University Physics II Honors Project:

Young's Double Slit Experiment

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Lab Section H3

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Introduction:

People as far back as ancient Greece have suggested that light was a particle. This theory was very prominent but virtually unchecked. Then, in the mid 17th century, Dutch physicist Christiaan Huygens proposed that light was a wave. This theory was bolstered by another principle of the Universe that Huygens discovered. He and French physicist Augustin-Jean Frensel established a principle called the Huygens-Frensel Principle, which proposed light as a wave instead of the widely held view of it as a particle. This principle stated that "as a wave propagates through a medium each point on the advancing wavefront acts as a new point source of the wave." (Padley)

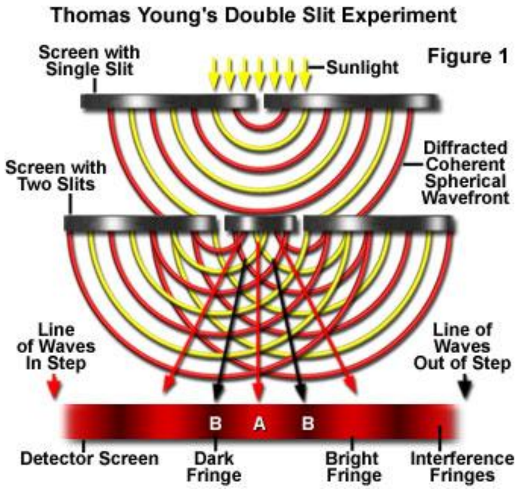
To make this a little simpler to understand, consider this comparison. Two rooms are connected by an open door. In one corner of one of these rooms there is music playing. When inside that room, a person can clearly hear that the music is coming from the music player in the corner. If a person is in the other room however, then the music seems to only be coming from the open door. When a wave travels through an open medium and it is then bottlenecked, the bottleneck (in our case the open door) is the "new point source of the wave". This same principle occurs at a microscopic level with light passing through a slit.

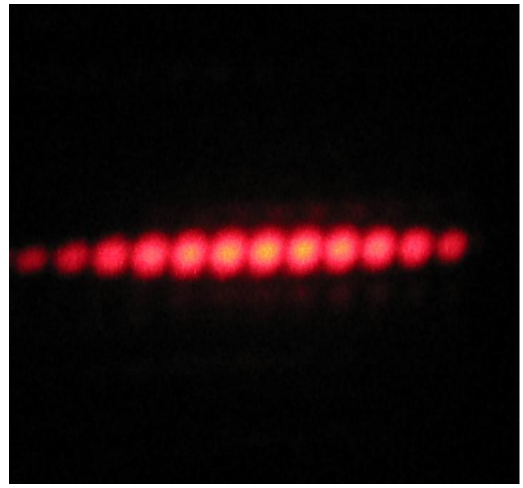
This theory paved the way for a scientist named Thomas Young more than a century later. In the early 19th century (sometime between 1801 and 1803) Young devised an ingenious experiment to test the nature of light, which is known today as the Double Slit Experiment.

Young's Double Slit Experiment

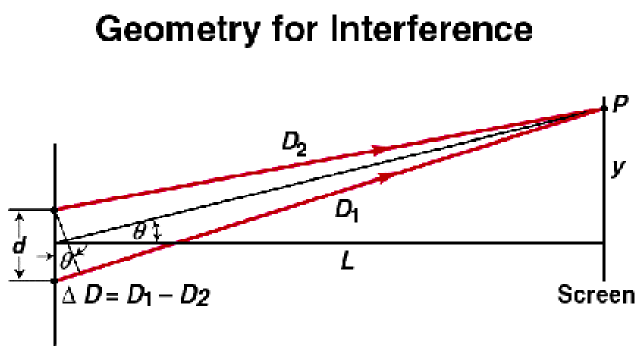
Young set up his experiment by focusing a small beam of sunlight onto the edge of a slip of card held vertically. This card, in essence, cut the middle out of the beam, leaving two separate parts on either side. If light was a particle then there would be only two distinct strips of light that reached the screen. This result was probably what was most expected to occur. Instead, what they found was "one of the most startling and counterintuitive experimental results ever fallen into the hands of scientists." (Young's)

This was not the case. Young observed multiple dots, meaning light couldn't be particles. The two remaining parts of the light went through the Huygens-Frensel Principle, meaning each new beam started spreading out as a new point source of a wave. Because these two waves are in close proximity, they react with each other. "Along certain lines… the waves are exactly in phase (crests are on top of crests, troughs on top of troughs) and reinforce. Along other lines they cancel because they are out of step in such a way that crests of waves from one slit coincide with troughs of waves coming from the other. In the first case, constructive interference enhances brightness. In the second case, destructive interference leads to darkness." (Schaffer, p154) (See below picture on the left) This results in the laser spreading horizontally where some areas are bright separated by areas that are dark. This is shown in the picture below (right).





It is possible to mathematically calculate how far these dots will be spaced. Look at the picture below.



Using trigonometry "the positions of dots on the screen measured from the central dot of the undiffracted beam may be obtained from the equation: y = (nλ)(L/d)." ("Physics") When only considering the distance between adjacent dots, this equation can be simplified to

$$\text{dot spacing} = (\lambda)(L/d)$$

where λ is the wavelength of the light, L is the distance from the slit to the screen, and d is the width of the slits.

I decided to try to recreate this experiment with household tools. Instead of a beam of light, I used a laser because it is more focused and easier to control. I set different objects in the path of the laser, measured the distance between the object and the screen, and measured the spacing of the dots. This way, I could rearrange the equation above to solve for the wavelength of the laser, giving λ= (dotspacing*d)/L . I know the wavelength of this laser (632.8nm) meaning I can check for accuracy.

Materials I used:

- Laser
- Two-inch Binder clips (2)
- CD
- Clear Plate (plastic or glass)
- Black Paint
- Wire of 2 different thicknesses
- Knife
- Poster or Wall to project on.

Here's How I Did It

In the first 5 tests I used a Metrologic Neon Laser from the University of Arkansas Physics Department to shine at the various objects. There was also a constant distance of 1.964m from the object to the screen. The only change I made between tests was switch out the object. Here is a diagram of the setup I used:

DIAGRAM OF APPARATUS

Test 1 – Note Card

I started out recreating the experiment using the "slip of card" that Young used. A card or piece of paper was held in place vertically and the laser was shone down the length of it, essentially slicing the laser down the middle. Instead of a piece of paper I used a 3x5 note card held up by a binder clip because the note card is thicker and would not only produce better diffractions. However, this didn't work well because no matter how much I tried to straighten it, the card did not want to be perfectly straight. Almost all of the laser was blocked by the warps in the paper and the tiny bit of light that made its way to the projection screen was too dim to measure. I decided to move on.

Test 2 – Thin Wire

I replaced the card with the thinnest wire I had, keeping the same distances between the laser and the wire and between the wire and the wall. I thought the wire would have great results because it is still very thin, just like the note card, but it has a much shorter horizontal distance when held up when compared to the note card. When held vertically the note card, at minimum, will be 3 inches in the direction of the laser whereas the wire will only be its diameter (.36mm) in the direction of the laser. This will make it much easier for the laser to be cleanly cut in two. This actually did work! The laser made 7 distinct dots approximately 2.31mm away from each other.

Test 3 – Thick Wire

I replaced the thin wire with the large wire with a diameter of 1.2mm. This wire did not work. The part of laser that reached the wall was dim and so blurred together that I couldn't see any individual dots.

Test 4 – Compact Disc

Next, I got an ordinary CD and used a modeling knife to cut fine slits out of the silver paint on the front. The first cuts I did were so thin that the laser didn't go through them, so I made new slits, this time holding the blade perpendicular to the direction I was cutting. This made the slits quite a bit larger and the following test was successful. Each slit was .25mm thick and they were .93mm apart. This produced a dot spacing of approximately 10.85 mm, which is very large in comparison to the rest of my tests.

Test 5 – Painted Plastic Sheet

The next object I decided to test was a sheet of clear plastic that I blackened by a lighter and cut fine slits in. This did not work because not only did the lighter blacken the plastic, it also partially melted it causing the imperfections in it to bubble up. This made the slide useless for an experiment. In rebound, I spray painted one end of the plastic and used a modeling knife to cut off slits of paint. I then clipped binder clips at the bottom of the edges of the slide so it would stand up. This object also had successful results. With the slits .49mm apart and each .43mm thick, seven visible dots .68mm apart were projected.

Results of First Set of Tests

I calculated the value for the wavelength of the laser for each of these tests and was shocked by how inaccurate they were. I'll use Test 5 as an example because it worked the best (relatively). Starting with this equation <u>λ= (dotspacing*d)/L</u> I plugged in .00068m for dotspacing, .00049m for d, and 1.964m for L. This gave me the value for wavelength $\lambda=1.700\times10^{-7}$m =170nm. The percent error of this is 73.1%, which is nowhere near accurate enough to be considered science. Because of this, I decided to perform Young's Double Slit Experiment using professionally developed tools (as seen below).

PICTURE OF PROFESSIONAL TOOLS

Test 6 – Professional Equipment

I set up the device where the laser was at 0cm, the first slide was at 10cm, and the second slide was at 20cm. The second slide was exactly 3m from the screen. For this first test I had the first slide set to a single wire of thickness .08mm. The second slide was two slits .5mm apart from each other with each slit .08mm thick. I switched on the laser and was shocked at what I saw. There were at least 37 distinct dots each approximately 4.14mm from each other. This result was so much better than when I used homemade tools.

Results of Professionally Equipment

Now for the moment of truth. I plugged in the recorded values into the same equation as I did for the other tests and got 6.9×10^{-7}m=690nm. This is much closer to the value I wanted! This value had only a -9.04% error, which is acceptable.

Error:

Obviously there was much error in my methods. One way I could have improved on my test of homemade tools was to use a more accurate tool to measure tiny spacing. Digital calipers are generally very accurate, but with this experiment it was still measuring things that were too small. I also could have put more distance between the objects and the screen. The farther away the projection is, the wider the dots become, the more accurate they can be measured.

Conclusion:

If light is a wave, then shining it through two close narrow slits would cause interference between them which would result in a horizontal stretching of the beam with varying brightness, looking like multiple individual dots. If light were a particle then when shone at the plate with two narrow slits in it, everything would be blocked except for at the slits, resulting in only two slits of light on the wall. So because Young's experiment resulted in multiple individual dots, Huygens theory seems to be correct. Light is a wave, right? Wrong!

However counterintuitive this may seem, light has been discovered to be both a wave *and* a particle. In theory the two are completely contradictory. "Waves interpenetrate, particles bounce off. Waves are continuous, particles discrete. Waves are…massless, particles are massy." (Schäfer, Lecture) Intuitively, an object can't be a wave and a particle because an object can't have both mass and no mass. But the test results of the last hundred years haven't lied. "At the turn of the 20th century light… was found to display the characteristics of waves in some experiments and of particles in others." (Schäfer, Lecture) This discovery raised many questions and opened the door into Quantum Physics.

Young's experiment was definitely a milestone in scientific discovery. It was a simple experiment, yet its results are very profound and have paved the way to our understanding of modern physics.

Bibliography

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Pictures

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crucial to our understanding of the universe. There's no wonder that Richard Feynman, the father of quantum physics, was fond of saying

This occurrence is a mystery to scientists because the properties of waves and particles are contradictory to each other, yet both can still be seen in light. Though we don't currently know scientifically how this works, maybe in future years it will finally be learned.

"Double Slit", "Single Slit", "Three Slit", "Four Slit", "Five Slit". Online Image. Hyperphysics. 15 Apr. 2010. <http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/mulslidi.html#c2>.

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