lambda scientific

Construct, Conduct & Comprehend Physics Experiments

LEOK-3-24 Studying on Fresnel Zone Plate

- *Complete set*
- *Cost effective solution*
- *Detailed instructional manual*
- *Easy alignment*

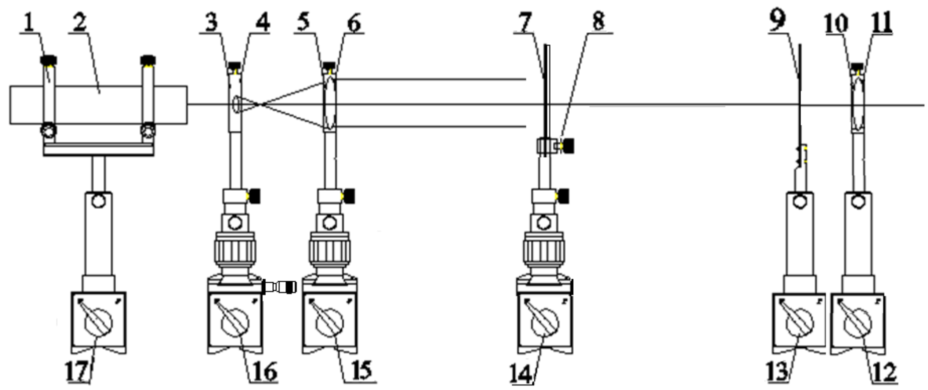


Figure 24-1 Schematic of experiment setup

1: Laser holder (SZ-42)
2: He-Ne laser tube
3: Beam expander lens (f' = 4.5 mm)
4: Lens holder (SZ-08)
5: Collimation lens (f' = 190 mm)
6: Lens holder (SZ-08)
7: Fresnel zone plate
8: Plate holder (SZ-12)
9: Ground glass screen (SZ-49)
10: Magnifying lens (f' = 50 mm)
11: Lens holder (SZ-08)
12—17: Magnetic base (SZ-04)

* Other parts: Measurement microscope, meter ruler or tape measure (not included)

Theory

Light has characteristics of wave and particle duality. Unlike conventional lenses or mirrors, zone plates works based on light wave diffraction other than refraction or reflection.

According to Fresnel's principle, interference of waves diffracted by obstacles may be treated simply by splitting the primary wave front into so called zones. A zone plate consists of a set of concentric rings, known as Fresnel zones, which alternate between being opaque and transparent. Light hitting the zone plate will diffract around the opaque zones, as shown in Figure 24-2.

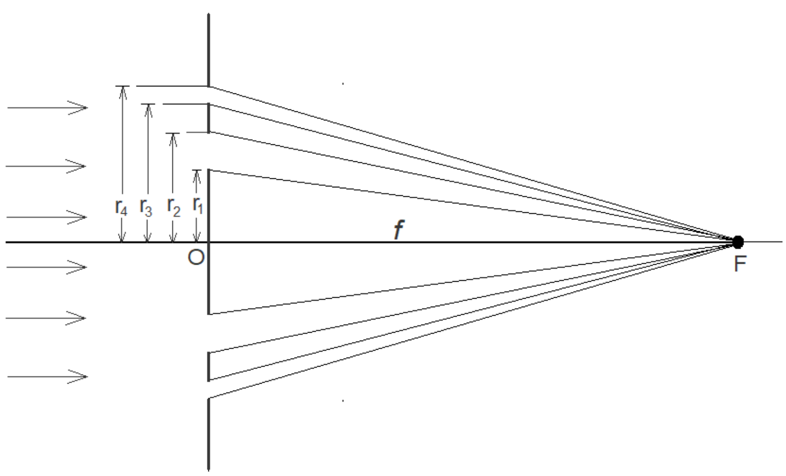


Figure 24-2. Principle schematic of a zone plate

The zones can be spaced that the optical path difference between two light rays from the adjacent edges of a pair of transparent and opaque zones to the observation point F is always half of a wavelength ($\lambda/2$). Since the zone plate consists of alternating transparent and opaque rings, only light rays of either the odd or the even zones are allowed to pass through and reach the point F, so that these diffracted light rays have optical path differences of integer times of wavelength and therefore constructively interfere at point F, which is the focal point if the incident beam is a collimated beam, and the distance between O and F is focal length f.

Refer to Figure 24-2, we can calculate the radii of these zones as: $r_n = \sqrt{\left(f + n * \frac{\lambda}{2}\right)^2 - f^2} \approx \sqrt{nf\lambda},\ n = 1,2,3,\ldots$ (24-1)

where it is assumed $nf\lambda \gg n^2 * \lambda^2/4$.

Point *F* is the main focal point of the zone plate, which is formed by the first diffraction order of these zones. If the radius of 1st zone is known as r_1, focal length can be calculated as: $f = \frac{r_1^2}{\lambda}$. (24-2)

Since there exist light rays with higher diffraction orders, higher orders of focal points will also be created when there are an odd number of half-wave phase delays between adjacent zones. The focal lengths of these focal points are:

$$f_m = \frac{f}{m},\ m = 1,3,5,7\ldots \quad (24\text{-}3)$$

In theory, these locations with even number of half-wave phase delays (i.e. *m=2,4,6*, …) will be absolutely dark since amplitudes of alternative half-wave wavefronts are cancelled out each other. However, in this experiment, the FZP is made from a photograph film, it is not perfectly dark for those dark zones, therefore the transmitted light from those dark zones will created weaker focal points at these locations: *f/2, f/4, f/6,* …..

A computing simulation of light propagation after a Fresnel Zone Plate is shown in Figure 24-3, where the main focal point at *f* and other higher orders at *f/3, f/5, f/7* ,… are presented.

Like conventional refractive/reflective lenses, a zone plate can be used as imaging lens, and the relationship between object distance and image distance meets the lens equation, that is:

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}, \quad (24\text{-}4)$$

where *p* and *q* are respectively the object and image distances.

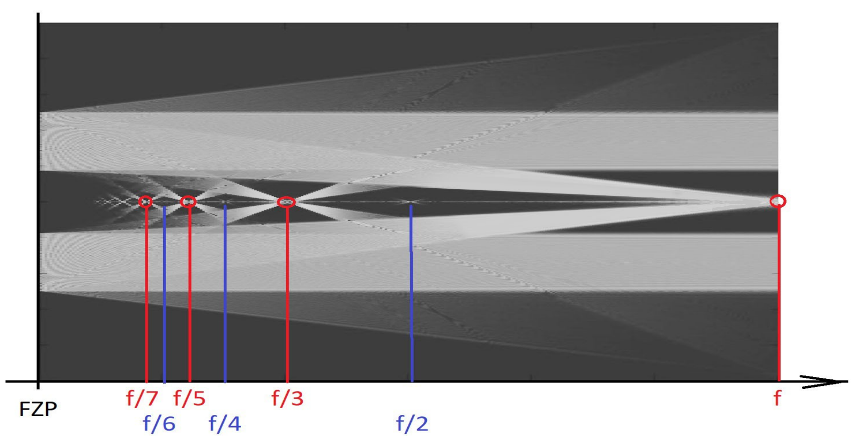


Figure 24-3 Computing simulated light propagation after FZP.

Zone plates eliminate the need for finding transparent, refractive, easy-to-manufacture materials for every region of the spectrum. They have been widely applied to X-ray imaging and sound waves focusing and imaging, even to focus matter waves such as neutrons and helium atoms.

Experiment Procedures

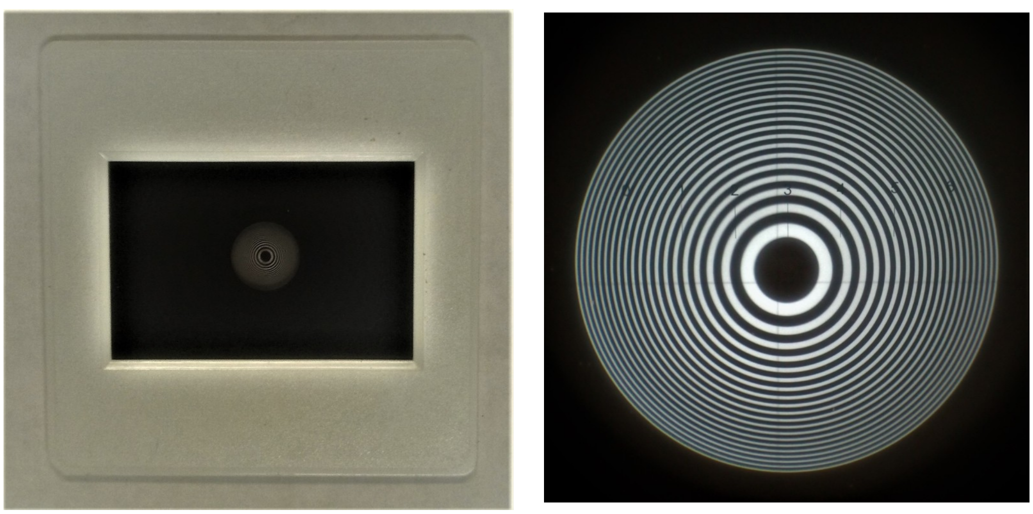
1. Refer to Figure 24-1, place a meter ruler or a tape measure on the optical table; place the laser on the end of the ruler.
2. Use the beam expander and the collimation lens to create a collimated laser beam along the ruler. Finely adjust the distance between the two lenses and check the beam size with a large range to achieve the optimal collimation effect.
3. Place the zone plate into the optical path. Adjust its position to let the laser beam illuminate on the center of the plate and cover all the zone area.
4. Place the two magnetic bases of the ground glass screen and the magnifying lens close to each other, starting from remote end, shift them together toward to the zone plate and observe the focusing situations on the ground glass through the magnifying lens. Record the positions of focal points of all orders.
5. Measure the radii of these zone rings of the plate using a measurement microscope. Verify if these focal lengths meet the theoretical calculations of Eqs. (24-2) and (24-3).

Experiment results:

The zone plate used for the experiment has 40 zones (20 dark + 20 bright), the radius of the dark central circle was measured under a reading microscope as 0.63 mm. The wavelength of He Ne laser is λ =632.8 nm.

The measured and theoretical focal lengths are shown in the table below:

Order No.	1	3	5	7
f (measured) (cm)	63.0	20.8	12.5	8.8
f (theoretical) (cm)	62.7	20.9	12.5	9.0



Photos of the FZP: mounted in a slide frame and magnified central area

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