EM Waves; Wave Optics

Knight Sections 31.6-31.7, 17.7
Knight Ch. 33

Physics 2C, Spring 2025

Agenda Today (May 12 & 13, 2025)

- Path-Difference vs. Phase-Difference
  - Sound Waves, review of discussion
  - New setup: coherent light, 2 slits
- 2-Slit interference
  - Formula, Introductory Clicker questions
  - Small-Angle approximation
  - Intensity vs. position on viewing screen
  - Diffraction Gratings (lots of slits!!!)

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Definitions: Path Length Diff.; Phase Diff.

Path-length difference: $\Delta r = r_2 - r_1$

Phase difference: $\Delta\phi = \frac{\Delta r}{\lambda}(2\pi)$

Warning: this is the phase difference if the two sources are initially in phase; if not, there must be an additional offset taken into account!

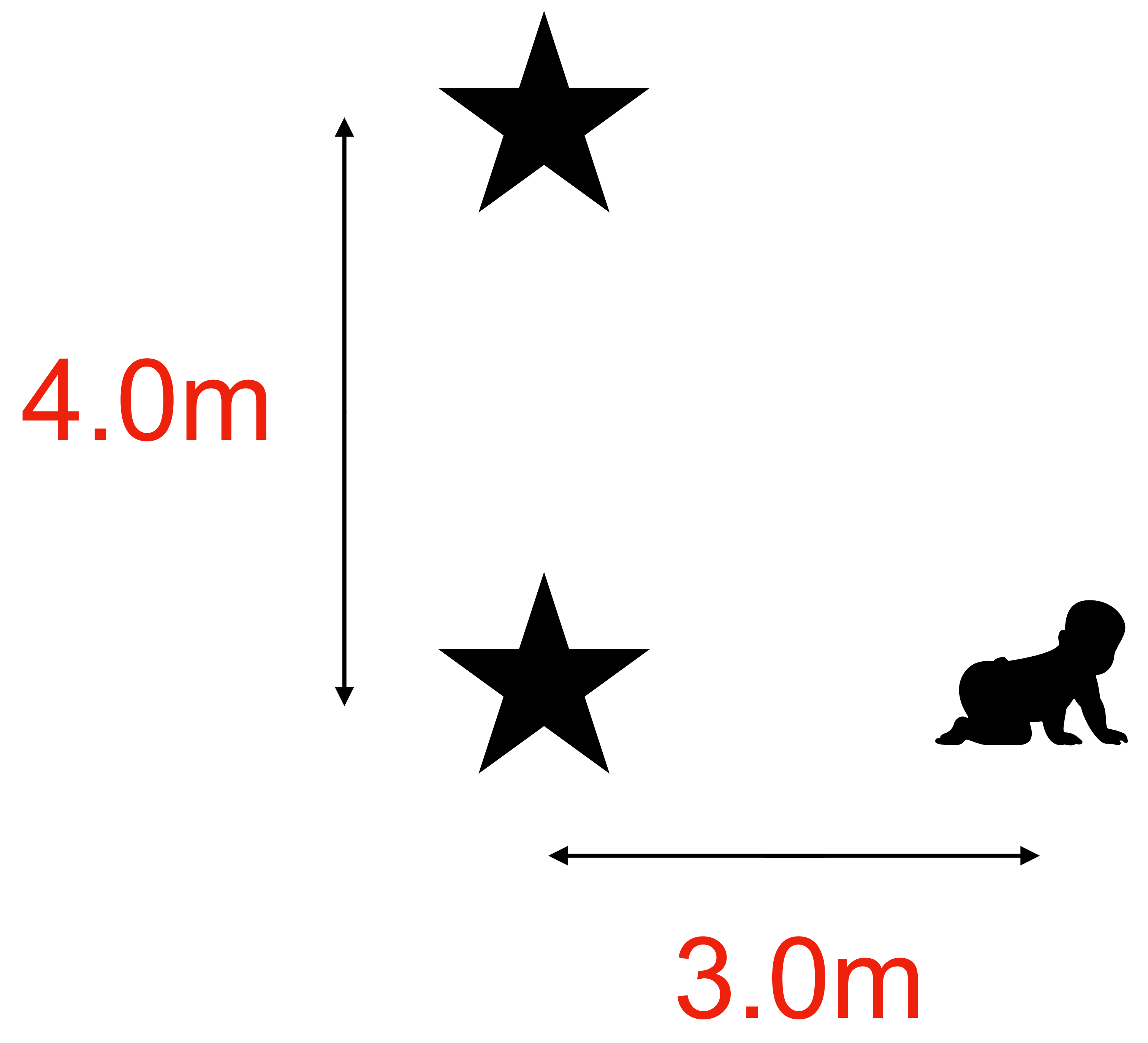
Constructive Interference: $\Delta\phi = 2\pi k$

Destructive Interference: $\Delta\phi = \pi + 2\pi k$

Clicker/Poll Question

Two speakers are 4.0m apart, and you're standing at the point shown (3.0m from one speaker, and farther from the other).

You hear destructive interference. Of the following, which is a possible wavelength of the sound waves?



A. 1.5m
B. 2.5m
C. 4.0m

Clicker/Poll Question

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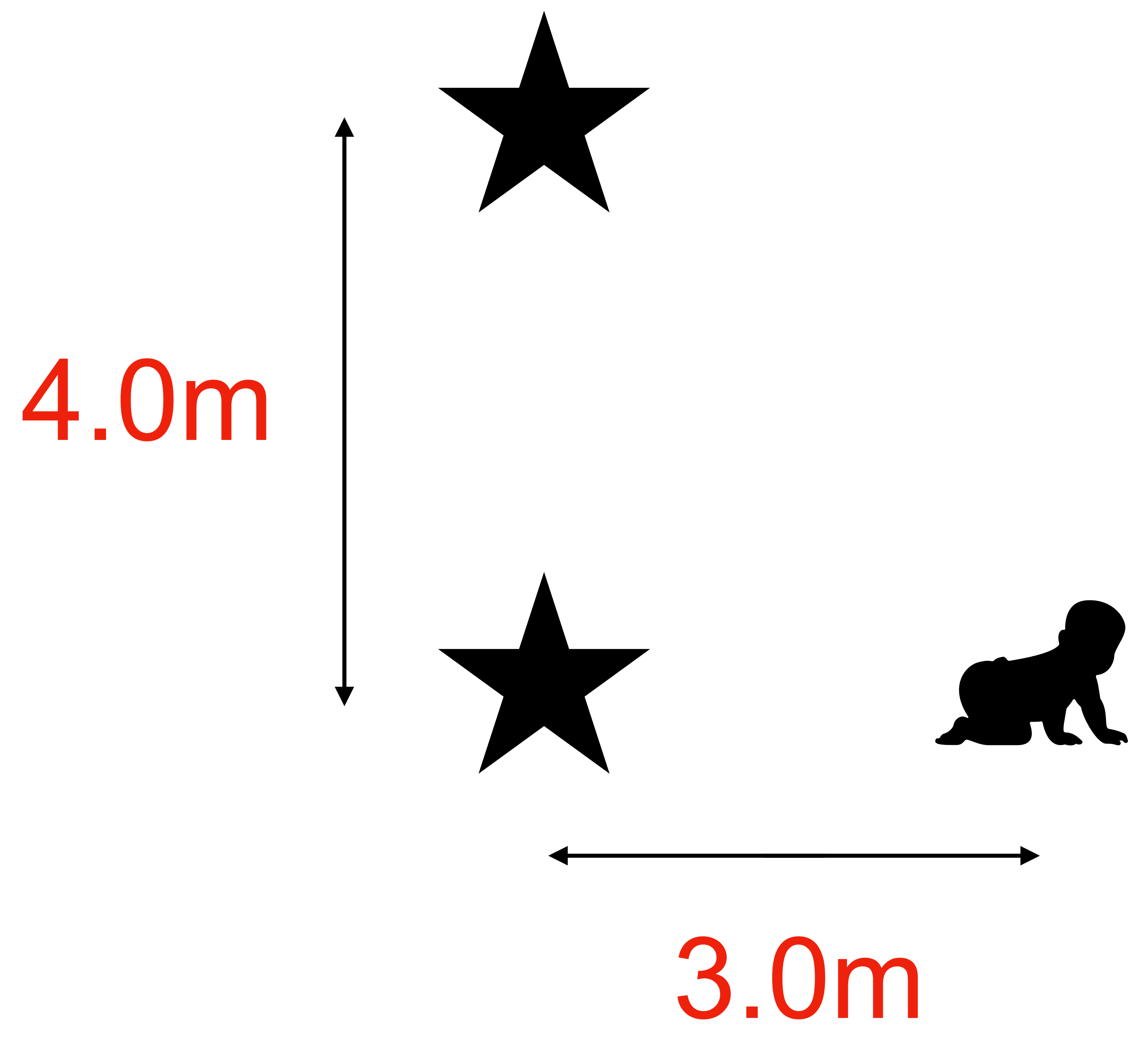
Two speakers are 4.0m apart, and you're standing at the point shown (3.0m from one speaker, and farther from the other).

Suppose someone adjusts the phase of the top star so that you now hear constructive interference.



A. The phase was shifted ahead by 90^0 (leads other)
B. The phase was shifted behind by 90^0 (lags other)
C. The phase was shifted 180^0, either way.

Double-Slit Interference

Now suppose the two “sources” are light entering two holes (=“slits”)

Double-Slit Interference

Now suppose the two "sources" are light entering two holes (="slits")

Condition for Constructive Interference: $\boxed{\Delta r = d \sin\theta_m = m\lambda}$

- θ: angle between two lines: line from center of slits to center of viewing screen, and line from center of slits to the point on the viewing screen we're interested in.
- m: any integer (…, -2, -1, 0, +1, +2, …)
- d: (center-to-center) distance between the two slits.

Double-Slit Interference

$$\boxed{d \sin \theta_m = m\lambda}$$

What happens for small angles?

Clicker/Poll Question

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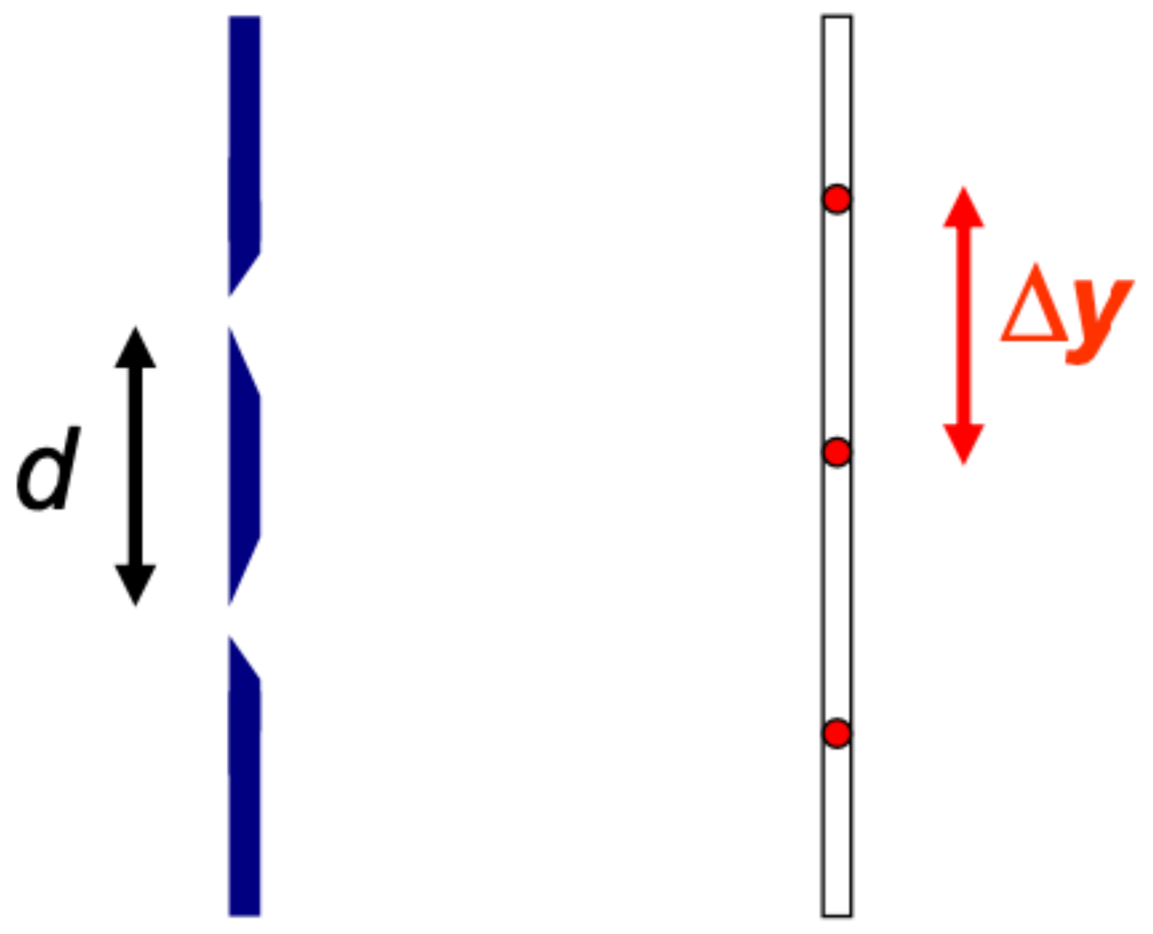
A double-slit interference pattern is produced on a screen using monochromatic light of wavelength 600nm.

What will happen to the separation of the interference fringes (Δy) if you decrease the separation of the two slits?



A. Δy will increase

B. Δy will decrease

C. Δy will remain the same

Clicker/Poll Question

sli.do #401391

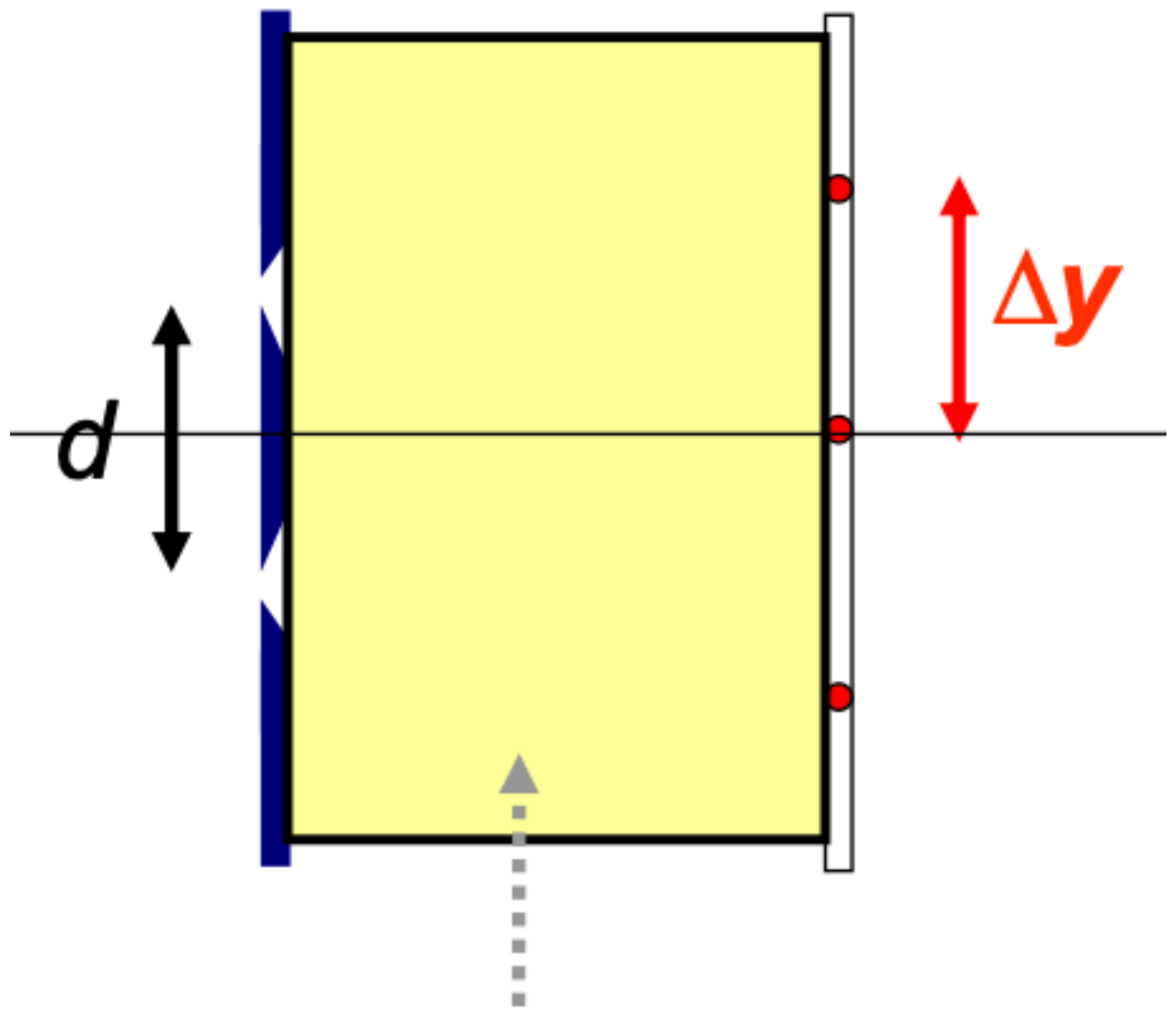
A double-slit interference pattern is produced on a screen using monochromatic light of wavelength 600nm.

What will happen to the separation of the interference fringes (Δy) if you put a tank of kerosene everywhere ($n_{\text{kerosene}} > 1$)?

A. Δy will increase

B. Δy will decrease

C. Δy will remain the same



A tank of kerosene

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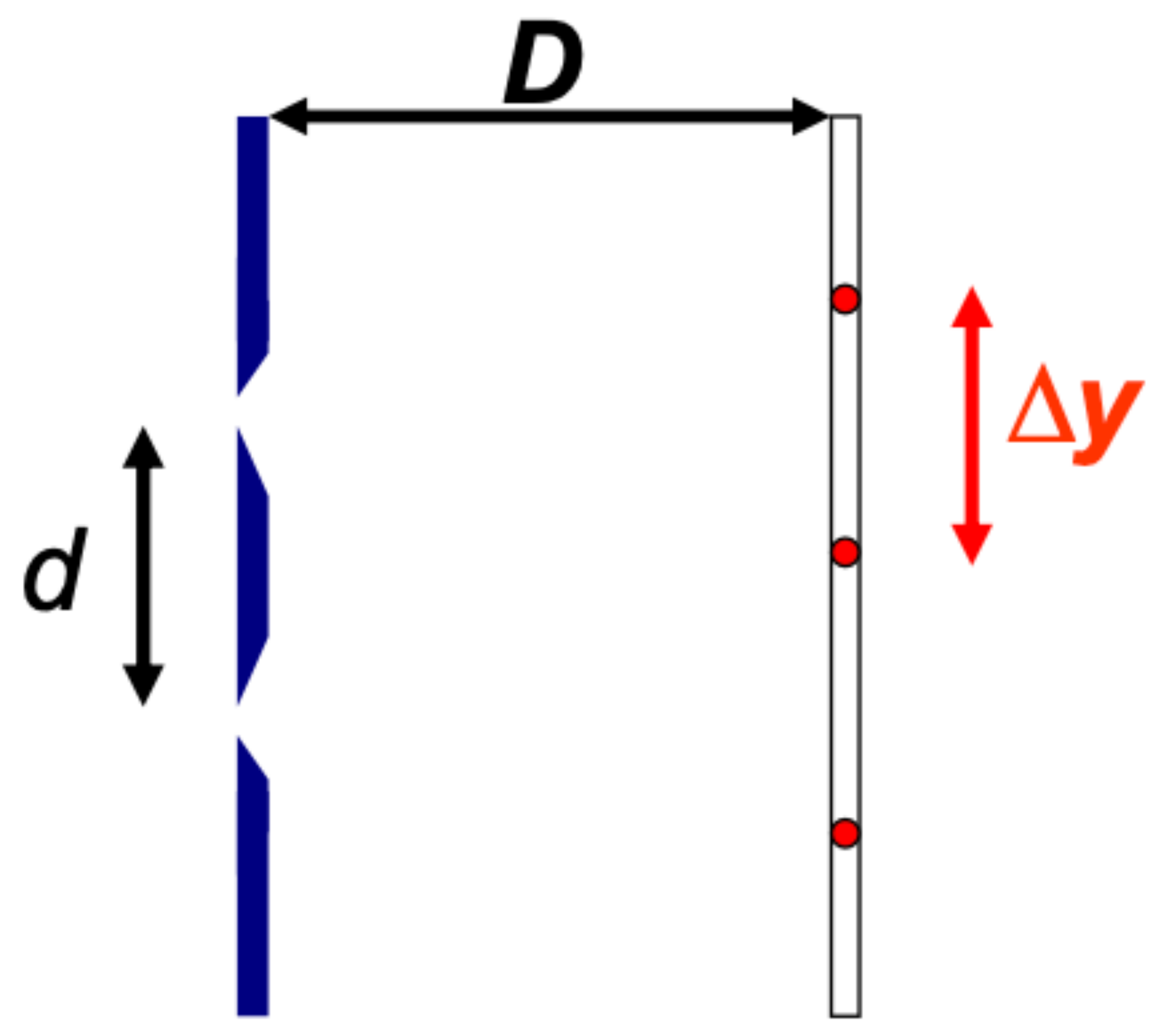
Clicker/Poll Question

A double-slit interference pattern is produced on a screen using monochromatic light of wavelength 600nm.

What will happen to the separation of the interference fringes (Δy) if you decrease the slit-screen distance, D?



A. Δy will increase

B. Δy will decrease

C. Δy will remain the same

Clicker/Poll Question

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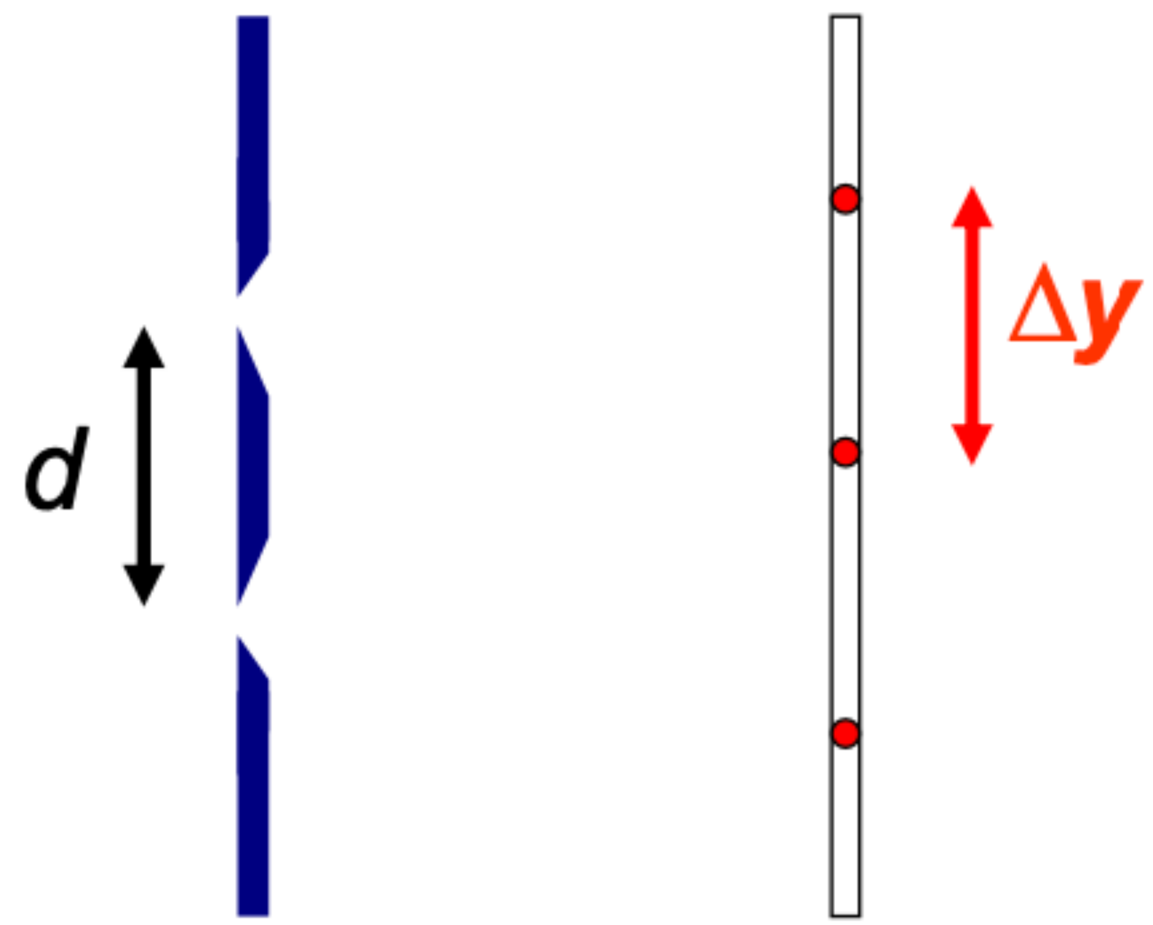
A double-slit interference pattern is produced on a screen using monochromatic light of wavelength 600nm.

What will happen to the separation of the interference fringes (Δy) if you instead use another monochromatic light of wavelength 632nm?



A. Δy will increase

B. Δy will decrease

C. Δy will remain the same

Double-Slit Interference

$$\boxed{d \sin \theta_m = m\lambda}$$

What happens for small angles?

Example

A double-slit interference pattern is produced on a screen using monochromatic light of wavelength 600nm.

On a viewing screen 3.0m away, we measure the distance between one bright spot m and another (m+8) [that is, 8 bright spots away], getting a distance of 24cm. What is the slit-separation?

Try it yourself…

Two satellites 100.0m apart are emitting EM waves with wavelength 22.0m. How many points of constructive interference surround the circle?

Intensity (2-slit)

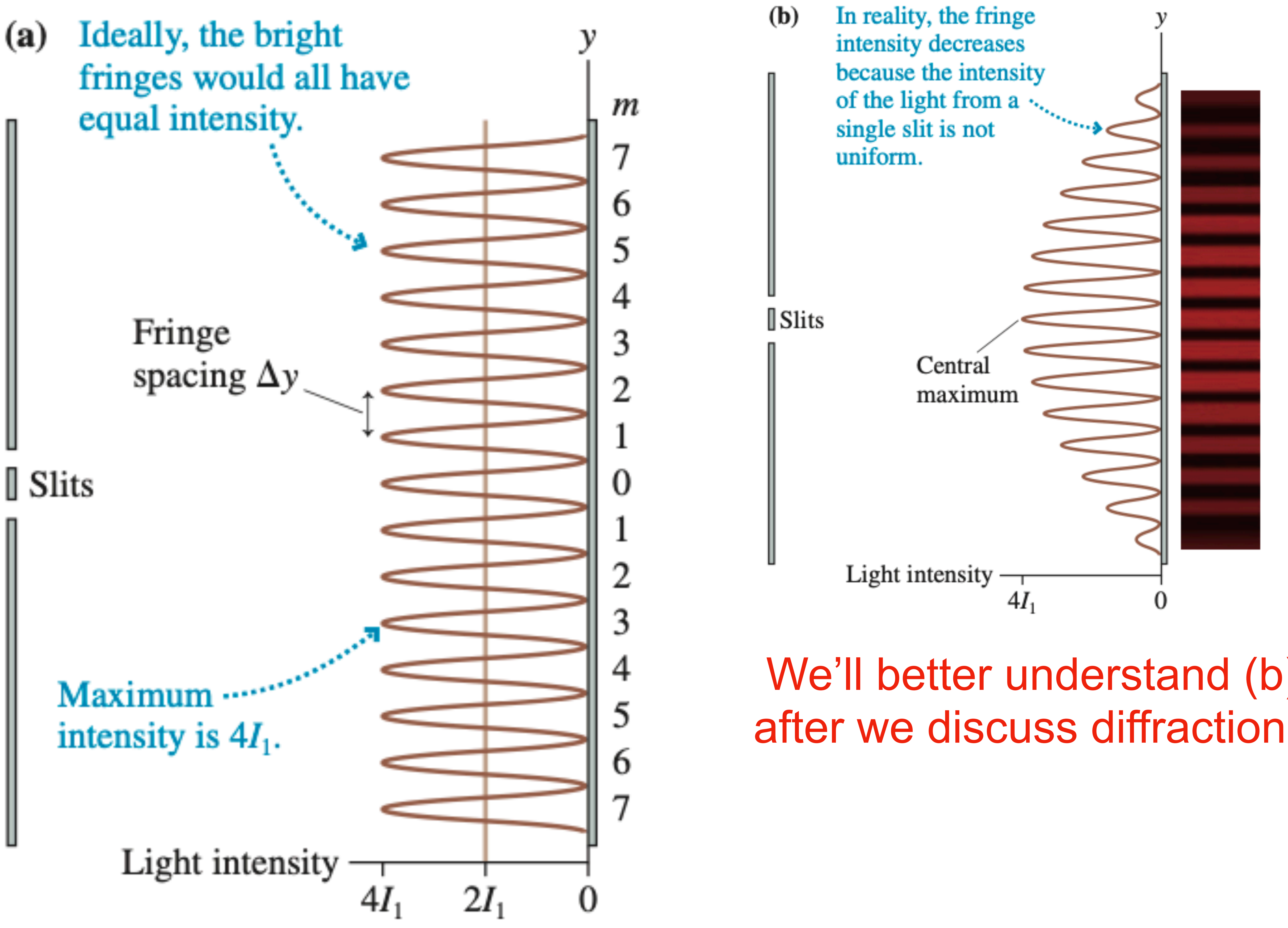
The intensity on the viewing screen is $I = I_0 \cos^2\left(\dfrac{\Delta\phi}{2}\right)$.

Since $\Delta\phi = 2\pi(\Delta r/\lambda)$ and $\Delta r = d\sin\theta = dy/L$,

$$I = I_0 \cos^2\left(\frac{2\pi d y}{L\lambda}\right)$$

(Used small-angle approx.)

FIGURE 33.6 Intensity of the interference fringes in a double-slit experiment.



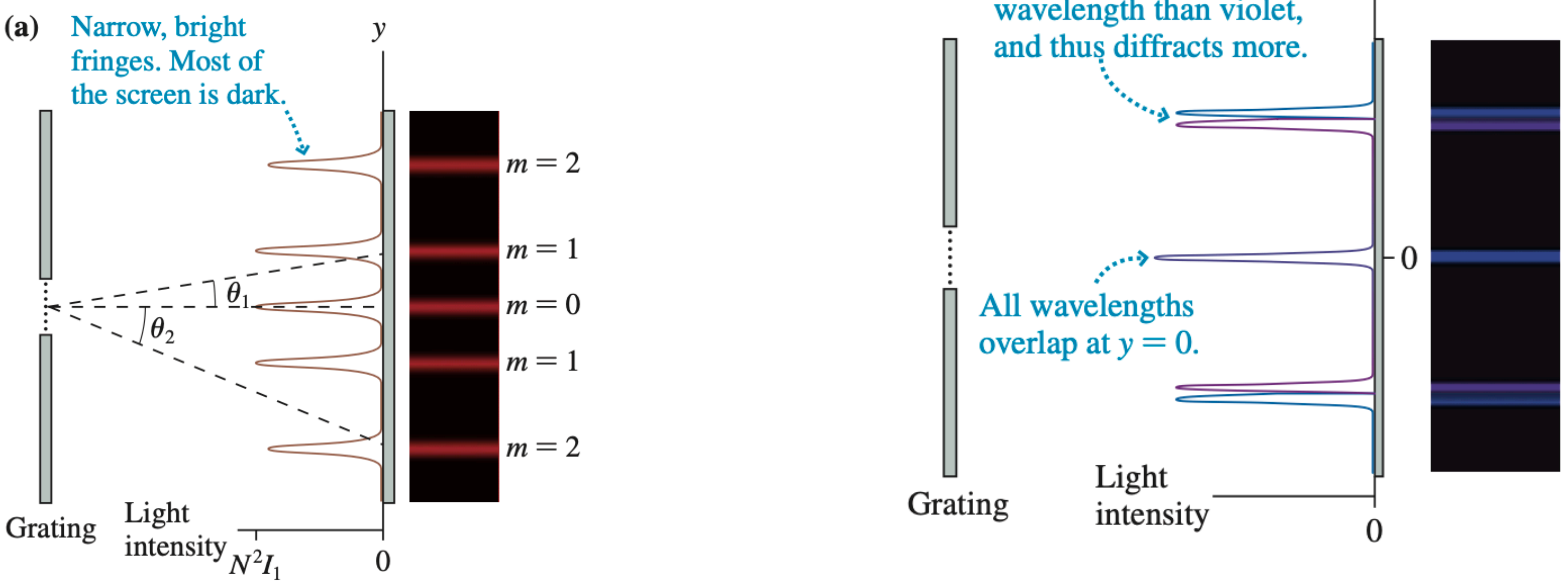
We'll better understand (b) after we discuss diffraction.

Diffraction Gratings

$$\boxed{d \sin \theta_m = m\lambda}$$

What happens if use have $N \gg 2$ slits? The formula for where the bright spots are is unchanged, but the bright spots get much more clearly-defined.

FIGURE 33.9 The interference pattern behind a diffraction grating.



Example 1

A diffraction grating 1.00 cm wide has 10,000 parallel slits. Monochromatic light that is incident normally is diffracted through $30°$ in the first order. What is the wavelength of the light?

Example 2

Monochromatic green light, of wavelength 550nm , illuminates two parallel narrow slits $7.70\,\mu$m apart. Calculate the angular deviation theta of the third-order (m=3) bright fringe (a) in radians and (b) in degrees.

Optional topic (not on quiz): thin films

Thin films can show interference effects.

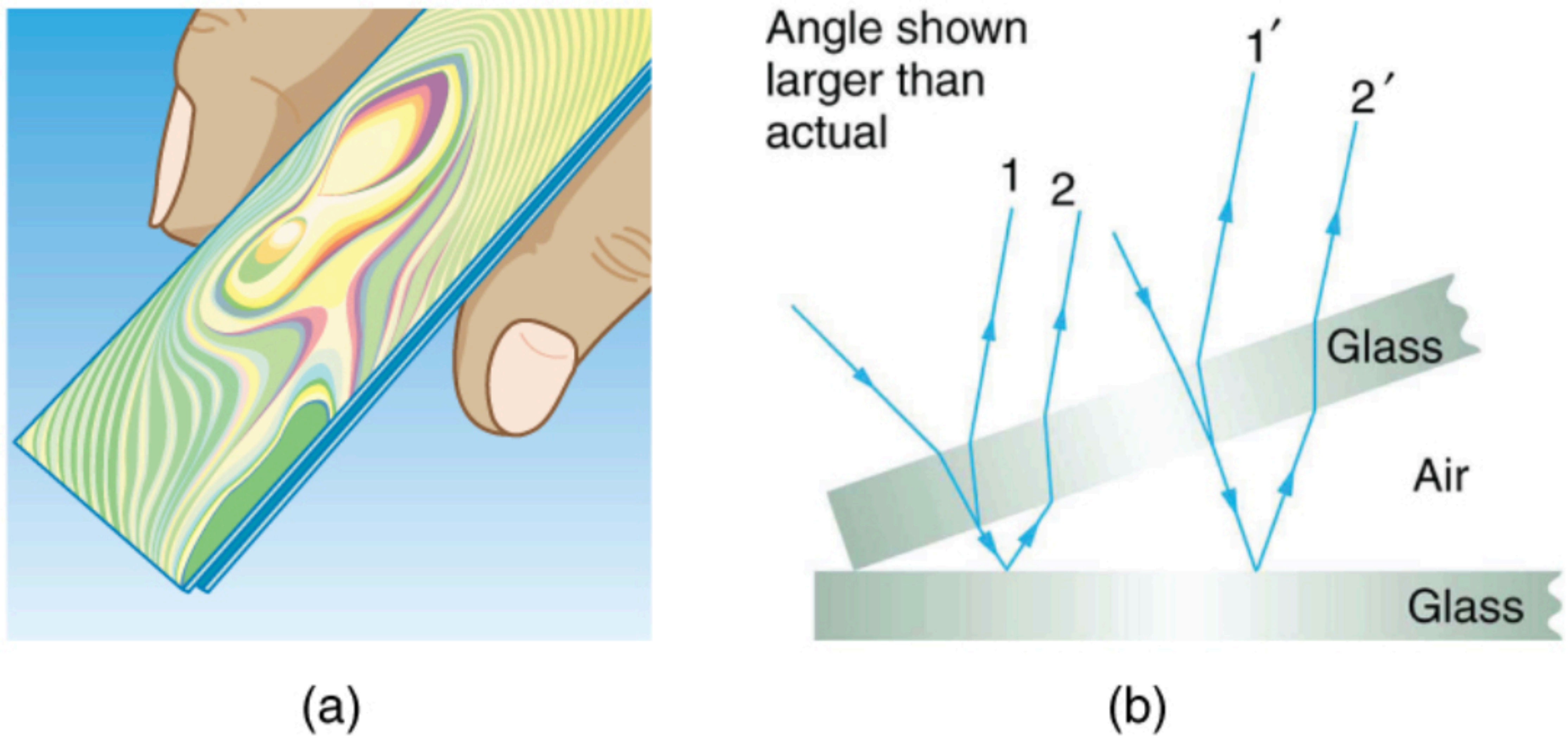
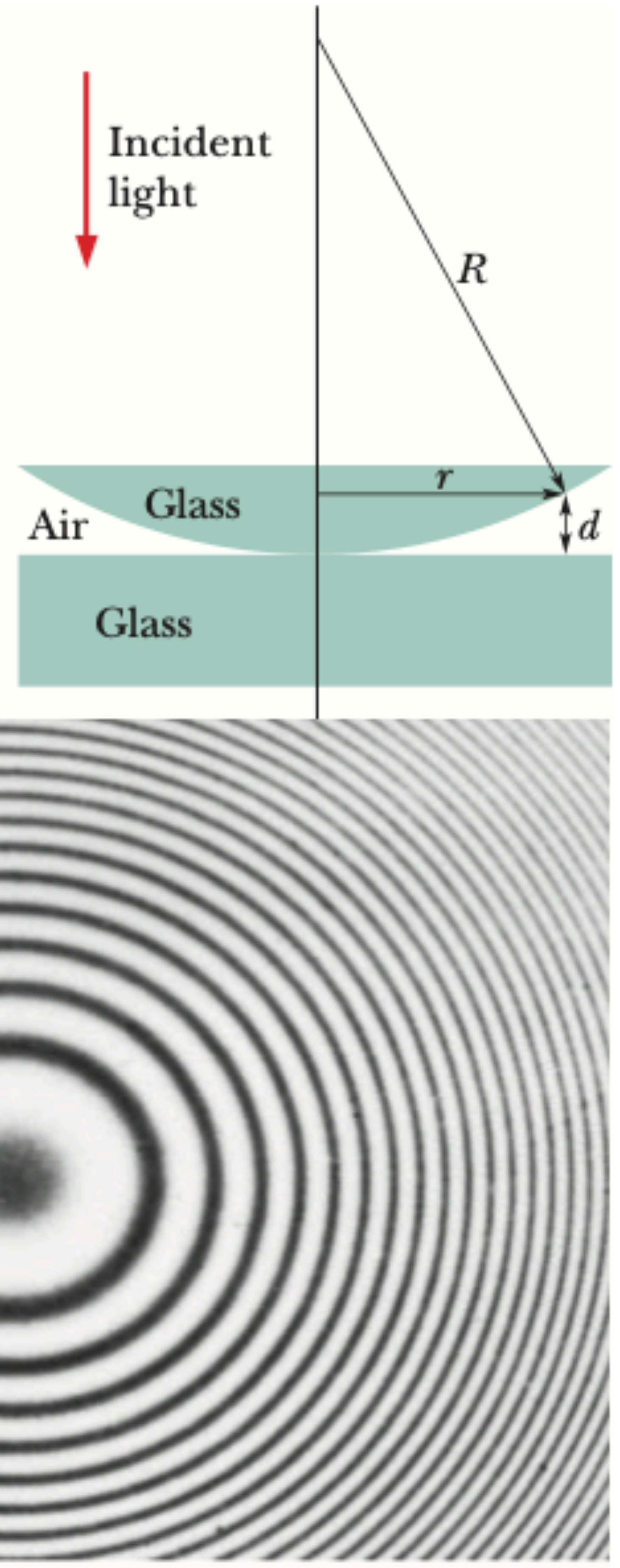


Figure 3. (a) The rainbow color bands are produced by thin film interference in the air between the two glass slides. (b) Schematic of the paths taken by rays in the wedge of air between the slides.



Courtesy Bausch & Lomb

Agenda Today (May 14, 2025)

- Review of Interference? Questions?
- Diffraction (different from diffraction gratings!)
    - Formula, Introductory Clicker questions
    - Intensity of single-slit diffraction
    - Combining single- and double-slit effects.
    - Rayleigh Criterion / Limits of resolution
    - Examples

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Diffraction: Light interference within a slit

Key Idea: Light from one part of a slit can destructively interfere with light from another part of the same slit.

Diffraction: Light interference within a slit

Clicker/Poll Question

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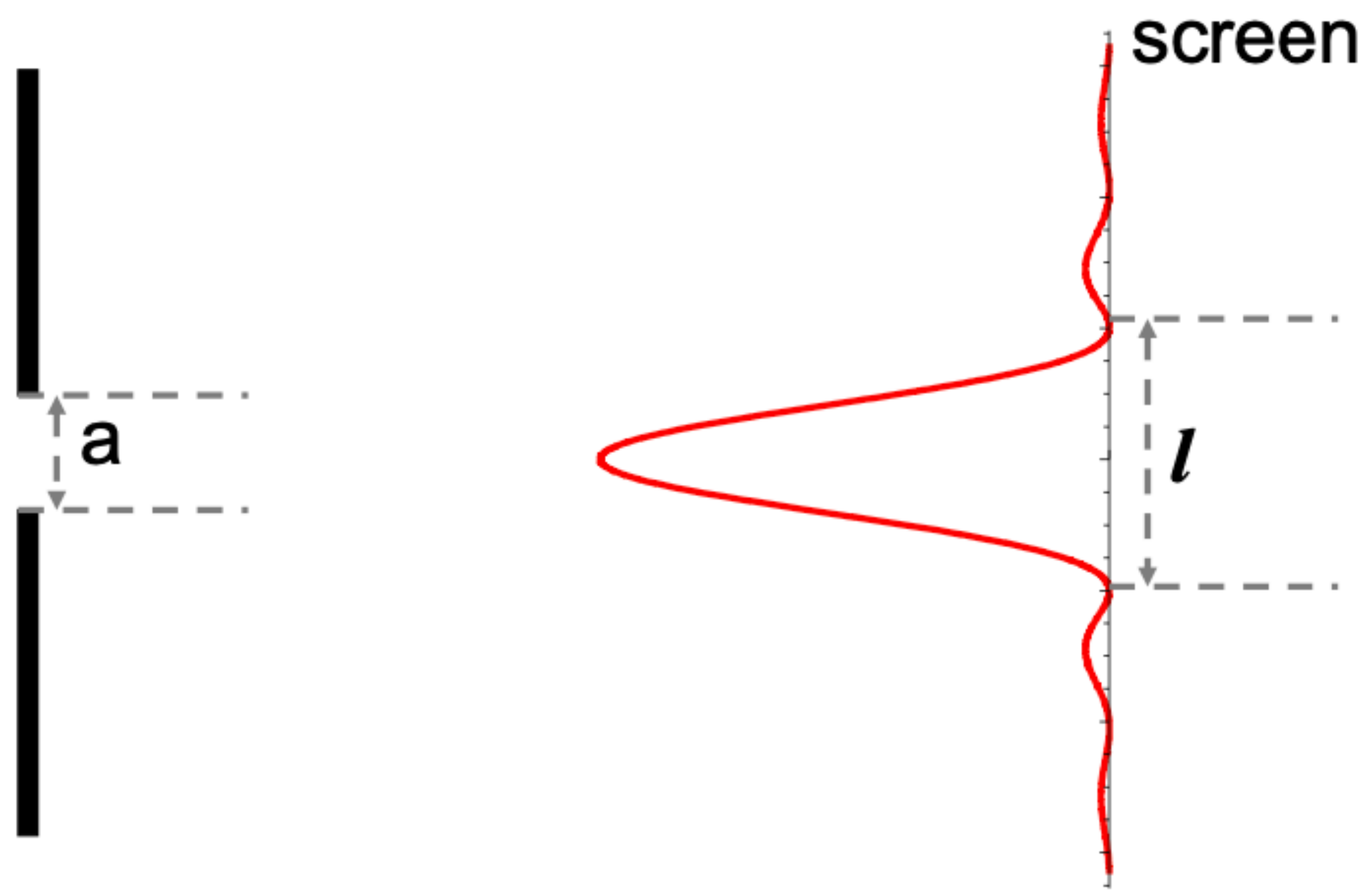
A single slit of width a is illuminated by light of wavelength λ so that the width of the central diffraction maxima is l. Now you decrease the slit width to a/2. What is the width of the central diffraction maxima?



A. $l/2$

B. $2l$

C. $l/4$

D. $4l$

E. l

Clicker/Poll Question

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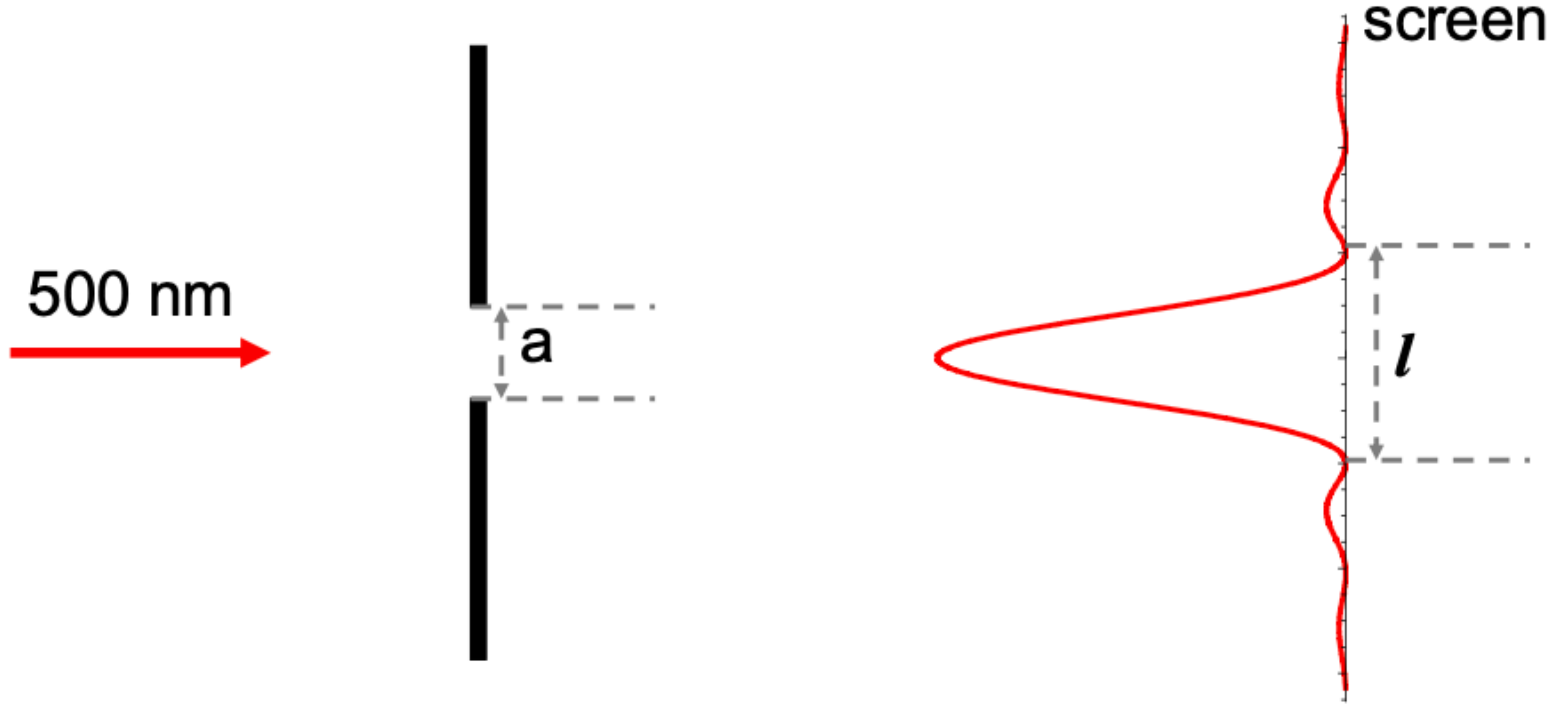
This time you keep the same slit width, but use another monochromatic light of wavelength 500 nm. How does the broadness of the central bright fringe change compared to that produced by the 600 nm wavelength?



A. Increases

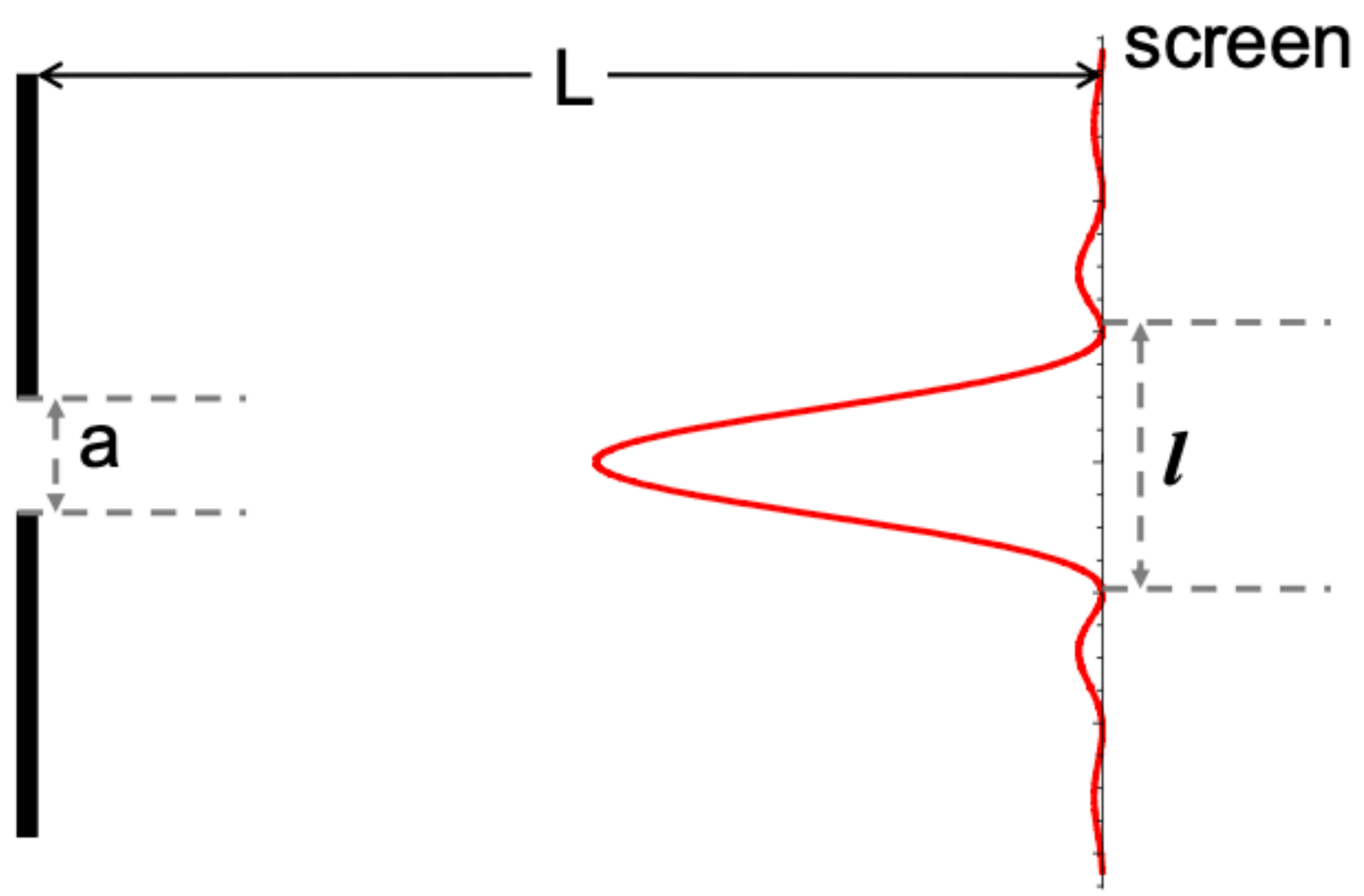
B. Decreases

C. Stays the same

D. Depends on the exact value of the slit width

Clicker/Poll Question

The slit opening is $a = 10\,\mu$m and the distance between the slit and the screen is $L = 3$ m. Find l for light of wavelength 500 nm.



A. 0.050m
B. 0.10m
C. 0.15m
D. 0.20m
E. 0.30m

Diffraction: Intensity

$$I = I_0 \left(\frac{\sin(\beta/2)}{\beta/2} \right)^2$$

$$\text{where } \beta = \frac{2\pi a \sin\theta}{\lambda}$$

FIGURE 33.19 The single-slit diffraction pattern.

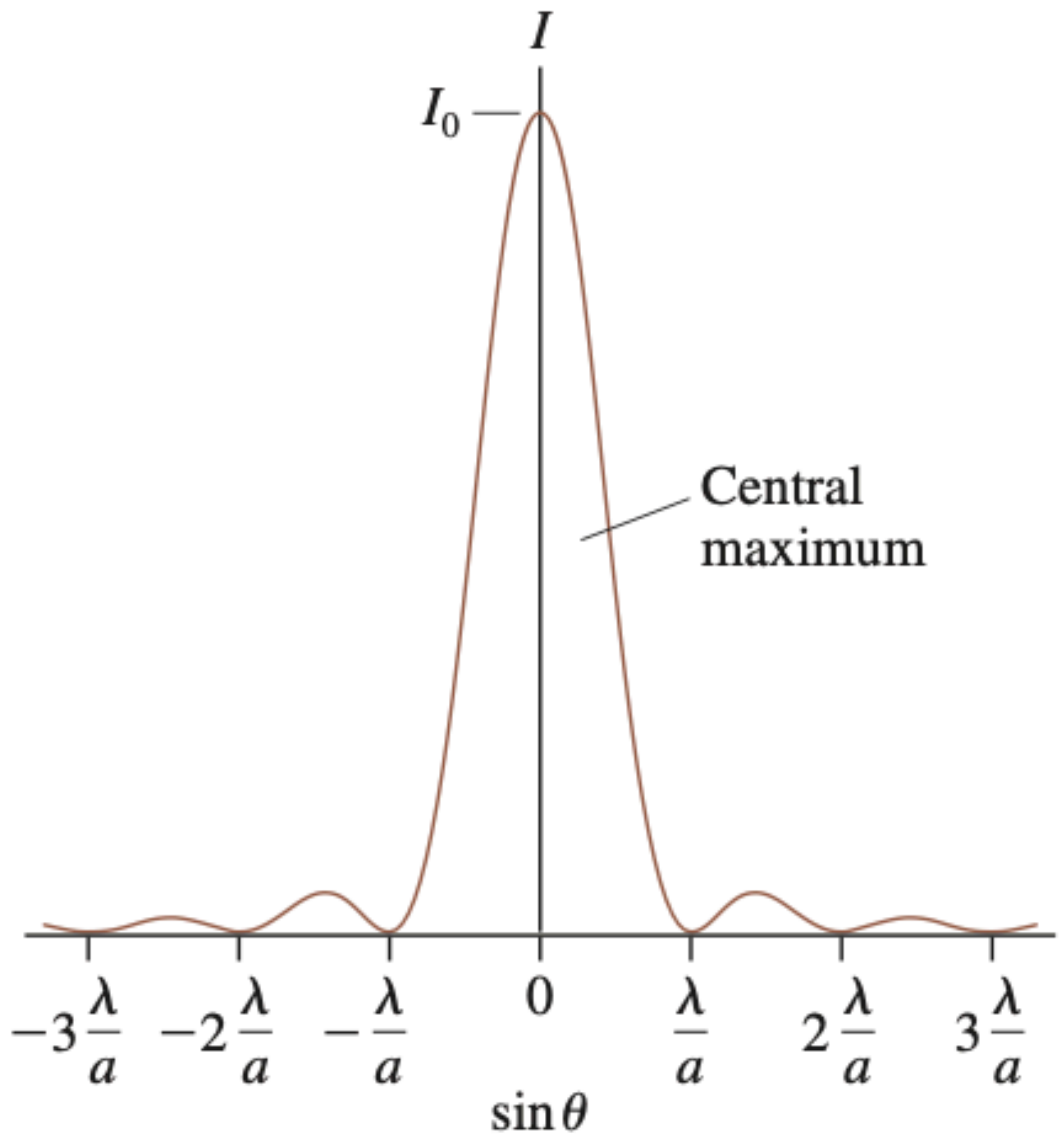
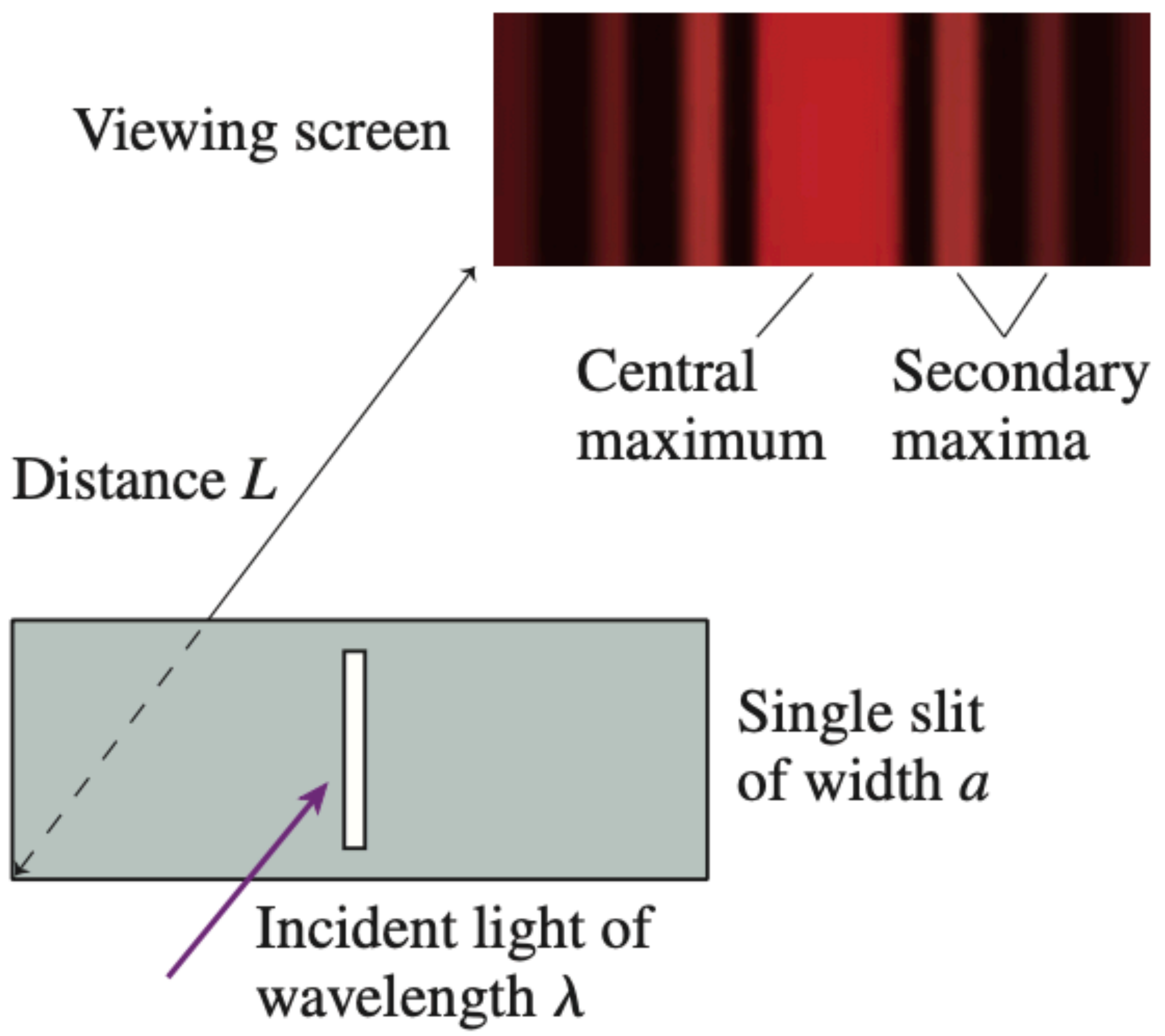
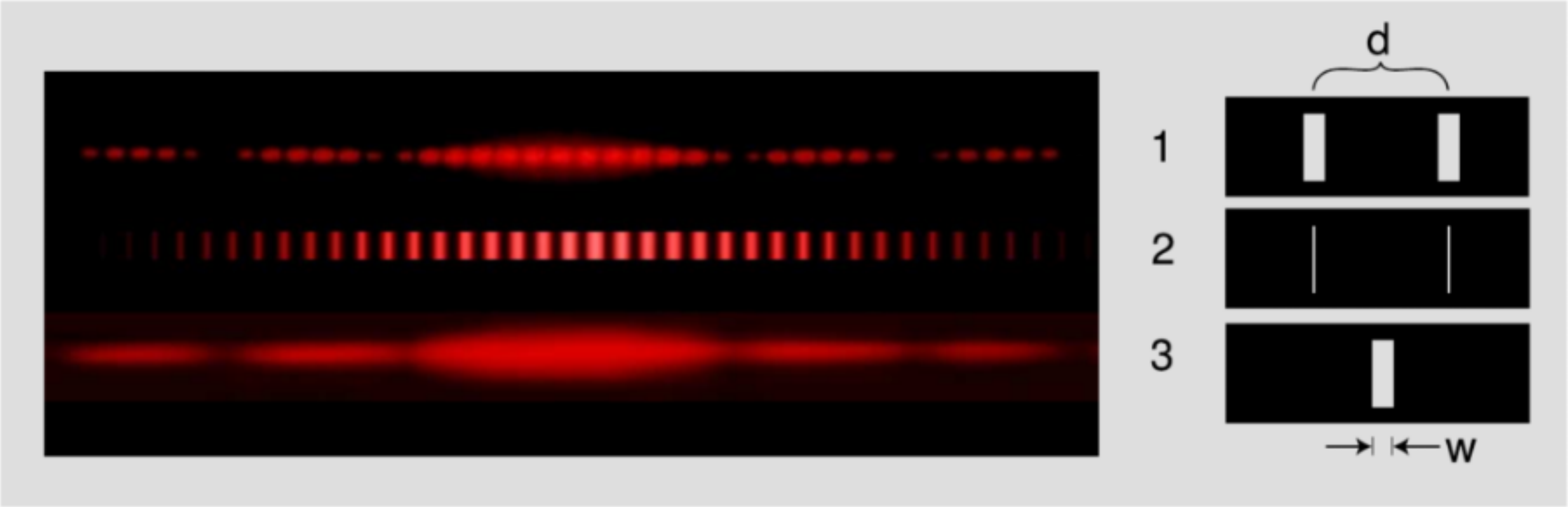


FIGURE 33.11 A single-slit diffraction experiment.



Combining 1- and 2-slit effects

The combined effect (with d>a) is that there is a spread-out “diffraction envelope” with a closely-spaced interference pattern.



aa / 1. A diffraction pattern formed by a real double slit. The width of each slit is fairly big compared to the wavelength of the light. This is a real photo. 2. This idealized pattern is not likely to occur in real life. To get it, you would need each slit to be so narrow that its width was comparable to the wavelength of the light, but that’s not usually possible. This is not a real photo. 3. A real photo of a single-slit diffraction pattern caused by a slit whose width is the same as the widths of the slits used to make the top pattern.

Combining 1- and 2-slit effects

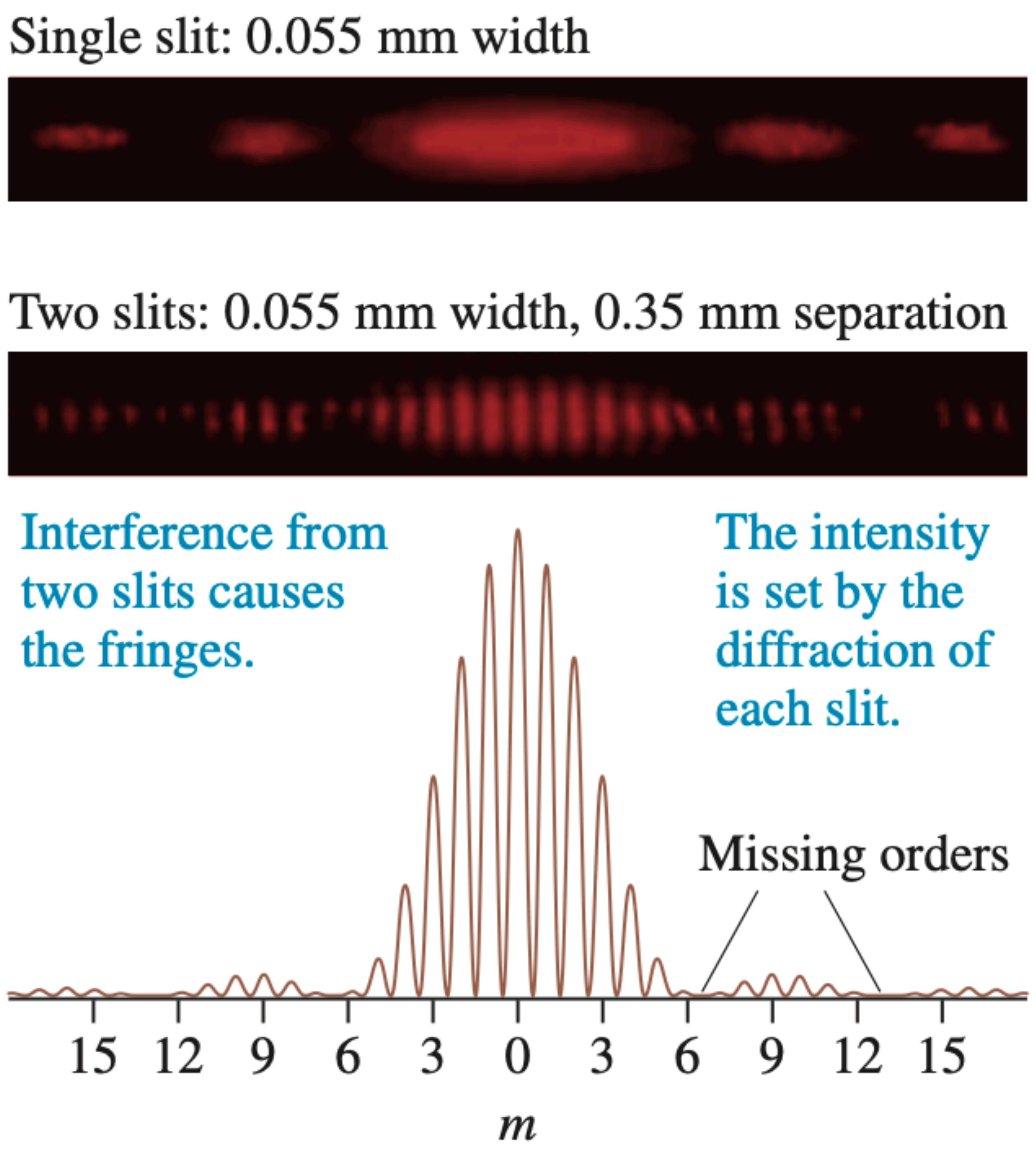
The combined effect (with d>a) is that there is a spread-out “diffraction envelope” with a closely-spaced interference pattern.

Also, there are “missing bright spots” where interference maxima correspond to diffraction minima.

$$m_{\text{missing}} = p\frac{d}{a}$$

(p=1,2,3,…)

FIGURE 33.20 The overall intensity of a double-slit interference pattern is governed by the single-slit diffraction through each slit.



Clicker/Poll Question

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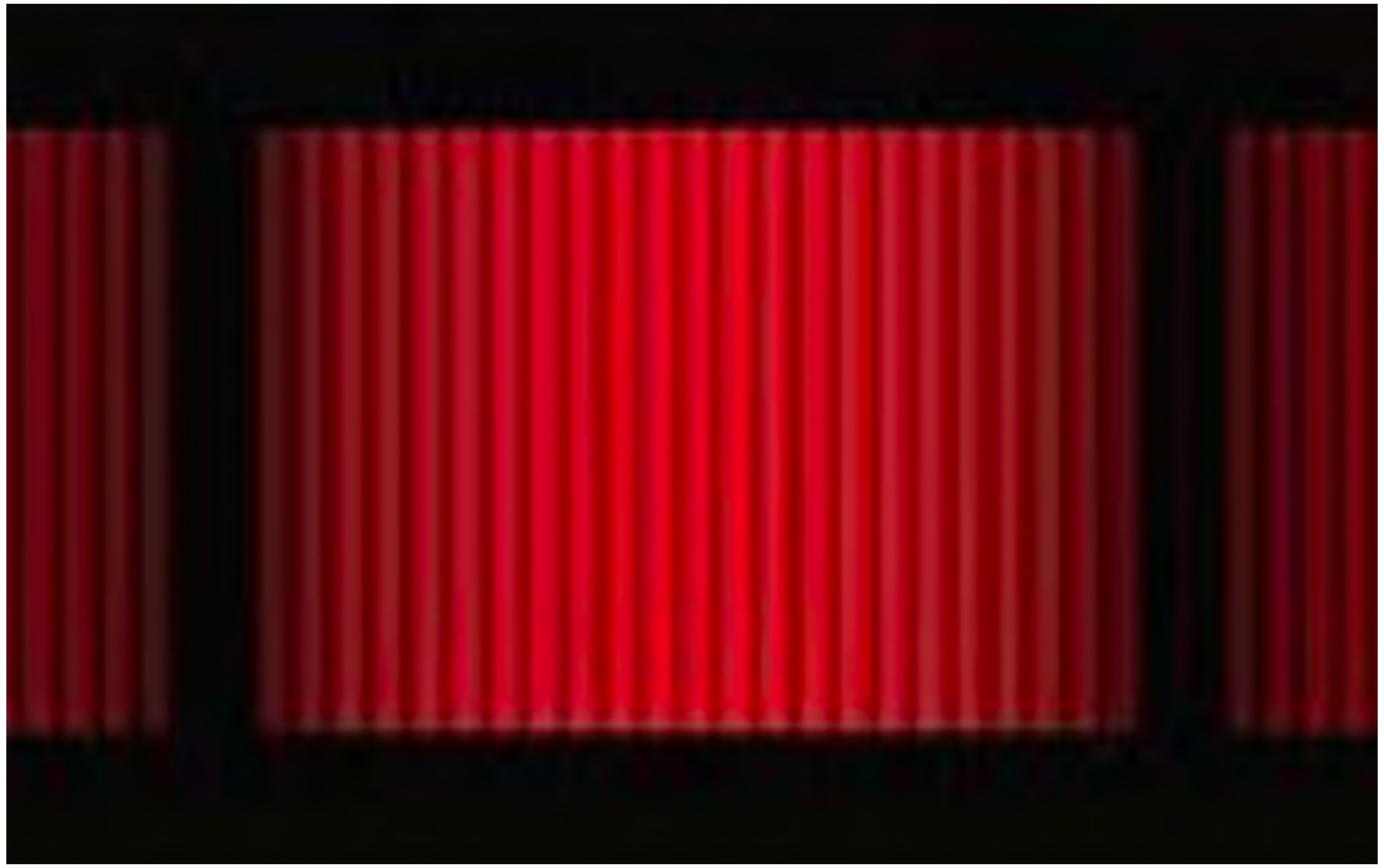
The following picture shows the interference pattern from two slits a distance 0.26mm apart.

What is the width of each slit?

A. 0.010mm
B. 0.013mm
C. 0.020mm
D. 0.026mm



Example 1

A beam of light of a single wavelength is incident perpendicularly on a double-slit arrangement. The slit widths are each $46\,\mu$m and the slit separation is 0.30mm . How many complete bright fringes appear between the two first-order minima of the diffraction pattern?

Diffraction places limits on resolving 2 objects

Because of diffraction, it's impossible to resolve objects w/ $\theta < \theta_{\text{min}} \approx 1.22\frac{\lambda}{D}$

Example 2

If you look at something 40 m from you, what is the smallest length (perpendicular to your line of sight) that you can resolve according to Rayleigh's criterion? Assume the pupil of your eye has a diameter of 4.00 mm, and use 500 nm as the wavelength of the light reaching you.

Diffraction places limits how straight a beam can be

A laser beam will naturally spread out; impossible to have $\theta < \theta_{\text{min}} \approx 1.22 \frac{\lambda}{D}$