Arvind Borde / PHY 12, Week 9: Light as a Wave

(1) Why bother with waves? Aren't rays/particles good enough?

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1) ______________________________________,

and

2) ______________________________________

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1

Particles/Rays v. Waves: The Smackdown

	Particle →	Wave ⟿
Reflection		
Refraction		
Diffraction		
Interference		
Photoelectric effect		

2

Huygens' Principle

Every point on a wave front can be considered a source of tiny wavelets that spread out in the forward direction at the speed of the wave. The new wave front is the envelope of all the wavelets (the tangent to all of them).

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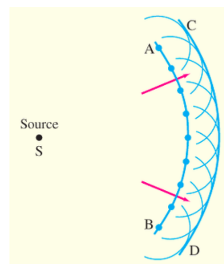

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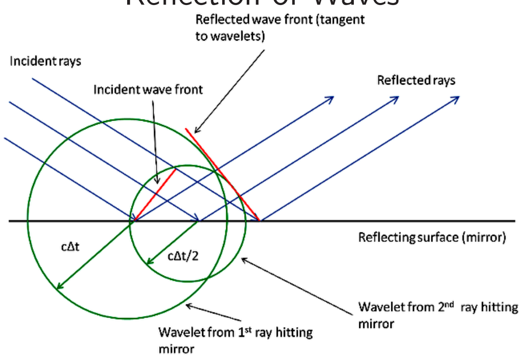
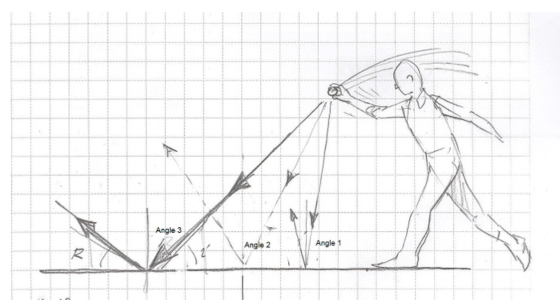
Reflection of Waves



5 It follows that $\theta_r = \theta_i$.

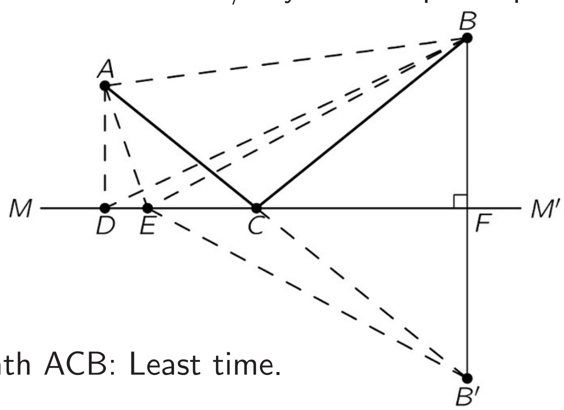
Reflection of Particles/Rays: One Explanation



6 It follows that $\theta_r = \theta_i$.

ADDITIONAL NOTES

Reflection of Particles/Rays: A Deeper Explanation



Path ACB: Least time.

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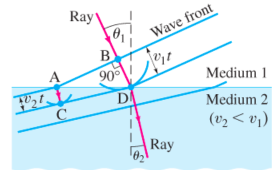
Refraction of Waves



Δ ABD: $sin\,\theta_1 = \text{BD}/\text{AD} = v_1 t/\text{AD}$.

Δ ACD: $sin\,\theta_2 = \text{AC}/\text{AD} = v_2 t/\text{AD}$.

So, $t/\text{AD} = sin\,\theta_1/v_1 = sin\,\theta_2/v_2$.

Or, $n_1\, sin\,\theta_1 = n_2\, sin\,\theta_2$ (Snell's Law).

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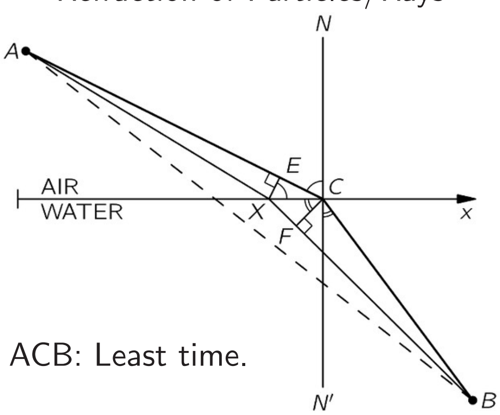
Refraction of Particles/Rays



Path ACB: Least time.

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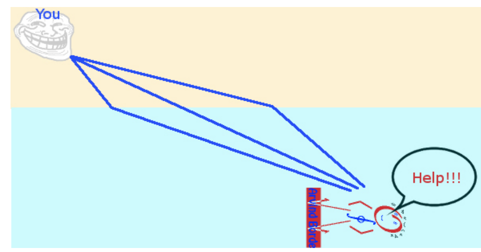

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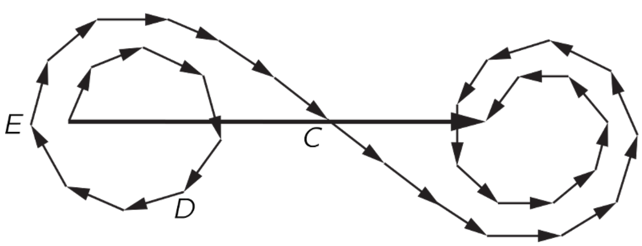
The Principle of Least Time

The Quantum Underpinning



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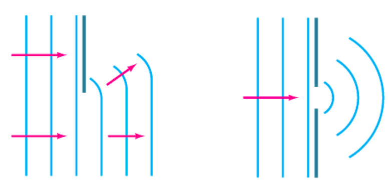
Diffraction of Waves



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ADDITIONAL NOTES

In the mid-1600s, Francesco Grimaldi observed that when sunlight entered a darkened room through a tiny hole in a screen, the spot on the opposite wall was larger than you'd expect if light traveled as straight rays.

He also observed that the border of the image was not clear but was surrounded by colored fringes.

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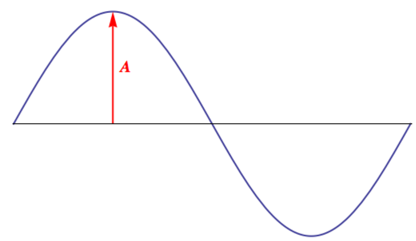
Interference of Waves



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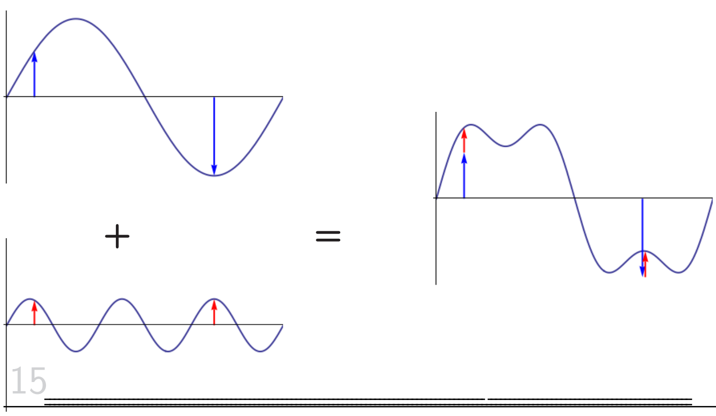
Superposing Waves



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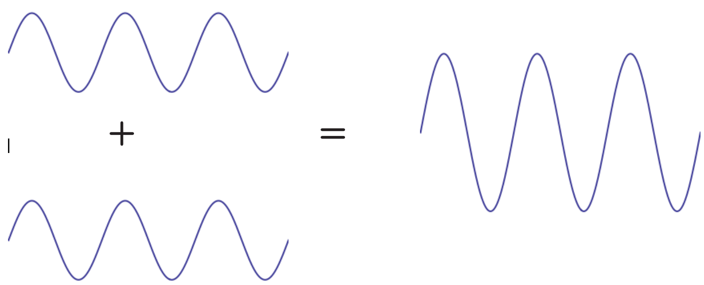
Constructive Interference



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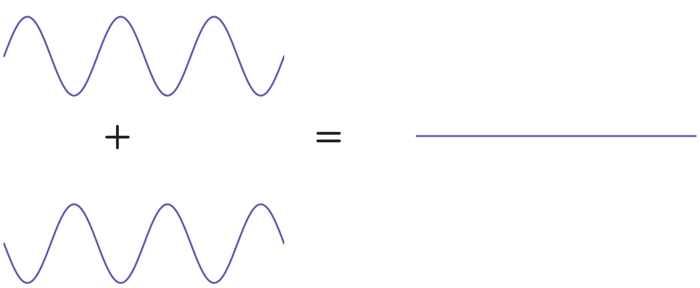
Destructive Interference



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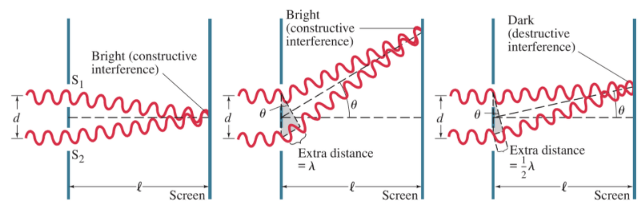
These effects, where waves can reinforce each other or cancel each other, lead to patterns of dark and light lines called an interference pattern.



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ADDITIONAL NOTES

When light moves from medium 1 to medium to 2, its speed and wavelength change, ______________

In other words, $v_1 = f\lambda_1$ and $v_2 = f\lambda_2$.

Now, $n_1 = c/v_1$ and $n_2 = c/v_2$. So

$$n_1 = \frac{c}{f\lambda_1} \quad \text{and} \quad n_2 = \frac{c}{f\lambda_2},$$

or

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$$n_1\lambda_1 = n_2\lambda_2.$$

A light beam in air with $\lambda = 500\,\text{nm}$, $f = 6.0 \times 10^{14}\,\text{Hz}$, and $v = 3.0 \times 10^8\,\text{m/s}$ goes into glass which has an index of refraction $n_2 = 1.5$. What are the wavelength, frequency, and speed of the light in the glass?

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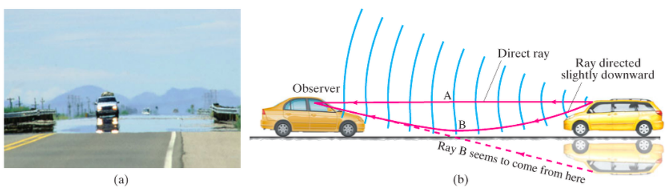
Mirages



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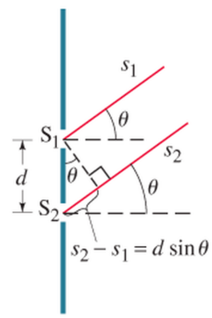
Interference



Constructive:
$d\,sin\,\theta = m\lambda$

Destructive:
$d\,sin\,\theta = (m + \frac{1}{2})\lambda$

$m = 0, 1, 2, \ldots$

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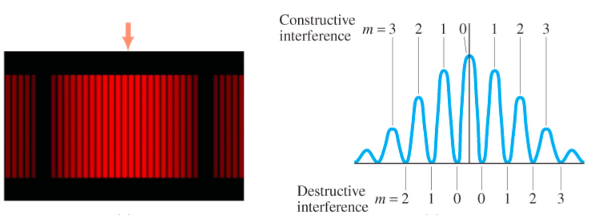
Interference Pattern



The bands are called "fringes." m is called the order of the fringe and the placement is symmetrical about $m = 0$.

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(2) For $\theta = 10^{-1}, 10^{-2}, 10^{-3}, 10^{-4}$ radians what is $sin\,\theta$?

____

(3) For $\theta = 10^{-1}, 10^{-2}, 10^{-3}, 10^{-4}$ radians what is $tan\,\theta$?

____

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ADDITIONAL NOTES

Therefore, for small angles θ expressed in radians, we have

(4) How "small" is 10^{-3} radians? (Convert to degrees.)

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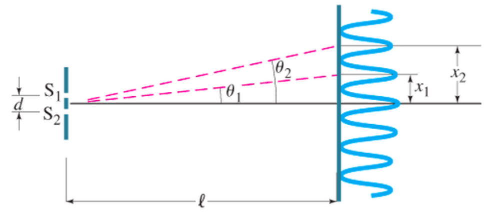
So, for closely spaced interference fringes,



we have

etc.

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The formula for constructive interference was $d\,sin\,\theta = m\lambda$. Or

Putting that together with the previous, we get

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etc.

(5) A screen containing two slits 0.100 mm apart is 1.20 m from the viewing screen. Light of wavelength $\lambda = 500$ nm falls on the slits from a distant source. Approximately how far apart will adjacent bright interference fringes be on the screen?

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(6) What happens to an interference pattern as the wavelength goes up?

(7) What happens to an interference pattern as the gap between slits goes up?

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(8) White light passes through two slits 0.50 mm apart, and an interference pattern is observed on a screen 2.5 m away. The first-order fringe resembles a rainbow with violet and red light at opposite ends. The violet light is about 2.0 mm and the red 3.5 mm from the center of the central white fringe. Estimate the wavelengths for the violet and red light.

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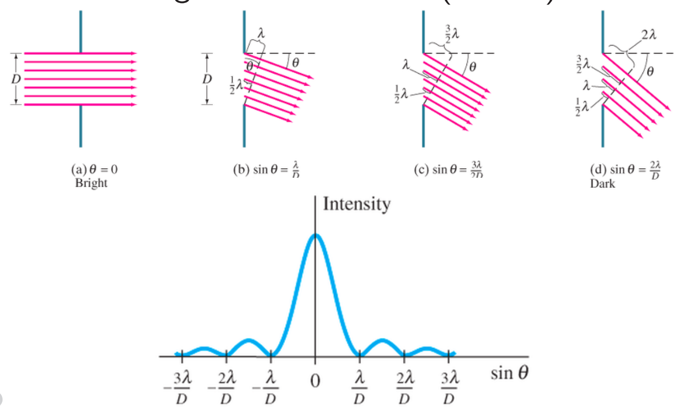
ADDITIONAL NOTES

Violet:

Red:

31 Color comes from wavelength.

Single Slit Diffraction ($D \sim \lambda$)



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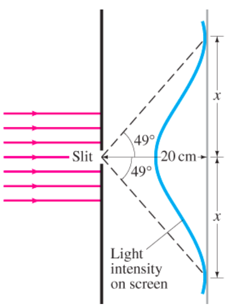

(**9**) Light with $\lambda = 750$ nm passes through a slit 10^{-3} mm wide.

How wide is the central maximum (a) in degrees, and (b) in centimeters, on a screen 20 cm away?

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ADDITIONAL NOTES