Research Article

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A Simple and Easy Tabletop Double-Slit Experiment to Directly Visualize Optical Intensity Distribution Pathways of Laser Light Beyond Diffracting Obstacles

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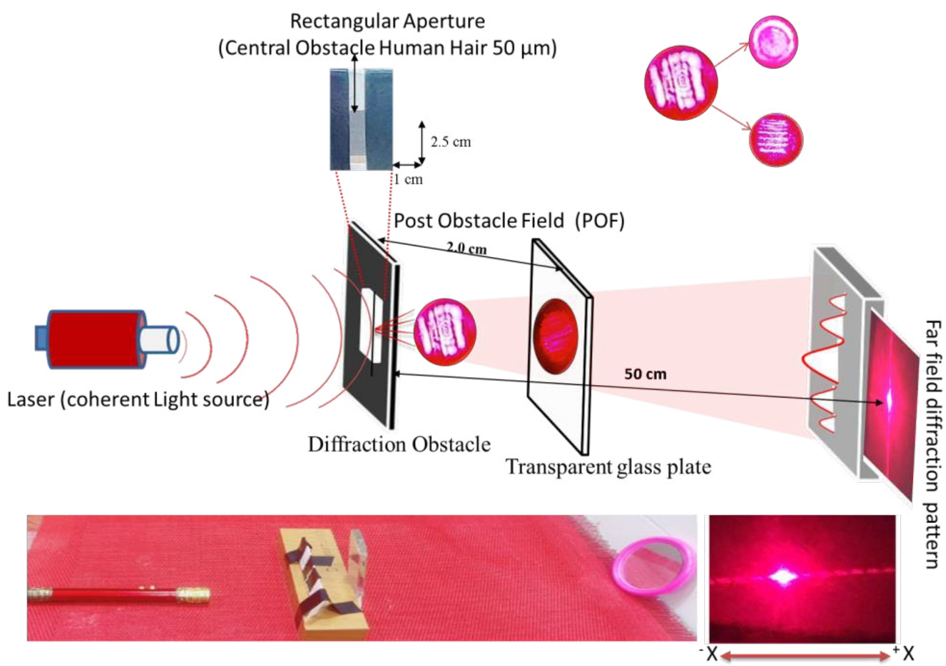

Graphical Abstract

Abstract
Young's double-slit experiment, which represents the mystery of quantum physics and the diffraction that goes along with it, has long been used as a fundamental experiment to demonstrate how light is a wave by looking at interference patterns on a distant screen. In conventional diffraction experiments, which normally only show on a far field screen using photons, electrons, atoms, molecules, and other quantum systems. The evolution of the optical field in the Fresnel region is well-established theoretically, but there has not yet been much direct experimental observation of this intermediate field. In this work, we present the first direct experimental visualization of a structured Post-Obstacle Field (POF) immediately beyond a diffracting obstacle. The double-slit assembly consisted of two rectangular transmitting regions separated by a 50 µm diameter human hair acting as the central obstacle. A continuous-wave 632.8 nm He–Ne laser was used to illuminate the diffracting obstacle.

The Post obstacle Field (POF), an operational term that characterizes the optical intensity right after the diffraction barrier, is the name given to the experimentally observed intensity distribution referred to here as N dominant intensity pathways. POF exhibited two distinguishable but simultaneously occurring spatial structures: an approximately banded pattern and a radially organized, ring-like structure surrounding a structured central region. To independently verify that these structures represent a physical optical field rather than an imaging artifact, a transparent glass plate was positioned approximately 2 cm behind the obstacle. These observations suggest that spatial structure established in the near-field region may provide an experimentally observable precursor to the interference structure that develops during subsequent propagation. The experiment's simplicity of accessibility, affordability, and visual clarity make this work ideal for undergraduate labs and serve as a useful link between theoretical explanations of diffraction and experimental observation.

Keywords: Diffraction, Post-Obstacle Field, Optical Intensity Distribution Pathways, He–Ne Laser, Experimental Optics, Undergraduate Laboratory

1. Introduction

The study of light has historically been influenced by two competing ideas: wave and particle. Huygens first put forward the wave theory in 1690 and later Newton, in 1704, introduced the corpuscular theory [1,2]. The wave nature of light is explained by Young's double-slit experiment [3,4]. Einstein's first use of the photon concept in 1905 and Bohr's complementarity principle in 1927 developed the current understanding that both wave-like and particle-like properties are necessary for describing a light [5,6]. As emphasized by Einstein and Feynman interference remains one of the most fundamental phenomena in physics [7,8].

In order to explore the mystery of double-slit experiments and assess the interpretation a number of different double-slit experiments carried out [9-11]. Diffraction is one of the fundamental manifestations of the wave nature of light and forms an essential component of undergraduate optics education. Since the pioneering work of Fresnel and Fraunhofer, diffraction has been successfully explained within the framework of classical wave optics through the Huygens–Fresnel principle, which describes every point on a wavefront as a secondary source of spherical wavelets. The superposition of these wavelets produces the characteristic diffraction patterns observed after light interacts with an obstacle or aperture [12,13]. On the other hand, in the double slit experiments, the optical characteristics of the diffraction pattern is described by three factors, wave length, the spacing between two slits and distance between the double slit and screen [14-16].

Despite these advances, the formation and evolution of diffraction and interference patterns have continued to attract scientific interest. In the present work, we introduce a simple experimental approach for visualizing the optical intensity distribution immediately behind a diffracting obstacle. This experimentally observed region is referred to as the POF and is defined operationally as the N dominant channels recorded immediately behind the obstacle under coherent laser illumination. The term is used solely as a convenient experimental description of the observation plane and does not imply the existence of a new physical field or modification of established diffraction theory.

2. Experimental

2.1. Experimental Approach

A double-slit assembly formed by two rectangular transmitting regions separated by a 50 µm human hair produces a reproducible intensity distribution composed of distinct dominant intensity pathways immediately after diffraction was illuminated by a coherent 632.8 nm He–Ne laser. This arrangement produces a rich optical intensity distribution that is perfect for studying propagation outcomes. Human hairs were chosen because they are affordable, easily accessible, and thin enough to display distinct diffraction behaviours when exposed to coherent laser light.

Their application demonstrates how simple materials can be employed for pertinent diffraction studies without requiring sophisticated optical components. A transparent glass plate was positioned at 2 cm behind obstacle each observing distance to establish an observation plane because the propagating light field cannot be directly observed in free space. The glass plate could be used as a passive imaging surface to capture the distribution of light intensity. This technique eliminated the need for imaging lenses or other optical components that could alter the observed intensity distribution and allowed for the direct visualisation of the light field's continuous evolution during free-space transmission.

A OnePlus 8 Pro smartphone camera (Model IN2025) with the camera zoom set to 10 was used to record the Post-Obstacle Field (POF) that developed on the glass plate. For analysis and presentation, sample still frames were extracted from the recorded videos. These recordings were then used to extract representative still frames for presentation and qualitative analysis. This method allowed for the analysis of many frames for consistency while ensuring that the chosen images accurately reflected the stable optical intensity distributions seen during the experiment. Every video was recorded using the identical experimental setup, which included fixed laser alignment, obstacle position, observation geometry, camera settings, and ambient illumination. The Post-Obstacle Field (POF), a term that has only been used as an operational description in the context of classical wave optics, is utilised throughout this study to refer to the experimentally determined optical intensity distribution right behind the diffracting obstacle.

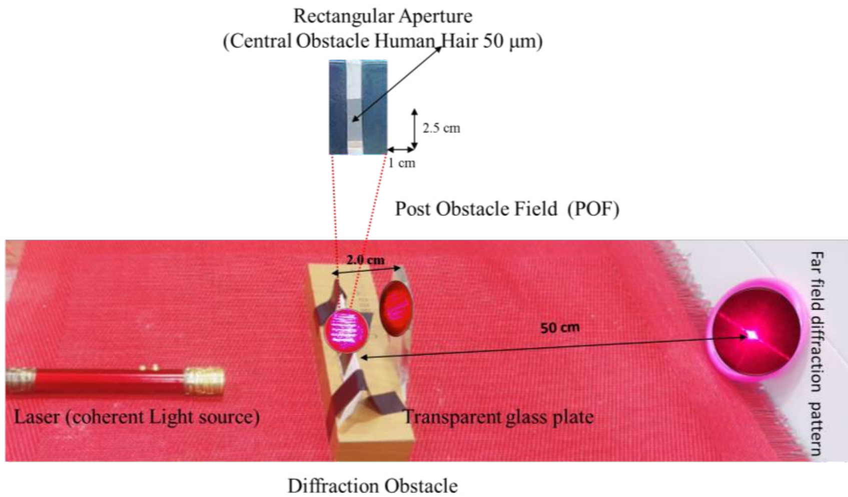

Figure 1: Double Slit Experiment Along with Illustrating the Evolution of the Optical Intensity Distribution Pathways in POF

2.2. Visualization of the Post-Obstacle Field of Intensity Distribution Pathways

The Post-Obstacle Field (POF) was visualized by recording the optical intensity distribution at several propagation distances behind the diffracting obstacle. Observations were performed at distances of 2 cm and while maintaining identical experimental conditions throughout the investigation. Direct visualization of the optical field in free space was not possible because the propagating light does not produce a directly observable intensity distribution without an observation surface. Therefore, a transparent glass plate was positioned perpendicular to the propagation direction at each selected observation distance behind the obstacle.

A Samsung Galaxy smartphone camera was used to capture the optical intensity distribution that developed on the glass plate. The glass plate was not meant to alter the diffraction process; rather, it was just meant to be used as an observation surface for taking pictures of the POF. Before it reached the glass panel, the optical field travelled freely through the air from the barrier to the selected observation plane. The images were taken using the same experimental parameters: ambient lighting, camera settings, obstacle position, fixed laser alignment, and observation geometry. This experimental arrangement enabled reproducible visualization of the optical intensity distribution immediately behind the diffracting obstacle and permitted the evolution of the Post-Obstacle Field to be examined as a function of propagation distance.

3. Results and Discussion

As illustrated in Figure 2, the conventional double-slit experiment can be described as follows. According to the conventional idea, light travels as waves both before and after it enters the double slit, causing interference thereafter. The detecting screen displays the interference pattern. To describe the pattern, the standard formula is, for $L \gg d$

$$y_m = m\frac{\lambda L}{d} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where “d” is the spacing of the double slit, “L” is the distance between the double slit and the screen, and “ym” is the distance of the mth fringe from the position of the primary maximum [17].

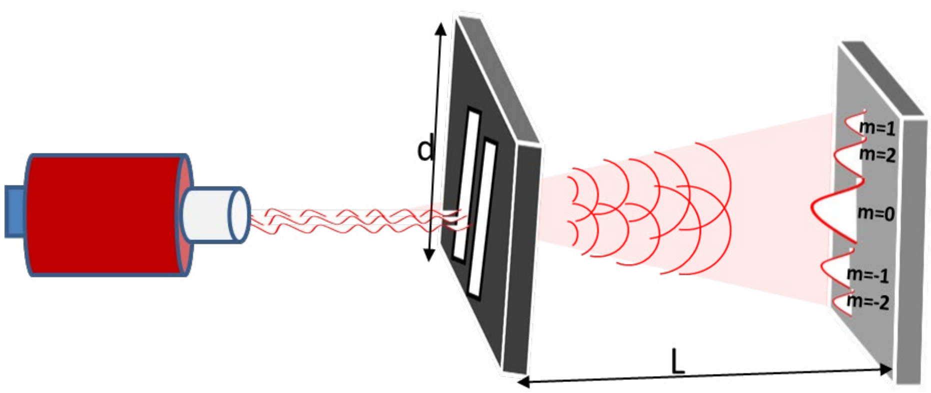

Figure 2: Classical Double Slit Experiment Setup

The intensity I is proportional to the time average of the square of the total electric field E. For the small angle θ, the intensity is

$$I \propto \langle E^2 \rangle = I_0 cos^2 \frac{\pi d}{\lambda L} y_m \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Thus, according to the standard wave descriptions, there is an interference pattern with multiple intensity maxima and minima when $L \gg d$. In the double slit experiment, the pattern is studied in the far field. Although the theoretical evolution of diffraction is well established, undergraduate laboratory experiments generally emphasize only the final far-field diffraction pattern recorded on a distant screen. Consequently, the continuous evolution of the optical intensity distribution between the obstacle and the observation screen is rarely visualized directly. In the present work, a transparent glass plate is introduced at selected propagation distances behind the diffraction obstacle to serve as an intermediate observation plane. The optical intensity distribution recorded on this plane is referred to as the POF.

The POF is an operational experimental term describing the measured optical intensity immediately behind the diffracting obstacle under coherent illumination. It does not refer to a new physical field, but rather to the empirically observed intermediate diffraction pattern predicted by classical wave optics. The evolution of the Post-Obstacle Field (POF) was investigated by recording the optical intensity distribution at propagation lengths of 2 cm, and 20 cm beyond the diffracting obstacle. Representative images are shown in Figure 3.

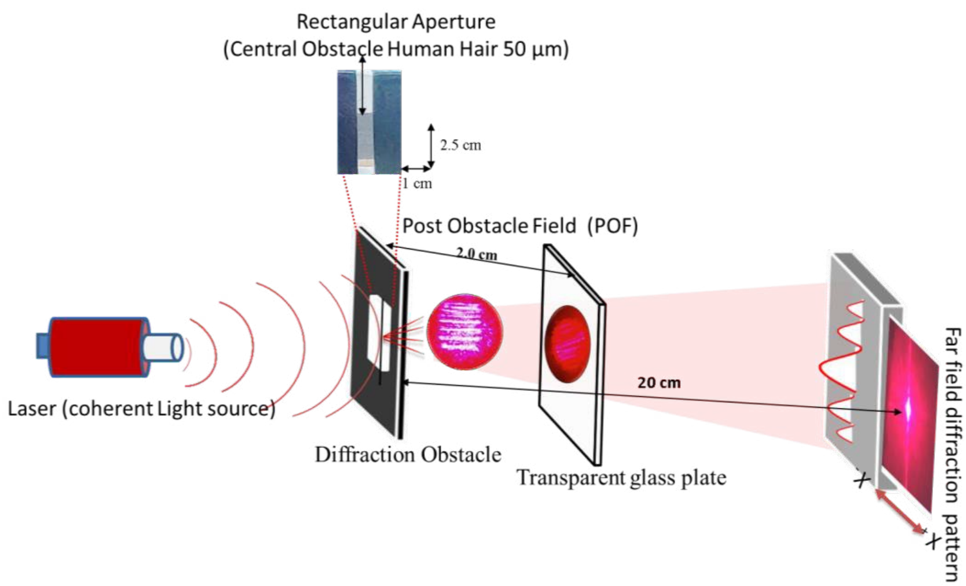

Figure 3: Direct Visualization of the Post-Obstruction Field (POF) at 2 cm and 50 cm Final Fare Field Interference was Observed Experimentally Behind an Obstacle

The Post-Obstacle Field exhibits two localized spectacular intensity distributions with distinct internal intensity patterns at a distance of 2 cm (Figure 3). High repeatability and spatial confinement near the optical axis are characteristics of the detected features. The overall optical field topology does not change when the observation distance is increased to 2 cm (Figure 3), but the interior intensity structures exhibit a discernible redistribution and become more compact. The experimental observations demonstrate that the optical intensity distribution immediately behind a diffracting obstacle evolves continuously with propagation distance.

At shorter observation distances, the Post-Obstacle Field contains localized bright intensity structures. As the observation plane is moved farther from the obstacle, these structures gradually redistribute, producing broader and smoother intensity distributions. The present work introduces the Post-Obstacle Field (POF) as an operational observation plane located immediately behind a diffracting obstacle. The POF provides a direct experimental visualization of the spatial intensity distribution that develops during free-space propagation before the optical field reaches the final observation screen.

The results indicate that the observed intensity distributions pathways depend on the propagation distance and evolve continuously as the optical wave propagates. The observations reported here are interpreted within the framework of classical diffraction theory. No new diffraction mechanism is proposed. Instead, the study demonstrates that inexpensive optical components and a smartphone camera can be used to visualize the propagation-dependent evolution of the optical intensity distribution immediately behind diffracting obstacles. This simple experimental approach may provide an effective educational tool for demonstrating the continuous transition from the near-field optical region toward the final diffraction pattern observed at larger propagation distances.

3.1. Structured Intensity Pathways in Post-Obstacle Field and Far-Field Diffraction

Analysis of more than twenty paired observations reveals a direct linear correlation between these quantities. The linear fit indicates that the number of dominant channels in the POF is equal to the number of corresponding diffraction features in the far field for the experimental dataset analyzed as shown in Figure 4. This constant association suggests that the optical intensity structure created immediately behind the diffraction obstacle is strongly related to the generation of the far-field diffraction pattern during free-space propagation.

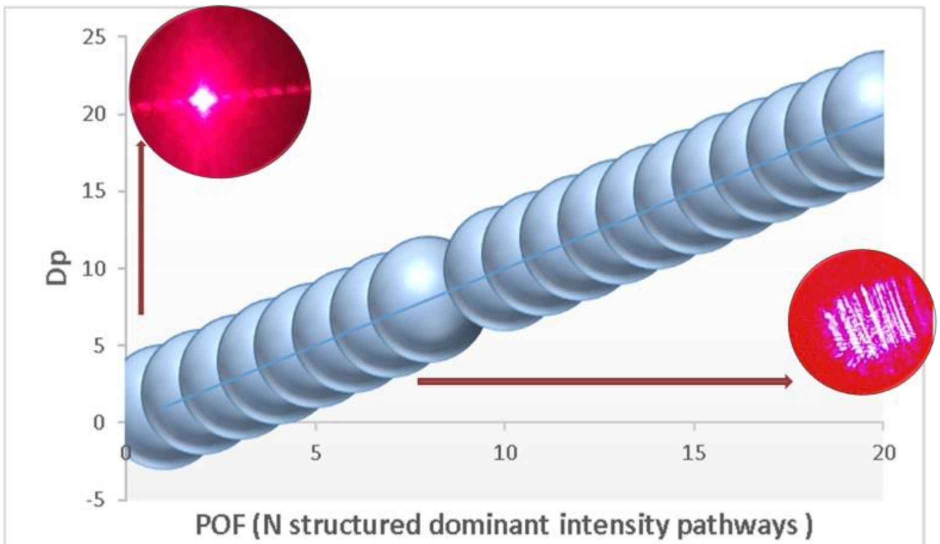

Figure 4: The Number of Prominent Intensity Pathways Observed in the Post-Obstacle Field (POF) and the Corresponding Diffraction Pattern (DP) in the Far-Field Pattern Show a Linear Relationship

3.2. Comparison Between Conventional Diffraction and Post-Obstacle Field Visualization

The suggested Post-Obstacle Field (POF) visualization technique and the traditional diffraction experiment is contrasted in Figure 5. A coherent laser beam travels through a diffraction obstacle in the traditional arrangement, and only the final diffraction pattern is visible on a distant screen. Between the blockage and the screen, there is no discernible optical field.

By placing a transparent glass plate behind the diffraction obstacle to serve as an observation plane, the proposed method allows direct viewing of the optical intensity distribution during free-space propagation. This experimentally observed distribution is referred to as the Post-Obstacle Field (POF) and is defined as an operational observation region within the framework of classical wave optics. This simple modification enables direct observation of the continuous evolution of diffraction, providing an inexpensive and effective teaching tool for undergraduate optics laboratories.

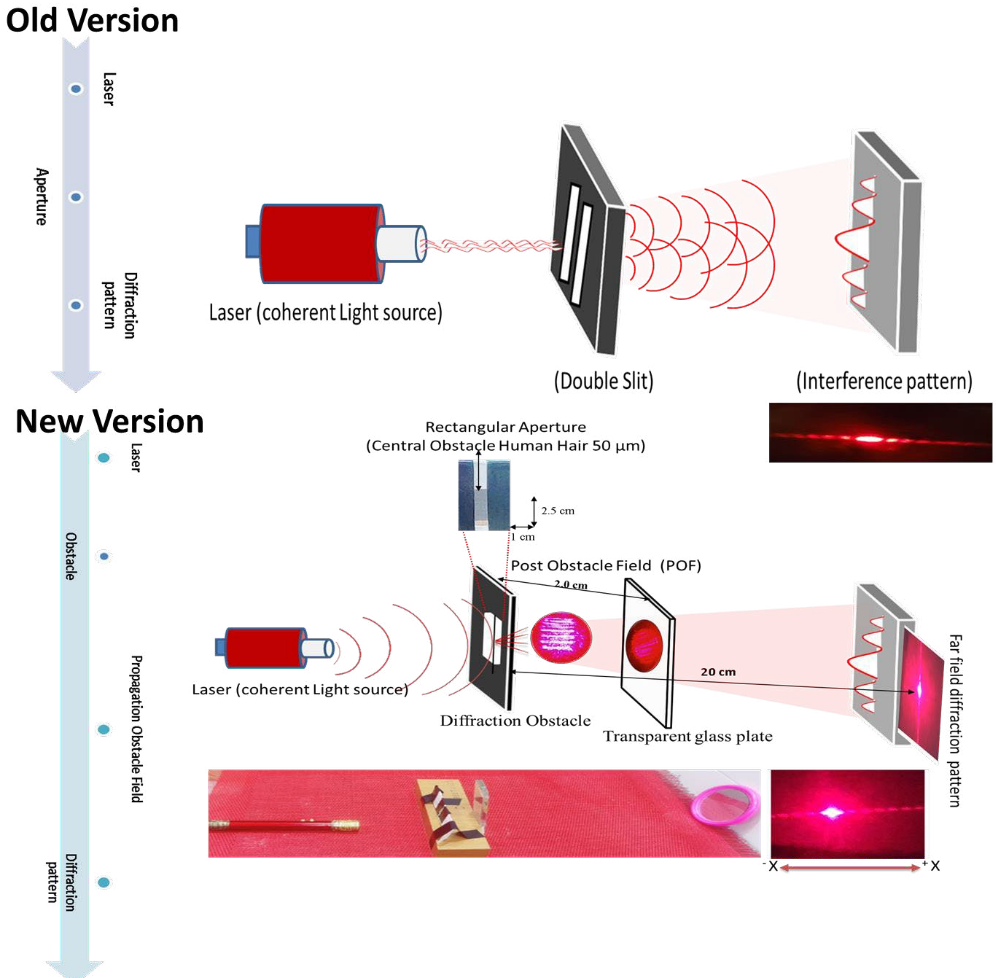

Figure 5: Comparison of the Conventional Diffraction Experiment (Top) and the Proposed Post-Obstacle Field (POF) Visualization Method (Bottom)

4. Conclusion

This work presents a simple, inexpensive tabletop experiment for directly visualizing the Post-Obstacle Field (POF) and its evolution during free-space propagation within the framework of classical Fresnel diffraction. The observations demonstrate that the optical intensity distribution immediately behind the diffraction obstacle undergoes a continuous propagation-dependent evolution before the formation of the fully developed far-field diffraction pattern.

Analysis of more than twenty paired observations revealed a repeatable correspondence between the number and arrangement of dominant channels in the POF and the subsequently observed far-field diffraction features, providing quantitative experimental evidence of the relationship between the near-field optical intensity distribution and the final diffraction pattern. The method's smartphone-based photography and simple experimental setup make it suitable/useful for undergraduate optics laboratories and inquiry-based learning.

Future research will concentrate on quantitative picture analysis, various optical combinations, and comparisons with Fresnel diffraction models, although the present study is primarily qualitative and restricted to a single wavelength and diffraction geometry. Future studies of diffraction and interference under single-photon double-slit conditions, where similar propagation-dependent optical structures could be examined using photon-counting techniques within the well-established framework of quantum optics, may benefit from the experimental strategy presented here.

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