ORIGINAL PAPER

Alternative Way to Magnify the Pattern of Light Interference and Diffraction

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Abstract: The experiments of diffraction by using a single slit, and interference by using a double slit, are standard physics laboratory for teaching student. The standard experiment setup uses screen that perpendicular to the laser beam. When using a large size of slit's gaps, the fringe's pattern shown on screen would be very small and not easy to be measured by naked eyes. In this paper, we propose an alternative way to set up the experiment, by rotating the screen, this results in more separation of fringes pattern and could enhance the accuracy of displacement measuring. The approximate solution also provided. The experiment results are satisfied with the error of less than 6%. The method also makes experiment of using a large slit becomes possible.

Keywords: Tilt diffraction screen, Enlarge diffraction pattern, Teaching physics laboratory

1. Introduction

One of the ways to visualize the interference and diffraction patterns of light is to perform an experiment of shining light through a tiny gap and observe the pattern behind the screen. Furthermore, there are many other methods to visualize this phenomenon. Some of these patterns are able to make calculation of light's wavelength. The razor blade could show the diffraction pattern (Ivica Aviani and Berti Erjavec 2011). The CD-rom that consists of a micron size of many indentations on its surface would also diffract light (Dragia Trifonov Ivanov and Stefan Nikolaev 2010). The small diffraction pattern from a razor, droplet, and pin's head are magnified by adopting the projector (Dragia Ivanov and Stefan Nikolov 2011). A homemade diffraction using thin wire and LEDs could be performed and analyze by recorded video and tracker software (Pasquale Onorato et al. 2022). Termite's wing also used for demonstrate the diffraction of light (Mahardika Prasetya Aji et al. 2022) The stretched plastic bag would create many small wrinkles that could produce diffraction (Mahardika Prasetya Aji et al. 2019). In our work, we purpose an effective way to help the visualization of fringe patterns become easier, by rotating the screen. Only a protractor is required additionally from the standard tool setup of interference and diffraction experiment.

2. Materials and Methods

2.1 Teaching interference and diffraction

Teacher normally first explains the theory behind it and may visualize by pointing a laser pointer through slit and ask students to observe the pattern on the wall. The problem may arise if the wall is too far, together with ambient light, the pattern would be too dim to be observed by far student. If teacher moves slit closer to the wall, the pattern would become more visible but it would be harder to observe the separation between bright fringes. However, the using of a smaller slit would help increasing the separation. Anyway, after finishing demonstration and explanation of the theory, student may be asked to do the actual experiment in order to physically understand the parameters used in the equation and in the real experiment setup. By the limitation of the size of apparatus, that might be around one meters, this would create a pattern that quite small to be measured by naked eyes when using a large slit. The following teaching process may apply. First, students are asked to compare the results of using different size of slits and make calculation of that by using a standard setup. Next, a large slit, the one that gap's size may be greater than 0.4 mm, are given to student with a task to do any calculation of that from the pattern. In this case, the observed pattern would be so small. If the distance to screen cannot extend anymore, teacher may suggest student to rotate the screen instead, this would make pattern becomes more separate and help increasing the accuracy of the measurement. By measuring the angle of rotation of the screen, student may easily modify the equation of path difference and be able to do the calculation.

2.2 Diffraction and Interference

The diffraction pattern could be shown by using a single slit, it is just a single tiny gap. When light pass through a single slit, the pattern shown up on screen. This pattern consists of many bright and dark stripes as show in the figure 1. The position of the highest intensity for bright stripe are not simple, its analytic solution could be found in (William Moebs Samuel J. Ling, Jeff Sanny 2016). However, the positions of the darkest points are simple that could be explained by

$$d\sin(\theta) = n\lambda \quad \ldots(1)$$

where d is the gap's size of a single slit, n is the number order of dark stripe, θ is the angle between the normal line and the n^{th}-dark stripe as shown in the figure 3, and λ is the wavelength of light. In most experiment, if the distance between slit and screen (L) are large enough, it is common to use the approximation

$$d\frac{x}{L} \approx n\lambda, \qquad \text{for } L \gg x \quad \ldots(2)$$

Where x is the displacement of dark stripe from the center. For the interference pattern, that could be demonstrated by using a double slit, the position of center of bright stripe could be also explained by the same relation in equation 2 with changing some of the definition of parameters. Now, d is the distance between two gaps of a double slit and x is the displacement of bright stripe from the center.

2.3. Angle between beam and screen

In the standard experiment setup, the angle between laser beam and screen is 90°. When rotating the screen by an angle of β, the displacement of fringes changes from x to x_1 and x_2, as shown in the figure 3. The cos β could be written as

$$\cos(\beta) = \frac{x+c_1}{x_1} = \frac{x-c_2}{x_2} \quad \ldots(3)$$

we also have the relation from the similar triangles in the figure 3.

$$\tan(\theta) = \frac{x}{L} = \frac{c_1}{h_1} = \frac{c_2}{h_2} \quad \ldots(4)$$

write down $c_{1,2}$ in equation 4 in terms of x, L, and $h_{1,2}$, then insert back to equation 3, the result would be

$$cos(\beta) = \frac{x+\frac{h_1 x}{L}}{x_1} = \frac{x-\frac{h_2 x}{L}}{x_2} \quad \ldots(5)$$

rearrange to get

$$cos(\beta) = \frac{x}{x_1}\left(1+\frac{h_1}{L}\right) = \frac{x}{x_2}\left(1-\frac{h_2}{L}\right) \quad \ldots(6)$$

From the figure 3, when β is small, both h_1 and h_2 would be closed to zero, when β is large, h_1 and h_2 would be maximum and closed to x_1 and x_2 respectively. In the real experiment, (x_1+x_2) is in the range of 1-5 cm while the L would be at least 100 cm. The h/L term would be maximum at about number 5/100 = 0.05. By equation 6, this number causes the error of 5% to the value of cos β. This small error is comparable to the others systematic error in the real experiment, e.g. the distance measurement, the angle measurement, etc. Hence it is acceptable for the low-cost student laboratory experiment.

Next, we are going to combine all equations together, first, rewrite x in the equation 6

$$x = \frac{x_1 cos(\beta)}{\left(1+\frac{h_1}{L}\right)} = \frac{x_2 cos(\beta)}{\left(1-\frac{h_2}{L}\right)} \quad \ldots(7)$$

Averaging x in equation 7 would result in

$$x = \frac{cos(\beta)}{2}\left(\frac{x_1}{\left(1+\frac{h_1}{L}\right)} + \frac{x_2}{\left(1-\frac{h_2}{L}\right)}\right) \ldots(8)$$

The h_1 and h_2 parameters are not practically measured in the real experiment, hence we prefer to calculate them, from the figure 3, it obvious that

$$h_1 = x_1 \sin(\beta) \text{ and } h_2 = x_2 \sin(\beta) \ldots(9)$$

combine equation 8 and 9 to the diffraction equation in equation 2, the result would be

$$d\,\frac{\frac{cos(\beta)}{2}\left(\frac{x_1}{\left(1+\frac{x_1\sin(\beta)}{L}\right)}+\frac{x_2}{\left(1-\frac{x_2\sin(\beta)}{L}\right)}\right)}{L} \approx n\lambda \quad \ldots(10)$$

rearrange to get

$$\lambda \approx \frac{d cos(\beta)}{2nL}\left(\frac{x_1}{\left(1+\frac{x_1\sin(\beta)}{L}\right)} + \frac{x_2}{\left(1-\frac{x_2\sin(\beta)}{L}\right)}\right) \quad \ldots(11)$$

Equation 11 is the exact solution for any tilt screen angle β. Note that the approximation sign is from the diffraction equation in equation 2 that required $L >> x_1, x_2$. Anyway, if we still use this approximation again, let's x_1 and x_2 are much smaller than L, the result in equation 11 would be a lot simpler, which is

$$\lambda \approx \frac{d(x_1+x_2)cos(\beta)}{2nL} \ldots(12)$$

In the real practical student laboratory, by using the exact solution of equation 11, one needed to measure x_1 and x_2 separately, while using the approximated solution of equation 12, one may need to only measure (x_1+x_2), the latter would give better measurement error due to its longer distance measured.

To summary, if using the exact solution in equation 11, the error from the measurement could be large, while using the equation 12 would approximately get haft the measurement error (due to double distance) but the approximation error would be related to how small of h/L ratio. In this paper, we compared both calculations and show that there is no significant difference in either methods.

3. Experiment setup and results

A double slit of width 0.4 mm and a red color laser of 635 nm were used to demonstrate the experiment. The apparatus setup is shown in the figure 2. We attached a 1mm-grid graph paper to the screen in order to easily measuring the displacement of fringes. We limit not to use others higher accuracy equipment to measure, e.g. Vernier and micrometer, due to the paper objective is to improve the low-cost experiment without changing the equipment. The distance between screen and a slit was setting to be 100 cm. We marked the central fringe and count the number of bright stripes that are visible. The center of bright (or dark) fringe are estimated by eyes, this should not cause a problem because the fringe width has a size in range of 1-5 mm while the error from the eye's estimation is less than the resolution of the grid paper of 0.5 mm. At first, when did not rotate the screen, it would be very hard to count those fringes by naked eyes due to the very small size of fringes. After the screen rotation of $\beta = 40^o$, 60^o, and 80^o, counting would be a lot easier as shown in the figure 4. We can measure the displacement between the left n^{th}-bright stripe (x_1) to the right-n^{th} bright stripe (x_2). The results are shown in Table 1. Note that the error comes from the limitation of displacement measuring from 1mm-grid graph paper, that is the scope of this paper to improve to low-cost student experiment without changing the equipment.

Table 1. The results of interference pattern calculated by equation 10 and 11.

Tilt screen angle β	Order of bright fringe n	Approximated solution (Eq. 12)		Exact solution (Eq. 11)		
		Displacement x_1+x_2 (mm)	λ / error	Displacement x_1 (mm)	Displacement x_2 (mm)	λ / error
0^o	11	34.5	627.27 / 1.21%	17.0	17.5	627.27 / 1.21%
40^o	10	41.5	635.81 / 0.12%	20.5	21.0	636.13 / 0.17%
60^o	5	30.0	600.00 / 5.83%	15.0	15.0	600.10 / 5.49%
80^o	4	74.0	642.49/ 1.18%	38.0	36.0	642.08 / 1.11%

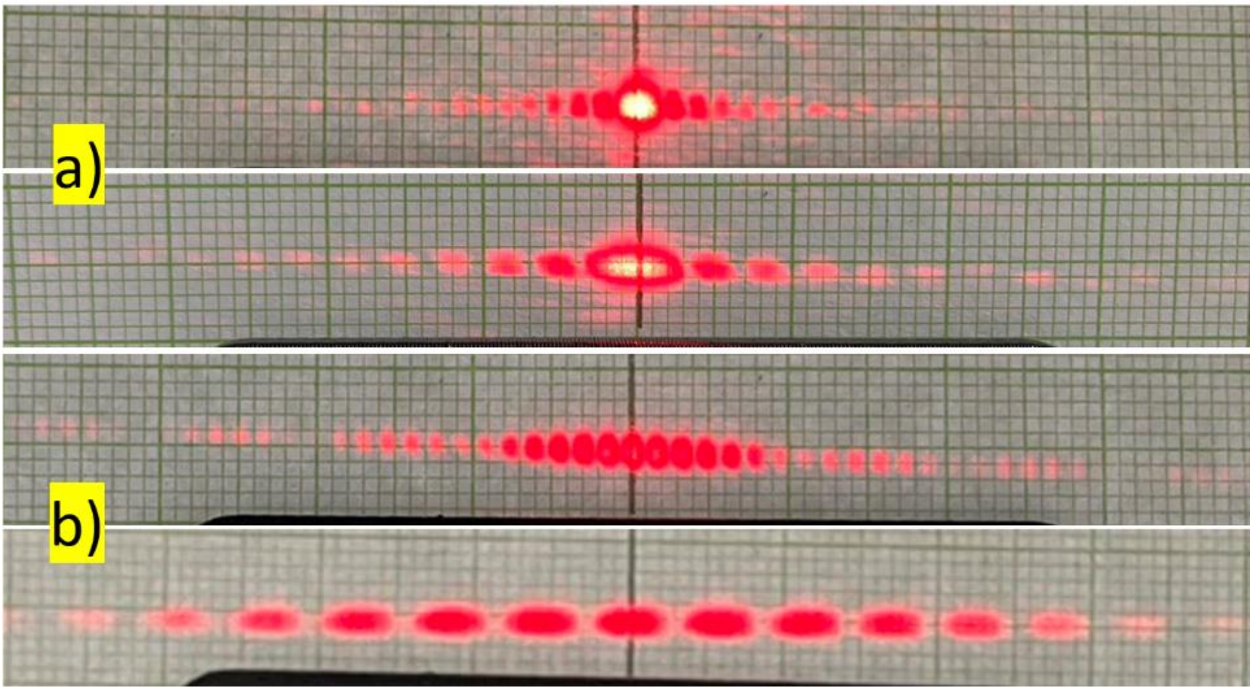

Figure 1. a) Fringes from a single slit (top) and a double slit (bottom) that appeared in the standard setup. b) When rotating the screen, fringes become wider.

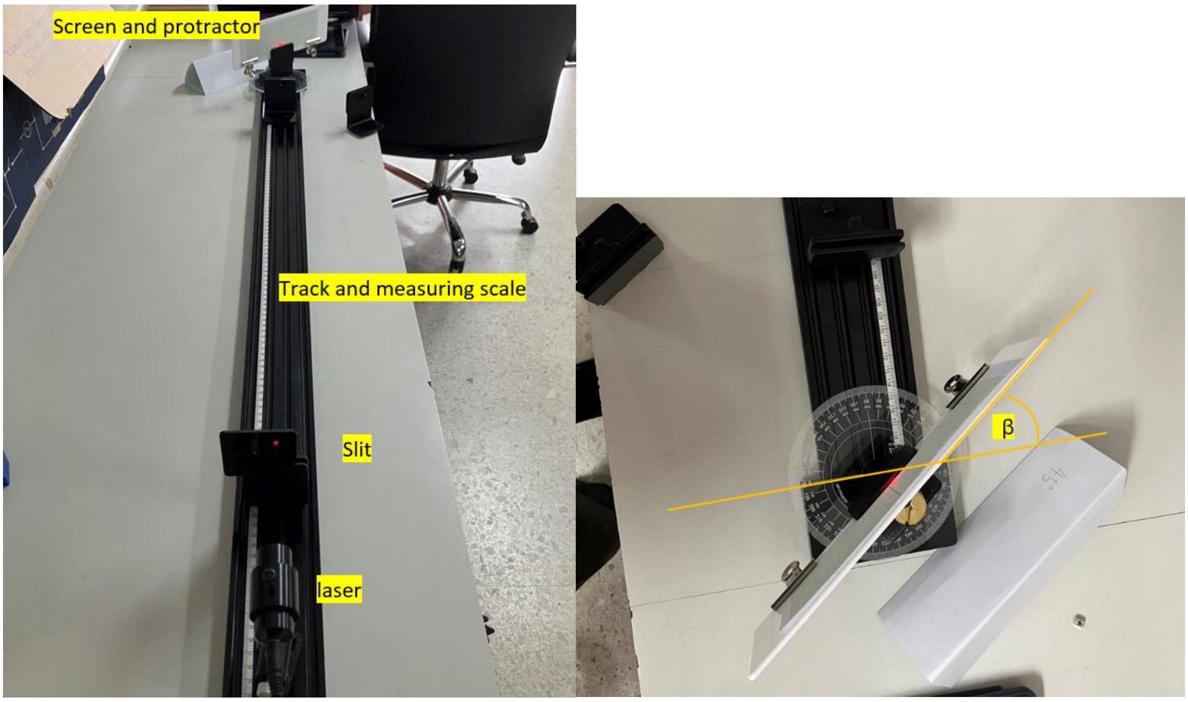

Figure 2. The picture shows the experiment setup. Laser, slit, and screen are placed on a track with *a* measuring scale. A protractor is using for measuring the screen angle β.

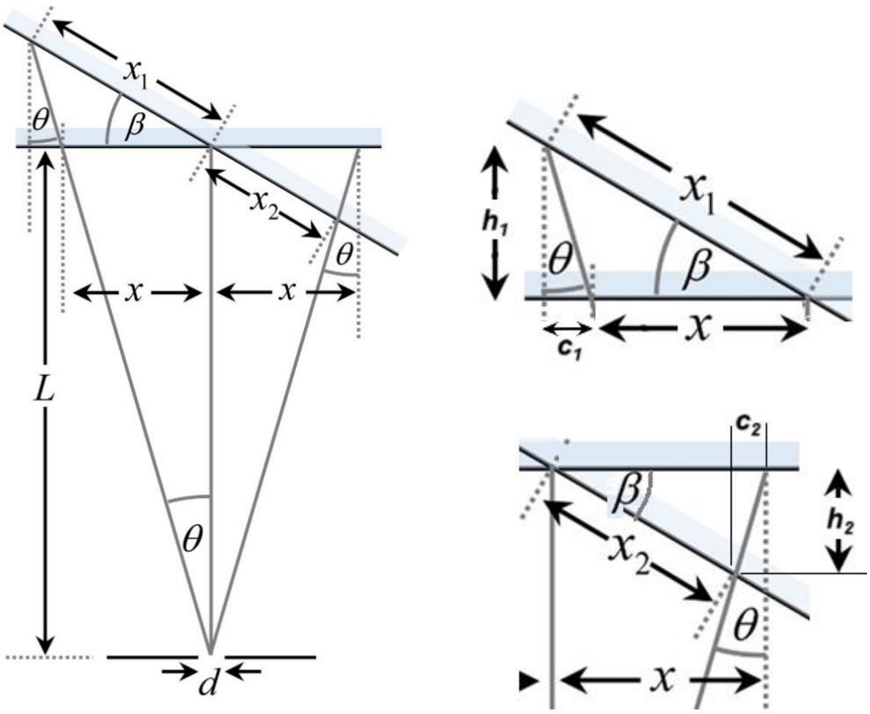

Figure 3. (left) The parameter diagram of experiment, the standard screen is perpendicular to the laser beam, β is the angle of the rotating screen. (right) The enlarged image of the triangles in the left picture

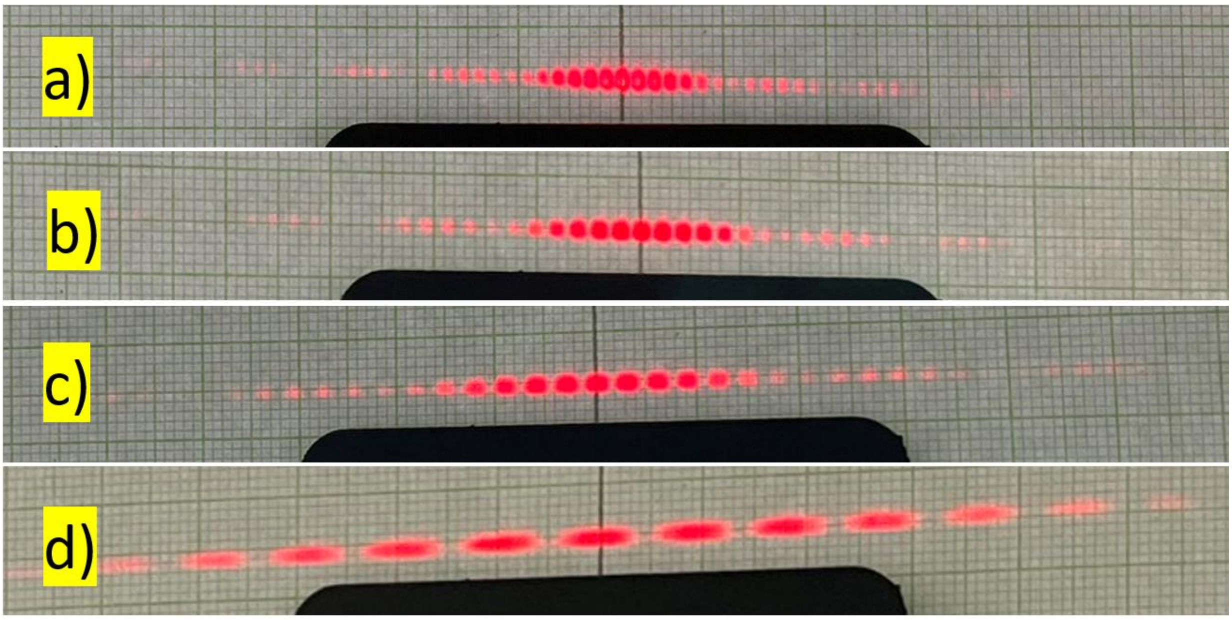

Figure 4. a) Interference pattern of using a double slit of width d=0.4 mm, laser of wavelength 635 nm, and distance to screen of 100 cm. b) Rotate the screen by angle of β = 45°. c) Rotate the screen by angle of β = 60°. d Rotate the screen by angle of β = 80°.

4. Discussion

The results in the table 1 compared the error between using the exact solution and the approximated solution. We found that there is no significant in the difference of error in both methods. The highest error is 5.83% that is acceptable. To clarify this, the author limits the distance measurement by using only 1-mm grid graph paper. Hence the measured distance would be valid at the resolution of 0.5 mm (measurement can be 1.0, 1.5, 2.0, …, but not 1.7, 1.8 mm, … etc.). By including the error from the others sources, e.g. the measurement of angle and the screen distance, this error number would not be too much.

In the experiment of light diffraction and interference, when the equipments are carefully and precisely align, the error would be very small. However, in most high-school or even in undergraduate physics laboratory, the limitations of equipment are the big problem. Although there are many others better way to measure the distance between fringes, e.g. by using a better scale like Vernier caliper or micrometer, instead of just using a very broaden scale 1-mm grid graph. Our technique and idea presented in this paper would help the large-slit experiment become possible and enhance the result for those laboratories that have a limitation of equipment quality. Furthermore, this would help students improve their creativity in doing physics experiment.

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