Physics 1C

Lecture 27A

"*Any other situation in quantum mechanics, it turns out, can always be explained by saying, 'You remember the experiment with the two holes? It's the same thing.'* "

--Richard Feynman

Outline

- Ray diagrams, most easily understood by considering particle nature of light.
- Two mirror system.
- Interference, reflecting wave nature of light.
- Double slit experiment.
- Thin films.

Unregistered Clicker Scores

Microscope – two lens system

Two lenses – objective and eyepiece

Real image formed by objective

Becomes object for eyepiece

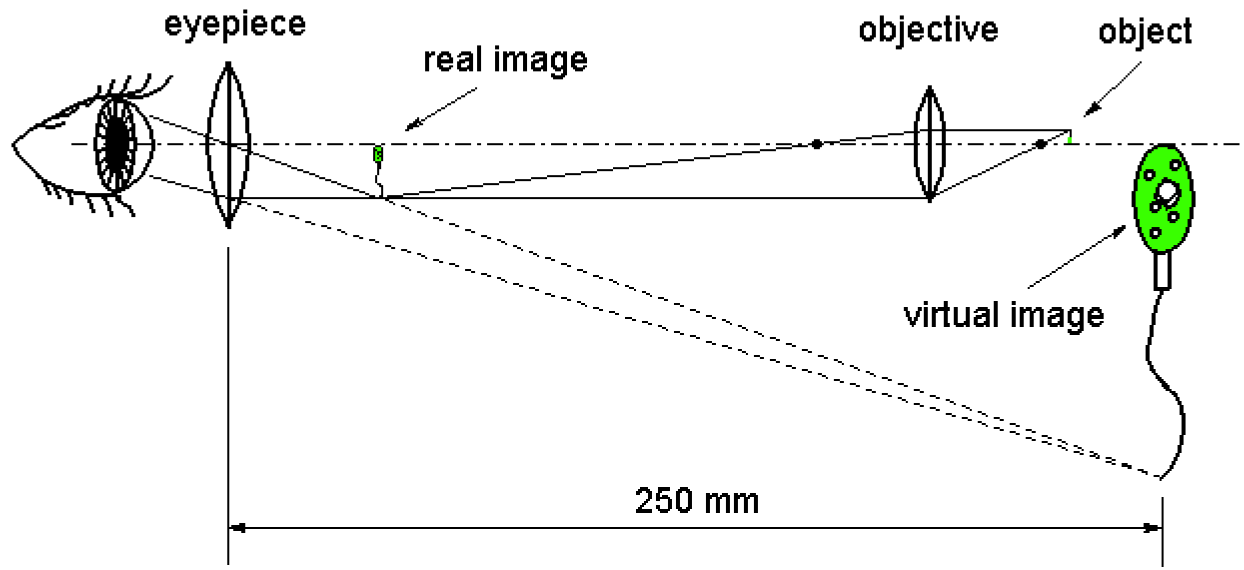


Fig. 7 - Compound microscope (schematic). Notice the likeness to the telescope scheme. What changes is the object distance from the two instruments.

Virtual enlarged image formed by eyepiece.

Magnification the product of those of the two lenses.

Interference

Treating light as a particle (geometrical optics) helped us to understand how images are formed by lenses and mirrors by constructing ray diagrams.

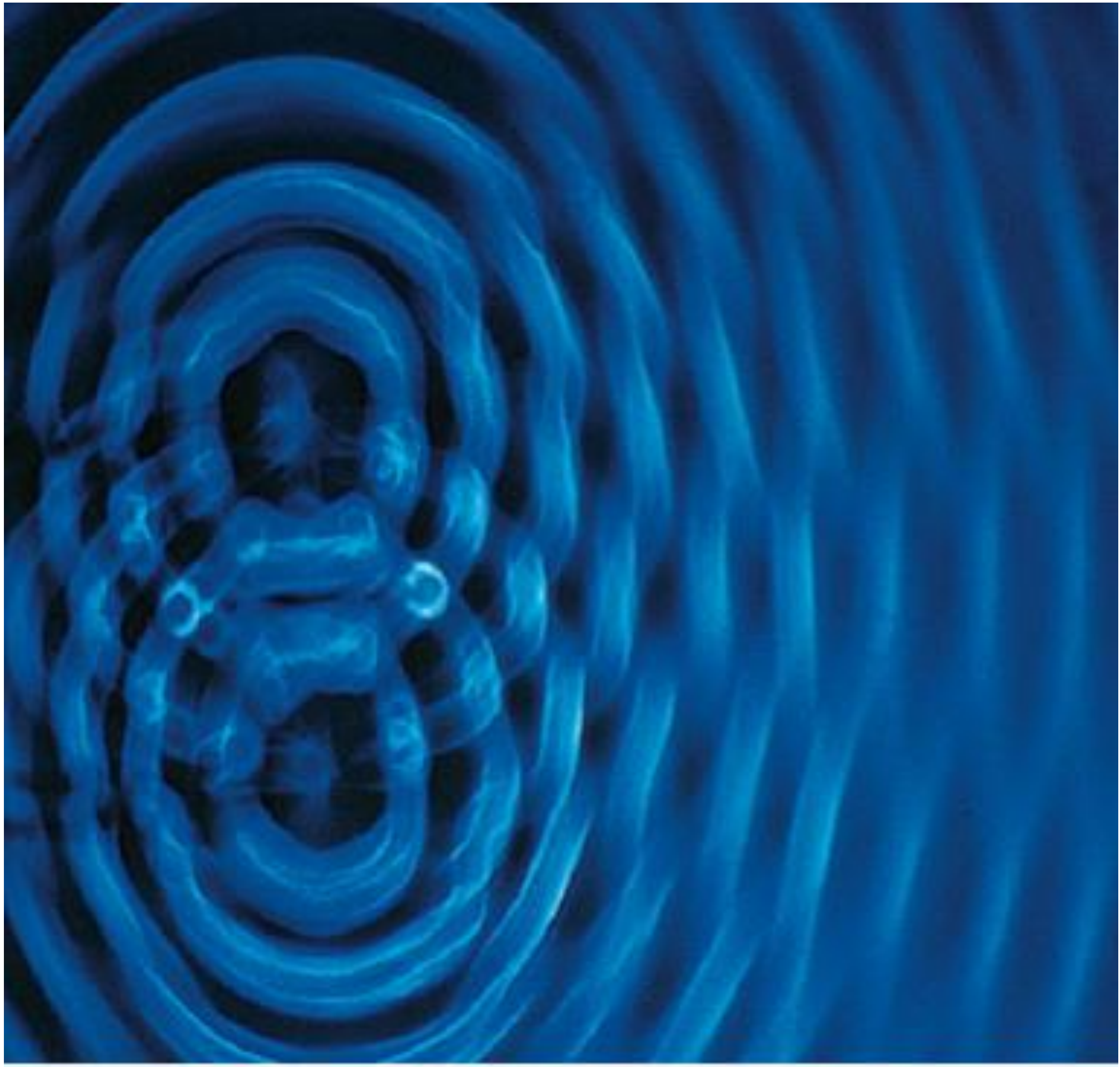
But we can understand different phenomena by treating light as a wave.

For example, light waves will interfere with each other just like the sound waves and waves on a string that we dealt with earlier.

This means we can get areas of constructive interference and destructive interference just like we had when we produced standing waves.

Interference

In order to create sustained interference, you need two sources with identical wavelengths (**monochromatic**) that are **coherent**.



Interference

Coherence means that the waves must maintain a constant phase with respect to each other. (Demo)

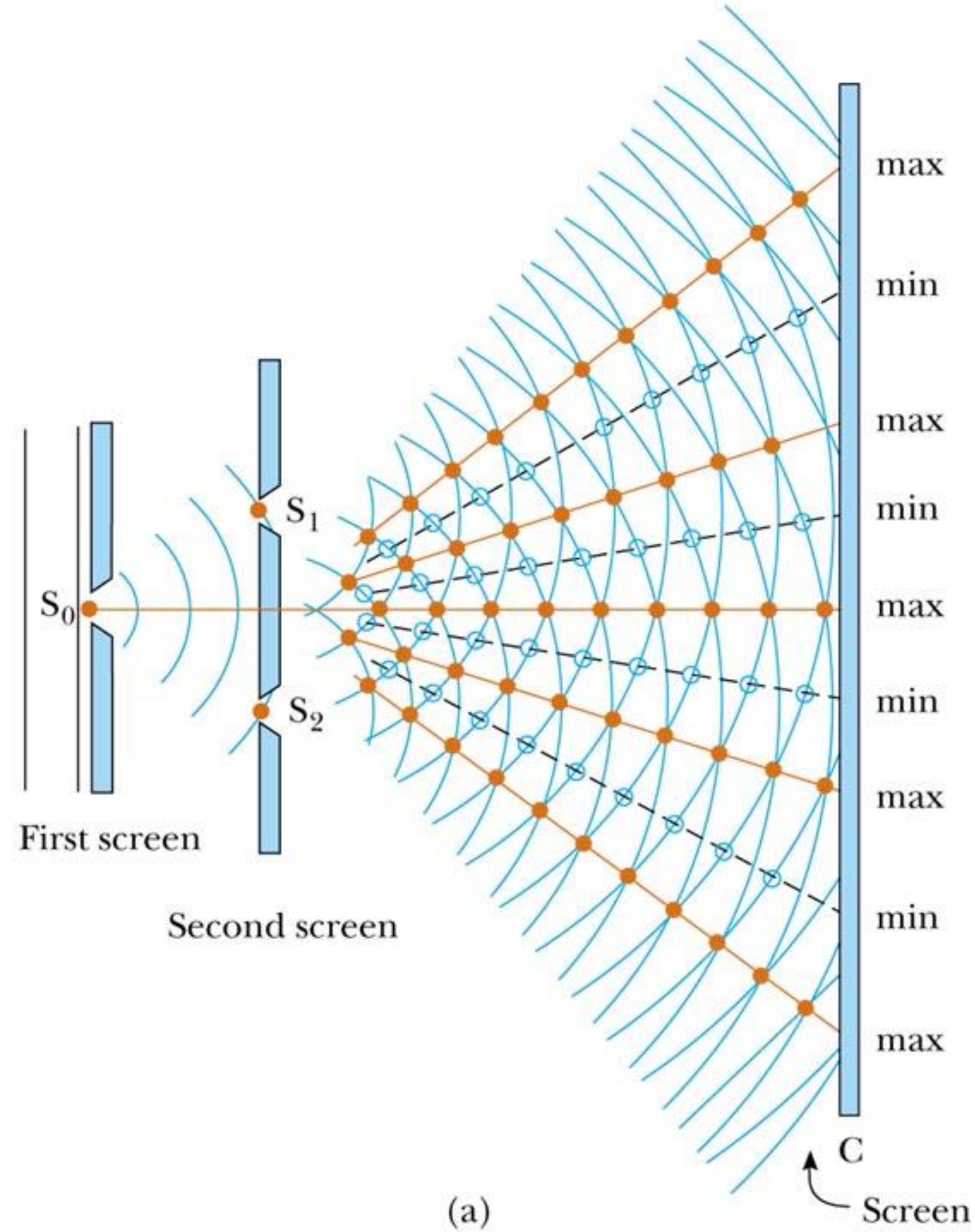
Double Slit Experiment

Two narrow slits, S_1 and S_2, can act as sources of waves.

The waves emerging from the slits originate from the same wavefront and therefore are always in phase (coherence).

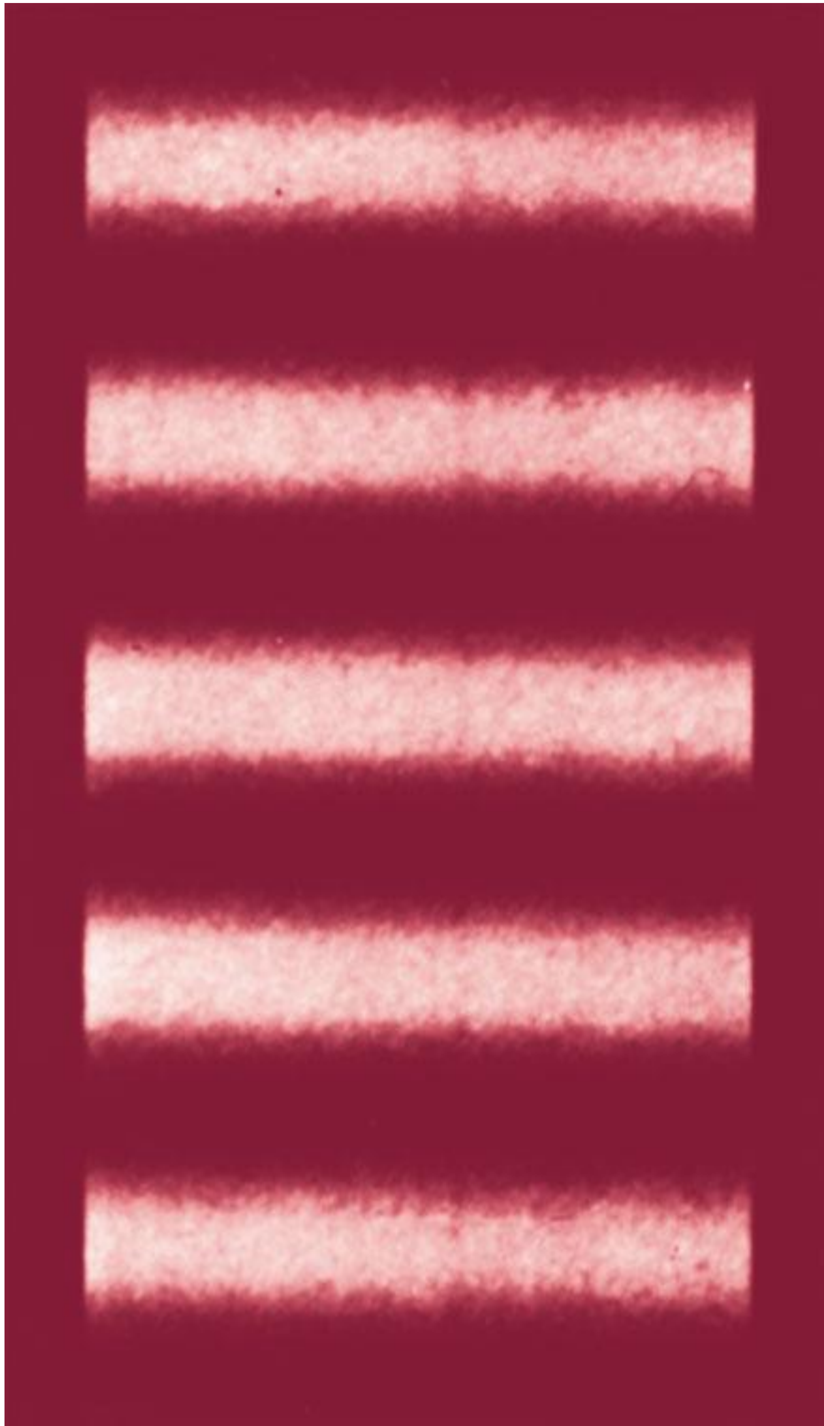
The light from the two slits forms a visible pattern on a screen.

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



Double Slit Experiment

The fringe pattern formed by a Young’s Double Slit Experiment would look like the picture to the right.



Alternating bright and dark fringes are created.

Constructive interference occurs where a **bright** fringe appears.

Destructive interference results in a **dark** fringe.

Double Slit Experiment

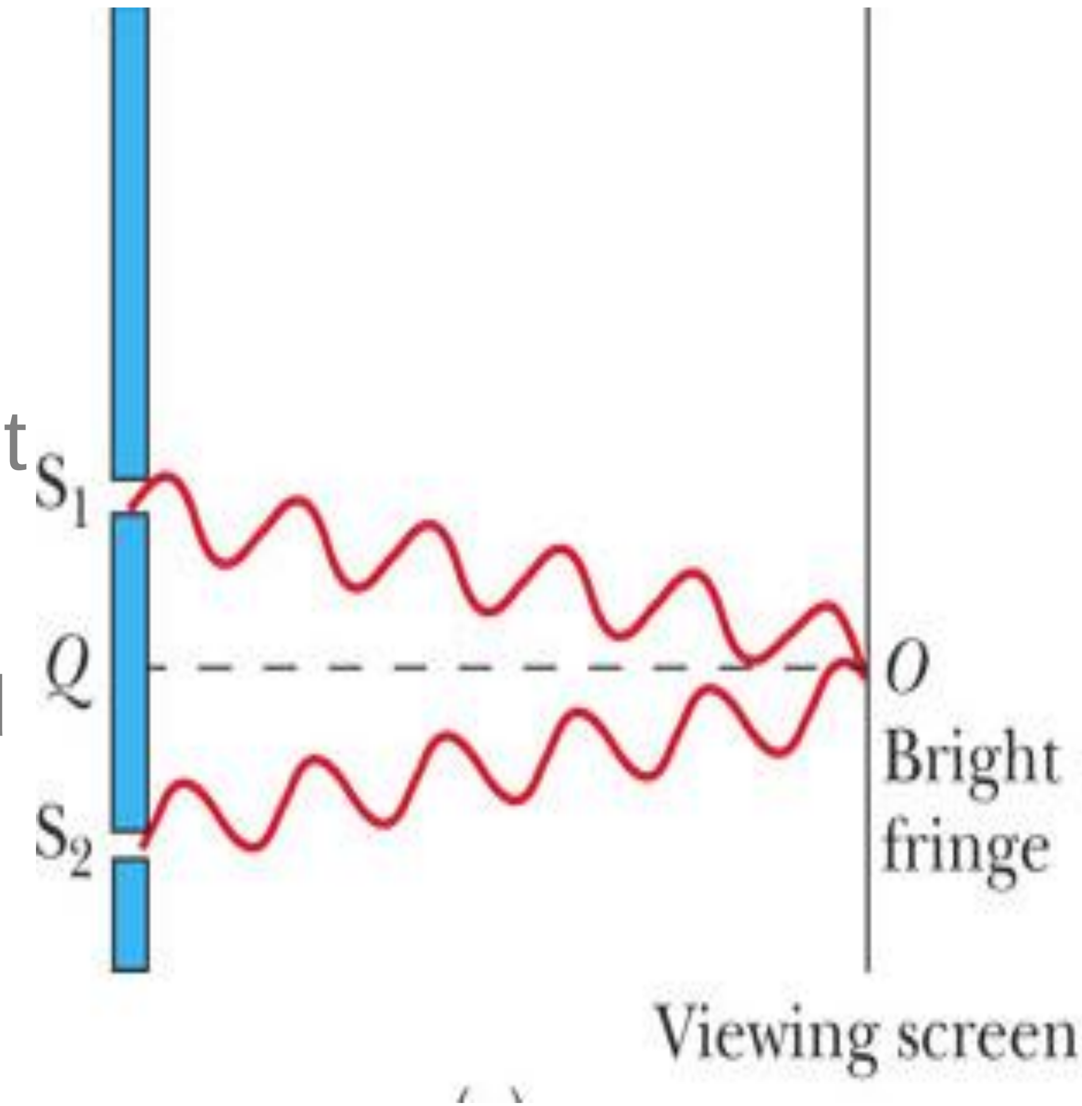
Constructive interference occurs at the center, *O*.

There is no path length difference between these two waves.

Therefore, they arrive in phase with each other.

This will result in a bright area on the screen.

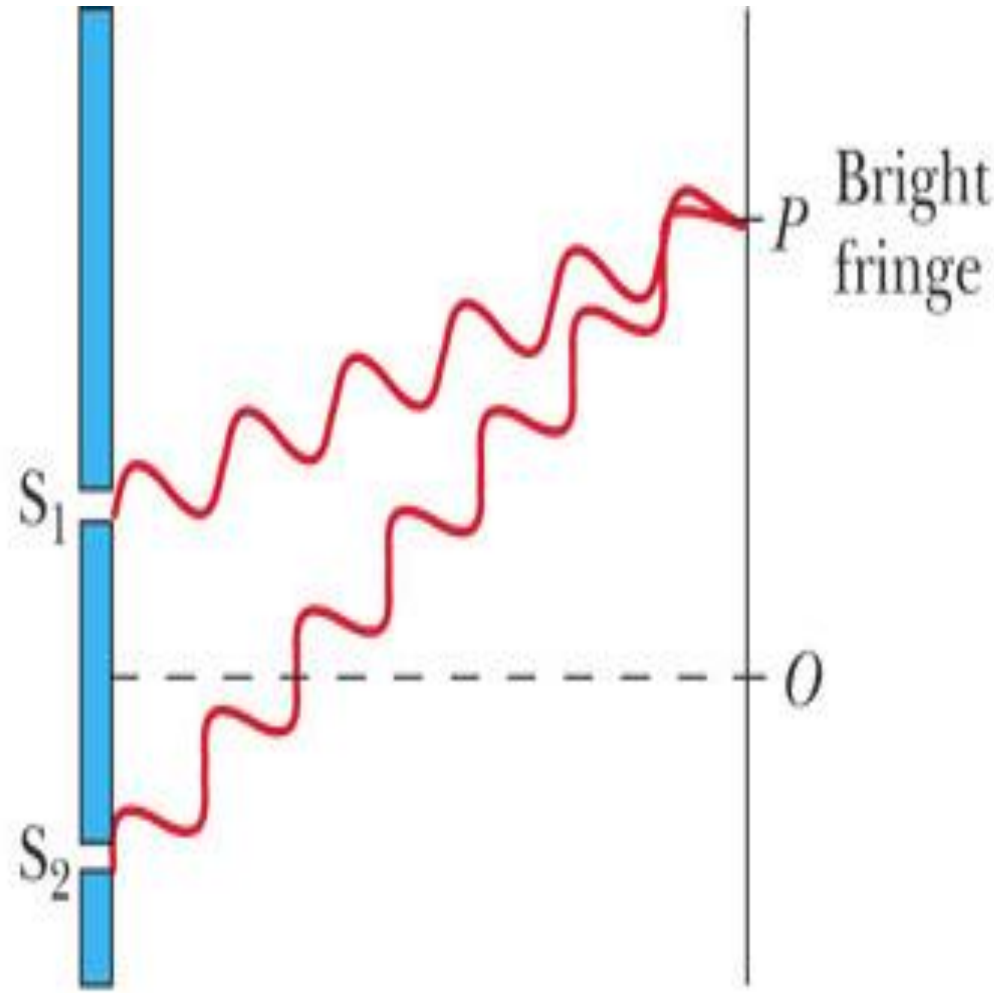
This bright spot is called the central maximum (**zeroth order maximum**).



Double Slit Experiment

If we moved to a spot, *P*, above the center spot, *O*, we find that the lower wave, S_2, travels farther than the upper wave, S_1.

If the lower wave travels one wavelength farther than the upper wave; the waves will still arrive in phase.



A bright spot will occur.

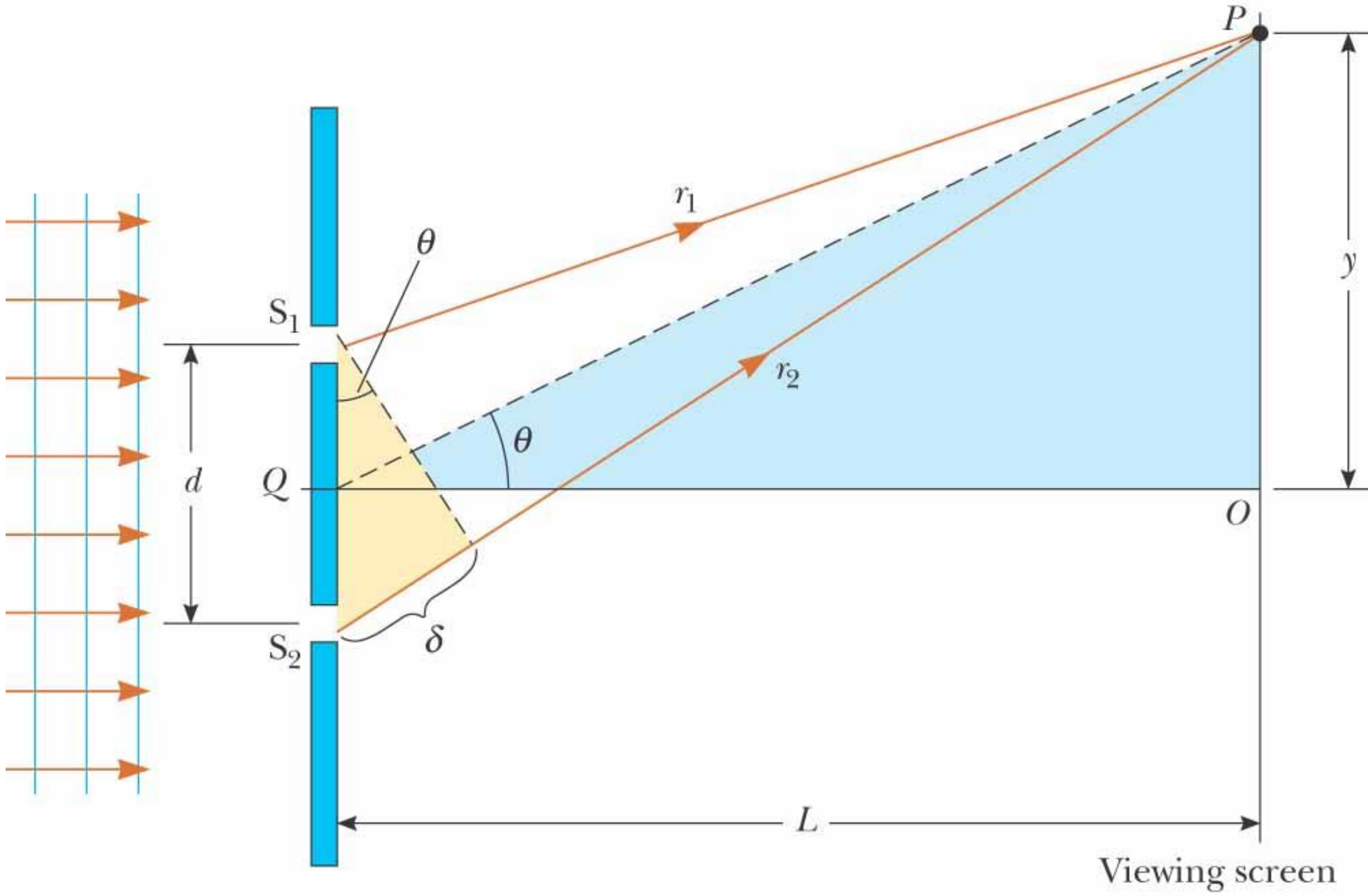
This bright spot is called the **first order maximum**. (Action Figure)

Double Slit Experiment

Looking at ray view of the particles of light, we see that for a point above the center spot the distance travelled by the lower wave, r_2, is longer than the upper wave, r_1.

The path length difference, δ, will be:

$$\delta = r_2 - r_1$$



Double Slit Experiment

What does the path length difference have to be in order to get constructive interference?

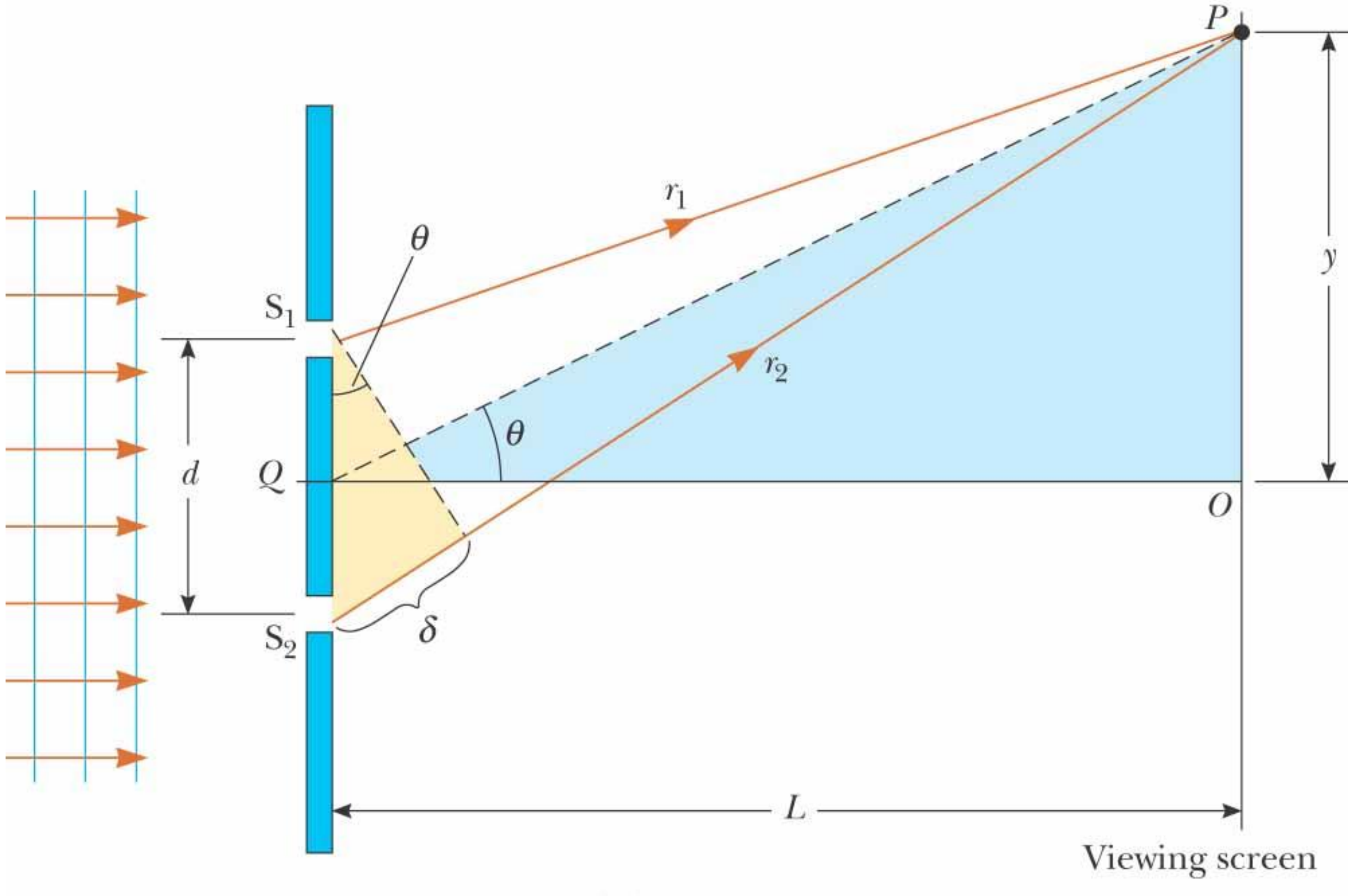
δ = 0 or λ or 2λ or ...

Basically any integer times the wavelength.

So for constructive interference to occur:

$$\delta = m\lambda$$

where *m* is 0, ±1, ±2, ...



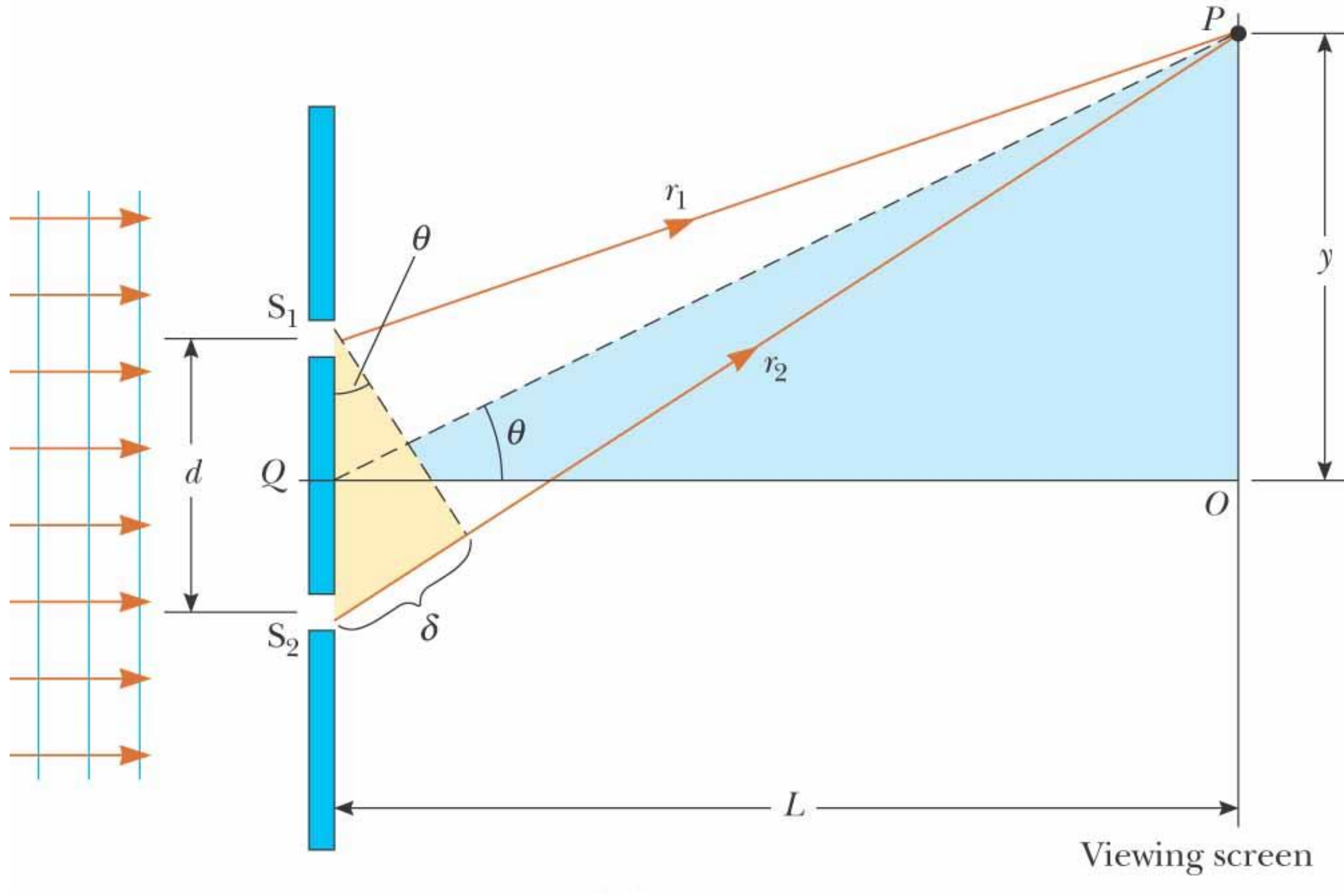
Double Slit Experiment

We define the line between the middle of the two slits and the central maximum as the centerline.

We also define an angle *θ* as the angle from the centerline to the fringe you are looking at.

The distance between the slits is labeled, *d*.

The central maximum has an angle of 0º.



Double Slit Experiment

Using trigonometry we find that the path length difference, *δ*, is related to the slit distance, *d*, and the angle *θ* by:

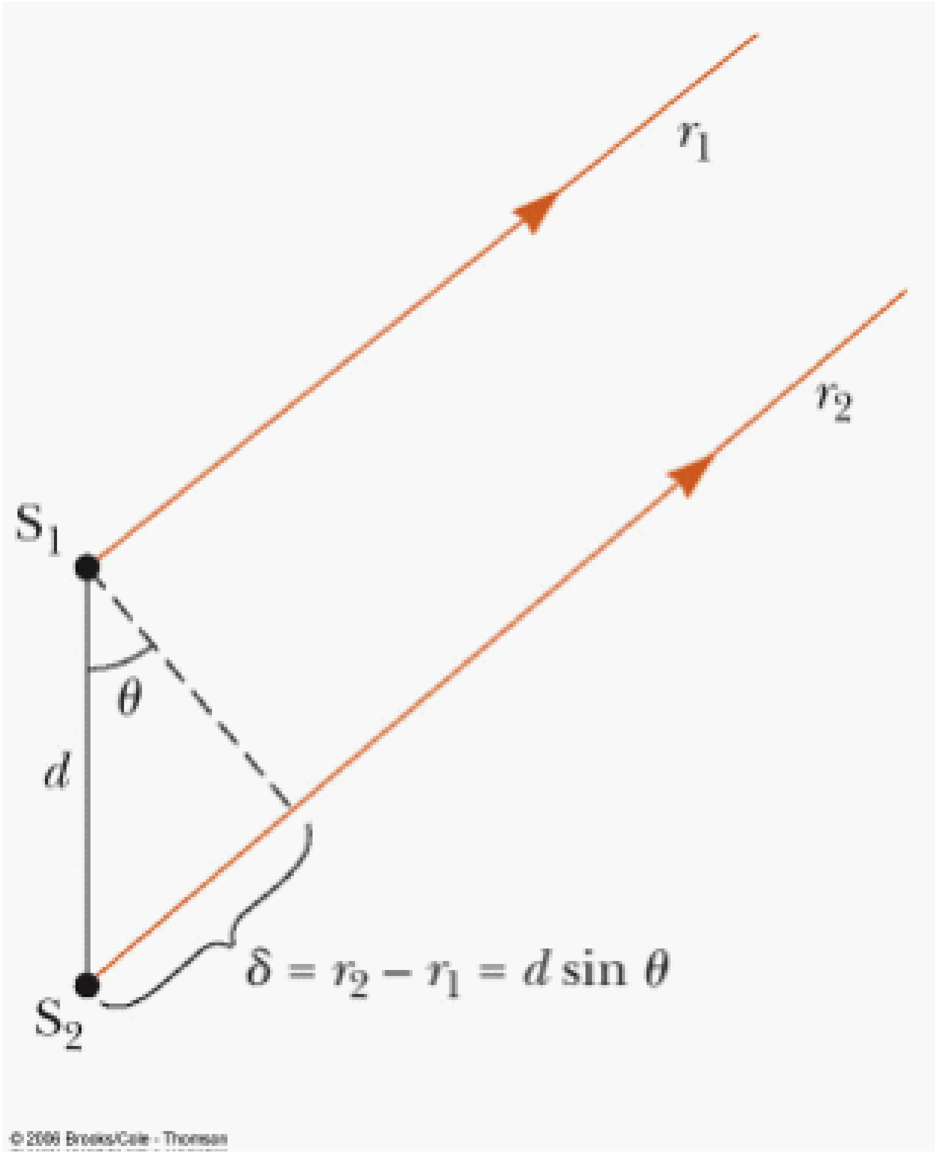
$$\delta = d\sin\theta$$

Thus, for constructive interference to occur:

$$\delta = m\lambda = d\sin\theta$$

where *m* is 0, ±1, ±2, ...

m is called the order number.



Double Slit Experiment

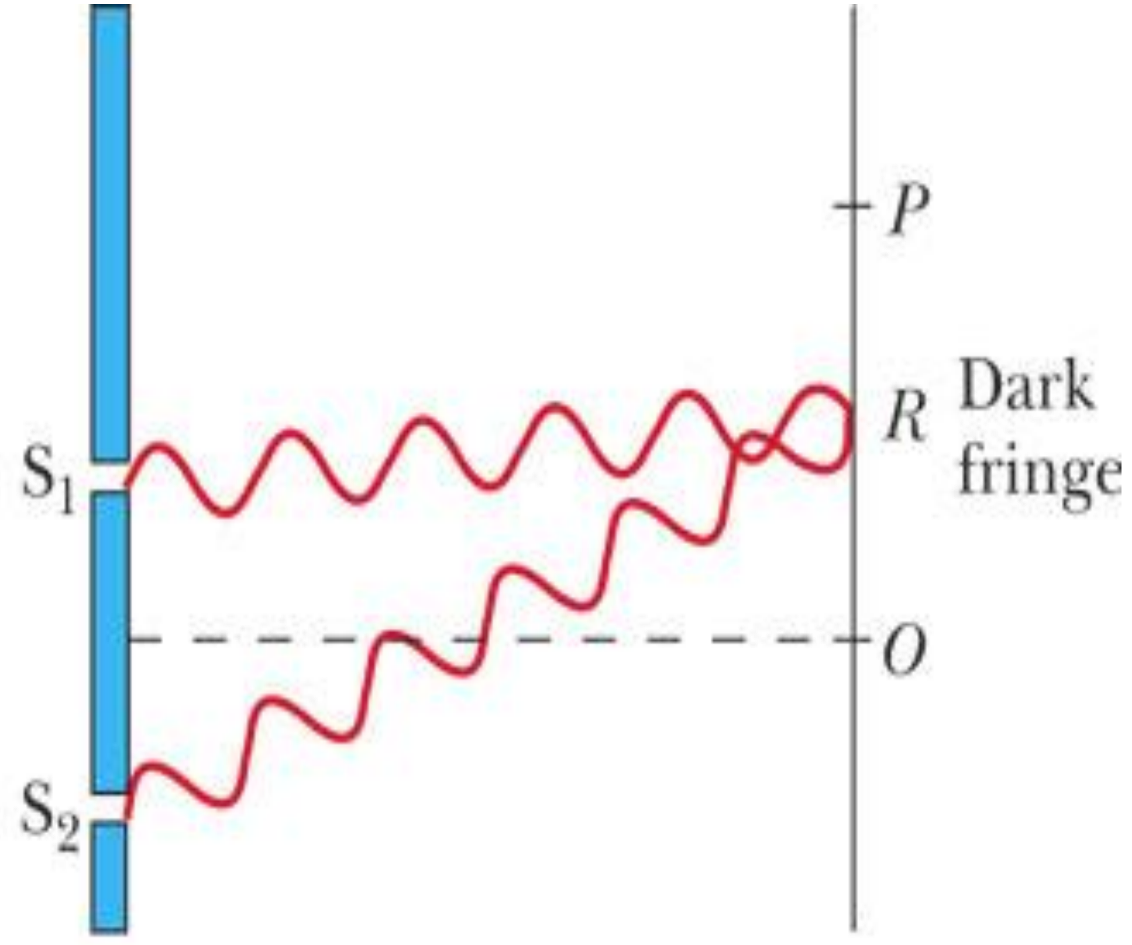
If we moved to a spot, *R*, halfway between *P* and *Q*, we would find a dark area.

The lower wave travels one-half wavelength farther than the upper wave; the waves will arrive out of phase.

This results in destructive interference.

In this exact case the path length difference would be:

$$\delta = r_2 - r_1 = \tfrac{1}{2}\lambda$$



Double Slit Experiment

What does the path length difference have to be in order to get destructive interference?

(1/2)λ or (3/2)λ or ...

Basically any half integer times the wavelength.

So for destructive interference to occur:

$$\delta = \left(m + \tfrac{1}{2}\right)\lambda$$

where m is 0, ±1, ±2, ...

And we can extend this to:

$$\delta = \left(m + \tfrac{1}{2}\right)\lambda = d\sin\theta$$

Double Slit Experiment

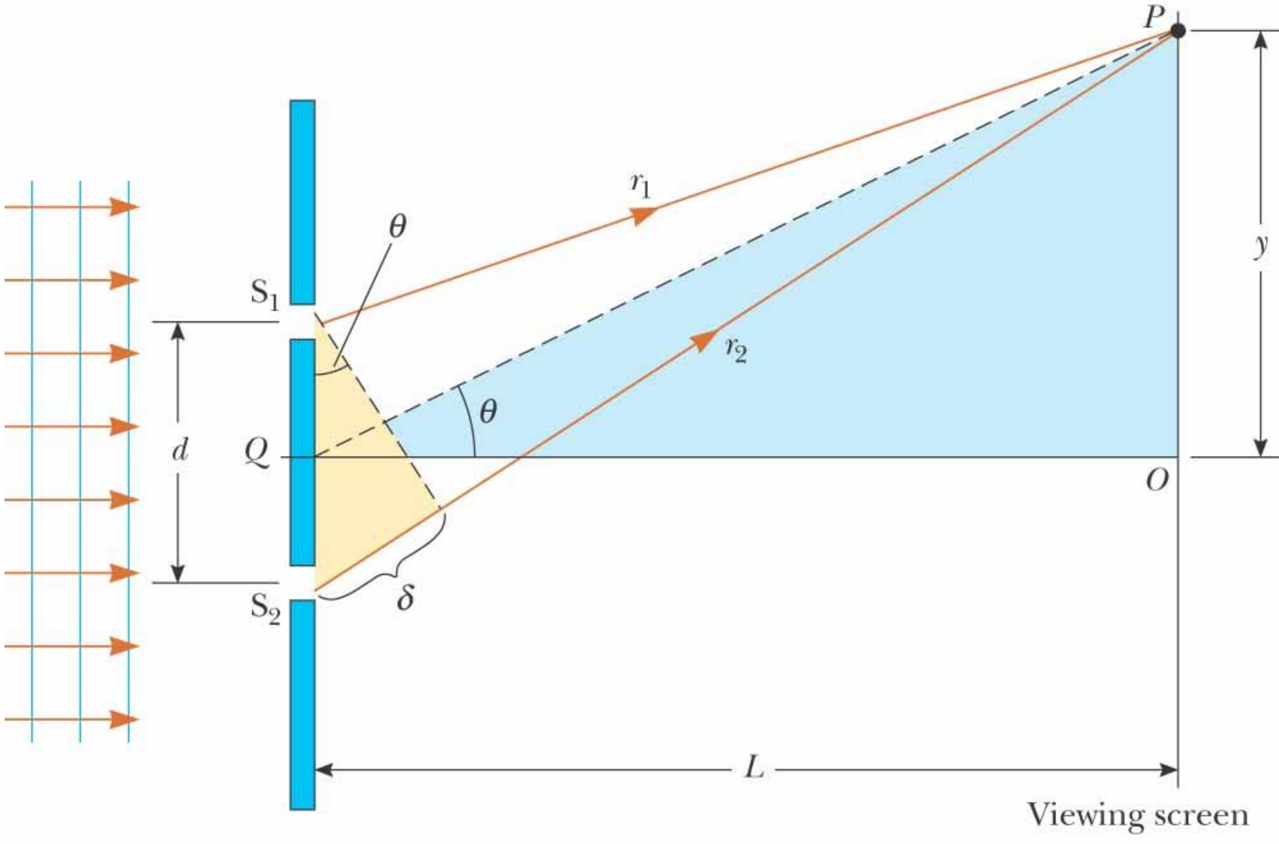
If the distance from the double slits to the screen, *L*, is much larger than the slit distance, *d*, then we can make an approximation.

The perpendicular distance, *y*, from the centerline to the fringe you are observing can be related by:

$$y = L\tan\theta \approx L\sin\theta$$

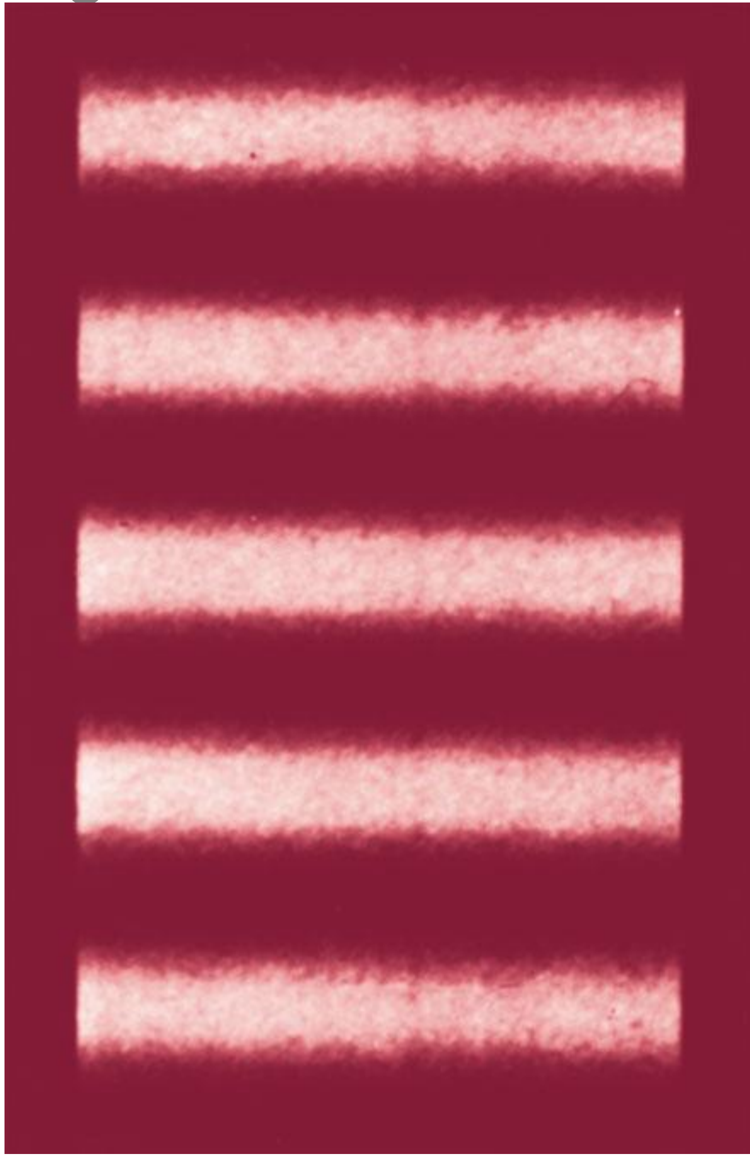
since at small angles:

$$\theta \approx \sin\theta \approx \tan\theta$$



Clicker Question 27A-1

Suppose the viewing screen in a double-slit experiment is moved closer to the double slit apparatus. What happens to the interference fringes?



A) They get brighter but otherwise do not change.

B) They get brighter and closer together.

C) They get brighter and farther apart.

D) No change will occur.

E) They fade out and disappear.

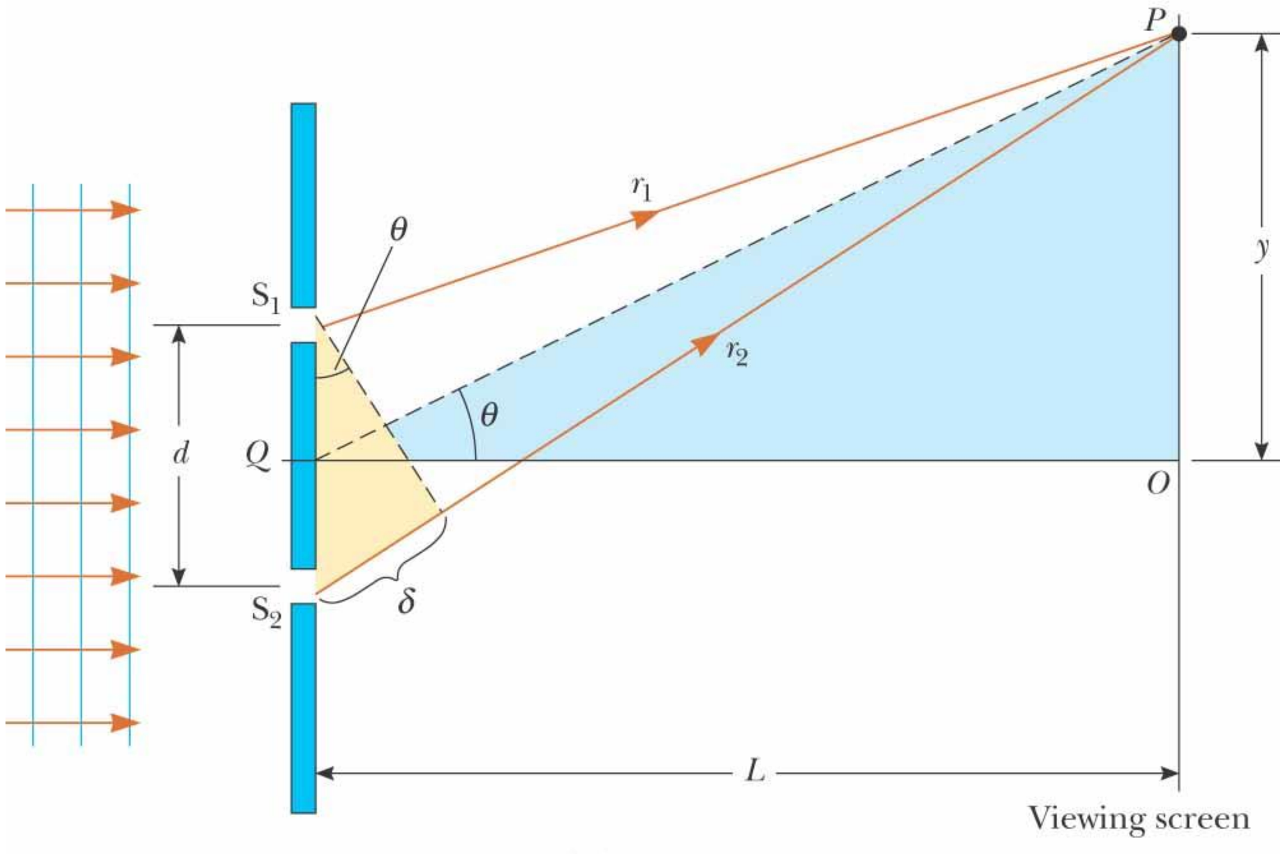
Double Slit Experiment

For small angles (*L* >> *d*), these equations can be combined and for bright fringes we get:

$$y_{bright} = L\left(\frac{m\lambda}{d}\right) \quad (m = 0, \pm 1, \pm 2 \ldots)$$

Note *y* is linear in the **order number** *m*, so the bright fringes are equally spaced.

Action figure



Double Slit Experiment

Young’s Double Slit Experiment provides a method for measuring wavelength of the light.

This experiment gave the wave model of light a great deal of credibility.

The bright fringes in the interference pattern do not have sharp edges.

The derived equations give the location of only the centers of the bright and dark fringes.

We can also calculate the distribution of light intensity associated with the double-slit interference pattern.

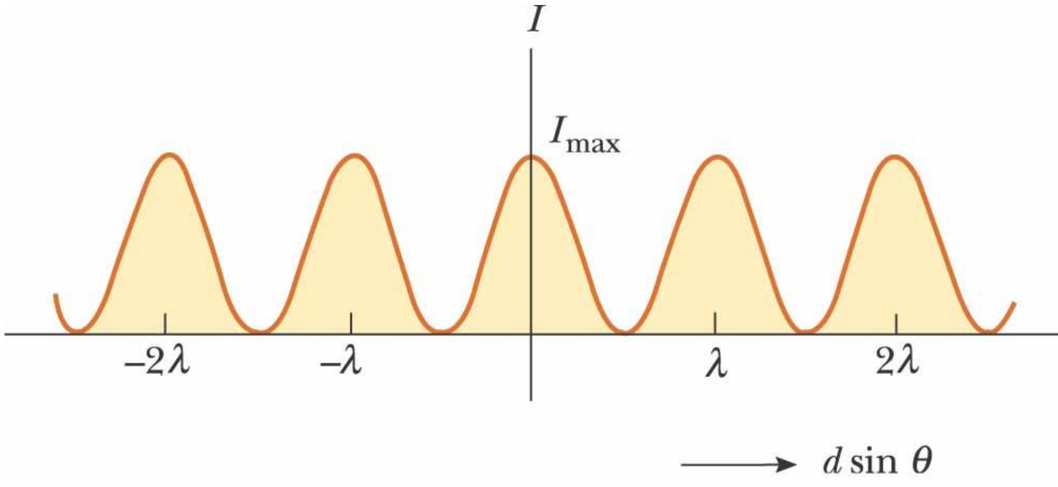
Double Slit Experiment

The interference pattern consists of equally spaced fringes of equal intensity.

This result is valid only if $L >> d$ and for small values of θ.

The phase difference between the two waves at *P* depends on their path difference.

The time-averaged **light intensity** at a given angle θ is



Interference in Thin Films

Have you ever looked a soap bubble and observed patterns of different colors?

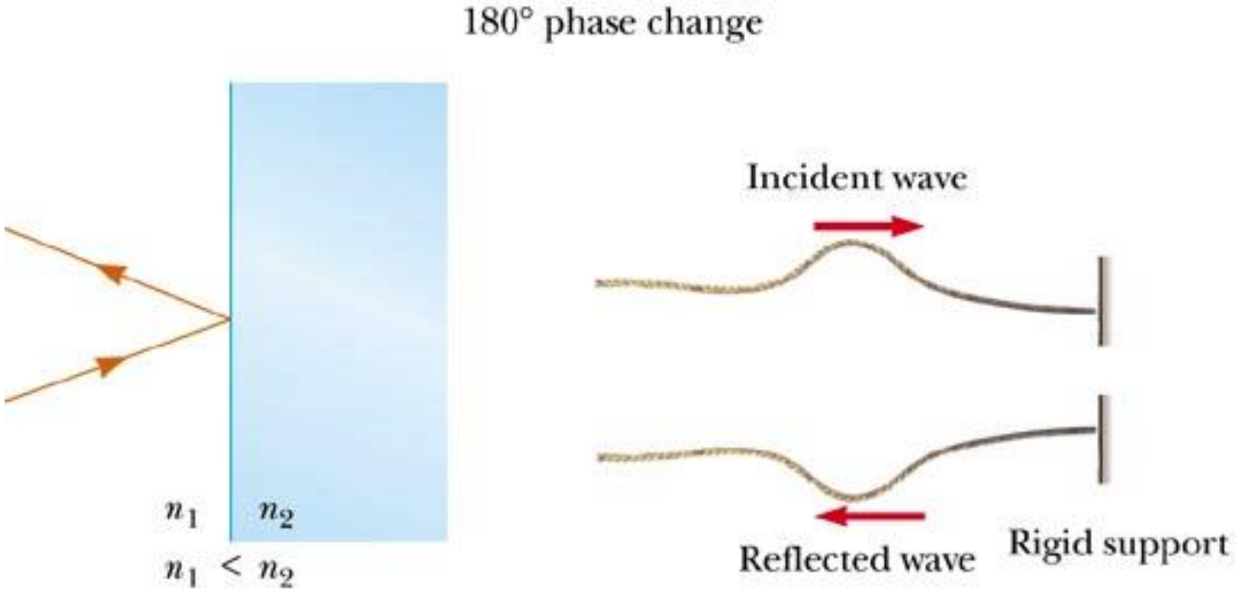
Light wave interference can also be observed in thin films (such as an oil film on water or soap bubbles).

The interference in thin films is caused by not only a **path length difference** but also by a **phase shift** as the light ray reflects off of a different medium.

Interference in Thin Films

A light wave will undergo a phase change of 180º upon reflection from a medium of higher index of refraction than the one in which it was traveling.

So, an electromagnetic wave traveling in air will undergo a 180º phase shift if it reflects off an oil surface.

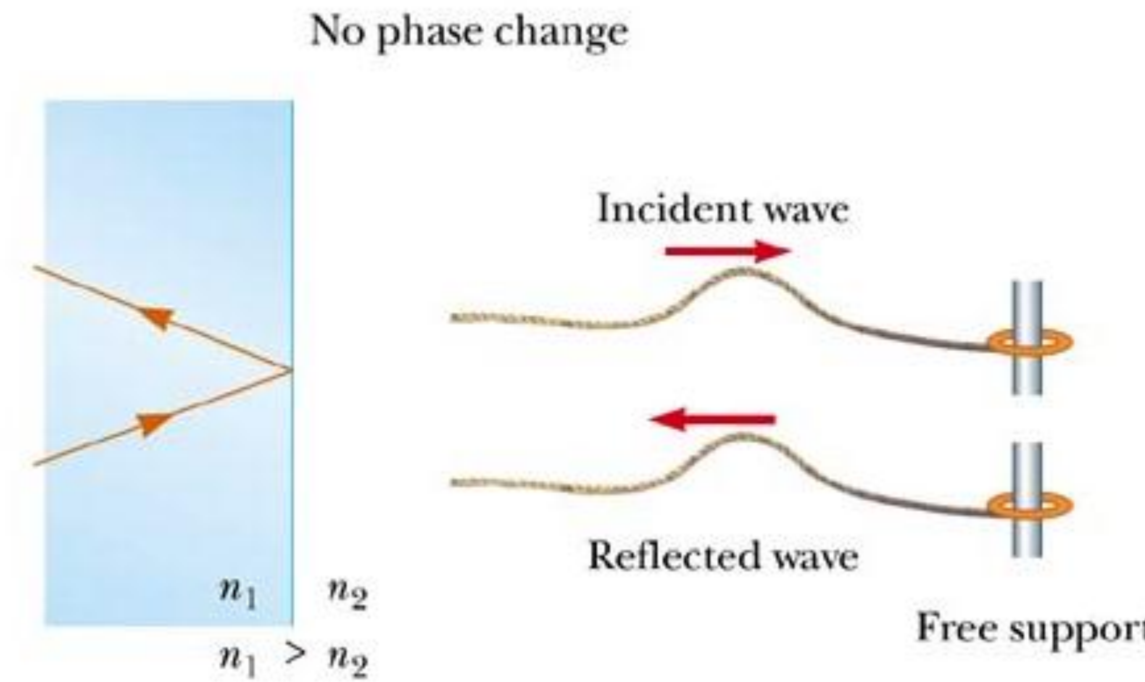


This is similar to the reflection of a transverse wave that we observed earlier off of a rigid surface.

Interference in Thin Films

A light wave will not undergo a phase change upon reflection from a medium of lower index of refraction than the one in which it was traveling.

So, a light wave traveling in oil will not undergo a phase shift if it reflects off an air boundary.



This is similar to the reflection of a transverse wave that we observed earlier off of a free surface.

For Next Time (FNT)

Continue reading Chapter 27

Start homework for Chapter 27