Optics
Wave Behavior in Optics
Diffraction

Lana Sheridan

De Anza College

June 19, 2020

Last time

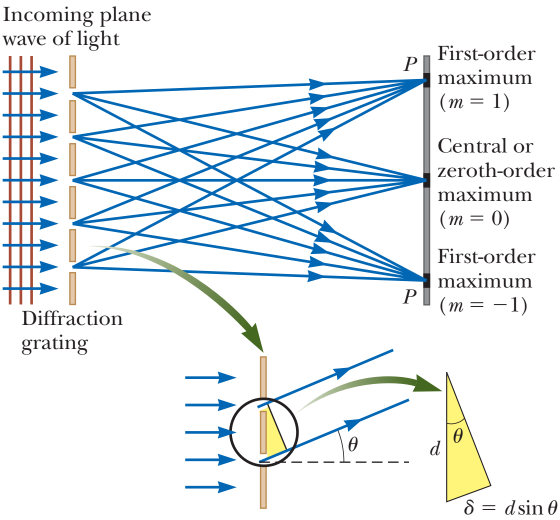
- Interference of light: the Double-Slit experiment
- multiple slit interference
- diffraction gratings

Overview

- diffraction gratings
- diffraction patterns
- diffraction and interference
- resolution and Raleigh's criterion

Diffraction Grating

We can find the maxima (bright fringes) of the pattern produced in a diffraction grating in exactly the same way we did for Young's slits.



Diffraction Grating

Once again, light from different slits interferes constructively when the path differnce $\delta = m\lambda$ (m is an integer).

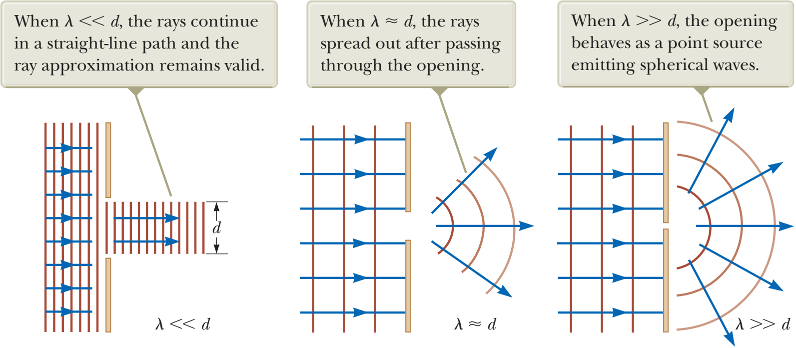
$$\delta = d \sin \theta$$

Maxima (bright fringes) occur when

$$d \sin \theta_{\text{max}} = m\lambda \qquad \text{where } m \in \mathbb{Z}$$

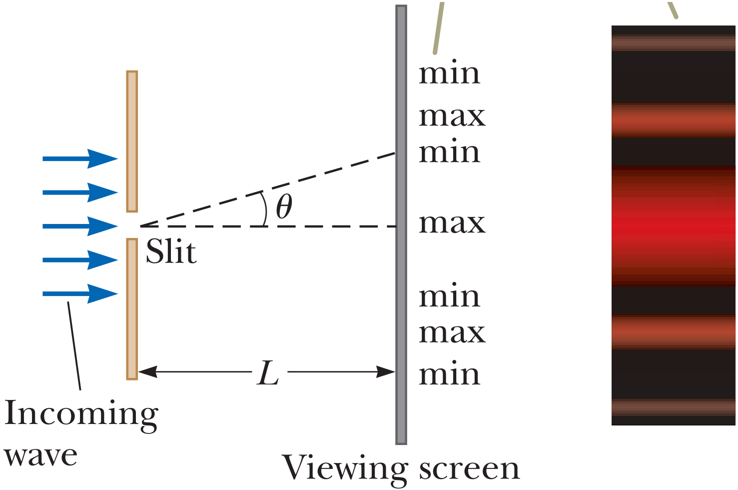
Diffraction

We already know that light and other waves that travel through a small gap ($< \lambda$) diverge, and that the smaller the gap, the more divergence.

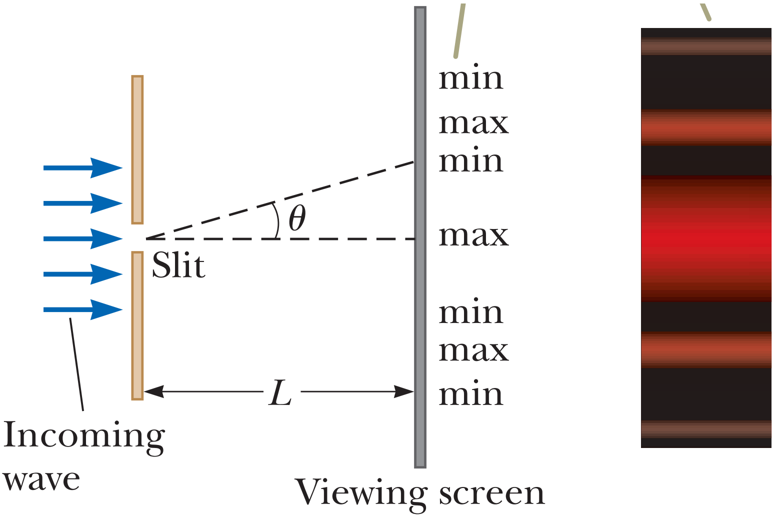


The intensity of light in each direction is not the same however.

Diffraction Patterns

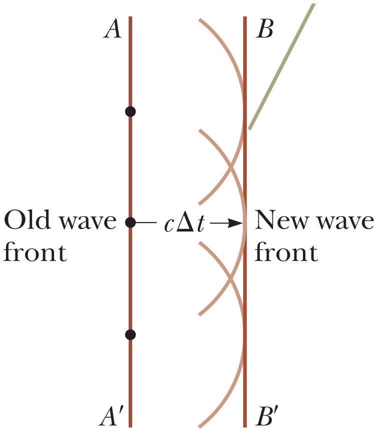


Understanding the Diffraction Pattern from a Single Slit



Diffraction and Huygens' Principle

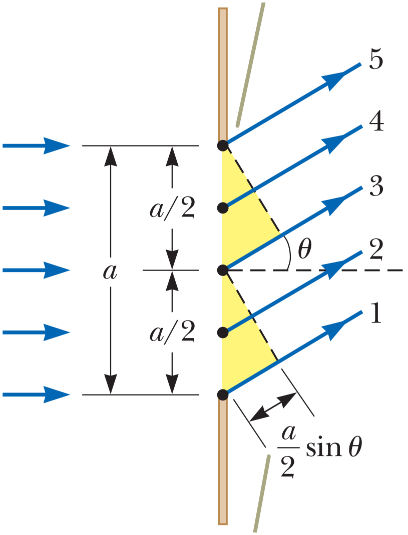
When we have a slit or aperture illuminated by coherent light, each part of the aperture acts as a point source of spherical wavelets.



These wavelets interfere to produce a diffraction pattern.

Understanding the Diffraction Pattern from a Single Slit

Consider a series of point sources in different parts of the slit. The slit has width *a*.



Understanding the Diffraction Pattern from a Single Slit

We can find minima (dark fringes) in the pattern by breaking up our point sources into pairs that cancel each other out.

Matching point sources in the top half of the slit with ones in the bottom half, the source separation distances will be $d = a/2$.

This will be a fringe dark when:

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

Understanding the Diffraction Pattern from a Single Slit

However, we could also break the slit up into 4 equal parts and match sources from the 1st and 2nd, and match from the 3rd and 4th.

This will be dark when:

$$\delta = \frac{a}{4}\sin\theta = \frac{\lambda}{2}$$

If we break the slit up into 6 equal parts and match sources from the 1st and 2nd, the 3rd and 4th, and the 5th and 6th.

This will be dark when:

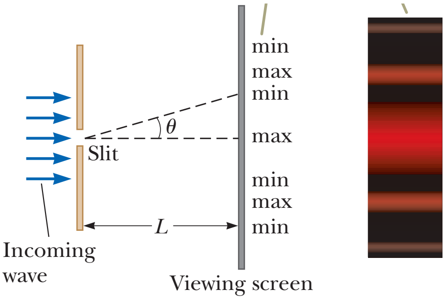
$$\delta = \frac{a}{6}\sin\theta = \frac{\lambda}{2}$$

Understanding the Diffraction Pattern from a Single Slit

In general we expect dark fringes when:

$$\sin\theta_{\min} = m\frac{\lambda}{a} \qquad \text{where } m = \pm 1, \pm 2, \pm 3, \ldots$$

Question



Quick Quiz 38.1[1] Suppose the slit width in the figure is made half as wide. Does the central bright fringe

(A) become wider,

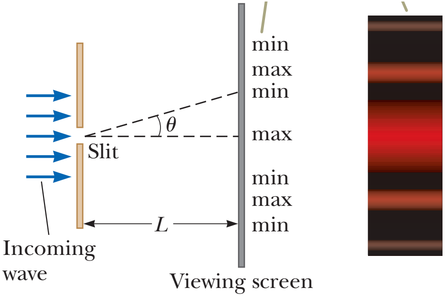
(B) remain the same, or

(C) become narrower?

---

[1]Serway & Jewett, page 1163.

Question



Quick Quiz 38.1[1] Suppose the slit width in the figure is made half as wide. Does the central bright fringe

(A) become wider, ←

(B) remain the same, or

(C) become narrower?

[1] Serway & Jewett, page 1163.

The Intensity Pattern from a Single Slit

For a single slit:

$$I = I_{\max}\left(\frac{\sin((\pi a/\lambda)\sin\theta)}{(\pi a/\lambda)\sin\theta}\right)^2$$

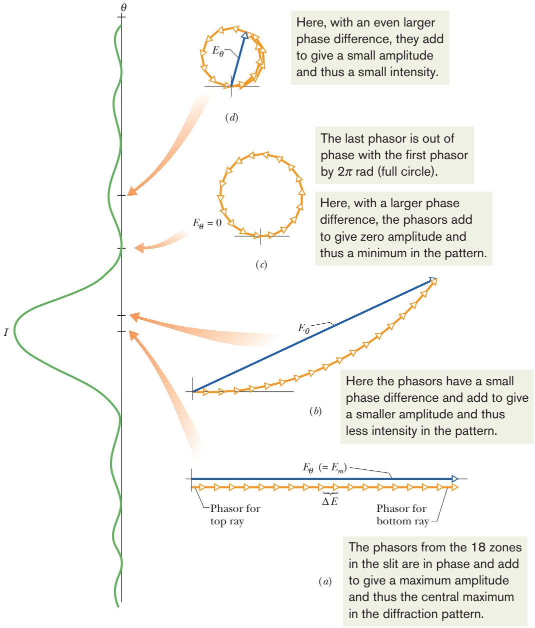
This is a sinc-function squared.

Just to check, we said the minima should be

$$\sin\theta_{\min} = m\frac{\lambda}{a}$$

This corresponds to
$\sin((\pi a/\lambda)\sin\theta_{\min}) = 0 \;\Rightarrow\; (\pi a/\lambda)\sin\theta_{\min} = m\pi$

The Intensity Pattern from a Single Slit

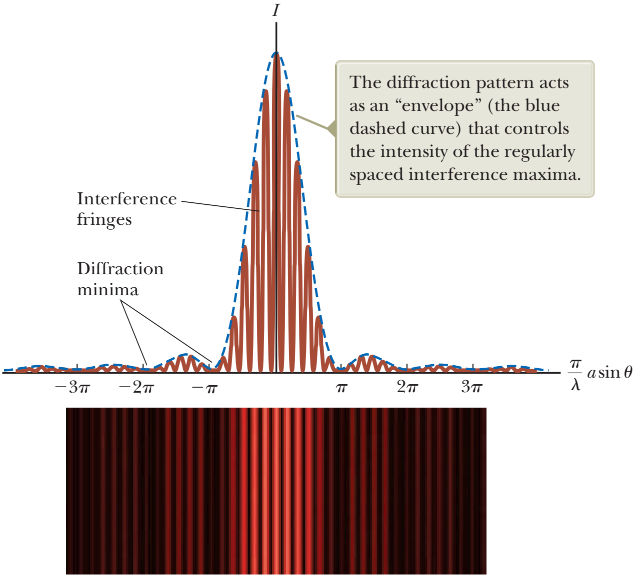


Two Slits that have some width

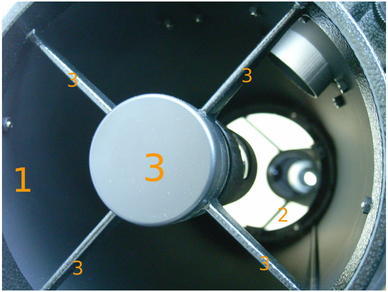
Suppose two slits each have width a and their centers are a distance d apart.

What intensity pattern do they create?

Two Slits that have some width



Diffraction Patterns: Diffraction Spikes

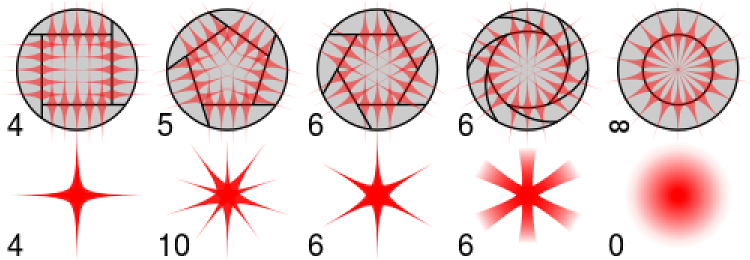


[1]NASA, ESA, and H. Richer (University of British Columbia); Svon Halenbach

Diffraction Spikes in Camera Apertures

Iris diaphragms adjust the amount of light allowed into a camera body.

They cause characteristic diffraction patterns on photos taken of bright lights.

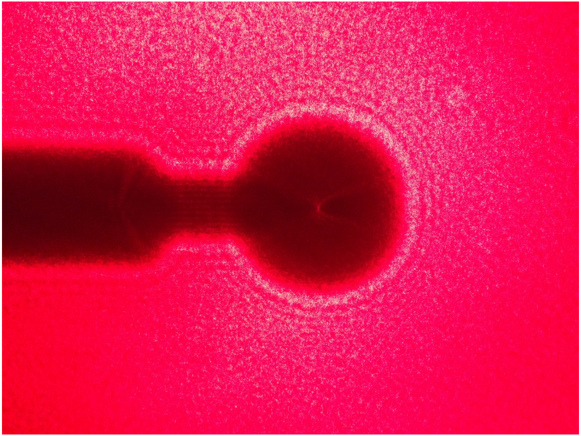


[1]Wikipedia user Cmglee

Diffraction Patterns: Arago Spot

Directly in the center of the shadow produced by a round object lit with coherent light, a spot of light can be observed!

This is called the Arago spot, Fresnel bright spot, or Poisson spot.



[1] Photo taken at Exploratorium in SF, own work.

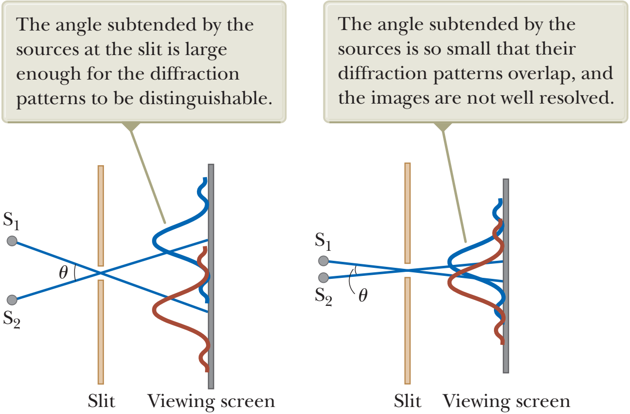
Resolution and the Rayleigh criterion

We use optical systems like our eyes, a camera, or a telescope to view distant objects and interpret them.

Imagine two distant stars. If they are very close together, or so far away that they make a very small angle to each other in the sky, they may look like only one star.

When can we distinguish them as two separate points?

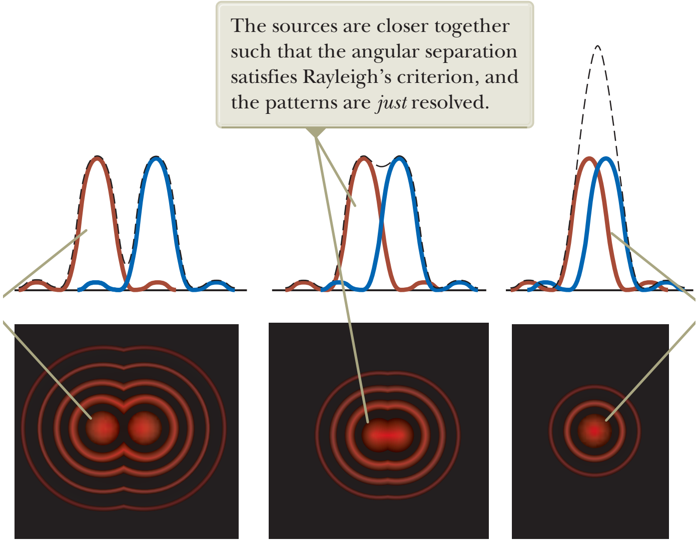
Resolution and the Rayleigh criterion



When the central maximum of one falls on the first dark fringe of the other, the two images begin to look like they came from one object.

$$\theta_{\min} \approx \sin\theta_{\min} = \frac{\lambda}{a}$$

Resolution and the Rayleigh criterion



Resolution and the Rayleigh criterion

For circular points being resolved, the Rayleigh Criterion is:

$$\theta_{\text{min}} = 1.22\frac{\lambda}{D}$$

where D is the diameter of the aperture.

The 1.22 factor comes from a full analysis of the 2-dimensional diffraction pattern for a circular aperture.

Summary

- diffraction gratings
- diffraction patterns
- diffraction and interference
- resolution and Raleigh's criterion

Final Exam 9:15-11:15am, Tuesday, June 23.

Homework Serway & Jewett:

- Ch 37, onward from page 1150. OQs: 3, 9; CQs: 3, 5; Probs: 19, 21 (Young's experiment)
- Ch 38, onward from page 1182. Probs: 10, 15, 21 (diffraction and resolution)
- prev: Ch 38, onward from page 1182. CQs: 5; Probs: 25, 60