# Inner and Outer Diffraction-Fringes at Circular Openings

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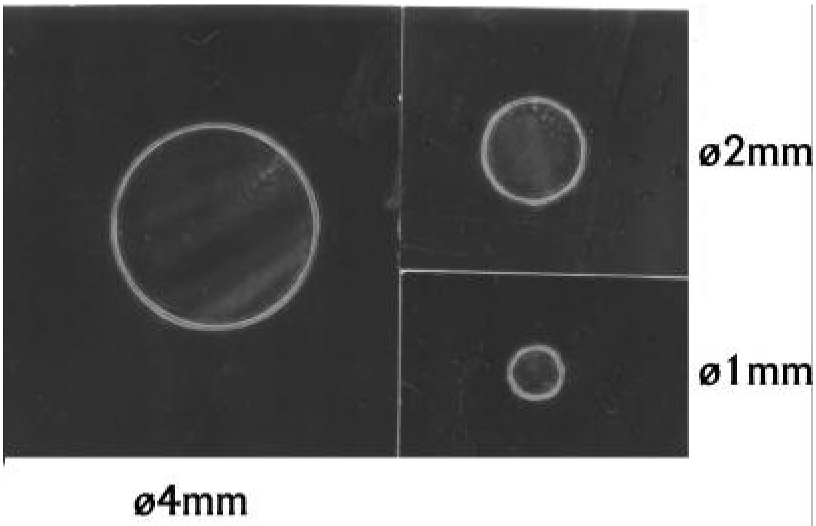
Abstract
In a schlieren-apparatus is shown that also at circular-openings bent light comes only from a small (<0.1 mm) surroundings of edges. It is important, also for circular-opening, to distinguish between inner and outer diffraction-rings, only in this way it is possible to comprehend the nature of diffraction. The differences of Fresnel's and Fraunhofer's manner of observation are demonstrated.

## I. Circular-openings in the schlieren-apparatus

As already Newton [1] III observation 5 had established, bent light comes only out of the small surroundings of edges. Nieke [2] showed this in a schlieren-apparatus by Abbe. Therefore it was to suppose that this was the case at circular-openings too. It is examined experimentally in a schlieren-apparatus, indeed in figure l bent light is coming out only of less than 0.1 mm of the surroundings oft the circular edges. Particulars are already discussed by Nieke [3].




*Figure, 1. Photos of circular-openings in a schlieren-apparatus. The circular-openings of the diameters of 1, 2 and 4 mm were drilled in an aluminium sheet and bevelled that only an edge about 0.1 mm was remaining which was blacken. Scale ratio 1 : 1 and optically enlarged.*

## II. Inner and outer diffraction-rings of circular-openings

The most solid experiments at diffraction by circular-openings delivered Arkadiew [4], whose photos often are taken over without statements of details. Arkadiew used no optics, therefore Fresnel's manner of observation, and only very large distances, namely from the light source to the circular openings or screen of 27.77 m and from the circular opening or screen to the photoplate of 11.70 m. Also in these extreme distances the discussion with Fresnel's zones was not successful at all diffraction-rings.

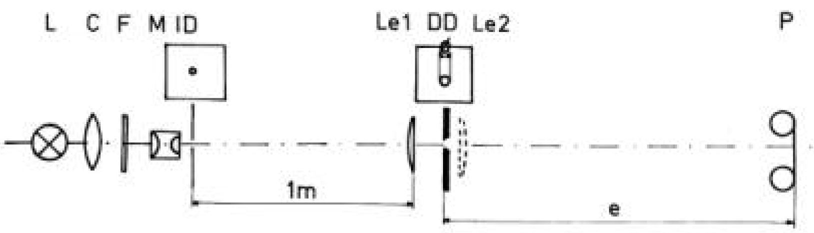



*Figure 2. Experimental arrangement to examine the diffraction-figures of circular-openings in dependence of distance and of their diameter. L -light-source, a high-pressure mercury lamp HBO 100; C - condenser; F - green filter; M - microscope objective; ID - illumination diaphragm, a spinning-nozzle Ø 0.1 mm; Le 1 lens f' = 1 m; DD -circular diffraction diaphragm with diameters of 4, 2 and 1 mm; Le 2 - fallen off in Fresnel's observation manner, used with $f'_2 = e$ in Fraunhofer's observation manner; P - miniature reflex camera without optics.*

Inner and outer diffraction-rings appear at circular-openings also. The transitions of inner to outer fringes are hitherto not to explain, so is reported scarcely nothing about this transition. Inner and outer diffraction-rings are related to the size within or outside the shadow-limits of diffraction-object like at slit by Nieke [2] and [5]. In the apparatus after figure 2 the examination ensued with different diameter of circular-openings and in different distances. It is to notice that here is irradiated parallel, the shadow-limits run farther with the same interval.

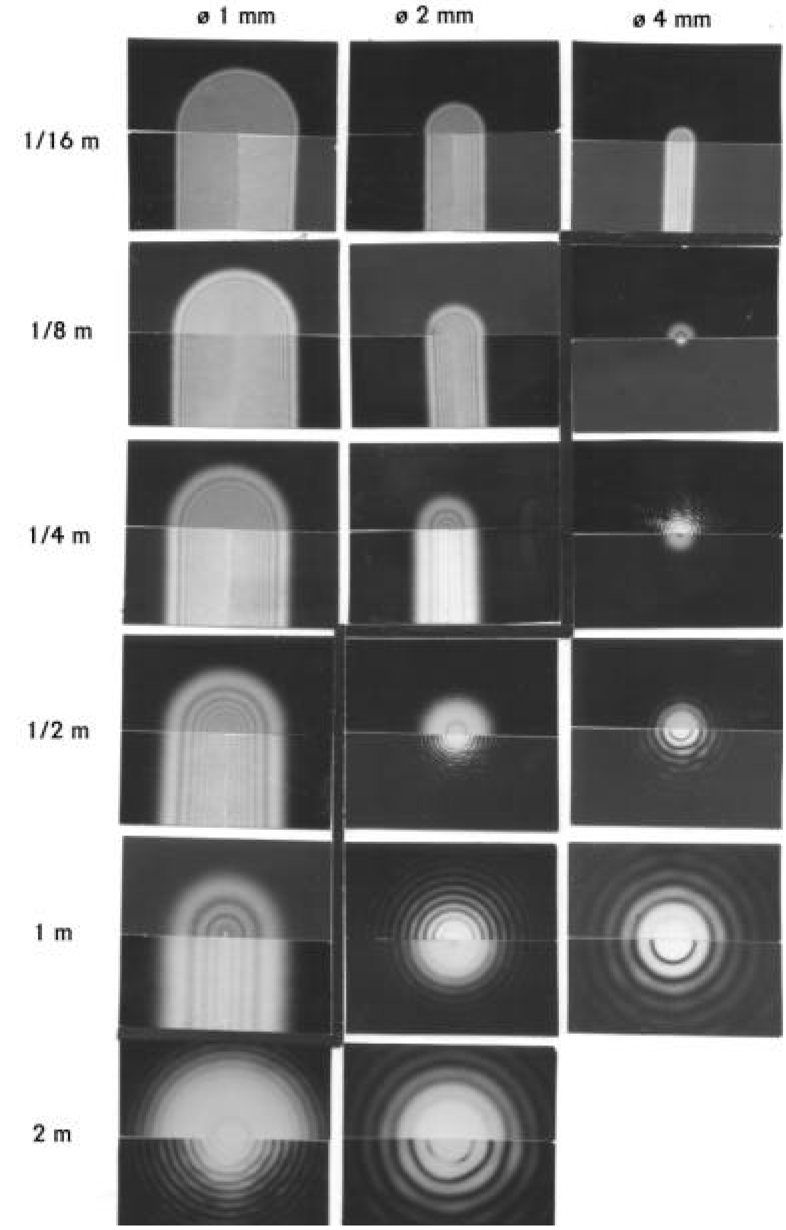



*Figure 3. Diffraction-figures at circular-openings in the arrangement of figure 2. The upper halves of all photos show the rings in Fresnel's manner of observation with parallel incident light. Left above the drawing line for comparison are arranged the diffraction figures from the half-plane in the same distance. They are so below arranged that equivalent rings and fringes border together. Right and below this line as lower halves of half-photos are arranged the photos in Fraunhofer's manner of observation, thus is with the lens Le 2 with $f'_2 = e$. The distance e in m is given left outside and the diameter of the used circular-opening DD in mm on the top.*

Figure 3 shows the results of these examinations. The upper half of every photo shows always the diffraction-figure in Fresnel's manner of observation, this is without optics. If the upper half of photos show a predominance of inner rings, in the below half of photos the diffraction figures are shown for comparison of the half-plane in the same distance. The part-photos are cut and put together in such way that equivalent rings reps. fringes adjoined another. Inner rings are visible in the upper parts of the photos left above the line from 1/16 m - f 1 mm to 1 m - f 4 mm.

However, if outer rings are predominant in Fresnel's manner of observation, as lower half are figured for comparison the photos of diffraction-figures in Fraunhofer's manner of observation in the same distance, therefore with a lens of the focal-length equal to distance of photo-film. This case takes place right and below the above described line.

III. Fresnel's and Fraunhofer's observation at circular openings

Like Newton in his diffraction experiments, Fresnel [6] used no optics. Fraunhofer [7] put in a collecting-lens of focal-length of interval to light-source or illumination-slit before the diffraction-object, therefore the light entered parallel the diffraction-object. Behind the diffraction-object he arranged an infinite set telescope and observed so the diffraction-figure. Equivalent is to arrange a collecting-lens with the focal-length of distance to the screen. In every case

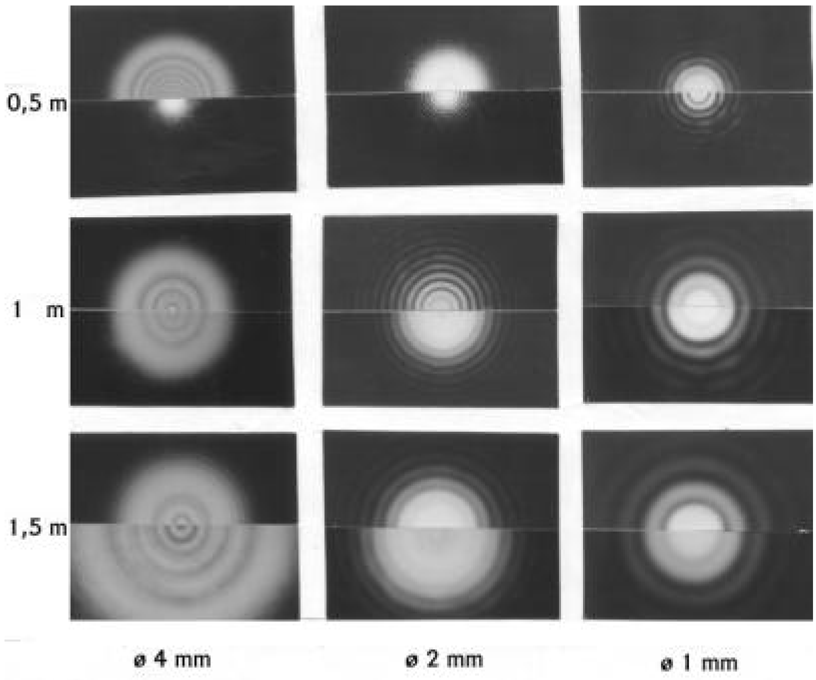



*Figure 4. Diffraction with and without imagery at circuit-openings in the arrangement of figure 2. Below rank: diameter of the used circular aperture in mm; left column: distance in m. The upper half of all photos are taken in Fresnel's manner of observation without the lens Le 2. The lower halves of the photos are taken with the lens Le 2 with a focal-length f' = 0.5 m. The first rank of photos shows the results in 0.5 m resp. in the focal-length. The second rank shows the results in 1 m distance resp. in the double focal-length, the third rank in 1.5 m resp. in the threefold focal-length.*

light-source or illumination-opening is imaged on the screen. In these case limits of shadow of the diffraction-object join with images of light-source or illumination-opening and it is reached that no inner diffraction-fringes or -rings can appear. So diffraction is to describe more simply and authors of text-books favoured this manner of observation. In this connection it is introduced a simplified interpretation of diffraction. Only with the totality of all diffraction-phenomenons is to catch the nature of diffraction.

To demonstrate the results of Nieke [5] in the double focal-length also with circular-openings, in figure 4 are compared Fresnel's and Fraunhofer's manner of observation in distance of double and threefold focal-length. In the first rank the upper half of 4 and 2 mm f shows inner diffraction-rings but not that of 1 mm f. In the second rank equal diffraction-figures originates with and without optics with inner and outer diffraction-fringes (inner rings only with 4 mm f). In the third rank are shown the results of threefold distance. Therefore outside the focal-plane in Fraunhofer's manner of observation appears inner diffraction-rings also in circular-openings.

## IV. General remarks to diffraction-rings at circular-openings

By Fresnel's manner of observation in short distances and large circular-openings originate inner diffraction-rings that correspond to inner diffraction-fringes of slit or diffraction-fringes of half-plane. The (unequal) intervals of diffraction-rings are non noticeable dependent in diameter of opening but only of distance, where by parallel illumination the intervals grow only with the root of distance as already Fresnel [6] found experimentally for half-planes. As Nieke [3] has proved, this dependence is valid first in distances greater than $10^5\ \lambda$ (at visible light about 50 mm.), before the diffraction-figure of half-plane is erected.

However, in sufficient large distances or smaller openings outer rings instead of inner rings appear. Their intervals of rings harmonize with the intervals of rings, finding in Fraunhofer's manner of observation in the same distance, but with different intensities. They are proportional to the reciprocal diameter of opening. The transition from inner to outer in Fresnel's manner of observation (upper half in figure 3) takes place at f 4 mm between 1 and 2 m, at 2 mm f between 1/4 and 1/2 m and at 1 mm f between 1/16 and 1/8 m.

Whereas the intervals of outer diffraction-fringes at the slit are constant, so is that not the case at outer rings of circular openings, even if this is not so evident than in the intervals of fringes in half-plane or inner diffraction-fringes of slit. According Huygen's principle and integration over the circular plane with the radius R or outer diffraction-rings were calculated formally with the presupposition of large distances and not too great and not too small radii. With that (and only then) these outer rings were calculated by means of Bessel-functions

$$\sin \alpha = \chi \lambda / R \qquad (1)$$

for minima $\chi$ = 0,61, 1,116, 1,619 ...
and
for the maxima $\chi$ = 0,819, 1,346, 1,850 ... .
The derivation from constancy is small but notable.

Deviations from all calculations by wave-hypothesis appear at size of slit or diameter of circular-openings at smaller than 0.1 mm. Hönl, Maue and Westphal [8] quoted many formal or approximate estimations for this case. By Nieke [2] and [3] at slit width of 0.1 mm touch the two spheres from which bent light is coming. So a physical argument can be given because here at small slit-widths or circular-openings must rule other conditions. Here the presupposition of (inadmissible and wrong) extrapolation (cf. Nieke [9]) of formula for diffraction at slit with outer fringes in the slit-plane was fulfilled, that bent light has to come from the whole slit, but just here the calculation does not agree.

Fresnel's zone-construction describes a system of rings in the plane of diaphragm where the way of light from light-source to test-point grows respectively for $\lambda / 2$. Sommerfeld [10] wrote to that (translated): „A very descriptive, if only qualitative understanding, of these results yields the construction of Fresnel's-zones“. This theory constructs a system of rings that yield only in special cases the right radius of diffraction-rings.

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