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Proof of the Wave Properties of Light Using Diffraction

Abstract

The purpose of this study had two parts, as well as a broader concept. The broader concept of this lab was to prove the wave nature of light, while the secondary and ternary objectives of this lab were to prove the relationship given in Young's Equation (Equation 1.1), and test the effect of slit depth on this relationship. The first two goals of this lab were obviously demonstrated, with Young's Equation accurately predicting the interference pattern generated, but experimentation failure prevented the third objective from being completed.

Introduction

The debate surrounding the nature of light, particle or wave, endured for many centuries. In the 17th century, Isaac Newton weighed in on the side of light being made up of particles. Due to Newton's large prior contribution to the world of physics, his opinion carried a lot of weight and thus it was hard for scientists to refute his ideas. That was until 1801 when Thomas Young performed the double slit experiment. (This Month in Physics History) Young's experiment was inspired by errors he found in Newton's book Opticks. To show that light was a wave, Young attempted to show that it can interfere with itself, and form interference patterns in which there were destructive and constructive spots. Young's first version of the double slit experiment consisted of a large piece of paper attached over a window, with a narrow slit in it. Young then placed a card in the resulting beam of light, and observed an interference pattern caused by the split beam of light. (This Month in Physics History) This was later reformed into the well known double slit experiment. Young developed an equation (Equation 1.1), which showed the relationship between various aspects of his experiment. The purpose of this lab was to observe the strange wave nature of light, as well as test the relationship between the variables in Young's equation. Experimentation on the depth of the slits was also attempted, but had inconclusive results. The hypothesis for the initial experiment was that the factors of the double slit experiment would be related as stated in the Young equation. The hypothesis for the second experiment was as follows. The depth of the slits would be inversely proportional to the distance between the center bright spot and first order line.

Materials and Methods

Initial Experiment

Before the lab was started, the tested variable was chosen to be the distance between the observer and the light source (L). The other variables (wavelength, meters/slit, order line) were kept constant throughout the experiment.

A meter stick was attached at the 50cm point to a stand, above a single filament light bulb which was plugged into the wall. Two rubber bands were placed on either end of the meter stick. A constant observer sat on a stool (to keep a constant height) at different distances from the lightbulb/meter stick stand. These distances ranged from 0.25 meters to 1.25 meters at intervals of 0.25 meters. These distances were measured using a string attached to the same stand.

After the observer was in the correct position, a grating with 300 lines per mm was looked through. The observer would locate the first yellow band of the spectrum to the left and right of the light source. The observer would then communicate with other lab partners to line the rubber bands on the meter stick up with where the observer saw the center of the yellow portion of the spectrum. Yellow was chosen as a wavelength because it has a relatively narrow range of frequencies, and is very easy to consistently identify for the observer. The distance the rubber bands were from the 50cm mark was then recorded, and the experiment was then repeated at a different distance.

Secondary Experiment

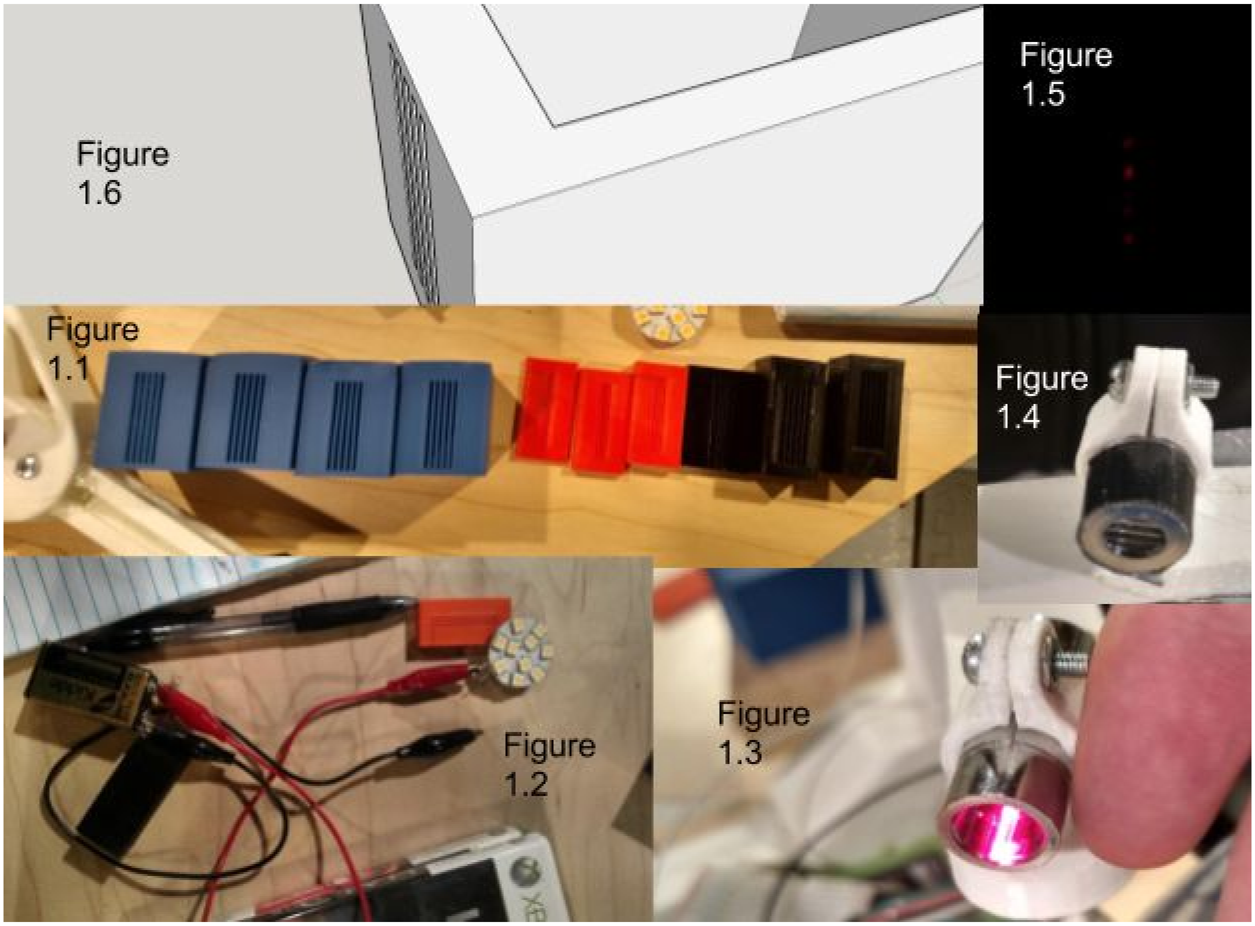
To further explore the topic, a secondary hypothesis was explored. Various 3D models were designed and printed with slit widths as small as 0.5/0.6mm, which was limited by the printer. (Figure 1.1) These printed slits were then put in front of three different light sources: bright white LED's (Figure 1.2), an unfiltered laser (Figure 1.3), and a laser put through a cylindrical lens to focus its light into a narrow line. (Figure 1.4). While each of the filters shown in Figure 1.1 were placed in front of the light source(s), the resulting pattern on the wall 2.286 meters away was observed and recorded.

Results

The chosen meter/slit ratio was 3.3×10^{-6} meters/slit. The chosen wavelength was based on the chosen color, which was yellow. Yellow is defined to have a wavelength anywhere from 577 to 597 nm (LivePhysics). The average of these values (587) was used for calculations in this experiment.

Table 1.1: Recorded, Expected and Calculated Results of Diffraction Experiment

Distance (m)	Left Rubber Band (m)	Right Rubber Band (m)	Average Distance (m)	Expected Distance (m)	Percent Error (%)
0.25	0.055	0.057	0.056	0.044	27.2
0.50	0.081	0.088	0.085	0.088	3.46
0.75	0.137	0.139	0.138	0.132	4.49
1.0	0.186	0.187	0.187	0.176	6.19
1.25	0.231	0.232	0.232	0.220	5.39



Figures 1.1-1.6: Various Elements of the Second Experiment

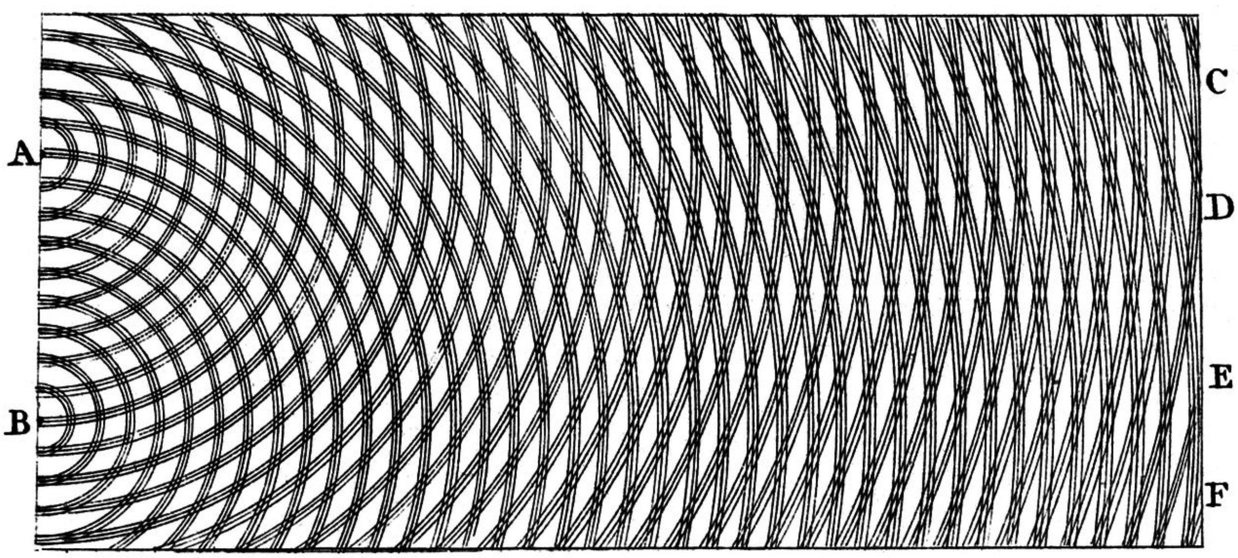


Figure 1.7: Young's Sketch of Double Slit Diffraction (Wikipedia)

Equation 1.1: Young's Formula

$$M\lambda = \frac{dx}{L}$$

- M was always one in this experiment, because the first order line was consistently the one measured.
- λ, or the wavelength, was explained earlier. (580nm)
- L stands for the distance from the source (0.25m-1.25m), and was the independent variable in this experiment.
- X was the distance from the center bright spot to the first order line, and was the dependant variable in this experiment.
- D is the number of meters per slit, which was 3.3×10^{-6} meters/slit throughout the first experiment.

There were no numerical measurements from the second experiment. The attempted grate sizes were 5×10^{-4} meters/slit and 6×10^{-4} meters/slit. The tested depths of the slits was 2.5-12.5mm by intervals of 2.5mm. (Observable in the blue slits in Figure 1.1)

Discussion

When the light was observed through the grate at different distances, multiple "rainbows" could be seen at similar distances from the light source. A bright white light appeared at the light source, called the center bright spot. The "rainbows", or spectra of color occurred at what were called the order lines.

Two important lessons can be pulled from what was seen through the grate. First, the patterns that were observed were interference patterns, showing that light can act like a wave. These interference patterns are caused by the grate. When the light wavefront reaches the grate and passes through one of the slits, it diffracts, or spreads out. This is the reason you can hear someone talking to you around an object. Due to this diffraction, the light waves travel different distances to reach the screen. When light diffracts out of the multiple slits, the light waves hit the screen in or out of phase due to the different distances the waves traveled, resulting in the bright and dark spots. This is visible in Figure 1.7. Where the lines intersect you get a crest meeting a crest/trough meeting trough, where waves are in phase causing a bright spot. Otherwise, when waves are out of phase and troughs meet crests, a dark spot.

The second lesson to take from this is that the different colors of light are different frequencies. As shown by Young’s Equation, if everything but frequency and x are kept constant, the distance from the center bring spot increases as the wavelength goes up. This perfectly explains the “rainbows” visible through the grating. White light, the light being observed through the grating, is actually made up of (almost) every frequency of light. When all this light with varying frequencies hits the grating, the different frequencies/colors spread out as according to Young’s formula, meaning colors with lower frequencies such as purple and blue will be seen closer to the center bright spot, while colors like red will be seen farther away because it has a higher frequency.

With the exception of the 0.5 meter trial, every expected value was smaller than the measured value, suggesting that some sort of consistent error was present. It was observed during the experiment that holding the grate non-parallel with the meter stick would warp the visible order lines farther out on the side of the grate that was farther away from the meter stick. A consistently slanted grate would explain the right rubber band measurement consistently being larger than the left measurement, it does not explain the percent error because there is no correlation between the relative closeness of the left and right bands (resulting in a skewed average), and the percent error. In fact, the percent error seems to be the smallest when there is the biggest difference between the left and right measurements. The relatively low percent error proves the first hypothesis because it shows that the relationship between the values of the double slit experiment can be predicted within experimental accuracy (with the exception of the 0.25 meter trial).

Although the second experiment couldn't be completed, some interesting results were observed. In almost every combination the light pattern on the wall would look as it would be expected by a particle model, just a shadow of the slits, for the 0.5mm/slit and 0.6mm/slit for every light source. However, if the 2.5mm thick double 0.5mm/slit grating was slanted so the slits were perpendicular, the pattern shown in Figure 1.5 was observed, which somewhat resembled an interference pattern. The issue was the pattern was much too large to actually be an interference pattern predicted by Young's formula, as it would have a center bright spot to first order line distance of 3 millimeters, whereas the resulting image was around 100 millimeters between.

This strange behaviour doesn't have any obvious explanations, but further experimentation should be performed. Based on Young's equation the interference patterns of the other tested slit scenarios should have been visible with wavelengths ranging from 2-3 millimeters assuming the laser light is red. Further experimentation could explore the effects of the laser lens and scaled laser line created.

An additional interpretation of the results observed in this experiment can be attributed to the heisenberg uncertainty principle, which states that the known position and momentum of a particle cannot both be known. The more you know about one of these two measurements, the less you know about the other. Normally this relation has no noticeable effect on our everyday lives, because the constant they are related to is very small. However when light passes through the tiny slits in this experiment, it's position is "known" to a high enough degree that it's momentum must be variable, resulting in the spreading out of the photons as they pass through the slits. More research should be done on the subject, but it is likely that the predictions due to Heisenberg's uncertainty principle go hand in hand with Young’s equation.

References

Works Cited

Wikipedia. Wikimedia Foundation. Web. 13 June 2016.

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