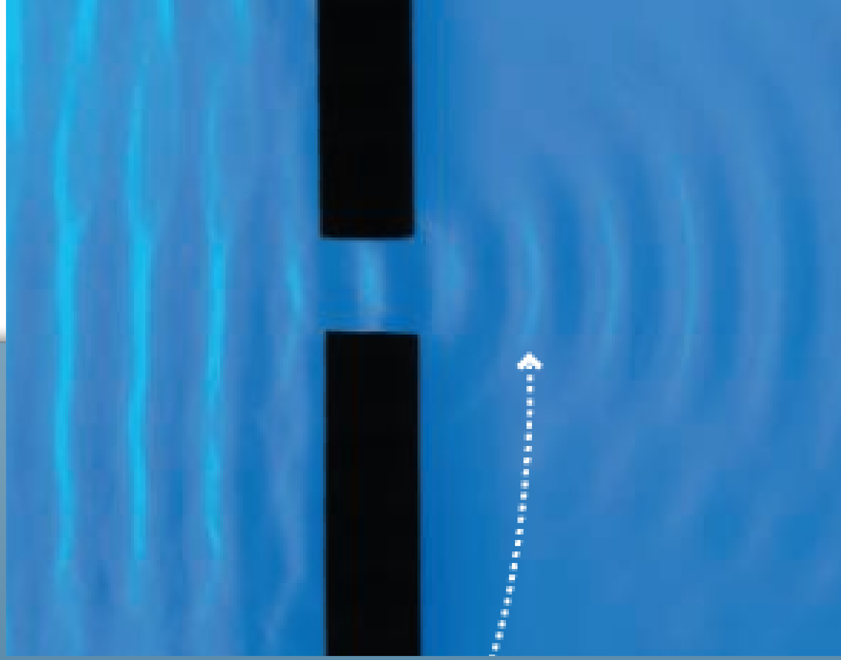
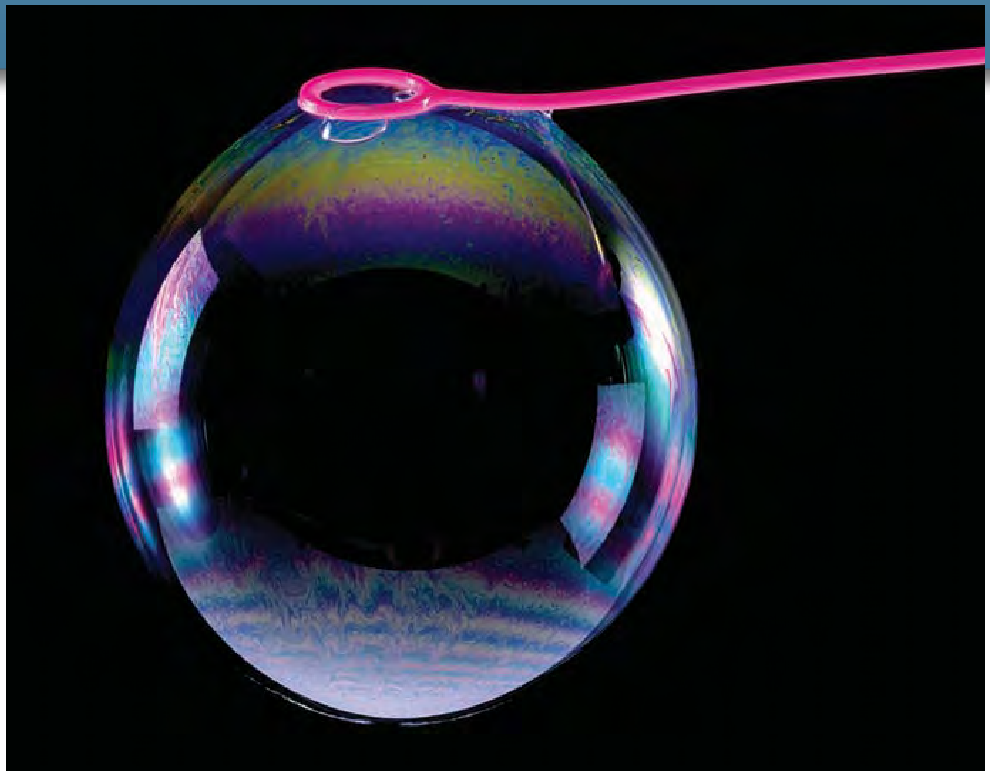
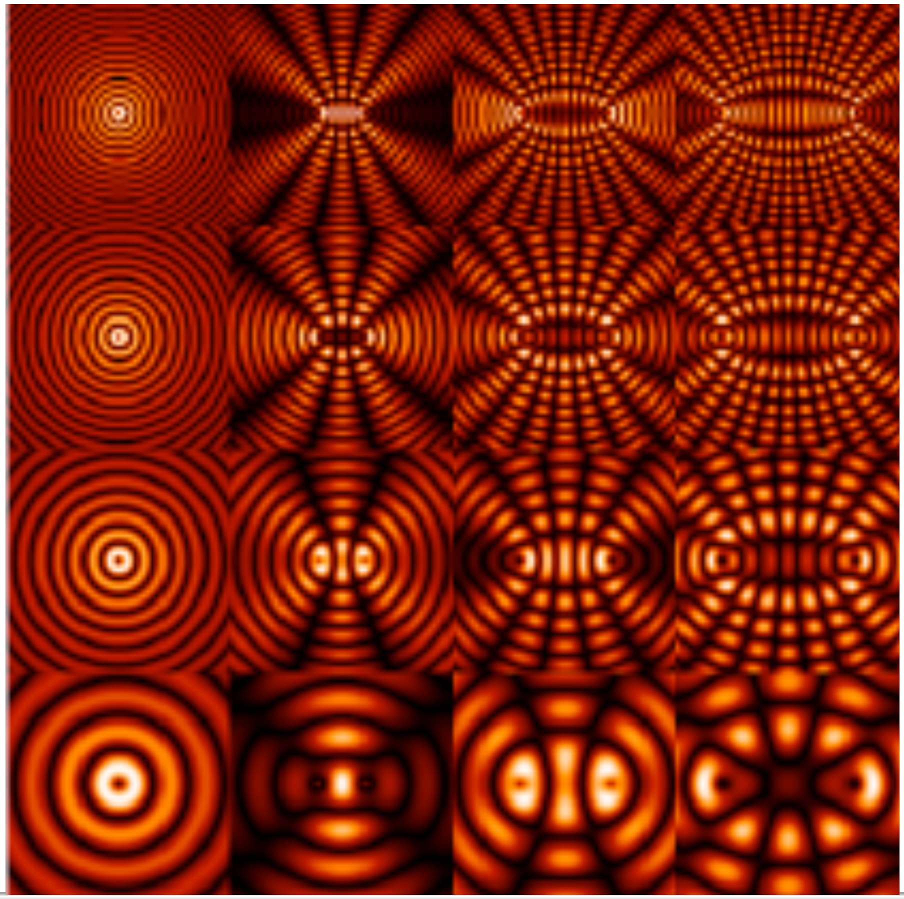


Electromagnetism & Light

Interference & Diffraction





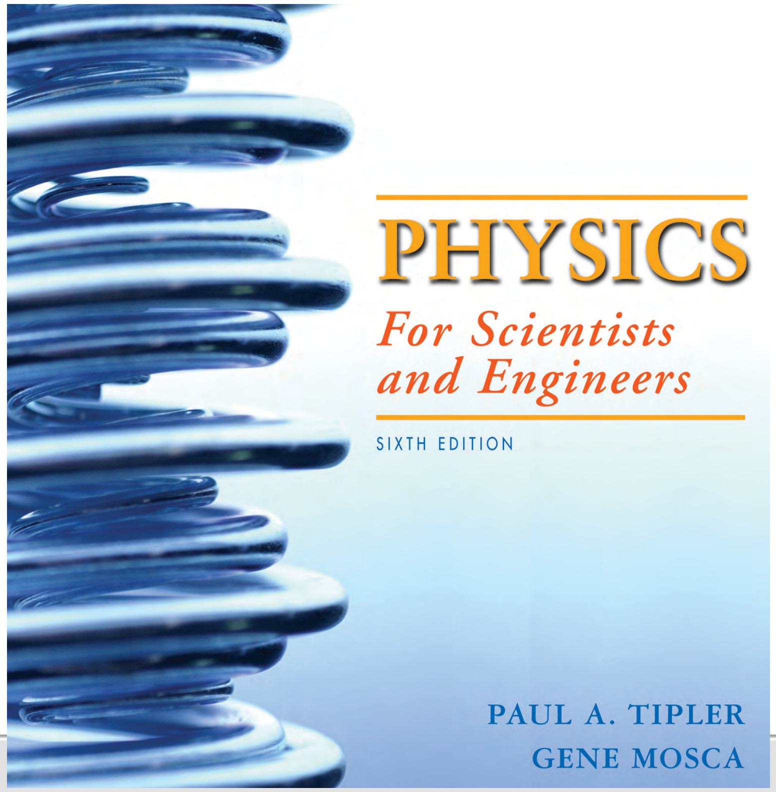
Your opinion is very important to us.

What study material would you recommend for future classes of Phys140/141?

A. *SmartPhysics* alone

B. *SmartPhysics* + a textbook such as Tipler & Mosca

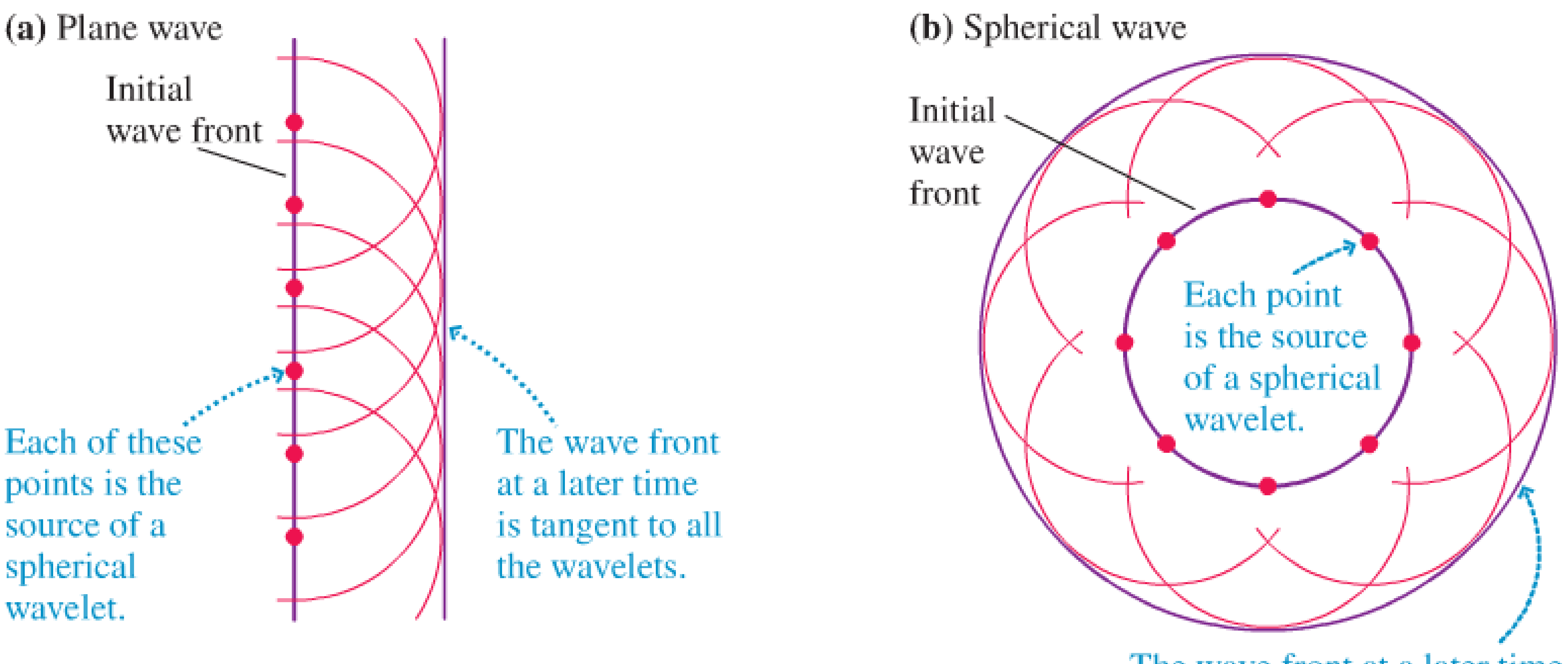
C. Only a textbook (Tipler&Mosca or other) without *SmartPhysics*



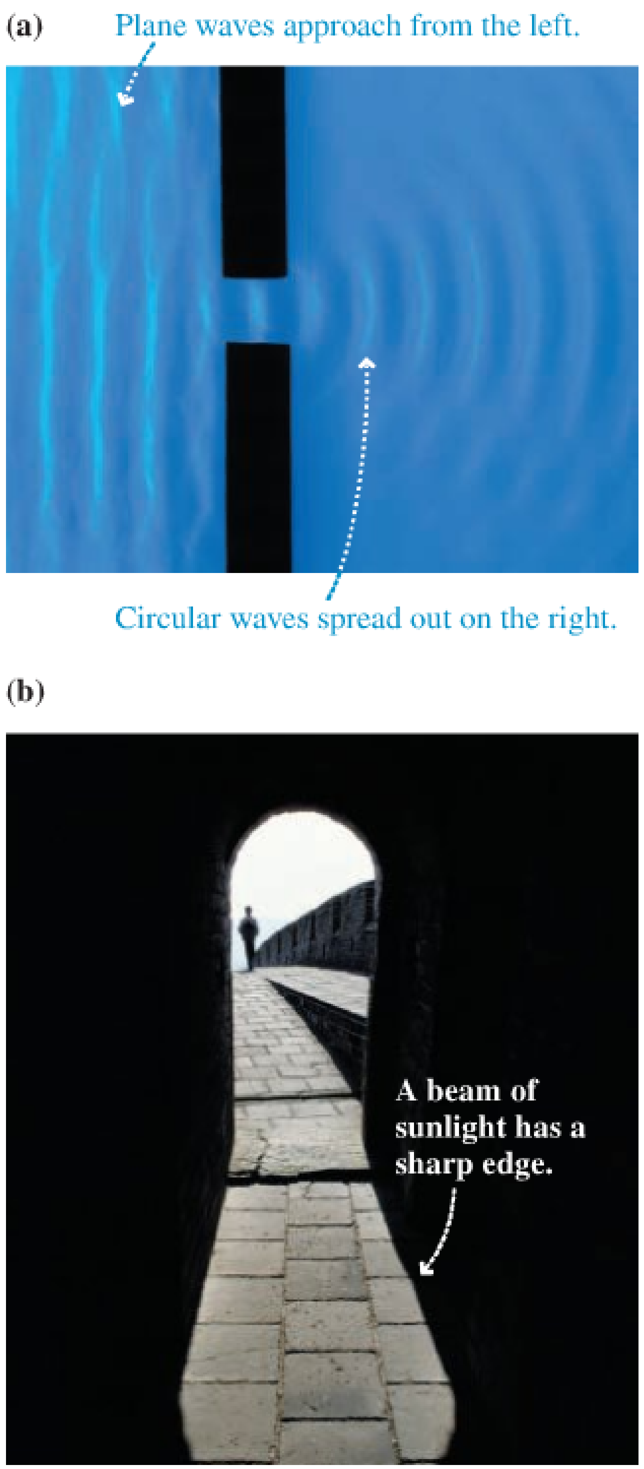
Diffraction - Huygen's Principle

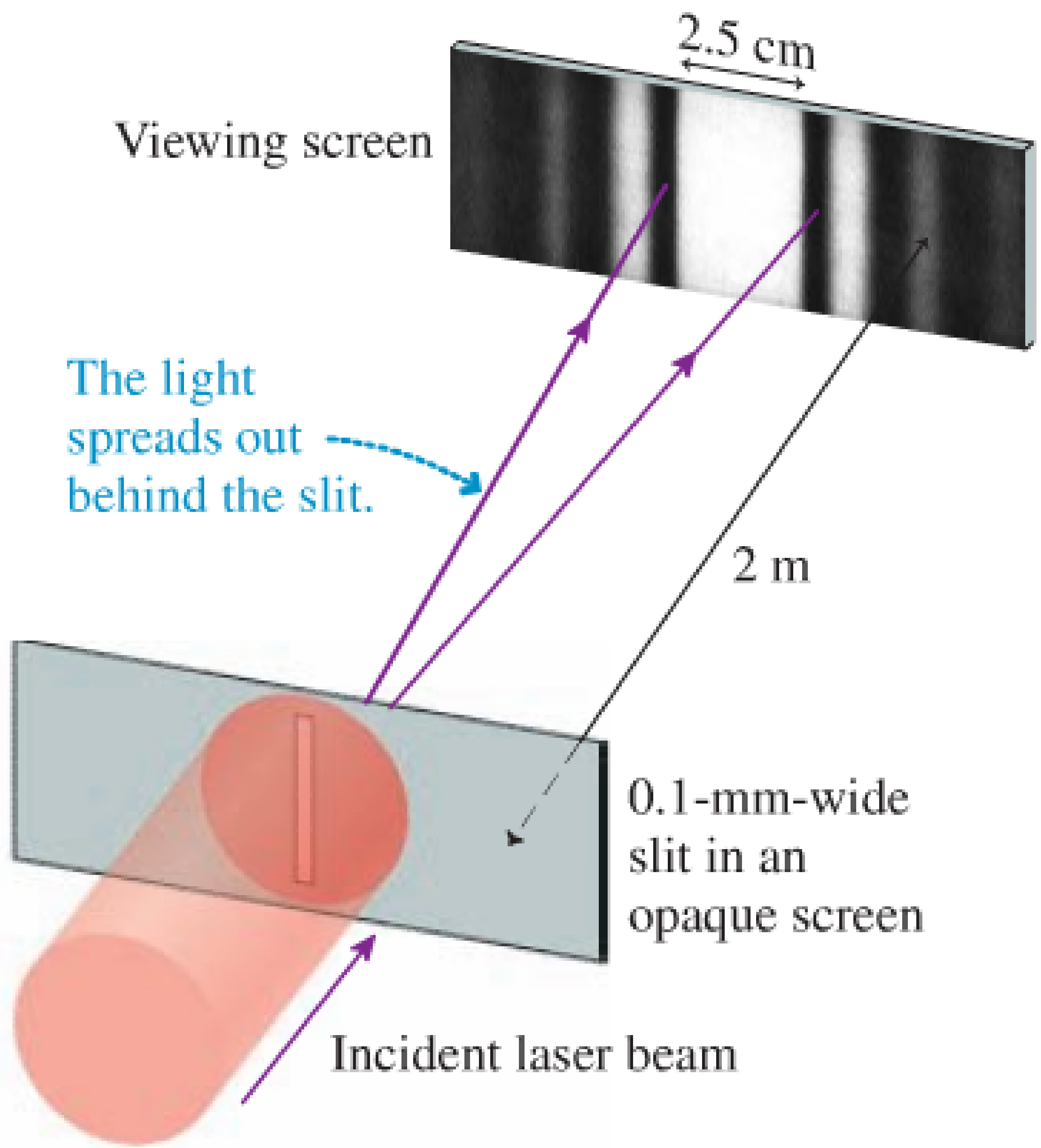
Huygen's Principle

1. Each point on a wave front is the source of a spherical wavelet that spreads out at the wave speed.
2. At a later time, the shape of the wavefront is the tangent line to all of the wavelets.

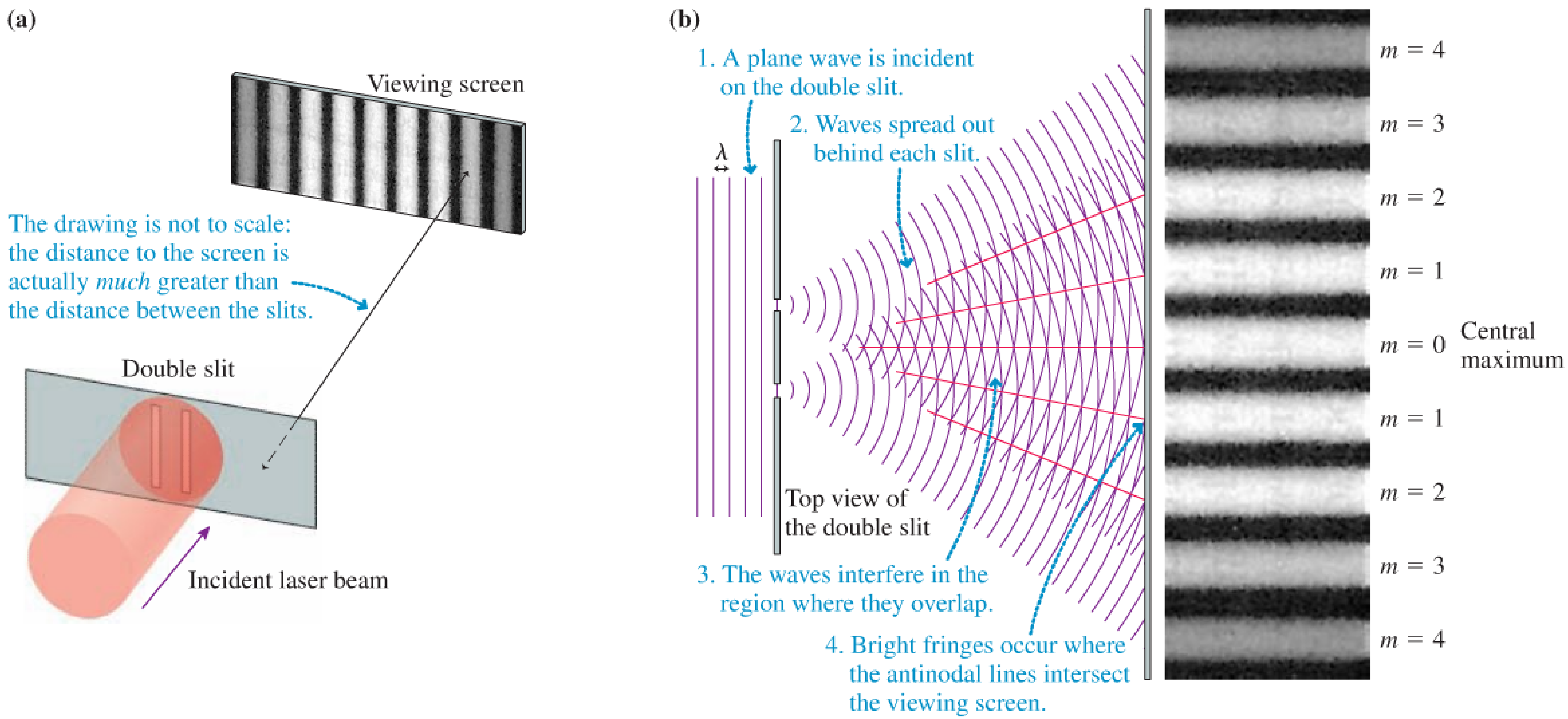


Diffraction - Single Slit





Young's Double-Slit Experiment

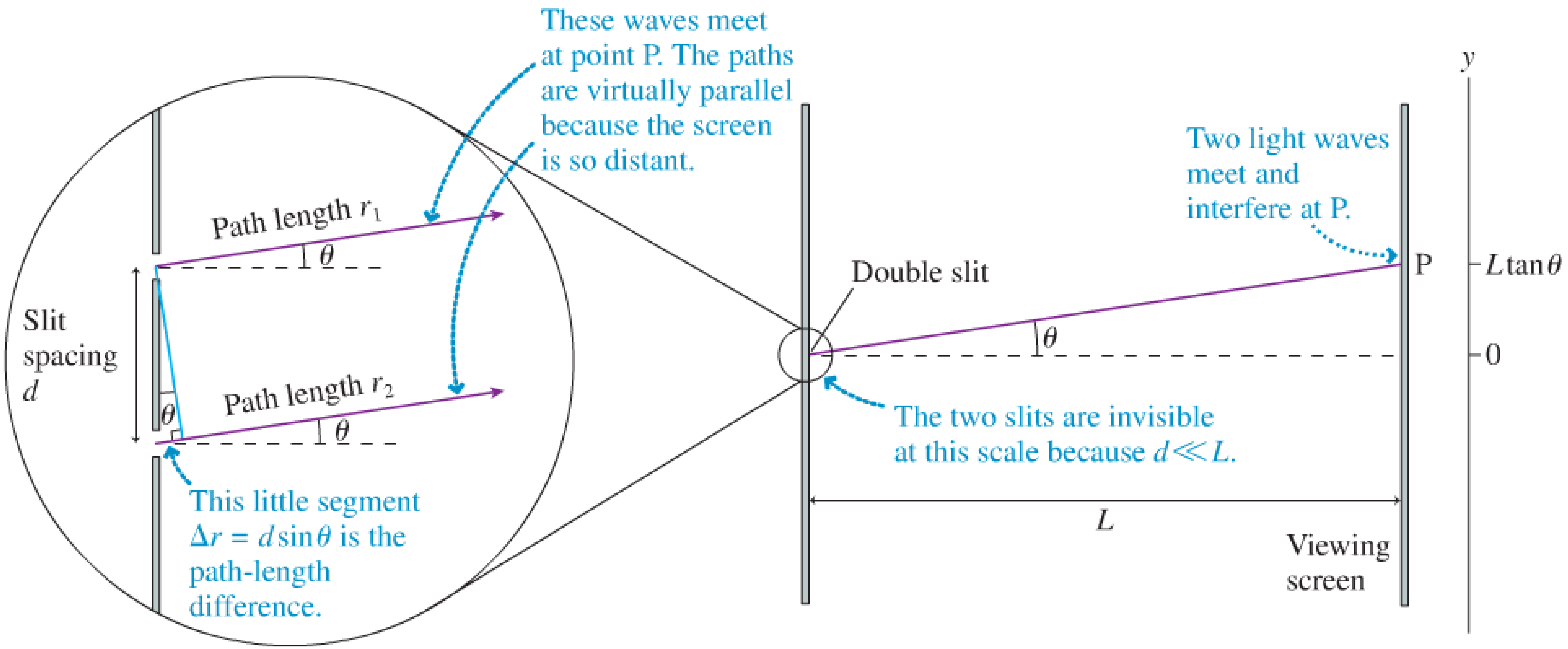


Young's Double-Slit Experiment

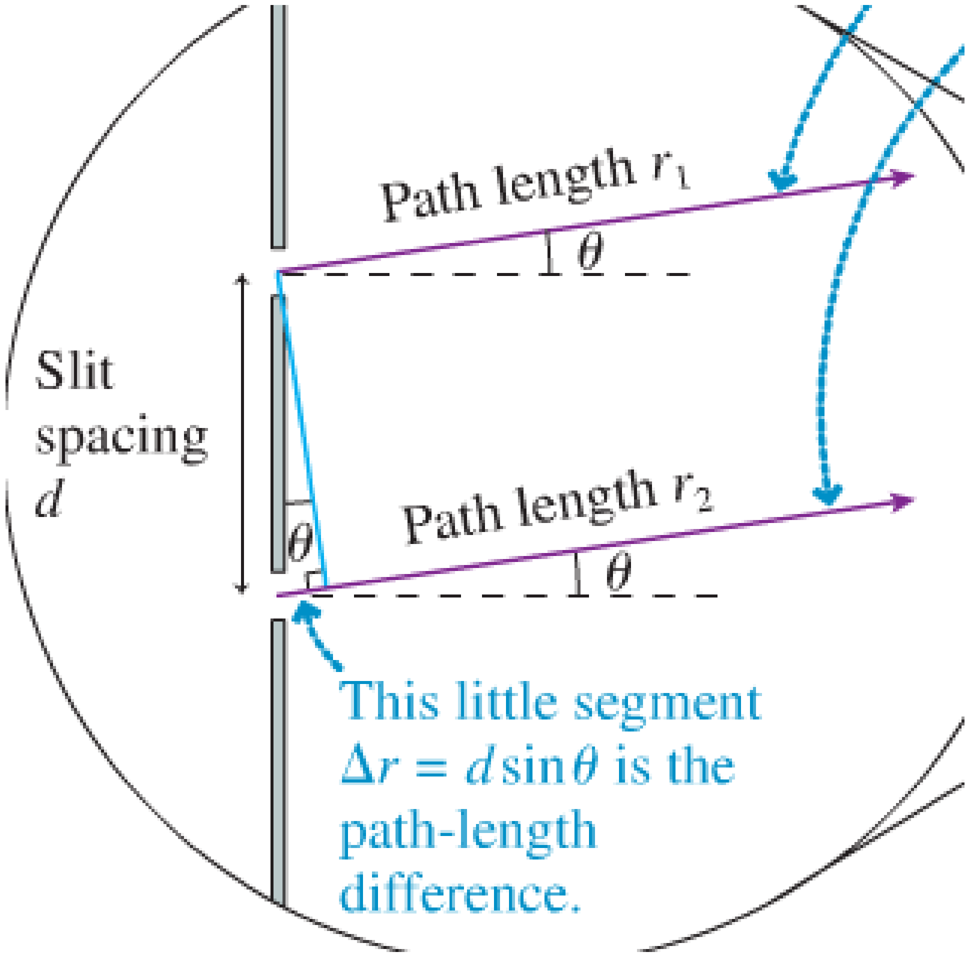
Notes

- The slit-width (*a*) and slit-separation (*d*) are similar in size to the wavelength of light (λ)
- The wave fronts arrive at the two slits from the same source in about the same time - they are in phase ($\Delta\phi = 0$).
- Each slit acts like a point-source by Huygen's principle.

Analyzing Young's Double-Slit Experiment



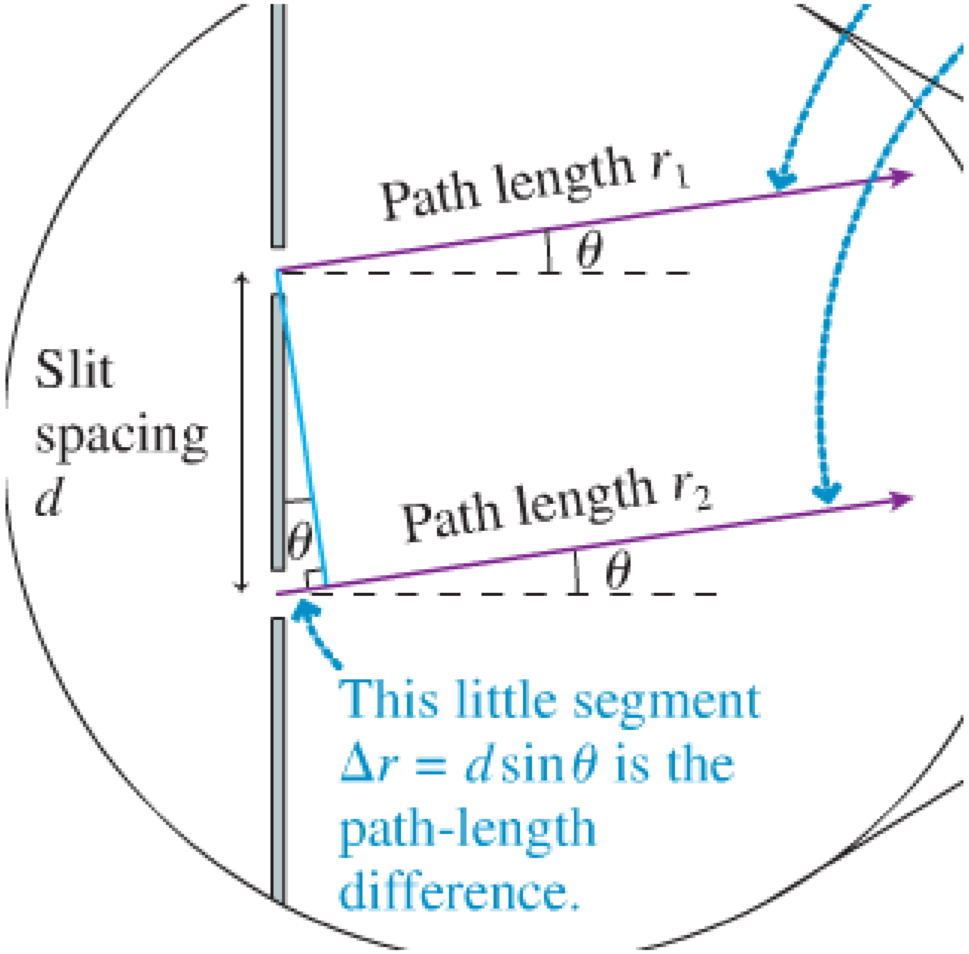
Analyzing Young's Double-Slit Experiment



- Constructive interference occurs when

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

Analyzing Young's Double-Slit Experiment



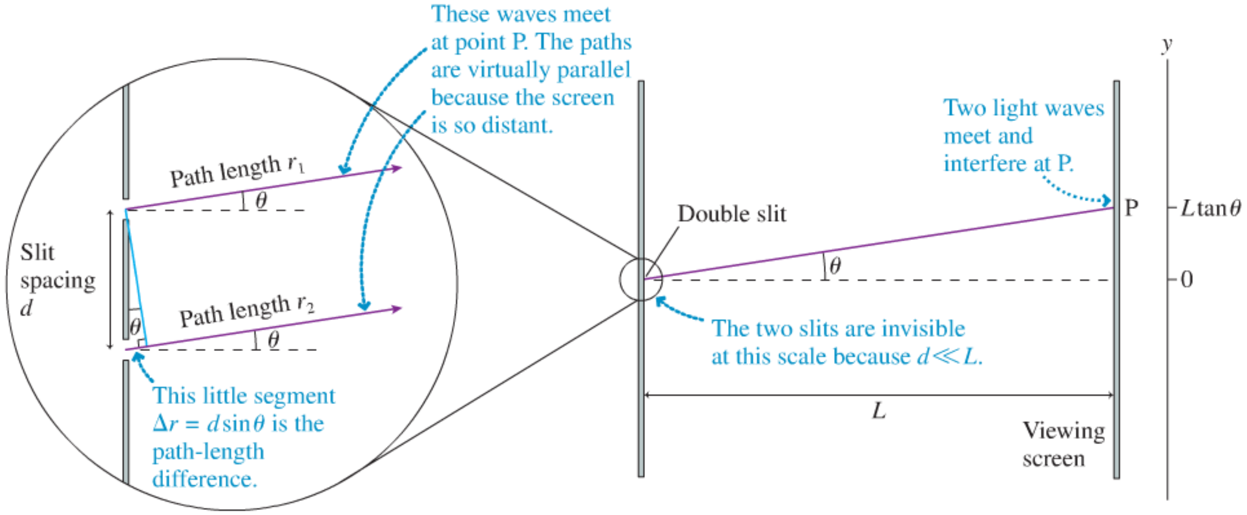
- Constructive interference occurs when

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

- In practice, the angle is small and $\sin\theta \approx \theta$

$$\theta_m = m\frac{\lambda}{d}$$

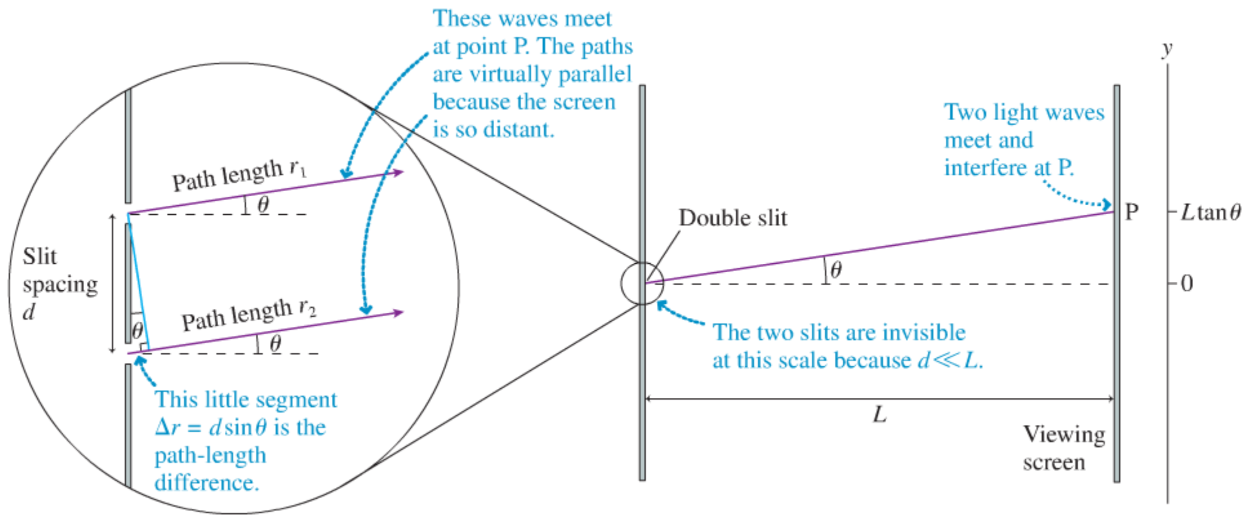
Analyzing Young's Double-Slit Experiment



- Using some simple trigonometry:

$$y_m = \frac{m\lambda L}{d}, m = 0, 1, 2, 3, \ldots$$

Analyzing Young's Double-Slit Experiment



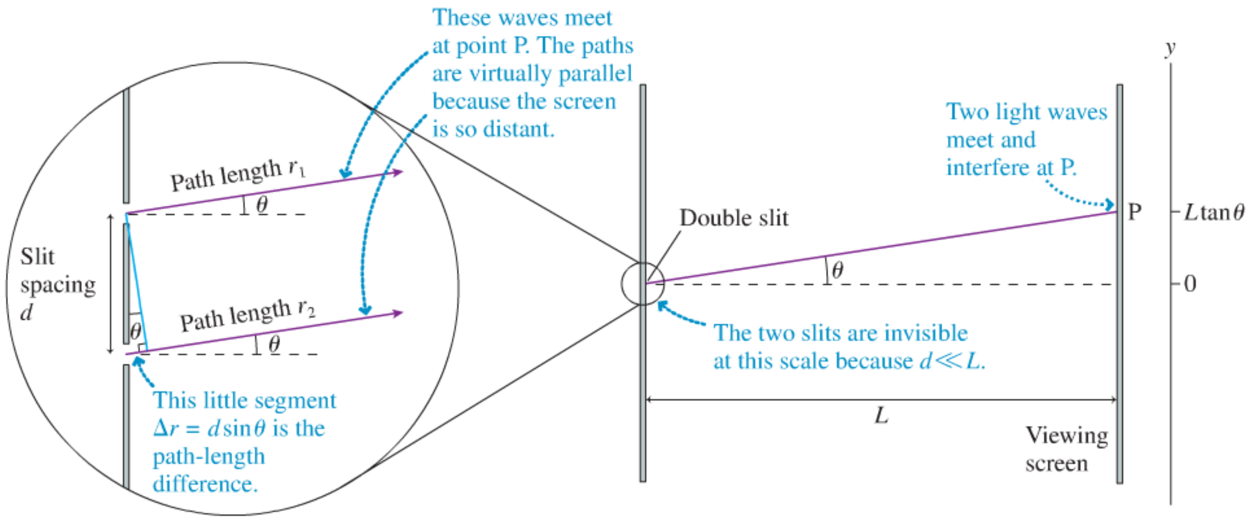
- Using some simple trigonometry:

$$y_m = \frac{m\lambda L}{d}, m = 0, 1, 2, 3, \ldots$$

- Similarly, we can get the dark fringe positions:

$$y'_m = \left(m + \frac{1}{2}\right)\frac{\lambda L}{d}, m = 0, 1, 2, \ldots$$

Analyzing Young's Double-Slit Experiment



- Using some simple trigonometry:

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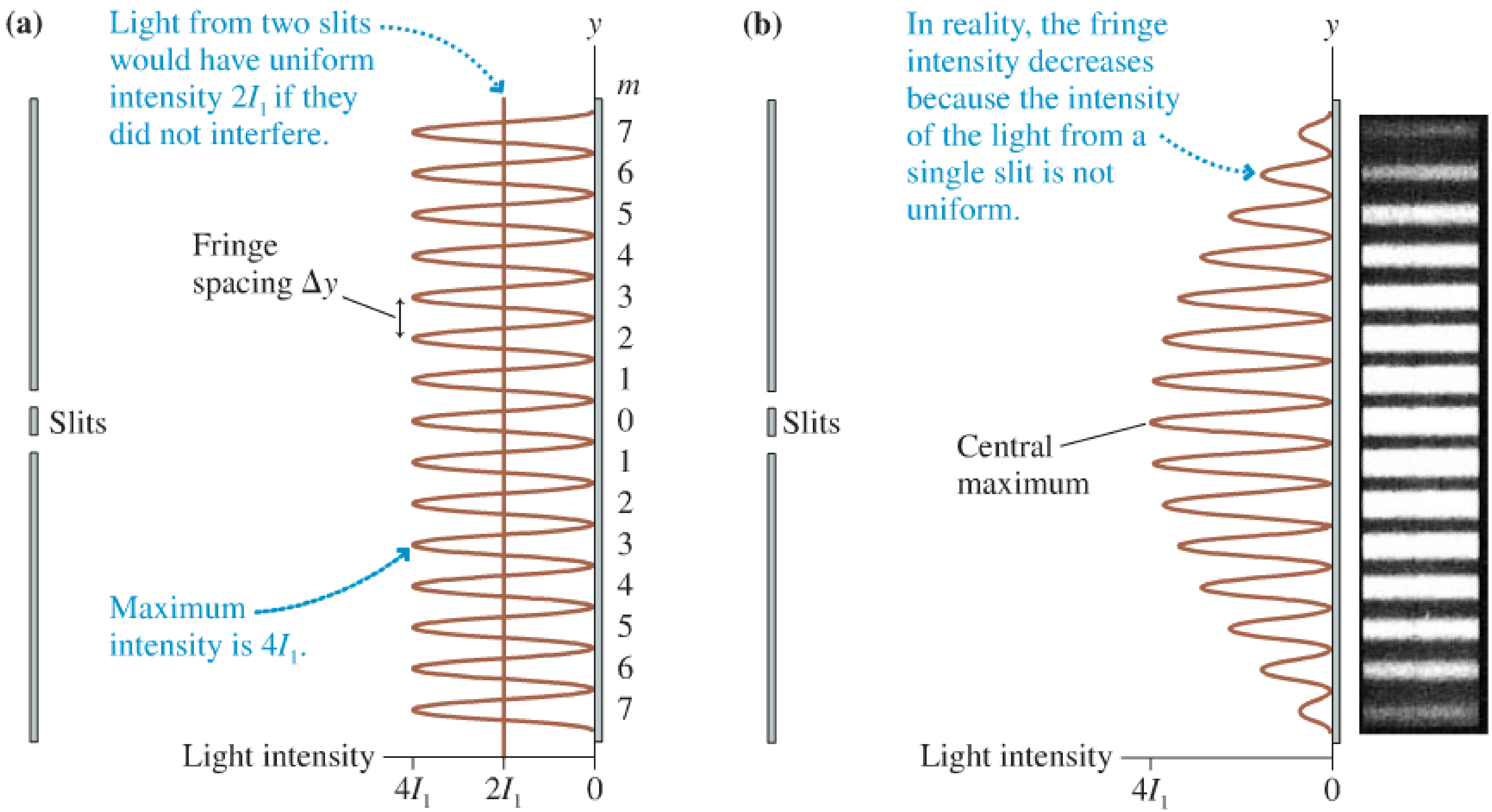
- Similarly, we can get the dark fringe positions:

$$y'_m = \left(m + \frac{1}{2}\right)\frac{\lambda L}{d}, m = 0, 1, 2, \ldots$$

- And we can get the fringe spacing

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

Young's Double-Slit Fringe Intensity



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

Two-slit Pattern

A two-slit interference pattern is formed using monochromatic laser light that has a wavelength of 450 nm. What happens to the distance between the first maximum and the central maximum as the two slits are moved closer together?

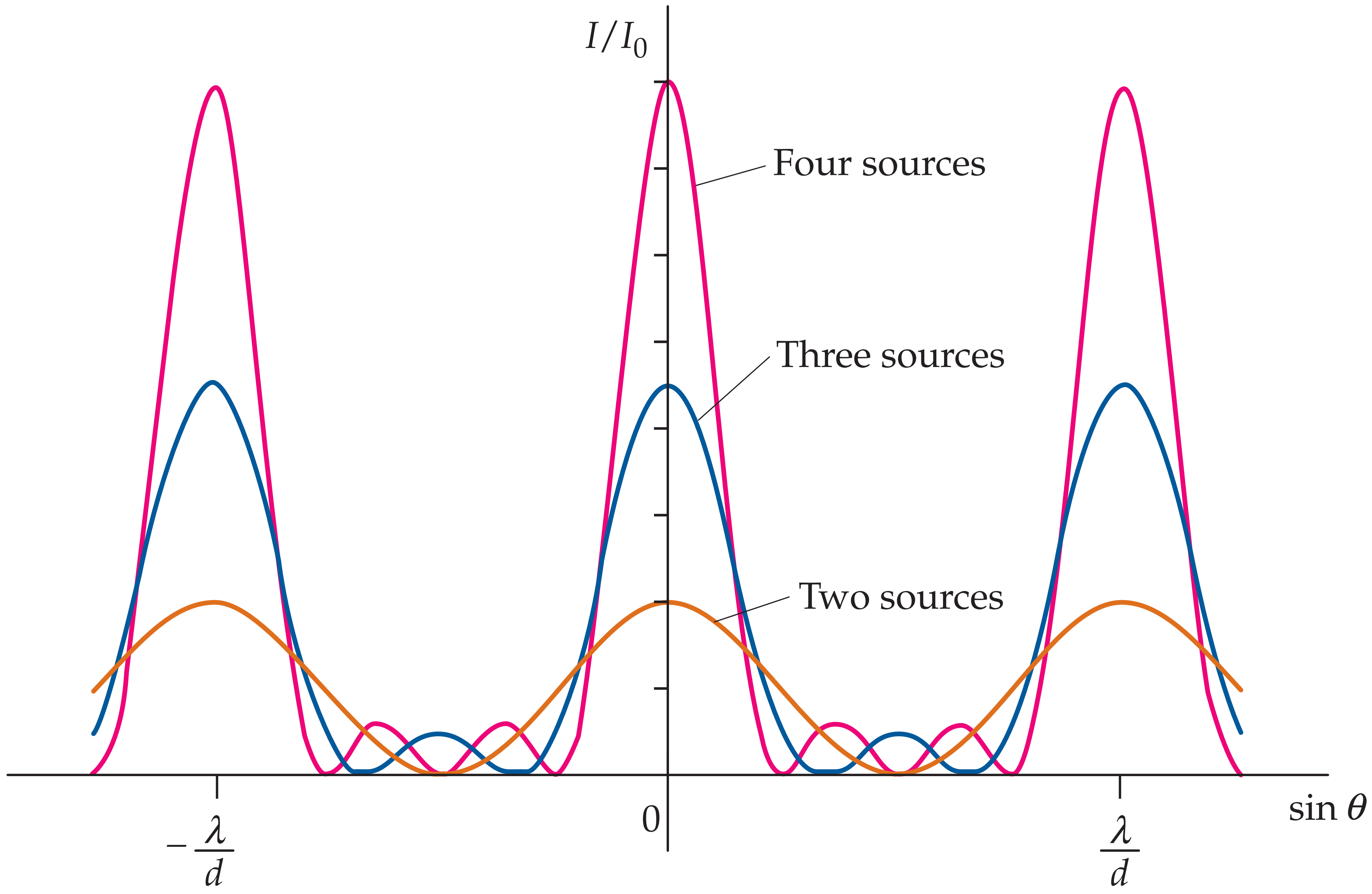
(A) The distance increases.

(B) The distance decreases.

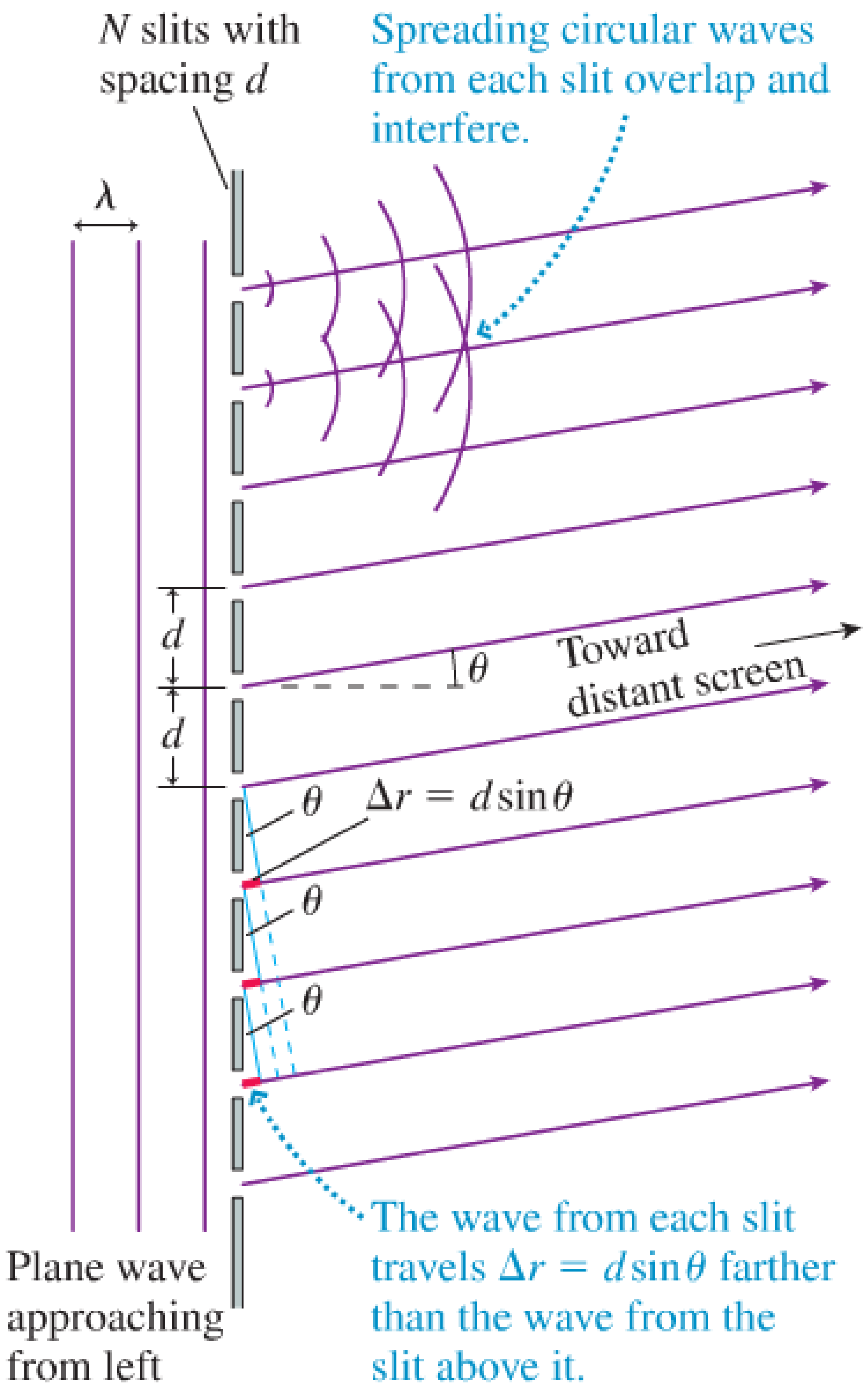
(C) The distance remains the same.

Multiple Slits

- If you have more than two slits, the maxima get brighter and better separated.



Diffraction Grating



If one extends the double slit to large number of slits very closely spaced, one gets what is called a diffraction grating. $d \sin\theta$. Maxima are still at

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

The difference is that the fringes are thinner and brighter.

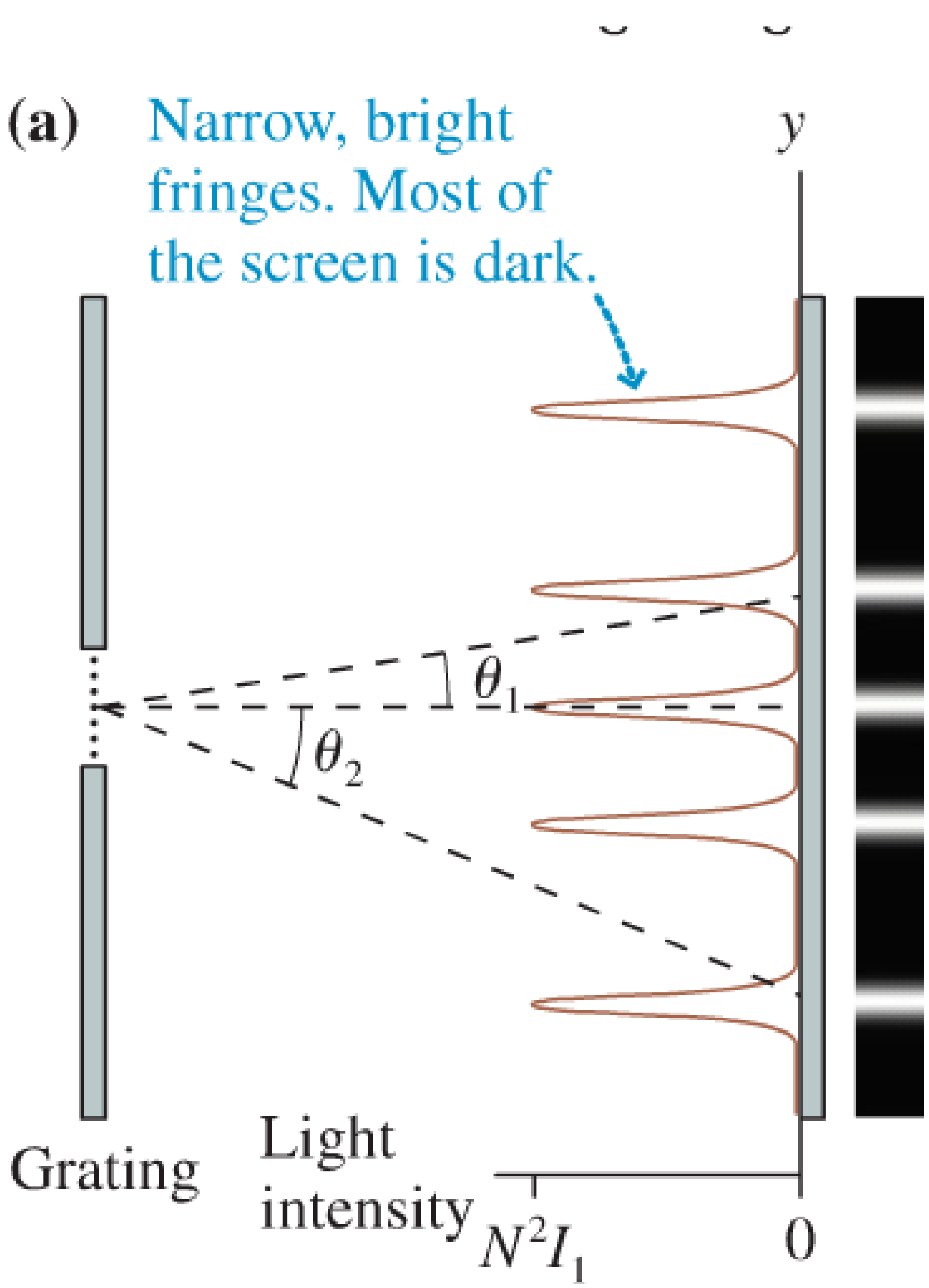
Diffraction Grating

- Lines of high intensity occur only where the wavefronts from all the slits interfere constructively. Therefore the maxima are very intense and very narrow.
- The angle from the middle of the grating to the maxima is given by

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

- The distance from the central maximum to the next maximum is given by

$$y_m = L \tan \theta_m$$

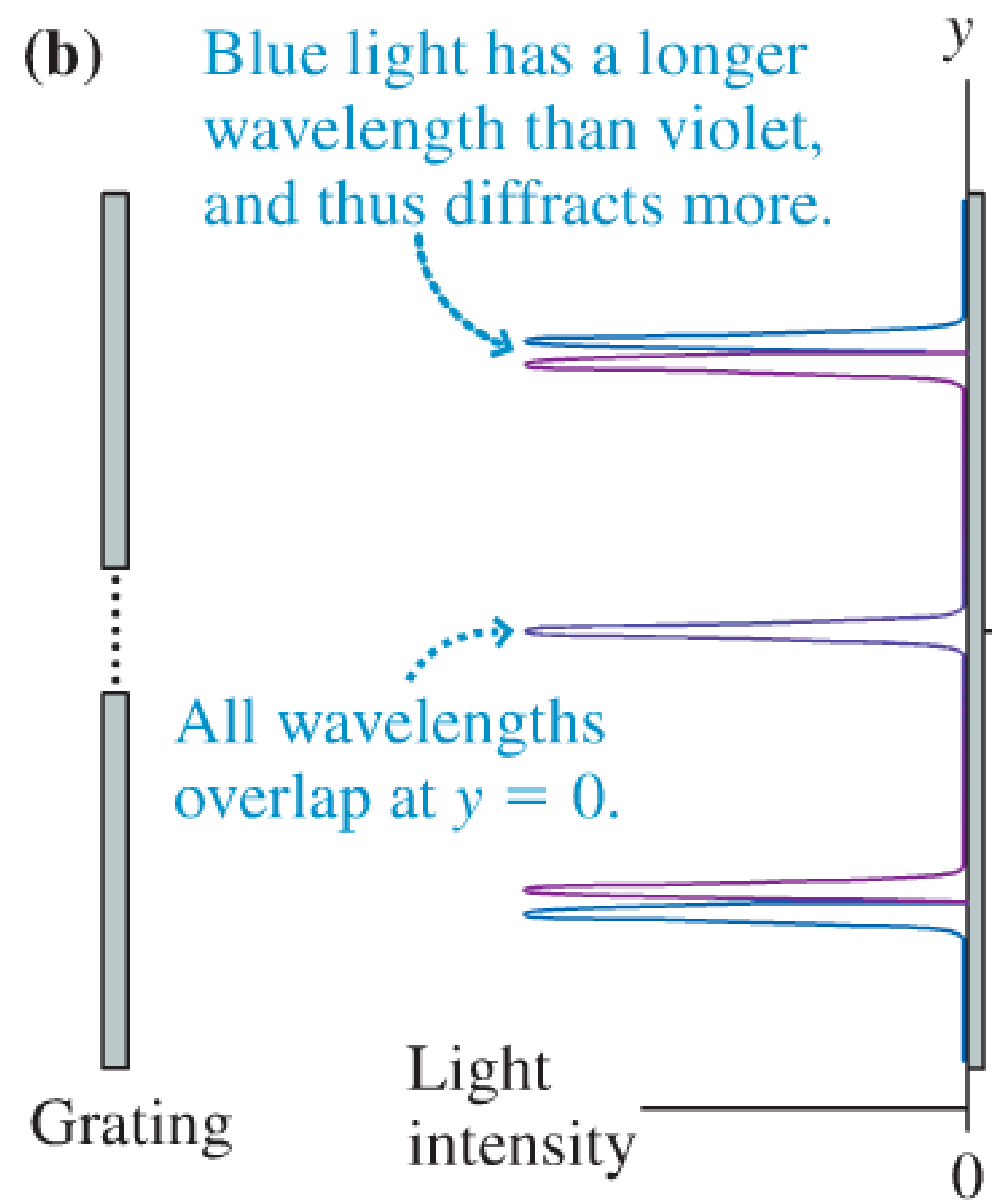


Diffraction Grating

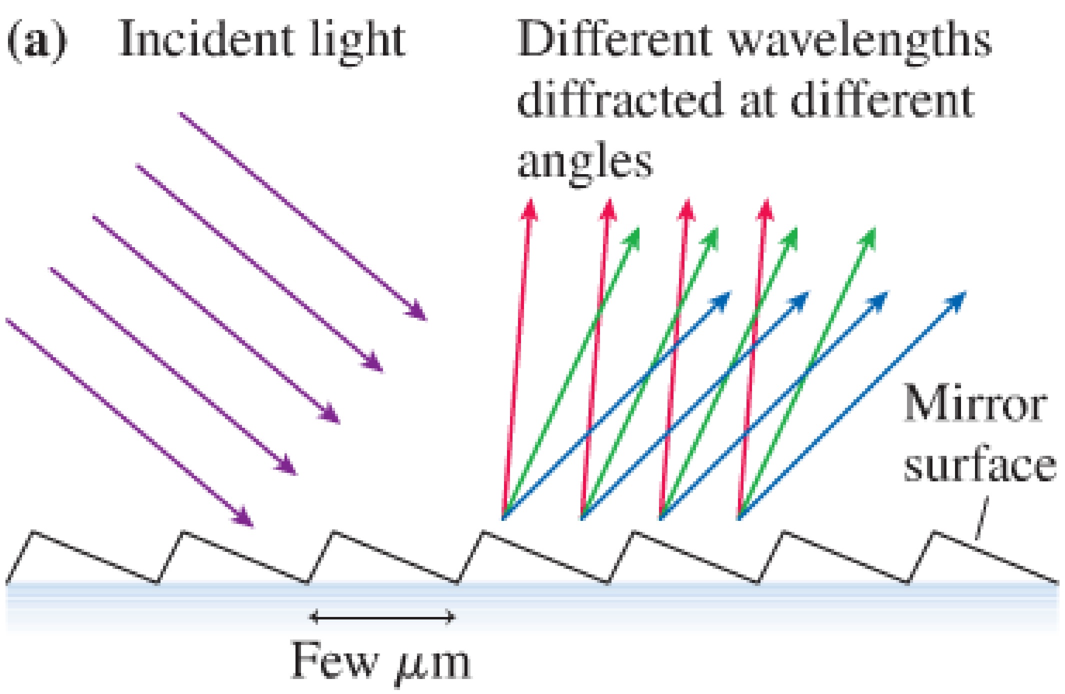
- The angles to the maxima are not small. Therefore, the small angle approximation cannot be used. The distance on the screen to the bright lines is given by

$$y_m = L \tan\left[\sin^{-1}\left(\frac{m\lambda}{d}\right)\right]$$

- The distances to the maxima provide a good way of determining wavelengths of light.
- Diffraction gratings are essential components of optical spectrometers.



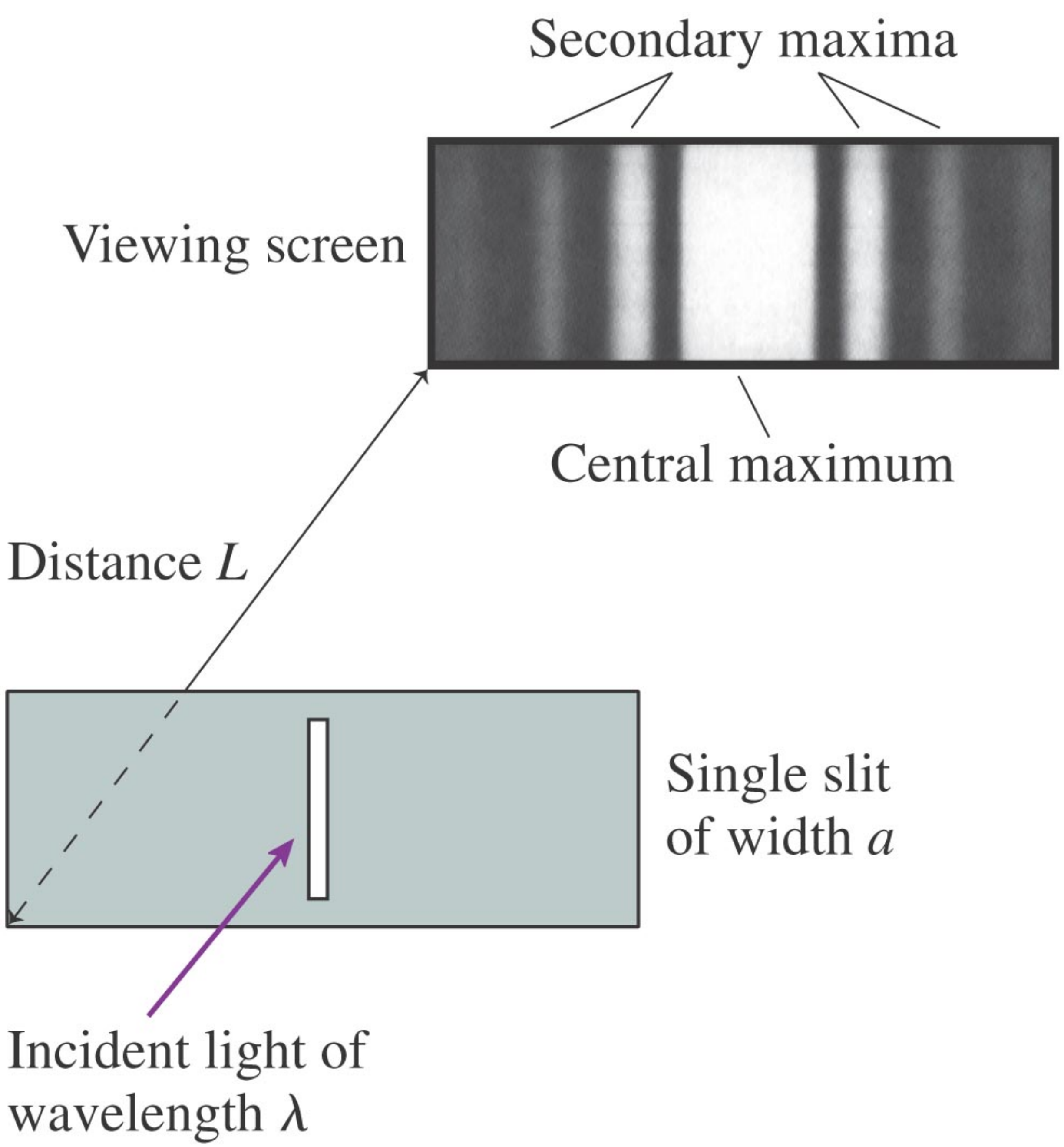
Reflection Diffraction Gratings



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.

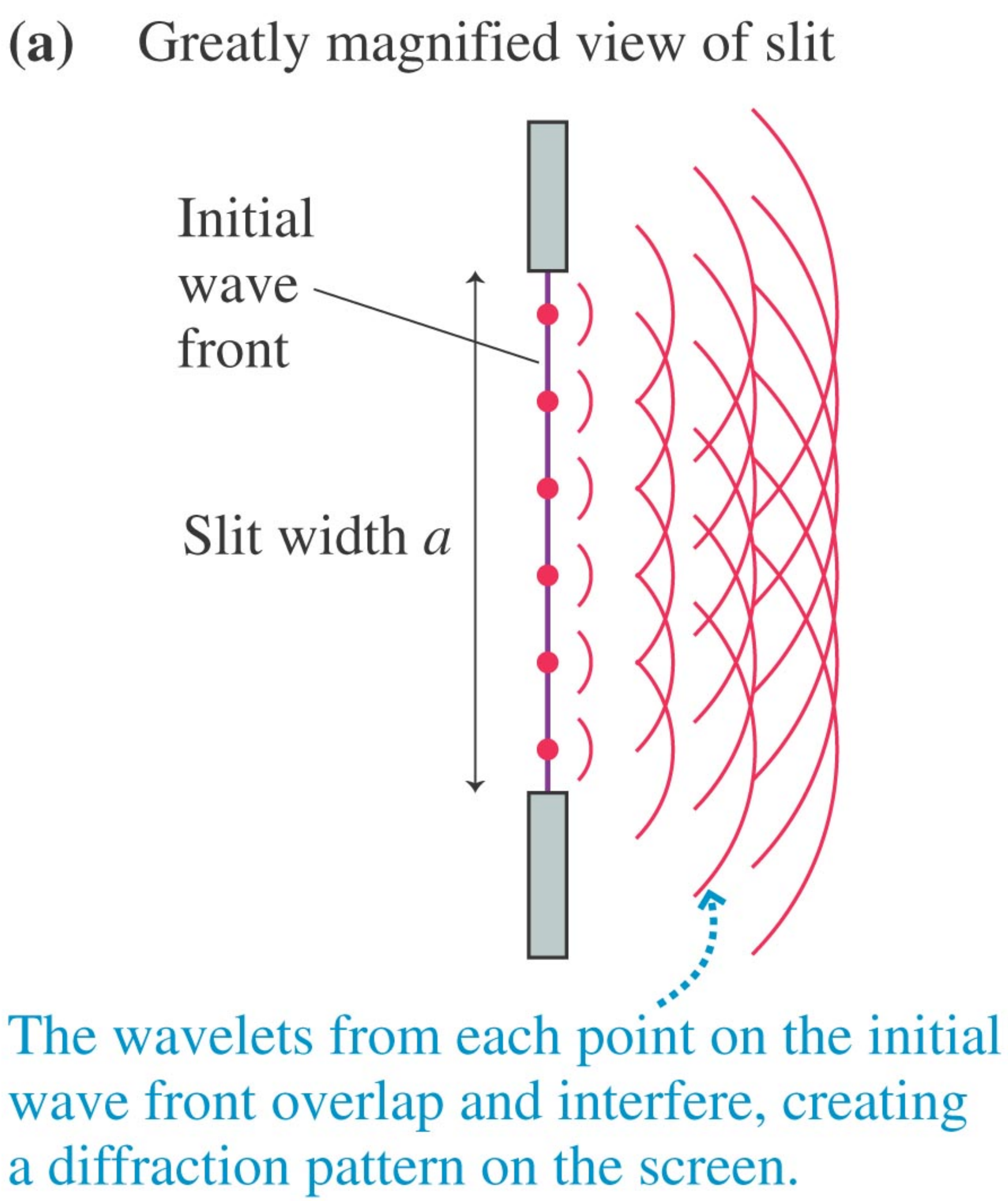
- Many common gratings are actually reflection gratings rather than transmission gratings.
- A mirror with thousands of narrow parallel grooves makes a grating which reflects light instead of transmitting it, but the math is the same.
- A CD is an excellent example.

Single Slit



- It is rather strange to talk about thousands of slits before talking about 1. However, thousands are actually a little easier.
- A single slit diffraction pattern involves a wide central maximum flanked by weaker secondary maxima and dark fringes.
- It would appear that we have only one light source in this case, so how do we understand the interference?
- We have to go back to Huygen's principle.

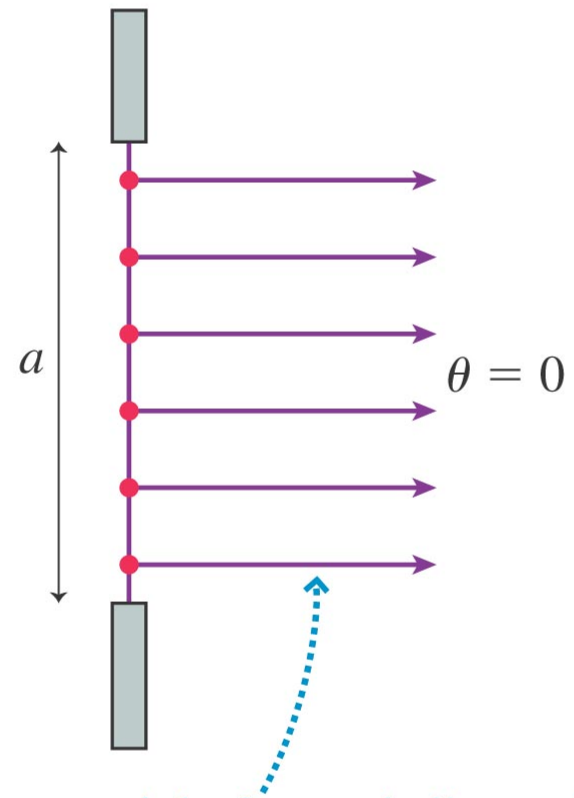
Diffraction Grating



- A wave front passes through a narrow slit (width *a*). Note that narrow is important.
- Each point on the wave-front emits a spherical wave
- One slit becomes the source of many interfering wavelets.
- A single slit creates a diffraction pattern on the screen.

Single Slit

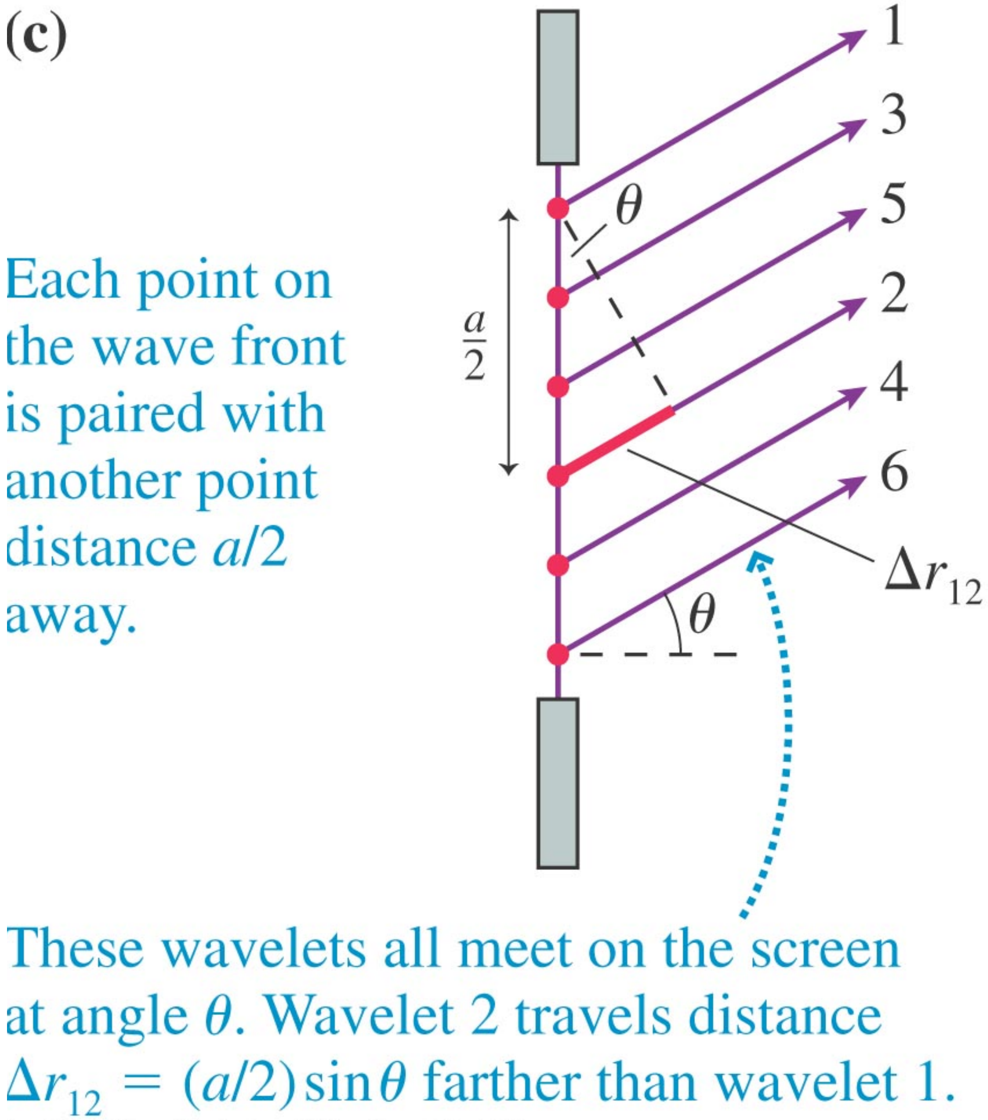
(b)



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.

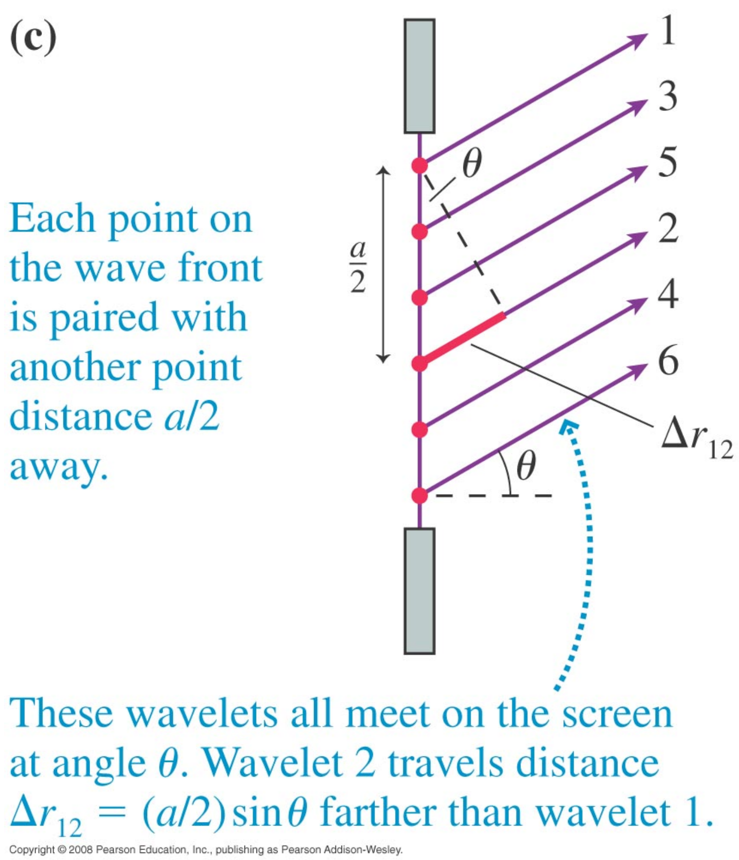
- Wavelets from any part of the slit have to travel approximately the same distance to reach the center of the screen.
- A set of in-phase wavelets therefore produce constructive interference at the center of the screen.

Single Slit



- Consider the path-lengths well away from the centre axis
- For any wavelet it is possible to find a partner which is $a/2$ away.
- If the path difference between partners happens to be $\lambda/2$ then this pair will create total destructive intereference. A dark band will be created.
- For any given wavelength there will be an angle for which this condition is true! There will always be dark bands, as long as a is greater than λ and the slit is narrow.

Single Slit



- The path difference between 1 and 2 is

$$\Delta r_{12} = \frac{a}{2}\sin\theta_1 = \frac{\lambda}{2}$$

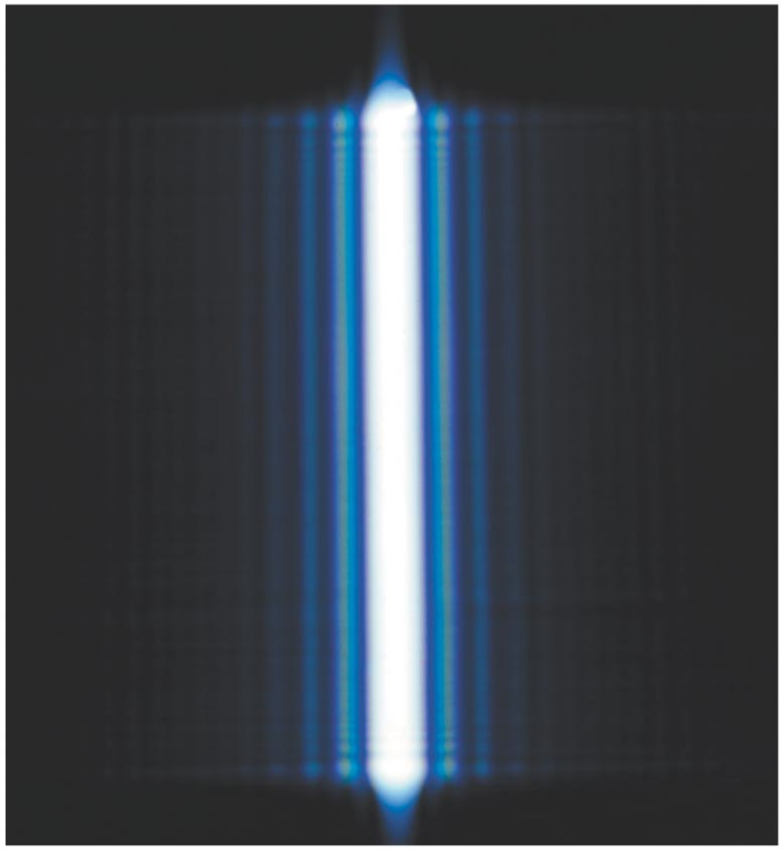
- What about the other angles for destructive interference? The general formula becomes

$$a\sin\theta_p = p\lambda, p = 1, 2, 3, \ldots$$

The small angle approximation means we can write

$$\theta_p = p\frac{\lambda}{a}, p = 1, 2, 3, \ldots$$

- But if a is small then θ_p is large and the small angle approximation is not valid.



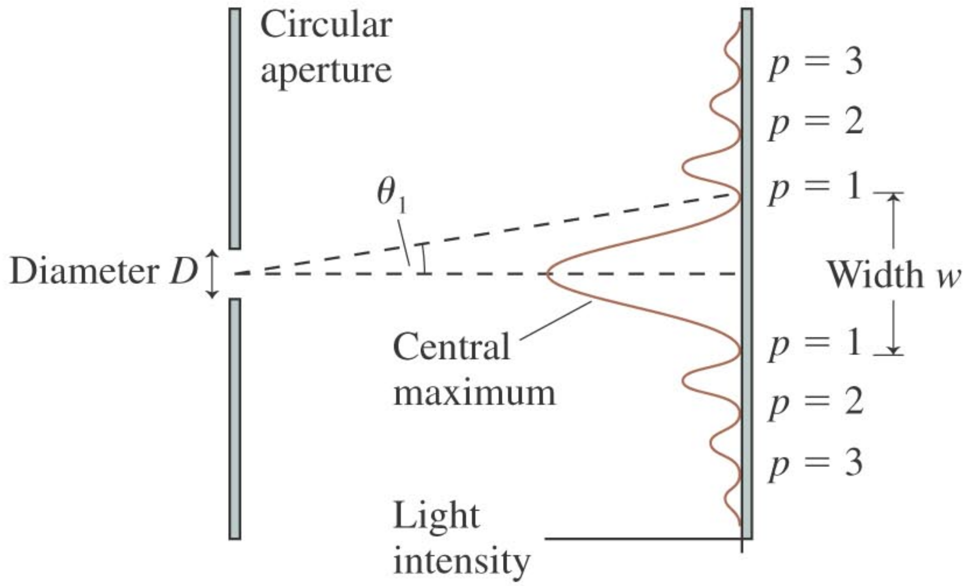
- It can be useful to express the fringe position in distance rather than angle.
- The position on the screen is given by $y_p = L\tan\theta_p$. This leads to

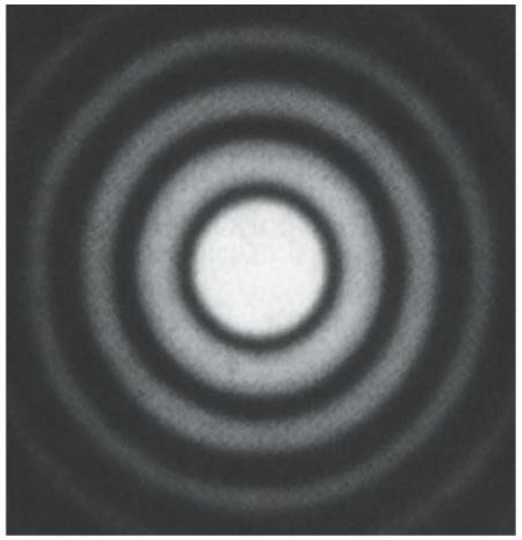
$$y_p = \frac{p\lambda L}{a}, p = 1, 2, 3, \ldots$$

- The width of the central maximum is give by twice the distance to the first dark fringe

$$w = \frac{2\lambda L}{a}$$

It is important to note that: 1) the width grows if the screen is farther away 2) A thinner slit makes a wider central maximum.



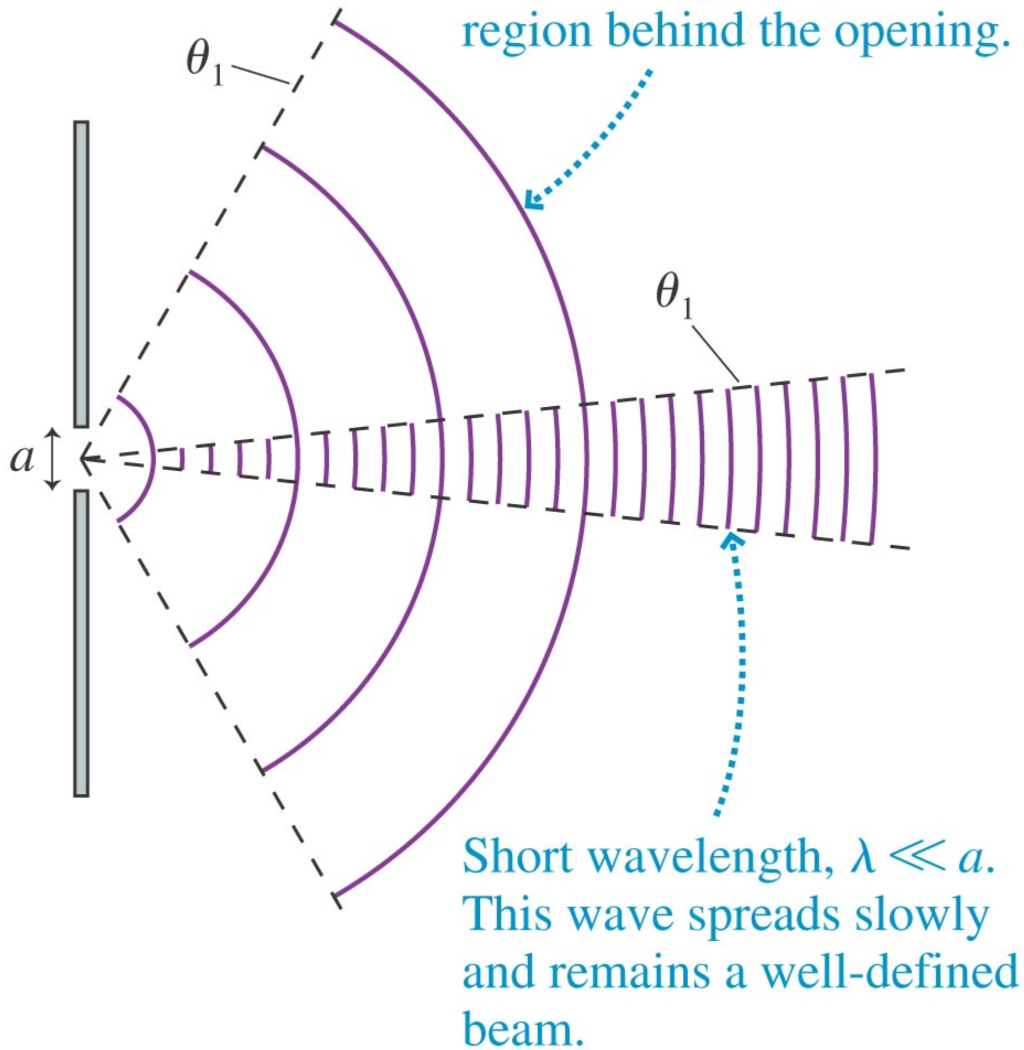


$$\theta_1 = \frac{1.22\lambda}{D}$$

And the width of the central maximum is

$$w = 2y_1 = 2L\tan\theta_1 \approx \frac{2.44\lambda L}{D}$$

Wave vs. Ray Models of Light



- The factor that determines how much a wave spreads out is λ/a
- With water or sound we see diffraction in our everyday lives because the wavelength is roughly the same as the macroscopic openings and structures we see around us.
- We will only notice the spreading of light with apertures of roughly the same scale as the wavelength of light.

Waves or Rays?

Sometimes we treat light like a stream of particles, sometimes like a wave and sometimes like a ray. Does light travel in a straight line or not? The answer depends on the circumstances.

Choosing a Model of Light

- When light passes through openings $<$ 1mm in size, diffraction effects are usually important. Treat light as a wave.
- When light passes through openings $>$ 1mm in size, treat it as a ray.

Diffraction Grating

When a diffraction grating is illuminated by white light, the first-order maximum of green light

(A) is closer to the central maximum than the first-order maximum of red light,

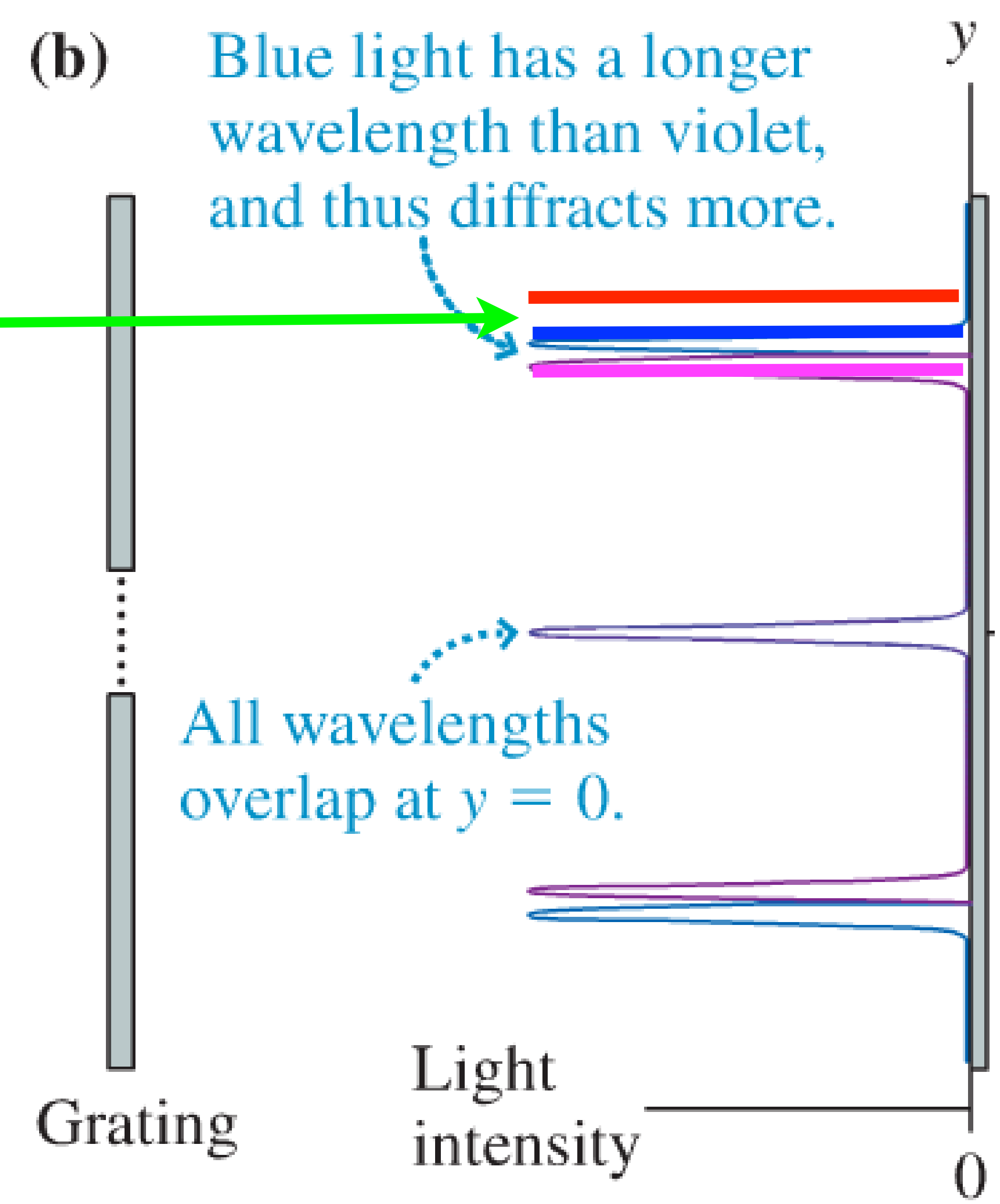
(B) is closer to the central maximum than the first-order maximum of blue light,

(C) overlaps the second-order maximum of red light,

(D) overlaps the second-order maximum of blue light.

Green is between red and blue

(A) Green is closer to the central maximum than the first-order maximum of red light,



Single Slit Diffraction

A single-slit diffraction pattern is formed using monochromatic laser light that has a wavelength of 450 nm. What happens to the distance between the first maximum and the central maximum as the slit is made narrower?

(A) The distance increases.

(B) The distance decreases.

(C) The distance remains the same.