Applied Physics for Engineers

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Lecture 20

Wave Optics

Wave Optics

- There are certain phenomena such as, interference, Diffraction and polarization where ray or geometric optics is not valid.
- We have already learned that light is fundamentally a wave, and in some situations we have to consider its wave properties explicitly.
- If two or more light waves of the same frequency overlap at a point, the total effect depends on the phases of the waves as well as their amplitudes. The resulting patterns of light are a result of the wave nature of light and cannot be understood on the basis of rays.
- Optical effects that depend on the wave nature of light are grouped under the heading physical optics.

Young's double slit experiment

Interference

The term interference refers to any situation in which two or more waves overlap in space. When this occurs, the total wave at any point at any instant of time is governed by the principle of superposition

- Constructive Interference

In constructive interference, the amplitude of the resultant wave is greater than that of either individual wave

- Destructive Interference

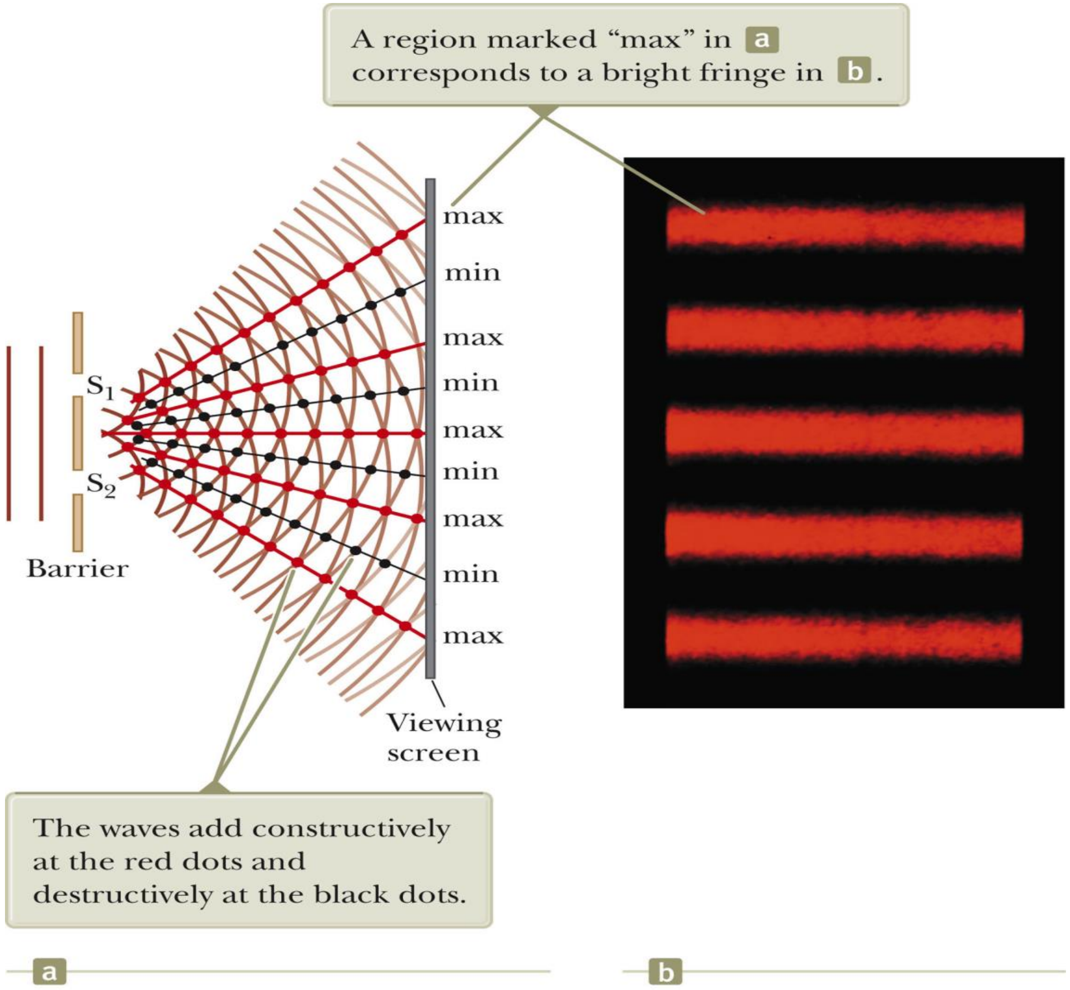
In destructive interference, the resultant amplitude is less than that of the larger wave.

Young's double slit experiment: Schematic

Thomas Young first demonstrated interference in light waves from two sources in 1801.

The narrow slits S_1 and S_2 act as sources of waves.

The waves emerging from the slits originate from the same wave front and therefore are always in phase.



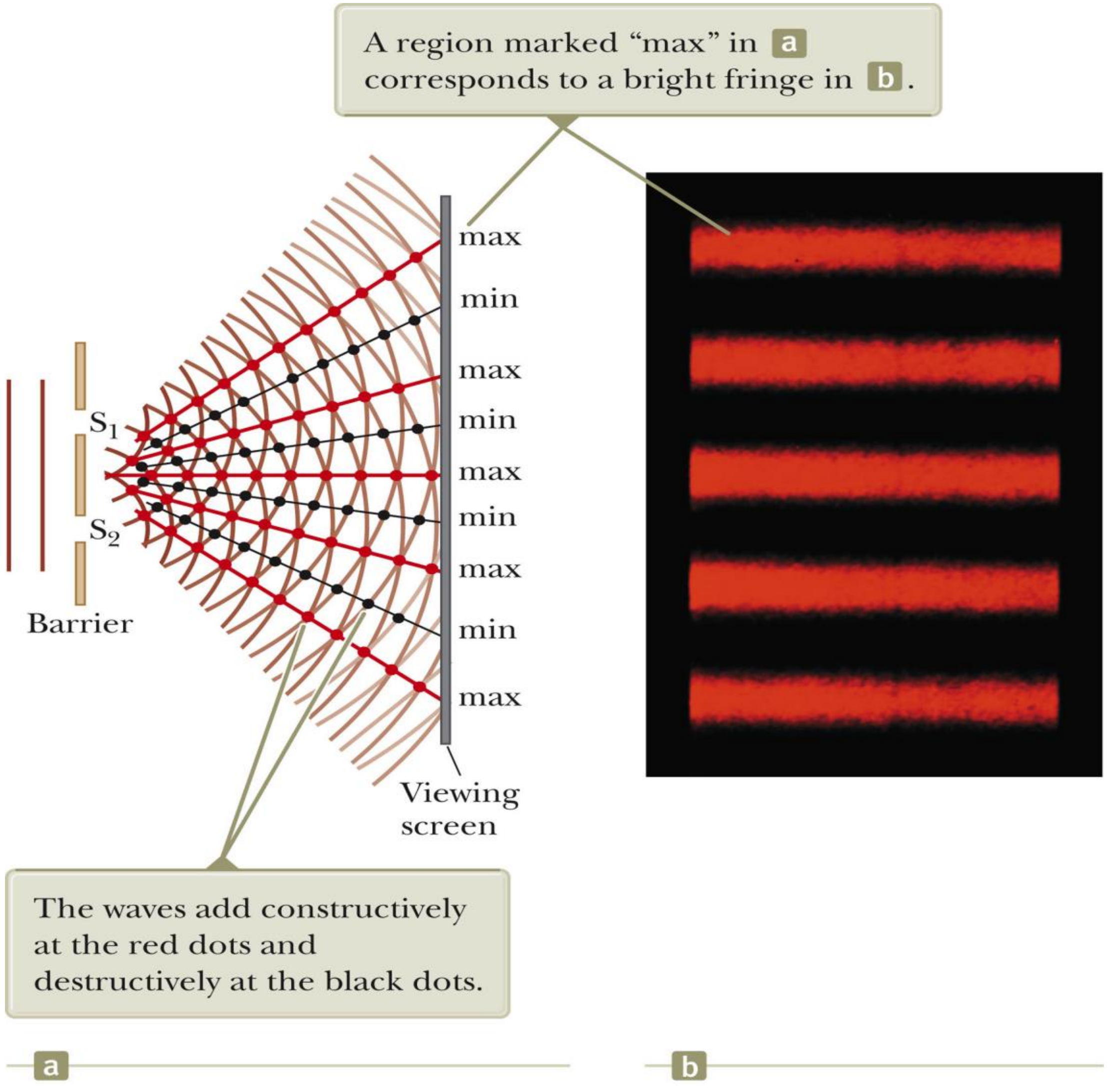
Resulting Interference Pattern

The light from the two slits forms a visible pattern on a screen.

The pattern consists of a series of bright and dark parallel bands called *fringes.*

Constructive interference occurs where a bright fringe occurs.

Destructive interference results in a dark fringe.



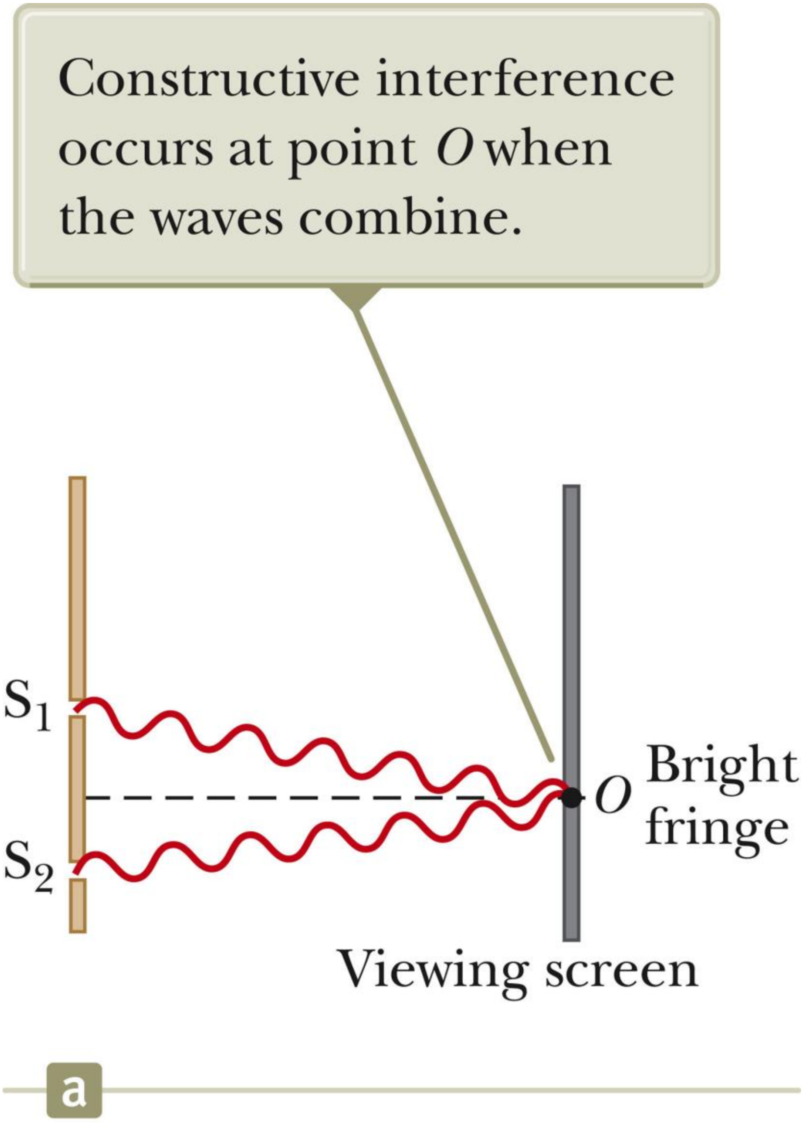
Interference Patterns, 1

Constructive interference occurs at point O.

The two waves travel the same distance.

- Therefore, they arrive in phase

As a result, constructive interference occurs at this point and a bright fringe is observed.



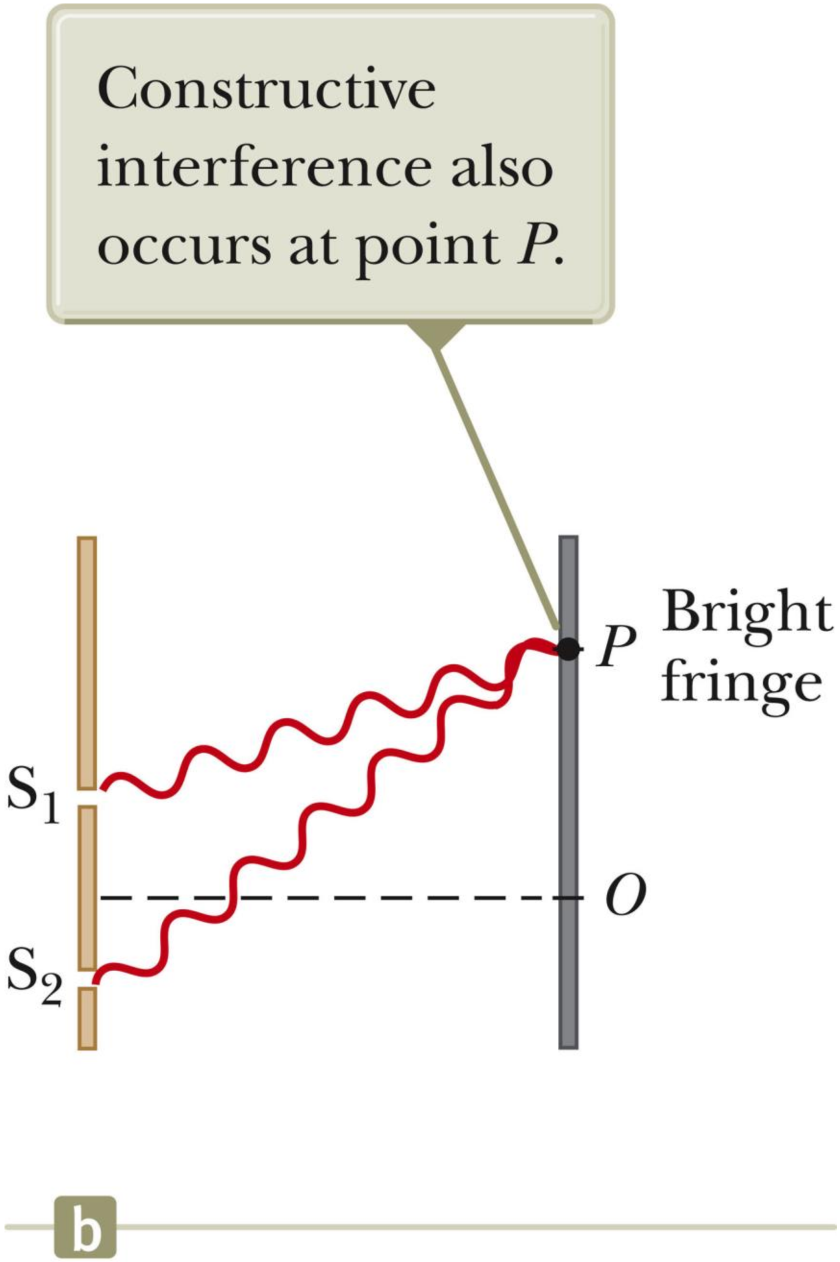
Interference Patterns, 2

The lower wave has to travel farther than the upper wave to reach point *P*.

The lower wave travels one wavelength farther.

- Therefore, the waves arrive in phase

A second bright fringe occurs at this position.



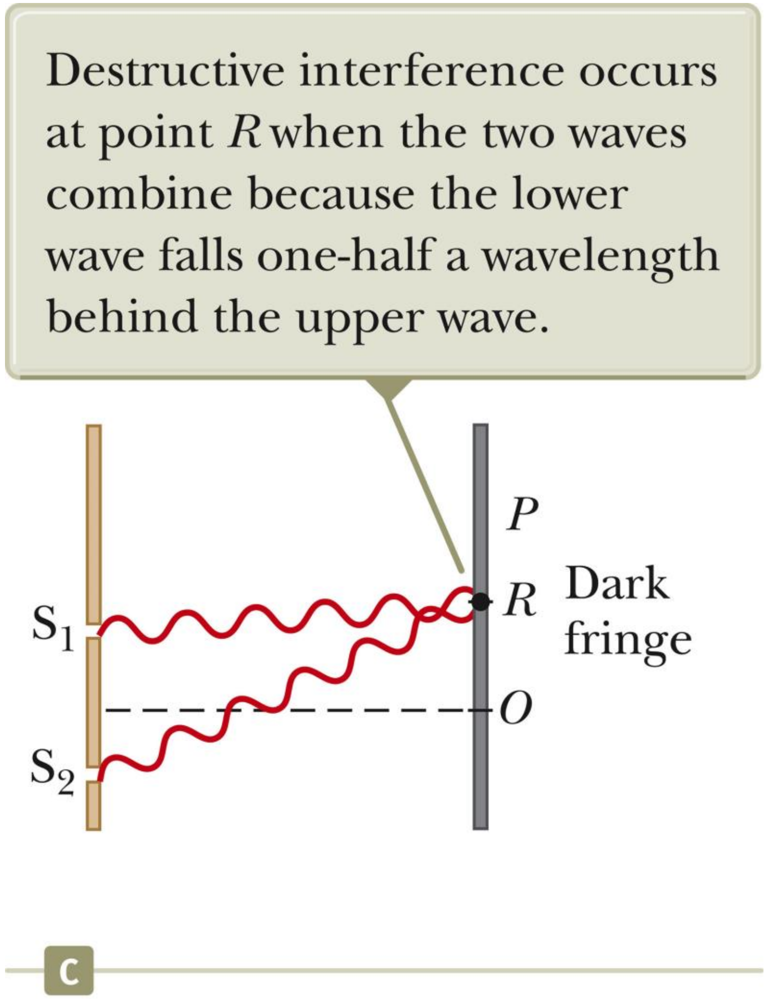
Interference Patterns, 3

The upper wave travels one-half of a wavelength farther than the lower wave to reach point R.

The trough of the upper wave overlaps the crest of the lower wave.

This is destructive interference.

- A dark fringe occurs.



Conditions for Interference

To observe interference in light waves, the following two conditions must be met:

- The sources must be **coherent.**
  - They must maintain a constant phase with respect to each other.
- The sources should be **monochromatic.**
  - Monochromatic means they have a single wavelength.

Producing Coherent Sources

Light from a monochromatic source is used to illuminate a barrier.

The barrier contains two small openings.

- The openings are usually in the shape of slits.

The light emerging from the two slits is coherent since a single source produces the original light beam.

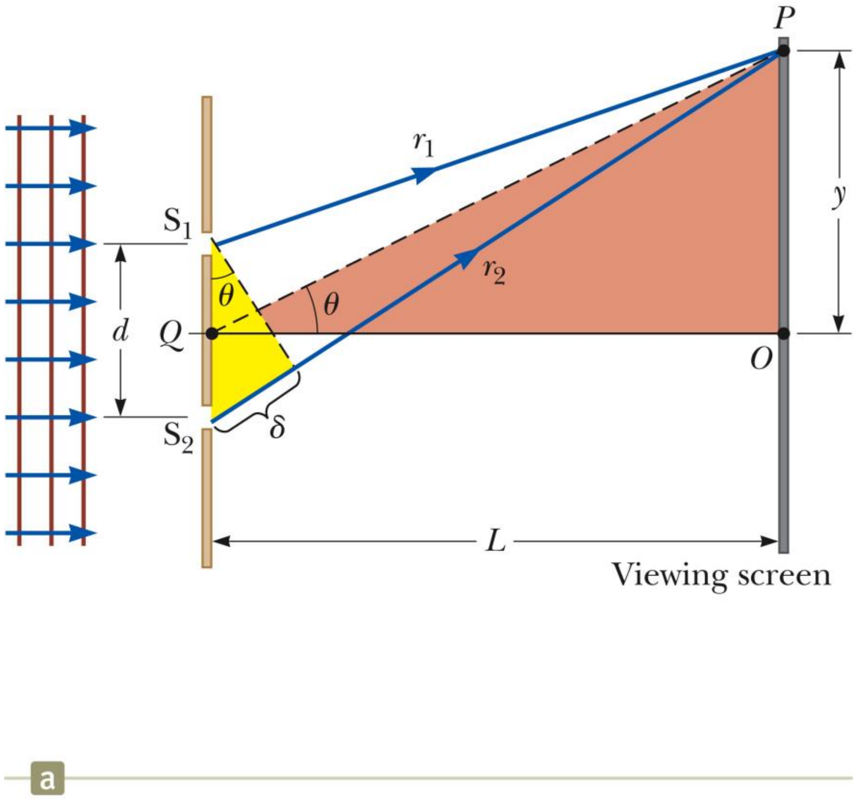
This is a commonly used method.

Young’s Double-Slit Experiment: Geometry

The path difference, δ, is found from geometry.

$$\delta = r_2 - r_1 = d \sin\theta$$

- This assumes the paths are parallel.
- Not exactly true, but a very good approximation if L is much greater than d



Interference Equations

For a bright fringe produced by constructive interference, the path difference must be either zero or some integer multiple of the wavelength.

$$\delta = d \sin \theta_{bright} = m\lambda \qquad \textbf{(Angular position)}$$

- m = 0, ±1, ±2, …
- m is called the order number
  - When m = 0, it is the zeroth-order maximum
  - When m = ±1, it is called the first-order maximum

When destructive interference occurs, a dark fringe is observed.

This needs a path difference of an odd half wavelength.

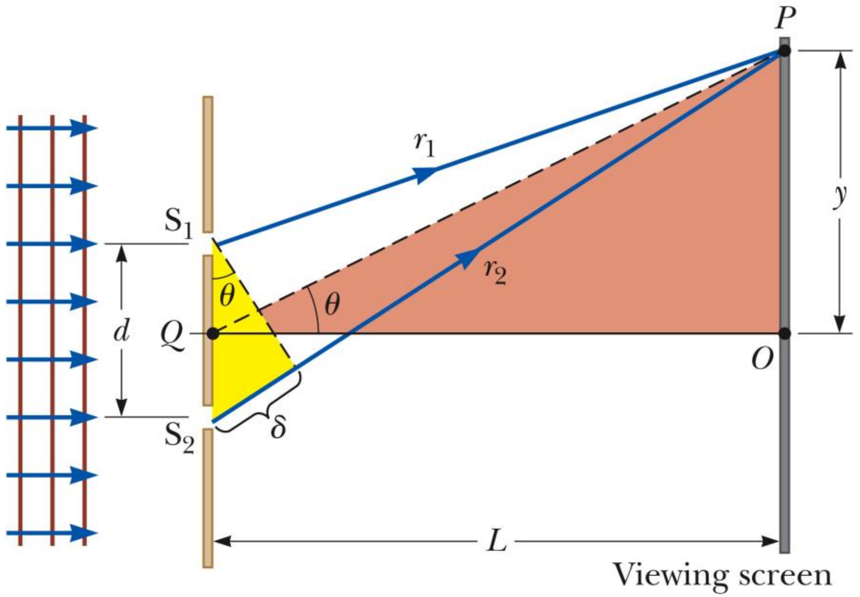
$$\delta = d \sin \theta_{dark} = (m + \tfrac{1}{2})\lambda \qquad \textbf{(Angular position)}$$

- m = 0, ±1, ±2, …

The positions of the fringes can be measured vertically from the zeroth-order maximum.

Using the large triangle in fig. a,

- $y_{bright} = L \tan \theta_{bright}$
- $y_{dark} = L \tan \theta_{dark}$



a

Assumptions in a Young's Double Slit Experiment:

- L >> d
- d >> λ

Approximation:

- θ is small and therefore the small angle approximation tan θ ~ sin θ can be used

y = L tan θ ≈ L sin θ

For small angles,

$$y_{\text{bright}} = L\frac{m\lambda}{d} \text{ and } y_{\text{dark}} = L\frac{(m + \frac{1}{2})\lambda}{d}$$ **(Linear position)**