The Nature of the Wave Function

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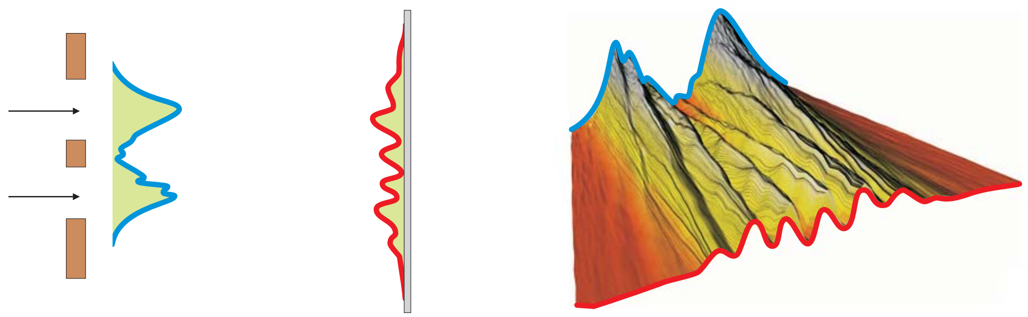
Abstract

Which of our basic physical assumptions are wrong? *Superposition of quantum states* and *collapse of the wave function* are significant assumptions. We address the *physics of the wave function*, the *wave function as probability*, the *extent of the wave function*, quantum correlations, Bell's *theorem*, spaces in which wave functions are formulated, and discuss recent experiments that support our interpretation.

Almost a century of confusion is captured in the following from 1926 and 2012:

> [1926] Heisenberg:[1] "*the state of a system is given by its wave function, ... the question [is] whether the latter should be seen as a 'spread-out' entity, a 'guiding field', a 'statistical state', or something else.*"
>
> [2012] *Physical Review Letters:*[2] *"The wave function* Ψ *is at the heart of quantum mechanics, yet its nature has been debated since its inception."*

One of the hottest topics[3] in 2012 is: *"Does the wave function correspond directly to some kind of physical wave?"* The question had been unanswerable, but two experiments[4,5] in 2011 based on Aharonov *weak measurement* techniques[6] answered *Yes!* (see Appendix [A]) The data, shown below, argue for de Broglie-Bohm type trajectories, incompatible with Copenhagen 'collapse' interpretations Experiments indicate that the wave is real.



This result argues against Schrödinger's fictitious wave packet—a Fourier superposition of abstract plane wave solutions to his equation. Schrödinger derived his equation based on de Broglie's *particle-plus-wave*, then he simply deleted the particle in favor of 'pure waves'. His wave packets always disperse, yet experiments[8,9] show that a non-dispersing Rydberg electron in a Bohr orbit can be maintained *indefinitely* via a circulating polarized μ-wave beam, unlike always-dispersing *wave packets*. The electron *persists*, it does *not* disperse. In fact, with respect to *wave packets in atoms,* in 1927 Lorentz noted[1] the mathematical difficulties of constructing packets in the atom:

> *"…we do not have at our disposal wavelengths sufficiently small or sufficiently close together…The frequencies of stable waves in the atom (eigenvalues) are more or less separate from each other [but] to construct a packet, one must superpose waves of slightly different wavelengths: now one can use only eigen-functions ψ_n, which are sharply different from one another. In atoms then, one cannot have wave packets."*

The problem (ignored for almost a century) isn't *dispersing wave packets* in the atom, but the impossibility of such wave packets even existing in the atom.

The Nature of the Wave Function

The particle-plus-wave is real, but de Broglie failed to specify just what the wave *is*. We do so here, beginning with an equation from *general relativity*[10]

$$\vec{\nabla}\times\vec{C} = -\frac{16\pi\kappa g}{c^2}\rho\vec{v} \tag{1}$$

The reduced equation $\vec{\nabla}\times\vec{C} = -\vec{p}$ suppresses constants (see [B]) and density dependence for simplicity. NASA's *Gravity Probe B* measured the C-field of the Earth and in 2011 reported agreement with general relativity [11]. But this was the *decoherent* C-field of a thermal body (the Earth)—and in 2006 Tajmar found[12] a C-field quantum *coherency* factor $\kappa = 10^{31}$. Thus electrons, arguably the highest matter density ρ in the Universe, maximize local C-fields induced by mass current density $\rho\vec{v}$ or momentum $\vec{p}$ as shown:

$$\vec{\nabla}\times\vec{C} = -\vec{p} \qquad \vec{\nabla}\times\vec{C} = -\vec{p} \sim \vec{E}\times\vec{B} \tag{2}$$

In the reduced equation, momentum $\vec{p}$ induces a left handed *gravito-magnetic* circulation much as *electro-magnetic charge-current-density*-based circulation is induced in the B-field equation $\vec{\nabla}\times\vec{B} = \vec{j}$. This C-field circulation provides the *wave* of de Broglie's *particle-plus-wave* basis of quantum mechanics. One might view the circulating C-field as analogous to a *3D bow wave* with the electron as boat analog. Every moving particle is accompanied by its induced C-field wave. 'Mass current' is 'particle momentum', so photons, with non-zero momentum, also induce C-field circulation $\vec{\nabla}\times\vec{C} \propto -\vec{E}\times\vec{B}$ as shown in (2). The *mass-based* Lorentz force equation[13], $\vec{F} = m(\vec{G} + \vec{v}\times\vec{C})$ implies that *gravito-magnetic* C-field circulation has units of frequency $1/t$, just as *gravito-electric* G-field has units of acceleration l/t^2. The C-field circulation is thus described by exponential $\exp[iCt]$, which, via Einstein's energy equation $E = \hbar C$ we can rewrite as $\exp[iEt/\hbar]$, showing C-field-based wave functions to be plane wave solutions to Schrödinger's equation.

The Quantum Theory of the C-field

How else does the C-field connect with quantum mechanics? Sakurai [14] describes a neutron interference experiment and concludes that "*gravity is not purely geometric at the quantum level because the effect depends on* $(m/\hbar)^2$*.*" In his development of quantum mechanics, a state ket $|\alpha\rangle$ evolves with time according to a unitary time evolution operator $U(t,t_0)$ via equation $|\alpha(t)\rangle = U(t,t_0)|\alpha(t_0)\rangle$. For an infinitesimal time change dt Sakurai asserts that a satisfactory time-evolution operator is

$$U(t_0+dt,t_0) = 1 - i\Omega\, dt \qquad (3)$$

where Ω is an operator having dimensions of frequency, then he asks:

> "*Is there a familiar observable with dimensions of frequency?*"

The C-field has dimensions of frequency, so we replace Ω by C and, following Sakurai, it is easy to derive the differential equation $i\,\partial U(t,t_0)/\partial t = CU(t,t_0)$ then to multiply both sides by Planck's constant $\hbar$ to obtain Schrödinger's equation for the time evolution operator

$$i\hbar\frac{\partial}{\partial t}U(t,t_0) = \hbar C\, U(t,t_0)\,. \qquad (4)$$

Note that $E = \hbar C$. Of this fundamental equation Sakurai states:

> *"Everything that has to do with time development follows from [it]."*

Since (4) is an operator equation, we multiply by a state ket and obtain

$$i\hbar\frac{\partial}{\partial t}|\alpha(t)\rangle = \hbar C\,|\alpha(t)\rangle \qquad (5)$$

where the C-field may depend upon time. So an equation of general relativity yields a *coherent* circulating wave—induced in *density dependent* manner by the densest material in the universe, the electron—leading to Schrödinger's wave equation.

The Wave Function as Probability

With experimental evidence of *particle plus real wave*, and a path to Schrödinger's equation of quantum mechanics, we now ask how *real physical waves* provide abstract *probability amplitudes*? The partition function is well known from statistical theory:

$$Z = e^{-E/kT} \qquad (6)$$

The partition function,[15] and *Fermi-Dirac, Bose-Einstein*, and *Maxwell-Boltzmann* versions, tells us that the probability of finding a microstate of a given energy is inversely related to the energy—the greater the energy, the smaller the probability of occurrence and vice versa. A free particle with momentum $p = h/\lambda$ has energy:

$$E = \frac{p^2}{2m} \quad \Rightarrow \quad \frac{-h^2}{2m}\left(\frac{1}{\lambda^2}\right) \tag{7}$$

Thus the basic relation between energy and wavelength combined with the partition function yields probability $P(E) \sim f(1/E) \sim f(\lambda^2)$. The quantum mechanical expectation value of any observable is $\langle O \rangle = \int \Psi^* O \Psi \, d\tau \Big/ \int \Psi^* \Psi \, d\tau$ hence the expectation energy is

$$\langle E \rangle = \frac{\int \Psi^* E \Psi \, d\tau}{\int \Psi^* \Psi \, d\tau} \quad \sim \quad \int \Psi^* \left(\frac{p^2}{2m}\right) \Psi \, d\tau \quad \sim \quad f\left(\frac{1}{\lambda^2}\right) \tag{8}$$

Thus particle energy is *always* a function of wavelength. Non-normalizable free particles have any energy, but most quantum systems of interest are *bound* states, with discrete energy eigenvalues E_n that correspond to discrete wavelengths with $P(E_n) \sim P({\lambda_n}^2)$. Physical wave functions [7] $\Psi(\vec{r},t) = C_0 \exp[i(\vec{p}\cdot\vec{r} - \hbar Ct)/\hbar]$ are functions of wavelength.

A physical wave is non-normalizeable—one must sum the square of all possible waves and normalize by the root of the sum to obtain a *probability amplitude* or specific measure of probability in an energy basis. But this wave function is based on a *real local particle* and a *real physical field*, not a superposition of fictitious waves that *collapse* upon measurement. Quantum systems are always found in real ("pure") states, with probability implicit in the physical wave by virtue of the partition function and of de Broglie's relation, $p = h/\lambda$.

So quantum mechanics is based on *real local particle-plus-induced-wave*, not on *mystical non-local superposition of non-real wavefunctions* of the kind Bohr, Feynman and others insist “no one can understand.” Recall that John Bell was inspired by de Broglie’s theory and noted that the wave is just as real as Maxwell’s fields, stating

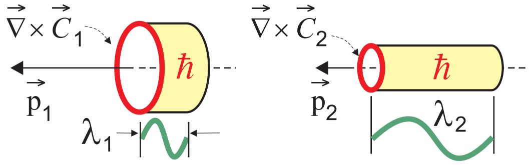
> *“No one can understand this theory until he is willing to think of* Ψ *as a real objective field rather than just a ‘probability amplitude’.”* [16]

Bell also noted “*…two particles interact at short range and strong spin correlations are induced which persist when the particles move far apart.”* This is *entanglement*, a very fragile resource,[17] but just how far can one particle interfere with another or with itself?

Diagram (2) for $\vec{\nabla} \times \vec{C} = -\vec{p}$ simply shows a circle around momentum $\vec{p}$ but from orbital dynamics, we know that the wave *must* extend over several wavelengths in order to support self-interference. De Broglie's $\lambda = h/p$ defines a wavelength and thus a minimum extent of the wave function, but maximum extent could range from one wavelength to infinity, since Schrödinger’s wave packet is conceptually built of monochromatic plane waves of infinite extent. We can safely ignore wave functions of infinite extent, but all treatments of atomic orbits are based upon the assumption of an integral number of wavelengths—the link that connects wavefunction to both energy and probability. How many wavelengths? No maximum number is found in Schrödinger’s equation.

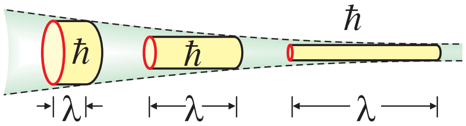
The Extent of the Wave Function

Electron orbits can extend over a trajectory hundreds of wavelengths long. Underlying the quantum mechanical idea of discrete energies is interference of an extended wave with itself, so the wave itself must extend at least over the length of an orbit. For an intuitive feel for such extended waves consider a *trailing vortex* based on an imperfect but relevant analogy: A real experience—flying into New York—suddenly *"Bam! Bam!"* sounded and felt like a car crossing a railroad track at high speed—we had flown through the *trailing vortices* of another aircraft. FAA-required separation between aircraft implies the vortex extended at least a mile behind that aircraft (see [C]). Considering the aircraft as a 'point', its trailing wave was hundreds to thousands of times larger in extent than the point generating the wave. An aircraft vortex may not represent a coherent quantum effect; nevertheless this example of a real vortex is informative.

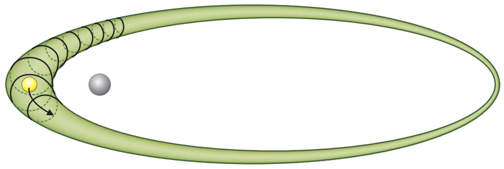


Vortices are notoriously difficult to model so we simplify by introducing the reduced wave equation $\vec\nabla \times \vec C = -\vec p$ and using de Broglie's $p = h/\lambda$ to obtain $\vec\lambda \cdot \vec\nabla \times \vec C \sim h$ where the ~ reminds us that scale factors are omitted. This view [18] of $\vec\lambda \cdot \vec\nabla \times \vec C \sim h$ is of a *volume* shown as a cylinder with cross section depicting C-field circulation $\vec\nabla \times \vec C$ and with wave-length λ and volume proportional to Planck's constant of action h. This *wave function conservation* relation gives a simple physical picture that fits perfectly with the equation $\oint p\, dq = nh$ describing orbital angular momentum as an integral number of Planck actions:

$$\sum_j \vec\lambda_j \cdot \vec\nabla \times \vec C_j = nh \qquad \Leftrightarrow \tag{9}$$



Schrödinger, acknowledging that de Broglie's approach led him to his own theory of the wave function in configuration space[1], said, *"I have tried in vain to make for myself a picture of the phase wave of the electron in the Kepler orbit."*



We, however, view an elliptical orbit as a thin cylinder near apogee, that smoothly thickens near perigee as the momentum increases, wavelength decreases, and C-field circulation grows. Intuitively we input $n-1$ units of 'action' to drive a ground state $(n=1)$ to high orbital states $(n>1)$. The *extent* of the wave function then is dependent on the number of units of angular momentum imparted to the system.

Thus quantum theory derived from general relativity, consistent with recent experiments, possessing intuitive connections between physical wave and probability amplitude, is *real* and *local.* But many physicists believe John Bell proved this to be impossible.

The C-field Wave Function and Quantum Correlations

John Bell claimed: "*…quantum mechanically* $E(a,b)$ *is given by the expectation value …* $\langle \vec{\sigma}_1 \cdot \hat{a}, \vec{\sigma}_2 \cdot \hat{b} \rangle = -\hat{a} \cdot \hat{b}$ *. [This] quantum mechanical result cannot be reproduced by a hidden-variable theory which is local.*" Here $\vec{\sigma}$'s are Pauli spin matrices and a and b are filter angles chosen respectively by generic experimenters 'Alice' and 'Bob', and *expectation value* refers to correlated measurements over a *series* of runs. Bell can be mathematically correct but physically wrong [19] and Christian has constructed a *framework* to challenge Bell based on the most powerful tool available today, geometric algebra [20], in which every element is defined algebraically *and* geometrically in coordinate-free manner (see [D]).

Based upon geometric product $ab = a \cdot b + a \wedge b$ Christian's framework[21, 22] uses a trivector defined by $\mu = e_x \wedge e_y \wedge e_z$ as the *volume form* representing physical space. The bivector $\mu \cdot n$ is the bivector projection on the vector n, satisfying the identity

$$(\mu \cdot a)(\mu \cdot b) = -a \cdot b - a \wedge b \tag{10}$$

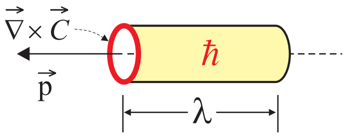
We desire to use Christian's framework as even his detractors have informally expressed qualified approval of it (see [E]). But Christian's *hidden variable* μ allows left- or right-handed orientation while the C-field has left-handed circulation. So this aspect of his framework is not open to us even if we can link a C-field-based hidden parameter to a trivector. Additional points about Christian's framework are noted in Appendix [F].

Pusey, Barrett and Rudolph ask, "*Does the wave function correspond directly to some kind of physical wave?*" They logically prove [3] that "*states interpreted as mere information about an objective physical state cannot reproduce [the] predictions of quantum theory.*" Generalizing their 'no-go' theorem M.J.W. Hall states [23]:

> *"It is possible for the wave function* Ψ *to be one of the properties (or possibly the only property) described by* λ *[the hidden variable]."*

Thus the wave function itself will be our hidden variable. Yet we must express this as a trivector to employ Christian's framework. To do so we represent the wave function, the hidden variable in our local realistic quantum mechanics model, by the volume form

$$\mu \sim \vec{\lambda} \cdot \vec{\nabla} \times \vec{C} \sim \hbar . \tag{11}$$



where $\mu = e_{x \approx Cx} \wedge e_{y \approx Cy} \wedge e_{z \approx \lambda}$. Substituting this in (10) we obtain the expectation value based on the *average* correlation over many experimental runs, which we write as

$$E(a,b) = -\left(\frac{1}{N}\right)\sum_{i=1}^{N}(a_i \cdot b_i) - \left(\frac{1}{N}\right)\sum_{i=1}^{N}(a_i \wedge b_i) \tag{12}$$

Here we call upon John Bell himself to rid us of unwanted terms involving bivectors $a_i \wedge b_i$. Bell specifies that Alice and Bob must freely and independently choose respective settings a_i and b_i for each i^{th} run, so half the time Alice chooses a smaller angle and half the time a greater angle than Bob and the relevant bivectors ($a_i \wedge b_i$ and $b_i \wedge a_i$) are anti-symmetric: $a_i \wedge b_i = -b_i \wedge a_i$. So in the limit of large N, $(1/N)\sum_{i=1}^{N}(a_i \wedge b_i) \Rightarrow 0$ yielding $E(a,b) = -a \cdot b$, which Bell claims to be *impossible*, since our particle-induced C-field-based wave function is both *local* and *real*. Thus Bell is wrong— quantum mechanics *is* local.

Yet some physicists believe that quantum mechanics is *inherently* non-local. To examine this we must understand the spaces in which quantum mechanics is formulated…

Quantum mechanics spaces: *3-space*, *Hilbert* , and *configuration space*

Physical space, in which the particle momentum induces a C-field *wave,* $(\vec{\nabla} \times \vec{C} \sim -\vec{p})$, has 3 dimensions of space (plus time). It is the space we know and love.

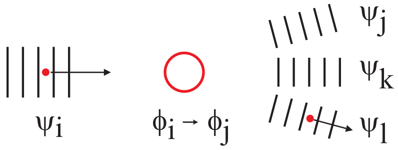
Hilbert space is an *n-dimensional vector space* spanned by wave (eigen) functions $\{\Psi_j\}$

$$\frac{-\hbar^2}{2m}\nabla^2\Psi_j + V(x)\Psi_j = E_j\Psi_j \qquad (13)$$

with integral wavelengths associated with the quantum state or wave function. The 3-space wavelength $\{\lambda_j\}$ correlation with *energy basis* $\{E_j\}$ is the basis of the link between a *physical wave in 3-space* and a *normalized probability amplitude in Hilbert space*.

But one more space regularly appears in quantum mechanics—*configuration space*.

Einstein and others[1] considered a plane wave impinging on an atom, initially in the state Φ_i. They decided that the wave was scattered in various directions:



Applying the probability interpretation to wave function Ψ_i of the incoming wave and Ψ_j, Ψ_k, Ψ_l etc. for the outgoing waves, they assumed that the particle was in *one and only one* of the outgoing waves! In other words, they conceived that waves could exist and propagate without the particle (as if multiple bow waves could propagate without a boat). This had <u>major</u> consequences—it implied the *collapse* of the other waves when the particle was found, and it also implied that the probability of the atomic state Φ_j and probability amplitudes Ψ_j, Ψ_k, Ψ_l , were independent, and therefore Einstein concluded that [1],

> "*momentum and energy were conserved only statistically.*"

Schrödinger next considered a many-particle system with N particles and wrote *one* wave function $\Psi(x_1, x_2, ...x_N)$ where, paradoxically, x_k refers to the *position* of the k^{th} particle that he had replaced with a dispersing wave packet! This wave function was *forced* to satisfy a multi-particle version of his basic wave equation—just an operator equation for conservation of energy. This wave function for N particles in *3-space* is formulated as a 3N-dimensional vector in *configuration* space and is then *forced* to conserve total energy.

The Origin of Non-locality in Quantum Mechanics

If, as Einstein thought, *local* collisions did not conserve energy, then Schrödinger's wave function was forced to *non-locally* conserve energy over the entire configuration space. Thus did *local real particle-plus-wave function* evolve to *fictitious non-local wave function* by virtue of the confusion of those who mistakenly thought (based on Schrödinger's particle-less *wave packets*) that *waves could propagate without particles*.

Probability waves sans particle, interpreted as real in *3*-space, implied conservation would only hold *on average*, while 3N-configuration space wave functions enforce conservation over the entire system (by construction) at the cost of non-locality. This cost, imposed by erroneous belief in *waves without particles*, leads to consequent erroneous ideas that the "other" (particle-less) waves *collapse* when the particle is found associated with one wave packet, i.e., in one state. But if local wave functions *do* conserve energy and momentum, as opposed to Einstein's conclusion about fictitious waves—propagating without an inducing 'boat'—then this 'non-locality' is fictitious, and the non-locality disappears from quantum mechanics. Basically, 3-space physical waves are *real*, 3N-space probability waves *abstract*. The 3N *formulation* is exact, but *solutions* are approximate, obtained by averaging via Hartree-Fock [24] and Fermi-Dirac methods. The 3N *formulation* has confused physicists.

The Source of the Error

Why did these great physicists believe matter waves could exist without particles? They were confused about *physical waves* and *probability waves*, understanding neither the physical field induced by a particle (the C-field circulation) nor why it correlated with probability (based on wavelength). And Schrödinger's 'pure wave' approach deleted the particles in favor of Fourier-based fictitious wave packets.

Why *does* quantum mechanics predict various outgoing wave packets (probabilistic waves) from a scattering process, if only *one* such wave actually exists—a real wave induced by the actual particle? Because any alternate path consistent with *3*-space physics is a possibility, and thus represented by a solution of Schrödinger's energy equation despite the fact that a physical particle induces a real wave on only one path. This path—one of many possible paths (~ Schrödinger equation solutions)—has confused physicists for decades and has led to ideas of *superposition of wave functions* and subsequent *collapse of wave packets*.

Conclusion

The C-field circulation induced by momentum (or mass current) provides a solution to the general relativistic field equation and also solves the quantum mechanical wave equation:

General Relativity **Quantum Mechanics**

$$\vec{\nabla} \times \vec{C} = -\vec{p}/\mu \qquad \Leftrightarrow \qquad i\hbar \frac{\partial}{\partial t} \Psi = \hbar C \Psi \tag{14}$$

Using Christian's geometric-algebra-based framework, our theory produces the quantum correlation $E(a,b) = -a \cdot b$ that Bell's over-simplified approach claimed to be impossible. But to do so we employ a novel *wave function conservation* relation that is not found in 'standard' quantum mechanics, but derives from the de Broglie relation, $p = h/\lambda$ combined with the C-field relation from general relativity. This quantized volume form allows extension of the wave function in increments $\sim \hbar$ and supports self-interaction, yielding discrete energies for bound states. These physical wave functions—formulated in an energy basis—span a Hilbert space and can be normalized and interpreted as probability based on the partition function and correlated with wavelength.

Each possible solution has a probability yet only one physical solution occurs.

All physical solutions have waves induced by particles. Confusion about this led to ideas of 'collapse' and of 'non-locality' required (erroneously) to conserve momentum and energy. As further evidence of physical realism we note that differentiating $\vec{\nabla} \times \vec{C} \sim -\vec{p}$ with respect to time yields a Lenz-like-force-law supporting conservation of momentum. Contrast this with Einstein's idea that "momentum and energy are conserved only statistically" and also with Feynman's statement [26] that "the law of inertia has no known origin".

As shown by a number of different experiments, the wave function is physically real [25], and the real *coherent* C-field wave—induced locally by maximally dense particles according to general relativity—leads to a probability amplitude based on 3-space. Confused concepts, *superposition and collapse*, based on Schrödinger's idea of *particle-less wave packets* falsely implied non-locality. Lorentz noted the impossibility of wave packets in atoms but this 'inconvenient truth' was ignored. Bell claimed the impossibility of local reality but in Christian's framework we predict *exactly* the $-a \cdot b$ correlations of quantum mechanics.

Assumptions of *superposition* and *collapse* of wave functions are wrong!

Assumptions of *non-locality* and *non-reality* of quantum particles are wrong!

Note that this is NOT de Broglie-Bohm theory (nor is the particle a 'singular' solution to the wave equation). Uniquely based on general relativity <u>and</u> quantum mechanics, our theory is grounded in local physical reality rather than floating on abstractions and near-mystical assumptions. And all major aspects of the theory are backed up by experiments.

A nine page essay addressing a century of confusion about *the nature of the wave function* probably is too condensed to be fully comprehended in one reading. I hope those interested in a *local realistic theory of quantum mechanics* will re-read as necessary.

Edwin Eugene Klingman

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Appendices:

[A] Measurement of the Wave Function:

In 2011, experiments based on Aharonov *weak measurement* techniques measured the wave function *directly* by performing first a weak measurement on one conjugate variable, *momentum* or *position,* that does not disturb the particle, then a strong measurement on the other variable that does—finally averaging over weak measurements. They conclude *the wave function is real*—since particles exhibit de Broglie-Bohm type *trajectories*.

[B] Gravito-magnetic Quantum Coherence Factor:

Despite the general failure of relativity to solve the two body problem, a *free particle is a one body problem* and the weak field approximation yields $\vec{\nabla} \times \vec{C} = \frac{-16\pi g \rho}{c^2} \vec{v}$ where g is Newton's gravitational constant, ρ is (local) mass density and $\vec{v}$ is local velocity. Derived *before* quantum mechanics, this equation lacks a "coherency factor" which Martin Tajmar has shown [12] to be $\kappa = 10^{31}$. The physical field induced by mass current density $\vec{j} = \rho \vec{v}$ is the basis of our wave function $\psi \sim \exp[i(\vec{p} \cdot \vec{r} - \hbar C t)/\hbar]$. The term 'weak' can be misleading, since [10] *"even at the surface of a dense object like a white dwarf… the weak field limit will be an excellent approximation."* We do not attempt to extend the theory into a black hole.

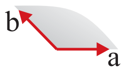
[C] Example of Vortex Length many multiples of the size of the inducing 'particle':

Pilots of small aircraft are told to avoid following too closely behind large jets taking off or landing, as induced vortices can turn small planes upside down! The photo below shows the scale of real vortices, with dashes emphasizing the clearly visible vortices:

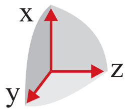
[D] Brief Mention of Geometric Algebra 'Framework'

Point

Vector



Bivector



Trivector

It's impossible to present *geometric algebra* in few pages so we provide some links [20, 21]. Christian's trivector is a unit volume ($I = e_x \wedge e_y \wedge e_z$, $I^2 = -1$). The photon's complete state is specified: $\mu = \pm I$, plus identity $(\mu \cdot a)(\mu \cdot b) = -a \cdot b - a \wedge b$ (where $a \cdot b$ is the familiar scalar product and $a \wedge b$ is $i \cdot (a \times b)$.) Alice and Bob detect photon polarizations along vectors $\hat{a}$ and $\hat{b}$, with bivector basis fixed by trivector μ. Christian takes randomness $\mu = +I$ or $\mu = -I$ shared by Alice and Bob as "*the initial orientation (or handedness) of the entire physical space"*. After a series of experiments "*an external observer…collects the data…and compares the two series of results*". The experiments find $E(a,b) = -a \cdot b$. The C-field theory of local real quantum mechanics predicts $-a \cdot b$, based on our trivector μ as the left-handed volume $\mu \sim \vec{\lambda} \cdot \vec{\nabla} \times \vec{C} \sim \hbar \;\Rightarrow\; E(a,b) = -a \cdot b$

[E] Qualified approval of Christian's framework: [27]

In 2012, I asked key critics of Christian's the following: "If the computed result was -a.b - a^b then would the rest of the framework be mathematically correct? If not, what?"

Florin Moldoveanu replied on Apr. 2, 2012 @ 04:48 GMT: "Answer: yes, it would be. Assuming Joy's POSTULATES in the 1 pager (with a left algebra in some runs, and a right algebra in others - together with his 50-50% rule) and computing the math correctly you get - a.b - a^b and yes, the framework is consistent in this case.

But [...] it leads to -a.b-a^b [and] no longer reproduces exactly QM's predictions. To bypass [the] hurdle, you may find physical reasons why it does not matter. …Another way you can take the -a.b-a^b result is: "well, this is a nice model, it almost gets the QM correlation, can I improve it to indeed obtain -a.b?" …this is a valid scientific pursuit and to date [no] result prohibits this 100%."

Richard Gill replied on Mar. 31, 2012 @ 08:20 GMT: "Edwin, that's a good question. Accepting Joy's initial postulates and definitions, the result is -a.b-a^b. The raw product moments are all -1, satisfying Bell-CHSH, as they must, since Joy's model for the measurement outcomes is a genuine local realistic model. [but] Dividing by bivector standard deviations results in a mixed real and bivector correlation coefficient."

[F] Additional points about Christian's framework:

1) "The complete state specifying all of the elements of reality in [Christian's] model is [21] taken to be the trivector", as is true in our model. 2) "every trivector in the algebra differs only by its volume and orientation", hence our wave function trivector is mathematically the same as Christian's, except that our orientation is fixed. 3) Christian details eight requirements "arising from either predictions of quantum mechanics or the premises of Bell's theorem." His framework satisfies all eight, as does our model.