Single Photon diffraction and interference

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Abstract

Interference experiments with only one photon in the experiment at a time have also showed interference patterns. A previous paper that studied photon diffraction and interference (IntellectualArchive, Vol.1, No. 3, P. 20, ISSN 1929-4700, Toronto, July 2012.) required several photons in the experiment at the same time. The Scalar Theory of Everything (STOE) model of photon, plenum, screen and mask; the Bohm Interpretation of Quantum Mechanics; and the Transaction Interpretation of Quantum Mechanics are combined. The speed of the plenum wave is much faster than the speed of photons/light. The reverse wave required by the Transaction Interpretation is provided by a reflected plenum wave rather than a reverse time wave. The photon distribution on a screen results in an intensity pattern well fit by the Fraunhofer diffraction equation. The resultant mathematical model corresponds to the Fraunhofer mathematical model without the peculiar assumptions.

Interference, Young's experiment, Afshar's experiment PACS 42.50Ct, 42.25Hz, 42.25.Fx

1 INTRODUCTION

A single model of light has remained a mystery. Black body radiation, the photoelectric effect, and the Compton effect observations reject the wave-in-space model of light. The reflection, diffraction, interference, polarization, and spectrographic observations reject the traditional particle model of light.

The Fractal Principle is that the universe is a collection of reproduced, self-similar mechanisms. The Fractal Principle suggests the microphenomina of the hods and plenum is duplicated in the macro environment. Fractal cosmology has been shown to fit astronomical data on the scale of galaxy clusters and larger (Baryshev and Teerikorpi 2002). At the opposite extreme, models such as Quantum Einstein Gravity have been presented that suggest a fractal structure on the near Planck scale (Lauscher and Reuter 2005). However, the Democritus' concept of the smallest particle suggests a lower limit of the fractal self-similarity. The challenge is to find the proper analogies.

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Physics in the Newtonian and cosmological scales revolve around the concept that the motion of a single particle can be modeled with forces acting on the particle. The challenge of uniting the Newtonian and quantum worlds is to develop force laws of motion of photons that obtain the diffraction experimental observations.

Diffraction and interference of light have been observed since Newton's time. Young noticed in his diffraction experiment that the slit edges appear luminous (Jenkins and White 1957, p.379). Therefore, his model consisted of the interference of the waves assumed to originate at the edges and of the direct wave. Fraunhofer and Fresnel models assumed the waves originated before the slit and the diffraction occurred in a plane across the slit. Both models were poor close to the slit. Work by later theorists such as Sommerfield (Sommerfield 1954, chaps. 5 and 6) and Kirchhoff also considered the diffraction pattern is caused by the interference of the direct wave and waves from each edge like Young (Jenkins and White 1957, Section 18.17). Sommerfield's model included a phase analysis. This model was better close to the slit but degenerated into the Fraunhofer model farther from the slit.

The peculiar assumptions of the Fresnel wave model of diffraction include: (1) The Huygens' Principle that each point in a wave front emits a secondary wavelet. (2) The secondary waves are emitted in only the forward direction, which is the so called "obliquity factor" (a cosine function). (3) The wavelet phase advances by one-quarter period ahead of the wave that produced them. (4) The wave has a uniform amplitude and phase over the wave front in a plane in the slit and zero amplitude and no effect behind the mask. These assumptions have no analogy in the classical world. Further, The wavelets destructive and constructive interference produces the diffraction pattern. The wave must originates on one side of the mask and goes through the slit while illuminating the screen. The Fresnel model with larger distance between the mask and the screen or with condensing lenses before and after the mask degenerates into the Fraunhofer diffraction model.

The Afshar experiment (Afshar 2005; Afshar et al. 2007) challenges the currently popular Copenhagen interpretation of quantum mechanics (CIQM). Coherent light was passed through dual pinholes, past a series of wires placed at interference minima, and through a condensing lens. The resulting images showed the dual pinholes that suggested the which-way information had been recovered. That is, photons are producing the interference effect. The Afshar experiment was repeated in the very low intensity photon regime with the same result. Afshar interpreted very low intensity as a single photon in the experiment at a time.

The Bohm interpretation of quantum mechanics (BIQM) is an alternative to the CIQM (Dürr,et al. 2009; Goldstein 2009; Goldstein, et al. 2009). It is a causal, "hidden variable", and, perhaps, a deterministic model. The BIQM posits particles have a definite position and momentum at all times. Particles are guided by a "pilot wave" in a Ψ–field that satisfies the Schrödinger equation, that acts on the particles to guide their path, that is ubiquitous, and that is non-local. The pilot wave originates on one side of the mask, travels through the slits, and directs the photon through an undefined mechanism. The probabilistic nature of the Schrödinger equation results because measurements on small scales detect a statistical distribution. The origin of the Ψ–field, the dynamics of a single photon, and the forces guiding the photon are unmodeled.

The Transactional Interpretation of Quantum Mechanics (TIQM) posits quantum events are a combination of advance and retarded waves. TIQM suggests the complex conjugate of the wave Ψ^* notation denotes time reversal. A wave is transmitted forward in time from an emitter and reflected back in time to the emitter from an absorber (a sensor). The waves are considered real. This is viewed as two–way contact between the future and the past. The combination of these waves is the net effect measured. That is, the future is affecting the present at the level of enforcing correlations. That the TIQM uses advanced solutions of the wave equation for retroactively affecting quantum events is inconsistent with the arrow of time concept.

The "walking drop" experiment also produces an interference result (Bush 2015). These experiments seem to have stumbling blocks to the suggestion that the walking drop is an analog of the light interference experiments. The characteristics of photons and the STOE's plenum to make this analogy are:
1st, the drop is matter. The drop induces a wave in the medium just like the matter in General Relativity causes a warp in "space" (gravitational ether)(plenum).
2nd, the wave in the medium is traveling (much) faster than the drop.
3rd, the medium wave causes the drop to change position and direction like "space" directs matter.
4th, the drop is traveling as fast as it can. This is more like Lorentz's idea that photons travel at the fastest of any other matter rather than Special Relativity's view of a maximum speed in a vacuum.
5th, the wave is emitted in all directions and reflects off obstructions.

The walking drop suggests a solution to the BIQM wave origination problem. BIQM and wave diffraction models assume the wave goes through the slit. But the single drop follows the diffraction path without a wave source on the input side of the mask. The waves that cause diffraction to guide the drop cannot originate on the other side of the mask because there is only one drop in the experiment.

The Scalar Theory of Everything (STOE) (Hodge 2012b) proposed a model of the photon and its dynamics(Hodge 2012a). The model considered only the photons caused the variation in the plenum wave and required several photons in the experiment at the same time. The low intensity experimental results are obtained with a laser that emits in bursts through stimulated emissions. The mask simply stopped all but one of the photons. The Scalar Theory of Everything (STOE) requires the speed of the plenum wave to be much greater than the speed of light as Newton suggested (Hodge 2012a).

This Paper proposes a model of light that postulates the necessary characteristics of photons to satisfy observations and yield diffraction phenomenon for experiments with one photon at a time in the experiment. The model combines the BIQM for the photon, the STOE model for the generation and effect of the plenum wave, and the TIQM for the idea of the reflected wave from mask and screen. The plenum waves are real. The extreme speed of the wave allows the reflected waves to influence the motion of the emitting photon without a retroactive component. The wave–like behavior of light results from the photons, mask, and screen changing the plenum (Ψ–field) that guides the path of the photons. The forces guiding the photon are suggested. The resulting model is tested by numerical simulation of diffraction and interference. Therefore, the wave characteristics of light may be obtained from the interaction of photons, matter (mask and screen), and plenum.

Section 2 describes the model of photons, mask, and screen and the equations are derived. Section 3 shows the results of the computer simulation. Section 4 discusses the correspondence of this model with the Fraunhofer model of diffraction. The Discussion and Conclusion are in section 5 and section 6, respectively.

2 Model

The equations and definition of terms are the same for this paper as in Hodge (2012a). The effect of the screen and the mask is added to determine the Ψ field's affect on the photon. Hodge (2012a) considered many photons in the experiment. If the experiment includes only one photon in the experiment, the effect of the mask and screen must be causing the ρ field that causes the diffraction effect. This can happen if the waves from the photon are reflected and the wave velocity is much greater than the speed of the photon $\vec{c}$. The result is nearly a standing wave directing the photon like in the walking drop experiment.

The waves that cause diffraction are generated by the photon, reflected from the atoms of the mask, and not reflected by the slit. The reflected waves interfere because they have a common source.

The hod action on the Ψ field and the Ψ field action on the hod are like in Hodge (2012a, Eqs. 1 through 10) except the $m_I = N_h K_\Psi \Psi_{\max}/\Psi$. If there is only one photon in the experiment between the mask and screen, the photon action on the Ψ field must be symmetrical forward and backward. The $\cos(K_\beta \beta)$ term of Hodge (2012a, Eqs. 11) is one ($K_\beta = 0$) and the

$$N_{\mathrm{effT}} = \cos\left(\frac{2\pi r}{\lambda_{\mathrm{T}}}\right) \left|\frac{\sin[N_{\mathrm{hT}}\pi \sin(\beta)]}{\sin[\pi \sin(\beta)]}\right|. \tag{1}$$

The Ψ wave is reflected from assemblies of hods on the mask and screen. A macroscopic analogy is water waves encountering an island. The result is the wave is reflected back out from the island. Similarly the wave from the photon encounters the low Ψ around hods and are reflected with a π phase shift. The strength of the wave reflected from an atom is the sum of the hods in the atom. The strength of smaller assemblies of hods is smaller and is ignored for this paper. Therefore, the contribution of each hod of the atom need not be considered. The region is assumed spherical when the measurement is relatively distant from the atom. A portion of each wave is reflected back to the photon that affects the motion of the photon. The Ψ_{T} from a photon that is reflected back is a function of β_i and r_i, where $_i$ is an index and r_i is twice the distance from the hod to the reflecting atom (Hodge 2012a, Eq. 10). The Ψ_{T} has a phase shift due to the reflection of π. The Ψ_i due to the ith atom is:

$$\Psi_i = -\frac{K_r}{r} N_{\mathrm{eff}i}, \tag{2}$$

where

$$N_{\mathrm{eff}i} = \cos\left(\frac{2\pi r_i}{\lambda_{\mathrm{T}}} + \pi\right) \left|\frac{\sin[N_{\mathrm{hT}}\pi \sin(\beta_i)]}{\sin[\pi \sin(\beta_i)]}\right|, \tag{3}$$

and $\lambda_{\mathrm{T}} = K_\lambda/(\Psi_{max} N_{\mathrm{hT}})$ where N_{hT} is the number of hods in the photon.

The total Ψ_{T} at the photon is:

$$\Psi_{\mathrm{T}} = \sum_i^{atoms} \Psi_i. \tag{4}$$

3 Simulation

The effect of the mask and screen are assumed instantaneous in the simulation. The simulation considers the reflected wave from only the atoms of the mask and screen.

3.1 Screen

The screen is many areas of very low Ψ caused by the presence of nuclei on the screen. The distance between the nuclei is several orders of magnitude greater than the distance between the hods in the photon. Therefore, the wavelength of the plenum wave from the photon is much smaller than the diameter of the nuclei.

The screen was modeled as a surface that reflects waves. The analogy used is of surface reflecting electromagnetic waves (Jordan 1950, p.410). The Ψ effect at the photon is of a mirror image of the photon at twice the perpendicular distance between the photon and the screen. Otherwise the photons striking the screen was like in Hodge (2012a).

3.2 Mask

The mask is similar to a screen except for the slits. Therefore, the assumption of a continuous, infinite surface is not valid. The reflecting atoms were considered 0.02 steps apart on the mask for a distance of 20 atoms beyond the perpendicular intercept of the photon in each direction for calculation convenience. Beyond the 20 atoms, the reflections were considered too small and phase canceling on the resultant Ψ at the photon.

Table 1: The values of the constants.

Parameter	value	units
$K_{\rm c}$	1×10^{-2}	step interval^{-1}
K_{Ψ}	2.207×10^{3}	gr. hod^{-1}
$K_{\rm r}$	-2.288×10^{-8}	erg step
$K_{\rm v}$	1.202×10^{8}	
$K_{\rm d}$	2.401×10^{-3}	gr. step^{-2} erg^{-1} interval^{-1}
$K_{\theta{\rm s}}$	8.991×10^{6}	gr. interval^{-2} erg^{-1}
$K_{\theta{\rm d}}$	1.501×10^{1}	gr. step^{-2} erg^{-1} interval^{-1}
K_{λ}	8×10^{-5}	erg step hod
$\Psi_{\rm max}$	1×10^{3}	erg

Because of the sampling error and of calculation errors, the calculation of the best-fit Fraunhofer curve used an average of 23 data points

$$\bar{B}(x_{\rm s}) = \sum_{i=x_{\rm s}-0.22}^{i=x_{\rm s}+0.22} B(i)/23, \tag{5}$$

where i increments by 0.02 steps.

Table 1 lists the values of the constants used in the simulation.

A mask with a single slit with a width $W_{\rm s} = 0.44$ step was placed at $y = 100$ steps and a screen was placed at $y = 150$ steps ($L = 40$ steps). The photons were released in 0.0005 step increments along the $y = 90$ step axis centered on the $x = 0$ step axis.

Figure 1 shows the resulting screen pattern. The thicker, solid line in each figure is the result of a least squares fit to the Fraunhofer equation. The correlation coefficient is 0.97.

Figure 2 shows the path followed for a sample of the photons through the single slit.

Figure 3 shows the screen pattern with the mask from the previous experiment replaced by a double slit mask. The slits were placed from 0.22 step to 0.66 step and from -0.66 step to -0.22 step. The thicker, solid line in each figure is the result of a least squares fit to the Fraunhofer equation for two slits. The correlation coefficient is 0.99.

Figure 4 shows the path followed for a sample of the photons through the double slit mask.

4 Correspondence with the Fraunhofer model

Why does the Fraunhofer equation work when the source of the wave is the photons reflected by the mask and not a wave through the slit? The Fraunhofer derivation peculiar assumptions such as the "obliquity factor" and the wavelet 1/4 phase advance are not needed in the STOE model. The mask is similar to

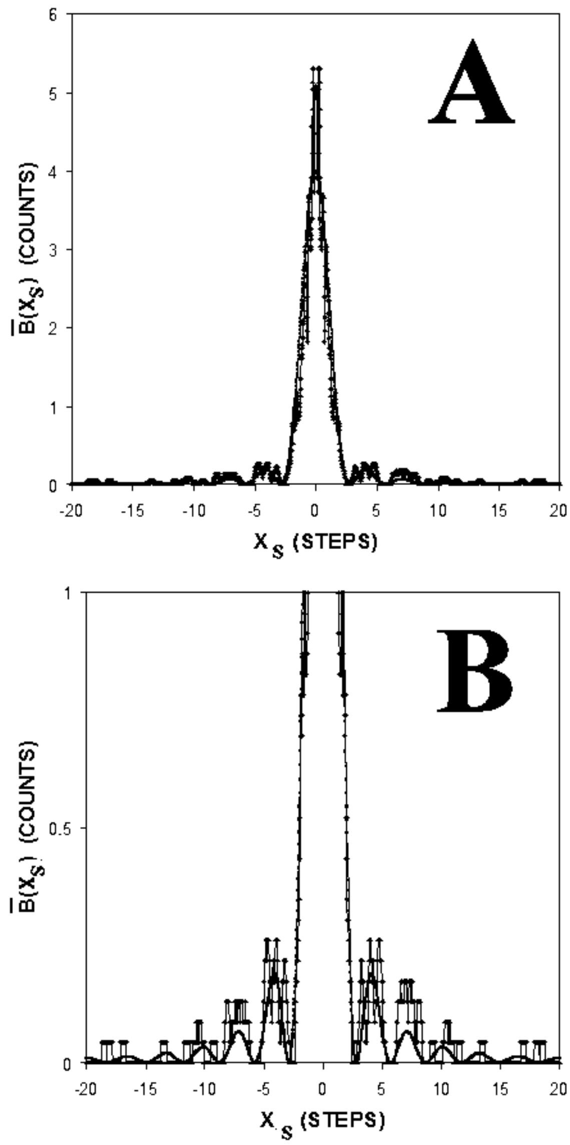

Figure 1: Plot of the single slit screen pattern.

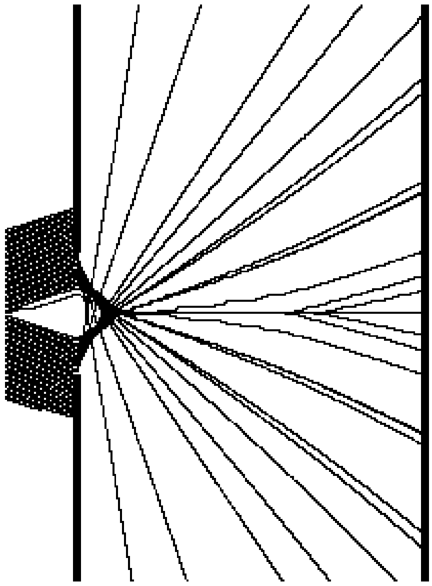

Figure 2: Plot of the trace of the paths of photons for a sample of the photons through the single slit mask.

the screen (see section 3.1) except the mask is necessarily thin and the mask has holes. Therefore, Eq. 4 with a term Ψ_{Th} subtracted that would have been the contribution of matter in the hole area(s) corresponds to the Fraunhofer model. That is, the phantom atoms that would be in the slit are the only sources of the waves and the wavelength of the waves is determined by the photon. Many closely spaced sources of coherent waves produce the same mathematics as the Fraunhofer mathematics. Mathematically subtract that portion of the wave that is lost through the slit in the present model from a screen contribution at the mask position to produce the mask with slit situation. The subtraction sign is neutralized because there is not a π reflection phase shift. The photon upon immediately passing the mask has no perpendicular component because that is where the slit is (see Fig. 2). This is equivalent to a wave through the slit with the required Fraunhofer assumptions with a small and ignorable component from a screen.

The present model solves the traditional, problematic assumptions with waves that reflect off real atoms.

5 Discussion

The low intensity points on the screen are zero in this simulation compared to just minimums but not zero in the Hodge (2012a) simulation. Also, this simulation has two fewer constants and assumes symmetry in the emitted wave

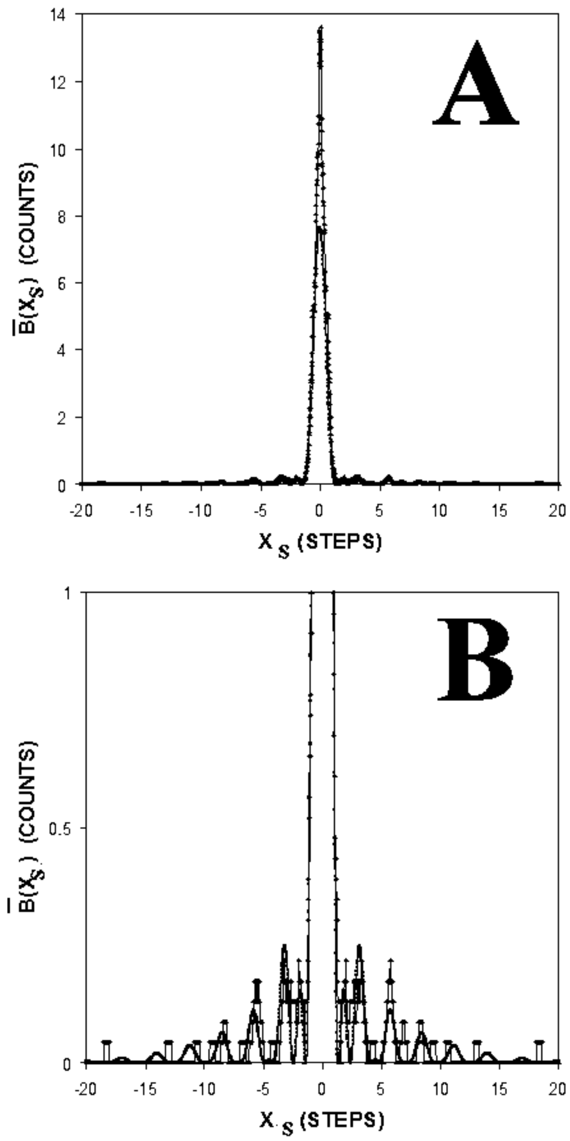

Figure 3: Plot of the double slit screen pattern.

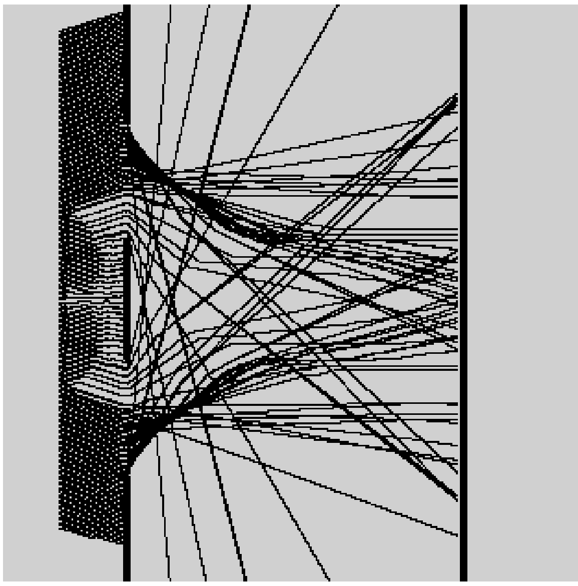

Figure 4: Plot of the trace of the paths of photons for a sample of the photons through the double slit mask.

from the photon. Therefore, this is a better description of the photon and wave actions.

Observed effects that are difficult to explain with the wave–through–the–slit models are seen in the figures. The edge luminous effect noted by Young is reproduced in this simulation (see Fig. 2). The figures also show the diffraction and interference patterns develop at a distance from the mask.

The walking drop interference, electromagnetic interference, and light interference are using the same type of interference mathematics that the Fractal Principle requires.

The constants may depend on the physical parameters of the experiment such as slit width. These relations are yet to be discovered.

6 Conclusion

Newton's speculations, Democritus's speculations, the BIQM, the TIQM, and the fractal philosophy were combined with the cosmological STOE. The resulting model of photon structure and dynamics was tested by a toy computer experiment.

Interference experiments with intensity light low enough that only one photon was in the experiment at a time have also showed interference patterns. The reverse wave required by the Transaction Interpretation is provided by a reflected plenum wave rather than a reverse time wave. The speed of the plenum wave is much faster than the speed of photons/light. The photon distribution on a screen results in same equation as the Fraunhofer diffraction intensity pattern. The mathematical model reduces to the Fraunhofer mathematical model.

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