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COMPARISON OF NEAR AND FAR FIELD DOUBLE-SLIT INTERFEROMETRY FOR DISPERSION OF THE PHOTON WAVEPACKET

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Abstract. Extending EM and Quantum Theory suggests the possibility of photon mass, additional terms for Maxwell's equations, reality of de Broglie-Bohm causality and the Vigier model of extended charged particles. Experimental tests indicative of these hypotheses can be performed with double-slit interferometry of single visible wavelengths comparing near and far field sources over laboratory and various cosmological distances to observe the possibility of spreading of the photon wavepacket during propagation. These observations could determine whether nonlinearities causing non-dispersivity are associated with Maxwell's equations. If so, this may be an indirect determination of non-zero restmass photon anisotropy, de Broglie photon piloting and vacuum permittivity reincarnating the Michelson-Morley experiment in terms of a Dirac covariant ether.

1. Introduction

Traditional thinking suggests that EM radiation coming from a point source is subject to spreading of the photon wave-packet over $x = -ict$. Recently however, families of nondispersive waves have been found for Maxwell, Klein-Gordon, Dirac, Weyl and Schrödinger field equations [1-7, 31-33]. Courant and Hilbert [8] were probably among the first to make this distinction.

In this paper we briefly review classical and extended theoretical predictions of photon propagation, present an experimental design for possible empirical tests and relevant discussion of the physical consequences for the de Broglie, Bohm and Vigier formalisms [9] of extended electromagnetic theory that suggest the photon wavepacket is piloted and does not spread over cosmological distances as suggested by current classically oriented interpretations of Maxwell's field equations. The experiment is accomplished by comparison of the double-slit fringes of monochromatic light from near and far field monochromatic emission sources.

Recent EM-Theory discussions on the possible existence of photon mass (m_γ) and U(1) group invariance of EM-Theory in view of the putative (m_γ) implies the introduction of new terms for Maxwell-Lorentz equations. This cannot be considered as purely theoretical as in the past because of recent new experimental evidence [10]. The aim of the present text is to discuss the two possible interpretations of Maxwell's equations:

1. Photon propagation without trajectory - random probability distributions [classical].
2. Photon propagation with trajectory - piloted with no or minute spreading of the wavepacket [extended].

The former is in accord with the standard model of classically oriented Copenhagen approaches to the EM and quantum formalism; and the latter the Vigier-Bohm-de Broglie extended charge particle causal approaches.

1.1 STAGES IN DEVELOPMENT OF THE THEORY OF LIGHT

As generally known the present status of the theory of light is the result of three stages of development.

a) The Maxwell – Heaviside – Hertz stage which developed (in the middle of the last century) the Maxwellian linear equations of light (and Hertzian waves) with transverse continuous waves (with zero-mass and U(1) invariance) of velocity *c* with the separate existence of instantaneous Coulomb interaction. Technically this led to the huge development of electrical/photographic devices in the modern world.

b) The Einstein stage (1905) with

1) The discovery of the photon « Lichtquanten » carrying an energy $E=h\nu$ [11].

2) The idea (1916) that photons carry the observed electromagnetic energy in the form of unidirectional *« Nadelstrahlung »*, of oriented beams and not in the form of spherical emission « *Kugelstrahlung* » which did not exist [12].

3) The observed quantized electromagnetic potential for inertial massive charges only emit energy when accelerated; except in the case of Bohr orbits, where it

was postulated if one introduced Poincaré forces to keep the sub-charges together and that the inertia of the gravitational and EM charged part in any particle was separately covariant [10].

c) The quantum stage (1920-2000) where the Copenhagen proponents dropped the step-by-step description of the propagation of light only discussing the statistical properties. Later photon emission and absorption was shown experimentally by Aspect [13] to correspond to (individual photon emission followed by absorption) linear recoils of the corresponding sources.

Two theories developed in parallel :

c_1) The Copenhagen interpretation. The QED version suggests probability waves or quantized photons ; never the two simultaneously.
c_2) The Einstein – de Broglie interpretation (dropped between 1925 and 1950) allowing simultaneous real waves and piloted photon particles where both carry energy momentum distributions mostly concentrated on the latter.

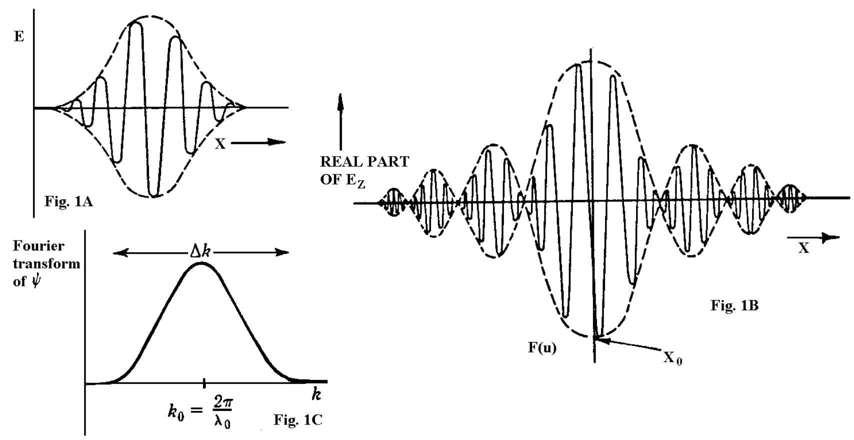
Both interpretations recover FAPP the same experimental facts.

d) The recent period in which new properties of EM waves have been discovered that are generating renewed discussion of differences between the c_1 & c_2 interpretations.
We only mention here

- the simultaneous existence of two different electron radii (the Compton and charge radii) in scattering experiments [14].
- observed anomalies in e^+e^- scattering [10].
- Recent observations in EM theory [15] and excess energy in $Li^7 + p + e$ scattering [16].

2. General Nature Of The Photon Wave-Packet

A wave-packet is a balanced superposition of waves of one predominant wave number *k* with phase amplitudes that interfere constructively over the small region *ct* or Δx outside of which the amplitude reduces to zero quickly by destructive interference. This is not true for ideal monochromatic wavepackets; Figure 1A shows a wave function or amplitude Ψ that depends on space coordinates *x,y,z* and time *t* simplified to Ψ *x,t* with average wavelength λ_0 over the limit Δx defined by a light pulse passing through a shutter, since an ordinary plane wave would be spread over all space [17,18].



$$E_z(x) = \int_{k_0-\Delta k}^{k_0+\Delta k} dk e^{ik(x-x_0} = 2\frac{\sin \Delta k(x-x_0)}{(x-x_0)} e^{ik_0(x-x_0)} \tag{1}$$

Figure 1A is plotted in Figure 1B according to equation 1 [17] as a function of $x - x_0$ reaching a maximum at $x = x_0$ to zero where $x - x_0 = \pi / \Delta k$; thus obtaining a wave function concentrated in a packet where $\lambda = 2\pi / k_0$. The Fourier transform of which, as shown in Figure 1C, is the wavepacket for a single photon. Equation 2 is a general type of wavepacket for any function thus defined [17, 18].

$$\psi = \int_{-\infty}^{\infty} f(k-k_0) e^{ik(x-x_0)} dk \tag{2}$$

2.1 REVIEW OF THE CLASSICAL DOUBLE-SLIT EXPERIMENTAL FORMALISM

A description of Young's 1801 classic fringe experiment for two slits [19] of width *a*, at a distance *A* apart as shown in Figure 2 is described by [20]:

$$f(x) = s(x) \times [\delta(x + A/2) + \delta(x - A/2)] \tag{3}$$

where *s(x)* is the transmission function for one slit of width *a*. For very narrow slits *a* goes to zero and the incident amplitude is proportional to 1/*a* so that *s*(*x*) becomes $\delta(x)$.

$$F(u) = 2a\frac{\sin(\pi a u)}{\pi a u}\cos(\pi A u) \tag{4}$$

The intensity of the diffraction pattern (Figure 2B) [20] is $\cos^2$ fringes of period 1/2*A* modulated by a $(\sin^2 x)/x^2$ function going to zero for $\mu = a^{-1}$. This is Young's well known fringe experiment [19,20].

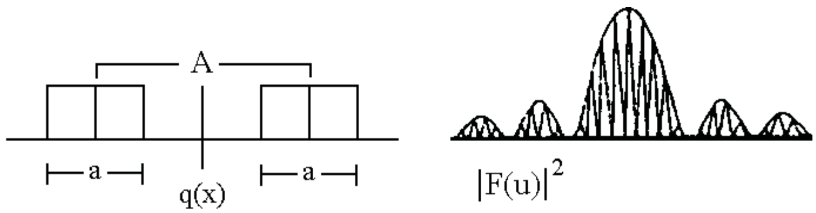


Figure 2. Diagram of a double-slit set up distance *A* apart and showing the observed intensity of the diffraction pattern from equation 4 [20].

For a coherent wavepacket passing through a double-slit interference creates phase difference $\Delta\phi$ such that a maximum occurs at $d \sin\theta = m\lambda$ where m = 0,1,2 ; and a minima at $d \sin\theta = m1/2\lambda$ where m = 1,2,3 represents $\Delta\phi$ of 180°. d is the distance between slits (A in fig. 2) and θ is the angle made by an arbitrary point *P* on the screen, the central point between the slits q(x) and the corresponding center of the screen. The distance between the two screens D must be much larger than d so that the distances r_1 & r_2 from the slits to P can be considered parallel [21].

2.2 CURRENT CLASSICAL INTERPRETATION OF DOUBLE-SLIT PHENOMENA

Historically Einstein first proposed in 1905 that radiant electromagnetic energy should appear as « *Lichtquanta* » About 10 years later he assumed that these quanta should also be spatially quantized with a unique orientation. The essential conclusion of his research was that Maxwell's « *Kugelstrahlung* » - spherical radiation around a source – does not exist but that elementary light energy $h\nu$ always appears in a unique direction creating a recoil upon emission $h\nu / c$ which he called « *Nadelstrahlung* » or 'needle radiation', giving deference to Einstein's original term [12]. This « *nadelstrahlung* » is also responsible for radiation pressure. According to classical interpretations of Maxwell's theory dispersion of the wave-packet over distance is expected [17,18]. This is partly due to the fact that in the Copenhagen view emission is point-like so any packet should expand. The uncertainty principle can be derived from propagation of the wavepacket which in classical terms propagates according to the Schrödinger equation. This is described by Bohm [17] as :

$$\Delta x = \Delta x_0 \sqrt{1 + \frac{\hbar^2 t^2}{m^2 (\Delta x_0)^4}} \rightarrow \frac{\hbar}{m \Delta x_0} t \qquad as \quad t \rightarrow \infty \tag{5}$$

where a wavepacket with an initial diameter of Δx_0 will spread to $\Delta x \cong \hbar t / \Delta x_0$ as t becomes limitless. The narrower the wavepacket originally the more rapid the spreading. (see Figure 3) According to Bohm [17] the reason for the spread is in terms of the uncertainty principle. The region Δx_0 confining the packet has a number of wavelengths near Δx_0 so that even though the average velocity of the wavepacket is equal to the group velocity, the actual velocity will fluctuate, and the distance propagated by the packet isn't fully determined. It can fluctuate by

$$\Delta x \cong t\Delta v \cong \frac{\hbar t}{m\Delta x_0} \tag{6}$$

According to Bohm [17] photons have momentum as evidenced in the radiation pressure during absorption , such that the energy and momentum of light quanta is the same as a zero mass particle in 3D space. It is the wave properties of a wavepacket that produces the $\Delta x \Delta k \geq 1$ that allows spreading because a particle will never spread ; but a collection of particles because of uncertainty in velocity gradually spread with Δt. (x)

Thus although equations (5) & (6) used for illustration of classical wavepacket spreading are Schrödinger type equations, Maxwellian equations give a similar result for photons in the classical limit – i.e. – spreading. In our extended theoretical approach that includes photon mass [10,22]; piloting effects prevent spreading as $\Delta t \to \infty$. There may be an infinitesimal spreading over cosmological distance. This is the current empirical knowledge limit; where further understanding can only be achieved by experimentation like the suggestion in section 3.

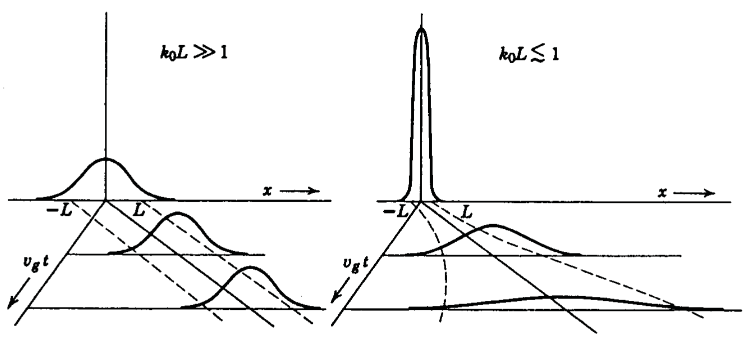


Figure 3. Dispersion and change of shape of a wavepacket during propagation. Broader packets with many wavelenghts near k $(k_0 L \geq 1)$ distort relatively little; a narrow k packet $(k_0 L \leq 1)$ rapidly broadens [23].

2.3 EXTENDED THEORETICAL APPROACH TO PHOTON PROPAGATION

De Broglie wave mechanics creates a relationship between wave numbers and momentum not considered in classical mechanics. In the de Broglie mode a classical wave of a wave number k can be of arbitrary amplitude and momentum; and whenever position or momentum is measured a definite number results. The de Broglie relation $p = \hbar k$ implies a definite wave number k for a definite momentum. This is contrary to a classical description of a wavepacket, which suggests a range of wave numbers and positions [17].

Concurrently defined position and momentum values is considered equivalent to the assumption of « hidden variables » that constantly determine these values. This is inconsistent with the standard Copenhagen interpretation of quantum theory which is statistical and not causal.

2.4 RECENT WORK ON NON-DISPERSIVE PROPAGATION MODES

Rather than the classically oriented Schrödinger equation which suggests spreading of the wavepacket (in a variation of Figure 3), non-dispersive wave modes would be expected to propagate according to the de Broglie relativistic Klein-Gordon type equation [1,24]. Recent work on non-dispersive modes of the wavepacket by numerous authors [1-8] has demonstrated mathematically the possibility for the existence of 'real' non-dispersive modes of the photon wavepacket satisfying linear Maxwell equations but considered contrary to the prevailing opinion. This has urged empirical testing of the issues at the heart of the matter and is our main inspiration for writing this paper. We give here only the very briefest review of this recent theoretical work and refer parties interested in deeper analysis to the main references [1-8].

According to established wave mechanics a de Broglie wave with infinite wavelength is said to be associated with all particles and have a wave function uniform throughout all space. A particle's internal vibration and infinite de Broglie wave stays in phase at the particle's location. This suggests how the de Broglie wave pilots a particle's motion with no spreading; whereas a Schrödinger wavepacket spreads because of uncertainty in momentum [1]. Because the de Broglie relation is relativistic a Lorentz transformation might be involved between the particle's point of origin and present position during propagation, canceling insertion of any would be classical uncertainty effects and maintaining phase coherence between the particle's internal motion and the wave function in the de Broglie relativistic-piloted regime. This might be considered reminiscent of error correction modes discussed in terms of quantum computing.

If $\omega(k_{1)} - \omega(k_0) = \mu(k_1 - k_0)$ then $d\omega(k_1)/dk_1 = \mu$ for all k_1 and therefore $d^2\omega(k_1)dk_1 = 0.$ With these conditions de Broglie theory yields [1]

$F(x) \propto \{\exp \quad i[\omega(k_0)t - k_0 x]\}[\sin \Delta k(x - ut)]/\Delta k(x - ut)$ or also in the form

$$F(x,t) = G(x,t)H(x,t) \tag{7}$$

Using a different technique, Hillion [2] uses electromagnetic theory to derive <u>nonhomogenious</u> nondispersive waves from Maxwell's equations. With the variables $\zeta = x + iy, \overline{\zeta} = x - iy, \xi = z - x^0, \eta = z + x^0, i = \sqrt{-1},$ the wave equation $\Delta\psi - \partial^z_{x_0}\psi = 0$ becomes $\partial_\zeta \partial_{\overline{\zeta}} \psi + \partial_\xi \partial_\eta \psi = 0.$ This was first shown by Courant and Hilbert [8] and has nondispersive solutions of the type $\psi = g(x, x_0)F(u), x = (x, y, z,)$ where the phase u is a solution of the characteristic equation $\partial_\zeta u \partial_{\bar{\zeta}} u + \partial_\xi u \partial_\eta u = 0$, where F is arbitrary with continuous partial derivatives and g is an attenuation factor [2].

Brittingham [7] derives on the other hand homogenous nondispersive solutions to Maxwell's equations in the soliton regime with both linear and nonlinear parameters. Beil [31-33] has applied the Brittingham solutions to modeling of the photon as a specific realization of *Nadelstralung*, which Einstein conjectured was the only kind of radiation that is consistent with relativistic dynamics. Finally Shaarawi [6] derives Brittingham like nondispersive solutions for the wavepacket applicable to Klein-Gordon equations which can be used as local de Broglie scalar wave particles.

3. Proposed Experimental Design

A. Stellar objects with emission spectra compatible with the telescopes instrumentation are chosen for observation. As a baseline fixed sources in our galaxy of about 100 light years distance are selected for each of 3 wavelengths (red, yellow/green, blue). Narrow pass filters of single wavelengths are used with 3 far-field stars of about 2 million light years from the local group in the Coma cluster and beyond for comparison with the control stars from our galaxy for each of the 3 wavelengths.

B. The comparisons with near and far-field stars are made for possible spreading during propagation of the photon wavepacket over cosmological distances in the fringe patterns of standard double-slit interferometry. It is suggested that 3 control stars be compared with 3 far-field stars for a 12 star database. To ensure uniformity of stellar types, we suggest bright Cepheid's or M-giants and O-supergiants in the local group of galaxies, and the Virgo and Coma clusters. Or sources of greater observational ease such as emission nebulae with Balmer and HII and H_α lines [25].

C. Because of the foregoing discussions on the nature of the photon wavepacket during propagation the experiment might optimally be performed with additional filters allowing passage of only single photons. However in case any physical parameters might be missing from current theoretical predictions it would be useful if practical to also perform the experiment with continuous wave trains of multi photon wavepackets for experimental diversity and exploration of group dynamics. As in figure 2 and accompanying discussion it is deemed important to perform the experiment with double-slit designs with 3 *A* dimensions or spacing; 1. Optimally maximum, 2. Median and 3; Optimal minimum. Account of work on measurements of photon radius [26] should probably also be taken into account for optimal *a* distance as also shown in figure 2A.

D. To simplify the experiment for preliminary results the model can be done initially with the near-field control group performed in an Teran laboratory setting. The far field sources could then be H_α emission lines in the solar chromosphere.

E. Anticipated results. The current model formalism suggests significant spreading of the wavepacket over cosmological distance because of uncertainties in momentum. However our view according to extended theoretical models of Vigier, de Broglie, and Bohm that there might be infinitesimal spreading of the wavepacket because of de Broglie-Bohm piloting. Until we have preliminary tests we are unsure of sufficient limits in discerning the degree of spreading within the current instrumentation limits of CCD cameras and computer analysis of the data. The mathematical predictions for spreading will be included in the proposals for telescope time. By the time of publication we anticipate having at least preliminary data.

F. Comparison of dispersion for dust-free and clear spacetime regions as test of gravity effects and redshift from TIFFT.

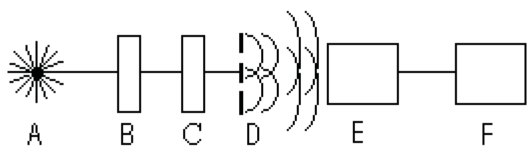


Figure 4. Experimental set up. A. source, B. monochromatic filter, C. intensity filter, D. double slits, E. CCD array, F. analyzer.

4. Conclusion And Summary

Superficially the nature of a wavepacket and its spreading during propagation seems straight forward; but the subtleties involved are at the heart of wave mechanics and quantum theory which is by no means complete and entails persistent discussion on the merits of Copenhagen vs. extended forms of quantum theory. A definitive delineation is not possible in terms of any type of current theoretical discussion alone. Therefore if technically feasible experiments on the nature of the wavepacket and its propagation like those proposed here might advance our understanding of Quantum Theory.

Classical approaches predict wavepacket spreading because of uncertainty relationships. The de Broglie-Bohm approaches predict coherence over all space and time in view of putative causal action of the pilot wave or quantum potential. This is the well known assumption of hidden variables deemed inconsistent with the classically oriented Copenhagen model.

A final understanding of the photon and its propagation is far from being understood [27]. To understand the anticipated experimental results photon propagation may not only have to be perceived in terms of internal de Broglie Lorentz transformations [1] but also deeper aspects of nonlocality [28] which might only be clarified in terms of a post big bang cosmology and the attendant understanding of spacetime hyperstructure [29] which non-zero photon restmass seems to demand.

A Newtonian ether was disallowed by Einstein's relativistic dynamics and the Michelson-Morley experiment. Einstein himself said that relativity did not preclude an ether. We revisit this issue in terms of a Dirac covariant subquantum stochastic ether with correspondence to relativity and inclusive of de Broglie Bohm Vigier charged particle models [30].

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