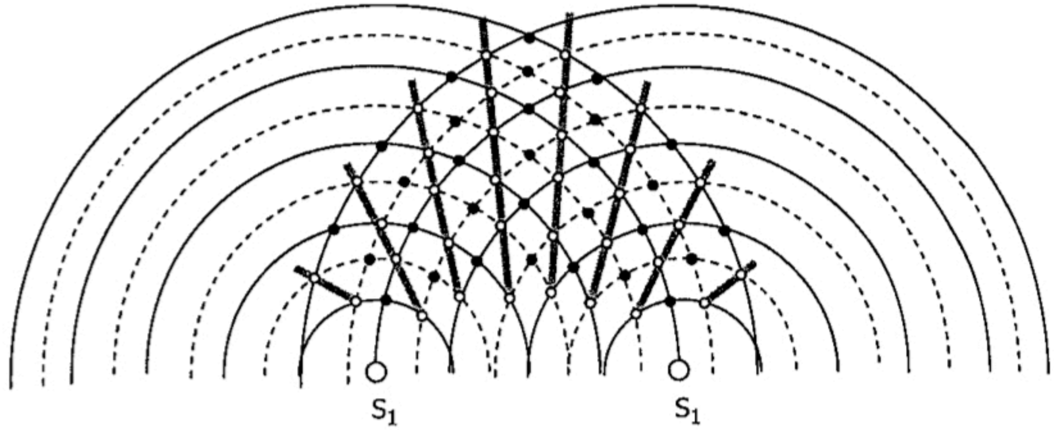
Young's Experiment

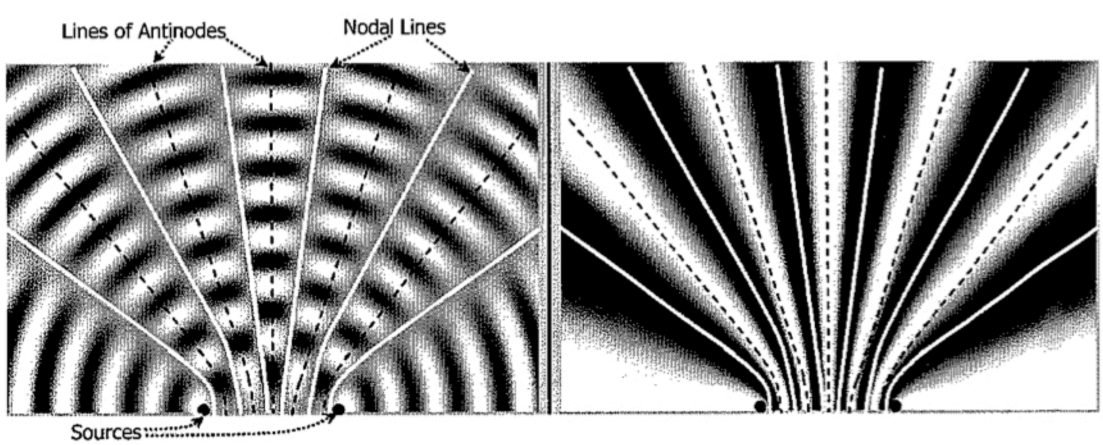
The research by Thomas Young (1773-1829) into the interference of light was critical in demonstrating that light has wave-like properties. His famous experiment has become known as Young's experiment.

In our study of waves in two dimensions, we learned that waves generated by two point sources interfere with each other to produce areas of constructive and destructive interference, as shown below.



In this diagram, the empty circles represent areas of destructive interference, where troughs and crests meet. The shaded circles represent areas of constructive interference, where crest meets crest or trough meets trough. The lines connecting the empty circles are the nodal lines.

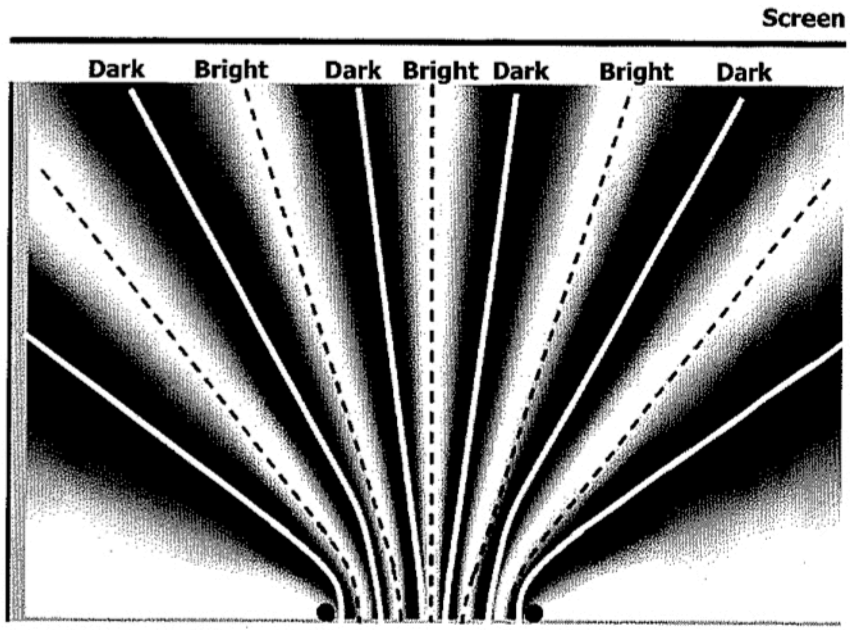
If light has wave properties, then two sources of light waves should produce a result similar to that for waves in a ripple tank. In the image below, the picture on the left shows the interference pattern formed by two point source waves in a ripple tank. The picture on the right shows how this pattern should appear for two point sources of light.



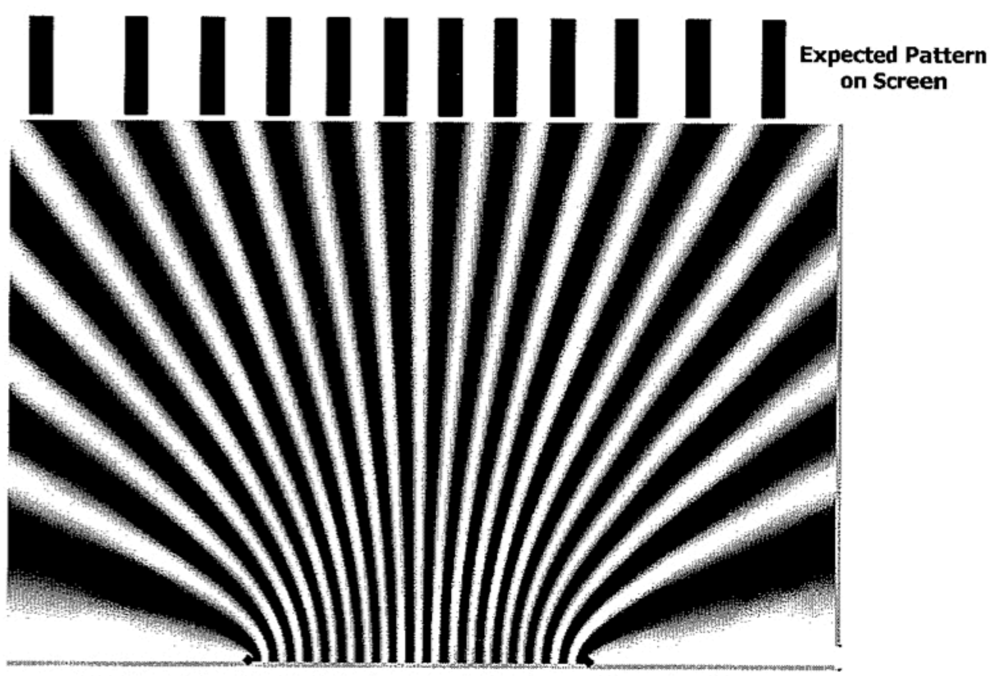
Ripple Tank Pattern of Displacement on Water's Surface Showing Lines of Nodes and Antinodes

This is the ripple tank pattern of light intensity showing the dark lines of nodes and the bright lines of antinodes.

Notice that, in the case of light, the nodal lines (areas of destructive interference) are dark, and the antinodal lines (areas of constructive interference) are bright. If a screen was placed some distance away from the two point sources, then we would expect to see a pattern on the screen consisting of alternating bright and dark lines, as shown below.



The light from two sources of light placed side by side should interfere and cast on a screen a pattern of alternating bright and dark lines.



As more nodal lines appear in the interference pattern, the lines become more evenly spaced apart.

In Newton's time, many scientists attempted to observe the interference of light. In most cases, they placed two sources of light side by side. The light from the two sources, falling on a nearby screen, was carefully examined but no interference was observed.

There were two main problems with the methods used by these early scientists. The first was that the wavelength of light was unknown. By examining the interference pattern for two point source waves, it is evident that as the wavelength gets smaller, there are more nodal lines produced. In addition, the nodal lines get closer together. If the wavelength of the waves is small enough, the distance between two nodal lines becomes too small to see. Thus, in these early experiments, any interference pattern would have been too small to see.

The second problem was that the scientists used white light. In order for an interference pattern to be visible, both sources must produce the same frequency of light. Unfortunately, white light is a blend of all frequencies, so it should not show any interference pattern. Thus, we would need to use light that is **monochromatic** – that is, of only one color. Even better would be two monochromatic light sources that are **in phase**.

Young's Experiment

Thomas Young addressed these problems in a very clever way. He sent a beam of monochromatic light through a single slit. When this light then spread out a little, he placed a second barrier in the way that had two very small slits, placed very close together. The light coming from the original slit struck the following two slits at the same time, and continued through them. Since the first slit is acting as the source for both of them, the light emerging from the two new slits has the same frequency and is in phase. Thus, it should produce an interference pattern exactly like the one we have described earlier.

A light source sends out light waves towards a single slit in a barrier. | The single slit acts as a point source sending out wave fronts that arrive at the two slits at the same time (in phase). | The two slits act as two point sources producing the usual interference pattern.

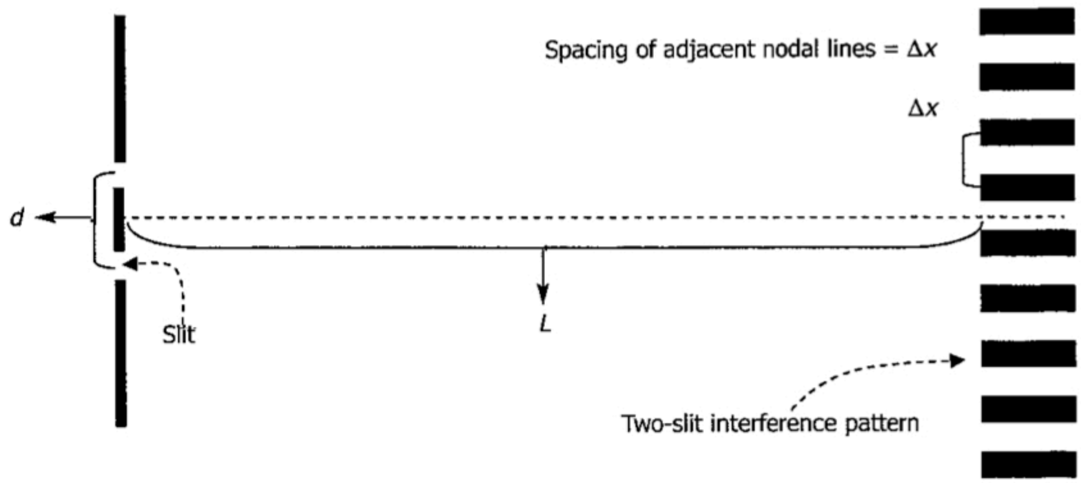
This experiment, now commonly called Young's experiment, solved the two major problems in observing the interference of light and provided very strong evidence for the wave model of light.

Young's Equation

For a two-slit interference pattern, the spacing of adjacent nodal lines, Δx, is given by the product of the wavelength of the light, λ, and the distance from the slits to the screen, L, divided by the separation of the slits, d.

$$\Delta x = \frac{\lambda L}{d}$$

Any unit of length may be used, but **the units must be the same for each quantity in the equation**.



In Young's equation, you can see that the spacing of the nodal lines in a two-slit interference pattern varies with each of the other three quantities – wavelength, distance from slits to screen, and separation of the slits. Specifically:

- the longer the wavelength, the farther apart the nodal lines
- if the distance to the screen increases, so does the spacing of the nodal lines
- if the spacing of the slits is increased, the spacing between the nodal lines decreases

Example 1

In a typical Young's experiment, red light of wavelength $612\ nm$ is used. The pattern is viewed at a distance of $2.50\ m$ with a viewer that had the slits separated by $0.158\ mm$. What is the spacing of the nodal lines?

Example 2

What would the spacing be for the nodal lines in Example 1 if blue light ($\lambda = 452\ nm$) was used instead of red light?

Example 3
Suppose we use red light ($\lambda = 612\ nm$) to view a pattern from two slits at a distance of $3.25\ m$. The spacing of the nodal lines is $1.25\ cm$. What is the separation of the slits?

Electromagnetic Theory of Light

At the end of the 1800s, a man by the name of James Clerk Maxwell combined electricity, magnetism, and light into one masterful theory. He called his theory the electromagnetic theory of light.

According to Maxwell, light was an electromagnetic wave with the same properties as other electromagnetic waves (such as radio waves). Light was, in fact, shown to be nothing more than electromagnetic waves of a particular frequency.

Physicists during this time became so confident in their physics that they felt they had everything worked out except for a few small details. Newton's laws appeared to be able to explain motion entirely, and Maxwell's theory appeared to be able to explain all there is to know about such things as light, radio waves, etc.

One of the small details that still needed to be worked out was the photoelectric effect, which we shall examine in an upcoming lesson.

Worksheet

1. A student is measuring the wavelength of light produced by a sodium vapor lamp. The light is directed through two slits with a separation of $0.15\ mm$. The interference pattern was created on a screen $3.0\ m$ away. The student found that the distance between the first and eighth consecutive dark lines was $8.25\ cm$. What was the wavelength emitted by the sodium vapor lamp? ($589\ nm$)

2. An interference pattern is formed on a screen when a helium-neon laser light ($\lambda = 632.8\ nm$) is directed towards it through two slits. If the slits are $43\ \mu m$ apart and the screen is $2.5\ m$ away, what will be the separation of adjacent nodal lines? ($3.68\ cm$)

3. Two slits have green light of wavelength $525\ nm$ passing through them. The interference pattern is observed at a distance of $1.75\ m$. The distance from the first dark line to the eighth dark line is $10.2\ cm$.

   a) What is the spacing of the nodal lines? ($1.46\ cm$)
   b) What is the separation of the slits? ($63.1\ \mu m$)

4. Violet light falls on two slits separated by $1.90 \times 10^{-5}\ m$. The first-order bright line appears $13.2\ mm$ from the central bright line on a screen $0.60\ m$ from the slits. What is the wavelength of the violet light? ($418\ nm$)

5. Yellow-orange light from a sodium lamp of wavelength $596\ nm$ is aimed at two slits separated by $1.90 \times 10^{-5}\ m$. What is the distance from the central bright line to the first-order bright line, if the screen is $0.60\ m$ from the slits? ($18.8\ mm$)

6. In a double-slit experiment, physics students use a laser with a known wavelength of $632.8\ nm$. The slit separation is unknown. A student places the screen $1.0\ m$ from the slits and finds the first-order bright line $65.5\ mm$ from the central line. What is the slit separation? ($9.66\ \mu m$)

7. A double slit apparatus, $d = 15\ \mu m$, is used to determine the wavelength of an unknown green light. The first-order bright line is $55.8\ mm$ from the central line on a screen that is $1.6\ m$ from the slits. What is the wavelength of the light? ($523\ nm$)

8. Light falls on a pair of slits $19\ \mu m$ apart and $80.0\ cm$ from the screen. The first-order bright line is $1.90\ cm$ from the central bright line. What is the wavelength of the light? ($451\ nm$)

9. Light of wavelength $542\ nm$ falls on a double slit. First-order bright lines appear $4.0\ cm$ from the central bright line. The screen is $1.2\ m$ from the slits. How far apart are the slits? ($16.3\ \mu m$)