Newton's and Fresnel's Diffraction Experiments

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Abstract

Photos of diffraction figures of triangular slit and Grimaldi's luminous edge confirm Newton's observations. Newton described the transition from inner to outer fringes of triangular slit and showed that bent light (Grimaldi's luminous edge) only comes out of narrow surroundings of every edge and not of the whole slit. On the contrary Fresnel communicated only easily calculable borderline cases and disregarded transitions of inner to outer fringes and localization of bent light. Since 1850 textbook authors took over Fresnel's theory and intercepted Newton's diffraction experiments.

I. Newton's and Fresnel's diffraction experiments

Newton [1] reported completely about diffraction, even where he was not able to explain or to represent mathematically his results of measurement.

If one verify the diffraction experiments from Fresnel [2], so is to establish that his statements are right. But exactly there where his theory did not fulfil sufficiently the results of measurement no longer, exact there he broke off the communication without hint to deviation. For excuse to Fresnel is to remark that he else gave attention to his opponents in official positions for weak-points of his theory. Fresnel was not acknowledged in his lifetime

Above all Fresnel [2] worked on outer diffraction-fringes of hindrances that correspond to diffraction at the half-plane, and there are shadow-limits easy geometrical definable from which diffraction fringes are to measure. In a limited sphere he could formulate borderline cases from the diffraction-figure of half-plane and outer fringes of slit in large distances mathematically with help of Fourier's theorem (Fresnel integrals) which is a permanent merit for him.

Since 1850 in textbooks are considered only Fresnel's border-line cases and left out Newton's diffraction experiments.

II. Inner and outer diffraction fringes at the slit

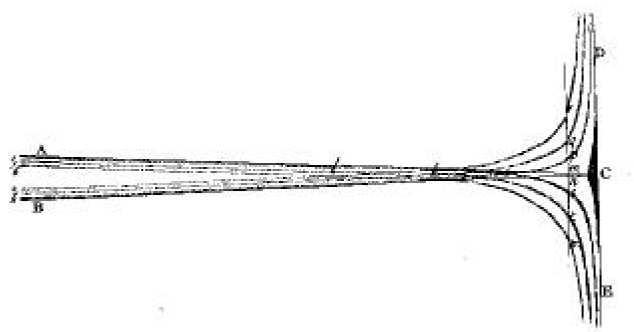
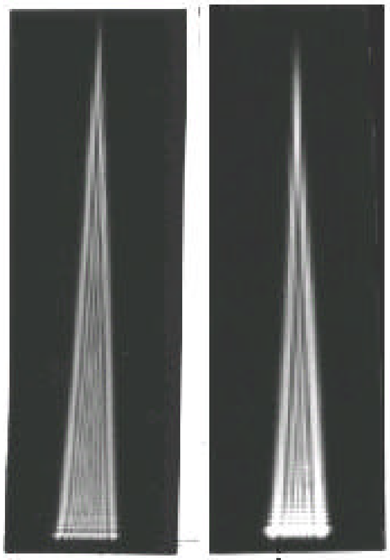


Figure. 1. Newton's drawing of diffraction at the triangular slit. Newton [1] III 10th observation. Newton used sunlight and a narrow hole in a shutter, distance to triangular slit 10 feet, and drawing plane 9 feet. With sunlight there are to observe only three (coloured) diffraction fringes but corresponding more with monochromatic light. ABC projection at triangular slit (shadow-limit).

Newton [1] described in III 10th observation the diffraction figure of a triangular-slit. His drawing was taken over as figure 1. The outer fringes (near the top outside shadow-limits) run here hyperbolically with equal intervals reciprocal to slit width. The inner fringes (near the basis inside shadow-limits) run parallel to the limits of shadow (A-C and B-C), they give the same appearance as fringes in diffraction with edges at half-planes. As inner fringes of slit they are named in transition-sphere until no more inner fringes really can exist (figure 1: i,k,l).

Figure 2 and 3 show photos of diffraction at triangular-slit in divergent and parallel light and in different distances that correspond to Newton's drawing (and contradict Fresnel's concept). In figure 2 b is to see that the first inner fringe has continued until the place of transition. In this sphere also spilt off outer fringes, but here this does not call attention because exposure was fitted to inner fringes. Newton [1] concluded from the transition of inner to outer in III query 3: „Are not the rays of light, in passing by the edges and fides of bodies, bent several times backwards and forwards, with a motion like that of an eel? And do not the three fringes of coloured light above-mentioned, arise from three such bendings?“

III. Grimaldi’s luminous edge



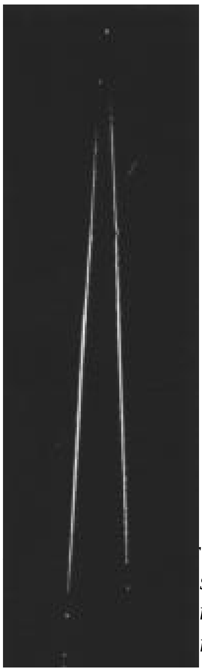
a b

a b

Figure 2. The diffraction figure of a triangular-slit with divergent light. A super-pressure mercury lamp with green filter was imaged by a condensor on a pinhole-diaphragm Æ 0.1 mm. In 1 m distance stood the triangular-slit 0... 3 mm. Exposure was fit to inner fringes.
a: A photoplate caught up the diffraction figure in a distance of 0.5 m from the slit. Supplementary two fold enlarged.
b: A photoplate in a distance of 2 m from the slit in original size.

In 1665 Grimaldi [3] was the first who reported about diffraction of light. He described the phenomenon of luminous edge, which is appearing, if a source of light is hidden by a half-plane.

Newton [1] examined this exactly in III 5th observation. He found that the luminous edge was the smaller the farther shadow sideways he observed. He wrote: „For placing my eye in the light, beyond the end of the stream which was behind the knife, and looking towards the knife, I could see a line of light upon its edge; and that not only when my eye was in the line of streams, but also when it was without that line, either towards the point of knife or towards the handle. This line of light appeared continuous to the edge of the knife, and was narrower than the light of the innermost fringe, and narrowest when my eye was farthest from direct light; and therefore



seemed to pass between the light of that fringe and the edge of the knife, and that which passed nearest the edge, to the most bent, through not all of it.“ Newton [1] III query 1: „Do not bodies act upon light at a distance; and by their action bend its rays; and is not this action (caeteris paribus) strongest at the least distance?“
The statement of query 1 is also called Newton’s principle.

In every case it is to conclude that bent light is coming out of a luminous sphere and neither from the edge nor from the whole slit.

Figure 4. The luminous edge at the triangular slit. A super-pressure mercury lamp with a green filter illuminated with a condenser a 0.1 mm pinhole-diaphragm. In a distance of 1 m stood the triangular-slit, a razor-blade slit with a basis of 3 mm A plate camera with double extension and tessar 1 : 4,5, f' = 135 mm was focused at the triangular slit and set so far sideways that the direct light fell beside the lens.

Fig. 3

raction figure of a triangular slit with parallel light. The same arrangement as in figure 2 but before stood a lens f' = 1 m, a and b are supplementary two folds enlarged.
re in 0.5 m distance,
re in 2 m distance.

Young [4] established that bent light did not come only from the shadow-side of an edge but also from the light-side of the edge of a slit. Certainly Newton observed this but he could not exclude a reflection and therefore he did not report about. But Young remained behind Newton's results because he limited the sphere of bent light to the edge. Presumable, Young thought of a stimulation of the edge but this is impossible with visible light as we know today. Young derived from this his interference principle that gives diffraction at double slit and grating in large distances.

IV. Photos of Grimaldi's luminous edge

Grimaldi, Newton, Young and Fresnel could only describe their observations and not prove these by photographic documents. If so one observes luminous edge of triangular-slit with the eye so figure 4 shows the impression. There are manifested in the photo that light is bent preferably perpendicular to edges, only near edges, shadow- and light-side, so this vindicates the designation of fine light-line.

For exact observation this phenomenon is to photograph in macro-scale that is shown in figure 5 with incident and transmitted light. The plane side of a precision-slit could not be applied here because all the present slits the edges were beleved. Hence copper-foils formed the used slit. To photograph the slit, the angle between optical-axis of transmitted illumination and the camera was chosen least so that no direct light fell in the photographic lens. The complete aperture in of lens is to use, or the aperture diaphragm is standing in front of lens. So direct light could not cause scattering or reflection in the objective.

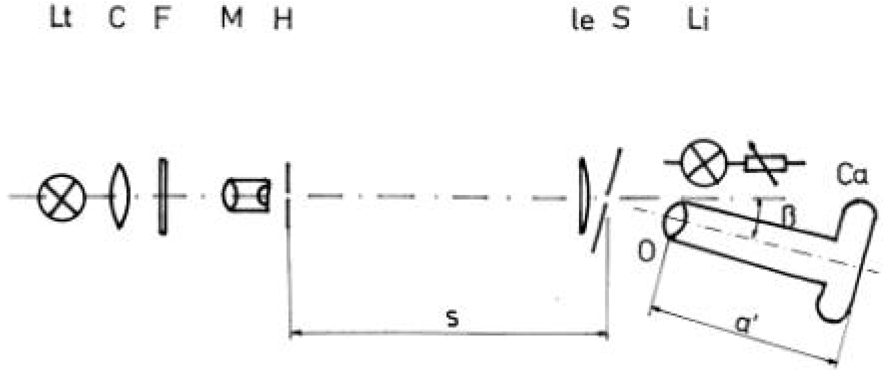


Figure. 5. Experimental arrangement for photography of luminous edge in macro-scale. Lt - light source for transmitted light, a super-pressure mercury lamp HBO 100; C - condenser; F - green filter; M - microscope-objective; H - pinhole diaphragm; Le - lens for parallel illumination; S - slit with 0.4 mm slit width consisting of 0.03 mm copper foil; S - distance from H to S; Li - light-source for incident light, a filament lamp operated with a adjustable transformer; O - photo lens; Ca - single lens reflex miniature camera with extension tubes; a' - image distance so that the same scale-ratio. In figures the upper edge of S is named light-side and the below edge shadow-side.

At different illumination-apertures, angles, and focal-lengths of camera lens photos of the slit are shown in figure 6 and 7. As known is to notice that after imagery light is to follow rectilinear backwards. So the light seams to come from bright places of positive prints. At first it is to see that the luminous-edge appears as well shadow- as light-side as it was to expect according to Young. Further the appearance of luminous edge is not bounded to the edge but there exists a finite luminous-sphere in surroundings of the edge as Newton already observed this rightly at shadow-side.

Next the position of luminous edge is notable. Light-side light seems to come out of a light-side sphere of the edge but shadow-side light seems to come from shadow-side sphere of the edge and therefore from the slit-jaws. This demands a sideways transfer of shadow-side diffracted light. It is to remark that the special position of luminous spheres are greatly dependent on position of focal-plane. If perhaps in slit-plane the direction of light is changed or displaced lateral as a result of diffraction, so by defocusing the position of this light in screen will be changed as to expect conformably in geometrical optics. In right position of focusing distance, which should be the sharply focused surface of slit as setting-plane, in the image-plane are ascertaining the points of intersection of projections of light with setting-plane, also after alateral displacing. Therefore the critical focusing to surface of slit was executed with great care.

Further is to mark that luminous spheres are not equally bright but at small illumination aperture in figure 6 a and c they are resolved single fringes. The fringes have disproportionate spacings as at diffraction-fringes of half-plane. Figure 6 d shows that at greater angles b the fringes become smaller, as already observed by Newton. If the focal-plane lies, seen from the lens, behind the surface so the number of visible fringes will increase, and if the focal-plane lays before the surface so the number of visible fringes will be reduced where narrow fringes disappear. Four or five bright fringes appear by focusing the surface. At great illumination aperture as in figure 6 b, the fringes become blurred. The breadth of luminous spheres amounts mostly about 0.1 mm at little angles. With a longer focal length of camera lens as 50 mm results in figure 7 a and b the same properties. Different properties gave a microscope objective with shorter focal length of 10 mm in figure 7 c and d. In this case was visible only one small fringe that could correspond to the building up of the diffraction figure of the half-plane. In a later following paper will be reported that the well-known diffraction figure appears first in a distance of about 50 mm.

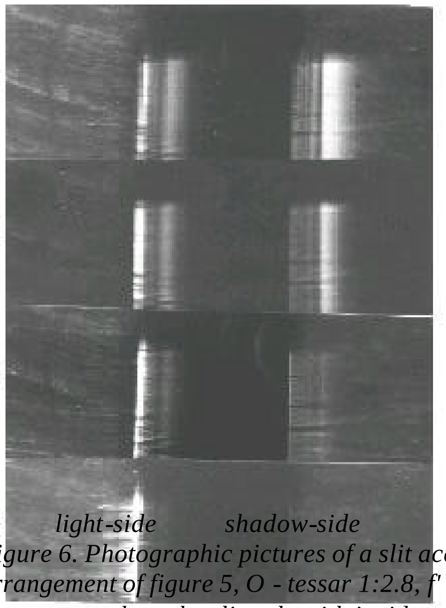


Figure 6. Photographic pictures of a slit according the arrangement of figure 5, O - tessar 1:2.8, f'   50 mm. The upper parts show the slit only with incident light, the lower parts additional with transmitted light illumination.
a. f H = 50 mm, s = 1 m,   f' = 50 mm, b = 7°,
b. f H = 50 mm, s = 0,5 m, f' = 50 mm, b = 7°,
c. f H = 50 mm, s= 1 m,   f' = 50 mm, b = 15°,
d. f H = 50 mm, s = 1 m,   f' = 50 mm, b = 30°.

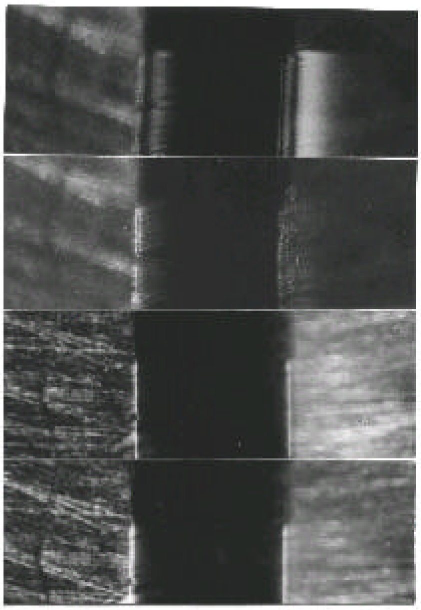


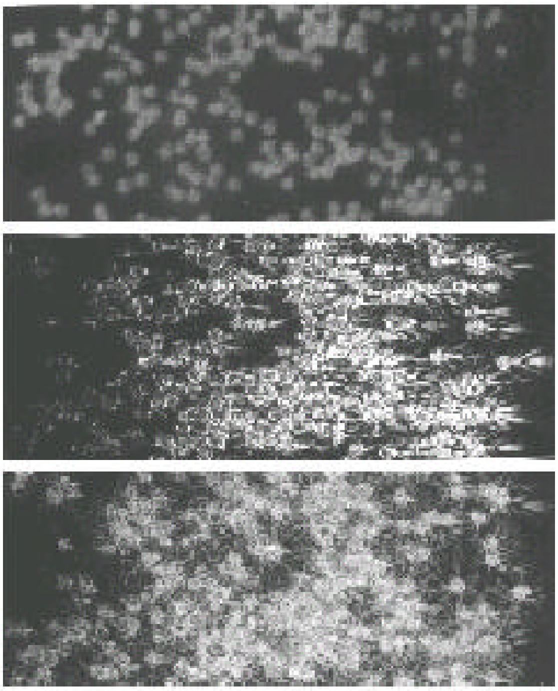
Figure 7. As figure 6. O - tessar 1:4.5, f' = 135 mm or microtar f' = 10 mm.
a. f H = 50 mm, s = 1 m, f' = 135 mm, b = 7°,
b. f H = 50 mm, s = 1 m, f' = 135 mm, b = 14°,
c. f H = 50 mm, s = 1 m, f'= 10 mm, b = 7°,
d. f H= 50 mm, s = 1 m, f' = 10 mm, b = 14°.

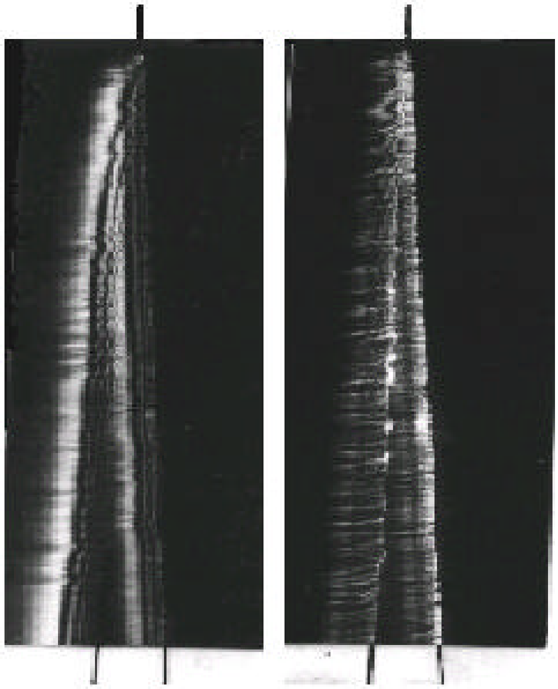
V. Complementary experiments for luminous edge

In addition to bent light there is also to see scattered light. Scattered and bent light are easily to distinguish because scattered light does not show fringes parallel to the edge. The part of light-side scattered light increases at greater angles. The use of copper-foil as material for slit caused a relative strong scattering because it is not to clean as a precision slit. To test the scattering separately there were strewed spores of ground pine or club moss (lycopodium) on a glass disk. This disk was set at the place of slit in the same optical path of figure 5 at which ground pine showed to the camera. Spores of ground pine are described as round with a diameter of 30 µm. As light source was used here a He-Ne laser HNA 188. A mercury lamp yields analogous results but with uncomfortable long exposure times. Figure 8 shows analogous appearances as seen in figure 6. At small angles the star-like fringes are one-side formed and shadow-side arranged, whereas at great angles appear all-round fringes. A comparison of the length of star-like fringes points to nearly the same size as the breadth of luminous reaches. The star-like form of the scattering figures is presumably caused by a structure of scattering centres. Already Laue [5] reported about radial fringes at scattering.

To examine the luminous edge in small width of slit, the top of a triangular-slit was placed in the same optical path of figure 5. Figure 9 shows no particularities.

a
b
c





a b

Figure 8. Photos of the scattering figures of spores of ground pine (lycopodium) according to figure 5 but instead of Lt up to H a helium-neon laser HNA 188 and instead of the slit S a glass-disk with the spores of ground pine in the same scale ratio as figure 6.
a: Only incident light,
b: Only transmitted light, b = 7°,

Figure 9. Photos of the top of a triangular-slit according figure 5 in the same scale as figure 6. íÆ B = 0.5 mm, s = 1 m. The outside lines point to the position of the slit.
a: b = 7°,
b: b = 15°.

<u>VI. Discussion of inner and outer fringes of slit</u>

With knowledge of Newton's diffraction experiments the presented experiments are not astonishing but to expect. On the contrary with Fresnel's diffraction experiments and general with the wave-theory of light they are not to expect. The reasons are to explain.

Fresnel [2] derived his theory with use of Huygens' principle chief for fringes of the hindrance. He wrote (translated): „The swinging of a light-wave can be considered in every of their points as sum of elementary movements, which all parts of this wave in the same moment, during every single is working, would send out if one considered them in one of their early position." As remark: „I always consider the succession of an immense number of waves or a main swinging of a fluid. Only in this sense one can say that two waves of light extinguish themselves, ..."

This shall be discussed in diffraction-figure at slit that is better known as the equivalent at hindrance. In very large distance maxima and minima of outer fringes of slit obey the known formula:

$$\sin \alpha = m \lambda / d \qquad (1)$$

with α as angle, m as measure-number of order n, λ as so called wave-length, and d as slit-width. (Min: m = n, max: m = 0 and m = (2n + 1)/ 2, n = 1, 2, ...). For discussion the formula (1) is usually extrapolated to the distance nought or to the slit-plane. This is geometrically printed in every textbook for optics. As result is stated everywhere: 'The slit limits a wave front and every point of this wave front becomes initial-point of a new sphere-wave.' If in this book is remarked as presupposition: distance » λ, so already this extrapolation is marked as inadmissible.

For that Newton [1] had shown the diffraction figure of the triangular-slit that is reproduced in figure 1. Only in large distances and small slit widths, so at the top of the triangular-slit, outer diffraction fringes appear which correspond to formula (1). In large slit widths or corresponding near distances, therefore in the left part of figure. 1, the inner diffraction fringes of slit appear which correspond to diffraction at half-plane with edges as half-planes. These fringes run parallel inside the limits of shadow ABC, therefore light-side of edges. The intervals of fringes are disproportionate, they do not correspond to formula (1). The intervals of fringes increase not proportionally to distance as Fresnel [2] showed experimentally (and not out of wave-theory) e. g. by parallel incident light the intervals grow only with the root of distance. Out of this is to infer: The extrapolation was inadmissible, for formula (l) does not be valid in short distances because there appear inner fringes.

Arkadiew [6] repeated diffraction experiments at the triangular slit in distances about more than 20 m and could so obtain a photo without inner fringes like figure 3 b. This photo was used everywhere in order not to be forced to discuss the transition from inner to outer fringes. That would be necessary if Newton's drawing would be used, but in that time one stood helpless opposite this transition or transformation.

If someone objects that wide separated edges of half-planes have to bring the diffraction figure of half-plane, so this is right. But here is to explain why at the same slit-width are resulting in short distances inner fringes and in large distances outer fringes.

Then one can object that there are still other arguments for light as wave. No, there are not. Mach [7] had shown that all diffraction and interference experiments only proof the periodicity of light and not the wave. If you examine all these experiments critically, so Mach is only to confirm. As well periodicity is not limited in swing or wave but e. g. possible in rotation, compare Siemens [8]. An exhibition with help of the Fourier-theorem is possible for any every piecemeal monotonous result. Pohl [9] wrote (translated): ,,A transfer of the wave conception on the vacuum is true a vast abstraction."

Schwarzschild [10] attempted with throwing over the solutions from one edge to the other edge to explain mathematically the change of inner to outer fringes, but never that was valued as a solution.

VII. Discussion of Grimaldi's luminous edge

Formula (1) and the inferences out of outer fringes of slit presuppose that bent light comes from the whole slit. That is also wrong and was known long before Fresnel. Grimaldi [3] observed by hidden light source at the edge a fine light-line, named Grimaldi's luminous edge. Newton [1] observed this more exactly as reported in section III. Young [4] reduced falsely the luminous edge only on the edge. Fresnel [2] wrote (translated): „After I had made sure that the fringes go out of the bodies self, in that measure as I could judge this with a strong magnifier ... ." With these facts and Young's interference principle Fresnel was not succeeded to calculate diffraction at slit according formula (1) as it is easy to verify. (Double-slit and grating: max.: m = n, min: m = (2n + 1)/2, n = 0, 1, 2 ... with d = slit-interval). Therefore he attempts it with the above called consequence of Huygens's principle.

Inference: The extrapolation of formula (1) is not only inadmissible but wrong too, for bent light does not come from the whole slit but out of narrow surroundings of every edge.

Sommerfeld [12] inferred out of his diffraction theory, which used Huygens' principle, that no light can go out from the edge. Hence he denoted Grimaldi's luminous edge as an illicit extrapolation of the eye. Indeed, from the edge come no light, but bent light comes out of the narrow surroundings of the edge and not out of the whole slit. Nevertheless Sommerfeld integrated over the whole plane. Sommerfeld ignored Newton's diffraction experiments.

VIII. General remarks on Newton's diffraction experiments

Jordan [13] criticized Newton's interpretation of his diffraction experiments without to offer some news. Right was that the hole in the shutter delivered divergent light but the area-formed sun does this too.

Rosenberger [14] wrote that Newton's diffraction experiments did not exceed substantially Grimaldi's results. This opinion is to expect in the year 1895.

Burkhardt [15] extended Fresnel's experiments to the slit but only in so large distances where the results harmonize sufficiently with Fresnel's theory.

Hall [16] confirmed in his introduction to Newton's optics that Newton worked very carefully in his diffraction experiments but Hall did not emphasize the third book.

IX. Consequences

Fresnel [2] confirmed in his first paper about diffraction that bent light comes only 'from the edge', but with it he could not calculate the inner diffraction-fringes of hindrance (and the outer of slit). Also he established that it is not permitted to mask within the slit simple the sphere between the spheres of which bent light is coming. If one do so, the diffraction figure of double-slit will arise. Therefore in his second paper Fresnel took as pretend Huygens' principle and gave no more mention or respect to physical contradiction in origin of bent light; the mathematical description in large distances was satisfied to him, and later he drew his waves as circles not up to the hindrance. Fresnel was conscious of the weaknesses of his theory. From about 1850 the textbook authors left out Newton's diffraction experiments and so they could feigned a simple but misleading description. That the sphere between bent light is coming should not be masked,

Therefore it is not necessary that everyone have to test experimentally the communications of Fresnel [2] over his measurements; it is sufficient to examine the extrapolation of formula (1) as inadmissible and wrong by comparison with Newton's diffraction experiments.

Here Rubinowicz [11] attempted to bridge over this contradiction. In the function theory it is possible to transform a line integral into a plane-integral. With light, exhibited by an e-function as analytic function, he believed to have removed that contradiction; according to this it is indifferent if bent light is coming from the edge or from the plane. However, light is no analytic function and bent light is coming neither from the edge nor from the whole plane but out of narrow surroundings of every edge. The light-line of Grimaldi is not to exhibit as a line-integral. That bent light is coming only out of the surroundings of edges is a well-known fact since centuries, never one has shown that bent light comes from the whole slit-plane, but nevertheless general plane-integrals were used for calculation of diffraction. has to be establish in future papers, but it does not justify the extrapolation.

It is to sumarize that Fresnel in later papers

1st: Could calculate the diffraction-figure of half-plane, they have characteristic unequal intervals of diffraction-fringes, by Fouriertheorem with the Fresnel-integral, Huygens' principle, and Young's interference-principle.

2nd: Could calculate diffraction at hindrance with inner and at slit with outer diffraction-fringes, at, which have characteristic constant intervals of diffraction-fringes, by Fourier-theorem with goniometric function {formula (1)}.

Especially point 2nd is valid only in very large distances.

The (intercepted) Newton's diffraction experiments show:

1st: By Newton bent light is coming out of a small surroundings of edge and falsely by Young and Fresnel only from the edge.

2nd: The diffraction at triangular-slit demonstrates that in short distances and great slit-width arise the inner diffraction-fringes of slit (resp. outer of hindrance), which correspond to the diffraction figure of half-plane with the edges as half-plane. First in larger distances arise the outer diffraction-fringes of slit (resp. the inner of hindrance) which stated in text-books after 1850 as only diffraction-figure of slit. First here the inadmissible and wrong extrapolation is shown evidently.

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