Rediscovering Poisson's Spot

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Poisson's spot, a bright point at the center of the silhouette of a circular obstruction in a beam of light, played a critical role in the history of scientific research into the nature of light. The appearance of a spot of light in the shadow cast by a solid object, just where one might expect no illumination at all, can still provide very convincing proof of the wave nature of light.

Before the early 1800s, Newton's corpuscular theory, which described light as being composed of particles subject to attractive and repulsive forces, was the only accepted theory. However, some of Newton's contemporaries (most notably philosopher Robert Hooke), contemplated the nature of light and the manner in which luminous objects produce the sensations of light and color, and surmised that light must travel as a wave through some unknown medium.

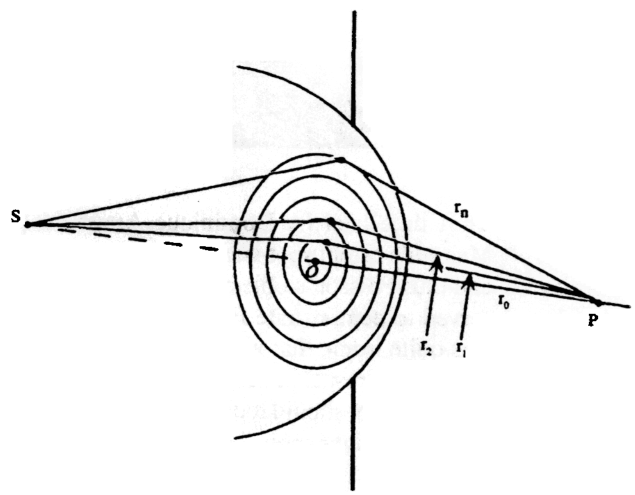

Fig. 1. Fresnel circular half-period zones on a spherical wavefront emerging from an aperture (after Pedrotti and Pedrotti[2]).

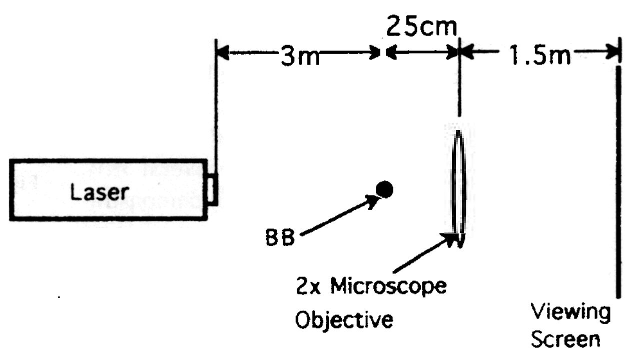

Fig. 2. Arrangement for projecting Poisson's Spot.

It was Dutch scientist Christian Huygens who, in 1687, first proposed a well-reasoned wave theory of light. He hypothesized that light propagates in a wavelike fashion, similar to a wave on the surface of water, and through a medium he called *luminiferous ether.* He proposed that as a spherical wave front expands through the ether and about a source point, a myriad of smaller spherical waves, or *wavelets,* form at each point along the original and combine to produce a new, eventually planar wave front. With no experimental evidence, however, Huygens's theory did not win many converts from the accepted corpuscular theory.

Substantiation of Huygens's theory was provided in 1801 by Thomas Young, whose double-slit experiment demonstrated that at certain points in the vicinity of two sources of coherent light, the light waves conspire and cancel each other, producing an observable interference pattern. This interference phenomenon can be explained suitably only by a wave theory of light.

The Huygens wave theory predicted a true geometrical projection of the contours of an obstruction in the path of a distant point source of light. Experimental observation, however, reveals interference bands in a region on either side of the silhouette border, rather than an abrupt change to uniform illumination at the border. When Huygens constructed his wave model, he supposed that all wavelets could be ignored except where they combined to form a common wave front, and it is for this reason that his theory fails to predict the interference patterns observed near the silhouette of the obstruction contours.

In 1818, French physicist Augustin Fresnel presented to the Prize Essay Committee of the French Academy an improved version of the Huygens construction, in which all wavelets were taken into account and which agreed with experimental observation. He provided a technique for describing the diffraction of light through apertures

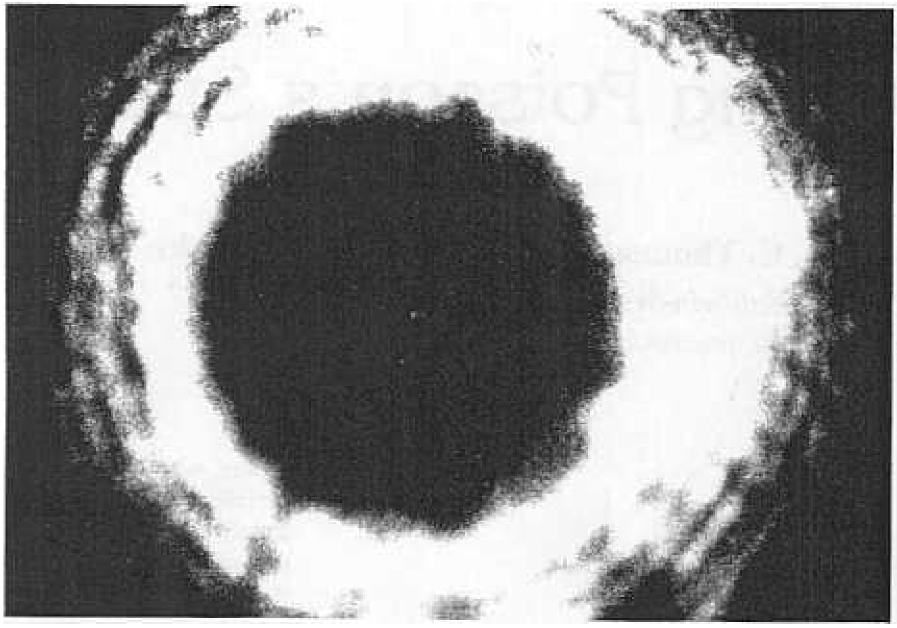

Fig. 3. Poisson's Spot.

and around solid obstructions. His construction is sketched in Fig. 1, which shows a spherical wave front emerging from a circular aperture.[1,2] Fresnel defined circular zones on the wave front such that each zone is $\lambda/2$ farther from the point P than the preceding one, so the phase of each successive zone is opposite that of the one preceding it. In Fig. 1, this means that $r_N = r_0 + N\lambda/2$. It can be shown[2] that the amplitude A_N at point P resulting from N zones, each contributing amplitude a_N, is approximated by

$A_N \approx \frac{a_1}{2} - \frac{a_N}{2}$ when N is even, and by

$A_N \approx \frac{a_1}{2} + \frac{a_N}{2}$ when N is odd.

Simeon Poisson, a member of the committee, dismissed Fresnel's theory as implausible. He reasoned that if a circular obstruction just covering the first zone were substituted for the aperture, so that all the zones except the first contribute to the light reaching point P, light of amplitude $a_2/2$ should reach P. The result would be illumination at the center of the obstruction's silhouette nearly as intense as if no obstruction were present. He made this objection not knowing that such a bright spot had already been observed by Maraldi[1] over half a century earlier. When Poisson's thought experiment was performed a short time later by Dominique Arago, Maraldi's bright spot was rediscovered, and thus Poisson's objection eventually served to demonstrate Fresnel's theory. It is quite ironic that what Maraldi first observed, Fresnel predicted, and Arago rediscovered, should today be known as *Poisson's* bright spot.

It is a fairly simple matter to "rediscover" the bright spot in even a modestly equipped high school or undergraduate physics lab.[3–5] A laser is the main ingredient in presenting a classroom demonstration of Poissons's spot; even an inexpensive diode laser pointer can be employed, although this may require the use of a spatial filter. A HeNe laser with an output of several mW works well and produces a demonstration which, when used in conjunction with a lens or microscope objective (positioned either in front of or behind the circular obstruction), can be viewed by a large group.

Such an arrangement using a 0.177-caliber BB as the circular obstruction, is shown in Fig. 2. BB's work well and are readily available, although ball bearings can also be used to avoid irregularities in the diffraction pattern caused by flat spots on the BB. The BB is held in position by a pin taped to a strong magnet. The BB can also simply be attached to the surface of the lens, or to a microscope slide, with a tiny amount of adhesive such as Super Glue, although this method can sometimes result in clouding of the lens due to the effects of the glue. The best demonstration results from the proper spacing of the laser, obstruction, and lens; this spacing varies with the components used. The projection in Fig. 3, which clearly shows Poisson's spot, was produced by the arrangement of Fig. 2, and was about 50 cm in diameter.

If an object larger than a BB is to be used, the lens can be positioned so that the beam passes through the lens before striking the object. The spacing must then be adjusted so that the beam, when it strikes the obstruction, has diverged to a diameter sufficient to produce the spot. Alternatively, a beam expander can be constructed from a pair of positive lenses, as shown in Fig. 4. The lens separation is $f_1 + f_2$, and the resulting expansion ratio is f_2/f_1. Beam expansion can also be achieved by simply directing the laser beam into the eyepiece of a telescope or binoculars.

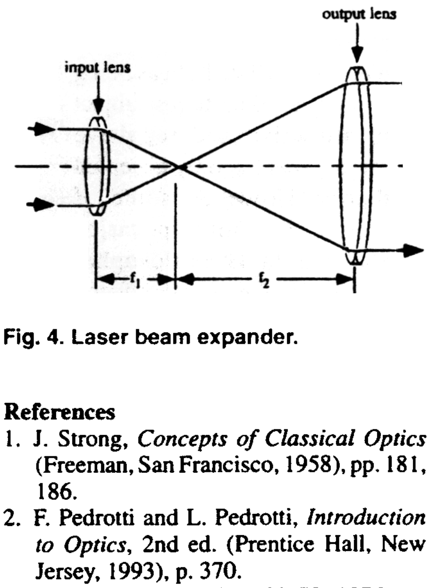

Fig. 4. Laser beam expander.

References

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