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Measuring CD Pit Spacing with a Laser: Applying Fundamental Physics Principles and the Diffraction Grating Method

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ABSTRACT

Purpose of the study: This study aimed to measure the distance between data pits on a Compact Disc (CD) by utilizing its reflective surface as a diffraction grating. When a laser beam strikes the CD, the alternating pits and lands create a diffraction pattern of bright and dark fringes. The pit spacing can then be determined from this pattern and compared with literature values.

Methodology: A red laser was used as the light source, and the resulting diffraction pattern was analyzed using simple Python code based on the diffraction principle. This approach provides an efficient and low-cost method to perform quantitative analysis using readily available tools.

Main Findings: The measured distance between pits on the Compact Disc was 1.607 ± 0.017 µm, with an accuracy error of 0.004%. The results closely matched reported literature values, though slight deviations may have arisen from parallax errors, the difficulty of identifying the laser’s exact reflection point, or ruler precision. From these results, it can be seen that a simple basic physics experiment can easily performed by students because the equipment and procedures are simple yet still produce good results.

Novelty/Originality of this study: This work demonstrates that meaningful physics experiments can be conducted with everyday materials and simple instruments, offering a time- and cost-efficient way to explore fundamental concepts such as diffraction. The study highlights the potential of using familiar objects like compact discs to make physics learning more engaging and accessible for students and young researchers.

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1. INTRODUCTION

Physics is one of the fundamental subject in our life. It used observation or experiment to understand. But for some student, physics is quiet challenging to learn [1], [2]. Ideally, learning physics should foster a mindset that embodies the essence of the subject. That is, physics as a discipline can investigates natural events. Students can gain a deeper understanding of physics concepts and learn to relate them to everyday phenomena by studying these natural events for example understanding the optical diffraction through simple. Previous studies have explored diffraction using laboratory-grade gratings and specialized equipment [3]-[5]. However, physics education often faces challenges due to the limited availability of affordable and accessible learning resources. Many instructional tools or experimental media are either too expensive or difficult to obtain. One example of such equipment is the diffraction grating [6], [7]. Thus, the researcher employed a compact disc (CD), as a diffraction grating to get around this issue [8].

CD is a data storge media. It most widely used in the 1990s [9]. Music, movies, and other kinds of data could be stored on CDs because they had a bigger storage capacity than alternative storage medium that were available at the time [10]. A laser beam reflected from the disc's surface may read data due to optical technology employed in CDs [11]. Both the storage capacity and the quality of data reading on the CD depend on the distance between pits, which are microscopic indentations on the surface that store data. Optical is one branch of physics study. One of the most crucial optical elements in the optical study is the diffraction grating [12].

A diffraction grating is made up of several grooves that are uniformly spaced. Phase changes occur when light interacts with the grooves, causing it to be reflected or transmitted along different paths. Due to the interference between these reflected and transmitted beams, a diffraction pattern consisting of bright spots appears at specific intervals from the center of the pattern [13]. Bright maxima occur at angles where the path difference between the two beams equals an integer multiple of the laser's wavelength [14].

Using a light source such as a laser, the diffraction pattern projected onto a screen can be analyzed by measuring the distance between the central maximum and the nth-order bright spot, as well as the distance between the grating and the screen (L). Stimulated emission, in which electrons transition from higher to lower energy levels, is the fundamental mechanism by which a device known as a laser emits light [15]. The term “laser” stands for Light Amplification by Stimulated Emission of Radiation [16]. A laser operates based on quantum mechanical principles to generate a coherent beam of light. Laser light is an electromagnetic wave that typically lies within the visible region of the spectrum [17]. A red laser was used in this experiment to shows the diffraction pattern from CD.

A CD's unprinted surface features a helical design that alternates between flat and elevated regions. These elevated regions are visible as lengthy, equal-but-varying-height ridges from the underside of the CD. These regions are called “pits” when seen from above, as in Figure 1 [18]. There are both non-reflective bumps and flat reflective sections along the track [19]. Together, they serve as slits in a diffraction grating, with the surface between the elevated areas referred to as "land". The mix of pits and lands on the CD's underside diffracts light when it is reflected, creating a diffraction pattern on the screen [20].

This study assessed the separation between pits on a Compact Disc (CD). Due to its data storage tracks' sensitivity to laser light, a CD can function as a diffraction grating [21]. The distance between the pits is determined using the pattern of bright and dark fringes that the laser beam creates when it is reflected off the surface of the CD. After that, the measurement findings are contrasted with values from related literature. There are several research that use some basic principles of physics and things that we can found in daily life as a study. For example, about rope jumping game [22], Determining Glass Refractive Index from Scattered Laser Interference [23], Bamboo Rifle [24], sarong rolled around body [25], windflow on joglo roof [26] and several daily life examples.

There are also some other research that utilizes CD such as Detrmining refraction index of a fluid using diffraction of CD [27], and CD as a solar panel emergency [28]. This shows that experiment of a research can be started from simple daily life experiences. Through active observation, analysis, and conclusion-drawing, experiments give students the chance to experience and validate what they have learned [29]. By enabling them to validate and uncover ideas through practical actions rather than only theory, experiments assist students in developing their abilities and self-assurance [30].

Events or phenomena, as well as issues in daily life, can serve as catalysts for the popularity of physics and make it an engaging subject to study [31]. This study shows that it is feasible to carry out fascinating experiments employing items that are frequently encountered in daily life by applying basic physics concepts. It also shows that some simple and inexpensive tools can be used as an experiment for student. It is hoped that this study would encourage students and young researchers to begin studying easy-to-understand phenomena.

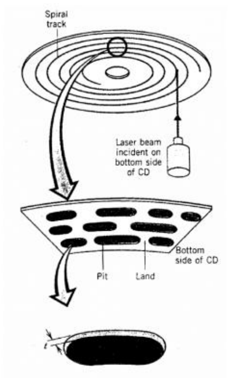

Figure 1. Parts of Compact Disc

2. RESEARCH METHOD

2.1 Interference

Light interference occurs when two light waves overlap and combine. To produce a stable interference pattern, the two waves must be coherent, meaning they share the same frequency, amplitude, and a constant phase difference [32], [33]. The resulting pattern of alternating bright and dark patterns, as illustrated in Figure 2, appears on the screen. The bright patterns correspond to constructive interference, where the light intensity increases, while the dark patterns correspond to destructive interference, where the intensity decreases [34], [35]. This pattern arises because the light passing through the two narrow slits travels different path lengths, creating a path difference that leads to interference.

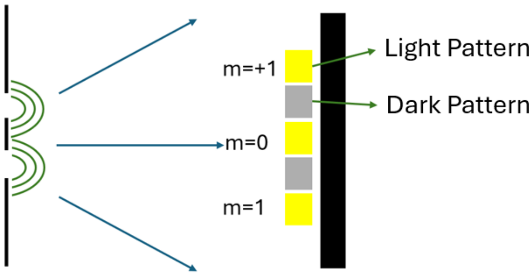

Figure 2. Light and dark pattern of interference

2.2 Difraction

The semicircular wave bends and extends out behind the slit when a wavefront travels through a narrow slit (one whose width is less than the wavelength). This process referred as diffraction [36]. The periodic structure of a diffraction grating causes light to be deflected into several beams that move in various directions [37]. Similar to a lens or mirror, a diffraction grating can be either transmissive or reflective. A reflective diffraction grating, as illustrated in Figure 3, has grooves or lines etched onto its surface that reflect light to produce a diffraction pattern. In contrast, a transmission grating generates its diffraction pattern from the light that passes through slits or openings on its surface.

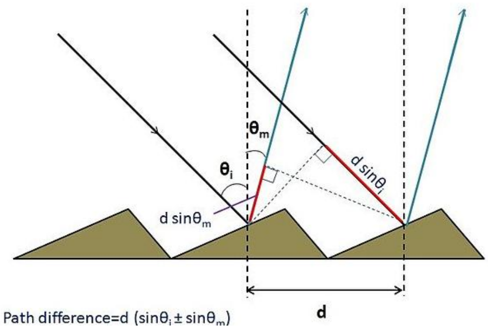

Figure 3. The difference in spacing is caused by the reflective grating

The interference pattern produced on this reflective grating resembles that observed in Young's double-slit experiment or a diffraction grating shown in (1) and (2), specifically [38], [39]:

$$d \sin\theta = m\lambda \quad \text{for bright pattern} \tag{1}$$

$$d \sin\theta = \left(m + \frac{1}{2}\right)\lambda \quad \text{for dark pattern} \tag{2}$$

with $m = 1, 2, 3, \ldots$ for the order of the pattern, d is the distance between the grating.

2.3 Experimental Setup

This experiment utilized a red laser pointer with a wavelength of 630 nm and a power output of 5 mW, signifying its safety for minor laboratory applications. The distance between the laser pointer and the paper screen, utilized for capturing the diffraction pattern, was adjusted to 20 cm, 15 cm, and 10 cm. A ruler with a measuring precision of ±0.5 mm was used for distance measurements. The room was adjusted to be dimly lit to enhance the visibility of the laser light and diffraction pattern.

The periodic structure of the CD's data tracks, which are made up of alternating pits and lands that function as a reflective diffraction grating, is what causes the diffraction pattern shown in this investigation. This happens because the array of pits and lands on the CD's surface changes the direction of light when it is reflected, creating a unique pattern on the screen. The microscopic structure of the CD is directly linked to optical interference phenomena because the observed pit spacing matches the grating spacing that determines the diffraction angles. Bright and dark fringes appear on the screen when the laser light hits these uniformly spaced grooves because the reflected waves interfere constructively and destructively at particular angles. To find the distance at which the CD acts as a diffraction grating, an experiment was carried out.

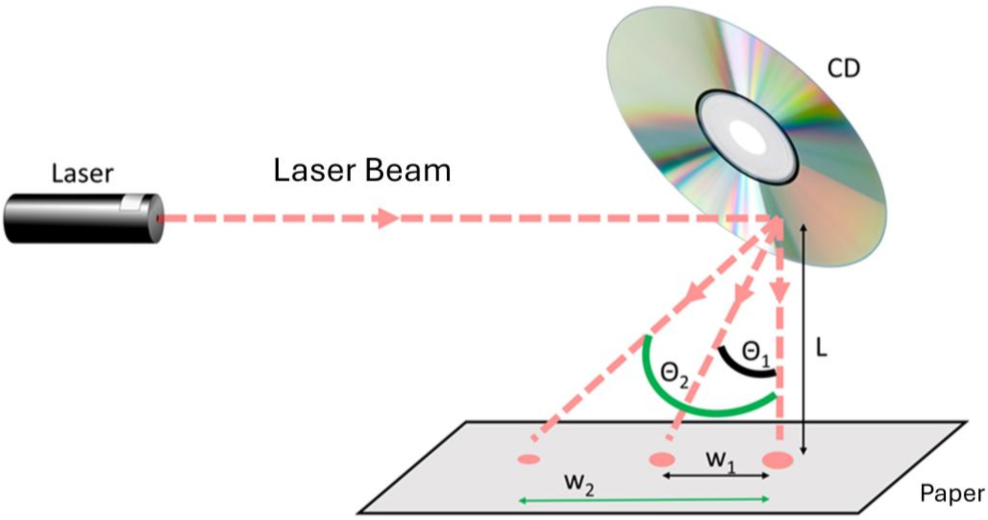

Figure 4. Experimental setup for determining the grating spacing of a Compact Disc using a laser

As indicated in the schematic in Figure 4, the laser is pointed at the reflective portion of the CD, and the reflected beam is projected onto a sheet of paper. The distance between the point where the laser strikes the Compact Disc and the paper (L) is measured first, followed by marking the locations of the central bright spot, first-order bright spot, and second-order bright spot, and then measuring the distances between the central bright spot and the first-order bright spot (w_1) and between the central bright spot and the second-order bright spot (w_2), as shown in Figure 5.

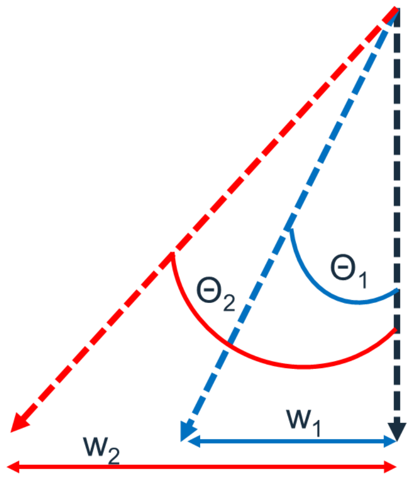

Figure 5. Schematic of the light pattern used to determine the grating spacing of a Compact Disc

To determine the distance between the pits of the reflective grating on the CD, the following equations are used:

Bright pattern in diffraction	:	$d \sin \theta = m\lambda$
First-order bright pattern	:	$d \sin \theta_1 = \lambda$
Second-order bright pattern	:	$d \sin \theta_2 = 2\lambda$

By eliminating the equations for the first- and second-order bright fringes, the result is:

$$d\,(\sin\theta_1 - \sin\theta_2) = -\lambda$$

Or the distance between the grating can be calculated by using the formula (3).

$$d = \frac{\lambda}{(sin\theta_2 - sin\theta_1)} \tag{3}$$

Based on Figure 5, we can determine $sin\ \theta_1$ and $sin\ \theta_2$ shown in (4).

$$sin\theta_1 = \frac{w_1}{\sqrt{w_1^2 + L^2}}\ ; sin\theta_2 = \frac{w_2}{\sqrt{w_2^2 + L^2}} \tag{4}$$

By substituting the values of $sin\ \theta_1$ and $sin\ \theta_2$, the equation for determining the spacing of the reflective grating can be formulated as shown in (5).

$$d = \frac{\lambda}{\left(\frac{w_2}{\sqrt{w_2^2 + L^2}} - \frac{w_1}{\sqrt{w_1^2 + L^2}}\right)} \tag{5}$$

3. RESULTS AND DISCUSSION

It is known that λ = 630 nm for the red laser. Next, measurements were made of the distances from the central bright spot to the first- and second-order bright spots. The example of the bright pattern shown in figure 6. The calculation results are presented in Table 1.

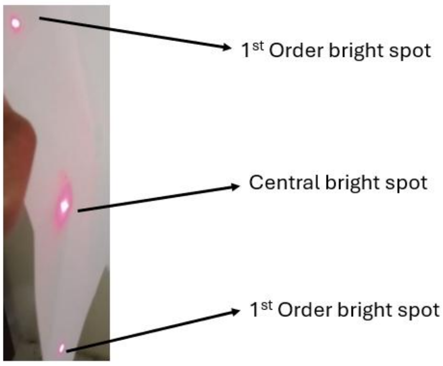

Figure 6. The results shown the bright pattern from the experiment

Table 1. The distances from the central bright to the first-order bright (w_1) and the second-order bright spot (w_2).

No	L (cm)	w_1 (cm)	w_2 (cm)
1.	20.0	9.6	30.0
2.	15.0	6.3	22.0
3.	10.0	4.6	18.3

Using equation (5), the pit spacing on the Compact Disc was calculated. Below is an example calculation for data entry number 1.

$$d = \frac{\lambda}{\left(\frac{w_2}{\sqrt{w_2^2 + L^2}} - \frac{w_1}{\sqrt{w_1^2 + L^2}}\right)}$$

$$d_1 = \frac{630.0 \times 10^{-9} m}{\left(\frac{30.0\times10^{-2} m}{\sqrt{(30.0\times10^{-2})^2 m + 20.0\times10^{-2} m^2}} - \frac{9.6\times10^{-2}\ m}{\sqrt{(9.6\times10^{-2})^2 m + 20.0\times10^{-2} m^{2^2}}}\right)}$$

We found that

$$d_1 = 1.735 \times 10^{-6} m$$

For overal, the results are shown in table 2. Next, we need to calculate the average of the pit spacing.

$$\bar{d} = \frac{\Sigma d}{N} = \frac{4.820\ \mu m}{3} = 1.607\ \mu m$$

Next, the uncertainty of the calculation was determined using the formula:

$$\Delta\bar{d} = \sqrt{\frac{\Sigma|d_i - \bar{d}|^2}{N-1}} = \sqrt{\frac{(0.027\mu m)^2}{3-1}} = \Delta\bar{d} = 0.117\ \mu m$$

Table 2. The results of the spacing of the pits in CD

No	d (μm)	$\lvert d_i$ - $\bar{d}\rvert$ (μm)	$\lvert d_i$ - $\bar{d}\rvert^2$ (μm)
1.	1.735	0.128	0.016
2.	1.578	0.029	0.001
3.	1.507	0.100	0.010
Σd	4.820	$\Sigma\lvert d_i - \bar{d}\rvert^2$	0.027

Therefore, the average distance between the pits on the Compact Disc is:

$$\bar{d} \pm \Delta\bar{d} = (1.607 \pm 0.017)\mu m$$

When compared with the reference value in [40], where the distance between pits on a Compact Disc is stated as $d_{\text{literature}}$ = 1.6 μm, the accuracy error can be calculated as follows:

$$Accuracy\ Error = \left|\frac{\bar{d} - d_{literature}}{d_{literature}}\right| \times 100\%$$

$$Accuracy\ Error = \left|\frac{1.607 - 1.6}{1.6}\right| \times 100\%$$

$$Accuracy\ Error = 0.004\%$$

Next, a graph of d versus L is plotted along with its linear regression. The correlation coefficient R of the linear regression is also calculated. R represents how closely the experimental data fit the regression line. The results of the graph in figure 7 shown that the R value is 0.997, which near |1|. This means that the data are fitted to the regression line.

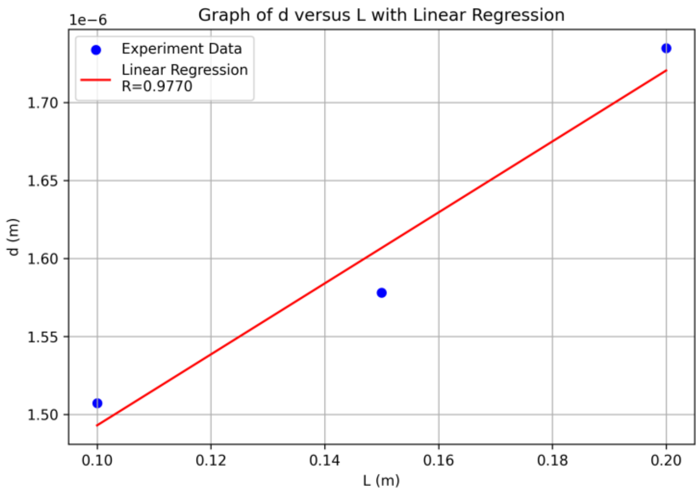

Figure 7. Graph of d versus L with linear regression

From the results obtained in this experiment, the measured value is close to the literature value with error 0.004%, although some differences remain. The results of this study are also very close to those of the following study with *d* of 1.47 µm [41], *d* of 1.65 µm and error of 1.16% [42], and *d* of 2.8 µm and error of 75% [43]. Comparatively, the results of this study are closer to the literature values with d = 1.6 µm [40]. Furthermore, this study used a simpler system and instrument setup because the previous study used lab grade setup. Meanwhile, in this study we used a setup that can be implemented in classroom. However, there are several limitations to this study, such as the room being relatively dark and the measuring instrument having relatively high accuracy. These discrepancies may be caused by several factors, such as:

a. Parallax error,
b. Difficulty in accurately determining the laser reflection point, and
c. The precision of the measuring instrument used. In this experiment was a ruler with an accuracy of 0.5 mm.

This paper shows that it is easy and inexpensive to perform a simple experiment using the diffraction method with a CD, which is an application of fundamental physics. The findings suggest that everyday materials can be effectively utilized to teach and demonstrate optical principles, thereby making physics education more engaging and accessible. Such practical approaches promote inquiry-based learning and encourage students and researchers to conduct simple, hands-on experiments. Overall, this study implies that basic physics experiments using readily available tools can yield meaningful results and be easily performed in educational settings.

4. CONCLUSION

Based on the calculation results, several conclusions can be drawn. The distance between the pits on the Compact Disc was found to be (1.607 ± 0.017) µm, with an accuracy error compared to the literature value of 0.004%. In this experiment, the results obtained were close to the values reported in the literature, although some differences were observed. These discrepancies may be caused by several factors, such as parallax error, difficulty in precisely determining the laser reflection point, and the limited precision of the measuring instrument used in the experiment, namely a ruler with an accuracy of 0.5 mm. This work demonstrates that a basic experiment utilizing the diffraction method with a CD an application of fundamental physics can be carried out with ease and at a low cost. The findings imply that everyday materials can be effectively used to teach and visualize optical principles, making physics education more accessible and engaging. Such approaches can encourage inquiry-based learning and inspire students to explore physics through simple, hands-on experimentation. Therefore, it is hoped that this study would inspire and motivate researchers and students to do simple experiments, enhancing the interest and engagement of physics education. Recommendations for further research include trying other tools, such as a DVD as a diffraction grating, and using other laser colors, such as green. Furthermore, it is hoped that this simple research example will lead to more simple experiments in the future to pique students' interest in learning physics.

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