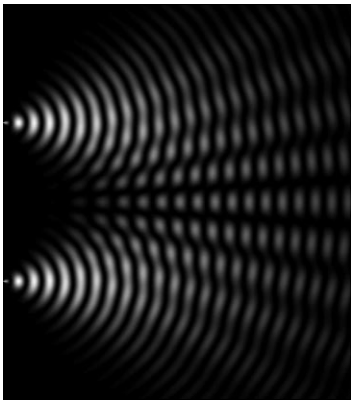
PHY132 Introduction to Physics II
Class 5 – **Outline:**

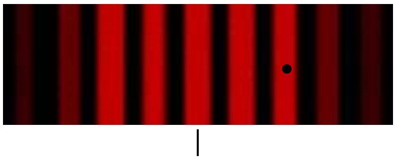
- Ch. 22, sections 22.1-22.4
- (Note we are skipping sections 22.5 and 22.6 in this course)
- Light and Optics
- Double-Slit Interference
- The Diffraction Grating
- Single-Slit Diffraction



Clicker Discussion Question

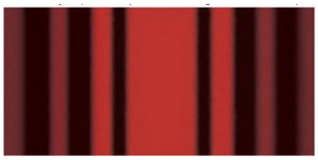
A laboratory experiment produces a double-slit interference pattern on a screen. The point on the screen marked with a dot is how much farther from the left slit than from the right slit?

A. 1.0 λ
B. 1.5 λ
C. 2.0 λ
D. 2.5 λ
E. 3.0 λ



Class 5 Preclass Quiz on MasteringPhysics

- This was due this morning at 8:00am
- 685 students submitted the quiz on time
- 94% of students got: A **diffraction grating** is an opaque object with many closely spaced slits. (Or a smooth surface with many closely spaced rectangular mirrors, separated by black strips.)
- 96% of students got: The first experiment to show that light is a wave was **Thomas Young's double-slit experiment** (1803).
- 71% of students got: The spreading of waves behind an aperture is **more** for long wavelengths and **less** for short wavelengths.
- 73% of students got: The **narrower** the slit in a single-slit diffraction experiment, the **wider** the central maximum (all fringes get farther apart)



Class 5 Preclass Quiz student comments/questions

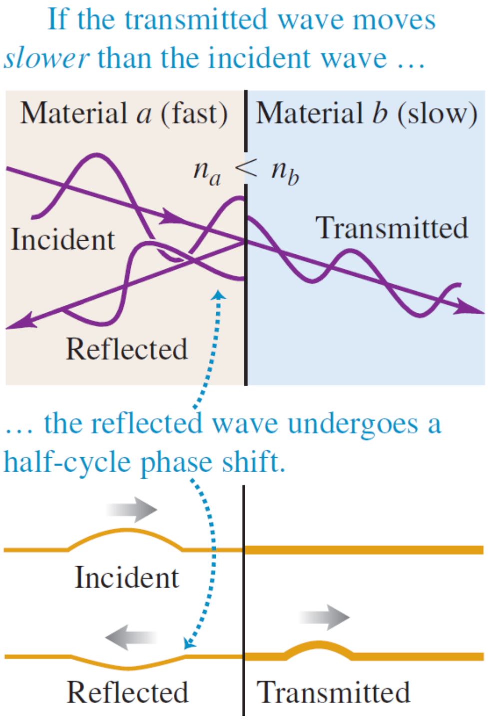
- *"Huygean wavelets are theoretical, right? Are we just imagining all of the light coming from a few tiny sources of waves?"*
- **Harlow answer:** There is a proper, mathematical wave of describing how waves travel (wave equation). Huygen's wavelets are a trick for visualizing this mathematical result.
- *"In the diffraction grating section of your video, the equation (I max) = (N^2)(I 1) is given for the intensity of bright fringes. Does this give the intensity of all bright fringes or just that of the central maximum?"*
- **Harlow answer:** It's all the maxima.

Class 5 Preclass Quiz student comments/questions

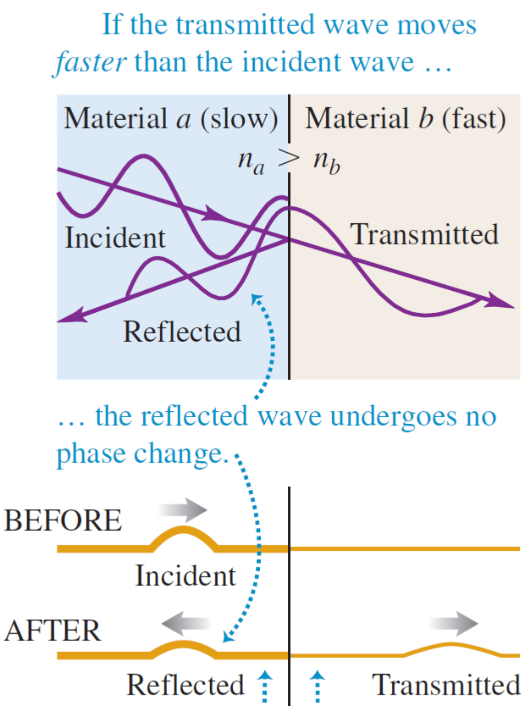
- *"Why does the intensity decrease when the angle from the slit (be it single or double) increases? I mean, what is the explanation for it because I would have thought that the intensity would osicillate about 2I?"*
- **Harlow answer:** For a double-slit of infinitesimally narrow slits, it does just oscillate. For a single slit, there is a bright central maximum, then it falls off very quickly. A real double slit is a combination of both of these.

Class 5 Preclass Quiz student comments/questions

- *"i would like to know how to prepare for this chapter for the exam/midterm like do we just remember the results and we'll do good or should we know how it got derived because the problem set 1 had stuff THAT YOU DIDNT GO THROUGH IN LECTURES .. like how the phase changes by pi when light goes from higher refractive to lower."*
- **Harlow answer:** That's a good point. I don't have time to go over everything in the lectures, but you are responsible for all the reading in these four chapters for test 1.



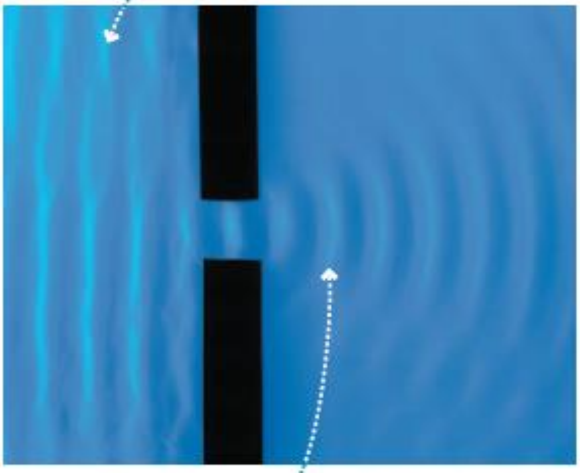
- When the index of a film is less than the index of the material beyond it (ie glass), then the half-cycle phase shift occurs for both reflections, and the wavelengths of constructive and destructive interference were as mentioned in class:



- When the index of a film is greater than the index of the material beyond it (ie glass), then the half-cycle phase shift occurs for the front surface, but not the back-surface of the film.
- This flips the constructive vs destructive equations:

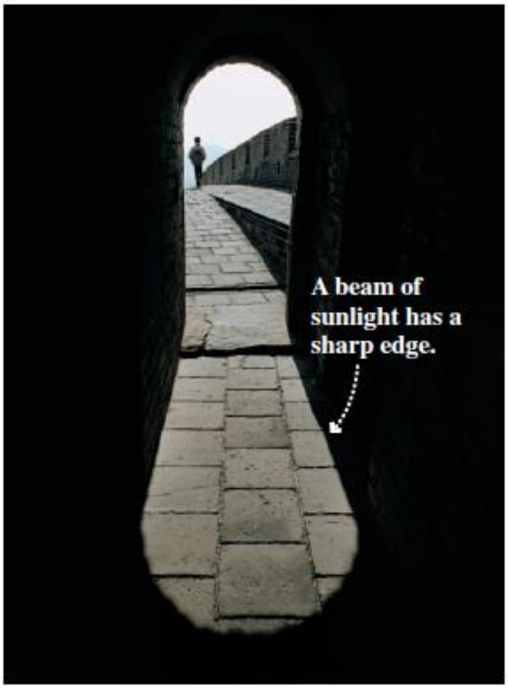
Diffraction of Water Waves

- A water wave, after passing through an opening, *spreads out* to fill the space behind the opening
- This well-known spreading of waves is called **diffraction**



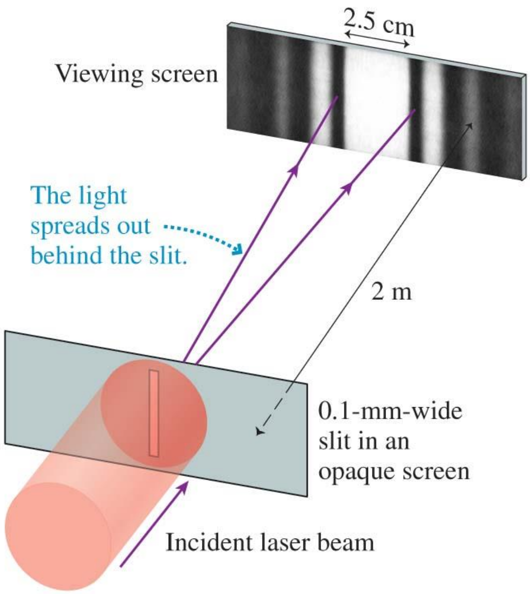
Models of Light

- Unlike a water wave, when light passes through a a large opening, it makes a sharp-edged shadow
- This lack of noticeable diffraction means that if light is a wave, the wavelength must be very small



Diffraction of Light

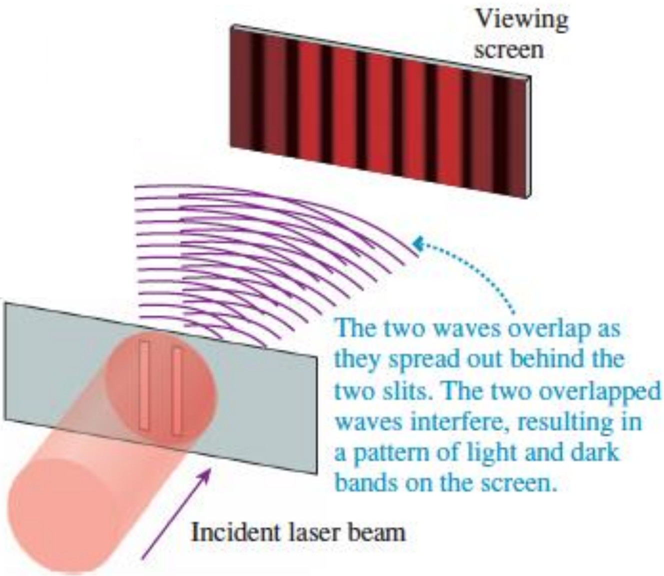
- When red light passes through an opening that is only 0.1 mm wide, it does spread out
- Diffraction of light is observable *if* the hole is sufficiently small

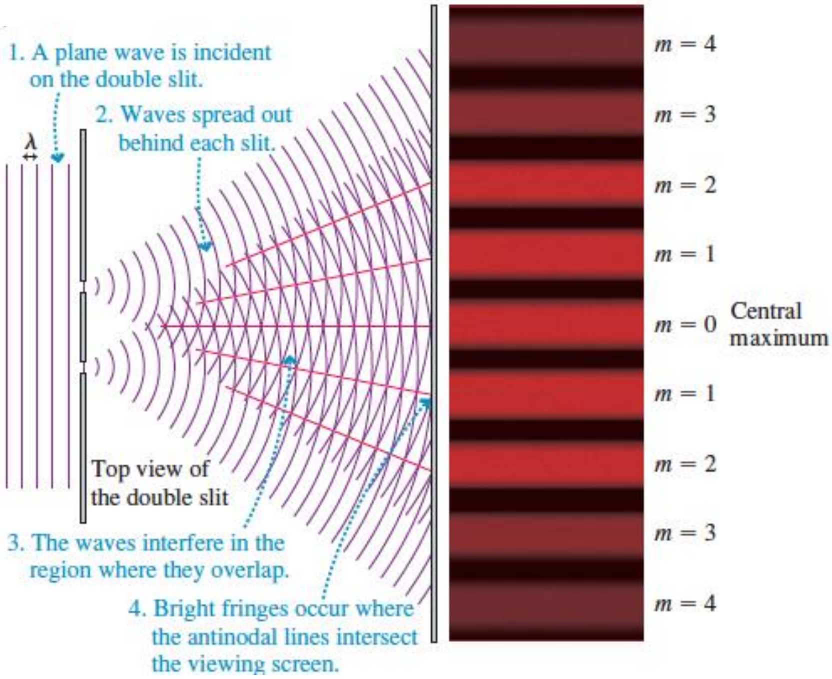


Models of Light

- **The wave model:** under many circumstances, light exhibits the same behavior as sound or water waves. The study of light as a wave is called *wave optics***.**
- **The ray model:** The properties of prisms, mirrors, and lenses are best understood in terms of *light rays*. The ray model is the basis of *ray optics*.
- **The photon model:** In the quantum world, light behaves like neither a wave nor a particle. Instead, light consists of *photons* that have both wave-like and particle-like properties. This is the *quantum theory* of light.

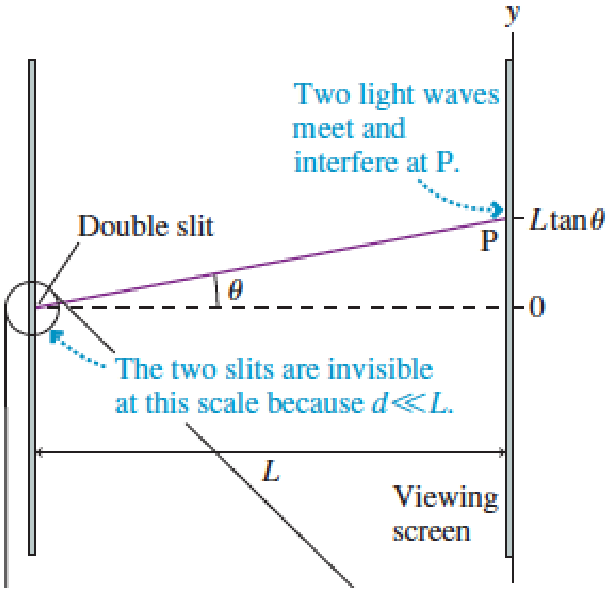
Young’s Double-Slit Experiment





Analyzing Double-Slit Interference

- The figure shows the "big picture" of the double-slit experiment
- The next slide *zooms in* on the area inside the circle

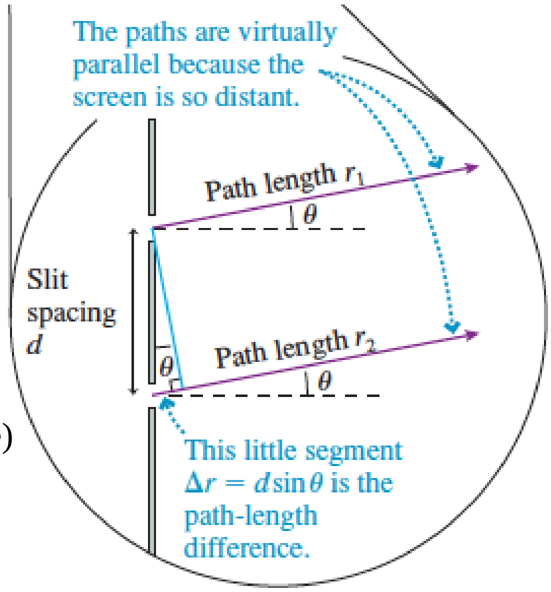


Analyzing Double-Slit Interference

- The figure shows a magnified portion of the double-slit experiment
- The wave from the lower slit travels an extra distance

$$\Delta r = d\sin\theta$$

- Bright fringes (constructive interference) will occur at angles θ_m such that $\Delta r = m\lambda$, where $m = 0, 1, 2, 3, \ldots$



Analyzing Double-Slit Interference

- The *m*th bright fringe emerging from the double slit is at an angle

$$\theta_m = m\frac{\lambda}{d} \qquad m = 0, 1, 2, 3, \ldots \qquad \text{(angles of bright fringes)}$$

where θ_m is in radians, and we have used the small-angle approximation

- The *y*-position on the screen of the *m*th bright fringe on a screen a distance *L* away is

$$y_m = \frac{m\lambda L}{d} \qquad m = 0, 1, 2, 3, \ldots \qquad \text{(positions of bright fringes)}$$

Clicker Discussion Question

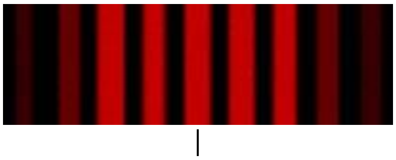
A laboratory experiment produces a double-slit interference pattern on a screen. If the screen is moved farther away from the slits, the fringes will be

A. closer together.

B. in the same positions.

C. farther apart.

D. fuzzy and out of focus.



Clicker Discussion Question

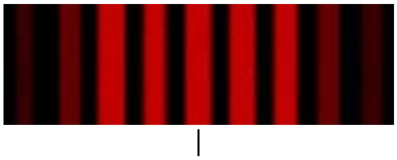
A laboratory experiment produces a double-slit interference pattern on a screen. If green light is used, with everything else the same, the bright fringes will be

A. closer together.

B. in the same positions.

C. farther apart.

D. There will be no fringes because the conditions for interference won't be satisfied.



Clicker Discussion Question

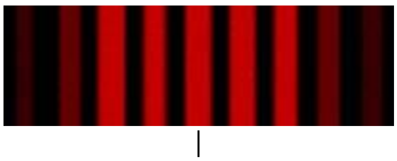
A laboratory experiment produces a double-slit interference pattern on a screen. If the slits are moved closer together, the bright fringes will be

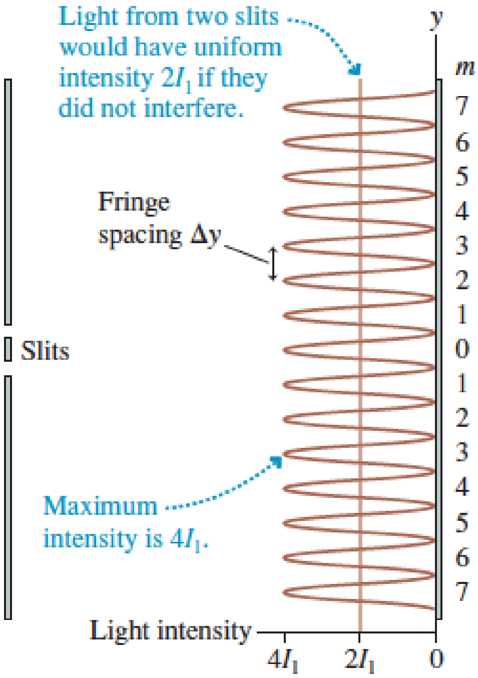
A. closer together.

B. in the same positions.

C. farther apart.

D. There will be no fringes because the conditions for interference won't be satisfied.

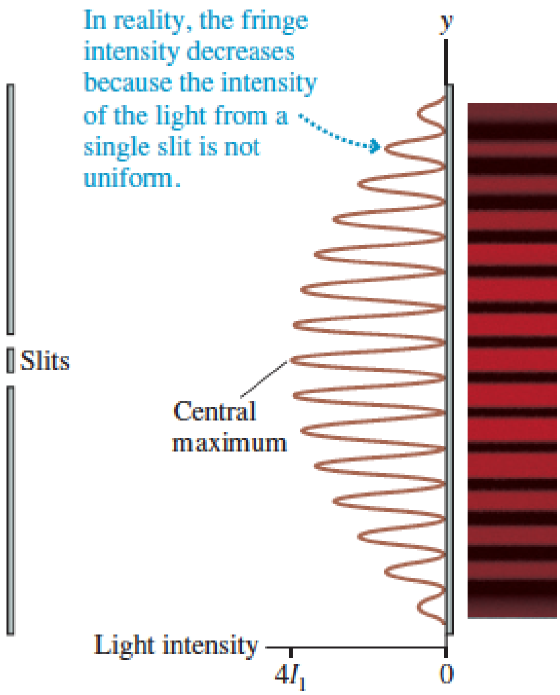




Intensity of the Double-Slit Interference Pattern

The intensity of the double-slit interference pattern at position *y* is:

$$I_{\text{double}} = 4I_1 \cos^2\left(\frac{\pi d}{\lambda L} y\right)$$



Intensity of the Double-Slit Interference Pattern

The actual intensity from a double-slit experiment slowly decreases as $|y|$ increases.

The Diffraction Grating

- Suppose we were to replace the double slit with an opaque screen that has *N* closely spaced slits
- When illuminated from one side, each of these slits becomes the source of a light wave that diffracts, or spreads out, behind the slit
- Such a multi-slit device is called a **diffraction grating**
- Bright fringes will occur at angles θ_m, such that:

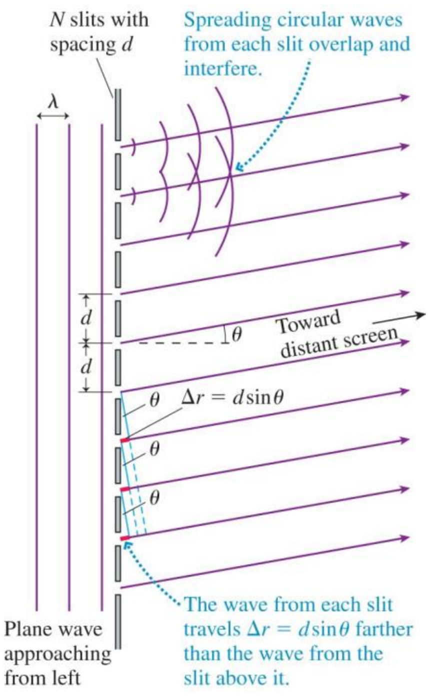
$$d \sin\theta_m = m\lambda \qquad m = 0, 1, 2, 3, \ldots$$

- The *y*-positions of these fringes will occur at:

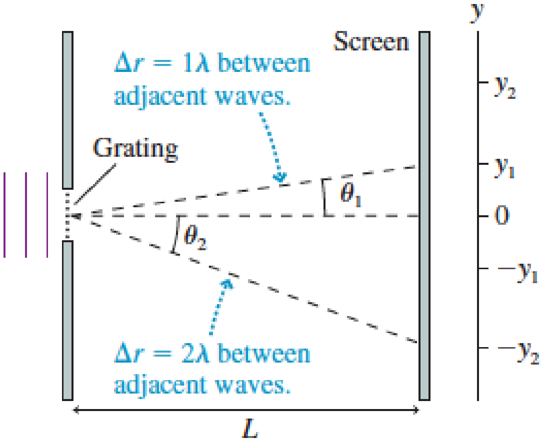
$$y_m = L \tan\theta_m \qquad \text{(positions of bright fringes)}$$

The Diffraction Grating

- Suppose we were to replace the double slit with an opaque screen that has *N* closely spaced slits
- When illuminated from one side, each of these slits becomes the source of a light wave that diffracts, or spreads out, behind the slit
- Such a multi-slit device is called a **diffraction grating**



The Diffraction Grating



Bright fringes will occur at angles θ_m, such that

$$d \sin\theta_m = m\lambda$$

where $m = 0, 1, 2, 3, \ldots$

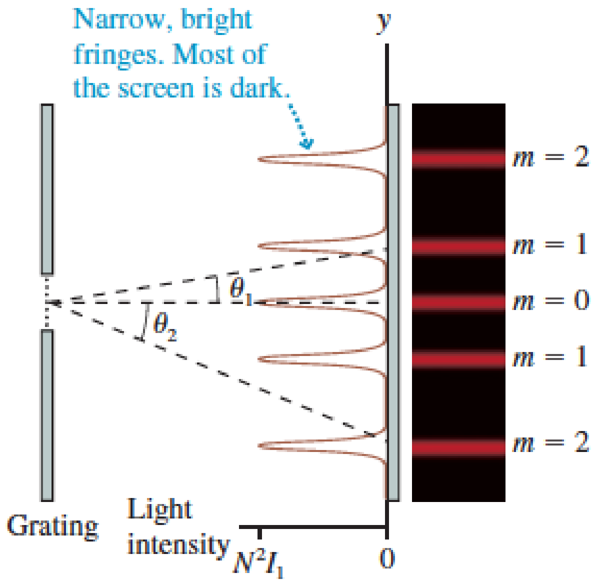
The y-positions of these fringes are:

$$y_m = L\tan\theta_m \qquad \text{(positions of bright fringes)}$$

The Diffraction Grating

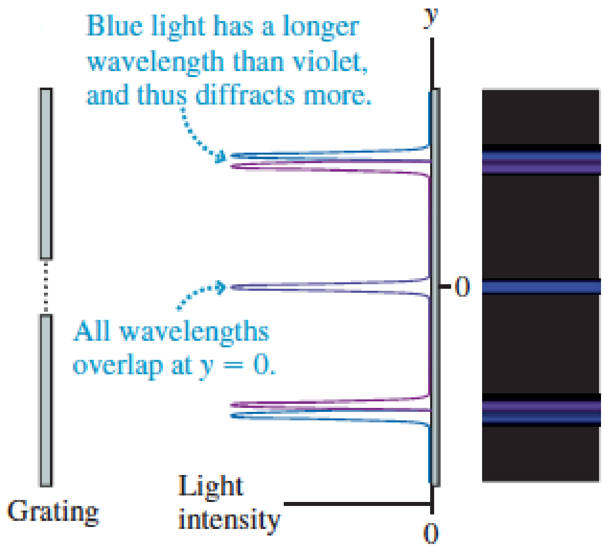
- The integer m is called the **order** of the diffraction
- The wave amplitude at the points of constructive interference is Na
- Because intensity depends on the square of the amplitude, the intensities of the bright fringes are

$$I_{max} = N^2 I_1$$



The Diffraction Grating

- Diffraction gratings are used for measuring the wavelengths of light
- If the incident light consists of two slightly different wavelengths, each wavelength will be diffracted at a slightly different angle



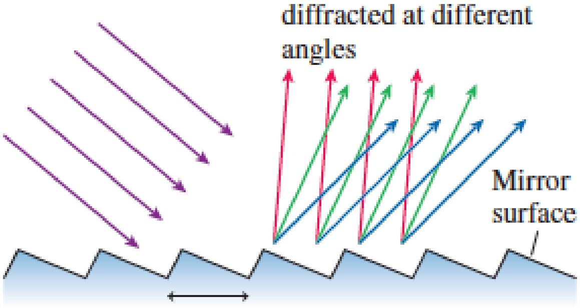
Clicker Discussion Question

In a laboratory experiment, a diffraction grating produces an interference pattern on a screen. If the number of slits in the grating is increased, with everything else (including the slit spacing) the same, then

A. The fringes stay the same brightness and get closer together.
B. The fringes stay the same brightness and get farther apart.
C. The fringes stay in the same positions but get brighter and narrower.
D. The fringes stay in the same positions but get dimmer and wider.
E. The fringes get brighter, narrower, and closer together.

Reflection Gratings

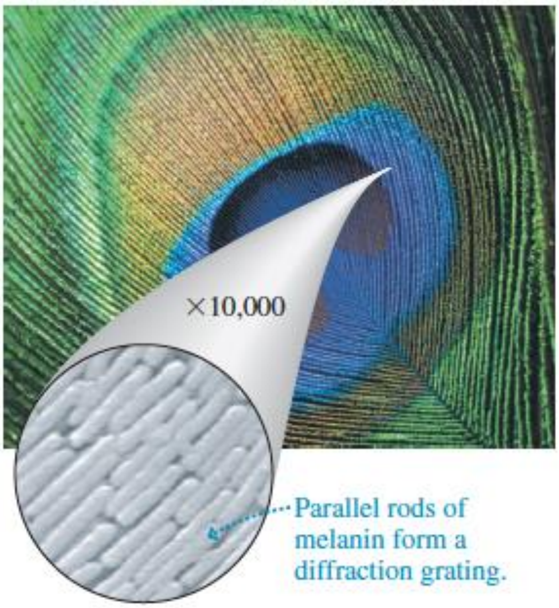
- In practice, most diffraction gratings are manufactured as *reflection gratings*
- The interference pattern is exactly the same as the interference pattern of light transmitted through *N* parallel slits



A reflection grating can be made by cutting parallel grooves in a mirror surface. These can be very precise, for scientific use, or mass produced in plastic.

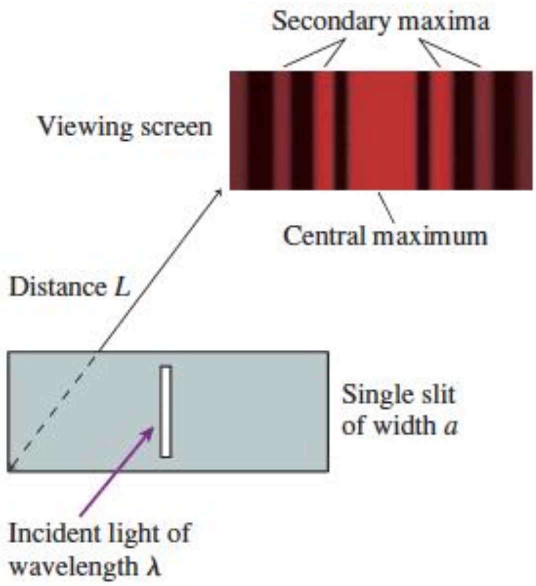
Reflection Gratings

- Naturally occurring reflection gratings are responsible for some forms of color in nature
- A peacock feather consists of nearly parallel rods of melanin, which act as a reflection grating



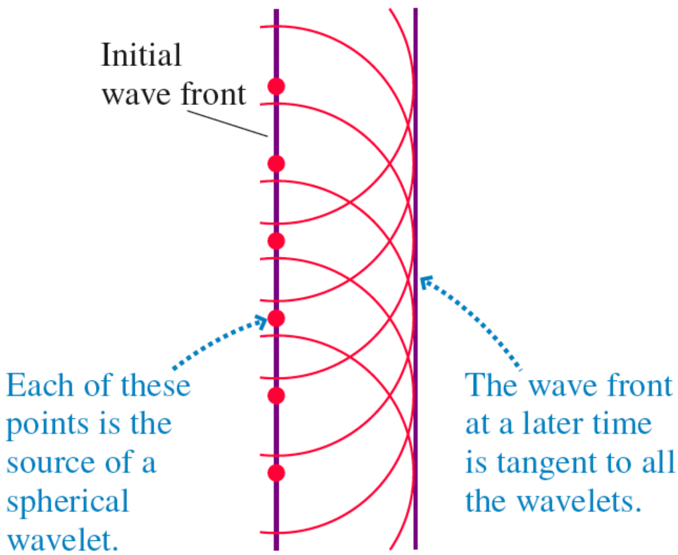
Parallel rods of melanin form a diffraction grating.

Single-Slit Diffraction

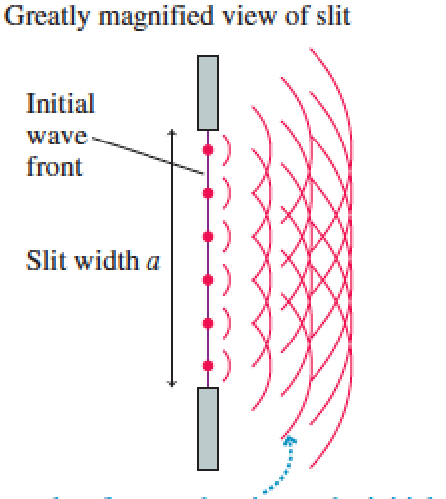


- Diffraction through a tall, narrow slit is known as single-slit diffraction
- A viewing screen is placed distance L behind the slit of width a, and we will assume that $L >> a$

Huygens' Principle: Plane Waves



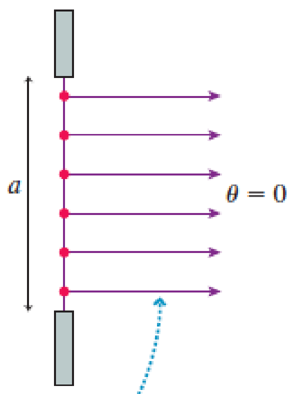
Analyzing Single-Slit Diffraction



The wavelets from each point on the initial wave front overlap and interfere, creating a diffraction pattern on the screen.

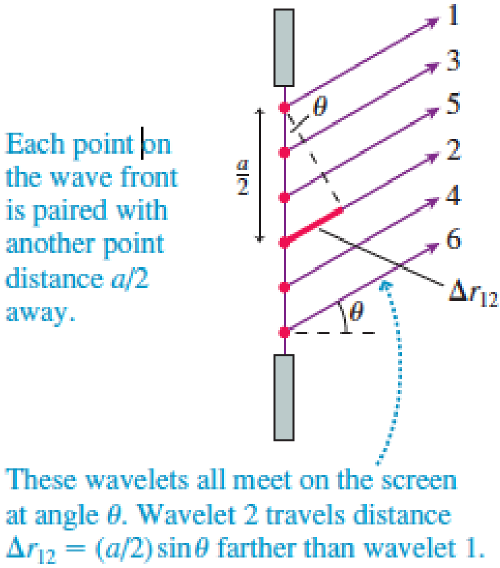
- The figure shows a wave front passing through a narrow slit of width *a*
- According to Huygens' principle, each point on the wave front can be thought of as the source of a spherical wavelet

Analyzing Single-Slit Diffraction



The wavelets going straight forward all travel the same distance to the screen. Thus they arrive in phase and interfere constructively to produce the central maximum.

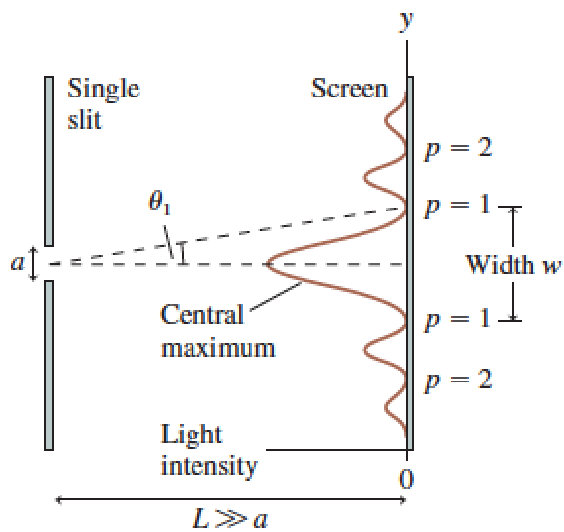
- The figure shows the paths of several wavelets that travel straight ahead to the central point on the screen
- The screen is *very* far to the right in this magnified view of the slit
- The paths are very nearly parallel to each other, thus all the wavelets travel the same distance and arrive at the screen *in phase* with each other



- In this figure, wavelets 1 and 2 start from points that are $a/2$ apart
- Every point on the wave front can be paired with another point distance $a/2$ away
- If the path-length difference is $\Delta r = \lambda/2$, the wavelets arrive at the screen out of phase and interfere destructively

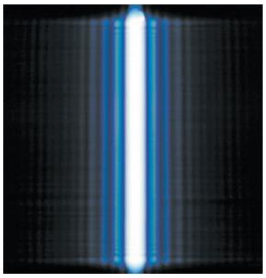
Single-Slit Diffraction

- The light pattern from a single slit consists of a *central maximum* flanked by a series of weaker **secondary maxima** and dark fringes
- The dark fringes occur at angles:



$$\theta_p = p\frac{\lambda}{a} \qquad p = 1, 2, 3, \ldots \qquad \text{(angles of dark fringes)}$$

The Width of a Single-Slit Diffraction Pattern



- The central maximum of this single-slit diffraction pattern is much brighter than the secondary maximum
- The width of the central maximum on a screen a distance L away is *twice* the spacing between the dark fringes on either side:

$$w = \frac{2\lambda L}{a} \qquad \text{(single slit)}$$

- The farther away from the screen (larger L), the wider the pattern of light becomes
- The narrower the opening (smaller a), the wider the pattern of light becomes!

Clicker Discussion Question

A laboratory experiment produces a single-slit diffraction pattern on a screen. If the slit is made narrower, the bright fringes will be

A. closer together.

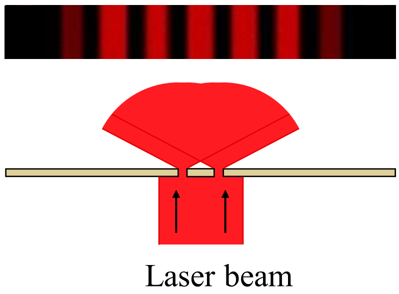
B. in the same positions.

C. farther apart.

D. There will be no fringes because the conditions for diffraction won't be satisfied.

Clicker Discussion Question

A laboratory experiment produces a double-slit interference pattern on a screen. If the left slit is blocked, the screen will look like



A. 

B. 

C. 

D. 

Before Class 6 on Wednesday

- Please read Knight Ch. 23, sections 23.1-23.5
- Please do the short pre-class quiz on MasteringPhysics by Wednesday morning at the latest.
- Something to think about: Is it possible to see a ray of light if it does not actually enter your eye?