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On the Grimaldi Phenomenon

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Abstract: This paper deals with a short but exhaustive historical development of two different viewpoints about the diffraction phenomenon. This foreword to introduce the first and dramatic phenomenology observed since the end of the XVII century. Pedagogical observations are revisited about this first phenomenon observed. Impetus to this paper was given by a critical question posed by a student wen Author was teaching some Optics experiments.

Keywords: Theories of Diffraction, Scalar Theory, Half Plane Sommerfeld's solution, "Reality" in Physics

1. Introduction

The beginnings in Physical Optics start with the monumental book of Father Franciscus Maria Grimaldus (Grimaldi 1665) who had the misfortune to begin his investigations starting with the more complex phenomenon: the diffraction of light. In the historical development of the diffraction theories, two approaches to the problem are found.

A first viewpoint considers the diffraction as an edge effect. The "edge effect" means that the edge acts as a secondary source of light and that waves from the secondary source is the interfering with the unperturbed waves from the original source at the viewing screen. in the domain above the geometrical shadow edge. A second and successive viewpoint consider the propagation of the light and the diffraction as a superposition of elementary wavelets in agreement of the Huygens principle (Huygens 1690). The first approach is usually attributed to Thomas Young (Young 1802; 1804) in the context of the wave theory of light. Before Thomas Young, the idea of considering the diffraction as an edge-phenomenon was not new as the concept was previously employed in emissive theory, see for example the work of Du Tour (Du Tour 1774) and De Mairan (De Mairan 1740) where the problem is referred to as a refraction problem[1] in agreement with the Newtonian viewpoint (Newton 1730). The 1802 paper of Young seems to reflect an uncertainty about the edge effect. At first, he refers to "a kind of reflection at the edge" and later in the same paper he changes and introduces an aether atmosphere around the edge giving rise to an enhanced deviation of the ray closer to the edge than the deviation it inflicts on more distanced rays. This is illustrated by Young in his 'Table A' (Fig. 1), by the sketch at the far-right hand side of his *Fig. 1*.

Omnipresent in Young's thought is the analogy between sound and light. So, the point source of light in first sketch in the left-hand side of Fig. 1, shows the effect of a source point of light as propagating reminiscent of illustration of sound waves emanating from a tuning fork. The word diffraction appeared

[1] From the paper of M. De Mairan: "Je crois donc être fondé `à regarder la Diffraction comme une véritable Réfraction; & cela par la grande Regle de M. Newton même, qu'il ne faut point multiplier sans nécessité des causes des effects amenées". To explain the greater size of the shadow both M. De Mairan and M. Du Tour claim that this shadow is the geometrical shadow of an (unspecified) atmosphere surrounding a hair or a fibre ("mais d'un autre milieu invisible, & vraisemblablement de cette petite atmosphére que mille experiences démontrent, qui environne des corps"). Neither M. De Mairan nor M. Du Tour reported on or referred about these experiments. Any reference to the superposition principle is not found in M. De Mairan or in M. Du Tour papers.

the first time only in his 1804 paper while usually the (Newtonian) word “inflection” predominantly appears in the 1802 and 1804 papers.

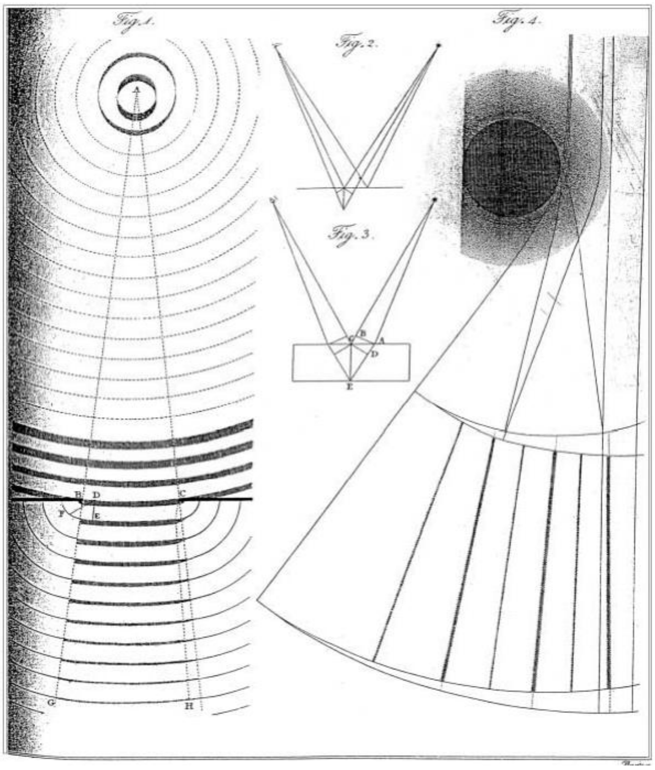

Fig. 1. ‘Table A’ is a compendium of Figures 1 to 4 in Young’s 1802 paper (Young 1802). These are referred to as *Fig.1, Fig.2,* etc. in the text.

After virulent personal attacks by Lord H. Brougham in the Edinburg Review and because of difficulties in describing the edge effect in a mathematical form, Young’s theory was forgotten for about 80 years.

The young A. Fresnel (1866) started his investigation adopting the basic idea of diffraction as an edge-effect independently from knowledge of Grimaldi’s book and T. Young’s papers. A careful control of the influence of edge parameters (material and cross-sectional geometry of the edge), led to a modification of his approach to a systematic treatment of the superposition of Huygens wavelets to obtain a successful description of the phenomenon. Therefore, during the first half of the XIX century Young’s theory was forgotten. Huygens principle was the only mathematical tool for diffractive phenomena, but both Young’s idea and Huygens-Fresnel theory did not have any theoretical support.

Fresnel’s arguments received a firmer theoretical foundation when the Helmholtz and Kirchhoff integral formula (Kirchhoff 1883) was applied to the concepts of spherical wavelets superposition and the addition of a somewhat arbitrary factor in the form an “obliquity” factor to account for the absence of a wave propagating in the negative direction. This formula, in the context of the Scalar Theory, integrates the elementary wavelets 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 (Maggi 1888). The papers by A. Rubinowicz (1917; 1924; 1957, 1966) can be considered as the first direct to validate Young’s viewpoint of edge boundary wave theory as edge effect. Assuming a conical frustum in free space (Born & Wolf 1980, pp. 449-453) 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 Γ forming the boundary of the aperture.

As is well known, the fundamental law of the mechanics of Galilei-Newton, which is known as the law of inertia, can be stated thus: A body removed sufficiently far from other bodies continues in a state of rest or of uniform motion in a straight line.

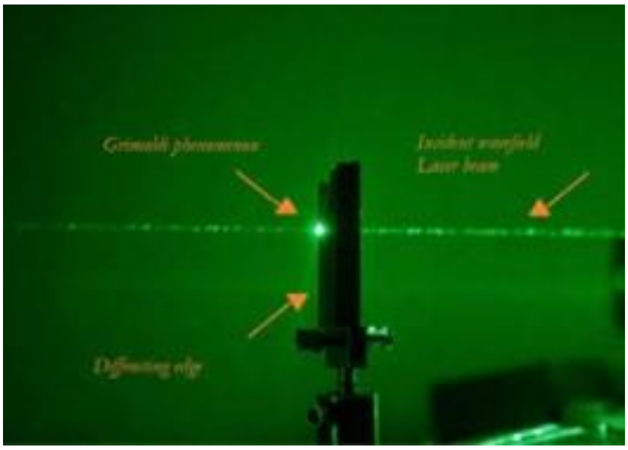

Fig. 2. Grimaldi's phenomenon: the brilliant spot of light at/near the edge.

2. Experiments

Fig. 2 shows what is intended for "Grimaldi's phenomenon: the shining at the edge of a half plane. This phenomenon appeared unnoticed in I. Newton's *Opticks* (Newton 1730). In T. Young paper of 1804 reference to knowledge of Grimaldi's book is quoted three times (Young 1804).

In the special case of diffraction by a half plane this phenomenon is explicitly analyzed by A. Sommerfeld in his "exact" solution of diffraction by a perfectly (electrical) conducting half plane and considered as an optical illusion ("optische täuschung") because he considered the edge does not emit and nor adsorb energy (Sommerfeld 1954, par. 38). The phenomenon is well observed in all directions of observation; (Fig. 2) it is "real" in the sense that the bent light around/at the edge gives phenomenon of diffraction and interference first noticed by G. Burniston Brown (1963) using old pointolite lamps. In addition, a pair of papers (Ganci 1989; 2012).

To reveal the Grimaldi phenomenon a new razor blade is illuminated by a source. While a pointolite light was used in (Burniston Brown 1963) a laser source was considered to be more convenient and coherent. The center of the beam was positioned orthogonally to the edge, and it was confirmed that this shining attribute was visible from all direction of sight. Also, no significant intensity variations at various angles of sight was discernable by naked eye. In spite of being of good quality razor blade edges has sharpening marks orthogonal to the edge giving rise to spurious effects. Remembering Sommerfeld's remarks about the shining being an optical illusion, a trivial experimental is serves to refute that: Fig.1 shows a photograph taken with Canon Camera EOS2000D with standard 18-55 mm objective from a camera position behind the blade. The light from the blade image forms a real image through a lens so the shining features indicated as the Grimaldi effect are thus not due to an optical illusion. In the particular condition employed, spurious scattering and diffraction effects due to the blade sharpening marks are avoided. Viewing the shining edge through a single slit or a double slit, it was confirmed that the typical Fraunhofer diffraction patterns relevant to such slits are seen. Photographs given in Fig. 3 show Fraunhofer diffraction through a single slit of width lx while Fig. 4 and Fraunhofer diffraction through a double slit of width lx at a slit separation of d. The effect noticed is strong and the fringe contrast high. Same effects are visually observed if the "edge source" is viewed through a transmission or reflecting grating held near the eye.

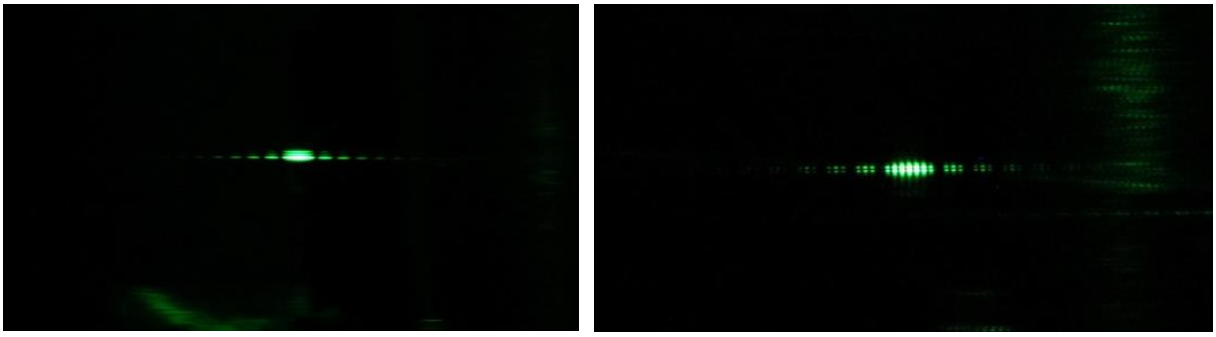

Fig. 3, left. Fraunhofer diffraction through a single slit.
Fig. 3, right. Fraunhofer diffraction through a double slit. Photographs were taken with Canon Camera EOS2000D with standard 18-55 mm objective. The solid state Laser employed (nominal wavelength 632 nm) was at a distance 0.7 m form the blade. Image taken assembling a single slit (Leybold –Heraeus 459 93 system of slits) in front of the camera lens. Distance from Camera lens and edge 0.45 m. The good quality blade, never used, shows a kind of multiple pattern: the edges is not straight as would be assumed. Slit width lx= 0.12 mm

3. Conclusions

These observations on the Grimaldi phenomenon emphasizes critical aspects and doubts when Physical Optics is discussed in General Physics courses, where Huygens wavelets-superposition is presented as the only approach. In general, such teachings leave students confused. A typical question from a student with the elementary form of Huygens' Principle perspective only was: "why can we not see the Huygens source-points inside an aperture?" The normal answer that these "are virtual sources" was not received with conviction. Certainly, no light is seen in the aperture of a large single slit (say 0.8-1.5 mm) if the sight is not in the direct propagation, while the unique phenomenological effect seen in the plane of aperture is the Grimaldi phenomenon at each edge.

General Physics textbooks explain Fraunhofer diffraction of a single slit as an interference of light-source points in the single slit aperture, taken at a pair in symmetrical position to the center and the explication works for the minima (Halliday, Resnick & Walker 1993, pp. 1077-1082; Wolfson & Pasachoff 1987, chap. 3). Minima formula can be equally explained taking two "edge sources" having opposite phases in agreement with Boundary Diffraction Theory.

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