The Continuation of Newton's Diffraction Experiments

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Abstract

Newton's diffraction experiments are continued in a schlieren apparatus. The image of slit consists of a double-stripe with a small dark space at ever place of the image of an edge. This is to expect by Newton's diffraction experiments but with new details. The breadth of a double-stripe is < 0.l mm dependent to aperture of imagery. With masking of orders in the diffraction figure can determine ever order two places of bent light in the slit image. An attaching within the order did not succeed. Measurement technique, diffractive-optics and diffraction-limited-optics are fields of technical applications.

I. Introduction

Nieke [1] reported about Newton and Fresnel diffraction experiments. Indeed, Newton's diffraction experiments were no more noticed unjustifiably after 1850. As motive is to consider that Newton [2] could not establish his diffraction experiments with (punctiform) light-particles, whereas Fresnel [3] could calculate borderline cases of diffraction by waves, but not Newton's diffraction experiments. By leaving out of Newton's diffraction experiments important aspects of diffraction were left out too. Newton [2] III wrote at the end of diffraction-experiments: „When I made the foregoing observations, I designed to repeat most of them with more care and exactness; and to make some new ones, for determining the manner how the rays of light are bent in their passage by bodies for making the fringes of colours with the dark lines between them. But I was then interrupted, and cannot now think of taking these things into farther consideration. And since I have not finish this part of my design, I shall conclude with proposing only some Queries, in order to a farther search to be made by others“. Obviously nobody was found to do so.

II. Continuation of Newton's diffraction experiments in the schlieren apparatus

In these experiments there were already predecessors but without reference to continue Newton. Banjeri [4] projected a punctiform light-source in the middle of the front-lens of a telescope. In this optical-path stood the investigated object so that it was transited perpendicular. The image of light-source was masked and the telescope sharply focused on the diffraction-object. Because he

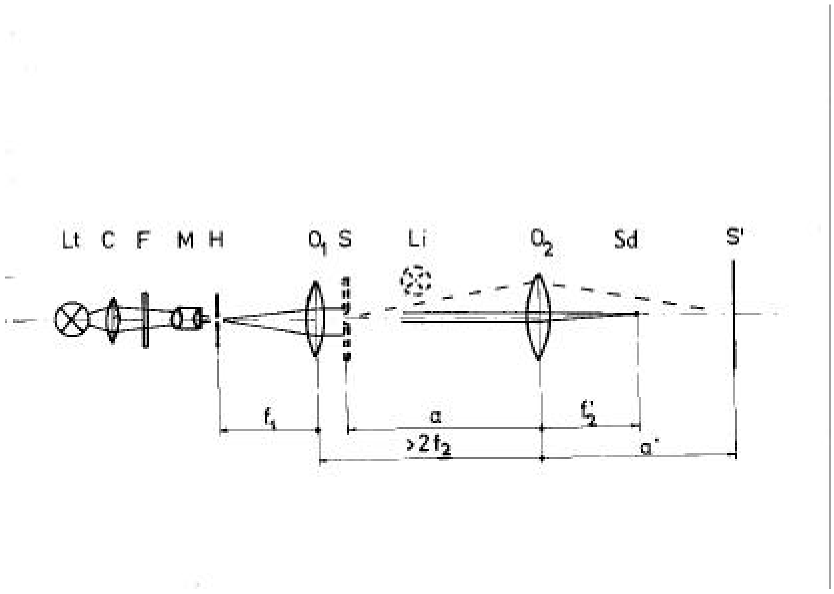

Figure 1. Experimental arrangement for diffraction experiments in a schlieren-apparatus according to Abbe. Lt - light-source, a super-pressure mercury lamp or a laser. C - condenser f' 0.90 mm; (F - filter for mercury lamp); H - hole-diaphragm in the image of Lt pinhole diaphragm ϕ 1 ... 0,1 mm; O_1 - lens 1; objective f' = 400 mm; S- diffraction slit or half-plane; Li - incident light source; O_2 - lens 2, objective f’ = 400 mm; SD - schlieren-diaphragm, less larger as H'; S' - image of S, this image is to view with a magnifier or the place of photo-plane or television-layer. Dot-lines shall indicate bent light.

proceeded from a cylinder-wave that goes out from the edges, the exact image of edge was of no interest for him. However, he wrote: „... more or less well define regions lying near the boundary of the aperture.“ He already reported from the dark stripe between the two bright stripes and carried out masking.

Noack [5] described the image of a half-plane in a schlierenapparatus as a ‘peculiar diffraction interference’. He found a double fringe accompanied by equidistant fringes. Laue [6] reported about similar results in dark-field illuminations.

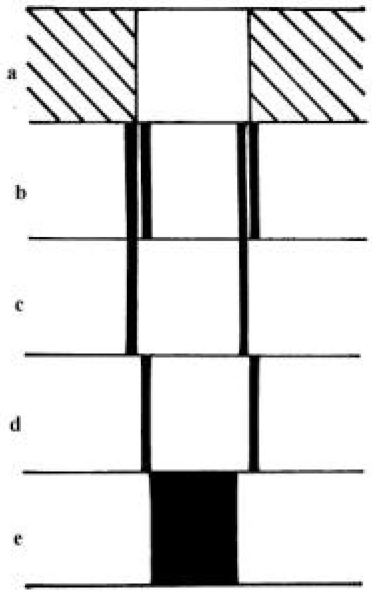

Figure 2. Show experiment as line-drawing (negative) with apparatus figure 1.
a: image of a slit in incident light,
b: image of a slit in a schlieren-apparatus,
c: one side of the figure of diffraction is masked before O_2,
d: the other side is masked,
e: negative schlieren-apparatus, instead schlieren-diaphragm a hole-diaphragm.

Figure 1 shows a drawing of the used schlieren-apparatus by Abbe. A high-pressure mercury lamp with green filter or a He-Ne laser (by radiation-enlarging without C till O_1) can be applied as light-source. A narrow hole-diaphragm H is illuminated and the objective O_1 produces parallel light. The slit or half-plane as the examined objects are placed in this path of light. Shall this object be imaged in the same size, so follows the second objective O_2 in distance of double focal-length as image-objective. In the image-side focus of this objective O_2 is standing the schlieren-diaphragm SD that catches the image of hole-diaphragm H’, therefore the non-diffracted light contributes nothing for the image. The field of image is practical dark without diffraction object. In the image-plane of object S' is caught up the image of slit or half-plane, it can be viewed with a magnifier, caught by ground-glass, screen, or photo-plate. With the named light-sources the image is too light-faint for projection in a lecture-hall. Therefore the image of the slit S' was imaged on the light-sensitive layer of a television-camera without optic. So this experiment can be shown brilliant on television-screens.

The results of this show-experiment are represented as drawing in figure 2. Figure 2a shows the position of the silt in incident light. Figure 2b shows the image of the slit in trans-illumination in a schlieren-apparatus. This image consists of two double-stripes inside and outside the edge-images ever a small dark space is to find in the place of every edge-image. The sharpest image is to get if the size of schlieren-diaphragm is set so, that it masked the zeroth order and the edge of schlieren diaphragm lies in the minimum between zeroth and first order. The light-sensitive layer of this camera works hard so that additional diffractions at the schlieren-diaphragm are scarcely observable, direct with the eye they are to observe but easy recognizable as such. On principle such disturbances are not completely avoidable for the intensity in a minimum is not nought in contrary to calculations or constructions by wave theory, especially not in minima of lower orders. An objective O_2 with long focal-length diminishes this disturbance. A half-plane delivers only one double-stripe as image of the edge in a schlieren-apparatus.

If one half of the diffraction figure of slit is masked in front of the objective O_2, with the same result one can also be masked one side beside the schlieren-diaphragm, so result in figure 2c only two single stripes. The other side of the diffraction figure is masked in figure 2d and so the other parts of double-stripes are to see. If the intensity of illumination is sufficiently reduced, that no irradiation takes place, so the schlieren-diaphragm can be substituted by a hole-diaphragm that let transmit only the zeroth order. The edges of this diaphragm have to stand in the first minima. So in figure 2e is to see that the zeroth order illuminates only the middle of slit-image.

III. Discussion of the results in the schlieren apparatus

With knowledge of Newton's diffraction experiments the results in a schlieren-apparatus are not astonishing, for indeed bent light comes only out of the narrow surroundings of every edge as Grimaldi’s luminous edge. These results bring still essential details.

Natural it is astonishing that the outer part of every double-stripe seems to come from the slit-jaws, this light must be displaced lateral. Lotsch [7] reported of lateral displacing of light in total reflection. He reported of displacing up to 20 wave lengths. The spectroscopists was known long that every slit image was spread, for ex- ample Brauer and Fröhlich [8]. Now this can be established with the shadow-side displacement of shadow-side bent light.

At all phenomena is to notice that the position of bent light is shown in the slit image, but not where that light has passed the slit. The dark intermediate-stripe between every double-stripe shall be interpreted as trace of the displaced light. By change of slit-width only the two double-stripes are correspondingly shift, at a slit-width of 0.1 mm the two double-stripes touch another and 0.1 mm is also the (maximal) breadth of one double-stripe. The real observed breadth is dependent on aperture of imaging-optic and angle of observation as Newton already had shown.

Newton [2] III 5th observation viewed the shadow-side bent light of a half-plane that passed the edge in a distance below about 0.03 millimetre. Newton did not report about a shadow-side displacing of bent light. Newton observed with the eye and only shadow-side, so he only could discover at most the half of one double-stripe.

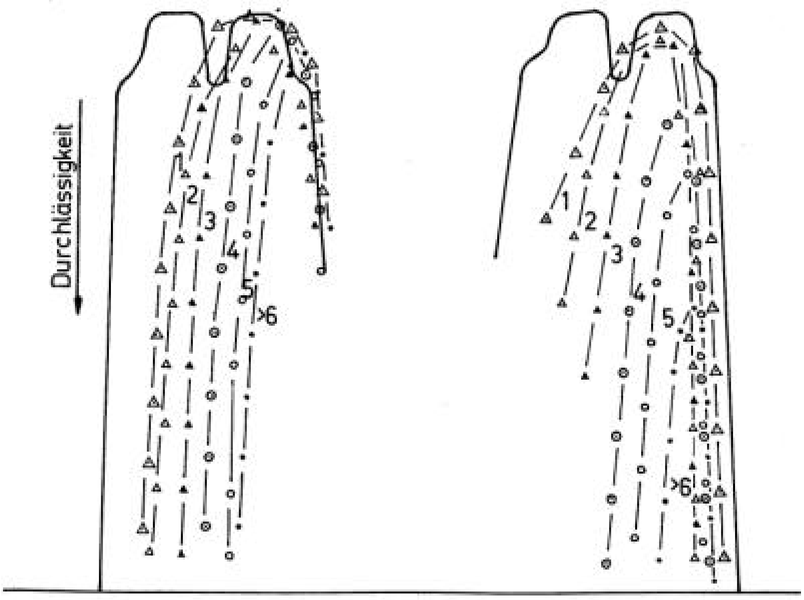

Figure 3. Photometer curves of the negatives of slit-images in the schlieren-apparatus figure 1 with partial masked diffraction figures in front of the lens O_2. H: f 0.5 mm; S: slit 0.2 mm; a' : a = - 5. All negatives are equally exposed on the same plate one over another and taken with the same photometer setting. The diffraction fringes inside and outside the double stripes are left out because they are caused by diffraction at the schlieren-diaphragm or the mask plane. ● - more than half masked including the 5th order, ○ - till the 4th order. ⊙ -till the 3rd order, ▲ - till the 2nd △ - till the 1st order, ⚠ - till the 0th order. Traced curves: the whole diffraction figure free.

IV. Masking of diffraction orders by steps

The diffraction figures had been masked in front of imaging objective O_2 step by step respectively in minimum for observation the attaching of orders of diffraction and spheres in image of slit. In figure 3 the half of diffraction figure was always masked and every farther masked order is marked between the photometer curves. In figure 4 was more than the half of diffraction figure free. It was necessary to reduce the exposure time for irradiation appeared and there was new adjusted. With these tests are proved an attaching of order in the diffraction figure to the place in slit-image. Every order is attached two spheres in the slit-image

In order to show with one photo the whole phenomenon, the diffraction figure was masked obliquely before the objective O_2. At the top of figure 5 only the highest orders of one side contribute to image of slit, whereas below all orders of both sides took part. It is to remark that the objective O_2 causes an imaging and so exists a focusing where the two part-stripes of a double-stripe must cross (but of cause not the two double-stripes). This position is not to find with the eye for our eyes accommodate always on the dark stripe between the part-stripes.

Therefore Banjeri [4] and Noack [5] always reported from this dark stripe. In figure 5a the focusing- plane lay something before and in figure 5b something behind this crossing-plane.

In the attaching of diffraction-order and slit-image there exists a restriction. A masking in the diffraction figure in a schlieren-apparatus is only practicable in a minimum, for within a maximum there appear additional diffraction at masking-plane that disturb the attaching in slit-image.

V. Comparison with Heisenberg's uncertainty relation

The sizes of luminous spheres are to compare with the statements of Heisenberg's uncertainty relation. According to Heisenberg [9] results with $\Delta x \, \Delta p_x > h$ the uncertainty of locality to $\Delta x > d / m$ with d as grating-spacing or slit-width (the formulae for grating or slit in great distances differ only by the factor 2, but Heisenberg related only on grating) and m the order. For m = 1 the uncertainty of locality would be the slit-width, a determination in the slit would be impossible. As present usual is to place $\Delta x \, \Delta p_x > h / 4 \pi$ but leaving the impulse by Broglie $p_x = h / \lambda$, so results $\Delta x > h / 4 \pi m$. Therefore about 1/12 of the slit-width would be analysable with m = 1.

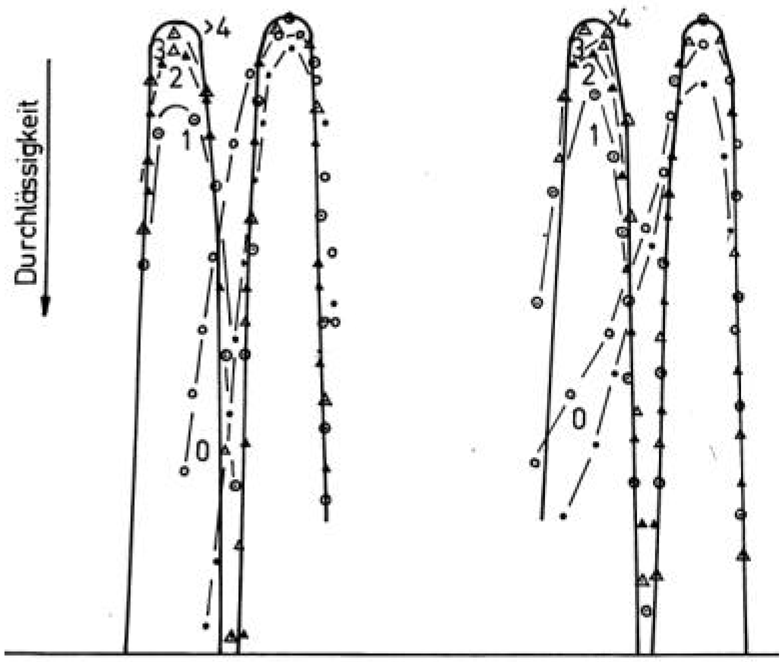

Figure 4. Photometer curves as figure 3 but with a new setting and a shorter exposure time. · - one half and the 0th order masked, ○ one side and the 0th order free, ⊙ - additional the 1st order free, ▲ -additional the 2nd order free, △ - additional the 3rd order free, ⧊- additional the 4th order free.

In every case, this calculation is incorrect for diffraction at the slit, for bent light is coming only out of the narrow surroundings of edges as Newton [2] showed and Nieke [1] confirmed. In a schlieren-apparatus the images of slit contain out of two double-stripes that are independent of slit-width, the slit-width determines only the spacing of both double-stripes. Therefore Heisenberg's uncertainty relation is not applicable for diffraction at slit. These experiments show the localization of bent light and permit only the statement that the order is the limit of localization in a slit-image. The exactness of localization in the slit self is limited by displacement of shadow-side bent light or the eel-like motion of light-particles or photons, but this does not make uncertain the fact of localization.

VI. Published farther experimental papers

Newton [2] reported in III 6^{th} observation that with a slit-width of about 0.0065 mm the zeroth order is splitting up. Arndt a. Nieke [10] controlled this and established that during a contraction of slit-width at narrow slits the zeroth order split up indeed. However, after some second at constant slit-width disappears the split-up. If a split-up appears by a constant slit-width, Newton had this marked in his drawing of diffraction at the triangular-slit. This is therefore a physiologic effect during enlarging of interval of diffraction fringes. This effect is easy to demonstrate with a laser in a lecturehall, but by known effect this is also to observe by illumination with conventional light-sources.

Nieke [11] showed that the diffraction figure of double-slit resulted also if the so called coherence-condition was violated extremely. That happened when the illumination-slit had such a width that the first or a higher order dropped in ever a single-slit and the zeroth order on the intermediate-stick.

Ganci [12] let drop the light of a laser grazing at the edge of a half-plane and focused the light with a cylindrical lens on the intermediate-stick of a double-slit. The bent light yields nevertheless the diffraction figure of double-slit although the so called coherence-condition was violated. Ganci tried to explain this with the transform by Rubinowicz [13] as edge-diffracted wave.

In both cases Newton's diffraction experiments gave an explanation. The bent light comes out of narrow surroundings of every edge of silt or half-plane and the unbent light is masked by the intermediate-stick of double-slit. In both papers only the bent light caused diffraction at the double-slit and this comes only out of a narrow sphere of edge, and for it the coherence-condition was accomplished. Nieke [11] could interpret his results corresponding to the double-star experiment. The double-star is replaced by both edge-spheres out of bent light is coming. The interpretation of Rubinowicz [13] is to sort out, for from a luminous sphere of an edge can not be formed a line-integral and a sphere of slit-

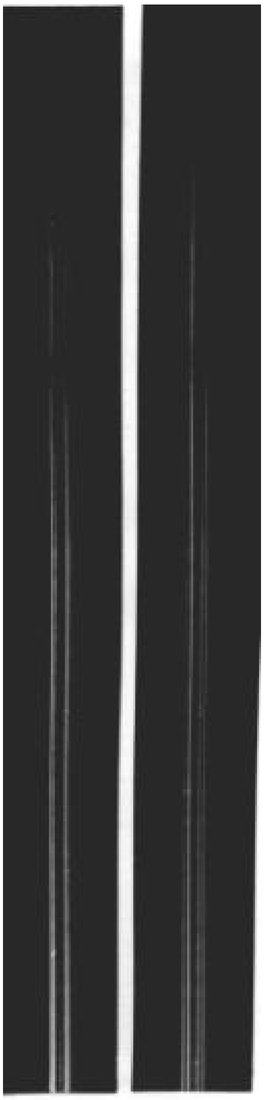

Figure 5. Image of a slit 0.25 mm in a schlieren-apparatus figure 1 with a scale-ratio a' : a = 1 : -1. 30° oblique masked diffraction-figure before O_2 , with 12 visible orders. O_1 and O_2 f' - 320 mm, the negatives are ten folds enlarged.
a: film in front of the overcrossing plane,
b: film close behind this plane.

width of bent light does not exist.

VII. Technical applications

The consideration of shadow-side displacing of shadow-side bent light appears importantly for measurement technique by commutation from incident- to transmitted-light and also by switching from bright- to dark-field.

For high-performance lens with diffraction-limited correction and already previously in microscopically observation was found empirically an optimal imaging of the aperture of illumination amounts 0.6 to 0.8 parts of aperture of objectives. For example Hoffmann [14] interpreted this as part-coherence and this value is denoted as coherence-parameter. According to this paper this optimum is to interpret, that at a smaller aperture of illumination the border-parts of aperture-diaphragm are less illuminated as the middle. Because only near the edge passing light is diffracted so the influence of diffraction will be smaller if this intensity is smaller. It is to notice that here the diffraction results at the aperture-diaphragm, Abbe's theory of imaging considered diffraction at the object which is limited by aperture-diaphragm.

Knop [15] described that diffractive optics have exhibited in dramatic manner the insufficiency of Huygens' approximation. By this paper this consequence by Knop is caused only by wave-interpretation which has no experimental foundation. Already by Newton's proof of localization of bent light was refuted the possibility of diffractive optics in such a form.

VIII. General discussion

According to these facts one would ask the question why wave-theory of diffraction could keep so long. The answer is simple: Newton and his follower could not establish diffraction with light-particles, which are only thinkable as mass-points, for a force perpendicular to propagation-direction of light is not provided in Newton's mechanics. On the other side the wave-theory offered for large distance calculations and explanations were considered more importantly as the whole experimental security. To the begin of our century, as the quantum nature of light was discovered, one had to give Newton really right, but nothing was altered in the case of impossibility of explanation diffraction with punctiform particles of light or photons. So retained for diffraction Fresnel's wave-interpretation.

Newton was right if he asserted that light never can be a wave, he had proved this with his proof of transformation of inner to outer diffraction fringes and the localization of bent light. Marshall [16] discussed the locality-debate. Newton's diffraction experiments brought the decisive experiments for local realism in diffraction. There are no doubts: The extrapolation of diffraction of outer fringes at the slit (formula (1) by Nieke [1]) to the distance nought or in the slit-plane was inadmissible and wrong.

The remark that for punctiform light-particles or photons as mass-points no explanation was possible, give the supposition that with space-filling, therefore with structure, seems possible an explanation. Indeed, off 1960 to all elementary particle are attached a structure, for it is to call the name of Hofstadter [17]. Also heavy elementary particles show the phenomenon of diffraction as for example reported by Carnal and Mlynak [18]. These particles have uncontested a structure that causes diffraction as deflexion, for nobody will suppose that atoms extinguish themselves.

First further experiments shall be put forward to obtain sufficient knowledge that permit an interpretation.

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