Perspective

On the Natural State of Subatomic Particles: Implications for Superposition & Quantum Entanglement

Jack H. Hiller*

Abstract

Five recent experiments employed "weak" measurement of subatomic particles by "low energy" techniques. The techniques for inferring particle status by observation were so delicate that the particles were not affected by the energy of observation, and the particles were found to have a definite and real existence, instead of hazy probability distributions. Such observations by weak measurement seem to invalidate the premise of Heisenberg's Uncertainty Principle (HUP). While the HUP and the Schrodinger wave equation serve to accurately model particle behavior when energetically measured, the particles before their energetic observations had been philosophically speculated to be in a probability distribution which is now contradicted by the five experiments. So, it seems that the superposition principle could be in error. Further, quantum entanglement may not require instantaneous "spooky" signaling, because paired particles acquire complementary features required by conservation of energy.

Keywords: Quantum mechanics, uncertainty principle, weak measurement, quantum entanglement, nonlocal action, superposition.

When Heisenberg constructed the Uncertainty Principle (HUP), laboratory measurement technology then available employed observational energies at or higher than the energy of the particles to be observed. Although the HUP originated from particle measurement difficulties for more than one particle variable at the same time, the Principle is now understood and defined to reflect the nature of particle reality as hazy at the Planck level, regardless of any technical measurement difficulties. Thus particle reality according to the HUP is now modeled by mathematics which bar the possibility of accurate measurement for more than one variable at a time, such that momentum and location, for example, could not in principle be measured at the same time; from such modeling it is inferred that momentum and location do not actually exist in Nature for an unobserved particle.

Therefore, any proposed technology for simultaneously measuring particle momentum and location would a priori be regarded as futile by current HUP math modeling. However, this paper argues from the empirical evidence cited [3-7] that math modeling that bars multi-variable measurement is not veridical with the underlying physical reality of particles. Regarding the status of the Schrodinger wave equation for particle behavior, this paper does not challenge the accuracy of calculations made by it, but does refute the interpretation that asserts particles must

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*Correspondence: Jack H. Hiller, PhD, JD, Independent Researcher, USA. E-mail: jh7138@gmail.com

Notes: I express my appreciation to Lee Whitt, Christopher Wallace, and Neil Siegel for their comments that helped me to communicate the ideas developed about the nature of particle reality. This essay extends my recent essay entitled "Uncertainty Principle in Light of the 'Weak' Measurement Experiments" published in JCER 11(7): pp. 752-756.

exist in the superposition state supposed to exist until the energy of measurement collapses the wave function.

At the outset, the author would like to point out that there are two different contexts for employing the term "superposition," with one likely a mistake as this paper explains, and the other perfectly good, the other being about the Young double slit arrangement. In the double slit, the physical arrangement created by the slits causes light to interact with the slits as transverse waves. This is a well-studied situation for which the term "superposition" makes good sense. By contrast, the superposition state of particles employed in the interpretation of Schrodinger equation may be a misguided concept corresponding to the mistake of Heisenberg and Bohr in assuming that particles in their natural state lack a definite, real existence as particles, with Einstein having argued against their assumption.

In general, this paper relies on Immanuel Kant's distinction between directly observable phenomena, and the underlying existence of noumena responsible for observable phenomena. As a consequence, even math modeling found practically useful for engineering and physics, such as Newton constructed for gravity, does not ensure model veridicality with the underlying physical reality modeled.

However, weak measurement technologies, as reviewed here, imply that the premise of the HUP (that particles in their natural state must be regarded as owning feature values best modeled as probability distributions instead of having any definite real existence) was overgeneralized.

The HUP seems to apply only to energetic particle observation/measurement:

(1) The HUP is valid for energetic particle observation, but not for weak observation.

(2) The Copenhagen interpretation of reality may be invalid, because it is based on extrapolating from the HUP when substantial energy is applied for particle observation, but observation is now demonstrated as possible without altering the natural state of particles. Bohr applied a strong form of Operationalism to assume that particles must not own a definite reality if they could not actually be observed to exist without perturbing their states of existence. Particle reality was assumed to develop from an energetic observation capable of “collapsing” the Schrodinger wave equation modeling their observable behavior.

(3) The standard interpretation of the Schrodinger wave equation, as implying superposition state until energy is applied to a particle, may be invalid, because particles have a definite, real existence before their observation/measurement.

(4) Quantum entanglement of particles appears to be found by experiment, but no mysterious instantaneous signaling between particles is required, because their complementary values are set when created, and maintained until the measurement.

Masanao Ozawa [1] deduced that the HUP, as originally theorized by Heisenberg, overestimated the potential impact of energetic particle observation on disturbances to the particle's state. Ozawa's analysis led eventually to the development of "weak" particle measurement technology which served to empirically support the validity of his analysis.

However, the results of weak particle measurement are generally interpreted as affecting only the observer/measurement effect that originally motivated formulation of the HUP by Heisenberg, but not the basic principle that subatomic particles, conceptualized as waves (by de Broglie), are inherently, naturally uncertain in character. By supposing that particles are naturally randomly hazy until energetically measured (and then collapsing their Schrodinger wave function to a discrete value), the paired particles employed by EPR Paradox type experiments force speculation about a *signal* from the first measured particle to the second to inform it about what its complementary value must be. For example, if the first measured particle manifests after energetic observation to have an Up spin, then the second particle must manifest with a complementary Down spin, just as the EPR tests have found. While the *signal is generally analyzed to carry no information, because the complementary spin value for the second particle is predetermined,* there yet is a signal of some sort thought to be required.

Because this signal operates instantaneously at any distance however large, and no mechanism for signal transmission was known about, Einstein derided the idea for such a quantum entanglement signal as instantaneous "spooky action at a distance." But no mechanism for such a spooky instantaneous signal has ever been found (granted that Bohm proposed the concept of a pilot wave, but such a pilot wave must yet possess a nonlocal character to enable spooky action at a distance). So, physics now passively accepts that some sort of magical, nonlocal, quantum entanglement signal must exist.

Experiments employing weak measurement of particles, such as the one led by Lee Rozema [2] imply that particles exist in definite states without requiring energetic observation to emerge out of the supposed random haze currently postulated by quantum mechanics. Thus, consider that when the paired particles employed by an EPR type of experiment are created, they do not emerge as randomly hazy particles, but instead as having definite properties, such as their complementary spin values. Thus, if their spin values were set at their creation and maintained until measured by the EPR type of experiment, then there is no need to speculate about any instantaneous spooky signaling. The results from weak particle measurement experiments, coupled with a parsimonious explanation for EPR Paradox experimental results, imply that Einstein's intuition that particles are real, without any observation required, is thus supported.

Quantum particle entanglement results have been well documented by numerous experiments, but do not require the hypothesized mysterious, instantaneous signaling (*i.e.*, “spooky action at a distance”) between the entangled particles. The need to invent a mysterious signaling mechanism was, however, the fault of the Copenhagen Interpretation of reality as an indeterminate flux until operated on by an energetic observation as based on the HUP. The HUP was a principle that was inferred by conceptualizing particle observation/measurement technology that operated at basically the same energy level as the particle to be observed, and so the energy of observation/measurement substantially altered its values by the act of measurement. However, modern “weak” observation technology has now advanced, so that a particle’s characteristics may be inferred accurately without materially affecting the particle.

Heisenberg had correctly reasoned that as he would attempt to measure both the location and momentum of an electron, as he tweaked his apparatus making use of electromagnetic fields to observe, measure, and record his data, when he would improve one of the measures, the other would invariably lose its precision; for example, if he were to shower an electron with strong light to gain a good shadow of where it was, the energy of the light would substantially affect what had been the particle's momentum; likewise, a highly precise measure for momentum would affect its location. He supposed that his measurement techniques were fundamentally set, and so concluded that the measurement issue had not to do with the measurement technology available at that time, but instead reflected an inherent uncertainty in the status of quantum particles. He thus concluded that quantum particles necessarily existed in a random haze, although within an extremely small physical space, at the Planck level. Bohr, working from the requirement of Operationalism that any statement of reallity must be supported by direct observation, generalized this idea to declare that particles could not be considered as having a definite, real existence in Nature (e.g., a fixed location and a specific momentum), but naturally existed in a random flux (the so called Copenhagen Interpretation of reality, which Einstein objected to, i.e., the Moon does not exist until observed, foolish as that appears to common sense).

Schrodinger defined a wave equation (Heisenberg had previously defined a matrix equation) to mathematically model quantum particle behavior, and this equation likewise did not pin down a particle into a definite existence--until it was observed/measured with the energy of the observation "collapsing" the wave function from an infinity of potentially existing positions to manifest as a definite particle existence. Now, this is where spooky quantum entanglement emerged, and Einstein analyzed it as suspicious.

By application of the Copenhagen Interpretation, a particle does not have any manifest, definite reality until observed. When a particle, say a photon, is sent into a beam splitting crystal, two would emerge, and from the principle of the Conservation of Energy, they would remain in balance with their origin; net result is that one would have one type of polarization (say Horizontal, H), but the other a counterbalancing polarization (say Vertical, V). Because the photons are not measured as they leave the crystal, their polarizations and location are speculated to not manifest, but remain indefinite and random as an infinity of potential superposition states according to the Copenhagen Interpretation.

Now, when one photon is measured for its polarization (say it manifests as H), the Schrodinger wave equation would calculate that the other photon would instantaneously acquire the required complementary polarization (say V). The problem here is that somehow the first photon measured would have to signal what its manifest state had become to the other (H or V), and the signal would have to exceed the speed of light, by being instantaneous. When experiments on quantum entanglement were eventually performed, magically the second photon measured always adopted its expected complementary polarization. However, there is another interpretation of the entanglement results possible, and that is that the two paired particles or electrons/photons are created with complementary spins/polarization, retain those spins/polarization, and reveal them when measured.

What has changed since the HUP was conceived is that quantum particle measurement technologies have advanced to the point that very delicate measurement has been enabled, and the measurement is so delicate that a quantum particle observed is not significantly affected. Thru modern experiments, quantum particles are seen to exist without having to collapse their inferred wave functions to become real. Thus, if Bohr were wrong, and Einstein's intuition about particle reality were correct, then there is no mysterious entanglement signal required between the paired particles. Furthermore, the HUP is not universally valid, but only a quirk of the relatively cumbersome particle measurement technology available to him. Also, the many worlds interpretation that flows from the infinite superposition possibilities in the Schrodinger wave drop out. The proposed paradox of the cat in Schrodinger's Box of being both alive and dead until the box is opened (so that the hypothetical wave equation is then collapsed into a live or a dead cat) is invalidated.

The following five experiments [3-7] illustrate that particles naturally have a definite, real existence, *i.e.*, they do not exist in any random flux prior to observation:

(1) Origin of quantum-mechanical complementarity probed by a 'which-way' experiment in an atom interferometer [3]:

> The principle of complementarity refers to the ability of quantum-mechanical entities to behave as particles or waves under different experimental conditions. For example, in the famous double-slit experiment, a single electron can apparently pass through both apertures simultaneously, forming an interference pattern. But if a 'which-way' detector is employed to determine the particle's path, the interference pattern is destroyed. This is usually explained in terms of Heisenberg's uncertainty principle, in which the acquisition of spatial information increases the uncertainty in the particle's momentum, thus destroying the interference. Here we report a which-way experiment in an atom interferometer in which the 'back action' of path detection on the atom's momentum is too small to explain the disappearance of the interference pattern. We attribute it instead to correlations between the which-way detector and the atomic motion, rather than to the uncertainty principle.

(2) Hologram of a Single Photon [4]:

> The spatial structure of single photons … is becoming an extensively explored resource used for facilitating the free-space quantum key distribution … and quantum computation … as well as for benchmarking the limits of quantum entanglement generation … with orbital angular momentum modes … or reduction of the photon free-space propagation speed ….. Albeit nowadays an accurate tailoring of photon's spatial structure is routinely performed using methods employed for shaping classical optical beams …, the reciprocal problem of retrieving the spatial phase-amplitude structure of an unknown single photon cannot be solved using complimentary classical holography techniques … exhibiting excellent interferometric precision. Here we introduce a method to record a hologram of a single photon (HSP) probed by another reference photon, based on essentially a different concept of quantum interference between two-photon probability amplitudes. Similarly to classical holograms, HSP encodes full information about photon's "shape", i.e. its quantum wave function whose local amplitude and phase are retrieved in the demonstrated experiment.

(3) To catch and reverse a quantum jump mid-flight [5]:

> In quantum physics, measurements can fundamentally yield discrete and random results. Emblematic of this feature is Bohr's 1913 proposal of quantum jumps between two discrete energy levels of an atom1. Experimentally, quantum jumps

> were first observed in an atomic ion driven by a weak deterministic force while under strong continuous energy measurement.... The times at which the discontinuous jump transitions occur are reputed to be fundamentally unpredictable. Despite the non-deterministic character of quantum physics, is it possible to know if a quantum jump is about to occur? Here we answer this question affirmatively: we experimentally demonstrate that the jump from the ground state to an excited state of a superconducting artificial three-level atom can be tracked as it follows a predictable 'flight', by monitoring the population of an auxiliary energy level coupled to the ground state. The experimental results demonstrate that the evolution of each completed jump is continuous, coherent and deterministic. We exploit these features, using real-time monitoring and feedback, to catch and reverse quantum jumps mid-flight—thus deterministically preventing their completion. Our findings, which agree with theoretical predictions essentially without adjustable parameters, support the modern quantum trajectory theory... and should provide new ground for the exploration of real-time intervention techniques in the control of quantum systems, such as the early detection of error syndromes in quantum error correction.

(4) Violation of Heisenberg's Measurement-Disturbance Relationship by Weak Measurements [6]

> While there is a rigorously proven relationship about uncertainties intrinsic to any quantum system, often referred to as "Heisenberg's uncertainty principle," Heisenberg originally formulated his ideas in terms of a relationship between the precision of a *measurement* and the disturbance it must create. Although this latter relationship is not rigorously proven, it is commonly believed (and taught) as an aspect of the broader uncertainty principle. Here, we experimentally observe a violation of Heisenberg's "measurement-disturbance relationship", using weak measurements to characterize a quantum system before and after it interacts with a measurement apparatus. Our experiment implements a 2010 proposal of Lund and Wiseman to confirm a revised measurement-disturbance relationship derived by Ozawa in 2003. Its results have broad implications for the foundations of quantum mechanics and for practical issues in quantum measurement.

(5) Quantifying the presence of a neutron in the paths of an interferometer [7]:

> It is commonly assumed that no accurate experimental information can be obtained on the path taken by a particle when quantum interference between the paths is observed. However, recent progress in the measurement and control of quantum systems may provide the missing information by circumventing the conventional uncertainty limits. Here, we experimentally investigate the possibility that an individual neutron moving through a two-path interferometer may actually be physically distributed between the two paths. For this purpose, it is important to distinguish between the probability of finding the complete particle in one of the paths and the distribution of an individual particle over both paths. We accomplish this distinction by applying a magnetic field in only one of

> the paths and observing the exact value of its effect on the neutron spin in the two output ports of the interferometer. The results show that individual particles experience a specific fraction of the magnetic field applied in one of the paths, indicating that a fraction or even a multiple of the particle was present in the path before the interference of the two paths was registered. The obtained path presence equals the weak value of the path projector and is not a statistical average but applies to every individual neutron, verified by the recently introduced method of feedback compensation.

Conclusion

The cited five experiments [3-7] serve to demonstrate that subatomic particles in their natural state have a definite, real existence as had been intuited by Einstein. Bohr had incorrectly asserted, although consistent with the HUP, that particles must exist in a state of random flux until observed, but these five experiments demonstrate his interpretation was led astray by an invalid HUP. Contemporary elegant "weak" particle measurement technology thus vindicates a century later Einstein in his dispute with Bohr in which he famously declared, " …[God] does not play dice." Interpretation of the particle dynamics for the Schrodinger wave equation continues to imagine particles as naturally existing in the random flux philosophized by the false Copenhagen Interpretation of reality. When particles are recognized to have a definite, real state when they emerge from the quantum flux, then the spooky mysteries of quantum mechanics fade away.

Computers are now being engineered to capitalize on quantum entanglement based an the assumption that instantaneous signaling is a real phenomenon validated by EPR Paradox experiments. However, the so-called decoherence problem now frustrating reliable computation, seeking to employ the expectation of instantaneous signaling in prototype quantum computers, is not any problem to be solved by better engineering, because particles are never in superposition states.

HUP models well the behavior of subatomic particles when energetically observed, but fails to apply to weak measurement conditions. Heisenberg and Bohr erred by over-applying the philosophy of operationalism to declare that the natural state of particles must be regarded as a probabilistic haze lacking objective, definite reality; ironically, this presupposition about the natural state of particle actually violated the spirit of operationalism by lacking an observational basis, but weak measurement now provides objective evidence for this mistake about particle reality.

But yet there does remain a true mystery about the nature of particles and the world in which they exist. Prior publication in [1] presented a theory attempting to reduce this mystery. Perhaps the next major hurdle is understanding how the material world we may observe by our senses, aided by instrumentation, relates to dark matter and energy. It is also curious that in the thousands of OBE reports documented there has never been any mention of the role of the dark realm that cosmologists now believe dominates all of reality, with only 5% allocated to our observable world.

Received May 22, 2022; Revised May 26, 2022; Accepted August 14, 2022

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