Interference and Diffraction

Outline

- Particles or Waves
- Young's Double-Slit Experiment
- Huygen's Principle
- Interference
- Diffraction

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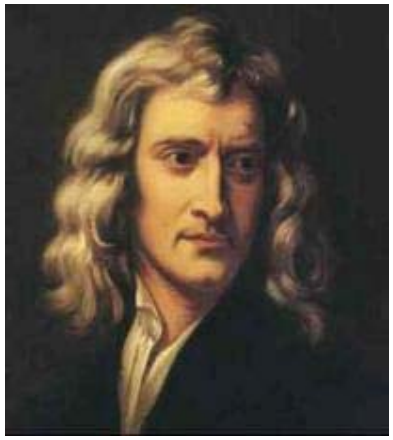
Acknowledgement:
Some slides were adopted from PHY106 Particle Physics Module at Syracuse University by Dr. Steve Blusk

Are Photons Particles or Waves ?

Newton believed that light was particles:

- light travels in straight lines !



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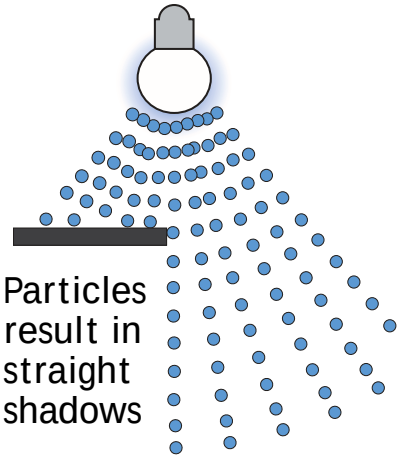

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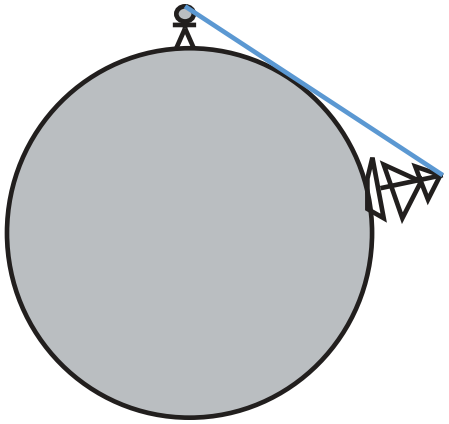
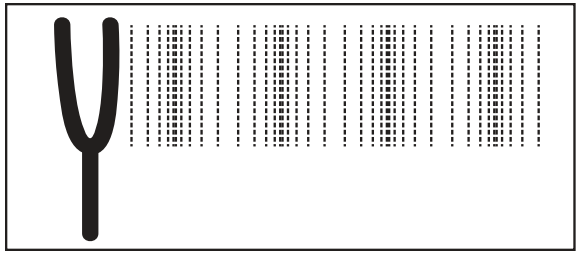


- what is 'waving' in an EM wave ?

A wave is a vibration of some medium through which it propagates, e.g., water waves, waves propagating on a string



Are Photons Particles or Waves ?

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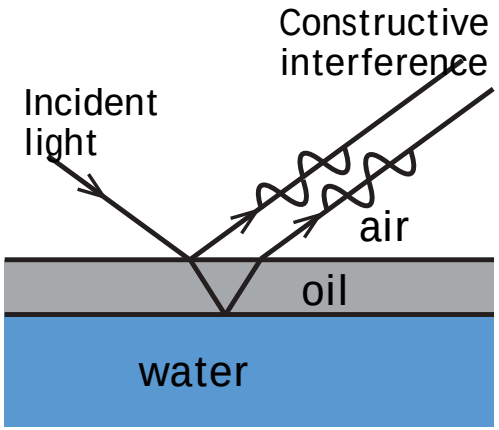

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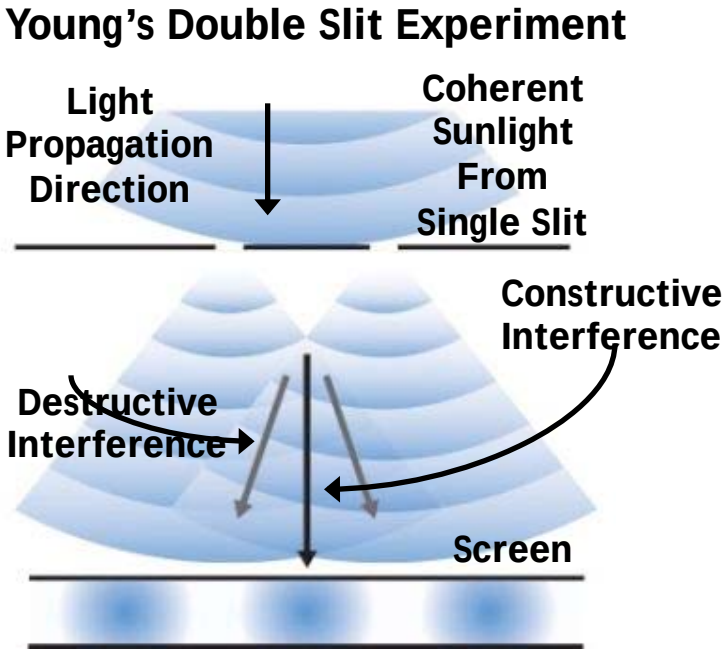

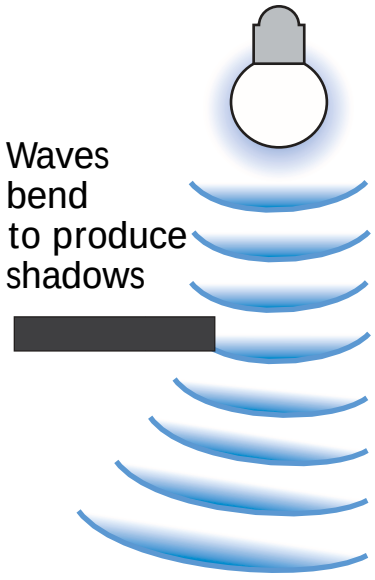

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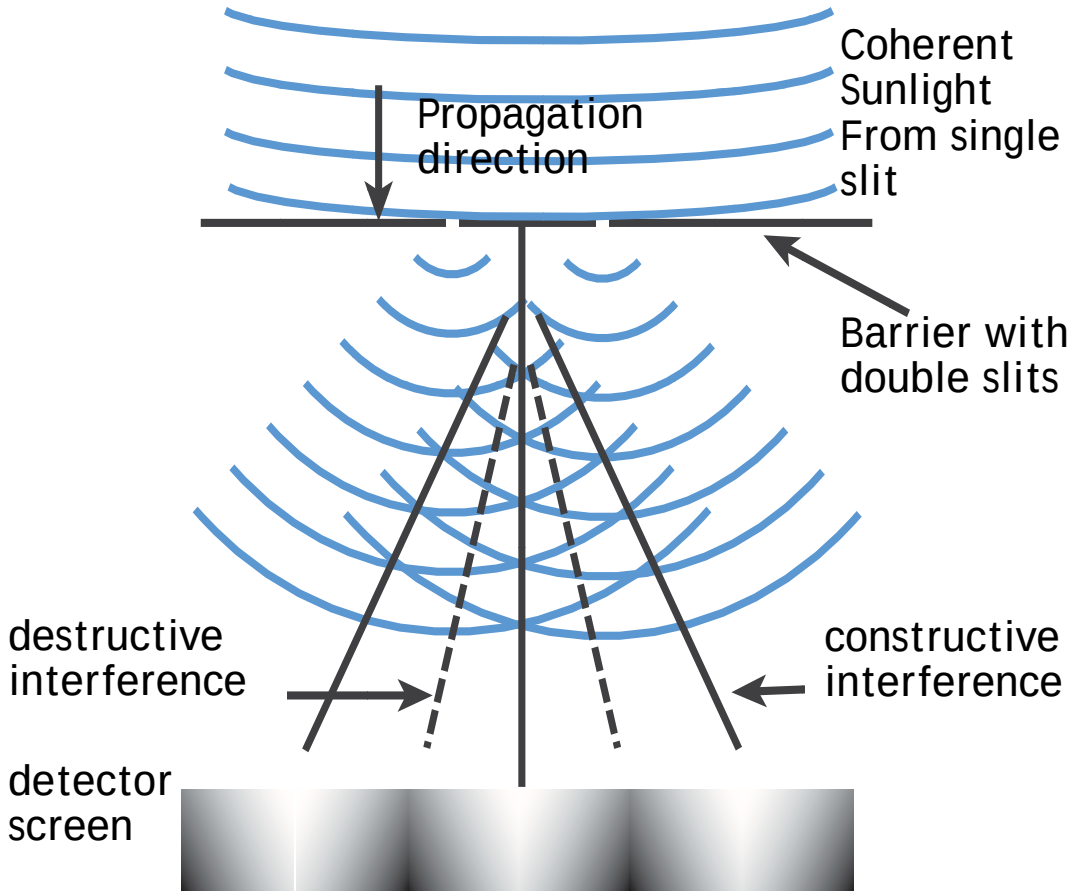
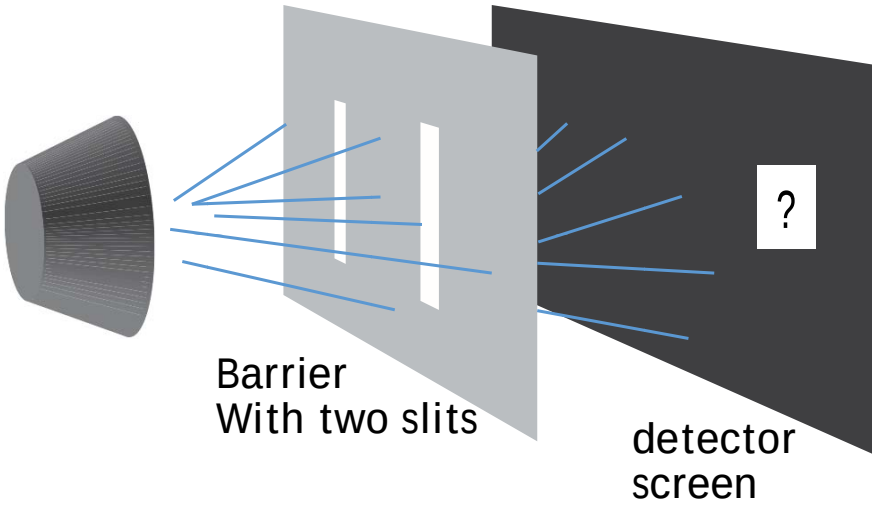
Thomas Young's Double Slit Experiment

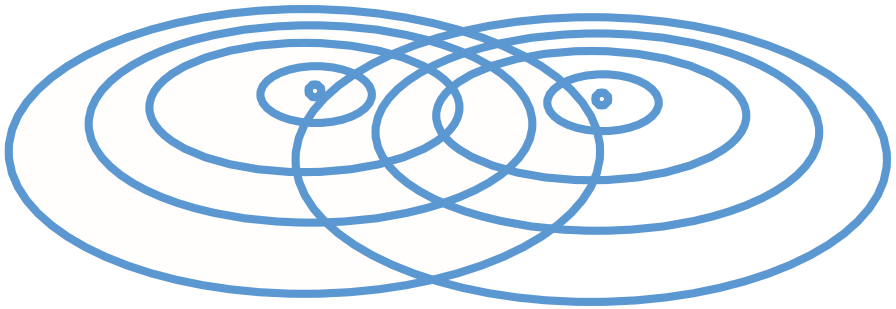


Historical Note:
When Thomas Young published his result in 1802 he encountered a great deal of criticism from the proponents of Newton's particle theory of light. One objection was that the interference experiment was inconsistent with the law of energy conservation (at points of constructive interference, the light intensity is twice the intensity calculated by adding the intensities associated with each individual slit).
- Is energy conservation violated ?

Young was discouraged by the criticism of his work, and gave up his research in optics for other endeavors.
(He made a major contribution to Egyptology by deciphering the Rosetta stone. His theory of color vision is widely cited today, so is his work on elasticity. He made pioneering contributions in studies of sound, tides, and human voice.)

Thomas Young's Double Slit Experiment





Interference is the defining characteristic of waves

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Huygen's Principle

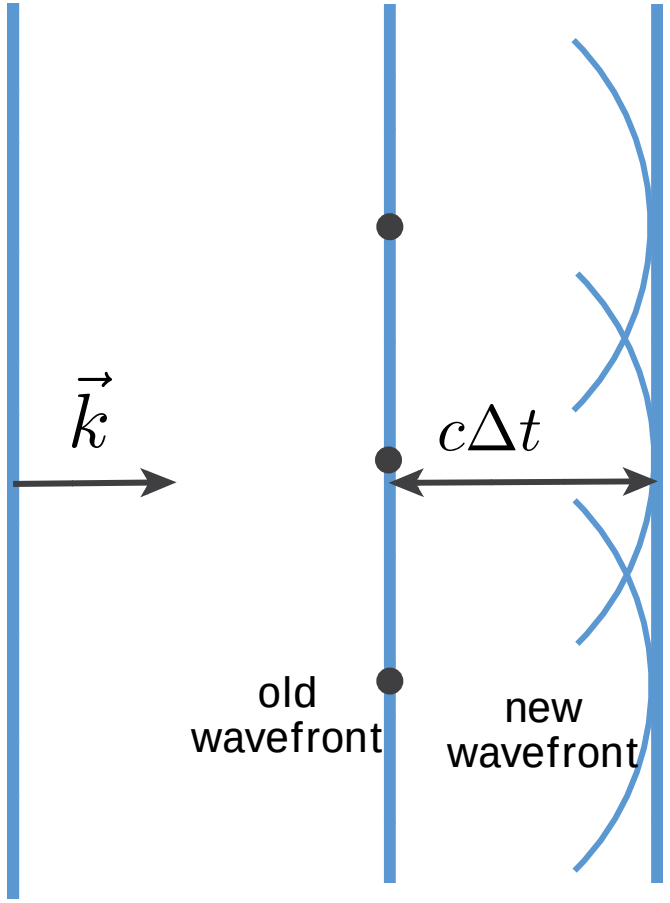
- Huygen assumed that light is a form of wave motion rather than a stream of particles
- Huygen's Principle is a geometric construction for determining the position of a new wave at some point based on the knowledge of the wave front that preceded it

- All points on a given wave front are taken as point sources for the production of spherical secondary waves, called wavelets, which propagate in the forward direction with speeds characteristic of waves in that medium
  - After some time has elapsed, the new position of the wave front is the surface tangent to the wavelets

As you might expect, the heuristic idea of Huygens can be fully justified through various derivations associated with the Maxwell equations.

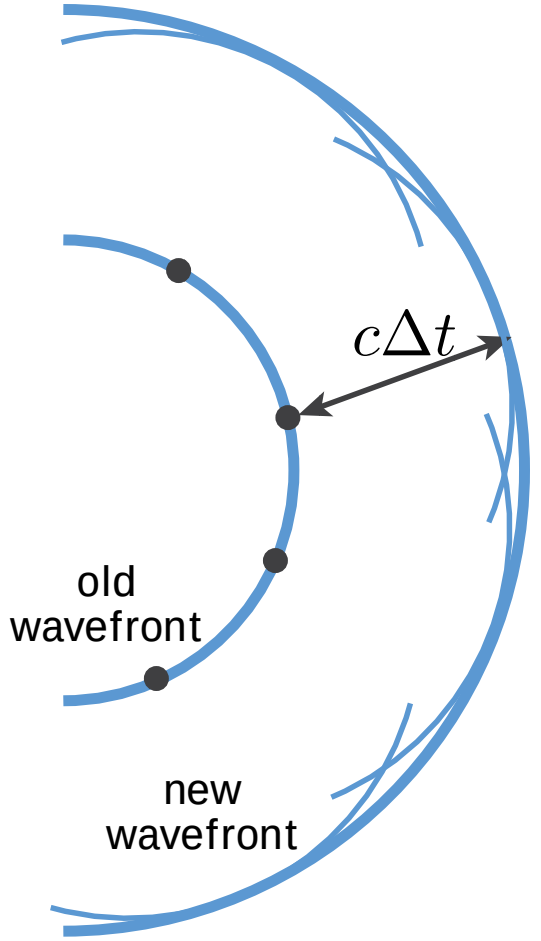
Huygen's Construction for a Plane Wave

- At t = 0, the wave front is indicated by the plane AA'
- The points are representative sources for the wavelets
- After the wavelets have moved a distance cΔt, a new plane BB' can be drawn tangent to the wavefronts

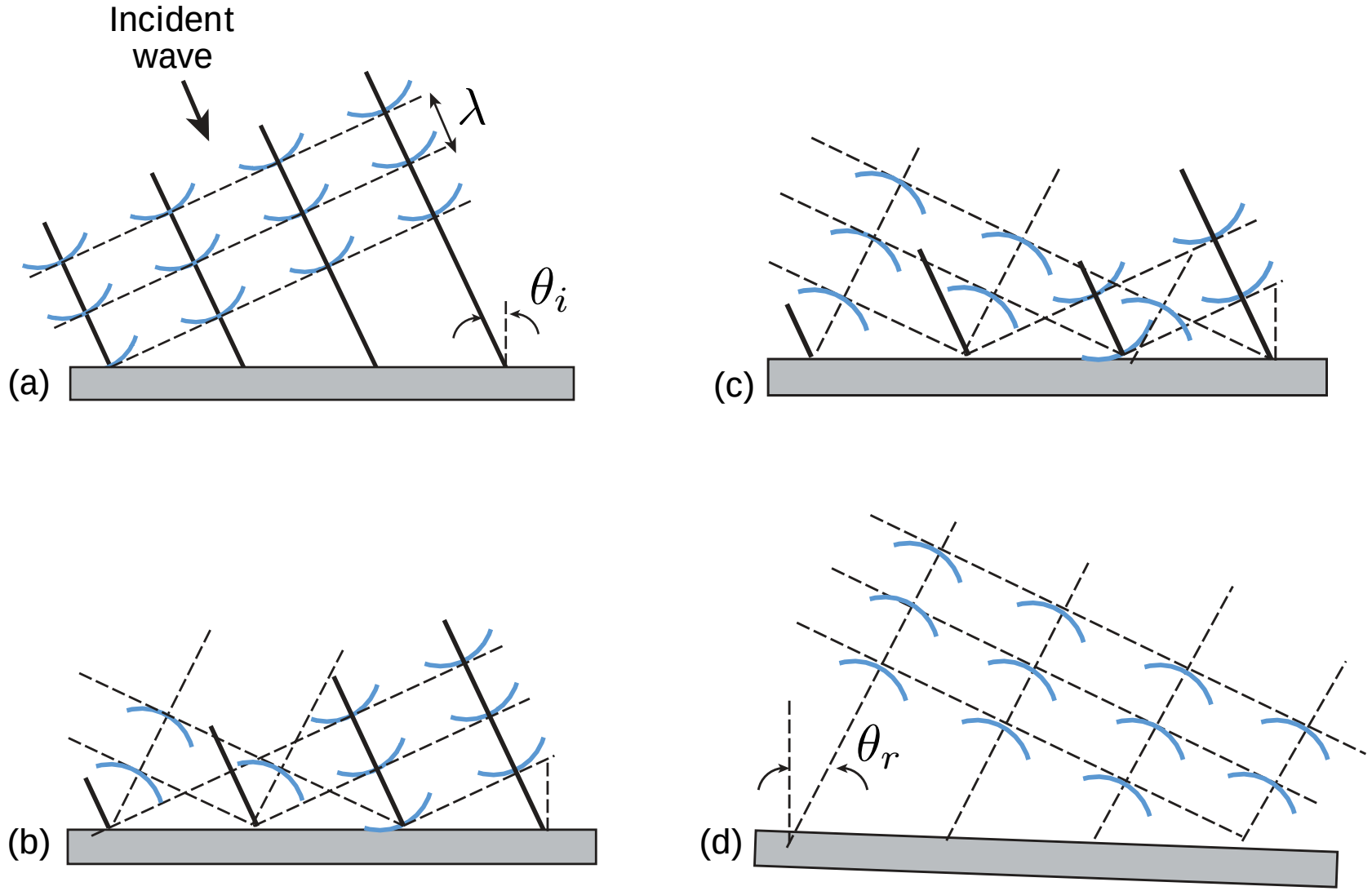


Huygen's Construction for a Spherical Wave

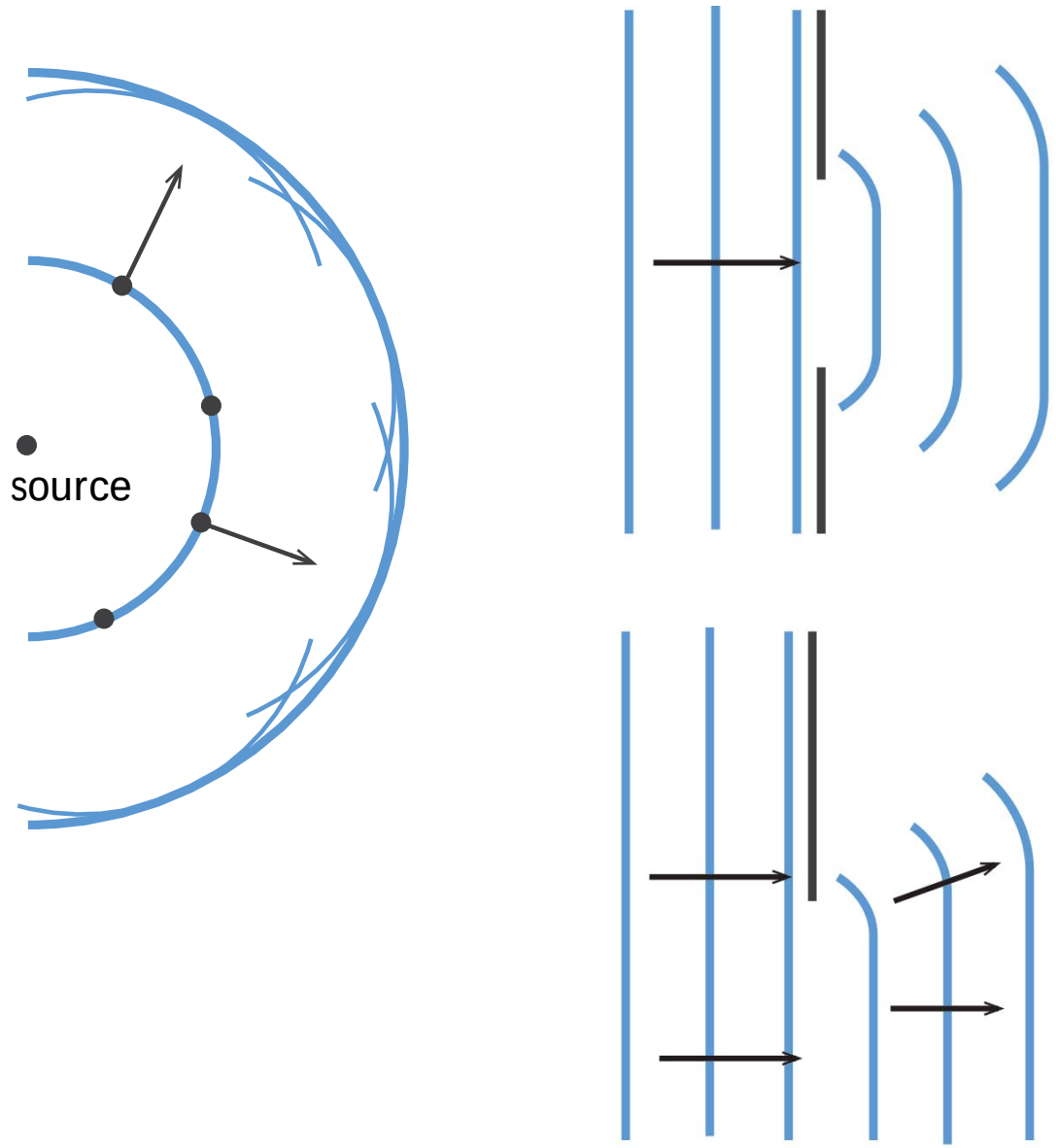
- The inner arc represents part of the spherical wave
- The points are representative points where wavelets are propagated
- The new wavefront is tangent at each point to the wavelet



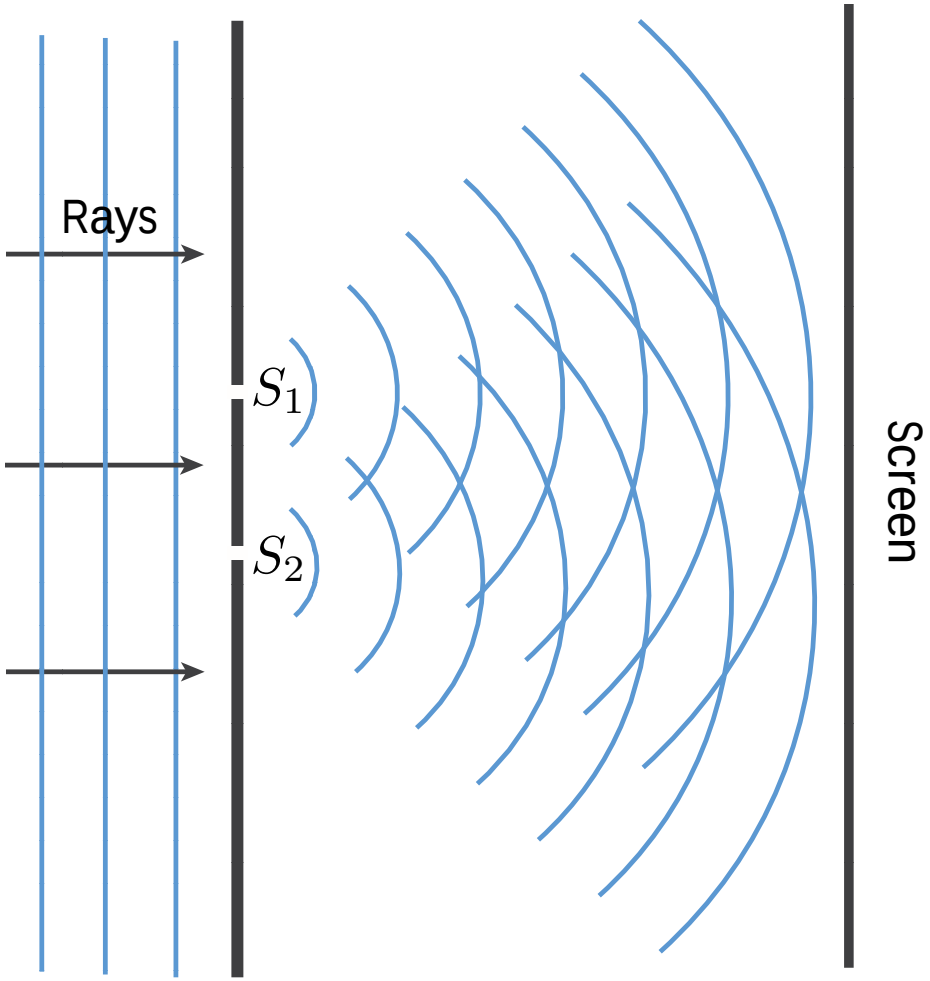
Huygen's Construction for a Reflection



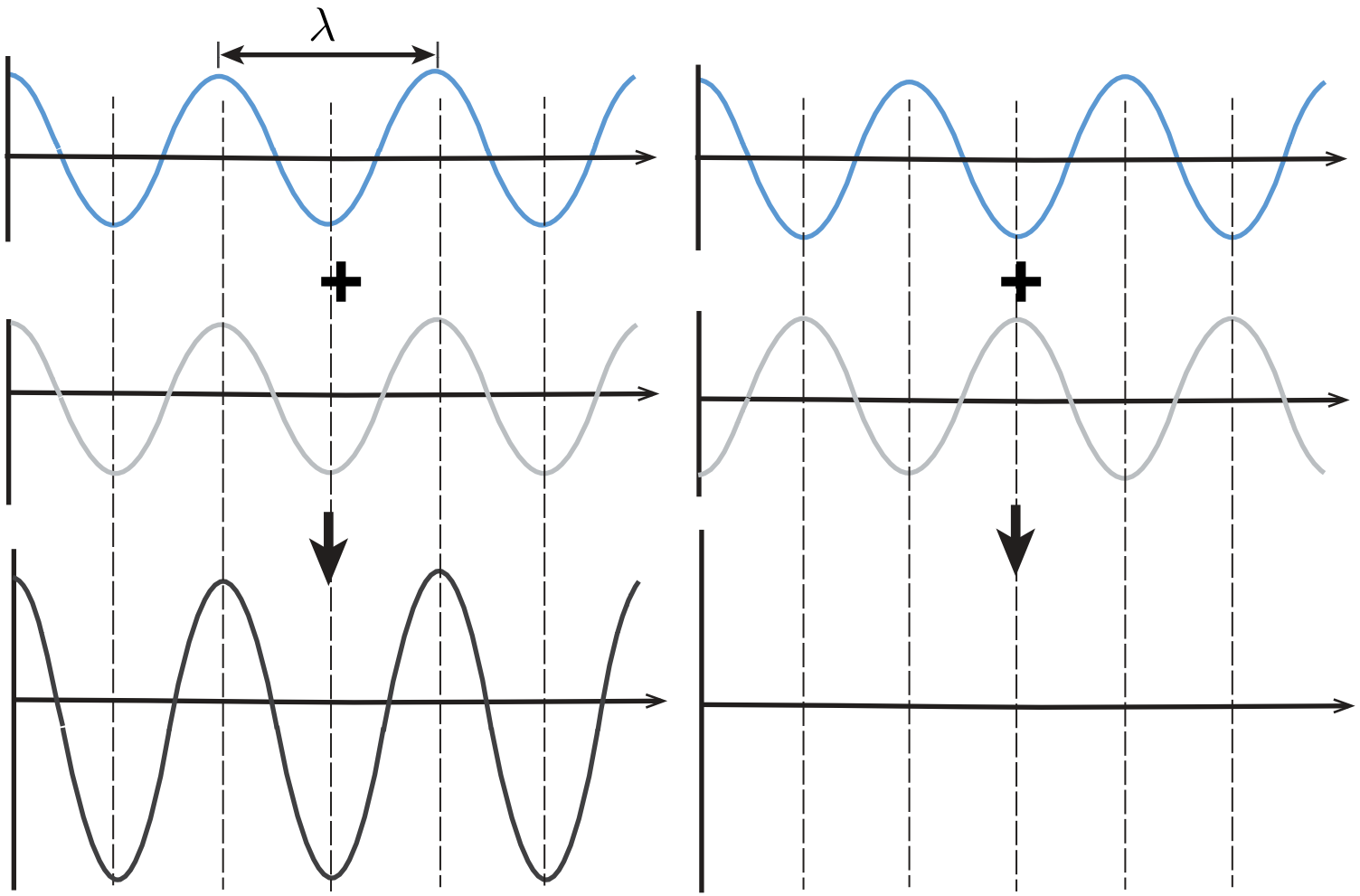
Huygens' Principle Explains Diffraction



Applying Huygens' Principle to Two Slits

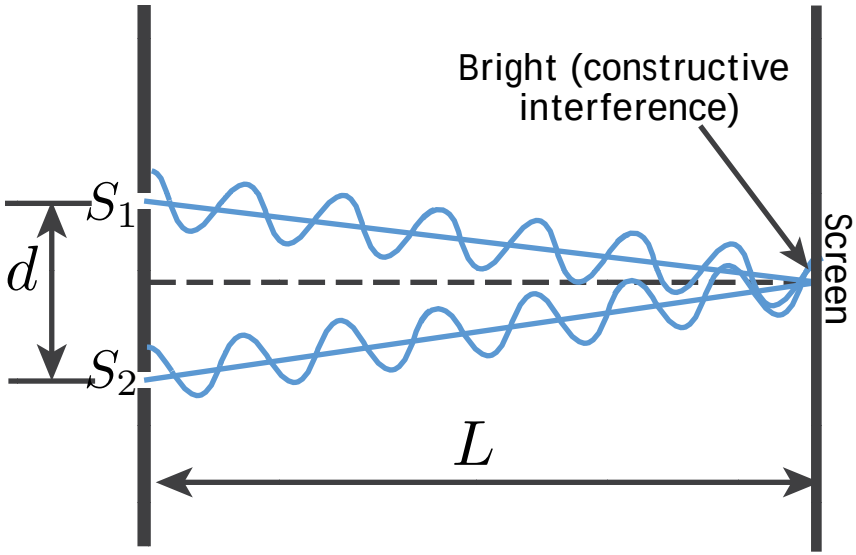


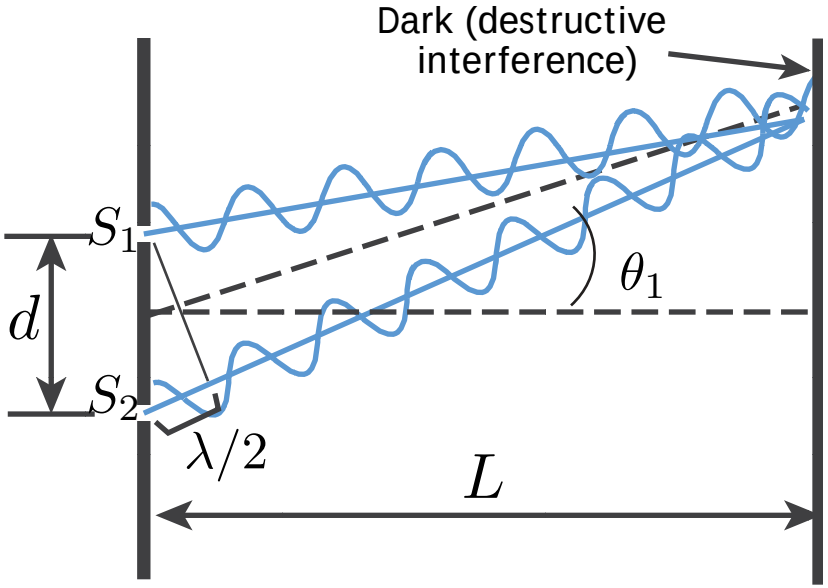
Wave Interference



CONSTRUCTIVE DESTRUCTIVE

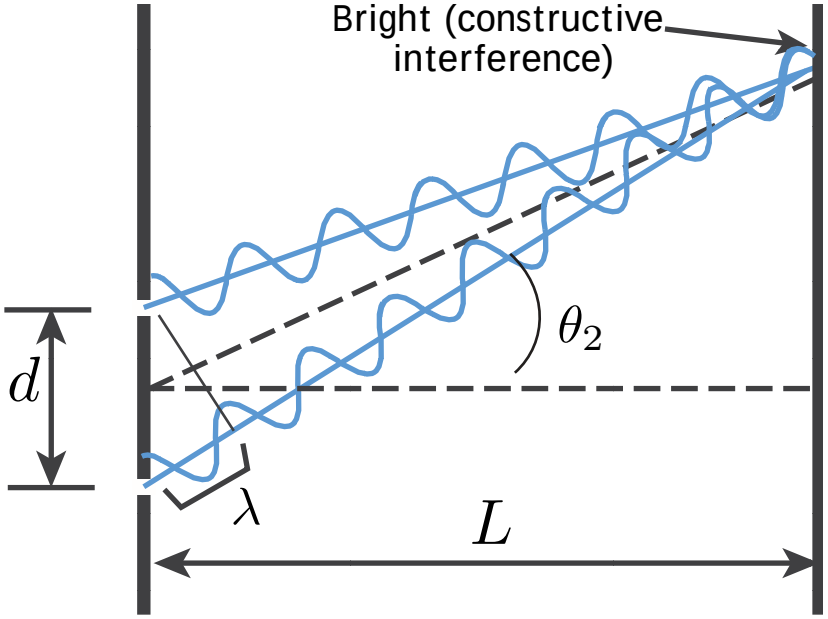
Interference of Coherent Waves In the Double-Slit Experiment



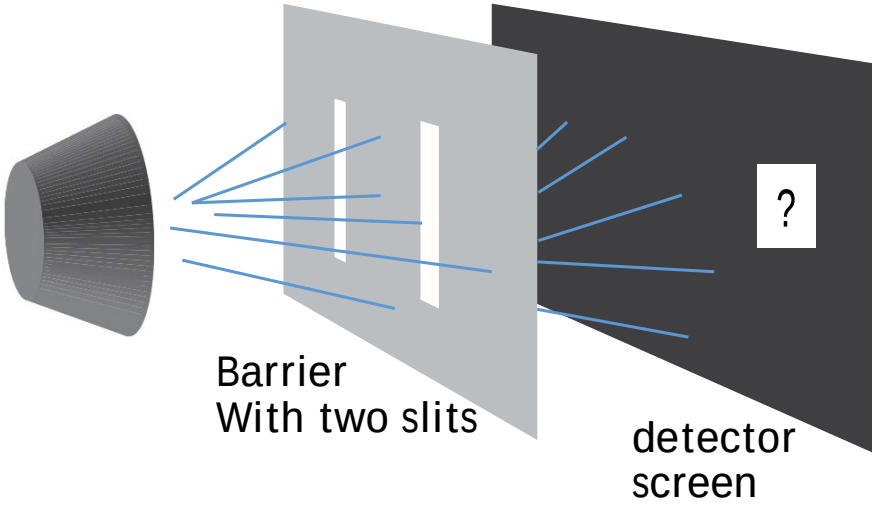


Waves at slits have to be *coherent* for interference to occur!

Two different light bulbs in front of each slit will not give interference pattern.



Light Particles or Waves?
Young's Double-Slit Experiment!

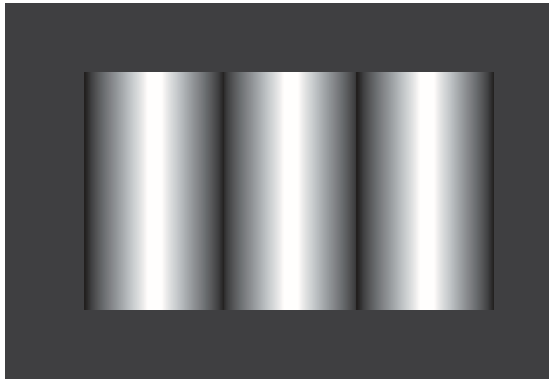


What should we see on the detector screen ?

we expect to see the following patterns for …

particles

waves



Interference Preconditions

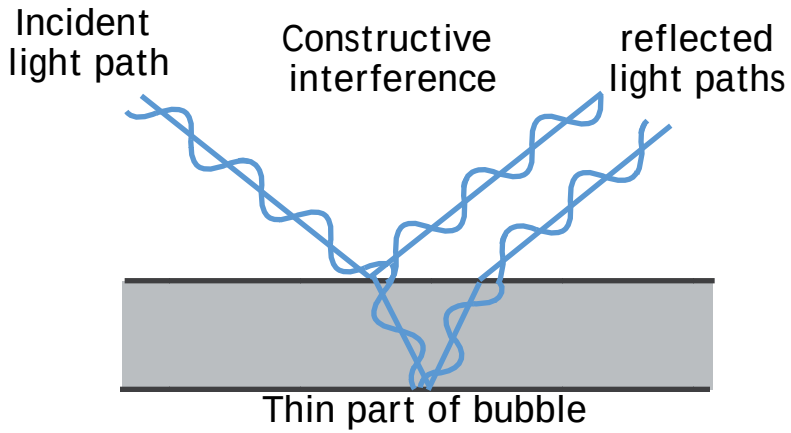
1. Light must be *monochromatic*, i.e., involve just a single frequency (single wavelength).

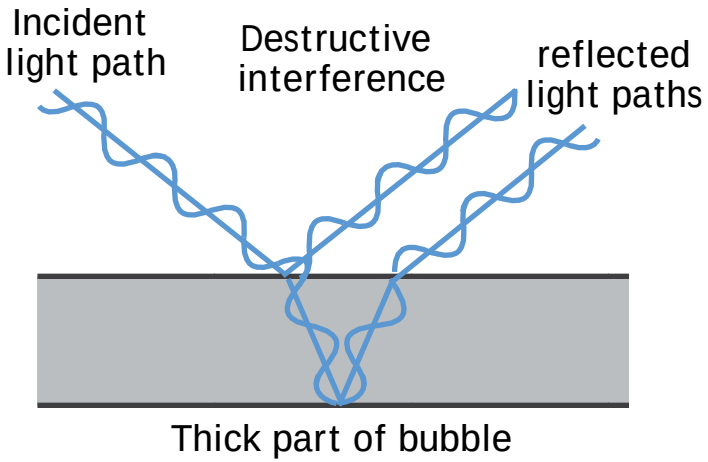
2. Light sources must be *coherent*, the relative phase is always the same.

3. Light sources must have the *same amplitudes*.

If these conditions do not hold, one still gets constructive and destructive interference but the interference pattern can change with time or not be complete (destructive interference leads to a decrease in amplitude but not to zero amplitude).

Interference in Soap Bubbles





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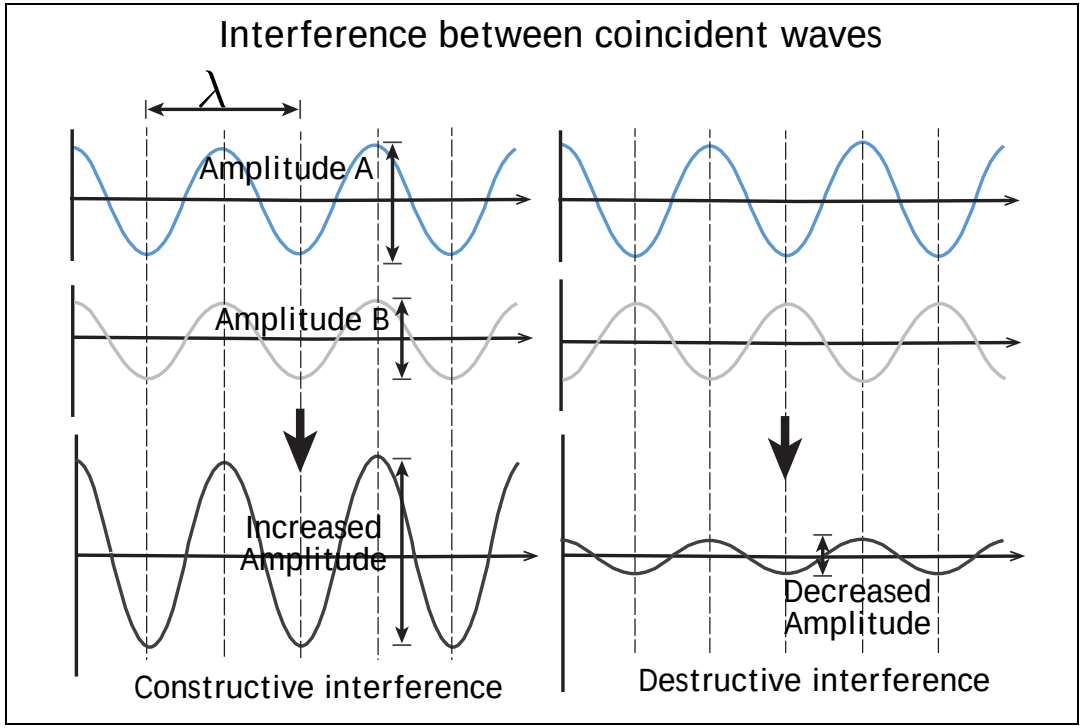


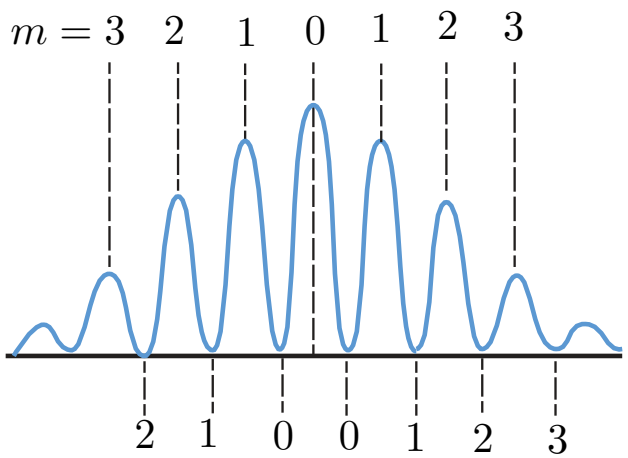
Interference Fringes

$dsin(\theta) = m\lambda,$	$m = 0, \pm 1, \pm 2, ...$	Constructive
$dsin(\theta) = (m + 1/2)\lambda,$	$m = 0, \pm 1, \pm 2, ...$	Destructive

m is the **order** of an interference fringe

constructive interference

destructive interference



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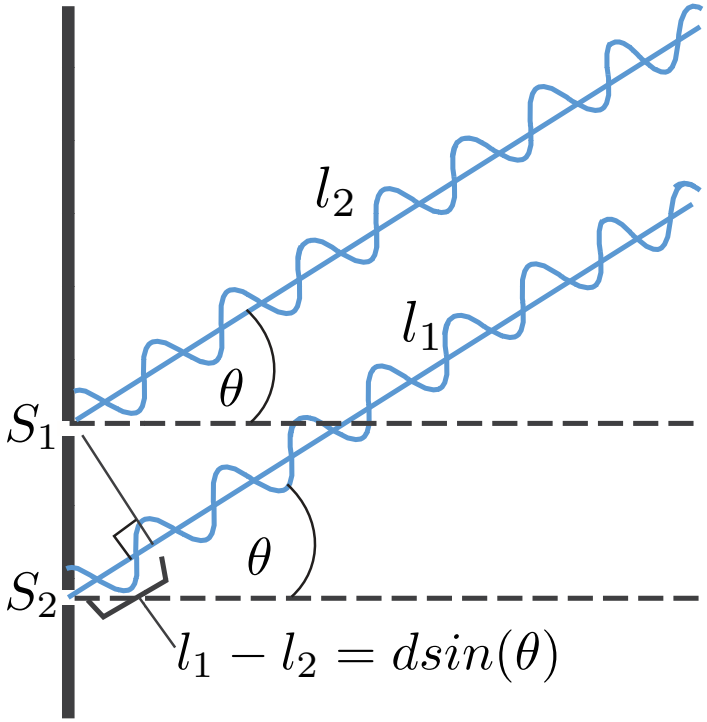
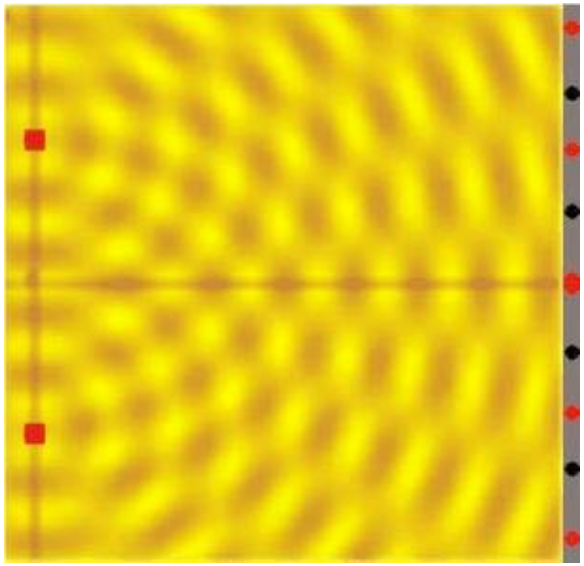


Interference Fringes

$$d\sin(\theta) = m\lambda, \qquad m = 0, \pm 1, \pm 2, \ldots \quad \text{Constructive}$$
$$d\sin(\theta) = (m + 1/2)\lambda, \qquad m = 0, \pm 1, \pm 2, \ldots \quad \text{Destructive}$$

If distance *d* between slits is decreased,
then the angles θ corresponding to the bright fringes will …



(Choose one)

1. all become smaller.
2. all become larger
3. some will become larger, some smaller.
4. remain unchanged but the fringes will all become dimmer.
5. remain unchanged but the fringes will all become brighter.

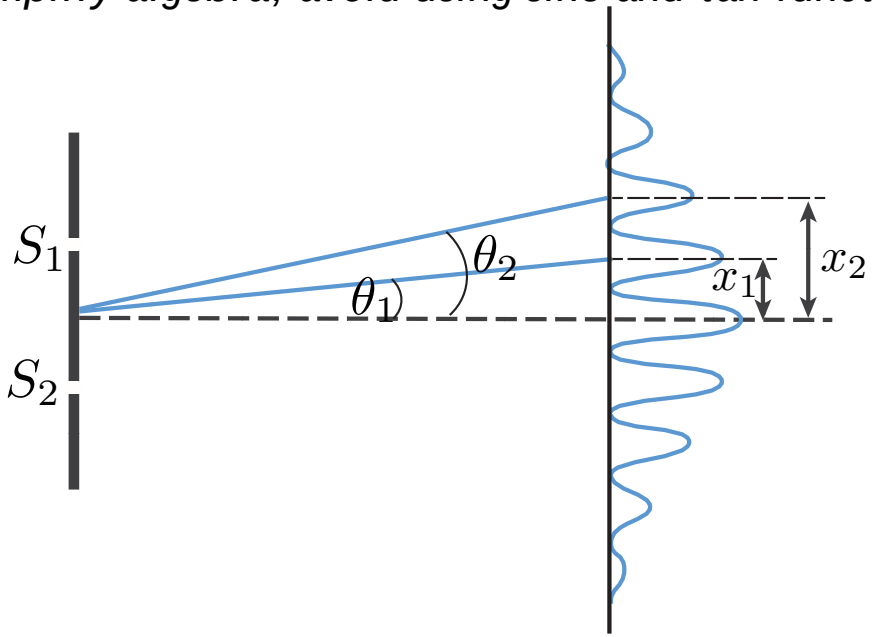
Animated image is in the public domain

Worked Example

A screen contains two slits distance *d* = 0.100 mm apart and is length L = 1.20 m from a viewing screen. Monochromatic light of wavelength λ = 500 nm falls on the slits from a distant source.

About how far apart $\Delta x = x_2 - x_1$ will the bright interference fringes be on the screen?

Answer: About 6 mm. Use small angle approximations to simplify algebra, avoid using sine and tan functions.



Interference Fringes

$$d\sin(\theta) = m\lambda, \qquad m = 0, \pm 1, \pm 2, \ldots \quad \text{Constructive}$$
$$d\sin(\theta) = (m + 1/2)\lambda, \qquad m = 0, \pm 1, \pm 2, \ldots \quad \text{Destructive}$$

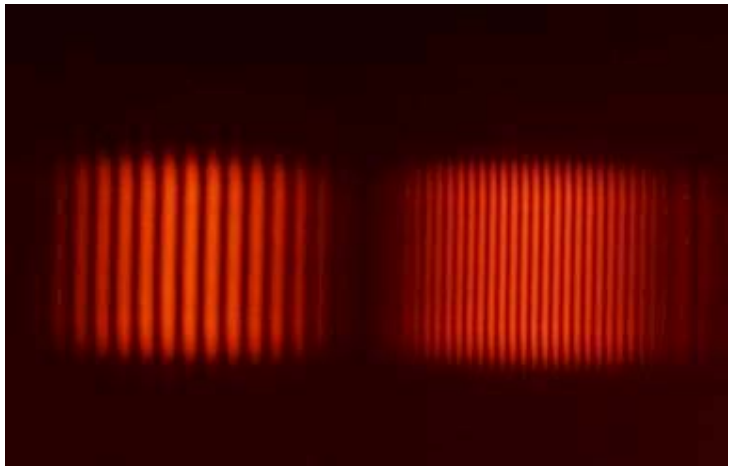
If wavelength λ of monochromatic light impinging on two-slits experiment *increases*, then bright fringes …

(Choose one)

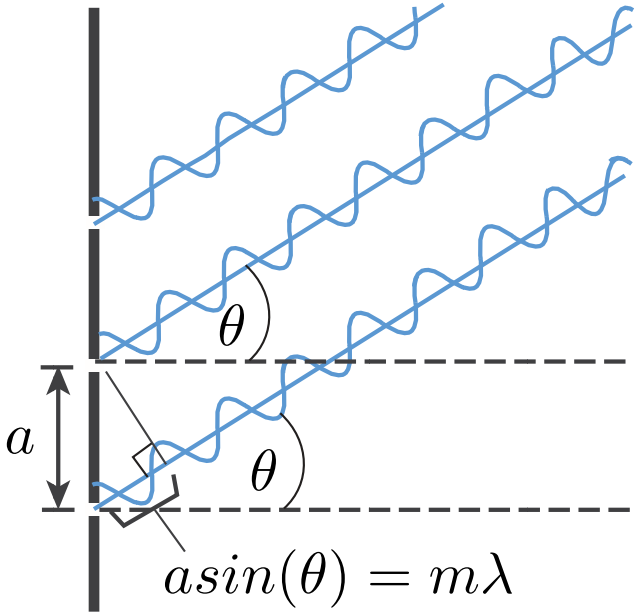
1. all become closer.
2. all spread further apart.
3. some become closer, some further apart.

Diffraction of Light From Periodic Slit Source

One of world's largest multilayer dielectric diffraction gratings



Double slit diffraction fringes with different slit separation



Maxima in the intensity occur if this path length difference is an integer number of wavelengths.

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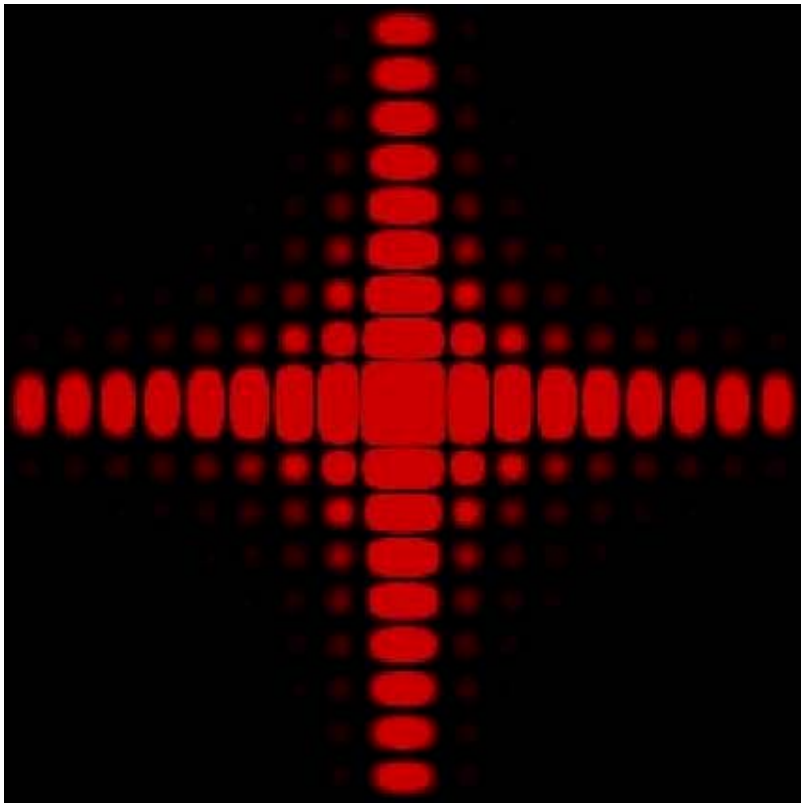
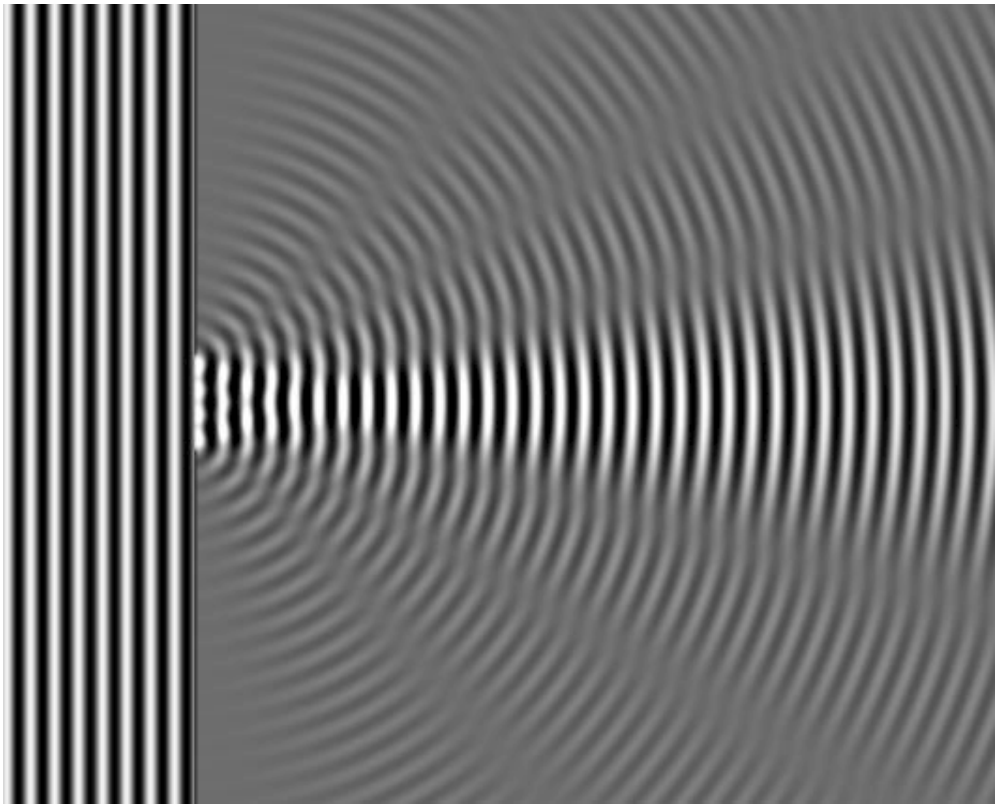
Diffraction Pattern from a Single Slit

The intensity pattern formed on a screen by diffraction from a single square aperture



Numerical approximation of diffraction pattern from a slit of width four wavelengths with an incident plane wave.



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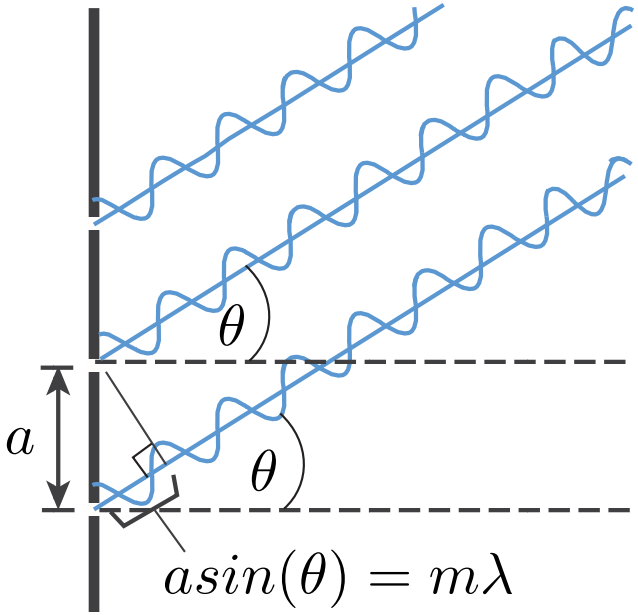
Key Takeaways

In 1802 Thomas Young's Double Slit Experiment demonstrated wave-nature of photons. (Much later, a similar double-slit experiment will be used to demonstrate wave nature of electrons, and of matter in general.)

Huygen's Principle is a geometric construction for determining the position of a new wave at some point based on the knowledge of the wave front that preceded it



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6.007 Electromagnetic Energy: From Motors to Lasers

Spring 2011