Remove the Blinders: How Mathematics Distorted the Development of Quantum Theory

Alan M. Kadin, Princeton Junction, NJ 08550 USA, amkadin@alumni.princeton.edu
February 2015

It is widely believed that mathematics provides the fundamental basis for physics. On the contrary, it is argued here that pictures of real objects moving in real space provide the proper basis for physics, and that mathematics merely provides quantitative models for calculating the dynamics of these objects. Such models may distort or even hinder the development of new physics, particularly if a consistent physical picture is lacking. This is discussed in connection with quantum mechanics, which discarded realism in favor of mathematical abstraction almost a century ago. A realistic, spin-quantized wave picture of quantum mechanics is presented that avoids the paradoxes and abstractions of the orthodox quantum theory. Quantum indeterminacy stems from an inappropriate application of a statistical point-particle model to extended soliton-like wave packets. Quantum transitions are continuous, rather than the abrupt transitions of the Hilbert space model. Quantum entanglement is an artifact of mathematical constructions incompatible with local realism. These are not merely matters of philosophical interpretation; several experimental implications are presented. It is time to remove the mathematical blinders that have prevented consideration of realistic quantum pictures.

"Oh, what a tangled web we weave, when first ***ourselves*** *we do deceive."*

I. Introduction: Local Realism vs. Abstract Math

This epigram is slightly modified from the original quotation of Sir Walter Scott, the final clause of which reads "when first we practise to deceive". But self-deception is far more pernicious that mere deception, and collective self-deception is even worse. This essay focuses on a form of collective self-deception enabled by mathematics. The orthodox foundations of quantum mechanics are inconsistent with logic and local realism, as pointed out by leading physicists such as Einstein, Schrödinger, and de Broglie (see Gilder [2008]). But once a mathematical formalism was established for quantum mechanics, this seemed to resolve the cognitive dissonance, and questioning of the foundations was henceforth forbidden. This apparent resolution is illusory, but the collective self-deception remains to this day.

There are several fallacies associated with the use of mathematical models in physics, related to *uniqueness*, *universality*, and *abstraction*. A model that yields a valid result may be assumed to be correct, even if other explanations may also be valid. It may be believed to be universal, applicable over a much wider regime than first observed. New physics may be derived from generalized abstract mathematics that go well beyond the original physical pictures. All of these occur in quantum mechanics.

Quantum mechanics is believed to represent a universal theory of dualism and indeterminacy in nature. On the contrary, I have proposed that quantum mechanics constitutes instead a mechanism for real continuous fields to behave as discrete particles [Kadin 2006]. Further, the abstract Hilbert space model for quantum mechanics is believed to represent the core of quantum theory, and when its predictions (such as entanglement) are contrary to local reality, then we must give up local reality. While there have long been some skeptics (see, e.g., Mendes [2014]), I have proposed a novel deterministic model of quantum waves consistent with local reality [Kadin 2011, 2012, 2013, also called the "New Quantum Paradigm"], which was never considered back in the old days. This realistic model makes predictions for experimental measurements that deviate sharply from those of the Hilbert space model, while reproducing other standard results [Kadin 2014a,b,c]. Both the realistic model and its experimental predictions are considered heretical (and unpublishable) by the orthodoxy.

Fig. 1 illustrates some of the paradoxes in orthodox quantum theory. Fig. 1a shows a wave packet following a trajectory in space, with a point particle lying somewhere within it. Is the wave the real physical object, or the particle, or both, or neither? Is the motion of this object deterministic or statistical in nature? Fig. 1b shows two quantum particles moving away from an initial combination state, with opposite spins. Are these spins definite, and are the two particles still coupled (entangled) even after they have moved far apart? In contrast to these paradoxical pictures, Fig. 2 shows a wave packet representing a realistic quantum particle. This is a distributed real coherently rotating vector field, which carries spin angular momentum. This is also a relativistic de Broglie wave, as shown by a Lorentz transformation to a moving reference frame. There is no uncertainty and no entanglement.

Section II presents a "particle" that maintains its integrity as a soliton wave following a classical trajectory, while composites are not quantum waves at all. Section III addresses the central role of quantized spin, showing how the classic Stern-Gerlach experiment and quantum transitions in magnetic resonance may be understood using real trajectories of spin-quantized waves, without superposition or uncertainty. Section IV describes how the Pauli exclusion principle represents a real-space local interaction of an electron field, rather than an abstract mathematical construction in Hilbert space, and how the Einstein-Podolsky-Rosen (EPR) paradox may be resolved without quantum entanglement. Finally, the Notes at the end show how the motion of these soliton-like particles leads directly to classical trajectories without decoherence, and how a particle may scatter from a periodic crystal to yield the standard diffraction result in the absence of any wave nature of the particle.

II. Soliton Waves and Quantum Uncertainty

The central paradox of quantum mechanics is wave-particle duality (see also Kadin [2012]). The wave nature was discovered by Louis de Broglie [1923], who showed that a distributed oscillator of frequency $\omega_0 = mc^2/\hbar$ becomes a wave with wavevector $\mathbf{k} = m\mathbf{v}/\hbar$ when it is Lorentz-transformed with velocity $\mathbf{v}$. This established a relativistic quantum wave with dispersion relation $\omega^2 = (kc)^2 + {\omega_0}^2$, associated with energy-momentum relation $E^2 = (pc)^2 + (mc^2)^2$. A wave packet will follow a trajectory with velocity $v_g = \frac{\partial\omega}{\partial k}$, much like a particle. However, a classical wave packet will spread as it moves, and can split if it collides, unlike a particle that maintains its integrity.

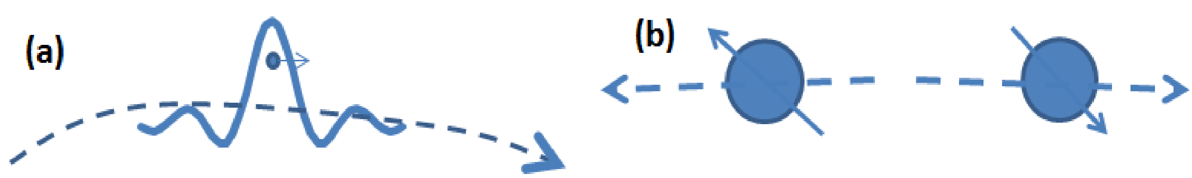

Fig. 1. Duality and uncertainty in orthodox quantum theory. (a) A wave packet following a spatial trajectory with a point particle inside the wave. Is the real physical object the wave or the particle or both, and is it deterministic or statistical? (b) Two quantum particles with opposite spins moving apart from an initially coupled state. Are the spins definite, and do the particles remain coupled (entangled)?

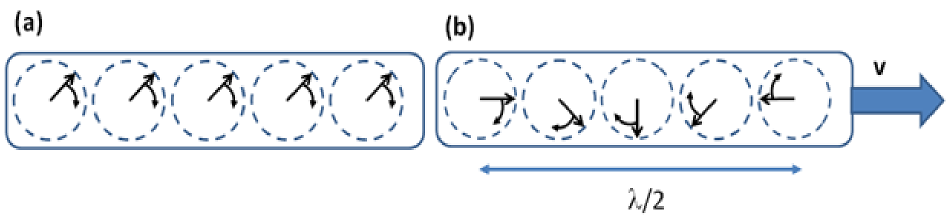

Fig. 2. Realistic picture of a quantum "particle" consisting of localized coherently rotating vector field with quantized total spin. (a) The particle in its rest frame, with all of the vectors synchronized in phase. (b) The particle in a moving reference frame, with relativistic phase shifts constituting a de Broglie wave.

The physicists developing quantum theory could not conceive of a way for a wave packet to maintain its integrity, unless there was also an associated point particle that comprises the mass and charge. In the orthodox Copenhagen interpretation, the wave represents a statistical distribution of the locations of a point particle that is associated with the mass. In an alternative "pilot-wave" interpretation (suggested by de Broglie and refined by David Bohm), both particle and wave are real, and the wave guides the trajectory of the particle.

But a more natural way out of this dilemma is to dispense with the point particle entirely, and obtain the discrete particle nature from purely wave phenomena [Kadin 2006]. A soliton is a wave packet of fixed amplitude that maintains its shape as it moves without attenuation or dispersion, and cannot split on collisions, much like a particle. Further, two solitons cannot merge to form one that is twice as big, but repel each other in a way similar to the Pauli exclusion principle for electrons. This requires a *nonlinear* wave equation of a certain type, unlike the *linear* wave equations in classical physics and the Schrödinger equation, and unlike the linearity required for application of Hilbert space theory. The mathematics of solitons goes back to Lord Rayleigh in the 1870s, but the physicists in the 1920s were not familiar with it. Recently others have considered nonlinearity in quantum mechanics [McHarris 2013].

Let us assume that both an electron and a photon are distributed soliton-like objects, which represent spin-quantized coherently rotating vector fields like a circularly-polarized (CP) electromagnetic field. Here are some implications of this realistic quantum theory:

1. No intrinsic indeterminacy

The motion of a wave packet is completely deterministic, with both position and momentum being arbitrarily defined (*no uncertainty principle!*). A wave packet must be spread over at least about a wavelength, but the center of energy follows a definite trajectory. The standard textbook proof of the Heisenberg Uncertainty Principle is a mathematical identity about waves, and provides for uncertainty only if one assumes the orthodox statistical interpretation.

2. Classical trajectory for quantum wave packet

If the entire wave packet is characterized by a single coherent frequency ω, the wave will move in a potential so as to maintain ω constant. If the potential energy increases, the particle will slow down to maintain E (and ω) constant. This is true for an EM wave packet moving through a medium with a changing dielectric constant; the wavelength changes but the frequency remains the same. This constant-ω trajectory is exactly the constant-E trajectory of a classical particle with $E = \hbar\omega$ (Note A). No "quantum decoherence" is necessary to obtain classical trajectories, which apply at all levels.

3. No linear superposition of quantum states of different frequencies

The general solution to a linear wave equation is a linear combination of eigenstates, each of which corresponds to a characteristic frequency. For example, for vibrations on a string of fixed length, the eigenstates are a series of harmonics. A two-level system with eigenstates Ψ_1 and Ψ_2 has the general solution is $\Psi = c_1\Psi_1 + c_2\Psi_2$, where c_1 and c_2 are complex numbers. This is the basis for the Hilbert space model, which is usually represented using abstract vectors $|\Psi\rangle$ from linear algebra. In contrast, in the present quantized field model (based on a *nonlinear* wave equation yet to be determined), the soliton-like solution for a single electron has only a single resonant frequency present, with photon-mediated transitions from one eigenstate to another. The superpositions of the Hilbert space model do not apply to a quantum system, even if the model correctly identifies the resonant eigenstates.

4. Composites are not waves but still have quantized energies

A composite consists of a bag of confined waves, each with its own frequency, but with no extended wave corresponding to the entire particle. Contrary to the orthodox dogma, *only* the fundamental fields of electrons and photons (and presumably also quarks and gluons are de Broglie waves. A neutron is a 1-fm bag of three quarks, each quark comprising a rotating vector field. It is believed that observations of neutron diffraction prove that neutrons are indeed de Broglie waves, but an alternative explanation in terms of quantum transitions with quantized momentum transfer reproduces these standard results (Van Vliet [1967,2010] and Note B).

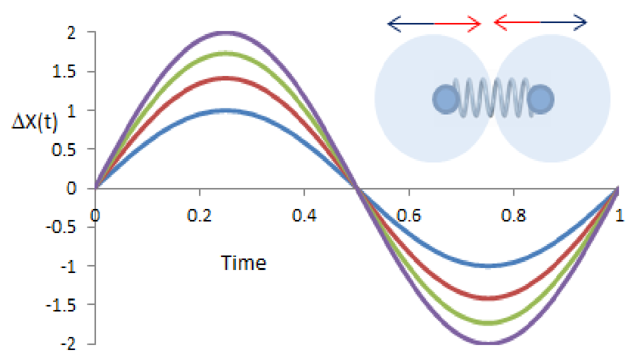

Fig. 3. Vibrating diatomic molecule with classical vibration having quantized amplitude, not standing waves.

Further, quantized energies of electrons in an atom reflect resonant frequencies of a wave equation, but quantized energies of vibrating and rotating molecules have a different physical basis – they reflect the quantized energies of the wave components. Consider the vibrations of a diatomic molecule in this realistic picture (Fig. 3), where the two atoms follow real-space classical oscillating trajectories at a resonant frequency ω. But only certain classical trajectories are allowed, specifically the ones that can be generated from the ground state by photons with $E = \hbar\omega$. The oscillating amplitude $\propto \sqrt{N}$, where N is the number of vibrational quanta.

The question of whether macroscopic objects (necessarily composites) can be quantum superpositions was addressed early by Schrödinger [1935], where he constructed a state of a cat being in a superposition of dead and alive. Schrödinger clearly thought this was nonsense, but the existence of such "Schrödinger cat states" is now widely accepted as an inevitable aspect of quantum mechanics. On the contrary, in this realistic picture, composites cannot be superpositions since they are not waves, and superposition is present only for electron and photon wave components at a single frequency.

Furthermore, in recent years, there has been considerable interest in the possibility of a quantum computer composed of qubits [DiVincenzo 1995], where each qubit represents a quantum system with two possible quantum states. The computing ability depends on the each qubit being a quantum superposition of the two states, which is not present within the realistic picture even on the microscopic level. For macroscopic qubits, energy levels may be quantized, but this does not indicate that quantum superposition is present. The basis for quantum computing is further questioned in Section IV.

III. Spin and Quantum Transitions

Within the orthodox quantum theory, spin is a mysterious angular momentum (with nothing actually spinning!) associated with a point particle, which comes out of the relativistic Dirac equation. On the contrary, consider a simple realistic picture of spin [Kadin 2005], which has its origins in classical EM fields. A real vector field is indeed rotating, although this is not solid-body rotation. Consider first a linearly polarized (LP) EM wave packet with frequency ω. This carries energy density $\mathcal{E}$ and momentum density $\mathcal{P} = \mathcal{E}/c$ distributed through the wave, but no angular momentum. In contrast, a circularly polarized (CP) EM wave packet, with a transverse electric field vector rotating at ω, also has angular momentum density $\mathcal{S} = \mathcal{E}/\omega$. If the wave packet has total spin $S = \hbar$, then the entire wave packet has

$E = \hbar\omega$ and $\mathbf{p} = \hbar\mathbf{k}$. This represents a consistent realistic picture of a single photon with spin $\hbar$ and energy $\hbar\omega$. This picture of a photon as a CP wave packet is well known, but has never been taken seriously, because it conflicts with the prevailing belief in quantum superposition and uncertainty.

Quantization of spin is a natural assumption for a relativistic theory based on quanta of $\hbar$, since angular momentum is one of the few simple dynamical quantities that is Lorentz invariant. The spin of the photon is $\hbar$ in any reference frame, while E and $\mathbf{p}$ change. More generally, $S = N\hbar$ for any EM wave packet, where N is a non-zero integer of either sign. A linearly polarized (LP) two-photon state is composed of two photons of opposite helicity $\Psi = \Psi_L + \Psi_R$, but a single LP photon is impossible. This is in contrast to the Hilbert space picture, where an LP single photon can be expressed by $\Psi = (\Psi_L + \Psi_R)/\sqrt{2}$, which is interpreted as a 50% likelihood of measuring the photon to have spin of $\pm\hbar$. It is believed that LP single photons are routinely measured in experiments, but traditional optical photon detectors are really event detectors rather than energy detectors, and cannot distinguish one from two simultaneous photons. However, new energy-sensitive superconducting single-photon detectors can distinguish these [Kadin 2014a].

Electrons can also be defined by spin quantization in a wave packet, but with a rest-frame frequency $\omega_0 = mc^2/\hbar$. The energy-spin relation is given by $\boldsymbol{\mathcal{E}} = \boldsymbol{\mathcal{S}}/2\omega$, so that $S = \frac{\hbar}{2}$ corresponds to $E = \hbar\omega$, with only values $\pm\frac{\hbar}{2}$ allowed. This represents the exclusion principle, due to a real interaction of the electron field (Section IV).

Note that the spin axis for a photon is defined by the direction of motion, while the spin axis for an electron is defined by the direction of a quasi-static magnetic field B, which may be independent of the direction of motion. If we define the direction of B as the $+z$-direction, then the two states are spin up ($\Psi_\uparrow$) and spin down ($\Psi_\downarrow$). For an electron with magnetic moment $\mu = -\frac{eS}{m}$, the two states differ in energy by $2\mu B$, with $\Psi_\downarrow$ the ground state and $\Psi_\uparrow$ the excited state. The electron is in either one of these states with no spin uncertainty, *not* in a superposition of the states as assumed by the Hilbert Space model. If the spin is in $+z$-direction, the spin components in x and y directions are precisely zero. If the electron sees a B field that is gradually rotating its direction, the spin direction of the electron will track the direction of the B field, so that it will always remain spin up or spin down in the local B field. A spin in the ground state will remain in the ground state, and one in the excited state will remain in the excited state, unless there is a quantum transition from one to the other.

Consider now a neutral gaseous atom with a single unpaired electron, such as a free univalent atom. If this atom moves in a uniform B in the $+z$-direction, it will follow a straight line, since there is no Lorentz force. But if B has a gradient in the $+z$-direction, μ of the $\Psi_\downarrow$ electron will cause the atom to accelerate in the $+z$-direction, in order to keep its total E (and ω) constant in the laboratory frame. Potential energy decreases, and kinetic energy increases. In contrast, if the electron is in the $\Psi_\uparrow$ state, then its μ causes the atom to accelerate in the $-z$-direction. These are classical Hamiltonian trajectories, with no quantum uncertainty. If one has a beam that is a mixture of $\Psi_\uparrow$ and $\Psi_\downarrow$, then the beam will split into two sub-beams (Fig. 4a). This was demonstrated in the 1923 Stern-Gerlach (SG) experiment [Friedrich 2003], which provided the first experimental evidence of spin quantization. A hot beam of univalent atoms (Ag in the first experiment) was directed toward a magnet with B and ∇B in the $+z$-direction.

But the explanation in the orthodox quantum theory is different and more obscure. The spin is initially in an indefinite superposition of $\Psi_\uparrow$ and $\Psi_\downarrow$: $\Psi = (\Psi_\uparrow - \Psi_\downarrow)/\sqrt{2}$. The magnetic field gradient somehow breaks this coherent superposition into a mixture with 50% in each state, which then separate. This matches both the experiment and the realistic spin-quantized wave picture.

However, these two approaches diverge sharply for the two-stage SG experiment shown in Fig. 4b. This is widely presented in quantum mechanics texts (including the Feynman Lectures [1965]) as a standard paradigm for quantum measurement, but has apparently never been tested (as Feynman admitted). The second stage is the same as the first, but rotated by an angle θ. Because of fringe fields B remains nonzero outside the apparatus, and in the spin-quantized picture, the spins in the excited state will all rotate smoothly into the rotated excited state, yielding 100% in Detector 1 and 0% in Det. 2. In contrast, the orthodox quantum theory states that the excited-state spins will project onto a rotated spin basis with a superposition of spins in the 2nd polarizer, yielding $\cos^2\theta$ in Det. 1 and $\sin^2\theta$ in Det. 2. This orthodox prediction is so well established that it has an online Flash Demo. An experiment using modern atomic-beam equipment should distinguish these two alternative approaches.

Spin-½ particles in a static B field are also the basis for the phenomenon of Magnetic Resonance, where a resonant RF field at a frequency $\omega = 2\mu B/\hbar$ can produce a quantum transition between the ground state and the excited state, in either direction. This applies to either nuclear magnetic resonance (NMR) of an atomic nucleus, or electron spin resonance of an unpaired electron. The classical behavior of a magnetic moment aligned in a B field is identical to that of a rotating bicycle wheel in a gravitational field [MIT Video, 2008]. If the rotating wheel initially points up, then as it loses energy and starts to tilt down, it also precesses around the vertical with a fixed frequency, eventually ending up pointing down. In the same way, if one starts with as assemblage of magnetic moments all in the excited state, these relax down to the ground state via coherent precession of μ around the B-axis at ω. This precession causes the resonant RF magnetic field detected in an NMR measurement.

In the realistic picture, this real coherent precession also occurs on the microscopic scale of every electron (Fig. 5). This continuous transition from $\Psi_\uparrow$ to $\Psi_\downarrow$ violates the earlier assertion that the only allowed states are $\Psi_\uparrow$ or $\Psi_\downarrow$. However, in a more complete model, the incipient photon is bound to the electron as part of the quantum system. During the transition, both angular momentum and energy are continuously and gradually being transferred from the electron to the photon. Indeed, the rotating magnetic field B_{rot} *is* the incipient CP photon, and the transition is complete when a complete $\hbar$ of spin has been transferred,

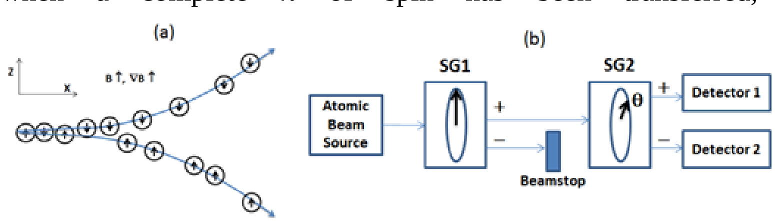

Fig. 4. Stern-Gerlach (SG) Experiment showing spin quantization in magnetic field. (a) Single polarizing magnet showing split output beam. (b) Sequential magnets at different angles, predicting a split final output beam (orthodox theory) or a single output beam (spin-quantized wave theory).

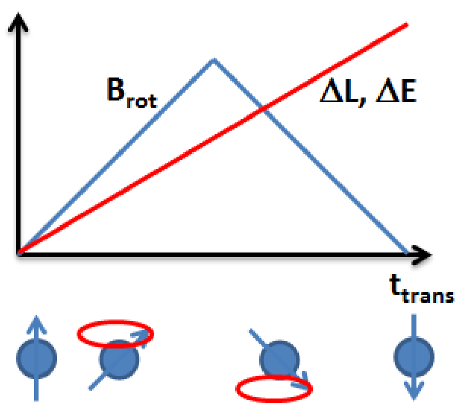

Fig. 5. Continuous quantum transition between spin states $\Psi_\uparrow$ and $\Psi_\downarrow$ in magnetic field via spin precession and rotating field B_{rot}. Energy and angular momentum transferred to photon at resonant ω.

and the photon is now free to move away from the electron. In contrast to this realistic picture, the orthodox picture requires a sudden probabilistic transition from $\Psi_{\uparrow}$ to $\Psi_{\downarrow}$, associated with sudden emission of a point photon. It is difficult to reconcile this with the continuous fields measured on the macroscopic level.

IV. Particle Exchange and Quantum Entanglement

The Pauli exclusion principle states that two electrons may not be in the same quantum state (spin included). So one may have two electrons of opposite spins in the same atomic orbital, providing the basis for electronic filling of atoms. This also provides for hard-core repulsion of atoms in a solid – two electrons in the same state repel each other. In the realistic picture proposed here, this is not a principle, but rather a real force, part of the self-interaction that causes the electron field to self-organize into spin-quantized domains. One configuration that is allowed by the exclusion principle is shown in Fig. 6, and represents an anti-bonding configuration whereby two identical states lie next to each other with a node between them (corresponding to anti-phase fields), so that the wavefunctions do not overlap.

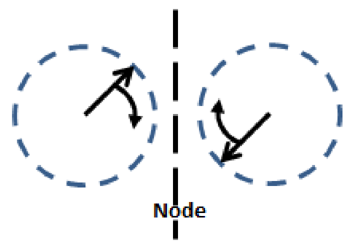

Fig. 6. Real-space configuration of two adjacent electrons of same spin and frequency, but 180º out of phase. These form a node between them, compatible with the Pauli exclusion principle, but not with particle exchange.

But in the orthodox theory, the exclusion principle is not a real-space interaction, but rather a mathematical construction in Hilbert space. It is argued that a configuration such as that in Fig. 6 is not a proper two-electron state, because the electrons would be distinguishable. Instead, all electrons in a quantum system should be in identical states, and hence intrinsically indistinguishable. One can formally construct identical states by exchanging the two electrons and taking linear combinations of the two configurations. This anti-symmetric linear combination is selected to reproduce the exclusion principle: $\Psi_{anti} = [\Psi_1(r_1)\Psi_2(r_2) - \Psi_2(r_1)\Psi_1(r_2)]/\sqrt{2}$. Note that if Ψ_1 and Ψ_2 represent the same state, $\Psi_{anti} = 0$ by definition, indicating a non-allowed state.

In the orthodox quantum theory, this principle of identical particles via particle exchange was generalized to *N* particles, with symmetric or antisymmetric combinations depending on whether the particle spin is integral or half-integral (bosons vs. fermions). However, it was not initially realized that these abstract Hilbert-space constructions are incompatible with local realism, and should have been questioned on that basis. By the time this was realized, it was too late – these *entangled* constructions (linear combinations of product states) had been fully accepted into the foundations of quantum mechanics, and were no longer considered open to question by the theoretical physics community.

The nonlocal nature of particle exchange can be easily seen by considering that the two anti-symmetrized electrons in Fig. 6 move far apart. Then, if a quantum measurement on one electron changes its state, the state of the other electron must also instantly change. This action-at-a-distance is nonlocal, and would appear to violate special relativity. In contrast, in the realistic picture, the two electrons are real-space relativistic wave packets, and once they move far apart, there is no quantum interaction between them. Further, if the electrons represent domains in an electron field, there is no reason why they should be identical. After all, an EM field can have different values in different locations, without any particle exchange. In this picture, *there is no particle exchange and no quantum entanglement*.

The concept of quantum entanglement did bother some prominent physicists, most notably Albert Einstein. In the famous paper by Einstein, Podolsky and Rosen [EPR 1935], they proposed a gedanken experiment whereby two coupled quantum particles move apart, and are measured separately. If a measurement on one particle also measures the other, they questioned whether this might violate the Uncertainty Principle. Another form of the EPR paradox was later proposed by David Bohm, in which he described two correlated electrons of opposite spin, which could be measured using SG magnets.

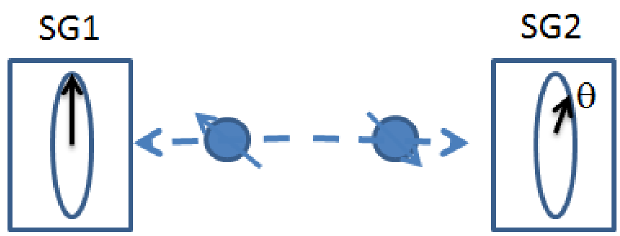

Fig. 7. EPR Paradox in Quantized-Spin Picture. Two SG magnets (which may be oriented differently) measuring spins of two outgoing particles with definite opposite spins. Each spin will rotate into alignment with measurement field, while remaining in anticorrelated ground and excited states.

In the realistic spin-quantized picture (Fig. 7), the two particles are created in a small ambient field, one in the ground state and the other with opposite spin in the excited state. They move in opposite directions into SG magnets, with spin axes tracking the local B field. First, suppose that both SG magnets are configured with B and ∇B in the $+z$-direction. Since the trajectories maintain constant E, the measurements will be anti-correlated; one will be in the ground state and the other in the excited state, with opposite spins, which is also what the orthodox theory predicts. However, if we invert one of the SG magnets, the orthodox theory states that the spins will still be antiparallel, while the realistic theory states that the spins will be parallel, but with (as always) anti-correlated energies – one in the ground state and the other in the excited state. This experiment should distinguish these two contradictory predictions.

There have been many experiments that have addressed quantum entanglement, based on Bell's Inequalities for correlations between two photons [Zeilinger 1999]. These have confirmed the predictions of the orthodox Hilbert-space model, but the experiments all involved LP single photons. The realistic spin-quantized picture described here does not allow for single LP photons, and suggests that the experiments may really be measuring correlations of photon pairs [Kadin 2014a]. The analyses need to be reexamined.

For many years, the foundations of quantum mechanics were viewed as an obscure field with no real-world applications. However, in recent years, there have been major theoretical and experimental efforts to design a quantum computer that could solve problems that are virtually impossible using conventional computers, such as factoring large integers, enabling one to break standard unbreakable codes [DiVincenzo 1995]. These quantum algorithms depend on quantum entanglement of N qubits, which yields an exponential parallelism as 2^N in computing speed. The realistic quantum picture proposed here has no quantum entanglement, undermining the entire basis for quantum computing [Kadin 2014b].

V. Conclusions: Pictures Should Guide Physics

In this essay, an outline of a realistic theory of quantized wave packets has been presented, whereby spin quantization of primary quantum fields gives rise to localized objects that follow classical trajectories. There is no indeterminacy, entanglement, or decoherence, in sharp contrast with the orthodox theory, with directly measurable implications. The basis for this primary quantization has not yet been derived, and is a subject for future research. One insight is to arrays of coupled nonlinear oscillators, which form coherent domains. In retrospect, the exclusive focus on the linear Hilbert-space model has prevented consideration of nonlinear models. Mathematical models were adopted prematurely in the development of quantum theory, providing blinders that discouraged more promising approaches.

Continuous deterministic dynamics of real objects in real space, described by differential equations, formed the basis of physics since Isaac Newton. Indeed, Newtonian dynamics provided the model for other sciences through the 19th century. But humans are not as orderly as particles and fields, and a rebellion against the Newtonian paradigm began to dominate the arts by the 20th century, celebrating the subjective and paradoxical nature of humanity. For example, Pablo Picasso's paintings showed fractured views of both sides of a face, and existential philosophy (e.g., Martin Heidegger) asserted the dualism and contradictory nature of human existence. These concepts found their way back into physics with Bohr's Complementarity Principle, whereby an object can be a particle and a wave at the same time.

But physicists view themselves as more rational than artists and other scientists, and the mathematical formalism of the Hilbert-space model was developed to enable accurate quantitative prediction of experiments, even as it hid the illogical foundations of quantum mechanics. The key lesson taught to generations of physics students was "Shut Up and Calculate" (Mermin [2004], but attributed to Richard Feynman), whereby realistic pictures and questioning quantum foundations were highly discouraged. This admonition has become virtually religious dogma, and must change if physics is to advance.

As a consequence of elevating abstract mathematics and denigrating realistic pictures, exploratory theoretical physics has wasted decades wandering in the desert, caught up in a tangled web of self-deception. By removing the blinders and allowing ourselves to be guided by realistic pictures, we may find a path toward the promised land of understanding physical reality.

References

Louis **de Broglie** (1923), "Waves and Quanta", *Nature*, vol. 112, no. 2815, p. 540. Available free online at http://www.nature.com/physics/looking-back/debroglie/index.html.

D. **DiVincenzo**, "Quantum Computation", *Science* **270**, p. 255, Oct. 1995. http://www.sciencemag.org/content/270/5234/255.short

A. **Einstein**, B. Podolsky, and N. Rosen (1935), "Can quantum mechanical description of physical reality be considered complete?", *Phys. Rev.* vol. 47, p. 777. http://journals.aps.org/pr/abstract/10.1103/PhysRev.47.777

R. **Feynman**, et al. (1965), *The Feynman Lectures on Physics, Vol. 3: Quantum Mechanics*, available online at http://www.feynmanlectures.caltech.edu/III_05.html#Ch5-S1.

B. **Friedrich** and D. Herschbach (2003), "Stern and Gerlach: How a Bad Cigar Helped Reorient Atomic Physics", *Physics Today*, Dec. 2003, p. 53. Available online at http://faculty.chemistry.harvard.edu/files/dudley-herschbach/files/how_a_bad_cigar_0.pdf

Louisa **Gilder** (2007), *The Age of Entanglement: When Quantum Physics Was Reborn*, Random House, New York. http://www.amazon.com/The-Age-Entanglement-Quantum-Physics/dp/1400095263

A.M. **Kadin** (2005), "Circular polarization and quantum spin: a unified real-space picture of photons and electrons", http://arxiv.org/abs/quant-ph/0508064.

A.M. **Kadin** (2006), "Wave-Particle Duality and the Quantum Domain Picture", http://arxiv.org/abs/quant-ph/0603070.

A.M. **Kadin** (2011), "Waves, particles and quantized transitions: A new realistic model of the microworld", http://arxiv.org/abs/1107.5794.

A.M. **Kadin** (2012), "The Rise and Fall of Wave-Particle Duality", FQXi 2012 Essay, http://www.fqxi.org/community/forum/topic/1296.

A.M. **Kadin** (2013), "Watching the Clock: Quantum Rotation and Relative Time", FQXi 2013 Essay, http://www.fqxi.org/community/forum/topic/1296.

A.M. **Kadin** and S.B. Kaplan (2014a), "Is a Single Photon Always Circularly Polarized? A Proposed Experiment Using a Superconducting Microcalorimeter Photon Detector", http://arxiv.org/abs/1407.2605.

A.M. **Kadin** and S.B. Kaplan (2014b), "Superconducting Quantum Computing Without Entanglement?", http://arxiv.org/abs/1407.2605.

A.M. **Kadin** (2014c), "Single-Spin Devices & the Foundations of Quantum Mechanics", http://vixra.org/abs/1409.0004.

William C. **McHarris** (2013), "Nature and Nonlinear Logic", FQXi Essay http://fqxi.org/community/forum/topic/1908.

Teresa **Mendes** (2014), "Physics Needs a Paradigm Shift", FQXi Video, http://fqxi.org/community/forum/topic/2246.

N. David **Mermin** (2004), "Could Feynman have said this?", *Phyics Today*, May 2004. Available online at http://scitation.aip.org/content/aip/magazine/physicstoday/article/57/5/10.1063/1.1768652

MIT Video (2008), "Bicycle Wheel Gyroscope", http://video.mit.edu/watch/mit-physics-demo-bicycle-wheel-gyroscope-3039/.

E. **Schrödinger** (1935), "Die Gegenwartigen Situation in der Quantenmechanik", *Naturwiss.* vol. 23, p. 807, English translation in *Proc. Am. Phil. Soc.*, vol. 124, p. 133 (1980) https://www.tuhh.de/rzt/rzt/it/QM/cat.html.

K.M. **Van Vliet** (1967), "Linear momentum quantization in periodic structures", *Physica*, vol. 35, p. 97. http://www.sciencedirect.com/science/article/pii/0031891467901383

C.M. **Van Vliet** (2010), "Linear momentum quantization in periodic structures II", *Physica A*, vol. 389, p. 1585. http://www.sciencedirect.com/science/article/pii/S0378437109010401

A. **Zeilinger** (1999), "Experiment and the Foundations of Quantum Physics", *Rev. Mod. Phys.*, vol. 71, p. S288. http://journals.aps.org/rmp/abstract/10.1103/RevModPhys.71.S288

Note A: Classical trajectories on the microscopic level

If quantum mechanics provides the microscopic foundation for matter, where does classical mechanics come from? In the orthodox theory, the microscopic world is comprised of indeterminate, entangled superpositions, associated with quantum coherent states. The macroscopic classical world consists of realistic, deterministic trajectories without superposition or entanglement. The interface between these two domains is rather fuzzy. Classical physics is believed to come about via interaction of a given quantum system with a classical measurement apparatus, causing decoherence, i.e., loss of microscopic coherent degrees of freedom. Exactly how this occurs has never been made clear, and the logic seems rather circular; if everything is ultimately quantum, how is this classical apparatus initiated?

In contrast, in the realistic theory described here, there is no quantum-classical separation, with deterministic realism at all levels. The microscopic world is composed of relativistic vector fields, which self-organize into localized coherent domains based on quantization of spin. Within each domain, the vector field is rotating coherently at a characteristic frequency $\omega_0 = E/\hbar$, where the rotating angle θ itself is the quantum phase and the rotating field carries angular momentum. Classical trajectories derive *directly* from the *coherent* quantum behavior of θ. There is no decoherence or entanglement, and no special role for measurement in the theory.

Recall some key aspects of the classical theory of waves. For a general dispersion relation $\omega(\mathbf{k},\mathbf{r})$, the group velocity $\mathbf{v}_g = \frac{\partial\omega}{\partial\mathbf{k}}$ defines the velocity of a localized wave packet, and the frequency ω of a wave packet is a constant of the motion. Therefore, the trajectory of a wave packet is defined by $\frac{d\omega}{dt} = 0 = \frac{\partial\omega}{\partial k}\frac{dk}{dt} + \frac{\partial\omega}{\partial r}\frac{dr}{dt}$. But since $\frac{d\boldsymbol{r}}{dt} = \mathbf{v}_g = \frac{\partial\omega}{\partial\mathbf{k}}$, this yields $\frac{d\boldsymbol{k}}{dt} = -\frac{\partial\omega}{\partial\mathbf{r}}$. Now add spin quantization, which yields the standard relations $E = \hbar\omega$ and $\mathbf{p} = \hbar\mathbf{k}$. The dynamical equations for the trajectory can now be written $\frac{d\boldsymbol{r}}{dt} = \frac{\partial E}{\partial\boldsymbol{p}}$ and $\frac{d\boldsymbol{p}}{dt} = -\frac{\partial E}{\partial\boldsymbol{r}}$, with E a constant of the motion. These are precisely the equations for the standard Hamiltonian formulation of classical mechanics. This shows that classical particle mechanics follows directly from microscopic wave mechanics, and firmly links E and $\mathbf{p}$ with wave properties ω and $\mathbf{k}$.

Now apply this to an electron on a neutral gaseous atom moving in a B field, as in the Stern-Gerlach experiment. The characteristic frequency $\omega_0 = mc^2/\hbar$ is shifted by $\pm eB/2m$, depending on whether it is spin up or spin down. A gradient ∇B yields $d\mathbf{k}/dt = (\pm e/2m)\nabla B$, whereby the velocity changes so that the frequency ω in the laboratory frame is constant. (Note that ω is *not* constant in the rest frame of the atom.) This also allows the spin to track the direction of the field, and to remain in either the ground or the excited state.

Note that this realistic picture focuses on real relativistic vector waves in real space. In contrast, the non-relativistic Schrödinger equation $i\hbar\frac{\partial\Psi}{\partial t} = -\frac{\hbar^2}{2m}\nabla^2\Psi + V\Psi$ has complex scalar solutions $\Psi = |\Psi|e^{i\varphi}$. The more proper quantum equation for the present realistic picture is a modified Klein-Gordon equation $\frac{\partial^2 F}{\partial t^2} = c^2\nabla^2 F - [\omega_0 + u(x)]^2 F$, which corresponds to the relativistic dispersion relation $\omega^2 = (ck)^2 + (\omega_0 + u)^2$, where $E = mc^2 + V = \hbar(\omega_0 + u)$ is the rest energy. This has real solutions, and can be generalized to a vector equation with polarized solutions modulated by the potential V. The Schrödinger equation is essentially a mathematical transformation of the KG equation with the carrier wave suppressed, and $\Psi = Fe^{i\omega_0 t}$ represents the complex envelope function carrying the modulation. So the vector solution F can be real, even if Ψ is a complex derived quantity.

Note B: Quantum diffraction without waves

Diffraction off periodic structures was developed for classical waves, for wavelength λ comparable to the periodicity d, following the standard diffraction formula $n\lambda = 2d \sin\theta$, where θ is the angular shift of the diffracted beam. An equivalent formulation is expressed in terms of the wave vectors $\mathbf{k}_i$ and $\mathbf{k}_d$ of the incident and diffracted waves (where $|\mathbf{k}| = 2\pi/\lambda$) and the reciprocal lattice vectors $\mathbf{G}$ of the crystal ($|\mathbf{G}| = 2\pi/d$), essentially the peaks of three-dimensional Fourier transform of the spatial distribution of the crystal: $\Delta\mathbf{k} = \mathbf{k}_d - \mathbf{k}_i = \mathbf{G}$. This analysis assumes that the incident wave is coherent over a distance much larger than the periodicity d (Fig. 8a) This same explanation was used to explain quantum diffraction from crystals (by electrons, neutrons, and atoms) by assuming that the incident particles are de Broglie waves with $\lambda = h/mv$.

However, there is a novel explanation of crystal diffraction that does not require waves at all. This considers the quantized momentum transfer $\Delta\mathbf{p}$ between an incident particle and a periodic quantum crystal, as illustrated for neutron diffraction in Fig. 8b. In this analysis [Van Vliet 1967, 2010], a spatially periodic crystal is limited to $\Delta\mathbf{p} = \hbar\mathbf{G}$, directly analogous to quantized energy transfer $\Delta E = N\hbar\omega$ to a quantum state that oscillates in time (such as a vibrating molecule). The key point is that instead of a matter wave diffracting from a classical crystal, one has a particle inducing a transition in a periodic quantum structure. This can also be understood in terms of phonons (quantized collective vibrational modes) in the crystal; a diffraction event represents excitation of a (degenerate) phonon with $E = 0$ and $\mathbf{p} = \hbar\mathbf{G}$, which is an allowed quantum transition. The result is the same whether the excitation is caused by a particle or a wave packet, coherent or incoherent. A similar analysis may also apply to other interference problems such as two-slit diffraction, considered a standard paradigm for quantum uncertainty.

Therefore, one must use a different type of measurement to prove the presence of coherent waves. For example, electronic standing waves in atomic orbitals give rise to directional bonds and energy bands in crystals. No alternative explanation without electron waves would seem to be available. In contrast, there are no standing-wave observations for neutrons or atoms, suggesting that they are indeed not waves.

Finally, this analysis shows the central importance of a consistent physical picture. Logical paradoxes (such as wave-particle duality and entanglement) represent problems that cannot be solved by abstract mathematical formalism. Experimental measurements cannot prove a theory, if there is a viable alternative, and the repetition of invalid assertions to generations of students does not make them correct.

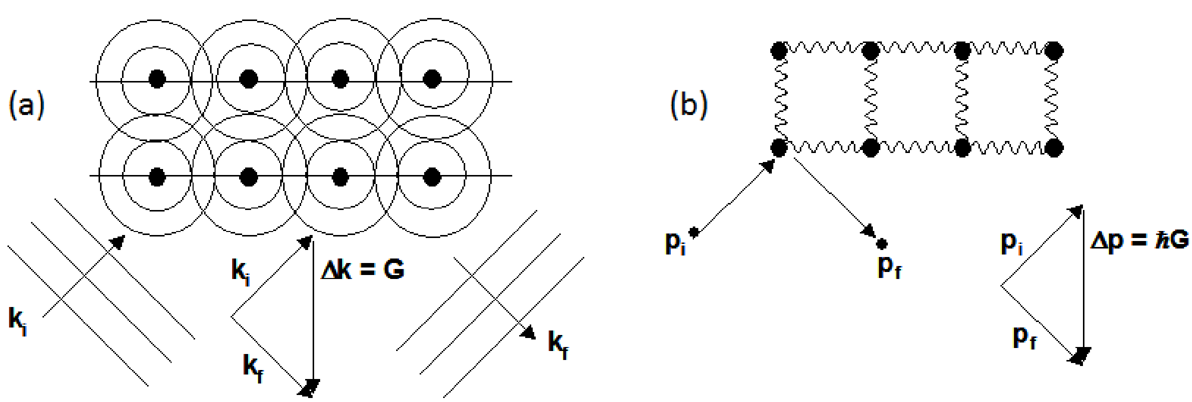

Fig. 8. (a) Wave picture of diffraction, which requires a coherent wave much larger than the lattice spacing. (b) Picture of quantized momentum transfer to periodic lattice, giving the same results as wave diffraction, but with a small particle-like neutron.