Middle East Technical University
Department of Physics
PHYS222 Optics and Waves Laboratory

Experiment OW-3 Diffraction and Interference Laboratory Report

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April 26, 2015

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Theory

When an opaque object is placed between a point source of light and white screen, it is obvious that the shadow which is produced by object departs from the perfect sharpness as predicted by geometrical optics. If we look at this examination more closely shadow edges reveals that some light goes over into dark zone of the geometrical shadow. This phonemena known as *diffraction*. The first detailed publishing about diffraction published by Francesco Grimaldi in the 1600s [1]. If there is an obstacle which is encounter by light, either transparent or opaque, a region of the wavefront is altered in amplitude or phase, diffraction will occur [1]. For example, sound waves bend around corners much more than light does. That is why we can hear but not see around corners. For a given type of waves, such as sound waves, how much the waves diffract depends on two factors: the size of the obstacle or opening in the obstacle and the wavelength. At this point we have to

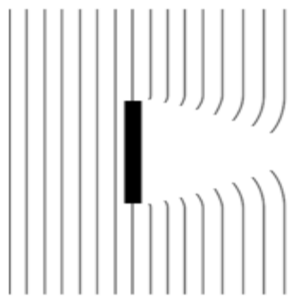

Figure 1.1: Diffraction caused by an obstacle

clarify that diffraction is minor if the length of the obstacle or opening is greater than the wavelength and diffraction is major if the length of the obstacle or opening is less than the wavelength. The essential features of diffraction phenomena can be explained more widely by *Huygens' principle*. This phenomena states that *propagation of a light wave can be predicted by assuming that each point of the wave front acts as the source of a secondary*

[1] Answer to Teaching Assistant's question.

wave that spreads out in all direction [2]. When we investigate diffraction

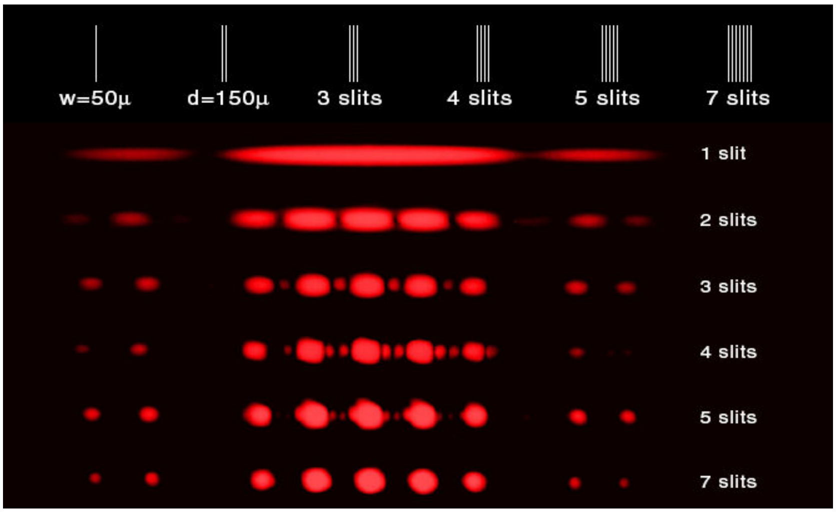

Figure 1.2: An illustration for different numbers of slits

more widely we should look at *Fraunhofer* and *Fresnel* diffraction. When the source source and observing plane are effectively at an infinite distance from the diffracting apertures, diffraction at finite distances is called *Fresnel diffraction*. To understand the Huygens-Fresnel principle firstly we should give attention to the Fresnel Approximation.

$$\mathrm{E}\ (\mathrm{x,y,z}) \cong -\frac{ie^{ikz}e^{i\frac{k}{2z}(x^2+y^2)}}{\lambda z}\int\int E(x',y',0)e^{i\frac{k}{2z}(x'^2+y'^2)}e^{-i\frac{k}{z}(xx'+yy')}dx'dy'$$

Previous equation known as Fresnel approximation. This approximation is valid when the observer is said to be in the region of Fresnel diffraction, or equivalently in the near field of the aperture [3].

Another important topic about diffraction is Fraunhofer diffraction. For a single slit incident plane waves are produced by placing a monochromatic source at the focus of a positive lens. These waves are incident normally on an opaque plane sheet pierced by a single long slit. Beyond this sheet another positive lens images the diffraction pattern onto a screen in its focal plane. The use of lenses brings the source and image plane in from infinity, so making a compact experimental setup with which to observe Fraunhofer diffraction.

The explanation of the single-slit pattern lies in the interference of the Huygens secondary wavelets which can be thought of as sent out from every point on the wave front at the instant that it occupies the plane of the slit. In this sence we have a new term which is interference.

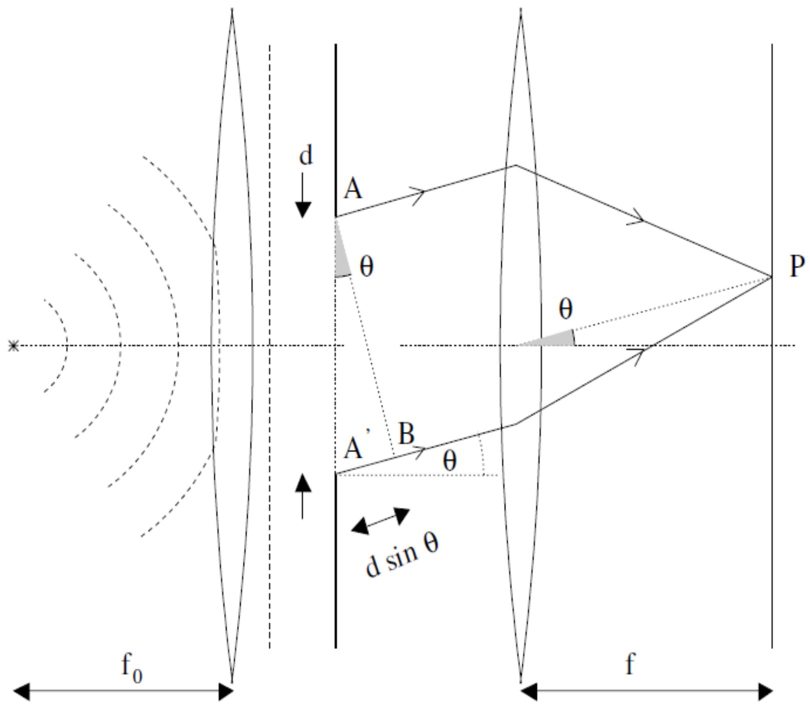

Figure 1.3: Fraunhofer diffraction at a finite width slit

When two beams of light cross each other they do not interfere with each other. However, at the point where two beams of light crossing we are expecting that the resultant amplitude and intensity may be different from sum of two light beams. This modification of intensity obtained by the superposition of two or more beams of light we call as *interference* [4]. If the resultant intensity is zero or less than expecting resultant then we have *destructive* interference. Destructive interference occurs when $\delta = \pm\pi, \pm 3\pi, \pm 5\pi, ...$, and it is defined as

$$I_{min} = I_1 + I_2 - 2\sqrt{I_1 I_2}$$

On the other hand, if we have greater intensity than expecting resultant then we have *constructive* interference. Constructive interference occurs when $\delta = 0, \pm 2\pi, \pm 4\pi, ...$, and it is defined as

$$I_{max} = I_1 + I_2 + 2\sqrt{I_1 I_2}$$

Note that when $I_1 = I_2 = I_0$, $I_{min} = 0$ and $I_{max} = 4I_0$. About the constructive and destructive interference, Richard Feynman wrote this definition in his lecture notes; *"We call it interference whether it is positive or negative. (Interference in ordinary language usually suggests opposition or hindrance, but in physics we often do not use language the way it was originally designed!) If the interference term is positive, we call that case constructive interference, horrible though it may sound to anybody other than a physicist! The opposite case is called destructive interference"* [5]. The first experi-

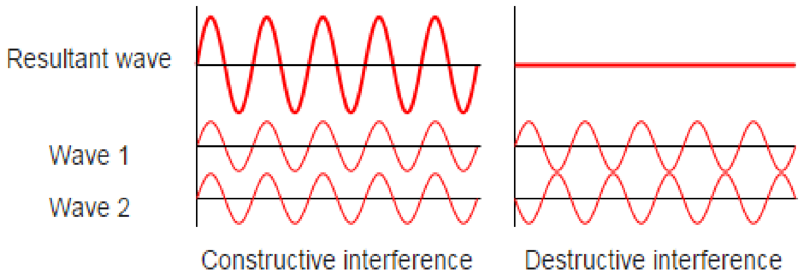

Figure 1.4: Constructive and destructive interference of EM waves

ments was done by Thomas Young. In the Young's experiment' setup (See Figure 1.5), a monochromatic light which has a wavelength λ, a tiny hole S with a diameter δ of the order of fifty to hundred times the wavelength. In

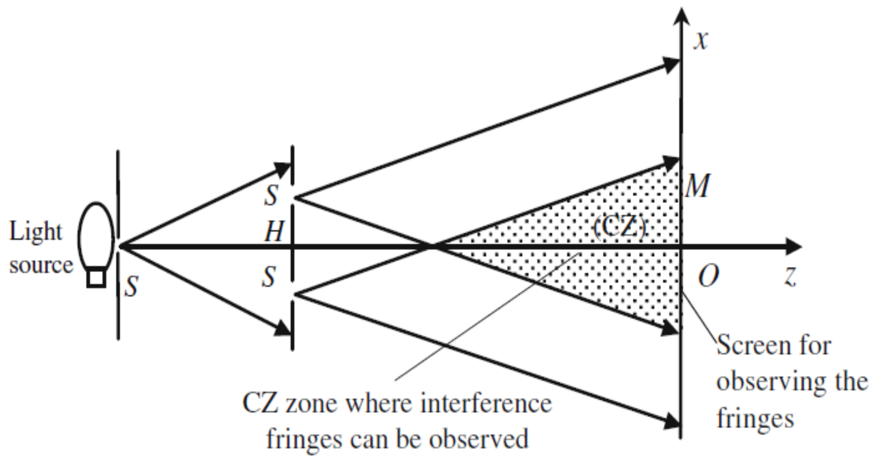

Figure 1.5: Young's experiment setup

this experiment Thomas Young define the following equations for interference fringes:

$$\text{Maxima: } \psi = \frac{2\pi}{\lambda}(MS_2 - MS_1) = (2p+1)\pi \longrightarrow (MS_2 - MS_1) = p\lambda$$

Minima: $\psi = \frac{2\pi}{\lambda}(MS_2 - MS_1) = (2p+1)\pi \longrightarrow (MS_2 - MS_1) = (2p+1)\lambda/2$

The above formulas define hyperboloids and each hyperboloids are labeled by the integer p which called the *order of interference* along the related hyperboloids [6].

Young's experiment is an example for Heisenberg uncertainity principle. Heisenberg uncertainity principle states that *it is impossible to determine simultaneously with unlimited precision the position and momentum of a particle* [7].

$$\Delta p_x \Delta x = \frac{\hbar}{2}$$

In Young's double slit experiment one may either know which slit the photon passes through or one may observe the two slit interference pattern, but not both. If the paths are indistinguishable then interference is seen, but if the path is known interference no longer occurs. To be more precise we should look at wave-particle duality. The connection between the particle and wave properties of light is statistical. The probability of finding a photon in a given volume is simply related with instantaneous energy density of the electromagnetic wave

$$PdV = IdV / \int IdV$$

where P is called the *probability density* [8]. Young's double slit experiment provides a simple example about this relation [2].

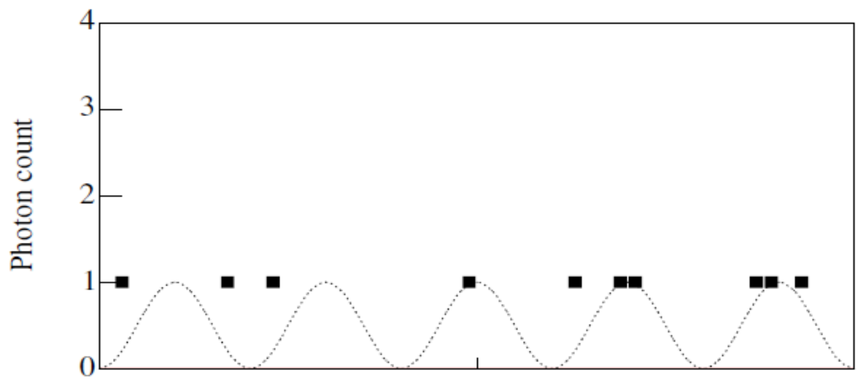

Figure 1.6: Distrubution of photons in Young's two slit experiment for 10 photons

[2]Answer to Teaching Assistant's question.

Data and Results

2.1 Part A: Single Slit

Pattern	A	B
Width of the slit, a	0.08 mm	0.16 mm
Distance from the slit to the screen, L	1.0 m	1.0 m
Average distance between minima, $\bar{y}$	0.79 cm	0.44 cm
$\bar{\lambda} = \frac{a\bar{y}}{L}$	635.0 nm	710.0 nm
Error Δy on $\bar{y}$	0.121 cm	0.084 cm
Error $\Delta\bar{\lambda}$ on $\bar{\lambda}$	84.2 nm	59.2 nm
$\lambda = \bar{\lambda} \pm \Delta\lambda$	550.8-719.2 nm	650.8-769.2 nm

Table 2.1: Sample Data for Single Slit Pattern

2.2 Part B: Double Slit

Pattern	C	D
Width of the slit, a	0.04 mm	0.08 mm
Distance between the center of the slits, d	0.5 mm	0.5 mm
Distance from the slit to the screen, L	1.0 m	1.0 m
Average distance between minima, $\bar{y}$	0.32 cm	0.16 cm
$\bar{\lambda} = \frac{a\bar{y}}{L}$	475.5 nm	790.0 nm
Error Δy on $\bar{y}$	0.058 cm	0.034 cm
Error $\Delta\bar{\lambda}$ on $\bar{\lambda}$	68.1 nm	159 nm
$\lambda = \bar{\lambda} \pm \Delta\lambda$	407.4-543.6 nm	631.0-949.0 nm

Table 2.2: Sample Data for Double Slit Pattern

In this experiment we have used a diode laser which produces a monochromatic beam with a wavelength of 650 nm. When we look our wavelength data we have a range from 407.4 nm and 949.0 nm. Our approximate value for wavelength almost same with theoretical one. That is why we can say that our data are valid. We can see this result by observing following graphs.

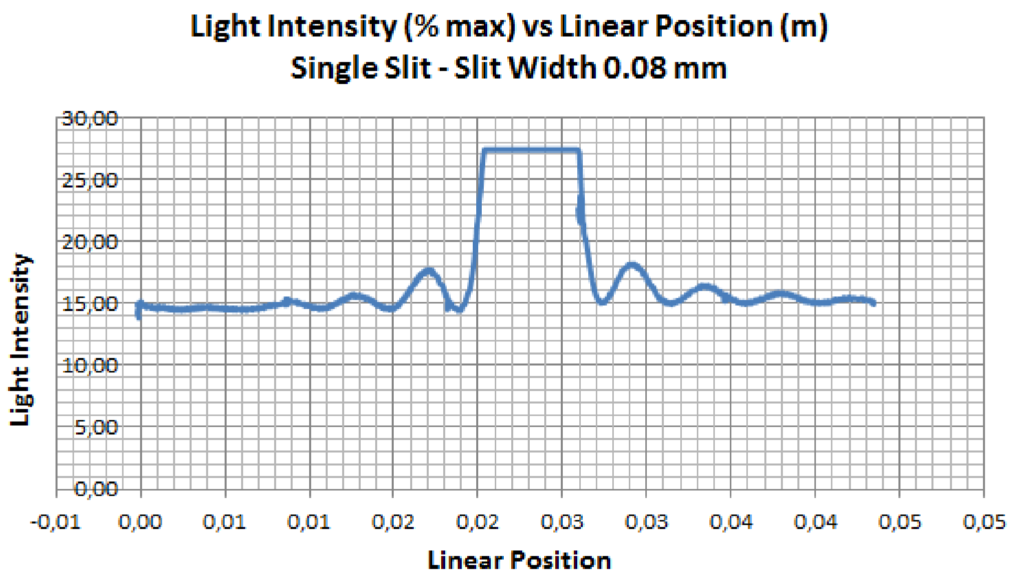

Figure 2.1: Light Intensity vs Linear Position for Single Slit (a=0.08mm)

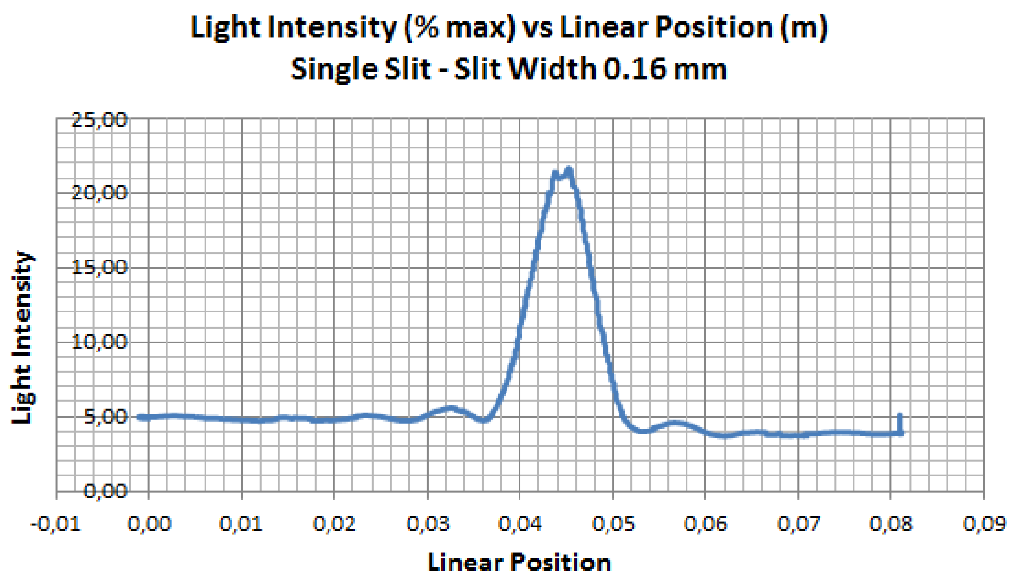

Figure 2.2: Light Intensity vs Linear Position for Single Slit (a=0.16mm)

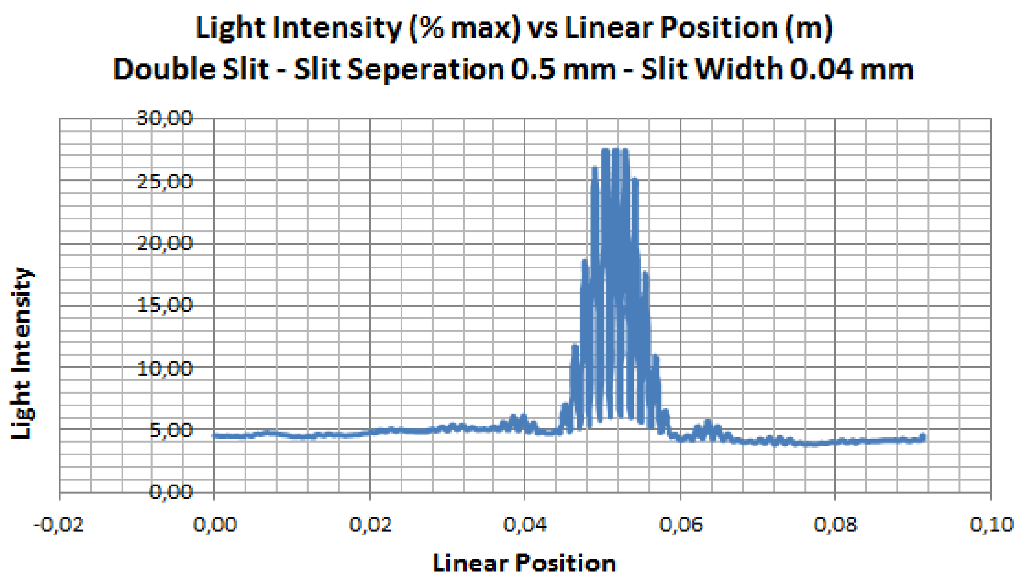

Figure 2.3: Light Intensity vs Linear Position for Double Slit (a=0.04mm)

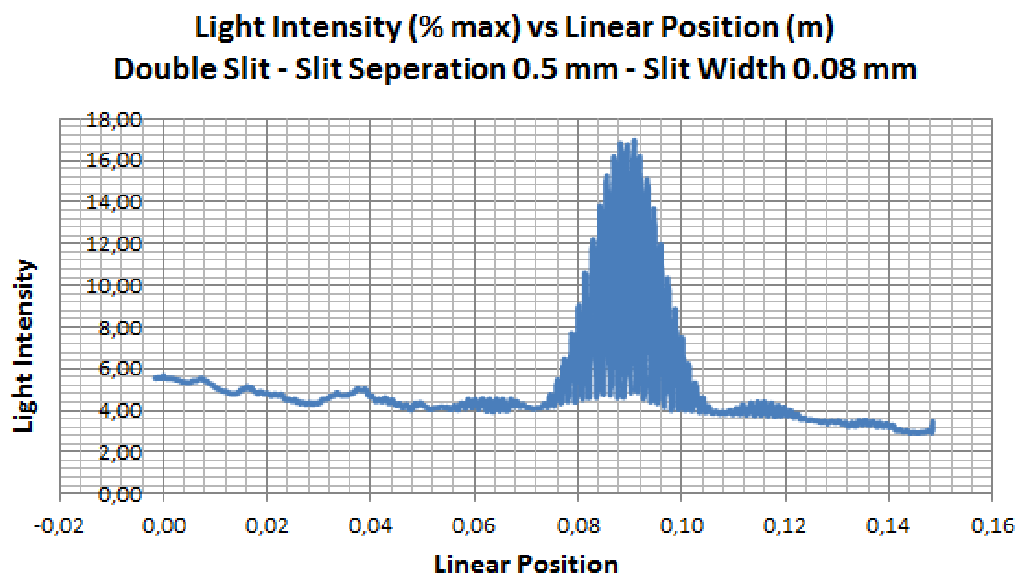

Figure 2.4: Light Intensity vs Linear Position for Double Slit (a=0.08mm)

Discussion and Conclusion

1.What are the possible errors in the experiment?
The most possible error cause may occur while moving light sensor. While moving light sensor we had some acceleration and deceleration and this caused some error. We can see this error in experiment graphs. Device which we took data has some error. Since we have some indoor light, this caused error also.

2.What kind of approximation did you take into consideration while you were obtaining the physical quantities and how do they affect your results?
We received experiment data via a computer based tool. That is why we do not have a lot of approximation. Only approximation is made while moving light sensor because we need to constant speed while reading intensity of light.

3.What discrepancies did you encounter between the calculated quantities and theoretical or literature values?
As mentioned in the lab manual we used a diode laser which has a wavelength of 650 nm. In single slit part we found that the wavelength as 635.0 nm. If we calculate percentage error

$$\text{Percentage Error}=\frac{TheoreticalValue-ExperimentalValue}{TheoreticalValue}\times 100\%$$

$$\text{Percentage Error}=\frac{650.0-635.0}{650.0}\times 100\% = 2.3\%\ \text{nm}$$

2.3 nm is a very small error when we compare theoretical value. That is why we can say that we do not have a certain discrepancy.

4.What is your overall conclusion?
To sum up, we studied interference and diffraction and their differences. We examine different results in single slit and double slit. In my opinion experiment is accomplished. We can see that our results have small amount of error.

Application

Blu-ray Disc

Blu-ray Disc (BD) is a next-generation optical disc format supported by a group of the world's leading consumer electronics and personal computer manufacturers, as well as major studios. It was developed to enable high-definition (HD) video and new forms of interactive entertainment. BD uses a shorter-wavelength blueviolet laser that can focus to a much smaller spot size compared to DVD's red laser. This allows data to be packed more tightly and stored in less space, giving a BD disc more than five times the capacity of a DVD Video disc. While a DVD uses a 650 nm red laser, Blu-ray Disc uses a 405 nm "blue" laser diode. Note that even though the laser is called "blue", its color is actually in the violet range. The shorter wavelength can be focused to a smaller area, thus enabling it to read information recorded in pits that are less than half the size of those on a DVD, and can consequently be spaced more closely, resulting in a shorter track pitch, enabling a Blu-ray Disc to hold about five times the amount of information that can be stored on a DVD. The lasers are GaN (gallium nitride) laser diodes that produce 405 nm light directly, that is, without frequency doubling or other nonlinear optical mechanisms. Conventional DVDs use 650 nm red lasers, and CDs use 780 nm near-infrared lasers [9] [10].

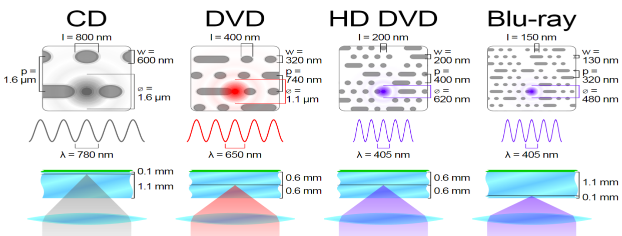

Figure 4.1: Comparison of CD, DVD, HD DVD and Blu-ray

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