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Single-Electron Double-Slit Experiment and Semi-Closed Friedman Model of Binary Black Hole Emitting Gravitational Wave

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I. Introduction

Since the advent of quantum mechanics in the mid-1920s, there have been recurring interpretational controversies surrounding the standard (time-asymmetric) theory seeking a physical reality in (a Newtonian) causal descriptive order of world processes in an open-ended time. With the development of precise measurements in quantum optics and electronics, semi-and super-conductors and so on, the past decades have seen a growing awareness of time-symmetric approaches [1]-[10] to quantum mechanics, seeking physical reality in (Aristotelian) causation-retrocausation symmetry of elementary quantum processes in closed time intervals. We here extend the previous time-symmetric interpetation of the particle-wave dual nature of the electron [10] to a relativistic interpetation of the the singular nature of the electron as a quantum anomaly in double-slit interference experiment said to contain “the only mystery of quantum mechanics.”[9].

II. Intermediate Amplitude of Transition

In the third edition of his book Dirac [2] related the scalar product <initial|final> of initial and final state vectors to the probability amplitude, so that the transition between two quantum states can be visualized in two-dimensional space spanned by two Hilbert space vectors. We here consider a visualization [10] of the particle transition in configuration space between two space-time points, particle source S at (x_0, t_0) and detection point D at $(x_1, t_1 > t)$ by plotting the 2-dimensional image of the (x, t) dependence of the absolute value of the complex valued intermediate amplitude of transition $|<x_0, t_0 \mid x, t><\mathbf{x}, t \mid x_1, t_1>|$ between S and D. From the known retarded and advanced wave solutions of Schrödinger equation:

$$[i\partial/\partial ct + \partial^2/\partial^2 x - (mc/\hbar)^2] < x_1, t_1 \mid x, t > = 0 \qquad (1)$$

for a free electron of mass m:

$$<x_0, t_0 \mid x, t> = [m/2i\pi\hbar(t-t_0)]^{3/2} \exp[-im(x-x_0)^2/2\hbar(t-t_0)],$$

$$<x_1, t_1 \mid x, t> = [m/2i\pi\hbar(t_1-t)]^{3/2} \exp[im(x_1-x)^2/2\hbar(t_1-t)], \qquad (2)$$

we get

$$< x_0, t_0 \mid x, t >< \mathbf{x}, t \mid x_1, t_1> = [m/2\pi\hbar\tau]^3 \exp[-im(x-z(t))^2/2\hbar\tau]. \qquad (3)$$

Here

$$t(t) = (t_1 - t)(t - t_0)/(t_1 - t_0) \qquad (4)$$

is the bi-directional ‘local time’ of a counter-propagating electron waves increasing from t = 0 at S and D towards $t = (t_1 + t_0)/2$ at an intermediate point $x = (x_0 + x_1)/2$ where the wavelike nature of the electron is maximally enhanced and the doubl-slit is placed in an ideal experiment; $z(t) = v(t - t_0) + x_0$ is the classical path and $v(x, t) = (x - x_0)/(t - t_0)$ the particle velocity. Eq.(3) shows that the mean square deviation $(x - z)^2$ of x from z is of the order of the de Broglie wavelength ħ/mv. The bi-directional wave was considerd by Schrödinger [1] in his early attempt to evade the collapse of his wave function at D.

III. Visualizaion of Particle-Wave Duality

Fig.1 shows the video-record of a serial arrival of independent 1，8．1600，8000，electrons

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forming an interference pattern on the detector screen. [11]

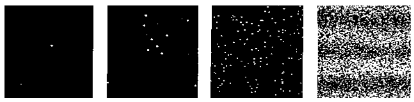


Fig.1 : Accumulation of single electrons on the detector sce

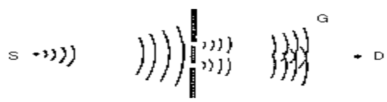
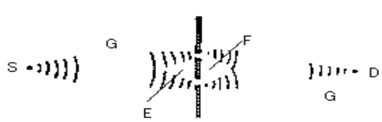


Fig.2 : Expanding wave front G of the retarded wave$< x_0, t_0 \mid x, t >$

Fig.2 shows an expanding wave front of retarded wave $< x_0, t_0 \mid x, t >$ from S, Fig. 3 is an image of the time-symmetric wave $< x_0, t_0 \mid x, t >< \mathbf{x}, t \mid x_1, t_1 >$ standing between S and D, showing an advanced bifurcation, merging and contraction of the retarded wave $< x_0, t_0 \mid x, t >$ towards D, as if guided by the advanced wave $< \mathbf{x}, t\ x_1, t_1 >$ from D, in accordance with Feynman's sum over classical paths construction of the quantum mechanical path between S and D.



Fihg.3 : Time-symmetric wave $< x_0, t_0 \mid x, t >< \mathbf{x}, t \mid x_1, t_1 >$ standing between S and D, showing the particle-wave dual nature of bifurcation and merging of the single electron

Points like E in the shadow of the advanced wave $< x, t \mid x_1, t_1 >$ from D in front of the slit are causally disconneted to D, while points like F in the shadow of the retarded wave $< x_0, t_0 \mid x, t >$ on the rear side of the slit is causally disconnected from S. Points like G are causally and retrocausally unrelated to both S and D, so that the electron wave does not expand beyond these points, as is proved by placing a tiny obstacle at G. By confining a magnetic flux within a slender tube standing perpendicular to the plane of the paper in E and F, the quantized shift of the interference pattern (Aharonov-Bohm effect) was observed by Tonomura and Nori.[12]

Fig.3 also shows the nonlocal EPR (Einstein-Podolsky-Rosen) correlation between bifurcated electron waves as verified by the delayed-choice experiment with one of the two slits equipped with a time-dependent switch which is generally closed but opens after the electron has left the source.

IV. Quantum Teleportation

We note that the wave $< x_0, t_0 \mid x, t >< \mathbf{x}, t \mid x_1, t_1 >$ takes a dumbbell shape in the single-slit experiment. The observed quantum entanglement of spatially separated two states of an electron introduced into a dumbbell shaped silicon cavity [13] could be understood in terms of the electron wave standing between fixed end points. A quantum teleportation of entangled pair of photons could likewise be understood as a W-shaped swapping of the V-shaped EPR pairs in the presence of a spacelike array of deep Coulomb potentials.[14]

V. Ultraviolet Anomaly in Double-Slit Experiment

To see the singular behavior of the electron as a quantum anomaly [15] in leaving the source $S(x_0, t_0)$ and entering the detector $D(x_1, t_1)$ in the double-slit experiment, we extend the Schrödinger equation in relatvistic Klein-Gordon form:

$$[\partial^2/\partial^2 ct - \partial^2/\partial^2 x - (mc/\hbar)^2] < x_0, t_0 \mid x, t > = 0 \qquad (4)$$

and consider the retarded wave solution:

$$< x_0, t_0 \mid x, t > = -(1/4\pi)\delta(s^2)$$

$$+ \ [mc/8\pi\hbar s)]^{3/2} H^{(2)}(mcs/2\hbar). \qquad (5)$$

where $s = [c^2(t-t_0)^2 - (x-x_0)^2]^{1/2}$ is the 4-dimensional distance between S and its neighboring point P(x, t); $H^{(2)}$ is the Hankel function of the second kind.

For $s^2 = 0$ (on the future light cone of S) we have a delta-singularity:

$$< x_0, t_0 \mid x, t > = (1/4\pi)\delta(s^2). \qquad (6)$$

For $s^2 >> 0$ (inside the future light cone of S) we get Schrödinger's wave function in its asymptotic form:

$$< x_0, t_0 \mid x, t > \sim (\lambda/s)^{3/2} \exp(-is/\lambda)$$

$$\rightarrow [\lambda/c(t-t_0)]^{3/2} \exp[-i(t-t_0)/\lambda], \qquad (7)$$

where $\lambda = \hbar/mc$ is the Compton electron wave length. For $s^2 << 0$ (outside the future light cone of S) we have $s = -i|s|$ and find

$$< x_0, t_0 \mid x, t >$$

$$\sim [\lambda/(x-x_0)]^{3/2} \exp(-(x-x_0)/\lambda). \qquad (8)$$

For $s^2 << 0$ (outside the past light cone of D) we have likewise

$$< x, t \mid x_1 - x >$$

$$\sim [\lambda/(x_1-x)]^{3/2} \exp(-(x_1-x)/\lambda) \qquad (9)$$

between D and its neighboring point Q(x, t).

Eqs.(8), (9) show the nonlocal and superluminal connections between S, D and P, Q separated by Compton scale spacelike distances, developing anomal ultraviolet regions [16] outside the future and the past light cones of S, D accumulating delta-singularities on the light cones in early and late stages of the expanding and contracting electron wave, recalling the accumulation of Planck scale black holes outside the event horizons in the inflationary epochs of expanding and contracting semiclosed Friedman model universe.[17],[18]

VI. Gravitational Lensing

Tonomura observed an intereference pattern (Fig.1) in his double-slit experiment using the electron-biprism for lensing action of the double-slit. Recent astronomical observations [19] showed characteristic interference images formed by the lensing action [20] of galaxy cluster or black hole in the foreground of an extragalactic light source using a Hubble telescope. There a double quasistellar objects is interpreted as the images of one and the same quasar, produced by the lensing action of intervening galaxy and a cluster of galaxies. Wheeler [21] proposed to extend a delyed-choice double-slit γ-ray experiment from the laboratory scale of meters to the cosmological scale of billions of light years.

VII. Gravitational Wave from Binary Black Hole

On February 11, 2016 [22] LIGO announced the detection of a trangent gravitational wave signal from a binary black holes at 1.3 billions light years from Earth. The black holes have 29 and 36 solar masses spiralling towards each other until they lose orbital energy, collide and merge into a single spinning black hole having 3 solar masses less than initial 65 solar masses. The 3 solar masses equivalent of energy is emitted as a trangent gravitational wave observed by twin LIGO detectors on September 14, 2015, sweeping upwards in frequency and strength in characteristic faint rising tone, streching the L-shaped arms of the laser interferometer from 4 km to one part in 10^{22}.

VIII. Semiclosed Friedman Model of Binary Black Hole

Friedman universe filled with uniform distribution of dust-like matter having constant density ρ_m is characterized by the density parameter $\Omega_m = \rho_m/\rho_c$, where ρ_c is the critical density for the universe to be closed, so that $\Omega_m = 0$ for empty space and $\Omega_m = 1$ for black hole.

In his seminal paper in 1918 [23] Einstein showed that the dumbbell-lik system rotating about two axes, such as binary stars and supernovas can make wave in space. LIGO image of computer simulations seem to indicate that the binary black hole has evolved from a pair of semiclosed Friedman black holes with $0.5 > \Omega_m > 0$ to a dumbbell shaped pair of black holes spiralling towards each other before merging into an almost closed spinning black hole. Recently updated density parameters [24] are: $\Omega_{atom} = 0.049$ for evolutionarily recent atomic matter, $\Omega_m = 0.266$ for nonrelativistic matter (luminous and dark) and $\Omega_\Lambda = 0.685$ for evolutionarily earlier dark energy of inflationary origin,[24] so that

$$\Omega_{tot} = \Omega_{atom} + \Omega_m + \Omega_\Lambda = 0.965. \qquad (10)$$

We note that the observed density parameter $\Omega_m = 0.266$ falls into the range $0.5 > \Omega_m > 1$ in the semiclosed Friedman model.

IX. Historical Comments

At the Tokyo Symposium [21] Wheeler allegorized the single electron in the double-slit experiment as a “smoky dragon” with its mouth biting the detector, leaving its tail at the particle source. The body of the dragon is smoky with double-connected and delayed-choice space time structure, so that nothing can be asked for before measurement.

A similar notion found in Nagarjuna (150-250) in his Middle Way doctrine [25] was translated from Tibetan text into English, restated in today's (quantum physicist's) words as: If, a cause (initial state) having ceased, the effect (final state) were a complete (unitary) transformation of the cause. Then the previously arisen cause would arise again: Reality (of intermediate state) is neither non-existent (virtual) in spacetime, nor permanent (trangent), while Fermat-Huygens exrtremum principle for a photon passing through double- and multi-layered media was known to Helon (100-200) [26]

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Erratum

In ref.[18] the loop integral, $\oint$, is missing in eq.2 defining magnetic monopoles.

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