

# Phase Manipulation and Young's Double Slit

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A phase manipulation measurement allows you to detect through which slit the photon passed.

## Introduction

The Young double slit experiment is used to establish a level of credence in both elementary and advanced exposes of quantum mechanics. When a laser light source is used to illuminate the double slit aperture, the far field image consists of the classic  $\cos^2\theta$  interference pattern, modulated by the  $(\sin z/z)^2$  diffraction pattern. See Figure 1. If one of the slits is blocked, the interference pattern (not the diffraction pattern) is destroyed. With modern equipment, this experiment is easily replicated, and often forms the basis of undergraduate laboratory experiments. The far field interference image pattern may be projected by the use of a simple thin lens.

What, evidently, is not well known is that if the double slit aperture is positioned at the focal length of the thin lens, then the resulting far field interference pattern is "reconstructed by the lens" to give the image of two slits. If one of the slits is blocked, only one of the slit images vanishes. If the other slit is blocked, then the opposite slit image vanishes. In otherwords, a thin lens can be used "to determine which slit the photon went through". The thin lens adds a phase shift and refraction to each of the component complex waves that pass through it such that the image is not the classic distribution of Figure 1, but instead is the Gibbs approximation to the Fourier transform of a pair of slits, Figure 2. For positions of the thin lens at distances less than or greater than the focal length the interference-diffraction pattern re-appears.

The fact that the measurement apparatus (the thin lens) is of finite diameter is the fact that yields the Norbert Wiener result that  $\Delta k \Delta x \geq 1$ . In simple terms, the thin lens is a compact set (truncated Fourier series) trying to cover a non-compact set (infinite Fourier series). When multiplied by  $\hbar$  the Wiener criteria becomes the physicists "uncertainty principle". The larger the lens diameter, the less the Gibbs "ringing" at the edges of the slit images.

When this experimental result first startled the present author (RMK in 1982), a back of the envelope computation was made using Papoulis' methods to show that the transform of the double slit aperture, times the transform of the translation for a distance equal to a focal length, times the transform of a thin lens, gave the identity transformation. By phase manipulation of the complex wave, the interference effects could be eliminated (almost).

## Some Experimental Results

Using modern equipment involving arrays of tiny photocell detectors that "digitize" the illumination, the original experiments have been improved and are demonstrated in Figures 3, 4, and 5. In these three cases, the thin lens is placed at a distance shorter than the focal length, at the focal length, and beyond the focal length of the "thin" lens.

Figures 3 and 5 demonstrates a combined interference-diffraction pattern, while Figure 4 demonstrates the recombined double slit image obtained by positioning the double slit

aperature at the focal length.

## Some Computational Results

A Maple symbolic math program was written to compute the actual phase shifts generated by rays emanating from a pair of slits, refracting at both the front and rear surfaces of a thin lens, and then recombining on a distant screen. When the lens was positioned at distances not equal to the focal length of the lens, the phase angle defect distribution for rays that traversed the lens form a non-linear distribution about the optical axis of symmetry, a non-linearity which leads to the classic interference patterns for the composition of two rays. However, when the lens was positioned at a distance from the slits equal to the focal length of the lens, the phase angle defect distribution was a linear function about the optic axis of symmetry, and the interference composition vanishes. Similar effects occur for the diffracted compositions. However not all rays traverse through the finite lens, hence the reconstruction is not perfect.

## Reprise

The fact that optical waves can have both their phase and amplitudes manipulated in experiments should give pause to those who insist on the Copenhagen interpretation of quantum mechanics, an interpretation that presumes that measureables must be expressed by real numbers, and then only in the sense of a probability distribution. The optical Young double slit experiment indeed gives justification for the Wiener - and perhaps the Heisenberg - uncertainty principle, but it does not justify the probability interpretation of quantum mechanics, especially if phase of the quantum wave can be manipulated. Note that the Bohm-Aharonov experiments for electrons indicates that phase effects in quantum mechanics indeed can be manipulated.

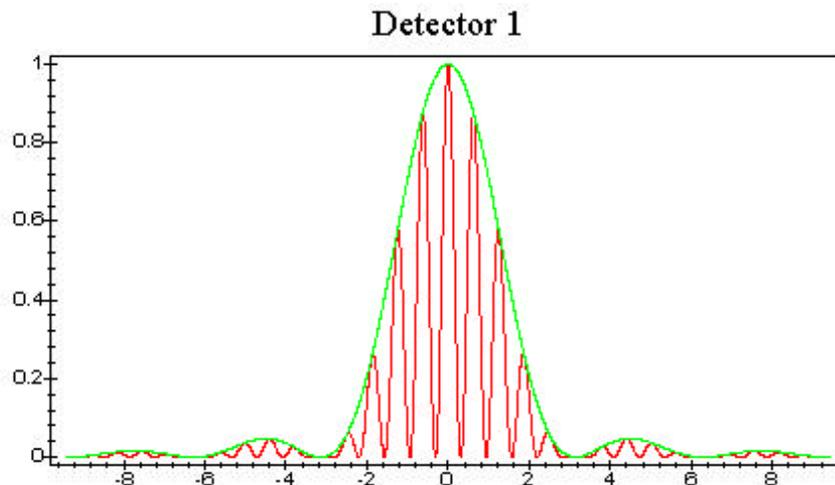


Figure 1. Classic interference pattern modulated by diffraction pattern

Other Figures to follow:

Figure 2. Truncated Fourier Transform of a double slit.

Figure 3. Digitized data for  $L <$  focal length

Figure 4. Digitized data for  $L = \text{focal Length}$

Figure 5. Digitized data for  $L > \text{focal Length}$