Continuous transition from Fraunhofer and Fresnel diffraction regimes with a triangular slit

Alessandro SALMOIRAGHI, Luigi GRATTON, Marco DI MAURO, Pasquale ONORATO, Stefano OSS

Department of Physics, University of Trento, Via Sommarive 14, 38123, Trento, Italy

Abstract. We introduce an economical quantitative optical experiment aimed at acquainting students with the near- and far-field diffraction regimes, as defined by the Fresnel-Kirkhoff and Fraunhofer models, respectively. This experiment demonstrates the transition using a triangular slit. It incorporates the use of cost-effective, easily accessible materials, along with a basic camera, typical of those available in common smartphones. The experimental setup was tested on graduate students in mathematics and physics who are prospective high school teachers.

Introduction

This research focuses on student comprehension of the dual limiting behaviors exhibited by electromagnetic waves in a standard diffraction experiment. It introduces a quantitative experimental approach that employs physical optics and utilizes smartphone cameras as measurement instruments. This methodology is adaptable for use in both classroom and home environments. Previous studies have highlighted the employment of the single slit diffraction experiment to facilitate discussions on quantum mechanics' uncertainty principle, providing a metaphorical basis for theoretical exploration and practical demonstrations by various scholars [1]. Here, the experimental setup's geometric configuration, particularly the distance between the diffracted field and a slit of specific width, delineates two distinct regimes in the intensity pattern observed: the near-field, characterized by Fresnel-Kirkhoff behavior, also described by geometrical optical laws, and the far-field, known as the Fraunhofer limit [2]. An intriguing aspect of practical experimentation would be to vary the slit width continuously and observe the resulting diffraction patterns at a fixed distance.

The experiment

In this experiment, we propose the use of a triangular slit, constructed by arranging two common cutter blades at an angle to vary the width from the vertex up to 2 mm. This method avoids the need for multiple slits of different widths, which typically results in a discretization of the phenomenon. Consequently, this approach facilitates a smoother transition and allows for a better appreciation of the continuous nature of these changes. Our primary experimental observation reveals that analyzing the central maximum width allows simultaneous observation of both regimes across the varying slit widths. Additionally, the intermediate width allows analysis of the crossover regime, corresponding to Fresnel diffraction, as Fraunhofer diffraction conditions cease to be satisfied as the slit widens. This approach contrasts with discontinuous mental models: students observe this smooth transition without cognitive disconnect, perceiving all phases simultaneously on screen, facilitating comprehensive understanding. The experimental setup (shown in fig. 1) consists in a diode laser (λ=630±20 nm), a lens with a focal length of +5.0 cm (at 5 cm from the diode laser), used as beam expander, the described triangular slit and a smartphone for capturing the diffraction pattern.

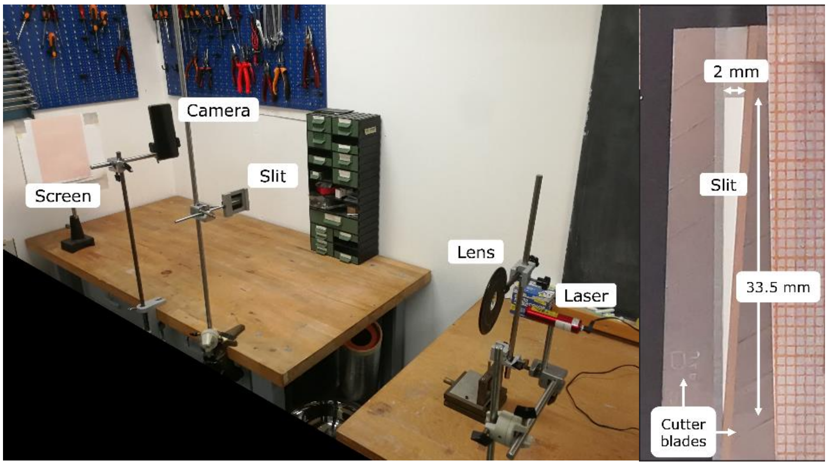

Figure 1: Experimental setup on the left, V-shaped slit on the right.

The resulting jpg format picture was gamma-corrected and analyzed using the ImageJ application [3] in order to measure the half width of the central peak along the triangular slit diffraction pattern.

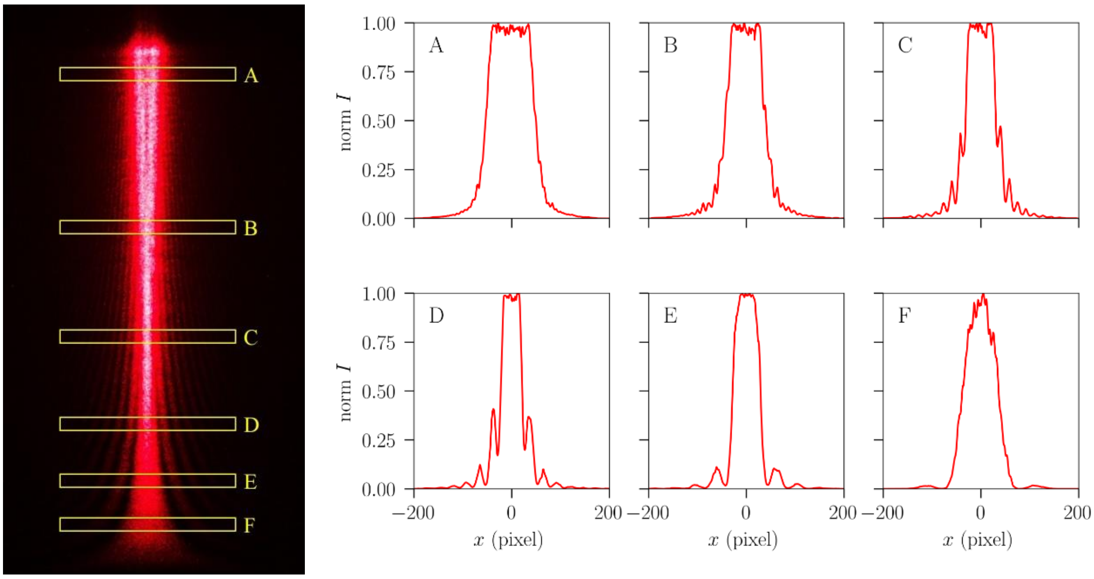

Figure 2: The diffraction pattern with some example analyzed areas highlighted on the left. Normalized measurements of intensity obtained with ImageJ.

Conclusions

The experiment described herein demonstrates the continuous transition between two diffraction limiting regimes using a cost-effective setup. Further analyses are currently underway to provide a reasonably simple theoretical interpretation of the two-dimensional intensity pattern observed.

References

[1] P. L. Muiño, Introducing the uncertainty principle using diffraction of light waves, *Journal of Chemical Education* **77**(8) (200) 1025.

[2] C. L. Panuski and C. E. Mungan, Single-slit diffraction: Transitioning from geometric optics to the Fraunhofer regime, *The Physics Teacher* **54**(6) (2016) 356-359.

[3] ImageJ. https://imagej.net/ij/