Laser Benders

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Grade 5

Abstract

Diffraction is the bending of light around barriers or through narrow openings. Diffraction helps understand the atomic structure of different materials and measure the thickness of very small objects that can't be measured with a ruler. Light energy travels in oscillating waves. The length of each oscillating wave, called wavelength, varies for different types of light. The objective of this experiment is to understand how the wavelength of light affects the amount of bending due to diffraction. The hypothesis is that the angle of diffraction increases when the wavelength of light increases.

Two light sources, a red laser with 635nm wavelength and a green laser with 532nm wavelength, a diffraction grating with 0.1mm slit width, and a screen to capture diffraction patterns are used for this experiment. Light is passed through the slit, and the angle of diffraction is calculated from the width of the central light blob recorded on a screen placed at a distance from the slit. The widths are recorded with both lasers for 3 different distances from the slit to the screen with 3 trials.

The hypothesis is proven by the results. The mean angles of diffraction are 0.36 degrees for the 635nm wavelength source and 0.29 degrees for the 532nm wavelength source. This shows that the angle of diffraction increases as wavelength increases.

Further research with different wavelength sources can help determine the pattern of relationship between diffraction and wavelength. The effect of different slit widths on the angle of diffraction can also be explored.

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Question

What is the effect of the wavelength of light on the angle of diffraction when light passes through a slit in a barrier?

Research

Scientific Principles

Wave, *wavelength*, *light*, *diffraction*, *Huygens' principle*, *constructive and destructive interference, and relationships between angles and sides of a right triangle* are the key principles related to this experiment.

I. Wave

Wave is an oscillation that travels through a medium. Waves travel in repeating **cycles**. In each cycle, a wave rises and falls as it travels. The maximum amount of rise or fall from the rest position is called the **amplitude**. The high points are called **peaks** and the low points are called **troughs**. A wave and its characteristics are shown in Figure 1.

II. Wavelength

Wavelength λ of a wave is the length of a repeating cycle. This is shown in Figure 1.

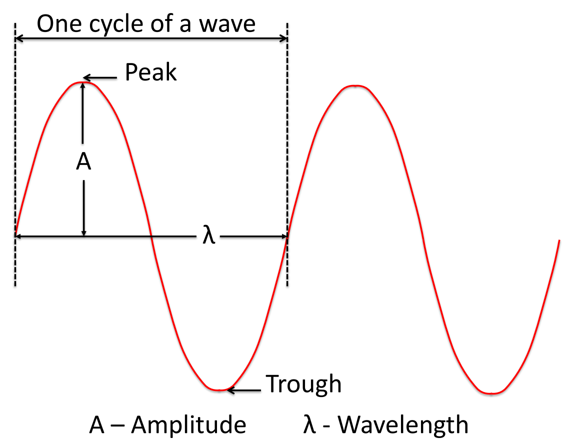


Figure 1. Features of a wave.

III. Light

Light is a form of energy and is an electromagnetic wave. Light travels in repeating cycle of waves. Natural and commonly used sources of light are usually composed of multiple wavelengths.

IV. Diffraction

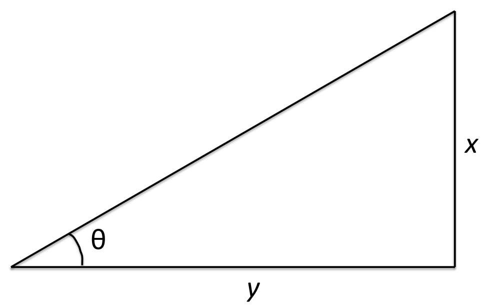
When a wave travels through a single medium, such as air, and encounters an obstacle, diffraction occurs. Diffraction occurs when a partial barrier is in the path of the wave, or if the wave passes through an opening. For example, if we place a small object in the middle of a water puddle, and then tap our foot on one side of the puddle to create a ripple, then the ripple will bend around the object. Each ripple can also be called a wave front. **Diffraction of light** is the deviation in direction of light when it encounters a partial barrier or passes through a narrow opening such as a slit.

V. Huygens' principle

The concept of diffraction is explained by **Huygens' principle**. This principle states that a wave front is the source of other infinite wave fronts. When a light wave front reaches a slit, the portion of that wave front at the slit generates new wave fronts that pass through the slit and propagate forward in different directions. This results in diffraction.

VI. Constructive and destructive interference

When two light waves of the same wavelength meet at a point at a distance from their source, due to the differences in the distance each traveled from the source, their individual amplitudes at that point may be different. If one wave is at its trough and the other is at its peak, they cancel out, forming absence of light resulting in destructive interference. If both are at their peak, they add up, doubling the amplitude resulting in constructive interference. If the waves meet in other positions, the resulting amplitude will be the algebraic sum of the individual amplitudes of the waves at that point. Because of this reason, the interference pattern that occurs at a screen is different for light of different wavelengths. So, in order to understand diffraction of light clearly, instead of using light composed of multiple wavelengths such as natural light or commonly used light sources, a light source of a single wavelength is used.



$\tan\theta = x/y$ $\sin\theta = x/(x^2 + y^2)^{1/2}$

$\theta = \tan^{-1}(x/y)$ $\theta = \sin^{-1}(x/(x^2 + y^2)^{1/2}$

Figure 2. Relationship between angles and sides of a right triangle

VII. Relationship between angles and sides of a right triangle

In this project, the angle of diffraction that needs to be measured can be too small to be accurately measured with a protractor. An alternative to this measurement is using trigonometry to calculate this angle. Trigonometry is a subject that describes the relationships between the angles and side lengths of a right triangle. In this method, lengths of the sides of a right triangle are measured with reasonable accuracy and then used to calculate the desired angle. The **sine of an angle** in a right triangle is the ratio of the length of the opposite side of the angle to the length of the hypotenuse. The **tangent of an angle** in a right triangle is the ratio of the length of the opposite side of the angle to the length of the adjacent side of the angle. These relationships are shown in Figure 2.

Applications

I. Finding the structure of an atom

Diffraction can be used for finding atomic structure of materials.

II. Finding the width of extremely thin objects

It can be used to measure the thickness of object that can't be measured manually, like a hair.

III. Determining the unknown wavelength of light using this experiment

In this experiment, a graph will be created with the results that can help us determine the wavelength of light based on its angle of diffraction.

Hypothesis

It is predicted that if the wavelength of light increases, then the angle of diffraction increases.

In an experiment conducted with light sources each of a single wavelength, such as laser light sources, it is predicted that a laser source that produces light of a larger wavelength results in an increased angle of diffraction than one that produces light of a shorter wavelength.

Scientific Principles and Reasoning

Based on Huygens' principle, when a wave front reaches a slit, only the waves generated by the wave fronts at the slit will pass through the slit. An infinite number of waves start from the slit and travel to the screen in all directions. If the distances traveled by these waves to a point on the screen differ by an odd multiple of half their wavelength (when peak of one wave meets the trough of another), then they will cancel each other out leading to absence of light. The point on the screen for which this cancellation happens will be off-center at a point where the difference in the distances traveled are just enough to cancel each other out. This difference in the distances traveled by the waves (half wavelength or an odd multiple of it) will have to be more for light of larger wavelengths to cancel out and hence will happen at a point further off center than for smaller wavelengths. Therefore, light with higher wavelengths will have more angle of diffraction.

Materials

- 532nm green laser source
- 635nm red laser source
- Single slit diffraction grating with 0.1mm width slit
- Pencil
- Laser/grating holder
- Calculator
- Cellophane tape
- Canvas screen
- Measuring tape
- Ruler

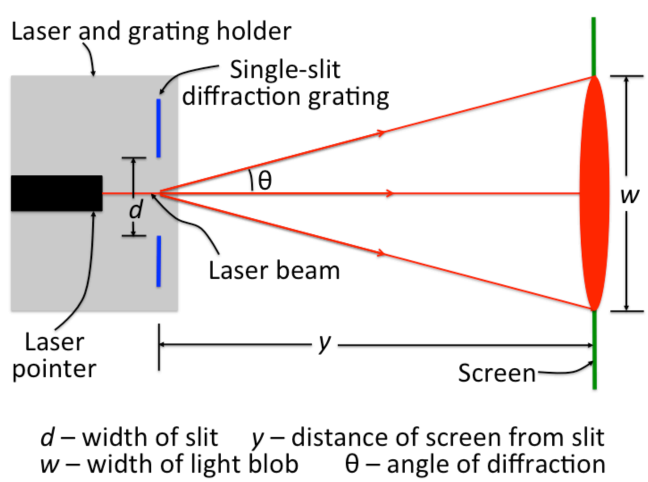


Figure 3. Setup

Methods

Preparing the Apparatus

1. Position the canvas screen vertically.
2. Measure distances of 2m, 2.5m, and 3m on a straight line perpendicular to the screen and mark these spots on the ground.
3. Place the red laser in the holder without the grating and place the holder at the closest (2m) marker with the laser facing the screen.

The initial setup is as shown in Figure 3 without the grating.

Conducting the Experiment

Steps

1. Turn on laser.
2. Mark the left and right ends of the central blob of light on the screen with pencil.
3. Turn off laser.
4. Measure the distance between the marks on the screen with a ruler and record it as *w.*
5. Use calculator to find angle as $\tan^{-1}((w/2)/y)$ and record it.
6. Repeat steps 1 through 5 for 3 trials.
7. Repeat steps 1 through 6 with the grating in the holder as shown in Figure 3.
8. Remove the grating and repeat steps 1 through 7 for laser positions at each of the remaining marked spots on the ground (2.5m and 3m marks).
9. Remove the grating and repeat steps 1 through 8 with the green laser in the holder.

Variables and groups

Independent variable

The wavelength of the light produced by the laser source is the independent variable. The experiment will be conducted for laser sources producing light of wavelengths 532nm and 635nm.

Experimental groups: The trials in which light travels from the two laser sources to the screen through the slit in the grating.

Control groups: The trials in which light travels from the two laser sources directly to the screen without the grating in the middle.

Dependent variable

The angle of diffraction is the dependent variable. It is predicted that this variable changes when the wavelength of the laser source is changed.

Constants

The width of the slit (0.1mm) and the medium (air) through which the light from the laser sources travel are constants in this experiment.

Problems encountered

The original plan was to perform this experiment with three laser light sources: red, green and blue. However, that plan was changed because reliable blue lasers in the market were too powerful and considered too risky to be safely usable by the investigator. Consequently, the blue laser wasn't bought and only the red and green lasers were used for this experiment.

Also, originally it was planned to measure the angle of diffraction with a protractor. But since the angle was too small to be accurately measured with a protractor, the investigator needed to learn and apply basic trigonometry to calculate the angle from measured lengths.

Photos

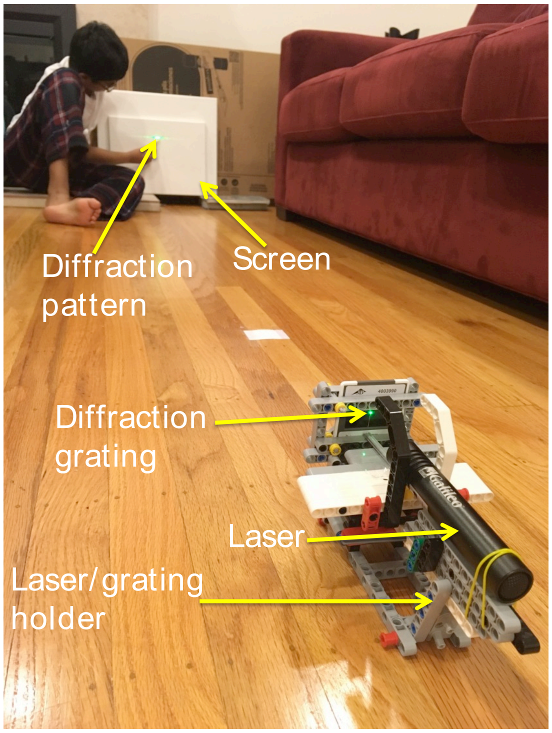


Image 1. Experiment setup.

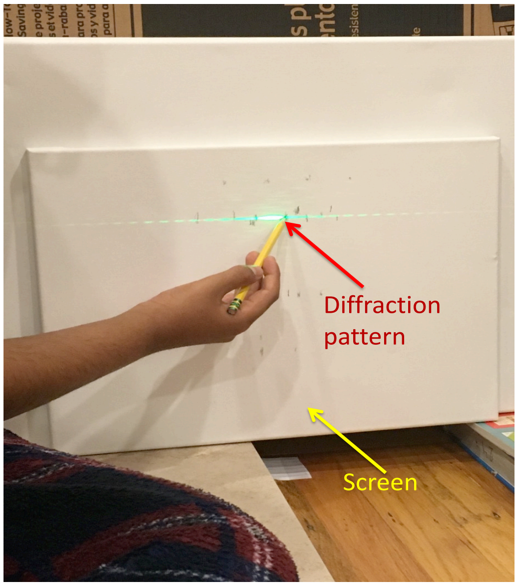


Image 2. Diffraction pattern on screen.

Data

The measurements of the widths of the central blob of light for different laser sources, for different distances of the source to the screen, and with and without the slit are shown in Table 1. For example, the first data row of Table 1 shows the case when the 532nm laser source is used and the screen is positioned at 2m from the source. Columns 3, 4 and 5 of the first data row give the widths of the central blob of light with no slit over three trials, while columns 6, 7 and 8 give the widths of the central blob of light with the slit over three trials. The angles of diffraction calculated from the widths recorded in Table 1 are shown in Table 2.

Table 1.Width of the central light blob with and without slit.

Wavelength of light source (nm)	Distance of screen from light source (m)	Width of central blob of light with no slit (cm)			Width of central blob of light with slit (cm)		
		Trials			Trials		
		1	2	3	1	2	3
532	2.0	0.3	0.3	0.3	2.0	2.0	2.0
532	2.5	0.4	0.35	0.4	2.6	2.7	2.5
532	3.0	0.5	0.4	0.45	3.0	3.1	3.1
635	2.0	0.3	0.3	0.3	2.4	2.5	2.6
635	2.5	0.4	0.4	0.4	3.1	3.2	3.2
635	3.0	0.3	0.4	0.4	3.8	3.9	3.9

Table 2. Angles of diffraction calculated from widths of light blobs.

Wavelength of light source (nm)	Distance of screen from light source (m)	Angle of diffraction with no slit (degrees)			Angle of diffraction with slit (degrees)		
		Trials			Trials		
		1	2	3	1	2	3
532	2.0	0.04	0.04	0.04	0.29	0.29	0.29
532	2.5	0.05	0.04	0.05	0.30	0.31	0.29
532	3.0	0.05	0.04	0.04	0.29	0.30	0.30
635	2.0	0.04	0.04	0.04	0.34	0.36	0.37
635	2.5	0.05	0.05	0.05	0.36	0.37	0.37
635	3.0	0.03	0.04	0.04	0.36	0.37	0.37

The mean angle of diffraction for each case calculated from the results recorded for the three trials in Table 2 is given in Table 3.

Table 3. Mean angles of diffraction from results of trials in Table 2.

Wavelength of light source (nm)	Distance of screen from light source (m)	Mean angle of diffraction with no slit (degrees)	Mean angle of diffraction with slit (degrees)
532	2.0	0.04	0.29
532	2.5	0.04	0.30
532	3.0	0.04	0.29
635	2.0	0.04	0.36
635	2.5	0.05	0.36
635	3.0	0.04	0.37

The results in Table 3 are plotted in Figures 4, 5, and 6. Figure 4 shows the change in the angle of diffraction with change in the wavelength when the screen is 2m from the light source. The red line indicates the case with no slit present and corresponds to data in data rows 1 and 4 and column 3 in Table 3. The blue line indicates the case with slit present and corresponds to data in data rows 1 and 4 and column 4 in Table 3. Figures 5 and 6 are for the cases when the screen is at 2.5m and 3m, respectively, from the light source.

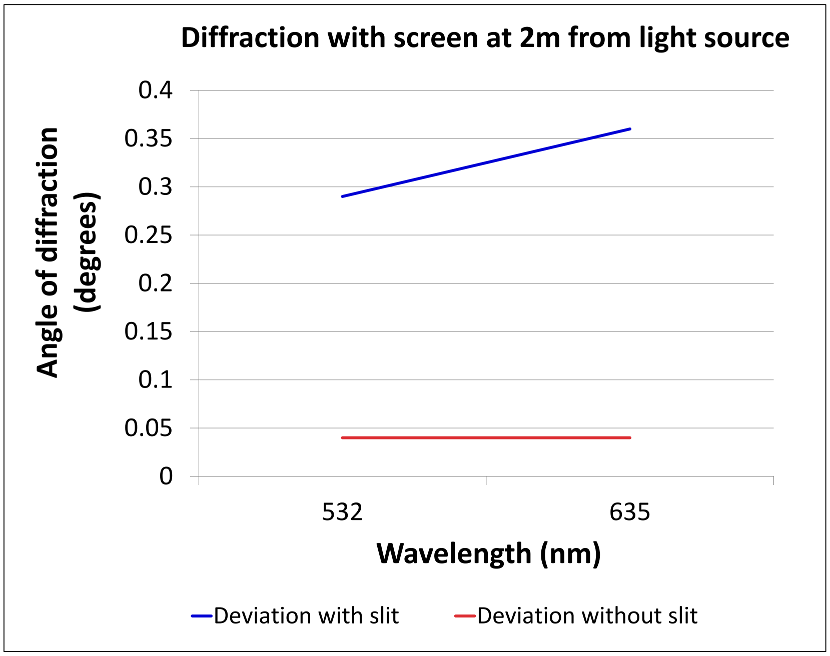


Figure 4. Angle of diffraction vs. Wavelength, with screen at 2m from light source.

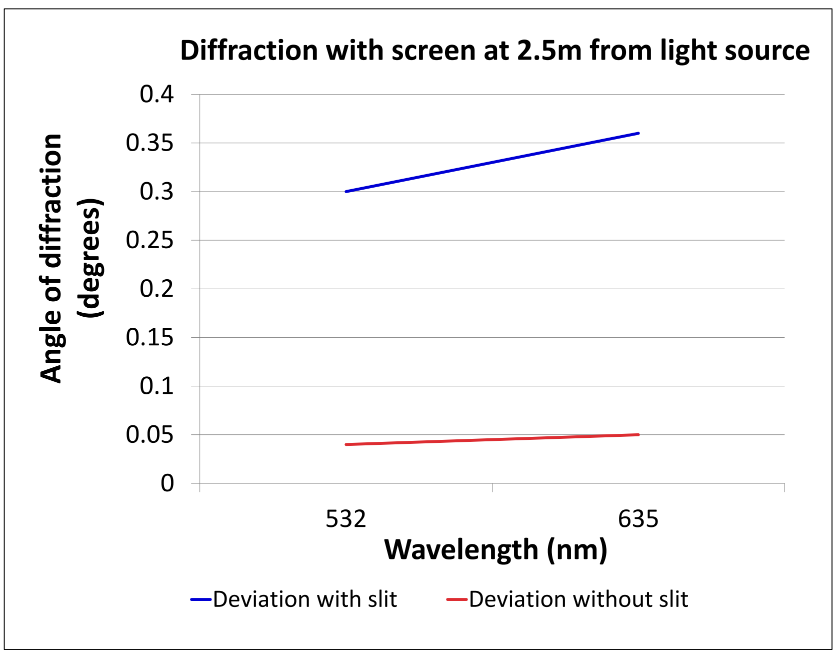


Figure 5. Angle of diffraction vs. Wavelength, with screen at 2.5m from light source.

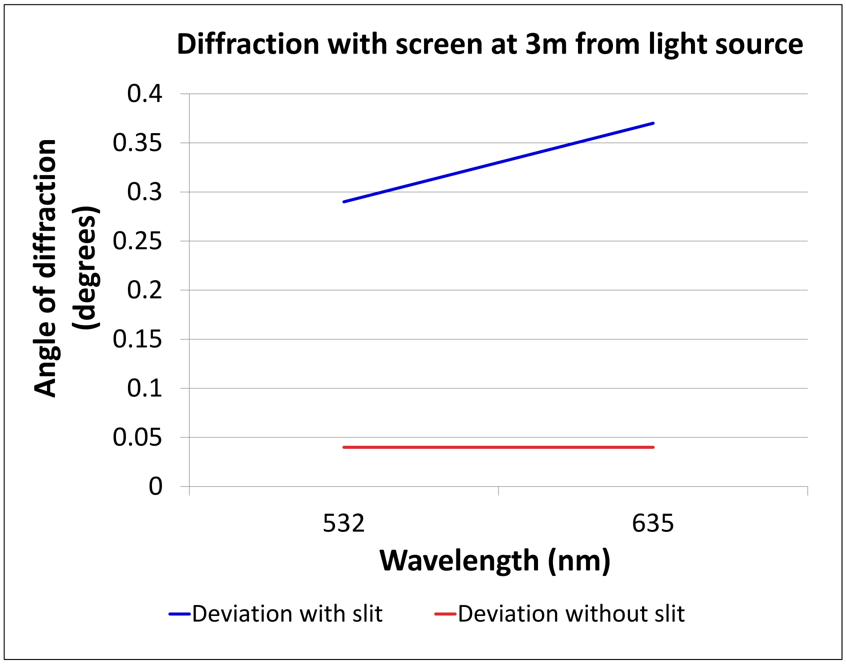


Figure 6. Angle of diffraction vs. Wavelength, with screen at 3m from light source.

Results

Figure 4 will be used to explain the results. The red line in Figure 4 indicates that there is not much diffraction at all when there is no slit present. The blue line in Figure 4 indicates that there is comparatively much higher diffraction when the slit is present. For example, the angle of diffraction with the 532nm laser source is less than 0.05 degrees without the slit, while it is 0.29 degrees with the slit. The angle of diffraction with the 635nm laser source is less than 0.05 degrees without the slit, while it is 0.36 degrees with the slit. It can also be seen from the red line that the angle of diffraction is almost the same for both the 532nm source and the 635nm source when there is no slit present.

From the blue line in Figure 4, the case when the slit is present, it is observed that the 635nm source results in an angle of diffraction of 0.36 degrees, which is larger than the angle of diffraction of 0.29 degrees observed with the 532nm source. Therefore, this case shows that the angle of diffraction increases with increase in the wavelength of the light source.

The conclusions reached from Figure 4 are also observed in Figure 5 and Figure 6 when the distance from the screen to the source is changed to 2.5m and 3m, respectively. The conclusions drawn from Figure 4, Figure 5, and Figure 6 confirm that the hypothesis is correct.

Sources of small inaccuracies in the experiment come from small errors in the positioning of the laser and difficulty in precisely recording the measurements on the screen while avoiding hand contact with possibly harmful laser radiation.

Conclusions

The hypothesis is that when the wavelength of light increases, the angle of diffraction increases. The results of experiments with two laser light sources of wavelengths 532nm and 635nm and a 0.1mm slit grating show that the hypothesis is correct.

The hypothesis is supported by the results because of Huygens' principle and the principle of constructive and destructive interference. Based on Huygens' principle individual wavelets are created by each wave front at the slit and diverge outward and these wavelets experience interference. Wavelets from light of shorter wavelength traveling from the slit tend to cancel out at shorter distances from the center of the screen leading to smaller angles of diffraction, and vice-versa. This also explains the fact that there is no diffraction in the control experiment when there is no slit.

Suggestions for improvement and further research

This investigation can be extended to explore the change in the angle of diffraction with change in the width of the slit. Further research can also be performed to determine the pattern of increase in the angle of diffraction with the wavelength of light by conducting this experiment with more laser light sources of different wavelengths.

Acknowledgments

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