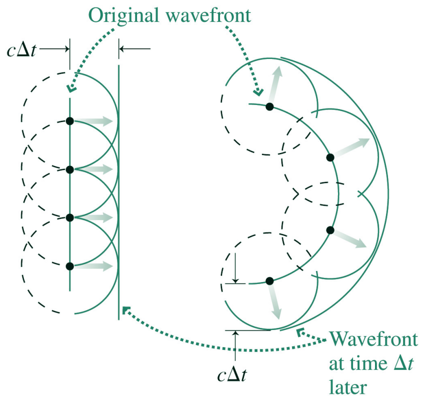
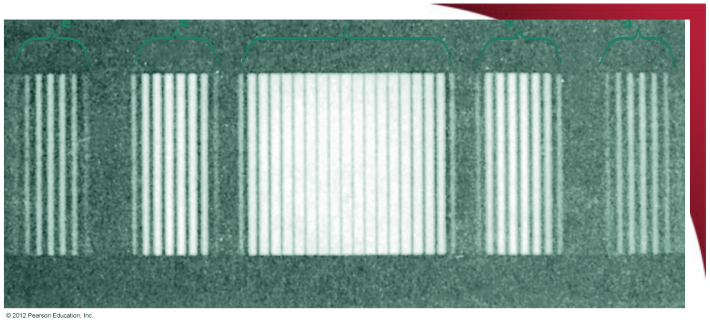




University Physics 227N/232N

Interference and Diffraction

Optional review session next Monday (Apr 28)

Bring Homework Notebooks to Final for Grading

Dr. Todd Satogata (ODU/Jefferson Lab)

satogata@jlab.org

http://www.toddsatogata.net/2014-ODU

Friday, April 25 2014

Happy Birthday to DeAngelo Williams, Renee Zellweger, Al Pacino, Meadowlark Lemon, Ella Fitzgerald, and Wolfgang Pauli (1945 Nobel)!

Review: Double-Slit Interference

- Interference from two coherent sources produces a pattern of light and dark **interference fringes**
- A convenient way to produce the two sources is to pass light from a single source through two narrow slits.

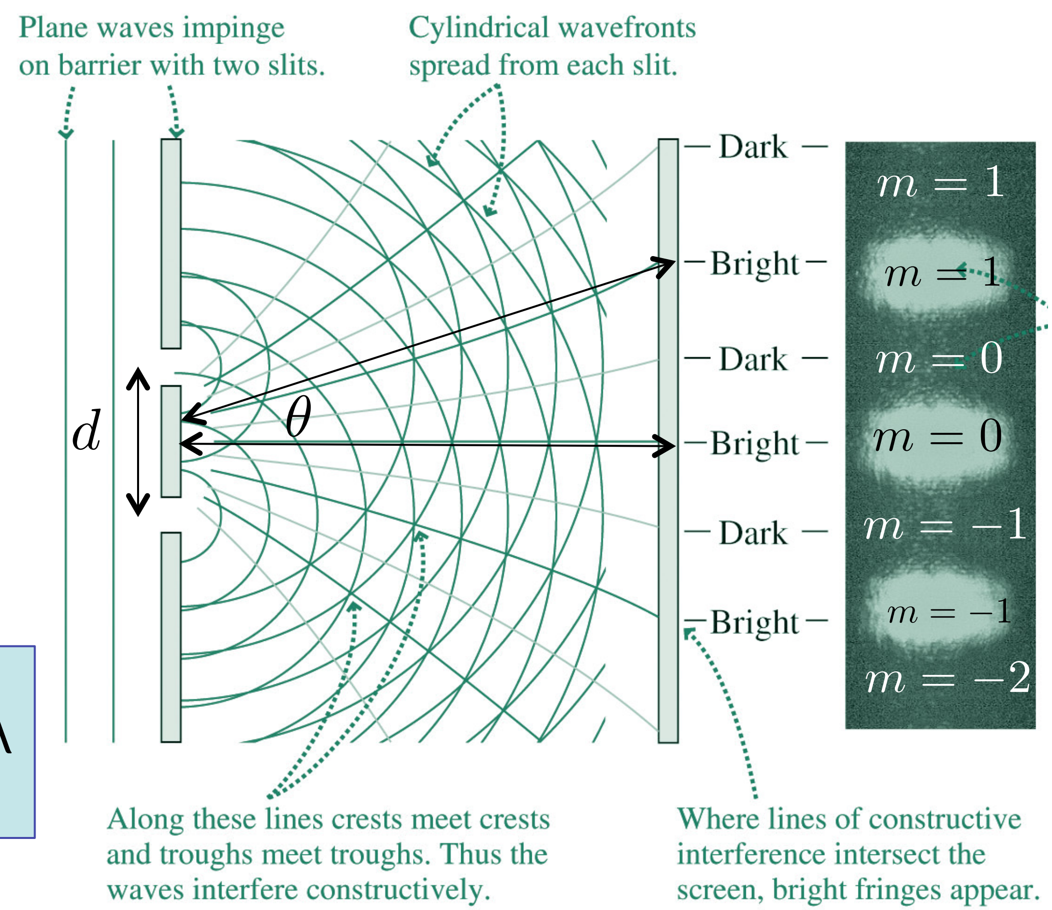
- Positions of bright fringes are given by

$$d \sin \theta_{\text{bright}} = m\lambda$$

where *m* is the m$^{\text{th}}$ fringe, and λ is the wavelength.

- Dark fringes occur where

$$d \sin \theta_{\text{dark}} = \left(m + \frac{1}{2}\right)\lambda$$



Trig Happy

- We can also calculate the distances between fringes as measured on the screen

Small-angle approximation for x<<L!!

$$\tan\theta = \frac{x}{L} \quad \Rightarrow \quad \sin\theta \approx \frac{x}{L}$$

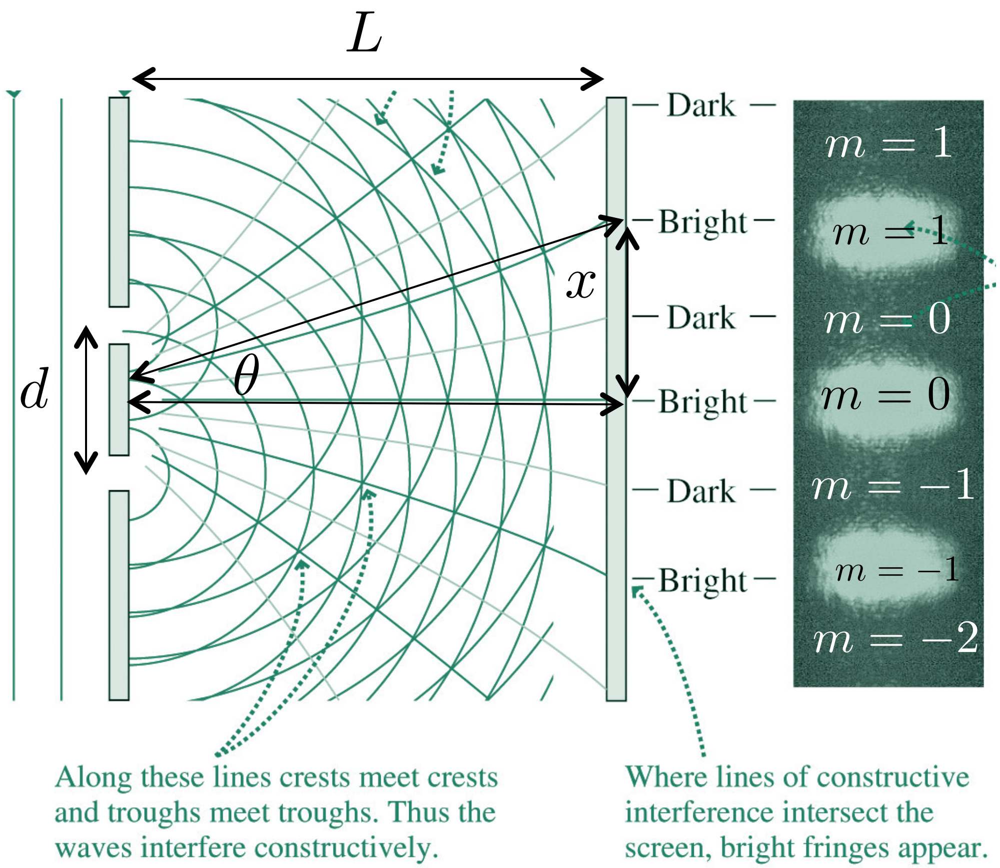
$$\sin\theta = \frac{x}{\sqrt{x^2+L^2}}$$

$$d\sin\theta_{\text{bright}} = m\lambda$$

$$x_{\text{bright}} = \frac{m\lambda L}{d}$$

$$d\sin\theta_{\text{dark}} = \left(m+\frac{1}{2}\right)\lambda$$

$$x_{\text{dark}} = \frac{\left(m+\frac{1}{2}\right)\lambda L}{d}$$

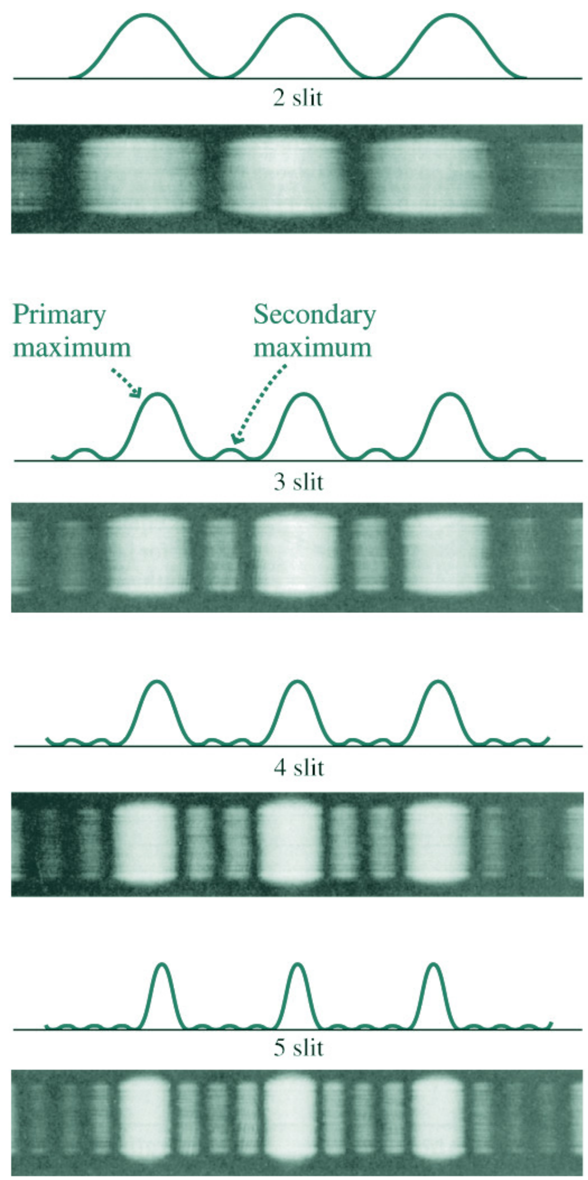


Multiple-Slit Interference

- For three or more slits, the condition for constructive interference remains the same as with two slits, namely

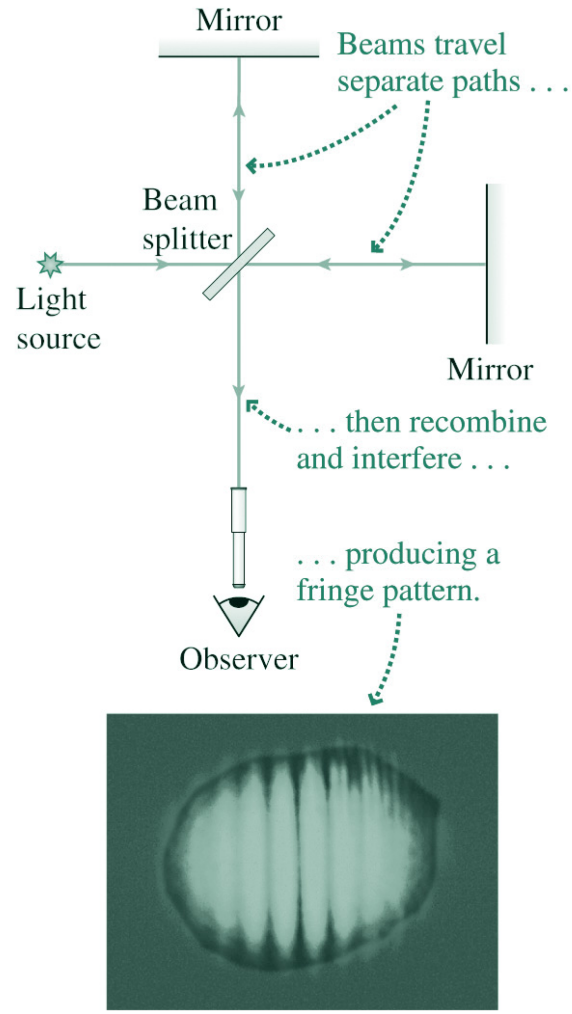
$$d \sin\theta_{\text{bright}} = m\lambda$$

  - As the number of slits increases, the intensity maxima become higher and narrower.
  - The intervening regions, which consist of minima interspersed with secondary maxima, become more uniformly dark in contrast with the bright maxima.
  - With a very large number of slits, the interference pattern becomes a set of very bright, narrow lines at the primary maxima, with dark regions between.



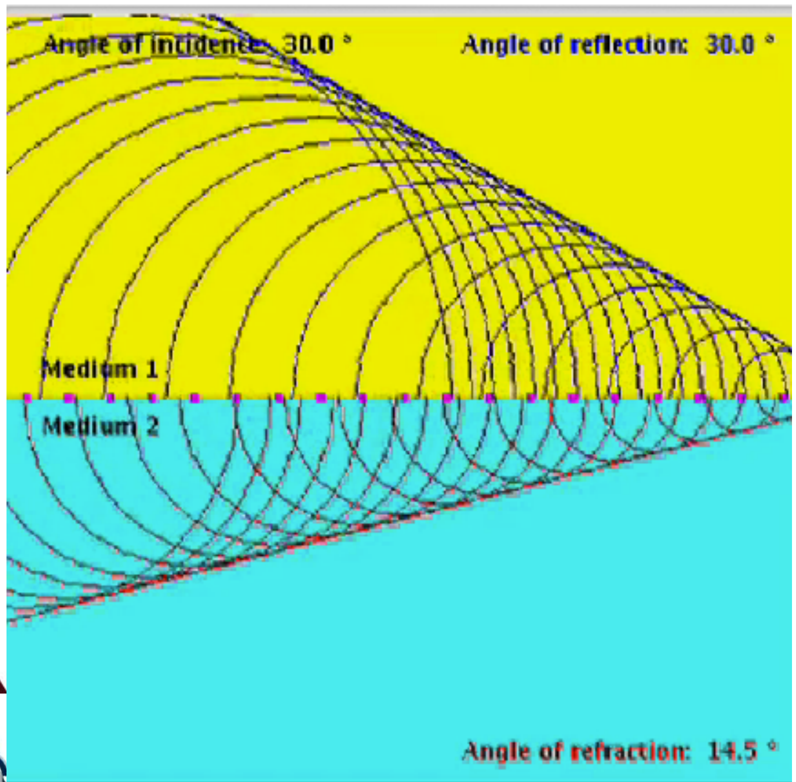
The Michelson Interferometer

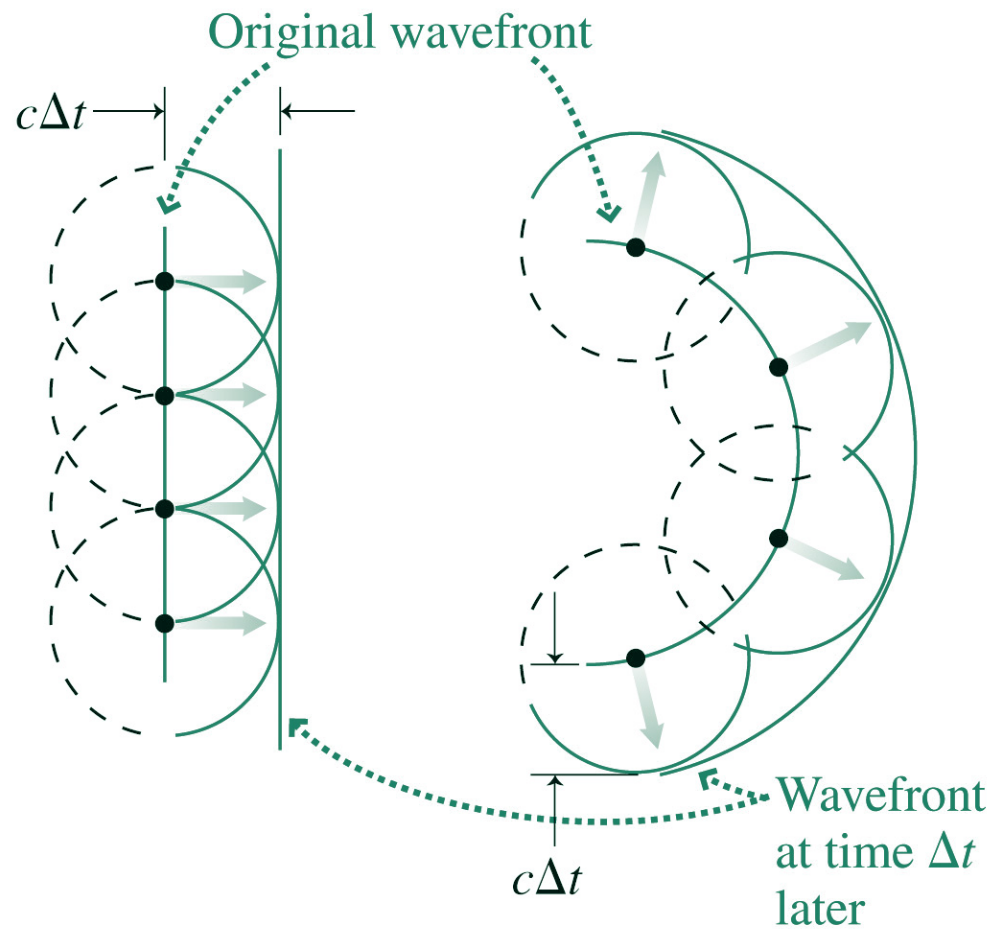
- The **Michelson interferometer** uses interference to make very precise measurements of distance, wavelength, and other quantities.
  - The device was developed by A. A. Michelson in the 1880s for the famous Michelson-Morley experiment (more in the next chapter).
  - Michelson's design is still in widespread use for precision measurements in science and technology.
  - The interferometer splits a beam of light, sends it traveling on two perpendicular paths, and recombines the beams to produce an interference pattern.
  - Details of the pattern depend on the difference in travel times for light on the two paths.



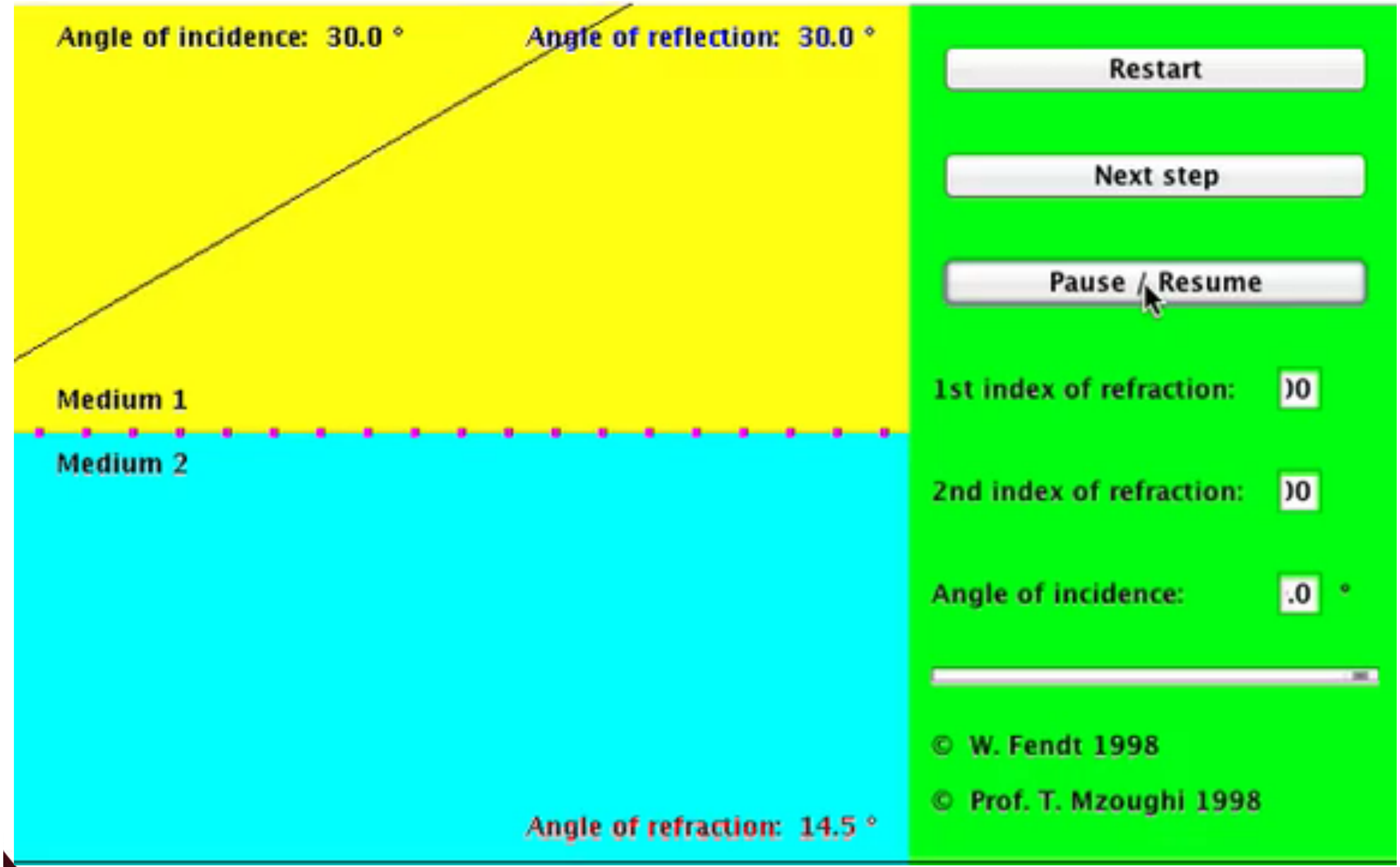
Huygens' Principle

- **Huygens' principle** states that all points on a wavefront act as point sources of spherically propagating "wavelets" that travel at the speed of light appropriate to the medium. At a short time later, the new wavefront is the unique surface tangent to all the forward-propagating wavelets.



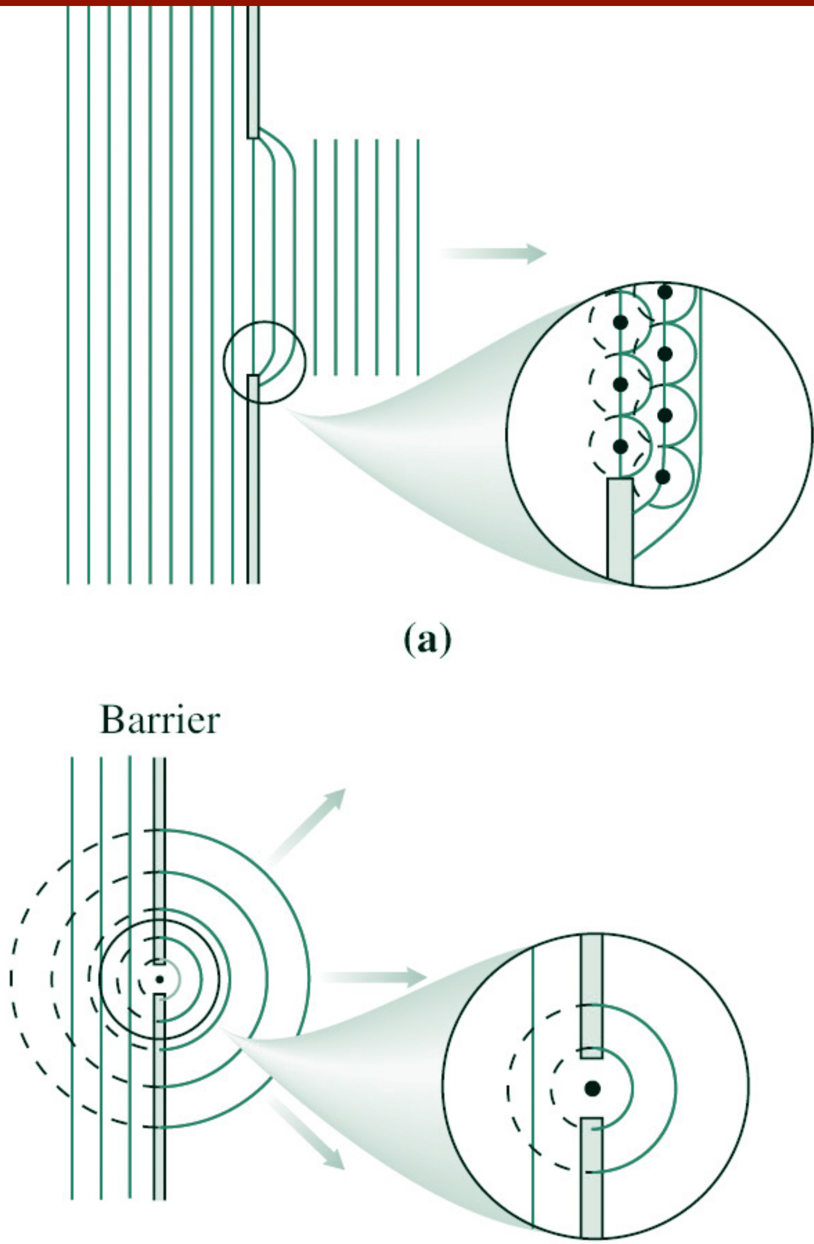


Huygens' Principle Movie



Diffraction

- **Diffraction** is the bending of waves as they pass around objects or through apertures.
  - Huygens' wavelets produced near each barrier edge cause the wavefronts to diffract, or bend at the barrier.
  - Diffraction is most notable when the size of objects is comparable to or smaller than the wavelength.

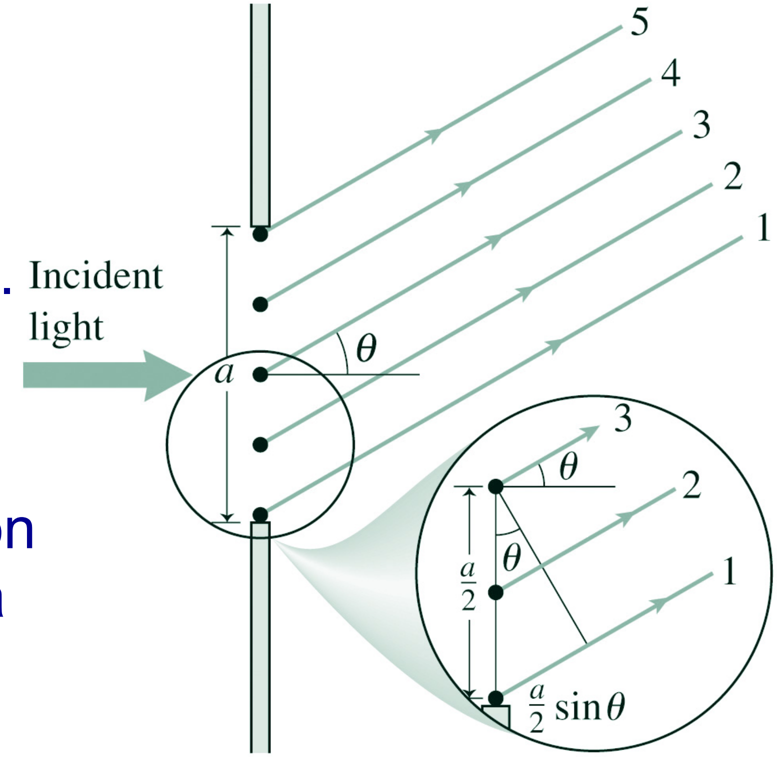


Single-Slit Diffraction

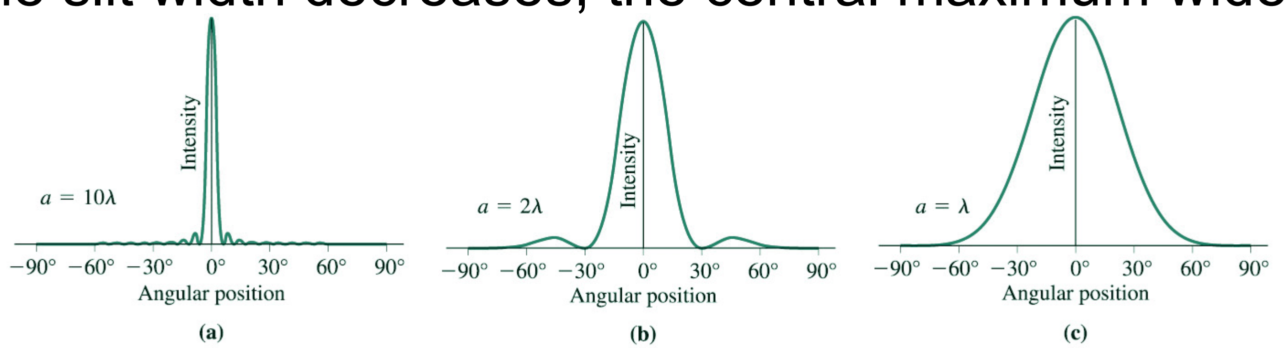
- Each point within a slit acts like a source of circular waves.
  - These waves interfere to produce a **diffraction pattern** from a single slit.
  - Intensity minima occur where

$$a \sin\theta = m\lambda$$

  - Again, this is really just an expression of a difference in path length being a multiple number of wavelengths

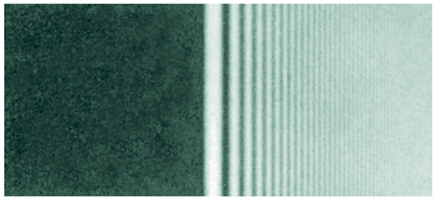


– As the slit width decreases, the central maximum widens.

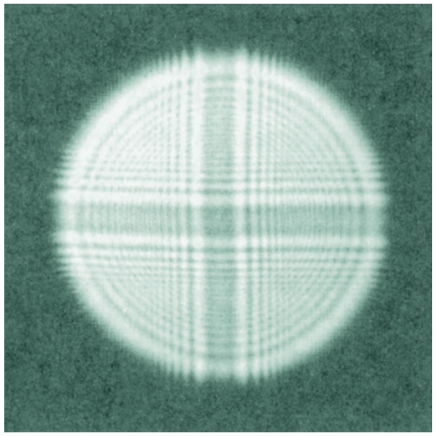


Examples of Diffraction Patterns

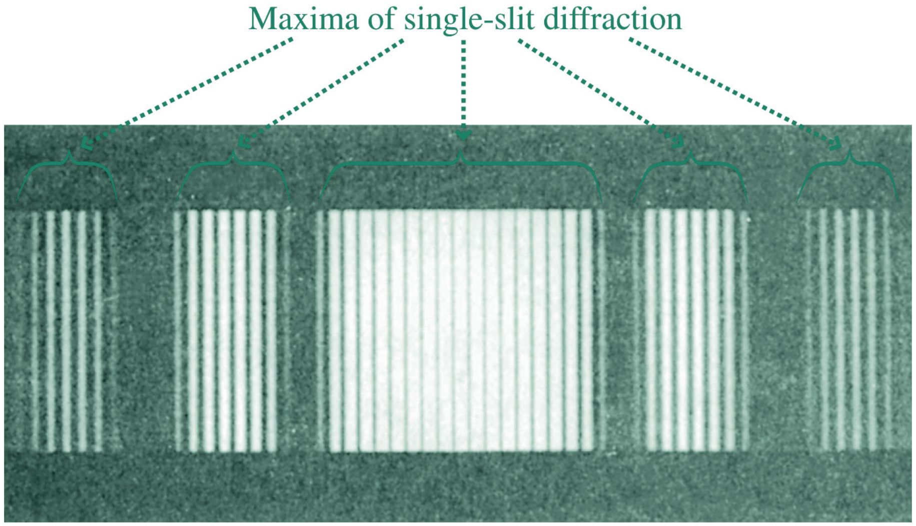
- Diffraction at a sharp edge:



- Diffraction through a circular aperture with crosshairs:

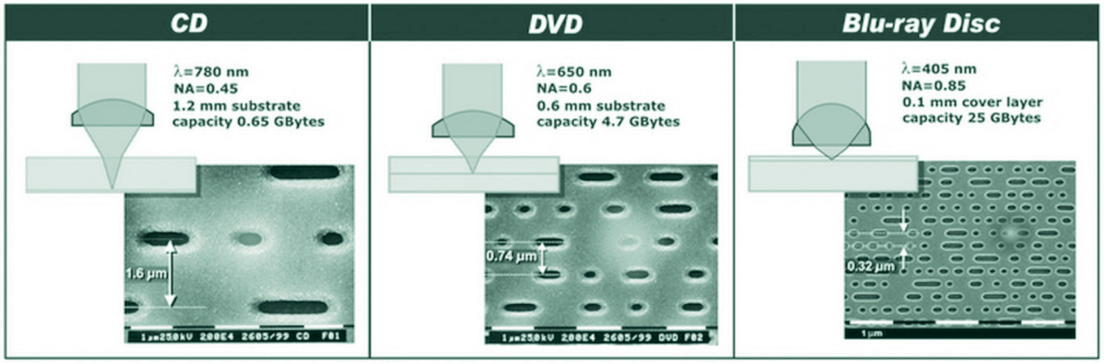


- Two-slit interference combined with diffraction through the individual slits:



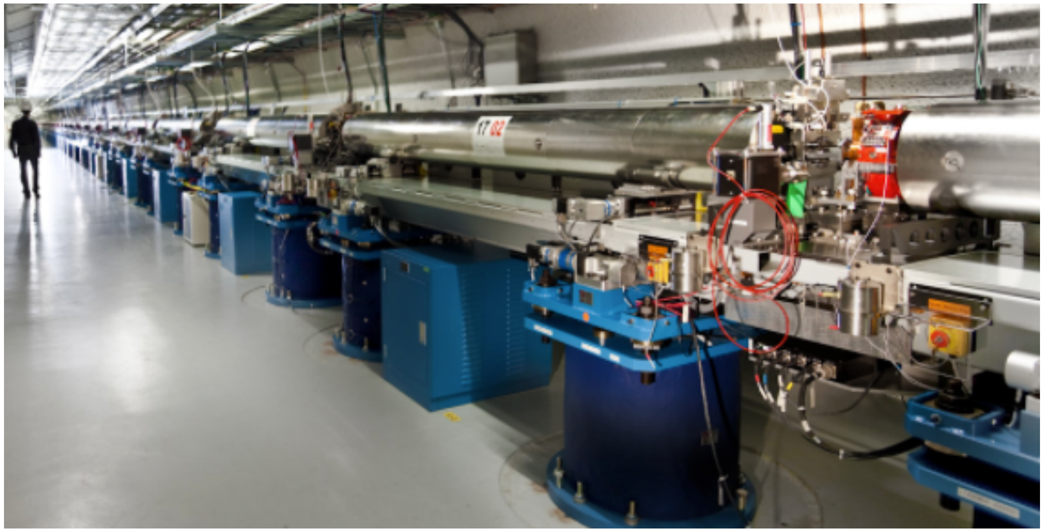
Applications of the Diffraction Limit

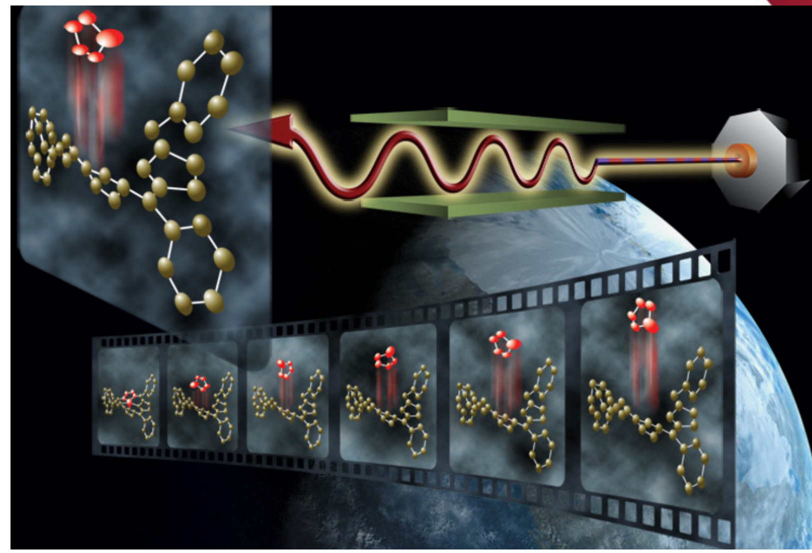
- The diffraction limit makes it impossible for microscopes to resolve objects smaller than the wavelength of the light used.
  - Ultraviolet light or high-energy electrons have short wavelengths, allowing microscopy of smaller objects than is possible with visible light.
- The diffraction limit makes it impossible for telescopes to resolve closely spaced objects, or to see details of distant objects.
  - The larger the telescope aperture, the better the resolution.
  - Atmospheric turbulence, not diffraction, limits most ground-based telescopes.
- The diffraction limits the "pit" size and therefore determines the amount of information storage on optical discs.



- CDs use infrared lasers.
- DVDs use red lasers, have smaller "pits," and hold more information.
- HD-DVDs and Blu-ray discs use violet lasers and hold still more.

Accelerator Light and LCLS-II





- LCLS-II: Linac Coherent Light Source at SLAC (Stanford, CA)
  - Ultra-intense, short-pulse X-ray laser beams
    - Over 10^{20} times brighter than conventional lasers
    - λ down to ~0.075 nm, pulse time ~10^{-13} s: can image *individual atoms*
  - Series of fast pulses => molecular movies
  - A "free electron" laser
    - generated by wiggling high energy electron beams in a very strong oscillating magnetic field in a large (2+ miles) particle accelerator