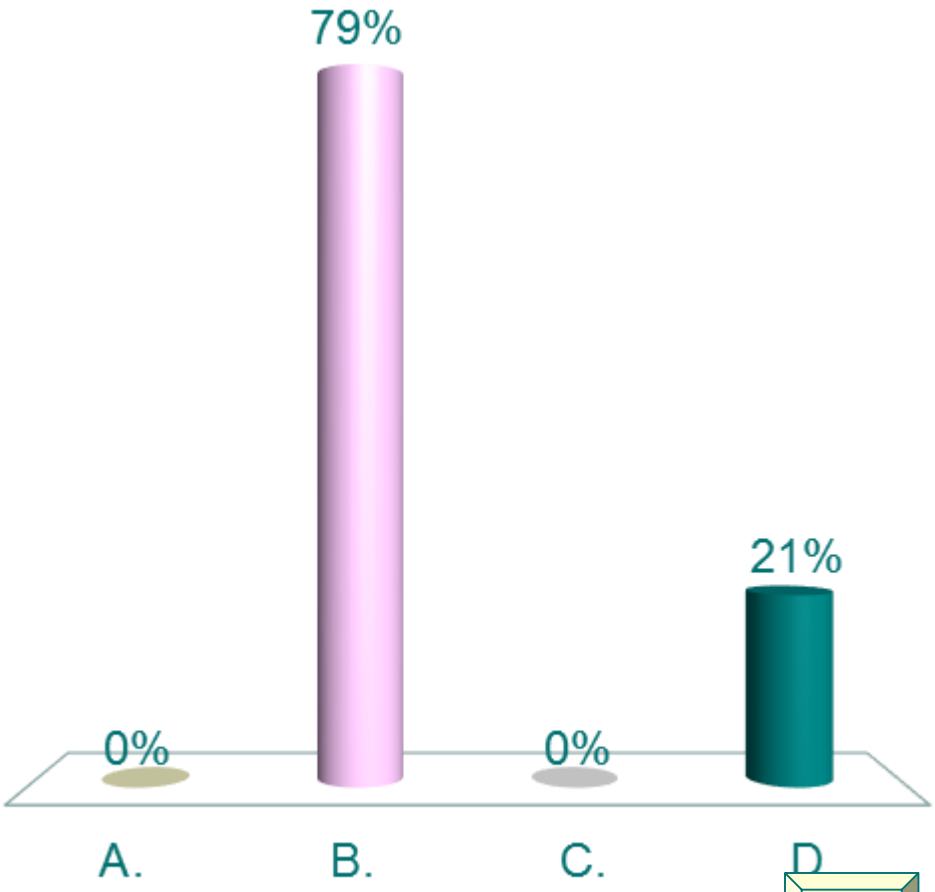
Physics 115 Lecture 21

Refraction and Diffraction

March 13, 2018

Class Quiz: A 88-dB sound wave reflects from a surface with absorption coefficient $\alpha = 0.50$. What is the sound level of the reflected wave?

A. 22 dB
B. 44 dB
C. 82 dB
D. 85 dB



Class Quiz: **An 88.0-dB sound wave reflects from a surface with absorption coefficient $\alpha = 0.50$. What is the sound level of the reflected wave?**

A. 22 dB

B. 44 dB

C. 82 dB

D. 85 dB

The reflected intensity will have half the incident intensity. When the intensity is cut in half, the sound level decreases by 3 dB.

$$I_0 = I_r 10^{L_0/10} = I_r 10^{88/10}$$

$$= 6.31\times10^{-4}\ \text{W/m}^2$$

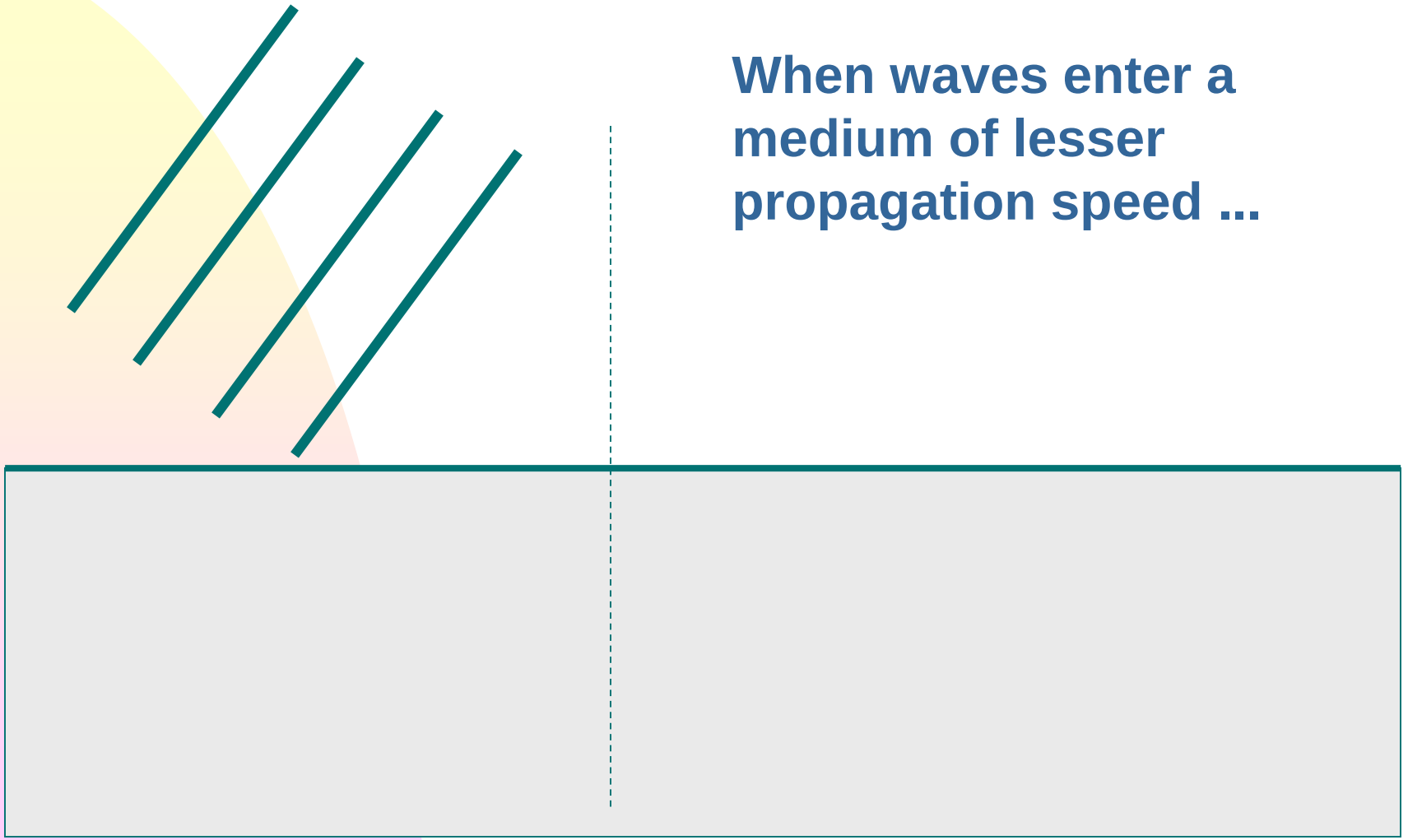
$$\beta = 1-\alpha = 0.50$$

$$I_{\text{reflected}} = \beta I_0 = 0.50 I_0$$

$$L_{\text{reflected}} = 10\log\left(\frac{0.50\times6.31\times10^{-4}\ \text{W/m}^2}{1.0\times10^{-12}\ \text{W/m}^2}\right)$$

$$= \boxed{85.0\ \text{dB}}$$

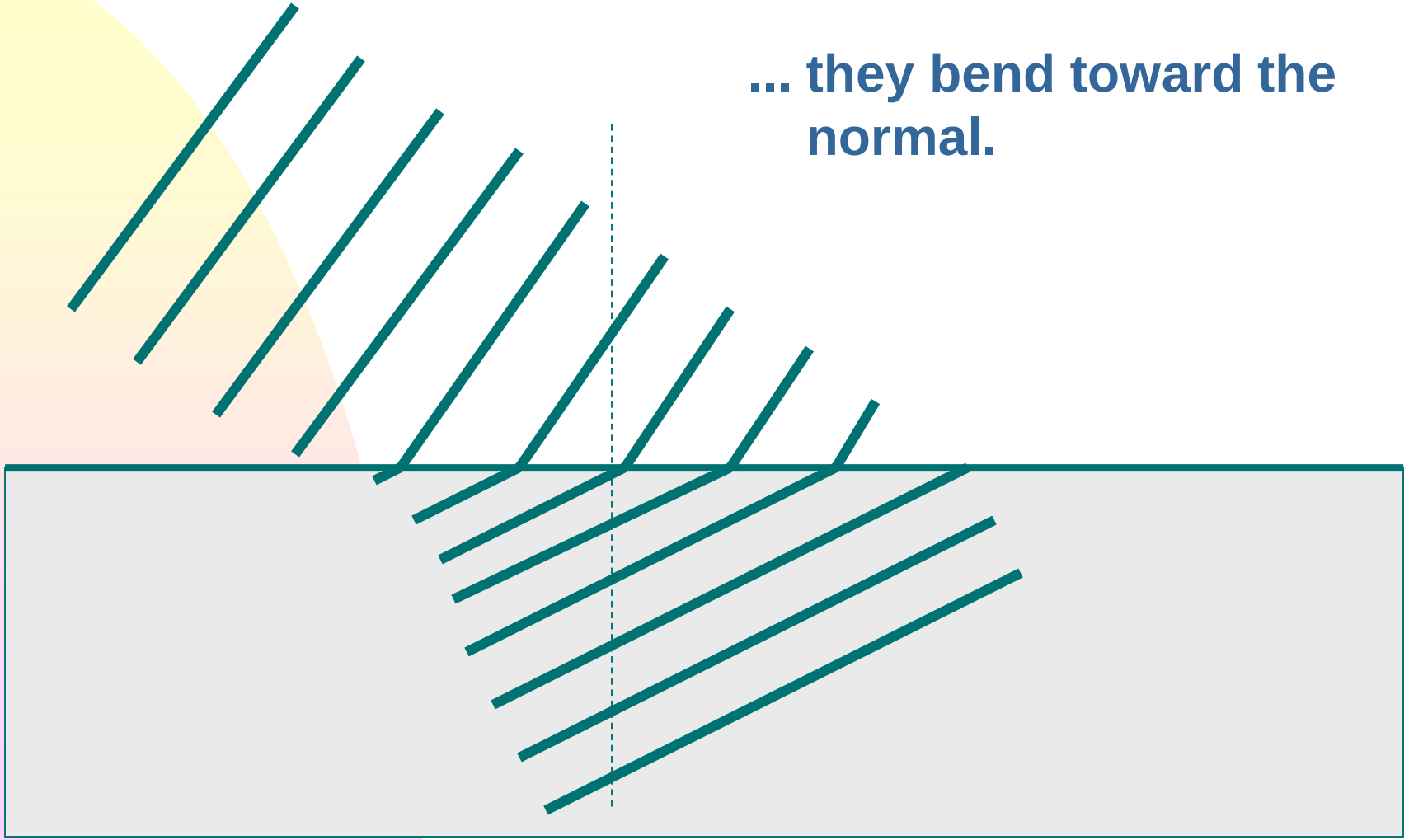
REFRACTION



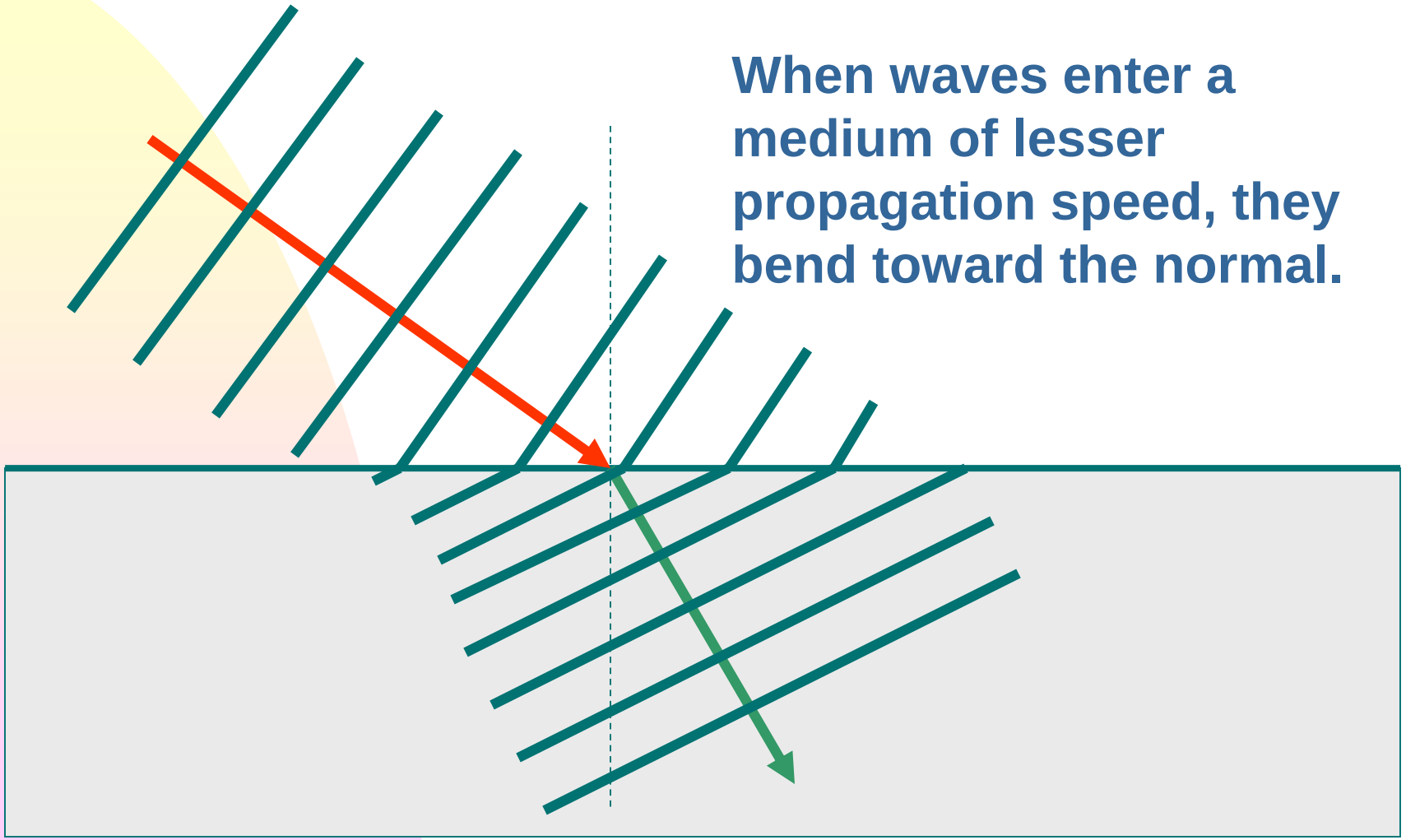
When waves enter a medium of lesser propagation speed ...

REFRACTION

... they bend toward the normal.



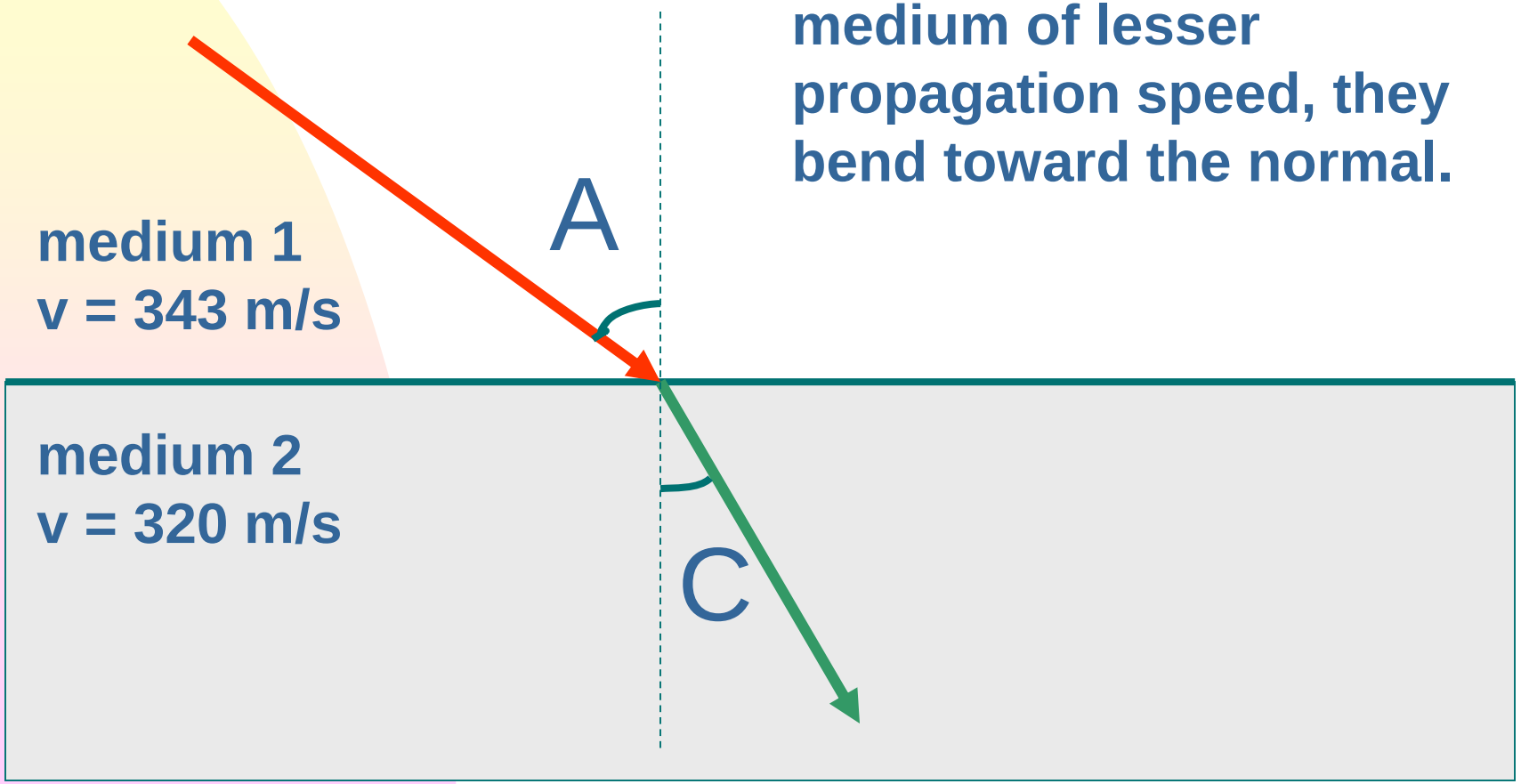
REFRACTION



When waves enter a medium of lesser propagation speed, they bend toward the normal.

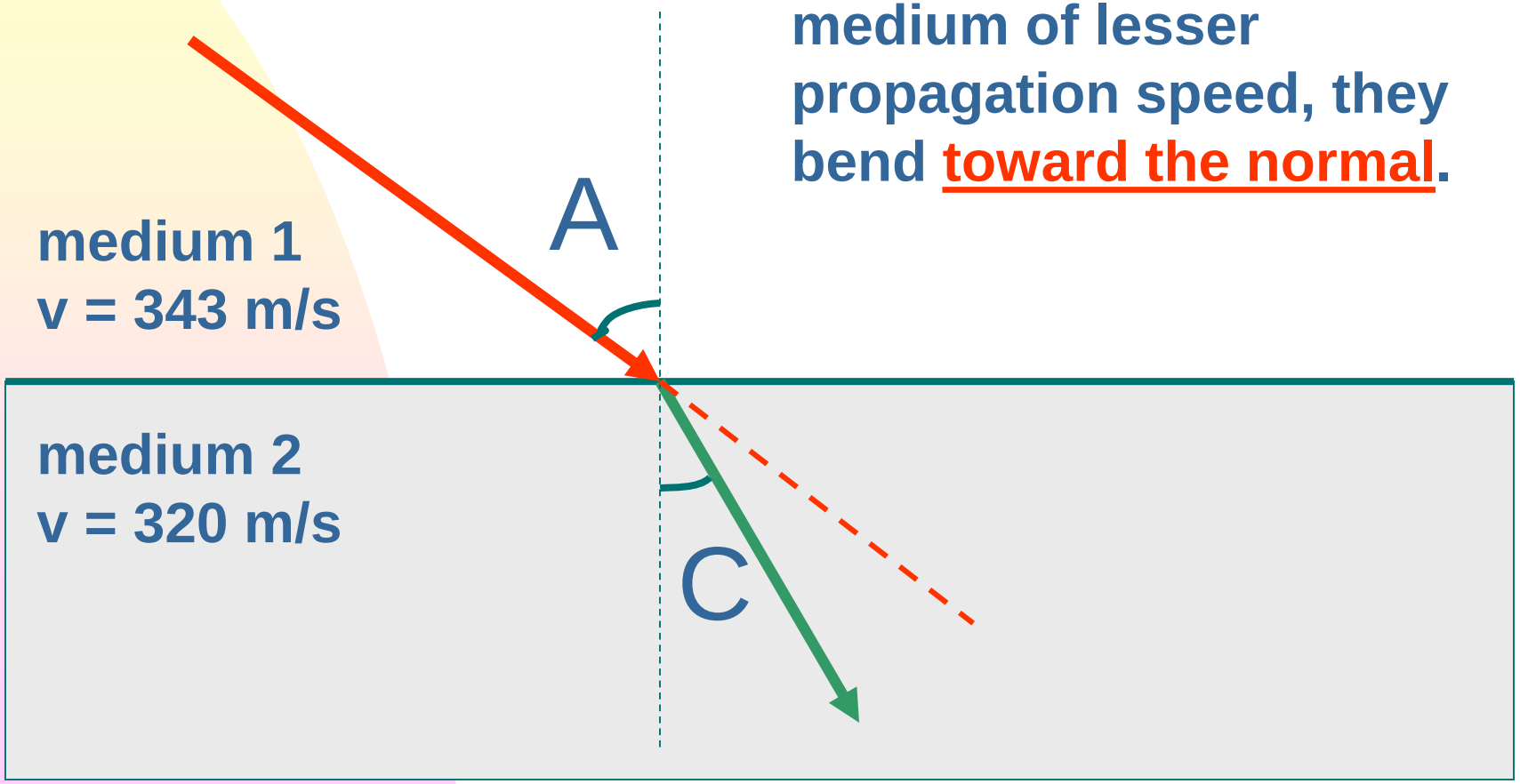
REFRACTION

When waves enter a medium of lesser propagation speed, they bend toward the normal.



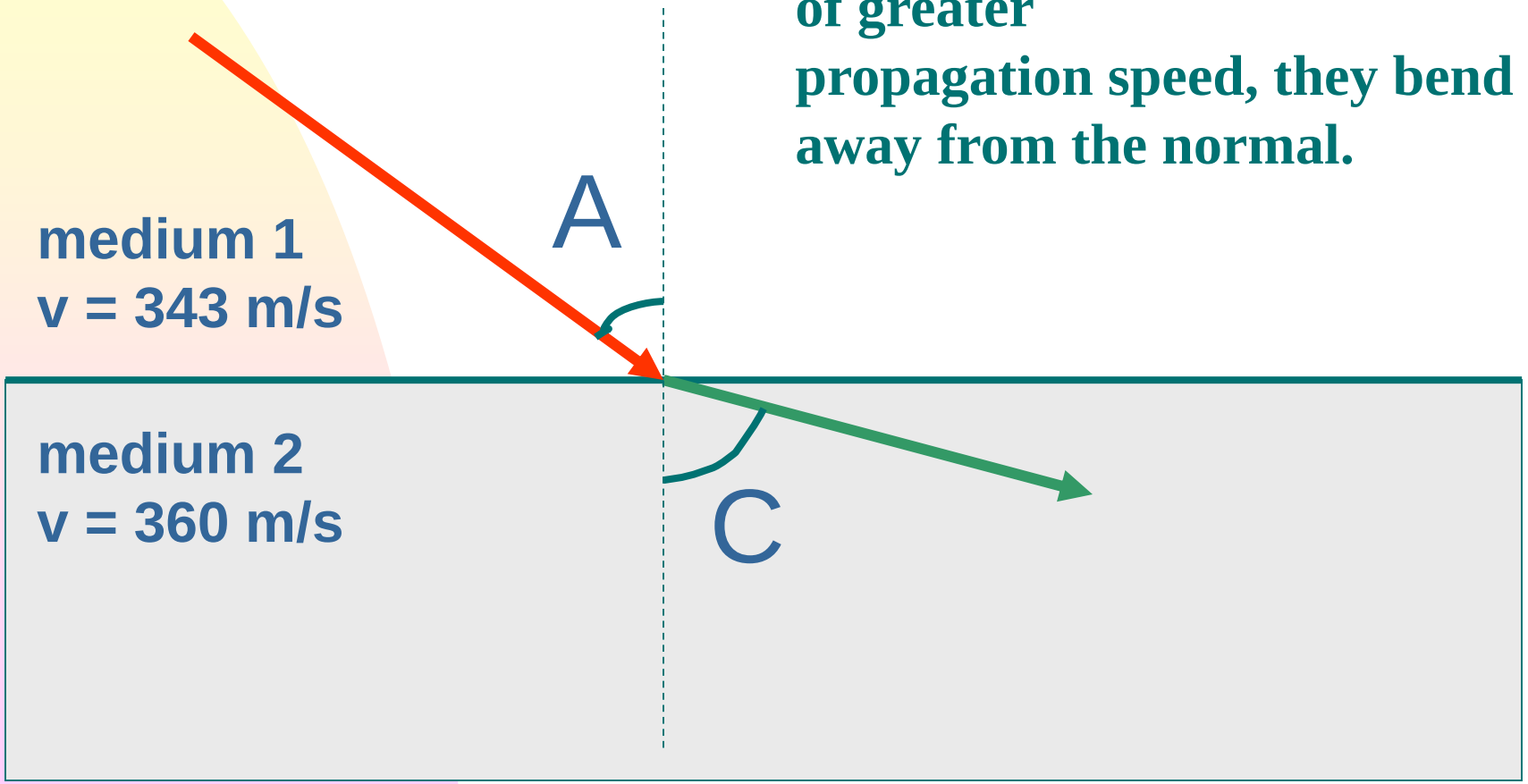
REFRACTION

When waves enter a medium of lesser propagation speed, they bend <u>toward the normal</u>.



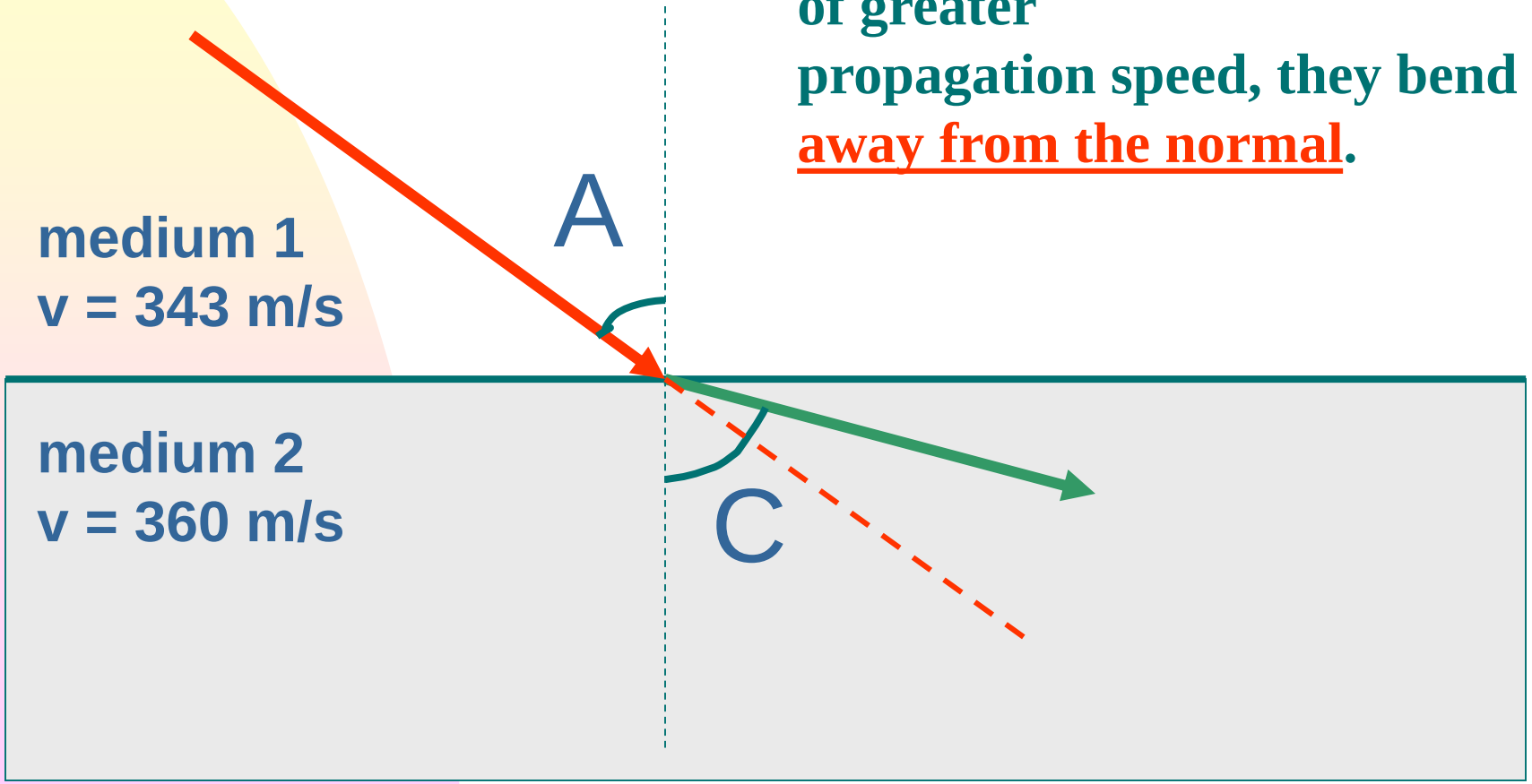
REFRACTION

When waves enter a medium of greater propagation speed, they bend away from the normal.



REFRACTION

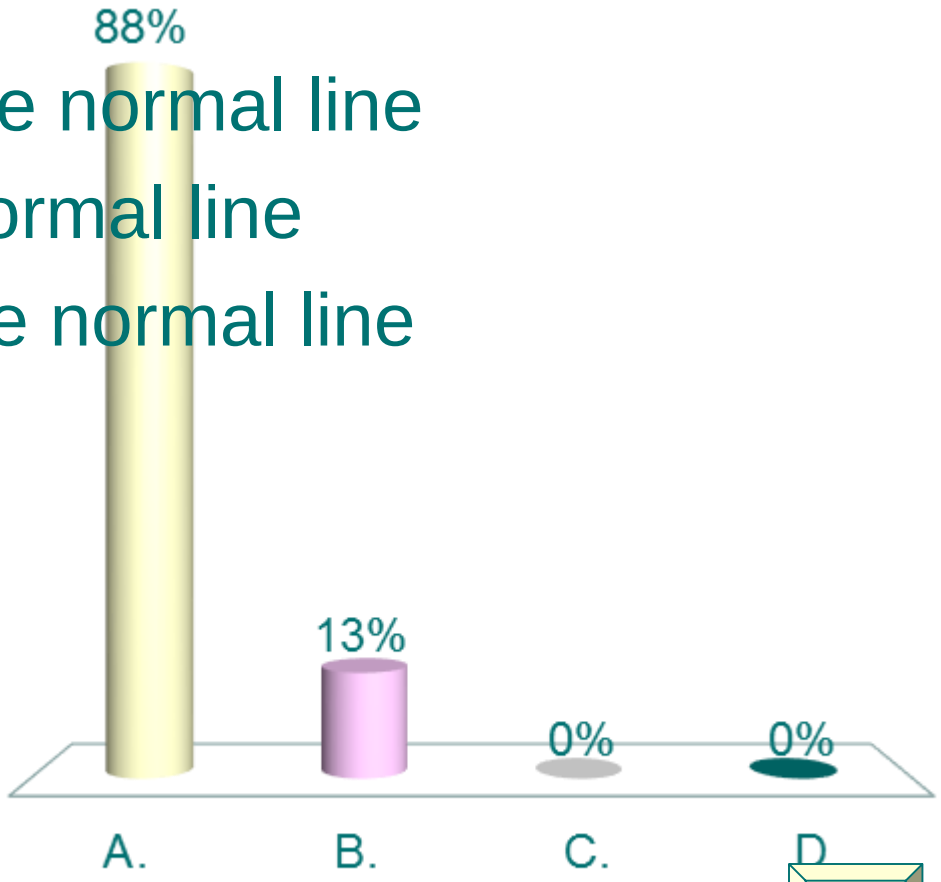
When waves enter a medium of greater propagation speed, they bend away from the normal.



Animated applet that illustrates refraction

Sound waves travel from wood into aluminum, a stiffer medium than wood. If the waves are incident at an angle, they will _____ after entering the aluminum.

A. bend away from the normal line
B. bend toward the normal line
C. bend and follow the normal line
D. not bend at all



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Sound waves travel from wood into aluminum, a stiffer medium than wood. If the waves are incident at an angle, they will _____ after entering the aluminum.

A. bend away from the normal line

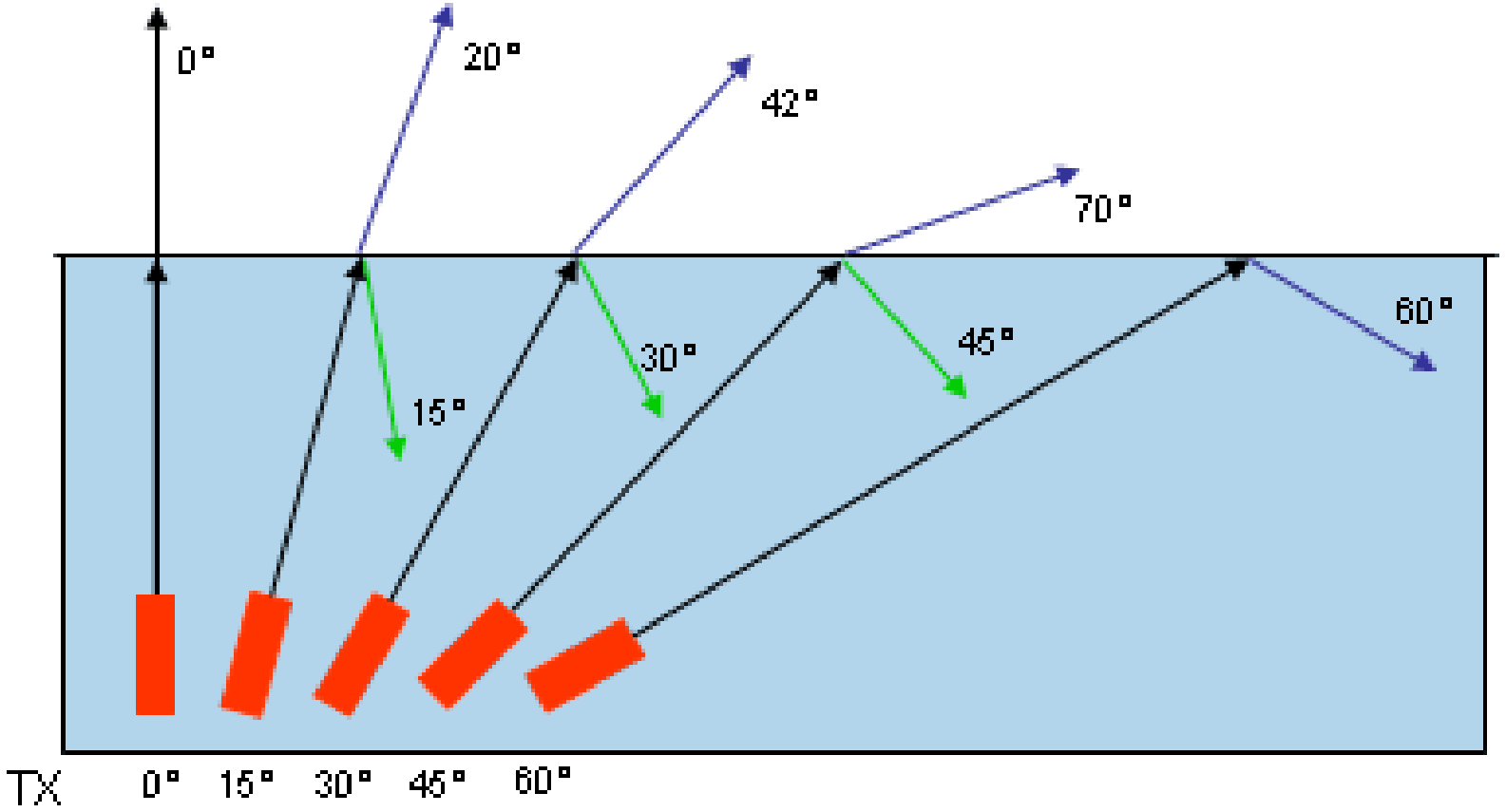
B. bend toward the normal line

C. bend and follow the normal line

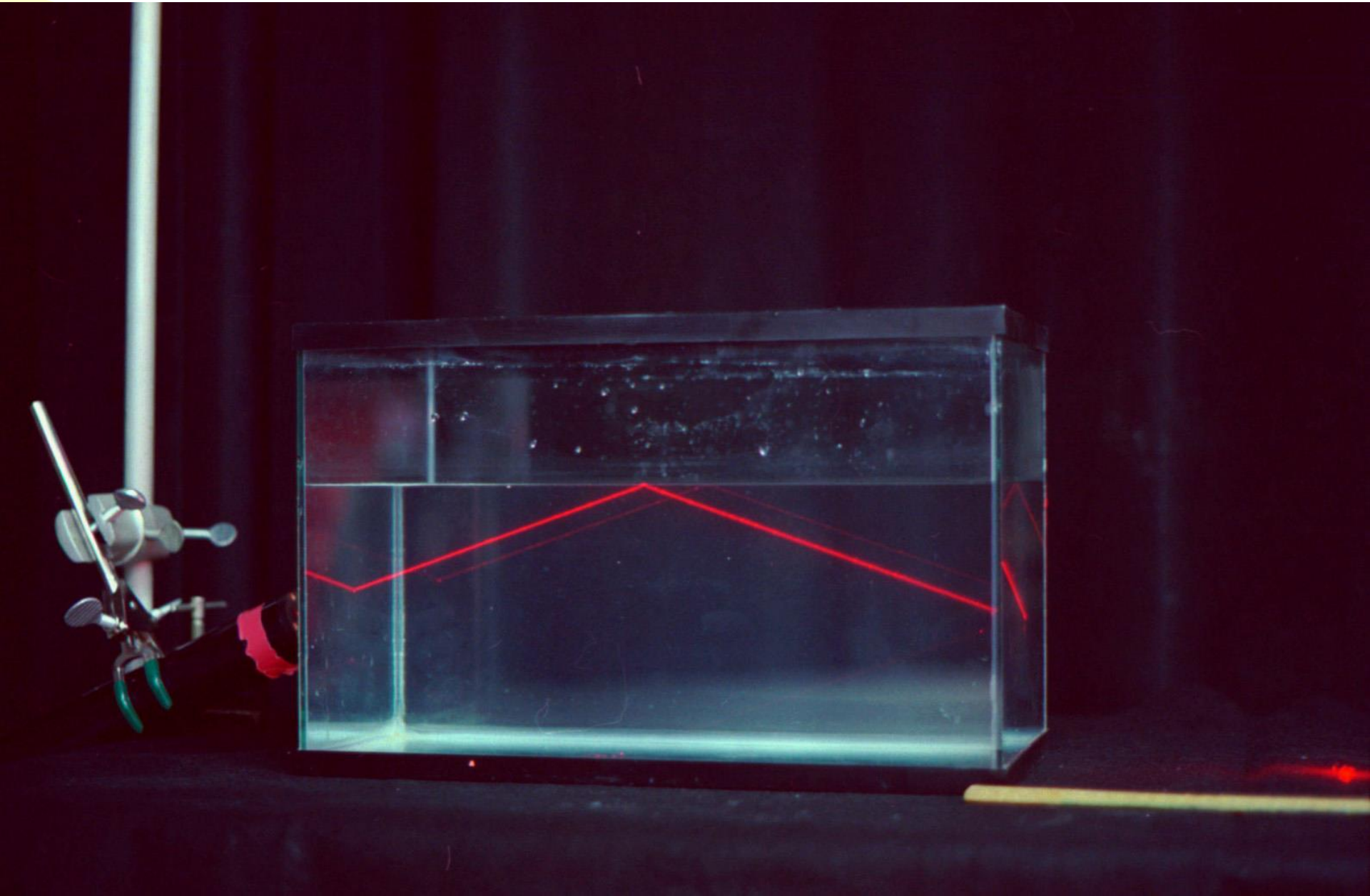
D. not bend at all

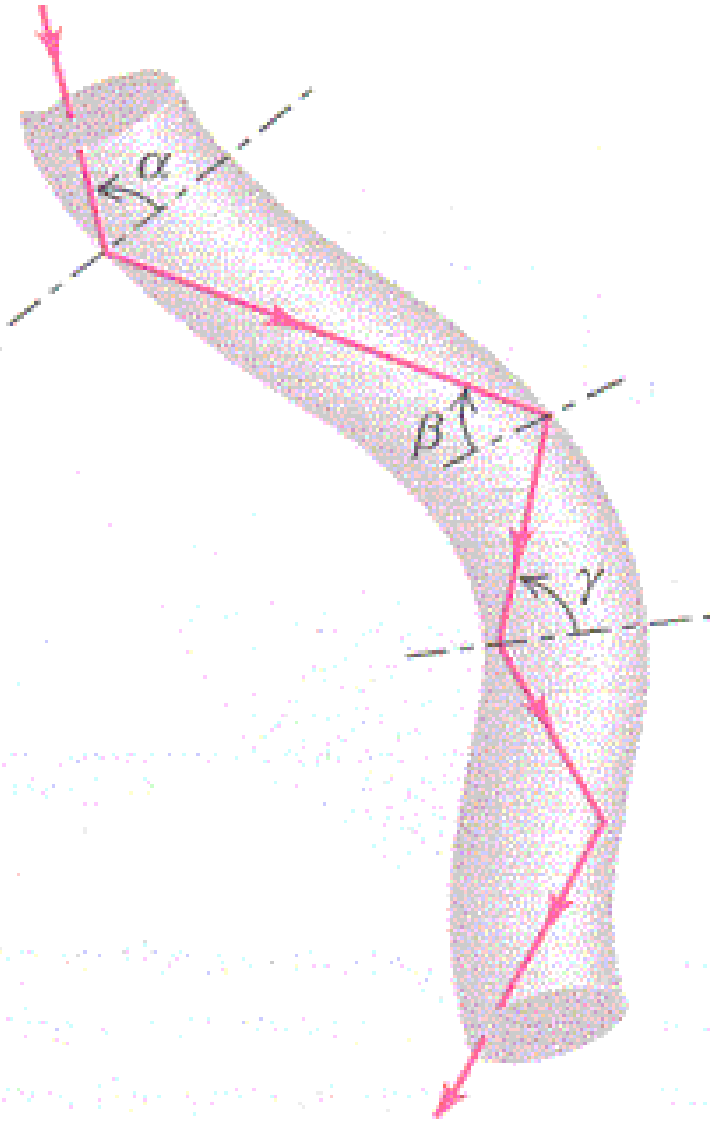
The wave speed will be faster in the aluminum, a stiffer medium than wood. Thus the wave travels from a slow medium to a fast medium, and it will bend away from the normal.

Total Internal Reflection



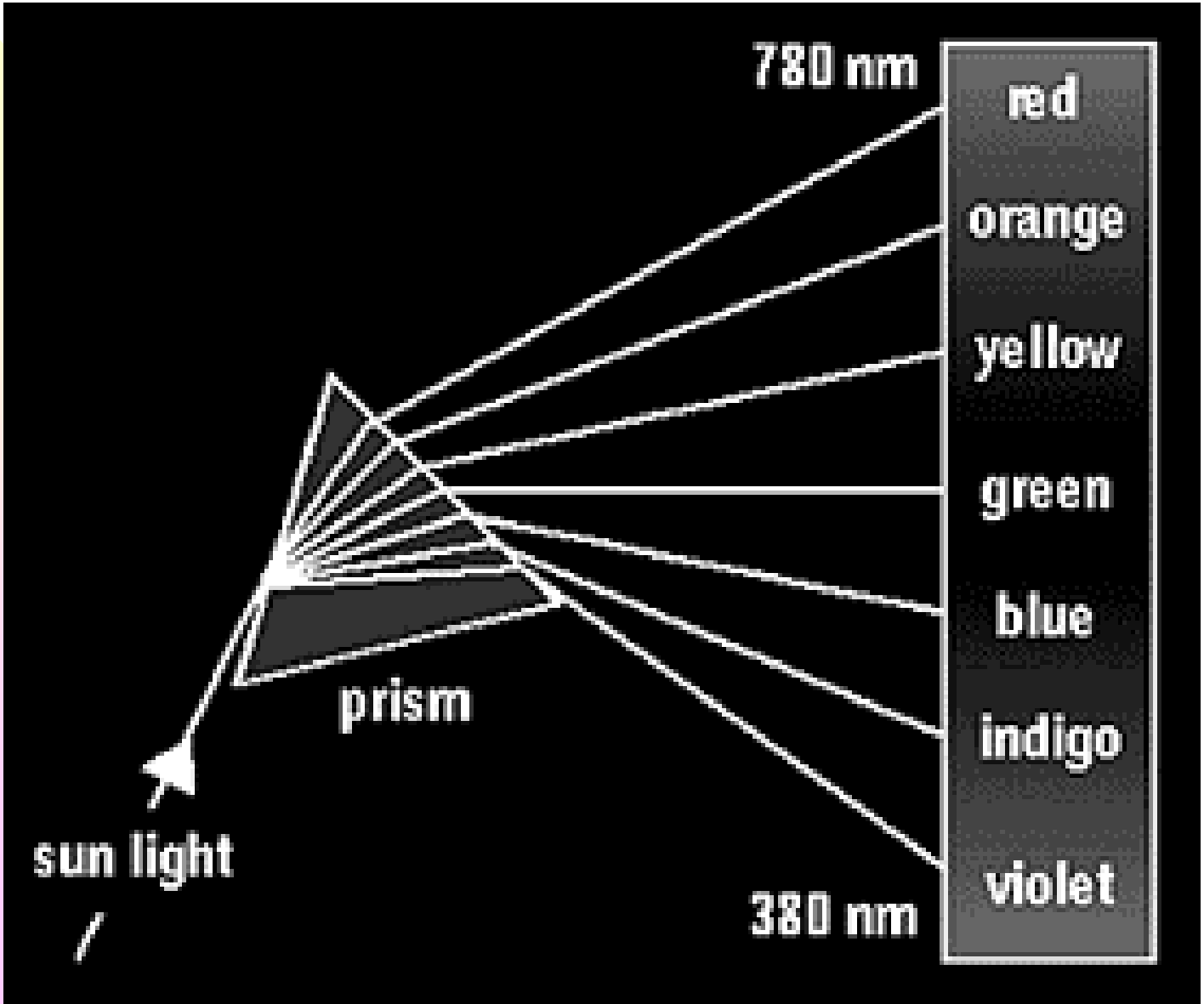
Total Internal Reflection



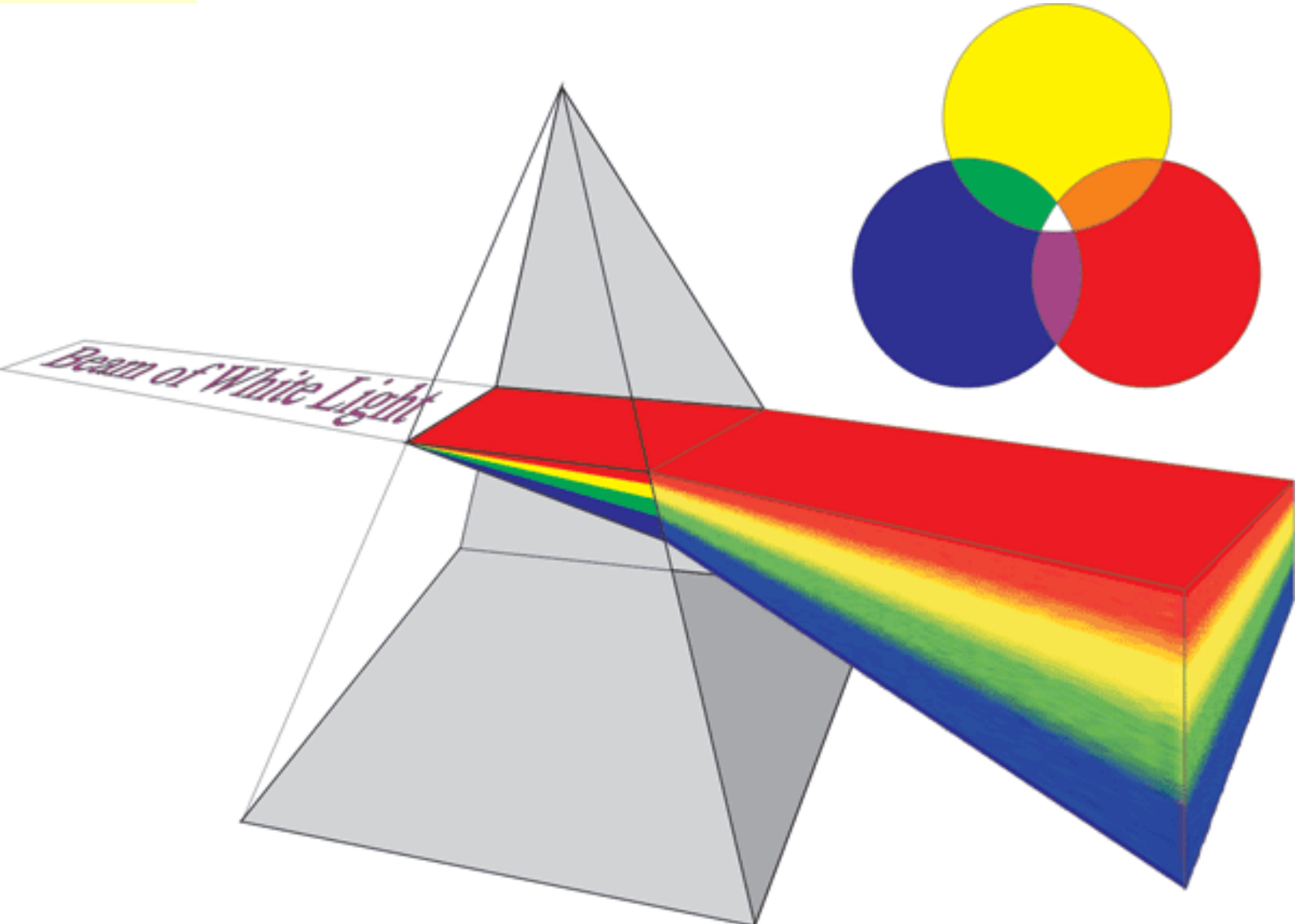


Total Internal Reflection: Fiber Optics

Refraction of light: Prism

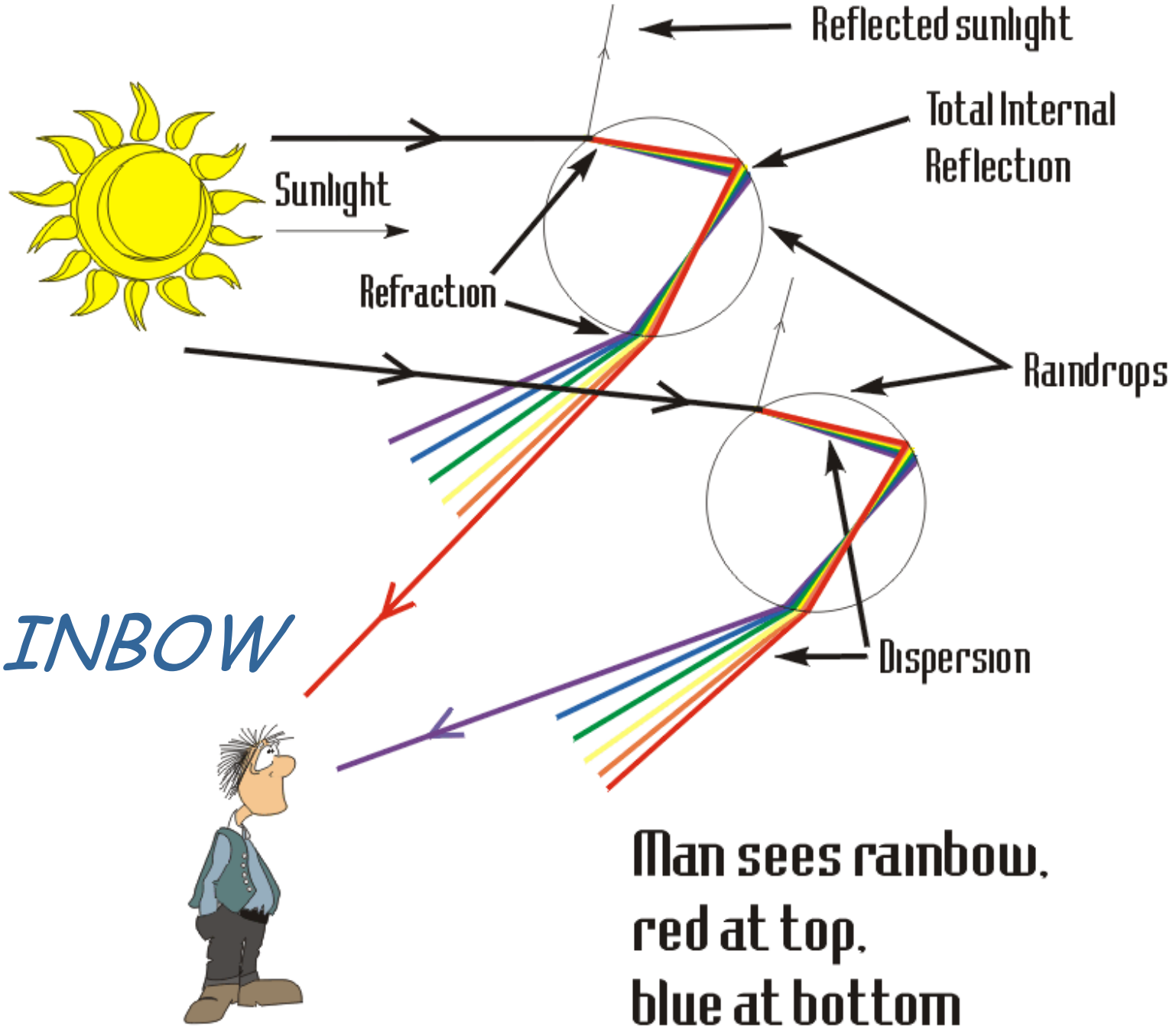


Refraction of light: Prism



Refraction of light: Rainbow

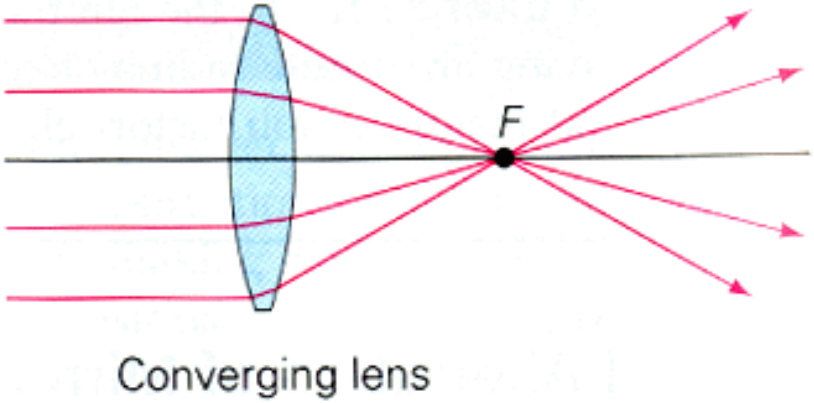
RAINBOW



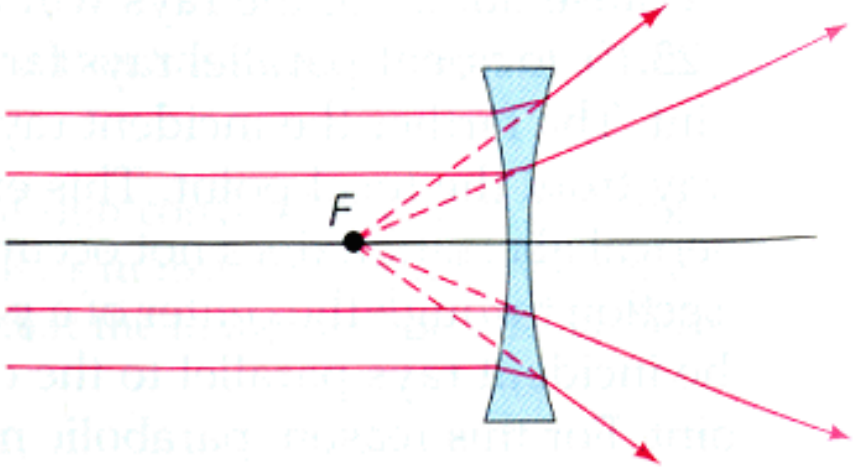
Man sees rainbow,
red at top,
blue at bottom

Refraction of light: Rainbow

Refraction of light: Halo



Converging lens



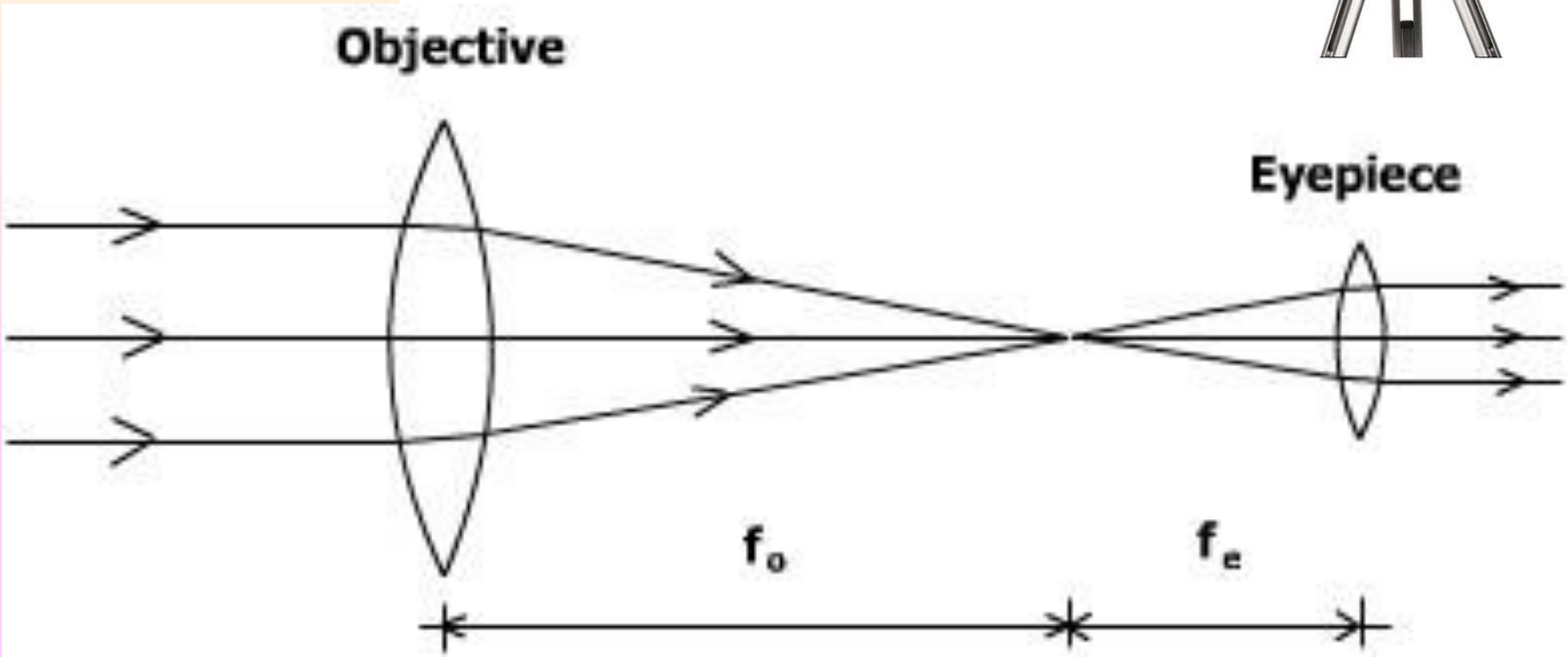
Diverging lens

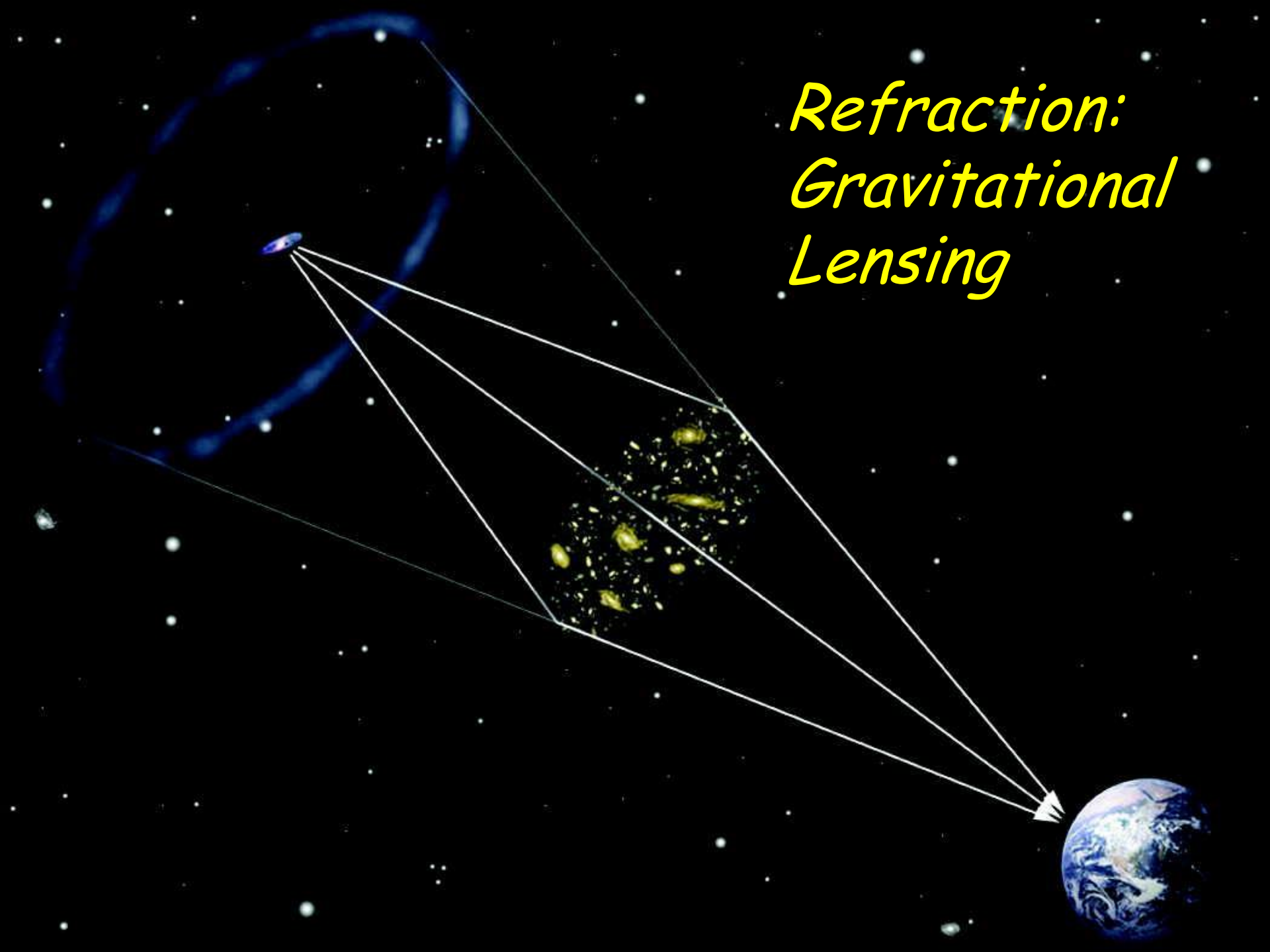
Refraction of light waves:

Converging lens and diverging lens

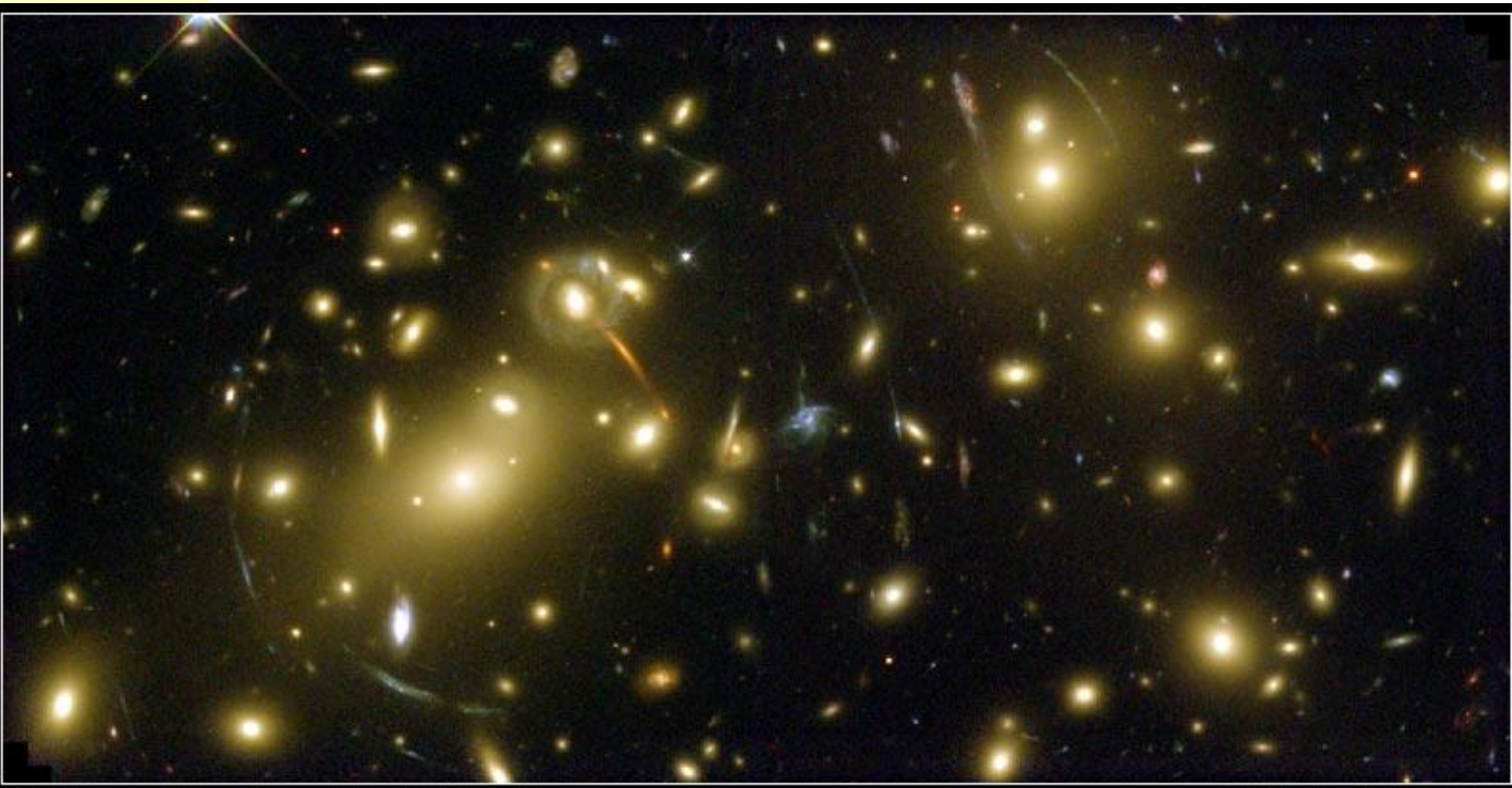
Refraction: Focusing light waves

The Refracting Telescope




Refraction:
Gravitational
Lensing

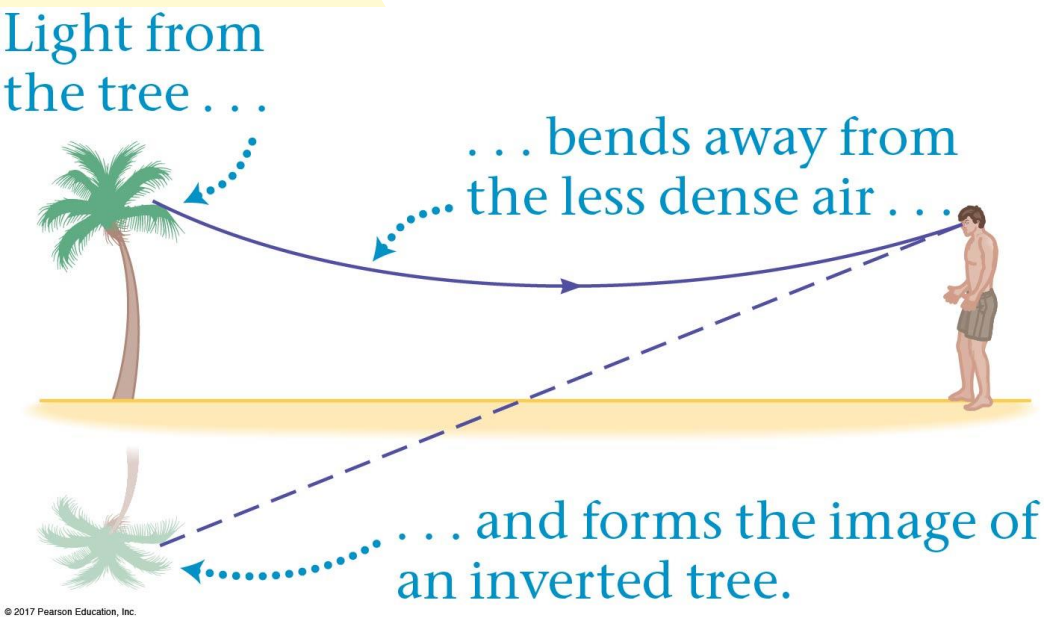
Refraction: Gravitational Lensing



Galaxy Cluster Abell 2218 **HST • WFPC2**

NASA, A. Fruchter and the ERO Team (STScI) • STScI-PRC00-08

The Common mirage

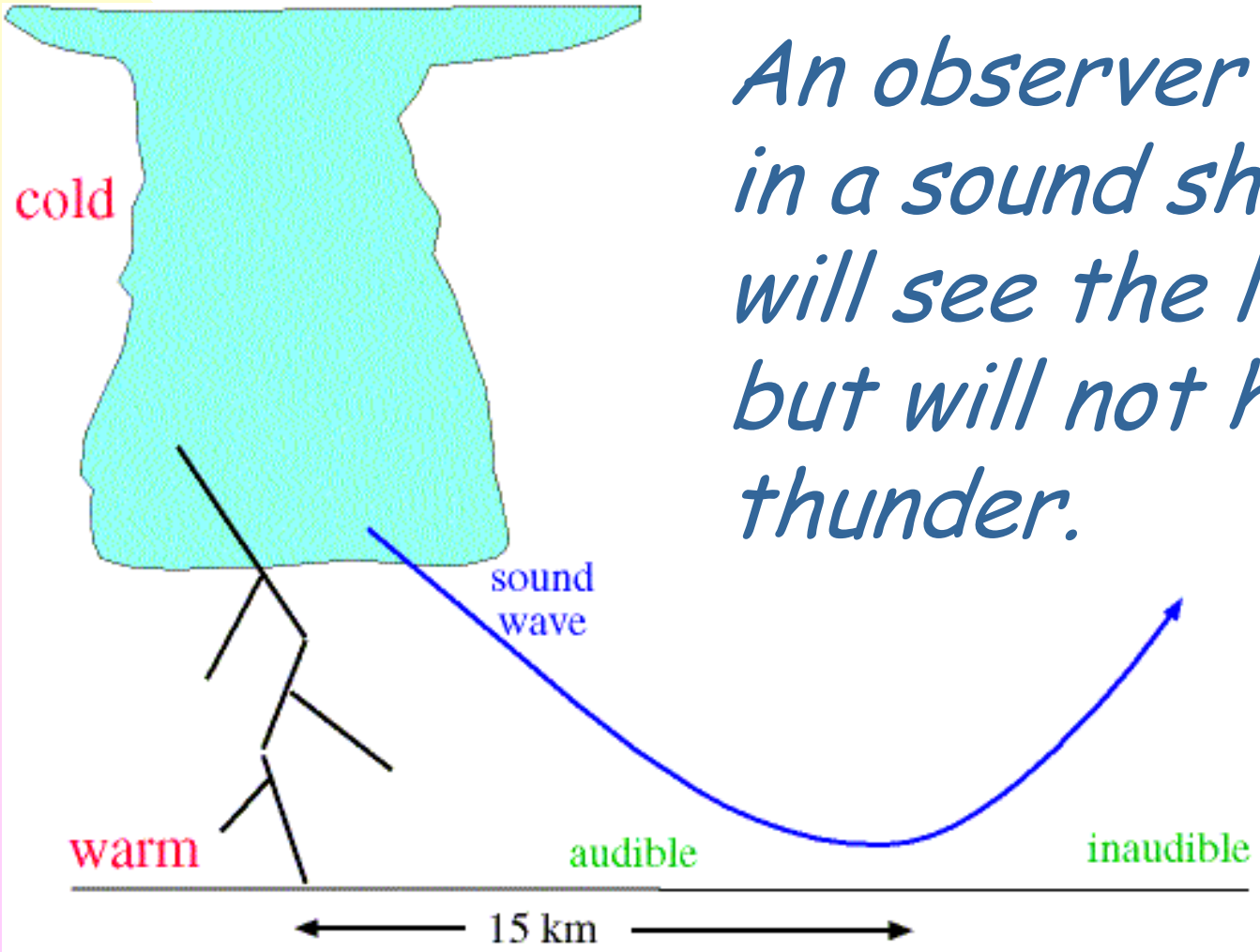


Images from J. S. Walker, *Physics*, 5th ed., Ch. 26 (Pearson Education, Inc., 2017).

Refraction of Sound Waves

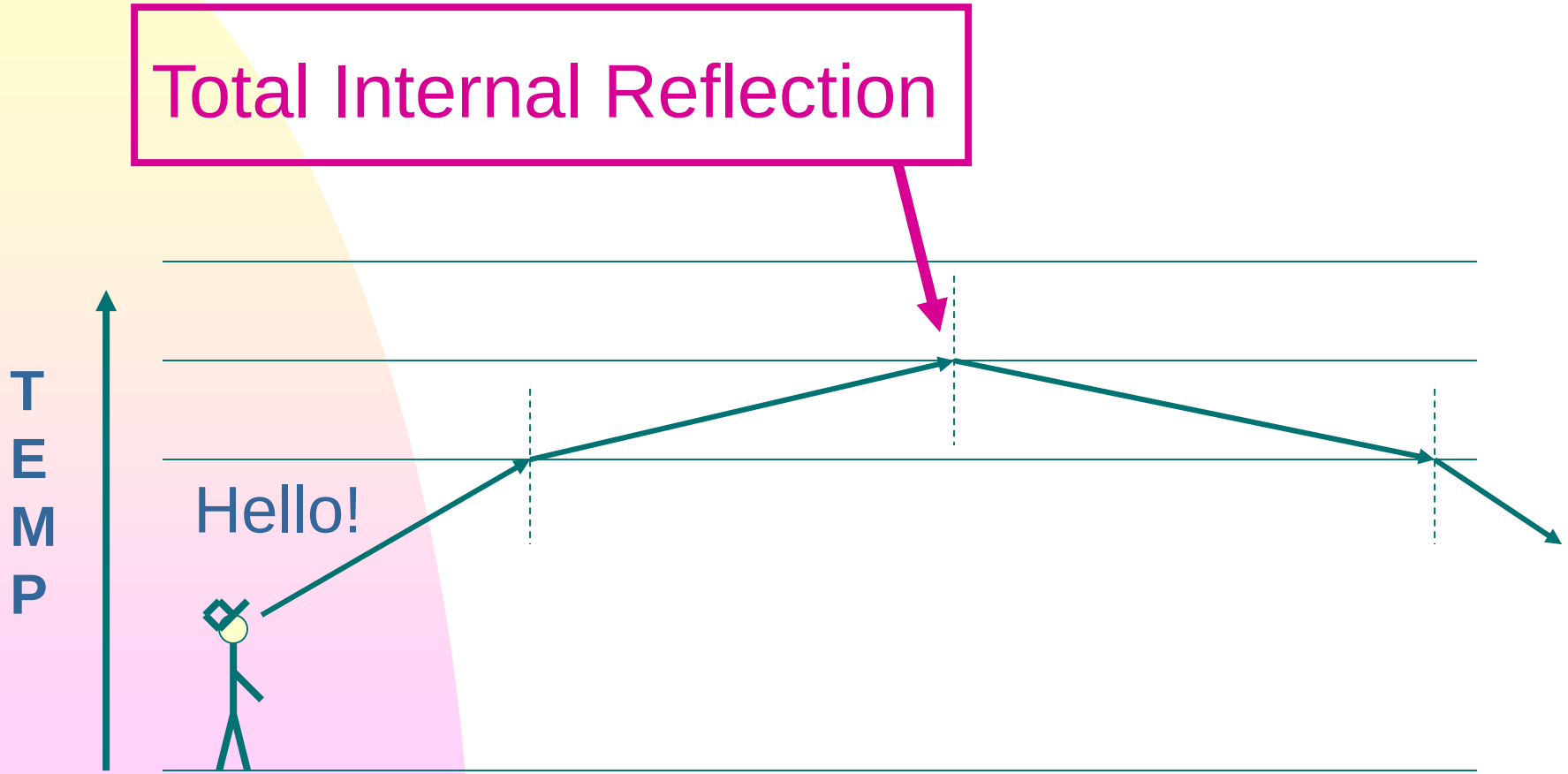
- Video: CO_2 sound lens
- Acoustic shadowing
  - Lightning without thunder
  - Lurking submarines
- Seismic waves

Refraction of sound waves: Lightning without Thunder



An observer located in a sound shadow will see the lightning but will not hear the thunder.

Sound Travels Farther ...



Refraction of sound waves

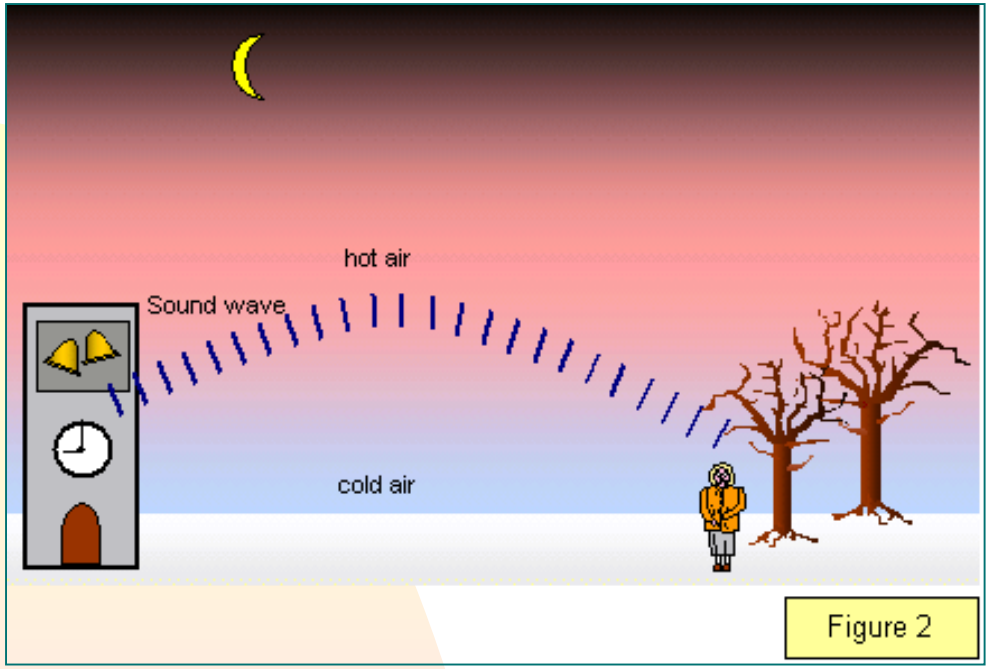


Figure 2

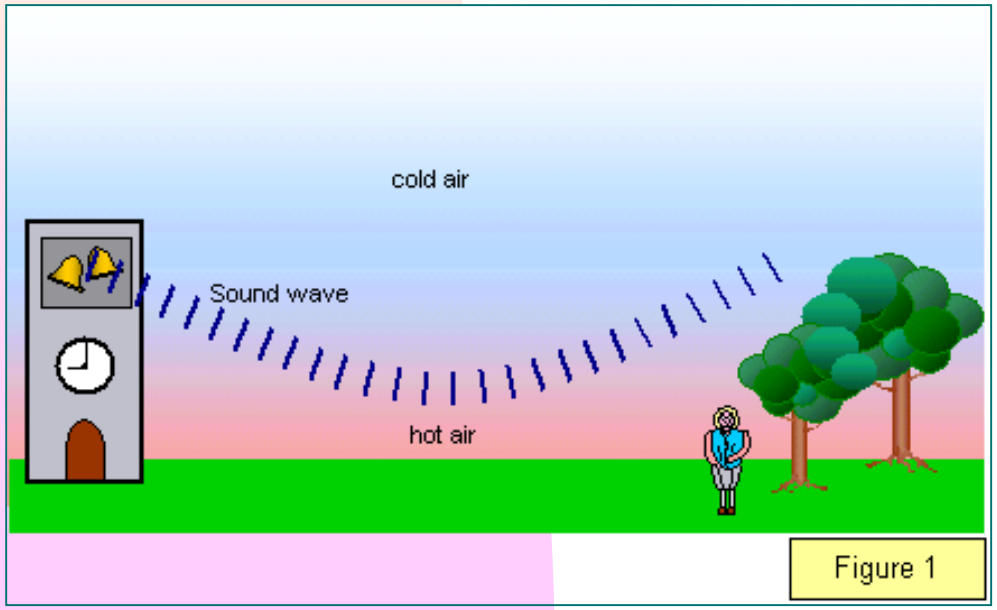
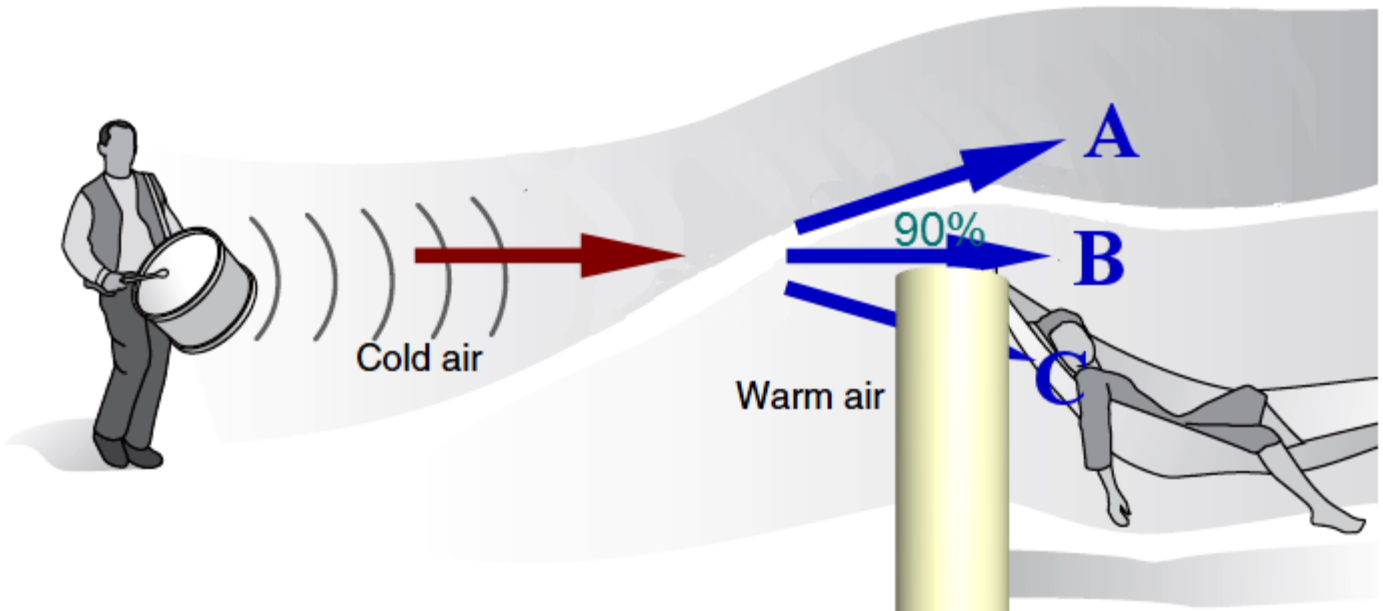


Figure 1

Which way will the sound waves bend?

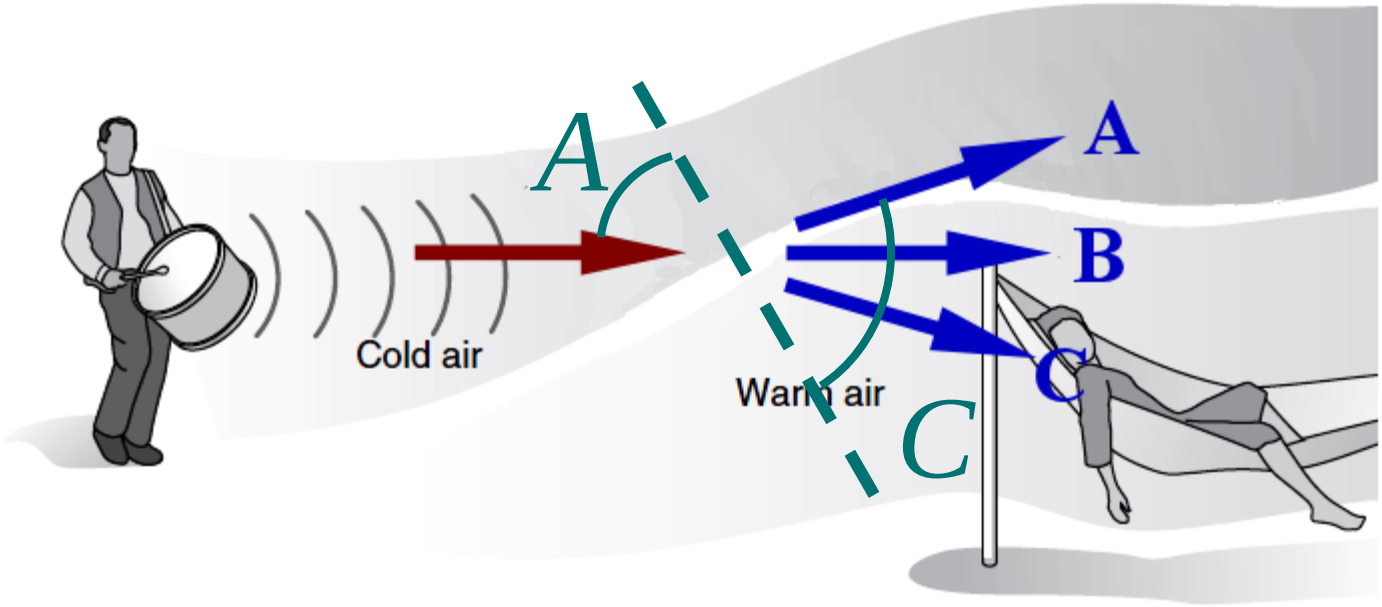


A. A

B. B

C. C

Which way will the sound waves bend?



A. A

B. B

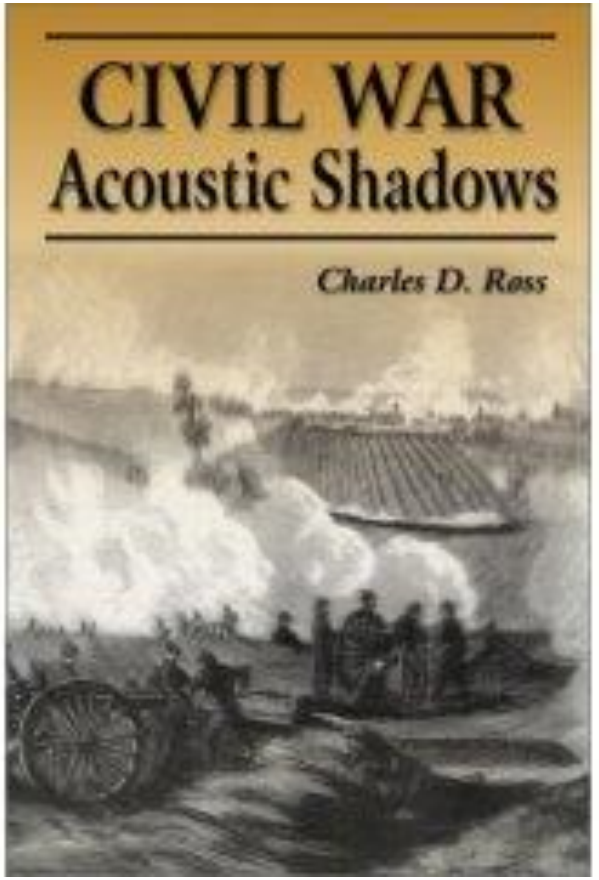
C. C

The warm air has a higher wave speed so the waves will bend away from the normal

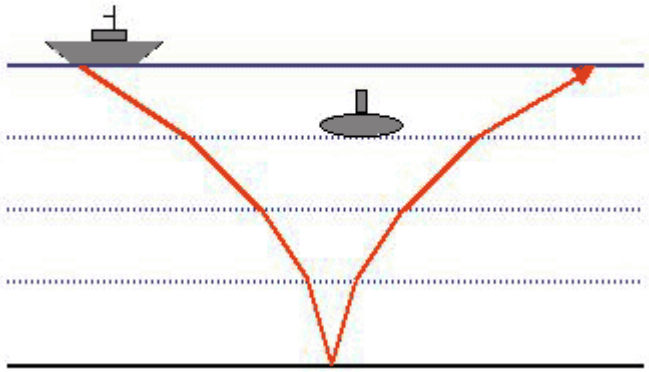
Refraction of Sound Waves

Acoustic shadows

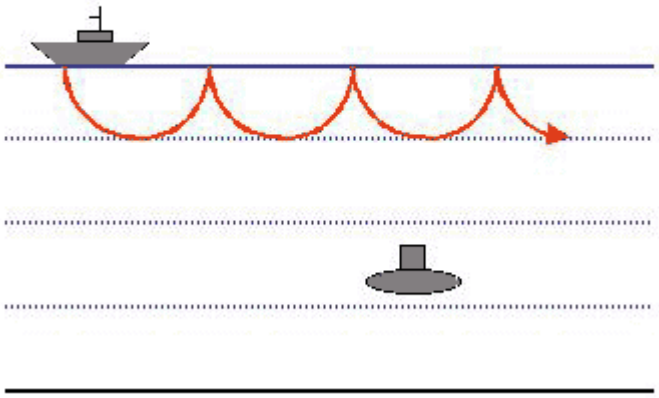
- In *CIVIL WAR ACOUSTIC SHADOWS*, Charles D. Ross argues that refraction of sound waves influenced the outcome of several battles. Military commanders were sometimes unable to hear gunfire and artillery fire occurring nearby.



Picture 1: Negative refraction



Picture 2: Positive refraction



Refraction of sound waves:

Acoustic shadows provide sites for lurking submarines

Seismic waves

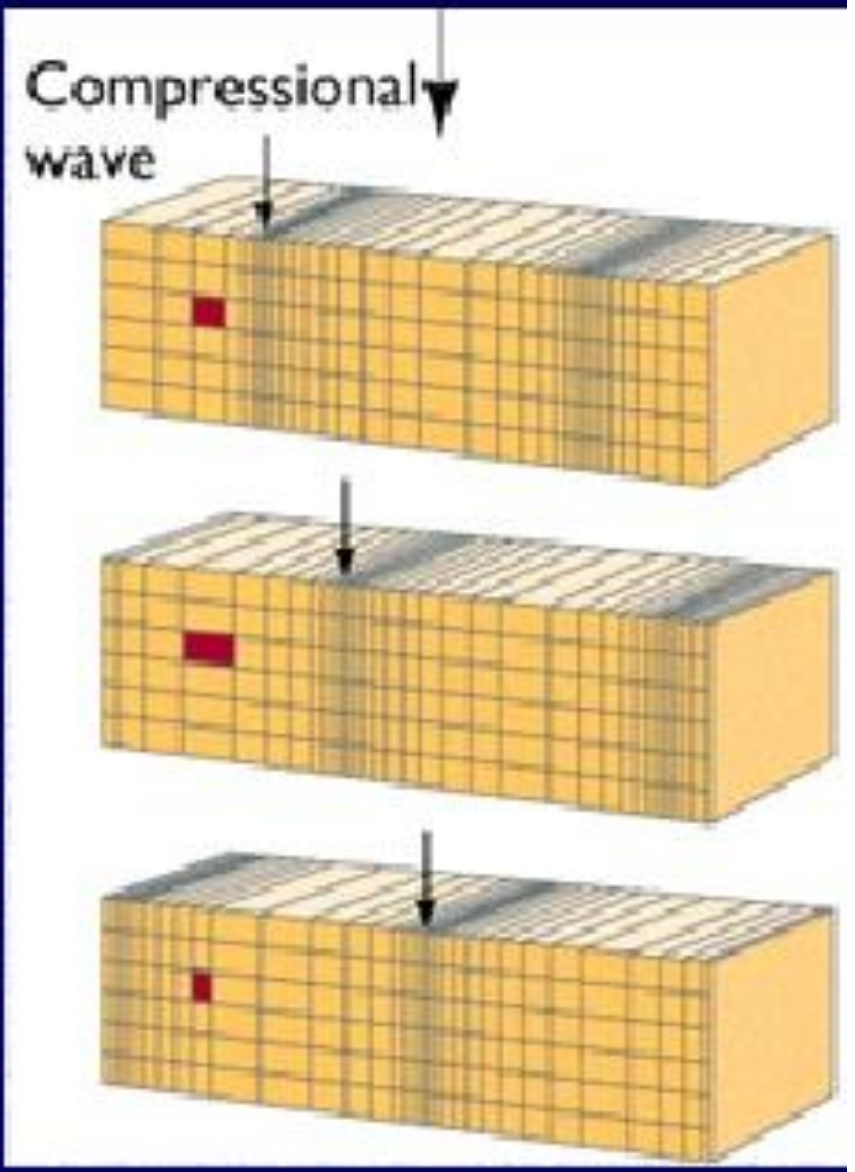
Body waves: travel ***through*** **the earth**

P waves:

Primary wave

compressional wave

P waves travel by compression and dilation of the rock volume; they move the fastest of the three wave types and in an earthquake are felt first (if at all).



Body waves:

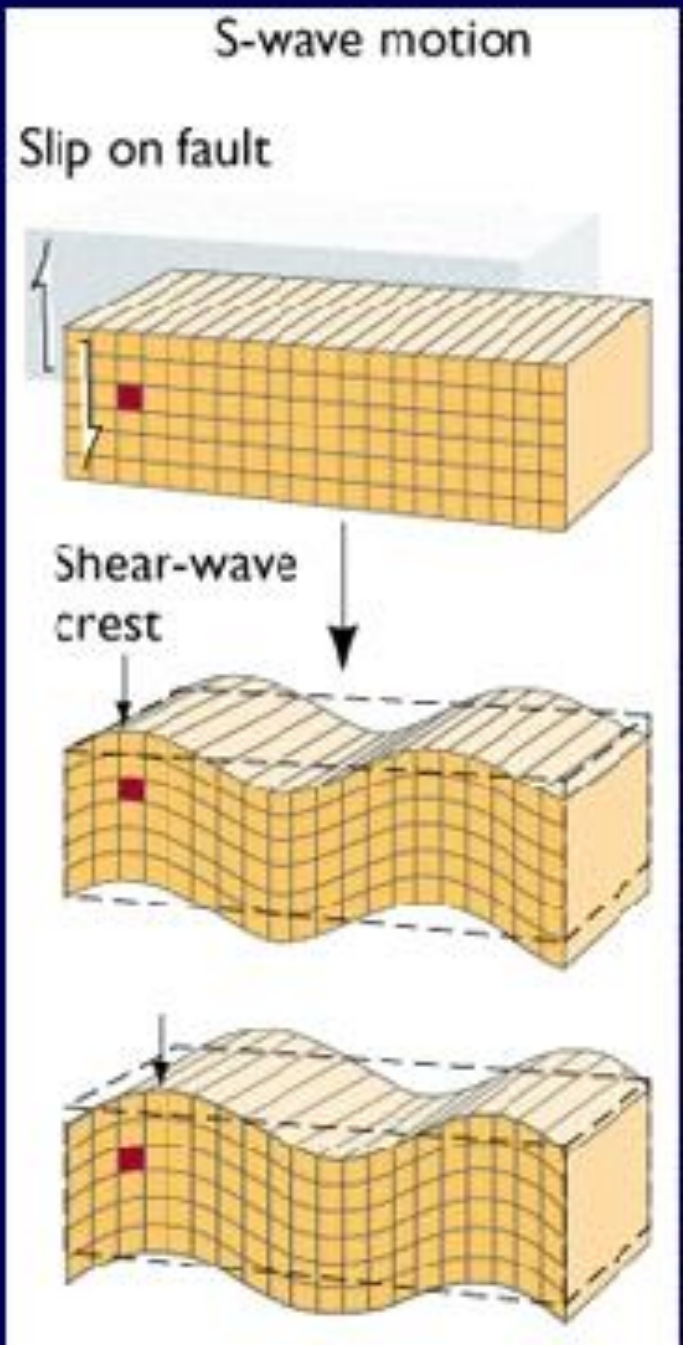
S waves:

Secondary wave

shear wave

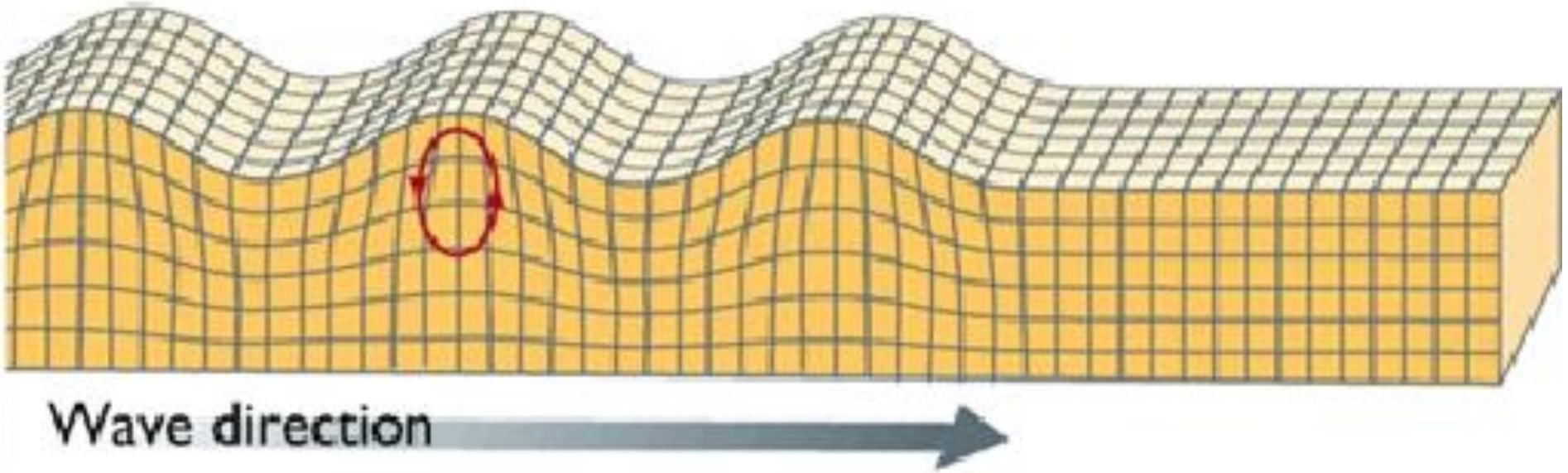
S waves result in shearing of the rock volume; they travel more slowly than P waves, but faster than surface waves.

S-waves do not travel through liquids.

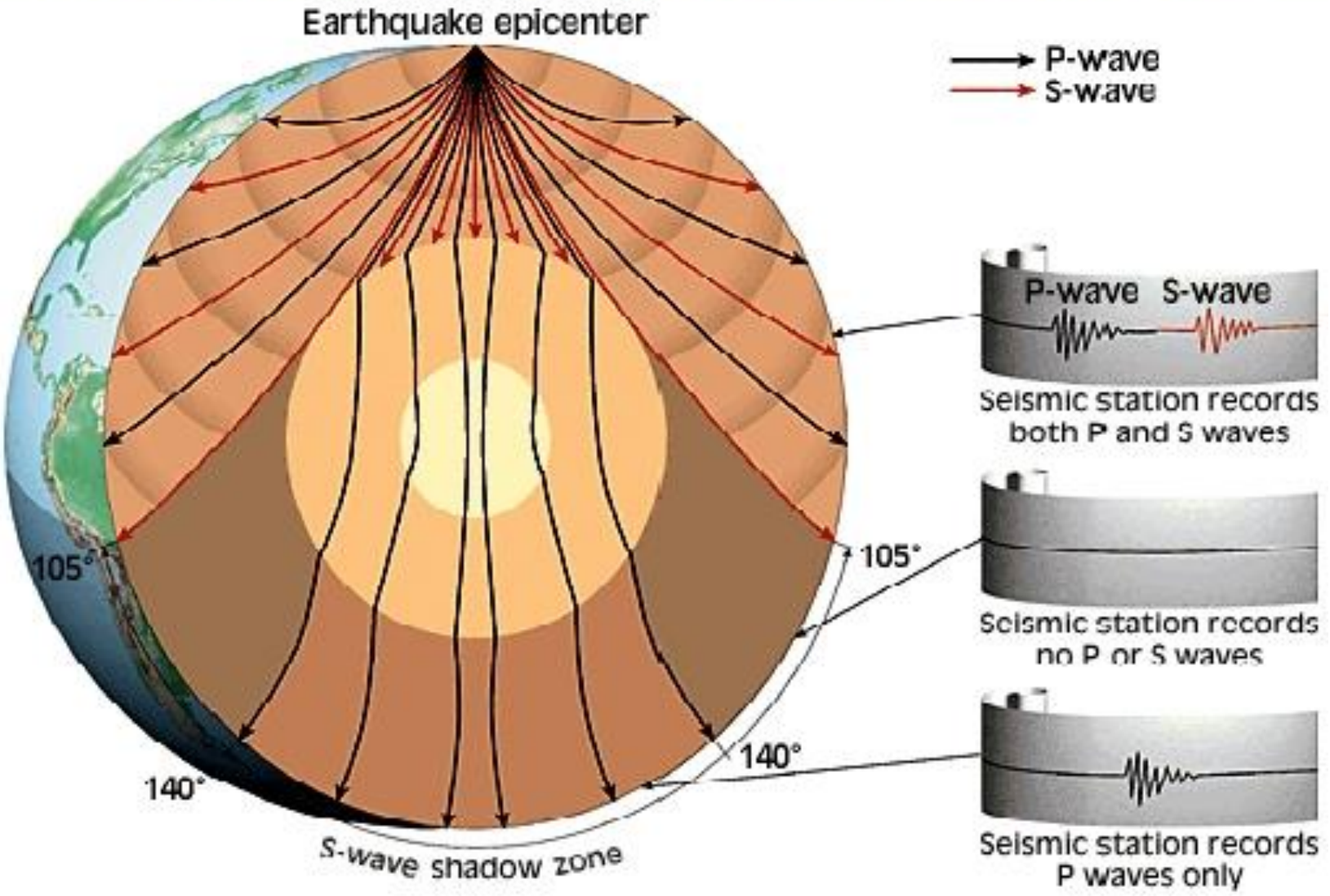


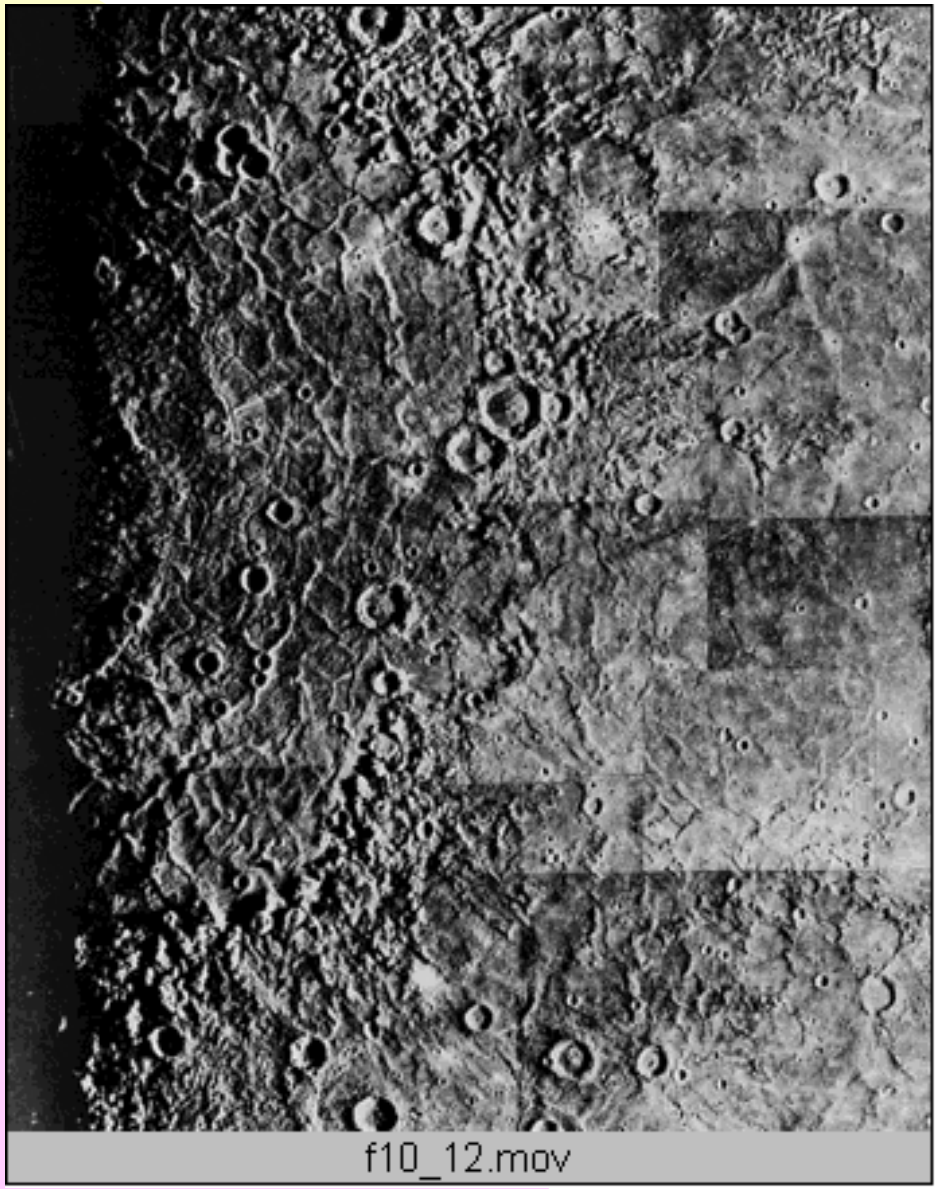
Surface waves

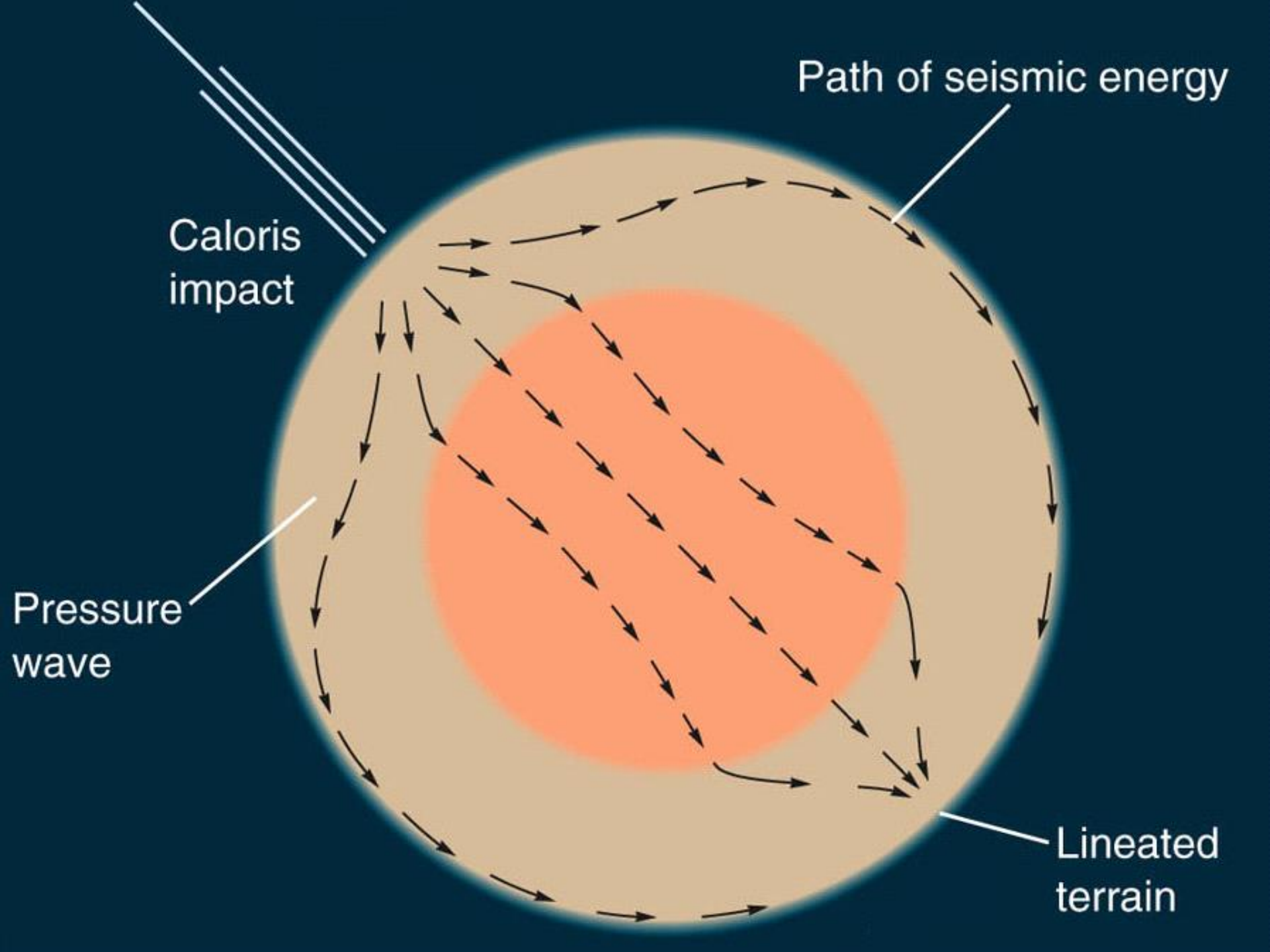
Surface waves are limited to the surface of the Earth; they cause vertical motion of the surface and most of the structural damage due to earthquakes; they travel the slowest of the three waves reviewed here.



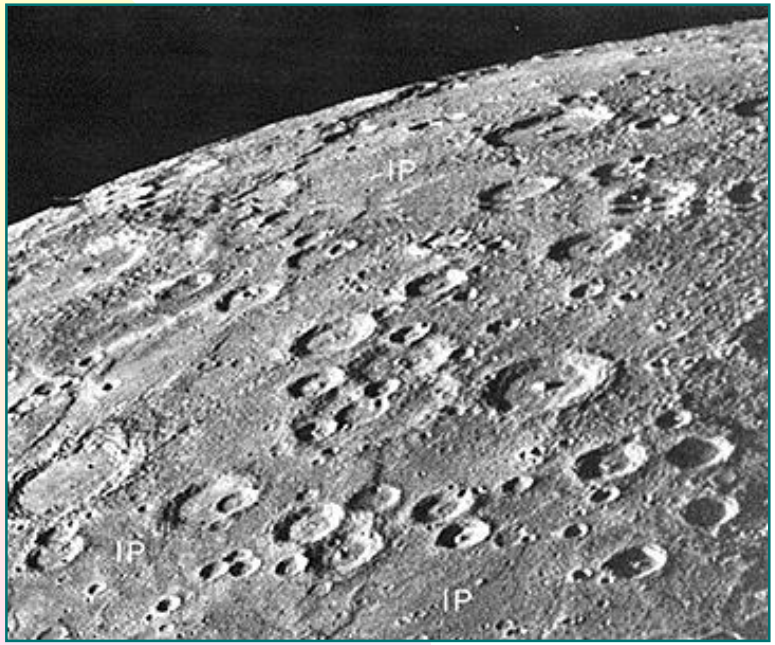
Mapping the Earth's Interior with Body Waves



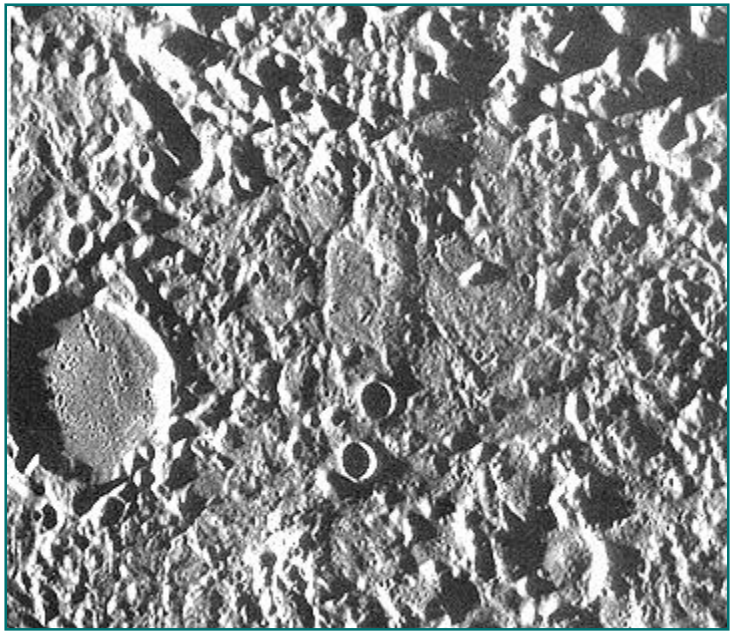

f10_12.mov


Path of seismic energy
Caloris impact
Pressure wave
Lineated terrain

MERCURY



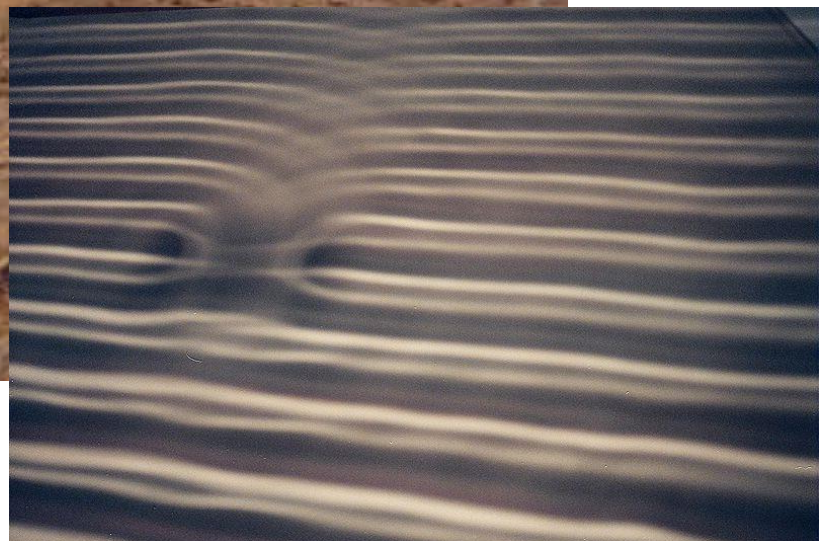
TYPICAL TERRAIN



LINEATED TERRAIN (Antipodal to Caloris Basin)

Diffraction

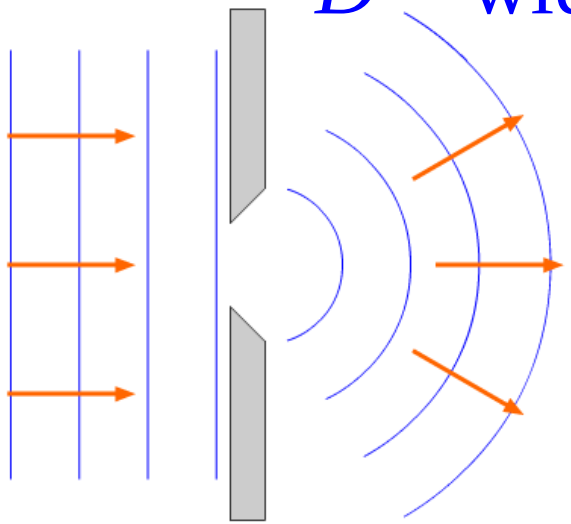
- A wave bends when it travels through an opening or around an obstacle



Diffraction

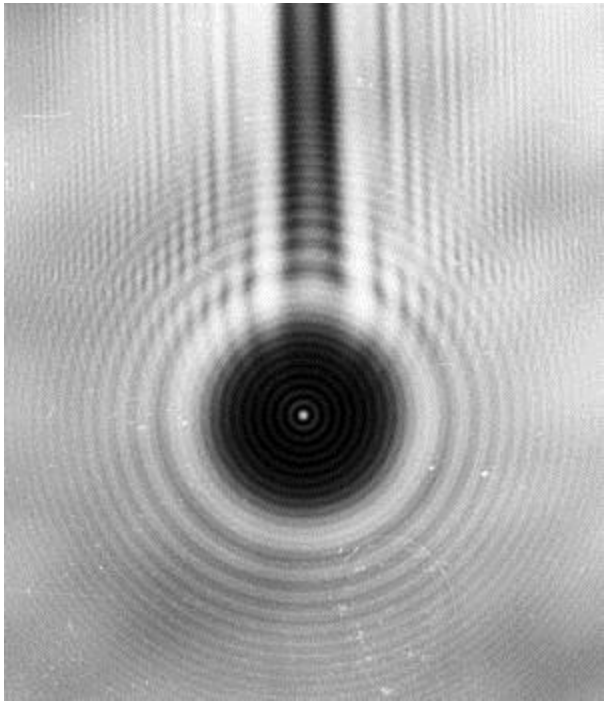
- Diffraction through an opening produces a pattern with a central maximum whose width is inversely proportional to the size of the opening
- Interactive applet: wave animation
- Interactive applet: diffraction of light

$$\theta_{\text{central maximum}} \propto \frac{\lambda}{D} = \frac{\text{wavelength}}{\text{width of opening}}$$



Diffraction

- Diffraction around an obstacle can produce a bright spot in the middle of the “shadow”
- Interactive applet: ripple tank (choose Setup: Obstacle)
- Video of sound wave diffraction

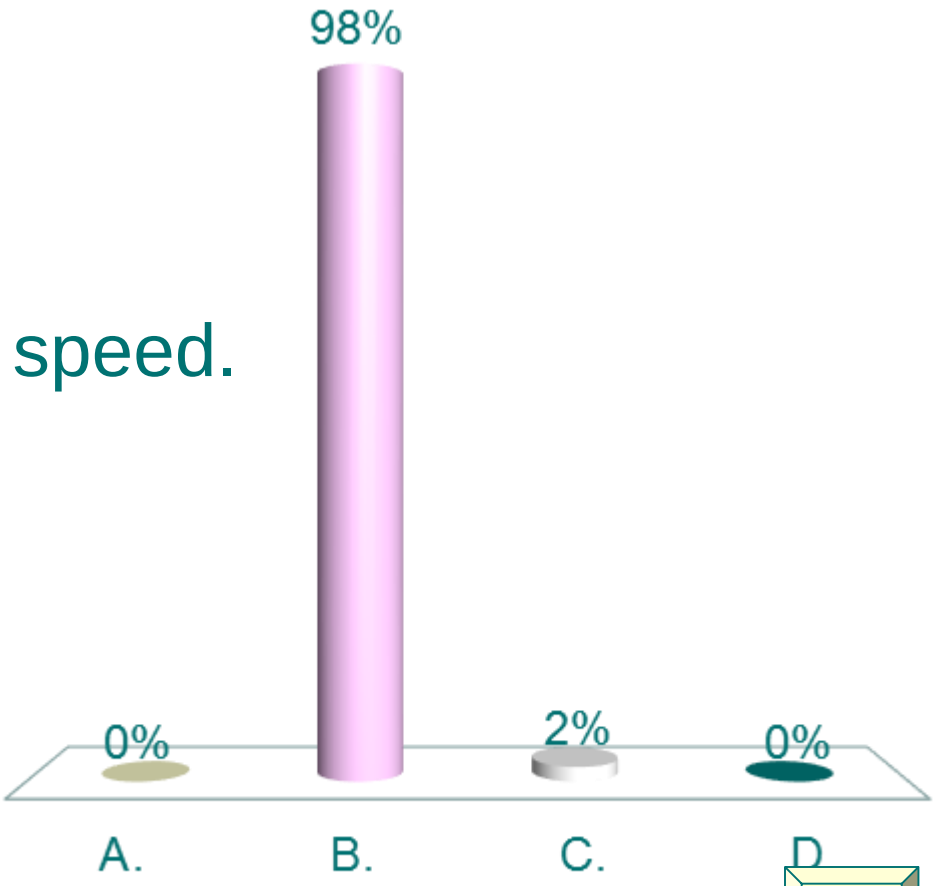


Diffraction of light waves around a ball bearing suspended on a needle. Photo by C. C. Jones, Union College.

Interesting tidbit: Fresnel predicted this bright spot and, believing it ridiculous that a bright spot would appear in the middle of a shadow, used it as proof that light is NOT a wave. Arago quickly verified in the laboratory that the bright spot does indeed appear, and that light is, in fact, a wave.

As the opening is made wider, the width of the central maximum of the resulting diffraction pattern

A. increases.
B. decreases.
C. stays the same.
D. depends on the wave speed.



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$$\theta_{\text{central maximum}} \propto \frac{\lambda}{D} = \frac{\text{wavelength}}{\text{width of opening}}$$