Lectures: Physics 3306

Provides an introduction to a wide variety of topics in classical (pre-quantum) physics as a bridge to prepare students for subsequent upper-level courses in physics. The topics covered include thermodynamics, fluid mechanics, mechanical waves, optics, radiation, electromagnetic phenomena, atoms, and laboratory techniques. Prerequisites: C- or better in PHYS 1106; and in PHYS 1304 or PHYS 1308.

Saptaparna Bhattacharya

May 1st, 2026

Based on Simon Dalley's lectures taught in Spring 2025

Labs

Lectures

Schedule

No class

Month	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
January	19	20	21 ✅	22	23 ✅	24	25
	26 ❄️🌨️❄❄❄	27	28 ❄️🌨️❄❄❄	29	30 ✅	31	1
February	2 ✅	3	4 ✅	5	6 ✅	7	8
	9 ✅	10	11 HWB due ✅	12	13 ✅	14	15
	16 ✅	17	18 ✅	19	20 HWC due ✅	21	22
	23 Hegi Center ✅	24	25 HWD due ✅	26	27 ✅	28	1
March	2 ✅	3	4 HWE due	5	6 ✅	7	8
	9 ✅	10	11	12	13 Midterm	14	15
	16	17	18	19	20	21	22
	23 ✅	24	25	26	27 ✅	28	29
April	30 Lecture 11 ✅	31	1 HWF due	2	3	4	5

Labs

Lectures

Schedule

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Month	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
April	6 Midterm 2 ✅	7	8 HWG due	9	10 Lecture 15 ✅	11	12
	13 Lecture 16 ✅	14	15 HWH due	16	17 Lecture 17 ✅	18	19
	20 Lecture 18 ✅	21	22 HWI due	23	24 Lecture 19 ✅	25	26
May	27 Lecture 20 ✅	28	29 HWJ due	30	1 Lecture 21 ✅	2	3
	4 Lecture 22	5 Lecture 23	6	7	8	9	10

Halliday & Resnick: 35.4-35.5

Key concepts: Thin films

- When light is incident on a thin transparent film, light waves reflected from the front and back surfaces interfere
- For near-normal incidence, the wavelength conditions for maximum and minimum intensity of the light reflected from a film in air are:
  - Maxima: $2L = (m + \frac{1}{2})\frac{\lambda}{n_2}, m = 0,1,2,\cdots$
  - Minima: $2L = m\frac{\lambda}{n_2}, m = 0,1,2,\cdots$

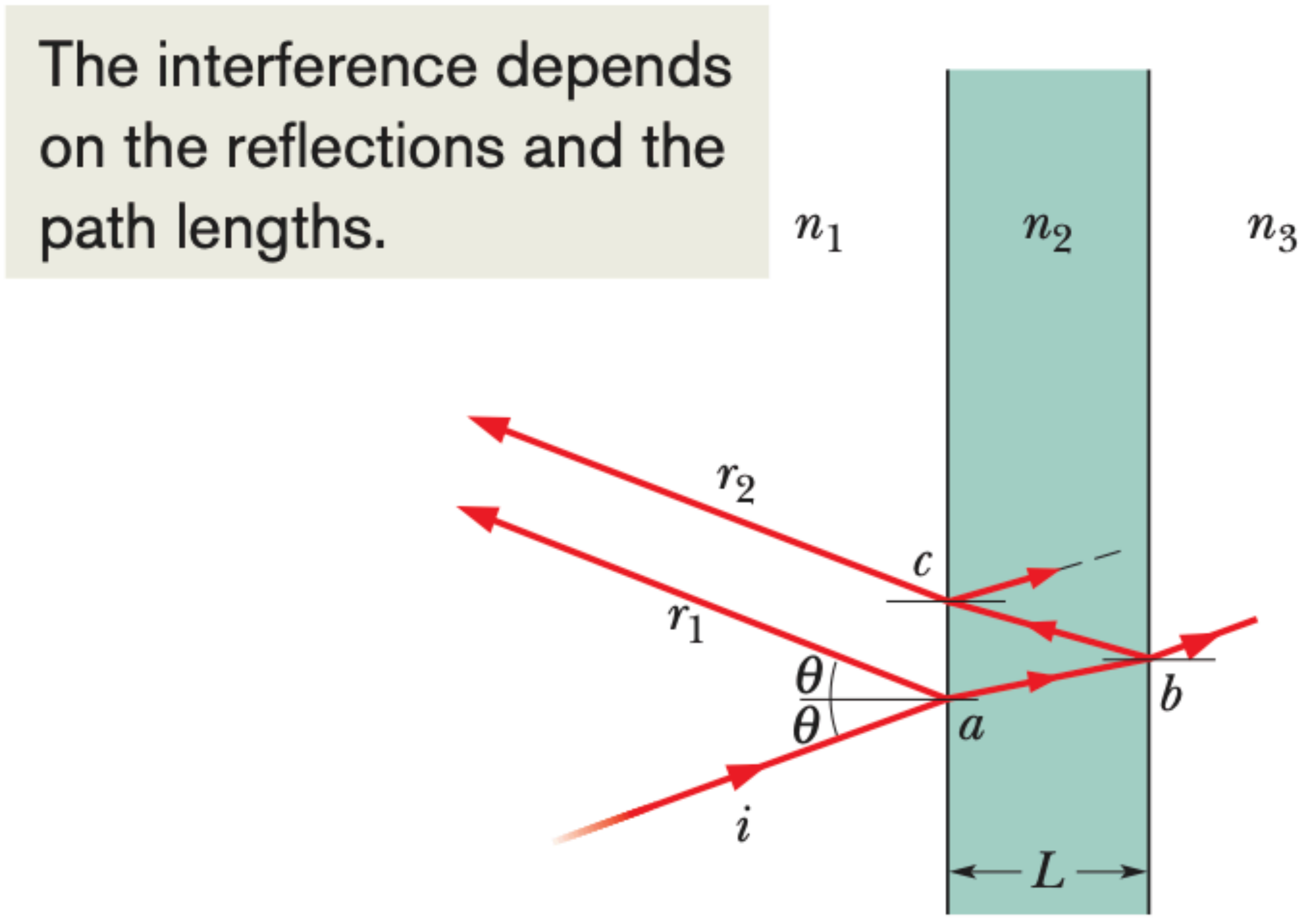


Figure 35-15 Light waves, represented with ray i, are incident on a thin film of thickness L and index of refraction n_2. Rays r_1 and r_2 represent light waves that have been reflected by the front and back surfaces of the film, respectively. (All three rays are actually nearly perpendicular to the film.) The interference of the waves of r_1 and r_2 with each other depends on their phase difference. The index of refraction n_1 of the medium at the left can differ from the index of refraction n_3 of the medium at the right, but for now we assume that both media are air, with $n_1 = n_3 = 1.0$, which is less than n_2.

Key concepts: Thin films

- Refraction at an interface never causes a phase change:
  - Reflection can, depending on the indexes of refraction on the two sides of the interface
- Transmitted pulse has the same orientation as the incident pulse, but the reflected pulse is inverted
  - For a sinusoidal wave, such an inversion involves a phase change of π rad, or half a wavelength
  - For light, this situation corresponds to the incident wave traveling in the medium of lesser index of refraction (with greater speed)
  - The wave that is reflected at the interface undergoes a phase shift of π rad, or half a wavelength

Reflection	Reflection phase shift
Off lower index	0
Off higher index	0.5 wavelength

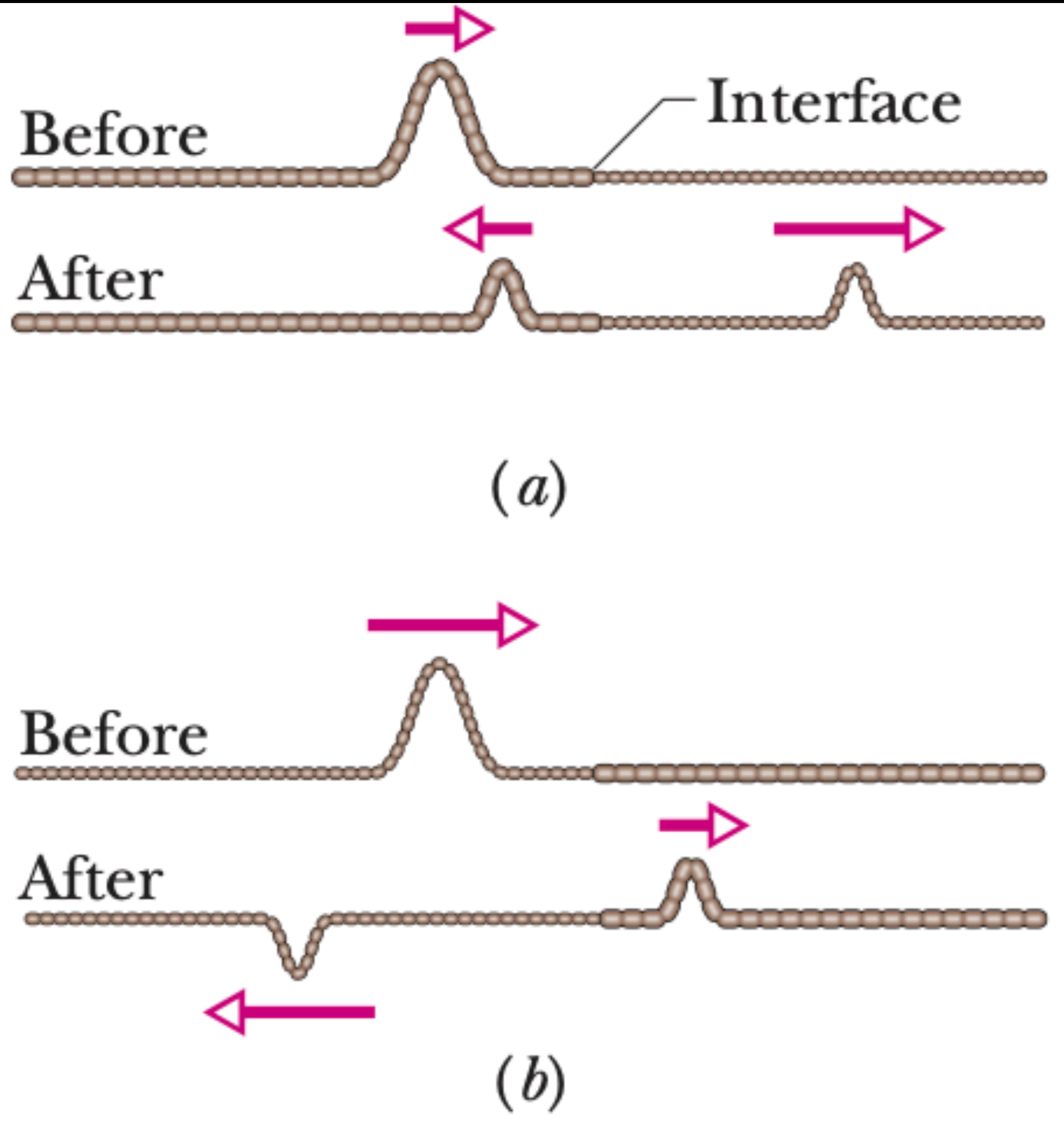


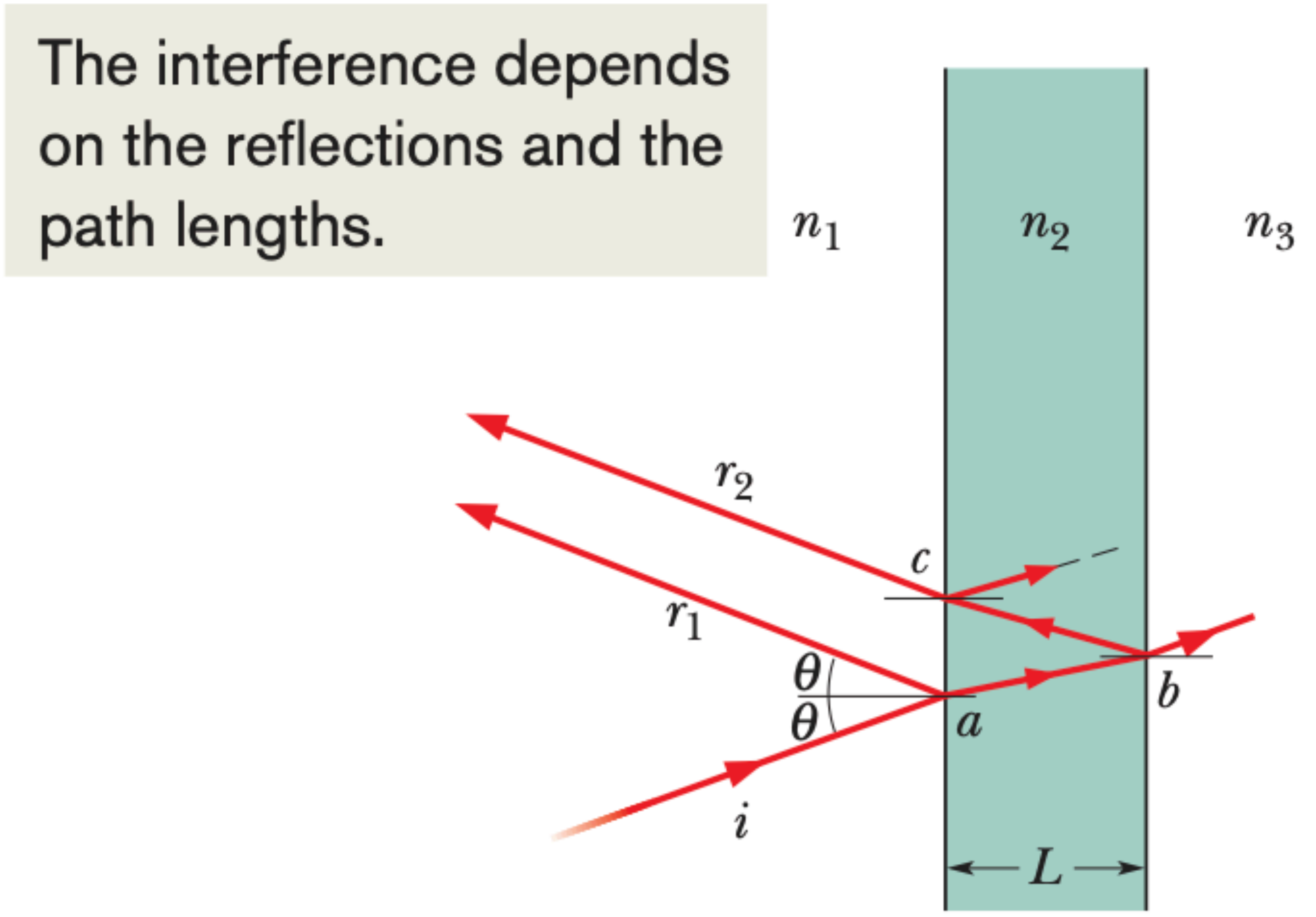
Figure 35-16 Phase changes when a pulse is reflected at the interface between two stretched strings of different linear densities. The wave speed is greater in the lighter string. (*a*) The incident pulse is in the denser string. (*b*) The incident pulse is in the lighter string. Only here is there a phase change, and only in the reflected wave.

Key concepts: Thin films

- Equations for Thin-film interference:
  - Phase difference between two waves can change:
    - By reflection
    - By the waves traveling along path of different lengths
    - By the waves traveling through media of difference indexes of refraction

Key concepts: Thin films

- Reflection shift:
  - Point a on the front interface, the incident wave (in air) reflects from the medium having the higher of the two indexes of refraction; so the wave of reflected ray r_1 has its phase shifted by 0.5 wavelength
  - At point b on the back interface, the incident wave reflects from the medium (air) having the lower of the two indexes of refraction; so the wave reflected there is not shifted in phase by the reflection, and thus neither is the portion of it that exits the film as ray r_2



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Key concepts: Thin films

- Path length difference:
  - Consider the path length difference $2L$ that occurs because the wave of ray r_2 crosses the film twice
  - If the waves r_1 and r_2 are in phase they interfere constructively:
  - Maxima: $2L = (m + \frac{1}{2})\frac{\lambda}{n_2}, m = 0,1,2,\cdots$
  - Minima: $2L = m\frac{\lambda}{n_2}, m = 0,1,2,\cdots$

Which of the following don’t affect the phase of perpendicular reflected light above a thin film in air?

A. The light wavelength
B. Reflection at the top interface
C. Reflection at the bottom interface
D. The refractive index of the film
E. The thickness of the film

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D. The refractive index of the film
E. The thickness of the film

When analyzing thin film interference, the relative phase of the reflected light depends on two main mechanisms: the extra distance the light travels inside the film, and any sudden phase shifts that occur at the boundaries when the light reflects.

1. **Path Length Factors (Wavelength, Thickness, Refractive Index):** The light that enters the film has to travel down to the bottom and back up. The amount of phase it accumulates over this extra distance is called the optical path length. This depends directly on the film's **thickness**, the **refractive index** of the film (which changes the speed and wavelength of the light inside it), and the original **wavelength** of the light. Therefore, these three factors definitely affect the phase.

2. **Top Interface Reflection:** When light traveling in air (a lower refractive index) reflects off the surface of the film (a higher refractive index), it hits a "hard" boundary. This causes a sudden phase shift of 180° (or π radians). So, the reflection at the top interface affects the phase.

3. **Bottom Interface Reflection:** When the light traveling *inside* the film reaches the bottom boundary and reflects off the air outside, it is hitting a "soft" boundary (going from a higher refractive index to a lower one). Physics dictates that a reflection at a lower-index boundary produces **no phase shift** (0°).

Because the reflection event at the bottom interface adds exactly zero phase shift to the wave, it is the only factor listed that does not affect the final phase of the reflected light.

Problem 1: Thin Film Phase Shifts

Question: Which of the following don't affect the phase of perpendicular reflected light above a thin film in air?
Correct Answer: Reflection at the bottom interface.
Explanation: The total phase difference between the light reflected from the top and bottom interfaces of a thin film depends on the film's thickness, its refractive index, the wavelength of the light, and any phase shifts upon reflection. For a thin film in air ($n_{\text{air}} < n_{\text{film}}$), the light reflecting at the top interface (air to film) undergoes a π (or 180°) phase shift because it is reflecting off a medium with a higher refractive index. However, the light reflecting at the bottom interface (film to air) reflects off a medium with a lower refractive index, resulting in a 0 phase shift. Because this phase shift is 0, the act of reflection at the bottom interface itself does not add a phase shift to the wave.

If the incident light is not perpendicular but at angle θ to the normal to the film, the angle of reflection is

A. Not unique
B. θ
C. Depends on the film thickness
D. Too difficult to work out…

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B. θ
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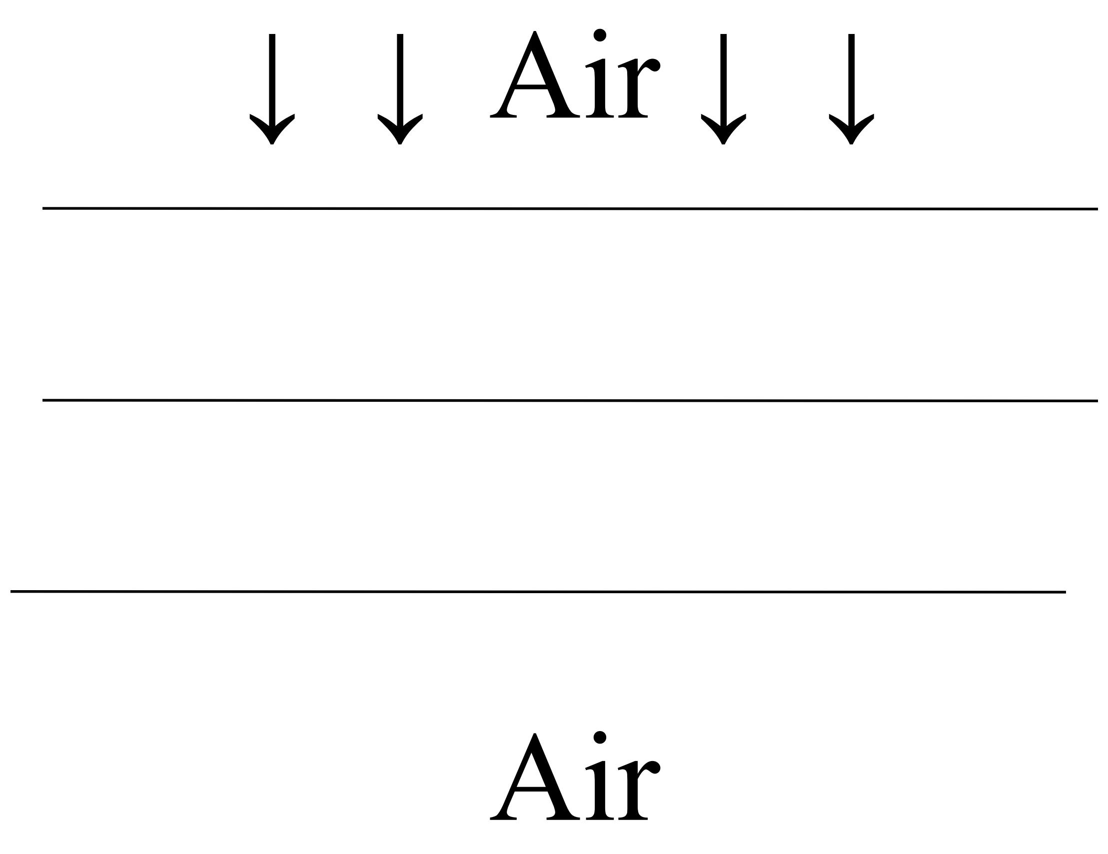
Problem 2: Law of Reflection

Question: If the incident light is not perpendicular but at angle θ to the normal to the film, the angle of reflection is:
Correct Answer: θ
Explanation: According to the Law of Reflection, the angle of incidence is always equal to the angle of reflection. Since both angles are defined relative to the normal (perpendicular) to the surface, an incident angle of θ perfectly guarantees a reflection angle of θ, regardless of the material's properties or thickness.



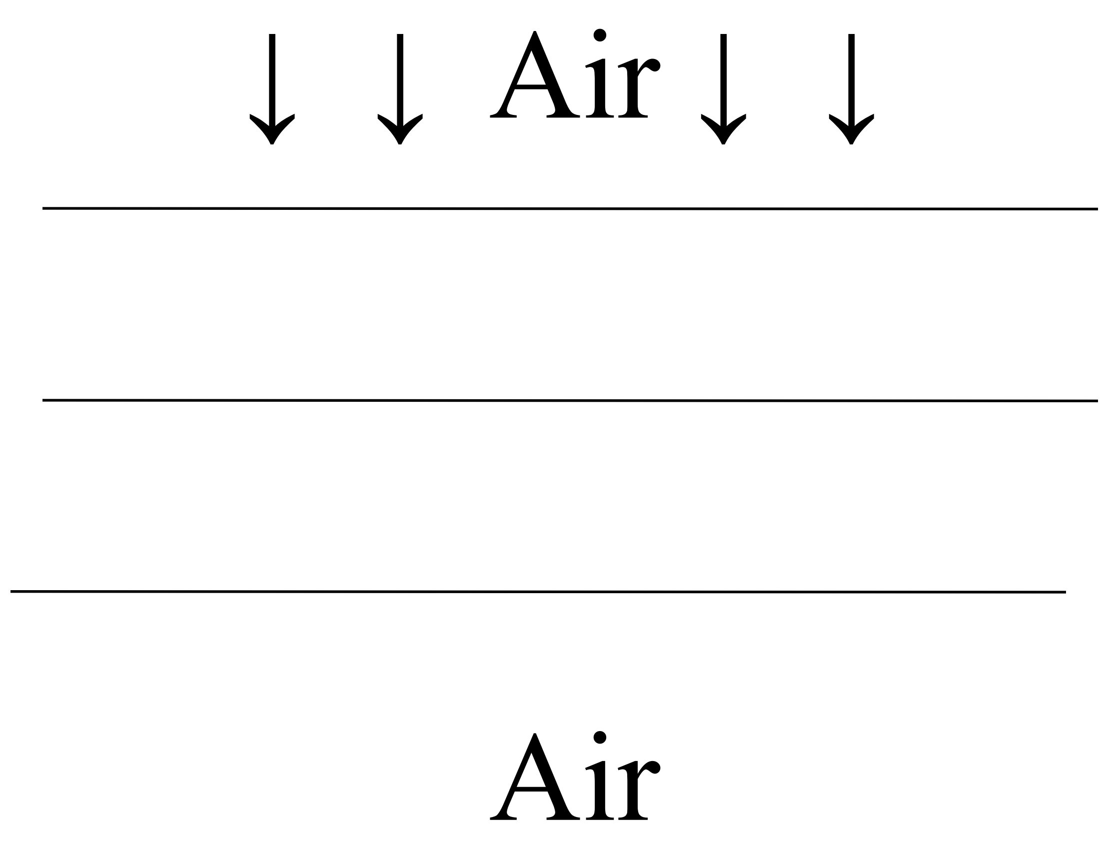
Shown are two stacked thin films, of the same negligible thickness, illuminated from above.

Rank their refractive indices from top to bottom if the interfaces between them cause constructive interference in lowest order for the light reflected back from the stack.

A. 1.5, 3

B. 3, 1.5

C. The order doesn't matter



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A. 1.5, 3

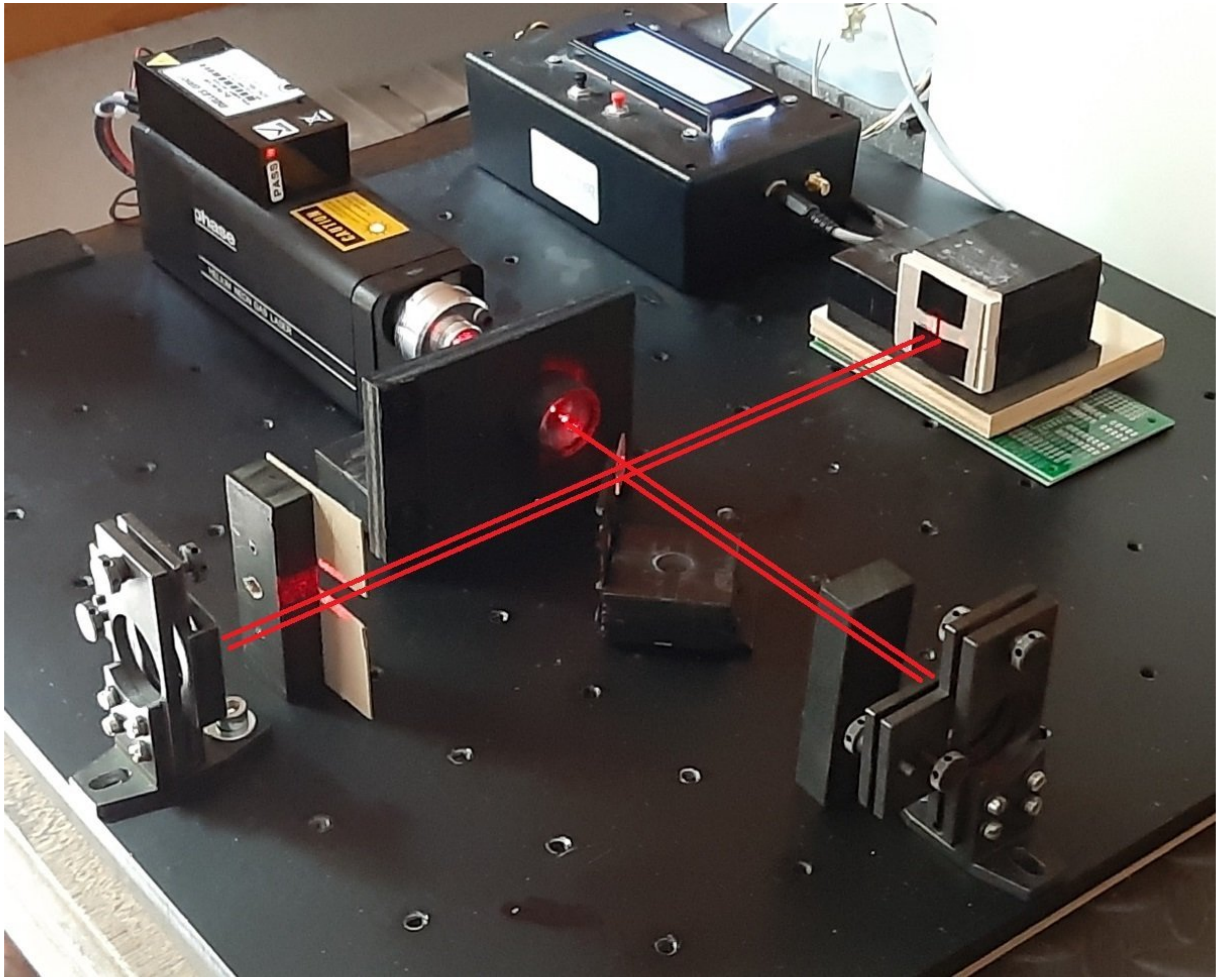
B. 3, 1.5

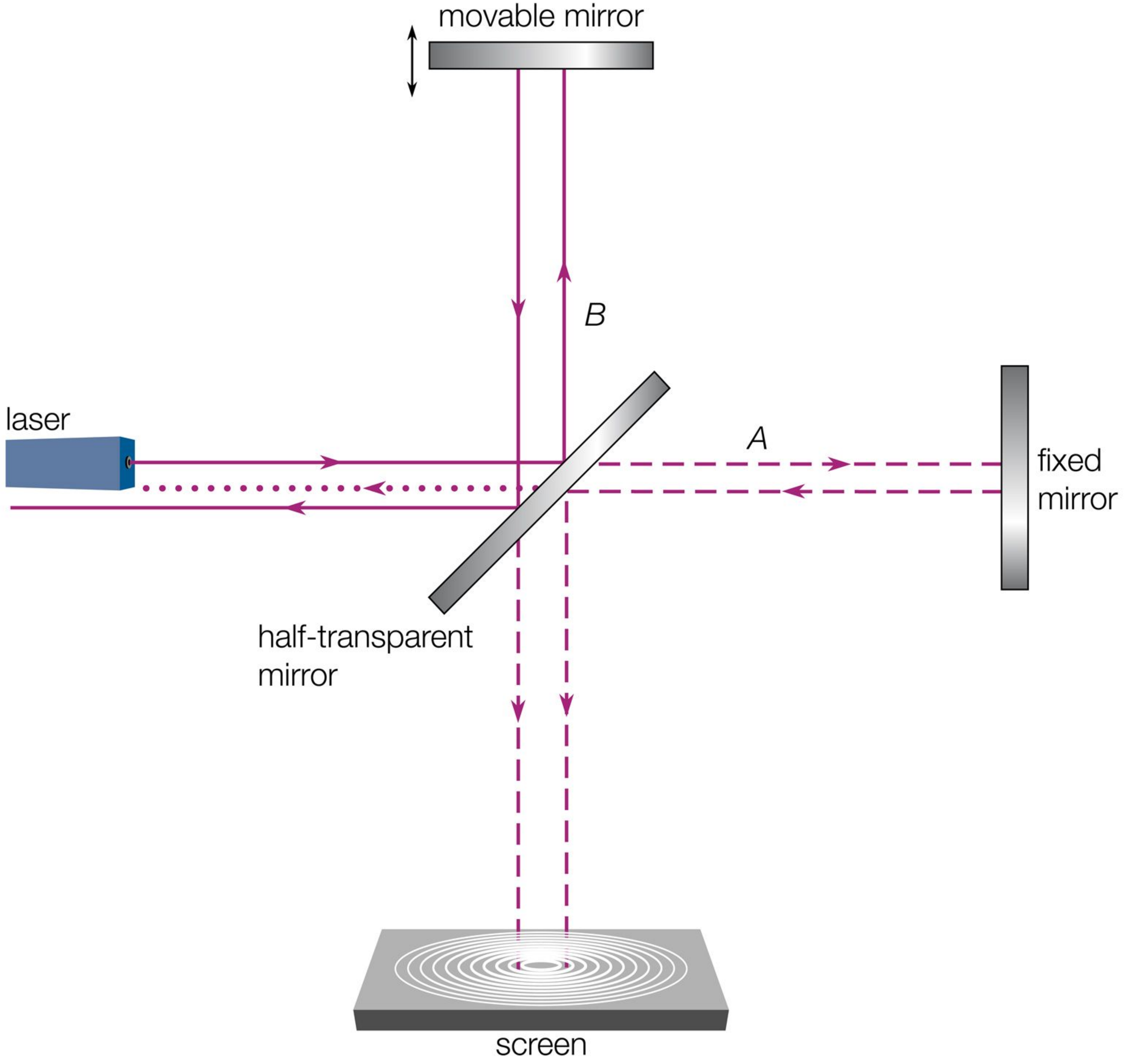
C. The order doesn't matter

Correct Answer: 1.5, 3

Explanation: For films of negligible thickness ($t \to 0$), the physical path length difference inside the films is approximately zero ($2nt \approx 0$). Therefore, any interference depends solely on the relative phase shifts acquired at the reflective boundaries.

- If the refractive indices are ordered $1.0 \to 1.5 \to 3.0$: The reflection at the first interface (1.0 to 1.5) gets a π phase shift. The reflection at the second interface (1.5 to 3.0) also gets a π phase shift. Because both waves experience the exact same phase shift, they remain in phase and interfere constructively.
- If the indices were $3.0, 1.5$, the top reflection would have a π shift, but the second reflection (3.0 to 1.5) would have a 0 shift, leading to destructive interference.


phase



movable mirror
B
laser
A
fixed
mirror
half-transparent
mirror
screen

Which of the following affect the path length difference in an interferometer? (*assume all movement keeps the interferometer in the same arrangement*)

A. The position of the source

B. The position of the beam splitter

C. The position of one mirror

D. A material inserted on one path

E. The position of the detector

F. The orientation of the interferometer

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B. The position of the beam splitter

C. The position of one mirror

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E. The position of the detector

F. The orientation of the interferometer

- **The position of one mirror:** Moving one mirror directly alters the physical distance that light travels in that specific arm of the interferometer ($\Delta L = 2\Delta x$), thus changing the physical path length difference between the two arms.
- **A material inserted on one path:** Inserting a dielectric material (with $n > 1$) slows down the light in that arm, increasing the *optical* path length ($L_{\text{optical}} = nL_{\text{physical}}$). This shifts the interference fringes just as changing the physical length would.

Moving the source or detector does not change the *difference* between the two paths, only the overall baseline distance both beams must travel together.

At a given point, gravitational waves traveling along the *z* axis

A. stretch the *z* axis and squeeze the *x, y* axes
B. stretch the *z* axis and the *x, y* axes
C. squeeze the *x, y* axes
D. stretch the *x* axis and squeeze the *y* axis
E. squeeze the *z* axis

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A. stretch the z axis and squeeze the x, y axes
B. stretch the z axis and the x, y axes
C. squeeze the x, y axes
D. stretch the x axis and squeeze the y axis
E. squeeze the z axis

Correct Answer: stretch the x axis and squeeze the y axis.
Explanation: Gravitational waves are transverse waves. They stretch and compress spacetime in the plane perpendicular to their direction of propagation. For a wave propagating along the z-axis, the spatial distortions occur exclusively in the x-y plane. For the standard "+" polarization state, as a wave passes, it will stretch the space along the x-axis while simultaneously squeezing the space along the y-axis (and vice versa half a cycle later). It does not stretch or squeeze along the z-axis.

Key concepts: Diffraction

- First minimum occurs for:
  - $a \sin \theta = \lambda$
  - Slit width: a

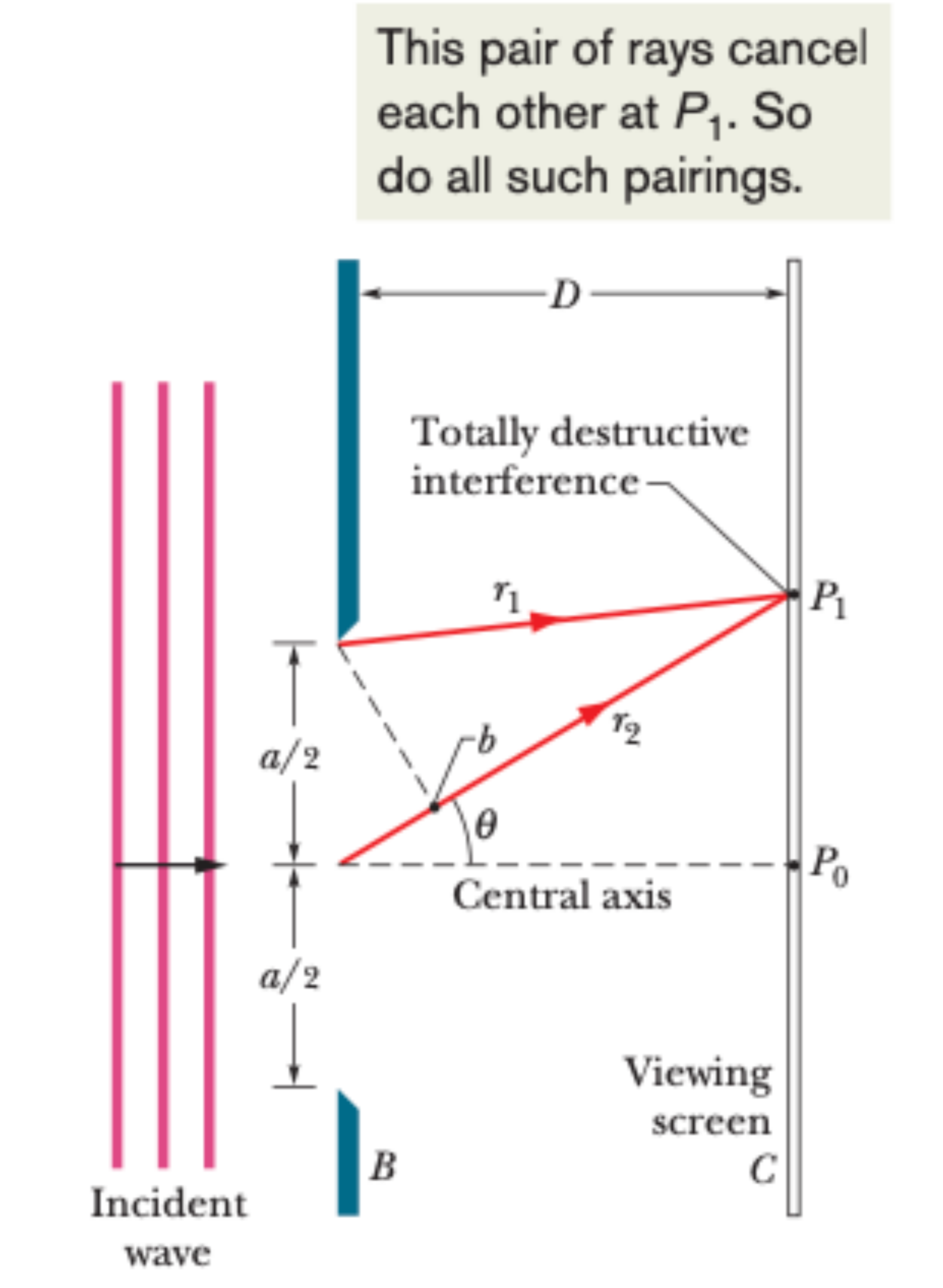


Figure 36-4 Waves from the top points of two zones of width $a/2$ undergo fully destructive interference at point P_1 on viewing screen C.

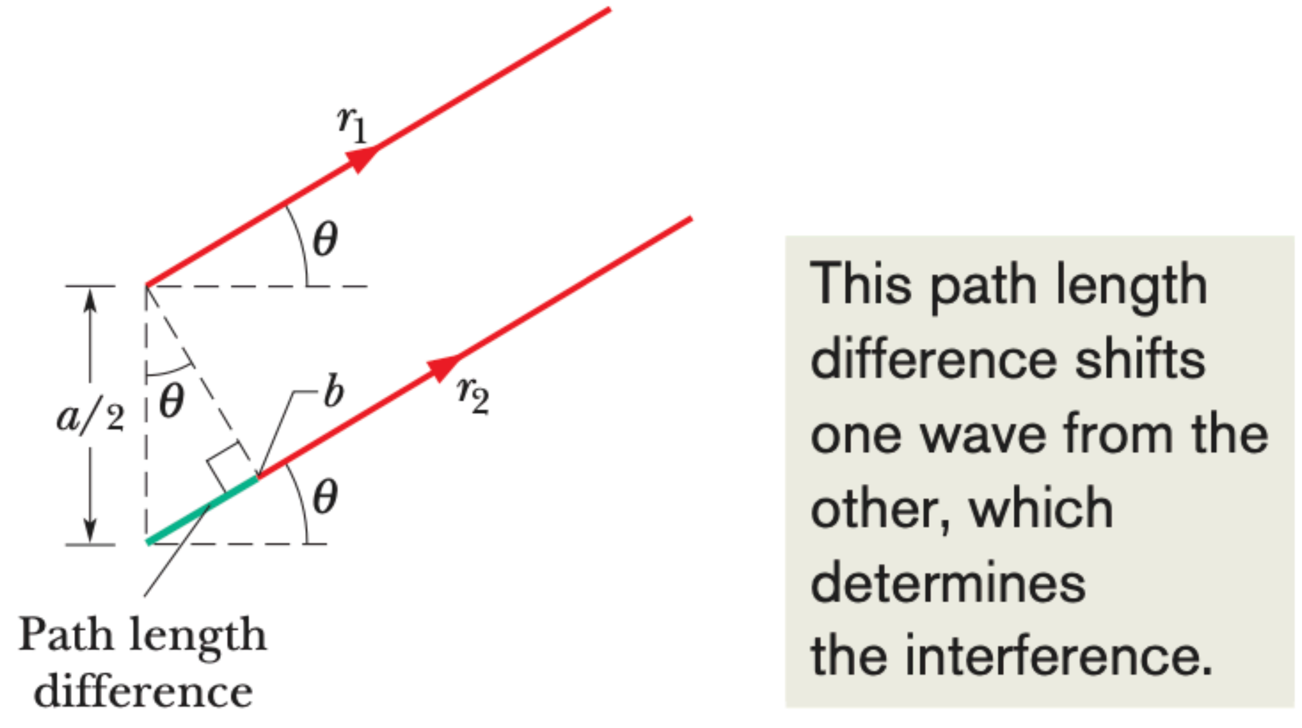
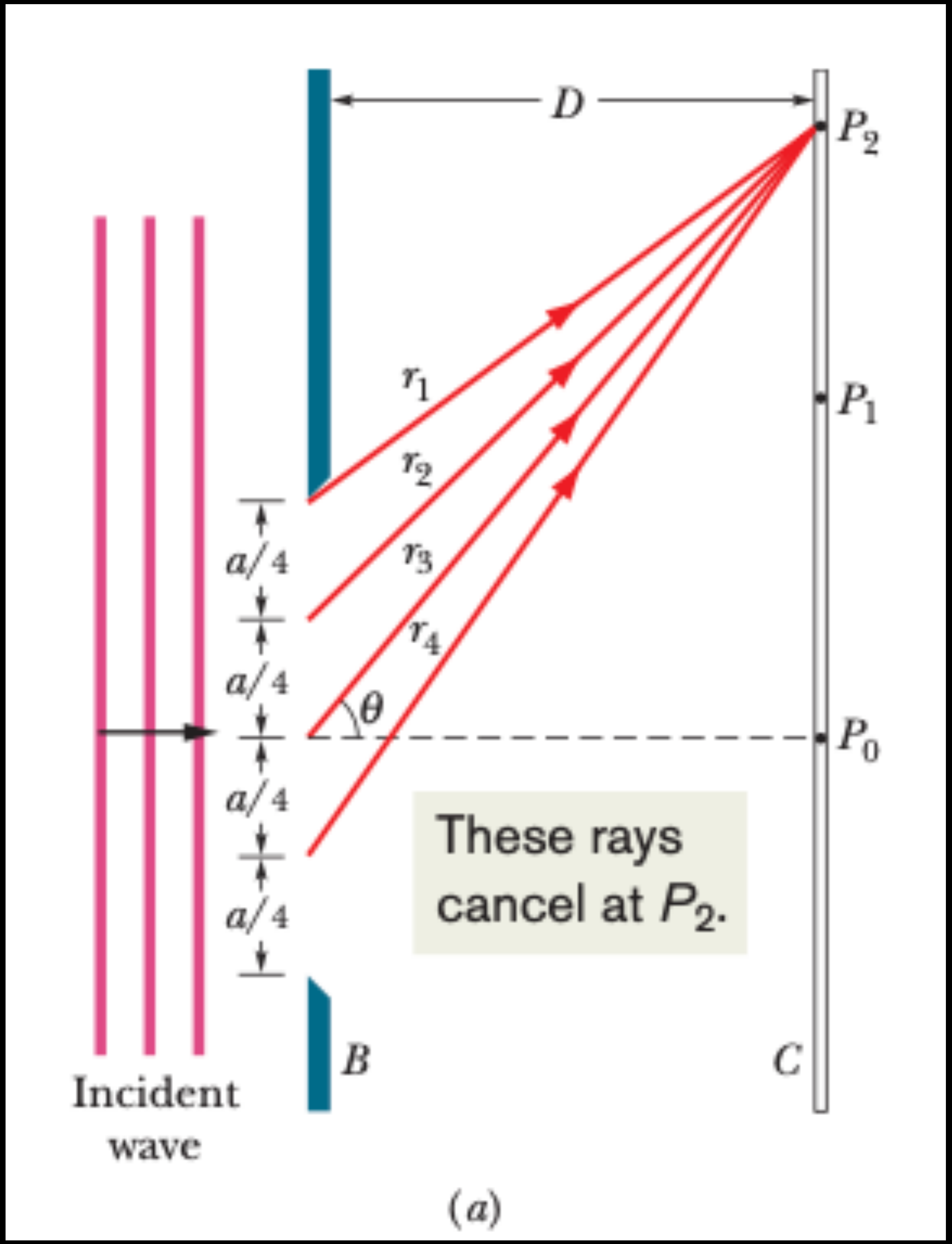


Figure 36-5 For $D \gg a$, we can approximate rays r_1 and r_2 as being parallel, at angle θ to the central axis.

Courtesy Jearl Walker

Figure 36-3 A photograph of the diffraction pattern of a disk. Note the concentric diffraction rings and the Fresnel bright spot at the center of the pattern. This experiment is essentially identical to that arranged by the committee testing Fresnel's theories, because both the sphere they used and the disk used here have a cross section with a circular edge.

Key concepts: Diffraction



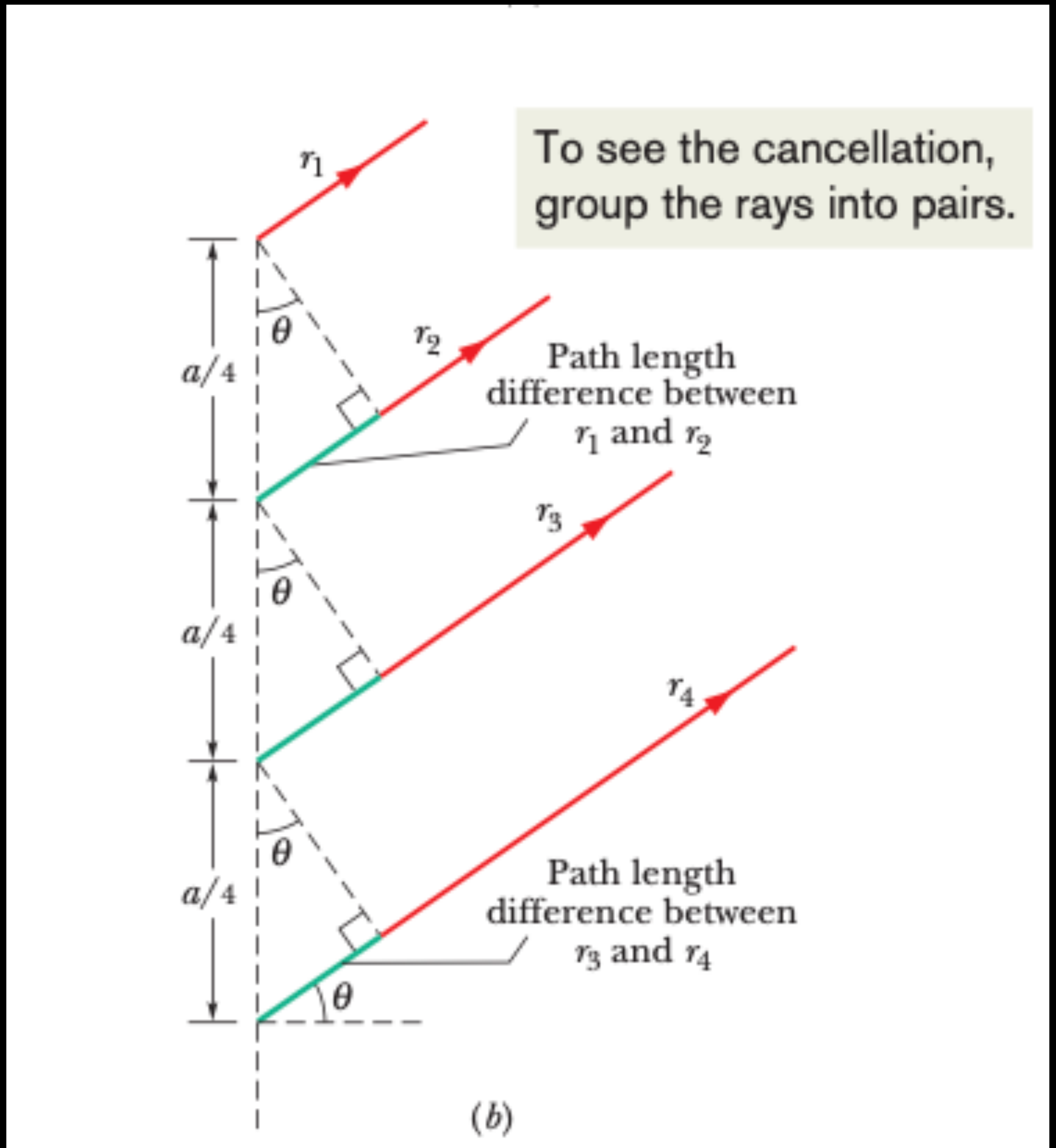
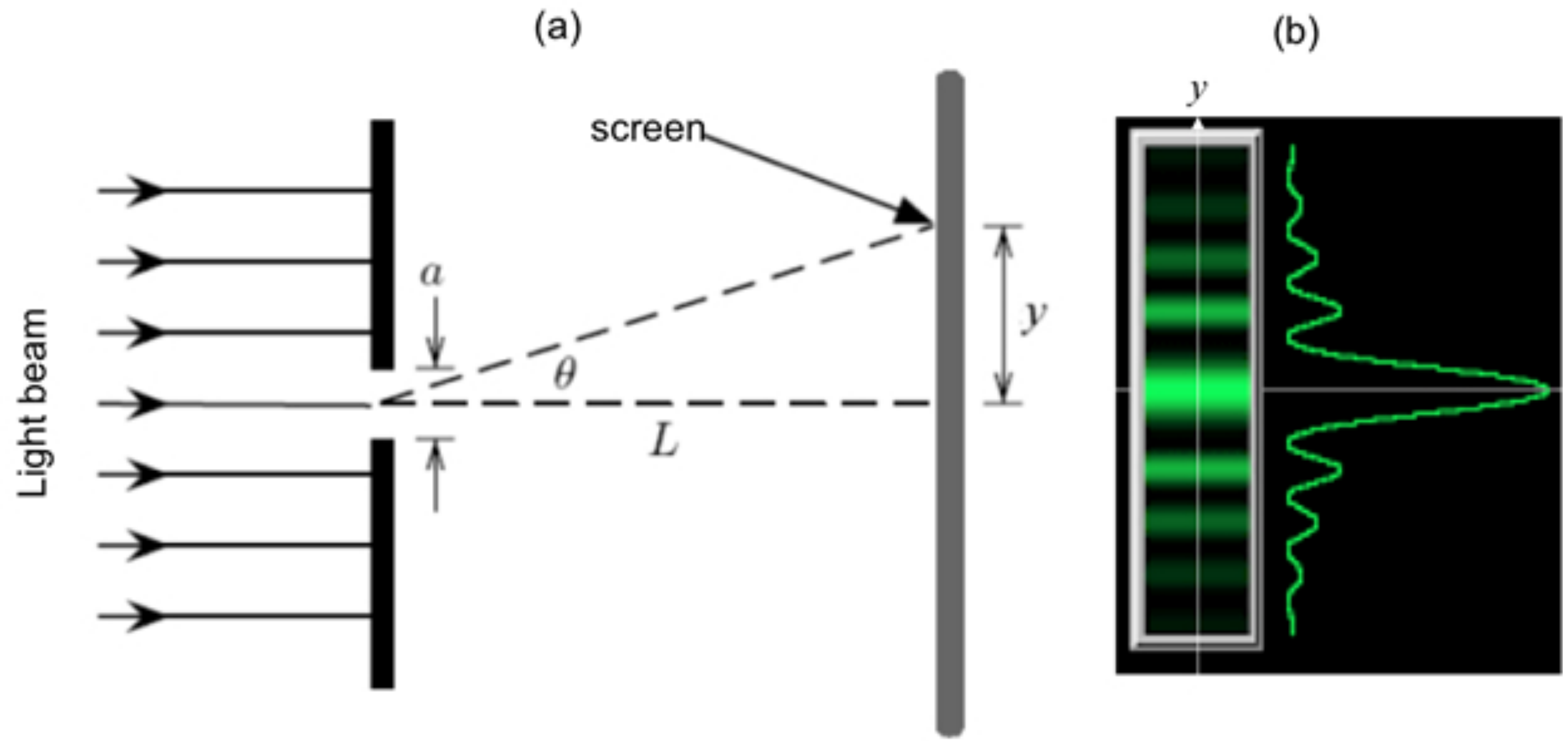
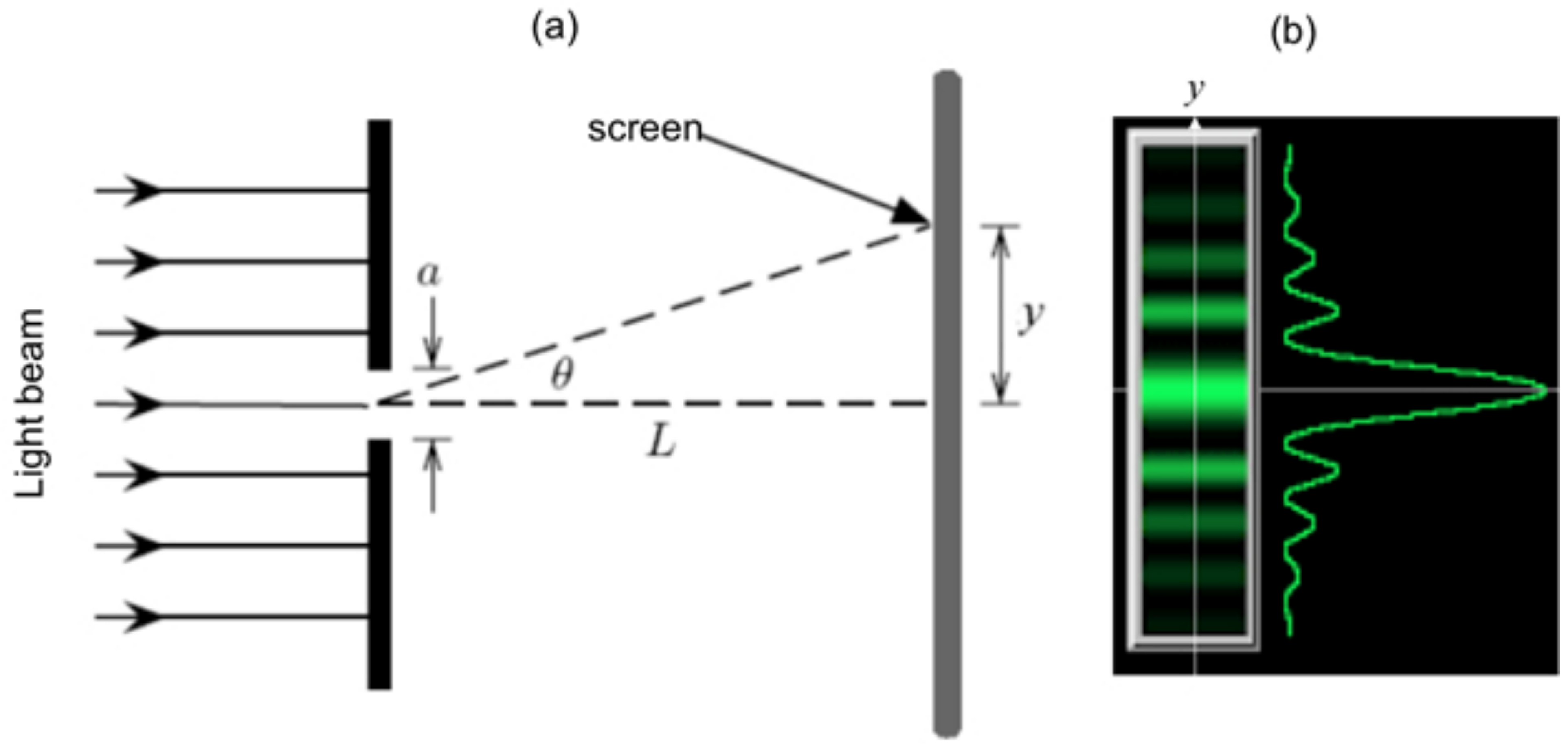


Figure 36-6 (*a*) Waves from the top points of four zones of width $a/4$ undergo fully destructive interference at point P_2. (*b*) For $D \gg a$, we can approximate rays r_1, r_2, r_3, and r_4 as being parallel, at angle θ to the central axis.


(a)
(b)
screen
Light beam
a
θ
L
y
y



What is the condition that the simple trigonometric construction for the angle θ of minima is valid?

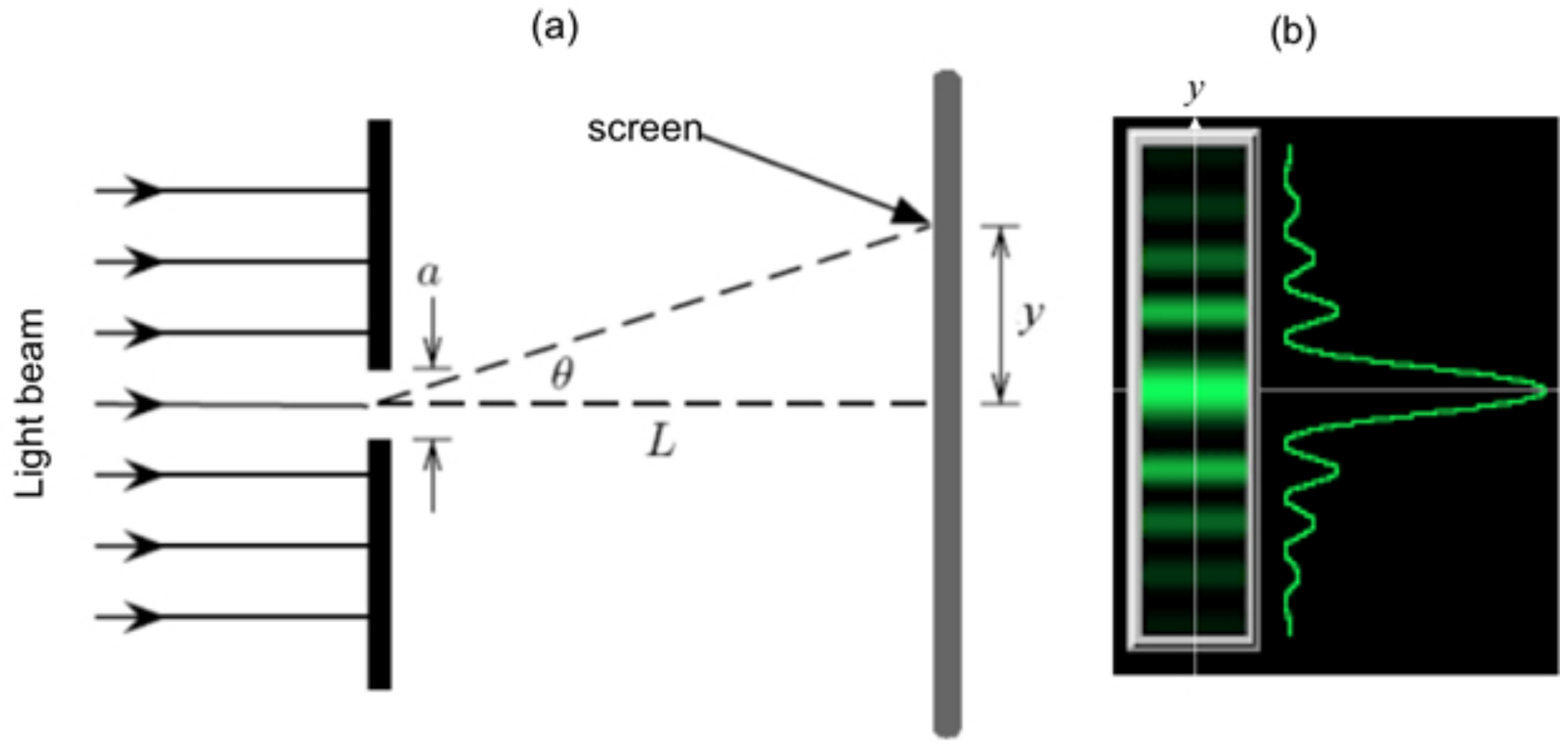
a) $y \approx a$

b) θ rad << $\sin \theta$

c) $L >> a$

d) $y \approx L$

e) $\tan \theta \approx y/L$



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The diagram illustrates Fraunhofer (far-field) diffraction. To derive the standard formula for the locations of the minima ($a\sin\theta=m\lambda$), we use a simple trigonometric construction that assumes the light rays traveling from different points within the slit to the same point y on the screen are essentially parallel.

This "parallel ray" approximation is only valid when the distance to the screen (L) is vastly larger than the width of the slit (a). If the screen were close to the slit, the rays would converge at significantly different angles, meaning you would have to use the more complex mathematics of Fresnel (near-field) diffraction.

Therefore, the condition $L \gg a$ ensures the setup is in the far-field regime, making the simple geometric derivation valid.

What is the slit width *a* that just eliminates all the minima of intensity from the diffraction?

a) λ

b) ½ λ

c) The other minima cannot be eliminated

d) It’s complicated

e) I don’t know how to work it out.

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a) λ

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e) I don't know how to work it out.

- $a \sin \theta = \lambda$
- $a = \lambda$
- $\sin \theta = 1$
  - $\theta = 90°$

How would you determine the value of (sin x)/x as $x \to 0$?
The value of (sin x)/x as $x \to 0$ is

a)0

b)1

c)∞

d)undefined

How would you determine the value of (sin x)/x as x → 0 ?
The value of (sin x)/x as x → 0 is

a)0

b)1

c)∞

d)undefined

$$\sin x \approx x - \frac{x^3}{3!} + \cdots$$

L'Hospital's rule

$$\frac{\cos x}{1} = 1$$

How would you determine the value of (sin x)/x as x → 0 ?

The value of (cos x)/x as x → 0 is

a)0

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d)undefined

How would you determine the value of (sin x)/x as x → 0 ?

The value of (cos x)/x as x → 0 is

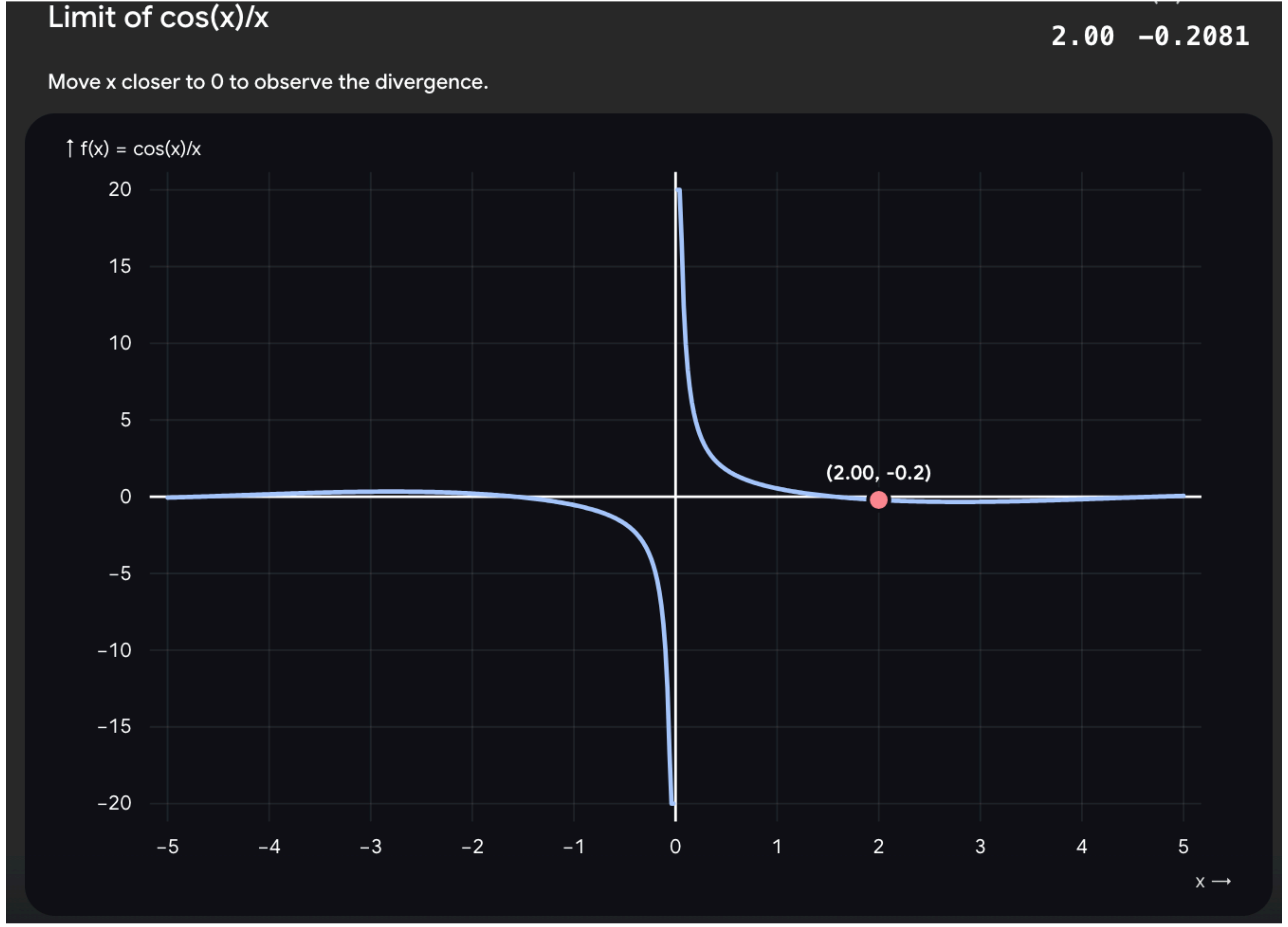
a)0

b)1

c)∞

d)Undefined

How did you decide?



$$\cos x \approx 1 - \frac{x^2}{2!} + \cdots$$

$$\frac{\cos 0}{0} = \frac{1}{0}$$