Countering the Bohr Thralldom

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Abstract The Copenhagen interpretation of quantum mechanics and the notion of superposition of states are examined and found problematical.

Introduction

In 2013, a short article by Carver Mead[1] appeared online,[2] in which he deplores the stultifying effect of competition for position and influence by the pioneers and originators of contemporary science, particularly relativity and quantum mechanics. In his words, "A bunch of big egos got in the way", and stalled the revolution which had started in the early twentieth century.

Mead recounts the story of Niels Bohr and Werner Heisenberg laughing at Charles Townes, inventor of the maser and laser, when he presented his ideas to them. They dismissed him with the condescending judgment that he didn't understand how quantum mechanics works. The subsequent development of laser technology constitutes a cogent reminder of the perils inherent in casual dismissal of novel ideas.

Mead also expresses concern regarding the subsequent development of physics in the twentieth century. The opening statement in his book *Collective Electrodynamics* declares "It is my firm belief that the last seven decades of the twentieth century will be characterized in history as the dark ages of theoretical physics". The present note proposes that the currently accepted picture of quantum mechanics, the so-called *Copenhagen interpretation of quantum mechanics* (hereinafter CIQM), brings in its wake certain difficulties which call for further consideration, perhaps even a thorough revision.

One of the strongest proponents of this interpretation, and surely one of the most influential, was Niels Bohr, a Dane (hence *Copenhagen* interpretation) . At the same time, we note that one prominent critic of this interpretation, John G. Cramer[3], has declared "Despite an extensive literature which refers to, discusses, and criticizes the Copenhagen interpretation of quantum mechanics, nowhere does there seem to be any

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[1] Carver Mead, Gordon and Betty Moore Professor Emeritus of Engineering and Applied Science at the California Institute of Technology, retired

[2] http://www.kurzweilai.net/carver-mead-a-bunch-of-big-egos-are-strangling-science

[3] John Gleason Cramer, Jr., Professor Emeritus of Physics, University of Washington

concise statement which defines the full Copenhagen interpretation."[4] This declaration, written in 1986, is a warning that we must tread carefully in discussing this topic. Currently, a Google search on ‘copenhagen interpretation of quantum mechanics’ turns up about 626,000 hits in 0.66 seconds. After this note, there will be 634,001 such hits, and the list must continue to grow. The very profusion of papers on this topic illustrates the difficulty in interpreting quantum mechanics. For reference, here is a current popular-level attempt to describe just what the CIQM is: https://science.howstuffworks.com/innovation/science-questions/quantum-suicide4.htm

In this note, we restrict our attention to the following feature of the CIQM: a system which can exist in multiple eigenstates may exist in several (or all) of them simultaneously (*superposition of states*), any measurement causing a *collapse of the wave function* into the eigenstate which exhibits the eigenvalue which the measurement revealed.

Niels Bohr

Niels Bohr, who must surely be mentioned in any listing of the creators of modern physics, was so influential that his name appears repeatedly in the very language of atomic theory and quantum mechanics. ‘Bohr model’, ‘Bohr atom’, ‘Bohr radius’, ‘Bohr magneton’, are all familiar to contemporary physicists, and the known breadth of his influence is remarkable. His Nobel citation (1922) lends further persuasiveness to this description of his widely felt presence. Even so, not all Bohr’s contributions stood up to careful scrutiny. His pioneering model of the atom needed modification, being supplanted by quantum mechanics. To be fair, we note that Bohr himself contributed greatly to the new physics which replaced his original simple Bohr atom. But this only underscores the progressive nature of scientific inquiry: it is an interactive and iterative enterprise, in which new experimental results require updating and modification of previous understanding. Even his celebrated exchanges with Einstein resulted in his vindication, time after time. With an established record such as Bohr achieved, it behooves us to take great care in departing from what he advocated.

What is knowable?

It seems uncomfortably pedantic to state the obvious, but we must begin somewhere. Here is the central conclusion of this note:

> *We can know only what is observable*.

We accept, of course, deductions which established physical laws allow us to make from related observations, such as Fermi’s postulation of the neutrino from the spread of energies in beta decay. If we accept the above italicized assertion, then discourse

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[4] Cramer, John G. (July 1986). “The Transactional Interpretation of Quantum Mechanics”. *Reviews of Modern Physics*. **58** (3): 649.

about unobservable states or processes is not science -- it is speculation. Speculation has its uses, of course, particularly in deciding where to invest resources while investigating uncharted territory.

Restricting our attention to what is observable means that some topics are not proper subjects for scientific investigation.

Parallel universes

No one has yet proposed a method for observing anything except what exists in this universe which we inhabit. If a parallel universe is observable, it would seem sensible to augment our definition of ‘universe’ to include it as part of our own. This is effectively what we do with reaches of the universe previously beyond our ken, now revealed by modern technology such as the Hubble telescope and the LIGO.

Many worlds

This is similar in spirit to parallel universes, but need not postulate a parallel universe in which the many worlds evolve. Where multiple evolutionary courses are *possible* from a given state, it is said that *all of them occur*, each in its own world. Experimental techniques for observing many worlds have yet to be described. Meanwhile, consider the simple case of one radioactive atom. It could decay this very instant, or an infinitesimal time later, or a half-life later, or many half-lives later; it could decay at *any* instant in this timespan, each possibility having its concomitant world in the many-worlds interpretation. Thus we have a single radioactive atom begetting an uncountably infinite[5] number of worlds, assuming (as is traditional) that time is continuous and non-quantized. It seems the right place for Occam’s razor, or else we need an infinite supply of material in order to create all those worlds, and our universe seems to be limited to about 10^{82} atoms.

Wave functions

Who knows how to observe a wave function? A wave function is not a physical entity, but merely a mathematical construct, which interacts physically with nothing at all. Beyond that, a wave function *per se* doesn’t even describe anything physical, like an atom. Rather, its squared magnitude allows us to calculate probabilities regarding the system in the state described by the wave function. So a wave function may produce an expectation value, but it will never scatter a photon or anything else, and can never be observed.

Superposition of states

If a wave function is unobservable, a superposition of multiple wave functions is also unobservable. The notion of superposition of states underlies the idea that ‘the wave function collapses’. This is often given as a description of what happens when a measurement is made. The system, alleged to be initially in a superposition of its possible states, with probabilities for each assigned by the squared magnitude as

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[5] That is, cannot be put in one-to-one correspondence with the natural numbers.

described above, somehow 'collapses' into the eigenstate observed by the measurement process, and the value measured is the eigenvalue of that eigenstate.

Take a moment to reflect carefully on the meaning of 'the wave function collapses'. It is easy enough to picture the collapse of a building or a bridge. A physical entity undergoes some failure of its support mechanisms, and the physical material, once forming a recognizable structure, ends up as a heap of rubble on the ground or in the water. When a wave function 'collapses', there is no physical material involved, and it's not possible to say exactly what collapsed.

To investigate more carefully the notion of measurement causing wave function collapse, consider sunlight incident on a triangular prism. Sunlight consists of a mix of photons of varying wavelengths (energies) which we customarily call 'white'. With no *a priori* knowledge regarding any particular photon, each of them could come from the decay of any excited state of hydrogen or helium . In the accustomed CIQM formulation, prior to measurement each photon's wave function is the sum of the wave functions for each of its possible states, suitably normalized. Every one of those incident photons has its energy *measured*, as evidenced by its angle of diffraction. Each photon, with its associated wave function, approaches the prism, passes through it, and continues on its way in the direction determined by its energy. In this *measurement* of photon energy, what 'collapsed'? It's true that exact details of what happens at the air-glass interface are complex, but how does 'wave function collapse' aid our understanding?

Perhaps the most persuasive evidence in favor of superposition is the work done by Dr. David Wineland and his team when he was at Boulder, Colorado (Wineland now holds the Philip H. Knight Distinguished Research Chair at the University of Oregon). They trapped a single ion, did laser cooling to put it into its lowest energy state, then illuminated it with a carefully tuned laser pulse driving it toward a higher energy state. This resulted in a state such that subsequent measurement had an equal probability of finding it in either the higher or lower energy state. This has been interpreted to mean that the state thus produced is a superposition of the higher and lower states, with equal probability of being in either. It needs to be noted that this is an *ex post facto* interpretation, not an observation. An alternative interpretation is possible: the carefully tuned laser pulse has an equal probability of leaving the ion in the lower state or boosting it to the higher state, i.e., it provides just enough energy to put the ion close enough to the higher state so that quantum tunneling to the higher state has a probability of one-half. One trembles at taking issue with a Nobel laureate, but the point is crucial and must be emphasized: an interpretation is not an observation.

We will contend later that an alternate description of a measurement event supplies a satisfactory picture of what is happening, without reference to wave functions or collapse thereof.

Schrödinger's cat

Much mischief follows in the train of the notion of superposition, the most famous of which is no doubt Schrödinger's cat. The cat is alive, or it is dead, but not some of each. It is only the computed probability, i.e., our expectation value for the results of measurement, that is split 50-50.

We acknowledge that Schrödinger's intent was to illustrate how to describe a situation where some information is available, but not all, i.e., the life/death status of the cat. We can have no quarrel with his formulation of the problem, but we can doubt very much that he himself believed in an alive/dead cat. It may be protested that Schrödinger's real subject was a quantum mechanical entity, like an atom, and his cat was just an illustration of a principle. What is at stake is calculation of probabilities, not declaration of some physical fact.

The pervasiveness of the superposition paradigm can be illustrated with a few sentences written by J. S. Bell in *Speakable and unspeakable in quantum mechanics* (1987), a well-known collection of essays on the conceptual problems of quantum mechanics. In the twenty-second essay he broaches the topic of Schrödinger's cat:

> It is the problem that he had had[6] with his cat. He thought she could not be both dead and alive. But the wavefunction showed no such commitment, superposing the possibilities. Either the wavefunction, as given by the Schrödinger equation, is not everything, or it is not right.

Schrödinger was unduly pessimistic in the conclusion he gives in the closing sentence of the above quotation. The wave function in the Schrödinger equation *is* everything, in the sense that it supplies the means for calculating all that can be known about the system without measurement, i.e., the probabilities for its being in any of its several possible states. The successes encountered in utilizing the wave function and the Schrödinger equation (for nearly a century) constitute ample justification for calling it 'right'.

Another bit of mischief wrought by the collapse-of-wave-function paradigm occurs in the production of particles or photons of opposite spin. When one particle/photon has its (unknown) spin/polarization measured, the alleged wave function collapse occurs. The partner particle/photon must have the opposite spin/polarization, and the wave function collapse must somehow convey this information, so that the partner 'knows' the proper state to assume upon wave function collapse. In the photon case, it is obvious that this requires superluminal information transfer. The partner photon is fleeing at the speed of light, and the information must catch up to it.

In this note we take the attitude that all we know (or *can* know) is what is observable. Here is a consequence of the central conclusion stated above:

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[6] Schrödinger, E. (1935) *Naturwissenschaften* **23**, 807-12, 823-8, 844-9

> With regard to a system which is observable but has not yet been observed, it is a mistake to make any declaration about it, except possibly for some generalities which follow from conservation laws or symmetry principles.

Most physicists would agree that it is not justifiable to assert, prior to a measurement, that a system is in *any particular one* of its eigenstates; but many would argue that we can assert, following the CIQM, that it is in *several* or *all* of its eigenstates via superposition of states. Contrary to the ideas being presented here, the latter option is commonly adopted by contemporary physicists. What they really mean is that you can write a wave function which allows the calculation of probabilities for it being in any one of its possible states, as mentioned previously. But, as we have noted, a wave function is not a physical entity, only a mathematical construct, and is not observable.

Unobserved reality

Silence regarding the state of a system does not preclude the fact of the system being in some state; rather, it is merely the appropriate acknowledgment of our ignorance. The system itself is free to exist in whatever state is available to it, irrespective of our knowledge thereof. We adopt the term *unobserved reality* to denote this situation. As follows from the italicized central conclusion offered above, the only proper time to make a statement regarding a system is after a determination has been made by actual observation.

Nothing herein denies the existence of unobserved reality. One is reminded of Einstein's famous question: "Does the moon exist when I'm not looking at it?"

A New Paradigm

The concept of unobserved reality is offered in this paper as an alternative to the CIQM. It needs to be considered, most urgently perhaps, in discussing entanglement and superluminal information transfer. As is typical in contemporary physics, the literature on this topic is large. Leonard Susskind[7] produced a series of nine lectures on the topic running approximately fifteen hours. Currently, a google search on 'entanglement superluminal communication' yields 45,300 results. This astounding surfeit of claims, counterclaims, proofs, debunking, and the whole panoply of academic wrangling springs from the CIQM.

The idea of unobserved reality can be illustrated in the context of atomic spectra. We excite an atom by some means, elevating an electron to some excited state; the atom decays to its ground state, emitting a photon whose wavelength is readily known to us if we know the spectrum of the atom. We have no trouble agreeing that, prior to the photon emission, the atom was in thus-and-so excited state, even though we made no measurement of the atom in that state. One may argue that observing the photon constitutes a measurement of the excited state of the atom, but no one would insist that the excited atom was in an indeterminate state before decaying to its ground state and

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[7] Leonard Susskind, Professor (Theoretical Physics), Stanford University, https://www.youtube.com/view_play_list?p=A27CEA1B8B27EB67

emitting the photon whose observation constitutes measurement of the initial state.. On the contrary, it was in a properly defined state whose decay produced the photon we observed. (There is no intention here of claiming that the initial state, before the photon emission, is perfectly precise. The slight spread of energies in the initial state produces the line width of the observed spectral line, some of which are sharper than others.) Each excited-state atom, unobserved by us until it decays to its ground state, constitutes an exemplar of unobserved reality.

Superposition

Consider a reaction which produces a photon pair. A simple conservation law requires that if one is spin +1, the other is spin -1. The usual attitude is exemplified by the following quote[8]:

> Until you measure the spin of either one, they both exist in an indeterminate state; but once you measure even (sic; he probably means *either*) one, you immediately know both.

There it is, the explicit presupposition of the CIQM, that the status of the photons is indeterminate until we make a measurement. In this note we assert that acceptance of unobserved reality neatly solves the conundrum. The photons are created in the status they exhibit upon measurement, and do not need a measurement by us to put them in their configuration.

Paul Sutter[9] corroborates the indeterminacy viewpoint in his article (“Quantum Weirdness May Seem to Outrun Light – Here’s Why It Can’t”, https://www.space.com/41968-quantum-entanglement-faster-than-light.html, 09/29/2018).

Here is one more example, from another contemporary physicist, Sean Carroll[10]:

> Quantum mechanics says that the state of the particle can be a superposition of both possible measurement outcomes. It’s not that we don’t know whether the spin is up or down; it’s that it’s really in a superposition of both possibilities, at least until we observe it.

It is the contention of this paper that quantum mechanics says no such thing. It is the CIQM which supports this idea. It would require very little effort (with google) to multiply

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[8] Ethan Siegel, https://medium.com/starts-with-a-bang/ask-ethan-can-we-use-quantum-entanglement-to-communicate-faster-than-light-e0d7097c0322

[9] Paul Sutter, Astrophysicist, Ohio State University

[10] Sean M. Carroll, Research Professor of Physics, Caltech, http://www.preposterousuniverse.com/blog/2014/06/30/why-the-many-worlds-formulation-of-quantum-mechanics-is-probably-correct/

such examples as the preceding trio into the scores or hundreds. The point is the same with all of them: observational physics does not require superposition of states. That is only superfluous baggage carried by the CIQM. Quantum mechanics *per se* says no more than $H\Psi = E\Psi$.

It will not do to shrug and attribute impossible behavior to the weirdness of quantum mechanics. How can anything which is A simultaneously be *not* A? That is what is needed for superposition of states. A spin (or polarization) pair [+-] must be capable of existing simultaneously as its antithesis [-+], in order to create the superposition of states. No one advocating superposition of states deserves further attention until they can describe experimental means for

> (1) verifying that [+-] and [-+] are the *same* pair of particles (or photons), and
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> (2) that [+-] and [-+] were observed *simultaneously* to eliminate the possibility that one transmuted into the other while no one was looking.

Nature is as it is; we merely observe and describe. Weirdness in the present topic arises from accepting the CIQM at face value. Avoiding this path is what we advocate here.

These considerations need to be properly weighed in evaluating the results of Alain Aspect[11] regarding his use of ‘entangled photons’ in his tests of Bell’s inequalities. Detailed analysis of his work is beyond the scope of this paper. [These same remarks apply, of course, to any work which invokes superposition of states to achieve its results.]

Entanglement

The CIQM lies at the very heart of the notion of entanglement. If a correlated pair of particles (or photons) are created *in an indeterminate state*, then indeed a measurement ‘causes the wave function to collapse’ and take on the eigenvalue revealed by the measurement**.** But if we do not adhere to the requirement of indeterminacy and accept the notion of unobserved reality, then the particle(or polarization) pair are in a perfectly well-defined state (albeit unknown to us), and the mystery of entanglement goes away without a whimper. Measurement merely tells us what that well-defined state is – it doesn’t put it into that state by causing the collapse of an indeterminate wave function.

There is a stark contrast here. The CIQM brings with it superposition of states, collapsing wave functions, entanglement, and superluminal information transfer, whereas the unobserved reality viewpoint exhibits none of those features and is greatly simplified thereby. A paradigm shift may be unsettling to some, but in time (long enough for the old guard to retire) the radical notion becomes orthodoxy, and life goes on.

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[11] Alain Aspect, Augustin Fresnel Professor, Laboratoire Charles Fabry

Final note

In all this, we do not advocate a simple naïve realism. Appearances can indeed be deceiving at times -- a realistic humility is appropriate in this regard. We claim only that reality is independent of our ability to observe it. Think of astronomy before the invention of the telescope. Galaxies, neutron stars, and black holes have been in existence for billions of years, but our ancestors were blissfully unaware of them until the invention and refinement of the telescope. Microorganisms existed since the appearance of life on our planet, but were never seen before the microscope was invented. There are indubitably a great many wonders still unobserved by us, even with the astounding advances in technology made in the last few centuries. We await with eager anticipation such revelations to come, but in the meantime, and for all time, we can know nothing regarding the physical cosmos except what is observable.

References

The following papers, available on preprints.org, treat several aspects of the issues raised here.

Roots of Quantum Computational Supremacy: Superposition? Entanglement? Or Complementarity?
Andrei Khrennikov, doi:10.20944/preprints201912.0006.v1

Quantum Mechanics Requires an Observer Context Distinguishing between Reality and its Mental Representation
Franz Klaus Jansen, doi:10.20944/preprints201802.0068.v1

Identical Quantum Particles, Entanglement and Individuality
Dennis Dieks, doi:10.20944/preprints201912.0019.v1

A Feasible Attempt of Classical Interpretation of Quantum Physics
Jack Van, Working paper at preprints.org

Every Entangled Stuff Has Its Own Avatar
Mario Mastriani, doi:10.20944/preprints201809.0221.v1