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An alternative view of the history of optical diffraction emphasising a neglected observation first reported by Francisco Grimaldi.

BY

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Abstract
Historical treatments of optical diffraction give due credit to Grimaldi`s work as predating, as early as the 1600s, the conventionally recognised authors, such as Huygens and Young. However, the scientific literature hardly acknowledged this and thereby overlooked the potential significance of the observation about the shiny spot at the edge of the half-plane in relevant diffraction experiments. The present work proposes that concentration on this spot may have an interesting role in an alternative approach to the subject. This paper reviews the correct order of the historical developments, revisits some prior experimental/theoretical works on the topic, and refutes the dismissal by Sommerfeld of the bright spot as an optical illusion. Impetus to the paper was given by a provocative question of a student regarding the postulate of virtual point sources in the simplified Huygens view of single slit diffraction patterns which one fails to observe.

Keywords: *Observations and theories of Diffraction; Observations of Grimaldi, Young, and Huygens; Scalar Theory, Half Plane Sommerfeld's solution, "reality" in Physics.*

1. Introduction:

This paper is restricted to views of optical diffraction from the classical physical optics perspective. The subject was significantly accelerated by the monumental book of Father Franciscus Maria Grimaldus [1]. He had the apparent misfortune that his initial investigations involved the more complex phenomenon of the diffraction of light. Important for the present paper is the presence of a luminous spot at the edge of the illuminated half-plane in his experiments. The purpose of the present work is threefold:

a) To call attention to the existence of accurate experimental works of Newtonian authors [2-4], who discussed fringes in diffraction patterns, prior to the work of Young [5, 6] and Fresnel [7] who are normally but incorrectly regarded as initiating the opposition to Newton's corpuscular viewpoint [9]. All these authors effectively followed, but perhaps unintentionally, did not explicitly quote Grimaldi when mentioning the presence of "inner fringes in (the) shadow".

b) To emphasise applicability of the scalar theory of diffraction to two different descriptions; namely the Huygens model [8] and the boundary wave view attributed to Young [5,6].

c) To explore the role of the shiny spot by examining whether it is simply some form of spurious reflection or whether it has the attributes of "real" optical sources when used in conventional diffraction configurations. The route followed in the original experiments by G. Burniston Brown in 1963, [10] was judged to be well suited towards this aim but he utilised instrumentation which lacked the current sophistication. Some of his experiments were thus revisited, using instead of his "Pointolite" source, a solid-state laser for the sake of convenience and improved optical coherence as well as digital recording.

2. The actual history:

In the historical theoretical and experimental classical physics expositions of diffraction, normally two approaches to the problem are favoured. Young considered diffraction as arising from an edge effect. Thus, the edge acts as a secondary source of light thus entering the domain of the geometrical shadow edge as well as interfering with the unperturbed waves from the original source in the domain above the geometrical shadow. A second and later viewpoint, theoretically treated by Fresnel [7], following Huygens who postulated that every point on the wavefront acts as a source of secondary spherical wavelets which combines with others to form a new wavefront. Fresnel added the principle of interference in a mathematical framework to explain diffraction. He had to

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introduce an arbitrary obliquity factor to account for the absence of the resulting wave towards the negative direction. In 1991 it was shown by Miller [11] that such ad hoc assumption was not needed if the sources are considered to be dipoles and not monopoles.

To be historically correct, before Thomas Young, the idea of considering the diffraction as an edge phenomenon was not entirely new at all; the concept was previously employed in emissive theory, see for example the work of M. Maraldi, Du Tour, and M- De Marians [5--7], where the problem is referred to as a refraction in agreement with the Newtonian viewpoint [9]. The paper of M. De Mairan stated: “Je crois donc être fondé `à regarder la Diffraction comme une véritable Réfraction; & cela par la grande Règle de M. Newton même, qu’il ne faut point multiplier sans nécessité des causes des effets amenées...” Freely translated as: “*I, therefore, believe that I am justified in regarding Diffraction as a true Refraction; as stated by the great Rule of Mr. Newton himself, that we must not unnecessity amplify the causes of the effects present*”

To explain the greater size of the shadow, reported by Grimaldi in his work with pencils of sunlight, both M. De Mairan and M. Du Tour claimed that this is the geometrical (shadow) effect of an unspecified atmosphere surrounding a hair or a fiber (“. . . mais d’un autre milieu invisible, & vraisemblablement de cette petite atmosphère que mille expériences démontrent, qui environne des corps….”). Namely: *but from another invisible medium, and probably from this small atmosphere that a thousand experiments demonstrate, which surrounds bodies.*

Neither M. De Mairan nor M. Du Tour reported on or referred to, any of the thousand experiments. No mention of the superposition principle is found in M. Maraldi, M. De Mairan, or in M. Du Tour papers. In reading these Newtonian authors one observes that their attention is very accurate but limited to the appearance of *colours only* in the fringes and not much on the geometrical aspects namely the order of colours’ appearance. This is not meant to subtract from their accuracy of observation, indeed in one of the planches later in the De Mairan papers, the invariant presence of a small luminous feature at the centre of shadows of obstacles with axial- or circular symmetry is noticed. Strictly speaking, the custom of labelling this phenomenon the Arago-spot or Fresnel-spot, is thus not historically well founded and followed later after ad hoc experiments by these two [12].

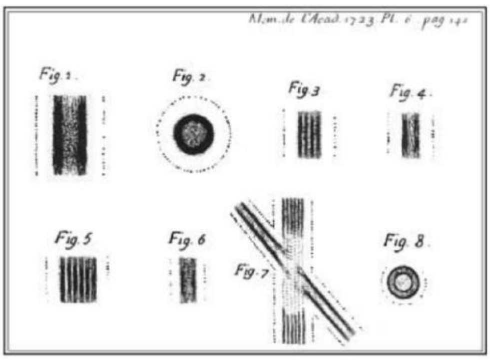

Illustration A: ‘*Planche’ from Maraldi`s paper*
Figs 2 and 8 refers to circular obstacle and the others of needles. Note the clear presence of a brighter central area of light. A central light fringe is everywhere well evidenced in the interior shadow of a needle. A single fringe (Fig, 4) occurs when the needle is very thin and the (point) source at great distance,

Above taken from Maraldi's memoir. The figures, ascribed to by the word diffraction, all highlight the presence of (a) either fringes or bright features in the centers of the shadows of both rectilinear and circular obstacles. The different descriptions of the colours of the central features (reddish violet by Maraldi and greyish in the case of Mairan) seems to be due to the darkness in the room. They used small holes, of order of 0.1mm diameter, to send sunlight into a darkened room to ensure reasonable areas of spatial coherence at a white observation sheet placed several metres downstream. The screen was tilted to improve visibility of the detail.

The 1802 paper of Young seems to reflect an uncertainty about the edge effect. Initially, he refers to “a kind of reflection at the edge” and later in the same paper his narrative changes to an “aether atmosphere around the edge” giving rise to an enhanced deviation of the ray closest to the edge compared to the effect on more distantly removed rays. This is illustrated in his illustration reproduced below:

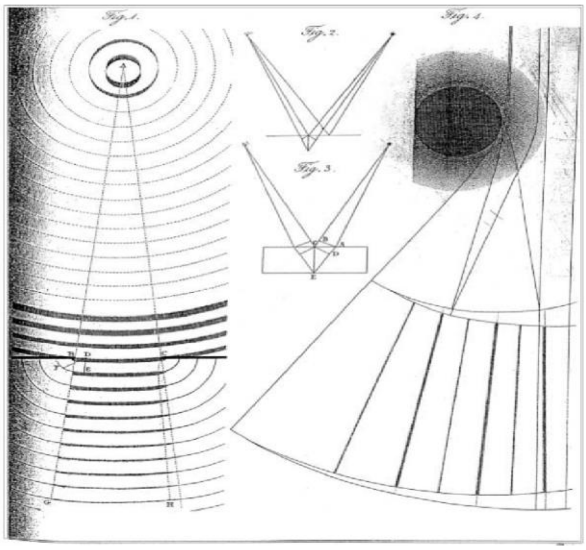

Illustration B. Published by Young in 1802
The constant guideline of Thomas Young is the analogy between sound and light. The reader can observe the naivety of the point source emitting like a tuning fork in sub-Fig 1 of the illustration. Sub figs 2 and 3 refer to another paper in the same volume while Sub-Fig. 4 shows an atmosphere of ‘Aether’ around the edge of a hair. The sketches do not illustrate a superposition of a boundary wave with the unperturbed light.

Young does not elaborate on reasons for accepting this aether atmosphere around a hair whereby he in effect followed the previously mentioned Newtonian French authors. Details

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about the fringe construction are also not clear. The Newtonian word "inflection" is used throughout this paper.

Interestingly, the *provocative* word "Diffraction", historically first used by Grimaldi [1], was employed by Young in an 1804 paper [4] without referring to the same. Because of rather personal, but virulent and anonymous attacks, attributed to Henry Brougham in the Edinburg Review [13], Thomas Young's diffraction work ceases with incomplete description of the phenomenon. Therefore, during the first half of the XIX century, Young's theory was forgotten.

Augustin Fresnel, in the beginning of his experimental research, adopted an "edge description" [7], apparently independent of knowledge of Young's papers, but he chose to not utilise this edge effect but rather adopted Huygens` principle by theoretically treating the virtual secondary wavelets. At the time the Huygens-Fresnel description was the only mathematical tool for diffractive phenomena. Throughout the XIX Century, both Young's idea and Huygens-Fresnel theory enjoyed no further theoretical development.

It is of interest that Isaac Newton, in his third book [9], in passing only, mentioned Grimaldi by the words "*Grimaldo has informed us…*". To the authors' knowledge, all the early Newtonian French authors ignored the book of Grimaldi although his book was well known by Thomas Young, as evidenced by the fact that he referred to it three times in his 1804 papers. Augustin Fresnel ignored Latin and English Languages and F. Arago did not evidence knowledge of French Literature in Refs. 2 – 4.

Fresnel's arguments received a firmer theoretical foundation when the Helmholtz and Kirchhoff integral formula [14] is applied to the concepts of superposition of spherical wavelets and the addition of a Fresnel`s arbitrary "obliquity" factor to account for the absence of a wave propagating in the negative direction. The integral formula, in the context of the scalar theory, integrates the elementary wavelets originating on the surface of an aperture in an adsorbing screen.

Independently from the idea to validate Young's arguments, G. A. Maggi was able to transform the Helmholtz-Kirchhoff integral formula by an integral formula to obtain a line integral around the edge of an aperture at an opaque screen [15]. The papers by A. Rubinowicz [16-19] can be considered as the first direct validation of Young's viewpoint of a boundary wave theory as a concrete edge effect. Assuming a conical frustum in free space [16] having the source as vertex of the cone and the surface of the aperture as base, the Helmholtz and Kirchhoff integral formula is converted into a line integral around the edge of an aperture in an opaque screen. The general formula holds for both spherical and plane waves.

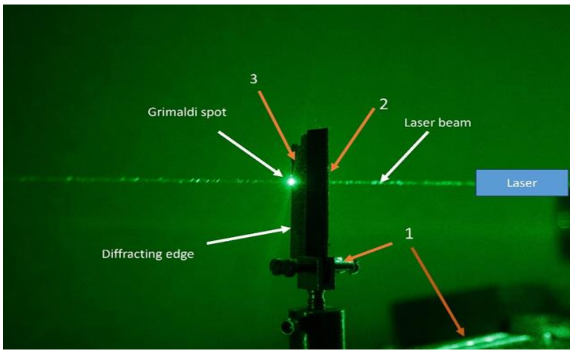
Therefore, the integration over a surface becomes an integration along a simple closed line forming the boundary of the aperture.

3. Experiments.

G. Burniston Brown [10] used a so-called Pointolite as a source in classical half-plane diffraction configuration. The Pointolite is an arc lamp using Zirconium electrodes and would thus have a reasonably small spot, high brightness but inferior coherence. In the present work, a solid-state laser (nominal wavelength λ=532 nm) was used and results were photographed with a rigidly supported Canon EOS2000D digital camera, with standard 18-55 mm objective. Distance between photographic camera and the luminous edge of the magnitude order of 1 metre.

The rather well-published experimental situation is given in Fig. 1 below. Specific attention is directed to the bright luminous spot where the beam strikes the edge, henceforth termed the "Grimaldi effect" creating a "Grimaldi spot".

Despite using new high-quality razor blades some marks remaining from the sharpening process were visible. The faint features marked 3 is thought to be reflections of the Grimaldi spot from these grinding marks. On the laser side of the blade several reflections, such as marked 1 and 2, are visible. These appears typical of what is to be expected as due to reflections of the incident beam from the blade edge facing the laser. To test whether the Grimaldi effect itself was due to some kind of reflection, the spot was viewed from many directions in the opposite direction, that is from a direction "downstream" of the blade. Due attention was given to take note of possible differences in intensity of the spot. The negative result obtained clearly indicated that this phenomenon was not due to reflections.



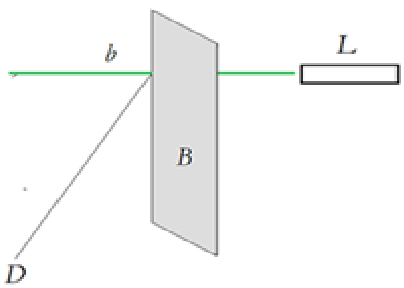


Fig. 1. Grimaldi effect is shown as the indicated luminous "source" as the first spot at the left of the diffracting edge. The photo was taken along direction D, at an angle of 60° with the beam b in a plane orthogonal to the edge as is shown

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in the accompanying sketch at the right-hand side. This was done to demonstrate that the spot was not the consequence of a reflection of the incident beam on the laser side of the blade.

Experiments were also carried out by revisiting Burniston Brown`s work demonstrating that the Grimaldi spot act as a real illuminating source for single and double-slit diffracting objects. Slits chosen from a Leybold –Heraeus 459 93 system of slits were mounted directly in front of the lens of the Cannon camera used to document results. The results are shown in Figures 2 and 3 below.

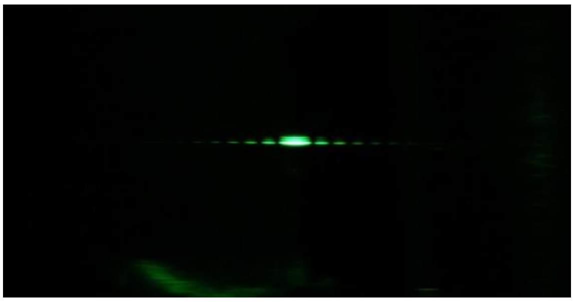

Fig. 2. Dif*fraction pattern observed when the Grimaldi spot, as is present in the diffraction pattern of a good quality new blade, is used as the illuminating source on a single slit 0.12mm wide. Distance from camera lens and Grimaldi spot 0.45 m. Laser at a distance 0.7 m from the blade. Contrary to expectation, and not understood, are the multiple features observed. It was noted that the edges were not straight*

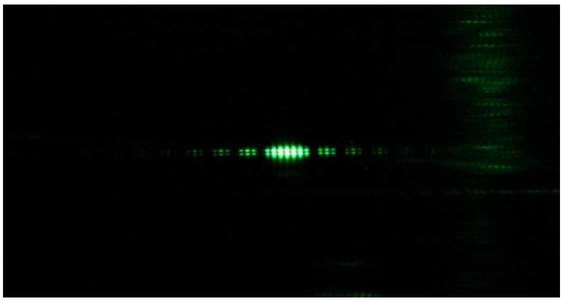

Fig. 3: *Double slit diffraction using the spot as source. Diffractive object is a slit pair of 0.12 mm wide slits, slit separation of 0.6mm, mounted in front of the camera lens. Slit pair chosen from the same system as above. Distance from Camera lens and spot 0.45 m. Laser at a distance 0.7 m from the blade. Again, a kind of multiple patterns seen.*

The slits were mounted on a diapositive and were not entirely straight. In both figures shown the effect is strong and the fringe contrast high, demonstrating the good spatial coherence of this 'source'. Defining the contrast γ of the fringes as $\gamma = \frac{I_{max}-I_{min}}{I_{max}+I_{min}}$, it follows that for γ = 0 no fringes present while for γ =1 perfect spatial coherence is observed.

In the conventional physics texts Fraunhofer diffraction of a single slit is presented as an interference of virtual Huygens source points in the free space present in the slit itself. Pairing of waves originating at positions symmetrical about the center is then used to construct resulting minima and maxima at the screen [20, 21]. The absence of luminosity in the free space of the slit in contrast to the edges of the slit, as viewed from an angular direction, was the essence of the question raised by the student mentioned earlier in this paper. A related question arose about what would happen if the symmetry present for planar slits is removed by forming "slits" in different ways? This was examined experimentally by using separated half-planes in the manner represented in Figures 4a and 4b below.

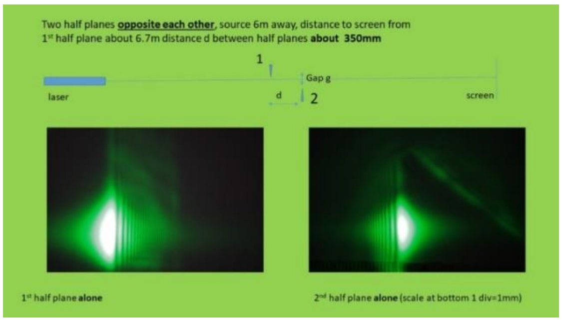

Fig 4a. Geometry and diffraction patterns for individual half-planes, new utility baldes used in the geometry sketched above the diffration patterns.

The half-plane patterns of each individual blade alone are conventional. The superimposed finer structure present on the "1st half plane" image was not a general feature and is thought to be an artifact, perhaps due to grinding marks.

Results for the situation where the effective `gap` between the half-planes were progressively reduced are shown in Figure 5. Because every individual blade gave fringe patterns above the shadow edge it was initially intuitively expected that some kind of overlap between their patterns would be observed in the space between shadows. Alternatively, the introduction of the second blade can be thought of as an attempt at spatial filtering, albeit with a filter open to one side. In that case, a mere reduction in the number of fringes, as was reported in passing by Burniston Brown, was also expected. None of these two expectations were experimentally observed. Rather, when the second blade was still several mm away from the beam axis, faint evidence of the conventional type slit patterns became visible, as shown in the centre image of the top row. When the effective gap between the half-planes were like those of conventional planar slits, order mm or less, the fringe patterns were similar to conventional ones for single *planar* slits. However, the normally observed symmetry of fringe spacings about the main beam was absent. Larger fringe spacings always occurred on the side of the half planar more distant from the laser. Such single slit patterns were observed with the distance, d, between half-planes of several centimetres. While this aspect was not investigated in detail such patterns were observed even for d values of 10 cm and more.

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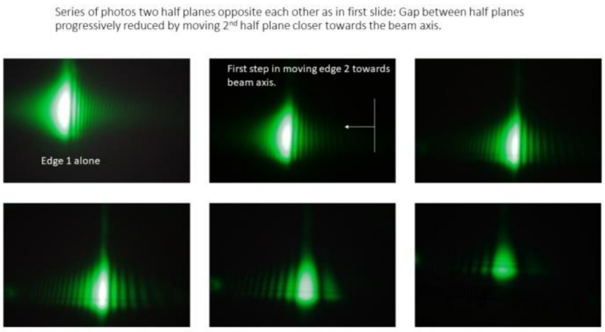

Fig. 4b *Diffraction patterns obtained with another set of half-planes where the first is kept fixed and the second one is progressively moved into positions closer to the beam axis.*

An alternative arrangement form of spatial filtering was also carried out. Half-plane no.2 was positioned on the *same side of the beam axis* as half-plane no.1 and again moved progressively closer to the beam axis. The geometry used is shown in Figure 5a while Figure 5b show a typical result. Contrary to the expected progressive reduction in the number of fringes, as reported by Burniston Brown [10], the above figures show an altogether different diffraction pattern.

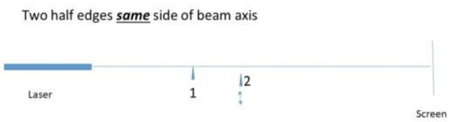

Fig. 5a *Geometry of experimental arrangements with two half-planes arranged on the same side of the beam axis.*

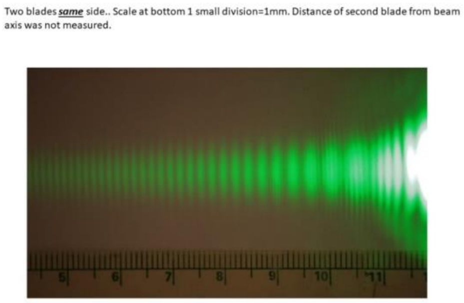

Fig. 5b *Diffraction pattern obtained. Conditions: Distance source to 1st half edge = 4.375m Distance 1st half plane to screen 10.877m Distance 2nd half plane to screen 10.275m Distances measured with a Robert Bosch laser device (GML80) accuracy of order 1mm or better. Scale at bottom 1 div=1mm.*

4. Discussion

The Huygens -Fresnel principle is almost exclusively offered in general physics books as explanation of slit or half-plane data. This led to the general ill-informed acceptance of the superiority of elementary treatment of superimposition of wavelets intersected by obstacles over the rigorous boundary wave diffraction theory. It is pointed out that the treatment of the boundary wave viewpoint by the scalar theory as was developed independently by Rubinowicz and Maggi can explain minima or maxima by simply only taking the phases of radiation from only the *edge sources itself* into account and disregard any perceived Huygens-Fresnel "free space" source contributions. In this way in-phase and out-of-phase edge sources would result in integrals representing, respectively, constructive- and destructive results. This theory is thus able to treat the diffraction phenomenon independently of seemingly different points of departure by considering boundary waves only.

In this regard, A. Wood [22] in a biography of Thomas Young treat the boundary wave ideas of Young with some ungenerous sentences such: *"…Young's diffraction theory was untenable…" and "…Fresnel's views must be regarded as superseding Young's explanations…".* Also, *in* the book by Bouasse and Carriére the superiority of Fresnel viewpoints is emphasized throughout [23].

While not mentioned in Newton's Opticks [9] and in any of the work of the French Newtonian authors quoted above, the shining spot appears to have indeed been noticed, in the case of diffraction by a half-plane, by Young [5,6]. This phenomenon was explicitly addressed by A. Sommerfeld in his "exact" solution of diffraction by a perfectly (electrical) conducting half plane and rejected as an optical illusion ("optische täuschung") because he proposed that the edge of a zero-thickness, perfect conductor, to not emit or absorb energy [24,25], as explicitly stated as the last hypothesis in the Sommerfeld's solution.

Burniston Brown disagreed with this dismissal and pointed out that Sommerfeld later in his paper contradicted himself. He stated: *One of Sommerfeld's postulates, however, amounts to assuming that "the edge of the screen neither radiates nor absorbs energy". Moreover, he took as a boundary condition that "the field at infinity must behave like an outgoing spherical wave exp.*(ikr/r)*". As he took r to be the distance from the edge (and not the source) this conflicts with his postulate so that his 'rigorous' proof is not convincing.*

In a review paper [26] on the theory of diffraction Bouwkamp pointed out all the attempts to justify an internal inconsistency of Kirchhoff theory and in [27]. that:

a) Sommerfeld does not give the E and H components,
b) If E is zero H is not zero, hence a singularity happens at the edge.
c) Bouwkamp verifies that E and H components fulfils the wave equation

As shown in Figs 2 and 3, for both single- and double-slit diffraction arrangements, typical Fraunhofer patterns, well-known for normal sources, were observed. The light originating from the Grimaldi spot clearly forms real images through lenses, which would not be the case if the spot was an optical illusion.

These observations confirm previous observations labelled as "reality of edge waves" and the "reality of edge sources" in a pair of papers [27, 28] covering the topic. In these papers the change of phase referred to above was dramatically demonstrated in experiments by isolating the boundary wave and blocking the geometrical wave.

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The results obtained in the present work by spatial filtering with 'open' filters are new. In each case surprising additional features were observed. Both cases represent a situation where two boundary waves interfere with the undisturbed portion of the main beam in the passage to the screen. In addition, there are near-field interactions to be considered as well as the Gaussian nature of the relatively broad laser beam. A Fourier optics approach was not attempted because of the inability to define a satisfactory transfer function as input.

5. Conclusions.

The inaccuracy in the commonly held perspective of the historical facts of experimental work on optical diffraction by scientific workers is corrected. Such biased opinion and omissions of the earliest work most likely had negative consequences for the theoretical musings of the subject. While well covered in historical reviews, recognition in scientific literature of the significance of the observation of the shiny nature at the edge of diffracting structures was largely ignored, even dismissed as an optical illusion. Several experiments and some arguments are raised which strongly argue in favour of the reality of the Grimaldi phenomenon. Some novel results for alternative slit arrangements are given that needs scientific attention.

The authors favour an opinion that the Grimaldi spot is due of the excitation of electrons present in the diffractive objects by the incident radiation with corresponding emission of light following the prior excitation. Excitation of electrons, which may or may not be entirely free as in conductive and non-conductive materials, is common in models of the interaction of radiation with matter. Such a view was explicitly stated by Burniston Brown [10] in his discussion of luminous edges (p 23). The presence of the spot for the thin portions of the obstacles, particularly downstream of the object, is telling. A possible analogy to optical (nano) antennas comes to mind and begs further theoretical development. Using such a model could conceivably lie at the root of the reason why the boundary wave theory can successfully treat diffraction phenomena independent of the different viewpoints of the mechanisms active as expressed by Young and Fresnel. The observations on the Grimaldi phenomenon emphasizes critical aspects and doubts when Physical Optics is discussed. What is "real" in Physics? Surely any phenomenological aspect that are seen, touched, and measured qualifies. Authors are not able to experimentally address such an open problem. For example, accurate measurements of the fringe contrast could give a plausible evaluation of the spatial coherence of this "edge source" with the implication that we can give a measure of the spatial coherence.

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