## OPTICAL METHODS Back to Basics *by Gary Cloud*

# Optical Methods in Experimental Mechanics

## Part 6: Another Classic Interferometry: Young's Experiment

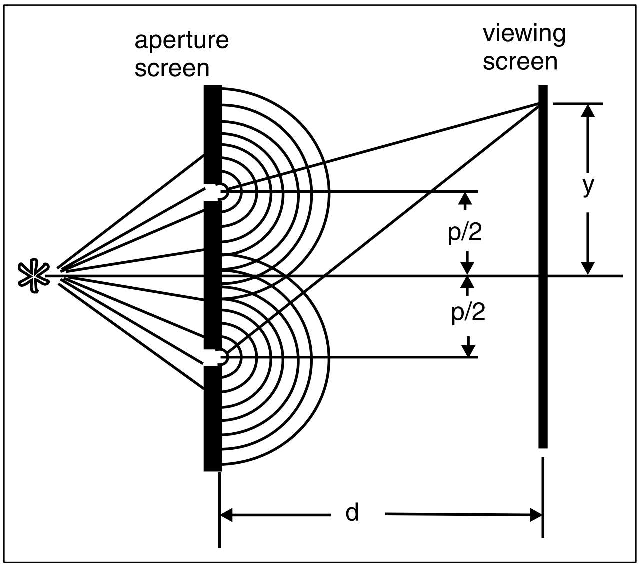
### REVIEW AND PURPOSE

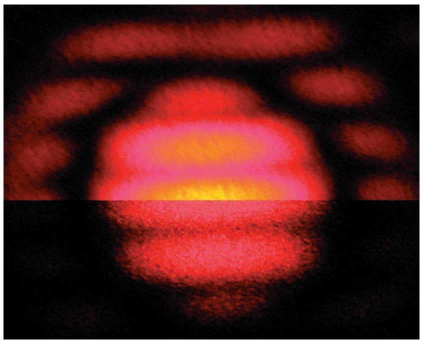
Part 5 described Newton's fringes as a first example of a "classic interferometry." In this segment, a second example of a classic interferometric experiment is described. Young's experiment is historically important, it is a valuable instructional paradigm, and it is a good fundamental example of diffraction at an aperture. It is also of fundamental importance in several measurement techniques, including speckle interferometry.

### Young's Experiment

In 1801–2 (75 years after Newton's death) Thomas Young (1773–1829) conducted an elegantly simple experiment that confirmed for the first time the wave theory of light that had been founded by Christiaan Huygens (1629–1695) a century or so earlier and well in advance of Newton's work in optics. Young's results were rejected, even derided, for many years because they contradicted the then-dominate particulate theory that had been espoused by Newton (1643–1727), who was, by then, approaching sainted status. Young was an epic prodigy. Among his awesome contributions were demonstration of the elastic properties of materials and the first decoding of the rosetta stone.

Here is a schematic of Young's setup:





*Young's fringes created using HeNe laser and pinholes in aluminum foil. Top portion of photograph is overexposed to show modulation of Young's fringes by diffraction pattern from circular apertures (Airy disc) resulting in rapid decrease of intensity with distance from optical axis and interruption of fringes. Bottom portion is properly exposed to show fringes.*

*Digital photos and composite by Gary Cloud, Jan. 2003.*

*Young's experiment:*

- *demonstrated the wave nature of light for the first time*
- *confirmed the wave theory devised by Huygens a century earlier*
- *contradicted the particulate theory of Newton.*

---

***Editor's Note:*** Optical Methods: Back to Basics, *is organized by ET Technical Editor, Kristin Zimmerman, General Motors, and written by Prof. Gary Cloud (SEM Fellow) of Michigan State University in East Lansing, MI. The series began by introducing the nature and description of light and will evolve, with each issue, into topics ranging from diffraction through phase shifting interferometries. The intent is to keep the series educationally focused by coupling text with illustrative photos and diagrams that can be used by practitioners in the classroom, as well as in industry. Unless noted otherwise, graphics in this series were created by the author.*

*The series author, Prof. Gary Cloud (SEM Fellow), is internationally known for his work in optical measurement methods and for his recently published book* Optical Methods of Engineering Analysis.

*If you have any comments or questions about this series, please contact Kristin Zimmerman, Kristin.b.Zimmerman@gm.com.*

An opaque aperture screen containing two tiny holes or slits very close together is illuminated. One might expect that shadows of the slits would appear on the viewing screen that is placed downstream from the apertures. Instead, a broad illuminated halo is seen, and this halo contains interference fringes such as are shown in the photo above. How can this happen?

Two different approaches predict the formation, orientations and spacings of the fringes seen in Young's experiment. The sophisticated method is to treat the problem as one involving diffraction at an aperture, which implies that the pattern observed is the Fourier transform of the aperture function. Diffraction theory was not available to Young, and it has not yet been discussed in this series of articles. A simpler analysis is based on Huygens' Principle, which allows an illuminated aperture to be replaced by an array of point sources of light.

*Young's fringes are explained in two ways:*

- *diffraction theory*
- *a geometric construction based on Huygens' Principle.*

In applying the principle to the problem at hand, the two slits are assumed to be linear arrays of point sources of coherent light (kind of a leap of faith). Spherical wavefronts radiate outward from these sources. The figure offers a hint as to what happens. The two sets of waves eventually overlap and interfere in a way that is similar to oblique interference of two beams as discussed in Part 4 of this series. This interference creates a 3-dimensional system of fringes, a cross section of which appears on the viewing screen.

*The apertures are considered to be point sources that emit spherical wavefronts. The waves overlap and create an interference pattern in space. A viewing screen shows a cross section of this pattern.*

To quantify the result, calculate by the Pythagorean Theorem the path length difference (PLD) between the waves that arrive at any point on the screen from each of the two slits. The solution is simplified by assuming that the distance to the screen is much larger than the separation of the slits (a paraxial approximation). Since slits are used, the problem is merely two-dimensional. The result is,

$$y = \frac{N\lambda d}{p}$$

where: $y$ = distance to a bright fringe
$d$ = distance from aperture plane to observing screen
$p$ = distance between the slits
$\lambda$ = wavelength of light
$N = 0, 1, 2, \ldots$ = fringe order

*The spacing or order of Young's fringes depends on:*

- *distance between the apertures*
- *distance to the viewing plane or screen*
- *wavelength of light.*

Diffraction theory shows this solution to be correct except for a missing obliquity factor, meaning it does not explain the observed fact that the fringe brightness diminishes with increased distance from the optical axis.

Young's fringes are of the "wavefront division" category, because different waves from the cross section of the beam are brought together to interfere.

*Young's fringes are an example of "interferometry by wavefront division."*

In addition to teaching the wave nature of light, Young's experiment demonstrates basic two-beam interference; in this case, the wavefronts are actually spherical or cylindrical depending on whether holes or slits are used.

*Young's experiment:*

- *teaches much about the nature of light*
- *demonstrates two beam interference*
- *is an example of diffraction at an aperture*

## Demonstration and application

Young's experiment is quite easy to reproduce with minimal equipment. Use a fine pin to punch a pair of small holes as close together as you can manage in a slip of aluminum foil. A magnifier helps, and, while you are at it, punch several pairs of holes in the foil and mark their locations with ink so you can find them easily. The reason for making several pairs of holes is that most of them will not work very well because the holes are not round, do not match, or are too far apart. If you would rather use slits than holes, you can scratch parallel lines through the emulsion in a fogged and developed photographic plate or film. Put the foil in front of a light source in a darkened room and look for the fringes on a screen that is placed a meter or so downstream. If using a point light source, you will need to mask off the unused holes. It is far simpler to use a laser – an inexpensive laser pointer serves very well in giving highly visible fringes. The only problem with the laser is that it can be difficult to zero in on the hole pairs.

A significant application of Young's fringes is in speckle photography for measuring displacement. The speckle pattern in the image of a specimen illuminated with a laser is captured on film. The specimen is then displaced and a second exposure is taken. The doubly exposed film contains a multitude of aperture pairs. The separation of the apertures in each pair is equal to the local surface displacement vector in image space. When the doubly exposed speckle photograph is interrogated with a laser beam, Young's fringes form. These fringes allow determination of both the magnitude and direction of the local specimen displacement.

*One practical application of Young's fringes is in speckle photography for measuring displacement:*

- *a doubly exposed speckle photo contains a multitude of speckle pairs*
- *when interrogated with a laser beam, Young's fringes form*
- *the spacing and orientation of the fringes give magnitude and direction of the local displacement vector*

A nice animated demonstration of the formation of Young's fringes is available on the web at: www.mapleapps.com/categories/science/physics/html/interference.html#MapleAutoBookmark3. The code appears at the top of the page, so one needs to scroll down to see the animation. The motion is too rapid for easy study, but slowing it down should be possible. Some informative details of the diffraction process appear near the bottom of the web page.

## What lies ahead?

The next articles will deal with Michelson interferometry, colored fringes, laser Doppler interferometry, and the diffraction problem, not necessarily in that order. ■

N