PURDUE UNIVERSITY DEPARTMENT OF PHYSICS

Physics 24100

Electricity & Optics

Lecture 27 – Chapter 33 sec. 7-8

Fall 2012 Semester

Matthew Jones

ANNOUNCEMENT

***Exam 1**: Friday December 14, 2012, 8 AM – 10 AM

***Location:** Elliot Hall of Music

*Covers all readings, lectures, homework from Chapters 29 through 33.

*The exam will be multiple choice.

Be sure to bring your student ID card and a hand-written one-page (two sided) crib sheet plus the crib sheets that you prepared for exams 1 and 2.

NOTE THAT FEW EQUATIONS WILL BE GIVEN – YOU ARE REMINDED THAT IT IS YOUR RESPONSIBILITY TO CREATE WHATEVER TWO-SIDED CRIB SHEET YOU WANT TO BRING TO THIS EXAM.

The equation sheet that will be given with the exam is posted on the course homepage. Click on the link on the left labeled "EquationSheet"

Clicker Question

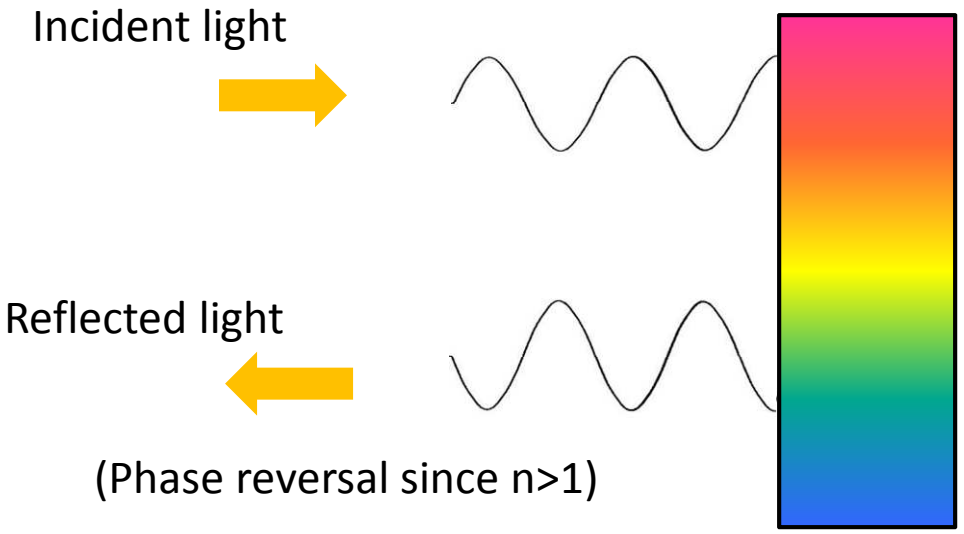
- Bright light of wavelength 585 nm is incident perpendicularly on a soap film (n = 1.33) of thickness 1.21 microns, suspended in air. Is the light reflected by the two surfaces of the film closer to interfering fully destructively or fully constructively?

(A) **fully constructively**

(B) fully destructively

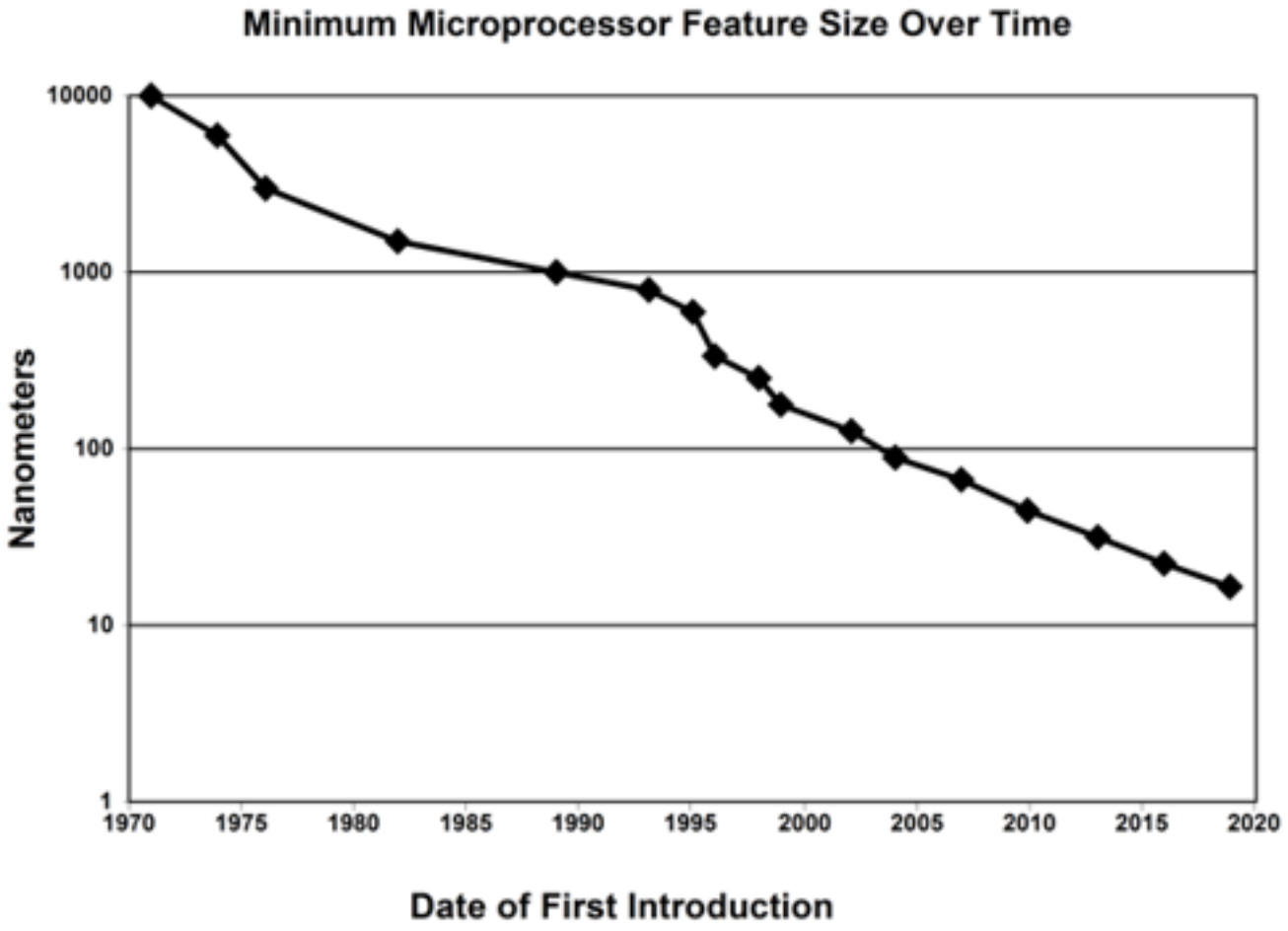
Interference

- Three ways to introduce a phase difference in two beams of coherent light:
  - Different path length
  - Different index of refraction
  - Reflection from a material with a larger n



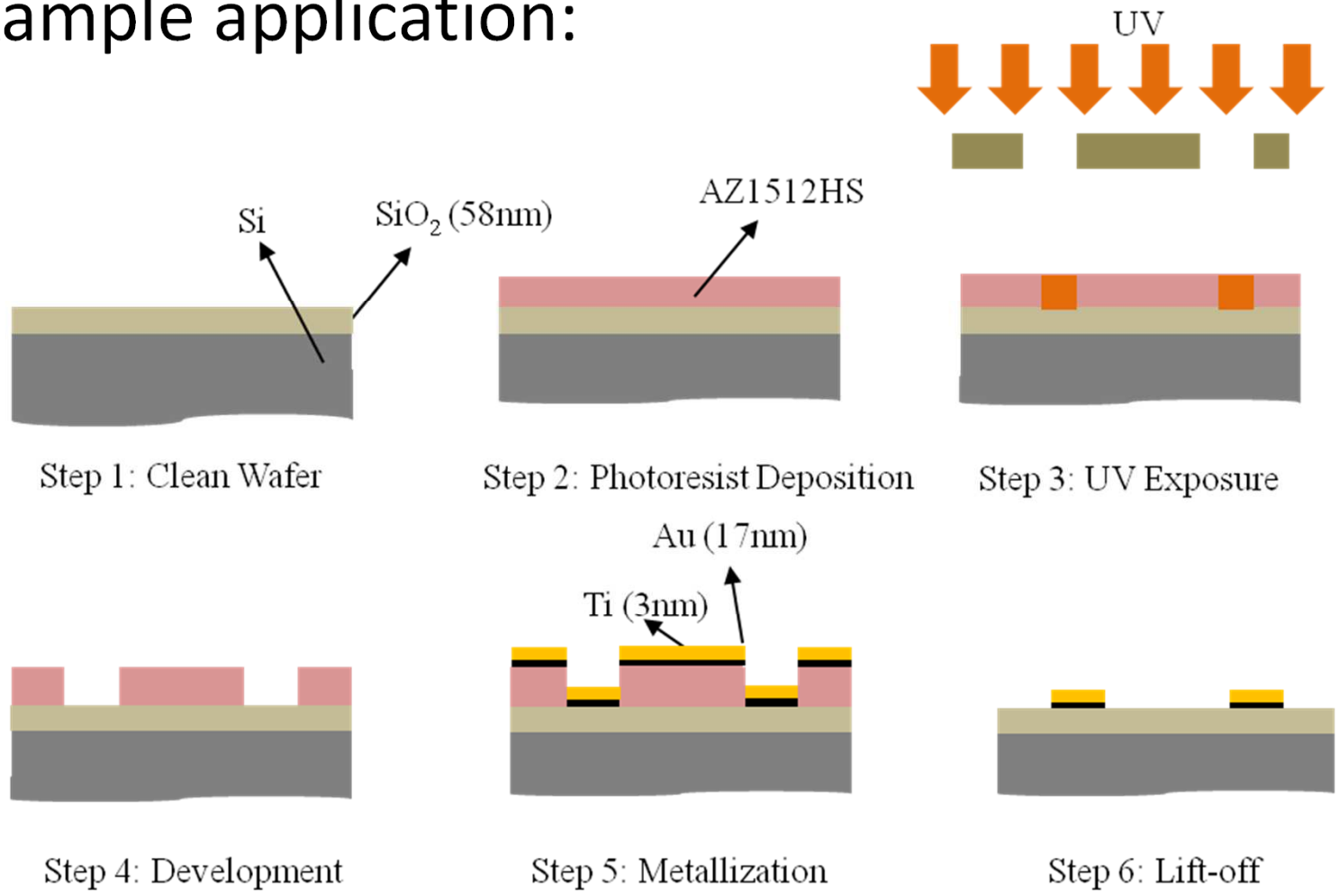
t = 1.21 μm
n= 1.33
λ_{air} = 585 nm
λ_{soap} = (585 nm)/1.33 = 440 nm
Number of wavelengths in the soap film: $2t/\lambda_{soap}$= 5.5
In phase with the reflected light. (constructive interference)

Moore's Law


Minimum Microprocessor Feature Size Over Time
Nanometers
10000
1000
100
10
1
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Date of First Introduction

Interference, Diffraction and Resolution

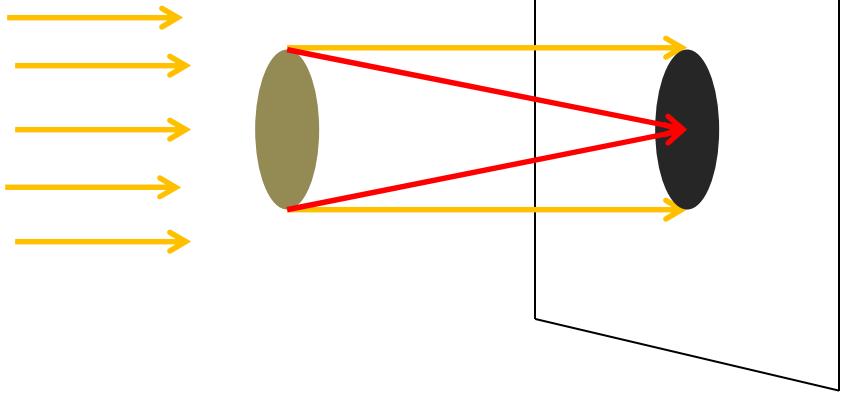
Example application:

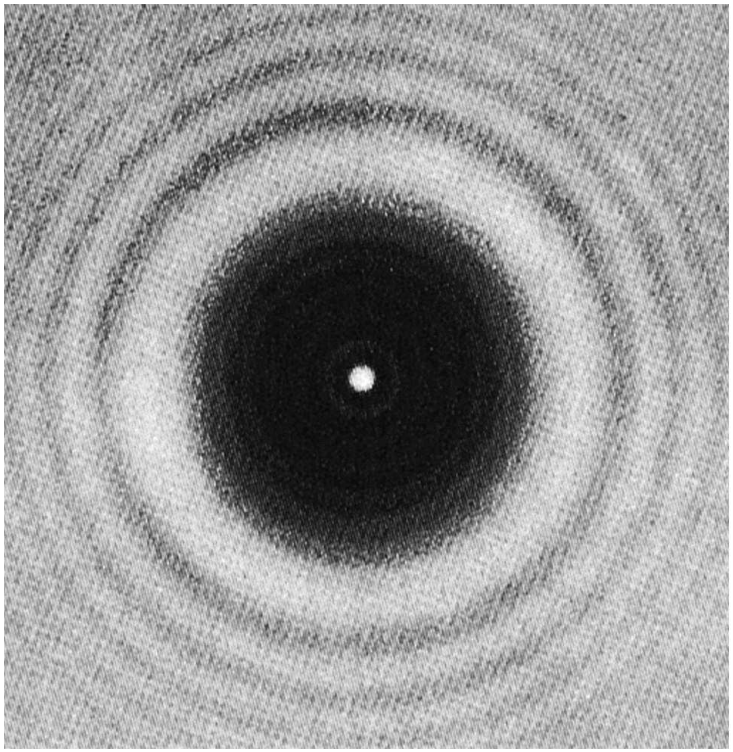


Diffraction

- Geometrical optics:
  - Edge, obstacle or aperture much larger than λ
  - Light travels in straight lines
  - Shadows have distinct, sharp edges
- Wave optics:
  - Feature sizes are similar to the wavelength, λ
  - Waves spread out around objects and can interfere constructively or destructively
  - Interference patterns of light and dark fringes

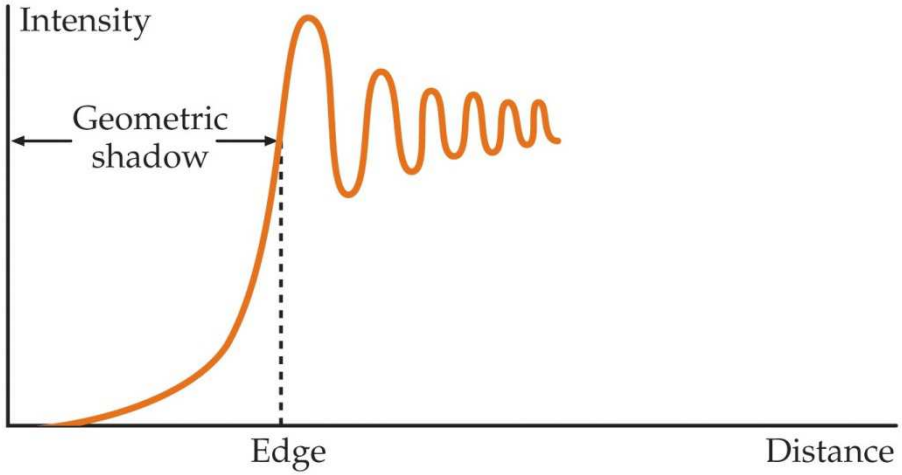
Fresnel Diffraction

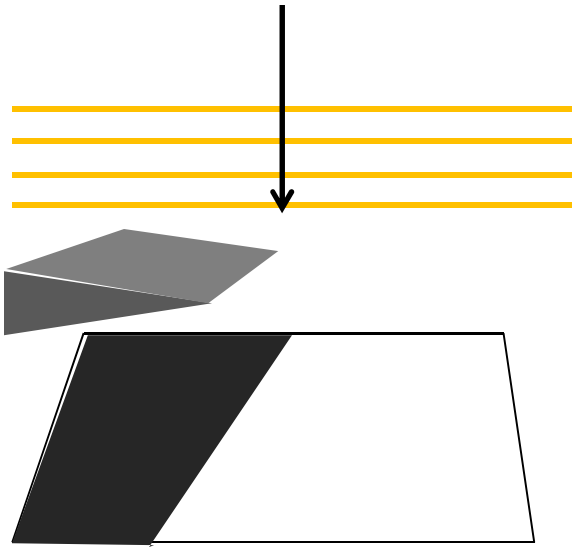


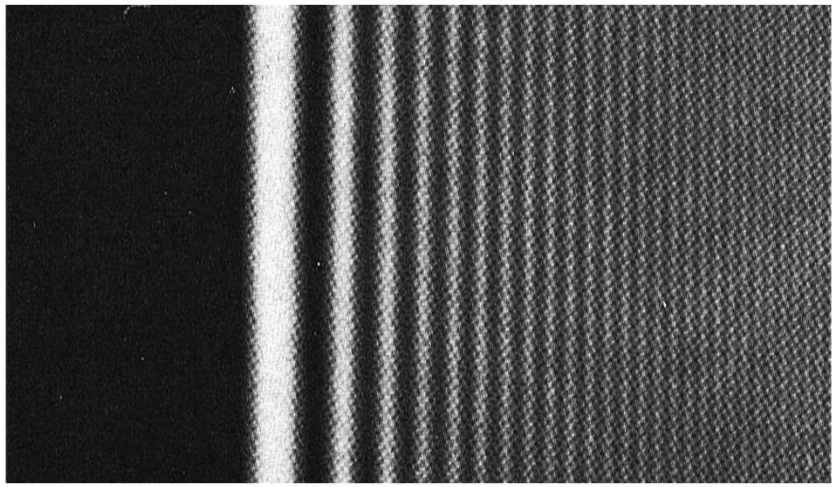


Two waves that touch the top and bottom parts of the disk travel the same distance to the center and interfere constructively.

Diffraction from and Edge

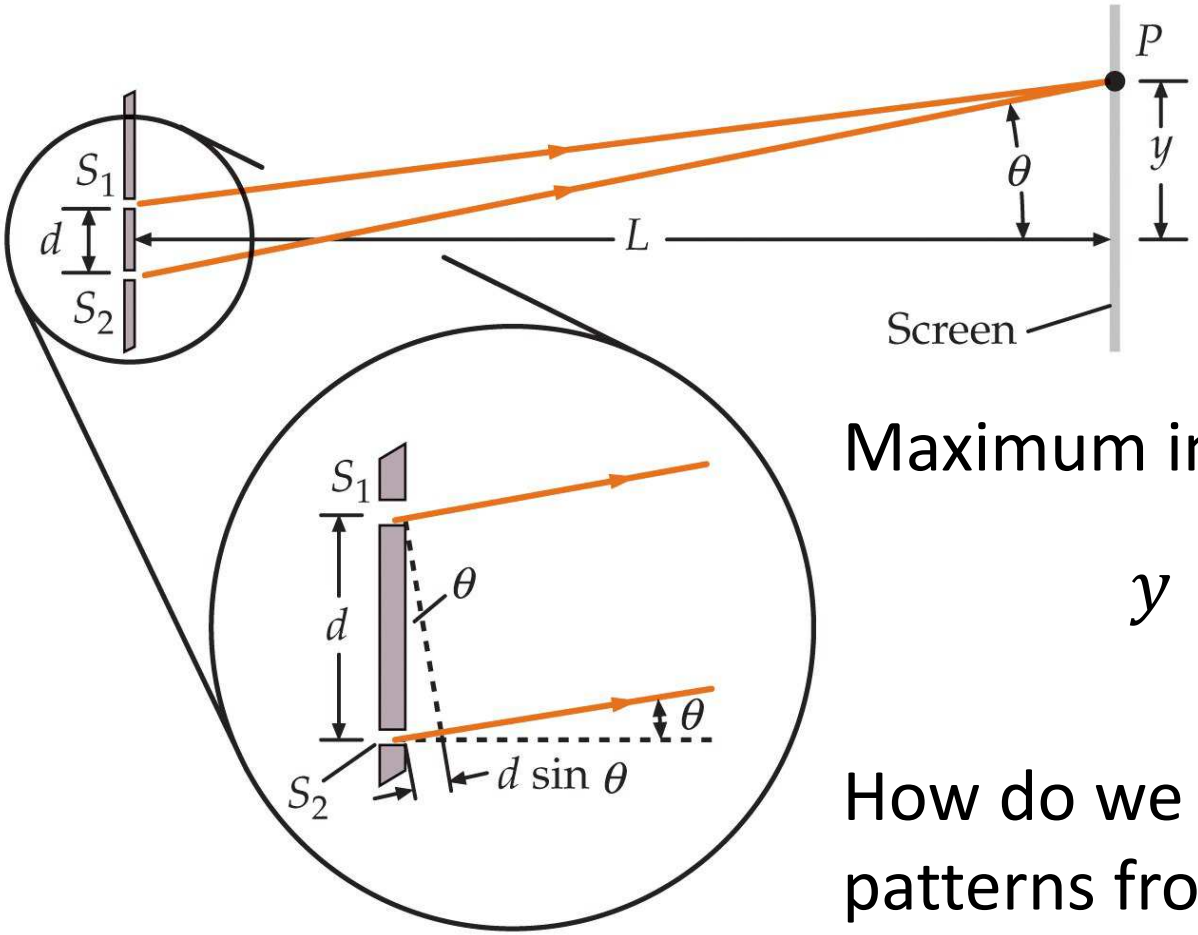






The shadow has a diffraction pattern within a few wavelengths of the edge.

Double Slit Diffraction

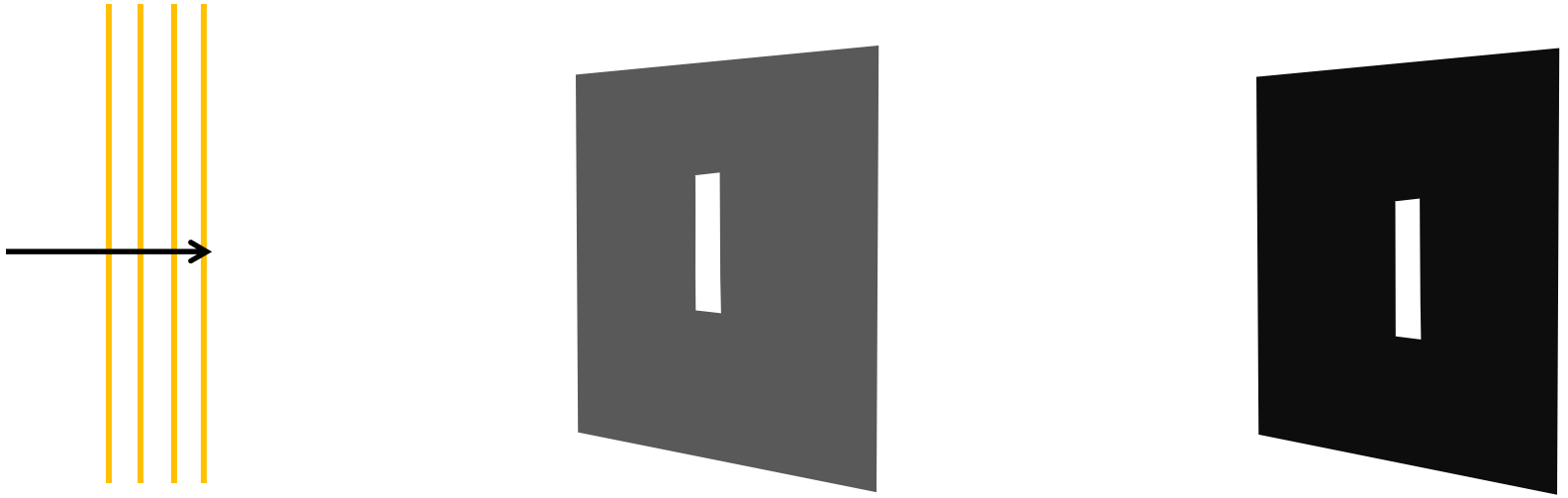


Maximum intensity occurs at

$$y = m\,\frac{\lambda\, L}{d}$$

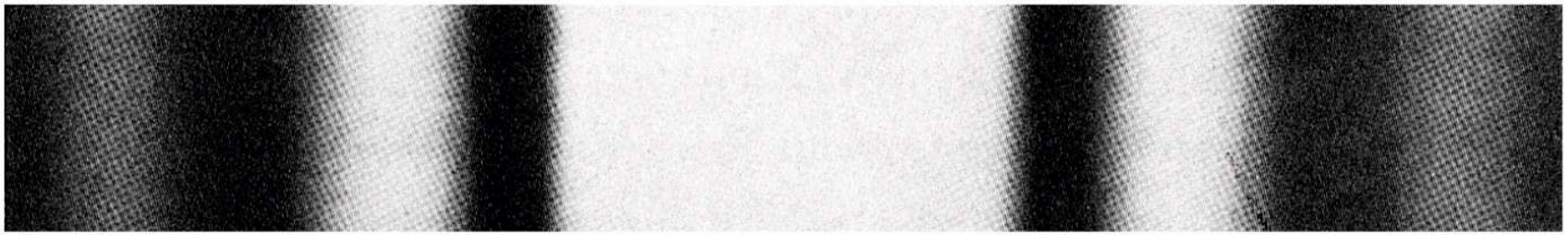
How do we get interference patterns from a single slit?

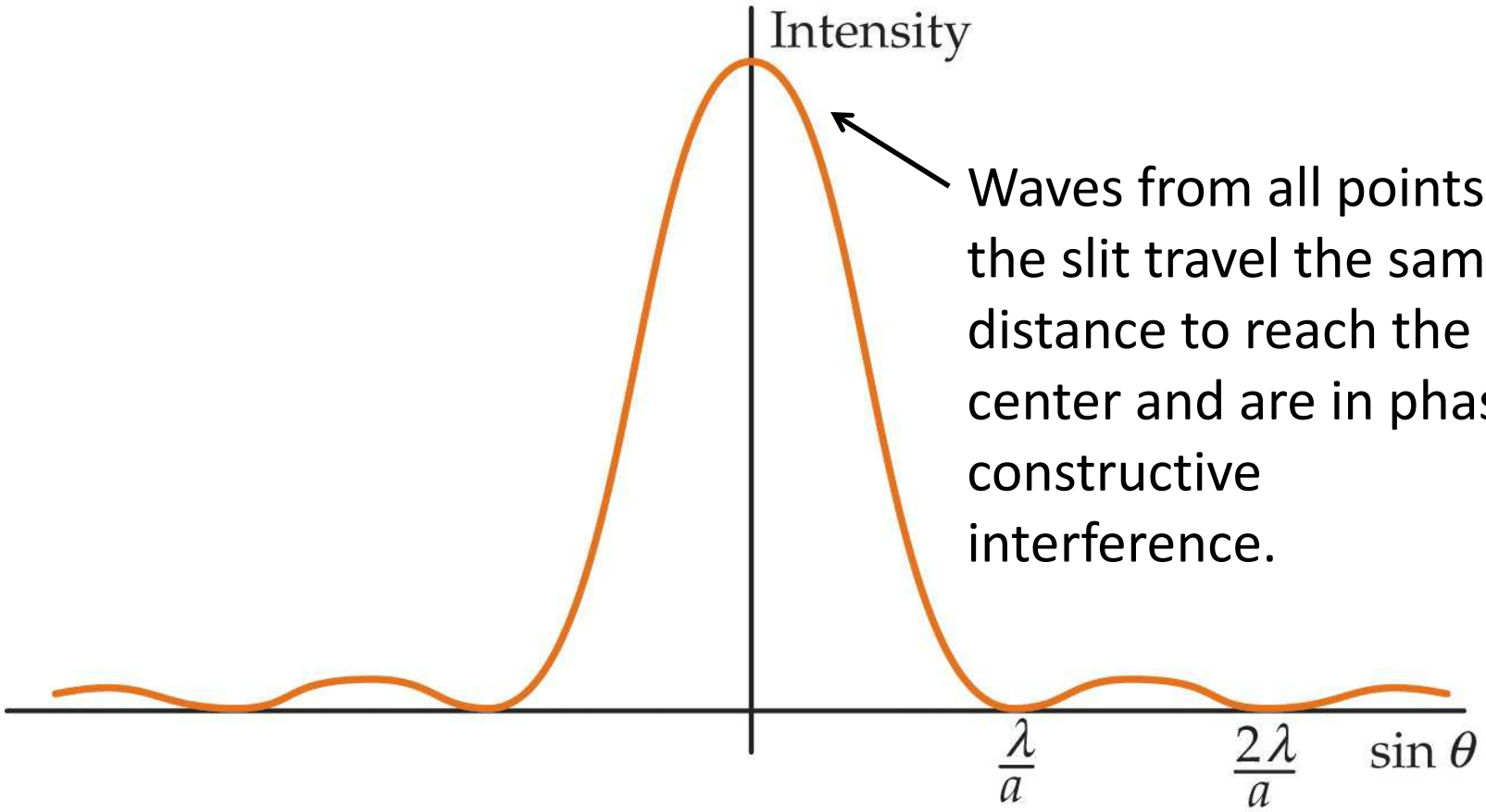
Single Slit Diffraction



- Consider monochromatic light incident on a single narrow slit.
- Geometric optics predicts that the image has the same cross section as the slit.
- Wave optics predicts a central bright band that is wider than the width of the slit, with interference fringes on either side.

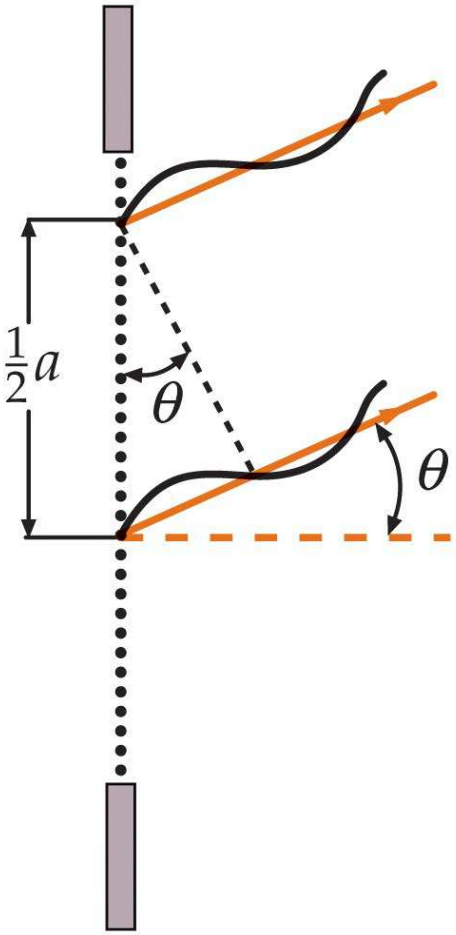
Single Slit Diffraction





Waves from all points in the slit travel the same distance to reach the center and are in phase: constructive interference.

Single Slit Diffraction



Think of the slit as a number of point sources with equal amplitude. Divide the slit into two pieces and think of the interference between light in the upper half and light in the lower half.

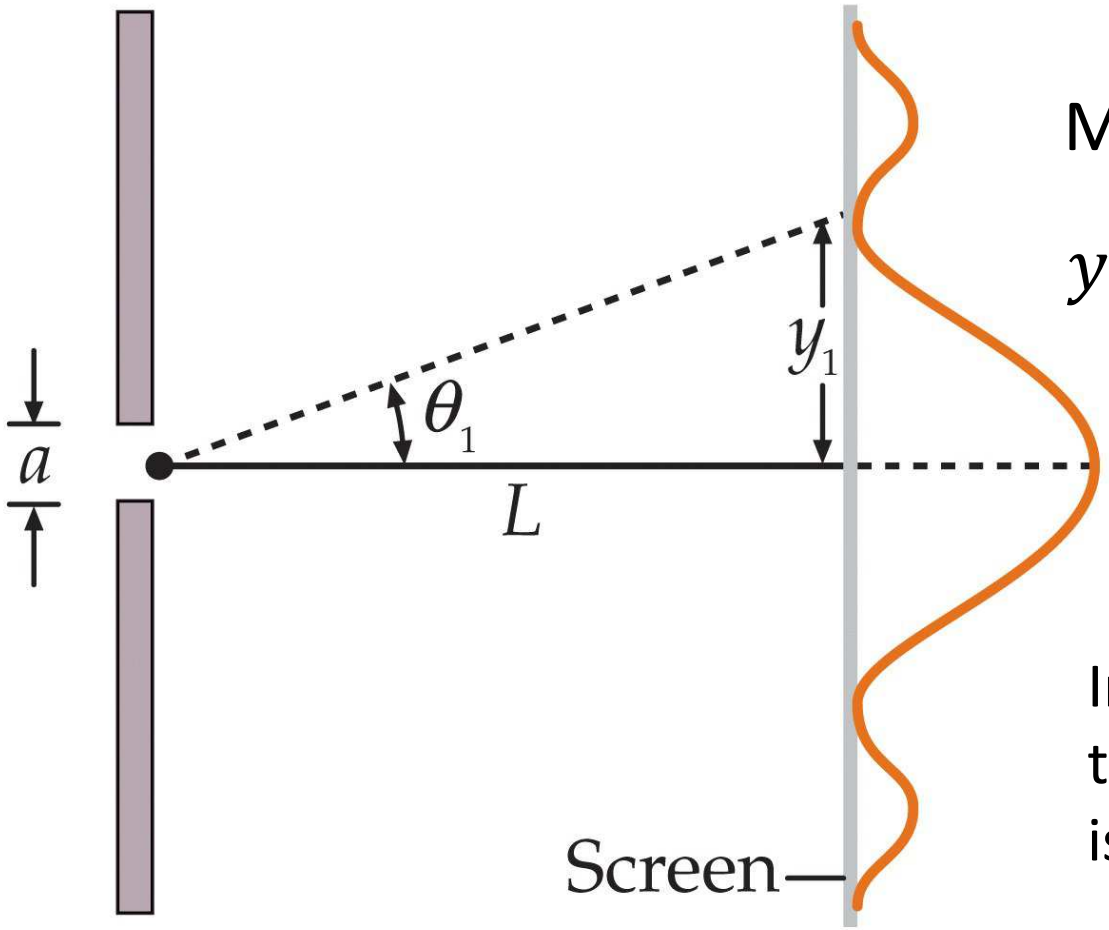
Destructive interference when

$$\frac{a}{2}\sin\theta = \frac{\lambda}{2}$$

Minima when

$$\sin\theta = {}^{\lambda}/_{a}$$

Single Slit Diffraction



$$\sin\theta \approx \tan\theta = y/L$$

Minima located at

$$y = \frac{mL\lambda}{a}, m = 1,2,3, \ldots$$

In general, the "width" of the image on the screen is not even close to a.

Single Slit Diffraction

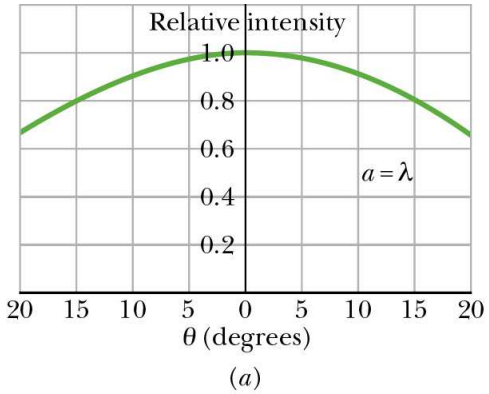
- How to reduce the spread of the image, defined by the position of the first minimum:

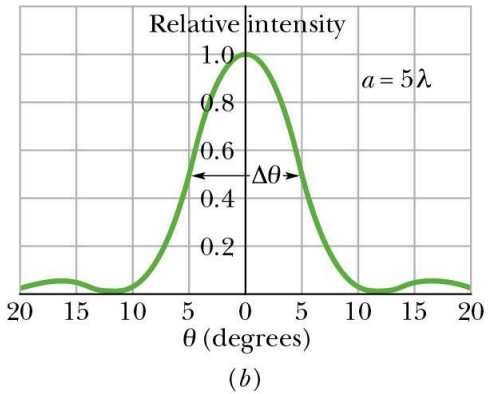
$$y = \frac{L\lambda}{a}$$

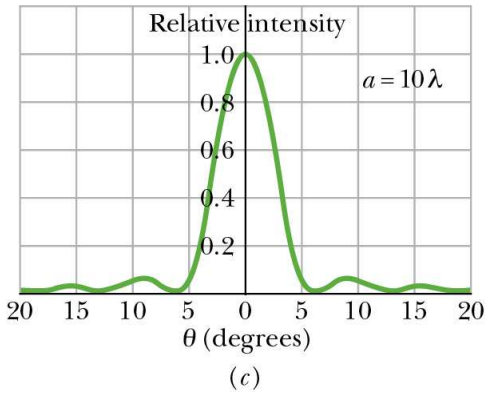
  - Decrease L: put the mask close to the screen
  - Decrease λ: use blue or ultraviolet light (not easy)
  - Increase a (counter intuitive)

Extreme Ultraviolet Photolithography

$\lambda \sim 13.5\ nm$







Single Slit Diffraction

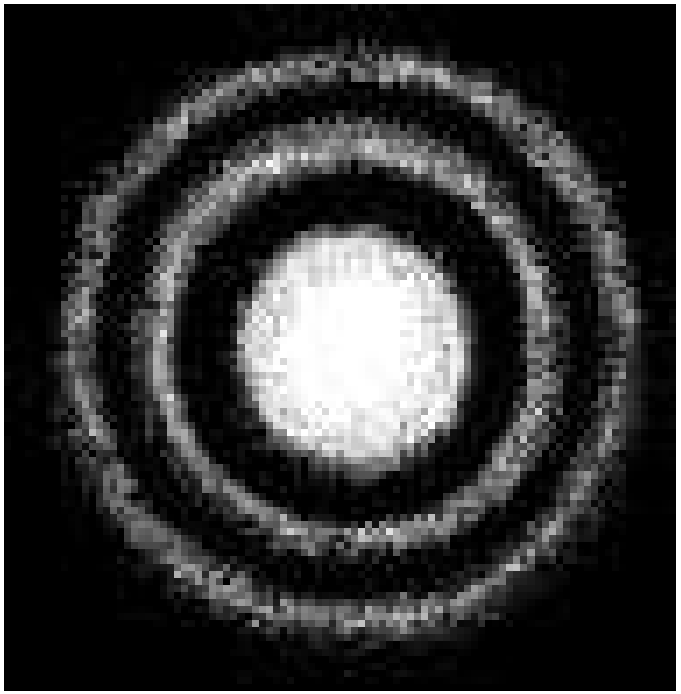
Angle of first minimum:

$$\sin\theta \approx \theta = \frac{\lambda}{a}$$

When $a < \lambda$ there is no minimum and the slit emits light uniformly in all directions.

The larger the aperture, the less flaring of the transmitted light.

Diffraction from a Circular Aperture



The central bright spot is called Airy disk. About 85% of the power is in this area.

The dark fringes are found at:

$$\sin\theta_1 = 1.22\,\frac{\lambda}{d}$$

$$\sin\theta_2 = 2.23\,\frac{\lambda}{d}$$

$$\sin\theta_3 = 3.24\,\frac{\lambda}{d}$$

Diffraction from a Circular Aperture

The bright fringes are found at:

$$\sin\theta_1 = 1.63\,\frac{\lambda}{d}$$

$$\sin\theta_2 = 2.68\,\frac{\lambda}{d}$$

$$\sin\theta_3 = 3.70\,\frac{\lambda}{d}$$

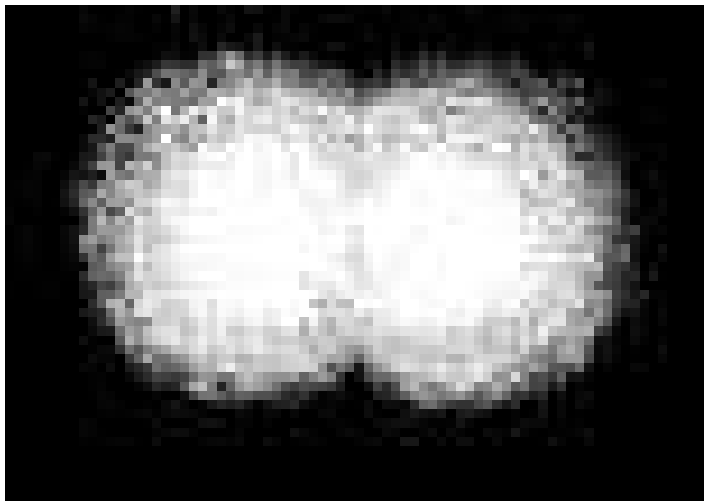
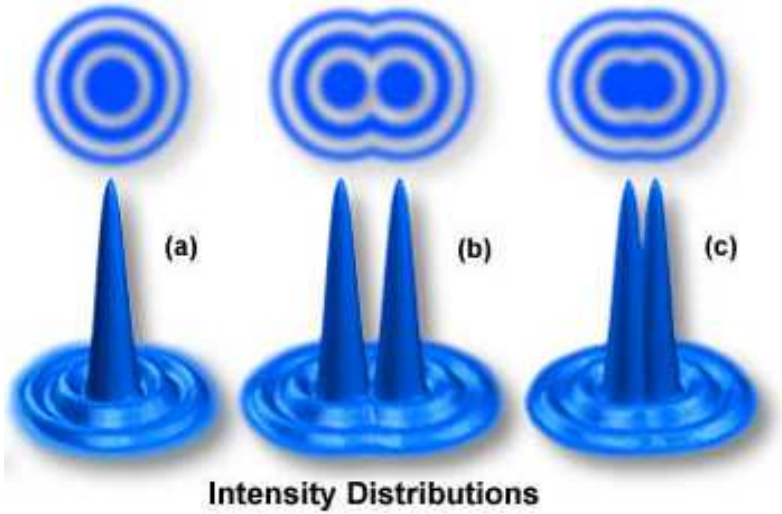


Image of two nearby binary stars can't be clearly resolved because their diffraction patterns overlap.

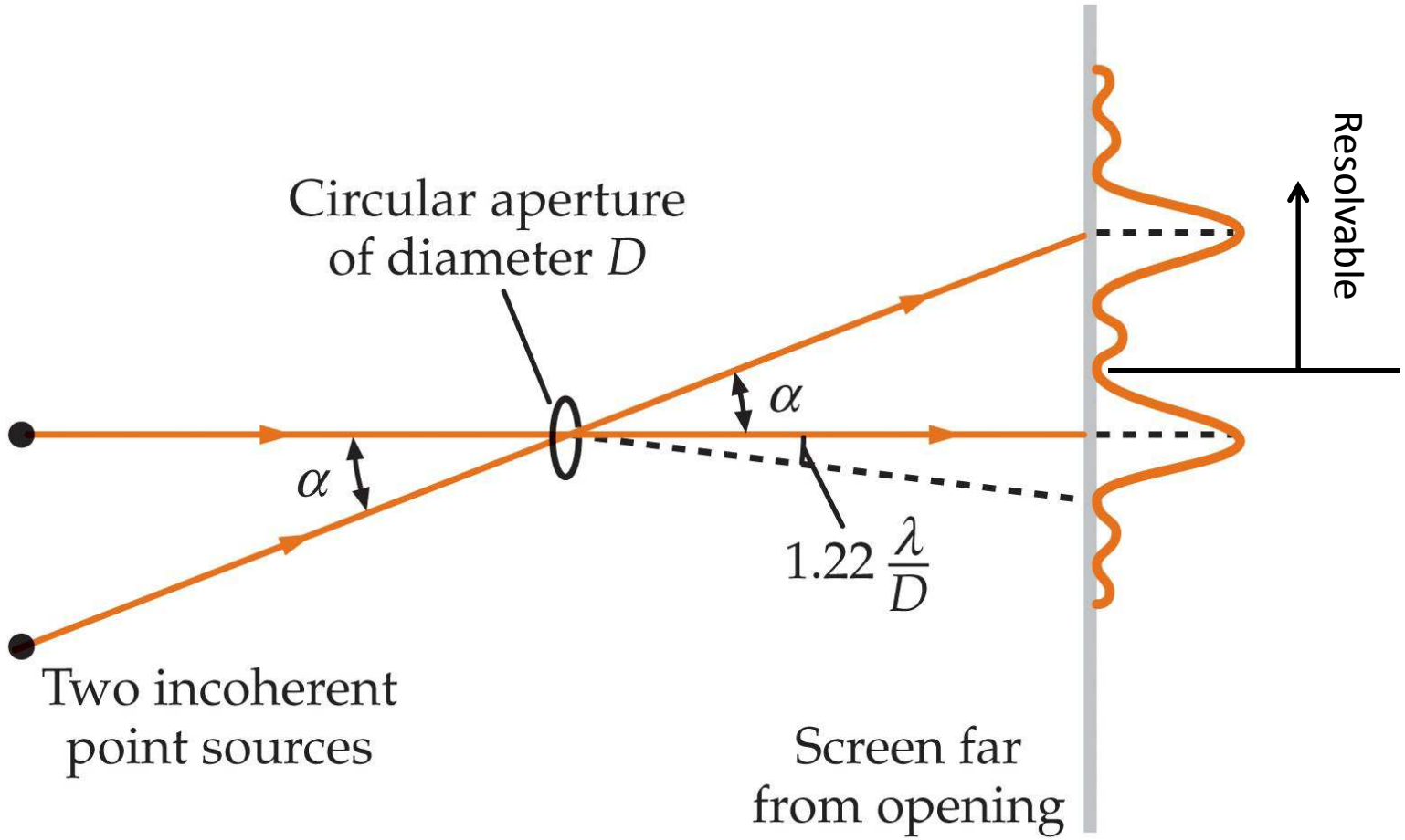
The Airy disk limits the resolvability of nearby objects.

Resolvability

- Rayleigh Criteria:
  - The minimum angular separation α_c of two marginally resolvable points is such that the maximum of the diffraction pattern from one falls on the first minimum of the diffraction pattern of the other.
  - First minima is at $\sin\theta = 1.22\frac{\lambda}{d}$ so $\alpha_c = \theta \approx 1.22\frac{\lambda}{d}$



Rayleigh Criteria



Resolvability

- Rayleigh Criteria:

$$\alpha_c = 1.22\frac{\lambda}{d}$$

- The minimum resolvable angle can be decreased by
  - Increasing d
  - Decreasing λ (use ultraviolet light or observe it in a medium with larger n)
  - Electrons behave like waves with very short wavelengths $\lambda(e) \approx \lambda(light)/10^5$

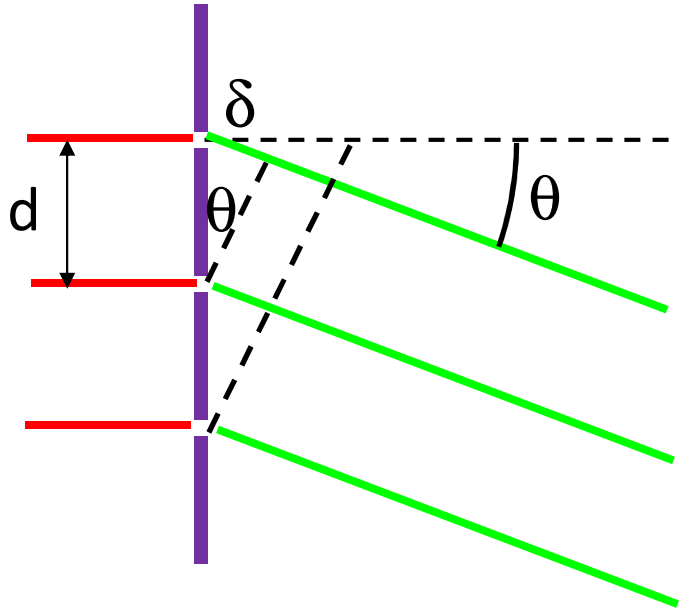
Lots of Slits

- Constructive interference when

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

- Lines become sharper: half-width of central line is

$$\Delta\theta = \frac{\lambda}{Nd}$$



When N is very large ($10^4/cm$) the lines are very sharp.

Diffraction Gratings

- Sharp, bright fringes occur when

$$d \sin\theta = m\lambda, \qquad m = 1,2,3, \ldots$$

- Resolving power: can we detect two spectral lines separated by $\Delta\lambda$?

$$d\,\Delta\theta = m\,\Delta\lambda$$

- Half width of central line:

$$\Delta\theta = \frac{\lambda}{Nd}$$

- Resolving power: $R = \frac{\lambda}{|\Delta\lambda|} = \frac{m\lambda}{d\,\Delta\theta} = mN$

Clicker Question

This is dead week and

(A) I'm still here & deserve 3 points.

(B) I'm doing fine in the course & don't need any more points... but I will take 3 points anyway.

(C) Can't decide.