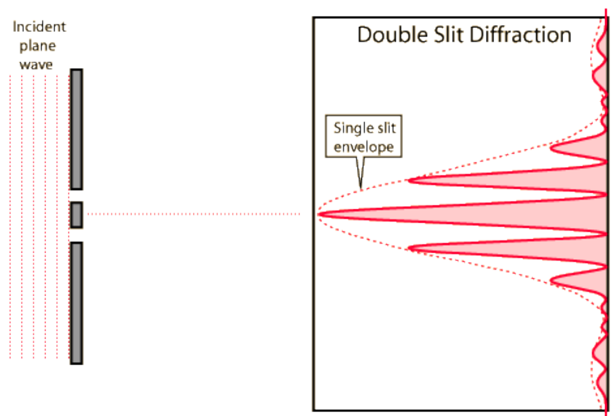
- Applying Conditions for interference:
    - Constructive Interference: $\delta = m\lambda \qquad m \in \mathbb{Z}$
        - Delta equals an integer times the wavelength
    - Destructive Interference: $\delta = \left(m + \frac{1}{2}\right)\lambda \qquad m \in \mathbb{Z}$
        - Delta equals a half integer times the wavelength

- For reflected light, if the index of refraction of the incident medium is less than the index for the reflected medium, then the reflected light will have a half-wavelength phase change.
    - $if\ \ n_r > n_i\ \ then\ light\ will\ have\ a\ \frac{\lambda}{2}\ phase\ change$
    - This is equivalent to increasing (or decreasing) the path difference

- Huygens Principle
    - Every point on a wavefront acts as a spherical point source of light, in phase with every other point on the wavefront. We see a coherent image when all of those point sources add up, we see interference when we block some of them.
- Diffraction Grating
    - A material with many closely spaced slits. These slits each act as a source of interference, and we get an exaggerated interference pattern by adding them together.
- Polarization
    - Light has a polarization defined by the orientation of its electric field. Most light sources create unpolarized light, we but can polarize that light, through either REFLECTION or with a POLARIZING FILTER.

__Young's Double Slit__





- L>>d
- Small Angle Approximation
  - $\sin\theta \approx \tan\theta \approx \theta \quad if \quad \theta < 0.1\, rad$

Path difference in this diagram is labeled as "s"

- Set path difference = m times wavelength for constructive (bright spot) interference
- Set path difference = (m+1/2) times wavelength for destructive (dark spot) interference

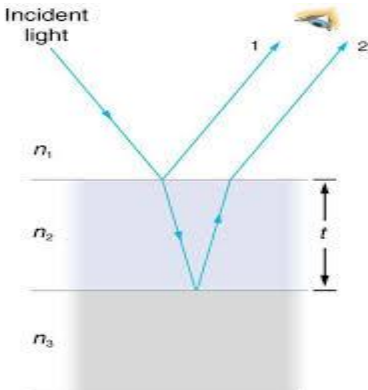
Equations for Young's Double Slit

1. $\boldsymbol{d\sin\theta = m\lambda \quad for\ constructive\ interference}$
2. $\boldsymbol{d\sin\theta = (m+\frac{1}{2})\lambda \quad for\ destructive\ interference}$

Using trigonometry and the Small Angle Approximation…

3. $\boldsymbol{\frac{dy}{L} = m\lambda \quad for\ constructive\ interference}$
4. $\boldsymbol{\frac{dy}{L} = (m+\frac{1}{2})\lambda \quad for\ destructive\ interference}$

Thin Film Interference



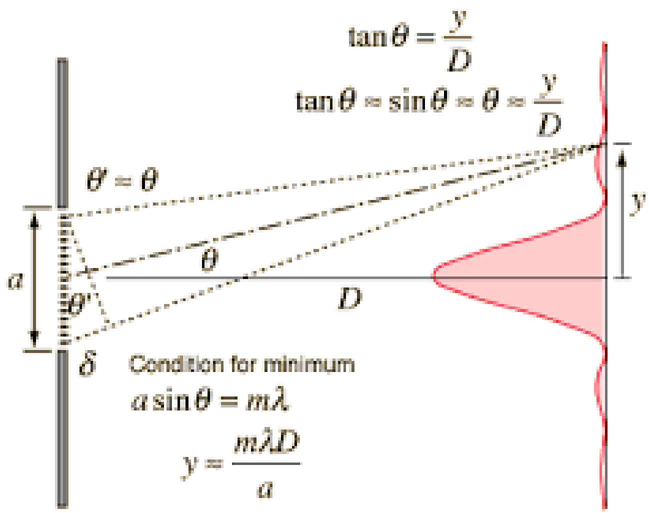
- Light that is incident upon a thin film will experience a path difference, and therefore we will observe interference
- Incident light will both reflect and transmit at the first boundary
  - The REFLECTED light may flip if the reflected medium has a higher index than the incident medium
- Light that transmits through the first boundary will hit the second boundary, where some will reflect and some will transmit.
  - The REFLECTED light may flip if the reflected medium has a higher index of refraction than the incident medium
- The transmitted light (ray 2 in the diagram) will travel a further distance than the reflected light (ray 1) and therefore we will observe interference.
- We apply the same conditions for interference:
  - Constructive Interference: $\delta = m\lambda \qquad m \in \mathbb{Z}$
    - Delta equals an integer times the wavelength
  - Destructive Interference: $\delta = \left(m + \frac{1}{2}\right)\lambda \qquad m \in \mathbb{Z}$
- However, delta will consist of two parts:
  1. Physical path difference (two times the thickness of the film)
  2. Possibly need to keep track of flips (phase changes)

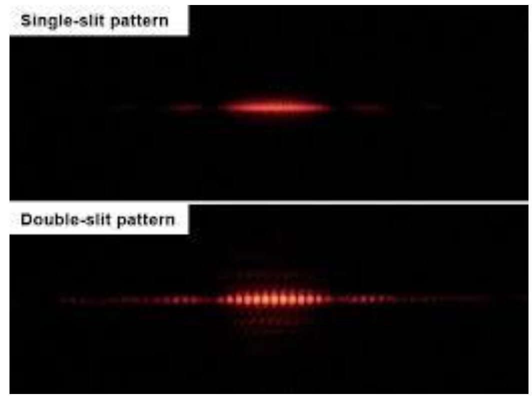
$$\delta = 2t + (\#\ of\ phase\ changes\ due\ to\ reflection)\frac{\lambda}{n}$$

- If the number of chase changes is even, they will cancel out. If the number of phase changes is odd, the net phase change will be one half wavelength.

Equations for Thin Film Interference	**Even Number of Phase Changes**	**Odd number of Phase Changes**
$\boldsymbol{2t = (m + \frac{1}{2})\frac{\lambda}{n}}$	**Destructive**	**Constructive**
$\boldsymbol{2t = m\frac{\lambda}{n}}$	**Constructive**	**Destructive**

Single Slit Interference





- Because of Huygen's Principle, each point on a wavefront acts as a spherical point-source. We block some of those sources, and only let a small portion pass through the slit. We will no longer have a wave-front that is fully constructive, but we will have destructive points as well.
- We can calculate the angle and position of dark spots, but we cannot for bright spots.

$$\delta = \frac{a}{2}\sin\theta = \left(m + \frac{1}{2}\right)\lambda \ \ \mathit{for\ destructive\ points}$$

- By simplifying this equation, we get that:

$$\boldsymbol{a\sin\theta = m\lambda \quad where\ m = \pm 1, \pm 2, \pm 3, etc \quad m \neq 0}$$

- We CANNOT calculate for bright spots!!!

Diffraction Grating

- A diffraction grating is a series of closely placed slits, each providing its own interference pattern. The summation of those interference patterns gives an easy to see, exaggerated interference pattern. We see almost completely destructive interference outside of peaks, and therefore we have very sharp, thin peaks.

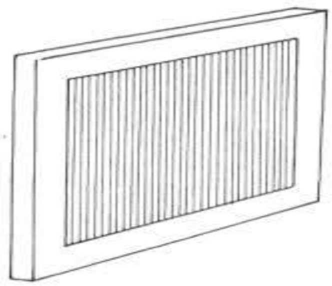
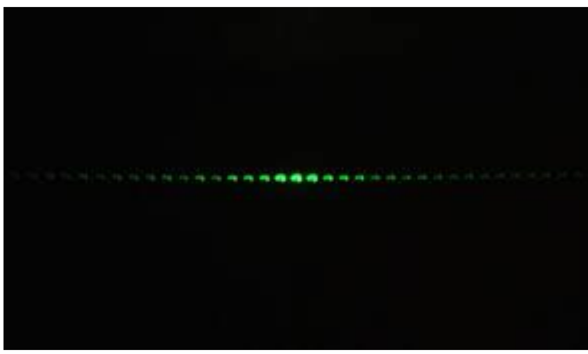
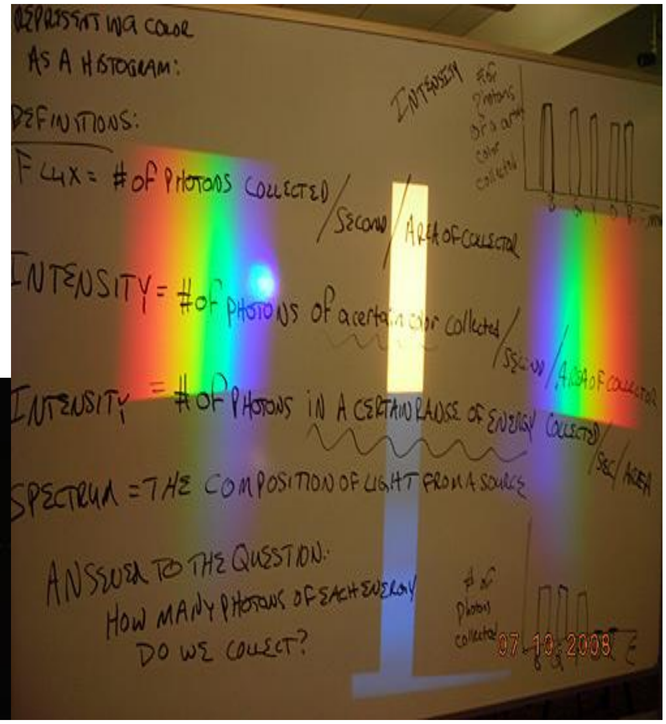


Figure 4 Diffraction grating





- Interference pattern is the same as for single-slit
- For maxima:

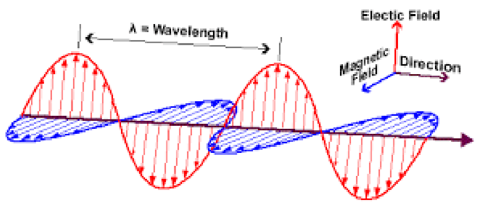
$$a \sin \theta = m\lambda \quad where\ m = 0, 1, 2, 3, etc$$

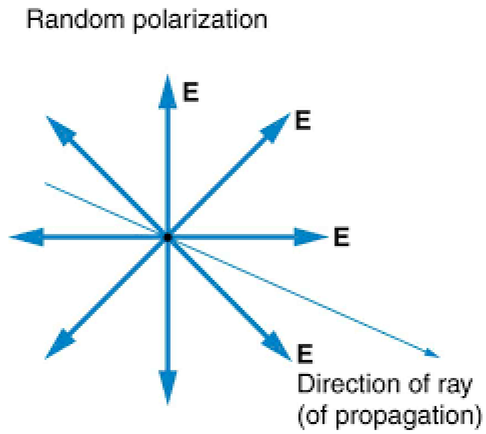
a = slit separation

m = order number

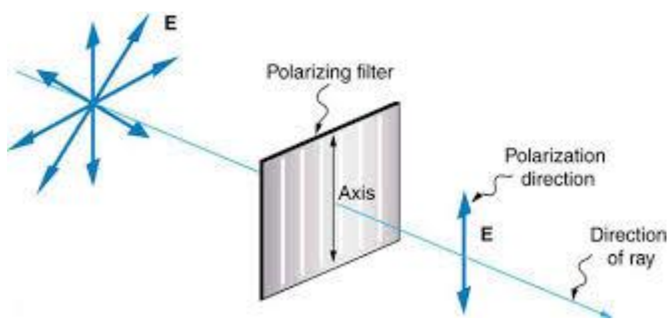
- Every other point not a maximum is very nearly a minimum.
- Bright spot in middle is zeroth order. Each peak passed this is numbered 1st, 2nd, etc.

Polarizing Filters

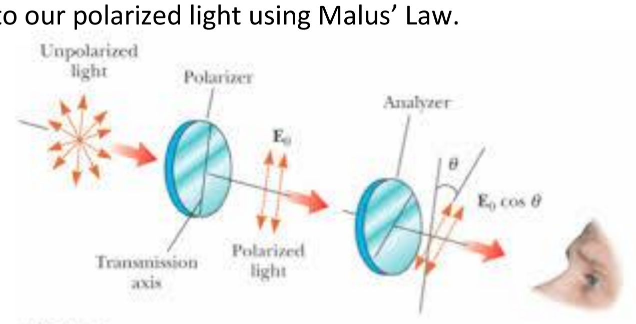




- Light has polarization which tells us the orientation of the electric-field.
- Most light sources produce unpolarized light. We can polarize with a polarizing filter or reflection.

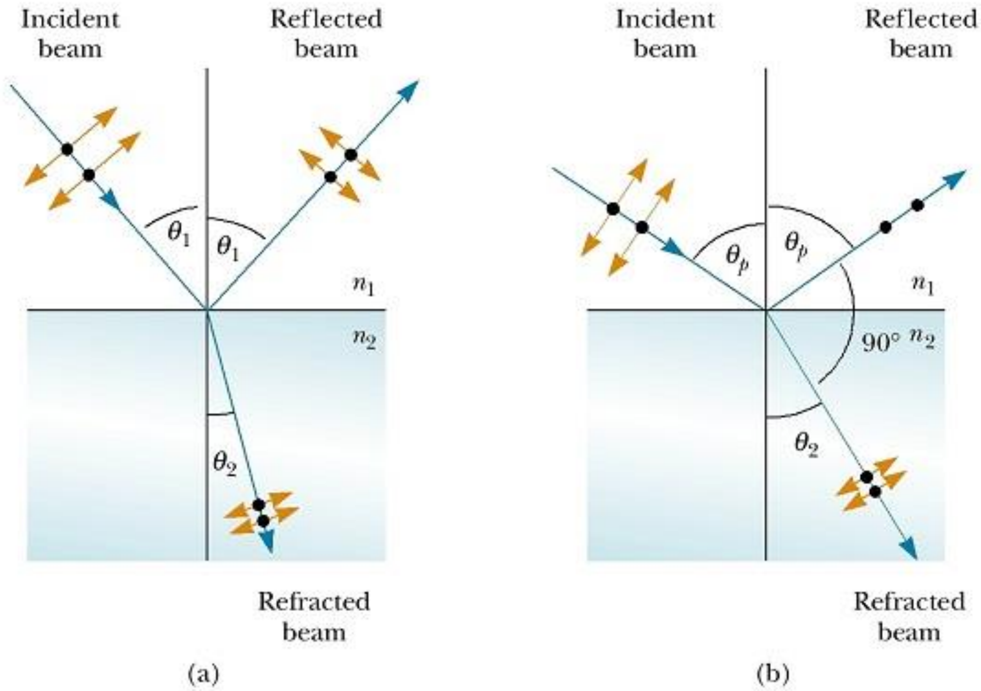


- If the unpolarized light has an intensity I_0, then after it passes through a filter it has intensity $0.5*I_0$
- Once we have polarized light, we can measure how much transmits through a polarizer oriented at some angle to our polarized light using Malus' Law.



$$I = I_0 \cos^2 \theta \quad where\ \theta = angle\ between\ polarization\ axis$$

Polarization by Reflection



- Light can be polarized when it reflects off a boundary between mediums with different indexes of refraction.
- When unpolarized light hits a boundary, some will refract through the medium and some will reflect off the boundary. When reflected and refracted rays are perpendicular, the reflected beam is completely polarized, parallel to the boundary (or surface). This critical angle is called Brewster's Angle.

$$\boldsymbol{n = \tan\theta_p}$$

Where: n = reflected medium

θ_p= Brewster's Angle