PAPER

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A unique diffraction pattern formed by a grating from a flying termite wing

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Abstract
In diffraction experiments, natural gratings often create uncommon diffraction patterns compared with those resulting from manufactured gratings. This study analyzed a unique diffraction pattern obtained by a grating from a flying termite wing. A ring-like diffraction pattern was formed because of the grating morphology from a flying termite wing, which consisted of horizontal- and vertical-structured slits. The mechanism of diffraction pattern formation is also provided. The distance between slits was measured using digital microscope images and a diffraction experiment, with the results coming to an agreement. Using this grating in a diffraction experiment can help educators provide an alternative diffraction experiment that supports students in studying the topic in a more complex manner.

Keywords: grating, flying termite wing, diffraction pattern

1. Introduction

Optical diffraction is an essential phenomenon for recognizing the wave behavior of light. Light diffraction can be defined as the spreading of light waves around obstacles [1]. Diffraction also takes place with sound and water waves, which occurs when the size of the aperture is of the same order of magnitude as the wavelength of the incident wave [2, 3]. Students can simply demonstrate a light diffraction phenomenon in physics class by passing a coherent light from a laser through a

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grating to display a diffraction pattern. Diffraction patterns are greatly influenced by the structure of the obstacles [4]. Slits with streaks of narrow lines exhibit the diffraction pattern in a regular line configuration of dark and bright dots. Meanwhile, circular diffraction patterns can be displayed from light that has traveled through circular aperture gratings [5]. Those are commercial gratings that students commonly use to perform diffraction experiments in the laboratory. Lab standard gratings have regular structures, which can yield regular diffraction patterns with an obvious appearance because they are precisely manufactured. As a part of science, physics can be taught by involving natural sources as supporting experiment media for students to study a specific topic.

In terms of diffraction experiments, natural gratings have been widely utilized. Gratings can be made from natural sources, such as plant stem fibers, butterfly wings, and extracted plants [4, 6–8]. Even waste of synthetic material such as plastic bags could also be deformed by certain forces to generate a periodic structure, which then behave like a simple grating [9]. Natural gratings often yield unique diffraction patterns that students might rarely observe, unlike manufactured gratings. A unique diffraction pattern must be generated by a unique structure or morphology of a grating. Therefore, observing unique diffraction patterns produced by natural gratings can lead students to study the diffraction topic more complexly.

Observing a unique diffraction pattern is not only about students examining the light or slit properties by investigating the obtained diffraction pattern but also having to observe the structure or morphology of the grating using an optical device such as a digital microscope. Furthermore, students are also driven to analyze a correlation between the structure of the grating and the obtained diffraction pattern with the assistance of the existing theory. This study presents a unique diffraction pattern formed by a grating from a flying termite wing. The investigation results of the grating structure on a flying termite wing and analysis of the formation of diffraction patterns are also provided. This study is hopefully beneficial for educators to provide an alternative diffraction experiment that supports students studying the topic in a more complex way.

2. Method

The main material used in this experiment was a flying termite wing as a natural grating. Flying termites are one-fourth to three-eighths of an inch-length insect with four wings, as given in figure 1(a) and are distributed on almost all continents except Antarctica [10]. Flying termites have a very short life, which once they take flight, they have about one hour before their wings fall off [11]. Therefore, we can collect fallen wings instead of deliberately taking them by force, potentially torturing the termite. A setup consisting of a power supply, a laser (helium–neon 5 mW) that was used to generate a beam of coherent light of 632.8 nm, a grating from a flying termite wing, and a screen, as depicted in figure 1(b), were used to conduct a diffraction experiment. A laser generated a coherent light and beamed through a grating from a flying termite wing. The light was then deflected and interfered with by the grating before ultimately drawing a diffraction pattern captured on a screen placed at a certain distance from the grating.

The intensity of the diffraction pattern was analyzed by the image processing software of MATLAB R2019a [12]. The intensity of the diffraction pattern can also be represented by a gray value that was obtained from image processing analysis using the freely available ImageJ Processing software of the National Institute of Health (USA) [13]. The slit distance of the grating was estimated using a graphical method. A linear equation can express the conditions under which the diffraction pattern is formed. In the experiment, the distance between the screen and grating was varied. The distance between slits in the grating was determined by the gradient of a linear equation graph. This linear equation is greatly influenced by the shape of the captured diffraction pattern. Furthermore, the morphology of a flying termite wing was observed using a digital microscope. The distance between the slits was also estimated from the microscope image using ImageJ software [13].

3. Results and discussion

A diffraction experiment using a grating from a flying termite wing developed a unique diffraction pattern, as shown in figure 2(a). The grating has

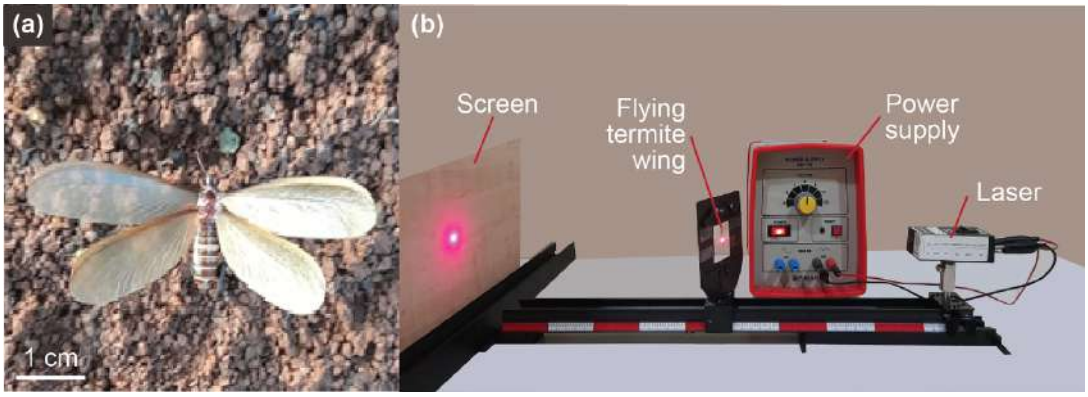

Figure 1. (a) A flying termite, (b) setup of diffraction experiment using grating from flying termite wing.

deflected coherent light from a laser and created a ring-like diffraction pattern. We initially assumed a ring-like diffraction pattern might be generated because the flying termite's wing has a circular aperture-structured grating. This pattern looks different from diffraction patterns resulting from other natural gratings. Generally, diffraction patterns coming from natural gratings have dark and bright dot configurations in a regular line [4, 6]. Figure 2(a) shows different intensities in a ring-like diffraction pattern, with the highest value being observed in the central pattern, indicating a zeroth order of the bright spot. Meanwhile, the lower intensities at the edge of the ring-like diffraction pattern denoted the first order of the bright spots. The difference in intensity in the diffraction pattern was also represented by the intensity and the gray value from the image processing result by MATLAB R2019a and ImageJ software, as given in figures 2(b) and (c), respectively. The spectra indicate the interference pattern due to the deflection of the plane wave from a laser beam through a narrow slit. Thus, a flying termite wing can be utilized as a grating for a diffraction experiment.

We conducted microscopic observation using a digital microscope to justify our initial assumption that a circular aperture grating constructed a ring-like diffraction pattern. The morphology of the flying termite wing is presented by microscope image as given in figure 3(a). Surprisingly, the grating structure of the flying termite wing consisted of regular barriers that were evenly distributed instead of a circular aperture. The empty spaces that regularly spread between the barriers were considered as slits, which, when light passed through, experienced deflection and drew a diffraction pattern. If we carefully look at the morphology of the flying termite wing as provided in figure 3(a), two groups of slits are perpendicularly distributed. They can be classified as horizontal and vertical slits in which each slit is separated by distance d, as illustrated in figure 3(b).

The mechanism of the diffraction pattern formation due to vertical and horizontal slits is illustrated in figure 4. Each group of vertical and horizontal slits created an individual diffraction pattern, but the pattern was also plotted perpendicular. The zeroth order of the bright spot in the diffraction pattern yielded by vertical and horizontal slits appeared at the same point, resulting in a bright spot with the highest intensity. At the same time, the first order or the bright spots yielded by vertical and horizontal slits were in perpendicular lines at a certain distance from the zeroth order of the bright spots. Therefore, this created a ring-like diffraction pattern, but it was not a circular form.

The distance between slits was estimated from the microscope image in figure 3(a). The distance between slits is obtained from the ratio of the pixel length between each slit with the calibration length on the microscope image using ImageJ software. The distributions of the distance between the horizontal and vertical slits are shown in figures 5(a) and (b). The average distances between the horizontal and vertical slits were (15.21 $\pm$ 0.21) μm and (10.79 $\pm$ 0.16) μm, respectively. The distance between slits affected the distance from zeroth order to the first order

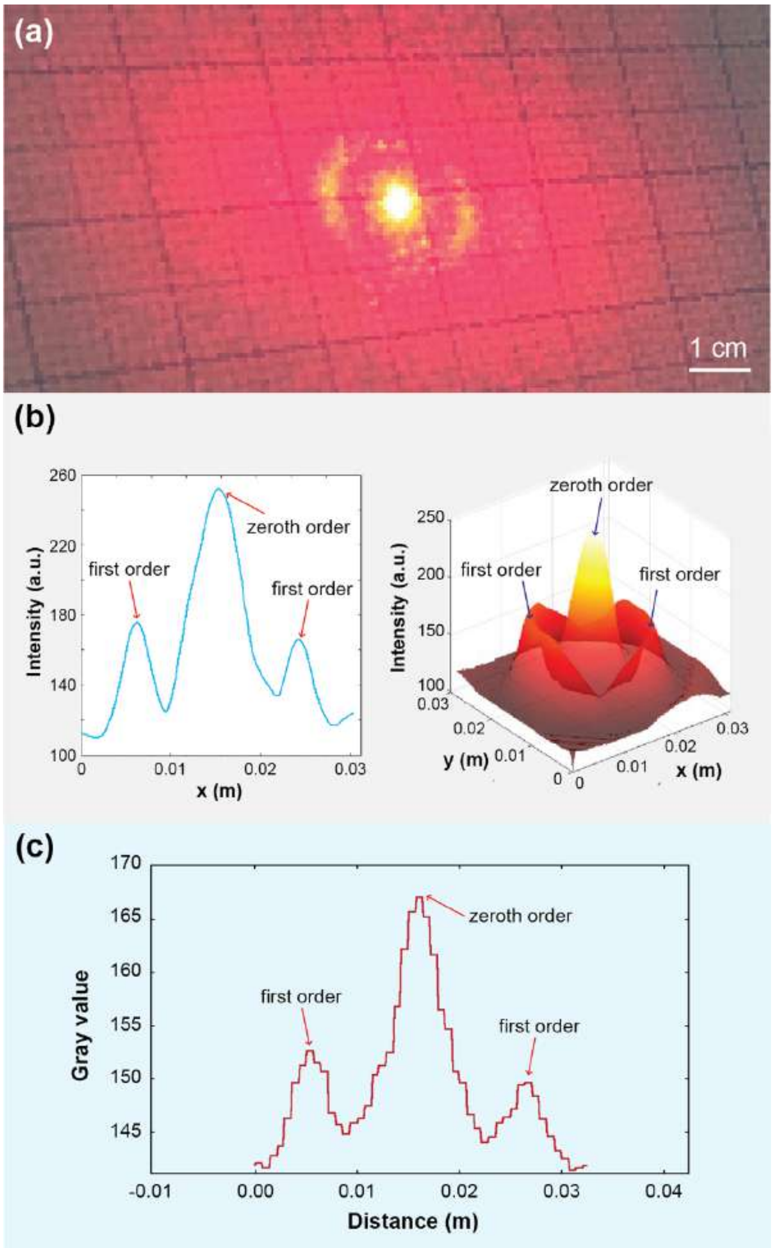

Figure 2. (a) The ring-like diffraction pattern produced by grating from a flying termite wing. The intensity of the diffraction pattern obtained from image processing analysis using: (b) MATLAB R2019a [12], and (c) ImageJ software [13].

of the bright spot. According to the diffraction equation ($d = \lambda L/y_1$, where d is the distance between slits, λ is the wavelength of light, L is the distance between the grating and the screen, and y_1 is the distance from the zeroth order to the first order of the bright spot), the larger the distance between slits, the smaller the distance from the zeroth order to the first order of the bright spots. This correlation was confirmed by a macroscopic observation as presented in figure 6. The distance from the zeroth order to the first order of the bright spot that resulted from vertical slits was larger

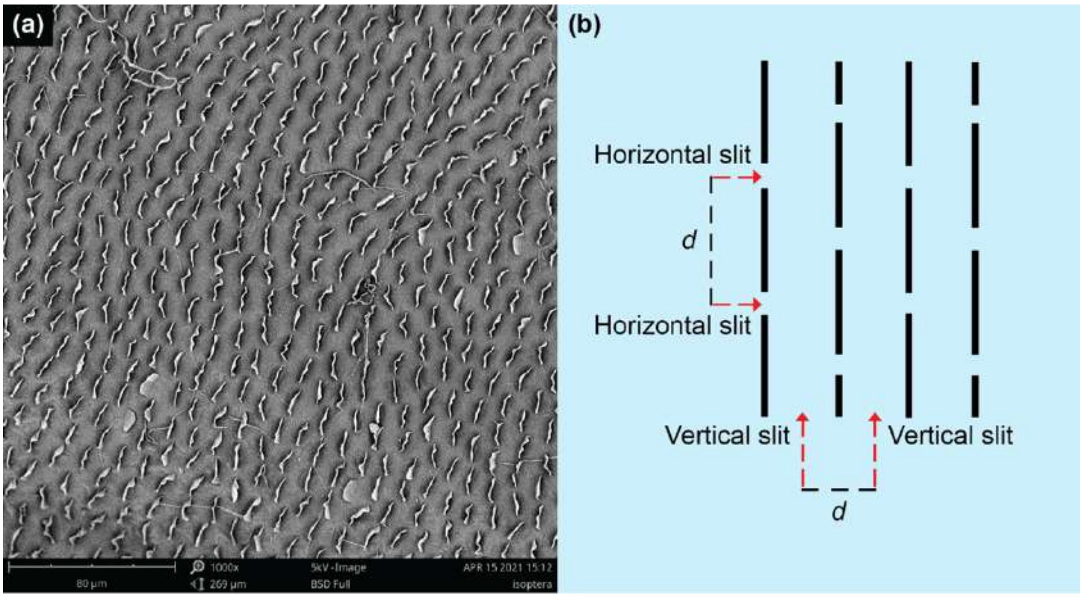

Figure 3. (a) Microscope image of a flying termite wing, (b) illustration of two kinds of slits of grating from a flying termite wing.

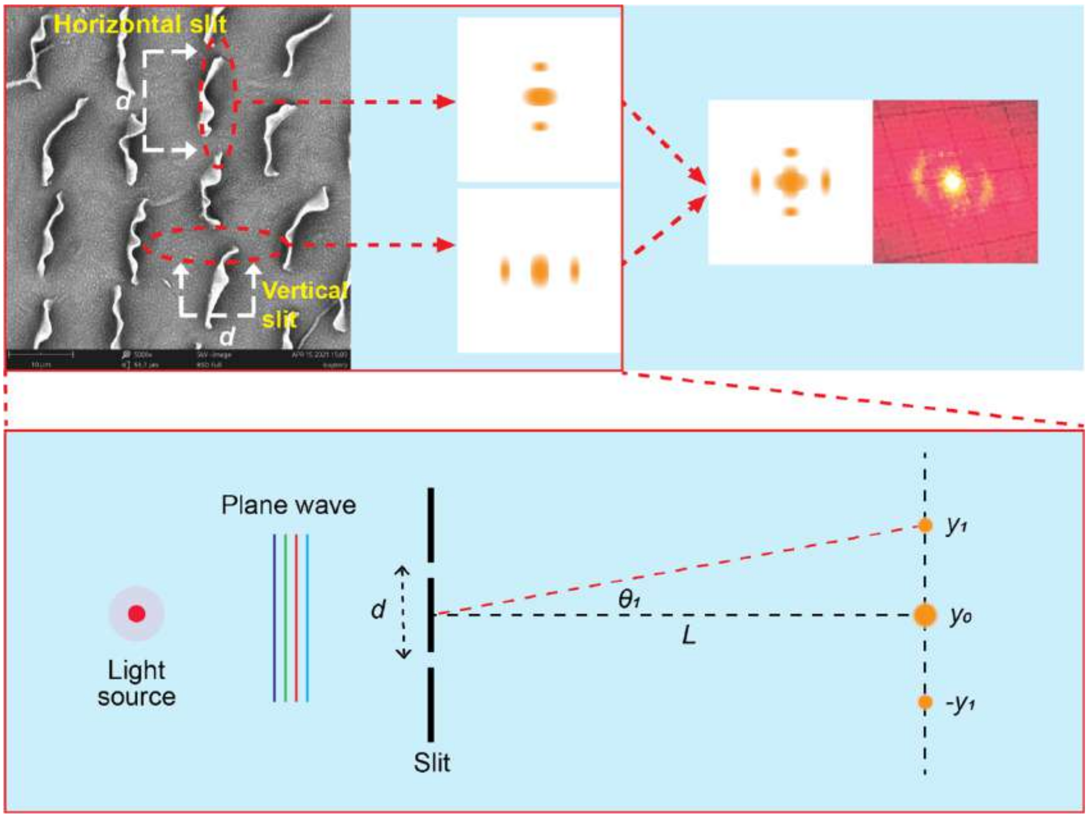

Figure 4. The mechanism of the diffraction pattern formation created by the vertical and horizontal slits.

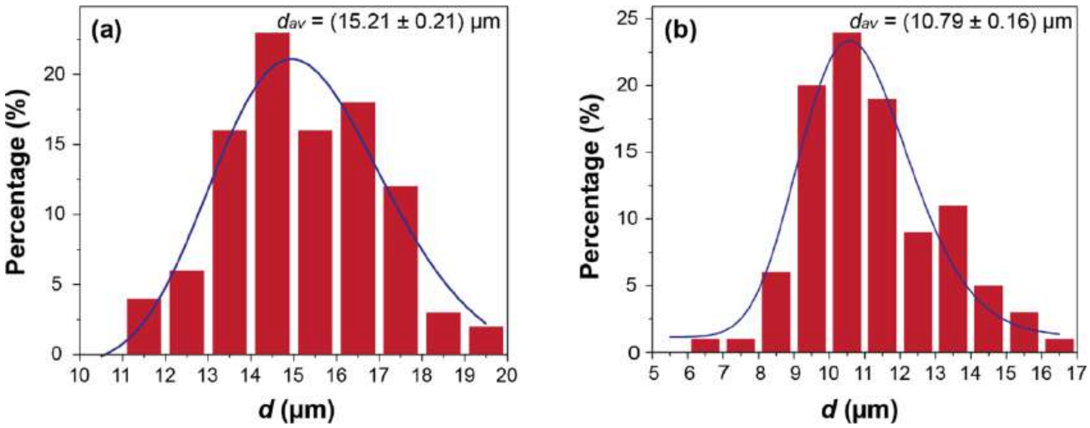

Figure 5. The distributions of d for: (a) the horizontal slits, and (b) the vertical slits.

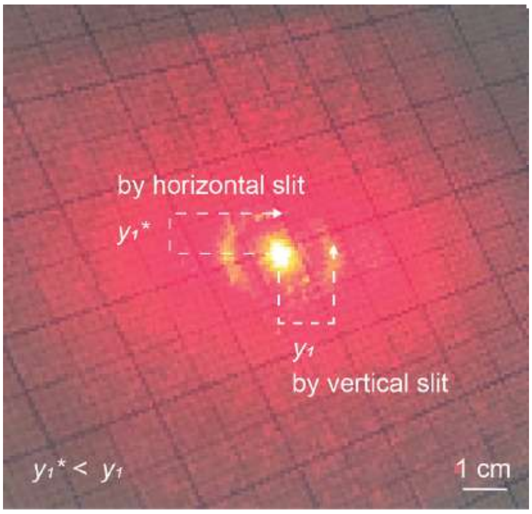

Figure 6. Comparison of zeroth order to the first order of the bright spot distance for the diffraction pattern from vertical and horizontal slits.

than that of horizontal slits. This was because the average distances between the vertical slits were smaller than the horizontal slits.

The distance between slits was also determined using an experiment by measuring the distance from the zeroth order to the first order of the bright spot captured on a screen. By varying the distance between the grating and the screen (L), various distances from the zeroth order to the first order of the bright spot (y_1) were achieved. Unfortunately, as distance L was varied, we could not measure the different values of the ordinate variable y_1 (figure 4), simply because the intensities of the corresponding diffraction patterns then obtained were too low for measuring that variable with enough accuracy. However, a diffraction pattern resulting from the horizontal slits with enough intensity was achieved when the grating was placed at $L = 0.3$ m. The distance between the zeroth and the bright spot's first order was measured in $y_1 = (0.013 \pm 0.002)$ m. Using this value of y_1 and equation (1), the distance between the horizontal slits can be calculated as $d = (14.69 \pm 1.81)\ \mu$m. This value of d is almost similar to the value obtained from microscope digital analysis, as shown in figure 5(a), with a relative error of 3.53%.

For the vertical slits, various L yielded the variation of the distance from the zeroth order to the first order of the bright spot y_1, which measurement result indicated that the value was raised as plotted in figure 7. If m is the slope of the line in figure 7, then the distance between the slits can be estimated using the relation between L and y_1, as expressed in equation (2):

$$d = \lambda \frac{L}{y_1} \quad (1)$$

$$d = \frac{\lambda}{m}. \quad (2)$$

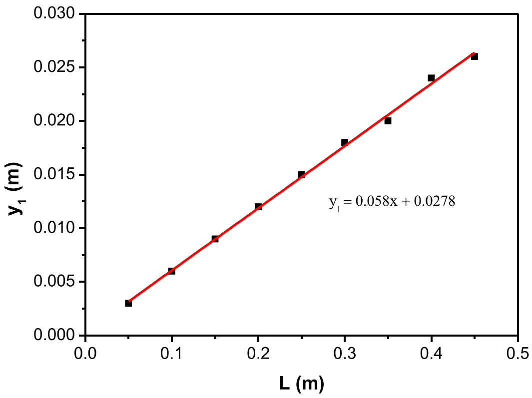

Figure 7. Variation of the distance y_1 from the zeroth order to the first order of the bright spot as the distance L from grating to screen is varied.

Using equation (2) and the value of m from the graph in figure 7, the distance between the vertical slits can be calculated as $d = 10.89$ μm. This value is almost identical to that collected from microscope image analysis in figure 5(b), with a relative error of 0.93%. Therefore, there was an agreement between the microscopic observation of the distance between slits and the experimental results.

4. Conclusion

A unique diffraction pattern produced by a grating from a flying termite wing was analyzed. A ring-like diffraction pattern was formed because a flying termite wing has a morphology of horizontal- and vertical-structured slits that played as natural grating. The diffraction experiment showed the distance between the horizontal slits was ($d = 14.69 \pm 1.81$) μm, which was almost similar to that obtained from microscope image analysis ($d = 15.21 \pm 0.21$ μm), with a relative error of 3.53%. In comparison, the distance between the vertical slits was $d = 10.89$ μm from the diffraction experiment, almost identical to the value obtained from microscope image analysis ($d = 10.79 \pm 0.16$ μm), with a relative error of 0.93%. Educators can use a grating from a flying termite wing to perform a diffraction experiment that supports students in studying the topic more complexly.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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