Lecture 21: Chapter 22, Paragraphs 22.1-22.3, April 28 2005

A little bit of history

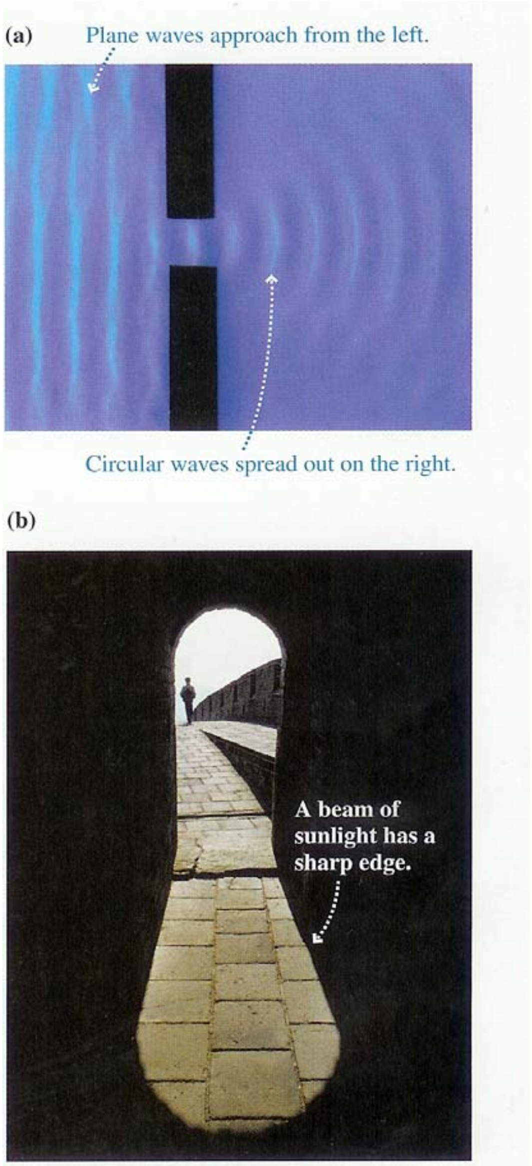
Famous polemic between Newton (~1660) and Robert Hooke and Christian Huygens:

Newton's argument: sharp-edge shadow
Indicates that light consists of particles, "corpusclus", propagating in straight lines.

1801 Young's experiment: observation of interference.

It means that light is a wave, but what is waving? Maxwell, Faraday and others showed (mid-XIX century): **the light is an EM wave**.

Back to the particle model (beginning of XX century): Einstein's hypothesis of photons with $E = h\nu$. Light is simultaneously a wave and a particle.

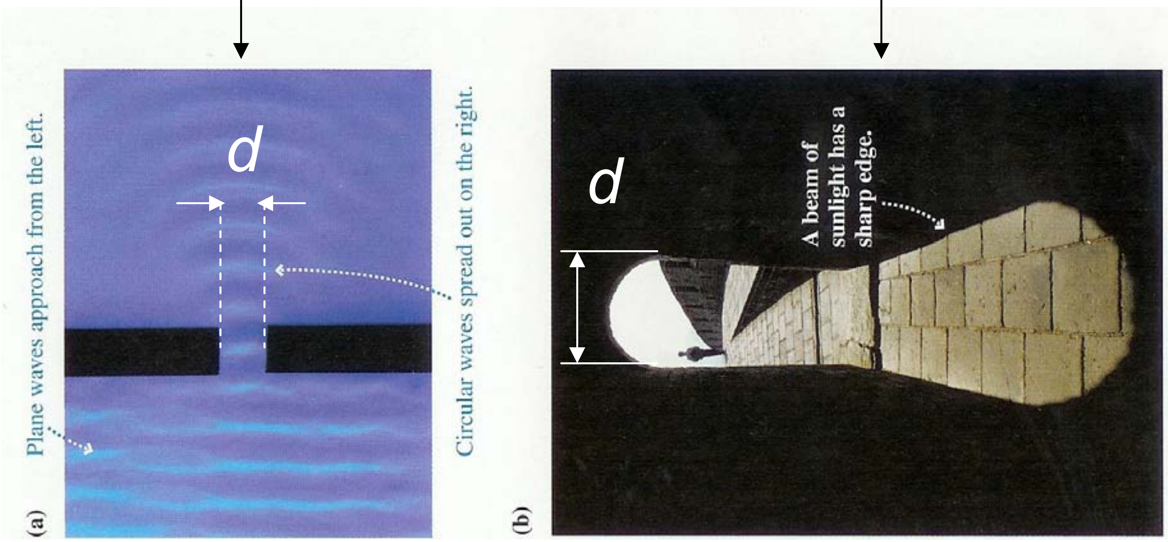


Models of Light

Wave Model
same behavior as sound or water waves

Ray model
light travels in a straight line

Photon model
both wave-like and particle-like properties



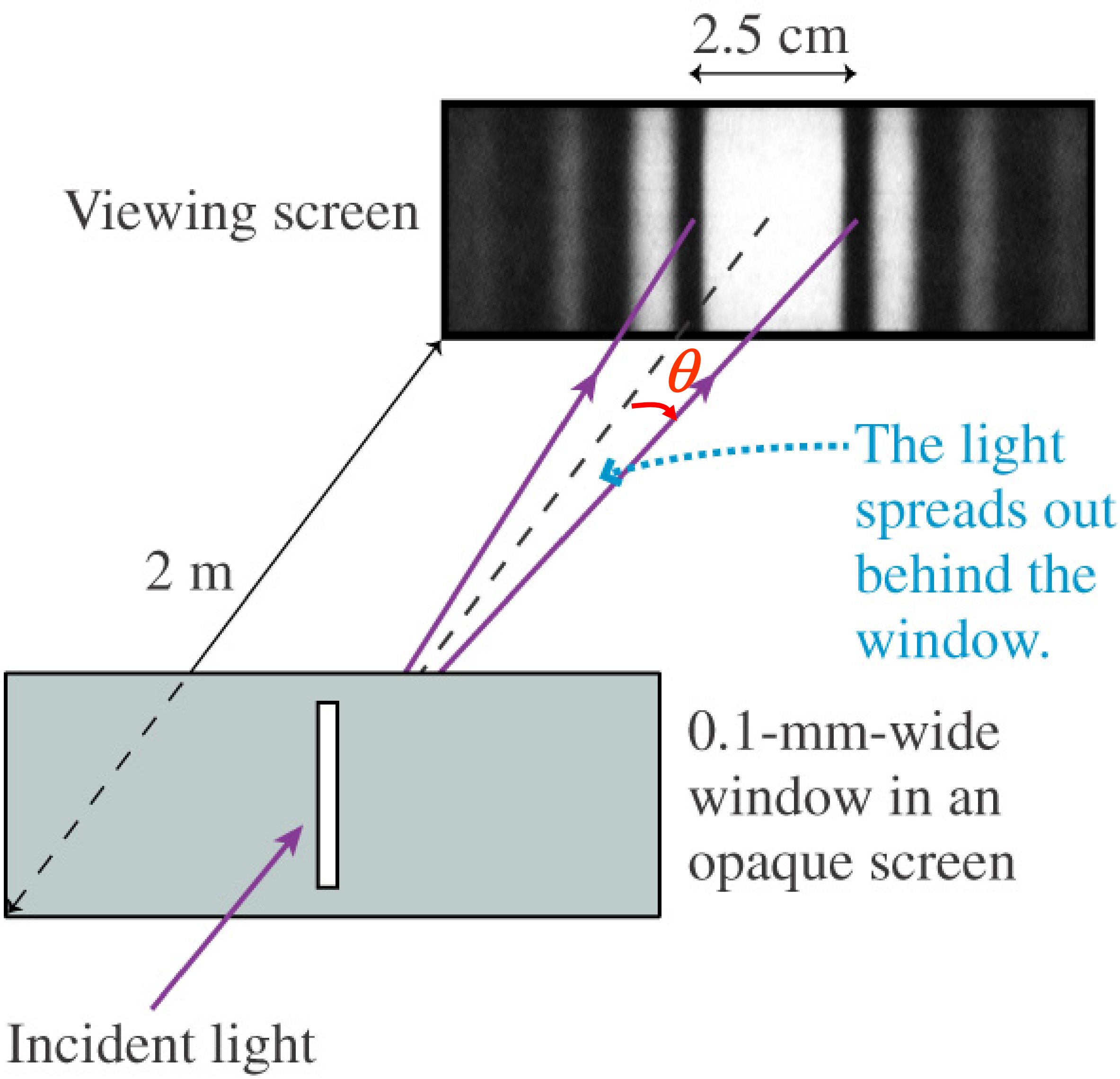
<u>All particles</u> have properties of waves and particles:

1923 De Broglie: $\lambda = h/p$

1920s Heisenberg: $\Delta p \Delta x \geq \hbar$

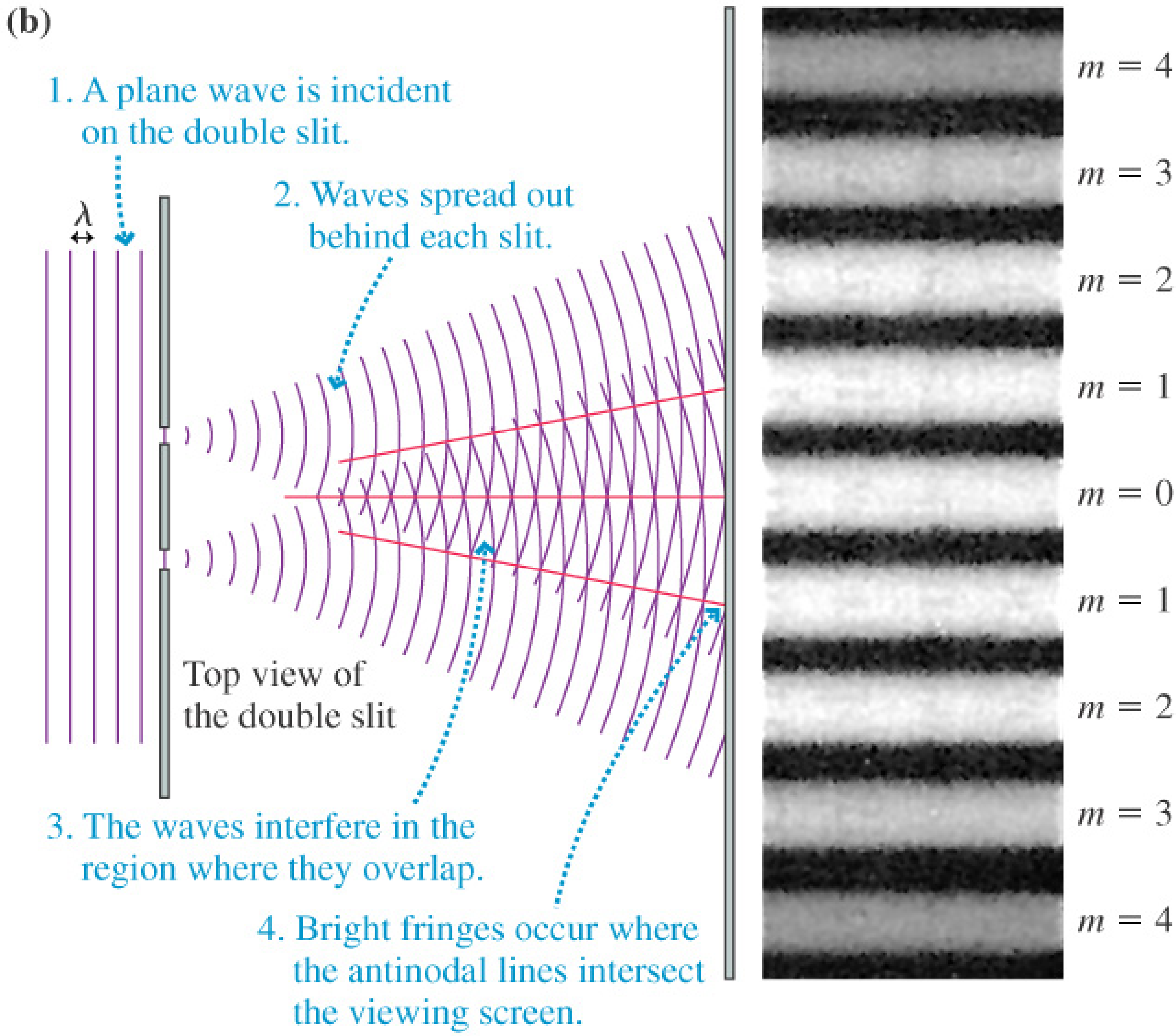
What is the most important parameter determining whether light behaves as a wave or as a beam of particles in experiments with a slit?

Diffraction on a Single Slit



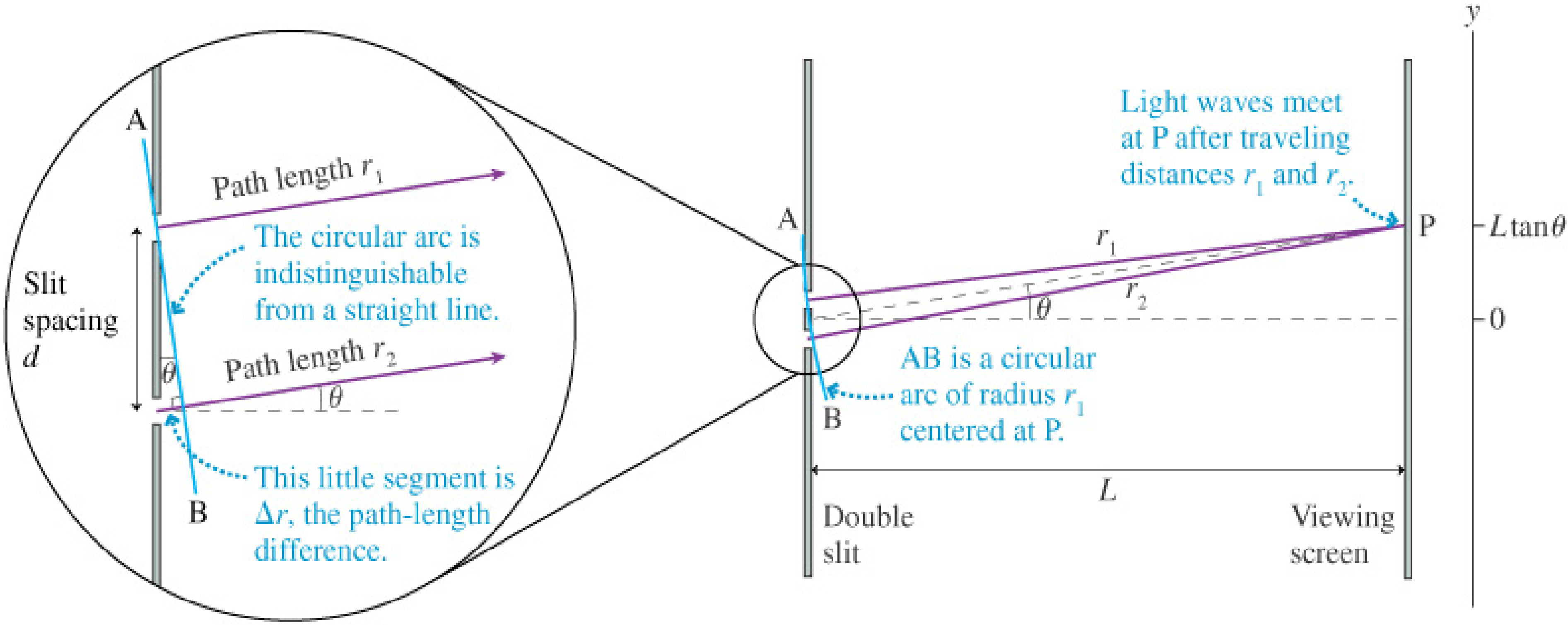
Spreading out behind a narrow slit with $\theta \sim \lambda / a$

Young's Double-Slit Experiment: Interference



What are the requirements to the waves for interference to be observed?

Maxima Positions



$$y = L\tan\theta,\_\Delta r = d\sin\theta$$

$$Maxima: \Delta r = m\lambda,\_m = 0,1,2,3,...\_(constructive\_case)$$

$$\Delta r = d\sin\theta_m = m\lambda\_(exact\_formula)$$

$$Small - angle\_approximation\_(\theta < 1^0):$$

$$\theta_m = m\frac{\lambda}{d},\_m = 0,1,2,3...(bright\_fringes)$$

Fringe Spacing, Dark Fringes

$$\Delta y = y_{m+1} - y_m = \frac{(m+1)\lambda L}{d} - \frac{m\lambda L}{d} = \frac{\lambda L}{d}$$

$$Minima:$$

$$\Delta r = (m + \frac{1}{2})\lambda, \_ m = 0,1,2,3,...$$

$$In \_ a \_ small - angle \_ approximation:$$

$$y_m^{'} = \left(m + \frac{1}{2}\right)\frac{\lambda L}{d}, \_ m = 0,1,2,3,...$$

Intensity Distribution

$$S = \frac{E^2}{c\mu_0}$$

$$I = S_{av} = \frac{P}{A} = \frac{1}{2c\mu_0} E_0^2 = CE^2$$

$$In\_the\_case\_of\_two\_waves\_with$$

$$same\_\omega\_and\_k,\_but\_different\_phases:$$

$$A = a\sin(kr_1 - \omega t + \phi_1) + a\sin(kr_2 - \omega t + \phi_2)$$

$$A = \left| 2a\cos\left(\frac{\Delta\phi}{2}\right)\right|,\_where:$$

$$\Delta\phi = 2\pi\frac{\Delta r}{\lambda} = 2\pi\frac{d\sin\theta}{\lambda} \approx 2\pi\frac{d\tan\theta}{\lambda} = \frac{2\pi d}{\lambda L}y$$

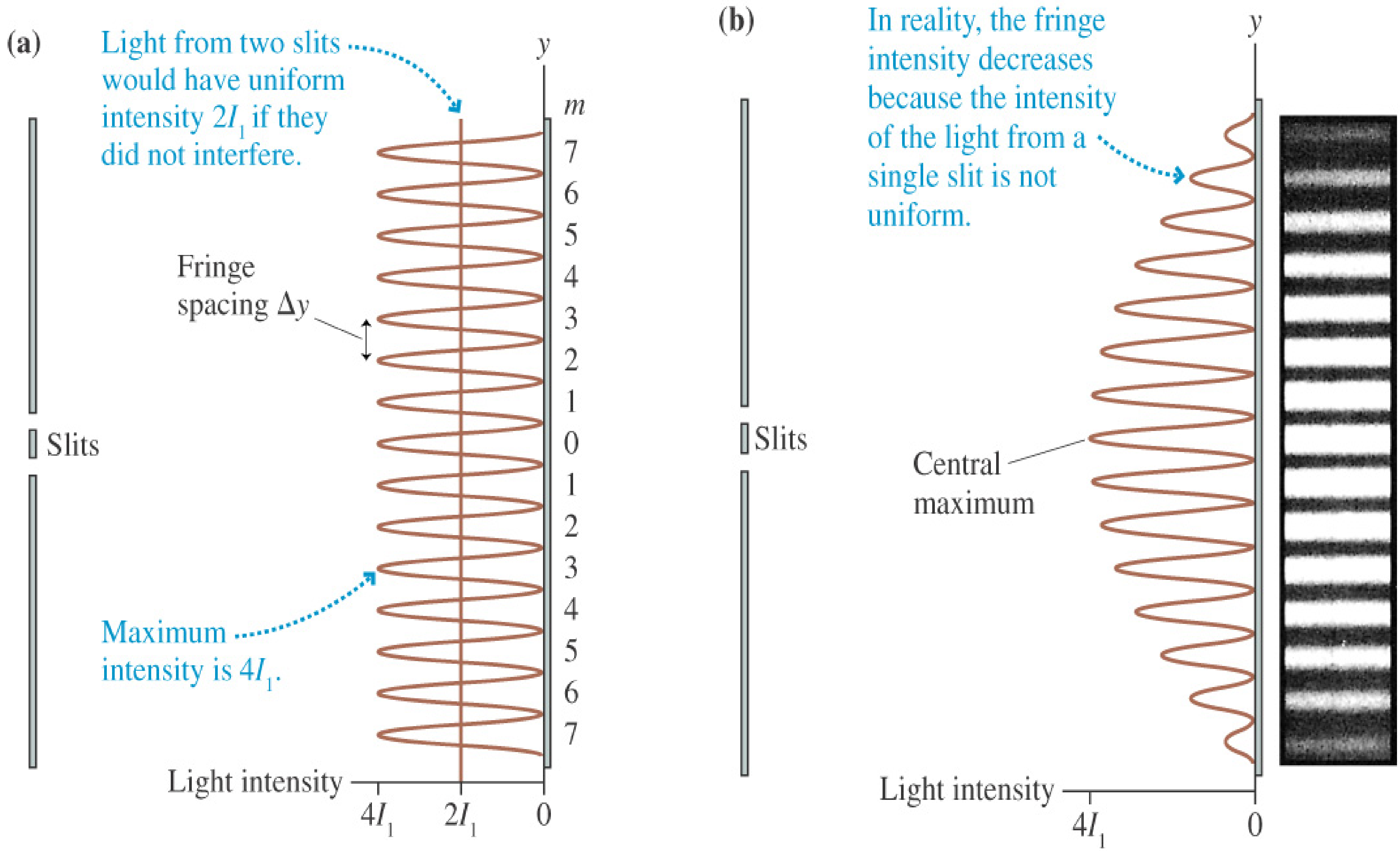
$$A = \left| 2a\cos\left(\frac{\pi d}{\lambda L}y\right)\right|$$

$$I = CA^2 = 4CE_0^2\cos^2\left(\frac{\pi d}{\lambda L}y\right)$$

Properties:

- $I(y) \sim \cos^2(by)$
- Peak intensities are $4I_1$.
- In the case of uniform illumination through two slits without interference it would have been $2I_1$.

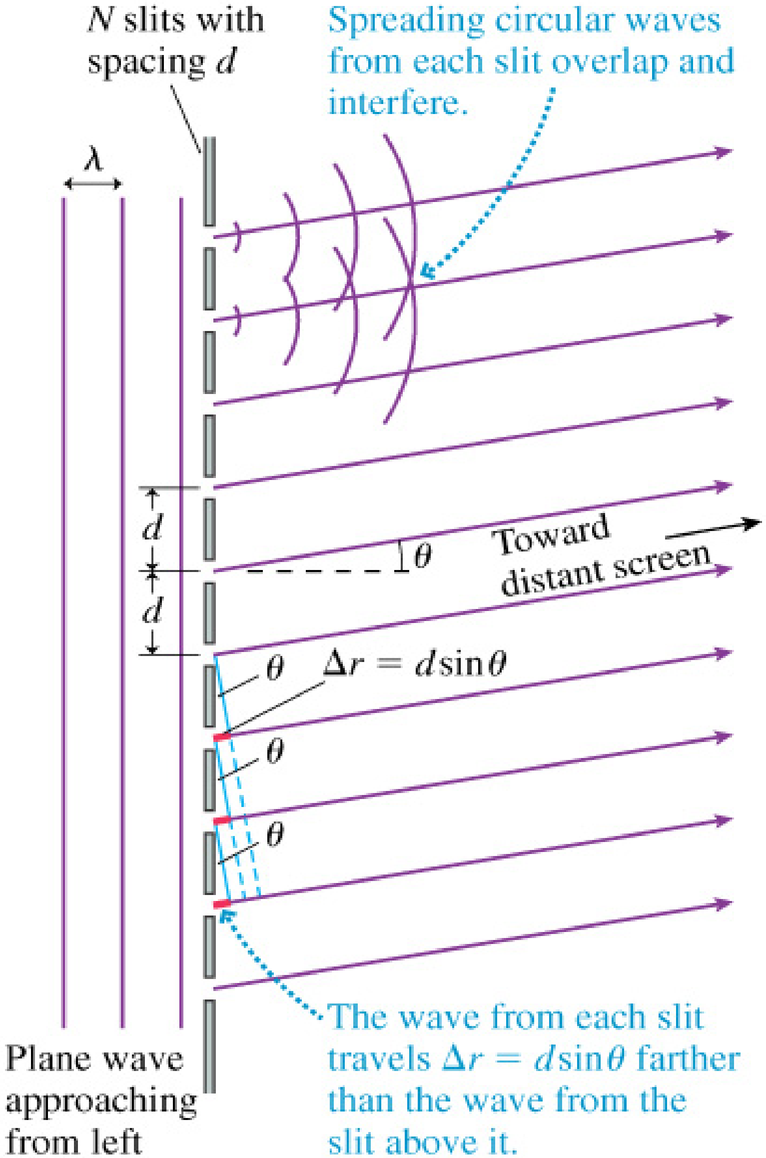
Intensity Distribution



Maxima are $4I_1$, without interference it would have been uniform $2I_1$.

Because of the distribution of intensity from a single slit there is an envelope.

The Diffraction Grating



- N light waves, from N different slits, will all be in phase if:

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

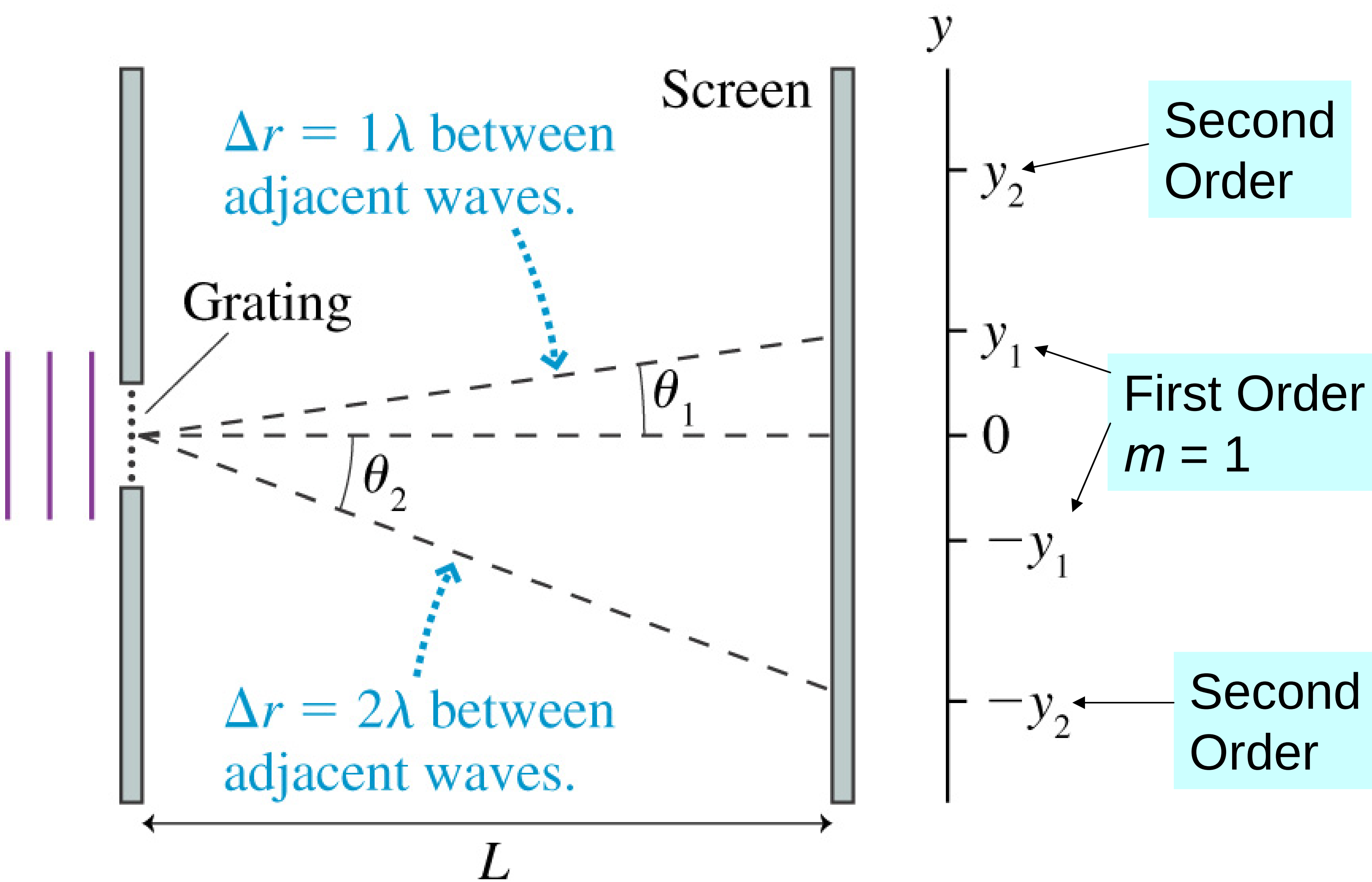
- The distance y_m from the center to the m-th maximum is

$y_m = L\tan\theta_m$

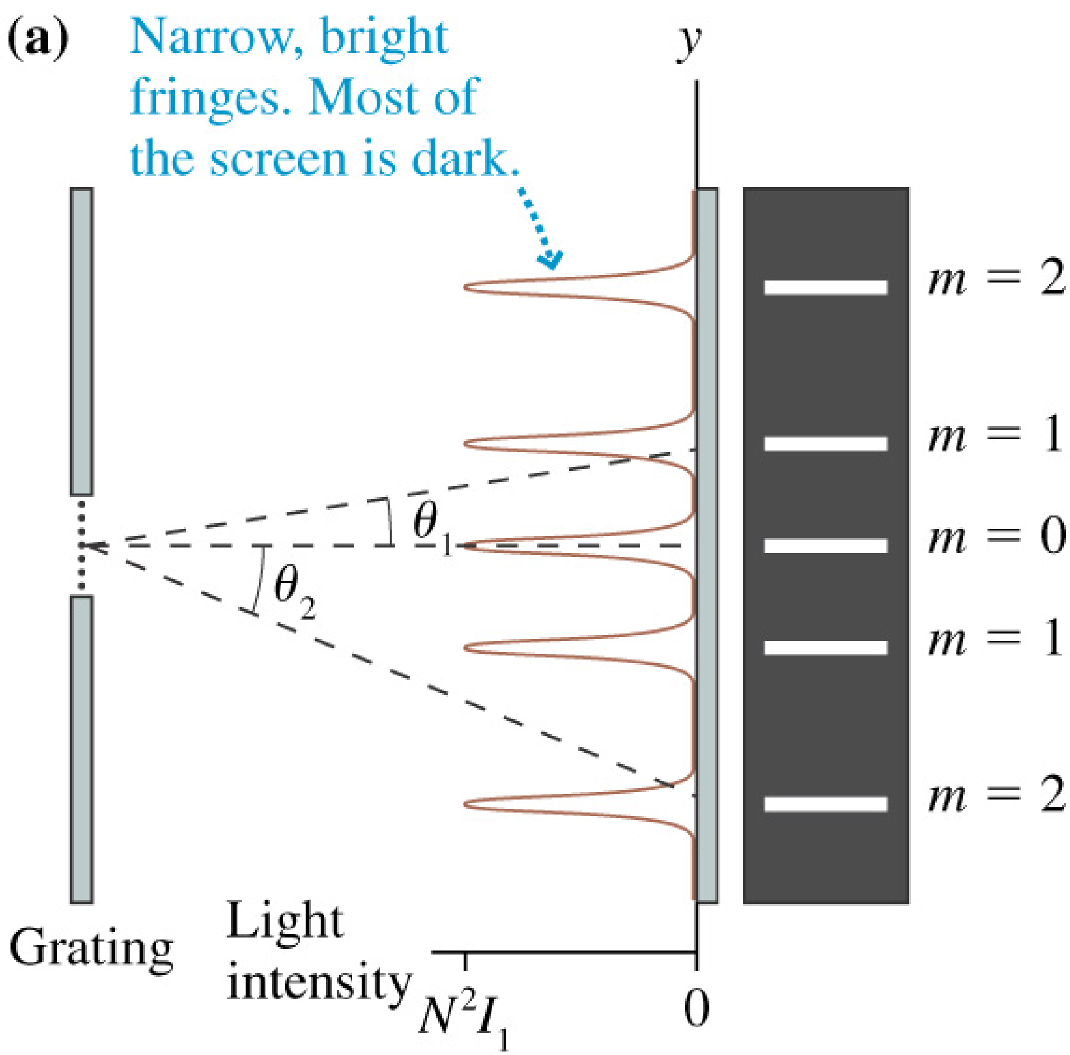
A grating is characterized by the number of lines per millimeter.

- At first sight looks indistinguishable from the case of double slit.
- The intensity distribution however differs strongly, see later.

Different Orders of Diffraction (*m*) are similar to Double Slit



The Width of the Fringes



- Due to constructive interference the peak amplitude is $A = Na$

- Since $I \sim A^2$ we have $I_{max} = N^2 I_1$ where I_1 is the intensity from a single slit

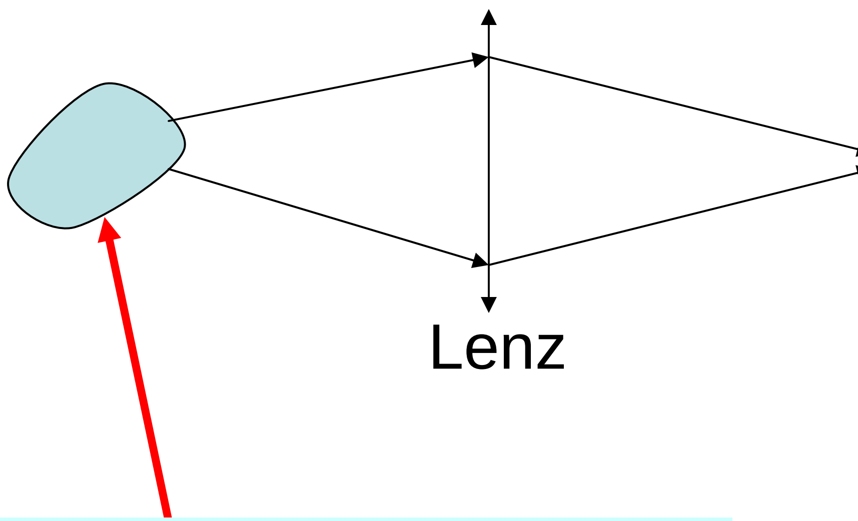
- Due to conservation of number of photons: $I_1 N = I_{max} \times$ (Relative Fringe Width)

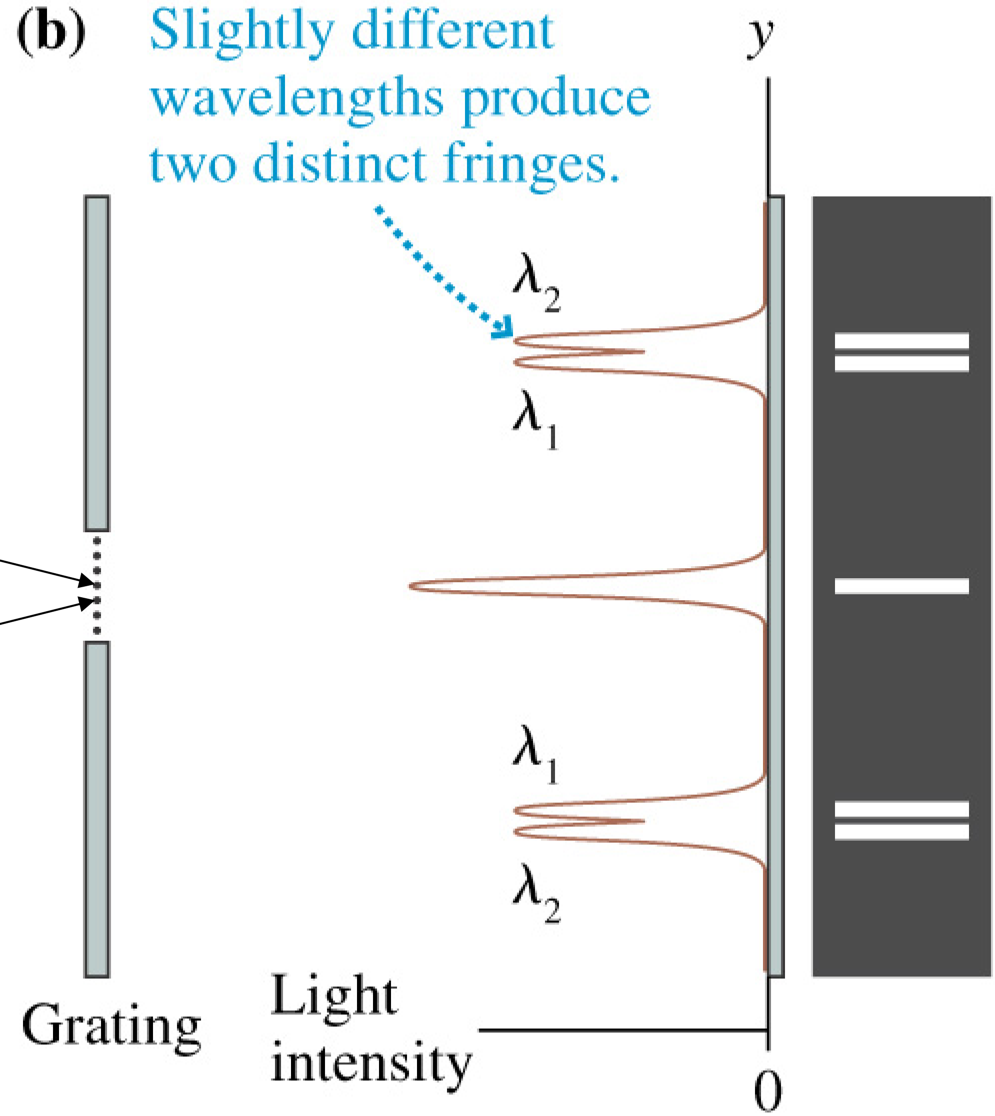
- This means that: Fringe Width ~ 1/N

The bright fringes of a diffraction grating are much sharper and more distinct than the fringes of a double slit

Spectroscopy

Applications:
- Forensic analysis
- Chemical analysis
- Blood alcohol test
- Studies of distant star
- Characterization of materials

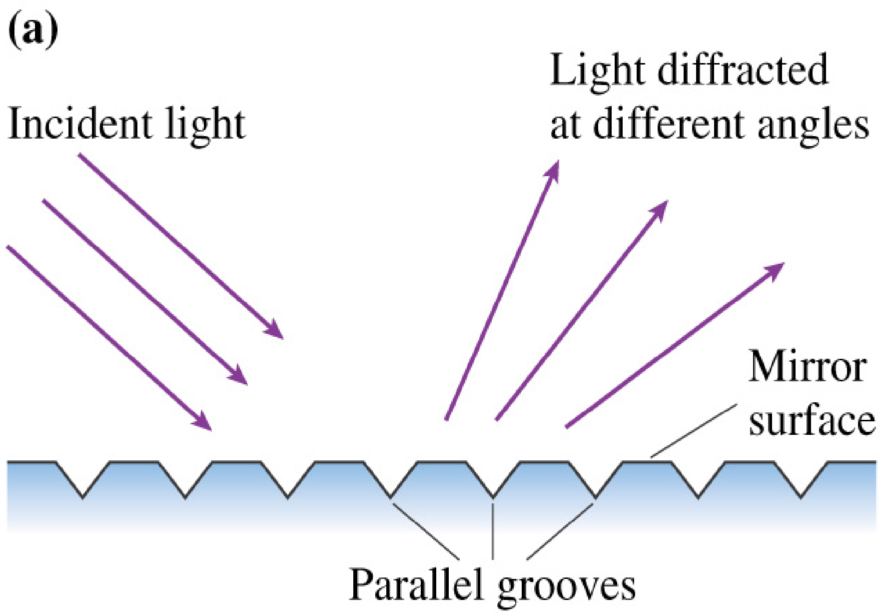




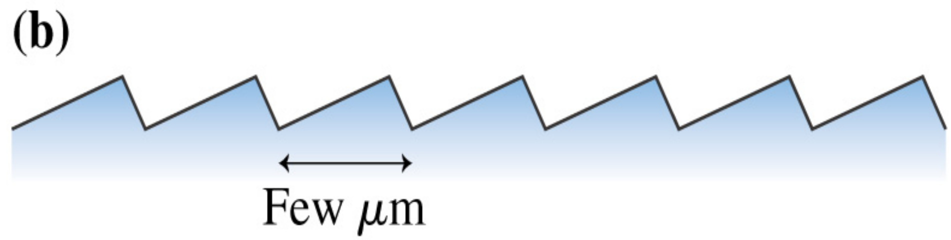
Fluorescence can be excited by using laser

The resolution of the spectrometers is determined by the width of the fringes

Reflection Gratings



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.



Naturally occurring microscopic ridges are present in some bird feathers and insect shells. These cause iridescence when white light reflects off them.

- Iridescence of some bird feathers and insect shells
- Gratings in spectrometers

End of Lecture 21
Reading: Paragraphs 34.4-34.8 from Chapter 34 HW11
HW for Chapter 22
Review for Quiz 10