Extended Abstract

DIFFRACTION OF LASER LIGHT FROM A CIRCULAR APERTURE IN A TRANSPARENT PLATE

Ali Mahmoudi

Department of Physics, Faculty of Science, University of Qom, Qom, Iran

Received: 16.04.2024 Final revised: 24.11.2024 Accepted: 21.07.2025

Doi: 10.22055/jrmbs.2025.20192

Abstract

In this study, we investigate light diffraction from a circular phase step, which is a circular aperture created in a transparent plate. The distribution of the scattered light amplitude in a plane at an arbitrary distance is derived, and the change of the diffracted intensity profile with respect to propagation distance is investigated. The difference between this type of diffraction and the diffraction of light from an aperture in an opaque plate is also described. One of the important aspects of this problem is its relevance to particle sizing methods based on laser diffraction, which assume that particles are light-absorbing disks, while transparent particles have not yet been investigated. Furthermore, in optical imaging systems, Rayleigh's criterion is defined by using the results of light diffraction from absorbent bodies to determine the resolution limit. However, as far as we know, no study has been done to check the case of microscopic transparent bodies.

Keywords: Wave optics, Diffraction, Circular phase step, optical measurement

1. INTRODUCTION

Scalar diffraction theory has undergone continuous evolution over the past 150 years, finding applications in numerous scientific and technological fields [1]. The Fraunhofer regime, for example, often simplifies the calculation of light intensity distribution [2], which is crucial for defining the resolution limit of imaging devices and the divergence of laser beams via the Rayleigh criterion or the diffraction limit. Furthermore, equations from scalar diffraction theory have been instrumental in developing methods for sizing fine particles and powders. The diffraction of light from a circular phase aperture (an aperture in a transparent plate) or a circular phase step (a cylindrical step on a

This work is licensed under a Creative Commons Attribution 4.0 International License

transparent plate) can be viewed as a generalization of diffraction from a one-dimensional phase step, a topic that has garnered significant attention over the past two decades. Researchers, including Tavassoly and his colleagues, have extensively explored light diffraction from a phase step in several key papers. Their work has led to numerous applications, such as the precise measurement of liquid refractive indices, nanometric displacement measurement, optical diffractometry, etching rate measurement in transparent materials, and quantitative phase imaging. The theory also finds use in live cell imaging and tracking, three-dimensional imaging, and the real-time study of liquid crystal phase transitions.

2. Diffraction of Light from a Circular Phase Aperture (Phase Step)

In Figure 1, a circular aperture with radius R is created at the center of a flat transparent plate with thickness h . A laser beam, parallel to the z -axis with wavelength λ, is incident perpendicularly on this plate. The refractive index of the plate is n, and thus the phase difference between the light rays passing through the aperture and those passing through the regions outside the aperture is $\varphi = \frac{2\pi}{\lambda} h(n-1)$ radians.

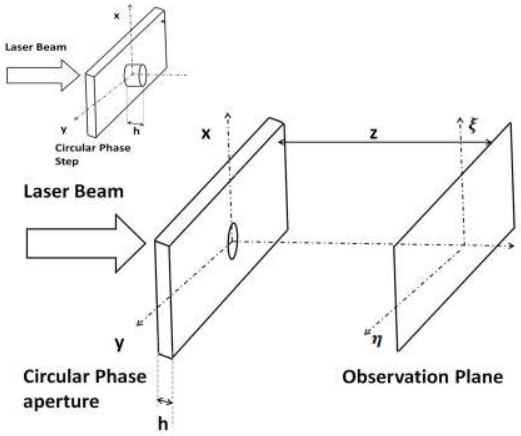


Figure 1- Diffraction of collimated laser light from a circular phase step or aperture.

It can be shown that the distribution of optical disturbance in the observation plane is as below equations:

$$for\ r < R:$$

$$U(r,z) = U_0 e^{jkz} + U_0 \frac{e^{jkz}}{j\lambda z} \pi e^{\frac{jk}{2z} r^2} (e^{j\phi} - 1) R^2 \left[\frac{\cos\frac{u}{2}}{\frac{u}{2}} U_1(u,v) + \right. \quad (1)$$

$$\left. \frac{\sin\frac{u}{2}}{\frac{u}{2}} U_2(u,v) + j \frac{\sin\frac{u}{2}}{\frac{u}{2}} U_1(u,v) - j \frac{\cos\frac{u}{2}}{\frac{u}{2}} U_2(u,v) \right]$$

This work is licensed under a Creative Commons Attribution 4.0 International License

And

$$for\ r > R: \qquad (2)$$

$$U(r,z) = U_0 e^{jkz} + U_0 \frac{e^{jkz}}{j\lambda z} \pi e^{\frac{jk}{2z}r^2} (e^{j\phi} - 1) R^2 \Big[\frac{\sin\frac{v^2}{2u}}{\frac{u}{2}} + \frac{\sin\frac{u}{2}}{\frac{u}{2}} V_0(u,v)$$

$$- \frac{\cos\frac{u}{2}}{\frac{u}{2}} V_1(u,v) + j\frac{\cos\frac{v^2}{2u}}{\frac{u}{2}} - j\frac{\cos\frac{u}{2}}{\frac{u}{2}} V_0(u,v) - j\frac{\sin\frac{u}{2}}{\frac{u}{2}} V_1(u,v) \Big]$$

Using these equations, one can calculate intensity distribution in the observation plane located at distance z from the aperture. Figure 2 shows intensity distribution and intensity profile in a plane at z=5cm when laser light with $\lambda = 632.8\,nm$ is diffracted from a circular aperture with $R = 50\mu m$ in a uniform transparent plate and phase $\varphi = \pi$ radians.

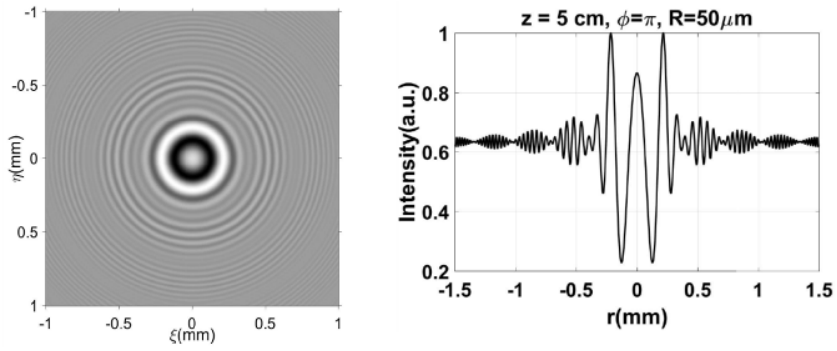


Figure 2- calculated intensity distribution and intensity profile when light with $\lambda = 632.8\,nm$ is diffracted from a circular aperture with $R = 50\mu m$ in a transparent plate. z=5cm and phase $\varphi = \pi$ radians.

3. RESULTS AND DISCUSSION

To experimentally verify the equations derived in the previous section, several circular phase steps were fabricated on microscope glass slides. The wet etching method using hydrofluoric acid was employed to create these circular phase steps. By adjusting the etching duration, the height of the phase step and, consequently, the phase difference, can be precisely controlled. Several phase steps with different radii and phase differences were fabricated and studied. A laser beam with λ=632.8 nm is collimated and then is incident on the circular phase step created on the flat glass plate. Figure 3 shows excellent agreement between the measured intensity profile and the calculated one for a circular phase step with R=20 μm, a distance of z=10 cm, and a phase of π radians.

This work is licensed under a Creative Commons Attribution 4.0 International License

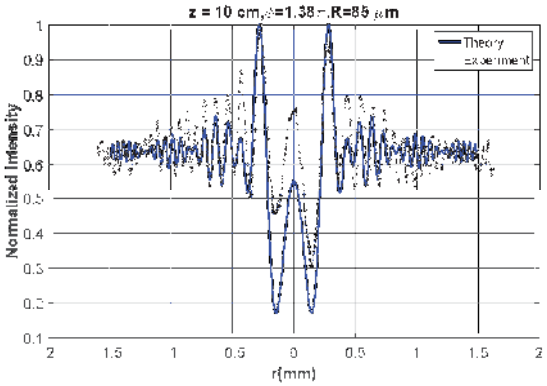


Figure 3- Experimental and calculated intensity profile when light with $\lambda = 632.8\,nm$ is diffracted from a circular phase step with $R = 85\mu m$ and fixed distance z=10cm and phase $\varphi = 1.38\pi$ radians.

In Figure 4 the calculated and experimentally recorded diffracted intensity profiles for $R = 70\mu m$, $\varphi \simeq 1.41\pi$ and different z distances are shown.

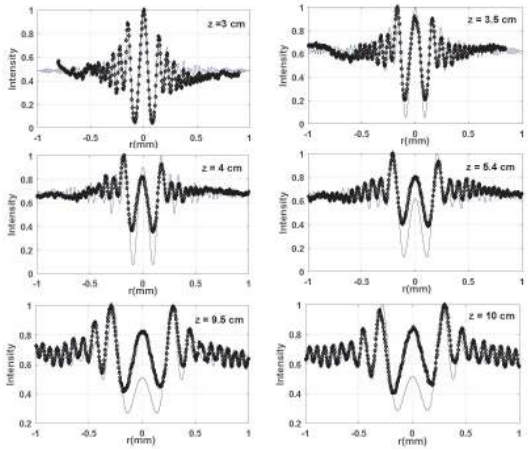


Figure 4- calculated and experimentally recorded diffracted intensity profiles for $R = 70\mu m$, $\varphi \simeq 1.41\pi$ and different z distances.

Reference

[1] Goodman, Joseph W. "Introduction to Fourier optics." Introduction to Fourier optics,3rd ed., by JW Goodman. Englewood, CO:Roberts & Co. Publishers, 2005 1 (2005)
[2] Hecht, Eugene. Optics. Reading, Mass.Addison-Wesley, 2002Soc. Am. A 34 (2017) 674-680 , https://doi.org/10.1364/JOSAA.34.000674

This work is licensed under a Creative Commons Attribution 4.0 International License